Yolo Bypass Salmon Habitat Restoration and Fish Passage Analytical Tool Review

A report to the

Delta Science Program

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October 2017

Delta Stewardship Council
Delta Science Program

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Executive Summary

The suite of data collection, analytical tools, and models applied to evaluate alternative notches in the Fremont Weir is an impressive and useful body of work to support decision-making required to proceed with the Program Environmental Impact Statement/Environmental Impact Report (EIR/EIS) process. The Panel found all of the selected approaches and tools appropriate for selecting a notch location and configuration. While the Panel found the approaches and tools appropriate, the effectiveness of the tools in differentiating between alternatives varied. Further, the limited treatment of uncertainties by the suite of tools resulted in an inability to differentiate between alternatives without making major assumptions about inputs that, if changed, could significantly change the results of the evaluations. However, the Panel ultimately decided that the assumptions made in the suite of applied tools were reasonable and allowed enough analytical differentiation between alternatives to support their use in the evaluation of alternative Fremont Weir notches.

The Panel also concluded that work on some of the tools and approaches should continue, but in support of design, implementation, and performance monitoring of the selected notch, as opposed to supporting notch selection for the EIR/EIS process. The Panel's recommended improvements are detailed in the body of this report. Notably, the Panel concluded that significant uncertainties in the tools regarding hydrodynamic boundary conditions, juvenile salmon behavior, and floodplain survival and growth need to be first resolved and then the tools applied in an adaptive management approach in which potential improvements in the selected notch are hypothesized and tested through monitoring. To this end, selection of the preferred notch alternative should rely on this suite of tools to provide scientific support and insights that will maximize the flexibility (configuration and operation) of the implemented notch.

Approach and Tool-Specific Findings

Hydrodynamics

The SRH-2D model is well established and appropriately applied in this evaluation. The Panel identified a number of areas, including boundary conditions, calibration, and mass balance, where improvements could be made, especially with better integration with other studies assessed by this Panel that collected empirical data on hydrodynamics in the region being considered for a notch in Fremont Weir. The Panel concluded that the selected hydrodynamic model is effective as an input to the Eulerian-Lagrangian-Agent Method (ELAM) model for relative comparisons of entrainment with alternative notches. However, the Panel also determined that revisions to the documentation that more clearly document model limitations with respect to boundary conditions, calibration, and mass balance would enhance the level of support that this model provides to the EIR/EIS decision-making and documentation.

Entrainment

The Juvenile Entrainment Evaluation Tool (JEET), Critical Streakline Analysis (Streakline) and ELAM models characterize fish entrainment with differing levels of detail. All three predicted that more flow capacity results in more entrainment. JEET did not address notch location or configuration. Streakline characterized potential differences in entrainment in the Western section of the weir but did not address effects of configuration. ELAM addressed entrainment for all alternative locations and configurations (Table 1 and 2). In addition, it explored configurations beyond those in the six alternatives. As denoted in the summary results of the ELAM analysis below (Table 2), Alternative 6, with the largest capacity results in the highest entrainments at all river stages. Of the other alternatives the model predicted that all but Alternative 2 results in highest entrainment at some river stage. Notably, Alternatives 1 and 3 have high entrainment as several stages. The Panel suggests that only Alternative 6 unequivocally ranks highest. Of the other alternatives 1 and 3 are functionally equivalent. It is not clear from the analysis why Alternative 2, which differs in location but not significantly in configuration from 1 and 3, ranks lower in entrainment. The Panel also suggests that further differentiation of the alternatives is not possible without improvements in the models and data. Thus, application of the models in an adaptive management context to improve notch efficiency is not warranted without out resolving the uncertainties in the tools.

TABLE 1: Summary of EIS/EIR Yolo Bypass Notch Alternatives (Newcomb & Nelson 2017)

Feature	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Notch Location	Eastern Fremont	Central Fremont	Western Fremont	Western Fremont	Central Fremont (Multiple)	Western Fremont
Maximum Notch Flow	6,000 cfs	6,000 cfs	6,000 cfs	3,000 cfs	3,400 cfs	12,000 cfs
Notch Invert Elevation	14	14.8	16.1	16.1	Multiple	16.1
Channel Bottom Widths	30' bottom, 30' bench	50' bottom, 30' bench	50' bottom, 30' bench	50' bottom, 30' bench	West: 40' 30' bench; Center: 90'; East: 90'	200' bottom
N. Bypass Water Control Structure?	No	No	No	Yes	Secondary channels (program level)	No

Supplemental Fish Passage	West	West	East	East	West	East
Inundation Operations	Nov 1 – Mar 15	Nov 1 – Mar 15	Nov 1 – Mar 15	Nov 1 – Mar 7 or Mar 15	Nov 1 – Mar 15	Nov 1 – Mar 15

TABLE 2: Entrainment estimates across flows and stage referenced to Fremont Weir Summary of EIS/EIR Yolo Bypass Notch Alternatives (Table 5 in Smith et al 2017)

Statge (ft) Fremont	Q (cfs) Fremont	EIS/EIR Alt 1	EIS/EIR Alt 2	EIS/EIR Alt 3	EIS/EIR Alt 4	EIS/EIR Alt 5	EIS/EIR Alt 6
20.23	14952	0.2	0.2	0.8	1.2	0	1.8
21.16	16161	0.4	0	0.4	0.6	0.8	3.6
22.32	17717	1	0.4	0.8	0.8	1.6	4.4
25.54	21261	4.8	3	5.8	4.4	5.6	17
27	22806	9.4	5.4	9	7.2	5	24
28.83	24640	13.8	9.4	11.4	5.4	2.6	37.4

Floodplain Rearing Benefit

The Salmon Benefits Model (SBM) appropriately applies juvenile salmon migration, growth, and timing relationships to inform understanding of the benefits to Chinook salmon of migration and rearing on the Yolo Bypass compared to in the Sacramento River. The Panel recognizes that the uncertainty around survival and growth rates for juvenile salmon on the Yolo Bypass and in the Sacramento determines the results from the model, but accepts the differentiation between notch alternatives illuminated by this model with relatively high assumed survival on the floodplain. As for the entrainment approaches and models, the Panel believes that the SBM effectively differentiates between notch capacities, but does not differentiate between notch locations or configurations. Therefore, the Panel considers the SBM as a useful framework for visualizing the tradeoffs of alternative notches and resolving uncertainty about notch performance if implemented in an adaptive management framework supporting alternative notch design, implementation, and performance monitoring.

Adult Fish Passage

The Yolo Bypass Adult Fish Passage (YBPASS) evaluation tool appropriately uses 1-D hydraulics, adult fish passage hydraulic criteria, and hydrology to assess how frequently alternative notches achieve fish passage criteria. The Panel concluded that this tool was effective in differentiating the performance of alternative notches for adult fish passage. The Panel also noted that while all notch alternatives shows significant improvements in adult fish passage at Fremont Weir, the results from the tool highlight significant proportions of time when fish passage criteria are not met, even with a notch. The Panel urges careful communication of these results so that reviewers are aware of the improvements in adult fish passage with notches and not focused only on the periods that still do not meet adult fish passage criteria even with a notch. This tool does not appear to need additional development, however, the project proponents should continue to refer to the information from this tool during design, implementation, and monitoring to optimize adult passage with the chosen notch alternative. The Panel urges more complete documentation for design criteria used for acipenserids (Sturgeons). Lastly, the Panel also urges the differentiation of model results for salmonid criteria and for acipenserid criteria, as the latter are both more restrictive from a design perspective and more poorly represented from a population perspective.

Agricultural Economics

The Bypass Production Model appropriately describes differences in agricultural production between project alternatives. Agriculture economic outcomes evaluated include the change in crop acreage, agricultural production value, and net farm income from a projected baseline to a projected outcome under each alternative. The panel concluded that this tool was effective in differentiating between project alternatives in terms of their effects on local agricultural production. The panel recommends that the consideration of the uncertainty and variability in the model results be further developed and notes that supporting documentation for some aspects of the modeling approach was not provided. Further, additional information on the relative magnitude of the effects of the project alternatives, the inter-annual variability of the projected impacts, and the spatial distribution of the impacts of each project alternative would make the results of the analysis more useful and easier to interpret.

Charge Question Findings

Appropriateness

The Panel agreed that all of the tools applied were appropriate for the questions being asked in the EIR/EIS process for the notch in Fremont Weir. Further, the models were developed by leading experts in their respective fields, and supported by significant validation and calibration field data.

Effectiveness

The Panel found that the effectiveness of the approaches and tools applied in differentiating between the performance of alternative notches varied substantially, and in most cases depended significantly on assumptions about model inputs and relationships. In some cases, relatively small changes in these assumptions could change the resulting relative performance shown by model outputs. The Panel strongly recommends that these assumptions and their uncertainties be more clearly documented and communicated very transparently as the EIR/EIS process for the notch alternatives moves forward. The Panel also recommends that work continue on the hydrodynamic model (improvements in boundary conditions, calibration, and mass balance), ELAM (improvements in the understanding of behavior of small juvenile salmon at proposed notches under a range of flows), and the SBM (improvements in the understanding of floodplain and river survival and growth). While the Panel feels these improvements are extremely important for future development of this project, the Panel concluded that the assumptions made in applying the suite of tools were founded on sound professional and scientific judgement, and therefore the differentiation they are able to quantify between notch alternatives is a reasonable foundation to support EIR/EIS decisions.

More specifically, the Panel found that the suite of tools is effective for differentiating between ***flow capacities*** of notch alternatives. The suite of tools is also effective differentiating between notch configurations (i.e. angled vs. perpendicular to Sacramento River flow direction). The suite of tools is less effective differentiating between alternative notch locations. While the suite of tools does indicate that eastern and western locations perform better than the central location, the Panel recommends that alternatives evaluation consider performance similar across locations, and prioritize the location shown by the suite of tools to offer the most flexibility to maximize capacity, implement the lowest invert elevation, and incorporate engineering elements to optimize adult fish passage. In other words, the Panel concluded that the suite of tools are best suited to supporting an EIR/EIS decision that prioritizes notch operational flexibility so that operation of the notch can be managed adaptively as performance monitoring reduces the critical uncertainties identified in this peer review that limit quantitative evaluation of alternative notches.

Integration

The Panel found the integration and coordination between the principal investigators working on each tool to be lacking. The Panel recognizes the structural and scheduling challenges that prevented better integration, but noted that significant synergies between tools and improvements to one tool using information from other tools were precluded by the lack of integration. More specifically, the Panel recommends that the ELAM and Critical Streakline tools complete as much integration as possible prior to completion of the EIR/EIS process to address as many of the issues raised in this peer review as possible. In addition, the Panel recommends that the SRH-2D and Critical Streakline tools complete as much integration as possible. While significant uncertainties will still remain after improved integration, it is possible that near-term integration could strengthen the scientific justification provided by the suite of tools for differentiation between notch alternatives in the EIR/EIS process.

Reporting

As with the integration across the suite of tools, the Panel found the reporting available on the suite of tools lacking. Again, the Panel recognizes the structural and scheduling challenges that prevented more detailed and refined reporting. Individual reports were mostly sufficient for a basic understanding of each tool as a stand-alone product. The more significant challenge in interpreting the appropriateness and effectiveness of the suite of tools was the lack of an overarching report clarifying the connections between individual tools, where tools could incorporate additional information from other tools, and how the scenarios and alternatives considered by each tool align. The Public Meeting presentations on each tool improved the Panel's understanding of the suite of tools immensely, but this information will not be easily accessible to reviewers of and stakeholders in the EIR/EIS when released for public comment. Therefore, the Panel strongly recommends that the EIR/EIS team craft a concise and well-illustrated report that clearly identifies and documents the connections between individual tools and the conditions evaluated by the suite of tools.

Next Steps

The Panel found the suite of models together present a sufficient analysis to move forward with notch selection. The information is not without uncertainties but, as is the case with many models, small differences between alternatives (e.g. table above) are unlikely to be significant. However, several consistent trends do emerge. Larger notch flow capacity produces larger juvenile salmon entrainment, a consistent finding across all three entrainment evaluation approaches. For determining the notch location, only the ELAM provides enough information to be useful for decision making in support of the EIR/EIS. For evaluating the basic notch configuration the ELAM model is most useful but a more complex form, including 3-D hydrodynamics and higher order fish responses, will be required for optimizing the design. The Panel notes that optimizing entraining fish is only the first step in using Yolo Bypass to benefit fish; improving growth and survival are equally important. For this task the Salmon Benefits model provides a framework for adaptive management of actions within the floodplain.

1. Background & Purpose

NOAA's National Marine Fisheries Service (NMFS) and the U.S. Fish and Wildlife Service (USFWS) have issued a Biological Opinion (BiOp) on the long-term operations of the Central Valley Project (CVP) and State Water Project (SWP) that includes Reasonable and Prudent Alternatives (RPA) designed to alleviate jeopardy to listed species and adverse modification of critical habitat. NMFS' RPA requires the U.S. Bureau of Reclamation (Reclamation) to increase juvenile floodplain rearing habitat and improve adult fish passage for ESA-listed salmonids and sturgeon. The BiOp requires seventy-three (73) habitat restoration actions, five of which are specific to the Yolo Bypass. The California Department of Water Resources (DWR) and Reclamation have developed project alternatives for the Draft Yolo Bypass Fish Passage and Habitat Restoration EIS/EIR focused on the following two Yolo Bypass actions, which are the subject of this review:

- I.6.1 - Increase seasonal floodplain inundation in the lower Sacramento River Basin
- I.7 - Improve fish passage throughout the Yolo Bypass Alternatives

The alternatives developed to address these two actions consist of a notch in the Fremont Weir, with alternative locations and configurations (width and weir crest elevations), designed to increase the frequency and duration of hydraulic connectivity between the mainstem Sacramento River and the Yolo Bypass and to improve fish passage. Six alternative locations/configurations for a notch were identified (Figure 1)

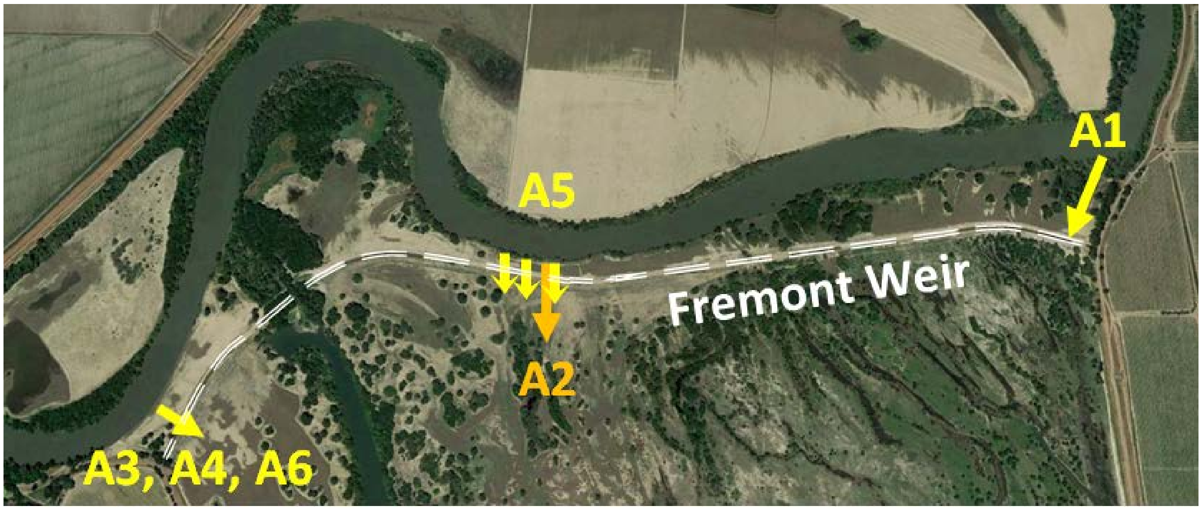

FIGURE 1. Alternative notch locations across the Fremont Weir. Derived from Newcomb and Nelson 2017). See Table 1 for dimensions of Alternative notches.

Several different types of analytical tools have been developed and applied to evaluate the performance of the alternative notch locations and configurations with respect to hydrodynamics, fishes (including their habitat and movement), and agricultural economics. The tools reviewed by this Panel are:

1. ***Hydrodynamics:*** SRH-2D and U^2RANS models;
2. ***Juvenile Salmon Entrainment***: Juvenile Entrainment Evaluation Tool (JEET) model, Eulerian Lagrangian Agent-Based Model (ELAM), and Critical Streakline Analysis;
3. ***Juvenile Salmon Floodplain Rearing:*** Yolo Bypass Salmon Benefits Model (SBM);
4. ***Adult Fish Passage***: Yolo Bypass Passage for Adult Salmon and Sturgeon (YBPASS) tool; and
5. ***Agricultural Economics***: Bypass Production Model (BPM).

The overall purpose of this review is to independently and externally evaluate these analytical tools for assessing the project alternatives being considered in the Draft Yolo Bypass Fish Passage and Habitat Restoration EIS/EIR. The goal is a scientific assessment of the tools and whether they use the best available science, appropriately applied assumptions, and adequately documented and interpreted results to support comparisons and differentiation between alternatives.

1.1 Panel Charge

The Panel was tasked with reviewing each of the modeling tools for appropriateness, effectiveness, integration, and reporting with specific application to differentiating between the alternatives identified in the Draft Yolo Bypass Fish Passage and Habitat Restoration Program EIS/EIR. Specific charge questions for the Panel are listed below. Not all charge questions apply to all tools. It is important to note that the Panel was not tasked with determining whether or not the Yolo Bypass Fish Passage and Habitat Restoration Program being evaluated will alleviate jeopardy to listed species and adverse modification of critical habitat. Rather, the charge to the Panel was to evaluate the ability of the tools as applied to differentiate between the alternative Fremont Weir notch locations and configurations. Any reference to potential preference by the Panel for an alternative location or configuration is unintended.

Model Appropriateness

The Panel considered the following questions with respect to the appropriateness of each tool to differentiate between the performance of alternative notch locations and configurations.

1. Does the tool consider appropriate spatial and temporal scales (i.e., periods simulated, duration of simulations, time step used)?
2. Does the tool use appropriate input data sufficient to justify the assumptions, parameter estimates, and conclusions?
3. How well does the tool explicitly incorporate variability and uncertainty?

Model Effectiveness

The Panel considered the following questions with respect to the effectiveness of each tool to differentiate between the performance of alternative notch locations and configurations.

1. Does the tool effectively capture the distribution and timing of fishes impacted by the project?
2. Does the tool effectively capture differences in growth rates and survival between floodplain and river channel habitats?
3. Does the tool effectively characterize effects on agricultural resources in the Yolo Bypass?

Model Integration and Reporting

The Panel considered the following questions with respect to the integration between tools and the documentation provided in reports for each tool.

1. Are the tools sufficiently integrated to evaluate and differentiate between alternative notch locations and configurations?
2. How well are the tools defined and discussed?
3. Where results from related tools differ or conflict, are the differences and conflicts clearly stated and appropriately addressed?
4. Are the conclusions drawn justified by the analytical outputs of each tool?
5. Where tools are integrated and/or linked, how well are the assumptions and uncertainties in one tool accounted for and communicated to the other tool?
6. How well do the tools characterize and convey uncertainties?
7. How clear are the presentation of results from each tool?

1.2 Review Panel Members

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2. Peer Review Panel Findings

The following sections provide detailed summaries of review Panel findings for each tool.

2.1 Hydrodynamic Models

Introduction

Multiple hydrodynamic models are being used to evaluate the very challenging problem of simulating alternative significant flow diversions from the Sacramento River into the Yolo Bypass through a new notch in Fremont Weir. SRH-2D is a hydrodynamic model developed by the Bureau of Reclamation. In this implementation, the model was used to provide hydrodynamic input data to the ELAM model representing existing conditions as well as alternative notch locations and configurations. SRH-2D has been applied elsewhere on the Sacramento River and on the San Joaquin River in California, as well as other rivers across the western United States. The SRH-2D model results have been compared with the ADH model applied to the same region by the US Army Corps of Engineers. In addition, the findings of SRH-2D were compared to a full 3-D hydrodynamic model (U^2RANS) to compare the results between a 2-D and 3-D representation of Fremont Weir.

Some of the challenges are outlined in the assumptions and uncertainties in the hydrodynamic simulations and captured in the review reports (Reclamation SRH-2015-33, SRH-2017-19) and the model documentation (references such as Lai, 2008). For the simulation of diversion flows at Fremont Weir these uncertainties include inaccurate or non-stationary bathymetry, lack of detailed information on tributary inflows (for example, Sutter Bypass Outflow) and uncertainties in water surface elevations for model calibration.

These hydrodynamic modeling studies are bolstered by one of the most comprehensive sets of field observations of the flow structure in the Sacramento River using Acoustic Doppler Current Profiler (ADCP) data collected by the USGS as part of the Yolo Bypass Utilization Study (YBUS). The combination of high-resolution modeling and detailed field measurements result in a robust approach to determine the effectiveness of the flow diversion.

Backwater effects result in a non-unique relation between water surface elevation and discharge that poses difficulties in setting the boundary conditions for the models that can potentially have a significant influence on the relationship between river discharge and water surface elevation along the Fremont Weir. If the boundary forcing cannot be specified accurately for a given flow condition, the model boundary should be set beyond the maximum influence of the boundary condition.

Calibration of the model is also difficult as the conditions change significantly between high and low flows – particularly complicating effects of backwater effects at confluences where the zone of influence can vary significantly with flow and tidal conditions

Model Appropriateness
SRH-2D is a model developed by Dr. Lai in the Technical Services Center, U.S. Bureau of Reclamation. The model is well documented and has been used extensively by agencies, consultants and academia over the past decade. U^2RANS solves the unsteady Reynolds averaged Navier Stokes equations. Originally developed by the Iowa Institute of Hydraulic Research, this model has been widely used for more than a decade. The modeling team is led by a respected computational hydrodynamics expert that was the developer of the former model and with extensive experience in the development and application of the latter. The models are appropriate for evaluating the hydrodynamic performance of alternative Fremont Weir notch sizes, locations, and configurations.

Model Effectiveness
Overall, the SRH-2D model provides effective hydrodynamic output for use as input to the ELAM evaluation for relative comparisons of Sacramento River and notch flow entrainment characteristics. Several important improvements must be made to the SRH-2D model for it to accurately simulate boundary conditions, mass balance, and, potentially, three dimensional hydrodynamics.
The assessment of bathymetry resolution and mesh size was informative and contributes to an understanding of the sensitivity and uncertainty of the SRH-2D modeling. This careful analysis demonstrated that discrepancies are not due to grid selection, but rather the accuracy of bathymetric information (Chapter 4 SRH-2017-19, for example Figure 15). However, the hydrodynamic modeling analyses do not provide a comprehensive summary of uncertainty and sensitivity to important factors such as ungauged inflows, backwater effects created by Sutter Bypass and other tributaries, or potential changes in bathymetry in the region proposed for alternative notches in Fremont Weir. Consideration should be given to estimating differences in water surface elevations at proposed notch locations that considers the empirical understanding of hydrodynamics in the region developed by Stumpner (2017), which are described below.

The SRH-2D and U^2RANS models appear to give similar results for predicting water surface elevations and discharge. U^2RANS is more computationally intensive, with significantly longer run times than SRH-2D. However, care should be taken in selecting the appropriate model for future hydrodynamic simulations related to design, implementation, and monitoring of the selected notch in Fremont Weir. The selection of the model should be driven by the type of question posed by the ELAM modelers and fish biologists. If juvenile fish behavior must be simulated at a range of depths in the water column, upwelling on the upstream face of Fremont Weir or other large scale turbulent structures could initiate attraction or repulsion responses from the fish. For these conditions, the U^2RANS may be warranted.

Juvenile salmon behavior in the region of proposed notches in Fremont Weir is sensitive to the volume of flow being diverted, the location in the water column where fish are present, turbulent structures such as eddies as well as the local flow characteristics such as the local strain and/or shear. Therefore, the Panel does not agree with the conclusion that the 2-D hydrodynamic model is adequate, unless the fish are known to frequent close to the surface of the Sacramento River. Observations from the Streakline evaluation (described below) indicate that juvenile salmon behavior does vary with depth and in response to vertical flow dynamics. The decision on the choice of the model depends on the question that is posed by the fish behavior experts. If the fish are capable of dynamic responses to changes in the flow characteristics such as strain (or lateral shear), eddies or upwelling at the weir crest, the 3-D hydrodynamic model would be warranted. If the water surface elevations and depth averaged velocities are adequate, then the 2-D model would suffice. A meeting of the experts on fish behavior to share data and knowledge of where fish have been observed and how they respond at other areas of flow separation or channel intersections would help inform this decision. The Streakline analysis based on field measurements is a very valuable tool in guiding the final selection of the location of the diversion along the weir if the desire is to maximize entrainment.

Model Integration and Documentation

The SRH-2D model was well-documented, but included some unresolved issues (e.g. Sutter Bypass boundary conditions) and presented some unexpected results (e.g. cross sectional velocity distributions) that would benefit from improved reporting. The integration of detailed field measurements under existing conditions to calibrate the high resolution 2-D and 3-D models is an appropriate approach. The analysis has demonstrated that the model results are relatively insensitive to the computational mesh established for these simulations. The model results were shown to be very sensitive to the bathymetry, and after the 2015 report, updated bathymetry was used where available in the model domain and high resolution bathymetry was shown to be very important. The low resolution model (large domain from River Mile 47.6 to 117) results from this study were also compared to earlier simulations with the ADH model (US Army Corps of Engineers, 2013). Close comparisons were reported in SRH-2015-33.

From the presentations and SRH-2015-33 and SRH-2017-19, there has been an evolution in the model calibration. In the initial model simulations, it was difficult to match the model results with the field observations and adjustments were made to the inflows in the model domain to match water surface elevations and achieve a mass balance of the water (i.e. total inflows match total outflows within the model domain under a steady discharge). The model was then recalibrated using updated bathymetry and high resolution bathymetry and a better match to the field observations was obtained. However, recent field observations (see Critical Streakline section below) have highlighted the complexities of the flow characteristics in the region of the proposed notch in Fremont Weir, raising concerns about the potential variance in water surface elevations for a given discharge.

Appendix 1 of *ERDC TR/EL-17-Draft* summarized the differences between the field observations of stage, discharge, and velocity with the model simulation results. Given the date of these reports and when the latest field data was used, there was insufficient time for the study team to complete a thorough analysis. Similarly, there is insufficient information provided in the reports for the Panel to conduct a structured analysis as there are differences in the scenarios analyzed. Examples include differences in the Sacramento River of up to 3 feet in river stage and up to 70% in estimate of river discharge.

From the reports and materials presented to the Panel it is difficult to draw definitive comparisons between the two modeling approaches, but there appear to be some significant discrepancies between the stage-discharge relationships derived from the two approaches. There is inadequate comparison of the model and field water surface profiles in the reports to understand these differences.

In this simulation exercise, it is assumed that fish respond passively to the flow structure based on field observations in the region. However, the results of the modeling indicate that the effects of the notch in Fremont Weir could trigger very different turbulence characteristics and flow structure than is experienced in the confined trapezoidal channel of the Sacramento River. The ‘entrapment zone’ for diverting flow into the Yolo Bypass is going to be highly dependent on the location, alignment and size of the notch in Fremont weir.

In addition, there are differences between the observed and predicted velocity distribution across the channel (for example Figures 19d, SRH-2017-19). This indicates a potential difference between predicted and observed discharge at the section and the difficulties with mass conservation have not been fully resolved. This could also be significant if the ELAM modelers require more detail on the lateral velocity structure to simulated more complex fish behavior, as discussed in the ELAM section below. A joint collaborative analysis between the field team and modeling team will allow a systematic analysis of the predictive ability of the model under existing conditions and with the diversion. This integration is not expected to be a major undertaking, and specifically the following questions could be addressed:

1. Can the hydrodynamic model adequately capture the backwater effects detected in the field studies? If not, remedies should be considered such as relocating the boundaries of the high-resolution model and supplementing discharge and water surface elevations measurements with additional gauging stations as recommended by Stumpner et al., 2017.
2. What is the expected accuracy of predictions in water surface elevation at the weir under different discharges, and if this elevation is influenced by tidal elevation or other backwater effects due to Sutter Bypass, what is this variation? Since the flow over the Fremont Weir varies with the water depth in a non-linear manner, it is important to accurately capture the stage.
3. The choice between the 2-D or 3-D simulation should be made by the ELAM modelers and fish behavior experts on the basis of whether the fish respond passively or to cues in the turbulence or flow structure.
4. It is worth noting that several other hydrodynamics models (e.g. TUFLOW and HEC-RAS 2D) have been applied to this region. While this review focused specifically on the SRH-2D model, future analyses related to Fremont Weir and Yolo Bypass should leverage all available models (and supporting data) as well as the unique set of field observations amassed during this study.

2.2 Juvenile Entrainment Evaluation Tool (JEET)

Introduction

The Juvenile Entrainment Evaluation Tool (JEET) (DWR, 2017a) is designed to evaluate the effects of notch dimensions on juvenile salmon entrainment for different fish runs and river stage levels. It does not evaluate effects of notch location, fish distributions across the river, or effects of notch-induced changes in the hydrodynamic field on entrainment. The model assumes the proportion of fish entrained is equal to the proportion of water entrained. The model provided information for the SBM model, the adult upstream passage model and the economics model. The flows in the model are generated from the TUFLOW Classic hydraulic model (only evaluated by this Panel as background information).

Model Appropriateness

The model's strength is its simplicity and clear characterization of the historical passage distributions of juvenile salmon migrations past Fremont Weir. The model characterizes notches by their invert elevation, width, and maximum flow. JEET does not consider effects of location and notch hydraulic flow properties, or fish spatial distribution. Thus, the JEET entrainment index is appropriate for identifying the relative effects of notch dimension on run-specific entrainment (i.e., the interaction of migration timing river stage and notch dimension). The model assumes fish are distributed uniformly in the flow so that the fraction of fish entrained equals the fraction of flow entrained. In actuality, fish are not distributed uniformly. The fish entrainment fraction can be greater than or less than the water entrainment fraction. Fish distributed closer to a notch entrance might have greater proportional entrainment than that predicted by JEET, with the opposite result for fish distributed farther away from the notch entrance. However, the interaction of flow and fish distributions cannot be inferred by qualitative models. The Streakline model (Section 2.1) illustrates the complexities typical of flow and fish distributions with data, while the ELAM model attempts to computationally capture these complexities.

The JEET model is used to define fish inputs in the Salmon Benefits Model (Section 2.5), and Agricultural Economic Model (Section 2.7). Given the uncertainties associated with results of these models, arguably the JEET has the appropriate level of complexity for evaluating these secondary aspects of different notch alternatives.

Model Effectiveness

The model is effective in identifying the relative of notch flow capacity on entrainment. Like most of the models, JEET uses species composition and timing of juvenile salmon migration at Knights Landing for input. These juvenile outmigration trapping data are a valuable resource for evaluation of fish entrainment.

Model Integration and Documentation

The model documentation is clear and the model is appropriately integrated with the SBM and Agricultural Economic models. The fact that JEET is implemented on a spreadsheet adds to its accessibility to a wider audience. The model contains many simplifying assumptions, which for the most part are identified in the report. The Panel suggests that the uncertainties generated from the assumptions are not significant if the model output is viewed as an index of entrainment.

2.3 Critical Streakline Analysis

Introduction

Two USGS reports describe an analysis of entrainment potential of 63 potential notch locations across the Fremont Weir. The analysis was based on a comprehensive set of high-resolution hydrodynamic flow/stage data (Stumpner et al. 2017) and hatchery fish acoustic tag data (Blake et al. 2017). The data sets were collected simultaneously along the western side of the Fremont Weir in Water Year 2016, a “Below Normal” flow year according to DWR’s Sacramento River Index (http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST). The study area corresponded to Alternatives 3, 4 and 6. The study did not include the eastern (Alternative 1) and central (Alternatives 2 and 5) locations. The entrainment potentials at incremental distances along the western section were defined by comparing the cross-channel fish distributions to cross-channel locations of the “critical streakline”—defining the point separating water that continues downstream from water predicted to enter a notch. The fraction of the fish distribution inside the streakline location immediately upstream of a notch defines the entrainment potential of the notch.

The analysis found that at some locations of the study area, more of the fish cross-channel distribution was located within the entrainment zone, and therefore at these locations the fraction of fish entrained into a notch would be higher than other locations. The report concluded these locations are candidates for a notch in the Fremont Weir. One location was also identified where entrainment potential was very low.

Model Appropriateness

The model is based on high-resolution spatial hydrodynamic data that characterizes the 3-dimensional patterns of velocity and stage for a measured range of flows. Importantly, the model characterizes the secondary flow field that interacts with fish behavior to shape the vertical and cross-channel distribution of fish as they move along the Fremont Weir. The resolution of the measured primary and secondary flow fields was impressive and appears to be of very high quality. Importantly, the hydrodynamic analysis revealed stage-discharge patterns that affected the position of the entrainment zone. The model trajectories of fish were also of high resolution. The intersections of the critical streaklines with fish cross-sectional distributions provide high-resolution estimates of entrainment potential under the observed conditions.

The temporal scale of entrainment was more difficult to assess because the hydraulic and fish data were collected for one migration season only. Validity of extrapolation to years with different stages and discharges and with different fish trajectories would be difficult to assess with the existing data.

The model appears appropriate for identifying potentially viable locations for a notch as well as identifying locations that are less viable, based on the 2016 large-fish telemetry data used in the model (avg. ~165 mm). The analysis did not address notch configuration, nor possible perturbations of the hydrodynamic field and fish trajectories that would result from the presence of a notch. In other words, the model provides an initial evaluation of entrainment potential for each location while noting that actual entrainment would depend on specific characteristics of the notch, such as absolute dimension, relative position, and structural geometry.

The stage-discharge probability distribution was determined from historical data (1996-2010). This analysis characterized across-year entrainment as a function of water year. The pattern of entrainment potential with location across the weir was insensitive to water year type except in wet years where Yolo Bypass would be overtopped more than 200 hours over the season.
The conclusions from the study are expected to be valuable for identifying notch locations. Of particular value, the study identified a 100m long zone of near-maximum entrainment for all runs of salmon (based on telemetry of large hatchery fish only) and seasonal hydrology.

Critical Uncertainties

A strong assumption of the study is that conditions observed in the 2016 study are sufficient to infer entrainment patterns in a weir with one or more notches. The report listed a number of uncertainties associated with this assumption. Brief comments on these and other uncertainties are listed below.

1. The study characterized behavior of large hatchery fish (~165 mm late fall run). It is uncertain how these findings can be extrapolated to smaller wild juvenile salmonids, especially those that are approximately 30-90 mm. These smaller salmon would likely benefit more from rearing and growth on the Yolo Bypass than the large salmon examined in this model. The Panel agrees this is an important uncertainty and realize it is difficult to assess with acoustically-tagged fish that must be relatively large (~>90 mm). In the Appendix, the Panel identifies information from other studies indicating small Chinook salmon typically inhabit shallow, low velocity habitats including the inside of river bends. One potential approach might be to assess size effects with an analysis of the ELAM model (see Section 2.2 below) in which fish swimming velocity is determined by fish length. However, such an analysis would not characterize length-dependent responses to acceleration thresholds that induce fish behaviors (e.g. see Enders et al. 2012, Goodwin et al. 2014, Vowles et al. 2014), nor would it assess possible skewed distribution of small fish to the inside of the river bend. This skewed cross-channel distribution of small Chinook salmon might be examined with a beach seine (electrofishing is less effective for these smaller salmon (Friesen et al. 2007)).

2. The Panel agrees with the authors that the limited range of backwater conditions limits the extrapolation of the study to other conditions. The Panel also notes that the notch, which may at times divert a sizable fraction of the river flow, will affect both backwater conditions and cross-channel velocities. Determining the details of the effects will require computational fluid dynamics modeling to characterize the flow fields and ELAM-type models to characterize the response of fish to the flows. For example, the streamline analysis captures the downwelling on the outside of a bend, but the presence of a notch is likely to introduce some upwelling as the flow goes over the weir crest.

3. The study identified a 10 m long zone of minimum entrainment associated with a scour hole. The region had up to 400% lower entrainment than the zone of maximum entrainment located 40 m downstream. This strong lateral variation in entrainment may suggest that modifications in the topography of the river at Fremont Weir may have strong effects on the properties of the locations that are identified as optimum from the current analysis. Thus, the predictions of potential notch locations based on 2016 observations have an unresolved level of uncertainty for predicting the optimal location of notch. However, the Panel could not determine the significance of the uncertainty and

therefore recommends the selected notch location and configuration be managed adaptively to address this uncertainty.

4. Although this model and other models provide valuable information for identifying the location of the notch and important notch characteristics, remaining critical uncertainties highlight the need for monitoring, evaluation, and active adaptive management.

Model Effectiveness

The model focused on evaluating location-specific entrainment potential under varying conditions. For each scenario, the model also characterized notch discharge and fraction of total fish abundance entrained for stages. This information may be valuable in better defining the weir arrival spatial distributions of fish for ELAM and SBM models. In particular, the model identified weir locations where entrainment would be expected to be relatively low or high. However, the analysis was only relevant to western located alternatives.

Model Integration and Documentation

The study's integration of hydrodynamic and acoustic tag data was excellent. In particular, the analysis provides important insights on the complexity of stage/discharge relationships that affect the efficiency of alternative entrainment zone locations. The analysis also provides insights on the importance of secondary flows in determining the cross-stream movements of fish. The report highlights evidence that fish behavior and secondary circulation together influence cross-channel movements of fish. The report suggests that fish entrainment might be enhanced by modifying the secondary flow upstream of a notch location. These finding should motivate additional studies on the response of fish to complex flow patterns expected around a notch. For integration with the ELAM model, see section 2.4: Model Integration and Documentation

2.4 Eulerian-Lagrangian-agent method (ELAM)

Introduction

The ELAM models fish movement in response to variations in the flow field and fish behavior. The model was used to evaluate juvenile salmon entrainment potential of 12 notch scenarios varying in notch location and configuration in the Fremont Weir (Smith et al. 2017). Near the end of the project additional simulations were conducted to better capture the six alternatives. The model characterized the movement of juvenile salmonids through complex flow fields by resolving the combined effects of changes in the flow field and the induced swimming behavior in response to the changes. The model tracks four potential behaviors: [B1] in steady flow, fish drift downstream; [B2] encountering moderate flow acceleration, fish swim across the streamlines into the higher velocity; [B3] encountering strong flow acceleration, fish swim upstream against flow; [B4], fish swim against changes in vertical velocity in order to maintain depth. The switch from B1 to B2 and from B2 to B3 behaviors depends on the particle acceleration experienced by the fish, with higher accelerations required for B3 than B2. For this project, the flow field was characterized by a 2-D model (see Section 2.4 on SRH-2D); therefore, the modeled fish exhibit no B4 behavior. The ELAM model was described in a series of publications, the major ones being Goodwin, Nestler et al. (2006), and Goodwin, Politano et al. (2014).

Model Appropriateness

The ELAM model was initially developed to resolve the effects of complex small-scale spatial velocity patterns on passage of salmon smolts through Columbia River dams. Similar conditions are expected in a Fremont Weir notch, therefore the model spatial scales are highly appropriate for evaluating alternative notch entrance configurations for the weir.

In the current form, the ELAM model may under-predict the entrainment of the modeled fish (i.e, fish > 98mm) because of limitations in the SRH-2D hydrodynamic model. The authors speculated that the bias involves the inability of the 2D hydrodynamic model to capture the secondary currents associated with cross-channel differences in the vertical circulation. They suggest that the current report is for planning purposes. Once a design and location are further resolved, Smith et al (2017) suggest that a 3-D hydraulic model may be required. However, applying the more complex flow fields would only make sense in the context of evaluating more complex fish behaviors that respond to vertical flow characteristics.

Appropriate Behavior Responses

The simulations characterized fish movement using the B1 behavior only, in which fish drift with the flow in a 2-D velocity field. This behavior is typical of larger salmon smolts that are actively migrating, but it may not reflect behavior of smaller Chinook salmon that seek shallow, low velocity habitats (see Technical Appendix). The calibration of behavior was qualitative. As written in Smith et al. (2017), “The [fish trajectory] estimates were compared to the measured data, adjustments made to model parameters, and the model rerun until measured and computed values were similar.” To fit the model to data two parameters were adjusted: lambda_xy affected speed through the reach and c_xy affected the spatial distribution across the reach.

The model calibration illustrated in Fig. 8 of Smith et al. (2017) demonstrates the fish distribution (Fig. 8A) being more dispersed than was found for the measured fish positions (Fig. 8B). This suggests, as noted by Blake et al (2017), that fish exhibit some cross channel behavior that moves them towards the outer bend of the river. This is the type of response the model is expected to generate with the B2 behavior; as the water accelerates in the river bend, the B2 behavior would move the fish into the higher velocity in the outer region of the bend. Correspondingly, closer to the bank the B3 behavior potentially could move the fish back into the channel. While the actual model response would be complex and not easy to describe, the point is that B2 and B3 behavior are likely to be important, especially in a notch configuration in which the acceleration/deceleration patterns within the fish sensory ovoid can be significantly different from what fish experienced in the river and over the Fremont Weir in its current condition. Importantly, depending on the acceleration fields at a notch entrance, fish might be entrained at rates greater than or less than the rate water enters the notch. It appears that the current calibration and analysis with the ELAM model may not fully exploit the capabilities of the full model for evaluating the characteristics of the alternative notch configurations.

However, the Panel also realizes that behaviors B2 and B3 may have been in the model, but not invoked because the default acceleration thresholds were too high (possibly because they were calibrated for dam passage?). However, the full set of model parameters, and in particular the acceleration thresholds (k_beta(2) and k_beta(3)) for B2 and B3 were not reported. Furthermore, it seems plausible that B2 and B3 behaviors would be infrequently invoked in the existing Fremont Weir environment. Thus, while the general spatial distribution of fish tracks appear to be reasonably represented with B1, it is plausible that B2 and B3 are important during notch approach and boundary avoidance. Furthermore, it is plausible that a dominance of B2 behaviors will produce notch attraction while B3 produces notch rejection. Such patterns might then depend on the relationship of fish size to the acceleration thresholds that trigger the behaviors such that entrainment and rejection patterns would vary with fish size.

Model Effectiveness

The model evaluates both notch configurations and locations. When the calibration issues of the hydrodynamic and behavioral components of the model are resolved it is likely to be an effective tool for evaluating notch design. However, the model may not represent small Chinook salmon if smaller fish do not behave similarly to the fish modeled in the report. See Section 2.6 for a discussion of habitat selection by small Chinook salmon.

Model Integration and Documentation

Significant integration of the ELAM model with the Streakline tool had not yet occurred at the time of this review. While the Panel understands that the compressed schedule did not allow integration of the ELAM and Streakline projects, the Panel highly recommends that both groups integrate approaches and data to collaborate in providing guidance in finalizing the notch design, implementation and future monitoring. The model conclusions were generally comprehensive and useful. The general summary of findings notes that larger notch flows entrain more fish, but not proportionally with flow; western side notches entrain more fish than other locations, and intake entrained more fish than shelf configurations. The model persistently predicted entrainment levels below 5% for stages below 25 ft. These conclusions are particularly useful when considered in the concert with those of the Streakline analysis (Blake et al. 2017).

The presentation and discussion of results was limited and did not illustrate fully or support the general conclusions. The report also did not illustrate the character of fish responses to notches; for example paths and behavior modes of fish approaching and entering a notch. Such trajectory/behavior maps in Figure 4 of Goodwin, Politano et al. (2014) were instructive in revealing the factors underlying fish trajectories at dams. Such maps are likely to be useful for designing and understanding fish behavior to notches and during downstream passage

Critical Uncertainties

The acceleration thresholds for behavior transitions and their dependence on fish size are critical uncertainties in the model. If size-dependent differences in thresholds exist, conditions that entrain one size of fish could repel fish of another size. From the information in the report it was not possible to assess the threshold levels or if they would be induced in notch passage. These uncertainties were noted in the report but no solutions to resolve them were discussed. Additionally, the cross-channel distribution of small Chinook salmon (30-90 mm) was not evaluated because these fish are too small to receive acoustic tags. In other watersheds, smaller Chinook salmon often inhabit shallow, low velocity habitat along the inside of river bends. If this behavior occurs in the lower Sacramento River, then entrainment of small fish may be less than expected based on the results of this ELAM evaluation (see Technical Appendix on cross channel distribution of juvenile Chinook salmon).

Recommendation

The ELAM model could be more extensively calibrated so that effects of the parameters (e.g. acceleration thresholds) on deviations between the observed and model simulated fish trajectory are identified. One step in an expanded calibration might include a sensitivity analysis showing the effects of the acceleration threshold parameters on the cross-channel fish distributions and entrainment efficiencies. To gain further insight into the differences between alternative notches it would be useful to characterize the spatial/temporal distributions of behavior transitions (B1 B2 and B3) for the different alternatives and locations.

<u>Cross channel distribution of Juvenile Chinook salmon</u>

In both the Streakline and ELAM models a key factor influencing the number and size of juvenile Chinook salmon entrained into the Yolo Bypass via a notch is the cross channel distribution of the fish. This issue is well-recognized by the investigators and detailed cross channel distribution measurements were taken from acoustically-tagged fish in 2015 (low flow, winter-run and late fall-run Chinook; Steel et al. 2017) and 2016 (higher flows, late fall-run Chinook, Blake et al. 2017). The detail and resolution of these fish distributions is excellent; however, the distributions represent relatively large juvenile Chinook salmon that may not represent the distribution of smaller salmon. In 2015, the tagged fish size averaged 145 mm (late fall run range: ~98-180 mm) and 103 mm (winter run range: 98-125 mm). The tagged fish distribution reportedly followed the centerline regardless of discharge (Smith et al. 2017) or skewed slightly toward the outside bend (Steel et al. 2017). The cross channel distributions of the two salmon runs and two size classes of fish were generally similar but winter-run salmon tended to be distributed toward the outside river bend. In 2016, the average size of tagged Chinook salmon was 165 mm and these fish were distributed toward the outside of the river bend, a distribution that might enhance entrainment into a notch created along the outside bend (Blake et al. 2017). The 2015 fish telemetry data were used in the ELAM model, whereas the 2016 data were used in the Critical Streakline model.

Information about the cross channel distribution of small salmon is important when designing the notch configuration because entrainment into Yolo Bypass is likely to be most beneficial for smaller Chinook salmon that rear in floodplain habitats for extended periods, as described in the Salmon Benefits Model and other studies (Perry et al. 2016, Schroeder et al. 2016). No information was presented by any investigators on the cross channel or depth distribution of small Chinook salmon (30–95 mm) in the lower Sacramento River, although the investigators recognized that distribution and behavior of small salmon may differ from that of the larger tagged salmon and this may influence entrainment. Smith et al. (2017) state that:

> "USACE studies suggest very limited numbers of fry size salmon near the banks. Susceptibility of fry size salmon to a notch may be greater than smolts or, if fry size fish are migrating similarly to parr and smolts then entrainment estimates may correspond to results in this study."

Detailed information about these USACE studies, such as time, location and sampling gear type, was not provided in the reports, although electrofishing was identified as the gear type at the public meeting. Other studies show that electrofishing can be less efficient at capturing small wild Chinook salmon compared with beach seine (Friesen et al. 2007).

These smaller fish are important to runs of Chinook salmon in the Central Valley. For example, Miller et al. (2010) reported that 20% of fall Chinook salmon sampled in the ocean fishery had migrated as fry (<55 mm), 48% as parr (56-75 mm), and 32% as smolts (>75 mm), based on otolith analyses. Simenstad et al. (2017) examined USFWS beach seine data at Chipps Island (i.e., shallow estuarine habitat below Yolo Bypass) and reported that 51% of winter-run Chinook Salmon (549 fish sampled) were 35-70 mm long and 74% of spring-run Chinook salmon (1233 fish sampled) were 31-70 mm long. USFWS beach seine sampling in the lower Sacramento River (Oct-May, 2012-2016) yielded 20,800 Chinook salmon averaging 46 mm (mostly fall run); only 43 Chinook salmon exceeding 100 mm were captured in the nearshore areas (https://www.fws.gov/lodi/juvenile_fish_monitoring_program/jfmp_index.htm).

Smaller juvenile Chinook salmon (~30-70 mm) typically seek and rear in shallow, low velocity habitats, whereas larger fish exhibit smolt behavior and often migrate downstream in higher velocities near the deepest portion of the river. For example, in the lower Willamette River, Friesen et al. (2007) reported that nearshore, shallow beaches were an important habitat for small subyearling Chinook salmon, whereas larger Chinook salmon (>100 mm) were evenly distributed across the mid-channel area. Few small Chinook salmon were captured by electrofishing compared with beach seining. They noted that electrofishing primarily captured larger Chinook salmon (a common pattern) that were hatchery salmon and distributed farther offshore compared with the smaller (<100 mm) unmarked salmon (mostly natural) that were captured primarily by beach seine. These findings about habitat use by small Chinook salmon are supported by other observations, including those of Panel members, that indicate small juvenile Chinook salmon are often associated with the shallow, low velocity water along the inside of river bends rather than at mid-channel or along the outside of bends where velocity and depth is greater (Schroeder et al. 2013, 2016, van Remoortere 2014, S. Gregory, OSU, personal communication (Sept 18, 2017)).

2.5 Juvenile Salmon Benefits Model (SBM)

Introduction

The Yolo Bypass Salmon Benefits Model (SBM) (Hinkelman et al. 2017) was developed as a means to evaluate potential benefits to Chinook salmon of six alternatives related to improving juvenile salmon entrainment and rearing in the Yolo Bypass area and subsequent survival at sea. This tool is being used to evaluate alternative notch performance with respect to RPA Action I.6, to restore floodplain-rearing habitat through the increase of seasonal inundation within the lower Sacramento River.

The SBM is a mechanistic, deterministic simulation model used to evaluate juvenile salmon growth, survival, variability in size and timing of ocean entry, and subsequent adult returns from juveniles passing through Yolo Bypass versus migration through the mainstem Sacramento River. The SBM is a production model rather than a life cycle model in that it estimates adult returns from a scenario but it does not use these adults to begin the next generation. Rather, the model starts with observed escapement of Chinook salmon by race (spring-run, fall-run, late-fall-run, winter-run, 1997-2011), calculates juveniles produced by the spawning escapement based on simple egg to fry relationships, then applies these juvenile abundance values to daily proportions of Chinook salmon by race estimated at the Knights Landing rotary screw trap (11 km above Fremont Weir). The daily proportion of juvenile Chinook salmon at Knights Landing entrained into Yolo Bypass is assumed equal to the proportion of Sacramento River water entering the Yolo Bypass that day for each alternative as predicted by the JEET model of entrainment (see preceding Section on JEET).

Juvenile salmon entering Yolo Bypass are assumed to stop migration and rear when suitable habitat is available in inundated areas adjacent to the Yolo Canal Complex, then resume migration depending on size, temperature, density of juveniles, and date. In contrast, fish remaining in the mainstem Sacramento River are assumed to continually to migrate through the lower river without stopping to rear. Survival and migration rates are based on empirical estimates of large hatchery tagged juvenile salmon passing through Yolo Bypass and the mainstem Sacramento River during 2012, 2013, and 2016. Modeled survival in Yolo Bypass is dependent on time in the floodplain (assumed daily survival rate: 0.99) and extended rearing leads to higher mortality, whereas survival in the mainstem Sacramento River appears to be linked to one of the three years of survival measurement (no change in rearing or migration time). Modeled rearing and growth of salmon along the Yolo Bypass floodplain leads to greater size when the fish reach Chipps Island compared with similar sized fish that remained in the mainstem Sacramento River and migrated without rearing. Survival at sea is based on an empirical relationship between salmon size when released into San Francisco Bay and subsequent return of adult salmon (tagged hatchery fall-run Chinook salmon, 1978-2011).

The survival benefit estimated by the SBM primarily reflects a trade-off between the risk of mortality by rearing for an extended period in Yolo Bypass to gain greater size versus the benefit of greater survival at sea associated with extended rearing and growth in Yolo Bypass. This tradeoff provides an important framework for evaluating benefits of habitat restoration in the lower river. However, the assumptions of the modeled functional relationships are critical, and empirical data are limited. The SBM is the only model reviewed by the Panel that attempts to evaluate the benefit of the six alternatives to juvenile Chinook salmon.

Model Appropriateness

The SBM is appropriate for highlighting the tradeoffs between rearing benefits and mortality risk in Yolo Bypass versus reduced mortality at sea associated with greater smolt size of fish that reared in Yolo Bypass. The model is also appropriate for evaluating potential relative benefits to each run of Chinook salmon in relation to the body size and migration timing of each run. The model assumes fish entrainment is proportional to flow, such that fish outcomes are directly linked to entrainment flows associated with each alternative. The model does not attempt to address unique characteristics of each alternative, such as location or configuration of the notch, or effects of fish size on their behavior. It is important for readers and policymakers to recognize that the outcomes of SBM depend upon the assumptions of the functional relationships that drive the model. Data are limited for many of the functional relationships, therefore the investigators conducted a sensitivity analysis to evaluate the effect of some key assumptions, such as daily survival of salmon rearing in Yolo Bypass. The investigators appropriately discussed a number of model assumptions and limitations.

The model has three submodels: an arrival submodel generating the size and arrival timing of fish to Fremont Weir, an entrainment submodel describing entrainment based on flow entering Yolo Bypass, and a survival submodel describing adult survival based on the tradeoff between mortality and growth in the floodplain vs. length-dependent survival in the ocean.
The <u>arrival submodel</u> is unique in that it is the only one reviewed that addresses arrival time, size of salmon, and race of Chinook salmon, based on data collected at Knights Landing. Size is important to characterize survival in the floodplain.

Salmon size is key to behavior of fish approaching and entering the notch, but neither this model nor any of the other models directly considered salmon size and behavior at the notch.
The entrainment submodel describes entrainment as a function of flow and does not differentiate well between alternatives other than indicating that more flow (Alt06) should pass more fish into Yolo Bypass. The submodel is likely not sufficient for determining the location and configuration of a notch in the weir. The model assumes entrainment is independent of size of Chinook salmon (see discussion of cross channel distribution of juvenile Chinook salmon in Technical Appendix). This submodel could be enhanced if integrated with the ELAM or Streakline entrainment models.

The survival submodel is unique and important because it is the only one evaluating benefits of floodplain vs. river passage in terms of adult returns. The submodel reasonably characterizes the general relationships between residence time, and growth and mortality in the floodplain and ocean. The model has five critical parameters: floodplain residence time, growth rate, migration survival, rearing mortality rate, size-dependent ocean mortality rate. These parameters interact multiplicatively so they have equal importance in determining benefits (Eq. 1). Comments on these elements follow.

- Floodplain residence time (T) – Extended residence time in Yolo Bypass depends on temperature (<20°C in the Toe Drain), fish length (<120 mm), availability of habitat, and a day of year exit time. These factors have been observed to some extent, but may vary by run type. Fish greater than 120 mm are assumed to migrate rather than rear along the floodplain. Missing from the residence time calculation is the contribution of flow through the weir notch. This term may be important and provide additional criteria for determining notch size and operation schedule. Residence time (migration rate) among fish remaining in the mainstem Sacramento River was assumed not to affect survival per kilometer of river travelled.
- Growth rate (g) – Growth rate is set from studies. A power function form is applied, which may potentially overestimate the rate. The key assumption of this model is that fish of all sizes grow by the same proportion in a day, such that larger fish will increase their size by a greater absolute amount. This simple relationship is assumed because more detailed information is apparently not available in the Yolo Bypass. Not included in the SBM model is the effect of forage base, salmon density, and temperature on growth. These factors change with season and with flooded area. While the floodplain area and fish territory requirements are calculated it is not clear from the documentation how or if they relate to growth rate.
- Migration survival (S_{km}) – Migration survival is measured with three years of data and applied according to water year. This survival is applied to large migratory salmon (>120 mm) and is assumed independent of the migration rates in the river and floodplain.

- Rearing mortality rate (*r*) – This rate is not measured and it is unclear from the model if migration-phase mortality rate, which has been estimated, is replaced by *r* or whether both rates are applied in the floodplain. In either case, this is a critical determinant of floodplain rearing benefit. The model simply assumes that salmon <120 mm experience a daily survival of 0.99 while rearing on the floodplain, such that smaller fish that rear longer experience lower survival. This rate may depend on amount of water flowing through the floodplain and many other factors but these complex relationships are not easily measured or included in the model. Avian predation is expected to be important in rearing mortality and should be highlighted since additional habitat actions in the Yolo Bypass may reduce this source of mortality.
- Ocean mortality rate (*k*) – The mortality rate expresses the effect of fish length on adult returns and is generated from a logit function applied to tagged hatchery fall-run Chinook salmon released into San Francisco Bay, 1978-2011. Under the parameter range explored, the function is equivalent to an exponential function, which simplifies the representation of how the processes interact (see Eq. 1 below). The function assumes ocean survival is only determined by fish size when entering San Francisco Bay. It does not address stock specific factors, date when fish enter the ocean, and the year-to-year variability in ocean survival. These factors are less known but are important for assessing the benefits of floodplain vs. river passage routes. Recent research on factors affecting the survival of central California Chinook salmon could be examined as a means to refine the survival relationship (e.g., Wells et al. 2012, 2016). This information would be especially important if there is an interaction between smolt size and ocean conditions, such that the size/survival relationship changes with ocean conditions.

The SBM is a deterministic model that does not yet incorporate variability and uncertainty associated with parameters in the simulations. For example, mean length of juvenile Chinook salmon by date and run was estimated from Knights Landing data for input into the model; the high degree of salmon size variability was not utilized (see Fig. 4 in the SBM report). Also, mean survival at sea in relation to smolt size was used rather than attempting to incorporate the great variability in the size/survival relationship shown in Fig. 7 in the SBM report. This means that the precision of predicted benefits associated with each alternative is much lower than that expressed in summary Figures 8-12 of the SBM report, which provide error bars stemming from 15 years of mean estimates. The investigators noted that future versions of the model could incorporate variability and uncertainty. More specifically, given the non-linearity of the function, it is highly sensitive to small changes in smolt size though the underlying data are not highly determined (i.e., high variance). As such, the model would benefit from exploring the sensitivity of the function with respect to the envelope of confidence of the fitted function (e.g., upper and lower bounds, or quartiles of fit) to provide a greater sense of uncertainty in the SBM.

The SBM model was also used to examine diversity by examining variability in size when juveniles enter the estuary and the timing at which juveniles enter the estuary. Such diversity can be important to stabilizing overall production of Chinook salmon (Schroeder et al. 2016). Creation of the large floodplain-rearing habitat supports growth of smaller juvenile Chinook and contributed to maintenance of life history diversity.

Model Effectiveness

The model is effective and useful in capturing the timing of entrainment of each run of juvenile Chinook salmon because it relies on 15 years of data collected at the Knights Landing rotary screw trap. This long-term monitoring effort has been very beneficial. There may be some error associated with identification of fish by run, but this error is likely small compared with other relationships or uncertainties in the model. Mean size of entrained salmon by date of migration is empirically derived from long-term monitoring, but the model has not yet attempted to incorporate variability in fish size on growth and mortality.

Model survival and migration rates are based on empirical estimates of large acoustically-tagged late-fall run juvenile salmon passing through Yolo Bypass and the mainstem Sacramento River during 2012, 2013, and 2016. The investigators linked values from these three years to other years, based on a statistical comparison (Euclidian distance) of seasonal hydrology among the years. This is a simple approach for expanding the modeled dataset to 15 years. Values from these three years therefore have a significant effect on model outcomes. Values from 2016 were unique: fast migration rates and higher survival in both routes. Migration rates (km/day) were slower and survival rates (per kilometer) were lower in Yolo Bypass than the mainstem Sacramento River. Importantly, these critical values were based on large juvenile salmon, which would benefit less from passage through Yolo Bypass compared with smaller salmon that would rear in the lower velocity, shallower floodplain habitat. Ideally, survival and migration rates would be based on information from smaller individuals. In response to the lack of empirical data, the model assumed a daily survival of 0.99 per day for fish rearing in Yolo Bypass and developed functional relationships to estimate potential rearing time based on several factors. These assumptions have a significant effect on model outcomes, i.e., survival when passing through Yolo Bypass and abundance of adult returns.

Survival of fish remaining in the mainstem Sacramento River appears to be based on the survival values derived from tagging large salmon in 2012, 2013, and 2016. Potential changes in survival of Chinook salmon remaining in the mainstem after water diversion into Yolo Bypass do not appear to be considered, apparently as a means to focus on changes in Yolo Bypass rather than on the overall population of Chinook salmon. Peak flows into Yolo Bypass occur when flows in the Sacramento River are extremely high and this spillage may have less effect on salmon remaining in the mainstem. But diversion of more moderate flows may have some effect on migration time, growth, and survival of salmon remaining in the mainstem Sacramento River (Perry et al. 2016).

The SBM model considers density dependence by incorporating a functional relationship involving territory size of salmon in the Yolo Bypass. Density dependence is an important factor affecting juvenile salmon growth, emigration, and survival, even in depleted populations (ISAB 2015). Passage of Chinook salmon into Yolo Bypass could have mixed effects on growth of the juvenile salmon passing through the mainstem. To further address this issue, the report could present graphs for each run of Chinook salmon showing residence time and growth of salmon in Yolo Bypass and the frequency at which capacity of habitat was reached in each location of the Yolo Bypass. At the public meeting, the investigators mentioned that capacity was rarely reached, a finding that was not clearly presented in the report. This finding, while considering uncertainty of model assumptions, is important because it supports the concept of trying to maximize entrainment of juvenile salmon relative to water.

Model Integration and Documentation

The model documentation, selection of submodel forms, and implementation of the model in NetLogo limited the transparency. The elements and properties of the model could have been improved by casting the model in an analytical form as illustrated below. An analytical representation illustrates the interactions and sensitivity of parameters and highlights both model properties and how the parameters might relate to possible future actions. For example, Eq. 1 below illustrates the tradeoff of growth vs. mortality rate and Figure 2 below illustrates how the rearing mortality rate affects the benefits of floodplain passage relative to river passage.

The model presents a number of metrics, many of which may be valuable for assessing dynamics of Chinook salmon on the floodplain, but they are not particularly useful for selecting between alternative notch configurations. Figure 12 of the SBM report contains useful information on relative change in adults (each alternative versus existing conditions) and synthesizes entrainment, floodplain rearing, and the survival submodels. Thus, relative change involves a mixed measure, which does not partition the individual effects. This measure might be problematic since the entrainment model is limited. By producing a benefits measure (e.g. Eq. 1) the survival submodel of SBM can be integrated with the other entrainment models. Additionally, as noted in the report, the model can be readily updated with new information and additional functional relationships, if desired.

Uncertainties in the other key model parameters (see model discussion below) are not well explored. It is unlikely that the uncertainties can be readily resolved. Effects of freshwater experience on saltwater survival are difficult to quantify and are an active area of research. However, an expanded discussion and further analysis of the uncertainties in how freshwater factors affect ocean survival is important. These carryover effects of experience in one environment on mortality in the next is an active topic in the ecological literature. The important point is that floodplain passage may not be beneficial for all runs and in all years. For example, the model indicates large late-fall Chinook salmon do not have an overall survival advantage because they are entrained into the Bypass at a large size and do not benefit from growth (Figure 12 in Hinkelman et al. 2017)).

Analytical Form of Mortality Submodel

The following analytical form of a mortality submodel highlights the Panel's reading of the SBM properties and parameters. In this example, growth and ocean mortality equations are simplified, expressing growth as linear and ocean survival as exponential with length. The Panel suggests these simplifications result in no difference in the model results while simplifying the presentation. In the example, carrying capacity is assumed not limiting.

- River passage survival: $P_{river} = 0.44$
- Yolo passage survival: $P_{yolo} = 0.39$
- Yolo rearing survival: $R_{yolo} = \exp(-rT)$ with r survival rate and T floodplain residence time
- Fish length exiting floodplain: $L = L_0 + gT$ with g growth rate and L_0 length entering floodplain
- Ocean survival: $O_j = O_0 \exp(kL_j)$ for passage route j with O_0 base ocean survival and k incremental length benefit on survival
- The adult survival A_j from juvenile Fremont Weir passage to the adult returns to the river for passage route j: $A_j = P_j R_j O_j$
- Benefit of Yolo passage: $B = \frac{P_{yolo} R_{yolo} O_{yolo}}{P_{river} O_{river}}$ signifies relative increase of fish survival if entrained into Yolo Bypass compared to continuing in river

The net benefit B of Yolo passage vs. river passage is defined as the ratio of adult returns from fish reaching the Fremont weir as

$$B = \frac{P_{yolo}}{P_{river}} \times \frac{\exp(-rT)}{1} \times \frac{O_0 \exp(k(L_0 + gT))}{O_0 \exp(kL_0)} = C \exp((kg - r)T)$$

where $C = P_{yolo} / P_{river}$.

The benefit of yolo passage then depends on whether $kg > r$. Figure 2 (below) illustrates the nature of the benefit with residence time T using estimates from Hinkelman et al. (2017) with k = 0.025 (mm^{-1}), g = 1 (mm d^{-1}), $C = S_{yolo} / S_{river} = 0.88$ and r = 0.01, which equates to a one day survival of 0.99. The figure illustrates two important properties of the SBM. First, floodplain residence is only beneficial when $kg > r$, which simply states that the rate of gain in ocean survival from floodplain growth must exceed the mortality rate on the floodplain. Second, because Yolo migration survival is lower than in the river migration survival, i.e. $C < 1$, the fish must remain on the floodplain for a critical time length of time, perhaps a few weeks if the mortality rate is high.

The properties of Eq. 1 are essentially equivalent to the SBM survival dynamics and express the benefits of the Yolo Bypass and the importance of the effects of the important parameters *k*, *g*, *r* and *T*.

The total relative benefit (TB) of Yolo entrainment for an entire run can be expressed

$$TB = \frac{fA_{yolo} + (1-f)\,A_{river}}{A_{River}} = f\,(B-1)+1$$

where *f* is the fraction of Knights Landing fish entrained into Yolo Bypass. The terms can represent either at annual or daily averages for a specific run. The *f* term could be supplied by other entrainment models or the flow proportion model used in the report and by CDWR.

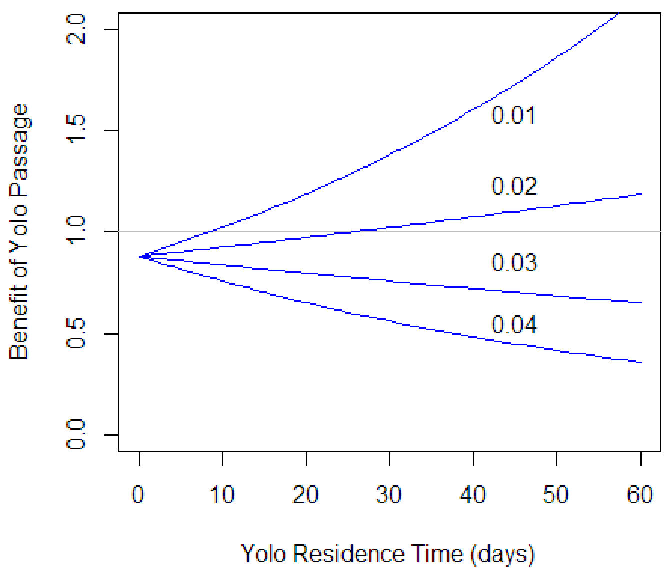

FIGURE 2. Relationship of Yolo passage benefits as a function of floodplain residence time and mortality rate *r* in 0.01 to 0.04 day^{-1}. Based on Eq. 1 using parameters extracted from the SBM (Hinkelman et al. 2017).

2.6 Adult Fish Passage (YBPASS)

Introduction

The goal of the adult salmon and sturgeon passage tool (YBPASS) is to:

> *"use modeled water depths and velocities to determine the frequency that adult fish passage criteria are met for planned facilities at the Fremont Weir."*

This effort supports Reasonable and Prudent Alternative (RPA) Action I.7 to improve fish passage through the Yolo Bypass and several studies that indicate that hydrologic connectivity is a major bottleneck for successful migration (e.g., Sommer et al. 2014). The YBPASS Tool was developed to evaluate six alternatives considered by the EIS/EIR for the Yolo Bypass Project. The species of interest are winter-run and spring-run Chinook salmon, steelhead, and green sturgeon, all of which are protected under the Endangered Species Act.

The fish passage tool compares modeled hydraulics (using a one dimensional HEC-RAS model) with fish passage criteria (velocity, depth, channel width, and channel length) that were established by the project team to maximize the probability of successful passage by all target species. The YBPASS Tool report is the only analysis examined by the Panel that evaluates upstream passage of salmon, steelhead and sturgeon. Currently, passage by these fishes is blocked or significantly constrained for a majority of flow conditions (Sommer et al. 2014).

Model Appropriateness

Salmon

The report states that the adult fish passage criteria used in this analysis are conservative because they want to ensure safe passage by the "weaker swimming fish" of each species. This approach could potentially mislead decision makers because the criteria are too conservative for all species. For example, the report states that fish passage criteria are met only 18% to 23% of the days depending on the alternative, implying significant adult migration constraints for all species. Passage criteria were primarily applied to the species most limited by migration conditions (large bodied acipenserids), rather than to individual species with better swimming performance. This all-in-one approach limited the evaluation of passage conditions for each species, which is necessary to develop engineering solutions for safe fish passage. In other words, if the passage constraints (i.e., velocity, depth) were relaxed, it is highly likely that the performance metrics for salmonids would markedly improve.

Realistic fish passage criteria should be identified for each species and used with modeled hydraulics to evaluate passage for each species separately, depending on species-specific criteria and migration timing. This information can then be used to better design structures that would allow safe passage. For example, the minimum depth criterion of 3 ft (if channel is <60 ft long) or 5 ft (channel >60 ft) are much deeper than the minimum depth of one foot recommended by NMFS (2011) for salmonids. Failure to meet the 3-5 ft depth criteria was the primary factor causing overall passage criteria to not be met (failure on 106-111 days per season depending on alternative evaluated).

Steelhead and Chinook salmon have burst speeds (duration <15 s) of 13.7-26.5 ft/s and 10.8-22.4 ft/s, respectively (Aaserude and Orsborn 1985, Powers and Orsborn 1985). Prolonged swimming speeds (15 s to 200 min) are reported to be 4.6-13.7 ft/s and 3.4-10.8 ft/s for steelhead and

Chinook salmon, respectively. Burst and prolonged swimming speeds are influenced by many factors, as discussed by Powers and Orsborn (1985). The velocity criterion used in the YBPASS Tool are conservative but suitable if the velocity encountered by migrating salmon is 6 ft/s over a ~60 ft reach or 4 ft/s for a longer reach (~100-200 ft). The report should identify the distances that fish would encounter high velocities when passing through the transport channel and weir notch of each alternative; Table 3 in the report only shows channel widths associated with each alternative.

Holding and resting areas should be evaluated in conjunction with the duration of flows that inhibit migrations. Are there any structures in the transport channels that would block high velocities and provide holding and resting areas? Salmon and steelhead are good at holding in the river, then resuming migration when flow conditions improve. Periodic flows that support passage may lead to successful migration of most fish compared with a prolonged period of inhibitory flows. As noted in the report, temperature and oxygen content of the water should be considered since water quality can inhibit migration or cause mortality if severe.

Sturgeon

Although the model criteria were developed to be conservative (i.e., specific to green sturgeon, using white sturgeon as a proxy, which is both larger-bodied and lesser in swimming ability than other targeted taxa), the model report and the supporting information provide insufficient information to determine the validity of the parameters used to accommodate acipenserids. For example, the underlying basis for the model report is a Department of Water Resources report (DWR, 2017b). In this report, the underlying scientific basis for coming to conclusions about passage design criteria are listed as FETT 2015 and FETT 2016. Upon further investigation, it has been concluded that FETT 2015 is an unpublished spreadsheet and FETT 2016 is an 8-slide presentation. The key bullets from FETT 2016 were from slide 4, which indicted that design parameters of minimum depth, width, and velocity were unknown (i.e, “?” or literally question marks), and the following bullet points: “Needed additional design guidance for sturgeon; Literature review for Sturgeon Passage; Sought input through Sturgeon Project Work Team.” The subsequent slide had parameter values for depth, width, and velocity, but there was no indication as to how those values were determined. Reference is also made to Turek et al. (2016) about sturgeon design criteria, using shortnose and Atlantic acipenserid species as surrogates. In this case, depth and width parameters are well documented, but velocity is listed as unknown with yet additional surrogate species used to justify reported values. That said, based on first principles of body size of adult sturgeon, the design requirements make sense as a function of body length (and tail beat frequency, amplitude, etc). Furthermore, the maximum velocities are supported by the studies of Webber et al. (2007), who showed that sections of low velocity are needed for rest and recovery, and that maximum velocities of 4.5 ft/s (140 cm/s) are required for lake sturgeon (Peake et al. 1997) and pallid sturgeon (USFWS 2014) alike. At minimum, further evidence should be provided as to the design criteria developed by FETT.

Model Effectiveness
The fish passage model adequately considered the overall migration timing of each species. However, as stated in the report, passage of steelhead in October, winter-run and spring-run Chinook salmon in May, and sturgeon migration in May were not evaluated because flow conditions were considered too low during these periods. As noted above, the YBPASS tool should be used to evaluate passage of each species based on their unique migration timing, hydrology during the period of migration, and species-specific migration criteria.

Model Integration and Documentation
The YBPASS tool has a number of assumptions and limitations discussed in its documentation. In some cases the presentation of results are limited by the assumptions of the model (e.g., relaxed passage criteria for salmonids would result in different results). The HEC-RAS model used by YBPASS is a well-tested and expedient model to estimate flow velocities in the vicinity of this type of structure. The model is well documented and easy to apply without extensive model set up required. While this analysis only requires the difference in water surface between the Sacramento River and Yolo Bypass to estimate the velocity through the notch structure, some level of QA/QC may be warranted to address the potentially significant backwater effects due to Sutter Bypass (described in Section 2.1 above). For consistency it would be worth evaluating if the number of days the passage criteria is met would vary significantly due to the complex stage discharge relationship revealed by the recent 2017 study.

The report recognized that the passage criteria were conservative, leading to a large number of days when passage was inhibited. Nevertheless, as stated above, the report should use more realistic criteria for each species. This may facilitate engineering solutions to improve passage for specific species and, given the significant differences between salmonids and acipenserids in swimming performance, separate passage solutions may be required. Designing to the lowest common denominator (i.e., *Acipenseridae*) results in overly conservative solutions for salmonids. While the Panel recognizes that resource agencies are limited in approach by regulatory requirements, more flexible solutions for ensuring adult passage of various species are possible.

Further, it is the understanding of the Panel that several adult passage solutions are currently under consideration in Yolo Bypass. These analyses, including those in the YBPASS effort, should be integrated to include the Wallace Weir improvement activity and other passage efforts, such as the Ag Crossing 2, 3, and 4. In other words, assessing Fremont Weir passage in isolation may not yield sufficient benefits if other locations remain problematic.

Other points of consideration are also warranted. One, the report itself does not present the details of the model domain or the suite of results typically available from HEC-RAS so it is difficult to assess efficacy of summary statistics. Two, the summary statistics lack sufficient detail to determine the reasonableness of the negligible differences between alternatives. Three, the model assumptions, with respect to swimming performance and passage criteria cite a NMFS 2011 publication (pg. 3, 4), but the bibliography lists a NMFS 2009 proceeding. There are other issues with the model documentation; however, the Panel recognizes that this critical concern can be addressed in the detailed design phase. Further, passage is presented as one of many considerations, and therefore its findings or lack thereof are not critical to decision making. If this observation is incorrect, further work is needed to better articulate potential differences in water year type, alternative passage threshold criteria, and lower invert elevations.

Conclusion
If the central question is whether YBPASS Tool is adequate to differentiate between alternatives with respect to differences in infrastructural design, the answer is presumably yes. However, too few data are presented to conclude that actual differences do not exist (as the difference of 18-24% between alternatives of successfully meeting criteria is arguably within margin of error). The HEC-RAS modeling approach is generally appropriate and technically sound and thus the failure to show differences, real or not, is likely around the design specifications and passage criteria. Simple simulations and sensitivity analyses should be able to expose any deficiencies in design or criteria. These results were not presented, however, and thus it is difficult to assess the quantitative and qualitative uncertainty inherent to the results.

There are a range of structural and non-structural features that could be incorporated into a final design to reduce the average velocity across the proposed structure and provide refuge or resting areas.

2.7 Agricultural Economic Impacts (BPM)

Introduction
The Bypass Production Model forecasts the number of acres for each crop and agricultural production quantities. The model, developed by the authors with the underlying approach applied in many other contexts and venues, was created specifically for the Yolo Bypass region and results for each of over 450 parcels can be identified. Agricultural economic outcomes are measured in terms of farm net income and crop acreage. Project alternatives are compared to the ExConn/No Action Alternative and are evaluated using hydrologic conditions from 1997-2012. Differences between project alternatives are driven by the last day wet for each field, as projected by the TUFLOW model, which is a function of the different flow conditions implied by each project alternative.

Overall, the BPM is useful and appropriate for evaluating differences in agricultural production between project alternatives. The agricultural economic model is linked to physical conditions that are determined by hydrologic conditions in the Yolo Bypass (last day wet for each farm field) and projects relevant economic outcomes in an appropriate way. Weaknesses of the approach, as presented in the review materials, include the absence of any consideration of uncertainty and lack of documentation for some aspects of the modeling approach. Providing additional information on the relative magnitude of the effects of the project alternatives, the inter-annual variability of the projected impacts, and the spatial distribution of the impacts of each project alternative would make the results of the analysis more useful and easier to interpret.

Model Appropriateness

1. How appropriate are the models' spatial and temporal scales (i.e., periods simulated, duration of simulations, time step used) to compare performance of the alternatives?

The BPM is run at the appropriate spatial and temporal scale. The model is run to generate annual crop production and land allocation results, which is an appropriate way to compare alternatives. The BPM generates results based on conditions observed over a select set of test years, 1997-2012. It is unclear whether this set of years accurately characterizes the distribution of hydrologic conditions that can be expected over the life of the proposed project. Therefore, reported "average annual change" are only the average over the selected years, not necessarily the expected future change from baseline conditions.

The spatial resolution of the BPM is a strength of the modeling approach. Model output is at the field level, which allows for the identification of which fields are impacted by each alternative. Though the analysts reported these findings in their presentation to the review Panel, the differences in the spatial distribution of impacts between alternatives was not well-treated in the report. The Panel recommends that the final EIR/EIS contain a more detailed description of where the projected agricultural impacts occur within the Yolo Bypass. This information could be useful in identifying any disproportionate impacts (i.e., if only a few property owners have large impacts versus many property having small impacts) and possible mitigation measures.

2. How appropriate are the models for evaluating and discriminating among the alternatives?

The agricultural economic results are differentiated by the projected last day wet (LDW) on each parcel. The LDW varies according which project alternative is modeled. Therefore, the methods used are able to appropriately discriminate between alternatives. The LDW input to the BPM is output from the TUFLOW model.

3. Are the data used in the models sufficient to justify the assumptions, parameter estimates, and conclusions?

The only observed data used in analysis is field-level land use from 2005-2009. The remainder of the quantitative information in the BPM are model outputs (last day wet and crop yield) elicited qualitative judgments from farmers and extension agents (field preparation time and dry-down adjustment factor).

4. How well do the models explicitly incorporate variability and uncertainty associated with parameters in their simulations?

Some treatment of potential variability of the results is illustrated by presenting the impacts for individual years in a test period (1997-2012). While these results are useful in showing a few potential outcomes, the range of years may not reflect the true distribution of flows that can be expected in any given year. Therefore, labeling the "average" annual change in the results in somewhat misleading. This representation of the inter-annual variability is used in other analyses in the EIS/EIR as well, so it is not unique to the agricultural economic analysis. It is beyond the scope of this analysis to determine if the period of performance is representative under current or future hydrologic conditions, though the period does include some categorical wet and dry years.

Uncertainty in the model is not incorporated and all results are presented as point estimates only. Again, this non-treatment of model uncertainty is found in other analyses in the EIS/EIR as well, so it is not unique to the agricultural economic analysis. However, there are several sources of possible uncertainty that are present, but not treated, in the analysis. First is prediction error associated with the Positive Math Programming approach. PMP generates an optimized prediction of farmer behavior (acreage, crop mix, input use, etc.) using parameters from structural models derived from technical production relationships. The prediction model parameters are then calibrated by reproducing observed outcomes in a test year (in this case, average values from outcomes observed over 5 years 2005-2009). The calibrated model is then used to generate a forecast. Mathematical programming models do not estimate the standard error associated with such predictions and previous studies typically do not attempt to quantify them (e.g. Howitt et al 2012, included in the supplemental materials). It is, however, possible to generate estimates of this prediction error by doing sensitivity analysis. For example, in this case, there is observed data from 5 years (2005-2009). The model can be calibrated to each of the five observed years and then used to forecast each of the four remaining years in the data set. Each forecast could be compared to each set of observed outcomes to generate a prediction error. There would therefore be 20 "residual values" that could be used to describe the uncertainty associated with a typical forecast.

A second source of uncertainty is uncertainty in the input data. The differences between alternatives are driven by outputs from two models. The TUFLOW model gives the last wetted day on each parcel. TUFLOW output appears to be deterministic and the documentation for the agricultural economic analysis does not describe how results might be affected by uncertainty in this input to the BPM. The DAYCENT model gives a relationship between the loss in crop yield and the last wetted day value. The DAYCENT model is based on a statistical (regression) model and can provide estimates of uncertainty surrounding the yield-loss curve parameters. The agricultural economic analysis does not describe how uncertainty in yield loss estimates might affect the reported results.

Model Effectiveness
The model does not explicitly address issues related to fish distribution, timing, growth or survival and therefore was not evaluated as such.

Model Integration and Documentation
8. How appropriate is the model integration for evaluating and discriminating among the alternatives?

The agricultural economic results are differentiated by the projected last day wet (LDW) on each parcel. The LDW varies according to which project alternative is modeled. The LDW input to the agricultural economic model is based on outputs from the TUFLOW model. Implicit within this approach is that the range of alternatives within TUFLOW reflect the range of hydrologic conditions to be incurred into the future. Not included in this analysis are simulations of potential future hydrologic conditions with respect to wet to dry year dynamics. Further, it is also implicit that the differences between modeled alternatives against base case conditions are sufficiently precise to be used to discriminate between such alternatives. However, given that these differences are modest, it is difficult to tell if such quantitative differences are qualitatively different.

9. How well are the proposed analytical tools defined and discussed?

One shortcoming of the analysis, as presented, is that the most of the documentation for the models used in the agricultural economic analysis is contained in materials not included in review material, supplemental material, or background documents. For example, most of the analysis used in the EIR/EIS appendix I2 is developed in a consultant's report (Yolo County 2013). It is not clear whether the models and analysis in this report are peer-reviewed or not, but the review Panel did not review them.

11. Are the conclusions drawn justified by the model output?

The model outputs are straightforward differences between the projected base case and projected agricultural output and associated economic impacts for each project alternative. Implicit in this approach is that the base case is a reasonable representation, and that modeled differences are discernable. Given that the magnitude of change is modest, interpretation of model results should be used with caution as the projected differences may very well be within the margin of error, so to speak. Given that the model has no formal means of quantifying uncertainty, it is impossible to know if the results are or are not in fact within this margin. The documentation in Appendix I1 does not explicitly draw additional conclusions.

12. When models are integrated and/or linked, how well are assumptions and uncertainties accounted for and communicated?

Appendix I1 briefly acknowledges that the BPM model results are dependent on TUFLOW model outputs and therefore sensitive to assumptions in the TUFLOW model. However, the appendix does describe or discuss these assumptions or describe how they might affect the results. The documentation does not describe how assumptions and uncertainties in the DAYCENT crop yield model affect model results.

13. How well do the models characterize and convey uncertainties?

Discussion of uncertainties is absent from the documentation. All model inputs and outputs are treated as deterministic and no attempt is made to describe possible sources of variation in the results.

14. How clear are the presentation of results?

Overall, the results of the analysis are straightforward. These are the change in crop acreage and agricultural production value from a projected baseline to a projected outcome under each alternative.

The results are presented for each alternative in a relatively clear manner. Clarity would be improved with two minor revisions to the results. First, the results of the baseline scenario (i.e., the ExCon/NAA) should be summarized so that the magnitude of the effects of each project alternative can be conveyed. It may also be useful to report the percent change in each metric in Tables 7-12 (note that the tables currently include this percentage change only for NED Farm Income). It appears that the economic effects of all of the alternatives are quite small on average, but more information would help the reader evaluate this. Second, the tables should contain more information on the inter-annual variability of the results. Currently only the average of the 16 year simulation is reported in Tables 7-12. The maximum and minimum values should also be reported as well as results for a representative wet year and dry year. The two figures provided for each alternative are useful for interpreting this inter-annual variability, but the additional results in tabular form are needed. Third, a more detailed description of the spatial distribution of the projected agricultural impacts should be provided. This information, in the form of maps of projected impacts, was provided in the presentation to the review Panel and is useful in interpreting the scale of the results and informing possible mitigation measures.

3. Recommendations

It should be recognized that this body of scientific investigation represents a remarkably comprehensive assessment of options for a notch at Fremont Weir. This is very important since the success of the implemented notch will depend on a well-resolved understanding of the flow structure and fish behavior at and adjacent to the notch, as well as the ability to adaptively manage the notch and its operation as the uncertainties identified in this review are resolved. The main shortcoming of this evaluation effort is the lack of integration between different teams, primarily due to the diverse sources of information (not all directly focused on the EIR/EIS) and lack of time for synthesis. Due to these time constraints in the preparation of reporting, the full potential of the remarkably detailed field observations of hydraulics and juvenile salmon behavior with fine scale hydrodynamic modeling has yet to be realized. Since the models are developed and data is available, the Panel does not consider some additional integration work to be a major undertaking in terms of time or personnel effort compared to the investment to date.

3.1 Tool Specific Recommendations

Hydrodynamics Models

Simulating flows in the Sacramento River and Delta using hydrodynamic models is a very challenging problem, particularly at the fine scale required to assess the various proposed configurations of the modifications to Fremont Weir. The modeling completed to date has made major progress but could benefit by including data from the most recent field campaign conducted in support of the Critical Streakline evaluation. There are advantages in running different hydrodynamic models to address this challenging simulation problem, particularly when a very significant investment such as a notch in Fremont weir is being evaluated. The following recommendations should be considered for both near-term (i.e. prior to completion of the EIR/EIS) efforts in support of implementing the notch at Fremont Weir.

1. The hydrodynamic alteration of Fremont Weir to entrain fish into the Yolo Bypass. This requires close collaboration modeling and field measurements are critical to the evaluation of the potential effectiveness of the proposed between the field scientists and modelers. This integration would be an ideal demonstration of the '*Modeling Collaboratory*' concept proposed by Medellin-Azuara et al., 2017. The Panel believes that this could be conducted quickly and efficiently. The agencies may also wish to consider adding another hydrodynamic model – perhaps one that is already covering the region of interest (examples include TUFLOW, RMA-2, UNTRIM, or DELFT-3d). This recommendation does not imply that U^2RANS or SRH-2D are inadequate but rather it would allow the various model assumptions, closure relations and grids to be tested rigorously. This analysis should also explore the 'optimum location' of the weir as

predicted by the semi-empirical (Streakline) method of the USGS. This additional step is warranted for a project of this magnitude where the fine design details of location, alignment and size of the inlet could make the difference between project success and failure. Based on the findings of this integration of modeling and field measurements, the design team may wish to assess the value of a physical model of the immediate locale of the diversion structure to confirm the numerical model findings about diversion alignment and design details. This effort could also be used to quantify the uncertainty and expected variance in duration and water surface elevations at the selected notch diversion.

2. The Panel was not charged with selecting a preferred notch alternative. However, based on the comprehensive review of notch alternative analyses, the Panel recommends that the final design include flexibility to allow for future modifications of depth and width of the diversion (perhaps 2 or 3 gates at different crest elevations).

3. Fish behavior is very sensitive to the volume of flow being diverted. In addition, fish behavior is sensitive to flow discontinuities such as eddies and vortices as well as local strain and/or shear caused by flow discontinuities. The Panel disagrees with the conclusion that the 2-D hydrodynamic model is adequate, unless the fish are known to frequent close to the surface of the Sacramento River. It all depends on the question that is posed by the fish behavior and ELAM experts. If the fish are capable of dynamic responses to changes in the flow characteristics such as strain (or lateral shear), eddies or upwelling at the weir crest, the 3-D hydrodynamic model would be warranted. Based on the USGS analysis, the location of the diversion along the weir could be critically important if the desire is to maximize entrainment.

Salmon Benefits Model (SBM)

The SBM highlights the tradeoff between the reduction in survival while growing in Yolo Bypass versus the resulting increase in ocean survival as a result of entering the ocean at a larger size. Whether the tradeoff is beneficial depends on assumptions of the growth and survival rates in the two environments, which are based on limited data. This is an important concept for decision makers because it highlights the potential actions to improve growth and survival in Yolo Bypass and subsequent adult returns. Current models do not attempt to incorporate alternative scenarios, such as enhanced rearing habitat in Yolo Bypass, and the only parameter that currently differentiates potential outcomes is discharge through the Yolo Bypass. Additional scenarios, such as enhanced habitat actions that could occur in Yolo Bypass are not yet incorporated, but should be considered in an adaptive management framework to enhance growth and survival of salmon in the Yolo Bypass. For example, having the ability to simulate the effect of discharge volume on floodplain fish residence time or the effects of direct habitat enhancements, such as adding structure (e.g., large wood) and complexity (pools) on providing shelter to rearing juveniles from piscivorous fishes and birds, could quantify the resulting response in both higher growth rates and survivorship. The lack of model extensibility, in other words the incorporation of difference scenarios such as potential enhancements, do not preclude the model's use in its current state. Rather it is to say that more complex actions within an adaptive management framework would require a more complex and extensible model.

Adult Fish Passage (YBPASS)

The Panel suggests that the selection of fish passage alternatives be based primarily on the passage of juvenile salmonids rather than on adult passage, and secondarily sturgeon passage. The YBPASS tool, as presently configured and applied, does not readily discriminate between these alternatives. Since there is strength in the use of HEC-RAS to evaluate depth and velocity around finely resolved features, the Panel suggests that once an alternative is selected for juvenile salmonid passage, a more precise approach to evaluating alternative engineering solutions be developed to facilitate safe passage of each species at a given location. Habitat that supports holding and resting should be identified in Yolo Bypass.

Critical Streakline Analysis

The model provides valuable information on the complexity of flows and fish distributions in the western portion of the weir. The analysis did not address effects of notches for the central and eastern alternatives. The estimates of entrainment along a series of locations along the western weir are based on the assumption that the fish follow flow into a notch, independent of how the hydrodynamics might be altered by the notch presence. These assumption cannot be evaluated without either hydrodynamic modeling or observing the flow field after the notch is constructed. For these reasons, predictions from the existing Streakline model are of limited value for decision making on notch location and of less value for selecting a notch configuration.

ELAM

The model, in combining CFD and fish behavior models, predicts entrainment for specific notch locations and configurations. In principle, it is the most appropriate model for selecting a notch in the Fremont Weir. However, there several caveats to consider in using the model. Firstly, the boundary conditions for CFD simulations were not fully resolved resulting in some uncertainty in representing the flow field that fish would experience. Secondly, the model only characterized fish movement with the follow-the-flow behavior (i.e. B1). Given these caveats, it appears to the Panel that in its current calibration the ELAM model acts very much like the Streakline model except the fish and flow distributions were simulated, rather than observed.

In essence, it appears the two models currently apply the same behavior rules using different levels of detail. Streakline applies a simple B1-type behavior to observed data, ELAM applies a complex B1 behavior to simulated date. Because of the equivalence of algorithms, further development of the Streakline approach is not likely to improve on the existing ELAM model. However, parallel development of models of differing complexity can be of value especially if the developers collaborate in the process and compare results. The Panel recommends that the value of further development of either model depends on whether uncertainty on decisions of site location and notch configuration will be reduced significantly. The Panel's suggestions on this matter are elaborated in the Executive Summary. However, if the entrainment models are to be used to refine a notch design the Panel recommends that the ELAM model be improved in collaboration with the Streakline model team. In particular, first steps could involve collaboration in calibrating the existing CDF and further calibration of ELAM behavioral rules using available data from Sacramento River fish movement studies.

Additionally the Panel recommends further field sampling to clarify the behavior of small salmonids. The Panel notes that while all investigators recognized the uncertainty in entrainment related to salmon size and behavior, none directly addressed the issue of smaller Chinook salmon being concentrated along the inside bend in the lower Sacramento River. Smith et al. (2017) noted that USACE sampling found few small Chinook along the river nearshore, but the Panel understands that this sampling was conducted by electrofishing which may catch fewer smaller Chinook compared with the beach seine (Friesen et al. 2007). Details about this electrofishing effort were not presented. Small juvenile Chinook salmon have been captured by beach seine on the lower Sacramento River according to the USFWS beach seine surveys described in section 2.6. Given the importance of entraining smaller Chinook salmon into Yolo Bypass, the Panel recommends that field sampling occur along the inside of select river bends and that entrainment of small salmon be considered in a monitoring and an active adaptive management framework. Additionally, it may be prudent to consider engineering solutions that enhance entrainment of smaller Chinook salmon.

Materials Provided for Review

Cut and paste from: http://deltacouncil.ca.gov/yolo-bypass-salmon-habitat-restoration-and-fish-passage-analytical-tool-independent-scientific

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