Yolo Bypass Salmonid Habitat Restoration and Fish Passage Project Draft Science Work Plan

Introduction

The U.S. Bureau of Reclamation (Reclamation) and the California Department of Water Resources (DWR) are jointly planning the Yolo Bypass Salmonid Habitat Restoration and Fish Passage (YBSHRFP) Project (Project). The purpose of the Project is to comply with Reasonable and Prudent Alternative (RPA) actions I.6.1 and I.7 of the 2009 National Marine Fisheries Service (NMFS) Biological Opinion and Conference Opinion on the Long-Term Operations of the Central Valley Project and State Water Project (BiOp). RPA Action I.6.1 requires Reclamation and DWR to increase seasonal floodplain rearing habitat availability in the lower Sacramento River basin for juvenile salmonids. RPA Action I.7 requires Reclamation and DWR to improve fish passage in the Yolo Bypass by reducing migratory delays and loss of adult salmonids and sturgeon. To satisfy these RPA actions, the Project would involve construction of one or more gated diversion channels along the Fremont Weir of the Yolo Bypass. These gated diversion channels would be operated to divert flow from the Sacramento River into the Yolo Bypass to benefit anadromous fish species protected by the federal Endangered Species Act (ESA). The diverted flows would entrain a portion of outward-migrating juvenile salmonids from the Sacramento River onto the Yolo Bypass, allowing juveniles access to floodplain rearing habitat. These flows will also provide a deeper, more reliable connection to the river for upward-migrating adult salmonids and sturgeon that have entered the Yolo Bypass from the Cache Slough Complex (Figure 1), allowing fish passage over a broader range of hydraulic conditions.

Reclamation, as the Federal lead agency under the National Environmental Policy Act (NEPA), and DWR, as the State lead agency under the California Environmental Quality Act (CEQA), have prepared a joint Draft Environmental Impact Statement/Environmental Impact Report (EIS/EIR) to assess environmental impacts and benefits of the alternatives being considered for the Project. Reclamation and DWR formally began the planning of the Project in 2013 by issuing a Notice of Intent (NEPA) and a Notice of Preparation (CEQA) to prepare an EIS/EIR and hold public scoping meetings. A majority, if not all, of the analytical tools needed to evaluate the proposed Project did not exist in 2013. An extensive data and tool development process was undertaken by Reclamation and DWR to help develop and differentiate between Project alternatives. The Yolo Bypass Fisheries and Engineering Technical Team (FETT) was established in 2013 to develop and refine models and tools for evaluating habitat restoration and fish passage alternatives, to develop approaches to analyze Project-related impacts, and to provide technical guidance on proposals related to Yolo Bypass 2009 NMFS BiOp projects. In addition to Reclamation and DWR staff, the FETT consists of representatives from State and Federal agencies, and local governments.

In September 2017, newly-developed tools that had been developed with FETT input and utilized by the lead agencies in the evaluation of Draft EIS/EIR alternatives were peer-reviewed by the Delta Science Program's Independent Review Panel (Panel). The Panel's two main charges were to determine the appropriateness and effectiveness of the suite of tools developed for the Draft EIS/EIR. The Panel found the suite of tools to be appropriate for the questions being asked in the Draft EIS/EIR, and pointed out that the effectiveness of the tools at differentiating between alternatives varied and that major assumptions regarding inputs were made. However, the Panel determined that the assumptions were founded on sound professional and scientific judgement. The Panel concluded that the approaches taken and the suite of tools were appropriate to select a preferred alternative's notch configuration and location. Key take-aways and additional recommendations from the Panel are listed below. The full report from the Panel is appended to this work plan.

- The current approach and suite of tools are appropriate for selecting a preferred alternative.
- Each of the three juvenile entrainment evaluation tools indicated that higher flow capacity would generate higher entrainment of juvenile salmon.
- The analytical tools used represent the best available science; however, like all models they include some uncertainty. To best accommodate this uncertainty, the selected alternative should provide sufficient adaptive management opportunities to maximize utility.
- Integration of analytical tools and data is recommended for adaptive management. The Panel recommended using the suite of analytical tools to provide scientific support and insights that will maximize the flexibility (configuration and operation) of the implemented alternative.
- Additional distribution data of smaller sized juvenile fish is needed to improve the entrainment tools for optimization and adaptive management purposes.
- More engineering solutions should be considered to improve fish passage.

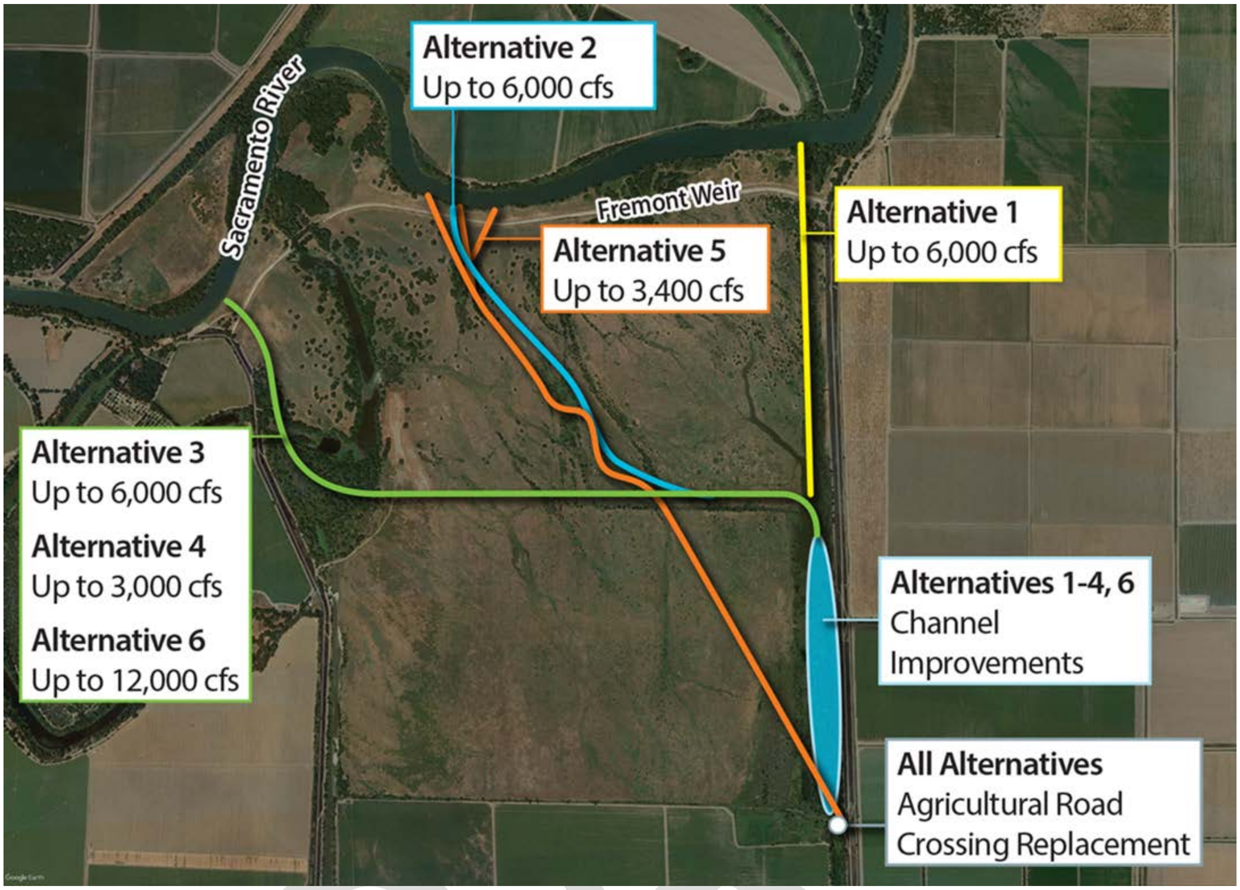

Figure 1. Map of the six proposed Project alternatives evaluated in the Draft EIS/EIR.

The Public Draft EIS/EIR was released in December 2017, which evaluated six proposed Project alternatives based on their ability to meet 2009 NMFS BiOp Project objectives, and the extent of each alternative's environmental impacts. The suite of peer-reviewed analytical tools were used to analyze the ability of each proposed alternative to meet Project objectives. A Final EIS/EIR for the Project will be released in December 2018, and will document the Project's preferred alternative. This Science Work Plan will serve two purposes: 1) outline the steps to incorporate key Panel recommendations; and 2) address uncertainties identified in the Project design and operations, which will require near-term attention and long-term adaptive management actions to improve the likelihood for successful implementation of the Project. Project actions will occur in three distinct phases:

Phase 1: EIS/EIR

As mentioned above, the EIS/EIR phase began in 2013 and it is expected that Reclamation and DWR will have completed sufficient analyses under NEPA/CEQA to select a Preferred Alternative, finalize the EIS/EIR, and file a Notice of Determination (NOD) and a Record of Decision (ROD) by the end of December 2018. This phase will rely on the existing suite of analytical tools to improve understanding of the relative benefits and impacts of each alternative feature; the Panel indicated that the existing tools were appropriate for this purpose. Reclamation and DWR may complete revisions to tools during this period that could enhance their understanding of the alternatives and can be completed within the timeframe, but no changes to the tools are necessary to allow decision-making.

Phase 2: Project Optimization

Project optimization actions will start as soon as possible and continue after the filing of the ROD/NOD. If the results of any tool being developed for Phase 2 are available prior to the completion of the EIS/EIR phase, the results will be appropriately incorporated into the Final EIS/EIR. The outcomes resulting from these actions will be used to validate EIS/EIR findings and refine Project design. The goal of the Phase 2 tool revisions is to identify modifications that can be made to the preferred alternative to improve the Project's ability to entrain juvenile salmonids and/or to meet adult fish passage criteria. Example modifications include moving the gated notch up- or downstream within the Project's alignment of the selected alternative to maximize entrainment potential, adjusting how the Project channel ties into the Sacramento River, and adding velocity refugia elements to Project channels to facilitate improved fish passage.

The modeling efforts in Phase 2 will be focused on optimization and refinements to the preferred alternative, but it could potentially indicate that a different location or configuration could result in improvements in entrainment and fish passage than what is included in the preferred alternative. In this case, Reclamation and DWR would consider whether to incorporate these changes into the preferred alternative using the full suite of evaluation criteria. These additional improvements or modifications, or change in preferred alternative, would have to pass an initial environmental impact screening and may require additional NEPA/CEQA evaluations or processes to be implemented.

Phase 3: Project Operation

Following construction of the Project, the Project will be adaptively managed to maximize its ability to entrain juvenile salmonids and to meet adult fish passage criteria while minimizing Project-related impacts. Performance monitoring will continue for no fewer than five years to inform adaptive management. In addition to the actions proposed in this Science Work Plan, additional operational studies may be proposed for the Project.

Project Workflow

The actions proposed in this Science Work Plan will be presented to the FETT. The FETT consists of interagency and cooperating agency technical specialists and provides input to the Yolo Bypass Planning and Environmental Compliance Project Management Team (PMT). The PMT is the entity responsible for recommending and seeking approval from Reclamation and DWR executive management for all proposals relating to Yolo Bypass 2009 NMFS BiOp actions, including those contained within this Science Work Plan. The PMT consists of

Reclamation and DWR management and staff, California Natural Resources Agency staff, and a consultant team.

Phase 1: EIS/EIR

Phase 1: EIS/EIR actions are planned to occur prior to filing the ROD/NOD.

1. Tool Refinement
    a. Yolo Bypass Passage for Adult Salmonid and Sturgeon (YBPASS) Tool
2. Analysis, Synthesis, and Modeling
    a. Sacramento River Discharge-Survival Analysis
3. Assessment of Adaptive Management Flexibility
    a. Examine analytical results and seek input from the FETT

Tool Refinement

The Yolo Bypass Passage for Adult Salmonid and Sturgeon Tool will be modified to improve understanding of relative benefits in the Final EIS/EIR, and is not expected to result in changes to impact findings.

<u>YBPASS Tool</u>

The YBPASS Tool uses the Hydrologic Engineering Center's River Analysis System (HEC-RAS) modeled water depth and velocity data to determine the frequency that adult fish passage criteria are met for each of the six proposed Project alternatives. While the Project will provide multi-species fish passage, the swimming capabilities of salmon and sturgeon are quite different, with salmon capable of navigating through shallower depths and faster velocities than sturgeon. To provide a conservative fish passage estimate, the YBPASS Tool currently uses fish passage criteria based upon the swimming capabilities of sturgeon. However, the Panel believed that this set of passage criteria was too conservative to provide a meaningful fish passage analysis for periods where salmon are expected to be present, but sturgeon are not. As a result, the YBPASS Tool will be separated into two separate, species-specific analyses for salmon and sturgeon.

The Panel also recommended updating the YBPASS document with a more detailed explanation of how the sturgeon passage criteria were determined, a detailed description of the HEC-RAS model domain, and a more robust statistical analysis. In addition to incorporating these suggestions into the YBPASS document, the YBPASS Tool will be updated to more accurately evaluate each alternative's ability to convey adult fish passage flows after the March 15 operational end date (March 7 for Alternative 4). These late-season diversions would be capped to avoid impacting existing land uses in the Yolo Bypass.

Analysis, Synthesis, and Modeling

Sacramento River Discharge-Survival Analysis

USGS (Perry et al. in press) developed a flow-dependent survival model for outward-migrating juvenile Chinook Salmon along various routes in the lower Sacramento River. They found that survival was positively related to increased Sacramento River flow discharge (measured at Freeport) at some of the study reaches, with significant reductions in survival beginning to occur as river discharge began to fall below 1,000 m^3s^{-1}($\simeq$3500 cfs). Under higher flows, travel time is decreased, thus reducing exposure to predators. Perry et al. (in press) found that river flow influences survival both directly and indirectly by affecting migration rate, route selection, water quality (e.g., turbidity and temperature), and even size at ocean entry. Survival was found to be positively related to fish size (measured in fork length).

2014 Yolo Bypass Two-dimensional Unstable Flow Hydrodynamic Model (TUFLOW) generated notch diversions and Freeport flow discharges for each alternative will be provided to USGS to be input into the discharge-survival model. Model results will be evaluated to identify Project-related effects to the survival of juvenile Chinook Salmon that remain in the Sacramento River (not entrained). Further, the results will be used to identify potential flow conditions that may increase the risk to in-river juvenile salmonids and operational changes to optimize conditions for fish in both the river and the Yolo Bypass.

Assessment of Adaptive Management Flexibility

A key recommendation from the Panel is to ensure the selected Project alternative provides the maximum flexibility to adaptively improve the ability to meet the Project's objectives. Reclamation and DWR will discuss the findings of all the analytical tools with the FETT, while taking into consideration assumptions used for developing the tools. The objective of this process will be to further characterize the notch location, notch configuration, and features providing the greatest flexibility in meeting the Project's objectives. These discussions will bolster the suite of activities to be considered during the first five years of the Adaptive Management Plan (EIS/EIR Appendix C).

Phase 2: Project Optimization

Phase 2: Project Optimization actions may be useful in optimizing the design of the selected alternative.

1. Tool Refinement
    a. SRH2D Model
    b. Eulerian-Lagrangian-agent Method (ELAM) Model
    c. Salmon Benefits Model
2. Analysis, Synthesis, and Modeling
    a. Develop a 3D Model
3. Additional Data Collection Efforts

a. Flow Data Collection for 2D and 3D Models
b. Study to Determine 3D Positioning of Fish

Tool Refinement

SRH2D Model

A new three-dimensional (3D) flow model will be developed during the Project Optimization phase to be integrated into an existing Eulerian-Lagrangian-agent Method (ELAM) fish distribution model. In the near term, the existing two-dimensional (2D) flow model will continue to be refined in a parallel track. This 2D model (Lai 2017) will be updated to allow for a comparison between 2D and 3D entrainment results, which could provide useful information for considering model performance and requirements for future entrainment projects.

SRH2D is a depth-averaged hydrodynamic model for river systems developed by Reclamation (Lai 2008; 2010). The model uses 2015 bathymetric data and the flow hydrograph from December 2014 to January 2015 to generate the flow hydrodynamics (Lai 2017). The 2015 model was calibrated using a Sacramento River stage of 15' (all elevations are citing the North American Vertical Datum of 1988 elevations, Fremont Weir gage data). Validation studies were completed by comparing model results with flow and stage gage data, as well as acoustic doppler current profiler (ADCP) velocity data over two time periods (2010-2011 and 2014-2015). Most ADCP data were recorded at lower river stages. The model domain used for Project alternative evaluation consists of an 18-km reach along the Fremont Weir section of the Sacramento River, beginning upstream at Knights Landing and ending downstream at the Verona gage station. Inflows from the Feather River, Karnak Slough, and Natomas Cross-Canal are included in the domain.

Additional ADCP data were recorded by the USGS in 2016 at higher stages (21-28' and 29-32'), however these data were not incorporated into the SRH2D model due to time constraints to meet the Independent Review Panel's submission deadline. The current version of the model begins to deviate from the observed flow data as the river stage rises during this high flow event due to the lack of high-flow calibration data collected during initial ADCP deployment. Per the Panel's recommendation, the model will be revised to incorporate the most recent ADCP data from 2016, which includes moderate- to high-flow events in the Sacramento River as the Fremont Weir approached overtopping. A two-step work plan is proposed:

1. **2D Model Validation Effort:** This additional validation work will increase the confidence in model results under high-flow conditions by incorporating the 2016 USGS ADCP data. Model uncertainty will be determined by analyzing the 2016 simulated and observed datasets for statistical differences. Boundary conditions and level of certainty in these results will be characterized by a FETT sub-team of subject matter experts. Should the 2016 data be deemed insufficient for high flow events, the FETT sub-team will use TUFLOW as the hydrodynamic model input during periods when the Sutter Bypass is flowing into the model. TUFLOW accurately modeled high-flow events and captured

back-water conditions well, and the grid-size and boundary conditions can be reduced to provide a finer-resolution flow input into the ELAM model.

2D model validation effort objectives include:

a. Model the range of flows occurring in 2016, using the USGS collected data, and compare to the 2D depth-averaged output from SRH2D for non-Sutter Bypass inflow conditions.
b. Incorporate FETT sub-team recommendations on the correct boundary conditions to use for the 2D model.
c. Convene a sub-team to develop a list of fish entrainment questions that can be answered by the 2D model, and determine the limitations of the model. Questions that cannot be answered by the 2D model will be addressed with a 3D model.

A FETT modeling subject matter sub-team assumes that the 2015 bathymetric data can be used for the model validation effort. However, the 2016 bathymetry data would be incorporated should the sub-team decide that it is more suitable for this effort.

The 2D model output will be compared to the measured 2D depth-averaged ADCP data using plots and statistical approaches as appropriate (defined by the FETT sub-team). At a minimum, standard deviation, correlation, and RMS differences from observed data will be used. Uncertainty estimates of the ADCP data will be incorporated into the assessment of the numerical model performance.

2. **2D Model Application Simulation:** The revised 2D model will be applied to scenarios which are most likely to be representative of the flow environments for the proposed notch alternatives. The major uncertainty of this step is related primarily to the selection and use of the boundary conditions, not the model itself. In the current model, boundary condition uncertainty can be significant under high-flow conditions, particularly as the Fremont Weir approaches overtopping and a high proportion of flow enters the system from the Sutter Bypass. The FETT sub-team will collaborate to develop the flow scenarios to be simulated and the appropriate boundary conditions to be used.

The timeline to complete the SRH2D validation effort is highly variable. Assuming the 2015 bathymetry data are used, the validation effort should take roughly two months to complete once the FETT sub-team identifies the appropriate boundary conditions. The model report will be updated to document new work performed, model limitations, assumptions, and sensitivities.

To further model flows under periods with Sutter Bypass inflow, additional data will be collected during water year 2019 and 2020. These data will not be available in time to be included in the Final EIS/EIR. However, sufficient data exists for non-Sutter Bypass inflow conditions to confidently evaluate alternatives. See *Project Optimization* for more information on this data collection effort.

ELAM Model

The ELAM model is a mechanistic representation of individual fish movement that accounts for local hydraulic patterns represented in computational fluid dynamic models. As described in Appendix G1 of the Draft EIS/EIR, Smith et al. (2017) used the ELAM model to estimate entrainment of juvenile Chinook Salmon into the Yolo Bypass by using simulated hydraulics from the SRH-2D model and behavioral inputs based on observed fish movement along the Fremont Weir. Hydrodynamic information generated at discrete points was interpolated to locations anywhere within the physical domain where fish could be present, which allowed the generation of directional sensory inputs and movements in a reference framework similar to that perceived by real fish.

The SRH-2D model was integrated with LIDAR (light detection and ranging) landscape topography, bathymetry, and basic notch designs. The model approach was informed by 2D observations of hatchery late fall-run and winter-run Chinook Salmon collected during a telemetry study on the Sacramento River at Fremont Weir (Steel et al. 2017). Individual fish telemetry tracks were not modeled directly, but rather statistical properties of the measured tracks were used to develop model coefficients, which imbue behavioral characteristics on modeled particles being tracked through the simulated hydraulic environment. Because observed entrainment estimates into the alternative notch configurations do not exist, the entrainment estimates using ELAM should not be viewed as absolute numbers and should be used as relative entrainment rates to highlight differences across scenarios (Smith et al. 2017).

The ELAM model may underestimate entrainment onto the Yolo Bypass based on two key factors. First, the Sacramento River discharge simulated by the SRH2D model is artificially high, leading to reduced water and particle (fish) entrainment rates. As explained in the SRH2D section, this is due to lack of high-flow calibration data and the boundary conditions used. Second, the SRH2D model does not replicate the secondary circulation experienced at river bends, which is hypothesized to be a primary driver for accumulating juvenile salmonids on the outside of bends.

Below are potential approaches to address the issue of artificially biasing fish away from the bank in the ELAM model:

2. **Update 2D Hydrodynamic Inputs:** The existing SRH2D flow model will be updated in accordance with the plan detailed in the SRH2D section. The FETT sub-team will use TUFLOW as the hydrodynamic model input during periods when the Sutter Bypass is flowing into the model. TUFLOW accurately modeled high-flow events and captured back-water conditions well, and the grid-size and boundary conditions can be reduced to provide a finer-resolution flow input into the ELAM model.

3. **Incorporate 3D Hydrodynamics:** ELAM will also be updated to accept a 3D hydrodynamic flow input (see Develop 3D Model in the Project Optimization section). Reclamation and DWR will work with USACE to facilitate this change.

Salmon Benefits Model

The Salmon Benefits Model (SBM) will be updated to meet the key recommendations of the Panel. The major changes will be updating the entrainment and survival parameters, and incorporating uncertainty in model parameters and relationships. The model will move away from using the proportion of flow entrainment approach, where the proportion of river diverted equals the proportion of juvenile Chinook Salmon entrained on a daily timestep. Once the ELAM model is updated, the ELAM entrainment results will become the new entrainment inputs for the SBM.

The model developers will examine the possibility of replacing in-river survival assignments with reach-specific, discharge-dependent survival metrics adapted from Perry et al. (in press). Survival inputs are key parameters in determining model results, and a discharge-dependent survival curve provides a more meaningful output across a wider range of hydrologic conditions. In conjunction with the updated entrainment estimates, these new survival parameters will allow for a more detailed representation of Project-related effects.

New ocean survival relationships that consider not only fish size at ocean entry, but additional factors known to affect ocean survival, such as variation in timing of ocean entry will be developed. Size or growth rate may only be strong predictors of survival in stressful years (Holtby et al. 1990, Tomaro et al. 2012, Woodson et al. 2013), and therefore size at ocean entry may not be the most appropriate metric. Satterthwaite et al. (2014) found that poor survival of small fish was also coincident with an early ocean arrival time when upwelling had not yet occurred. Similarly, Bilton et al. (1984) and Morley (1988) reported stronger effects of timing of ocean entry than size on survival of Coho Salmon, and Whitman (1987) found similar results for Chinook Salmon. Variability of timing of ocean entry is an important bet-hedging strategy to increase the odds of at least a portion of the population arriving during periods of upwelling and adequate food availability. Fish rearing on the Yolo Bypass often entered the ocean later in the season than those that remained in the mainstem Sacramento River.

The updated SBM will be a helpful optimization tool by allowing managers to visualize the potential outcomes of Project optimization efforts and proposed adaptive management actions. By incorporating more detailed survival parameters, the SBM will account for costs of diverting flow into the Yolo Bypass on the survival of fish remaining in-river. The SBM also serves as a key tool in monitoring the performance of the Project.

Analysis, Synthesis, and Modeling

Adding a physical Project structure to the Fremont Weir will modify the hydrodynamics of the Sacramento River at the Project site. Not only will flow be diverted into the Yolo Bypass, but complex changes in circulation will likely occur as flows encounter the concrete intake structure. The ELAM model will be an important tool for Project optimization and adaptive management, but the current modeled 2D flow input will not be able to fully capture the complex hydrodynamic interactions that will occur at the Project site. A 3D model has been proposed as a means of predicting how the flow field will change as river flow encounters a concrete structure. An ELAM model with a 3D flow input would allow Project engineers to model how proposed Project modifications would affect the entrainment of juvenile salmonids. Identifying and implementing design features that improve entrainment would be a key component of the Project optimization effort.

<u>Develop 3D Model</u>

As part of the Phase 2: Project Optimization, a 3D model will be developed and incorporated into the ELAM model. The 3D model-based ELAM model will be an important tool for evaluating structural design changes that will be proposed during the Project Optimization phase to improve the entrainment of juvenile salmonids. Similar modifications could be evaluated during the Adaptive Management of the constructed structure.

The steps to develop a 3D model are as follows:

1. **Determine Scope of Model:** A FETT sub-team, including the ELAM model developers, will be responsible for drafting model specifications for a 3D model.

2. **Select Model Approach:** The FETT sub-team will evaluate proposed model approaches to select the most appropriate 3D modeling team.
    a. The most recent 2016 flow data collected by USGS will be used to calibrate the model (see SRH2D section).

3. **Implement 3D Model:** Upon calibration, additional data will be used to validate the model at high flows (similar to the 2D model modifications described above). Complete report documenting new 3D model.

4. **Update ELAM Model:** The FETT sub-team will work with the ELAM modeling team to prepare the ELAM model to accept 3D hydrodynamic inputs.

Sutter Bypass inflow validation data are not currently available; thus, model calibration will only include non-Sutter flows. The 3D model will be updated to handle backwater conditions caused by Sutter Bypass inputs in the winter/spring of 2018/19 once additional high flow data are collected.

Additional Data Collection Efforts

<u>Additional Flow Data Collection for 2D and 3D model</u>

Additional flow data will be recorded during water years 2019 and 2020 to validate the SRH2D and the newly-developed 3D models under high-flow conditions with Sutter Bypass inflow. The FETT sub-team will identify strategic locations to deploy ADCP equipment in the Feather River and in the Sacramento River along the Sutter Bypass to measure flow inputs into the model domain. This data collection effort is dependent on high-flow conditions occurring during these water years. Data collection will not take place if drought conditions persist and high-flow conditions do not occur. At this point, the FETT and the PMT will weigh in on the value of attempting to collect these data in subsequent years.

<u>Study to Determine 3D Positioning of Fish</u>

To complement the 3D flow model as a component of the ELAM model, 3D fish positional data should also be recorded. There is a data gap in the current literature regarding the vertical positioning of fish in regions with complex flow fields (i.e., secondary circulation). Vertical positioning data would be included into the ELAM model to improve the reliability of the model output.

A FETT sub-team will be developed to draft a study proposal to monitor the vertical position of fish in the Sacramento River along the Fremont Weir. Split beam, side-imaging sonar arrays (i.e., Bio Sonic) would be used to record the vertical position of hatchery-origin juvenile Chinook Salmon that would be released upstream of the array. Ideally, the release would include a broad range of fry- and smolt-sized fish to identify size-dependent variances in vertical and lateral position. Side-imaging sonar has the benefit of being able to monitor smaller fish than traditional telemetry studies.

Side-imaging sonar could be used to get positional data, and a sub-sample of PIT (passive integrated transponder) or acoustically-tagged fish and ARIS (adaptive resolution imaging sonar, Sound Metrics, Inc.) sonar imaging station monitoring could be used to count, measure, and identify differences in distribution between fish of different sizes. The results of this study could be compared with the previous Fremont Weir telemetry datasets collected using larger fish. The tagged fish included in each release group could be mobile monitored downriver with telemetry equipment to give further information about when fish will arrive at the side-imaging array and how to aim the ARIS equipment.

Phase 3: Project Operation

Outstanding Management Questions

The following table was adapted from Appendix 3 of the Adaptive Management Program for the California Water Fix and Current Biological Opinions on the Coordinated Operations of the Central Valley and State Water Projects.

Table 1. Key uncertainties and potential research actions relevant to the 2009 NMFS Operations BiOp RPA elements for the Yolo Bypass.

Key Uncertainty	Potential Research, Monitoring, and Evaluation Actions
1. How effective are the fish passage modifications at Fremont Weir?	Monitor the effectiveness of the fish passage gates at Fremont Weir and the effectiveness of the sturgeon ramps.
2. How effective are the fish passage modifications within the Yolo Bypass itself?	Monitor whether stilling basin modification has reduced stranding risk for listed fishes. Evaluate effectiveness of Tule Canal/Toe Drain and Lisbon Weir improvements in reducing the delay, stranding, and loss of migrating salmon, steelhead, and sturgeon.
3. Is the modified inundation regime affecting predation on listed fishes in the Bypass?	Research severity of predation effects on listed fish that use the Yolo Bypass.
4. Is the modified inundation regime improving production of forage for listed fishes?	Monitor plankton and invertebrate production rates during periods of Fremont Weir operation.
5. Is the change in foraging resources producing improved growth rates among rearing salmonids?	Monitor growth rates of juvenile salmonids that have entered the Yolo Bypass during Fremont Weir operation.
6. What proportion of upstream migrating adult salmonids and sturgeons enter the Yolo Bypass and may be subject to delay at passage barriers?	Research adult salmonid and sturgeon movements to assess use of different routes through the Yolo Bypass and Delta to upstream spawning areas. Evaluate 3-5 years of data collection after passage improvement projects compared to the 3-5 years of data currently being collected (prior to Yolo Bypass passage improvement projects).

Monitoring and Adaptive Management

As described in Table 1, biological monitoring for the YBSHRFP Project will include plans for studying juvenile entrainment, juvenile rearing and survival, and adult fish passage. The results of these monitoring efforts will inform adaptive management decisions to maximize the Project's ability to meet its objectives. Specific monitoring efforts and potential adaptive management responses are listed below. Many monitoring studies are time limited. If intervention thresholds are not exceeded, then these studies will be expected to be discontinued for five-year increments. To ensure intervention thresholds are not being exceeded, monitoring for these metrics will be undertaken at least three out of every ten years from the start of the Project's Phase 3. The monitoring efforts may evolve as new information is gathered or as agreed upon through the FETT. Additional monitoring and adaptive management information is available in Appendix C: Adaptive Management Biological Objectives of the Draft EIS/EIR.

Juvenile Entrainment

Mark/Recapture Study

Reclamation and DWR will release PIT- or acoustically-tagged, hatchery-origin juvenile Chinook Salmon into the Sacramento River upstream of the Fremont Weir to monitor the entrainment rate of fish as they pass the Fremont Weir. This monitoring action will occur each year for five years (if river stage is sufficient) following the construction of the Project.

Metric: Juvenile Chinook Salmon entrainment.

Goal: Measure the entrainment of tagged, hatchery-released juvenile Chinook Salmon.

Intervention Threshold: Results from the telemetry study of juvenile entrainment does not support the expected outcome (0.9:1 fish-flow entrainment) being met.

Potential Management Response: Improve upstream bank channel. Develop model for behavioral guidance structures to improve entrainment. Implement the use of such structures if model results indicate the potential to achieve desired objective.

Juvenile Rearing

Yolo Bypass Rotary Screw Trap Monitoring

DWR will continue to monitor an existing rotary screw trap located in the lower Yolo Bypass. All juvenile Chinook Salmon, including tagged fish, will be recorded.

Metric: Juvenile Chinook Salmon presence.

Goal: Observe presence of juvenile Chinook Salmon at the southern Yolo Bypass rotary screw trap site.

Intervention Threshold: The duration of juvenile Chinook Salmon presence (during times when juvenile salmon are typically present at the southern Yolo Bypass rotary screw trap site) is shorter during years with operation of the Project than without operation.

Potential Management Response: Consider modifying operations to reduce flows or adding features to increase residence time.

Metric: Enhanced growth rate of juvenile Chinook Salmon during Project operation.

Goal: Measure juvenile Chinook Salmon at southern Yolo Bypass rotary screw trap site.

Intervention Threshold: The range of sizes of juvenile Chinook Salmon at the southern Yolo Bypass rotary screw trap site are narrower during years with operation of the Project than without operation.

Potential Management Response: Evaluate water control structures at select locations to extend the duration of floodplain inundation and increase growth.

Adult Fish Passage

Direct Observation

Reclamation, DWR, and CDFW staff will continue to visually inspect the Fremont Weir splash basin, the deep pond, and all Project channels for stranded fish following Project operation. This may be done in conjunction with regular CDFW fish rescue operations. CDFW periodically inspects the deep pond for sturgeon presence following an overtopping event using DIDSON sonar-imaging and gill nets. Reclamation and DWR staff may supplement monitoring with ARIS sonar-imaging equipment if necessary.

Metric: The number of salmonids and sturgeon observed or rescued from the Fremont Weir splash basin, the deep pond, and the Project channels once flows begin to recede.

Goal: Compare numbers of adult and juvenile salmonids and sturgeon stranded in the Fremont Weir splash basin, the deep pond, and the Project channels following Project operation to historical records.

Intervention Threshold: Any adult or juvenile salmonid or sturgeon stranded in the Fremont Weir splash basin, the deep pond, or the project channels.

Potential Management Response: Should one southern distinct population segment (sDPS) Green Sturgeon or >0.1% of the 10-year average of the annual escapement or juvenile production estimate of any evolutionarily significant unit (ESU) of Chinook Salmon become stranded, the hydraulic conditions in the structure will be examined to determine if fish passage criteria have been exceeded. If stranding is found to be a result of shallow depth, excessive velocity, or turbulence, evaluate physically modifying the structure. Note that any sturgeon observed via sonar imaging will be assumed to be a sDPS Green Sturgeon. Potential modifications include, but are not limited to:

- Adjust gate operations to add depth, reduce velocity, or to increase attraction flows
- Add roughness to reduce velocities
- Add velocity refugia to allow fish to better navigate through structure
- Remove or modify features that may cause turbulence
- Modify entrance to structure to improve transition to and from the Sacramento River

Additionally, the splash basin could be re-graded so that it drains towards the fish passage structure and isolated low spots that may cause juvenile stranding could be leveled to improve connectivity.

To divert adult salmonids out of the Yolo Bypass sooner (i.e., farther downstream), the potential for constructing a low-flow fish ladder in the Sacramento Weir could be evaluated.

ARIS Sonar Imaging Study
Reclamation and DWR will operate an ARIS sonar imaging station in the fish passage structure to monitor the behavior and passage success for adult salmonids and sturgeon during the Project's first five years.

Metric: The percentage of adult salmonid and sturgeon passage attempts that result in successful passage. The ARIS sonar imaging station will monitor the entrance of the structure and it is anticipated that some milling behavior may be observed prior to a passage attempt. Therefore, fish will not be counted as attempting to pass until they have completely passed the midpoint of the ARIS frame (also known as "Finish Line Mode Counting" in the ARISFish software).

Goal: Use sonar imaging to document how adult salmonids and sturgeon behave upon encountering the fish passage structure.

Intervention Threshold: More than 10% of the adult salmonids and sturgeon that encounter the structure fail to pass using the "Finish Line Counting" approach.

Potential Management Response: ARIS footage will be analyzed in conjunction with depth and velocity measurements (see "Flow Monitoring" below) to determine if shallow depth, excessive velocity, or turbulence in the structure are found to negatively affect passage efficiency. Once a source of passage inefficiency has been identified, evaluate options for modifying structure to provide more favorable flow conditions as described previously (see Direct Observation).

Yolo Bypass Adult Salmon and Sturgeon Acoustic Telemetry Study
Reclamation and DWR will maintain an acoustic telemetry array in the Yolo Bypass and in the Sacramento River along the Fremont Weir to monitor the movement of adult fall-run Chinook Salmon and White Sturgeon during the Project's first five years. Upward-migrating adult fall-run Chinook Salmon and White Sturgeon will be captured in the lower Yolo Bypass and affixed with acoustic transmitters. Receivers will be located downstream of the fish passage structure and upstream of the structure in the Sacramento River to provide information on fish passage success. The Sacramento River rarely overtops the Fremont Weir coincident with the arrival of adult fall-run Chinook Salmon, so this dataset may be limited.

Metric: The percent of acoustically tagged adult fall-run Chinook Salmon and White Sturgeon that successfully pass the Fremont Weir.

Goal: Acoustically tagged fish will be tracked above and below the Fremont Weir.

Intervention Threshold: More than 10% of tagged fish that are detected at the fish passage structure are not subsequently detected at the receiver upstream of the structure in the Sacramento River.

Potential Management Response: Telemetry results will be analyzed in conjunction with depth and velocity measurements (see “Flow Monitoring” below) to determine if shallow depth, excessive velocity, or turbulence in the structure are found to negatively affect passage efficiency. Once a source of passage inefficiency has been identified, evaluate options for modifying structure to provide more favorable flow conditions as described previously (see Direct Observation).

Flow Monitoring (November 1-March 7/15, TBD)
Reclamation and DWR will monitor water velocity and depth in the Project structure. The YBSHRFP structure will cease to inundate the Yolo Bypass in March (March 7 or March 15, depending on the selected Project alternative). Following this operational end date, the Project will continue to convey flows to pass adult fish with a maximum flow capacity of roughly 1,000 cfs. This flow cap will be dictated by the downstream capacity of the Tule Canal/Toe Drain to avoid causing out of bank flow. Avoiding out of bank flow will minimize effects to farming operations in the Yolo Bypass while still providing adult fish passage at the Fremont Weir.

Metric #1: Length of time adult fish passage criteria are exceeded at the fish passage structure.

Goal: Combine ARIS monitoring with velocity and depth measurements to identify sources of fish avoidance or failure to pass the fish passage structure.

Intervention Threshold: Adult fish passage criteria in the fish passage structure are exceeded for 36 hours or more following cessation of natural overtopping events and YBSHRFP Project operation.

Potential Management Response: Compare depth and velocity measurements to telemetry results, ARIS recordings, and direct observations to determine if shallow depth, excessive velocity, or associated turbulence are negatively affecting adult fish passage. Once a source of passage inefficiency has been identified, examine modifying structure to provide more favorable flow conditions beginning with roughening the fish passage channel as described above (see Direct Observation).

However, if target species can pass under conditions deemed outside of the prescribed fish passage criteria, consider adjusting criteria to include observed conditions. This would be useful in planning future fish passage projects.

Metric #2: Wetted acres.

Goal: Monitor acres of inundation as a result of the Project operating after March 7/15 at 1,000 cfs.

Intervention Threshold: Flows overtop the banks of the Tule Canal/Toe Drain after the March 7/15 operational end date creating new wetted habitat.

Potential Management Response: Adjust flow cap such that all diverted water stays within the banks of the Tule Canal/Toe Drain. If overtopping is confined to only a few low spots, determine if this is acceptable. If not, investigate adding material to repair weak slopes or fill the low spots to prevent overtopping.

Inventory of Applicable Special Studies

There are several upcoming (and ongoing) studies and monitoring efforts in the Yolo Bypass and in nearby reaches of the Sacramento River that could provide beneficial information to managers undertaking activities as part of the Project. These ongoing studies are also likely to inform the Outstanding Management Questions identified in Table 1. Information from these efforts could be useful in planning adaptive management solutions and as performance monitoring options. Additionally, the Project could provide a platform for expanding the scope of certain studies.

Yolo Bypass Adult Salmon and Sturgeon Acoustic Telemetry Study

From 2018 to 2022, DWR will tag adult fall-run Chinook Salmon between mid-September and mid-November. From 2019 to 2023, DWR will tag adult White Sturgeon between February and April. All fish will be tagged with acoustic transmitters and tracked throughout the Yolo Bypass Continuous Telemetry Array to monitor fish residence time and movement through fish passage structures. DWR will maintain the array throughout the study period of fall 2018 through summer 2023. DWR will extend the study period pending construction of additional EcoRestore projects in the Yolo Bypass. This study will monitor and evaluate adult fish passage performance for Yolo Bypass EcoRestore projects. Data collected will help inform fish passage operations and adaptive management for Yolo Bypass adult fish passage projects, particularly Outstanding Management Questions #1, 2, and 6.

Yolo Bypass Fish Monitoring

As part of the IEP Long-Term Fish Monitoring Program, DWR operates a rotary screw trap and a fyke trap in the lower Yolo Bypass, and conducts regular beach seines in the Toe Drain and Tule Canal of the Yolo Bypass. These monitoring efforts collect presence and abundance data on fish species of management concern, which may be informative regarding Outstanding Management Questions #3 and 4.

Comparative Salmon Predation Study

Beginning in 2019, DWR will conduct tethering studies using hatchery Chinook Salmon to evaluate differences in the relative predation risk for juvenile salmon in the Sacramento River and the inundated Yolo Bypass floodplain. This study is contingent upon Fremont Weir overtopping events occurring between February and April to allow for a comparison between Sacramento River and Yolo Bypass conditions. Tethering has been used across many taxa, including salmonids, to evaluate relative predation risk between habitats, regions, or environmental parameters. While tethering introduces some behavioral artifacts for prey species, it provides an effective experimental field technique for measuring the combined effects of predator abundance and foraging intensity comparatively across areas of interest. As such, this study aims to utilize tethering to evaluate relative predation risk between the Yolo Bypass floodplain and the mainstem Sacramento River, which could help resolve our understanding regarding Outstanding Management Question #3.

Investigation of a Unique Isotopic Signature of Yolo Bypass Floodplain Rearing in Juvenile Salmon

The objective of this study element is to determine whether the sulfur isotopic signature contained in juvenile Chinook Salmon stomach contents, muscle tissue, eye lenses, or otoliths (ear bones) serves as a unique marker of Yolo Bypass residence. If isotopic examination of juvenile salmon tissues can reliably identify Yolo Bypass residence time, this tool would offer a way to determine the degree to which Yolo Bypass rearing benefits Chinook Salmon survival, growth, and condition, and under what environmental conditions. This work started in 2014 and the study is ongoing, with examination of tissues from juvenile salmon having varied periods of residence on Yolo Bypass. This study addresses Outstanding Management Questions #4 and 5.

Yolo Bypass Floodplain Transect Study

The Yolo Bypass consistently exhibits hydraulic banding during inundation events, with distinct bands visible in imagery. Each band represents one of the major inputs to the floodplain. These bands remain visually separated along the entire 61 km north-south length of the Yolo Bypass, indicating that latitudinal mixing across inputs is limited. In this study, researchers examined spatial and temporal patterns of hydraulic banding in chemical, physical and lower trophic samples collected on an east-west transect throughout the extended and unusual flooding of 2017. Physical water quality parameters were reflective of hydraulic banding, but biological results were spatially heterogeneous, often differing several-fold between sample sites on the same date. Chlorophyll a and zooplankton were generally highest on the shallower western side of the floodplain, decreasing eastward toward the primary flow path. Temporally, synchronous and distinct peaks in phytoplankton, zooplankton and drift invertebrates were observed three weeks after flooding began, and during the first descending limb of the floodplain hydrograph. Phytoplankton biomass and zooplankton densities were consistently higher than the adjacent Sacramento River at the westernmost floodplain sites under all conditions, and across the remaining floodplain sites during drainage. Drift invertebrate densities were always 10 to 100 times higher on the floodplain in comparison to the Sacramento River. This study addresses Outstanding Management Questions #4 and 5.

Juvenile Chinook Salmon Diet and Growth Study

This study examined how juvenile Chinook Salmon responded to extreme drought (2012-2015) versus flood (1998-1999) conditions on the Yolo Bypass. Specifically, researchers looked at changes in diet composition, food abundance, foraging behavior, and metabolic costs under varying hydrologic conditions. These data may be beneficial for comparing pre- and post-Project conditions on the Yolo Bypass. This study addresses Outstanding Management Questions #4 and 5.

CDFW Fish Rescue and Juvenile Stranding Reduction

Started in 2015, CDFW has undertaken adult fish rescue and juvenile stranding reduction on the Yolo Bypass. CDFW also synthesized existed data on these topics, and cumulatively these activities provide an understanding for the magnitude, timing, and spatial orientation of these risks. CDFW will continue these activities until Phase 3 is initiated.

Opportunities for Collaboration/Coordination

As Reclamation and DWR learn from ongoing special studies, efforts will go into using gained insight to further inform life cycle models and structured decision models to support adaptive management actions regarding habitat restoration and adult and juvenile fish passage through the Yolo Bypass. Integrating observed data into models will improve learning and allow managers to take a holistic approach to improve ESA-listed species populations that may be affected by the Central Valley Project and State Water Project. These models will help identify opportunities for additional studies to quantify the mechanisms and processes linking the biological responses of fish on the Yolo Bypass with management actions in, as well as outside, the Yolo Bypass.

Currently, three models are being advanced in collaboration and coordination with Reclamation and DWR. These models could potentially be informed by ongoing or future studies to improve collaborative learning regarding the Project's risk and benefits to ESA-listed species. Projects that will benefit from new data include the Central Valley wide multispecies structured decision modeling effort, species-specific life cycle models being developed by the USFWS and NMFS, and the Salmon Benefits Model that was developed for this Project. The advantage to each of these tools is that they can incorporate what is learned from the previously-listed special studies. Further, they can help contextualize potential future actions that may change a predicted biological response on the Yolo Bypass or other region of the Central Valley or Delta. Opportunities for coordination and collaboration will be enhanced as agencies and stakeholders learn from ongoing studies and articulate future actions through modeling.

References

Bilton, H.T., D.F. Alderdice, J.T. Schnute. 1982. Influence of time and size at release of juvenile Coho salmon (*Oncorhynchus kisutch*) on returns at maturity. Canadian Journal of Fisheries and Aquatic Sciences, 39 (1982), pp. 426-447.

Blake, A. and M.J. Horn. 2003. Acoustic tracking of juvenile chinook salmon movement in the vicinity of Georgiana Slough, Sacramento River, California – 2003 study results – Draft report. U.S. Department of the Interior, U.S. Geological Survey.

Cavallo, B., P. Gaskill, J. Melgo, and S.C. Zeug. 2015. Predicting Juvenile Chinook Salmon Routing in Riverine and Tidal Channels of a Freshwater Estuary. Environmental Biology of Fishes 98: 1571-82.

Holtby L.B., B.C. Andersen, and R.K. Kadowaki. 1990. Importance of smolt size and early ocean growth to interannual variability in marine survival of Coho salmon (*Oncorhynchus kisutch*). Can J Fish Aquat Sci 47: 2181−2194.

Lai, Y.G. 2008. SRH-2D Theory and User's Manual version 2.0. Technical Service Center, U.S. Bureau of Reclamation. Denver, CO.

Lai, Y.G. 2010. Two-Dimensional Depth-Averaged Flow Modeling with an Unstructured Hybrid Mesh. J. Hydraul. Eng. ASCE. 136(1): 12-23.

Lai, Y.G. 2017. SRH-2D Modeling of Fremont Weir Notch Configurations in Support of Fish Movement Simulation. Technical Report No. SRH-2017-19. Technical Service Center, U.S. Bureau of Reclamation. Denver, CO.

Morley, R.B. 1988. The influence of time and size at release of juvenile Coho salmon (*Oncorhynchus kisutch*) on returns at maturity: results of studies on three brood years at Quinsam Hatchery, B.C. Can Tech Rep Fish Aquat Sci. 1620.

Northwest Power and Conservation Council. 2000. "Return to the River." Council Document 200-12 Portland, Oregon.

Perry, R.W. 2010. Survival and migration dynamics of juvenile Chinook salmon in the Sacramento-San Joaquin River Delta. Doctoral dissertation. University of Washington.

Perry, R.W., Pope, A.C., Romine, J.G., Brandes, P.L., Burau, J.R., Blake, A.R., Ammann, A.J., and Michel, C.J., In press, Flow-mediated effects on travel time, routing, and survival of juvenile Chinook salmon in a spatially complex, tidally forced river delta: Canadian Journal of Fisheries and Aquatic Sciences, *In press*.

Satterthwaite, W.H., S.M. Carlson, S. D. Allen-Moran, S. Vincenzi, S.J. Bograd, and B.K. Wells. 2014. Match-mismatch dynamics and the relationship between ocean-entry timing and relative ocean recoveries of Central Valley fall run Chinook salmon. Marine Ecology Progress Series 511:237:248.

Smith, D.L., T. Threadgill, Y. Lai, C. Woodley, R.A. Goodwin, and J. Israel. 2017. Scenario Analysis of Fremont Weir Notch – Integration of Engineering Designs, Telemetry, and Flow Fields. United States Army Corps of Engineers, Engineer Research and Development Center Report.

Steel, A., B. Lemasson, D. Smith, J. Israel. 2017. Two-Dimensional Movement Patterns of Juvenile Winter-Run and Late-Fall-Run Chinook Salmon at the Fremont Weir, Sacramento River, CA. ERDC/EL TR-17-10.

Tomaro, L.M., D.J. Teel, W.T. Peterson, and J.A. Miller. 2012. When is bigger better? Early marine residence of middle and upper Columbia River spring Chinook salmon. Mar Ecol Prog Ser 452: 237−252.

Whitman, R.P. 1987. An analysis of smoltification indices in fall chinook salmon (*Oncorhynchus tshawytscha*). MS thesis, University of Washington, Seattle, WA.

Woodson, L.E., B.K. Wells, P.K. Weber, R.B. MacFarlane, G.E. Whitman, and R.C. Johnson. 2013. Size, growth, and origin-dependent mortality of juvenile Chinook salmon *Oncorhynchus tshawytscha* during early ocean residence. Mar Ecol Prog Ser 487: 163-175.