Draft Technical Memorandum 003

To:	Kurt Conger Northern Wasco County People's Utility District	Project:	North Fishway Hydroelectric Project
From:	Morton McMillen, PE	cc:	Kevin Jensen and Nathan Cox File
Date:	January 27, 2015	Job No.:	13-045
Subject:	The Dalles Dam North Shore Fishway System Updated Hydraulic Analysis – CFD Modeling		

1.0 Introduction

1.1 Purpose

The purpose of this technical memorandum (TM) is to present the results of the hydraulic analysis of The Dalles Dam North Fishway System (NFS) entrance conditions under a range of spillway discharge scenarios and associated tailwater conditions, and corresponding increase of attraction flow from the NFS entrances from 800 cubic feet per second (cfs) to 1,600 cfs. The increase in attraction flow is proposed as part of the North Fishway Hydroelectric Project (Project).

1.2 Scope

The scope of this analysis consisted of the following work elements:

a. Obtain the existing STAR-CD computational fluid dynamics (CFD) model from the U.S. Army Corps of Engineers (USACE).

b. Update the existing CFD model to represent the proposed increased NFS entrance flow from 800 cfs to 1,600 cfs and associated use of entrances N-1 and N-2.

c. Develop and evaluate the NFS entrance and tailwater hydraulic conditions utilizing the updated CFD model to determine the change in upstream fish passage conditions created by increasing the attraction flow from 800 cfs to 1,600 cfs.

d. Prepare a draft TM that documents the CFD model development, analysis, and results.

1.3 Authorization

McMillen Jacobs Associates (McMillen Jacobs) was retained by the Northern Wasco County Public Utility District (NWCPUD) to complete the design, construction, and startup and commissioning of the Project. The project is authorized under a contract between NWCPUD and McMillen Jacobs (formerly McMillen, LLC) dated April 18, 2013.

1.4 Background

NWCPUD proposes to restore flows through the auxiliary water supply system (AWSS) to pre-1980's volume in order to increase hydroelectric generation at its North Fishway Hydroelectric Project and to increase AWSS attraction flows. NWCPUD's Federal Energy Regulatory Commission (FERC) license amendment proposes to add approximately 800 cfs to the current AWSS flows (for a total flow of about 1,600 cfs) and use these additional flows for hydroelectric power generation. Other important benefits of the proposed capacity amendment include additional attraction flow and salmon, steelhead, and lamprey improved fish passage conditions in the north fishway from a number of other structural and operational changes to the AWSS.

To support the Project development, NWCPUD has proposed to update the USACE CFD model and utilize the model to evaluate the hydraulic conditions at the fishway entrance due to the increased AWSS flow of 800 cfs to 1,600 cfs. The analysis presented in this TM is intended to demonstrate the change in near-field attraction conditions that occurs at an AWSS flow of 1,600 cfs.

2.0 North Fishway System Description

2.1 General

The NFS is located on the north shore of The Dalles Dam between the navigation lock and Spillway Bay 1 (Figures 1 – 3). The fish ladder is 1,761 feet (ft) long, 24 ft wide, has a slope of 1 on 16 and is operated at a flow of approximately 75 cfs. There are three main entrances in the fish ladder located adjacent to Spillway 1. Historically, fish move from the project tailrace into the fish ladder through these three entrances. As currently operated, only one of the entrances is used. The fish ladder is a weir and orifice designed to operate with a 1-ft rise over each weir. The ladder extends from Weir 70 immediately upstream from the fishway entrance to Weir 157 at the exit, allowing operation down to the minimum tailwater elevation of 70.0 ft at the fishway entrance. The operating forebay elevation is normally between 157.0 and 158.5 ft.

Attraction water is provided through an AWSS, which pulls water from the forebay and routes it to diffusers located in the lower fish ladder pools. A brief description of the major components of the AWSS system is presented in the following paragraphs.

2.2 Intake and Trashrack

The AWSS intake is located on the face of the dam immediately north of Spillway Bay 1. A trashrack is located on the entrance to the AWSS intake. The trashrack is divided into four sections, each approximately 10 ft wide. The bottom of the trashrack is located at elevation 135 ft. The normal minimum forebay elevation is maintained at near 157.0 ft, which provides a minimum gross wetted trashrack area of approximately 880 square feet (sf). The existing trashrack is manually cleaned by USACE.

2.3 Intake Conduit and Tainter Gate

The AWSS flow passes through the trashrack, then converges into an intake channel that passes through the dam concrete non-overflow section. The intake conduit through the dam has a floor elevation of 145 ft, top of conduit elevation of approximately 162 ft, and is 20 ft wide. Prior to construction of the NWCPUD first powerhouse, flow to the AWSS system was controlled by a tainter gate located on the downstream side of the intake conduit. As originally configured, the tainter gate was 20 ft wide by 17 ft tall and had a maximum gate opening of 10 ft. This system was modified in 1989 to allow the gate to be completely lifted above the normal minimum forebay operating level of 157.0 ft. With this modification, the top of wall downstream from the intake conduit was raised to elevation 165 ft. The intake conduit is also fitted with stoplog guides located on the upstream end of the conduit, allowing the tainter gate to be dewatered for maintenance and inspection.

2.4 Fish Screen and Bypass

As part of the NWCPUD first powerhouse construction, a new criteria fish screen, bypass system, and juvenile fish evaluation structure were constructed. During normal operation, the AWSS flow passes through the fish screen and enters a penstock feeding the powerhouse. The fish screen structure was designed for a hydraulic capacity of 800 cfs at a design screen approach velocity of 0.5 feet per second (fps). A total effective screen area of approximately 1,760 sf is provided in the existing screen structure at a minimum operating elevation of 157.0 ft on the upstream side of the fish screens. The existing screen structure has a floor elevation of 140.0 ft, top of screen panel elevation of 161.5 ft, and a top of deck elevation of 165.0 ft. There are a total of seven screen bays with an open screen panel width of 15.5 ft wide per screen. The screen structure guides downstream migrants to a bypass pipe located at the downstream end of the screens where they are carried back to the tailrace via a bypass pipe. The screened water then continues to the penstock intake and on to the powerhouse.

During periods when the powerhouse is not in operation, the flow is bypassed down the original AWSS channel via two 6 ft wide by 7 ft high sluice gates.

2.5 AWSS System

From the turbine unit draft tubes, the turbine discharge enters the AWSS through a rectangular conduit that connects to the AWSS conduit system. The AWSS system is a pressurized conduit system and supplies diffusers located in the fishway entrance channel and to the even-numbered ladder pools located downstream of Weir 93. The amount of flow distributed to each diffuser depends on the pressure head in the AWSS conduit at the location of the diffuser as well as the type of diffuser control. The two types of diffuser controls used in this system include the ladder “chimney weirs” for the ladder diffusers and slide gates for the fishway entrance channel diffusers. The chimney weirs are set 2 ft above the fish ladder weir elevation. As a result, the AWSS head must be higher than this chimney weir elevation to provide flow into the fish ladder. For the fishway entrance diffusers, the amount of discharge is contingent upon the head in the AWSS conduit and the diffuser sluice gate setting. The sluice gates are typically operated either fully open or fully closed. There are number of head losses in the AWSS system that are associated with bends, constrictions, expansions, and other changes to the flow area.

Table 1 provides information on the diffuser screen areas, types of diffuser control, and locations of the diffusers.

Table 1. AWSS Diffuser Areas and Locations

Weir/Pool Number (from d/s)	Ladder 'Unit' Number [a]	Diffuser Control	Approximate Diffuser Area (sf)
Entrance	18	3 slide gates	1,038
Curved Section	17	2 slide gates	750
Straight Section	16	4 slide gates	1,500
70	15	Weir	368
72		Weir	368
74	14	Weir	368
76		Weir	368
78	13	Weir	368
80		Weir	368
82	12	Weir	368
84		Weir	368
86	11	Weir	368
88		Weir	368
90	10	Weir	368
92		Weir	368

a) Based on USACE design drawings (See Appendix A).

2.6 Fish Ladder Entrances

The NFS has three entrances located adjacent to Spillway Bay 1. The entrances are labeled North Entrance 1 (N-1), North Entrance 2 (N-2), and North Entrance 3 (N-3). The N-1 weir consists of 3 leaves, each approximately 6 ft 9 inches tall with a weir length of 15 ft. The minimum weir or sill elevation is 62 ft, which provides the minimum submergence depth of 8 ft down from tailwater elevation 70 ft. It should be noted that the minimum recorded daily tailwater elevation is 72.7 ft, which would indicate that operation down to tailwater elevation 70.0 ft is unlikely. As currently configured, entrance N-3 is permanently closed with a concrete bulkhead and entrance N-2 is a fixed bulkhead weir blocking flow. During normal operation, either entrance N-1 or N-2 is operated to pass the AWSS flow, estimated to range from 870 cfs to as high as 940 cfs, which is routed through the NWCPUD existing powerhouse.

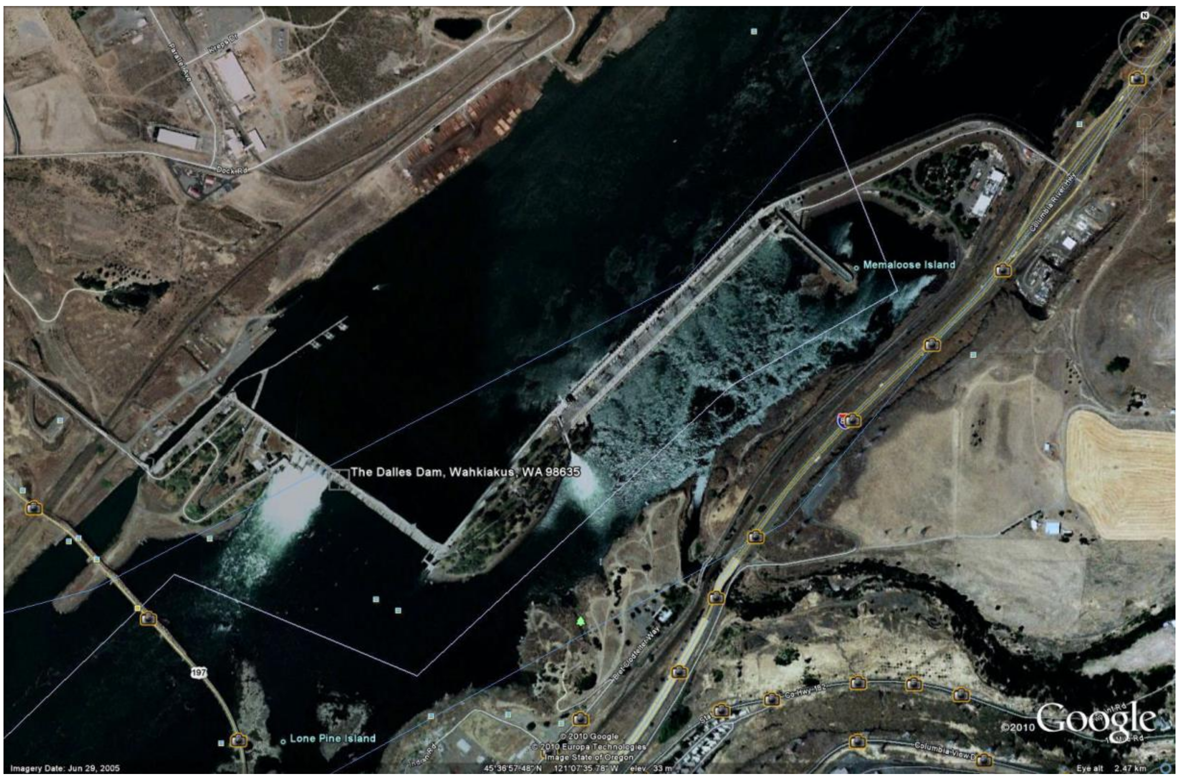
2.7 Fish Ladder

The NFS is 24 ft wide with a 6 ft high weir fitted with two orifices, each 21 inches wide by 23 inches high. The orifices are located at the base of the weirs with the orifice centerline located 3 ft from the outside walls. The ladder floor slope is 1 vertical on 16 horizontal extending from Weir 70 to Weir 153 from the ladder entrance to the exit. The weir number corresponds to the crest elevation of the weir.

2.8 Fish Ladder Exit

Modifications were made to the original ladder exit and counting station in the 1980s. The existing weirs were replaced with vertical slot weirs spaced at 14 ft on center. Flow through the fish ladder was approximately 75–102 cfs, depending on ladder control head. A make-up water supply conduit was added along the south fish ladder wall. This conduit continues downstream just past Weir 152. The fish ladder channel in this area is reduced from the original 24 ft width to a 20 ft inside width. Flow through the make-up water supply conduit is regulated by a sluice gate and discharged through a floor diffuser.

The upstream migrant counting station is located between Weir 151 and Weir 152. It has an underwater viewing window and horizontal crowder capable of varying the slot wide from 1 to 3 ft. The counting station is flanked by fish leads to guide fish past the window.



Source: Initial Consultation Document for Application to Amend Existing License for The Dalles Dam North Fishway Hydroelectric Project, April 1, 2013

Figure 1. The Dalles Dam North Shore Fish Ladder Overview

Source: Initial Consultation Document for Application to Amend Existing License for The Dalles Dam North Fishway Hydroelectric Project, April 1, 2013

Figure 2. The Dalles Dam North Fish Ladder

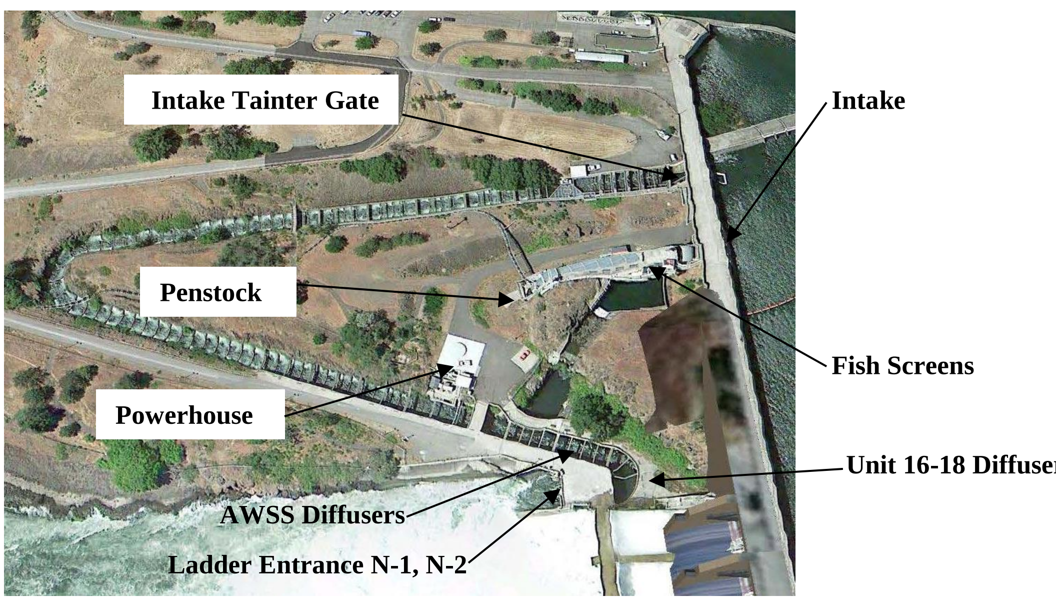


Figure 3. Hydraulic Constraint Locations

3.0 North Fishway Hydroelectric Project Description

The Project is located on the Washington State side of The Dalles Dam on the Columbia River. The Dalles Dam is operated by USACE, and the hydroelectric power from the dam is marketed by the Bonneville Power Administration. NWCPUD currently owns and operates a 5-megawatt (MW) hydroelectric facility at the North Fishway of The Dalles Dam. The Project will be constructed adjacent to this existing facility on federal land.

The Project is conceptualized to consist of adding an additional 5-MW hydroelectric facility to be constructed adjacent to the existing Project. The Project consists of rehabilitating a second fishway entrance and adding approximately 800 cfs to the existing 800 cfs AWSS flow, for a total attraction flow of approximately 1,600 cfs. The additional flows will be used for hydroelectric generation with a new 5-MW powerhouse and supporting infrastructure. The proposed facilities would be integrated into the existing infrastructure and would use the existing AWSS intake structure on the upstream face of The Dalles Dam, as well as the existing auxiliary water supply conduit system. The new facility would require construction of a second screened intake water channel and penstock on the north side of the existing facility using similar designs in order to maintain existing design characteristics. The new tailrace would discharge into the existing AWSS lower plunge pool, enter the AWSS supply conduit, and then distribute into the lower ladder through existing floor diffusers.

4.0 Hydraulic Analysis

4.1 CFD Model Development History

The original CFD model of The Dalles Dam was developed by Pacific Northwest National Laboratory (PNNL) in coordination with USACE, Portland District (CENWP) in 2006. The original model, which was built in the STAR-CD v.4 CFD software package, was developed to support the siting and design of a behavioral guidance system (BGS) structure for downstream migrant juvenile salmonids at The Dalles Dam (Rakowski et al., 2006a). The model was based on bathymetric survey from 1999, and included detailed representations of the engineered structures within the forebay of The Dalles Dam, including the spill bays and powerhouse main, among others. Finer resolution was later added to this model near the spill bays to investigate suppression of a surface vortex forming in the southern-most spill bay (Rakowski et al., 2006b).

Around the same time in 2006, a second CFD model of The Dalles Dam was developed, also by PNNL, in coordination with USACE CENWP. This model was developed using the Flow-3D software package (Flowscience, 2014), which was validated against several reduced-scale physical models and prototype data collected at the dam (Cook et al., 2006). The Flow-3D code was chosen at this time because of the presumed computational demand of a partial volume-of-fluid (PVOF) solver, such as STAR-CD, and the reported issues related to representing a sharp air-water interface in highly transient, “frothy” areas of the model, such as in the tailrace.

The STAR-CD model of 2006 was modified in 2008 and indirectly validated using a two-dimensional model to evaluate the impacts of alternative locations of a proposed full-length spillwall at The Dalles Dam. This spillwall extends approximately 600 ft downstream of the endsill (Rakowski et al., 2008). The spillwall was ultimately designed, and constructed, between Spill Bays 8 and 9, in an effort to improve tailrace egress and survival of juvenile fish passing through the spill bays.

The STAR-CD model was again modified in 2010 to simulate tailrace hydraulics between the new spillwall and the Washington shore for six different river flow scenarios (Rakowski and Serkowski, 2010). This model was validated against a reduced-scale physical model, imparting end-user confidence in the model.

4.2 Model Run Scenarios

To evaluate increasing the AWSS flow from 800 cfs to 1,600 cfs through the NFS on near-field attraction flows, several different flow scenarios were developed and tested. The total river flows chosen were selected to encompass the range of flows reasonably expected at The Dalles Dam during normal operations within the fish passage window. Gage data were evaluated to provide annual peak-, average-, and low-flow conditions. These three total river flows determined through this gage analysis then provided the basis for determining the associated discharges through each of the spill bays. Because far-field attraction and upstream migration have been reported to improve with a more uniform flow distribution across the spill bays, each of the three spill bay flows tested was distributed uniformly across all eight of the North Shore spill bays. However, after several initial runs, it became clear that closing Spill Bays 1 and 2 may improve fish passage conditions, both by reducing the dampening effect of spill bay flows on attraction flows, and by opening up a fish passage corridor farther downstream under high flow conditions. For these reasons, simulating the model with Spill Bays 1 and 2 closed was also tested. Also, to compare each simulation with a baseline condition without added flow through the fishway, each spill bay flow scenario was tested at the existing baseline flow of 800 cfs, as well as at the proposed flow of 1,600 cfs. A summary of the model run scenarios is provided in Table 2.

Table 2. Summary of the Model Run Scenarios

Scenario No.	Description	River Flow (cfs)	Spillway Flow* (cfs)	Fishway Flow (cfs)
1	Average River Flow, 1,600 cfs Fishway Flow, Spill Bays 1–8	195,000	78,400	1,600
2	Average River Flow, 800 cfs Fishway Flow, Spill Bays 1–8	195,000	78,400	800
3	High River Flow, 1,600 cfs Fishway Flow, Spill Bays 1–8	439,000	175,600	1,600
4	High River Flow, 800 cfs Fishway Flow, Spill Bays 1–8	439,000	175,600	800
5	Low River Flow, 1,600 cfs Fishway Flow, Spill Bays 1–8	62,800	25,120	1,600
6	Low River Flow, 800 cfs Fishway Flow, Spill Bays 1–8	62,800	25,120	800
7	High River Flow, 1,600 cfs Fishway Flow, Spill Bays 3–8	439,000	175,600	1,600
8	High River Flow, 800 cfs Fishway Flow, Spill Bays 3–8	439,000	175,600	800

*Spillway flow distributed evenly across open gates.

4.2.1 Scenario 1 Description—Average River Flow, 1,600 cfs Fishway Flow, Spill Bays 1–8

Under Scenario 1, the total river flow is 195,000 cfs, which represents the average river flow condition. Due to the 40% spilling constraint for river flows over 84,000 cfs, the spilling flow is 78,400 cfs distributed approximately evenly over all eight spill bays. Spill gates are determined by rating curves to have openings of 6.7 ft for Spill Gates 1–7, and 7.0 ft for Spill Gate 8. For this scenario, the fishway flow is set at 1,600 cfs, with both weirs N-1 and N-2 operational. Weir crest elevations (70.4 ft) are set to meet the 8-ft minimum submergence criterion, and are therefore determined by the tailwater elevation. The tailwater elevation is set to 78.9 ft in accordance with the tailwater rating curve developed for The Dalles Dam.

4.2.2 Scenario 2 Description—Average River Flow, 800 cfs Fishway Flow, Spill Bays 1–8

Under Scenario 2, the total river flow is 195,000 cfs, which represents the average river flow condition. Due to the 40% spilling constraint for river flows over 84,000 cfs, the spilling flow is 78,400 cfs distributed approximately evenly over all eight spill bays. Spill gates are determined by rating curves to have openings of 6.7 ft for Spill Gates 1–7, and 7.0 ft for Spill Gate 8. For this scenario, the fishway flow is set at 800 cfs to reflect average existing operational conditions, with only weir N-1 open. The weir elevation (70.4 ft) is set to meet the 8-ft minimum submergence criterion, and is therefore determined by the tailwater elevation. The tailwater elevation is set to 78.9 ft, in accordance with the tailwater rating curve developed for The Dalles Dam.

4.2.3 Scenario 3 Description—High River Flow, 1,600 cfs Fishway Flow, Spill Bays 1–8

Under Scenario 3, the total river flow is 439,000 cfs, which represents the high river flow condition. Due to the 40% spilling constraint for river flows over 84,000 cfs, the spilling flow is 175,600 cfs distributed approximately evenly over all eight spill bays. Spill gates are determined by rating curves to have openings of 15 ft for all spill gates. For this scenario, the fishway flow has been set at 1,600 cfs, with both weirs N-1 and N-2 operational. Weir crest elevations (77.5 ft) are set to meet the 8-ft minimum submergence criterion, and are therefore determined by the tailwater elevation. The tailwater elevation is set to 86.0 ft in accordance with the tailwater rating curve developed for The Dalles Dam.

4.2.4 Scenario 4 Description—High River Flow, 800 cfs Fishway Flow, Spill Bays 1–8

Under Scenario 4, the total river flow is 439,000 cfs, which represents the high river flow condition. Due to the 40% spilling constraint for river flows over 84,000 cfs, the spilling flow is 175,600 cfs distributed approximately evenly over all eight spill bays. Spill gates are determined by rating curves to have openings of 15 ft for all spill gates. For this scenario, the fishway flow is set at 800 cfs, to reflect average existing operational conditions, with only weir N-1 open. The weir elevation (77.5 ft) is set to meet the 8-ft minimum submergence criterion, and is therefore determined by the tailwater elevation. The tailwater elevation is set to 86.0 ft in accordance with the tailwater rating curve developed for The Dalles Dam.

4.2.5 Scenario 5 Description—Low River Flow, 1,600 cfs Fishway Flow, Spill Bays 1–8

Under Scenario 5, the total river flow is 62,800 cfs, which represents the low river flow condition. Due to the minimum power generation requirement at the Dalles Dam, the total spilling flow is less than 40% of the total river flow. The total spilling flow is 25,120 cfs and is distributed approximately evenly over all eight spill bays. Spill gates are determined by rating curves to have openings of 1.1 ft for all eight spill gates. Note that this height does not meet the recommended minimum 4-ft gate opening. For this scenario, the fishway flow has been set at 1,600 cfs, with both weirs N-1 and N-2 operational. Weir crest elevations (66.5 ft) are set to meet the 8-ft minimum submergence criterion, and are therefore determined by the tailwater elevation. The tailwater elevation is set to 75.0 ft in accordance with the tailwater rating curve developed for The Dalles Dam.

4.2.6 Scenario 6 Description—Low River Flow, 800 cfs Fishway Flow, Spill Bays 1–8

Under Scenario 6, the total river flow is 62,800 cfs, which represents the low river flow condition. Due to the minimum power generation requirement at the Dalles Dam, the total spilling flow is less than 40% of the total river flow. The total spilling flow is 25,120 cfs and is distributed approximately evenly over all eight spill bays. Spill gates are determined by rating curves to have openings of 1.1 ft for all eight spill gates. Note that this height does not meet the recommended minimum 4-ft gate opening. For this scenario, the fishway flow is set at 800 cfs, to reflect average existing operational conditions, with only weir N-1 open. The weir elevation (66.5 ft) is set to meet the 8-ft minimum submergence criterion, and is therefore determined by the tailwater elevation. The tailwater elevation is set to 75.0 ft in accordance with the tailwater rating curve developed for The Dalles Dam.

4.2.7 Scenario 7 Description—High River Flow, 1,600 cfs Fishway Flow, Spill Bays 3–8

Under Scenario 7, the total river flow is 439,000 cfs, which represents the high river flow condition. Due to the 40% spilling constraint for river flows over 84,000 cfs, the spilling flow is 175,600 cfs distributed approximately evenly over Spill Bays 3 through 8. Spill Bays 1 and 2 have been closed to evaluate the high-flow hydraulic conditions in the tailrace, and specifically at the fishway entrance. Spill gates are determined by rating curves to have openings of 15 ft for all spill gates. For this scenario, the fishway flow has been set at 1,600 cfs, with both weirs N-1 and N-2 operational. Weir crest elevations (77.5 ft) are set to meet the 8-ft minimum submergence criterion, and are therefore determined by the tailwater elevation. The tailwater elevation is set to 86.0 ft in accordance with the tailwater rating curve developed for the Dalles Dam.

4.2.8 Scenario 8 Description—High River Flow, 800 cfs Fishway Flow, Spill Bays 3–8

Under Scenario 8, the total river flow is 439,000 cfs, which represents the high river flow condition. Due to the 40% spilling constraint for river flows over 84,000 cfs, the spilling flow is 175,600 cfs distributed approximately evenly over Spill Bays 3 through 8. Spill Bays 1 and 2 have been closed in order to evaluate the high-flow hydraulic conditions in the tailrace, and specifically at the fishway entrance. Spill gates are determined by rating curves to have openings of 15 ft for all spill gates. For this scenario, the fishway flow is set at 800 cfs, to reflect average existing operational conditions, with only weir N-1 open. The weir elevation (77.5 ft) is set to meet the 8-ft minimum submergence criterion, and is therefore determined by the tailwater elevation. The tailwater elevation is set to 86.0 ft in accordance with the tailwater rating curve developed for The Dalles Dam.

4.2.9 Scenario 9 Description—Baseline No Spill, Average River Flow Aug. – Sept.

Under Scenario 9, the total river flow is 113,000 cfs, which represents the mean daily flow from August through September, based on the last 13 years of USACE gage data. Also, there is no water spilling through Spill Bays 1-8. For this scenario, the fishway flow is set at 800 cfs, to reflect average existing operational conditions, with only weir N-1 open. The weir crest elevation (68.0 ft) is set to meet the 8-ft minimum submergence criterion, and is therefore determined by the tailwater elevation. The tailwater elevation is set to 76.5 ft in accordance with the tailwater rating curve developed for The Dalles Dam.

4.2.10 Scenario 10 Description—Alternative No Spill, Average River Flow Aug. – Sept.

Under Scenario 10, the total river flow is 113,000 cfs, which represents the mean daily flow from August through September, based on the last 13 years of USACE gage data. Also, there is no water spilling through Spill Bays 1-8. For this scenario, the fishway flow has been set at 1,600 cfs, with both weirs N-1 and N-2 operational. The weir crest elevation (68.0 ft) is set to meet the 8-ft minimum submergence criterion, and is therefore determined by the tailwater elevation. The tailwater elevation is set to 76.5 ft in accordance with the tailwater rating curve developed for The Dalles Dam.

4.3 Current CFD Model Configuration

The latest STAR-CD model was chosen for the Project due to the availability of the volume mesh, the ability of the STAR-CD solver to simulate multiphase fluids, and the reduced computational cost of PVOF codes as a result of recent advances in computing power. However, STAR-CD is no longer the flagship program of the software developer (CD-adapco), and is therefore no longer fully supported. Additionally, neither CD-adapco nor USACE CENWP currently have the resources to either run or re-export from the legacy version of STAR-CD originally used to develop the model (McMillen Jacobs, 2014). For these reasons, the STAR-CD model was translated into a STAR-CCM+ model. STAR-CCM+ is CD-adapco's new flagship program, and represents a complete re-write of the STAR-CD graphical user interface (GUI), with several improvements to certain of the solver's subroutines (CD-adapco, 2014).

Translating the model from STAR-CD to STAR-CCM+ included the following steps:

1. Import volume mesh into STAR-CCM+ and mimic physics models of STAR-CD model.
2. Re-create 3D CAD geometry from volume mesh to manipulate the height of fishway entrance weirs; re-create boundary surfaces to allow flexibility in manipulating spill bay and fishway boundary conditions.
3. Re-write boundary conditions and field functions to match STAR-CD model.
4. Re-write initialization schemes to match STAR-CD model.
5. Triangulate model domain and re-mesh VOF model.

6. Copy/edit runtime options.

Each of these tasks is described in further detail in the following paragraphs.

4.3.1 Model Physics

The Dalles Dam model uses a segregated flow approach to solve the governing Navier-Stokes equations, which is a suitable approach to incompressible flow problems like the one treated here. This approach solves the equations of momentum and continuity separately, before linking the solutions using a predictor-corrector subroutine (CD-adapco, 2014).

The Dalles Dam model simulates the free surface of water entering the tailwater from the spill bays and the fishway through an Eulerian multiphase physics approach. The two fluids simulated in The Dalles Dam model are air and liquid water, the mixing of which is estimated at a macroscopic scale rather than at a molecular scale. The effect of this macroscopic mixing is a less resolved interface between the air and water, particularly in highly turbulent areas. Table 3 lists the modal constants.

Table 3. Model Constants

Physics Parameter	Constant Value	Description	References
Turbulence Intensity (-)	0.01	Measure of RMS of local velocity fluctuation relative to reference velocity	CD-adapco (2014)
Turbulence Length Scale (ft)	0.03281	Represents the (isotropic) size of large eddies in turbulent flow	CD-adapco (2014)
Turbulent Velocity (ft/s)	32.81	Estimate of initial turbulent kinetic energy	CD-adapco (2014)
Turbulent Prandtl Number (-)	0.9	Ratio of momentum diffusivity over the volume fraction diffusivity due to continuous phase velocity fluctuations	CD-adapco (2014)
Gravitational Acceleration (ft/s^2)	-32.185	Gravitational acceleration	General reference
Water Density (lb/ft^3)	62.28	Water density at 21°C	General reference
Water Dynamic Viscosity (atm-s)	8.771	Water dynamic viscosity at 21°C	General reference
Air Density (lb/ft^3)	0.07392	Air density at 75°F	General reference
Air Dynamic Viscosity (atm-s)	1.831×10^{-10}	Air Dynamic Viscosity at 75°F	General reference

4.3.2 3D Model Manipulation

In order to correctly simulate gravity-flow conditions at the spill bay and fish ladder boundaries, the boundary surface areas were altered based on the desired inflow at each of the inlets. For the spill bays, the height of the tainter gate opening was linearly interpolated from tainter gate rating curves. The latest available rating curve provides the required openings for a given discharge and a given set of active bays. In the case of low river flow, this rating curve provides openings associated with only two active bays (7 and 8), whereas for medium and high river flows, openings are available for all eight active bays. Therefore, in the case of low river flow, the older rating curve provided in Table 2-3 of Rakowski (2006a) was used to interpolate the gate opening height of all eight active bays (reproduced in Appendix B). The differences between the older and newer ratings curves are attributable to the fact that the older curve was based on a forebay elevation of 160 ft, whereas the newer curve is based on a forebay elevation of 158.5 ft (The Dalles Dam median forebay elevation between April and August from 2009 through 2012).

Adjustment of the tainter gate openings involved redefining the boundary surface, remeshing the domain, and regenerating the volume mesh within the STAR-CCM+ GUI. For the fishway boundary surface, the height of the free surface boundary was determined by back-calculating the channel slope from the original CFD model using Manning's equation (n=0.013) and then solving for the required free surface height given the desired inflow. The calculated slope is 0.000088, which compares well with the flat slope measured from the model. Inflow boundary surface geometries are provided in Table 4 for the simulated scenarios.

Table 4. Inflow Boundary Surface Geometrics

Scenario No.	Description	Spill Bay Gate Opening (ft)	Fishway Boundary Surface Height (ft)
1	Average River Flow, 1,600 cfs Fishway Flow	6.6	16.9
2	Average River Flow, 800 cfs Fishway Flow	6.6	10.0
3	High River Flow, 1,600 cfs Fishway Flow	15.0	16.9
4	High River Flow, 800 cfs Fishway Flow	15.0	10.0
5	Low River Flow, 1,600 cfs Fishway Flow	1.1	16.9
6	Low River Flow, 800 cfs Fishway Flow	1.1	10.0

In order to meet National Oceanic and Atmospheric Administration/National Marine Fisheries Service (NOAA Fisheries) fish passage criteria, the head drop over the fishway entrance weir(s) must be between 1.0 and 2.0 ft, with an optimal head drop of 1.5 ft. In the model, this is achieved by manipulating the elevation of the entrance weir crests, provided a particular fishway inflow and tailwater elevation. In the case of only one weir operating (existing conditions), a rating curve available from USACE provides the weir crest elevation given a particular tailwater elevation. This rating curve is reproduced in Table 5. The tailwater elevation for each river flow scenario was determined by developing a rating curve from USACE discharge and tailwater elevation data available on the USACE website. This tailwater rating curve is provided in Figure 4. In the case of two weirs operating simultaneously, it was assumed that doubling the existing operational flow and opening the second weir would induce the same head drop as simulating only one weir with the existing operational flow. Therefore, weir crest elevations were changed for different river flows only, and not for different fishway inflows. Entrance weir crest elevations are provided for each of the three flow regimes in the Table 5.

Table 5. Entrance Weir Crest Elevation Rating Table*

River Flow Scenario	Total River Flow (kcfs)	Tailwater Elevation (ft)	Weir Crest Elevation (ft)	Submergence (ft)
Low	62.8	75.0	66.5	8.5
Average	195.0	78.9	70.4	8.5
High	439.0	86.0	77.5	8.5

*Reproduced from USACE (2005).

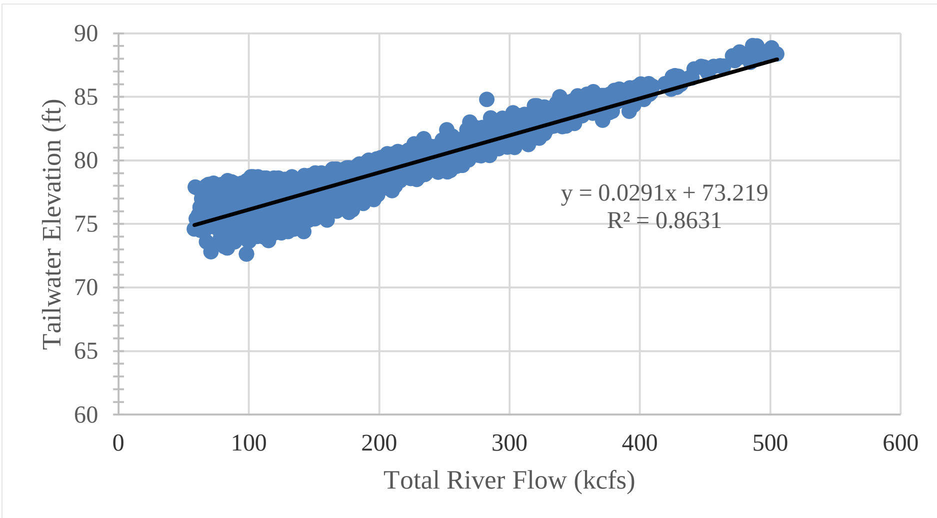


Figure 4. Tailwater Rating Curve Developed from USACE Data

Weir crest elevations were manipulated manually in the STAR-CCM+ GUI by adding or deleting areas of the original triangulated surface as appropriate, remeshing the surface, and regenerating the volume mesh.

4.3.3 Boundary and Initial Conditions

Model boundary conditions are summarized in Table 6. Boundary conditions were required for the spill bay, the fish ladder, the downstream outlet, and any impermeable surfaces, including spillwalls, spillways, the river bed, headwalls, weirs, and related structures.

Table 6. Model Boundary Condition Configuration

Boundary Name	Boundary Type	Physics Specification
Spill Bays 1 through 8	Velocity Inlet	Boundary Normal Velocity Magnitude (ft/s)
Fish Ladder	Mass Flow Inlet	Boundary Normal Mass Flow Rate (lb/s)
Downstream Outlet	Pressure Outlet	Pressure Field Function
Wall	Wall	Blended Wall Function

Model initial conditions are summarized in Table 7. Initial conditions were required to specify the pressure, volume fraction, and velocity of fluids in the domain prior to beginning the simulation.

Table 7. Model Initial Condition Configuration

Initial Condition Name	Boundary Type	Description
Pressure	Field Function	See Appendix C
Volume Fraction	Field Function	See Appendix C
Velocity	Constant	1 ft/s Downstream

4.3.4 Volume Meshing

As a VOF program, STAR-CCM+ requires the development of a volume mesh to provide a spatial discretization of the governing equations. The regularly triangulated surface geometry is first meshed using an unstructured tessellation, which results in a triangulated irregular network (TIN). This TIN is then transformed into a volume mesh using local mesh refinement. Local refinement of The Dalles Dam model allowed the program to correctly simulate the flow physics in areas of the model domain where a high solution resolution was needed, such as near the fishway weirs and the spill bay baffles.

4.3.5 Runtime Options

Runtime residuals were monitored throughout the simulations to assess convergence of the model. Residuals included those for continuity, momentum, energy, turbulent kinetic energy, and turbulent dissipation. As a general rule of thumb, the model was considered stable if the residuals were maintained below 0.1 and were decreasing monotonically. At that point, time steps were allowed to be increased, to accelerate the simulation and reduce the overall runtime. Time steps for all simulations began at 0.05 second and generally ended around 1.0 second. Time steps were controlled using an implicit unsteady solver. The maximum number of iterations per time step was set to 8 for all runs. Each scenario was simulated for 300 seconds of physical time.

4.4 CFD Model Results

CFD model results are presented graphically in Appendix A. The following section describes the results of each scenario investigated, as described previously.

4.4.1 General Observations

In general, the model simulations performed well with computed results falling within expected flow conditions, given the model configuration. Spill bay flows exited the tainter gates, entering the model under supercritical conditions, and then transitioned through a hydraulic jump into subcritical flow near the slope break of the spillways and downstream baffles. Due to the higher tailwater, this generally formed a reverse roller hydraulic, with flows near the water surface traveling upstream. Also, velocity contours near the baffles suggest the presence of von Karman vortex sheets, indicative of flow separation around blunt bodies. Downstream of the energy dissipation sill, the flows from the spillways generally converged and transitioned into a relatively uniform flow regime.

Depending on the extent to which the fishway flow was submerged by the tailwater, the fishway discharges formed a jet that extended downstream from the fishway entrance to varying degrees and at varying depths. Under lower flow conditions, the jet occupied most of the water column and extended well into the near-field of the domain, whereas at higher flows, the jet was submerged, restricted to areas near the bed and confined predominantly to the low flow channel downstream of the fishway entrance. Also, a localized eddy tended to form near the north shore downstream of the fishway entrance, which was more pronounced at high flows, and less so at low flows.

Specific results for each of the scenarios tested are discussed in the following paragraphs.

4.4.2 Scenario 1 Results - Average River Flow, 1,600 cfs Fishway Flow, Spill Bays 1-8

Results for Scenario 1 are presented graphically in Figure A1 in Appendix A. Figures A.1.1 and A.1.2 depict the plan-view velocity scalars and vectors in the downstream direction cut at plane elevations 74.5 ft and 70.0 ft, respectively. In comparing these figures, it is evident that the downstream plume of water exiting the fishway is more pronounced at a lower elevation, suggesting the presence of a submerged jet entering the low flow channel from the fishway.

This submerged jet is further depicted in Figure A.1.3, which shows a cut section perpendicular to the jet just beyond the entrance to the fishway and clipped at the top to represent the average tailwater elevation (78.9 ft). The fishway discharge plume exhibits velocities up to about 8 fps, and is moderately well-defined, with a width of about 20 ft within the low flow channel. This figure also depicts the high velocities generated from the spillways, shown in the upper right-hand corner, which exceed 22 fps. Also of note in Figure A.1.3 is the area of negative velocities in the upper left-hand corner, where water flows upstream at velocities above 7 fps due to the presence of a local eddy.

This eddy is also shown in Figure A.1.4, which depicts streamlines seeded at each of the upstream boundaries at various elevations. These streamlines are color-shaded by elevation to illustrate helical flow patterns and other characteristics of the turbulent flow regime. From this figure, the width of the plume is on the order of 50 ft.

4.4.3 Scenario 2 Results – Average River Flow, 800 cfs Fishway Flow, Spill Bays 1-8

Results for Scenario 2 are presented graphically in Figure A2 in Appendix A. Figures A.2.1 and A.2.2 depict the plan-view velocity scalars and vectors in the downstream direction cut at plane elevations 74.5 ft and 70.0 ft, respectively. In comparing these figures, it is evident that the downstream plume of water exiting the fishway is more pronounced at a lower elevation, suggesting the presence of a submerged jet entering the low flow channel from the fishway.

This submerged jet is further depicted in Figure A.2.3, which shows a cut section perpendicular to the jet just beyond the entrance to the fishway and clipped at the top to represent the average tailwater elevation (78.9 ft). The fishway discharge plume exhibits velocities up to about 8 fps, and is moderately well-defined, with a width of about 15 ft within the low flow channel, which is slightly less than in Scenario 1. This figure also depicts the high velocities generated from the spillways, shown in the upper right-hand corner, which approach 25 fps. The influence of the spillway flows is noticeably greater than in Scenario

1, likely due to the smaller fishway flow of 800 cfs. Figure A.2.3 also shows an area of negative velocities in the upper left-hand corner, where water flows upstream at velocities above 7 fps due to the presence of a local eddy.

This eddy is also shown in Figure A.2.4, which depicts streamlines seeded at each of the upstream boundaries at various elevations. These streamlines are color-shaded by elevation to show helical flow patterns and other characteristics of the turbulent flow regime. From this figure, the width of the plume is on the order of 40 ft, which is slightly less than in Scenario 1.

4.4.4 Scenario 3 Results – High River Flow, 1,600 cfs Fishway Flow, Spill Bays 1-8

Results for Scenario 3 are presented graphically in Figure A3 in Appendix A. Figures A.3.1 and A.3.2 depict the plan-view velocity scalars and vectors in the downstream direction cut at plane elevations 82.0 ft and 70.0 ft, respectively. These figures show velocities clipped at 20 fps, such that red areas in the figure are greater than or equal to 20 fps in the downstream direction. Of note are the areas in the lower right-hand corners of the figures, which show the downstream extents of the fish corridor connecting the tailrace with the fishway.

In comparing Figures A.3.1 and A.3.2 it is evident that the downstream plume of water exiting the fishway is more pronounced at a lower elevation, suggesting the presence of a submerged jet entering the low flow channel from the fishway.

This submerged jet is further depicted in Figure A.3.3, which shows a cut section perpendicular to the jet just beyond the entrance to the fishway and clipped at the top to represent the average tailwater elevation (86.0 ft). The fishway discharge plume exhibits velocities up to about 7 fps, and is moderately well-defined, with a width of about 20 ft within the low flow channel. This figure also depicts the high velocities generated from the spillways, shown in the upper right-hand corner, which approach 35 fps and encroach further into the section than in Scenarios 1 and 2. This is likely due to the substantially higher spill rates in this scenario. Figure A.3.3 also shows an area of negative velocities in the upper left-hand corner, where water flows upstream at velocities above 5 fps due to the presence of a local eddy. The area of this upstream flow is noticeably larger than in Scenarios 1 and 2, suggesting that the eddy is due more to the spill rates and less to the fishway flows.

This eddy is also shown in Figure A.3.4, which depicts streamlines seeded at each of the upstream boundaries at various elevations. These streamlines are color-shaded by elevation in order to show helical flow patterns and other characteristics of the turbulent flow regime. From this figure, the width of the plume is on the order of 40 ft.

4.4.5 Scenario 4 Results – High River Flow, 800 cfs Fishway Flow, Spill Bays 1-8

Results for Scenario 4 are presented graphically in Figure A4 in Appendix A. Figures A.4.1 and A.4.2 depict the plan-view velocity scalars and vectors in the downstream direction cut at plane elevations 82.0 ft and 70.0 ft, respectively. These figures show velocities clipped at 20 fps, such that red areas in the figure are greater than or equal to 20 fps in the downstream direction. Of note are the areas in the lower right-hand corners of the figures, which show the downstream extents of the fish corridor connecting the tailrace with the fishway.

In comparing Figures A.4.1 and A.4.2 it is evident that the downstream plume of water exiting the fishway is more pronounced at a lower elevation, suggesting the presence of a submerged jet entering the low flow channel from the fishway.

This submerged jet is further depicted in Figure A.4.3, which shows a cut section perpendicular to the jet just beyond the entrance to the fishway and clipped at the top to represent the average tailwater elevation (86.0 ft). The fishway discharge plume exhibits velocities up to about 6 fps, and is moderately well-defined, with a width of about 20 ft within the low flow channel. This figure also depicts the high velocities generated from the spillways, shown in the upper right-hand corner, which approach 35 fps and encroach further into the section than in Scenarios 1 and 2. This is likely due to the substantially higher spill rates in this scenario. Figure A.4.3 also shows a relatively large area of negative velocities above the submerged jet, where water flows upstream at velocities above 5 fps due to the presence of a local eddy. The area of this upstream flow is noticeably larger than in Scenarios 1 and 2, suggesting that the eddy is due more to the spill rates and less to the fishway flows. Also, the area of the submerged jet, compared with the flows from the spill bays and the eddy flows, is measurably smaller in this scenario than in Scenario 3, likely due to the smaller fishway flow of 800 cfs.

The local eddy is also shown in Figure A.4.4, which depicts streamlines seeded at each of the upstream boundaries at various elevations. These streamlines are color-shaded by elevation in order to show helical flow patterns and other characteristics of the turbulent flow regime. From this figure, the width of the plume is on the order of 40 ft, and the eddy itself is much more well-defined than in previous scenarios.

4.4.6 Scenario 5 Results – Low River Flow, 1,600 cfs Fishway Flow, Spill Bays 1-8

Results for Scenario 5 are presented graphically in Figure A5 in Appendix A. Figures A.5.1 and A.5.2 depict the plan-view velocity scalars and vectors in the downstream direction cut at plane elevations 71.0 ft and 70.0 ft, respectively. In comparing Figures A.5.1 and A.5.2, both show fairly well-defined plumes of water discharging from the fishway, suggesting that the discharge jet is present throughout the water column.

This discharge jet is further depicted in Figure A.5.3, which shows a cut section perpendicular to the jet just beyond the entrance to the fishway and clipped at the top to represent the average tailwater elevation (75.0 ft). The fishway discharge plume exhibits velocities up to about 5 fps, and is spread out over the entire width of the low flow channel, about 50 ft. This figure also depicts the high velocities generated from the spillways, shown in the upper right-hand corner, which approach about 9 fps. In comparison to higher flow scenarios, Figure A.5.3 also shows very little evidence of an eddy forming near the fishway entrance, so that the downstream velocities of the fishway appear more pronounced and the jet more well-defined.

Figure A.5.4 depicts streamlines seeded at each of the upstream boundaries at various elevations. These streamlines are color-shaded by elevation to show helical flow patterns and other characteristics of the turbulent flow regime. From this figure, the width of the plume is on the order of 70 ft, and exhibits very few characteristics of eddies or helical flow.

4.4.7 Scenario 6 Results – Low River Flow, 800 cfs Fishway Flow, Spill Bays 1-8

Results for Scenario 6 are presented graphically in Figure A6 in Appendix A. Figures A.6.1 and A.6.2 depict the plan-view velocity scalars and vectors in the downstream direction cut at plane elevations 71.0 ft and 70.0 ft, respectively. In comparing Figures A.6.1 and A.6.2, both show fairly well-defined plumes of water discharging from the fishway, suggesting that the discharge jet is present throughout the water column.

This discharge jet is further depicted in Figure A.6.3, which shows a cut section perpendicular to the jet just beyond the entrance to the fishway and clipped at the top to represent the average tailwater elevation (75.0 ft). The fishway discharge plume exhibits velocities up to about 4 fps, and is spread out over much of the width of the low flow channel, about 35 ft. This figure also depicts the high velocities generated from the spillways, shown in the upper right-hand corner, which approach about 10 fps. In contrast to Scenario 5, Figure A.6.3 shows the presence of an eddy, represented by upstream velocity contours in the upper left-hand corner of the figure. This is likely due to the lower fishway flow of 800 cfs, and its inability to “drown out” the eddy. As a consequence, the fishway discharge jet has a smaller area under this scenario than in Scenario 5.

The local eddy is also shown in Figure A.6.4, which depicts streamlines seeded at each of the upstream boundaries at various elevations. These streamlines are color-shaded by elevation to show helical flow patterns and other characteristics of the turbulent flow regime. From this figure, the width of the plume is on the order of 40 ft, and the eddy itself is much more well-defined than in previous scenarios.

Figure A.6.4 depicts streamlines seeded at each of the upstream boundaries at various elevations. These streamlines are color-shaded by elevation to show helical flow patterns and other characteristics of the turbulent flow regime. From this figure, the width of the plume is on the order of 45 ft, which is appreciably smaller than in Scenario 5.

4.4.8 Scenario 7 Results – High River Flow, 1,600 cfs Fishway Flow, Spill Bays 3-8

Results for Scenario 7 are presented graphically in Figure A7 in Appendix A. Figures A.7.1 and A.7.2 depict the plan-view velocity scalars and vectors in the downstream direction cut at plane elevations 82.0 ft and 70.0 ft, respectively. These figures show velocities clipped at 6 fps, such that red areas in the figure are greater than or equal to 6 fps in the downstream direction. Figure A.7.2 shows velocities at the very downstream extent of the figure in the range of 1 to 4 fps, which is excellent for upstream migration. The opening of this corridor is quite different than that shown in Figures A.3.1 and A.3.2, whose scenarios may represent an obstruction to certain species. This is most certainly due to the closing off of Spill Bays 1 and 2 during high flows, which prohibits the spill bay flows from fully encroaching on the fish passage corridor until beyond the spillwall between to Spill Bays 8 and 9.

In comparing Figures A.7.1 and A.7.2, it is also evident that the downstream plume of water exiting the fishway is more pronounced at a lower elevation, suggesting the presence of a submerged jet entering the low flow channel from the fishway.

This submerged jet is further depicted in Figure A.7.3, which shows a cut section perpendicular to the jet just beyond the entrance to the fishway and clipped at the top to represent the average tailwater elevation (86.0 ft). The fishway discharge plume exhibits velocities up to about 4 fps, is moderately well-defined, and covers the entire low flow channel and extends beyond it by about 15 ft. Noticeably absent from this figure are the high velocities generated from the spillways, suggesting that the high velocity contours shown in other scenarios originated from Spill Bays 1 and/or 2. Figure A.7.3 also shows an area of negative velocities in the entire upper portion of the water column, where water flows upstream at velocities approaching 5 fps due to the presence of a large eddy.

Figure A.3.4 depicts streamlines seeded at each of the upstream boundaries at various elevations. These streamlines are color-shaded by elevation to show helical flow patterns and other characteristics of the turbulent flow regime. From this figure, the width of the plume is on the order of 70 ft.

4.4.9 Scenario 8 Results – High River flow, 800 cfs Fishway Flow, Spill Bays 3-8

Results for Scenario 8 are presented graphically in Figure A8 in Appendix A. Figures A.8.1 and A.8.2 depict the plan-view velocity scalars and vectors in the downstream direction cut at plane elevations 82.0 ft and 70.0 ft, respectively. These figures show velocities clipped at 6 fps, such that red areas in the figure are greater than or equal to 6 fps in the downstream direction. Figure A.8.2 shows velocities at the very downstream extent of the figure in the range of 1 to 4 fps, which is excellent for upstream migration. The opening of this corridor is quite different than that shown in Figures A.4.1 and A.4.2, whose scenarios may represent an obstruction to certain species. This is most certainly due to the closing off of Spill Bays 1 and 2 during high flows, which prohibits the spill bay flows from fully encroaching on the fish passage corridor until beyond the spillwall between to Spill Bays 8 and 9.

In comparing Figures A.8.1 and A.8.2 it is also evident that the downstream plume of water exiting the fishway is more pronounced at a lower elevation, suggesting the presence of a submerged jet entering the low flow channel from the fishway.

This submerged jet is further depicted in Figure A.8.3, which shows a cut section perpendicular to the jet just beyond the entrance to the fishway and clipped at the top to represent the average tailwater elevation (86.0 ft). The fishway discharge plume exhibits velocities up to about 5 fps, is very well-defined, and extends the entire width of the low flow channel. In contrast to Scenario 7, the presence of high velocity contours due to the spill bay flows is present in this scenario, most likely due to the lower fishway flow of 800 cfs. The effect of this encroachment is to reduce the area of the fishway discharge jet relative to Scenario 7. Figure A.8.3 also shows an area of negative velocities in most of the upper portion of the water column, where water flows upstream at velocities approaching 5 fps due to the presence of a large eddy.

Figure A.8.4 depicts streamlines seeded at each of the upstream boundaries at various elevations. These streamlines are color-shaded by elevation to show helical flow patterns and other characteristics of the turbulent flow regime. From this figure, the width of the plume is on the order of 50 ft.

4.4.10 Scenario 9 Results – Average River Flow Aug-Sept, Baseline No Spill

Results for Scenario 9 are presented graphically in Figure A9 in Appendix A. Figures A.9.1 and A.9.2 depict the plan-view velocity scalars and vectors in the downstream direction cut at plane elevations 72.5 ft and 70.0 ft, respectively. These figures show velocities clipped at 3 fps, such that red areas in the figure are greater than or equal to 3 fps in the downstream direction.

Figure A.9.3 shows a cut section perpendicular to the submerged jet discharging from the fishway that is cut just beyond the entrance to the fishway and clipped at the top to represent the average tailwater elevation (76.5 ft). The fishway discharge plume exhibits velocities up to about 5 fps, is very well-defined, and extends most of the width of the low flow channel. The jet is very well-pronounced due to the absence of spilling flows, such that the fishway discharge plume enters an area of quiescent water with very low velocities. Figure A.9.3 also shows an area of negative velocities near the right bank headwall, where a small localized eddy has formed.

Figure A.9.4 depicts streamlines seeded at each of the upstream boundaries at various elevations. These streamlines are color-shaded by elevation to show helical flow patterns and other characteristics of the turbulent flow regime. From this figure, the width of the plume is on the order of 40 ft.

4.4.11 Scenario 10 Results – Average River Flow Aug-Sept, Alternative No Spill

Results for Scenario 10 are presented graphically in Figure A10 in Appendix A. Figures A.10.1 and A.10.2 depict the plan-view velocity scalars and vectors in the downstream direction cut at plane elevations 72.5 ft and 70.0 ft, respectively. These figures show velocities clipped at 3 fps, such that red areas in the figure are greater than or equal to 3 fps in the downstream direction. Compared with Figures A.9.1 and A.9.2, these figures show a larger discharge plume exiting the fishway, corresponding with the 1,600 cfs flow rate.

Figure A.10.3 shows a cut section perpendicular to the submerged jet discharging from the fishway that is cut just beyond the entrance to the fishway and clipped at the top to represent the average tailwater elevation (76.5 ft). The fishway discharge plume exhibits velocities up to about 5 fps, is very well-defined, and extends most of the width of the low flow channel. The jet is very well-pronounced due to the absence of spilling flows, such that the fishway discharge plume enters an area of quiescent water with very low velocities. In contrast to Figure A.9.3, Figure A.10.3 does not indicate any areas of upstream flow, where small localized eddies may have formed.

Figure A.10.4 depicts streamlines seeded at each of the upstream boundaries at various elevations. These streamlines are color-shaded by elevation to show helical flow patterns and other characteristics of the turbulent flow regime. From this figure, the width of the plume is on the order of 50 ft. The streamlines also indicate the presence of a large eddy. The upstream velocities of this eddy approach 1.5 fps and occur over 400 feet away from the fishway entrance. This eddy is significantly dampened once spilling occurs.

4.5 Summary of Fish Passage Conditions Comparison

The CFD model was developed to assist in evaluating increasing the existing AWSS flow from 800 cfs to 1,600 cfs through the NFS entrances. To accomplish this, the existing fishway entrance N-2 would have to be reconditioned and brought back online operating concurrently with entrance N-1 to deliver a total flow of 1,600 cfs.

In general, increasing the AWSS flow from 800 cfs to 1,600 cfs indicates a larger area of influence in the near-field of the NFS entrance for low and average river flow conditions. The hydraulic penetration into the tailrace is greater as well as the physical size of the AWSS flow plume entering the tailrace. The highest velocities tend to occur at mid-point of the flow depth over the fishway entrances. At high river flow conditions, the discharge from Spillway Bays 1 and 2 tends to shear-off the AWSS flow plume. This results in a narrow band of lower velocity flow along the north bank of the tailrace.

5.0 Conclusions and Recommendations

McMillen Jacobs Associates modified an existing CFD model of The Dalles Dam to investigate changes in river hydraulics associated with increasing attraction flows at the north fishway for upstream migrants by increasing fishway flows from 800 cfs to 1,600 cfs. All eight spill bays at The Dalles Dam flowed uniformly under three river flow regimes: low, average, and high. In scenarios 7 and 8, modelers closed Spill Bays 1 and 2 under high flow conditions.

Results indicate that adding 800 cfs to the fishway attraction flow would improve attraction flows for upstream salmon and steelhead migrants, particularly at low and average river flows. At high flows, closing Spill Bays 1 and 2 appears to improve passage conditions both in the near-field, near the fishway entrance, and at the downstream end of the tailrace, where a fish passage corridor opens up with acceptable velocities.

Based on the CFD model scenario results, it appears that increasing the fishway entrance flow from 800 to 1,600 cfs would improve attraction to the fishway entrance.

6.0 References

CD-adapco, 2014. STAR-CCM+ Product Documentation. Available at www.cd-adapco.com.

Cook, C.B., Richmond, M.C., Serkowski, J.A., 2006. The Dalles Dam, Columbia River: Spillway Improvement CFD Study. PNNL-14768, Pacific Northwest National Laboratory.

Flowscience, 2014. Flow-3D Product Documentation. Available at www.flow3d.com.

McMillen Jacobs (McMillen Jacobs Associates), 2014. Personal communication with CD-adapco, October 8, 2014.

Rakowski C., Richmond, M., Serkowski, J., and Johnson, G.E., 2006a. Forebay Computational Fluid Dynamics Modeling for The Dalles Dam to Support Behavior Guidance System Siting Studies. PNNL-15689, Pacific Northwest National Laboratory.

Rakowski C.L., Richmond, M.C., Serkowski, J.A., 2006b. Forebay Computational Fluid Dynamics Modeling for The Dalles Dam to Support Vortex Suppression Device Studies: Memorandum for Record. PNNL-16121, Pacific Northwest National Laboratory.

Rakowski C.L., Perkins, W.A., Richmond, M.C., and Serkowski, J.A., 2008. Simulations of The Dalles Dam Proposed Full Length Spillway. PNNL-17322, Pacific Northwest National Laboratory.

Rakowski C.L., and Serkowski, J.A., and Richmond, M.C., 2010. Computational Fluid Dynamics Modeling of The Dalles Project: Effects of Spill Flow Distribution between the Washington Shore and the Tailrace Spillwall Draft Report. PNNL-20064, Pacific Northwest National Laboratory.

USACE (U.S. Army Corps of Engineers), 2005. Hydraulic Evaluation of the Lower Columbia River Adult Bypass Systems (HELCRABS), The Dalles Dam North Fish Ladder Hydraulic/Operational Evaluation.

Appendix A

CFD Modeling Figures

Scenario 01 – Alternative, Average Flow, Bays 1-8 Active

Figure A1: Freedom Project CFD Draft Results

McMILLEN JACOBS ASSOCIATES

Date: 1/16/15

Revision Number: 1

Prepared By: Kevin Jensen

Checked By: Morton McMillen

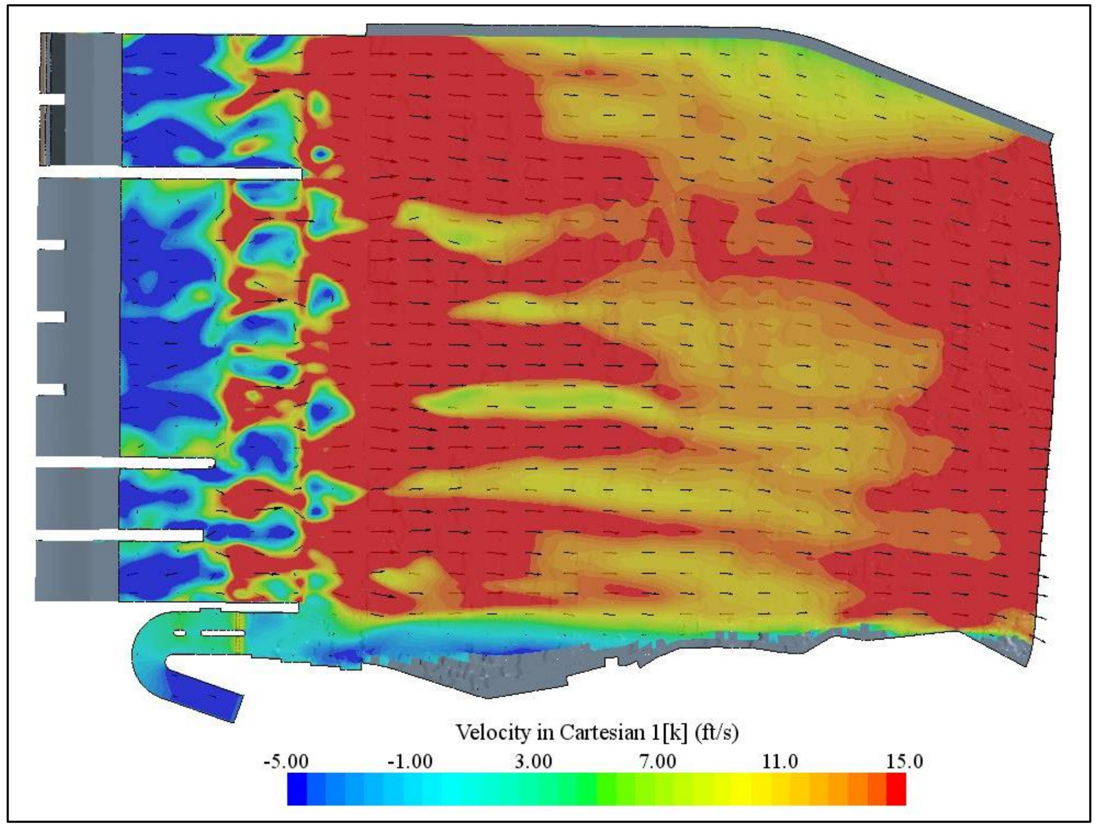
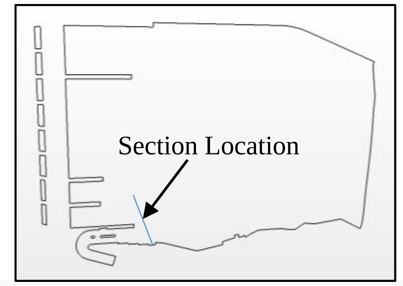


Figure A.1.1 Velocity Scalar and Vector, Plan View—Plane Section Elevation = 74.5 ft (Cut Midway between Weir Crest and Tailwater Elevation)



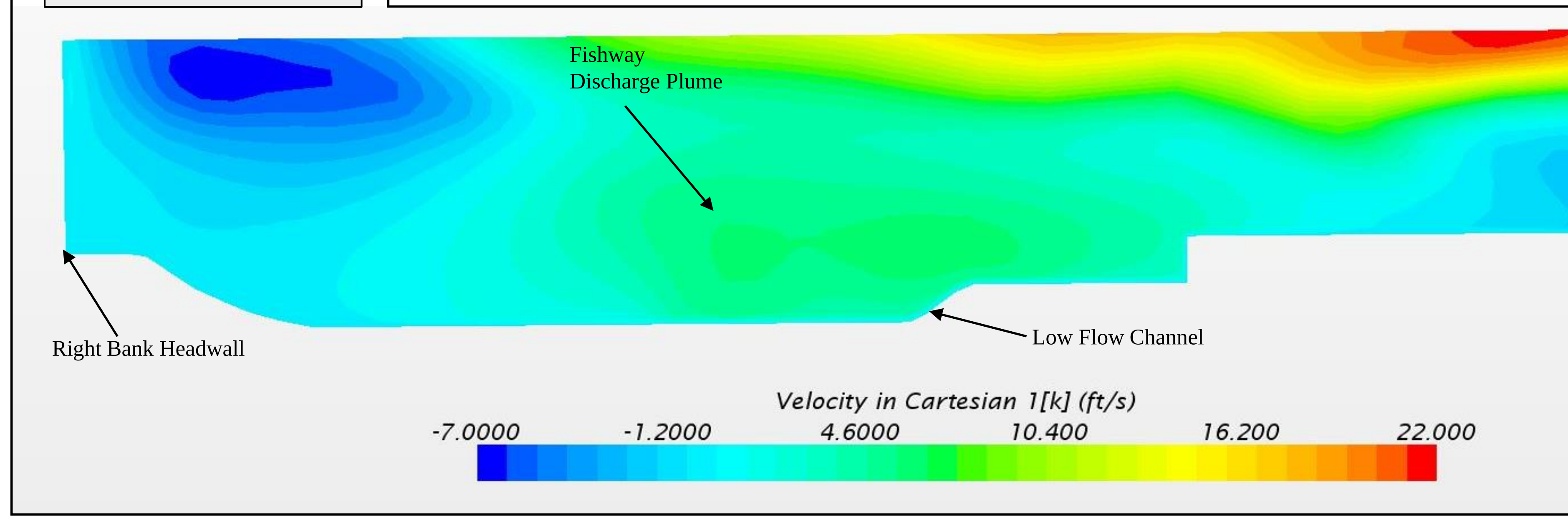


Figure A.1.3 Velocity Section Perpendicular to Fishway Discharge Plume

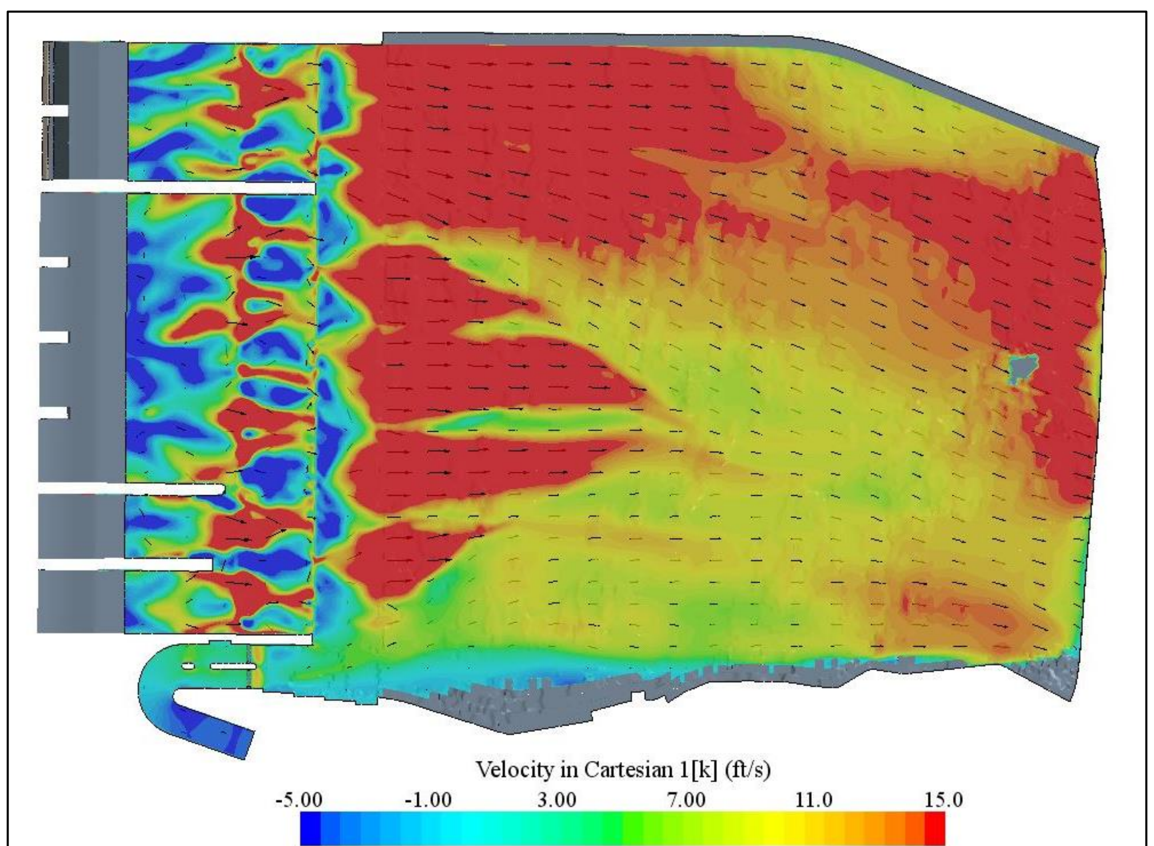


Figure A.1.2 Velocity Scalar and Vector, Plan View—Plane Section Elevation = 70.0 ft

Spillway Bay Boundaries	
Active Bays	1-8
Spillway Flow through Each Bay (kcfs)	9.8
Spill Bay Gate Height (ft)	6.6
TW Elevation (ft)	78.9
Fish Ladder Boundary	
Total Fish Ladder Flow (kcfs)	1.6
Mass Inflow (kips/s)	99.8
Active Fishway Weirs	N1, N2
Fishway Boundary Height (ft)	16.9
Weir Crest Elevation (ft)	70.4
Display Details	
Direction of Positive Velocity	Downstream
Time Step of Display (s)	300

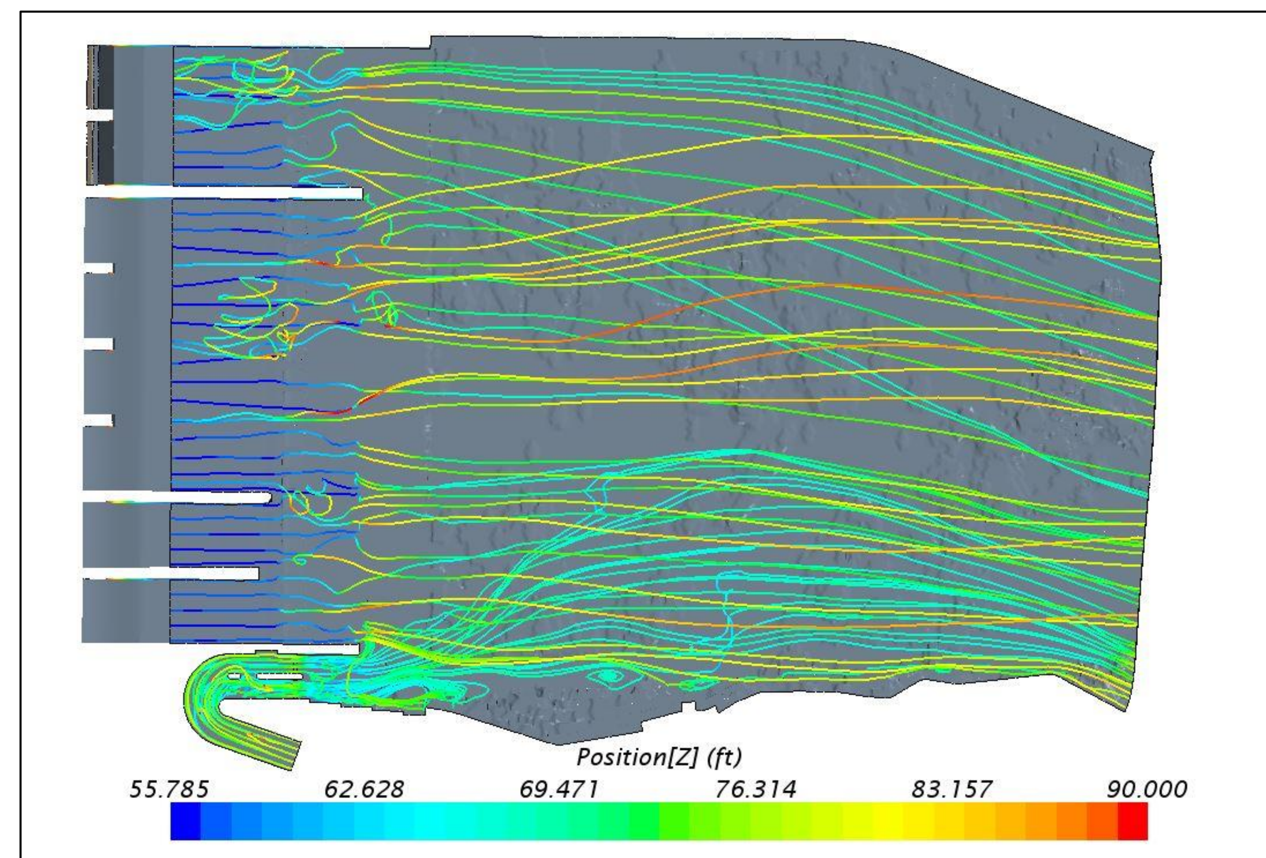


Figure A.1.4 Streamlines Color-Scaled by Elevation

Scenario 02 – Baseline, Average Flow, Bays 1-8 Active

Figure A2: Freedom Project CFD Draft Results	
McMILLEN JACOBS ASSOCIATES	Date: 1/16/15
	Revision Number: 1
	Prepared By: Kevin Jensen
	Checked By: Morton McMillen

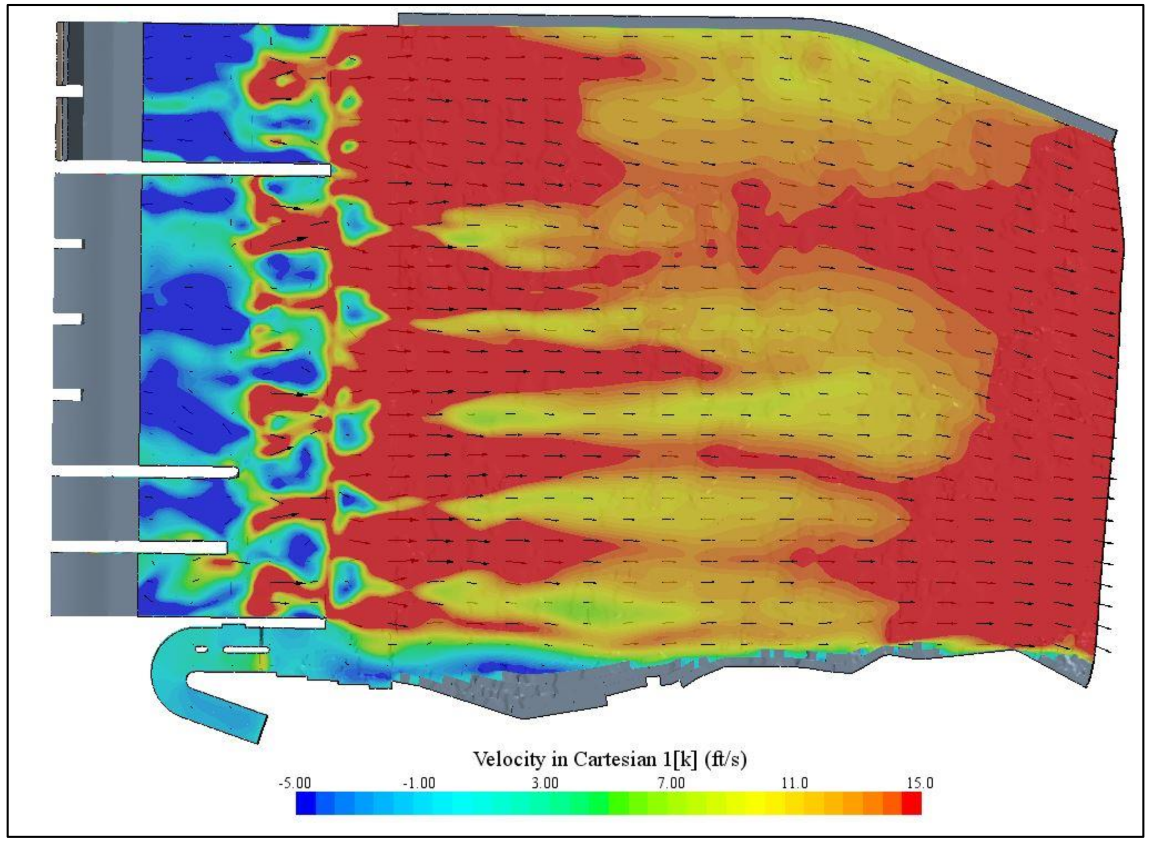
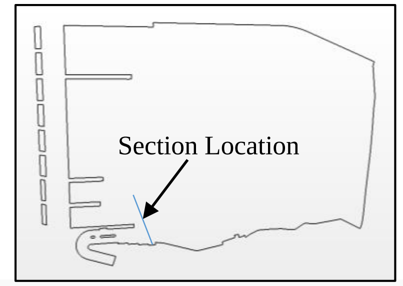


Figure A.2.1 Velocity Scalar and Vector, Plan View—Plane Section Elevation = 74.5 ft (Cut Midway between Weir Crest and Tailwater Elevation)



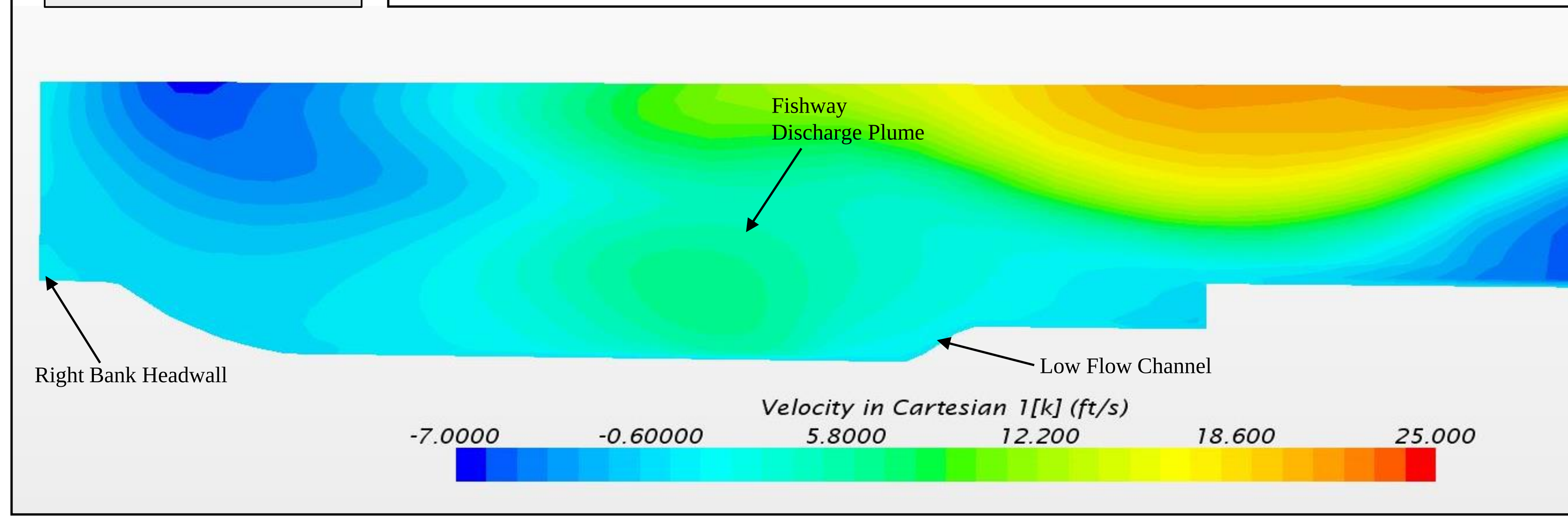


Figure A.2.3 Velocity Section Perpendicular to Fishway Discharge Plume

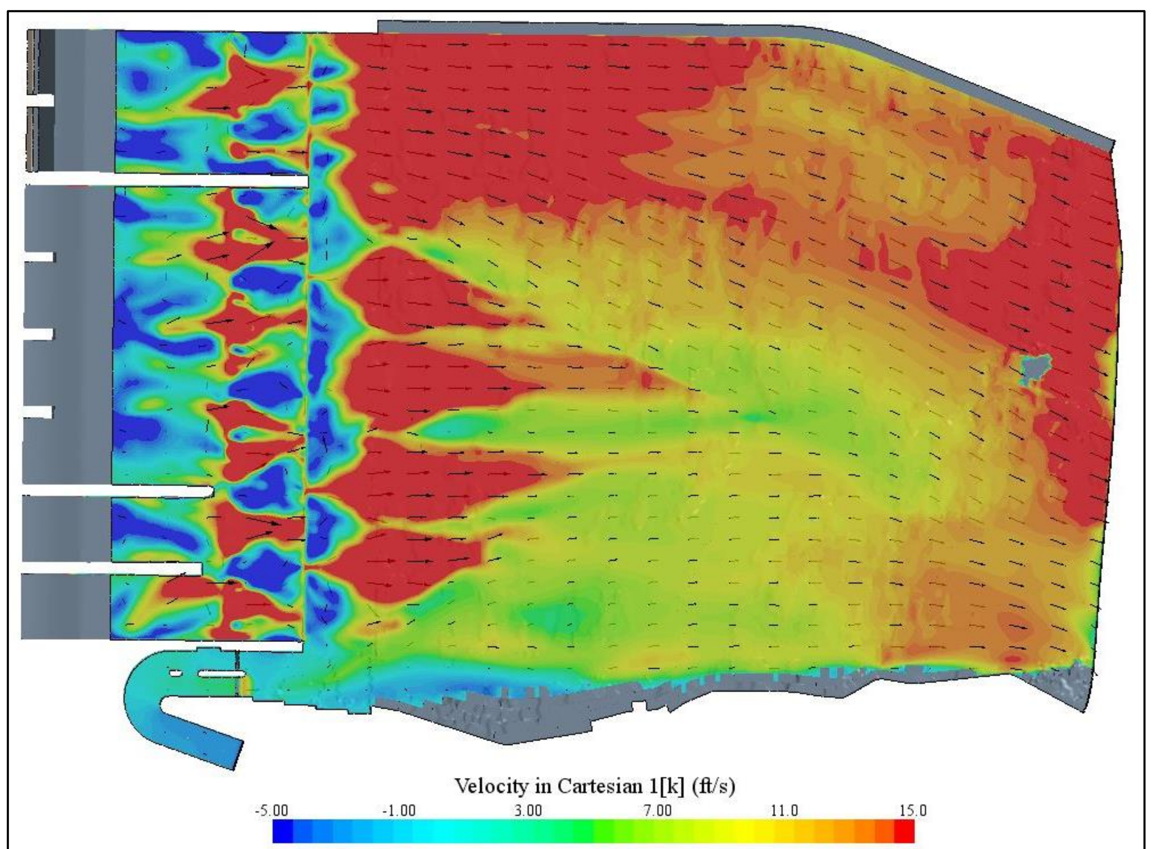


Figure A.2.2 Velocity Scalar and Vector, Plan View—Plane Section Elevation = 70.0 ft

Spillway Bay Boundaries	
Active Bays	1-8
Spillway Flow through Each Bay (kcfs)	9.8
Spill Bay Gate Height (ft)	6.6
TW Elevation (ft)	78.9
Fish Ladder Boundary	
Total Fish Ladder Flow (kcfs)	0.8
Mass Inflow (kips/s)	49.9
Active Fishway Weirs	N1
Fishway Boundary Height (ft)	10
Weir Crest Elevation (ft)	70.4
Display Details	
Direction of Positive Velocity	Downstream
Time Step of Display (s)	300

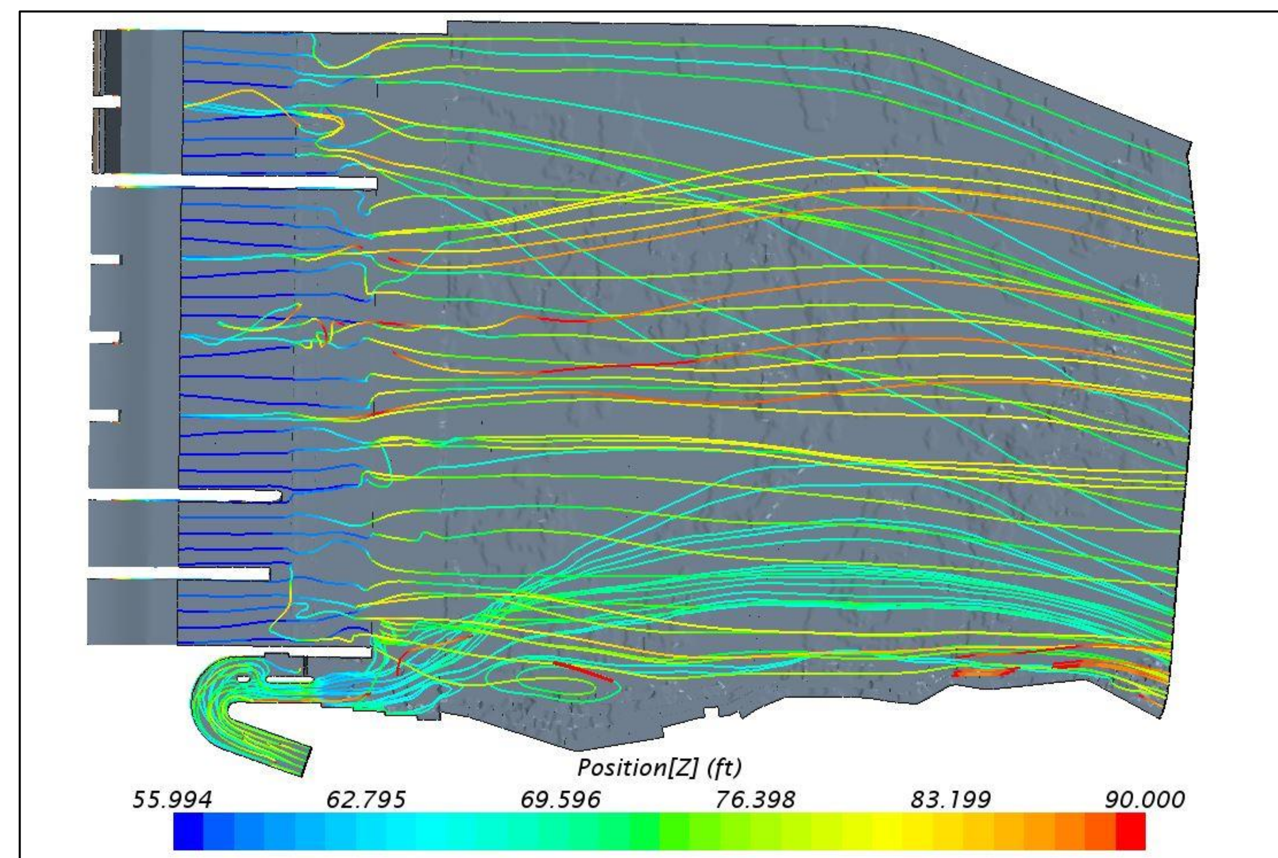


Figure A.2.4 Streamlines Color-Scaled by Elevation

Scenario 03 – Alternative, High Flow, Bays 1-8 Active

Figure A3: Freedom Project CFD Draft Results	
McMILLEN JACOBS ASSOCIATES	Date: 1/16/15
	Revision Number: 1
	Prepared By: Kevin Jensen
	Checked By: Morton McMillen

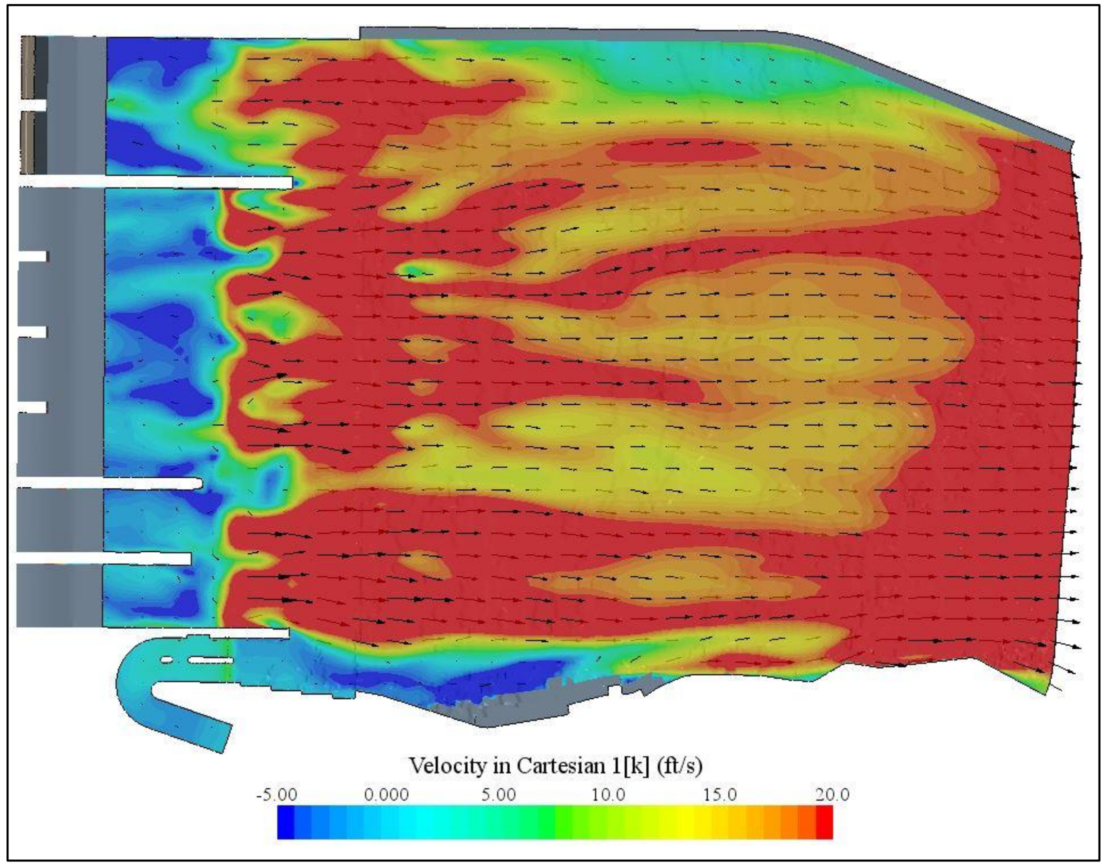
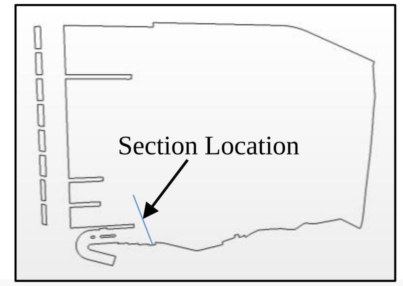


Figure A.3.1 Velocity Scalar and Vector, Plan View—Plane Section Elevation = 82.0 ft (Cut Midway between Weir Crest and Tailwater Elevation)



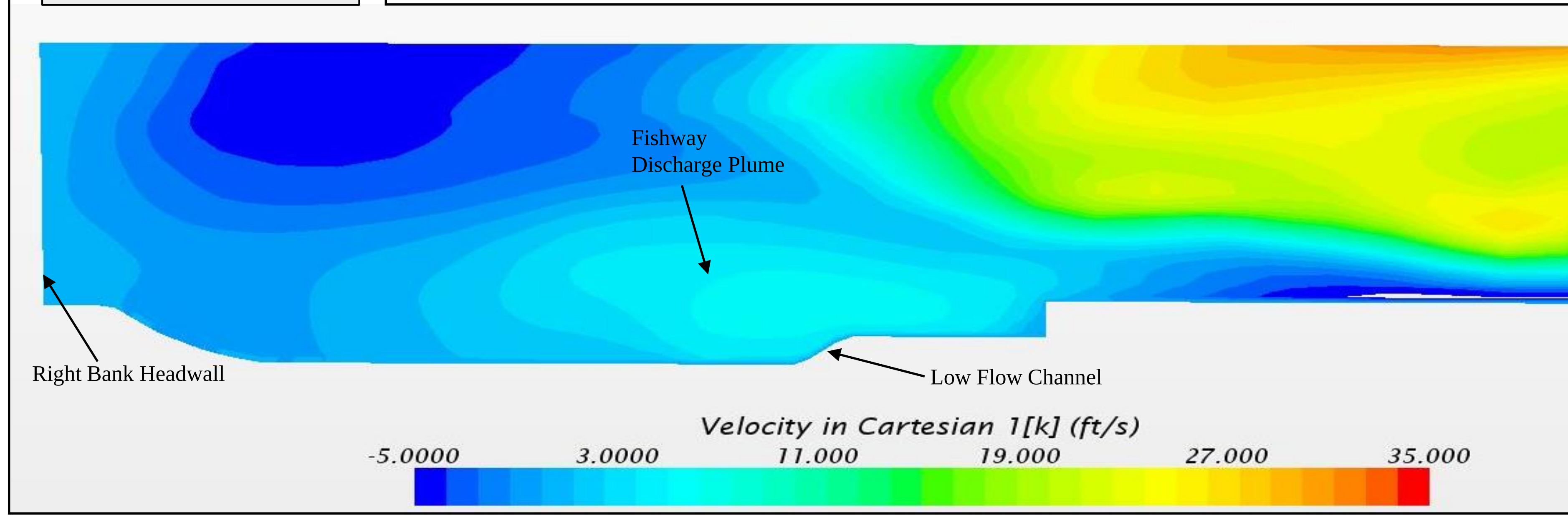


Figure A.3.3 Velocity Section Perpendicular to Fishway Discharge Plume

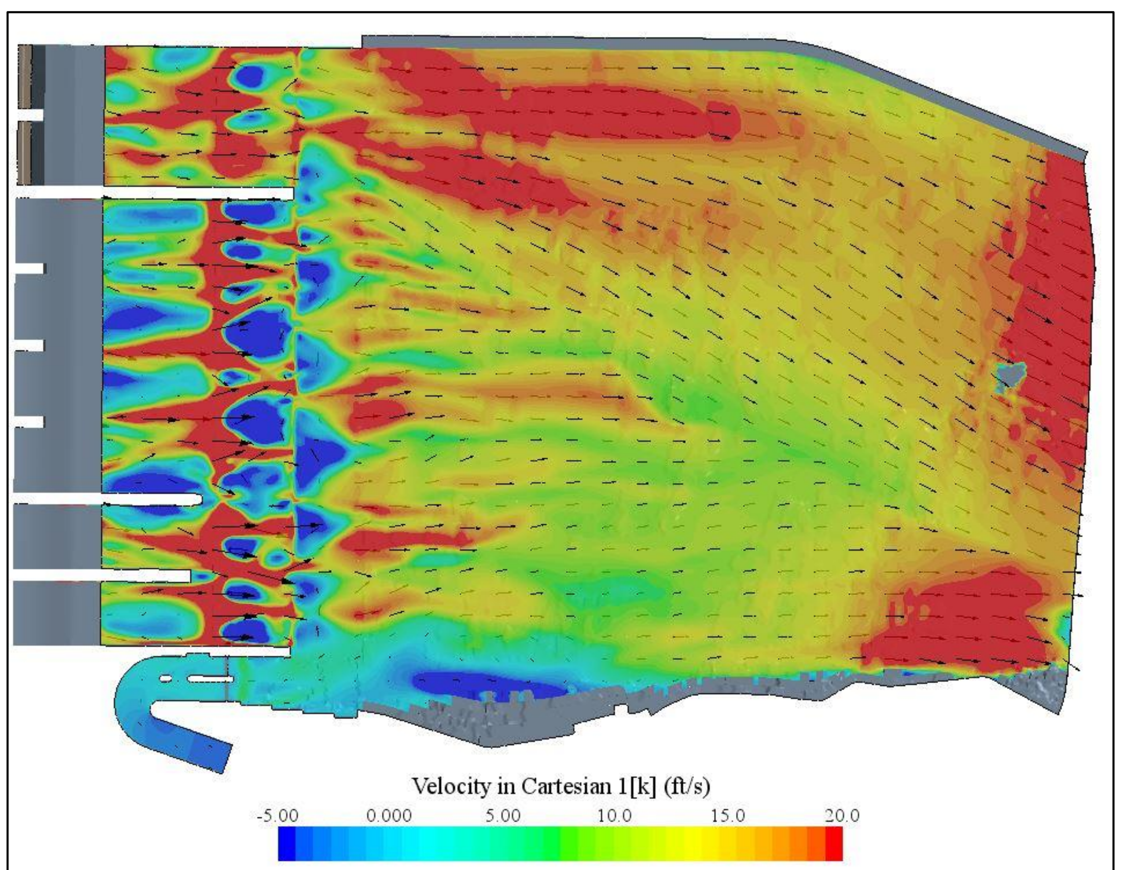


Figure A.3.2 Velocity Scalar and Vector, Plan View—Plane Section Elevation = 70.0 ft

Spillway Bay Boundaries	
Active Bays	1-8
Spillway Flow through Each Bay (kcfs)	22.0
Spill Bay Gate Height (ft)	15.0
TW Elevation (ft)	86.0
Fish Ladder Boundary	
Total Fish Ladder Flow (kcfs)	1.6
Mass Inflow (kips/s)	99.8
Active Fishway Weirs	N1, N2
Fishway Boundary Height (ft)	16.9
Weir Crest Elevation (ft)	77.5
Display Details	
Direction of Positive Velocity	Downstream
Time Step of Display (s)	300

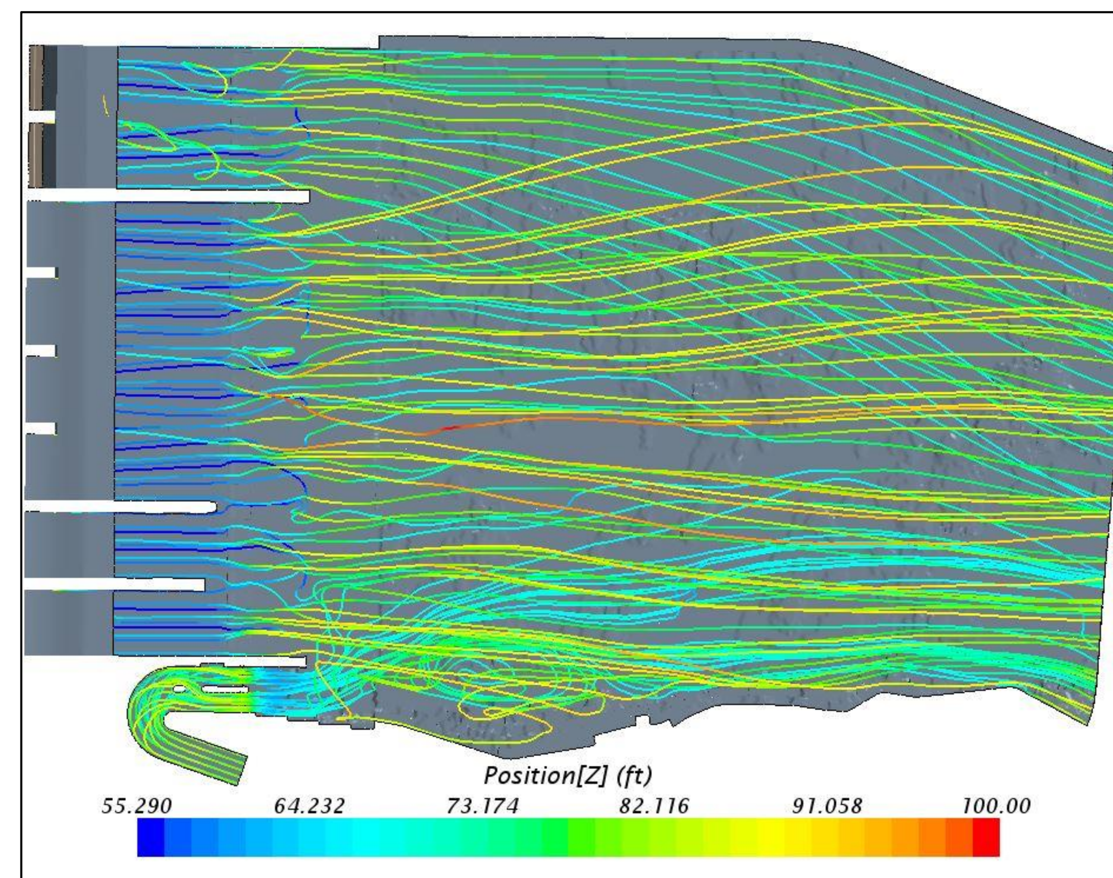


Figure A.3.4 Streamlines Color-Scaled by Elevation

Scenario 04 – Baseline, High Flow, Bays 1-8 Active

Figure A4: Freedom Project CFD Draft Results

McMILLEN JACOBS ASSOCIATES	Date: 1/16/15
	Revision Number: 1
	Prepared By: Kevin Jensen
	Checked By: Morton McMillen

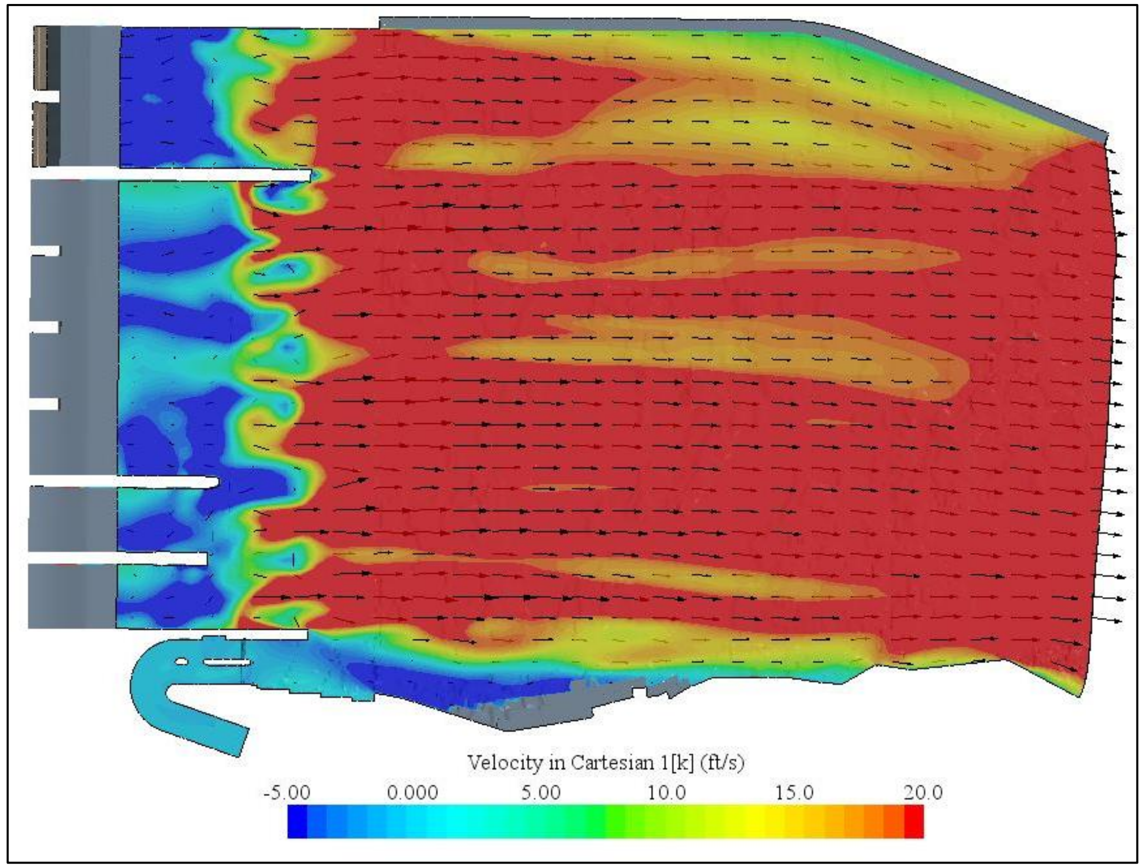
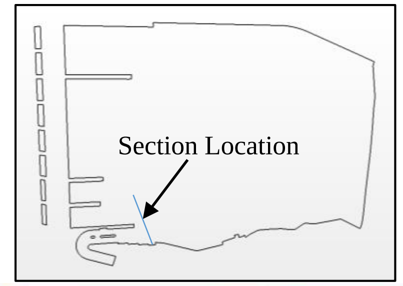


Figure A.4.1 Velocity Scalar and Vector, Plan View—Plane Section Elevation = 82.0 ft (Cut Midway between Weir Crest and Tailwater Elevation)



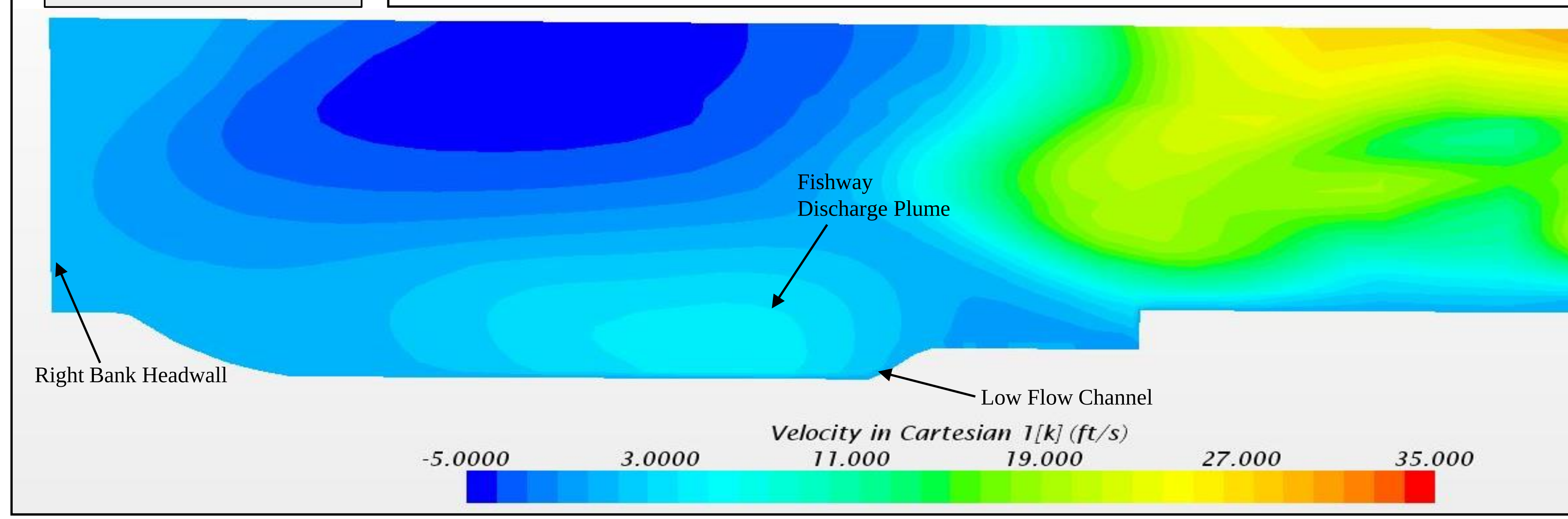


Figure A.4.3 Velocity Section Perpendicular to Fishway Discharge Plume

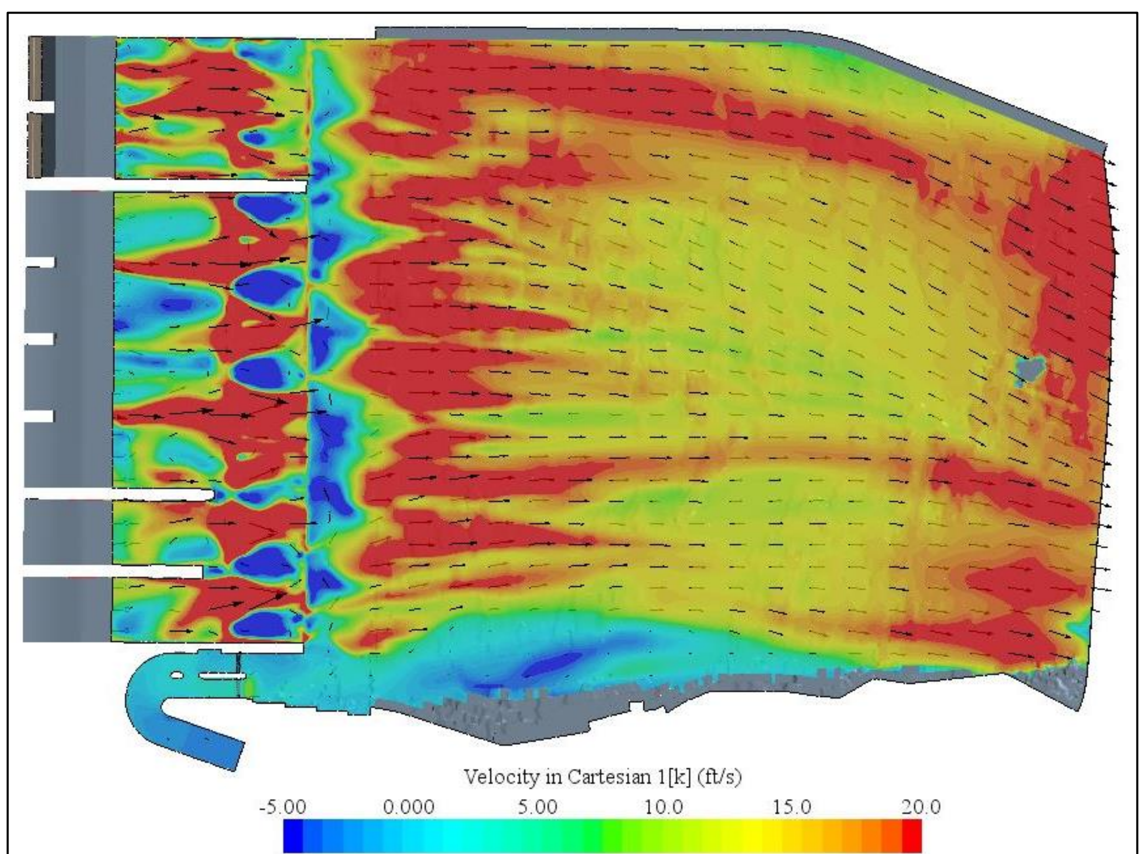


Figure A.4.2 Velocity Scalar and Vector, Plan View—Plane Section Elevation = 70.0 ft

Spillway Bay Boundaries	
Active Bays	1-8
Spillway Flow through Each Bay (kcfs)	22.0
Spill Bay Gate Height (ft)	15.0
TW Elevation (ft)	86.0
Fish Ladder Boundary	
Total Fish Ladder Flow (kcfs)	0.8
Mass Inflow (kips/s)	49.9
Active Fishway Weirs	N1
Fishway Boundary Height (ft)	10
Weir Crest Elevation (ft)	77.5
Display Details	
Direction of Positive Velocity	Downstream
Time Step of Display (s)	300

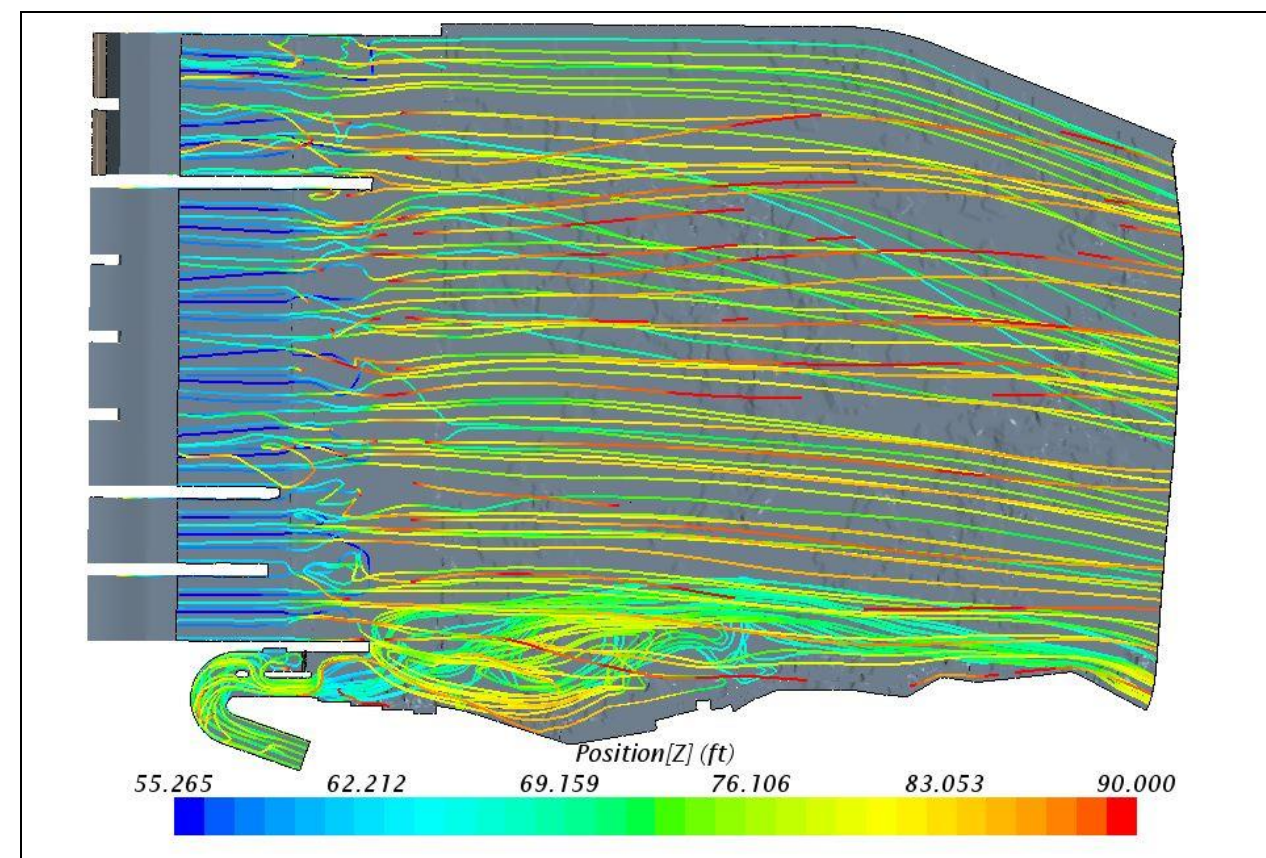


Figure A.4.4 Streamlines Color-Scaled by Elevation

Scenario 05 – Alternative, Low Flow, Bays 1-8 Active

Figure A5: Freedom Project CFD Draft Results	
McMILLEN JACOBS ASSOCIATES	Date: 1/16/15
	Revision Number: 1
	Prepared By: Kevin Jensen
	Checked By: Morton McMillen

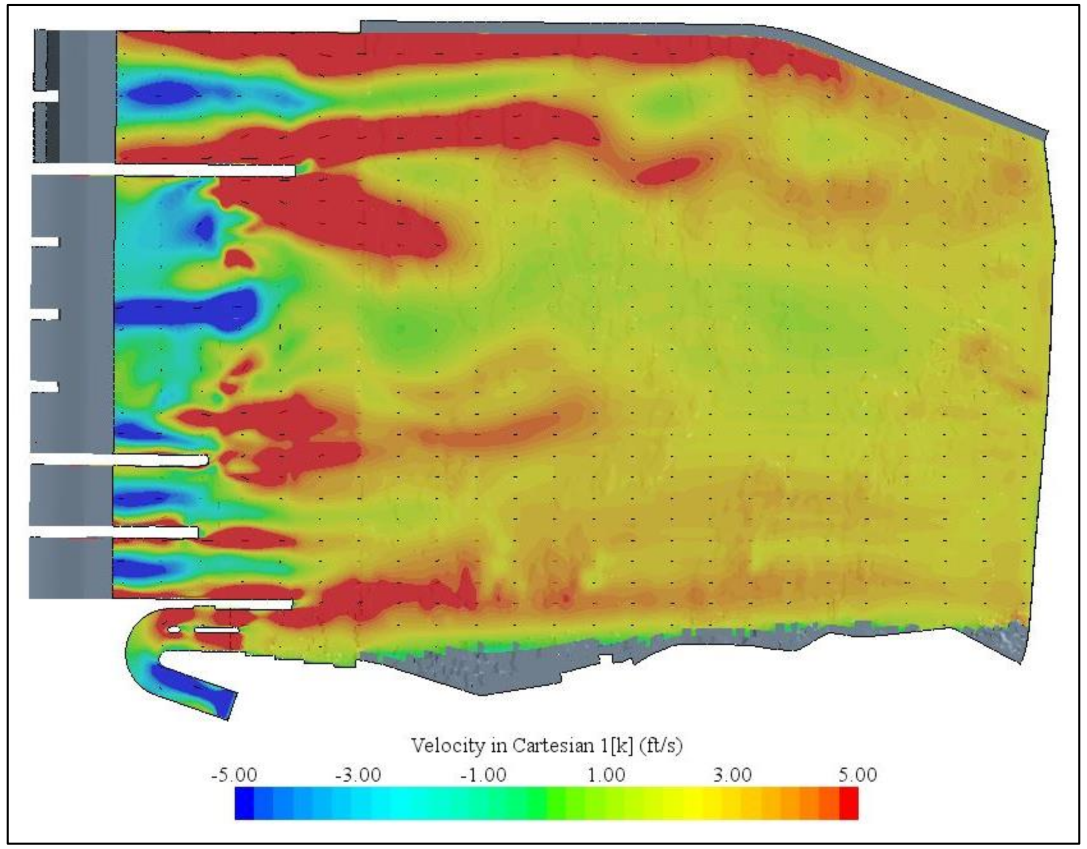


Figure A.5.1 Velocity Scalar and Vector, Plan View—Plane Section Elevation = 71.0 ft (Cut Midway between Weir Crest and Tailwater Elevation)

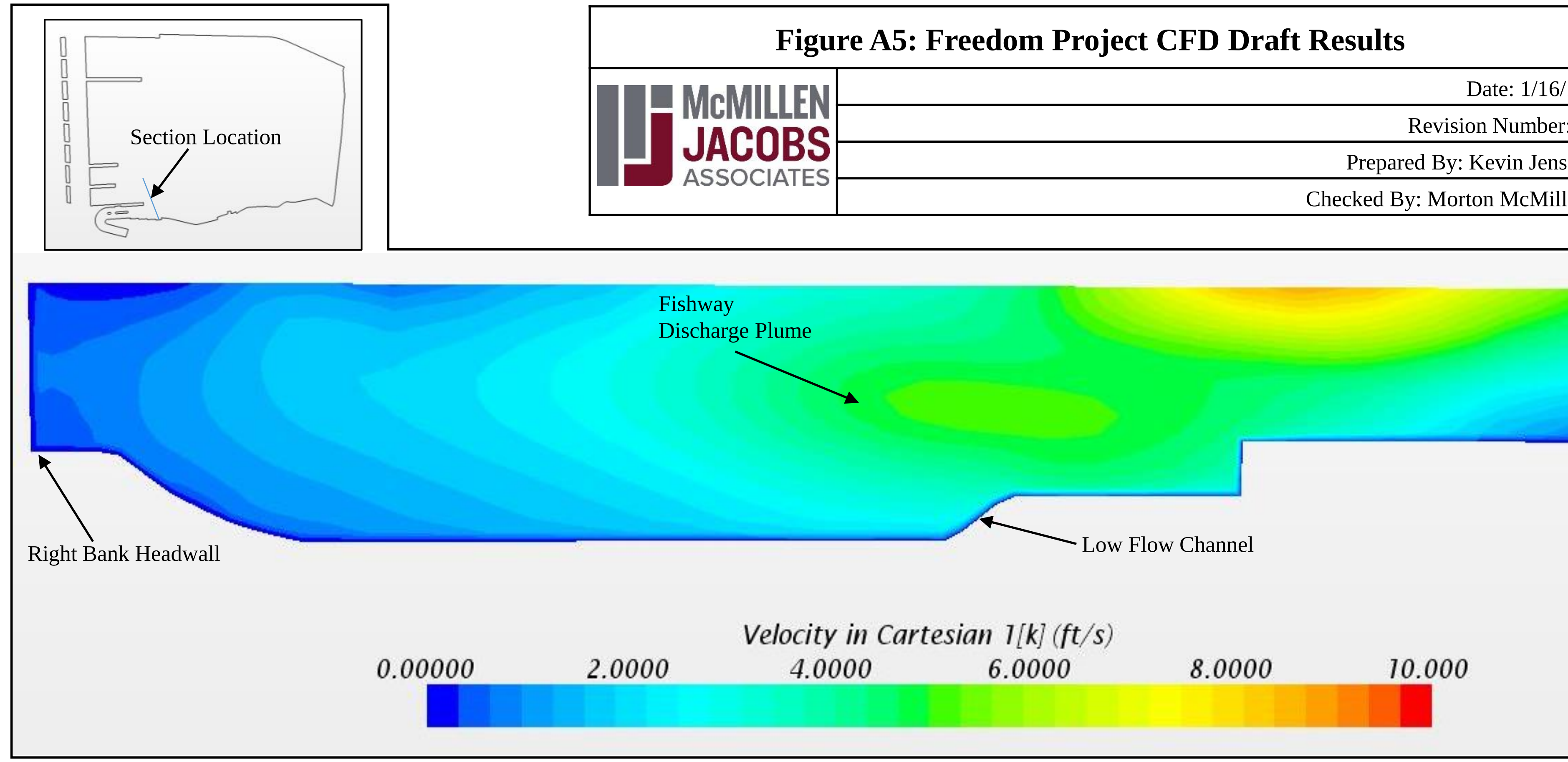


Figure A.5.3 Velocity Section Perpendicular to Fishway Discharge Plume

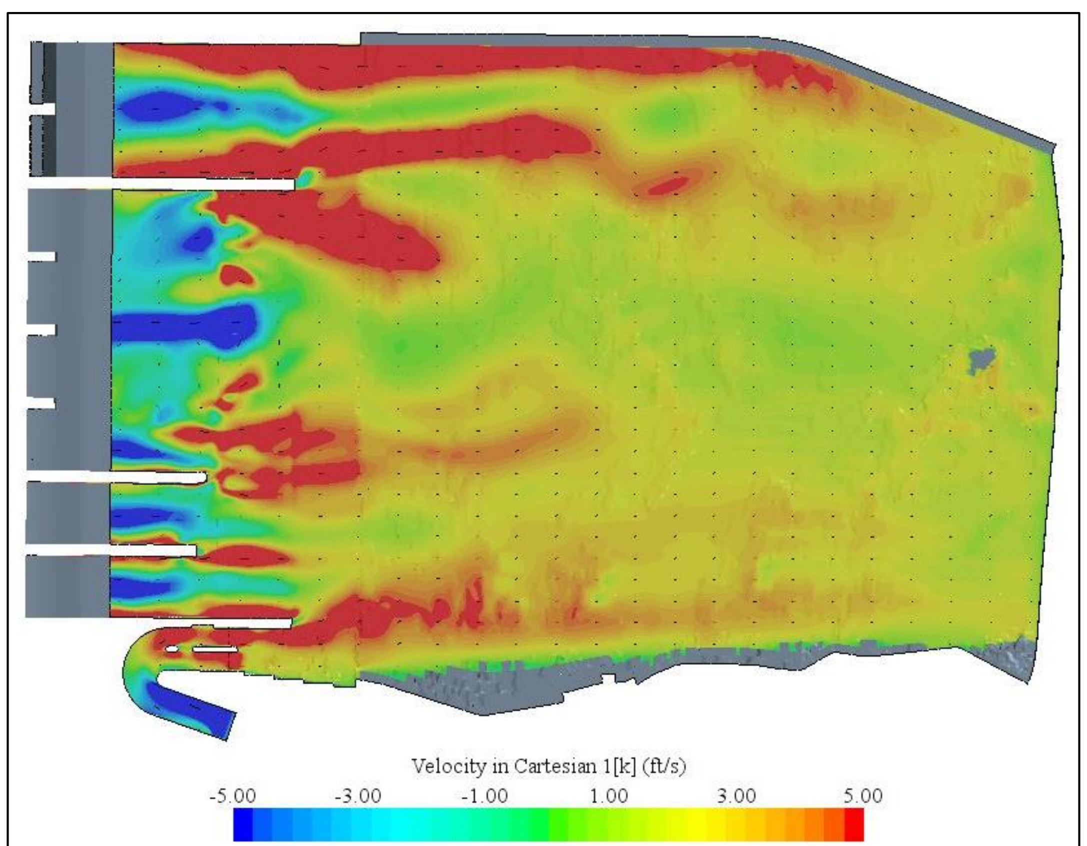


Figure A.5.2 Velocity Scalar and Vector, Plan View—Plane Section Elevation = 70.0 ft

Spillway Bay Boundaries	
Active Bays	1-8
Spillway Flow through Each Bay (kcfs)	1.6
Spill Bay Gate Height (ft)	1.1
TW Elevation (ft)	75.0
Fish Ladder Boundary	
Total Fish Ladder Flow (kcfs)	1.6
Mass Inflow (kips/s)	99.8
Active Fishway Weirs	N1, N2
Fishway Boundary Height (ft)	16.9
Weir Crest Elevation (ft)	66.5
Display Details	
Direction of Positive Velocity	Downstream
Time Step of Display (s)	300

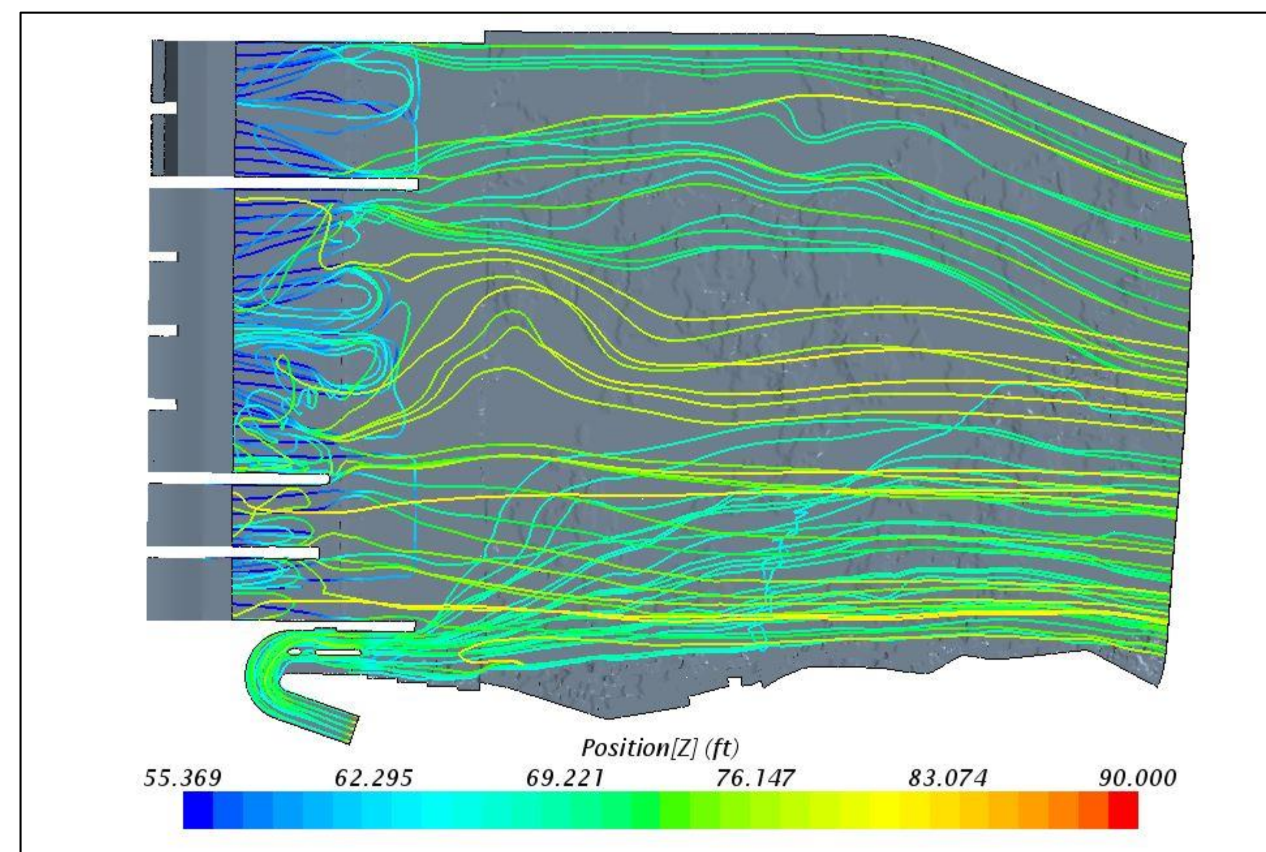


Figure A.5.4 Streamlines Color-Scaled by Elevation

Scenario 06 – Baseline, Low Flow, Bays 1-8 Active

Figure A6: Freedom Project CFD Draft Results

McMILLEN JACOBS ASSOCIATES	Date: 1/16/15
	Revision Number: 1
	Prepared By: Kevin Jensen
	Checked By: Morton McMillen

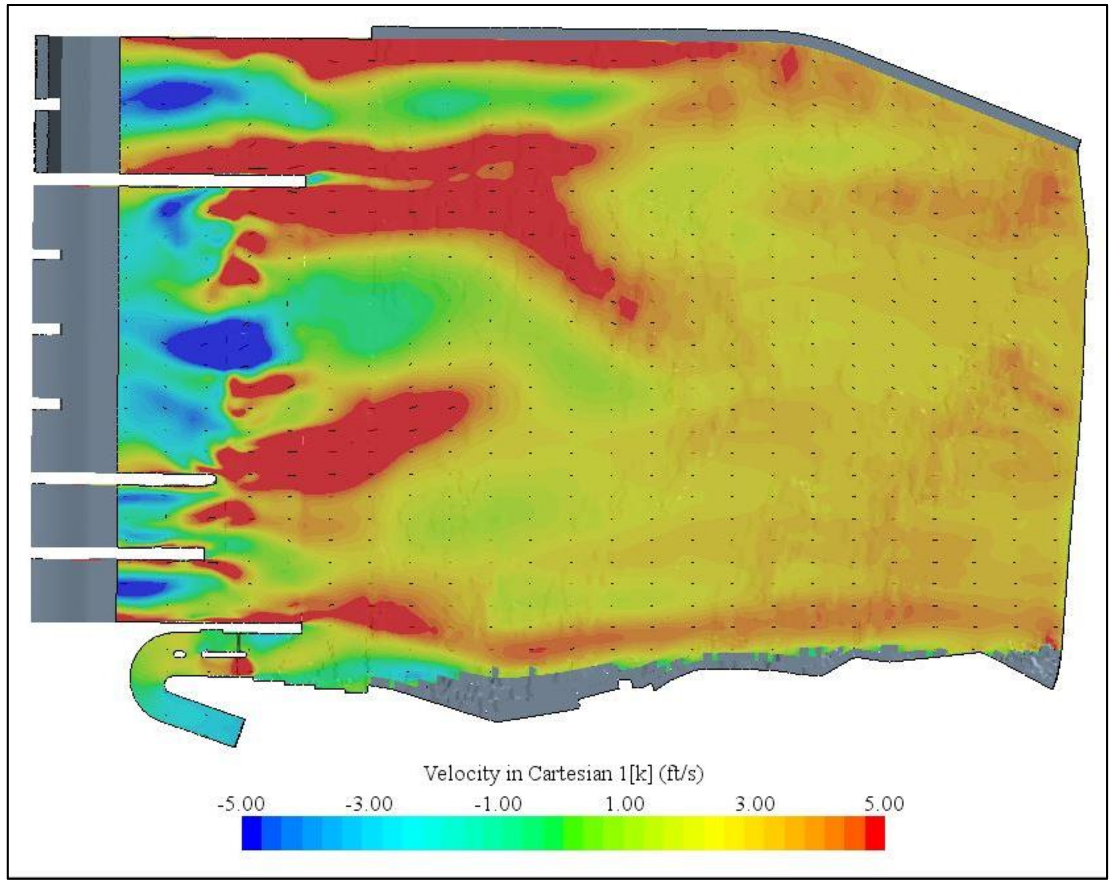


Figure A.6.1 Velocity Scalar and Vector, Plan View—Plane Section Elevation = 71.0 ft (Cut Midway between Weir Crest and Tailwater Elevation)

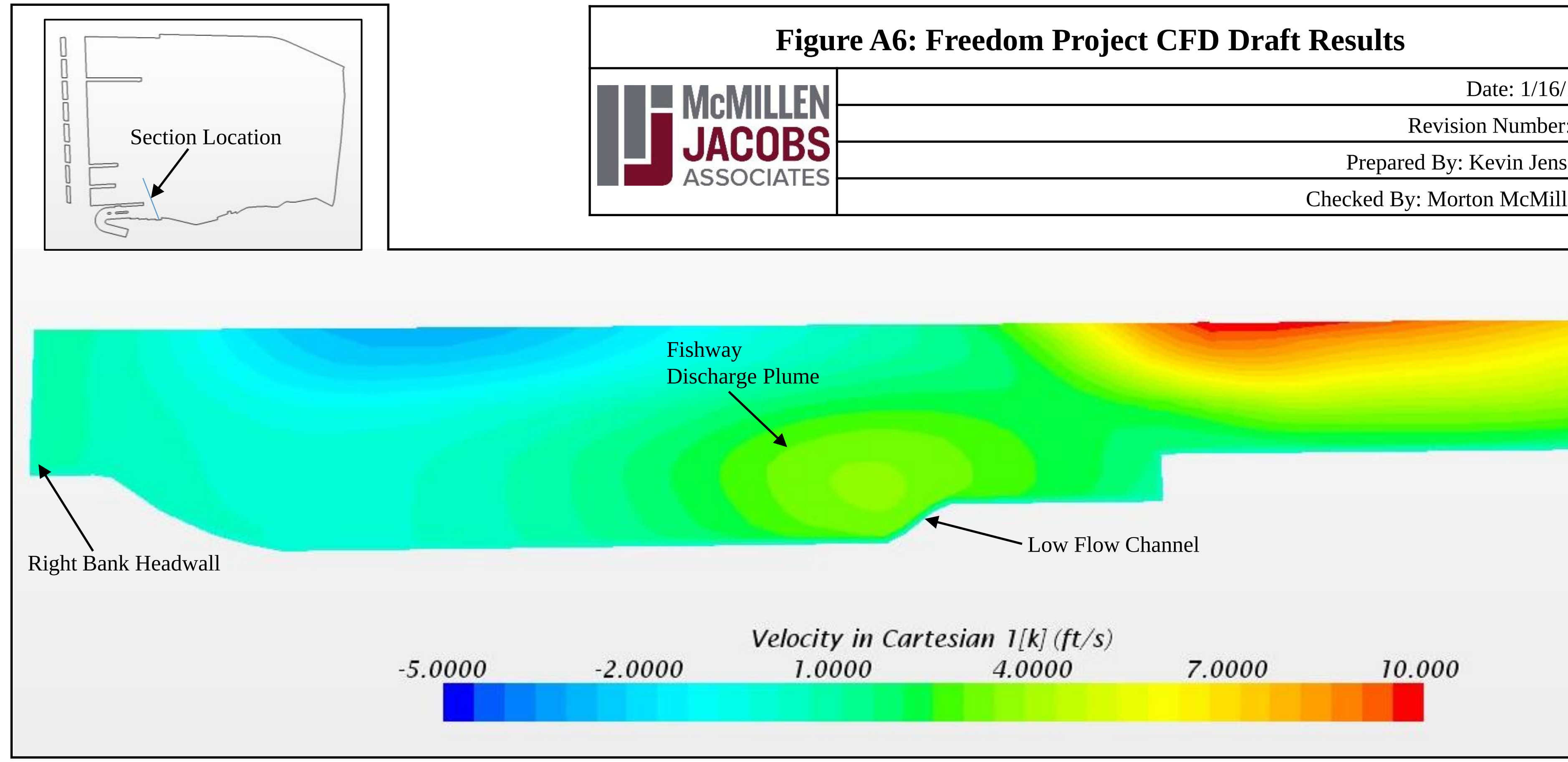


Figure A.6.3 Velocity Section Perpendicular to Fishway Discharge Plume

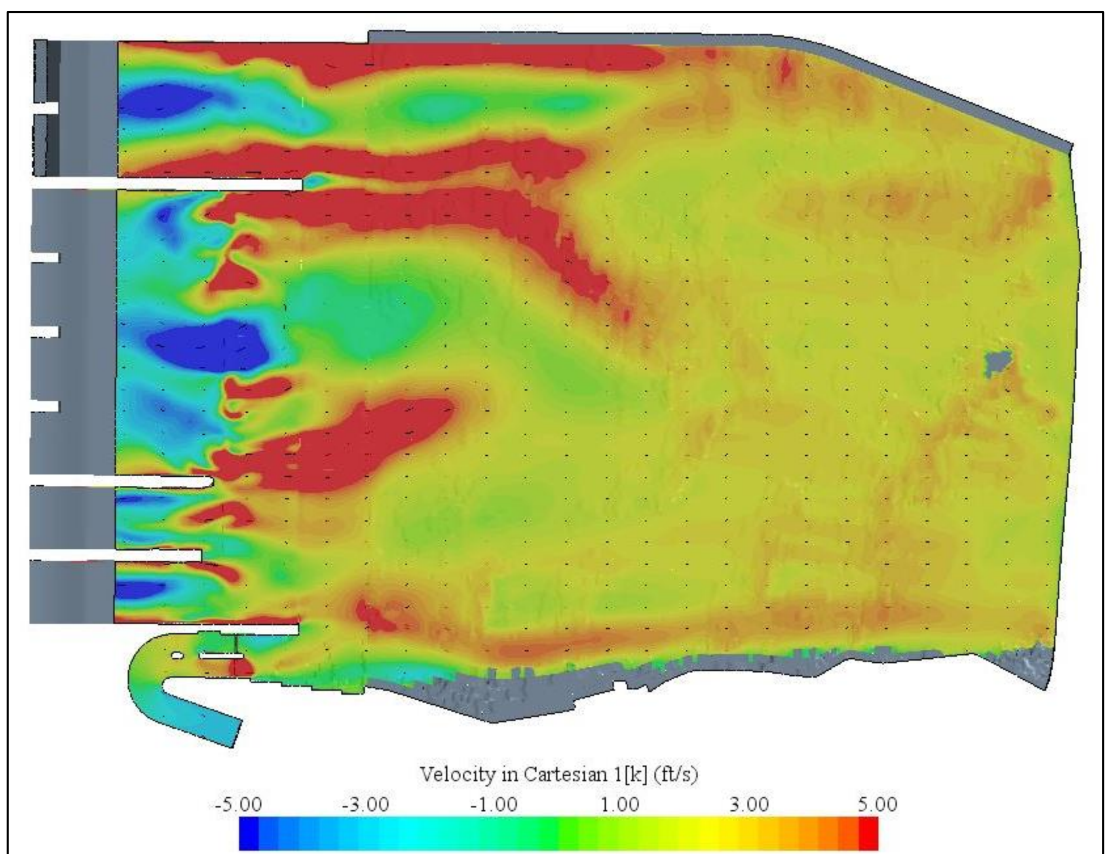


Figure A.6.2 Velocity Scalar and Vector, Plan View—Plane Section Elevation = 70.0 ft

Spillway Bay Boundaries	
Active Bays	1-8
Spillway Flow through Each Bay (kcfs)	1.6
Spill Bay Gate Height (ft)	1.1
TW Elevation (ft)	75.0
Fish Ladder Boundary	
Total Fish Ladder Flow (kcfs)	0.8
Mass Inflow (kips/s)	49.9
Active Fishway Weirs	N1
Fishway Boundary Height (ft)	10.0
Weir Crest Elevation (ft)	66.5
Display Details	
Direction of Positive Velocity	Downstream
Time Step of Display (s)	300

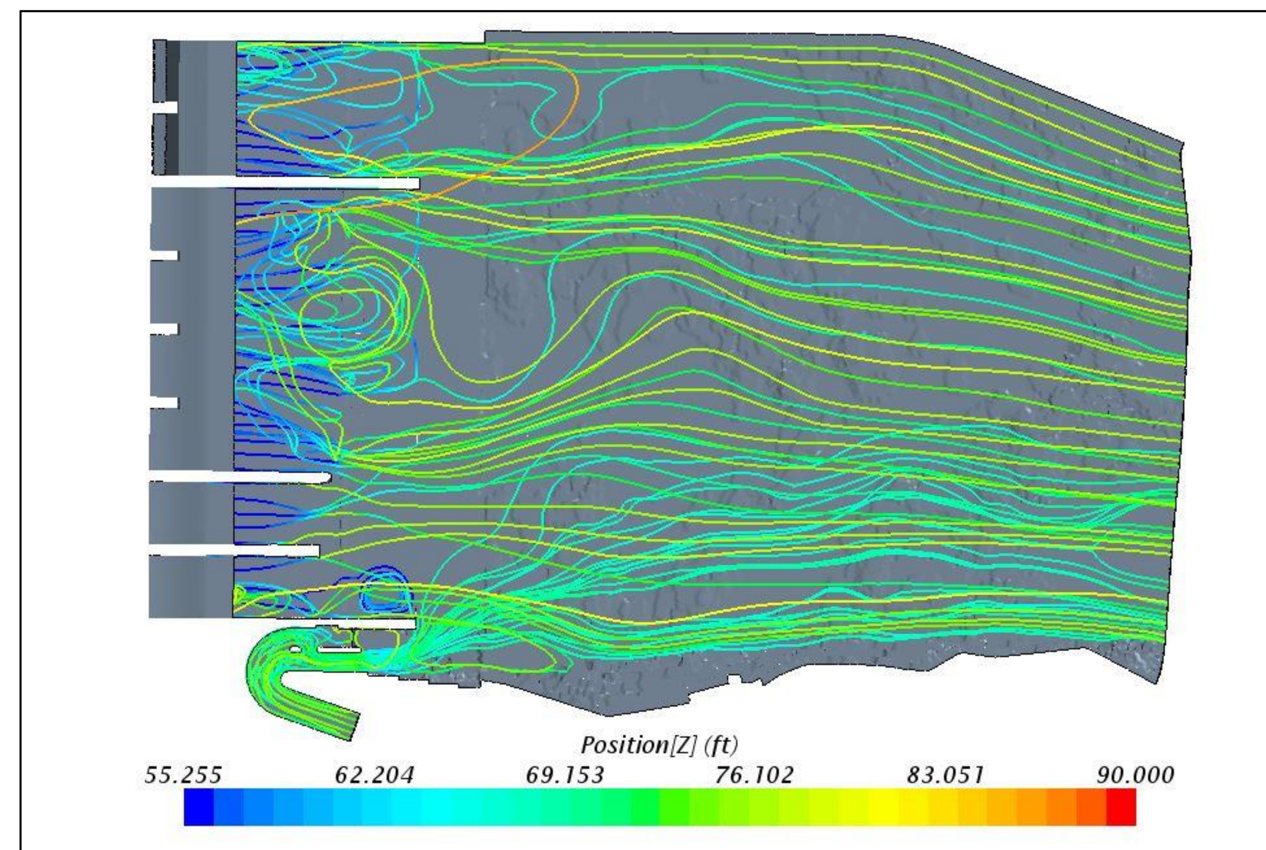


Figure A.6.4 Streamlines Color-Scaled by Elevation

Scenario 07 – Alternative, High Flow, Bays 3-8 Active

Figure A7: Freedom Project CFD Draft Results

Date: 1/16/15

Revision Number: 1

Prepared By: Kevin Jensen

Checked By: Morton McMillen

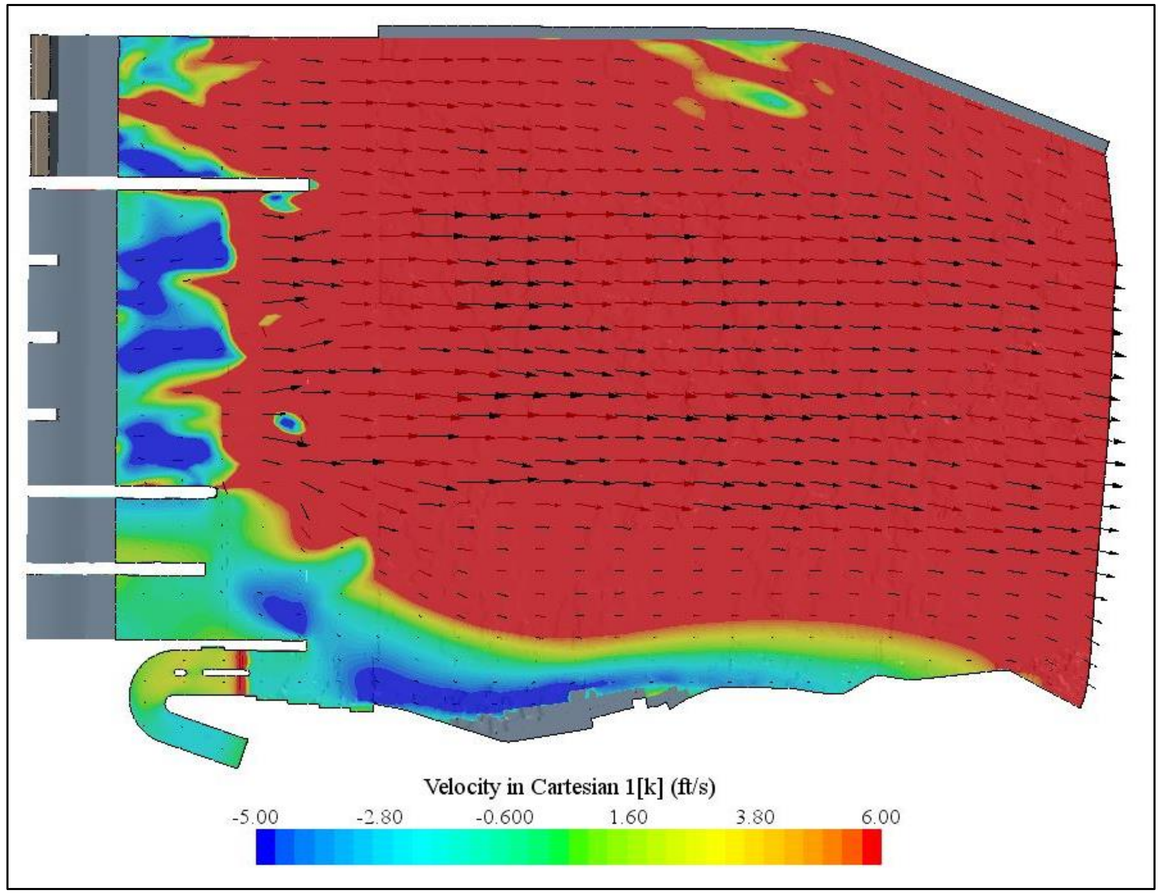


Figure A.7.1 Velocity Scalar and Vector, Plan View—Plane Section Elevation = 82.0 ft (Cut Midway between Weir Crest and Tailwater Elevation)

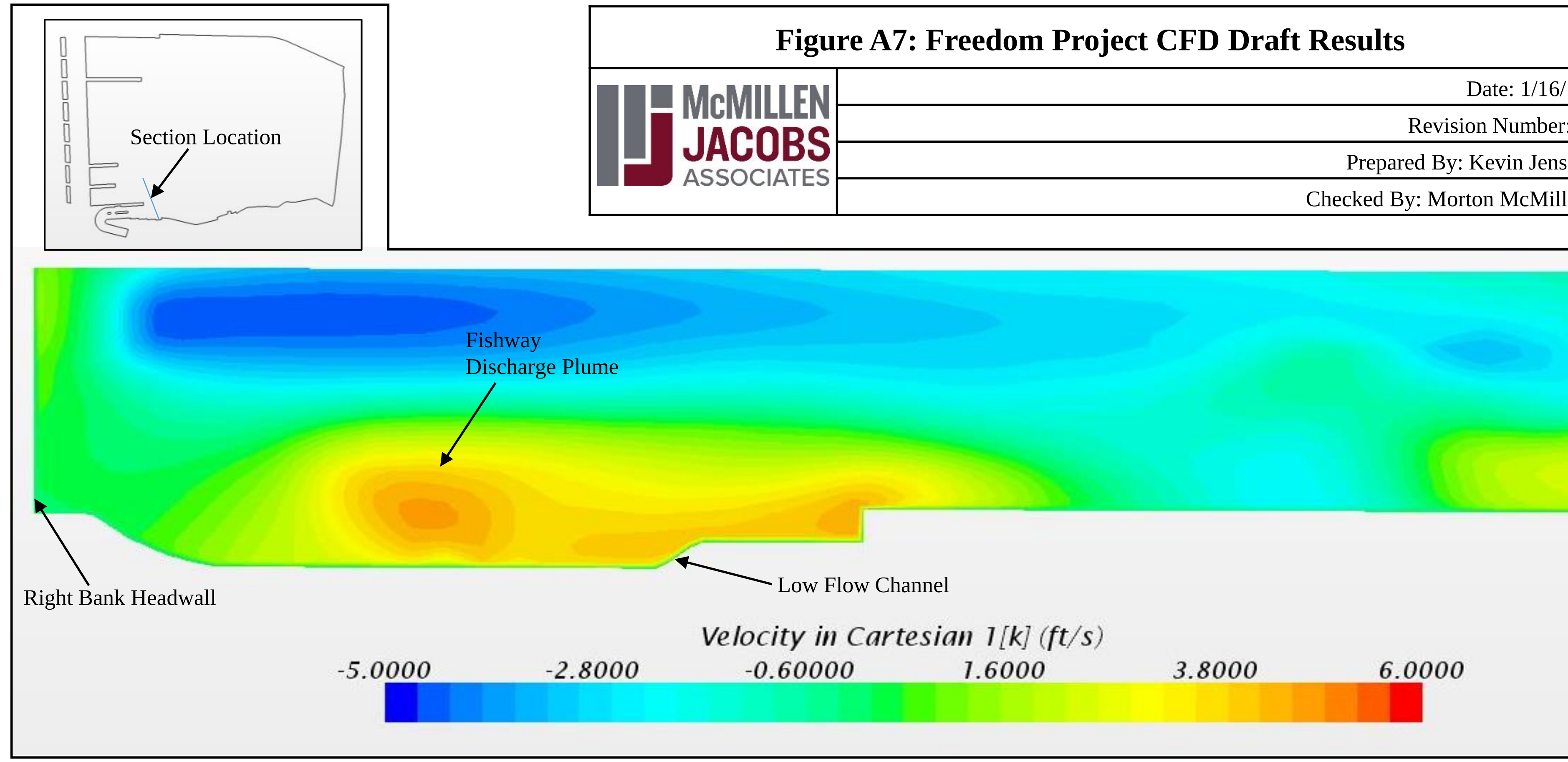


Figure A.7.3 Velocity Section Perpendicular to Fishway Discharge Plume

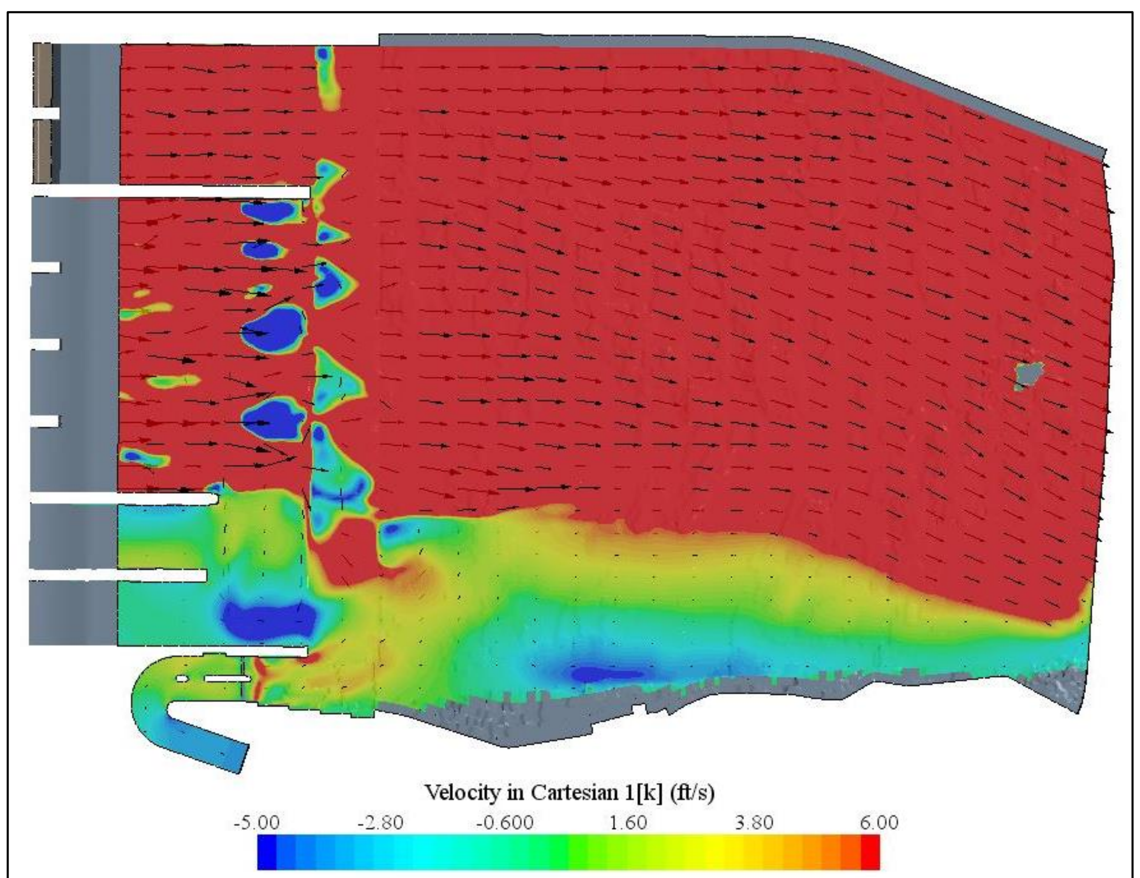


Figure A.7.2 Velocity Scalar and Vector, Plan View—Plane Section Elevation = 70.0 ft

Spillway Bay Boundaries	
Active Bays	3-8
Spillway Flow through Each Bay (kcfs)	29.2
Spill Bay Gate Height (ft)	20.1
TW Elevation (ft)	86.0
Fish Ladder Boundary	
Total Fish Ladder Flow (kcfs)	1.6
Mass Inflow (kips/s)	99.8
Active Fishway Weirs	N1, N2
Fishway Boundary Height (ft)	16.9
Weir Crest Elevation (ft)	77.5
Display Details	
Direction of Positive Velocity	Downstream
Time Step of Display (s)	300

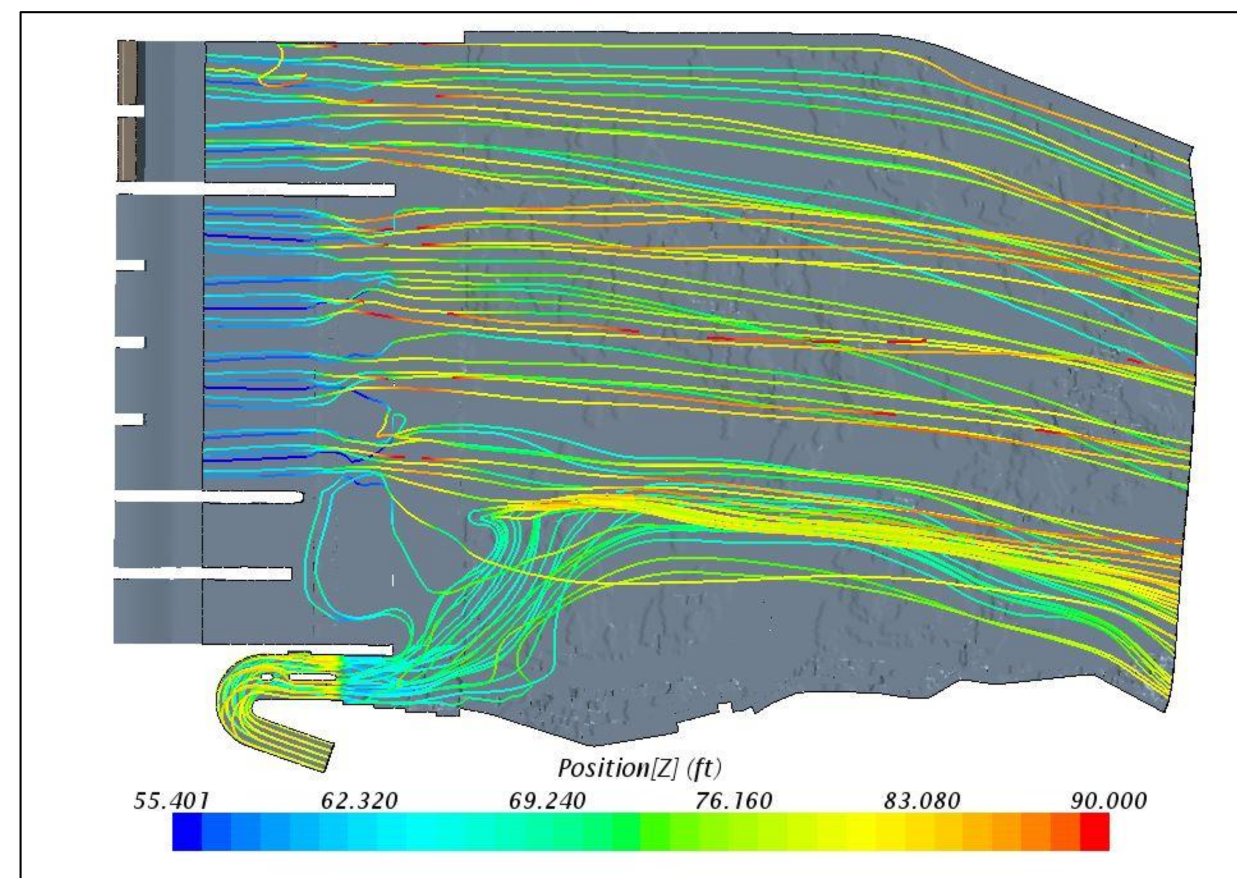


Figure A.7.4 Streamlines Color-Scaled by Elevation

Scenario 08 - Baseline High Flow, Bays 3-8 Active

Figure A8: Freedom Project CFD Draft Results	
McMILLEN JACOBS ASSOCIATES	Date: 1/16/15
	Revision Number: 1
	Prepared By: Kevin Jensen
	Checked By: Morton McMillen

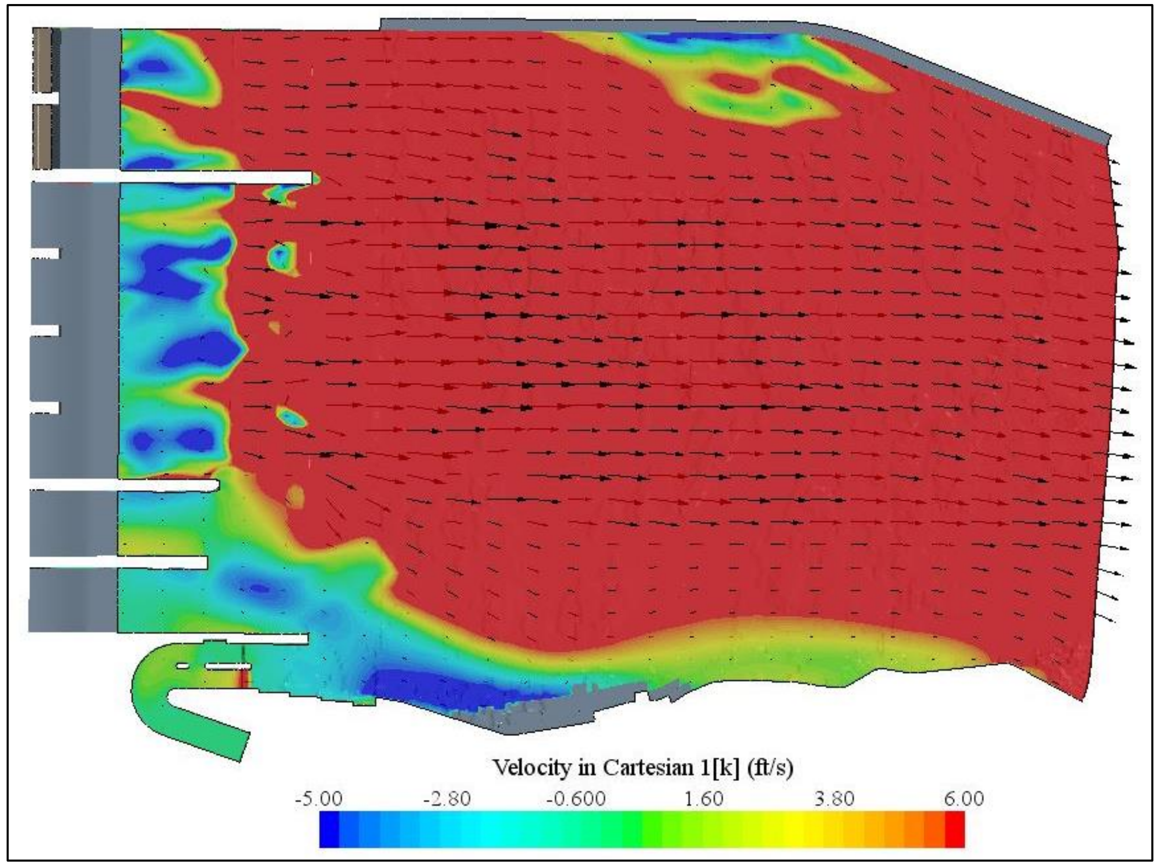
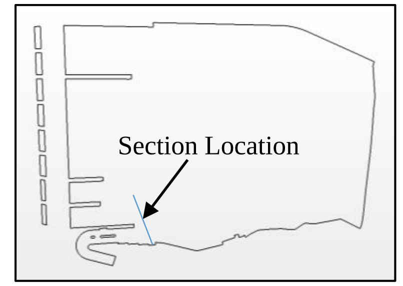


Figure A.8.1 Velocity Scalar and Vector, Plan View—Plane Section Elevation = 82.0 ft (Cut Midway between Weir Crest and Tailwater Elevation)



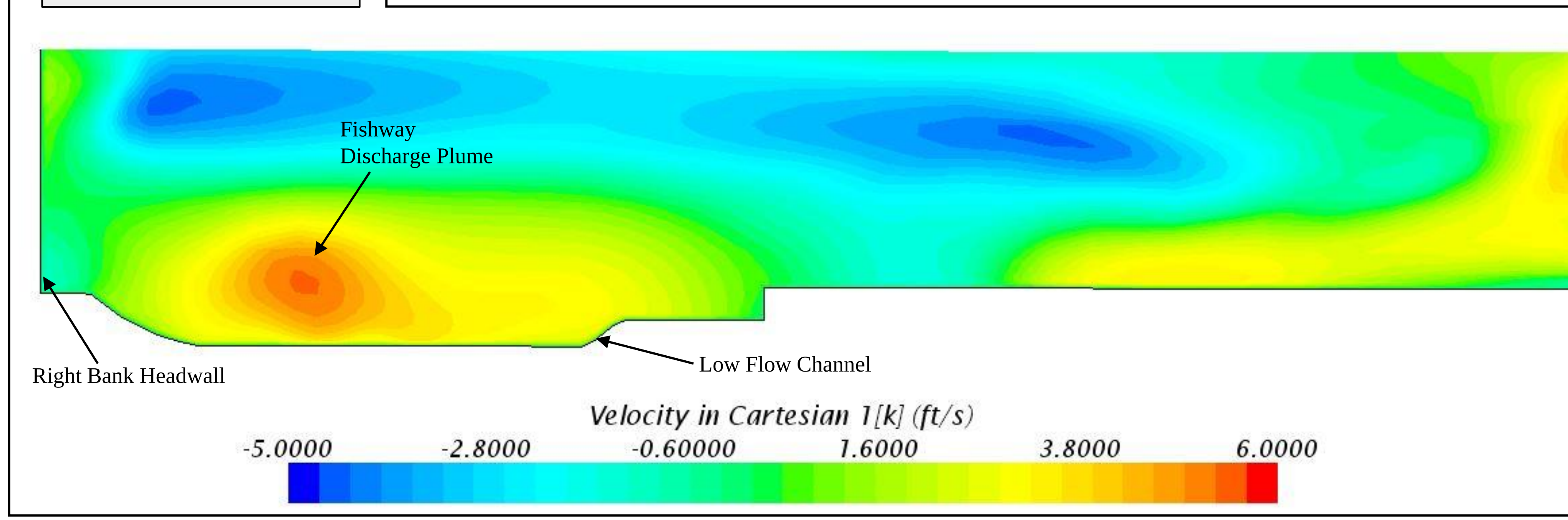


Figure A.8.3 Velocity Section Perpendicular to Fishway Discharge Plume

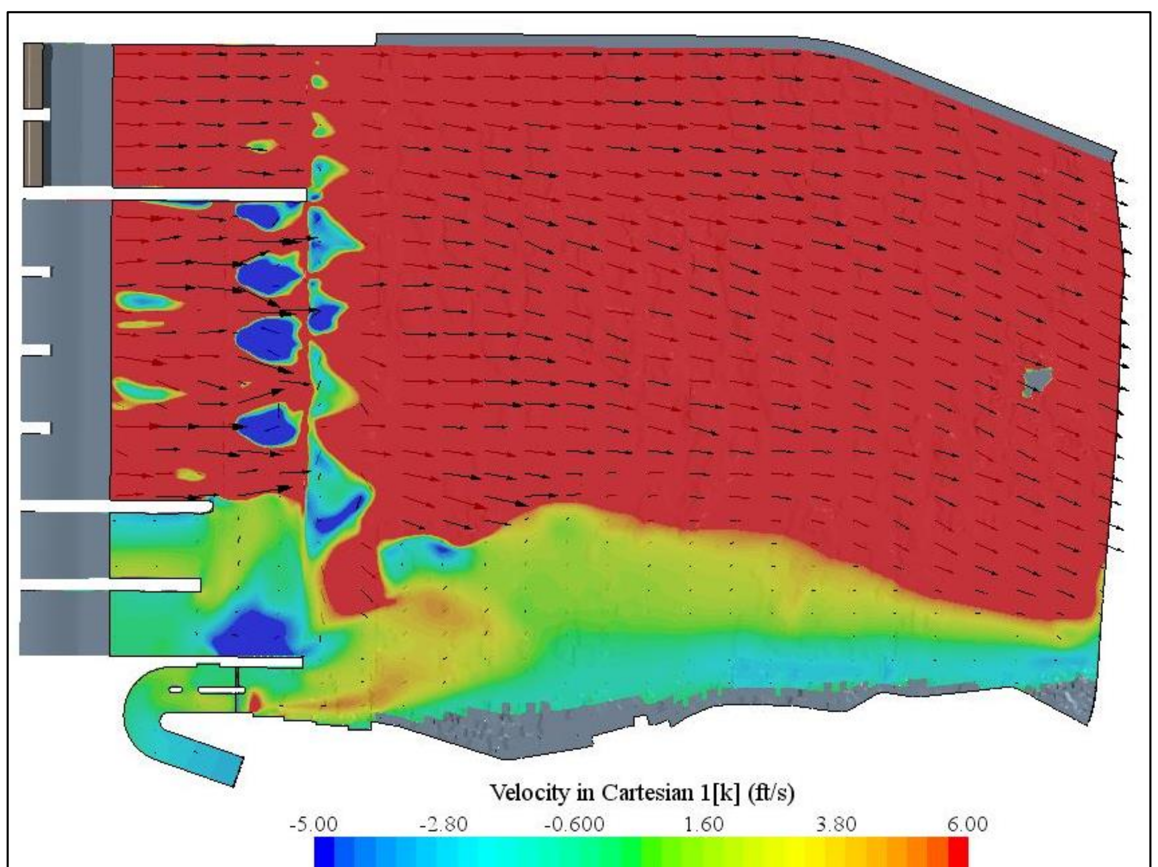


Figure A.8.2 Velocity Scalar and Vector, Plan View—Plane Section Elevation = 70.0 ft

Spillway Bay Boundaries	
Active Bays	3-8
Spillway Flow through Each Bay (kcfs)	29.2
Spill Bay Gate Height (ft)	20.1
TW Elevation (ft)	86.0
Fish Ladder Boundary	
Total Fish Ladder Flow (kcfs)	0.8
Mass Inflow (kips/s)	49.9
Active Fishway Weirs	N1
Fishway Boundary Height (ft)	10.0
Weir Crest Elevation (ft)	77.5
Display Details	
Direction of Positive Velocity	Downstream
Time Step of Display (s)	300

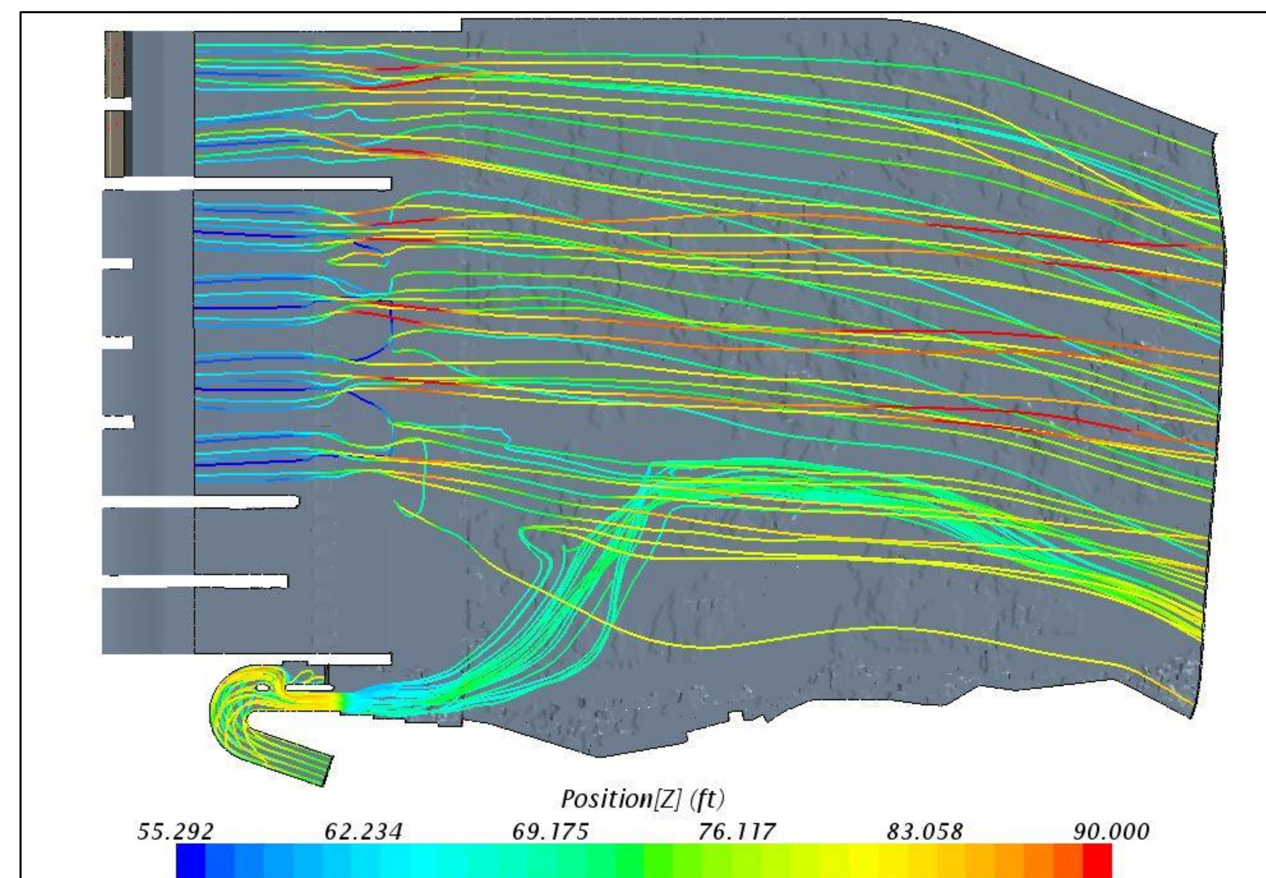


Figure A.8.4 Streamlines Color-Scaled by Elevation

Scenario 09 - Baseline No Spill, Average River Flow Aug. – Sept.

Figure A9: Freedom Project CFD Draft Results

McMILLEN JACOBS ASSOCIATES

Date: 2/6/15

Revision Number: 1

Prepared By: Kevin Jensen

Checked By: Morton McMillen

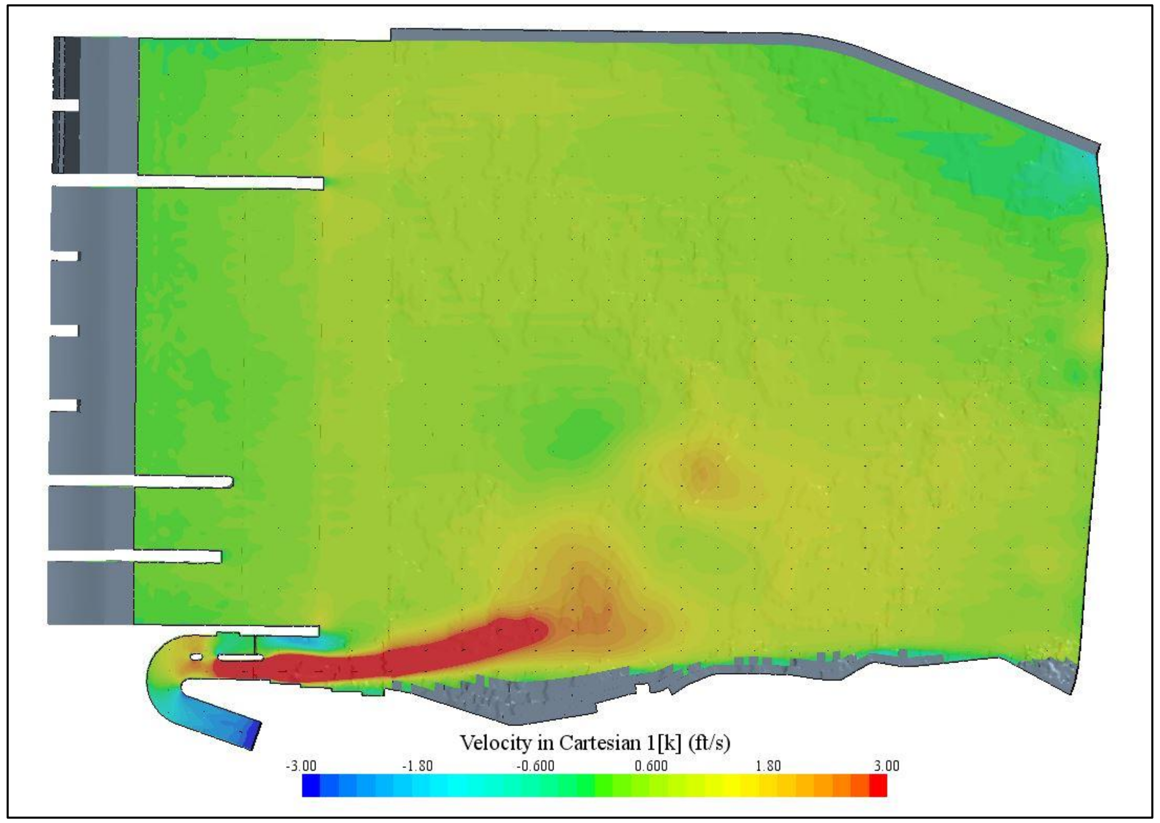
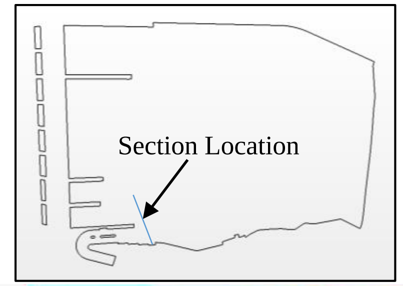


Figure A.9.1 Velocity Scalar and Vector, Plan View—Plane Section Elevation = 72.5 ft (Cut Midway between Weir Crest and Tailwater Elevation)



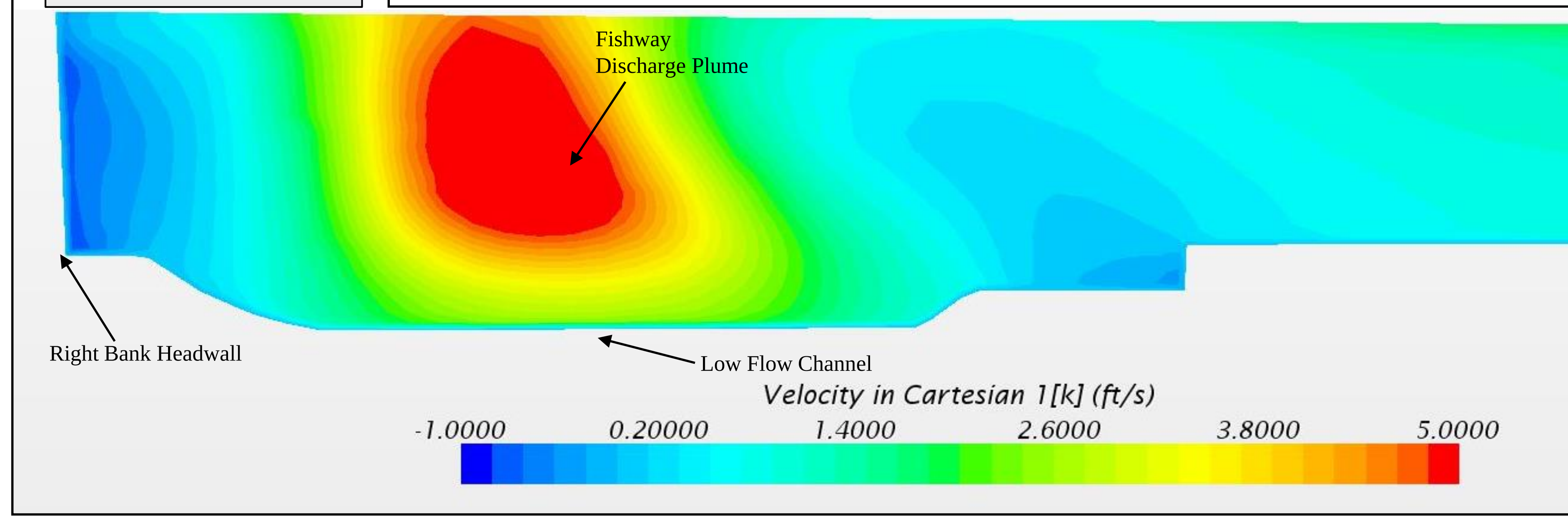


Figure A.9.3 Velocity Section Perpendicular to Fishway Discharge Plume

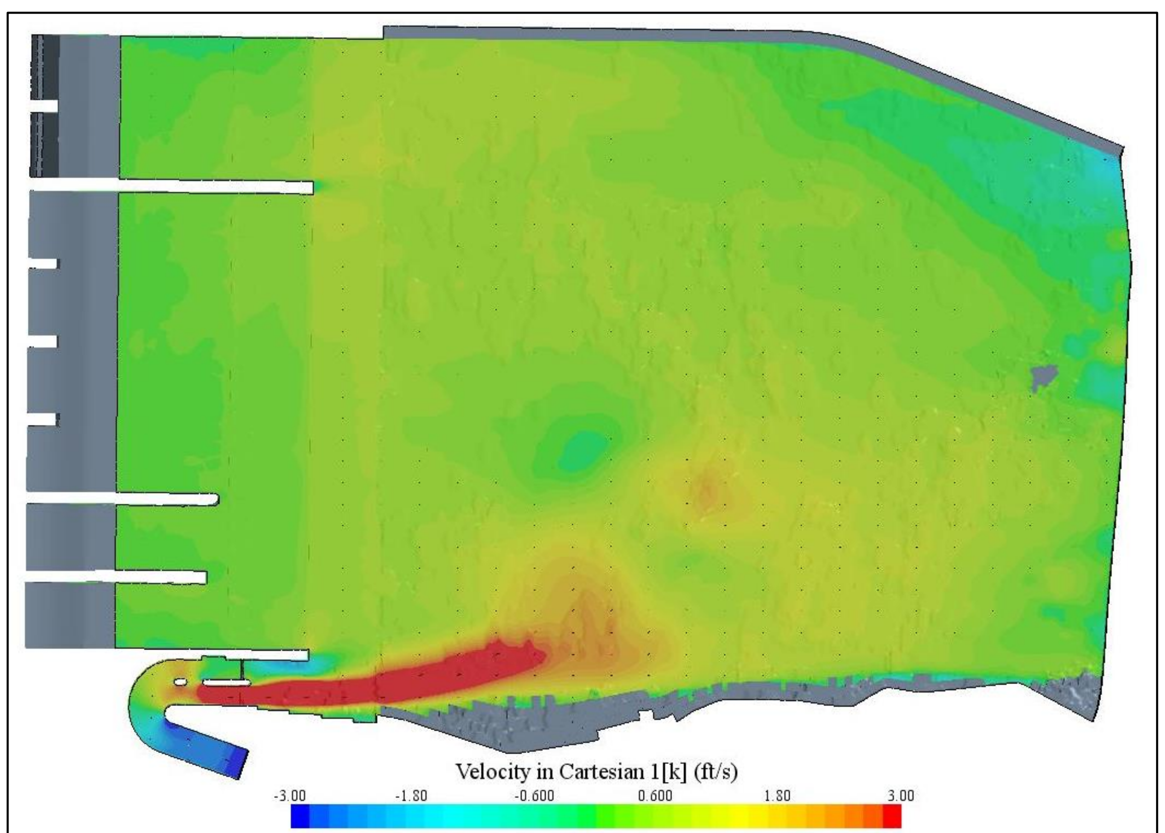


Figure A.9.2 Velocity Scalar and Vector, Plan View—Plane Section Elevation = 70.0 ft

Spillway Bay Boundaries	
Active Bays	None
Spillway Flow through Each Bay (kcfs)	0.0
Total River Flow (kcfs)	113.0
TW Elevation (ft)	76.5
Fish Ladder Boundary	
Total Fish Ladder Flow (kcfs)	0.8
Mass Inflow (kips/s)	49.9
Active Fishway Weirs	N1
Fishway Boundary Height (ft)	10.0
Weir Crest Elevation (ft)	68.0
Display Details	
Direction of Positive Velocity	Downstream
Time Step of Display (s)	430

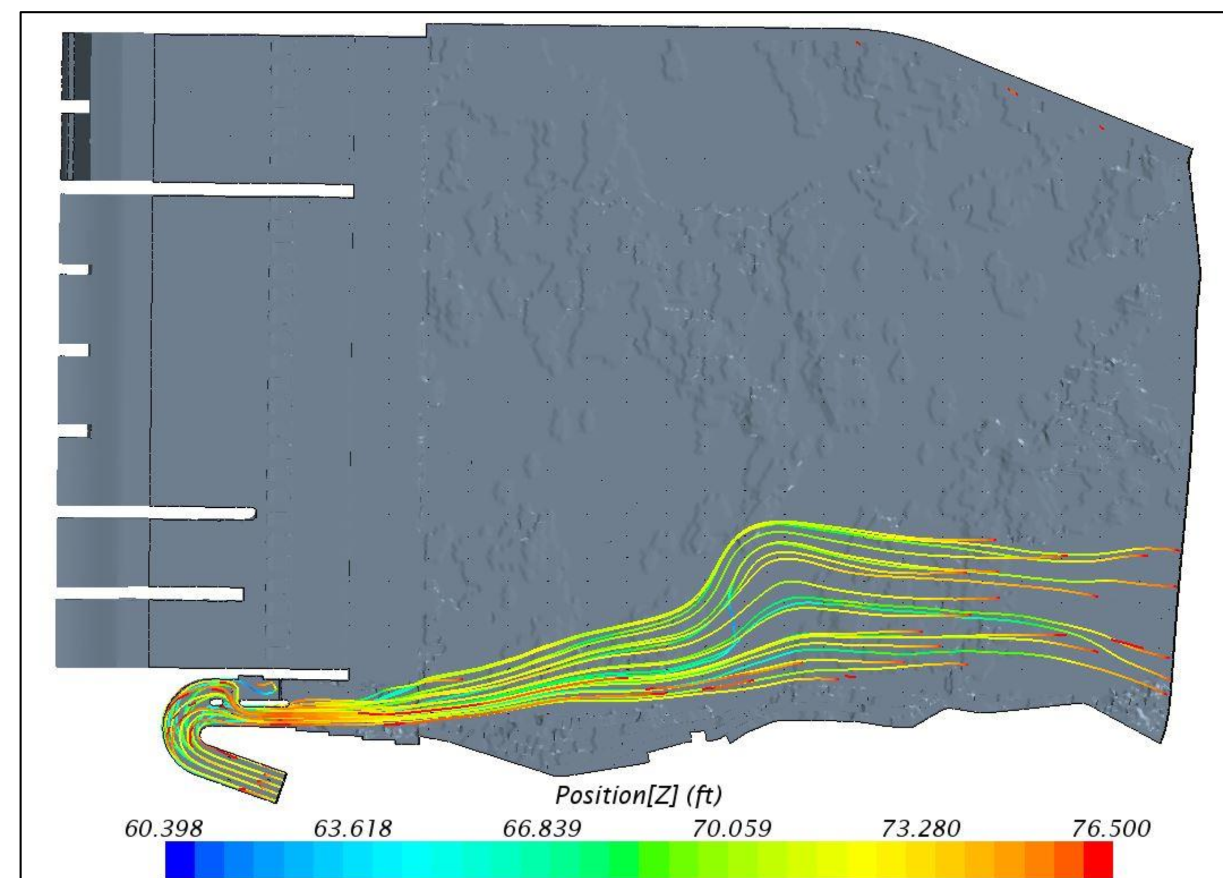


Figure A.9.4 Streamlines Color-Scaled by Elevation

Scenario 10 - Alternative No Spill, Average River Flow Aug. – Sept.

Figure A10: Freedom Project CFD Draft Results

McMILLEN JACOBS ASSOCIATES

Date: 2/6/15
Revision Number: 1
Prepared By: Kevin Jensen
Checked By: Morton McMillen

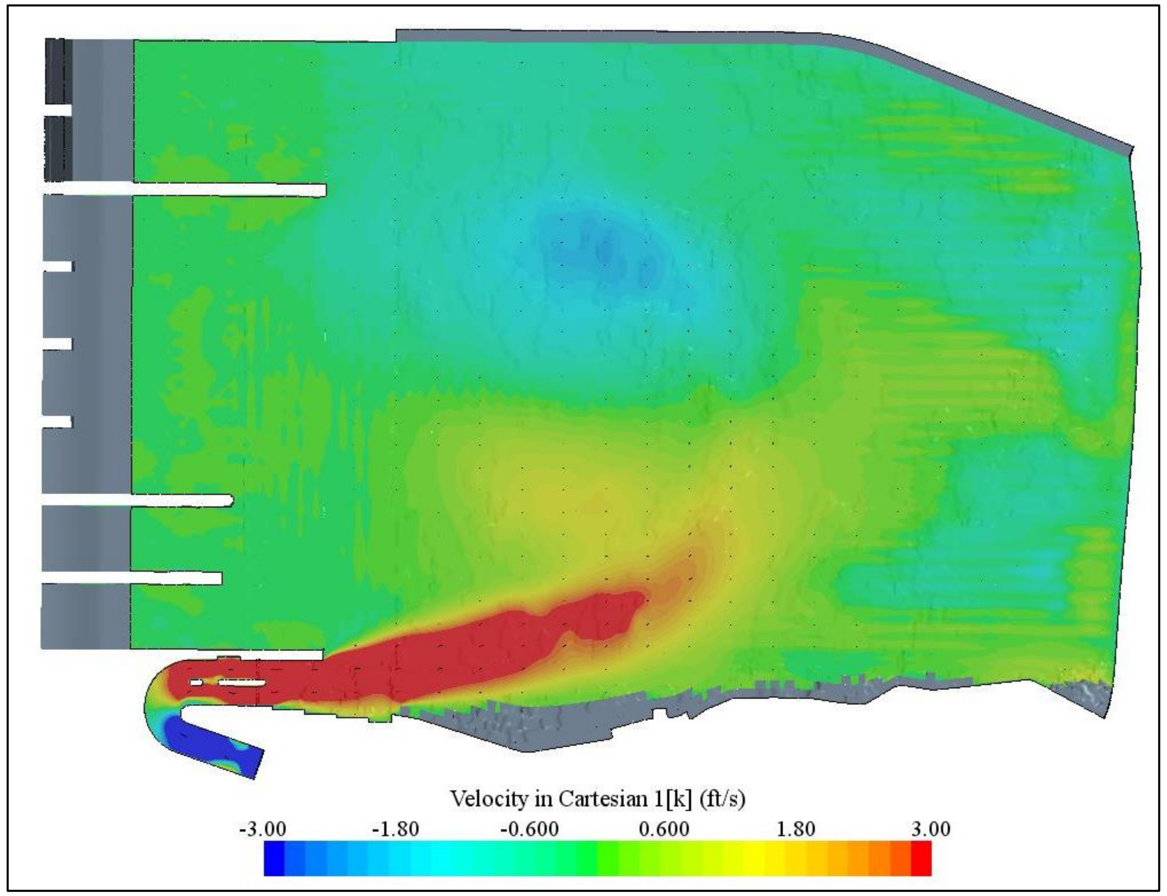


Figure A.10.1 Velocity Scalar and Vector, Plan View—Plane Section Elevation = 72.5 ft (Cut Midway between Weir Crest and Tailwater Elevation)

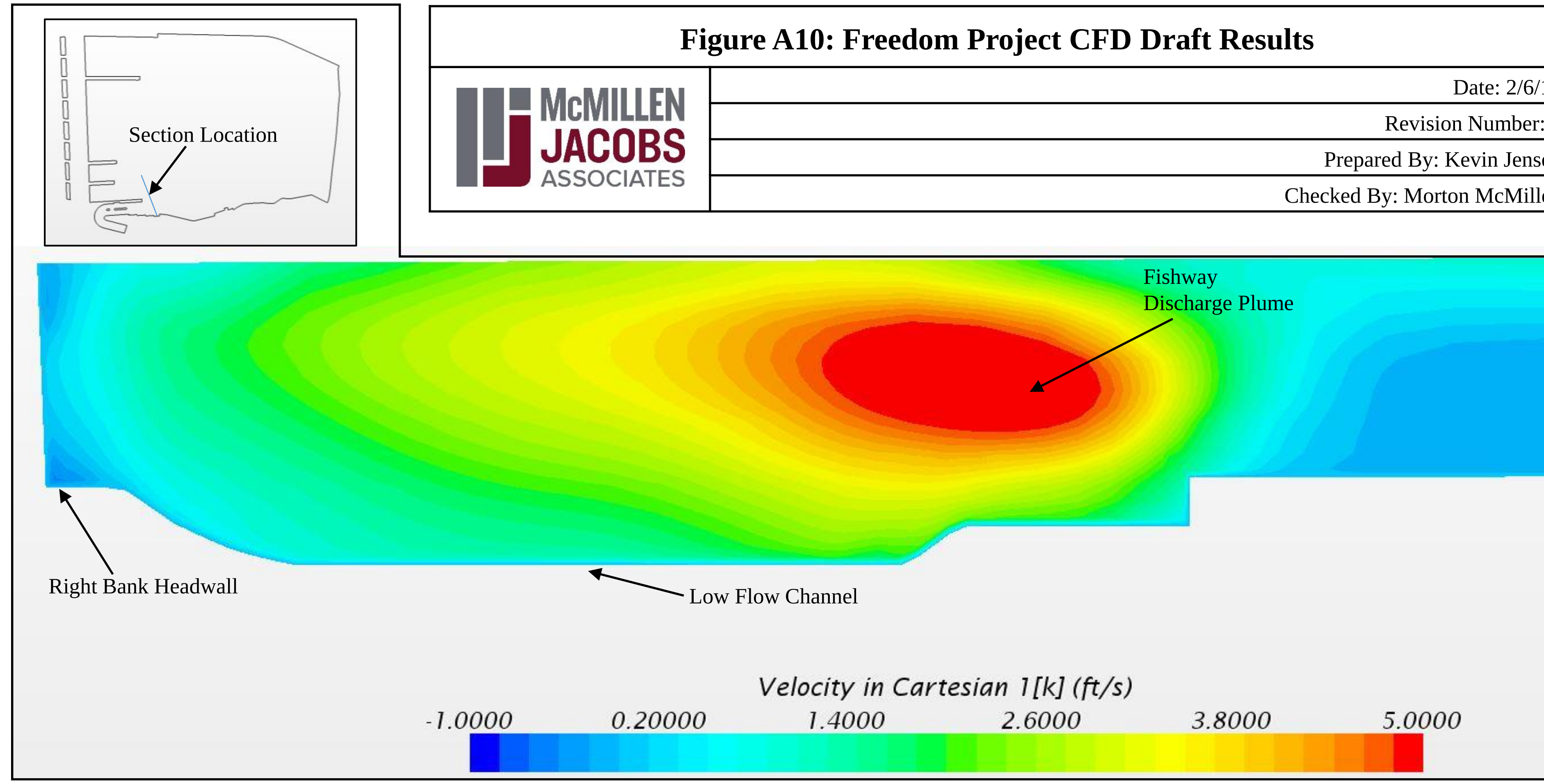


Figure A.10.3 Velocity Section Perpendicular to Fishway Discharge Plume

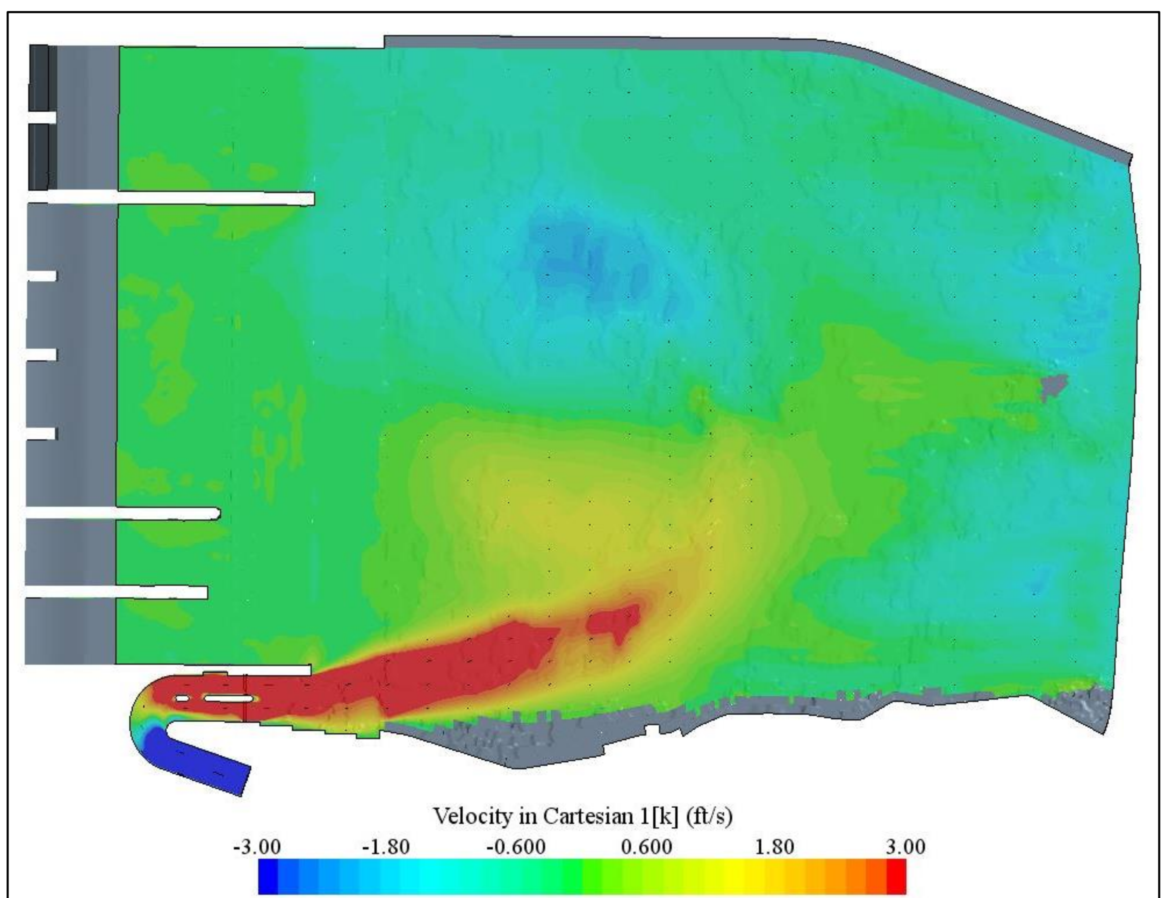


Figure A.10.2 Velocity Scalar and Vector, Plan View—Plane Section Elevation = 70.0 ft

Spillway Bay Boundaries	
Active Bays	None
Spillway Flow through Each Bay (kcfs)	0.0
Total River Flow (kcfs)	113.0
TW Elevation (ft)	76.5
Fish Ladder Boundary	
Total Fish Ladder Flow (kcfs)	1.6
Mass Inflow (kips/s)	99.8
Active Fishway Weirs	N1, N2
Fishway Boundary Height (ft)	16.9
Weir Crest Elevation (ft)	68.0
Display Details	
Direction of Positive Velocity	Downstream
Time Step of Display (s)	430

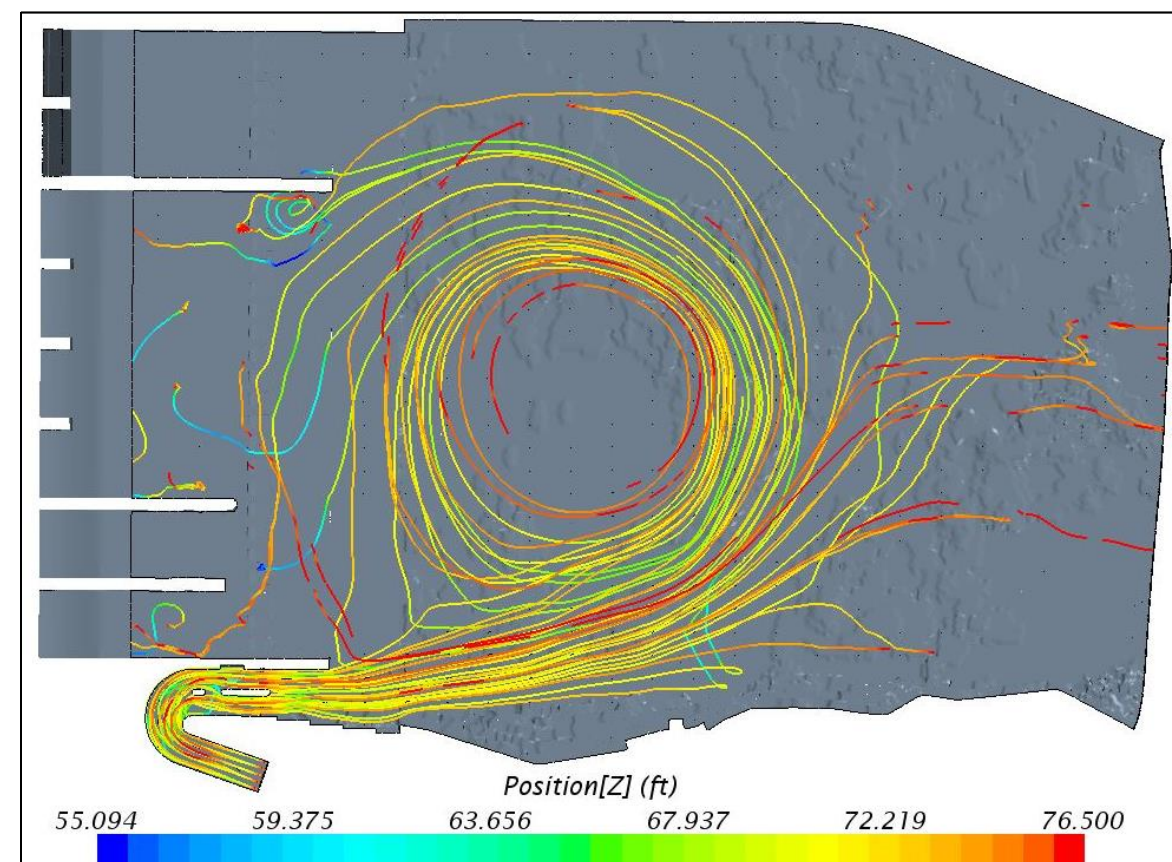


Figure A.10.4 Streamlines Color-Scaled by Elevation

Appendix B

Tainter Gate Rating Curve

Spill Bay Tainter Gate Rating Curve*

Opening	Discharge	Opening	Discharge	Opening	Discharge	Opening	Discharge
0.0	-	8.0	11,913	16.0	23,508	24.0	34,485
0.5	711	8.5	12,658	16.5	24,219	24.5	35,184
1.0	1,464	9.0	13,402	17.0	24,891	25.0	35,778
1.5	2,215	9.5	14,145	17.5	25,631	25.5	36,469
2.0	2,969	10.0	14,864	18.0	26,370	26.0	37,156
2.5	3,720	10.5	15,580	18.5	27,029	26.5	37,735
3.0	4,475	11.0	16,316	19.0	27,722	27.0	38,468
3.5	5,223	11.5	17,050	19.5	28,412	27.5	39,036
4.0	5,970	12.0	17,782	20.0	29,056	28.0	39,707
4.5	6,725	12.5	18,484	20.5	29,780	28.5	40,263
5.0	7,469	13.0	19,211	21.0	30,501	29.0	40,926
5.5	8,210	13.5	19,935	21.5	31,131	29.5	41,586
6.0	8,962	14.0	20,633	22.0	31,801	30.0	42,124
6.5	9,700	14.5	21,357	22.5	32,420	30.5	42,834
7.0	10,450	15.0	22,077	23.0	33,175	31.0	43,361
7.5	11183	15.5	22,761	23.5	33,880	Full Open	46,199

* All openings in feet and discharges in cubic feet per second.

Appendix C

STAR-CCM+ Field Functions

Volume Fraction Initialization

```
($${Centroid}[2] < <75 ft> ||
($${Centroid}(@CoordinateSystem("csys1"))[0] < <475 ft> &&
$${Centroid}(@CoordinateSystem("csys1"))[1] < <12.7 ft>))?1:0
```

Velocity Initialization

```
[($${Centroid}(@CoordinateSystem("csys2"))[1] < 0) ? 0 : 10, 0, 0]
```

Hydrostatic Pressure Distribution

```
($${Centroid}[2] <= $refalt)?998.97*9.81*($refalt-$${Centroid}[2]):1.18*9.81*($refalt-
$${Centroid}[2])
```

Reference Altitude

22.8

Outlet Volume Fraction

```
($${Centroid}[2] < <75 ft>)?1:0
```