A Simulation Method for Combining Hydrodynamic Data and Acoustic Tag Tracks to Predict the Entrainment of Juvenile Salmonids onto the Yolo Bypass Under Future Engineering Scenarios

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1. Executive Summary

During water year 2016 the U.S. Geological Survey California Water Science Center (USGS) collaborated with the California Department of Water Resources (DWR) to conduct a joint hydrodynamic and fisheries study to acquire data that could be used to evaluate the effects of proposed modifications to the Fremont Weir on outmigrating juvenile Chinook salmon. During this study the USGS surgically implanted acoustic tags in juvenile late fall run Chinook salmon from the Coleman National Fish Hatchery, released the acoustically tagged juvenile salmon into the Sacramento River upstream of the Fremont Weir, and tracked their movements as they emigrated past the western end of the Fremont Weir.

The USGS analyzed tracking data from the acoustically tagged juvenile salmon along with detailed hydrodynamic data collected in the Sacramento River during the winter/spring of water year 2016 in the vicinity of the western end of the Fremont Weir to assess the potential for enhancing the entrainment of Sacramento River Chinook salmon onto the Yolo Bypass under six different Fremont Weir modification scenarios. Each modification scenario consists of a notch or multiple notches in the Fremont Weir which are designed to divert a portion of the Sacramento River onto the Yolo Bypass when the Sacramento River is below the crest of the Fremont Weir. The primary goal of this entrainment analysis was to investigate how the location of the notch or notches in each scenario affected the entrainment of juvenile Chinook salmon onto the Yolo Bypass, and to predict the notch location or locations that would result in maximum entrainment under each modification scenario.

Stumpner et al.’s (in review) analysis of hydraulic data collected during the 2016 study period showed that backwater effects in the Sacramento River created significant variability in the relationship between Sacramento River stage and the proportion of the Sacramento River flow that we expect to be diverted onto the Yolo Bypass under the modification scenarios. Because of this variability, accurately evaluating the entrainment potential of possible notch locations for each scenario required combining historic abundance data for juvenile Sacramento River Chinook salmon with historic hydraulic data for the Sacramento River in the vicinity of the Fremont Weir, so that the entrainment estimates would reflect the covariance between Sacramento River stage, Sacramento River discharge, and juvenile salmon abundance within the historic record.

We used a Monte Carlo simulation framework to combine the high resolution hydrodynamic data and acoustic tag track data collected in 2016 with historic juvenile salmon abundance, Sacramento River stage, and Sacramento River discharge data from a period spanning water years 1996-2010 to assess the entrainment potential of different weir modification scenarios under historic conditions. The scenarios we simulated consisted of four single notch configurations, and two multiple notch configurations in the vicinity of the western end of the Fremont Weir. For each notch configuration the 15-water-year entrainment simulation was repeated for 63 possible notch locations in the vicinity of the western end of the Fremont Weir. This approach allowed us to assess the effect of notch location on the entrainment of juvenile salmonids onto the Yolo Bypass for each of the six notch configurations that we evaluated.

The entrainment simulations showed that the location of each notch configuration had a major impact on the entrainment for each scenario; the predicted entrainment of some scenarios varied by as much as 400% based on where the notch (or notches) was (were) located in the study area. All of the single notch scenarios performed best when they were located within a 330 ft (100 meter) long section of the Sacramento River bank adjacent to the western terminus of the Fremont Weir (Table 1). Both of the multiple notch scenarios performed best when their upstream notches were located about 660 ft (200 meters) upstream of the western terminus of the Fremont Weir (Table 1). The results of the entrainment simulations indicated that for each notch configuration the same notch location produced near-maximum entrainment regardless of run abundance timing; this result suggests that there are areas within the study are where a notch (or notches) can be sited to achieve maximum entrainment for all runs (barring significant behavioral or physiological differences between runs). In addition, the simulation results indicate that for each notch configuration the same location is expected to produce near-maximum entrainment for both wet water years and dry water years.

Based on the results of the entrainment simulation we make three general recommendations for strategies to improve the entrainment potential of a notch in the Fremont Weir:

1) Comparisons between the maximum entrainment potential for each scenario suggested that total entrainment of winter run, spring run, and fall run salmon onto the Yolo Bypass can be increased by increasing the amount of water entering a notch when the Sacramento River stage is between 19 ft and 22 ft NAVD88; this could be accomplished by lowering notch invert elevations or by adding a control section to the Sacramento River to raise stage for a given discharge.
2) The relationship between Sacramento River stage and entrainment for each scenario indicated that entrainment efficiency for each scenario declined significantly once Sacramento River stage exceeded bankfull (approximately 28.5 ft NAVD88). This effect was likely due to inundation of the floodplain between the Sacramento River and the Fremont Weir; Stumpner et. al (In Review) have documented a reduction in the strength of the secondary circulation and centralization of the downwelling zone in the Sacramento River when this floodplain is inundated. Therefore, increasing the height of the river right bank of the Sacramento River to coincide with the height of the Fremont Weir is recommended to increase entrainment at higher stages.
3) Bathymetric features upstream of notch openings appeared to have a major impact on the entrainment potential of the simulated notches. For this reason we recommend taking care to avoid siting notches immediately downstream of bank features that alter the sidewall boundary layer, and we expect that smoothing the bank bathymetry upstream of a notch will enhance entrainment.

Finally, we caution that the entrainment simulation was based on the behavior of large hatchery smolts, so it is likely that our results will be sensitive to any differences in behavior and physiology between these hatchery surrogates and naturally migrating juvenile salmon.

Table 1 - Summary of scenario performance

Percent of yearly juvenile salmon abundance entrained onto the Yolo Bypass under each scenario, by run, for the notch locations that resulted in maximum fall run entrainment for each scenario. The mean yearly percent of yearly abundance entrained is given along with 90% bootstrap confidence intervals in parentheses. The final row gives the along-stream coordinate of the notch location that resulted in peak entrainment for fall run under each scenario; see figure 4 for a map showing the along-stream coordinate system in the study area.

	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**
Fall Run	12% (6%-21%)	9% (2%-21%)	28% (12%-43%)	15% (3%-28%)	6% (2%-12%)	8% (2%-15%)
Spring Run	9% (4%-15%)	7% (4%-14%)	22% (6%-42%)	16% (9%-20%)	5% (1%-11%)	7% (2%-13%)
Winter Run	9% (2%-17%)	7% (2%-15%)	23% (4%-42%)	15% (8%-23%)	5% (2%-11%)	7% (4%-13%)
Late Fall Run	5% (0%-12%)	4% (0%-11%)	11% (0%-38%)	9% (1%-20%)	2% (0%-10%)	3% (0%-12%)
Location of notch at peak entrainment (UTM Zone 10S, m, NAD83)	615849E, 4290952N	615849E, 4290952N	615780E, 4290905N	615849E, 4290952N	615636E, 4290860N	615636E, 4290860N
Along stream coordinate of notch at peak entrainment	495 m	495 m	415 m	495 m	265 m	265 m

2. Acknowledgements

We wish to thank the State and Federal water contractors and the Department of Water Resources (DWR) for their support in funding the 2016 experiment, the analysis of the data and the writing of this draft report. Thanks to Curt Schmutte (DWR, retired) and managers at the Metropolitan Water District (MWD) for their support for this effort. To our DWR program manager, Brett Harvey and our DWR contracting manager Jacob McQuirk: thanks for dealing with all the contracting/purchasing issues associated with doing things on short notice, and in helping to guide the experiment and facilitating interagency coordination/communication. Ted Sommer, DWR, provided insightful comments on the initial draft proposal for this work and, along with Brett Harvey, helped guide the adaptive management of the study.

As always, these experiments involve many dedicated and talented folks spending lots of time in the field under challenging conditions - nasty weather and high water, in this case. None of the results from any of our studies would be possible without our exceptional field teams: the heroic efforts of our fish tagging and release teams, led by Marty Liedtke (USGS Columbia River Research Laboratory), and our instrument programming, deployment, and recovery teams, led by Chris Vallee (USGS California Water Science Center), are gratefully acknowledged.

3. Introduction

During the winter and spring of water year 2016 the U.S. Geological Survey California Water Science Center (USGS) collaborated with the California Department of Water Resources (DWR) to conduct a joint hydrodynamic and fisheries study to acquire data that could be used to evaluate the effects of proposed modifications to the Fremont Weir on outmigrating Chinook salmon. During this study the USGS and CADWR deployed and operated an array of hydrophones in a bend in the Sacramento River upstream of the confluence with the Feather River (figure 1, figure 2), that allowed researchers to track acoustically tagged juvenile Chinook salmon in the horizontal plane as they emigrated through the hydrophone array. During the winter and spring of water year 2016 researchers surgically implanted juvenile late fall run Chinook salmon from the Coleman National Fish Hatchery with acoustic tags and released the fish in small batches upstream of the study area, with the goal of obtaining fish tracks over the range of Sacramento River stage values that were likely to be relevant to the design of weir modifications (Liedtke and Hurst, 2017). During this time period the USGS and CADWR collected high resolution water velocity measurements throughout the study area over a range of Sacramento River stage values. Additionally, the USGS deployed, rated, and operated a temporary index velocity gauge in the vicinity of the study area to estimate the discharge in the Sacramento River entering the study area.

The USGS analysis of the data from the 2016 study was focused on three primary areas:

1) summarizing the information obtained from the acoustic tag tracking array and estimating the spatial distribution of the acoustically tagged study fish;
2) analyzing the hydrodynamic data to improve our understanding of the physical processes in the Sacramento River that may influence the design of weir modifications, and
3) Combining the hydrodynamic analysis with the acoustic tag data to estimate the entrainment potential of notch modification scenarios.

The USGS's hydrodynamic analysis is presented in Stumpner et al., In Review, while this report focuses on combining the fish tracking data with the high resolution hydrodynamic data to evaluate the entrainment potential of weir modification scenarios in order to answer the following questions: (1) Which location or locations resulted in maximum entrainment for each run under each scenario? (2) How robust are these locations to changes in run abundance and water year? (3) What can we learn from the relationship between stage and entrainment for each scenario that may be useful for optimizing weir modifications?

In past studies the USGS has found that the spatial distribution of acoustically tagged fish can be combined with hydrodynamic data to reveal, and in some cases predict, the entrainment rate of juvenile Chinook salmon at tidally forced riverine junctions on the Sacramento River (California Department of Water Resources, 2012, 2015, and 2016). This past research at the Georgiana Slough junction showed that the proportion of water diverted into a junction branch was a key variable affecting the entrainment of acoustically tagged juvenile Chinook salmon transiting a junction (California Department of Water Resources, 2012, 2015, and 2016).

Our analysis of the temporary index velocity gauge data from the Sacramento River upstream of the Fremont Weir (Stumpner et al., In Review) showed that backwater effects in the Sacramento River caused by the Sutter Bypass and the Feather River created substantial variability in the stage-discharge relationship for the Sacramento River at the study area (Figure 3). This variability meant that the proportion of Sacramento River discharge that was expected to be diverted onto the Yolo Bypass under each modification scenario would not be a constant function of Sacramento River stage (The ratio of Sacramento River discharge to notch discharge is called the scenario Discharge Ratio, see Stumpner et al., In Review, for a more detailed discussion). As a result, our expectation was that entrainment under each scenario would vary as a function of Sacramento River backwater condition, because the proportion of the Sacramento River that was diverted onto the Yolo Bypass would be controlled by backwater conditions.

Because of the variation in scenario discharge ratios caused by backwater effects, assessing the entrainment potential of each scenario required an approach that accounted for the structure of the joint probability distribution that describes the probability of a fish belonging to a specific run of Sacramento River Chinook salmon transiting the study area under any possible backwater condition. We addressed this challenge by using a Monte Carlo simulation approach for evaluating the entrainment potential of modification scenarios using historical time series of Sacramento River stage, Sacramento River discharge, and the abundance of fall run, winter run, spring run, and late fall run Chinook salmon. The result of this simulation approach was a time series of estimated entrainment for each run under each modification scenario; when these time series were summed they produced an estimate of total entrainment for a run that was a function of the hydraulic conditions (discharge, stage, backwater condition) during the simulation period weighted by the relative abundance of the run over the range of hydraulic conditions measured during the simulation period. Thus, this approach implicitly accounted for the joint probability of run abundance and backwater condition within the simulation period.

The basic structure of the entrainment simulation was a Monte Carlo bootstrap simulation; at each time step within the simulation a bootstrap sample of acoustic tag tracks for each run was drawn from the pool of all acoustic tag tracks collected during the 2016 study, and then hydrodynamic data collected during the 2016 study period was used to determine which of the tracks in each bootstrap sample were entrained under each modification scenario. The key to the entrainment simulation was that at every time step the bootstrap sample size for each run was determined by the historic abundance data for each run, and the sampling weights used for the bootstrapping were a function of the hydraulic conditions when each acoustic tag passed through the study area relative to the hydraulic conditions for the simulation time step.

The primary goal of the entrainment simulation was to estimate the effect of notch location on the entrainment of juvenile Chinook salmon for each modification scenario in order to provide insights that can be used to aid in site selection for each of the proposed alternatives. Because the cross-stream distribution of discharge at any location within the study area is a function of Sacramento River stage and discharge (see Stumpner et al., In Review for more details), we expect that differences in entrainment between possible scenario locations will also be a function of Sacramento River stage and discharge. As a result, we performed the full Monte Carlo bootstrap simulation process for each run of Sacramento River Chinook salmon under each modification scenario **at each of the 63 alternative scenario locations within the study area** (Figure 5, Appendix A). This approach allowed us to explore the effects of notch location on entrainment over a range of hydraulic conditions given the historic abundance timing for fall run, winter run, spring run, and late fall run Chinook salmon. The entrainment stimulation resulted in an extremely rich dataset that consisted of covariate values and the resulting entrainment estimates for each run, at each location, under each scenario for every time step.

4. Methods

The basic structure of the entrainment simulation was a Monte Carlo bootstrap simulation that performed three fundamental functions at each time step: (1) Estimating covariate values (Sacramento River stage, Sacramento River discharge, notch discharge) and run abundance for each time step, (2) Selecting a bootstrap sample of acoustic tag tracks based on time step covariate values for each run of Chinook salmon, and (3) determining whether each track was entrained under each scenario. In this section we will provide an overview of the simulation with pseudocode summarizing the simulation process, followed by a detailed description of the methods used to perform each of the core simulation functions. The final section of the methods contains a detailed description of the weir modification scenarios included in the entrainment simulation.

4.1. Overview of entrainment simulation process

4.1.1. Along-channel cross-channel coordinate system

We created an along-channel, cross-channel curvilinear coordinate system for the study domain that was used to place each of the 63 scenario evaluation location cross-sections at uniform increments in the along-channel direction. The along-channel axis is roughly parallel to the river right bank of the Sacramento River in the study area at a stage of 28 ft, USGS survey, NAVD88, and the cross-channel axis is defined as always instantaneously normal to the along-channel axis. The along-stream coordinate systems is shown in figure 4, and the 63 notch evaluation cross-sections are shown for a Sacramento River stage of 28.5 ft in figure 5.

4.1.2. Simulation Period

For consistency with other analyses we used Knights Landing catch data provided by the Yolo Bypass Salmonid Habitat Restoration and Fish Passage Project team to estimate abundance for each run of juvenile Chinook salmon within the entrainment simulation (see California Department of Water Resources, 2017). The abundance time series limited the simulation period to water years 1997-2011. Within these water years the simulation only estimated entrainment during the prescribed structural operational window of November 1 through March

15, outside of this period entrainment was set to zero within the simulation. Within this document we refer to the structural operational window as the “notch operation season” or “season”. Within this document notch operation seasons are named by the year in which operations began for the season, so the notch operation season from November 1, 1996 - March 15, 1997 is referred to herein as the 1996 season.

4.1.3. Simulation Time Step

Our analysis of historic data from the Fremont Weir gauge operated by CADWR showed that Sacramento River stage in the vicinity of the Fremont Weir can increase rapidly during the winter and spring freshets associated with juvenile salmon outmigration on the Sacramento River. For example, during the 2016 study period Sacramento River stage increased 13.45 feet over a two day period (Figure 6). Additionally, the Knights Landing rotary screw trap data Catch Per Unit Effort (CPUE) is highly episodic in nature; a large percentage of the yearly CPUE for a run can occur of the course of several days (Figure 7). The combined effect of these two factors is that there are days within the simulation period when there is significant CPUE for a run of Sacramento River Chinook salmon and Sacramento River stage changes rapidly (Figure 8). As a result, we chose a time step of 4 hours for the simulation, because this time step would limit the maximum change in stage between time steps to about 1 foot during days when the yearly fraction of CPUE was much greater than 1%.

4.1.4. Pseudocode summary of entrainment simulation

The core functionality of the entrainment simulation is summarized in pseudocode below:

```
For every time step
    1. Estimate Sacramento River Discharge, Sacramento River Stage and Abundance of each
       run of Chinook salmon
    For every location in the study area
        1. Estimate the cross stream distribution of discharge at this location, given
           Sacramento River Stage; F(Sacramento River stage, notch location)
                For every scenario
        (There is another loop nested here for multi notch scenarios that is not
        shown)
            1. Estimate the discharge through the notch(es) given Sacramento River
               Stage; F(Sacramento River stage)
            2. Estimate the location of the critical streakline (see Stumpner et al, in
               review) given Sacramento River discharge, notch discharge, and the
               cross stream distribution of Sacramento River discharge; F(Sacramento
               River stage, Sacramento River discharge, notch discharge)
            For every run
                1. Estimate a discrete abundance for this run using the Knights
                   Landing catch data
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            2. Draw a weighted random sample of tracks from the pool of observed 2016 tracks with weights determined by the Sacramento River Stage and Sacramento River discharge when each fish track was collected, based on the time step’s Sacramento River Stage and Sacramento River discharge.  The size of this sample is determined by the discrete abundance estimated above.
            For every track
                1. Determine if the track is entrained in the notch; if the track is to the notch side (river right) of the critical streakline at the cross section being evaluated, it is entrained, otherwise it is not entrained.
                2. Increment all entrainment logs
                3. Store all covariates for this location, run, scenario, and time step.
End All
```

4.2. Estimating covariate values at every time step

4.2.1. Estimating Sacramento River Stage and Sacramento River Discharge

The methods used to develop time series for the physical covariates used in the entrainment simulation are described in detail in Stumpner et al., In Review. Sacramento River stage in the study area was estimated by applying a correction of -0.5 ft to hourly historical data collected at the Fremont Weir gauge by CADWR, after this historical data had been corrected to the 2016 CADWR NAVD88 datum. The reasons for this correction are discussed in depth in Stumpner et al., In Review; in brief, this correction produced good agreement between the CDEC data and the USGS temporary index velocity gauge measurements (figure 6, lower panel), and this correction improved the agreement between CDEC data and USGS surveys of the water surface elevation. **Within this report and its figures we refer to the USGS estimate of Sacramento River stage at the western end of the Fremont Weir as “USGS survey, NAVD88”,** to avoid confusion between the USGS estimates of Sacramento River stage and the CDEC data.

Sacramento River discharge in the study area was estimated using a regression model using historic data from other stage and discharge gauges in the region (see Stumpner et al., In Review for details). This regression model produced hourly discharge estimates that are in good agreement with our 2016 index velocity data (Figure 6, upper panel), however, there were a limited number of time steps (2.3% of simulation time steps during notch operational periods) when the historic data needed for this regression was not available. For these time steps Sacramento River discharge was estimated by means of a weighted random draw on Sacramento River stage using the full range of historic stage and discharge estimates available

(Water years 1990-2016). The weights for each draw were calculated using a normal distribution with the distribution mean equal to the time step's stage, and a std of 0.167 ft; this weighting function resulted in ~95% of the randomly drawn discharge samples being selected from historic estimates for time periods when Sacramento River stage was within 4 inches of the stage value for the simulation time step. We used this stochastic approach to fill in missing data in order to assure that the resampled data reflected the historical covariance between Sacramento River stage and Sacramento River discharge at the study site.

4.2.2. Estimating abundance at each time step

At each time step the bootstrap sample size for each of four runs of Sacramento River Chinook salmon (fall run, spring run, winter run, and late fall run) was determined using historic estimates of abundance of these runs. We used the estimated daily percent of yearly catch per unit effort (CPUE) time series from the Knights Landing catch data provided by the Yolo Bypass Salmonid Habitat Restoration and Fish Passage Project team to estimate abundance for each run. The daily percent of yearly CPUE time series for each run normalized each run's daily CPUE by the total CPUE for that run over the trap operational season for each year, so that each water year's CPUE was weighted equally within the simulation; the total abundance for the 15-water-year simulation period sums to 1500% (see California Department of Water Resources, 2017 for more information on this normalization). Using the normalized daily CPUE data assured that the results of the entrainment simulation were not weighted towards years of extremely high CPUE because each water year's daily percent of yearly CPUE summed to 100%. For consistency with other analysis performed by the Yolo Bypass Salmonid Habitat Restoration and Fish Passage Project team we filled in missing values in the Knights Landing daily percent of yearly CPUE data with zeroes.

In order to use the Knights Landing data to calculate a bootstrap sample size for each time step the daily Knights Landing data had to be apportioned between 4 hour time steps. We chose to apportion the daily catch data uniformly between the six time steps that occurred within each day (based on a 4 hour time step), with a new day's catch beginning at the time step that occurred at 00:00 hours on each day. With this approach the catch for time step 1-6 on any day summed to the Knights Landing catch for the entire day (Figure 9). Within the context of the entrainment simulation this approach was analogous to assuming a uniform probability distribution for abundance as a function of hour for each hour within a day; this approach allowed us to run the simulation at a fine enough time scale to capture rapid changes in stage and discharge while maintaining the temporal resolution of the Knights Landing catch data.

The final step in converting the Knights Landing daily percent of yearly CPUE data into a discrete bootstrap sample size for each run was to convert time step proportion of daily percent of yearly CPUE to a discrete sample size. Because daily percent of yearly CPUE could be quite low, we multiplied the time step fraction of daily percent of yearly CPUE by 1000 and rounded the result to the nearest integer to obtain a discrete sample size for each time step (Figure 9). We chose the multiplier of 1000 so that the majority of time steps with low abundance would have a non-zero sample size. This approach resulted in bootstrap sample sizes of one or two tracks for periods of extremely low abundance, sample size of 100-1000 for many of the time steps when abundance was non-zero, and extremely high sample sizes for a small number of time steps when abundance was large (Figure 10). Within this report we refer to the time series of discrete sample sizes for each run at each time step as the “discrete abundance” for each run. These time series summed to slightly less than 1500% for the entire simulation period due to the conversion from continuous catch data to discrete sample sizes. For the purpose of our analyses we used the discrete abundance time series for all entrainment normalizations.

4.3. Drawing the bootstrap sample

At each time step, we drew a discrete sample of acoustic tag tracks to represent the fish available for entrainment for each run based on the discrete abundance time series. For each bootstrap sample tracks were drawn from the pool of all 2016 tracks using weighted random sampling with replacement. Bivariate weights for each of the 2016 tracks were calculated at each time step based on the stage and discharge at the time that each 2016 track entered the study area, given the stage and discharge for each simulation time step. The bivariate weights were calculated using the Matlab ® mvnpdf function (MathWorks ®, Inc. 2017) to estimate a bivariate normal distribution with mean discharge and stage values equal to the time step discharge and stage values, and the covariance matrix computed from a subset of the USGS estimates of historic Sacramento River stage and discharge for water years 1990-2016. The subset of data used to compute the covariance matrix at each time step was defined as all historic data having a stage value within +/- 0.623 ft of the time step stage, and having a discharge value within +/- 638 cfs of the time step discharge. The stage and discharge radii criteria used to select the covariance data for each time step were 1/10th the standard deviation of the stage and discharge values for the entire pool of 2016 fish tracks. The radii criteria was chosen as a balance between the need to maintain diversity in the bootstrap pool against the need to select a bootstrap pool that reflected the covariate values for each time step. Figure 12 and figure 13 illustrate the bivariate weighting function and resulting sampling for two combinations of Sacramento River stage and discharge.

We chose to use a bivariate weighting function because of the variance in the relationship between stage and discharge within simulation period and within the period when the 2016 acoustic tag tracks were collected (figure 11). Because of this variance the relative “suitability” of a track for estimating entrainment should be a function of both the stage and discharge when the track was collected (figure 12, figure 13). By computing the covariance matrix for the weighting function at every time step we allowed the historic covariance between stage and discharge to determine the relative importance of stage and discharge to the weighting function at any point in the stage-discharge space. Finally, the bivariate weighting improved sample selection over univariate approaches (not shown) at locations in the stage-discharge space where the pool of acoustic tag tracks was sparse by allowing the sampling to select tracks based on both stage and discharge (figure 13). The same bootstrap sample drawn for each run at a given time step was used to evaluate entrainment under each scenario at each of the 63 evaluation locations.

4.4. Determining entrainment of bootstrap sample tracks

For every time step, each track in a run's bootstrap sample was classified as either entrained or not entrained under each scenario based on the cross-stream location of each fish track relative to the cross-stream location of the critical streakline, at each of the notch evaluation locations shown in figure 5. The techniques used to estimate the location of the critical streakline are discussed in detail in Stumpner et al. (In Review), and the theory behind using the location of the critical streakline to predict the routing of juvenile Chinook salmon in river junctions is covered in detail in California Department of Water Resources, 2016. We present a summary of the critical streakline method below, followed the application of this approach to the methods used in the entrainment simulation. Within these sections we describe the approach to estimating entrainment at a single possible notch location; these steps are repeated for each of the 63 possible notch locations shown in Figure 5. The details of each simulated notch are discussed in section 4.5 below.

4.4.1. Fundamentals of the critical streakline method

For the purpose of this analysis, the critical streakline was the hypothetical cross-stream dividing line upstream of the notch that separated water that would go into the notch from water that would continue down the Sacramento River under each scenario. The cross-stream location of the critical streakline upstream of the notch was estimated from the cross-stream distribution of bathymetry and discharge immediately upstream of the notch, using techniques that the USGS developed for estimating the location of the critical streakline in tidally forced river junctions.

The USGS hydrodynamics group has worked on refining and testing various techniques for estimating the location of the critical streakline in tidally forced river junctions since 2009, and we have worked with members of the USGS Columbia River Research Lab to test whether the location of the critical streakline can be used to predict the fate of fish moving through tidally forced river junctions, using data collected during the CADWR Georgiana Slough studies (CADWR, 2012, 2015, 2016). Our analysis of the 2011, 2012, and 2014 Georgiana Slough barrier studies showed that the cross-stream location of the critical streakline relative the cross stream location of a fish immediately upstream of a junction is a good predictor of an individual fish's fate within the junction, and a very good predictor of aggregate entrainment rates when these predictions are summed over a group of fish (ibid). Based on this body of work, the USGS hydrodynamics group has developed the critical streakline approach to estimating entrainment in tidally forced riverine junctions, which can be simply summarized as follows:

1. Use hydrodynamic data to estimate the location of the critical streakline immediately upstream of a junction (or notch), and
2. Use the cross stream location of the critical streakline to apportion fish mass into the downstream branches of the junction, either in an aggregate sense (using fish density distributions), or on an individual basis (one track at a time).

For the purpose of this analysis we considered the upstream end of each scenario's notch to be a river junction, with the one branch of the junction being the Sacramento River, the other branch of the junction being flow passing through the notch. Fish tracks were classified as either entrained or not entrained based on their cross-channel location relative to the critical streakline when they reached the junction of the notch and the Sacramento River.

4.4.2. General approach to estimating the location of the critical streakline

Over the course of previous Georgiana Slough studies the USGS hydrodynamics group has explored various techniques for estimating the location of the critical streakline (ibid). The most accurate approach (CADWR 2016) developed by the USGS, and the approach used herein, is to integrate an estimate of the two-dimensional cross-stream velocity distribution upstream of the junction to estimate the cross-stream distribution of discharge immediately upstream of the junction. The first step in this approach is to estimate a cross-stream velocity field upstream of the junction.

For this analysis we estimated the cross-stream velocity field at multiple locations in the Sacramento River by combining multiple velocity profiles measured at uniform intervals in the river cross-section using downward-looking ADCPs (see Stumpner et al., In Review) along with extrapolated velocity profiles for unmeasured areas near each bank. We extrapolated velocity profiles using a ⅙ -power law for the shape of the horizontal and vertical velocity profile (see Stumpner et al., In Review). The mean location of the critical streakline was then determined by integrating the resulting velocity field from the river bed to the water surface across the channel starting from the river right bank until the discharge from this integration matched the discharge entering the notch. This location was the estimated mean location of the critical streakline; we refer to this location as the “mean location” because in real flows turbulent perturbations to the mean velocity field will result in changes in the instantaneous location of the critical streakline.

4.4.3. Estimating entrainment within the simulation: estimating cross stream distribution of discharge at each location given Sacramento River Stage.

4.4.3.1 Estimating cross-stream distribution of discharge at measured transect locations and stages

During 2015, 2016, and the spring of 2017 the USGS and DWR collected downward looking ADCP transects at 9 transect locations throughout the western end of the study area at multiple Sacramento River stage values (see Stumpner et al., In Review). The USGS then processed this data to develop an estimate of the cross-stream distribution of Sacramento River discharge at each cross-section, for each stage value sampled (ibid).

4.4.3.2 Estimating the cross stream distribution of discharge at unmeasured locations and stages

In order to implement the critical streakline method within the simulation, we needed to use our estimates of the cross-channel distribution of Sacramento River discharge obtained from our ADCP measurements to estimate the cross-channel distribution of Sacramento River discharge over the full range of hydraulic conditions represented in the simulation. Further, we needed to estimate the cross-channel distribution of Sacramento River discharge at all 63 notch evaluation locations in the study area. We accomplished this by using our measurements to perform multidimensional linear interpolation to estimate the cross-stream distribution of discharge for combinations of along-stream location and Sacramento River stage that we did not measure.

Because we could only measure the cross-channel distribution of Sacramento River discharge for a small subset of all possible Sacramento River stage and discharge conditions we could not estimate the location of the critical streakline with a high degree of precision; to account for this limitation we added a stochastic perturbation to our estimated location for the critical streakline (see section 4.4.5). Additionally, we did not perform any hydrodynamic measurements when the weir was overtopping (due to safety concerns), so our estimates of the cross-channel distribution of discharge during overtopping periods contain additional uncertainty. However, our simulated entrainment for all scenarios is extremely low during overtopping events due to low notch discharge ratios when the weir was overtopping, so the overall entrainment for single notch scenarios will not be very sensitive to the estimated cross-channel distribution of Sacramento River discharge during overtopping events (recall that the multiple notch scenarios are closed during overtopping events).

This interpolation was performed as follows: First, the cross-stream discharge distributions obtained from measured data were normalized to give the cross-stream distribution of discharge as a function of fraction of channel width (because channel width varied greatly within the study area). Second, the normalized cross-stream discharge distributions were integrated to create CDFs of the cumulative fraction of Sacramento River discharge as a function of distance from the river right bank expressed as a fraction of channel width. We then combined these CDFs using multidimensional linear interpolation to estimate cumulative fraction of cross-stream discharge as a function of: stage, along-channel coordinate, and fraction of cross-channel width. The multidimensional interpolation was performed via gridded interpolation using the Matlab ® griddedInterpolant function (MathWorks ® , Inc., 2017), and this interpolation allowed us to estimate the cross-channel cumulative fraction of Sacramento River discharge as a function of fraction of channel width for unmeasured combinations of along-channel location and stage.

We did not include Sacramento River discharge as an independent variable in the interpolation because we lacked the measurements needed to explain changes in the cross-channel distribution of Sacramento River discharge at each measurement location as both a function of stage and discharge (recall that there is not a constant relationship between stage and discharge in the study area due to backwater effects). As a result, we modeled the effects of discharge (at any given stage) stochastically as a random effect. We chose a normal distribution to represent the effects of discharge (and other unmeasured covariates) on the location of the critical streakline. This process is described below in Section 4.4.5.

4.4.4. Estimating entrainment within the simulation: estimating the discharge through each notch

We used linear interpolation to estimate discharge through each notch as a function of the estimated stage for each time step based on the stage-discharge relationships for each scenario. The stage discharge relationships for each scenario are discussed in detail below, and are summarized in Table 3.

4.4.5. Estimating entrainment within the simulation: estimating the cross-channel location of the critical streakline

At each time step we divided the notch discharge by the estimated Sacramento River discharge to calculate the notch discharge ratio. The estimated cross-channel discharge CDF obtained from the gridded interpolant was then used to find the cross-channel location where the fraction of Sacramento River discharge equaled the discharge ratio. This was the estimated location of the mean critical streakline. We then added a random perturbation to this location to account for uncertainty in the location of the critical streakline.

The random perturbation was added to account for uncertainty in the location of the critical streakline due to the fact that the hydrodynamic measurements used for this simulation were made during a small subset of all possible Sacramento River stage and discharge conditions. For each time step this perturbation was drawn from an error distribution which we parameterized by measuring the cross-stream distribution of discharge during periods of extreme backwater using vessel based ADCP transects, and then calculating the difference between the measured cross-channel distribution of discharge and the estimated cross-channel distribution of discharge produced by the interpolant described in section 3.4.3.2 at multiple locations within the study area. Based on this approach we modeled the error distribution using a normal distribution with a mean of zero, and a standard deviation of 6.5 ft; see Stumpner et al., In Review for more details on the parameter selection for this distribution.

4.4.6. Estimating entrainment within the simulation: estimating entrainment for each track a bootstrap sample

For each track in each of the bootstrap samples drawn for each run the cross-channel location of the track was computed at the point where the track crossed a line instantaneously normal to the along stream axis at each of the notch evaluation locations (These locations are shown in figure 5). If the track's location was to the river right of the location of the critical streakline, then the track was marked as entrained, if the track was to the river left of the critical streakline, the track was not entrained. There were a few additional details for multiple notch scenarios (scenario 5 and scenario 6)

- Only fish tracks from the bootstrap pool that were not entrained in upstream notches were available for entrainment in subsequent downstream notches, thus, the number of fish tracks available for entrainment in each notch decreases for downstream notches to prevent “double entrainment” for a single fish track.
- Entrainment for all notches in a scenario had to be estimated for each of the 63 evaluation locations. In the case of multiple notch scenarios, we assumed that the center of the upstream-most notch was at the evaluation location being used, and then compute entrainment for each downstream notch as occurring at a point located in the center of each downstream notch. The location of each downstream notch was based on the spacing of the notches in the engineering drawings provided for Alternative 5, see Appendix C. As the simulation iterated through along stream evaluation locations, the whole multiple notch simulation was shifted downstream.
- The fish tracks in the bootstrap pool were not altered to account for possible effects of the upstream notches on water velocity or fish behavior prior to downstream notches. As a result, entrainment estimates for multiple notch scenarios have an additional source of uncertainty that is not shared by the single notch scenarios, and which may result in a negative bias in our entrainment estimates for these scenarios.

4.4.7. Estimating entrainment within the simulation: estimating entrainment over the Fremont Weir during overtopping events

The purpose of the entrainment simulation was to explore the effects of scenario location and scenario design on the entrainment of juvenile Chinook salmon under each scenario. As a result, the entrainment simulation did not estimate entrainment over the Fremont Weir. During periods when the weir was overtopping entrainment for each scenario was based only on the computations described above, and thus, represents an estimate of the entrainment during overtopping events that would be due to modifications made to the Fremont Weir under each scenario.

4.5. Simulated scenarios

We simulated entrainment onto the Yolo Bypass for six weir modification scenarios that included four single notch configurations and two multiple notch configurations (Table 2). Four of the scenarios (Scenarios 1,2,3, and 5) used notch stage-discharge rating curves based on real design alternatives, the other two scenarios (scenario 4 and 6) used notch stage-discharge rating curves that were created for analytical purposes. The California Department of Water Resources (DWR) provided stage vs discharge rating tables for the notches simulated in Scenario 1,2,3, and 5.

Scenario 4 and scenario 6 were simulated for analytical purposes only, because including these scenarios allowed us to draw inferences about how changing a notch’s invert elevation might affect entrainment if the notch rating curve was held constant with respect to the difference between invert elevation and Sacramento River stage. The stage discharge relationships for scenario 4 and scenario 6 were derived by modifying the alternative 3 and the alternative 5 notch rating curves so that scenario 4 and scenario 6 would both begin taking water through the notch at a Sacramento River stage value of 15 ft. Scenario 4 and scenario 6 are not indicative of any alternatives currently under review.

Table 2 summarizes the key parameters of the scenarios analyzed in the entrainment simulation, and Table 3 summarizes the notch rating curves for all scenarios in 1 ft increments from 15 ft to 35 ft, and gives an estimate of the magnitude of the Sacramento River discharge that is likely to occur at each stage value based on the USGS 2016 stage-discharge rating. Because of backwater effects there can be a wide range of Sacramento River discharge values which occur at any Sacramento River stage, so the discharge given in Table 3, Column 1 is only indicative of the order of magnitude of Sacramento River discharge for each stage value. A spreadsheet containing more details on the multi-notch configuration simulated in scenario 5 and scenario 6 is contained in Appendix B.

Table 2- Summary of scenario parameters

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Notch Configuration	Based on Alternative 3	Based on Alternative 4	Based on Alternative 6	Based on Alternative 4, with a lower invert	Based on Alternative 5	Based on Alternative 5, with a lower invert
Stage when notch flow exceeds 200 cfs	19 ft	19 ft	19.5 ft	15 ft	20 ft	18.5 ft
Stage when maximum notch flow is reached	31 ft	27 ft	30 ft	23 ft	27 ft	24 ft
Maximum notch flow	6,105 cfs	3,166 cfs	12,253 cfs	3,166 cfs	3,400 cfs	3,400 cfs
Notch flow ends at overtopping	No	No	No	No	Yes	Yes
Notes				This scenario was included for analytical		This scenario was included for analytical

				purposes only		purposes only

Table 3- Notch rating curves for simulated scenarios

DWR provided the USGS with notch ratings as a function of Sacramento River stage for scenarios 1, 2, 3, and 5. The USGS developed the ratings for the analytical scenarios (scenarios 4 and 6). In Table 1 the Sacramento River stage and discharge values shown are USGS estimates.

Sacramento River Stage, ft, NAVD88	2016 Stage – Discharge Rating For Sacramento River Discharge, CFS	Scenario 1 Notch Flow, CFS	Scenario 2 Notch Flow, CFS	Scenario 3 Notch Flow, CFS	Scenario 4 Notch Flow, CFS	Scenario 5 Notch Flow, CFS (Total flow through all notches)	Scenario 6 Notch Flow, CFS (Total flow through all notches)
15	8,680	0	0	0	218	0	12
16	9,693	0	0	0	349	0	45
17	10,706	0	0	0	551	35	94
18	11,720	0	0	0	804	79	177
19	12,733	218	218	0	1,142	152	316
20	13,746	349	349	679	1,547	274	498
21	14,759	551	551	1,195	2,013	443	769
22	15,772	804	804	1,831	2,555	678	1,073
23	16,785	1,142	1,142	2,661	3,166	982	1,776

Sacramento River Stage, ft, NAVD88	2016 Stage – Discharge Rating For Sacramento River Discharge, CFS	Scenario 1 Notch Flow, CFS	Scenario 2 Notch Flow, CFS	Scenario 3 Notch Flow, CFS	Scenario 4 Notch Flow, CFS	Scenario 5 Notch Flow, CFS (Total flow through all notches)	Scenario 6 Notch Flow, CFS (Total flow through all notches)
24	17,798	1,547	1,547	3,664	3,166	1,565	2,381
25	18,811	2,013	2,013	4,787	3,166	2,200	3,084
26	19,825	2,555	2,555	6,067	3,166	2,873	3,223
27	20,838	3,166	3,166	7,502	3,166	3,171	3,259
28	21,851	3,845	3,166	9,041	3,166	3,405	3,182
29	22,864	4,624	3,166	10,675	3,166	3,424	3,407
30	23,877	5,365	3,166	12,253	3,166	3,182	3,246
31	24,890	6,105	3,166	12,253	3,166	3,376	3,403
32	25,903	6,105	3,166	12,253	3,166	3,325	3,863
33	26,916	6,105	3,166	12,253	3,166	0	0
34	27,930	6,105	3,166	12,253	3,166	0	0
35	28,943	6,105	3,166	12,253	3,166	0	0

5. Results

5.1. Simulation of entrainment as a function of notch location

The primary goal of this analysis was to understand how the performance of each notch scenario was affected by the location of the notch or notches within the study area given historical relationships between Sacramento River stage, Sacramento River discharge, and run abundance. To this end we used a Monte Carlo simulation to estimate time series of entrainment for each run, for each scenario, at each of 63 locations within the study area spaced 32.8 ft (10 meters) apart in the along stream direction (figure 5, Appendix A). This approach allowed us to use a variety of metrics to compare entrainment at each of the potential locations for the six simulation scenarios. The rich dataset provided by the simulation also allowed us to consider strategies for optimizing entrainment rates in future designs.

The entrainment simulation period (water years 1997 - 2011) included a mix of dry years when the weir did not overtop during the notch operation period (November 1 - March 15), years when the weir overtopped infrequently during the notch operation period, and wet years when the weir frequently overtopped during the notch operation period (Figure 14). Because the simulation period contains a mix of water year types, estimates of the total entrainment and the total entrainment ***rate*** for each location over the course of the simulation provide a good summary of how notch location affects scenario performance in the long run by incorporating a wide range of conditions. Figure 15 shows the overall total entrainment for each run for each scenario at each location in the study area; this data is summarized below in table 4, while Appendix B contains tables showing mean yearly total entrainment with 90% confidence intervals for each run under each scenario at each of the 63 notch evaluation locations.

For this analysis, total entrainment is expressed as the overall fraction of the yearly abundance time series for each run that is entrained in the notch over the period indicated (usually the 15-water-year simulation period); because the yearly abundance time series sums to 100% for each season, entrainment for each year is weighted equally. This Normalization allows between year comparisons. Figure 16 is similar to Figure 15, but expresses scenario performance as overall entrainment rate for each scenario, which is calculated as the fraction of the simulation fish that passed through the study area during the notch performance period when notch flow was greater than zero which were entrained under each scenario. Figure 15 addresses the question “where should a notch be located to maximize the overall entrainment of a run”, while Figure 16 addresses the question “where should a notch be located to maximize the entrainment of that proportion of each run that passes through the study area when the notch is operating”.

The good news is that the total entrainment and entrainment rate curves for each run show similar trends in scenario performance as a function of notch location. For single notch scenarios (scenarios 1 - 4) notch performance for all run has a peak around 902 ft (275 meters), a sharp decrease in performance between 984 ft (300 meters) and 1,230 ft (375 meters), followed by a broad peak in performance that slowly drops off after 1,640 ft (500 meters). For single notch scenarios the maximum entrainment and entrainment rate for all run is located between 1,312 ft (400 meters) and 1,640 ft (500 meters). Figure 4 shows the along-channel coordinate system for the study area, figure 17 shows the zones of maximum and minimum entrainment described above, and Appendix A provides a table that can be used to convert between along-channel coordinates and UTM.

The relationship between notch locations and performance for multiple notch scenarios (scenario 5 and scenario 6) is similar, but these scenarios had the highest entrainment and entrainment rate for all run between 853 ft (260 meters) and 916 ft (280 meters). For multiple notch scenarios the location indicated on the entrainment and entrainment rate plots is the along-channel location of the center of the first notch, so a peak entrainment listed at 886 ft (270 meters) indicates that peak entrainment occurred for the scenario when the center of the first notch was located 886 ft (270 meters), the center of the second notch was located at 925 ft (282 meters), the center of the third notch was located at 1,410 ft (430 meters), and the center of the fourth notch was located at 1,673 ft (510 meters) (See Appendix C for notch spacing for scenario 5 and scenario 6). The spacing of the notches for the multiple notch scenarios explains why these scenarios reached peak performance when the center of the first notch was located near 885 ft (270 meters), because this location placed all 4 notches in regions where the single notch scenarios had high entrainment.

It is likely that the dramatic drop in entrainment and entrainment rate for all scenarios shown in Figures 15 and 16 around 984 ft (300 meters) is caused by interactions between the study fish's behavior and hydrodynamic effects of the sudden change in bathymetry near the river right bank (Figure 17) in this area of the river. Figure 18 shows the location of the notch evaluation cross-section at 1,198 ft (365 meters) on a bathymetry map of the study area with some example fish tracks; it appears that fish near the river right bank of the study area upstream of the scour hole on the outside of the bend avoid the area around the scour hole. Additionally, it appears that the geometry of the bend interacts with the outmigration behavior of the study fish in a way that resulted in many fish on the river left side of the Sacramento River passing by this portion of the bend (Figure 19). The net result of these effects is that there is a drop in the density of fish tracks in the near-bank area in the vicinity of this scour hole (Figure 20), while the area of peak water velocity moves closer to the bank in the scour hole. Accordingly, a notch located in the vicinity of the scour hole will likely need to entrain a large amount of water to move the critical streakline into locations in the cross-section with high fish densities. The effects of the scour hole on scenario performance suggest that the bathymetry and hydrodynamics immediately upstream of a notch can have significant impacts on the notches entrainment rate.

Because the entrainment simulation is based on tracks of acoustically tagged hatchery late fall run Chinook, the differences between the simulated entrainment for each run are entirely the result of the difference in abundance timing for each run during the simulation period. Thus, differences in scenario performance between run show the expected effect of each run' outmigration timing on the entrainment of hatchery late fall run Chinook, and are not indicative of any behavioral differences between run. Nevertheless, the differences between scenario performance for each run can inform our understanding of how the covariance between abundance timing, Sacramento River stage, Sacramento River discharge and scenario notch rating curves combine to affect entrainment.

The most significant observation from Figures 15-16 is that the entrainment and entrainment rate curves for each run suggest that differences in abundance timing between runs determine the maximum entrainment and entrainment rate for each run under each scenario, but, differences in abundance timing do not significantly alter the relationship between along-channel location and scenario performance. In other words, these results suggest that a notch location that maximizes entrainment for fall run abundance timing is likely to have near maximum entrainment for winter and spring run abundance timing as well. Again, we caution that these results are based only on run abundance timing, and do not incorporate behavioral and physiological differences between runs, nor between the size and degree of smoltification of the juvenile salmon that can vary between years and throughout any given outmigration season.

Table 4 - Summary of scenario performance

Percent of yearly juvenile salmon abundance entrained onto the Yolo Bypass under each scenario, by run, for the notch locations that resulted in maximum fall run entrainment for each scenario. The mean yearly percent of yearly abundance entrained is given along with 90% bootstrap confidence intervals in parentheses. The final row gives the along-stream coordinate of the notch location that resulted in peak entrainment for fall run under each scenario, see figure 4 for a map showing the along-stream coordinate system in the study area.

Run	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**
Fall Run	12% (6%-21%)	9% (2%-21%)	28% (12%-43%)	15% (3%-28%)	6% (2%-12%)	8% (2%-15%)
Spring Run	9% (4%-15%)	7% (4%-14%)	22% (6%-42%)	16% (9%-20%)	5% (1%-11%)	7% (2%-13%)
Winter Run	9% (2%-17%)	7% (2%-15%)	23% (4%-42%)	15% (8%-23%)	5% (2%-11%)	7% (4%-13%)
Late Fall Run	5% (0%-12%)	4% (0%-11%)	11% (0%-38%)	9% (1%-20%)	2% (0%-10%)	3% (0%-12%)
Location of notch at peak entrainment (UTM Zone 10S, m, NAD83)	615849E, 4290952N	615849E, 4290952N	615780E, 4290905N	615849E, 4290952N	615636E, 4290860N	615636E, 4290860N
Along stream coordinate of notch at peak entrainment	495 m	495 m	415 m	495 m	265 m	265 m

5.2. Effects of notch rating curves and run abundance timing on entrainment

While differences in abundance timing between each run did not result in significant differences in the relationship between notch location and notch performance for each run, the differences in abundance timing did have a significant effect on the maximum entrainment rate and maximum total entrainment for each run. With the exception of scenario 4, all scenarios showed the same pattern in the relative entrainment rate between run throughout the study area: fall run had the highest entrainment rate, spring run and winter run had similar entrainment rates that were lower than fall run, and late fall run had the lowest entrainment rates (Figure 16).

Scenario 4 is the exception, as all run experienced similar entrainment rates under this scenario (Figure 16, panel 4). Patterns in the relative differences between total entrainment for each run are similar to the patterns in the relative difference between entrainment rate for each run, with scenarios 1,2,3,5, and 6 showing the highest total entrainment for fall run, the lowest entrainment for late fall run, and middle values for spring run and winter run. Again, the exception was scenario 4, which showed similar total entrainment for fall run, spring run, and winter run, and the highest overall entrainment for winter run rather than fall run.

The reason that scenario 4 had the most consistent entrainment rates between runs is that this scenario had the highest notch flows for stages below 22 ft, when a large proportion of spring run, winter run, and fall run were present in the study area during the simulation period (Figure 21). The cumulative distribution functions (CDFs) for each run' simulation abundance as a function of stage shown in figure 21 show that during the simulation period around half of the spring run, winter run, and late fall run yearly abundance passed through the study area when stage was below 22 ft, while only about 30% of fall run abundance passed through the study area when stage was below 22 ft. Additionally, the CDFs for spring run, winter run, and late fall run all show a rapid increase in cumulative abundance between 19 ft and 22 ft that does not occur in the CDF for fall run. This rapid rise in abundance between 19 ft and 22 ft for spring run, winter run, and late fall run suggests that there is some interaction between watershed hydrology and the life history of these run that consistently results in these runs moving through the study area during outflow events that result in Sacramento River stages in the study area between 19 ft and 22 ft. As a result, scenario 4, which entrains about 10% of Sacramento River water at 19 ft, and reaches a peak discharge ratio at 23 ft has the second highest total entrainment for all run. Scenario 3 has higher total entrainment for all run, but, scenario 3 reaches a peak discharge of 12,000 cfs, while scenario 4 has a peak discharge of only 3,166 cfs.

Finally, scenario 4 has similar entrainment rates for all runs, and similar total entrainment for fall run, spring run, and winter run, but lower total entrainment for late fall run. The lower total entrainment for late fall run under scenario 4 (and all other scenarios) is the result of two factors: first, during the simulation period about 25% of late fall run yearly abundance passed through the study area at stages below 16 ft, while only about 10% of other run yearly abundance passed through the study area below 16 ft during the simulation (all scenarios entrained little to no water below 16 ft), and second, during the simulation period, late fall run had lowest proportion of total yearly abundance that occurred during the notch operation period (Table 5). Thus, even though scenario 4 entrained late fall run at the same rate as other run, there was a lower overall proportion of late fall run available for entrainment during periods when the notch was operating.

Table 5 - Percent of simulation abundance for each run that passed through the study area during notch operation periods over the 15-water-year simulation.

Run	Percent of simulation total yearly abundance for the simulation period that transited the study area during notch operation periods (Abundance present during notch operation period / total yearly abundance)*100%
Fall Run	79%
Spring Run	81%
Winter Run	98%
Late Fall Run	68%

5.3. Entrainment rate and entrainment efficiency for each scenario as a function of stage.

As discussed above, the entrainment simulation is only based on acoustic tag tracks from hatchery late fall run chinook, so the differences in simulated entrainment between run reflects the differences in the frequency of the relative timing of stage, discharge and run abundance during the simulation period. In order to better understand how abundance timing affected entrainment under each scenario we computed stage vs entrainment rate curves for each scenario (Figure 22), and stage vs entrainment efficiency curves for each scenario (Figure 23). Entrainment rate indicates the fraction of the bootstrap sample at each time step that was marked as entrained under each scenario, and entrainment efficiency is the ratio of the time step entrainment rate for each scenario divided by the time step discharge ratio for each scenario. When entrainment efficiency is greater than one a notch is entraining a greater proportion of fish than water.

The underlying stage vs entrainment relationship for each scenario is the same for each run, so we chose to compute the relationship for winter run because the winter run abundance timing resulted in the largest number of entrainment “trials” within the simulation. Because the spatial distribution of discharge and fish tracks changes throughout the study area and, thus, the stage vs entrainment rate/efficiency curves for each scenario change throughout the study area; it is possible to compute a stage-entrainment rate curve for each of the 63 along-channel notch locations evaluated in the simulation. For the sake of brevity, we chose to present curves for the location in the study area that had the highest total entrainment of winter run for each scenario (These locations are shown in Figure 17).

Because of backwater effects in the study area, a range of Sacramento River discharge values occur in the historical record for any Sacramento River stage value (Stumpner et al., in review). As a result, there is a range of notch discharge ratios for each scenario at any stage, and, because of this variability in discharge ratio and variability in behaviors and other environmental covariates, we expect that run of the river fish will experience a range of entrainment rates at any Sacramento River stage under all future notch scenarios. Within the entrainment simulation the range of entrainment rates predicted for any stage is a function of three processes: firstly, the entrainment simulation is driven by historic stage and discharge data, so the historic variance in discharge ratio for each scenario is captured in the simulation. Secondly, there is stochasticity inherent in the bootstrapping approach used to draw the track pools at each timestamp, so any particular stage-discharge pair will not always draw from the same track pool. Thirdly, we add stochastic error to the computed critical streakline location for each scenario at each time step to account for uncertainty in our ability to predict the critical streakline location given the effects of backwater condition on cross-channel velocity distributions within the study area (Stumpner et al., in review). As a result of these three factors the stage vs entrainment rate and stage vs entrainment efficiency curves presented in Figures 22 and 23 are in the form of a 90% confidence interval and median value for scenario entrainment rate as a function of stage. The range of discharge ratios at each stage is shown for each scenario to illustrate the variability in discharge ratio. For the multiple notch scenarios the entrainment rate and median discharge ratio are based on total entrainment of water and fish through all notches operating at any stage value.

The scenario stage vs entrainment rate curves shown in Figure 22 indicate how efficient each scenario is at entraining fish at any stage: when the scenario entrainment rate is greater than the scenario discharge ratio the scenario is entraining proportionally more fish than water, and when the entrainment rate is lower than the discharge ratio the scenario is entraining proportionally more water than fish. Figure 23 shows the range of entrainment efficiency values for all time steps at a particular stage. The entrainment efficiency of each scenario at any location is controlled by the balance between the cross-channel distribution of fish and the cross-channel distribution of flow. Figures 24 and 25 illustrate the cross-channel distribution of fish and flow in the study area. The interaction between fish distribution, flow distribution, and notch rating curves controls entrainment efficiency. This interaction is complex; however, in general, the effects of discharge ratio on entrainment can be summarized for the locations in the study area that produced maximum scenario entrainment as follows:

1. There is a zone very near the river bank where there are few fish, so extremely low discharge ratios produced low entrainment rates for all scenarios.

2. There is a zone a little further from the bank where fish densities are high and water velocities are not the peak within the cross section: increasing the discharge ratio to the point where the critical streakline enters this zone will result in rapid increase in entrainment and entrainment efficiency for all scenarios (this is a highly non-linear

relationship - almost a step function process due to the high gradient in the fish densities).

3. There is a zone beginning at about 49 ft - 82 ft (15-25 meters) from the river right bank (Figure 25) where water velocities reach a peak. A large proportion of the total discharge in the cross-section is contained in this region. Once a scenario's discharge ratio is high enough that the critical streakline reaches this zone, a large increase in discharge ratio is required to move the critical streakline further out into the river cross section, and entrainment efficiency decreased.

4. The spatial distribution of 2016 study fish tracks for periods when Sacramento River was below bankfull (see figure 24) was dramatically different than the spatial distribution of 2016 fish tracks for periods when the Sacramento River was above bankfull (Figures 26, 27). In general, fish tracks collected after the Sacramento River stage exceeded bankfull (28.5 ft) were less concentrated on the outside of the bend, so that at higher stage scenarios needed a very high discharge ratio to entrain many fish. This observation is likely related to the influence of the slow velocity water associated with the overbank region pushing the influence of the sidewall boundary layer into the center of the channel (See Stumpner et al., In Review). It is important to note that the accuracy of the acoustic tag tracking array decreased when the Sacramento River was above bankfull so we cannot be sure of the exact magnitude of the effect, but, the spatial extent of the shift in the observed spatial distribution of tracks between below bankfull conditions and bankfull conditions was large enough that we believe that the effect is due to true changes in the location of study fish.

The entrainment rate and entrainment efficiency curves shown in Figures 22 and 23 reflect these general trends. For all scenarios entrainment efficiency increased rapidly once the discharge ratio exceeded 10%, with most scenarios reaching a peak entrainment efficiency between 25 ft and 27 ft and a discharge ratio of about 15%. Because of the covariance between stage and discharge ratio for all of the scenarios tested, we cannot ascertain whether the location of peak entrainment efficiency is a function of discharge ratio, a result of the spatial distribution of fish and flow at 25 ft - 27 ft of stage, or some combination of the two. In the future, we recommend simulating scenarios with constant discharge ratios which will allow us to explore the effects of stage and discharge ratio independently.

For all scenarios except scenario 3, entrainment rate and entrainment efficiency dropped off rapidly once stage exceeded bankfull. Scenario 3 maintained high entrainment rates and an entrainment efficiency near 1 for stages greater than bankfull because of the high discharge ratio for this scenario places the critical streakline near the center of the river at high stage values. The multiple notch scenarios had lower entrainment rates that scenarios 2 and 4 (which have similar overall notch rating curves), because at many stages the discharge for these scenarios was spread between multiple notches, so the lower discharge ratio for each individual notch (not shown) was less likely to push the critical streakline into the region in the cross-section where fish were more concentrated.

Finally, there are several features of the entrainment rate and entrainment efficiency curves that are a result of the mechanics of the simulation process. First, the dip in the entrainment rate for scenario 4 at 20 ft is a result of the small number of study fish tracks that passed through the study area at 20 ft of stage (figure 11); because of the limited fish tracks collected at this stage the bootstrap samples for stages around 20 ft are heavily influenced by a small number of fish tracks that happened to be far away from the bank at the location which we chose to compute the stage vs entrainment curves. When stage vs entrainment curves are computed for locations where these fish tracks were closer to the bank (not shown) the dip in entrainment is not evident, and the plots showed a smooth entrainment curve for scenario 4 from 15 ft to the peak in entrainment located around 24.5 ft. Secondly, the extremely high entrainment efficiency for scenarios 1,2,5, and 6 at low notch flows are due to the extremely low discharge ratios for these scenarios when the notches first begin to take water. Entrainment efficiency is calculated using discrete numbers and cannot change with the same precision as discharge ratio, which is a continuous variable. As a result, when discharge ratios are very low entrainment of a single fish track can cause the entrainment rate to increase out of proportion with the discharge ratio, and entrainment efficiency becomes large. Note that the two scenarios that took more water at low flows do not indicate the very high entrainment efficiencies at the lowest notch flows.

5.4. Entrainment as a function of water year

Because of the complex relationship between Sacramento River stage, run abundance, and scenario entrainment rate, we wanted to be sure that the along-stream location vs entrainment curves we computed for the entire simulation were not being disproportionately influenced by water years with extremely high or low Sacramento River stage values. To explore the effects of water year on simulated entrainment, we placed each notch operation season (November 1 - March 15) into one of three water year categories based on the number of hours within the operation season that the weir overtopped (Tables 6 and 7), and then computed total entrainment vs along-stream location curves for each water year category (overtopping was defined as Sacramento River stage > 32.3 ft). The operation season classifications are shown in Table 7, and the entrainment vs along-stream location curves for each water year class, run, and scenario are shown in figure 28 through figure 33. The most important result of analysis of the water year entrainment vs along-stream location curves is that these curves suggest that water year type has a large influence on the maximum entrainment for each run under each scenario, but, water year type doesn’t change the overall trends in scenario performance vs along-stream location. This is a positive result because it suggests that the same location in the cross section will produce maximum entrainment for a variety of abundance timing and water years.

The entrainment vs along-stream location curves shown in Figures 28 through 33 show many interesting differences in the maximum entrainment for each water year category for each run and scenario. Some of the most important observations are:

1. Most scenarios entrained the most fall run in seasons when the weir did not overtop. This is because fall run are most likely to be present in the study area at high Sacramento River stage values when entrainment efficiency for most scenarios is lowest; in dry years fall run most likely pass through the study area at lower stages when entrainment efficiency was higher.

2. During years when the weir did not overtop, scenario 4 had the highest peak entrainment for spring run, winter run, and late fall run. This is despite the fact that scenario 3 has maximum notch flows that are nearly 4 times higher than the maximum notch flows for scenario 4. This observation suggests that lowering scenario stage-discharge curves to capture fish passing through the study area between 19 ft and 22 ft could be an efficient way to increase entrainment of these run in dry years.

3. Late fall run tended to experience the highest overall entrainment during wet or moderately wet years, as opposed to the other runs which experienced the highest overall entrainment during dry or moderately wet years.

Table 6 - Water year type classifications based on number of hours that the weir overtopped during each season in the simulation

Number of hours that the weir overtopped per season (Overtopping is defined as Sacramento River stage>32.3 ft, USGS survey, NAVD88)	
0	No overtopping, Category 1
1-200	Few overtopping, Category 2
200 +	Wet, Category 3

Table 7 - Number of hours that the Fremont Weir overtopped during each season in the simulation

Season	Hours of weir overtopping per season	Season classification
1996	1204	Wet
1997	1268	Wet
1998	744	Wet
1999	712	Wet
2000	0	No Overtopping
2001	112	Few Overtopping
2002	156	Few Overtopping
2003	448	Wet
2004	0	No Overtopping
2005	1120	Wet
2006	0	No Overtopping
2007	0	No Overtopping
2008	0	No Overtopping
2009	12	Few Overtopping
2010	36	Few Overtopping

6. Discussion

6.1. Primary sources of uncertainty in the entrainment simulation

The entrainment simulation uses hydrodynamic data and acoustically tagged fish track data collected under a limited range of field conditions to predict entrainment for future weir modification scenarios over a range of hydraulic conditions and run abundance timing scenarios. As a result, we view the entrainment simulation results primarily as a tool for exploring the interaction between factors which we expect to be the primary drivers of scenario efficacy: a scenario's stage-discharge rating, a scenario's location within the study area, the covariance between stage and discharge at the study location, and the timing of salmon run abundance. However, the entrainment simulation was not designed to explore the fifth factor that we expect to control scenario entrainment: the physiology and behavior of naturally migrating juvenile salmon, both smolts and pre-smolts. The entrainment simulation is entirely based on a limited sample of tracks from acoustically tagged hatchery late fall run Chinook salmon smolts. At this time we lack the data to evaluate the suitability of using large (~150mm fork length) hatchery-raised late fall run smolts as surrogates to predict the high resolution movement patterns of juvenile salmon from multiple runs that emigrate as both smolts and pre-smolts, but it is reasonable to expect that the behavior of the hatchery surrogates will not be a good predictor of the behavior of some, or all, of the naturally migrating juvenile salmon that are the focus of this project. Given the physiological differences between naturally migrating winter run and spring run juveniles and the large hatchery origin smolts used for this experiment, we expect that the use of large, hatchery origin smolts to predict the movement patterns of naturally migrating juvenile salmon is the single largest source of uncertainty within the entrainment simulation. Nevertheless, there is little that can be done to directly address this uncertainty in the absence of detailed data on the fine scale movement patterns of the naturally migrating juvenile salmon that will be affected by modifications to the Fremont Weir.

There are additional sources of uncertainty in the entrainment simulation that we view as secondary to the fundamental limitation of using hatchery surrogate fish to predict the movements of naturally migrating juvenile salmonids. These other primary sources of uncertainty are:

1. The limited range of Sacramento River backwater conditions and other covariates represented in the 2016 track data set. The bivariate weighting function used in the

bootstrap sample selection process helps to mitigate the limited range of backwater conditions within the 2016 track data set, but given the limited data collection window for the 2016 track data there may be covariates which are first order drivers of entrainment that we do not account for within the entrainment simulation.

2. The possibility that weir modifications will alter the hydrodynamics within the study area. We expect that weir modifications will alter the water velocity patterns within the study area in the immediate vicinity of a notch, but, with the exception of Scenario 3 we do not expect that modifications to the weir will greatly change the cross-channel distribution of flow at a notch because of the low ratio (0.1-0.2) of notch flow to Sacramento River flow. As a result, we only expect local changes to water velocity patterns to affect entrainment if these velocity changes cause fish to alter their behavior in the vicinity of a notch, and, if water velocities in the vicinity of the notch are low enough for the altered behavior to affect entrainment. Scenario 3 is the exception because it is likely to entrain up to 50% of the flow in the Sacramento River for stage values between 28 ft and the crest of the Fremont Weir; it is difficult to predict the effects of such large notch flows on the cross channel distribution of discharge in the Sacramento River, so the results for Scenario 3 should be viewed with greater skepticism than the results for scenarios with lower peak discharge ratios.

3. The effects of backwater condition on the cross-channel distribution of flow in the study area. We have directly incorporated this uncertainty into the simulation by adding a stochastic perturbation to our estimated location for the mean critical streakline; the uncertainty in the stage-entrainment rate curves for each scenario are a direct result of this stochastic error.

7. Recommendations

The USGS's past analyses of entrainment at the Georgiana Slough junction demonstrated that the location of the critical streakline in a riverine junction is a good predictor of entrainment probabilities for individual acoustically tagged juvenile salmon, and a good predictor of the entrainment rate for aggregated groups of acoustically tagged juvenile salmon (CADWR 2012, 2015, 2016). For this reason, the critical streakline approach was used in the entrainment simulation to estimate entrainment under future scenarios based on fundamental hydrodynamic principles and observed acoustic tag tracks. We view the entrainment simulation as a sophisticated "back of the envelope calculation" that combines physical principals with the observed track data to produce entrainment estimates. We expect that the results of the entrainment simulation are a good order-of-magnitude predictor for the entrainment and entrainment rate of **fish that are physiologically and behaviorally similar to the 2016 study fish** under each scenario. While we caution that the results of the entrainment simulation may not be applicable to naturally migrating fish, the reality is that we lack the high resolution tracking data needed to improve on these estimates for naturally migrating salmonids. Given these limitations, the results of the entrainment simulation suggest the following:

- Locating single notch configurations in a ~100 meter (328 ft) long region adjacent to the western terminus of the Fremont Weir (Figure 17, see Appendix A for UTM locations) will result in near maximum entrainment, and near maximum entrainment rates for all single notch scenarios. Performance of scenarios located in this area will likely be robust to changes in abundance timing and water year type.

- Locating multiple notch configurations with the first notch approximately 705 ft (215 meters) upstream of the western terminus of the Fremont Weir (Figure 17, see Appendix A for UTM locations) will result in near maximum entrainment, and near maximum entrainment rates for alternatives with notch spacing similar to Alternative 5. Further, the performance of scenarios located in this area will likely be robust to changes in abundance timing and water year type.

- Bathymetry and hydrodynamics upstream of a weir modification could have large impacts on performance. Care should be taken to avoid siting modifications in areas where fish are likely to respond to bathymetric gradient in the along-channel direction. It may be possible to enhance entrainment in a weir modification by altering (reducing) the along channel bathymetric gradients upstream of the modification.

- Either lowering notch invert elevation or installing a control section downstream of a notch will likely increase the entrainment of winter run, spring run, and late fall run, especially during very dry years. Specifically, entrainment of winter run and spring run may be greatly increased by designing a weir modification to enhance entrainment of fish at Sacramento River discharges that currently occur between Sacramento River stage values of 19 ft NAVD88 and 22 ft NAVD88. This result is likely to be robust to differences between naturally migrating salmonids and the hatchery surrogates used in the analysis, because it is primarily driven by run abundance timing. If physical constraints, such as land surface elevations in the Yolo Bypass adjacent to the Fremont Weir, make it impractical to lower the notch invert elevation sufficiently to achieve an adequate notch discharge ratio at 19 ft stage, it may be possible to design a hydraulic control section in the Sacramento River to increase entrainment through notches with higher invert elevations at lower Sacramento River stage values. Specifically, a control section installed downstream of the notch could be used to increase water levels at the notch for Sacramento River discharges that initiate winter run and spring run outmigration during very dry years.

- It is likely that the entrainment efficiency of multiple notch configurations could be improved by optimizing the tradeoff between the number of notches utilized, and the discharge ratio for each notch. Further analysis could be performed to estimate the most efficient discharge ratio for each notch location as a function of stage, and then the total number of notches could be set based on the targeted total discharge as a function of stage.

- The decrease in entrainment efficiency observed for Sacramento River stages above bankfull for all scenarios was likely the result of the hydrodynamic effects of inundation of the floodplain between the Sacramento River and the weir (Stumpner et al., In Review), combined with the study fish's response to these hydrodynamic effects. In another bend on the Sacramento River that lacks a floodplain the USGS has observed increased cross channel velocities towards the outside of the bend (Dinehart and Burau, 2005); in general we would expect increased cross channel velocities to enhance entrainment under most scenarios. For this reason it may be possible to increase entrainment in the study area for most scenarios by extending the Sacramento River levee from the western end of the Fremont Weir to the upstream end of a notch to prevent this floodplain area from inundating prior to weir overtopping.

8. References

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9. Figures

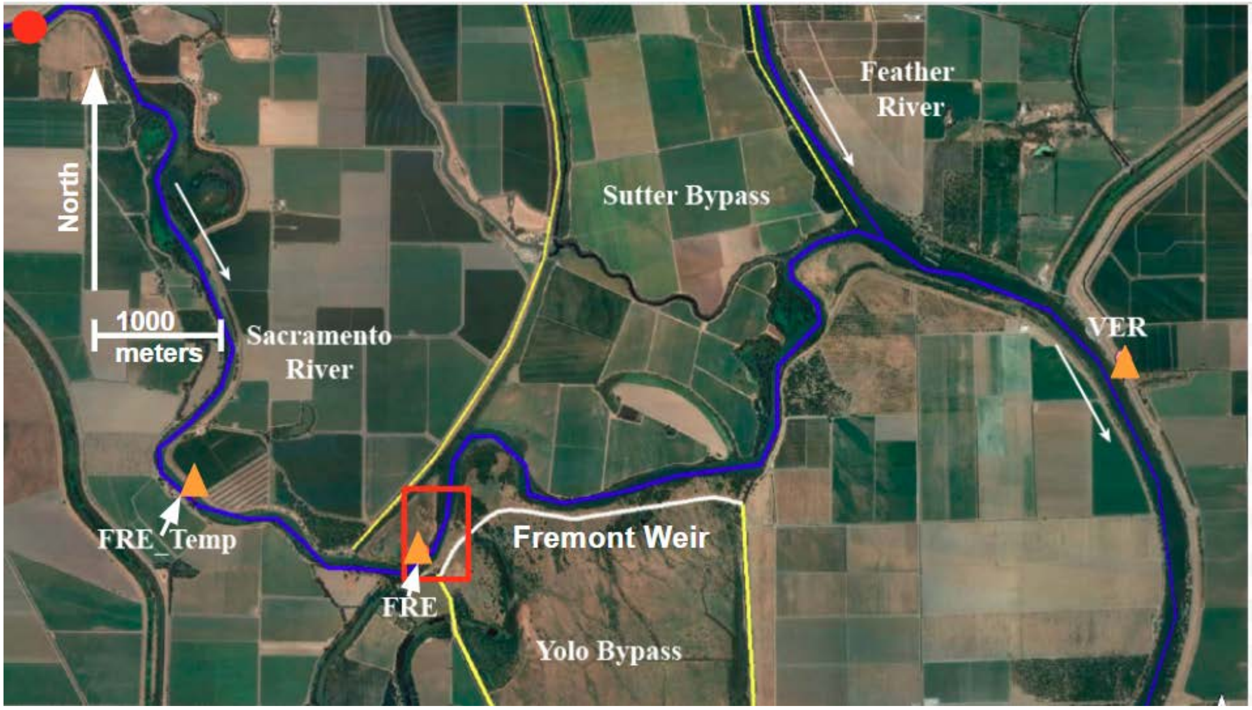


Figure 1 - Aerial photograph showing the approximate boundary of the USGS study area

The portion of the Sacramento River on the western end of the Fremont Weir where the USGS collected water velocity data and high resolution two dimensional acoustic tag tracks is outlined in red. The Fremont weir is highlighted with a thick white line, and the approximate boundary of the northern end of the Yolo Bypass is shown in yellow. The location of gauging locations is indicated with orange triangles; the USGS temporary index velocity gauge is labeled “FRE_Temp”, the location of the DWR gauge at the western end of the Fremont Weir is labeled “FRE”, and the location of the DWR gauge on the Sacramento River at Verona is labeled “VER”. The large red dot in the upper left corner of the image shows the approximate location of the Knights Landing rotary screw traps which provided the abundance timing data used in the simulation.

Figure 2 - Aerial photograph showing the bathymetry and hydrophone locations in study area

Aerial photo showing the portion of the Sacramento River on the western end of the Fremont Weir where the USGS collected water velocity data and high resolution two-dimensional acoustic tag tracks. The photo is overlaid with a bathymetry map in the study area, cooler colors on the bathymetry map denote deeper areas. Hydrophone locations are shown as white circles.

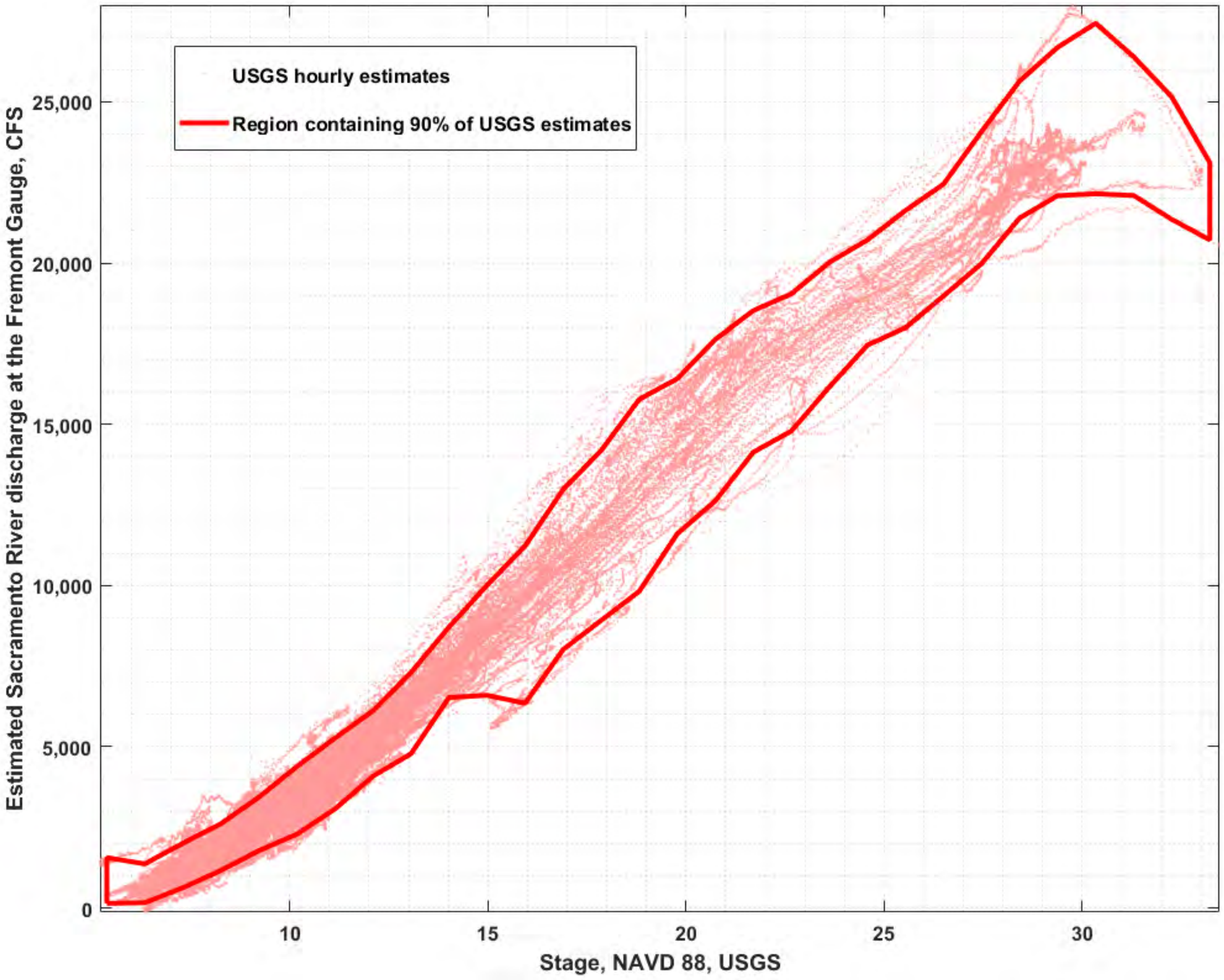


Figure 3 - Plot showing the range of estimated stage-discharge values for the Sacramento River in the vicinity of the western end of the Fremont Weir from 1996 to 2011.

Red dots indicate hourly stage-discharge estimates, and the thick red line indicates the region containing 90% of the discharge observations for any given stage. Because discharge through the proposed notch scenarios will be a function of stage only, the variability in the relationship between Sacramento River stage and Sacramento River discharge will result in variability in the fraction of Sacramento River water diverted under each scenario.

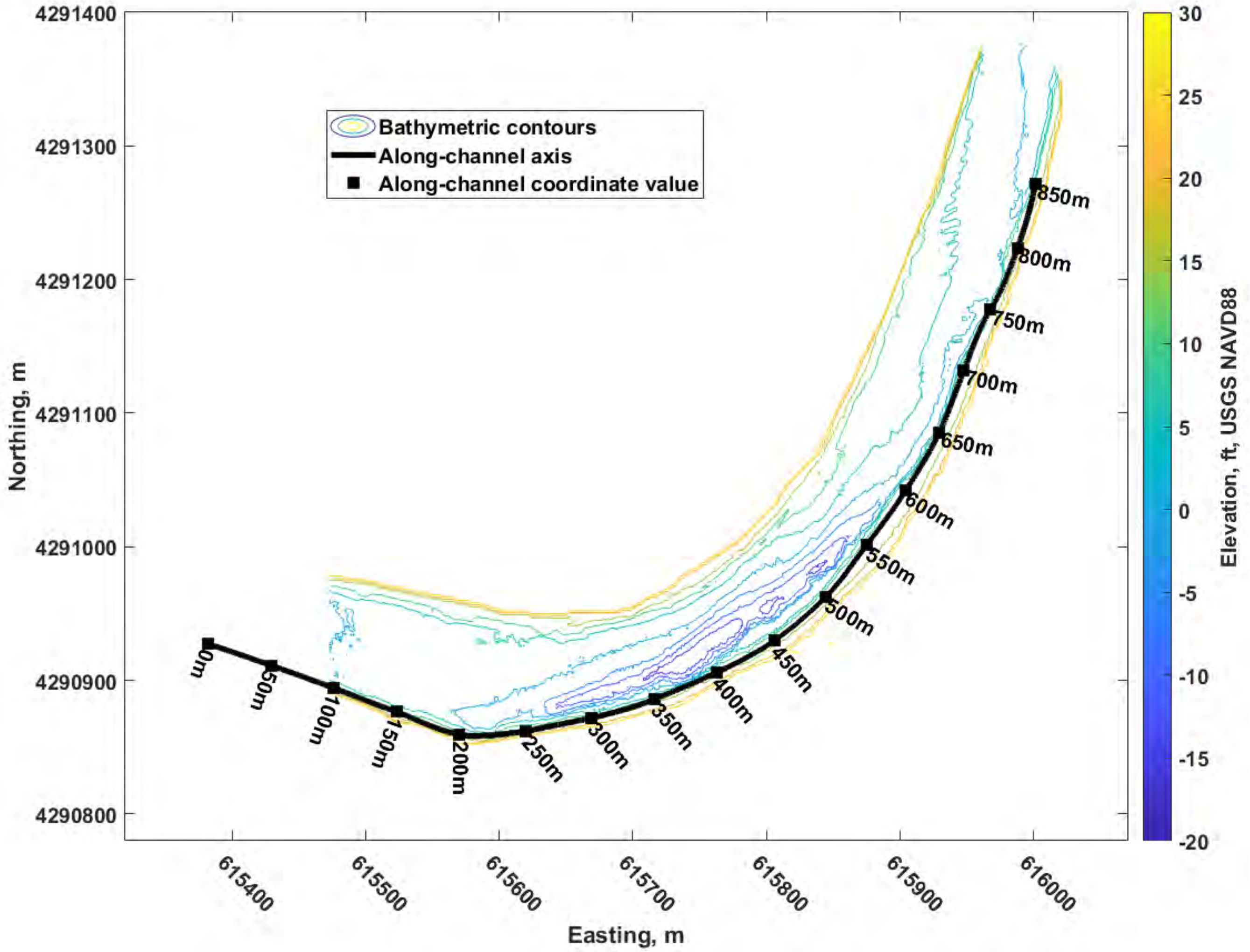


Figure 4 – Along-stream coordinate system

Plot showing the along-stream axis used to locate notch evaluation locations. The thick black line is the along-stream axis, the cross-stream axis is always perpendicular to this line. The black squares on the along-stream axis demarcate 50 meter increments in the along-stream direction. The thin colored lines indicate bathymetric contours.

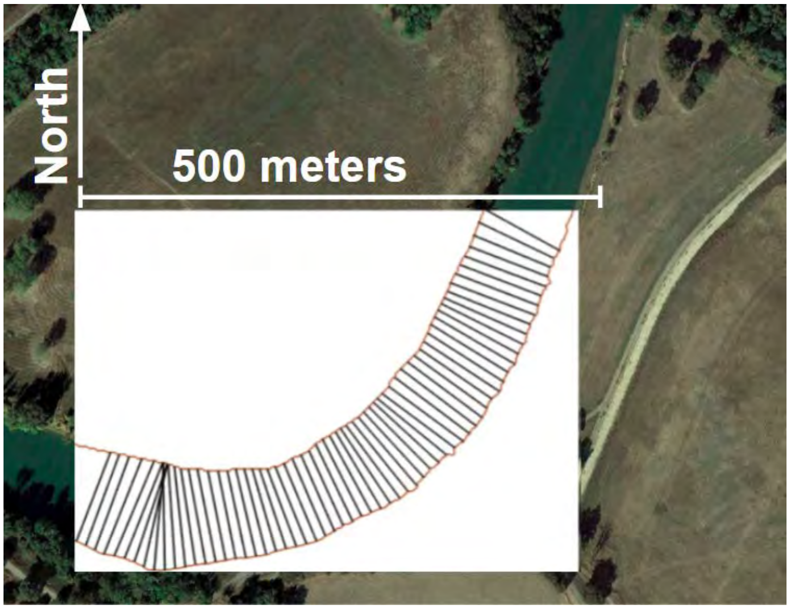


Figure 5 – Notch evaluation locations

The white box indicates the study area for the simulation; the black lines indicate the 63 notch evaluation cross-sections where entrainment was estimated for each scenario at each time step. See Appendix A for UTM coordinates for these locations.

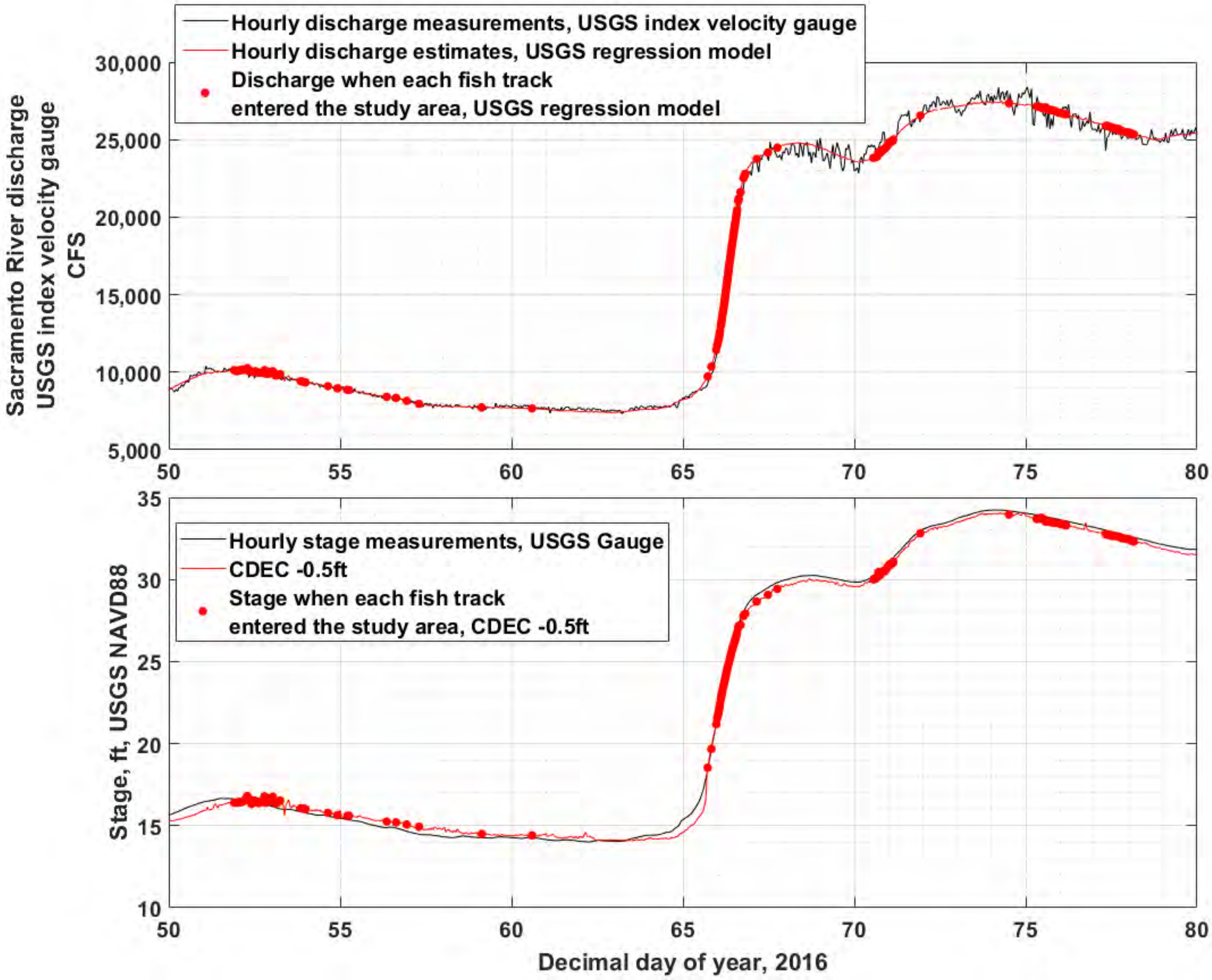


Figure 6 - Plot showing Sacramento River discharge and Sacramento River stage during the time period that 2016 acoustic tag tracks were collected

The top panel shows a time series of Sacramento River discharge based on the temporary index velocity gauge (black line) and the regression equation developed to estimate historic discharge (red line), and the discharge estimates when 2016 acoustic tag tracks were collected (red dots) (See Stumpner et al., in review for details on the discharge estimates). The bottom panel shows time series of Sacramento River stage measurements during time periods when 2016 acoustic tag tracks were collected, and USGS stage estimates when 2016 acoustic tag tracks were collected (red dots). Note the rapid rise in stage and discharge following day 65.

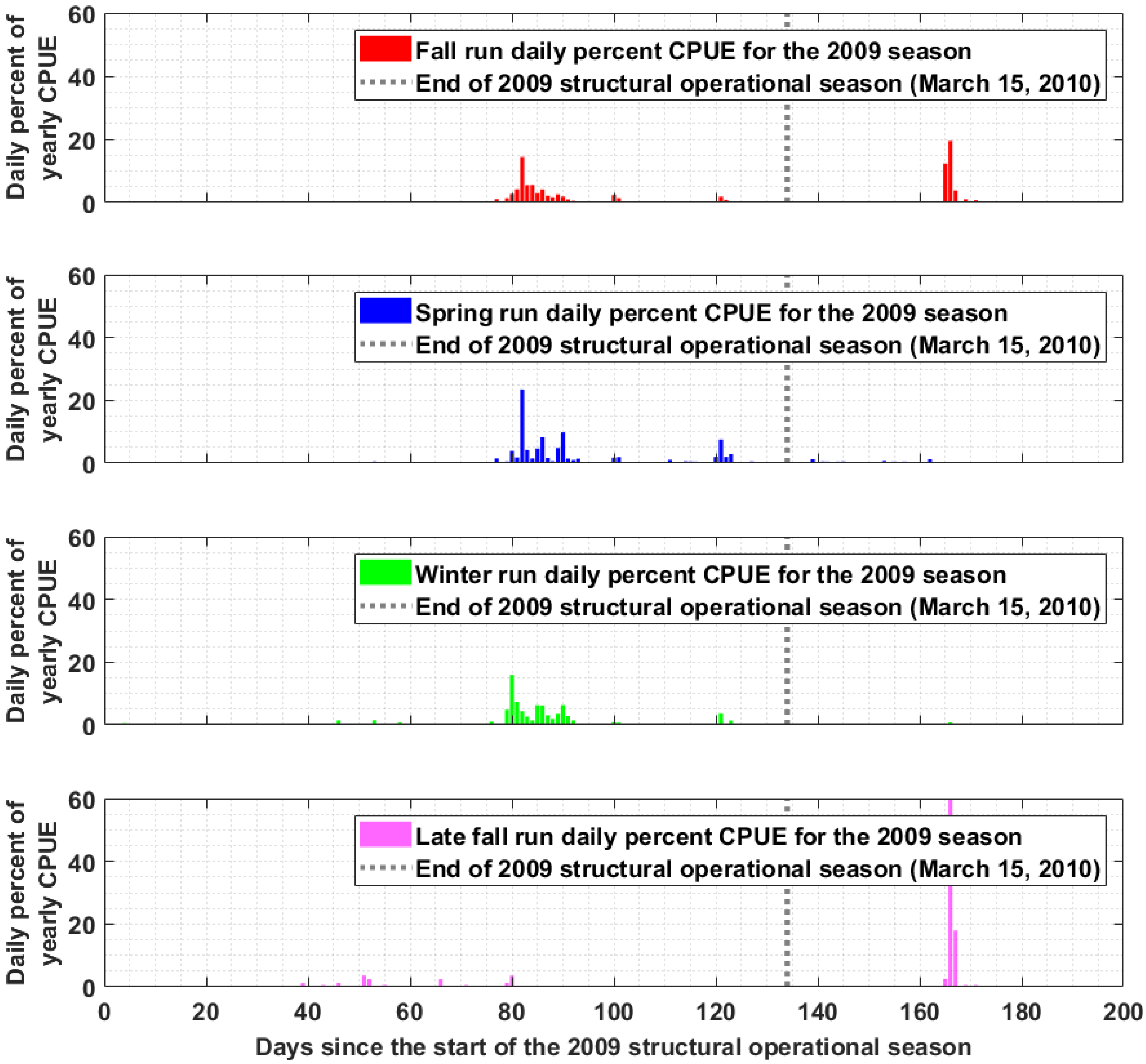


Figure 7 - Daily catch data from the Knights Landing rotary screw trap for the 2009 season (Water year 2010)

Catch is expressed as daily percent of the yearly total Catch Per Unit Effort (CPUE):

Daily percent of yearly CPUE =((Daily Catch/Daily Effort) / (Yearly Catch/Yearly Effort)) *100%

The location of the Knights Landing rotary screw traps is shown in Figure 1.

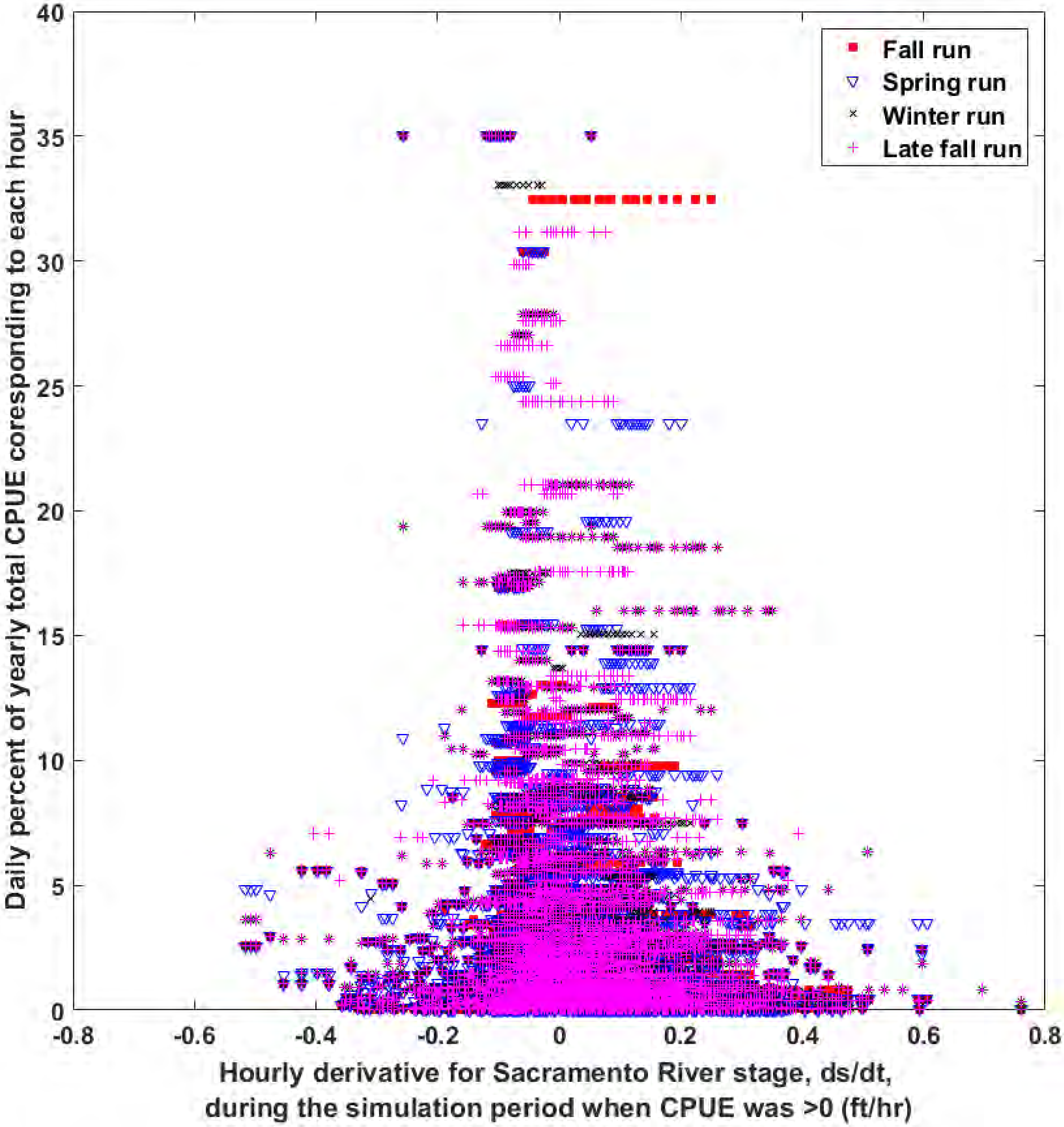


Figure 8 - Plot showing the hourly derivative for Sacramento River stage during the simulation period when Knights Landing catch was greater than zero during the notch operational window (November 1 – March 15).

There are many time steps when Sacramento River stage was changing at a rate faster than 0.2 feet/hr (1 foot change in 5 hours) when naturally migrating fish were likely to be passing the Fremont Weir. Because naturally migrating fish are likely to pass the Fremont Weir during periods when Sacramento River stage changes rapidly we chose to use a 4 hour timestep.

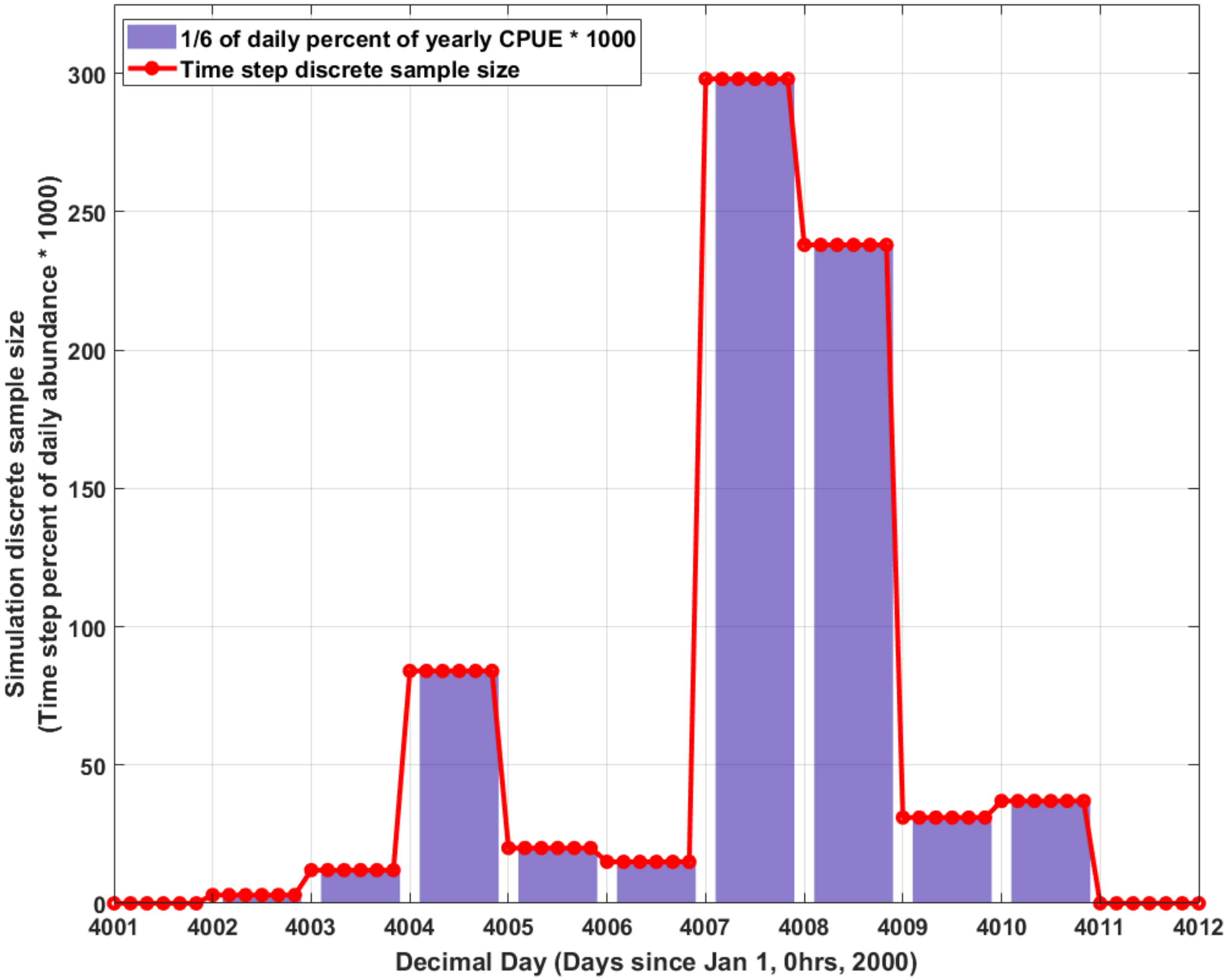


Figure 9 – Daily percent yearly CPUE data converted into discrete sample sizes for each time step.

The blue bars indicate a value that is 1/6 (for a four hour time step) of the daily discrete abundance. Daily discrete abundance is calculated as:

Daily discrete abundance = round(Daily CPUE * 1000)

The red line shows the resulting time series time step discrete abundance showing that each time step within a day has the same abundance.

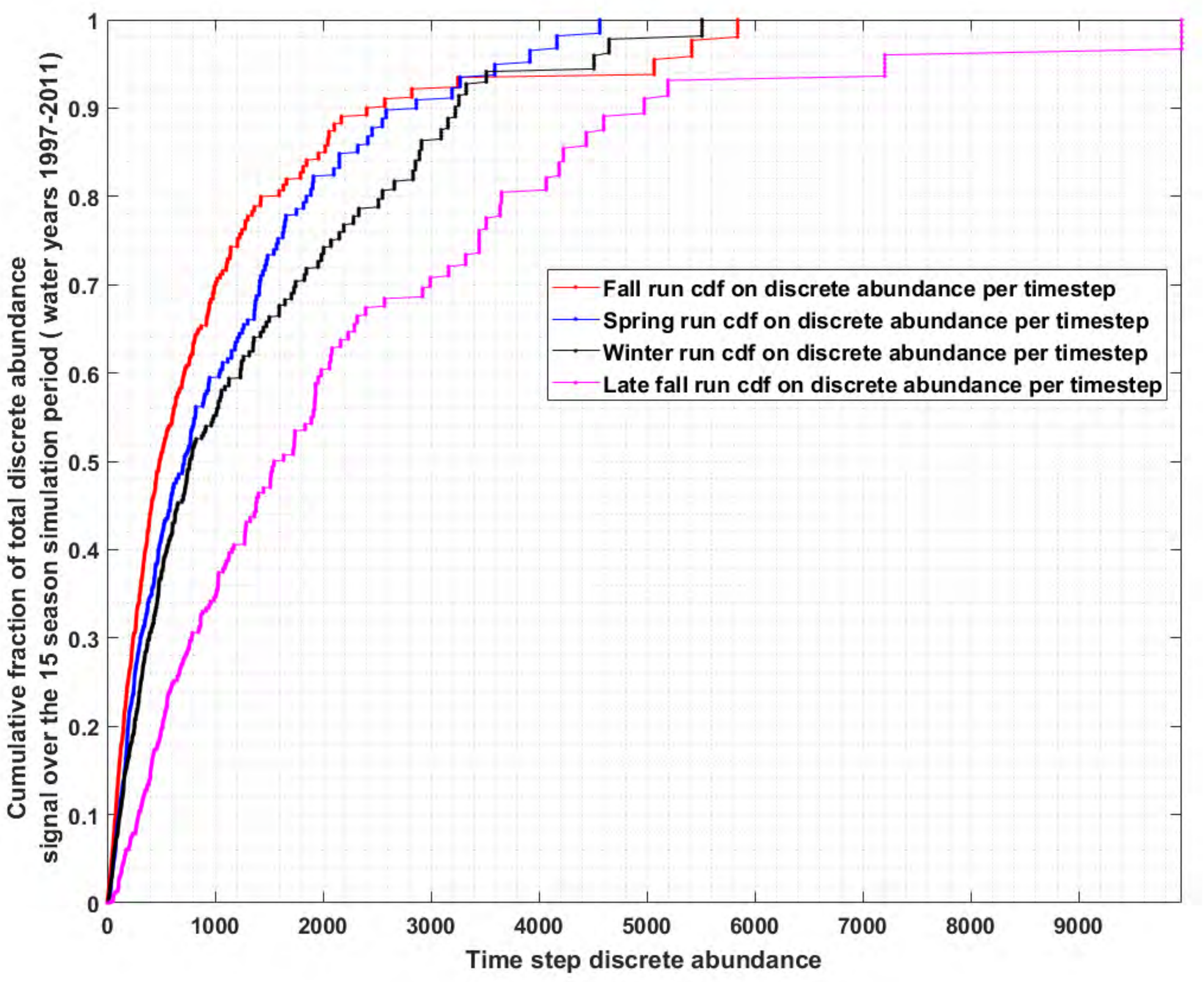


Figure 10 - Plot showing cumulative distribution functions for time step discrete abundance for time steps with non-zero discrete abundance values.

Within the entrainment simulation the size of the bootstrap sample for each time step is set by the discrete abundance for each run at the time step. The lines for each run above indicate the fraction of time steps within the 15-water-year simulation period that had discrete abundance values less than or equal to the sample sizes shown on the x axis; this plot shows the relative frequency of the size of bootstrap sample pools drawn over the simulation period.

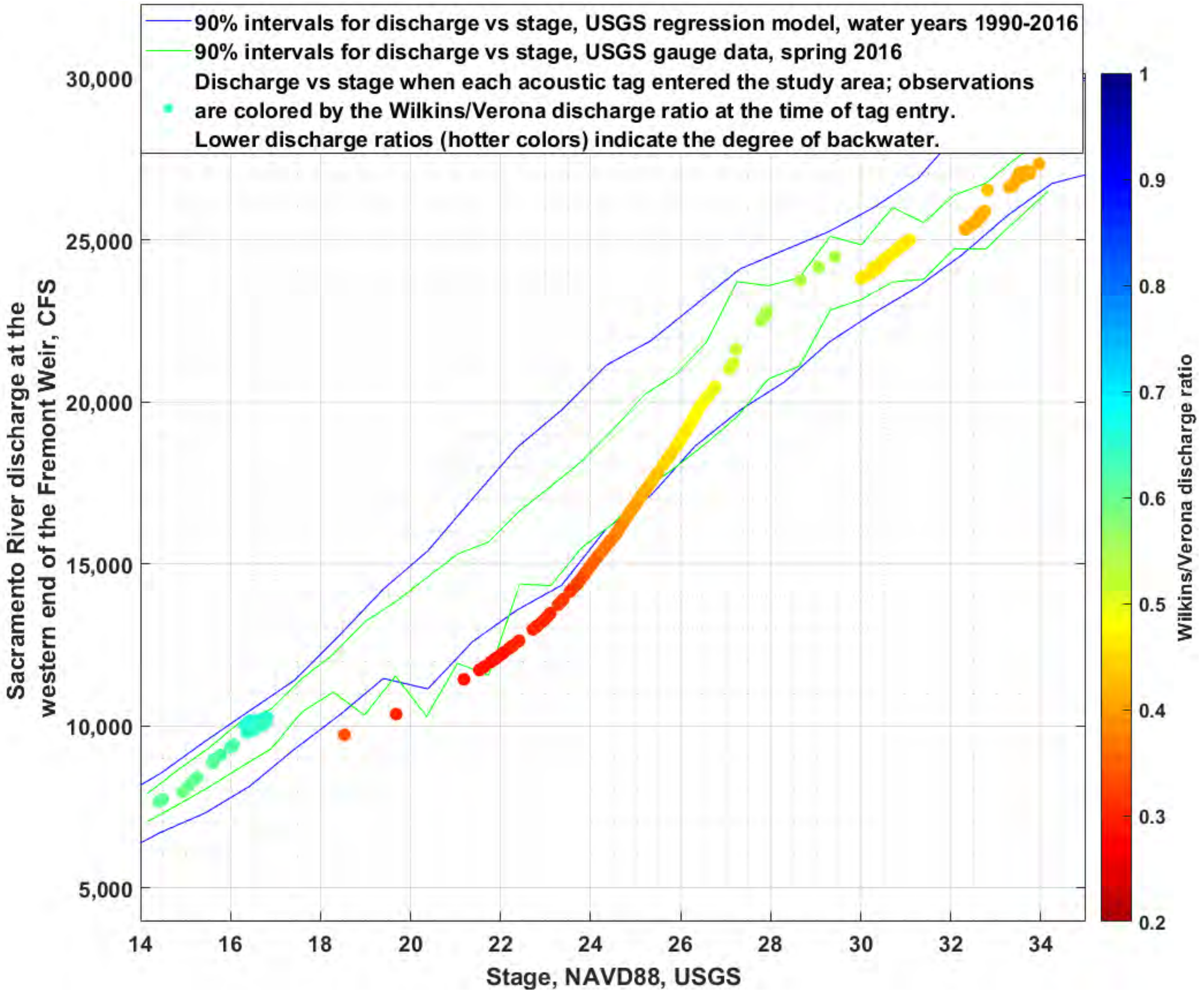


Figure 11 - Plot showing the range of stage and discharge conditions associated with each of the 2016 acoustic tag tracks

The colored lines indicate the 90% intervals (bounded by the 5th and 95th percentiles for discharge vs stage) for the USGS index velocity data (green lines), and the USGS estimate of Sacramento River hourly discharge at the Fremont Weir for water years 1990-2016. The colored dots indicate the stage and discharge value at the time when each acoustic tag entered the study area; the color of the dots indicates the severity of the backwater conditions when each tag entered the study area. Hotter colors indicate more extreme backwater conditions (lower discharge for a given stage). See Stumpner et al., in review, for more details on the Wilkins/Verona discharge ratio.

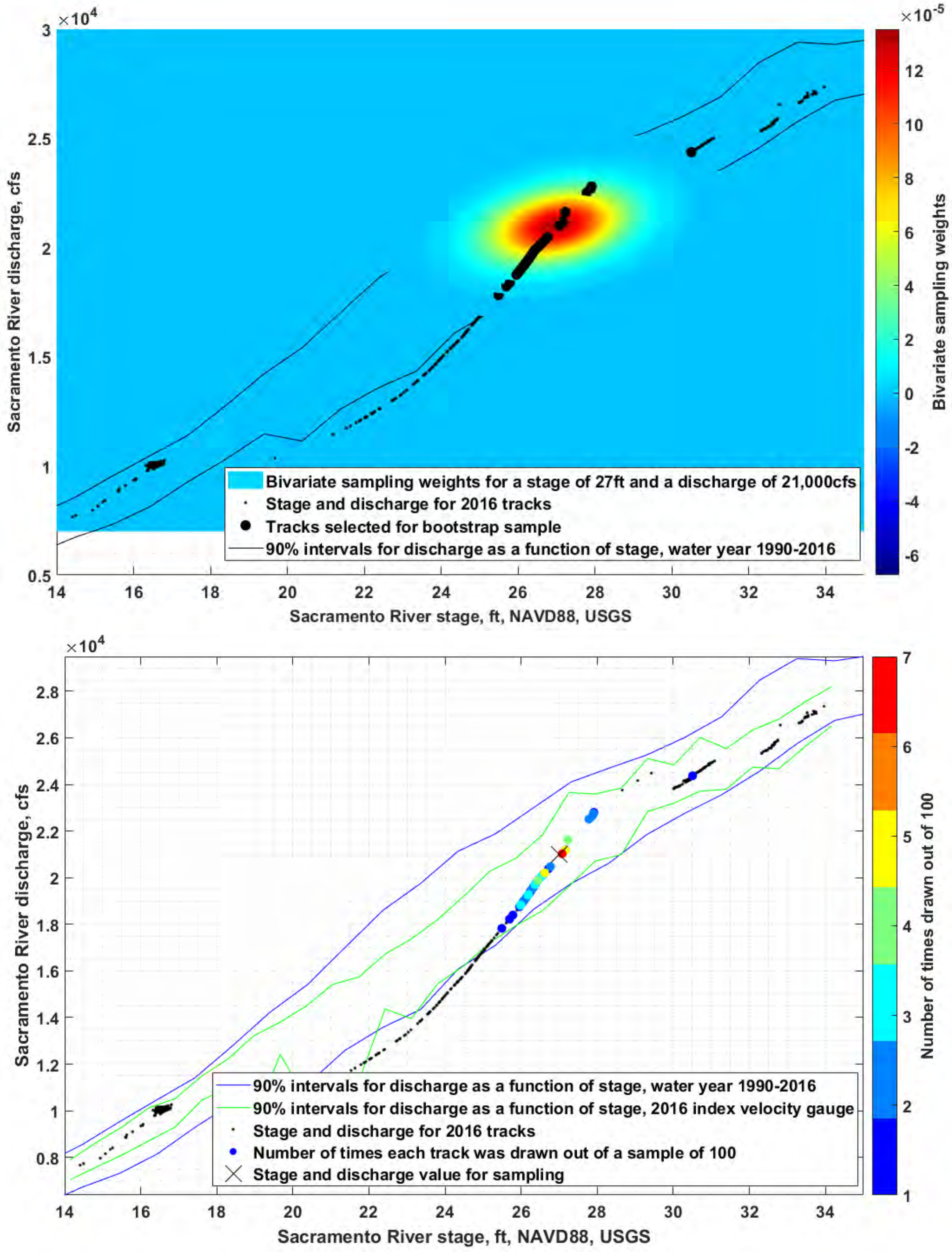


Figure 12 - Plots illustrating the bivariate weighting and the resulting bootstrap sampling for a stage of 27ft and a discharge of 21,000 cfs.

A heat plot indicating the bivariate weighting distribution for this combination of discharge and stage (upper panel), and a scatter plot indicating the frequency of selection for each fish track for a bootstrap sample of 100 tracks (lower panel).

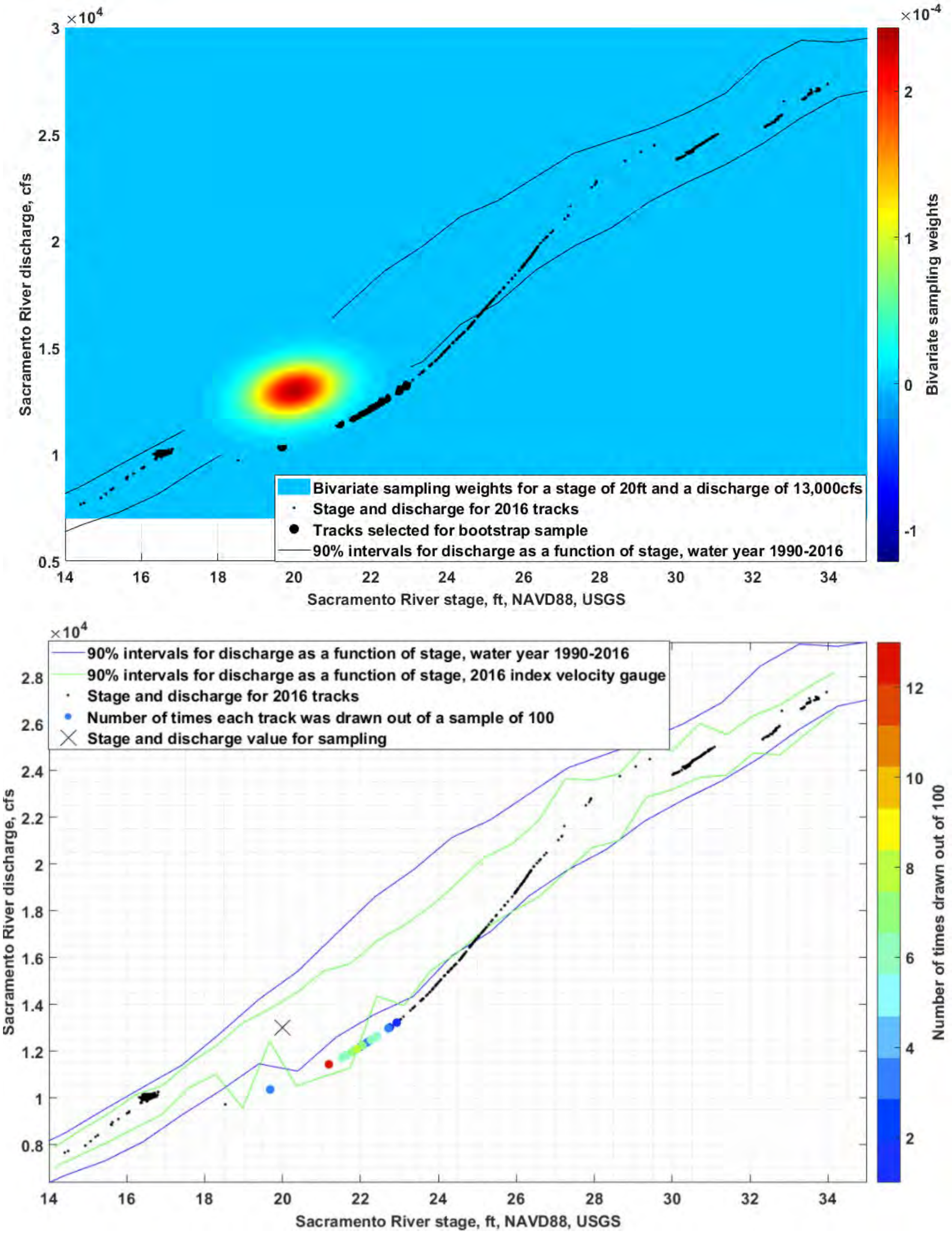


Figure 13 - Plots illustrating the bivariate weighting and the resulting bootstrap sampling for a stage of 20ft and a discharge of 13,000 cfs.

A heat plot indicating the bivariate weighting distribution for this combination of discharge and stage (upper panel), and a scatter plot indicating the frequency of selection for each fish track for a bootstrap sample of 100 tracks (lower panel).

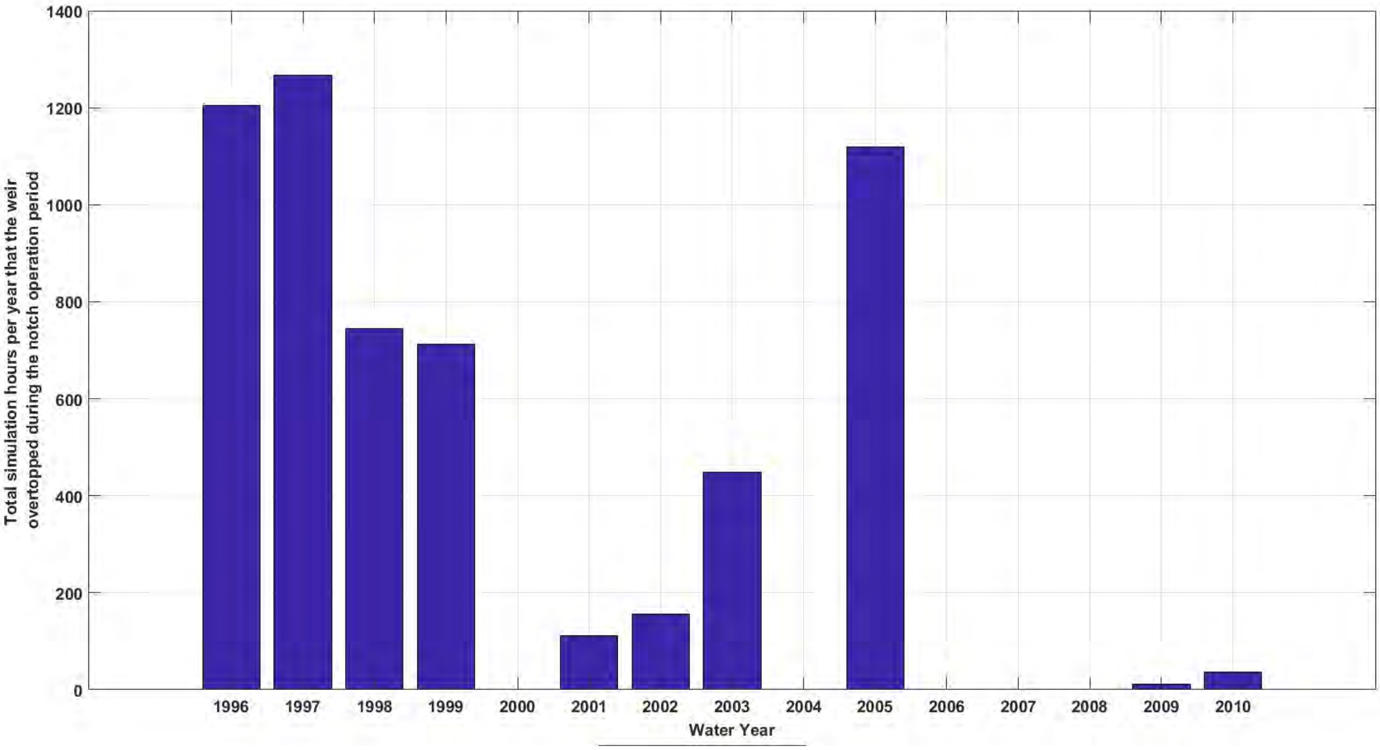


Figure 14 - Number of hours per year that the weir overtopped during the prescribed notch operation period for water years simulated.

The blue bars indicate the number of hours per season that the weir overtopped during the prescribed notch operation period (November 1 - March 15) for water years simulated. Missing bars indicate water years when the weir did not overtop during the simulation. For the purposes of the simulation overtopping is defined as periods when Sacramento River stage is greater than 32.3 ft, USGS survey, NAVD88.

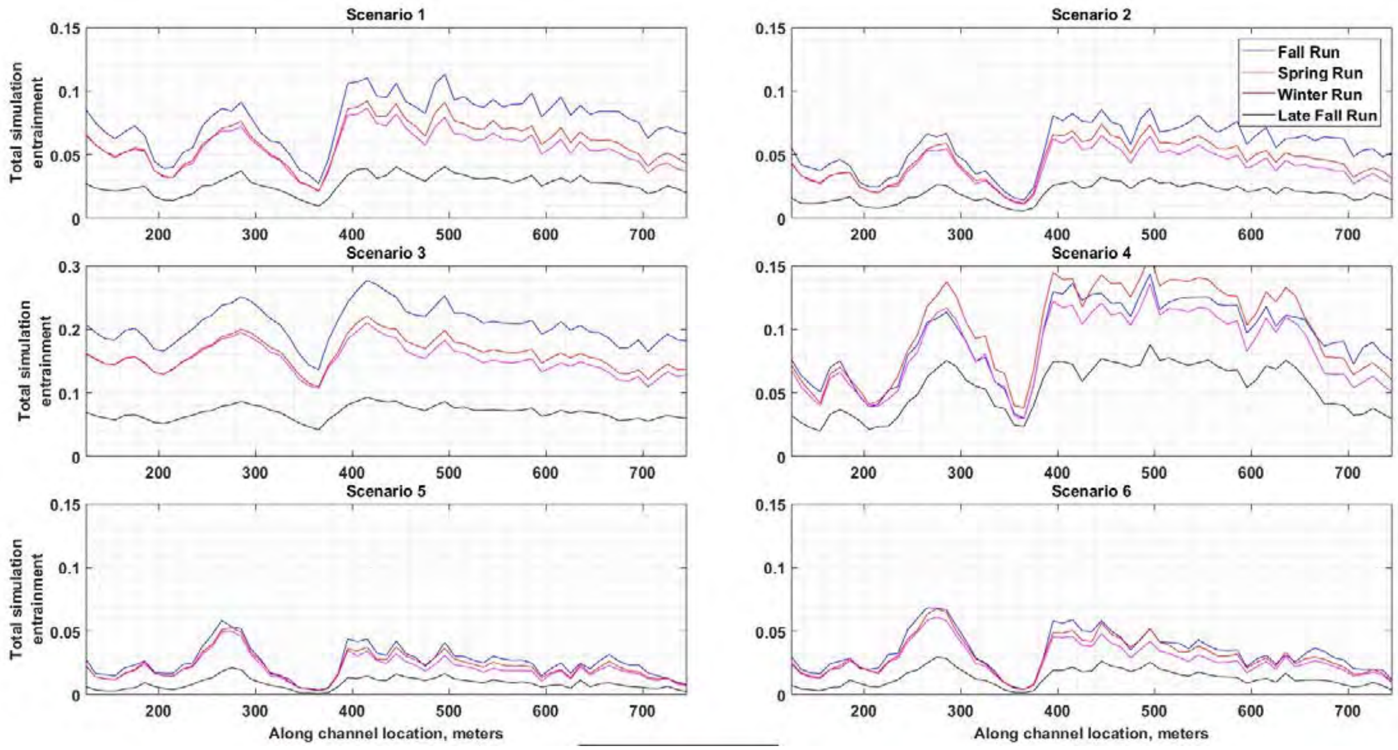


Figure 15 - Total entrainment as a function of notch location for each scenario.

Each panel shows the total entrainment for each scenario at each location in the study area, by run. Total simulation entrainment is expressed as the fraction of the total yearly abundance for the entire simulation period entrained in each scenario location. The blue, pink, orange, and black lines indicate the total entrainment for fall run, spring run, winter run, and late fall run, respectively. Note that the simulation is based on data from acoustically tagged hatchery surrogates, and so differences between run entrainment are entirely driven by differences in the historical timing of run abundance, and are not indicative of behavioral differences evident in the acoustic tag data. Also note that the range of the y axis is greater in panel 3 due to the large notch flows for scenario 3. The along-channel coordinate system referenced on the x axis of these plots is shown in Figure 4.

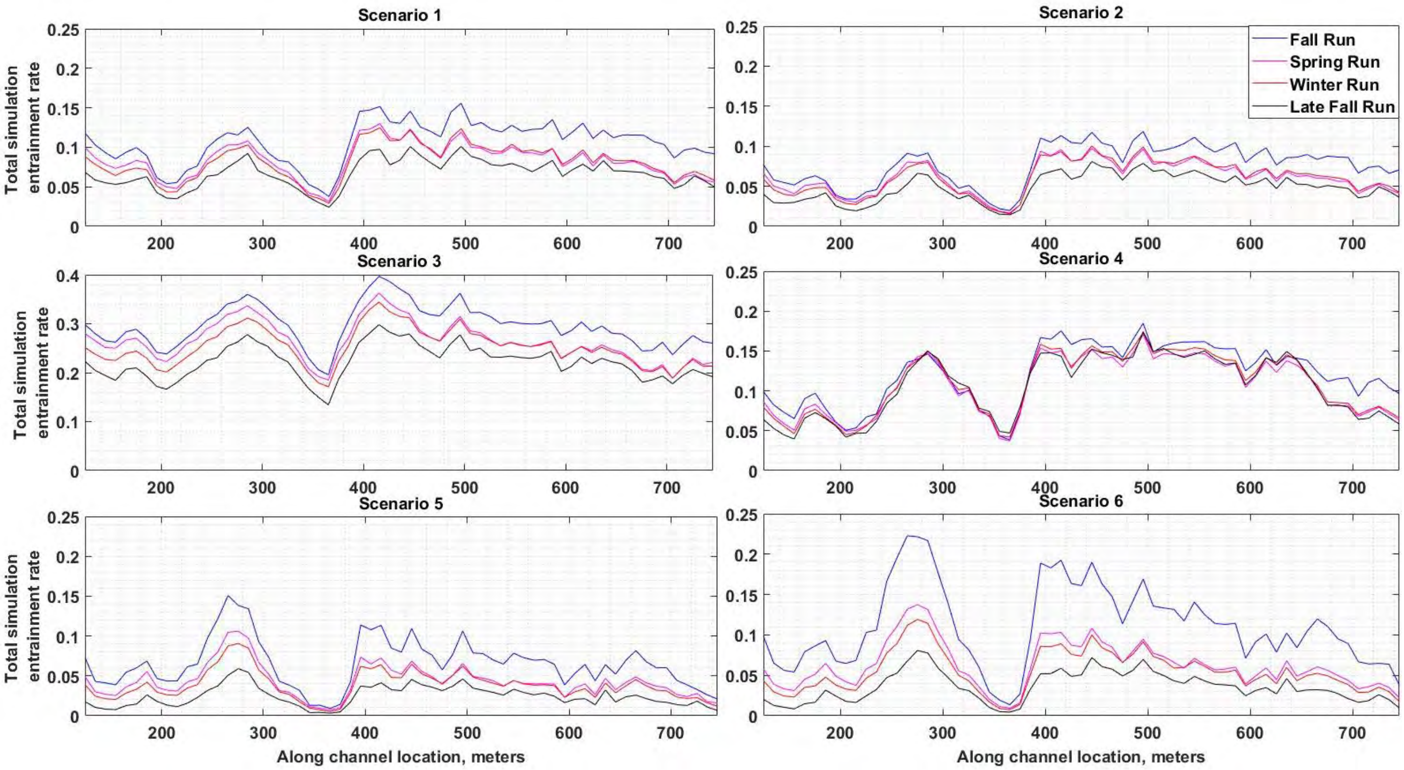


Figure 16 - Entrainment rate as a function of notch location for each scenario

Each panel shows the total entrainment for each scenario at each location in the study area, by run. Entrainment rate is expressed as the fraction of fish passing the notch that are entrained in the notch when notch flow was greater than zero for each scenario. Entrainment rate differs from total entrainment in that entrainment rate reflects the fraction of the fish which are present when the notch is flowing that are entrained, while total entrainment reflects the fraction of the overall yearly abundance that is entrained. The blue, pink, orange, and black lines indicate the total entrainment rate for fall run, spring run, winter run, and late fall run, respectively. Note that the simulation is based on data from acoustically tagged hatchery surrogates, and so differences between run entrainment rates are entirely driven by differences in the historical timing of run abundance, and are not indicative of behavioral differences evident in the acoustic tag data. Also note that the range of the y axis is greater in panel 3 due to the large notch flows for scenario 3. The along-channel coordinate system referenced on the x axis of these plots is shown in Figure 4.

Figure 17 - Figure showing the location of maximum and minimum entrainment for fall run for all scenarios overlaid on an aerial photograph of the study area.

We simulated entrainment under six different weir modification scenarios: scenarios 1 – 4 included a single notch in the Fremont Weir, scenario 5 and 6 included multiple notches in the Fremont Weir. The simulation predicted the highest entrainment under single notch scenarios when the notch was located in the zone indicated by the white box, and the simulation predicted the highest entrainment under multiple notch scenarios when the upstream notch was located in the zone indicated by the blue box. The simulation predicted the lowest entrainment for all scenarios when the notch or upstream most notch was located in the zone indicated by the red box.

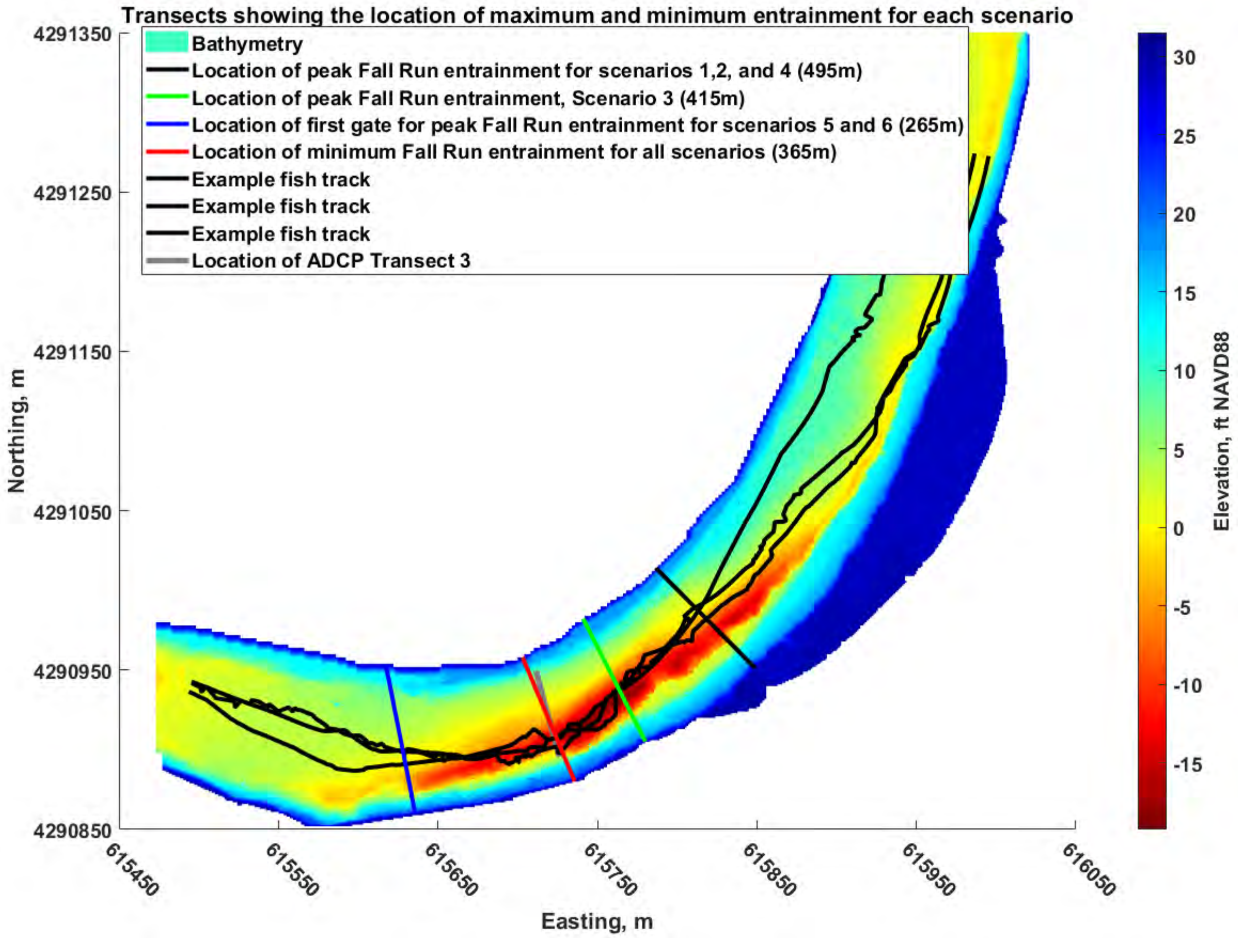


Figure 18 - Plan view of study area showing the location of minimum and maximum entrainment along with example fish tracks.

Colored surface indicates the study area bathymetry, the black lines show fish tracks that entered the study area on the river left half of the Sacramento River and then moved towards the river right bank until encountering a scour feature and moving back towards the river left bank of the Sacramento River. The colored cross section lines indicate locations where the entrainment simulation predicted maximum and minimum fall run entrainment for each scenario.

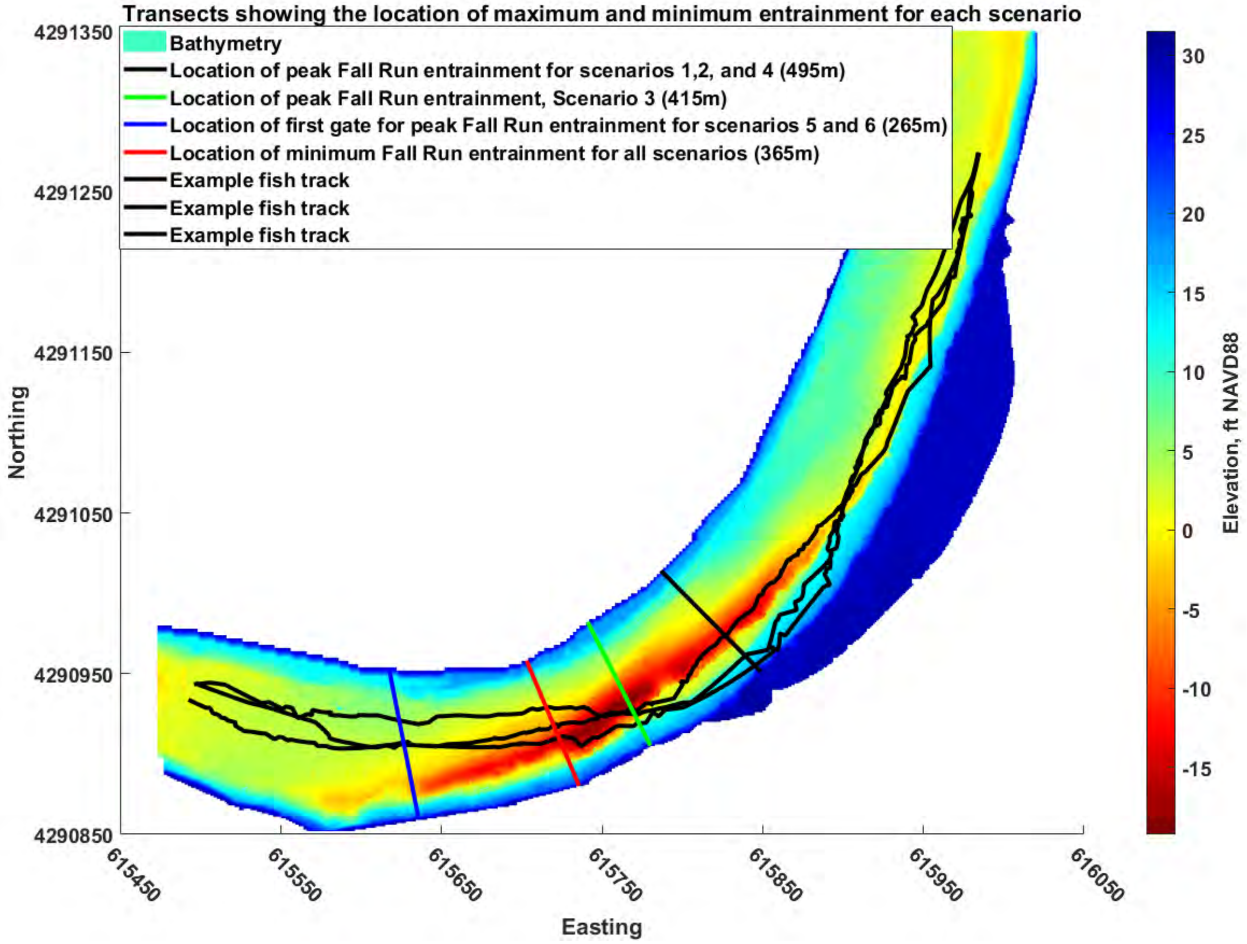


Figure 19 - Plan view of study area showing the location of minimum and maximum entrainment along with example fish tracks.

Colored surface indicates the study area bathymetry, the black lines show fish tracks that entered the study area on the river left half of the Sacramento River and then moved towards the river right bank passing the scoured area corresponding to the lowest predicted notch entrainment. The colored cross section lines indicate locations where the entrainment simulation predicted maximum and minimum fall run entrainment for each scenario.

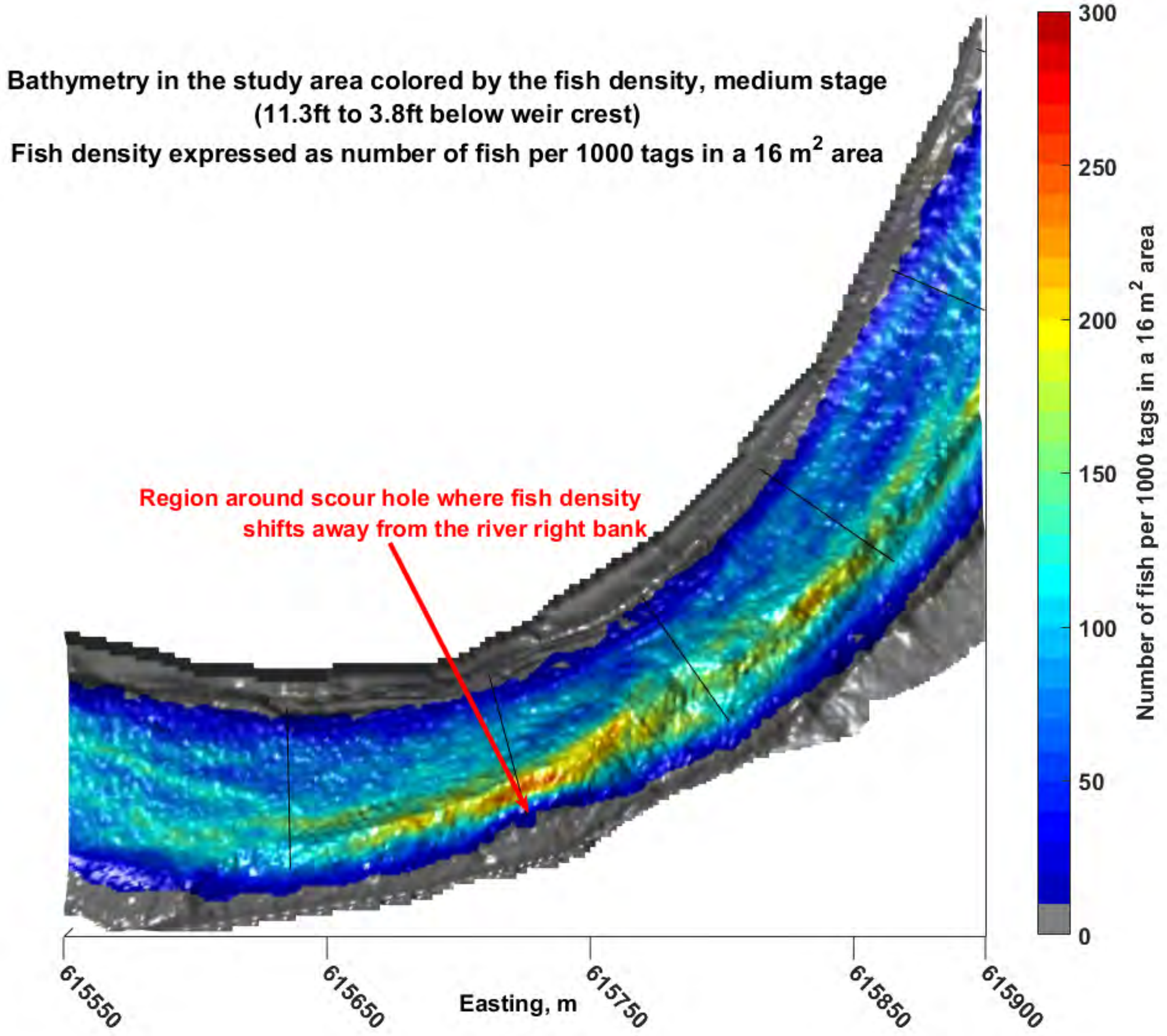


Figure 20 - Plan view of the study area bathymetry colored by fish density

Plan view of a surface representing the study area bathymetry, colored by the spatial density of 2016 fish tracks during medium stage periods. Gray areas on the bathymetry indicate areas where there were no fish tracks. The red arrow indicates the region in the vicinity of along-channel coordinate 370 where fish density near the bank decreases in the vicinity of a scoured section in the levy. Note that in the area around the black arrow the cross-stream gradients in fish density are stronger, and the area where the density colormap transitions from blue (low density) to green (moderate density) shifts towards the center of the channel.

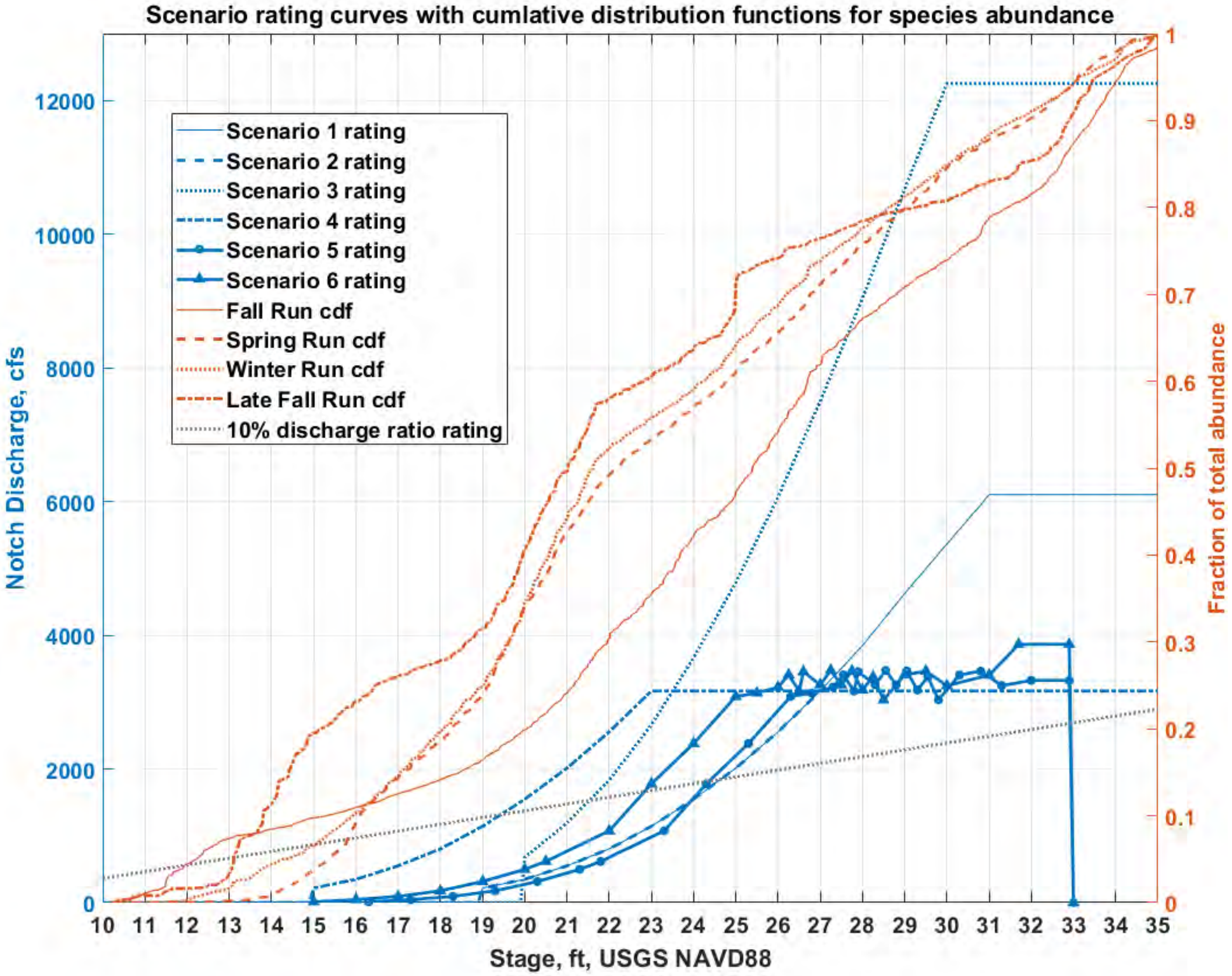


Figure 21 - Stage-discharge curves for each scenario and run abundance CDFs on stage

Stage discharge curves for each scenario are shown in blue, with scenario discharge shown on the left (blue) y-axis. The stage-discharge curves for multiple notch scenarios indicate the total flow through all notches in the scenario at each stage. The rating curves for scenario 1 and scenario 2 overlap for stages below 27 ft. Cumulative distribution functions for the simulation period showing the cumulative fraction of run abundance passing through the study area at each stage in red. These curves show the fraction of each run that pass through the study area at a stage less than or equal to the stage given on the x axis. Note the rapid increase in cumulative abundance between 19 ft and 22 ft for winter run and spring run. The dotted gray line indicates the amount of notch flow that corresponds to 10% of the Sacramento River stage-discharge rating from the 2016 USGS gauge data. The location of each scenario's rating curve relative to the 10% discharge ratio line is an indicator of the fraction of the Sacramento River flow that is passing through the notch at any stage: if the a rating curve is above the grey line at any stage the notch is likely entraining more than 10% of the Sacramento River at that stage.

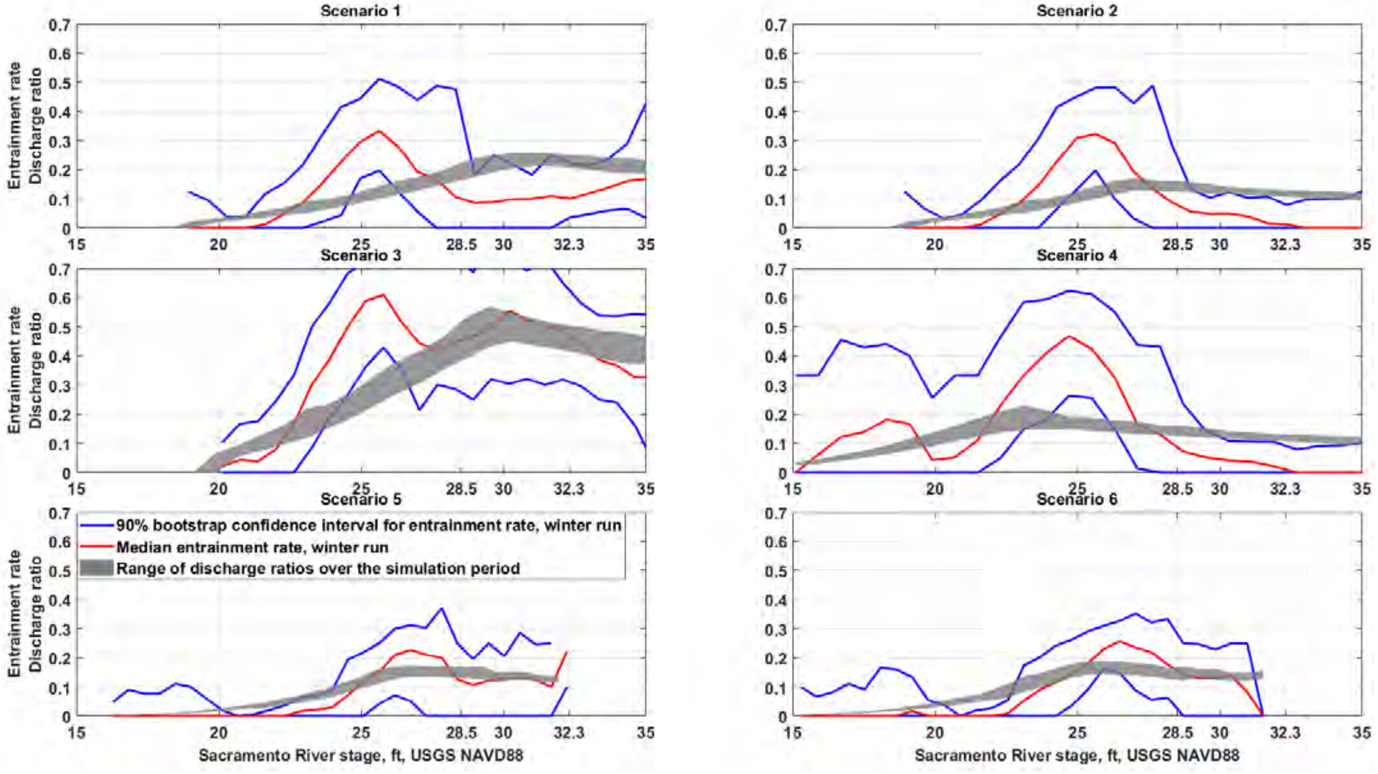


Figure 22 - Entrainment rate and discharge ratio for each scenario as a function of Sacramento River stage.

Panels 1-6 show entrainment rate and discharge ratio as a function of stage for scenarios 1-6, respectively. For each scenario the blue lines indicate the 90% bootstrap confidence interval for entrainment rate at each stage, the red line indicates the bootstrap median entrainment rate for each stage, and the gray region indicates the range of discharge ratios each scenario experienced during the simulation period. The notch discharge ratio indicates the fraction of Sacramento River discharge flowing into each scenario at each stage; because of backwater effects there are a range of possible discharge ratios for each stage, as indicated by the vertical range of the gray band at each stage. When the entrainment rate is greater than the discharge ratio the notch is entraining proportionally more fish than water. Note that the Sacramento River reaches a bankfull state in the study area at a stage value of around 28.5 ft, and the weir overtops at a stage value of 32.3 ft.

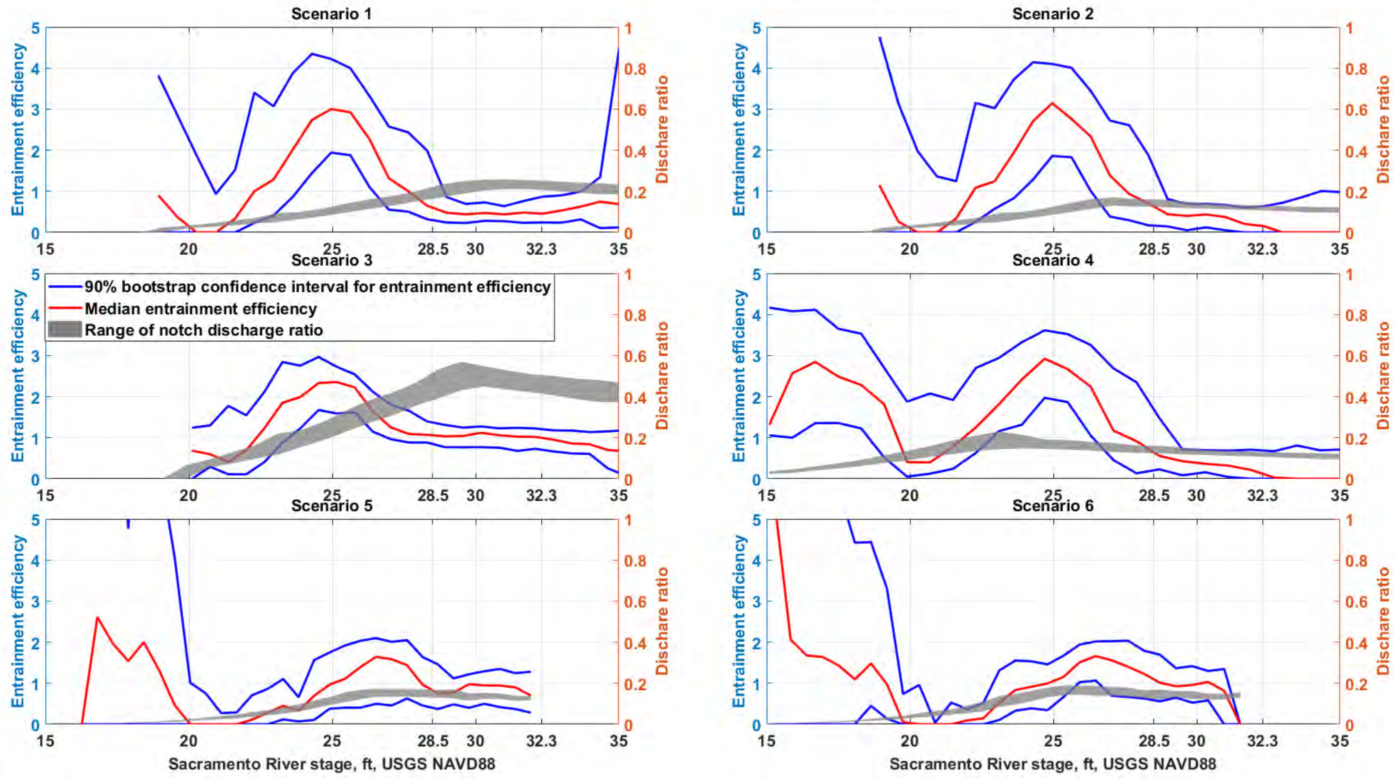


Figure 23 - Entrainment efficiency and discharge ratio for each scenario as a function of Sacramento River stage, with small sample sizes removed.

Panels 1-6 show entrainment efficiency and discharge ratio as a function of stage for scenarios 1-6, respectively, for days when more than 0.5% of the yearly total abundance transited the study area. Removing time steps from days when less than 0.5% of the yearly total abundance transited the study area removed 10% of the time step entrainment data from the fall run entrainment estimates used to produce these curves. The y-axis on the left of each panel (blue) indicates the scale for the entrainment efficiency. The y-axis on the right of each panel (red) indicates the scale for the discharge ratio. For each scenario the blue lines indicate the 90% bootstrap confidence interval for entrainment efficiency for each stage, the red line indicates the bootstrap median entrainment efficiency for each stage, and the gray region indicates the range of discharge ratios each scenario experienced during the simulation period. The notch discharge ratio indicates the fraction of Sacramento River discharge flowing into each scenario at each stage; because of backwater effects there are a range of possible discharge ratios for each stage, as indicated by the vertical range of the gray band. When the entrainment efficiency is greater than one the notch is entraining proportionally more fish than water. Note that the Sacramento River reaches a bankfull state in the study area at a stage value of around 28.5 ft, and the weir overtops at a stage value of 32.3 ft.

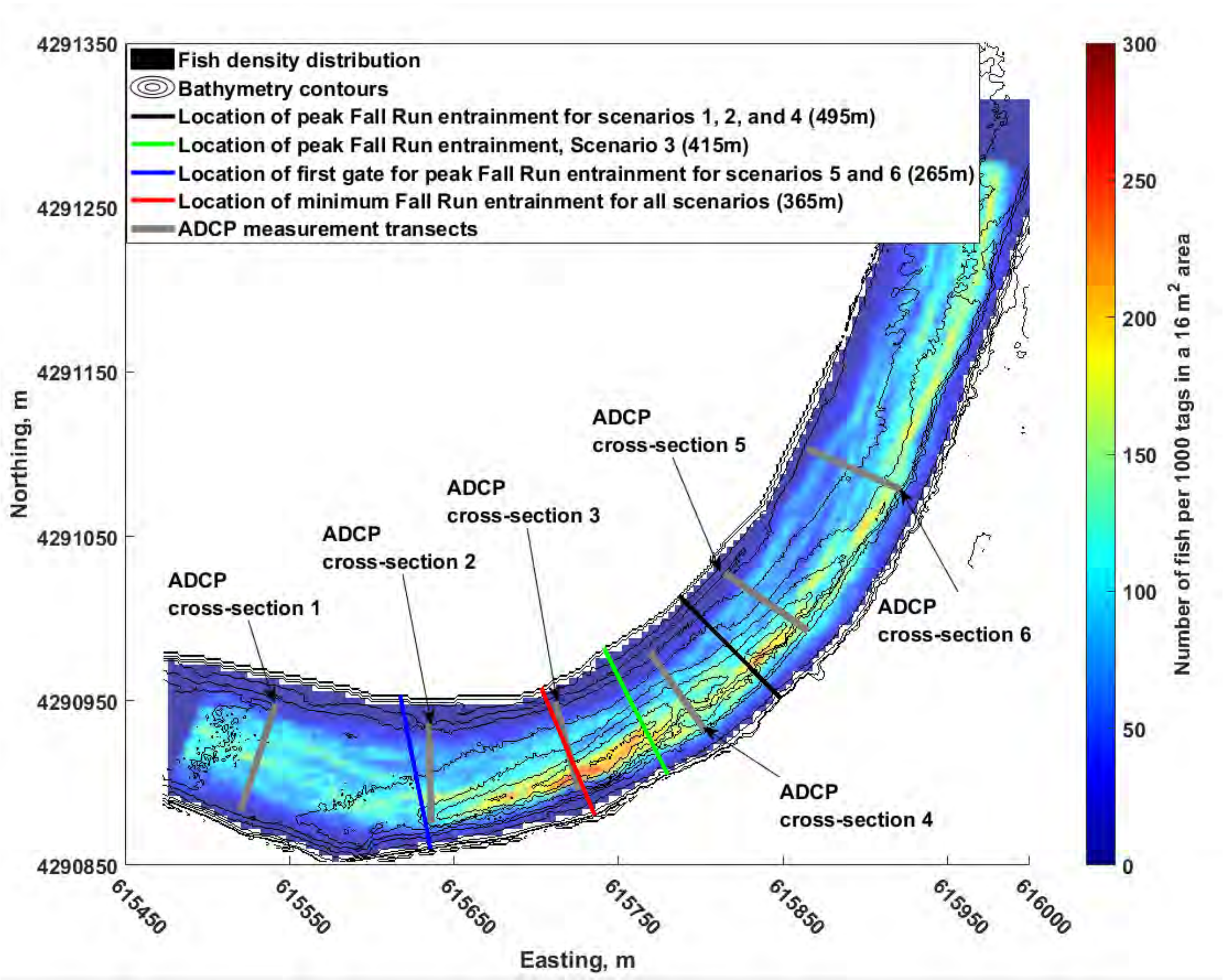
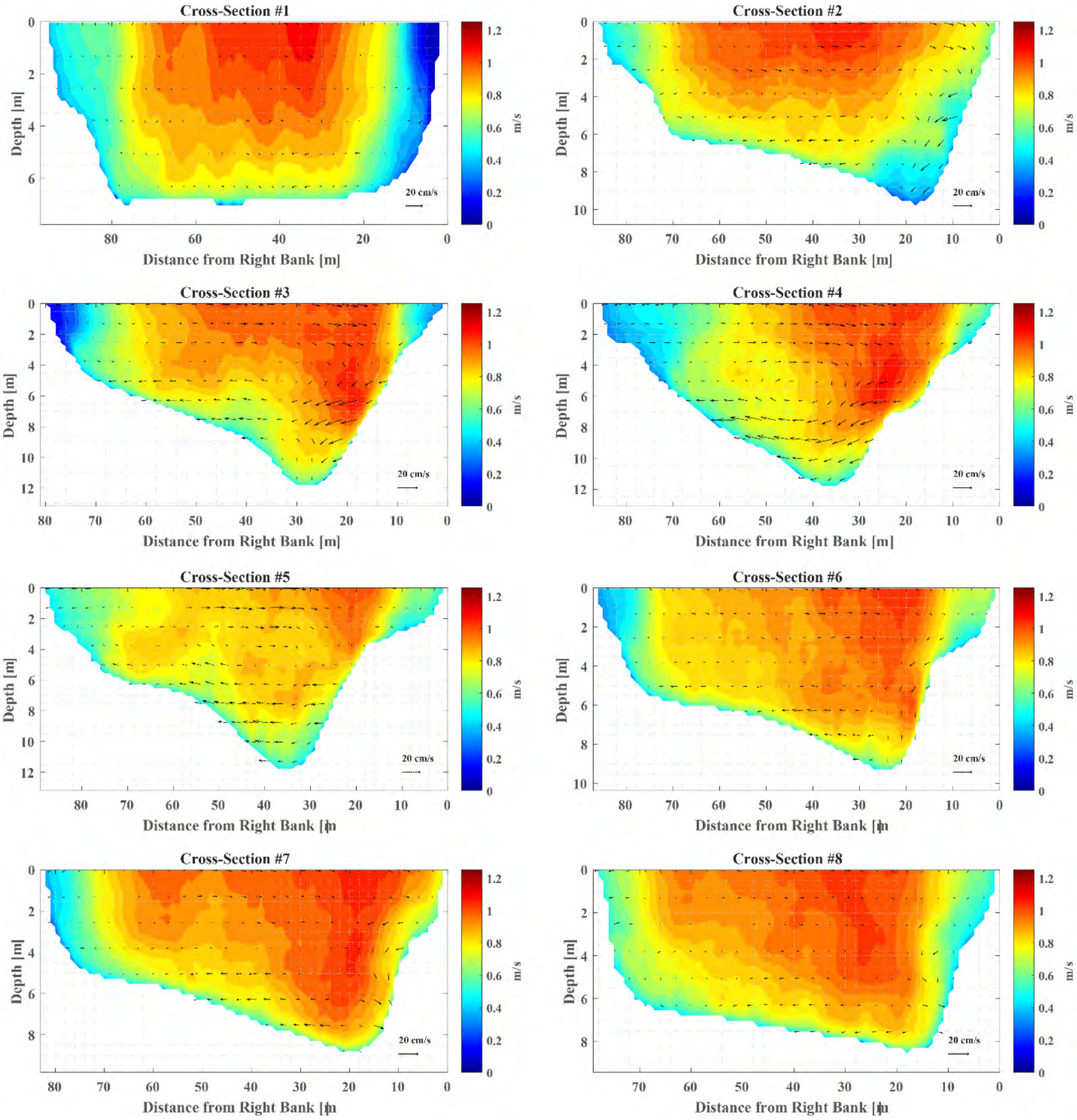


Figure 24 - Figure showing the location of maximum and minimum entrainment for fall run for all scenarios overlaid on fish density distribution for medium stage covariate group.

The colored surface shows the fish density distribution for all acoustic tag tracks recorded during the 2016 study when Sacramento River stage was between 21 ft and 28.5 ft. The location of downward looking ADCP transects are shown as gray lines and labeled, the cross-channel velocity distribution computed from these measurements made at a Sacramento River stage of 24.2 ft are shown on Figure 25. The notch locations corresponding to maximum and minimum entrainment for single notch and multiple notch configurations are shown with colored lines. Note that the Sacramento River reaches bankfull in the study area at around 28.5 ft.


Cross-Section #1

Cross-Section #2

Cross-Section #3

Cross-Section #4

Cross-Section #5

Cross-Section #6

Cross-Section #7

Cross-Section #8

Figure 25 - Figure from cross-channel velocity transect data collected during 2016

Contour plot showing along-stream velocity magnitude and arrows indicating secondary velocity currents for each velocity cross-section (1-8) at a stage of 24.2 ft. and discharge of 15,930 cfs. Taken from Stumpner et al., In Review.

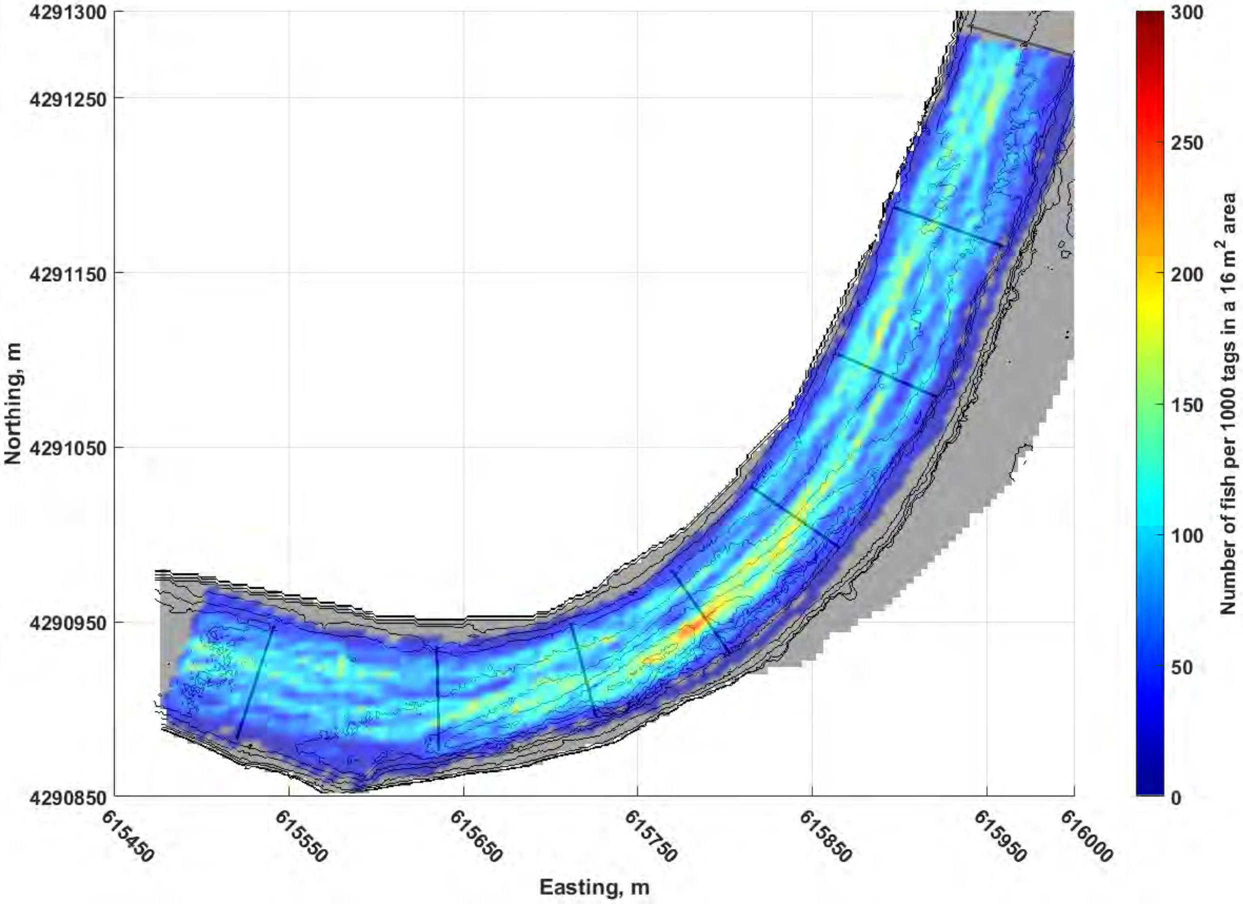


Figure 26 - Spatial distribution of 2016 study fish tracks for periods when Sacramento River was greater than bankfull and below the weir crest.

Plan view of the study area colored by the spatial density of 2016 fish tracks collected when the Sacramento River was above bankfull (28.5 ft), but below the crest of the Fremont Weir. Gray areas on the bathymetry indicate areas where no fish were detected. Thin black lines indicate bathymetric contours.

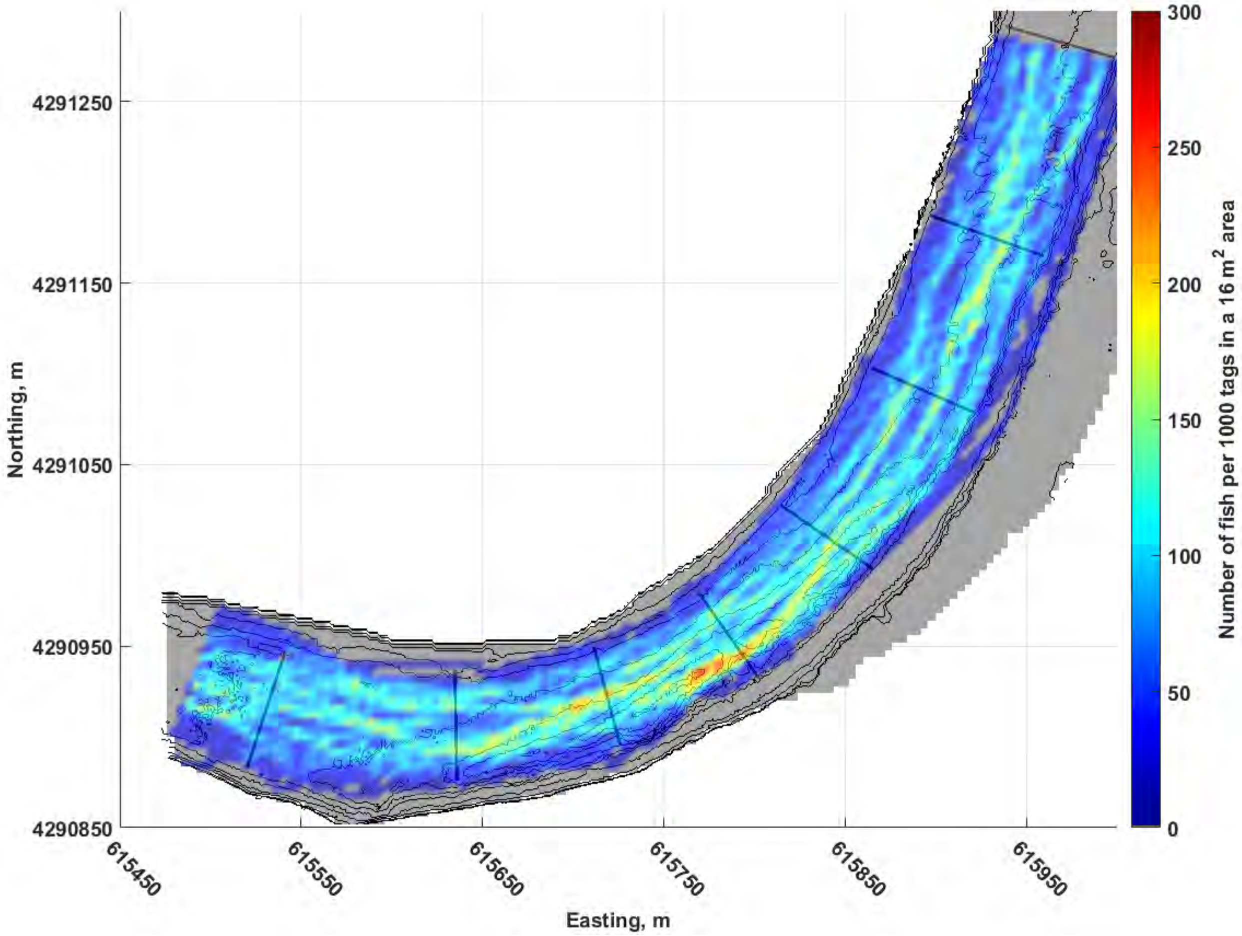


Figure 27 - Spatial distribution of 2016 study fish tracks for periods when the Fremont Weir was overtopping

Plan view of the study area colored by the spatial density of 2016 fish tracks collected when the Fremont Weir was overtopping. Gray areas on the bathymetry indicate areas where no fish were detected. Thin black lines indicate bathymetric contours.

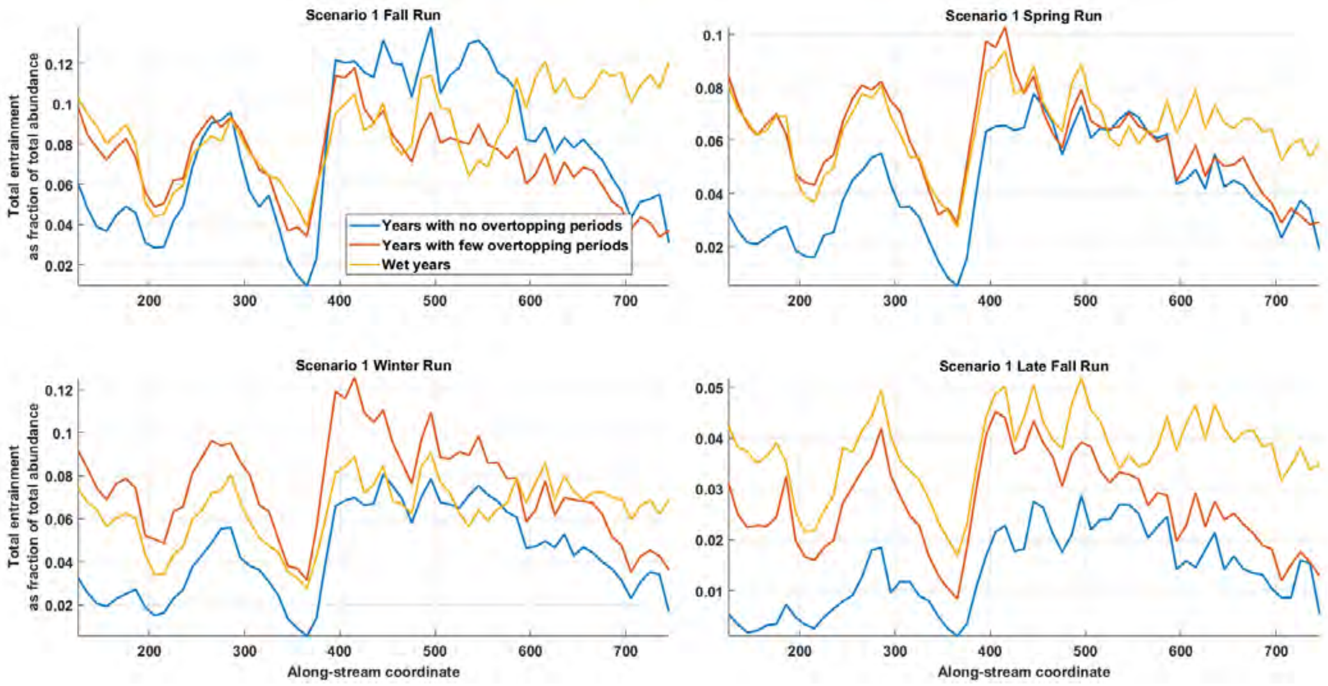


Figure 28- Scenario 1 water year type total entrainment curves.

Plots showing total entrainment for each run as a function of notch along-channel location within the study area calculated for three water year types for scenario 1. The blue lines indicates total entrainment over all seasons when Fremont Weir did not overtop, the red line indicates total entrainment over all seasons when the Fremont Weir overtopped for fewer than 200 hours, and the gold line indicates total entrainment over all seasons when the Fremont Weir overtopped for more than 200 hours (wet years). Each panel shows water year entrainment for a run. For the purposes of the simulation weir overtopping was defined as Sacramento River stage exceeding 32.3 ft, USGS survey, NAVD88. Note that the simulation is based on data from acoustically tagged hatchery surrogates, and so differences between run entrainment are entirely driven by differences in the historical timing of run abundance, and are not indicative of behavioral differences between runs.

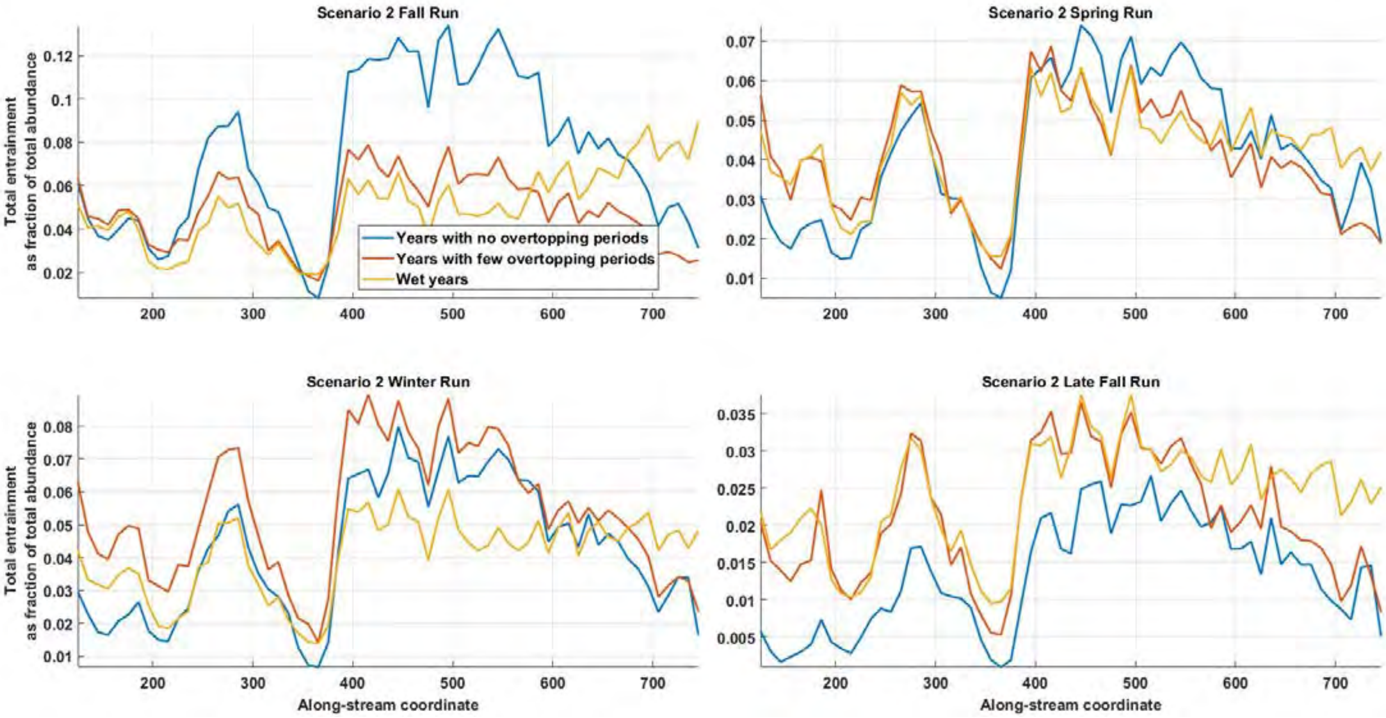


Figure 29- Scenario 2 water year type total entrainment curves.

Plots showing total entrainment for each run as a function of notch along-channel location within the study area calculated for three water year types for scenario 2. The blue lines indicates total entrainment over all seasons when Fremont Weir did not overtop, the red line indicates total entrainment over all seasons when the Fremont Weir overtopped for fewer than 200 hours, and the gold line indicates total entrainment over all seasons when the Fremont Weir overtopped for more than 200 hours (wet years). Each panel shows water year entrainment for a run. For the purposes of the simulation weir overtopping was defined as Sacramento River stage exceeding 32.3 ft, USGS survey, NAVD88. Note that the simulation is based on data from acoustically tagged hatchery surrogates, and so differences between run entrainment are entirely driven by differences in the historical timing of run abundance, and are not indicative of behavioral differences between runs.

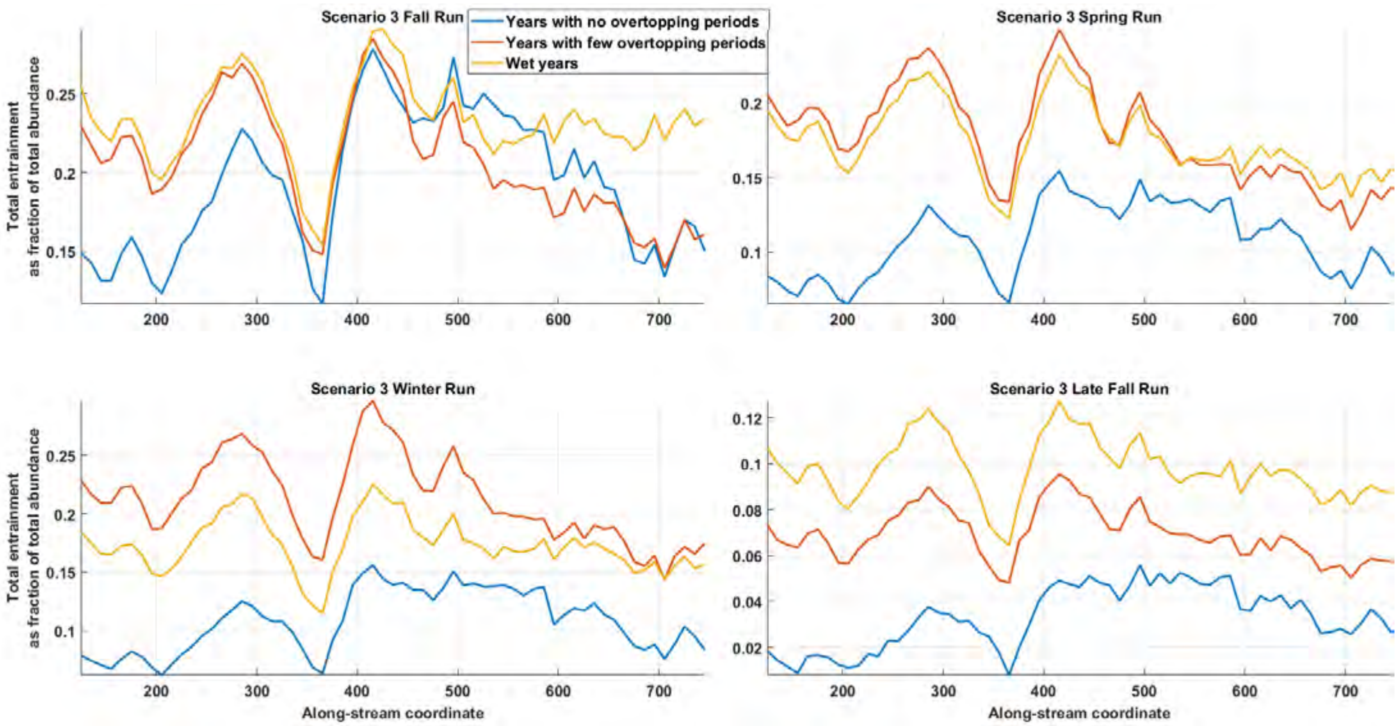


Figure 30- Scenario 3 water year type total entrainment curves

Plots showing total entrainment for each run as a function of notch along-channel location within the study area calculated for three water year types for scenario 3. The blue lines indicates total entrainment over all seasons when Fremont Weir did not overtop, the red line indicates total entrainment over all seasons when the Fremont Weir overtopped for fewer than 200 hours, and the gold line indicates total entrainment over all seasons when the Fremont Weir overtopped for more than 200 hours (wet years). Each panel shows water year entrainment for a run. For the purposes of the simulation weir overtopping was defined as Sacramento River stage exceeding 32.3 ft, USGS survey, NAVD88. Note that the simulation is based on data from acoustically tagged hatchery surrogates, and so differences between run entrainment are entirely driven by differences in the historical timing of run abundance, and are not indicative of behavioral differences between runs

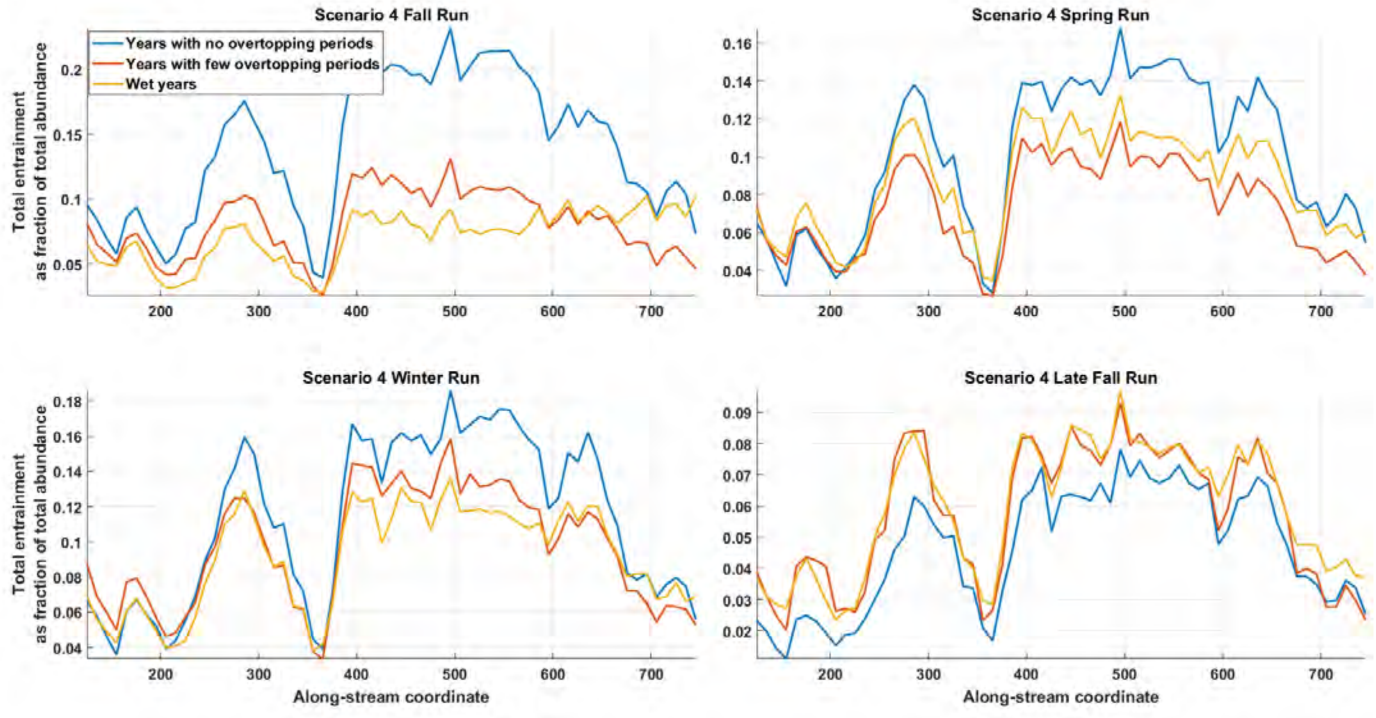


Figure 31- Scenario 4 water year type total entrainment curves

Plots showing total entrainment for each run as a function of notch along-channel location within the study area calculated for three water year types for scenario 4. The blue lines indicates total entrainment over all seasons when Fremont Weir did not overtop, the red line indicates total entrainment over all seasons when the Fremont Weir overtopped for fewer than 200 hours, and the gold line indicates total entrainment over all seasons when the Fremont Weir overtopped for more than 200 hours (wet years). Each panel shows water year entrainment for a run. For the purposes of the simulation weir overtopping was defined as Sacramento River stage exceeding 32.3 ft, USGS survey, NAVD88. Note that the simulation is based on data from acoustically tagged hatchery surrogates, and so differences between run entrainment are entirely driven by differences in the historical timing of run abundance, and are not indicative of behavioral differences between runs.

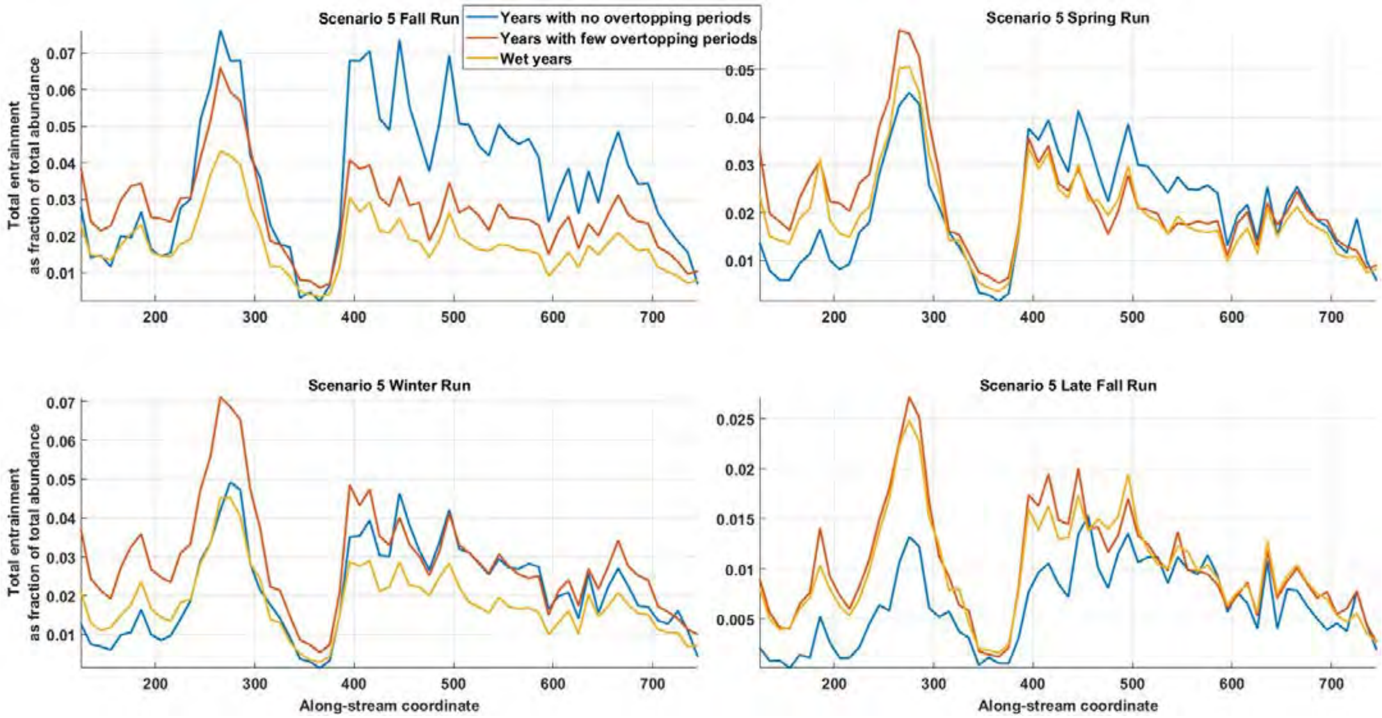


Figure 32- Scenario 5 water year type total entrainment curves

Plots showing total entrainment for each run as a function of notch along-channel location within the study area calculated for three water year types for scenario 5. The blue lines indicates total entrainment over all seasons when Fremont Weir did not overtop, the red line indicates total entrainment over all seasons when the Fremont Weir overtopped for fewer than 200 hours, and the gold line indicates total entrainment over all seasons when the Fremont Weir overtopped for more than 200 hours (wet years). Each panel shows water year entrainment for a run. For the purposes of the simulation weir overtopping was defined as Sacramento River stage exceeding 32.3 ft, USGS survey, NAVD88. Note that the simulation is based on data from acoustically tagged hatchery surrogates, and so differences between run entrainment are entirely driven by differences in the historical timing of run abundance, and are not indicative of behavioral differences between runs.

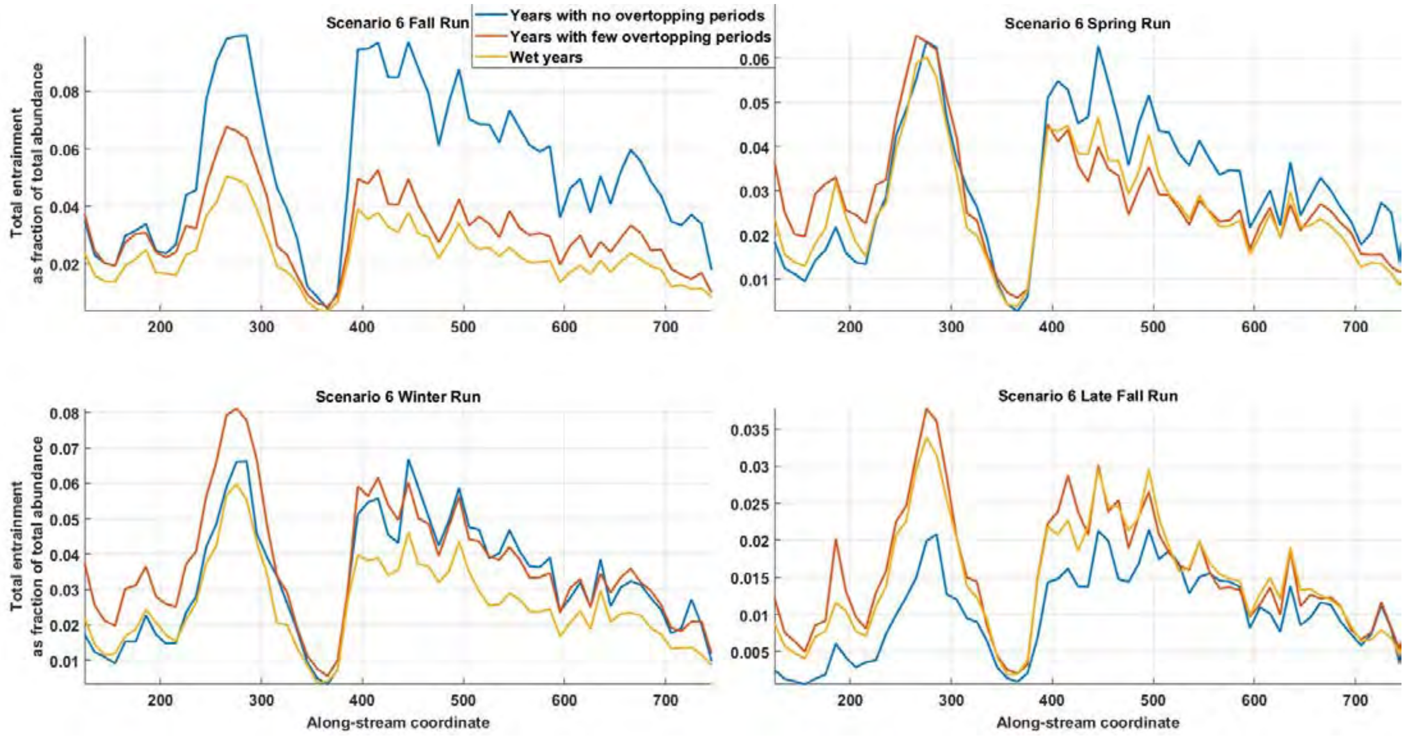


Figure 33- Scenario 6 water year type total entrainment curves

Plots showing total entrainment for each run as a function of notch along-channel location within the study area calculated for three water year types for scenario 6. The blue lines indicates total entrainment over all seasons when Fremont Weir did not overtop, the red line indicates total entrainment over all seasons when the Fremont Weir overtopped for fewer than 200 hours, and the gold line indicates total entrainment over all seasons when the Fremont Weir overtopped for more than 200 hours (wet years). Each panel shows water year entrainment for a run. For the purposes of the simulation weir overtopping was defined as Sacramento River stage exceeding 32.3 ft, USGS survey, NAVD88. Note that the simulation is based on data from acoustically tagged hatchery surrogates, and so differences between run entrainment are entirely driven by differences in the historical timing of run abundance, and are not indicative of behavioral differences between runs.

10. Appendix A - Conversion between along-channel coordinates and UTM for the River Right bank of the Sacramento River

Table A1 - Conversion between along-channel location and UTM coordinates

Table giving the along stream coordinate and UTM coordinates of the river right bank of the Sacramento River at 29 feet stage, USGS survey, NAVD88, from the bathymetric model used in the simulation. The along stream coordinate system is shown in plan view in figure 4.

Notch evaluation location	Along-stream coordinate, m	Easting, UTM Zone 10S, m, NAD83	Northing, UTM Zone 10S, m, NAD83
1	124.9	615497.6	4290880.5
2	134.9	615506.8	4290876.3
3	144.9	615515.8	4290871.8
4	155.0	615524.9	4290868.0
5	165.2	615535.1	4290866.2
6	175.5	615545.3	4290863.8
7	185.6	615555.0	4290860.1
8	195.6	615564.3	4290855.0
9	205.4	615574.7	4290851.9
10	215.3	615585.2	4290852.0

Notch evaluation location	Along-stream coordinate, m	Easting, UTM Zone 10S, m, NAD83	Northing, UTM Zone 10S, m, NAD83
11	225.3	615595.5	4290854.0
12	235.3	615605.6	4290855.1
13	245.3	615615.6	4290857.1
14	255.3	615625.7	4290858.2
15	265.3	615635.7	4290860.0
16	275.4	615645.6	4290861.6
17	285.4	615655.5	4290863.3
18	295.4	615665.6	4290864.3
19	305.4	615675.7	4290865.5
20	315.4	615685.7	4290867.4
21	325.4	615695.4	4290870.7
22	335.3	615705.4	4290873.2
23	345.3	615715.6	4290875.3
24	355.4	615725.6	4290878.1
25	365.4	615735.6	4290880.5
26	375.4	615744.4	4290885.6

Notch evaluation location	Along-stream coordinate, m	Easting, UTM Zone 10S, m, NAD83	Northing, UTM Zone 10S, m, NAD83
27	385.4	615753.4	4290890.3
28	395.4	615761.8	4290896.2
29	405.5	615771.4	4290899.7
30	415.5	615780.0	4290905.4
31	425.5	615789.9	4290908.7
32	435.4	615799.4	4290913.0
33	445.5	615808.6	4290918.1
34	455.4	615818.3	4290922.7
35	465.4	615826.0	4290929.9
36	475.5	615835.5	4290934.8
37	485.6	615841.8	4290943.7
38	495.6	615848.5	4290951.8
39	505.6	615856.9	4290958.3
40	515.5	615864.4	4290965.9
41	525.5	615872.6	4290972.9
42	535.5	615881.0	4290979.3

Notch evaluation location	Along-stream coordinate, m	Easting, UTM Zone 10S, m, NAD83	Northing, UTM Zone 10S, m, NAD83
43	545.6	615887.5	4290986.8
44	555.6	615894.7	4290993.8
45	565.6	615899.9	4291002.6
46	575.6	615904.8	4291011.8
47	585.6	615909.0	4291021.4
48	595.6	615917.0	4291028.5
49	605.6	615920.8	4291038.2
50	615.6	615925.2	4291047.6
51	625.7	615932.2	4291055.5
52	635.7	615935.7	4291065.6
53	645.6	615940.0	4291075.3
54	655.6	615943.3	4291085.4
55	665.6	615947.0	4291095.2
56	675.6	615952.2	4291104.1
57	685.6	615955.0	4291113.7
58	695.6	615957.9	4291123.4

Notch evaluation location	Along-stream coordinate, m	Easting, UTM Zone 10S, m, NAD83	Northing, UTM Zone 10S, m, NAD83
59	705.6	615962.8	4291132.3
60	715.7	615964.9	4291142.1
61	725.7	615967.4	4291151.6
62	735.6	615971.6	4291159.9
63	745.6	615976.1	4291168.1

11. Appendix B - Summary of simulation entrainment at each evaluation location for each run

Table B1 - Percent of yearly fall run abundance entrained under each scenario for each evaluation location

Notch evaluation location	**Percent of yearly abundance entrained. The mean for the 15-year simulation period is given along with the 90% bootstrap confidence interval in parentheses**					
	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**
1	9% (2%-15%)	6% (1%-10%)	22% (5%-36%)	8% (4%-13%)	3% (1%-6%)	3% (1%-6%)
2	8% (1%-14%)	4% (1%-8%)	20% (5%-33%)	7% (3%-11%)	2% (0%-4%)	2% (0%-5%)

Notch evaluation location	**Percent of yearly abundance entrained. The mean for the 15-year simulation period is given along with the 90% bootstrap confidence interval in parentheses**					
	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**
3	7% (1%-13%)	4% (1%-7%)	19% (3%-32%)	6% (3%-9%)	2% (0%-3%)	2% (0%-5%)
4	6% (1%-12%)	4% (1%-7%)	19% (4%-32%)	5% (3%-9%)	2% (0%-4%)	2% (0%-4%)
5	7% (1%-12%)	4% (1%-8%)	20% (5%-33%)	7% (4%-11%)	2% (0%-5%)	2% (0%-5%)
6	8% (1%-13%)	5% (1%-8%)	21% (5%-34%)	8% (4%-12%)	2% (0%-5%)	3% (1%-5%)
7	7% (1%-11%)	4% (1%-7%)	19% (5%-31%)	6% (3%-9%)	3% (1%-5%)	3% (1%-6%)
8	5% (1%-8%)	3% (1%-6%)	17% (4%-29%)	5% (2%-7%)	2% (1%-4%)	2% (1%-4%)
9	4% (1%-8%)	3% (1%-4%)	17% (3%-29%)	4% (2%-6%)	2% (1%-4%)	2% (1%-4%)
10	4% (1%-7%)	3% (1%-5%)	18% (4%-30%)	4% (2%-7%)	2% (0%-4%)	2% (0%-4%)
11	5% (1%-9%)	3% (1%-6%)	19% (5%-31%)	5% (1%-11%)	2% (0%-5%)	3% (1%-7%)
12	6% (2%-10%)	3% (1%-7%)	21% (6%-32%)	6% (1%-10%)	3% (1%-5%)	3% (1%-7%)
13	7% (2%-12%)	5% (2%-11%)	22% (7%-34%)	8% (2%-16%)	4% (1%-8%)	5% (1%-12%)

Notch evaluation location	Percent of yearly abundance entrained. The mean for the 15-year simulation period is given along with the 90% bootstrap confidence interval in parentheses					
	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**
14	8% (3%-13%)	6% (2%-13%)	23% (8%-35%)	9% (2%-17%)	5% (1%-10%)	6% (1%-14%)
15	9% (4%-15%)	7% (2%-13%)	24% (8%-38%)	11% (4%-19%)	6% (2%-12%)	7% (1%-15%)
16	9% (4%-14%)	6% (3%-13%)	25% (8%-37%)	11% (4%-19%)	5% (2%-11%)	7% (2%-14%)
17	9% (4%-13%)	7% (2%-14%)	26% (9%-38%)	12% (4%-20%)	5% (2%-11%)	7% (2%-15%)
18	8% (3%-13%)	5% (2%-12%)	25% (10%-37%)	11% (3%-17%)	4% (1%-7%)	6% (1%-13%)
19	7% (3%-11%)	5% (2%-9%)	24% (9%-36%)	9% (2%-17%)	3% (1%-7%)	4% (1%-10%)
20	6% (3%-10%)	4% (2%-7%)	22% (7%-33%)	8% (3%-14%)	2% (1%-3%)	3% (1%-7%)
21	6% (2%-9%)	4% (2%-8%)	21% (8%-32%)	8% (3%-14%)	2% (1%-3%)	3% (1%-6%)
22	5% (2%-9%)	3% (2%-5%)	19% (6%-29%)	6% (2%-12%)	1% (0%-2%)	2% (0%-4%)
23	4% (1%-8%)	2% (1%-4%)	17% (6%-25%)	6% (2%-9%)	1% (0%-1%)	1% (0%-2%)
24	4% (1%-8%)	2% (1%-3%)	15% (4%-23%)	4% (2%-5%)	1% (0%-1%)	1% (0%-2%)

Notch evaluation location	**Percent of yearly abundance entrained. The mean for the 15-year simulation period is given along with the 90% bootstrap confidence interval in parentheses**					
	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**
25	3% (0%-6%)	2% (0%-3%)	14% (3%-23%)	3% (2%-4%)	0% (0%-1%)	0% (0%-1%)
26	5% (1%-10%)	2% (1%-5%)	19% (5%-29%)	6% (2%-11%)	1% (0%-1%)	1% (0%-2%)
27	8% (3%-14%)	5% (1%-12%)	22% (9%-34%)	10% (2%-20%)	2% (0%-4%)	3% (1%-7%)
28	11% (4%-20%)	8% (3%-18%)	25% (10%-38%)	13% (4%-25%)	4% (1%-11%)	6% (1%-14%)
29	11% (5%-19%)	8% (2%-17%)	27% (12%-40%)	13% (3%-25%)	4% (1%-11%)	6% (1%-13%)
30	11% (5%-20%)	8% (2%-19%)	28% (12%-43%)	14% (3%-28%)	4% (1%-11%)	6% (1%-14%)
31	10% (4%-18%)	8% (2%-18%)	28% (12%-42%)	13% (3%-25%)	3% (1%-8%)	5% (1%-13%)
32	10% (4%-18%)	8% (2%-20%)	27% (13%-38%)	13% (3%-26%)	3% (0%-7%)	5% (1%-13%)
33	11% (6%-20%)	9% (3%-18%)	26% (13%-37%)	13% (4%-25%)	4% (1%-12%)	6% (1%-13%)
34	9% (4%-18%)	8% (2%-18%)	23% (12%-34%)	12% (3%-24%)	3% (0%-8%)	5% (1%-13%)
35	9% (4%-18%)	7% (2%-19%)	23% (12%-35%)	12% (2%-24%)	3% (0%-8%)	5% (0%-11%)

Notch evaluation location	**Percent of yearly abundance entrained. The mean for the 15-year simulation period is given along with the 90% bootstrap confidence interval in parentheses**					
	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**
36	8% (4%-16%)	6% (1%-15%)	23% (12%-34%)	11% (2%-23%)	2% (0%-6%)	4% (0%-9%)
37	11% (6%-18%)	8% (2%-19%)	24% (12%-36%)	13% (2%-26%)	3% (0%-8%)	4% (1%-11%)
38	12% (6%-21%)	9% (2%-21%)	26% (14%-39%)	15% (3%-28%)	4% (0%-11%)	5% (1%-12%)
39	9% (5%-16%)	7% (1%-16%)	23% (12%-37%)	12% (2%-23%)	3% (0%-8%)	4% (1%-10%)
40	10% (6%-17%)	7% (1%-16%)	23% (12%-36%)	13% (2%-24%)	3% (0%-8%)	4% (1%-10%)
41	9% (4%-19%)	7% (1%-18%)	22% (12%-38%)	13% (2%-26%)	3% (0%-7%)	4% (0%-10%)
42	9% (3%-20%)	8% (1%-19%)	21% (12%-37%)	13% (2%-27%)	3% (0%-6%)	4% (0%-9%)
43	9% (3%-19%)	8% (1%-19%)	22% (12%-35%)	13% (2%-26%)	3% (0%-8%)	4% (0%-10%)
44	9% (4%-19%)	7% (1%-18%)	22% (13%-33%)	13% (2%-26%)	3% (0%-7%)	4% (0%-10%)
45	9% (5%-17%)	7% (1%-16%)	21% (13%-32%)	12% (2%-23%)	3% (0%-6%)	4% (0%-8%)
46	9% (5%-15%)	7% (2%-15%)	21% (13%-31%)	12% (3%-23%)	3% (0%-7%)	4% (0%-8%)

Notch evaluation location	Percent of yearly abundance entrained. The mean for the 15-year simulation period is given along with the 90% bootstrap confidence interval in parentheses					
	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**
47	10% (5%-16%)	8% (4%-16%)	22% (12%-32%)	12% (5%-20%)	3% (0%-6%)	4% (0%-9%)
48	8% (4%-13%)	6% (3%-11%)	20% (10%-30%)	10% (4%-17%)	2% (0%-4%)	2% (0%-5%)
49	9% (4%-16%)	7% (3%-12%)	21% (9%-31%)	11% (5%-18%)	2% (0%-5%)	3% (0%-6%)
50	10% (5%-17%)	7% (3%-14%)	22% (11%-33%)	12% (5%-20%)	3% (0%-5%)	3% (0%-7%)
51	8% (4%-15%)	6% (3%-11%)	20% (9%-30%)	11% (4%-18%)	2% (0%-4%)	2% (0%-5%)
52	9% (5%-15%)	6% (3%-12%)	21% (11%-31%)	12% (5%-18%)	3% (1%-5%)	3% (1%-7%)
53	8% (4%-14%)	6% (3%-12%)	20% (10%-29%)	11% (6%-18%)	2% (0%-4%)	3% (1%-6%)
54	9% (4%-14%)	7% (3%-12%)	20% (10%-30%)	11% (5%-19%)	3% (0%-6%)	3% (0%-8%)
55	9% (4%-15%)	6% (3%-11%)	19% (9%-28%)	10% (5%-17%)	3% (0%-7%)	4% (0%-9%)
56	9% (4%-16%)	7% (3%-12%)	18% (8%-28%)	9% (5%-14%)	3% (1%-6%)	3% (0%-8%)
57	8% (3%-17%)	6% (3%-12%)	18% (7%-29%)	9% (5%-15%)	2% (0%-5%)	3% (0%-7%)

Notch evaluation location	**Percent of yearly abundance entrained. The mean for the 15-year simulation period is given along with the 90% bootstrap confidence interval in parentheses**					
	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**
58	8% (3%-17%)	6% (2%-13%)	19% (7%-30%)	9% (5%-14%)	2% (1%-6%)	3% (0%-7%)
59	7% (2%-16%)	5% (2%-11%)	17% (6%-28%)	8% (4%-12%)	2% (0%-4%)	2% (0%-5%)
60	7% (2%-17%)	6% (2%-12%)	19% (7%-30%)	9% (4%-14%)	2% (0%-3%)	2% (0%-5%)
61	7% (3%-17%)	6% (2%-12%)	20% (9%-30%)	9% (4%-15%)	1% (1%-3%)	2% (1%-5%)
62	7% (2%-16%)	5% (2%-11%)	19% (8%-29%)	8% (4%-13%)	1% (0%-2%)	2% (0%-4%)
63	7% (1%-19%)	5% (1%-15%)	19% (6%-30%)	8% (4%-15%)	1% (0%-2%)	1% (0%-3%)

Table B2 - Percent of yearly spring run abundance entrained under each scenario for each evaluation location

Notch evaluation location	**Percent of yearly abundance entrained. The mean for the 15 year simulation period is given along with the 90% bootstrap confidence interval in parenthesis**					
	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**
1	7% (1%-15%)	4% (1%-10%)	16% (2%-34%)	7% (4%-13%)	2% (0%-6%)	2% (0%-7%)
2	6% (0%-13%)	3% (1%-9%)	15% (2%-33%)	6% (4%-10%)	1% (0%-3%)	2% (0%-5%)
3	5% (0%-12%)	3% (0%-8%)	15% (2%-32%)	5% (3%-9%)	1% (0%-3%)	1% (0%-4%)
4	5% (0%-11%)	3% (0%-7%)	15% (2%-32%)	4% (2%-7%)	1% (0%-3%)	1% (0%-4%)
5	5% (1%-12%)	3% (1%-8%)	15% (2%-34%)	7% (4%-11%)	2% (0%-4%)	2% (0%-5%)
6	5% (1%-12%)	4% (1%-8%)	16% (2%-34%)	7% (5%-10%)	2% (0%-5%)	2% (0%-6%)
7	5% (1%-11%)	4% (1%-7%)	15% (2%-33%)	6% (4%-9%)	2% (1%-5%)	3% (1%-5%)
8	4% (1%-8%)	2% (1%-5%)	13% (2%-29%)	5% (4%-7%)	2% (1%-4%)	2% (1%-4%)
9	3% (1%-8%)	2% (1%-5%)	13% (2%-29%)	4% (3%-6%)	2% (0%-4%)	2% (1%-4%)
10	3% (0%-7%)	2% (0%-5%)	14% (2%-31%)	4% (3%-6%)	1% (0%-4%)	2% (0%-4%)

Notch evaluation location	**Percent of yearly abundance entrained. The mean for the 15 year simulation period is given along with the 90% bootstrap confidence interval in parenthesis**					
	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**
11	4% (1%-9%)	3% (1%-6%)	15% (2%-33%)	5% (3%-8%)	2% (0%-5%)	3% (1%-7%)
12	5% (1%-9%)	3% (1%-6%)	16% (3%-34%)	6% (4%-9%)	2% (1%-5%)	3% (1%-7%)
13	6% (1%-12%)	4% (1%-9%)	17% (3%-37%)	8% (5%-11%)	3% (1%-8%)	4% (2%-10%)
14	6% (2%-14%)	5% (1%-10%)	18% (4%-38%)	10% (7%-13%)	4% (1%-9%)	5% (2%-11%)
15	7% (2%-14%)	5% (2%-12%)	19% (4%-40%)	12% (9%-15%)	5% (2%-11%)	6% (3%-13%)
16	7% (3%-14%)	6% (3%-11%)	19% (5%-40%)	13% (9%-16%)	5% (2%-10%)	7% (4%-12%)
17	8% (3%-14%)	6% (3%-11%)	20% (5%-40%)	14% (10%-18%)	5% (2%-10%)	7% (3%-12%)
18	6% (2%-13%)	4% (2%-9%)	20% (5%-39%)	13% (8%-17%)	3% (1%-6%)	5% (3%-10%)
19	6% (2%-11%)	4% (1%-7%)	18% (4%-37%)	11% (7%-14%)	3% (1%-5%)	4% (2%-7%)
20	5% (2%-9%)	3% (1%-5%)	17% (4%-34%)	9% (6%-13%)	2% (1%-3%)	3% (1%-5%)
21	5% (1%-8%)	3% (1%-5%)	17% (4%-32%)	10% (5%-13%)	2% (1%-3%)	2% (1%-4%)

Notch evaluation location	**Percent of yearly abundance entrained. The mean for the 15 year simulation period is given along with the 90% bootstrap confidence interval in parenthesis**					
	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**
22	4% (1%-7%)	2% (1%-4%)	15% (3%-28%)	7% (3%-10%)	1% (0%-2%)	2% (1%-2%)
23	3% (1%-6%)	2% (0%-3%)	13% (3%-25%)	7% (3%-9%)	1% (0%-1%)	1% (0%-2%)
24	3% (0%-6%)	1% (0%-3%)	12% (1%-24%)	4% (2%-5%)	0% (0%-1%)	1% (0%-1%)
25	2% (0%-5%)	1% (0%-2%)	11% (2%-23%)	4% (2%-7%)	0% (0%-1%)	0% (0%-1%)
26	4% (0%-9%)	2% (0%-5%)	14% (3%-30%)	7% (4%-10%)	0% (0%-1%)	1% (0%-2%)
27	6% (1%-13%)	5% (1%-10%)	16% (4%-33%)	11% (7%-15%)	2% (1%-3%)	3% (1%-5%)
28	9% (2%-17%)	7% (2%-14%)	20% (5%-38%)	15% (10%-18%)	4% (1%-8%)	5% (2%-10%)
29	9% (3%-17%)	7% (2%-12%)	21% (5%-42%)	14% (8%-18%)	3% (1%-7%)	5% (2%-9%)
30	9% (3%-18%)	7% (2%-13%)	22% (6%-42%)	14% (9%-19%)	4% (1%-7%)	5% (2%-10%)
31	8% (2%-16%)	6% (2%-12%)	21% (5%-39%)	12% (7%-16%)	3% (1%-6%)	4% (2%-8%)
32	8% (3%-15%)	6% (2%-13%)	20% (5%-38%)	13% (8%-18%)	3% (1%-5%)	4% (2%-8%)

Notch evaluation location	**Percent of yearly abundance entrained. The mean for the 15 year simulation period is given along with the 90% bootstrap confidence interval in parenthesis**					
	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**
33	9% (4%-15%)	7% (4%-13%)	20% (6%-37%)	14% (9%-19%)	4% (2%-7%)	6% (2%-9%)
34	8% (3%-14%)	7% (3%-12%)	18% (5%-33%)	14% (8%-17%)	3% (2%-5%)	5% (2%-7%)
35	7% (3%-13%)	6% (3%-12%)	18% (5%-31%)	14% (8%-18%)	3% (1%-5%)	4% (2%-7%)
36	6% (3%-11%)	5% (2%-9%)	17% (5%-31%)	13% (7%-16%)	2% (1%-4%)	4% (2%-6%)
37	8% (3%-14%)	6% (3%-12%)	19% (5%-34%)	14% (8%-17%)	3% (1%-5%)	4% (2%-7%)
38	9% (4%-15%)	7% (4%-14%)	20% (6%-37%)	16% (9%-20%)	4% (2%-6%)	5% (2%-8%)
39	8% (4%-13%)	6% (3%-11%)	18% (5%-33%)	13% (8%-18%)	3% (1%-5%)	4% (2%-6%)
40	7% (3%-12%)	6% (3%-11%)	18% (5%-32%)	14% (8%-19%)	3% (1%-5%)	4% (2%-7%)
41	7% (2%-13%)	6% (2%-12%)	17% (5%-30%)	14% (8%-19%)	2% (1%-5%)	3% (1%-6%)
42	7% (2%-14%)	6% (2%-12%)	16% (5%-28%)	14% (8%-19%)	2% (1%-4%)	3% (2%-6%)
43	8% (3%-15%)	7% (2%-13%)	17% (6%-28%)	14% (8%-19%)	3% (1%-4%)	4% (2%-7%)

Notch evaluation location	Percent of yearly abundance entrained. The mean for the 15 year simulation period is given along with the 90% bootstrap confidence interval in parenthesis					
	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**
44	7% (2%-13%)	6% (2%-13%)	17% (5%-28%)	14% (8%-19%)	2% (1%-4%)	3% (1%-6%)
45	7% (2%-13%)	6% (2%-11%)	16% (5%-28%)	13% (8%-18%)	2% (1%-4%)	3% (1%-5%)
46	7% (2%-11%)	6% (2%-10%)	17% (5%-27%)	13% (8%-18%)	2% (1%-4%)	3% (1%-5%)
47	7% (2%-11%)	6% (2%-9%)	17% (6%-28%)	13% (9%-17%)	2% (1%-4%)	3% (1%-6%)
48	6% (2%-10%)	4% (2%-8%)	15% (4%-26%)	10% (7%-13%)	1% (1%-3%)	2% (1%-3%)
49	6% (2%-12%)	5% (2%-9%)	16% (4%-27%)	11% (8%-15%)	2% (1%-3%)	3% (1%-4%)
50	7% (2%-13%)	5% (2%-10%)	16% (5%-28%)	13% (9%-17%)	2% (1%-3%)	3% (1%-5%)
51	6% (2%-10%)	4% (2%-8%)	16% (5%-27%)	12% (8%-16%)	1% (0%-3%)	2% (1%-4%)
52	7% (3%-11%)	5% (3%-7%)	16% (5%-28%)	13% (8%-18%)	2% (1%-4%)	3% (2%-5%)
53	6% (2%-11%)	5% (2%-8%)	16% (4%-27%)	13% (8%-17%)	2% (1%-3%)	2% (1%-5%)
54	6% (2%-10%)	5% (2%-9%)	15% (5%-27%)	11% (8%-14%)	2% (1%-4%)	3% (1%-5%)

Notch evaluation location	**Percent of yearly abundance entrained. The mean for the 15 year simulation period is given along with the 90% bootstrap confidence interval in parenthesis**					
	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**
55	6% (2%-11%)	5% (1%-8%)	14% (4%-25%)	10% (7%-13%)	3% (1%-5%)	3% (1%-6%)
56	6% (2%-11%)	5% (2%-8%)	13% (3%-23%)	8% (5%-10%)	2% (1%-5%)	3% (1%-5%)
57	5% (1%-11%)	4% (1%-8%)	13% (3%-23%)	8% (5%-9%)	2% (1%-3%)	2% (1%-5%)
58	5% (1%-11%)	4% (1%-9%)	14% (3%-24%)	8% (5%-11%)	2% (0%-3%)	2% (1%-4%)
59	4% (1%-10%)	3% (1%-7%)	12% (2%-22%)	6% (4%-8%)	1% (0%-3%)	2% (1%-3%)
60	5% (1%-11%)	4% (1%-8%)	14% (3%-24%)	7% (4%-10%)	1% (0%-2%)	2% (1%-3%)
61	5% (2%-11%)	4% (1%-7%)	15% (4%-25%)	7% (4%-10%)	1% (1%-2%)	2% (1%-4%)
62	5% (1%-10%)	4% (1%-7%)	14% (3%-24%)	7% (4%-10%)	1% (0%-2%)	2% (0%-3%)
63	4% (1%-12%)	3% (1%-9%)	14% (2%-26%)	6% (3%-10%)	1% (0%-1%)	1% (0%-2%)

Table B3 - Percent of yearly winter run abundance entrained under each scenario for each evaluation location

Notch evaluation location	Percent of yearly abundance entrained. The mean for the 15 year simulation period is given along with the 90% bootstrap confidence interval in parenthesis					
	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**
1	3% (0%-15%)	2% (0%-10%)	9% (0%-35%)	4% (0%-11%)	1% (0%-5%)	1% (0%-7%)
2	3% (0%-13%)	2% (0%-7%)	8% (0%-33%)	3% (0%-9%)	1% (0%-3%)	1% (0%-4%)
3	3% (0%-13%)	2% (0%-7%)	8% (0%-33%)	3% (0%-8%)	0% (0%-2%)	1% (0%-4%)
4	3% (0%-13%)	2% (0%-7%)	7% (0%-31%)	2% (0%-8%)	0% (0%-2%)	1% (0%-3%)
5	3% (0%-12%)	2% (0%-7%)	8% (0%-33%)	4% (0%-9%)	1% (0%-3%)	1% (0%-5%)
6	3% (0%-13%)	2% (0%-7%)	8% (0%-33%)	4% (0%-9%)	1% (0%-4%)	1% (0%-5%)
7	3% (0%-12%)	2% (0%-6%)	8% (0%-31%)	4% (0%-8%)	1% (0%-4%)	1% (0%-5%)
8	2% (0%-8%)	1% (0%-4%)	7% (0%-27%)	3% (0%-6%)	1% (0%-3%)	1% (0%-4%)
9	2% (0%-7%)	1% (0%-4%)	7% (0%-27%)	2% (0%-5%)	1% (0%-3%)	1% (0%-4%)
10	2% (0%-7%)	1% (0%-4%)	7% (0%-29%)	3% (0%-5%)	1% (0%-3%)	1% (0%-4%)

Notch evaluation location	**Percent of yearly abundance entrained. The mean for the 15 year simulation period is given along with the 90% bootstrap confidence interval in parenthesis**					
	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**
11	2% (0%-8%)	1% (0%-5%)	8% (0%-31%)	3% (0%-7%)	1% (0%-4%)	1% (0%-6%)
12	2% (0%-8%)	1% (0%-5%)	8% (0%-32%)	3% (0%-7%)	1% (0%-4%)	1% (0%-5%)
13	3% (0%-11%)	2% (0%-8%)	9% (0%-35%)	5% (0%-11%)	2% (0%-7%)	2% (0%-8%)
14	3% (0%-12%)	2% (0%-8%)	9% (0%-36%)	5% (0%-11%)	2% (0%-8%)	2% (0%-9%)
15	4% (0%-13%)	3% (0%-9%)	10% (0%-37%)	7% (0%-13%)	2% (0%-10%)	3% (0%-11%)
16	4% (0%-12%)	3% (0%-9%)	10% (0%-37%)	7% (0%-14%)	3% (0%-8%)	4% (0%-11%)
17	4% (0%-13%)	3% (0%-9%)	11% (0%-38%)	8% (0%-15%)	2% (0%-9%)	3% (0%-10%)
18	3% (0%-12%)	2% (0%-7%)	10% (0%-36%)	8% (0%-15%)	1% (0%-5%)	3% (0%-9%)
19	3% (0%-10%)	2% (0%-6%)	10% (0%-34%)	6% (0%-13%)	1% (0%-3%)	2% (0%-5%)
20	3% (0%-9%)	2% (0%-4%)	9% (0%-31%)	6% (0%-12%)	1% (0%-2%)	1% (0%-3%)
21	3% (0%-9%)	2% (0%-4%)	8% (0%-30%)	6% (0%-13%)	1% (0%-2%)	1% (0%-3%)

Notch evaluation location	Percent of yearly abundance entrained. The mean for the 15 year simulation period is given along with the 90% bootstrap confidence interval in parenthesis					
	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**
22	2% (0%-8%)	1% (0%-4%)	7% (0%-26%)	4% (0%-9%)	1% (0%-1%)	1% (0%-2%)
23	2% (0%-7%)	1% (0%-3%)	6% (0%-22%)	4% (0%-8%)	0% (0%-1%)	0% (0%-1%)
24	1% (0%-7%)	1% (0%-3%)	6% (0%-21%)	3% (0%-6%)	0% (0%-1%)	0% (0%-1%)
25	1% (0%-6%)	1% (0%-3%)	5% (0%-22%)	3% (0%-6%)	0% (0%-0%)	0% (0%-1%)
26	2% (0%-8%)	1% (0%-4%)	7% (0%-27%)	4% (0%-8%)	0% (0%-1%)	0% (0%-1%)
27	3% (0%-12%)	2% (0%-7%)	8% (0%-30%)	7% (0%-13%)	1% (0%-3%)	1% (0%-4%)
28	4% (0%-15%)	3% (0%-11%)	10% (0%-33%)	8% (0%-16%)	2% (0%-7%)	2% (0%-8%)
29	5% (0%-15%)	3% (0%-10%)	11% (0%-36%)	8% (0%-17%)	2% (0%-6%)	2% (0%-7%)
30	5% (0%-15%)	3% (0%-11%)	11% (0%-38%)	8% (0%-19%)	2% (0%-6%)	3% (0%-7%)
31	4% (0%-12%)	3% (0%-9%)	11% (0%-36%)	7% (0%-15%)	1% (0%-5%)	2% (0%-7%)
32	4% (0%-13%)	3% (0%-10%)	10% (0%-34%)	7% (0%-17%)	1% (0%-5%)	2% (0%-6%)

Notch evaluation location	**Percent of yearly abundance entrained. The mean for the 15 year simulation period is given along with the 90% bootstrap confidence interval in parenthesis**					
	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**
33	5% (0%-13%)	4% (0%-10%)	10% (0%-32%)	8% (0%-16%)	2% (0%-5%)	3% (0%-7%)
34	4% (0%-12%)	3% (0%-10%)	9% (0%-29%)	8% (0%-16%)	2% (0%-4%)	2% (0%-6%)
35	4% (0%-10%)	3% (0%-10%)	9% (0%-26%)	8% (0%-16%)	1% (0%-3%)	2% (0%-5%)
36	3% (0%-9%)	3% (0%-7%)	9% (0%-26%)	7% (0%-17%)	1% (0%-2%)	2% (0%-4%)
37	4% (0%-11%)	3% (0%-10%)	10% (0%-30%)	8% (0%-16%)	1% (0%-4%)	2% (0%-5%)
38	5% (0%-12%)	4% (0%-11%)	10% (0%-32%)	9% (1%-20%)	2% (0%-5%)	3% (0%-6%)
39	4% (0%-11%)	3% (0%-9%)	9% (0%-28%)	8% (0%-18%)	1% (0%-4%)	2% (0%-5%)
40	4% (0%-10%)	3% (0%-10%)	9% (0%-27%)	8% (0%-19%)	1% (0%-4%)	2% (0%-6%)
41	4% (0%-10%)	3% (0%-9%)	9% (0%-25%)	8% (0%-18%)	1% (0%-4%)	2% (0%-6%)
42	4% (0%-11%)	3% (0%-10%)	9% (0%-24%)	8% (0%-17%)	1% (0%-3%)	2% (0%-4%)
43	4% (0%-12%)	3% (0%-11%)	9% (0%-25%)	8% (0%-18%)	1% (0%-4%)	2% (0%-5%)

Notch evaluation location	Percent of yearly abundance entrained. The mean for the 15 year simulation period is given along with the 90% bootstrap confidence interval in parenthesis					
	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**
44	4% (0%-11%)	3% (0%-9%)	9% (0%-24%)	8% (0%-19%)	1% (0%-4%)	2% (0%-5%)
45	3% (0%-9%)	3% (0%-9%)	9% (0%-24%)	8% (0%-17%)	1% (0%-3%)	2% (0%-5%)
46	4% (0%-9%)	3% (0%-7%)	9% (0%-24%)	7% (0%-16%)	1% (0%-4%)	2% (0%-5%)
47	4% (0%-10%)	3% (0%-8%)	9% (0%-26%)	7% (0%-17%)	1% (0%-3%)	2% (0%-4%)
48	3% (0%-9%)	2% (0%-6%)	8% (0%-23%)	6% (0%-13%)	1% (0%-2%)	1% (0%-3%)
49	3% (0%-11%)	3% (0%-7%)	8% (0%-26%)	7% (0%-13%)	1% (0%-3%)	1% (0%-3%)
50	4% (0%-12%)	3% (0%-8%)	9% (0%-27%)	8% (0%-15%)	1% (0%-3%)	2% (0%-4%)
51	3% (0%-10%)	2% (0%-5%)	8% (0%-25%)	7% (0%-15%)	1% (0%-2%)	1% (0%-3%)
52	4% (0%-11%)	3% (0%-7%)	8% (0%-26%)	8% (0%-17%)	1% (0%-3%)	2% (0%-4%)
53	3% (0%-11%)	2% (0%-6%)	8% (0%-26%)	7% (0%-15%)	1% (0%-3%)	1% (0%-4%)
54	3% (0%-10%)	2% (0%-6%)	8% (0%-25%)	6% (0%-14%)	1% (0%-4%)	1% (0%-4%)

Notch evaluation location	Percent of yearly abundance entrained. The mean for the 15 year simulation period is given along with the 90% bootstrap confidence interval in parenthesis					
	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**
55	3% (0%-11%)	2% (0%-6%)	8% (0%-25%)	5% (0%-12%)	1% (0%-4%)	1% (0%-5%)
56	3% (0%-11%)	2% (0%-6%)	7% (0%-23%)	4% (0%-10%)	1% (0%-3%)	1% (0%-4%)
57	3% (0%-11%)	2% (0%-7%)	7% (0%-25%)	4% (0%-11%)	1% (0%-3%)	1% (0%-4%)
58	3% (0%-12%)	2% (0%-8%)	7% (0%-26%)	4% (0%-10%)	1% (0%-3%)	1% (0%-3%)
59	2% (0%-10%)	2% (0%-6%)	7% (0%-23%)	3% (0%-8%)	1% (0%-2%)	1% (0%-3%)
60	3% (0%-11%)	2% (0%-6%)	7% (0%-26%)	4% (0%-9%)	1% (0%-2%)	1% (0%-3%)
61	3% (0%-12%)	2% (0%-7%)	8% (0%-26%)	4% (0%-10%)	1% (0%-2%)	1% (0%-3%)
62	3% (0%-10%)	2% (0%-7%)	7% (0%-25%)	4% (0%-10%)	0% (0%-1%)	1% (0%-2%)
63	2% (0%-12%)	2% (0%-8%)	7% (0%-27%)	3% (0%-9%)	0% (0%-1%)	0% (0%-1%)

Table B4 - Percent of yearly late fall run abundance entrained under each scenario for each evaluation location

Notch evaluation location	**Percent of yearly abundance entrained. The mean for the 15 year simulation period is given along with the 90% bootstrap confidence interval in parenthesis**					
	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**
1	7% (1%-16%)	5% (1%-10%)	17% (2%-37%)	7% (3%-12%)	2% (0%-6%)	3% (0%-7%)
2	6% (0%-14%)	4% (0%-8%)	16% (2%-35%)	6% (2%-11%)	1% (0%-4%)	2% (0%-5%)
3	6% (0%-13%)	3% (0%-7%)	16% (1%-34%)	5% (2%-8%)	1% (0%-4%)	2% (0%-4%)
4	5% (0%-12%)	3% (0%-6%)	15% (1%-34%)	4% (1%-7%)	1% (0%-3%)	1% (0%-4%)
5	6% (0%-12%)	4% (0%-7%)	17% (2%-35%)	7% (3%-10%)	2% (0%-5%)	2% (0%-6%)
6	6% (0%-14%)	4% (0%-8%)	17% (2%-35%)	7% (3%-10%)	2% (0%-5%)	2% (0%-6%)
7	6% (1%-12%)	4% (1%-7%)	16% (2%-33%)	6% (2%-8%)	3% (0%-6%)	3% (1%-6%)
8	4% (0%-9%)	3% (0%-5%)	14% (1%-30%)	5% (2%-7%)	2% (0%-4%)	2% (1%-5%)
9	4% (0%-8%)	2% (0%-5%)	14% (1%-30%)	4% (2%-6%)	2% (0%-4%)	2% (0%-4%)
10	3% (0%-8%)	2% (0%-4%)	15% (1%-31%)	4% (2%-6%)	2% (0%-4%)	2% (0%-4%)

Notch evaluation location	Percent of yearly abundance entrained. The mean for the 15 year simulation period is given along with the 90% bootstrap confidence interval in parenthesis					
	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**
11	4% (1%-9%)	3% (0%-6%)	16% (2%-34%)	5% (2%-9%)	2% (0%-5%)	3% (0%-6%)
12	5% (1%-10%)	3% (1%-5%)	17% (2%-35%)	6% (3%-9%)	2% (0%-5%)	3% (1%-6%)
13	6% (1%-12%)	4% (1%-9%)	18% (2%-37%)	8% (4%-12%)	3% (1%-8%)	5% (1%-10%)
14	7% (1%-13%)	5% (1%-11%)	19% (3%-38%)	9% (5%-14%)	4% (1%-9%)	5% (1%-11%)
15	7% (1%-14%)	6% (1%-11%)	20% (3%-40%)	11% (6%-16%)	5% (1%-11%)	6% (2%-12%)
16	7% (1%-13%)	6% (1%-11%)	20% (3%-39%)	12% (7%-16%)	5% (1%-10%)	7% (2%-12%)
17	8% (1%-13%)	6% (1%-11%)	21% (4%-40%)	12% (7%-17%)	5% (1%-10%)	6% (2%-12%)
18	7% (1%-13%)	5% (1%-9%)	20% (4%-39%)	11% (7%-16%)	3% (1%-7%)	5% (2%-9%)
19	6% (1%-12%)	4% (1%-7%)	19% (3%-38%)	10% (6%-13%)	3% (1%-5%)	4% (1%-7%)
20	5% (1%-10%)	3% (1%-6%)	18% (3%-35%)	8% (4%-12%)	2% (0%-3%)	3% (1%-5%)
21	5% (1%-10%)	3% (1%-6%)	17% (3%-33%)	9% (5%-14%)	2% (0%-3%)	2% (1%-5%)

Notch evaluation location	Percent of yearly abundance entrained. The mean for the 15 year simulation period is given along with the 90% bootstrap confidence interval in parenthesis					
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
22	4% (1%-8%)	3% (1%-5%)	15% (3%-30%)	6% (3%-10%)	1% (0%-2%)	2% (1%-3%)
23	3% (0%-7%)	2% (0%-4%)	13% (2%-25%)	6% (3%-11%)	1% (0%-2%)	1% (0%-2%)
24	3% (0%-7%)	1% (0%-3%)	12% (2%-24%)	3% (2%-5%)	0% (0%-1%)	1% (0%-1%)
25	2% (0%-6%)	1% (0%-3%)	12% (1%-24%)	3% (2%-5%)	0% (0%-1%)	0% (0%-1%)
26	4% (0%-10%)	2% (0%-4%)	15% (2%-30%)	6% (3%-9%)	1% (0%-1%)	1% (0%-1%)
27	6% (1%-13%)	5% (1%-10%)	17% (3%-33%)	11% (6%-16%)	2% (0%-4%)	3% (1%-6%)
28	9% (2%-17%)	7% (1%-14%)	20% (4%-36%)	13% (7%-19%)	4% (1%-9%)	5% (1%-10%)
29	9% (2%-16%)	7% (1%-13%)	21% (4%-40%)	13% (6%-20%)	3% (1%-7%)	5% (1%-11%)
30	9% (2%-17%)	7% (2%-13%)	23% (4%-42%)	13% (7%-20%)	4% (1%-8%)	5% (1%-10%)
31	8% (1%-15%)	6% (1%-12%)	21% (4%-40%)	11% (5%-20%)	3% (1%-8%)	4% (1%-9%)
32	8% (2%-15%)	6% (2%-14%)	21% (5%-38%)	12% (6%-20%)	3% (1%-6%)	4% (1%-8%)

Notch evaluation location	**Percent of yearly abundance entrained. The mean for the 15 year simulation period is given along with the 90% bootstrap confidence interval in parenthesis**					
	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**
33	9% (2%-16%)	7% (2%-14%)	20% (5%-35%)	13% (7%-21%)	4% (1%-7%)	5% (2%-10%)
34	8% (2%-15%)	7% (2%-13%)	18% (4%-31%)	12% (6%-19%)	3% (1%-6%)	4% (2%-8%)
35	7% (2%-14%)	6% (2%-13%)	17% (4%-29%)	12% (6%-20%)	3% (1%-5%)	4% (2%-8%)
36	6% (2%-11%)	5% (2%-11%)	17% (4%-29%)	11% (5%-19%)	2% (1%-4%)	3% (1%-6%)
37	8% (2%-15%)	6% (2%-12%)	18% (5%-32%)	13% (6%-21%)	3% (1%-6%)	4% (1%-8%)
38	9% (2%-17%)	7% (2%-15%)	20% (5%-35%)	15% (8%-23%)	3% (1%-7%)	5% (2%-8%)
39	7% (2%-13%)	6% (2%-11%)	18% (4%-31%)	12% (6%-19%)	3% (1%-6%)	4% (2%-7%)
40	7% (2%-13%)	6% (2%-12%)	18% (4%-31%)	12% (6%-20%)	2% (1%-6%)	4% (1%-7%)
41	7% (2%-14%)	6% (1%-13%)	17% (5%-30%)	12% (6%-20%)	2% (1%-6%)	3% (1%-7%)
42	7% (2%-14%)	6% (1%-13%)	16% (4%-28%)	12% (6%-21%)	2% (1%-5%)	3% (1%-6%)
43	7% (2%-14%)	6% (2%-14%)	17% (5%-29%)	13% (6%-20%)	2% (1%-5%)	4% (1%-7%)

Notch evaluation location	Percent of yearly abundance entrained. The mean for the 15 year simulation period is given along with the 90% bootstrap confidence interval in parenthesis					
	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**
44	7% (2%-14%)	6% (2%-13%)	16% (5%-27%)	13% (6%-21%)	2% (1%-5%)	3% (1%-6%)
45	7% (2%-13%)	6% (2%-12%)	16% (5%-27%)	12% (6%-19%)	2% (1%-5%)	3% (1%-6%)
46	7% (2%-12%)	5% (2%-11%)	16% (5%-27%)	11% (6%-19%)	2% (1%-5%)	3% (1%-6%)
47	7% (2%-13%)	6% (2%-11%)	17% (5%-28%)	11% (7%-19%)	2% (1%-4%)	3% (1%-5%)
48	5% (2%-9%)	4% (2%-9%)	14% (4%-24%)	9% (5%-14%)	1% (0%-2%)	2% (1%-4%)
49	6% (2%-10%)	5% (2%-8%)	15% (4%-25%)	10% (6%-14%)	2% (1%-4%)	2% (1%-4%)
50	7% (2%-11%)	5% (1%-10%)	16% (4%-27%)	12% (7%-17%)	2% (1%-4%)	3% (1%-5%)
51	6% (1%-9%)	4% (1%-8%)	15% (4%-25%)	10% (6%-15%)	1% (0%-3%)	2% (1%-4%)
52	7% (2%-10%)	5% (2%-9%)	16% (5%-27%)	12% (6%-18%)	2% (1%-4%)	3% (1%-5%)
53	6% (2%-10%)	5% (2%-9%)	15% (4%-26%)	11% (6%-17%)	2% (0%-3%)	2% (1%-4%)
54	6% (2%-9%)	5% (2%-9%)	15% (4%-26%)	10% (6%-16%)	2% (0%-4%)	3% (1%-5%)

Notch evaluation location	**Percent of yearly abundance entrained. The mean for the 15 year simulation period is given along with the 90% bootstrap confidence interval in parenthesis**					
	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**
55	6% (2%-10%)	4% (1%-8%)	14% (4%-25%)	9% (5%-13%)	3% (1%-5%)	3% (1%-6%)
56	6% (1%-10%)	4% (2%-8%)	13% (3%-24%)	7% (4%-11%)	2% (0%-5%)	3% (1%-6%)
57	5% (1%-10%)	4% (1%-7%)	13% (3%-24%)	7% (4%-11%)	2% (0%-4%)	2% (1%-5%)
58	5% (1%-10%)	4% (1%-7%)	14% (3%-25%)	7% (4%-11%)	2% (0%-4%)	2% (0%-4%)
59	4% (1%-8%)	3% (1%-5%)	12% (3%-22%)	6% (3%-9%)	1% (0%-3%)	2% (0%-4%)
60	4% (1%-9%)	3% (1%-7%)	13% (3%-25%)	6% (3%-9%)	1% (0%-3%)	2% (1%-4%)
61	5% (1%-9%)	4% (1%-7%)	14% (4%-25%)	7% (4%-12%)	1% (0%-3%)	2% (1%-4%)
62	4% (1%-8%)	3% (1%-6%)	14% (3%-23%)	6% (3%-11%)	1% (0%-2%)	2% (0%-4%)
63	4% (1%-10%)	3% (1%-7%)	14% (2%-26%)	5% (3%-8%)	1% (0%-2%)	1% (0%-2%)

12. Appendix C - Detailed rating curves and drawings for Scenario 5 and Scenario 6

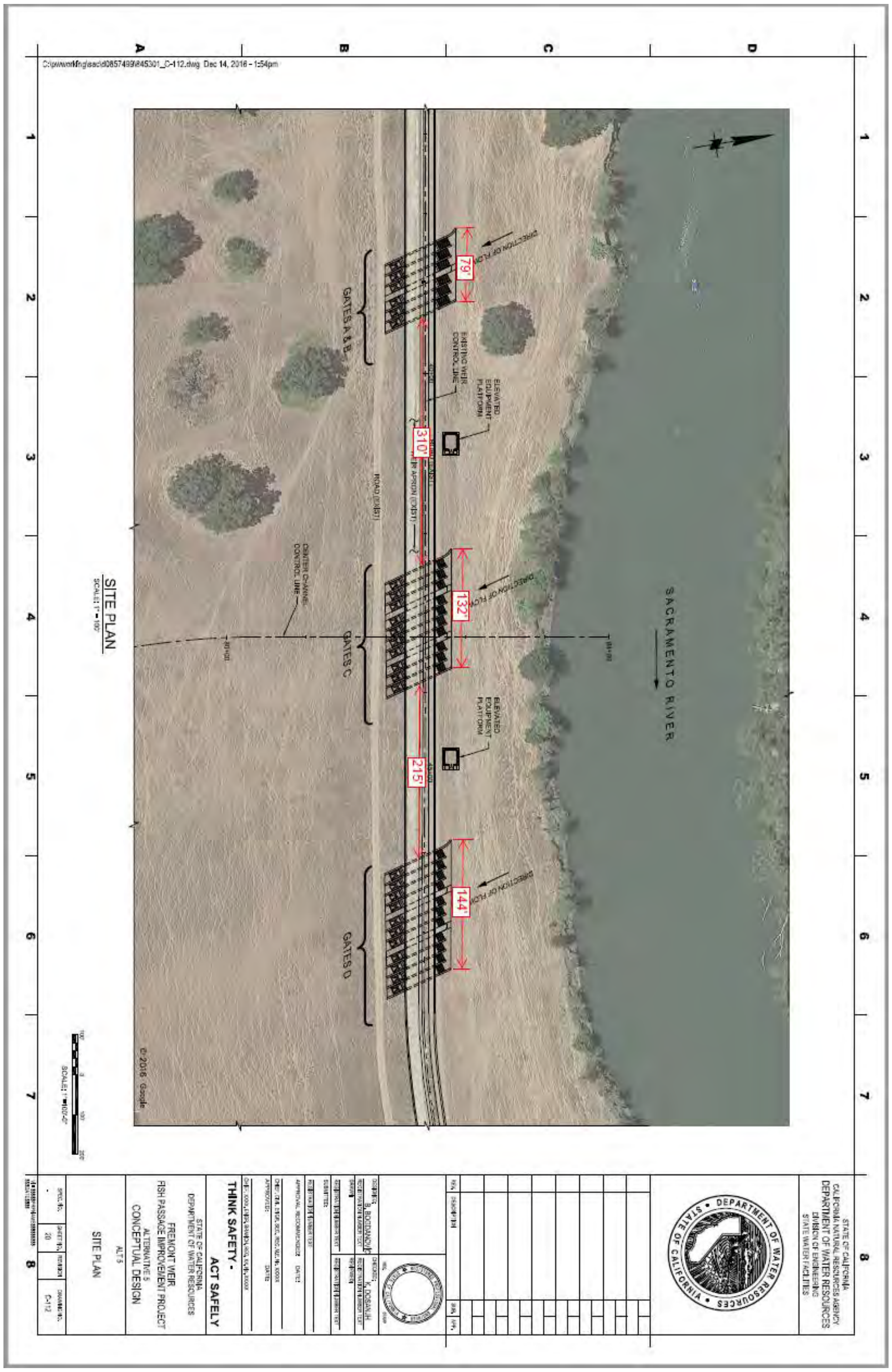


Figure C1 – Plan view of alternative 5 showing the gate spacing used for scenario 5 and scenario 6

Note that alternative 5 is located outside of the 2016 study area, while scenario 5 and scenario 6 evaluated notch locations within the 2016 study area.

Table C1 - Stage - discharge relationships for scenario 5 and scenario 6

Stage, Scenario 6, ft, USGS survey, NAVD88.	Stage, Scenario 5, ft, USGS survey, NAVD88.	Intake A discharge, cfs	Intake B discharge, cfs	Combined Discharge, Intake A and B, cfs	Intake C discharge, cfs	Intake D discharge, cfs
15.00	16.30	12		12		
16.00	17.30	45		45		
17.00	18.30	94	0	94		
18.00	19.30	157	20	177		
19.00	20.30	245	71	316		
20.00	21.30	340	158	498		
20.50	21.80	398	219	617		
22.00	23.30	659	414	1073	0	
23.00	24.30	711	428	1139	636	
24.00	25.30	860	607	1467	915	
25.00	26.30	1025	800	1825	1259	
25.50	26.80	0	1464	1464	1671	
26.00	27.30		1169	1169	2054	
26.25	27.55		1220	1220	2188	

Stage, Scenario 6, ft, USGS survey, NAVD88.	Stage, Scenario 5, ft, USGS survey, NAVD88.	Intake A discharge, cfs	Intake B discharge, cfs	Combined Discharge, Intake A and B, cfs	Intake C discharge, cfs	Intake D discharge, cfs
26.50	27.80		672	672	2493	0
26.60	27.90		0	0	2084	1369
27.00	28.30				1400	1859
27.25	28.55				1476	1998
27.50	28.80				1032	2226
27.75	29.05				1084	2381
28.00	29.30				563	2619
28.25	29.55				589	2790
28.50	29.80				0	3032
29	30.30					3407
29.5	30.80					3463
30	31.30					3246
31	32.00					3325
32.3	32.30					0

Table C2 - Notch spacing for scenario 5 and scenario 6

For scenario 5 and Scenario 6 entrainment for each notch is calculated based on the location of the bootstrap sample fish tracks relative to the location of the critical streakline at the along stream location that corresponds to the center of each notch. The location of the center of the downstream notches (B, C, and D) is calculated by adding the offsets listed below to the along-stream location of Notch A.

Notch	Offset from center of Notch A, meters in the along stream direction
A	0
B	40 ft (12.2 meters)
C	436 ft (133 meters)
D	789 ft (240.5 meters)