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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July 21, 2017

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1. Executive Summary

During water year 2016 the U.S.G.S. California Water Science Center (USGS) collaborated with the California Department of Water Resources (CADWR) 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. The primary goal of this entrainment analysis was to investigate how the location of the notch or notches in each scenario could influence the entrainment of Chinook salmon 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 diverted into the Yolo Bypass under the modification scenarios. Because of this variability, the USGS felt that accurately evaluating the entrainment potential of possible locations for each scenario would require 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 run abundance within the historic record. As a result the USGS chose to use a Monte Carlo simulation framework to combine the high resolution hydrodynamic data and acoustic tag track data collected in 2016 with historic abundance, stage, and discharge data from a period spanning water years 1996-2010 to assess the entrainment potential of weir modification scenarios under historic conditions. The USGS evaluated the entrainment potential of four single notch modification scenarios, and two multiple notch modification scenarios in the vicinity of the western end of the Fremont Weir. For each modification scenario, the 15 water year entrainment simulation was repeated at each of 63 possible notch locations in the vicinity of the western end of the Fremont Weir which allowed us to asses the effect of notch location on entrainment of juvenile salmonids onto the Yolo Bypass.

The entrainment simulations showed that the location of each modification scenario had a major impact on the entrainment potential for each scenario; the predicted entrainment potential of some scenarios varied by as much as 400% based on where the scenario was located in the study area. All of the single notch scenarios performed best when they were located within a 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 gates were located about 200 meters upstream of the western terminus of the Fremont Weir (Table 1). The entrainment simulation indicated that these regions resulted in near-maximum entrainment under all water year types simulated, and for all run abundance histories simulated, indicating that these locations are likely to be near-optimal under a range of conditions for fish that behave similarly to the hatchery surrogates used in the study.

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. Firstly, comparisons between the maximum entrainment potential for each scenario suggested that total entrainment of winter run, spring run, and fall run can increased by increasing the amount of water entering a notch when the Sacramento River is between 19 ft NAVD88 stage and 22 ft NAVD88 stage; 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. Secondly, 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. Finally, bathymetric features upstream of notch/gate openings appeared to have a major impact on the entrainment potential of weir modifications. For this reason we recommend taking care to avoid citing 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. It is likely that all of these results are sensitive to any differences in behavior and physiology between the hatchery surrogates used for the 2016 study and naturally migrating juvenile salmon.

Table 1 - Summary of scenario performance

Percent of yearly abundance entrained under each scenario, by run. The mean yearly percent of yearly abundance entrained is given along with 90% bootstrap confidence intervals in parenthesis. The final row gives the UTM coordinates of the location of overall maximum entrainment for each scenario.

	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%)	7% (1%-15%)
Spring Run	9% (4%-15%)	7% (4%-14%)	22% (6%-42%)	16% (9%-20%)	5% (2%-11%)	6% (3%-13%)
Winter Run	5% (0%-12%)	4% (0%-11%)	11% (0%-38%)	9% (1%-20%)	2% (0%-10%)	3% (0%-11%)
Late Fall Run	9% (2%-17%)	7% (2%-15%)	23% (4%-42%)	15% (8%-23%)	5% (1%-11%)	6% (2%-12%)
Location of maximum entrainment (m, UTM, NAD83)	615849E, 4290952N	615849E, 4290952N	615780E, 4290905N	615849E, 4290952N	615636E, 4290860N	615636E, 4290860N

2. Acknowledgements

We wish to thank the State and Federal water contractors and the Department of Water Resources 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 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 CRRL), and our instrument programming, deployment, and recovery teams, led by Chris Vallee (USGS CWSC), are gratefully acknowledged.

3. Introduction

During the winter and spring of water year 2016 the U.S.G.S. California Water Science Center (USGS) collaborated with the California Department of Water Resources (CADWR) 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 (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 (ref fish tagging and condition report). 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: summarizing the information obtained from the acoustic tag tracking array and estimating the spatial distribution of the acoustically tagged study fish, 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 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 the 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 past studies the USGS has found that the spatial distribution of acoustically tagged fish can be combined with hydrodynamic data to understand, 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, 2016). This 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, 2016). For this study, our analysis of the temporary index velocity gauge data found that backwater effects in the Sacramento River caused by the Sutter Bypass and the Feather River created substantial variance in the amount of Sacramento River discharge that passed through the study area at any stage value (Figure 3). This variance ment that the proportion of Sacramento River discharge that was expected to be diverted into 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 variance 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 timestep 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 timestep 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 track passed through the study area relative to the hydraulic conditions for the simulation timestep.

The primary goal of the entrainment simulation was to explore the relationship between notch location and entrainment 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 under each modification scenario **at each of the 63 alternative scenario locations within the study area** (Figure 4, 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 timestep. Our analysis of these results focused on answering 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?

4. Methods

The basic structure of the entrainment simulation was a Monte Carlo bootstrap simulation (Davison and Hinkley,1997) 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 NAVD88, USGS, and the cross-channel axis is defined as always instantaneously normal to the along-channel axis. The resulting cross-channel evaluation sections for a Sacramento River stage of 28.5 ft is shown in figure 4.

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 times 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 5). 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 6). 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 7). 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 1foot 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(s) given Sacramento River Stage; F(Sacramento River stage)
      2. Estimate the location of the critical streakline 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
         2. Draw a weighted random sample of tracks from the pool of observed 2016 tracks with weights determined by the time steps

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 5, lower panel), and this correction improved the agreement between CDEC data and USGS surveys of the water surface elevation (Appendix C). **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 "NAVD88, USGS",** to avoid confusion between the USGS estimate 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 5, 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. We used this approach to make sure the missing discharge estimates were filled in using data that 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 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 sumed to 100%. Per conversations with 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 zeros.

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 hr 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 8). 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 timestep 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 8). 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 9). Within this report we refer to the time series of discrete sample sizes for each run at each timestep 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 timestep 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 timestep. Figure 11 and figure 12 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 10). 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 11, figure 12). By computing the covariance matrix for the weighting function at every timestep 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 12). The same bootstrap sample drawn for each run at a given timestep 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 4. 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 4.

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 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 the 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 variance 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.

3.4.3.1 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).

3.4.3.2 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 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.

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 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 using an error 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 3.4.5.

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 2.

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

At each timestep 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 uncertainty in the location of the critical streakline due to the effects of Sacramento River backwater condition on the cross-channel distribution of water velocity. (See Stumpner et al., In Review). The random perturbation was drawn from an error distribution which we modeled as a normal distribution with a mean of zero, and a standard deviation of 6.5 ft; see Stumpner et al., In Review for 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 4). 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 multi-gate scenarios (scenario 5 and scenario 6)

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

The entrainment analysis simulation evaluated entrainment for six scenarios:

1. Scenario 1 consisted of a single notch in the weir with the notch rating curve for Alternative 3. Under scenario 1 flow through the notch began at 19 ft, and notch discharge reached a maximum flow of 6,105 cfs at 31ft, and notch flow was maintained at 6,105 cfs for all Sacramento River stages above 31 ft.
2. Scenario 2 consisted of a single notch in the weir with the notch rating curve for Alternative 4. Under scenario 2 flow through the notch began at 19 ft, and notch discharge reached a maximum flow of 3,166 cfs at 27 ft, and notch flow was maintained at 3,166 cfs for all Sacramento River stages above 27 ft.
3. Scenario 3 consisted of a single notch in the weir with the notch rating curve for Alternative 6. Under scenario 3 flow through the notch began at 20 ft, and notch discharge reached a maximum flow of 12,253 cfs at 30 ft, and notch flow was maintained at 12,253 cfs for all Sacramento River stages above 30 ft.
4. Scenario 4 consisted of a single notch in the weir with a notch rating curve similar to Alternative 4, but with flow through the notch beginning at 15 ft instead of 19 ft. Under scenario 4 flow through the notch began at 15 ft, and notch discharge reached a maximum flow of 3,166 cfs at 23 ft, and notch flow was maintained at 3,166 cfs for all Sacramento River stages above 23 ft. The purpose of scenario 4 was to evaluate how entrainment was affected by changing notch invert elevation for single gate alternatives; because scenario 2 and scenario 4 share the same relationship between notch flow and stage relative to invert elevation, performance differences between scenario 2 and scenario 4 are indicative of the effects of invert elevation on entrainment within the simulation process.
5. Scenario 5 consisted of four gated notches in the weir. The notch rating curves and gate dimensions and spacing are based on the design for Alternative 5, but the inverts for all notches are raised by 1.3 ft Under scenario 5 flow through the notch began at 17 ft, reached a maximum of 3,424 cfs at 29 ft, then flow through the notch ceased upon overtopping at 32.3 ft. The purpose of scenario 5 was to increase our understanding of the performance of multi-gate scenarios located on the outside of a bend.
6. Scenario 6 consisted of four gated notches in the weir. The notch rating curves and gate dimensions and spacing are based on the design for Alternative 5. Under scenario 6 flow through the notch began at 15 ft, reached a maximum of 3,863 cfs at 31.7 ft, then flow through the notch ceased with overtopping at 32.3 ft. The purpose of scenario 6 was to evaluate how entrainment was affected by changing notch invert elevation for multiple gate alternatives; because scenario 5 and scenario 6 shared the same relationship between notch flow and stage relative to invert elevation, performance

differences between scenario 5 and scenario 6 are indicative of the effects of invert elevation on entrainment within the simulation process.

Table 2 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. Note that because of backwater effects there can be a wide range of Sacramento River discharge values which occur for any stage, so the discharge given in Table 2, 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-gate scenarios is contained in Appendix B.

The same simulation procedure and covariate data was used to evaluate entrainment under each scenario, with the exception that extra steps were used to estimate entrainment for the multi-gate scenarios as described in section 3.4.6.

It is important to note that scenario 4 and scenario 6 were simulated for analytical purposes only, because including these scenarios allowed us to draw inferences about how changing a scenario's invert elevation might affect entrainment if the scenario's notch rating curve was held constant with respect to the difference between invert elevation and Sacramento River stage. Scenario 4 and scenario 6 are not indicative of any alternatives currently under review.

Table 2- Notch rating curves for simulated scenarios

Sacramento River Stage, ft, NAVD88, USGS	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 gates)	Scenario 6 Notch Flow, CFS (Total flow through all gates)
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
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 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 10 meters (32.8 ft) apart in the along stream direction (figure 4, 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 13). 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 14 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 3, while Appendix B contains tables containing mean yearly total entrainment and 90% confidence intervals for yearly total entrainment 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 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 15 is similar to figure 14, 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 14 addresses the question “where should a scenario be located to maximize the overall entrainment of a run”, while figure 15 addresses the question “where should a scenario 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 gate scenarios (scenario 1 - scenario 4) notch performance for all run has a peak around 275 meters, a sharp decrease in performance between 300 meters and 375 meters, followed by a broad peak in performance that slowly drops off after 500 meters. For single gate scenarios the maximum entrainment and entrainment rate for all run is located between 400 meters and 500 meters. Figure 16 shows where these along channel coordinates are located in the study area, 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 multigate scenarios (scenario 5 and scenario 6) is similar, but these scenarios had the highest entrainment and entrainment rate for all run between 260 meters and 280 meters. For multigate scenarios the location indicated on the entrainment and entrainment rate plots is the along-channel location of the center of the first gate, so a peak entrainment listed at 270m indicates that peak entrainment occurred for the scenario when the center of the first gate was located 270m, the center of the second gate was located at 282m, the center of the third gate was located at 430m, and the center of the fourth gate was located at 510 meters (See Appendix C for gate spacing for scenario 5 and scenario 6). The spacing of the gates for the multigate scenarios explains why these scenarios reached peak performance when the center of the first gate was located near 270 meters, because this location placed all 4 gates in regions where the single gate scenarios had high entrainment.

It is likely that the dramatic drop in scenario entrainment and scenario entrainment rate shown in figure 14 and figure 15 around 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 16) in this area of the river. Figure 17 show the location of the notch evaluation cross-section at 365m 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 18). 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 19), 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 14-15 is that the entrainment and entrainment rate curves for each run suggest that differences in abundance timing between run 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 3 - Summary of scenario performance

Percent of yearly abundance entrained under each scenario, by run. The mean for the 15 water year simulation is shown along with 90% bootstrap confidence intervals in parenthesis. The final rows give the evaluation location and the UTM coordinates for the location of overall maximum entrainment for each scenario.

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%)	7% (1%-15%)
Spring Run	9% (4%-15%)	7% (4%-14%)	22% (6%-42%)	16% (9%-20%)	5% (2%-11%)	6% (3%-13%)
Winter Run	5% (0%-12%)	4% (0%-11%)	11% (0%-38%)	9% (1%-20%)	2% (0%-10%)	3% (0%-11%)
Late Fall Run	9% (2%-17%)	7% (2%-15%)	23% (4%-42%)	15% (8%-23%)	5% (1%-11%)	6% (2%-12%)
Evaluation location with maximum entrainment	38	38	30	38	15	15
Coordinates of max (m UTM, NAD83)	615849E, 4290952N	615849E, 4290952N	615780E, 4290905N	615849E, 4290952N	615636E, 4290860N	615636E, 4290860N

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 15). Scenario 4 is the exception, as all run experienced similar entrainment rates under this scenario (figure 15, 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 run 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 20). The cumulative distribution functions (cdfs) for each run' simulation abundance as a function of stage shown in figure 20 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 only 3,166 cfs.

Finally, scenario 4 has similar entrainment rates for all run, 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 4). 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 4 - percent of simulation abundance for each run that passed through the study area during the notch operation period.

	Percent of simulation total yearly abundance for the simulation period that transited the study area during notch operation periods
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 21), and stage vs entrainment efficiency curves for each scenario (Figure 22). Entrainment rate indicates the fraction of the bootstrap sample at each timestep 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 16).

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 figure 21 and 22 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 multigate scenarios the entrainment rate and median discharge ratio are based on total entrainment of water and fish through all gates operating at any stage value.

The scenario stage vs entrainment rate curves shown in figure 21 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 22 shows the range of entrainment efficiency values for all timesteps 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. Figure 23 and figure 24 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 step function process due to the high gradient in the fish densities).

3. There is a zone beginning at about 15-25 meters from the river right bank (figure 24) 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 23) was dramatically different than the spatial distribution of 2016 fish tracks for periods when the Sacramento River was above bankfull (figure 25, figure 26). 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 figure 21 and figure 22 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 multigate 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 10); 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 5 and 6), 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 5, and the entrainment vs along-stream location curves for each water year class, run, and scenario are shown in figure 27 through figure 32. 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 figure 27 through figure 32 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 5 - 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 >32.3 ft, NAVD88, USGS)	
0	No overtopping, Category 1
1-200	Few overtopping, Category 2
200 +	Wet, Category 3

Table 6 - 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 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, and we feel that this is the single largest source of uncertainty within the entrainment simulation. 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. 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. 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.

6.2. Implications for design of weir modifications

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 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 scenarios between 400m and 500m in the along-channel direction (see Appendix A for UTM locations - shown in figure 7) will result in near maximum entrainment and entrainment rates for all single notch scenarios, and that performance of scenarios located in this area will likely be robust to changes in abundance timing and water year type.

- Locating multiple notch scenarios with the first gate near 265m in the along-channel direction (see Appendix A for UTM locations - shown in figure 7) will result in near maximum entrainment and entrainment rates for alternatives with gate 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 the multi-notch scenarios can be improved by optimizing the trade off 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 desired total scenario 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.

7. References

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8. 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.

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 bathymetry maps in the study area, hotter colors on the bathymetry map denote deeper areas. Hydrophone locations are shown as dots with hydrophone labels.

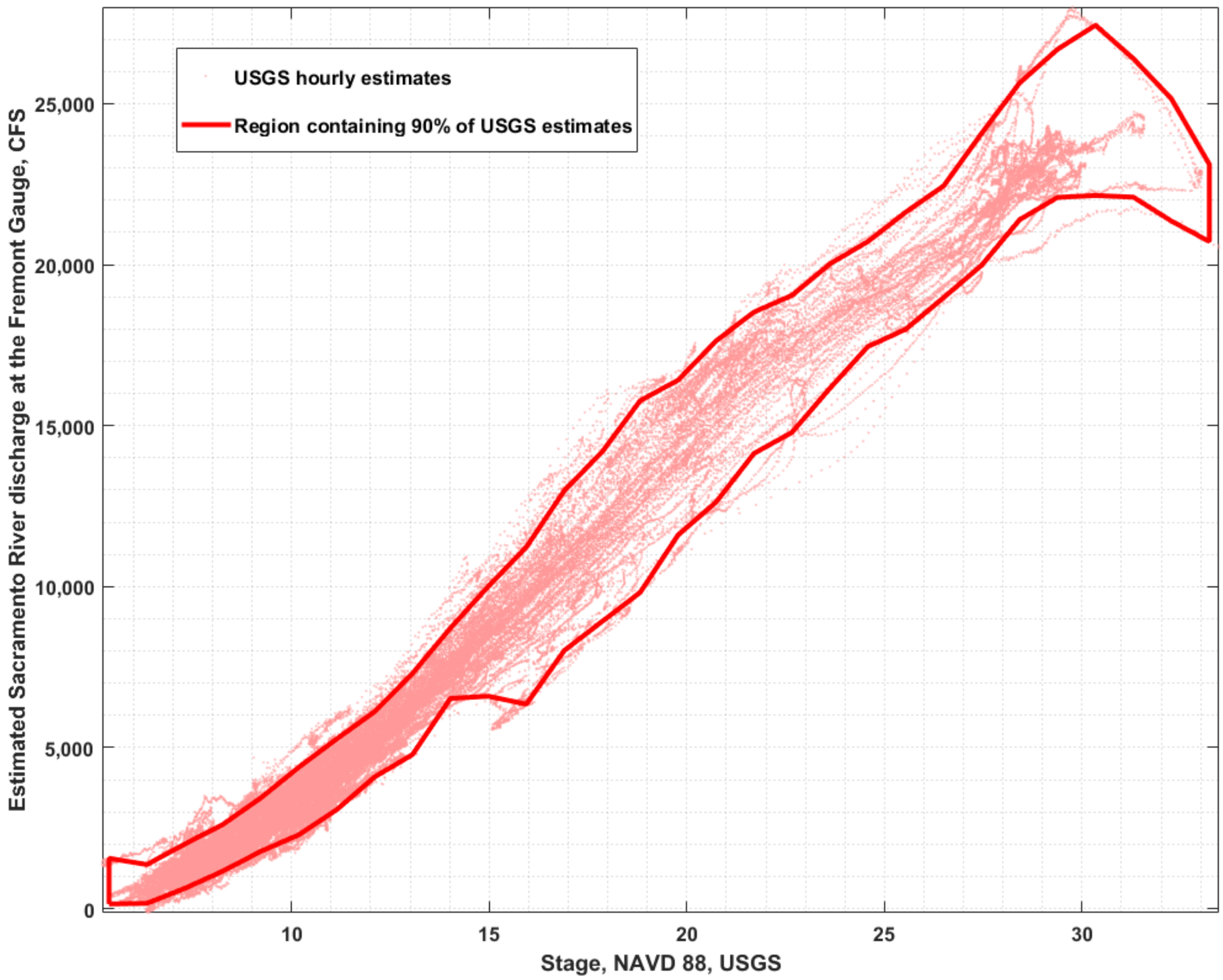


Figure 3 - Plot showing the range of estimated stage-discharge values for the Sacramento River in the vicinity of the western end of the Fremont Weir from 1996 to 2011

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 - Aerial photo of the vicinity of the western end of the Fremont Weir overlaid with scenario evaluation locations.

The white box indicates the study area for the simulation entrainment; the black lines indicate the 63 notch evaluation cross-sections where entrainment was estimated for each scenario at each timestep. The 15 water year simulation was repeated 63 times for each scenario to model entrainment for a notch at each point where one of the black lines intersects the river right bank of the Sacramento River. See Appendix A for UTM coordinates for these locations.

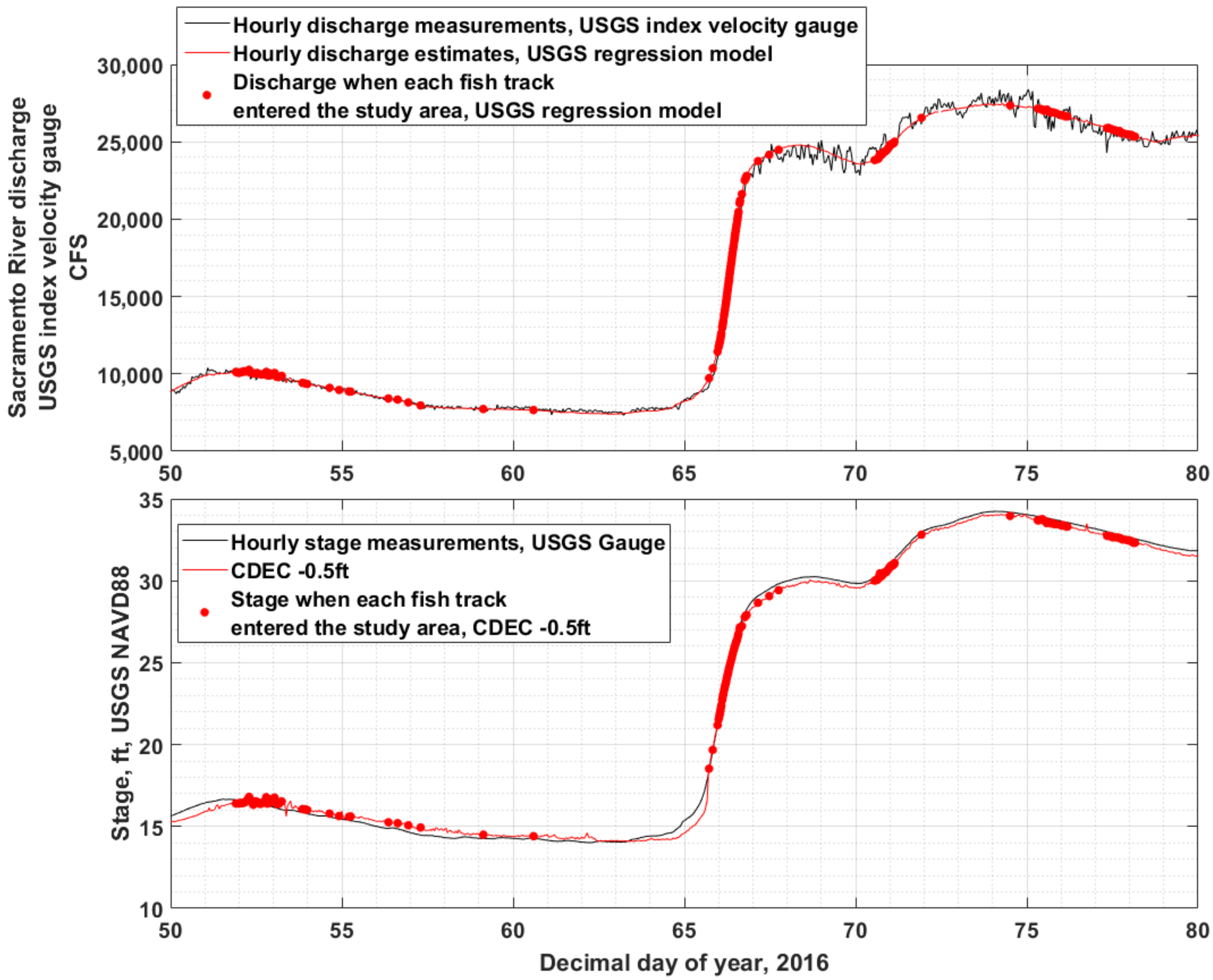


Figure 5 - Plot showing Sacramento River discharge and Sacramento River stage during the time period that 2016 acoustic tag tracks were collected

The top panel shows a time series of Sacramento River discharge measurements and discharge estimates when 2016 acoustic tag tracks were collected, the bottom panel shows time series of Sacramento River stage measurements during time periods when 2016 acoustic tag tracks were collected. Note the rapid rise in stage and discharge following day 65.

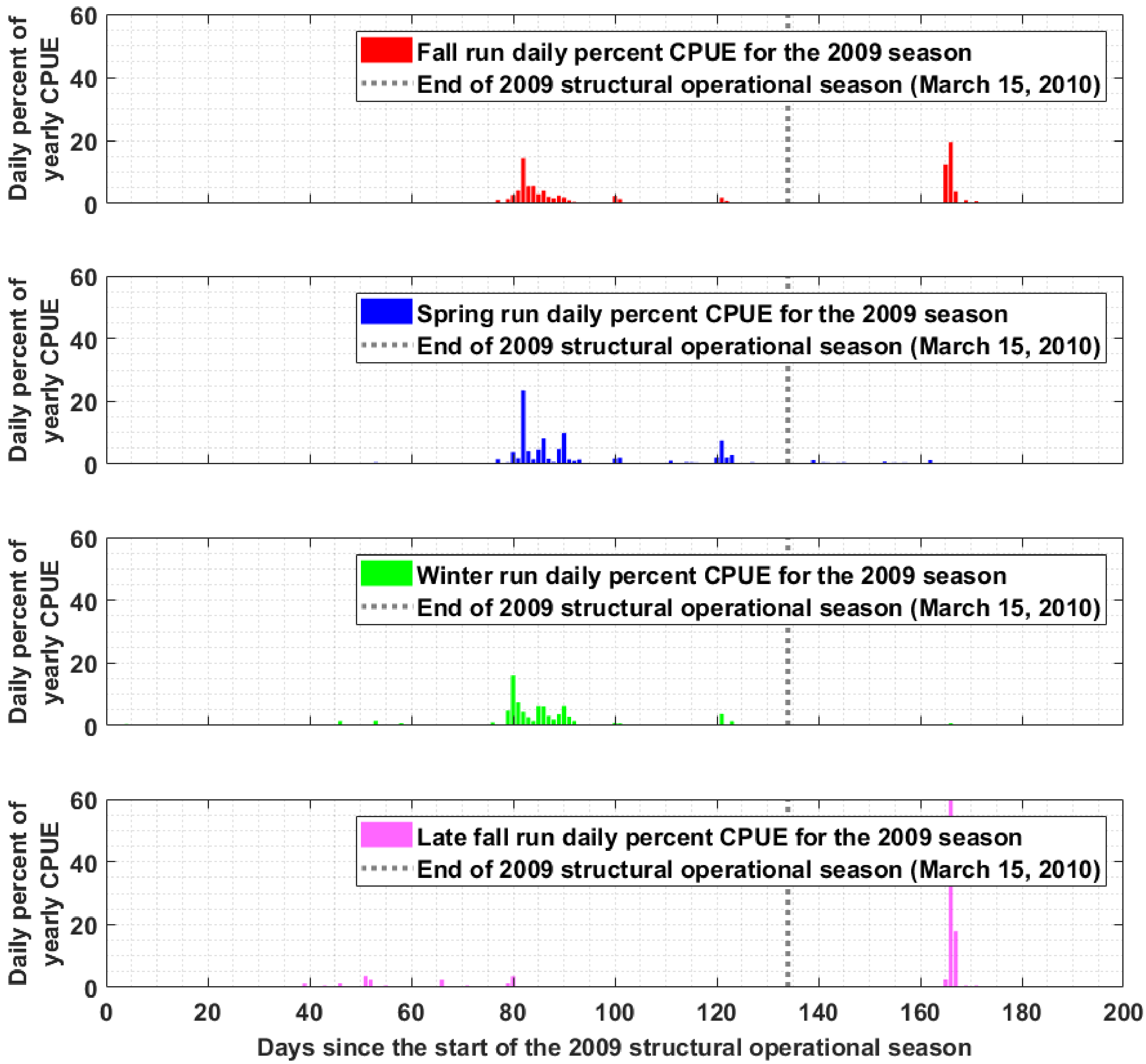


Figure 6 - Daily catch data from the Knights Landing rotary screw trap for the 2009 season (Water year 2010)

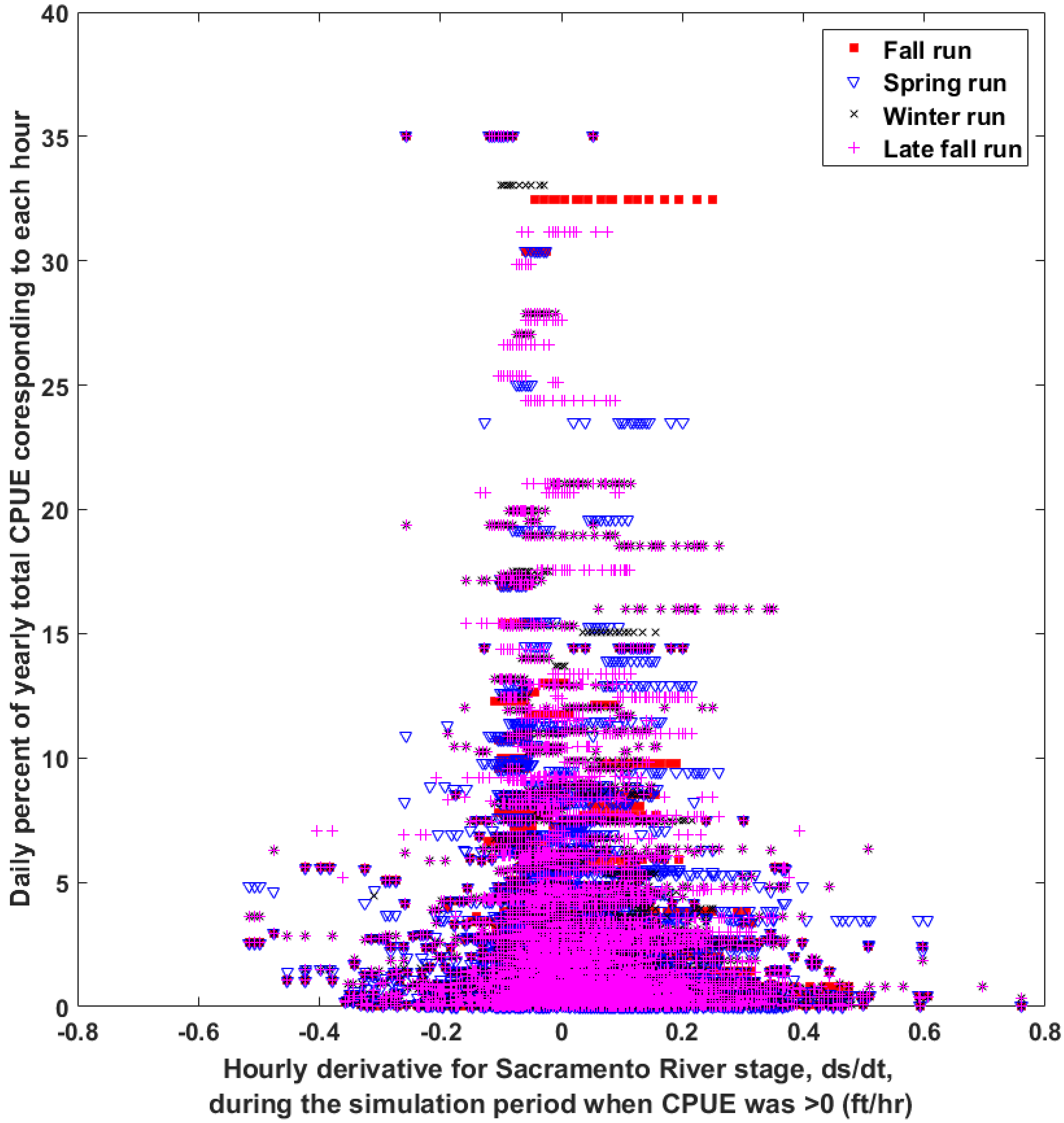


Figure 7 - Plot showing the hourly derivative for Sacramento River stage during the simulation period when Knights Landing catch was greater than zero during the operational window

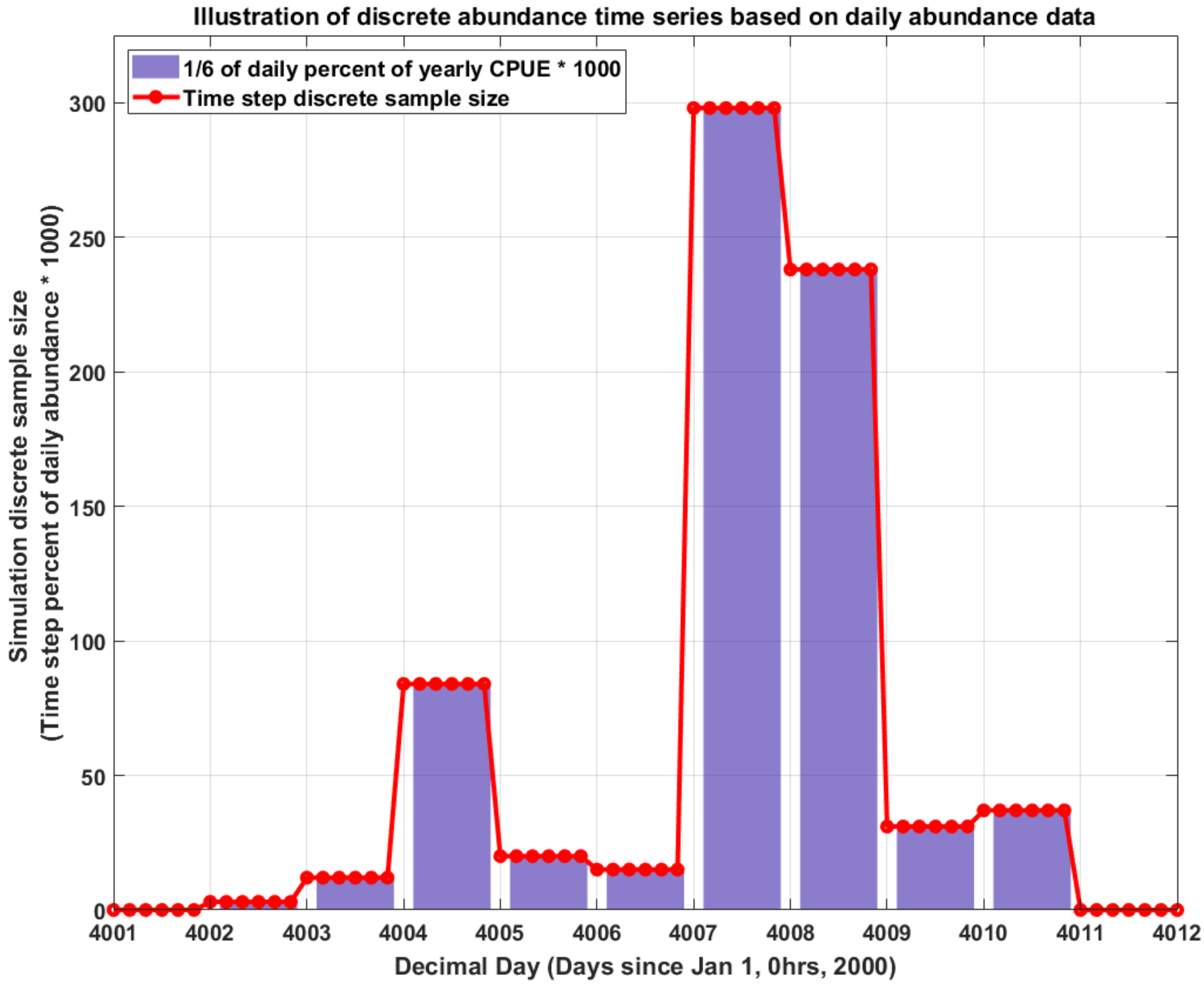


Figure 8 - Plot showing how the daily percent yearly CPUE data was converted into discrete sample sizes for each time step

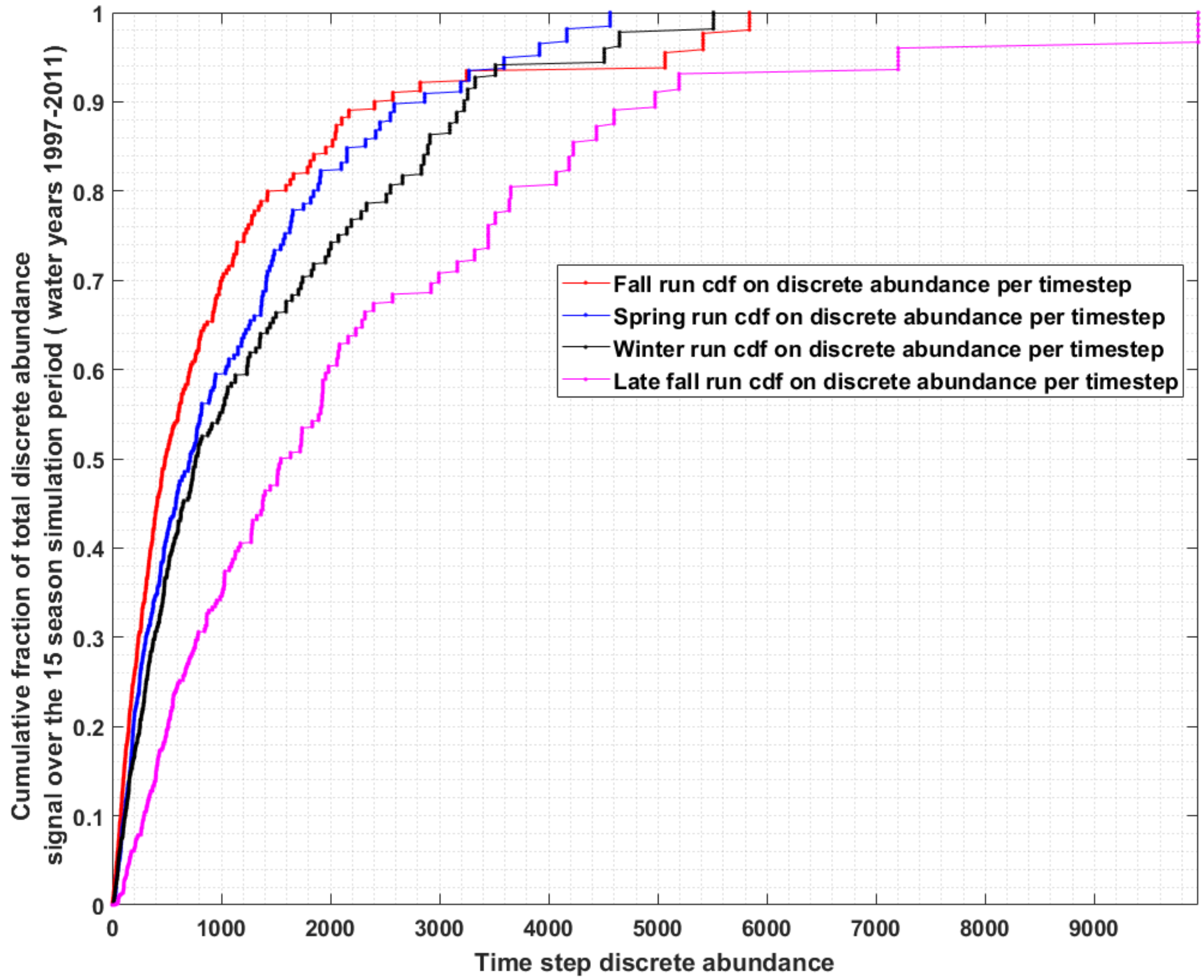


Figure 9 - Plot showing cumulative distribution functions on time step discrete sample size for each run

The lines for each run indicate the fraction of times steps within the 15 water year simulation period that had time steps less than or equal to the sample sizes shown on the x axis.

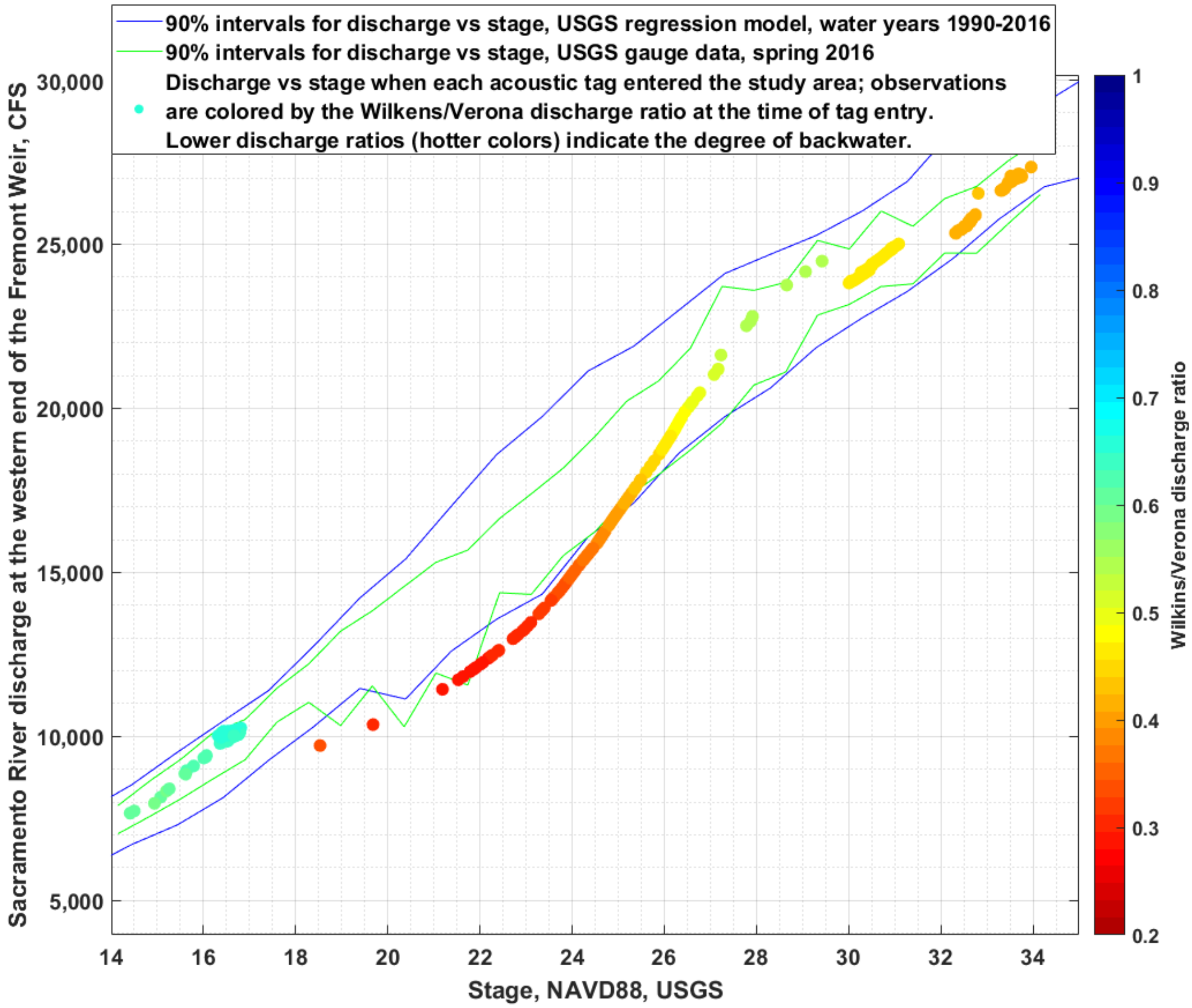


Figure 10 - Plot showing the range of stage and discharge conditions associated with each of the 2016 acoustic tag tracks

The colored lines indicate the 5th and 95th percentiles for discharge vs stage for USGS discharge estimates. 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).

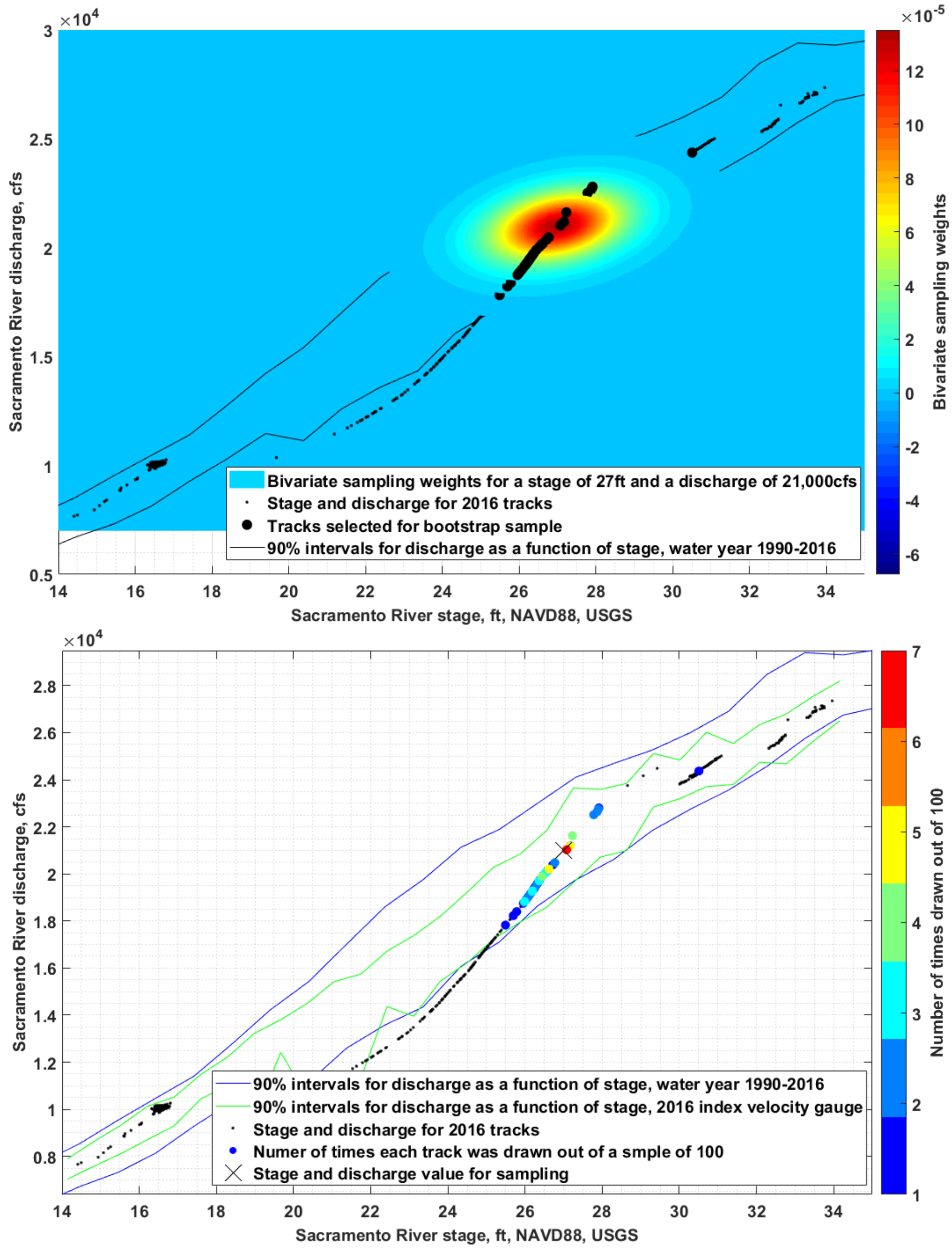
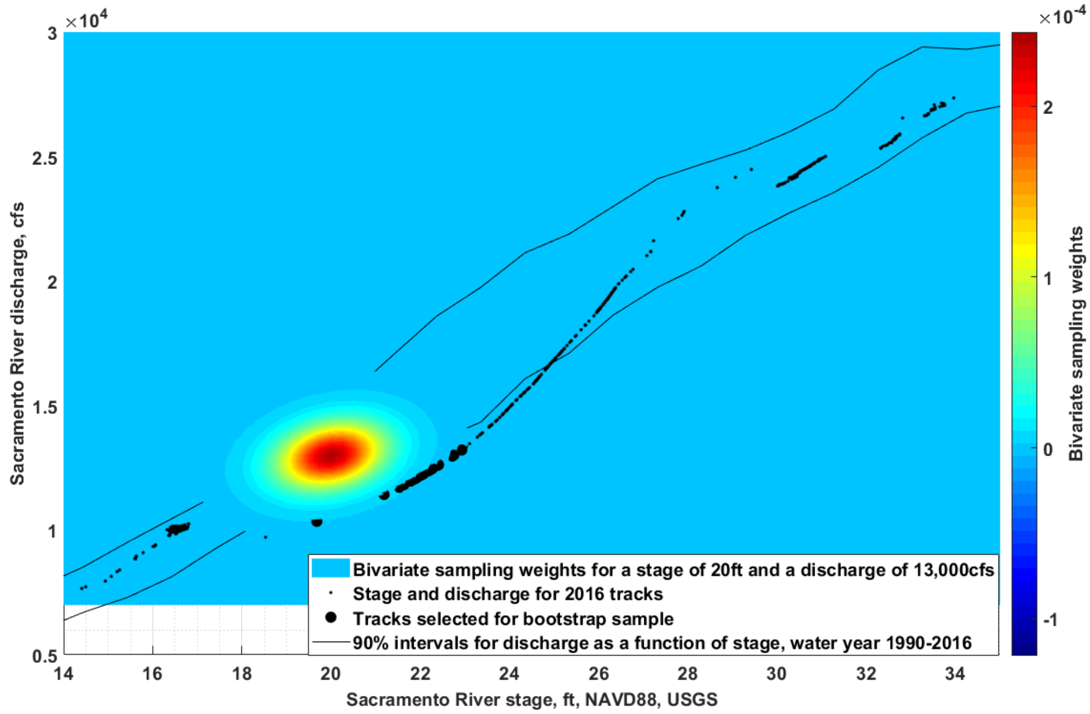


Figure 11 - Plots illustrating the bivariate weighting and the resulting bootstrap sampling for a stage of 27 ft and a discharge of 21,000cfs

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).



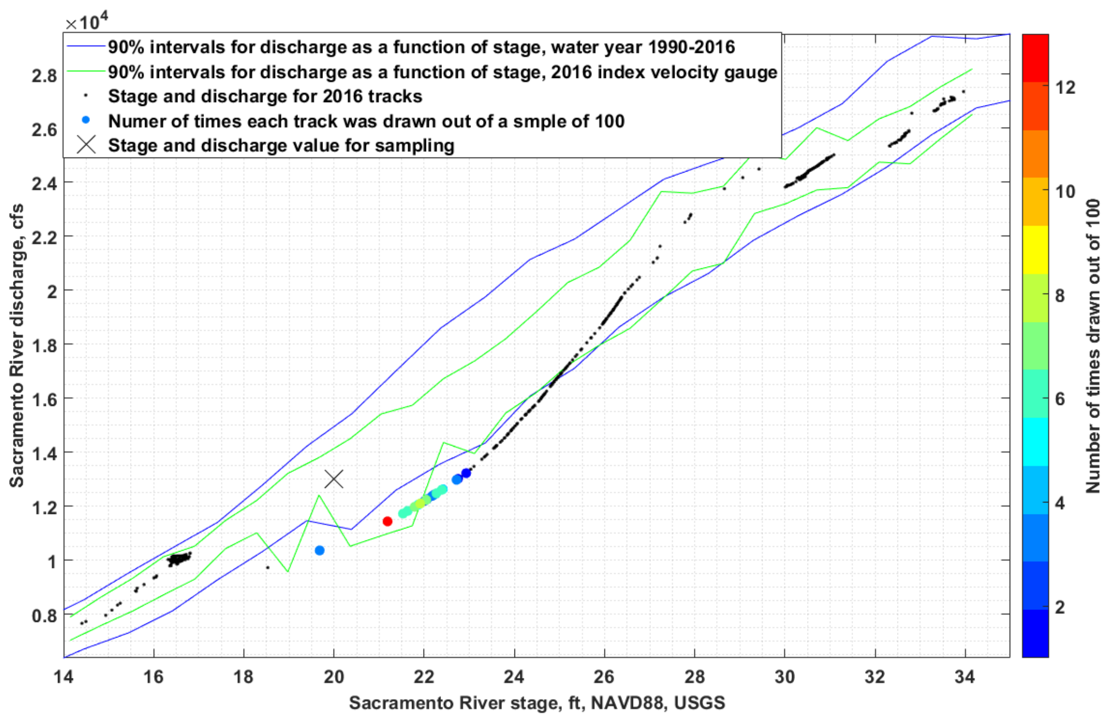


Figure 12 - Plots illustrating the bivariate weighting and the resulting bootstrap sampling for a stage of 20ft and a discharge of 13,000cfs

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).

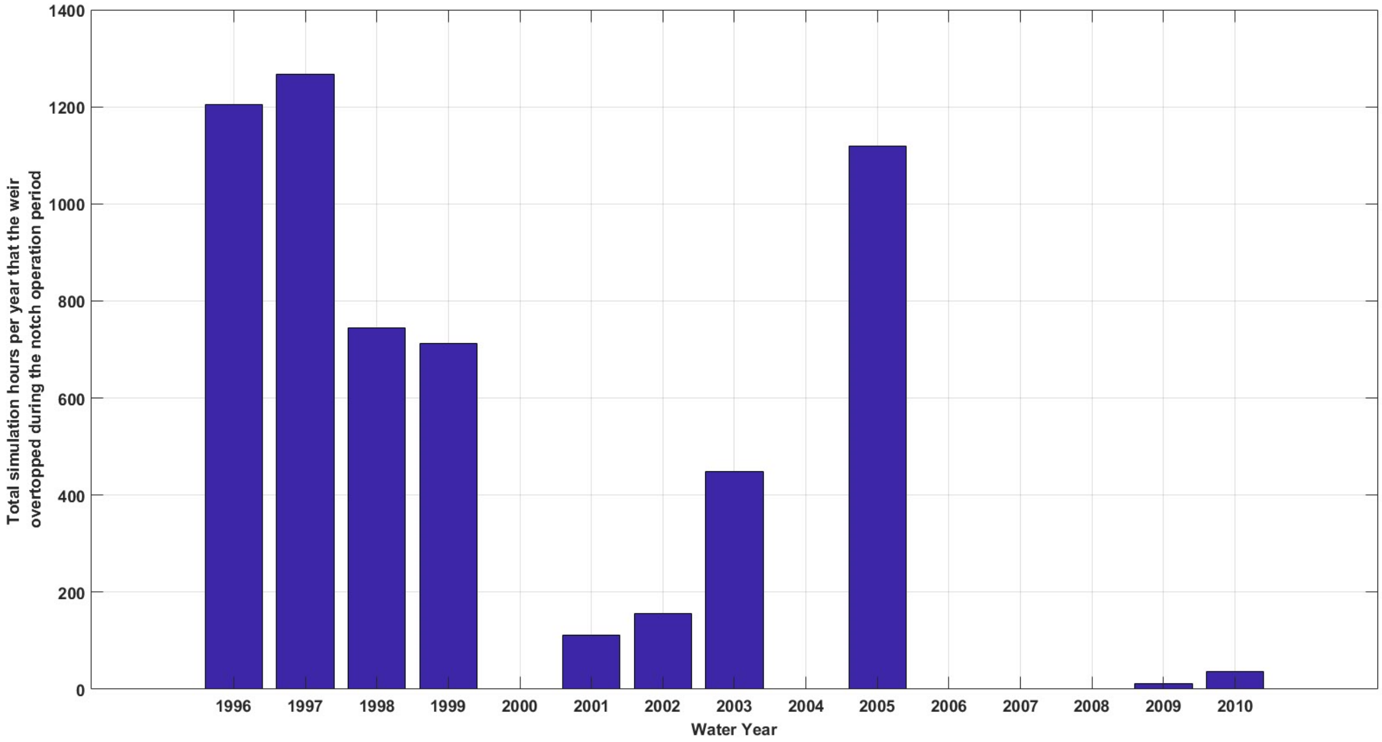


Figure 13 - Number of hours per year that the weir overtopped during the notch operation period

The blue bars indicate the number of hours per season that the weir overtopped during the notch operation period (November 1 - March 15). Missing bars indicate water years when the weir did not overtop during the simulation. For the purposes of the simulation over13 is defined as periods when Sacramento River stage is greater than 32.3 ft, NAVD88, USGS. For the purposes of this plot season years indicated by the year the operation period began.

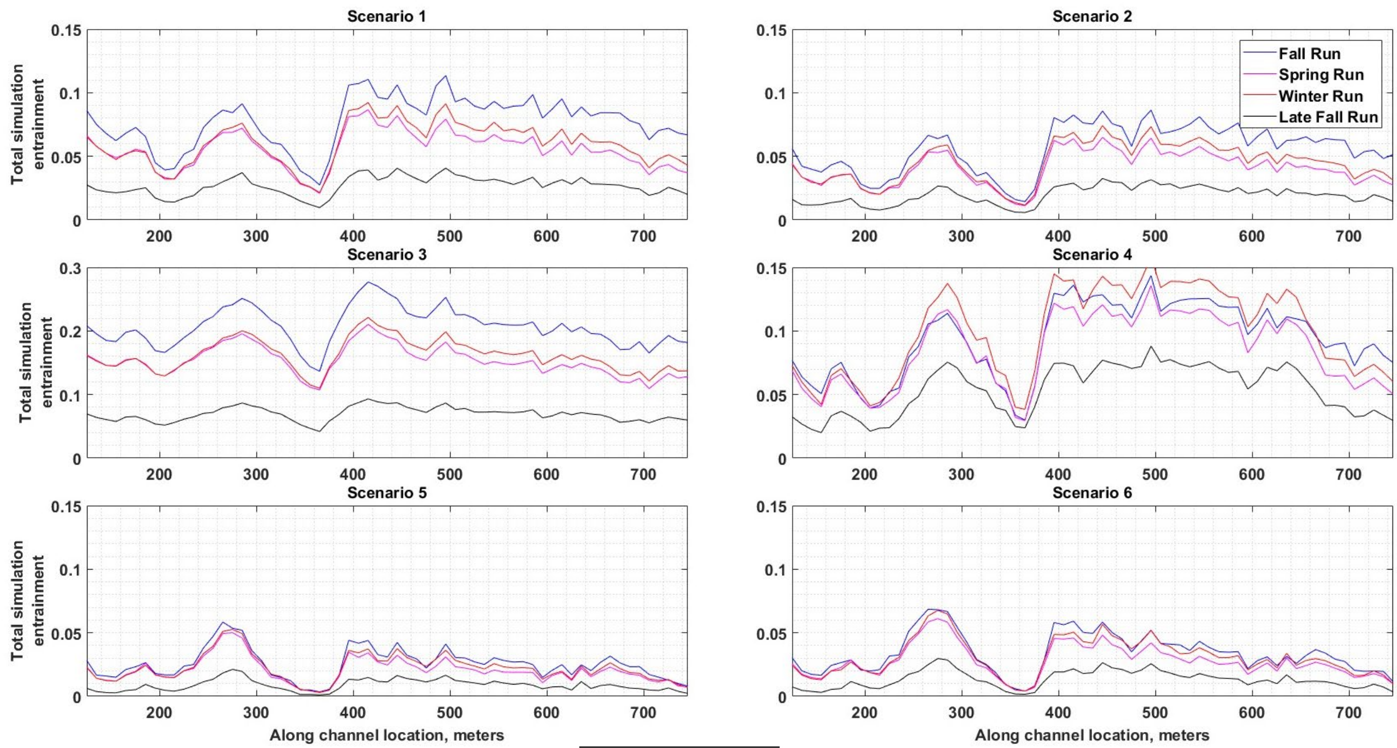


Figure 14 - Total entrainment as a function of notch location for each scenario

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 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.

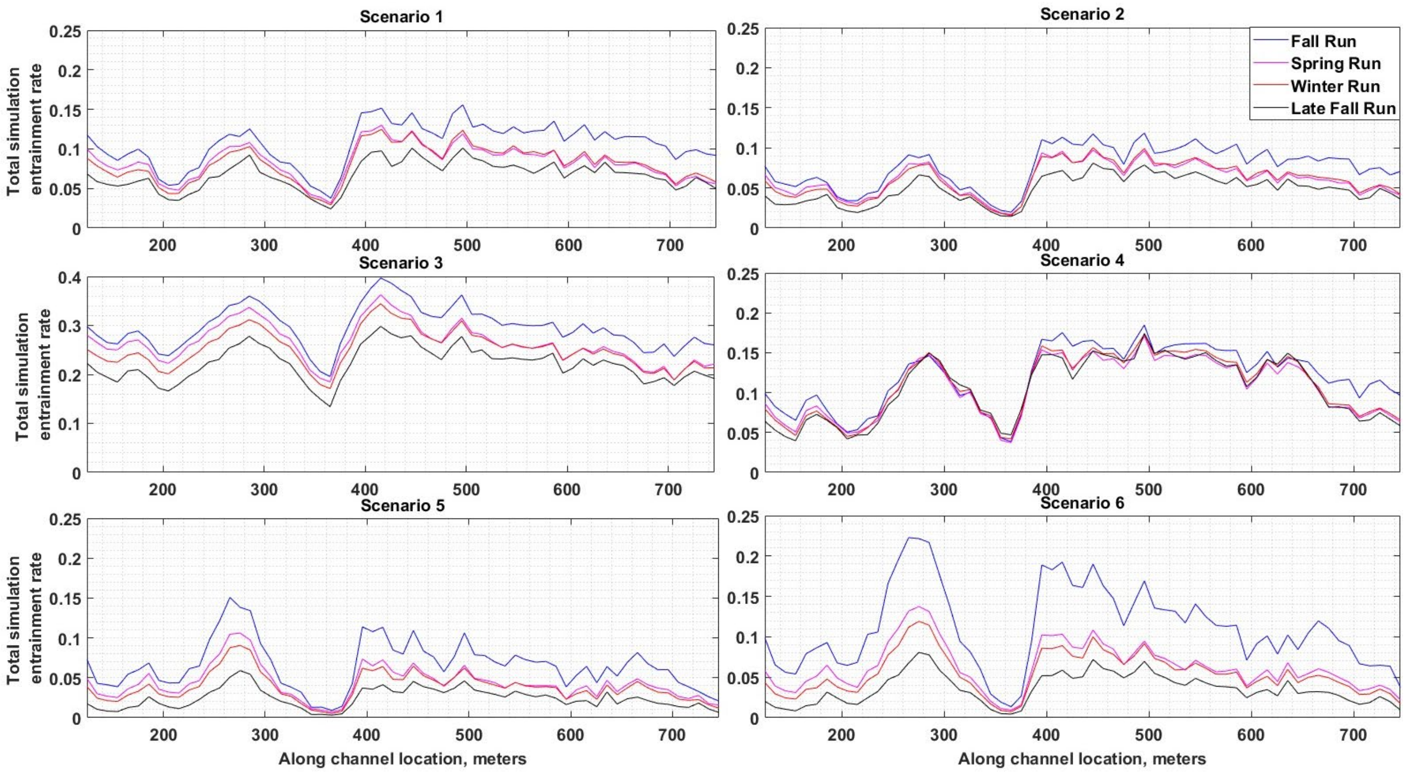


Figure 15 - Total entrainment rate as a function of notch location for each scenario

Each panel shows the total entrainment for each scenario at each location in the study area, by run. Total simulation entrainment rate is expressed as the fraction of fish passing the notch when notch flow was greater than zero entrained for each scenario. 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 rate are entirely driven by differences in the historical timing of run abundance, and are not indicative of behavioral differences 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.

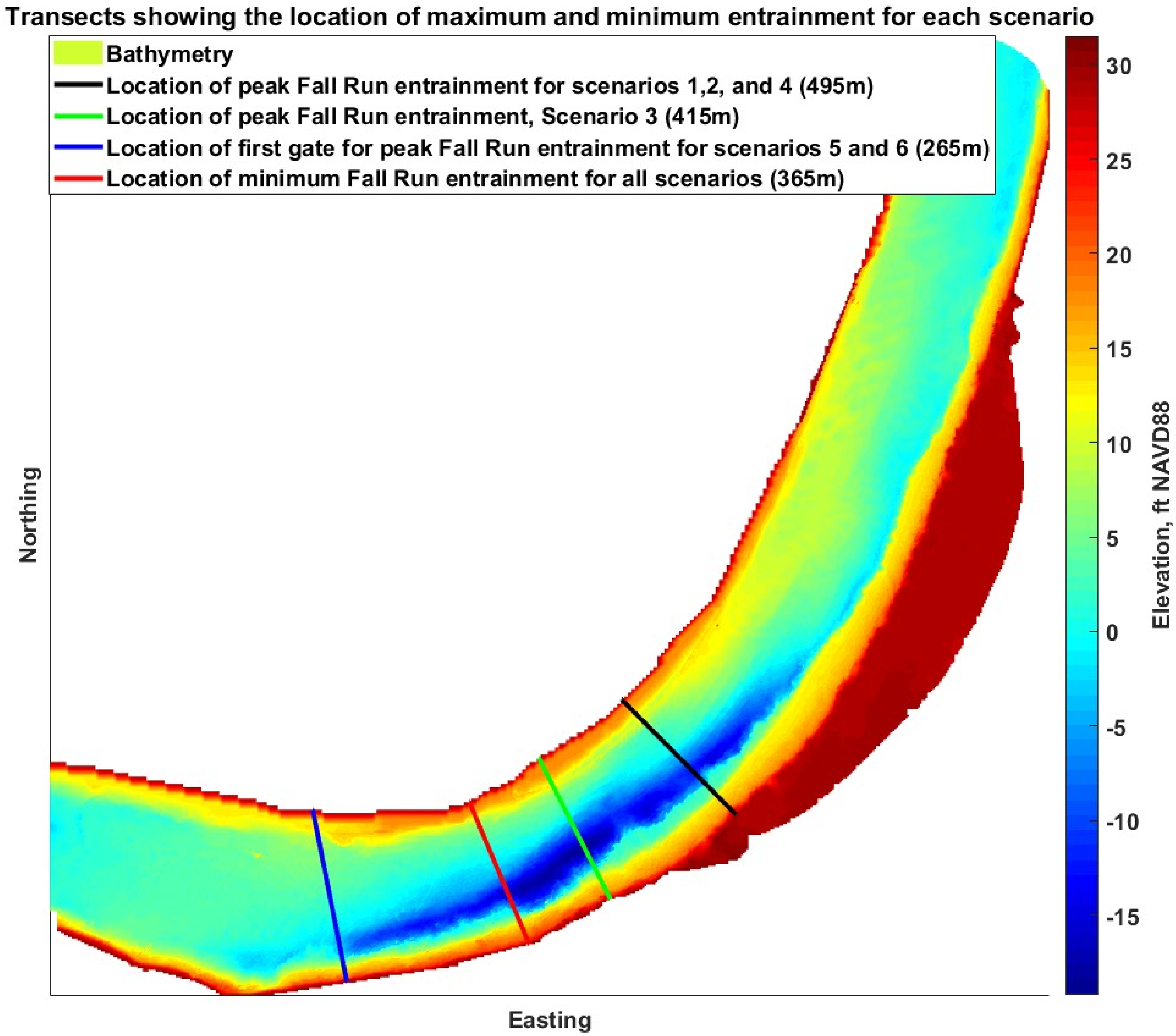


Figure 16 - Figure showing the location of maximum and minimum entrainment for fall run for all scenarios overlaid on the study area bathymetry model used for the entrainment simulation

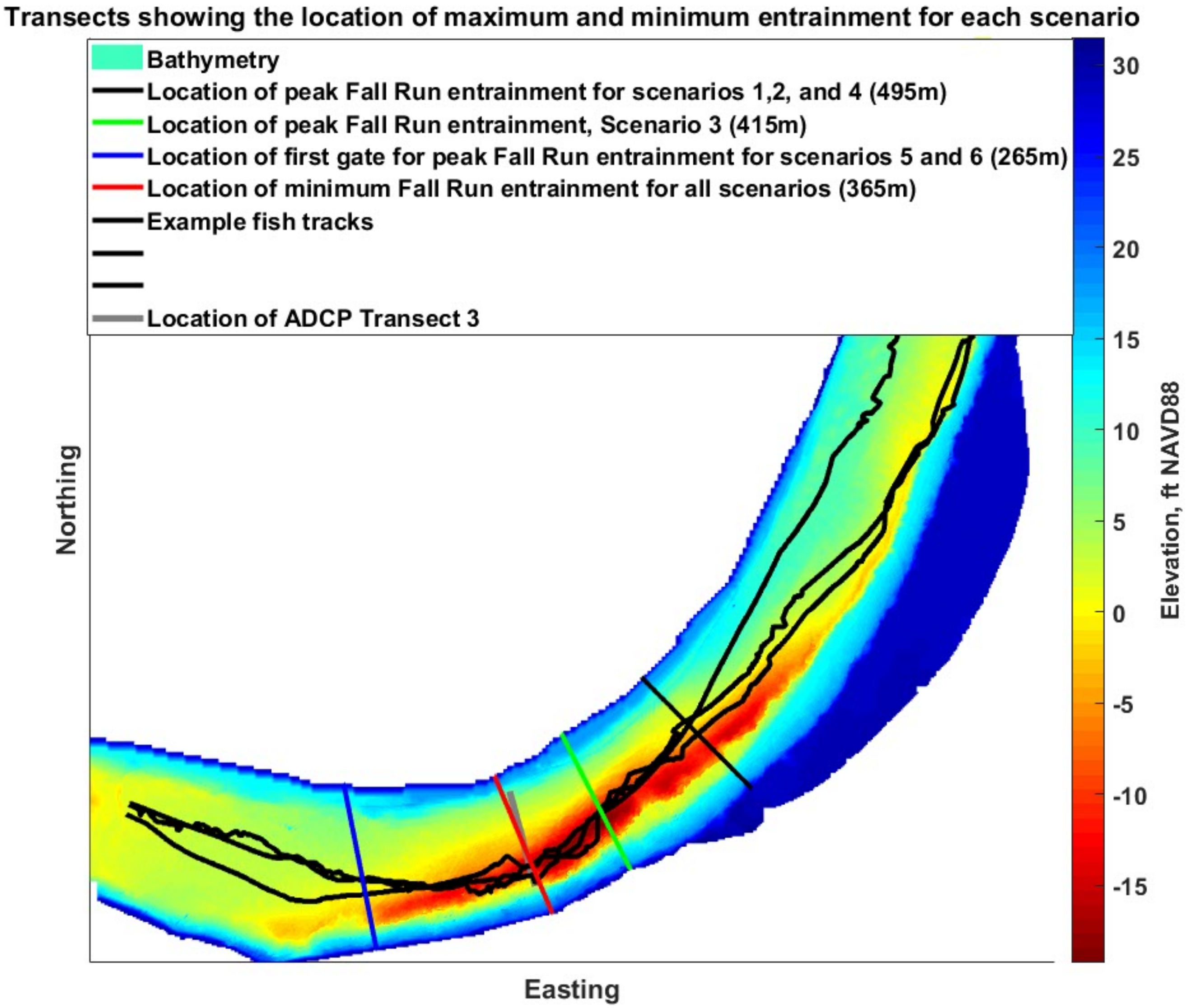


Figure 17 - Plan view of study area showing the location of minimum and maximum entrainment along with example fish tracks.

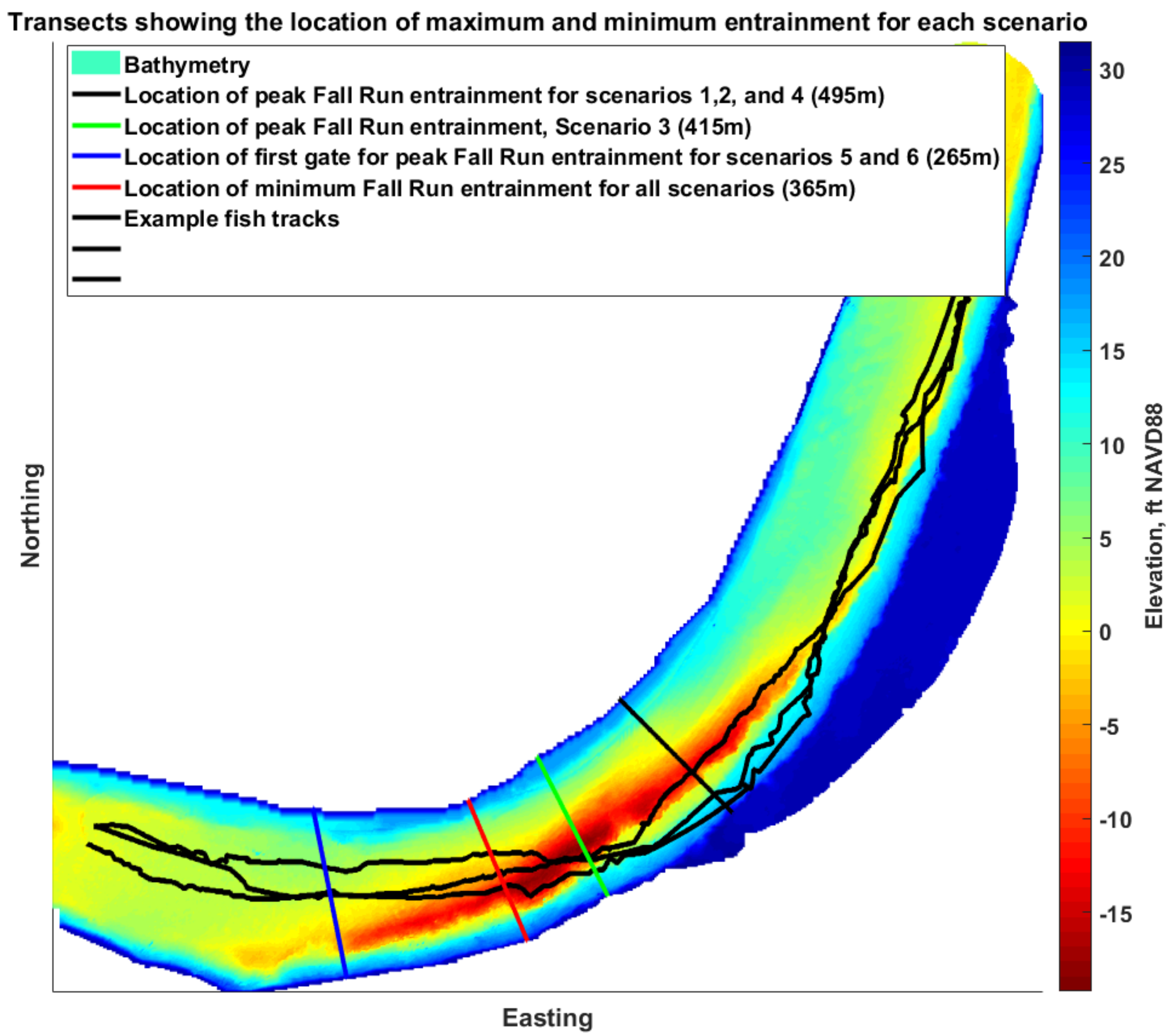


Figure 18 - Plan view of study area showing the location of minimum and maximum entrainment along with example fish tracks

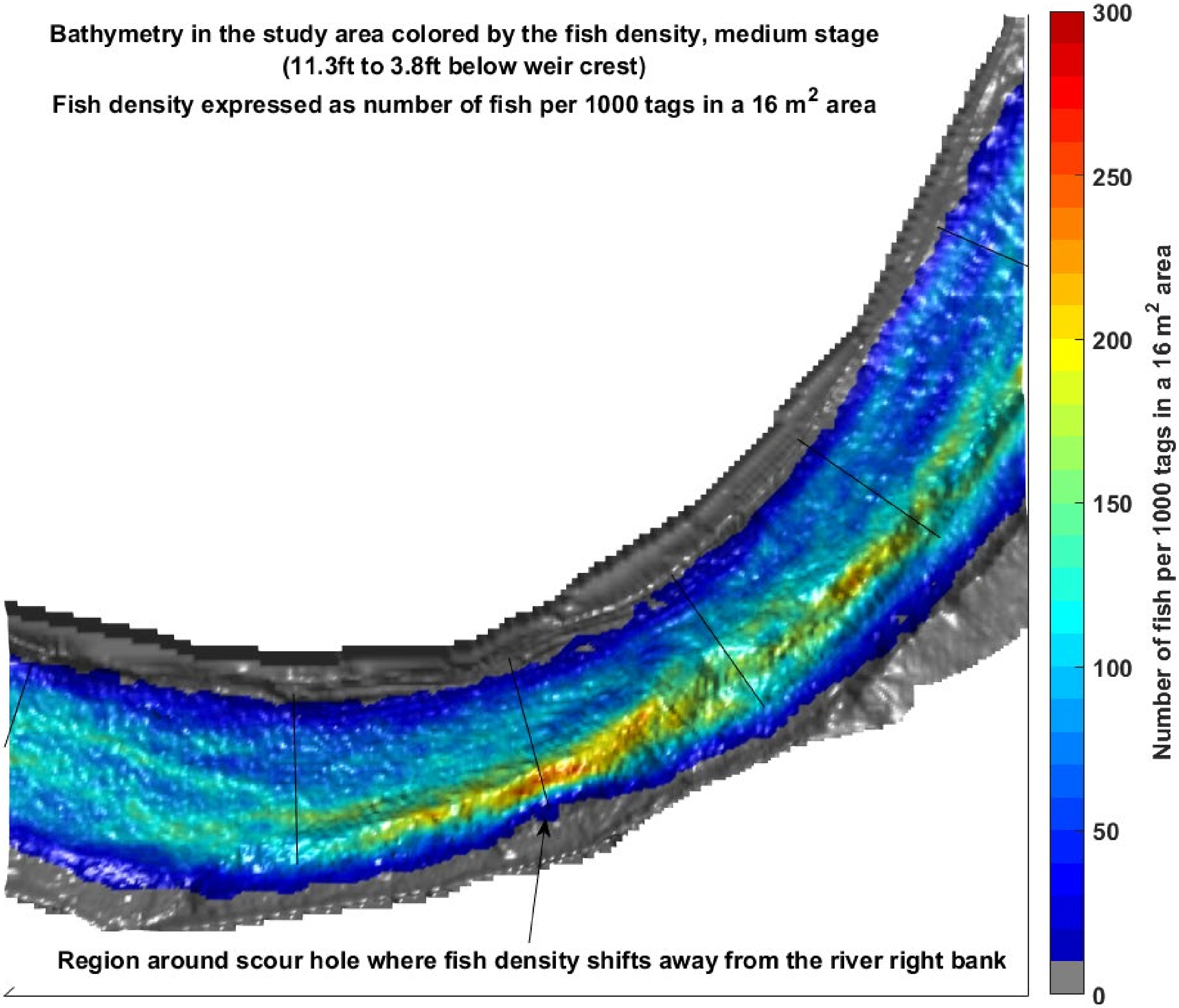


Figure 19 - Plan view of the study area bathymetry colored by fish density

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 black 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.

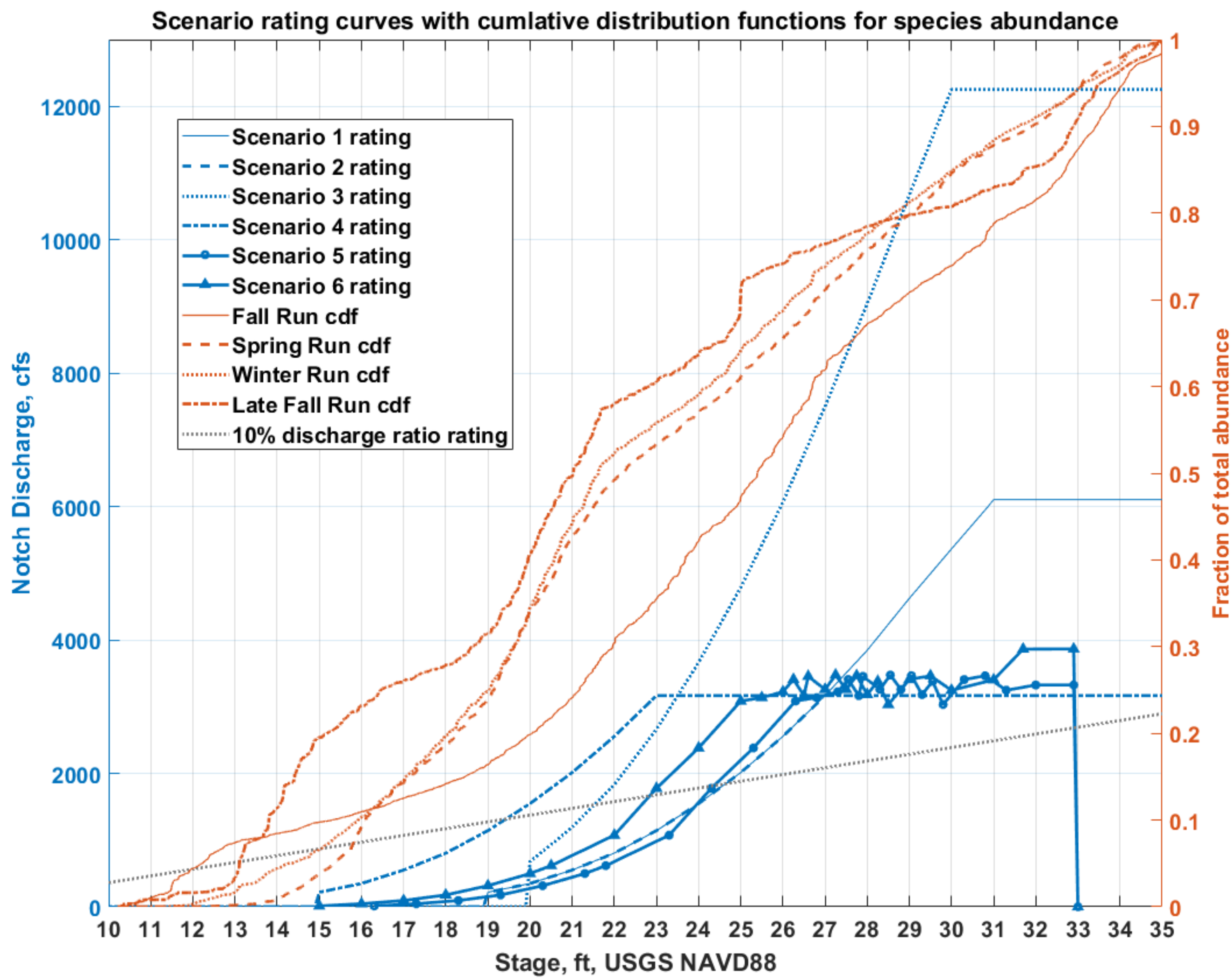


Figure 20 - Stage-discharge curves for each scenario and run abundance cdfs on stage

Stage discharge curves for each scenario are shown in blue, with scenario discharge shown on the left (blue) yaxis. The stage-discharge curves for multi-gate scenarios indicate the total flow through all gates 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 cumulative run abundance as a function of stage are shown in red, with the cumulative fraction of total abundance shown on the right (red) yaxis. 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.

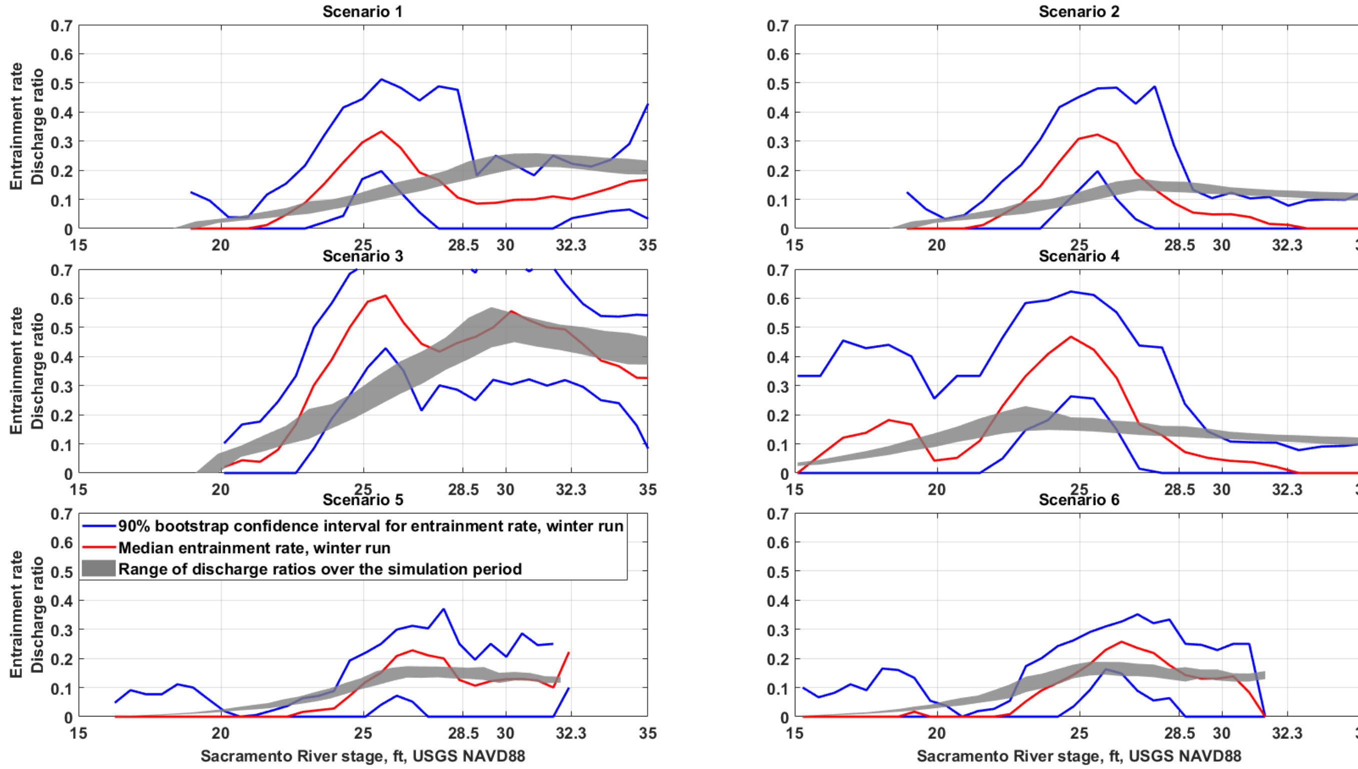


Figure 21 - Entrainment rate and discharge ratio for each scenario as a function of Sacramento River stage

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.

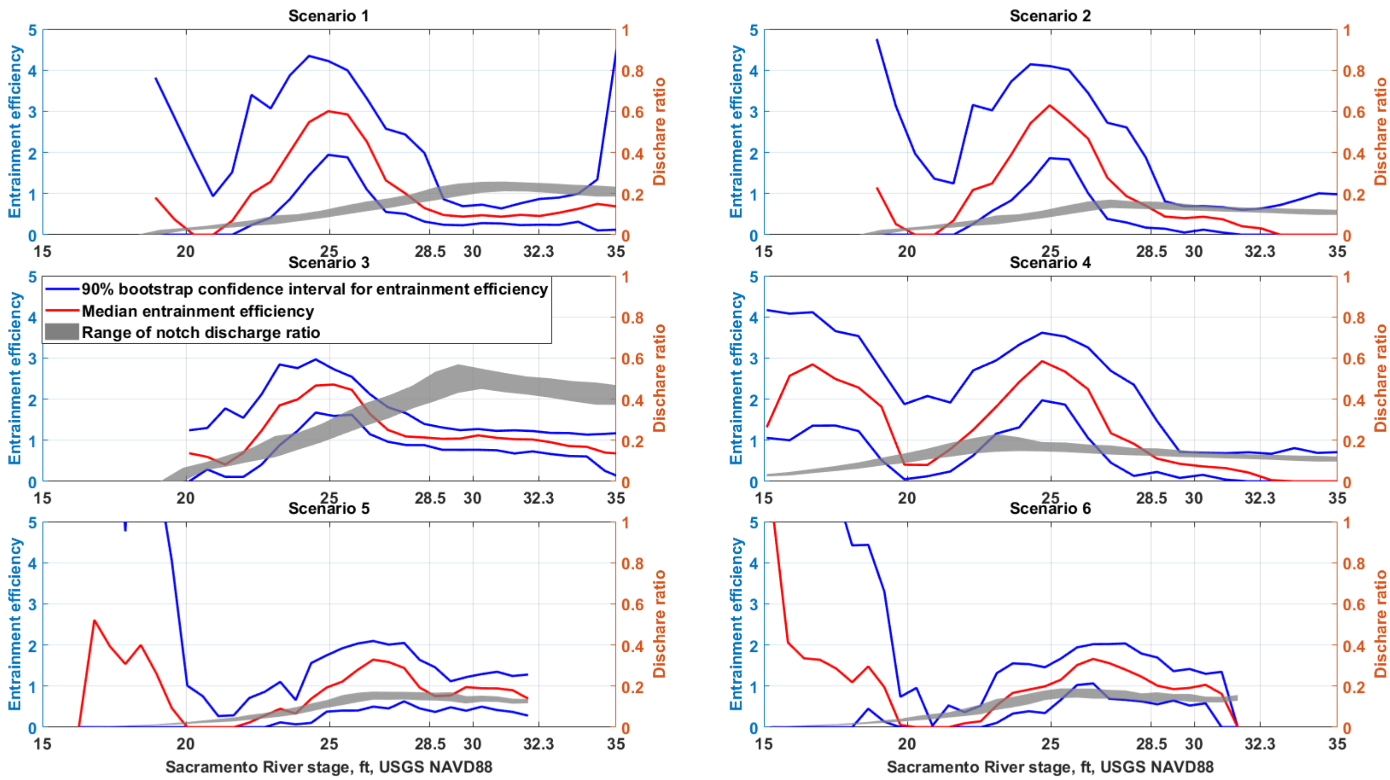


Figure 22 - Entrainment efficiency and discharge ratio for each scenario as a function of Sacramento River stage, with small sample sizes removed

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 yaxis on the left of each panel (blue) indicates the scale for the entrainment efficiency. The yaxis 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.

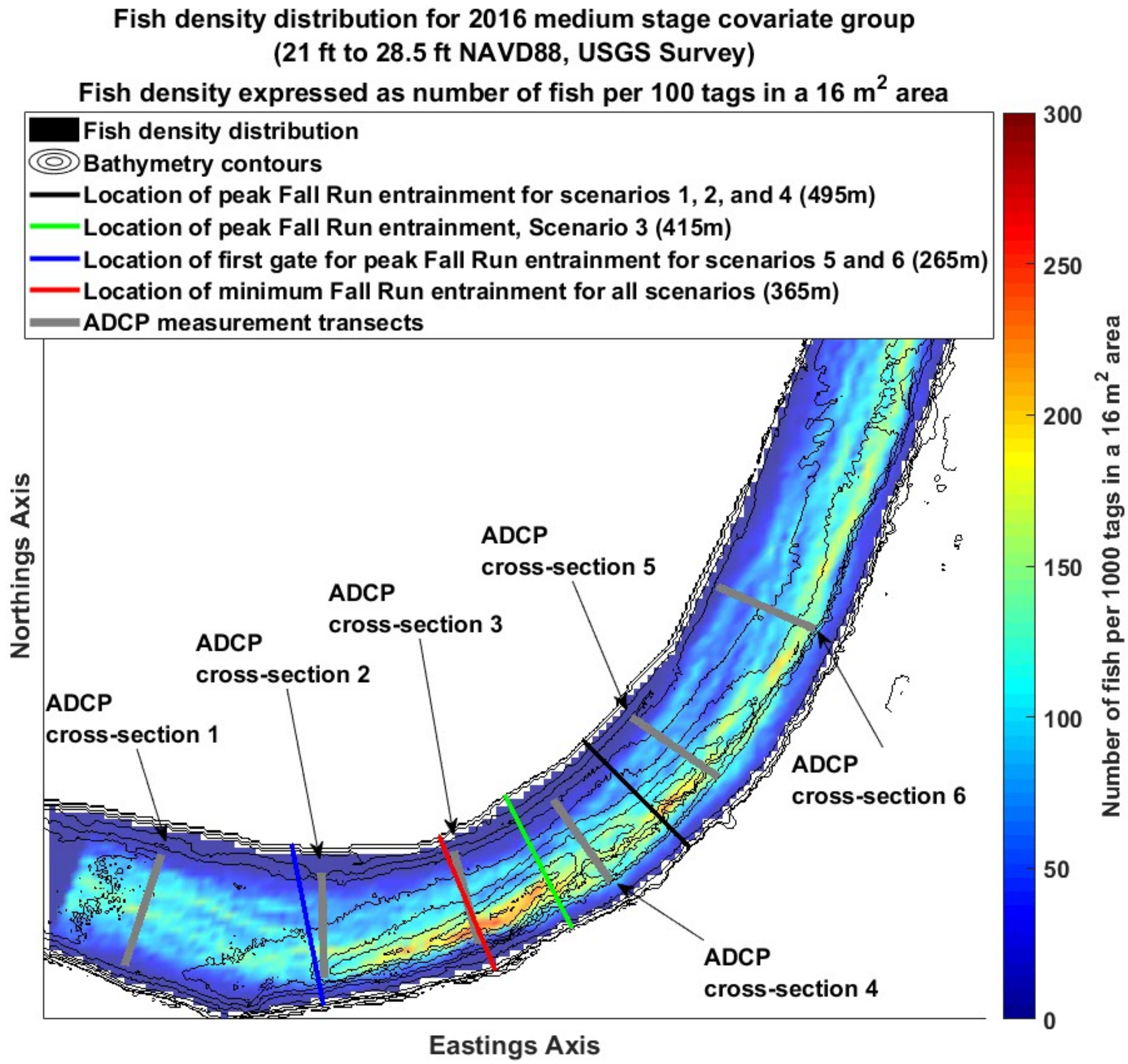


Figure 23 - Figure showing the location of maximum and minimum entrainment for fall run for all scenarios overlaid on fish density distribution

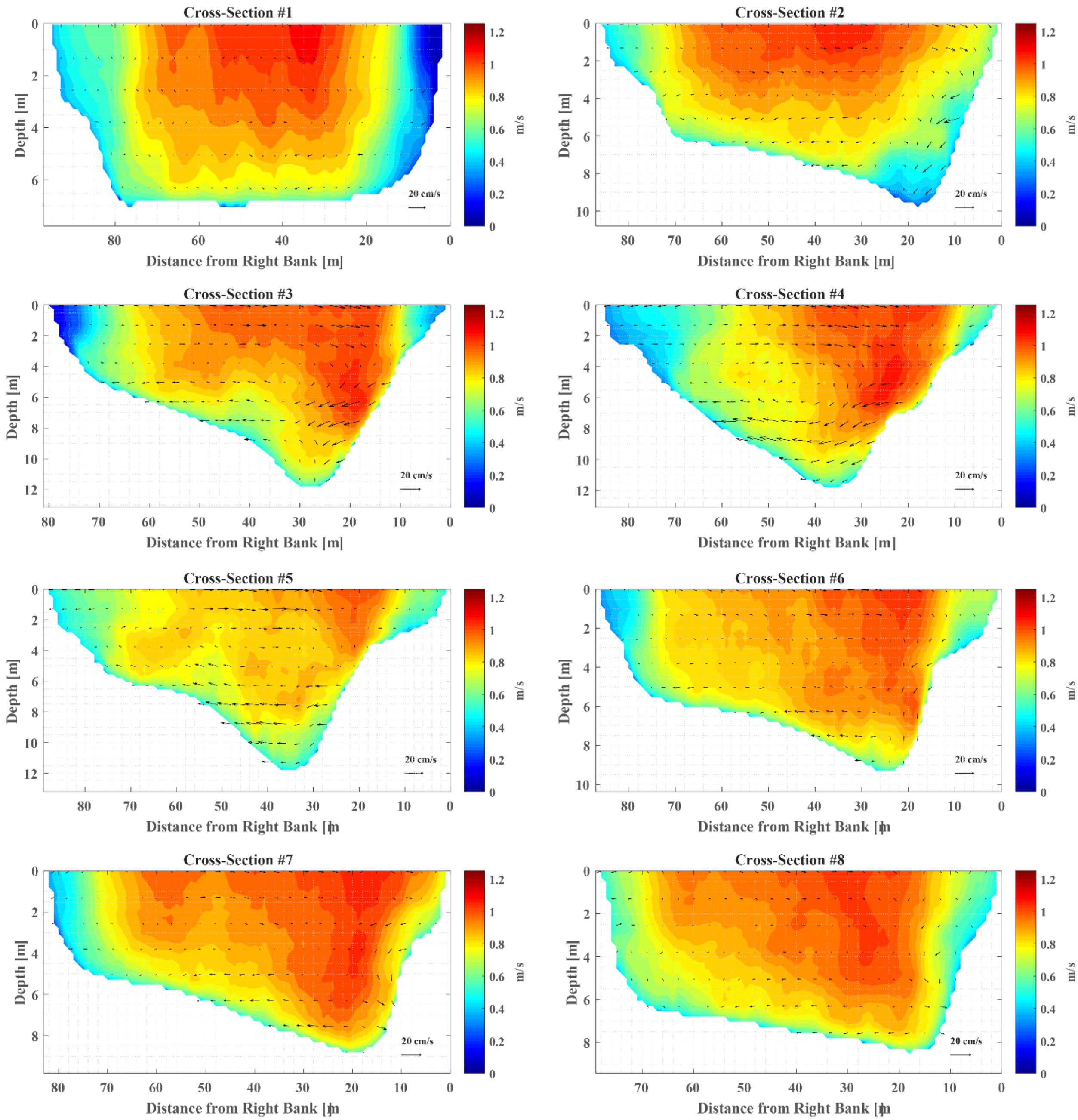


Figure 24 - Figure from cross-channel velocity transect data collected during 2016

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

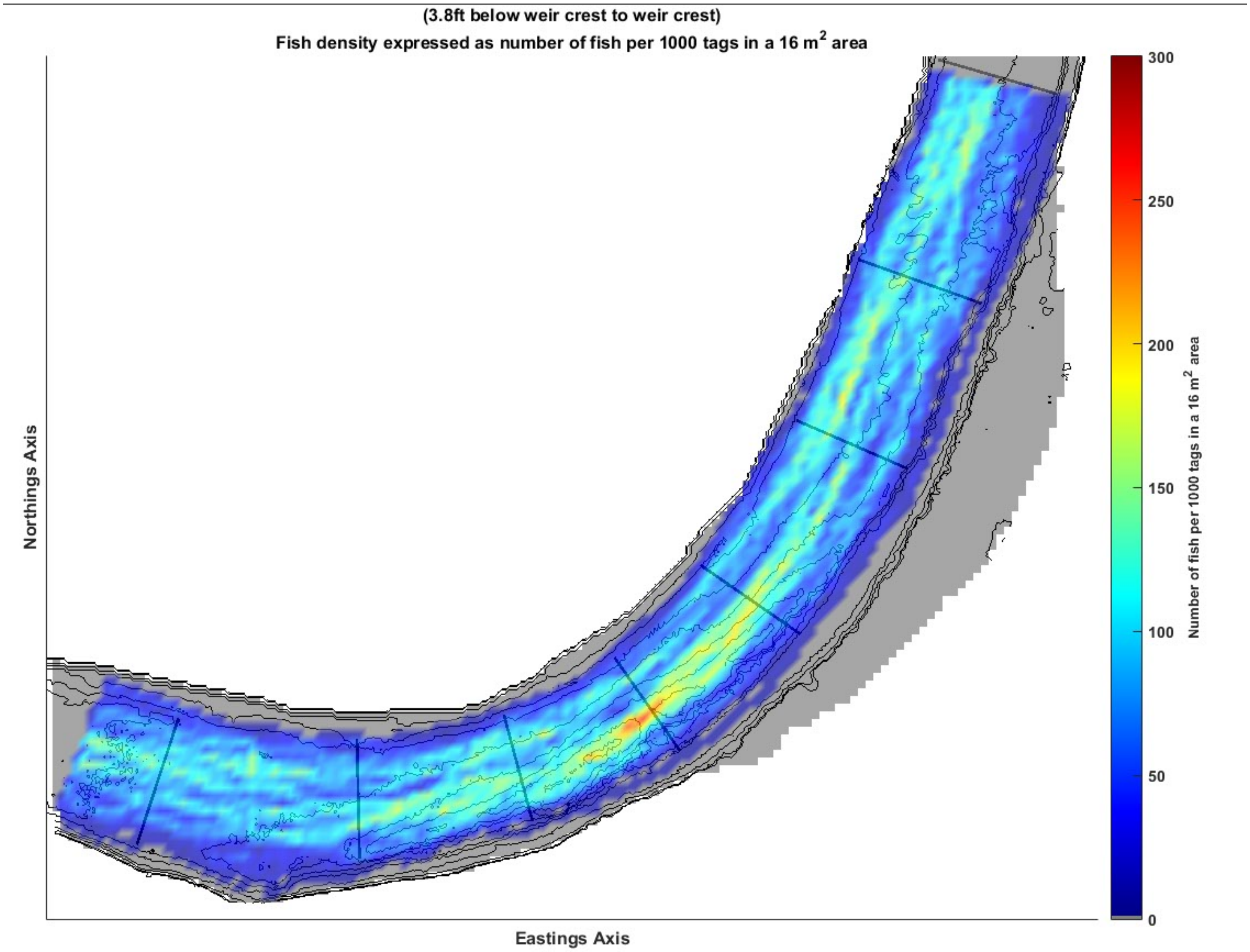


Figure 25 - Spatial distribution of 2016 study fish tracks for periods when Sacramento River was greater than bankfull and below the weir crest

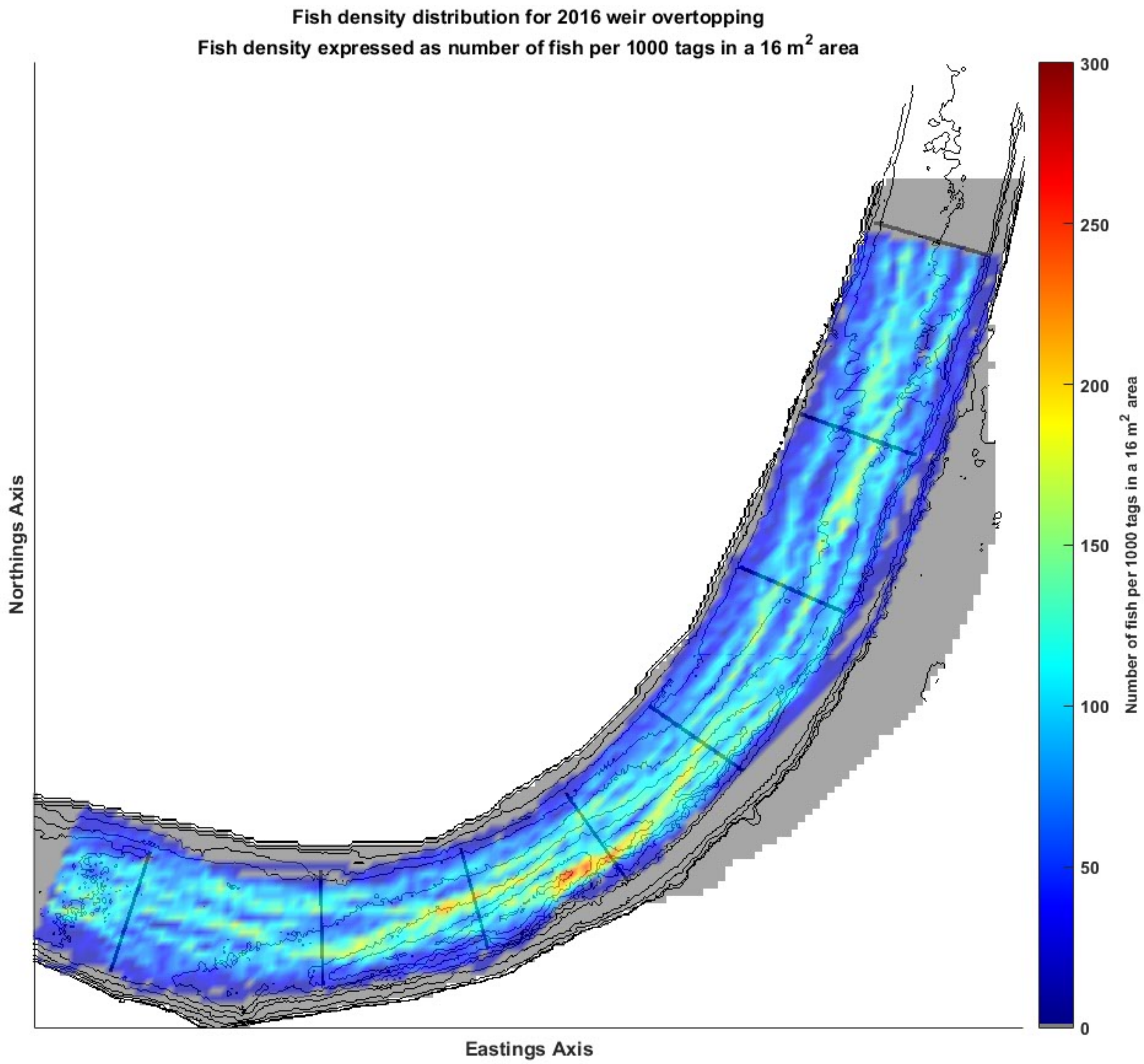


Figure 26 - Spatial distribution of 2016 study fish tracks for periods when the fremont weir was overtopping

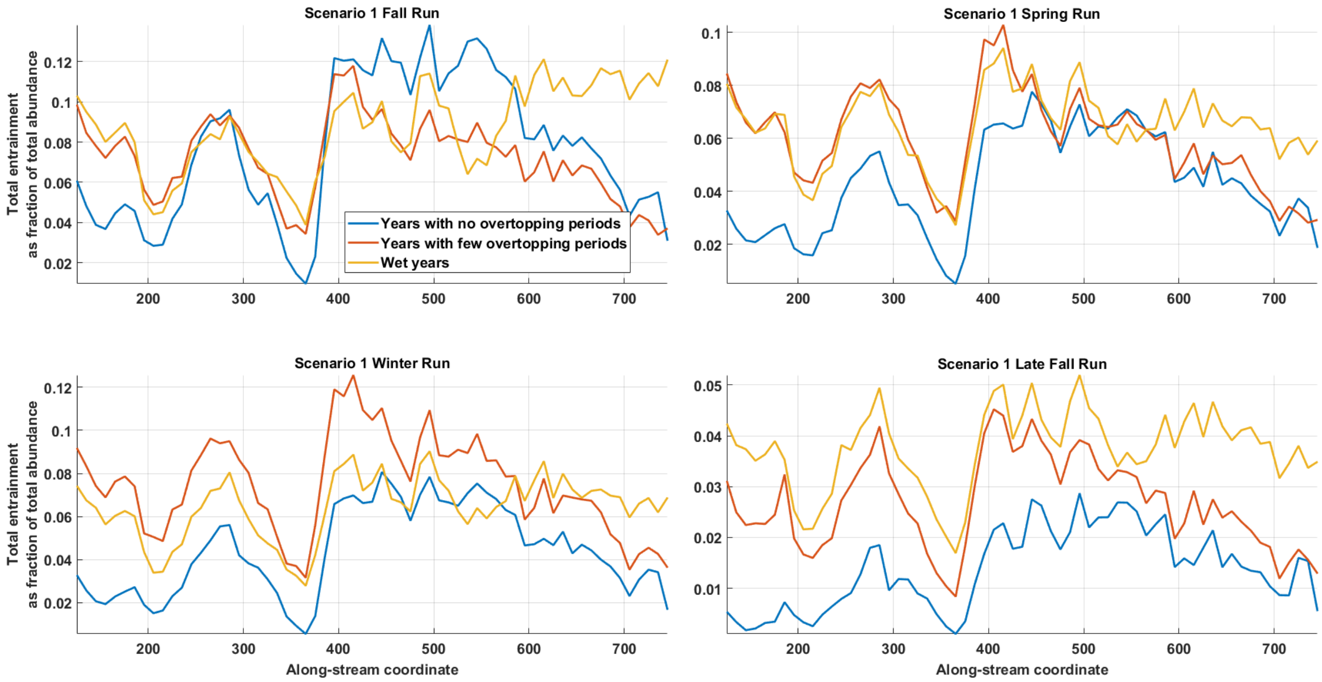


Figure 27- Scenario 1 water year type total entrainment curves

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 NAVD88, USGS datum. 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 in the acoustic tag data.

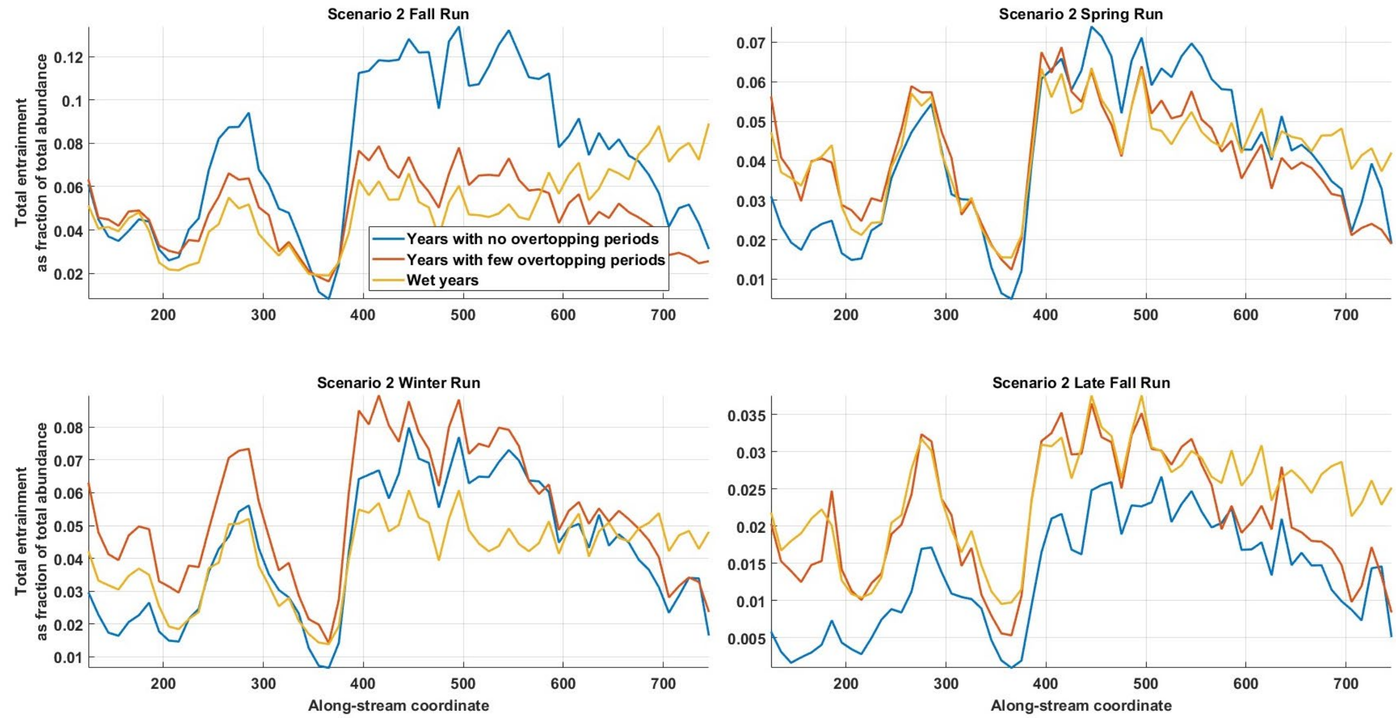


Figure 28- Scenario 2 water year type total entrainment curves

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 NAVD88, USGS datum. 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 in the acoustic tag data.

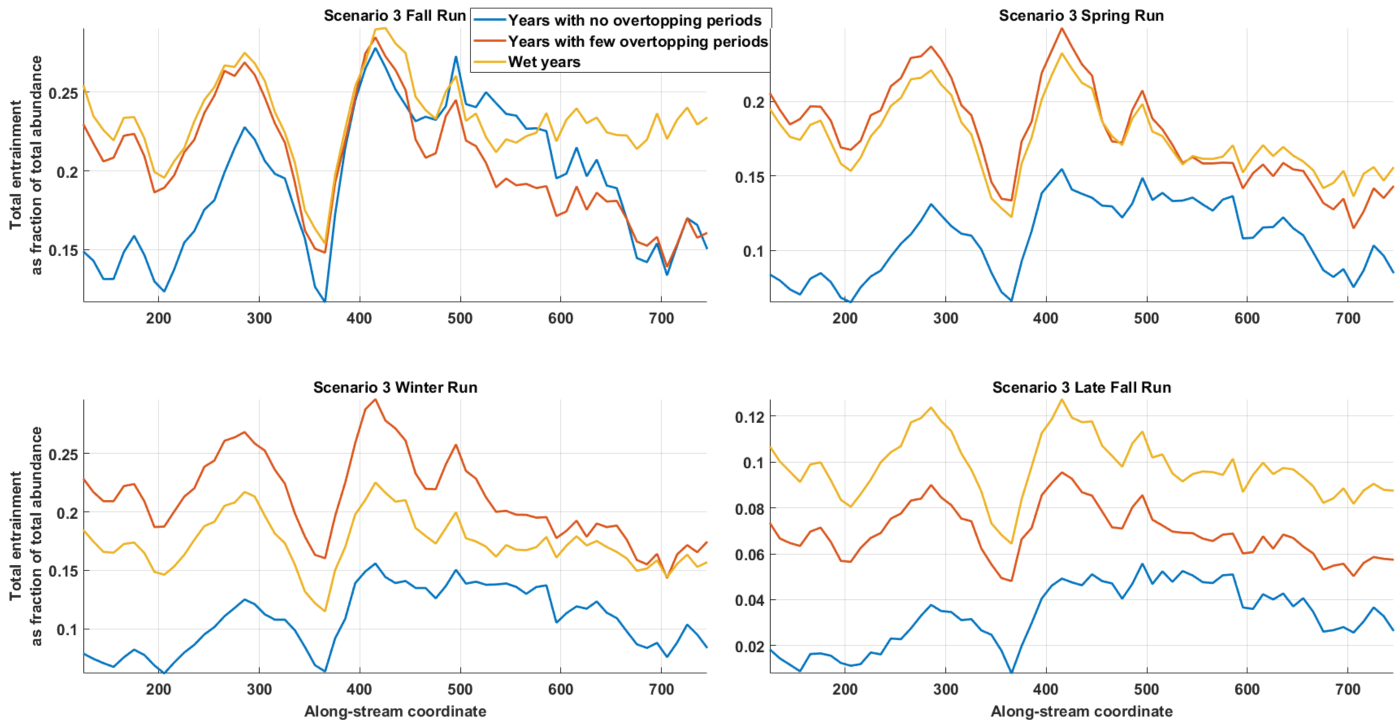


Figure 29- Scenario 3 water year type total entrainment curves

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 NAVD88, USGS datum. 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 in the acoustic tag data.

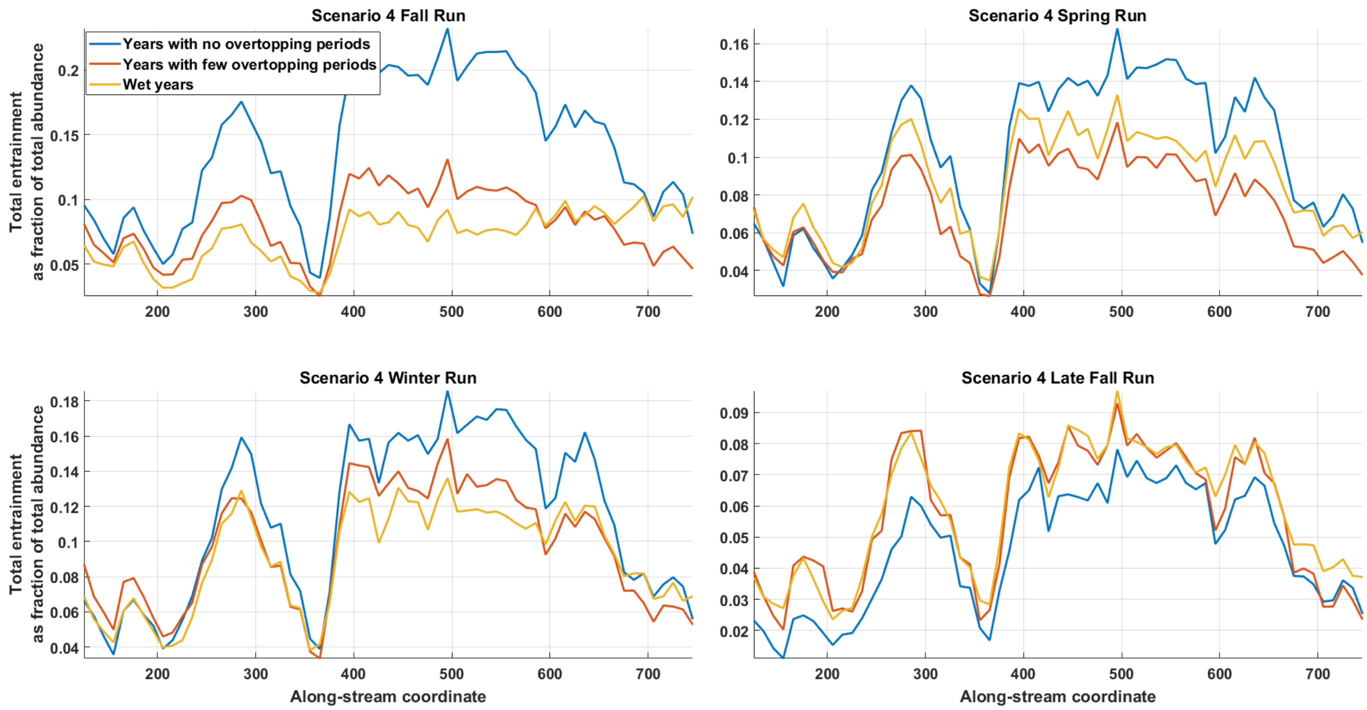


Figure 30- Scenario 4 water year type total entrainment curves

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 NAVD88, USGS datum. 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 in the acoustic tag data.

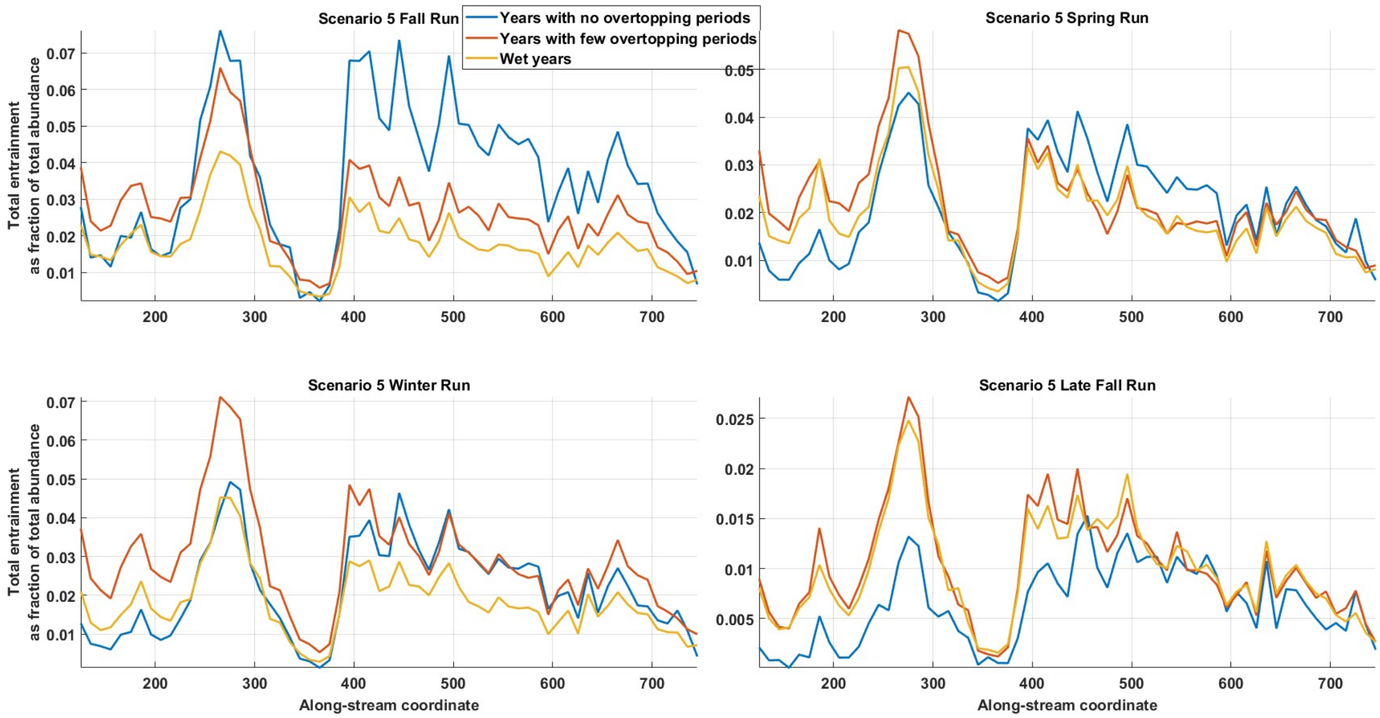


Figure 31- Scenario 5 water year type total entrainment curves

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 NAVD88, USGS datum. 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 in the acoustic tag data.

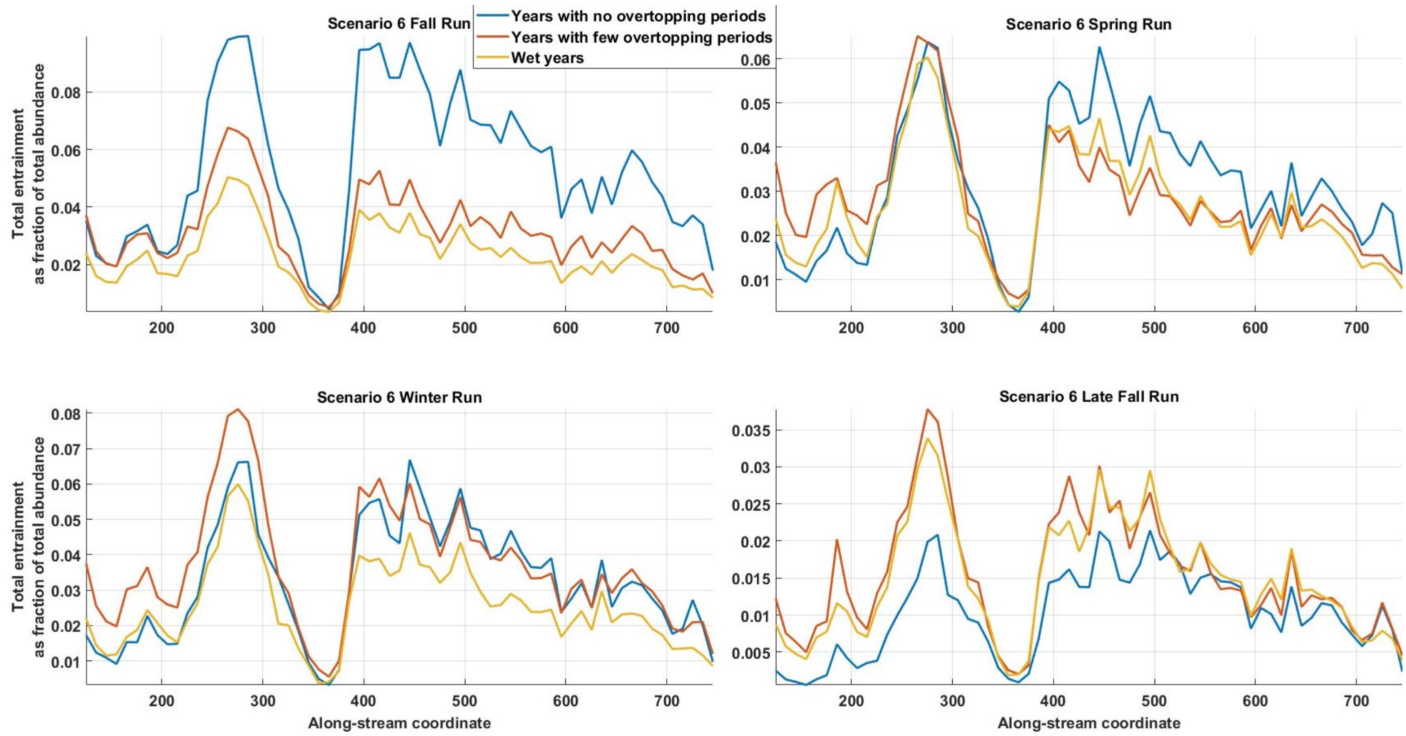


Figure 32- Scenario 6 water year type total entrainment curves

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 NAVD88, USGS datum. 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 in the acoustic tag data.

9. 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, NAVD88, USGS, from the bathymetric model used in the simulation.

Notch evaluation location	Along-stream coordinate, m	Easting, m, UTM, NAD83	Northing, m, UTM, 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

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
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
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
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

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 parenthesis**					
	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%)
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%)
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%)
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%)
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%)
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%)
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%)

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%)
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%)
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%)
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%)
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%)

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%)
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%)
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%)
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%)
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%)

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%)
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%)
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%)
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%)
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%)

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

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

Stage, Scenario 6, ft, NAVD88, USGS	Stage, Scenario 5, ft, NAVD88, USGS	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	
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 - Gate spacing for scenario 5 and scenario 6

For scenario 5 and Scenario 6 entrainment for each gate 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 gate. The location of the center of the downstream gates (Gates B, C, and D) is calculated by adding the offsets listed below to the along-stream location of Gate A.

Gate	Offset from center of Gate A, meters in the along stream direction
A	0
B	12.2
C	133
D	240.5

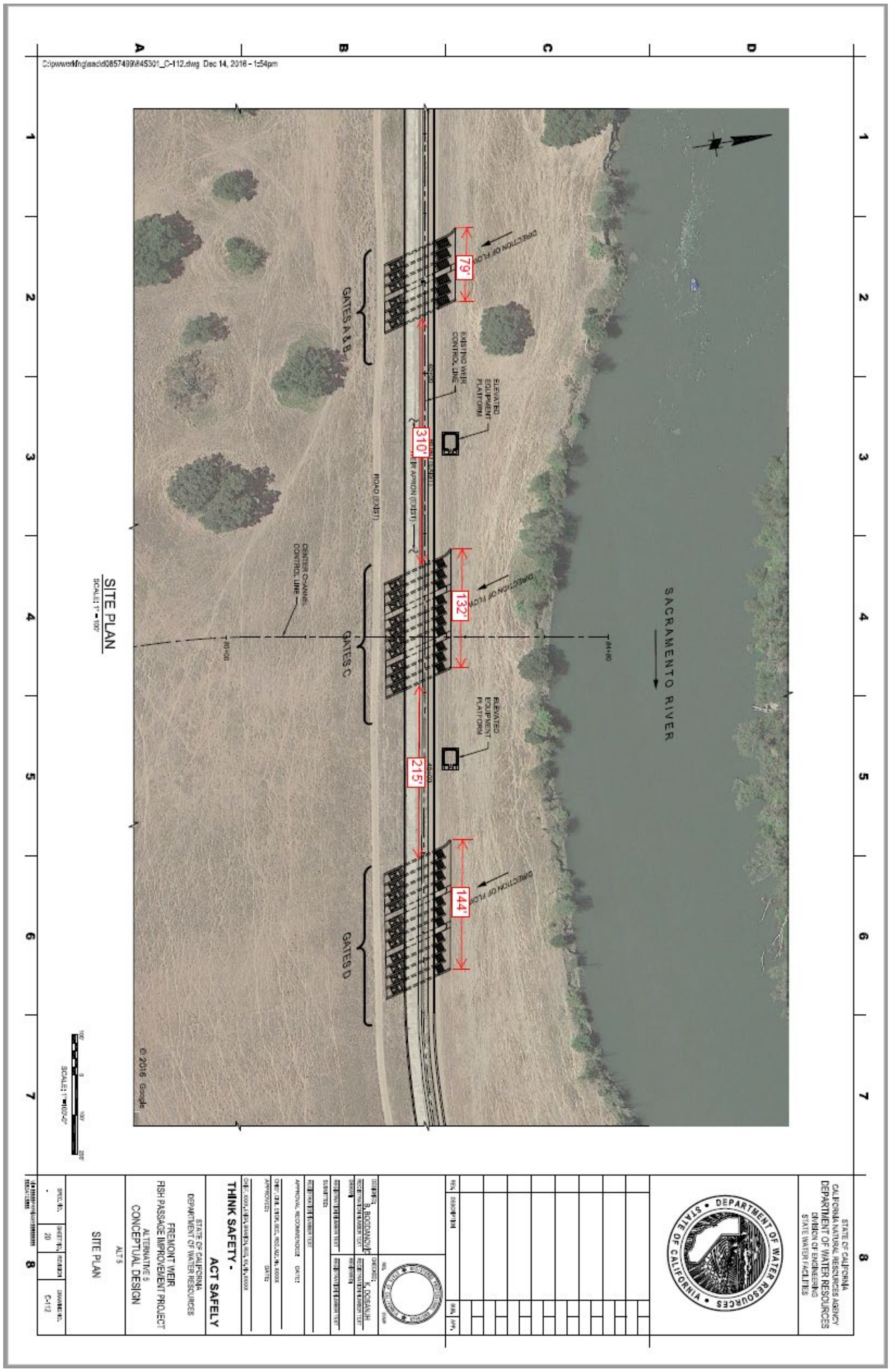


Figure C1 - Conceptual drawing of alternative 5 showing the gate spacing used for scenario 5 and scenario 6