Yolo Bypass
Juvenile Salmon
Utilization Study (YBUS)

Photo Courtesy of DWR

Water Year 2016
Proposal and Implementation Plan

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Funding provided by the California Department of Water Resources (DWR)

Study conducted in collaboration with

DWR, the US Bureau of Reclamation (USBR) and the US Army Corps of Engineers (ACOE).

Revision 2.0

March 8, 2016

1 BACKGROUND

Several flood bypasses have been constructed on the Sacramento River in California's Central Valley. Flows into the bypasses are regulated by weirs so that water is confined to the river channel until stage increases above the weir level. The Sacramento River is important for migration of several species of fish, and some of these fish enter the bypasses while traveling downstream during elevated flow periods. 2009 NMFS Salmon Biological Opinion and in recent Eco restore documents (http://resources.ca.gov/ecorestore/) call for increasing access of juvenile salmon to flood plain habitats as a means of increasing survival through the delta. A planning and design process is underway to build a notch in the Fremont Weir to increase access of juvenile salmon to the Yolo Bypass. Thus, there is interest in studying the spatial distribution of juvenile salmon within the Sacramento River adjacent to the Fremont Weir to help in the notch planning and design process and to compare travel times and survival rates between salmon smolts that take the Yolo Bypass route versus alternative routes in the North Delta.

This document describes an acoustic telemetry study of juvenile salmon habitat utilization Fremont Weir and Yolo Bypass, near the city of Sacramento (
Figure 1). We are proposing to implement this study this winter (2016) because the current and strengthening El Niño ocean conditions this year increase the likelihood of elevated Sacramento River flows, which are needed to assess a full range of juvenile salmon outmigrant responses to the river near Fremont Weir and within the Yolo Bypass. Some of the biggest flows in the Yolo Bypass have occurred during El Niño events (Ward et al., 2014a,b; Dettinger, 2013; Dettinger and Ingram, 2013).

The Yolo Bypass floods in more than 70% of years in response to large uncontrolled runoff events (Sommer et al. 2008). During high flow periods it is difficult to routinely acquire data on the utilization and survival of juvenile salmon in the Yolo Bypass. Drought conditions over the previous five years have significantly reduced opportunities to study salmon passage in the Yolo Bypass. For example, the weir regulating flow into the Yolo Bypass (the Fremont Weir) was overtopped briefly (for 9 days) in 2012 with a peak discharge of 29K cfs and again in 2011 for 25 days with a peak flow 90K cfs. Both of these events were relatively low flows considering the maximum capacity of the Yolo Bypass is 340K cfs.

A series of landmark investigations on the Yolo Bypass (Sommer, et al. 2001a,b; 2005) demonstrated that flood plain habitats increase juvenile salmon condition and perhaps population level survival through the Sacramento- San Joaquin River delta. Results from these studies provide the technical underpinning for recommendations in the 2009 NMFS Salmon Biological Opinion and in recent Eco restore documents (http://resources.ca.gov/ecorestore/) for increasing access of juvenile salmon to flood plain habitats as a means of increasing overall salmon populations in the delta.

1.1 Study Objectives

The proposed study has two phases aimed at understanding the process of juvenile salmon outmigration by studying:
(1) time-dependent spatial distributions in the Sacramento River adjacent to the Fremont Weir, and,
(2) survival and migration time through the Yolo Bypass and north delta.

The primary objective of component (1) is to determine fish temporal and spatial distributions in the Sacramento River channel adjacent to the Fremont Weir, where a physical modification is proposed – the so-called Fremont Weir project, or "notch". Specifically, an understanding of fish distributions and behavior adjacent to the Fremont Weir will allow us to optimize the design of the notch by maximizing the number of fish per unit volume of water entering the facility under a broad range of conditions. The design effort for Fremont Weir is at a critical stage, and these data are essential for moving this project forward. This study builds on a similar effort during the previous winter (2014-2015), when there were extreme low flow conditions because of an extended drought.

The primary objective of component (2) is to examine the following questions:

(1) What is the survival probability of salmon migrating through the Yolo Bypass? And,

(2) How does survival in the Yolo Bypass compare to survival throughout the North Delta?

The available data suggests that the Yolo Bypass results in faster growth rates and perhaps improved survival. Although not studied in detail, the floodplain habitat is also thought to increase life history diversity (Goertler et al. 2015), a key factor that has contributed to changes in the resilience of salmon (Lindley et al. 2009). By taking the Yolo Bypass route, juvenile salmon (a) completely avoid the north, central and south delta (and the proposed water conveyance tunnel intakes downstream, if they are built), where survival is generally lower (DWR Report (Perry, et.al., in press) and (b) the fish condition is improved because of increased rearing habitat, longer travel times in the bypass, and increased prey density (Sommer et al. 2001; 2005). This study will directly address route selection and survival, (a) by using a network of receivers (Figure 1) and a mark recapture statistical approach based on a generalized linear model (GLM) (Figure 2), Cormack, 1964; Jolly 1965; Seber 1965; Skalski et.al. 2001; Skalski et.al. 2001; Perry et.al. 2010; Perry et.al. 2015) and will only indirectly address the question of improved fish condition, (b), since we will not be able to recapture study fish. Nevertheless, travel time distributions will allow us to infer fish condition. For example, if study fish transit the bypass in a relatively short period of time (~days), we can infer they did not have ample time to significantly improve their condition regardless of the prey density. Conversely, longer travel times (~weeks) could suggest significant foraging and improved condition.

In summary, the study objectives are to (in order of priority): (1) gather data on the temporal evolution of the spatial structure of tagged salmon in the Sacramento River near the Fremont Weir, (2) estimate travel time and survival rates in the Yolo Bypass (3) estimate survival through the north delta under different flow rates and throughout the season, and (4) compare survival of study fish to Chipps Island between fish that take the various routes through the delta, including the Yolo Bypass route. This work is designed to inform restoration design (e.g. Fremont Weir intake), and to provide additional key information for a behavioral model being developed by ACOE.

1.2 REVIEW OF PREVIOUS STUDIES ON JUVENILE SALMON SPATIAL DISTRIBUTIONS IN THE SACRAMENTO RIVER ADJACENT TO THE FREMONT WEIR

A multi-agency study was conducted during Water Year 2015 on a bend in the Sacramento River on the far western end of the Fremont Weir (Figure 3) involving the USBR, DWR, ACOE and the USGS. This study was focused on understanding the influence of secondary circulation on the spatial distribution of fish (Figure 4). Secondary circulation in bends is well-known (since Roman times, actually; more recently: Nezu and Rodi, 1985), but the methodology to measure it in the field has only recently been developed (Dinehart and Burau, 2005a,b) and the implications for fish distributions only recently hypothesized (Figure 4).

In this study, two groups of approximately 250 fish each were released in the Sacramento River near Knights Landing at similar, but relatively low discharges with a stage of approximately 14.5 feet, below the design water levels for the notch (18-25 feet NAVD88) (Figure 5). The positions of fish passing through a 2D acoustic telemetry array were determined at 3-second intervals, with a relative position accuracy of ~1 m based on the telemetry array shown in Figure 3 and Figure 6. Several tracks from the WY2015 study are shown in Figure 7, and an aggregate spatial distribution of all tracks is shown in Figure 8 and Figure 9 (see Appendix A for a detailed

description of how these figures were generated). Velocity transects were measured concurrently (Figure 10) and the data processed using the methodology outlined by Dinehart and Burau, 2005a. These data clearly show that at a discharge of ~30K cfs the secondary circulation was strong in this bend (
Figure 11), on the order of 20 cm/s at the bend's apex. Fish appeared to show a significant bias in their position with increased fish concentrated on the outside of the bend adjacent to the Fremont Weir (Figure 8 and Figure 9). However, it was also clear that the distribution begin to "relax", or become more evenly distributed, a very short distance downstream of the bend's apex, suggesting a well-defined, though relatively narrow window of opportunity, in terms of location along the flow path, to place a structure to maximize the density of fish entering the bypass.

Fish were released relatively close to the study site (Knights Landing) and arrived at the study site ~ 6 hours after release. These data, therefore, are based on fish that had a short in-river acclimation time and were not allowed the time needed to develop the diurnal outmigration pattern of holding during the day and migrating at night observed in numerous previous telemetry investigations (Chapman, et al., 2012; Pumb et al., 2015). We feel that sufficient in-river acclimation is needed in any study to insure that the behavioral responses of fish are not biased by the time of arrival in the study area.

2 STUDY IMPLEMENTATION - OVERVIEW

This section provides the study implementation plan for this experiment. This study has essentially 2 phases (given in preferred order of implementation):

(1) Two (2) fish releases aimed at documenting fish distributions in the Sacramento River channel adjacent to the Fremont Weir. These data are intended to inform notch placement and design. These releases will be conducted when the Sacramento River stage is below the height of the Fremont Weir – targeting stages of 18-25 feet (NAVD88).

(2) Three (3) fish releases will be used to compute, compare and contrast survival and transit times in the Yolo Bypass and the north delta. These releases will occur during a period when Sacramento River water enters the Yolo Bypass via the Fremont Weir. Releases are targeted to include the ascending, peak and receding limbs of the Yolo Bypass inflow hydrograph.

This implementation plan includes a detailed description of the proposed acoustic telemetry deployments, hydrodynamic measurements, fish release locations and release strategy. The acoustic telemetry gear deployed includes (a) a 2D array, (b) remote receivers (for survival model), and (c) coarse resolution arrays. Measurements of hydrodynamics processes include (a) discharge time series on the Sacramento River at two (2) locations; (a) immediately upstream and (b) downstream of the Fremont Weir, and (b) measurements of secondary circulation. The fish release strategy includes a description of both the release (a) location and (b) timing based on target Sacramento River water levels and hydrology.

Finally, the broad outlines of an adaptive management strategy are presented. This strategy, at its core, involves the formation of an adaptive management team who will make decisions regarding the day-to-day implementation of the experiment, including: (1) deployment and recovery of the 2D and coarse telemetry arrays, (2) fish release location and (3) timing.

2.1 STUDY TIMING AND DURATION - OVERVIEW

We will begin deploying acoustic telemetry receivers and fixed site hydrodynamic data collection equipment (Figure 1) the second week of January. The earliest the 2D and coarse arrays (Figure 1) can be deployed will be the 2nd week of February due to contracting constraints. Deployment of this gear will depend on river conditions and weather. Thus, the earliest fish will be released is the 2nd week of February. We expect to leave all of the equipment associated with the survival model in the water for a least 50 days (tag life) after the last release so study fish can clear out of the delta. The 2D and coarse arrays will be pulled after the 2D tracking phase of the experiment is over, once conditions in the river allow the equipment to be safely removed.

3 STUDY IMPLEMENTATION - DETAILS

The following description of the implementation plan follows the timing of the work flow. Therefore, we begin our discussion with the acoustic telemetry gear associated with phase 2 of the study because this equipment has to be deployed well in advance of fish release. This equipment is distributed throughout the delta and will take a couple of weeks to deploy. In contrast, the 2D and coarse arrays are at considerable risk while deployed due to debris in the river and due to potential burial by bed load sediment transport, so this gear will be deployed as close in time to the release of fish as possible and will be removed as soon as possible after study fish have moved through the 2D and coarse arrays. We hope to have all the gear associated with the 2D and coarse arrays removed prior to the Fremont Weir overtopping. We then discuss the hydrodynamic measurements because some of this gear also must be deployed before fish are released. We finish this section with a description of the fish release and adaptive management strategy.

3.1 ACOUSTIC TELEMETRY GEAR

3.1.1 Array Locations

An overview of where the acoustic telemetry gear will be deployed is shown in

Figure 1.

From north to south, these telemetry deployments include:

(1) A real-time telemetry gate in the Sacramento River upstream of the Fremont weir (westernmost yellow square in

Figure 1, yellow ellipse in Figure 6). The real-time receivers upstream of the Fremont Weir will be used to adaptively manage the release strategy to: (1) optimize arrival time in the bend and (2) so we know, in real time, the exact number of fish that make it to the Fremont Weir study site. These data will allow us to optimize recovery of the 2D array and coarse arrays. This capability is important given the equipment in this array is autonomous and at great risk while deployed (more on risk management in the adaptive management section).

(2) A 2D array in a bend upstream of the Fremont Weir (magenta ellipse in

Figure 1, and yellow ellipse in Figure 6 and shown in more detail in Figure 12). Data from this array will be used to document the role secondary circulation plays in concentrating fish on the outside of bends.

The proposed 2D array, aimed at understanding fish position in the Sacramento River adjacent to the Fremont Weir, will be designed to be virtually identical to the 2D array deployed in 2015 so that the data collected this year will be consistent with, and therefore comparable with, data collected in 2015 (Figure 3).

(3) Two (2) coarse arrays deployed downstream of the 2D array (Figure 12). Each of these arrays will have 6 HR2 receivers. The coarse array immediately downstream of the 2D array is aimed at understanding the rate at which the fish spatial distribution in the bend "relaxes" (e.g. becomes more uniformly distributed). This is important for knowing how much latitude there is in notch placement. This array will be placed in the straight section of the river channel, immediately downstream of the 2D array, but upstream of the next downstream bend.

The 2nd coarse array will be placed at proposed notch location 5,6,7 to get baseline information on the lateral distribution of fish at this location (see

Figure 13, for notch locations). The outside bank of the bend immediately upstream of this coarse array has failed (Figure 14 and Figure 15), so the geomorphology of this bend is completely un-natural (Figure 16) and thus this bend is not expected to generate secondary circulation nor the concomitant increase in fish density on the outside of the bend. Rip-rap from the failed bank protection and pilings occupy the center of the channel in this bend. From a purely hydrodynamic perspective, notch location 5,6,7 is likely the best choice because the bend has a small radius where the upstream orientation of the river is perpendicular to the Fremont Weir and thus along channel momentum will likely carry fish into the bypass through the notch more effectively than elsewhere on the weir. Based on this observation we recommend repairing the bank revetment at this location in a manner consistent with proposed notch designs and conduct another 2D telemetry experiment at this location, using a full size range of juvenile salmon, including small, fry-sized fish.

(4) a telemetry gate deployed in the Sacramento River immediately downstream of the Feather River (Figure 6). This receiver is in place to document the number of fish that make it past the Fremont Weir, giving us a solid estimate of the number of fish that enter the north delta for the survival model.

(5) telemetry receivers south of the Fremont Weir shown in

Figure 1 make up the remainder of the receiver locations needed for the survival model for both the Yolo Bypass and the north delta. All of the icons in

Figure 1 represent telemetry receiver locations, except the blue triangles, which represent flow stations.

All of the telemetry stations (e.g. icons) shown in

Figure 1 will be used to compare the travel time distribution and survival probabilities between the Yolo Bypass and the North Delta as a whole. Data from these stations will allow us to compute travel time and survival in all of the various channels in the north delta and the exchange of study fish into and survival within the Central Delta, as a whole (Stations MOK and LPS in

Figure 1).

Real-time data collection will occur at two (2) critical sites. Survival estimates in the Yolo Bypass critically depend on receivers functioning upstream of the Fremont Weir (yellow square in

Figure 1) and at the downstream terminus of the Yolo Bypass at Cache Slough (red square in

Figure 1). Real-time data will allow us to rapidly detect and fix problems should they occur at these sites.

A 2-gate array will be deployed at Chipps Island (Figure 17), funded as part of the BOR funded 6-year study, so survival from the Tisdale Weir release location to Chipps Island will be possible.

We propose to also deploy receivers in the lower Mokelumne River and in Little Potato Slough as part of the 6-year study, so a full north delta survival model is possible. Finally, as part of the 6-year study, VEMCO gear will be deployed at the export facilities. However, given the predation rates in the delta and the myriad of possible outmigration pathways, the sample size at receivers placed at the export facilities from releases in this study will likely be small.

All of the figures in this document represent the proposed deployment configuration at the time of this draft. However, the actual deployment details may change as the study is implemented. Accordingly, a comprehensive Google Earth "kmz" file has been developed, YBUS.deployment.plan.xx/xx/2016.kmz, where xx/xx/2016 is latest version, that will be updated to reflect the as-deployed status of equipment as it is put in place. This file contains information on the: (a) hydrodynamics, (b) acoustic telemetry gear, (c) fish release locations, and, at this writing, (d) possible COE deployments.

Finally, the kmz file above was created because there are a number of details associated with each telemetry location shown in

Figure 1 that are virtually impossible to convey in a word document for every site. For example, there are at least two (2) receivers deployed at each location. At locations where the river is relatively "wide", a pair of receivers is deployed to define a line perpendicular to the flow (an example in given in Figure 18, stations with this configuration are shown as yellow icons in

Figure 1). Similarly, at locations where we expect high velocities (e.g. "fast"), say order 5 ft/s, during flood stage, receivers are deployed along the channel to increase the detection range (an example is given in Figure 19, stations with this configuration are shown as green icons in

Figure 1). At locations where the channels have fast currents and are wide, four (4) receivers are deployed (an example is given in Figure 19 and stations with this configuration are shown with the red icons in

Figure 1).

3.1.2 Deployment Timing

We propose to have ALL of the telemetry equipment shown in

Figure 1 deployed before fish are released for phase 1. We expect this to occur on or before February 5, 2016. Release of fish for phase 2, aimed at evaluating transit times and survival in the Yolo Bypass and north delta, do not require that the 2D and coarse arrays be deployed, thus, fish releases associated with phase 2 may (and likely will) occur when the 2D and coarse arrays are out of the water.

3.2 Hydrodynamic Measurements

Hydrodynamic measurements specific to this study involve the establishment of two (2) temporary flow gauges in the Sacramento River up and downstream of the Fremont Weir (FWu and FWd, respectively, white dots in Figure 20) and measurements of secondary circulation in the bend associated with the 2D acoustic telemetry array. With the exception of the installation of these temporary flow stations, all of the telemetry receivers will be placed near existing long term flow and water quality monitoring stations (the blue triangles in

Figure 1), so we will have the relevant physical data (stage, velocity, flow, temperature, turbidity) associated with each transit of each tag past every telemetry array in the network.

3.2.1 Discharge Measurements

We propose to deploy and rate Acoustic Doppler Current Profilers (ADCPs) in the Sacramento River up and downstream of the weir (FWu and FWd, respectively, white dots in Figure 20) (Ruhl and Simpson, 2005), to document the interaction/exchange of the Sacramento River, Sutter Bypass, and Feather River into the Yolo Bypass. Because of these interactions, backwater conditions near the Fremont Weir are likely to occur during the study period. Stage-discharge relationships don't work under conditions where there are significant backwater effects. Thus, rather than using stage to measure discharge, as is done at Verona and at Knights landing, we plan to temporarily deploy index velocity stations at (FWu and FWd, respectively, white dots in Figure 20).

To determine if backwater effects are an issue in the Sacramento River at flood stage we pulled the stage records at Fremont, Verona, and the American River (Figure 21 and for WY1995, Figure 22). We didn't find convincing evidence that flow reversals occur in the Sacramento River into the Yolo Bypass from the American River at Verona based on the 20 years of overlapping records (1987-2008). The water surface elevation at the American River gage is higher than the Fremont gage because the American River gage is 10.3 km (6.4 miles) upstream of the confluence, so looking at the difference between Verona and the American River is not particularly useful.

We also looked at stage differences between Fremont and Verona. The stage difference, controlling the water surface slope, is nominally ~2.5 - 3 feet. However, when the Fremont weir crests this difference is significantly lower, noted by the black dots in the time series plots. Therefore, the decrease in head between Fremont and Verona is likely not related to overbank flow at Verona. The other two possibilities include: (1) a significant increase in discharge from the Feather River when the stage at the Fremont Weir did not increase or (2) when the weir crests it actually pulls water in from up and downstream which may cause water velocity to slow at Verona and invalidate the stage-discharge relationship there. It is difficult to see this when using the complete record, however, by looking at a single water year (1995) one can see that each time the weir crests there is a corresponding 1-2 foot drop in the water level difference, or a decrease in water surface slope. The ADCPs deployed at FWu and FWd will document whether backwater is an issue in this region and how flow between the Sutter and Yolo Bypass, Sacramento and Feather Rivers interact when the weir crests.

Finally, a Probability Density Function (PDF) for stage at the Fremont Weir is given in Figure 23. In this case, the PDF describes the relative likelihood stage will take on a given value. For example, if one wanted to flood the Yolo Bypass more often, the stage most likely to occur is roughly 15', with stages above this happening less frequently. Of course, if you wanted to look at the optimum stage for putting juvenile salmon on the Yolo Bypass, one would need the joint probability distribution of stage and presence of juvenile salmon at the Fremont Weir.

3.2.2 Measurements of Secondary Circulation

3.2.2.1 Spatial Resolution

The focus of the WY2015 study was to document the presence of secondary circulation in the apex of the bend under the conditions when study fish were passing through the 2D array. Accordingly, velocity transect measurements using a boat-mounted downward-looking ADCP in WY2015 were made at four (4) locations in the bend as is shown in Figure 10.

This year we propose to focus on the ***evolution*** and relaxation of both secondary circulation and fish spatial distributions within the entire bend. Therefore, we propose to expand the number of transects in WY2016 to include additional cross sections both upstream and downstream of the bend's apex. We'd like to document the absence of secondary circulation at the bend's upstream boundary, through the peak in secondary circulation at the bend's apex, to the cessation of secondary circulation at the downstream boundary (Figure 24). In addition, if time allows, we propose to document the evolution of secondary circulation from the upstream of the bend with the 2D array (Figure 24) through the 180 degree bend immediately downstream of the 2D array (Figure 25) as a numerical model calibration data set.

3.2.2.2 Temporal Resolution

As with WY2015, we propose to take transect measurements as close to the fish arrival time as is possible because the boat-mounted ADCP will likely interfere with the acoustic telemetry monitoring equipment in the bend. In addition, this year we propose to take secondary circulation measurements at a range of notch design discharges (e.g. at stages less than overtopping stage of the Fremont Weir (33.5 feet)) to see if an analytical relationship between discharge and secondary circulation strength can be developed.

The same data processing procedures will be used on the WY2016 as were used in WY2015 (http://pubs.usgs.gov/fs/2013/3028/pdf/fs2013-3028.pdf).

3.2.2.3 Particle Tracking/Individual Based Modeling (IBM)

The expanded spatial coverage of secondary circulation measurements shown in Figure 24 and Figure 25 will allow us to release neutrally buoyant and particles with behavior into flow fields that are based solely on field data. As a proof of concept, we released particles in flow fields based on linear interpolation of transects collected in WY2015 (a significantly shorter reach than is proposed in WY2016). Particle tracks are shown for surface releases (the portion of the water column juvenile salmon are known to inhabit while outmigrating) during high flow measurements (stage of ~32 feet measured on 12/22/2014) (Figure 26). Figure 26A,B show tracks from two different viewpoints for neutrally buoyant particles. These tracks show the classic corkscrew pattern where particles released at the surface dive down on the outside of the bend and move toward the bend's inner bank at depth (Figure 4).

Particles in this simulation appear to "disappear" into the bed. This is because ADCP's are unable to measure the currents immediately adjacent to the riverbed and thus the vertical velocities in the measured flow fields are directed towards the bed because the flow field incompletely described. In future iterations of the methodology used to generate these flow fields, corrections for the lack of resolution near the bed (and banks, for that matter) could be made using rudimentary boundary layer theory (Schlichting, 1955; Chen, 1991; Oberg and Muller, 1194)). Finally, we explored the idea that juvenile salmon want to remain near the surface while transiting the bend (e.g. resist downwelling: e.g. Figure 4) by setting the vertical velocity to zero in the flow field (Figure 26C). Figure 27 shows the same sequence as in Figure 26, except during low flow (stage of 14.5 feet). In both the low and high flow cases, the response of particles with this simple behavior more closely matches the observed fish spatial distribution from the WY2015 study (Figure 8) over the truncated region where velocity transects were collected in WY2015 (Figure 10). The ability to generate a velocity field through the entire bend based on field data will allow us to compare particle behaviors with observed fish spatial distributions independent of a numerical modeling framework. This approach would provide an independent and complementary check on the numerical computer modeling approach of the ELAM group.

3.3 Fish Release Strategy

As described above, a total of five (5) releases are proposed using a total of 1200 tagged fish (Figure 28), with release timing determined by monitoring weather and river conditions and forecasts in the upper Sacramento River basin. The earliest possibility of a fish release will be the 1st week of February, after all the telemetry gear described above is deployed.

3.3.1 Fish Tagging Details

Late fall run chinook salmon obtained from the Coleman National Fish Hatchery will be used in this study. Given the elevated water temperatures at Coleman last summer during drought conditions, study fish will be large; we are expecting most fish to be greater than 100 mm. All the typical morphometric data: length, weight, etc. will be collected on each fish released during the study. Fish will be tagged using the latest USGS standard tagging procedures (see Liedtke, T.L., J. W. Beeman, and L. P. Gee. 2012. A Standard Operating Procedure for the surgical implantation of transmitters into juvenile salmonids. U.S. Geological Survey Open File Report 2012-1267).

3.3.2 Tag Specifications

Given that the fish in this study will be large, VEMCO 180 khz V5 tags, with a longer battery life, will be used. The V4 and V5, operating at 180 kHz, are designed to work well in both fresh and salt water. Given that the study fish in 2014 were smaller (~< 100mm), V4 tags were used.

Tag Family	Length (mm)	Height (mm)	Width (mm)	Weight in Air (g)	Weight in Water (g)	Power Output (dB)	Battery Life Example (Delay: 60 secs) *
V4-180kHz	11 mm	3.6 mm	5.7	0.42	0.24	134	62 days
V5-180kHz	12.7 mm	4.3 mm	5.6	0.65	0.38	143	131 days

** Typical life – Estimated that 50% of tags will reach this life based on a 95% confidence level (Table courtesy of VEMCO)*

3.3.3 Tag Programming

There are many factors (trade-offs) associated with tag programing: principal among them balancing battery life and ping rate. The ping rate affects: (1) how easily tags are detected, especially in fast moving (and noisy) water, (2) the possibility of tag collusions on the VR2W's and the (3) temporal and spatial resolution within the 2D and coarse arrays. Given that high flows are targeted in this study, a fast ping rate is desired so the receiver has as many detections as possible to identify an individual tag while fish are within the detection range of hydrophones. On the other hand, we need sufficient tag life to ensure all tags are operational when they pass Chipps Island. Moreover, a fast ping rate increases the spatial and temporal resolution of fish positions within the 2D array. To best accommodate all of these factors, the tags will be programmed so they have a faster ping rate (on the high residency transmission) for seven days to accommodate the needs of the 2D array. The ping rate will be programmed to slow down after seven days to extend battery life.

Accordingly, the V5 acoustic tags will be programmed for this study as follows:

To optimize the precision and temporal resolution of 2D positions:
ON 7 days; PPM (pulse position modulation) @ 180 kHz transmission every 17-23 second for absence/presence detection
HR (High Residence) transmission @ 170 kHz every 1-2 seconds for positioning & absence/presence detection

To optimize survival receiver detections:
ON until tag expiry; PPM (pulse position modulation) @ 180 kHz transmission every 17-23 second for absence/presence detection
HR (High Residence) transmission @ 170 kHz every 17-23 seconds for absence/presence detection

Tag life estimate = 41 days @ 95% based on VEMCO statistical tests and 52 days @ 50%.

Depending on conditions, the V4 and V5 tags can have 150-200 m detection range. However, under the high flows we expect during this study, VEMCO predicts a 75-100 m range with the V5. To account for this reduced range and high water velocities multiple receivers will be deployed at each location (See section 3.1.1).

3.3.4 Tag life study

Thirty (30) randomly selected tags from the same production as tags used in the field will be programmed identically to the tags used in the field and monitored for premature tag failure. Premature tag failure can negatively bias survival estimates: corrections can be applied if the tag failure rate is known – hence the tag life study.

3.3.5 Fish release timing

3.3.5.1 Fish release strategy for phase 1: Documenting increased fish density on the outside of bends

In phase 1, two releases of 240 tagged fish each are proposed to document the distribution of fish in the 2D and coarse arrays upstream of the Fremont Weir (Figure 12). We propose to target two distinct discharges in the notch design stage range of 18-25 feet during the ascending limb of the hydrograph, prior to flow into the Yolo Bypass over the Fremont Weir (e.g. the first two releases in Figure 28 or last two releases in Figure 29).

We propose to release fish in the Sacramento River immediately below the Tisdale Weir (R1 in Figure 20) for phase 1, at least 2 day/night cycles upstream of the Fremont Weir so the study fish can acclimate to in-stream conditions. Study fish will be released at the Tisdale Weir in four groups over the course of 24 h, to avoid day/night biasing of fish arrival time in the 2D and coarse arrays. We will release 60 fish in each group, with releases separated by 6 hours (for example: releases at 9 am, 3 pm, 9 pm and 3 am).

Finally, it is possible Fremont weir will crest prior to having the telemetry gear in place. If this happens, we will target a later period for phase 1 releases, once river conditions sufficiently subside (stage < 18') to make it safe to install equipment (Figure 29).

3.3.5.2 Fish release strategy for Phase 2: Travel time and Survival in the Yolo Bypass and north delta

In phase 2, three (3) releases of 240 tagged fish each are proposed: (1) initial over topping, (2) peak flow into the Bypass and the (3) descending limb of bypass flooding. For each of the three fish releases, we propose to release 30 study fish at the Tisdale Weir release site (R1 in Figure 20) to determine how many fish enter the bypass from the Sacramento River, 105 fish will be released directly into the Yolo Bypass (R2 in Figure 20), and 105 fish will be released in the Sacramento River downstream of the Fremont Weir Bypass (R3 in Figure 20) to assure an adequate sample size for downstream receivers in both the Yolo Bypass and in the north delta survival arrays.

The 240 fish for each release in phase 2 will be divided across both time and space. We will release 40 fish at R1, and 100 fish each at R2 and R3. Releases at R1 will occur 18 to 24 hours prior to releases at R2 and R3 to allow tagged fish time to travel between the Tisdale and Freemont weirs to have all of the fish released experience the same exact flow conditions. Releases at R2 and R3 will be conducted simultaneously. Each release, at each site will consist of three separate release efforts over the course of 24 h. For example the 40 fish at R1 will be released as 13-14 fish at 6 am,2 pm, and 10 pm. The 100 fish at each of R2 and R3 will be released as 33-34 fish at approximately 6 am, 2 pm, and 10 pm. Release times may be adjusted based on travel times between R1 and R2, R3.

We expect all of the study fish released at R1 will go into the Yolo Bypass when the Sutter Bypass is flooded given the much greater discharge in the Sutter Bypass. Release of 30 fish at the Tisdale release site (R1 in Figure 20) are aimed at confirming this hypothesis. Alternatively, we could release all of the fish as a paired release between the Yolo Bypass (R2, in Figure 20) and the Sacramento Weir (R3 in Figure 20).

4 PERMITS

USGS will be responsible for obtaining the necessary permitting for placing equipment in the field and associated with tagging and fish release operations, should they be needed. Unless plans change, most of the equipment will be autonomous, so land access and therefore property owner permission is not needed. All of the real-time sites are associated with either USGS or DWR long-term monitoring stations, for which long-term permits have been established. Marty Liedke is working with Mike Cain (DWR) to obtain the necessary permits for fish release operations. Fish will not be released until the proper permits are acquired.

5 SCOPE OF WORK:

TASK 1 – PROJECT PLANNING AND COORDINATION

Numerous planning and execution activities including meetings, emails, and field reconnaissance will be required for successful implementation of this study. USGS shall provide appropriate staff to support the development and implementation of appropriate planning activities in order to successfully implement this study.

TASK 2 - HYDRODYNAMIC INSTRUMENTATION

A boat-mounted Acoustic Doppler Current Profiler (ADCP) will be used to characterize the hydraulic environment within the area monitored by the multi-dimensional acoustic telemetry array in the Sacramento River just upstream of the Freemont Weir. These data will be compared and related to statistical and spatial analysis of multi-dimensional acoustic telemetry data collected within the Sacramento River. The USGS will also deploy and rate two sideward-looking ADCPs to monitor the discharge in the Sacramento River immediately upstream and downstream of the Fremont weir to account for backwater conditions in the River during flood stage. These instruments will be deployed until at least April to make sure that the possibility of additional high water events is over for the year.

TASK 3 – DEPLOY, MAINTAIN, AND RECOVER ACOUSTIC TELEMETRY EQUIPMENT (MULTIDIMENSIONAL ARRAY UPSTREAM OF FREEMONT WEIR)

Acoustic telemetry equipment will be used to track tagged salmonids in multiple dimensions. This equipment will need to be installed, operated, and eventually recovered from the Sacramento River near the Fremont Weir. The multidimensional arrays will consist of equipment installed above and below the water. Pound-in or tower mounts may be used to deploy monitoring equipment on the river bottom for Task 4 – Deploy, Maintain, and Recover Acoustic Telemetry Equipment throughout Delta (Remote Receivers)

In order to apply a mark-recapture statistical model to evaluate how fish use the Yolo bypass and to estimate survival through this route, hydrophones will be deployed at key locations upstream and downstream of the Fremont Weir, and downstream of Yolo bypass including at Rio Vista and/or near Chipps Island (Figure 3). Remote receivers will also be deployed throughout the North Delta to calculate entrainment rates at key junctions within the Sacramento River (Sutter, Steamboat and Georgiana Sloughs), travel times and survival probabilities in the various north delta channels to compare with travel time and survival in the Yolo Bypass (Figure 3).

Task 4 - Deploy, Maintain, and Recover Acoustic Telemetry Equipment Thoughout the delta (remote recievers)

This task covers the deployment, maintenance and recovery of the icons shown in Figure 1, discussed in section 3.1.

Task 5 – Conduct Tag and Release Operations

A senior scientist from USGS (CRRL) will manage the overall tag-release operations. Surgical implantation of transmitters into the study fish, and regular monitoring of the fish collection and transport operations will be conducted by USGS.

Task 6 – Intake telemetry gates (or coarse arrays)

This task covers the deployment, maintenance and recovery of the icons shown in Figure 12, discussed in section 3.1.

Task 7 – Route Selection and Survival Analysis

USGS will conduct analysis to evaluate survival and the probability of entering Yolo bypass relative to flows.

Task 8 - Final Reporting and Technical Review

USGS (CRRL and CAWSC) will complete the deliverables is given in section 5.1.

5.1 Deliverables

All of the preliminary and processed data will be provided to DWR in digital form for archival purposes and for further analysis, if needed. At least two reports are planned as the deliverables associated with this proposal, focused on the two study components:

(1) On the hydrodynamics and juvenile salmon spatial distribution in a bend adjacent to the Fremont Weir (Aaron Blake, Paul Stumpner, Jon Burau)

(2) A comparison of route selection, survival and transit times on Juvenile Salmon in the Yolo Bypass and North Delta (Russell Perry)

The following reports will written:

1. Methods, results, and discussion sections for the analysis of hydrodynamic data.
2. Methods for the tagging, release, and transport of study fish.

3. Methods, results, and discussion sections for the spatial analysis of 2D fish track data.
4. Methods, results, and discussion sections of the Generalized Linear Model.
5. Methods, results, and discussion sections for the survival analysis.
6. Methods, results, and discussion sections for the tag life tests.

Based on the results, and in consultation with DWR, reports may be submitted for publication as journal articles, with draft reports due within 8 months following equipment retrieval and data download.

USGS will present initial findings to interested parties including DWR, Metropolitan Water District (MWD), the state and federal water contractors including presentations at venues such as the annual IEP conference and Bay/Delta Science conference, sponsored by the Delta Stewardship Council.

6 COORDINATION AND ADAPTIVE MANAGEMENT

This experiment is targeting a specific sequence of episodic events aimed at capturing the full range of hydrologic variability that can occur at the Fremont Weir – from pre-overtopping discharges to the ascending, peak and descending limb of the inflow hydrograph into the Yolo Bypass. Therefore, the deployment and recovery of the equipment in the 2D and coarse arrays, as well as fish release timing and location, will have to be heavily adaptively managed. The formation of an adaptive management team, its charge and various adaptive management alternatives are discussed in this section.

In general, the USGS will coordinate with agency partners (DWR, USBR and ACOE) through conference calls, meetings, presentations, etc. In terms of study implementation, the USGS will work with a specific small group of individuals from the agencies assigned to an adaptive management team whose charge is to adaptively manage the fish release strategy based on daily weather and hydrologic conditions and forecasts. Precipitation and river flow forecasts are subject to a considerable margin of error. Thus, the timing of fish releases will involve a roll of the dice on an uncertain future.

6.1 ADAPTIVE MANAGEMENT TEAM MEMBERS:

USGS: Jon Burau, Noah Adams, Russell Perry, Marty Liedtke

DWR: Ted Sommer, Brett Harvey, Loise Conrad, James Newcomb, Jacob McQuirk, Ryan Reeves, Edmund Yu,

USBR: Josh Isreal,

USCOE: Dave Smith, Brian Mulvey,

MWD (Contractors): Alison Collins,

UCD: Anna Steel

6.2 Phase 1 Adaptive management strategy: Fish releases associated with the 2D and coarse arrays

Bottom line:

A “go” decision for phase 1 will be based on the follow conditions:

(1) Forecast stages at the Fremont Weir are at or below 18 feet for 5 days (18’ is the maximum stage where equipment can be safely deployed. Deployment of 2D and coarse arrays requires divers),

(2) Forecasts indicate there will be an additional 5-10 days available to perform 2 fish releases

(3) Forecasts indicate there be an additional 5 days of stages below 25 feet to allow recovery of the 2D and coarse arrays, (25 feet is the maximum stage where equipment can be recovered safely – this step does not require divers).

It takes roughly 6 days to get fish to the Fremont Weir after a “green light”. This is based on: 4 days to release fish after receiving a “go” and we estimate it will take 2 days for fish to travel from Tisdale to the Fremont Weir, depending on the Sacramento River discharge.

Discussion:
The adaptive management decisions for phase 1 primarily involve risk management because the 2D and coarse arrays are at significant risk from debris and burial while they are in the water. The majority of the equipment deployed in these arrays will be autonomous, so the loss of equipment means loss of data, which can severely degrade the overall positioning accuracy of the array. Therefore, our deployment and recovery strategy is focused on minimizing the time the equipment is deployed in the field.

Thus, when forecasted conditions look favorable the 2D and coarse arrays will be deployed, closely followed by the fish releases at the targeted stages. Favorable conditions include: (1) river Stages < 18’ (so the arrays can be deployed safely) with a slowly rising hydrograph with sufficient time to deploy the array, conduct two fish releases and recover the gear (stages < 25’) as is shown in Figure 28 and Figure 29.

Deployment of the 2D and coarse arrays requires divers, which can only be done safely at stages ~< 18 feet. Divers are not required for gear recovery, but this gear cannot occur safely much above a stage of ~ 25 or so feet. Our goal is to have study fish move through the array before the river flows make it unsafe to recover the gear in the arrays (river stages of < 25’). So, timing will be tight.

Travel time from Tisdale to the Fremont Weir (river distance of 54.7 km, 34 miles) assuming an outmigration speed of 1 m/s (3.28 ft/s) and 0.5 m/s (1.64 ft/s) (based on velocities measured at station FWu in Figure 20) would be roughly 15 and 30 hours respectively.

The arrival time distribution at acoustic telemetry receivers is typically characterized by a steep increase followed by a slow decline. Although we have never released fish at Tisdale under high flow conditions, a period of 4 days after release is a reasonable planning estimate for how long it will take fish to clear the array after release (i.e. travel time 1.5 days and 2.5 days to accommodate the stragglers).

It will take approximately 5 days to deploy and 5 days to recover the equipment in the 2D and coarse arrays.

In summary, timing/duration of phase 1 includes the following sequence after a "go" decision is made:

(1) 4 days to release fish,
(2) 5 days for 2D and coarse arrays to be deployed (stage < 18 feet). (1) and (2) can and will be done in parallel,
(3) Fish are released for 24 hours (1 day),
(4) Maximum of 2 days (estimate) for fish to travel from Tisdale to Fremont (see below),
(5) 2 days for stragglers to clear 2D array,
(6) 5 days to recover 2D and coarse arrays (stage < 25 feet).

Minimum phase 1 implementation time of 15 days for a single release. Therefore, a minimum of 20 days of "favorable conditions (as outlined above) are needed to conduct 2 releases.

6.3 PHASE 2 ADAPTIVE MANAGEMENT STRATEGY: TRAVEL TIME AND SURVIVAL ESTIMATES FOR THE YOLO BYPASS AND NORTH DELTA

Bottom Line:

A "go" decision for phase 1 will be based on the following conditions:

(1) stages ***rapidly*** approaching 33.5 feet (overtopping stage) and a forecast that exceeds 33.5 feet, and

(2) significant precipitation forecast in the future (next week-month).

As with phase 1 releases, it will take roughly 6 days for fish to arrive the Fremont Weir after we give the green light.

Discussion:

The constraints on phase 2 are considerably less onerous and, for the most part, do not involve decisions regarding the safety of field staff and equipment. The adaptive management decisions for phase 2 essentially involve targeting fish releases to cover a broad range of conditions in the Yolo Bypass: the rising, peak and falling limb of the Yolo Bypass hydrograph as is shown in Figure 28 and Figure 29 in the context of uncertain weather and river forecasts. The challenge will be making the most of three (3) releases given the uncertainty associated with hydrologic prediction. In so far as targeting specific flows at the Yolo Bypass, it takes roughly 4 days to gear up to release fish and roughly 2 days for fish to travel from Tisdale to the Fremont Weir, so a 6 day lead time is expected. River forecasts are typically made 5 days out.

6.4 PLAN B- IF THE FREMONT WEIR DOES NOT OVERTOP OR IT IS UNSAFE TO DEPLOY THE 2D AND COARSE ARRAYS

If the Fremont Weir is not overtopped this year OR we are unable to deploy the 2D and coarse arrays due to unfavorable river conditions, paired releases in the Yolo Bypass and Sacramento River at the I5 Bridge at locations R4, R5 (Figure 20), respectively, will be made with the remaining fish. There is often significant flow in the Yolo Bypass at the I5 Bridge from water that enters the Yolo Bypass from Knights Landing Ridge Cut and Cache Creek even when the Fremont Weir is not spilling. We propose to compare the survival of salmon outmigrants using the Yolo Bypass and the Sacramento River during the period when the Fremont Weir is not spilling, essentially studying a series of low flow conditions in the Bypass, a possible surrogate for the proposed "notch" flows.

6.5 Roles and Responsibilities.

6.5.1 Field Work

(1) Coordination with the hatchery, trucking, tagging and release of fish in the Sacramento River (Marty Liedtke, PI),

(2) Deployment, operations, maintenance, recovery of all telemetry receivers, including the 2D array and real-time data collection and status checks (Jon Burau, Noah Adams),

(3) Programming, downloading and processing data associated with the remote acoustic telemetry receivers (e.g. all of the receivers not associated with the 2D array)(Chris Vallee).

(4) Collecting and processing bathymetry data in the bend to inform instrument placement and for numerical modeling efforts (Paul Stumpner),

(5) Deployment and recovery and processing of hydrodynamic equipment (Paul Stumpner),

(6) Making hydrodynamic measurements and processing of the data to calculate secondary circulation (Paul Stumpner).

VEMCO will be responsible for:

(1) Designing the array layout, programming, downloading and processing fish tracks from receivers in the junction.

(2) Tag programming.

6.5.2 Data analysis and Reporting

Paul Stumpner will take the lead in processing and analyzing and writing-up the hydrodynamics data. Aaron Blake will perform the spatial analysis (see Figure 8 and Figure 9 and appendix A) and the write-up associated with the 2D fish tracks provided by VEMCO in collaboration with Anna Steel (UCD). VEMCO will be responsible for producing fish tracks at the 2D and coarse arrays. Russ Perry will take the lead in constructing the Mark-Recapture statistical model and for taking the results of the statistical model to publication.

6.6 STUDY IMPLEMENTATION BENCHMARKS

During the implementation of the study progress on key benchmarks (see below) will be communicated to the adaptive management team, the DWR program managers and other interested parties, such as the State and Federal Water contractors on a regular ongoing basis. Black text indicates task to be completed, blue text indicates task is complete.

6.6.1 Field work (Details)

6.6.1.1 Preparation/Equipment Deployment:

(1) Recon of deployment and fish release sites
(2) Bathymetry data collected at 2D and coarse array locations
(3) Remote receivers deployed
(4) Chipps Island gate deployed (funded by USBR - 6yr study)
(5) Real-time receivers deployed
(6) ADCP's deployed up (FWu) and downstream (FWd) of Fremont weir
(7) 2D and coarse arrays deployed

6.6.2 Implementation

6.6.2.1 Fish releases

(a) Target stages, # fish released and where
(b) Secondary circulation measurements
(c) Calibration measurements of ADCP's
(d) Report from real-time receivers
(e) Issues?

6.6.2.2 Equipment Recovery

(Report on what was recovered and downloaded)
(1) 2D and coarse arrays
(2) Remote receivers
(2) ADCP's deployed up and downstream of Fremont weir

(4) Chipps Island

6.6.3 Data Processing
(1) Secondary circulation
(2) Rating of ADCP's up and downstream of Fremont Weir, calculation of discharge
(3) Remote receivers
(4) Chipps Island receivers

6.6.4 Analysis
(1) Construction of statistical model, prelim results
(2) Prelim results from Spatial Analysis
(3) Prelim results from hydrodynamic measurements

6.6.5 Reporting
(1) Draft reports complete
(2) Responded to review comments
(3) Final report

6.7 Possible Acoustic Telemetry Deployments by DWR, COE

Data were collected to document the baseline survival in the Sacramento River adjacent to proposed Tunnel locations (Figure 30) as part of the Fish Fence Guidance System barrier study ((http://baydeltaoffice.water.ca.gov/docs/Final%20Phase%20II%20-%20Appendices.pdf). It is possible the COE will have the equipment and manpower to deploy gear in these locations during this experiment.

In addition, if sufficient telemetry receivers are found, a gate may be deployed within the Yolo Bypass immediately downstream of the I-80 Bridge in collaboration with staff from the Yolo Bypass Wildlife Refuge.

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8 FIGURES

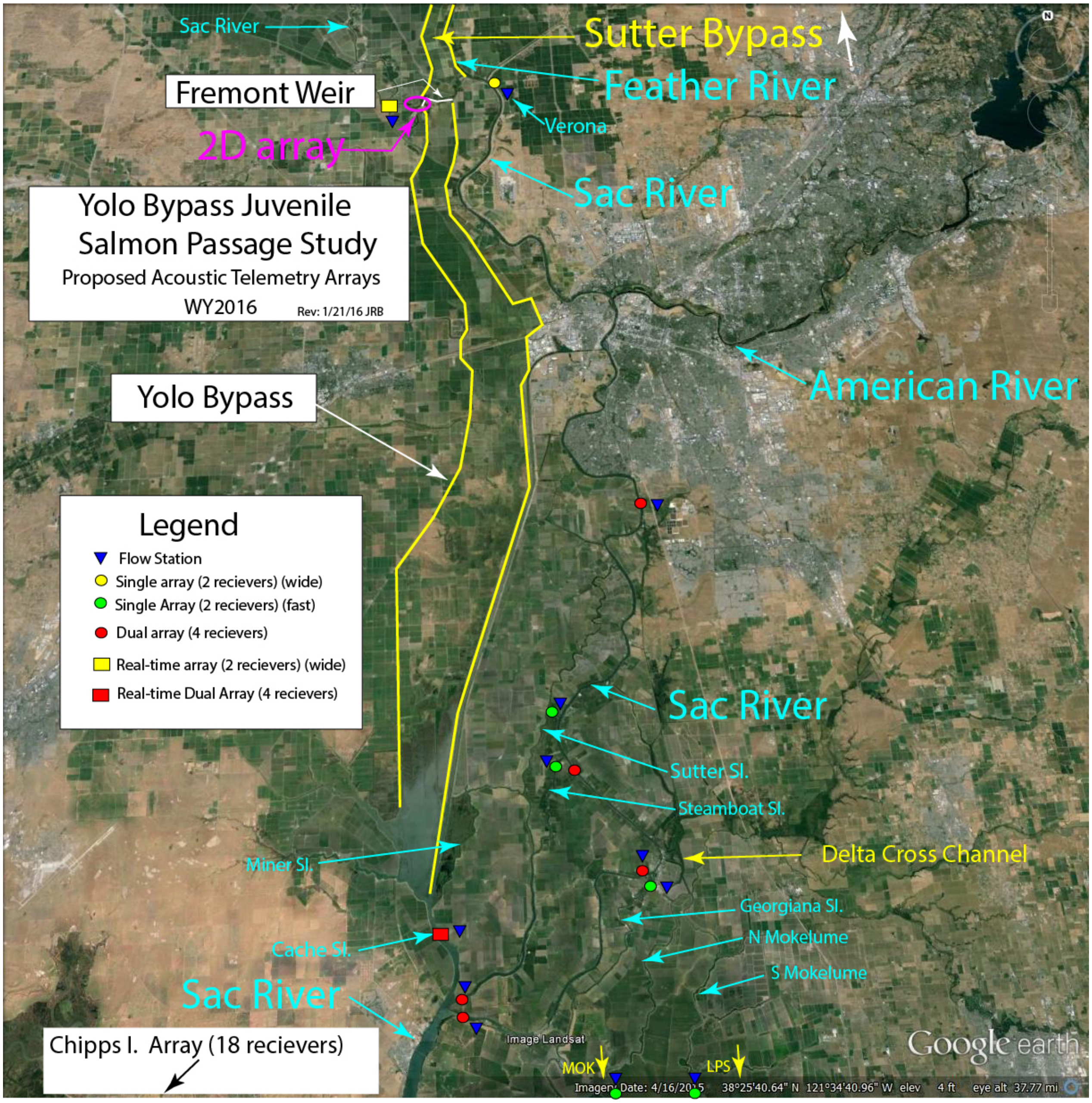

Figure 1 – Aerial view of Sutter Bypass, Yolo Bypass and the north delta including proposed locations of acoustic telemetry and flow station deployments. Not every telemetry station is configured the same. For example, each color and icon share represents a different configuration from number of receivers, to orientation relative to the channel to whether the data are telemetered in real-time. (See YBUS.deployment.plan.xx/xx/2016.kmz for details, where xx/xx/2016 is latest version).

Example Multistate Mark Recapture Model

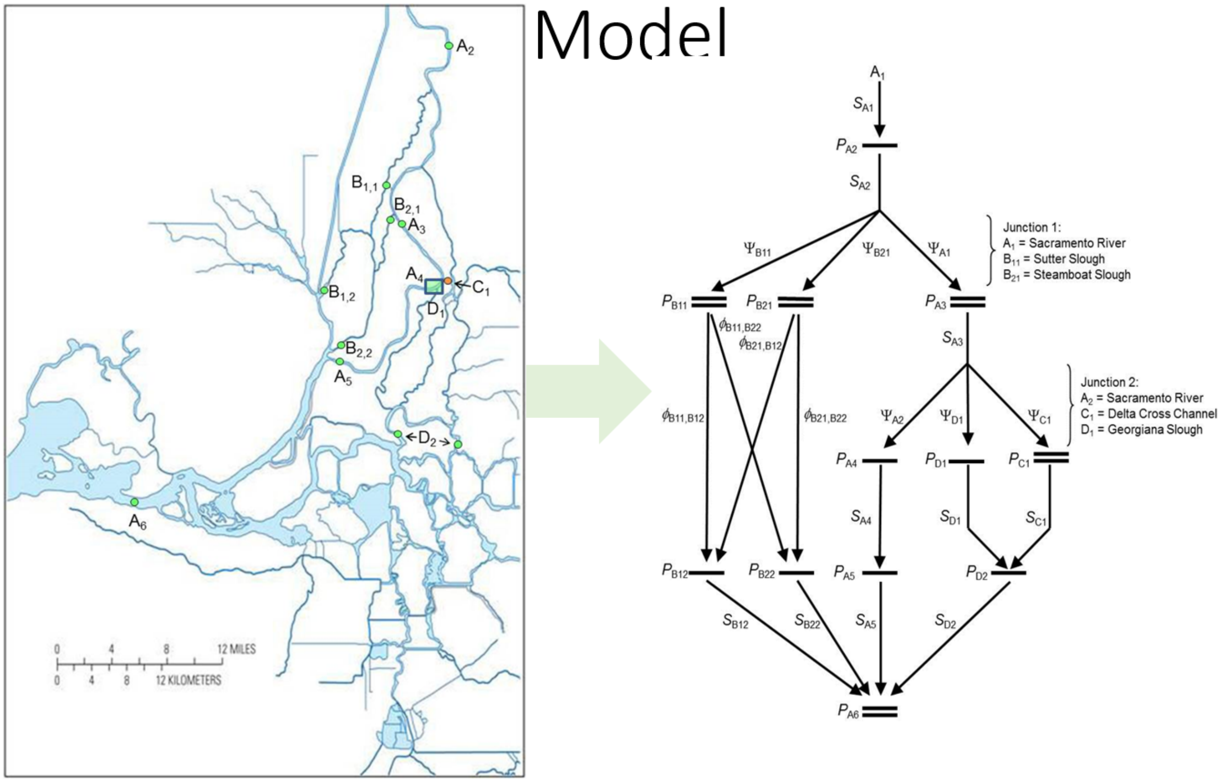

Figure 2 - Example multistate mark recapture model where a receiver network (left) is represented by a series of interconnected branches (right).

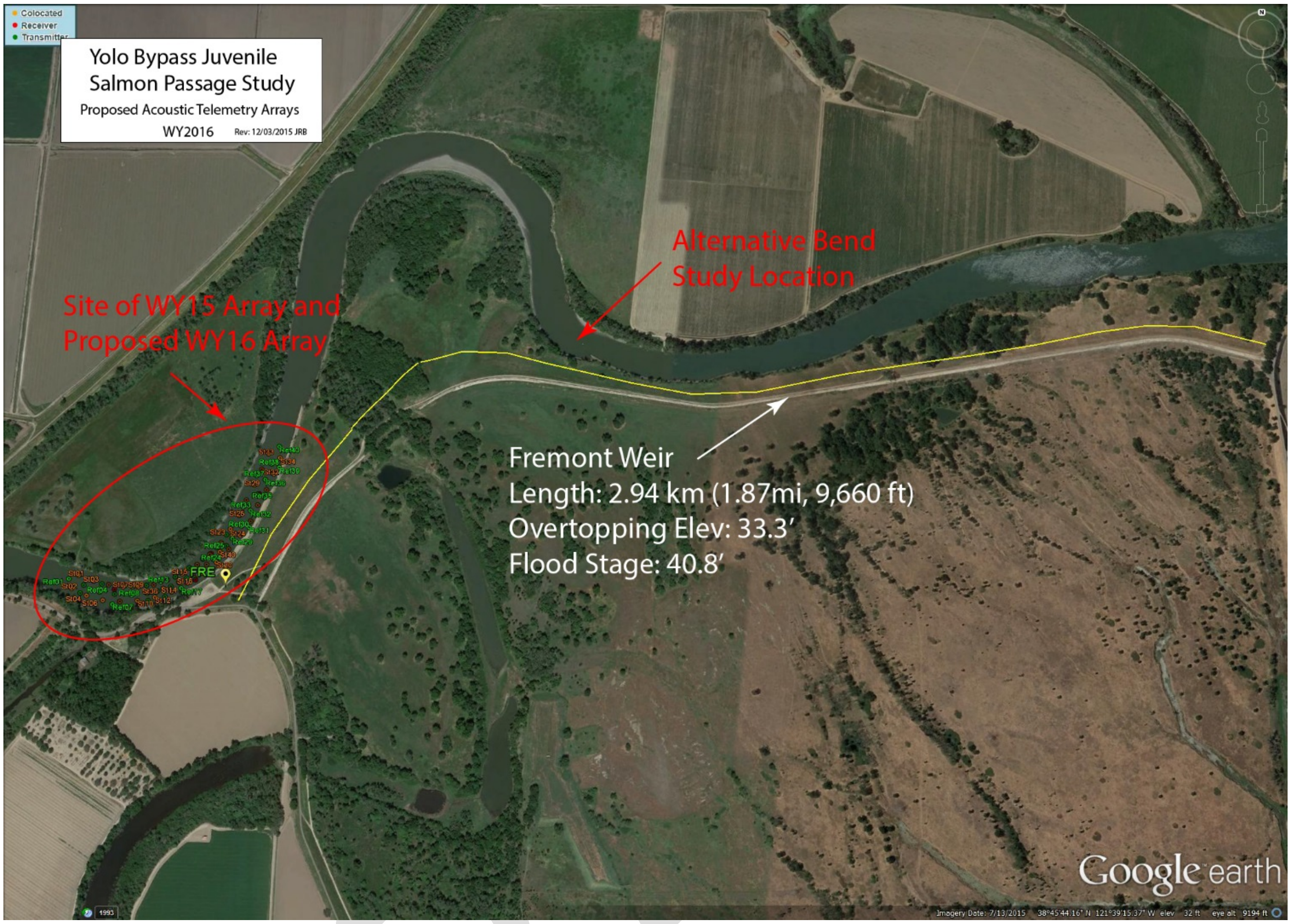

Figure 3 - Aerial view of the Fremont Weir with the bordering Sacramento River to the north of the weir. This picture shows the location of the 2D-array in the bend on the upstream edge of the Fremont Weir. An alternative bend study location is also shown. While this may be an excellent long-term location for the "Notch" in the Fremont Weir, the bank revetment has failed, the remnants of which are now center channel along with a series of pilings making this location unsuitable for a study and as a location for the notch. This site could be made a suitable alternative "notch" location if the levee were repaired and rock and pilings removed from the river.

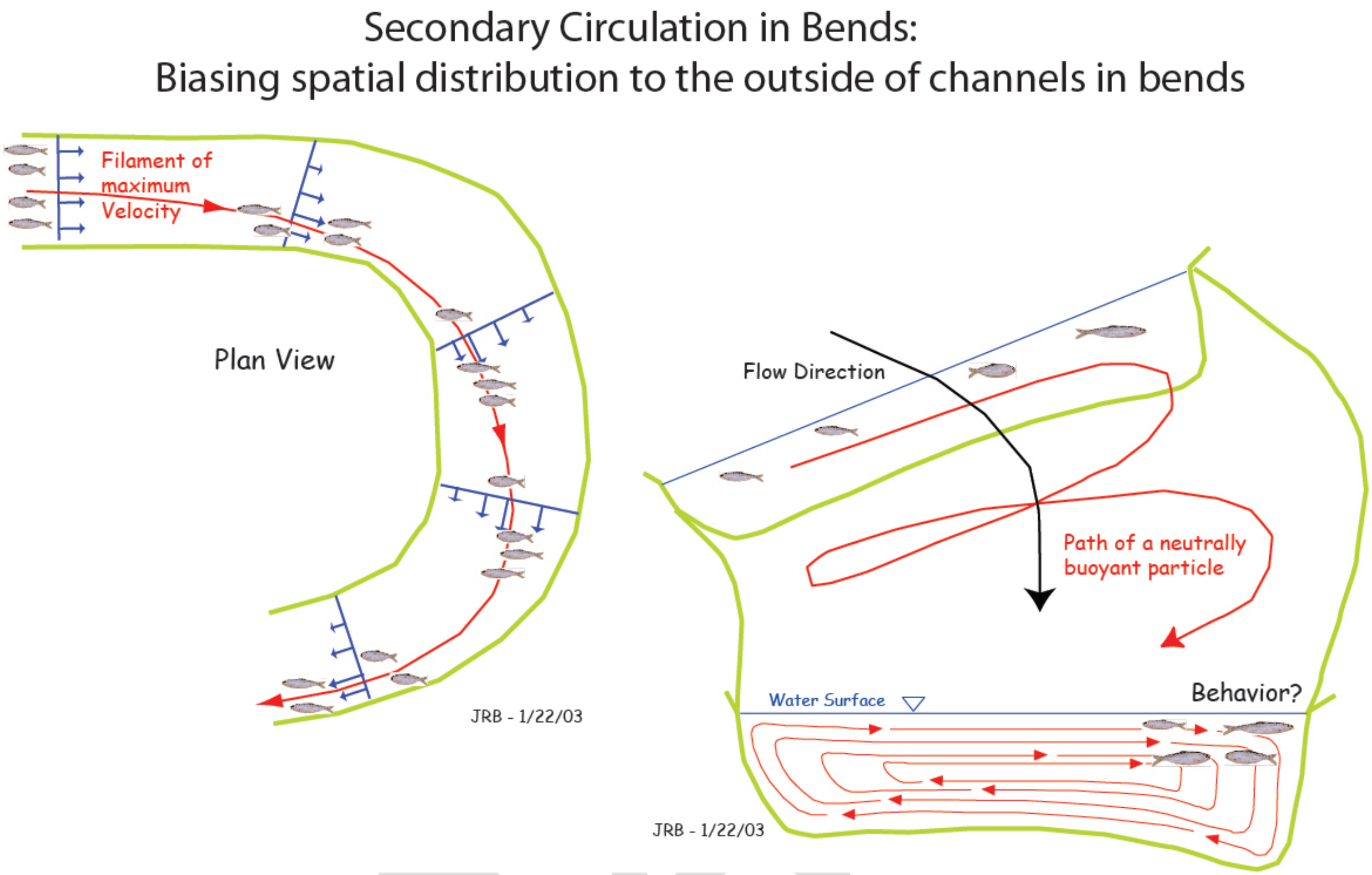

Figure 4 - Conceptual model of secondary circulation biasing the fish spatial distribution towards the outside of a bend, (left) top view, (right) cross sectional view. Secondary circulation is created when along channel momentum is exchanged for cross channel momentum as water moves around a bend. This circulation is characterized by enhanced cross-channel surface currents toward the outside of the bend, down-welling at the outside of the bend and return currents toward the inside of the bend at the bottom. The path that a neutrally buoyant particle without behavior would take resembles a corkscrew. Thus, for fish to accumulate on the outside of the bend, as is shown, they must slightly swim toward the surface.

River Stages during the 2D study period

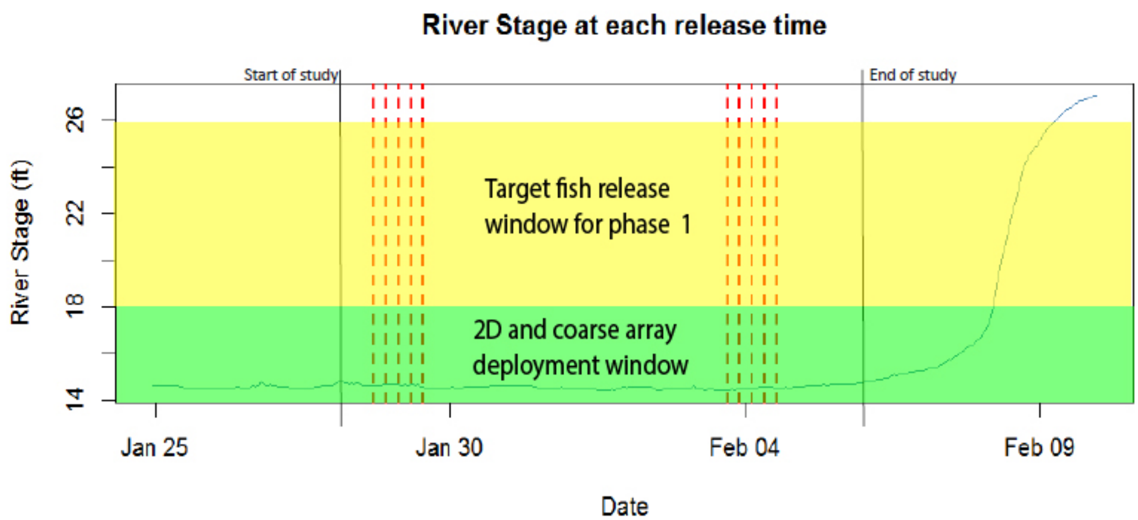

Figure 5 - Time series of water surface elevation (stage) at the Fremont Weir collected during the 2015 2D study. Vertical red dashed line indicates the two periods when fish were released.

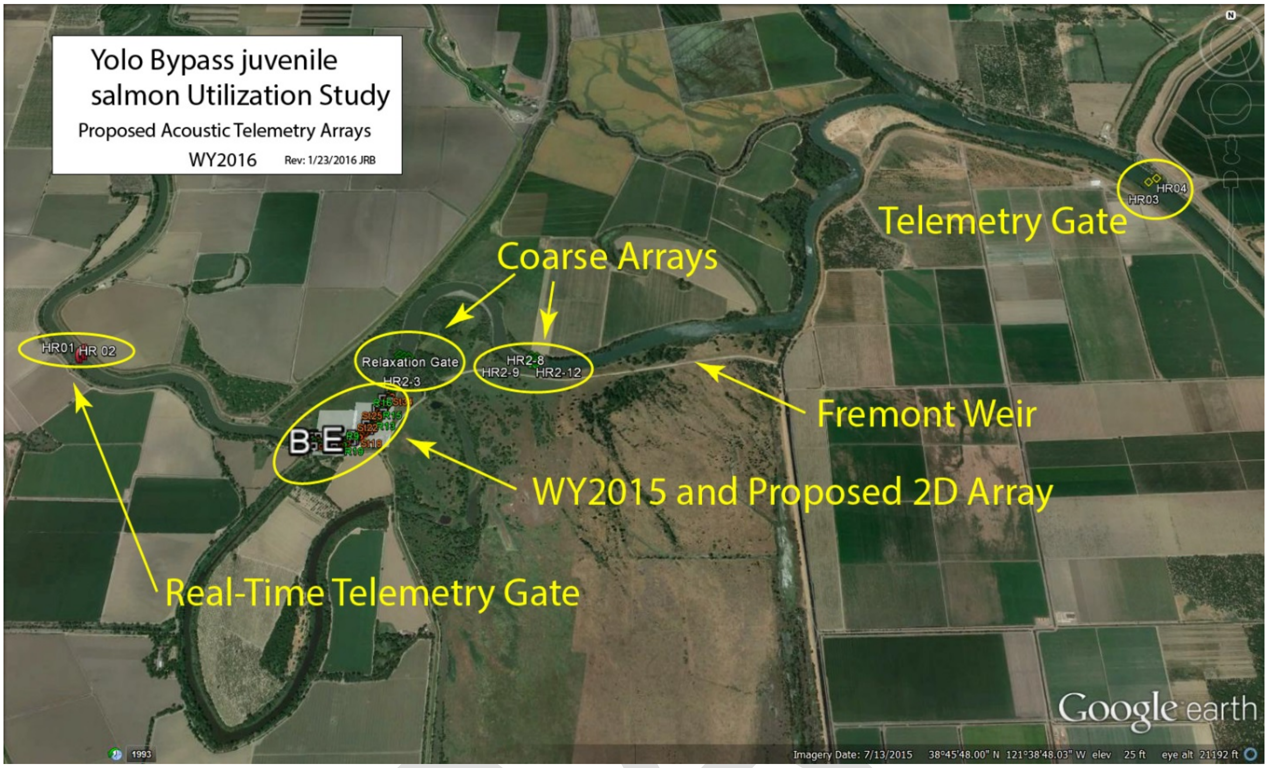

Figure 6 - Aerial view of the Fremont Weir with the bordering Sacramento River to the north of the weir. This image shows the location of: (a) a realtime telemetry gates and (b) the proposed 2D-array in the bend upstream of the Fremont Weir, (c) two proposed Coarse Arrays, and (c) a downstream telemetry gate near Verona. (See YBUS.deployment.plan.xx/xx/2016.kmz for details, where xx/xx/2016 is latest version).

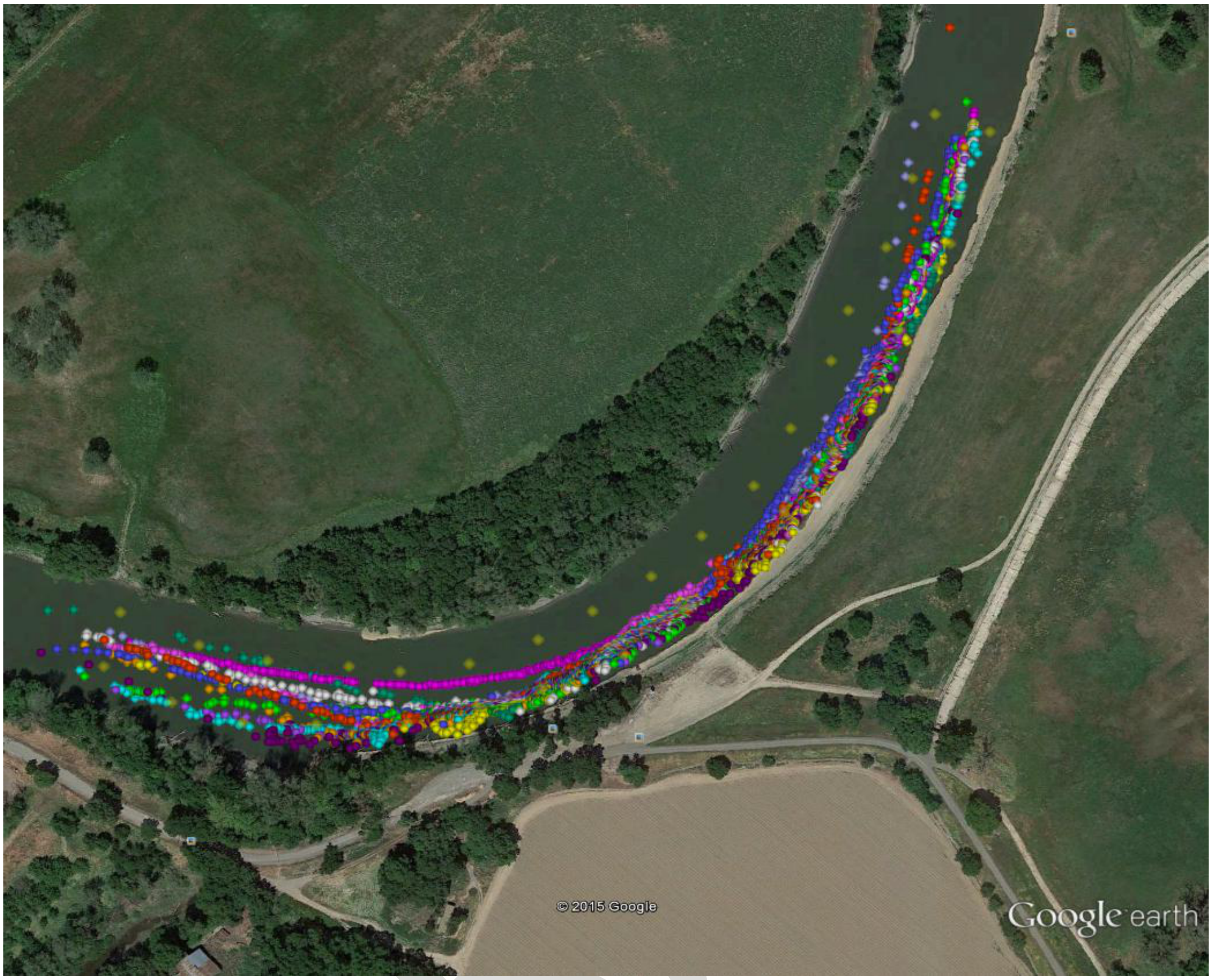

Figure 7 - Tracks of roughly a dozen tagged fish within the acoustic telemetry array from the first release (January 28-29, 2015).

Aggregate of fish spatial distribution (2D)

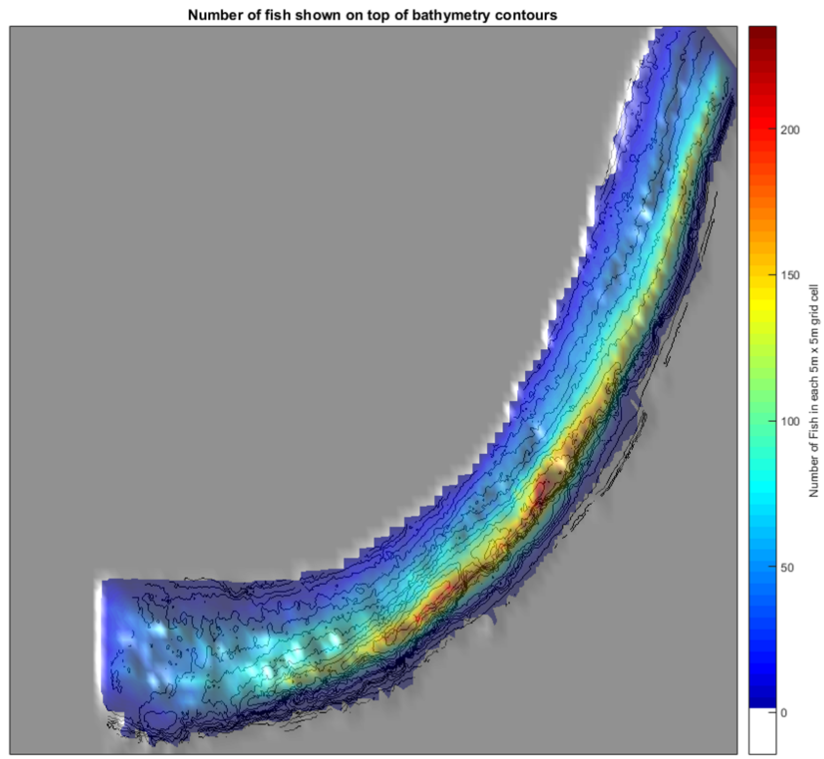

Figure 8 - Color plot of fish spatial distribution (2D) based all tracks from both releases (~ 500 tracks) overlaid on bathymetry contours where the color is scaled to the number of fish traversing each cell (see appendix A for details).

Aggregate of fish spatial distribution (3D)

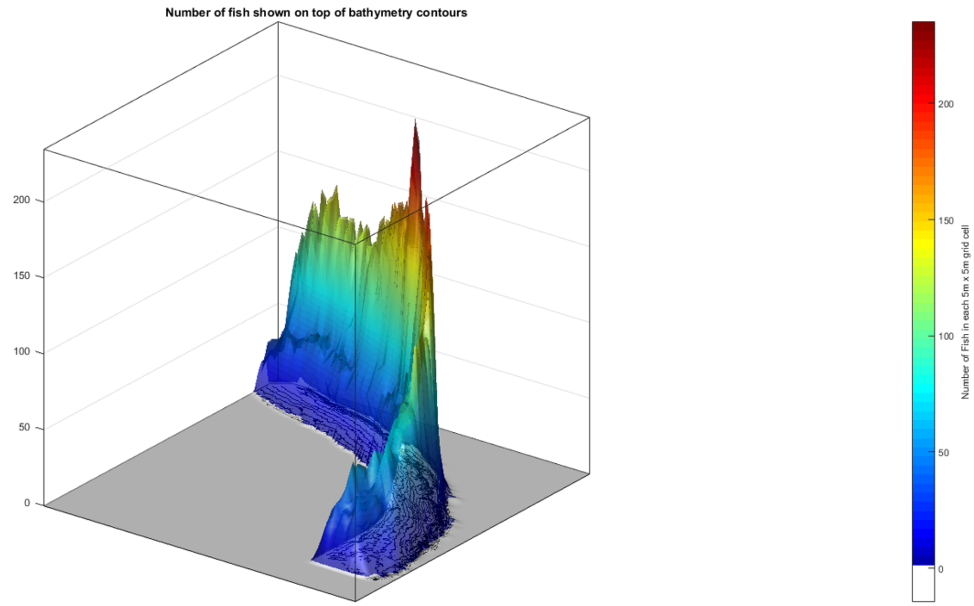

Figure 9 - Color plot of fish spatial distribution (3D) based all tracks from both releases (~ 500 tracks) where the vertical dimension and the color is scaled to the number of fish traversing each cell (see appendix A for details).

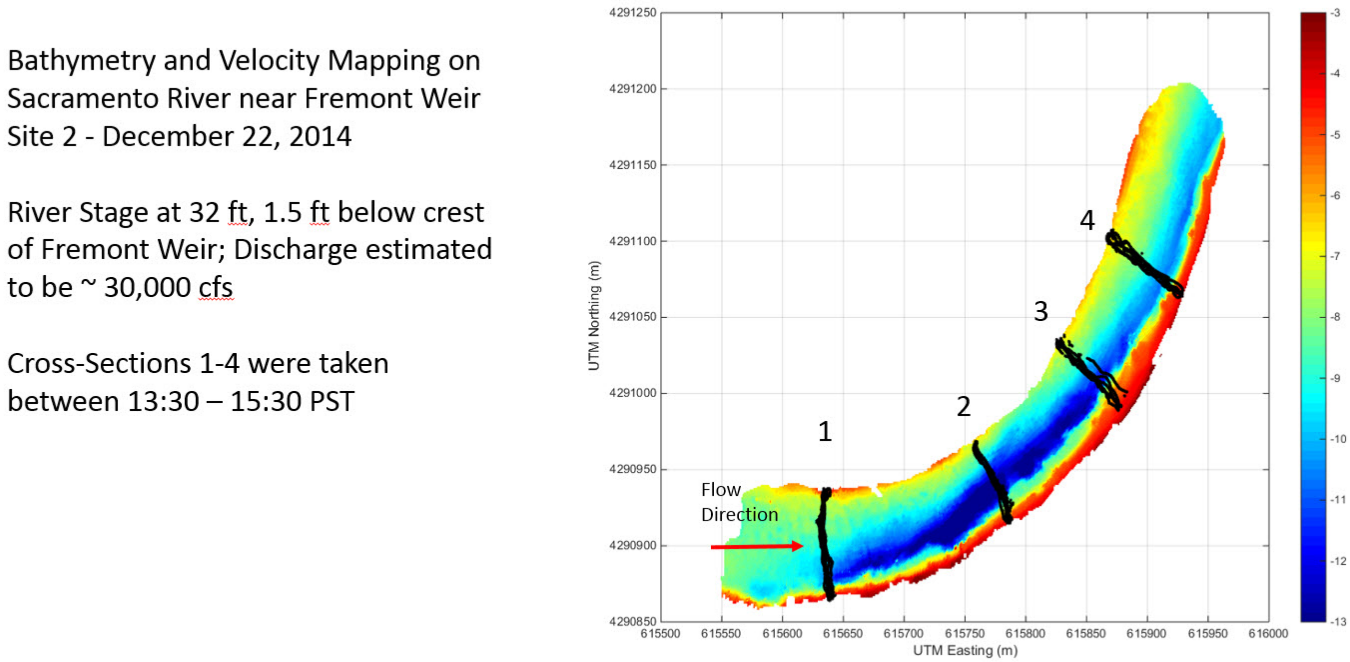

Figure 10 - Color plot of bathymetry in the bend with the transect locations for boat-based measurement of velocities with downward-looking ADCPs indicated by the black lines.

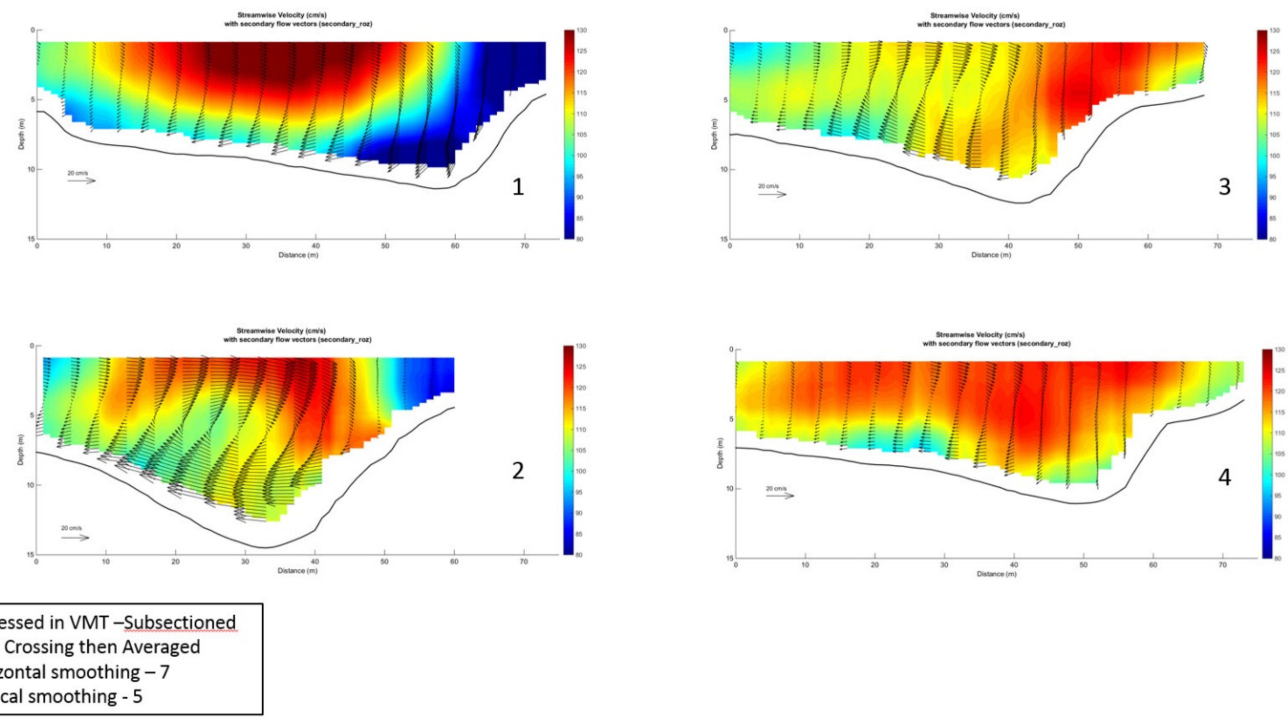

Figure 11 - Cross channel velocity distributions are shown by the arrows (length proportional to the speed) at the numbered cross sections in the previous figure. The strength of the along-channel speed is proportional to the color – red is fast blue is zero. As predicted by theory, the strength of the gravitational circulation is zero at it enters the bend, strengthens to its maximum strength in the apex of the bend and then weakens as water exits the bend.

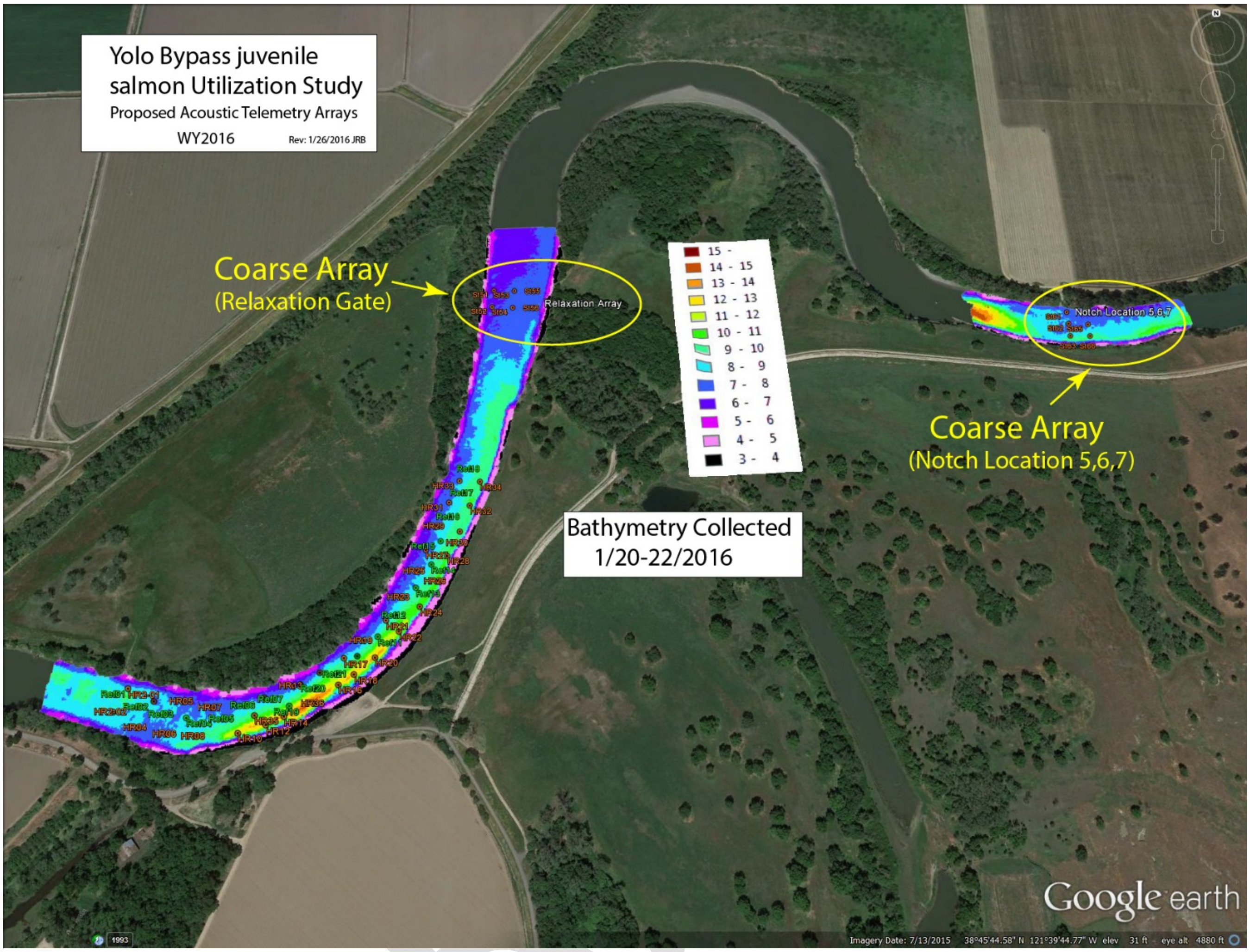

Figure 12 - Aerial view of the Sacramento River upstream of the Fremont Weir and the locations of receivers in the proposed 2D acoustic telemetry array, which included 44 receivers, 80 transmitters. The array was roughly 220ft wide, 2590 ft long. The proposed coarse arrays aimed at studying the relaxation of the fish spatial distribution exiting a bend and at notch locations 5,6,7 are also shown. (see YBUS.deployment.plan.x/xx/2016.kmz for details, where x/xx/2016 is latest version).

Id	Configuration	Invert (ft.)	Sides	Flow (cfs)
1	East Fremont Weir (FRE) Shelf	14	10:1	6000
2	East FRE Intake	14	3:1	6000
3	FRE Fish Ladder Shelf	14	10:1	6000
4	FRE Fish Ladder Intake	14	3:1	6000
5	Central FRE Shelf	14	10:1	6000
6	Central FRE Intake	14	3:1	6000
7	Central FRE Intake	14	10:1	6000
8	West of FRE Shelf	14	10:1	6000
9	West of FRE Intake	14	3:1	6000
10	Elkhorn Shelf	14	10:1	6000
11	Elkhorn Intake	14	3:1	6000
12	FRE Fish Ladder	22	3:1	1000
13	FRE Fish Ladder	22	10:1	1000
14	East FRE Shelf	17	10:1	3000
	Notes:			
	Shelf configuration is diagonal orientation to river with larger footprint			
	Intake configuration is perpendicular to river with smaller footprint			

Figure 13 - Location of the Fremont Weir notch alternatives that are currently being modeled in ELAM. These notch alternative locations were considered for the placement of a coarse telemetry array aimed at documenting baseline spatial distributions at these locations. Figure prepared by Joshua Urias (DWR) on 12/18/15 for Jon Burau (USGS).

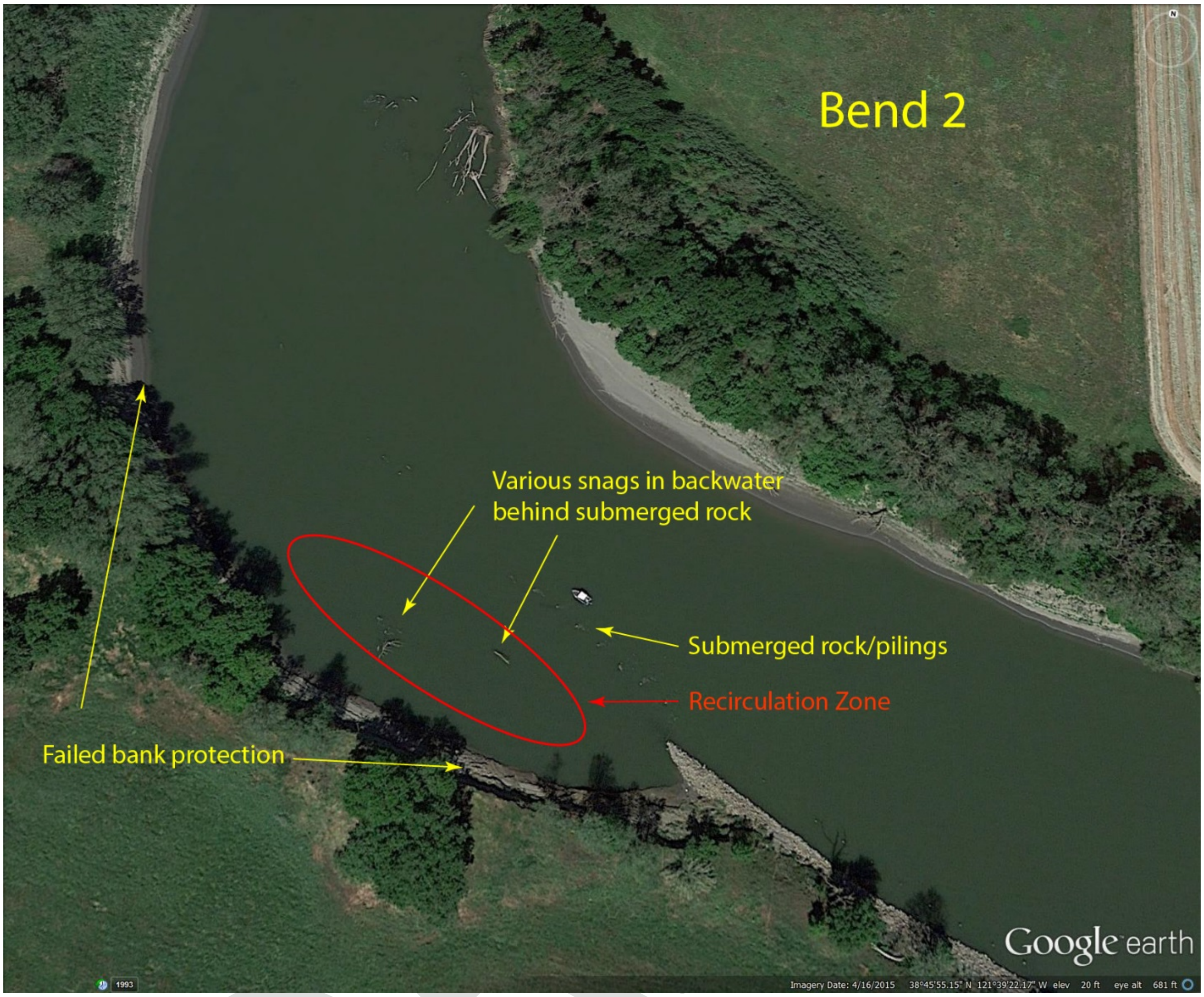

Figure 14 – Areal view of bend #2 showing the failed bank protection, the location of submerged rocks, pilings and snags captured within a recirculation zone that exists shoreward of the rock pile.

Figure 15 – Photograph of bend #2 taken from the outside of the bend where the bank protection failed looing northeast.

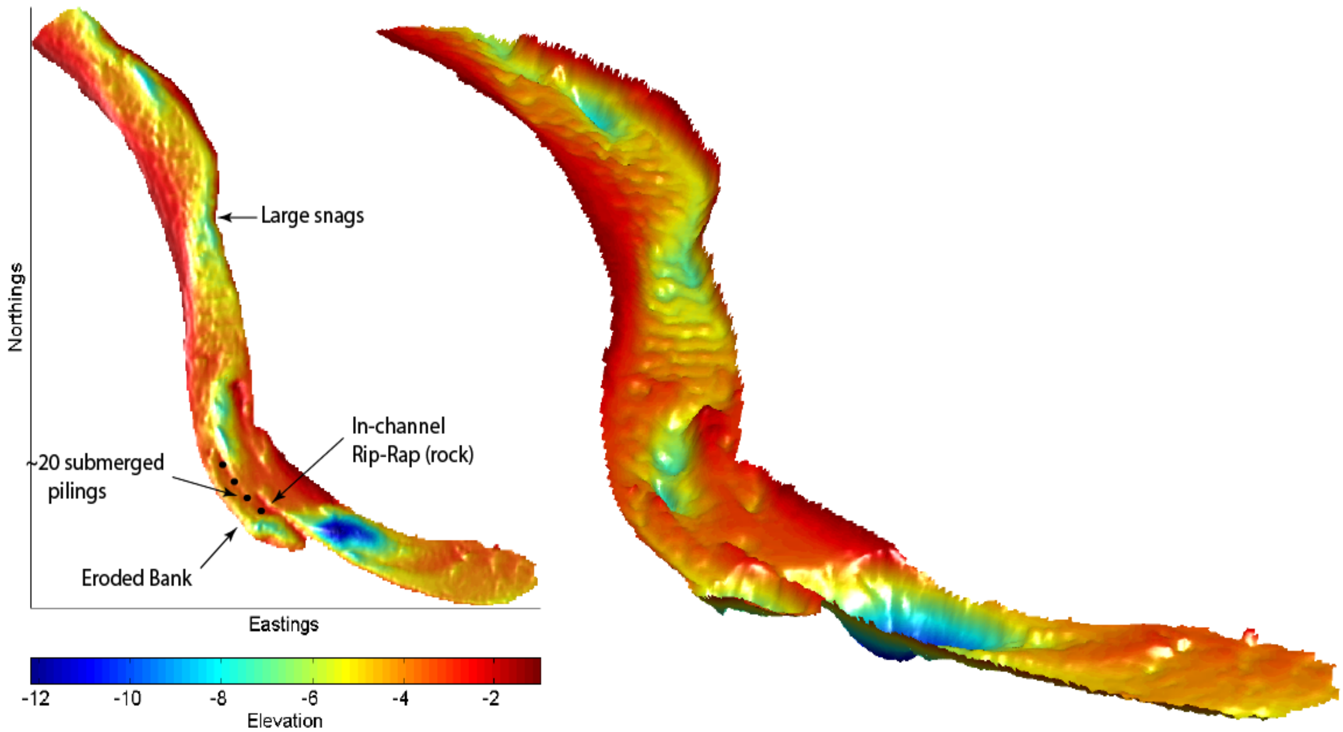

Figure 16 - Bathymetry at the coarse array at notch 5,6,7 (data in meters). Survey dates: 11/24-25/2014. Collected by USGS (Chris Vallee, Norbert Vandenbranden), Survey based on ADCP data.

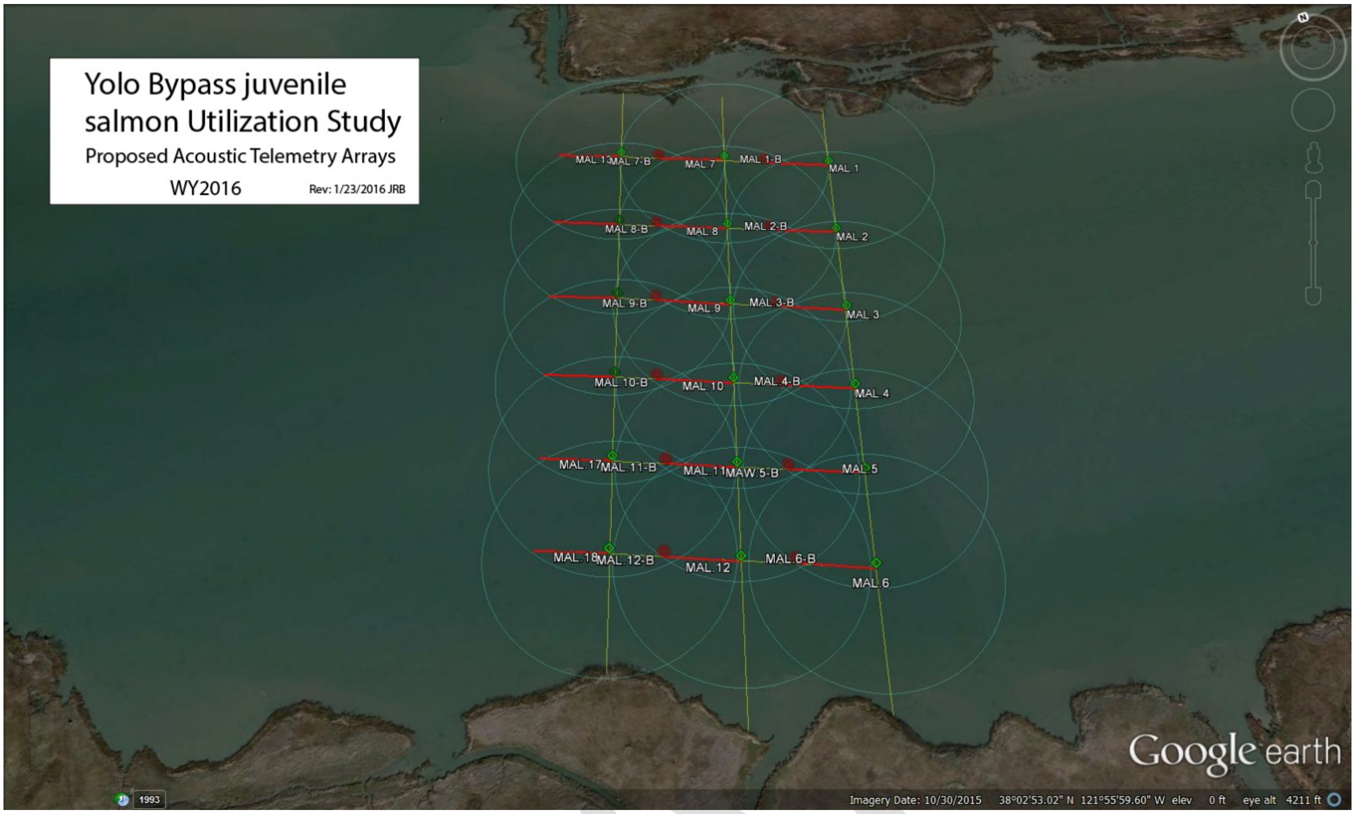

Figure 17 - Chipps Island telemetry array, funded by the USBR's 6-year study.

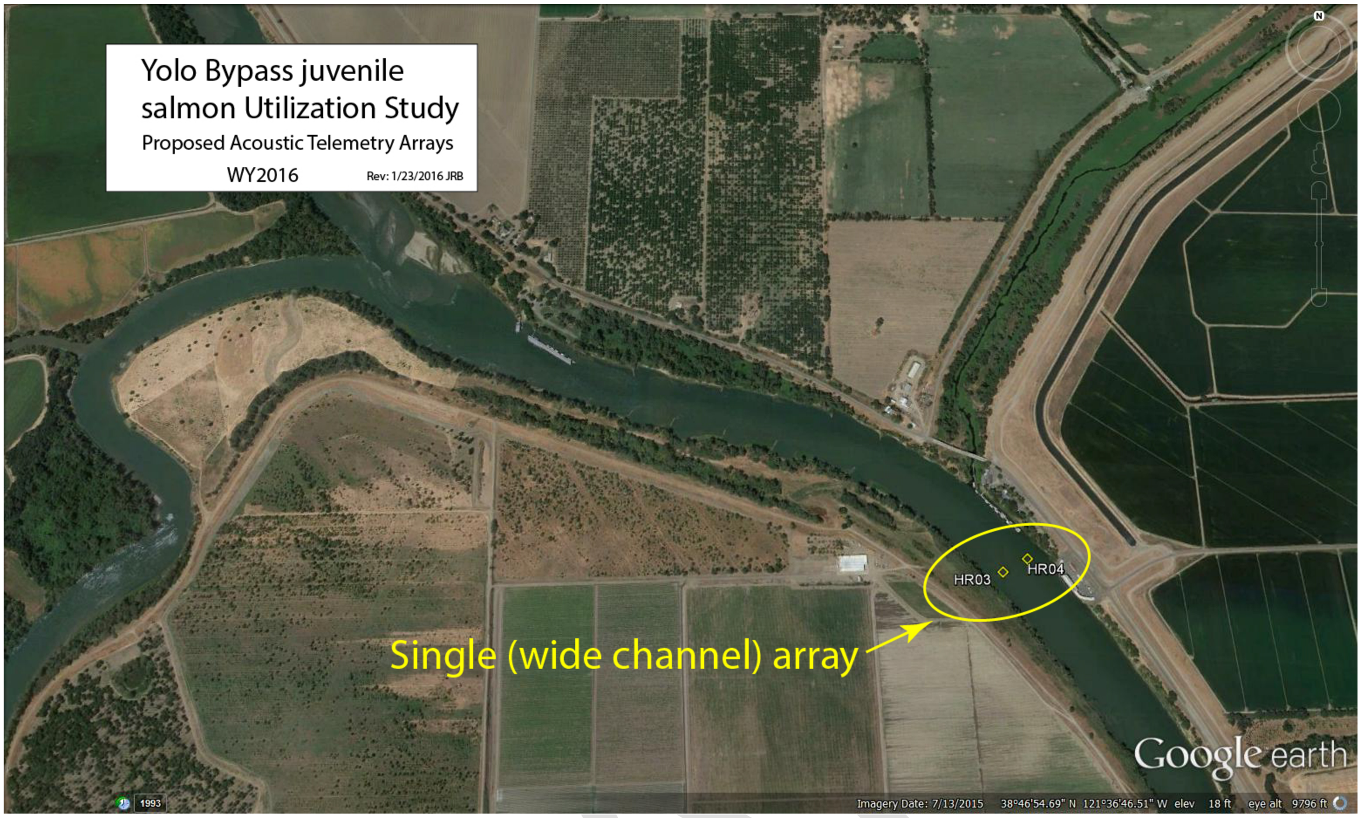

Figure 18 - Example telemetry gate for a wide channel, in this case the Sacramento River at Verona. Two receivers deployed across the channel to make sure there is adequate cross-channel coverage. (see YBUS.deployment.plan.x/xx/2016.kmz for details, where x/xx/2016 is latest version).

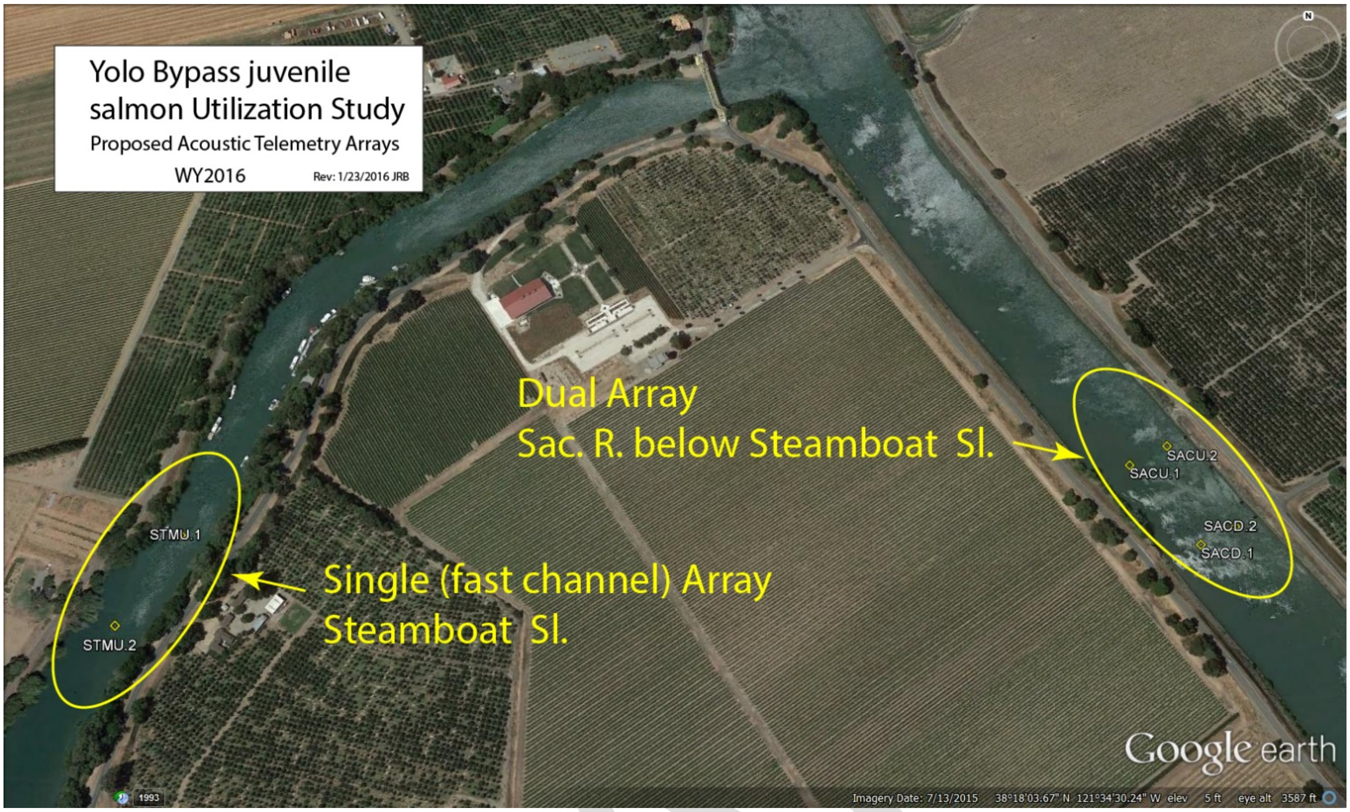

Figure 19 - Example telemetry gate for a fast channel (Sutter and Steamboat Sloughs) and dual array (Sacramento River downstream of Steamboat Slough). Receivers are deployed along the river channel to make sure these telemetry gates can hear fast moving tags. During high flows the velocities in these locations can reach nearly 5 ft/s. In the case of the Sacramento River downstream of Steamboat Slough, four receivers are deployed because it is wide and the currents are fast in this location. (see YBUS.deployment.plan.x/xx/2016.kmz for details, where x/xx/2016 is latest version).

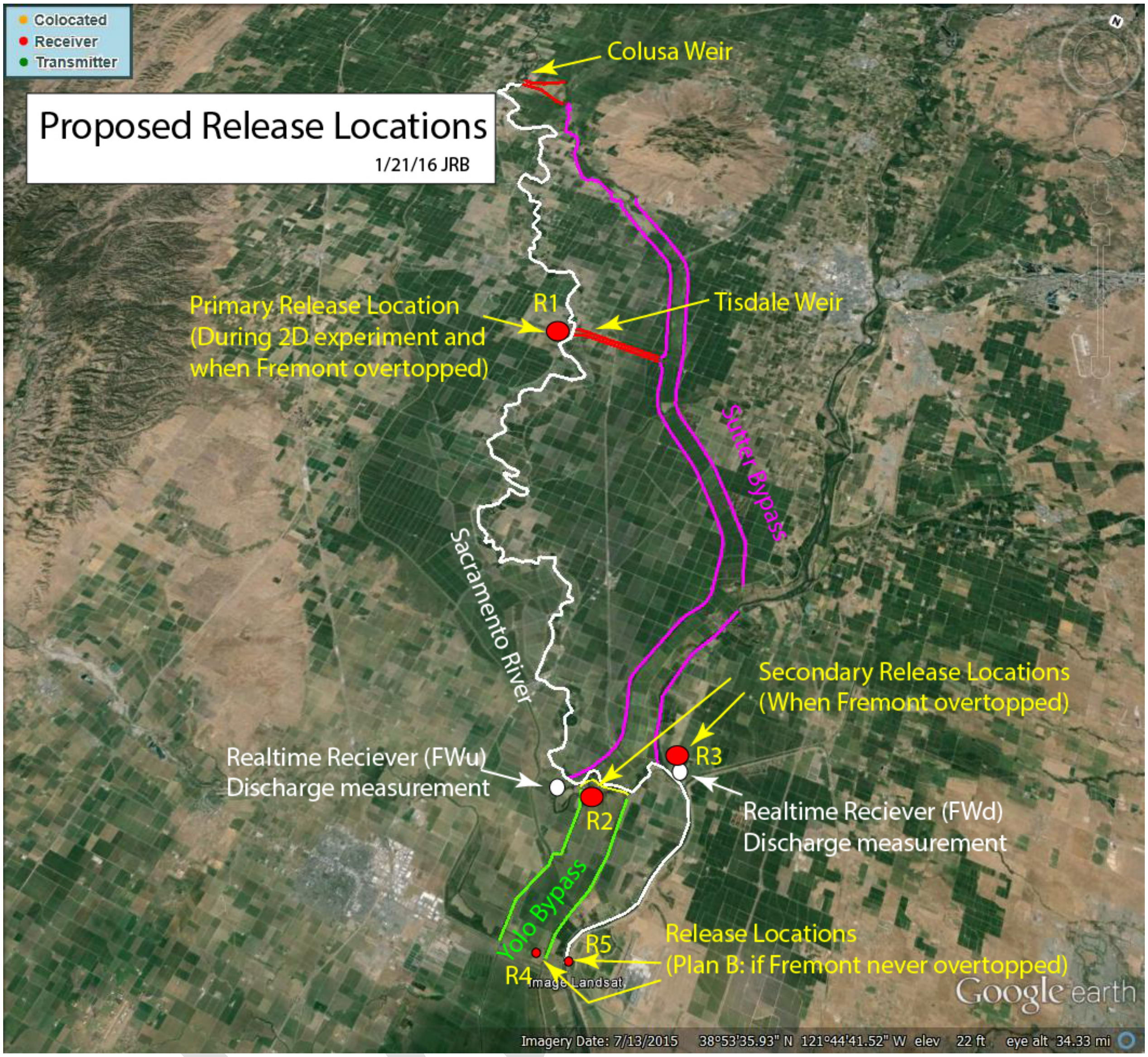

Figure 20 - Aerial photo showing Sutter Bypass (magenta), Tisdale (red, south) and Colusa (red, north) Weir's, the Sacramento River (white) and northern end of the Yolo Bypass (green). Primary and secondary release locations, R1 and R2, respectively are shown by the red dots. If the Fremont Weir does not overtop paired releases in the Yolo Bypass and Sacramento River (R3 and R4, respectively) will be made to compare survival in the Bypass relative to the Sacramento River under low flow conditions, subject to the adaptive management team concurrence.

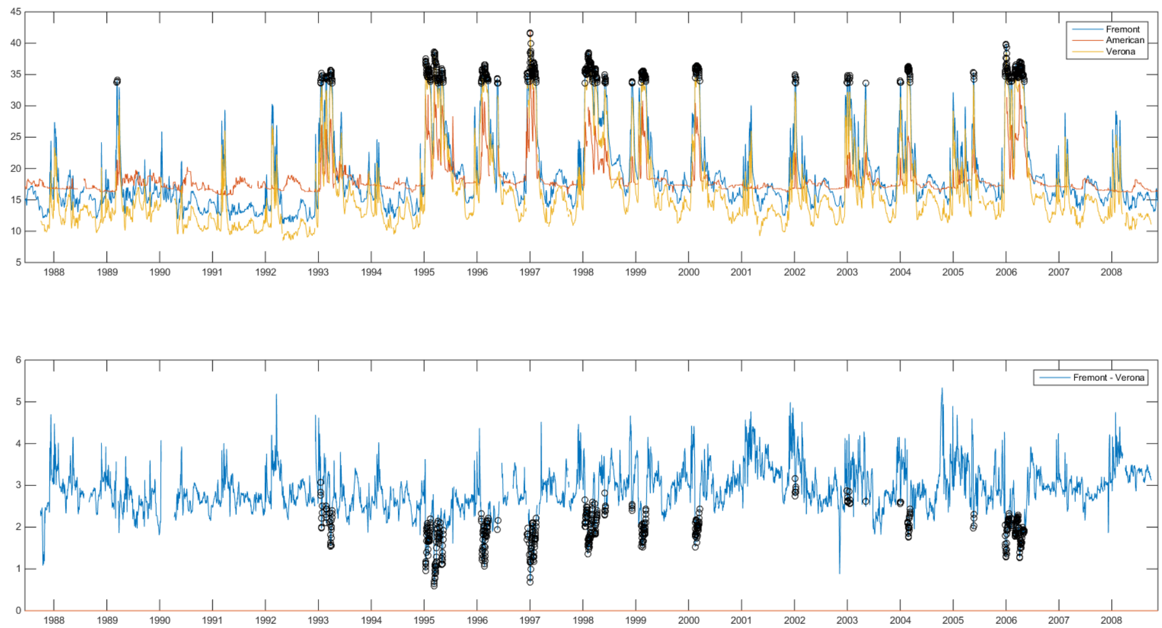

Figure 21 - Time series of stage is the Sacramento River at (top panel) the Fremont Weir (cyan), Verona (yellow), American River (at H St bridge – 10 km (6.3mi) upstream from the confluence with the Sacramento River) for a period of record. In the bottom panel the difference in stage between the Fremont Weir and Verona is plotted. Periods when the Fremont Weir Crests are indicated by the black circles.

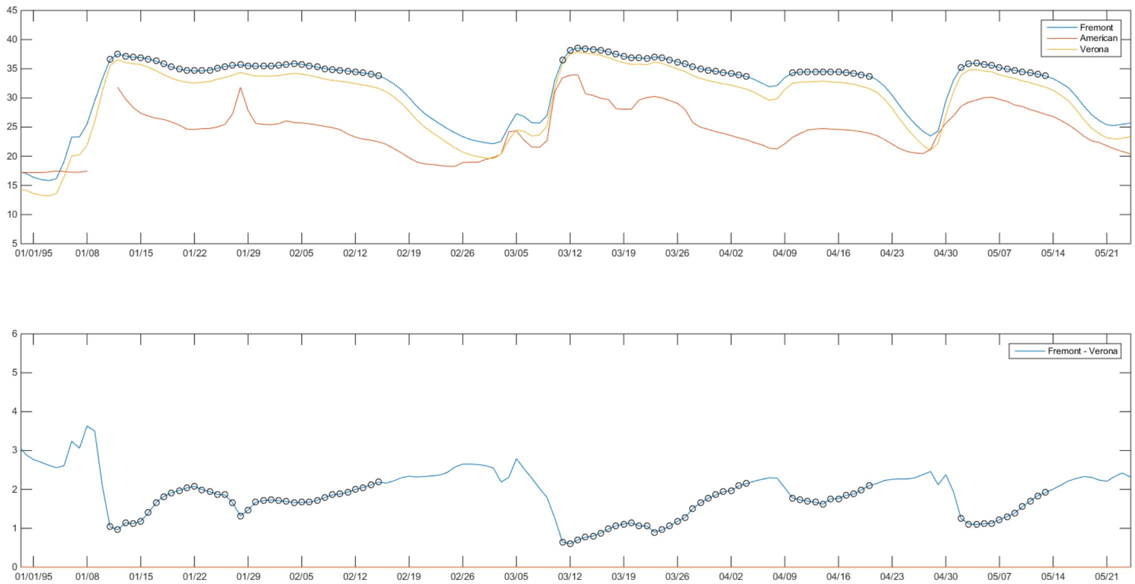

Figure 22 - Time series of stage is the Sacramento River at (top panel) the Fremont Weir (cyan), Verona (yellow), American River (at H St bridge – 10 km (6.3mi) upstream from the confluence with the Sacramento River) for a period of record. In the bottom panel the difference in stage between the Fremont Weir and Verona is plotted. Periods when the Fremont Weir Crests are indicated by the black circles.

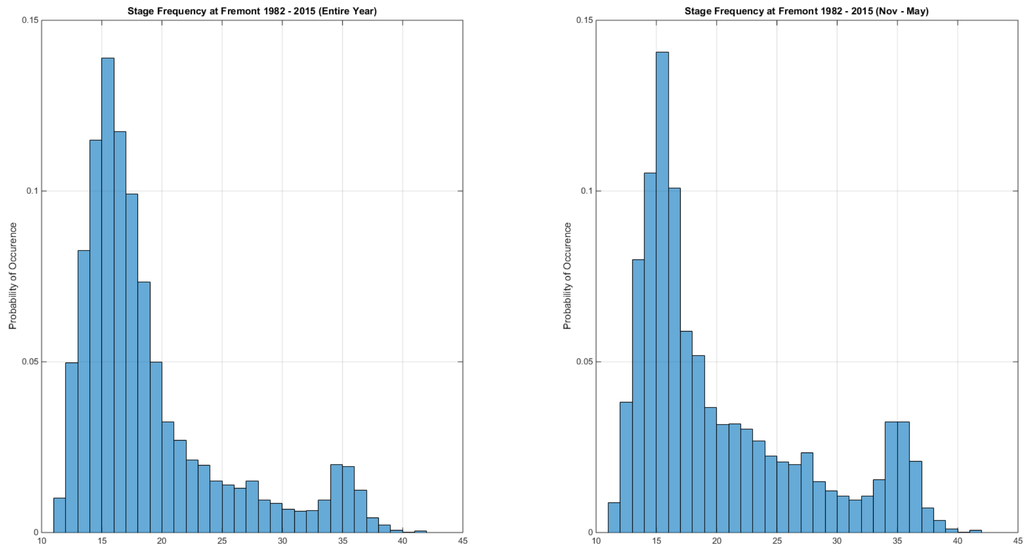

Figure 23- Probability Density Function (PDF) for stage at the Fremont Weir for (left panel) the entire year, (right panel) the salmon outmigration period of Nov-May).

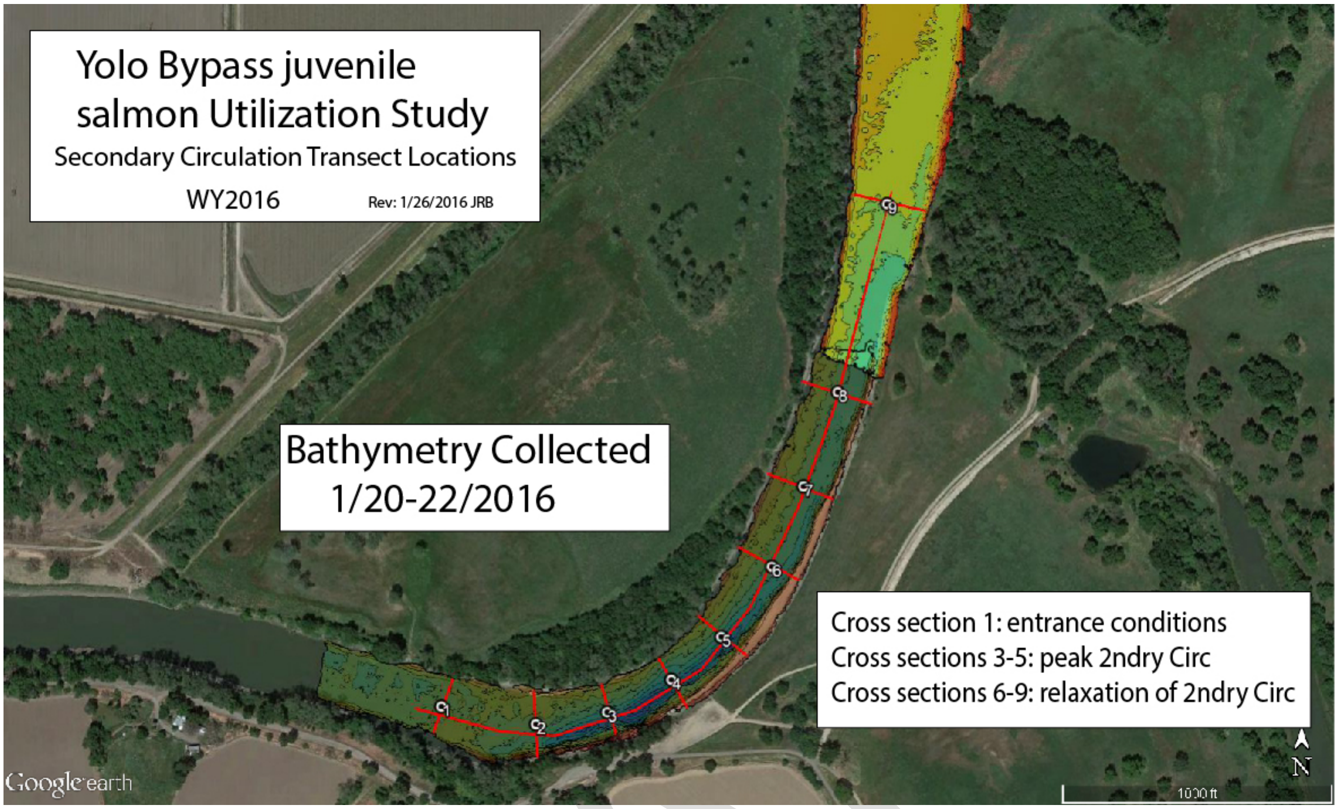

Figure 24 - Location of the proposed 2016 study secondary circulation transect locations indicated by the red lines. Three additional transect locations are proposed to document the transverse currents up and downstream of the bend. Theory suggests that the transverse currents will be weak entering the bend and will trend toward zero as the water leaves the bend. The additional transect locations are aimed at documenting this evolution of the secondary currents: cross section 1: entrance conditions; cross sections 2-4, peak secondary circulation; cross sections 5-7 relaxation of secondary circulation.

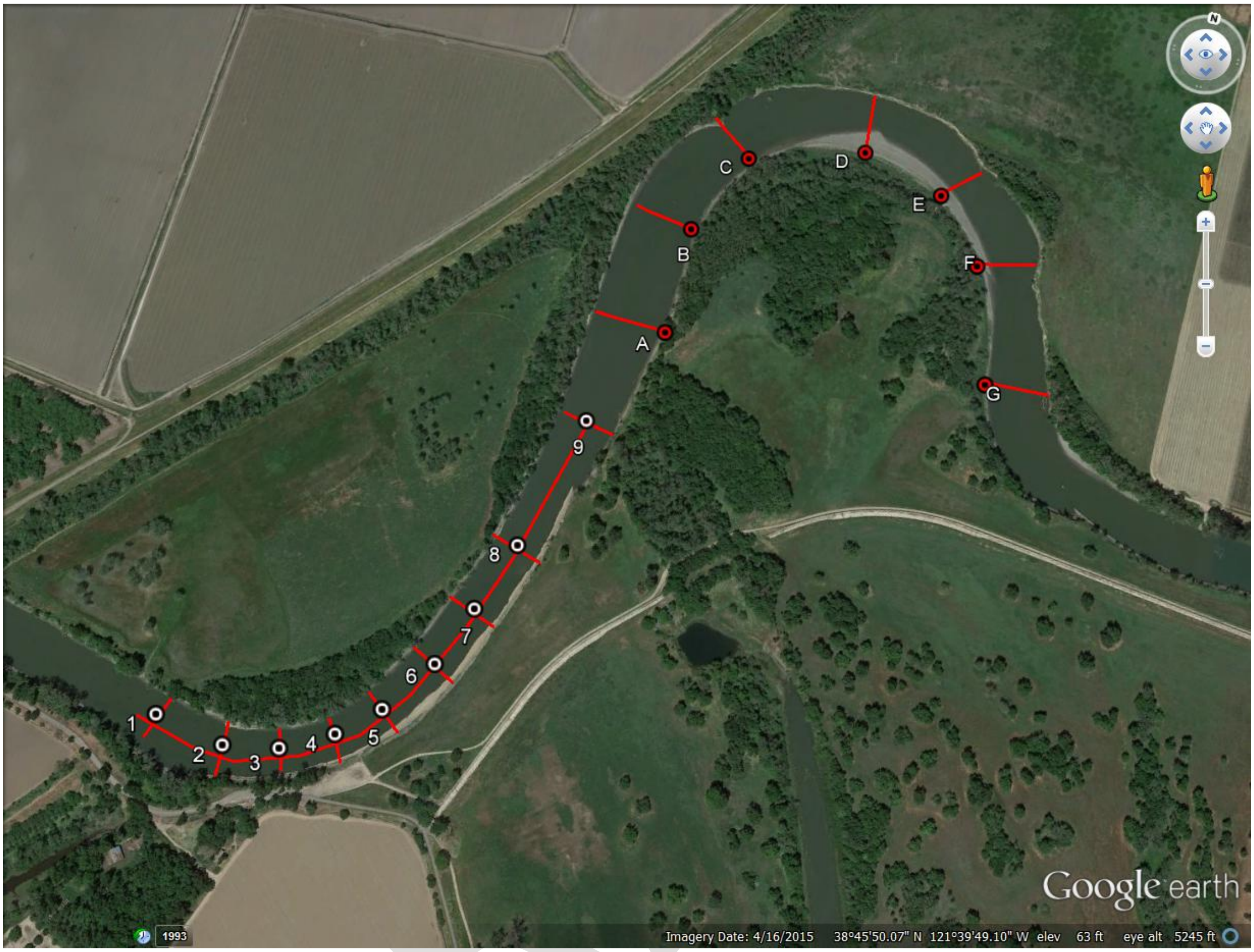

Figure 25 - Location of the proposed 2016 study secondary circulation transect locations (transects 1-6) associated with the 2D-array. Collecting secondary circulation in the 180 degree oxbow at transects A-G are also proposed, if time allows. Understanding the transition of secondary circulation from a 90 deg bend (transects 1-7) immediately into the 180 deg bend will be useful in determining the spatial scales of secondary circulation initiation, peak and relaxation and as a validation data set for numerical models of the region.

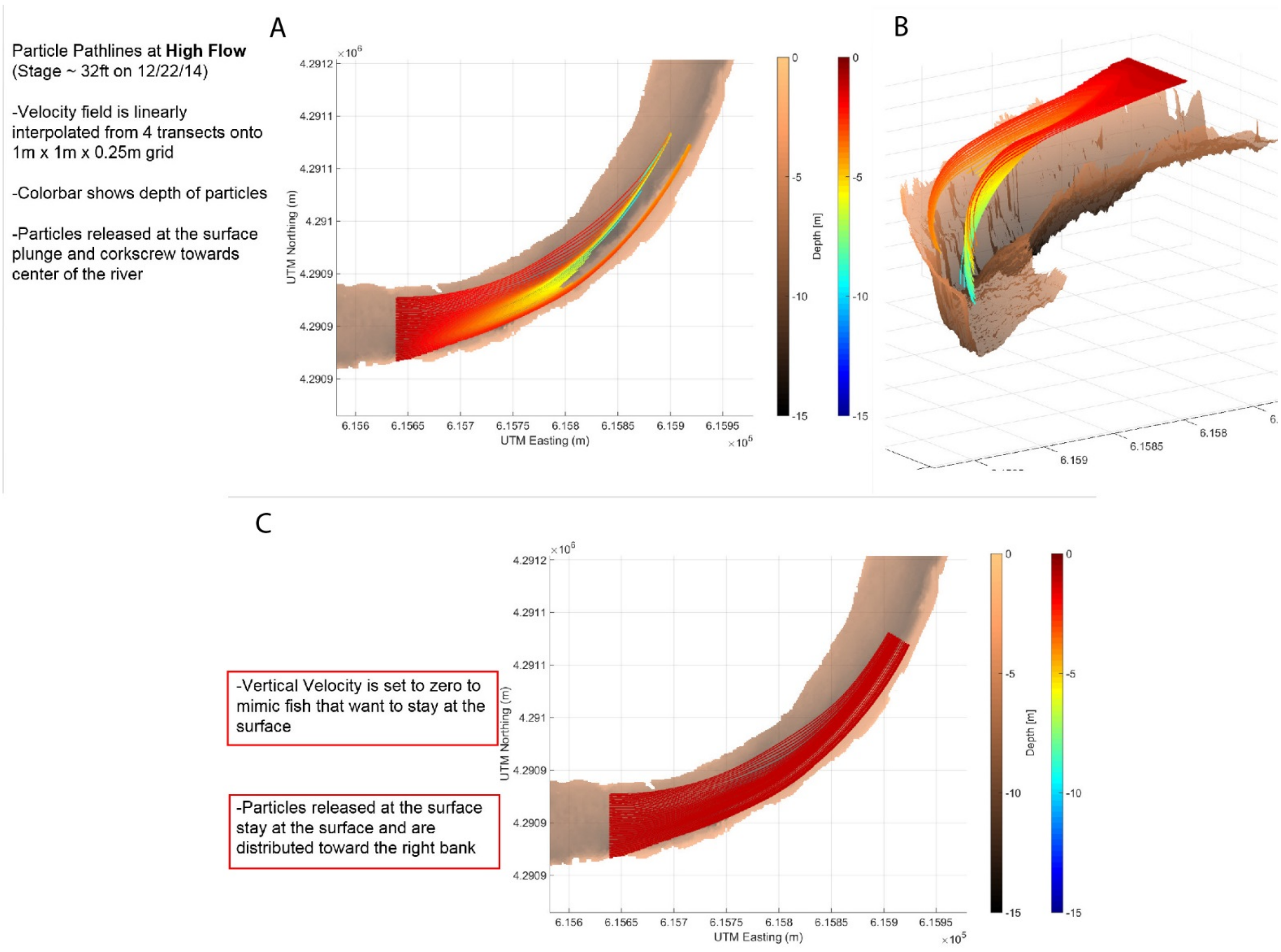

Figure 26 - Particle pathlines for a linearly interpolated flow field in a bend in the Sacramento River immediately upstream of the Fremont Weir at a stage of 32 feet – high flow. Panel A and B show the paths particles take when subject to the full 3D flow field. Whereas panel C shows the particle distribution when the vertical velocity is set to zero to mimic a fish that wants to stay at the surface in the face of downwelling on the outside of the bend.

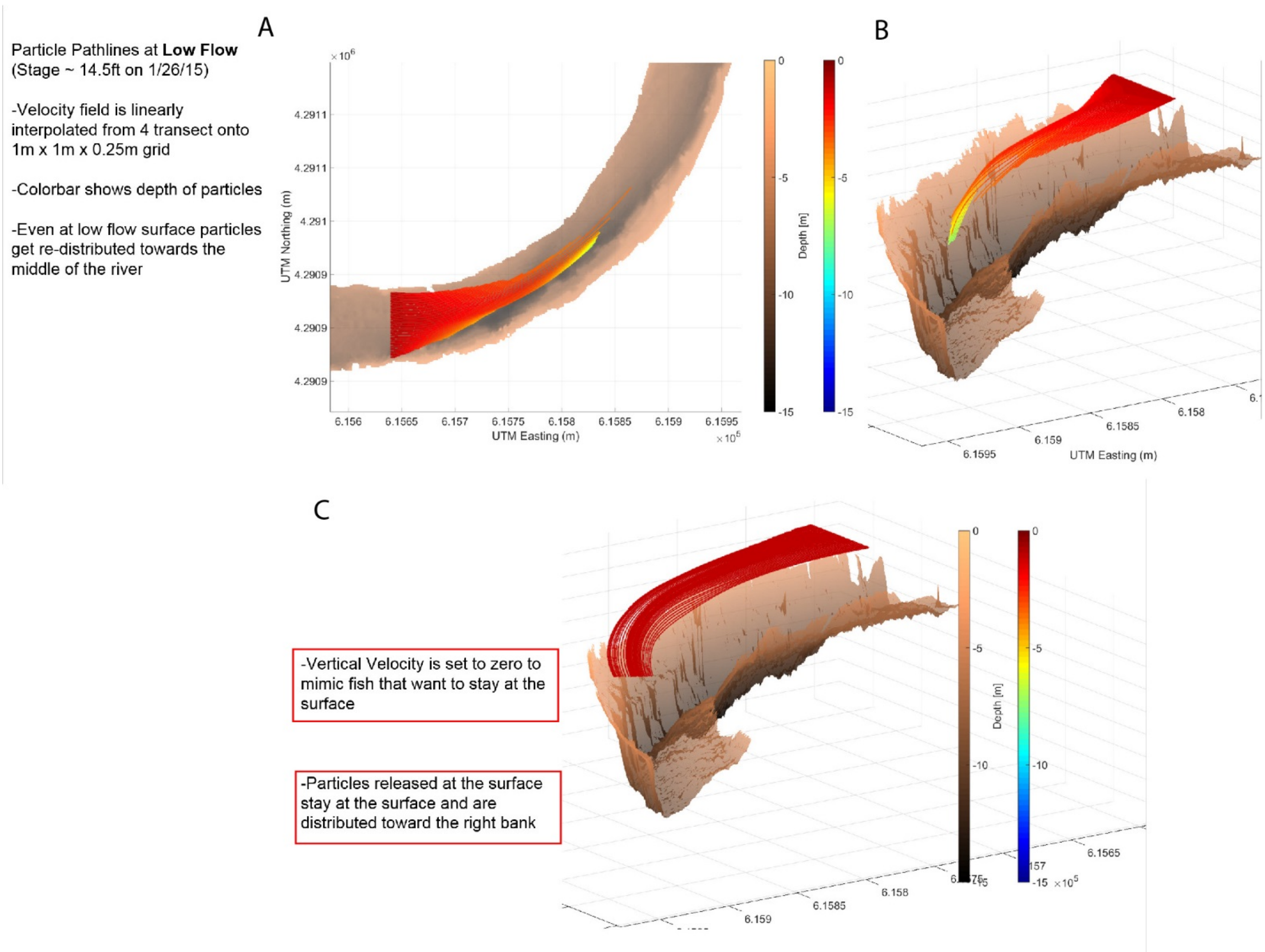

Figure 27 - Particle pathlines for a linearly interpolated flow field in a bend in the Sacramento River immediately upstream of the Fremont Weir at a stage of 14.5 feet – low flow (under the conditions the WY2015 study fish experienced). Panel A and B show the paths particles take when subject to the full 3D flow field. Whereas panel C shows the particle distribution when the vertical velocity is set to zero to mimic a fish that wants to stay at the surface in the face of downwelling on the outside of the bend.

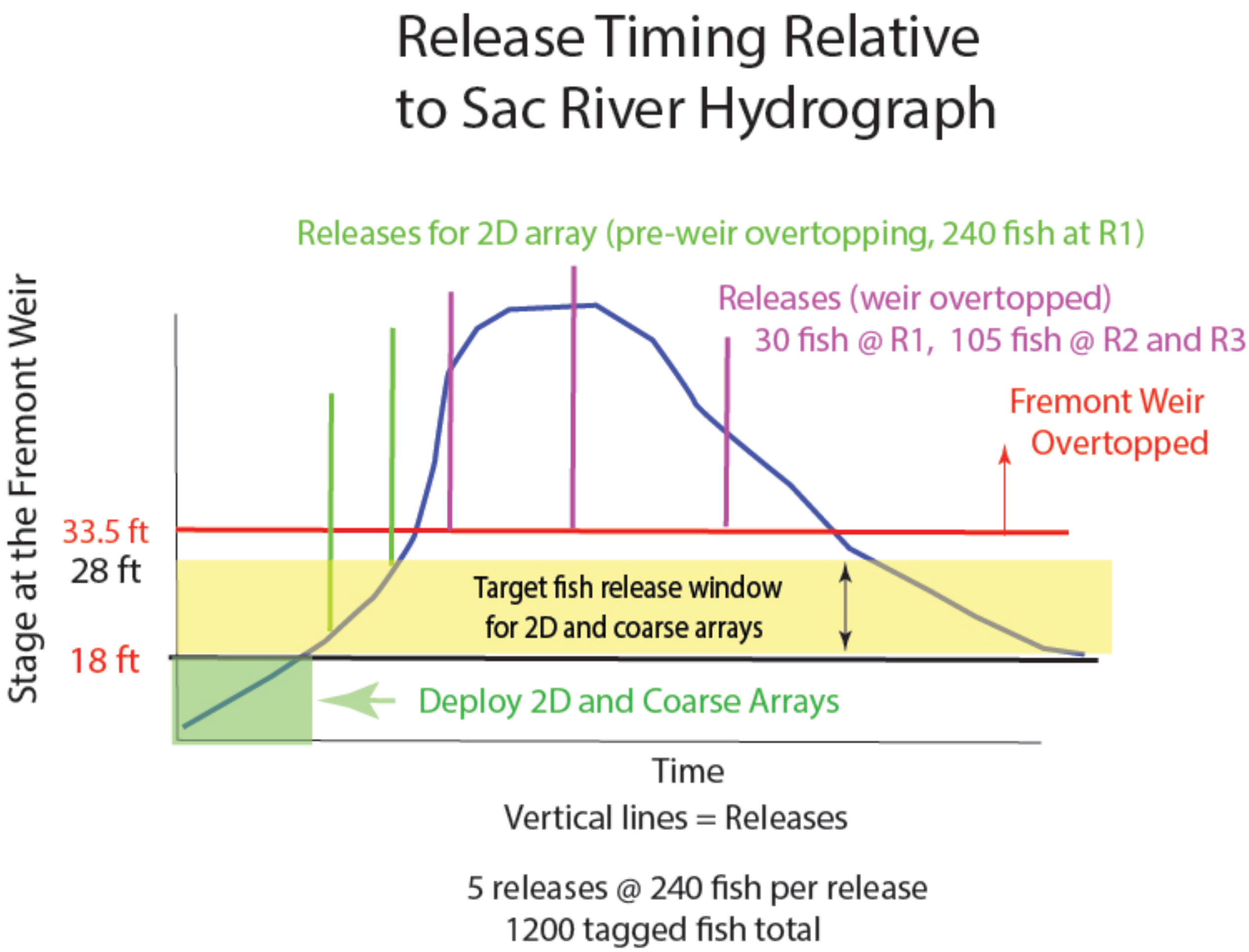

Figure 28 - Fish release strategy, assuming Fremont Weir is overtopped after the 2D and coarse arrays are successfully deployed, fish are released and the gear is recovered.

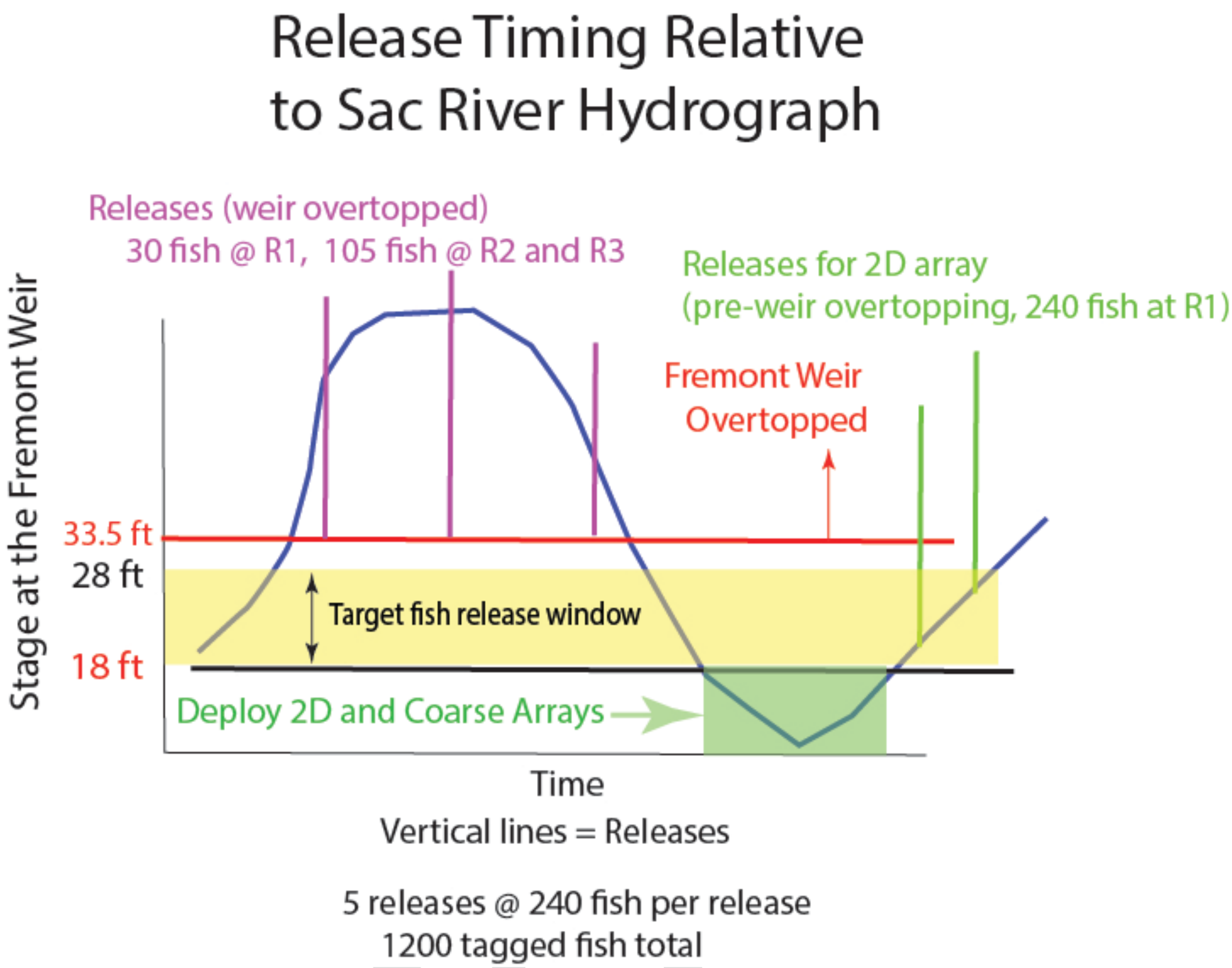

Figure 29 - Fish release strategy, assuming Fremont Weir is overtopped before the 2D and coarse arrays are successfully deployed, fish are released and the gear is recovered.

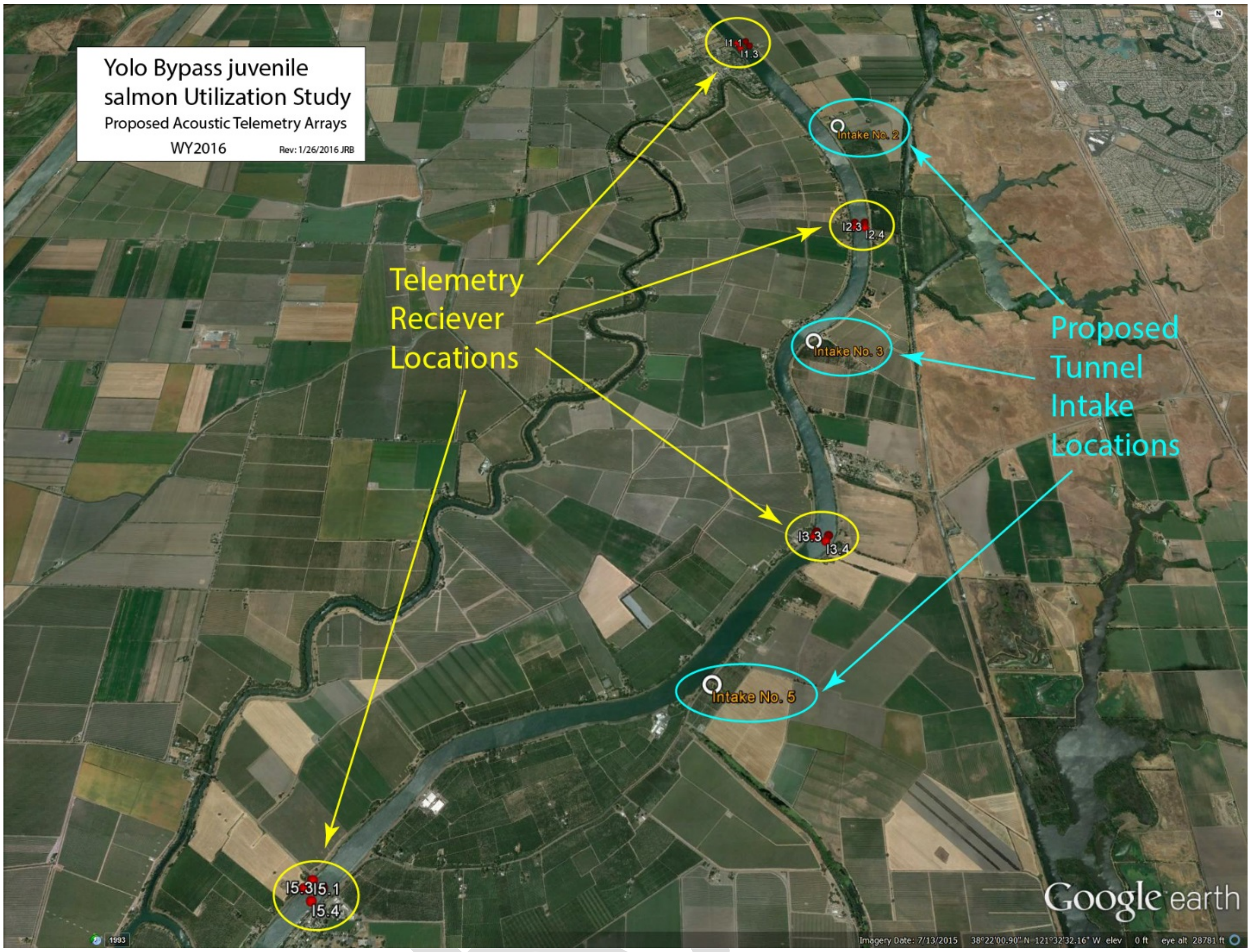

Figure 30 – Possible telemetry arrays deployed by the COE to collect baseline survival information near proposed Tunnel Intake locations. These arrays would be deployed, recovered and downloaded

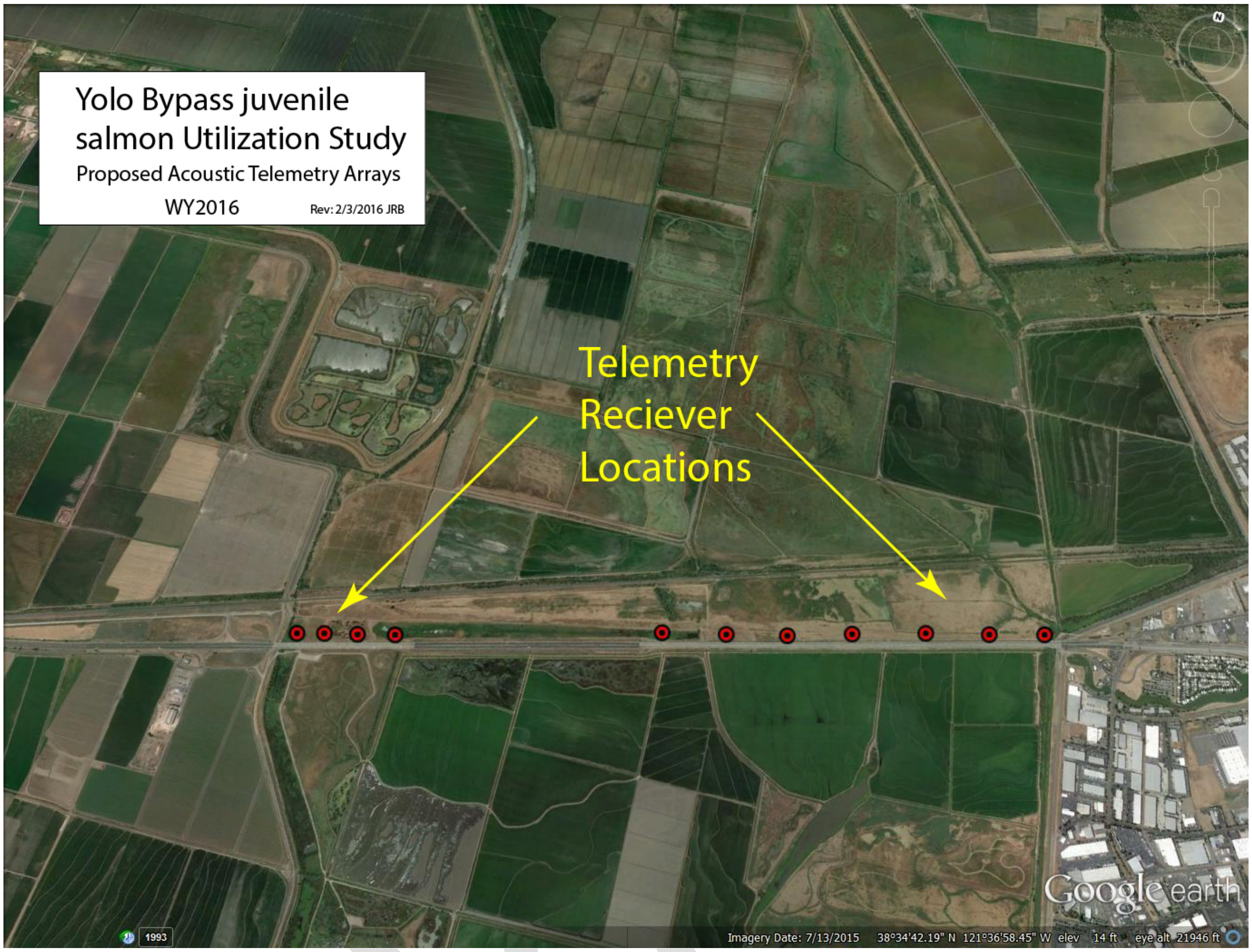

Figure 31 - Possible telemetry arrays deployed by the DWR south of I-80 to collect survival and spatial distribution information within the Yolo Bypass.

9 APPENDIX A – DESCRIPTION OF SPATIAL ANALYSIS

9.1 SPATIAL AGGREGATION/APPORTIONMENT

Software written by the USGS was used to extract spatial statistics from the group of tracks shown in Figure 8 and Figure 9. This process was performed in the following steps:

1. Bathymetric data was used to generate a 5 meter by 5 meter two dimensional grid of discrete cells within the junction area. Bathmetry data was used to classify each grid cell as dry (outside of the river banks), or wet (inside of the river banks). The grid used for this analysis is shown in Figure A1. A 5 meter grid size was chosen so that grid cells would be large enough to contain enough fish to compute entrainment rates for each covariate group, while maintaining enough grid cells in the study area to resolve spatial gradients in two dimensional statistics.

2. Linear interpolation was used to estimate a position at one second intervals for each fish track to ensure that at least one position would fall within each of the grid cells that the track passed through.

3. Each interpolated position was assigned to a grid cell, and the tag code and covariate information for the track was entered into a binary data structure for the grid cell. If that tag code had already passed through that grid cell, its information was not entered a second time. Each grid cell was limited to containing one record for each tag code in order to avoid auto-correlation errors and double counting errors. This limitation also reduced the bias introduced by resident predators, because a predator that spent weeks in the array would only be counted once in each grid cell it passed through.

4. Each interpolated point was assigned to a separate structure that kept track of the total amount of time each tag code spent in each cell. This information can be used to estimate residence time for covariate groups.

5. The above process was repeated for all tracks and the results were stored in a binary data structure that was used for the covariate aggregation. For this analysis all 539 VEMCO tracks were aggregated together without further separation by covariate groups

6. The software writes out a csv file defining the number of fish in every grid cell in the domain.

7. These output files are loaded into the Matlab data processing environment, and scripts written by the USGS are used to compute a variety of spatial statistics using this foundation data.

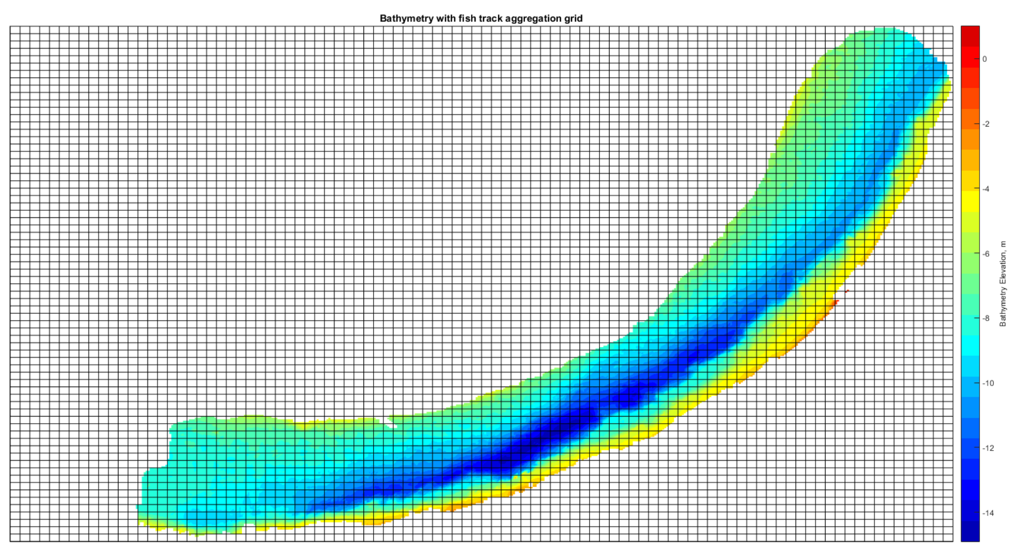

Figure A1 - Illustration of the 5m x 5m grid used for spatial apportionment in the junction area. During spatial apportionment, the covariate information from each fish track is assigned to each of the 5m x 5m grid cells that the track passes through. The tops of the levies and the outside edges of the levies were classified as dry, the inside edges of the levies were classified as wet.