Santa Maria River Instream Flow Study: Flow Recommendations for Steelhead Passage

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A Note on Units of Measurement

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

Metric/English unit conversions (abbreviations in parentheses).

Metric	English
1 degree Centigrade (°C)	1.8 degrees Fahrenheit (°F)
1 centimeter (cm)	0.39 inch (in)
1 cubic meter per seconds (cms)	35.3 cubic feet per second (cfs)
1 hectare-meter (hm)	0.12 acre-feet (ac-ft) [1.98 ac-ft = 1 cfs × one day]
1 kilometer (km)	0.62 mile (mi) 3280 feet (ft)
1 meter (m)	3.28 feet (ft)
1 meter per second (m/s)	3.28 feet per second (ft/s)
1 milligram per liter (mg/L)	1 part per million (ppm)
1 milligram per milliliter (mg/mL)	1 part per thousand (ppt)
1 millimeter (mm)	0.04 inch (in)

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EXECUTIVE SUMMARY

Study Purpose

The focus of this study is on the flow necessary to promote and provide effective steelhead passage to and from the Pacific Ocean to areas of documented spawning and rearing habitat in upper parts of the Santa Maria watershed. This requires not only the determination of a “minimum” flow necessary for passage in the lower river, but also the reestablishment of a flow regime along the mainstem Santa Maria River that more closely approximates historic conditions.

Under California Public Resources Code §10001, the California Department of Fish and Game (CDFG) is obligated to identify and list “those streams and watercourses throughout the state for which minimum flow levels need to be established in order to assure the continued viability of stream-related fish and wildlife resources.” California Water Code §1257.5 requires the State Water Resources Control Board (SWRCB) to consider stream flow requirements when acting on applications to appropriate water. In 2008, CDFG identified the Santa Maria River on a list of twenty-two priority streams that require instream flow analysis in order to provide the scientific basis for flow recommendations to the SWRCB to support anadromous fish passage. To assist CDFG in developing stream flow recommendations for use by the SWRCB, the California Ocean Protection Council (OPC) authorized funding to complete four instream flow analyses in three coastal rivers in California, including the Santa Maria River.

The Santa Maria River watershed is approximately 1,860 mi^2, and elevations range from 8,820 ft in the headwaters to sea level at the estuary and coast. The mainstem Santa Maria River is approximately 24 mi long and is formed by the joining of its two major tributaries, the Cuyama and Sisquoc rivers. The Cuyama River is approximately 107 miles long and flows through the agricultural lands of Cuyama Valley and the Sierra Madre Mountains before being intercepted by Twitchell Dam. Twitchell Dam, which impounds Twitchell Reservoir, was built in 1959 and first began operation in 1962. The reservoir has a nominal capacity of 224,300 ac-ft, of which the majority is used to store water during winter storms and then released at a rate to maximize percolation into the riverbed of the mainstem Santa Maria River and so recharge the groundwater. There is no fish passage past Twitchell Dam. The Sisquoc River is 58 miles long and has no major dams or water diversions. A persistent resident population and abundant *O. mykiss* spawning and rearing habitat have been documented in the Sisquoc River watershed.

The Santa Maria River watershed is one of the four largest river systems within the northern range of the federally endangered Southern California Steelhead Distinct Population Segment (DPS). The Santa Maria River watershed supports a self-sustaining population of rainbow trout (the resident life-history form of *Oncorhynchus mykiss*) in the Sisquoc River watershed. It also supports anadromous spawning of adult steelhead (the ocean-going life-history form of *O. mykiss*) during some wet years. Nearly the entire Santa Maria River watershed, including the Cuyama and Sisquoc rivers, are designated critical habitat for the Southern California Steelhead DPS.

A combination of hydraulic calculations and field measurements were used to identify the flow *magnitude* for adult and juvenile steelhead passage to and from the Pacific Ocean and spawning and rearing habitat in the Sisquoc River watershed. The recommended *duration* of these flows was developed based on documented steelhead migration speeds, migration distances within the watershed, and location of the critical passage reach along the migration route. The recommended *frequency* of ecologically meaningful flows is based on analyses of pre-Twitchell Dam hydrologic conditions.

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Methods

Characterization of estuary conditions were primarily based on field observations during winter–spring 2010/2011, supplemented by direct and indirect historical records to infer the general behavior of the estuary and its outlet over time. Since systematic observations of historic outlet conditions of the Santa Maria River estuary are not available, the hydrologic record was evaluated to determine the degree to which open-outlet conditions can be correlated with steelhead-passable flows, or otherwise inferred from the flow record of the river. Photographic evidence of the outlet condition from 1994–2009 as compiled on GoogleEarth©, together with a more sporadic but longer record of aerial photographs archived at the County of Santa Barbara Flood Protection District from 1966–1998, were reviewed.

Hydraulic criteria to define thresholds for suitable passage conditions for adult steelhead upstream migration and juvenile and adult steelhead downstream migration through the Santa Maria and lower Sisquoc rivers were developed using available information on existing steelhead passage criteria from other studies and applications including peer-reviewed journals, agency reports, and other scientific literature, as well as information from technical and local experts. The required water depth of riffles, maximum water velocity and swimming ability were all considered, with a focus on the herein-named "critical passage reach," a five-mile stretch of the mainstem Santa Maria River bracketing the Bonita School Road crossing where the river bed is most commonly dry. In addition to the hydraulic passage criteria, the time required for both upstream and downstream migration was used to constrain subsequent hydrologic analyses, based on review of available information, necessary transit distances, and presumed swimming velocities.

To improve the relevance of the hydraulic calculations to actual fish-passable conditions, field evaluation of fish-passable flows and field measurements of discharge were conducted on seven separate dates between January and April 2011. They were conducted at a variety of locations in and surrounding the critical passage reach, and they were used to provide a field-based determination of passable flows under actual conditions of flow and channel formation.

Hydrologic analyses were based almost entirely on the extensive gage record of the Santa Maria River and its two major tributaries, the earliest dating from 1929 and continuing to this day. In addition, flow releases have been monitored daily from Twitchell Reservoir since it first began full operation in February 1962. The flow records are neither continuous at any given gage nor of particularly high quality, and so a variety of methods were used to reconstruct a reasonably accurate picture of daily discharges in the Santa Maria, Cuyama, and Sisquoc rivers, beginning in 1941 with the installation of the one mainstem gage and continuing through to the summer of 2011.

Development of a groundwater model was judged to be an important element of the overall study, in order to express downstream surface flow as an explicit function of upstream flow, antecedent flow (i.e., preceding flow conditions), depth to groundwater, and releases from Twitchell Dam. The primary need of this study was to quantify the magnitude of surface water infiltration, or "transmission loss," that occurs between the confluence of the Sisquoc and Cuyama rivers and the critical passage reach in the mainstem Santa Maria River. This is a relatively narrow need, because simultaneous operation of three stream gages on the lower Cuyama River, lower Sisquoc River, and mainstem Santa Maria River at Guadalupe from 1941 through 1987 provide direct daily measurement of transmission losses for this 46-year period. Even a relatively simple model

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displays typical relationships between the various drivers of transmission loss, and provide an analytical expression that usefully approximates the complexities of the true hydrogeologic system for use in this study.

Results

Estuary: Fish-passable flows rapidly lead to conditions of an open estuary, because the maximum volume of the lagoon is small relative to the volume of flow required for fish passage. The consequence for this study is that the condition of the estuary outlet is not limiting for steelhead passage: during periods when fish can successfully pass up- or down-river, they will not be blocked at the mouth. Based on first-hand observations of the estuary and aerial photograph interpretation during open-mouth conditions, however, juvenile steelhead are unlikely to have much opportunity for (or run much risk from) estuary rearing. This is due to the fact that under open-mouth conditions, the estuary is nearly entirely drained and there does not appear to be off-channel, or impounded areas available for out-migrating juvenile steelhead to access before reaching the Pacific Ocean.

Passage criteria for steelhead: A minimum depth for adult steelhead passage of 0.7 ft was selected to account for the body size of the largest adult steelhead expected to pass with additional buffer to avoid abrasion. A minimum depth for juvenile of 0.5 ft was selected to match CDFG criteria for juvenile upstream passage. A minimum width of contiguous 10 ft, for both adult and juveniles, was selected to provide sufficient width for steelhead to pass and added buffer to increase the likelihood that a continuous migration path through braided sections is available, and to reduce potential for predation from terrestrial predators. A maximum velocity of 6 ft/sec (applicable to upstream migration only) was selected because it is well under critical thresholds from the literature to account for the long migration distance with limited resting habitat.

Discharge required to meet passage criteria: Field measurements of discharges and evaluation of steelhead-passable flows between January and April 2011 throughout the critical passage reach show that a discharge of 250 cfs is a reasonable threshold value for upstream adult steelhead passage through the critical passage reach. Absent field evaluation of downstream passage opportunities, hydraulic calculations indicate that a (likely conservative) value of 150 cfs should be used to presume downstream (juvenile) passage, based on available information.

Pre- and post-dam fish-passage conditions: Conditions suitable for fish passage through the critical reach have never been common along the Santa Maria River, and they are confined to a relatively well-defined period for the five months of December, January, February, March, and April. For upstream adult passage, the number of years with at least one passage opportunity has increased modestly, particularly for minimum-length events (3 days). However, any such opportunities within a "passage year" are now typically of shorter duration, and they are separated by longer gaps between passage opportunities. For downstream juvenile passage, the tally of suitable days has not changed appreciably between pre-dam (1941–1961) versus post-dam (1962–1987) conditions, although with a slight increase in the percentage of years without any passage opportunities at all. Both short (1–3 days) and long (>12 days' duration) events have been reduced in frequency, but the number of days they include have been largely balanced by an increase in passage events of intermediate durations (4–12 days long).

In summary, reduction in the availability of conditions suitable for upstream steelhead migration are on average about 2 days per year. Because this represents a reduction in surface discharge of

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250 cfs to the estuary for those two days, the equivalent magnitude of increased groundwater recharge is approximately 1,000 ac-ft/year. This volume represents about 2% of the average annual water storage in Twitchell Reservoir and less than 3% of the annual water yield of the Cuyama River.

Pre- and post-dam tributary flows: Pre-dam, flows from the Sisquoc and Cuyama rivers were relatively well-correlated, with the former contributing about two-thirds of the mainstem flow and the latter the remaining one-third, synchronized on a seasonal and even daily basis. Post-dam, however, flows from the two tributaries are no longer correlated; indeed, their lack of correlation, particularly during high-flow events on the Sisquoc River when the reservoir is presumably capturing all flow from the Cuyama River, is the explicit intention of dam operations. These flows are subsequently released during periods of low or no flow in the Sisquoc River to achieve a more uniform discharge down the mainstem Santa Maria River, promoting infiltration in the Santa Maria River valley with little or no surface flow released to the estuary.

Key changes in the flow regime: Flow releases from Twitchell reservoir have almost certainly imposed a modest reduction in the number of successful opportunities for both upstream and downstream steelhead migration along the Santa Maria River. The following alterations to the flow regime (in approximate rank order) are likely of greatest significance:

1. Increased frequency of "false positives" in the flow of the Sisquoc River (i.e., discharges in the Sisquoc River that historically correlated with upstream- or downstream-passable conditions from or to the estuary, but which no longer do).
2. Reduced overall frequency of downstream steelhead-passable conditions.
3. Increased number of days with upstream steelhead-passable flows that are *not* followed by at least two additional steelhead-passable flow days.
4. Reduced frequency of long-duration upstream steelhead-passable intervals (which may be partly mitigated by the increased frequency of shorter duration intervals).

Recommendations

Recommendations for flow modifications to enhance fish passage along the Santa Maria River are based on two key assumptions, as documented or developed in this study. (1) Upstream migration of adult steelhead is possible at 250 cfs in the critical reach of the mainstem of the Santa Maria River, and it
requires at least three days of flow greater than or equal to this level. (2) Downstream juvenile passage requires at least one day of flow greater than or equal to 150 cfs through the critical reach, with at least two preceding days of passable flows upstream in the Sisquoc River. Based on the pre-dam hydrologic record, however, upstream steelhead-passable conditions of substantial duration (i.e., substantially more than 3 days) is unlikely to occur in more than one or two years per decade; in contrast, flow conditions suitable for downstream steelhead passage should occur in about one-half of all years, on average.

The recommendations for modified operation of Twitchell Dam to approximate pre-dam hydrologic conditions in the mainstem Santa Maria River, relative to steelhead migration, are summarized as follows:

1. Flow releases should occur when average daily flows in the lower Sisquoc River, as measured at the Garey gage (USGS 11140000), are between 350 and 550 cfs and have already remained at or above that level for at least two previous days. Once started,

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supplemental discharges should occur if/as needed to ensure passage flows in the mainstem Santa Maria River (i.e., 250 cfs) for at least three days.

2. Releases from Twitchell Dam should be sufficient to maintain flows in the critical reach of the mainstem Santa Maria River at 250 cfs; absent direct measurement of flow, this is assumed to be achieved with combined discharges from the Sisquoc and Cuyama rivers of 600 cfs (i.e., transmission losses are 350 cfs unless observations show otherwise). Direct measurement of flow in the critical passage reach, however, is strongly recommended as an alternative to presuming that passable conditions have been achieved.
3. Flow releases to support steelhead passage should not occur, or should stop once started, if (a) discharges fall below 150 cfs in the lower Sisquoc River, or (b) 12 or more days of adult steelhead-passable conditions have been achieved during the current water year.

Had these recommendations been applied during the period 1962–1987, additional surface-water flows reaching the estuary over this 26-year period would have averaged about 1,500 ac-ft per year. This volume reflects releases of water from Twitchell Reservoir that would not have recharged groundwater, and constitutes about 3% of the average volume of water stored in the reservoir. Over the period 1988–2011, these recommendations would have resulted in additional surface-water flows reaching the estuary at an average rate of about 1,020 ac-ft per year, about 2% of the average volume of water stored in the reservoir.

Uncertainties and Recommended Monitoring

Study recommendations are inescapably constrained by uncertainties in the underlying data. The most substantive uncertainties are the quality of the past hydrologic data, on which the analysis of pre- and post-dam conditions are based; the rapidly varying nature of the mainstem Santa Maria River channel, which compromises most available analytical techniques for determining fish-passable flows; and the details of the complex life history of *O. mykiss*, particularly its migratory strategies in the face of a highly variable and unpredictable hydrologic setting. To reduce these uncertainties over time, the following monitoring activities are also proposed as critical adjuncts to any future flow-management actions:

1. Field monitoring in the critical passage reach during any flow augmentation from Twitchell Dam, and subsequent modification of release rates if/as needed, is critical to ensure that steelhead passage is provided while conserving water from Twitchell Reservoir to the greatest extent possible.
2. Field measurements should evaluate whether: 1) discharge recommendations meet steelhead passage criteria throughout the critical passage reach, and 2) the recommended flow frequency rules result in steelhead-passable conditions that are of sufficient duration and periodicity for both adult and juvenile steelhead migration.
3. During flow events that are of sufficient magnitude for steelhead passage, monitoring should verify that allocated flows are sufficient to breach the sandbar and provide access to/from the Pacific Ocean.
4. Monitoring steelhead passage through the Santa Maria River, although challenging, should be conducted to evaluate directly the adequacy of any flow modifications.

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1 INTRODUCTION

1.1 Study Purpose

Under California Public Resources Code §10001, the California Department of Fish and Game (CDFG) is obligated to identify and list "those streams and watercourses throughout the state for which minimum flow levels need to be established in order to assure the continued viability of stream-related fish and wildlife resources." California Water Code §1257.5 requires the State Water Resources Control Board (SWRCB) to consider stream flow requirements when acting on applications to appropriate water. In 2008, CDFG identified the Santa Maria River on a list of twenty-two priority streams that require instream flow analysis in order to provide the scientific basis for flow recommendations to the SWRCB to support anadromous fish passage. The list was developed with input from regional CDFG staff, SWRCB staff, U.S. Fish and Wildlife Service (USFWS), and NOAA National Marine Fisheries Service (NOAA Fisheries). In developing the list of priority streams, CDFG staff considered criteria such as: (1) presence of anadromous fish species, (2) likelihood that CDFG flow recommendations would provide a significant level of habitat improvement for anadromous fish, (3) availability of recent flow studies or other relevant data, and (4) the possibility of partners and willing landowners to work with CDFG on the instream flow analysis. To assist CDFG in developing stream flow recommendations for use by the SWRCB, the California Ocean Protection Council (OPC) authorized funding to complete four instream flow analyses in three coastal rivers in California, including the Santa Maria River.

The Santa Maria River watershed is one of the four largest river systems, in addition to the Santa Ynez, Ventura, and Santa Clara rivers, within the northern range of the federally endangered Southern California Steelhead Distinct Population Segment (DPS; formerly referred to as Evolutionarily Significant Unit [ESU]) (62 FR 43937). The Santa Maria River watershed supports a self-sustaining population of rainbow trout (the resident life-history form of *Oncorhynchus mykiss*) in the Sisquoc River watershed (Davis and Jackson ca. 1934, Evans 1947, Douglas and Richardson 1959, Edwards et al. 1980, Kautzman and Uyehara 1999, and others, all as cited in Becker and Reining 2008; also, Shapovalov 1944, Cardenas 1996, Boughton and Fish 2003, Stoecker 2005). It also supports anadromous spawning of adult steelhead (the ocean-going life-history form of *O. mykiss*) during some wet years (Shapovalov 1944, Shapovalov 1945, Titus et al. 2010, Stoecker 2005). Nearly the entire Santa Maria River watershed, including its two primary tributaries, the Cuyama and Sisquoc rivers, are designated critical habitat for the Southern California Steelhead DPS (70 CFS 52488). Steelhead populations in the four major watersheds in the northern portion of the DPS have experienced declines in run sizes of 90% or more (NOAA Fisheries 2012). In the 2012 *Southern California Steelhead Recovery Plan*, NOAA Fisheries identified the following principal threats to the viability of the DPS: (1) dams, surface water diversions, and groundwater extraction; (2) agricultural and urban development, roads, and other passage barriers; (3) flood control, levees, and channelization; (4) non-native species; (5) estuary loss; (6) marine environmental threats; and (7) natural environmental variability. Re-establishing access to upper watersheds through the removal of physical barriers and restoring natural hydrologic patterns (to facilitate fish migration and maintain suitable freshwater habitat conditions) have been identified by NOAA Fisheries as the two highest priorities for the recovery of the Southern California Steelhead DPS. The Santa Maria River is one of four Core 1 populations within the Monte Arido Population Group within the Southern California Steelhead DPS which must be recovered in order to meet the DPS viability criteria identified for the recovery and ultimately de-listing of the Southern California Steelhead DPS. Specific critical recovery actions for the Santa Maria River include: (1) Implement operating criteria to ensure that pattern and magnitude of water releases from Twitchell Dam provide the essential fish habitat

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functions to support the life history and habitat requirements of adult and juvenile steelhead; and (2) Physically modify Twitchell Dam to allow steelhead natural rates of migration to upstream Cuyama River spawning and rearing habitat and passage of smolts and kelts downstream to the estuary and ocean (NOAA Fisheries 2012).

The OPC staff recommendation that led to the funding authorization for the Santa Maria River Instream Flow Study stated that the focus of the study should be on the flow necessary to promote and provide effective steelhead passage to and from the Pacific Ocean to the Sisquoc River watershed, where abundant spawning and rearing habitat have been documented (Stoecker 2005, OPC 2010). Although this focus is consistent with the NOAA Fisheries priority for the recovery of Southern California steelhead to re-establish access to upper watersheds, it requires not only the determination of a “minimum” flow but also the reestablishment of a flow regime on the Santa Maria River that more closely approximates pre-Twitchell Dam conditions. Therefore the scope of the Instream Flow Study was expanded to embrace this broader objective as well.

1.2 Study Area

The Santa Maria River is located primarily in Santa Barbara County, California, although smaller portions of the watershed also fall within San Luis Obispo, Kern, and Ventura counties (Figure 1.2-1). The Santa Maria River watershed is approximately 1,860 mi^2, and elevations range from 8,820 ft in the headwaters (at Sawmill Mountain) to sea level at the estuary and coast. The mainstem Santa Maria River is approximately 24 mi long and is formed by the joining of its two major tributaries, the Cuyama and Sisquoc rivers (Figure 1.2-1). The Cuyama River is approximately 107 miles long and flows through the agricultural lands of Cuyama Valley and the Sierra Madre Mountains before being intercepted by Twitchell Dam. Twitchell Dam, which impounds Twitchell Reservoir, was built in 1959 (TMA and MNS 2010). The reservoir has a nominal capacity of 224,300 ac-ft, of which the majority is used to store water during winter storms and then released at a rate to maximize percolation into the riverbed of the mainstem Santa Maria River and so recharge the groundwater. There is no fish passage past Twitchell Dam. The Sisquoc River is 58 miles long and has no major dams or water diversions. A persistent resident population and abundant *O. mykiss* spawning and rearing habitat have been documented in the Sisquoc River watershed (Davis and Jackson ca. 1934, Evans 1947, Douglas and Richardson 1959, Edwards et al. 1980, Kautzman and Uyehara 1999, and others, all as cited in Becker and Reining 2008; also, Shapovalov 1944, Cardenas 1996, Boughton and Fish 2003, Stoecker 2005).

The Santa Maria River Instream Flow Study area comprises the mainstem Santa Maria River, which flows through the northern portion of the Santa Maria Valley, between a steep bluff to the north and the cities of Santa Maria and Guadalupe and their associated agricultural lands to the south (Figure 1.2-1). In particular, the study is focused on the approximately 5-mile reach of the Santa Maria River above and below Bonita School Road crossing (Figure 1.2-2). This reach, referred throughout this report as the “critical passage reach,” is where surface flows are most commonly the shallowest or absent altogether, thus forming a barrier to upstream and downstream fish migration.

The instream flow study area also includes portions of the watershed upstream and downstream of the mainstem Santa Maria River. The lower Sisquoc River (i.e., the downstream-most ten miles, from the confluence with Cuyama River to the upstream extent of valley alluvium) is included in the study area insofar as flows in the lower Sisquoc River (which, as noted previously, is uncontrolled by any major dam or water diversion) must be sufficient for steelhead passage before the flow requirements for the Santa Maria River identified in this report would

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need to be implemented. The Santa Maria River estuary is also included in the study area because conditions in the estuary have the potential to influence steelhead passage and survival in two primary ways. First, the sandbar separating the estuary and the Santa Maria River from the Pacific Ocean must be open in order for steelhead to migrate upstream and downstream between the river and the ocean. Second, juvenile steelhead may remain in the estuary if the sandbar closes before downstream migration has stopped.

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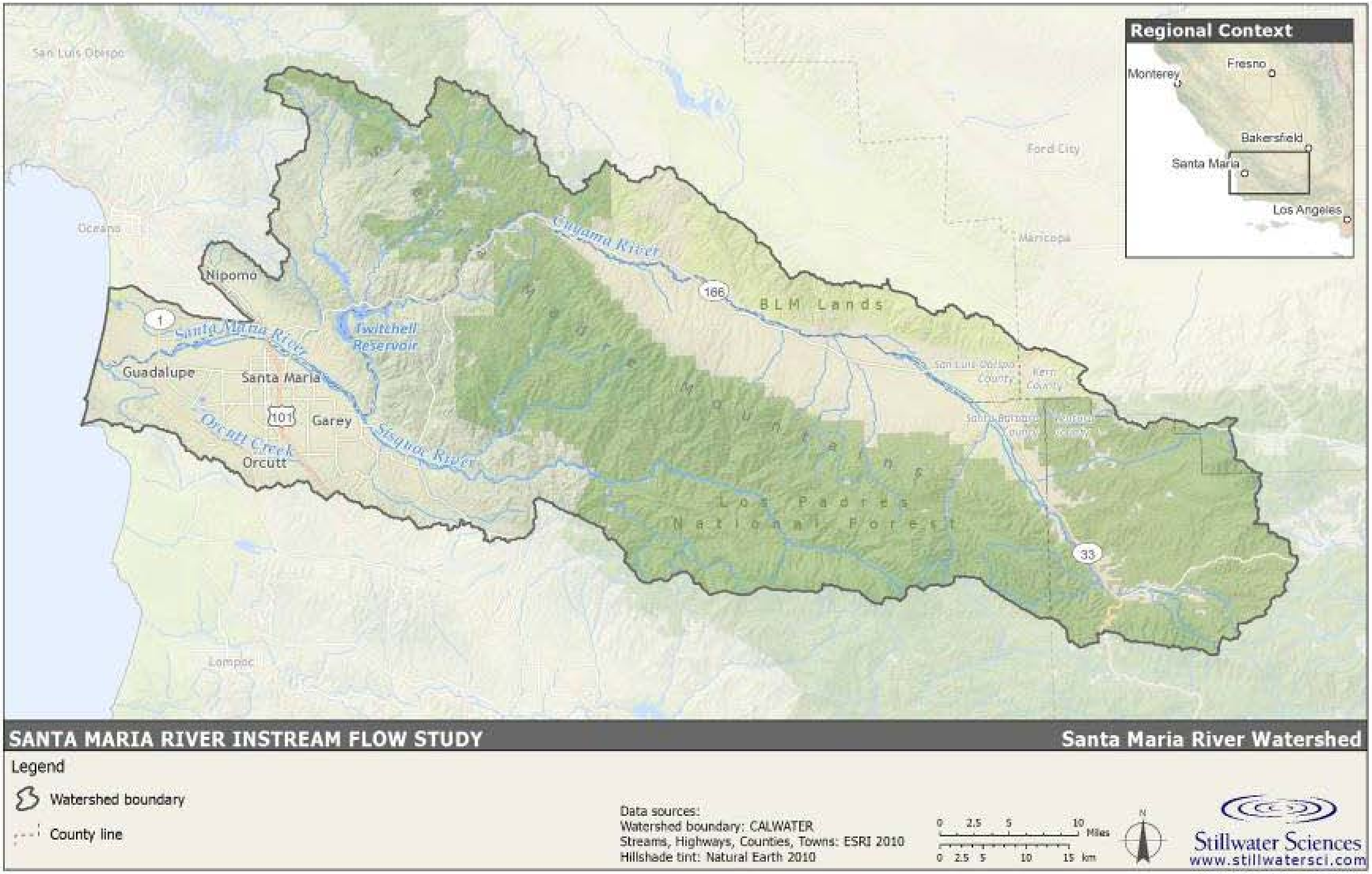

Figure 1.2-1. Santa Maria River watershed and location (inset map).

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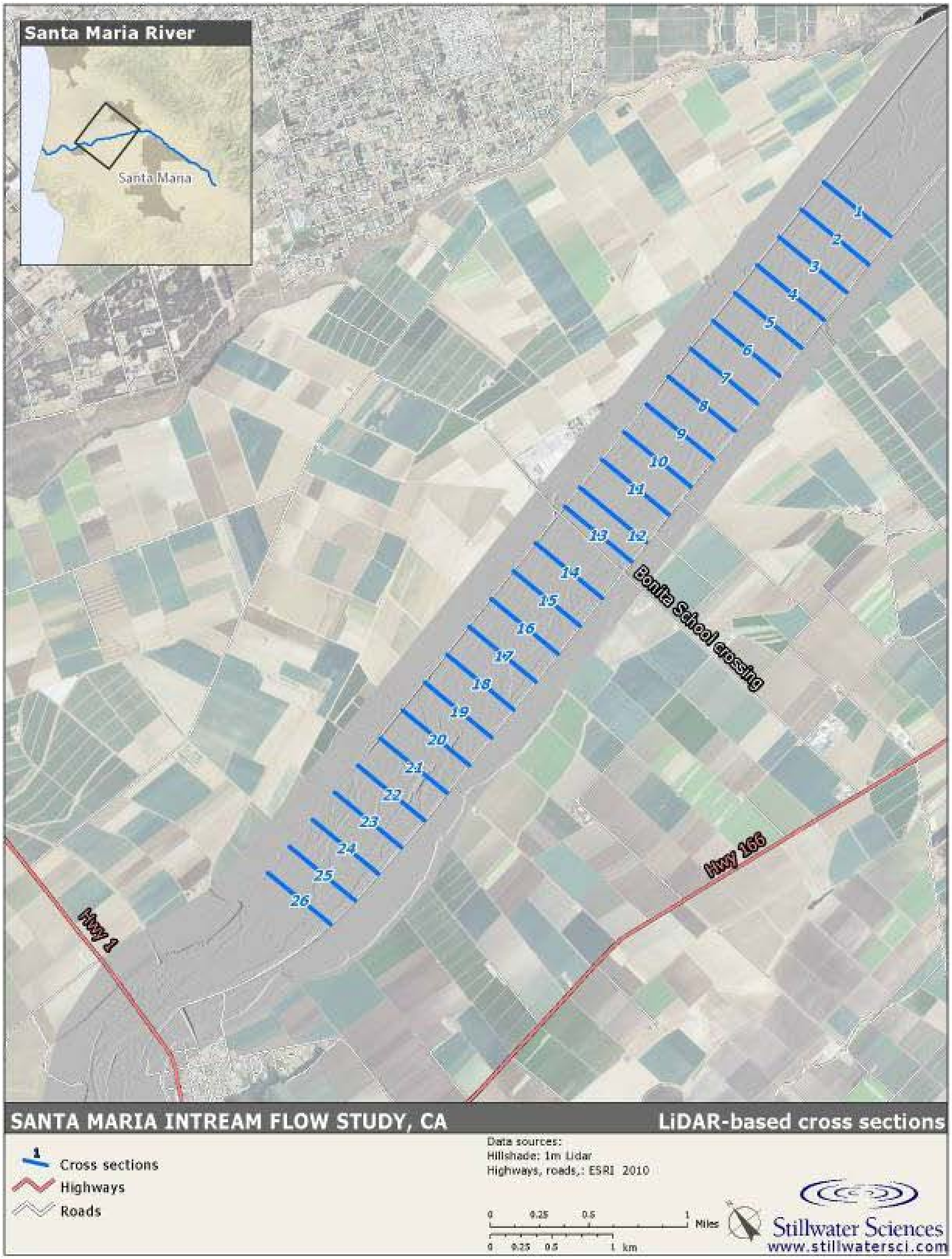

Figure 1.2-2. Santa Maria River critical passage reach, showing the location of the 26 LiDAR-based surveyed cross sections.

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1.3 Study Approach and Scope of Work

Establishing a suitable study approach to assess instream flow needs for the Santa Maria River was one of the most challenging aspects of this study. This was due to the fact that the river does not naturally exhibit regular, annual surface flow to the ocean, and experimental flow releases from Twitchell Dam during the study were not feasible. Additionally, the river has a highly mobile sand bed whose configuration can change rapidly, making accurate flow measurements difficult, particularly at low flow levels. For the same reason, common methods of predicting flow widths and depths on the presumption of a stable channel cross-section would yield meaningless results.

Much consideration was given to a variety of existing techniques to assess instream flow needs, but few seemed appropriate. Physical habitat simulation (PHABSIM) models, as a component of the Instream Flow Incremental Methodology (IFIM) framework, are typically used by CDFG for instream flow analyses. IFIM is a framework for developing and implementing instream flow studies in which study methods are applied in a step-by-step manner (Stalnaker et al. 1995, Annear et al. 2004). However, PHABSIM was quickly determined to be an inappropriate and infeasible tool for modeling the flow needed for fish passage on the Santa Maria River. First, the flow and field sampling conditions necessary for development of PHABSIM models are not suitable during the steelhead migration period (or any other time of year) in the mainstem Santa Maria River. Twitchell Dam operators were not legally required to release flows for field sampling during the study period, and very likely cannot release flows solely for the purposes of study as a result of the adjudication of the groundwater basin. Therefore, any flows would have to be sampled opportunistically and, as was quickly learned, flows suitable for sampling typically occur only during storm events and are too high and the channel bed too mobile to sample safely.

Moreover, flows are commonly too brief to mobilize field crews in time to conduct the detailed field sampling needed to collect data to populate a PHABSIM model. Complex hydrology, including a dramatic longitudinal gradient in discharge (typically, 10–20 cfs change per mile but with much local variability), in combination with short-duration, high-magnitude flow events and a highly mobile, braided sand bed, result in flow and geomorphic conditions that vary widely over time and space. This combination makes data collection during stable flow conditions virtually impossible and violates key data-collection assumptions of PHABSIM, making key components of a PHABSIM modeling approach infeasible and inappropriate. In addition, fish passage on the Santa Maria River is not typically limited by micro- and macro-scale habitat parameters, but rather by the simple presence/absence of any flow at all. Indeed, entire years go by without any flow whatsoever in the mainstem river.

Due to the study constraints described above, a hybrid instream flow assessment method was developed for the Santa Maria River Instream Flow Study by Stillwater Sciences in consultation with the study's technical coordination team (Robert Holmes and Mary Larson of CDFG, and Mark Capelli and Lee Harrison of NOAA Fisheries). This method conforms to the IFIM framework by incorporating problem identification, collaborative study planning and implementation, evaluation of alternatives, and collaborative problem resolution. The method, described in detail in Section 3, also takes into account the complex hydrology, geomorphology, and natural and historical flow conditions of the watershed, to produce a useful and meaningful outcome using the primarily remotely-sensed data that is available.

A combination of hydraulic calculations and field measurements were used to identify the flow *magnitude* for adult and juvenile steelhead passage to and from the Pacific Ocean and spawning and rearing habitat in the Sisquoc River watershed (see Sections 3.2.1 and 3.3). The

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recommended *duration* of these flows was developed based on documented steelhead migration speeds, migration distances within the watershed, and location of the critical passage reach along the migration route (see Section 3.2.2). The recommended *frequency* of ecologically meaningful flows is based on analyses of pre-Twitchell Dam hydrologic conditions (see Section 3.4).

The Santa Maria River Instream Flow Study included eight discrete tasks summarized below.

Task 1. Data compilation, collection, and field reconnaissance. Historical and contemporary existing reports and data sources related to watershed hydrology, hydraulics, morphology, water quality, fisheries biology, and the estuary were compiled and reviewed. In addition, detailed topography was collected for the lower 35 miles of the Santa Maria and Sisquoc rivers using airborne-based Light Detection And Ranging (LiDAR). Much of this information is incorporated into this report and referenced in Section 6. A bibliography of all compiled reports and data sources is available upon request.

Task 2. Groundwater–surface water investigations. Historical and contemporary existing reports and data related to groundwater patterns and management in the Santa Maria groundwater basin were reviewed and summarized. In addition, groundwater models generated as part of the adjudication of the Santa Maria groundwater basin were reviewed for relevancy to the Instream Flow Study. The results of these reviews are documented in technical memoranda (Daniel B. Stephens and Associates, Inc. [DBS&A] 2010, Kear Groundwater 2011) and synthesized in Section 2.4. Lastly, a new and simplified groundwater–surface water model was developed, using a single iterative regression equation, to quantify the relationships between surface water and groundwater along the critical passage reach, and to display the typical interplay between downstream surface flow and upstream flow, antecedent flow, depth to groundwater, and releases from Twitchell Dam. This model is described in Sections 3.5 and 4.5.

Task 3. Estuary/breach studies. The objective of Task 3 was to document whether steelhead currently use the Santa Maria River estuary and whether estuarine conditions are suitable for juvenile steelhead rearing. This task was included out of a concern that habitat conditions in the Santa Maria River estuary become unsuitable or lethal to juvenile steelhead over the summer/fall and that out-migrating juvenile steelhead may become "trapped" in these conditions. Water levels and water temperature in the Santa Maria River estuary were monitored using continuously-recording data loggers. Habitat conditions related to potential steelhead rearing in the estuary were evaluated and estuary sandbar breaching patterns were researched. Water level and quality monitoring methods and results are reported in Appendix A and are summarized in Sections 3.1 and 4.1, along with a description of estuary habitat conditions and sandbar breaching patterns, and an evaluation of steelhead rearing potential in the estuary. Originally this task was to include sampling for *O. mykiss* and (secondarily) tidewater goby (*Eucyclogobius newberryi)* in the Santa Maria River estuary, but permits to sample for these federally endangered species were not granted in time for the Instream Flow Study.

Task 4a. Steelhead passage criteria. Hydraulic criteria (water depths, widths, and velocities) for steelhead passage were compiled, reviewed, and selected for use in this study. In addition, swimming speeds and life history timing information for southern steelhead was assembled to inform the timing and duration of passage flows. The selection of passage criteria is described in a technical memorandum (Stillwater Sciences 2011a) and summarized in Sections 3.2 and 4.2.

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Task 4b. Sisquoc River Habitat Suitability Index (HSI) model. The quantity and quality of instream and riparian habitat for steelhead in the Sisquoc River watershed was assessed using the US Fish and Wildlife Service (USFWS) Habitat Suitability Index (HSI) model approach (Raleigh et al. 1984). The results of the HSI study, which are reported in a separate technical memorandum (Stillwater Sciences 2012), demonstrate the relative value of the Sisquoc River watershed for steelhead rearing, illustrate limiting habitat factors and potential restoration options, and are comparable to other recent HSI studies in nearby watersheds.

Task 5. Assess instream flows required to provide suitable passage conditions for adult and juvenile steelhead migration. Hydraulic calculations (based on Manning's equation) were used to determine the flows necessary, given losses to groundwater, to achieve steelhead passage criteria (i.e., adequate depth and width and sufficiently low velocity) at critical passage locations. In addition, field measurements of surface water depth, velocity, and discharge were made under a range of flow conditions in the winter of 2010/2011. Historical and contemporary U.S. Geological Survey (USGS) gage data were used to evaluate how frequently and for what duration those flows occurred under pre- and post-Twitchell Dam hydrologic conditions. The methods and results associated with Task 5 were reported in a series of technical memoranda (Stillwater Sciences 2011b, 2011c, 2011d, and Stillwater Sciences and Kear Groundwater 2011) and are discussed in detail in Sections 3.3, 3.4, 4.3, and 4.4.

Task 6. Recommendations. Utilizing the results of Tasks 1, 2, 4a, and 5, flow recommendations were developed that should allow juvenile and adult steelhead migration through the Santa Maria River, that reflect the frequency of migration opportunities under the pre-Twitchell Dam flow regime, and that ensure synchronization of migration opportunities through the Santa Maria River with those in the Sisquoc River. These recommendations, which specify the magnitude (cfs), duration, and frequency of flows necessary to meet adult and juvenile steelhead passage criteria in the critical passage reach under dry, intermediate, and wet hydrologic year types, are reported in Sections 4.3, 4.4, and 5. In addition, operational rules that could be used to achieve the recommended flows in the mainstem Santa Maria River are described.

Task 7. Public outreach and coordination. A technical coordination team (see Acknowledgements) was convened and met on an approximately quarterly basis to discuss the study scope of work, approach, and technical issues, and to review interim technical memoranda. Technical coordination team meeting dates, topics of discussion, and key decisions made are summarized in Section 6.2. Three public meetings were held in Santa Maria to ensure that all stakeholders were aware of the study and approach, and to receive input from and answer the questions of interested stakeholders.

1.4 Southern Steelhead (*Oncorhynchus mykiss*) Life History in the Santa Maria River Watershed

Steelhead are the anadromous, or ocean-going, form of the species *Oncorhynchus mykiss*. Rainbow trout are the resident form of the same *O. mykiss* species. Both anadromous and resident life history forms are expressed within the Santa Maria River watershed. The two forms are capable of interbreeding and current evidence suggests that that, under some conditions, either life history form can produce offspring that exhibit the alternate form (i.e., resident rainbow trout can produce anadromous progeny and vice-versa) (Hallock 1989, Burgner et al. 1992, Donohoe et

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al. 2008, Zimmerman et al. 2009), although in some watersheds the two life histories are distinct (Pearse et al. 2009, Sogard et al. 2011). The mechanisms or conditions that trigger or promote the expression of these life history forms, and the portion of each form that may comprise a particular population is not well-understood, but is an active area of research. A genetic study of *O. mykiss* in the Sisquoc River watershed is currently underway by NOAA Fisheries, but results were not available at the time of report production.

The Santa Maria River watershed currently supports a self-sustaining population of native rainbow trout (the resident life-history of *O. mykiss*) in the Sisquoc River watershed (Davis and Jackson ca. 1934, Evans 1947, Douglas and Richardson 1959, Edwards et al. 1980, Kautzman and Uyehara 1999, and others, all as cited in Becker and Reining 2008; also, Shapovalov 1944, Cardenas 1996, Boughton and Fish 2003, Stoecker 2005). It also supports anadromous spawning of adult steelhead (the ocean-going life-history of *O. mykiss*) during some wet years (Shapovalov 1944, Shapovalov 1945, Titus et al. 2006, Stoecker 2005). Based on newspaper articles and historical records from CDFG (CFGC 1919, Shapovalov 1944; various, as compiled and cited in Stoecker and Stoecker 2003; various, as cited in Becker and Reining 2008), the Santa Maria River watershed historically supported a larger population of anadromous steelhead than is observed under current conditions. However, neither Shapovalov (1944) nor any other identified sources provide quantitative population estimates.

Coastal watersheds in central and southern California, including the Santa Maria River watershed, have highly variable stream flows and are frequently isolated from the Pacific Ocean by sandbars (which impound seasonal lagoons). Despite these challenges, southern California steelhead continue to persist in much of their former range (Boughton and Fish 2003, Bell et al. 2011a), including the Santa Maria River (Boughton and Fish 2003, Stoecker 2005, Titus et al. 2006). As discussed below, life history diversity allows southern California steelhead to adapt to the inherent environmental challenges of supporting populations under the variable hydrologic conditions in central and southern California. Figure 1.4-1 provides a generalized schematic description of typical resident and anadromous *O. mykiss* life histories believed to occur in southern California. The Instream Flow Study and resulting flow recommendations focus specifically on the short period of transition between marine and freshwater habitats that occurs during adult and juvenile (smolt) migration. However, it should be recognized that one of the hallmarks of *O. mykiss* is their extreme variability in life-cycle histories, including the timing and duration that they spend at different times during their development, growth, and maturation in freshwater and marine habitats (Shapovalov and Taft 1954, Quinn 2005, Mangel and Satterthwaite 2008, NOAA Fisheries 2012).

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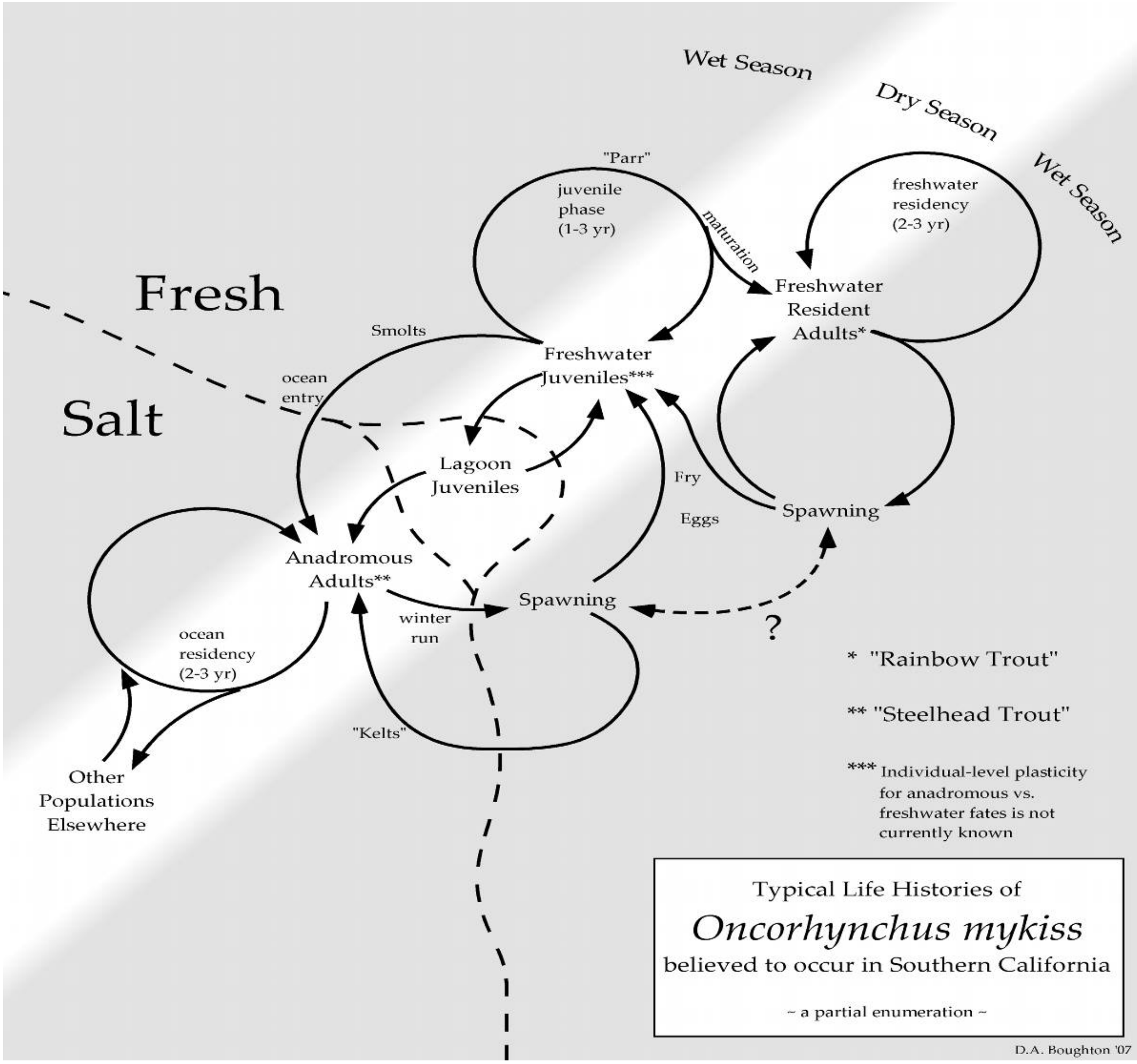

Figure 1.4-1. Southern California *O. mykiss* life history diagram, depicting life-cycle complexity (modified from Boughton 2007).

1.4.1 Adult migration

Steelhead in California return to spawn in their natal stream, usually in their third or fourth year of life (Shapovalov and Taft 1954, Behnke 1992) (Figure 1.4-1). Adult steelhead have been observed migrating upstream within the Santa Maria River watershed under suitable conditions (Shapovalov 1944, Shapovalov 1945, Stoecker 2005, Titus et al. 2006). Based on data from nearby rivers (Fukushima and Lesh 1998) and hydrologic patterns on the Santa Maria River (see Section 4.4), adult steelhead migration in the Santa Maria River watershed is estimated to occur between December and April, although even within this period specific migration timing is contingent upon adequate flow conditions. Historically and currently, opportunities for adult steelhead to return to the Santa Maria River watershed to spawn are limited by the frequency and

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duration of migration opportunities. Migration opportunities, which are a focus of this report, are related to two primary factors: 1) lagoon sandbar formation, and 2) flow in the seasonally dry Santa Maria and lower Sisquoc rivers.

Southern California steelhead's life history flexibility appears adapted to infrequent or otherwise limited migration opportunities. This flexibility includes the ability to postpone migration if conditions are not suitable, and to stray to other southern California streams when the need arises (Clemento et al. 2009, Pearse et al. 2009). Growth conditions in the ocean also play a role in determining whether adult steelhead are in suitable physical condition to undertake the rigors of migration and spawning. Steelhead that return to the Santa Maria River only to encounter a closed sandbar or unsuitable migration conditions are likely to stray to other available watersheds. Conversely, in years with suitable migration conditions, steelhead may stray from other watersheds to the Santa Maria River. Straying into watersheds with suitable migration conditions provides an important component in the maintenance of population viability and genetic diversity (Boughton et al. 2006). Recent work on *O. mykiss* population genetics in south-central and southern California suggest that steelhead populations within this range are genetically very similar and indicates high rates of gene flow resulting from straying and reproducing (Clemento et al. 2009).

1.4.2 Spawning, egg incubation, and emergence

Because the Santa Maria and lower Sisquoc rivers are seasonally dry, adults are required to migrate through this reach to access suitable spawning sites in the Sisquoc River watershed (steelhead passage in the Cuyama River is blocked by Twitchell Dam). Female steelhead construct redds in suitable gravels, often in pool tailouts and heads of riffles, or in isolated patches in cobble-bedded streams. Surveys of available habitat and observations of multiple age classes of *O. mykiss* have concluded that suitable spawning habitat is abundant in the Sisquoc River watershed, including within the upper mainstem Sisquoc and South Fork Sisquoc rivers, and Manzana and Davey Brown creeks (Davis and Jackson ca. 1934, Evans 1947, Douglas and Richardson 1959, Edwards et al. 1980, Kautzman and Uyehara 1999, and others, all as cited in Becker and Reining 2008; Shapovalov 1944, Cardenas 1996, Boughton and Fish 2003, Stoecker 2005). Spawning does not appear to have been historically supported, nor is currently supported, in the seasonally dry Santa Maria River.

Steelhead eggs incubate in the redds for 3–14 weeks, depending on water temperatures (Shapovalov and Taft 1954, Barnhart 1991). After hatching, alevins remain in the gravel for an additional 2–5 weeks while absorbing their yolk sacs, and then emerge in spring or early summer (Barnhart 1991). In the Santa Maria River watershed, spawning would likely occur shortly after migration and, based on water temperatures, fry likely emerge between February and July (Shapovalov and Taft 1954, Barnhart 1991).

Wildfires are common across this region, and they can result in: 1) loss of riparian vegetation, which helps moderate stream temperatures, and 2) dramatic increases in ash and fine sediment, which can embed spawning substrates and smother incubating eggs. Both of these effects are temporary, but for a period of a few years they can degrade the quality and decrease the extent of suitable spawning habitat until riparian vegetation re-establishes and/or fine sediment is flushed out of the area by flow events. Surveys of the Sisquoc River watershed have documented impacts to *O. mykiss* spawning and incubation habitat as a result of fires (e.g., Shapovalov 1944, Titus et al. 2006, Love and Stoecker 2009, Stillwater Sciences 2012), but they have also documented subsequent recovery (Richardson 1959, Stoecker 2005).

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1.4.3 Fry and juvenile rearing

After emergence, steelhead fry move to shallow, low-velocity habitats, such as stream margins and low-gradient riffles, and forage in open areas lacking instream cover (Hartman 1965, Fontaine 1988). As fry grow and their swimming abilities improve in the late summer and fall, they increasingly use areas with cover and show a preference for higher velocity, deeper mid-channel areas near the thalweg (the deepest part of the channel) (Hartman 1965, Everest and Chapman 1972, Fontaine 1988). Juvenile steelhead occupy a wide range of habitats, including deep pools and higher-velocity riffle and run habitats (Bisson et al. 1982, 1988). During periods of low temperatures and high flows in winter months, steelhead prefer low-velocity pool habitats with large rocky substrate or woody debris for cover (Hartman 1965, Raleigh et al. 1984, Swales et al. 1986, Fontaine 1988). During high winter flows, juvenile steelhead seek refuge in interstitial spaces in cobble and boulder substrates (Bustard and Narver 1975). Based on surveys conducted by Stoecker (2005), suitable rearing habitat for fry and juveniles appears abundant in the Sisquoc River watershed. Rearing habitat does not appear to have been historically supported, nor is currently supported, in the seasonally dry lower Sisquoc or Santa Maria rivers (Becker et al. 2010). However, intermittent stream reaches can, under certain conditions, provide seasonally favorable rearing conditions (Boughton et al. 2009).

As with spawning habitat, the primary natural threat to suitable rearing habitat within the Sisquoc River watershed is wildfire. Wildfires can result in loss of riparian vegetation, which helps moderate stream temperatures, provides cover from predators, and is a source of prey. Dramatic increases in ash and fine sediment after a wildfire can temporarily fill pools and interstitial spaces used for summer and winter rearing. As with spawning habitat, those same surveys of the Sisquoc River have documented both impacts to (and subsequent recovery of) *O. mykiss* rearing habitat as a result of fires.

1.4.4 Smolt outmigration

Juvenile steelhead rear in freshwater before out-migrating to the ocean as smolts. Smolts are usually between one and two years old and have undergone the physiological changes that will allow them to survive in brackish and saltwater conditions. The duration of time that juvenile steelhead spend in fresh water appears to be related to growth rate, with larger, faster-growing individuals out-migrating to the ocean earlier (Peven et al. 1994). Steelhead in California typically spend two years in freshwater prior to out-migrating (Shapovalov and Taft 1954), although there are watersheds where juveniles with high growth rates have been observed to out-migrate after just one year (Smith 1990, Bell et al. 2011b). Based on data from nearby rivers, steelhead outmigration commonly occurs between January and June (Fukushima and Lesh 1998), although outmigration timing is also contingent upon adequate flow conditions (see Section 4.4). In the Santa Maria River, flows that provide fish passage opportunities are relatively short and infrequent, making juvenile and adult migration highly opportunistic, and likely cause juvenile outmigration and adult spawning migrations to substantially coincide.

Due to the flexibility in age at outmigration, steelhead do not require suitable flows for juvenile outmigration to the ocean in all years. In many populations steelhead are observed to out-migrate opportunistically when conditions are suitable. In some of these same populations, such as in San Gregorio and Scott creeks in San Mateo and Santa Cruz counties, seasonal lagoons provide additional rearing habitat for out-migrants prior to entering the ocean. Depending partly on the productivity and growth potential of rearing habitats, steelhead may out-migrate to lagoons or estuaries, or they may continue to rear in upstream riverine habitats for up to four years (most frequently two years) before out-migrating to the estuary and ocean (Shapovalov and Taft 1954).

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In Scott Creek, for example, three life-history pathways have been documented, including juvenile steelhead that rear only in the upper watershed, those that rear primarily in the lagoon/estuary, and those that rear partially in the upper watershed and partially in the lagoon/estuary (Hayes et al. 2008). Although the Santa Maria River has a relatively large seasonal estuary, no data are available on its use by *O. mykiss*, and opportunities for out-migrating *O. mykiss* to access and persist in the estuary appear to be limited (see Section 4.1).

1.4.5 Marine residence

Upon entering the marine environment, steelhead transition both physiologically and in the food resources they rely on to persist. Their early success is dependent upon the availability of sufficient food resources and their ability to locate and capture it. This transition period can be difficult to survive and is a potential source of significant mortality when ocean conditions are inhospitable. Once established in the marine environment, steelhead utilize a wide range of food items and are able to grow quickly with sufficient resources. The majority of steelhead spend one to three years in the ocean, with smaller smolts tending to remain in salt water for a longer period than larger smolts (Chapman 1958, Behnke 1992). Larger smolts have been observed to experience higher ocean survival rates (Ward and Slaney 1988). Steelhead grow rapidly in the ocean compared to in freshwater rearing habitats, with growth rates potentially exceeding 2.5 cm (1 inch) per month (Shapovalov and Taft 1954, Barnhart 1991). Unlike other salmonids, steelhead do not appear to form schools in the ocean. Consequently, the movement patterns of steelhead at sea are poorly understood. Some anadromous salmonids have been found in coastal waters relatively close to their natal rivers, while others may range widely in the North Pacific (Grimes et al. 2007, Quinn 2005, Quinn and Myers 2005, Myers et al. 2000, Myers et al. 1996, Groot et al. 1995, Groot and Margolis 1991, Burgner et al. 1992, 1980). Steelhead in the southern part of the species' range appear to migrate close to the continental shelf, while more northern populations of steelhead may migrate throughout the northern Pacific Ocean (Barnhart 1991). Ocean conditions can vary based on regional or seasonal conditions (e.g., El Niño, upwelling) and can have dramatic effect on steelhead populations from year to year.

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2 WATERSHED CHARACTERIZATION

2.1 Watershed Physiography and Geology

The Santa Maria River watershed is one of the largest along the southern California coast, draining approximately 1,900 mi^2 from elevations reaching over 8,800 ft above sea level (Table 2.1-1). The watershed is effectively divided into three parts, or sub-watersheds, where the two major tributaries (the Cuyama and Sisquoc rivers) join east of the city of Santa Maria to form the Santa Maria River before discharging into the Pacific Ocean. The Cuyama and Sisquoc rivers originate from the east in steep headwaters in the Caliente, Sierra Madres, and San Rafael mountain ranges. Overall, the landscape topography (and drainage network pattern) is strongly influenced by the orientation of different rock types and fault control on long-term patterns of erosion.

Table 2.1-1. Santa Maria River watershed and subwatershed areas, stream lengths, and maximum relief.

Subwatershed	Area* (mi^2)	Stream length* (mi)	Maximum relief* (ft)
Cuyama	1,145	107	8,464 (8,818–354)
Sisquoc	475	58	6,474 (6,828–354)
Santa Maria	237	24	1,902 (1,902–0)
Entire watershed	1,857		8,818

* Determined from a USGS 10-m digital elevation model.

The watershed lies at the boundary of two geomorphic regions: the Coast Ranges and the Transverse Ranges—both highly influenced by right-lateral movement along the San Andreas Fault Zone (Figure 2.1-1). The majority of the watershed is crossed by several northwest-trending faults—Pine Mountain, Morales, Ozena, South Cuyama, La Panza, East and West Huasna, Santa Maria River, and Hosgri (offshore)—that continue northwestward providing the northwestern grain of the watershed and the Coast Range province. The headwaters of the watershed are also influenced, however, by a western deflection in the San Andreas Fault Zone trace within the Transverse Range province, which includes the Big Pine Fault. This deflection causes a convergence of north-migrating rocks of the Pacific Plate (which include those of the Santa Maria River watershed), resulting in rapid rates of landscape uplift in this region. Uplift rates in the nearby Santa Ynez Mountains have been estimated to range from 0.75 to >5 mm[1] per year (Metcalf 1994, Trecker et al. 1998, Duvall et al. 2004). In contrast to the rising mountain ranges, coastal subsidence of Santa Maria Valley has occurred throughout the Quaternary likely as a result of displacement along bounding faults (Orme 1998).

[1] As noted in Section 1.5, conventional units for all data are reported.

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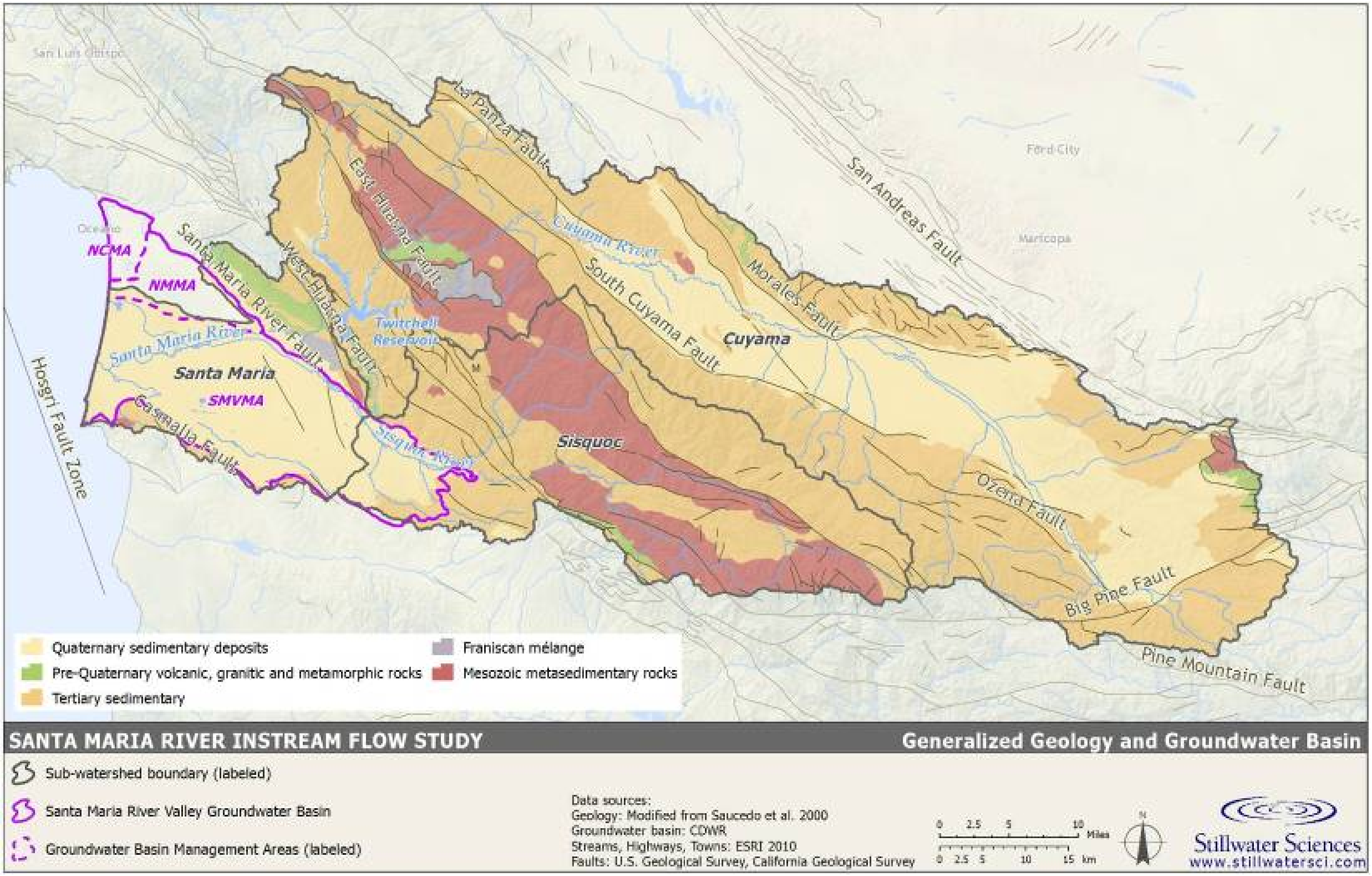

Figure 2.1-1. Generalized geology of the Santa Maria River watershed with the Santa Maria River groundwater basin boundaries (SMVMA = Santa Maria Valley Management Area, NMMA = Nipomo Mesa Management Area, NCMA = Northern Cities Management Area).

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The lithology of the watershed is characterized as a mix of geologically old, competent plutonic basement and metasedimentary rocks, principally found along the high-relief mountain ranges; and young, weakly consolidated marine and some non-marine sedimentary rocks composing the valley bottoms (Figure 2.1-1) (Gutierrez et al. 2010). Several distinct assemblages of similar rock units (i.e., age and formation type) are present between bounding faults. The most significant assemblages relevant to this study are the two Quaternary alluvium assemblages, one of the Cuyama Valley bounded between the South Cuyama–Ozena and La Panza–Morales faults, and the other of the Santa Maria Valley bounded between the Santa Maria River and Casmalia–Hosgri faults. The Cuyama and Santa Maria valleys are the two principal depositional basins in the watershed and, accordingly, support the watershed's two main groundwater basins (see Section 2.4 below). It has been estimated that each basin has a maximum thickness of sediments reaching 2.0 and 2.9 km, respectively, that have been filling continuously over the past 4 million years (Christiansen and Yeats 1992).

2.2 Climate/Precipitation

The Santa Maria River watershed lies in a Mediterranean climatic zone, with a long dry season and episodic wet-season storms. Most precipitation occurs between November and March, with precipitation varying significantly throughout the watershed and most strongly influenced by elevation and distance from the Pacific Ocean (Figure 2.2-1). The wettest areas are found along the Sierra Madre Mountains in the center of the watershed, while the driest areas are found in the lowlands of the Santa Maria and Cuyama valleys. Overall, average annual precipitation in the watershed has ranged between 3 and 50 inches during the years 1971–2000, with the wettest areas historically in the southern headwaters of the Sisquoc River. At higher elevations, some winter precipitation occasionally falls as snow.

In the Santa Maria River watershed, the two major tributaries occupy different physiographic regions with different precipitation patterns (Figure 2.2-1). The Sisquoc River drains the marine face of the Sierra Madre Mountains, and it receives an annual average of 20–30 inches of precipitation (almost all as rainfall). The Cuyama River drains the "back" side of the Sierra Madre Mountains and the lower, drier hills and mountains farther inland; its average annual precipitation is about half that of the Sisquoc River watershed.

Climate in the watershed is also subject to hemispheric variability in climate trends, most strongly the El Niño-Southern Oscillation (ENSO) (Figure 2.2-2), which expresses itself in the watershed by high year-to-year variability in rainfall and resulting streamflow. ENSO is characterized by warming and cooling cycles in the waters of the eastern equatorial Pacific Ocean, which typically have a 1–1.5 year duration and a 3–8 year recurrence interval (NWS CPC 2010). In southern California, El Niño years (those with a relative high sea-surface temperature) are commonly accompanied by relatively high rainfall intensities, with rivers and streams (such as those in the Santa Maria River watershed) exhibiting higher annual peak flow magnitudes than they do in non-El Niño ("La Niña") years. The most recent ENSO event occurred in water year[2] 2010 (NWS CPC 2010).

[2] A water year is the 12-month period from October 1 of a given year through September 30 of the following year. The water year is designated by the calendar year in which it ends. For example, the water year beginning October 1, 1998 and ending September 30, 1999 is called the 1999 water year (or "WY 1999").

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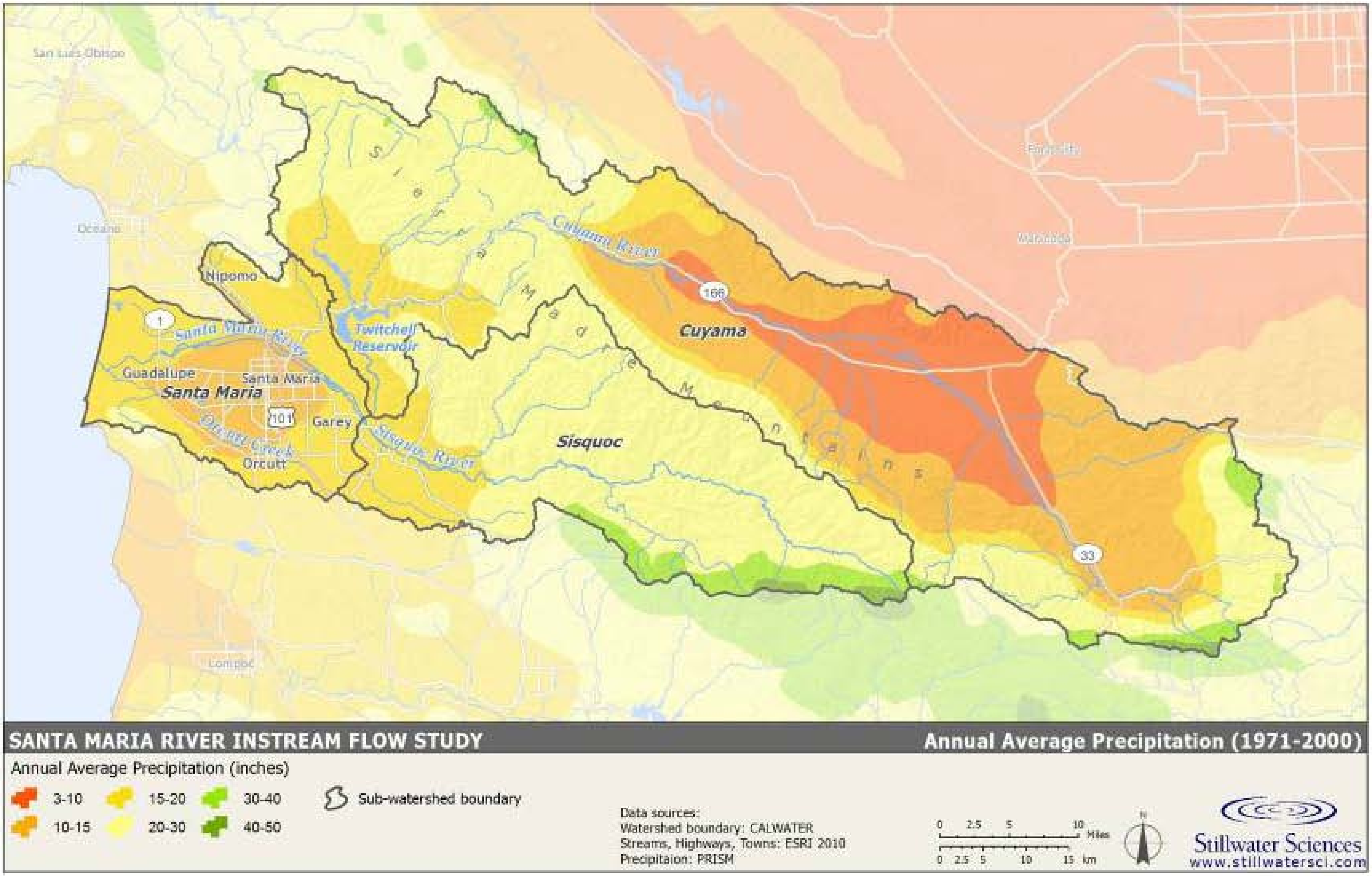

Figure 2.2-1. Average annual precipitation in the Santa Maria River watershed (data from PRISM [www.prism.oregonstate.edu/]).

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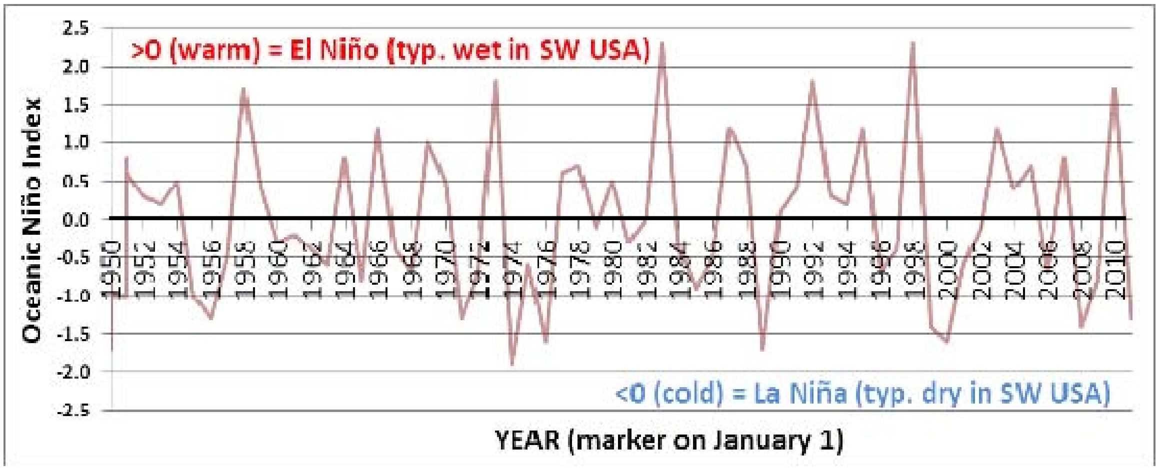

Figure 2.2-2. Three-month running average of the "Oceanic Niño Index," plotting monthly departures relative to the 1971–2000 base period (data from National Weather Service, Climate Prediction Center; http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml; accessed December 13, 2011).

2.3 Surface Water Hydrology and Geomorphology

Surface flow conditions in the Santa Maria River have been characterized by numerous USGS gages maintained in the watershed for more than 80 years. Table 2.3-1 and Figure 2.3-1 summarize the key stream gage locations and data used for this study.

Table 2.3-1. Major flow-gaging sites in the Santa Maria River watershed (see Figure 2.3-1 for locations).

USGS Gage No.	Gage location	Period of record					
		1920–30s	1940s	1950s	1960s	1970–80s	1990–present
11141000	Santa Maria River near Guadalupe		Start: 10/1940			End: 9/1987	
11140585	Santa Maria River at Suey						4/1999–present
11136800	Cuyama River below Buckhorn			Start: 10/1959			present
11137000	Cuyama River near Santa Maria	Start: 10/1929			End: 9/1962		
11138100	Cuyama River below Twitchell Dam			Start: 10/1958		End: 9/1983	
11140000	Sisquoc River near Garey		Start: 2/1941				present
SMVWCD[3] gage	Twitchell Dam outflow				Start: 2/1962		present

[3] Santa Maria Valley Water Conservation District (www. smvwcd.org/)

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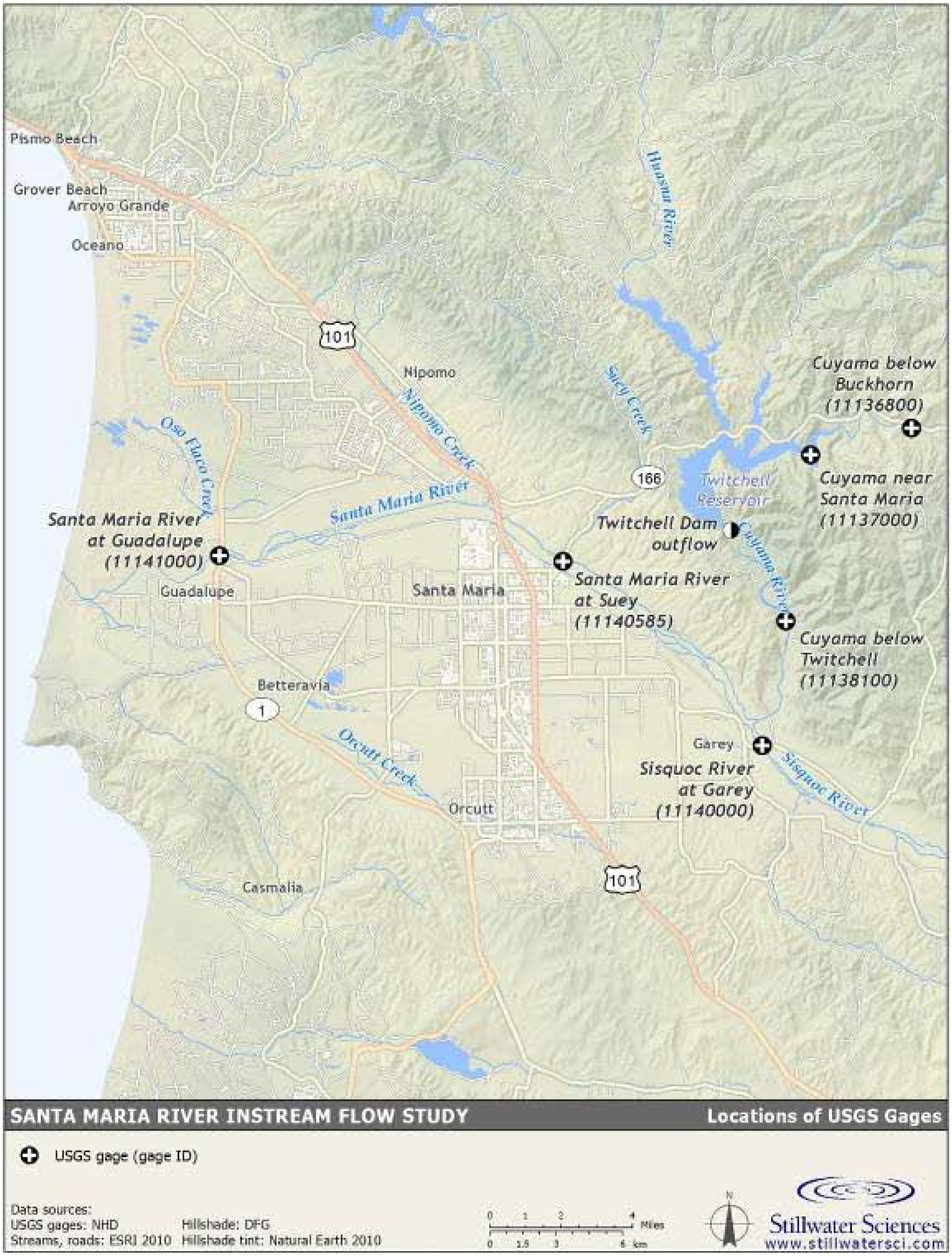

Figure 2.3-1. Key gage locations (including gage name and number) in the Santa Maria River watershed.

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2.3.1 Sisquoc River watershed

The Sisquoc River watershed is primarily mountainous, draining a largely forested and chaparral-covered landscape. Streams in the upper watershed are generally confined and single-threaded with coarse bed substrate (e.g., gravel/cobble) and a narrow riparian zone bordering the channel. The small to moderately-sized channels tend to have perennial flow, riparian cover, and a diversity of aquatic habitat (e.g., pool, riffle, run). As drainage area increases, the mainstem Sisquoc River channel exhibits confined reaches interspersed with moderately-confined and unconfined reaches where multiple channels and islands may develop. The lowermost 10 miles of the river flow in the flat sediment-filled valley that also contains the mainstem Santa Maria River, and so they have a geomorphic and hydrologic character much more akin to the mainstem river than to its upslope tributaries. The lower Sisquoc River has a braided, sand and gravel dominant channel with comparatively less riparian vegetation or habitat diversity and is seasonally dry for longer periods, especially in the lower reaches near the confluence with the Cuyama River. Located about one mile upstream of the confluence with the Cuyama River, the Sisquoc River at Garey gage (USGS 11140000) best reflects the hydrologic condition of the Sisquoc River as it enters the mainstem.

Although the river drains the wettest parts of the Santa Maria River watershed, its flow in the lowermost reach is still intermittent. In the daily record from 1941 to the present, the lower channel has been dry (i.e., <1 cfs average daily flow) on average more than nine months of the year (Figure 2.3-2).

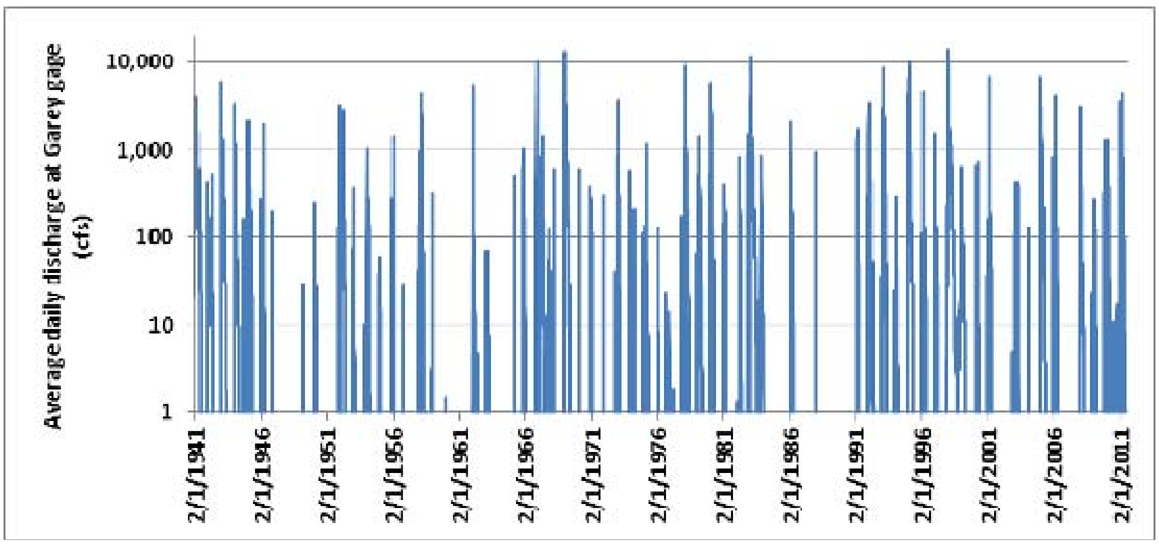

Figure 2.3-2. 60 years of average daily discharges in the Sisquoc River at Garey (USGS 1114000). Average flow for this period is 55 cfs (although the median flow is zero).

2.3.2 Cuyama River watershed

2.3.2.1 Cuyama River

The Cuyama River is a dryland river (Bull and Kirby 2002) over much of its length, with a braided channel pattern confined by low and sparsely vegetated banks, a sandy channel bed, and long periods of no flow. Although it drains a watershed area more than twice that of the Sisquoc River, it is the lesser contributor of surface flow to the mainstem Santa Maria River, with an

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average flow of only 18 cfs at the Cuyama River near Santa Maria River gage just above Twitchell Reservoir (USGS 11137000) for the period 1941–1962.

The channel of the Cuyama River abruptly changes its form as it crosses the axis of the Sierra Madre Mountains. It has carved through a ridge of up-arched rocks, presumably reflecting a rate of channel down-cutting that has kept pace with the uplift of the surrounding rocks over the past thousands to millions of years. Upstream of this ridge, the channel is low gradient and unconfined; where it crosses the mountains, through and downstream of the axis of uplift, it is a steep bedrock-confined channel. Near the southern rangefront, Twitchell Dam was constructed across the lower valley of the river.

2.3.2.2 Twitchell Dam and Reservoir

Twitchell Dam impounds the Cuyama River approximately six miles upstream of its confluence with the Sisquoc River, collecting drainage from a 1,135 mi^2 catchment in the driest portion of the overall Santa Maria River watershed. Twitchell Dam was constructed between 1956 and 1958 as a joint project of the U.S. Bureau of Reclamation (Reclamation) and the U.S. Army Corps of Engineers. It was designed primarily to provide relatively short-term storage and release of flows from the Cuyama River to replenish the Santa Maria Valley groundwater basin. Its design also included flood control for infrequent, very high flows. General information about the facility is readily available from Reclamation's website (http://www.usbr.gov/projects/Facility.jsp?fac_Name=Twitchell Dam). The Santa Maria Valley Water Conservation District (the District) operates the dam during all non-flood periods, and it has maintained continuous daily records of water elevation, releases, and meteorological data since the first recorded closure of the dam outlet gates (February 16, 1962).

The reservoir has a nominal capacity of 224,300 ac-ft, of which the majority is used to store water during winter storms and then released at a rate to maximize percolation into the riverbed of the mainstem Santa Maria River and so recharge the groundwater. Releases are timed to minimize any surface-water flow reaching the Pacific Ocean; thus, more than 90% of all releases have occurred when the Sisquoc River at Garey is flowing less than 250 cfs. The reservoir is usually far from full; the maximum recorded storage volume from the Twitchell Dam daily operations report was 189,539 ac-ft on May 1, 1983, with the water-surface elevation at 641.49 ft. The other large storage periods were in 1969 (maximum water elevation 636.38 ft [189,063 ac-ft] on March 1), 1995 (maximum water elevation 629.18 ft [152, 102 ac-ft] on April 2), and 1998 (maximum water elevation 636.87 ft [154,842 ac-ft] on May 17) (Figure 2.3-3).

Sedimentation is a serious problem for the reservoir operators, as the record of extreme events demonstrates. Between the two peak storage events of 1969 and 1998, for example, the recorded volume of stored water decreased by more than 34,000 ac-ft (15% of the total reservoir volume) for an average rate of loss of almost 1,200 ac-ft/year. This is also reflected in the elevation of zero storage volume: after operations began, the reservoir was first recorded as dry on May 27, 1964, at water-surface elevation 477 ft; most recently (January 2010), the level of a dry pool was about 527 ft elevation. In addition, the water inlet to the control gates is episodically blocked, requiring periodic flushing and, for the sediment deposited below the dam, localized channel dredging. Releases from Twitchell Dam are presently held below 400 cfs in order to avoid flooding of property that is downstream of the dam and adjacent to the river channel (T. Gibbons, Santa Maria Valley Water Conservation District board member, pers. comm., 2011).

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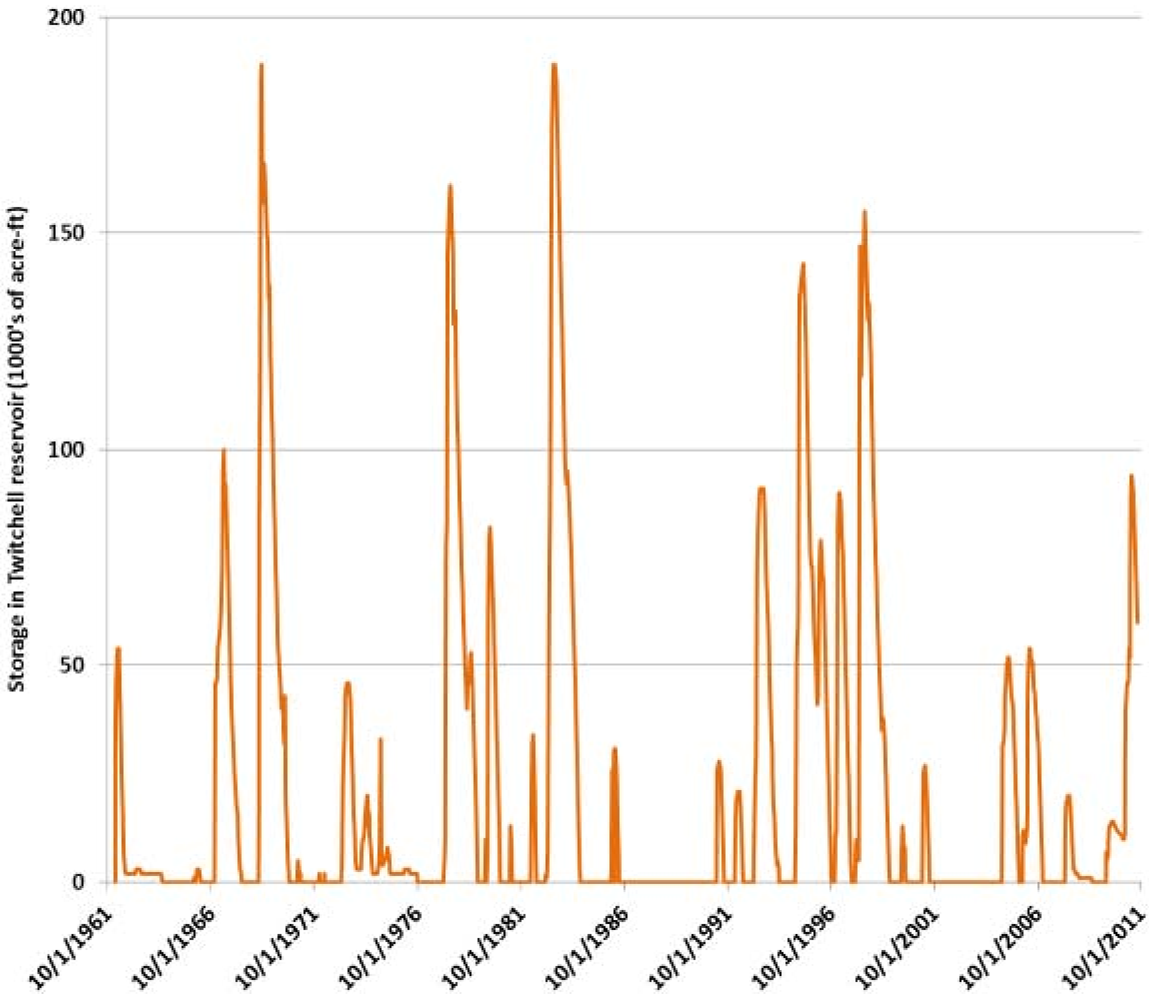

Figure 2.3-3. Volume of water stored behind Twitchell Dam over the period of operation (February 16, 1962–present). Over these 41 years, about two million acre-feet have been held behind the dam for periods ranging from a few weeks to more than a year (i.e., almost 50,000 ac-ft of average annual storage). Data compiled from daily records of the Santa Maria Valley Water Conservation District.

2.3.3 Mainstem Santa Maria River

The mainstem Santa Maria River is a 24-mile reach that extends from its estuary at the Pacific Ocean, east through the city of Santa Maria, to the confluence of the Cuyama and the Sisquoc rivers. It is a classic braided, sand-bedded channel that is dry, on average, more than 90% of the time; the Guadalupe gage (USGS 11141000) record from 1941–1987 reported periods every year of continuous zero discharge, some up to three years in duration. When the river does flow, the transported sediment is highly mobile and channels are rapidly eroded into the (past) channel and floodplain surfaces. Human disturbance is also common, which includes both agency-sponsored activities to improve flood conveyance and unauthorized off-road vehicle access. All of these conditions combine to render the topography of the channel a transient and rapidly changeable attribute of the river.

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The Santa Maria River is disconnected from the underlying groundwater table from the confluence of the Sisquoc and Cuyama rivers (River Mile 24.5) to approximately nine miles upstream of the Pacific Ocean (River Mile 9.0). Within this 15.5-mile reach, the relationship between surface flow and groundwater is unidirectional, with surface water consistently flowing downward through the unsaturated zone and into the groundwater table (i.e., a losing reach). Conditions in the lowest nine miles of the Santa Maria River, however, are distinctly different. Here, due to an underlying geology of confining clay lenses just beneath the river bed, groundwater levels are shallower and the surface and groundwater appear to act in relative equilibrium in the range of discharges required for steelhead passage (approximately 100–1,000 cfs ranges) (see Section 4.3).

The five- to six-mile reach of the Santa Maria River that begins about 1 mile downstream of Highway 1 and continues past Bonita School Road was identified early in this study as the area most limiting to steelhead passage, or the "critical passage reach" (Figure 1.2-2). This reach is the widest along the river and is where the channel is the most braided; surface flows are generally the shallowest during flow events. This is also the reach where, during the flow events of winter 2010/2011, receding surface flows were observed to first disappear completely into the subsurface (although the specific location varies within the critical passage reach by flow event). Above this reach, the channel begins to narrow and channel substrates coarsen (e.g., in the vicinity of Highway 101). Below this reach, the groundwater table rises due to the underlying geology, and the proximity of groundwater supports dense riparian vegetation that confines the channel width.

2.3.4 Santa Maria River estuary

When the Santa Maria River outlet is blocked by the sandbar at the beach, surface flows impound behind the sandbar and form the Santa Maria River estuary (Figure 2.3-4). Lagoon-type estuaries such as the Santa Maria River estuary are seasonally isolated from ocean waters by barrier beaches or sandbars. When the sandbar is intact, the estuary is separated from the Pacific Ocean and interaction between the ocean and river is limited to seawater and/or freshwater seepage through the sandbar and wave overwash from the ocean into the estuary. When the sandbar is breached, freshwater from the river flows directly into the ocean and the estuary is drained and subject to tidal cycles. The Santa Maria River estuary sandbar is occasionally breached artificially, such as when a person digs a small channel through the sandbar, but also breaches when the estuary fills completely and/or when high river flows break through the sandbar. Information on the size, habitat conditions, and sandbar breaching patterns of the estuary are provided in Section 4.1.

In many California coastal rivers and streams, instream flow conditions allow juvenile steelhead to migrate downstream into a lagoon that is closed off to the ocean (see Section 1.4). This condition can persist for months, and during that time steelhead have been observed to rear and grow before the lagoon opens to the ocean and they continue their migration and marine development (Smith 1990). These habitats can provide conditions that promote growth and improve juvenile fish condition prior to entering the Pacific Ocean, potentially resulting in higher marine survival (Hayes et al. 2008).

In the Santa Maria River estuary, however, water quality conditions are known to be degraded (e.g., SAIC et al. 2004, Anderson et al. 2010, CCAMP 2011) (see Section 2.5.4), and there is concern that habitat conditions in the Santa Maria River estuary could be unsuitable or lethal to any out-migrating juvenile steelhead trapped there over the summer/fall. Orcutt Creek (see Figure 1.2-1) is one of the primary sources of flow into the estuary during most of the year (CCWQP

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2009) and has been shown to display highly toxic and otherwise degraded water quality and sediment characteristics (Anderson et al. 2010, CCAMP 2011). Water-quality conditions in the estuary are summarized in Section 2.5 and 4.1.

Figure 2.3-4. The Santa Maria River estuary in August 2010.

2.3.5 Hydrology and fire in the Santa Maria River watershed

The Santa Maria River watershed lies in a fire-prone region of California, with about three-quarters of all years since 1940 recording at least one fire within the boundaries of the watershed (Figure 2.3-5). Only four years have seen fires that burned more than 5% of the watershed since stream gage records began on the Santa Maria River, however; each of the three largest fires of the last half-century (the 1966 Wellman fire, the 2007 Zaca fire, and the 2009 LaBrea fire) burned between 8 and 11% of the whole watershed (including more than 25% of the Sisquoc River watershed).

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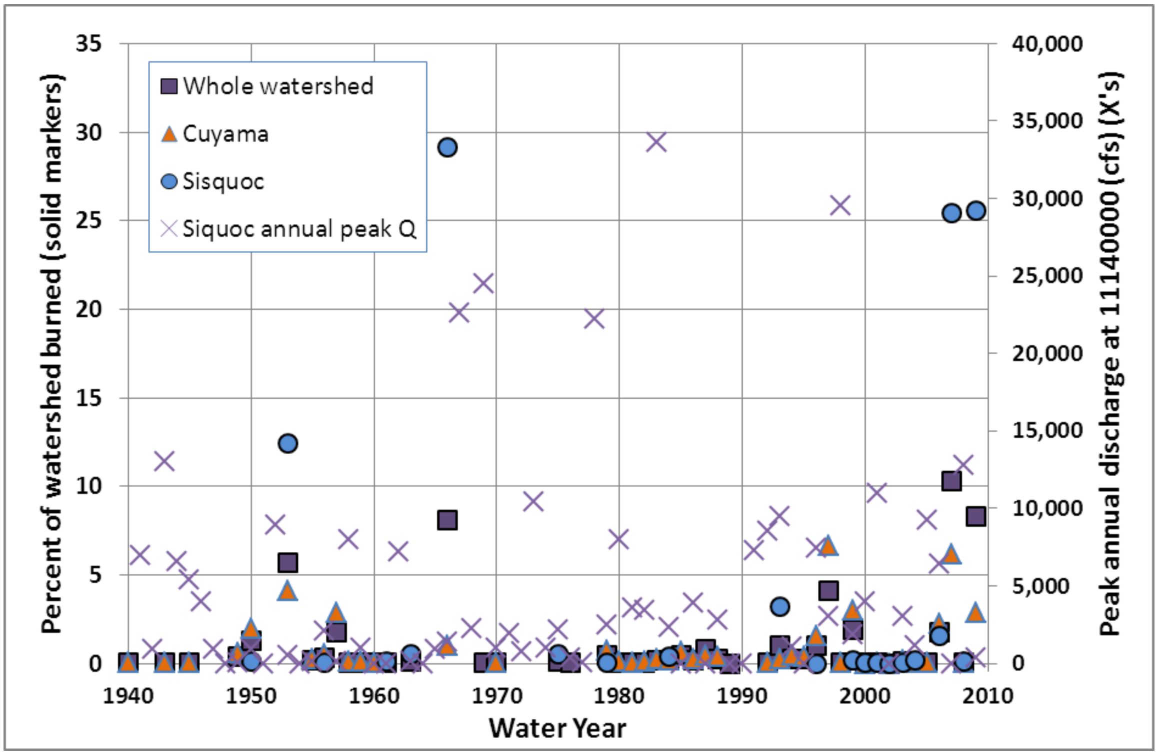

Figure 2.3-5. Percent of Santa Maria River watershed burned and peak annual flows on the Sisquoc River at Garey (USGS 1114000) over the past 60 years. The solid markers indicate the fraction of the watershed area burned in each year, with percentages calculated and plotted independently for the Sisquoc River and Cuyama River watersheds. Those for the "Whole watershed" include all burned areas of the two major tributaries, plus any region that drains directly to the mainstem Santa Maria River. Data from California Department of Forestry and Fire Protection (CAL FIRE; http://www.fire.ca.gov/index.php).

Relationships between fires and floods have been recognized for many years, because of the varying consequence of each depending on how they follow one another in time. Floods correspond to periods of unusually high rainfall and generally wet conditions that promote abundant vegetation growth in the following one to three years (Fry and Stephens 2006, Syphard et al. 2007). In turn, this raises the fuel load for wildfires and increases the chance that an initial ignition will spread more widely. Conversely, once a fire has occurred, the hydrology of the watershed can be strongly affected for up to a decade, with a higher fraction of rainfall moving directly into stream channels as overland flow instead of being slowed by vegetation and infiltrated into the ground or evapotranspirated back into the atmosphere (Rulli and Rosso 2007, Cannon et al. 2008).

The fire-and-flood record provides some anecdotal support for both phenomena, but the overriding conclusion is that fire is not a significant determinant of flows in the Santa Maria River or its major tributaries (Figure 2.3-6).

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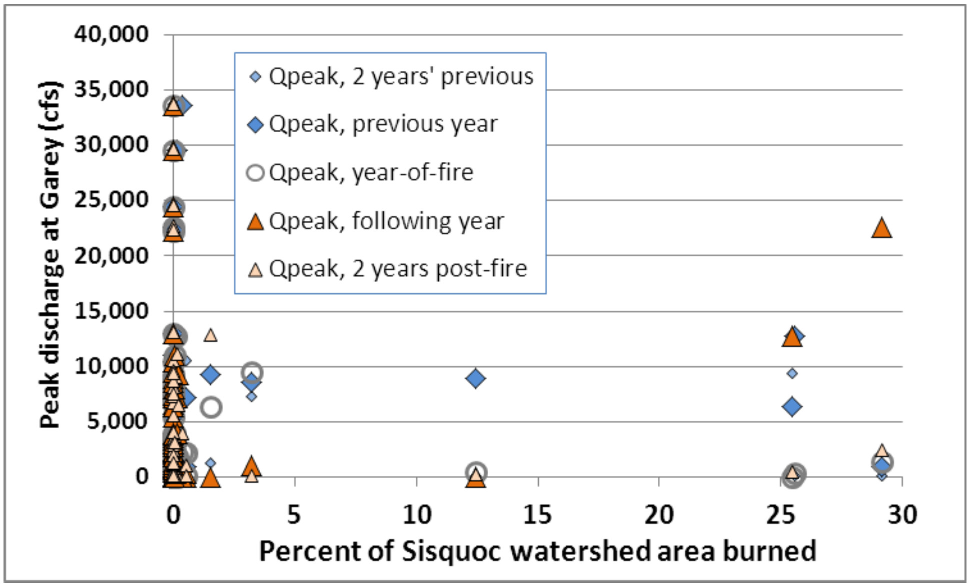

Figure 2.3-6. Relationship between burned percentage of the Sisquoc River watershed and peak flows on the Sisquoc River at Garey (USGS 11140000). Five independent relationships (burned area vs. same-year peak discharge [open circle], plus one and two years' pre-fire [diamond markers] and post-fire [triangle markers] peak discharges) are plotted; none of these relationships are statistically significant and all $r^2<0.1$.

Figure 2.3-6 plots the peak annual discharge ("Q_{peak}") for the entire gage record for which these data are available in final form for the Sisquoc River at Garey gage (USGS 11140000) (1941–2009) against the percentage of the Sisquoc River watershed burned in a given year. The discharge record has also been offset one and two years, both forwards and backwards, to evaluate the potential effects of increased plant growth and subsequent fuel load (the "previous year" markers) and the effects of fire on peak annual discharge (the "post-fire" markers). In 63 of the 69 years, fires burned less than 1% areal extent of the watershed. Of the remaining six years with significant fires, five of those years had peak discharges of 5,000–15,000 cfs in the previous year (large blue diamonds), suggesting some influence of increased vegetation growth on subsequent fire severity (note, however, that there were 17 other years with flows in or above this range without any significant fires in the following year at all). Two large flood years (those of 1967, with a Q_{peak} of 22,600 cfs, and 2008, with Q_{peak} of 12,800 cfs) both followed years with very large fires, and their peak discharges may well have been increased by the effects of fire; but the four largest floods in this record show no fire–flood correspondence at all. As inspection of this graph suggests, there are no correlations between the area burned and any of the offset flood variables with r^2 values greater than 0.1 (i.e., the presence of fire explains less than 10% of the observed variability in discharge) and no relationships are statistically significant.

2.4 Groundwater Hydrology

This section provides a brief summary of hydrogeologic conditions and groundwater issues in the Santa Maria groundwater basin, which were described in greater detail by DBS&A (2010). A prior, comprehensive characterization of hydrogeologic conditions in the basin is also available from California Department of Water Resources (CDWR) (2004).

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2.4.1 Hydrogeologic conditions

The Santa Maria groundwater basin spans approximately 184,000 acres and, as described by CDWR (2004), underlies and maintains direct hydrologic connectivity with the aquifers of Nipomo and Tri-Cities Mesas, Arroyo Grande Plain, and Nipomo, Arroyo Grande, and Pismo Creek valleys (Figure 2.1-1). The groundwater basin is composed of a deep accumulation of marine and non-marine sedimentary units of the Orcutt, Paso Robles, Pismo, and Careaga formations (CDWR 2004). Average total thickness of the water-bearing materials is about 1,000 ft, with a maximum thickness of 2,800 to 3,000 ft (Worts 1951, SBCWA 1994; both as cited in CDWR 2004). Except along the coast where it is confined beneath low-permeable silt and clay strata, groundwater is generally unconfined throughout much of the basin (SBCWA 2009). As a result, there is direct hydrologic connectivity between surface flows in the Santa Maria River and the groundwater table. Seawater intrusion, a condition of concern for many coastal communities, has not been observed in the groundwater basin (SBCWA 2009). This is due to the fact that there is sufficient east-to-west flow through the groundwater aquifer (see below), which extends under the ocean for several miles, to prevent seawater from moving eastward into the aquifer.

Groundwater flow direction follows the Santa Maria River toward the west. Groundwater flow is disrupted in part by the Santa Maria River Fault (see Figure 2.1-1) (SBCWA 1977). CDWR (2004) describes natural and artificial recharge of groundwater in the Santa Maria groundwater basin as follows:

> Natural recharge to the basin comes from seepage losses from the major streams, percolation of rainfall, and subsurface flow (CDWR 2002). Percolation of flow in Pismo Creek provides recharge for the northern portion of the basin (CDWR 2002). Percolation of flow in Arroyo Grande Creek, controlled by releases from Lopez Dam, provides recharge for the Tri-Cities Mesa, Arroyo Grande Plain, and Arroyo Grande Valley portions of the basin (CDWR 2002). Percolation of flow in Santa Maria River, controlled in part by releases from Twitchell Dam, provides recharge for the Santa Maria Valley portion of the basin (CDWR 1999, 2002). Both Twitchell and Lopez Dams are operated so as to optimize groundwater recharge for the Santa Maria Groundwater Basin (CDWR 2002). Incidental recharge includes deep percolation of urban and agricultural return water, treated wastewater return and septic tank effluent. Some subsurface inflow comes from consolidated rocks surrounding the basin and also from San Antonio Creek Valley Groundwater Basin (SBCWA 1977).

The total storage capacity of the Santa Maria groundwater basin is not well known but has been estimated to be greater than 14.9 million ac-ft, based on estimates of groundwater in storage for 1968 (CDWR 2002). Groundwater in storage has fluctuated since records began nearly 100 years ago, as reflected by groundwater levels measured in the numerous production and monitoring wells located throughout the basin. Water levels throughout the basin declined throughout the 20th century as a result of cumulative pumping for agricultural, municipal, and industrial uses (Figure 2.4-1). Groundwater levels have fluctuated continuously both seasonally and in response to annual precipitation, but in recent decades they have not dropped below the 1960s-era minimum levels. This is due in part to leveling of agricultural demand, the importation of state water for municipal use (from the State Water Project via the Coastal Branch Aqueduct), and recharge from Twitchell Dam releases. Recovery of groundwater levels has been observed to occur quickly. As recently as 2002 groundwater levels were near the 1918 historical high (SBCWA 2009) (Figure 2.4-1), but as of 2008 have since declined by 40 ft (USGS 2011a).

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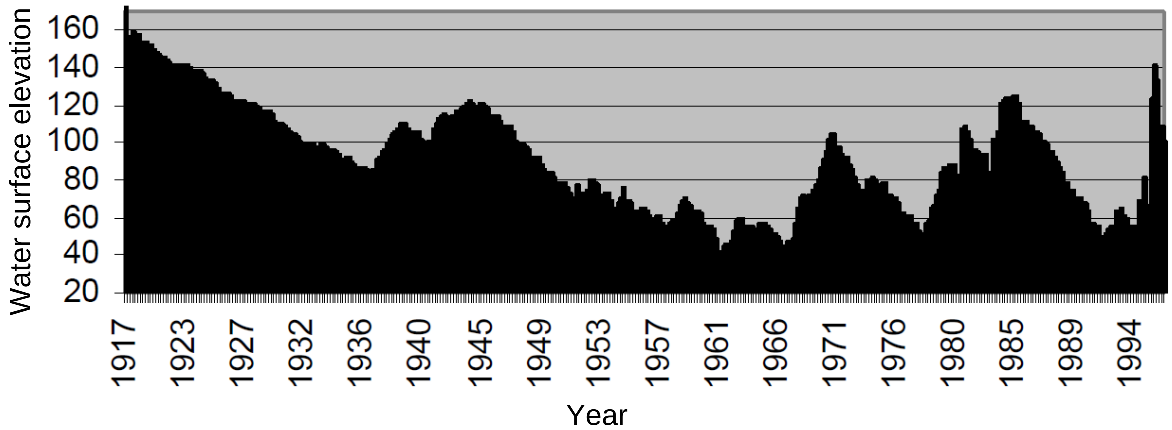

Figure 2.4-1. Groundwater levels (in ft) in the Santa Maria groundwater basin as measured in State Well 10N/34W-14E5 (at Simas Park) between 1917 and 2002. Modified from SBCWA (2009).

2.4.2 Groundwater use and adjudication

Groundwater from the Santa Maria groundwater basin is used extensively by the City of Santa Maria, Golden State Water Company, the City of Guadalupe, Casmalia Community Services District, oil operations and private agriculture. Agriculture has historically been the largest consumer of groundwater, but municipal uses have steadily increased with a growing population in recent decades. Releases from Twitchell Dam to promote groundwater recharge began in 1962. In 1997, importation of water from the State Water Project's Coastal Branch Aqueduct through the City of Santa Maria began to supplement the area's water supply. As a result of continued groundwater and surface water use in the watershed, pumping from the Santa Maria groundwater basin exceeds recharge (SBCWA 2009). Based on the average conditions of the years 1943–1999, the modeled groundwater pumping exceeds recharge by approximately 2,400 ac-ft per year (SBCWA 2009).

In 1997 litigation was initiated regarding the status and use of groundwater in the basin[4]. Ultimately, hundreds of parties with claims to groundwater were involved. In 2005, many of the parties entered into a binding agreement, or Settlement Stipulation, with additional parties issuing agreement after its execution. A judgment was signed in 2008 but is currently under appeal. The Settlement Stipulation is intended to accomplish the following, as defined by the California State Superior Court (2005):

> …impose a physical solution establishing a legal and practical means for ensuring the Basin's long-term sustainability. This physical solution governs groundwater, SWP [State Water Project] water and storage space, and is intended to ensure that the Basin continues to be capable of supporting all existing and future reasonable and beneficial uses.

The Settlement Stipulation divides the groundwater basin into three separate Management Areas, the largest of which is the Santa Maria Valley Management Area (Figure 2.1-1). The Santa Maria Valley Management Area contains the Santa Maria, Cuyama, and Sisquoc rivers, Twitchell

[4] Records of these proceedings are available from the State Superior Court website: http://www.sccomplex.org/home/index.htm.

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Reservoir recharge area, and the majority of the Santa Maria groundwater basin. Each Management Area is required to conduct monitoring and characterize groundwater and surface water resources within its boundaries. The Santa Maria Valley Management Area Engineer is charged with determining "severe water shortage conditions" based on the monitoring program. Water shortage conditions are considered to exist when: (1) groundwater levels decline for five or more years; (2) the groundwater level decline is not due to drought conditions; (3) there is a material increase of groundwater use over the 5-year period; and (4) monitoring wells find that groundwater levels are below the lowest recorded levels (California State Superior Court 2005).

The Settlement Stipulation and judgment adjudicated water rights for nearly all parties. Rural Santa Maria valley landowners generally retain their rights to pump form the groundwater basin, but limitations would occur if their pumping exceeds a "safe yield". Large groundwater users such as the City of Santa Maria and Golden State Water Company retain rights to pump a portion of the State Water Project return flows that they purchase and water released from Twitchell Reservoir for groundwater recharge, provided their pumping does not exceed the safe yield. In the event the safe yield is exceeded, groundwater extractors would be required to take appropriate actions, including voluntary cutbacks, to maintain healthy basin conditions. Other parties owning appropriative rights are limited to native groundwater that is surplus to reasonable and beneficial uses of the Stipulating Parties who are overlying owners of the Santa Maria Valley Management Area. The judgment did not specifically address surface water rights, except for the assignment and allocation of the yield from Twitchell Reservoir (assumed to be 32,000 ac-ft per year; but see Figure 2.3-2), but states "Nothing in this Stipulation affects or otherwise alters common law riparian rights or any surface water rights, unless expressly provided in this Stipulation."

Finally, the judgment specifically states that the judgment shall not relieve any party of its responsibilities to comply with state and federal laws for the protections of water quality or the provisions of any permits, standards, requirements, or order promulgated there under. These various requirements may include, for example, Comprehensive Environmental Response, Compensation, and Liability Act, Endangered Species Act, Clean Water Act, Resource Conservation and Recovery Act, California Environmental Quality Act, Porter-Cologne Act, California Water Code, surface water regulation through the State Water Resources Control Board, groundwater well permitting, if applicable, through the County of Santa Barbara, and local ordinances.

2.5 Water Quality

Water quality in the lower Santa Maria River is highly degraded, primarily as a result of non-point pollution, such as sedimentation and pesticides and nutrients associated with agricultural products (Cachuma RCD 2000, CCRWQCB 2011). No significant pollutant sources or water quality degradation that would affect steelhead has been reported for the rural-area portions of the watershed upstream of the Santa Maria River valley. Several tributaries to the Sisquoc and Cuyama Rivers are included in a proposal to establish Total Maximum Daily Loads [TMDLs] for fecal indicator bacteria [CCRWQCB 2011], but these bacteria are not known to affect steelhead or their preferred invertebrate prey species. Previous surveys of the Sisquoc River watershed generally rated water quality in terms of suitability for steelhead as excellent (e.g., Cardenas 1996, Stoecker 2005).

This section summarizes water quality parameters with the greatest potential to affect steelhead during their upstream and downstream migration: temperature, dissolved oxygen (DO), and total suspended solids (TSS). In reporting water quality data, particular emphasis is made to conditions

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during the steelhead migration period (November to May). Water quality monitoring and evaluation on the Santa Maria River have focused primarily on the estuary, which is considered one of the most polluted water bodies on the Central Coast (Anderson et al. 2010). Therefore, a summary of water quality conditions in the estuary that have the potential to affect juvenile steelhead that may over-summer there is also provided. Additional information on the estuary is included in Section 4.1.

The Central Coast Ambient Monitoring Program (CCAMP) of the Central Coast Regional Water Quality Control Board is the source of much of the water quality data reported in the sections below. CCAMP has measured a variety of water quality parameters since 2000 at three locations on the Santa Maria River: At Bull Run Rd, Highway 1, and at the upstream end of the estuary, downstream of Orcutt Creek. While the period of water quality sampling and number of samples varies by site, the CCAMP data helps characterize general water quality conditions in the river.

2.5.1 Temperature

CCAMP rates water temperatures based on ideal temperatures for steelhead based on Moyle (1976): 13–21°C (55–70°F) (CCAMP 2011). More recent estimates of optimal temperatures for steelhead growth are reported in the range of 15–19°C (59–66.2°F) (Myrick and Cech 2005), and the highest growth rates of juvenile steelhead in a central California coastal lagoon were observed at temperatures between 15–24°C (59–75.2°F) (Hayes et al. 2008). Suitable water temperatures in lagoon habitats have also been shown to be less than 26°C (Daniels et al. 2010). Stressful temperatures that can reduce steelhead growth are typically greater than 25°C (Myrick and Cech 2000), and temperatures greater than around 27.5–29.6°C result in steelhead mortality, depending on acclimation temperatures (Myrick 1998). Steelhead in southern California have been observed to grow and survive at higher temperatures than steelhead in other more northern watersheds, and to tolerate short periods of temperatures up to 27°–29°C (81–84°F).(e.g., Spina 2007, Stillwater Sciences et al. 2010). The lethal temperature for steelhead has been shown to be higher when the fish have been previously acclimated to high (but sublethal) temperatures (Cherry et al. 1977, Threader and Houston 1983). Further, it has been hypothesized that steelhead populations acclimated to higher temperatures may also be adapted to a higher temperature range for optimal growth (Spina 2007). When food availability is high, steelhead in their southern range have been observed to have high growth rates despite temperature fluctuations within the typical upper range of optimal growth conditions for the species (e.g., up to 24°C [75°F]) (Boughton et al. 2007).

Water temperatures at CCAMP monitoring stations on the Santa Maria River are summarized in Table 2.5-1. CCAMP characterizes water temperatures in the Santa Maria River as slightly impacted to impacted, again based on the ideal temperatures for steelhead from Moyle (1976) (CCAMP 2011). Based on the CCAMP data, temperatures in the lower Santa Maria River during the steelhead migration period are suitable for steelhead. Temperatures in the mainstem river and estuary may exceed tolerance thresholds for steelhead in the summer and early fall.

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Table 2.5-1. Water temperatures in the Santa Maria River.

Location on the Santa Maria River	Sample no.	Sample period	Temperature (°C)			
			Average	Maximum	Minimum	During steelhead migration (approx.)
Bull Canyon Rd	5	2000–2001	14	20 (April)	11 (February)	11
Highway 1	35	2000–2008	17	26 (July)	5 (January)	15
Estuary	156	2000–2009	16	26 (July)	8 (February)	10–15

Source: CCAMP 2011

2.5.2 Dissolved oxygen

CCAMP rates DO levels based on a range of 7–13 mg/L: with 7 mg/L considered protective of cold water habitats and 13 mg/L being indicative of nearly full oxygen saturation levels (CCAMP 2011). Variation in DO levels is also considered, since widely varying DO levels (e.g., <7 mg/L to >13 mg/L) are indicative of excessive algal activity (CCAMP 2011). DO levels at CCAMP monitoring stations on the Santa Maria River are summarized in Table 2.5-2; CCAMP characterizes these levels as good to slightly impacted (CCAMP 2011). Based on the CCAMP data, DO levels in the Santa Maria River appear to be suitable for steelhead throughout the year, although the CCAMP measurements may not account for depressed DO levels at night, when plant material in the water would be taking up oxygen and decreasing DO.

Table 2.5-2. Dissolved oxygen in the Santa Maria River.

Location on the Santa Maria River	Sample no.	Sample period	DO (mg/L)			
			Average	Maximum	Minimum	During steelhead migration (approx.)
Bull Canyon Rd	6	2000–2001	10	11	9	10–11
Highway 1	36	2000–2008	9	16	7	7–16
Estuary	156	2000–2009	10	16	5	6–16

Source: CCAMP 2011

2.5.3 Total suspended solids

Exposure to excessive concentrations and durations of suspended sediment can result in physiological stress, reduced growth rates, or mortality for steelhead (Newcombe and Jensen 1996). Based on initial observations of highly turbid water in the Santa Maria River, depth-integrated grab-samples were collected as a part of the Instream Flow Study during a series of winter 2010/2011 storm events to characterize the general level of total suspended solids (TSS) in the water column, and to provide some indication of whether spatial or temporal patterns in TSS might exist for this series of storm events. Grab samples for measuring TSS were collected on December 30 and 31, 2010 and January 4, 2011 at five locations on the Santa Maria River (Table 2.5-3). TSS samples were generally collected near the channel thalweg, preserved in polyethylene bottles for 6 to 7 days, and analyzed by Clinical Laboratory of San Bernardino, Inc.

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Table 2.5-3. Total suspended solids sample dates, locations, and results (all in mg/L).

Location	December 30, 2010	December 31, 2010	January 4, 2011
Sisquoc River at Garey	1,200 1,000	none collected	none collected
Suey Creek (at Santa Maria River)	none collected	50	46
Santa Maria River at Suey	1,600 1,800	990	870
Santa Maria River at Bonita School Rd	2,300 3,300	2,500	2,400
Santa Maria River at Hwy 1	3,500 4,100	none collected	2,400

These data suggest a general trend of increasing TSS in the downstream direction, and a modest decline in TSS following the discharge peak of approximately 300 cfs in the mainstem Santa Maria River at the Suey crossing on December 30, 2010. Note, however, that samples were not collected during the major peaks on December 20 and 22, 2010 when TSS values were almost certainly higher. No discharge from Twitchell Reservoir occurred during this period.

By comparison, USGS (2011b) reported TSS values between 3,000 and 60,000 mg/L across a range of discharges up to about 10,000 cfs, at the Highway 1 bridge during the winter of 1969 (Figure 2.5-1). TSS data from December 30, 2010 at this same site (when flow was approximately 180 cfs and TSS was 4,100 mg/L) would plot at the lower edge of the region defined by the USGS 1969 data.

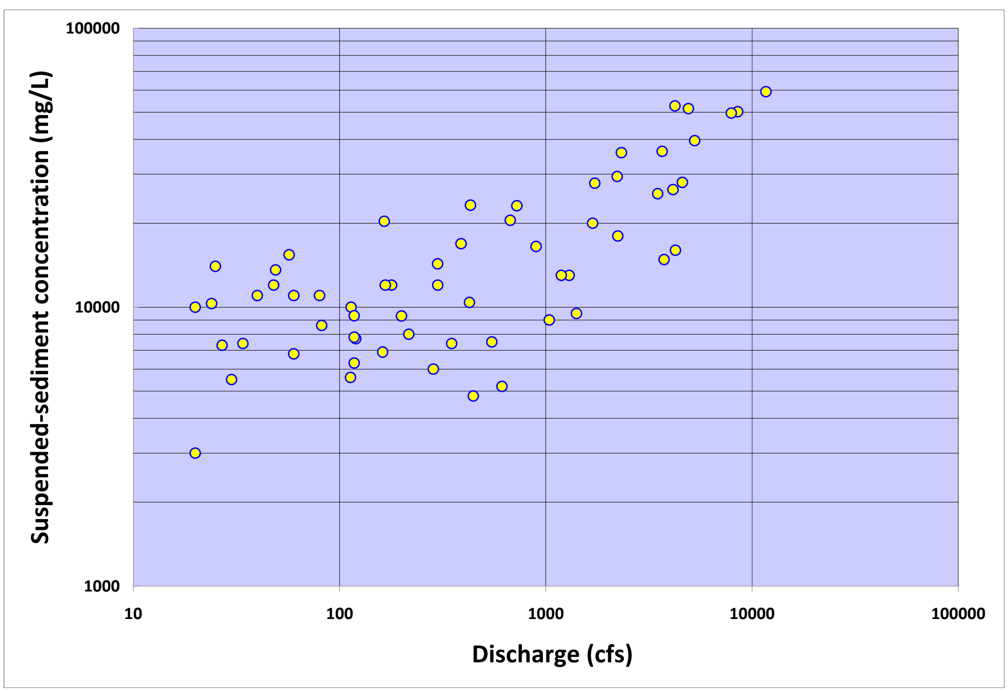

Figure 2.5-1. Total suspended solids during 1969 high flows on the Santa Maria River at Guadalupe. Source: USGS (2011b).

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CCAMP (2011) TSS data is summarized in Table 2.5-4. CCAMP characterizes TSS levels in the Santa Maria River as impacted to severely impacted, but they also acknowledge that TSS values can be naturally elevated during storm events and that establishing a single value as an indicator of impacted conditions is problematic (CCAMP 2011). It is important to note that for the Bull Canyon Road site, four of the five measurements were less than 30 mg/L; only one sample in February was 750 mg/L. At the Highway 1 site, the only TSS measurement above 500 mg/L occurred in June 2000 (1,600 mg/L). Based on the low TSS levels of CCAMP samples collected during the steelhead migration period compared to the data collected for the Instream Flow Study and by USGS in 1969 (when TSS exceeded 2,000 mg/L during steelhead-passable flow events), it is highly unlikely that any of the CCAMP samples were collected during steelhead-passable flow events.

Table 2.5-4. Total suspended solids in the Santa Maria River.

Location on the Santa Maria River	Sample no.	Sample period	TSS (mg/L)			
			Average	Maximum	Minimum	During steelhead migration (approx.)
At Bull Canyon Rd	5	2000–2001	174	750	20	20–750
At Highway 1	18	2000–2007	173	1600	2	<100
At the estuary	106	2000–2009	139	720	2	<500

Source: CCAMP 2011

Newcombe and Jensen's (1996) Severity Index is a common approach to rank the effects of suspended sediment on salmonid species, and their Suspended Sediment Dose Index (SSDI) is used to relate salmonid exposure time to suspended sediment using a natural log relationship:

SSDI = ln (suspended sediment [mg/L] x exposure time [hrs])

Based on TSS levels during winter 2010/2011 storm events (1,000 to 4,100 mg/L), and an estimated steelhead migration time of up to three days (72 hours) between the Pacific Ocean and Sisquoc River (see Section 4.2.2), the SSDI for migrating steelhead in the Santa Maria River ranges from 11.2 to 12.6. These values correspond to a Severity Index Rank of approximately 9.0 to 10.0. According to Newcombe and Jensen (1996), these Severity Index values correspond to major physiological stress, poor condition, and/or long-term reduction in feeding rates, but would not be expected to cause mortality. They are also unlikely to be materially different from conditions that have historically, and prehistorically, existed along the Santa Maria River and its tributaries. High TSS can be a serious impediment to the reproductive and early growth phases (incubation, emergence, early rearing) in a steelhead's life-cycle, but is less critical to upstream migrating adults. This is because steelhead can navigate by hydrologic, rather than visual cues, and, therefore, high TSS does not necessarily prevent or impede passage. High TSS is typically greatest during the initial rise of the hydrograph of a storm event (USGS, 2011b). Due to the flashy nature of flow events on the Santa Maria River and the fact that the estuary must be open prior to migration, steelhead migration typically occurs on the falling limb of the hydrograph as TSS levels are declining. In addition, it is possible that adult steelhead have adapted to short durations of high TSS by using channel margins where TSS concentrations tend to be lower, or by increasing migration rates to locate areas farther upstream where concentrations are lower. However, during large events such as the flood of 1969, TSS could be high enough (> 60,000 mg/l) to substantially reduce the success of adult migration.

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2.5.4 Estuary

Water quality in the Santa Maria River estuary is highly degraded, primarily as a result of runoff from irrigated agricultural lands and from Orcutt Creek in particular (Anderson et al. 2010, CCAMP 2011). There is a chance that out-migrating juvenile steelhead could become trapped in the estuary if the sandbar closes while there is still surface flow in the Santa Maria River. The water quality parameters in the estuary that could affect such steelhead are primarily temperature, DO, pesticides, and toxicity (which can include pesticides).

As discussed above, water temperature and DO levels in the estuary are generally within the tolerance range of steelhead and would not be expected to affect steelhead prey availability. Water temperatures in the summer and fall may exceed those for optimal growth of steelhead, but are not expected to be lethal, as described in Section 2.5.1 above. Salinity levels in the estuary (almost always less that 2 ppt [CCAMP 2011]) are indicative of freshwater conditions.

In a recent study by Anderson et al. (2010), the majority of water samples and a high percentage of sediment samples collected in the Santa Maria River estuary were highly toxic to invertebrates, likely as a result of pesticides. In addition, sand crabs and fish collected in and adjacent to the Santa Maria estuary were contaminated with numerous fungicides, herbicides, and pesticides, including high concentrations of DDT. While high levels of pesticides can alter invertebrate species assemblages and reduce prey availability for steelhead, invertebrate groups that are important prey species for migrating salmon (Shreffler et al. 1992) and estuarine species (Grimmaldo et al. 2009) have been documented in the estuary (Anderson et al. 2010). Pesticides may also disrupt olfactory sensory neurons necessary for salmonid species homing and predator avoidance. While pesticide concentrations are certainly alarming in the estuary, most did not exceed the concentrations shown to affect salmonid olfactory response and predator avoidance (Scholz et al. 2000, Moore and Waring 2001, Sandahl et al. 2004, Anderson et al. 2010).

CCAMP monitors several indicators of toxicity at the Highway 1 and estuary sites (no toxicity sampling or analysis is reported for the Bull Canyon Road site), with fish survival being the most relevant to the Instream Flow Study. Larval fathead minnow (*Pimephales promelas*) survival, which can be impacted by pollutants such as ammonia, metals, and pyrethroid pesticides, is evaluated in a 7-day chronic test that compares survival under control and treatment conditions. A sample is considered to show toxicity when survival is 80% or less of the control. Toxicity based on fish survival at the Highway 1 and estuary monitoring stations on the Santa Maria River are summarized in Table 2.5-5; CCAMP characterizes these levels as good to slightly impacted (CCAMP 2011). Based on the CCAMP data, steelhead should be tolerant of toxicity levels in the Santa Maria River and estuary, particularly during the migration period and for the short period of time that they are likely to be present there (see Section 4.1).

Table 2.5-5. Toxicity based on fish survival in the Santa Maria River.

Location on the Santa Maria River	Sample no.	Sample period	% survival relative to control*			
			Average	Maximum	Minimum	During steelhead migration (approx.)
Highway 1	9	2005–2008	100	113	89	110–113
Estuary	20	2005–2009	92	125	72	95–125

Source: CCAMP 2011

* Percent survival can exceed 100% when survival under treatment conditions is higher than survival under control conditions.

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3 METHODS

3.1 Estuary Conditions

Field observations of estuary outlet conditions were made during winter–spring 2010/2011. To better characterize the behavior of the estuary under a wider range of flow conditions, we also investigated direct and indirect historical records to infer the general behavior of the estuary and its outlet over time. Since systematic observations of historic outlet conditions of the Santa Maria River estuary are not available, we investigated the hydrologic record to evaluate the degree to which open-outlet conditions can be correlated with steelhead-passable flows, or otherwise inferred from the flow record of the river. Photographic evidence of the outlet condition from 1994–2009 as compiled on GoogleEarth©, together with a more sporadic but longer record of aerial photographs archived at the County of Santa Barbara Flood Protection District from 1966–1998, were reviewed.

The volume of water needed to overtop the beach berm was calculated, using the September 2010 LiDAR topography as a base map. At the time of the survey, the estuary was at a low stage and its volume was not calculated, because the LiDAR could not penetrate the water surface and no on-site bathymetry was conducted. This volume was ignored in subsequent calculations because it was judged to be one or two orders of magnitude smaller than that needed to overtop the berm, and because it would likely be the minimum volume already present at the start of any overtopping event.

The volume of the estuary at various water-level elevations was calculated as the average of the maximum and minimum areas associated with each 0.25-m elevation band above the LiDAR-surveyed base. This volume of water is a high-end estimate of the volume needed for breaching, since it only presumes the erosive action of surface-flowing water from the estuary and ignores any potential erosive contribution from emergent groundwater or wave action.

Water quality measurements were made in the Santa Maria River estuary from October 13–15, 2010 to assess conditions during the late summer and fall when the estuary mouth is closed to the Pacific Ocean and juvenile steelhead could potentially be present in the estuary. The sandbar was open during this time, and the estuary was completely drained. In the north-east portion of the drained estuary, there was one small isolated area of ponded water. Data loggers for measuring water temperature and stage were also installed to assess conditions in the estuary through the winter and spring.

In situ measurements of water temperature, pH, conductivity, and dissolved oxygen (temperature compensation, manual salinity correction, self-stirring probe) were made on October 14, 2010 using a portable Yellow Springs Instruments (YSI) 600XL multi-parameter probe (Table 3.1-1). The *in situ* measurement locations ranged from the north end of the estuary to the south end, near the upstream extent of estuarine habitat to assess whether water quality was dependent on location (Figure 3.1-1). At each location, a measurement was taken approximately 4 to 6 inches below the surface water surface and approximately 6 inches above the bottom of the estuary.

A YSI 6820 continuously recording water quality sonde was deployed from October 13–15, 2010 to monitor diel fluctuation of water quality parameters in the estuary. The sonde was located along the southwest edge of the estuary and collected information on the same water quality parameters as the *in situ* measurements, with the addition of turbidity (Figure 3.1-1). The sonde recorded measurements every 15 minutes over the 36-hour period.

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Also on October 14, 2010, two continuous water temperature data loggers (Onset Tidbit Model U21) and a Solinst Levelogger (model 3001) stage recorder were deployed in the estuary. The temperature data loggers were deployed at the north end and east side of the lagoon (two additional data loggers deployed at the south end and west side of the estuary were never recovered) (Figure 3.1-1). The loggers recorded measurements every 15 minutes, with an accuracy of 0.01º C. The data loggers were recovered in February 2011.

The stage recorder, which measured changes in water level in the estuary as well as temperature, was located along the southwest edge of the estuary (Figure 3.1-1). Water stage and temperature were recorded every 30 minutes with a precision of 0.0001 ft and 0.001º C, respectively. The stage recorder measured relative changes in water level, not changes in level from a fixed elevation (e.g., mean sea level). The stage recorder was washed away during a high flow event in late December 2010, but was recovered by Santa Barbara County Parks Department personnel.

Table 3.1-1. Water quality parameters measured in the Santa Maria River estuary.

Parameter	Method No.	Specified instrument accuracy	Reference
Temperature	170.1	0.1 C	USEPA 2003
Dissolved oxygen	4500-O	0.03 mg/L (0.03 %)	APHA et al. 1999
Conductivity	2510-B	1.0 umhos/cm	APHA et al. 1999
pH	4500-H	0.1s.u.	APHA et al. 1999

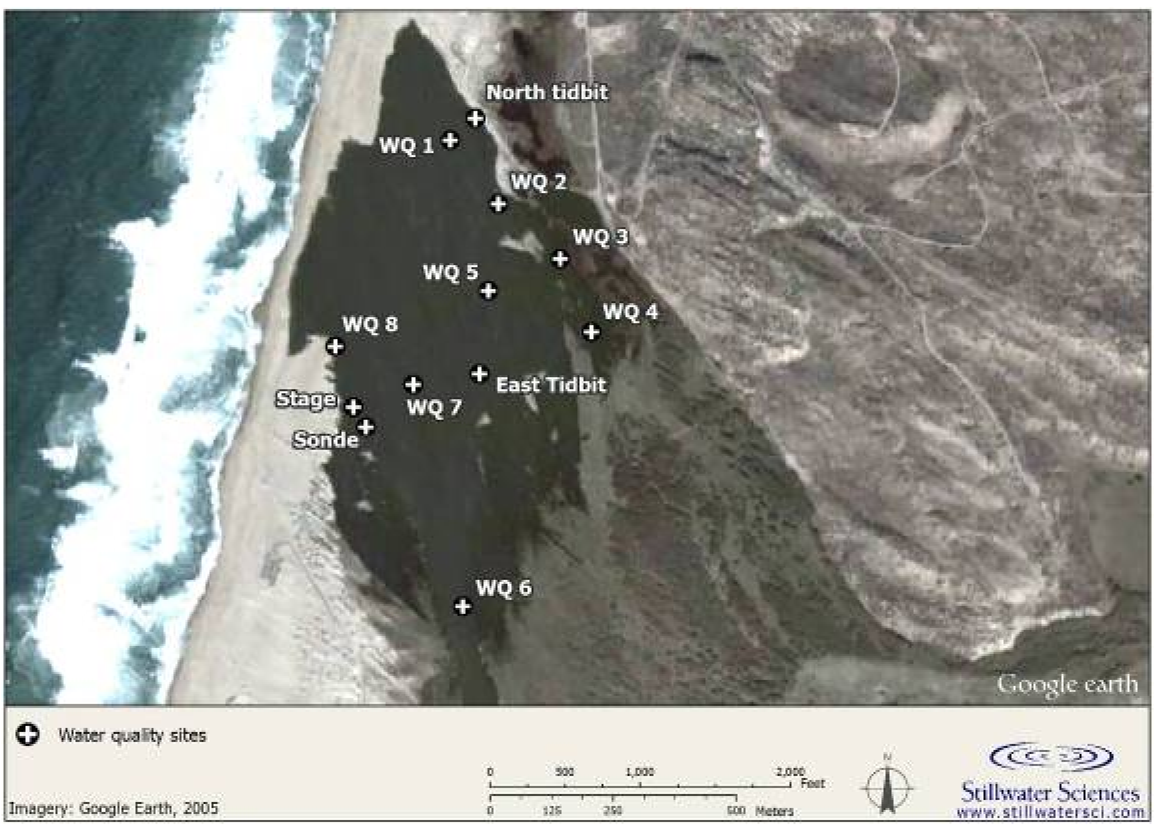

Figure 3.1-1. Locations of in situ water quality measurements (WQ), temperature data loggers (Tidbits), data sonde (Sonde), and stage recorder (Stage) in the Santa Maria River estuary.

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Unfortunately, the permits needed to sample for *O. mykiss* in the estuary, as was originally planned, were not granted in time for the Instream Flow Study.

3.2 Steelhead Passage Criteria

3.2.1 Hydraulic criteria

Hydraulic criteria were established and used to define thresholds for suitable passage conditions for adult steelhead upstream migration and juvenile steelhead downstream migration through the Santa Maria and lower Sisquoc rivers. Hydraulic criteria were developed using available information on existing steelhead passage criteria from other studies and applications including peer-reviewed journals, agency reports, and other scientific literature, as well as information from technical and local experts. Available information was reviewed and hydraulic thresholds related to passage conditions were summarized, focusing on criteria used to assess fish passage conditions in natural channels (rather than in experimental flume conditions). In developing hydraulic criteria for adult and juvenile steelhead, we considered the required water depth of riffles, maximum water velocity and swimming ability, the distribution of suitable flow conditions for passage across the channel (e.g., Thompson 1972), as well as the maximum longitudinal length of shallow riffles.

Apart from physical barriers, water depth and velocity were the leading hydraulic factors constraining successful upstream passage of steelhead and other anadromous salmonids. During low flows, the depth of water in riffles or at riffle crests was generally considered most limiting to successful passage in natural (alluvial) channels (Thompson 1972, Mosley 1982, Lang et al. 2004). High water velocity was also identified as a possible factor limiting migration particularly in locations where a channel becomes constrained or confined. Minimum water depth and maximum water velocity criteria, and the channel width over which these criteria are applied, can have a substantial effect on establishing the flow required to meet the criteria, particularly in wide channels such as the Santa Maria River.

The selection of passage criteria was a collaborative process with the Instream Flow Study's technical coordination team: the summary of available information was reviewed and discussed, and consensus opinion among the group was achieved. The majority of discussions occurred during the technical coordination team meeting on June 7, 2011. Ultimately, three criteria were selected to evaluate adult upstream passage: (1) minimum depth, (2) maximum velocity, and (3) minimum width over which the [minimum] depth and [maximum] velocity criteria are met. Two criteria were selected for juvenile (smolt) and adult downstream passage: (1) minimum depth and (2) minimum width over which the depth criterion is met. Velocity was not considered for downstream passage because the migration direction is with the current.

Sensitivity values to evaluate the influence of the selected criteria on the calculated minimum discharge were also determined by consensus opinion among the technical coordination team members. The minimum depth and maximum velocity criteria threshold values were selected during the June 7, 2011 meeting along with sensitivity values for all criteria. Selecting an appropriate width criteria threshold values required additional investigations and collaboration with CDFG. A detailed description of the passage criteria development is available in Stillwater Sciences (2011a).

It should be noted that while the seasonal timing of upstream migration of steelhead is generally understood, and is strongly associated with the natural increase in river flows (Fukushima and

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Lesh 1998), it was not possible to determine precisely what range of flows serve as hydrologic attraction cues that initiate the upstream migration of adult steelhead into the Santa Maria River. This parameter likely differs widely between watersheds, and will require long-term monitoring to be better understood. For purposes of this study, we assumed that the pre-Twitchell Dam hydrograph is the most reliable indicator of the magnitude, frequency, and duration of hydrologic conditions suitable for migration.

3.2.2 Temporal criteria

In addition to the hydraulic passage criteria, the time required for both upstream and downstream migration was used to constrain the hydrologic analyses (see Sections 3.4 and 4.4). These criteria were developed based on our review of available information and watershed hydrology. The hydraulic analysis focused on conditions in the mainstem Santa Maria River and the influence of the Cuyama and Sisquoc rivers on this reach. The migration distance from the Pacific Ocean to the confluence of the Cuyama and Sisquoc rivers is approximately 24 miles. An additional 11 miles (35 miles total) is needed to reach the upstream end of the lower Sisquoc River canyon (upstream of which flow loss to groundwater is minimal). Spawning and rearing habitats are located in the upper mainstem and tributaries of the Sisquoc River watershed, are located as much as an additional 45 miles upstream (80 miles total). The Guadalupe gage (USGS 11141000) was used for measuring the duration of passage events since it is the nearest gage to the critical passage reach, and because the hydrological analysis (see Section 4.4) indicates that flows are consistently adequate for passage in the Sisquoc River at Garey whenever they are sufficient for passage at the Guadalupe gage.

3.3 Hydraulic Analyses

3.3.1 Discharges for effective steelhead passage

Once the minimum width and depth of flow for steelhead passage were established, the next step was to identify *where* these conditions will first be reached in a waning flow along the course of the river (i.e., the "critical passage reach," where passage is most likely to be limiting), and then to identify the range of discharges at this critical passage location(s) under which the conditions for passage (i.e., minimum depth, minimum width, and maximum velocity) will be met. Unlike many other streams throughout California with perennial flow and a relatively fixed bed, however, the critical passage reach for steelhead cannot be determined by channel geometry at a specific location where low flows are always found to be at their shallowest or narrowest. Instead, the limiting factor for passage up the Santa Maria River is most commonly determined by the mere presence or absence of water. As such, the critical passage reach is the location in the river where receding flows have been observed to first disappear completely into the subsurface.

Prior studies of the river and groundwater basin, field work for this study, and common knowledge all affirm that there is no singular point where this condition is always located. However, it can be reliably found within a reach of a few miles' extent, roughly centered on the Bonita School Road crossing. This reach also corresponds to some of the widest separation between the left- and right-bank levees of the Santa Maria River (about 2,000 ft), minimizing any confining effects of artificial structures on flow. The river through this reach is a largely sand-bedded, braided channel complex, with actively eroding banks and beds under even the lowest flow conditions (for example, active sediment transport has been observed in a 3-inch-deep channel flowing at less than 1 cfs near Bonita School Road). These conditions of high bed mobility, rapidly changeable channel geometry, and variable magnitude and location of

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infiltration to groundwater pose significant challenges for determining a unique effective passage discharge for the Santa Maria River.

3.3.1.1 Geomorphic attributes of the critical passage reach

A comprehensive topographic survey of the entire river channel and surrounding floodplain, conducted via airborne LiDAR in September 2010, provided one "snapshot" view of the river topography. It was conducted after seven months of no-flow conditions in the river and an indeterminate amount of human and natural alterations to the channels that remained at the end of flow events of February and April 2010. Twenty-six cross sections were evaluated from the LiDAR topography (Figure 1.2-2), and they display multiple shallow, ill-defined channels with little topographic relief across much of the width of the valley between the levees (Figure 3.3-1). The LiDAR cross sections were aligned perpendicular to the overall valley trend, whereas the local channel orientation diverged by as much as 20 degrees from that downvalley direction at the specific cross-section locations. This results in an increase in the measured width, but trigonometry shows this error to be less than 7% of the total width and judged negligible relative to the far greater uncertainties associated with rapid channel shifting.

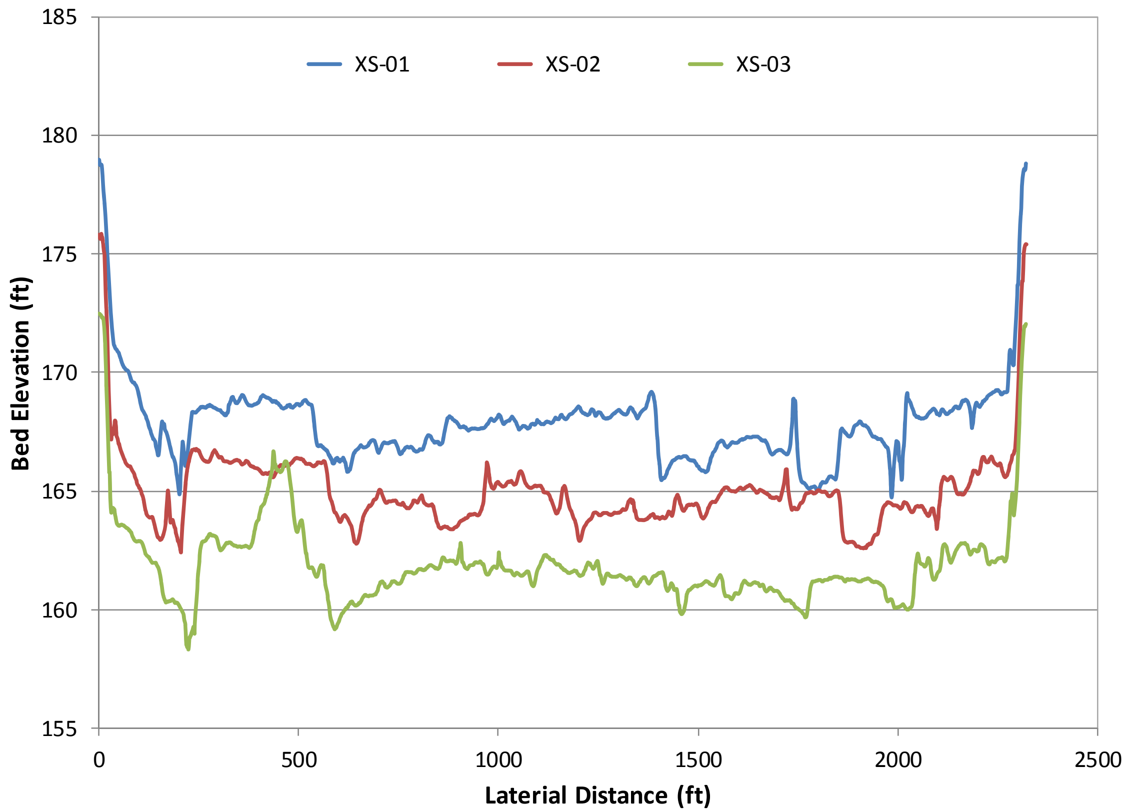

Figure 3.3-1. LiDAR cross sections 1, 2 and 3 (see Figure 1.2-2), demonstrating the indistinct channels and laterally undulating river bed.

3.3.1.2 Hydraulic calculation of steelhead passage based on LiDAR cross sections

In order to identify the discharge necessary to meet the steelhead hydraulic passage criteria, functional relationships between flood stage and selected width parameters were developed for

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each of the 26 LiDAR cross section (based solely on channel cross-section data). Those parameters were (1) the wetted channel width, (2) the width of the channel where water is deeper than the minimum required water depth for fish passage, (3) the width of the channel with continuous water deeper than minimum required water depth, and (4) the wetted channel area.

Water discharge at any flood stage was then calculated with Manning's equation:

$$Q_w = \frac{1.49}{n} A_w R_h^{2/3} S^{1/2} \qquad (1)$$

where Q_w denotes water discharge in cfs; n denotes Manning's n value; R is hydraulic radius in ft; and S is channel gradient (= 0.0033 from the LiDAR survey). Manning's n was set to a value of 0.025 based on suggested values for this type of river (Henderson 1966). Because the Santa Maria is a typical wide river (i.e., channel width-to-depth ration >>1), its hydraulic radius R_h was approximated with its mean depth.

Equation 1 was solved at each cross section to obtain predicted relationships between the width criteria and discharge.

During the time of a storm when the flow starts to pass through the reach, however, the flow will normally carve out a deeper section in the river, although this channel is not always fully preserved as the flood recedes. This will tend to concentrate the flow and produce a deeper flow than calculated based on the channel cross sections obtained when the channel is dry. The results of this analysis are therefore conservative (i.e., they yield a maximum value for the critical discharge).

3.3.1.3 Field measurements of steelhead passage based on field-based cross sections

These hydraulic calculations assume that the river maintains the same cross-section dimensions, even during flow events. To test the consequences of this assumption, field-based cross sections were collected in the critical passage reach during a moderate flow event on March 26–28, 2011. They documented a deeper primary channel during flowing conditions that was not present earlier during dry conditions when the LiDAR data were collected (Stillwater Sciences 2011d). When surface flow starts to pass through the reach, the flow will usually mobilize the sediment and carve out a deeper section in the river, mimicking a "stormflow" channel that is commonly not preserved as the flow recedes. This channel concentrates the flow and produce a deeper flow than calculated based on a cross section measured when the channel is dry. In consequence, the results of the analysis of the 26 LiDAR-based cross sections are likely not representative of channel-geometry conditions when potential fish-passage flows are actually occurring (e.g., Figure 3.3-2).

To improve the relevance of the hydraulic calculations to actual fish-passable conditions, field evaluation of fish-passable flows and field measurements of discharge were conducted on seven separate dates between January and April 2011. They were conducted at a variety of locations between Highway 101 and Highway 1, and they were used to provide a field-based determination of passable flows under actual conditions of flow and channel formation.

3.3.2 Sensitivity analysis of passage criteria

To assess the sensitivity of the selected hydraulic steelhead passage criteria (Section 3.2.1) on the minimum discharges required for passage, criteria threshold values for width and depth were replaced with sensitivity values, and the resulting minimum discharge for steelhead passage was

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calculated for the 26 LiDAR cross sections using Equation 1, above. In addition to testing the sensitivity in criteria values for width and depth criteria, the effect of using various Manning's n values on minimum flows required for passage was also evaluated. Manning's n values from 0.025 to 0.05 were used to test a range of values potentially representative of conditions in the critical passage reach. Flow calculations were performed for LiDAR cross section 11 (Figure 1.2-2), which was considered representative of limiting flow conditions in the critical reach.

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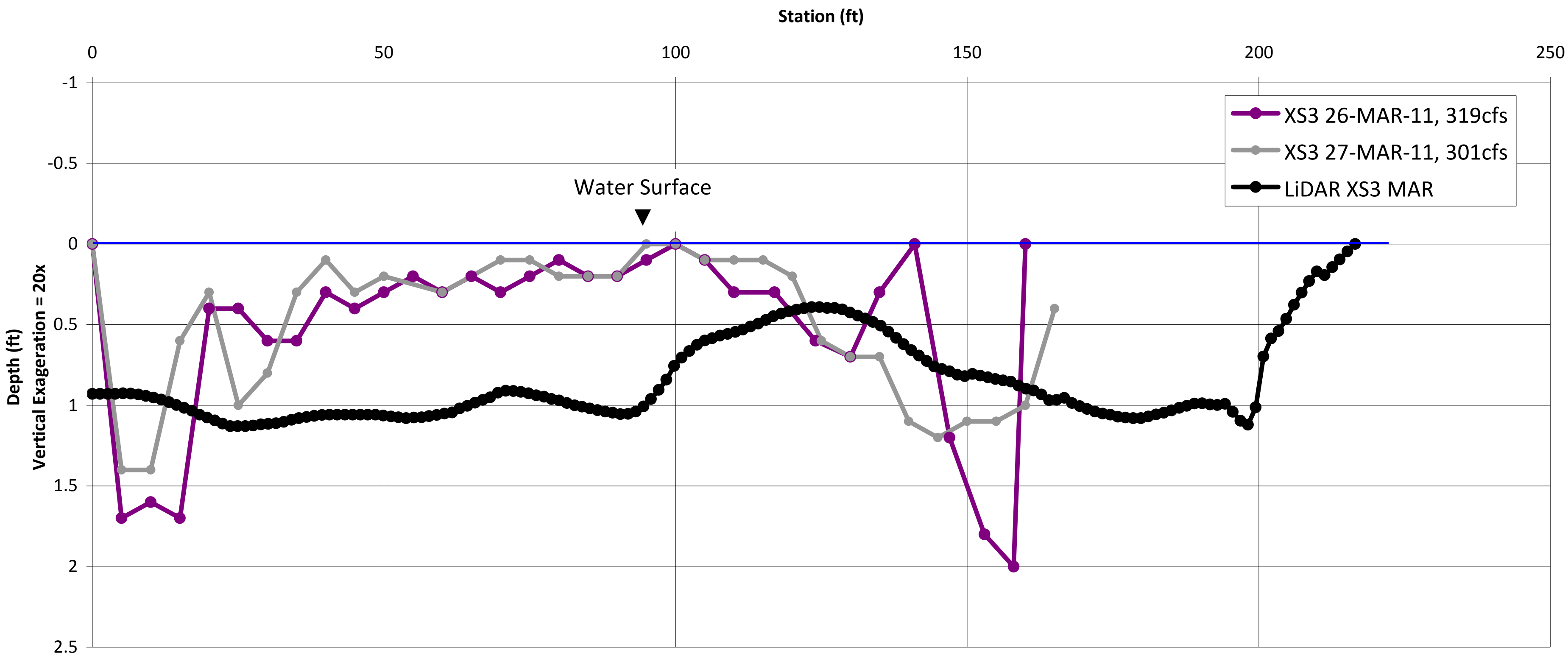

Figure 3.3-2. Comparison of field-based cross sections during a moderate flow event (March 26-28, 2011) with LiDAR-derived cross sections under dry conditions (October 2010) from the same location.

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3.4 Hydrologic Analyses

The Santa Maria River and its two major tributaries have been host to more than a dozen stream gages maintained by the USGS, the first beginning in 1929 and continuing to this day. In addition, flow releases have been monitored daily from Twitchell Reservoir since it first began full operation in February 1962. Owing to the geomorphic and hydrologic nature of the Santa Maria River, however, the flow records are neither continuous at any given gage, nor are they of particularly high quality. We therefore have applied a variety of methods to reconstruct a reasonably accurate picture of daily discharges in the Santa Maria, Cuyama, and Sisquoc rivers, beginning in 1941 with the installation of the one mainstem gage and continuing through to the summer of 2011.

3.4.1 USGS gage records

Of the stream gages along the mainstem and two major tributaries of the Santa Maria River, never more than five have been operational at the same time (see Table 2.3-1). The one of greatest relevance to the present study, that at Guadalupe (USGS 11141000, at the Highway 1 crossing) in the critical passage reach was maintained for only 46 years (1941–1987). Although a mainstem gage is presently in operation at the Suey Crossing (USGS 11140585), it has been in operation only since 1999 and many parts of the record are either intermittent or provisional. This gage may be a useful measurement point for the river for future management programs, but its record was too short for the surface-water hydrologic analyses conducted for this study.

The quality of flow records at the gage locations used in this study are generally quite poor (i.e., measured values >15% different from "true" values), owing to the channel geomorphology and extreme variability of discharge. At the Guadalupe gage (USGS 11141000), for example, flows range from more than three years with no water (occurring both in water years 1959–1961 and in water years 1963–1965) to an instantaneous flow of more than 32,000 cfs (January 16, 1952) during the period of record (with likely even higher instantaneous peak discharges in 1983 and 1998). Throughout the Santa Maria River, the width of flow can be more than 1,000 ft during extreme events, but it commonly shrinks to a few hundred feet (or less) at discharges less than a few hundred cfs. We have also observed the channel at less than four feet wide at measurable discharge (Figure 3.4-1).

Figure 3.4-1. Channel width variability on the Santa Maria River. Left: Approx. 350 cfs on March 26, 2011 upstream of Highway 1; active channel was 132 ft wide. Right: Approx. 1 cfs on September 11, 2011 downstream of Bonita School Road; active channel was distinct but only a few feet wide.

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The 47-year history of the Guadalupe gage is punctuated with long periods having "lack of communication" (between flow in the channel of the river and the location of the gage), sedimentation (and so changing relationships between depth and discharge), and shifting channels. A particularly pointed commentary was offered by a USGS stream-gage operator in the annual station notes from water year 1978:

> …It is readily evident that the entire record is worse than poor and there is really nothing we can do about it. It is just a spot where we should <u>not</u> be trying to streamgage. Daily measurements whenever there is flow would help, but no one has that kind of manpower. The slope-conveyance measurement made this year is considered to be an estimate and the new rating curve drawn to it is just <u>not possible</u> but is used because there is nothing else…I go along with the record as worked and consider it all to be an estimate. If someone else can make more sense out of it, they have my blessings (emphasis in original).

For the Sisquoc River at Garey gage (USGS 11140000), the record is only slightly more encouraging. Most years are rated "fair" in the station summary reports (i.e., measured within 10–15% of actual), but the following statement was repeated in several years and appears to apply to much of the record:

> The natural sand and gravel channel is the control for the gages. The channel control for the low stages easily changes due to natural meandering, excavation, and road construction in the riverbed, associated with the mining operations, which alters the low-flow course…These conditions contribute to unpredictable shifting, poorly defined ratings for the lower channel, and generally fair to poor records.

Based on the annual station notes, USGS personnel typically visited these sites between 8 and 16 times each year. They repositioned gages and/or dug channels to provide flow–gage communication, they measured the flow and adjusted the rating curve as needed, and they adjusted the final record of flow since the previous measurement as deemed appropriate by referring to other flow and rainfall gages in the watershed. In total, the gaged flow record is only an estimate of discharge, and likely particularly inaccurate during the largest annual or multi-year discharges (by virtue of rapidly changing channel conditions during high flow events) and below a few cfs (for lack of flow–gage communication). Neither condition, however, is judged critical to the present study, because inaccuracies in gaging at either extreme of the range of discharges will not alter the reconstruction of the frequency or duration of past (or future) fish-passable flows.

In the course of preparing the present study, we have adjusted the flows on two dates from their published USGS values and note likely problems with a third period:

- March 29, 1970 (329 cfs published, 0 entered): the discharge notes for the Guadalupe gage recorded no flow on March 10 and April 28, the bracketing field visits. The station notes for this year discuss rating-curve shifts only for early March flows, which "…ended on Mar. 8th." Discharge on the 29th was 0 cfs at Garey and 187 cfs at Cuyama, consistent with zero discharge at Guadalupe (and not at all consistent with over 100 cfs of accreted flow).
- January 16, 1952 (17,900 cfs published, 10,000 cfs entered): on this date, the peak discharge for water year 1952, the Guadalupe gage station notes acknowledge extrapolation of the rating curve above 8,000 cfs; the first discharge measurement was on January 17th, when flow had already declined to under 3,000 cfs. The combined discharge past the Cuyama and Sisquoc gages was 6,200 cfs; based on the entire record, accretion of more than 4,000 cfs appears very improbable and likely a result of extrapolation error (Figure 3.4-2).

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- The period from late January–early March 1969 was exceptional throughout southern California for rainfall and consequent river discharge, as much so in the Santa Maria River as anywhere else. Although flows were measured several times per week during this time, the relationship between recorded discharges on the Santa Maria River and its two major tributaries is unlike any other period in the river's recorded history, suggesting a high likelihood of gaging error or incorrect extrapolation. Discharge notes record as much as three feet of stage shift between measurements only a few days apart, suggesting a high likelihood of unrecognized channel changes. We did not adjust any of these flow records, but actual daily discharges at Guadalupe were likely one to several thousand cfs higher than the record indicates. An equivalent magnitude of error for gaged flows on the Cuyama River is also likely for the first week of March 1969 (see Section 4.4).

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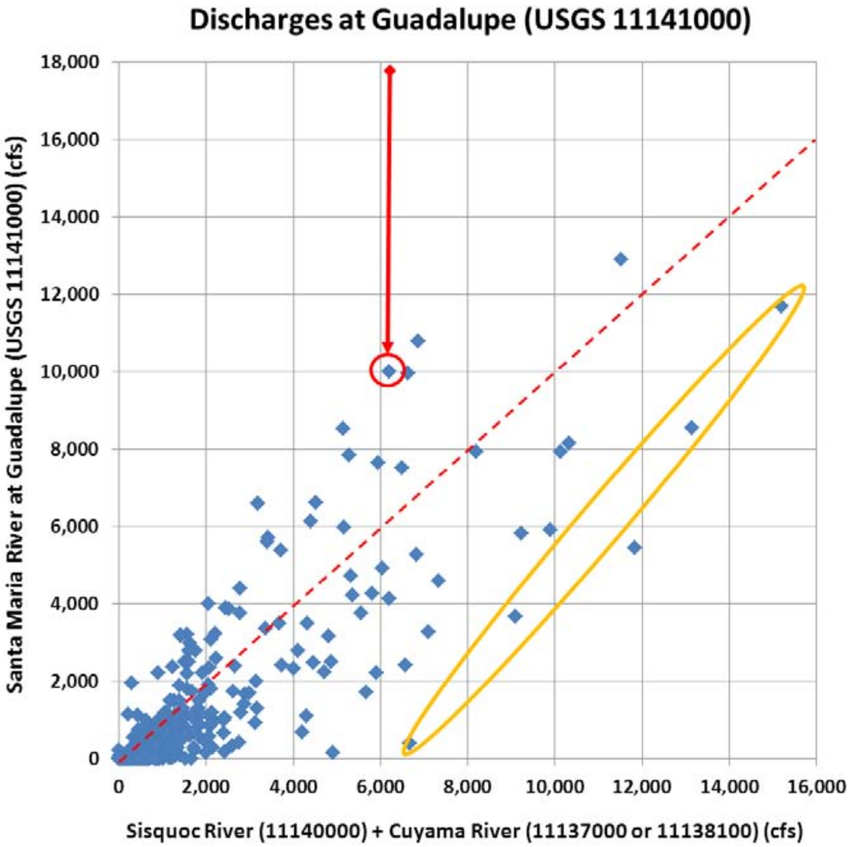

Figure 3.4-2. Comparison of same-day flows for 1941–1987 (i.e., the period of record of the Guadalupe gage). Flows above the red-dotted line imply accretion of water downstream of the confluence of the Cuyama and Sisquoc rivers; those below the line imply loss (the more likely condition; see Section 3.5). At discharges above a few thousand cfs, however, measurement errors likely account for the largest fraction of any apparent disparity. For flows less than about 1000 cfs, the historic data show a median loss between the confluence and the Guadalupe gage of about 350 cfs.

Red-outlined data point highlights the adjusted discharge of January 16, 1952 (original data at red dot); orange-outlined points (4) include those with the greatest disparity recorded during the high-flow period January–March 1969, suggesting inaccurate (low) gage readings at Guadalupe for those measurements. One other outlying point (nearly 12,000 cfs for the combined tributaries, under 6,000 cfs at Guadalupe) occurred on February 11, 1962 and greatly exceeded prior measured discharges for the rating curve being used; though likely incorrect, its value was not changed for this report.

3.4.2 Releases from Twitchell Dam

Daily operation of Twitchell Dam was recorded on hand-written sheets from 1964 through 2003, and on electronic forms thereafter to the present day. The record is largely, but not entirely, complete: for years 1964–1966 and 1968, more than half of the monthly data sheets are missing from the Santa Maria Valley Water Conservation District files. Fortunately, the Cuyama below Twitchell gage (USGS 11138100) was operational during this time, providing a reliable surrogate for releases. Other, brief gaps also exist elsewhere throughout the record but could normally be

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bridged from alternative data sources (either the Cuyama below Twitchell gage or a discharge estimate corresponding to the recorded daily change in reservoir storage). Examples of typical and incomplete data sheets are shown in Figure 3.4-3

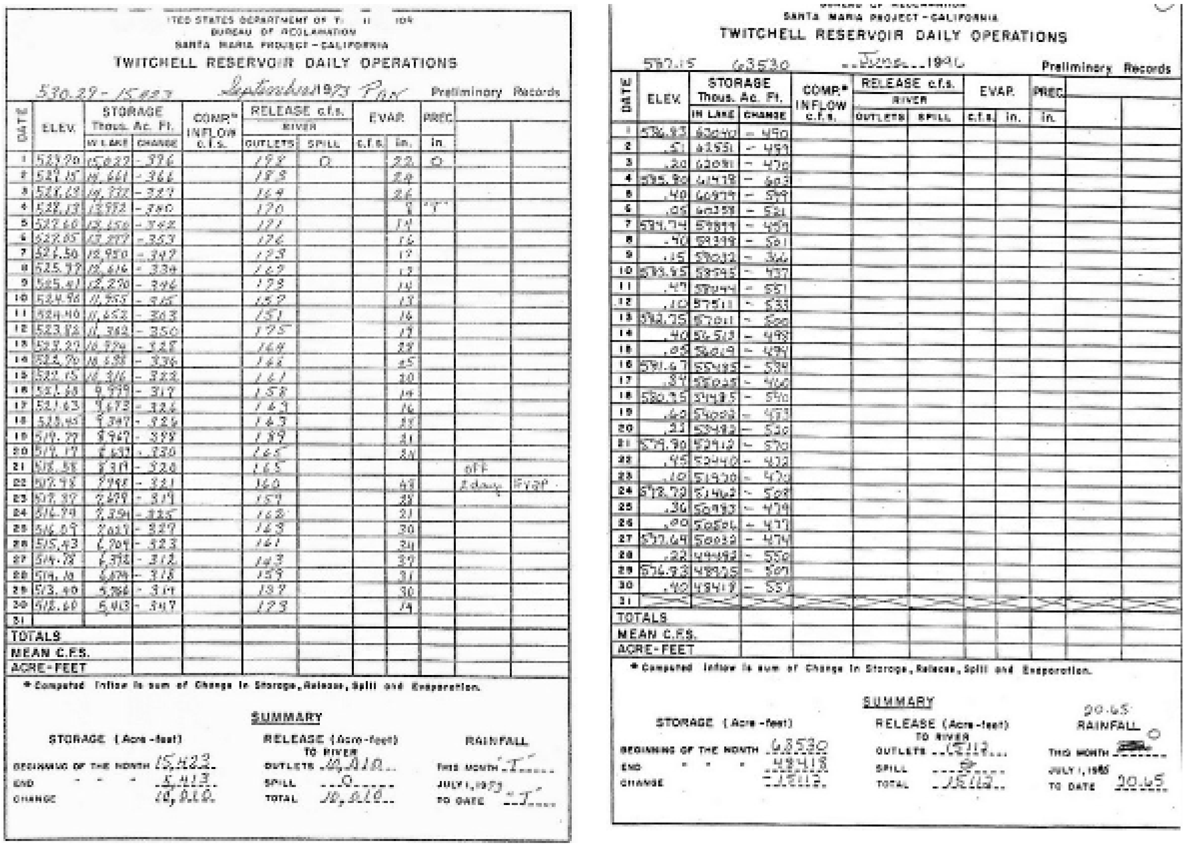

Figure 3.4-3. Monthly data sheets for Twitchell Dam operation. Left, a typical set of entries, showing water-level elevations, ac-ft of storage (and day-on-day change), average daily discharge through the outlet gates, and pan evaporation. Summary data at bottom can be used to double-check the data: a change in storage of 10,010 ac-ft is equivalent to 30 days' continuous discharge of 168 cfs, close to the average of recorded values in the "OUTLETS" column. Right, a less common, incompletely filled-out form—although the reservoir lost over 15,000 ac-ft during the month, no releases are recorded. Daily evaporation values, where recorded, commonly range from 0.1 to 0.3 inches (i.e., up to about one foot per month), but the reservoir level dropped more than 10 ft during this period. Thus, unrecorded releases were assumed to have occurred during this period and were included as synthetic data for subsequent calculations, using a uniform value based on other months with recorded releases and similar change in storage.

The quality of the reconstructed Twitchell release data can be independently assessed for the period 1969–1983 when both the Santa Maria Valley Water Conservation District's records and those of the Cuyama below Twitchell gage (USGS 11138100) coincide. The plotted data show very good correspondence (Figure 3.4-4) with a few dominant patterns:

1. Overall, the two records align with no systematic under- or over-prediction. The diagonal line is the best-fit linear trend, and it shows strong correlation throughout the range of data.

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2. Most Twitchell releases are below 400 cfs (right panel, Figure 3.4-4); the comparison with the USGS gage suggests that District-reported values are commonly averaged (note the preponderance of uniform releases at 25-cfs multiples at and above 200 cfs).
3. Over the range 100–400 cfs, the two records agree to within 100 cfs on nearly all days. Below 100 cfs, the agreement is generally within about 50 cfs.
4. The very largest recorded flows from Twitchell (>2,000 cfs) tend to plot well above the trend line, suggesting that they were either estimated or not full-day releases at that level. Every such flow occurred between February 25 and March 10, 1969, a period of particularly challenging flow-gaging conditions throughout California.
5. The zero-recorded Twitchell discharges with measured USGS flows (i.e., points plotting on the x-axis) likely reflect a combination of downstream accretion and blank entries on the data form being (mis)construed as zero discharges, particularly for those with USGS flows above about 50 cfs. These comprise only 24 of the 5,386 (0.4%) of the dual records, however, and so are not judged consequential for subsequent analyses.

Based on this review, we judge that the Twitchell record is adequate to support a meaningful reconstruction of (post-dam) flow conditions in the Santa Maria River. The record is almost certainly inadequate to meet USGS standards for even “fair” gaging (i.e., 95% of flows within 15% of their true value), but the relatively small disparity from the USGS gage (about 10%, average across all records) and the absence of systematic bias suggests imprecision rather than inaccuracy, a shortcoming that is not anticipated to alter final analyses or ultimate flow recommendations.

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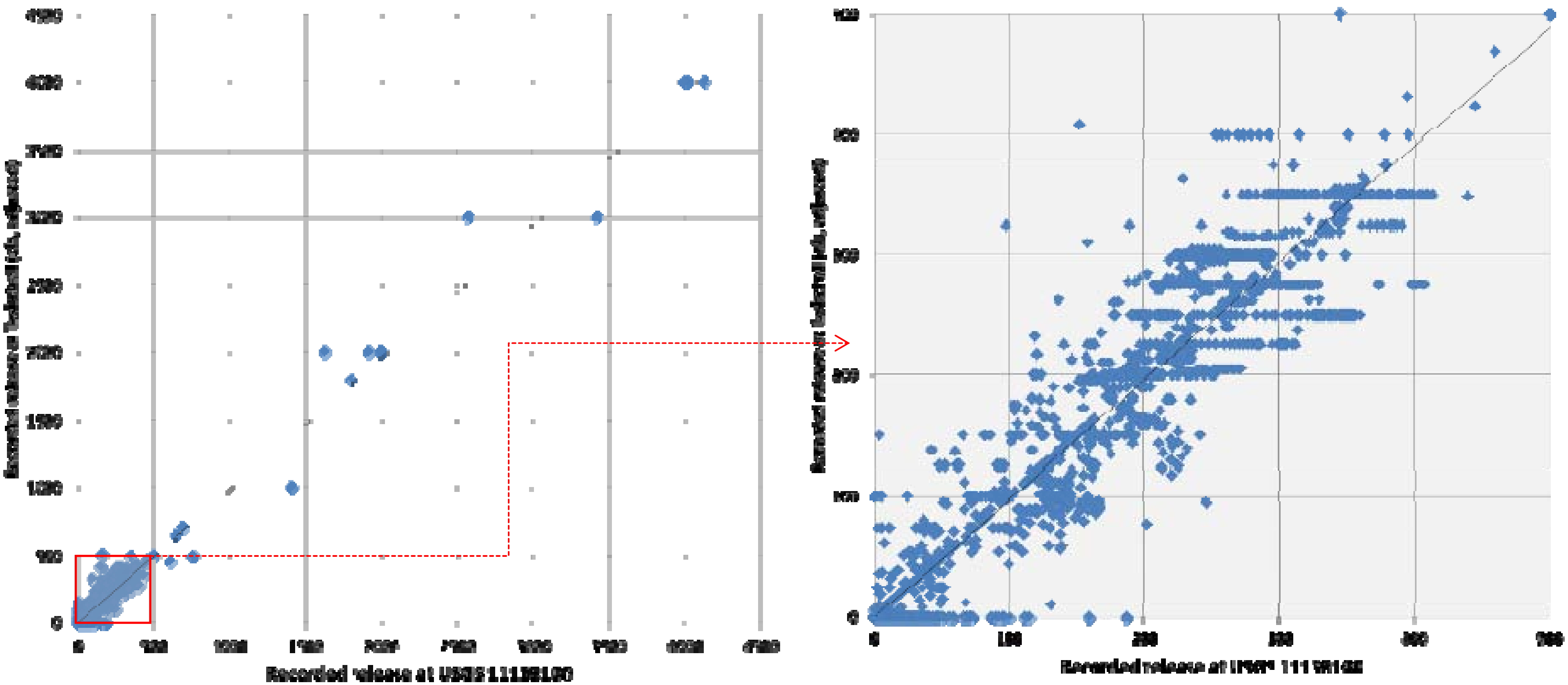

Figure 3.4-4. The 5,386 days of simultaneous record 1969–1983 for Twitchell Dam and the Cuyama below Twitchell gage (USGS 11138100), following adjustment to the raw Twitchell Dam records as described in the text. Blue diagonal shows linear trend line of the full data set. Left panel, full data range. Right panel shows only flows up to 500 cfs (99.6% of all records; from red box at left).

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3.4.3 Defining hydrologic year categories—dry, intermediate, and wet

Although most of the hydrologic analyses described in previous sections were conducted across a multi-year period of record, the actual year-to-year variability of the Santa Maria River and its tributaries is extreme. One of the largest discharges on record, for example (January 16, 1952) came only four days after the end of a multi-year drought.

The hydrologic years (i.e., the period October 1–September 30) of the Santa Maria River were stratified by their overall pattern of discharges to provide a convenient and meaningful way to inform the past distribution of steelhead-passable events across the decades of the available record. The pre-dam record of flows at Guadalupe (USGS 11141000) was used in this analysis, insofar as it is the only systematic, least modified expression of these patterns, even though it includes only 20 complete water years in the pre-dam period (October 1, 1941–September 30, 1961). For purposes of evaluating steelhead-passable conditions, average daily flows at the Guadalupe gage were stratified by those periods of one or more days with a reported discharge of ≥250 cfs, corresponding to the discharge for upstream adult migration (note, however, that actual migration requires a duration of 3 days' flow at this level; see Section 4.2.2).

3.5 Groundwater Modeling

Like many streams in arid and semi-arid regions, the Santa Maria River is intermittent; surface flow occurs only during, and for a period following, infrequent storms. When flow occurs in normally dry stream channels, the volume of flow is reduced at downstream points by evapotranspiration and infiltration to the bed, stream banks, and (for overbank flows) the floodplain. This reduction in the volume of flow at downstream points along a channel is termed *transmission loss*. Quantifying transmission loss provides useful information about both surface flow volume and groundwater recharge. For the past half century, the Santa Maria River, and specifically releases from Twitchell Dam, have been managed to optimize the groundwater recharge component of the transmission loss.

Use of a groundwater model was judged to be an important element of the overall Instream Flow Study, in order to express downstream surface flow as an explicit function of upstream flow, antecedent flow, depth to groundwater, and releases from Twitchell Dam. The primary need of this study is to quantify the magnitude of surface water infiltration, or "transmission loss," that occurs between the confluence of the Sisquoc and Cuyama rivers and the critical passage reach in the mainstem Santa Maria River. This is a relatively narrow need, because simultaneous operation of three stream gages on the lower Cuyama River, lower Sisquoc River, and mainstem Santa Maria River at Guadalupe from 1941 through 1987 provide direct daily measurement of transmission losses for this 46-year period, of which more than 11,000 days had non-zero flows recorded at the confluence of the two upstream tributaries with corresponding discharges at Guadalupe, near the lower end of the critical reach for fish passage. No surface–groundwater model, regardless of its rigor or complexity, could equal the accuracy of such a voluminous (and real) data set—but even a relatively simple model can show typical relationships between the various drivers of transmission loss, and provide an analytical expression that usefully approximates the complexities of the true hydrogeologic system for use in this study.

A review of existing groundwater models of the Santa Maria groundwater basin for this study (Kear Groundwater 2011) found none already existing that were particularly well-suited to these specific needs, while being significantly more complex than necessary for the requirements of this project. A more general review of groundwater modeling literature indicated procedures,

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ranging in complexity, for estimating transmission loss volumes and rates in intermittent and ephemeral stream channels. In general, simplified procedures require less information about the physical features of the channel, but are less general in application. More complex procedures are typically more physically based, but they require correspondingly more data. For the Santa Maria River, a two-dimensional infiltration model (SMR2DIM) was developed with the goals of utilizing easily measurable channel conditions, aquifer characteristics, and flow volumes; and to inform conditions in the Santa Maria River at rates of flow critical to steelhead passage (approximately 100 to 1,000 cfs; see Section 4.3).

To model the surface water and groundwater interaction over the critical passage reach of the Santa Maria River, a river-specific regression equation was developed for surface water loss rate as a function of the factors most affecting transmission losses: channel length or area, thickness of the unsaturated zone, days of antecedent flow, permeability of the surface sediments, flow at the Sisquoc River at Garey gage (USGS 11140000), and releases from Twitchell reservoir. This method is based chiefly on empirical information unique to the Santa Maria River at flows in the 100 to 1,000 cfs range, and in particular is intended to reflect conditions on the receding limbs of the flood hydrograph, the period when managed flow releases to improve fish-passage conditions would likely be most effective. Model results are subsequently used (Section 4) to identify a single value for transmission loss within this range of critical flows for fish passage, and to characterize the magnitude of uncertainty associated with this estimate of loss. The surface water–groundwater system of the Santa Maria groundwater basin is sufficiently complex, however, that SMR2DIM results are not recommended (nor are they intended) as the operational management tool for directing flow releases.

3.5.1 Transmission loss variables

Several sets of hydrologic, geologic, geophysical and geotechnical parameters were compiled to develop the database employed in the development of the regression equations that predict streamflow in SMR2DIM.

3.5.1.1 Stream flow

Flows from the Sisquoc River at Garey gage (USGS 11140000) and the Santa Maria River at Suey gage (USGS 11140585) were compared to approximate transmission losses over the 8.5-mile reach between the two gages. The Sisquoc at Garey gage represents the flow contributions from the Sisquoc River and is used to approximate flow near the confluence of the Sisquoc and Cuyama rivers. The Suey gage represents flow at the Santa Maria River approximately 7 miles downstream from the Sisquoc/Cuyama river confluence, and it is influenced by operations at Twitchell Dam. Flow events for comparison were selected using the following criteria:

- Only dates with flow at both gages were selected.
- Daily mean flow at the Garey gage was between 100 and 1,000 cfs.
- Data from 2008 to 2011 were selected, due to availability and apparent precision of the measurements.
- Only those flows when no releases from Twitchell reservoir were recorded were selected, thus reflecting only transmission losses between the Garey and Suey gages.

Flow on 115 dates met the selection criteria and are plotted in Figure 3.5-1. A best-fit line was plotted and reflects a linear relationship, as is common in sandy ephemeral streams (Walters 1990).

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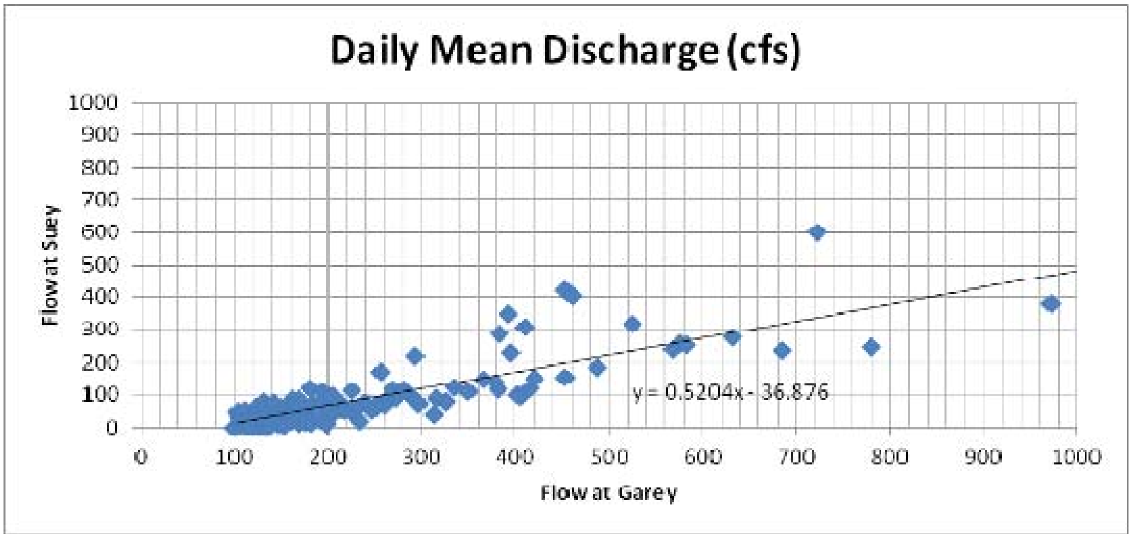

Figure 3.5-1. Daily mean discharge relationship between the Sisquoc River at Garey (USGS 11140000) and Santa Maria River at Suey (USGS 11140585), the latter gage about 10 miles upriver of the bottom of the critical passage reach. All values in cubic feet per second (cfs). Transmission losses between these two gages range between about 50 and almost 600 cfs, with a median value around 100 cfs.

3.5.1.2 Groundwater levels

Depth to groundwater is an indication of the whether there is sufficient groundwater storage capacity to allow free infiltration of surface water into the groundwater aquifer. When groundwater levels are shallower (i.e., closer to the channel bed), infiltration rates typically decrease. When groundwater levels are deeper, surface flow infiltration rates tend to be higher. This relationship is more pronounced in the downstream portion of the Santa Maria River where the groundwater and surface water is typically more connected. This factor was included in the SMR2DIM to address the issue of inhibited transmission loss by inadequate ground water storage capacity. Over much of the critical passage reach, depths to groundwater are at least 30 ft below the channel bed, as shown on Figure 3.5-2. Records of groundwater wells were inspected, and no selected sample flow event was found to completely fill the groundwater storage capacity over the critical passage reach. For modeling purposes, the shallower depths to groundwater are reflected in the minimization of transmission losses over the last 9 miles of the Santa Maria River.

A “key well” was selected to represent the groundwater-level hydrograph in the critical passage reach in the SMR2DIM (Figure 3.5-3), on the basis of its proximity, length and continuity of record, and data quality. The well, 11N/34W-30Q1 (also referred to as the Mary Bolton Well) is located on the north side of the Santa Maria River, approximately one mile east of the Bonita School Road crossing. It has been in operation since 1930 and is monitored by the USGS and the Santa Maria Valley Water Conservation District. Over the well’s entire period of record, depths to groundwater have ranged from 32.0 to 114.9 ft, with an average elevation of about 78 ft. Groundwater levels during the potential steelhead migration period (December through May) are similar, ranging from 32.0 to 113.0 ft with an average of 75 ft. Although additional data from multiple wells both up- and downvalley of the Mary Bolton Well would be useful in creating and calibrating a spatially explicit groundwater model of the valley, this objective was explicitly *not* part of the modeling effort.

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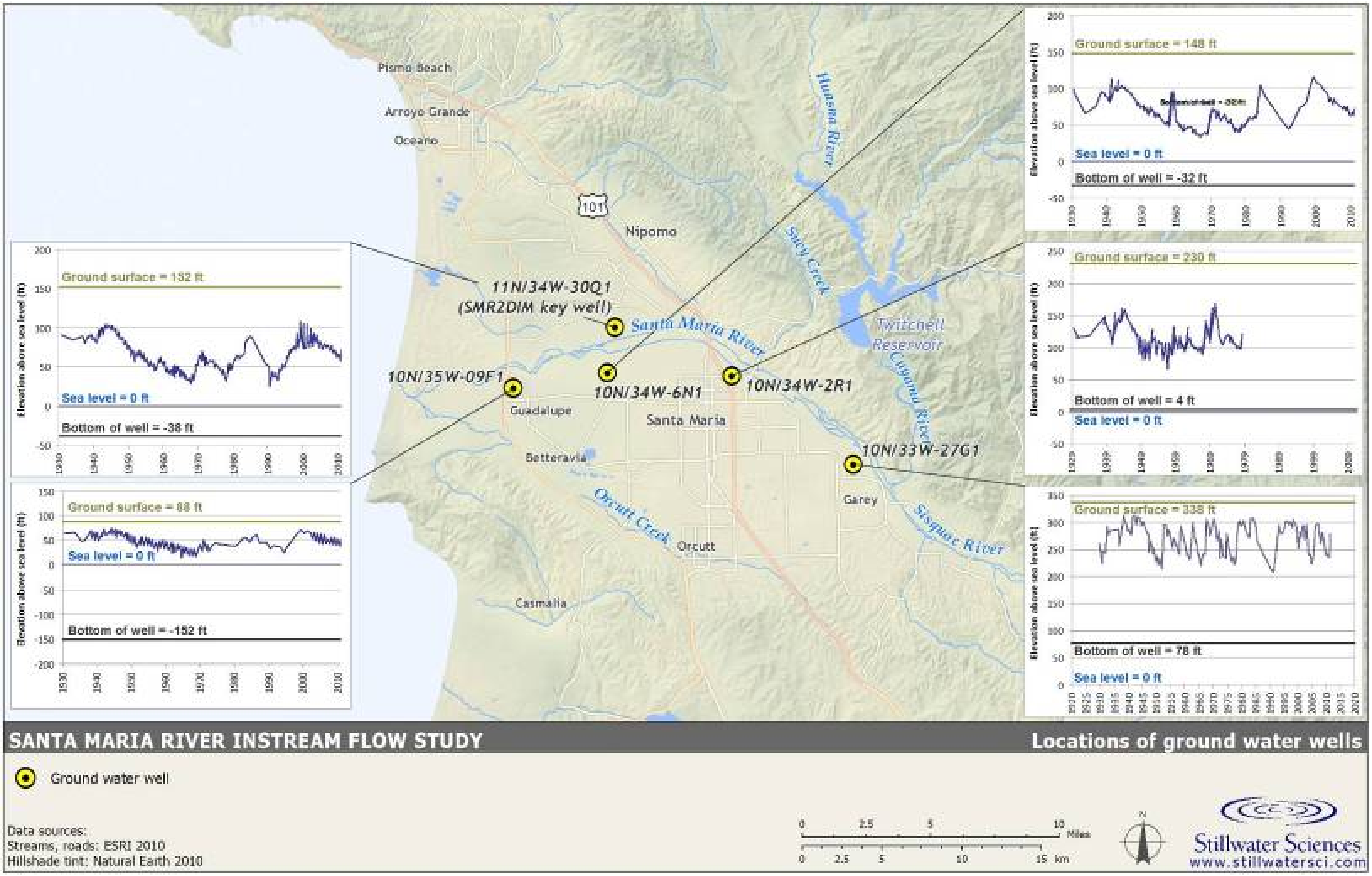

Figure 3.5-2. Groundwater level hydrographs in selected wells along the Santa Maria River. Dotted lines=ground surface, light blue lines=sea level, black lines=bottom of well, y-axis of graphs=ft, zeroed at sea level. Note the greater distance between the ground surface and groundwater levels upstream of Bonita School Road crossing (i.e., in the critical passage reach).

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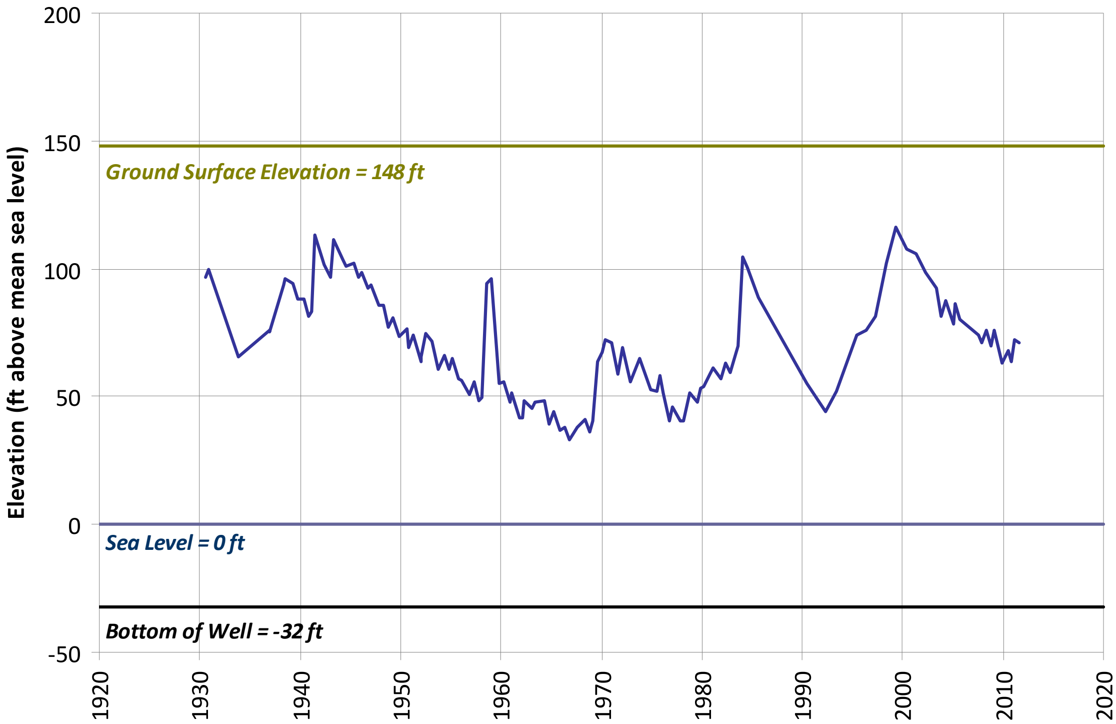

Figure 3.5-3. Groundwater level hydrograph of the "key well" (11N/34W-30Q1) for the SMR2DIM.

3.5.1.3 Subsurface geologic units

The presence and depth of subsurface sand and clay layers influence the infiltration of surface water to groundwater. To develop an understanding of subsurface properties for the model, over 800 water well logs, oil well logs, and monitoring well logs were collected and reviewed. Key data obtained from these logs were depths to the shallowest clay strata, which would impede infiltration of river water. A total of 178 logs were found to contain usable information on lithology, and their respective well locations were plotted on a pre-levee geologic map to establish proximity and representation to river properties. Thickness of the shallowest sand unit (equivalent to depth to shallowest clay) was also plotted where available.

As shown on Figure 3.5-4, the major zones of thick sand units underlie the uppermost 6 miles of the Santa Maria River and two 3-mile reaches between Suey Bridge and Bonita School Road crossing. Relatively shallow clay zones (i.e., overlying sand is about half as thick as in surrounding areas) appear to be present beneath the river for one mile upstream from Suey Bridge and for a few hundred yards about a mile downstream from Highway 101. Downstream from Bonita School Road crossing, over the last 9-mile reach of the Santa Maria River, the upper sand unit is nearly absent with a maximum thickness of less than 20 ft, or about an order of magnitude thinner than the thickest sands underlying the river. This sand thickness is a significant controlling factor to the infiltration of river water to the groundwater basin.

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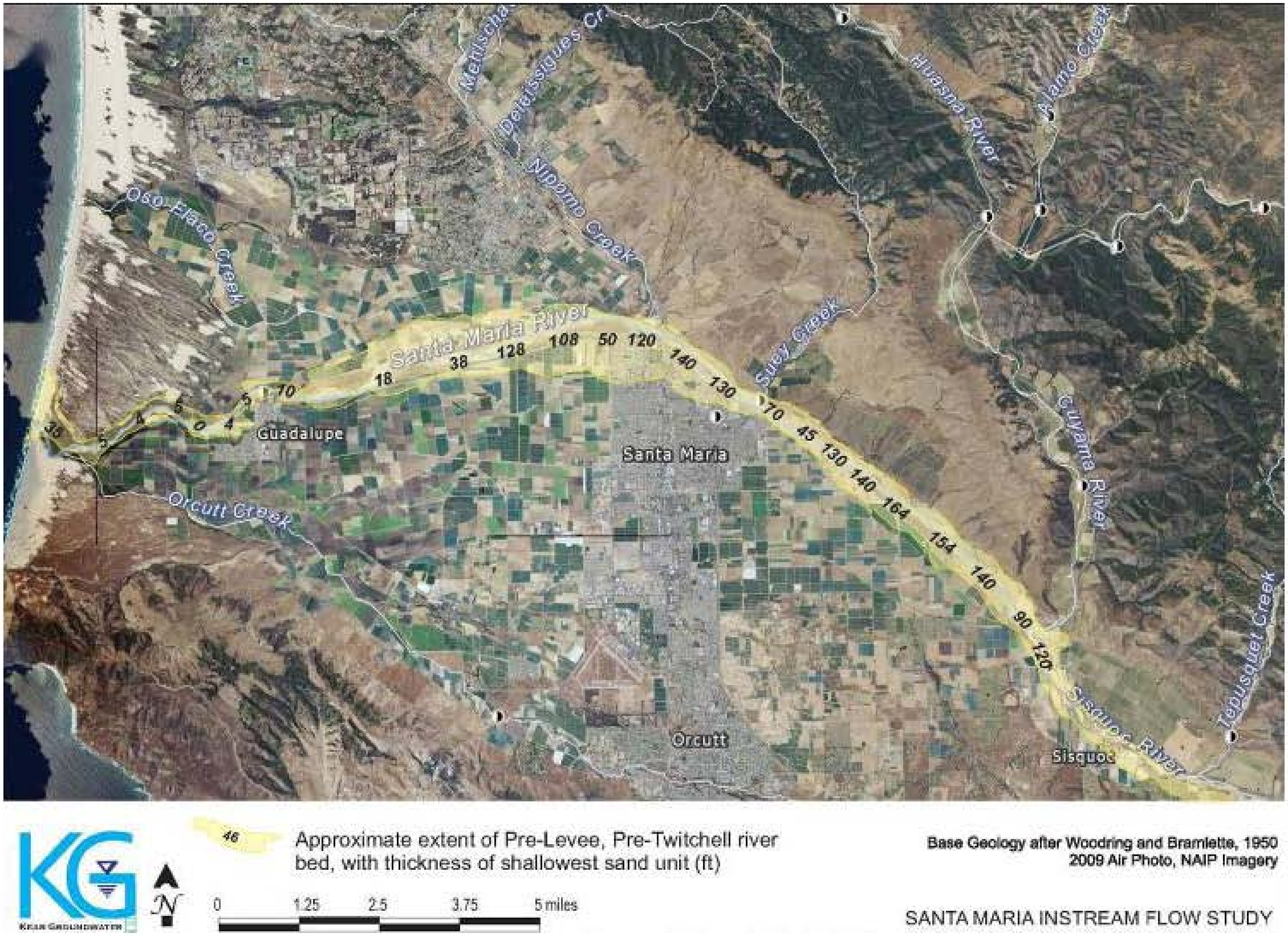

Figure 3.5-4. Geologic map showing shallow sand thickness.

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3.5.1.4 Stream-bed sediment properties

Although on a smaller scale than subsurface geology, stream-bed sediment properties also control infiltration rates of surface water. Measurements indicate that these properties are relatively consistent over much of the length of the Santa Maria River (Figure 3.5-5). Although there is a greater component of gravel-, pebble-, and cobble-sized clasts in the river near the Sisquoc/Cuyama river confluence, it appears that the "effective grain size" with respect to permeability (i.e., the grain size presumed to control the rate of flow and typically represented by the finest 10% fraction) is fine-to medium grained. Worts (1951) presented permeability data based on falling-head permeameter tests from various locations in channel sediments; he found that less than an order of magnitude separated the highest values from the lowest values along the Santa Maria River. For the development of the SMR2DIM, samples of channel sediment were collected and grain-size distribution analyzed at eight locations along the river between Garey and Guadalupe; they show similar sorting, effective grain size, and general characteristics of the sediment (Figure 3.5-5).

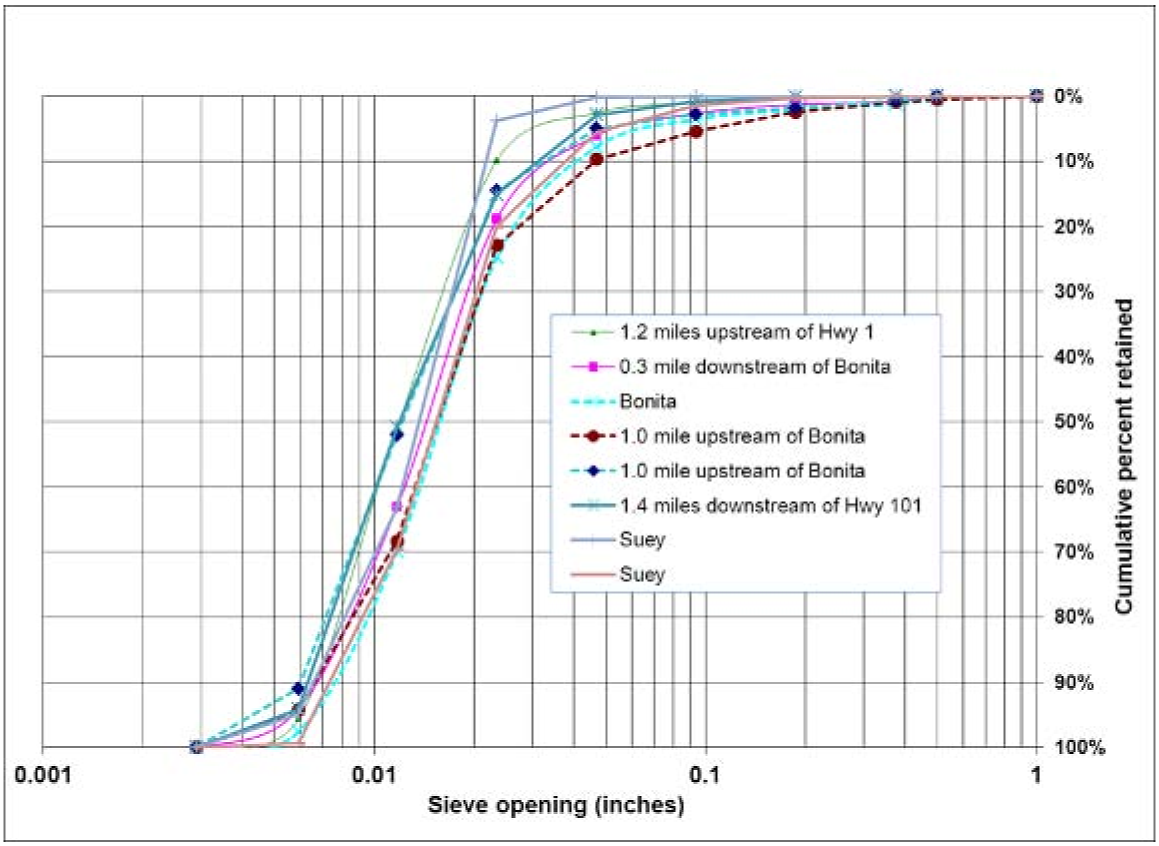

Figure 3.5-5. Grain-size distribution analyses of various samples of Santa Maria River stream-bed sediment.

3.5.1.5 Topography and river morphology

Longitudinal position (i.e., distance from the ocean) and elevation are critical to transmission loss and provide the frame of reference for model input variables. The distance from the ocean and elevation, both obtained at 10-ft intervals between the ocean (0 ft elevation) to Garey Bridge (330 ft elevation), were used.

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Owing to the highly dynamic and braided channels of the Santa Maria River, and the tendency for the channels to change significantly at very small time steps when surface flow is present, the SMR2DIM is based on current general river morphology. Over longer geologic time, however, the Santa Maria River appears to have behaved as a distributary fan-delta depositional environment, with active channeling that migrated over a 7-mile swath in a north–south direction between Oso Flaco and Betteravia.

3.5.1.6 Antecedent flow conditions

The duration of flow prior to a modeled period has an effect on infiltration rates. On the receding limb of the hydrograph, the duration of antecedent flow is typically inversely proportional to infiltration rates (i.e., infiltration rates typically decline over time).

3.5.2 SMR2DIM model development

Transmission-loss estimates have been made using a variety of techniques, including field investigation (Burkham 1970, Dames and Moore 1988), analytical approaches (Parissoponlos et al. 1991) and statistical approaches (Sharp and Saxton 1962, Lane et al. 1971, Walters 1990). Field investigations of infiltration losses in alluvial channels (Dames and Moore 1988, Abdulrazzak et al. 1991) revealed that factors controlling the amount and rate of transmission losses are flood hydrograph, channel and soil-profile characteristics, and tributary-runoff inflow.

Depending on initial conditions, certain parameters are typically more important than others. Key factors are generally runoff distribution (tributary contribution) in relation to storm duration, channel configuration in terms of length and type of bed material, and soil type in relation to permeability and their degree of saturation. The magnitude of transmission losses (i.e., cumulative infiltration over the length of the channel) was investigated through the water-loss and curve-fitting approach, starting with a given inflow from tributary(s). A regression equation was then used to relate the magnitude of loss to channel and soil parameters.

The Santa Maria River is a relatively simple, uniform system: it tends to behave as a single unit with two main tributaries, the soil types and properties of the channel-bed sediment are nearly uniform, and the surface water and groundwater are disconnected over the majority of the river's reaches. The current application requires prediction of transmission losses over a relatively narrow range of discharge (i.e., those of relevance to critical fish passage) with a focus on multi-day flows (i.e., on the receding limb of a storm hydrograph). Using these constraints, the simplest form of a regression equation was used that could account for the dominant factors controlling transmission losses (soil properties, depth to groundwater, and duration of flow). It was calibrated with the data from just one day’s measurements and then evaluated against the much broader record of surface-water flows.

The equation is of the form:

$$y = x\,k\,C + cz(t)^{-1} \qquad (2)$$

in which:
y = transmission loss over a given reach (cfs);
x = length of given reach (ft)
k = permeability (cfs/ft^2)
C = constant based on shallowest sand thickness (ft)

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c = constant (ft^2·days/sec)
z = depth to groundwater in the key well (ft)
t = period of antecedent flow in river (day)

This regression equation is based on empirical observations of the flow in the Santa Maria River over the range of discharges critical for fish passage (see Section 4.3). The equation returns the magnitude of loss along a reach of length x; integrating the sum of the transmission losses over individual reaches results in a modeled loss along the entire river.

The equation returns a predicted linear decrease in surface-water flow with downstream distance (first term), which although not strictly correct is likely adequate for reaches averaging less than one mile in length and with no more than a 10-ft elevation change. Differences in permeability and sand thickness are the most significant factors in calculating loss differences among reaches; depending in part on the magnitude of the constant c, depth to groundwater is important only early in the flow event (i.e., low value of z).

Required inputs to the model are flow at the Garey gage and contributions from Twitchell Reservoir releases, together with several other parameters described below and summarized in Table 3.5-1.

3.5.2.1 Permeability

Using Worts's (1951) data, permeability of channel sediment was assigned to various reaches as follows:

- Ocean to Highway 1/Guadalupe = 0.0002 cfs/ft^2
- Highway 1/Guadalupe to Highway 101 = 0.0004 cfs/ft^2
- Highway 101 to River Mile 18 = 0.0006 cfs/ft^2
- River Mile 18 to Garey = 0.001 cfs/ft^2

3.5.2.2 Sand thickness

Sand thickness ranges from as much as 160 ft between the Sisquoc/Cuyama river confluence and Suey Bridge, to less than 10 ft between Highway 1 and the Santa Maria River estuary (Figure 3.5-4). Sand thickness stratified the selected values for the constant C; the calibration data (see Section 3.5.2.5) resulted in the following values:

Sand less than 10 ft: $C = 0.06$
Sand between 10 and 30 ft: $C = 0.6$
Sand greater than 30 ft thick: $C = 6$

3.5.2.3 Depth to groundwater

Directly proportional to infiltration rates, the depth to groundwater is a key factor in transmission loss estimation. Because of the reach-averaged simplicity of the model, only a single key well was used to inform this factor. The calibration data indicated that a value of 0.05 ft^2/s for the constant c should be used to multiply by the depth to groundwater (which has historically ranged between 30 and 120 ft) to adequately match the measured data.

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3.5.2.4 Antecedent flow

Channel antecedent flow condition affects the infiltration rates, particularly at the beginning of a flood. A dimensionless index of the antecedent condition was defined as the inverse of the number of days of flow over the complete Santa Maria River.

Table 3.5-1. Key factors in the SMR2DIM model.

Distance from ocean (mi)	Landmark	River bed elevation (ft)	Sand thickness (ft)	Top clay elevation (ft)	Permeability (cfs/ft^2)
0.000	Pacific Ocean	0	35	-35	0.0002
0.693		10	34	-24	0.0002
1.912		20	5	15	0.0002
2.775		30	4	26	0.0002
3.637		40	5	35	0.0002
4.659		50	7	43	0.0002
5.417	Highway 1	60	6	54	0.0004
6.162		70	10	60	0.0004
6.947		80	15	65	0.0004
7.683		90	18	72	0.0004
8.275		100	20	80	0.0004
8.805	Bonita School Rd	110	30	80	0.0004
9.347		120	25	95	0.0004
9.9727		130	110	20	0.0004
10.546		140	120	20	0.0004
11.112		150	118	32	0.0004
11.598		160	108	52	0.0004
12.062		170	50	120	0.0004
12.937		180	120	60	0.0004
13.423	Highway 101	190	140	50	0.0004
14.063		200	130	70	0.0006
14.800		210	130	80	0.0006
15.444	Suey	220	63	157	0.0006
16.055		230	46	184	0.0006
16.720		240	35	205	0.0006
17.344		250	130	120	0.0006
18.098		260	140	120	0.0006
18.699		270	160	110	0.001
19.100		280	154	126	0.001
19.830		290	150	140	0.001
20.498		300	140	160	0.001
21.250		310	90	220	0.001

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Distance from ocean (mi)	Landmark	River bed elevation (ft)	Sand thickness (ft)	Top clay elevation (ft)	Permeability (cfs/ft^2)
22.769	Fugler Point	320	90	230	0.001
23.446	Garey Bridge	330	120	210	0.001

3.5.2.5 Calibration of the model

Based on the available data, a calibration data set was developed using field measurements recorded in a letter from J.D. McGregor, dated January 23, 1932 and located in the Water Resources Center Archive in Riverside, CA. The data (see below) were used to determine optimal values for the two constants in the regression equation, *c* and *C*. Groundwater conditions in 1932, based on water level hydrographs from multiple wells, appear to be similar to current conditions and within the ranges of maxima and minima observed since that time. Most importantly, the key driver of the surface water–groundwater system, namely the disconnection between surface water and groundwater over the critical reach, has remained unchanged throughout the last 80 years and is quite likely to remain. Observations, such as by the study team during winter 2010-2011, corroborate the magnitude of the observed and simulated 1932 values; and the gage record is consistent with the magnitude of overall transmission losses for both the calibration data set and the range of scenarios explored in Section 4.5.

Observed (J.D. McGregor, unpublished letter 1/23/1932):

- Fugler Point: 312.09 cfs
- Five miles downstream from Fugler Point: 101.5 cfs
- Highway 101: 63.32 cfs
- Bonita School Road: 17.4 cfs

Simulated:

- Fugler Point: 311.3 (Model -0.8 cfs, error = 0.25%)
- Five miles downstream from Fugler Point: 147.9 (Model +46.4 cfs, error = 31.35%)
- Highway 101: 69.9 cfs (Model +6.58 cfs, error = 9.39%)
- Bonita School Road: 14.7 (Model -2.6 cfs, error = 17.83%)

The errors are not systematic in either space or in sign; they suggest that model results are likely to be useful within a range of ±20%. This precision is sufficient to evaluate the benefits and relative cost (in released water) of any flow alternatives (Section 5), but it also serves as a reminder that direct measurements during any future flow releases will be necessary to achieve presumptive benefits for fish passage without requiring excessively conservative (i.e., voluminous) releases to ensure that such management goals are achieved.

3.6 Data Quality Assurance/Quality Control

Data quality plans were executed for each of the data sets generated during the Instream Flow Study. These included: LiDAR data, water quality measurement and samples, hydraulic data, and hydrologic data.

Quality assurance/quality control of the LiDAR data was undertaken at two levels. First, the LiDAR vendor, Airborne 1, extracted 323 random points from the ground-based dataset, created an elevation surface with the remaining points from which basic statistics were calculated

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between the point's surveyed elevation and the point's estimated elevation in the surface created without the extracted points. This does not show the absolute accuracy against an independent, high accuracy set of points, but is a good indication of the relative accuracy of the points within the dataset. The elevation root mean square error was 6 cm and 93.8% of the points had an uncertainty of +/- 5 cm. Second, Stillwater Sciences further checked the LiDAR surface accuracy assessment for two cross sections in zones with very low relief and high fish passage concern. Cross section points were found to have an elevation root mean square error of 0.005 m with respect to source LiDAR points. The average horizontal distance between a cross section point and a LiDAR source point was under 25 cm.

Water-quality measurements in the estuary and TSS samples from the Santa Maria River were taken using relevant industry standards. Water quality measurement instruments were maintained, calibrated, and used in accordance with instrument manufacturer instructions. *In situ* water quality measurements were recorded in field notebooks. Field notebook entries were reviewed for completeness and reasonableness in the field and were entered into Excel databases in the office. Entered data was compared to field notebook entries and corrected as needed. All field notebooks were copied and archived. TSS samples were collected and preserved following industry standards for TSS sample chain of command, and were prepared and analyzed by Clinical Laboratory of San Bernardino, Inc.

Hydraulic data, including flow depths, widths, and velocities, were collected in the field in December 2010/January 2011, February 2011, and March/April 2011. Observations and measurements were recorded in field notebooks. Field notebook entries were reviewed for completeness and reasonableness in the field and were entered into Excel databases in the office. Entered data was compared to field notebook entries and corrected as needed. All field notebooks were copied and archived.

Hydrologic data used in the Instream Flow Study were acquired from the USGS and Santa Maria Valley Water Conservation District. The steps taken to check and correct these data are described in detail in Sections 3.4.1 and 3.4.2.

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4 RESULTS

4.1 Estuary Conditions

Our understanding of estuary outlet conditions are grounded in field observations made during winter–spring 2010/2011. During that water year, the sandbar breached on or about December 19, 2010, within a day of the first continuous flows in the Santa Maria River. As such, this flow event marked the first opportunity for juvenile migration into the estuary since February 2010. Direct observations during this period showed that continuous flows in the Santa Maria River coincided with the outlet being and remaining open. With the outlet open, the impounded estuary was nearly entirely drained, the Santa Maria River channel was braided and shallow with very little cover (Figure 4.1-1). Only one small ponded area, disconnected from the river channel unless the estuary is relatively full, remained in the northeastern corner of the drained estuary. This single observation provides a context for interpreting past estuary conditions, but it does not characterize the behavior of the estuary under all flow conditions. To accomplish this goal we investigated all available direct and indirect historical records to infer the general behavior of the estuary and its outlet over time.

The conditions observed during the winter–spring 2010/2011suggested that there was no opportunity for out-migrating juvenile steelhead to access or remain in an impounded estuary for extended rearing. Rather, any out-migrating juvenile steelhead most likely entered the Pacific Ocean directly. Rearing opportunities in the lower river and estuary are limited when the sandbar is open since the majority of the estuary (extent when full) is dewatered, and any remaining water is shallow (<1 ft, and mostly <0.1 ft) with little cover (juvenile steelhead generally prefer depths greater than about 1 ft for rearing and older age classes [e.g., age 2+] tend to prefer deeper water).

It has been hypothesized that the Santa Maria River estuary could provide important rearing habitat for juvenile steelhead (e.g., SAIC et al. 2004, Becker et al. 2010), and steelhead have been documented to rear in lagoons to the north and south of the Santa Maria River (e.g., in Santa Rosa Creek in San Luis Obispo County [Nelson et al. 2005] and the Santa Ynez and Santa Clara rivers in Santa Barbara County [Kelley 2008]), as well as elsewhere in California. There is, however, no documentation of steelhead rearing in the Santa Maria River estuary, although there is also no indication that field surveys have been conducted for this purpose. The presence or absence of *O. mykiss* rearing in the estuary could not be verified by this study (the permits necessary to sample the estuary were not granted in time).

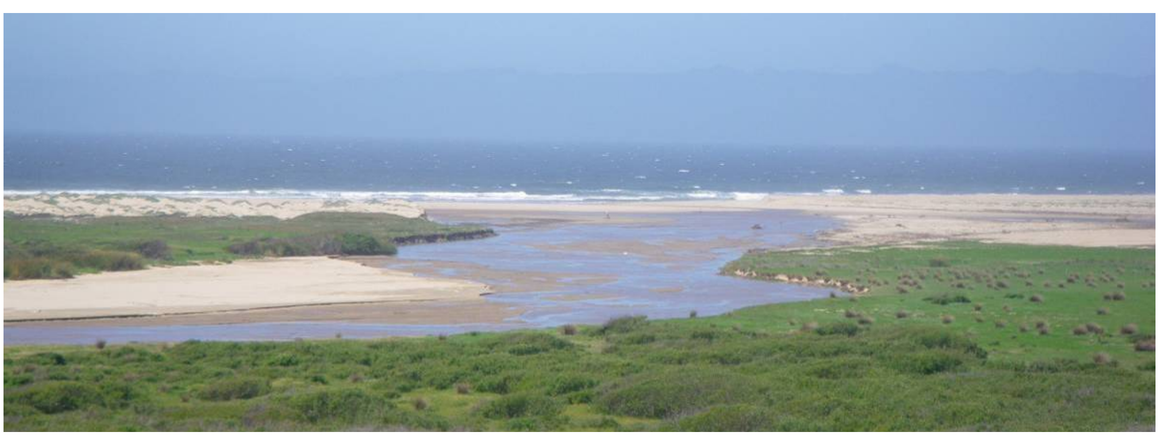

Figure 4.1-1. The Santa Maria River estuary in April 2011 when outlet was open.

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4.1.1 Estuary outlet/sandbar breaching patterns

Available photographs of the estuary from GoogleEarth© (1994–2009) and the County of Santa Barbara Flood Protection District (1966–1998), plus the results of LiDAR topographic survey in September 2010, are summarized in Table 4.1-1.

Table 4.1-1. Observations/measurements of the Santa Maria River estuary.

Photo date	Estuary outlet	Comments	Approx. wetted area (ft)	Approx. wetted area (ac)	Last passable flow[3]	Time since last passable flow[3]
7/25/1966[1] (Figure 4.1-1a)	Open	Narrow channel appears dug through last 70 ft of beach	200 x 1,000	4.6	12/30/1965	7 months
12/9/1966[1] (Figure 4.1-1b)	Open	25 ft wide channel, obvious natural breaching from broad wetted beach zone	200 x 700	3.2	12/6/1966	same week
2/25/1970[1]	Open	Narrow channel, barely clear through beach; disturbance suggests excavation	200 x 350 (in two lobes)	1.6	4/7/1969	10 months
10/17/1992[1]	Closed	Barely blocked at beach	500 x 700	8.0	marginal, 3/27/1992	≥7 months
9/14/1994[2]	Open	Narrow (10–30 ft) channel flowing across beach	200 x 1,000	4.6	3/31/1993	>1 year
4/23/2002[2]	Closed	Channel within 80 ft of ocean; looks recently breached or soon to be breached	900 x 900	18.6	3/11/2001	>1 year
6/3/2003[2]	Open	20 ft wide channel	700 x 770	11.2	3/11/2001	1 month
1/3/2004[2] (Figure 4.1-1c)	Closed	Channel blocked ~140 ft from coast	800 x 800	14.7	3/11/2001	8 months
6/30/2004[2]	Closed	Channel blocked ~60 ft from coast	Obscured by clouds		3/11/2001	1 year
6/11/2005 (also with imagery date 12/31/2004[2])	Open	20 ft wide channel	300 x 700 (isolated pond north of channel	4.8	12/31/2004	same day?
11/25/2005[2] (Figure 2-1d)	Closed	Channel blocked ~110 ft from coast	1,400 x 2,700	86.8	3/23/2005	8 months
4/27/2006 (also with imagery data 6/25/2006[2])	Open	20 ft wide channel	300 x 350	2.4	4/11/2006	2 weeks
5/24/2009[2]	Closed	Channel blocked ~70 ft from coast	350 x 900 + 620 x 520	7.2	2/4/2008	>1 year
9/2010 (topo survey)	Closed				2/27/2010	7 months
12/18/2010[2]	Open	Verbal report from County Park staff	Not measured	Not measured	12/19/2010	same day

[1] Source = County of Santa Barbara Flood Protection District
[2] Source = GoogleEarth©; estuary was still open as of May 30. 2011 imagery.
[3] Passable flow considered to be 250 cfs at Guadalupe (if data available) or 550 cfs at Sisquoc/Cuyama River confluence (i.e., transmission losses assumed to be 300 cfs; see Section 4.5)

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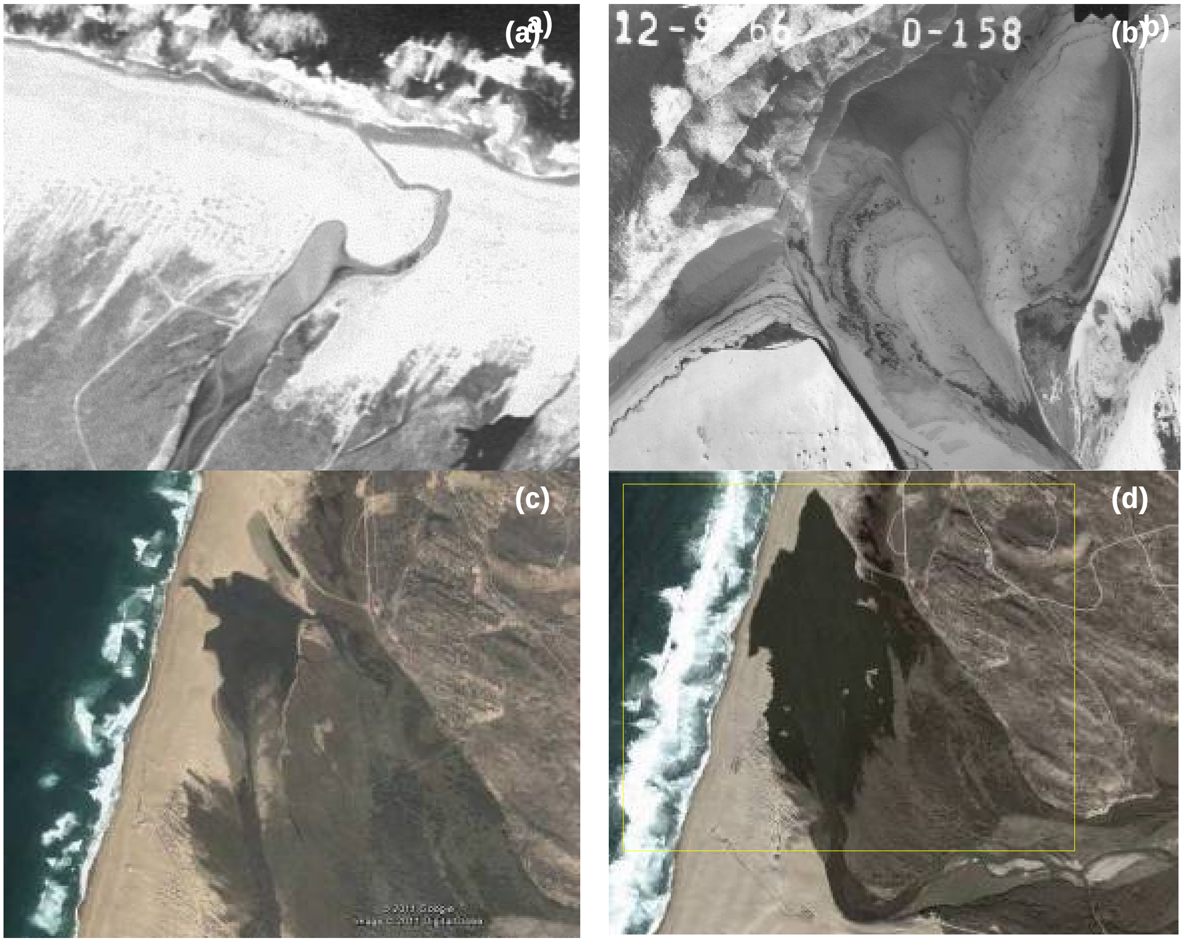

Figure 4.1-2. Selected views of the Santa Maria River estuary. (a) open conditions of July 1966, with suggestion of an artificial breach; (b) open conditions of December 1966, with an extensive area of wetted and eroded beach adjacent to the open channel; (c) closed conditions of January 2004 with a fairly typically sized estuary impounded; (d) closed conditions of November 2005 with the largest lagoon (84 acres) seen in the photographic record (for reference, yellow box outlines the area shown in [c]).

From these observational data, an open-estuary condition has resulted from every instance with fish-passable flows (as measured at Guadalupe, pre-1987, or as inferred from flows farther upstream at the Sisquoc/Cuyama River confluence) having occurred with the previous few months. In most cases, longer delays result in a closed-estuary condition, with the exception of two recorded periods of likely artificial breaches (e.g., Figure 4.1-2a) and one open condition (September 14, 1994) without obvious artificial cause. Conversely, recent occurrences of fish-passable flows also uniformly correspond with open-estuary conditions, at least from this limited photographic record.

Topographic analysis provides further support for these findings. As noted in Section 3.1, a topographic survey using airborne LiDAR was flown of the entire Santa Maria River valley in September 2010, including the estuary area. River discharges were very low, the estuary was closed, and no flows greater than 400 cfs at the confluence had occurred since February 2010. From the topography of the impounded estuary (Figure 4.1-3), the volume of water needed to

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overtop the beach berm can be readily calculated. This volume of water is a high-end estimate of the volume needed for breaching, since it only presumes the erosive action of surface-flowing water from the estuary and ignores any potential erosive contribution from emergent groundwater or wave action.

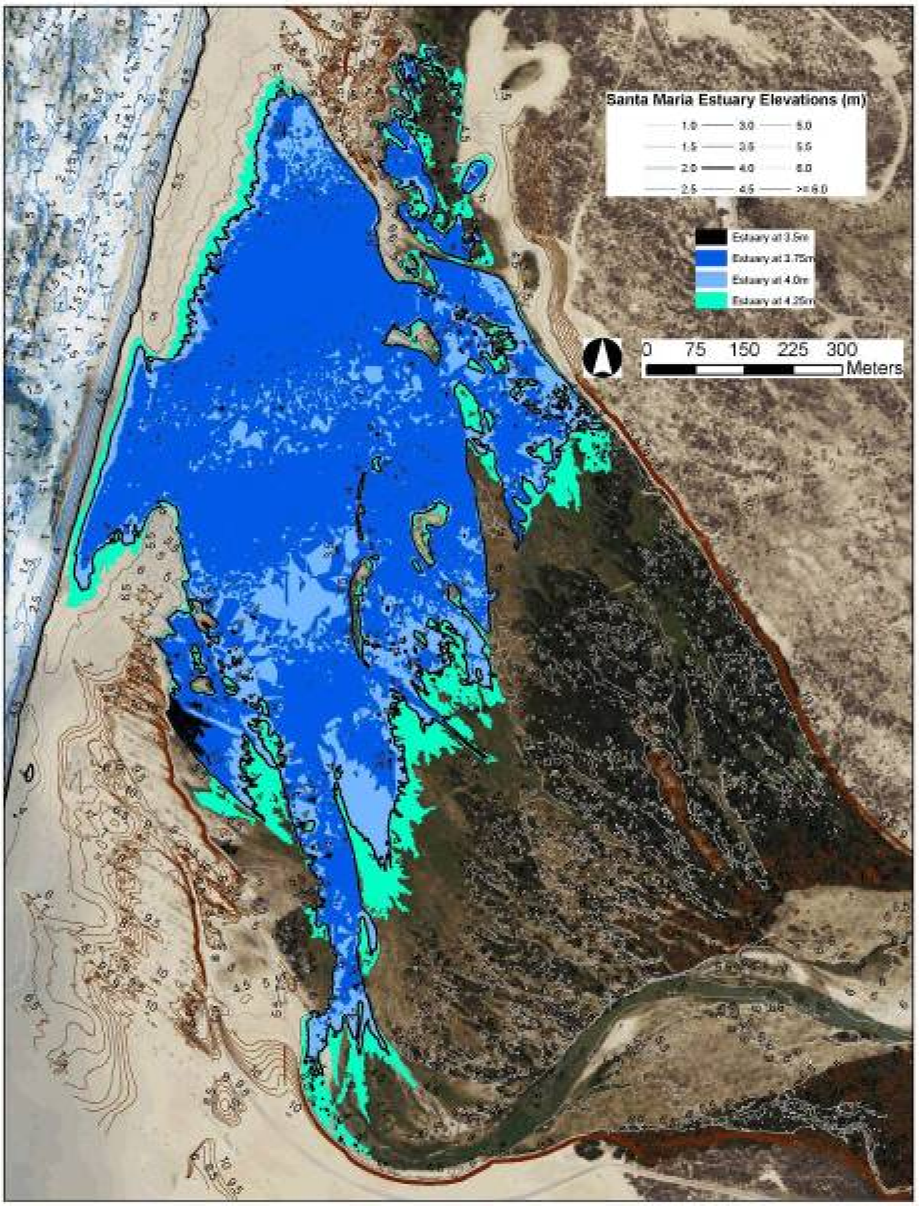

Figure 4.1-3. LiDAR survey of the Santa Maria River lagoon in September 2010 during closed-outlet conditions and an actual water level below 3.75-m elevation. Areas of inundation at various higher water levels are color-coded; overtopping of the beach berm would occur at an (indeterminate) water-surface elevation between 4.0 and 4.25 m.

The volume of the estuary at various water-level elevations was calculated as the average of the maximum and minimum areas associated with each 0.25-m elevation band (Figure 4.1-4 and Table 4.1-2).

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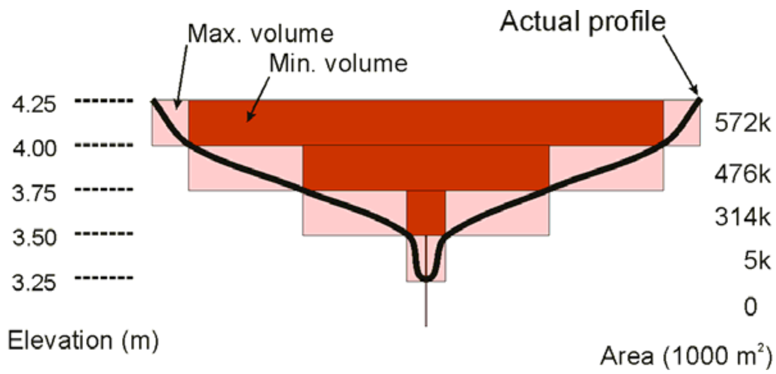

Figure 4.1-4. Estuary volume at different water-level elevations, based on the topographic survey of September 2010. Area inundated at the upper elevation contour for each 0.25-m elevation interval (derived from GIS) shown at right. The true volume lies between estimates based on the maximum area (light-colored block) and minimum area (dark-colored band) in each elevation interval, and will be approximately equal to the average of these two values.

Table 4.1-2. Calculated estuary volume under closed-outlet conditions. Under conditions of zero initial volume and maximum outlet elevation, the lagoon would overtop the berm in less than half a day with flows suitable for upstream (adult) fish passage, and less than one day with flows suitable for downstream (juvenile) fish passage.

Elevation (m)	Area (m^2)	Maximum volume (m^3)	Minimum volume (m^3)	Average volume (m^3)
4.25	572,172	143,043	119,012	131,028
4.00	476,048	119,012	78,463	98,737
3.75	313,851	78,463	1166	39,815
3.50	4,665	1,166	0	583
3.25	0			

270,163	**m^3**
219	**ac-ft**
0.4	**days to fill at 250 cfs**
0.7	**days to fill at 150 cfs**

The results of this analysis are consistent with those of the aerial photograph review and our field observations in December 2010: fish-passable flows (discussed below in Section 4.3.2) rapidly lead to conditions of an open estuary, because the maximum volume of the lagoon is small relative to the volume of flow required for fish passage. This is ultimately a consequence of the geologic and geomorphic origins of the Santa Maria River estuary, namely that of a geologically "recent" (i.e., 1000's of years) drowning of the estuary by rising sea level (the "inherited space" category of Jacobs et al. 2011). The overall morphology of the lower river, therefore, is that of a fluvial system, and so little volume is available to maintain closed conditions during periods of high incoming flow.

The consequence for the Santa Maria River Instream Flow Study is that the condition of the estuary outlet is not limiting for steelhead passage: fish can successfully pass up- or down-river, they will not be blocked at the mouth. Based on first-hand observations of the estuary and aerial photograph interpretation during open-mouth conditions, however, juvenile steelhead are unlikely

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to have much opportunity for (or run much risk from) estuary rearing. This is due to the fact that under open-mouth conditions, the estuary is nearly entirely drained and there does not appear to be off-channel, or impounded areas available for out-migrating juvenile steelhead to access before reaching the Pacific Ocean.

4.1.2 Water quality

The *in situ* water-quality measurements collected on October 14, 2010 are included in Table 4.1-3. The sandbar was open during this time, and the estuary was completely drained. Water temperature and conductivity were consistent throughout the estuary, with the exception of site WQ 6 (see Figure 3.1-1) which had notably lower temperature and conductivity that the other locations. WQ 6 is located at the upstream end of the estuary and is influenced by flow entering from the Santa Maria River and Orcutt Creek. Dissolved oxygen concentration and pH also did not vary greatly throughout most of the estuary, with the exception of sites WQ 3 and WQ 4, where low values were measured. These sites are both located in the northwest corner of the estuary where there is emergent vegetation.

Table 4.1-3. *In situ* water quality measurements in the Santa Maria River estuary on October 14, 2010.

Site	Depth (ft)	Time	Depth	Water temperature (ºC)	Conductivity (µS/cm)	Dissolved oxygen (%)	Dissolved oxygen (mg/L)	pH
WQ 1	3.1	11:15	Surface	18.18	3,826	108.2	10.09	8.25
			Bottom	18.00	3,826	116.5	10.90	8.22
WQ 2	4	11:35	Surface	18.26	3,736	101.4	9.43	8.18
			Bottom	18.20	3,751	103.1	9.57	8.10
WQ 3	4	11:50	Surface	18.27	3,694	68.4	6.34	7.85
			Bottom	18.25	3,710	66.4	6.17	7.80
WQ 4	3.9	11:55	Surface	18.08	3,622	46.0	4.25	7.70
			Bottom	18.03	3,627	40.8	3.80	7.65
WQ 5	3.5	12:05	Surface	18.15	3,613	98.9	9.23	8.04
			Bottom	18.13	3,618	97.5	9.11	8.05
WQ 6	2	12:35	Surface	16.65	2,882	95.7	9.23	8.09
			Bottom	16.64	2,881	95.4	9.20	8.07
WQ 7	3.2	15:10	Surface	18.48	3,609	106.9	9.95	8.17
			Bottom	18.47	3,626	109.5	10.15	8.17
WQ 8	4.1	15:50	Surface	18.57	3,902	112.6	10.41	8.21
			Bottom	18.53	3,919	116.0	10.71	8.21

Data collected with the water quality sonde indicate that very little diurnal fluctuation in water-quality parameters occurred during the 36-hour sampling period (Figure 4.1-5). Conductivity and pH essentially did not vary over the sampling period. Relatively small variations in water temperature, dissolved oxygen, and turbidity were observed, although diurnal patterns were not obvious. Turbidity varied the greatest of the parameters measured, and may be a result of wind and wave action, or contributions from water entering the estuary from the Santa Maria River and Orcutt Creek.

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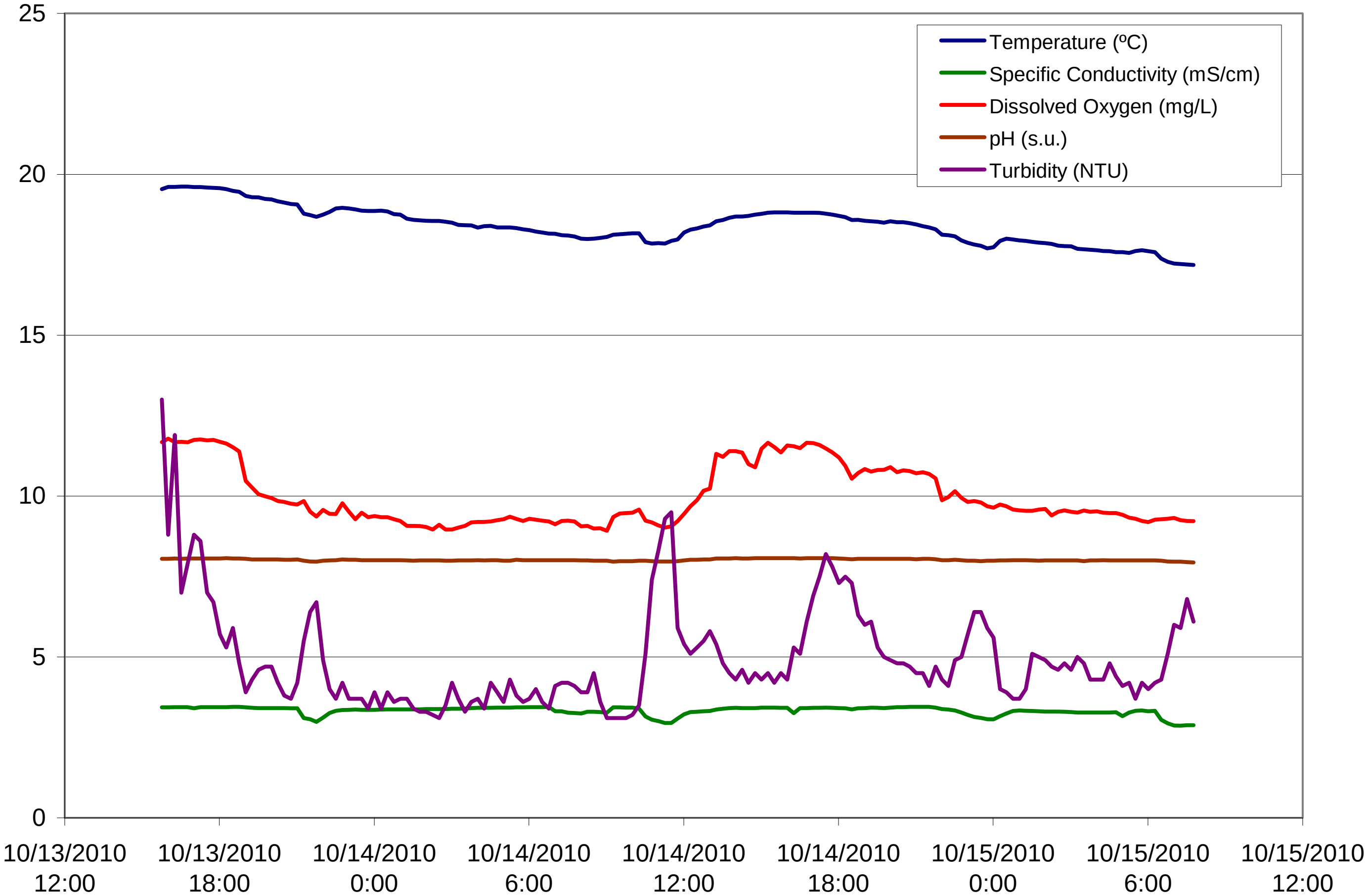

Figure 4.1-5. Water quality parameters collected in the Santa Maria River estuary using a continuous-recording data sonde, October 13–15, 2010.

In lagoon habitats, suitable water quality for steelhead rearing has been shown to include dissolved oxygen concentration greater than 5 mg/L and salinity less than 10 ppt (Daniels et al. 2010). Additionally, dissolved oxygen concentrations near saturation are generally required for steelhead growth, but they can survive with oxygen concentrations as low as 1.5–2.0 mg/L at low temperatures (Moyle 2002). Although in situ water quality measurements were taken on only one date, the results suggest that, based on the water-quality parameters measured, the Santa Maria River estuary would be hospitable to juvenile steelhead in the late summer/early fall. None of the water-quality parameters measured would prevent juvenile steelhead rearing or induce mortality, although there is little opportunity for out-migrating juvenile steelhead to access or rear in the estuary (see Section 4.1.1 above). One minor exception was the WQ 4 site, which was an isolated pond in the northeast corner of the estuary in October 2010. This site showed depressed dissolved oxygen levels compared to other areas in the estuary, although these levels would still not exclude or kill juvenile steelhead. Low dissolved oxygen at this site may be due to the relatively high amounts of decomposing organic material found in this area. Interestingly, this is one of the few areas with ponded water when the estuary was drained.

The data patterns from the continuously recording sonde suggest very little diel fluctuation in water quality. Much larger diel fluctuations in water quality, specifically dissolved oxygen levels,

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have been observed in other estuaries in southern California that are home to juvenile steelhead (Stillwater Sciences 2011e).

Water temperatures from the two continuous data loggers located on the northern and eastern edges of the estuary generally followed similar trends over the period of record (Figure 4.1-6). Daily average water temperature ranged between 16 and 18°C from mid to late October, decreased to about 10°C in late November, and then increased to about 14°C in mid-December (Figure 4.1-6). Large temperature fluctuations starting on about December 19, 2010 are due to exposure of the logger to ambient air temperature. This is a result of the estuary sandbar breaching and the estuary draining. These large fluctuations continued until the data logger was recovered in February 2011, indicating that the estuary was drained for the majority of this time (mid-December through February).

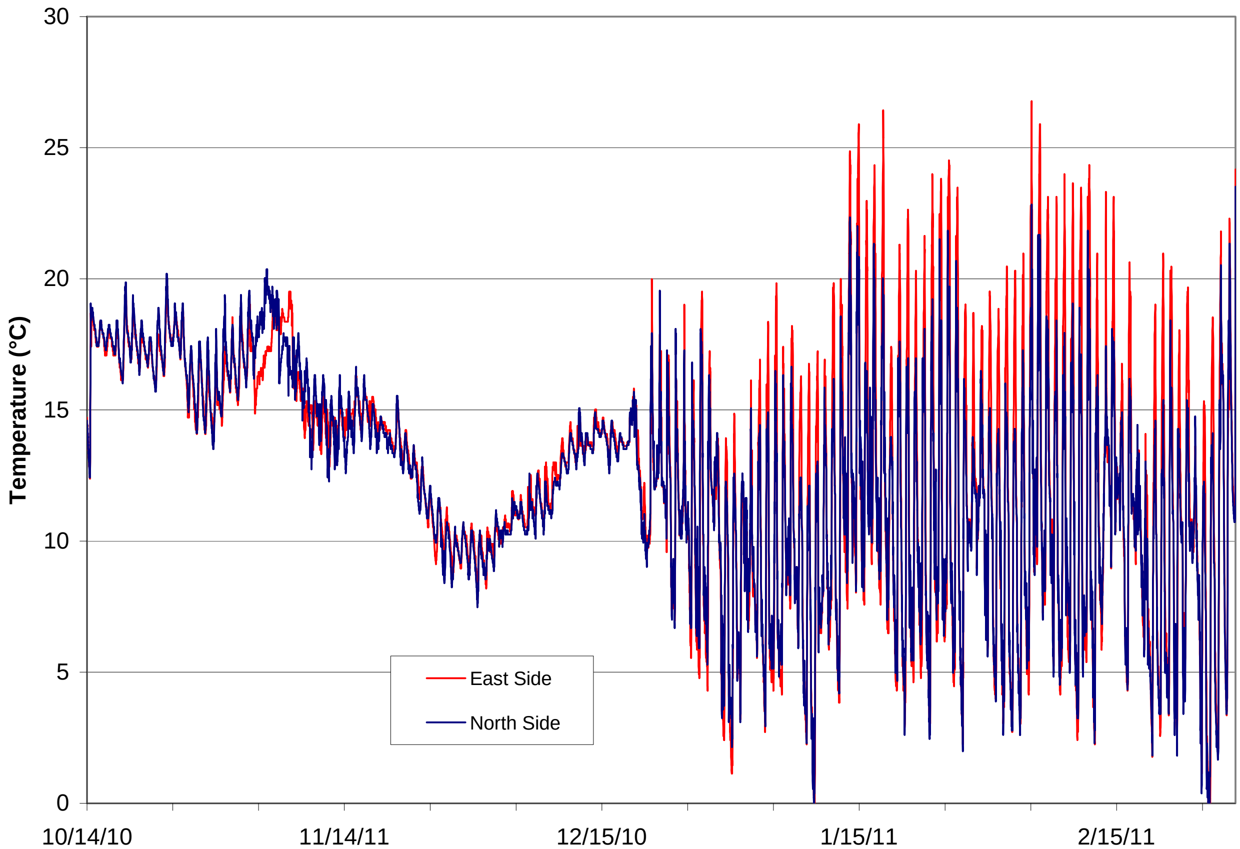

Figure 4.1-6. Water temperatures in the Santa Maria River estuary at the northern and eastern data logger locations, October 2010 through February 2011.

Based on the data loggers, water temperature in the Santa Maria River estuary remained within a range considered suitable for steelhead growth and survival during the sampling period, although measurements likely did not capture the warmest temperatures in the lagoon during 2010 and 2011 (temperatures as high as 26°C have been recorded in the estuary by CCAMP; see Section 2.5.1). Proximity to the Pacific Ocean and a typical summer pattern of cool, foggy weather at the estuary likely help to moderate summer water temperatures in the estuary.

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Data from the recovered stage recorder indicates that the water level in the estuary continued to increase over the fall and winter, up until the point that the recorder was washed away (Figure 4.1-7). Large changes in water level are likely the result of storm/flow events, and minor changes in the water level are likely the result of tidal fluctuations. Analysis of the stage data generally shows that when the sandbar is closed, there is a sufficient volume of water in the estuary that juvenile steelhead rearing could be supported. Although most of the estuary is fairly shallow, the water is generally deep enough to provide some protection for rearing steelhead from terrestrial predators. Based on the observations described in Section 4.1.1, however, when the sandbar is open and the estuary drains, there is no suitable rearing habitat available in the estuary for out-migrating steelhead to access.

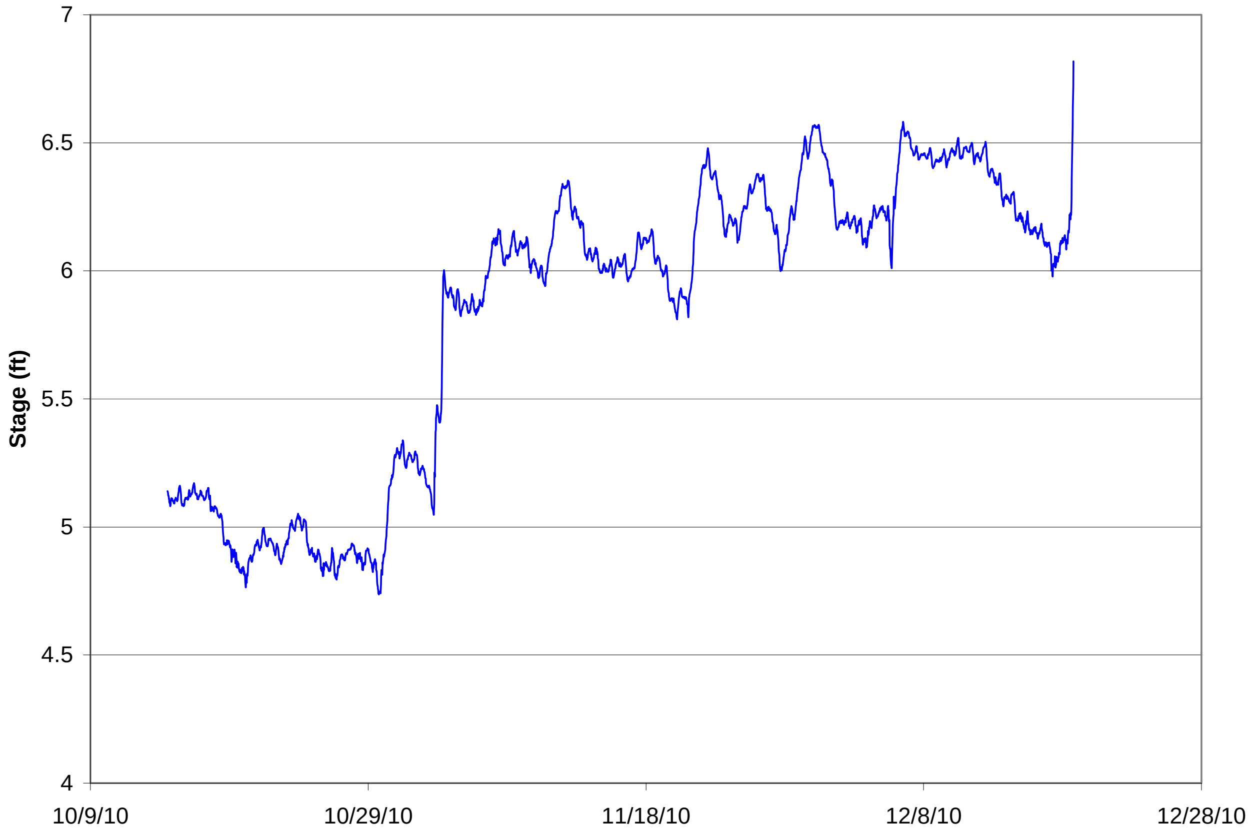

Figure 4.1-7. Water level in the Santa Maria estuary from October to December 2010.

4.2 Steelhead Passage Criteria

4.2.1 Hydraulic criteria

The Santa Maria River is a wide, sand-bed, intermittent river. The majority of the mainstem river is a losing reach; when there are surface flows a significant amount percolates into the groundwater table. During periods of surface flow in the river, shallow water depth is expected to limit fish passage more than other factors: surface flows are both lost to the subsurface and spread out over the wide, sandy bed. The width criterion defines a minimum cross sectional distance for which the other criteria (i.e., minimum depth and maximum velocity) must be met. Since the Santa Maria River is relatively wide during low flow, the width and depth criteria are both very

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sensitive to flow (see Section 4.3.4). Therefore, passage criteria for juvenile and adult steelhead criteria focus primarily on depth and width.

At critically low flows, water velocity is not likely to restrict passage in the Santa Maria River since the channel is not confined and water velocity for depths less than about 1 ft are expected to remain well within suitable cruising and sustained swimming thresholds for steelhead within natural channel reaches. This is supported by field observations and hydraulic calculations for the Santa Maria River (Stillwater Sciences 2011c, 2011d; see also Section 4.3.3). The few locations where the channel is constricted are generally associated with bridges and are relatively short in length.

The hydraulic criteria and sensitivity values selected for the Instream Flow Study are summarized in Table 4.2-1 and discussed in additional detail below. Sensitivity values were selected to represent a range of alternative values identified during the information review.

Table 4.2-1. Passage criteria and sensitivity values selected for assessing steelhead passage opportunities in the Santa Maria River.

Life stage	Criteria	Criteria values	Sensitivity values
Adult Steelhead	Depth (minimum)	0.7 ft	0.6, 0.8, 0.9, 1.0 ft
	Velocity (maximum)	6 ft/s	8 ft/s
	Contiguous width	10 ft	5 ft, 10%
Juvenile steelhead	Depth	0.5 ft	n/a
	Contiguous width	10 ft	5 ft, 10%

Passage criteria selected for steelhead include three criteria for adult upstream migration, and two criteria for adult and juvenile steelhead (i.e., smolt) downstream migration (Table 4.2-1). Adult steelhead depth criteria of 0.7 ft was selected to account for the body size of the largest adult steelhead expected to pass with additional buffer to avoid abrasion (Webb 1975, Dryden and Stein 1975, both as cited in Powers and Orsborn 1985). The maximum velocity criterion of 6 ft/sec was selected because it is well under critical thresholds from the literature to account for the long migration distance with limited resting habitat. The width criterion of contiguous 10 ft, for both adult and juveniles, was selected to provide sufficient width for steelhead to pass and added buffer to increase the likelihood that a continuous migration path through braided sections is available, and to reduce potential for predation from terrestrial predators. The juvenile depth criteria of 0.5 ft was selected to match CDFG criteria for juvenile upstream passage. Additional information on criteria selection is presented in Stillwater Sciences (2011a).

4.2.2 Temporal criteria

A three-day window was selected as the minimum time needed for adult steelhead to migrate the 24 miles from the Pacific Ocean to the confluence with the Sisquoc and Cuyama rivers. Adult steelhead have been reported to migrate upstream over 35 mi/day, although they tend to average less than 20 mi/day in streams with perennial passage (Greene 1911, Lough 1981, Bjornn et al. 2003). Bell (1986) reports cruising speeds (typically used for steelhead upstream migration) up to 4.6 ft/s. The average speed a steelhead would need to travel a distance of 24 miles in one day is 1.5 ft/s, well within this range. Although possibly conservative (since steelhead could traverse 24 miles in one day), the temporal criteria for steelhead allows for a modest migration rate of 8.0 mi/day (or 0.5 ft/sec) and some amount of lag time for the estuary to fill, the sandbar to

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breach, and for steelhead in the ocean to detect the migration opportunity, negotiate the surf, and begin active migration.

Though not all fish will move at the same rate or initiate migration at the same time, one day was selected for the hydraulic analysis as the minimum time needed for juvenile steelhead to migrate the 24 miles from the Cuyama–Sisquoc confluence downstream through the critical reach of the Santa Maria River to the Pacific Ocean. This is equivalent to an average outmigration rate of approximately 1.5 ft/s. Steelhead out-migration rates in rivers with similar hydrology to the Santa Maria River within south-central or southern California were not identified. Presuming smolt out-migration rates in the Santa Maria River are largely passive and approach stream velocities during migration periods, which occur during storm-flow conditions, travel rates would generally be higher than 1.5 ft/s.

The timing of juvenile steelhead outmigration has been correlated with photoperiod, streamflow, water temperature, and growth (Bjornn and Reiser 1991). In the Santa Maria River, however, a correlation with streamflow is critical for successful emigration of smolts, since outmigration requires continuous flow from the Sisquoc River tributaries to the Pacific Ocean. Assuming downstream migration is generally passive and near the rate of flow, outmigration rates significantly greater than 1 ft/s would be common, if not expected, and so passage through the 24-mile reach subject to potential flow management (i.e., from the confluence of the Sisquoc and Cuyama rivers through the critical reach) is assumed to require only one day of fish-passable flows in the mainstem.

Beyond this minimum requirement, larger flow events likely provide the greatest opportunity for migration, not only because they generally provide a longer period for migration but also because they likely provide stronger hydrologic cues for migration. Climatic conditions and pressure gradients (e.g., barometric pressure) are typically greater for larger storm/flow events, flow cues in the upper watershed are higher, and flow volume from the Sisquoc River to the ocean is much greater for transport (downstream) and detection (upstream).

4.3 Hydraulic Analyses

4.3.1 Discharge requirements for effective steelhead passage based on LiDAR cross sections

As an initial approach to determining the critical discharge for steelhead passage, the channel geometry defined by the aerial LiDAR survey of September 2010 (see Figure 1.2-2) was used to calculate water discharge at any flood stage, using Manning's equation (Equation 1 of Section 3.3). This equation was solved at each cross section to obtain predicted relationships between minimum depth and width criteria, and discharge (summarized in Table 4.3-1), on the assumption of a stable cross section that corresponded to that delineated by the no-flow channel topography of September 2010.

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Table 4.3-1. Critical water discharge (Q_{crit}) for both upstream (adult) and downstream (juvenile) steelhead passage, calculated based on 26 LiDAR cross sections. The largest critical discharge amongst the 26 cross sections would, ideally, identify the "limiting" discharge of the reach, since passage would be achieved at every other cross section once this discharge is achieved there (cross section 19 is about midway between the Bonita School Road and Highway 1 crossings). This analysis is fatally compromised, however, by the documented disparity in channel cross sections with (Section 4.3.2) and without (this section) flowing water.

Life stage	Minimum depth	Minimum width	Discharge (cfs)			
			Mean of Q_{crit}, all sections	Smallest Q_{crit}	Largest Q_{crit}	XS #, largest Q_{crit}
Adult steelhead	0.7 ft	10 ft contiguous	128	33	351	19
Juvenile steelhead	0.5 ft	10 ft contiguous	58	16	148	19

During the time of a storm when the flow starts to pass through the reach, however, the flow will normally carve out a deeper section in the river, although this channel is not always fully preserved as the flood recedes. This will tend to concentrate the flow and produce a deeper flow than calculated based on the channel cross sections obtained when the channel is dry. We therefore anticipate that the results of this analysis are conservative (i.e., a maximum value).

4.3.2 Discharge requirements for effective steelhead passage based on field observations and measurements

Evaluation of steelhead-passable flows and field measurements of discharge were conducted on four additional dates between January and April 2011. They were conducted at a variety of locations between Highway 101 and Highway 1; the findings are tabulated in Table 4.3-2. All reported channel sections were surveyed, with the resulting data evaluated using the criteria of Table 4.2-1. Based on these results, a discharge of 250 cfs is judged to be a reasonable minimum threshold value for successful upstream adult steelhead passage through the critical reach.

Table 4.3-2. List of all field-measured discharges and evaluation of fish passage made in the winter and spring of 2011, sorted by discharge at the time of measurement and using the passage criteria of Table 4.2 1. Based on these data, a discharge of 250 cfs in the critical reach of the Santa Maria River (shaded) appears to provide adult passage under essentially all measured combinations of channel geometry and flow along the critical passage reach.

Location	Date	Flow (cfs)	Passable width?
Highway 1 vicinity	4/5/2011	1	none
Highway 1 vicinity	4/5/2011	2	none
Suey vicinity	1/12/2011	5	depth ok, too narrow
Bonita School Rd to Highway 101	4/5/2011	7	none
Highway 1 to Bonita School Rd	4/5/2011	7	depth ok, too narrow
Bonita School Rd to Highway 101	4/5/2011	10	none
Highway 1 vicinity	1/4/2011	10	depth ok, too narrow
Bonita School Rd vicinity	1/4/2011	11	none
Bonita School Rd vicinity	2/27/2011	25	none
Suey vicinity	1/4/2011	153	>30 ft

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Location	Date	Flow (cfs)	Passable width?
Bonita School Rd to Highway 101	3/28/2011	192	>20 ft
Bonita School Rd to Highway 101	3/28/2011	251	>20 ft
Highway 1 to Bonita School Rd	3/28/2011	251	10 ft
Highway 1 to Bonita School Rd	3/28/2011	272	>40 ft
Highway 1 vicinity	3/27/2011	301	>30'
Highway 1 to Bonita School Rd	3/27/2011	313	>70'
Highway 1 vicinity	3/26/2011	319	>15'
Bonita School Rd to Highway 101	3/27/2011	337	>30'
Highway 1 vicinity	3/27/2011	373	>40'
Highway 1 vicinity	3/26/2011	381	>50'
Highway 1 vicinity	3/26/2011	385	>50'
Highway 1 vicinity	3/26/2011	388	>40'

In contrast to the field evaluation of adult passage summarized above, no explicit measurements were made to evaluate the likelihood of downstream passage under flows different from that determined from the hydraulic calculations using the LiDAR topography (i.e., about 150 cfs at the critical cross section; Table 4.3-1). Only one flow was observed at this approximate discharge in the critical reach (that below Highway 101 on March 28, 2011 at 192 cfs) and it provided more-than-adequate passage at that time and place. Although the conditions of channel erosion are surely active at flows approaching 150 cfs, we have no independent data to support a smaller recommended discharge for downstream (juvenile) passage at this time.

4.3.3 Velocity limitations for upstream steelhead passage

Although conditions of low flow are assumed to be those critical for restricting adult steelhead passage up the Santa Maria River, a limitation based on maximum discharge is also imposed by the ability of steelhead to swim against high velocity. For two reasons this limitation was not explored comprehensively: first, high flows on the Santa Maria River occur very rarely (for example, an average daily discharge of 1,000 cfs is exceeded only 0.7% of the time); and second, there are likely no management actions on the Santa Maria River (either past or future) that would affect discharges in this range (for example, the maximum current capacity of the outlet channel below Twitchell Reservoir is 400 cfs). Nonetheless, some evaluation of velocities in the channel was deemed appropriate.

Hydraulic calculations akin to those above were conducted, using Equation 1 (Section 3.3) as applied to the bed geometry of the 12 cross sections surveyed in late March 2011. Because these surveys did not extend the entire width of the Santa Maria River floodplain between the levees (i.e., they were all significantly less than 2,000 ft wide), the sections were computationally extended on a 2:1 (horizontal:vertical) slope beyond their actual surveyed endpoints. This resulted in an unrealistically confined channel, since nowhere in the actual floodplain of the river does the ground rise this steeply, and thus this assumption will result in an artificially confined and so higher calculated flow velocity than would actually occur.

Despite this assumption, every cross section showed a section-averaged velocity below 6 ft/sec for discharges below 1,300 cfs and below 8 ft/sec for discharges below about 2,400 cfs (Figure 4.3-1). Because these results are averaged over the entire cross section, they do not recognize the near-certain existence of lower velocity zones near the channel margins. Based on these results, a velocity limitation for upstream passage is not anticipated to have relevance for the findings and recommendations of the Instream Flow Study.

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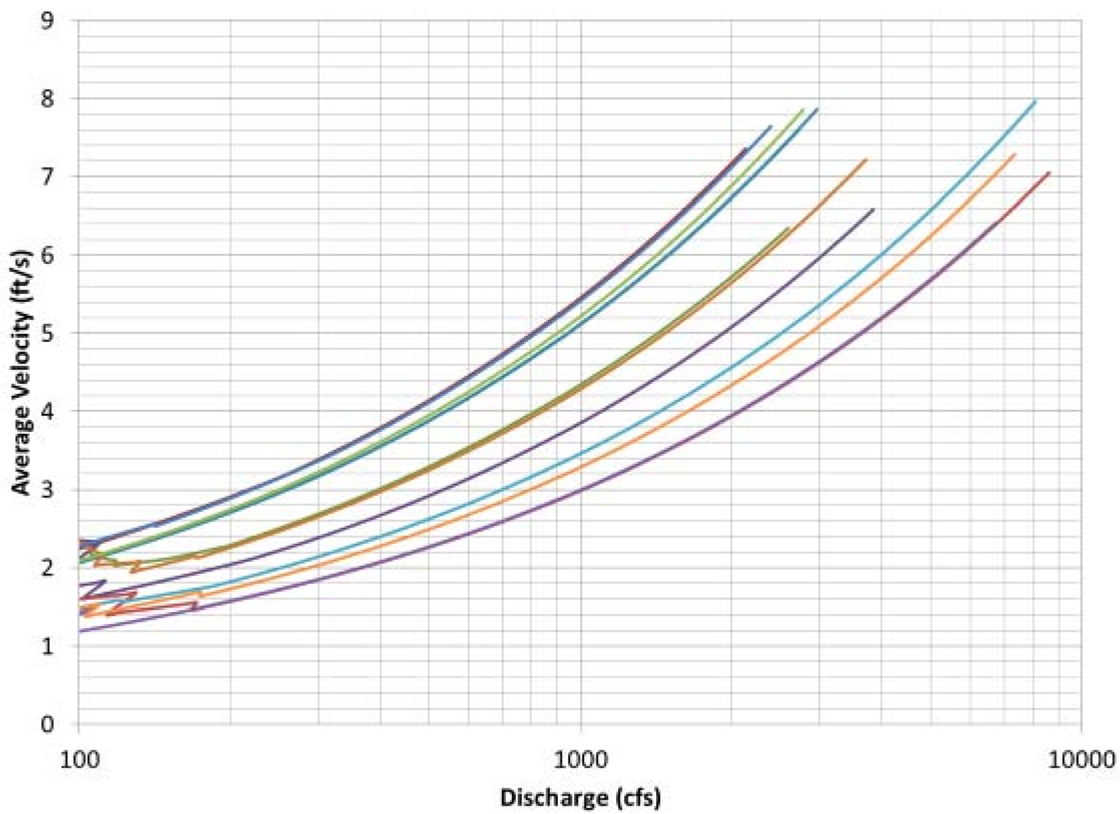

Figure 4.3-1. Relationship of section-averaged flow velocities with their corresponding discharge for 12 field-surveyed cross sections. Channel geometry beyond the margins inundated by observed flows of about 500 cfs is presumed to be a steeply confining bank at 2:1 slope; actual conditions at higher discharges would results in a wider flow with lower resulting velocities than calculated here.

4.3.4 Sensitivity analysis of passage criteria

In addition to determining the flow required for effective steelhead passage through the mainstem Santa Maria River (250 cfs for upstream adult passage and 150 cfs for downstream passage), we also explored the sensitivity of these values to the selected hydraulic criteria. The sensitivity analysis indicates that fish-passable discharges depend critically on both minimum depth and minimum width criteria (Table 4.3-3). As the depth criteria values increase from 0.5 ft to 1.0 ft, there is a corresponding increase to discharge. The steps also become incrementally larger as values increase. For the minimum width criteria, discharges moderately increase when stepping from the 5 ft to 10 ft width criteria, and a larger increase is evident stepping from 10 ft to 10% of the total channel width (Figure 4.3-2). The greatest sensitivity is seen when comparing the 10% width and other width criteria, which becomes more pronounced as the minimum depth criteria increases. This illustrates the high sensitivity of a width criterion based on a relative value in this type of wide and shallow channel.

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Table 4.3-3. Sensitivity of discharges to a range of depth and width criteria (channel geometry derived from 26 LiDAR data based cross sections).

Life stage	Minimum depth	Minimum width	Discharge (cfs)			
			Mean	**STD**	**MIN**	**MAX**
Adult Steelhead	0.6 ft	5 ft contiguous	71	49	12	186
		10 ft contiguous	89	57	25	240
		10% contiguous	138	146	6	678
	0.7 ft	5 ft contiguous	105	74	14	281
		10 ft contiguous	128	83	33	351
		10% contiguous	203	200	9	952
	0.8 ft	5 ft contiguous	148	106	20	398
		10 ft contiguous	179	116	41	469
		10% contiguous	296	294	12	1,398
	0.9 ft	5 ft contiguous	202	141	30	503
		10 ft contiguous	239	153	50	603
		10% contiguous	417	372	30	1,760
	1.0 ft	5 ft contiguous	270	190	40	678
		10 ft contiguous	312	203	60	814
		10% contiguous	593	519	40	2,094
Juvenile Steelhead	0.5 ft	5 ft contiguous	44	30	9	116
		10 ft contiguous	58	36	16	148
		10% contiguous	79	86	4	357

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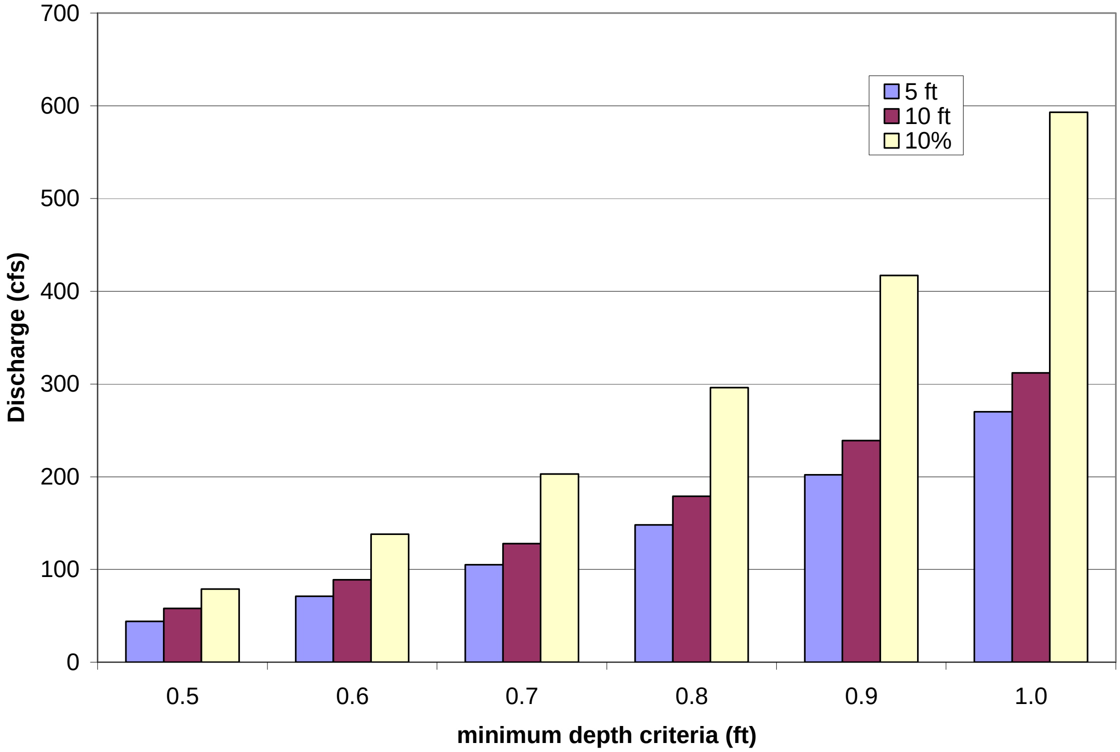

Figure 4.3-2. Sensitivity of discharges to a range of width (5 ft, 10 ft, 10% of total width) and depth criteria (0.5 to 1.0 ft). Discharge presented is the mean calculated for the 26 LiDAR based cross sections.

The calculated critical discharge is also sensitive to the Manning's n value. The discharge required for successful steelhead passage based on LiDAR cross section 11 changed from 280 to 140 cfs with a change in Manning's n value from 0.025 to 0.05. Manning's n value of 0.025 was used for the hydraulic analysis based on the channel conditions in the critical passage reach, and because it is a relatively conservative value. However, with vegetation in the channel or other roughness elements, a Manning's n value locally as high as 0.05 is plausible.

4.4 Hydrologic Analyses

4.4.1 General attributes of the flow regime of the Santa Maria River

The general patterns of flow in the Santa Maria River over a multi-decadal period are best described by the Guadalupe gage (USGS 11141000) (see Figure 2.3-1). This gage was operated by the USGS from February 1, 1941 through September 30, 1987. It therefore includes 20 years of record prior to the closure of Twitchell Dam and more than 26 years after closure. For a river as highly episodic as the Santa Maria, this is not a particularly lengthy record, but it is sufficient to make a general characterization of the flow regime and to draw defensible conclusions about the changes to that regime that have resulted from dam operation.

The first two decades of gaging show a highly episodic, mainly dry river (Figure 4.4-1). During this period, the river was dry over 93% of the time (an average of 341 days/year); the longest dry period was nearly three and a half years long, ending on February 9, 1962.

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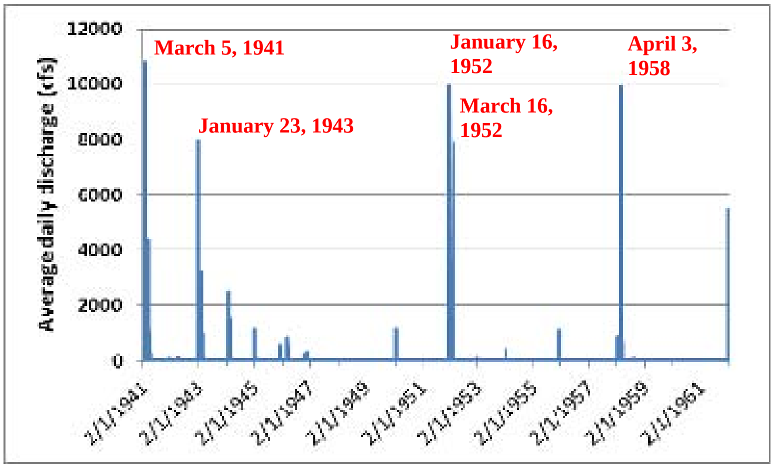

Figure 4.4-1. Discharge of the Santa Maria River at the Guadalupe gage (USGS 11141000) for the full period of the pre-Twitchell Dam record. Dates of the largest daily discharges labeled.

Three years after construction, Twitchell Dam began holding back flows on February 16, 1962, one week after the 1959–1962 drought ended. Post-dam, the overall hydrograph suggests little overall change, at least to the moderate and high flows that are readily visible in such a flow record (Figure 4.4-2). True zero discharges (i.e., not counting near-zero values in the record between 0.01 and 1.0 cfs) were recorded almost precisely as frequently during this period as pre-dam (average of 340 days/year, compared to a pre-dam average of 341 days/year). Multi-year periods of no flow also occurred during this period, particularly 1962–1965 and throughout the decade of the 1970's.

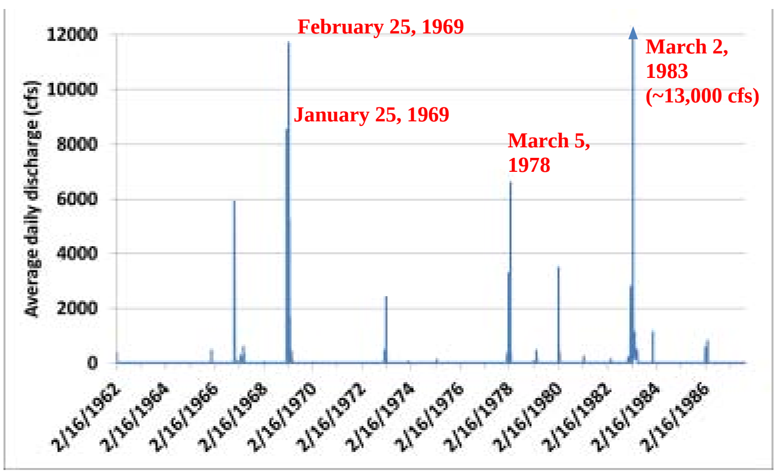

Figure 4.4-2. Discharge of the Santa Maria River at the Guadalupe gage (USGS 11141000) for the full period of the post-dam record. Dates of the largest daily discharges labeled.

Precipitation records for this later period suggest little systematic change to rainfall over the western portion of the watershed (Figure 4.4-3), although average annual discharge in the (unregulated) Sisquoc River suggests progressively wetter conditions over the last 70 years of

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record (Figure 4.4-4), likely reflecting the increased frequency of strong El Nino years (see Figure 2.2-2; the Oceanic Niño Index was >1.5 in only one water year in the pre-Twitchell s record [1958], in two of the post-Twitchell water years through 1987 [1969 and 1983], and three water years since [1992, 1998, 2010]). Much of the increasing trend in average annual discharges is a result of these very wet, high-flow years, with discharges well beyond the range needed for successful steelhead passage (but not necessarily altering the frequency of hydrologic attraction cues to initiate upstream migration from the ocean); and so for analytical purposes in assessing instream flows, the pre- and post-Twitchell periods are treated as equivalent. Potential decadal-scale climatological influences, however (both in the past and in the future), cannot be dismissed entirely.

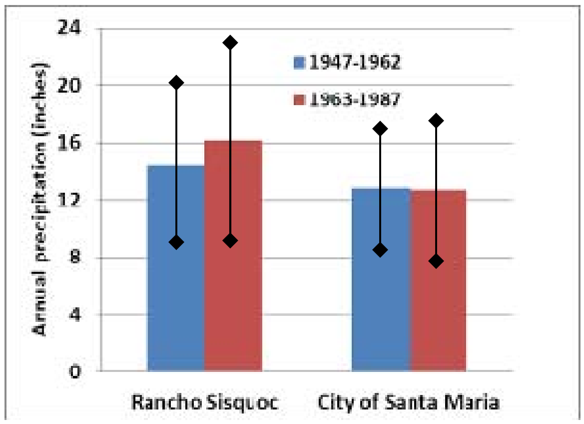

Figure 4.4-3. Annual rainfall at two rain gages in the Santa Maria River watershed (Rancho Sisquoc is in the western foothills of the Sisquoc River watershed; City of Santa Maria is in the mainstem valley bottom), with the data segregated into pre- and post-dam periods. When considering the 1σ year-on-year variability (error bars on each graph) there is no statistical difference between these periods.

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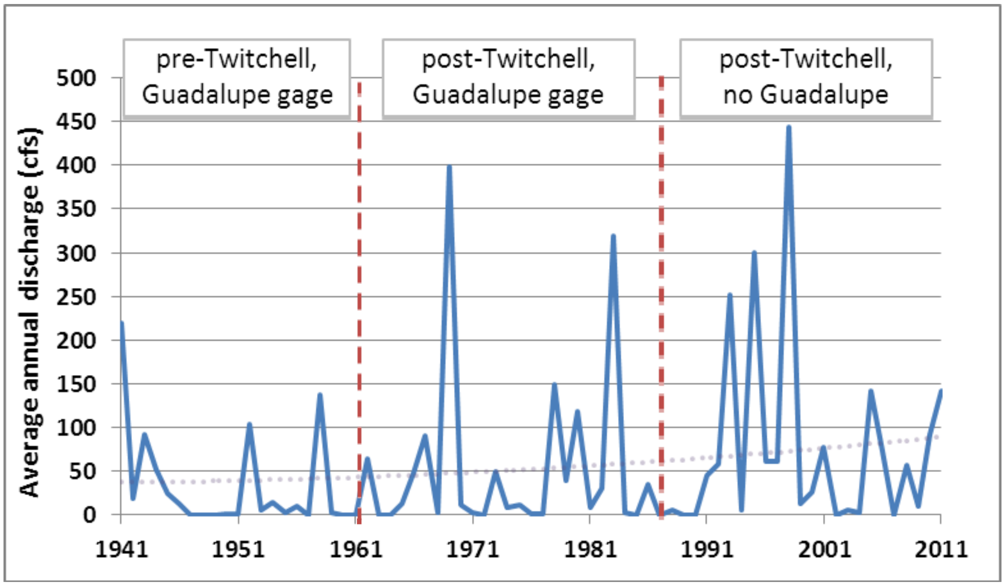

Figure 4.4-4. Average annual discharge in the lower Sisquoc River, as recorded at the Garey gage (USGS 11140000). Red dashed lines separate the major periods in the record; dotted light blue line is the second-order polynomial trend, which (in contrast to the rainfall record) suggests progressively wetter conditions over this 70-year period.

Given the infrequency with which flow is present in the Santa Maria River, conditions suitable for fish passage are uncommon and episodic. When they do, they are confined to a relatively well-defined period of the year when climatological conditions are favorable for extended rainfall and river flow. Conversely, the Santa Maria River is predictably dry (or nearly so) for more than seven months of the year, a condition that has not materially changed with operation of Twitchell Dam (Figure 4.4-5). In all subsequent analyses, achieving hydrologic conditions suitable for fish passage is evaluated only for the five months of December, January, February, March, and April.

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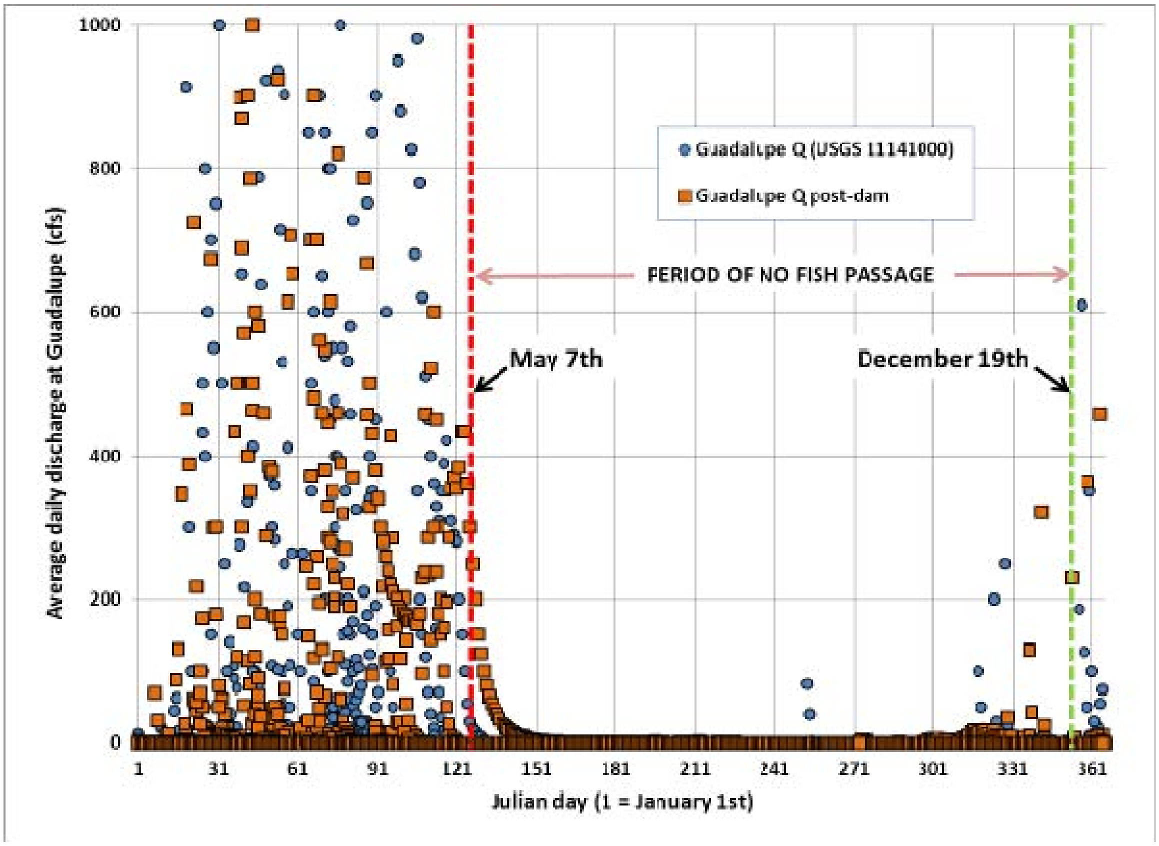

Figure 4.4-5. All recorded flows at the Guadalupe gage (USGS 11141000), plotted by Julian day and discriminated by pre- and post-dam periods (blue and orange markers, respectively). Only flows up to 1,000 cfs are shown, to emphasize the range of discharges over which the conditions of fish passage are most critical. Passable conditions have ended (red dashed line) in nearly every year by the end of April; they restart (green dashed line) in mid- to late December.

4.4.2 Changes in the flow regime pre- and post-Twitchell Dam

Although the overall pattern of flows in the Santa Maria River do not show significant changes between the pre- and post-dam periods, Twitchell Dam operations have unquestionably (and quite intentionally) altered flows. To evaluate the significance of these changes on fish passage in the Santa Maria River, the analyses focus on discharges between 100 and 500 cfs, the range of flows in the mainstem that is likely to control the availability of fish passage (See Section 4.3).

4.4.2.1 Santa Maria River

The overall pattern of both no-flow conditions and extreme floods in the mainstem river suggest little or no change in pre- and post-dam flow regimes, but neither very low flows nor very high flows are significantly influenced by dam operations—conditions of low flow simply reflect the intrinsic characteristics of this highly seasonal dryland river, whereas high floods lie beyond the capacity of the dam to influence under normal operations.

Changes to the duration of flows in the range of steelhead passability, however, are discernible by comparison of the two periods of record at the Guadalupe gage (Figure 4.4-6). This range also

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corresponds to conditions when gaging quality is likely highest, overcoming the problems of "no communication" common to very low flows and an inadequate, rapidly shifting rating curve at very high flows.

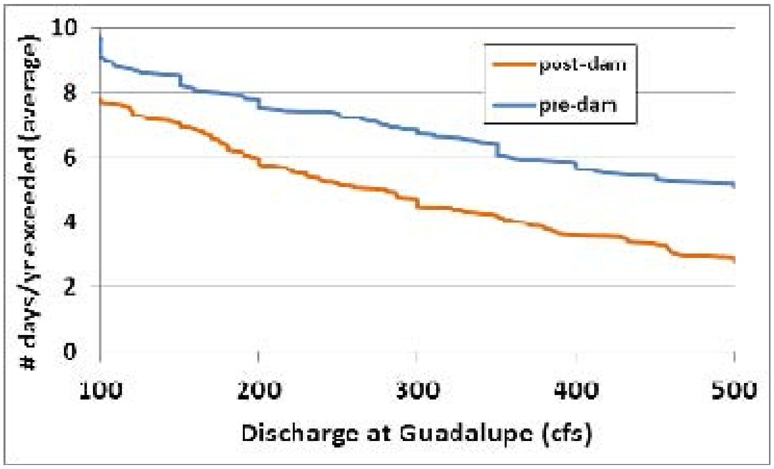

Figure 4.4-6. Flow-duration curve for daily discharges of the Santa Maria River at the Guadalupe gage (USGS 11141000), with the fraction of daily discharges above the specified discharge expressed as the average number of days per year (e.g., 3.65 days ≈ 1% of the time). The curves for the pre-dam (orange line; February 1, 1941—February 15, 1962) and post-dam (blue line; February 16, 1962—September 1987) converge at very low and very high flows, beyond the range displayed on this graph. The 100—500 cfs portion of the flow-duration spectrum is emphasized because it brackets the range of effective steelhead-passable flows, suggesting a reduction of about 1.5 to 2.5 days per year, on average, in the duration of such discharges.

These data, however, do not provide any insight into either the *sequence* or the *continuity* of such flows. This issue is primarily of concern for adult steelhead passage, because juvenile steelhead moving downstream are presumed to pass from the Sisquoc River through the entire 24 miles of the mainstem Santa Maria River in about a day or less (for example, a steelhead travelling with a 3 ft/sec flow would traverse this distance in about 12 hours). Adult steelhead are presumed to require three continuous days of mainstem flow >250 cfs to reach the confluence and to traverse 10 additional miles to the upstream end of the lower Sisquoc River canyon, which requires an analysis of not only the aggregate "number of days" but also the persistence of three (or more) such days in sequence (Figure 4.4-7).

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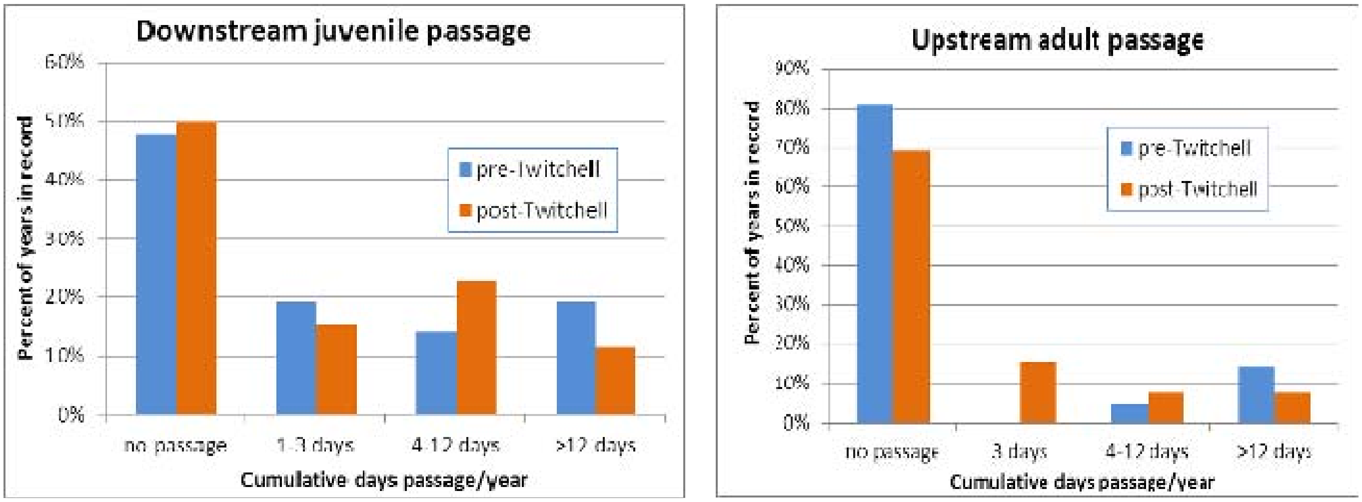

Figure 4.4-7. Tally of the fraction of years in the record (total of 20 years, pre-dam; 26 years post-dam) that meet the discharge for effective steelhead passage (≥150 cfs for juveniles, ≥250 cfs for adults). Passable flows (i.e., above the appropriate discharge threshold) are stratified into categories of duration; note that for adult passage, 3 days is the minimum passable condition.

Inspection of these data suggests several broad findings with respect to the effects of Twitchell Dam operations:

- Within the mainstem, the overall tally of days suitable for downstream juvenile passage (as defined by this study) has not changed appreciably between pre- versus post-dam conditions, with only a slight increase in the number of years without any passage opportunities. Both short (1–3 days) and long (>12 days' duration) events have been reduced in frequency, but the number of days they include have been largely balanced by an increase in passage events of intermediate durations (4–12 days long).
- For upstream adult passage, the number of years with at least one passage opportunity (as defined by this study) has increased modestly, particularly for minimum-length events (3 days). In contrast, the frequency of long- duration periods of passage has decreased by almost half (from occurring in an average of 14% of years to 8% of years).

The flow records can also be evaluated with respect to the gaps between passage events—in other words, how long will a fish have to wait for the next passage opportunity to occur? As with the tally of passage years, these results must be discriminated by the different criteria for upstream adult and downstream juvenile passage (Figure 4.4-8).

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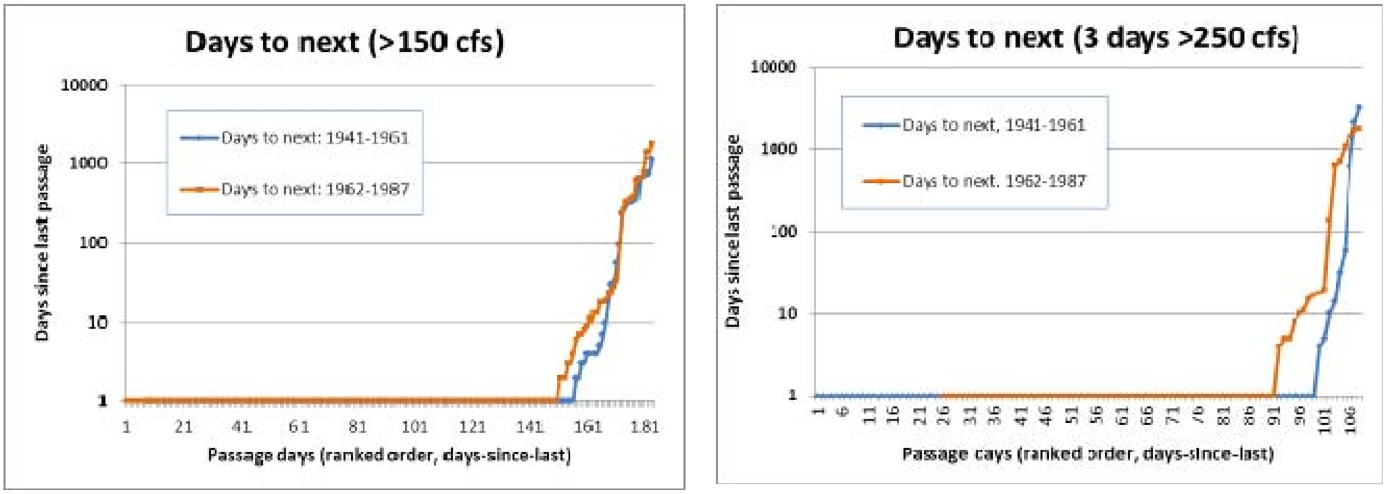

Figure 4.4-8. Rank order of the gap, in days, between any given passage event (i.e., 1 day at ≥150 cfs for downstream juvenile passage, or 3 continuous days ≥250 cfs for upstream adult passage) and the next such event. The criteria for downstream juvenile passage are met in 176 days pre-dam and 183 days post-dam (left graph; data aligned to end at the right-hand edge of the graph); most such passage days are followed by another day that also provides passage, but in one instance (post-dam) the delay is 1,798 days (almost 5 years) before the next such event. With the more restrictive passage criteria for adults (right graph), fewer days are part of passage events, and the delay between the end of a prior event and the beginning of the next event can be as much as 3,223 days (almost 9 years, occurring in the pre-dam period from 1943–1951).

Using this expression of the flow record, potentially more significant differences in the two periods begin to emerge. The post-dam period has more, and longer, multi-day gaps in passage opportunities, for either downstream or (especially) upstream movement. Although there are more years with at least one upstream passage event in post-dam time, any such opportunities within a “passage year” are now typically of shorter duration.

These data highlight the importance of understanding which hydrologic parameter(s) are most important to the migration of steelhead. For example, during a “good” hydrologic year do these fish benefit from multiple migration opportunities well-distributed throughout the winter (conversely, do they benefit from fewer but longer passage windows, vs. more but shorter ones)? Or, is successful migration enhanced by maximizing the number of separate years in which such an event happens at least once? Clearly, these data do not answer these questions of migration behavior, but they point to critical parameters of the flow regime that must be considered to evaluate the nature and relevance of past changes to the flow regime, and to inform meaningful alternatives for future flow modifications (see Section 5).

4.4.2.2 Sisquoc-Cuyama flow relationships

Although the aggregate behavior of flows in the Santa Maria River suggest only modest alteration to the flow regime imposed by Twitchell Dam operations (e.g., Figures 4.4-1 and 4.4-2), the magnitude of reservoir storage is sufficiently large to create significant changes to the overall flow regime of the mainstem (as an example, the current storage volume of the reservoir could support a release of 200 cfs for more than a year). The relative importance of the Cuyama River to the system as a whole, as well as that of dam-imposed flow modifications, can be explored by

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considering both the relative contributions of water from the two major tributaries and by a direct comparison of simultaneous flows from each of them.

Pre-1962, the pattern of simultaneous discharges from the Sisquoc and Cuyama rivers is quite regular (Figure 4.4-9). The correlation between discharge at the lowermost gage on the Sisquoc River (USGS 1114000) and the same-day discharge at the lowermost Cuyama River gage (USGS 11137000) is quite good ($r^2 = 0.78$), with discharges in the Cuyama River averaging about 60% of those in the Sisquoc River (corresponding to a flow contribution of about 40:60 to the mainstem).

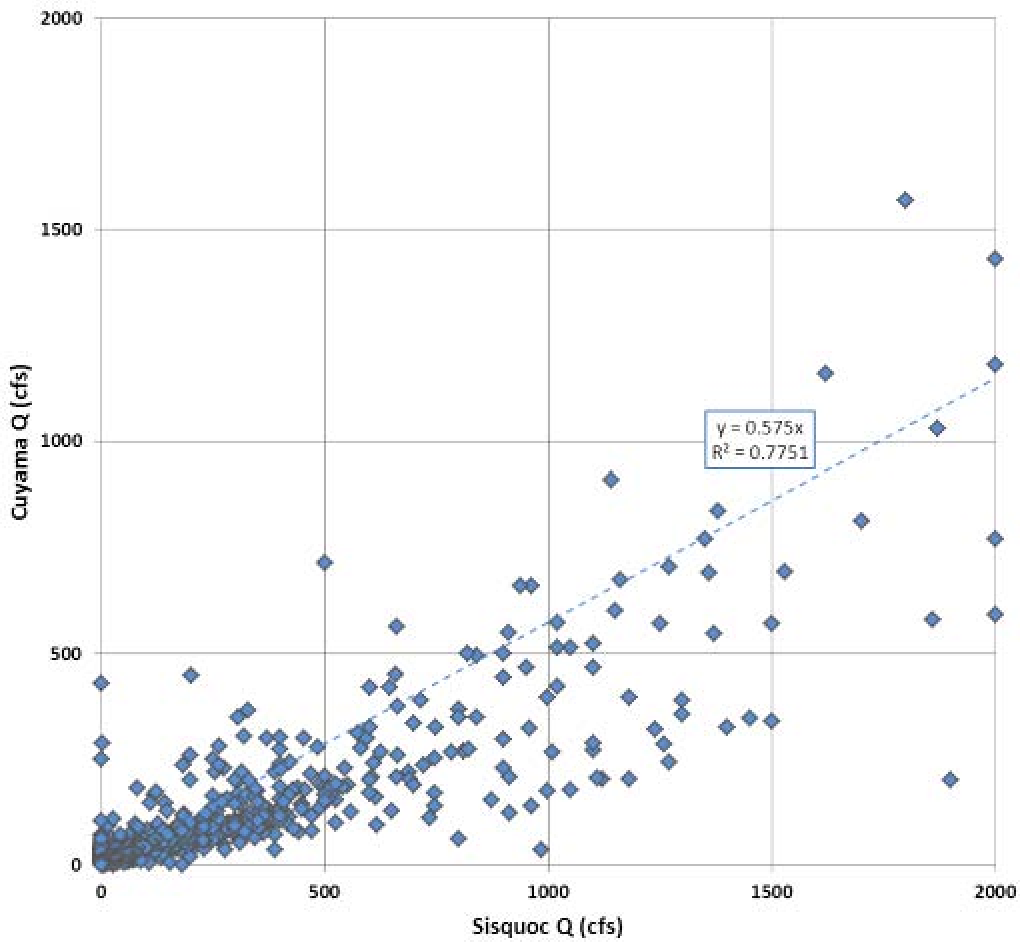

Figure 4.4-9. Correlation of pre-dam daily average flows for the Sisquoc River at Garey (USGS 1114000) and the Cuyama River near Santa Maria (USGS 11137000) for the same date. Trend line is calculated on the full range of data (maximum Sisquoc value is 5,900 cfs; maximum Cuyama value is 3,000 cfs), but only those below 2,000 cfs are plotted here.

This interrelationship of flows from the two tributaries is also expressed in their cumulative mass-balance plot for the same period (Figure 4.4-10). Representing the flows in terms of the aggregate volume of water passing each of the gages affirms the relative synchronicity of the contributions (i.e., the curves rise more-or-less in concert with each other).

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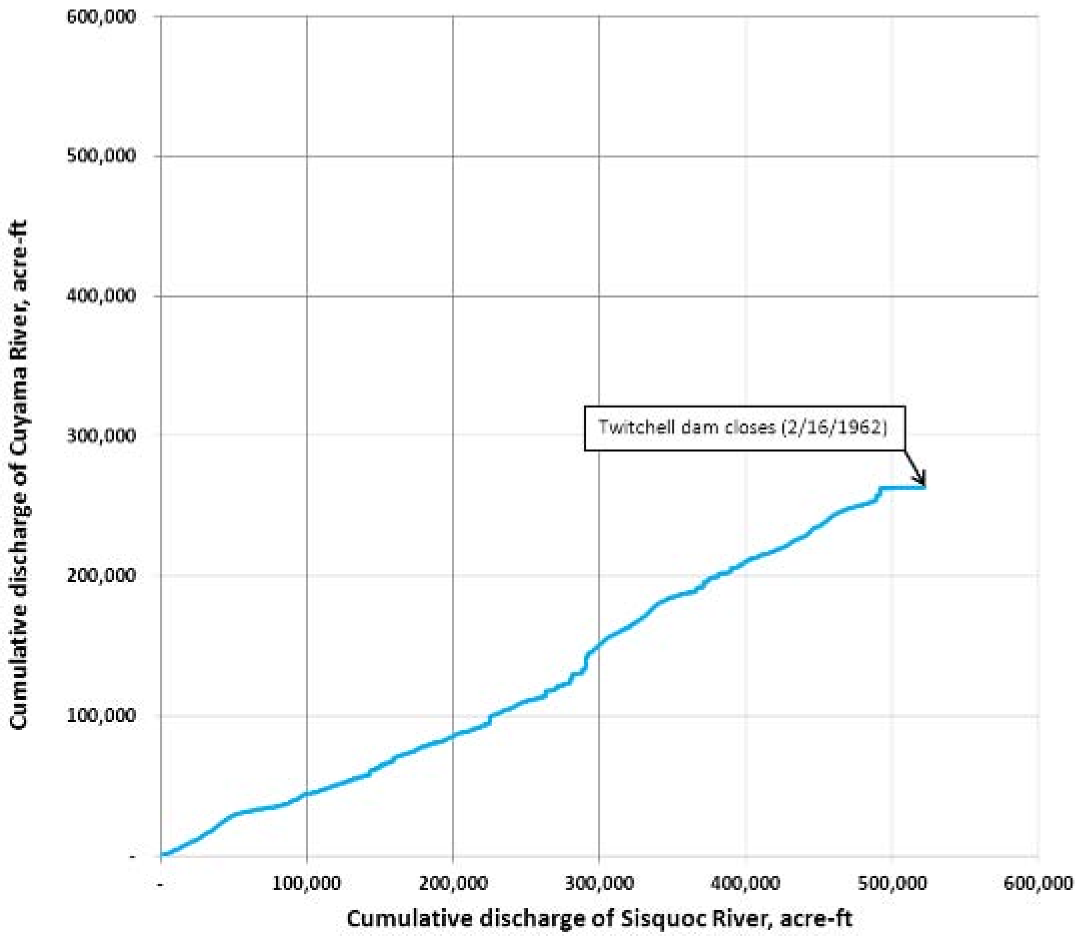

Figure 4.4-10. Pre-dam cumulative mass balance for the Sisquoc and Cuyama rivers (as recorded at USGS gages 1114000 and 11137000). Each point on the line represents a daily plot of the cumulative volume of water that has passed each gage since the beginning of the record (February 1, 1941, corresponding to the point [0,0] at the graph's origin). For the 21 years covered by this record, almost twice as much water was carried by the Sisquoc River as by the Cuyama River (524,000 ac-ft vs. 263,000 ac-ft).

Post-dam, the patterns of both discharges and cumulative mass balance are very different. Flows are no longer correlated between the two tributaries (Figure 4.4-11); indeed, their lack of correlation, particularly during high-flow events on the Sisquoc River when the reservoir is presumably capturing all flow from the Cuyama River (thus resulting in a zero plotted discharge), is the explicit intention of dam operations. These flows are subsequently released during periods of low or no flow in the Sisquoc River (i.e., the mass of points when the Sisquoc River is <250 cfs and the Cuyama River discharges are up to twice as great) to achieve a more uniform discharge down the mainstem Santa Maria River, promoting infiltration in the Santa Maria River valley with little or no surface flow released to the estuary.

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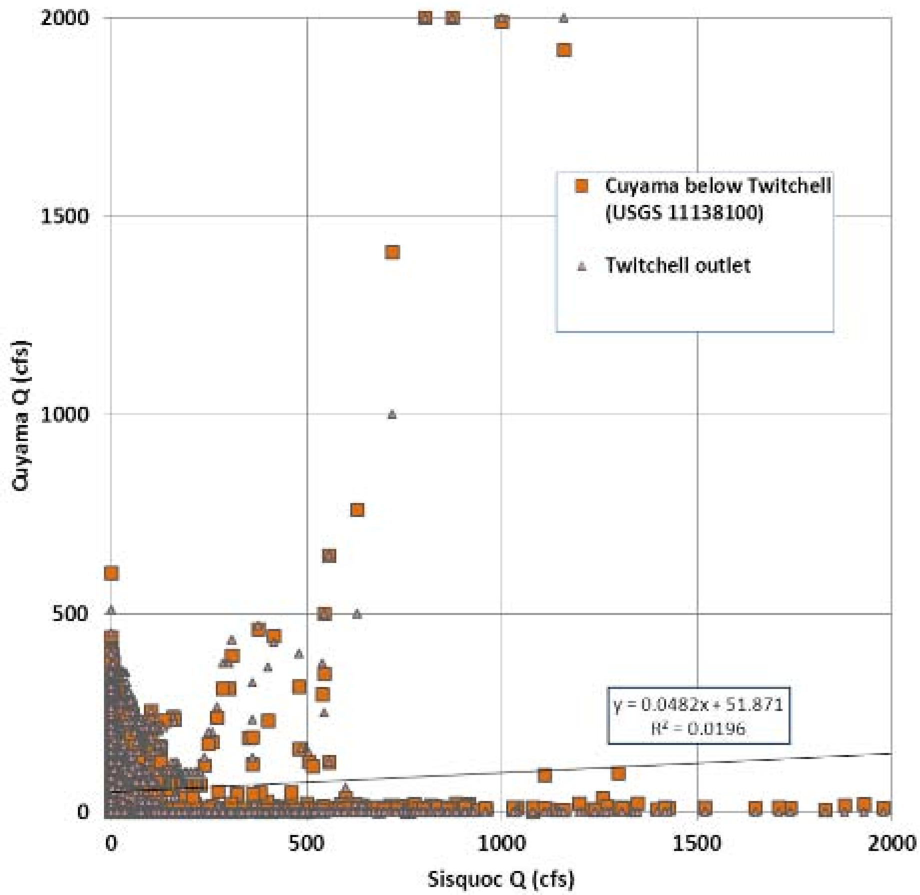

Figure 4.4-11. Correlation of post-dam daily average flows for the Sisquoc River at Garey (USGS 1114000) and the Cuyama River below Twitchell (USGS 11138100; in operation through September 30, 1983). Trend line is calculated on the full range of data and shows essentially no correlation between flows from the two tributaries. Discharges from the Twitchell Dam outlet for the corresponding period as recorded by the SMVWCD are also plotted; their generally close alignment with the USGS gage data immediately downstream provide good corroboration for both data sources.

The cumulative mass-balance curve over the entire period of record (1941–2011, using releases from Twitchell Dam as the metric of flow down the Cuyama River) shows a corresponding pattern (Figure 4.4-12). The “stairstep” pattern after 1962 emphasizes those periods when the Sisquoc River is flowing but Twitchell Dam is retaining all flow in the Cuyama River (horizontal ‘treads’) and when the dam is releasing water into an otherwise dry river (the vertical ‘risers’).

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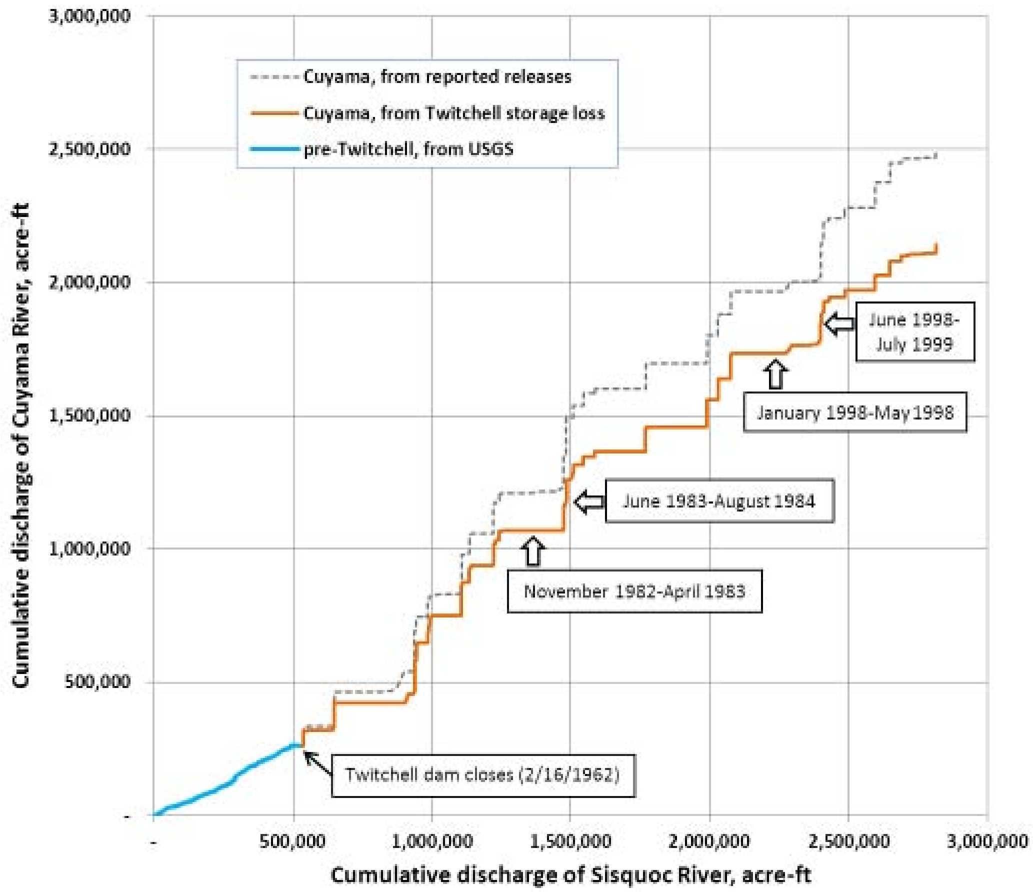

Figure 4.4-12. Cumulative mass balance for the Sisquoc and Cuyama rivers, as recorded at the Sisquoc gage (USGS 1114000) and Twitchell Dam outlet (from SMVWCD dam-operation records, showing both volume changes [orange line] and reported discharges [gray dashed line; see Section 3.4.2]). The pre-dam period (blue line) is shown in greater detail in Figure 4.4-10. Dates of a few major flood periods are highlighted. Periods of increasing storage in Twitchell reservoir (i.e., no release to the river) are indicated by a horizontal trend to the plotted data, those of reservoir discharge during no flow in the Sisquoc River by a vertical trend.

In summary, operation of Twitchell Dam has had the following consequences for the flow regime of the Santa Maria River:

1. By aggregate metrics (e.g., average number of days of passage), reduction in the availability of steelhead-passable conditions are on the order of 2 days per year. Because this represents the surface discharge of 250 cfs to the estuary for those two days, the equivalent magnitude of increased groundwater recharge is approximately 1,000 ac-ft/year (1 cfs of flow, if sustained for one day, is equivalent to 1.98 ac-ft of volume). This volume represents about 2% of the average annual water storage in Twitchell Reservoir (Figure 2.3-3) and less than 3% of the annual water yield of the Cuyama River (Figure 4.4-12).
2. The frequency of steelhead-passable events has changed little: more years now provide adult passage, but for both adult and juvenile passage these events are now of generally shorter duration.

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3. The gaps between steelhead-passable events are unchanged for a majority of passable days. For about 10–20% of such events, however, the time between the ending of one and the beginning of the next has now increased by a few days to a few weeks.
4. The loss of correlation between Sisquoc River and Cuyama River flows is the likely underlying cause of these changes, because it tends to “smooth” out the resulting discharge in the Santa Maria River with a bias towards achieving flows that are insufficient to maintain a surface-water connection to the estuary.

4.4.2.3 Flow cues for migration in the Santa Maria River system

River flows provide one of the most important cues available to anadromous steelhead in triggering migratory behavior, both into freshwater from the marine environment, and from freshwater into the marine environment. The characteristics of these flows (ascending and receding magnitudes, duration, and timing) provide information not only on the hydrologic conditions immediately relevant to steelhead migration, but also to subsequent life-cycle phases, including redd construction, spawning, rearing, and out-migration.

Because steelhead can only evaluate the prospects for upstream or downstream passage success on the basis of the flow occurring at a single point in time and space (i.e., where the fish is located), any changes in the correlation between that flow and future conditions farther up- or downstream along the channel network will have potentially significant consequences for the success of the migration, and ultimately for successful reproduction.

For adult steelhead, upstream migration is presumably triggered by flows emerging from the estuary. The hydraulic analysis of steelhead passage conditions in the mainstem Santa Maria River indicates that 250 cfs in the critical passage reach (presumably well-represented by flows at the Guadalupe gage) is needed for three continuous days. Comparison of the pre- and post-dam record shows the total reduction in passable days (about 2 per year; see also Figure 4.4-6) and also the likelihood of an adult steelhead beginning its passage under favorable flow conditions at the estuary but encountering the receding limb of a hydrograph that blocks further upstream passage prior to reaching the confluence of the Sisquoc and Cuyama rivers (Figure 4.4-13).

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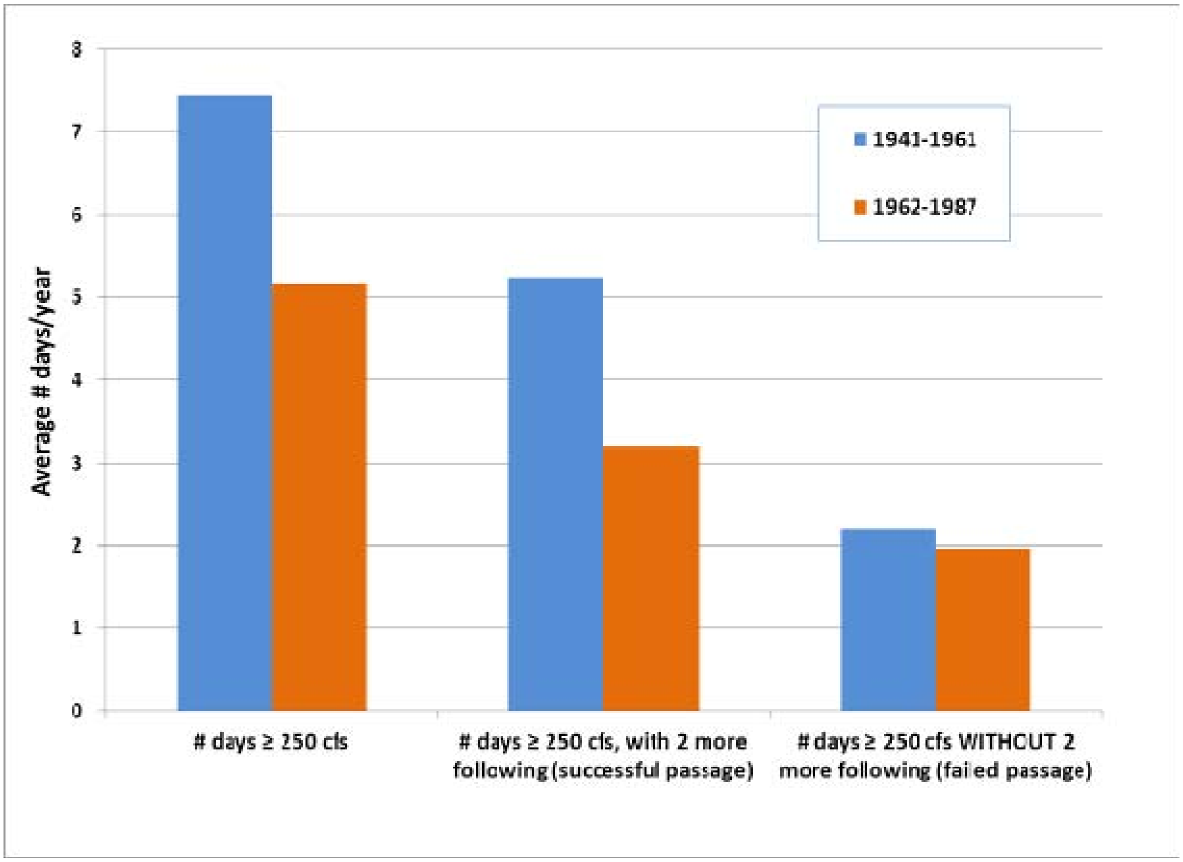

Figure 4.4-13. Comparison of pre-dam and post-dam flow regimes relative to upstream adult passage. Opportunities for successful passage are reduced by an average of about 2 days per year (middle set of bars); fish will not encounter excessively low flows during their 3 days' migration any more frequently in the post-dam period, but those "failed" attempts now represent almost 40% of potential events (as indicated by an initial day of ≥250 cfs flow). In the pre-dam period, this condition occurred for about 30% of such events.

Another potential impediment to achieving adult passage, namely the attainment of steelhead-passable conditions in the mainstem Santa Maria River (i.e., 3 days of flow ≥250 cfs) but insufficient discharge for passage through the (unregulated) lower Sisquoc River, is a rare occurrence in either the pre- or post-dam periods. For the period 1941-1961, this occurred for 6 of 110 passage days (5.4%); for 1962-1987, 3 of 83 such days (3.6%).

For downstream juvenile passage, the criteria for mainstem passage are less complex (1 day of mainstem flow ≥150 cfs) but the only "cue" available for juvenile steelhead is the flow in the Sisquoc River. Pre-dam, this flow was strongly correlated with the contribution from the Cuyama River (Figure 4.4-9) and thus in the mainstem Santa Maria River as well; but post-dam, this correlation has been severely weakened. In other words, juvenile steelhead in the Sisquoc River watershed experience flows that once signaled free-flowing conditions all the way to the estuary (indeed, they will need two or more days of such flows in the upper Sisquoc River just to reach the confluence), but operations of Twitchell Dam now result more frequently in an impassable mainstem for their last day of presumptive "passage."

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In the pre-dam period, flows in the Sisquoc River (as measured, for example, at the Garey gage) are a relatively good predictor of downstream-passable flows in the mainstem Santa Maria River (as measured at the Guadalupe gage) (Figure 4.4-14). With Sisquoc River flows in the range of 350–450 cfs, downstream passage through mainstem Santa Maria River has a 50/50 chance of success (also suggesting that typical infiltration losses are about 300 cfs , consistent with the groundwater model; see Section 4.5). Once the daily average flow exceeds 450 cfs in the Sisquoc River, passage is promising; and above 500 cfs, passage is all-but-assured.

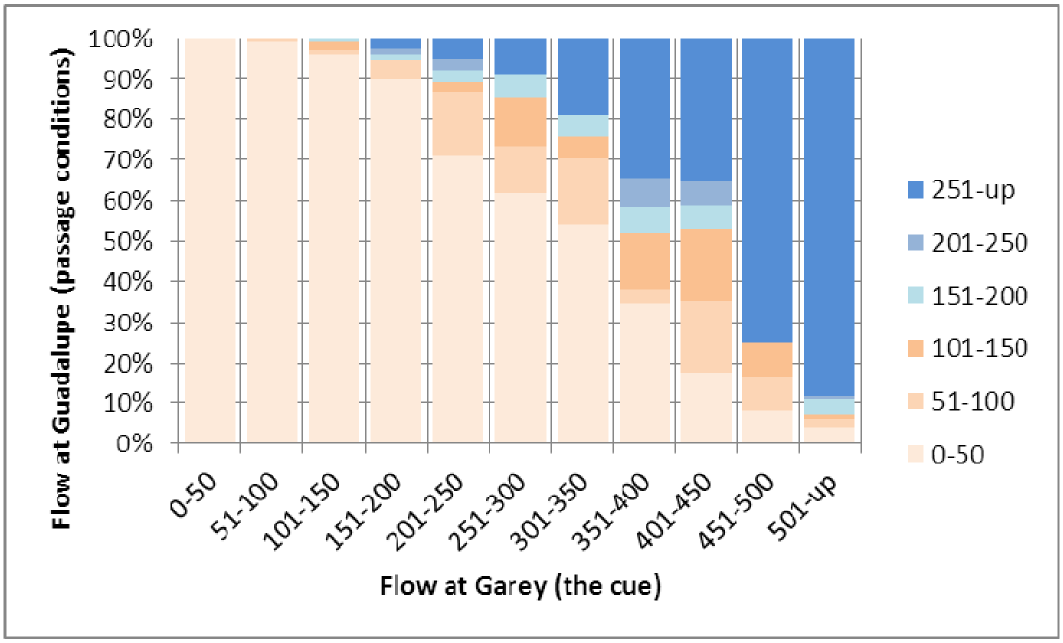

Figure 4.4-14. Predicting steelhead passage through the mainstem Santa Maria River (colored bars) based on same-day flows in the Sisquoc River (x-axis), for the pre-dam period (1941–1961). This graph "bins" the flows at the Sisquoc River at Garey gage (USGS 11140000), displaying the relative fraction of flows at the Guadalupe gage (USGS 11141000). The blue and green bars indicate successful juvenile passage conditions in mainstem Santa Maria River, which occur about half the time for flows in the Sisquoc River at Garey in the range of 350–450 cfs and even more reliably at higher discharges

In the post-dam period, however, the flow cues in the Sisquoc River that promised near-certain passage downstream in the mainstem Santa Maria River no longer provide the same guidance to juvenile steelhead emigrating towards the estuary and the ocean (Figure 4.4-15). Now, Sisquoc River flows of 350–450 cfs offer less than a 30% chance of successful downstream passage; and those of >500 cfs will still fail to support passage one-third of the time. There are no records of smolt outmigration to guide our expectation of the specific discharge that provides the cue for downstream migration, but over a relatively wide range of such flows the potential for downstream stranding is now quite high.

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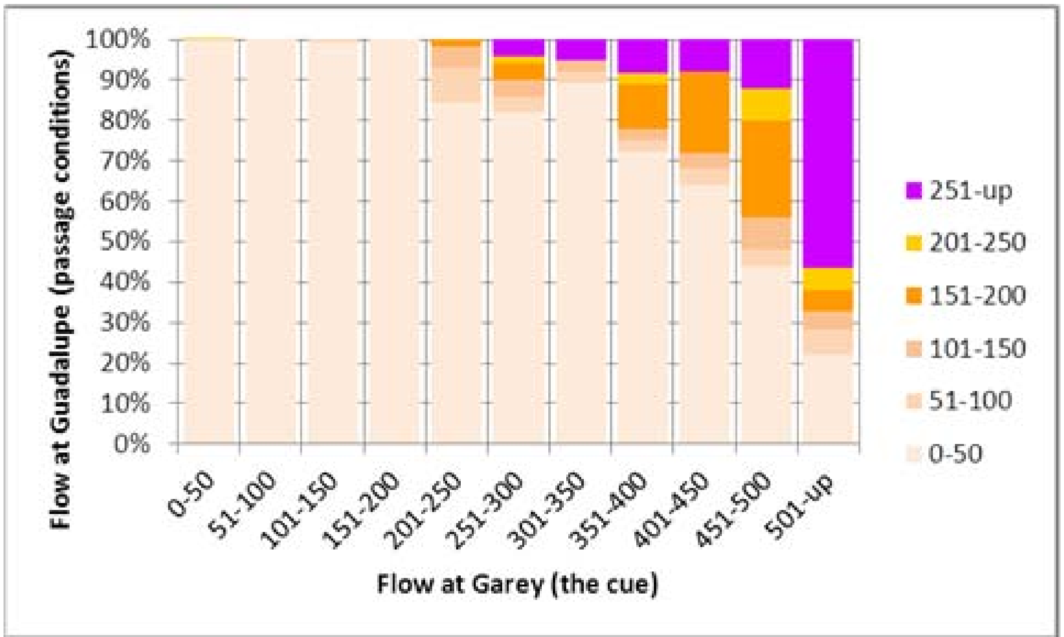

Figure 4.4-15. Predicting steelhead passage through the mainstem Santa Maria River (colored bars) based on same-day flows in the Sisquoc River (x-axis), for the post-dam period (1962–1987). Convention is the same as for Figure 4.4-14, but with a different color scheme.

4.4.2.4 Summary of key changes in the flow regime

Flow releases from Twitchell reservoir have almost certainly reduced the number of successful opportunities for both upstream and downstream steelhead migration along the Santa Maria River. Based on the magnitude of documented changes and the presumed migration behavior of steelhead, the following alterations to the flow regime (in approximate rank order) have the potential to be of greatest significance to any reduction in successful upstream and downstream migration that has occurred:

1. Increased frequency of "false positives" in the flow of the Sisquoc River (i.e., discharges in the Sisquoc River that historically correlated with upstream- or downstream-passable conditions from or to the estuary but no longer do) (see Figure 4.4-14 and 15).
2. Reduced overall frequency of downstream steelhead-passable conditions (see Figure 4.4-7, left panel).
3. Increased number of days with upstream steelhead-passable flows that are *not* followed by at least two additional steelhead-passable flow days (see Figure 4.4-13).
4. Reduced frequency of long-duration upstream steelhead-passable intervals (which may be partly mitigated by the increased frequency of shorter duration intervals) (see Figure 4.4-7, right panel).

4.4.3 Hydrologic year categories—dry, intermediate, and wet

Any future management of the Santa Maria River will surely need to recognize the extreme variability in year-to-year flows: when the mainstem is dry, flow augmentation from any source is likely to be futile; when the mainstem is running at many thousands of cfs, augmentation is entirely unnecessary. The relative "wetness" of individual water years (i.e., from October 1st of

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the preceding year through September 30th of the present one), particularly in the context of fish passage up the Santa Maria River, is clearly displayed by a tally of all flow events with average daily flows at the Guadalupe gage with periods of one or more days with a reported discharge of ≥250 cfs, stratified by the year in which they occurred (Figure 4.4-16).

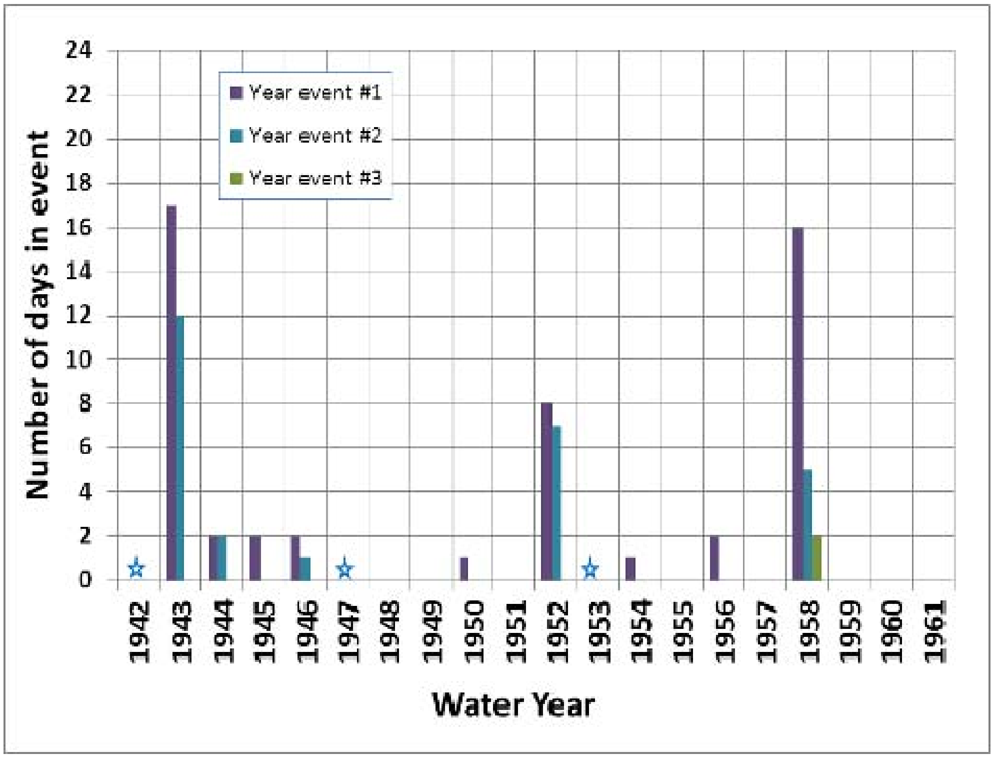

Figure 4.4-16. Duration (in days) and distribution (by water year, i.e., October 1 of previous year through September 30 of named year) of flow "events", defined as an average daily discharge of 250 cfs or more as recorded at the Guadalupe gage (USGS 11141000). Multiple bars for a single year indicate multiple flow events, arranged in order of decreasing duration (2 additional events of 1- and 2-days' duration occurred in 1958). Starred years had one or more recorded flows but all less than 250 cfs. Blank years (7, in total) had no days of recorded flow whatsoever.

This record suggests three categories of annual hydrologic conditions. The first ("dry") is that of no flow in the mainstem Santa Maria River, which includes about one-third of the years in this record (1948, 1949, 1955, 1957, 1959, 1960, and 1961). In these years, 95% of all days recorded flow under 1 cfs in the Sisquoc River at Garey (USGS 11140000) (and every other year recorded non-zero flow on one or more days), suggesting that this gage can provide a reasonable present-day surrogate for the now-defunct Guadalupe gage with respect to this criterion.

The second category suggested by this record is that of one or more multi-day flows in the mainstem Santa Maria River suitable for steelhead passage ("wet", expressed in 1943, 1952, and 1958). The final category ("intermediate") are the balance of years, representing 50% of the record and indicating the type of water year for which targeted future flow manipulations might be successful at altering the frequency and duration of steelhead-passable intervals. Note that if the flow threshold is reduced to 150 cfs, every "intermediate" year but 1953 provides one or more days of downstream passage).

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The utility of these categories for future flow management can be evaluated by reference to the post-Twitchell period of record on the Guadalupe gage (Figure 4.4-17). In this 26-year record, 7 years were "dry" and 4 (1969, 1978, 1980, and 1983) were clearly "wet." Unlike the pre-dam period, almost 20% of days during the seven "dry" water years also had recorded discharge in the Sisquoc River at Garey (USGS 11140000).

Of the remaining 15 years with some flow, three (1962, 1967, and 1973) met the minimum 3-day passage window either once or twice; the balance were moderately or substantially below the requirements for adult passage. Storage in Twitchell reservoir during these 15 years ranged from zero (1966, 1967, 1975, 1977, 1981, and 1985) to nearly 100,000 acre-feet (1984), suggesting a wide range of hydrologic conditions (and potential management alternatives) within this "intermediate" category of water year. A more careful discrimination between them, for purposes of achieving a frequency and distribution of fish-passable conditions that approach pre-dam conditions with the most effective use of Twitchell-stored water, will be the focus of Section 5.

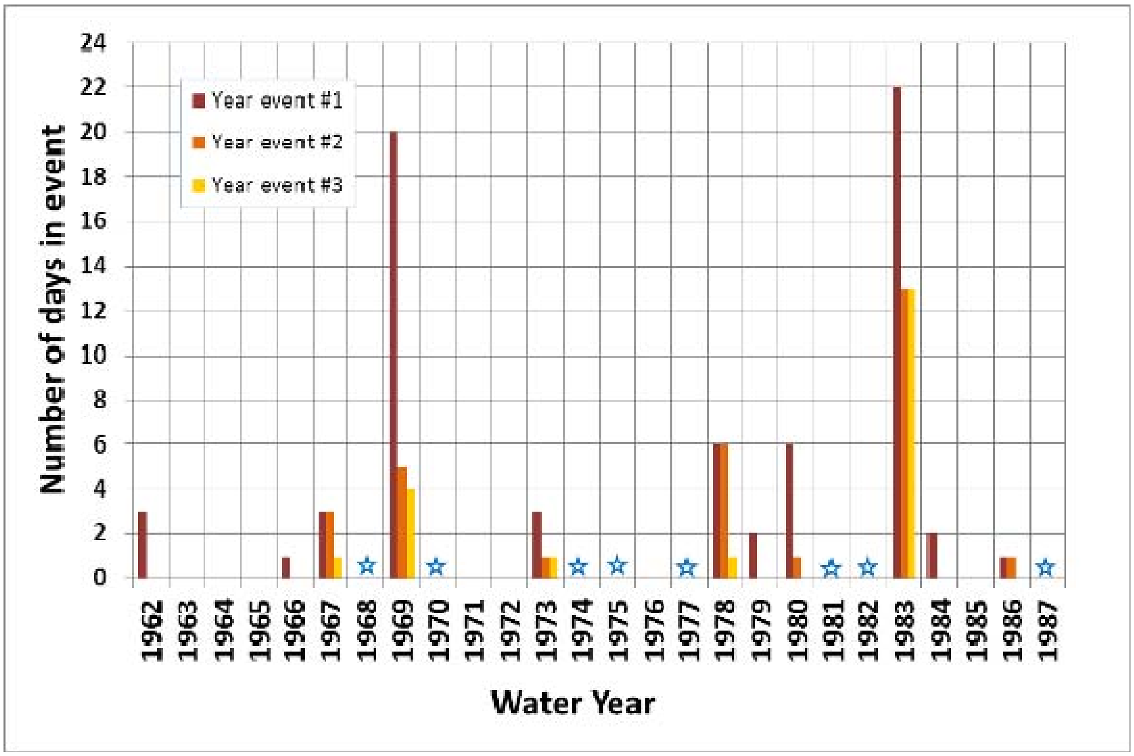

Figure 4.4-17. Duration (in days) and distribution (by water year) of 250-cfs flow events at the Guadalupe gage (USGS 11141000). Multiple bars for a single year indicate multiple flow events, arranged in order of decreasing duration (2 additional events of 2–6 days' duration occurred in both 1969 and 1983). Starred years had one or more recorded flows but all less than 250 cfs. Blank years (7, in total) had no days of recorded flow whatsoever.

4.5 Groundwater Modeling

The SMR2DIM was developed to estimate the flow in the full Santa Maria River based on a minimum set of user-entered parameters. In the absence of direct flow measurements, the model

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provides estimates of flows in the mainstem river using discharges from the Sisquoc and Cuyama rivers, groundwater level in the "key well," and days of antecedent flow (all of which must be provided).

To use the model, the following variables must be entered:

- Flow at the Sisquoc River at Garey gage (cfs)
- Flow released from Twitchell reservoir (cfs)
- Number of antecedent days of flow in the mainstem Santa Maria River (days)
- Depth to groundwater in the key well (ft)

The model output is a graphical depiction of the model results as well as data labels quantifying flow estimates in a two-dimensional setting. Figures 4.5-1 through 4.5-3 present the model output for three scenarios, representative of a range of flow and groundwater conditions.

Scenario 1 (a relatively typical wet-season regime, based on qualitative review of the available record of flow and groundwater conditions):

- Flow at the Sisquoc River at Garey gage = 522 cfs
- Flow released from Twitchell reservoir = 0 cfs
- Number of antecedent days of flow in the mainstem Santa Maria River = 2 days
- Depth to groundwater in the key well = 40 ft

Under this scenario, flows in the critical passage reach range from approximately 200 to 230 cfs. These flows would be sufficient for juvenile downstream migration, but just under the flow necessary for adult upstream migration (Figure 4.5-1).

Scenario 2 (a long-duration, but waning, flow regime):

- Flow at the Sisquoc River at Garey gage = 315 cfs
- Flow released from Twitchell reservoir = 0 cfs
- Number of antecedent days of flow in the mainstem Santa Maria River = 100 days
- Depth to groundwater in the key well = 40 ft

Under this scenario, flows in the critical passage reach range from approximately 19 to 25 cfs, which is insufficient for juvenile downstream and adult upstream migration (Figure 4.5-2).

Scenario 3 (a moderate-duration, dam-supplemented flow regime):

- Flow at the Sisquoc River at Garey gage = 300 cfs
- Flow released from Twitchell reservoir = 200 cfs
- Number of antecedent days of flow in the mainstem Santa Maria River = 10 days
- Depth to groundwater in the key well = 80 ft

Under this scenario, flows in the critical passage reach range from approximately 194 to 205 cfs. These flows would be sufficient for juvenile downstream migration but just under the flow necessary for adult upstream migration (Figure 4.5-3).

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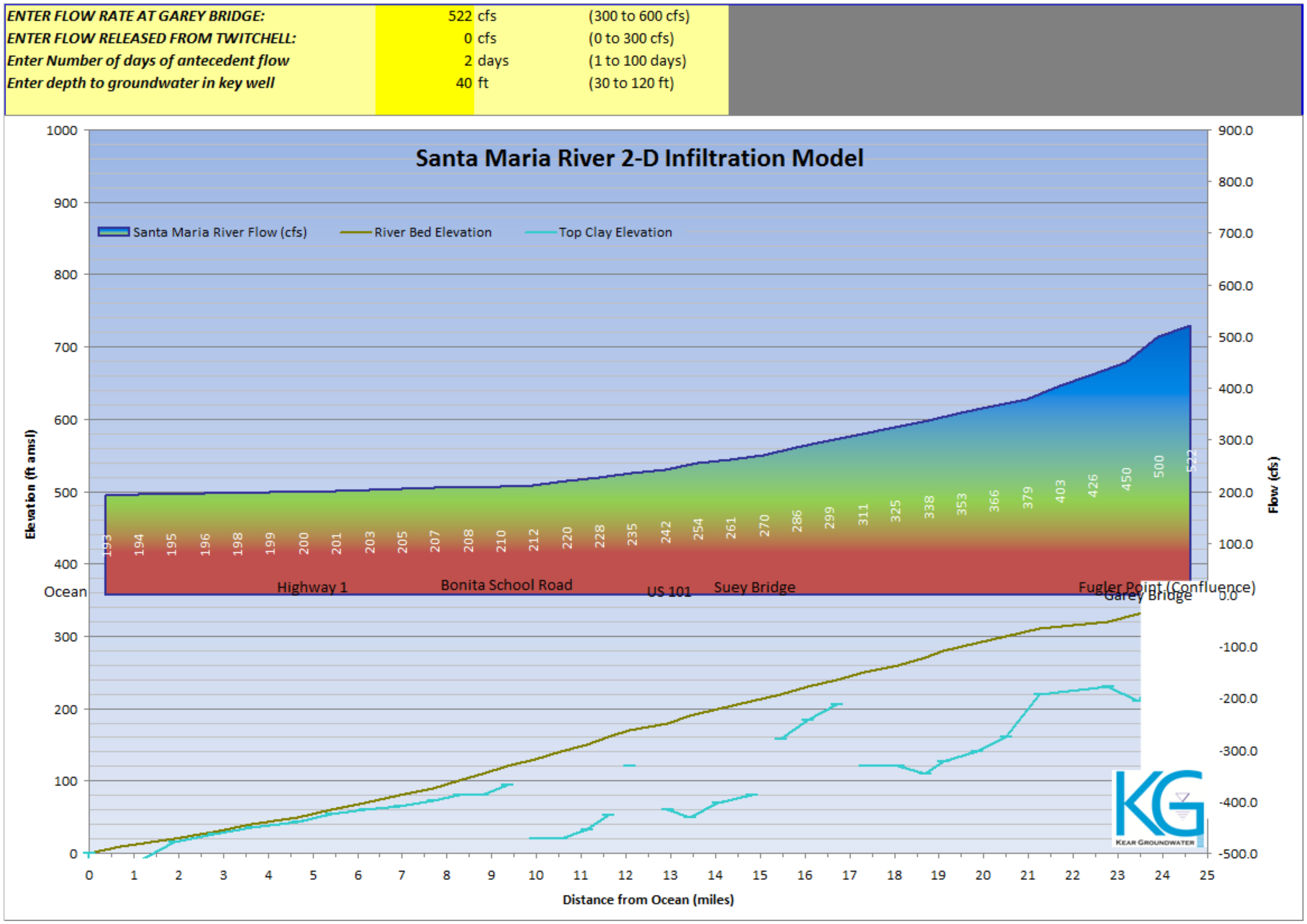

Figure 4.5-1. SMR2DIM output screen for a flow scenario of 522 cfs at the Sisquoc River at Garey gage. Surface-water flow is right-to-left, with declining river discharge graphically displayed by the falling upper boundary of the "rainbow"-colored area. Flow values (in cfs) can be read off the right-hand scale and are shown in white numbers in 0.7-mile intervals. Passable flows lie in the green-to-blue shaded areas (i.e., ≥150 cfs for downstream migration, ≥250 cfs for upstream migration). River-bed and clay-layer elevations plotted on left-hand scale.

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ENTER FLOW RATE AT GAREY BRIDGE:	315	cfs	(300 to 600 cfs)
ENTER FLOW RELEASED FROM TWITCHELL:	0	cfs	(0 to 300 cfs)
Enter Number of days of antecedent flow	100	days	(1 to 100 days)
Enter depth to groundwater in key well	40	ft	(30 to 120 ft)

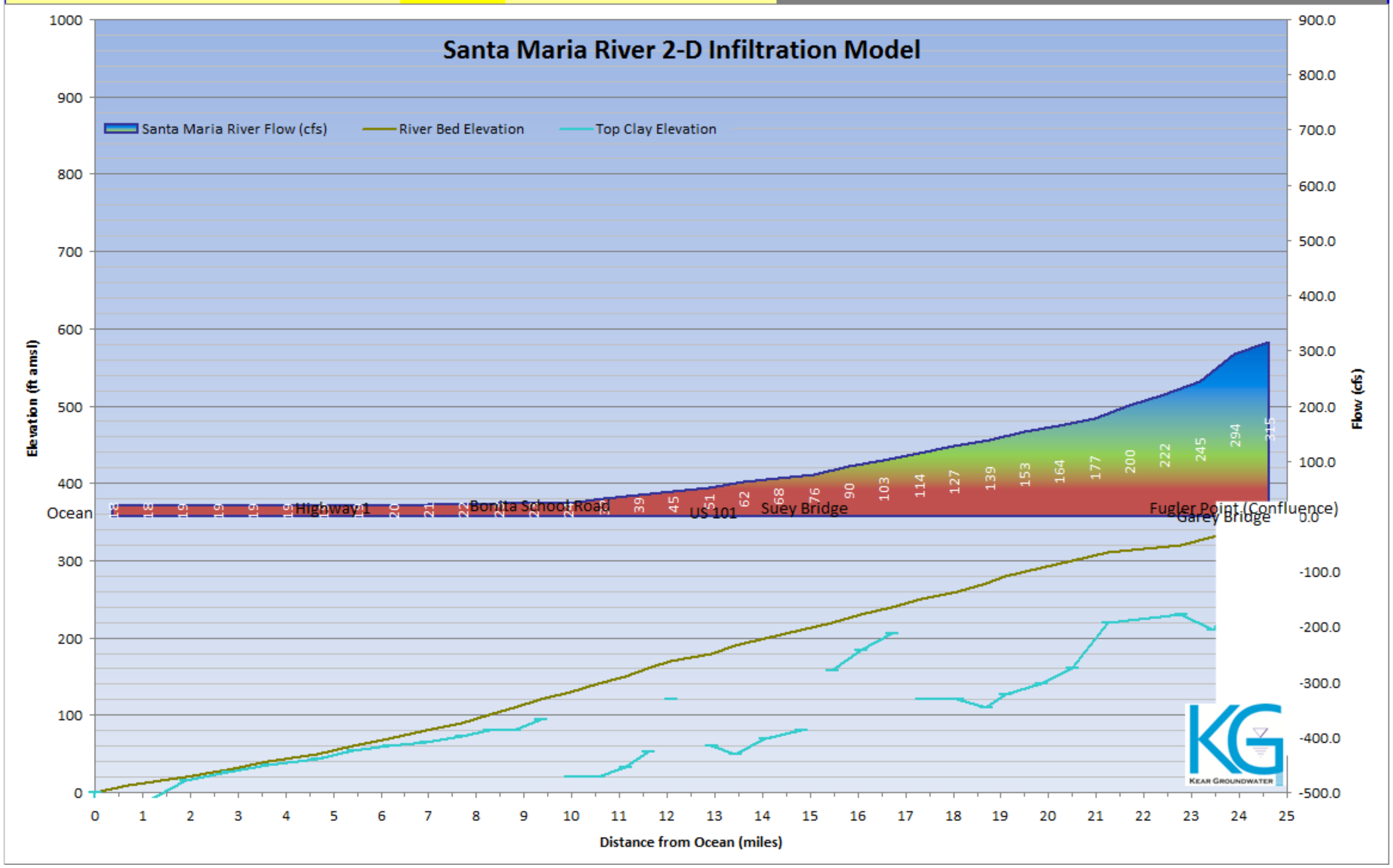

Figure 4.5-2. SMR2DIM output screen for a flow scenario of 315 cfs at the Sisquoc River at Garey gage (symbology as for Figure 4.5-1). A transmission loss of ~300 cfs is predicted by the model for this scenario, even with high groundwater levels and an unusually long duration of antecedent flow.

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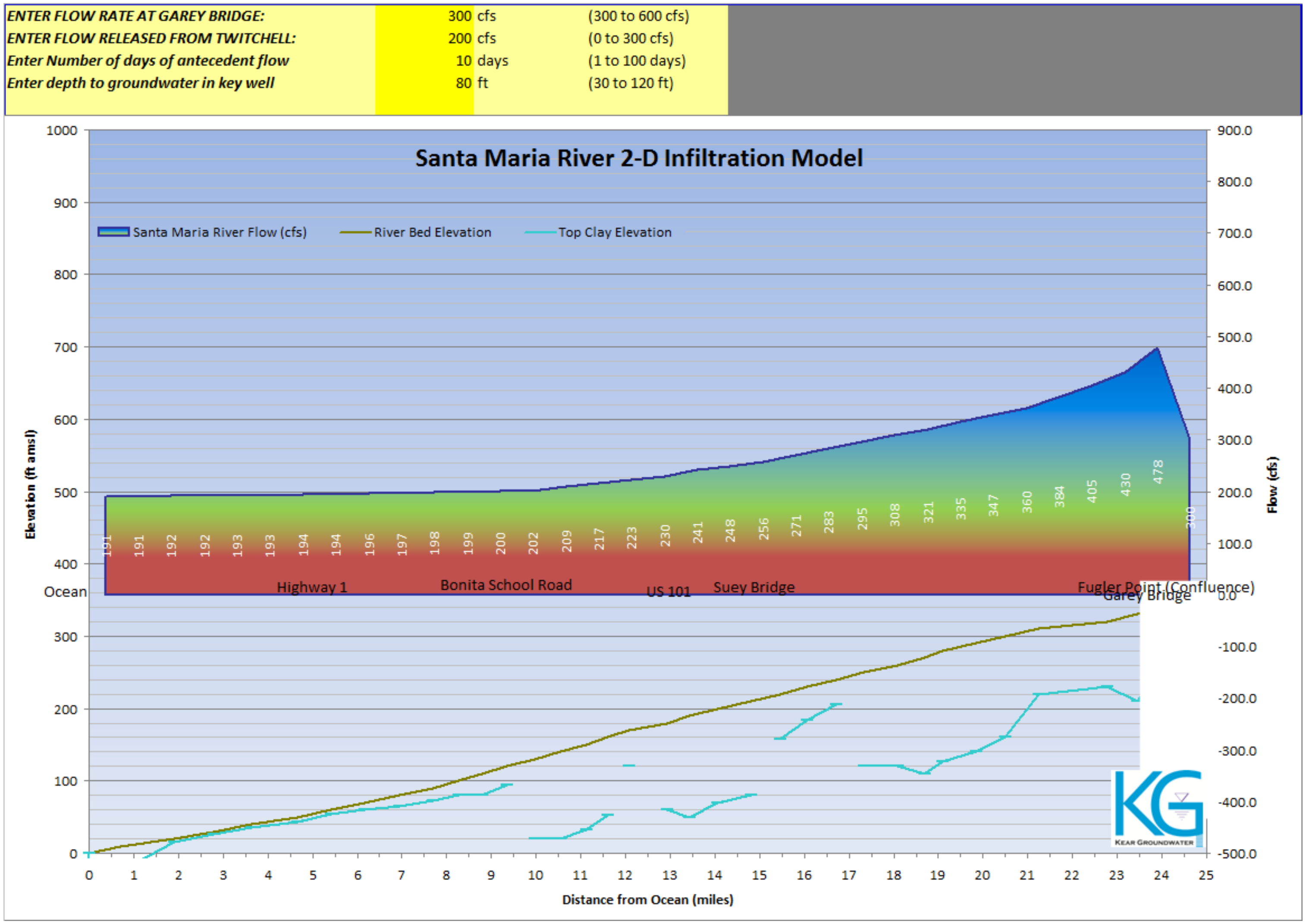

Figure 4.5-3. SMR2DIM output screen for a flow scenario of 300 cfs at the Sisquoc River at Garey gage and a 200 cfs release from Twitchell Reservoir (symbology as for Figure 4.5-1).

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These examples provide useful context for a more general characterization of the SMR2DIM predictions. Transmission losses along the mainstem Santa Maria River, from the confluence through the critical reach, are strongly dependent on depth to groundwater but only in the early period of a multi-day flow event (Figure 4.5-4). After just a few days (and certainly within a week) of mainstem flow, transmission losses converge to values at or slightly above 300 cfs, consistent with long-term observations of the river and supporting this value as a presumptive loss between the confluence and the critical passage reach.

In the first 1–3 days of flow, however, groundwater conditions are critical determinants of surface-water losses, with as much as 450 cfs of loss after one day (and even more during the initial day of [unmodeled] flow). Thus, transmission losses in the first few days of a potential passage event must be anticipated to exceed the long term rate by as much as 100–150 cfs, an additional discharge that must be incorporated in any proposed flow-management scenarios.

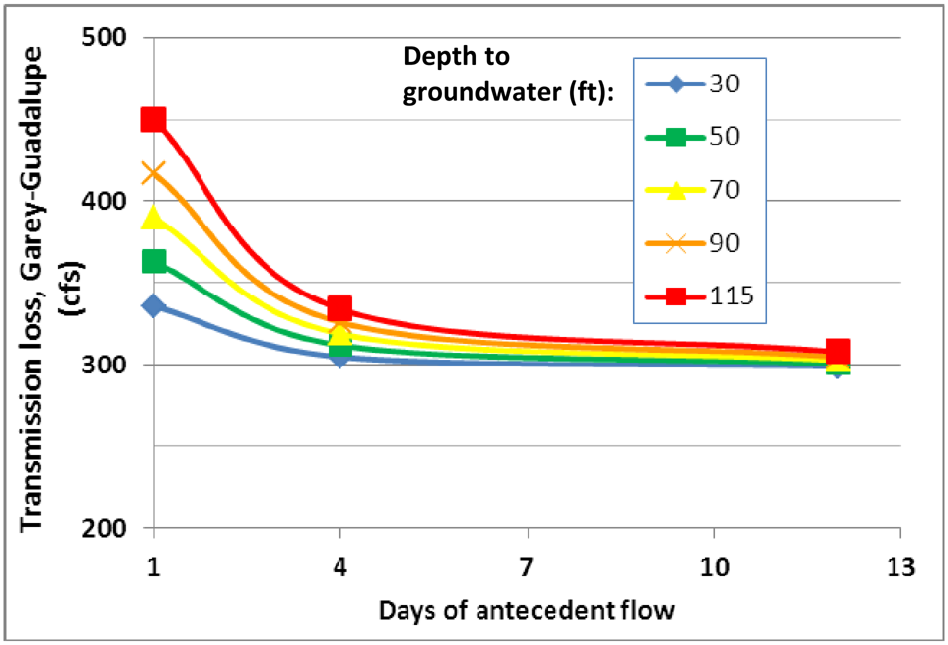

Figure 4.5-4. Summary of SMR2DIM results for transmission losses between the lower Sisquoc River and the Guadalupe gage on the Santa Maria River, in the critical reach for fish passage. Each line traces the reduction in losses over time for a different depth to groundwater, spanning the full observed range of this parameter.

Although the depth to groundwater is a readily measured parameter, its value cannot be easily predicted *a priori* (Figure 4.5-5). Thus, SMR2DIM can display the range in which transmission losses are likely to be found and predict the pattern of those changes through time, but it cannot offer a precise estimate of those losses (or their inverse, the river discharge), particularly during the early stages of a flow event when groundwater conditions are most influential. Although these transient conditions are not critical for evaluating the overall effectiveness of alternative flow-release scenarios (Section 5), they provide a reminder that SMR2DIM predictions are not adequate to guide real-time operational management actions.

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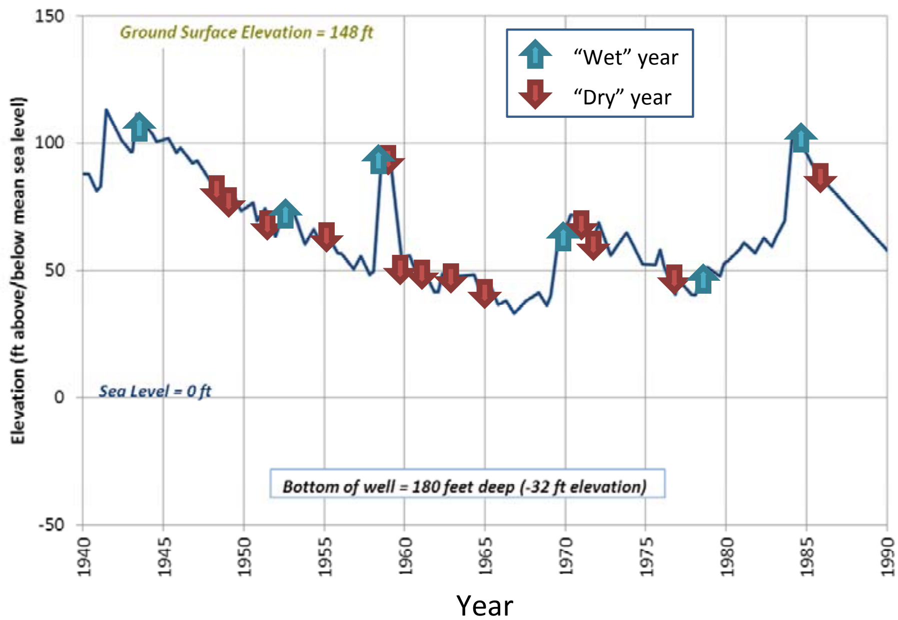

Figure 4.5-5. Comparison of groundwater elevations in the "key well" (see Section 3.5) with years of particularly high flow in the mainstem Santa Maria River ("wet years") and those with no flow ("dry years") over the period of record for the Guadalupe gage (USGS 11141000) (Section 4.4.3). Although the average of measured depths to groundwater is about 10 ft lower in the dry vs. the wet years (87 ft deep vs. 78 ft deep), the two ranges of groundwater depths are nearly identical and do not suggest a useful systematic relationship that could be applied to use SMR2DIM in a future-scenario, "predictive" mode.

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5 DISCUSSION AND RECOMMENDATIONS

The purpose of this study is to characterize the historic and current conditions of instream flow in the Santa Maria River and to determine what, if any, modifications to the current flow regime would improve upstream passage for adult steelhead through the mainstem into the upper watershed, and downstream passage of juvenile steelhead through the mainstem to the estuary and ocean. This section offers a set of recommendations and the rationale behind them, proceeding from a relatively general set of instream flow "goals" (Section 5.1) to a concrete set of measureable "objectives" that support these goals (Section 5.2), and then to a short list of operational "rules" to meet the instream flow objectives (Section 5.3).

5.1 Steelhead-Passage Improvement Goals

From the analysis of flow records pre- and post-Twitchell Dam, the following goals for improving steelhead passage are indicated (see Section 4.4.2.), in declining order of relative importance:

- #1. Reduce the frequency of "false positives" in the flow of the Sisquoc River (i.e., discharges in the Sisquoc River that historically correlated with downstream-passable conditions to the estuary but no longer do) (see Figures 4.4-13 and 4.4-14);
- #2. Increase the overall frequency of downstream steelhead-passable conditions (see Figure 4.4-7, left panel), with no more than two consecutive passage-free years (unless a product of climatological drought);
- #3. Reduce the number of days with upstream steelhead-passable flows that are *not* followed by at least two additional steelhead-passable flow days (see Figure 4.4-8); and
- #4. Increase the frequency of long-duration upstream steelhead-passable intervals (see Figure 4.4-7, right panel).

To this list of goals, some reasonable constraints to future flow modifications are suggested by the aggregate flow record of the 1942–1961 (pre-dam) period:

- #5. The *increase* in the number of upstream steelhead-passable days as a result of operational changes should be on the order of 2 days/year, as averaged over periods of not less than a decade.
- #6. Upstream steelhead-passable conditions of substantial duration (i.e., substantially more than 3 days) should not be anticipated in more than one or two years per decade, given historical climatic conditions.
- #7. Flow conditions suitable for downstream steelhead passage should occur in about one-half of all years, on average.

5.2 Flow Objectives for Achieving Steelhead-Passage Improvement Goals

5.2.1 Objective #1: Reduced "false positives" for downstream migration

Figure 4.4-14 and 4.4-15 demonstrate the degree to which the high certainty (>75%) of downstream steelhead passage to the estuary that historically accompanied flows of 450 cfs or more in the Sisquoc River at Garey has been compromised by the loss of synchronicity between Siquoc River discharges and Twitchell Dam releases. Inspection of the post-dam flow record shows that downstream passage at Guadalupe is now achieved more than 75% of the days only when flows have exceeded 550 cfs at the Sisquoc River at Garey gage. Even for flows as low as

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350 cfs at Garey, downstream passage was once a 50/50 prospect but now fails most of the time. These conditions suggest that achieving goal #1 above will require flow augmentation from Twitchell Dam when the Sisquoc River at Garey gage lies in the range of about 450–550 cfs (and, more conservatively, for Sisquoc River flows down to 350 cfs).

In the 26 years of the post-dam record when the Guadalupe gage was operating, flows at Garey fell into the 450–550 cfs range on 51 days. Of the ten years in which this occurred, one was a "dry" year (1965); all four "wet" years (1969, 1978, 1980, and 1983) are also represented. In the five "intermediate" years (1962, 1967, 1975, 1979, and 1986), Twitchell Reservoir was holding water on every such day (storage ranged from a low of 5,000 ac-ft to 93,000 ac-ft), but on only one day (February 14, 1979) was there any release from the dam at all. These conditions suggest that flow augmentation would have been feasible on any or all of these days in the "intermediate" years.

5.2.2 Objective #2: Increased overall frequency of downstream migration

This goal should be achieved through any successful implementation of Objective #1. In other words, it provides no additional guidance for either prioritizing or constraining the choice of specific conditions (or days in which those conditions are met) during which additional flow releases from Twitchell reservoir would be most beneficial.

5.2.3 Objective #3: Reduced "false positives" for upstream migration

Both Figures 4.4-7 and 4.4-13 show that the total number of days with 250 cfs in the mainstem river has decreased by two days per year, on average, but essentially the entire loss has occurred in those days that, pre-dam, had been followed by at least two additional days of equivalently passable flows. The necessary objective for meeting this goal, therefore, is to identify and increase the duration of one-day or two-day periods of >250 cfs in the mainstem Santa Maria River at Guadalupe that were *not* part of a three-day continuous period of flow >250 cfs at Guadalupe.

This condition occurred for 13 days in the post-dam record for water years 1962–1987, and they fell into six years (corresponding to each of the four "wet" years and two of the "intermediate" years) (and none of the "dry" years). The four intermediate years with this condition (1966, 1967, 1979, and 1986) had one "pair" of days (i.e., requiring only one additional day to achieve full 3-day upstream passage conditions, in March 1979) and five single days widely distributed across the calendar. Thus, to meet this objective for every instance in the non-"wet" years would require 11 new days of flow >250 cfs in the 26-year period, an average increase of slightly less than ½ day per year.

However, in three of these six instances the flows in the Sisquoc River at Garey at the end of the three-day period were under 100 cfs, raising the uncertainty of passage through that reach for half of the potentially created "events." This offers an important reminder that flows in the mainstem alone are not sufficient to assure passage throughout the system, and that a final protocol for upstream steelhead-passage flow releases must account for the need to traverse the (unregulated) lower Sisquoc River.

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5.2.4 Objective #4: Increased frequency of long-duration upstream migration intervals

Figure 4.4-7 suggests that long-duration (>12 days) passage intervals have been reduced in the post-Twitchell Dam period. However problematic, this is a condition that is unlikely to be resolved by managed flow releases. Pre-Twitchell Dam, this condition occurred in one "intermediate" year and two of three "wet" years (1941, 1943, and 1958), and post-Twitchell Dam in 1969 and 1983, two of the four post-dam "wet" years. In the latter period, no other passage interval was longer than six days, suggesting that although lengthening of passage intervals is feasible within the parameters of overall flow changes, the long-duration events are still more strongly controlled by meteorological events than dam operations. The best management opportunity for achieving this objective is likely by "bridging" two short-duration passage events that are separated by only one or two non-passable days.

5.3 Steelhead Migration Flow Requirements and Flow Rules

Table 5.3-1 summarizes the flow magnitude and duration for steelhead passage through the Santa Maria River from Section 4.3. There is no evidence that sandbar conditions at the estuary or flow conditions in the lower Sisquoc River would limit the attainment of these elements of steelhead passage.

Table 5.3-1. Flow magnitude and duration required for effective adult and juvenile steelhead migration through the Santa Maria River. These flows are necessary for passage throughout the mainstem; conditions are likely to be most limiting in the critical reach, for which evaluation at the Bonita School Road crossing is likely to be representative.

Flow component	Adult migration	Juvenile migration
Magnitude in the critical passage reach	≥250 cfs	≥150 cfs
Corresponding magnitude at the confluence[1] (i.e., Sisquoc River at Garey gage + Twitchell Dam release)	≥600 cfs	≥500 cfs
Flow duration at prescribed magnitude	3 continuous days	3 continuous days, headwaters to mouth; 1 day in mainstem

[1] Based on median transmission loss from gage record 1941–1987 (Figure 3.4-2); equivalent results obtained from SMR2DIM (Section 4.5), assuming two days of antecedent flow and an "average" groundwater depth of 70 ft.

As described previously, determining the appropriate *frequency* of flow magnitudes and durations that meet the criteria of Table 5.3-1 is less straightforward because it is not based on physical requirements of steelhead. Also, the efficacy of these flows to initiate upstream migratory behavior can only be determined through long-term monitoring of fish behavior. During the course of the Instream Flow Study, it became apparent that releases from Twitchell Dam are the only available "tool" with the potential to recover pre-dam steelhead passage frequency. There are no other reservoirs in the watershed, and any manipulation to the critical passage reach (e.g., excavation of pilot channels) would be short-lived and likely irrelevant, since a stormflow channel is carved naturally under any notable surface flow. The operational rules described below

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thus rely exclusively on releases from Twitchell Reservoir, but they seek to balance the effectiveness of these releases for facilitating steelhead passage with efficient water use.

The fundamental change to the flow regime of the Santa Maria River, namely the decoupling of flows from the Sisquoc and Cuyama rivers (Figures 4.4-9 and 4.4-11) indicate the general strategy that should be employed to achieve the fish-passage objectives: namely, increased flow in the Cuyama River when the Sisquoc River is flowing at a rate that, historically, would have resulted in potentially suitable steelhead-passage conditions in the mainstem Santa Maria River.

Guided by the hydrologic analysis of pre- and post-dam conditions (Section 4.4), this can be framed in a set of operational "rules":

- #1. Flow augmentation from releases at Twitchell Dam should be made whenever discharge in the lower Sisquoc River (at the Garey gage) falls between 350 and 550 cfs, reflecting the range of flows when steelhead passage in the mainstem would have likely been possible at least half of the time, pre-dam, but that have become most severely compromised, post-dam. SMR2DIM results can offer general guidance (in particular, Twitchell Dam will likely need to release between 100 and 300 cfs to ensure passage through the critical passage reach, depending on Sisquoc River flows, current groundwater conditions, and duration of the flow supplementation), but field measurement of mainstem discharges will provide more precise guidance.
- #2. Flow augmentation should only occur during the period of potential steelhead passage (December–April).
- #3. Flow augmentation to more closely mimic pre-dam flow patterns requires stored water in Twitchell Reservoir.

In addition to this set of rules, one additional requirement is indicated from the pattern of pre- and post-dam flows:

- #4. When an average daily discharge of 250 cfs in the critical passage reach has been achieved, flows should be released if/as needed to ensure that this condition is maintained for *at least* two additional days, dependent on passable flow persisting in the lower Sisquoc River (i.e., a discharge at the Garey gage of at least 150 cfs).

5.4 Testing the Flow Rules

The overall success of these rules in reestablishing a multi-year flow regime suitable for steelhead passage can be evaluated by reference to the general patterns suggested by the 20-year pre-dam hydrologic record (refer to Figure 4.4-16): releases should achieve downstream passage in at least one year in three and upstream passage in at least two years in ten (dependent, of course, on flows in the lower Sisquoc River). The timing, frequency, and duration of passage will be constrained by the occurrence of "naturally" passable conditions at a time coincident with the presence of stored water in Twitchell Reservoir, and a long-term running totally of the total releases from Twitchell Dam with the expressed goal of steelhead passage. As a first approximation, based on the assessment of pre- and post-dam flow durations, about 1,000 ac-ft/year (averaged over a multi-year period) should be sufficient to correct the alterations to the flow regime that are significant to steelhead passage that have likely occurred since dam closure in 1962.

Application of these rules requires knowledge of the flows in the lower Sisquoc River as recorded at the Garey gage, but this is not a precise predictor of flows in the mainstem Santa Maria River, the location of most critical conditions for steelhead passage. The performance of these rules is

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therefore evaluated under two alternatives: a “naïve” approach where their application is guided only by these four rules; and a “smart” approach, whose primary modification is to minimize the number of single-day flow events of insufficient duration to provide passage.

5.4.1 “Naïve” rule application

In the 26-year post-dam period 1962–1987, daily average flows at Garey fell in the range of 351–550 cfs for a total of 115 days. All but five of these days fell in the months of December–April, and all but an additional five occurred with stored water behind Twitchell Dam. Of the 105 days that met the first three rules, 10 already had flow in the mainstem greater than 250 cfs; thus, steelhead passage on 95 days in total would have benefitted from releases at Twitchell Dam.

To estimate the amount of water needed at the confluence (i.e., Sisquoc + Cuyama) to achieve a flow of 250 cfs in the mainstem at Guadalupe, the following analysis uses typical results from SMR2DIM to assume that all of the water added from Twitchell Dam will be reflected in flow increases at Guadalupe. The amount of water released from Twitchell Reservoir would normally be greater than the volume of potential groundwater recharge “lost” to surface water, because any releases from the dam that infiltrate before reaching Guadalupe represent groundwater recharge that would have occurred under any scenario. Thus the volume of released water that reflects a net redirection from recharge to surface flow is equal to:

1. 500 ac-ft/day, equivalent to a “new” (fish-passable) 250-cfs surface-water discharge to the estuary if no flow would have otherwise occurred; or
2. The (lesser) volume associated with the increase in surface flow needed to achieve 250 cfs flow, if some surface flow to the estuary already would have been occurring.

Under the naïve application of the four rules, additional releases from Twitchell Dam result in an increase of 17,475 cfs-days of flow past Guadalupe, equal to a volume of additional flow to the estuary that averages about 1,300 ac-ft per year. The results are graphed in Figure 5.4-1 (compare with Figure 4.4-16).

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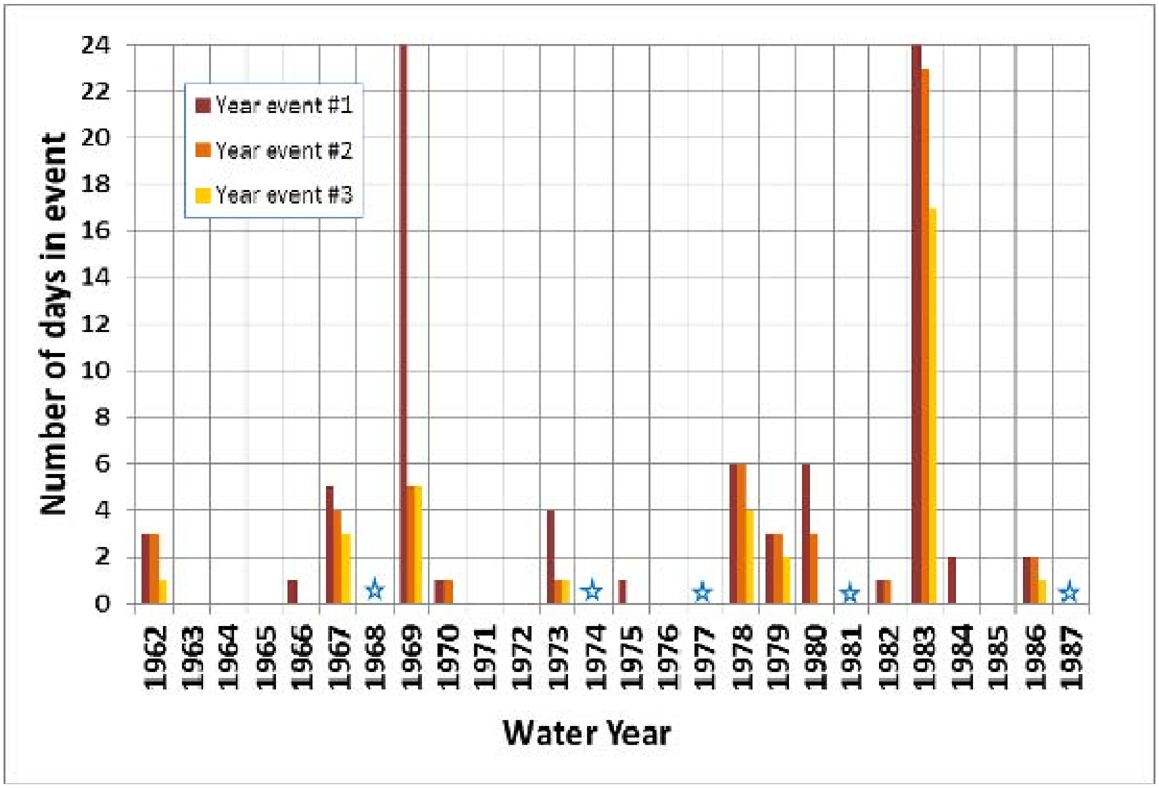

Figure 5.4-1. Duration (in days) and distribution (by water year) of ≥250-cfs flow events at the Guadalupe gage (USGS 11141000), under the assumption of additional flow releases from Twitchell Dam to improve steelhead-passage conditions following the "naïve" rules. Multiple bars for a single year indicate multiple flow events, arranged in order of decreasing duration (additional events of 2–6 days' duration occurred in both 1969 and 1983). Starred years had one or more recorded flows but all less than 250 cfs. Blank years (7, in total) had no days of recorded flow in the mainstem whatsoever.

The primary effect of these additional flow releases is to "strengthen" the years where steelhead passage would have historically occurred—more separate passage events and/or longer such events. A secondary effect, however, is to increase the number of years with single days of flow ≥250 cfs at Guadalupe. This suggests that the mechanical application of these rules may have the unintended consequence of providing more single-day steelhead-passable conditions without conditions supportive of full 3-day passage. Because of this outcome, additional rules were included (next section) to guide the release of water from Twitchell Reservoir to improve the effectiveness of results.

5.4.2 "Smart" rule application

The naïve addition of water from Twitchell Reservoir does not achieve unequivocal benefits for steelhead passage for two reasons. Most importantly, a single day of Sisquoc River flow in the triggering range of 351–550 cfs is not always followed by more such days. When it is not, the effect of the naïve augmentation rules is to increase the number of single-day passable flows (but not the number of true passage "events"). This can be corrected by releasing flows from Twitchell Dam only after two days of passable discharge in the lower Sisquoc River have already occurred; and by maintaining releases until at least three days of passage in total have been achieved (or

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until the flow in the lower Sisquoc River drops below 150 cfs, the presumed flow requirement for adult passage). These changes result in 35 days that are "dropped" from those being augmented under the naïve rules and 19 days that are added. While this management scheme would potentially result in the more efficient use of water supplies, its long-term effects on steelhead populations in the Santa Maria River system merits additional investigations beyond the scope of this study.

Second, certain flow and meteorological situations, in particular a one-day lull in flow between two large storms, can result in a similarly brief interval when the discharge falls below passage thresholds between two multi-day and "naturally" passable events. When such a situation can be recognized (e.g., by a weather forecast of back-to-back storms), a judicious flow release in the lull between passable flows could lengthen two marginally passable events (e.g., 3 or 4 days) into a single period of passage that lasts for a week or more. This would address the fourth goal of this effort. Only five such days are recognized in the 1962–1987 period (once each in 1967, 1969, 1978, 1983, and 1986). Tools such as the National Weather Service's California-Nevada River Forecast Center (http://www.cnrfc.noaa.gov/) may be useful for predicting when conditions are expected to trigger these rules.

A third modification to the naïve rules was also applied, on the assumption that extending the duration of fish passage can reach a point of diminishing returns, corresponding to those "wet" hydrologic years when passage opportunities are so plentiful that additional extension using stored water may be unnecessary. This occurred four times in the relatively wet years of the 1962-1987 period (and in particular during water years 1969 and 1983); for purposes of the simulation, the "smart" rule modification was to terminate all artificial releases for a given water year once a continuous 12-day passage window had been achieved in that water year. However, as noted above, the long-term effects of this modification on steelhead populations merits additional investigation.

The summary of results for these three rule modifications are graphed in Figure 5.4-2, presenting an alternative scenario to that of Figure 4.4-16. Releases of water from Twitchell Reservoir required to achieve the "smart" augmentation of flows averages about 1,500 ac-ft per year over the 26-year period 1962–1987.

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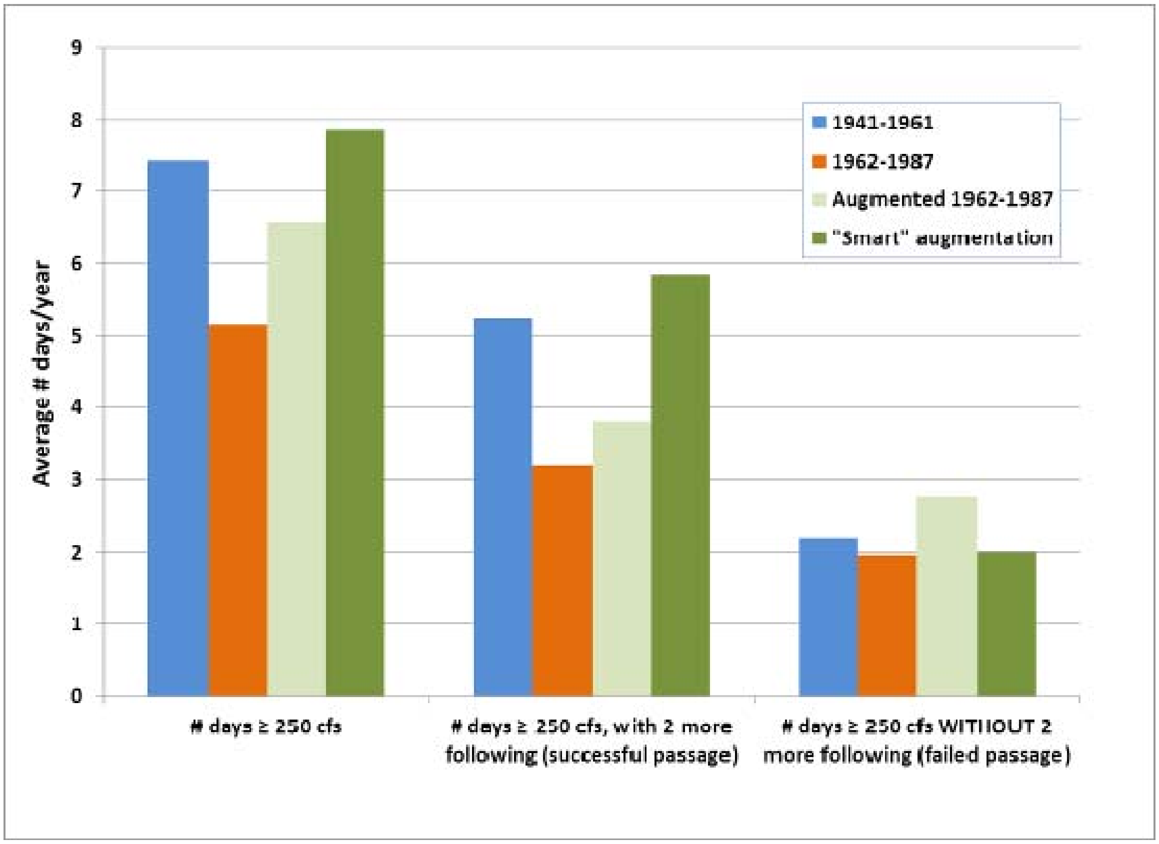

Figure 5.4-2. Opportunities for successful passage are returned to slightly better than pre-dam levels through operational modifications at Twitchell Dam (dark green bars), but only through the intentional lengthening of 1- and 2-day passage events plus the recognition of single-day lulls between major flow events.

As evidenced by a comparison of the duration of actual flows (blue and orange bars in Figure 5.4-2) with the final recommended flows (dark green bars), the augmented flow regime actually increases the opportunities for fish passage over (actual) post-dam levels by nearly three days per year. Although this flow regime exceeds the overarching goal of returning the post-dam flow regime to pre-dam levels with respect to fish passage, a range of other "rules" designed to reduce the total water release from Twitchell Reservoir were explored but were ineffective at meeting this fundamental goal.

A further check on effectiveness can be made by assessing the success of the recommended flow regime at meeting the key objective (#1 in the list above) of reducing the frequency of "false positives" for juveniles in Sisquoc River tributaries, who must anticipate the likelihood of passable conditions all the way to the estuary only on the basis of local flows in the Sisquoc River. The "smart" augmentation rules produce a probability distribution for full passage as a function of Sisquoc River flows that it close to (but does not improve upon) pre-dam conditions (Figure 5.4-3), and which offers a marked improvement over actual post-dam conditions in the 1962–1987 period (refer to Figure 4.4-15).

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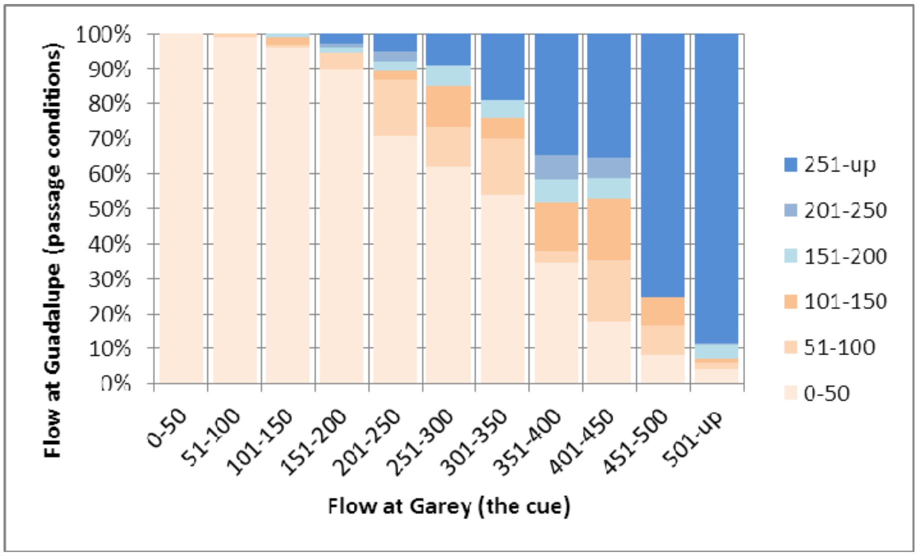

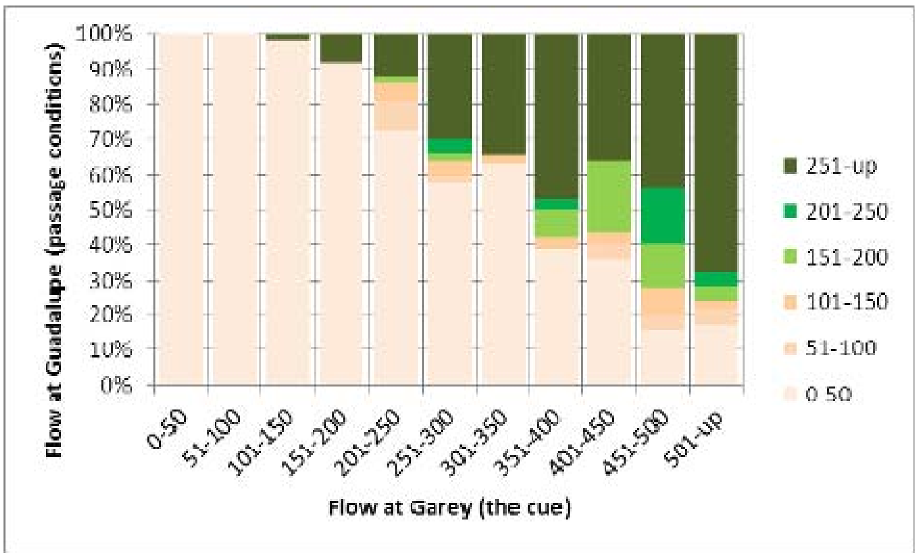

Figure 5.4-3. Predicting steelhead passage through the mainstem Santa Maria River (colored bars) based on same-day flows in the Sisquoc River (x-axis; all values in cfs). Top, the pre-dam flow regime (repeated from Figure 4.4-14). Bottom, the post-dam "smart augmentation" flow regime, which suggests near-equivalency with the unregulated period, particularly for the range of flows suitable for juvenile migration (i.e., ≥150 cfs).

5.4.3 Application of flow-augmentation rules to the 1988-2011 record

Although the post-1987 record can provide no direct assessment of steelhead passage along the mainstem (owing to the retirement of the Guadalupe gage), it is still possible to evaluate the consequences of the rules on "presumptive" steelhead passage in the mainstem during this period, and to quantify the consequences on the volume of additional water that would have been released from Twitchell Reservoir had these rules been in effect.

The right-hand-most bars (dark purple) in Figure 5.4-4 reflect the presumptive outcome of applying the recommended "smart" flow-release rules to the actual record of flows in the lower

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Sisquoc and Cuyama rivers for the 1988–2011 period. They are very successful in achieving an average of about 2 additional days of passage per year in comparison to actual dam operations (light purple bars of Figure 5.4-4) with almost no increase in the frequency of "failed" passage (i.e., less than three contiguous days of passable flow). Application of the smart rules during the 1988–2011 period would have resulted in an additional 23,500 ac-ft of surface water discharged to the estuary over this 23-year period, reflecting an average reduction in groundwater recharge of about 1,020 ac-ft/year.

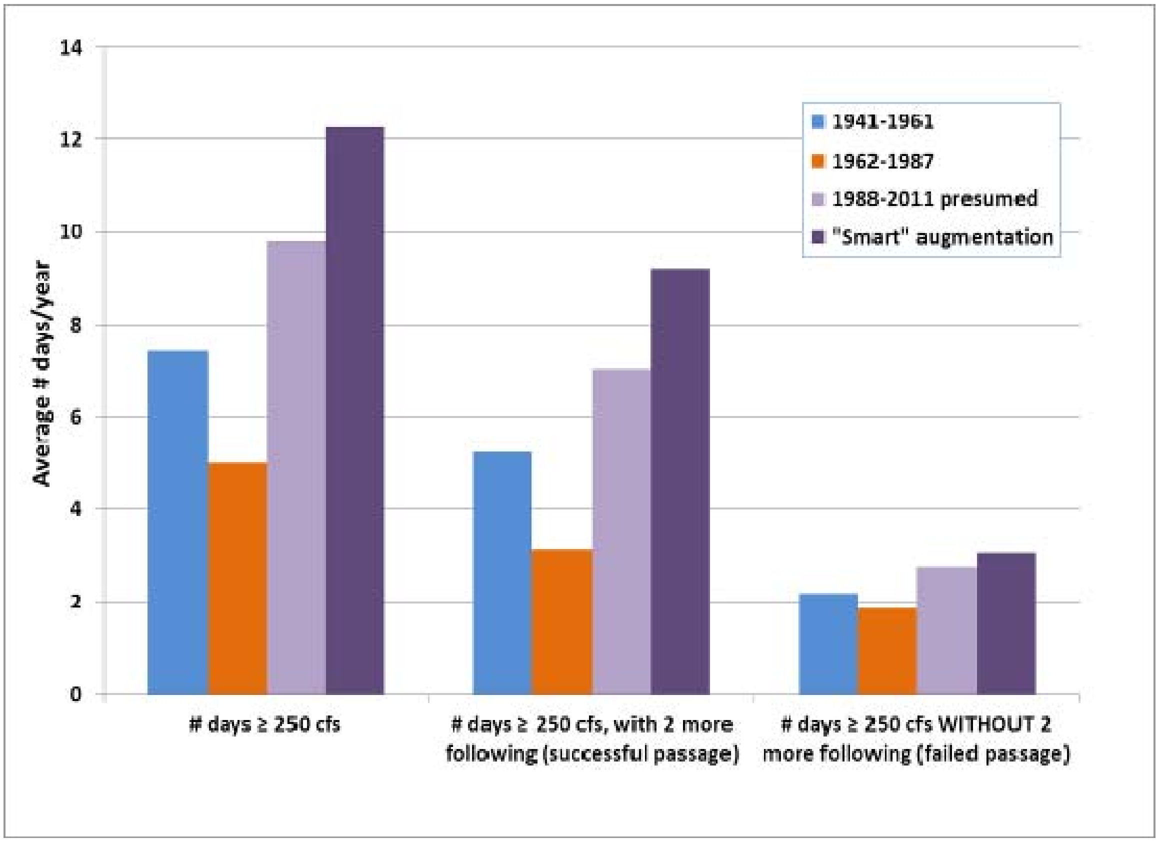

Figure 5.4-4. Presumptive opportunities for successful passage for the period 1988-2011 ("presumptive" because direct measurement of the mainstem flows do not exist for this period). "Smart" augmentation rules as previously described for the 1962–1987 period are used for the last scenario, which provides about 2 days/year additional passage over unmodified dam operations (light purple bars).

The period 1988–2011 has been wetter than the preceding decades, as suggested by both the net discharge of the Sisquoc River (Figure 4.4-4) and the summary statistics for passage conditions (Figure 5.4-4, light purple bars). Comparisons between this period and early ones, however, are challenged most severely by the different methods of ascertaining passage: for the period 1941–1987, it was evaluated using the measured flow at the Guadalupe gage; for the period 1988–2011, it was evaluated by the *presumptive* flow at Guadalupe guided by SMR2DIM results, namely 350 cfs less than the combined flow of the two major tributaries at their confluence. Although the *relative* changes in passage days as a result of simulated flow augmentation (i.e., comparisons between the light purple and dark purple bars) are probably reasonable estimates, differences between the absolute number of passable days 1941–1987 (Figure 5.4-4, blue and orange bars)

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and absolute number of passable days 1988–2011 (purple bars) should be evaluated with great reservation.

5.5 Summary of Assumptions and Flow Recommendations

1. Initiation of upstream migration of adult steelhead is coincident with flows of 250 cfs in the critical reach of the mainstem of the Santa Maria River.
2. Upstream adult steelhead passage requires at least three days of flow greater than or equal to 250 cfs through the critical reach of the mainstem Santa Maria River, as measured in the vicinity of the Bonita School Road and Highway 1 crossings. Flows must also be at least 150 cfs in the lower Sisquoc River to achieve passage through that reach.
3. Downstream juvenile passage requires at least one day of flow greater than or equal to 150 cfs through the critical reach of the mainstem Santa Maria River, with at least two preceding days of passable flows in the upstream Sisquoc River.
4. Flow releases from Twitchell Reservoir to improve steelhead passage windows should occur in accord with the following rules during the months of December–April.
5. Flow releases should occur when average daily flows in the lower Sisquoc River, as measured at the Garey gage (USGS 11140000), are between 350 and 550 cfs and have already remained at or above that level for at least two previous days. Once started, supplemental discharges should occur if/as needed to ensure passage flows in the mainstem Santa Maria River for at least three days.
6. Releases from Twitchell Dam should be sufficient to maintain flows in the critical reach of the mainstem Santa Maria River at 250 cfs; absent direct measurement of flow, this is assumed to be achieved with combined discharges from the Sisquoc and Cuyama rivers of 600 cfs (i.e., transmission losses are 350 cfs unless observations show otherwise).
7. Flow releases to support steelhead passage should not occur, or should stop once started, if (a) discharges fall below 150 cfs in the lower Sisquoc River, or (b) 12 or more days of adult steelhead-passable conditions have been achieved during the current water year.

5.6 Constraints of the Study Approach

The Instream Flow Study encountered a number of constraints that influenced the selection of study methods and necessitated procedures to correct and/or contend with imperfect data used in the study. These constraints and the efforts made to address them are summarized below.

- The collection of field data to measure depth, width, and velocity under a range of flows was constrained by two factors. First, it was not possible for flows to be released from Twitchell Dam to measure hydraulic conditions. The District is not a partner in the Instream Flow Study (although they provided free access to all of their dam-operation related records) and releases from Twitchell Dam are largely reserved for groundwater recharge in the summer and fall. As a result, and in combination with the fact that the Santa Maria River can be dry for several years in a row, the study design assumed that field-based measurements would not be possible and employed remote-sensing (i.e., the collection of LiDAR data) and hydraulic modeling approaches instead. These methods were agreed upon by the study's technical coordination team.
- In the first winter of the study, however, there were a series of storms that provided continuous surface water flow through the Santa Maria River on approximately four

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occasions. Field crews were deployed for flow events and targeted flows that were considered (based on the Sisquoc River at Garey gage) or observed to be potentially suitable for steelhead passage (i.e., there was continuous flow to the Pacific Ocean). It was quickly realized, however, that taking field measurements in the river's public right-of-way while water is actively flowing in the Santa Maria River is both logistically challenging and hazardous. Flow events were often very short in duration, severely limiting the time available to take field measurements, and the range of steelhead-passable flow that was still safe to measure occasionally occurred at night. When the right range of flows did occur for a more prolonged period (usually for 2 to 6 days), highly turbid water and quick-sand conditions throughout the channel made it very hazardous to access, let alone wade across, the river. As a result, observations and measurements of hydraulic conditions during high to moderately high flow events were made from road crossings (e.g., Suey Bridge, Bonita School Road crossing, and Highway 1). When moderate to low flows persisted for long enough, direct measurements of hydraulic conditions were made along transects in the public right-of-way, primarily within the critical passage reach.

- The original study design called for the use of airborne-based LiDAR data in the hydraulic calculations/modeling used to identify the flow necessary to achieve selected steelhead passage criteria. However, initial hydraulic calculations that utilized cross sections derived from the LiDAR data resulted in flows that were notably higher than those observed in the field to provide adequate steelhead passage. The LiDAR cross sections were compared with field-based cross sections and it was discovered that the LiDAR data, since it was collected during dry channel conditions, did not capture the stormflow channel that is carved in the Santa Maria River when flow (even very low flow) is present. As the LiDAR-based hydraulic calculations over-estimated the flow necessary for steelhead passage, hydraulic calculations were abandoned in favor of empirical field observations and measurements as the basis of the recommendations for flow magnitudes.
- The quality of flow records at the gage locations used in this study are generally quite poor (i.e., measured values >15% different from "true" values), owing to the channel geomorphology and extreme variability of discharge. The gaged flow record is only an estimate of discharge, likely very inaccurate particularly during the largest annual or multi-year discharges (by virtue of rapidly changing channel conditions during high flow events) and below a few cfs (for lack of flow–gage communication). Neither condition, however, is critical to this study, because inaccuracies in gaging at either extreme of the range of discharges will not alter the reconstruction of the frequency or duration of past (or future) steelhead-passable flows. On a select number of dates, recorded flows in the range of interest for this study were adjusted or excluded to account for the poor gage records. These adjustments are described in Section 3.4.
- As with virtually all southern California watersheds, there is a paucity of data on steelhead population dynamics, including specific run-times, age-class and size of annual runs, flow levels which may initiate upstream migration of adult steelhead, and the relative importance of factors (e.g., flow levels and water temperatures, genetic mechanisms, etc.) which may initiate emigration of juvenile steelhead out of the Santa Maria River system to the estuary and ocean. These aspects of southern steelhead life history and physiology can only be investigated through long-term autecological studies, including the monitoring of fish behavior.

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5.7 Monitoring Recommendations

The following monitoring is recommended and/or critical to refine the flow recommendations, improve their efficiency, and evaluate their effect on the steelhead population.

1. When flow releases for steelhead passage are made from Twitchell Dam, it will be critical for a field monitor to verify that sufficient surface flow for steelhead passage is achieved in the critical passage reach and continues to the estuary. In light of the scatter in the hydrologic data used in this study (Figure 4.4-4), the dynamic nature of the channel bed (see Section 2.3.3), and the influence of variable factors on the rate of surface water loss to groundwater (see Section 4.5), the presumed transmission losses of 350 cfs between the confluence and the critical reach of the mainstem Santa Maria River may over- or under-estimate the actual losses. Field monitoring in the critical passage reach during any flow augmentation from Twitchell Dam, and subsequent modification of release rates if/as needed, is critical to ensuring that steelhead passage is provided while conserving water from Twitchell Reservoir to the greatest extent possible.
2. The flow recommendations should be empirically tested to determine their suitability and to further test that: 1) the discharge recommendations meet steelhead passage criteria throughout the critical passage reach, and 2) the recommended flow frequency rules result in steelhead-passable conditions that are of sufficient duration and periodicity for both adult and juvenile steelhead migration. Since the direct detection of migrating steelhead will be very difficult on the Santa Maria River, both because of the very few steelhead expected to migrate and the hydraulic and geomorphic constraints to various detection methods (see #4 below), physical monitoring and empirical testing will be key to evaluating the sufficiency of the flow recommendations.
3. During flow events that are of sufficient magnitude for steelhead passage, but that do not notably exceed flow requirements, a field monitor should verify either that previous flows have broken the sandbar, or that allocated flows are sufficient to break the sandbar and permit steelhead in the Pacific Ocean to enter the river. In either case, documenting continuity between the riverine and marine environments during the upstream and downstream migration period will be essential to evaluating the efficacy of the flow recommendations and the likelihood of steelhead to benefit from their implementation.
4. Monitoring steelhead passage (both upstream migrating adults and downstream emigrating juveniles) through the Santa Maria River is the most direct and relatively immediate (i.e., within days of a steelhead-passable flow event) way of evaluating the adequacy of the flow recommendations and, when compared to pre-flow recommendation monitoring, steelhead response to their implementation. Such monitoring in the Santa Maria River is constrained by a number of physical factors (e.g., a wide, dynamic channel, flashy flows, and high turbidity) that limit the effectiveness or appropriateness of many monitoring methods, as well as the currently very low number of steelhead that would be expected to pass through the Santa Maria River. Estimating the size of steelhead runs, and by extension the effectiveness of the flow regime identified in this study can be estimated by tagging juveniles during the freshwater phase and subsequently monitoring upstream migrants using a variety of methods, including the use of instream tag readers or variety of fish detection technologies. Duel-frequency Identification Sonar (DIDSON), which uses sound instead of light to capture video-like images and is less affected by suspended sediment in the water. The DIDSON would need to be installed in a relatively confined channel location in the very upstream reach of the Santa Maria River or the Sisquoc River (where the channel is more stable than in the critical passage reach) prior to and following a steelhead-passable flow event. The methods and logistics of deploying tagging or sonar

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based monitoring technology is further described in Boughton (2009) and Pipal et al. (2010); see also Carlson et al. (1998). The design of the fish monitoring program should be consistent with the strategy, design, and methods outlined in the California Coastal Salmonid Population Monitoring program (Adams et al. 2011).

5. Repeated snorkel surveys and/or spawning surveys in the Sisquoc River watershed could be another way to evaluate steelhead response to the implementation of the flow recommendations. Surveys could be conducted in a range of years following a steelhead-passable flow event (e.g., that year and two years following) to document the number of spawning redds, adult steelhead and juvenile steelhead in the Sisquoc River watershed. Such survey results would need to be compared to survey results under pre-flow recommendation implementation, or baseline, conditions. These types of surveys are also likely to be constrained by the currently very low number of steelhead that would be expected to pass through the Santa Maria River, as well as the difficulty in determining the ancestry of juvenile *O. mykiss* (i.e., whether they are the offspring of resident rainbow trout or steelhead), but could become more tractable as the steelhead run-size increases.

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