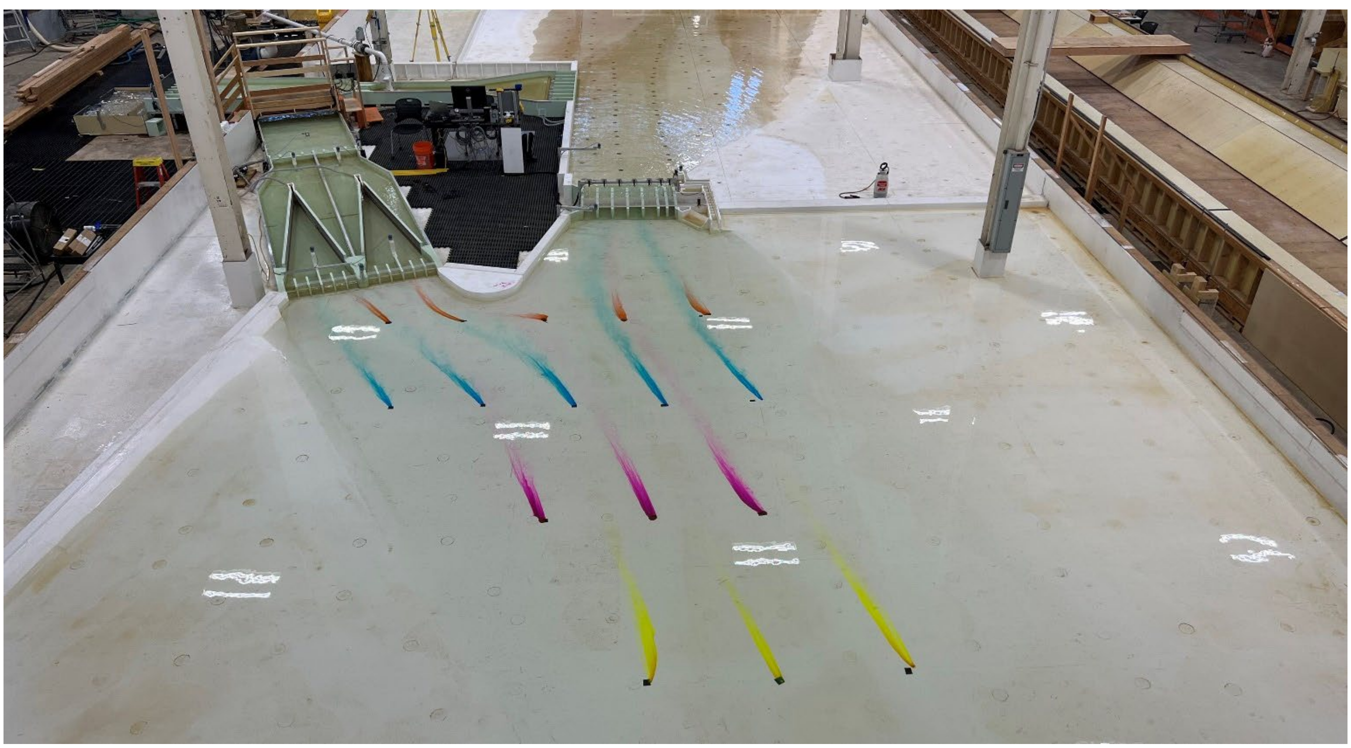
BUREAU OF RECLAMATION

Hydraulic Laboratory Report HL-2022-02

San Joaquin River Restoration Program – Reach 2B – Modeling Results and Data

Mendota Dam Fish Screen and Compact Bypass Control Structure

Central Valley Project, Delta Division, California
California-Great Basin Region 10



U.S. Department of the Interior

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Acknowledgments

Thank you to the many interns, rotation engineers, team members, SJRRP staff, and especially to the Hydraulics Laboratory construction staff for their endless efforts to keep this project moving forward despite continual changes and modifications throughout the modeling efforts.

Hydraulic Laboratory Reports

The Hydraulic Laboratory Report series is produced by the Bureau of Reclamation's Hydraulic Investigations and Laboratory Services Group (Mail Code 86-68560), PO Box 25007, Denver, Colorado 80225-0007.

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Cover Photo: Dye testing on the SJRRP 1:24 physical model.

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Glossary

Term	Definition
AWS	Auxiliary Water Supply
CBCS	Compact Bypass Control Structure
CFD	Computation Fluid Dynamics
cfs	cubic feet per second, ft^3/sec
DAQ	Data Acquisition
FRF	Fish Recapture Facility
MPFS	Mendota Pool Fish Screen
RFF	Reverse Flow Facility
SJR	San Joaquin River
SJRRP	San Joaquin River Restoration Program
TSC	Technical Service Center
WSE	Water Surface Elevation

Abstract

This report summarizes the findings of multiple modeling efforts that were completed at the Bureau of Reclamation Hydraulics Laboratory in Denver, CO. Three main modeling efforts presented include a 1:12 physical model of the Compact Bypass Control Structure, Fish Ladder and Auxiliary Water Supply, a 1:24 physical model of the Compact Bypass Control Structure and the Mendota Pool Fish Screen, and a CFD model of the Fish Screen Apex and Transitional Bypass Flume. Depths and velocities throughout each modeled structure are presented and are within an acceptable range given the complex balance of regulatory requirements and the wide range of operating scenarios needed for the structures to both provide restoration water to the San Joaquin River and deliver water to the Mendota Pool.

Executive Summary

The following report summarizes hydraulic modeling efforts conducted at the Bureau of Reclamation Hydraulics Laboratory in Denver, CO. The models were constructed for the San Joaquin River Restoration Program in response to the San Joaquin River Restoration Settlement. Each model is part of the Reach 2B restoration area, focused on the Compact Bypass Control Structure (CBCS) and the facilities that allow water to be delivered into the Mendota Pool. The first model, a 1:12 scale physical model of the Compact Bypass Control Structure, Fish Ladder and Auxiliary Water Supply, focused on ensuring that the structures will function hydraulically to meet fish passage and protection criteria. The second model, a 1:24 scale physical model of the Compact Bypass Control Structure and the Mendota Pool Fish Screen and associated facilities, focused on the interaction between the two structures over a wide range of operational conditions to ensure that water could be delivered, and fish passage and protection could be maintained. The third modeling effort was a Computational Fluid Dynamics (CFD) model that focused on the Apex of the Fish Screen and the Bypass Transition Flume.

The area surrounding the modeled structures is currently experiencing widespread subsidence of up to 0.1 ft per year. As the structures subside, they still need to function properly. Each structure is being designed to allow for up to 2.5 ft of subsidence without compromising the ability to operate. Tailwater conditions were established based on HEC-RAS results from a wider area model. The models represented over 50 flow scenarios to look at a wide range of operating conditions (between 250-4500 prototype cfs at various locations through the system). Each model looked at a day-1 operation which would occur immediately after construction with and without water delivery to Mendota Pool. The 1:12 model also looked at subsided conditions.

Depths and velocities throughout each modeled structure are presented. In general, the CBCS experienced through gate velocities of under 25 ft/sec when operating under delivery conditions. During restoration flows through gate bay velocities and depths were under 5 ft/sec and over 1.5-ft deep respectively during day-1 operation for all scenarios. Fish ladder depths and velocities remained over 2.5-ft and under 1.5 ft/sec. As the structures subside the velocities will be reduced, and the depths increased except for the fish ladder slot velocity (under 6 ft/sec) which remains constant as the structures subside. Attraction to the fish ladder entrance was increased to 5 percent of the CBCS discharge by using an Auxiliary Water Supply (AWS). AWS discharge was between 0 and 185 cfs depending on the flow scenarios modeled.

Flow from the Reverse Flow Facility (RFF) was visualized and found to be uniformly distributed as it enters the Compact Bypass Channel. Detailed velocity measurements were not obtained relating to the RFF due to the size of the physical model.

CFD results were used to fine tune the geometry of the Fish Screen Apex and Transitional Bypass Flume leading to the Fish Recapture Facility (FRF) to maintain a velocity gradient under 0.2 ft/sec/ft. A capture velocity of over 6 ft/sec is achieved over a 13-ft zone while maintaining 1-ft of depth in the 2-ft wide Bypass Flume.

Water surface elevations in the model are provided for each flow scenario tested. Head loss across the CBCS remained below 0.4 ft for restoration scenarios and vary greatly during deliver scenarios. Head loss into the fish ladder was maintained at 1 ft across the entrance which was controlled using an overshot style adjustable weir. Head loss across the Mendota Pool Fish Screen (MPFS) was below 0.5 ft, and velocity distributions appeared uniform with dye testing. Flow visualization of the interaction between the MPFS and CBCS were recorded and are presented. No adverse hydraulic conditions were identified during the modeling efforts.

Introduction

The San Joaquin River Restoration Program (SJRRP) is the direct result of the San Joaquin River Restoration Settlement reached in September 2006. Under direction of this settlement, federal agencies must meet two goals (www.restoresjr.net):

- To restore and maintain fish populations in "good condition" in the main stem of the San Joaquin River below Friant Dam to the confluence of the Merced River, including naturally reproducing and self-sustaining populations of salmon and other fish.

- To reduce or avoid adverse water supply impacts to all of the Friant Division long-term contractors that may result from the Interim Flows and Restoration Flows provided for in the Settlement.

To meet these goals the Program separates the 150 miles of river into multiple reaches and funding zones indicated by the map in Figure 1.

San Joaquin River Restoration Program Cost & Benefits Map

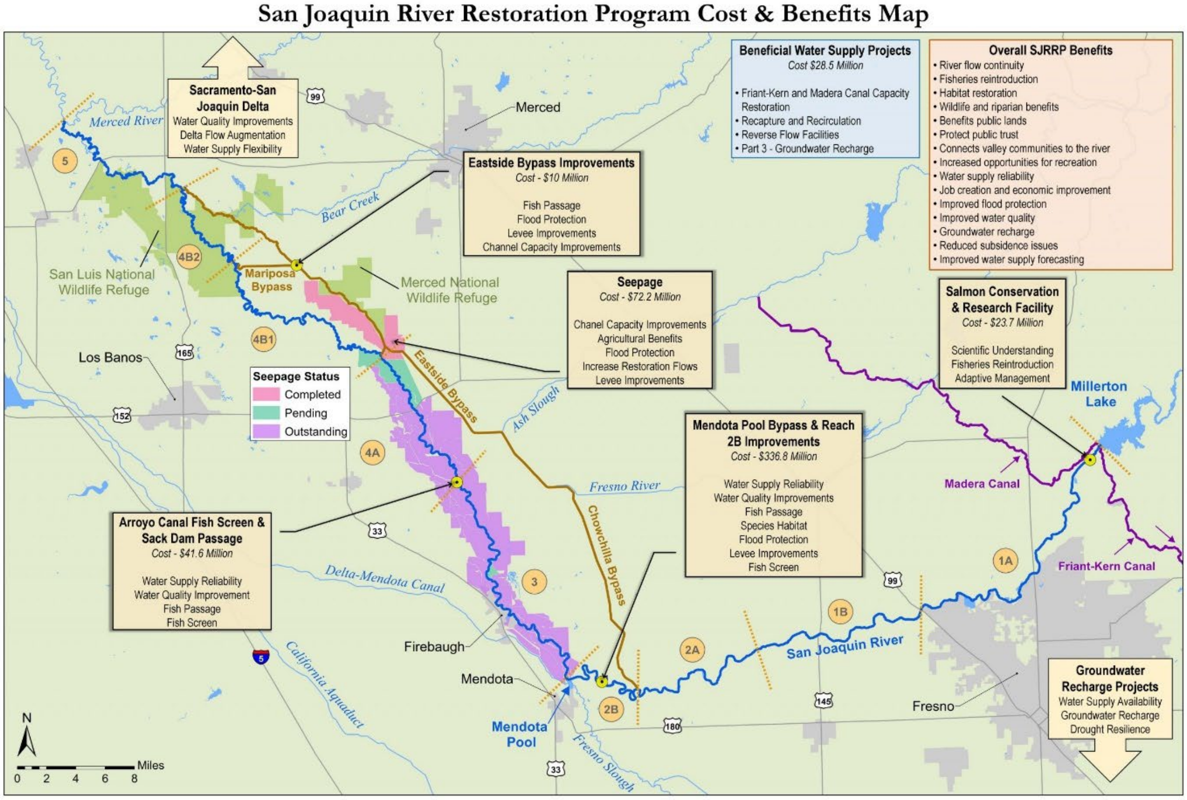

Figure 1. San Joaquin River Restoration Program cost and benefits map. Source: restore.sjr.net/about/background-and-history.

The work presented in this report covers a small portion of the overall restoration project and focused on the downstream end of Reach 2B at Mendota Dam near Mendota, California. The purpose is to aid in the design of the Compact Bypass Control Structure (CBCS), Mendota Pool Fish Screen and other associated facilities. These facilities work together to allow San Joaquin River flows to pass around Mendota Dam into the lower reaches of the system and allow a group of water users (the exchange contractors) to draw water from the San Joaquin River. These objectives are generally defined in the Stipulation of Settlement in *Natural Resources Defense Council, et al., v. Kirk Rodgers, as Regional Director of the United States Bureau of Reclamation, et al.* (United States Bureau of Reclamation 2006), which stems from Settlement Paragraph 11(a)(1) & (2):

> "(1) Creation of a bypass channel around Mendota Pool to ensure conveyance of at least 4,500 cfs from Reach 2B downstream to Reach 3. This improvement requires construction of a structure capable of directing flow down the bypass and allowing the Secretary to make deliveries of San Joaquin River Water into Mendota Pool when necessary.
>
> (2) Modifications in channel capacity (incorporating new floodplain and related riparian habitat) to ensure conveyance of at least 4,500 cfs in Reach 2B between the Chowchilla Bifurcation Structure and the new Mendota Pool bypass channel."

As a benefit to the public, the Project will greatly improve juvenile salmonid survival past Mendota Pool during flood events, which is crucial to establishing self-sustaining populations of salmonids. The creation of the Compact Bypass (the channel from the CBCS to the confluence of the river) will route the San Joaquin River around Mendota Dam and Pool. Deliveries from the river into the Mendota Pool will require a screen to keep the fish out of the pool, spillage over the Mendota Dam creates a false upstream migration pathway leading to a dead end. The goal is to minimize discharge through the dam to encourage adult fish to follow the Compact Bypass route. Figure 2 provides an annotated overview of the project from the 30% design drawings with the boundaries of the 1:24 scale full model and 1:12 CBCS model highlighted.

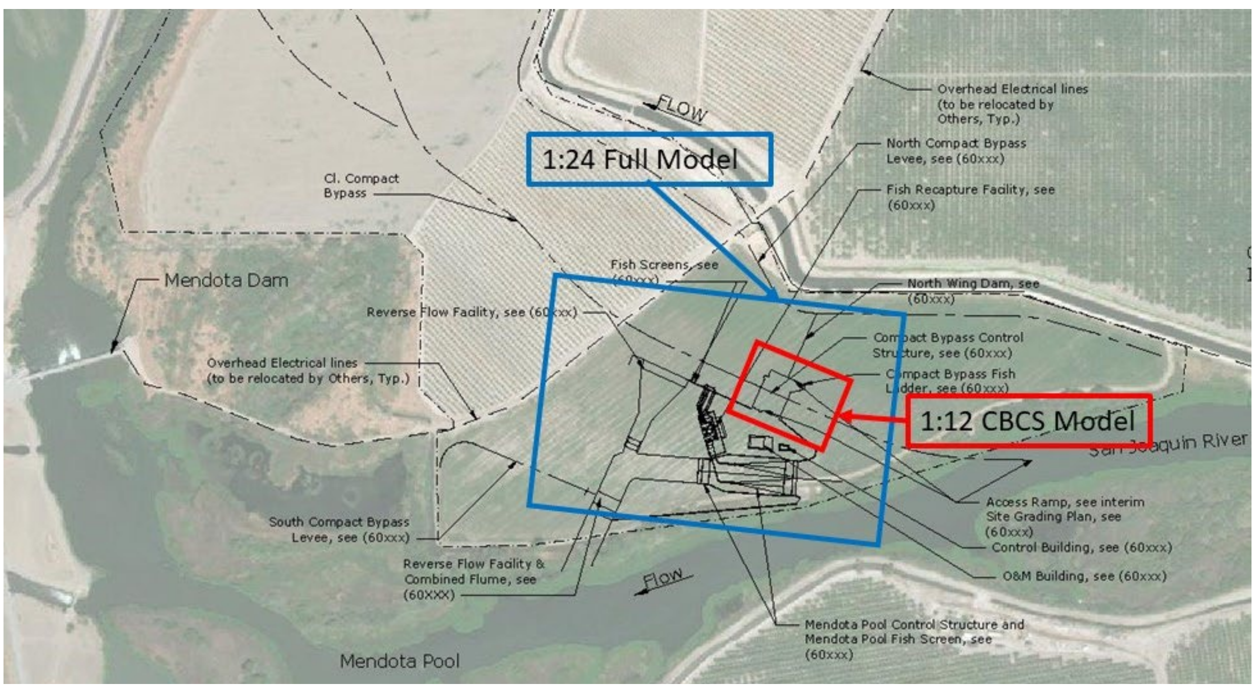

Figure 2. Annotated overview of the project from the 30% design drawings with outlines of the approximate model extents included.

Beginning in 2017 the SJRRP office and the Reach 2B design team entered into several modeling agreements with the Hydraulic Investigations and Laboratory Services group of Reclamations Technical Service Center (TSC) to study different aspects of the Reach 2B project. The first physical modeling effort was a 1:12 scale physical model (red outline in Figure 2) to investigate the near field hydraulics associated with the CBCS and its associated gates, Fish Ladder and Auxiliary Water Supply (AWS) features. This work included several small computational fluid dynamics (CFD) simulations. The second physical modeling effort was a 1:24 scale physical model to investigate the broader hydraulic interaction between the CBCS and the fish screen structure working together (blue outline in Figure 2). Several larger scale CFD simulations were used to look at different aspects of the design. One notable CFD model investigated the velocity and depths through the Apex of the fish screens that transfer the fish and water to a Fish Recapture Facility (FRF). A second CFD model focused on the FRF is underway but will be reported separately.

This report documents the results of the modeling efforts for the final configurations of each model. Intermediate steps and configurations are not included due to the large number of modifications that were made during each modeling effort. As changes, problems, or issues with the design were discovered, the data collection for that configuration was paused and modifications were made to remedy the issues. Some of the models went through over 15 different modifications before the final configuration was tested. Final configurations were selected to meet project goals and requirements as much as possible.

Model Description

Physical Model Scale

Each of the models represented the current state of the designs as provided by the respective design teams. Similitude between the models (what was built in the laboratory) and the prototypes (what will be built at the site) is achieved when the ratios of the major forces controlling the physical processes are equal in the model and prototype. The driving force in most open-channel flows (e.g., rivers, canals, spillways, etc.) is gravity, and motion is resisted by the inertia of the water. Froude-scale similitude was used to establish a kinematic relationship between the model and the prototype that is based on the ratio of inertia and gravitational forces. The Froude number is defined as

Equation 1 $$Fr=\frac{v}{\sqrt{gd}}$$

where v = velocity, g = gravitational acceleration, and d = flow depth. When Froude-scale similitude is used for a model, the Froude numbers of the model and prototype are made equal. Table 1 provides the relationships for a 1:12 and 1:24 scale physical model, where the r subscript refers to the ratio of model to prototype.

Table 1. Froude-scale similitude model ratios for the 1:12 and 1:24 physical models.

Description	Variable	Scale Parameter	1:12 Model		1:24 Model	
Length ratio:	L_r	$L_{model}/ L_{prototype}$	(1/12)	1/12	(1/24)	1/24
Area ratio:	A_r	L_r^2	$(1/12)^2$	1/144	$(1/24)^2$	1/576
Pressure ratio:	P_r	L_r	(1/12)	1/12	(1/24)	1/24
Velocity ratio:	V_r	$L_r^{1/2}$	$(1/12)^{1/2}$	1/3.46	$(1/24)^{1/2}$	1/4.90
Time ratio:	T_r	$L_r^{1/2}$	$(1/12)^{1/2}$	1/3.46	$(1/24)^{1/2}$	1/4.90
Discharge ratio:	Q_r	$L_r^{5/2}$	$(1/12)^{5/2}$	1/499	$(1/24)^{5/2}$	1/2822

Computational Fluid Dynamics models were all configured to use prototype or full-scale dimensions.

1:12 Scale Model - Compact Bypass Control Structure, Fish Ladder and Auxiliary Water Supply

Figure 3 shows an aerial ortho-photo of the 1:12 scale CBCS, AWS and Fish Ladder model. The model was constructed from marine grade plywood with concrete topography to establish the bed of the San Joaquin River and Compact Bypass channel. The gates in the CBCS and Fish Ladder were constructed of white expanded PVC sheeting, and the control structure gates were manufactured from grey PVC to the scaled dimensions of the prototype gates.

Discharge into the upstream channel was supplied through a 12-in PVC pipeline attached to the laboratory's pumped recirculation and discharge measurement system (accurate to ±0.25% of measured flow). Water into the model passed through a rock baffle that distributed the discharge across the entire upstream river channel similar to the expected river velocity. Discharge through the AWS was controlled through one of three 3-in pipes with full port inline magnetic flow meters (accurate to ±0.50%) and shut-off valves. Discharge through the Fish Ladder was calculated using the head loss and geometry of the vertical slots assuming a 0.75 discharge coefficient.

Water surface elevations were measured using ultrasonic level sensors (±0.01-in model scale) and Lory point gauges (±0.001-ft model scale) at six locations in the physical model as shown in Figure 3 and Figure 4. Other water surface elevation measurements and velocity measurements were obtained at various locations throughout the model as needed.

Each CBCS gate was manually adjustable. Each gate was snugly fitted between the piers which allowed a watertight seal when fully closed and allowed the gates to stay at set openings. Gate openings were measured using a custom-made staff gauge with a resolution of approximately ±0.01-in model scale.

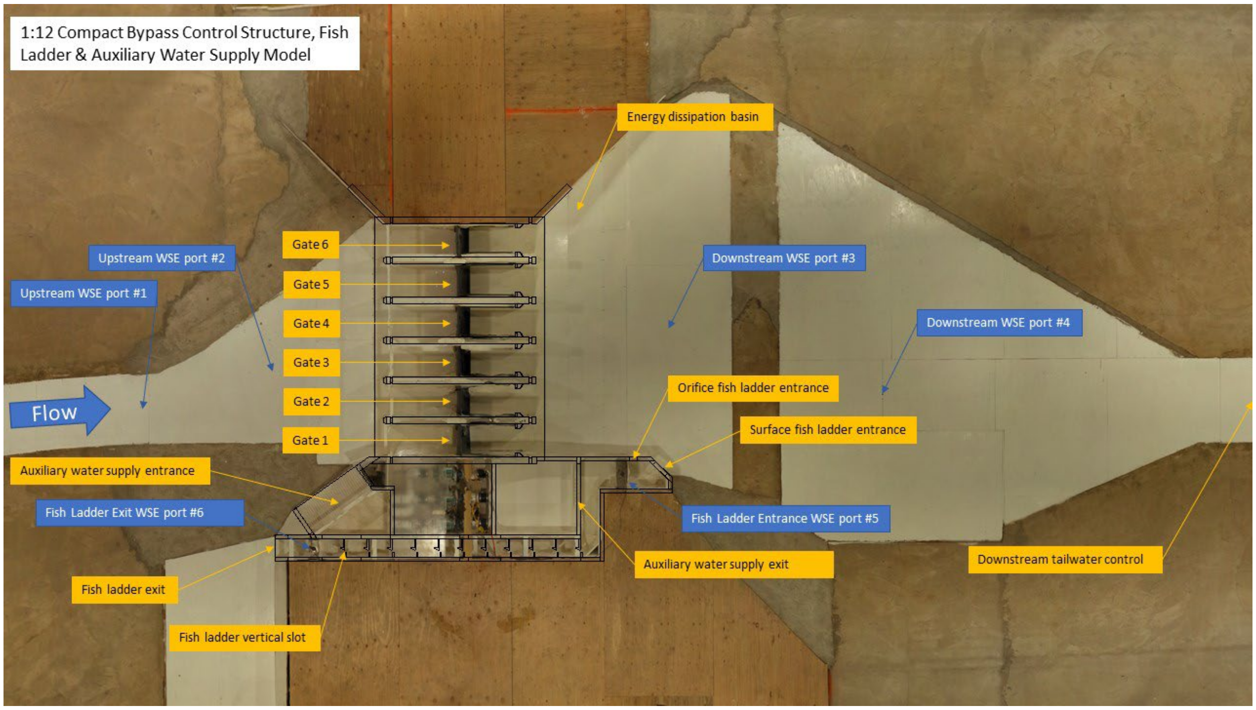

Figure 3. Annotated orthophoto image of the 1:12 physical model of the Compact Bypass Control Structure, Auxiliary Water Supply and Fish Ladder structures.

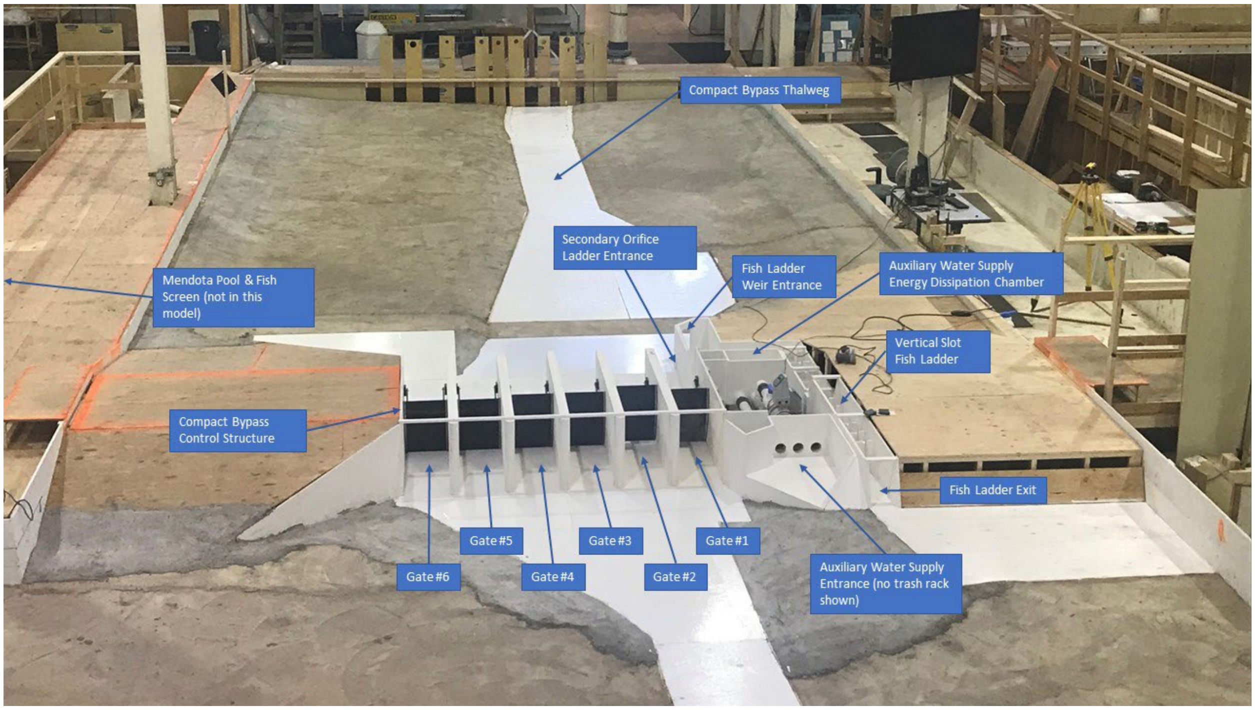

Figure 4. Annotated image of the 1:12 scale physical model (flow direction is from bottom to top).

1:24 Mendota Pool Fish Screen, Compact Bypass Control Structure and Reverse Flow Facility

Figure 5 and Figure 6 show the 1:24 scale Mendota Pool Fish Screen, CBCS and Reverse Flow Facility model. The model box was constructed from marine grade plywood with urethane foam block topography shaped to within 0.0625-in (1/16-inch) model of the expected 15-yr projected channel shape both upstream and downstream of the structures. The Mendota Pool Fish Screens, Reverse Flow Facility and CBCS were constructed of closed cell polyethylene high density foam. The Fish Ladder and AWS and Fish Screen Apex and Bypass structures were constructed from white expanded PVC sheeting and 3D printed parts. Each CBCS gate was manufactured to the scaled dimensions of the prototype gates using a 3D printer. The model allowed for the Fish Screen Bypass discharge but did not include any of the FRF that the bypass discharge would pass through. The small scale of the physical model would have rendered the FRF unusable from an observation standpoint.

Discharge into the upstream channel was supplied through a 12-in PVC pipeline attached to the laboratory's pumped recirculation and discharge measurement system (accuracy of ±0.25%). Flow passed through a rock baffle that distributed the discharge to match the flow distribution that is expected at that location in the San Joaquin River. Discharge through the AWS was controlled through a slide gate on the upstream end of the AWS and was measured using calibrated slide gates. Direct measurement of the discharge using magnetic flow meters like the 1:12 scale physical model was not possible with existing equipment, because no-full port magnetic flow meters were available. Discharge through the Fish Ladder was calculated using the head loss and geometry of the vertical slots.

Water surface elevations were measured using electronic ultrasonic level sensors (±0.01-in model scale) at ten locations shown in Figure 5 and Figure 6. Other water surface elevation measurements and velocity measurements were obtained using handheld equipment at various locations as needed.

All gates were electronically controlled with position feedback using a data acquisition and control (DAQ) system. Gate positions and water surface elevations were used to determine flow rates into the various portions of the model based on the needed operations. Discharge into the Mendota pool was measured using a custom calibrated v-notch weir with accuracy of ±2.0%. Due to the model scale and complex discharge scenarios for the model, an artificial bulkhead was installed to separate the reverse flow facility from the Mendota pool screened water. A separate pump and inline magnetic flow meter (accuracy ±0.5%) provided the necessary reverse flow discharge. Discharge down the Fish Ladder was controlled automatically based on the upstream and downstream water surface elevations. To maintain a 1-ft drop (prototype) into the Fish Ladder an adjustable overflow gate was connected to a linear actuator with position feedback.

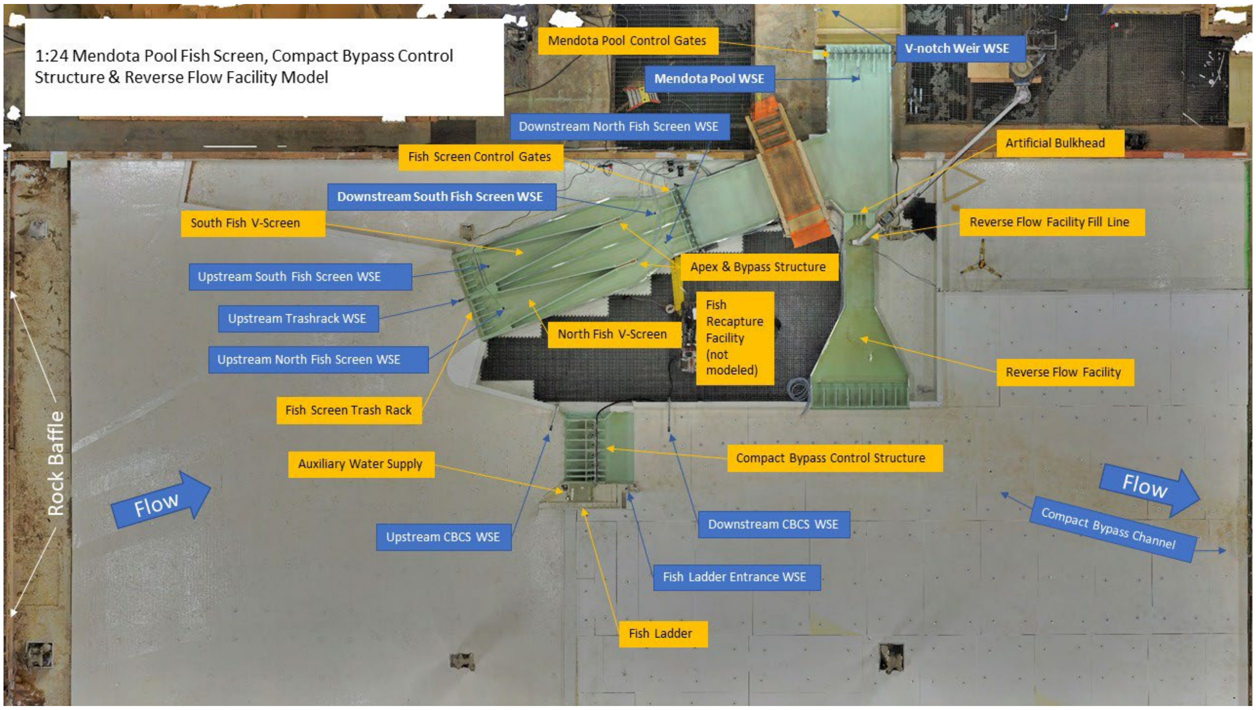

Figure 5. Annotated orthophoto image of the 1:24 scale physical model of the Mendota Pool Fish Screens, Reverse Flow Facility and Compact Bypass Control Structure.

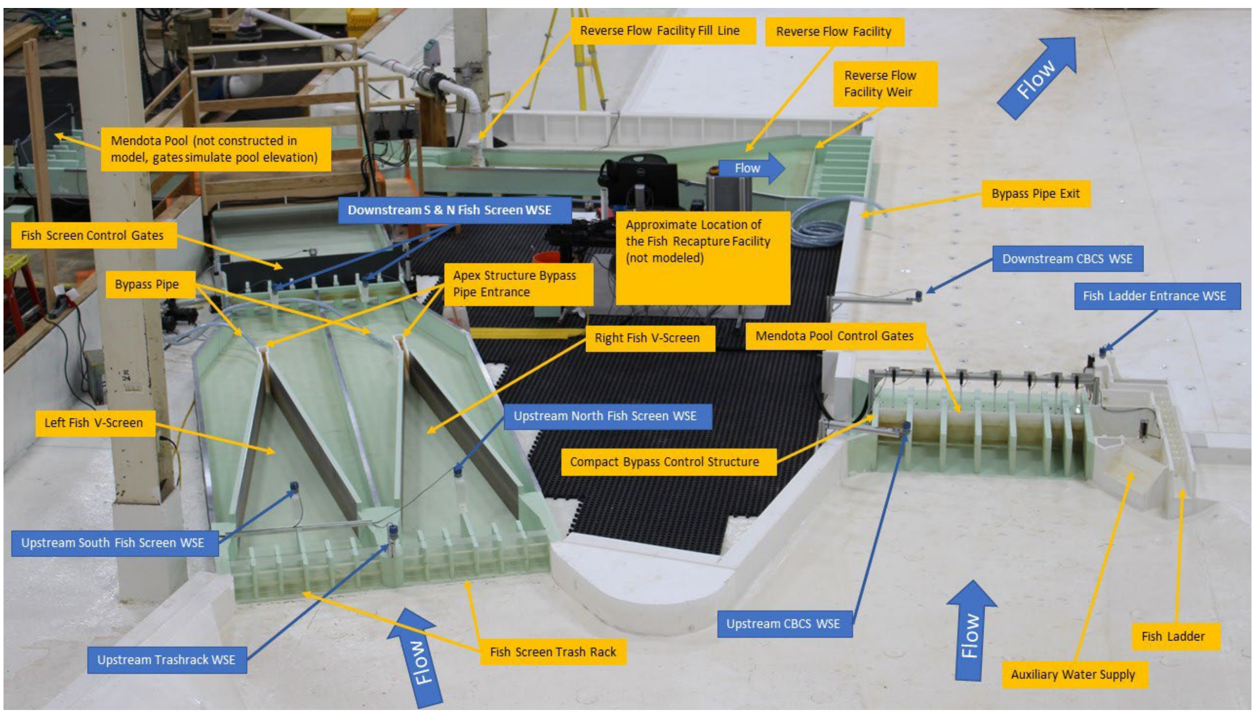

Figure 6. Annotated image of the 1:24 scale physical model including the Compact Bypass Control Structure, Fish Screen Facility and Reverse Flow Facility.

Computational Fluid Dynamics Modeling Description

The design team anticipated the need to study more structural changes than could be considered in the physical models in a timely manner. In order to facilitate development of a design with fish-friendly flow conditions, a computational fluid dynamics (CFD) model using FLOW-3D® was used to supplement the physical models. The focus was specifically on the Fish Screen Apex, Transitional Flume, and the FRF (the FRF study will be reported in a separate upcoming document). This allowed quick implementation of changes and direct mathematical evaluation of the results. A commercially available CFD program, FLOW-3D® Version 12.0.3.02 by Flow Science Inc. (1996), was used in this study. FLOW-3D® is a finite difference, free surface, transient flow modeling system that was developed from the Navier-Stokes equations, using up to three spatial dimensions.

The finite difference equations are based on a fixed Eulerian mesh of non-uniform rectangular control volumes using the Fractional Area/Volume (FAVOR) method (Sicilian 1990). Free surfaces and material interfaces are defined by a fractional volume-of-fluid (VOF) function. FLOW-3D® uses an orthogonal coordinate system as opposed to a body-fitted system.

The results from FLOW-3D® simulations were analyzed to identify, quantify, and qualify key hydraulic characteristics, including depth, velocity and acceleration of the fluid around the hydraulic structures.

Solids Model Development

Structural objects were defined using stereolithography files that were generated using commercially available AutoCAD 2021 and imported into FLOW-3D®.

In general, flow paths are modeled with FLOW-3D®. Structural details that do not intrude on the flow were ignored or grossly exaggerated to help simulations run smoothly. An example of this is a metal or thin wall which might be too thin to capture at reasonable cell sizes would be thickened away from the open volume so that the flow path dimensions are still accurately represented.

Simulation Configuration

The following settings were selected for each simulation:

- One fluid (water only; air is simulated as empty void space)
- Free surface
- Cubic cell volumes (length, width, and height of each cell were nearly equal) to reduce numerical errors
- Turbulence model: Renormalized Group (RNG) model with dynamically computed maximum turbulent mixing length
- Pressure Solver: Generalized Minimal Residual (GMRES)
- Default water properties at 20° Celsius (68° Fahrenheit)
    - Water density of 1.9403 slugs/ft^3
    - Dynamic viscosity of 2.08855×10^{-5} lbf-s/ft^2
    - Incompressible fluid

- Volume of Fluid Advection: Automatic fluid convection
- Momentum Advection: First Order Approximation
    - Higher orders of approximation are generally not recommended unless the computer does not have enough memory to accommodate additional cells.
    - Higher orders of approximation are generally slower and sometimes less stable
- The number of cells was increased until the changes in selected key output variables (e.g., velocity, velocity gradient, discharge…) were insignificant.
- Convergence controls: Default values were used
- Gravity: -32.2 ft/sec^2 in the vertical (Z) direction
- The Apex structure was parallel to the X-axis with the entrance at X=100 ft
- The centerline of the Apex structure was at Y= 100 ft
- Proposed elevations were used for the Z values

Controlling Conditions and Assumptions

- Apex entrance is required to be 2.5-ft-wide
- Water level entering both Mendota Pool Fish Screen (MPFS) bypass flume channels is at elevation 155.1 ft
- Water level in both MPFS flume return channels (downstream of the fish screens) is at elevation 154.8 ft
- Bottom elevation 147.0 ft
    - Depth at the entrance is 8.1 ft
- 50 cfs or greater entering at each Apex Structure
    - Average inflow velocity is greater than 2.5 ft/sec
- FRF flume requirements:
    - Minimum 2-ft-wide
    - Minimum 1-ft deep
    - A capture velocity greater than 6 ft/sec
- 12 cfs to 18 cfs in each of the 2-ft-wide elevated bypass flume channels to the FRF
- Secondary screens designed not to exceed 0.4 ft/sec approach velocity
- Velocity gradient
    - Preferred is 0.10 ft/sec/ft
    - Acceptable is 0.20 ft/sec/ft

Fish Screen Modeling

The fish screens were modeled using FLOW-3D® porous baffles. Porous baffles are placed by FLOW-3D® on cell faces which can give a stair-stepped appearance. FLOW-3D® calculates head loss across the cell faces using open area (porosity fraction) and a loss coefficient (Equation 2).

Equation 2 $$\Delta p = \rho(KBAF1 * u + KBAF2 * u|u|)$$

Where Δp is the pressure drop across the porous baffle plate (ft), $KBAF1$ is an input constant (ft/sec), $KBAF2$ is a dimensionless input constant, and u is the through-hole fluid velocity inside the porous baffle (ft/sec). Loss coefficients (KBAF2) for a given porosity (fractional open area) were determined using Figure 7. The screen parameters were adjusted to allow discharge of 12 to 18 cfs through the transitional bypass flume to the FRF. The choice of baffle coefficients and porosity was critical to properly representing the water entering the Apex structure.

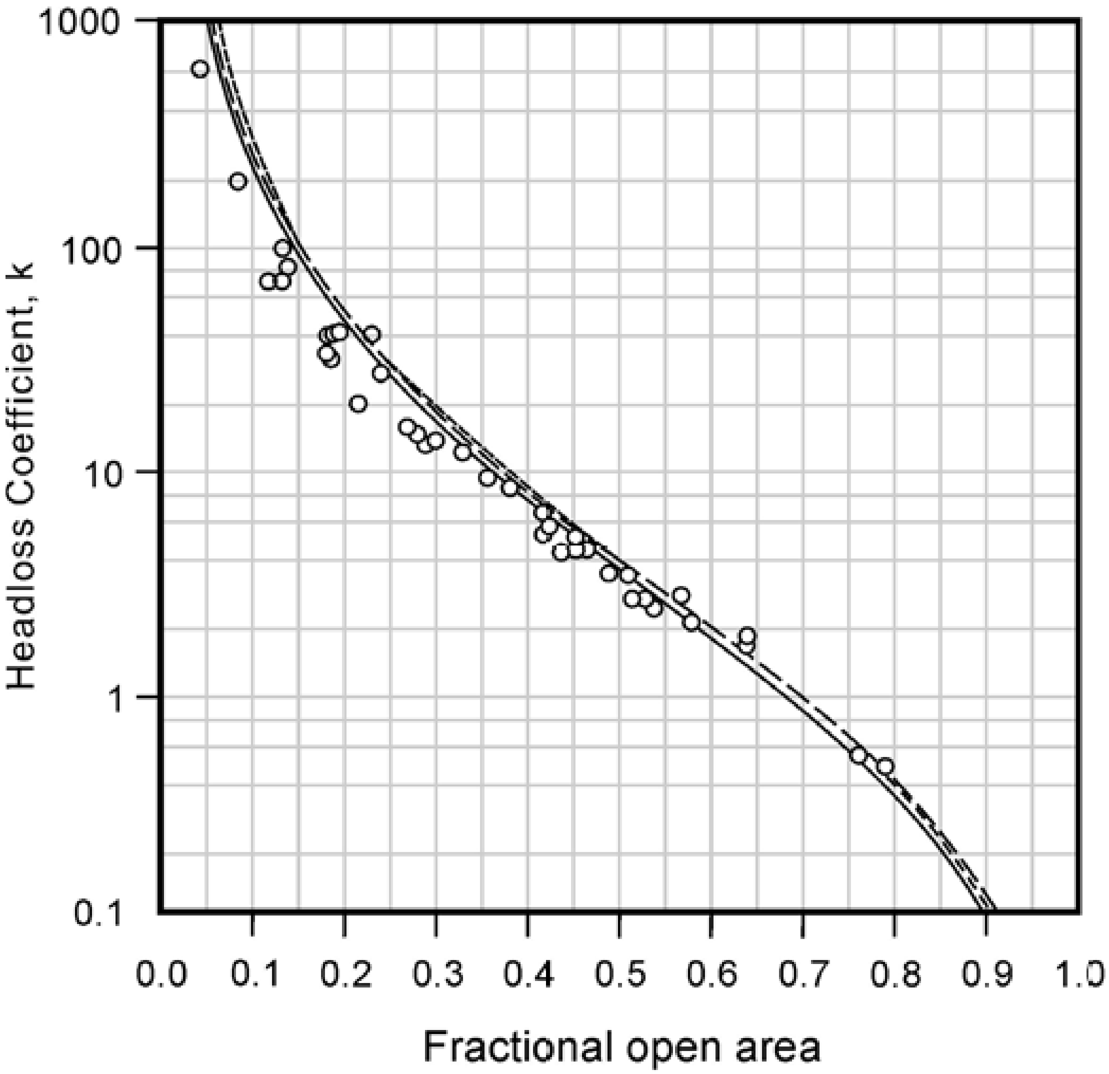

Figure 7. Head loss coefficient as function of fractional open area for thin perforated plate (Reclamation, 2006).

Fish Screen Apex and Transitional Flume Description

The Fish Screen Apex structure is used to bypass water from the fish screens to the FRF through an elevated transitional flume (Figure 8). A CFD model of the Apex structure and elevated transitional flume was built to ensure hydraulic performance objectives were achieved. The domain of the CFD model began 10 ft upstream of the Apex entrance and ran to the approximate location of the FRF building wall for the North flume (Figure 9). The upstream boundary water surface elevation was set to a water level of 155.15 ft (water surface elevation 155.10 ft plus approximate velocity head 0.05 ft).

About 10 ft of the Primary Screen was modeled to ensure appropriate flow conditions at the entrance of the Apex and the Secondary Dewatering Screen. The Primary Screen was modeled using a "sink" that simulated 0.4 ft/sec approach velocity perfectly distributed across the screen. For stability purposes, the exit flow of the flume used a "sink" which matched the average outflow velocity. Velocity profiles and depth may be influenced up to 5 feet upstream of the sink.

The water surface elevation at the exit of MPFS flume return channels was set to 154.8 ft. The complete sweeping velocity was not simulated because only a portion of the flow in channel leading to the Mendota Pool was modeled. Preliminary simulations showed that the sweeping velocity did not appear to influence the withdrawal attributes.

Figure 10 provides a view of the 3-dimensional Apex structure on a section line cutting through the flume centerline. Of note is the screen "window", and a ramp that consists of two straight-sloped portions, a curved portion, a slightly sloped straight portion, and a horizontal straight portion (also shown in Figure 8). The flow width of the structure narrows from 2.5 ft at the entrance to 2.0 ft at a distance of 12 ft downstream of the entrance.

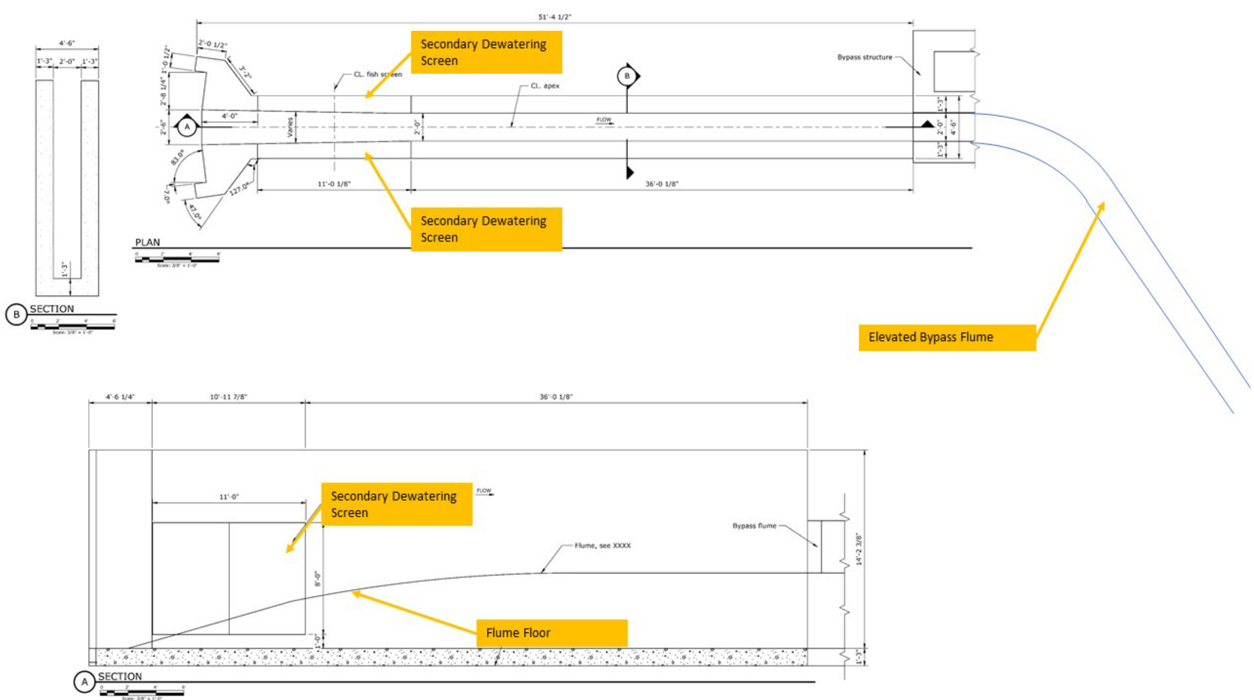

Figure 8. Plan (top) and profile view (bottom) of the proposed Apex and Elevated Bypass Flume with Secondary Screen.

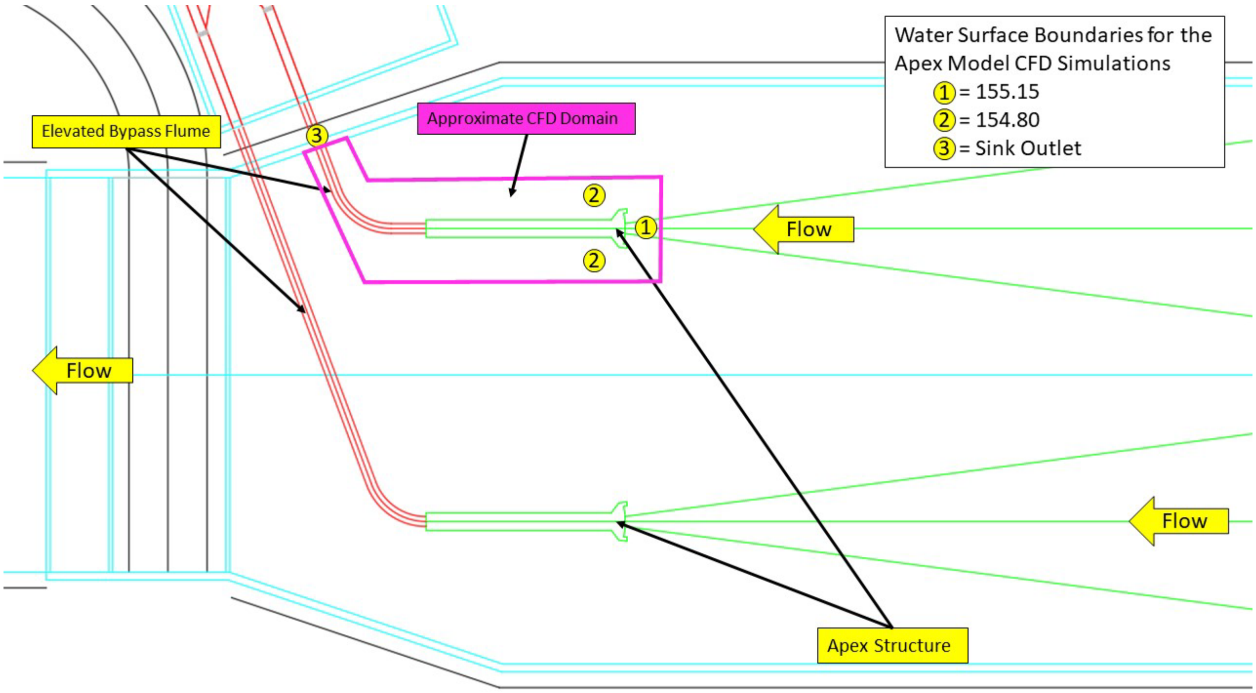

Figure 9. Approximate boundaries of the Apex and Elevated Bypass Flume CFD Modeling.

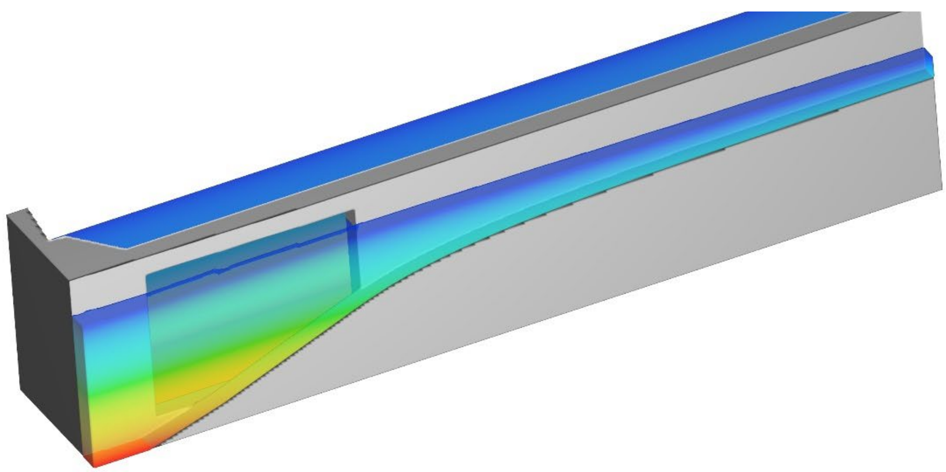

Figure 10. 3-dimensional rendering of the Apex structure cutting through flume centerline from the start of the CFD simulation (pressure contours of the fluid domain are displayed from the simulation start but no values are provided).

Post Processing

While most post processing of results used FLOW-3D®, plots with velocity gradients were evaluated using the commercially available Tecplot 360 EX 2022 R1, Version 2022.1.0.14449 (Jul 6 2022) by Tecplot, Inc. The analysis evaluated dU/dX (velocity changes or gradients in the X-direction). The main flow in the Apex structure is in the X-direction and the gradients in other directions were not included.

Results & Discussion

Subsidence

The San Joaquin Valley, where this project is located, is currently experiencing ground subsidence at a rate of about 0.1 ft per year. For structures to remain viable through the project life, modeling had to be performed that represented both the as-built conditions and the future water levels after subsidence. Reclamation designed all features to function properly through the next 2.5 feet of subsidence (assuming subsidence between 2015 & 2040). Reclamation assumes that after year 2040 the Sustainable Groundwater Management Act will be fully enforced, and subsidence will slow dramatically or stop.

During modeling efforts, the impacts of subsidence were investigated by adjusting the water levels in the model to accurately account for potential future water surface changes. It was assumed that tailwater elevations acting on the downstream side of the CBCS would change very little. As such, the water level acting on the upstream side of the model was increased to account for subsidence, while keeping the structures in the same space in the physical model but resetting our invert values to a lower elevation. This adequately simulates the subsidence of the structures without needing to do structural modifications to the model.

Tailwater

Tailwater elevations in each of the models were set downstream of the CBCS. This was accomplished by adjusting tailboards until the water surface elevation downstream of the CBCS was static with a set incoming discharge. Water levels were checked and monitored during testing to ensure that steady state was achieved (water levels and velocities are maintained over long periods of time). Due to the large physical extents of the models, and the fact that the majority of discharges are controlled by orifice flow conditions through gates, long stabilization times (1-6 hours) were needed to reach steady-state conditions.

Table 2 and Figure 11 provide the tailwater for the Compact Bypass near the Fish Ladder entrance for each of the physical models. The tailwater was determined with a multi-reach HEC-RAS model created by the Sedimentation and River Hydraulics group at the TSC. Slight adjustments to the tailwater were made between the various models based on the exact location of the level sensor that was used for setting the tailwater. Tailwater setpoints changed between model configurations as the downstream Compact Bypass slope and channel shape were modified over the several years of this modeling effort. The 1:12 scale physical model was constructed before the 30% designs were completed. The 1:24 scale model was constructed after 30% designs of the facilities were complete, with modifications to the downstream Compact Bypass channel including re-shaping of the channel and the addition of the reverse flow facility. These changes caused increased tailwater depths for the same CBCS discharge, which in result required larger gate openings at the CBCS to achieve the target discharges. There were also slight differences in the location of the level sensors between the two models. The 1:12 scale model measured the tailwater 115-ft downstream of the CBCS pier nose, whereas the 1:24 scale model measured the tailwater 173-ft downstream of the pier nose (Figure 3 and Figure 5).

Table 2. Tailwater setpoint elevations in the Compact Bypass channel for each of the physical models.

Compact Bypass Discharge	1:12 Model Water Surface Elevation at 115-ft (Prototype) downstream of CBCS pier nose	1:24 Model Water Surface Elevation at 173-ft (Prototype) downstream of CBCS pier nose
(cfs)	(ft)	(ft)
50	141.76	141.43
100	142.3	142.15
200	143.08	143.07
300	143.59	143.62
400	143.98	144.05
500	144.35	144.44
600	144.67	144.79
700	144.93	145.12
800	145.17	145.44
900	145.39	145.74
1000	145.65	146.02
1200	145.99	146.55
1500	146.64	147.29
2000	147.6	148.38
2500	148.53	149.36
3000	149.43	150.22
3500	150.2	151.02
4000	150.83	151.73
4500	151.21	152.4

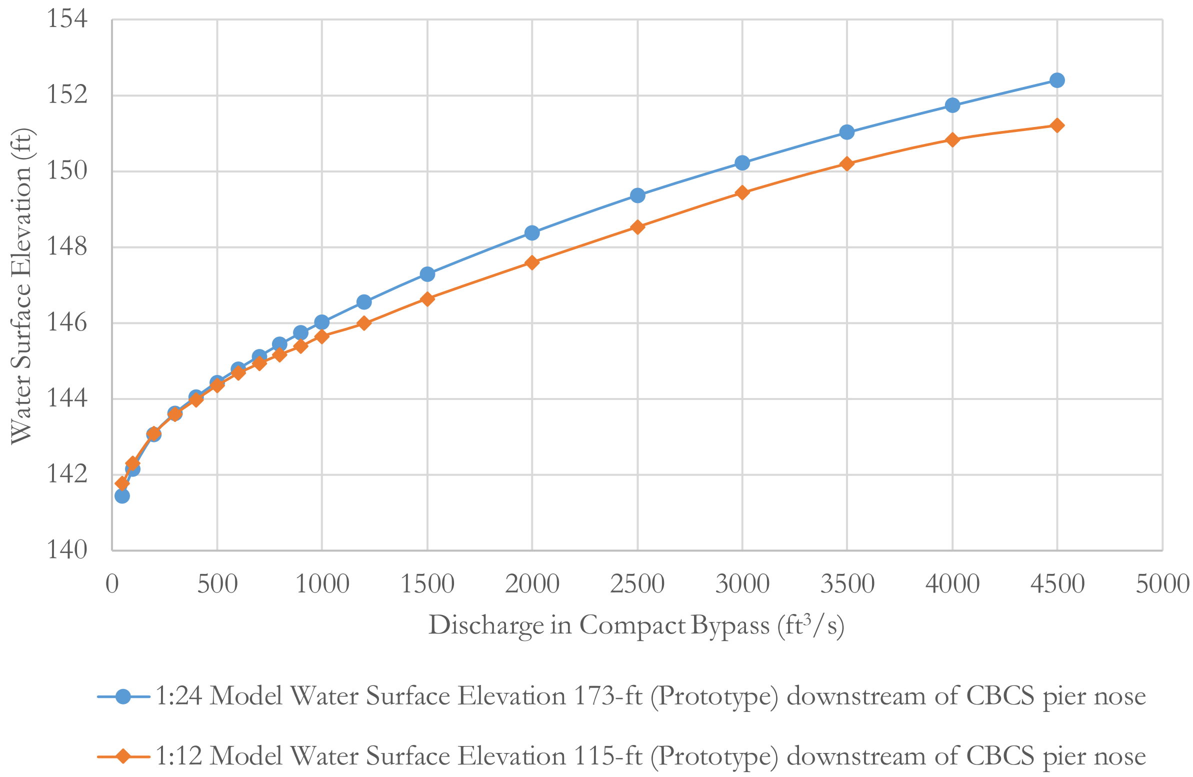

Figure 11. Tailwater elevation in the Compact Bypass channel.

Modeling Discharges and Operational Scenarios

1:12 Scale Physical Model

The 1:12 scale physical model study was performed early in the design process. A wide range of operating conditions was selected to ensure that the structures (CBCS gates, Fish Ladder, AWS and Fish Ladder entrance and exit) worked well hydraulically and met agency guidelines for both water delivery to the Mendota Pool and fish passage in both directions. The model was configured to be operated in three primary flow situations.

1. Mendota Pool deliveries assuming day-1 conditions (immediately after construction) (Table 3).
2. Mendota Pool deliveries assuming a future 2.5-ft subsided structure (Table 4).
3. No Mendota Pool deliveries for day-1 and 2.5-ft subsidence (Table 5).

Table 3 and Table 4 provide the operating set points for the 1:12 physical model when deliveries could be made to the Mendota Pool in the day-1 and future subsided cases respectively. The upstream San Joaquin River discharge represents what could be entering the upstream portion of reach 2B given the set CBCS, Fish Ladder and AWS discharges. The 1:12 physical model did not contain any features that represented the deliveries to the Mendota Pool, as the focus of the physical model was to ensure that the CBCS, Fish Ladder and AWS functioned satisfactorily to meet upstream pool and fisheries requirements. Fish ladder discharges were controlled automatically based on the vertical slot geometry and the upstream and downstream water surfaces. Auxiliary water supply discharges were set using individual ball valves for each of the three bypass pipes in the model to obtain attraction flows at the Fish Ladder entrance equal to 5% of the CBCS gate discharge.

Table 3. Model operating set-points for day-1 operation with Mendota Pool deliveries (water surface elevation upstream of CBCS = 156.0 ft).

Run #	Upstream San Joaquin River Discharge	Compact Bypass Control Structure (CBCS) Gate Discharge	Fish Ladder Discharge	Auxiliary Water Supply Discharge	Max Mendota Pool Discharge
-	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)
1:12 - 1a	4500	3802	13.5	184.7	500
1:12 - 2a	4500	3312	14.3	160.4	1000
1:12 - 3a	4500	2864	15.6	133.3	1500
1:12 - 4a	4500	2370	16.8	107.8	2000
1:12 - 5a	3990	1890	18.2	81.7	2000
1:12 - 6a	3500	1421	19.6	56.1	2000
1:12 - 7a	3000	947	21.0	29.8	2000
1:12 - 8a	2750	711	21.8	15.8	2000
1:12 - 9a	2500	474	22.2	2.7	2000
1:12 - 10a	2250	227	22.6	0.0	2000
1:12 - 11a	2125	101	23.6	0.0	2000

Table 4. Model operating set-points for subsided operation with Mendota Pool deliveries (water surface elevation upstream of CBCS = 156.0 ft).

Run #	Upstream San Joaquin River Discharge	Compact Bypass Control Structure (CBCS) Gate Discharge	Fish Ladder Discharge	Auxiliary Water Supply Discharge	Max Mendota Pool Discharge
-	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)
1:12 - 1b	4500	3800	22.4	177.6	500
1:12 - 2b	4500	3314	24.3	153.1	1000
1:12 - 3b	4500	2843	26.0	124.2	1500
1:12 - 4b	4500	2368	28.0	98.3	2000
1:12 - 5b	4000	1895	30.4	70.4	2000
1:12 - 6b	3500	1421	33.1	42.3	2000
1:12 - 7b	3000	948	34.7	15.4	2000
1:12 - 8b	2750	712	35.9	0.0	2000
1:12 - 9b	2500	462	36.9	0.0	2000
1:12 - 10b	2250	211	38.3	0.0	2000
1:12 - 11b	2125	85	39.4	0.0	2000

Table 5 provides the model operating set points for the 1:12 scale physical model during restoration flows when no deliveries are made to the Mendota Pool. During this operation all gates are fully opened and any discharge entering the upstream end of Reach 2B would pass through the fully opened CBCS gates and into the Compact Bypass. The Fish Ladder and AWS would both be closed during restoration flows, allowing full stream passage through the fully open CBCS gate structure.

Table 5. Model operating set-points for day-1 and subsided operations with no Mendota Pool deliveries (restoration flows).

Run #	Upstream San Joaquin River Discharge	Compact Bypass Control Structure (CBCS) Gate Discharge	Fish Ladder Discharge	Auxiliary Water Supply Discharge	Max Mendota Pool Discharge
-	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)
1:12 - 12	4500	4500	0.0	0.0	0.0
1:12 - 13	4000	4000	0.0	0.0	0.0
1:12 - 14	3500	3500	0.0	0.0	0.0
1:12 - 15	3000	3000	0.0	0.0	0.0
1:12 - 16	2500	2500	0.0	0.0	0.0
1:12 - 17	2000	2000	0.0	0.0	0.0
1:12 - 18	1500	1500	0.0	0.0	0.0
1:12 - 19	1000	1000	0.0	0.0	0.0
1:12 - 20	750	750	0.0	0.0	0.0
1:12 - 21	500	500	0.0	0.0	0.0
1:12 - 22	250	250	0.0	0.0	0.0
1:12 - 23	125	125	0.0	0.0	0.0

1:24 Physical Model

The 1:24 scale physical modeling included the CBCS, Mendota Pool Fish Screen, Bypass Pipes and Reverse Flow Facility. The San Joaquin River Restoration Program office identified the following flow scenarios to operate the physical model:

1. 1:24 - 1 Mendota Pool delivery with both fish screens operating while sending water through the Reverse Flow Facility.
2. 1:24 - 2 Mendota Pool delivery with both fish screens operating and no discharge through the Reverse Flow Facility.
3. 1:24 - 3 Maximum restoration discharge with only south fish screen operating
4. 1:24 - 4 Maximum restoration discharge with only north fish screen operating
5. 1:24 - 5 Flood discharge with a small delivery to the Mendota Pool
6. 1:24 - 6 Delivery to the Mendota Pool with the north screen while sending water through the Reverse Flow Facility.
7. 1:24 - 7 Flood discharge with a full delivery to the Mendota Pool
8. 1:24 - 8 Flood discharge with a partial delivery to the Mendota Pool

9. 1:24 - 9 Reduction in discharge through the Chowchilla Bypass to prevent overflowing the Mendota Pool
10. 1:24 - 10 Even discharge split through the CBCS and into the Mendota Pool
11. 1:24 - 11 Delivery to the Mendota Pool with additional downstream requirements being met with flood water released from the CBCS
12. 1:24 - 12 Partial delivery to Mendota Pool using a reduced discharge through both fish screens.
13. 1:24 - 13 Mendota Pool delivery during drought operations (no restoration discharge) with north screen
14. 1:24 - 14 Mendota Pool delivery during drought operations (no restoration discharge) with south screen
15. 1:24 - 15 Mendota Pool delivery during drought operations (minimal restoration discharge) with north screen
16. 1:24 - 16 Mendota Pool delivery during drought operations (minimal restoration discharge) with south screen
17. 1:24 - 17 Full delivery to the Mendota Pool with minimal restoration discharge
18. 1:24 - 18 Full delivery to the Mendota Pool with low restoration discharge
19. 1:24 - 19 Minimal restoration discharge with no Mendota Pool deliveries.

Table 6 provides a summary of the target discharges for each of the flow scenarios discussed above. For each scenario, target water surface elevations throughout the model were set to match the design water surface elevations. The water surface upstream of the fish screen trash rack was set to 155.6 ft, and the Mendota Pool water surface elevation was set at 153.6 ft. Due to the large size of the physical model and the number of undershot style gates used to regulate discharges through each part of the model, it took up to 6 hours for water levels and discharges to stabilize after gate adjustments were made.

Table 6. 1:24 scale physical model operational target discharges from each feature of the physical model, target water surface elevation upstream of the Fish Ladder trash rack was 155.60 ft.

Run #	Upstream San Joaquin River Discharge	Compact Bypass Control Structure (CBCS) Total Discharge	North Fish Screen Discharge	South Fish Screen Discharge	Total Fish Screen Discharge	Mendota Pool Discharge	Fish Screen Bypass Discharge	Reverse Flow Facility Discharge
-	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)
1:24 - 1	4500	2430	1000	1000	2000	2070	30	500
1:24 - 2	4500	2430	1000	1000	2000	2070	30	0
1:24 - 3	4500	3465	1000	0	1000	1035	15	0
1:24 - 4	4500	3465	0	1000	1000	1035	15	0
1:24 - 5	4500	3990	500	0	500	510	15	0
1:24 - 6	4500	3465	1000	0	1000	1035	15	500
1:24 - 7	3500	1430	1000	1000	2000	2070	30	500
1:24 - 8	3500	2465	0	1000	1000	1035	15	500
1:24 - 9	4000	4000	0	0	0	0	0	500
1:24 - 10	2000	965	1000	0	1000	1035	15	0

Run #	Upstream San Joaquin River Discharge	Compact Bypass Control Structure (CBCS) Total Discharge	North Fish Screen Discharge	South Fish Screen Discharge	Total Fish Screen Discharge	Mendota Pool Discharge	Fish Screen Bypass Discharge	Reverse Flow Facility Discharge
-	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)
1:24 - 11	1500	465	1000	0	1000	1035	15	0
1:24 - 12	2000	770	600	600	1200	1230	30	0
1:24 - 13	400	0	400	0	400	405	15	0
1:24 - 14	400	0	0	400	400	405	15	0
1:24 - 15	1175	140	1000	0	1000	1035	15	400
1:24 - 16	1175	140	0	1000	1000	1035	15	400
1:24 - 17	2175	105	1000	1000	2000	2070	30	0
1:24 - 18	2475	405	1000	1000	2000	2070	30	0
1:24 - 19	250	250	0	0	0	0	0	500

Depths and Velocities

Compact Bypass Control Structure

Mendota Pool Deliveries

During exchange contractor deliveries, the CBCS will be utilized to divert water into the Mendota Pool through the Fish Screen structure. Table 7 and Table 8 provide the gate openings, depths and velocities in the CBCS during the day-1 and subsided operation respectively when there are deliveries to the Mendota Pool. As the structure subsides, the upstream water surface elevation stays consistent, but the downstream water surface elevation is lowered to maintain the same depths in the downstream channel as were present prior to subsidence. As a result, upstream depths and through-gate velocities increase due to the larger differential head across the structures. After looking at the results of the 1:12 model, it was determined that the right-most gate bay (gate 1) would need to be split into two smaller gates to provide larger gate openings at low CBCS releases. The Fish Ladder would need to be used to achieve any fish passage upstream of the CBCS during delivery cases.

Table 7. CBCS gate openings and velocities under the day-1 operation (gate bay invert @ El. 141.00 ft) when the upstream water surface elevation is at 156.00 ft.

Run #	Compact Bypass Control Structure (CBCS) Gate Discharge	CBCS Gates in Operation	CBCS Gate Opening	Upstream @ Pier Nose			Downstream @ Pier End			Through Gate Velocity
				Water Surface Elevation	Depth	Velocity	Water Surface Elevation	Depth	Velocity	
-	(cfs)	(1,2,3,4,5,6)	(ft)	(ft)	(ft)	(ft/sec)	(ft)	(ft)	(ft/sec)	(ft/sec)
1:12 - 1a	3802	1-6	3.01	156.00	15.00	3.02	149.50	8.50	5.33	15.04
1:12 - 2a	3312	1-6	2.60	156.00	15.00	2.63	149.00	8.00	4.93	15.19
1:12 - 3a	2864	1-6	2.05	156.00	15.00	2.27	148.50	7.50	4.55	16.62
1:12 - 4a	2370	1-6	1.60	156.00	15.00	1.88	147.50	6.50	4.34	17.59
1:12 - 5a	1890	1-6	1.19	156.00	15.00	1.50	147.00	6.00	3.75	18.90
1:12 - 6a	1421	1-5	0.81	156.00	15.00	1.35	145.50	4.50	4.51	24.99
1:12 - 7a	947	1 & 2	1.58	156.00	15.00	2.25	142.50	1.50	22.54	21.39
1:12 - 8a	711	1 & 2	1.16	156.00	15.00	1.69	142.00	1.00	25.38	21.85
1:12 - 9a	474	1	1.51	156.00	15.00	2.26	142.50	1.50	22.57	22.35
1:12 - 10a	227	1	0.64	156.00	15.00	1.08	141.50	0.50	32.40	25.34
1:12 - 11a	101	1	0.21	156.00	15.00	0.48	141.25	0.25	28.89	34.16

Table 8. CBCS gate openings and velocities under the subsided operation (gate bay inverts @ El. 138.50 ft) when the upstream water surface elevation is at 156.00 ft.

Run #	Compact Bypass Control Structure (CBCS) Gate Discharge	CBCS Gates in Operation	CBCS Gate Opening	Upstream @ Pier Nose			Downstream @ Pier End			Through Gate Velocity
				Water Surface Elevation	Depth	Velocity	Water Surface Elevation	Depth	Velocity	
-	(cfs)	(1,2,3,4,5,6)	(ft)	(ft)	(ft)	(ft/sec)	(ft)	(ft)	(ft/sec)	(ft/sec)
1:12 - 1b	3800	1-6	3.01	156.00	17.50	2.59	148.50	10.00	4.52	15.03
1:12 - 2b	3314	1-6	2.60	156.00	17.50	2.25	148.50	10.00	3.95	15.20
1:12 - 3b	2843	1-6	2.04	156.00	17.50	1.93	147.50	9.00	3.76	16.59
1:12 - 4b	2368	1-6	1.60	156.00	17.50	1.61	147.50	9.00	3.13	17.58
1:12 - 5b	1895	1-6	1.19	156.00	17.50	1.29	146.50	8.00	2.82	18.94
1:12 - 6b	1421	1-5	0.81	156.00	17.50	1.93	142.50	4.00	8.46	24.99
1:12 - 7b	948	1 & 2	1.58	156.00	17.50	1.93	142.00	3.50	9.67	21.40
1:12 - 8b	712	1 & 2	1.16	156.00	17.50	1.45	142.00	3.50	7.27	21.91
1:12 - 9b	462	1	1.50	156.00	17.50	1.89	142.00	3.50	9.43	22.00
1:12 - 10b	211	1	0.63	156.00	17.50	0.86	141.50	3.00	5.03	23.93
1:12 - 11b	85	1	0.20	156.00	17.50	0.35	141.50	3.00	2.03	30.46

Restoration Flows

During restoration flows all water will be passing through the CBCS and into the Compact Bypass. All CBCS gates will operate fully open, and the Fish Ladder and AWS can be closed using the upstream and downstream isolation gates or bulkheads. Table 9 provides the water surface elevation, depth, and velocity at the upstream and downstream sections of the gate structure. Data is only provided for the day-1 scenario before subsidence occurs. As the structure subsides, depths will increase and velocities will decrease.

Table 9. CBCS depths and velocities through the gate bays for day-1 operation under restoration flows (invert @ elevation 141.00 ft).

Run #	Compact Bypass Control Structure (CBCS) Gate Discharge	CBCS Gates in Operation	CBCS Gate Opening	Upstream @ Pier Nose			Downstream @ Pier End		
				Water Surface Elevation	Depth	Velocity	Water Surface Elevation	Depth	Velocity
-	(cfs)	(1,2,3,4,5,6)	(ft)	(ft)	(ft)	(ft/sec)	(ft)	(ft)	(ft/sec)
1:12 - 12	4500	1-6	full	151.38	10.38	5.16	151.31	10.31	5.19
1:12 - 13	4000	1-6	full	150.88	9.88	4.82	150.75	9.75	4.88
1:12 - 14	3500	1-6	full	150.31	9.31	4.47	150.19	9.19	4.54
1:12 - 15	3000	1-6	full	149.50	8.50	4.20	149.38	8.38	4.26
1:12 - 16	2500	1-6	full	148.63	7.63	3.90	148.44	7.44	4.00
1:12 - 17	2000	1-6	full	147.63	6.63	3.59	147.56	6.56	3.63
1:12 - 18	1500	1-6	full	146.69	5.69	3.14	146.56	5.56	3.21
1:12 - 19	1000	1-6	full	145.81	4.81	2.47	145.63	4.63	2.57
1:12 - 20	750	1-6	full	145.30	4.30	2.08	145.00	4.00	2.23
1:12 - 21	500	1-6	full	144.50	3.50	1.70	144.38	3.38	1.76
1:12 - 22	250	1-6	full	143.50	2.50	1.19	143.44	2.44	1.22
1:12 - 23	125	1-6	full	142.75	1.75	0.85	142.50	1.50	0.99

1:24 Scale Mixed Restoration and Delivery Scenarios

Although the 1:24 scale physical model has features which are too small for high accuracy of flow measurement for the specific hydraulics of the CBCS, the data contained in Table 10 provides the measured gate positions, and estimated gate bay and through-gate velocities for each of the tested scenarios.

Table 10. Compact bypass control structure depths and velocities from the 1:24 physical model for each of the operating scenarios.

				Upstream @ Pier Nose			Downstream @ Pier End			
Run #	Compact Bypass Control Structure (CBCS) Gate Discharge	CBCS Gates in Operation	CBCS Gate Opening	Water Surface Elevation	Depth	Velocity	Water Surface Elevation	Depth	Velocity	Through Gate Velocity
-	(cfs)	(1,2,3,4,5,6,7)	(ft)	(ft)	(ft)	(ft/sec)	(ft)	(ft)	(ft/sec)	(ft/sec)
1:24 - 1	2291	1-7	2.00	155.59	14.59	1.87	150.11	9.11	2.99	13.64
1:24 - 2	2303	1-7	1.94	155.58	14.58	1.88	149.31	8.31	3.30	14.13
1:24 - 3	3295	1-7	3.19	155.53	14.53	2.70	150.96	9.96	3.94	12.30
1:24 - 4	3301	1-7	3.19	155.53	14.53	2.70	150.96	9.96	3.95	12.32
1:24 - 5	3796	1-7	3.89	155.54	14.54	3.11	151.75	10.75	4.20	11.62
1:24 - 6	3292	1-7	3.58	155.53	14.53	2.70	151.77	10.77	3.64	10.95
1:24 - 7	1350	1-7	1.21	155.59	14.59	1.10	148.28	7.28	2.21	13.29
1:24 - 8	2332	1-7	2.19	155.62	14.62	1.90	150.17	9.17	3.03	12.68
1:24 - 9	3802	1-7	4.22	155.58	14.58	3.10	152.39	11.39	3.97	10.73
1:24 - 10	895	1, 2 & 3	1.79	155.63	14.63	2.18	145.86	4.86	6.58	17.86
1:24 - 11	420	1 & 2	1.46	155.55	14.55	2.06	144.49	3.49	8.60	20.55
1:24 - 12	694	1, 2 & 3	1.18	155.63	14.63	1.69	145.36	4.36	5.69	21.01
1:24 - 13	0	0	0.00	155.62	14.62	0.00	141.00	0.00	0.00	NA
1:24 - 14	0	0	0.00	155.63	14.63	0.00	141.00	0.00	0.00	NA
1:24 - 15	0	0	0.00	155.61	14.61	0.00	144.71	3.71	0.50	NA
1:24 - 16	0	0	0.00	155.61	14.61	0.00	144.67	3.67	0.50	NA
1:24 - 17	57	1	0.35	155.70	14.70	0.02	141.54	0.54	1.72	0.97
1:24 - 18	370	1	1.30	155.66	14.66	0.15	144.18	3.18	0.29	1.69
1:24 - 19	250	1-7	FULL	145.30	4.30	0.69	145.28	4.28	0.40	NA

Fish Ladder and Auxiliary Water Supply

During any Mendota Pool delivery scenarios, the velocities through the gate bays of the CBCS are too high to allow fish to pass through the structure. To provide fish passage during Mendota Pool deliveries, a vertical slot fish passage with an AWS is located on the left side of the CBCS. The Fish Ladder is a single 1-ft wide vertical slot ladder (Figure 12 through Figure 14) with a 12-in-wide by 6-in-tall lamprey passage orifice in the bottom left corner of the passage channel.

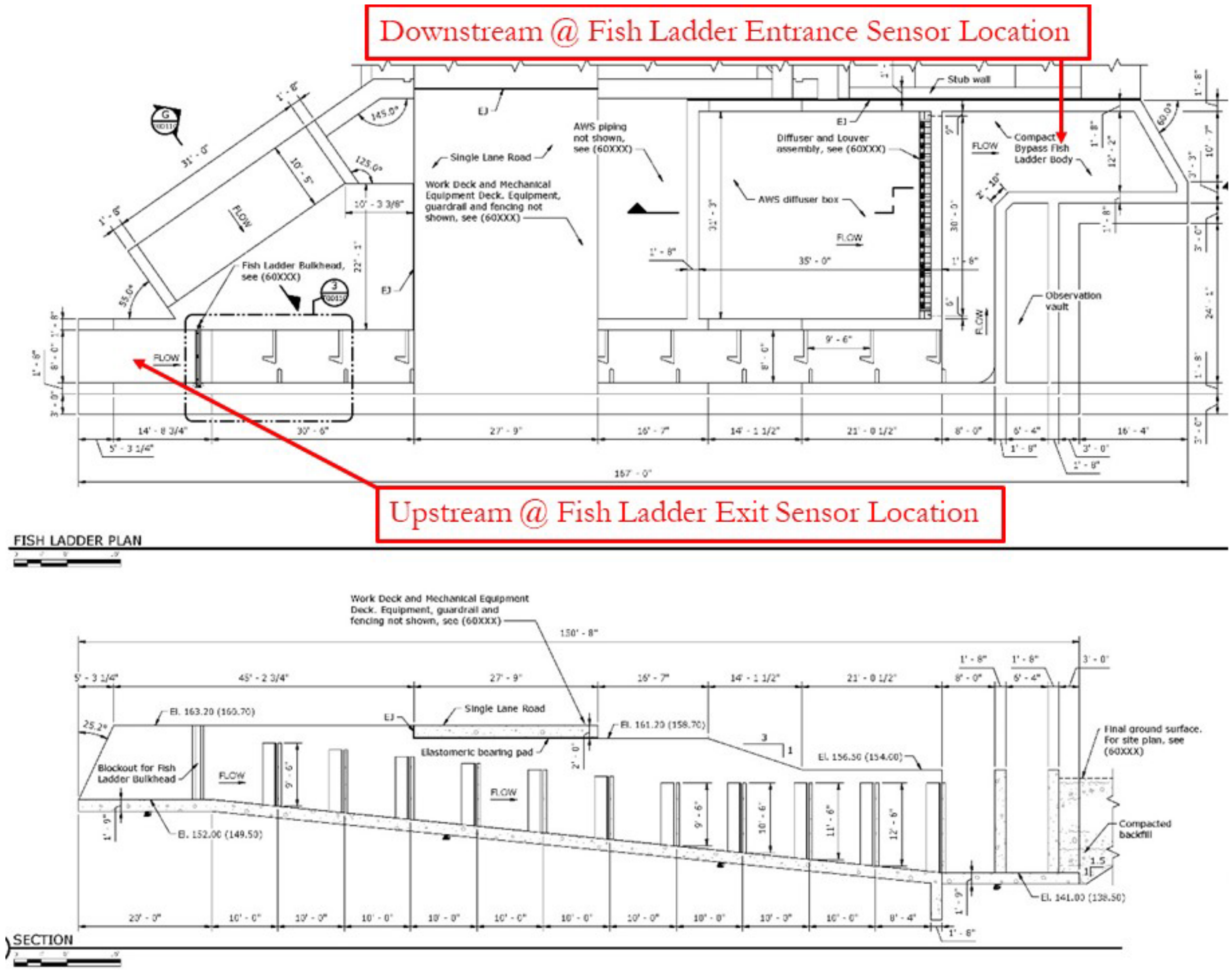

Figure 12. Plan and centerline section view of the 30% Fish Ladder.

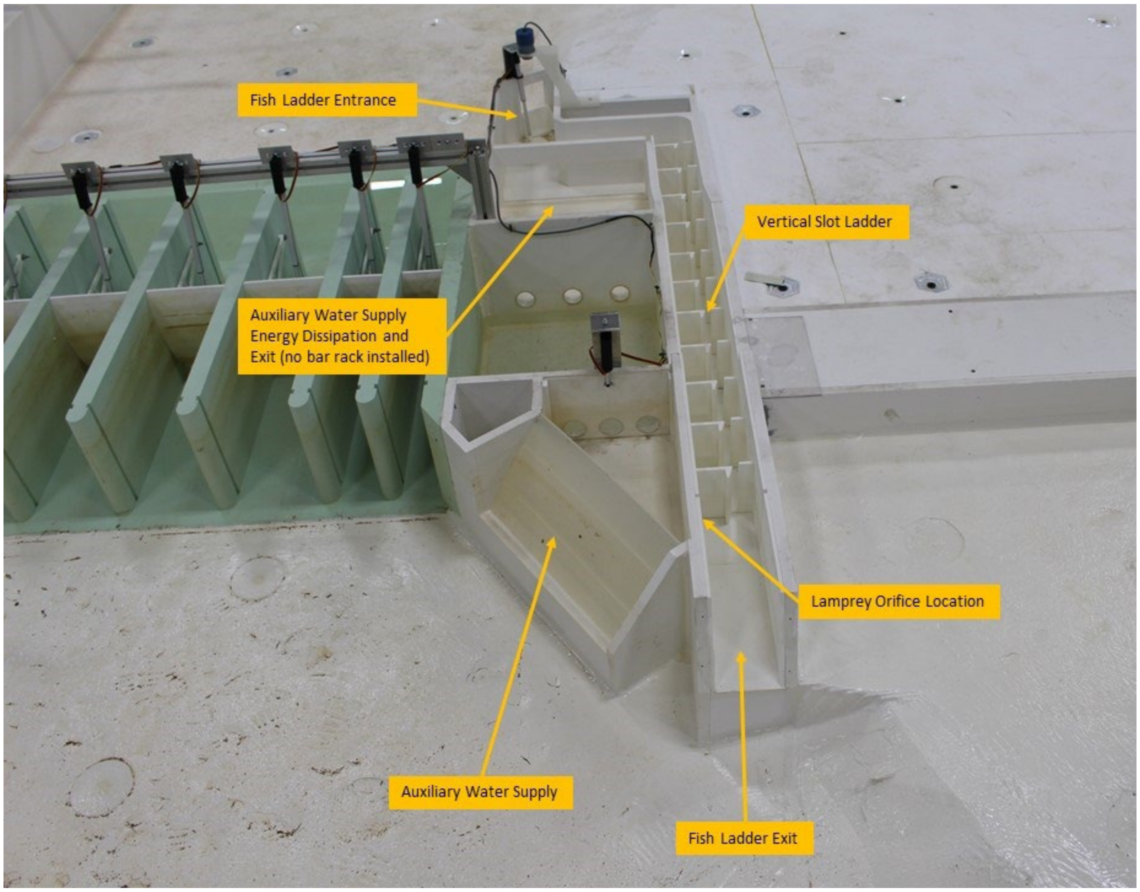

Figure 13. Fish ladder and Auxiliary Water Supply viewed from the upstream side (flow is from bottom to top).

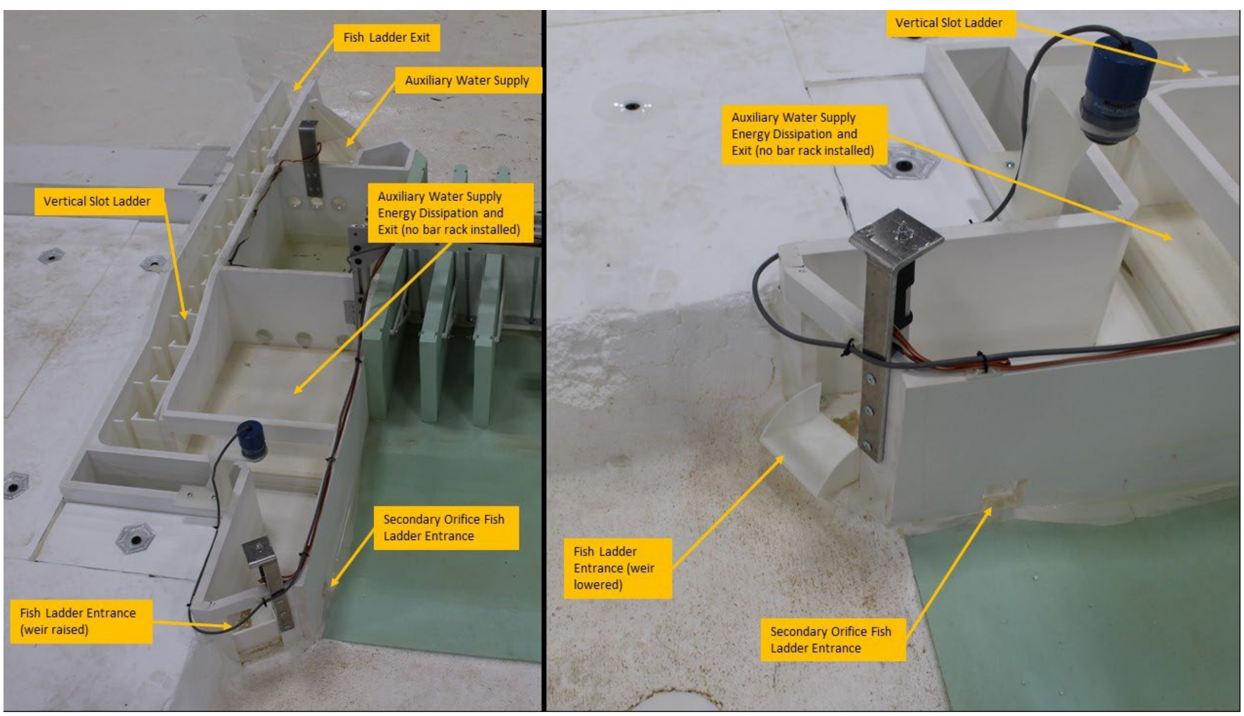

Figure 14. Fish ladder and Auxiliary Water Supply from the downstream side (left image flow is from top to bottom, right image flow is from right to left).

Discharge through the Fish Ladder is controlled by hydraulic head driving the water through the vertical slots and lamprey orifices. Downstream water surface elevation is controlled by the tailwater acting on the CBCS and the weir height at the Fish Ladder entrance. Table 11 and Table 12 provide the discharge, depth and velocity of the entrance and exit channels of the Fish Ladder. As the Fish Ladder structure subsides, more water can pass down the ladder due to the increase in vertical slot area, and less Auxiliary Water Supply is needed to meet attraction flow requirements.

Table 11. Fish ladder entrance and exit depths and velocities for the day-1 condition with delivery to the Mendota Pool.

			Upstream @ Fish Ladder Exit			Downstream @ Fish Ladder Entrance		
Run #	Fish Ladder Discharge	Auxiliary Water Supply	Water Surface Elevation	Depth	Velocity	Water Surface Elevation	Depth	Velocity
-	(cfs)	(cfs)	(ft)	(ft)	(ft/sec)	(ft)	(ft)	(ft/sec)
1:12 - 1a	13.5	184.7	155.74	3.74	0.45	151.81	10.81	1.51
1:12 - 2a	14.3	160.4	155.71	3.71	0.48	151.19	10.19	1.41
1:12 - 3a	15.6	133.3	155.73	3.73	0.52	150.44	9.44	1.30
1:12 - 4a	16.8	107.8	155.72	3.72	0.56	149.52	8.52	1.20
1:12 - 5a	18.2	81.7	155.74	3.74	0.61	148.54	7.54	1.09
1:12 - 6a	19.6	56.1	155.78	3.78	0.65	147.67	6.67	0.93
1:12 - 7a	21.0	29.8	155.74	3.74	0.70	146.14	5.14	0.81
1:12 - 8a	21.8	15.8	155.74	3.74	0.73	145.38	4.38	0.71
1:12 - 9a	22.2	2.7	155.73	3.73	0.74	144.94	3.94	0.52
1:12 - 10a	22.6	0.0	155.68	3.68	0.77	144.23	3.23	0.57
1:12 - 11a	23.6	0.0	155.71	3.71	0.79	143.45	2.45	0.79

Table 12. Fish ladder entrance and exit depths and velocities for the subsided condition with delivery to the Mendota Pool.

Run #	Fish Ladder Discharge	Auxiliary Water Supply	Upstream @ Fish Ladder Exit			Downstream @ Fish Ladder Entrance		
			Water Surface Elevation	Depth	Velocity	Water Surface Elevation	Depth	Velocity
-	(cfs)	(cfs)	(ft)	(ft)	(ft/sec)	(ft)	(ft)	(ft/sec)
1:12 - 1b	22.4	177.6	155.72	6.22	0.45	151.79	13.29	1.24
1:12 - 2b	24.3	153.1	155.75	6.25	0.49	151.17	12.67	1.15
1:12 - 3b	26.0	124.2	155.72	6.22	0.52	150.42	11.92	1.04
1:12 - 4b	28.0	98.3	155.71	6.21	0.56	149.54	11.04	0.94
1:12 - 5b	30.4	70.4	155.73	6.23	0.61	148.52	10.02	0.83
1:12 - 6b	33.1	42.3	155.77	6.27	0.66	147.33	8.83	0.70
1:12 - 7b	34.7	15.4	155.76	6.26	0.69	146.43	7.93	0.52
1:12 - 8b	35.9	0.0	155.72	6.22	0.72	145.59	7.09	0.42
1:12 - 9b	36.9	0.0	155.73	6.23	0.74	145.07	6.57	0.46
1:12 - 10b	38.3	0.0	155.72	6.22	0.77	144.20	5.70	0.55
1:12 - 11b	39.4	0.0	155.72	6.22	0.79	143.52	5.02	0.65

Table 13 and Table 14 provide additional hydraulic information for the day-1 and subsided conditions respectively. The model was able to meet the attraction flow requirement of 5% of the CBCS gate discharge by adding discharge through the AWS. An overshot weir gate at the downstream end of the Fish Ladder entrance allowed all scenarios to meet the recommended 1 ft entrance drop requirement for all tested scenarios. The 1:24 model showed similar results, with all tested scenarios able to achieve the required drop and attraction discharge.

Table 13. Fish ladder and Auxiliary Water Supply additional hydraulic information for the day-1 condition with delivery to the Mendota Pools.

Run #	Compact Bypass Control Structure (CBCS) Gate Discharge	Fish Ladder Discharge	Auxiliary Water Supply	Vertical Slot Velocities	Drop per Pool	Attraction Flow Percentage	Entrance Drop	Entrance Weir Height Required to get 1-ft Drop
-	(cfs)	(cfs)	(cfs)	(ft/sec)	(ft)	(%)	(ft)	(ft)
1:12 - 1a	3802	13.5	184.7	3.62	0.36	5.2%	0.92	6.25
1:12 - 2a	3312	14.3	160.4	3.86	0.41	5.3%	1.00	6.25
1:12 - 3a	2864	15.6	133.3	4.17	0.48	5.2%	1.01	6.25
1:12 - 4a	2370	16.8	107.8	4.51	0.56	5.3%	1.01	6.00
1:12 - 5a	1890	18.2	81.7	4.87	0.65	5.3%	0.98	5.75
1:12 - 6a	1421	19.6	56.1	5.17	0.74	5.3%	1.03	5.75
1:12 - 7a	947	21.0	29.8	5.62	0.87	5.4%	1.01	3.75
1:12 - 8a	711	21.8	15.8	5.84	0.94	5.3%	0.96	3.00
1:12 - 9a	474	22.2	2.7	5.95	0.98	5.3%	0.97	3.25
1:12 - 10a	227	22.6	0.0	6.14	1.04	10.0%	1.07	2.75
1:12 - 11a	101	23.6	0.0	6.36	1.11	23.3%	0.91	2.00

Table 14. Fish ladder and Auxiliary Water Supply additional hydraulic information for the subsided condition with delivery to the Mendota Pools.

Run #	Compact Bypass Control Structure (CBCS) Gate Discharge	Fish Ladder Discharge	Auxiliary Water Supply	Vertical Slot Velocities	Drop per Pool	Attraction Flow Percentage	Entrance Drop	Entrance Weir Height Required to get 1-ft Drop
-	(cfs)	(cfs)	(cfs)	(ft/sec)	(ft)	(%)	(ft)	(ft)
1:12 - 1b	3800	22.4	177.6	3.60	0.36	5.3%	0.96	8.75
1:12 - 2b	3314	24.3	153.1	3.88	0.42	5.4%	0.99	8.75
1:12 - 3b	2843	26.0	124.2	4.18	0.48	5.3%	0.96	8.75
1:12 - 4b	2368	28.0	98.3	4.51	0.56	5.3%	0.98	8.50
1:12 - 5b	1895	30.4	70.4	4.87	0.66	5.3%	0.95	8.25
1:12 - 6b	1421	33.1	42.3	5.27	0.77	5.3%	0.99	7.25
1:12 - 7b	948	34.7	15.4	5.54	0.85	5.3%	1.01	7.00
1:12 - 8b	712	35.9	0.0	5.78	0.92	5.0%	1.03	6.00
1:12 - 9b	462	36.9	0.0	5.92	0.97	8.0%	1.02	5.75
1:12 - 10b	211	38.3	0.0	6.16	1.05	18.1%	0.96	4.75
1:12 - 11b	85	39.4	0.0	6.34	1.11	46.2%	1.05	4.25

The 1:12 scale physical model did not incorporate the lamprey fish passage orifices. They were added to the 1:24 scale physical model and were also investigated using CFD analysis. The addition of the 12-in-wide by 6-in-tall orifices increased the discharge down the Fish Ladder by about 12-13% for the day-1 scenario and by about 7-8% for the subsided scenario. These increased discharges down the fishway decrease the amount of Auxiliary Water Supply needed to meet the 5% attraction requirement. The effect of the energy dissipation in the Fish Ladder was assessed through the CFD analysis and by visualizing flow patterns in the 1:24 physical model Fish Ladder. No significant changes to the flow patterns in the vertical slot Fish Ladder were noticed in either analysis. The submerged jet created by the Lamprey orifice seems to stay attached to the floor and left wall and does not disrupt the energy dissipation or circular flow pattern in the Fish Ladder pools.

Reverse Flow Facility

A reverse flow facility (see Figure 5 & Figure 15) provides a variable flow from the Mendota pool into the CBCS. The reverse flow from the Mendota Pool passes through a gate structure and weir and then is dispersed evenly into the Compact Bypass by a dissipation structure with bar racks at the front. Reclamation is not directly overseeing the design, specifications, or construction of this feature, but the discharge back into the Compact Bypass interacts with flows from the CBCS. The 1:24 scale physical model incorporated the reverse flow discharge from the Mendota Pool using a separate 3-in PVC supply line with a magnetic flow meter to accurately set the discharge within ±0.5%. The reverse flow facility control gates were installed as a solid wall to force the supplemental discharge to flow towards the weir and into the Compact Bypass. For all tested scenarios the reverse flow facility operated as expected. A uniform velocity distribution was observed entering the Compact Bypass, turbulence and depth limitations prevented physical velocity measurements. Based on the provided designs, the eight 4.5-ft-tall by 18-ft-wide openings into the Compact Bypass can pass up to 648 cfs into the Compact Bypass without velocities going above 1 ft/sec. After subsidence, no net change in velocity will be realized because the openings will stay the same size with effectively the same head loss across the structure. Figure 16 and Figure 17 provide a representative sample of the flow patterns from the reverse flow facility as it interacts with the Compact Bypass discharge for Scenarios 1:24 – 15 & 1:24 – 1, respectively.

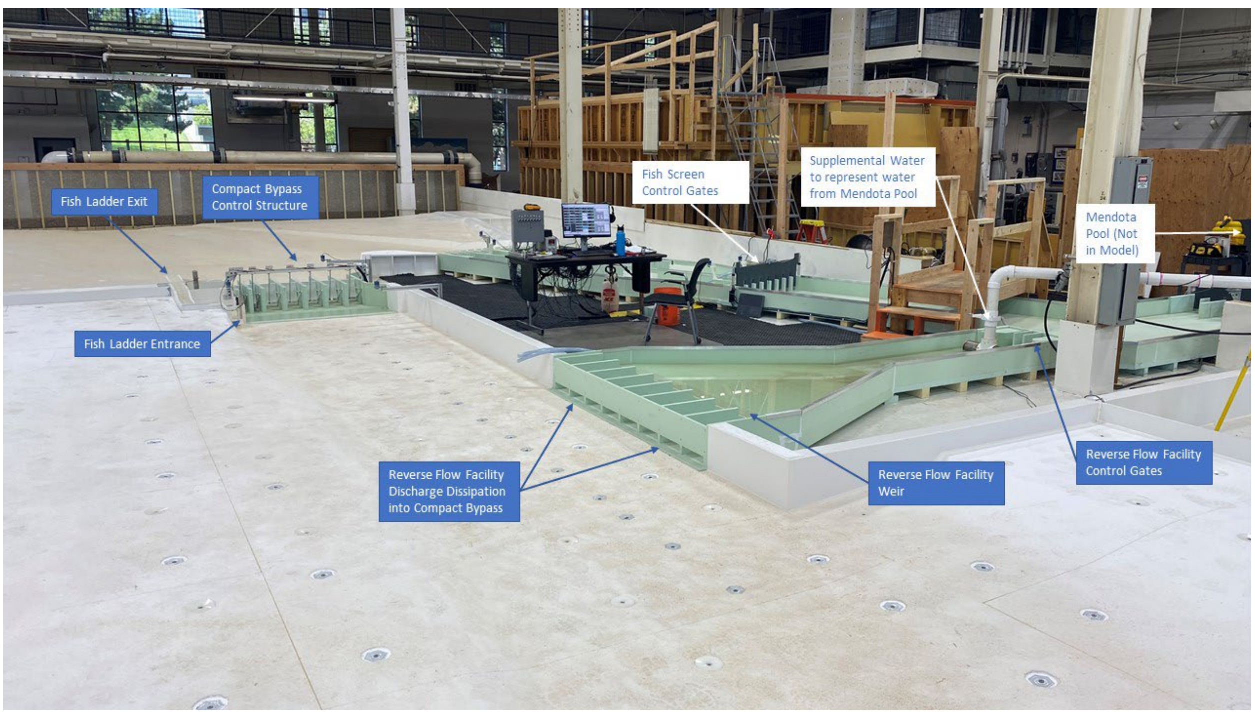

Figure 15. Reverse flow facility viewed from the downstream right bank of the Compact Bypass channel.

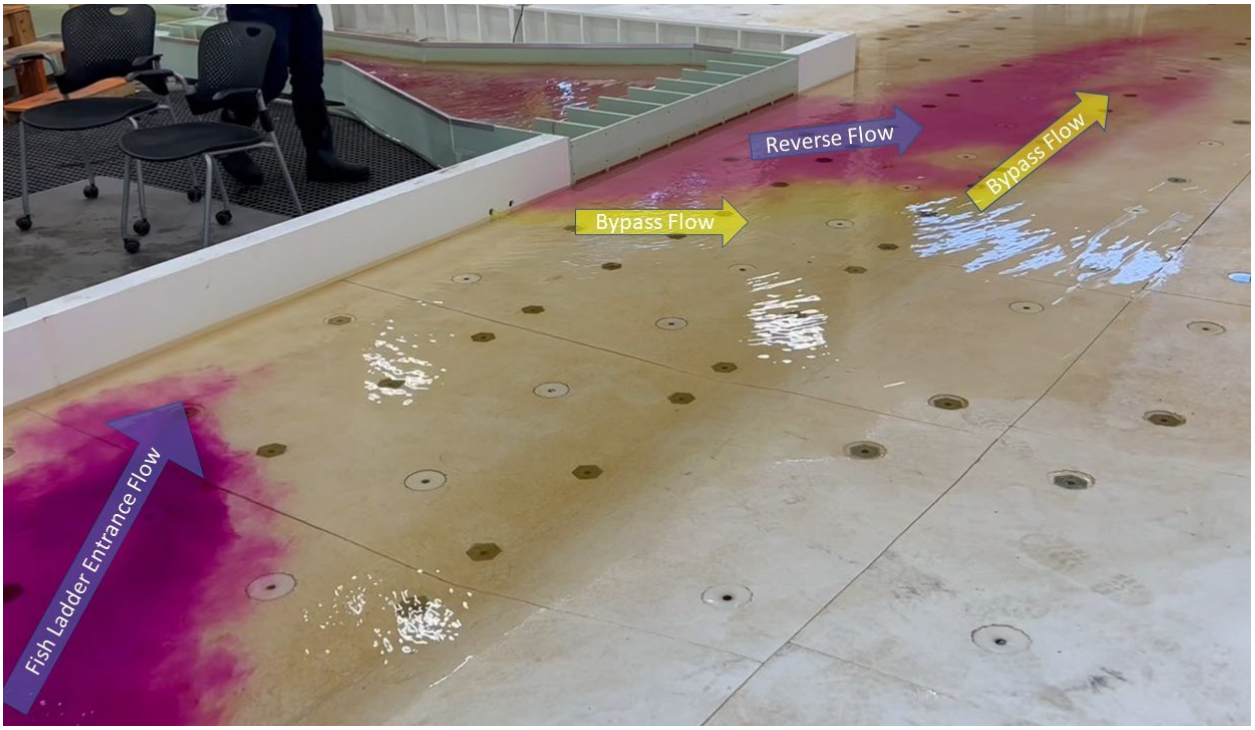

Figure 16. Visualization of discharge from the Reverse Flow Facility into the Compact Bypass channel under scenario 1:24 – 15 (140 cfs through CBCS, 1035 cfs to Mendota Pool, 400 cfs from reverse flow, 15 cfs from bypass).

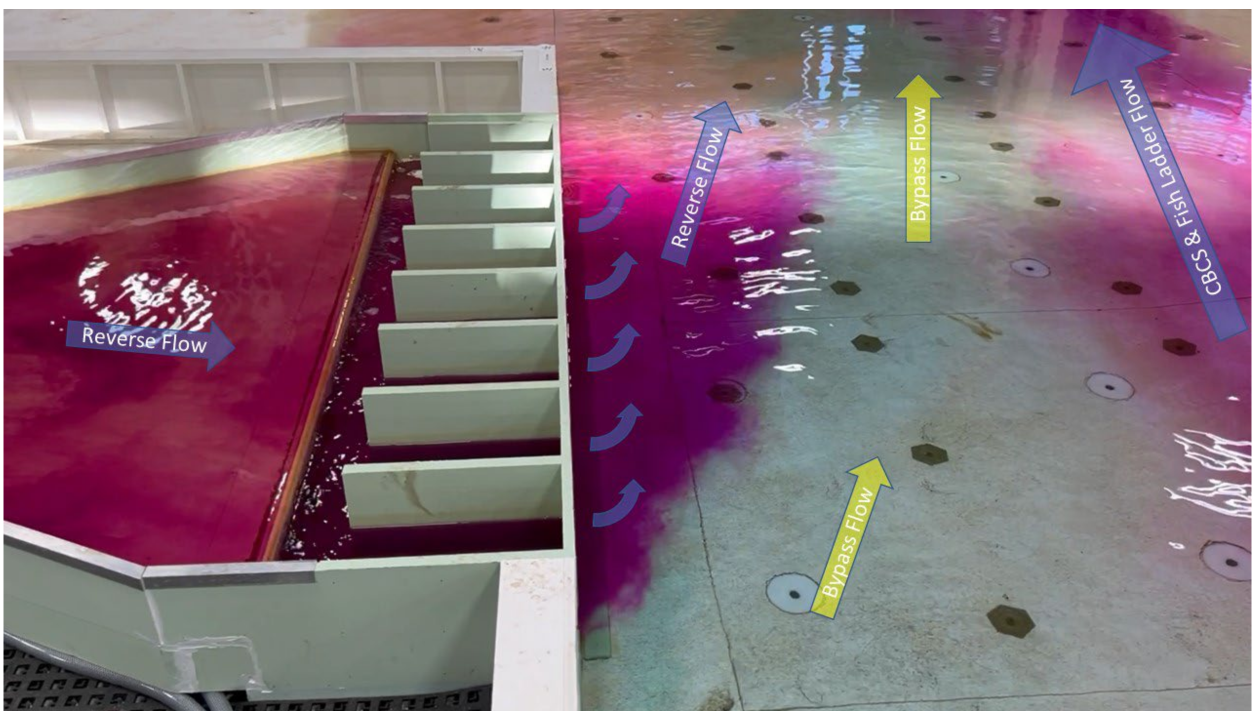

Figure 17. Visualization of discharge from the Reverse Flow Facility into the Compact Bypass channel under scenario 1:24 – 1 (2500 cfs through CBCS, 2070 cfs to Mendota Pool, 500 cfs from reverse flow, 30 cfs from bypass).

Fish Screen

Fish screens were included in the 1:24 scale physical model to help assess flow patterns as the CBCS and Fish Screen structures interacted with each other. To appropriately model the fish screens, aluminum perforated plates (1/8-in diameter holes at staggered 3/16-in spacing) were used with an open area of 40.31% (specifications for the prototype screens call for wedge wire with minimum open area of 40%). The perforated plate was installed over the top of a support structure with a variable baffle opening split into 13 sections across each of the four legs of the screens (see Table 15 and Figure 18). The scale of the physical model prevented physical velocity measurements along each leg of the fish screens. Dye testing was used to visualize the flow patterns and velocity distributions. Figure 19 shows four separate screen shots taken from a video recording of dye movement through the fish screens when 2000 cfs is being delivered to the Mendota Pool.

Table 15. Variable baffle openings downstream of the 40% open perforated plate on the fish screens.

Porosity Panel Number (from Upstream)	Porosity (%)
1	17.7
2	15.4
3	14.7
4	13.4
5	13.1
6	12.1
7	11.7
8	11.1
9	10.7
10	10.3
11	10.2
12	9.9
13	10.0

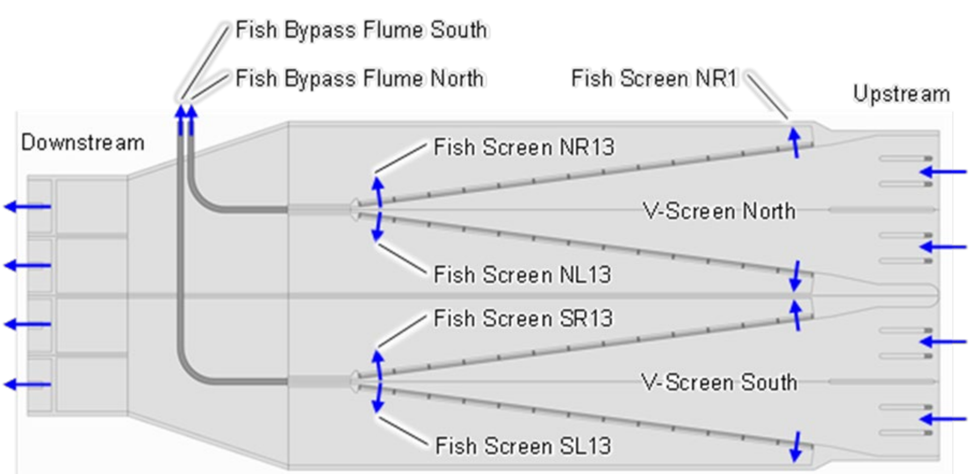

Figure 18. Diagram of the fish screen structure and panel designations. All four legs of the fish screen utilized the same baffling (compliments of Jacobs Engineering).

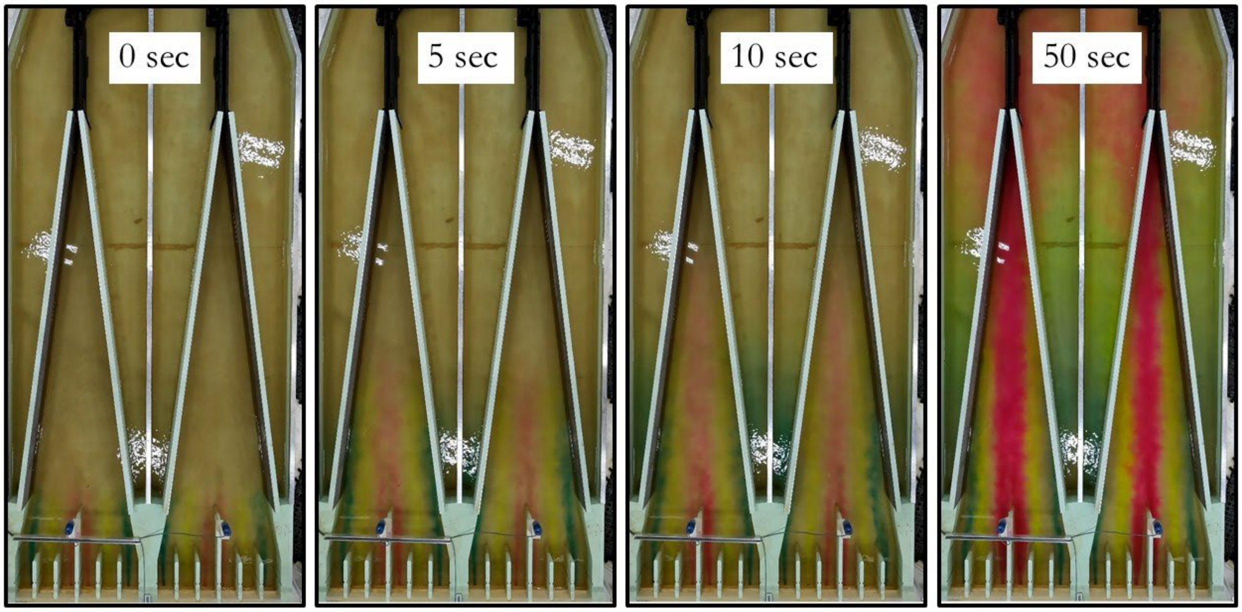

Figure 19. Progressive snapshots from video of dye testing when the fish screens deliver 2000 cfs to the Mendota Pool.

Apex and Transition Bypass Flume

All initial data collected on the 1:24 scale physical model were based on an assumption that the bypass channel from the fish screens would be piped to the fish recapture facility. Later in the design process it was determined that to carry the bypassed fish to the Fish Recapture Facility the channel needed to be a partially elevated channel, which would allow screened water flow to pass under the channel and into the Mendota Pool, but still allow the water in the bypass to flow by gravity into the Recapture Facility. Modifications to the 1:24 scale physical model removed the original Apex and Bypass Structure (Figure 20) and replaced them with an updated design (Figure 21 and Figure 8) determined during the CFD modeling of the Apex and Transition Flume. Modifying the Apex structure did not change the results when comparing several of the 1:24 scale scenarios which were modeled with the old design and the CFD-determined design.

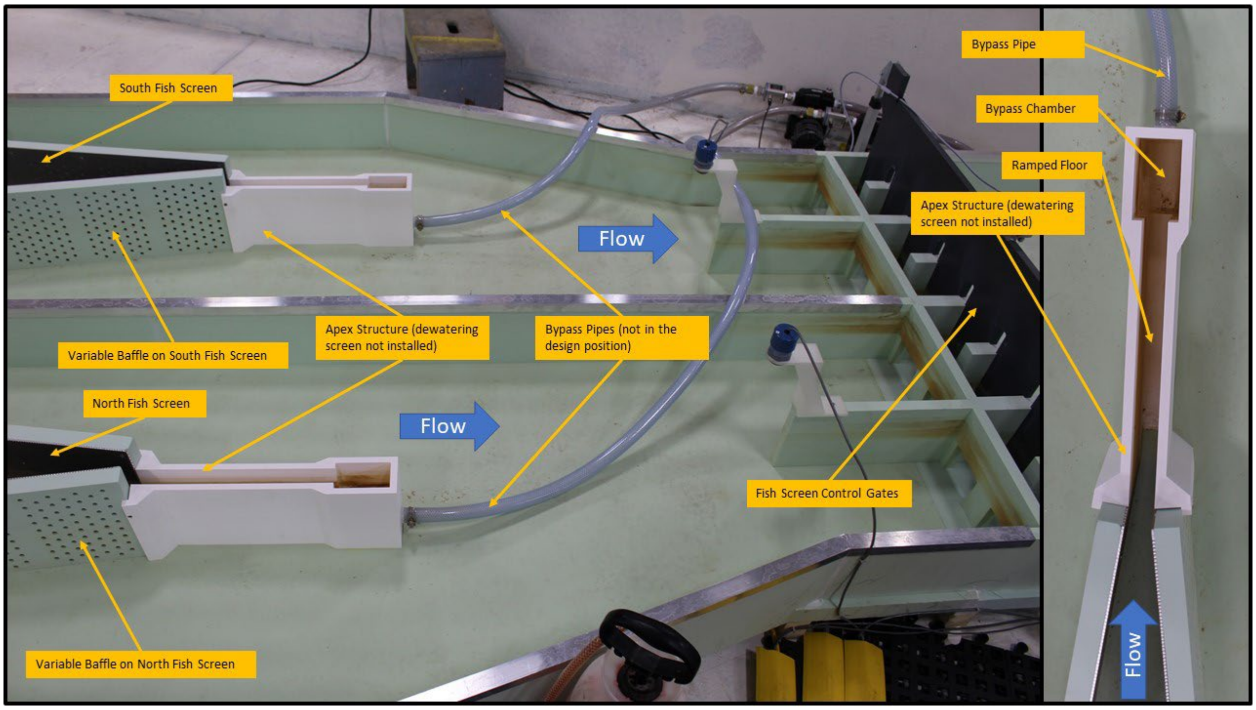

Figure 20. Isometric (left image) and plan (right image) view of the apex and bypass channel with annotations.

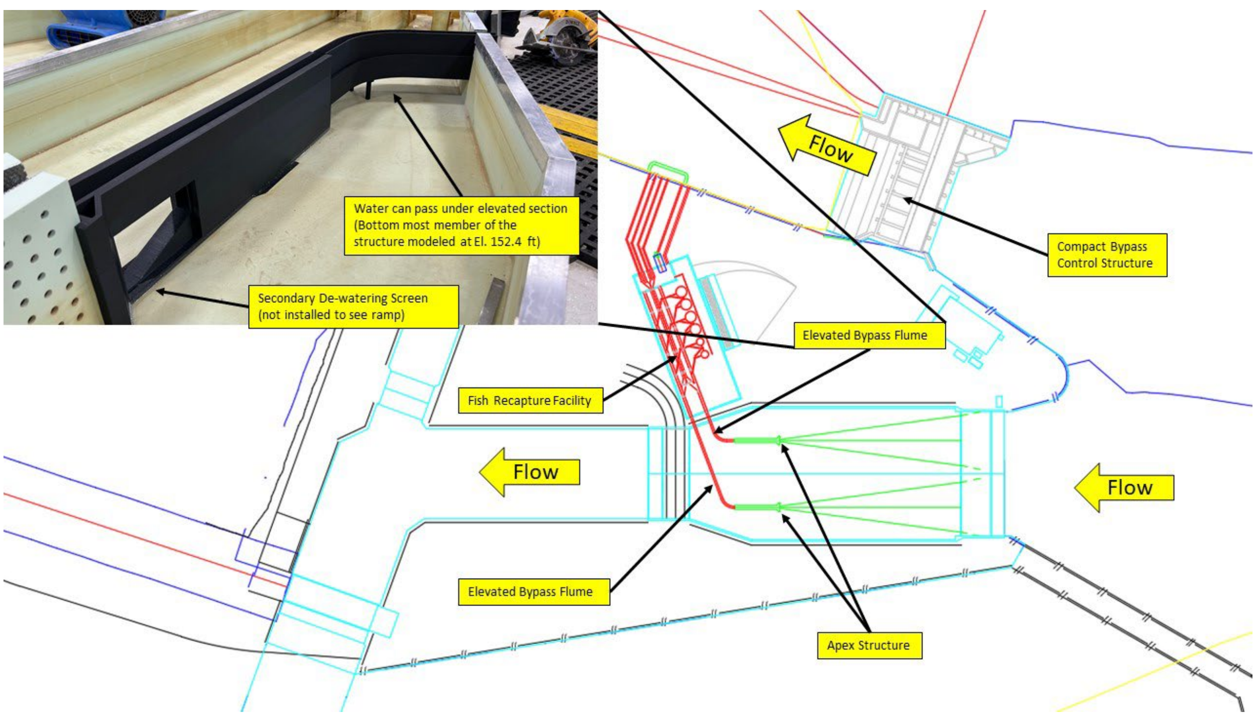

Figure 21. Elevated flume in the 1:24 scale physical model.

The Fish Screen Apex structure is used to pass fish and water to the Fish Recapture Facility (FRF) while meeting certain design criteria. Five percent of the screened water discharge is required to pass through each Apex structure. Thus, when 1000 cfs is delivered to the Mendota Pool, at least 50 cfs is required at the Apex structure. The 11-ft-long and at least 8-ft-tall secondary dewatering screens on either side of the Apex structure are used to reduce the discharge delivered to the FRF. Design guidance for the elevated transitional bypass flume requires a minimum depth of 1-ft, minimum width of 2-ft, and a minimum capture velocity of 6 ft/sec downstream of the secondary screens to prevent fish moving back upstream. To maintain the design guidelines, a discharge of around 12 cfs was required in the bypass flume.

Figure 22 provides a general isometric view of the Apex Structure and the 70-degree bend leading to the FRF. The bottom elevation of the secondary screen is at elevation 148 feet which is 1 ft above the fish screen floor invert. Portions of the screen are covered up in the image by the ramp that accelerates the discharge gradually before the 6 ft/sec capture velocity is achieved. It is recommended that the current 8-ft tall screen be extended an additional 2.5-ft to account for subsidence of the structure.

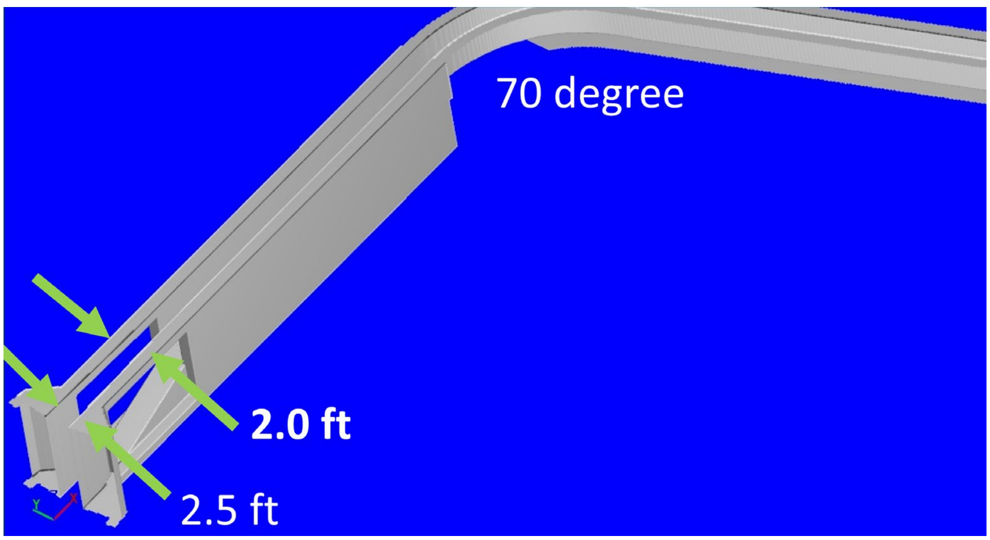

Figure 22. General layout of the Apex Structure.

Another critical design requirement is to maintain a velocity gradient of less than 0.2 ft/sec/ft throughout the Apex Structure to avoid deterring fish from entering the bypass. Early modeling of the Apex structure indicated that the side-screen withdrawal caused the water to decelerate significantly, creating a negative velocity gradient. Due to the velocity gradient restrictions, the slower water downstream of the withdrawal screens causes the ramp to be longer (e.g., accelerating from 2.5 ft/sec to 6 ft/sec with a velocity gradient of 0.2 ft/sec/ft requires a minimum of 17.5 feet in a perfect system, while 1.5 ft/sec requires 22.5 feet in a perfect system). The width of the flume was narrowed from 2.5 ft at the entrance to 2.0 ft over the first 12 ft of length which slightly increased velocities and smoothed the velocity gradient, reducing the length of the ramp and the required flow sent to the Fish Recovery Facility.

The first two sections of the ramp are straight slopes, selected largely based on velocities at the base of the ramp to reduce the size of the stagnation zone which may discourage bottom-swimmers from continuing down to the flume. The first section is envisioned as a concrete wedge to avoid the requirement of sediment cleaning underneath. The bend midway up the ramp could be used as a hinge-point to adjust the height of the exit flume if ever needed.

CFD simulations on different geometry found the velocity gradient was highly sensitive to the shape of the ramp beyond X = 114 ft (the start of the Apex was modeled at X = 100 ft). Energy based water surface profile calculations were completed to help determine the ideal ramp shape. A direct application of the energy equation to calculate ramp elevation by applying 0.20 ft/sec/ft starting at 114 feet at 1.788 ft/sec, and then at 1-foot increments was used to calculate velocity, water surface elevation, and depth required to achieve the target velocity, and then the ramp elevation (Equation 3 through Equation 7). This approach caused the simulated velocity gradient to overshoot the maximum target by 0.1 ft/sec/ft. To create a smooth shape and avoid overshooting, the calculated velocity gradient was reduced by 0.005 ft/sec/ft at every 1-foot increment and calculated as discussed above and shown in Table 16. The layout using a slightly sloped section between X = 134-ft and 141-ft and the horizontal section between 141-ft and 151-ft at elevation 153.40 ft was achieved through trial and error.

Equation 3 $$\frac{dU_i}{dX} = 0.20\,ft/s/ft - 0.005 * i$$

Equation 4 $$U_i = U_{i-1} - \frac{dU_i}{dX}$$

Equation 5 $$\mathrm{HGL}_i = \mathrm{EGL} - \frac{U_i^2}{2g}$$

Equation 6 $$D_i = \frac{Q}{U_i * W}$$

Equation 7 $$R_i = HGL - D_i$$

In the equations above, i is the segment increment starting at X=114 ft with $i = 0$; U_i = X-direction velocity at segment i (ft/sec); dU_i is the change of velocity in the X direction at segment $i;\ dX$ is 1 ft; $\frac{dU_i}{dX}$ is the velocity gradient at segment i in ft/sec/ft; EGL is energy grade line which was 151.195 ft; HGL_i is hydraulic grade line (water surface elevation in ft); D_i is water depth in ft at segment i; g is acceleration due to gravity, 32.2 ft/sec^2; D_i is the depth of flow at segment i in ft; W is the width of the flume which was 2 ft in the curved ramp zone; and R_i is the elevation of the ramp for segment i.

While the simulation modeled straight segments for each foot interval, the final design can use a smoothly bent ramp or minor bends at 1-foot intervals. Resulting elevations of this estimation are shown in Table 16.

Table 16. Ramp shape based on the energy equation using a decreasing velocity gradient. The flow parameters do not include effect of momentum and is only an estimate of depth and water surface elevation.

X	dUdX	X-Velocity	Estimated Water Surface Elevation	Depth	Elevation of Ramp
(ft)	(ft/sec/ft)	(ft/sec)	(ft)	(ft)	
100					147
103					147
107					148.25
114		1.788	155.19	4.19	151
115	0.2	1.988	155.15	3.77	151.37
116	0.195	2.183	155.13	3.44	151.7
117	0.19	2.373	155.12	3.16	151.96
118	0.185	2.558	155.11	2.93	152.18
119	0.18	2.738	155.09	2.74	152.35
120	0.175	2.913	155.08	2.57	152.5
121	0.17	3.083	155.06	2.43	152.63
122	0.165	3.248	155.05	2.31	152.74
123	0.16	3.408	155.03	2.2	152.83
124	0.155	3.563	155.01	2.1	152.91
125	0.15	3.713	155	2.02	152.98
126	0.145	3.858	154.98	1.94	153.04
127	0.14	3.998	154.96	1.88	153.09
128	0.135	4.133	154.95	1.81	153.13
129	0.13	4.263	154.93	1.76	153.17
130	0.125	4.388	154.91	1.71	153.2
131	0.12	4.508	154.9	1.66	153.23
132	0.115	4.623	154.88	1.62	153.26
133	0.11	4.733	154.86	1.58	153.28
134	0.105	4.838	154.85	1.55	153.3
141		4.838	154.83	1.55	153.4
151					153.4

Results of the CFD simulation are shown in Figure 23. This configuration resulted in 13.5 cfs at 1.01-ft depth with a velocity of 6.67 ft/sec at model STA 1+50.89. Up to reaching the capture velocity of 6 ft/sec the velocity gradient remained below 0.2 ft/sec/ft. Capture velocity is maintained for over 13 feet (when depth averaged velocities remained above 6 ft/sec with a peak above 8.0 ft/sec) (Figure 24). The length with velocities greater than 6 ft/sec are limited by the bend (helix) slope and slope of the straight channel to the FRF.

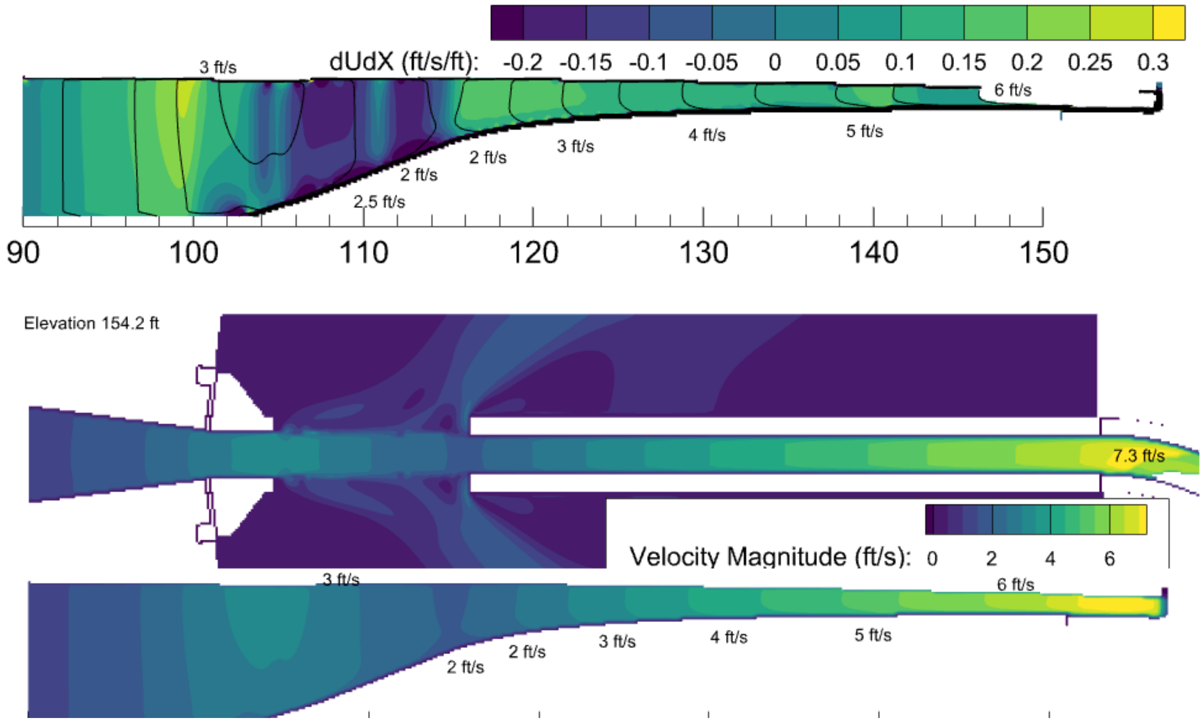

Figure 23. Velocity gradient profile and velocities of recommended flume. Top: Profile of centerline velocity gradients in X-direction with contours above 6 ft/sec "blanked out". Middle: velocity contours at elevation 154.2 ft. Bottom: Velocity profile contours along centerline of Apex Structure.

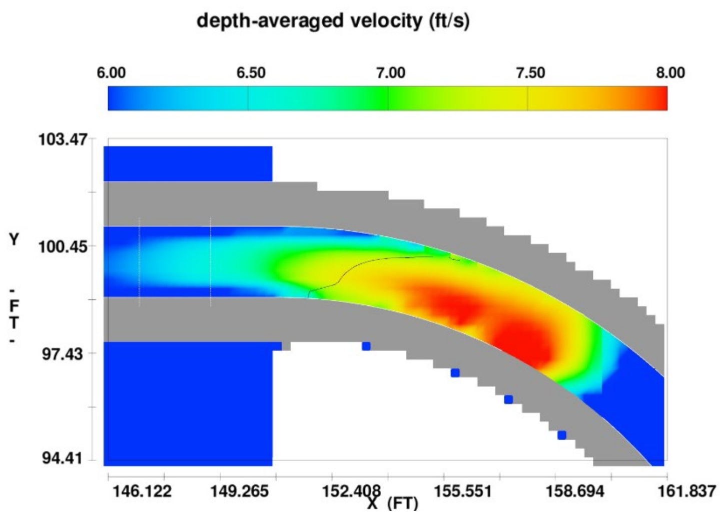

Figure 24. Depth-averaged-velocity contours above 6 ft/sec.
The length of the zone is about 13 ft.

The 70º bend was drawn using the AutoCAD helix function and sweep-loft to define the centerline of the 2 ft wide channel. The AutoCAD parameters of the helix are listed in Table 17. The elevation change of the helix is from elevation 153.40 ft to 152.90 ft, for a 0.50 ft drop. From the end of the helix to the FRF, the elevated flume is sloped at 1-ft vertical to 526.32-ft horizonal (0.10886185º). The backwater effect caused by the slope of the elevated flume causes a gradual transition to subcritical flow to begin about halfway through the 70º bend. The depth-averaged velocity in the straight elevated flume to the FRF was 4.16 ft/sec.

Table 17. Helix parameters for the 70º bend.

```
HELIX      Layer: "R16a turn"
           Space: Model space
 Handle = 748
Position: X =  150.8922, Y =   85.0000, Z =  153.3997
Length: 18.3328
Base radius: 15.0000
Top radius: 15.0000
Turns: 0.1944
Step Dist: 2.5714
Axis: X =    0.0000, Y =    0.0000, Z =   -1.0000
```

Water surfaces and flume bottom elevations are shown in Table 18.

Table 18. Water surface and bottom elevation from Apex structure to near the FRF.
The beginning and end of the 70º bend is designated with an "*" and light grey highlighting.

Stationing	Bottom Elevation	Water Surface Elevation
(ft)	(ft)	(ft)
1+22.00	152.74	155.01
1+24.00	152.91	154.98
1+26.00	153.04	154.95
1+28.00	153.13	154.92
1+30.00	153.2	154.88
1+32.00	153.26	154.85
1+34.00	153.3	154.82
1+36.00	153.33	154.79
1+38.00	153.36	154.76
1+40.00	153.39	154.71
1+42.00	153.4	154.66
1+44.00	153.4	154.62
1+46.00	153.4	154.62
1+48.00	153.4	154.56
1+50.00	153.4	154.58
1+50.89	153.4	154.41
*1+51.81	153.37	154.43
1+52.72	153.35	154.35
1+53.64	153.33	154.3
1+54.56	153.3	154.26
1+55.47	153.27	154.29
1+56.39	153.25	154.19
1+57.30	153.22	154.28
1+58.22	153.2	154.46
1+59.14	153.17	154.71

1+60.05	153.15	154.65
1+60.97	153.13	154.59
1+61.89	153.1	154.62
1+62.80	153.07	154.66
1+63.72	153.05	154.66
1+64.63	153.02	154.66
1+65.55	153	154.67
1+66.47	152.97	154.67
1+67.38	152.95	154.67
*1+68.30	152.93	154.68
1+89.21	152.86	154.63
1+93.93	152.85	154.61
1+99.21	152.84	154.59
2+09.21	152.82	154.57
2+14.34	152.81	154.58
2+19.21	152.8	154.54
2+23.73	152.8	154.5
2+32.13	152.78	154.47
2+39.21	152.77	154.5
2+49.21	152.75	154.43
2+59.21	152.73	154.35
2+65.17	152.72	154.34

Fish Recapture Facility

The Fish Recapture Facility is currently being modeled using CFD analysis. Once that modeling is complete, a separate report will be prepared to discuss the results.

Water Surface Elevations & Head Loss of Structures

Water surface elevations and the total head loss across the CBCS are provided in Table 19. The maximum head loss seen during restoration flows is 0.40 ft. Head loss across the CBCS during Mendota Pool deliveries can be calculated by subtracting the tailwater elevations from the upstream water surface elevation of 156.0 ft for the 1:12 physical model.

Table 19. Water surface elevations and total head loss during restoration flows through the CBCS at day-1 operation.

Run #	Water Surface Elevation 100-ft upstream of CBCS	Water Surface Elevation 50-ft upstream of CBCS	Water Surface Elevation 100-ft downstream of CBCS	Water Surface Elevation 150-ft downstream of CBCS	Total Head Loss
-	(ft)	(ft)	(ft)	(ft)	(ft)
1:12 - 12	151.56	151.48	151.2	151.16	0.40
1:12 - 13	151.12	151.07	150.81	150.77	0.35
1:12 - 14	150.51	150.45	150.22	150.19	0.32
1:12 - 15	149.67	146.63	149.41	149.38	0.29
1:12 - 16	148.72	148.62	148.49	148.46	0.26
1:12 - 17	147.73	147.66	147.58	147.56	0.17
1:12 - 18	146.75	146.7	146.63	146.62	0.13
1:12 - 19	145.7	145.68	145.65	145.64	0.06
1:12 - 20	145.13	145.13	145.07	145.07	0.06
1:12 - 21	144.44	144.39	144.34	144.34	0.10
1:12 - 22	143.43	143.35	143.33	143.32	0.11
1:12 - 23	142.61	142.54	142.51	142.51	0.10

Water surface elevations measured during the 1:24 physical model testing included nine locations shown in Figure 25. Table 20 contains the water surface elevations recorded during the operation of the model. Target setpoints were established to maintain the water surface upstream of the Fish Screen trash rack at 155.6-ft and maintain the Mendota Pool water surface elevation at 153.6-ft. Other water surface elevations were recorded based on what the model required to maintain the target elevations. Adjustments to the model to maintain the target water surface elevations included gate changes on the CBCS, Fish Screen Control Gates, the outflow boundary gates at the Mendota Pool, the end of the Compact Bypass Channel, the AWS discharge regulation and the Fish Ladder Entrance weir gate. Once all the gates were set and flows stabilized, the water surfaces were recorded.

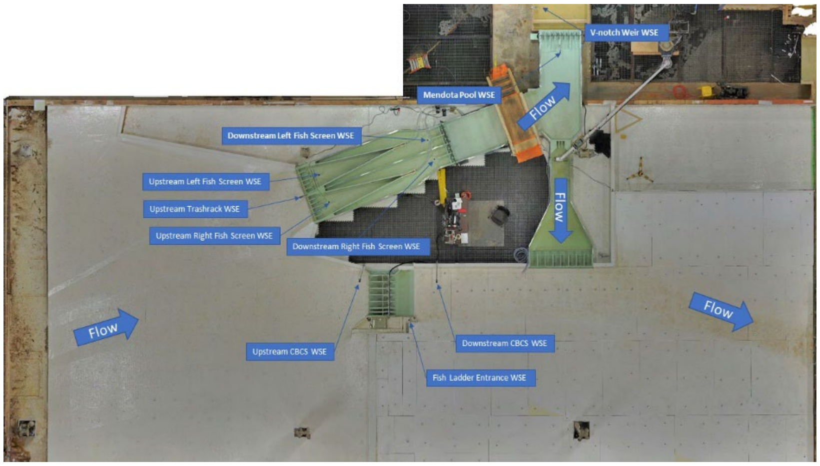

Figure 25. Locations of water surface elevation (WSE) measurements in the 1:24 scale physical model.

Table 20. Water surface elevations throughout the 1:24 scale physical model. The model was operated to maintain target elevations of 155.6-ft upstream of the Fish Screen Trashrack (column 5) and 153.6-ft at the Mendota Pool (column 10).

	Water Surface Elevation -								
Run #	50-ft Upstream of CBCS	220-ft Downstream of CBCS	Center of Fish Ladder Entrance	20-ft Upstream of Fish Screen Trash Rack	Entrance of North Fish Screen	Downstream of North Fish Screen Bypass	Entrance of South Fish Screen	Downstream of South Fish Screen Bypass	Mendota Pool
-	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)
1:24 - 1	155.59	150.11	153.68	155.56	155.33	154.86	155.34	154.89	153.7
1:24 - 2	155.58	149.31	150.25	155.5	155.32	154.85	155.34	154.89	153.56
1:24 - 3	155.53	150.96	151.85	155.49	155.27	154.86	155.49	155.51	153.63
1:24 - 4	155.53	150.96	151.85	155.49	155.47	155.53	155.29	154.91	153.5
1:24 - 5	155.54	151.75	152.42	155.56	155.47	155.41	155.55	155.52	155.53
1:24 - 6	155.53	151.77	152.4	155.49	155.28	154.85	155.5	155.5	153.63
1:24 - 7	155.59	148.28	149.34	155.51	155.31	154.85	155.32	154.92	153.54
1:24 - 8	155.62	150.17	151.16	155.58	155.56	155.56	155.39	154.97	153.66
1:24 - 9	155.58	152.39	152.89	155.61	155.54	155.56	155.6	155.57	147.52
1:24 - 10	155.63	145.86	146.98	155.6	155.39	154.98	155.65	155.62	153.57
1:24 - 11	155.55	144.49	145.68	155.51	155.28	154.83	155.27	155.5	153.63
1:24 - 12	155.63	145.36	146.35	155.62	155.5	155.41	155.57	155.42	153.66
1:24 - 13	155.62	140.64	141.37	155.61	155.49	155.48	155.59	155.57	153.43
1:24 - 14	155.63	140.52	141.4	155.6	155.58	155.64	155.64	155.54	153.26
1:24 - 15	155.61	144.71	146.25	155.55	155.34	154.93	155.62	155.57	153.62
1:24 - 16	155.61	144.67	145.7	155.54	155.55	155.57	155.42	154..97	153.44
1:24 - 17	155.7	141.54	144.32	155.63	155.38	155	155.46	155.03	153.67
1:24 - 18	155.66	144.18	145.16	155.6	155.33	154.97	155.43	155.02	153.61
1:24 - 19	145.28	145.28	NA	NA	NA	NA	NA	NA	NA

Table 21 includes head loss calculations for various structures around the model. The head loss across the fish screen structure remained below 6-in for all tested scenarios. After the elevated bypass channel was installed, tests were conducted to look at the head loss across the bypass channels when 2000 cfs is being delivered to the Mendota Pool. The bypass channels created a total of 0.25 and 0.44 ft of head loss for the south and north delivery channels respectively when the flume support members are no lower than El. 152.4 ft (Figure 26). The head loss generated from the elevated bypass flume is skewed in each of the conveyance channels downstream of the fish screens. A higher water surface elevation acting on the downstream side of the right leg of both vee screens would indicate that less water would be passing through that same side of the vee. Dye testing (Figure 27) showed that this mismatch in flow was insignificant enough that it could not be detected in the 1:24 scale physical model. If the right legs of each vee screen were passing significantly less water, one would see the dye traces drift to the left side of the vee screen.

Table 21. Head loss calculations and gate openings for the 1:24 scale physical model scenarios.

Run #	CBCS Gate Opening	Head Loss					Fish Screen Control Gate Opening
		CBCS	Fish Screen Trash Rack	North Fish Screen	South Fish Screen	Fish Screen Control Gates	
-	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)
1:24 - 1	2.00	5.48	0.22	0.47	0.45	1.18	3.75
1:24 - 2	1.94	6.27	0.17	0.47	0.45	1.31	4.06
1:24 - 3	3.19	4.57	0.22	0.41	OFF	1.23	3.76
1:24 - 4	3.19	4.57	0.20	OFF	0.38	1.41	3.76
1:24 - 5	3.89	3.79	0.09	0.06	OFF	1.87	1.70
1:24 - 6	3.58	3.76	0.21	0.43	OFF	1.22	3.75
1:24 - 7	1.21	7.31	0.19	0.46	0.40	1.35	3.83
1:24 - 8	2.19	5.45	0.19	OFF	0.42	1.31	3.81
1:24 - 9	4.22	3.19	0.04	OFF	OFF	OFF	0.00
1:24 - 10	1.79	9.77	0.21	0.41	OFF	1.41	3.48
1:24 - 11	1.46	11.06	0.23	0.45	OFF	1.20	3.60
1:24 - 12	1.18	10.27	0.09	0.09	0.15	1.76	2.14
1:24 - 13	0.00	14.98	0.12	0.01	OFF	2.05	1.18
1:24 - 14	0.00	15.11	0.02	OFF	0.10	2.28	1.21
1:24 - 15	0.00	10.90	0.21	0.41	OFF	1.31	3.52
1:24 - 16	0.00	10.94	0.05	OFF	0.45	1.83	3.61
1:24 - 17	0.35	14.16	0.21	0.38	0.43	1.35	3.83
1:24 - 18	1.30	11.48	0.22	0.36	0.41	1.38	3.84
1:24 - 19	FULL	0.00	OFF	OFF	OFF	OFF	0.00

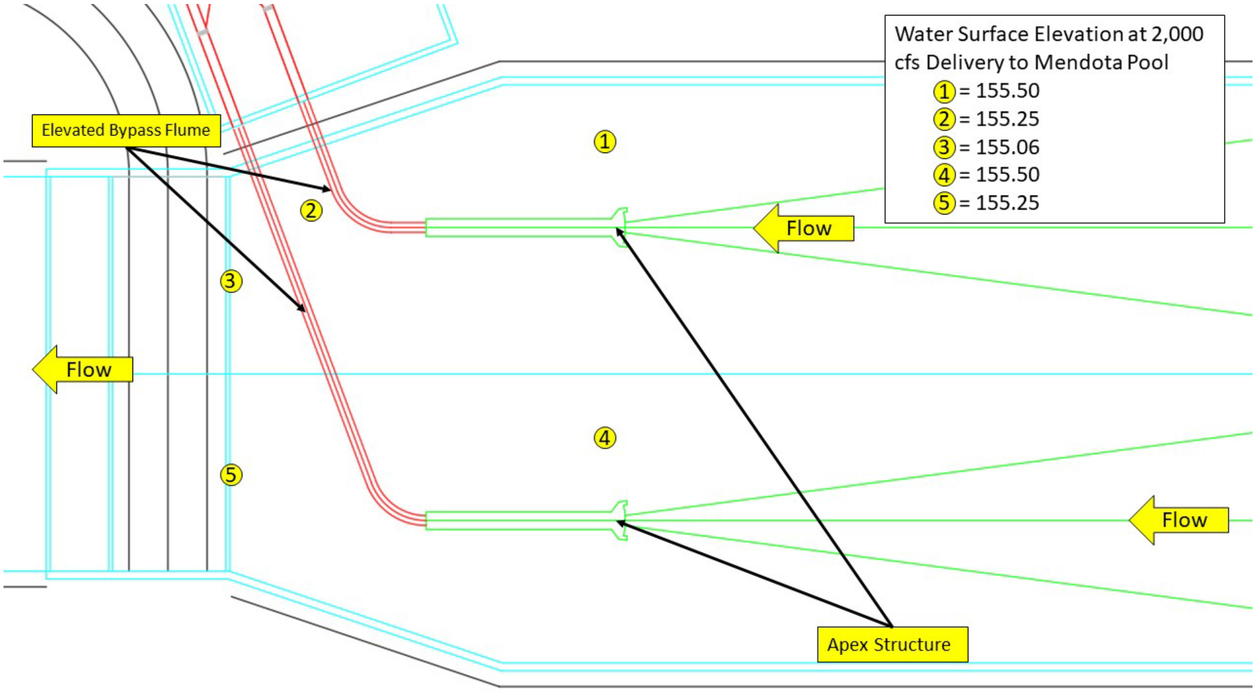

Figure 26. Water Surface Elevations in the north and south delivery channels downstream of the Fish Screen with 2000 cfs delivered to Mendota pool when the bypass channel was installed.

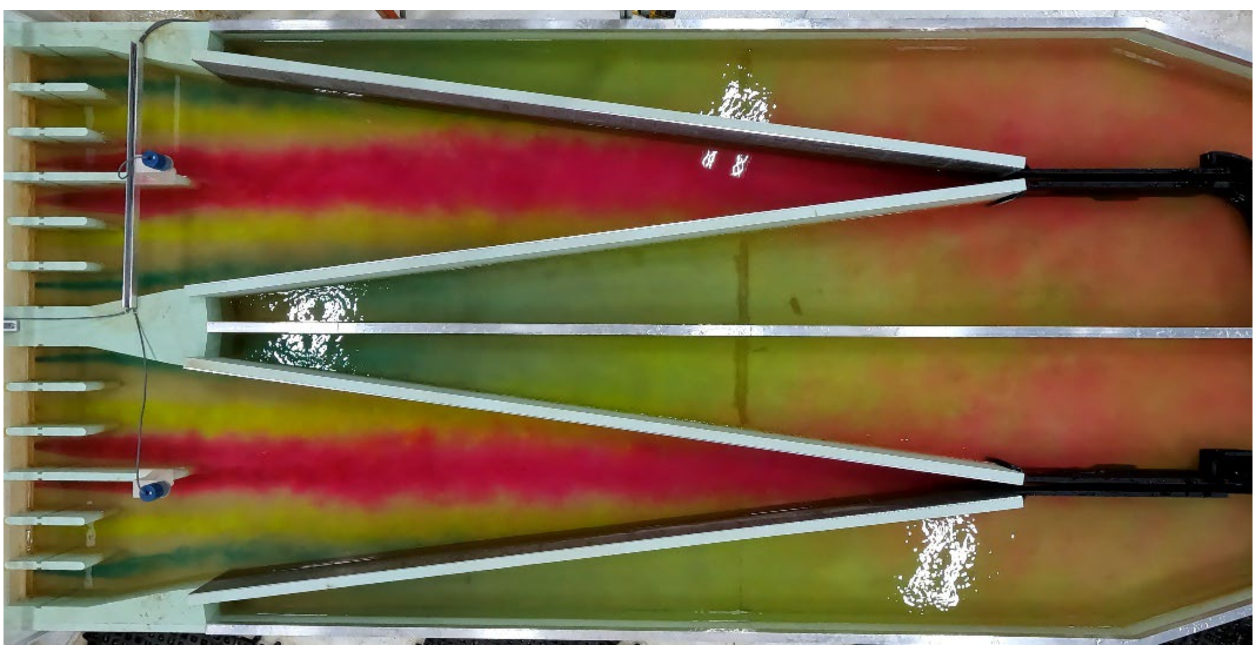

Figure 27. Dye testing of flow patterns after the bypass flumes were installed downstream of the Fish Screens.

Upstream Velocity Patterns

The interaction between the CBCS and the Fish Screen Structure were investigated using slow-dispersion dye tablets. Tablets were placed in the upstream channel using a similar pattern for each scenario. While the model was operating, the dye would trace the flow streamlines throughout the simulation. Additional potassium permanganate (dark magenta) crystals were used to add definition to critical velocity patterns in some scenarios. Figure 28 through Figure 35 provide the results of the dye tracer tests for eight flow scenarios viewed from a mosaic of 6 different angles. The mosaic images are being processed by the SJRRP office and will all become available once the processing is complete. Additionally, Appendix A provides images of the overhead view of the upstream channel for all 18 test scenarios.

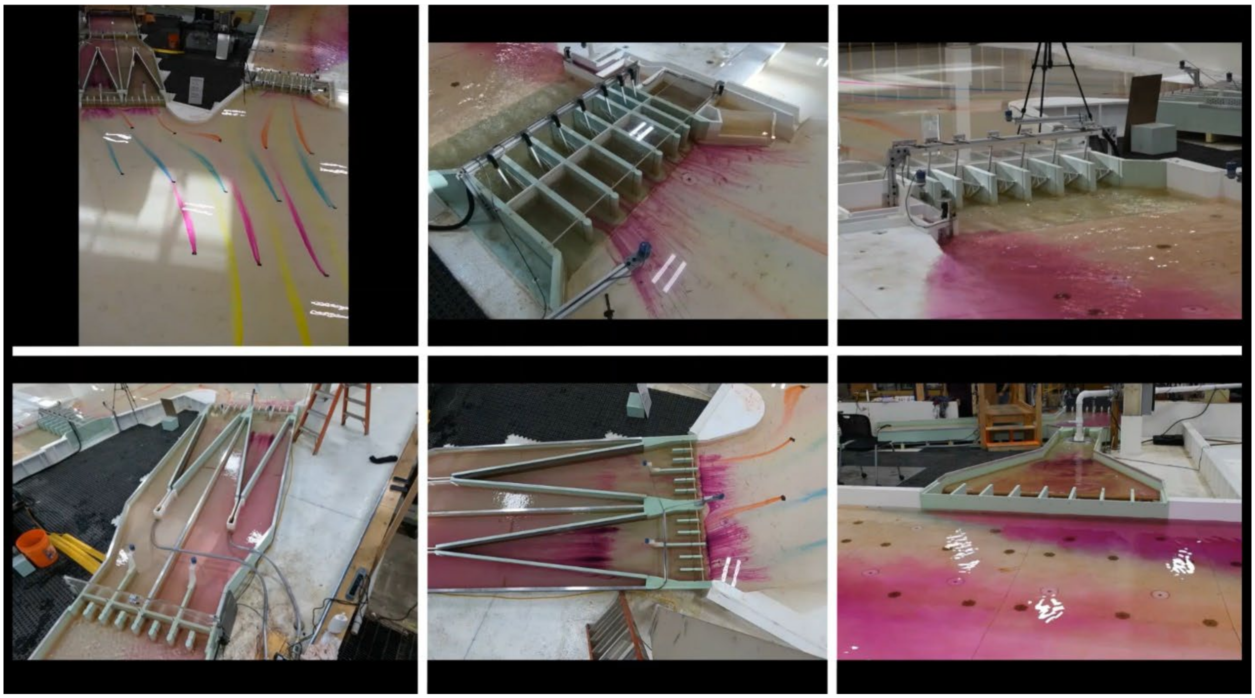

Figure 28. Mosaic image of dye testing on the 1:24 scale physical model for Scenario 1:24 – 1.

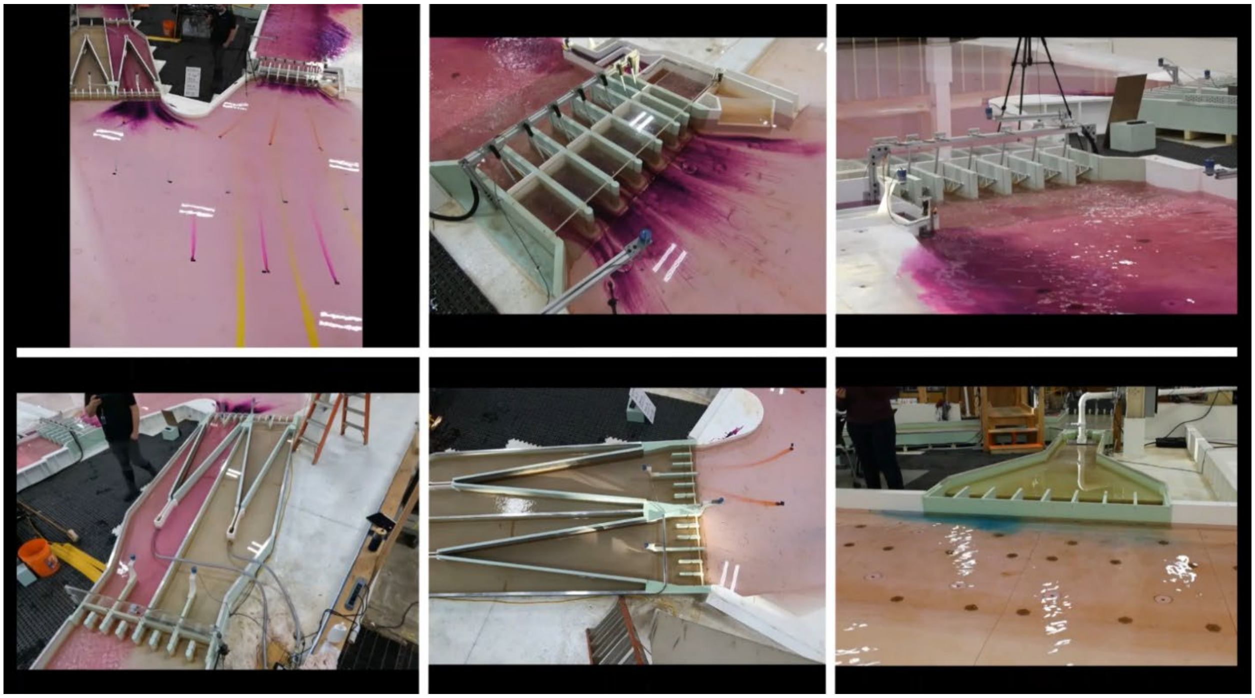

Figure 29. Mosaic image of dye testing on the 1:24 scale physical model for Scenario 1:24 – 3.

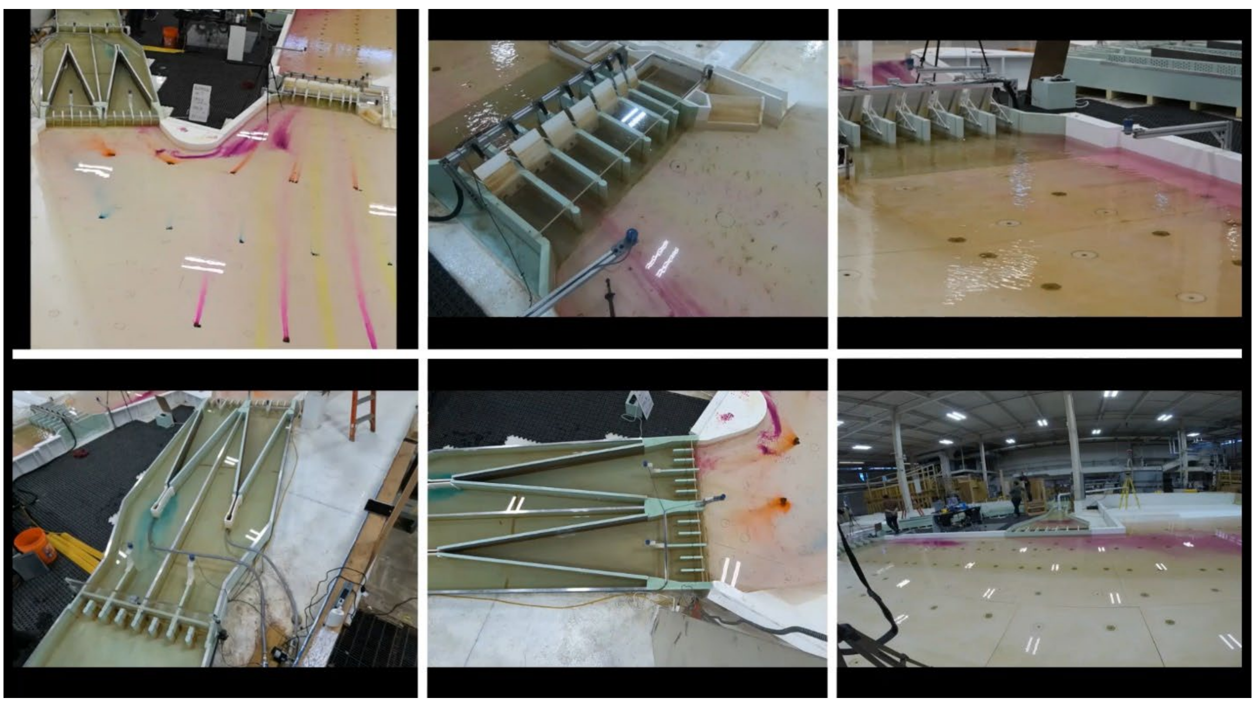

Figure 30. Mosaic image of dye testing on the 1:24 scale physical model for Scenario 1:24 –- 9.

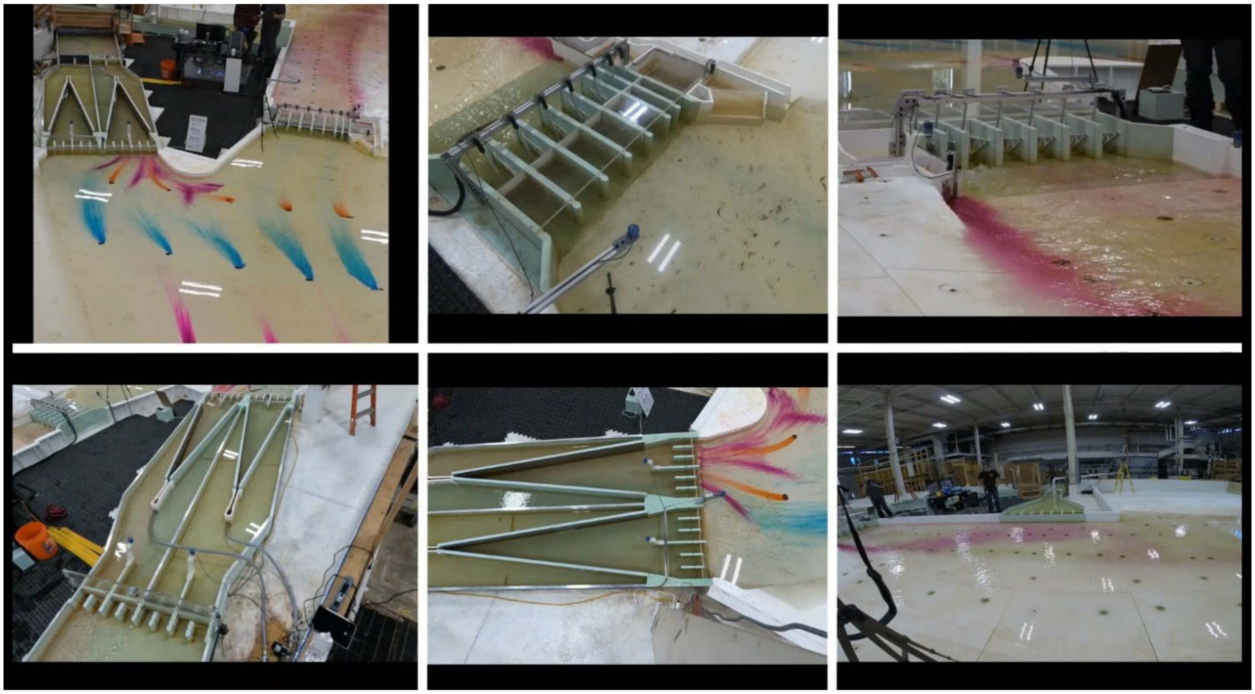

Figure 31. Mosaic image of dye testing on the 1:24 scale physical model for Scenario 1:24 – 10.

Figure 32. Mosaic image of dye testing on the 1:24 scale physical model for Scenario 1:24 – 11.

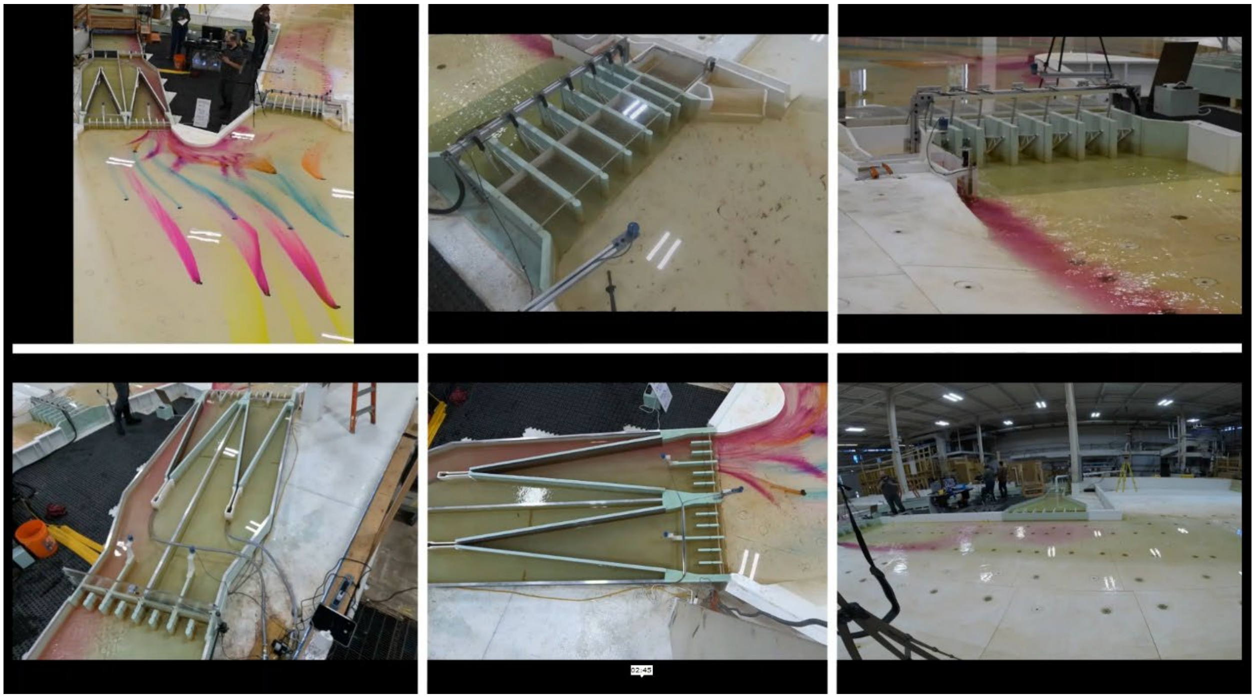

Figure 33. Mosaic image of dye testing on the 1:24 scale physical model for Scenario 1:24 – 18.

Figure 34. Mosaic image of dye testing the on the 1:24 scale physical model for an additional scenario (CBCS 300 cfs, Mendota Pool 2000 cfs Reverse Flow Facility 500 cfs).

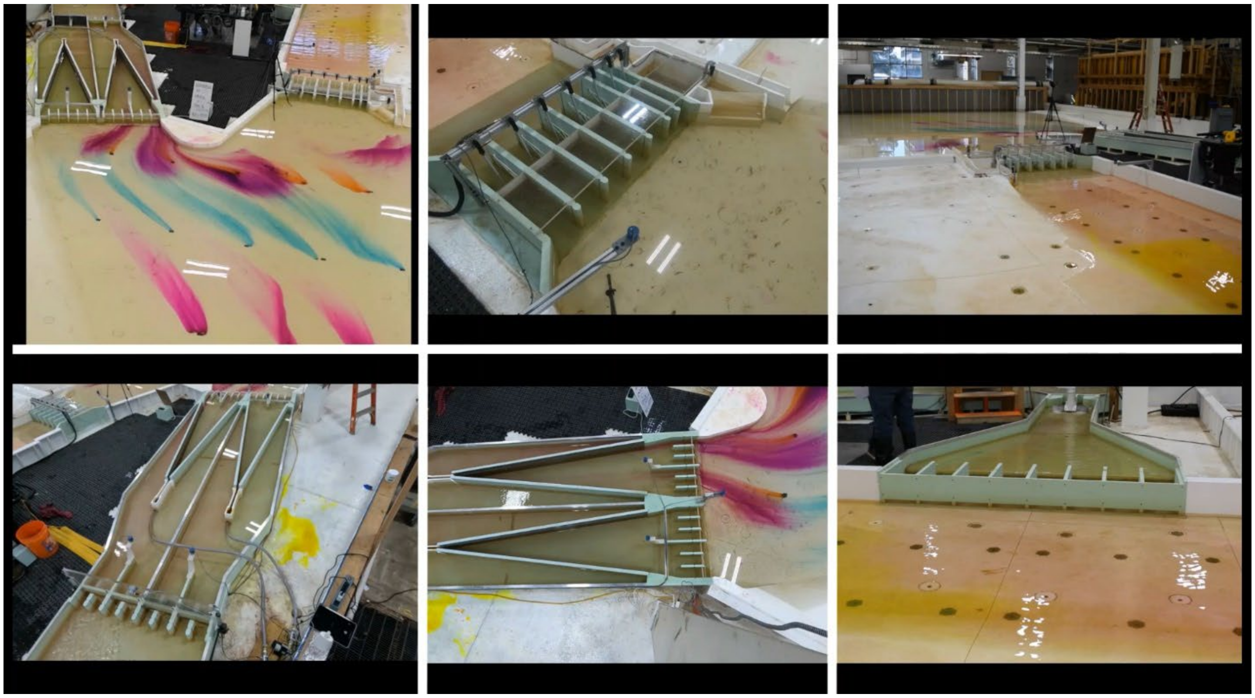

Figure 35. Mosaic image of dye testing on the 1:24 scale physical model for an additional scenario (CBCS 0 cfs, Mendota Pool 1000 cfs from North Screen, Reverse Flow Facility 500 cfs).

Conclusions

This report summarizes the findings of multiple modeling efforts that were completed at the Bureau of Reclamation Hydraulics Laboratory in Denver CO. Staff of the Hydraulic Investigations and Laboratory Services group were the principal investigators for the modeling efforts. Several site visits were conducted during the modeling to allow project staff, design engineers, stakeholders and regulatory agency partners to witness the interactions of the various structures under a range of flow scenarios. Many decisions were made during these visits that allowed the project to move past hurdles that were encountered during the design process. The results from the modeling indicate the structures should perform satisfactorily under expected operating conditions encountered from day-1 commissioning through structure subsidence of up to 2.5 ft.

Three main modeling efforts presented include a 1:12 physical model of the CBCS, Fish Ladder and AWS, a 1:24 physical model of the CBCS and MPFS, and CFD model of the Apex and Transitional Bypass Flume. Depths and velocities throughout each modeled structure are within an acceptable range given the complex balance of regulatory requirements and the wide range of operating scenarios needed for the structures to both provide restoration water to the San Joaquin River and deliver water to the Mendota Pool.

References

Bureau of Reclamation (Reclamation). *Fish Protection at Water Diversions.* U.S. Department of the Interior Denver, CO USA. (April 2006)

Bureau of Reclamation (Reclamation). *Settlement in Natural Resources Defense Council, et al., v. Kirk Rodgers, as Regional Director of the United States Bureau of Reclamation, et al.* (2006)

Flow Science Inc. Introduction to FLOW-3D® (1996).

Sicilian, J.M. *A FAVOR Based Moving Obstacle Treatment for FLOW-3D®* Flow Science, Inc. Technical Note #24, (April 1990) (FSI-90-TN24)

Appendix A

Images of slow-release dye testing of the upstream channel for the 1:24 scale physical model (scenario 1:24-1 to 1:24-18).

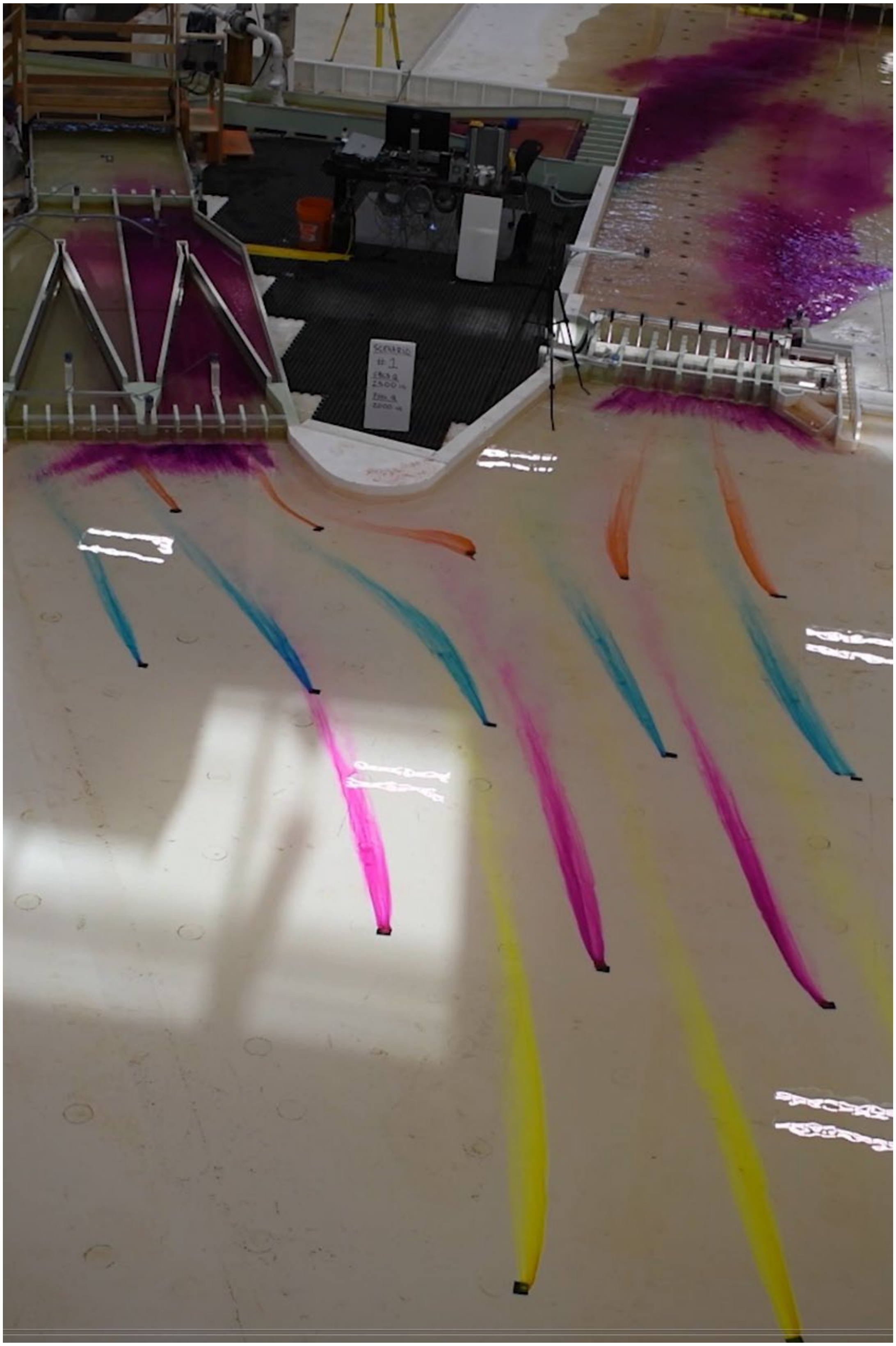

Figure 36. Upstream channel dye testing for Scenario 1:24 – 1.

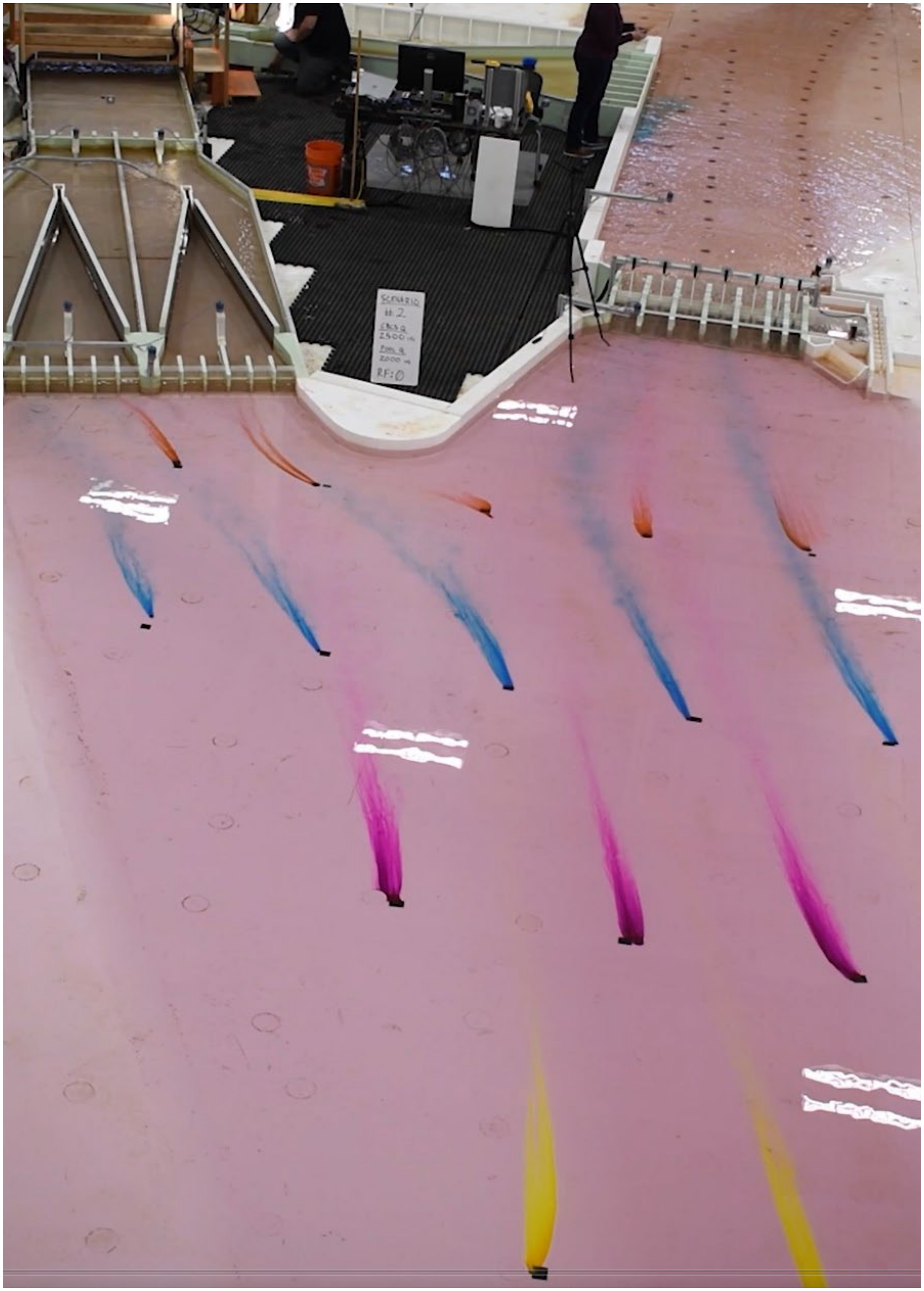

Figure 37. Upstream channel dye testing for Scenario 1:24 – 2.

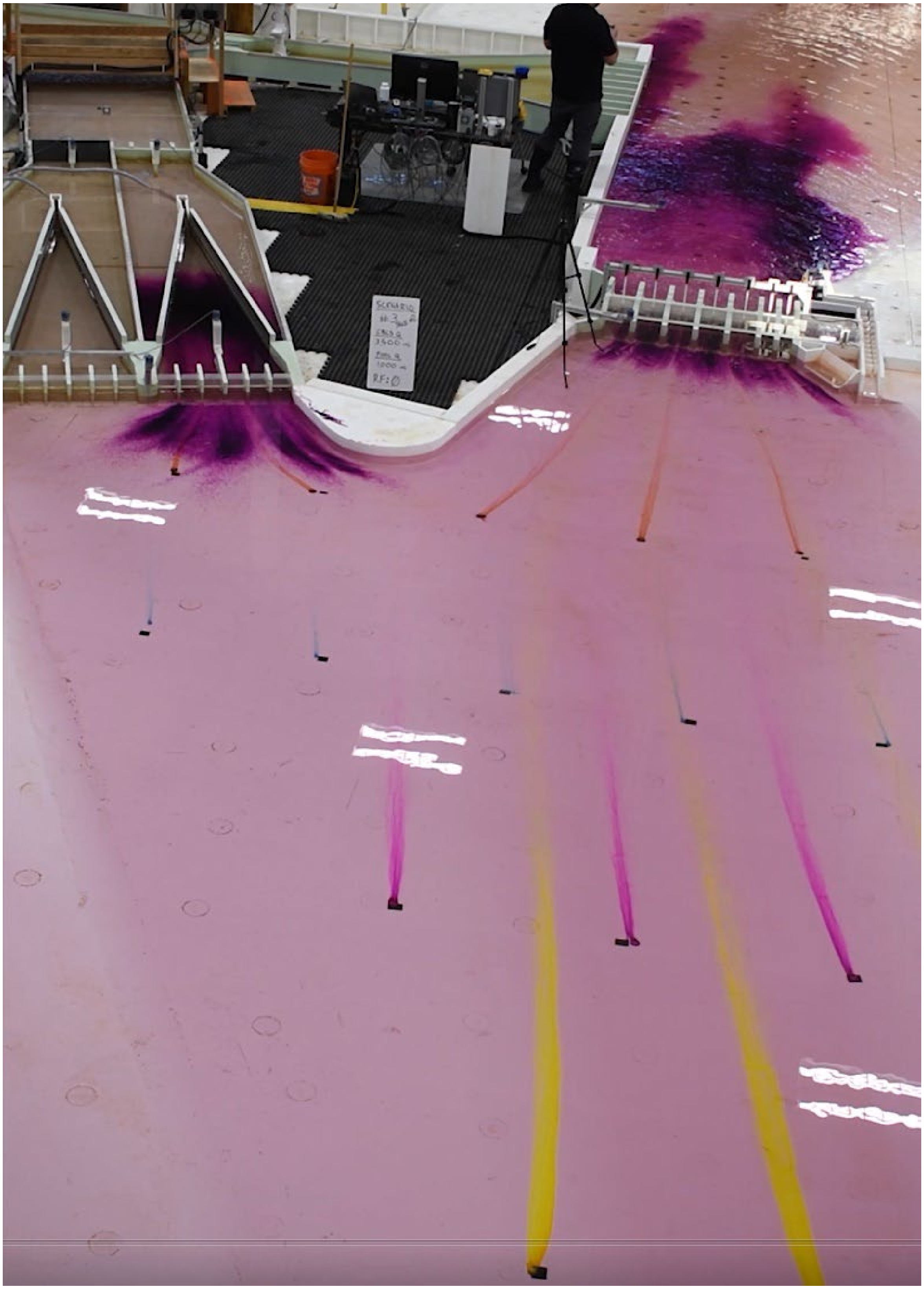

Figure 38. Upstream channel dye testing for Scenario 1:24 – 3.

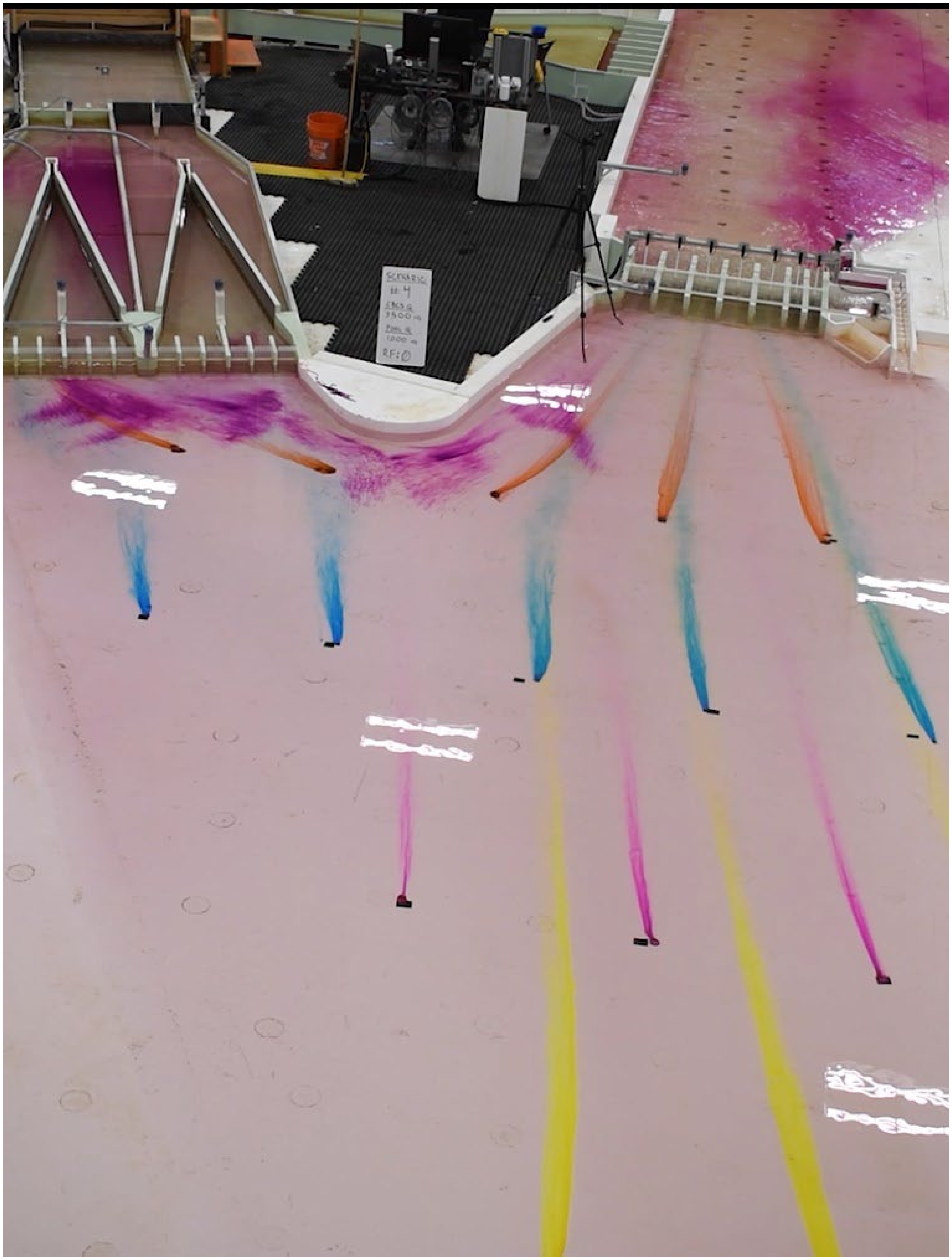

Figure 39. Upstream channel dye testing for Scenario 1:24 – 4.

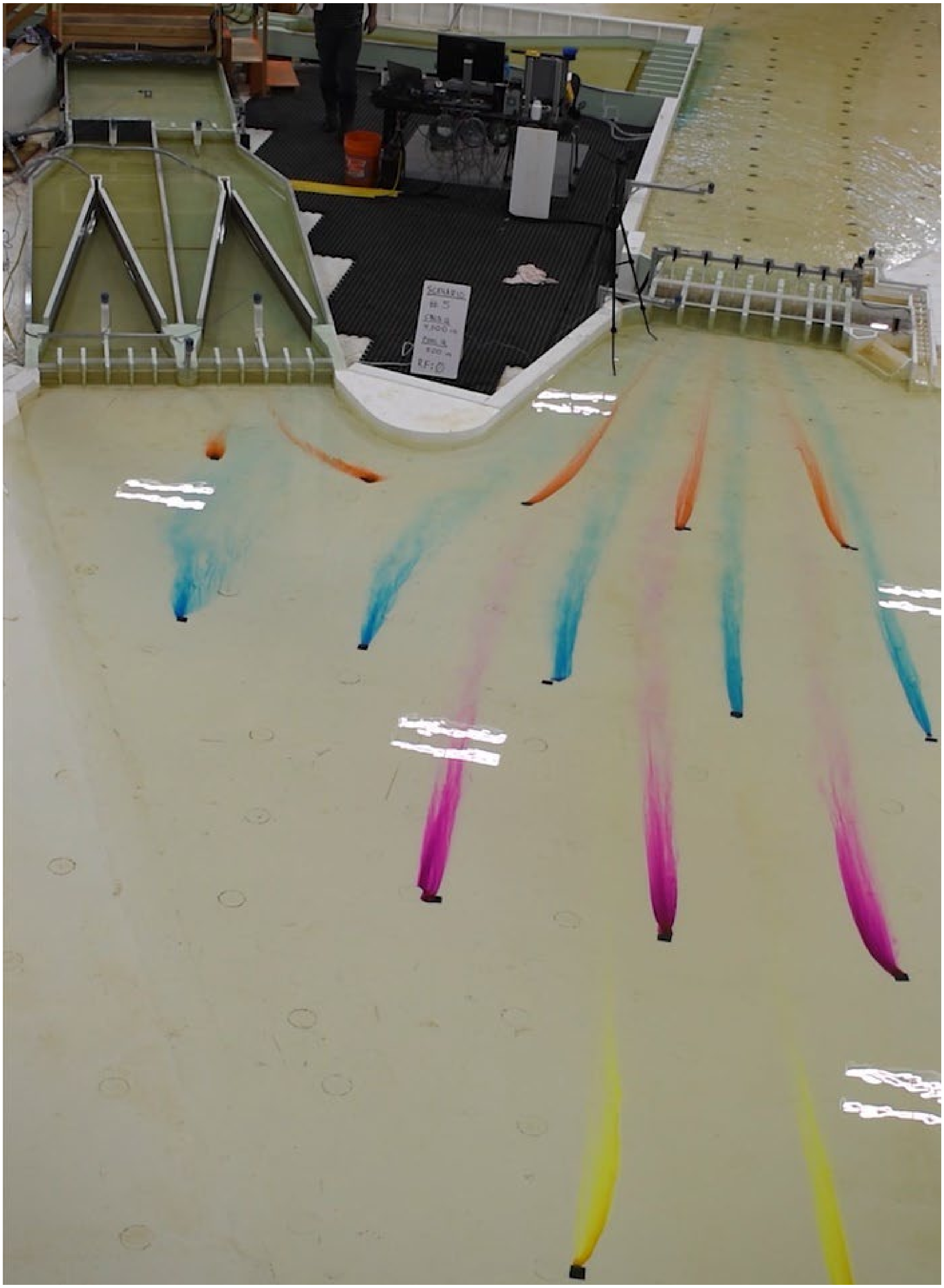

Figure 40. Upstream channel dye testing for Scenario 1:24 – 5.

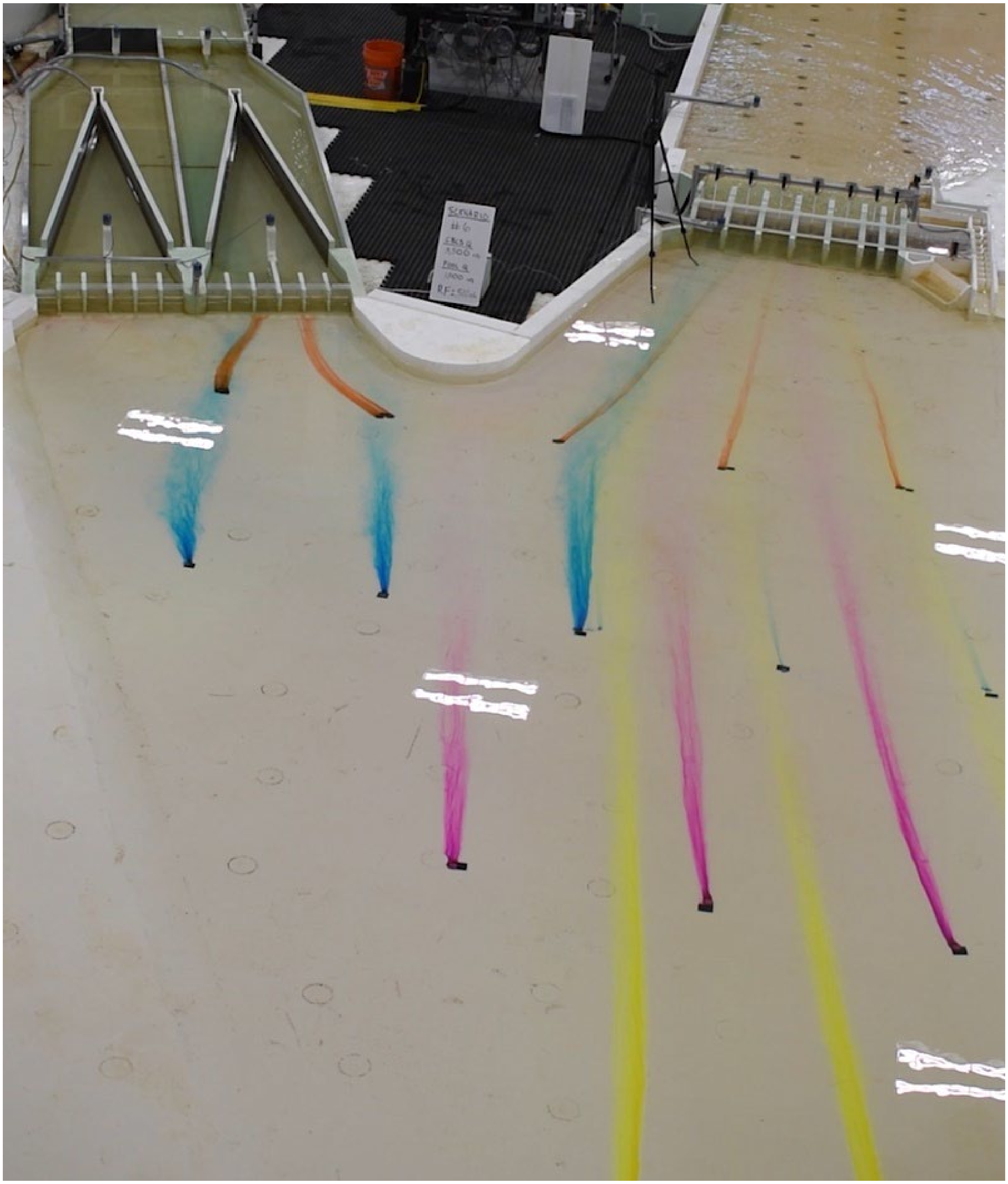

Figure 41. Upstream channel dye testing for Scenario 1:24 – 6.

Figure 42. Upstream channel dye testing for Scenario 1:24 – 7.

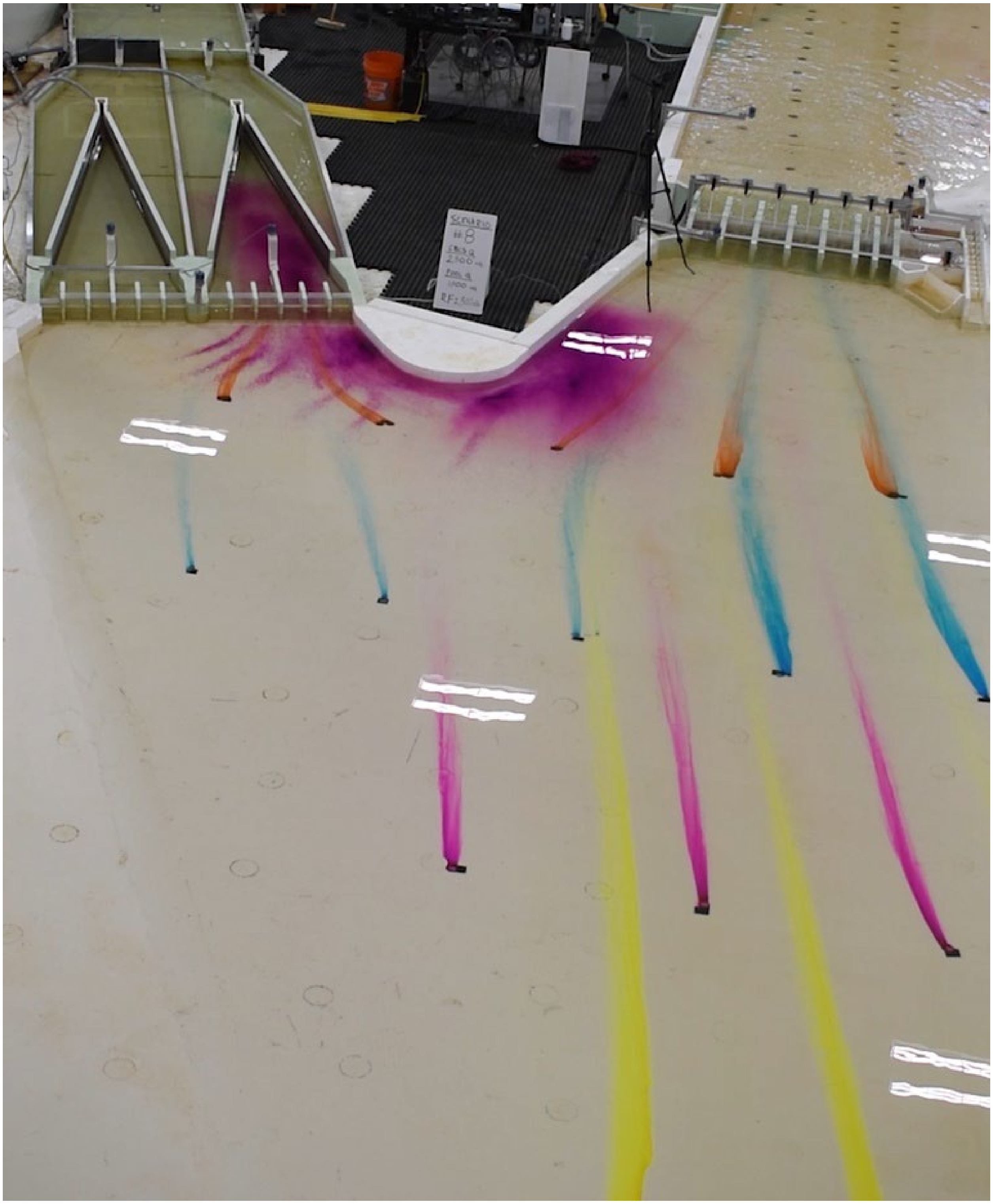

Figure 43. Upstream channel dye testing for Scenario 1:24 – 8.

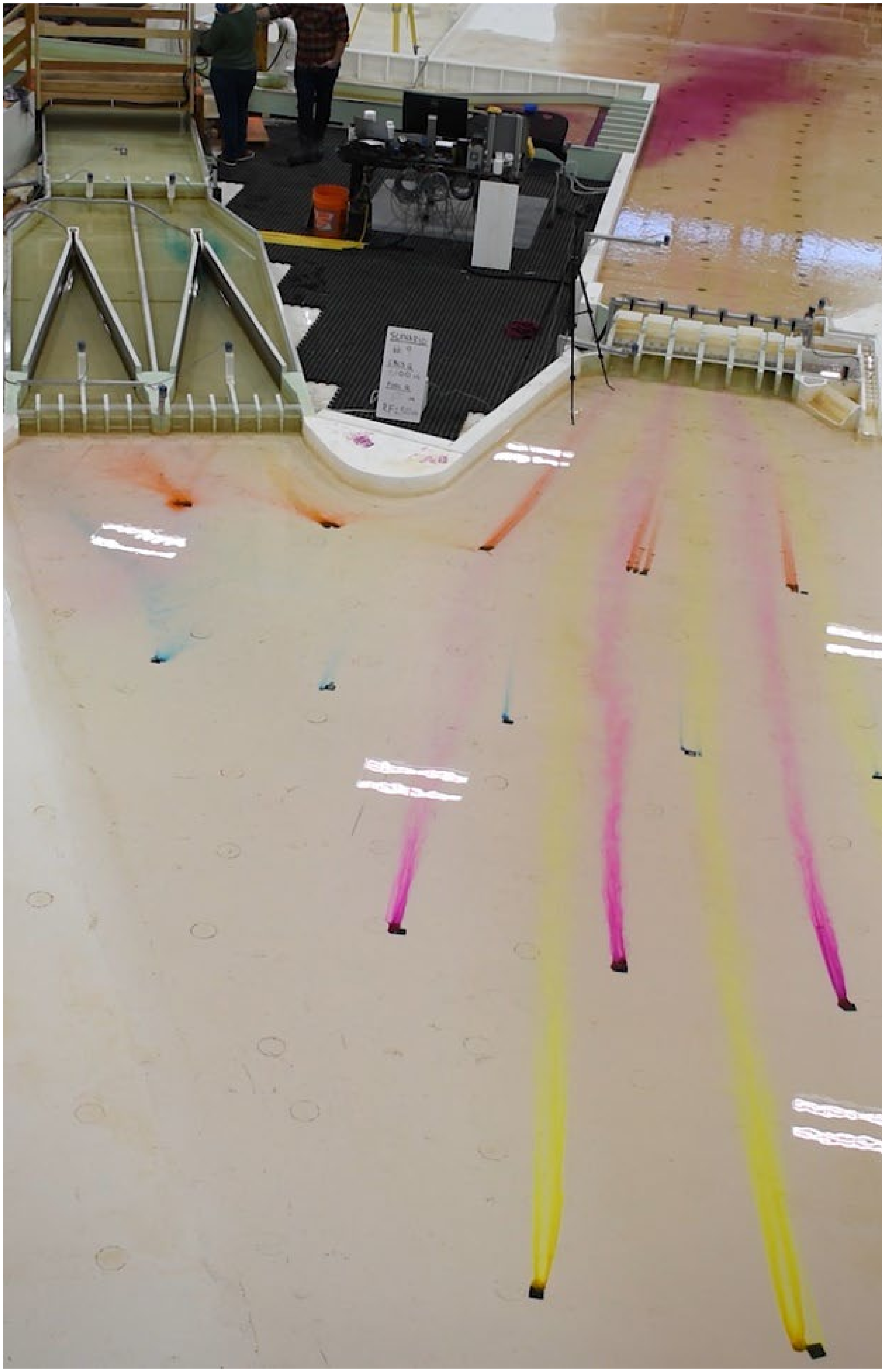

Figure 44. Upstream channel dye testing for Scenario 1:24 – 9.

Figure 45. Upstream channel dye testing for Scenario 1:24 – 10.

Figure 46. Upstream channel dye testing for Scenario 1:24 – 11.

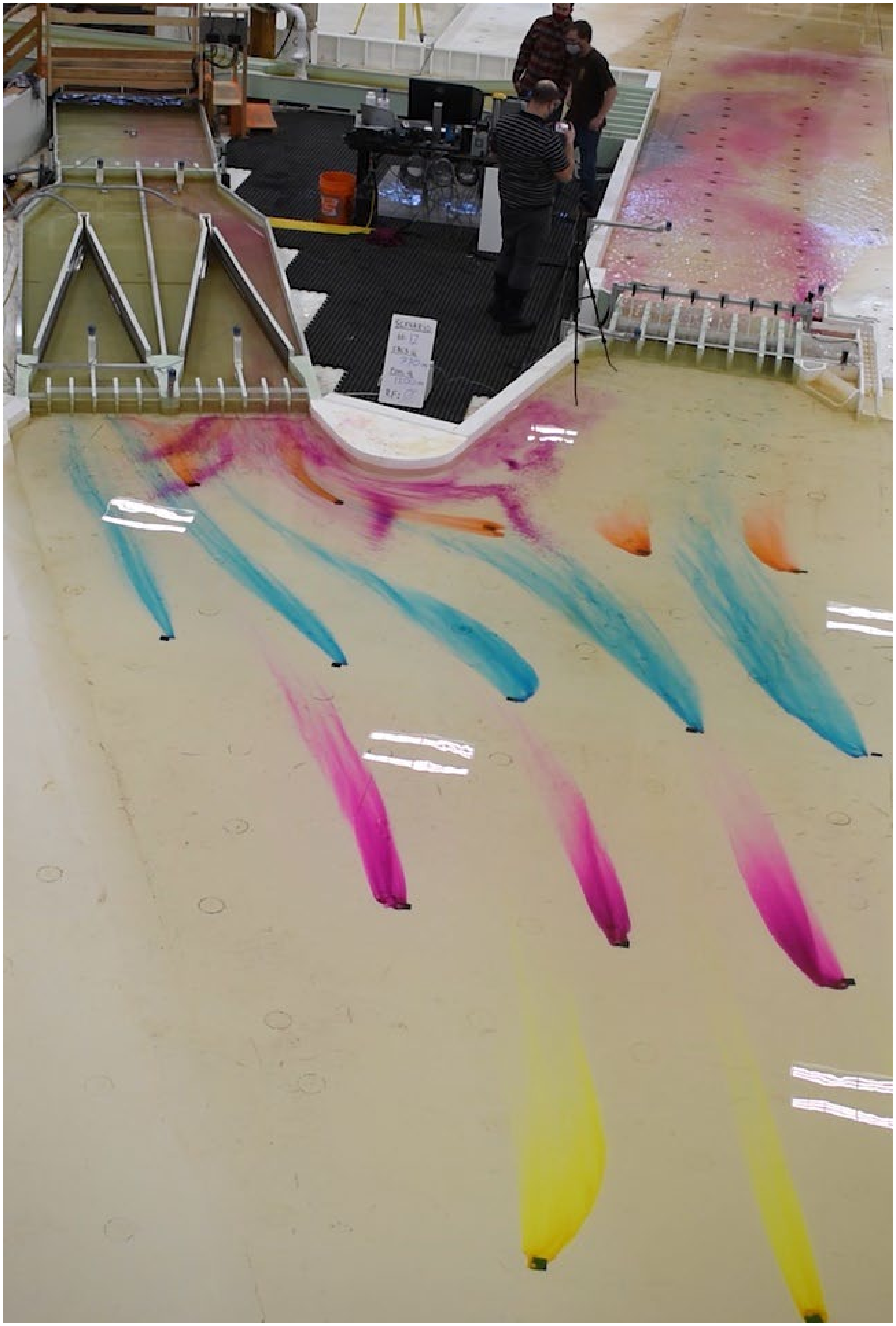

Figure 47. Upstream channel dye testing for Scenario 1:24 – 12.

Figure 48. Upstream channel dye testing for Scenario 1:24 – 13.

Figure 49. Upstream channel dye testing for Scenario 1:24 – 14.

Figure 50. Upstream channel dye testing for Scenario 1:24 – 15.

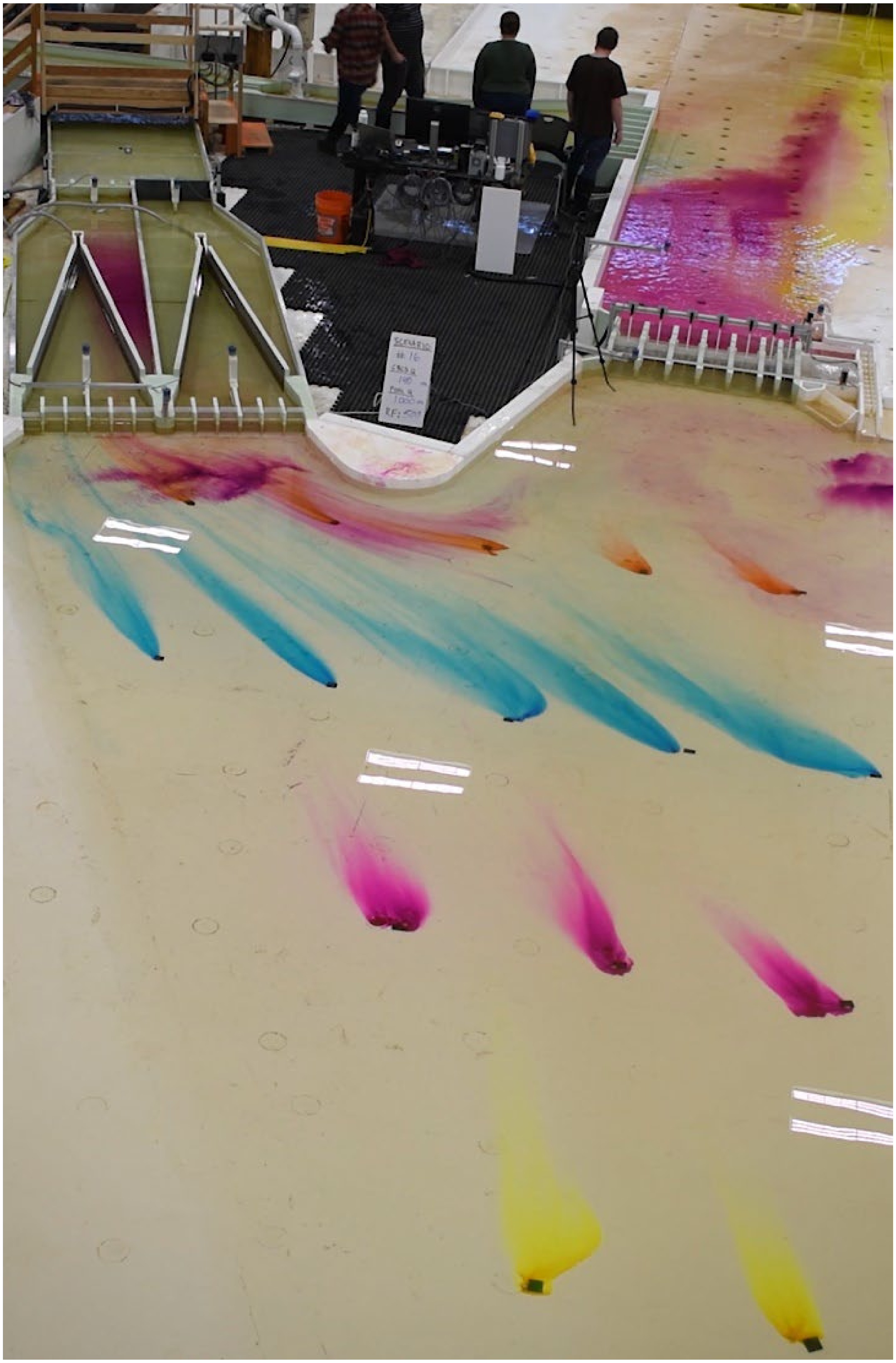

Figure 51. Upstream channel dye testing for Scenario 1:24 – 16.

Figure 52. Upstream channel dye testing for Scenario 1:24 – 17.

Figure 53. Upstream channel dye testing for Scenario 1:24 – 18.