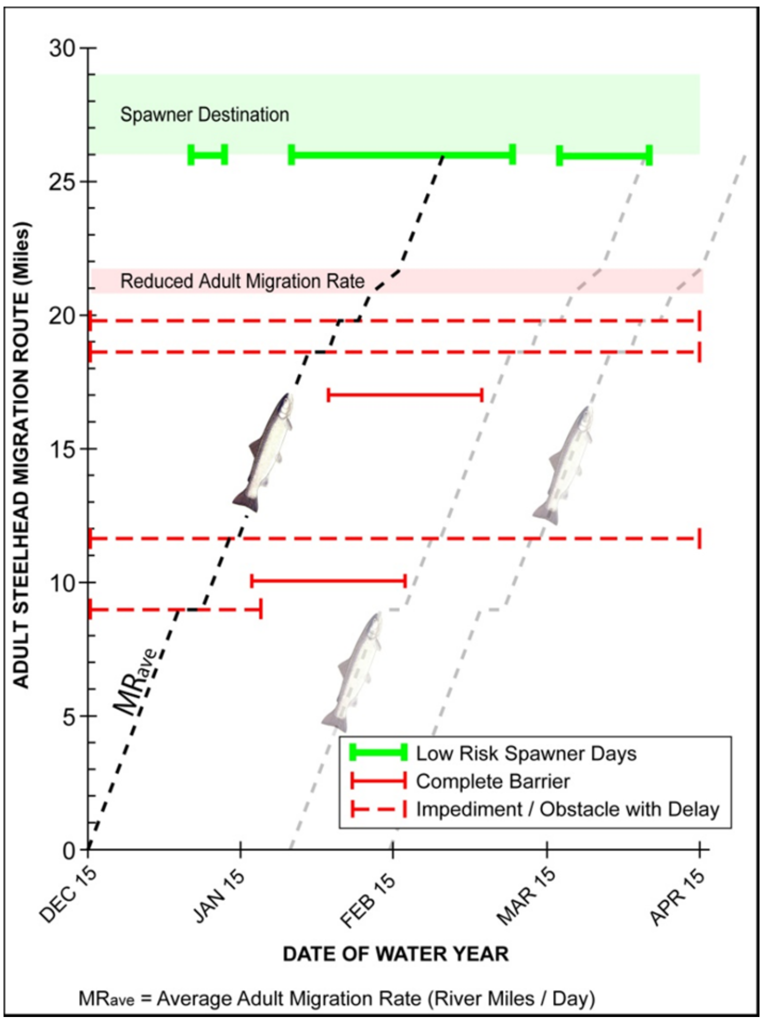
TECHNICAL MEMORANDUM

STEELHEAD SPAWNER RISK ASSESSMENT MODEL FOR ALAMEDA CREEK



March 25, 2011

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STEELHEAD SPAWNER RISK ASSESSMENT MODEL FOR ALAMEDA CREEK

Prepared for:

Alameda Creek Fisheries Restoration Workgroup

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1. INTRODUCTION

The goal of the Alameda Creek Fisheries Restoration Workgroup (WorkGroup) is to restore a healthy, self-sustaining steelhead population to the Alameda Creek Basin. Suitable habitat exists to support several life history tactics (LHTs) prioritized in the WorkGroup's study plan prepared by McBain and Trush (2008). However impediments to upstream adult and downstream smolt migration still impose one significant constraint to recovery. Several migration impediments already have been removed, with others slated - or under investigation - for removal or physical modification. Steelhead spawning success also may be significantly reduced by cumulative migration delay due to reduced streamflows and migration barriers. In the WorkGroup's study plan, a Spawner Risk Assessment model, also called the 'ascendograph', was recommended for evaluating potential impacts of migration delay on steelhead spawning success. This technical memo summarizes how the Spawner Risk Assessment model works, describes the field data and parameters needed to run it, and provides examples of its application to unregulated and regulated streamflows.

2. DEFINING STEELHEAD SPAWNING SUCCESS

Every adult female steelhead entering Alameda Creek wants to produce healthy fry. Her success at accomplishing this considerable feat will depend on surmounting several factors, though in the end luck could be the deciding factor. The Spawner Risk Assessment model (SRA) quantifies steelhead spawning success from a risk perspective. Each spawning site, for example a specific mainstem pool tail near the base of Little Yosemite Canyon, requires a unique combination of streamflow magnitude, duration, frequency, and timing to encourage a female to construct her redd and then to have sufficient streamflows for incubating (and not scouring away) her eggs through fry emergence. Consequently, some water years will offer surer migration and more opportunities to spawn successfully than other water years.

Spawning success entails more than just arriving at the spawning destination. Once a redd has been constructed, the fertilized eggs must incubate in an unpredictable environment before they hatch and eventually swim free of the redd's surface as fry. A lot can happen between fertilized egg and emerging fry. A flood could scour away the eggs or entomb them in sand. A long lag between winter storms could desiccate the redd before egg incubation or fry emergence is completed. Each spawning season will expose redds to variable levels of uncertainty (i.e., risk) starting on the day the redd was constructed and the eggs begin incubating. Defining a 'low-risk' day is therefore a necessary first step in the SRA. A low risk day is one in which the streamflows upon arrival at the spawning destination are within spawning thresholds, and streamflows remain above incubation requirements and below the danger of redd scour for the entire incubation period (40 to 60 days). These thresholds are model parameters that will require specific numerical values in running the SRA model. A redd constructed on a low-risk day will have considerably less chance of being scoured and desiccated between egg incubation and fry emergence than would a redd constructed on a high-risk day within the same spawning season. A fortunate female steelhead will migrate up the river and arrive at her spawning destination on a 'low-risk' day. If she does, her redd has a higher likelihood of successfully producing emergent fry. If not, her redd has a higher likelihood of failing.

3. ASSESSING THE IMPACT OF MIGRATION DELAY ON STEELHEAD SPAWNING RISK

The SRA model is just one tool for evaluating year-round instream flow needs. But it can be an important one. By estimating low-risk spawner days based on site-specific field data/observation, the model can assess the effects of migration delay on spawning success. For Upper Alameda Creek, the four primary sources for migration delay are: (1) physical barriers in the Flood Control Channel, (2) reduced streamflows from diversions, (3) surface streamflow loss through Sunol Valley, and (4) high turbidities. What if a female steelhead entering Alameda Creek on January 15th could have arrived at the base of Little Yosemite Canyon to spawn on a 'low risk' day, but had been delayed on her migration run and instead arrived later on a 'high risk' day. Her redd now has less chance of producing fry because of the imposed delay (e.g., hypothetically, she needed 2 extra days migrating through Sunol Valley). The capability to assess delay distinguishes the SRA model from other 'accepted' fish passage assessment methodologies. The Thompson Method (Thompson 1972) and the NMFS Exceedence Guidelines (2008) cannot account for migration delay or the effects of delay on spawning success. The Spawner Risk Assessment model compares the total number of spawner success days with and without delay to measure changes in spawning risk. Because delay can result from multiple sources, the model can isolate the effect (increase in risk) from a specific source of delay. The Spawner Risk Assessment or 'Ascendograph' model was used by Bates et al. (2010) for establishing a streamflow design window of 45 cfs to 6000 cfs to evaluate engineered fish passage alternatives at the Vern Freeman Diversion Dam on the Santa Clara River near Ventura.

4. THE SPAWNER RISK ASSESSMENT (SRA) MODEL

The SRA model (1) routes migrating adult steelhead upstream, from the mouth of Alameda Creek up to a specific spawner destination within the Alameda Creek watershed, and then (2) determines whether redds - built by steelhead that reach the spawning destination - will encounter low risk or high risk for their redds surviving to produce fry. The basic outcome from modeling spawner risk in a single water year's migration period at one spawner destination is called an ascendograph. Figure 1 illustrates an ascendograph produced for WY2009. The X-axis is the overall adult spawning migration period spanning December 1 to April 15. Each day on the X-axis is considered a potential adult steelhead 'entry date' in the SRA model (RM = 0 is the mouth of Alameda Creek). The Y-axis is the migration route (in miles) up to the spawning destination. The green line segments, located at the spawning destination (i.e., at RM 26 on the Y-axis of Figure 1), identify those days determined to be 'low-risk' spawner days. The SRA model routes each entry date upstream according to a prescribed daily average migration rate and imposes constraints that will delay migration.

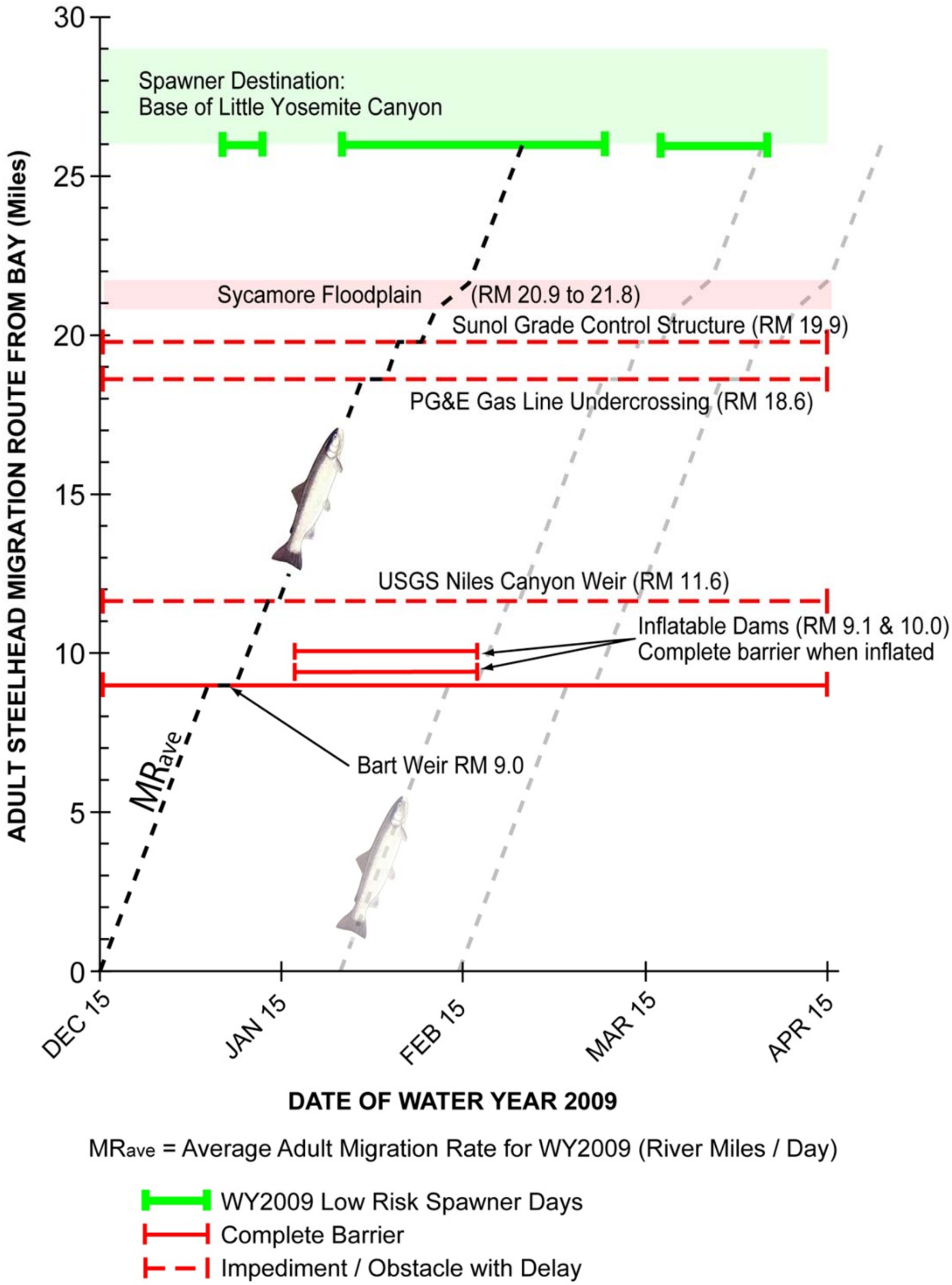

Figure 1. A hypothetical ascendograph for WY2009 targeting the base of Little Yosemite Canyon as the spawner destination.

To make Figure 1 informative, it deviates from the present reality (all migration routes presently end at RM 9.0 - the impassable ‘BART Weir’). Dotted horizontal lines indicate partial barriers that are passable but with some delay imposed, causing the migration trajectory to stall slightly. Solid lines are complete barriers. These can be year-round, as is the present BART Weir, or they can be passable but only within a range of specified streamflows. The green-lined days at the spawner destination (the base of Little Yosemite Canyon above the Calaveras Creek confluence with the mainstem of Upper Alameda Creek) are the ‘prize’ low risk days. If a female steelhead arrives at the spawner destination on a green day, her redd will have a higher likelihood of surviving to produce fry. A delay somewhere along the migratory route could cause her to miss arriving on a green day.

Not every low-risk spawner day within a spawning season at a given spawning destination will be visited by a female steelhead ready to build her redd. Unfavorable natural hydrologic conditions, frequently exacerbated by man-made migration barriers and streamflow diversions, can prevent or delay a steelhead’s arrival at a spawning destination. Dry water years tend to offer poor sustained migration streamflows and few low-risk spawner days, due to the high risk of redd desiccation. Wet water years tend to offer good migration streamflows and many low-risk spawner days, potentially offset by the high risk of scour. The timing/spacing of storm peaks and the duration of higher baseflows will dictate annual migration conditions and the frequency of low-risk spawner days.

Note that the SRA model can only look back in time. There is no way of knowing whether a redd built on February 10 could have been successful (i.e., built on a ‘low-risk’ day) until knowing subsequent daily streamflows leading up to, and including, the day of expected fry emergence. February 10 in WY2006 might have been a ‘low-risk’ day whereas February 10 in WY2007 might not. Using an annual hydrograph appropriate to the spawning destination, the fate of a redd built on either February 10th date can be deduced using streamflow thresholds for scour and desiccation. But there is no way of knowing whether February 10 in WY2011will be a ‘success’ day until knowing all the daily streamflows up through the projected fry emergence date (March 31 using a 50-day incubation period).

The SRA model, therefore, is not an operational model for use in a dam/diversion operations plan requiring real-time decision making (e.g., releasing daily streamflows based on real-time data). The SRA model does not estimate numbers of migrating adult steelhead, nor does it track individual fish. Rather, the SRA model evaluates risk in past annual hydrographs, with the modeler assuming future annual hydrographs will be similar. If future annual hydrographs will be managed differently, then the modeler must modify the past hydrographs by applying the proposed/new operational plan before estimating future risk. That is one reason why the WorkGroup had a flow model developed for Alameda Creek: to enable construction of future annual hydrographs under different operations plans, and possibly to anticipate global warming impacts and other management scenarios.

The SRA model takes each entry date of the migration period (i.e., 135 entry dates between December 01 and April 15) and routes cyber-steelhead upstream. Steelhead on some entry dates will never reach their destination (exceeding the max limit generally due to low streamflows and/or low flow impediments slowing or barring farther upstream progress), some will arrive at the spawner destination and spawn on a ‘high-risk’ day, and others will arrive and spawn on a ‘low-risk’ day. Figure 1 illustrates these generic fates. Steelhead entering the river’s mouth and beginning migration on Entry Date December 15 in WY2009 did reach the Spawner Destination:

the Base of Little Yosemite Canyon (located at RM 26). Entry on January 20 resulted in arrival on a 'low-risk' day, but just barely, whereas entry on February 15 resulted in arrival on a 'high-risk' day (possibly the redd was desiccated before successfully completing egg incubation). The SRA model tallies all entry dates arriving on a 'low-risk' day in a given water year and reports this annual tally as the 'total number of spawner success days.'

The 2008 Study Plan prioritized recovering several key Life History Tactics (LHTs). Each must have, or share, a spawner destination for producing fry. One important LHT will need successful adult spawning (i.e., fry) and good 0+ and 1+ juvenile rearing within the mainstem beginning directly below Little Yosemite Canyon. Migrating adult steelhead entering Upper Alameda Creek will encounter the steep cascades of Little Yosemite Canyon and not be able to advance farther upstream in most water years. Under this setting, adults typically will spawn in the closest habitat accessible, oftentimes even if the spawning site (e.g., a pool tail) has poor gravel quality. The SRA model will estimate the annual total of spawner success days over a wide range in water years and flow management scenarios at this given spawner destination. The minimum number of spawner success days needed for an LHT's recovery will not be known, and such a minimum threshold likely does not exist. However, a baseline will be used as a target by estimating the total number of spawner success days under unregulated streamflows and natural migratory conditions (only natural barriers) estimated by the SRA model; alternative flow and barrier scenarios will be compared to this unregulated baseline.

5. DOING A SPAWNER RISK ASSESSMENT

To do a SRA, the following steps are needed: (1) target spawner destinations within the watershed for high priority LHTs, (2) select a range WYs for assessment (ideally including a wide range of WY types), (3) develop annual hydrographs for each channel reach along the migratory routes of each targeted spawner destination, (4) define spawner risk at each spawner destination, (5) define ascendograph parameters and route migrating adult steelhead upstream, (6) evaluate spawning risk, egg incubation scour/desiccation during the spawning season, and (7) estimate the total number of spawner success days in each migration season assessed.

5.1. Steelhead Spawner Destinations for Recovering High Priority Life History Tactics

The 2008 Study Plan states that: "Sustaining diverse population recovery strategies, by spawning emergent fry in many basin locations, will be important for fisheries recovery under variable water years." Focusing on LHTs with spawning destinations that will produce fry over a range of water years will be essential for steelhead recovery. The following mainstem locations should be key LHT spawner destinations for Upper Alameda Creek:

- Alameda Creek mainstem below Sunol Water Treatment Plant Bridge
- Alameda Creek mainstems in the Sycamore Floodplain
- Alameda Creek mainstem below Calaveras Creek confluence
- Alameda Creek mainstem at the base of Little Yosemite Canyon
- Alameda Creek mainstem below ACDD

Three tributary also should be considered:

- Stonybrook Creek
- San Antonio Creek below San Antonio Dam
- Calaveras Creek 0.25 mi upstream of confluence with Alameda Creek

Spawner destinations can be a single pool tail-out, which historically attracted many spawners, or a channel segment harboring several spawning sites. Typically, a spawner destination is a discrete channel segment, comprised of many spawning sites that is several meander wavelengths long (i.e., approximately the length of habitat mapping study reaches, 800 to 1200 ft for mainstem Alameda Creek).

5.2. Modeled Annual Hydrographs

The SRA model requires daily average streamflows along the entire migratory route, from the mouth of Alameda Creek up to each spawner destination assessed. The Work Group assigned a Sub-Committee to generate annual hydrographs and thermographs at twelve locations or 'nodes' (Figure 2). Two types of annual hydrograph for WY2000 through WY2009 have been computed at each node: (1) regulated streamflows and (2) unregulated streamflows. Future streamflows under proposed regulatory scenarios will soon be produced. The regulated flow model simulates current flow management at Calaveras Dam, ACWD operations, losses through the Sunol Valley and gravel quarry pumping, operation of San Antonio Dam, and flow management on Arroyo de la Laguna.

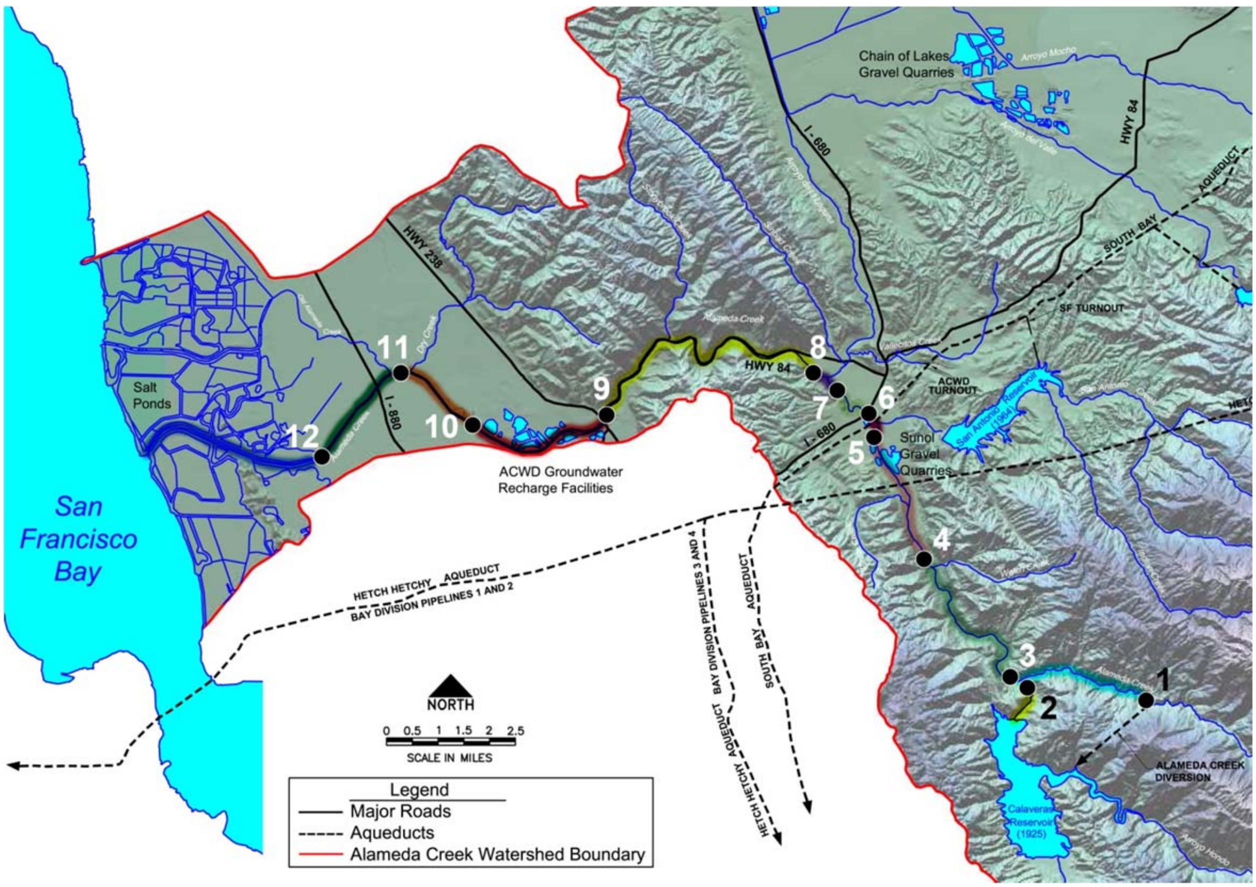

Figure 2. Hydrology nodes on Alameda Creek and the reaches used in the SRA model.

Annual hydrographs created at each node were assigned discrete channel reaches, i.e., streamflows between nodes were kept constant within these designated channel reaches. The twelve nodes and corresponding channel reaches are listed in Table 1.

Table 1.Channel reaches with similar flow/passage relationships. A hydrograph is developed for each reach.

Modeled Node	Name	RM	RM
12	Bay to Alameda Creek Below Coyote Hills Regional Park	0.0	3.6
11	Coyote Hills Regional Park to Alameda Creek below Dry Creek	3.6	6.3
10	Dry Creek to Alameda Creek below Rubber Dams	6.3	11.0
9	Alameda Creek below Rubber Dams to Niles Gage	11.0	11.9
9	Niles Gage Weir Barrier	11.9	12.1
8	Niles Gage to Alameda Creek below Arroyo de la Laguna Confluence	12.1	17.1
7	Below Arroyo de la Laguna to Above Arroyo de la Laguna	17.1	17.1
6	Above Arroyo de la Laguna to Alameda Creek below San Antonio Creek	17.1	18.5
5	Below San Antonio Creek to above San Antonio Creek	18.5	18.8
4	Above San Antonio Creek to Above of Pirate Creek	18.8	20.8
4	Above of Pirate Creek to top of Sycamore Floodplain	20.8	21.6
4	Head of Sycamore Floodplain to Alameda Creek below Welch Creek	21.6	21.9
3	Below Welch Creek to Confluence of Calaveras Creek	21.9	24.7
1	Confluence of Calaveras Creek to Alameda Creek at ACDD	24.7	28.5

Unregulated and regulated annual hydrographs between WY2000 and WY2009 exhibited a wide range in streamflows at: (1) the base of Little Yosemite Canyon where streamflow is assumed to equal streamflow below ACDD (Figures 3A and 3B), (2) below Welch Creek confluence (Figures 4A and 4B), and (3) Niles Gage (Figures 5A and 5B). All three locations show that 'baseflows' have not been steady, but change sharply and frequently throughout the spawning season.

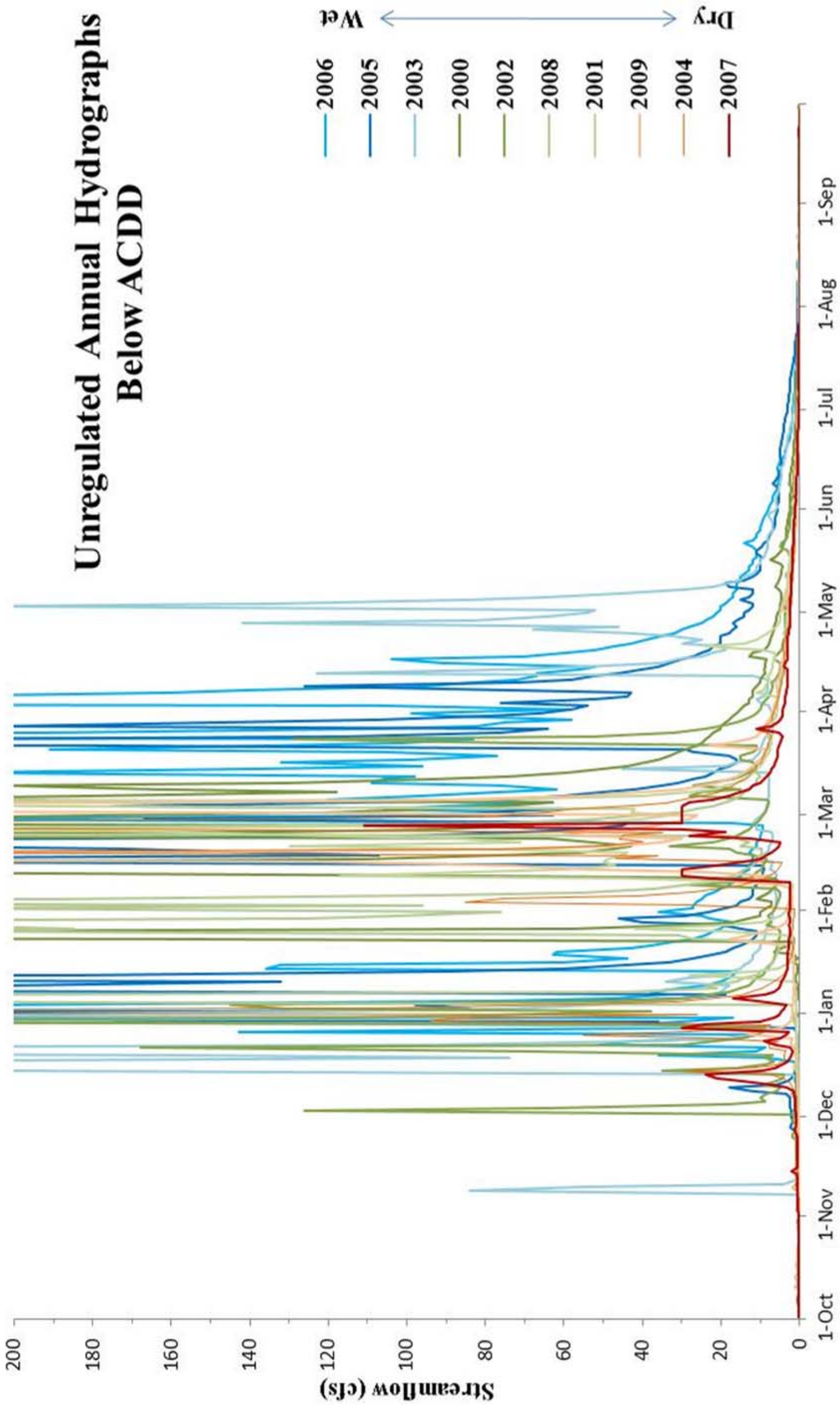

Figure 3A. Computed unregulated WY2000 to WY2009 hydrographs for Base of Little Yosemite Canyon (at ACDD, Node 1).

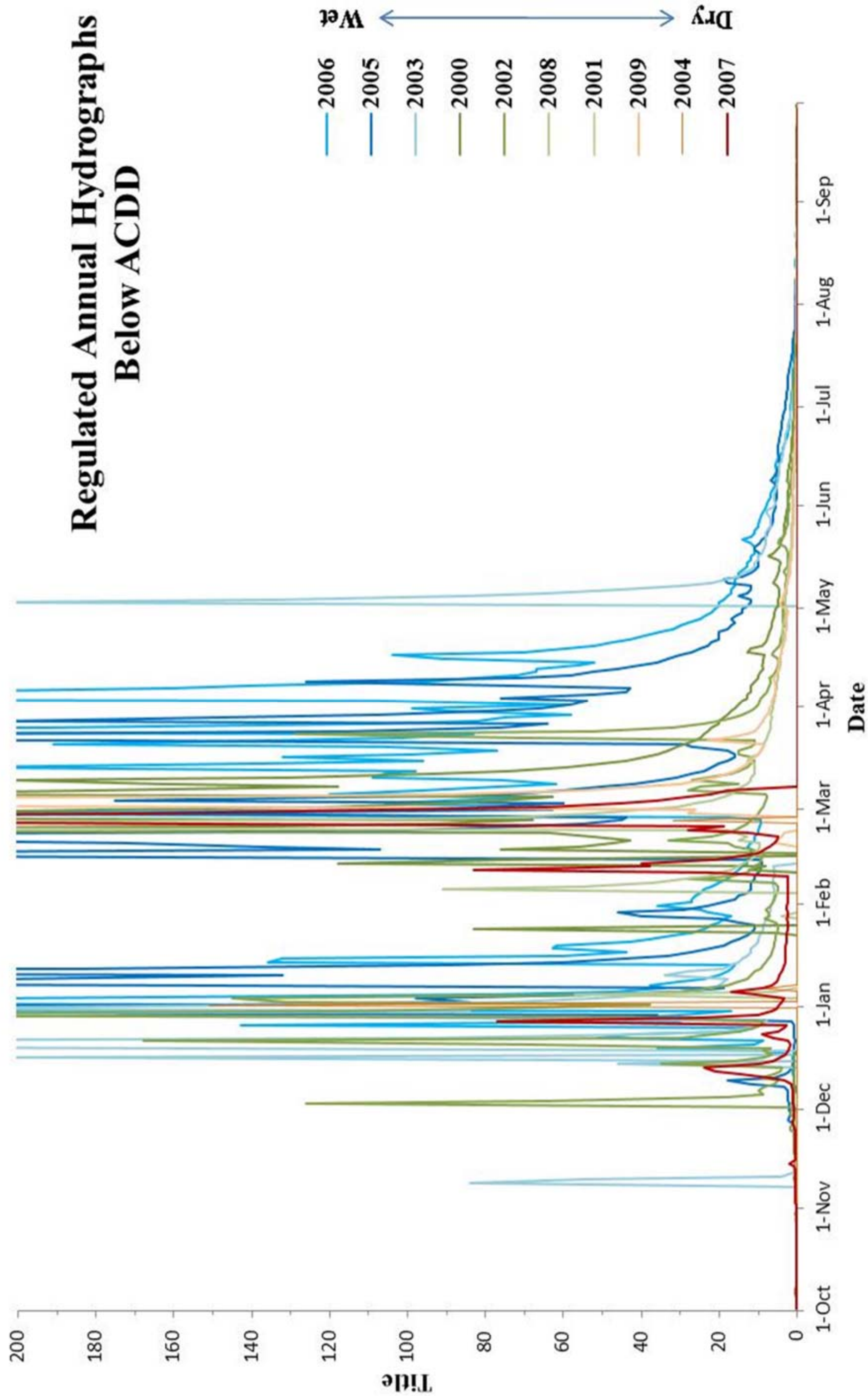

Figure 3B. Computed regulated WY2000 to WY2009 hydrographs for Base of Little Yosemite Canyon (at ACDD).

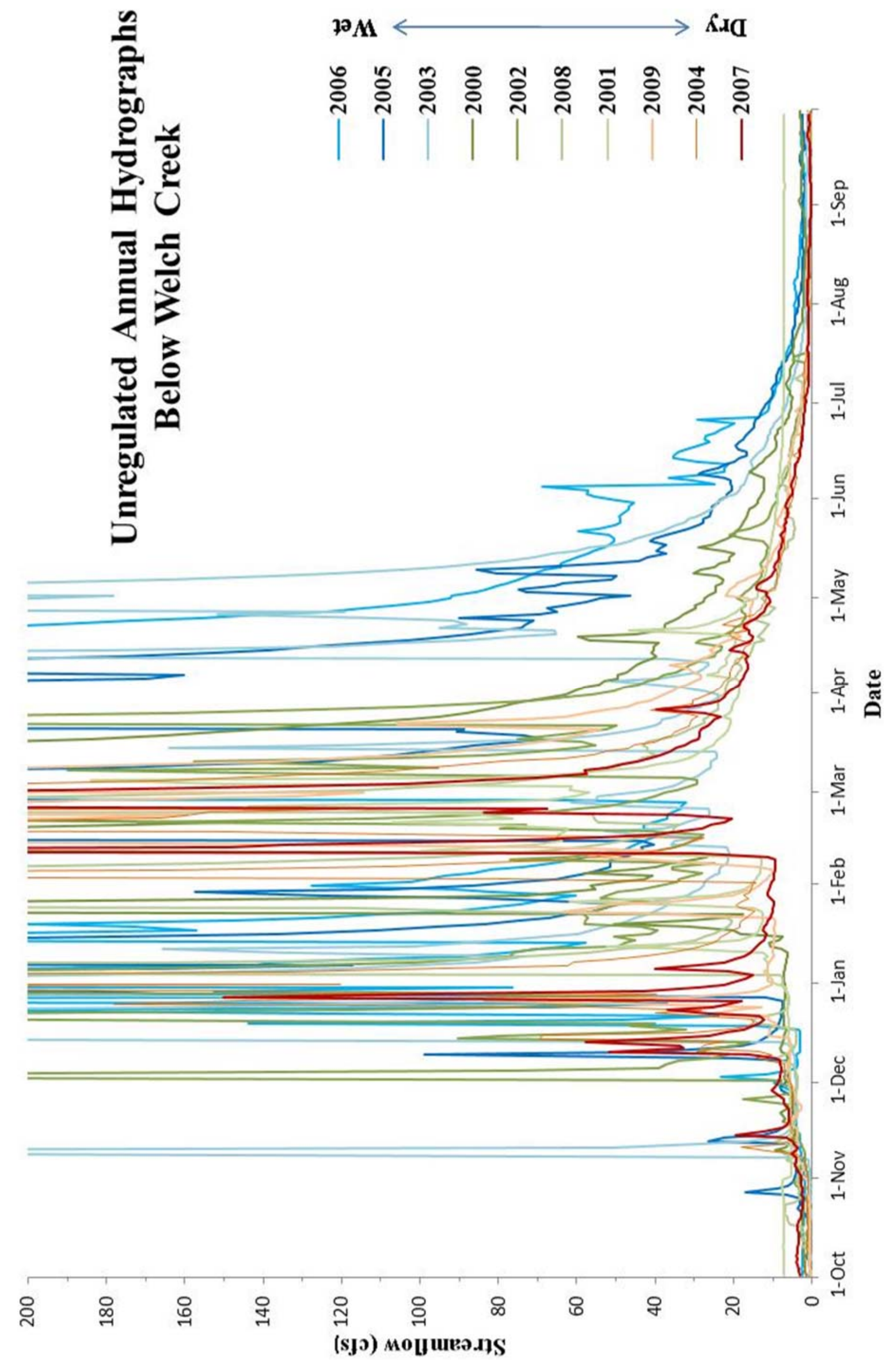

Figure 4A. Computed unregulated WY2000 to WY2009 hydrographs below Welch Creek confluence.

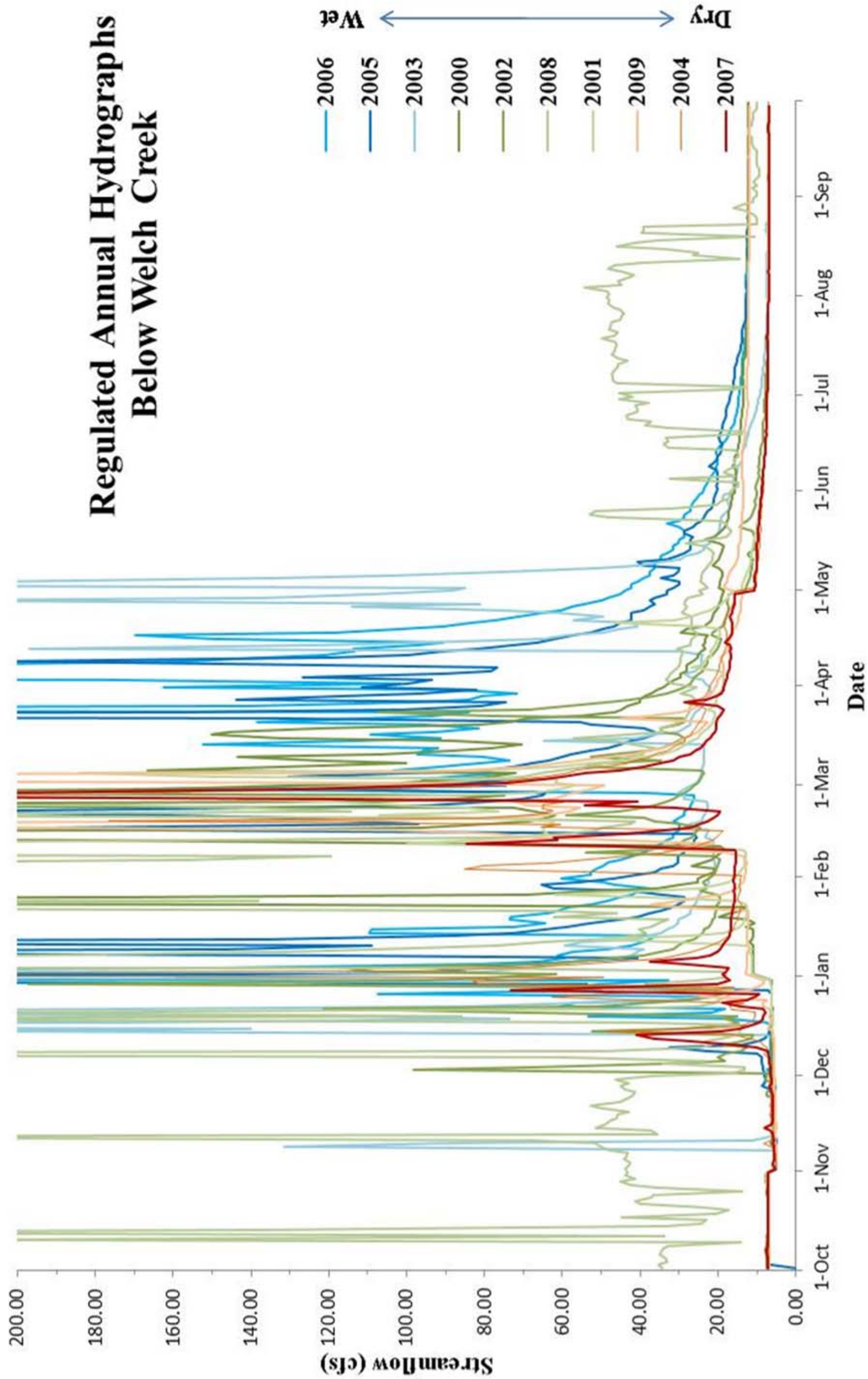

Figure 4B. Computed regulated WY2000 to WY2009 hydrographs below Welch Creek confluence.

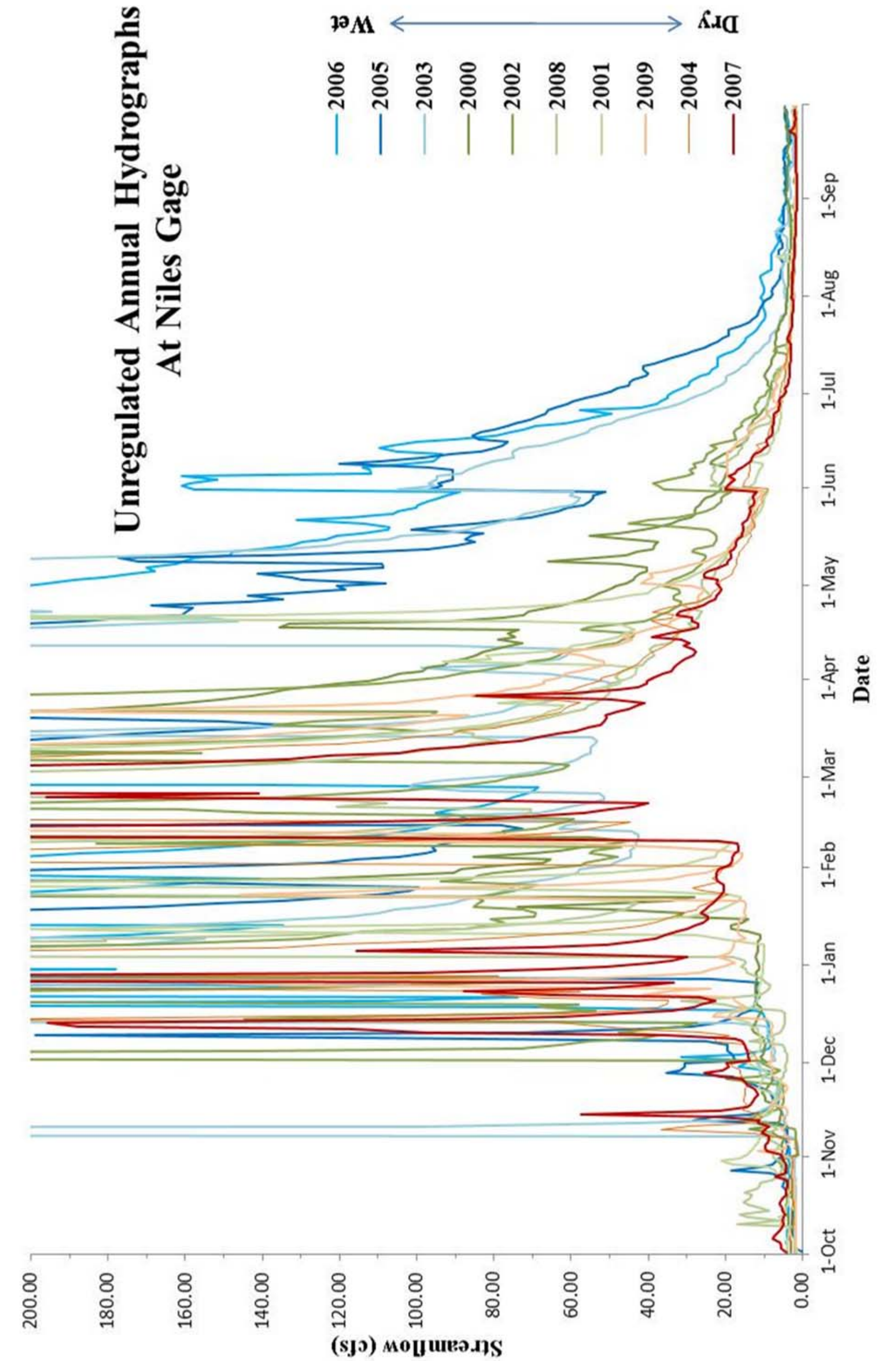

Figure 5A. Computed unregulated WY2000 to WY2009 hydrographs at Niles Gage.

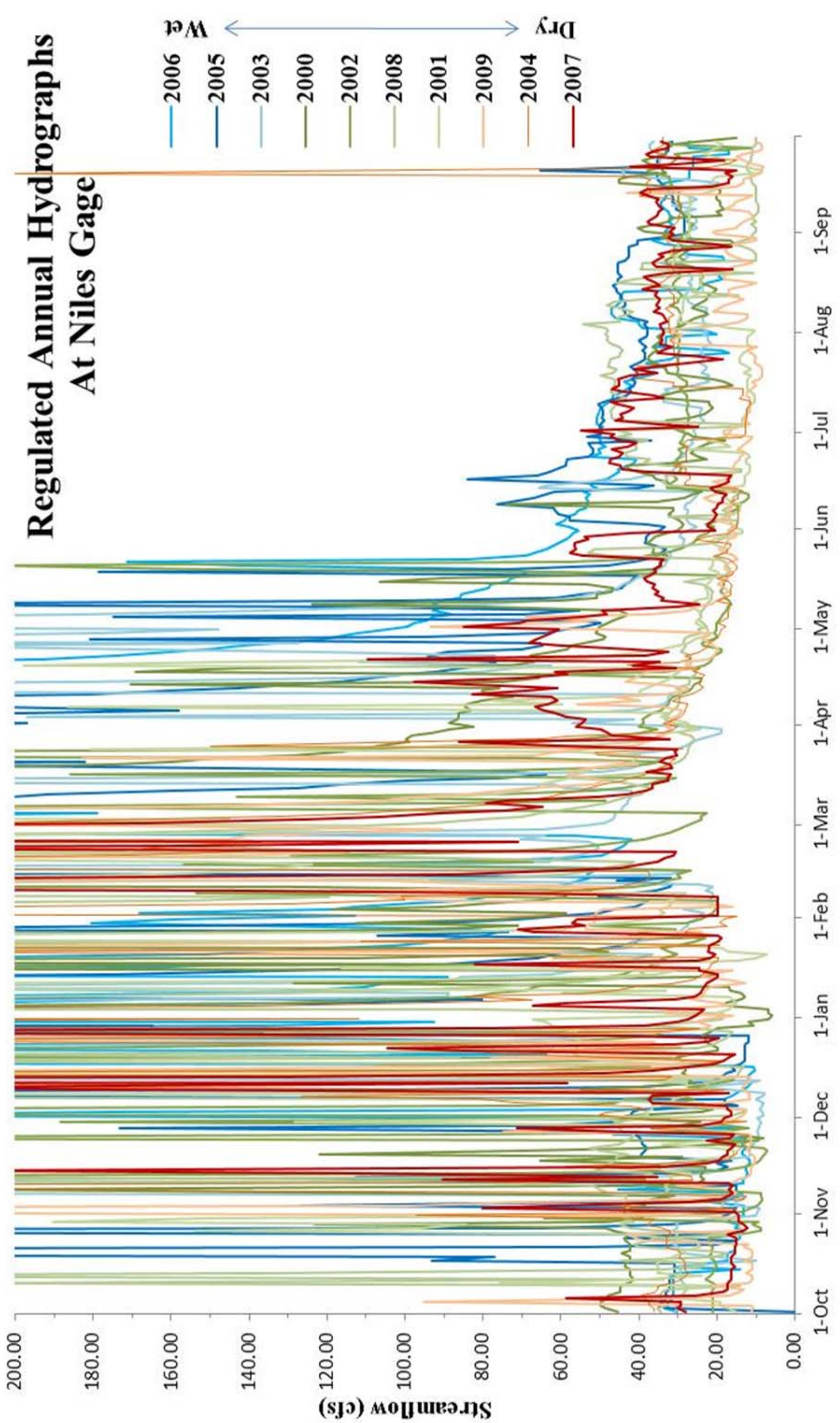

Figure 5B. Computed regulated WY2000 to WY2009 hydrographs at Niles Gage.

Daily average streamflows for all hydrographs where transcribed into hourly streamflows by linear interpolation for routing adult steelhead up to the spawner destinations. Using hourly streamflows is necessary for routing because fish can migrate through some of the shorter reaches in less than a day. This lets the cyber-steelhead encounter every significant change in the migration/flow relationship imposed by the model such as short delays (Niles Gage Weir) or fluctuations in streamflow (e.g., through the Sycamore floodplain). Using a daily average timestep, the cyber-steelhead could 'jump' over impediments that will in reality delay them.

6. SPAWNER DESTINATION PARAMETERS FOR DEFINING RISK

The SRA model does not predict which days are less risky than others for constructing redds in a given spawning season. Instead, these 'low risk' days are provided to the SRA model by meeting certain streamflow thresholds established by the following four spawner destination parameters:

6.1. Spawner Destination Parameter No.1. Streamflow Thresholds for Abundant, High Quality Spawning Habitat (Low Q_{SPWN} and High Q_{SPWN})

A cyber-steelhead needs to arrive at the spawner destination when good and abundant spawning habitat is available. Each spawning site within the spawner destination will have a unique rating curve between streamflow (cfs) and spawning habitat abundance (ft^2). Direct habitat mapping has produced habitat rating curves applicable to most segments of mainstem channel. All individual spawning habitat rating curves for a channel segment can be combined into one 'composite' spawning habitat rating curve. Recent direct habitat mapping on three mainstem channel reaches in Niles Canyon can be portrayed as rating curves for individual spawning sites (Figure 6) or as a composite curve for each reach (Figure 7). Only the split mainstem channel of the Sycamore Floodplain does not have a composite spawning habitat rating curve.

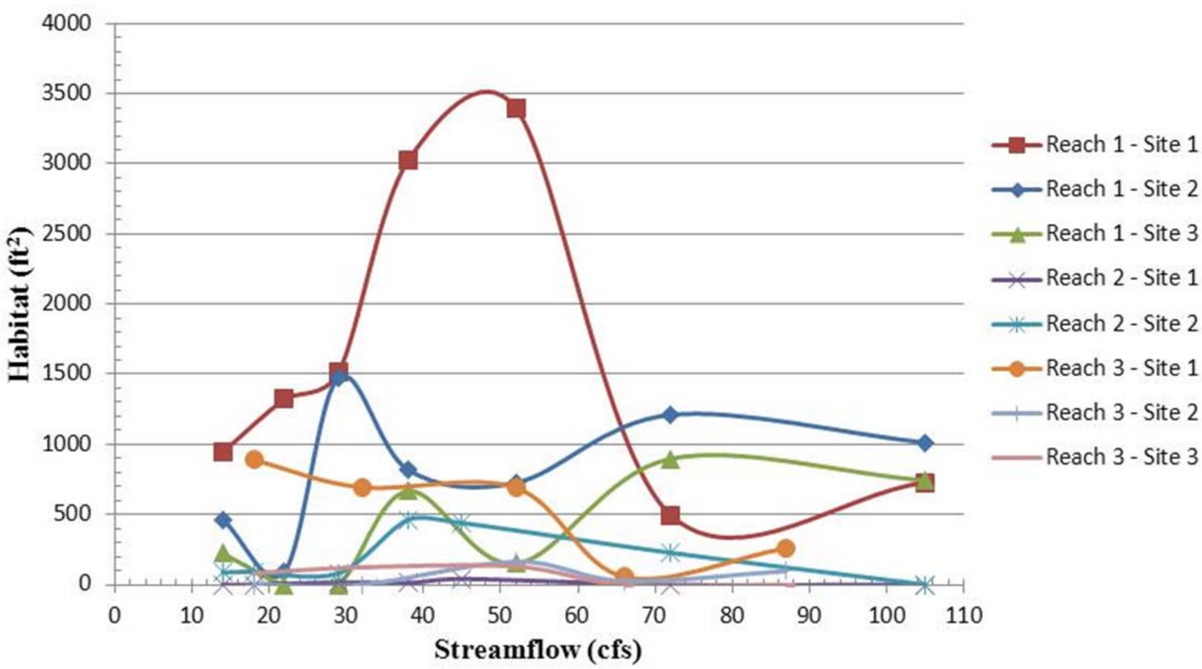

Figure 6. Spawning habitat rating curves at six individual spawning sites among three habitat mapping mainstem study reaches in Niles Canyon.

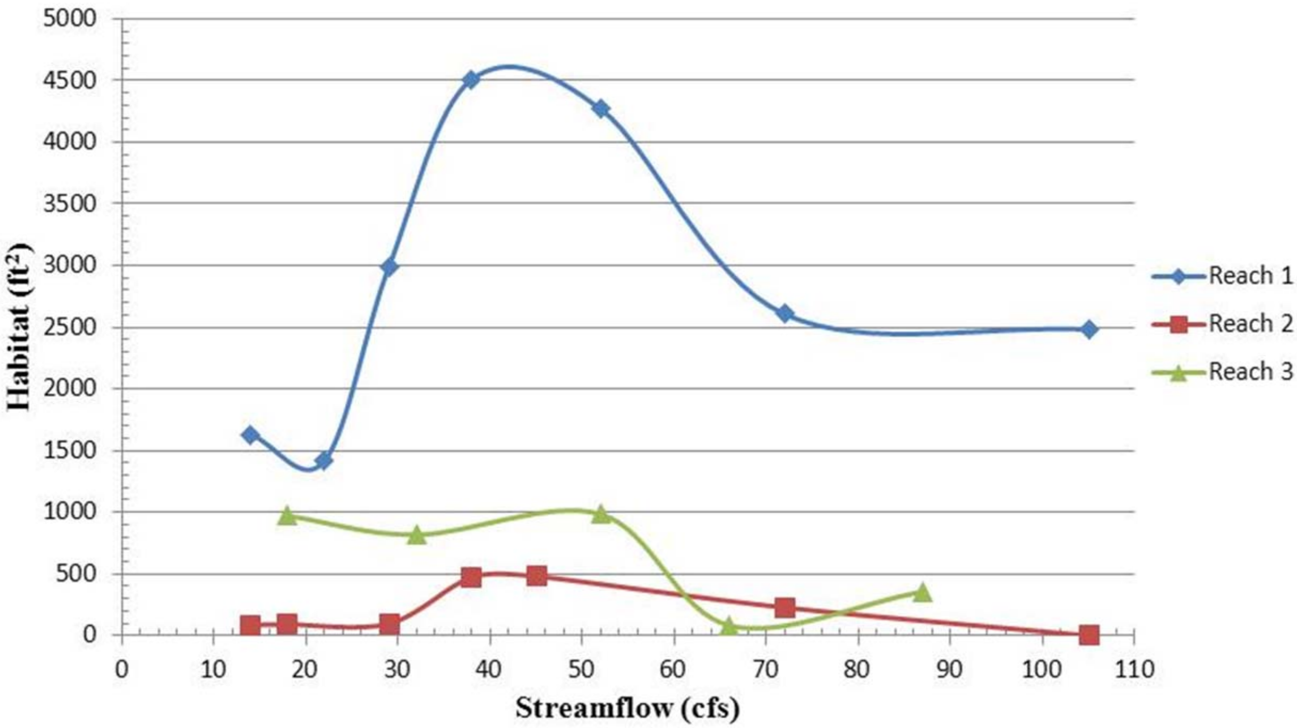

Figure 7. Composite spawning habitat rating curves for the three habitat mapping mainstem study reaches in Niles Canyon.

Spawning habitat availability in spawner destinations can be characterized exactly, as a collection of spawning habitat rating curves (Figure 6) or abstractly as a single composite habitat rating curve (Figure 7). For Alameda Creek, the SRA model will treat each spawner destination abstractly, commensurate with the level of accuracy and precision applied in modeling the ascendographs. Assessing the channel reach, rather than individual spawning sites, will entail identifying a high streamflow (High Q_{SPWN}) and low streamflow (Low Q_{SPWN}) from the composite spawning habitat rating curve bracketing abundant spawning habitat for the given spawner destination. The Niles Canyon DHM results (Figures 6 and 7) indicate a Low Q_{SPWN} = 30 cfs. An adult arriving at the spawner destination on a day when the daily streamflow is less than 30 cfs would not experience good spawning habitat conditions, where ‘good’ is defined as abundant spawning habitat among many sites within the channel segment defined as the ‘destination’.

6.2. Spawner Destination Parameter No.2. Redd Incubation Duration (T_{RI}) from Arrival Date to Fry Emergence

Steelhead redd incubation and fry emergence can require from 40 days to 50 days, or longer depending on water temperatures. The day a cyber-steelhead arrives at the spawner destination and constructs a redd, a timer is set: over the next 40 days to 50 days (or longer if temperatures are cold) the redd must experience good incubation streamflows (i.e., not get de-watered) and avoid being scoured away. A value of T_{RI} = 50 days would be a good initial parameter value, though given its importance, a sensitivity analysis (using 40 days through 70 days), or making incubation a specific function of daily average water temperature, would be warranted.

6.3. Spawner Destination Parameter No.3. Minimum Incubation Streamflow (Q_{MI})

A redd must remain inundated throughout the egg incubation period until fry emerge from the redd's surface. A minimum incubation streamflow (Q_{MI}) keeps redds inundated when constructed within (Low Q_{SPWN} and High Q_{SPWN}) of Parameter No.1. The riffle crest functions as a low flow hydraulic control maintaining an upstream pool tail's (a common spawning site) water surface elevation over a wide percentage change in low baseflows. A riffle crest depth as shallow as 0.25 ft to 0.30 ft will keep most of a pool tail inundated. These depths typically correspond to streamflows ranging from 3 cfs up to 6 cfs.

6.4. Spawner Destination Parameter No.4. Redd Scour Threshold (Q_{SCOUR})

Based on field observations in Alameda Creek, a 3-yr to 5-yr flood begins to significantly mobilize and scour finer grained alluvial and depositional deposits. A 3-yr flood below Calaveras Creek confluence is approximately 1800 cfs. A more conservative approach would be to use the bankfull discharge equivalent to the 1.5-yr flood.

'Low-risk' is not defined by modeling, but by the biologist identifying: (1) a range of streamflows that provide high quality and abundant spawning habitat (Parameter No.1), (2) an incubation period (Parameter No.2), (2) a lower streamflow threshold for redd desiccation (Parameter No.3), and a geomorphologist identifying (3) an upper streamflow threshold for redd scour (Parameter No.4) specific to each spawner destination. The eggs/alevins in the redd experience 'low-risk' only if every day of their incubation period, from the female's arrival day (redd constructed on same day) until the fry emergence day, has a daily average streamflow within these three streamflow thresholds. Risk is treated in a binary fashion. If a redd is not built on a 'low risk' day (i.e., the first day of an entire 'low-risk' incubation and emergence incubation period), the redd is considered at 'high-risk' for failure. A redd could still succeed at producing fry under 'high-risk', but a recovery program should not count on 'high-risk' spawning for reliably and sufficiently seeding rearing habitat with 0+ fry.

7. ASCENDOGRAPH PARAMETERS FOR ROUTING UPSTREAM MIGRATION

To achieve success in the SRA model, a female steelhead needs to reach the spawner destination on a 'low-risk' day (determined by the spawner destination parameters). Too little is known about how anadromous salmonids negotiate watersheds to quantify upstream adult steelhead migration confidently. In Alameda Creek, there is little choice but to model migration given the lack of adult steelhead. Modeling ascendographs, which basically is a fish routing routine, must be approached conservatively and should emphasize sensitivity analyses for key model parameters.

Each ascendograph is a product of specific values assigned to each model parameter. There are six parameters needed to compute one ascendograph, once the spawner destination (and therefore the actual migration route) and water year have been selected.

7.1. Ascendograph Parameter No.1. Selecting Entry Dates

Adult salmon and steelhead respond to many environmental cues initiating upstream migration. In most environmental planning studies, adult migration is assigned a broad time period, often as part of a life history periodicity table, within which adults might begin annual migration. Each day within this time period is not equally attractive, and therefore not equally important. For example, in some dry water years there might be extremely low streamflows during most of the designated annual migration period. However, in its simplest configuration, the SRA model routes steelhead up to the spawning destination equally and independently for all days within the general spawning migration period.

An ‘entry date’ is a day steelhead leave the estuary and begin their migration up Alameda Creek. Using a general spawning migration period of December 1 through April 15, there would be 135 entry dates. The SRA model does not decide which entry dates steelhead are most likely to begin migration (e.g., in response to a recent flood peak). Instead, all entry dates are modeled for migration up to the specified spawner destination. Would steelhead entering Alameda Creek Flood Control Channel on December 15th eventually reach the spawner destination? Would a steelhead beginning migration on December 16th? On December 17th? … On April 15th? In Figure 1, only 3 entry dates are illustrated on this ascendograph. A complete ascendograph would clutter the diagram with 135 routes, one for each entry date.

There are many options for refining the SRA routing without introducing unnecessary and distracting complexity. One simple but highly effective option would be to tag entry dates in individual annual hydrographs most likely to attract/initiate river entry and upstream migration (e.g., freshets exceeding X cfs at the mouth). Those tagged entry dates would be pulled from the general modeling results and evaluated separately.

7.2. Ascendograph Parameter No. 2. Selecting an In-River Time Limit (T_{IRL})

A cyber-steelhead routed through the SRA’s migration route could reach the spawner destination rapidly, gradually, or not at all. Under a ‘gradual’ scenario, a steelhead might migrate up to the first significant passage barrier on one storm’s hydrograph, wait, and then continue upstream on the next storm hydrograph … gradually ratcheting its way along the migration route up to its final spawning destination. However, as time between the steelhead’s entry date and arrival date at the spawner destination lengthens in the real world, the steelhead’s physiological condition deteriorates. How long will a female steelhead wait below a barrier before feeling compelled to spawn? How much physical deterioration is acceptable before stamina drops too low to effectively migrate farther?

The In-River Time Limit (T_{IRL}) sets a maximum duration within which a female steelhead must reach the spawner destination. If she does not reach the spawning destination within T_{IRL}, she cannot succeed and her entry date is considered unsuccessful for the spawner destination being assessed. For initial ascendograph modeling, a T_{IRL} = 30 days is used. However, a sensitivity analysis (i.e., keeping all other parameter values the same, but varying only this parameter) would be useful (e.g., use T_{IRL} = 15, 20, 35, and 40 days).

7.3. Ascendograph Parameter No. 3. Selecting Daily Average Migration Rates (MR_{AVE})

Realistic adult migration rates are crucial to a model routing fish. Streamflow magnitude, channel morphology, water temperature, and fish size are several of many variables influencing adult migration rates. The scientific literature provides limited documentation of steelhead migration rates that are also highly specific to the river system studied. Studies have shown steelhead migration rates from 0.5 miles/day to 12 miles/day with rates at the lower end of the range for smaller streams (DeHaven 2009, Logan 2010, Peery 1992, and Sinnen 2010). The distance from the mouth of Alameda Creek up to the base of Little Yosemite Canyon is 26 miles. In Figure 1, migration routing illustrated for an entry date of January 1 has steelhead arriving at this spawner destination approximately 60 days later. Actual migration would be considerably faster than 0.5 miles/day. A realistic, quick journey could be 5 days, or approximately 5 miles/day. MR_{AVE} is the average migration rate measured in miles/day. A range in MR_{AVE} of 2 miles/day up to 8 miles/day would be a good starting point for modeling the sensitivity of ascendographs to this parameter.

7.4. Ascendograph Parameter No.4. Selecting a Migration Delay Factor (DF)

The MR_{AVE} selected can be kept constant along the entire migration route and/or at all streamflow magnitudes. To add realism to the SRA model, at the risk of also adding complexity that might obscure results, a delay factor was developed based on the riffle crest thalweg depth (RCT): the shallower the riffle, the slower the average migration rate.

The thalweg depth at the top (crest) of a riffle is called the riffle crest thalweg (RCT). The RCT also functions as an hydraulic control for an upstream pool or run. If the streamflow was ‘turned-off’, the water surface elevation of a non-flowing pool and run would be set by the RCT bed elevation immediately downstream. The RCT is a shallow, if not the shallowest, riffle depth an adult steelhead must negotiate while swimming through a riffle.

A quantitative relationship between RCT depth and streamflow has been established for mainstem segments of Alameda Creek. Typically 15 or more RCT measurements are taken per sample reach to estimate the median riffle crest depth (mRCT) at a given streamflow. Buckland (2009) surveyed RCTs in the Alameda Flood Control Channel at three streamflows (Figure 8). By taking the median RCT (mRCT) depth at each streamflow surveyed, a rating curve can be constructed between streamflow (Q) and mRCT depth. For example, we surveyed RCTs at several streamflows in Niles Canyon at the DHM study sites (Figure 9). Note that the X-axis is expressed as a percentage of the ranked RCT depths (deepest to shallowest) so that surveys with variable numbers of RCTs measured will all span the X-axis equally. The median RCT depths are then taken from each streamflow survey (Figure 9), then plotted against the streamflow to produce a Q-mRCT rating curve (Figure 10).

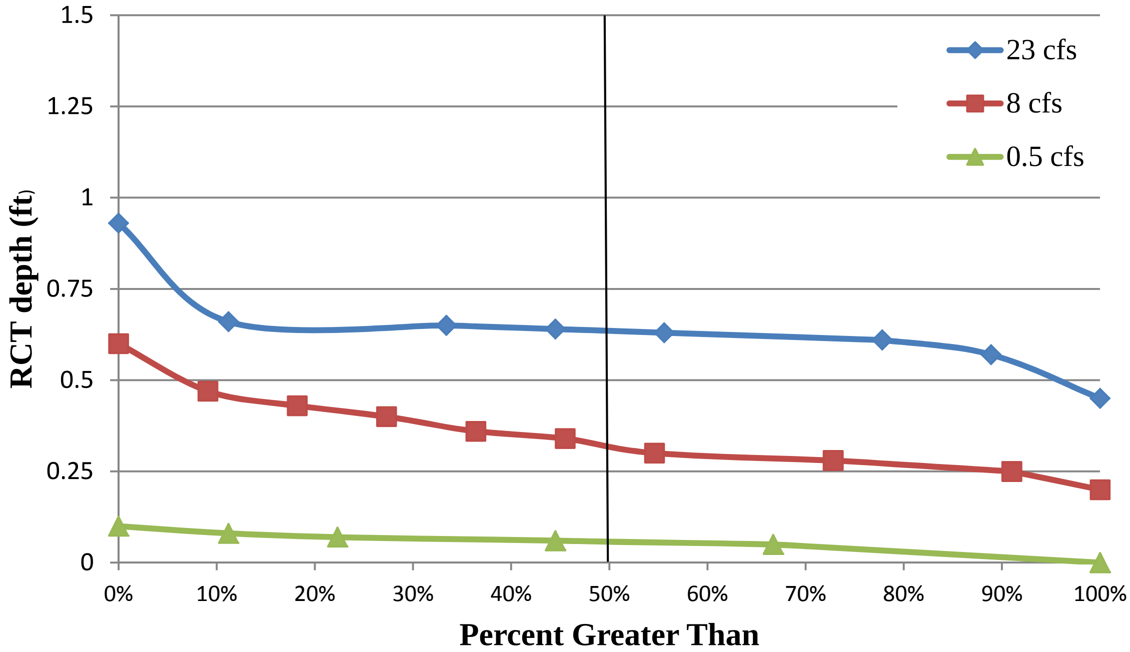

Figure 8. RCT curves for 0.5 cfs, 8 cfs, and 23 cfs streamflows in Reach 1 of the Alameda Creek Flood Control Channel surveyed by Alameda County Water District (reproduced from Buckland 2009).

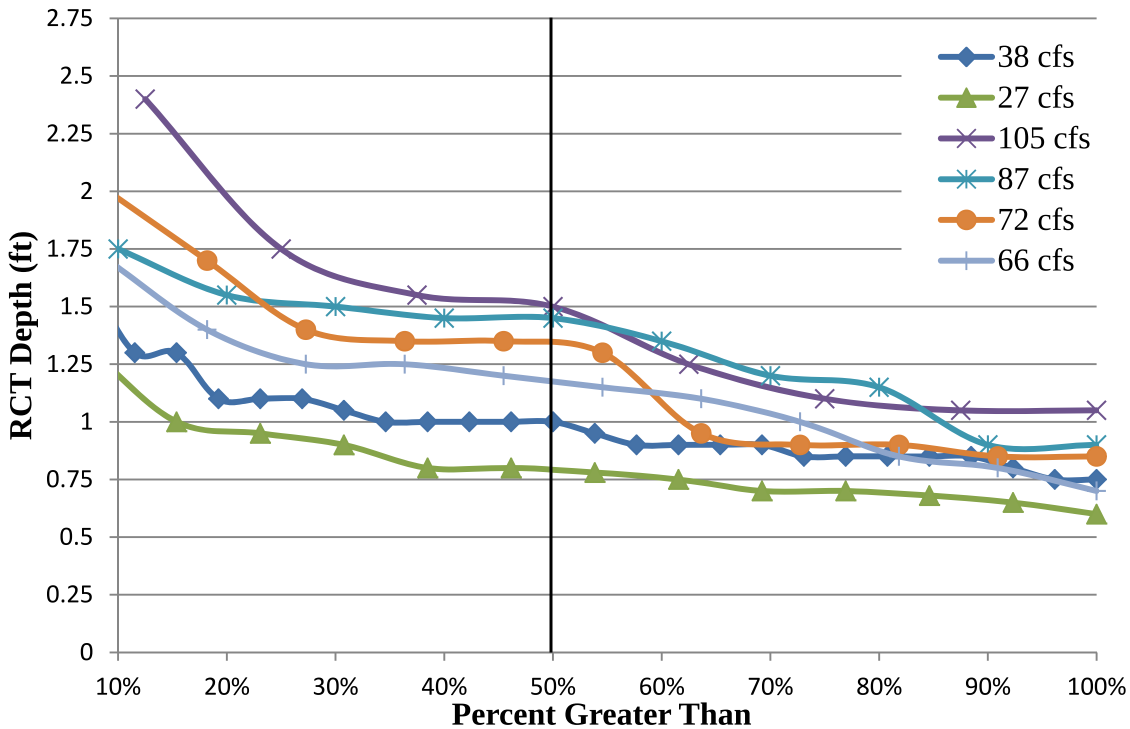

Figure 9. Ranked RCTs at Niles Canyon for six streamflows.

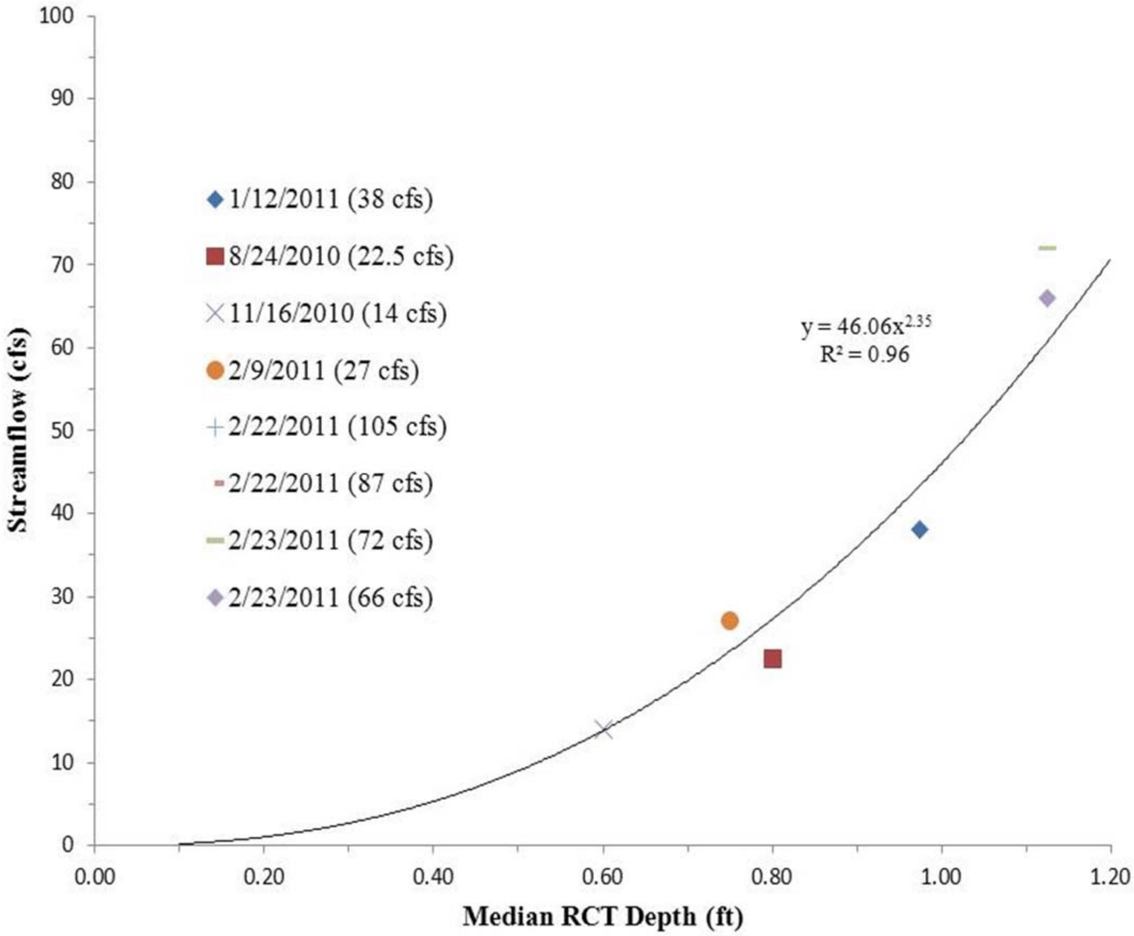

Figure 10. Q-mRCT rating curve for Niles Canyon.

Interpretation of mRCT depths for adult steelhead passage must consider that: (1) the RCT depth will not always be the shallowest passage depth in an entire riffle and (2) half the riffles surveyed will have a RCT depth less than the computed mRCT depth (by simple definition of the median), and some of these RCTs could be very shallow. Therefore, an mRCT depth of 0.8 ft may seem conservatively deep when evaluating adult steelhead passage approaching a minimum value, when the scientific literature sometimes recommends a minimum depth of 0.6 ft (or less) for steelhead passage. The Q-mRCT rating curve constructed for Niles Canyon has a few RCTs 0.1 to 0.2 ft shallower than the mRCT for the higher streamflows (e.g., 105 cfs). These mRCT-Q curves were not constructed from all RCTs throughout Niles Canyon. A walking survey down the entire Nile Canyon mainstem would be warranted to identify any conspicuous, extremely shallow RCTs that might warrant additional passage analysis (Hanson 2002).

Based on field surveys, two Q-mRCT rating curves will be used to characterize the mainstem channel from Niles Canyon up to the base of Little Yosemite Canyon (Figures 10 and 11). Only needing two rating curves was not a surprise. Gabe Rossi, a graduate student at Humboldt State University has constructed a single mRCT-Q rating curve for alluvial and depositional rivers in Northern California that applies to a wide range of streams and rivers (Figure 12). The Niles Canyon reach (Figure 9) tends to exhibit coarser bed material, greater confinement, and steeper slopes than the Sunol Water Treatment plant reach (Figure 11).

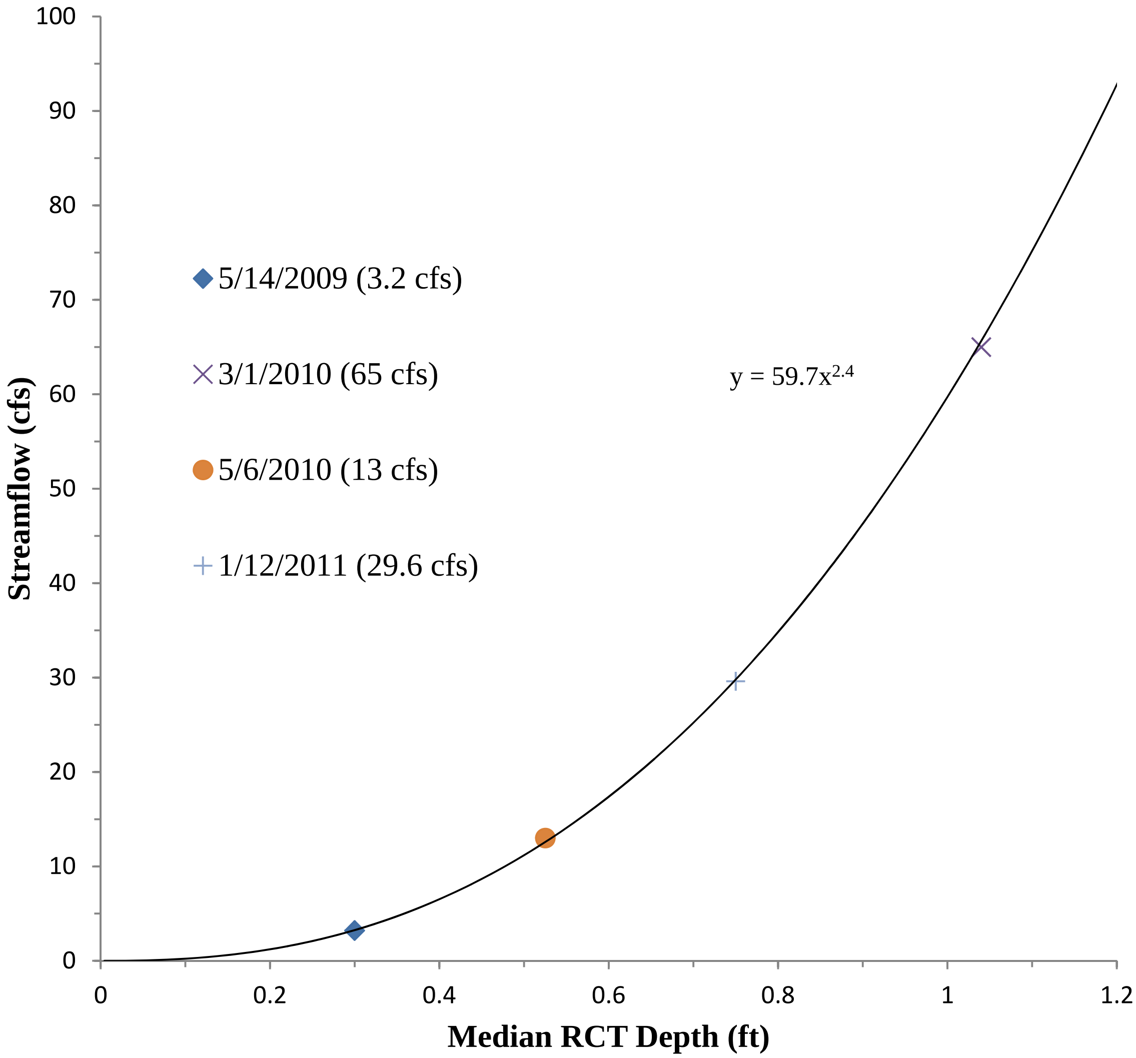

Figure 11. Q- mRCT rating curve for the Sunol Water Treatment Plant reach.

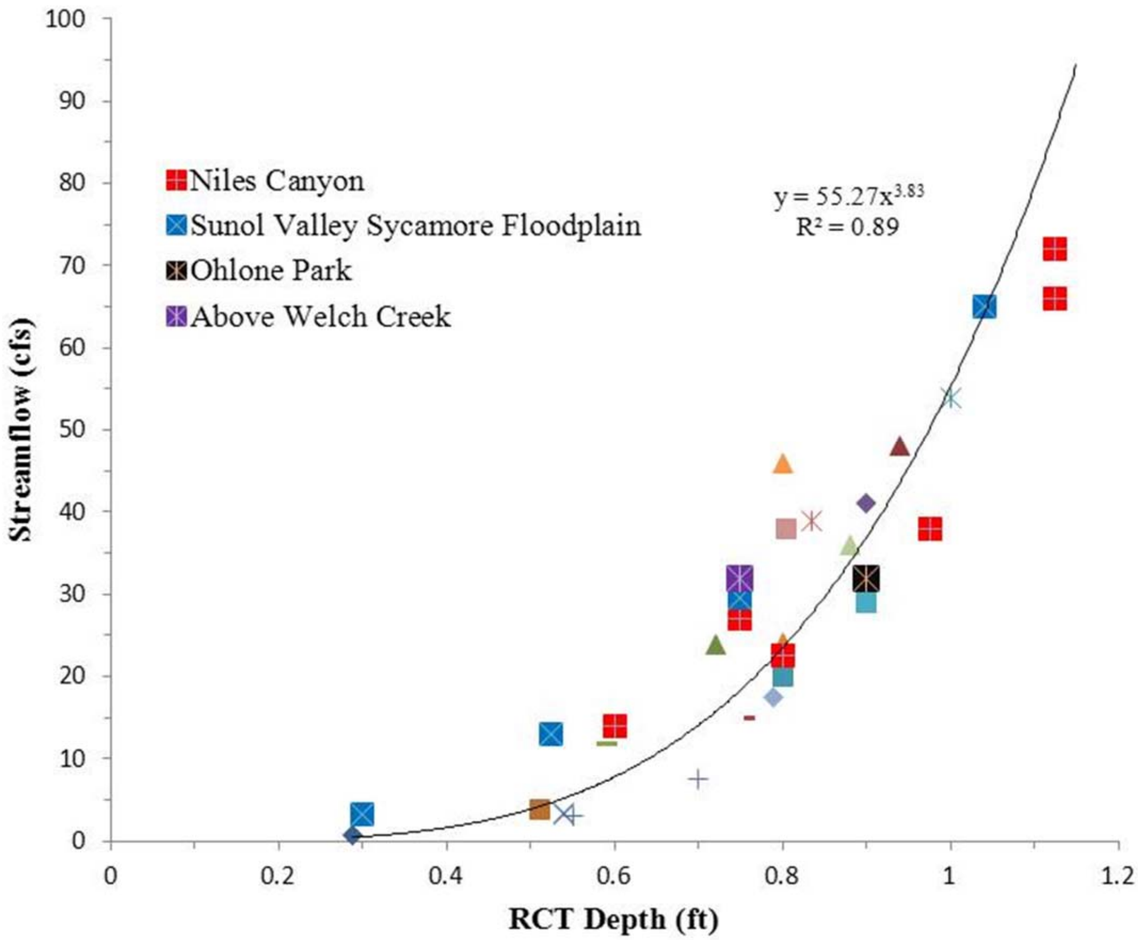

Figure 12. Northern California mRCT – Q rating curve from Gabe Rossi's thesis data, including Alameda Creek RCT values.

By having a Q-mRCT rating curve and annual hydrographs for each mainstem segment, daily mRCT depths could be computed and modeled for entire migration periods to assess adult steelhead passage. To model delays in steelhead migration due to shallow RCTs, MR_{ave} was multiplied by delay factors (DF) as a function of mRCT depth in Table 2.

Table 2. Delay factors associated with mRCT depths.

Upper mRCT [ft]	Lower mRCT [ft]	Migration Rate Delay Factor
1.00	0.85	0.90 * (MR_{ave})
0.85	0.75	0.80 * (MR_{ave})
0.75	0.60	0.65 * (MR_{ave})
0.60	0.50	0.50 * (MR_{ave})
0.50	0.40	0.30 * (MR_{ave})
0.40	0.30	0.20 * (MR_{ave})
0.30	0.25	0.10 * (MR_{ave})
0.25	0.20	0.05 * (MR_{ave})
0.20	0.00	0 * (MR_{ave})

These delay factors were estimated by us observing adult steelhead and salmon swim through riffles of varying RCT depths in other Northern California streams. A 0.6 ft deep streamflow (MR_{ave}) barely covers the back of a swimming adult steelhead, but is still passable (only with delay).

7.5. Ascendograph Parameter No. 5. Selecting a Ratio for Split Mainstem Streamflows in the Sycamore Floodplain

The mainstem channel that breaks-out onto the Sunol Valley bottomlands is usually split at the top of the Sycamore Floodplain reach (RM 20.9 to RM 21.8). Sometimes the entire streamflow will be confined to the left mainstem channel, but more commonly (at least recently) the streamflow ratio between left and right channels has varied from 7:3 to 6:4. Adult passage could be significantly delayed when lower baseflows are somewhat evenly split between the two mainstem channels. Presently the ratio for baseflows is approximately 6:4 (and used in the SRA model for winter baseflows).

7.6. Ascendograph Parameter No.6. Selecting an Allowable Wait (T_{AW}) at a Partial Barrier (OPTIONAL)

If a steelhead encounters a partial barrier (passable only within a prescribed range of streamflows), the choices are few: continue trying to migrate or spawn downstream. If the wait is very long, until streamflows improve and progress upstream is again possible, the In-River Time Limit (T_{IRL})(Parameter No.1) will expire. An allowable wait (T_{AW}) sets an upper limit to the number of days a cyber-steelhead (i.e., a given entry date) can remain stalled below an individual partial barrier. If exceeded, that entry date is considered unsuccessful. T_{AW} becomes a potentially important model parameter if T_{IRL} is long and/or if there are fish ladders. The longer the wait, the more fish condition deteriorates. T_{AW} values ranging from 2 days to 10 days should be considered in a sensitivity analysis.

8. SRA OUTPUT AND ANALYSIS

8.1. The Model

The Spawner Risk Assessment model is organized as an Excel-based input workbook with computational analysis executed in VBA. There are 7 pages within the Risk Assessment Excel workbook: Readme, Input, Data Log Hydrology, Full Results, Results, and Graphics. The Input Data and Hydrology sheets are where the user defines the hydrographs and model parameters for each iteration modeled. The Full Results sheet is the output of the migration time step equation computed in VBA. These data are than graphed by entry date on the X-axis and river miles on the Y-axis to illustrate an ascendograph. The Results page is a numerical summary of the full results showing total number and distribution of successful entry dates with their respective arrival and fry emergence dates, and information about unsuccessful entry dates including the reason for failure.

The VBA-based model allows the user to perform sensitivity analyses on any spawner destination or ascendograph parameter. A powerful capability for sensitivity analyses, given the uncertainties of modeling an Alameda Creek migration run in a creek with no migrating steelhead, will assist the user in understanding the systems sensitivity to changes in model parameters. Greater SRA model sophistication does not seem warranted at this time, however, sensitivity analyses should be encouraged to gage how influential assumed values for specific model parameters (e.g., values assigned to the daily average migration rate, MR_{AVE}) will affect the results.

8.2. Defining the Dependent Variable of Success

A female adult steelhead arriving at the spawning destination on a low-risk day has a much better chance of her redd producing fry than if she had arrived on a high-risk day. The SRA model considers this a success. Formally stated, from the model's perspective, a spawner success day occurs when an entry date routed upstream arrives at the spawner destination on a low-risk spawner day. Total annual spawner success is the sum of all spawner success days within one spawning season.

8.3. Basic Output: Ascendographs

Ascendographs are the basic output from the SRA model from which the total number of spawner success days for a particular water year and spawner destination is estimated. There will be a computed ascendograph for every combination of water year and spawner destination assessed. If more than one set of parameter values are modeled, then there will be as many ascendographs computed as there are parameter sets modeled. Figure 1 simplifies an ascendograph's basic structure. But within the SRA model, each ascendograph logs the fate of all entry dates. Figure 13 is an ascendograph computed with most of the detail expressed, rather than simplified.

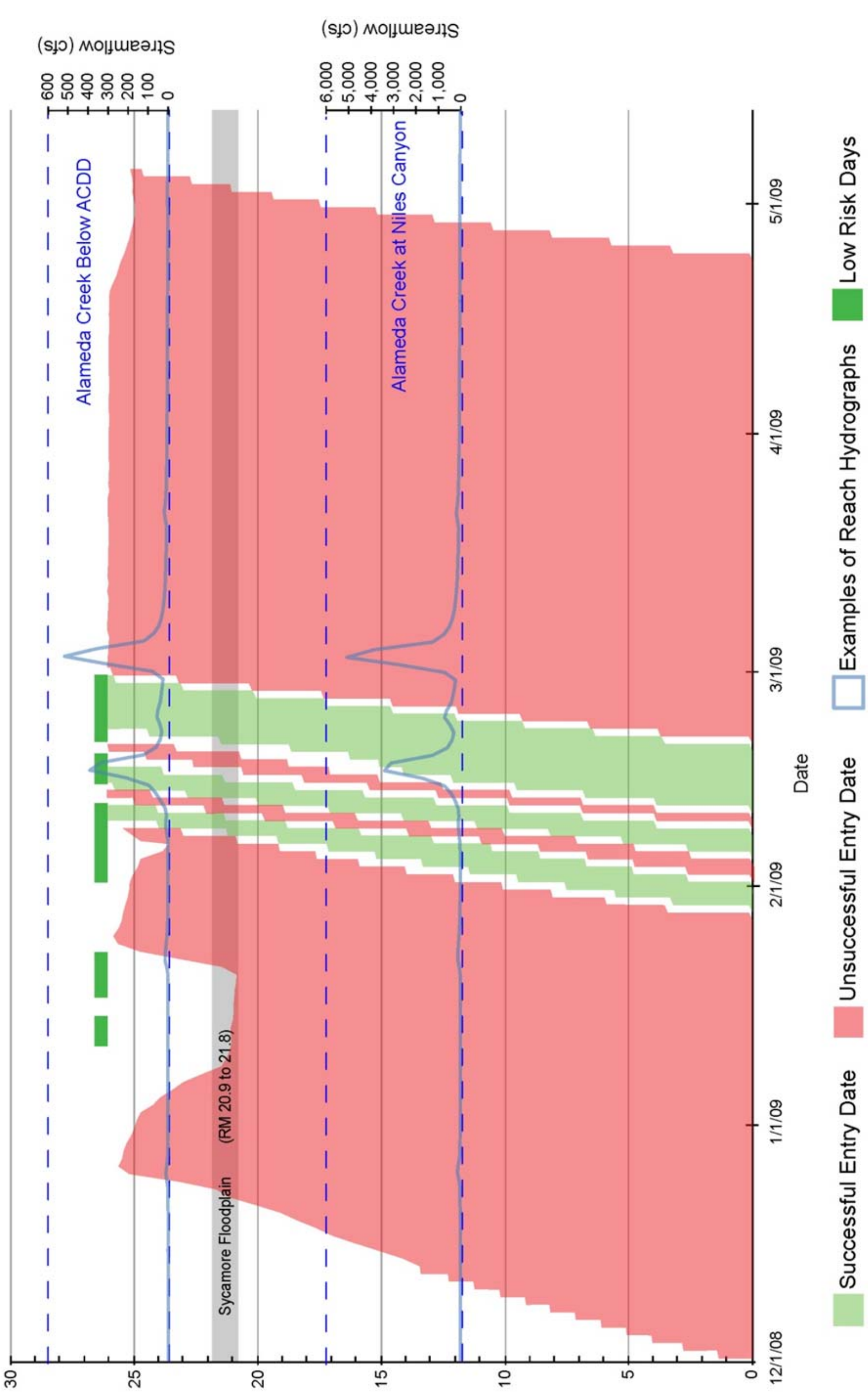

Figure 13. SRA output for one ascendograph.

Considerably more understanding can be gained than simply computing the total number of spawner success days from an ascendograph. For example, a frequency distribution can be re-constructed from one ascendograph characterizing the duration (in days) of all entry dates reaching the spawner destination. The centroid shift in frequency distributions generated from ascendographs computed from unregulated and regulated hydrographs would be an overall measure of delay (in days). This delay could then be plotted against the total number of spawner success days.

9. ANALYTICAL STRATEGY: GREATER DELAY EQUALS FEWER SPAWNER SUCCESS DAYS?

The SRA model cannot predict the minimum total number of spawner success days necessary for recovery. Instead, the SRA model will use modeled unregulated annual hydrographs absent man-made physical impediments to generate baseline ascendographs for WY2000 through WY2009 at the key mainstem spawner destinations. After thorough sensitivity analyses are performed, these baseline ascendographs will be contrasted with the total number of spawner success days computed from ascendographs modeled under current and proposed flow management and partial barrier management scenarios for the same set of water years.

A ratio of total successful spawner days under the unregulated hydrograph (denominator) and regulated hydrograph (numerator) reveals how well management is doing. A ratio less than 1 is not a failing grade, but low ratios should be cause for concern. The WorkGroup also should examine when in the overall season the SRA model predicted spawner success days. Biologists know that not all entry dates are equally attractive to steelhead staging the initial migration burst upstream. Biologists can examine the model output and subset portions of the spawning season in each WY that would be most important for steelhead (i.e., attractive streamflow conditions for entry dates that would bring steelhead into Alameda Creek).

10. PRELIMINARY SRA MODEL RESULTS

Applying Ascendograph Parameter Set No.1 (Table 2), annual ascendographs for WY2000 to WY2009 were modeled for unregulated annual hydrographs with natural partial barriers at one important mainstem spawner destination: the base of Little Yosemite Canyon (Figures 14a and 14b).The first step was to identify the ‘low-risk’ spawner days in each water year by assigning values to the spawner destination parameters. Hagar and Payne (2008) provide a composite curve for spawning habitat near the base of Little Yosemite Canyon (Figure 15). Streamflow thresholds for scour/desiccation and the range of spawning streamflows (providing abundant habitat at the destination) are listed in Spawner Destination Parameter Set No.1 (Tables 3a, 3b, and 3c).

Figure 14a. Spawning site below base of Little Yosemite Canyon.

Figure 14b. Spawning site below base of Little Yosemite Canyon.

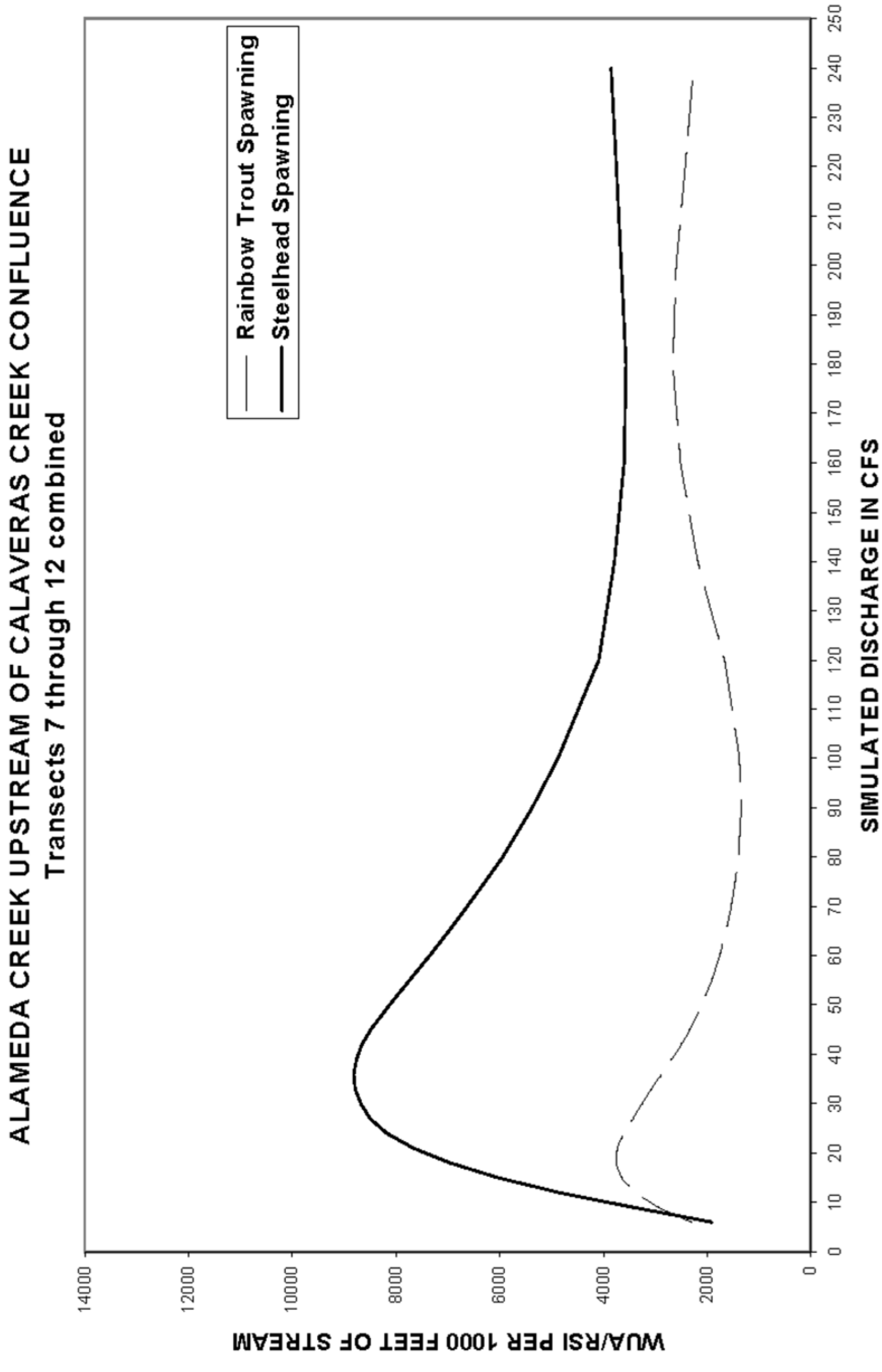

Figure 15. Composite spawning habitat rating curve above Calaveras Creek (taken from Hagar and Payne 2008).

10.1. SRA Parameter Set No.1 Unregulated Hydrographs

Table 3a. Ascendograph Parameter Set No.1 for unregulated hydrographs at Base of Little Yosemite Canyon.

Parameter	Name	Values
1	Entry Dates	Dec 01 to April 15
2	In-River Time Limit (T_{IRL})	30 Days
3	Average Migration Rate (MR_{ave}) ~Flood Control Channel~	4 miles/day
	Average Migration Rate (MR_{ave}) ~Niles Canyon and upstream~	3 miles/day
4	Delay Factors	See Table 3b
5	Sycamore Floodplain Flow Split	6:4
6	Allowable Wait Time (T_{AW})	10 days

Table 3b. Delay Factors for Ascendograph Parameter Set No.1.

Upper mRCT (ft)	Lower mRCT (ft)	Migration Rate Delay Factor
1.00	0.85	$0.90 \cdot (MR_{ave})$
0.85	0.75	$0.80 \cdot (MR_{ave})$
0.75	0.60	$0.65 \cdot (MR_{ave})$
0.60	0.50	$0.50 \cdot (MR_{ave})$
0.50	0.40	$0.30 \cdot (MR_{ave})$
0.40	0.30	$0.20 \cdot (MR_{ave})$
0.30	0.25	$0.10 \cdot (MR_{ave})$
0.25	0.20	$0.05 \cdot (MR_{ave})$
0.20	0.00	$0 \cdot (MR_{ave})$

Table 3c. Spawner Destination Parameters for Base of Little Yosemite Canyon.

Parameter	From	To
Spawning Habitat	15 cfs	120 cfs
Incubation Maintenance	3 cfs	1800 cfs
Incubation Period	50 Days	
Spawning Destination Location	RM 26	

Between December 01 and April 15, most unregulated water years offered more ‘low-risk’ spawner days than ‘high-risk’ spawner days (Figure 16). Regulated water years, especially the dry years, show a significant reduction in the number of low risk days (Figure 19). The relatively short gaps between ‘low-risk’ days are often during floods when the streamflow exceeded the upper limit for good spawning habitat set at High Q_{SPWN} = 120 cfs. Model parameters are generated for both unregulated (Tables 3a, 3b, 3c) and regulated streamflow (Tables 4a, 4b, 4c, and 4d). Running the SRA model routed adult steelhead upstream and calculated predicted arrival dates (the date at which steelhead reached the base of Little Yosemite Canyon) corresponding to specific entry dates (date at which the steelhead entered Alameda Creek). Arrival dates are shown in Figure 17 and Figure 20 for unregulated and regulated flow respectively. The model classifies arrival dates that occur on a low risk day to be a spawner success day. Success days are calculated for unregulated (Figure 18) and regulated (Figure 21) streamflows.

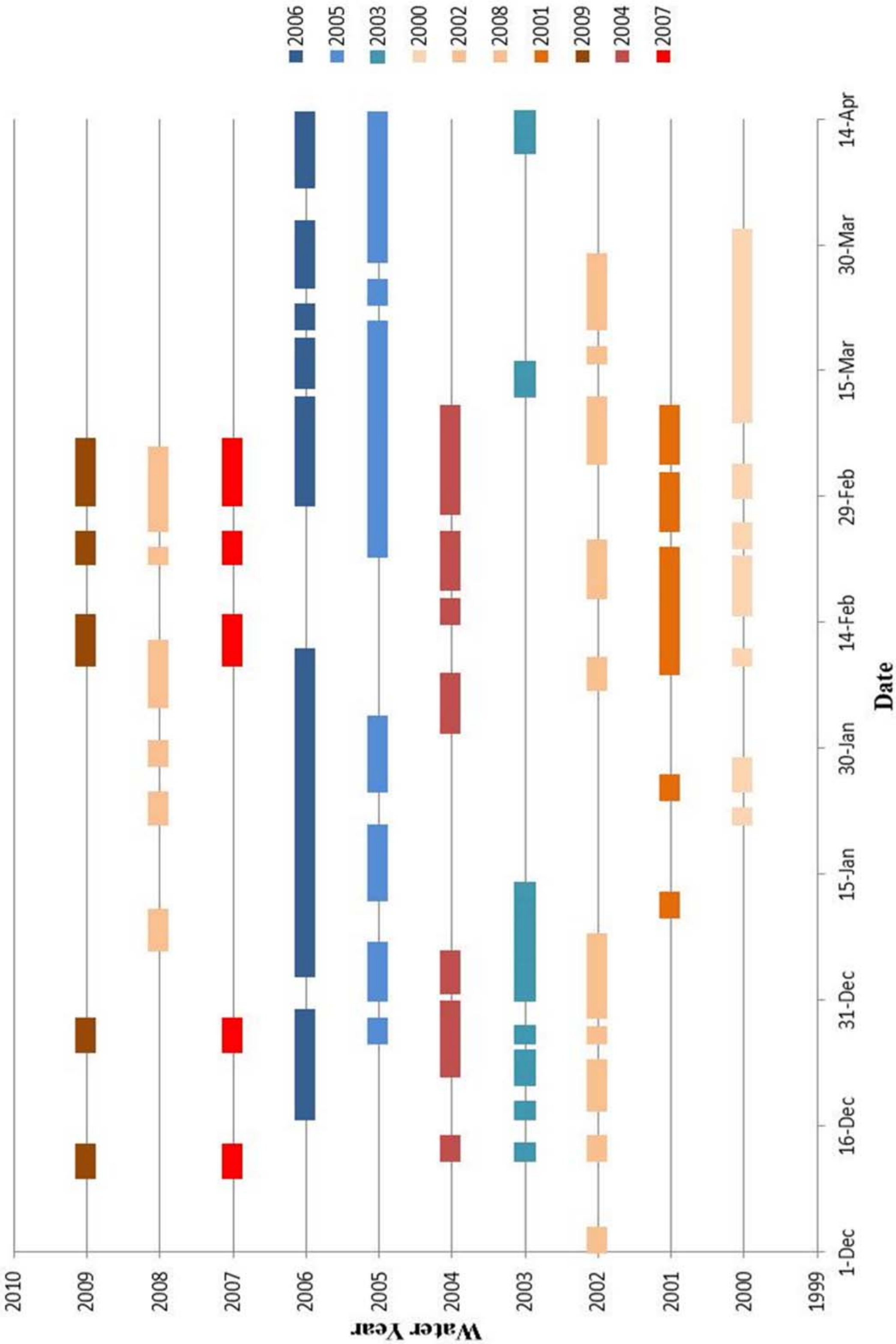

Figure 16. Low-Risk Spawner Days in each unregulated water year for the Little Yosemite Canyon spawner destination.

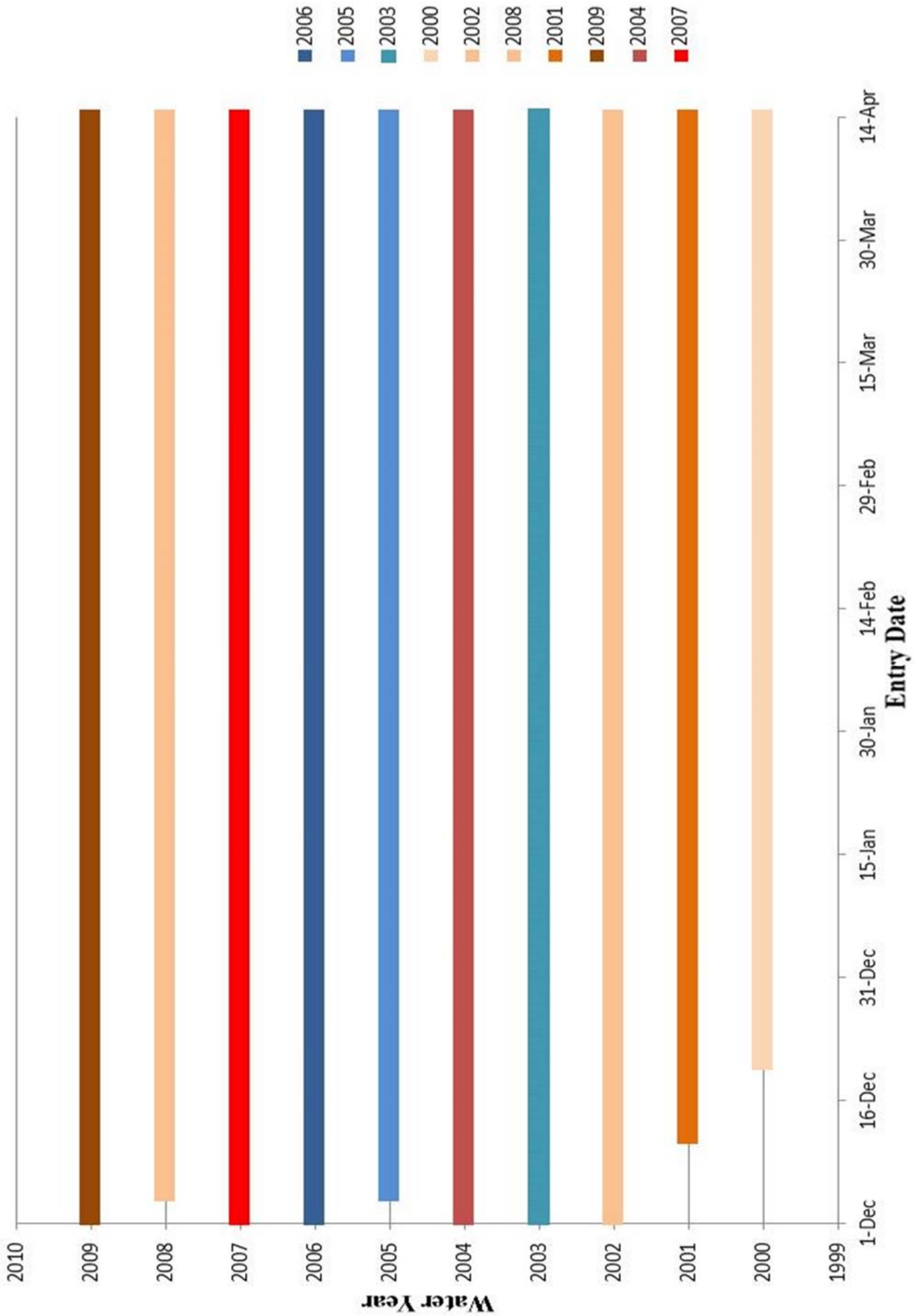

Figure 17. Spawner Arrival Dates in each unregulated water year for the Little Yosemite Canyon spawner destination.

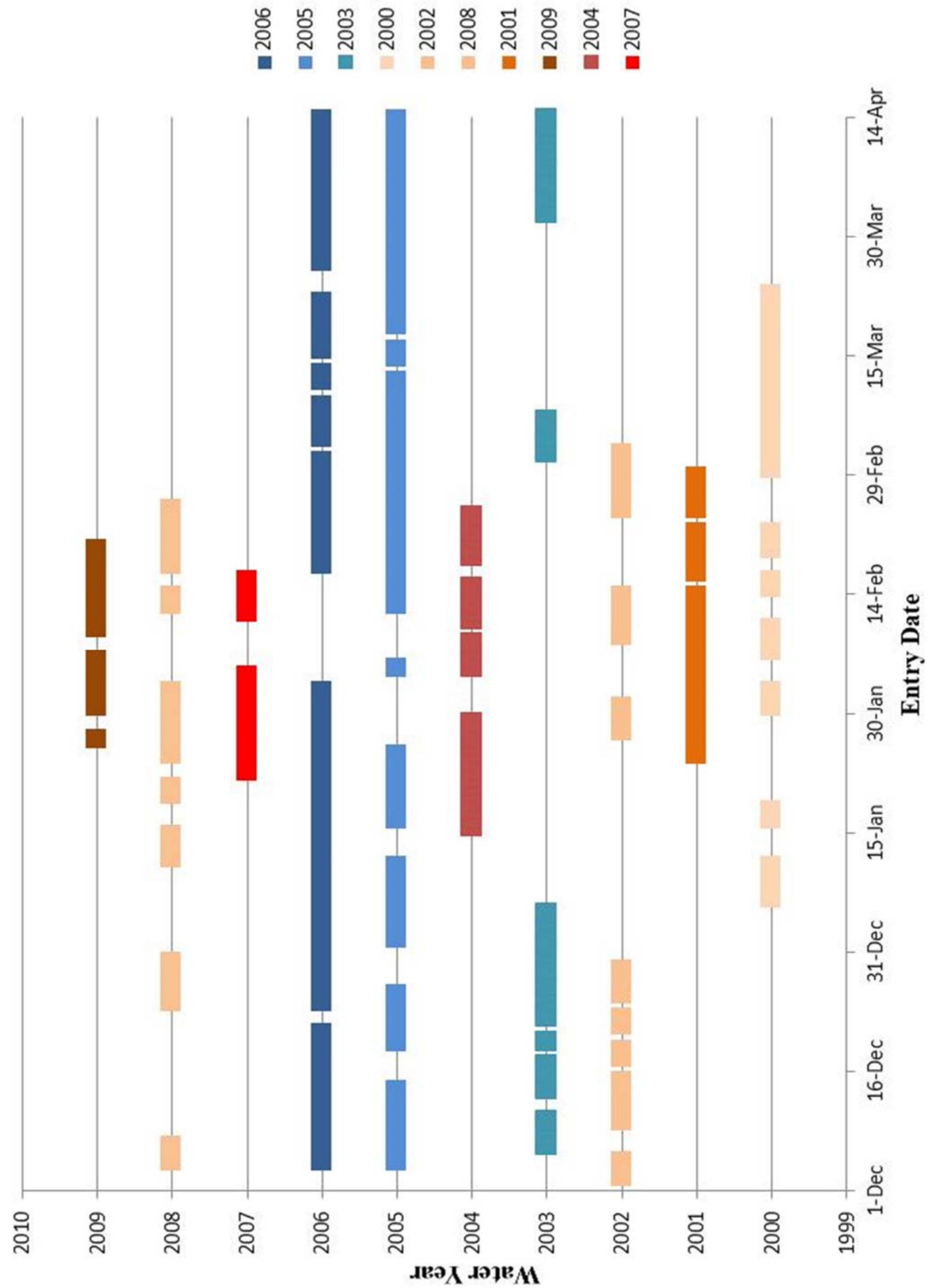

Figure 18. Occurrence of Spawner Success Days at Base of Little Yosemite Canyon for WY2000 to WY2009 under unregulated streamflows.

10.2. SRA Parameter set No.1 Regulated Hydrographs

Table 4a. Ascendograph Parameter Set No.2 for Regulated Hydrographs at Base of Little Yosemite Canyon.

Parameter	Name	Values
1	Entry Dates	Dec 01 to April 15
2	In-River Time Limit (T_{IRL})	30 Days
3	Average Migration Rate (MR_{ave}) ~Flood Control Channel~	4 miles/day
	Average Migration Rate (MR_{ave}) ~Niles Canyon and upstream~	3 miles/day
4	Delay Factors	See Table 2b
5	Sycamore Floodplain Flow Split	6:4
6	Allowable Wait Time (T_{AW})	10 days

Table 4b. Delay Factors for Ascendograph Parameter Set No.2

Upper mRCT (ft)	Lower mRCT (ft)	Migration Rate Delay Factor
1.00	0.85	$0.90 \cdot (MR_{ave})$
0.85	0.75	$0.80 \cdot (MR_{ave})$
0.75	0.60	$0.65 \cdot (MR_{ave})$
0.60	0.50	$0.50 \cdot (MR_{ave})$
0.50	0.40	$0.30 \cdot (MR_{ave})$
0.40	0.30	$0.20 \cdot (MR_{ave})$
0.30	0.25	$0.10 \cdot (MR_{ave})$
0.25	0.20	$0.05 \cdot (MR_{ave})$
0.20	0.00	$0 \cdot (MR_{ave})$

Table 4c. Spawner Destination Parameters for Base of Little Yosemite Canyon for regulated hydrographs.

Parameter	From	To
Spawning Habitat	15 cfs	120 cfs
Incubation Maintenance	3 cfs	1800 cfs
Incubation Period	50 Days	
Spawning Location	RM 26	

Table 4d. Barrier parameters for Ascendograph Parameter Set No.2.

Barrier	Location (RM)	Model Assumptions
BART Weir	9.0	No Delay
ACWD Rubber Dams	9.1 to 10.0	No Delay
USGS Weir	11.6	Total Barrier below 50 cfs.
PG&E Pipeline Crossing	18.6	No Delay
Gravel Quarry GCS	19.9	No Delay

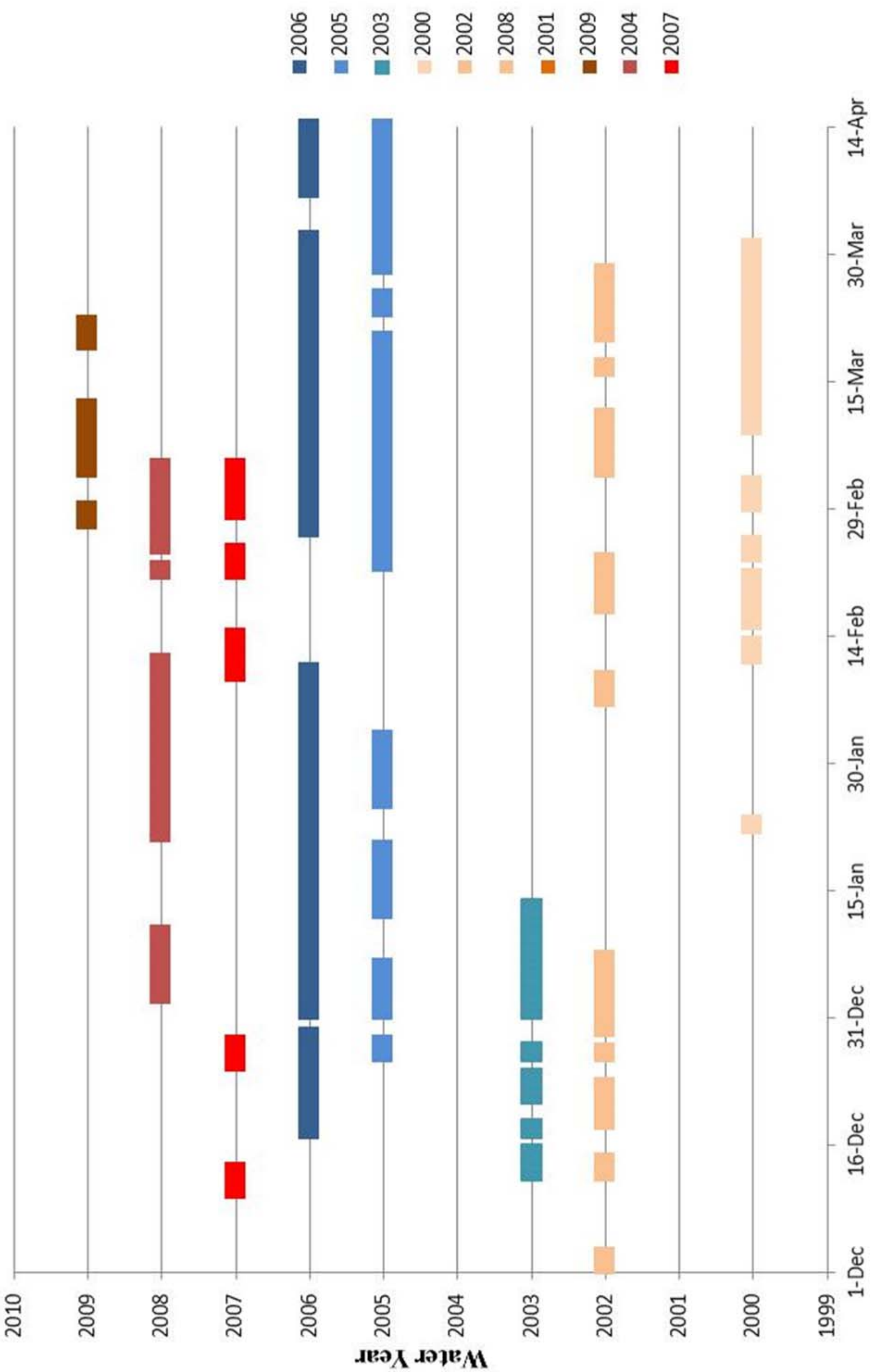

Figure 19. Low-Risk Spawner Days in each regulated water year for the Little Yosemite Canyon spawner destination.

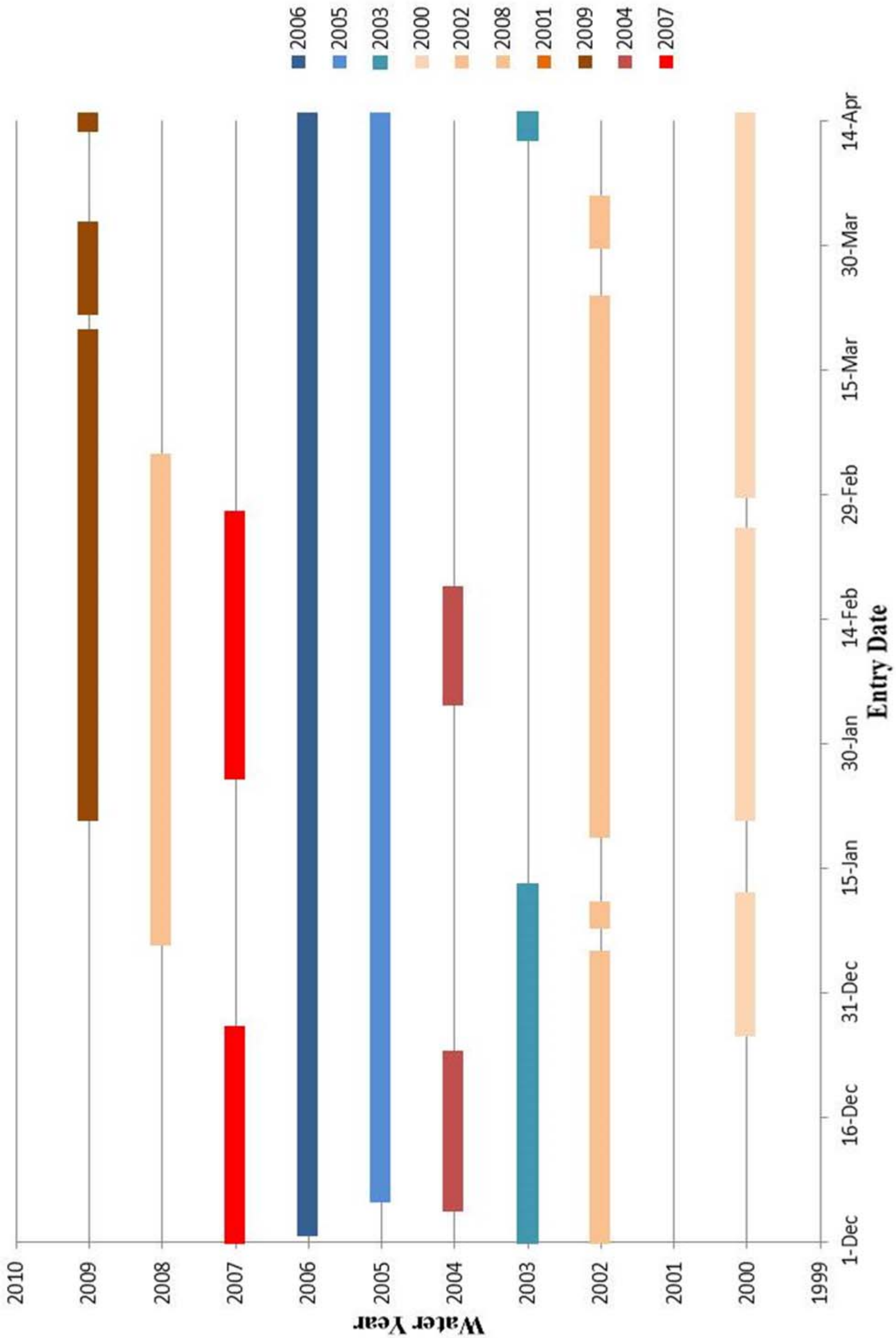

Figure 20. Spawner Arrival Dates in each regulated water year for the Little Yosemite Canyon spawner destination.

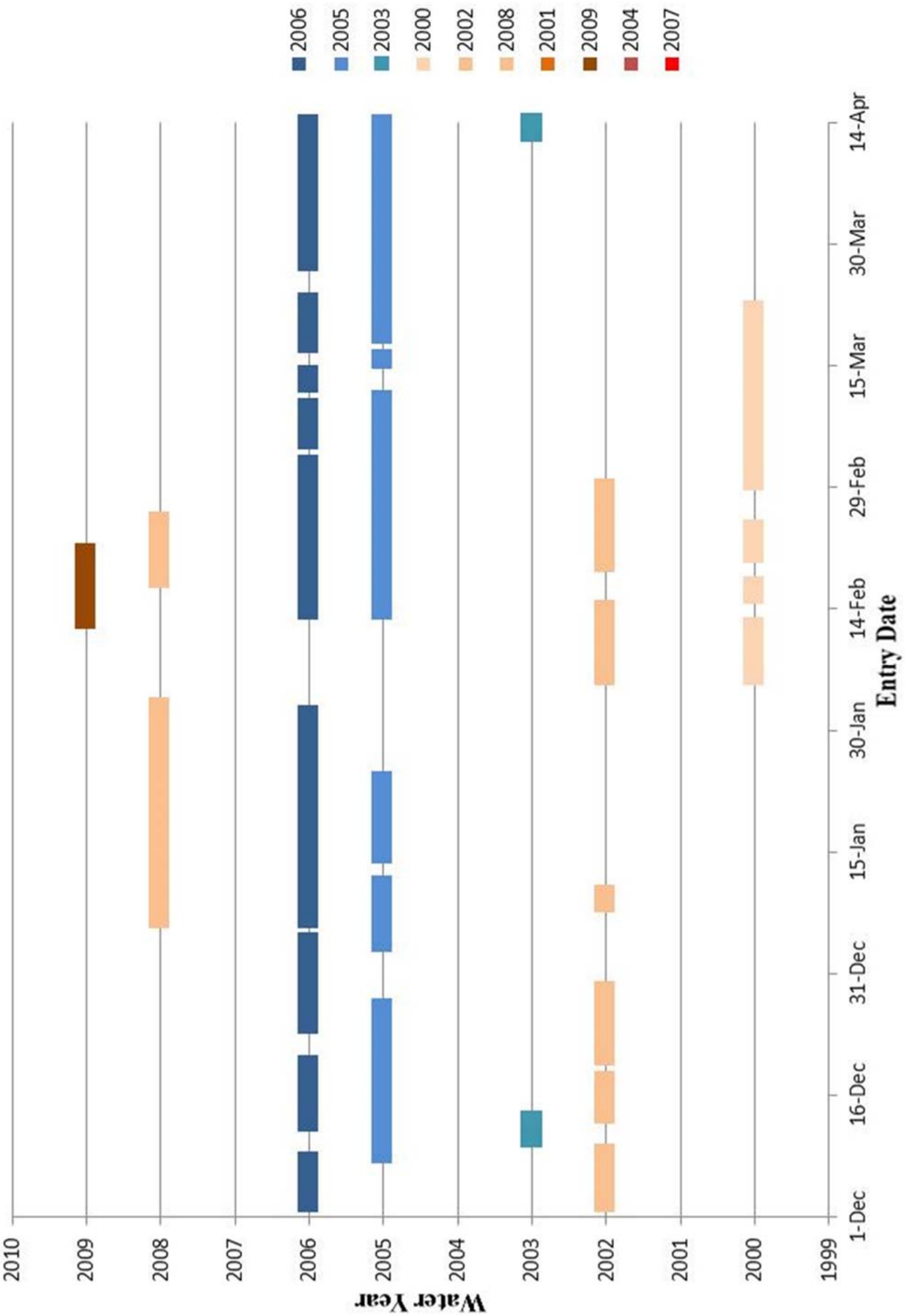

Figure 21. Spawner Success Days in each regulated water year for the Little Yosemite Canyon spawner destination.

The first level of analysis, and only level shown here, is a contrast (Table 5) between total spawner success days and the unregulated/regulated hydrographs (comparing Figure 17 with Figure 20). There are more short breaks in spawner success days for the unregulated hydrograph (Figure 17) because there were more peak streamflows exceeding High Q_{SPWN} = 120 cfs (Table 4c), the upper threshold for high quality, abundant spawning habitat. For the very dry WY2007, the number of spawner success days favored the unregulated hydrograph, 18 days to 0 days, as it does in all the drier years. The wetter water years show less distinction between regulated and unregulated hydrographs as in WY2005 and WY2006. In a complete evaluation of the Alameda Creek Basin, there would be many more ascendographs computed and many trends explored.

Table 5. Comparison of results from unregulated and regulated SRA exercise.

Water Year	Number of Low Risk Days		Number of Arrival Days		Number of Spawner Success Days	
	Unregulated	Regulated	Unregulated	Regulated	Unregulated	Regulated
2000	39	36	166	131	42	35
2001	29	0	151	0	31	0
2002	40	44	201	144	34	42
2003	24	31	214	86	43	6
2004	38	2	173	31	29	0
2005	71	85	229	203	93	91
2006	80	119	216	202	102	100
2007	21	20	180	67	18	0
2008	29	40	154	58	34	35
2009	26	13	163	81	19	9

Note: on several WY's the number of spawner success days is greater than the number of low risk days. This occurs when steelhead from multiple entry dates arrive at the spawning destination the same day. Delay caused by streamflow or physical barriers occasionally creates a stacking effect where fish are holding until they can pass a difficult reach. When passable streamflows return, multiple entry dates may proceed together and reach the spawning destination the same day.

11. ADDITIONAL DATA NEEDS

Any environmental modeling has a high demand for data. But there is a point of limited return for the effort/money spent. The following identified needs would improve the analysis, though a sensitivity analysis would help determine which would be necessary:

(1) More information on the streamflow split ratio at the top of Sycamore Floodplain;

(2) The Middle and Lower Upper Alameda Creek habitat mapping sites may need direct habitat mapping at higher streamflows to provide a good estimate for High Q_{SPWN};

(3) Begin gathering field observations of potential complete and partial barriers in the other half of the Alameda Creek watershed;

(4) No DHM mapping was done in the Sycamore Floodplain split channels. Estimates for Low Q_{SPWN} and High Q_{SPWN} could be made without DHM, or with one verification field effort. The primary concern is that steelhead may consider these significantly smaller channels the 'end-of-the-line' and begin spawning in what might appear a headwater tributary.

(5) Keep monitoring depths and velocities at the USGS gaging weir.

12. REFERENCES

Bates, K., Dorratcague, D., Mann, J., Postlewait, D., Thomas, S., and W. Trush. 2010. Vern Freeman Dam Fish Passage Conceptual Design Report. Prepared for: United Water Conservation District. Prepared by: Vern Freeman Dam Fish Passage Panel. September 15, 2010.

Bjorn, T. C., and C. A. Perry. 1992. A review of literature related to movements of adult salmon and steelhead past dams and through reservoirs in the lower Snake River. U.S. Army Corp of Engineers, North Pacific Division, Technical Report 92-1, Portland, Oregon.

Buckland, E. 2009. Alameda Creek Flood Control Channel Low Flow Passage Assessment. Alameda County Water District. 7 p.

DeHaven, R. W. 2009. *Secrets of Steelhead Biology*. Retrieved from Gualala River Steelhead Studies: http://www.dcn.davis.ca.us/vme/gualala-river/secrets.html.

Hagar Environmental Science and T.R. Payne and Associates. 2008. Assessment of relationship between Stream flow and spawning habitat for rainbow trout and steelhead in Alameda Creek. Appendix A. Prepared for SFPUC.

Hanson Enironmental Inc. 2002. Reconnaissance Investigation of the Relationship Between Instream Flow and Adult Steelhead Passage Within Alameda Creek: 2001-2002. Prepared for the Alameda Creek Fisheries Workgorup.

Logan, D. 2010. NOAA Research and Enhancement Permits Coordinator. (G. Rossi, Interviewer, April 29).

McBain and Trush. 2008. Alameda Creek Population Recovery Strategies and Instream Flow Assessment for Steelhead Trout, Final Study Plan. Prepared for: Alameda Creek Fisheries Restoration Workgroup. 56 p. http://www.cemar.org/alamedacreek/alamedacreekindex.html

National Marine Fisheries Service (Northwest Region). 2008. Anadromous salmonid passage facility design. Portland, Oregon.

Santa Ynez River Technical Advisory Committee. 1999. Adult steelhead passage flow analyses for the Santa Ynez River.

Sinnen, W. 2010. DFG Fisheries Biologist. (G. Rossi, Interviewer, August 21).

Thompson, K. 1972. Determining Stream Flows for Fish Life. Pacific Northwest River Basins Commission Instream Flow Requirement Workshop. March 15-16.