Department of Water Resources
FloodSAFE Environmental Stewardship and Statewide Resources Office
Fish Passage Improvement Program

Fremont Weir Fish Passage Proof of Concept

Final Engineering Report

This report was prepared by

Randy Beckwith, Senior Engineer, Water Resources
Trevor Greene, Engineer, Water Resources
Colin Hanley, Engineer, Water Resources

for

The Division of Flood Management

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The technical information contained in this report has been prepared by the following licensed engineers:
Fremont Weir Fish Passage Proof of Concept

Introduction

The Proof of Concept was initiated by DWR’s Division of Flood Management (DFM) to investigate the feasibility of providing fish passage at Fremont Weir by making modifications to the weir and constructing channels from the Sacramento River to the Tule Canal (the east side drainage for Yolo Bypass). The initial goal was to provide 1,000 cubic feet per second (cfs) of water into Yolo Bypass year round, meaning that no more than 1,000 cfs could enter the bypass at high river stages and no less than 1,000 cfs when stages were low in the river. Additionally, one of the main problems that DFM wanted to solve was how to dissipate the energy of 15 to 20 vertical feet of water entering the bypass (when the river is at a high stage and the bypass is not) through a channel while maintaining favorable passage conditions for upstream migrating salmonids and sturgeon.

This report details the design and modeling work that was completed to prove the concept. The results show that providing a connection from the Sacramento River to the bypass will work hydraulically and meet most of the initial goals for fish passage. The maximum flow into the bypass was limited to 1,000 cfs, but the goal of providing 1,000 cfs at low stages in the river was determined to not be feasible. It is possible to get 1,000 cfs into the bypass at low river stages, but this would require extensive lowering and widening of the existing channels downstream of the project site. For our design, the downstream channel was modified as little as possible and the flow into the bypass at low river stages was maximized as much as possible.

Note: All elevations are in the NAVD88 datum.

Goals, Assumptions, and Constraints

Goals

- Provide a year-round flow connection from the Sacramento River to Yolo Bypass at all river stages
- Design fish passage through open channels to provide many diverse fish passage routes and to enhance the passage of sediment and debris.
- Prove that a geomorphically stable channel can be built to pass flow under a high head scenario (when the stage is high in the Sacramento River, but not overtopping the weir, and the Tule Pond and Canal are at low stages)
- Determine geometry, dimensions, invert elevation, slope, and materials for the fish passage channel(s)
- Determine the types of gates that can be used to shut off flow into the bypass
- Follow accepted fish passage design guidelines
- Provide passage for upstream migrating fish species, namely salmonids and sturgeon by:
  - Providing at least 2 feet of water depth within constructed channels
  - Ensuring that water velocities are lower than the swimming capabilities of the design fish species
- Maximize flow through the fish passage channel at low river stages
- Minimize the potential for excessive erosion or sedimentation
- Provide a connection between Fremont Weir’s concrete apron and a fish passage channel
• Minimize the amount of modification to the Tule Pond and Canal as much as possible
• Minimize upstream fish migration delays due to project operations, such as switching flow from one channel to another
• Provide vehicle access across the channels at river stages below 28.8 feet
• Use realistic Manning’s n values for the modeling of all channels (existing and proposed)
• Keep design components below the elevation of the top of the weir
• Minimize flood impacts
• Keep the design as simple as possible

Assumptions
• 1,000 cfs is less than the capacity of the Tule Canal. Therefore, this project will not inundate any of the floodplain downstream
• The topographic data that we have is of good quality
• The Manning’s n values that we use for the existing Tule Canal are appropriate
• Using only four years of stage data (which is all that we have) for the Tule Pond is appropriate
• Data from the Tule Pond water level logger is accurate
• A minimum of 2 feet of depth is appropriate for sturgeon (regulatory agency criterion is 1 foot of depth for adult anadromous salmonids)
• Velocities near the banks and bottom of all the channels will be much lower than the average channel velocities shown in the models.
• Providing at least 2 feet of depth 89% of the time at low river stages is sufficient
• The Tule Pond and the wooded area downstream of the Tule Pond can be excavated

Constraints
• Limiting the fish passage flow into Yolo Bypass to a maximum of 1,000 cfs when the river stage is below the top of the weir to avoid downstream floodplain inundation
• Limited to using available topographic and bathymetric data (however current, accurate, or minimal it may be)
• Limited time to complete the Proof of Concept design investigation

Fish Passage Criteria and Recommendations

Swimming speeds for Chinook salmon and steelhead are well documented. The widely recognized reference, the *Fisheries Handbook of Engineering Requirements and Biological Criteria* by Milo Bell (1991), gives sustained (prolonged) and darting (burst) swimming speeds for Chinook salmon and steelhead. Sustained swimming mode is used for passage through difficult areas and can be maintained for minutes. Darting swimming mode is generally used for feeding or escape, and therefore is a single effort and is not sustainable for extended periods of time. For Chinook salmon, sustained swimming speed is between 3 – 11 feet per second (fps) and darting speed is between 11 – 22 fps. For steelhead, sustained swimming speed is between 5 – 15 fps and darting speed is between 15 – 27 fps. The handbook does not provide any swimming speeds for sturgeon (Bell 1991).

The swimming speeds represent the ability of salmonids to negotiate natural or engineered open channels and fish passage structures. DFG has developed fish passage criteria (2002) and NMFS has developed fish passage guidelines (2001) for adult anadromous salmonids. Both are intended for fish
passage through culverts. However, the culvert criteria can be used to inform the design of other fish passage structures. DFG’s maximum cross-sectional velocity criteria for passage through culverts are shown in Table 1. NMFS guidelines are the same. The criteria are conservative and intended for the smaller and weaker fish of the population. The criteria are applied to the entire length of a culvert

<table>
<thead>
<tr>
<th>Table 1: Culvert Length vs Maximum Average Water Velocity for Adult Anadromous Salmonids (DFG 2002)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Culvert Length (feet)</td>
</tr>
<tr>
<td>--------------------</td>
</tr>
<tr>
<td>&lt;60</td>
</tr>
<tr>
<td>60-100</td>
</tr>
<tr>
<td>100-200</td>
</tr>
<tr>
<td>200-300</td>
</tr>
<tr>
<td>&gt;300</td>
</tr>
</tbody>
</table>

or other hydraulically designed structures (DFG 2009). The minimum depth criterion for adult anadromous salmonids is one foot (DFG 2002, NMFS 2001). The depth criterion is applied to culverts, roughened channels, and other hydraulically designed structures for fish passage, and is the greatest depth in the channel or culvert cross section (DFG 2009).

For sturgeon, a 2007 sturgeon swimming study report by DWR and UC Davis provides recent swimming ability data and passage recommendations for adult white sturgeon. The report indicated 7.0 fps for maximum water velocity through a slot and 3.3 feet or greater for depth as criteria for white sturgeon passage. The report also suggested that white sturgeon would be an appropriate surrogate for the federally listed green sturgeon in terms of swimming performance and physiological and behavioral parameters until any future green sturgeon studies develop species specific criteria.

Based on the published salmonid passage criteria and the specific sturgeon study results, our design aimed to keep average channel velocities below 6 fps and depths greater than 2 feet. Velocities near the banks and bottom of all the channels will be much lower than the average channel velocities, and could be even lower if larger roughness elements, such as boulders, are added. Therefore, given that the fish passage channels should be designed to meet these criteria, the channels can be expected to be negotiable for adult salmonids and sturgeon, especially given the design roughness features that create hydraulic diversity within each channel.

Hydrology

Sacramento River stage data at Fremont Weir for years 1984-2000 was downloaded from the California Data Exchange Center (CDEC) and parsed into months, and monthly stage exceedance percentages were calculated (Table 2). As shown in the table, 12 feet is exceeded at least 89% of the time in all months. It was assumed that providing 2 feet of depth at least 89% of the time is sufficient (91% or greater for October – May), and therefore the channel invert elevation was set at 10 feet.

Initial Modeling and Design

Initially, we aimed to solve the problem of how to handle a high water surface differential between the Sacramento River and Yolo Bypass. This problem occurs when the Sacramento River is at a high stage
Table 2: Monthly Stage Exceedance Percentages for the Sacramento River at Fremont Weir

| SACRAMENTO RIVER AT FREMONT WEIR - MONTHLY PERCENT TIME STAGE IS EXCEEDED (1984-2000) |
|----------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|
| NAVD88  | JAN  | FEB  | MAR  | APR  | MAY  | JUNE | JULY | AUG  | SEPT | OCT  | NOV  | DEC  |
| >10'    | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% |
| >11'    | 100% | 100% | 100% | 99%  | 99%  | 98%  | 99%  | 98%  | 100% | 91%  | 92%  | 98%  |
| >12'    | 100% | 98%  | 100% | 97%  | 93%  | 89%  | 93%  | 98%  | 100% | 91%  | 92%  | 98%  |
| >13'    | 96%  | 96%  | 100% | 90%  | 83%  | 76%  | 85%  | 89%  | 96%  | 77%  | 72%  | 93%  |
| >14'    | 89%  | 93%  | 94%  | 84%  | 70%  | 62%  | 80%  | 85%  | 84%  | 46%  | 60%  | 85%  |
| >15'    | 79%  | 83%  | 86%  | 72%  | 55%  | 49%  | 75%  | 76%  | 64%  | 24%  | 34%  | 67%  |
| >20'    | 44%  | 61%  | 60%  | 38%  | 18%  | 20%  | 6%   | 6%   | 3%   | 0%   | 9%   | 25%  |

(but still below the top of Fremont Weir) and the bypass is not flooded. After analyzing four years of data (October 2002 – June 2006) collected by a water level logger in the Tule Pond (about 4,500 feet south of the east abutment of Fremont Weir) and comparing it to stage data for the Sacramento River, it appears the maximum known water surface differential between the Sacramento River and the Tule Canal is 13.51 feet. In addition, based on initial HEC-RAS modeling of our design, the water surface elevation in the Tule Pond is approximately 17 feet at 1,000 cfs. Since we needed our design to have a water surface elevation of 32.8 feet at Fremont Weir for 1,000 cfs of flow, our design would need to overcome a differential of 15.8 feet, which is more conservative than the differential based on water level logger data.

To overcome this water surface elevation differential, we developed a design for a rock ramp roughened channel fishway. This fishway design overcomes the differential using three 900 foot long rock ramps constructed in series at a 0.55 % slope. The rock ramps are separated by 300 foot long pools constructed at a 0.00 % slope. The invert of the channel was set at 26.8 feet at Fremont Weir and the fishway would be shallow (6 feet deep) and wide (94 feet wide). The fishway would operate at stages above 28.8 feet, so there would be a minimum depth of 2 feet. This design resulted in average channel velocities between 1.9 and 6.7 feet per second.

Next, we tried to design a second channel to pass fish for the remaining stages below those in which the rock ramp fishway would operate. To get the water surface in the second channel up to 28.8 feet at the weir for 1,000 cfs of flow, we had to severely narrow the channel cross-section. For example, one model run had a 500-foot-long, 15-foot-wide rectangular channel at the weir transitioning to an earthen trapezoidal channel with a 10-foot bottom width and 1:1 side slopes, connecting to the Tule Canal approximately 15,000 feet downstream. One of the negative outcomes of narrowing the channel cross-section was that flow into the channel at low river stages was very low. Flow in the channel was only 50 cfs when the river was at elevation 15 feet (5 feet of depth in the fish passage channel). Based on having to severely narrow the channel cross-section, use steep side slopes, and have low flows into the bypass at low river stages, we decided to abandon the two channel idea and increase the number of channels to three.

Summary of Hydraulic Modeling

The following sections describe the hydraulic modeling that was completed for the three channel fish passage concept. The channels are identified as low-stage (up to 20 feet), mid-stage (20 to 28.8 feet), and high-stage (28.8 feet and above).
Modeling Goals and General Model Assumptions
The overall goal of the modeling was to prove that a three channel configuration would be feasible to improve fish passage at Fremont Weir. The channels were designed so that a maximum of 1,000 cfs would pass through each channel. As the Sacramento River rises and the low-stage channel reaches 1,000 cfs, that channel will be gated off, and the mid-stage channel gate will open (Table 3). Similarly, when the mid-stage channel reaches 1,000 cfs, it will be gated off, and the high-stage channel gate will be opened. As the stage in the Sacramento River drops, the process reverses (Table 4). The high-stage channel is designed to pass 1,000 cfs as the weir begins to overtop. The channels are designed so that approximately 2 feet of depth in each channel at Fremont Weir would be provided when its gate is opened.

Table 3: Gate Operations When Sacramento River Stage is Rising from a Low Elevation (<15 feet)

<table>
<thead>
<tr>
<th>Channel</th>
<th>Water Surface Elevation at Fremont Weir (NAVD 88, feet)</th>
<th>Gate Opens</th>
<th>Gate Closes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low-stage</td>
<td>Open below 20</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Mid-stage</td>
<td>28.8</td>
<td>Open above 28.8</td>
<td></td>
</tr>
<tr>
<td>High-stage</td>
<td>28.8</td>
<td>Open above 28.8</td>
<td></td>
</tr>
</tbody>
</table>

Table 4: Gate Operations When Sacramento River Stage is Falling from Flood Elevation (>32.8 feet)

<table>
<thead>
<tr>
<th>Channel</th>
<th>Water Surface Elevation at Fremont Weir (NAVD 88, feet)</th>
<th>Gate Opens</th>
<th>Gate Closes</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-stage</td>
<td>Open above 28.8</td>
<td>28.8</td>
<td></td>
</tr>
<tr>
<td>Mid-stage</td>
<td>28.8</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Low-stage</td>
<td>20</td>
<td>Open below 20</td>
<td></td>
</tr>
</tbody>
</table>

In addition to maximum capacity goals, a second goal was to provide as much flow as possible at 2 feet of depth in each channel, when the gates are initially opened. A third goal was to ensure that the maximum velocities were passable for the design species: salmonids and sturgeon.

The three fish passage channels were modeled in the U.S. Army Corps of Engineers one-dimensional hydraulic modeling program, HEC-RAS. A different geometry file was created for each of the channels. For simplicity, the three fish passage channels were assumed to be the same length, approximately 3,700 feet. All three channels connect to the northern end of the existing Tule Pond. There is a wooded area south of the Tule Pond that is currently much higher in ground surface elevation than the invert of the Tule Pond. It was assumed that this area would be excavated to match more typical cross-sections upstream and downstream of this area.

Since the low-stage channel invert is set at 10 feet at Fremont Weir, the Tule Pond and Canal will need to be excavated so that at low river stages water will flow downstream in the channel (the existing Tule Pond invert is ~12 feet). The slope of the low-stage channel, 0.00006, was determined by connecting the invert at Fremont Weir (10') to a cross-section approximately 13,000 feet downstream of the weir. In HEC-RAS, a 25-foot-wide channel was excavated through the Tule Pond/Canal cross-sections to match the design slope of the low-stage channel.
Currently there are multiple scour channels oriented in a southeast direction from near the weir connecting to the Tule Pond. Survey data for these channels were not available, so they were not included in the modeling. While one of the new fish passage channels is flowing, it is possible there may be some backwater effect into these channels as well as into the other new fish passage channels. The models were run assuming steady-state conditions, and did not account for potential backwater in these channels.

Survey Data used for HEC-RAS cross-sections
The HEC-RAS cross-sections were created from several DWR surveys completed in the early 2000’s. Some of the cross-sections were unfinished (only a partial cross-section was surveyed) or appeared to have errors in the data. These were not included in the models. The survey data was imported into AutoCAD and alignments for each cross-section were drawn. Points within 25 feet on each side of the cross-section were plotted in Microsoft Excel and were then manually edited for input into HEC-RAS. The most downstream cross-section in the model is approximately 2,500 feet north of the I-5 crossing, near the USGS gaging station. The furthest upstream cross-section that is based on survey data is located at the northern end of the Tule Pond. All cross-sections in the models north of the Tule Pond were based on proposed channel designs. The farthest upstream cross-section for all the models is located at Fremont Weir. Since the spacing of cross-section data was not ideal, the built-in interpolation tool in HEC-RAS was used to interpolate between cross-sections so the model would run properly. Interpolations were used on the existing cross-sections as well as the design reaches.

Boundary Conditions
The models were run assuming subcritical flow, therefore only a downstream boundary condition was required. For a flow of 1,000 cfs, a water surface elevation of 14.6 feet (NAVD 88) was used for the downstream boundary condition, based on data from the USGS gaging station (north of I-5) downloaded from CDEC. Since the USGS gage is not rated below 1,000 cfs, the normal depth boundary condition was used for all other lower flow model runs. A downstream slope of 0.0007 was used, based on the average invert slope from the downstream boundary to approximately 12,000 feet upstream.

Manning’s n Values
A Manning’s n value of 0.035 was assumed for Tule Canal and Tule Pond cross-sections, based on typical book values. Manning’s n values for each of the three new fish passage channels were configured during the design process, as discussed in the sections below. The final values varied between 0.025 and 0.052 for the low-stage channel, 0.042 and 0.065 for the mid-stage channel, and 0.052 and 0.068 for the high-stage channel (See Design Elements section for roughness element descriptions). To simplify the modeling, the Manning’s n value of a cross-section was assumed to be constant for all flows.

Modeling Design Methods
HEC-RAS geometry files were created for each of the three fish passage channels. An iterative process was used to find an ideal cross-section shape for each channel. Since the models were run assuming subcritical flow, HEC-RAS calculated water surface elevations starting from the downstream end of the model, working upstream. The models ended at Fremont Weir, so it was assumed that adequate flow could be provided from the Sacramento River through a channel upstream of Fremont Weir. The channel upstream of the weir as well as the details of the connection to the Sacramento River, were not investigated in this phase (although a connection is shown on the design drawings for clarity).

If the initial cross-section dimensions did not provide adequate results, the cross-sections were modified slightly and the model was re-run. Besides cross-section dimensions, Manning’s n values were adjusted
for the cross-sections to achieve the design goals. Over 70 HEC-RAS geometries were created to optimize the configurations of the three fish passage channels.

Discussion of the Three Design Channels
Since each fish passage channel will have a gate at Fremont Weir, a rectangular cross-section shape was used at this location. After 100 feet of channel length, a transition of 200 – 300 feet (depending on the channel) from the rectangular shape to a trapezoidal cross-section was used. The rectangular and transition sections are made of concrete, and then embedded with roughness elements (e.g. cobbles and boulders) in the channel bottom and walls in order to achieve the Manning’s n required by the design.

The trapezoidal sections have a constant Manning’s n until 600 – 800 feet (depending on the design) upstream of the tie-in with the Tule Pond, where the channel shape and roughness will transition to meet the Tule Pond cross-section. Since each of the three fish passage channels has different Manning’s n values for the sections, some field studies and/or literature review will be necessary to determine rock size and vegetation required to achieve the design n value.

The following paragraphs describe each of the fish passage channels. For more details and drawings of the designs, please see the conceptual design drawings (Appendix A).

Low-stage Channel
The best low-stage channel design was determined to be a 100-foot-long, 26-foot-wide rectangular channel, followed by a 200-foot-long transition to a trapezoidal channel with a 26-foot-wide base and 1.5:1 side slopes. The channel is gradually graded from a location 800 feet upstream of the Tule Pond tie-in point, to meet the existing cross-section. The downstream slope of the low-stage channel is 0.006%.

The Manning’s n for the rectangular section is 0.025 and the upstream transition section will have Manning’s n values steadily increasing to 0.052, the roughness of the trapezoidal cross-sections. The 800-foot-long downstream transition has a Manning’s n gradually decreasing to 0.035, the value of the Tule Pond.

Mid-stage Channel
The best mid-stage channel design is a 100-foot-long, 15-foot-wide rectangular channel, followed by a 300-foot-long transition to a trapezoidal channel with a 26-foot-wide base and 1.5:1 side slopes. The channel is gradually graded from a location 800 feet upstream of the Tule Pond tie-in point, to meet the existing cross-section. The downstream slope of the mid-stage channel is 0.223%.

The Manning’s n for the rectangular section is 0.042 and the upstream transition will have Manning’s n values steadily increasing to 0.065, the roughness of the trapezoidal channel. The 800-foot-long downstream transition has a Manning’s n gradually decreasing from 0.052 to 0.035, the value of the Tule Pond.

High-stage Channel
The best high-stage channel design was determined to be a 64-foot-wide rectangular cross-section with a 10-foot-wide, 2-foot-deep low-flow channel in the center transitioning to an 86-foot-wide trapezoidal shape with a 10-foot-wide low-flow channel. The rectangular cross-section is 100 feet long, followed by a 300-foot-long transitional section. The trapezoidal channel is gradually graded to meet the Tule Pond tie-in point, starting 600 feet upstream of the tie-in point. The downstream slope of the high-stage
channel is 0.461%. It should be noted that the channel invert is above the existing ground elevation over a significant length. Therefore, a significant amount of fill will be needed to construct the channel.

The Manning’s n for the rectangular section is 0.052 and the upstream transition has Manning’s n values steadily increasing to 0.068, which is the roughness of the trapezoidal channel. The 600-foot-long downstream transition has Manning’s n gradually decreasing to 0.035, the Manning’s n of the Tule Pond.

**Flows**

HEC-RAS modeling results were used to create the relationship between stage and flow for each channel (Figure 1). The low-stage channel was designed to be as wide as possible while allowing only 1,000 cfs at its maximum operable depth of 10 feet. Modeling results show that when there is 2 feet of depth (elevation 12 feet) at the weir the low-stage channel will flow at 20 cfs. This flow increases to 50 cfs at 3 feet of depth, 200 cfs at 5 feet of depth, and 500 cfs at 7.5 feet of depth. At 10 feet of depth (elevation 20 feet in the river) flow in the low-stage channel is 1,000 cfs. At this stage, the mid-stage channel will have a depth of 2 feet at the weir and the low-stage channel gate will close and the mid-stage channel gate will open (Table 3). Flow in the mid-stage channel will be 50 cfs shortly after the gate is opened. This flow increases to about 100 cfs at 3 feet of depth, 225 cfs at 5 feet of depth, and 500 cfs at 7.5 feet of depth. At 10 feet of depth (elevation 28.8 feet in the river) flow is 1,000 cfs. At this stage, the high-stage channel will have a depth of 2 feet at the weir and the mid-stage channel gate will close and the high-stage channel gate will open. Modeling results show that the high-stage channel will flow at 45 cfs when there is 2 feet of depth at the weir. This flow increases to 140 cfs at 3 feet of depth, 360 cfs at 4 feet of depth, and 650 cfs at 5 feet of depth. At 6 feet of depth, when the river stage is at the top of the weir, flow is 1,000 cfs.

**Profiles**

Water surface elevation profiles and velocity profiles over a range of flows are provided at the end of this report (Figures 2 - 7). At 1,000 cfs, velocities range from <1.0 to about 3.7 fps in the low-stage channel, <2.0 to about 6.3 fps in the mid-stage channel, and <1.5 to about 4.1 fps in the high-stage channel. Note that the pattern of the profiles for 1,000 cfs differ from the lower flow profiles because a boundary condition based on a known water surface elevation was used for 1,000 cfs in the model. For all other flows, a normal depth boundary condition was used in the model. Normal depth is the depth of flow in a channel when the slope of the water surface and channel invert is the same, and water depth is constant.

**Design Elements**

From the modeling effort, we came up with the design elements for the three channels. For the low-stage channel, the rectangular concrete section, the concrete transitional section, and the trapezoidal section will have a natural substrate (except at the gate structure) called engineered streambed material (ESM). The ESM will be a mix of particle sizes ranging from large cobbles (10 inch) down to sand and silt (Table 5), and will be the same for all three channels. The upstream transitional section will gradually increase in roughness in the downstream direction. This increased roughness will be due to vegetation growing on the bed of the channel (types of plants to be determined) which will increase the Manning’s roughness from 0.025 to 0.052. The banks of the trapezoidal channel will be composed of a bankline rock mix, with particles ranging from 1.3 foot facing rock down to sand and silt (Table 5). The bankline rock mix will be the same for all three channels. In addition, the banks of the trapezoidal channel will be vegetated (types of plants to be determined). The rectangular channel is gated at the weir with a wall
extending from elevation 20 feet up to the top of the weir at 32.8 feet (see Gates section and design drawings).

For the mid-stage channel, the rectangular concrete section, the concrete transitional section, and the trapezoidal section will have a substrate of ESM (except at the gate structure). The ESM will have some larger boulders randomly scattered to provide additional roughness and resting areas for upstream migrants. The upstream transitional section will gradually increase in roughness in the downstream direction. This increased roughness will be due to vegetation growing on the bed of the channel (types of plants to be determined) which will increase the Manning’s roughness from 0.042 to 0.065. This vegetation will continue into the trapezoidal channel. The banks of the trapezoidal channel will be composed of the bankline rock mix. In addition, the banks of the trapezoidal channel will be vegetated (types of plants to be determined). The rectangular channel is gated at the weir (see Gates section and design drawings).

For the high-stage channel, the rectangular concrete section, the concrete transitional section, and the trapezoidal section will have a substrate of ESM (except at the gate structure). The ESM will have some larger boulders randomly scattered to provide additional roughness and resting areas for upstream migrants. The upstream transitional section will gradually increase in roughness in the downstream direction. This increased roughness will be due to vegetation growing on the bed of the channel (types of plants to be determined) which will increase the Manning’s roughness from 0.052 to 0.068. This vegetation will continue into the trapezoidal channel. The banks of the trapezoidal channel will be composed of the bankline rock mix. In addition, the banks of the trapezoidal channel will be vegetated (types of plants to be determined).

The rectangular section of the high-stage channel will have a 2-foot-tall, 10-foot-wide gate (see Gates section and design drawings) to shut off flow in its low-flow portion, but in lieu of a full channel gate, a flashboard type dam was assumed to be a much cheaper option to shut off flow in the upper portion of this channel.

<table>
<thead>
<tr>
<th>Material Mixes (for all constructed channels)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineered Streambed Material (ESM) Mix</td>
</tr>
<tr>
<td>7 parts 2.5” very coarse gravel to 10” cobbles</td>
</tr>
<tr>
<td>4 parts 1.26” to 2.5 &quot; very coarse gravel</td>
</tr>
<tr>
<td>5 parts 0.31” med gravel to 1.26” coarse gravel</td>
</tr>
<tr>
<td>2 parts 0.079” very fine gravel to 0.31” fine gravel</td>
</tr>
<tr>
<td>2 parts silt to 0.079” very coarse sand</td>
</tr>
</tbody>
</table>

**Design Layout**

The three channels run side-by-side near the east levee of Yolo Bypass and converge at the Tule Pond approximately 3,700 feet downstream of the east abutment of the weir (see design drawings in Appendix A). The rectangular channels are currently separated but could be brought closer together (potentially sharing concrete walls). The low-stage and mid-stage rectangular channels will have bridges.
across them to allow vehicle access to the interior of the bypass. The high-stage channel will have a low-water crossing a short distance upstream of the weir.

We did not do much work designing a channel from the Sacramento River to the Fremont Weir. This is because the main emphasis was proving that fish passage could work from downstream of the weir to the weir itself. For the sake of clarity, we do show a simple channel from the river to the weir on the design drawings.

**Operations**

One major drawback of the three channel design is fish delay associated with flow changes due to the operation of the three channels. For example, as stage increases to 20 feet in the Sacramento River, flow of 1,000 cfs is gated off in the low-stage channel and a much smaller flow of 50 cfs will begin flowing through the mid-stage channel after its gate is opened. In addition to the flow being greatly reduced, upstream migrating fish in the 3,700 foot long low-stage channel will be delayed as they try to find the open mid-stage channel. This problem is one that we would like to solve or at least minimize in the next design phase.

To aid in gate operations, it may be possible to use River Guidance Plots, available at the California Data Exchange Center, which provide predictions of future stages at Fremont Weir.

**Gates**

Flow into the low-, mid-, and high-stage channels will be controlled by gates at Fremont Weir. For this feasibility-level analysis, we researched a variety of gate types and actuation systems to determine if we have a feasible concept. The goals for the gate design were to present some feasible alternatives that reliably route water to the desired channel, minimize the potential for debris accumulation and hydraulic impacts during weir overtopping, minimize aesthetic impacts (avoid a large superstructure above the existing weir), minimize maintenance requirements, control the gates from a remote location, and keep construction and maintenance costs in the range of feasibility.

**Gate types**

A variety of gate types would satisfy the goals for this project. These include vertical lift gates, hinge crest gates, Obermeyer gates, radial gates, and miter gates. We spoke with several gate manufacturers who were confident that they could provide gates that would satisfy the goals of the project.

*Low-stage channel gate (height = 10 feet):*

A hydraulically actuated vertical lift gate could work for this application. In the closed position the gate would rest on the channel invert. To allow flow into the channel, the gate would be lifted up so the top of the gate would rest slightly below the existing top of Fremont Weir.

Hydraulically or air actuated hinged crest gates are another feasible alternative. The hinge could either be along the channel invert, raising the gate up to close off the channel, or the hinge could be placed at the top of the low-stage channel near elevation 20 feet, and lowering the gate to close the channel.

*Mid-stage channel gate (height = 14.8 feet):*

The hinged crest gate is a good alternative for this application, with the hinge along the invert of the channel at elevation 18 feet. The top of this gate would be flush with the adjacent crest of the existing
weir. The gate would nest along the invert of the channel when open, and rotate up to close. Vertical lift gates and radial gates are not recommended for this channel because they would extend above the weir crest elevation in the open position.

**High-stage channel gate (height = 2 feet):**
The purpose of this gate is to prevent water from entering the high-stage channel during stages of insufficient depth for sturgeon to swim (assumed to be less than 2 feet). The gate would only be actuated (closed) during stages from 26.8 to 28.8 feet. This would be a good case for a hydraulically or air bladder actuated hinged crest gate.

**Gate actuation**
Three actuation alternatives were researched: hydraulic, air, and electrical activation. Due to the requirement for an electrical gate actuation system to be placed above the flood stage and directly above the gate structure, this actuation type is not recommended. Hydraulic and air actuation allow for a low-profile actuation and both involve similar design requirements. The power supply and auxiliary equipment for either system would be placed in a building above the flood stage. This equipment could be placed on a small pad adjacent to the top of the existing east levee. Hydraulic fluid or air lines would be routed from the auxiliary equipment building to each individual gate, where hydraulic cylinders or Kevlar air bladders would open and close the gates. Both hydraulic and air actuation systems can be operated from a remote site. The hydraulic actuation system provides additional redundancy with the capability to utilize accumulators, devices that store energy, to actuate the gates in the event of a loss of power. This would provide a margin of safety during high flow events, where the low- and mid-stage channel gates will be required to be closed.

**Conclusions**
Fish passage at Fremont Weir is feasible. We designed three channels that will allow fish passage at almost all stages in the Sacramento River (the low-stage channel will not meet the adult anadromous salmonid depth criterion at stages below 11 feet). Depths in the designed channels are greater than 2 feet and average velocities are less than 6.3 fps, meaning that the channels will be negotiable for salmonids and should be negotiable for sturgeon, especially given the diversity that each channel will provide to these fish species.

The high-stage channel is able to handle a stage differential of over 15 feet from the river to the Tule Canal and, due to its wide and shallow cross-section, will keep average water velocities under 4.2 fps. The engineered substrate of this channel and the other two channels is designed to remain stable and is composed of a mix of particle sizes from 10” cobbles down to sand and silt, with larger boulders randomly scattered to provide additional roughness and resting areas for upstream migrants. The bankline rock mix for the channels will ensure that the banks will not erode. Both the bed and bank material mixes will allow vegetation to grow, which will provide additional roughness. The mid- and low-stage channels have maximum average velocities of 6.3 and 3.7 fps, respectively. The low-stage channel is designed to pass as much water as possible at low river stages and still provide 1,000 cfs when flowing at its maximum capacity. The low-stage channel will pass 50 cfs when the river is at 13 feet, and river stages are greater than that approximately 72% of the time in October and more in all other months. When the river is at 15 feet, the low-stage channel will pass 200 cfs. Velocities at higher flows in all of the channels should be enough to keep sedimentation to a minimum.
There are some issues to work out with this design, such as the delay of fish migration and changing flow regimes due to gate operations. New bathymetric surveys and detailed modeling will result in an accurate estimate of the flow capacity of the Tule Canal which may be larger than expected, possibly giving us a larger flow to work with for fish passage and more flexibility in design. More flow may allow us to develop a feasible two channel design, which would help to reduce the delay problem.

We have completed a conceptual design for fish passage at Fremont Weir, which is a starting point for future design work. More work is needed to refine this concept and determine a preferred alternative for fish passage at Fremont Weir.

**Next Steps**

Below is a list of tasks that we see as important for the immediate future of this project:

- Investigate other design configurations (see Steve Thomas’ design in Appendix B).
- Collect more detailed and current topography and bathymetry data for the northern Yolo Bypass. Along with floodplain elevation points, cross-sections in the Tule Canal should be re-surveyed due to discrepancies among the previous surveys. It is possible this has already been done and the data may just need to be purchased.
- To improve the boundary conditions for the low-flow model runs, a stage vs. flow relationship for flows less than 1,000 cfs should be developed for the channel at the location of the USGS gage north of I-5, the downstream boundary of the models.
- Model the Tule Canal and Toe Drain to determine the capacity to see if we can increase the maximum flow through the fish passage channels.
- Investigate the impact of fish passage flows on downstream water operations in Yolo Bypass.
- Since the Manning’s n values were estimated at 0.035 for the existing Tule Canal cross-sections, this value should be verified (or adjusted to the correct value). Water surface elevations throughout the lower reach of the model should be recorded over a range of flows, to calibrate the model in this area and determine appropriate n values.
- Investigate lowering the high-stage channel invert by several feet to determine if a two channel design is feasible.
- Seek review and detailed input from fishery biologists and experts in fish passage design.
- The connection between the Sacramento River and the Fremont Weir was not investigated in this phase (although we do show a potential design for this channel). Modeling (possible 2-D or 3-D) of this area may be necessary in a future phase to ensure proper hydraulics at the Sacramento River and fish passage channel interface.
- Investigate influence of flood flows and Sutter Bypass input on project components.
- Examine overlapping the channel gate operations more (e.g. providing 3 feet of depth before opening the next channel).

- Minimize the fish delay problem in the closed channels.

- Determine preferred gate alternatives.

- Design a connection from the apron of Fremont Weir to the low-stage channel.

- Determine the approximate project costs and earthwork quantities.

References


Figure 1: Flow vs Stage Relationship for Fish Passage Channels at Fremont Weir (based on HEC-RAS modeling)
Figure 2: Water Surface Elevation Profiles for the Low-stage Channel
Figure 3: Water Surface Elevation Profiles for the Mid-stage Channel
Figure 4: Water Surface Elevation Profiles for the High-stage Channel
Figure 5: Velocity Profiles for the Low-stage Channel
Figure 6: Velocity Profiles for the Mid-stage Channel
Figure 7: Velocity Profiles for the High-stage Channel
Appendix A

Conceptual Design Drawings
LOW-STAGE CHANNEL
SCALE: 1" = 1'-0"
STA 214+82 TO 307+10

MID-STAGE CHANNEL
SCALE: 1" = 1'-0"
STA 214+82 TO 307+40

HIGH-STAGE CHANNEL
SCALE: 1" = 1'-0"
STA 214+82 TO 307+40

TULE CANAL CONVEYANCE IMPROVEMENT
SCALE: 1" = 1'-0"
STA 214+82 TO 214+92
Appendix B

Comments
The design report was reviewed by Steve Thomas (NMFS Fisheries Engineering Team) and George Heise (DFG Fisheries Engineering Team). Below are comments received from them regarding our conceptual design for Fremont Weir fish passage.

Comments from Steve Thomas

To expedite a response I want to provide some informal comments here – topics for discussion and for your consideration. We can discuss next week and later I can provide more formal comments if you want.

Firstly, it looks like you put a lot of effort into optimizing the concept. The plots and drawings help show how the concept would work. As you and I already discussed, there are a couple downsides to the concept, namely, stepped discharges going up and down with flow and the possibility of stranding fish as flow is cut off from channels. I was wondering if the lower channels could be used while the upper channels were in service to reduce the cycling of channels (the lower channel would rarely or never be dewatered) and make up water could be discharged through a lower channel while passage is provided at higher channels. The attached diagram (BELOW) is one concept I’ve been running through my head. 

To explain the diagram, at lower stages flow is confined to the lowest channel only (Channel 1) up to your target flow (1,000 cfs). As the river stage rises, an undershot gate on Channel 1 (Gate 1) closes partially to reduce flow in Channel 1 and a gate opens on the middle stage channel (Channel 2, Gate 2). Fish passage can continue through Gate 1 if the head across the gate is limited to 1 – 1.5 feet. Channel 2 discharges into Channel 1 so Channel 1 does double duty and isn’t dewatered as the Sac River stage increases. The same thing happens with Channel 3 as stage increases. I haven’t analyzed the hydraulics over the expected range of flow, but I thought an arrangement like this could have several benefits. I think you’d need to develop the flow scheme and design the channels to meet those goals such as you did with the other design.

A technical-type of fish ladder would probably work better for this type of layout, but sturgeon don’t do well in technical ladders, and I’ve never seen a technical ladder with a 1,000 cfs
capacity. For a nature-like fishway you’d need wide sweeping bends in the channel and enlarged turning pools or confluences to dissipate energy and avoid distracting turbulence.

Brent Mefford at USBR’s TSC in Denver designed a high flow ladder for use at a dam in southern California. I and some others explored the abilities of that ladder concept to work over a range of design flows at another dam in so. Cal. Brent posted a video of a model of his design (Robles) on his web page. It looks promising but is unproven in the real world.  
http://www.usbr.gov/pmts/hydraulics_lab/bmefford/index.html

Randy also discussed the project with George Heise (DFG Fisheries Engineering Team) and learned that he will not be able to provide detailed comments at this time. He did say that he thought that providing better fish passage at Fremont Weir is a very important project and that he generally supported our concept, but has concerns about the switching of flow from one channel to another and possibly stranding fish in the channel that has been shut off. He also said that he did speak with Steve Thomas and thought that Steve’s idea is a good one. Randy discussed with George his concerns about how Steve’s fishway would operate, or handle flows once the weir is overtopped, since we still may want to pass sturgeon through a fishway when stages are possibly up to 3 feet over the top of the weir.

In addition, Stein Buer spoke with Robin Kulakow, Executive Director of the Yolo Basin Foundation. She voiced her concern regarding the impact that adding flow into the Yolo Bypass at Fremont Weir would have on the Yolo Bypass Wildlife Area. In the summer, Toe Drain water levels need to be low enough to allow the wildlife area ponds to drain efficiently before the wet season to facilitate food production, control noxious species, etc..