RELICENSING STUDY 3.3.8

COMPUTATIONAL FLUID DYNAMICS MODELING IN THE VICINITY OF THE FISHWAY ENTRANCES AND POWERHOUSE FOREBAYS

Northfield Mountain Pumped Storage Project (No. 2485)
and Turners Falls Hydroelectric Project (No. 1889)

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PREFACE

This study required the development of Computational Fluid Dynamic (CFD) models of the Station No. 1 forebay and powerhouse entrance, Cabot forebay and powerhouse entrance, Spillway Ladder entrance and Cabot Ladder entrance. The study is one of several relicensing studies intended to obtain information necessary to assess the hydraulic impact of Project operations on migratory fish relative to upstream and downstream passage. Four other relicensing studies were conducted in 2015 that also will contribute to the evaluation of Project operations on fish migration including a) Study 3.3.2 *Evaluate Upstream and Downstream Passage of Adult American Shad,* b) Study 3.3.3 *Evaluate Downstream Passage of Juvenile American Shad,* c) Study 3.3.5 *Evaluate Downstream Passage of American Eel,* and d) Study 3.3.15 *Assessment of Adult Sea Lamprey Spawning within the Turners Falls Project and Northfield Mountain Project Area*. The field work for these studies was conducted in 2015; however, the analysis and results will not be available until later in 2016. These studies include telemetry data to determine how tagged fish may respond to different operating conditions. These telemetry studies, coupled with the CFD hydraulic evaluation herein, will be used to determine the impact of Project operations on migratory fish movement. The CFD modeling conducted herein is based solely on hydraulic modeling; it does not represent how fish will react to *in-situ* conditions. Thus, to fully understand whether and how Project operations impact migratory fish movement, the results of the CFD modeling must be evaluated in conjunction with the aforementioned study results. Accordingly, one of the objectives of this study—to assess whether fish are directed to the surface bypass weir near Cabot Station—cannot be addressed in this report. Instead, the assessment will be included in the aforementioned studies.

EXECUTIVE SUMMARY

FirstLight Hydro Generating Company is the current licensee of the Northfield Mountain Pumped Storage Project (Northfield Mountain Project, FERC No. 2485) and the Turners Falls Hydroelectric Project (Turners Falls Project, FERC No. 1889). FirstLight has initiated with the Federal Energy Regulatory Commission (FERC, the Commission) the process of relicensing the Northfield Mountain and Turners Falls Projects using FERC's Integrated Licensing Process (ILP). The current licenses for the Northfield Mountain and Turners Falls Projects were issued on May 14, 1968 and May 5, 1980, respectively, with both set to expire on April 30, 2018. This report documents the results of Study No. 3.3.8 *Computational Fluid Dynamics Modeling in the Vicinity of the Fishway Entrances and Powerhouse Forebays*.

The methodology and scope for this study as outlined in the Revised Study Plan (RSP) was approved with modification by the Commission in its September 13, 2013 Study Plan Determination Letter (FERC, 2013). FERC made one modification to the RSP, directing that FirstLight provide, upon request, any study data and relevant project drawings to the stakeholders requesting it. FERC also noted that some project drawings may be considered Critical Energy Infrastructure Information (CEII) and, therefore, may not be provided.

As noted in the RSP, the specific study objectives of the Computational Fluid Dynamics (CFD) Study were as follows:

1. Characterize the hydraulics of current (existing) conditions and any changes to:
    a. Fishway attraction flows;
    b. Turbine operations; and
    c. log sluice gates
2. Develop a series of velocity maps at select discharges showing approach velocities and flow fields that may create a response in fish;
3. Characterize the flow field in front of the Cabot Station and Station No. 1 intakes using velocity maps and cross-sectional plots;
4. Assess whether fish are directed to the surface bypass weir near Cabot Station;

5. Characterize the near-rack "sweeping" velocities at the Cabot Station and Station No. 1 intakes

This study involved the collection of considerable field data to develop CFD models of the study areas described in Section 1.4, including the following:

- The collection of bathymetric data in the four study areas to define the shape of the below-water channel/canal;
- Obtaining upland and riverbank topography based on field survey and Light Detection and Ranging (LiDAR) data;
- The collection of water column velocities in the Cabot Forebay, Station No. 1 Forebay, and in the vicinity of the Cabot and Spillway Fishway entrances for use in validating the models;
- The collection of water surface elevations.

The CFD model simulations for this study were conducted using the Flow-3D CFD code developed by Flow Science, Inc. FLOW-3D is a general-purpose CFD software that employs numerical techniques to solve the equations of motion for fluids to obtain transient, three-dimensional (3D) solutions to multi-scale, multi-physics flow problems (Flow Science, 2012). Flow-3D solves the Reynolds Averaged Navier-Stokes (RANS) equations.

Each model built had a verification run as well as several RSP-defined production runs. The verification models were run for each of the CFD models in the study for the purpose of comparing CFD model results to field-collected 3D velocity data. The model verification runs were conducted under the same conditions as the field data collection. After completing and analyzing the verification runs, production runs were conducted to meet the model objectives as defined in the RSP. The CFD models were run until a nearly steady state condition was reached, which was determined by tracking model output variables (velocity, pressure, fluid fraction, etc.) over time. The model variables tend to oscillate as the model stabilizes, with the magnitude of the oscillations diminishing over time until they are small enough that the model has effectively reached a steady state.

Station No. 1 Forebay

In addition to the verification model run, three (3) production runs were executed for the Station No. 1 Forebay model. These production model runs (scenarios) are summarized in the following table.

Scenario Number	Model Run	Station No. 1 Flow (cfs)	Canal Pass-Through Flow (cfs)	Total Power Canal Flow (cfs)
1-1	1	1,433 (current min flow)	200	1,633
1-2	1	2,210 (Station No. 1 capacity)	200	2,410
1-3	1	2,210	13,928 (Cabot capacity of 13,728 cfs plus 200 cfs for log sluice)	16,138

The production model runs show that under both Scenario 1-1 and 1-2 the highest velocities are predominately in front of the intake racks and on the northern side of the forebay entrance from the power canal. Under these scenarios most of the water entering the power canal enters the Station No. 1 Forebay and passes through Station No. 1. Under Scenario 1-3, the predominant flow pattern is created by flow passing through the power canal and on to Cabot Station. As a result of the higher velocities in the power canal under this scenario, the flows (high velocities) tend to concentrate on the southern side of the forebay entrance and cause significant eddies just inside the forebay. The velocities immediately in front of the intake racks are very similar between Scenario 1-2 and 1-3 as they both have the same flow going through Station No. 1, so while the flow patterns in the power canal and near the forebay entrance are very different the flow fields in front of the racks are not.

Cabot Forebay

In addition to the verification model run, three (3) production runs were executed for the Cabot Station Forebay model. These production model runs (scenarios) are summarized in the following table.

Scenario Number	Model Run	Cabot Station Flow (cfs)	Log Sluice Flow (cfs)	Total Power Canal Flow (cfs)
3-1	3	1,700	200	1,900
3-2	3	7,500	200	7,700
3-3	3	13,728 (Cabot capacity)	200	13,928

The production model runs (scenarios) for the Cabot Station Forebay all exhibited similar flow patterns in front of the intake racks with the highest velocities in front of the units that are generating and flows generally flowing into the racks. Under all scenarios, the velocities in the power canal and forebay tend to be higher near the inside of the bend (north and west side) than near the outside of the bend (south and east side). Because log sluice flows are relatively low compared to the generation flows, the log sluice flows tend to have minimal impact of the flow fields in front of the intake racks.

Cabot Fishway

In addition to the verification model run, five (5) production runs were executed for the Cabot Fishway Entrance model. These production runs (scenarios) are summarized in the following table:

Scenario Number	Cabot Station Flow (cfs)	Bypass Reach Flow (cfs)	Cabot Fishway Flow (cfs)	Total Flow (cfs)
5-1	1,700	400	368	2,468
5-2	7,500	400	368	8,268
5-3	13,728	400	368	14,496
5-4	13,728	6,501	368	20,597 (April 75% exc.)
5-5	13,728	16,240	368	30,336 (April 50% exc.)

The Cabot Station fishway entrance model results showed considerable changes in the river hydraulics between the lower and higher flow scenarios. At low flows (2-4 units operating at Cabot), velocities tended to be highest around the riffle located on river left approximately halfway downstream of Smead Island, while velocities in the tailrace were generally slower and less turbulent around the Cabot tailrace. At moderate flows (at Cabot Station capacity), velocities were high in the riffle area as well as near the Cabot Station tailrace, and the water appeared to be more turbulent near the Cabot Station tailrace and fishway entrance. At the highest modeled flows (at Cabot Station capacity and higher bypass reach flows), hydraulic controls from downstream began to backwater the riffle area, reducing water velocities through most of the study reach compared to lower flows, and the flow conditions around the Cabot Station tailrace and fishway entrance showed they were being influenced by the upstream bypass reach flows. Eddies and areas of flow circulation were observed throughout all model conditions, though the intensity and location of these areas changed with flow.

Spillway Fishway

In addition to the verification model run, five (4) production runs were executed for the Spillway Fishway Entrance model. These production runs (scenarios) are summarized in the following table:

Scenario Number	Power Canal Flow[1] (cfs)	Spillway Ladder Flow (cfs)	Bascule Gate No. 1 Flow (cfs)	Other Bascule Gate Spill[2] (cfs)	Tainter Gate Spill[3] (cfs)	Total Turners Falls Flow (cfs)
6-1	7,282	318[4]	400	0	0	8,000
6-2	15,938	318	4,341	0	0	20,597
6-3	15,938	318	7,500	6,580	0	30,336
6-4	15,938	318	7,500	12,460	10,000	46,216

The Spillway fishway entrance model results showed how hydraulic conditions near the Spillway fishway entrance and the plunge pool area downstream of the bascule gates changed under the modeled flow conditions. Under low flows, with the exception of the area near Bascule Gate 1 and the Spillway fishway entrance, water velocities were generally slower (~4 fps or less) throughout much of the study reach. Under higher discharges from Bascule Gate 1 the velocities increased throughout most of the reach; some areas had velocities in the 6-9 fps range. Under the highest modeled discharge, velocities throughout the modeled reach increased, with some areas near Bascule Gate 2 and Bascule Gate 4 approaching 20 fps. Eddies and areas of flow circulation were observed throughout all model conditions, though the intensity and location of these areas changed drastically with flow.

The study objectives include characterizing the hydraulics of existing conditions in the vicinity of the fishway entrances and powerhouse forebays and assessing how the flow fields/velocities create a response in fish. This report includes an assessment of velocity data from the CFD model relative to established agency criteria for American shad swim speeds to determine potential impacts. However, the hydraulic assessment represents only a partial picture of potential impacts of Project operations. Two other studies are being conducted to evaluate the impact of Northfield Mountain Project operations on shad including Study No. 3.3.2 *Evaluate Upstream and Downstream Passage of Adult American Shad* and Study 3.3.3 *Evaluate Downstream Passage of Juvenile American Shad*. The field data for these studies were collected in 2015; however, the analysis and results will not be available until 2016. These studies include telemetry data to determine how tagged American shad adults and juveniles respond to different operating conditions. These telemetry studies, coupled with the hydraulic evaluation herein, will collectively be used to determine the impact of Project operations on migratory fish movement.

[1] The power canal is not included in CFD model 6, but is included in this table to show the flow distribution.
[2] As noted in the RSP, the bascule gates are typically operated in a set order of no. 1, no. 2, no. 4 and no.3, with gate no. 1 being opened first and closed last, and gate no. 3 being opened last and closed first. The bascule gates can be throttled.
[3] The tainter gates are typically opened to maintain some flexibility in the bascule gates' available capacity. Since the bascule gates do not require manual operation like the tainter gates, station personnel generally prefer to not utilize all of the bascule gate capacity. The tainter gates can be throttled, but the adjustments cannot be done remotely as they can for the bascule gates.
[4] The spillway fishway flow was modeled as a constant value of 318 cfs as specified in the RSP. In reality, the spillway fishway flow varies with changing tailwater elevations. No direct flow measurements exist to quantify this variation, and therefore this study represents spillway flow as a simplified constant flow under all tailwater conditions.

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3D	3 Dimensional
AC	Alternating current
ADCP	Acoustic Doppler Channel Profiler
CAD	Computer-aided drafting
CEII	Critical Energy Infrastructure Information
CFD	Computational Fluid Dynamics
cfs	cubic feet per second
CRASC	Connecticut River Atlantic Salmon Commission
CT	Connecticut
DC	Direct current
FAVOR	Fractional Area-Volume Obstacle Representation
ft	feet
ft^2	square feet
FERC	Federal Energy Regulatory Commission
FirstLight	FirstLight Hydro Generating Company
fps	feet per second
GIS	Geographic Information Systems
GPS	Global Positioning System
ILP	Integrated Licensing Process
kA	kiloampere
km	kilometer
kV	kilovolts
kW	kilowatts
LiDAR	Light Detection and Ranging
MA	Massachusetts
MABT	MaCORS network
mi	miles
mi^2	square miles
MTS	Maine Technical Source
MW	Megawatts
NAVD88	North American Vertical Datum of 1988
NGVD29	National Geodetic Vertical Datum of 1929
NH	New Hampshire
NMFS	National Marine Fisheries Service
NOI	Notice of Intent
Northfield Mountain Project	Northfield Mountain Pumped Storage Project
PAD	Pre-Application Document
PSP	Proposed Study Plan
RANS	Reynolds Averaged Navier-Stokes
RMSE	Root mean square error
RNG	Renormalized group
rpm	revolutions per minute
RSP	Revised Study Plan
RTK	Real-Time Kinematic
RTK-GPS	Real-Time Kinematic-Global Positioning System
SD1	Scoping Document 1
SD2	Scoping Document 2
SPDL	Study Plan Determination Letter
STL	Stereolithography

TFI	Turners Falls Impoundment
the Commission	Federal Energy Regulatory Commission
the Project	Northfield Mountain Pumped Storage and Turners Falls Hydroelectric Projects
TIN	Triangulated Irregular Network
Turners Falls Project	Turners Falls Hydroelectric Project
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
V	Volts
VA	Approach velocity
VOF	Volume of Fluid
VS	Sweeping velocity
VT	Vermont
VTD2	Vermont CORS network
WSEL	water surface elevation

1 INTRODUCTION

1.1 Background

FirstLight Hydro Generating Company (FirstLight) is the current licensee of the Northfield Mountain Pumped Storage Project (Northfield Mountain Project, FERC No. 2485) and the Turners Falls Hydroelectric Project (Turners Falls Project, FERC No. 1889). FirstLight has initiated with the Federal Energy Regulatory Commission (FERC, the Commission) the process of relicensing the Northfield Mountain and Turners Falls Projects using FERC's Integrated Licensing Process (ILP). The current licenses for the Northfield Mountain and Turners Falls Projects were issued on May 14, 1968 and May 5, 1980, respectively, with both set to expire on April 30, 2018. This report documents the results of Study No. 3.3.8 *Computational Fluid Dynamics Modeling in the Vicinity of the Fishway Entrances and Powerhouse Forebays*.

As part of the ILP, FERC conducted a public scoping process during which various resource issues were identified. On October 31, 2012, FirstLight filed its Pre-Application Document (PAD) and Notice of Intent (NOI) with FERC. The PAD included FirstLight's preliminary list of proposed studies. On December 21, 2012, FERC issued Scoping Document 1 (SD1) and preliminarily identified resource issues and concerns. On January 30 and 31, 2013, FERC held scoping meetings for the Northfield Mountain and Turners Falls Projects. FERC issued Scoping Document 2 (SD2) on April 15, 2013.

FirstLight filed its Proposed Study Plan (PSP) on April 15, 2013 and, per the Commission regulations, held a PSP meeting at the Northfield Visitors Center on May 14, 2013. Thereafter, FirstLight held ten resource-specific study plan meetings to allow for more detailed discussions on each PSP and on studies not being proposed.[5] On June 28, 2013, FirstLight filed with the Commission an Updated PSP to reflect further changes to the PSP based on comments received at the meetings. On or before July 15, 2013, stakeholders filed written comments on the Updated PSP. FirstLight filed a Revised Study Plan (RSP) on August 14, 2013 with FERC and addressed stakeholder comments. Included in the RSP was Study No. 3.3.8 *Computational Fluid Dynamics (CFD) Modeling in the Vicinity of the Fishway Entrances and Powerhouse Forebays* (hereinafter referred to as the CFD Study). The methodology and scope for the CFD Study outlined in the RSP was approved with modification by the Commission in its September 13, 2013 SPDL (FERC, 2013).

FERC made one modification to the RSP, directing FirstLight provide, upon request, any study data and relevant project drawings to the stakeholders requesting it. FERC also noted that some project drawings may be considered Critical Energy Infrastructure Information (CEII) and, therefore, may not be provided.

1.2 Objectives

As noted in the RSP, the specific study objectives of the CFD Study were as follows:

1. Characterize the hydraulics of current (existing) conditions and any changes to:
    a. Fishway attraction flows;
    b. Turbine operations; and
    c. log sluice gates
2. Develop a series of velocity maps at select discharges showing approach velocities and flow fields that may create a response in fish;
3. Characterize the flow field in front of the Cabot Station and Station No. 1 intakes using velocity maps and cross-sectional plots;
4. Assess whether fish are directed to the surface bypass weir near Cabot Station;
5. Characterize the near-rack "sweeping" velocities at the Cabot Station and Station No. 1 intakes

[5] The ten meetings were held on May 14, 15, 21, and 22, and June 4, 5, 11, 12, and 14 and August 8.

1.3 Project Description

The Turners Falls Project is located on the Connecticut River in the states of Massachusetts (MA), New Hampshire (NH) and Vermont (VT) (Figure 1.3-1). The greater portion of the Turners Falls Project, including developed facilities and most of the lands within the Project boundary, is located in Franklin County, MA; specifically, in the towns of Erving, Gill, Greenfield, Montague and Northfield.

The Turners Falls Dam is located on a "Z turn" in the river, and is oriented on a northeast-southwest axis, with the impounded area on the east side of the dam, and extending north. At the southwest end of the Turners Falls Dam is the gatehouse (Figure 1.3-2). Below the dam, originating at the gatehouse, is the Turners Falls power canal. Paralleling this power canal is a bypassed section of the Connecticut River. Associated with this power canal are the two hydroelectric generating facilities[6]: Station No. 1 and Cabot Station. Station No. 1 is located approximately one-third of the way down the power canal. Water is conveyed from the power canal, to a small branch canal feeding the Station No. 1 turbines, before discharging into the bypassed reach of the Connecticut River. Cabot Station is located at the downstream terminus of the power canal, where it rejoins the main stem of the Connecticut River. Station No. 1 and Cabot Station discharge into the Connecticut River approximately 0.9 miles (mi) and 2.7 mi downstream of the Turners Falls Dam, respectively.

The Turners Falls Project consists of: a) two individual concrete gravity dams separated by an island; b) a gatehouse controlling flow to the power canal; c) the power canal and a short branch canal; d) two hydroelectric powerhouses, located on the power canal, known as Station No. 1 and Cabot Station; e) a bypassed section of the Connecticut River and f) a reservoir known as the Turners Falls Impoundment (TFI). The project attributes which are pertinent to this study are described below.

1.3.1 Turners Falls Dam

The Turners Falls Dam consists of two individual concrete gravity dams, referred to as the Gill Dam and Montague Dam, which are connected by a natural rock island known as Great Island. The 630-ft-long Montague Dam is founded on bedrock and connects Great Island to the west bank of the Connecticut River. It includes four bascule type gates, each 120 ft wide x 13.25 ft high and a fixed crest section which is normally not overflowed. All four bascule[7] gates are operated by hydraulic cylinders. The bascule gate closest to the gatehouse (Bascule Gate No. 1) is typically used to provide any required flow releases to the bypass reach by means of "pond-following". Pond-following means that the gate can be set to discharge a certain magnitude of flow and the gate position automatically adjusts to release the same flow based on changes in the TFI elevation. The dam crest elevation is 172.26 ft (NGVD29[8]). When fully upright, the top of the bascule gates are at elevation 185.5 ft.

The Gill Dam is approximately 55-ft-high and 493-ft-long extending from the Gill shoreline (east bank) to Great Island. It includes three 40-ft-wide x 39-ft-high tainter spillway gates. The tainter gates discharge water from the base of the gates. Each tainter[9] gate is operated by a motor/gearbox driving a torsion shaft connected to two lifting chains. When closed, the elevation atop the tainter gate is at elevation 185.5 ft.

[6] In addition to Station No. 1 and Cabot there are three other facilities that can withdraw water from the canal including PaperLogic (113 cfs), Turners Falls Hydro, LLC (288 cfs) and the USGS Conte Lab (variable, ranging from 2 to 200 cfs).
[7] A bascule gate is a hinged crest gate. Each bascule gate is controlled by a pair of hydraulic cylinders, mounted in the concrete gravity dam.
[8] Unless otherwise noted in this License Application, reported elevations are based on the National Geodetic Vertical Datum (NGVD) of 1929.
[9] A tainter gate is a spillway gate whose face is a section of a cylinder; it rotates about a horizontal axis on the downstream end of the gate and can be closed under its own weight.

1.3.2 Gatehouse

The power canal gatehouse is located on the Montague side of the Connecticut River. It forms the abutment for connecting the Montague Dam spillway with the shoreline and is equipped with headgates controlling flow from the TFI to the power canal. The structure is of masonry and reinforced concrete foundations with a brick walled superstructure. The gatehouse is approximately 214-ft-long and houses 15 operable gates controlling flow to the power canal. Six (6) of the gates are 10 ft 8 in. high x 9 ft wide wooden gates and nine (9) of the gates are 12 ft 7 in. high x 9 ft 6 in. wide wooden gates. The Gatehouse fishway passes through the gatehouse at the west bank.

The local controls and operating equipment for the dam's bascule gates are in the gatehouse. They can also be operated remotely from the control room located at Northfield Mountain. The tainter gates are operated locally at the Gill Dam. The magnitude of flow passing through the gatehouse is a function of the gate(s) opening and the hydraulic head or the differential in the TFI elevation and the power canal elevation.

A CFD model of the Gatehouse fishway was recently completed (Songheng *et al*., 2013). The Alden report summarizing CFD modeling at the Gatehouse fishway can be found in Appendix F of the RSP.

1.3.3 Power Canal

The power canal is approximately 2.1 mi long and ranges in width from approximately 920 ft in the Cabot forebay (near the downstream terminus of canal) to 120 ft in the canal proper. The canal has a design capacity of approximately 18,000 cubic feet per second (cfs). There are several entities that can withdraw water from the canal; Table 1.3.3-1 lists the water users, approximate hydraulic capacity, and FERC project number (where applicable).

Paperlogic[10] and Turners Falls Hydro, LLC[11] have indentured water rights. FirstLight has an agreement with each of these entities which provides that the entity will not generate power unless the hydraulic capacity of the Station No. 1 and Cabot stations is exceeded. The United States Geological Survey (USGS), which withdraws water for the Conte Anadromous Fish Laboratory, also has a water use agreement with FirstLight; however, its water use is minimal.

Table 1.3.3-1: Entities Having Rights to Withdraw Water from Power Canal

Facility Name	Owner	Approximate Hydraulic Capacity (cfs)	FERC Project No.
Paperlogic	Southworth Company	113 cfs	N/A
Turners Falls Hydro, LLC	Turners Falls Hydro	288 cfs	2622
Station No. 1	FirstLight Hydro Generating Co.	2,210 cfs	1889
Cabot Station	FirstLight Hydro Generating Co.	13,728 cfs	1889
United States Geological Survey, Conte	United States Geological Survey	Variable[12]	N/A

[10] A water use agreement between then Esleeck Manufacturing Company (a predecessor to Paperlogic) and then Turners Falls Power and Electric Company (a predecessor to FirstLight) was signed in August 1928.
[11] A water exchange agreement between then Keith Paper Company (a predecessor to Turners Falls Hydro, LLC) and then Western Massachusetts Electric Company (a predecessor to FirstLight) was signed in September 1951.
[12] Per Exhibit B of the May 25, 1988 conveyance agreement, the allowable withdrawal rate (in cfs) and number of days of withdrawal varies based on the month. It can range from a maximum of 200 cfs for 13 days in October to a minimum of 2 cfs for 28 days in February.

Facility Name	Owner	Approximate Hydraulic Capacity (cfs)	FERC Project No.
Anadromous Fish Laboratory			

1.3.4 Station No. 1

From the power canal there is an approximate 700-ft-long x 100-ft-wide branch canal. At the end of the branch canal is the entrance to Station No. 1, consisting of eight 15-ft-wide bays for a total intake width of 120 ft. Trashracks are angled across the entire entrance, totaling 114 ft wide x 20.5 ft high. With a normal canal elevation of approximately 173.5 ft, the effective trashrack opening is approximately 114 ft wide by 15.9 ft high, resulting in a gross area of 1,812.6 square feet (ft^2). The bar rack thickness is 0.375 (3/8) inch and the bars are 3 in. on center, thus the clear spacing between bars is 2.625 (2 5/8) in.

After passing the trashrack, the intakes narrow down to four individual 13 ft 1.5 in. diameter penstocks feeding the original seven horizontal Francis turbines housed in the powerhouse. Only five of the turbines are operational. The powerhouse consists of brick masonry on concrete foundations. The powerhouse has five generators, all alternating current (AC) horizontal type, 60 cycle, and 2300 volt (V).

Penstock 1 feeds Unit 1, penstock 2 feeds Units 2 and 3, penstock 3 feeds Units 4 and 5, and penstock 4 feeds Units 6 and 7. Note that penstock 4 bifurcates into pipes leading to Units 6 and 7; Units 4 and 6 are no longer in service. Station No. 1 operates under a gross head of 43.7 feet, and has an approximate total electrical nameplate capacity and hydraulic capacity of 5,693 kilowatts (kW) and 2,210 cfs, respectively.

Table 1.3.4-1 includes information on Station No. 1's generators and turbines.

Table 1.3.4-1: Generator and Turbine Characteristics of Station No. 1

Unit No.	Generators		Turbines			
	Electrical Capacity (kW)	Amps	Runner Size	Hydraulic Capacity (cfs)	Horsepower (hp)	Speed (rpm)
1	1,500	376	Two 48 in.-horizontal runners	560	2100	200
2*	365	—	One 33 in.-horizontal runner	140	590	257
3	1,276	314	Two 42 in.-horizontal runners	500	1900	200
4						
5	1,276	252	One 39 in.-horizontal runner	490	1635	200
6						
7	1,276	251	Two 42 in.-horizontal runners	520	1955	200
Total	**5,693**			**2,210**		

*Unit 2 is directly connected to a 1600 amp, 257 rpm, 115 volt exciter.

1.3.5 Cabot Station

Cabot Station is located at the downstream terminus of the power canal. The trashrack opening is 217 ft wide x 31 ft high, resulting in a gross area of 6,727 ft^2. The trashracks are angled, and include upper and lower racks. The top 11 ft of the upper racks have clear bar spacing of 0.94 in. (15/16 in.), and the bottom

7 ft of the upper racks have clear bar spacing of 5 in. The entire 13 ft of the lower racks have clear bar spacing of 5 in. After passing through the trashracks, flow is conveyed through one of six penstocks to turbines housed in the powerhouse. The powerhouse is a brick and steel structure set on a concrete substructure on a rock foundation. It houses six identical vertical, Francis type, single runner turbines. At a 60-ft head, each unit is rated at 13,867 horsepower. The wicket gates for each unit are operated by two servomotors.

Transmission facilities at Cabot Station consist of (i) generator leads and two 13.8 kilovolts (kV) buses for three units each for a total of six units, (ii) one 13.8 kV transmission line, about 200 ft long and extending across the power canal to the Montague substation, and (iii) one 13.6/115 kV oil immersed air cooled transformer and appurtenant facilities. The six generators are vertical shaft 13.8 kV, 97.3 revolutions per minute (rpm) with Kingsbury thrust bearings.

Cabot Station has a total station nameplate capacity of 62.016 megawatts (MW) or approximately 10.336 MW/unit. The station has a total hydraulic capacity of approximately 13,728 cfs or 2,288 cfs/unit.

At the downstream terminus of the power canal and adjacent to the Cabot Powerhouse are eight wooden 16 ft 8 in. high x 13 ft 7 in wide spillway gates, which permit the discharge of approximately 12,000 cfs. These gates are used to rapidly draw down the power canal in the event of a Cabot Station load rejection or canal dike breach or to sluice ice and debris. In addition, there is a 16 ft 2 in. wide x 13 ft 1 in. high log sluice gate located at the downstream end of the forebay.

1.3.6 Fish Passage Facilities

1.3.6.1 Upstream Fish Passage Facilities

The Turners Falls Project is equipped with three upstream fish passage facilities, including (in order from downstream to upstream): the Cabot, Spillway, and Gatehouse fishways. These fish passage facilities were based on a design recommended by the United States Fish and Wildlife Service (USFWS). Fish ladders of similar design pass Pacific salmon species and American shad on the Columbia River. It was believed that these same designs could be applied to pass Atlantic salmon and American shad, the original target species. American shad is the primary species using these fish passage facilities.

The Cabot fishway is a modified “ice harbor” design; it consists of 66 pools, with each pool situated approximately one foot higher than the previous pool. Fish enter the Cabot fishway below Cabot Station. Fish pass through the Cabot fishway into the power canal; from there, they swim 2.1 mi upstream to the Gatehouse fishway.

Fish that bypass the Cabot fishway move upstream via the bypassed reach, where they will ultimately encounter the Turners Falls Dam. Fish arriving here are passed upstream via the Spillway fishway into a gallery leading to the Gatehouse fishway, where they rejoin fish that have passed to this point via the Cabot fishway. The Spillway fishway is also of modified ice harbor design, with 42 pools.

Fish from the upstream end of the power canal can enter the Gatehouse fishway gallery via two entrances: a 70-ft-long flume extending into the canal on the river side of the canal; and a 5-ft-wide opening on the town side of the canal. Once through the gatehouse fishway, fish are passed into the TFI. The Gatehouse fishway is a vertical slot fishway.

The Connecticut River Atlantic Salmon Commission (CRASC[13]) establishes an annual schedule for the operation of upstream fish passage facilities at the Connecticut River dams. The schedules are based on the projected movement of migratory fish and may be adjusted in season to address actual observations. Table 1.3.6.1-1 lists the 2015 schedule for upstream fish passage operations at the Turners Falls Project.

[13] CRASC membership consists of the USFWS, NMFS, and state fishery agencies from CT, MA, NH, and VT.

Table 1.3.6.1-1: Upstream Fish Passage Schedule for Cabot, Gatehouse, and Spillway Fishways

Project	Species	Life Stage	Dates of Operation	Hours of Operation
Turners Falls	salmon	adult	Apr 7-Jul 15	24 hours/day
	salmon	adult	Sep 15-Nov 15	24 hours/day
	shad & herring	adult	Apr 7-Jul 15	24 hours/day

Source: CRASC letter to FirstLight, 3/5/2015

1.3.6.2 Downstream Fish Passage Facilities

The downstream fish passage facilities are located at Cabot Station, at the downstream terminus of the power canal. Assuming no spill is occurring at Turners Falls Dam, fish moving downstream pass through the gatehouse (which has no racks) and into the power canal. Downstream fish passage facilities at Cabot Station consist of: reduced bar-spacing in the upper 11 ft of the intake racks; a broad-crested weir developed specifically to enhance fish passage at the log sluice; the log sluice itself, which has been resurfaced to provide a passage route; above-water lighting; and a sampling facility.

As described for upstream passage, the CRASC also establishes an annual schedule for the operation of downstream fish passage facilities at the Connecticut River dams. Table 1.3.7.1-2 lists the 2015 schedule for downstream fish passage operations at the Project.

Table 1.3.7.1-2: Downstream Fish Passage Schedule

Project	Downstream Fish Passage Exit	Species	Life Stage	Dates of Operation	Hours of Operation
Turners Falls	Log sluice and trash sluice	salmon	smolt	Apr 1-Jun 15	24 hours/day
		salmon	adult	Oct 15-Dec 31[1]	24 hours/day
		shad	adult	Apr 7-Jul 31	24 hours/day
		shad	juvenile	Aug 1-Nov 15	24 hours/day
		eels	adult	Sep 1-Nov 15	24 hours/day

[1]Downstream passage operation, for adults will only be required if 50 or more adults are documented as passing upstream of a dam/facility. Source: CRASC letter to FirstLight, 3/5/2015

1.4 Study Areas

This study includes CFD models for four (4) separate areas within the Turners Falls Project. The location and approximate extent of the CFD models as described in the RSP are shown in Figure 1.4-1.

The RSP called for a total of six (6) CFD models to be developed as follows:

1) the power canal in front of the Station No. 1 powerhouse (Labeled "Station No. 1 Intake Area" in figure);
2) the Station No. 1 intake racks (Labeled "Station No. 1 Intake Area" in figure);
3) the power canal in front of the Cabot Station powerhouse (Labeled "Cabot Intake Area" in figure);
4) the Cabot Station intake racks (Labeled "Cabot Intake Area" in figure);
5) the Cabot fishway entrance (Labeled "Cabot Fishway Entrance Area" in figure); and
6) the Spillway fishway entrance (Labeled "Spillway Fishway Entrance Area" in figure)[14]

The objective of the Station No. 1 intake rack model (Model 2) and Cabot Station intake rack model (Model 4) was to characterize the near-rack flow field conditions with respect to approach velocities and sweeping

[14] The spillway ladder becomes inundated by flow from bascule gate no. 1 if there is any substantial spill over the dam. At such flows, the CFD model may have difficulty identifying some hydraulic influences.

velocities. The Station No. 1 Forebay model (Model 1) and Cabot Forebay model (Model 3) have a 1-ft grid resolution in the area directly in front of the intakes racks which is sufficient for evaluating the approach and sweeping velocities. Because the approach and sweeping velocities are typically evaluated approximately 1 ft in front of the rack face, and the forebay models already included the trash rack area, it was determined that a highly detailed model of the intake rack was not necessary to meet the CFD study objectives. In addition, the computational time and resources required to complete a model with the level of detail necessary to resolve the individual intake rack bars was not compatible with this study (see Section 8.1 for more information regarding approach velocities and sweeping velocities).

The individual CFD Model Study Areas are described in the following subsections.

1.4.1 Station No. 1 Forebay

The Station No. 1 Forebay CFD model (Model 1) includes the penstocks and intakes, forebay and a portion of the power canal in front of the forebay entrance as shown in Figure 1.4.1-1. The power canal portion of the model extends from approximately 300 ft upstream of the forebay entrance to approximately 450 ft downstream of the forebay entrance, for a total length of approximately 750 ft. The forebay portion of the model extends from the power canal through the entire forebay and into the penstocks where the model terminates.

1.4.2 Cabot Station Forebay

The Cabot Station Forebay CFD model (Model 3) includes the penstock intakes, forebay, and a portion of the power canal as shown in Figure 1.4.2-1. The model extends from approximately 700 ft upstream of the powerhouse, downstream to a point inside the penstocks where the model terminates.

1.4.3 Cabot Fishway Entrance

The Cabot Fishway Entrance CFD model (Model 5) extends along the full-width of the Connecticut River from approximately 1600 ft upstream of Cabot Station to approximately 500 ft downstream of Smead Island. Since the area around the Cabot fishway entrance is greatly influenced by surrounding river conditions, the modeling area was extended to a much larger portion of the river than was specified in the RSP, as shown in Figure 1.4.3-1. The model area that was outside of the study area was represented as a coarser grid than was used within the detailed study area. More details on the model setup are included in Section 5.3.

1.4.4 Spillway Fishway Entrance

The Spillway Fishway Entrance CFD model (Model 6) extends from the Turners Falls Dam to approximately 300 feet downstream of the main Island just below the dam (hereinafter referred to as the "Island"), as shown in Figure 1.4.4-1. The model area extends beyond the study area described in the RSP, as the surrounding areas influenced river conditions in the study area. The model area that was beyond the RSP study area was represented as a coarser grid than was used within the detailed study area. More details on the model setup are included in Section 5.4.

1.5 Vertical Datum

All elevations for the CFD Study are referenced to the National Geodetic Vertical Datum of 1929 (NGVD29). The NGVD29 is the project datum used by FirstLight at the Northfield Mountain and Turners Falls Projects. Although the North American Vertical Datum of 1988 (NAVD88) is a more recent datum, FirstLight has historically used the NGVD29 datum for the project data, and as such it is also being used in this study for consistency.

The field data collected for this study as described in Section 3 were collected in the NAVD88 vertical datum and had to be converted to NGVD29 for use in developing the CFD model geometry. Table 1.5-1 shows the conversion factors from the VERTCON web application for each of the CFD Model Study Areas.

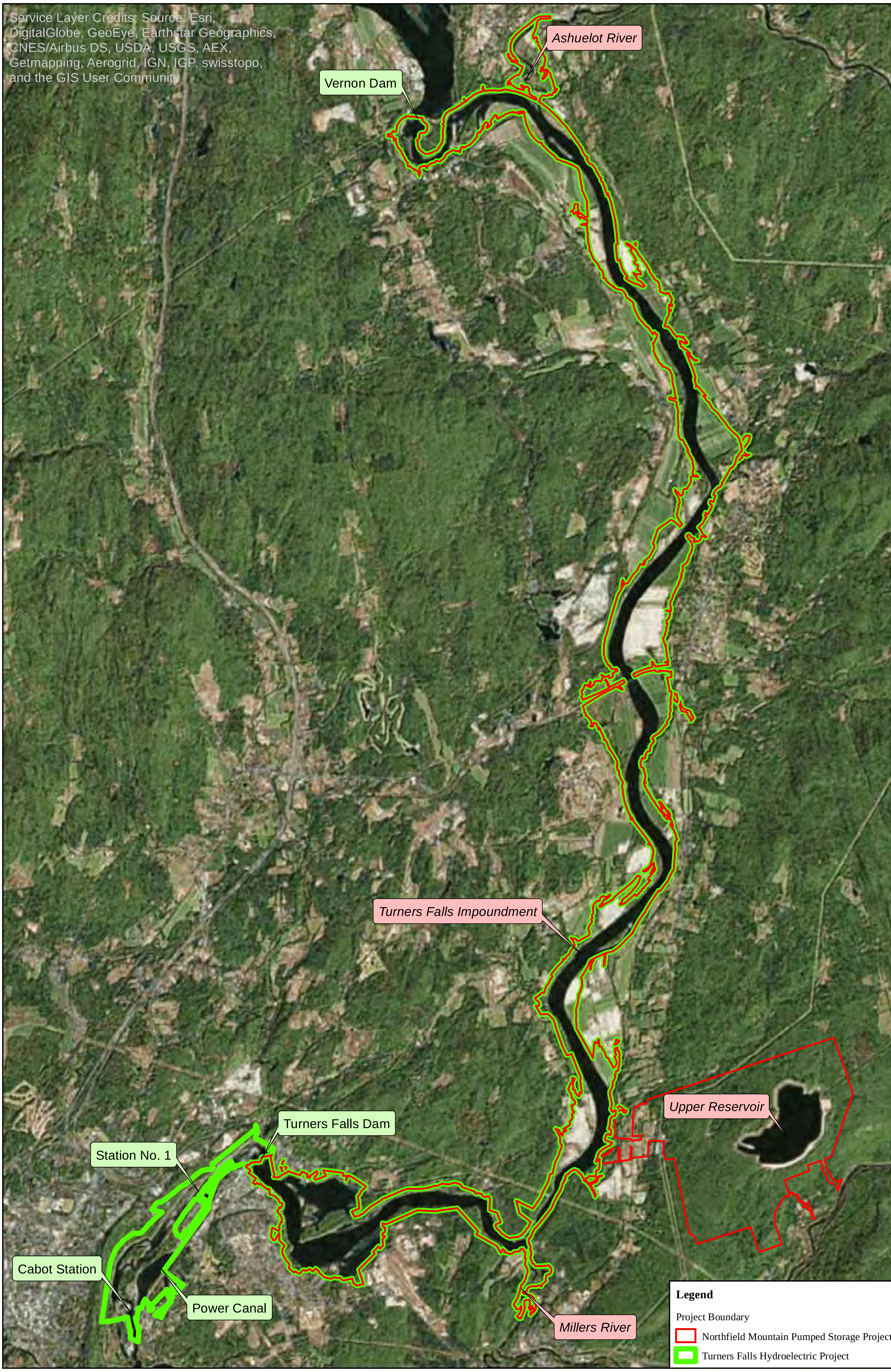
A single datum conversion value was used for the Station No. 1 Forebay and the Cabot Station Forebay datasets as shown in Table 1.5-1. Due to the large geographic extents of the datasets used in the Spillway Fishway Entrance and Cabot Fishway Entrance models (which were also used for other studies), the datum conversions for those datasets were developed using the VERTCON PC [15] executable computer program which provides location-specific conversion values for each point. Accordingly, the values provided in Table 1.5-1 for the Spillway Fishway Entrance and Cabot Fishway Entrance locations are average values for the model area and are only provided for reference.

Table 1.5-1: Vertical Datum Conversion Factors

Location	Datum Conversion (NAVD88 minus NGVD29)
Station No. 1 Forebay	-0.548 ft
Cabot Station Forebay	-0.554 ft
Spillway Fishway Entrance	-0.541 ft
Cabot Fishway Entrance	-0.554 ft

Note: All figures and larger tables appear at the end of each Section.

[15] http://www.ngs.noaa.gov/PC_PROD/VERTCON/



FirstLight Power Resources

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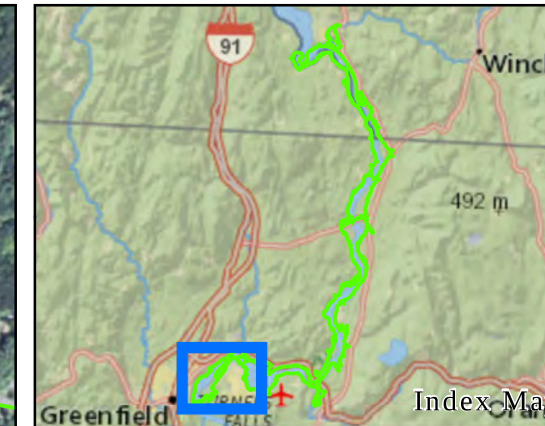
0 0.5 1 2 Miles

Figure 1.3-1
Turners Falls Project and Northfield Mountain Project Boundary Map

Path: w:\gis\studies\3_3_08\maps\Figures\CFD Study Report\TF Project Boundary Map.mxd



FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

Study Report 3.3.8

Figure 1.3-2
Turners Falls Project
Features

Legend

Project Boundary

N

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community
Content may not reflect National Geographic's current map policy.

0 600 1,200 2,400
Feet

1 inch = 1,200 feet

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Path: W:\gis\studies\3_3_08\maps\Figures\CFD Study Report\Project Overview Map from Exhib A.mxd

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Figure 1.4-1:
CFD Models - Study Area

Path: W:\gis\studies\3_3_08\maps\Figures\CFD Study Report\Total Project Study Area.mxd

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0 100 200 400 Feet

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Figure 1.4.1-1:
CFD Model Study Area
at Station No. 1

Path: W:\gis\studies\3_3_08\maps\Figures\CFD Study Report\Station No.1 Study Area.mxd

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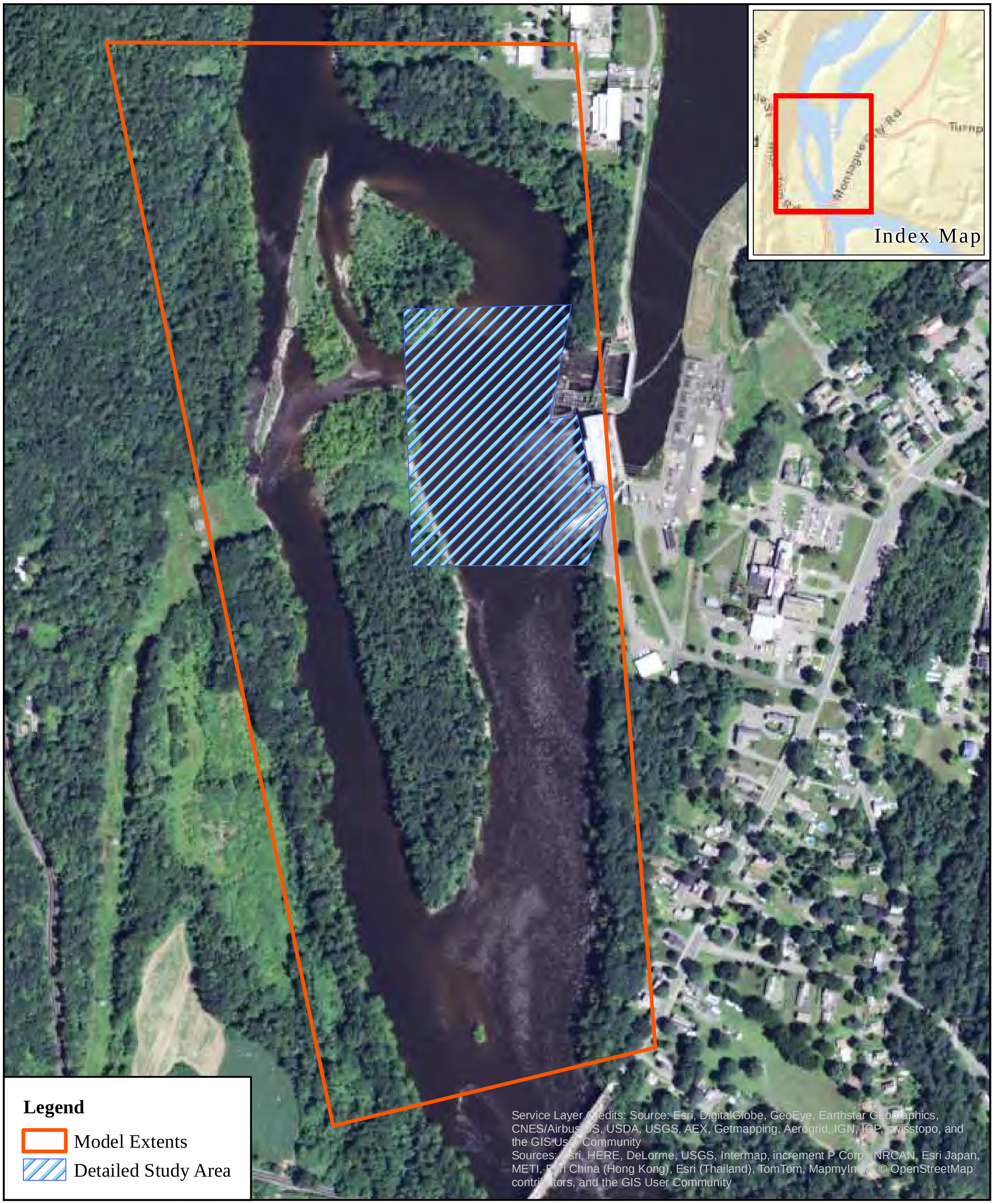
0 100 200 400 Feet

Figure 1.4.2-1:
CFD Model Study Area
at Cabot Station

Path: W:\gis\studies\3_3_08\maps\Figures\CFD Study Report\Cabot Forebay Study Area.mxd



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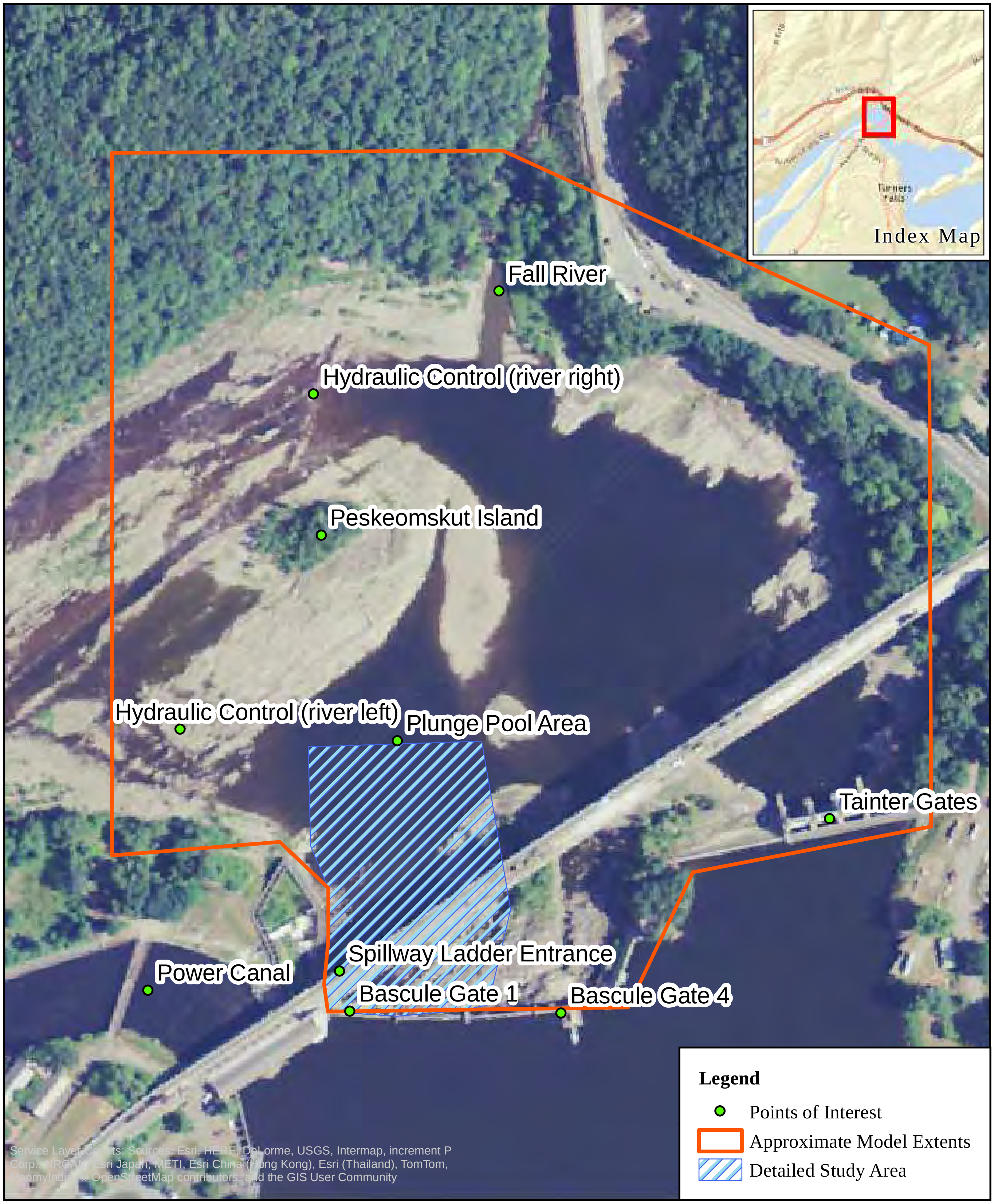
0 100 200 400
Feet

Figure 1.4.3-1:
CFD Model Study Area
at Cabot Station Entrance

Path: W:\gis\studies\3_3_08\maps\Figures\CFD Study Report\Cabot Fishway Study Area.mxd



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N

0 100 200 400
Feet

Figure 1.4.4-1:
CFD Model Study Area
of Spillway Fishway Entrance

Path: W:\gis\studies\3_3_08\maps\Figures\CFD Study Report\Spillway Study Area.mxd

2 CFD MODELING APPROACH

The CFD model simulations were conducted using the Flow-3D CFD code developed by Flow Science, Inc. FLOW-3D is a general-purpose CFD software that employs numerical techniques to solve the equations of motion for fluids to obtain transient, three-dimensional (3D) solutions to multi-scale, multi-physics flow problems (Flow Science, 2012). Flow-3D solves the Reynolds Averaged Navier-Stokes (RANS) equations.

In Flow-3D, the model geometry (e.g. bathymetry, canal walls, fishway walls, penstocks, etc.) is represented with solid models. The development of the solid models used for each model location is described in Section 4.

A significant aspect of accurately predicting flow in a CFD model is the development of the computational grid. In Flow-3D, a fully structured computational mesh is applied to the solid models to create the computational domain (i.e. the area where the fluid can flow). The computational mesh is created by one or more rectangular mesh blocks which are aligned with a Cartesian coordinate system. If multiple mesh blocks are used, they can either abut to one another, or one mesh block can completely contain another. The boundaries of the mesh blocks are referred by their plane (i.e. x-min, x-max, y-min, y-max, z-min and z-max). Herein, computational mesh cell sizes will be referred to by their x, y and z dimensions contained in parentheses. For example, a mesh block that is comprised of (1 ft x 2 ft x 3 ft) cells, is comprised of cells that are 1 ft in the x-direction by 2 ft in the y-direction and 3 ft in the z-direction[16].

Flow-3D uses the Fractional Area-Volume Obstacle Representation (FAVOR) method to block out parts of the computational mesh (volumes and areas) that are obstructed by the solid models (i.e. below the bathymetric surface, outside of the canal, etc.) (Flow Science, 2012). In general, the smaller the grid cell size the more accurate the solution, but also the longer it takes for the model to run. In order to balance computational time and accuracy for the CFD Study areas, nested meshes were used where a base cell size is used for a high level mesh block and areas of refinement are nested within it to increase the accuracy and resolution in areas of complex geometry or special interest (e.g. in front of the intake racks) while balancing increases in computation time. The block mesh configuration, including cell sizes and areas of refinement, for each CFD model in the CFD Study is described in Section 5.

Using Flow-3D the free water surfaces are modeled using the Volume of Fluid (VOF) technique. This method models the free water surface by tracking the amount of fluid that is in each 3D cell over time. In other words, at any given time a cell can either be empty, full or partially full of water. Partially full cells contain the free water surface. The variable used to track this is called the fluid fraction. The VOF technique consists of three parts, a scheme to describe the shape and location of the free surface, a method to track the evolution of the shape and location of the free surface through time and space and a means for applying boundary conditions to the free surface. The VOF method assumes a single fluid (water) and does not include the movement of the air above the water. For this study, it was assumed that the air has no significant effect on the movement of the water and as such it is neglected.

In Flow-3D (and all CFD codes) it is necessary to specify both the initial condition (all cells) and boundary conditions (edge cells) for each model variables (e.g. velocity, pressure, turbulent energy and dissipation, fluid fraction, etc.). The initial and boundary conditions, and simulation settings that are consistent across all models in the CFD Study are described in the following paragraphs. The initial and boundary conditions, and simulation settings that apply to a specific location or scenario are described in Section 5.

The Renormalized group (RNG) turbulence model was used to model turbulence for all simulations in the CFD Study. The RNG turbulence model uses turbulent kinetic energy and turbulent mixing length to model

[16] This mesh size is described for example purposes only. In Flow3D, typically a mesh's cells do not have any dimensions that vary by more than a factor of two. For example, if a mesh had a 1 foot X dimension, then it would normally not have greater than a 2 foot dimension in the Y or Z dimension.

turbulence. The default dynamically-calculated initial and boundary conditions in Flow-3D for turbulent kinetic energy and turbulent mixing length were used for the CFD models. All bathymetric surfaces and structures were assumed to by hydraulically smooth.

All models were oriented with gravity acting in the z-minus direction, meaning that the atmospheric boundary is located at z-max for all models. The atmospheric (z-max) boundary was set as a pressure boundary (gage pressure = 0 psi) with a fluid fraction equal to zero, meaning that any flux into the system through the z-max boundary would not be water.

The default fluid properties (density, viscosity, etc.) in Flow-3D for "Water at 293 K" used for all models, and the default Flow-3D VOF solver options were used for each CFD model unless otherwise noted.

The CFD models were run until a nearly steady state condition was reached. Model conditions (e.g. inflow, outflow, etc.) were tracked throughout the simulation to determine when the model had reached steady state conditions. Typically as the model is stabilizing the model variables (velocity, pressure, fluid fraction, etc.) oscillate, with the magnitude of the oscillations diminishing over time until they are small enough that the model has effectively reached a steady state. Model run times and criteria for determining if a steady state condition had been reached are discussed in for each CFD model in Section 6 and Section 7 for the verification and production runs, respectively.

3 FIELD DATA COLLECTION

This study involved the collection of considerable field data to develop CFD models of the study areas described in Section 1.4, including the following:

- Bathymetric data in the four study areas to define the shape of the below-water channel/canal.
- Upland and riverbank topography based on field survey and Light Detection and Ranging (LiDAR) data (LiDAR was collected by TransCanada as described below).
- Water column velocities in the Cabot Forebay, Station No. 1 Forebay, and in the vicinity of the Cabot and Spillway Fishway entrances for use in validating the models.
- Water surface elevations (WSELs) at the following locations:
    - within the Turners Falls Dam plunge pool (plunge pool) - needed for the Spillway fishway CFD model.
    - in the vicinity of the Cabot Station fishway- needed for the Cabot fishway model.
    - in the power canal at Keith Bridge (needed for Station No. 1 model) and in the Cabot Forebay (needed for Cabot and Station No. 1 models. Note, these data were collected by FirstLight from existing water level loggers as described below.

The following subsections describe the various data collection methods that were employed as part of this study. Figure 3-1 shows all field data collection points for the Station No. 1 Forebay CFD model. Figure 3-2 shows all field data collected for the Cabot Forebay CFD model. Figure 3-3 shows all field data collected for the Cabot Fishway CFD model. Figure 3-4 shows all field data collected for the Spillway Fishway CFD model. The subsections will all refer to these maps.

3.1 Acoustic Doppler Current Profiler Data

Bathymetric and velocity surveys of the study areas were completed over several days. The surveys were collected using a Sontek RiverSurveyor M9 Acoustic Doppler Channel Profiler (ADCP) linked to a Real-Time Kinematic Global Positioning System (RTK-GPS) unit, and included the collection of both bathymetry and velocity data during the survey dates. All bathymetric and topographic data were originally collected using the NAVD88 vertical datum, but were later adjusted to the NGVD29 datum for consistency with FirstLight's long term datum.

Bathymetric data were collected using a tethering system or a boat based system. The system used at each location is described below. A tethering system was used in the power canal, forebays and near the Spillway fishway entrance due to safety concerns, while a boat based system was used to collect bathymetry near the Cabot and Spillway[17] fishway entrance areas. For the tethering system, the ADCP was mounted on a floating platform ("boogie board") and then pulled across the water at a transect location.

3.1.1 Station No. 1 Forebay

The bathymetric survey for the Station No. 1 Forebay model was conducted on March 28, 2014. The ADCP unit was used along with the tethering system to collect transect data within the power canal and forebay areas (Figure 3-1). During data collection, Station No. 1 was running at maximum capacity (2,210 cfs) with

[17] Note that both a tethering system and boat based survey was conducted near the Spillway fishway entrance.

Cabot Station operating one unit (2,288 cfs) for a total inflow to the power canal of approximately 4,498 cfs.

3.1.2 Cabot Station Forebay

The bathymetric survey for the Cabot Station Forebay was conducted on March 29, 2014. The ADCP unit was used along with the tethering system to collect data from 25 transects (Figure 3-2). During field data collection, Cabot Station was generating with three units on (Unit 1, Unit 5 and Unit 6) for a total flow of approximately 6,684 cfs. The log sluice gate was open 10 ft during most of the fieldwork (with a crest elevation of 165.2 ft) and the bellmouth entrance (see inset) to the downstream fish passage weir was not installed. Based on a rating curve, approximately 1,290 cfs was passing through the log sluice.

3.1.3 Cabot Fishway Entrance

Bathymetric survey data near the Cabot Fishway Entrance were collected on August 6, 2014. The ADCP unit was attached to a motor boat and data from a series of transects and longitudinal profiles were collected from approximately 1000 ft upstream of Cabot Station to approximately 1000 ft downstream of the fishway entrance (Figure 3-3). During field data collection, Cabot was generating with two units on (Unit 1 at 2,218 cfs and Unit 2 at 1,832), the total bypass flow was approximately 625 cfs (computed based on rating curves), the fishway was operating at approximately 368 cfs (this is the approximate hydraulic capacity of the fishway), and the log sluice was passing approximately 184 cfs (computed based on a rating curve) for a total flow of approximately 5,227 cfs. These data were supplemented by additional bathymetric data that was collected in Reach 3 for Study No. 3.3.1: *Conduct Instream Flow Habitat Assessment in the Bypass Reach and below Cabot Station.*

3.1.4 Spillway Fishway Entrance

Bathymetric survey data near the Spillway Fishway Entrance were collected on September 4, 2014. As noted in Section 3.2 additional above water (topographic) survey was also collected. The ADCP unit was used with the tether line setup below Bascule Gate No. 1 and later attached to a kayak and paddled around the plunge pool and surrounding area to supplement the bathymetric data. Figure 3-4 shows a plan view of the areas where bathymetric data were collected.

3.2 Topographic and Structure Survey Data

Topographic and structure surveys were conducted at all of the study areas to supplement the bathymetric data collected with the ADCP unit and to allow for accurate development and placement of structures. Survey data were collected at all of the study areas with RTK-GPS and total station units. Table 3.2-1 summarizes the data collected.

The structure and topographic survey collected at each of the study areas is shown in Figure 3-1, Figure 3-2, Figure 3-3, and Figure 3-4.

Table 3.2-1: Topographic Survey and Summary of Data Collection Methods

Model Location	Survey Dates	Data Collection Methods	Comments
Station No. 1 Forebay Area	4/21/14	Data were collected using a base station and rover setup	Limited to "above water" survey including edge of water, top of wall, and top of structure points encircling the Station No. 1 forebay and along the power canal adjacent to Station No. 1
	9/29-30/14	Two GPS units connected to the Vermont CORS network (VTD2) or the MaCORS (MABT) network. Additional data were collected using a conventional total station to capture survey data where a GPS fix was not possible due to the high walls of the power canal and nearby buildings	Data during this period were collected during the annual canal drawdown. Water levels in the canal were very low, making access and observation of the canal features easier.
Cabot Station Forebay Area	4/22/14	Data were collected using a base station and rover setup	--
	7/29/14	Data were collected using a network setup, with the GPS unit connected to the MaCORS (MABT) network	--
Cabot Fishway Entrance Area	4/22/14	Data were collected using a base station and rover setup	--
	7/29/14	Data were collected using a network setup, with the GPS unit connected to the MaCORS (MABT) network	--
Spillway Fishway Entrance Area	6/12/14	Data were collected using a network connection to the Maine Technical Source (MTS) Northampton network.	GPS data were collected in and around shallow areas of the plunge pool. Water level loggers were concurrently installed.
	9/4/14	Data were collected using a connection to the Vermont CORS network (VTD2). Data were also collected using a conventional total station setup.	Total station data were tied in to the RTK-GPS benchmarks.

3.3 LiDAR Data

TransCanada provided FirstLight with LiDAR data of the topography covering the CFD study areas. The LiDAR[18] was flown from April 22–28, 2013 (leaf off), when flow on the Connecticut River, as measured at the Montague United States Geological Survey (USGS) Gage, ranged from 15,600 cfs–21,000 cfs. The LiDAR data were used to fill in the field collected topographic survey.

[18] The data were collected by US Imaging using an Optech M-300 Orion LiDAR Sensor and Integrated CS-10000 Digital CameraAircraft– Cessna T210N – N6258YQA. The LiDAR data were checked against the independently obtained QA/QC points throughout the project area and was found to have a Root Mean Square Error (RMSE) for the sample (RMSEz) of 6.1cm (vertical). The digital imagery was checked against more than 60 photo targets and Photo ID points along the project corridor and was found to have better than 12 cm horizontal standard deviation.

3.4 Water Level Loggers

Summarized in Table 3.4-1 are the location and number of water level loggers installed to help verify the CFD models. Figure 3.4-1 shows a plan view of the water level logger locations.

The temporary loggers (12) installed for this study were Onset HOBO Water Level Logger Model U20. The other two are long-term water level loggers maintained by FirstLight. These loggers record absolute pressure, which is proportional to the height of the water above the instrument, and are non-vented, thus must be barometrically compensated using an atmospheric pressure logger. Thus, an atmospheric logger was placed near the Conte Anadromous Fish Research Laboratory boat launch to record atmospheric pressure for barometric compensation. When installed, the loggers were set to record data on a 5-minute or 15-minute time increment, and were surveyed to the NAVD88 datum using a RTK-GPS unit. Elevations were later converted to the NGVD29 datum. The loggers were serviced periodically, which consisted of downloading the logger data, checking the logger for functionality/damage and re-installing the logger.

The raw water level logger data underwent a QA/QC procedure before the data were considered acceptable for use in this study.

Table 3.4-1: No. and Location of Water Levels Utilized for CFD Models

Model Location	No. of Water Level Loggers Installed	Comments
Station No. 1 Intake Area	1	FirstLight maintains a permanent water level logger in the power canal at Keith's Bridge; it was not installed specifically for this study.
Cabot Intake Area	1	FirstLight maintains a permanent water level logger in the power canal in the Cabot forebay; it was not installed specifically for this study.
Cabot Fishway Entrance Area	7	Temporary water level loggers were installed in the Cabot tailrace area and in the Connecticut River between Rock Dam and the Montague USGS Gage (the latter loggers were installed as part of the Instream Flow Study)[19]. Water level loggers were regularly surveyed with an RTK-GPS to check for any movement/settling and were reset to a common elevation datum.
Spillway Fishway Entrance Area	5	Water level loggers were installed in the Spillway fishway entrance area from June 2014 through October 2015. Two of the loggers were lost during high-flow events between early September and late October.

[19] Rock Dam is a natural rock ledge located approximately 0.7 mi upstream of the Cabot tailrace. The Montague USGS Gage is located approximately 0.9 mi downstream of the Cabot tailrace.

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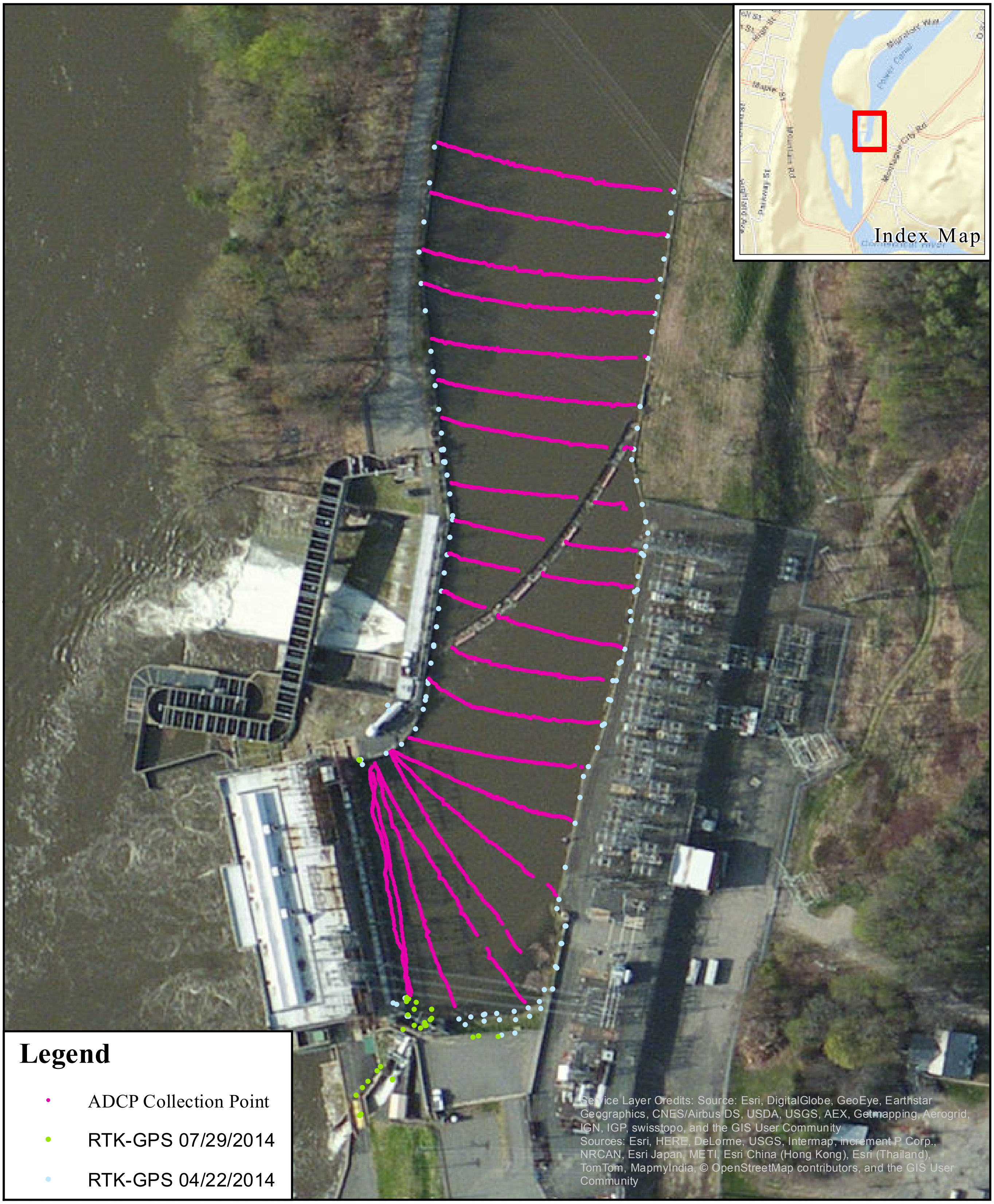
0 75 150 300 Feet

Figure 3-1: Field Data Collection in the Station No. 1 CFD Model Area

Path: W:\gis\studies\3_3_08\maps\Figures\CFD Study Report\Station No.1 All Field Data Collection.mxd



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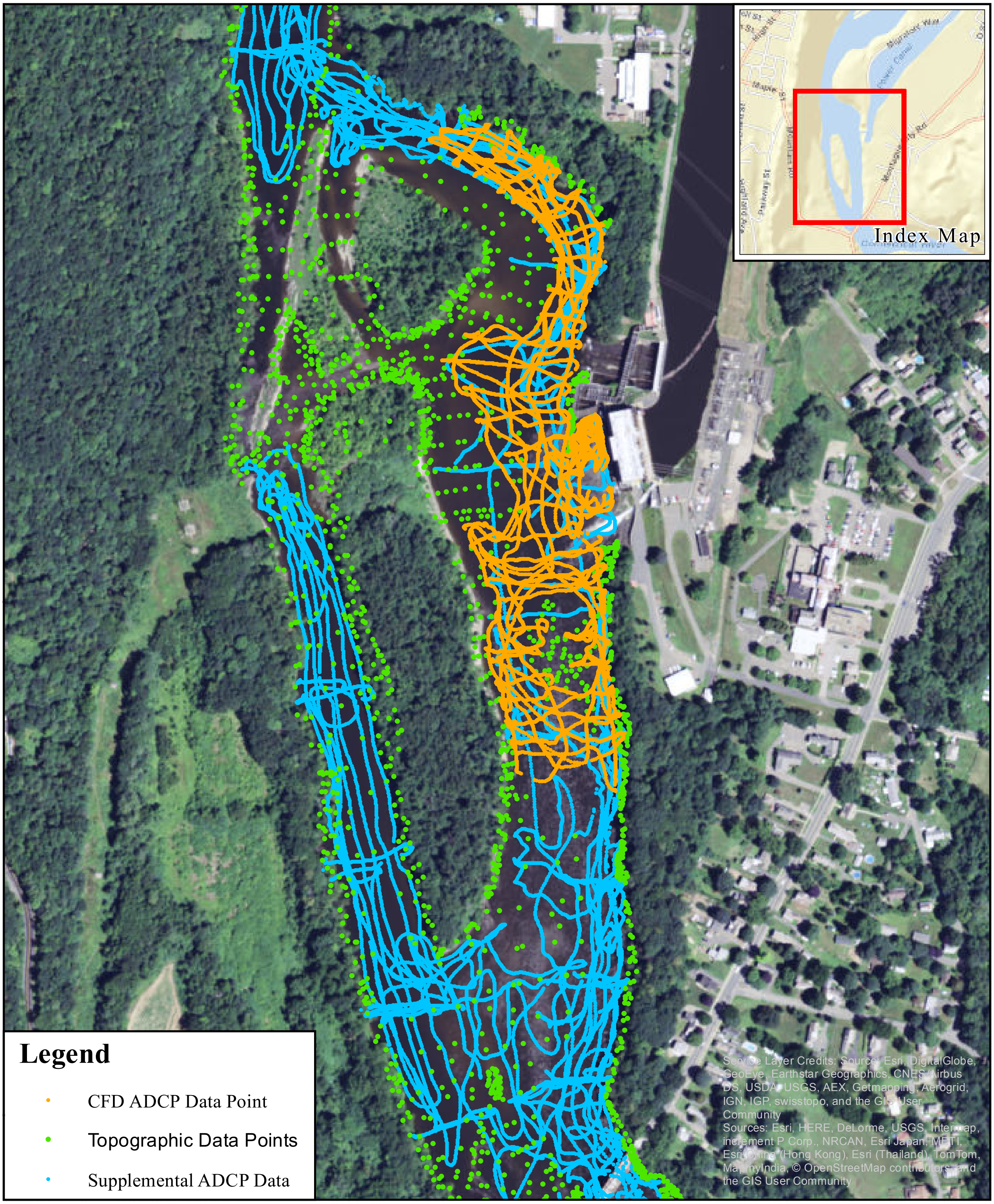
Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)
RELICENSING STUDY 3.3.8

N

0 75 150 300 Feet

Figure 3-2: Field Data Collection in the Cabot Forebay CFD Model Area

Path: W:\gis\studies\3_3_08\maps\Figures\CFD Study Report\Cabot Forebay All Data Collection.mxd



FirstLight
GDF SUEZ

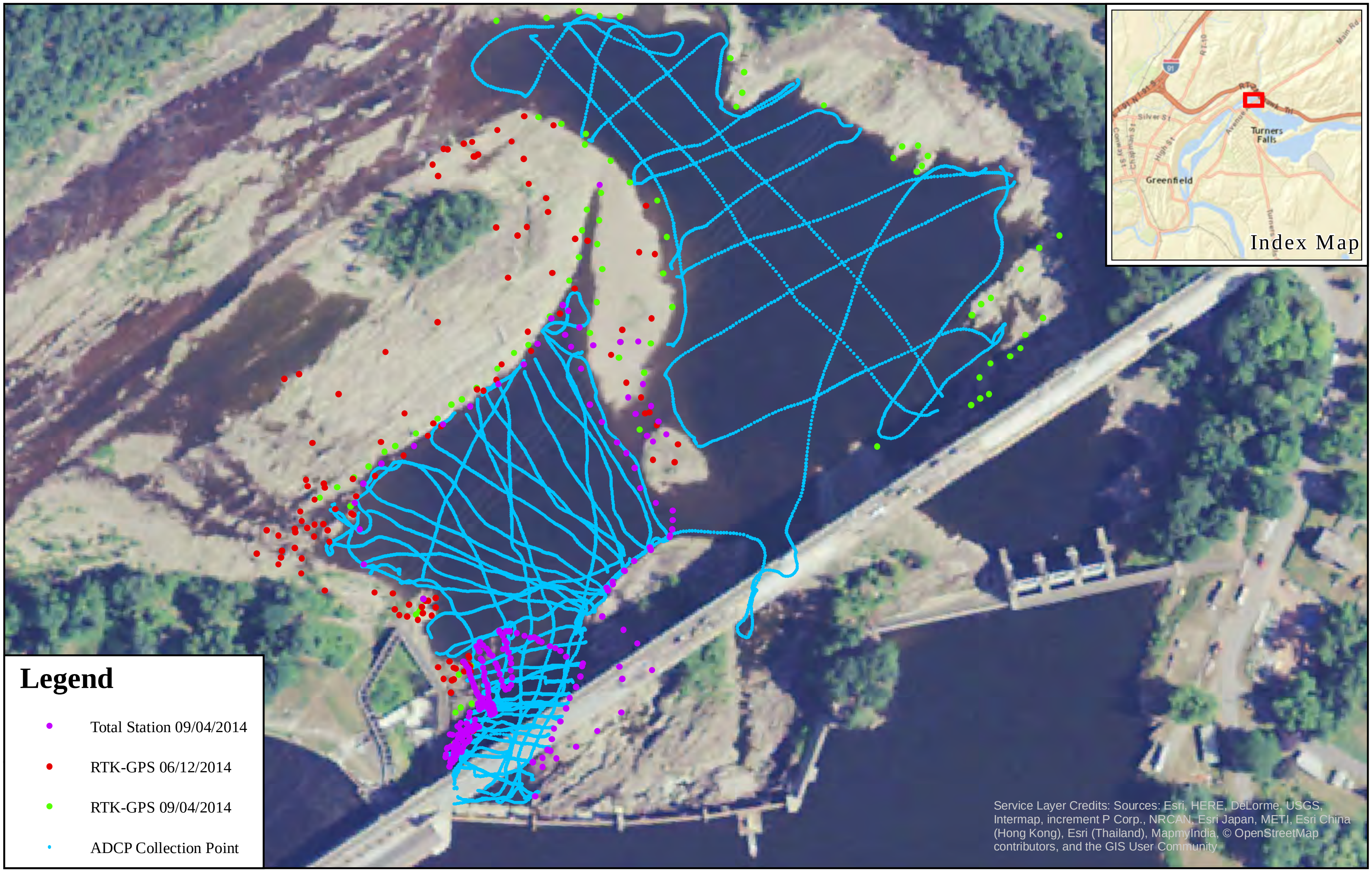
Northfield Mountain Pumped Storage Project (No. 2485)
and Turners Falls Hydroelectric Project (No. 1889)
RELICENSING STUDY 3.3.8

N

0 0.0425 0.085 0.17 Miles

Figure 3-3: Field Data Collection in the Cabot Fishway CFD Model Area

Path: W:\gis\studies\3_3_08\maps\Figures\CFD Study Report\Cabot Fishway All Field Data.mxd



FirstLight
GDF SUEZ

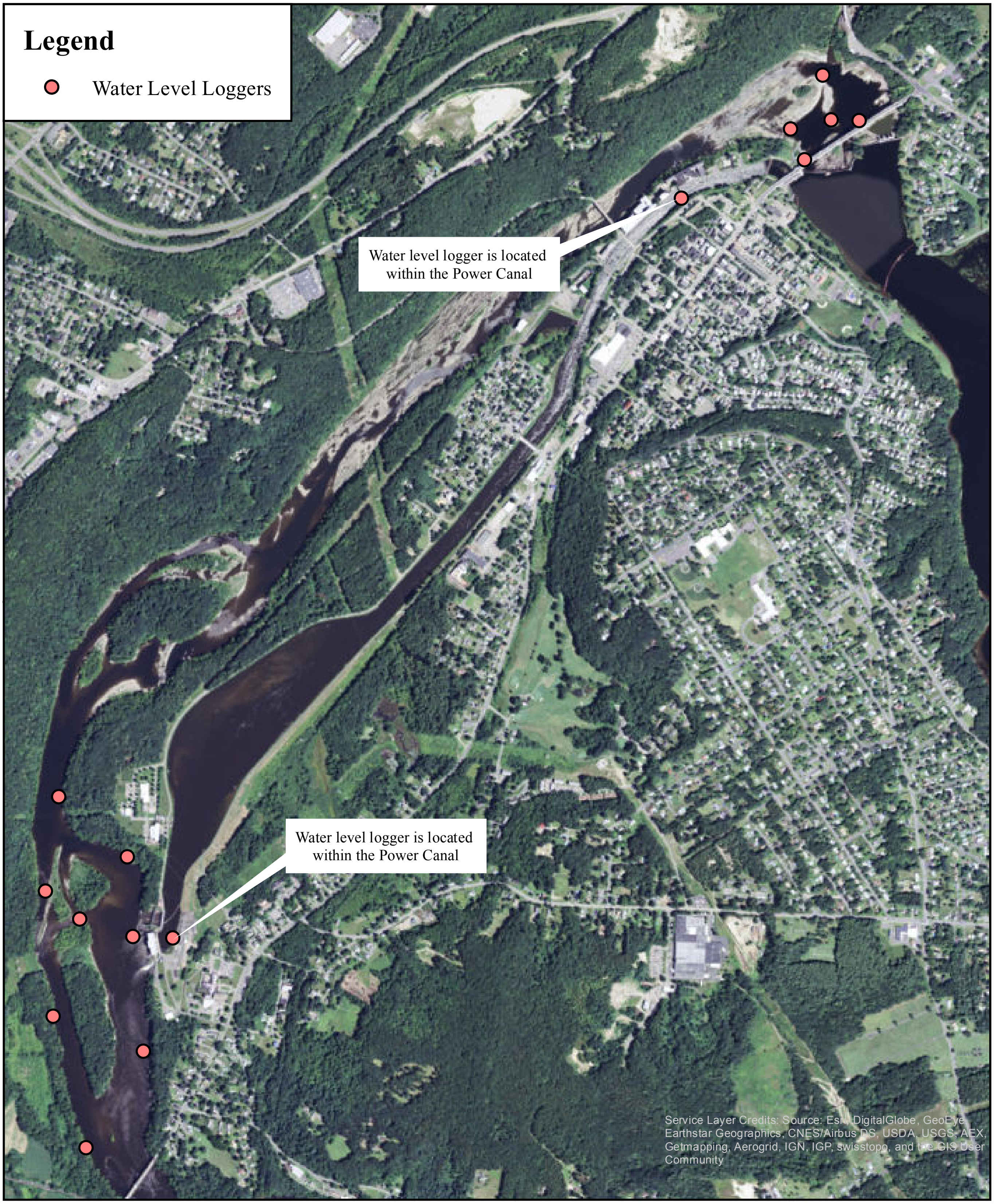
N

Northfield Mountain Pumped Storage Project (No. 2485)
and Turners Falls Hydroelectric Project (No. 1889)

RELICENSING STUDY 3.3.8

0 0.025 0.05 0.1 Miles

Figure 3-4: Field Data Collection in the Spillway Fishway CFD Model Area



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Northfield Mountain Pumped Storage Project (No. 2485)
and Turners Falls Hydroelectric Project (No. 1889)
RELICENSING STUDY 3.3.8

Figure 3.4-1:
Water Level Logger Locations

Path: W:\gis\studies\3_3_08\maps\Figures\CFD Study Report\Water Level Loggers.mxd

4 MODEL GEOMETRY DEVELOPMENT

As described in Section 2, Flow-3D requires that model geometry be defined using solid models exported to the Stereolithography (STL) file format. For the CFD Study, the solid models were developed using one of two different approaches, depending on the type of feature being represented. Generally the solid models for project structures, such as canal walls, bridges piers, intake racks, penstocks, fishway entrances, etc. were developed in AutoCAD Civil 3D (see Section 4.1), while the bathymetric surfaces were developed using a combination of ArcGIS, Meshlab, and Salome Platform (see Section 4.2). All solid models were ultimately exported as STL files for use in the CFD model.

4.1 CAD Model Development

Project drawings and field surveyed data were used to create 3D computer-aided drafting (CAD) drawings of pertinent project structures. FirstLight provided plans and documents related to the Project and 3D solid models of the relevant facilities were built for the Station No. 1 Forebay, Cabot Station Forebay, Cabot Fishway Entrance and Spillway Fishway Entrance models in AutoCAD Civil 3D.

All CAD drawings were first drafted without a coordinate system and then georeferenced into Massachusetts State Plane Coordinate System, Mainland (FIPS Zone 2001 feet) by aligning points from the processed topographic survey with points in the 3D solid models.

The purpose of the solid model geometry is to define the areas where water flows in each model. Accordingly, outside of the canal, forebay or other areas of interest, the CAD model geometry was artificially extended to fill the areas that are not being modeled. By blocking out areas where water is not expected to go, and where results are not required, the model runs are more efficient.

4.1.1 Station No. 1 Forebay

The Station No. 1 Forebay CAD model includes the power canal and forebay walls, trash boom and intake structures up to and including the penstocks. The CAD model extends approximately 1000 linear ft along the power canal and encompasses the entire Station No. 1 forebay.

To reduce the number of digits used for the model coordinates and align the intake racks with the mesh, the STL solid model was translated from Massachusetts State Plane Coordinate System, Mainland (FIPS Zone 2001) to a local coordinate system. This was accomplished by shifting the STL -363,746 ft in the x-direction and -3,038,582 ft in the y-direction (i.e. the origin of the for the CFD modeling STLs will be 363,746 ft east and 3,038,582 ft north in the Massachusetts State Plane Coordinate System). The STL was also rotated such that the intake racks are aligned with the Cartesian coordinate system used for the CFD model mesh. The rotation was 128.3995 degrees counterclockwise about a point (6167 ft, 8957 ft).

Figure 4.1.1-1 shows an overview of the STL files generated from the Station No. 1 Forebay CAD model and the bathymetric surface. Figure 4.1.1-2 shows a close up of the penstock intakes and the intake racks.

4.1.2 Cabot Station Forebay

The Cabot Station Forebay CAD model consists of the forebay and power canal walls, log sluice, fish weir and intake structures, including the intake racks and penstocks. The CAD model extends approximately 700 linear feet from the intake racks along the canal to the point at which the eastern side of the forebay begins to expand.

To reduce the number of digits used for the model coordinates and align the intake racks with the mesh, the STL solid model was translated from Massachusetts State Plane Coordinate System, Mainland (FIPS Zone 2001) to a local coordinate system. This was accomplished by shifting the STL file -363,746 ft in the x-direction and -3,038,582 ft in the y-direction (i.e. the origin of the for the CFD modeling STLs will be

363,746 ft east and 3,038,582 ft north in the Massachusetts State Plane Coordinate System). The STL was also rotated such that the intake racks are aligned with the Cartesian coordinate system used for the CFD model mesh. It was rotated 78.4187 degrees counterclockwise about a point (1,922 ft, 2,736 ft).

Figure 4.1.2-1 shows an overview of the STL files generated from the Cabot Station Forebay CAD model and bathymetric surface. Figure 4.1.2-2 shows a close up of the penstock intakes, the intake racks and fish weir.

4.1.3 Cabot Fishway Entrance

The Cabot Fishway Entrance model consists of the powerhouse, entrance gallery, fishway, emergency spillway, and log sluice. The CAD model was built based on a combination of station drawings and field measurements. The fishway channel is 16 ft wide, not including the exterior walls.

Fish typically enter through either one of the 4 ft wide gates at the northern end of the entrance gallery. The fishway entrance invert is at approximately elevation 104.5 ft when fully open, which is how it was modeled for this study. Flow can also pass by the main entrance gates and pass through the fishway entrance gallery. Historically, however, fish have not utilized the entrance gallery. Current operations, therefore, do not pass any water though any of the entrance gallery gates. The production runs in this study assume there is no flow passing through the entrance gallery, so the gallery area has been blocked off in the model.

Immediately below the entrance gallery are the six Cabot Station draft tubes whose top and bottom elevations are 105.75 ft and 91.25 ft respectively at the point of discharge into the tailrace. About 350 ft south of the primary fishway entrance gates is a log sluice that discharges into the river.

To reduce the number of digits used for the model, the STL solid model was translated from Massachusetts State Plane Coordinate System, Mainland (FIPS Zone 2001) to a local coordinate system. This was accomplished by shifting the STL file -363,746 ft in the x-direction and -3,038,582 ft in the y-direction (i.e. the origin of the for the CFD modeling STLs will be 363,746 ft east and 3,038,582 ft north in the Massachusetts State Plane Coordinate System). The STL for this model was not rotated.

Figure 4.1.3-1 shows an overview of the STL files generated from the Cabot Station Fishway CAD model and bathymetric surface. Figure 4.1.3-2 shows a close up of the fishway entrance and the Cabot Station draft tubes. The full fishway CAD model is shown for reference, but the majority of the fishway was not included in the model as it was outside of the target study area.

4.1.4 Spillway Fishway Entrance

The Spillway Fishway Entrance model consists of the Montague Dam, its four bascule gates, east and west abutments, and the fishway. The Spillway Fishway, which is on the west side of the bypass channel (river left), consists of a series of weir and baffle structures that provide resting pools for the fish so they may reach the Gatehouse Fishway. The fishway entrance's invert is at elevation 133.63 ft, and the two gate entrances are about 4 ft wide each. The Spillway Fishway is about 10 ft wide, not including the exterior walls. The Gill Dam, which is on the east side of the river and includes the tainter gates, was not explicitly included in this model.

For this model, CAD geometries were developed with the four bascule gates in a fully closed (crest elevation of 185.5 ft), halfway open (crest elevation of 177.91 ft), or fully open (crest elevation of 170.16 ft) position. Bascule gates that pass flow in a given model scenario were modeled as halfway open, while bascule gates that pass no flow in a given model scenario were represented in a fully closed position. The fully open bascule gate position was not used in any of this study's model scenarios.

To reduce the number of digits used for the model, the STL solid model was translated from Massachusetts State Plane Coordinate System, Mainland (FIPS Zone 2001) to a local coordinate system. This was accomplished by shifting the STL file -363,746 ft in the x-direction and -3,038,582 ft in the y-direction (i.e.

the origin of the for the CFD modeling STLs will be 363,746 ft east and 3,038,582 ft north in the Massachusetts State Plane Coordinate System). The STL for this model was not rotated.

Figure 4.1.4-1 shows an overview of the STL files generated from the Spillway Fishway CAD model and bathymetric surface. Figure 4.1.4-2 is a closeup view of the spillway ladder area.

4.2 Bathymetric Surface Development

Using the ADCP and topographic data that were collected as described in Section 3, a 3D surface and solid model were developed for the channel/canal bathymetry within each CFD model study area.

The procedure for converting collected ADCP LiDAR and topographic datasets to a solid model generally includes:

1. Convert the raw survey data (ADCP, RTK-GPS or total station) to a Geographic Information System (GIS) dataset with the required projection and vertical datum. This includes any collection specific post-processing that is required.
2. Review the data and address any identified issues. This could include, for example, removing outliers caused by the loss of GPS coverage during data collection or adjusting the collected ADCP data to more closely align with the RTK-GPS data.
3. Create a Triangulated Irregular Network (TIN) of the bathymetric surface using ArcGIS 3D Analyst. This TIN combines all of the available ADCP, LiDAR and topographic survey data to create a continuous surface that includes both above and below water topography/bathymetry.
4. Convert the TIN surface to a solid model in STL format for use in the Flow-3D model.

The following sections provide specific details regarding the development of the bathymetric surface for each CFD model.

4.2.1 Station No. 1 Forebay

The ADCP data collected for the Station No. 1 Forebay model underwent significant post-processing during the development of the bathymetric surface. This included shifting the data horizontally to align with the RTK-GPS survey, removing points that were within 1 foot of RTK-GPS survey data points, and thinning out data points that are within 2.0 ft horizontally or 1.0 ft vertically of another point. The purpose of these adjustments was to improve the overall surface and reduce sharp discontinuities due to differences in data collection methods.

The ADCP unit collected the depth of the water along each transect. In order to determine the elevation of the channel/canal bottom, the depth of the water had to be subtracted from the WSEL at the time the data was collected. A constant WSEL value of 173.3 ft was used when calculating bed elevations from the ADCP depth data. This WSEL was based on measured WSELs at Keith's Bridge (upstream) and Cabot Station (downstream) collected on 3/28/2014 when the ADCP data was being collected, as well as surveyed water levels (edge of water) in the forebay collected on 4/22/2014, as described in Section 3.1 and Section 3.2, respectively. The average WSELs at Keith's Bridge and Cabot Station on 3/28/2014 were 173.5 ft and 173.4 ft, respectively, during data collection. On 4/22/2014 the average water surface elevation in the forebay was approximately 173.3 ft. Based on field observations there is a WSEL gradient through the abandoned railroad bridge at the inlet to the forebay from the power canal to the forebay, and ultimately the ADCP bathymetry was only used to generate for the bathymetric surface within the forebay. Accordingly, the assumed WSEL used to convert the ADCP depth data to bed elevations was 173.3 ft, which is the assumed WSEL in the forebay when the ADCP data was collected.

After the ADCP data was converted to a GIS dataset, it was compared to the above-water RTK-GPS data (collected on 3/28/2014 and 4/21/2014) and available aerial photos. This comparison showed that ADCP data needed to be shifted 7.0 ft to the south and 4.5 ft to the east. Upon comparison of the collected ADCP transects to the RTK-GPS bathymetric survey in the forebay (collected 9/29/2014 and 9/30/2014), five (5) transects required an additional shift that ranged from -2.5 ft–2.0 ft to the east, and from -4.5 ft–3.5 ft to the north.

In addition to the processed ADCP data, all of the available and relevant RTK-GPS and total station survey data collected in the CFD model area were used to create the TIN. Lastly, some additional forcing GIS datasets (points and break lines) were created and used to control the triangulation of the TIN.

Figure 4.2.1-1 shows the resulting TIN developed for the Station No. 1 Forebay model.

The bathymetric surface TIN was converted to an STL file for input to the Flow-3D model. To reduce the number of digits used for the model coordinates and align the intake racks with the mesh, the STL solid model was translated from Massachusetts State Plane Coordinate System, Mainland (FIPS Zone 2001) to a local coordinate system. This was accomplished by shifting the STL -363,746 ft in the x-direction and -3,038,582 ft in the y-direction (i.e. the origin of the CFD modeling STLs will be 363,746 ft east and 3,038,582 ft north in the Massachusetts State Plane Coordinate System). The STL was also rotated such that the intake racks are aligned with the Cartesian coordinate system used for the CFD model mesh. The rotation was 128.3995 degrees counterclockwise about a point (6167 ft, 8957 ft).

Figure 4.1.1-1 shows an overview of the STL files generated from the Station No. 1 Forebay CAD model and bathymetric surface.

4.2.2 Cabot Station Forebay

The ADCP data collected for the Cabot Station Forebay model underwent significant post-processing during the development of the bathymetric surface, including shifting the ADCP data horizontally to align with the RTK-GPS survey.

The ADCP unit collected the depth of the water along each transect. In order to determine the elevation of the channel/canal bottom the depth of the water had to be subtracted from the WSEL at the time the data was collected. A constant WSEL value of 173.6 ft was used when calculating bed elevations from the ADCP depth data. This WSEL was based on the average measured WSELs at the Cabot Station water level logger collected on 3/29/2014 when the ADCP data was being collected. Details regarding this water level logger are provided in Section 3.4.

After the ADCP data were converted to a GIS dataset, it was compared to the above-water RTK-GPS data for the area and available aerial photos. This comparison showed that ADCP data needed to be shifted 3.0 ft to the south and 4.0 ft to the east to properly align with the RTK-GPS data.

Figure 4.2.2-1 shows the TIN developed for the Cabot Station Forebay model.

The bathymetric surface TIN was converted to an STL file for input to the Flow-3D model. To reduce the number of digits used for the model coordinates and align the intake racks with the mesh, the STL solid model was translated from Massachusetts State Plane Coordinate System, Mainland (FIPS Zone 2001) to a local coordinate system. This was accomplished by shifting the STL file -363,746 ft in the x-direction and -3,038,582 ft in the y-direction (i.e. the origin of the CFD modeling STLs will be 363,746 ft east and 3,038,582 ft north in the Massachusetts State Plane Coordinate System). The STL was also rotated such that the intake racks are aligned with the Cartesian coordinate system used for the CFD model mesh. It was rotated 78.4187 degrees counterclockwise about a point (1,922 ft, 2,736 ft).

Figure 4.1.2-1 shows an overview of the STL files generated from the Cabot Station Forebay CAD model and bathymetric surface.

4.2.3 Cabot Fishway Entrance

The bathymetric surface for this model was developed in GIS by combining topography and bathymetry data from a combination of field-collected data (described in Section 3) including ADCP data, topographic survey data (RTK-GPS and total station), and LiDAR data. Figure 4.2.3-1 shows the TIN developed for the Cabot Fishway entrance.

The bathymetric surface TIN was converted to an STL file for input to the Flow-3D model. The extruded STL file was shifted into the model coordinate system within Flow3D by shifting the STL solid model file -363,746 ft in the x-direction and -3,038,582 ft in the y-direction (i.e. the origin of the CFD modeling STLs will be 363,746 ft. east and 3,038,582 ft. north in the Massachusetts State Plane Coordinate System). The STL was not rotated.

Figure 4.1.3-1 shows an overview of the STL files generated from the Cabot Station Fishway CAD model and bathymetric surface.

4.2.4 Spillway Fishway Entrance

The bathymetric surface for this model was developed in GIS by combining topography and bathymetry data from a combination of field-collected data (described in Section 3) including ADCP data, topographic survey data (RTK-GPS and total station), and LiDAR data. Figure 4.2.4-1 shows the TIN developed for the Spillway Fishway entrance. As seen in the figure, field data were not collected in the tainter gate channel.

The extruded STL file was shifted into the model coordinate system within Flow3D by shifting the STL solid model file -363,746 ft in the x-direction and -3,038,582 ft in the y-direction (i.e. the origin of the CFD modeling STLs will be 363,746 ft. east and 3,038,582 ft. north in the Massachusetts State Plane Coordinate System). The STL was not rotated.

Figure 4.1.4-1 shows an overview of the STL files generated from the Cabot Station Fishway CAD model and bathymetric surface.

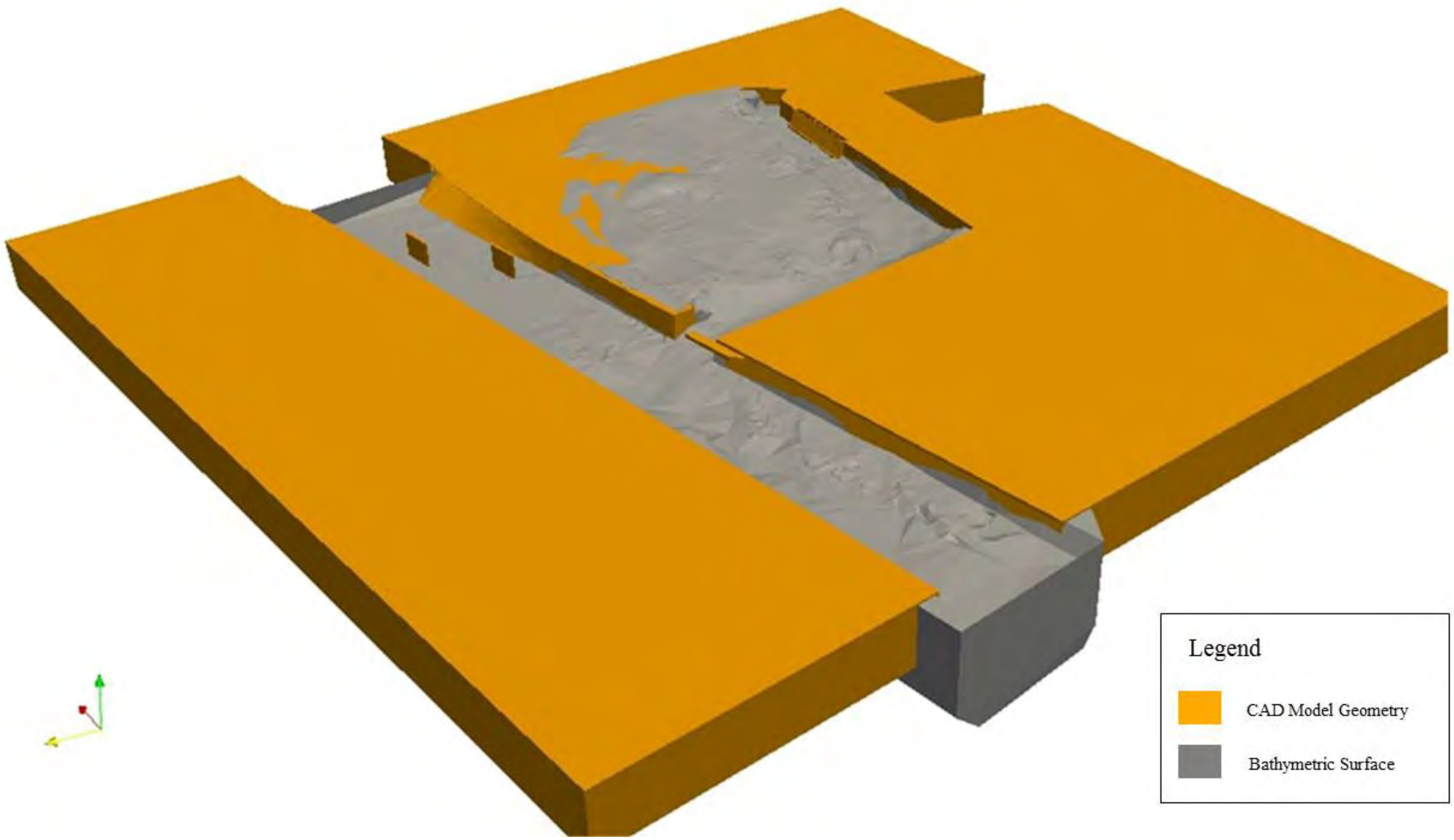


Figure 4.1.1-1: Station No. 1 CAD Model and Bathymetric Surface Overview

Figure 4.1.1-2: Station No. 1 CAD Model Penstock Close-up

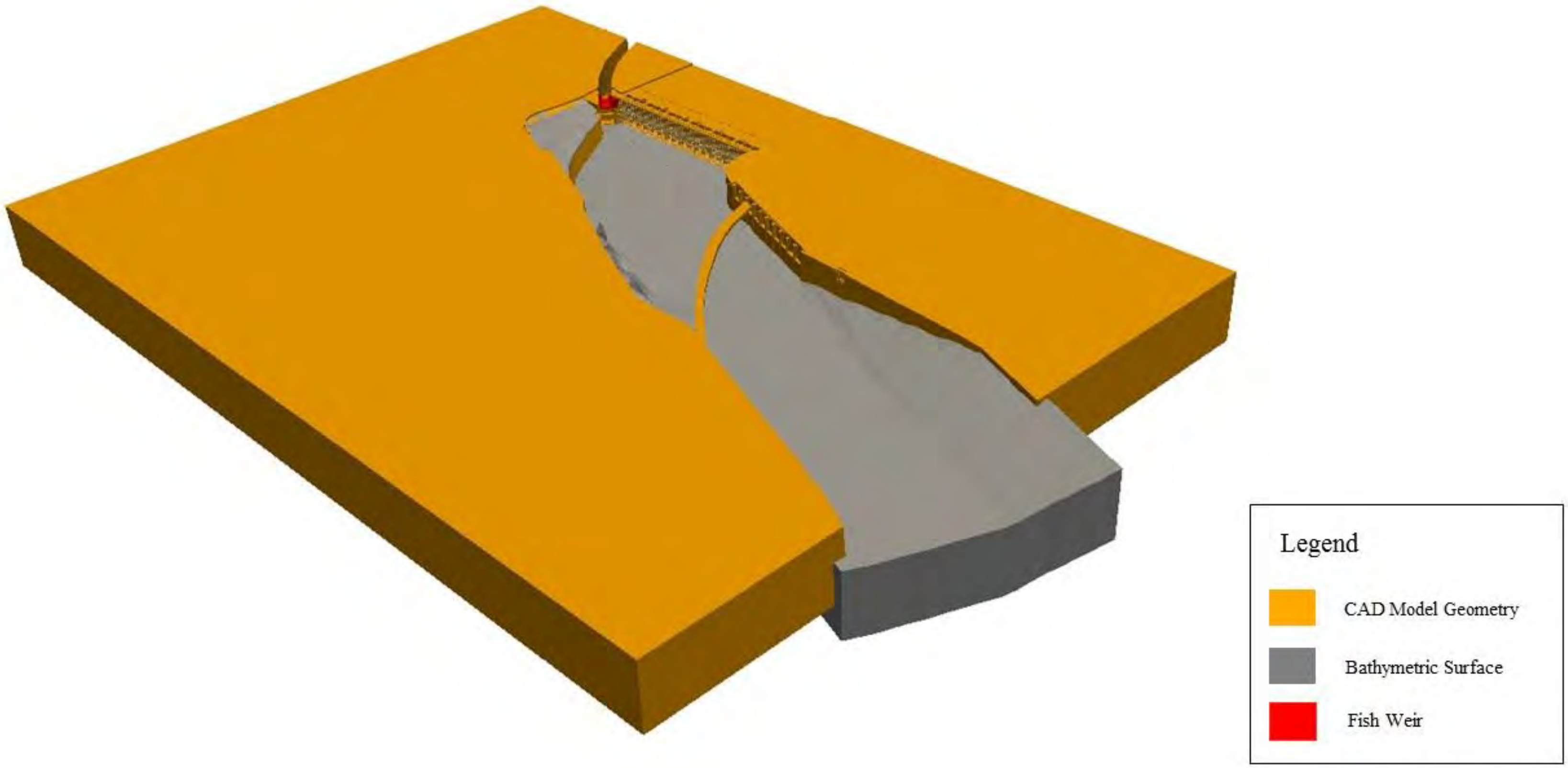


Figure 4.1.2-1: Cabot Station CAD Model and Bathymetric Surface Overview

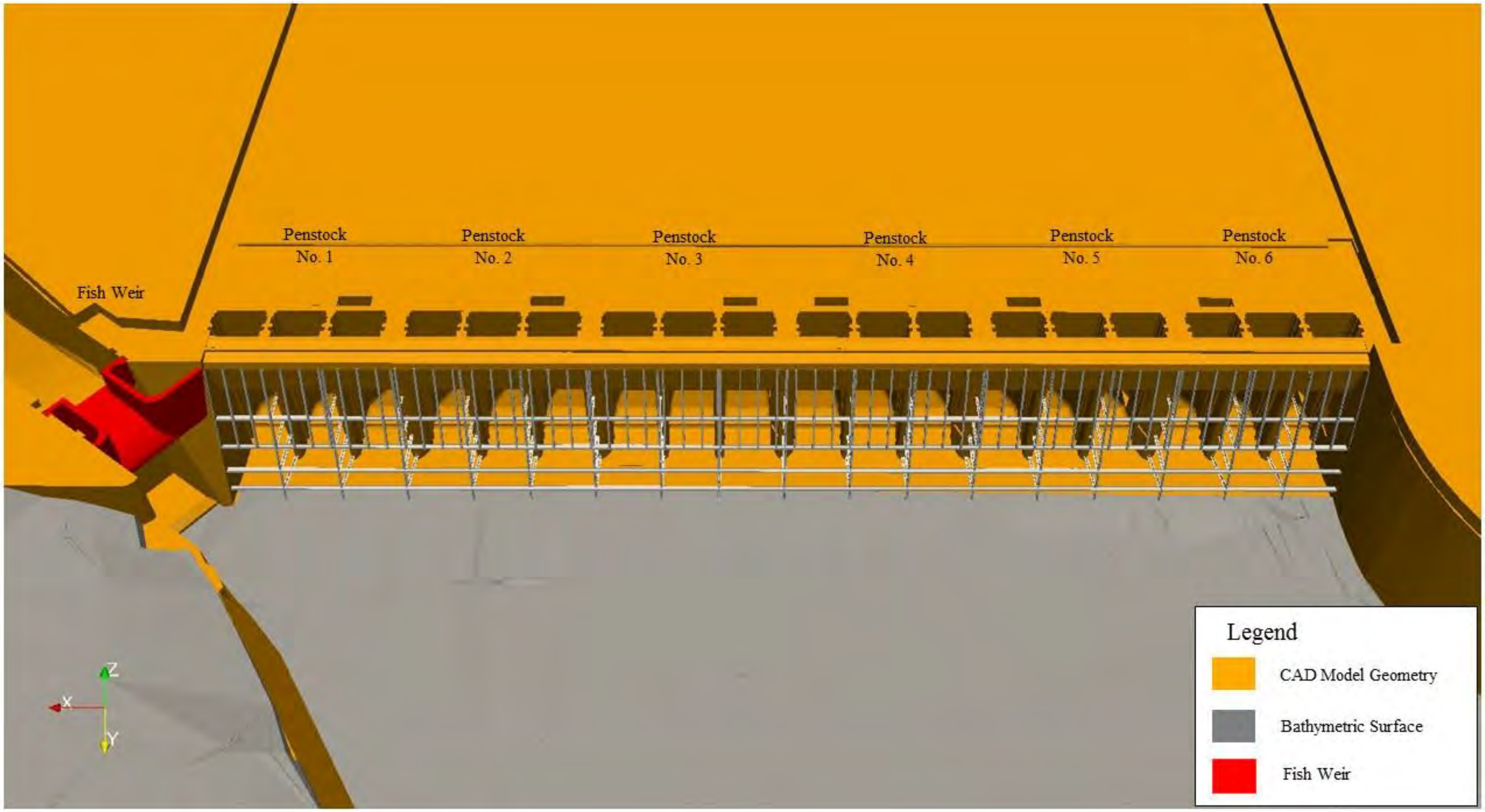


Figure 4.1.2-2: Cabot Station CAD Model Penstock Close-up

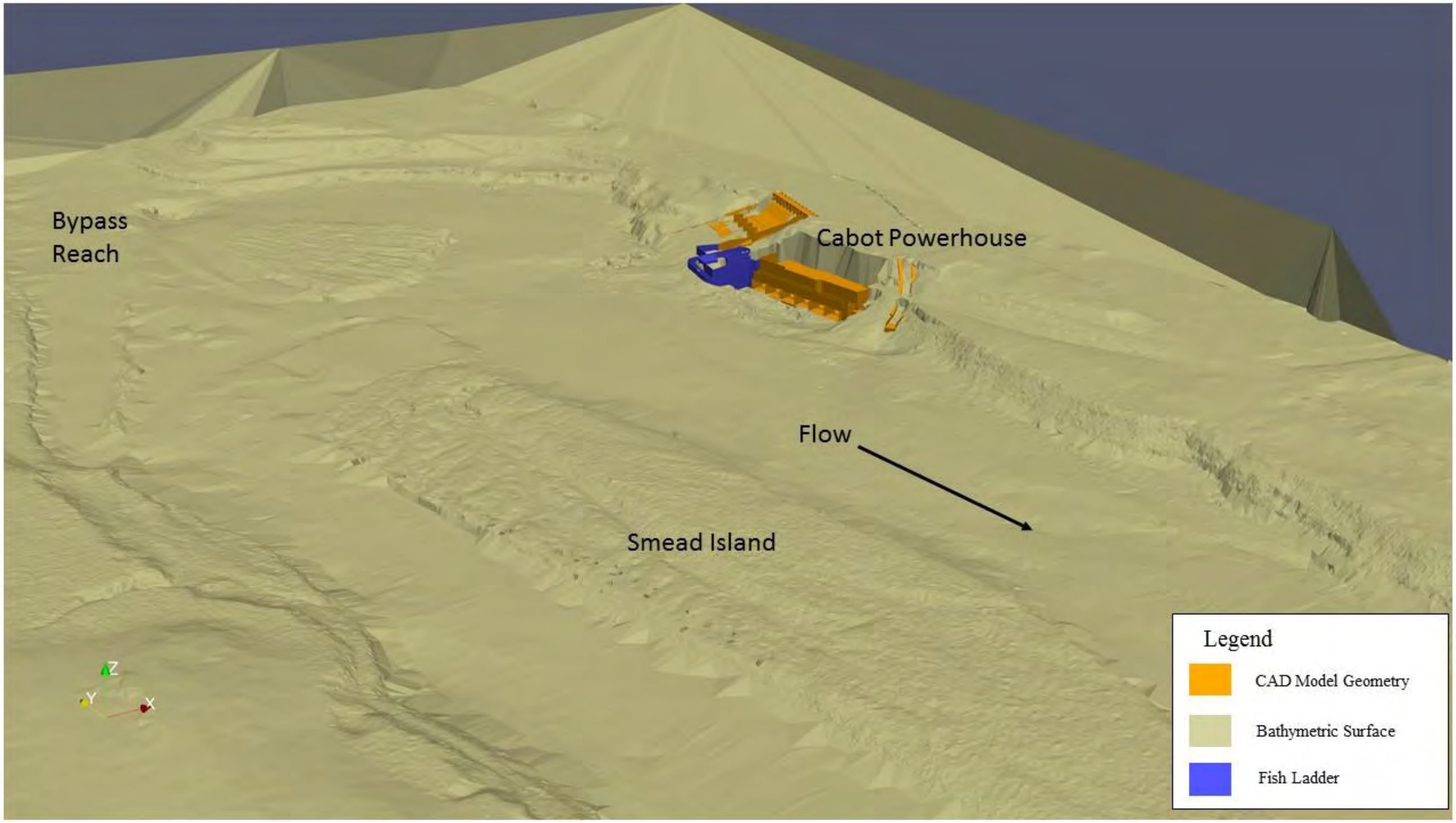


Figure 4.1.3-1: Cabot Station Tailrace CAD Model Overview

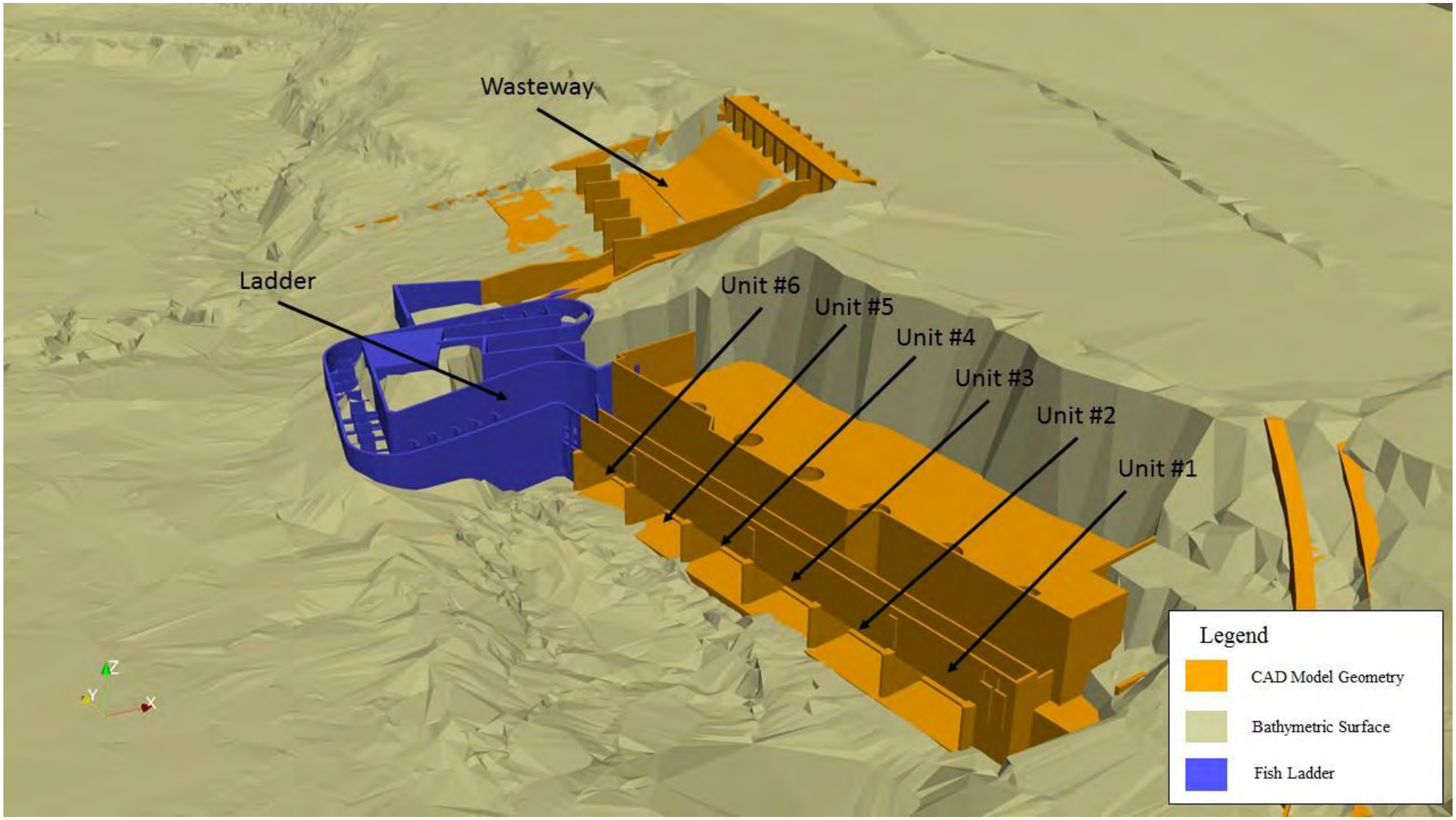


Figure 4.1.3-2: Cabot Station Tailrace CAD Model Close-up

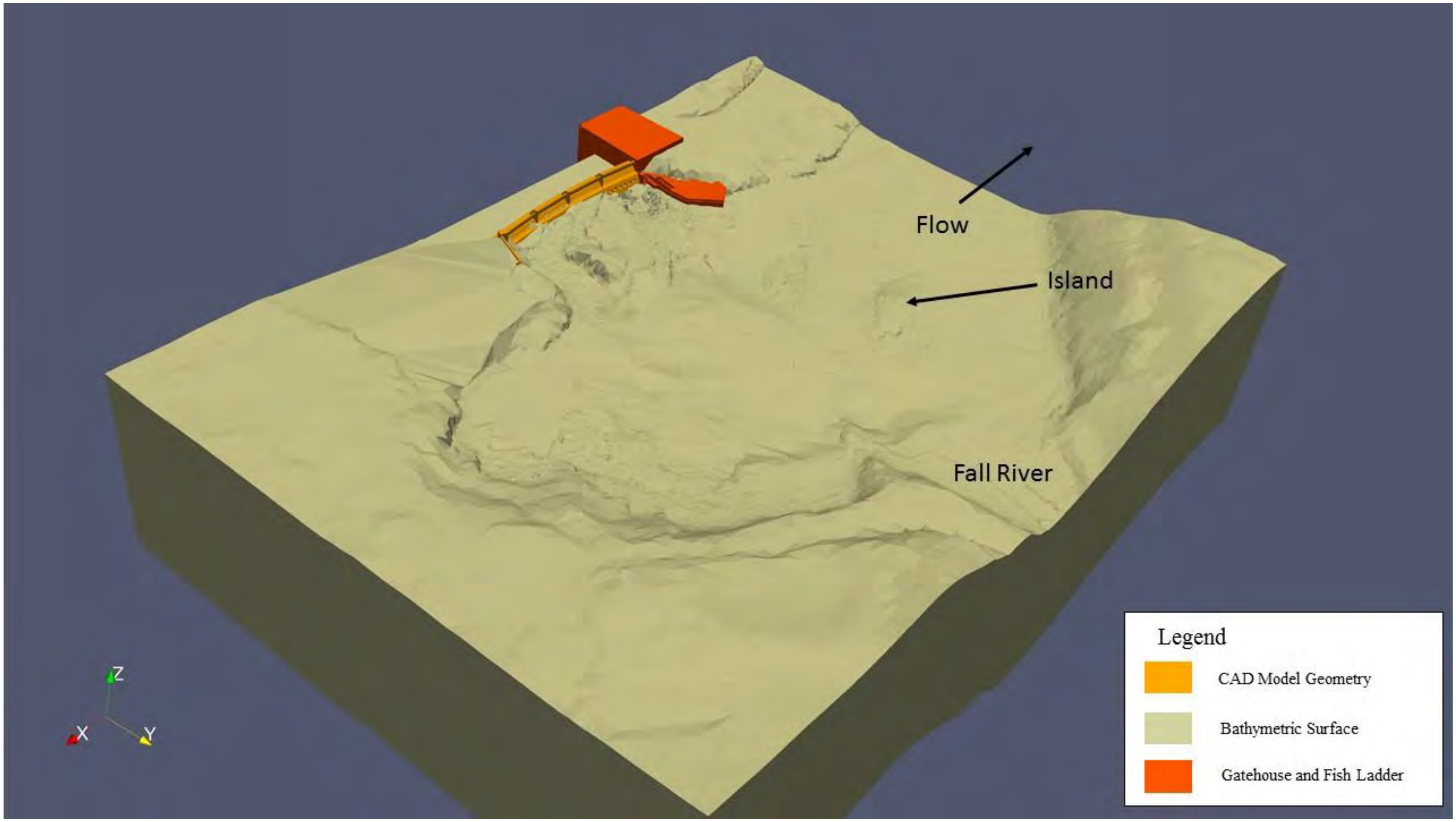


Figure 4.1.4-1: Spillway Ladder CAD Model Overview

Note: The orange shape just upstream of the bascule gate represents a portion of the gatehouse, while the orange shape just downstream of the bascule gates represents the fish ladder.

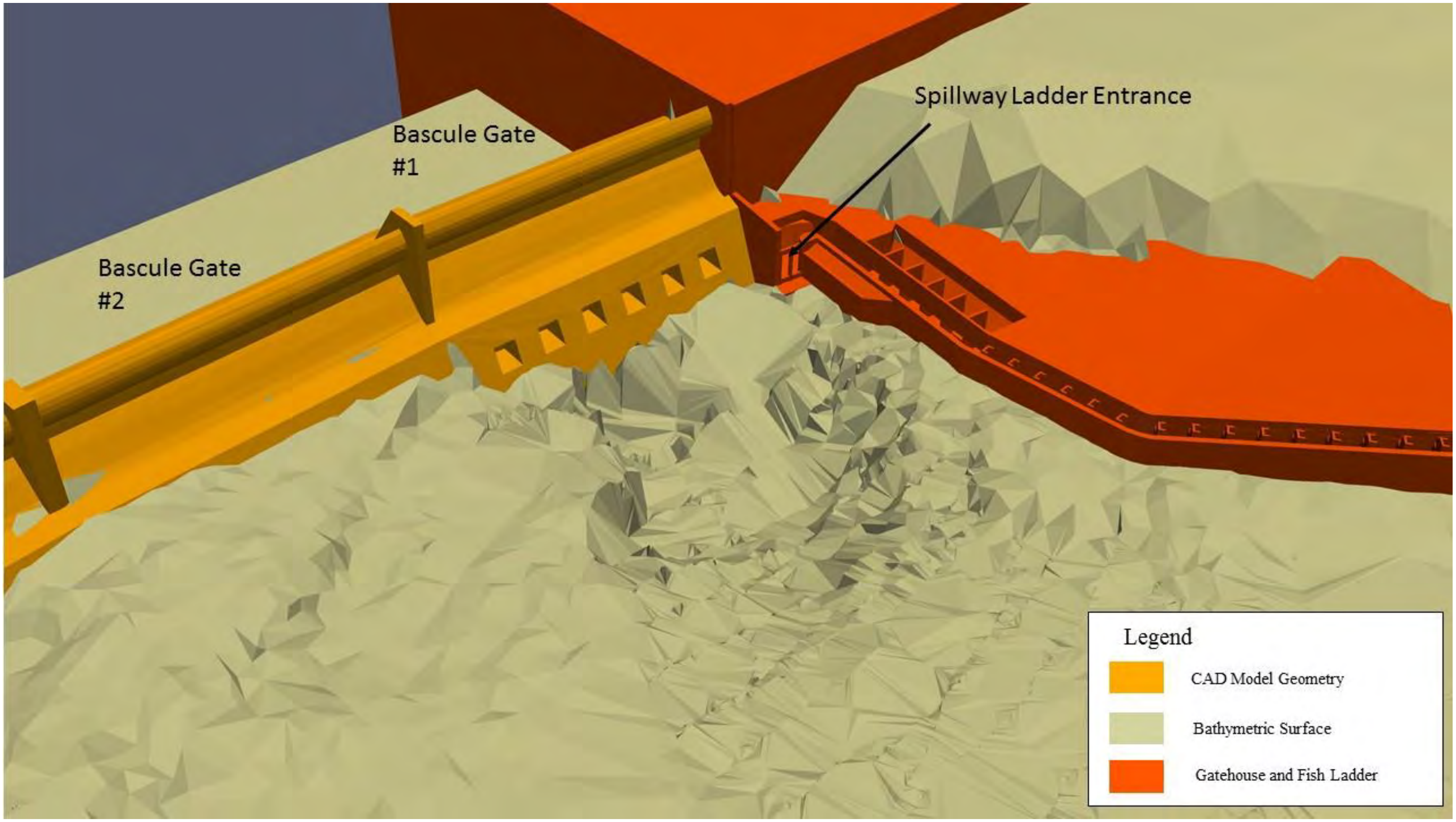
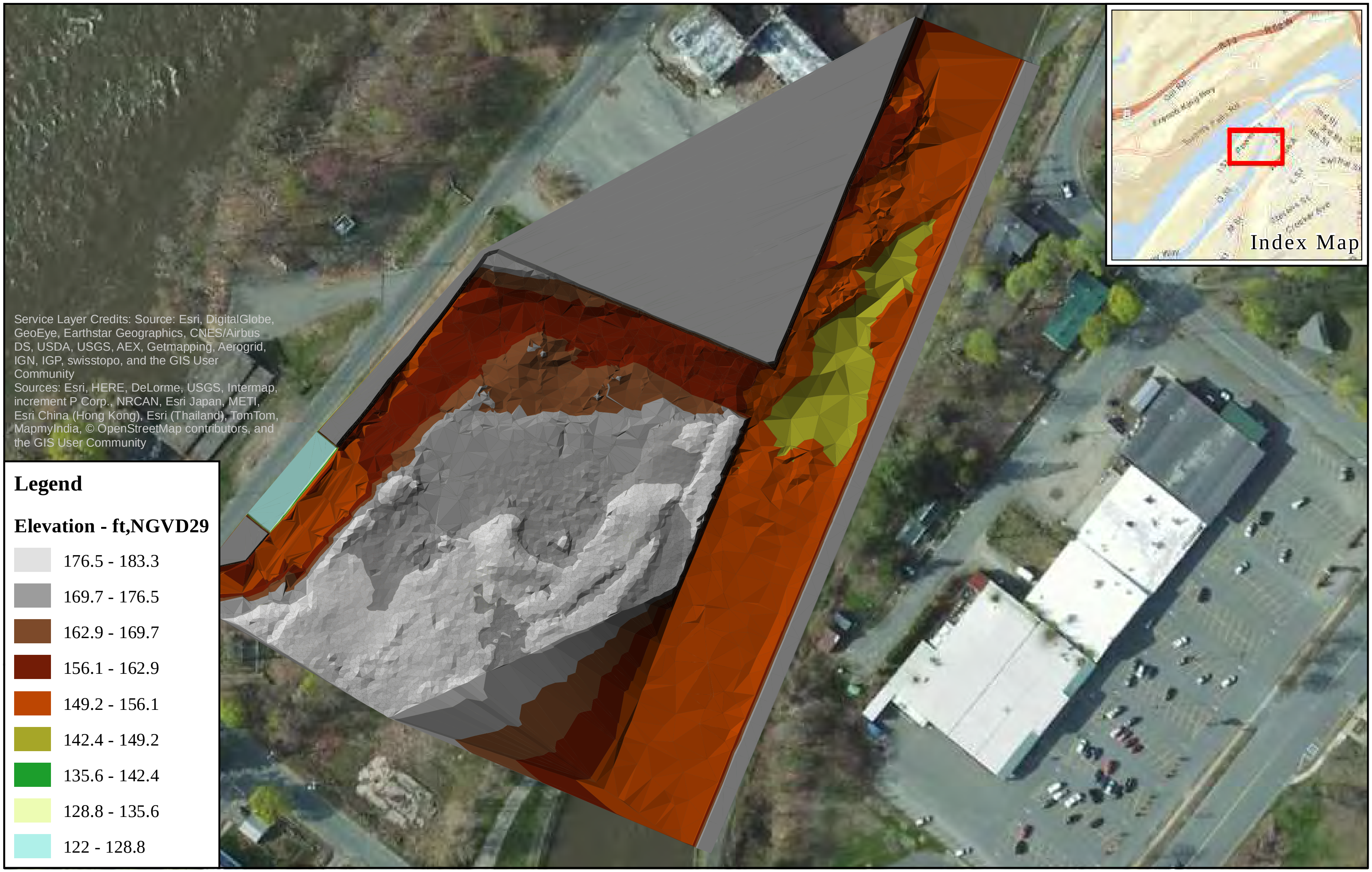


Figure 4.1.4-2: Spillway Ladder CAD Model Close-up

Note: The orange shape just upstream of the bascule gate represents a portion of the gatehouse, while the orange shape just downstream of the bascule gates represents the fish ladder.



Northfield Mountain Pumped Storage Project (No. 2485)
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Figure 4.2.1-1: Station No. 1 Intake Area TIN

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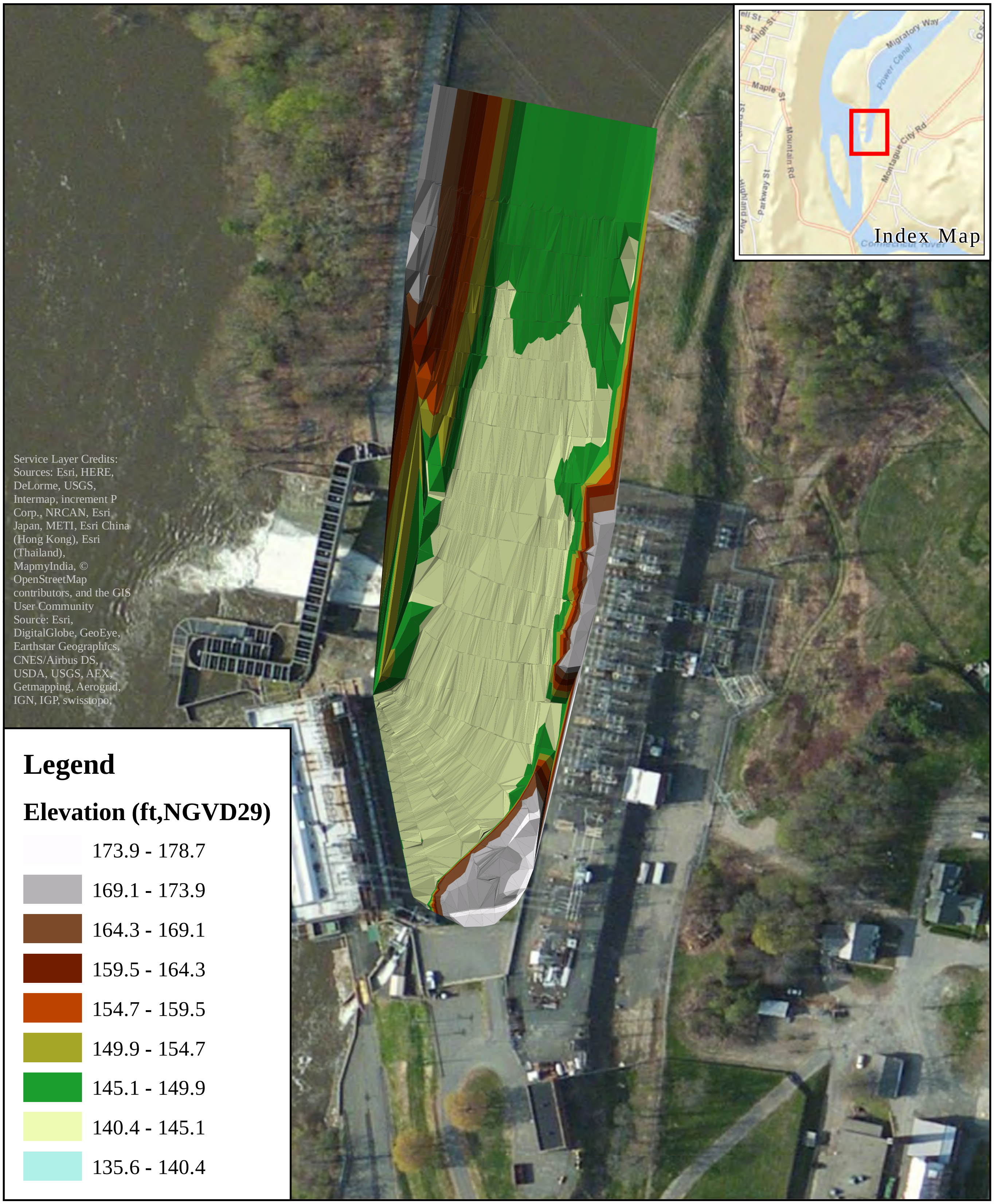

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Northfield Mountain Pumped Storage Project (No. 2485)
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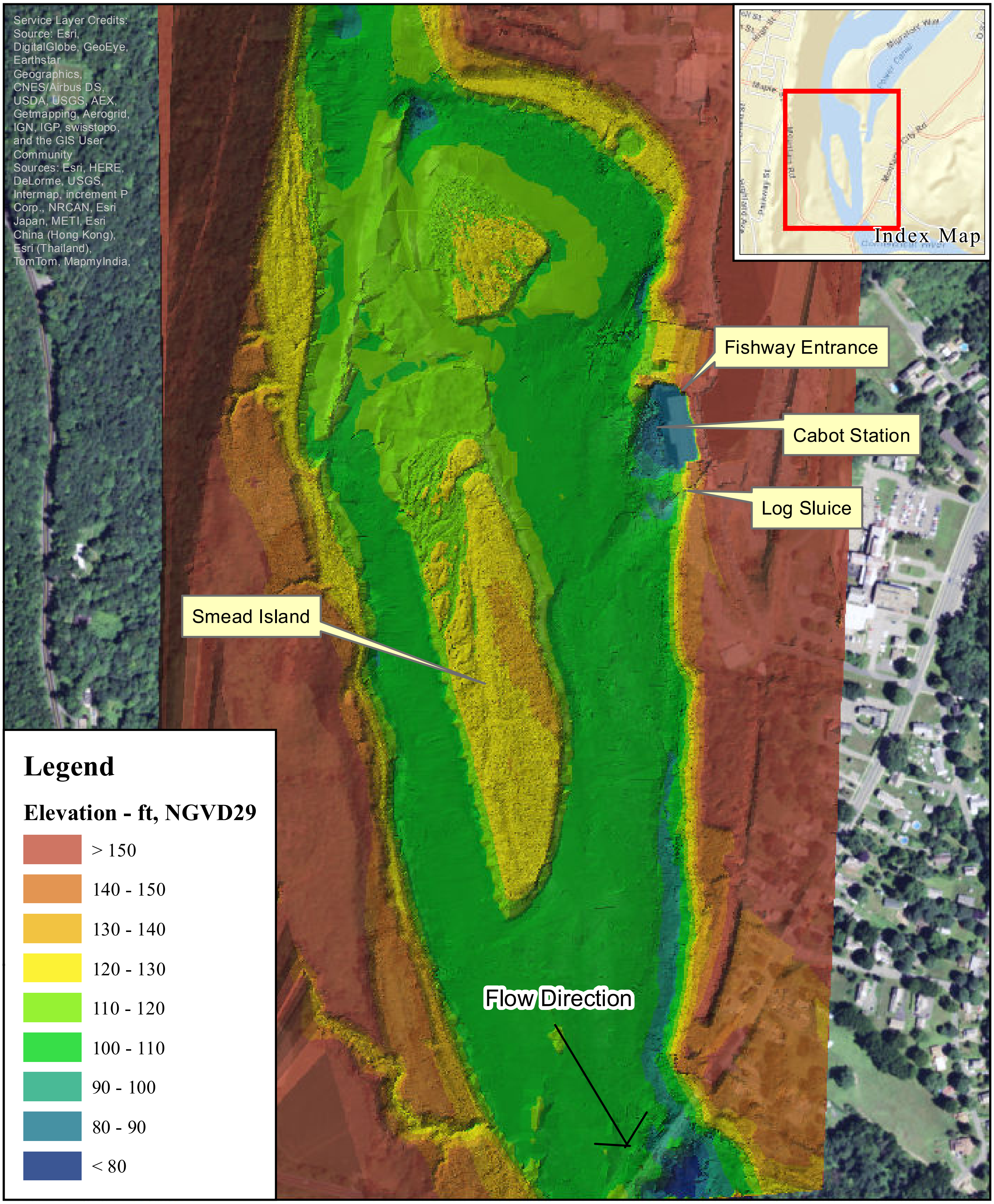
N

0 0.0125 0.025 0.05
Miles

Figure 4.2.2-1: Cabot Station Intake Area TIN

Path: W:\gis\studies\3_3_08\maps\Figures\CFD Study Report\Cabot Forebay TIN.mxd



Northfield Mountain Pumped Storage Project (No. 2485)
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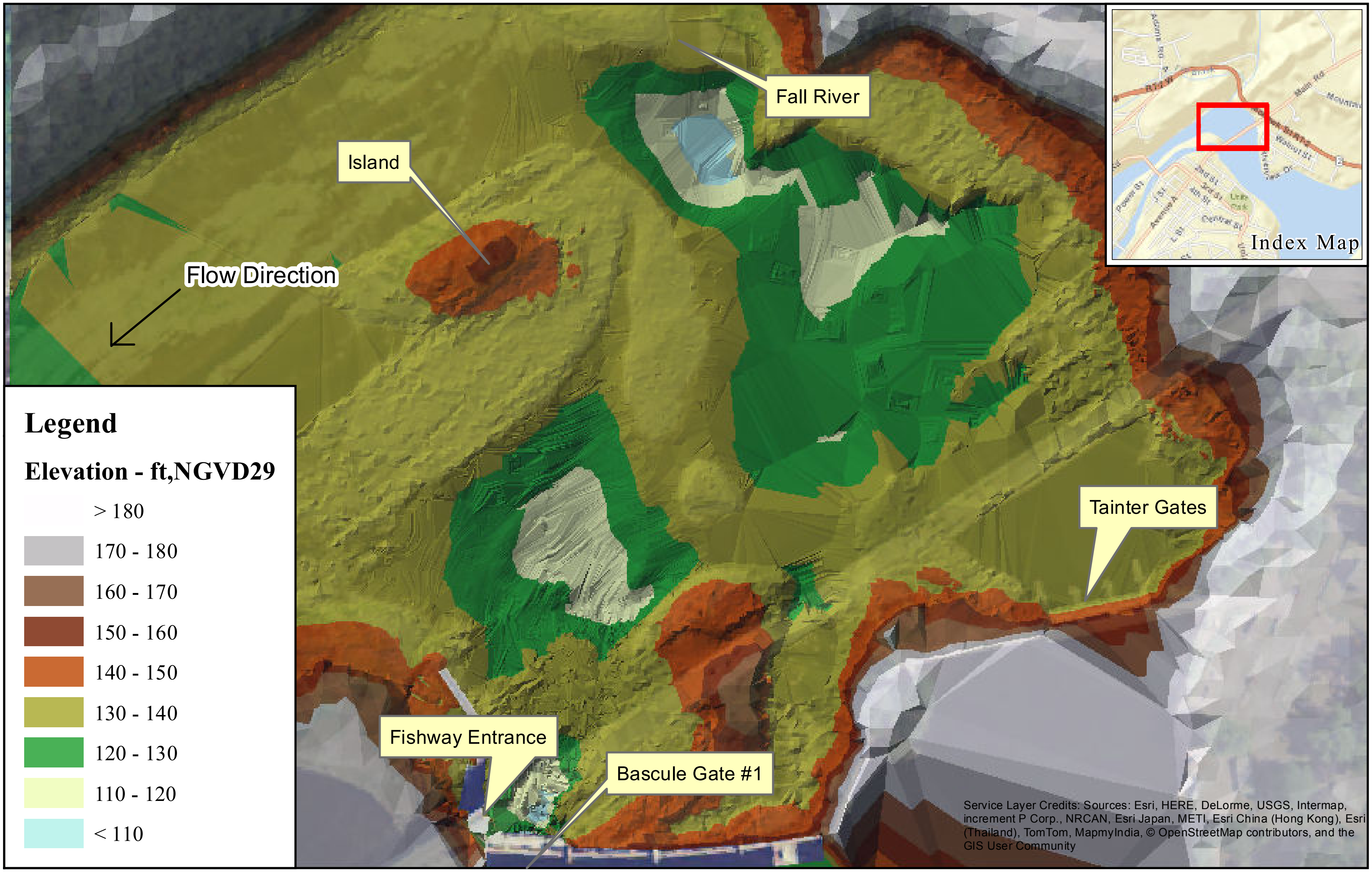
Figure 4.2.3-1: Cabot Fishway Area TIN

N

0 0.05 0.1 0.2 Miles

Path: W:\gis\studies\3_3_08\maps\Figures\CFD Study Report\Cabot Fishway TIN.mxd



Northfield Mountain Pumped Storage Project (No. 2485)
and Turners Falls Hydroelectric Project (No. 1889)
RELICENSING STUDY 3.3.8

N

0 0.025 0.05 0.1 Miles

Figure 4.2.4-1: Spillway Fishway Entrance Area TIN

Path: W:\gis\studies\3_3_08\maps\Figures\CFD Study Report\Spillway TIN.mxd

5 CFD MODEL DEVELOPMENT

A total of four (4) CFD models were developed for CFD Study. Details regarding each individual model are provided in the following sections.

5.1 Station No. 1 Forebay

The Station No. 1 Forebay CFD model includes the penstocks and intakes, forebay and a portion of the power canal in front of the forebay entrance. The power canal portion of the model extends from approximately 300 ft upstream of the forebay entrance to approximately 450 ft downstream of the forebay entrance, for a total length of approximately 750 ft. The forebay portion extends from the power canal through the entire forebay and into the penstocks where the model terminates.

Figure 5.1-1 shows the seven (7) block mesh regions used to define the computational mesh for the CFD model as well as the location of the inflow and outflow boundary condition locations.

The mesh block details are shown in Table 5.1-1. When combined with the CAD model and bathymetric surface STL files, the block mesh configuration shown in Figure 5.1-1 results in 28,296,156 total and 3,999,947 active cells. Active cells are the cells that remain for fluid to occupy after cells that are completely blocked by the solid model are removed. Initially the model was run without the Canal Refinement block mesh, but final runs included it.

In addition to the boundary conditions and initial conditions described in Section 2, Table 5.1-2 describes the boundaries that control the inflow and outflow from the model. The location of the boundaries are also shown in Figure 5.1-1.

The initial conditions used for fluid elevation (i.e. water surface elevation) and velocity in the models varied from run to run. For the first run (the verification run) the fluid elevation was set to 173.5 ft and the velocity to 0 fps (feet per second), however some subsequent runs (and scenarios) were started using the final conditions from previous runs to initialize the model with a velocity field that was closer to the expected steady state solution. This does not affect the final results, but reduces the amount of computation time required to reach a steady state solution.

Numerical "baffles" were used in the model to monitor the flow into and out of the computational domain and through the canal and penstocks over time.

Table 5.1-1: Station No. 1 Forebay Model Mesh Blocks

Mesh Block Name	Mesh Block Size (x, y, z) (ft)	Cell Size (x, y, z) (ft)
Canal	(700, 282, 54)	(2, 2, 2)
Canal Refinement	(680, 282, 54)	(1, 1, 1)
Forebay	(620, 282, 54)	(1, 1, 1)
Penstocks 1 through 4 (4 identical block meshes)	(16, 70, 54)	(1, 1, 1)

Table 5.1-2: Station No. 1 Forebay Model Boundary Conditions

Boundary Condition Name (Mesh Block Name, Plane)	Boundary Condition Type and Description
Canal Inlet (Canal, x-min)	The Canal Inlet is modeled as a "volumetric flow rate" boundary with the flow rate in cfs specified for each Scenario. In addition because the boundary is not perpendicular to flow, and unit vector of (0.9632, 0.269, 0.0) is also specified for the boundary.

Boundary Condition Name (Mesh Block Name, Plane)	Boundary Condition Type and Description
Canal Outlet (Canal, x-max)	The Canal Outlet is modeled as a "specified pressure" boundary with a fluid fraction of 1 and a fluid elevation of 173.5 ft. This is effectively a fixed water level boundary that allows the program to calculate the flux through the boundary (i.e. the discharge).
Penstocks 1 through 4 (Penstocks 1 through 4, y-min)	Penstocks 1 through 4 are technically modeled as having a "wall" boundary condition in the y-min plane that does not allow any fluid to pass through it, however, just inside of the wall (6 ft inside) are mass momentum sources (sinks) that are used to pull water out of the domain and control the amount of flow leaving the forebay through each of the penstocks.

5.2 Cabot Station Forebay

The Cabot Station Forebay CFD model includes the penstocks and intakes, forebay and a portion of the power canal in front of the forebay entrance. The model extends from approximately 700 ft upstream of the power house downstream to a point inside the penstocks where the model terminates.

Figure 5.2-1 shows the three (3) block mesh regions used to define computational mesh for the CFD model as well as the location of the inflow and outflow boundary condition locations.

The mesh block dimensions and cells sizes are shown in Table 5.2-1. Note the Fish Weir mesh block was only used during the production runs, which include the fish weir, as it is needed to resolve the fish weir but not the sluice gate that was modeled during the verification runs.

When combined with the CAD model and bathymetric surface STL files, the block mesh configuration shown in Figure 5.2-1 results in 10,479,261 total and 1,386,419 active cells. Active cells are the cells that remain for fluid to occupy after cells that are completely blocked by the solid model are removed.

In addition to the boundary conditions and initial conditions described in Section 2, Table 5.2-2 describes the boundaries that control the inflow and outflow from the model.

The initial conditions used for fluid elevation (i.e. water surface elevation) and velocity in the models varied from run to run. For the first run (the verification run) the fluid elevation was set to 173.5 ft and the velocity to 0 fps, however subsequent runs (and scenarios) were started using the final conditions from previous runs to initialize the model with a velocity field that was closer to the expected stead state solution. This does not affect the final results, but reduces the amount of computation time required to reach a steady state solution.

Table 5.2-1: Cabot Station Forebay Model Mesh Blocks

Mesh Block Name	Mesh Block Size (x, y, z) (ft)	Cell Size (x, y, z) (ft)
Canal	(900, 580, 68)	(2, 2, 2)
Powerhouse	(900, 70, 68)	(1, 1, 1)
Fish Weir	(40, 34, 68)	(0.5, 0.5, 0.5)

Table 5.2-2: Cabot Station Forebay Model Boundary Conditions

Boundary Condition Name (Mesh Block Name, Plane)	Boundary Condition Type and Description
Canal Inlet (Canal, x-min)	The Canal Inlet is modeled as a specified pressure boundary with a fluid fraction of 1 and a fluid elevation of 173.6 ft. This is effectively a fixed water level boundary that allows the program to calculate the flux through the boundary (i.e. the inflow).
Log Sluice Outlet (Canal, y-min)	The Log Sluice Outlet is modeled as an outlet, which allows the water to pass freely through it.
Penstocks 1 through 6 (Canal, y-min)	Penstocks 1 through 6 are technically modeled as having an outlet boundary condition in the y-min plane (same boundary as the Log Sluice Outlet), however two additional mechanisms are used to control flow through the penstocks. First there is a zero porosity baffle located just inside (4 ft inside) the outlet of the penstocks to prevent water from flowing out the y-min boundary of the Canal mesh block. Next, just inside of the baffle (1 ft inside), are Mass Momentum Sources (Sinks) that are used to control the amount of flow leaving the forebay/power canal through each of the penstocks.

5.3 Cabot Fishway Entrance

The Cabot Fishway Entrance CFD model (Model 5) extends along the Connecticut River from approximately 1600 ft upstream of Cabot Station to approximately 500 ft downstream of Smead Island. Since the area around the Cabot fishway entrance is greatly influenced by surrounding river conditions, the modeling area was extended to a much larger portion of the river than was described in the RSP (Figure 1.4.3-1). The model area that was outside of the detailed study area was represented as a coarse grid that functioned as the boundary conditions for the detailed study area.

The Cabot Fishway Entrance CFD model was set up as a set of nested meshes that are progressively more refined around Cabot Station and the Cabot Fishway. The coarsest mesh (mesh 1) encapsulated the entire model area and was primarily included in order to help the model determine the appropriate flow distribution and velocity boundary conditions within the detailed study area. Mesh 1 was dimensioned with 8-ft increments in the X (East) and Y (North) direction and 4-ft increments in the Z (Vertical) direction. The mesh was sized to incorporate an area large enough to include all potentially significant flow influences in the Cabot tailrace area while also keeping the model boundary conditions a reasonable distance away in order to minimize their impact on the model results in the area of interest. The next mesh (mesh 2) encompassed the detailed study area and was dimensioned with 4-foot increments in the X (East) and Y (North) direction and 2-ft increments in the Z (Vertical) direction. Mesh 3 encompassed the tailrace area near Cabot Station, plus the draft tubes for all six Cabot units and was dimensioned with uniform 2-ft cells in all directions. Mesh 4 was the most refined mesh in the model and included the fishway area as well as the Unit 6 draft tube (the unit nearest the fishway) and was dimensioned with uniform 1-ft cells in all directions.

This model included two inflow/outflow boundary conditions. The upstream boundary was set as a volume flow rate boundary condition that required specifying the bypass inflow rate (in terms of cfs). Volume flow rate boundary conditions only allow flow to enter the model domain, and they assume the inflow is distributed evenly. The downstream boundary was set as a pressure boundary that required the user to specify a downstream water surface elevation. The downstream water surface elevation for the verification run (Section 6.3) was developed using a water level logger located near the CFD model's downstream boundary. Since empirical water surface elevation data were not available for the exact production run scenarios described in this study plan, the downstream water surface elevations for all production runs were instead derived from model outputs from the River2D model that has been developed for Study No. 3.3.1:

Conduct Instream Flow Habitat Assessment in the Bypass Reach and below Cabot Station in Reach 3 which covers the Connecticut River from just upstream of the rock dam area to down below the Deerfield River confluence. Table 5.3-1 summarizes the downstream water surface elevation used for each run.

Figure 5.3-1 shows the four (4) mesh block regions in plan view, as well as the flow baffles that are used to check domain inflow and outflow rates. The mesh block details are shown in Table 5.3-2. When combined with the CAD model and bathymetric surface STL files, the block mesh configuration shown in Figure 5.3-1 results in 7,387,260 total and 1,737,586 active cells. Active cells are the cells that remain for fluid to occupy after cells that are completely blocked by the solid model are removed.

The model was set up as a series of four models, where each scenario was initially run with just the 'Very Coarse' mesh. The model results from the 'Very Coarse' mesh were then used as a 'hotstart' file to set the initial conditions for the next model, which contained the 'Very Coarse' mesh and the nested 'Coarse' mesh. This was then repeated until the fourth model was run with all four nested meshes. Each sub-model was run until hydraulic conditions were stable before progressing to the more refined sub-model. We considered the results within the Coarse Mesh, Fine Mesh, and Very Fine Mesh to reflect the area of interest for this study. As such, model outputs for the Very Coarse Mesh area are generally not shown.

Table 5.3-3 describes the boundaries that control the inflow and outflow from the model. Other than the z-max boundary (pressure boundary, fluid fraction of 0) and the boundaries specified in Table 5.3-3, all boundaries were modeled as "wall" boundaries that cannot pass any fluid to or from the model domain.

In addition to the boundary conditions, mass sources were used to represent inflows from the fish ladder and each unit's draft tube. The mass sources assume the flow is evenly-distributed across the mass source face. The draft tube mass sources were set approximately 20 ft in from the outside face of the draft tube (Figure 5.3-2). The fishway mass source was located just upstream of the two entrance gates (Figure 5.3-3). While the entrance gallery geometry was included in the model, flows through the entrance gallery were not modeled as the station no longer actively passes water through the entrance gallery during fish passage season.

The initial conditions used for fluid elevation (i.e. water surface elevation) and velocity in the models varied from run to run, and were only relevant for the 'Very Coarse' model run, as the other model runs were initialized using the final conditions from the corresponding lower resolution model. The initial starting water surface elevations were set to the same elevation as the downstream boundary elevation. Initial velocities were set to 0.

Numerical "baffles" were used in the model to monitor the flow into and out of the computational domain and through river over time.

Table 5.3-1: Cabot Fishway Model Downstream Boundary Elevation for Each Scenario

Scenario	Total River Flow (cfs)	Downstream Boundary Elevation (ft NGVD29)	Elevation Source
Verification	5,229	108.23	Water level logger 3-4
5-1	2,468	105.88	River2D model output
5-2	8,268	109.13	River2D model output
5-3	14,496	111.69	River2D model output
5-4	20,597	113.75	River2D model output
5-5	30,336	116.82	River2D model output

Table 5.3-2: Cabot Fishway Model Mesh Blocks

Mesh Block Name	Mesh Block Size (x, y, z) (ft)	Cell Size (x, y, z) (ft)
Very Coarse Mesh	(2000, 3856, 72)	(8, 8, 4)
Coarse Mesh	(1000, 1400, 64)	(4, 4, 2)
Fine Mesh	(400, 360, 56)	(2, 2, 2)
Very Fine Mesh	(72, 96, 48)	(1, 1, 1)

Table 5.3-3: Cabot Fishway Model Boundary Conditions

Boundary Condition Name (Mesh Block Name, Plane)	Boundary Condition Type and Description
Bypass Flow (Very Coarse, y-max)	The bypass flow is modeled as a "volumetric flow rate" boundary with the flow rate in cfs specified for each Scenario. Since the boundary is approximately perpendicular to flow, the default unit vector of (0.0, -1.0, 0.0) was used for the boundary.
River Outflow (Very Coarse, y-min)	River outflow is modeled as a "specified pressure" boundary with a fluid fraction of 1 and a fluid elevation that varied depending on the river flow. The boundary fluid elevation was determined using model outputs from the River2D model that was developed as part of Study 3.3.1. The boundary was placed well downstream of the area of interest for this study.

5.4 Spillway Fishway Entrance

The Spillway Fishway Entrance CFD model (Model 6) covers the upper end of the bypassed portion of the Connecticut River from Turners Falls Dam to approximately 300 ft downstream of the Island, including the area referred to as the 'plunge pool'. Since the hydraulics around the Spillway fishway entrance are greatly influenced by surrounding and downstream river conditions, the modeling area was extended to a much larger portion of the river than was described in the RSP (Figure 1.4.4-1). The model area that was outside of the detailed study area was represented as a coarse grid that functioned as the boundary conditions for the detailed study area.

Since the model was primarily focused on the channel in front of the Spillway Ladder, some areas were represented in a simplified manner. These simplified areas included the tainter gate channel, the Fall River, Bascule Gate No. 4's channel, and the hydraulic controls at the downstream end of the plunge pool. The tainter gate channel was not represented in the model; instead, tainter gate flows were added to the model just downstream of where the tainter gate channel enters the main pool area. This was done because tainter gate flows were only being included in the model to represent a backwatering effect on the Spillway Fishway under high flow conditions. Fall River inflows were not addressed in this model, as it was not discussed in the RSP. Bascule Gate No. 4's bedrock channel (i.e., the 'middle channel') was roughly included using LiDAR data, but detailed bathymetry was not collected in the channel since it was outside of the target detailed modeling area. The hydraulic controls near the Island, as well as the channel area downstream of the Island to the model's downstream boundary are roughly represented with some LiDAR data. Since LiDAR data does not detect elevations below the water line, the data in this area is acceptable for detecting hydraulic controls (which is verified in Section 7.4) but is not adequate for assessing passage criteria since the depths will be under-estimated (and velocities likely over-estimated).

The Spillway Fishway CFD model was set up as a set of nested meshes that become progressively more refined around the Spillway Fishway. The coarsest mesh (mesh 1) encapsulated the entire model area and was primarily included in order to help the model determine the appropriate flow distribution, water velocities and water surface elevations within the detailed study area. Mesh 1 was dimensioned with 8-ft increments in the X (East-West) and Y (North-South) direction and 2-ft increments in the Z (Vertical) direction. There is a significant hydraulic control (bedrock ridge) in the river located at adjacent to the Island, and the coarsest mesh was sized to incorporate all of this controlling ridge. An investigation of downstream water level logger data within the reach from the Island to Station No. 1's tailrace indicated that downstream water levels do not rise enough to potentially influence water levels upstream of the Island. The next mesh (mesh 2) encompassed the detailed study area, including the area where flow from Bascule Gates 1, 2, and 3 passes, and was dimensioned with 4-foot increments in the X (East-West) and Y (North-South) direction and 2-foot increments in the Z (Vertical) direction. Mesh 3 was dimensioned with uniform 2-ft cells in all directions, and encompassed the flow channel in front of Bascule Gates 1 and 2 and extended about 250 ft downstream of the dam's downstream face. Mesh 4 was the second most refined mesh in the model. Mesh 4 had uniform 1-ft dimensions and included the Spillway Fishway area. Mesh 5 was the most refined mesh in the model with uniform 0.5-ft dimensions, and it encompassed the Spillway Fishway entrance.

This model included an outflow boundary condition and five internal mass momentum sources to represent flow from the fish ladder, bascule gates and tainter gates. The downstream boundary was set as a pressure boundary that required the user to specify a downstream water surface elevation. Since the hydraulic control at the Island removed any influence from the downstream boundary on the area of interest, a single downstream boundary elevation of 133.55 ft (two feet below the lowest pool elevation of 135.55 ft) was used for all model runs. Inflow from the Fall River was not included in this model

Figure 5.4-1 shows the five (5) mesh block regions in plan view, as well as the flow baffles that are used to check domain inflow and outflow rates. The mesh block details are shown in Table 5.4-1.

When combined with the CAD model and bathymetric surface STL files, the block mesh configuration shown in Figure 5.4-1 results in 4,694,616 total and 968,742 active cells. Active cells are the cells that remain for fluid to occupy after cells that are completely blocked by the solid model are removed. The model was set up as a series of four models, where each model was initially run with just the 8 ft x 8 ft x 2 ft mesh. The model results from that model then used to set the initial conditions for the next model, which contained the 8 ft x 8 ft x 2 ft mesh and the nested 4 ft x 4 ft x 2 ft mesh. This was then repeated until the fourth model was run with all five nested meshes (the 0.5 ft mesh was added in at the same time as the 1 ft mesh). Each sub-model was run until hydraulic conditions were stable before progressing to the more refined sub-model. We considered the results within the 4 ft x 4 ft x 2 ft and finer meshes to reflect the area of interest for this study. As such, model outputs for the 8 ft x 8 ft x 2 ft mesh area are not usually shown in the model outputs.

Table 5.4-2 describes the boundaries that control the inflow and outflow from the model. None of the mesh boundary conditions were inflow conditions. Other than the z-max boundary (pressure boundary, fluid fraction of 0) and the boundaries specified in Table 5.4-2, all boundaries were modeled as "wall" boundaries that cannot pass any fluid to or from the domain.

In addition to the boundary conditions, mass momentum sources were used to represent inflows from the fish ladder, each bascule gate (individually), and the tainter gates (collectively). The mass momentum sources assume the flow is evenly-distributed across the mass source face. Due to computational limitations, we did not model flow over the spillway in this model. Instead, a separate model was run to estimate the location, angle, and thickness of the water nappe passing over the bascule gate for each modeled flow scenario. This was then used to create the thickness, angle, and location of the primary model's mass momentum sources that represent the spillway flow just before it impacts the modeled reach. The separate 'Spillway Only' models were run using a uniform grid size of 0.25 ft in all directions and were only a representative thickness of the bascule gates. The 'teeth' on the bascule gates were not accounted for in this model (Figure 5.4-2). The 400 cfs spill condition for PR 6-1 was handled differently, as the model predicted the nappe would contact the dam's concrete apron before spraying into the spillway area. Since CFD models have computational issues with handling large amounts of water spray, we instead modeled the 400 cfs spill condition for PR 6-1 as a strip of water traveling parallel to the dam's downstream face. Since the bed elevation is much higher in front of Bascule Gate No. 2 and Bascule Gate No. 4 relative to Bascule Gate No. 1, the mass momentum sources are set higher for those locations. Table 5.4-3 summarizes each bascule gate's mass momentum source model coordinates, angles, and thicknesses. Since each flow resulted in a different location, angle, and thickness, a unique mass momentum source was created for each modeled Bascule Gate flow.

The initial conditions used for fluid elevation (i.e. water surface elevation) and velocity in the models varied from run to run, and were only relevant for the 'Very Coarse' model run, as the other model runs were initialized using the final conditions from the corresponding lower resolution model. The initial starting water surface elevations were set to the same elevation as the downstream boundary elevation. Initial velocities were set to 0.

Numerical "baffles" were used in the model to monitor the flow into and out of the computational domain and through river over time.

Table 5.4-1: Cabot Tailrace Model Mesh Blocks

Mesh Block Name	Mesh Block Size (x, y, z) (ft)	Cell Size (x, y, z) (ft)
8' x 8' x 2' Grid	(1480, 1360, 72)	(8, 8, 2)
4' x 4' x 2' Grid	(440, 752, 64)	(4, 4, 2)
2' x 2' x 2' Grid	(360, 264, 56)	(2, 2, 2)
1' x 1' x 1' Grid	(56, 144, 48)	(1, 1, 1)
0.5' x 0.5' x 0.5' Grid	(40, 96, 40)	(0.5, 0.5, 0.5)

Table 5.4-2: Cabot Tailrace Model Boundary Conditions

Boundary Condition Name (Mesh Block Name, Plane)	Boundary Condition Type and Description
River Outflow (Very Coarse, x-min)	River outflow is modeled as a "specified pressure" boundary with a fluid fraction of 1 and a fluid elevation that varied depending on the river flow. The boundary is downstream of the hydraulic control at the Island, and had no impact on water levels or flow field upstream of the Island. Therefore, the pressure boundary was set at a constant elevation of 133.55 ft.

Table 5.4-3: Summary of Bascule Gate Mass Momentum Sources

Mass Momentum Source	Angle of Water Strip from Vertical (degrees)	Strip Thickness (ft)	Horizontal Angle from North (degrees)	X Centroid (ft Model datum)	Y Centroid (ft Model datum)	Z Centroid (ft Model datum)
Bascule Gate 1 – 400 cfs	65.1	0.50	3.76	8871.5	10704.9	138.55
Bascule Gate 1 – 4,341 cfs	74.4	0.75	3.76	8,871.7	10,707.5	143.55
Bascule Gate 1 – 7,500 cfs	73.2	1.25	3.76	8,871.9	10,711.1	143.55
Bascule Gate 2 – 6,580 cfs	70.8	1.25	-0.26	8,994.1	10,704.7	151.55
Bascule Gate 2 – 7,500 cfs	73.2	1.25	-0.26	8,994.1	10,705.4	151.55
Bascule Gate 4 – 4,960 cfs	74.4	1.00	-8.45	9,237.9	10,720.6	151.55

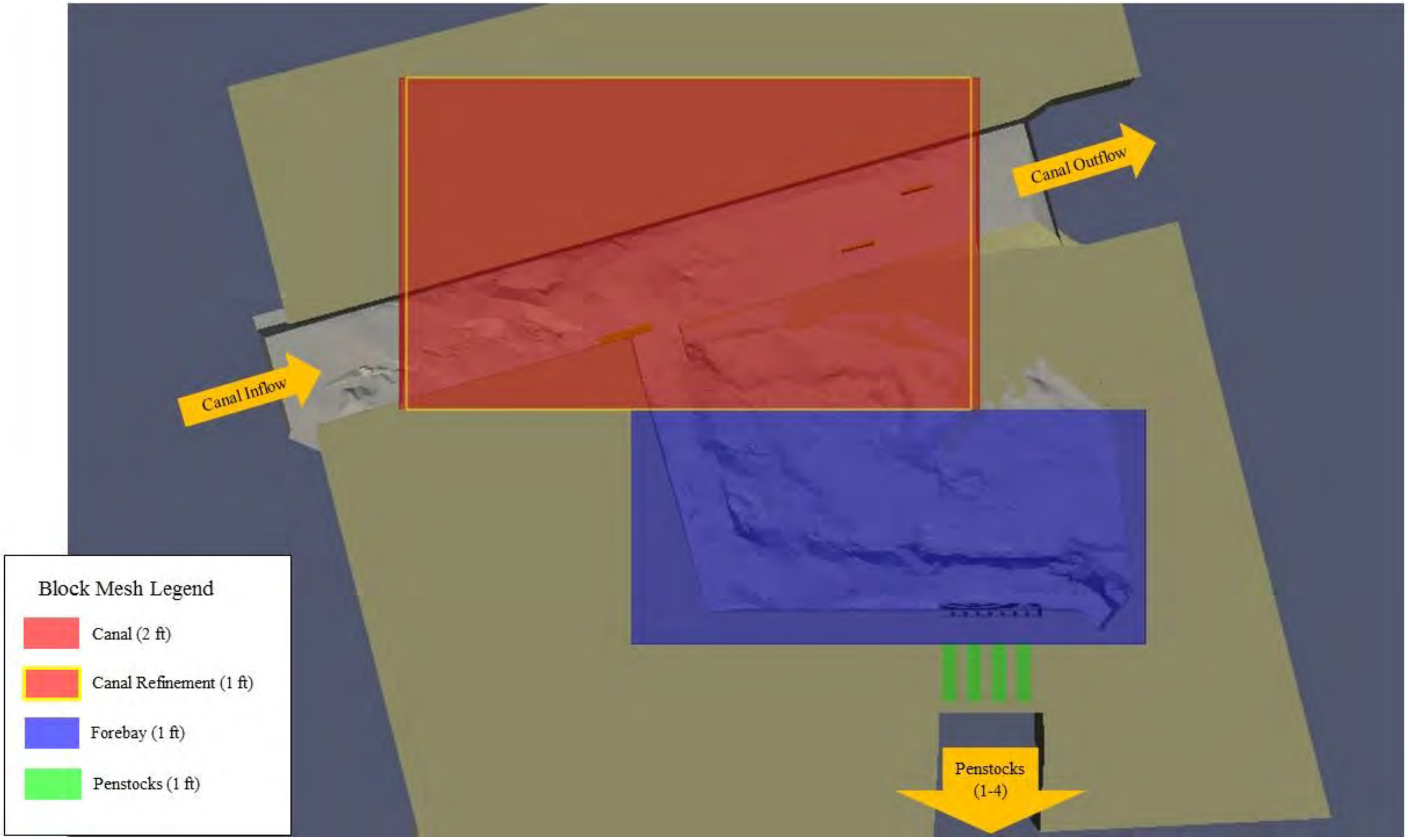


Figure 5.1-1: Station No. 1 Model Block Mesh Regions

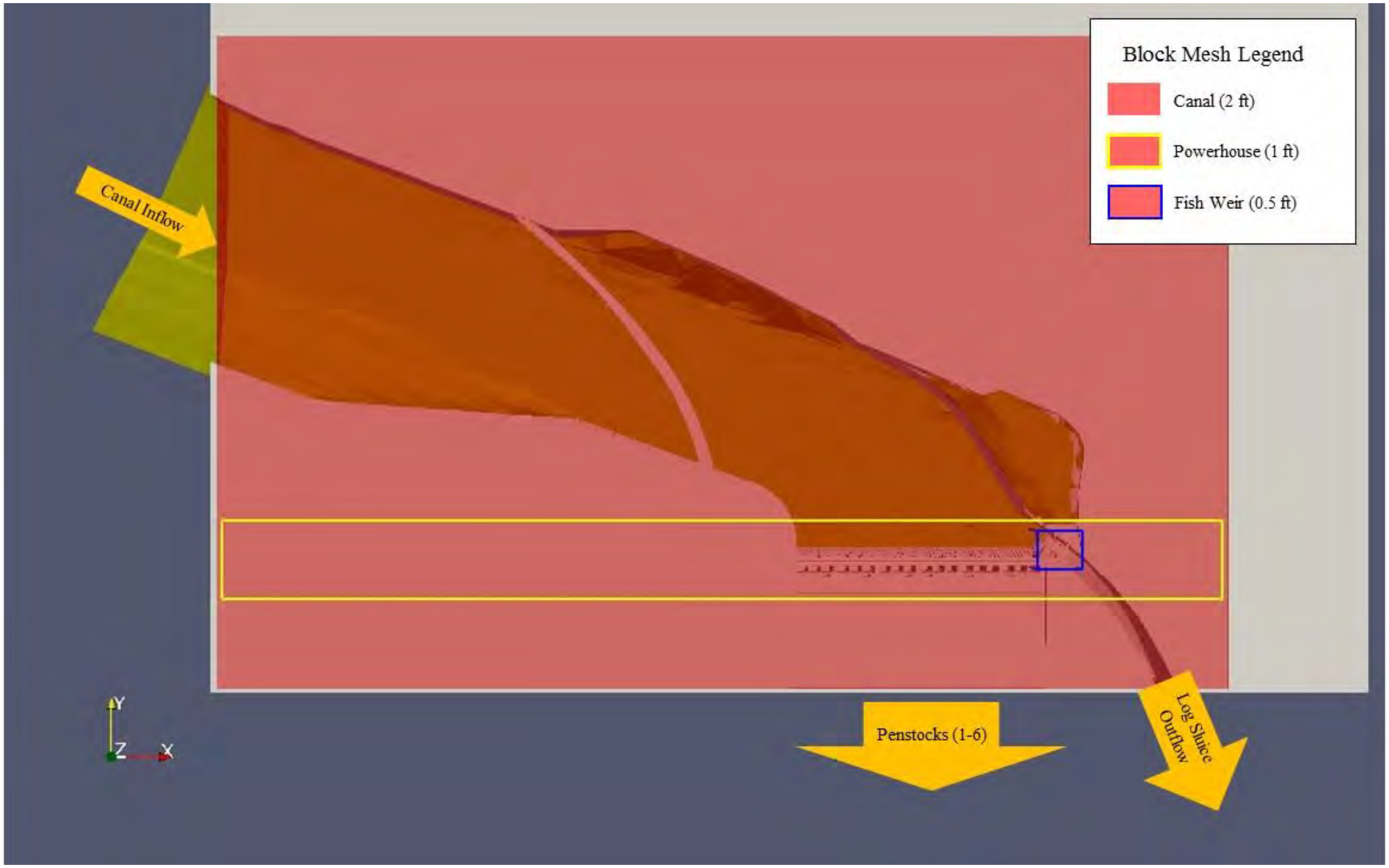
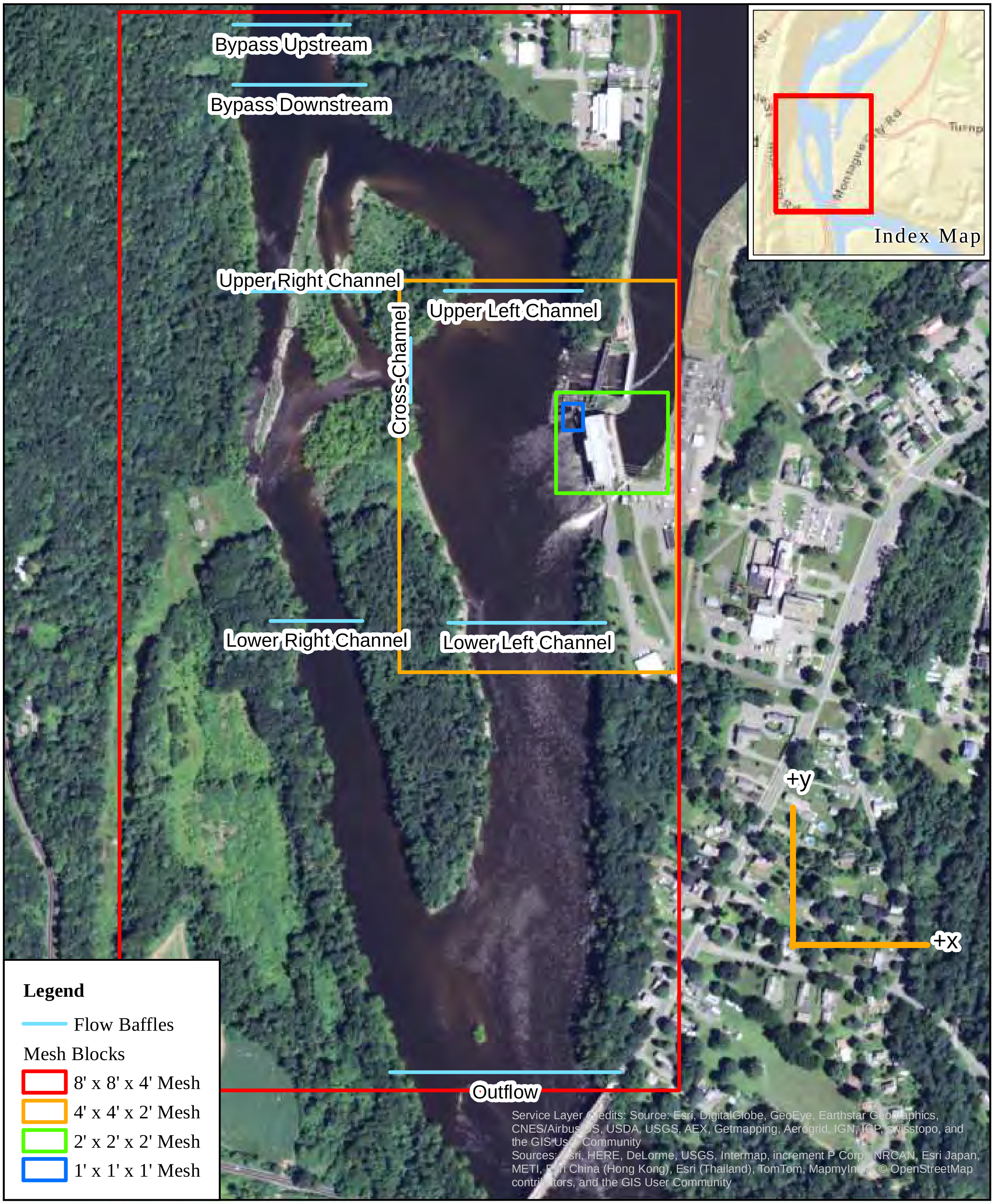


Figure 5.2-1: Cabot Station Model Block Mesh Regions



Northfield Mountain Pumped Storage Project (No. 2485)
and Turners Falls Hydroelectric Project (No. 1889)
RELICENSING STUDY 3.3.8

Figure 5.3-1:
Cabot Tailrace Model
Block Mesh Regions

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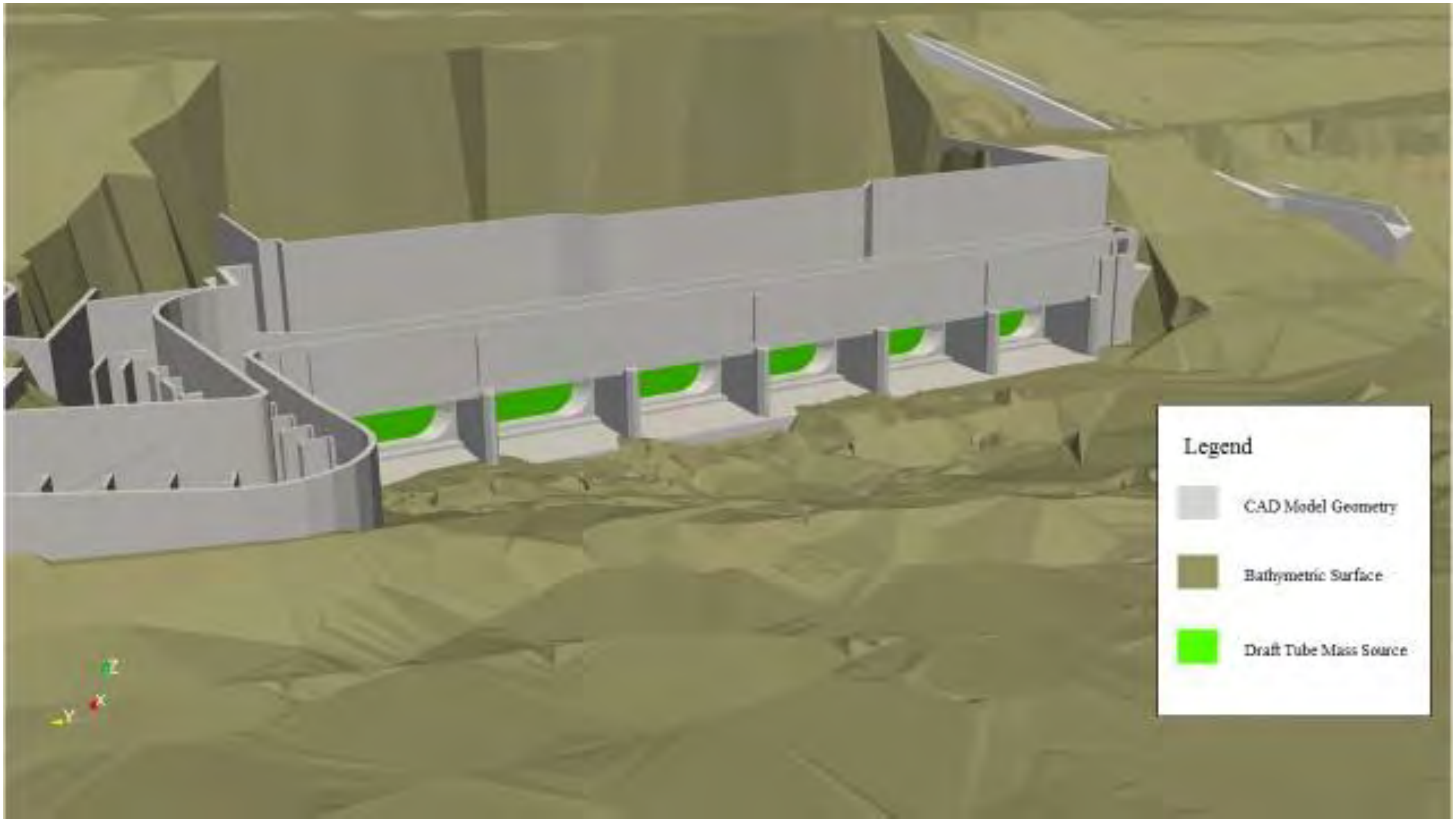


Figure 5.3-2: Cabot Station Model Block Mesh Regions

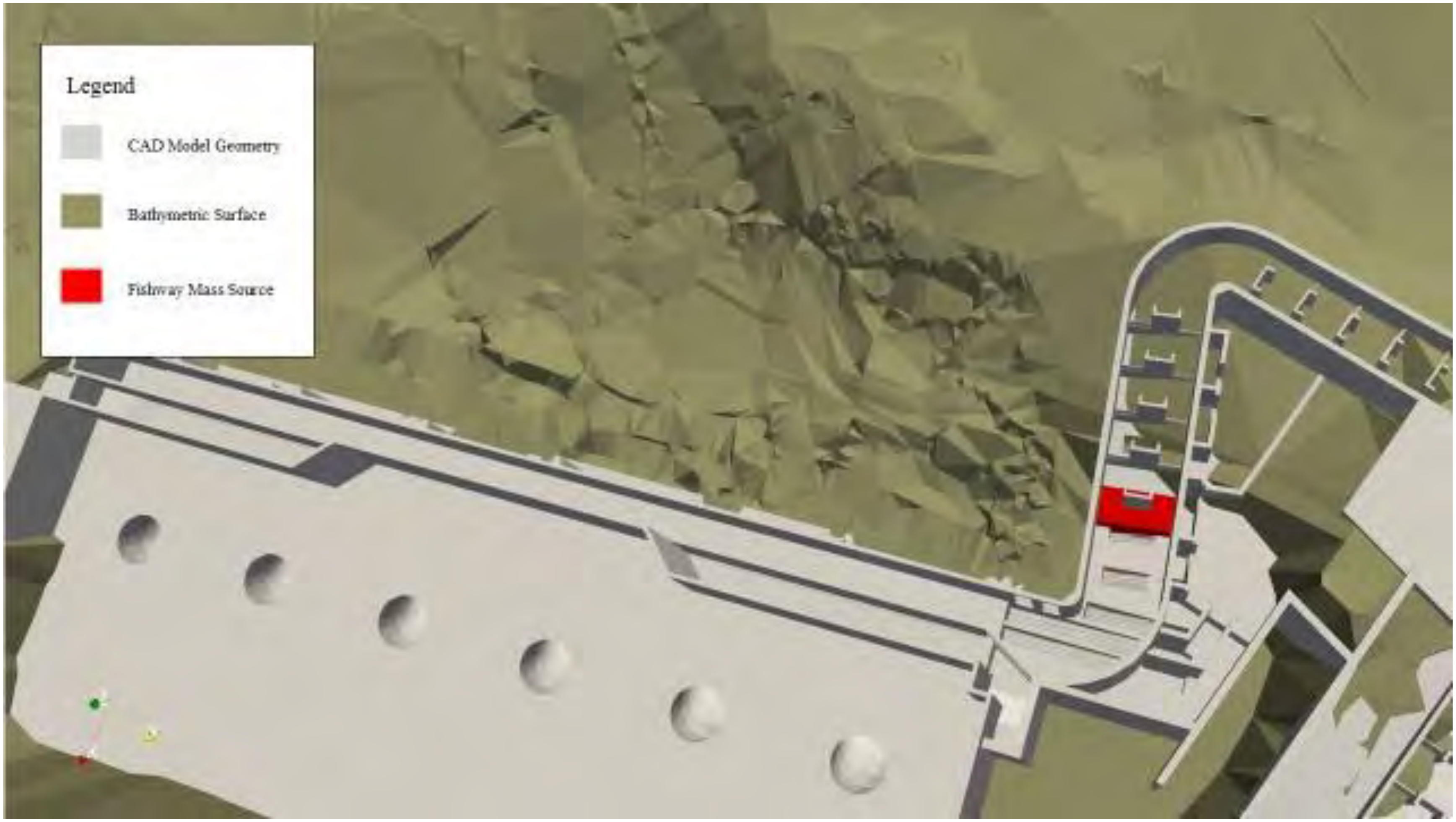
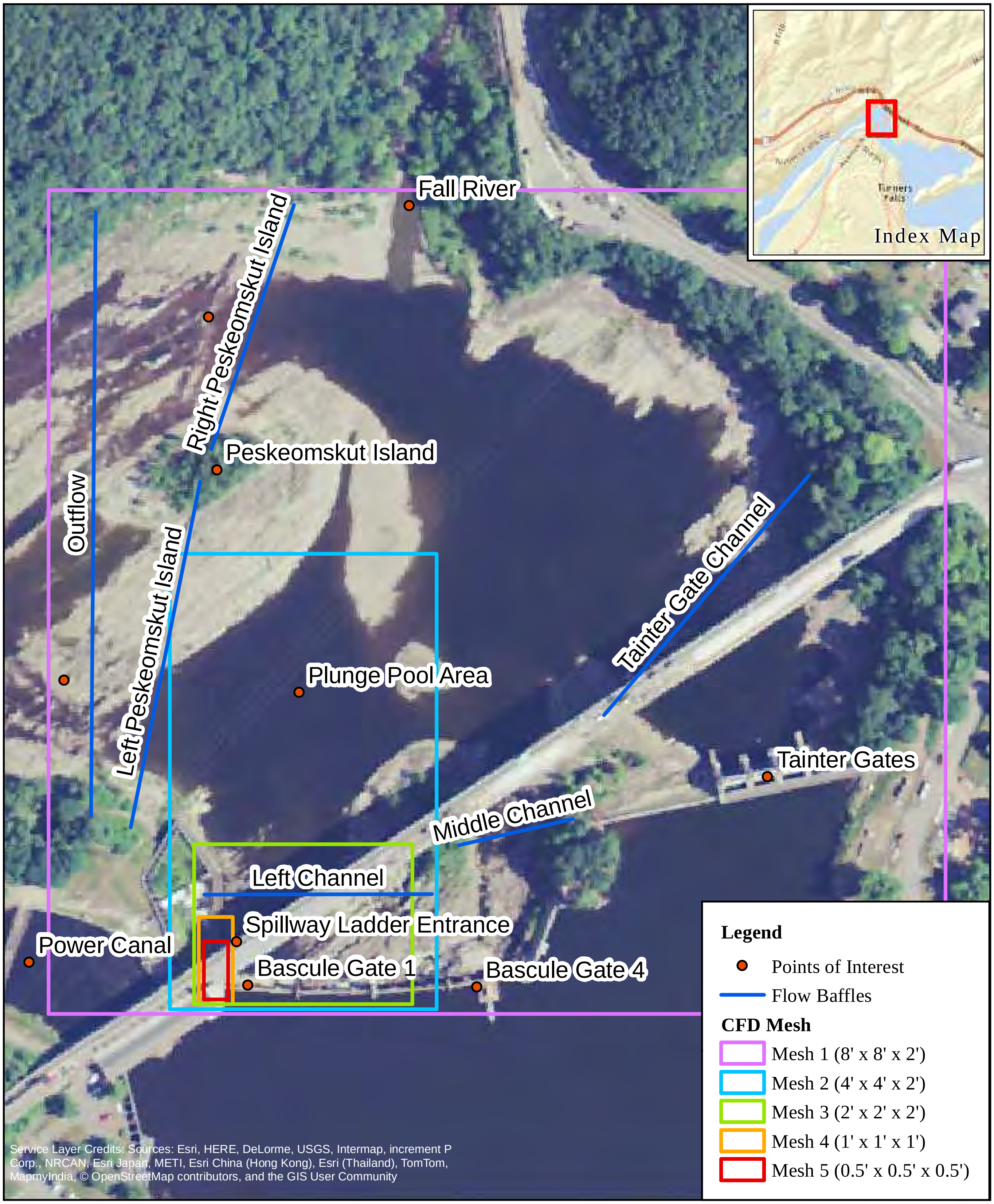


Figure 5.3-3: Cabot Station Model Block Mesh Regions



FirstLight GDF SUEZ

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Northfield Mountain Pumped Storage Project (No. 2485)
and Turners Falls Hydroelectric Project (No. 1889)
RELICENSING STUDY 3.3.8

0 100 200 400 Feet

Figure 5.4-1:
Spillway Ladder Model
Block Mesh Regions

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Figure 5.4-2: Spillway Gate 'Teeth' That Were Not Represented in the Spillway CFD Model

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6 VERIFICATION MODEL RUNS

Verification model runs were run for each of the CFD models in the CFD study. The model verification model runs were conducted under the same conditions under which the field data were collected. The purpose of running the verification runs is to compare the CFD model results to the measured velocity profiles collected with the ADCP unit as described in Section 3.1.

6.1 Station No. 1 Forebay

As described in Section 3.1.1, when the ADCP bathymetry and velocity data were being collected, Station No. 1 was running at maximum capacity (2,210 cfs) and Cabot Station was operating one unit (2,288 cfs), for a total inflow to the power canal of approximately 4,498 cfs. Table 6.1-1 shows the distribution of flows across the penstocks during data collection and the verification model run. These flows are defined in the model as mass momentum sources (sinks) as described in Section 5.1.

The Canal Inlet boundary has a volumetric flow rate of 4,498 cfs entering the computational domain based on the unit vector described in Section 5.1.

The verification model run had a total simulation time of 4,480 seconds to reach a steady state condition. This included 3,700 seconds using a course mesh in the power canal (i.e. without the Canal Refinement block mesh) and 1,180 seconds with the refined mesh.

Near the end of the simulated period the Flow-3D solver indicated that the model had reached a nearly steady state. To further evaluate the model run, the flow through the "baffles" during the last half cycle of outflow oscillation (120 seconds) was evaluated. This evaluation showed that the simulated average discharge at the Canal Outlet boundary was 2,297 cfs and was oscillating approximately ±5 percent. The average flow of 2,297 cfs is 0.4 percent more than the expected value of 2,288 cfs. The inflow to the canal (Canal Inlet boundary) and the discharge through the penstocks were specified as boundary conditions and their respective "baffles" had fluctuations of less than 0.1 percent.

Figure 6.1-1 shows a comparison of the measured ADCP velocity profiles and the verification model run results at the same locations. In general, the flow patterns and magnitudes between the measured and simulated compare well. The CFD simulation generally provides "smoother" velocity profiles and does not tend to resolve some of the localized higher "point" velocities measured with the ADCP unit. This is in part because the ADCP unit provides instantaneous values and the CFD model results are steady-state and representative of average values. Based on a comparison of the ADCP and CFD model results it is believed that the results from the CFD model production runs are appropriate for meeting the objectives of this study.

Table 6.1-1: Station No. 1 Verification Model Run Generation Flows

	Unit No. 1	Unit No. 2	Unit No. 3	Unit No. 5	Unit No. 7
Maximum Unit Capacity (cfs)	560	140	500	490	520
Simulated Flows (cfs)	560	140	500	490	520
Penstock Number Supplying Unit	1	2		3	4
Penstock Flow (cfs)	560	640		490	520

6.2 Cabot Station Forebay

As described in Section 3.1.2, when the ADCP bathymetry and velocity data was being collected, Cabot Station was generating with three (3) units for a total flow of 6,684 cfs. The generation flows are defined in the model as mass momentum sources (sinks) as described in Section 5.2.

Table 6.2-1 shows the distribution of flows across the penstocks during the verification model run.

The log sluice gate was open 10 ft during most of the fieldwork and the fishway weir was not installed, resulting in approximately 1,290 cfs (calculated) passing through the log sluice, for a total flow of 7,974 cfs.

The verification model run had a total simulation time of 5,180 seconds to reach a steady state condition.

Near the end of the simulated period the Flow-3D solver indicated that the model had reached a nearly steady state. To further evaluate the model run the flow through the "baffles" during the last complete cycle of oscillation of inflow and outflow (approximately 100 seconds) was evaluated. This evaluation showed that the average inflow calculated through the Canal Inlet boundary was 8,243 cfs and was oscillating approximately plus or minus 1 percent. The average flow of 8,243 cfs is 3.4 percent greater than the expected value of 7,974 cfs. The discharge through the penstocks were specified as boundary conditions and their "baffles" had fluctuations of less than 0.1 percent. The average simulated discharge out the log sluice for the same time period was 1,201 cfs with fluctuations of less than 1.0 percent.

Figure 6.2-1 shows a comparison of the measured ADCP velocity profiles and the verification model run results at the same transect locations. In general, the flow patterns and magnitudes between the measured and simulated compare well. The CFD simulation generally provides "smoother" velocity profiles and does not tend to resolve some of the localized higher "point" velocities measured with the ADCP unit. This is in part because the ADCP unit provides instantaneous values and the CFD model results are steady-state and representative of average values. Based on a comparison of the ADCP and CFD model results it is believed that the results from the CFD model production runs are appropriate for meeting the objectives of this study.

Table 6.2-1: Cabot Station Verification Model Run Generation Flows

	Unit No. 1	Unit No. 2	Unit No. 3	Unit No. 4	Unit No. 5	Unit No. 6
Maximum Unit Capacity (cfs)	2,288	2,288	2,288	2,288	2,288	2,288
Generation Flows During Run (cfs)	2,288	0	0	0	2,288	2,288

6.3 Cabot Fishway Entrance

As described in Section 3.1.3, when the ADCP bathymetry and velocity data were collected, Cabot Station was generating with two (2) units for a total powerhouse flow of 4,052 cfs and a total river flow of 5,230 cfs. As described in Section 5.3, the generation flows are defined in the model as mass sources, as are the fishway flows and the log sluice flow.

Table 6.3-1 shows the distribution of flows across the bypass, powerhouse, fishway, and log sluice during the verification model run.

The verification model was run through all four different resolution models before the final results were extracted. The final high-resolution model had a total simulation time of 2,375 seconds to reach a steady state condition, while the total simulation time for all four models was 9,840 seconds.

Near the end of the simulated period the Flow-3D solver indicated that the model had reached a nearly steady state. To further evaluate the model run's stability, the flow through the "baffles" during the last 600 seconds of simulation time was evaluated[20]. The baffle locations are shown in Figure 5.3-1, with the exception of the Cabot Powerhouse baffle that is directly across the Cabot Powerhouse's downstream face and the fish ladder baffle that is inside of the fishway. Table 6.3-2 summarizes the flow fluctuations at these baffles over the last 600 simulations seconds.

The flow stability evaluation showed the following key points:

1) The average inflow calculated through Cabot Station was 4,052 cfs and oscillated by less than 1 cfs throughout the run;
2) The average inflow for the bypass reach showed an average flow of 626 cfs, and 95%[21] of the instantaneous flows (taken every 1 second) were between 601 cfs and 651 cfs;
3) The average outflow calculated just upstream of the downstream boundary showed an average outflow of 5,037 cfs and 95% of the instantaneous flows were between 4,637 cfs and 5,389 cfs. The average outflow of 5,037 cfs is 3.7% less than the expected value of 5,229 cfs. This difference is likely due to small amounts of fluid gains and losses that occur at mesh block transitions.

Figure 6.3-1 shows a comparison of the measured ADCP velocity profiles and the verification model run results at the same transect locations while looking upstream, while Figure 6.3-2 shows a similar comparison for a smaller area near Cabot Station. In general, the flow patterns and magnitudes between the measured and simulated velocities compare well. The CFD simulation generally provided more diffuse-looking velocity profiles, and it appears that some more local flow phenomena were not represented as clearly.

The velocities immediately downstream of the powerhouse also appeared to be somewhat different between the measured and simulated data. This may be partially due to field measurement difficulties, as during field data collection the ADCP unit appeared to experience some difficulty recording velocities. This difficulty could be possibly due to air entrainment immediately downstream of the draft tubes.

Based on this comparison of the ADCP data and CFD model results, we believe the results from the CFD model production runs are appropriate for meeting this study's objectives.

Table 6.3-1: Cabot Station Verification Model Run Generation Flows

	Flow (cfs)
Bypass Reach	625
Log Sluice	184
Cabot Fishway	368
Unit 1	2,218
Unit 2	1,834
Unit 3	0
Unit 4	0
Unit 5	0
Unit 6	0
Total River Flow	**5,229**

[20] The Cabot Fishway run outflows were a bit noisier and did not have clear 'oscillations' like the Station No. 1 Forebay and Cabot Forebay models. This is possibly due to the larger model domain area and more heterogenous topography within the river versus the canal/forebay area.
[21] The 95% flow ranges reported for this study are calculated as the difference between the 2.5% exceedance flow and the 97.5% exceedance flow.

Table 6.3-2: Flow Stability Analysis at Several Baffles within the Cabot Fishway CFD Model

Baffle	Average Flow (cfs)	2.5% Exceedance Flow (cfs)	97.5% Exceedance Flow (cfs)
Bypass Upstream	-626	-601	-651
Bypass Downstream	-632	-571	-687
Upper Left Channel	-508	-359	-645
Upper Right Channel	-37	-1	-68
Cabot Powerhouse	-4,052	-4,052	-4,052
Cabot Fishway	368	368	367
Lower Left Channel	-4,941	-4,862	-5,001
Lower Right Channel	-44	201	-283
Outflow	-5,037	-4,637	-5,389

6.4 Spillway Fishway Entrance

The Spillway Fishway was passing 150 cfs (measured directly downstream of the fishway entrance via ADCP) and there was no spill flow (via the bascule or tainter gates) passing the Turners Falls Dam when the ADCP bathymetry and velocity data were collected. As described in Section 5.4, model inflows (fishway flows, individual bascule gate flows, and the collective tainter gate flows) are defined in the model as mass momentum sources.

Table 6.4-1 shows the flow distribution across the bypass, powerhouse, fishway, and log sluice during the verification model run.

The verification model was run through all four different resolution models before the final results were extracted. The final high-resolution model had a total simulation time of 3,500 seconds to reach a steady state condition, while the total simulation time for all four models was 8,700 seconds.

Near the end of the simulated period the Flow-3D solver indicated that the model had reached a nearly steady state. To further evaluate the model run's stability, the flow through the "baffles" during the last 600 seconds of simulation time was evaluated[22]. The baffle locations are shown in Figure 5.4-1, with the exception of the baffle that is inside of the fishway. Table 6.4-2 summarizes the flow fluctuations at these baffles over the last 600 simulations seconds.

The flow stability evaluation showed the following key points:

1) The average inflow calculated through the Spillway Fishway ladder was 150 cfs and oscillated by less than 1 cfs throughout the run;
2) The average flow in the left channel baffle averaged 145 cfs, and 95 percent[23] of the instantaneous flows (taken every 5 seconds) were between 138 cfs and 153 cfs;
3) The average outflow calculated just upstream of the downstream boundary showed an average outflow of 143 cfs and 95 percent of the instantaneous flows were between 115 cfs and 183 cfs. The average outflow of 143 cfs is 4.7 percent less than the expected value of 150 cfs. This difference is likely due to small amounts of fluid gains and losses that occur at mesh block transitions.

[22] The Cabot Fishway run outflows were a bit noisier and did not have clear 'oscillations' like the Station No. 1 Forebay and Cabot Forebay models. This is possibly due to the larger model domain area and more heterogenous topography within the river versus the canal/forebay area.
[23] The 95 percent flow ranges reported for this study are calculated as the difference between the 2.5 percent exceedance flow and the 97.5 percent exceedance flow.

Figure 6.4-1 shows a plan-view comparison of the measured and CFD-modeled depth-averaged ADCP data in the spillway fishway area. In general, the flow patterns and magnitudes between the measured and simulated velocities compare well. The CFD simulation generally provided more diffuse-looking velocity profiles, and it appears that some more local flow phenomena were not represented as clearly.

The velocities immediately downstream of the fishway also appeared to be somewhat different between the measured and simulated data. This difference may be due to the riverbed immediately downstream of the fishway being extremely jagged (Figure 6.4-2), as the bedrock in this area include many rapid rises and drops. Rapid changes in bed elevation (and thus water depths) may reduce the comparability of the modeled and measured data for two reasons:

a) Rapid changes in water depths may impact the ADCP's accuracy (as the depth is rapidly changing);

b) Rapid changes in bed elevations may be smoothed out when they are fit to the model's 2-foot grid size in that area.

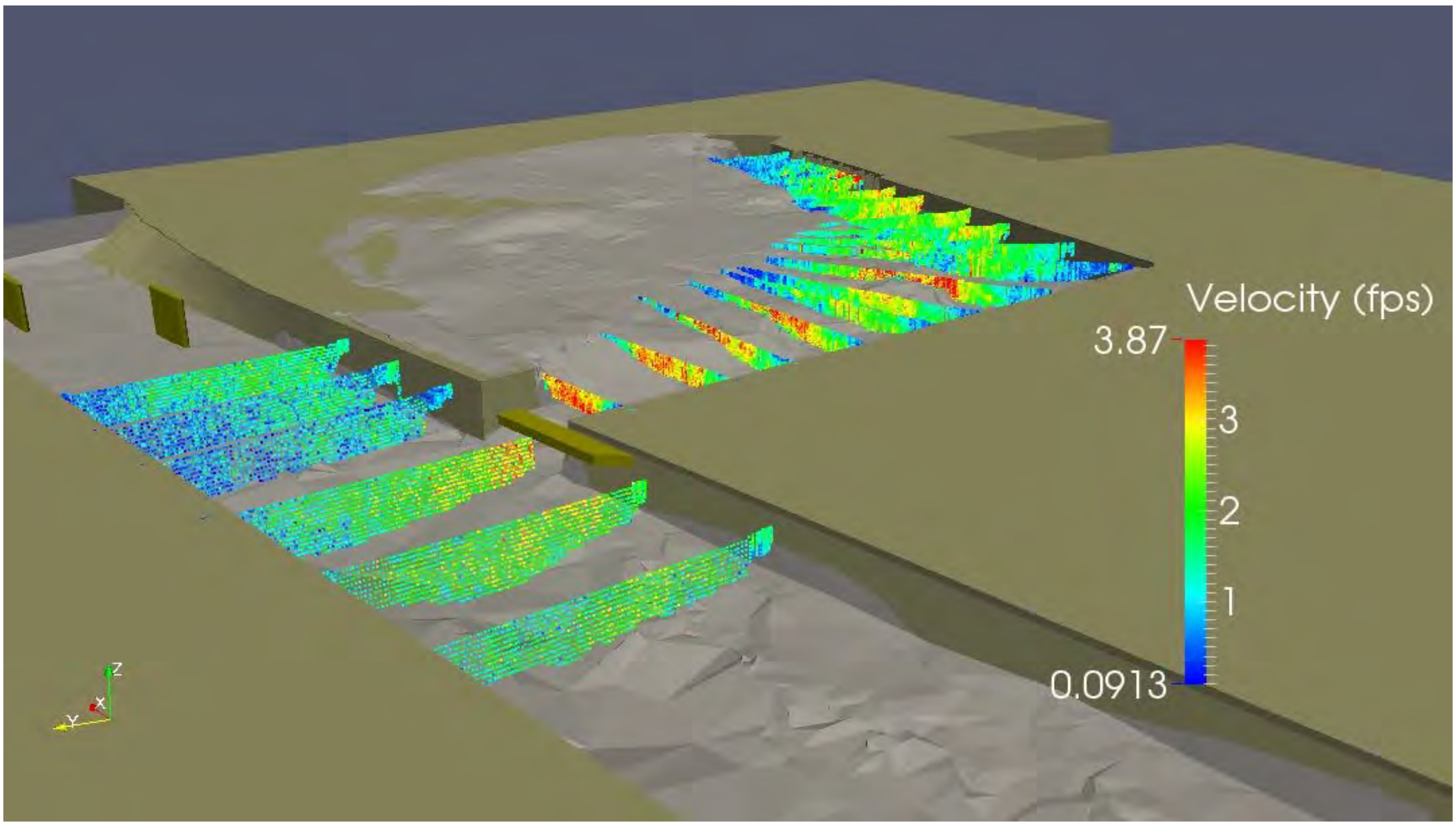
Based on this comparison of the ADCP data and CFD model results, we believe the results from the CFD model production runs are appropriate for meeting this study's objectives.

Table 6.4-1: Cabot Station Verification Model Run Generation Flows

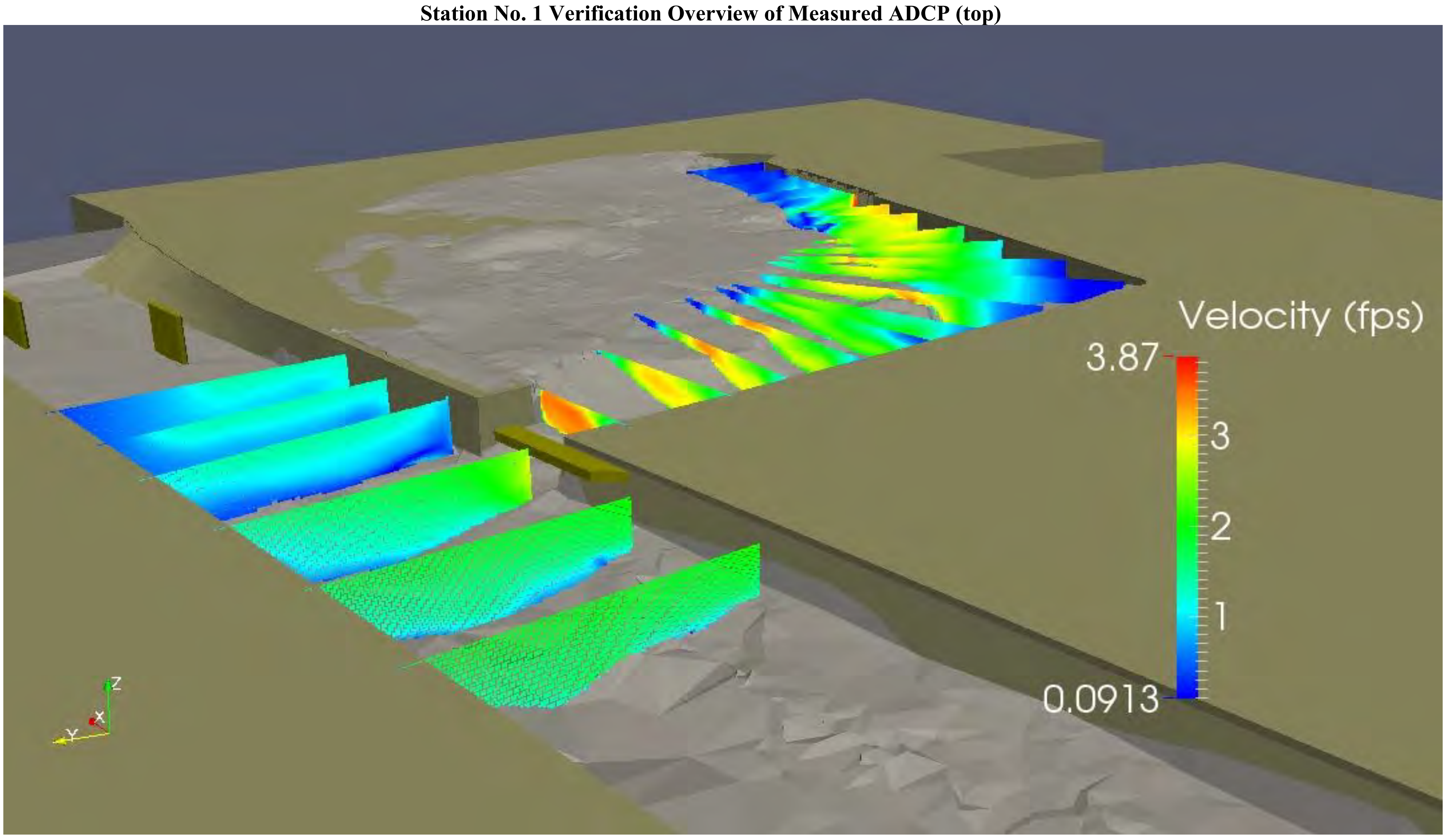
	Flow (cfs)
Bascule Gate #1	0
Bascule Gate #2	0
Bascule Gate #3	0
Bascule Gate #4	0
Spillway Fishway	150
Tainter Gates	0
Total River Flow	**150**

Table 6.4-2: Flow Stability Analysis at Several Baffles within the Spillway Fishway CFD Model

Baffle	Average Flow (cfs)	2.5% Exceedance Flow	97.5% Exceedance Flow
Inside Fishway	150	150	150
Left Channel	145	153	138
Middle Channel	0	2	-1
Tainter Gate Channel	0	4	-4
Left Island	48	56	41
Right Island	95	105	85
Outflow	143	183	115

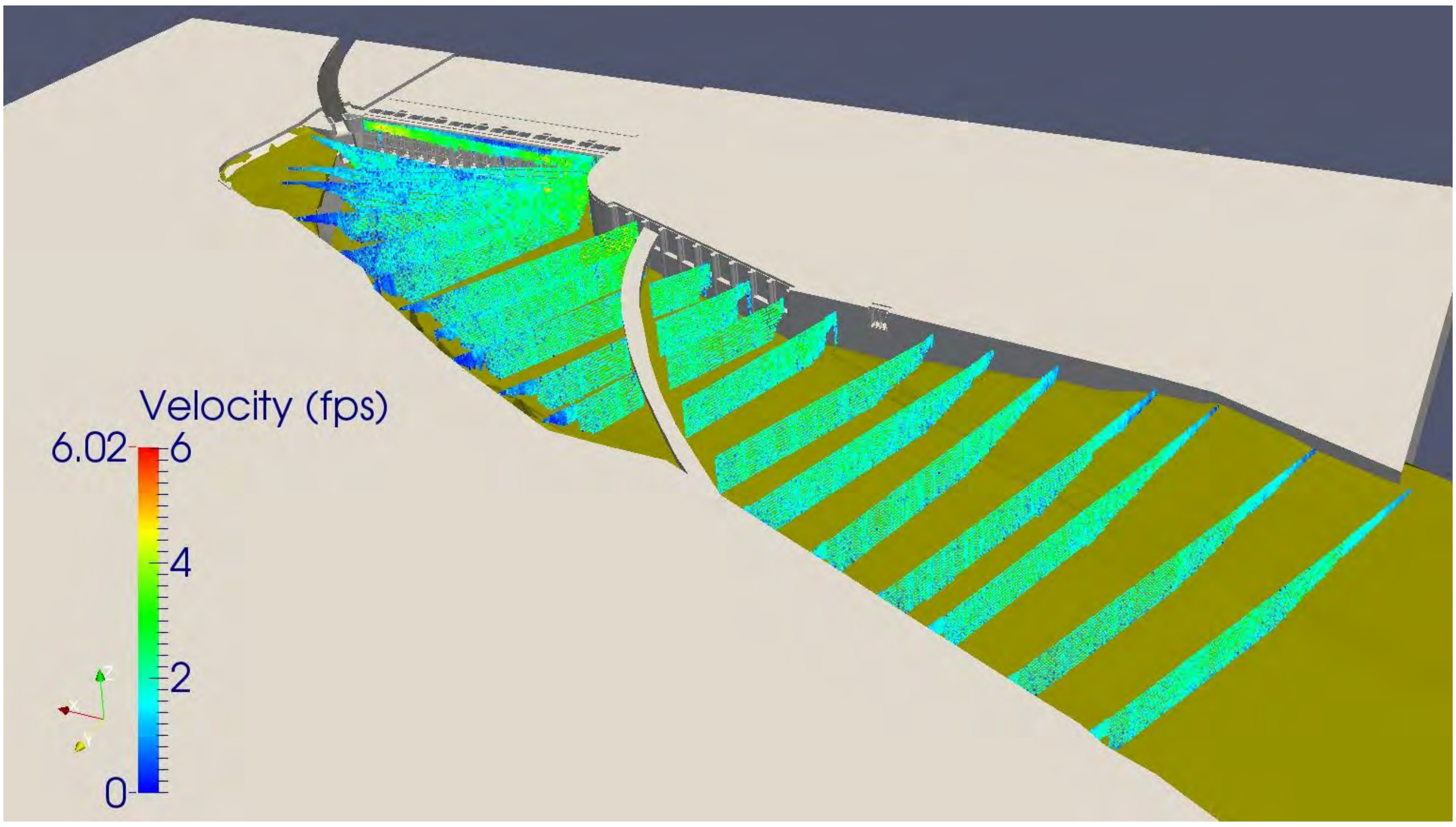


Station No. 1 Verification Overview of Measured ADCP (top)

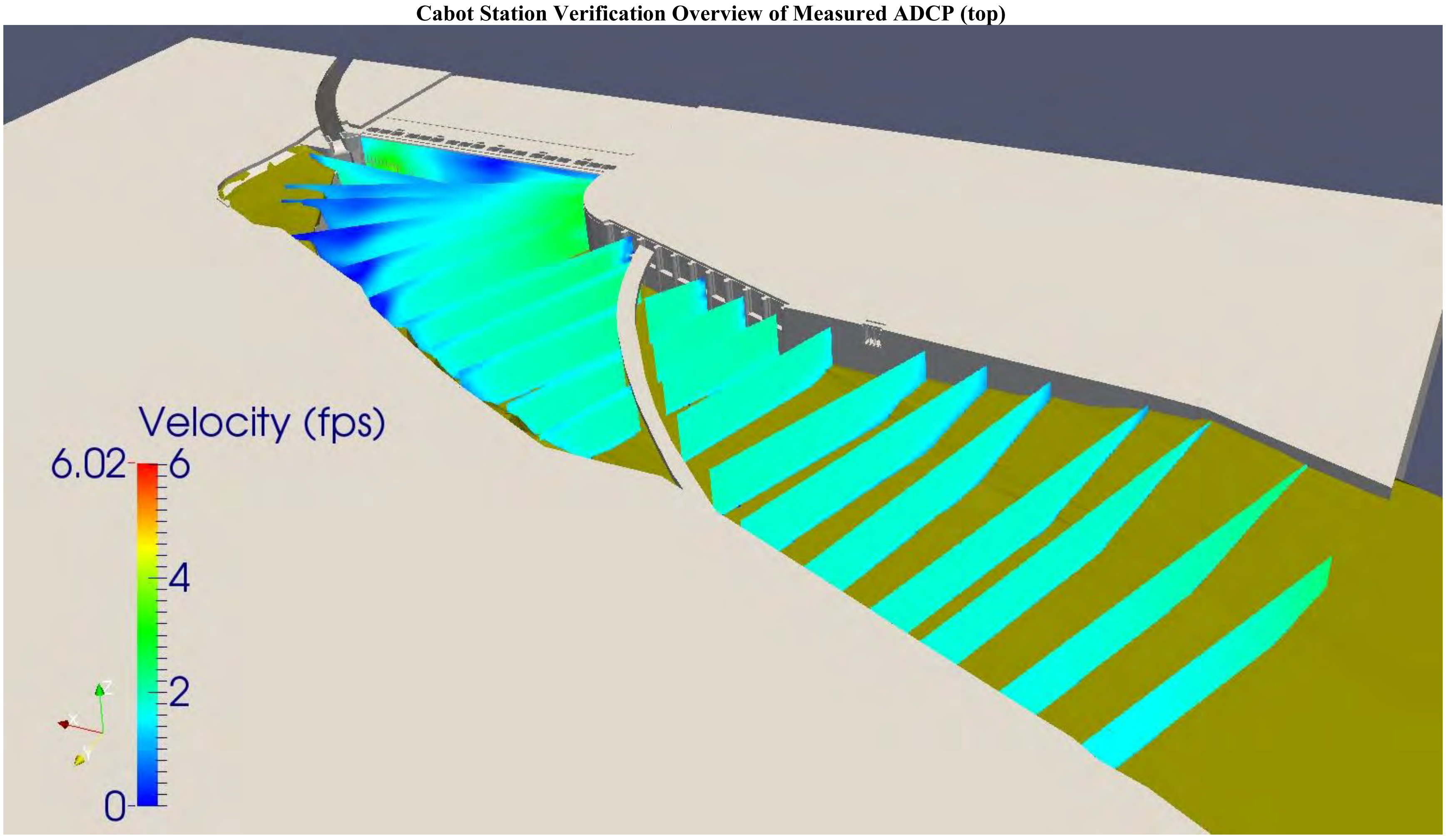


Station No. 1 Simulated Flow-3D (bottom)

Figure 6.1-1: Station No. 1 Verification Overview of Measured ADCP (top) and Simulated Flow-3D (bottom) Water Velocities

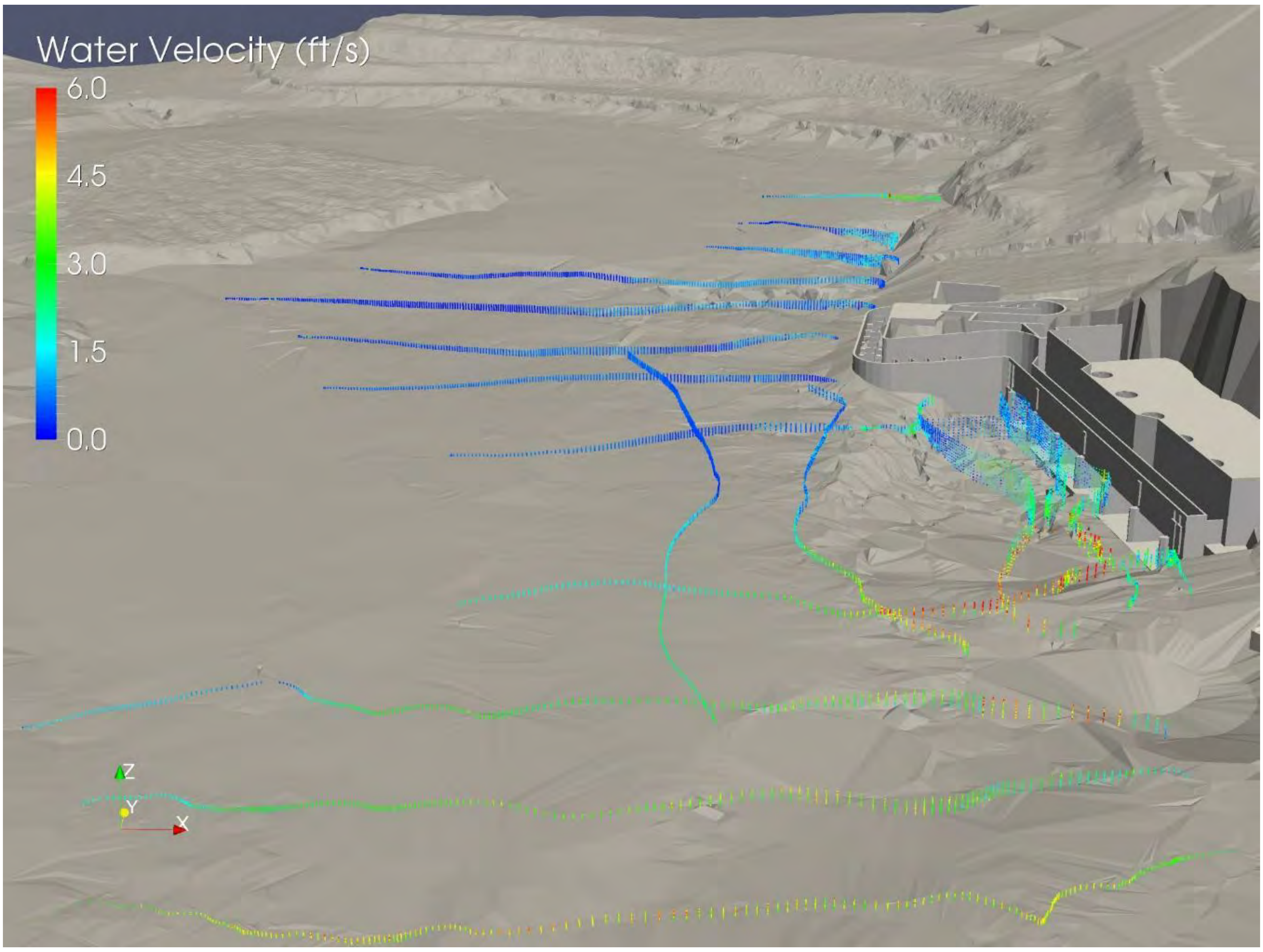


Cabot Station Verification Overview of Measured ADCP (top)

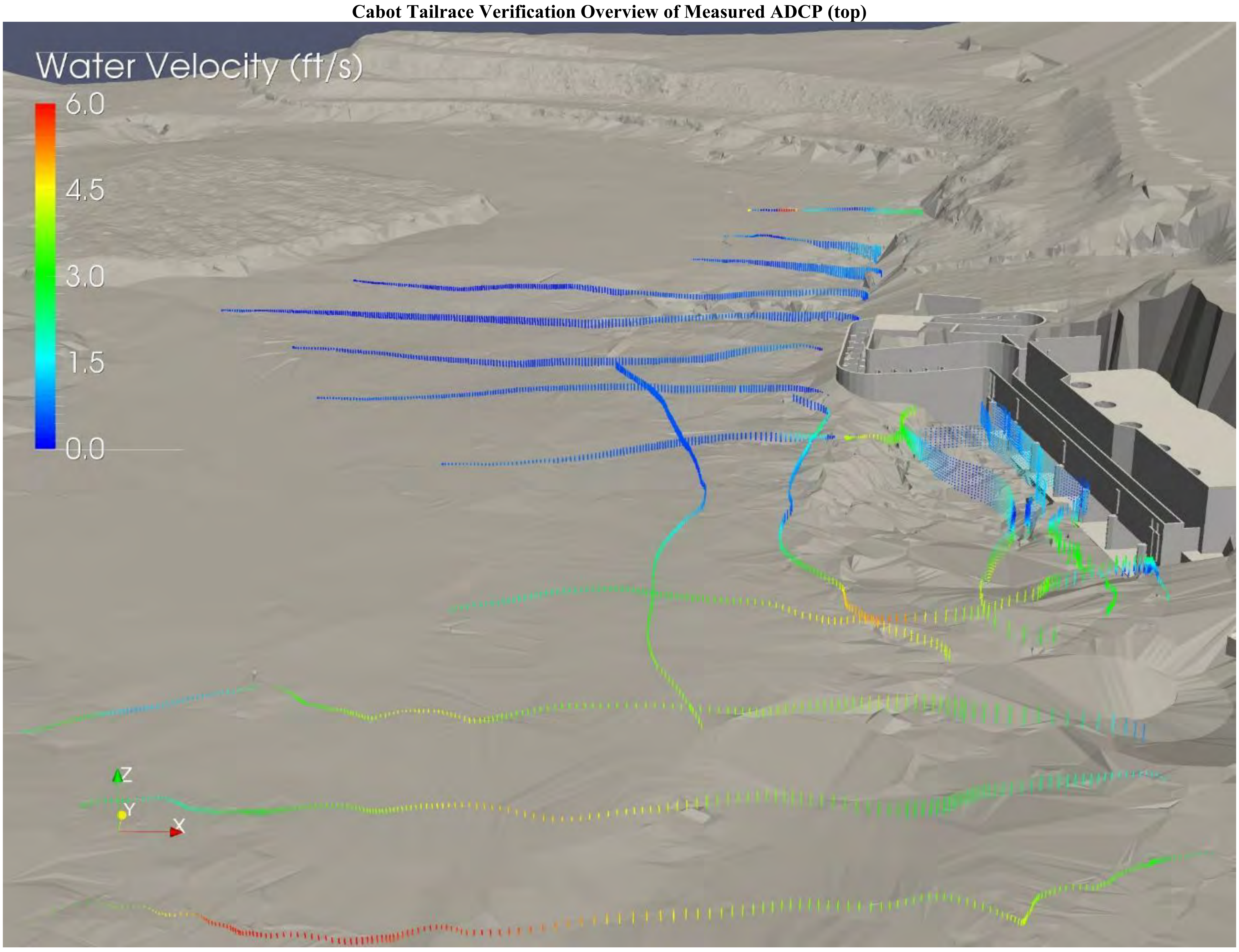


Cabot Station Simulated Flow-3D (bottom)

Figure 6.2-1: Cabot Station Verification Overview of Measured ADCP (top) and Simulated Flow-3D (bottom) Water Velocities

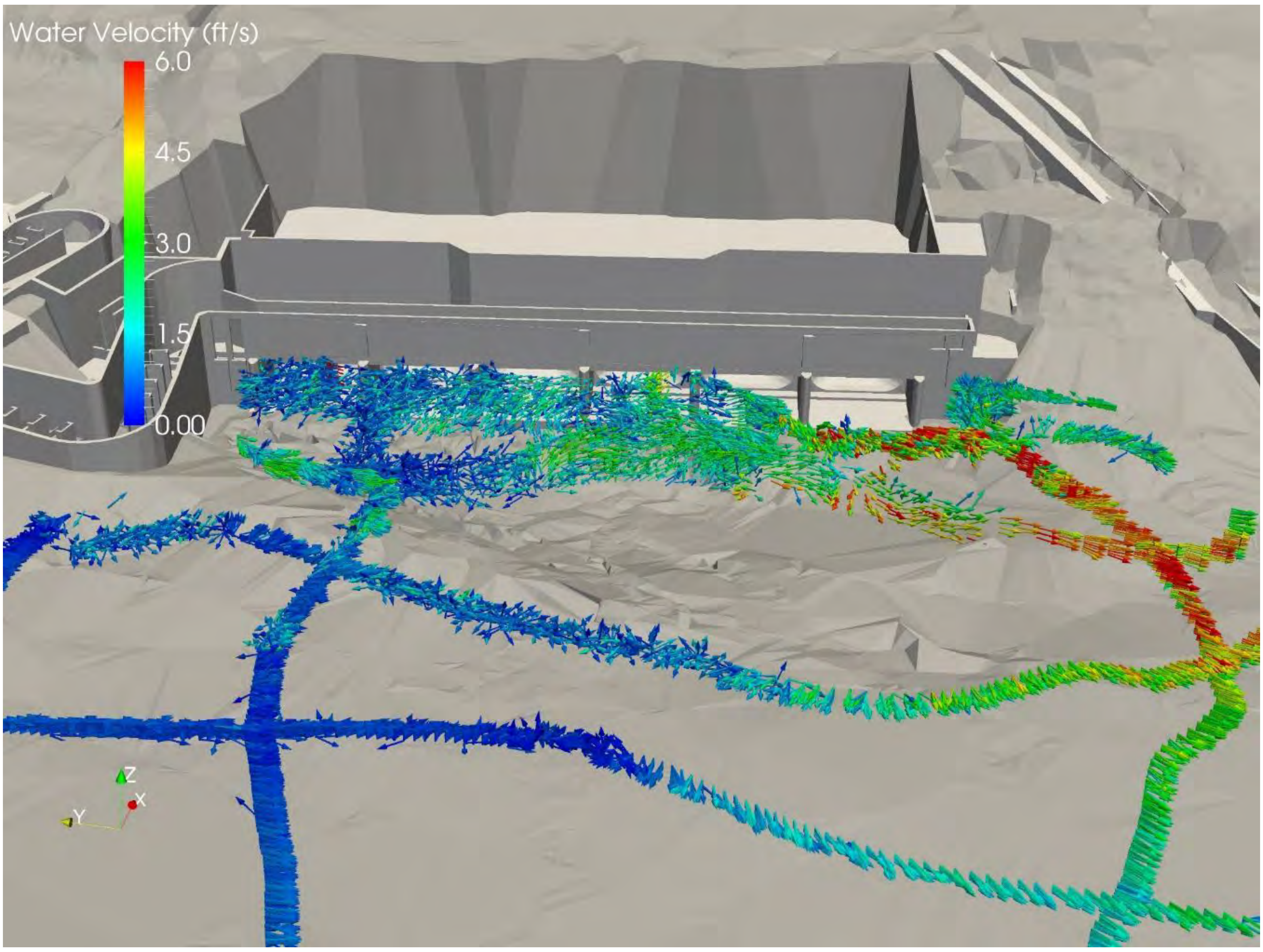


Cabot Tailrace Verification Overview of Measured ADCP (top)

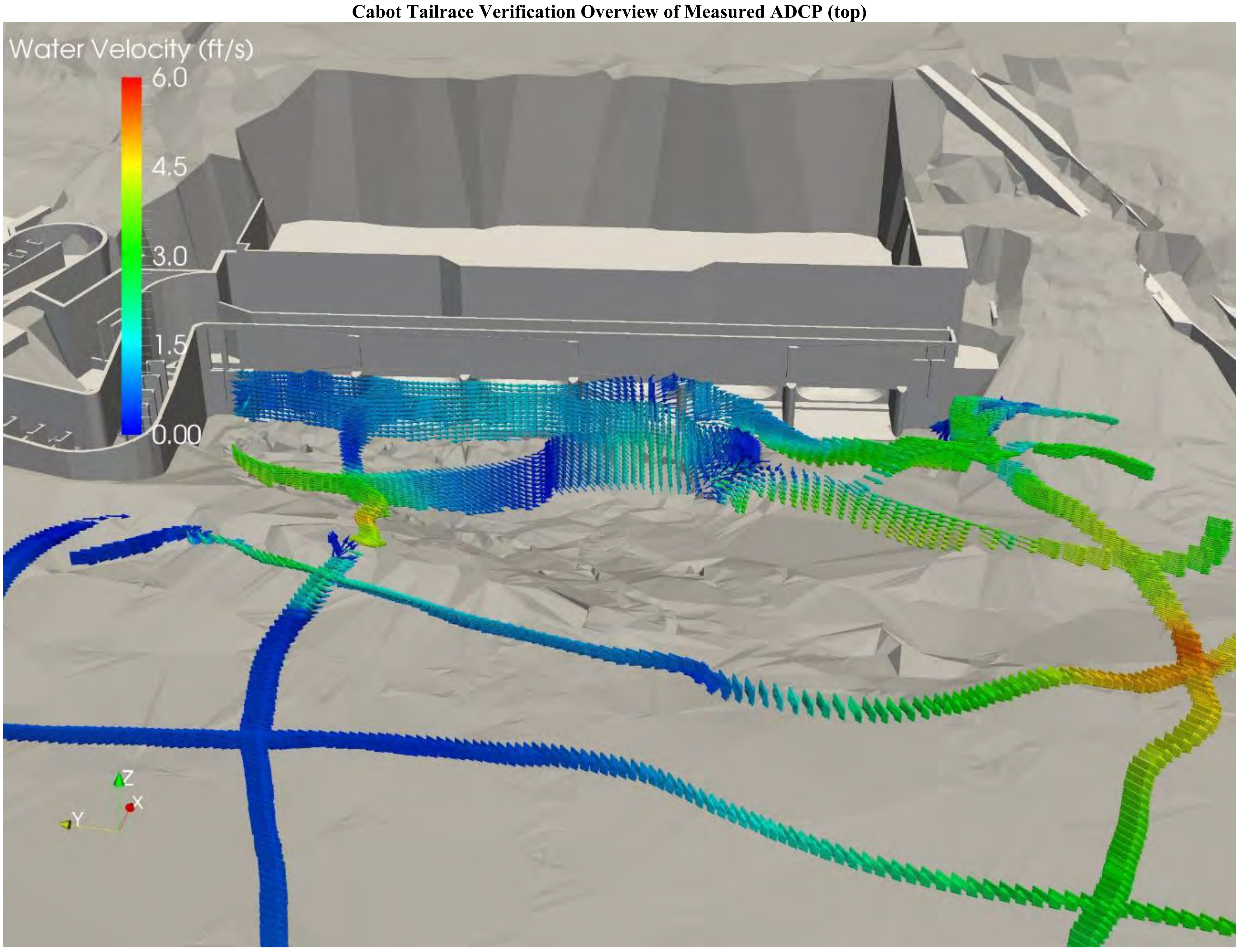


Cabot Tailrace Simulated Flow-3D (bottom)

Figure 6.3-1: Cabot Fishway Verification Upstream-Facing Overview of Measured ADCP (top) and Simulated Flow-3D (bottom) Water Velocities

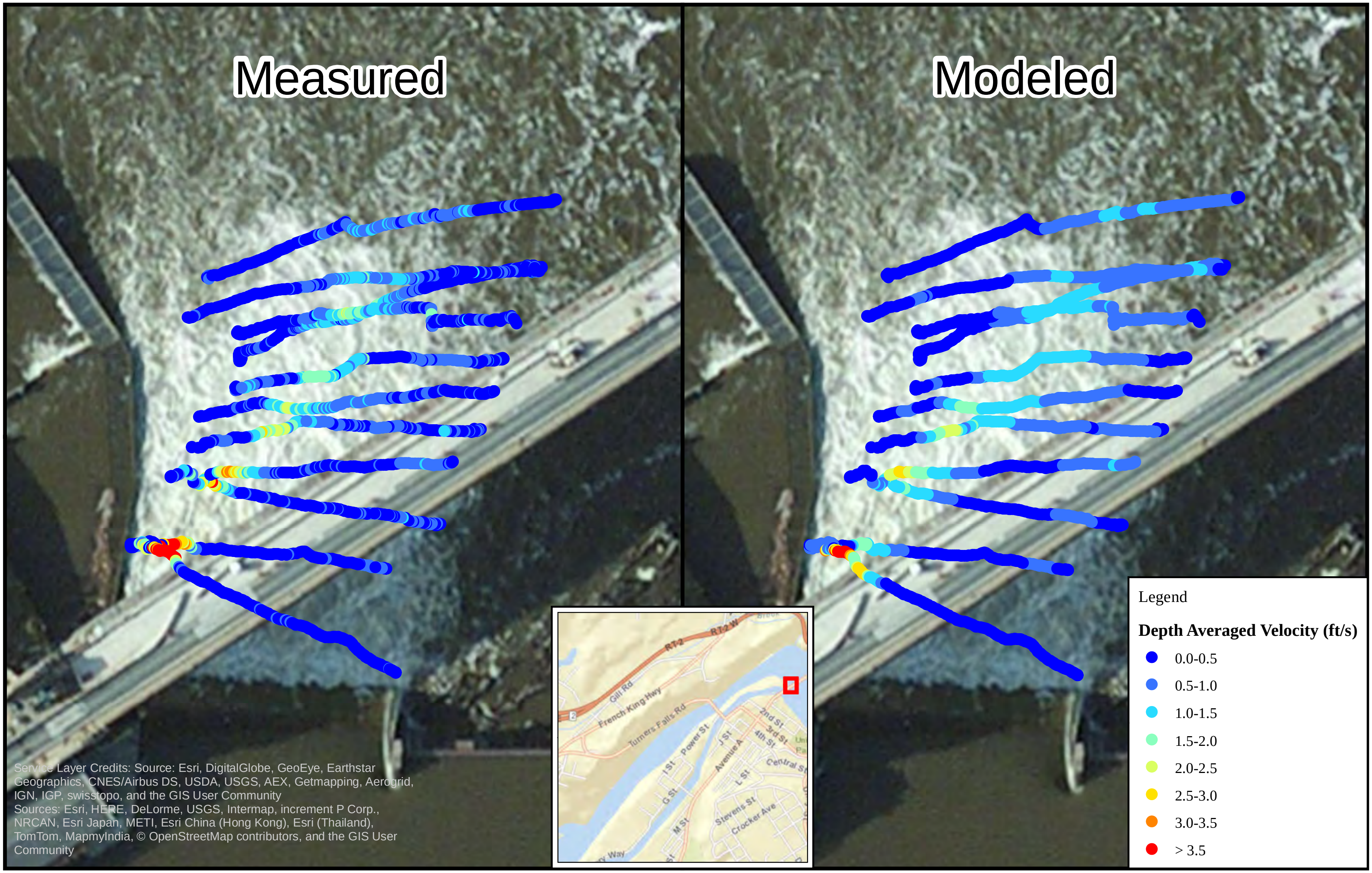


Cabot Tailrace Verification Overview of Measured ADCP (top)



Cabot Tailrace Simulated Flow-3D (bottom)

Figure 6.3-2: Cabot Fishway Verification Powerhouse-Facing Overview of Measured ADCP (top) and Simulated Flow-3D (bottom) Water Velocities



Northfield Mountain Pumped Storage Project (No. 2485)
and Turners Falls Hydroelectric Project (No. 1889)

RELICENSING STUDY 3.3.8

Figure 6.4-1: Comparison of depth-averaged model outputs for the verification scenario.

N

0 62.5 125 250 Feet

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Figure 6.4-2: Photograph Looking Downstream from the Spillway Fishway Showing the Jagged Bedrock Formations Along River Left

7 PRODUCTION MODEL RUNS (SCENARIOS)

Production runs were completed to meet the model objectives for each of the Study Areas as described in Section 1.2.

7.1 Station No. 1 Forebay

Three (3) production runs (scenarios) were completed for the Station No. 1 Forebay model as described in the following subsections and summarized in Table 7.1-1.

Table 7.1-1: Flow Scenarios for CFD Model 1 at Station No. 1

Scenario Number	Model Run	Station No. 1 Flow (cfs)	Canal Pass-Through Flow (cfs)	Total Power Canal Flow (cfs)
1-1	1	1,433 (current min flow)	200	1,633
1-2	1	2,210 (Station No. 1 capacity)	200	2,410
1-3	1	2,210	13,928 (Cabot capacity of 13,728 cfs plus 200 cfs for log sluice)	16,138

7.1.1 Scenario 1-1

Scenario 1-1 simulates a minimum flow through Station No. 1 (1,433 cfs) and 200 cfs being passed at Cabot Station through the log sluice. Based on discussions with FirstLight staff it was determined that the most likely generating scenario at Station No. 1, which would result in the minimum flow of 1,433 cfs, was to run Units 3, 5 and 7 at approximately 95 percent. Table 7.1.1-1 shows the flow through each unit and the flow through each penstock under this scenario.

With a volumetric flow rate of 1,633 cfs at the Canal Inlet boundary, and 1,433 cfs passing through the units, the remaining 200 cfs passes through the Canal Out boundary to account for flow through the log sluice at Cabot Station.

The Scenario 1-1 model run had a total simulation time of 9,960 seconds to reach a steady state condition. This included 7,200 seconds using a course mesh in the power canal (i.e. without the Canal Refinement block mesh) and 2,760 seconds with the refined mesh.

Near the end of the simulated period the Flow-3D solver indicated that the model had reached a nearly steady state. To further evaluate the model run, the flow through the “baffles” during the last half cycle of oscillation (186 seconds) was evaluated. This evaluation showed that the simulated average discharge at the Canal Outlet boundary was 209 cfs and was oscillating approximately ±40 percent. The average flow of 209 cfs is 4.5 percent more than the expected value of 200 cfs. While the percent fluctuation of the simulated outflow is somewhat high, the absolute fluctuation relative to the volume of water in the system was small and the total volume of water in the system was only fluctuating by 0.08 percent from the mean, indicating that overall the simulation was quite stable. In addition, particularly under the low canal flow conditions, the area of interest for the model is in front of the intake racks which is most heavily influenced by the turbine flows, and not in the power canal. The inflow to the canal (Canal Inlet boundary) and the discharge through the penstocks were specified as boundary conditions and their respective “baffles” had fluctuations of less than 0.5 percent.

Figures and discussion of the flow fields for this scenario are provided in Section 8.2.1.

Table 7.1.1-1: Station No. 1 Scenario 1-1 Generation Flows

	Unit No. 1	Unit No. 2	Unit No. 3	Unit No. 5	Unit No. 7
Maximum Unit Capacity (cfs)	560	140	500	490	520
Simulated Flows (cfs)	0	0	475	465	493
Penstock Number Supplying Unit	1	2		3	4
Penstock Flow (cfs)	0	475		465	493

7.1.2 Scenario 1-2

Scenario 1-2 simulates Station No. 1 generating at full capacity (2,210 cfs) and 200 cfs being passed through the log sluice at Cabot Station.

Table 7.1.2-1 shows the flow through each unit and the flow through each penstock under this scenario.

With a volumetric flow rate of 2,410 cfs at the Canal Inlet boundary, and 2,210 cfs passing through the units, the remaining 200 cfs passes through the Canal Out boundary to account for flow through the log sluice at Cabot Station.

The Scenario 1-2 model run utilized the verification run solution as an initial condition, it then took a total simulation time of 3,740 seconds to reach a steady state condition.

Near the end of the simulation period, the Flow-3D solver indicated that the model had reached a nearly steady state. To further evaluate the model run, the flow through the "baffles" during the last 100 seconds was evaluated. This evaluation showed that the simulated average discharge at the Canal Outlet boundary was 211 cfs and was oscillating approximately ±37 percent. The average flow of 211 cfs is 5.5 percent more than the expected value of 200 cfs. While the percent fluctuation of the simulated outflow is somewhat high, the absolute fluctuation relative to the volume of water in the system was small and the total volume of water in the system was only fluctuating by 0.04% from the mean, indicating that overall the simulation was quite stable. In addition, particularly under the low canal flow conditions, the area of interest for the model is in front of the intake racks and not in the power canal. The inflow to the canal (Canal Inlet boundary) and the discharge through the penstocks were specified as boundary conditions and their respective "baffles" had fluctuations of less than 0.5 percent.

Figures and discussion of the flow fields for this scenario are provided in Section 8.2.2.

Table 7.1.2-1: Station No. 1 Scenario 1-2 Generation Flows

	Unit No. 1	Unit No. 2	Unit No. 3	Unit No. 5	Unit No. 7
Maximum Unit Capacity (cfs)	560	140	500	490	520
Simulated Flows (cfs)	560	140	500	490	520
Penstock Number Supplying Unit	1	2		3	4
Penstock Flow (cfs)	560	640		490	520

7.1.3 Scenario 1-3

Scenario 1-3 simulates Station No. 1 generating at full capacity (2,210 cfs), Cabot Station generating at full capacity (13,728 cfs) and 200 cfs being passed through the log sluice at Cabot Station.

Table 7.1.3-1 shows the flow through each unit and the flow through each penstock under this scenario.

With a volumetric flow rate of 16,138 cfs at the Canal Inlet boundary, and 2,210 cfs passing through the units at Station No. 1, the remaining 13,928 cfs passes through the Canal Out boundary to account for the 13,728 cfs Cabot Station generation flows and the 200 cfs flow through the log sluice at Cabot Station.

The Scenario 1-3 model run utilized the verification run solution as an initial condition, it then took a total simulation time of 4,760 seconds to reach a steady state condition.

Near the end of the simulation period, the Flow-3D solver indicated that the model had reached a nearly steady state. To further evaluate the model run, the flow through the "baffles" during the last 100 seconds was evaluated. This evaluation showed that the simulated average discharge at the Canal Outlet boundary was 13,941 cfs and was oscillating approximately ±0.3 percent. The difference between the expected out flow (13,928 cfs) and the average simulated flow (13,941 cfs) is negligible (less than 0.1 percent), and the total volume of water in the system was fluctuating by 0.05 percent from the mean, indicating that overall the simulation was quite stable. The inflow to the canal (Canal Inlet boundary) and the discharge through the penstocks were specified as boundary conditions and their respective "baffles" had fluctuations of less than 0.5 percent.

Figures and discussion of the model results for this scenario are provided in Section 8.2.3.

Table 7.1.3-1: Station No. 1 Scenario 1-3 Generation Flows

	Unit No. 1	Unit No. 2	Unit No. 3	Unit No. 5	Unit No. 7
Maximum Unit Capacity (cfs)	560	140	500	490	520
Simulated Flows (cfs)	560	140	500	490	520
Penstock Number Supplying Unit	1	2		3	4
Penstock Flow (cfs)	560	640		490	520

7.2 Cabot Station Forebay

Three (3) production runs were completed for the Cabot Station Forebay model as described in the following subsections and summarized in Table 7.2-1.

Table 7.2-1: Flow Scenarios for CFD Model 3 at Cabot Station

Scenario Number	Model Run	Cabot Station Flow (cfs)	Log Sluice Flow (cfs)	Total Power Canal Flow (cfs)
3-1	3	1,700	200	1,900
3-2	3	7,500	200	7,700
3-3	3	13,728 (Cabot capacity)	200	13,928

7.2.1 Scenario 3-1

Under Scenario 3-1 Cabot Station is operating with one (1) unit generating at a flow of 1,700 cfs, and has 200 cfs passing through the log sluice. Based on a discussions with FirstLight staff, the units at Cabot Station are typically operated in sequence from Unit 1 to Unit 6, therefore, if only one unit were generating, it would most likely be Unit No. 1. Table 7.2.1-1 shows the maximum unit capacity for each turbine as well as the generation flow modeled for each turbine under this scenario.

With the minimum generation flow passing through Unit No.1 (1,700 cfs) and approximately 200 cfs passing through the log sluice, the total simulated inflow through the Canal Inlet boundary would be approximately 1,900 cfs.

The Scenario 3-1 model run was started with an initial water level of 173.6 ft and 0 fps velocity and took a total simulation time of 7,200 seconds to reach a steady state condition.

Near the end of the simulation period, the Flow-3D solver indicated that the model had reached a nearly steady state. To further evaluate the model run, the flow through the "baffles" during the last 400 seconds was evaluated. This evaluation showed that the average simulated inflow through the Canal Inlet boundary was 1,910 cfs and was oscillating by about 3 percent from the mean. The difference between the expected inflow (1,900 cfs) and the average simulated flow (1,910 cfs) is less than 1 percent. The average simulated flow through the log sluice is 178 cfs, which is approximately 11 percent less than the 200 cfs identified in the RSP. The total volume of water in the model was also evaluated and found to fluctuate by less than 0.05 percent from the mean, indicating that overall the simulation had reached a steady state. The discharge through the penstocks was specified as a boundary condition and the flow into the penstocks showed almost no fluctuation over time.

Figures and discussion of the model results for this scenario are provided in Section 8.3.1.

Table 7.2.1-1: Cabot Station Scenario 3-1 Generation Flows

	Unit No. 1	Unit No. 2	Unit No. 3	Unit No. 4	Unit No. 5	Unit No. 6
Maximum Unit Capacity (cfs)	2,288	2,288	2,288	2,288	2,288	2,288
Modeled Generation Flows (cfs)	1,700	0	0	0	0	0

7.2.2 Scenario 3-2

According to the RSP, under Scenario 3-2 Cabot Station should have generation flows of 7,500 cfs through the turbines and 200 cfs passing through the log sluice.

Based on a discussions with FirstLight staff, the closest Cabot Station would come to generating at 7,500 cfs would be to have three (3) units generating, which at 2,288 cfs per unit would result in a total generation flow of 6,864 cfs. The units at Cabot Station are typically operated in sequence from Unit 1 to Unit 6, therefore, if three (3) units were generating, it would most likely be Units 1, 2 and 3. Table 7.2.2-1 shows the maximum capacity for each unit as well as the generation flow modeled for each unit under this scenario.

With a generation flow of 6,864 cfs and approximately 200 cfs passing through the log sluice, the total simulated inflow through the model boundary should be approximately 7,064 cfs.

The Scenario 3-2 model run utilized the Scenario 3-3 (which was run first) solution as an initial condition, it then took a total simulation time of 4,800 seconds to reach a steady state condition.

Near the end of the simulation period, the Flow-3D solver indicated that the model had reached a nearly steady state. To further evaluate the model run, the flow through the "baffles" during the last 100 seconds (one cycle of oscillation) was evaluated. This evaluation showed that the average simulated inflow through the Canal Inlet boundary was 7,126 cfs and was oscillating less than 2 percent from the mean. The difference between the expected inflow (7,064 cfs) and the average simulated flow (7,126 cfs) is less than 1 percent. The average simulated flow through the log sluice is 167 cfs, which is approximately 17 percent less than the 200 cfs identified in the RSP. The total volume of water in the model was also evaluated and found to fluctuate by 0.05 percent from the mean, indicating that overall the simulation had reached a steady state.

The discharge through the penstocks was specified as a boundary condition and the flow into the penstocks showed almost no fluctuation over time (less than 0.05 percent).

Figures and discussion of the model results for this scenario are provided in Section 8.3.2.

Table 7.2.2-1: Cabot Station Scenario 3-2 Generation Flows

	Unit No. 1	Unit No. 2	Unit No. 3	Unit No. 4	Unit No. 5	Unit No. 6
Maximum Unit Capacity (cfs)	2,288	2,288	2,288	2,288	2,288	2,288
Modeled Generation Flows (cfs)	2,288	2,288	2,288	0	0	0

7.2.3 Scenario 3-3

Under Scenario 3-3, Cabot Station has generation flows of 13,728 cfs through the turbines and 200 cfs passing through the log sluice.

Table 7.2.3-1 shows the maximum capacity for each unit as well as the generation flow modeled for each unit under this scenario.

With a generation flow of 13,728 cfs and approximately 200 cfs passing through the log sluice, the total simulated inflow through the model boundary should be approximately 13,928 cfs

The Scenario 3-3 model run utilized the verification run solution as an initial condition, it then took a total of 3,600 seconds of simulation time to reach a steady state condition.

Near the end of the simulation period, the Flow-3D solver indicated that the model had reached a nearly steady state. To further evaluate the model run, the flow through the "baffles" during the last 100 seconds (one cycle of oscillation) was evaluated. This evaluation showed that the average simulated inflow through the Canal Inlet boundary was 14,088 cfs and was oscillating less than 1 percent from the mean. The difference between the expected inflow (13,928 cfs) and the average simulated flow (14,088 cfs) is approximately 1.1 percent. The average simulated flow through the log sluice is 169 cfs, which is approximately 16 percent less than the 200 cfs identified in the RSP. The total volume of water in the model was also evaluated and found to fluctuate by approximately 0.05 percent from the mean, indicating that overall the simulation was fairly steady. The discharge through the penstocks was specified as a boundary condition and the flow into the penstocks showed almost no fluctuation over time (less than 0.05 percent).

Figures and discussion of the model results for this scenario are provided in Section 8.3.3.

Table 7.2.3-1: Cabot Station Scenario 3-3 Generation Flows

	Unit No. 1	Unit No. 2	Unit No. 3	Unit No. 4	Unit No. 5	Unit No. 6
Maximum Unit Capacity (cfs)	2,288	2,288	2,288	2,288	2,288	2,288
Modeled Generation Flows (cfs)	2,288	2,288	2,288	2,288	2,288	2,288

7.3 Cabot Fishway Entrance

The RSP described five production run scenarios for the Cabot Fishway Entrance model, which are described in Table 7.3-1. As noted in Section 1.2, the objectives for this model were to characterize the hydraulics around the Cabot Fishway Entrance and develop a series of velocity maps for each of the production runs. Flow baffles were used to evaluate flow stability in each of these production runs; the baffle locations are shown in Figure 5.3-1. The following sections describe each production run scenario.

Table 7.3-1: RSP-Proposed Flow Scenarios for CFD Model 5

Scenario Number	Cabot Flow (cfs)	Bypass Reach Flow (cfs)	Cabot Fishway Flow (cfs)	Total Flow (cfs)
5-1	1,700	400	368	2,468
5-2	7,500	400	368	8,268
5-3	13,728	400	368	14,496
5-4	13,728	6,501	368	20,597 (April 75% exc.)
5-5	13,728	16,240	368	30,336 (April 50% exc.)

7.3.1 Scenario 5-1

Scenario 5-1 simulates Cabot Station operating with one (1) unit generating at a flow of 1,700 cfs. As discussed in Section 7.2.1, Cabot Station's units are typically operated in sequence from Unit 1 to Unit 6. Since each unit has a capacity of approximately 2,288 cfs, this scenario passed all 1,700 cfs through Unit 1. The total simulated flow in this model, including the powerhouse flow (1,700 cfs), bypass reach flow (400 cfs), and Cabot fishway flow (368 cfs) is approximately 2,468 cfs (Table 7.3.1-1). No flow was simulated through the log sluice.

Model scenario 5-1 was started with an initial water level that was equal to the downstream boundary elevation of 105.88 ft and 0 fps velocity. This model simulation took a total simulation time of approximately 9,200 seconds to reach a steady state condition.

Near the end of the simulation period, the Flow-3D solver indicated that the model had reached a nearly steady state. To further evaluate the model run, the flow through the "baffles" during the last 600 seconds of simulation time was evaluated. Table 7.3.1-2 summarizes the flow fluctuations at these baffles over the 600-second evaluation period.

The flow stability evaluation showed the following key points:

1) The average inflow calculated through Cabot Station was 1,700 cfs and oscillated by less than 1 cfs throughout the run;

2) The average inflow for the bypass reach showed an average flow of 400 cfs, and 95 percent of the instantaneous flows (taken every 1 second) were between 376 cfs and 426 cfs;

3) The average outflow calculated just upstream of the downstream boundary showed an average outflow of 2,619 cfs and 95 percent of the instantaneous flows were between 2,498 cfs and 2,752 cfs. The average outflow of 2,619 cfs is 151 cfs or 6.1 percent greater than the expected value of 2,468 cfs. This difference is likely due to small amounts of fluid gains and losses that occur at mesh block transitions;

4) The total volume of water in the model was also evaluated and found to fluctuate by approximately 0.2 percent from the mean water volume.

Table 7.3.1-1: Cabot Station Production Run 5-1 Model Inflows

Location	Flow (cfs)
Bypass Reach	400
Log Sluice	0
Cabot Fishway	368
Unit 1	1,700
Unit 2	0

Location	Flow (cfs)
Unit 3	0
Unit 4	0
Unit 5	0
Unit 6	0
Total River Flow	**2,468**

Table 7.3.1-2: Flow stability analysis at several baffles within the Cabot Fishway CFD model, model scenario 5-1

	Average Flow (cfs)	2.5% Exceedance Flow	97.5% Exceedance Flow
Bypass Upstream	400	426	376
Bypass Downstream	399	446	354
Upper Left Channel	319	536	56
Upper Right Channel	17	43	9
Cabot Powerhouse	1,700	1,700	1,700
Cabot Fishway	368	368	368
Lower Left Channel	2,349	2,442	2,270
Lower Right Channel	16	25	6
Outflow	2,619	2,752	2,498

7.3.2 Scenario 5-2

Scenario 5-2 simulates Cabot Station operating with four (4) units generating at a flow of 1,875 cfs per unit. As discussed in Section 7.2.1, Cabot Station's units are typically operated in sequence from Unit 1 to Unit 6. Additionally, Section 7.2.2 pointed out that the station is more likely to pass 2,288 cfs at three units for a total flow of 6,864 cfs than to pass 7,500 cfs through four units. It was decided, however, to model flow through four units to match the RSP flows since the focus of the Cabot tailrace model was more about overall river hydraulics than focusing specifically on conditions very close to the units (unlike the Cabot Forebay model which studied sweeping and approach velocities). Since each unit has a maximum hydraulic capacity of approximately 2,288 cfs, this scenario passed 1,875 cfs through Units 1, 2, 3, and 4. The total simulated flow in this model, including the powerhouse flow (7,500 cfs), bypass reach flow (400 cfs), and Cabot fishway flow (368 cfs) is approximately 8,268 cfs (Table 7.3.2-1). No flow was simulated through the log sluice.

Model scenario 5-2 was started with an initial water level that was equal to the downstream boundary elevation of 109.13 ft and 0 fps velocity. This model simulation took a total simulation time of approximately 6,785 seconds to reach a steady state condition.

Near the end of the simulation period, the Flow-3D solver indicated that the model had reached a nearly steady state. To further evaluate the model run, the flow through the "baffles" during the last 600 seconds of simulation time was evaluated. Table 7.3.2-2 summarizes the flow fluctuations at these baffles over the 600 second evaluation period.

The flow stability evaluation showed the following key points:

1) The average inflow calculated through Cabot Station was 7,500 cfs and oscillated by less than 1 cfs throughout the run;
2) The average inflow for the bypass reach showed an average flow of 400 cfs, and 95 percent of the instantaneous flows (taken every 1 second) were between 361 cfs and 443 cfs;

3) The average outflow calculated just upstream of the downstream boundary showed an average outflow of 7,907 cfs and 95 percent of the instantaneous flows were between 7,661 cfs and 8,185 cfs. The average outflow of 7,914 cfs is 354 cfs or 4.4 percent less than the expected value of 8,268 cfs. This difference is likely due to small amounts of fluid gains and losses that occur at mesh block transitions;
4) The total volume of water in the model was also evaluated and found to fluctuate by approximately 0.3 percent from the mean water volume.

Table 7.3.2-1: Cabot Station Production Run 5-2 Model Inflows

Location	Flow (cfs)
Bypass Reach	400
Log Sluice	0
Cabot Fishway	368
Unit 1	1,875
Unit 2	1,875
Unit 3	1,875
Unit 4	1,875
Unit 5	0
Unit 6	0
Total River Flow	**8,268**

Table 7.3.2-2: Flow Stability Analysis at Several Baffles within the Cabot Fishway CFD Model, Model Scenario 5-2

Baffle	Average Flow (cfs)	2.5% Exceedance Flow	97.5% Exceedance Flow
Bypass Upstream	400	443	361
Bypass Downstream	400	454	339
Upper Left Channel	71	124	9
Upper Right Channel	131	165	103
Cabot Powerhouse	7,500	7,500	7,500
Cabot Fishway	368	367	369
Lower Left Channel	7,865	7,912	7,826
Lower Right Channel	89	332	-129
Outflow	7,907	8,185	7,661

7.3.3 Scenario 5-3

Scenario 5-3 simulates Cabot Station operating with all six (6) units generating at their maximum hydraulic capacity of 2,288 cfs per unit for a total powerhouse flow of 13,728 cfs. The total simulated flow in this model, including the powerhouse flow (13,728 cfs), bypass reach flow (400 cfs), and Cabot fishway flow (368 cfs) is approximately 14,496 cfs (Table 7.3.3-1). No flow was simulated through the log sluice.

Model scenario 5-3 was started with an initial water level that was equal to the downstream boundary elevation of 111.69 ft and 0 fps velocity. This model simulation took a total simulation time of approximately 3,900 seconds to reach a steady state condition.

Near the end of the simulation period, the Flow-3D solver indicated that the model had reached a nearly steady state. To further evaluate the model run, the flow through the “baffles” during the last 600 seconds of simulation time was evaluated. Table 7.3.3-2 summarizes the flow fluctuations at these baffles over the 600 second evaluation period.

The flow stability evaluation showed the following key points:

1) The average inflow calculated through Cabot Station was 13,846 cfs and oscillated by less than 10 cfs throughout the run;
2) The average inflow for the bypass reach showed an average flow of 400 cfs, and 95 percent of the instantaneous flows (taken every 1 second) were between 279 cfs and 529 cfs;
3) The average outflow calculated just upstream of the downstream boundary showed an average outflow of 14,577 cfs and 95 percent of the instantaneous flows were between 14,089 cfs and 14,972 cfs. The average outflow of 14,577 cfs is 81 cfs or 0.6 percent greater than the expected value of 14,496 cfs. This difference is likely due to small amounts of fluid gains and losses that occur at mesh block transitions;
4) The total volume of water in the model was also evaluated and found to fluctuate by approximately 0.3 percent from the mean water volume.

Table 7.3.3-1: Cabot Station Production Run 5-3 Model Inflows

Location	Flow (cfs)
Bypass Reach	400
Log Sluice	0
Cabot Fishway	368
Unit 1	2,288
Unit 2	2,288
Unit 3	2,288
Unit 4	2,288
Unit 5	2,288
Unit 6	2,288
Total River Flow	**14,496**

Table 7.3.3-2: Flow Stability Analysis at Several Baffles within the Cabot Fishway CFD Model, Model Scenario 5-3

Baffle	Average Flow (cfs)	2.5% Exceedance Flow	97.5% Exceedance Flow
Bypass Upstream	400	529	279
Bypass Downstream	401	639	164
Upper Left Channel	248	861	141
Upper Right Channel	198	318	71
Cabot Powerhouse	13,846	13,853	13,844
Cabot Fishway	368	366	370
Lower Left Channel	14,081	14,267	13,869
Lower Right Channel	480	653	227
Outflow	14,577	14,972	14,089

7.3.4 Scenario 5-4

Scenario 5-4 simulates Cabot Station operating with all six (6) units generating at their maximum hydraulic capacity of 2,288 cfs per unit for a total powerhouse flow of 13,728 cfs. The total simulated flow in this model, including the powerhouse flow (13,728 cfs), bypass reach flow (6,501 cfs), and Cabot fishway flow (368 cfs) is approximately 20,597 cfs (Table 7.3.4-1). No flow was simulated through the log sluice.

Model scenario 5-4 was started with an initial water level that was equal to the downstream boundary elevation of 113.75 ft and 0 fps velocity. This model simulation took a total simulation time of approximately 4,850 seconds to reach a steady state condition.

Near the end of the simulation period, the Flow-3D solver indicated that the model had reached a nearly steady state. To further evaluate the model run, the flow through the "baffles" during the last 600 seconds of simulation time was evaluated. Table 7.3.4-2 summarizes the flow fluctuations at these baffles over the 600 second evaluation period.

The flow stability evaluation showed the following key points:

1) The average inflow calculated through Cabot Station was 13,855 cfs and oscillated by approximately ±1 cfs throughout the run;
2) The average inflow for the bypass reach showed an average flow of 6,501 cfs, and 95 percent of the instantaneous flows (taken every 1 second) were between 6,457 cfs and 6,572 cfs;
3) The average outflow calculated just upstream of the downstream boundary showed an average outflow of 20,485 cfs and 95 percent of the instantaneous flows were between 20,294 cfs and 20,627 cfs. The average outflow of 20,485 cfs is 112 cfs or 0.5 percent less than the expected value of 20,597 cfs. This difference is likely due to small amounts of fluid gains and losses that occur at mesh block transitions;
4) The total volume of water in the model was also evaluated and found to fluctuate by approximately 0.1 percent from the mean water volume.

Table 7.3.4-1: Cabot Station Production Run 5-4 Model Inflows

Location	Flow (cfs)
Bypass Reach	6,501
Log Sluice	0
Cabot Fishway	368
Unit 1	2,288
Unit 2	2,288
Unit 3	2,288
Unit 4	2,288
Unit 5	2,288
Unit 6	2,288
Total River Flow	**20,597**

Table 7.3.4-2: Flow Stability Analysis at Several Baffles within the Cabot Fishway CFD Model, Model Scenario 5-4

Baffle	Average Flow (cfs)	2.5% Exceedance Flow	97.5% Exceedance Flow
Bypass Upstream	6,501	6,572	6,457
Bypass Downstream	6,500	6,594	6,405

Baffle	Average Flow (cfs)	2.5% Exceedance Flow	97.5% Exceedance Flow
Upper Left Channel	4,465	4,539	4,409
Upper Right Channel	2,021	2,070	1,980
Cabot Powerhouse	13,855	13,856	13,855
Cabot Fishway	367	365	369
Lower Left Channel	16,912	16,979	16,842
Lower Right Channel	3,629	3,764	3,490
Outflow	20,485	20,627	20,294

7.3.5 Scenario 5-5

Scenario 5-5 simulates Cabot Station operating with all six (6) units generating at their maximum hydraulic capacity of 2,288 cfs per unit for a total powerhouse flow of 13,728 cfs. The total simulated flow in this model, including the powerhouse flow (13,728 cfs), bypass reach flow (16,240 cfs), and Cabot fishway flow (368 cfs) is approximately 30,336 cfs (Table 7.3.5-1). No flow was simulated through the log sluice.

Model scenario 5-5 was started with an initial water level that was equal to the downstream boundary elevation of 116.82 ft and 0 fps velocity. This model simulation took a total simulation time of approximately 6,160 seconds to reach a steady state condition.

Near the end of the simulation period, the Flow-3D solver indicated that the model had reached a nearly steady state. To further evaluate the model run, the flow through the "baffles" during the last 600 seconds of simulation time was evaluated. Table 7.3.5-2 summarizes the flow fluctuations at these baffles over the 600 second evaluation period.

The flow stability evaluation showed the following key points:

1) The average inflow calculated through Cabot Station was 13,855 cfs and oscillated by less than 1 cfs throughout the run;
2) The average inflow for the bypass reach showed an average flow of 16,240 cfs, and 95 percent of the instantaneous flows (taken every 1 second) were between 16,222 cfs and 16,258 cfs;
3) The average outflow calculated just upstream of the downstream boundary showed an average outflow of 30,293 cfs and 95 percent of the instantaneous flows were between 30,032 cfs and 30,586 cfs. The average outflow of 30,293 cfs is 43 cfs or 0.1 percent less than the expected value of 30,336 cfs. This difference is likely due to small amounts of fluid gains and losses that occur at mesh block transitions;
4) The total volume of water in the model was also evaluated and found to fluctuate by approximately 0.06 percent from the mean water volume.

Table 7.3.5-1: Cabot Station Production Run 5-5 Model Inflows

Location	Flow (cfs)
Bypass Reach	16,240
Log Sluice	0
Cabot Fishway	368
Unit 1	2,288
Unit 2	2,288
Unit 3	2,288
Unit 4	2,288

Location	Flow (cfs)
Unit 5	2,288
Unit 6	2,288
Total River Flow	**30,336**

Table 7.3.5-2: Flow Stability Analysis at Several Baffles within the Cabot Fishway CFD Model, Model Scenario 5-5

Baffle	Average Flow (cfs)	2.5% Exceedance Flow	97.5% Exceedance Flow
Bypass Upstream	16,240	16,258	16,222
Bypass Downstream	16,238	16,307	16,145
Upper Left Channel	9,805	10,039	9,539
Upper Right Channel	6,404	6,576	6,203
Cabot Powerhouse	13,855	13,855	13,855
Cabot Fishway	368	365	371
Lower Left Channel	22,646	22,873	22,484
Lower Right Channel	7,663	7,895	7,474
Outflow	30,293	30,586	30,032

7.4 Spillway Fishway Entrance

The RSP described four production run scenarios for the Spillway Fishway Entrance model, which are described in Table 7.4-1. As noted in Section 1.2, the objectives for this model were to characterize the hydraulics around the Spillway Fishway Entrance and develop a series of velocity maps for each of the production runs. Flow baffles were used to evaluate flow stability in each of these production runs; the baffle locations are shown in Figure 5.4-1. The following sections describe each production run scenario.

In addition to the verification run results described in Section 6.4 that were used to assess this CFD model's appropriateness in evaluating these production run conditions, water level logger data were used to confirm the model's predicted water surfaces within the plunge pool area. While five loggers were located within the study area, two loggers were lost or vandalized during the deployment period (June 2014 – October 2014). The other three loggers generally showed similar water surface elevations, so a single logger (logger 1-2) was used for this comparison. The coordinates of logger 1-2 are X=372,411 ft and Y =3,049,720 ft in Mass State Plane (feet) coordinates, or X = 8,665 ft and Y = 11,138 ft in model coordinates. The spillway logger locations and logger numbers are shown in Figure 7.4-1. Figure 7.4-2 compares observed versus modeled water surface elevations at water level logger 1-2 using model data from the same model coordinates as the logger. The figure shows that the model results appear to fit well within the scatter of the observed water level data for all three production run scenarios for which there are comparable data. There were no comparable data for production run 6-4.

Table 7.4-1: RSP-proposed flow scenarios for CFD Model 6.

Scenario Number	Power Canal Flow[24] (cfs)	Spillway Ladder Flow (cfs)	Bascule Gate No. 1 Flow (cfs)	Other Bascule Gate Spill[25] (cfs)	Tainter Gate Spill[26] (cfs)	Total Turners Falls Flow (cfs)
6-1	7,282	318[27]	400	0	0	8,000
6-2	15,938	318	4,341	0	0	20,597
6-3	15,938	318	7,500	6,580	0	30,336
6-4	15,938	318	7,500	12,460	10,000	46,216

7.4.1 Scenario 6-1

Scenario 6-1 simulates a lower-flow scenario, with 400 cfs spilling from Bascule Gate 1 and 318 cfs passing through the Spillway Fishway. The total simulated flow in this model, as summarized in Table 7.4.1-1, is approximately 718 cfs.

Model scenario 6-1 was started with an initial water level of 136.0 ft and 0 fps velocity. This model took a total simulation time of approximately 8,500 seconds to reach a steady state condition, with 1,000 seconds of simulation time at the highest-resolution model.

Near the end of the simulation period, the Flow-3D solver indicated that the model had reached a nearly steady state. To further evaluate the model run, the flow through the "baffles" during the last 600 seconds of simulation time was evaluated. Table 7.4.1-2 summarizes the flow fluctuations at these baffles over the 600 second evaluation period.

The flow stability evaluation showed the following key points:

1) The average inflow calculated through the fishway was 318 cfs and 95 percent of the instantaneous flows (taken every 5 seconds) were between 323 cfs and 314 cfs;
2) The flow in the left channel averaged 714 cfs, and 95 percent of the instantaneous flows (taken every 5 seconds) were between 654 cfs and 773 cfs;
3) The outflow calculated just upstream of the downstream boundary averaged 713 cfs and 95 percent of the instantaneous flows were between 686 cfs and 743 cfs. The average outflow of 713 cfs is 5 cfs or 0.1 percent less than the expected value of 718 cfs. This difference is likely due to small amounts of fluid gains and losses that occur at mesh block transitions;
4) The total volume of water in the model was also evaluated and found to fluctuate by approximately 0.01 percent from the mean water volume.

[24] The power canal is not included in CFD model 6, but is included in this table to show the flow distribution.
[25] As noted in the RSP, the bascule gates are typically operated in a set order of no. 1, no. 2, no. 4 and no.3, with gate no. 1 being opened first and closed last, and gate no. 3 being opened last and closed first. The bascule gates can be throttled.
[26] The tainter gates are typically opened to maintain some flexibility in the bascule gates' available capacity. Since the bascule gates do not require manual operation like the tainter gates, station personnel generally prefer to not utilize all of the bascule gate capacity. The tainter gates can be throttled, but the adjustments cannot be done remotely as they can for the bascule gates.
[27] The spillway fishway flow was modeled as a constant value of 318 cfs as specified in the RSP. In reality, the spillway fishway flow varies with changing tailwater elevations. No direct flow measurements exist to quantify this variation, and therefore this study represents spillway flow as a simplified constant flow under all tailwater conditions.

Table 7.4.1-1: Spillway Fishway Production Run 6-1 Model Inflows

Location	Flow (cfs)
Spillway Fishway	318
Bascule Gate 1	400
Bascule Gate 2	0
Bascule Gate 3	0
Bascule Gate 4	0
Tainter Gates	0
Total Modeled Flow	**718**

Table 7.4.1-2: Flow Stability Analysis at Several Baffles within the Spillway Fishway CFD Model, Model Scenario 6-1

Baffle	Average Flow (cfs)	2.5% Exceedance Flow	97.5% Exceedance Flow
Spillway Fishway	318	323	314
Left Channel	714	773	654
Middle Channel	0	8	-8
Tainter Gate Channel	0	19	-16
Left Island	256	246	268
Right Island	457	443	472
Outflow	713	686	743

7.4.2 Scenario 6-2

Scenario 6-2 simulates a moderate spill scenario, with 4,341 cfs spilling from Bascule Gate 1 and 318 cfs passing through the Spillway Fishway. The total simulated flow in this model, as summarized in Table 7.4.2-1, is approximately 4,659 cfs.

Model scenario 6-2 was started with an initial water level of 138.0 ft and 0 fps velocity. This model took a total simulation time of approximately 4,175 seconds to reach a steady state condition, with 825 seconds of simulation time at the highest-resolution model.

Near the end of the simulation period, the Flow-3D solver indicated that the model had reached a nearly steady state. To further evaluate the model run, the flow through the "baffles" during the last 600 seconds of simulation time was evaluated. Table 7.4.2-2 summarizes the flow fluctuations at these baffles over the 600 second evaluation period.

The flow stability evaluation showed the following key points:

1) The average inflow calculated through the fishway was 318 cfs and 95 percent of the instantaneous flows (taken every 5 seconds) were between 312 cfs and 324 cfs;
2) The flow in the left channel averaged 4,646 cfs, and 95 percent of the instantaneous flows (taken every 5 seconds) were between 4,532 cfs and 4,744 cfs;
3) The outflow calculated just upstream of the downstream boundary averaged 4,629 cfs and 95 percent of the instantaneous flows were between 4,574 cfs and 4,686 cfs. The average outflow of 4,629 cfs is 30 cfs or 0.6 percent less than the expected value of 4,659 cfs. This difference is likely due to small amounts of fluid gains and losses that occur at mesh block transitions;
4) The total volume of water in the model was also evaluated and found to fluctuate by approximately 0.06 percent from the mean water volume.

Table 7.4.2-1: Spillway Fishway Production Run 6-2 Model Inflows

Location	Flow (cfs)
Spillway Fishway	318
Bascule Gate 1	4,341
Bascule Gate 2	0
Bascule Gate 3	0
Bascule Gate 4	0
Tainter Gates	0
Total Modeled Flow	**4,659**

Table 7.4.2-2: Flow Stability Analysis at Several Baffles within the Spillway Fishway CFD Model, Model scenario 6-2

Baffle	Average Flow (cfs)	2.5% Exceedance Flow	97.5% Exceedance Flow
Spillway Fishway	318	324	312
Left Channel	4,646	4,744	4,532
Middle Channel	-1	19	-16
Tainter Gate Channel	1	38	-40
Left Island	2,203	2,241	2,164
Right Island	2,420	2,445	2,397
Outflow	4,629	4,686	4,574

7.4.3 Scenario 6-3

Scenario 6-3 simulates a moderate spill scenario, with 7,500 cfs spilling from Bascule Gate 1, 6,580 cfs spilling from Bascule Gate 2, and 318 cfs passing through the Spillway Fishway. The total simulated flow in this model, as summarized in Table 7.4.3-1, is approximately 14,398 cfs.

Model scenario 6-3 was started with an initial water level of 139.0 ft and 0 fps velocity. This model took a total simulation time of approximately 4,900 seconds to reach a steady state condition, with 650 seconds of simulation time at the highest-resolution model.

Near the end of the simulation period, the Flow-3D solver indicated that the model had reached a nearly steady state. To further evaluate the model run, the flow through the "baffles" during the last 300 seconds[28] of simulation time was evaluated. Table 7.4.3-2 summarizes the flow fluctuations at these baffles over the 300 second evaluation period.

The flow stability evaluation showed the following key points:

1) The average inflow calculated through the fishway was 321 cfs and 95 percent of the instantaneous flows (taken every 5 seconds) were between 289 cfs and 353 cfs;
2) The flow in the left channel averaged 14,170 cfs, and 95 percent of the instantaneous flows (taken every 5 seconds) were between 13,956 cfs and 14,352 cfs;
3) The outflow calculated just upstream of the downstream boundary averaged 14,447 cfs and 95 percent of the instantaneous flows were between 14,392 cfs and 14,514 cfs. The average outflow

[28] The higher-flow scenarios (PR 6-3, PR 6-4) required a shorter flow analysis period because the simulation approached steady-state conditions much quicker than the lower-flow scenarios (PR 6-1, PR 6-2).

of 14,447 cfs is 49 cfs or 0.3 percent greater than the expected value of 14,398 cfs. This difference is likely due to small amounts of fluid gains and losses that occur at mesh block transitions;

4) The total volume of water in the model was also evaluated and found to fluctuate by approximately 0.08 percent from the mean water volume.

Table 7.4.3-1: Spillway Fishway Production Run 6-3 Model Inflows

Location	Flow (cfs)
Spillway Fishway	318
Bascule Gate 1	7,500
Bascule Gate 2	6,580
Bascule Gate 3	0
Bascule Gate 4	0
Tainter Gates	0
Total Modeled Flow	**14,398**

Table 7.4.3-2: Flow Stability Analysis at Several Baffles within the Spillway Fishway CFD Model, Model Scenario 6-3

Baffle	Average Flow (cfs)	2.5% Exceedance Flow	97.5% Exceedance Flow
Spillway Fishway	321	353	289
Left Channel	14,170	14,352	13,956
Middle Channel	213	249	168
Tainter Gate Channel	0	68	-78
Left Island	7,470	7,570	7,379
Right Island	6,894	6,938	6,869
Outflow	14,447	14,514	14,392

7.4.4 Scenario 6-4

Scenario 6-4 simulates a higher-flow scenario, with 7,500 cfs spilling from Bascule Gate 1, 7,500 cfs spilling from Bascule Gate 2, 4,960 cfs spilling from Bascule Gate 4, 10,000 cfs passing through the tainter gates, and 318 cfs passing through the Spillway Fishway. The total simulated flow in this model, as summarized in Table 7.4.4-1, is approximately 30,278 cfs.

Model scenario 6-4 was started with an initial water level of 141.0 ft and 0 fps velocity. This model took a total simulation time of approximately 2,900 seconds to reach a steady state condition, with 650 seconds of simulation time at the highest-resolution model.

Near the end of the simulation period, the Flow-3D solver indicated that the model had reached a nearly steady state. To further evaluate the model run, the flow through the "baffles" during the last 400 seconds of simulation time was evaluated. Table 7.4.4-2 summarizes the flow fluctuations at these baffles over the 400 second evaluation period.

The flow stability evaluation showed the following key points:

1) The average inflow calculated through the fishway was 319 cfs and 95 percent of the instantaneous flows (taken every 5 seconds) were between 287 cfs and 349 cfs;
2) The flow in the left channel was averaged 15,041 cfs, and 95 percent of the instantaneous flows (taken every 5 seconds) were between 14,771 cfs and 15,314 cfs;

3) The outflow calculated just upstream of the downstream boundary averaged 30,279 cfs and 95 percent of the instantaneous flows were between 30,125 cfs and 30,428 cfs. The average outflow of 30,279 cfs is 1 cfs or 0.003 percent greater than the expected value of 30,278 cfs. This difference is likely due to small amounts of fluid gains and losses that occur at mesh block transitions.

4) The total volume of water in the model was also evaluated and found to fluctuate by approximately 0.06 percent from the mean water volume.

Table 7.4.4-1: Spillway Fishway Production Run 6-4 Model Inflows

Location	Flow (cfs)
Spillway Fishway	318
Bascule Gate 1	7,500
Bascule Gate 2	7,500
Bascule Gate 3	0
Bascule Gate 4	4,960
Tainter Gates	10,000
Total Modeled Flow	**30,278**

Table 7.4.4-2: Flow Stability Analysis at Several Baffles within the Spillway Fishway CFD Model, Model Scenario 6-4

Baffle	Average Flow (cfs)	2.5% Exceedance Flow	97.5% Exceedance Flow
Spillway Fishway	319	349	287
Left Channel	15,041	15,314	14,771
Middle Channel	5,207	5,425	5,001
Tainter Gate Channel	10,001	10,085	9,919
Left Island	15,451	15,619	15,298
Right Island	14,688	14,811	14,582
Outflow	30,279	30,428	30,125

Northfield Mountain Pumped Storage Project (No. 2485)
and Turners Falls Hydroelectric Project (No. 1889)
RELICENSING STUDY 3.3.8

Figure 7.4-1:
Spillway Area Water Level Logger Locations

Path: W:\gis\studies\3_3_08\maps\Figures\CFD Study Report\Water Level Loggers - Spillway.mxd

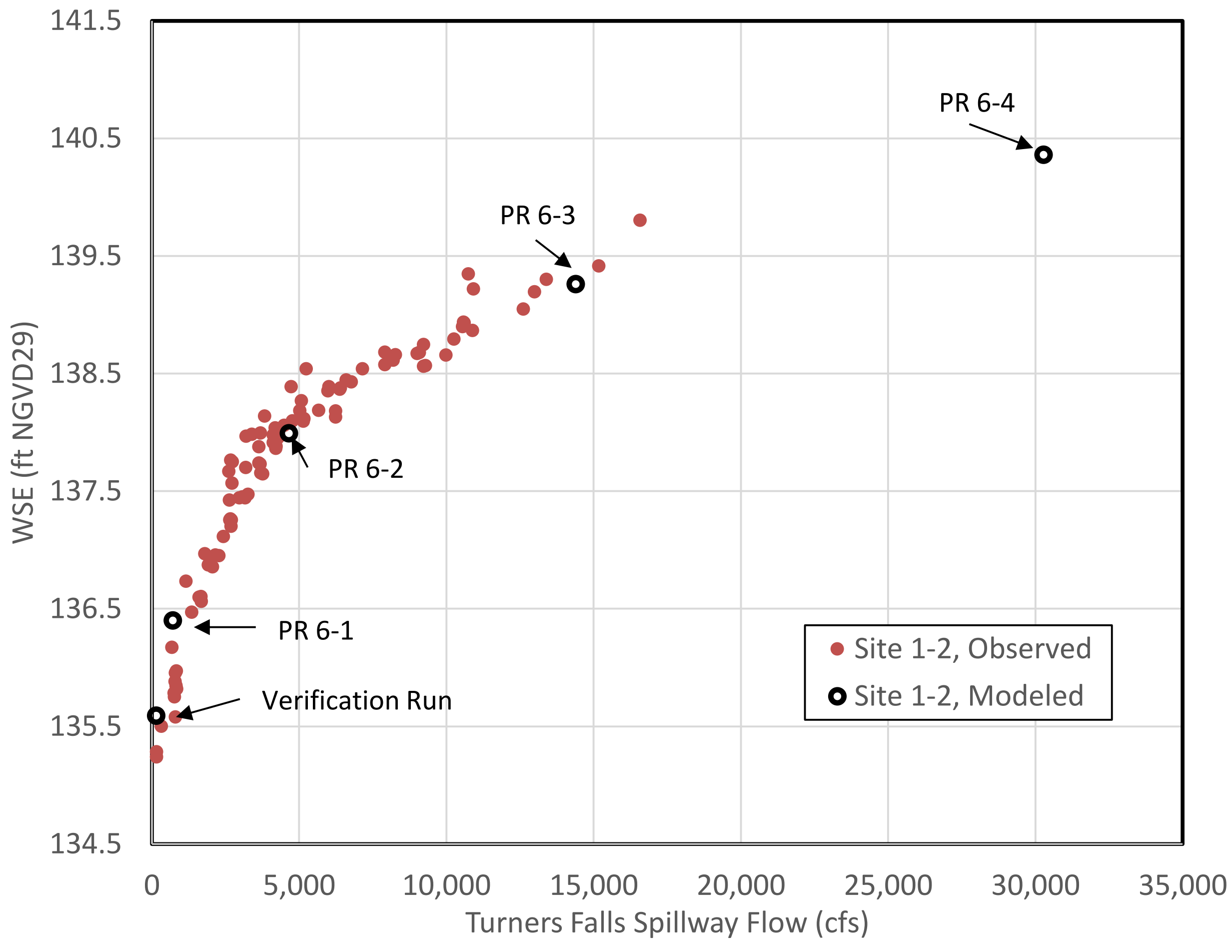


Figure 7.4-2: Spillway CFD Model Production Run Water Surface Elevation Comparison

8 RESULTS

As noted above, the study objectives for this assessment include characterizing the hydraulics of existing conditions in the vicinity of the fishway entrances and powerhouse forebays. In terms of evaluating the response in migratory fish, FL will integrate the CFD modeling results along with other studies being conducted to evaluate the impact of Project operations on migratory fish including a) Study 3.3.2 *Evaluate Upstream and Downstream Passage of Adult American Shad,* b) Study 3.3.3 *Evaluate Downstream Passage of Juvenile American Shad,* c) Study 3.3.5 *Evaluate Downstream Passage of American Eel,* and d) Study 3.3.15 *Assessment of Adult Sea Lamprey Spawning within the Turners Falls Project and Northfield Mountain Project Area*. The field work for these studies was conducted in 2015; however, the analysis and results will not be available until later in 2016. These studies include telemetry data to determine how tagged migratory fish respond to different operating conditions. The telemetry studies, coupled with the CFD hydraulic evaluation herein, will be used to determine the impact of Project operations on migratory fish movement. The CFD modeling conducted herein is based solely on hydraulic modeling; it does not represent how fish will react to *in-situ* conditions. Thus, to fully understand whether and how Project operations impact migratory fish movement, the results of the CFD modeling will be coupled with the aforementioned study results. Accordingly, one of the study objectives—to assess whether fish are directed to the surface bypass weir near Cabot Station—will be evaluated in the aforementioned studies.

8.1 USFWS Fish Passage Hydraulics Criteria

8.1.1 USFWS Downstream Fish Passage Hydraulics Criteria Relative to Velocity

The study objectives pertaining to downstream fish passage include:

- Develop a series of velocity maps at select discharges showing approach velocities and flow fields that may create a response in fish;
- Characterize the near-rack “sweeping” velocities at the Cabot Station and Station No. 1 intakes;
- Assess whether fish are directed to the surface bypass weir near Cabot Station. Note that this study objective will be evaluated from a hydraulics standpoint only in this report, but will be evaluated further in Study No. 3.3.2 *Evaluation Upstream and Downstream Passage of Adult Shad*, and 3.3.3 *Evaluation Downstream Passage of Juvenile American Shad*, and 3.3.5 *Evaluate Downstream Passage of American Eel*.

Following is a discussion of the USFWS criteria related to the objectives listed above, along with an explanation of how the criteria were related to the results of the CFD model.

Per the USFWS guidelines (B. Towler, personal communication, July 6, 2015), the “approach velocity” and “sweeping velocity” are defined below. These velocities were computed from the CFD model and characterized as:

- **Approach velocity** (VA) is the component of channel velocity normal to the screen and is measured approximately 1 foot upstream of the screen. VA of 2 fps or less was the criterion previously used on the CT River Projects.

- **Sweeping velocity** (VS) is the component of the channel velocity parallel to the screen and is measured approximately 1 foot upstream of the screen. There is no criterion for the value of VS; however, USFWS recommends that the ratio of VS/VA be greater than 1, such that VS is greater than VA.

8.1.2 USFWS Upstream Fish Passage Hydraulics Criteria Relative to Attraction Flow

The USFWS has indicated in the past that 3-5% of the total station hydraulic capacity should be provided as a minimum attraction flow at fishway entrances. The full hydraulic capacity at Cabot Station (all 6 units operating) is approximately 13,728 cfs. Thus, per the criteria, the attraction flow should be between 412 and 686 cfs. FirstLight currently maintains a Cabot fishway attraction flow of approximately 335 cfs, with an additional approximately 33 cfs passing through the fishway for a total flow of approximately 368 cfs.

At the Spillway fishway, the attraction flow is approximately 300 cfs with an additional 18 cfs passing through the fishway for a total of approximately 318 cfs.

8.2 Station No. 1 Forebay

Three (3) production runs (scenarios) were completed for the Station No. 1 Forebay model as described in Section 7.1. Table 7.1-1 is repeated below as Table 8.2-1 for reference.

Table 8.2-1: Flow Scenarios for CFD Model 1 at Station No. 1

Scenario Number	Model Run	Station No. 1 Flow (cfs)	Canal Pass-Through Flow (cfs)	Total Power Canal Flow (cfs)
1-1	1	1,433 (current min flow)	200	1,633
1-2	1	2,210 (Station No. 1 capacity)	200	2,410
1-3	1	2,210	13,928 (Cabot capacity of 13,728 cfs plus 200 cfs for log sluice)	16,138

8.2.1 Scenario 1-1

The highest velocity in the system (not including behind the intake racks and in the penstocks) under this scenario is 3.01 fps. Accordingly, this velocity was used to scale the velocity color scale for all of the Scenario 1-1 figures. This results in consistent coloring across figures but not necessarily the highest level of contrast on each individual figure.

Figure 8.2.1-1 shows an overview of the velocity profiles in the canal and forebay.

Figure 8.2.1-2 shows the power canal (looking upstream) at the point where Station No. 1 flows are diverted to the forebay. Figure 8.2.1-3 shows the forebay entrance (looking towards the power canal), including velocity vectors for the two (2) transects across the forebay entrance.

Figure 8.2.1-4 provides an overview of the intake rack in front of the four (4) penstocks, and shows the velocity vectors 1 ft in front of the intake racks. Figures 8.2.1-5 and 8.2.1-6 show a close-up view of the intake racks in front of Penstocks 1 and 2, and in front of Penstocks 3 and 4, respectively, and also show the velocity vectors 1 foot in front of the intake racks.

The velocity vectors were analyzed to quantify and summarize the flow conditions in front of the intake racks with respect to the criteria outlined in Section 8.1.1. Under this scenario, the maximum VS was 2.0 fps while the maximum VA was 1.4 fps across the intake racks. Because the velocities across the face of the intake racks are not uniform, a statistical evaluation of the flow distribution across the face was conducted. It looked at the percentage of the rack face that has VA values that are less than the VA threshold (VA_T) of 2.0 fps which was the criteria previously used on the CT River Projects (see Section 8.1.1). It also looked at the percentage of the racks that have VA less than VA_T ($VA < VA_T$) or VA less than VS ($VA < VS$). Under this scenario 100% of the rack face had VA values less than 2.0 fps and 100% of the rack face had VA values less than 2.0 fps or VA values less than VS values.

Figure 8.2.1-7 and Figure 8.2.1-8 provide plan views of the Station No. 1 forebay and canal, respectively, and show the velocity vectors at elevation 171.3 feet (i.e. not depth averaged velocities). Note that the velocity vectors are colored based on velocity but the vector size is not scaled (i.e. they are all the same size).

8.2.2 Scenario 1-2

The highest velocity in the system (not including behind the intake racks and in the penstocks) under this scenario is 5.41 fps. Accordingly, this velocity was used to scale the velocity color scale for all of the Scenario 1-2 figures. This results in consistent coloring across figures but not necessarily the highest level of contrast on each individual figure.

Figure 8.2.2-1 shows an overview of the velocity profiles in the canal and forebay.

Figure 8.2.2-2 shows the power canal (looking upstream) at the point where Station No. 1 flows are diverted to the forebay. Figure 8.2.2-3 shows the forebay entrance (looking towards the power canal), including velocity vectors for the two (2) transects across the forebay entrance.

Figure 8.2.2-4 provides an overview of the intake rack in front of the four (4) penstocks, and shows the velocity vectors 1 foot in front of the intake racks. Figure 8.2.2-5 and Figure 8.2.2-6 show a close-up view of the intake racks in front of Penstocks 1 and 2, and in front of Penstocks 3 and 4, respectively, and also show the velocity vectors 1 ft in front of the intake racks.

The velocity vectors were analyzed to quantify and summarize the flow conditions in front of the intake racks with respect to the criteria outlined in Section 8.1.1. Under this scenario, the maximum VS was 5.3 fps while the maximum VA was 3.0 fps across the intake racks. Because the velocities across the face of the intake racks are not uniform, a statistical evaluation of the flow distribution across the face was conducted. It looked at the percentage of the rack face that has VA values that are less than the VA threshold (VA_T) of 2.0 fps which was the criteria previously used on the CT River Projects for salmon (see Section 8.1.1). It also looked at the percentage of the racks that have VA less than VA_T ($VA < VA_T$) or VA less than VS ($VA < VS$). Under this scenario 90% of the rack face had VA values less than 2.0 fps and 95% of the rack face had VA values less than 2.0 fps or VA values less than VS values.

Figure 8.2.2-7 and Figure 8.2.2-8 provide plan views of the Station No. 1 forebay and canal, respectively, and show the velocity vectors at elevation 171.3 ft (i.e. not depth averaged velocities). Note that the velocity vectors are colored based on velocity but the vector size is not scaled (i.e. they are all the same size).

8.2.3 Scenario 1-3

The highest velocity in the system (not including behind the intake racks and in the penstocks) under this scenario is 8.25 fps. Accordingly, this velocity was used to scale the velocity color scale for all of the Scenario 1-2 figures.

Figure 8.2.3-1 shows an overview of the velocity profiles in the canal and forebay.

Figure 8.2.3-2 shows the power canal (looking upstream) at the point where Station No. 1 flows are diverted to the forebay. Figure 8.2.3-3 shows the forebay entrance (looking towards the power canal), including velocity vectors for the two (2) transects across the forebay entrance.

Figure 8.2.3-4 provides an overview of the intake rack in front of the four (4) penstocks, and shows the velocity vectors 1 foot in front of the intake racks. Figure 8.2.3-5 and Figure 8.2.3-6 show a close-up view of the intake racks in front of Penstocks 1 and 2, and in front of Penstocks 3 and 4, respectively, and also show the velocity vectors 1 ft in front of the intake racks.

The velocity vectors were analyzed to quantify and summarize the flow conditions in front of the intake racks with respect to the criteria outlined in Section 8.1.1. Under this scenario, the maximum VS was 4.8 fps while the maximum VA was 2.7 fps across the intake racks. Because the velocities across the face of the intake racks are not uniform, a statistical evaluation of the flow distribution across the face was conducted. It looked at the percentage of the rack face that has VA values that are less than the VA threshold (VA_T) of 2.0 fps which was the criteria previously used on the CT River Projects for salmon (see Section 8.1.1). It also looked at the percentage of the racks that have VA less than VA_T ($VA < VA_T$) or VA less than VS ($VA < VS$). Under this scenario 91% of the rack face had VA values less than 2.0 fps and 94% of the rack face had VA values less than 2.0 fps or VA values less than VS values.

Figure 8.2.3-7 and Figure 8.2.3-8 provide plan views of the Station No. 1 forebay and canal, respectively, and show the velocity vectors at elevation 171.3 ft (i.e. not depth averaged velocities). Note that the velocity vectors are colored based on velocity but the vector size is not scaled (i.e. they are all the same size).

8.3 Cabot Station Forebay

Three (3) production runs were completed for the Cabot Station Forebay model as described in Section 7.2. Table 7.2-1 is repeated below as Table 8.3-1 for reference.

Table 8.3-1: Flow Scenarios for CFD Model 3 at Cabot Station

Scenario Number	Model Run	Cabot Station Flow (cfs)	Log Sluice Flow (cfs)	Total Power Canal Flow (cfs)
3-1	3	1,700	200	1,900
3-2	3	7,500	200	7,700
3-3	3	13,728 (Cabot capacity)	200	13,928

8.3.1 Scenario 3-1

The highest velocity in the system (not including behind the intake racks and in the penstocks) during this scenario is 2.42 fps. Accordingly, this velocity is used to scale the velocity color scale for all of the Scenario 3-1 figures.

Figure 8.3.1-1 shows an overview of the velocity profiles in the canal and forebay and Figure 8.3.1-2 shows the same for just the forebay (i.e. closer to the intake racks).

Figure 8.3.1-3 provides an overview of the intake racks in front of the six penstocks and shows the velocity vectors 1 foot in front of the intake racks. Figure 8.3.1-4 and Figure 8.3.1-5 show a close-up view of the intake racks in front of Penstocks 1, 2 and 3, and in front of Penstocks 4, 5, and 6, respectively. Figure 8.3.1-6 shows velocities in front of the log sluice.

The velocity vectors were analyzed to quantify and summarize the flow conditions in front of the intake racks with respect to the criteria outlined in Section 8.1.1. Under this scenario, the maximum VS was 1.3 fps while the maximum VA was 1.5 fps across the intake racks. Because the velocities across the face of the intake racks are not uniform, a statistical evaluation of the flow distribution across the face was conducted. It looked at the percentage of the rack face that has VA values that are less than the VA threshold (VA_T) of 2.0 fps which was the criteria previously used on the CT River Projects (see Section 8.1.1). It also looked at the percentage of the racks that have VA less than VA_T ($VA < VA_T$) or VA less than VS ($VA < VS$). Under this scenario 100% of the rack face had VA values less than 2.0 fps and 100% of the rack face had VA values less than 2.0 fps or VA values less than VS values.

Figure 8.3.1-7 provides a plan view of the Cabot Station forebay and shows the velocity vectors at elevation 171.6 ft (i.e. not depth averaged velocities), which is approximately 2 ft below the WSEL in the forebay and approximately 1.8 feet above the crest of the log sluice weir (with the fish weir in place). Note that the velocity vectors are colored based on velocity but the vector size is not scaled (i.e. they are all the same size).

8.3.2 Scenario 3-2

The highest velocity in the system (not including behind the intake racks and in the penstocks) during this scenario is 3.03 fps. Accordingly, this velocity is used to scale the velocity color scale for all of the Scenario 3-2 figures.

Figure 8.3.2-1 shows an overview of the velocity profiles in the canal and forebay and Figure 8.3.2-2 shows the same for just the forebay (i.e. closer to the intake racks).

Figure 8.3.2-3 provides an overview of the intake racks in front of the six penstocks and shows the velocity vectors 1 ft in front of the intake racks. Figure 8.3.2-4 and Figure 8.3.2-5 show a closer view of the intake racks in front of Penstocks 1, 2 and 3 and in front of Penstocks 4, 5, and 6, respectively.

Figure 8.3.2-6 shows velocities in front of the log sluice.

The velocity vectors were analyzed to quantify and summarize the flow conditions in front of the intake racks with respect to the criteria outlined in Section 8.1.1. Under this scenario, the maximum VS was 2.5 fps while the maximum VA was 2.5 fps across the intake racks. Because the velocities across the face of the intake racks are not uniform, a statistical evaluation of the flow distribution across the face was conducted. It looked at the percentage of the rack face that has VA values that are less than the VA threshold (VA_T) of 2.0 fps which was the criteria previously used on the CT River Projects for salmon (see Section 8.1.1). It also looked at the percentage of the racks that have VA less than VA_T ($VA < VA_T$) or VA less than VS (VA < VS). Under this scenario 73% of the rack face had VA values less than 2.0 fps and 74% of the rack face had VA values less than 2.0 fps or VA values less than VS values.

Figure 8.3.2-7 provides a plan view of the Cabot Station forebay and shows the velocity vectors at elevation 171.6 ft (i.e. not depth averaged velocities), which is approximately 2 ft below the WSEL in the forebay and approximately 1.8 ft above the crest of the log sluice weir (with the fish weir in place). Note that the velocity vectors are colored based on velocity but the vector size is not scaled (i.e. they are all the same size).

8.3.3 Scenario 3-3

The highest velocity in the system (not including behind the intake racks and in the penstocks) during this scenario is 4.33 fps. Accordingly, this velocity is used to scale the velocity color scale for all of the Scenario 3-3 figures.

Figure 8.3.3-1 shows an overview of the velocity profiles in the canal and forebay and Figure 8.3.3-2 shows the same for just the forebay (i.e. closer to the intake racks).

Figure 8.3.3-3 provides an overview of the intake racks in front of the six penstocks and shows the velocity vectors 1 ft in front of the intake racks. Figure 8.3.3-4 and Figure 8.3.3-5 show a close-up view of the intake racks in front of Penstocks 1, 2 and 3 and in front of Penstocks 4, 5, and 6, respectively.

Figure 8.3.3-6 shows velocities in front of the log sluice.

The velocity vectors were analyzed to quantify and summarize the flow conditions in front of the intake racks with respect to the criteria outlined in Section 8.1.1. Under this scenario, the maximum VS was 1.7 fps while the maximum VA was 3.3 fps across the intake racks. Because the velocities across the face of the intake racks are not uniform, a statistical evaluation of the flow distribution across the face was conducted. It looked at the percentage of the rack face that has VA values that are less than the VA threshold (VA_T) of 2.0 fps which was the criteria previously used on the CT River Projects for salmon (see Section 8.1.1). It also looked at the percentage of the racks that have VA less than VA_T ($VA < VA_T$) or VA less than VS (VA < VS). Under this scenario 32% of the rack face had VA values less than 2.0 fps and 32% of the rack face had VA values less than 2.0 fps or VA values less than VS values.

Figure 8.3.3-7 provides a plan view of the Cabot Station forebay and shows the velocity vectors at elevation 171.6 ft (i.e. not depth averaged velocities), which is approximately 2 ft below the WSEL in the forebay and approximately 1.8 ft above the crest of the log sluice weir (with the fish weir in place). Note that the velocity vectors are colored based on velocity but the vector size is not scaled (i.e. they are all the same size).

8.4 Cabot Fishway Entrance

For display consistency, all scenarios' figures for this model that present water velocities are shown with two velocity scales. One scale is set to show velocities on a scale between 0 and 15 fps, which was approximately the maximum observed velocity among all model runs. A second set of figures has a scale set to show velocities between 0 and 7 fps, where velocities above 7 fps will be shown as solid red.

Similarly, all scenarios' figures that present water depth are scaled to a single value. While the maximum depth out of all of the model runs was approximately 35 feet, the figures have been scaled to show depth values between 0 and 25 feet so that the shallower depths (which are more important for fish passage purposes) can be more easily distinguished.

8.4.1 Scenario 5-1

Figure 8.4.1-1 (0-15 fps scale) and Figure 8.4.1-2 (0-7 fps scale) show an overview of the depth-averaged water velocities in the entire study area and near Cabot Station. The figures show that while velocities near the fishway are fairly slower (mostly 4 fps or less), most of the velocities in the riffle about halfway down Smead Island are equal to or greater than 7 fps. There appear to be some smaller zones of slower moving water near the channel edges along the riffle.

Figure 8.4.1-3 shows an overview of water depths throughout the study area and near Cabot Station. The figure shows that depths are generally fairly deep in most of the channel left of Smead Island, and there appears to be a continuous channel that is at least 1 foot deep from the model's downstream boundary to the model's upstream boundary at the bypass channel through the river left channel by Cabot Station. The channel to the right of Smead Island does not appear to have a continuous flow path at this flow.

Figure 8.4.1-4 shows the modeled wetted area in transparent blue, with superimposed streamlines and vectors to show the flow paths for water leaving the fishway and the Cabot powerhouse. The figure shows that there is an eddy that forms in front of Units 2 through 6. The figure shows that some of the water exiting the fishway enters into this vortex, while some water passes more directly downstream toward river right.

Figure 8.4.1-5 (0-15 fps scale) and Figure 8.4.1-6 (0-7 fps scale) show water velocities in cross-sections parallel to Cabot Station, while Figure 8.4.1-7 (0-15 fps scale) and Figure 8.4.1-8 (0-7 fps scale) show the same cross-sections at a different viewpoint. The figures show that there is a well-defined area with higher velocities near the fishway entrance, while also further detailing the eddy in front of Units 2 through 6 that was apparent in Figure 8.4.1-4. These figures show how the bathymetry around the rock ridge just downstream of the fishway entrance appears to have a noticeable impact on near-entrance velocities for this scenario, as velocities increase noticeably in this area where the water rapidly becomes shallower.

Figure 8.4.1-9 (0-15 fps scale) and Figure 8.4.1-10 (0-7 fps scale) show cross-sections across the river. They indicate that velocities are generally slower (1-3 fps) in the area directly in front of Cabot Station, but increase to the 5-10 fps range in the downstream riffle area.

Figure 8.4.1-11 (0-15 fps scale) and Figure 8.4.1-12 (0-7 fps scale) are zoomed-in on the same across-river cross-sections near Cabot Station. The vectors show that there is a noticeable eddy that forms just downstream of the Unit 1 draft tube.

8.4.2 Scenario 5-2

Figure 8.4.2-1 (0-15 fps scale) and Figure 8.4.2-2 (0-7 fps scale) show an overview of the depth-averaged water velocities in the entire study area and near Cabot Station. The figures show that while velocities near the fishway are fairly slower (mostly 5 fps or less), most of the velocities in the riffle about halfway down Smead Island, plus the main channel below that riffle, are equal to or greater than 7 fps. There appear to be some smaller zones of slower moving water near the channel edges along the riffle.

Figure 8.4.2-3 shows an overview of water depths throughout the study area and near Cabot Station. The figure shows that depths are generally fairly deep in most of the channel left of Smead Island, and there appears to be a continuous channel that is at least 1 foot deep from the model's downstream boundary to the model's upstream boundary at the bypass channel through the river left channel by Cabot Station. The flow baffles (Table 7.3.2-2) confirm the visual that indicates there is a small amount (70-90 cfs) of flow that continually passes through the river right channel, but it is not clear whether it would be deep enough to pass fish as it is less than 1 foot deep in several areas.

Figure 8.4.2-4 shows the modeled wetted area in transparent blue, with superimposed streamlines and vectors to show the flow paths for water leaving the fishway and the Cabot powerhouse. The figure shows that there is an eddy that forms in front of Units 5 and 6, which are not operating at this flow. The figure shows that some of the water exiting the fishway enters into this eddy and swirls around, while some water passes more directly downstream toward river right. The figure also shows that the bypass flow appears to cause a large-scale eddy where it interacts with the powerhouse flow just upstream of Cabot Station.

Figure 8.4.2-5 (0-15 fps scale) and Figure 8.4.2-6 (0-7 fps scale) show water velocities in cross-sections parallel to Cabot Station, while Figure 8.4.2-7 (0-15 fps scale) and Figure 8.4.2-8 (0-7 fps scale) show the same cross-sections at a different viewpoint. The figures show that there is a well-defined area with higher velocities near the fishway entrance, while also further detailing the eddy in front of Units 5 and 6 that was apparent in Figure 8.4.2-4. Similar to what we saw in Scenario 5-1, these figures show how the bathymetry around the rock ridge just downstream of the fishway entrance appears to have a noticeable impact on near-entrance velocities for this scenario, as velocities increase noticeably in this area where the water rapidly becomes shallower.

Figure 8.4.2-9 (0-15 fps scale) and Figure 8.4.2-10 (0-7 fps scale) show cross-sections across the river. They indicate that, like PR 5-1, velocities are generally slower near Cabot Station but increase to the 5-10 fps or greater range in the downstream riffle area.

Figure 8.4.2-11 (0-15 fps scale) and Figure 8.4.2-12 (0-7 fps scale) are zoomed-in on the same across-river cross-sections near Cabot Station. The vectors show that while there is not as clear of an eddy downstream of the draft tube like there was in PR 5-1, there does appear to be a cross-current where water at the top of the water column is traveling nearly perpendicular to water in the middle of the water column near the draft tube exit.

8.4.3 Scenario 5-3

Figure 8.4.3-1 (0-15 fps scale) and Figure 8.4.3-2 (0-7 fps scale) show an overview of the depth-averaged water velocities in the entire study area and near Cabot Station. The figures show that there are significant areas with velocities equal to or greater than 7 fps, particularly in the riffle area downstream of Cabot Station. There appear to be some smaller zones of slower moving water near the channel edges along the riffle.

Figure 8.4.3-3 shows an overview of water depths throughout the study area and near Cabot Station. The figure shows that depths are generally fairly deep in most of the channel left of Smead Island, and there appears to be a continuous channel that is at least 2 feet deep from the model's downstream boundary to the model's upstream boundary at the bypass channel through the river left channel by Cabot Station. The flow baffles (Table 7.3.3-2) confirm the visual that indicates there is some flow (250-500 cfs) that continually passes through the river right channel, but it is not clear whether it would be deep enough to pass fish as there are still a couple of small areas with depths of less than 1 foot in the upper right channel area.

Figure 8.4.3-4 shows the modeled wetted area in transparent blue, with superimposed streamlines and vectors to show the flow paths for water leaving the fishway and the Cabot powerhouse. The figure shows that flow projects fairly straight out of Cabot Station before slowly turning downstream. The figure shows that some of the water exiting the fishway may experience some turbulence as it interacts with the flow field from Unit 6, as some of the streamlines show water traveling straight across the river channel while others are swept downstream with the powerhouse flow. Because the bypass flow of 400 cfs is so low relative to the total model flow of 14,496 cfs, the velocity vectors upstream of Cabot station tend to have some scatter and are forming a small eddy just upstream of Cabot Station.

Figure 8.4.3-5 (0-15 fps scale) and Figure 8.4.3-6 (0-7 fps scale) show water velocities in cross-sections parallel to Cabot Station, while Figure 8.4.3-7 (0-15 fps scale) and Figure 8.4.3-8 (0-7 fps scale) show the same cross-sections at a different viewpoint. The figures clearly show the flow fields exiting the draft tubes, and it appears that there is a less defined flow field exiting the fishway as compared to PR 5-1 and PR 5-2. The rock ridge downstream of the fishway entrance is also clearly still impacting velocity fields at this flow, similar to PR 5-1 and PR 5-2.

Figure 8.4.3-9 (0-15 fps scale) and Figure 8.4.3-10 (0-7 fps scale) show cross-sections across the river. They indicate that there is a rather large area downstream of Cabot Station that experiences velocities above 7 fps at this flow. There does still appear to be an area of slower velocities around the river margins that may be more passable by up-migrating fish than mid-channel may be.

Figure 8.4.3-11 (0-15 fps scale) and Figure 8.4.3-12 (0-7 fps scale) are zoomed-in on the same across-river cross-sections near Cabot Station. The vectors show that there appears to be a cross-current where water at the top of the water column is traveling nearly perpendicular to water in the middle of the water column near the draft tube exit. Additionally, there appears to be an eddy forming in the deep channel area in front of Unit 3 near the bottom of the water column.

8.4.4 Scenario 5-4

Figure 8.4.4-1 (0-15 fps scale) and Figure 8.4.4-2 (0-7 fps scale) show an overview of the depth-averaged water velocities in the entire study area and near Cabot Station. The figures show that while there are significant areas with velocities equal to or greater than 7 fps, particularly in the riffle area downstream of Cabot Station, the velocities are generally lower than they were in PR 5-3. There also appears to be some moderate sized zones of slower moving water near the channel edges along the riffle.

Figure 8.4.4-3 shows an overview of water depths throughout the study area and near Cabot Station. The figure shows that depths are generally fairly deep in most of the channel left of Smead Island, and there appears to be a continuous channel that is at least 4-5 feet deep from the model's downstream boundary to the model's upstream boundary at the bypass channel through the river left channel by Cabot Station. The flow baffles (Table 7.3.4-2) confirm the visual that indicates there is a moderate amount of flow (2,000-3,500 cfs) that continually passes through the river right channel with a maximum channel depth of at least 3-4 feet.

Figure 8.4.4-4 shows the modeled wetted area in transparent blue, with superimposed streamlines and vectors to show the flow paths for water leaving the fishway and the Cabot powerhouse. The figure shows that flow projects fairly straight out of Cabot Station before slowly turning downstream. The figure shows that some of the water exiting the fishway may experience some turbulence as it interacts with the flow field from Unit 6, as some of the streamlines show water traveling straight across the river channel while others are swept downstream with the powerhouse flow. The flow vectors also show there may be a slight eddy forming downstream of the island that is just upstream of Cabot Station. There are still increased velocities near the rock ridge at this flow relative to the rest of the immediate tailrace, though the effect is less pronounced than it was in PR 5-1, PR 5-2, and PR 5-3.

Figure 8.4.4-5 (0-15 fps scale) and Figure 8.4.4-6 (0-7 fps scale) show water velocities in cross-sections parallel to Cabot Station, while Figure 8.4.4-7 (0-15 fps scale) and Figure 8.4.4-8 (0-7 fps scale) show the same cross-sections at a different viewpoint. It also appears that there is a less defined flow field exiting the fishway as compared to the lower flow scenarios.

Figure 8.4.4-9 (0-15 fps scale) and Figure 8.4.4-10 (0-7 fps scale) show cross-sections across the river. They indicate that there is a rather large area downstream of Cabot Station that experiences velocities above 7 fps at this flow. In general, the water velocities seem to be lower than they were in PR 5-3 and there are greater areas of lower velocity. This is likely because the riffle halfway downstream of Smead Island is now partially backwatered by the model's downstream boundary. Therefore, even though river flows are higher, water velocities at this section of the river are generally lower.

Figure 8.4.4-11 (0-15 fps scale) and Figure 8.4.4-12 (0-7 fps scale) are zoomed-in on the same across-river cross-sections near Cabot Station. The figures clearly show the flow fields exiting the draft tubes, and it appears there is a vortex forming along the upper part of the water column above the draft tube exits. The vectors also show that there appears to be a cross-current where water at the top of the water column is traveling nearly perpendicular to water in the middle of the water column near the draft tube exit.

8.4.5 Scenario 5-5

Figure 8.4.5-1 (0-15 fps scale) and Figure 8.4.5-2 (0-7 fps scale) show an overview of the depth-averaged water velocities in the entire study area and near Cabot Station. The figures show that while there are some smaller areas with velocities equal to or greater than 7 fps, the velocities are generally lower than they were in PR 5-3 and PR 5-4. There also appears to be some moderate sized zones of slower moving water near the channel edges along the riffle. This flow, however, also started to show the right channel experiencing higher velocities than the other four scenarios had shown.

Figure 8.4.5-3 shows an overview of water depths throughout the study area and near Cabot Station. The figure shows that depths are generally fairly deep in most of the channel left of Smead Island, and there appears to be a continuous channel that is at least 5-6 feet deep from the model's downstream boundary to the model's upstream boundary at the bypass channel through the river left channel by Cabot Station. The flow baffles (Table 7.3.4-2) confirm the visual that indicates there is a moderate amount of flow (2,000-3,500 cfs) that continually passes through the river right channel with a maximum channel depth of at least 4-5 feet.

Figure 8.4.5-4 shows the modeled wetted area in transparent blue, with superimposed streamlines and vectors to show the flow paths for water leaving the fishway and the Cabot powerhouse. The figure shows that flow projects fairly smoothly out of Cabot Station before turning downstream fairly quickly. The figure shows that some of the water exiting the fishway may experience some turbulence as it interacts with the flow field from Unit 6, as some of the streamlines show water traveling straight across the river channel while others are swept downstream with the powerhouse flow. This flow also showed a small eddy area in the area just downstream of the island that is just upstream of Cabot Station, similar to PR 5-4.

Figure 8.4.5-5 (0-15 fps scale) and Figure 8.4.5-6 (0-7 fps scale) show water velocities in cross-sections parallel to Cabot Station, while Figure 8.4.5-7 (0-15 fps scale) and Figure 8.4.5-8 (0-7 fps scale) show the same cross-sections at a different viewpoint. It also appears that there is a less defined flow field exiting the fishway as compared to the lower flow scenarios, even compared to PR 5-4, which is likely due to the greater backwater throughout the entire reach.

Figure 8.4.5-9 (0-15 fps scale) and Figure 8.4.5-10 (0-7 fps scale) show cross-sections across the river. They indicate that there is a rather large area downstream of Cabot Station that experiences velocities above 7 fps at this flow. In general, the water velocities seem to be lower than they were in PR 5-4 and there are greater areas of lower velocity. This is because the riffle halfway downstream of Smead Island is now impacted from downstream backwater (i.e., the water levels from downstream are high enough that they are drowning out the riffle). Therefore, even though river flows are higher, water velocities at this section of the river are generally lower. The velocities around the rock ridge area appear to be slightly elevated compared to the surrounding areas, but the impact is even less pronounced than it was in PR 5-4.

Figure 8.4.4-11 (0-15 fps scale) and Figure 8.4.4-12 (0-7 fps scale) are zoomed-in on the same across-river cross-sections near Cabot Station. The figures clearly show the flow fields exiting the draft tubes, and it appears there is a vortex forming along the upper part of the water column above the draft tube exits. The vectors also show that there appears to be a cross-current where water at the top of the water column is traveling nearly perpendicular to water in the middle of the water column near the draft tube exit.

8.5 Spillway Fishway Entrance

For display consistency, all scenarios' figures for this model that present water velocities are shown with two velocity scales. One scale is set to the show velocities on a scale between 0 and 15 fps, which was approximately the maximum observed velocity among all model runs within the main channel in front of the Spillway Fishway (higher velocities were observed where the bascule gate flow first enters the pool area). A second set of figures has a scale set to show velocities between 0 and 7 fps, where velocities above 7 fps will be shown as solid red. As noted in Section 8.1.2, a 7.0 fps threshold is approximately the upper limit of what is considered to be the 'prolonged' swim speed for American shad. Water velocities above 7.0 fps (up to potentially 13.0 fps) tend to be considered within the 'burst' speed swimming range for American shad. Therefore, even areas displayed as solid red may still be passable by some fish if they are short in distance or contain near-bed or other types of in-channel velocity refugia.

Similarly, all scenarios' figures that present water depth are scaled to a single value. While the maximum depth out of all of the model runs was approximately 40 feet, the figures have been scaled to show depth values between 0 and 20 feet so that the shallower depths (which are more important for fish passage purposes) can be more easily distinguished.

While model results are shown for the hydraulic control areas adjacent to the Island, these areas are only included in the model in order to properly approximate upstream water surface elevations. The velocities in these areas, as well as the flow distribution between the two sides of the island, are not validated and are based on very limited bed elevation data that don't fully reflect the complex bed geometry in that area. Therefore, while the velocities are shown for these areas in the following figures, it is important to remember that they are simply gross approximations of the bed included in the model to better model upstream areas.

8.5.1 Scenario 6-1

Figure 8.5.1-1 (0-15 fps scale) and Figure 8.5.1-2 (0-7 fps scale) show an overview of the depth-averaged water velocities in the entire study area and near the Spillway Fishway. The figures show that velocities near the fishway are fairly slower (mostly 4 fps or less with some smaller areas around 5 fps), with some faster velocities (5-7 fps) being experienced right near the fishway entrance.

Figure 8.5.1-3 (0-20 ft scale) and Figure 8.5.1-4 (0-40 ft scale) show an overview of water depths throughout the study area and near the Spillway Ladder. The figure shows that there are three primary pools that are approximately 20-ft to 30-ft deep at this flow with several shallower areas between the pools. Other than the areas at the downstream hydraulic control near the Island, which does not contain enough detailed bed elevation data to properly evaluate, water depths leading to the ladder are at least 2-3 ft deep at this flow. Flow appears to be passing around both sides of the Island at this flow.

Figure 8.5.1-5 shows the modeled wetted area in transparent blue, with superimposed streamlines and vectors to show the flow paths for water leaving the Spillway Fishway. The figure shows that eddies form in two locations primarily: one eddy is along the right side of the channel in front of Bascule Gate #1, while the second eddy is in the larger pool just upstream of the Island. The figure shows that the water passing from the fishway appears to become caught up in both of these eddies before traveling downstream.

Figure 8.5.1-6 (0-20 fps scale) and Figure 8.5.1-7 (0-7 fps scale) show water velocities in cross-sections near the Spillway Fishway, while Figure 8.5.1-8 (0-20 fps scale) and Figure 8.5.1-9 (0-7 fps scale) show the same cross-sections at a different viewpoint. The figures show that velocities are generally moderate (4 fps or less) throughout most of the channel near the Spillway Fishway, but there are some faster (7 fps or greater) velocities directly in front of the ladder.

8.5.2 Scenario 6-2

Figure 8.5.2-1 (0-15 fps scale) and Figure 8.5.2-2 (0-7 fps scale) show an overview of the depth-averaged water velocities in the entire study area and near the Spillway Fishway. The figures show that while a significant portion of the channel in front of the Spillway Ladder has velocities in the 7-10 fps range, there is some slower moving water along the left and right banks of this area. The figure also shows that there appears to be an eddy forming along river left just upstream of the Island.

Figure 8.5.2-3 (0-20 ft scale) and Figure 8.5.2-4 (0-40 ft scale) show an overview of water depths throughout the study area and near the Spillway Ladder. The figure shows that there are three primary pools that are approximately 20-ft to 35-ft deep at this flow with several shallower areas between the pools. Other than the areas at the downstream hydraulic control near the Island, which does not contain enough detailed bed elevation data to properly evaluate, water depths leading to the ladder are at least 3-4 ft deep at this flow. Most of the channels on both sides of the Island appear to be inundated at this flow.

Figure 8.5.2-5 shows the modeled wetted area in transparent blue, with superimposed streamlines and vectors to show the flow paths for water leaving the Spillway Fishway. The figure shows that water near the Spillway Fishway exit enters rather turbulent conditions, as many of the streamlines show water first traveling into the deep pool downstream of Bascule Gate #1 before passing downstream.

Figure 8.5.2-6 (0-20 fps scale) and Figure 8.5.2-7 (0-7 fps scale) show water velocities in cross-sections near the Spillway Fishway, while Figure 8.5.2-8 (0-20 fps scale) and Figure 8.5.2-9 (0-7 fps scale) show the same cross-sections at a different viewpoint. The figures show that flows near Bascule Gate 1 are fairly turbulent, with water near the bottom of the water column moving in the opposite direction as water along the top of the water column. Water velocities in the channel downstream of the Spillway Fishway appear to be in the 7-10 fps range, but there are slower moving areas along both banks.

8.5.3 Scenario 6-3

Figure 8.5.3-1 (0-15 fps scale) and Figure 8.5.3-2 (0-7 fps scale) show an overview of the depth-averaged water velocities in the entire study area and near the Spillway Fishway. The figures show that a significant portion of the channel in front of the Spillway Ladder has velocities in the 7-15 fps range. The velocities appear to extend all the way to the left bank in two locations.

Figure 8.5.3-3 (0-20 ft scale) and Figure 8.5.3-4 (0-40 ft scale) show an overview of water depths throughout the study area and near the Spillway Ladder. The figure shows that there are three primary pools that are approximately 20-ft to 35-ft deep at this flow with several shallower areas between the pools. Other than the areas at the downstream hydraulic control near the Island, which does not contain enough detailed bed elevation data to properly evaluate, water depths leading to the ladder are at least 3-4 ft deep at this flow. Most of the channels on both sides of the Island appear to be inundated at this flow.

Figure 8.5.3-5 shows the modeled wetted area in transparent blue, with superimposed streamlines and vectors to show the flow paths for water leaving the Spillway Fishway. The figure shows that water exiting the fishway is entering rather turbulent conditions, as many of the streamlines show water first traveling into the deep pool downstream of Bascule Gate #1 before passing downstream. The streamlines pass on both sides of the Island, which reflects the amount of turbulence within the deep pool itself as well.

Figure 8.5.3-6 (0-20 fps scale) and Figure 8.5.3-7 (0-7 fps scale) show water velocities in cross-sections near the Spillway Fishway, while Figure 8.5.3-8 (0-20 fps scale) and Figure 8.5.3-9 (0-7 fps scale) show the same cross-sections at a different viewpoint. The figures show that flows near Bascule Gate #1 are fairly turbulent, with water near the bottom of the water column moving in the opposite direction as water along the top of the water column. Water velocities in the channel downstream of the Spillway Fishway appear to be in the 3-5 fps range. Additionally, there may be a small zone of slower-moving water along the left channel near the bottom of the water column that was not apparent in the depth-averaged velocities presented above.

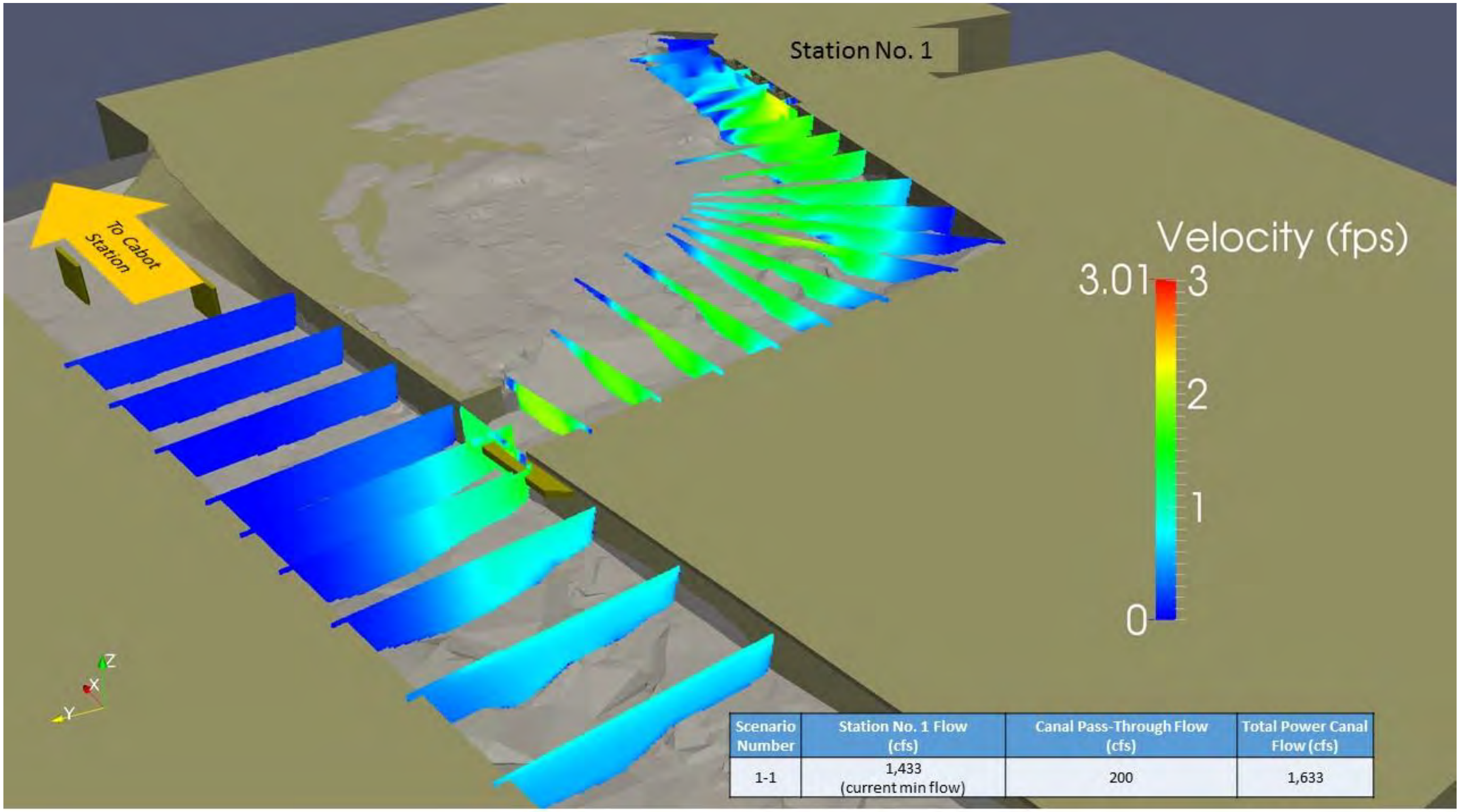
8.5.4 Scenario 6-4

Figure 8.5.4-1 (0-15 fps scale) and Figure 8.5.4-2 (0-7 fps scale) show an overview of the depth-averaged water velocities in the entire study area and near the Spillway Fishway. The figures show that a significant portion of the channel in front of the Spillway Ladder has velocities in the 7-15 fps range. The velocities appear to extend all the way to the left bank in two locations.

Figure 8.5.4-3 (0-20 ft scale) and Figure 8.5.4-4 (0-40 ft scale) show an overview of water depths throughout the study area and near the Spillway Ladder. The figure shows that there are three primary pools that are approximately 25-ft to 40-ft deep at this flow with several shallower areas between the pools. Other than the areas at the downstream hydraulic control near the Island, which does not contain enough detailed bed elevation data to properly evaluate, water depths leading to the ladder are at least 4-5 ft deep at this flow. Most of the channels on both sides of the Island appear to be inundated at this flow.

Figure 8.5.4-5 shows the modeled wetted area in transparent blue, with superimposed streamlines and vectors to show the flow paths for water leaving the Spillway Fishway. The figure shows that water exiting the fishway is entering rather turbulent conditions, as many of the streamlines show water first traveling into the deep pool downstream of Bascule Gate #1 before passing downstream. Once the streamlines exit the deep pool, they stay fairly well-aligned against the left channel as they pass downstream.

Figure 8.5.4-6 (0-20 fps scale) and Figure 8.5.4-7 (0-7 fps scale) show water velocities in cross-sections near the Spillway Fishway, while Figure 8.5.4-8 (0-20 fps scale) and Figure 8.5.4-9 (0-7 fps scale) show the same cross-sections at a different viewpoint. The figures show that flows near Bascule Gate #1 are fairly turbulent, with water near the bottom of the water column moving in the opposite direction as water along the top of the water column. Water velocities in the channel downstream of the Spillway Fishway appear to be in the 3-5 fps range, slower than the surrounding areas. There may be a small zone of slower-moving water along the left channel near the bottom of the water column that was not apparent in the depth-averaged velocities presented above.



Scenario Number	Station No. 1 Flow (cfs)	Canal Pass-Through Flow (cfs)	Total Power Canal Flow (cfs)
1-1	1,433 (current min flow)	200	1,633

Figure 8.2.1-1: Station No. 1 Scenario 1-1 Overview

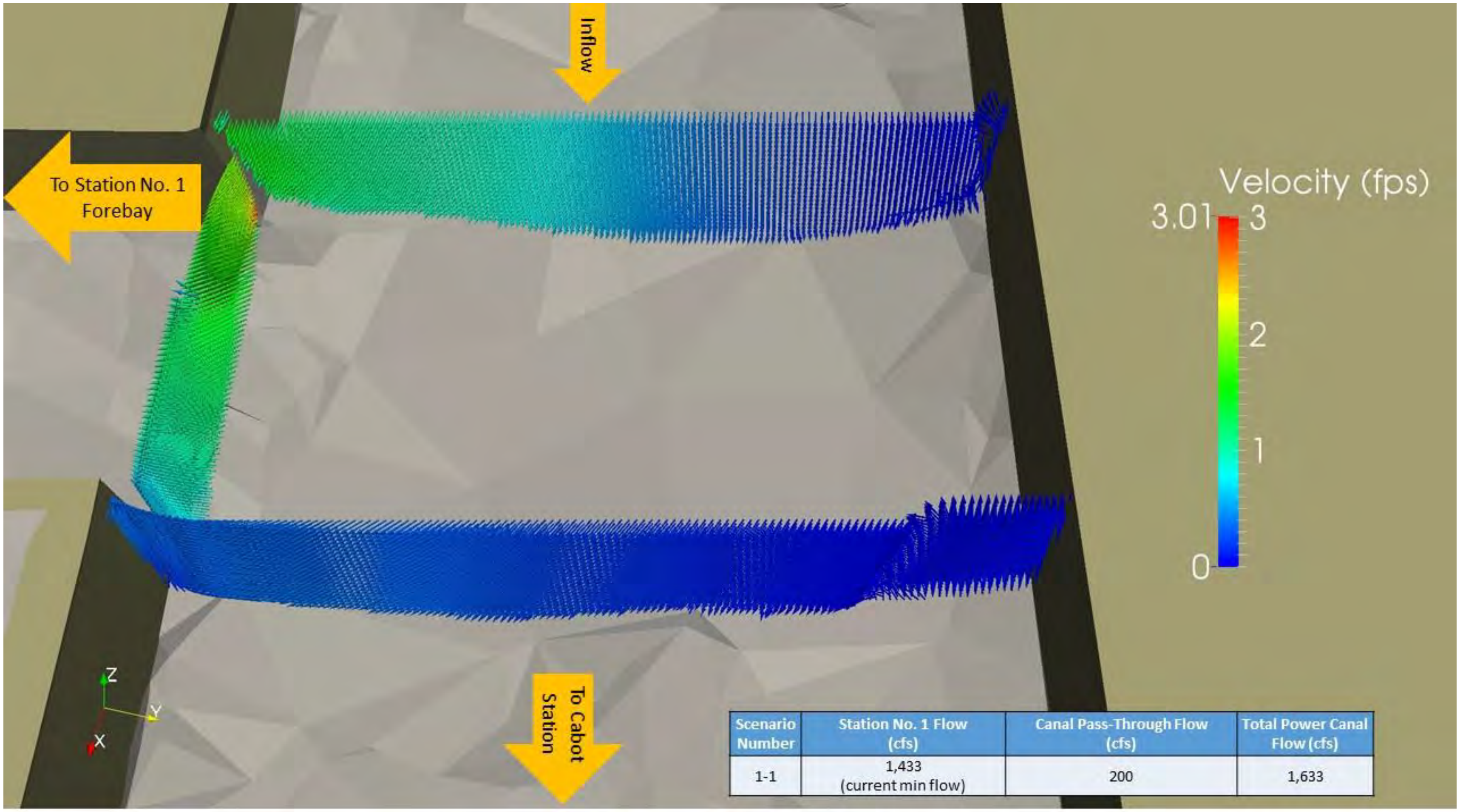


Figure 8.2.1-2: Station No. 1 Scenario 1-1 Power Canal

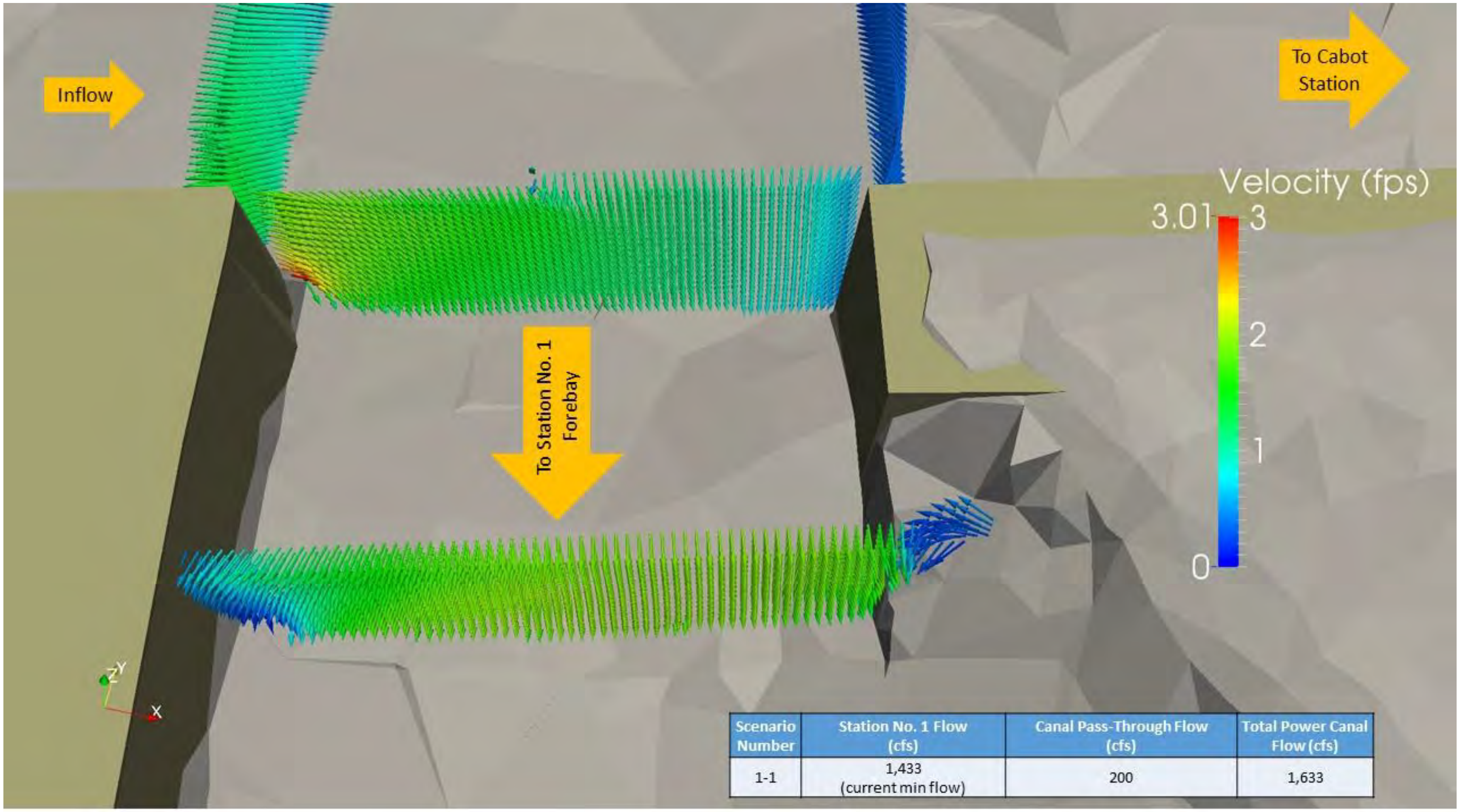
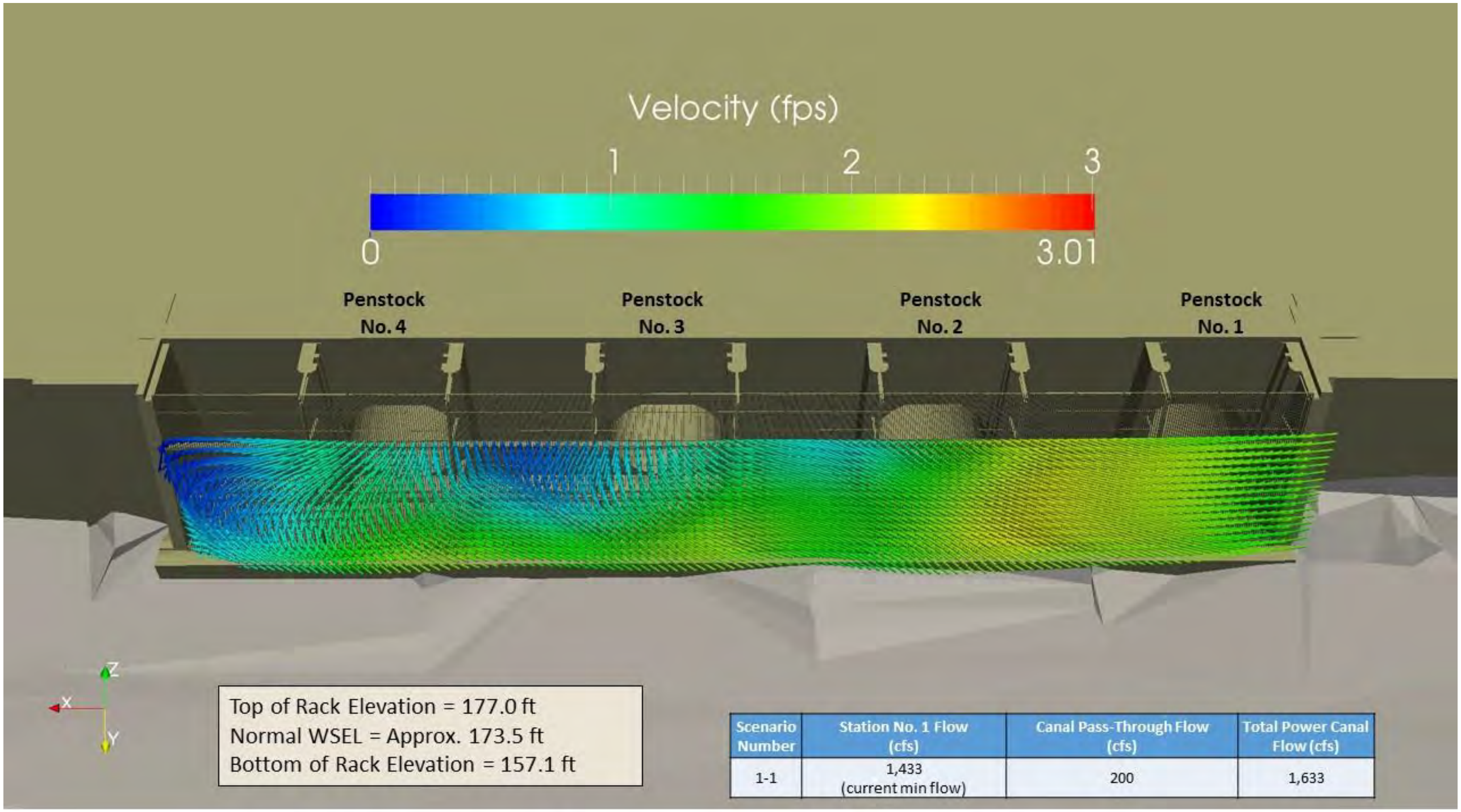
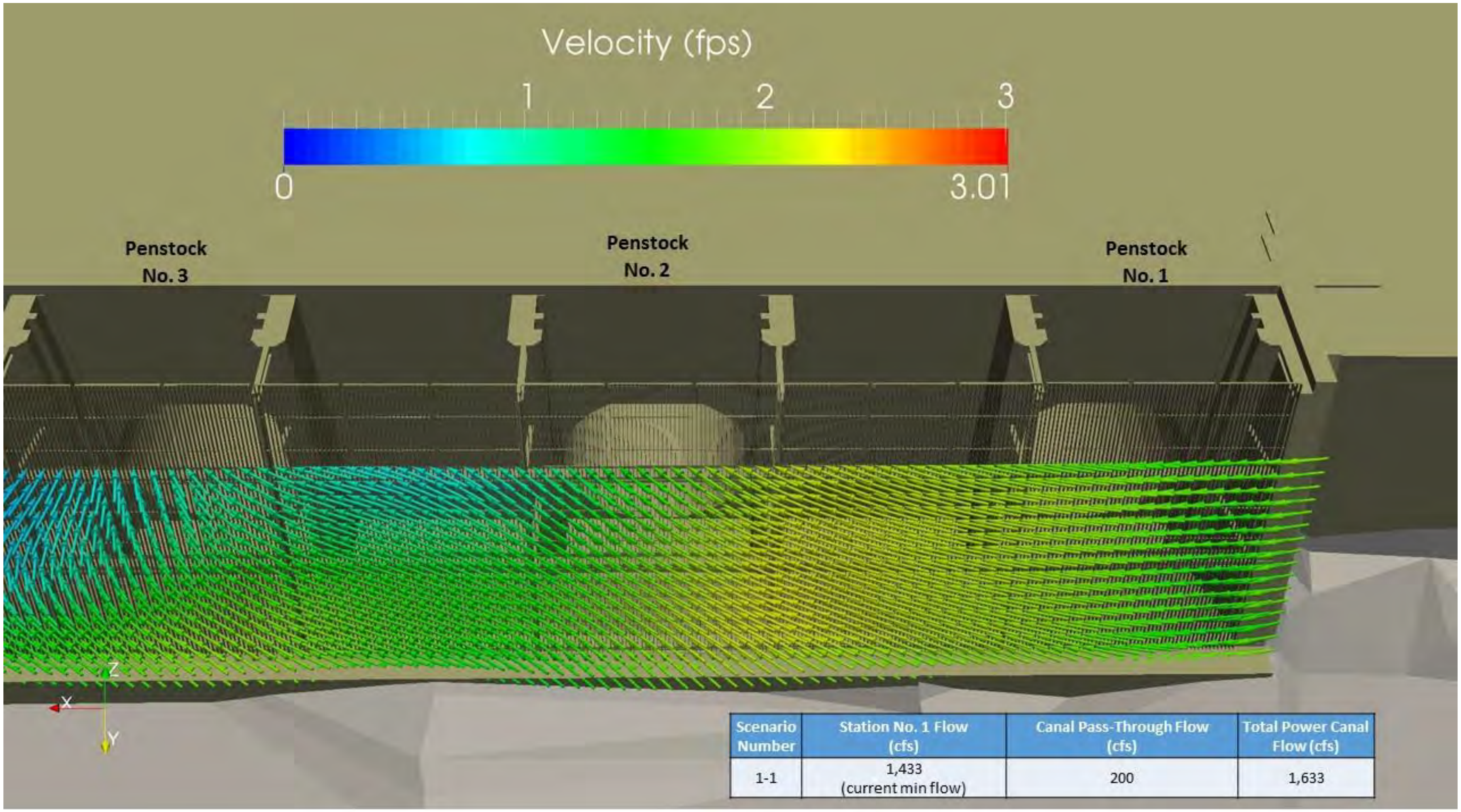


Figure 8.2.1-3: Station No. 1 Scenario 1-1 Forebay Entrance



Scenario Number	Station No. 1 Flow (cfs)	Canal Pass-Through Flow (cfs)	Total Power Canal Flow (cfs)
1-1	1,433 (current min flow)	200	1,633

Figure 8.2.1-4: Station No. 1 Scenario 1-1 Intake Rack Overview



Scenario Number	Station No. 1 Flow (cfs)	Canal Pass-Through Flow (cfs)	Total Power Canal Flow (cfs)
1-1	1,433 (current min flow)	200	1,633

Figure 8.2.1-5: Station No. 1 Scenario 1-1 Intake Rack at Penstocks 1 and 2

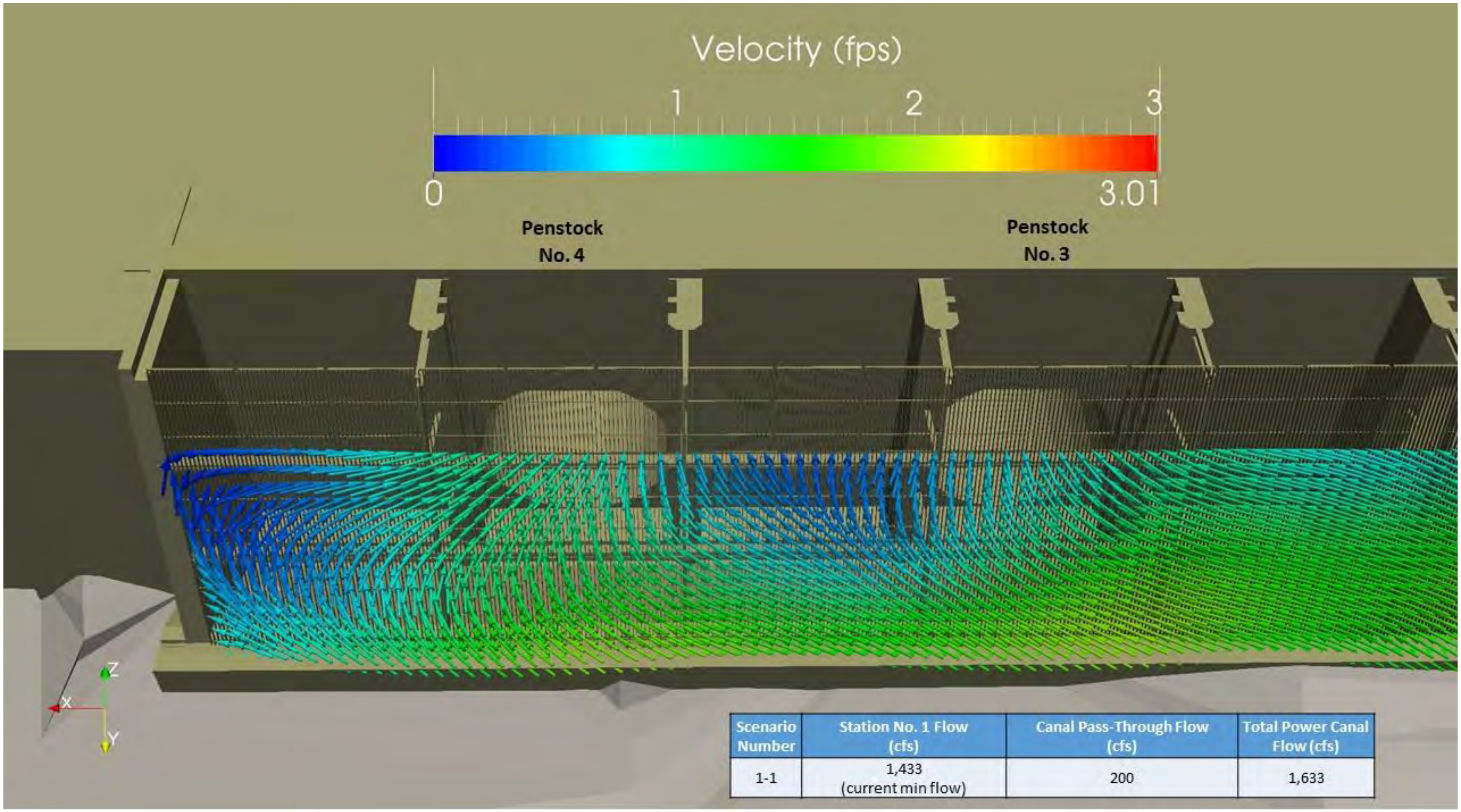
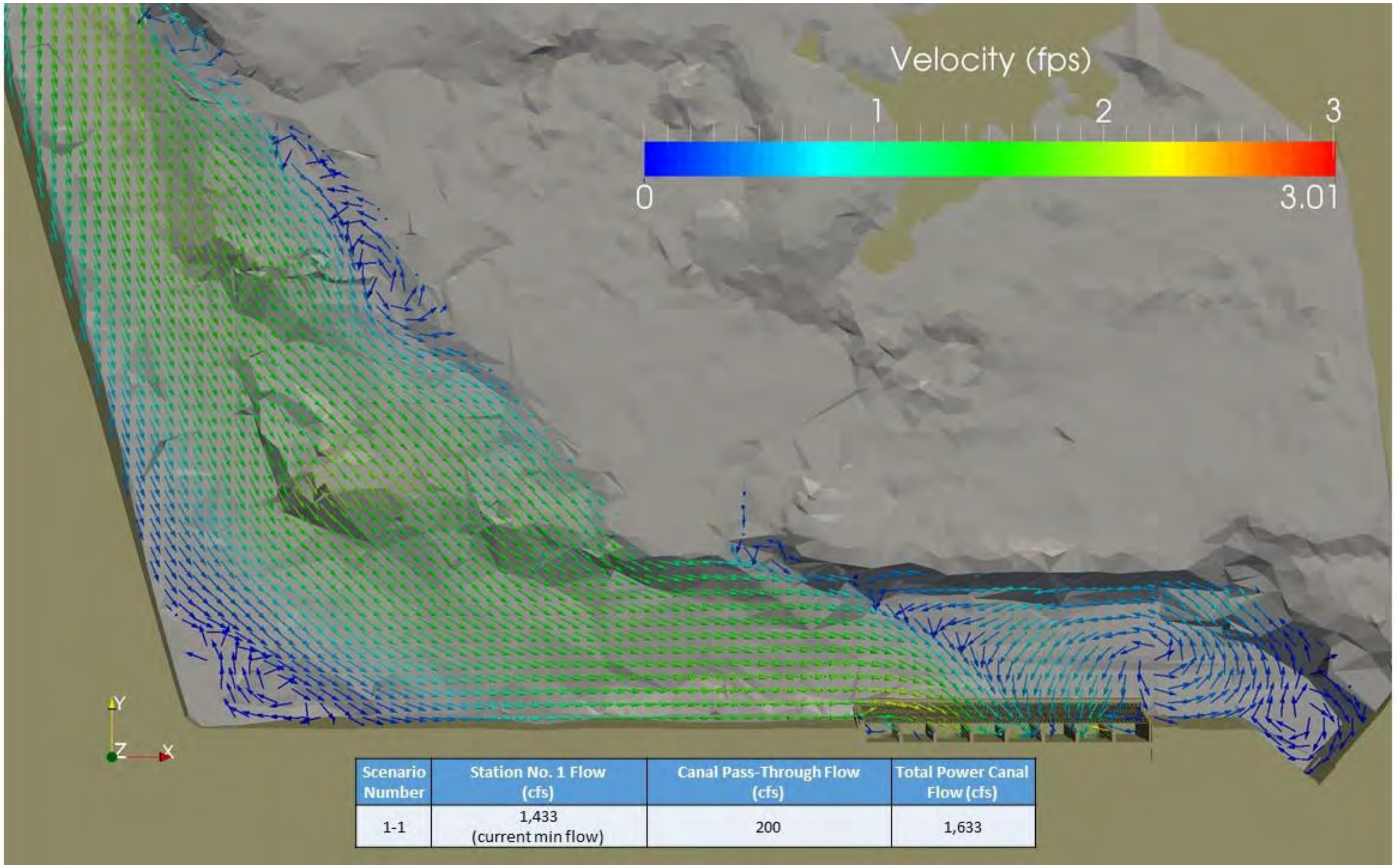


Figure 8.2.1-6: Station No. 1 Scenario 1-1 Intake Rack at Penstocks 3 and 4



Scenario Number	Station No. 1 Flow (cfs)	Canal Pass-Through Flow (cfs)	Total Power Canal Flow (cfs)
1-1	1,433 (current min flow)	200	1,633

Figure 8.2.1-7: Station No. 1 Scenario 1-1 Velocity Vectors in Forebay at Elevation 171.3

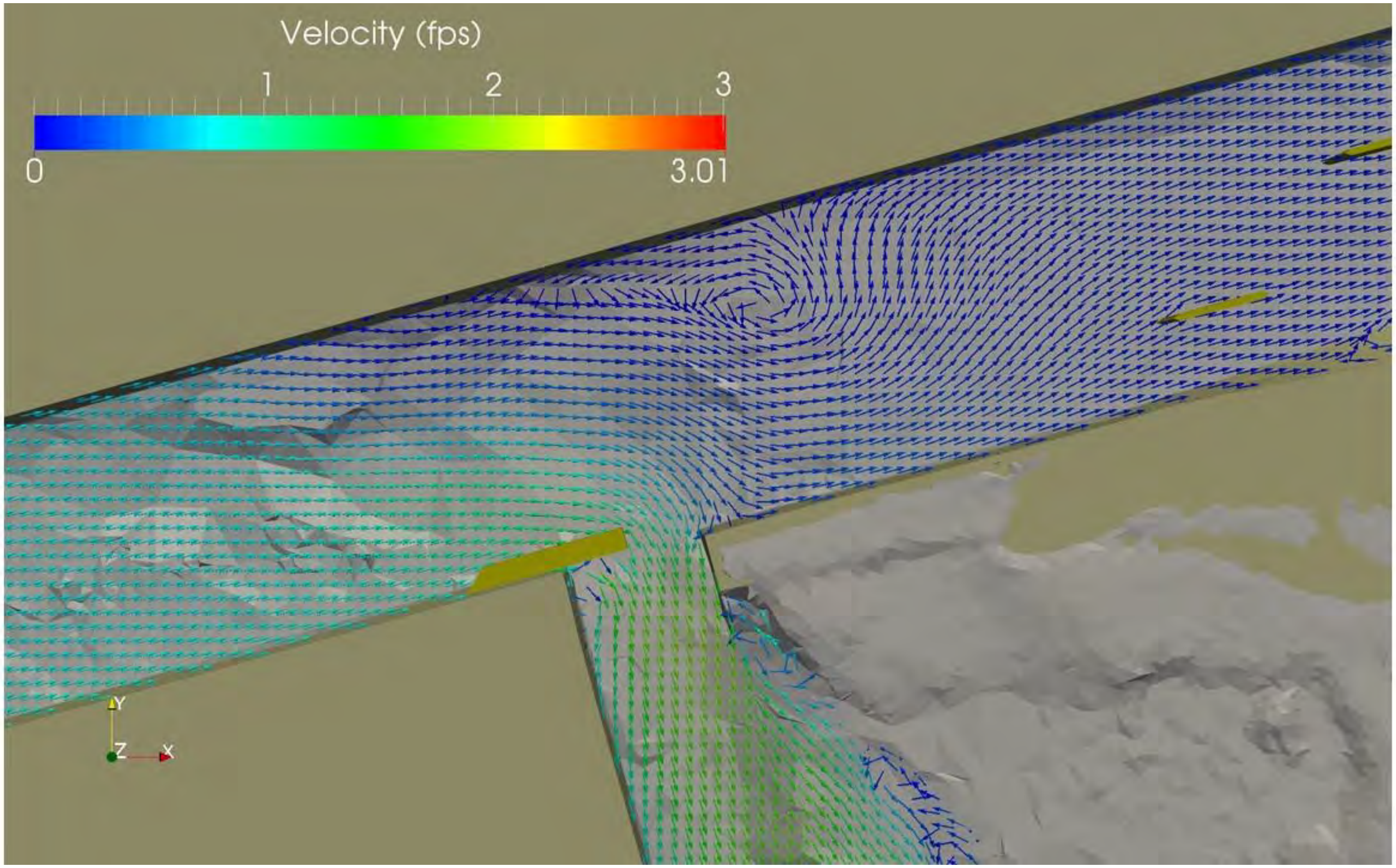
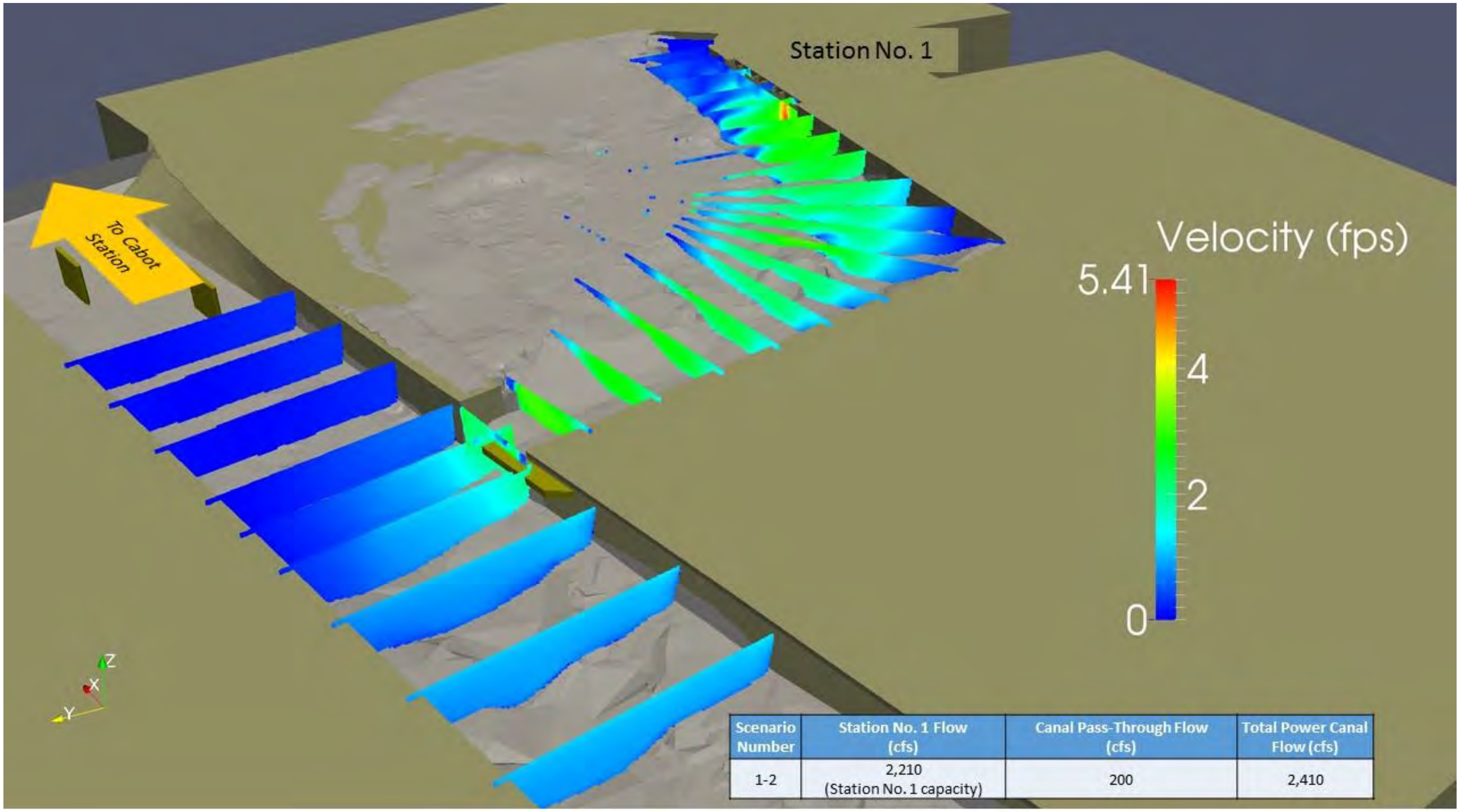
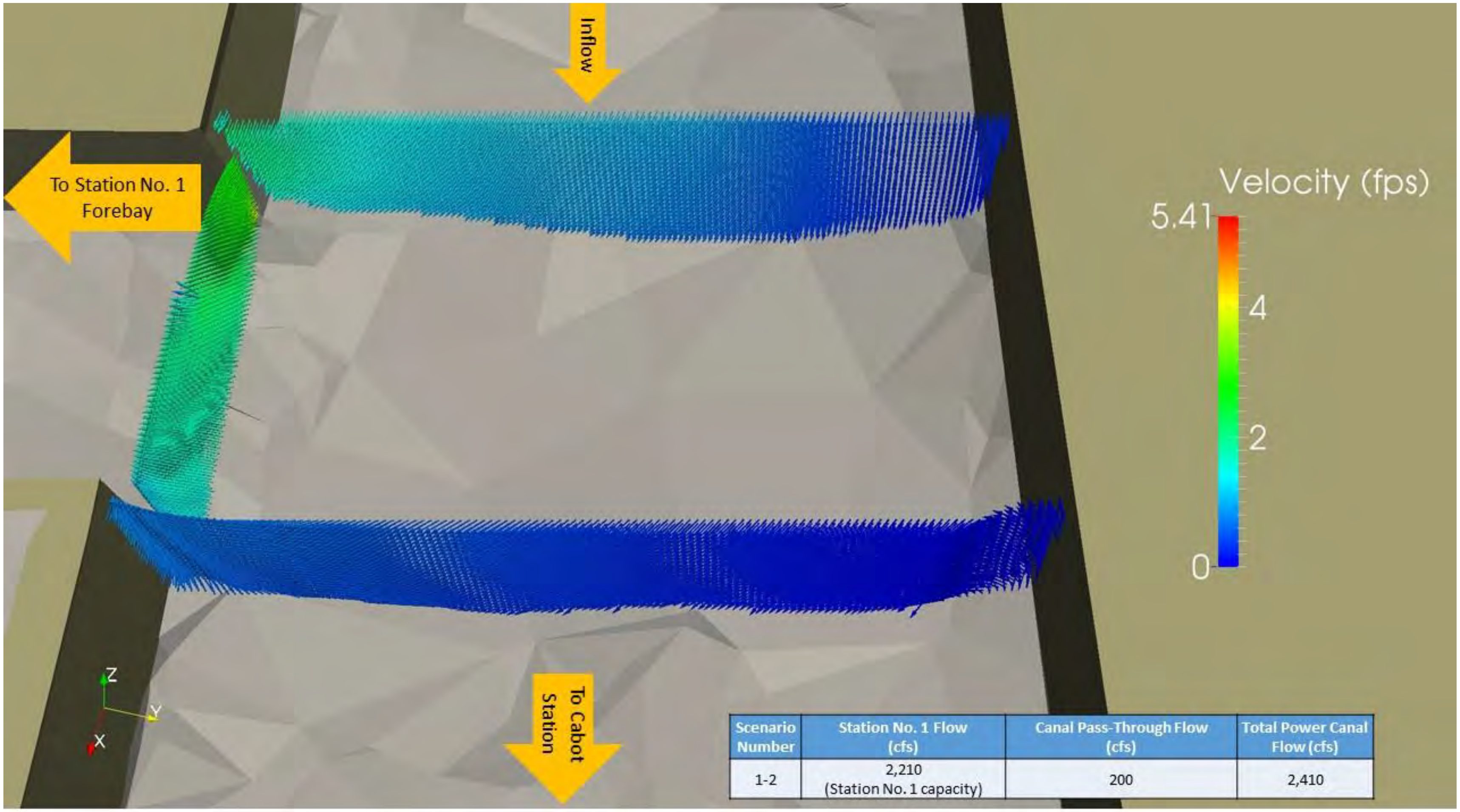


Figure 8.2.1-8: Station No. 1 Scenario 1-1 Velocity Vectors in Canal at Elevation 171.3



Scenario Number	Station No. 1 Flow (cfs)	Canal Pass-Through Flow (cfs)	Total Power Canal Flow (cfs)
1-2	2,210 (Station No. 1 capacity)	200	2,410

Figure 8.2.2-1: Station No. 1 Scenario 1-2 Overview



Scenario Number	Station No. 1 Flow (cfs)	Canal Pass-Through Flow (cfs)	Total Power Canal Flow (cfs)
1-2	2,210 (Station No. 1 capacity)	200	2,410

Figure 8.2.2-2: Station No. 1 Scenario 1-2 Power Canal

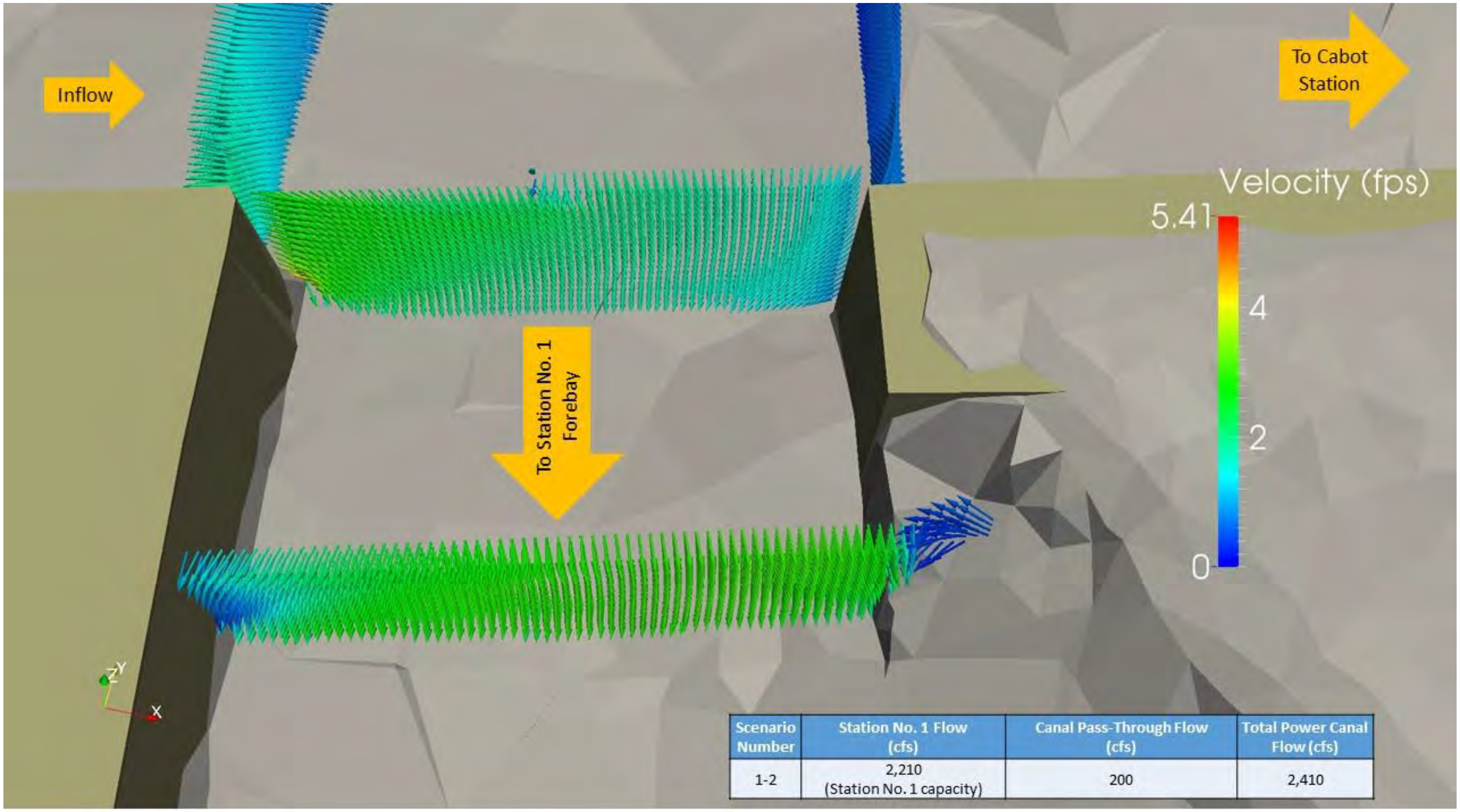
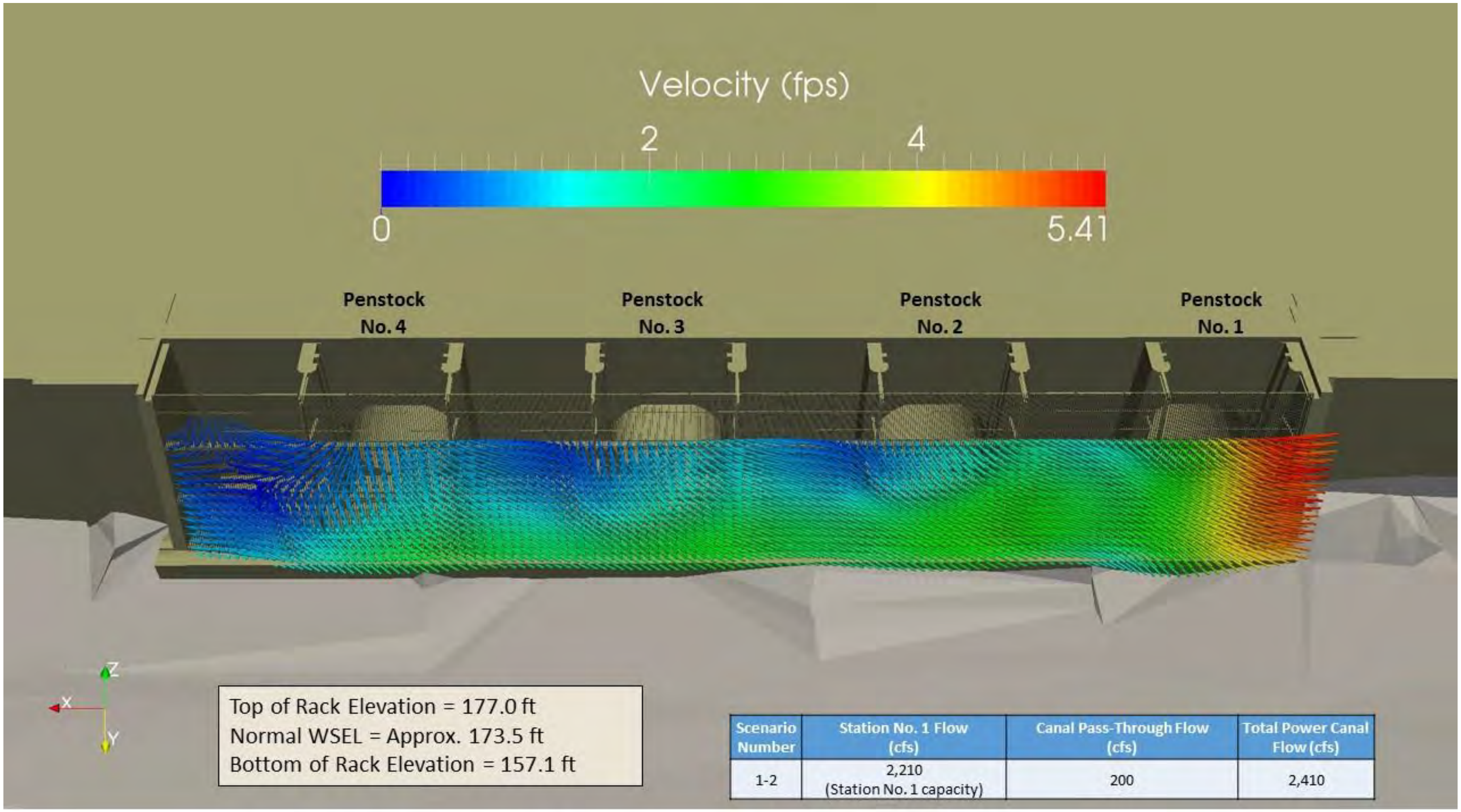
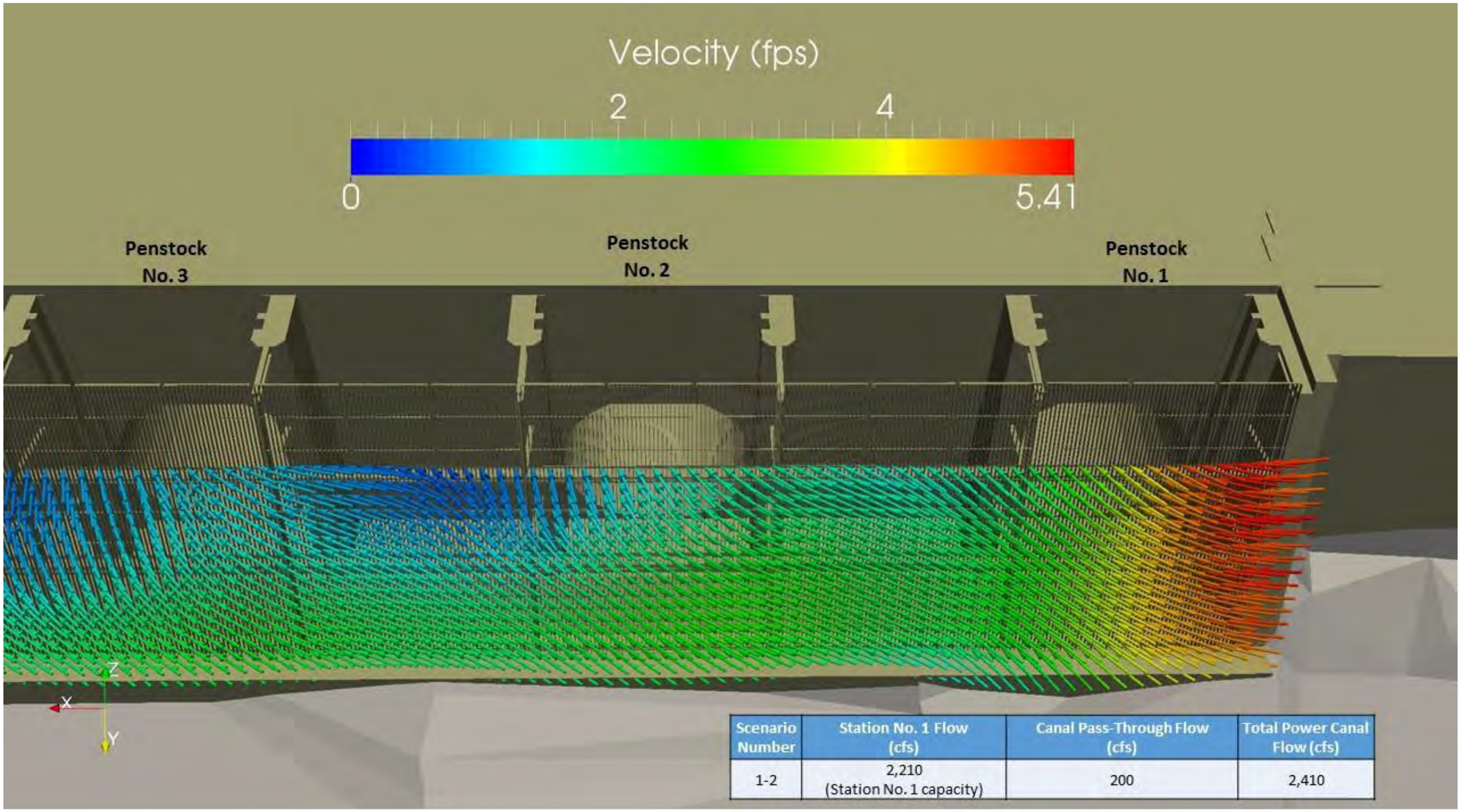


Figure 8.2.2-3: Station No. 1 Scenario 1-2 Forebay Entrance



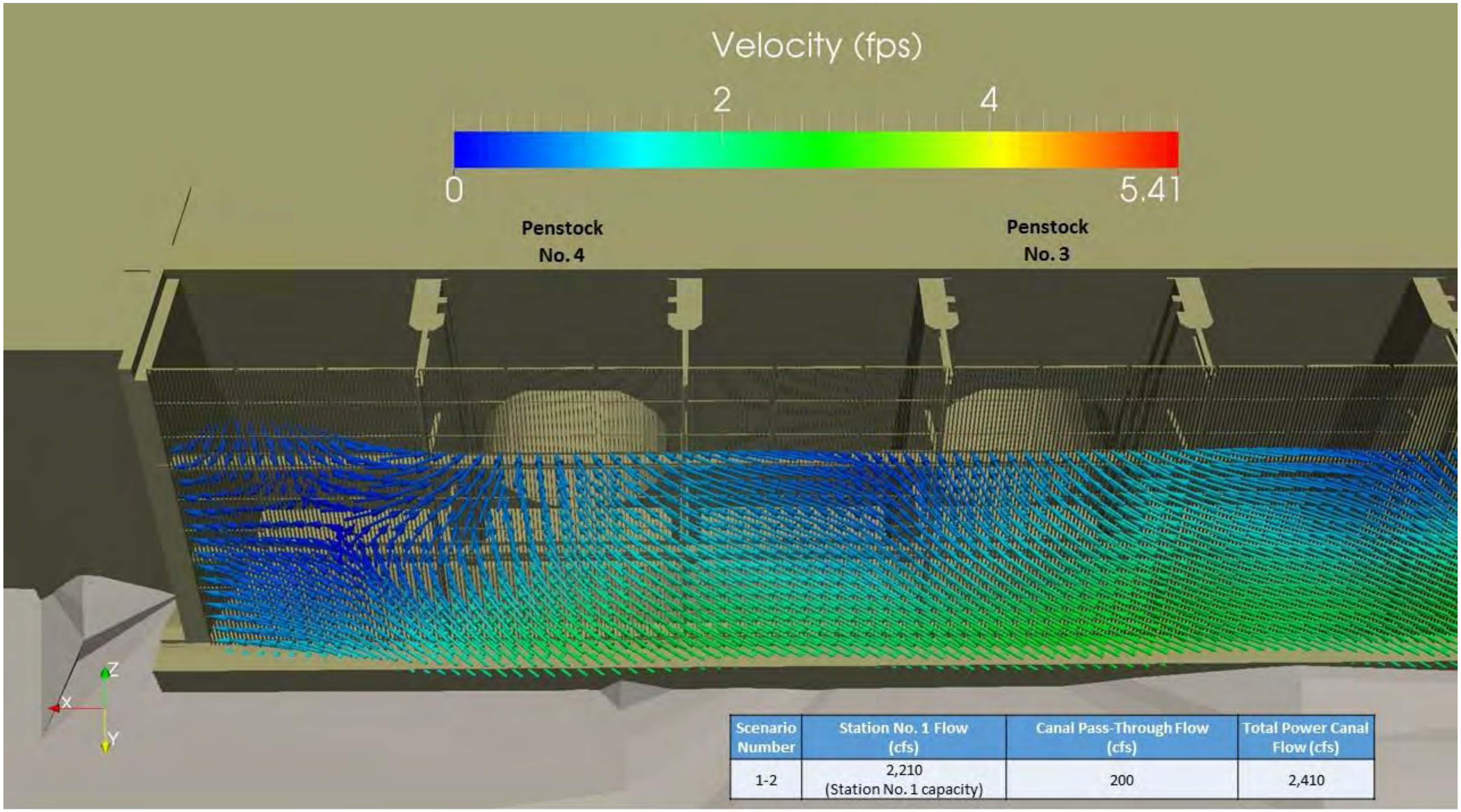
Scenario Number	Station No. 1 Flow (cfs)	Canal Pass-Through Flow (cfs)	Total Power Canal Flow (cfs)
1-2	2,210 (Station No. 1 capacity)	200	2,410

Figure 8.2.2-4: Station No. 1 Scenario 1-2 Intake Rack Overview



Scenario Number	Station No. 1 Flow (cfs)	Canal Pass-Through Flow (cfs)	Total Power Canal Flow (cfs)
1-2	2,210 (Station No. 1 capacity)	200	2,410

Figure 8.2.2-5: Station No. 1 Scenario 1-2 Intake Rack at Penstocks 1 and 2



Scenario Number	Station No. 1 Flow (cfs)	Canal Pass-Through Flow (cfs)	Total Power Canal Flow (cfs)
1-2	2,210 (Station No. 1 capacity)	200	2,410

Figure 8.2.2-6: Station No. 1 Scenario 1-2 Intake Rack at Penstocks 3 and 4

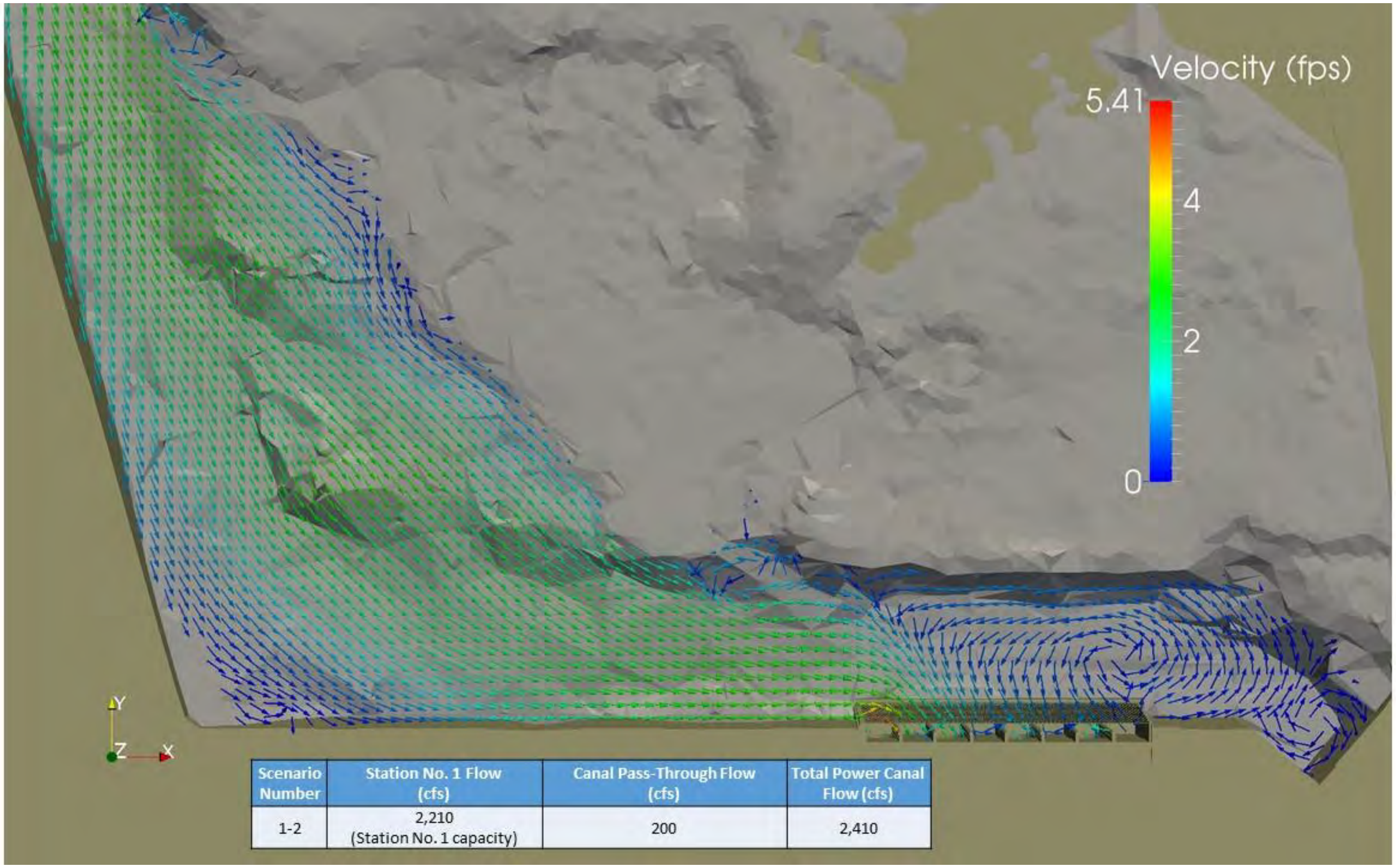


Figure 8.2.2-7: Station No. 1 Scenario 1-2 Velocity Vectors in Forebay at Elevation 171.3

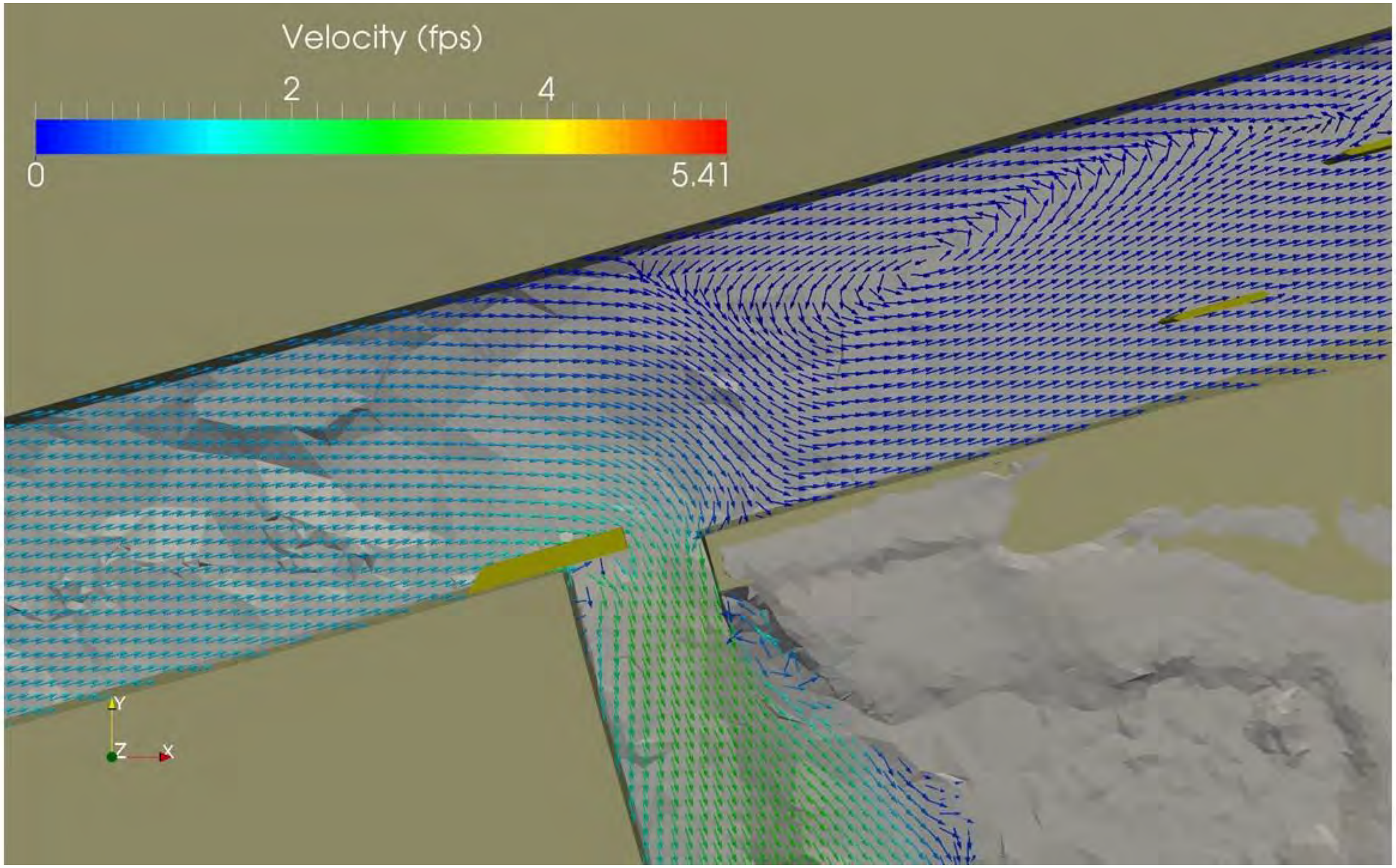
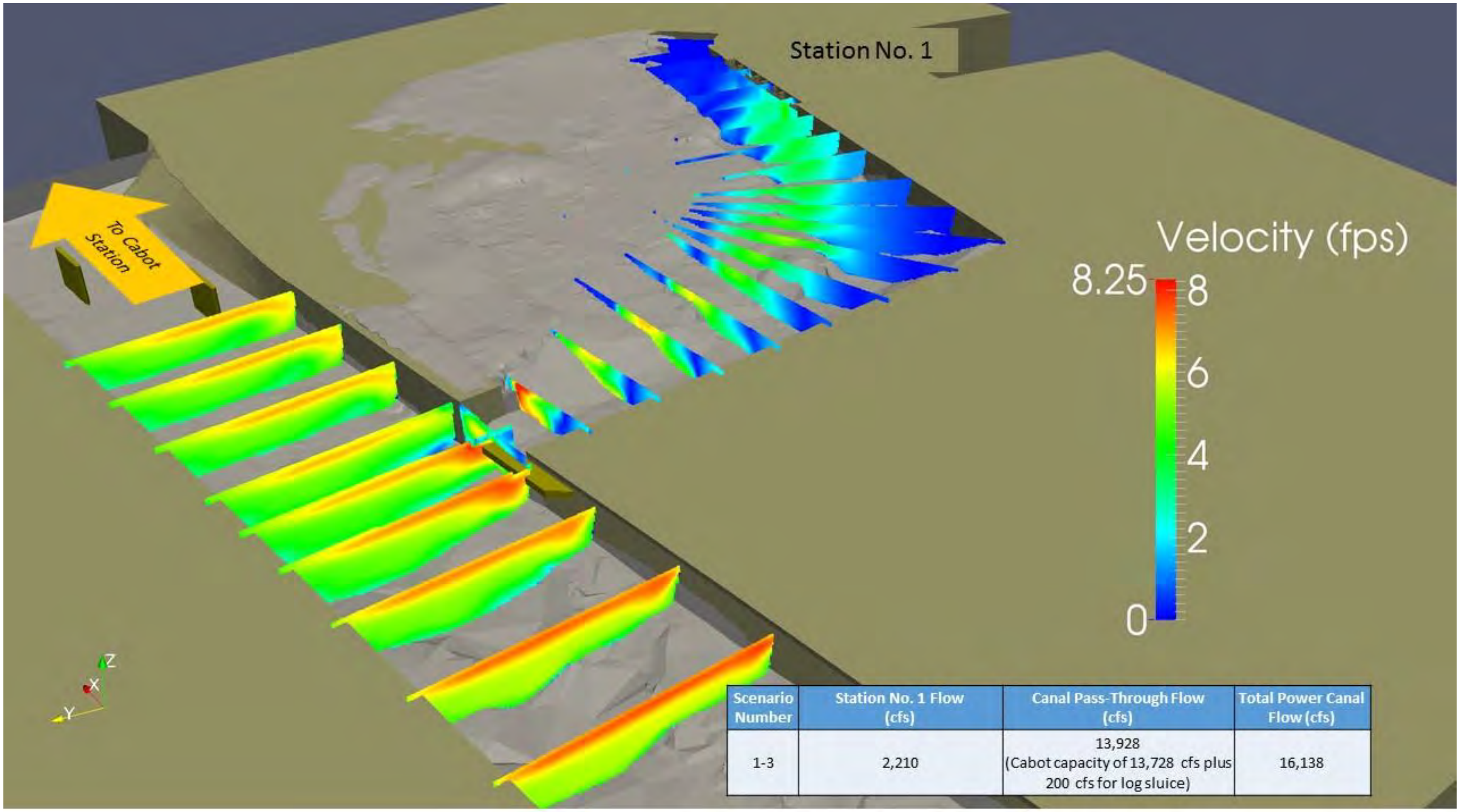
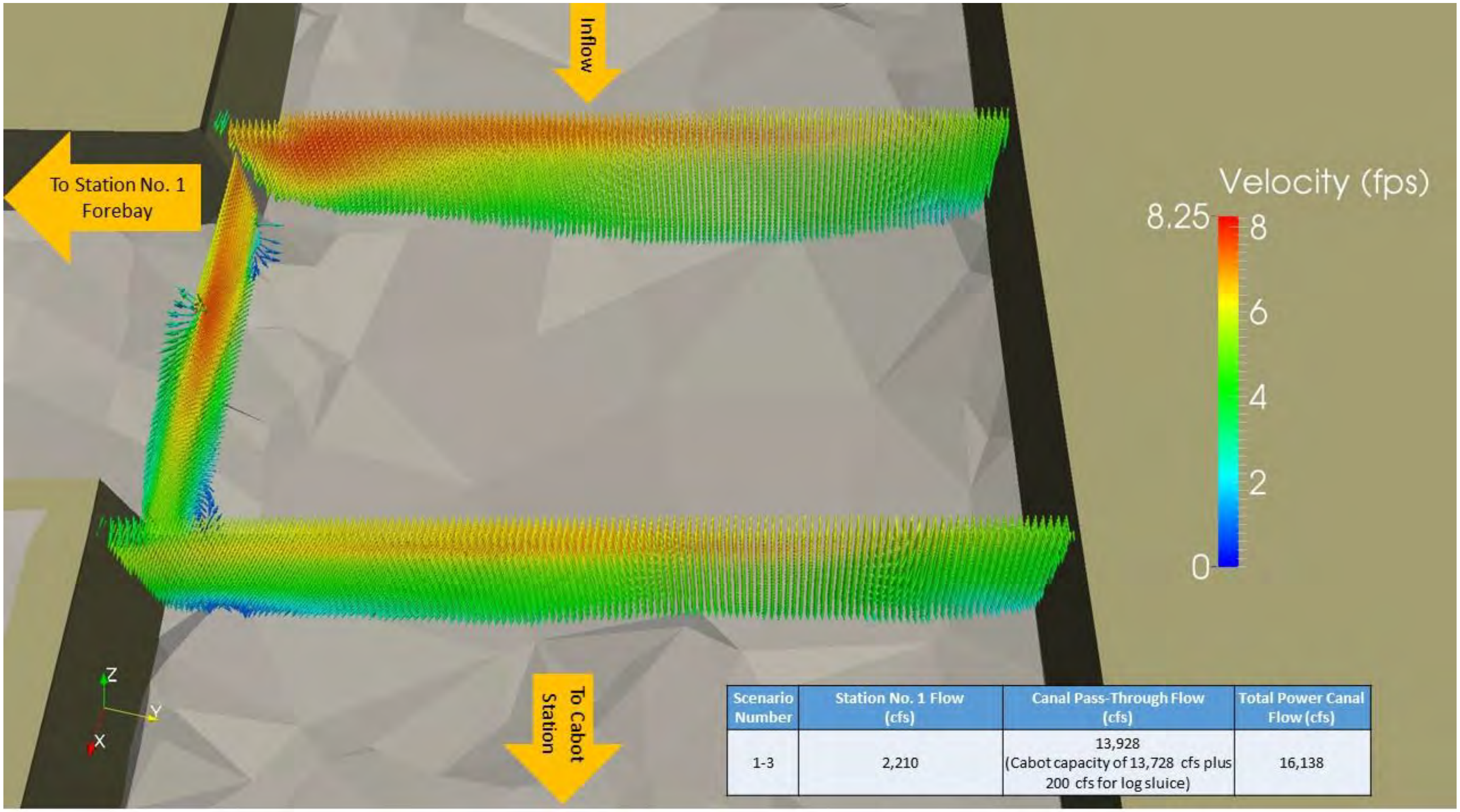


Figure 8.2.2-8: Station No. 1 Scenario 1-2 Velocity Vectors in Canal at Elevation 171.3



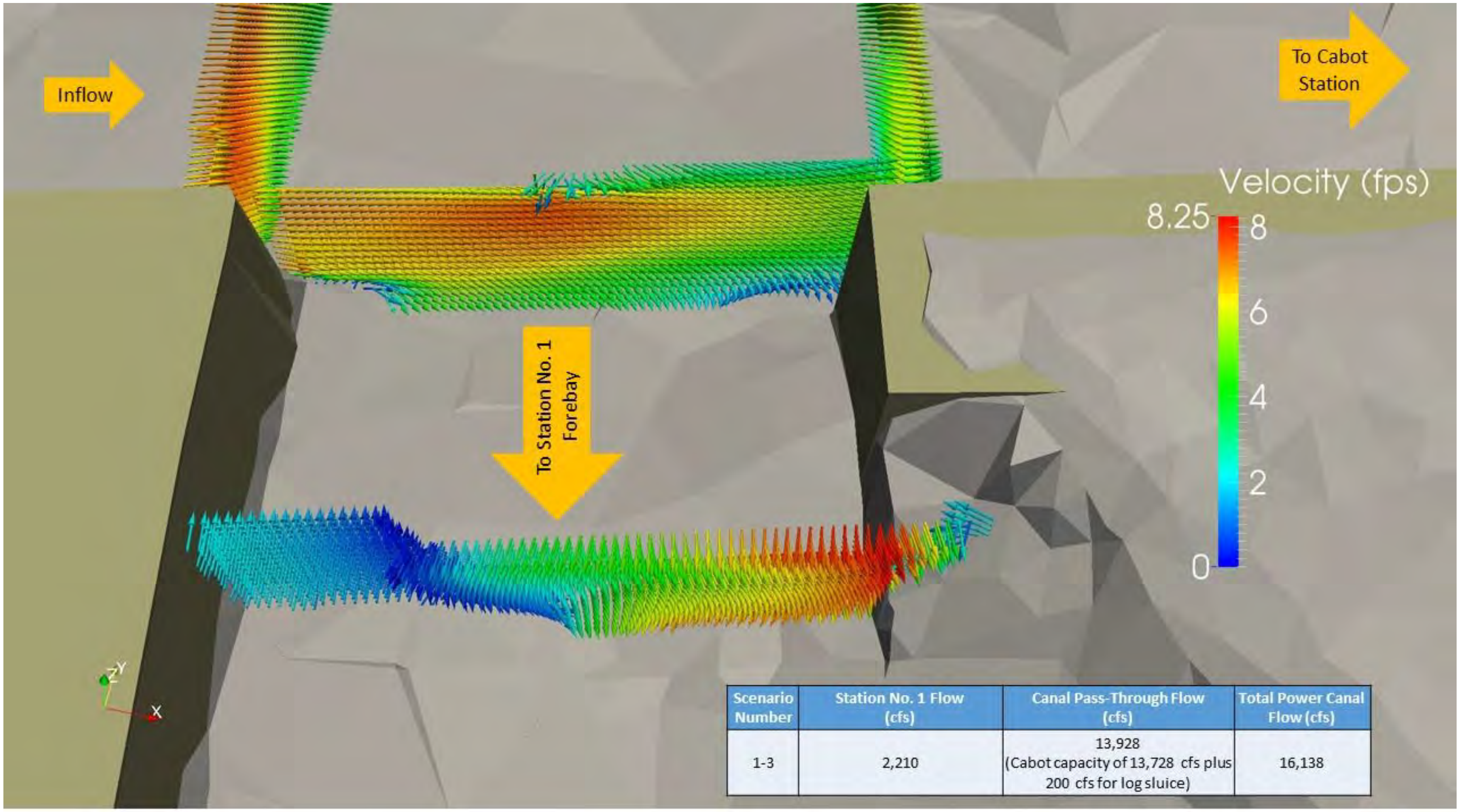
Scenario Number	Station No. 1 Flow (cfs)	Canal Pass-Through Flow (cfs)	Total Power Canal Flow (cfs)
1-3	2,210	13,928 (Cabot capacity of 13,728 cfs plus 200 cfs for log sluice)	16,138

Figure 8.2.3-1: Station No. 1 Scenario 1-3 Overview



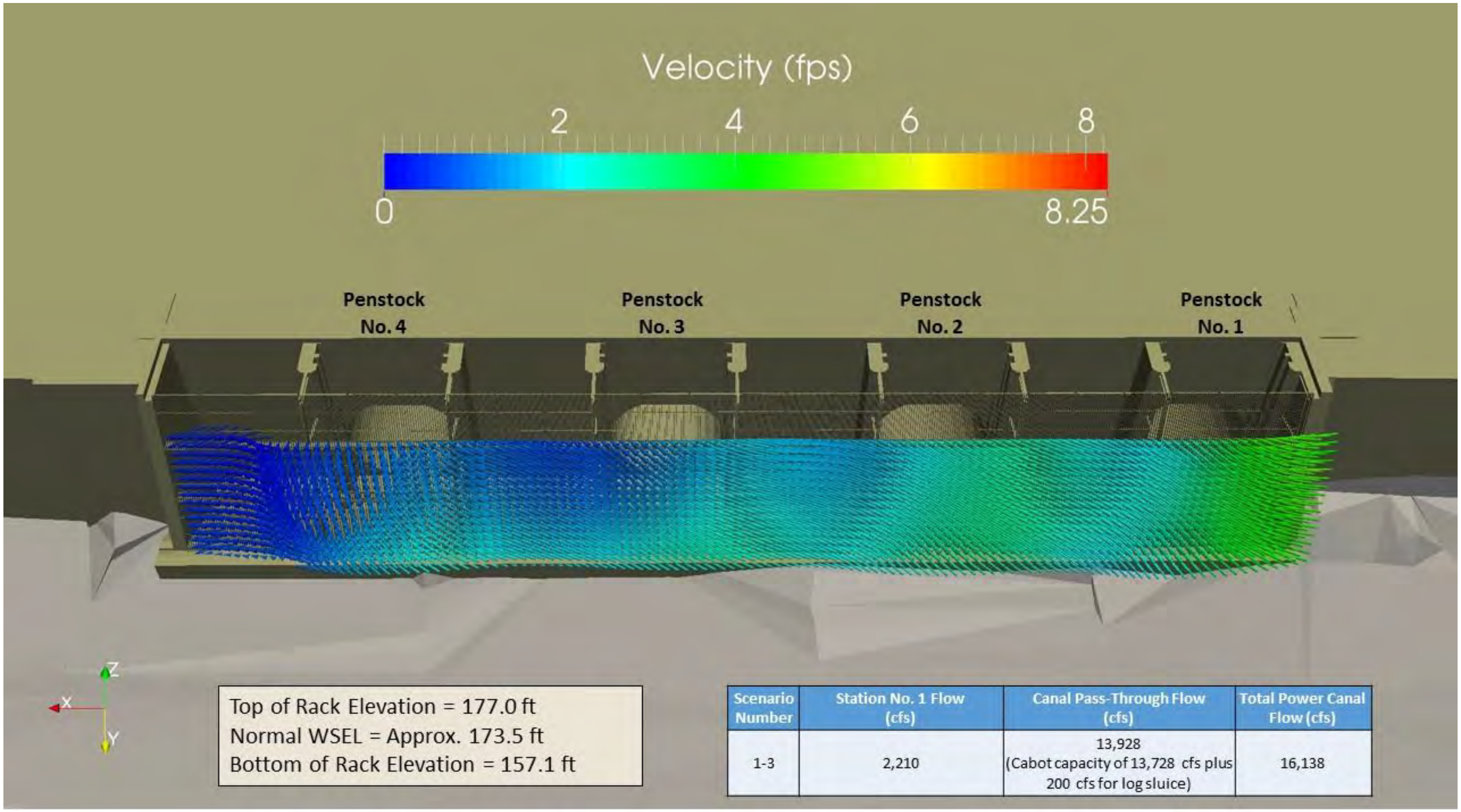
Scenario Number	Station No. 1 Flow (cfs)	Canal Pass-Through Flow (cfs)	Total Power Canal Flow (cfs)
1-3	2,210	13,928 (Cabot capacity of 13,728 cfs plus 200 cfs for log sluice)	16,138

Figure 8.2.3-2: Station No. 1 Scenario 1-3 Power Canal



Scenario Number	Station No. 1 Flow (cfs)	Canal Pass-Through Flow (cfs)	Total Power Canal Flow (cfs)
1-3	2,210	13,928 (Cabot capacity of 13,728 cfs plus 200 cfs for log sluice)	16,138

Figure 8.2.3-3: Station No. 1 Scenario 1-3 Forebay Entrance



Scenario Number	Station No. 1 Flow (cfs)	Canal Pass-Through Flow (cfs)	Total Power Canal Flow (cfs)
1-3	2,210	13,928 (Cabot capacity of 13,728 cfs plus 200 cfs for log sluice)	16,138

Figure 8.2.3-4: Station No. 1 Scenario 1-3 Intake Rack Overview

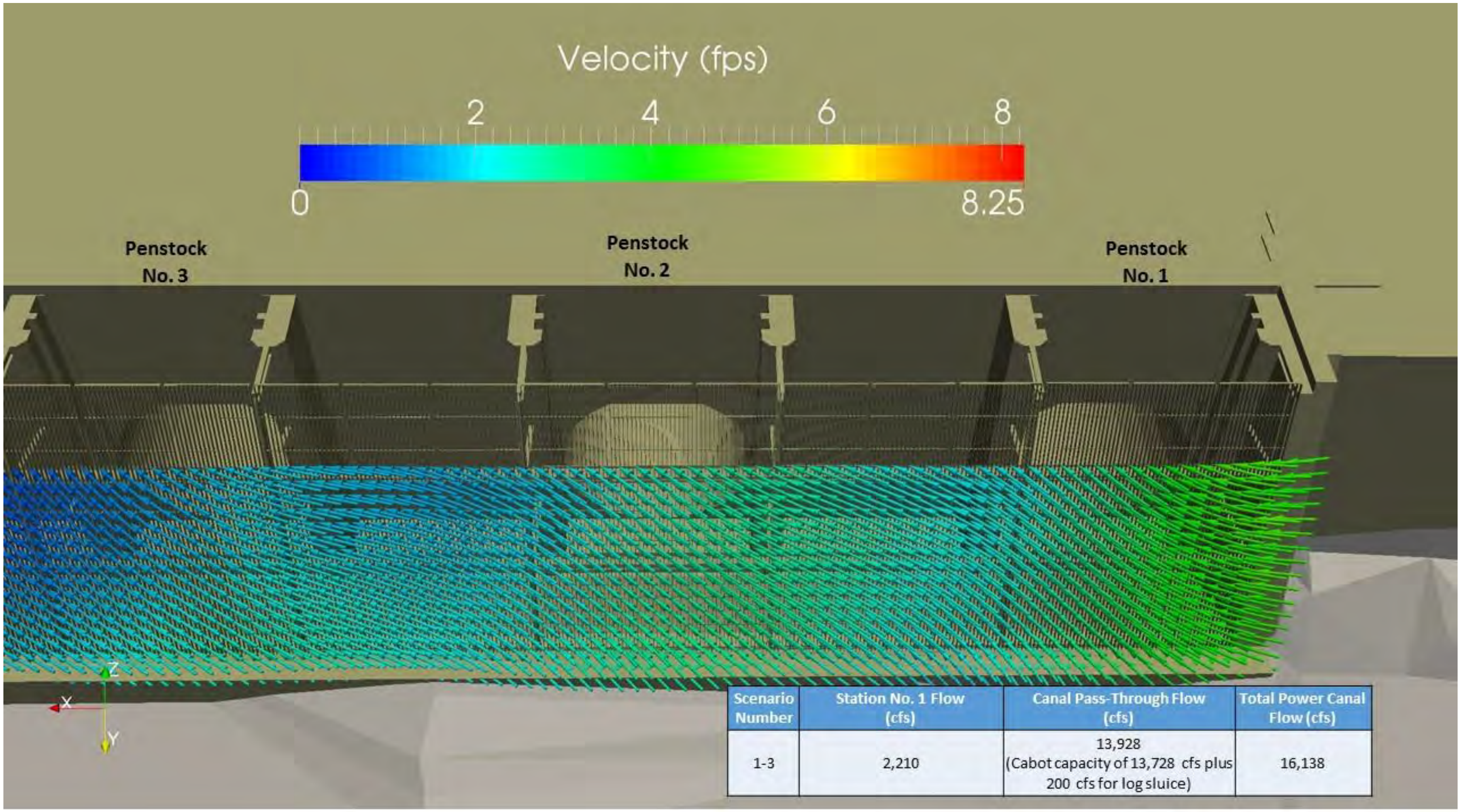


Figure 8.2.3-5: Station No. 1 Scenario 1-3 Intake Rack at Penstocks 1 and 2

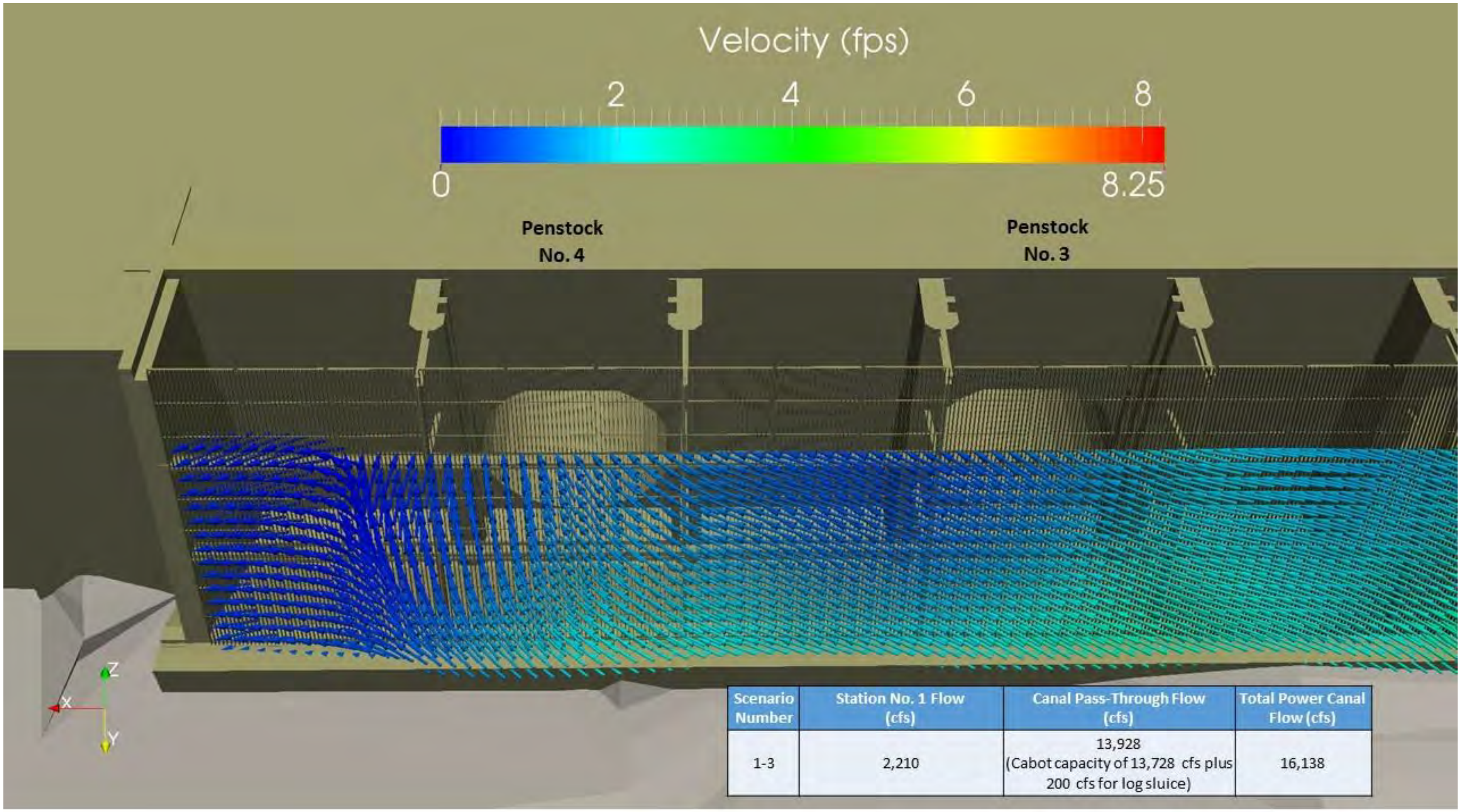
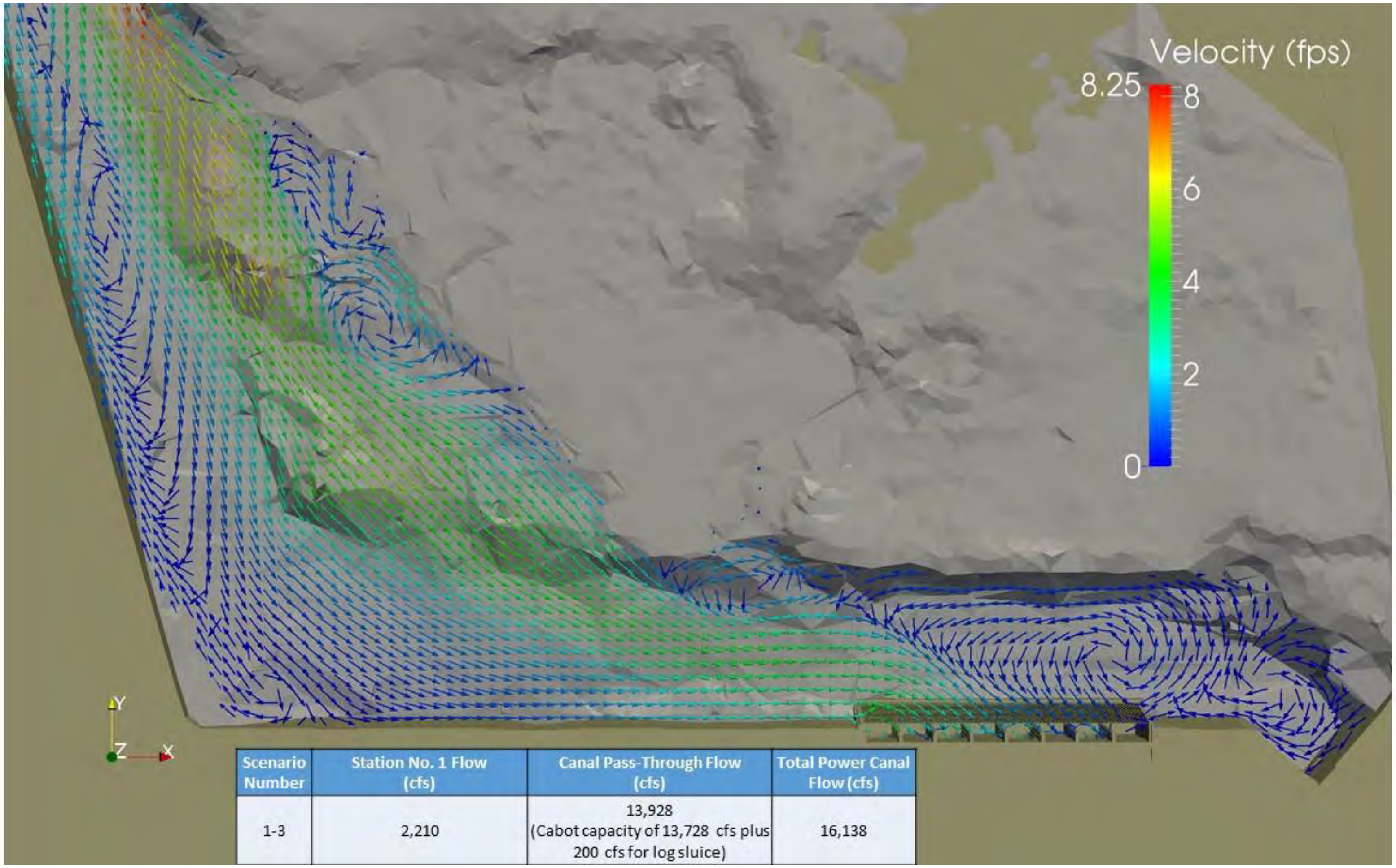


Figure 8.2.3-6: Station No. 1 Scenario 1-3 Intake Rack at Penstocks 3 and 4



Scenario Number	Station No. 1 Flow (cfs)	Canal Pass-Through Flow (cfs)	Total Power Canal Flow (cfs)
1-3	2,210	13,928 (Cabot capacity of 13,728 cfs plus 200 cfs for log sluice)	16,138

Figure 8.2.3-7: Station No. 1 Scenario 1-3 Velocity Vectors in Forebay at Elevation 171.3

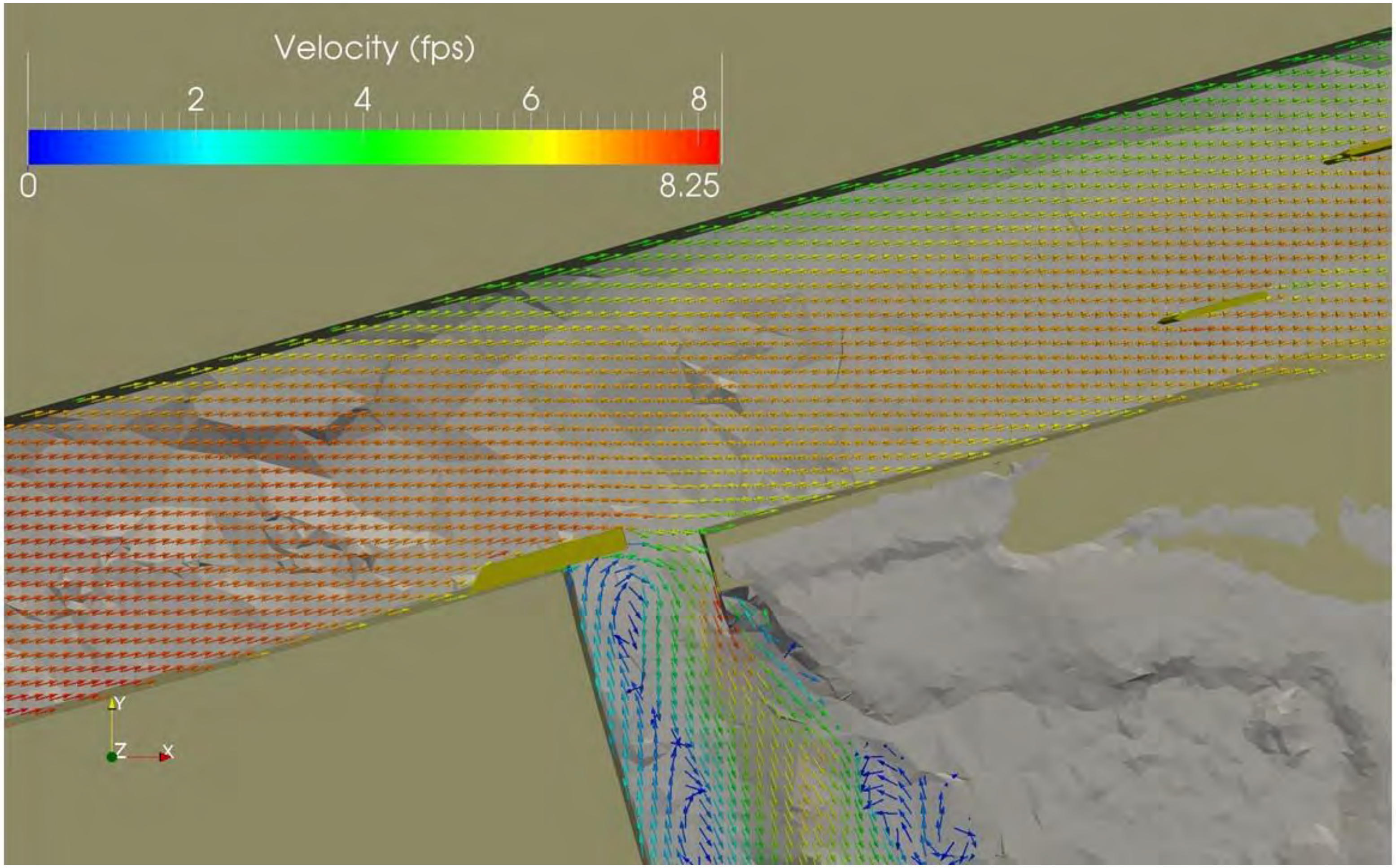


Figure 8.2.3-8: Station No. 1 Scenario 1-3 Velocity Vectors in Canal at Elevation 171.3

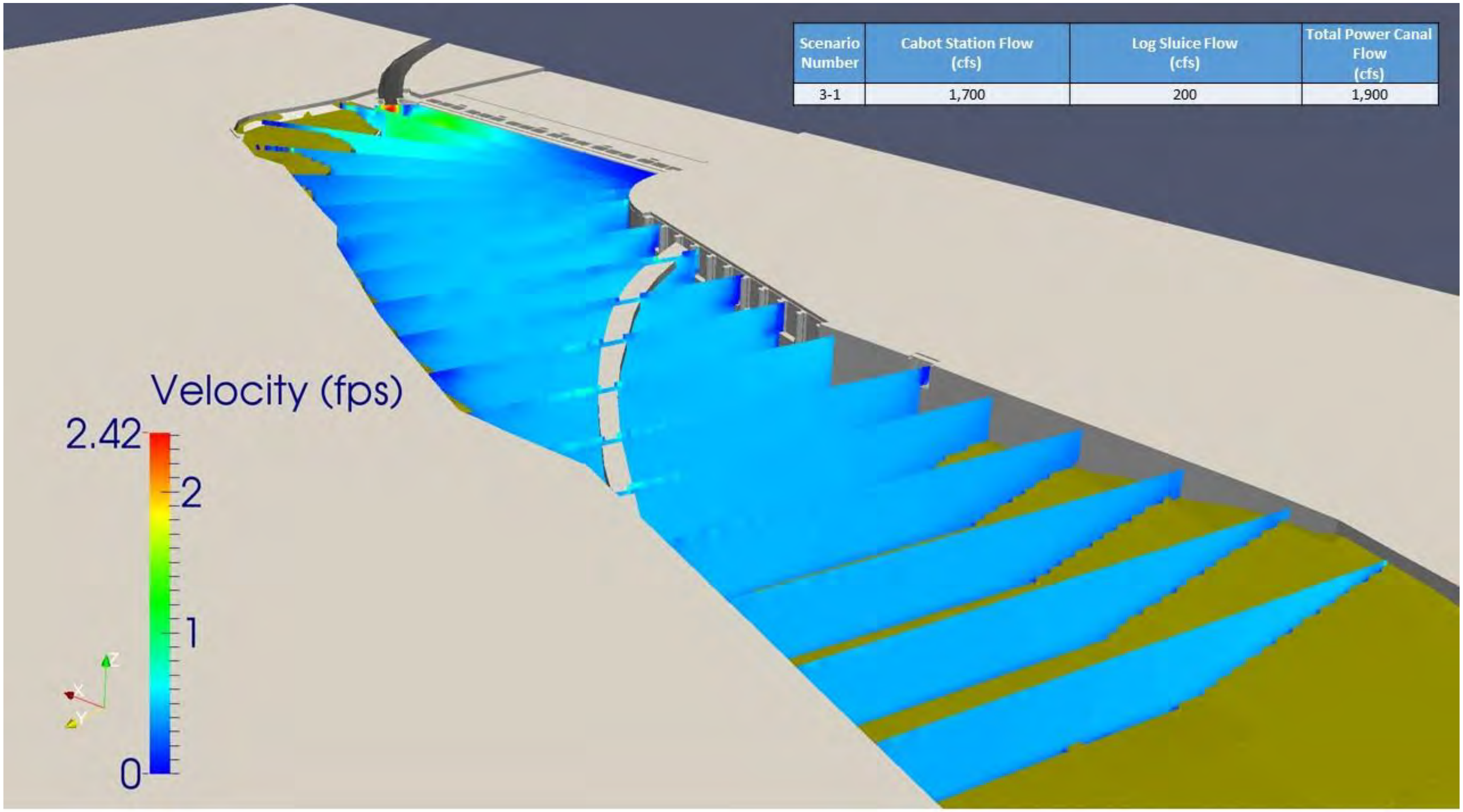


Figure 8.3.1-1: Cabot Station Scenario 3-1 Overview

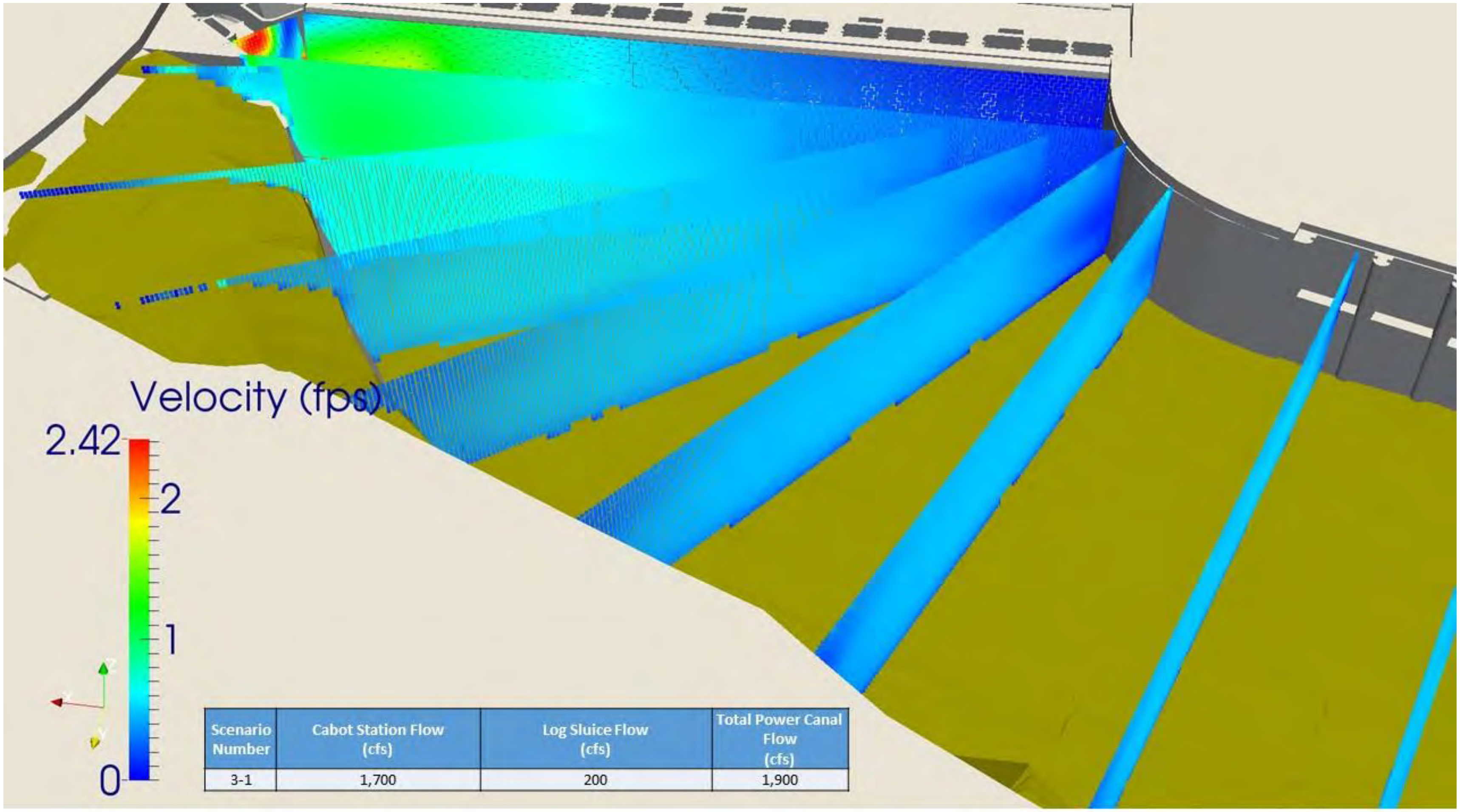
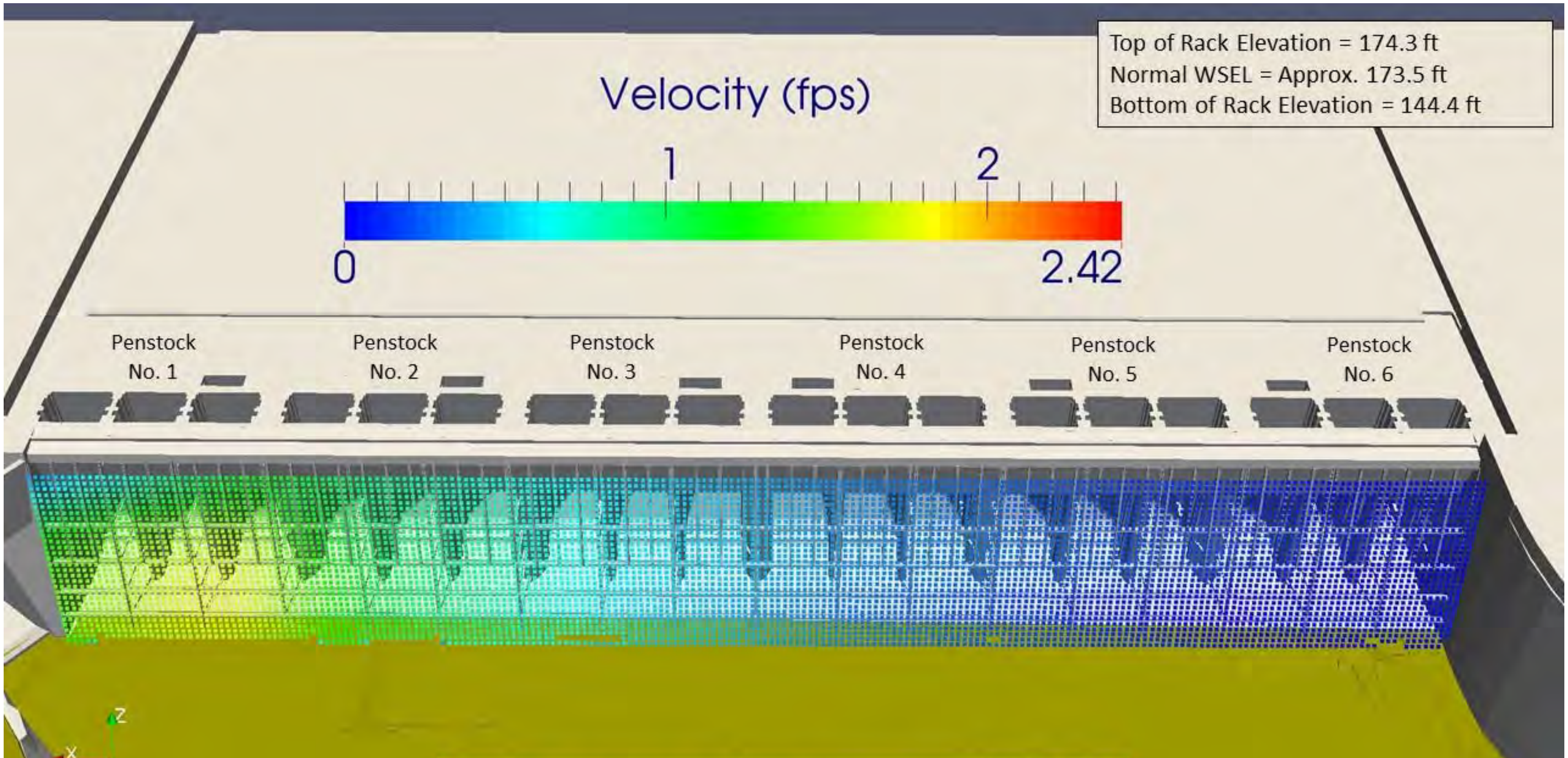
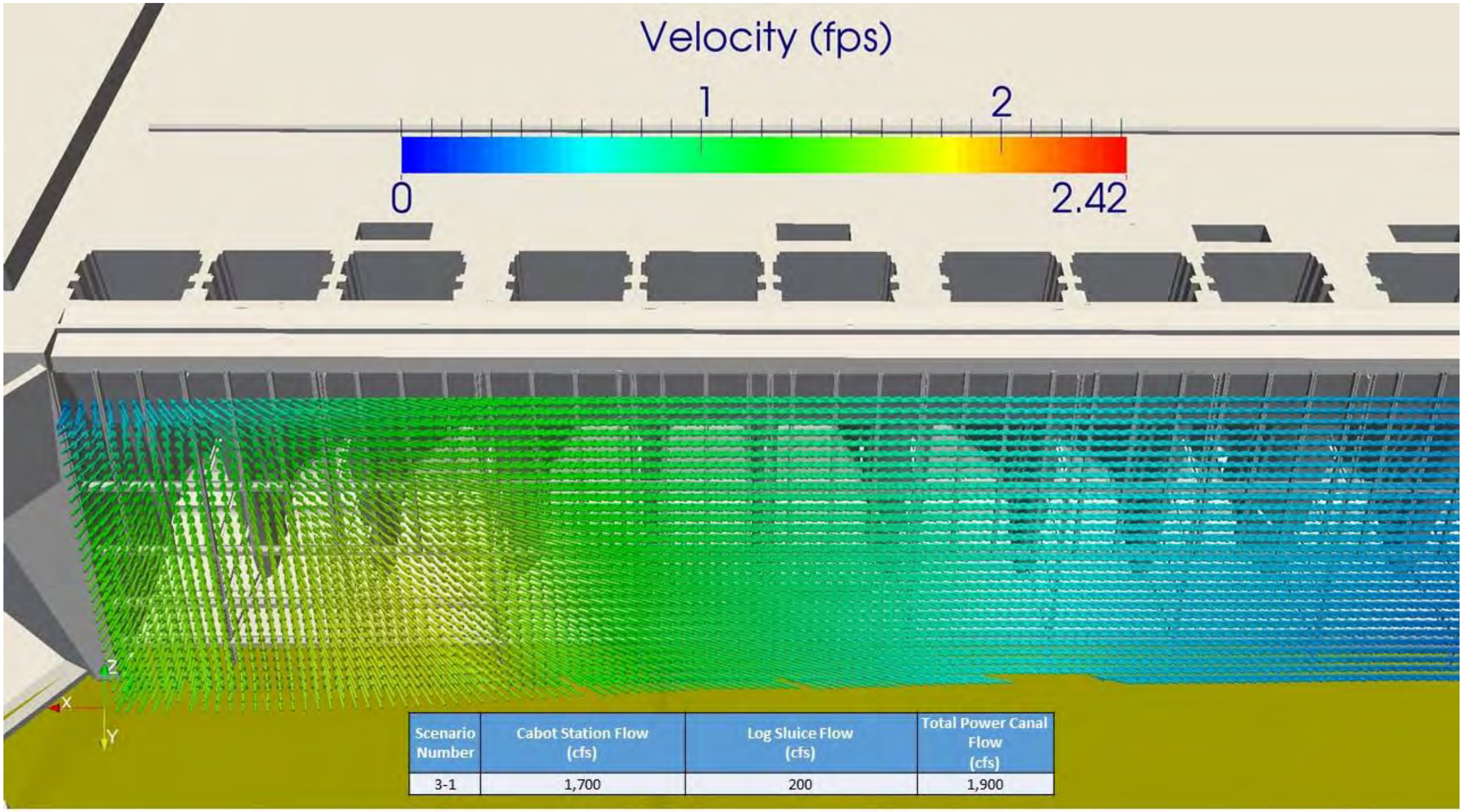


Figure 8.3.1-2: Cabot Station Scenario 3-1 Forebay



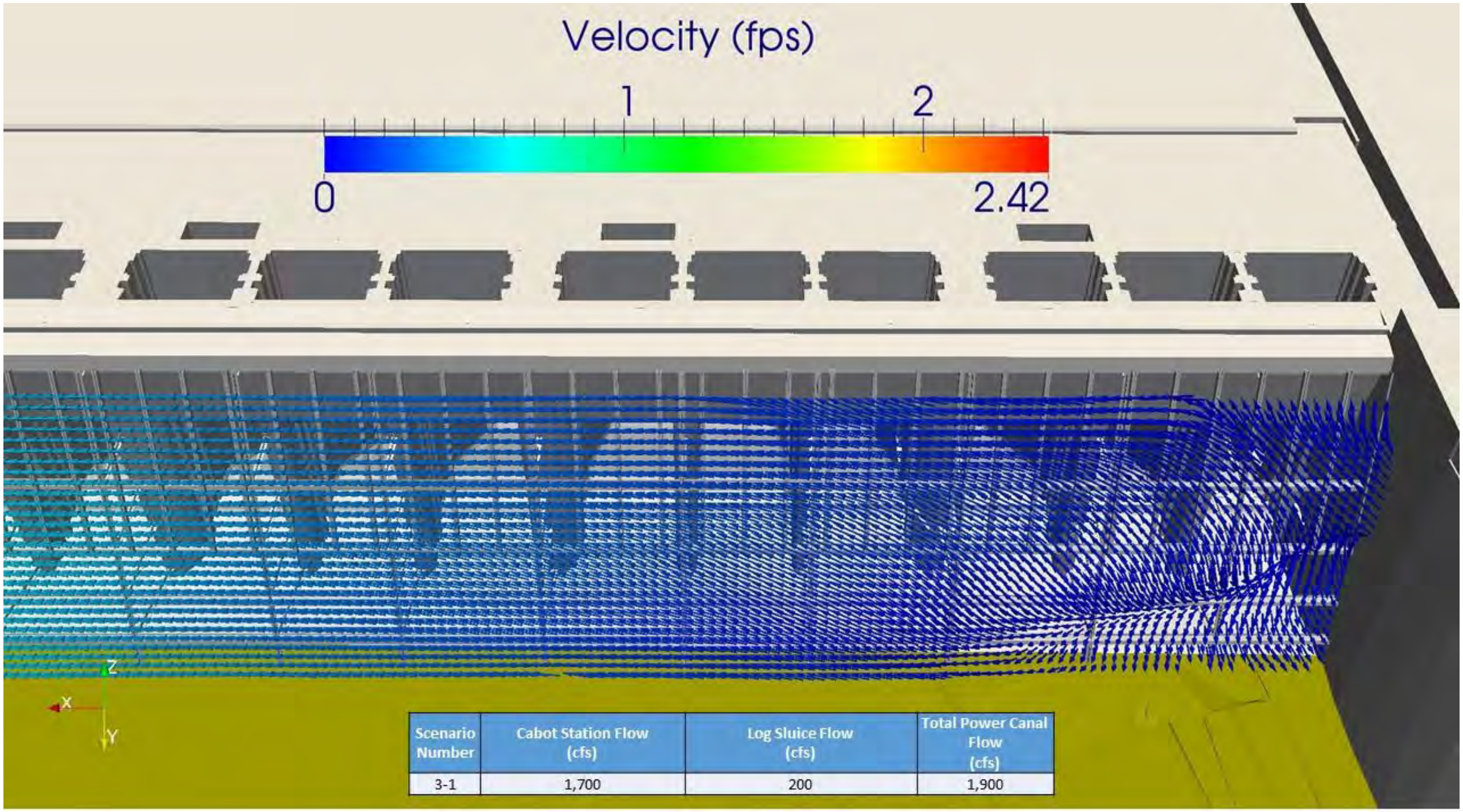
Scenario Number	Cabot Station Flow (cfs)	Log Sluice Flow (cfs)	Total Power Canal Flow (cfs)
3-1	1,700	200	1,900

Figure 8.3.1-3: Cabot Station Scenario 3-1 Intake Rack Overview



Scenario Number	Cabot Station Flow (cfs)	Log Sluice Flow (cfs)	Total Power Canal Flow (cfs)
3-1	1,700	200	1,900

Figure 8.3.1-4: Cabot Station Scenario 3-1 Intake Rack at Penstocks 1, 2, and 3



Scenario Number	Cabot Station Flow (cfs)	Log Sluice Flow (cfs)	Total Power Canal Flow (cfs)
3-1	1,700	200	1,900

Figure 8.3.1-5: Cabot Station Scenario 3-1 Intake Rack at Penstocks 4, 5, and 6

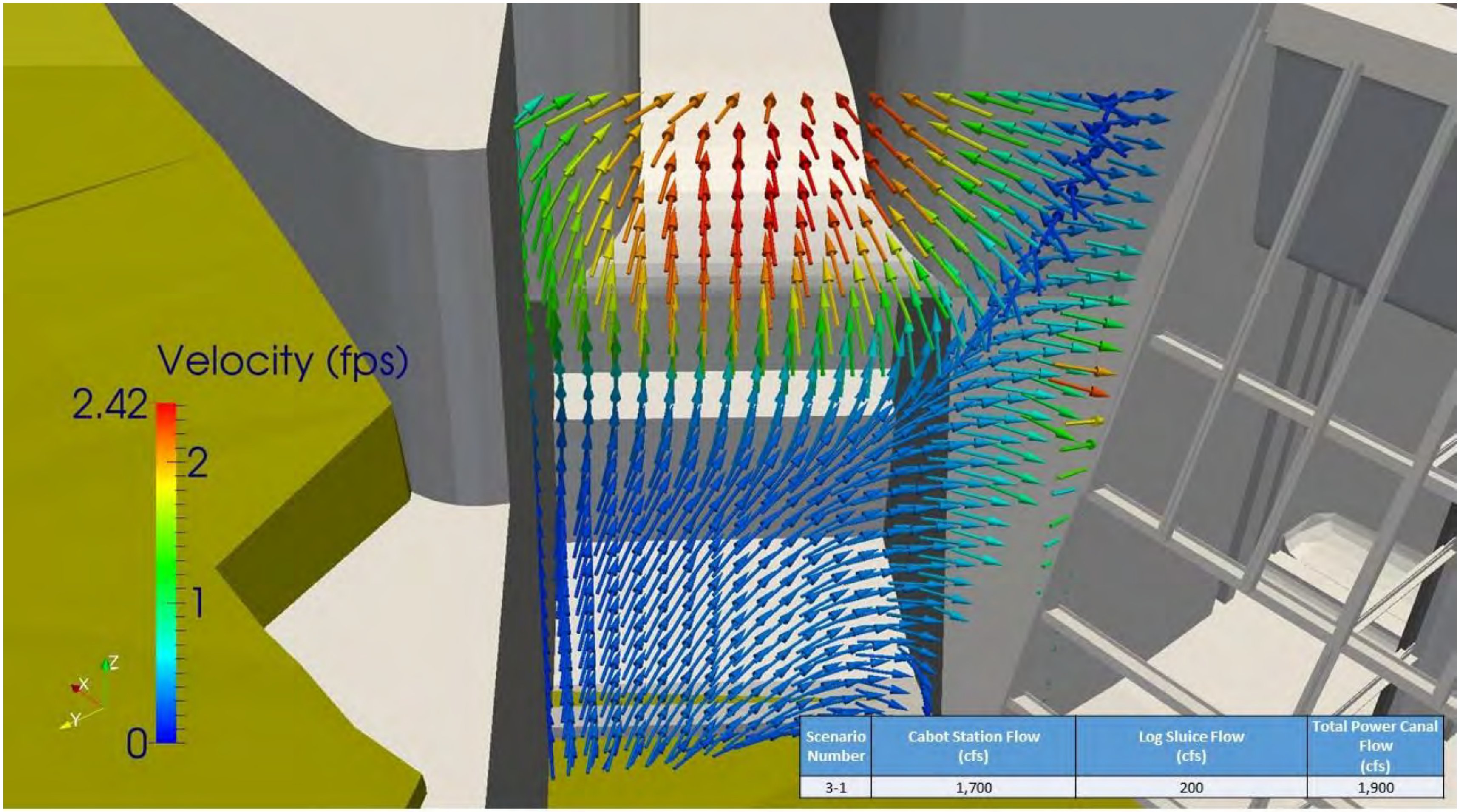


Figure 8.3.1-6: Cabot Station Scenario 3-1 Log Sluice

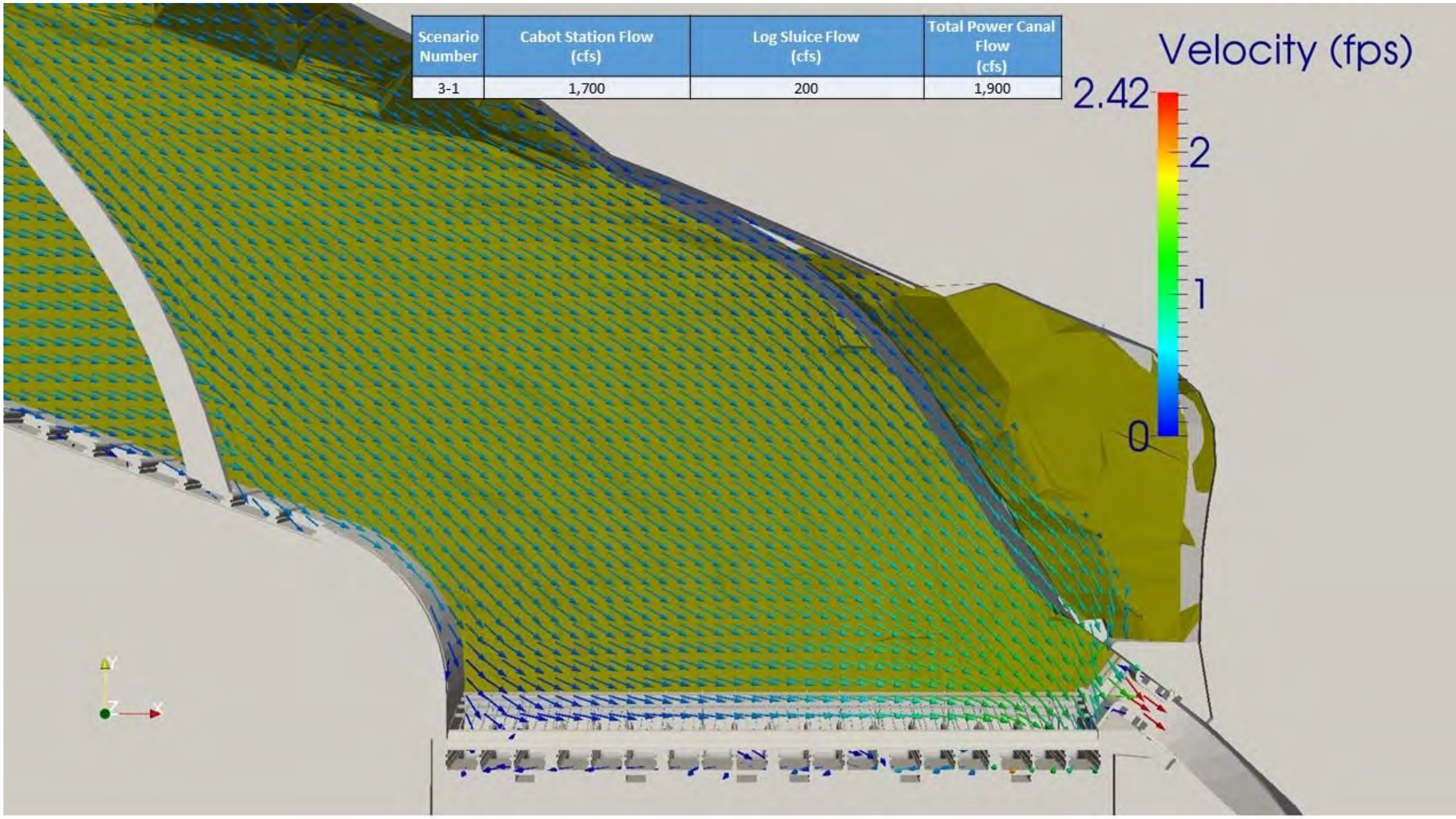


Figure 8.3.1-7: Cabot Station Scenario 3-1 Velocity Vectors in Forebay at Elevation 171.6

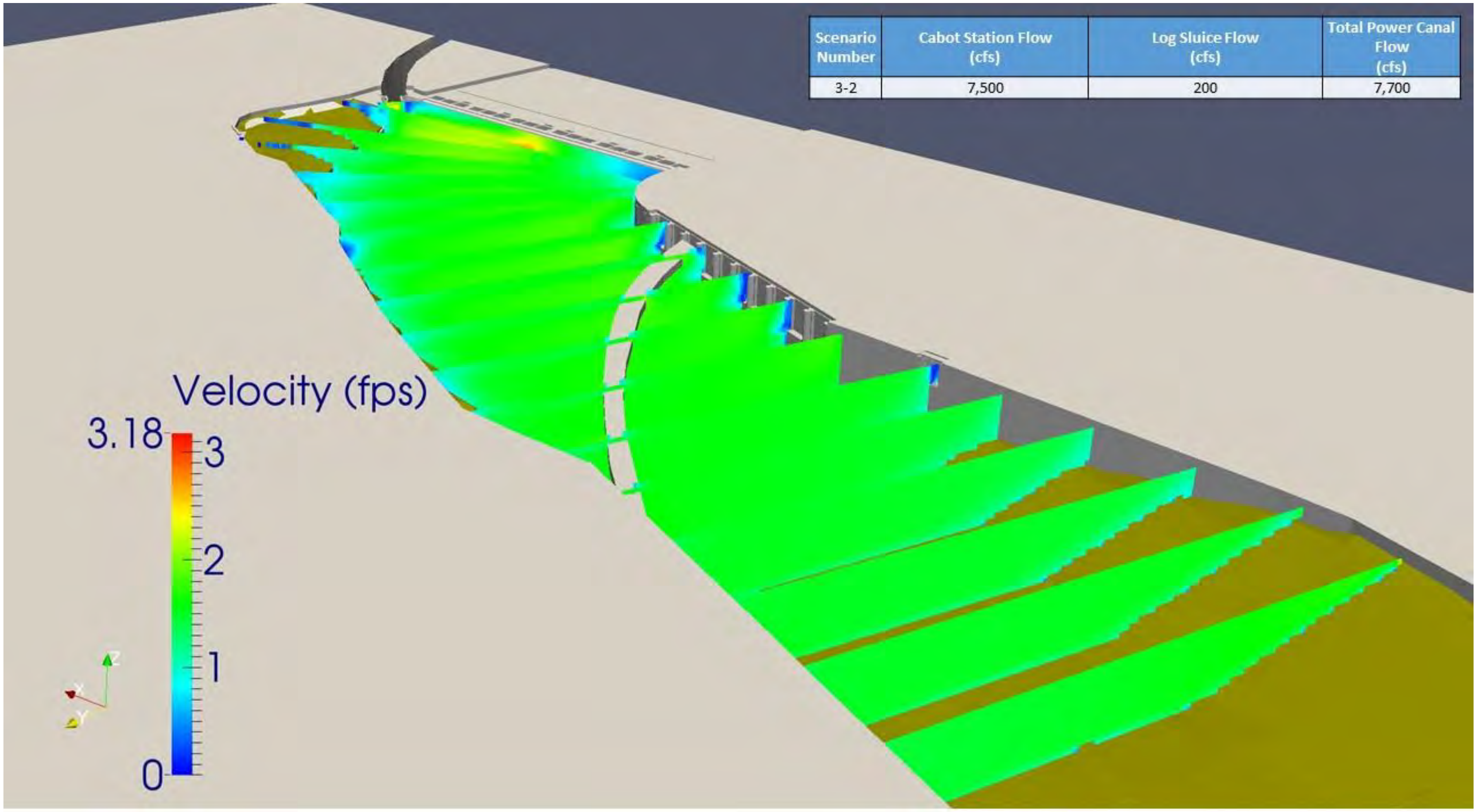
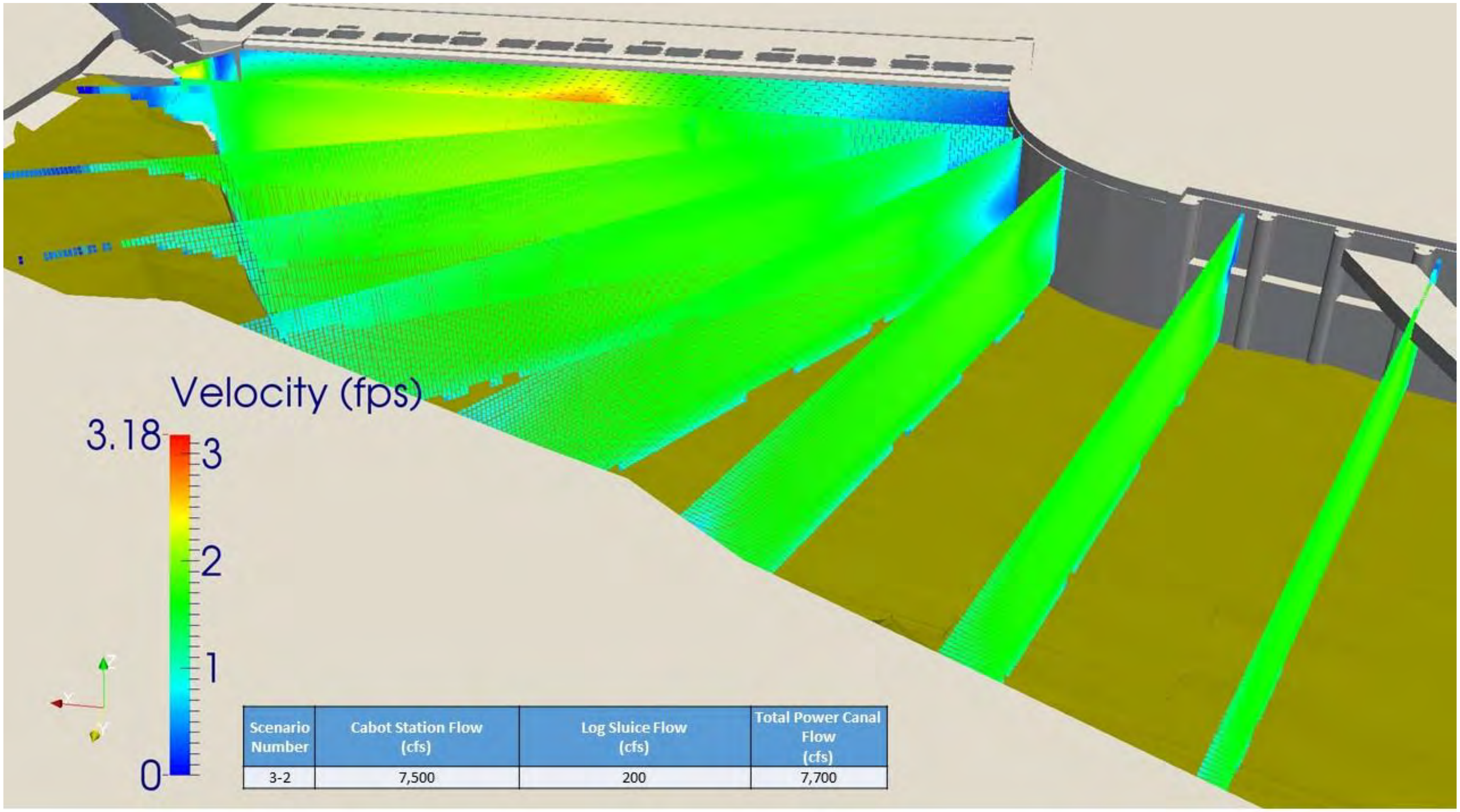


Figure 8.3.2-1: Cabot Station Scenario 3-2 Overview



Scenario Number	Cabot Station Flow (cfs)	Log Sluice Flow (cfs)	Total Power Canal Flow (cfs)
3-2	7,500	200	7,700

Figure 8.3.2-2: Cabot Station Scenario 3-2 Forebay

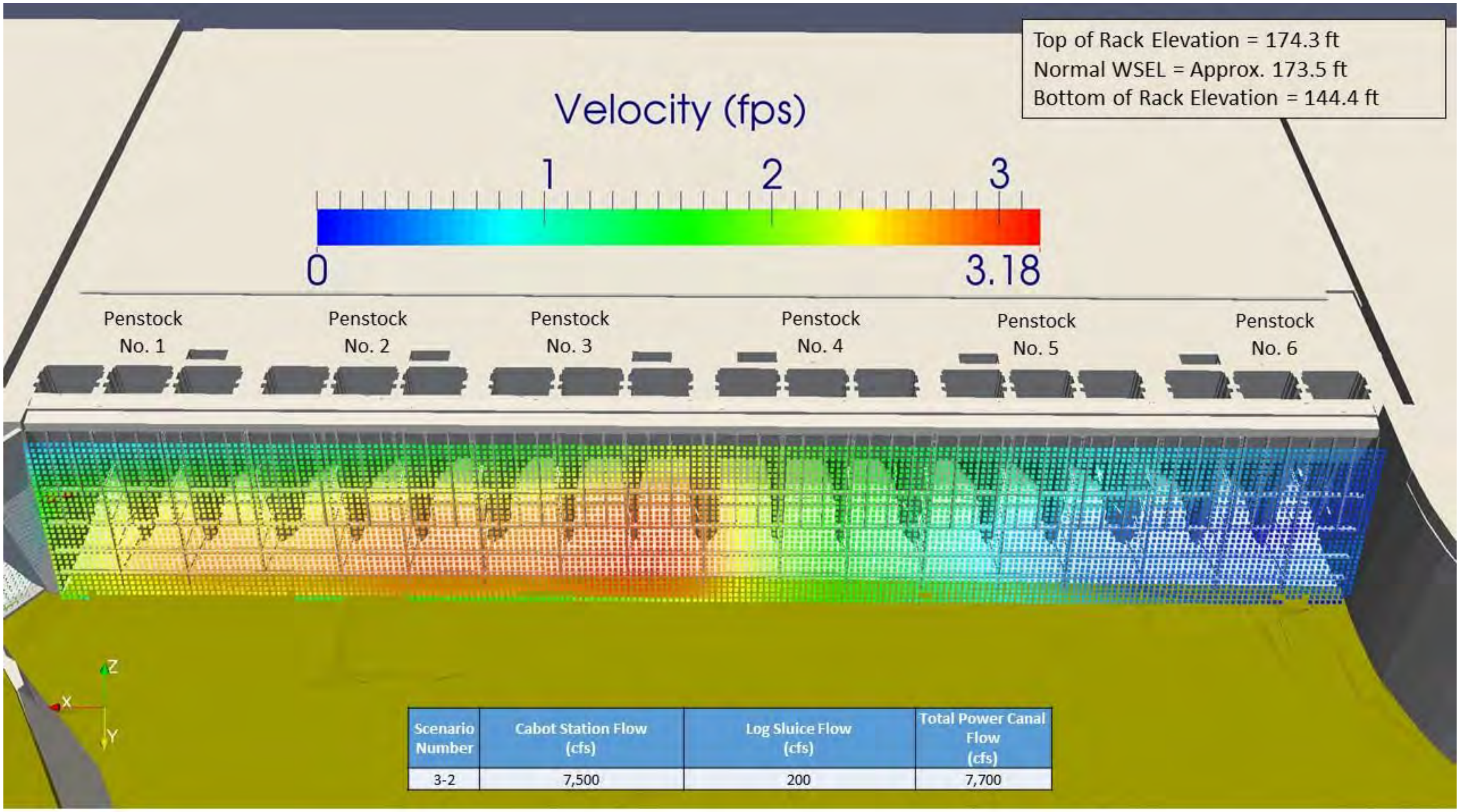


Figure 8.3.2-3: Cabot Station Scenario 3-2 Intake Rack Overview

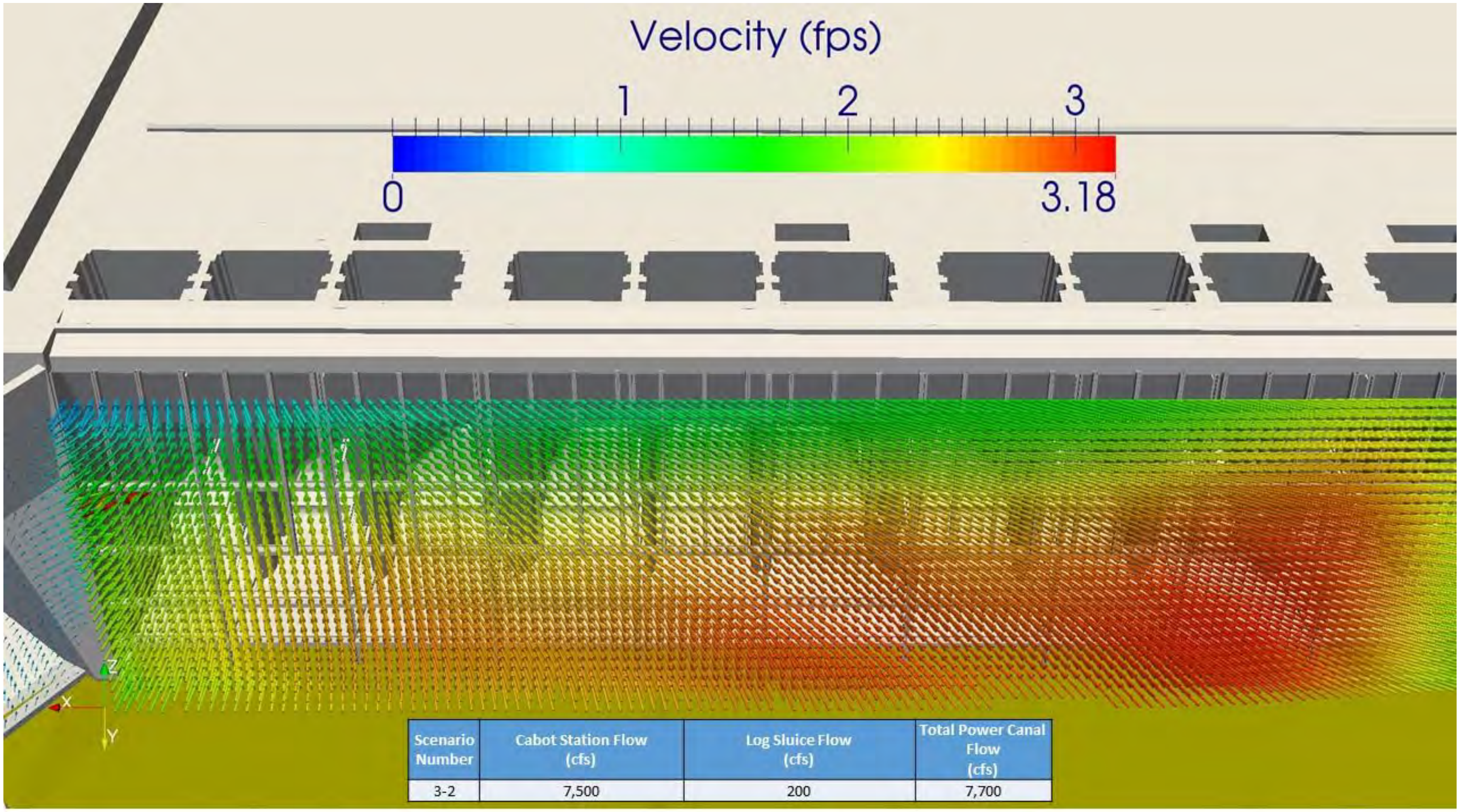
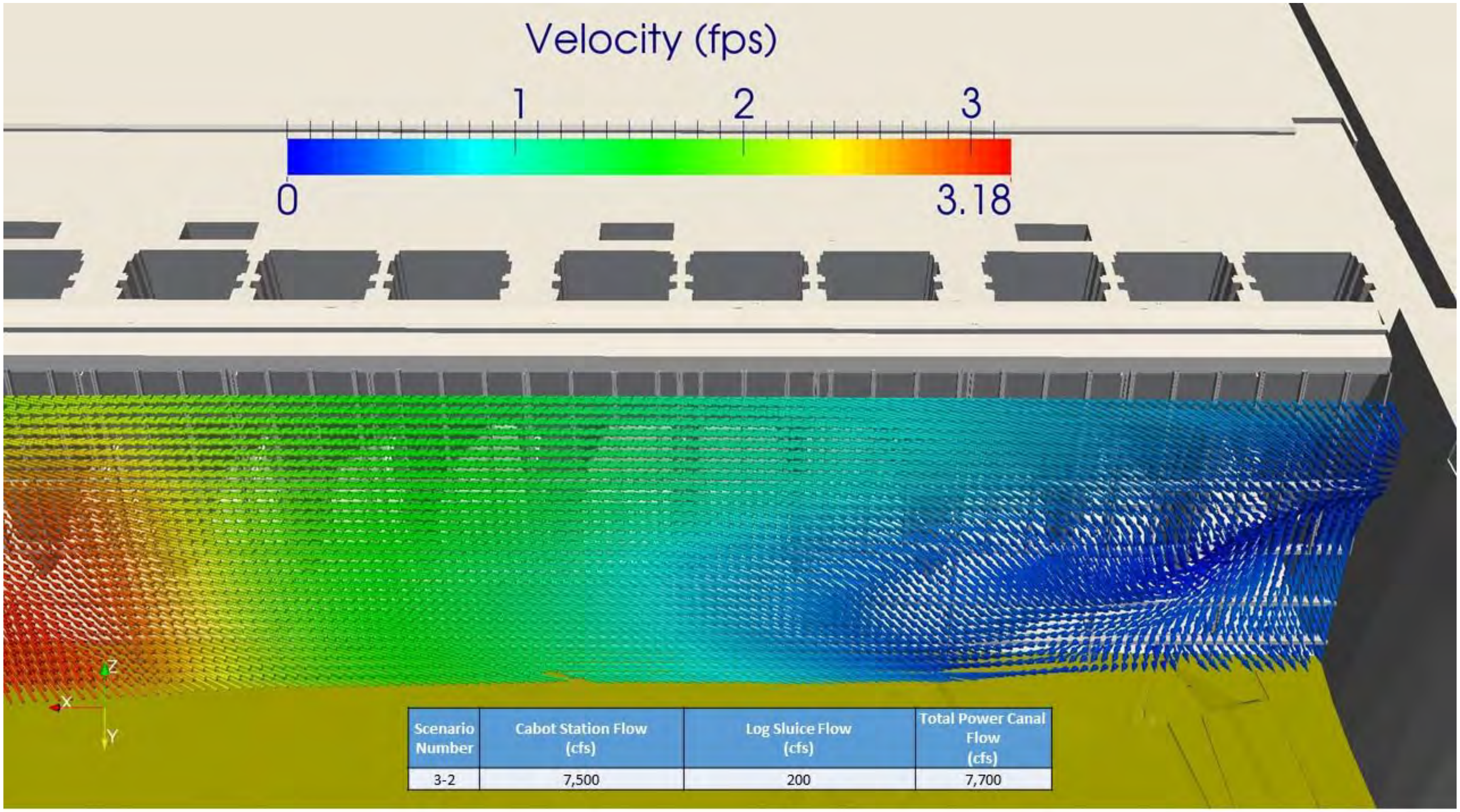
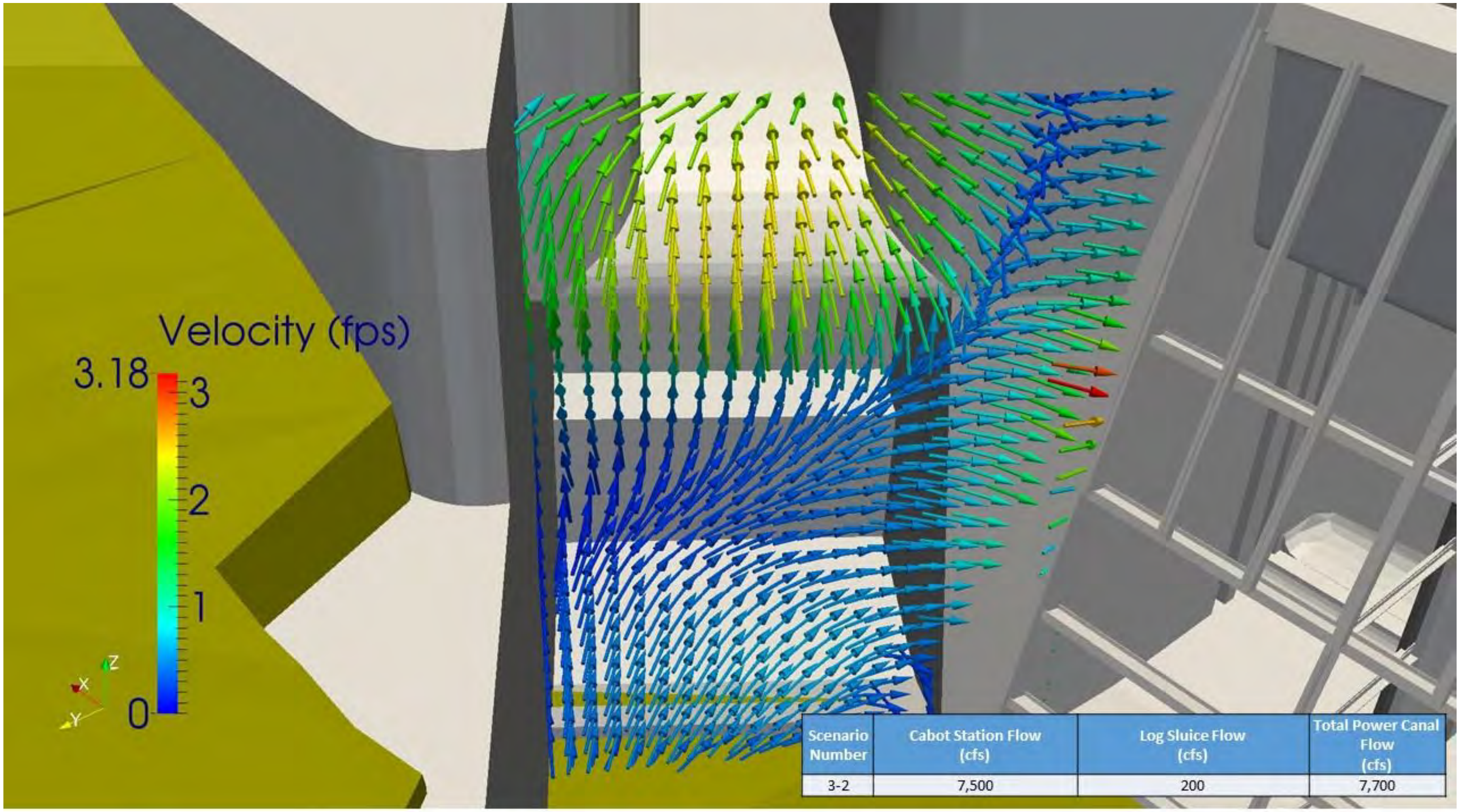


Figure 8.3.2-4: Cabot Station Scenario 3-2 Intake Rack at Penstocks 1, 2, and 3



Scenario Number	Cabot Station Flow (cfs)	Log Sluice Flow (cfs)	Total Power Canal Flow (cfs)
3-2	7,500	200	7,700

Figure 8.3.2-5: Cabot Station Scenario 3-2 Intake Rack at Penstocks 4, 5, and 6



Scenario Number	Cabot Station Flow (cfs)	Log Sluice Flow (cfs)	Total Power Canal Flow (cfs)
3-2	7,500	200	7,700

Figure 8.3.2-6: Cabot Station Scenario 3-2 Log Sluice

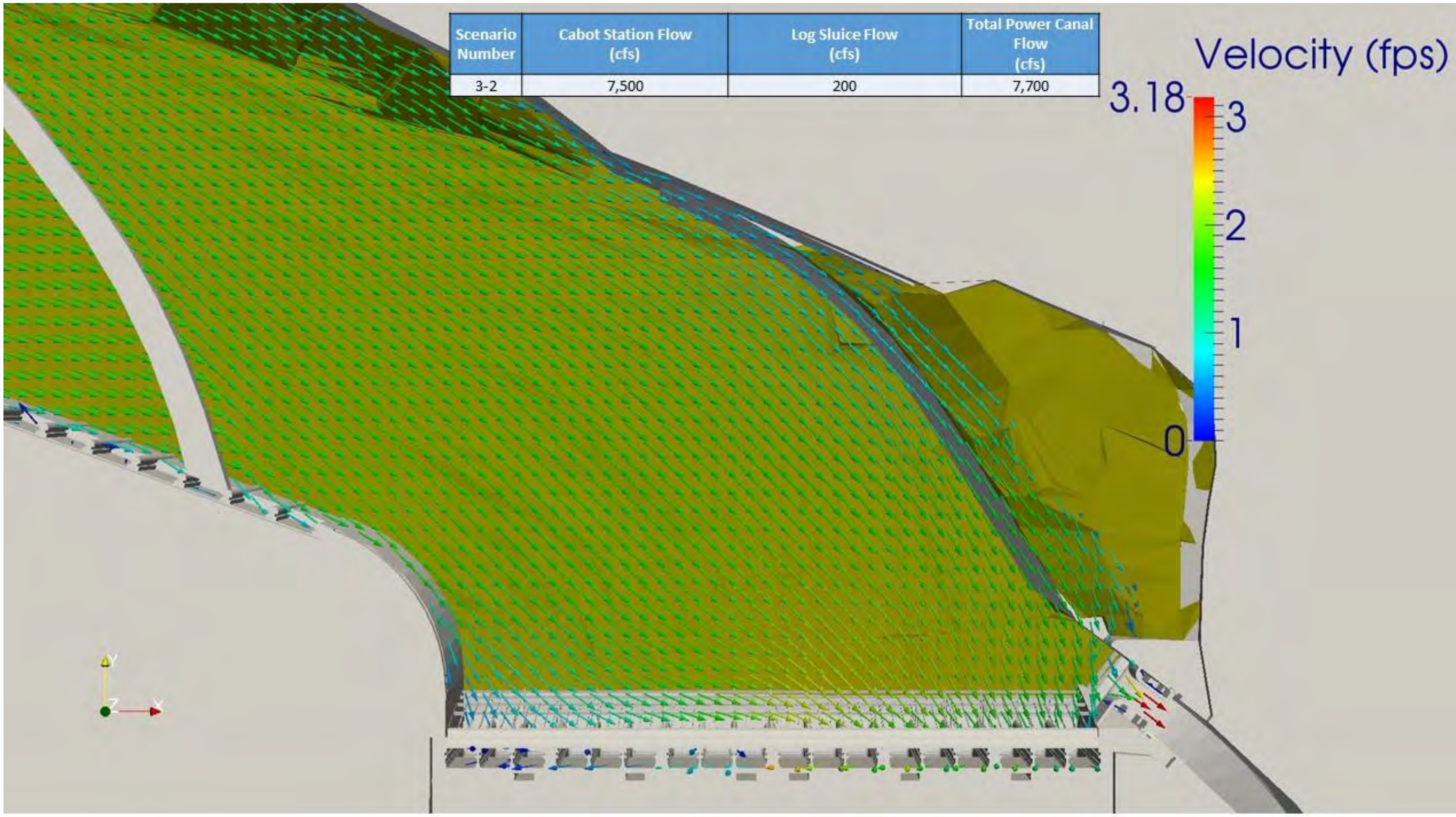


Figure 8.3.2-7: Cabot Station Scenario 3-2 Velocity Vectors in Forebay at Elevation 171.6

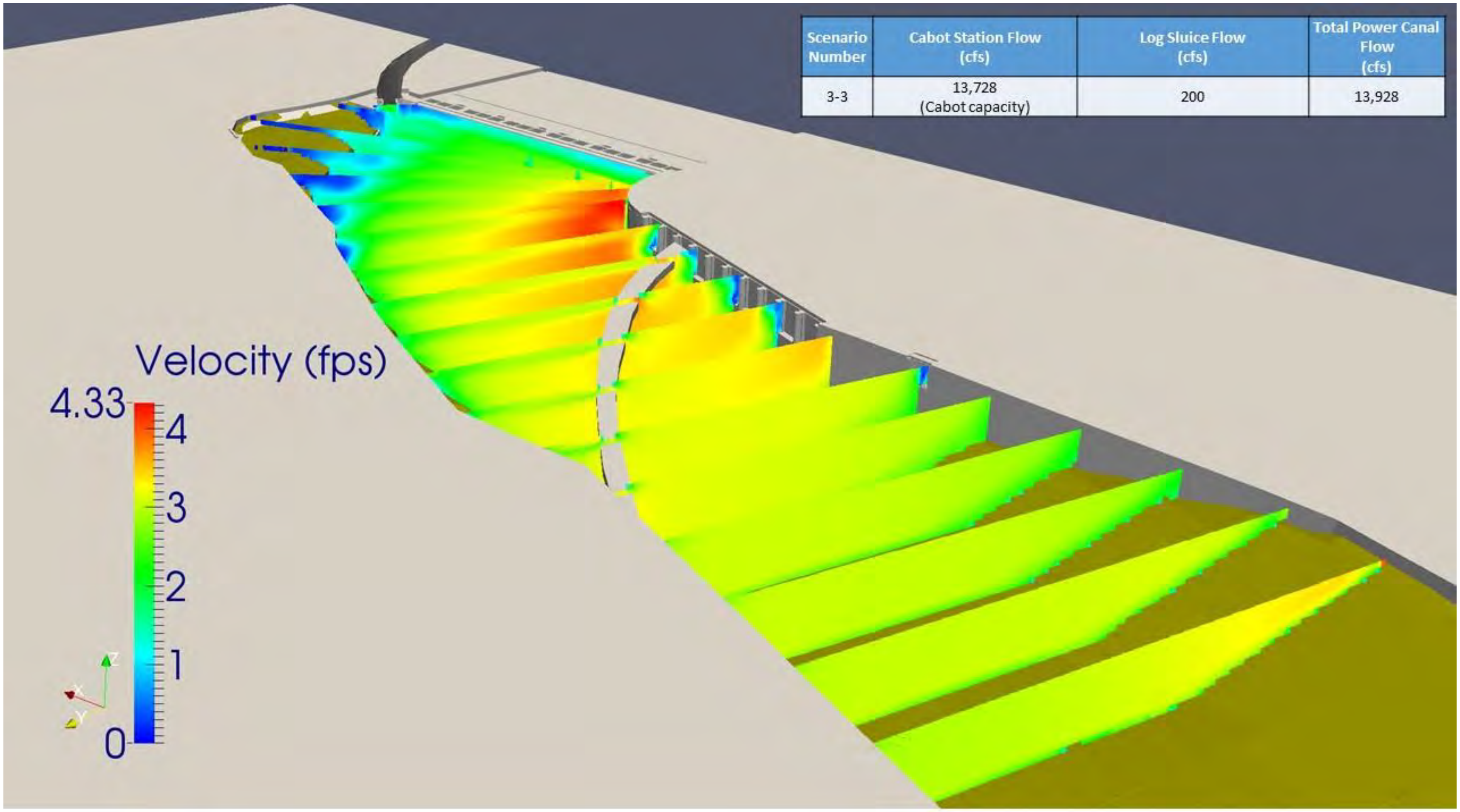
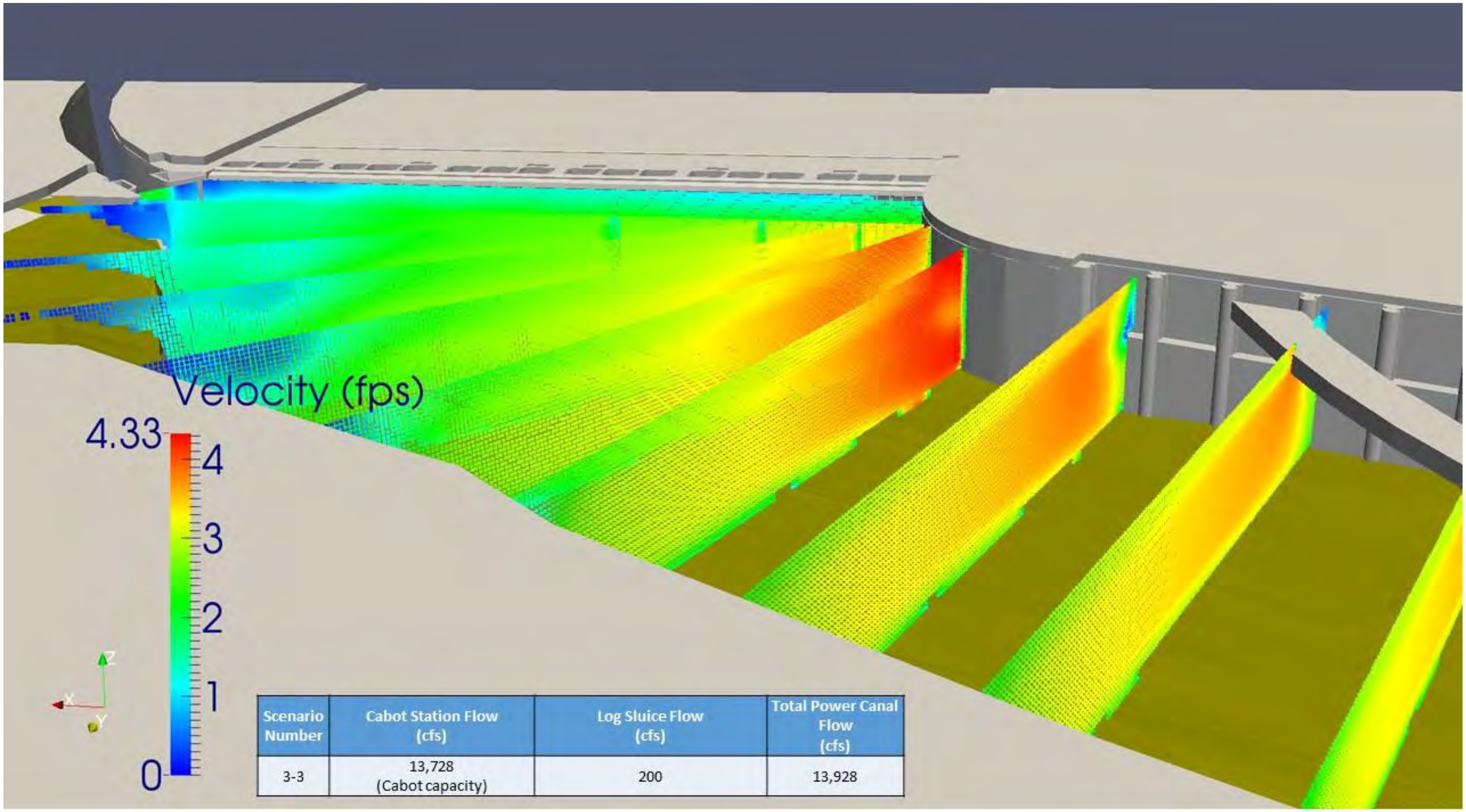
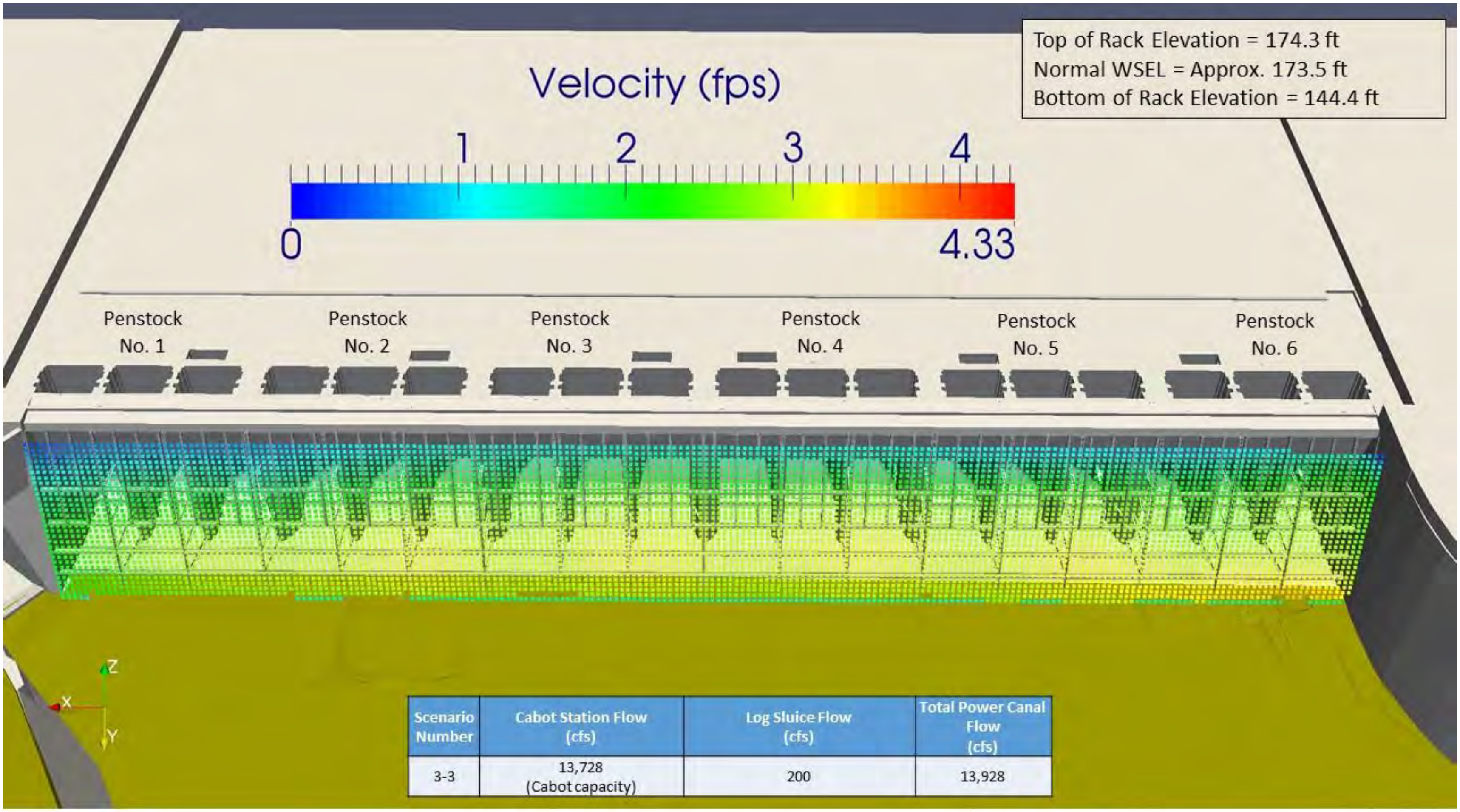


Figure 8.3.3-1: Cabot Station Scenario 3-3 Overview



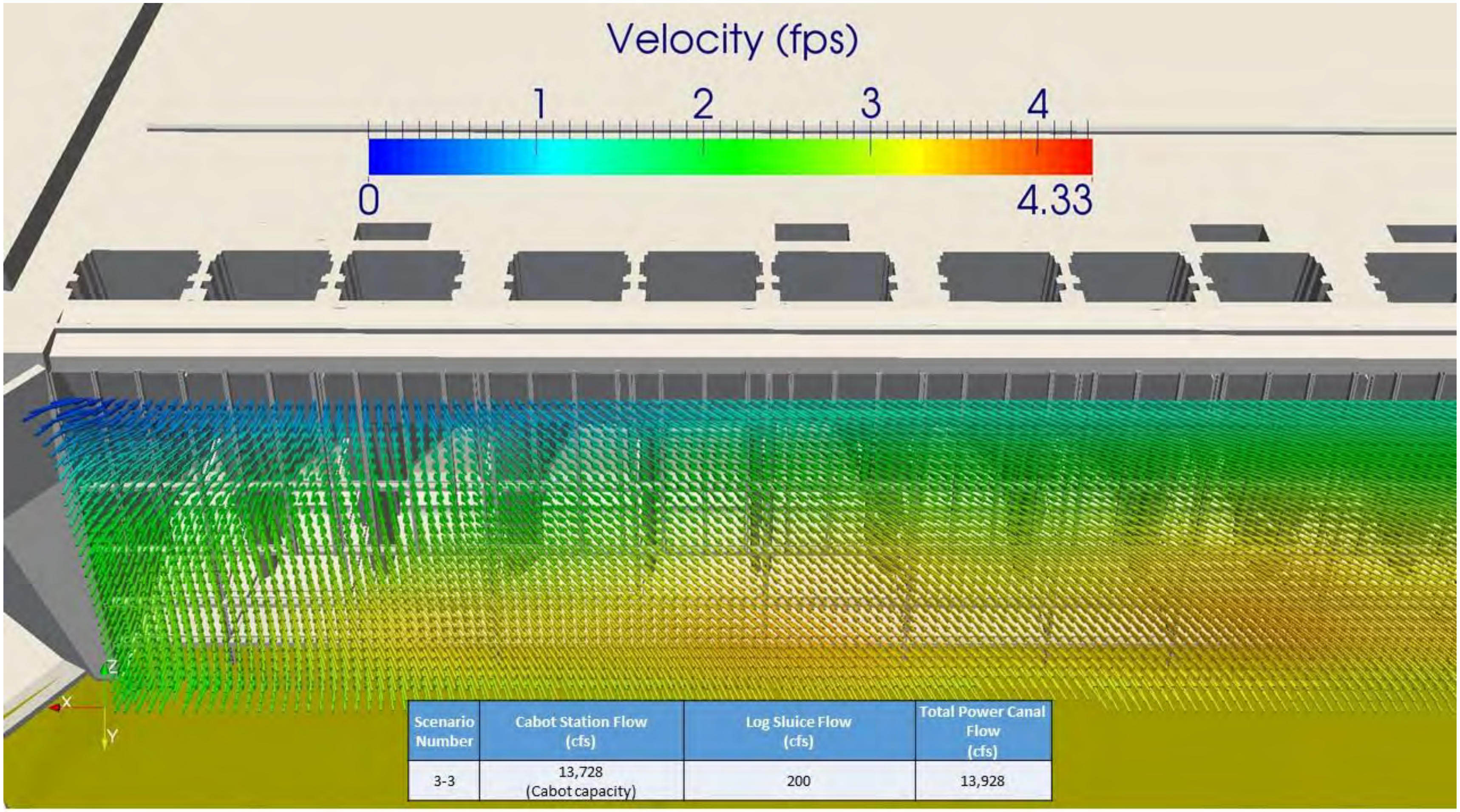
Scenario Number	Cabot Station Flow (cfs)	Log Sluice Flow (cfs)	Total Power Canal Flow (cfs)
3-3	13,728 (Cabot capacity)	200	13,928

Figure 8.3.3-2: Cabot Station Scenario 3-3 Forebay



Scenario Number	Cabot Station Flow (cfs)	Log Sluice Flow (cfs)	Total Power Canal Flow (cfs)
3-3	13,728 (Cabot capacity)	200	13,928

Figure 8.3.3-3: Cabot Station Scenario 3-3 Intake Rack Overview



Scenario Number	Cabot Station Flow (cfs)	Log Sluice Flow (cfs)	Total Power Canal Flow (cfs)
3-3	13,728 (Cabot capacity)	200	13,928

Figure 8.3.3-4: Cabot Station Scenario 3-3 Intake Rack at Penstocks 1, 2, and 3

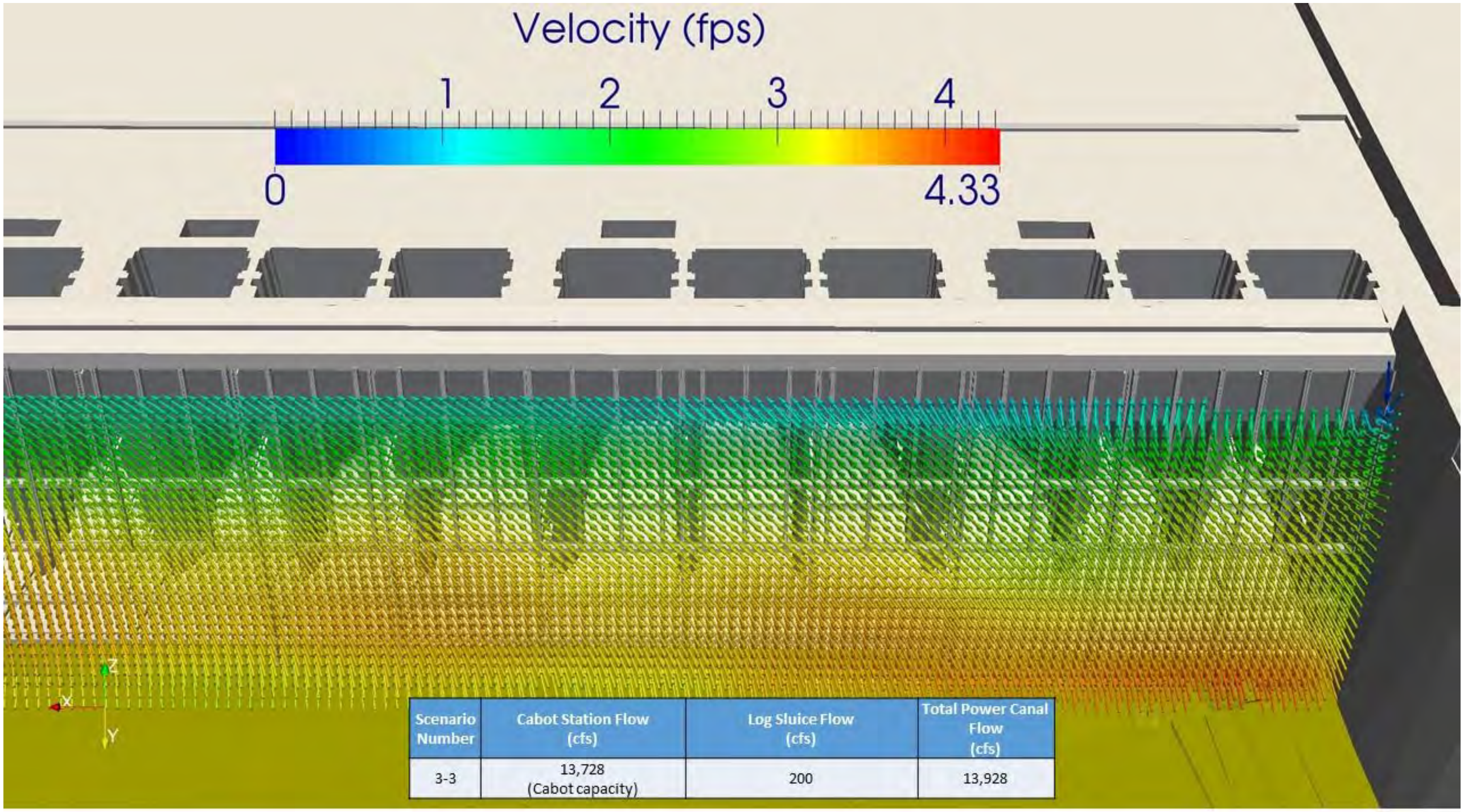
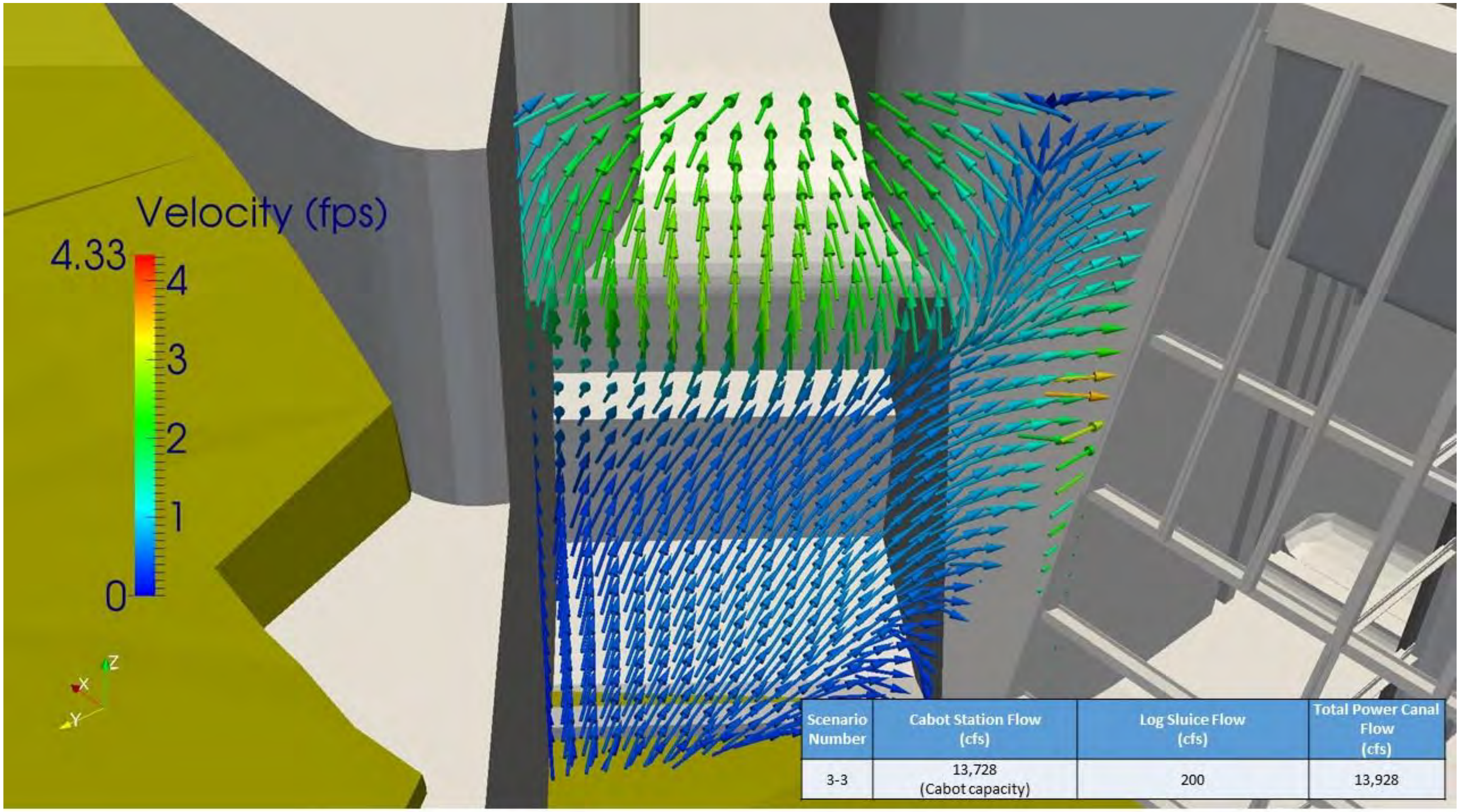


Figure 8.3.3-5: Cabot Station Scenario 3-3 Intake Rack at Penstocks 4, 5, and 6



Scenario Number	Cabot Station Flow (cfs)	Log Sluice Flow (cfs)	Total Power Canal Flow (cfs)
3-3	13,728 (Cabot capacity)	200	13,928

Figure 8.3.3-6: Cabot Station Scenario 3-3 Log Sluice

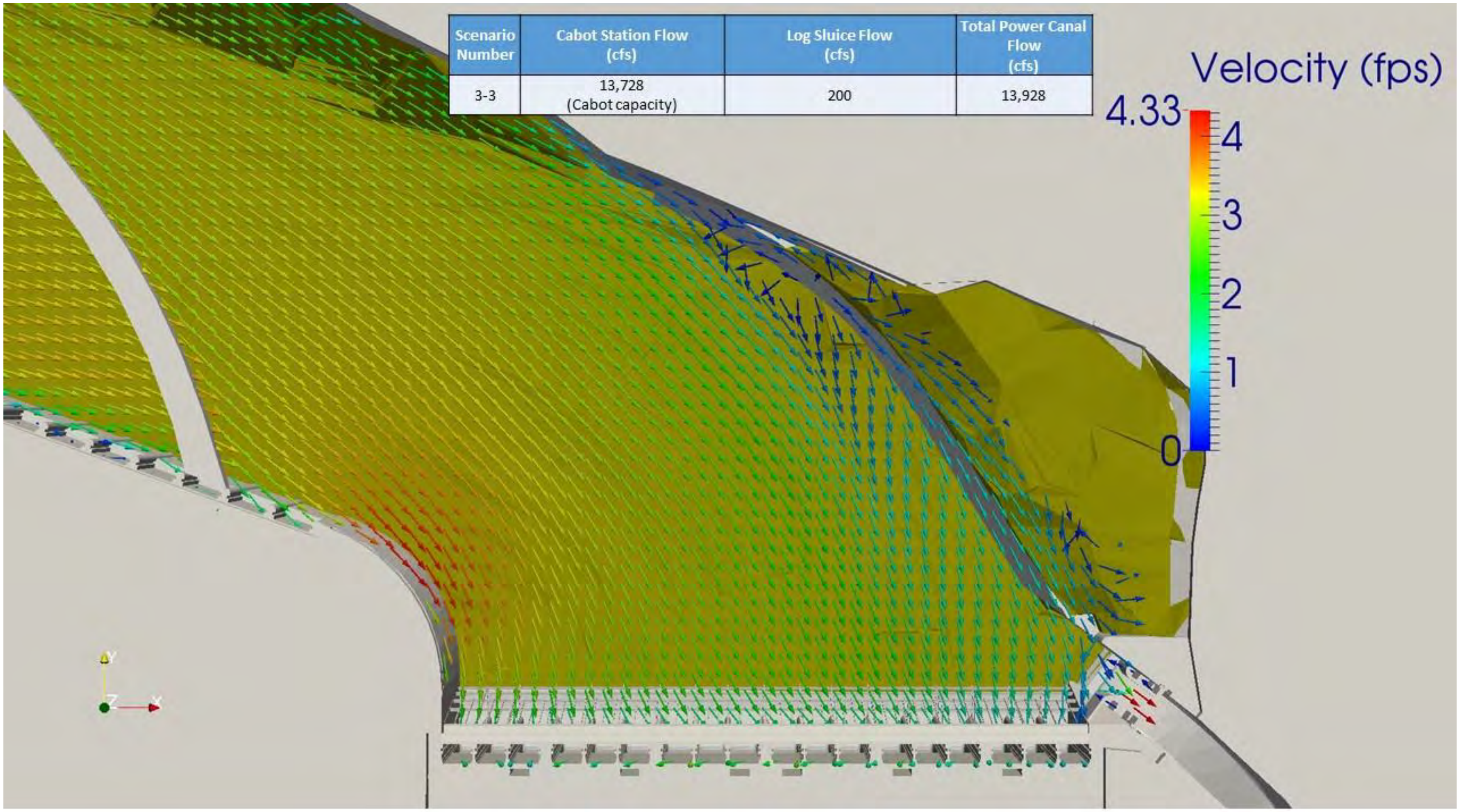


Figure 8.3.3-7: Cabot Station Scenario 3-3 Velocity Vectors in Forebay at Elevation 171.6

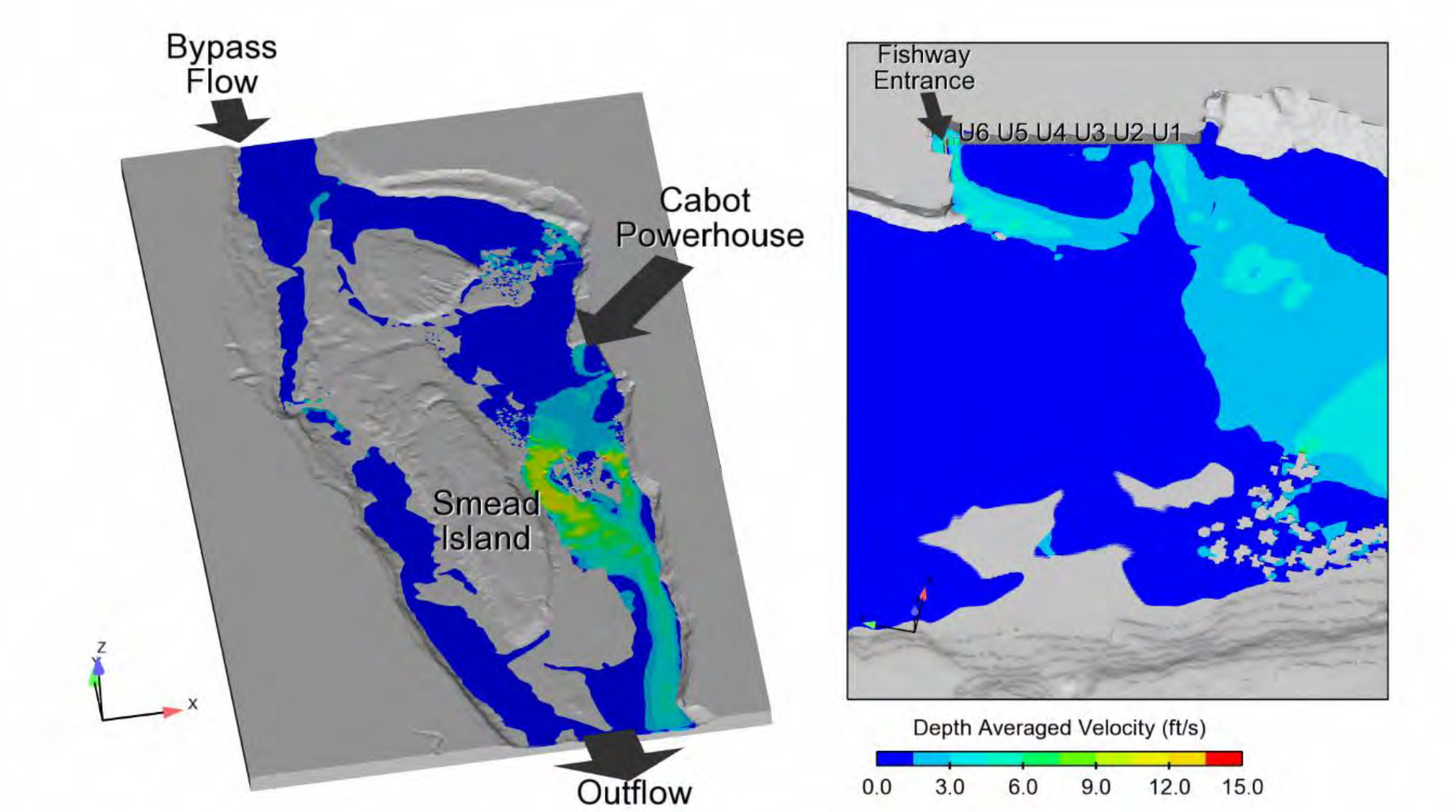


Figure 8.4.1-1: Depth-averaged water velocities for the full study area (left) and near Cabot Station (right) for PR 5-1
Total model flow is 2,468 cfs. Scaled from 0-15 fps.

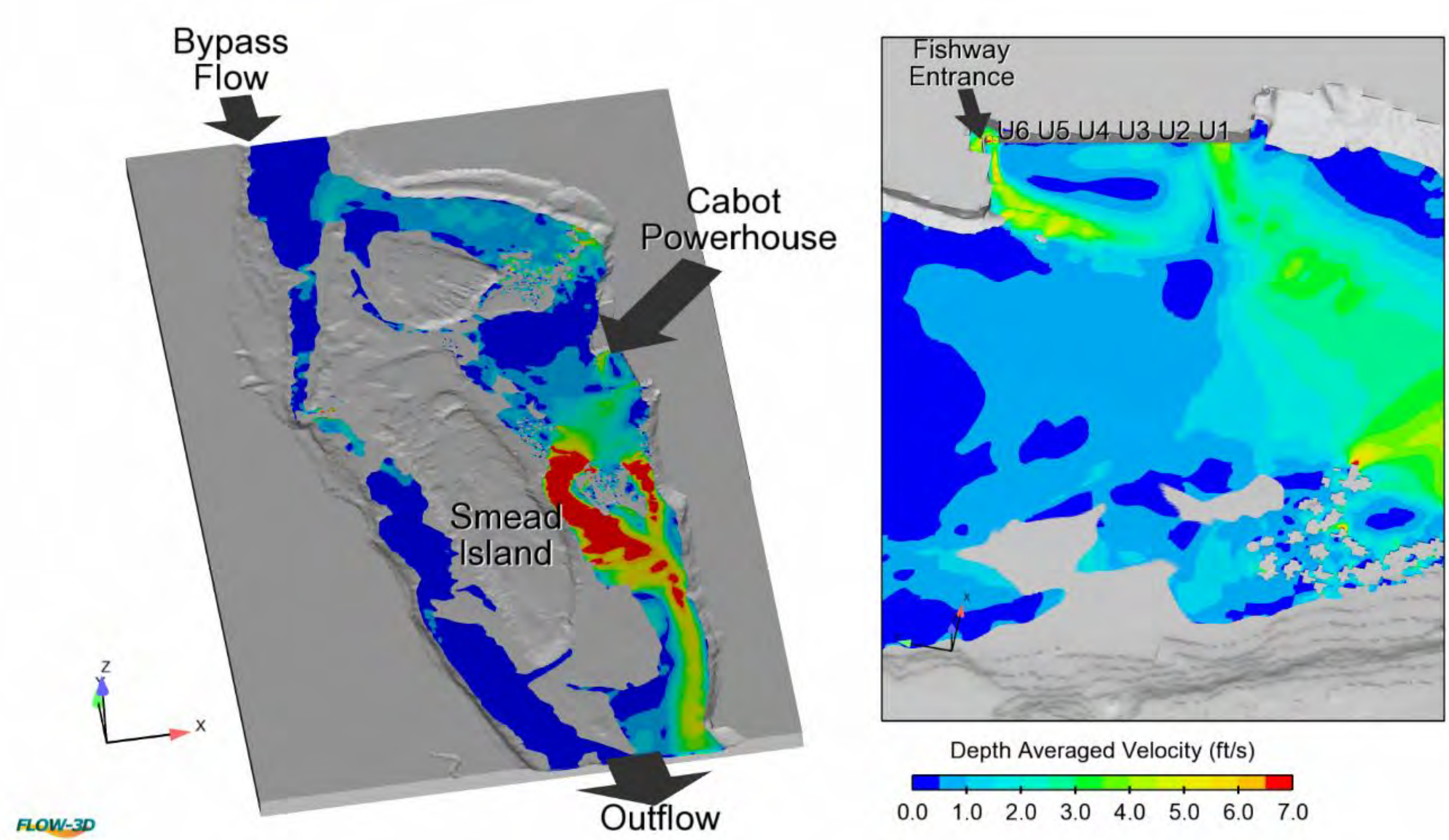


Figure 8.4.1-2: Depth-Averaged Water Velocities for the Full Study Area (Left) and Near Cabot Station (Right) for PR 5-1
Total model flow is 2,468 cfs. Scaled from 0-7 fps.

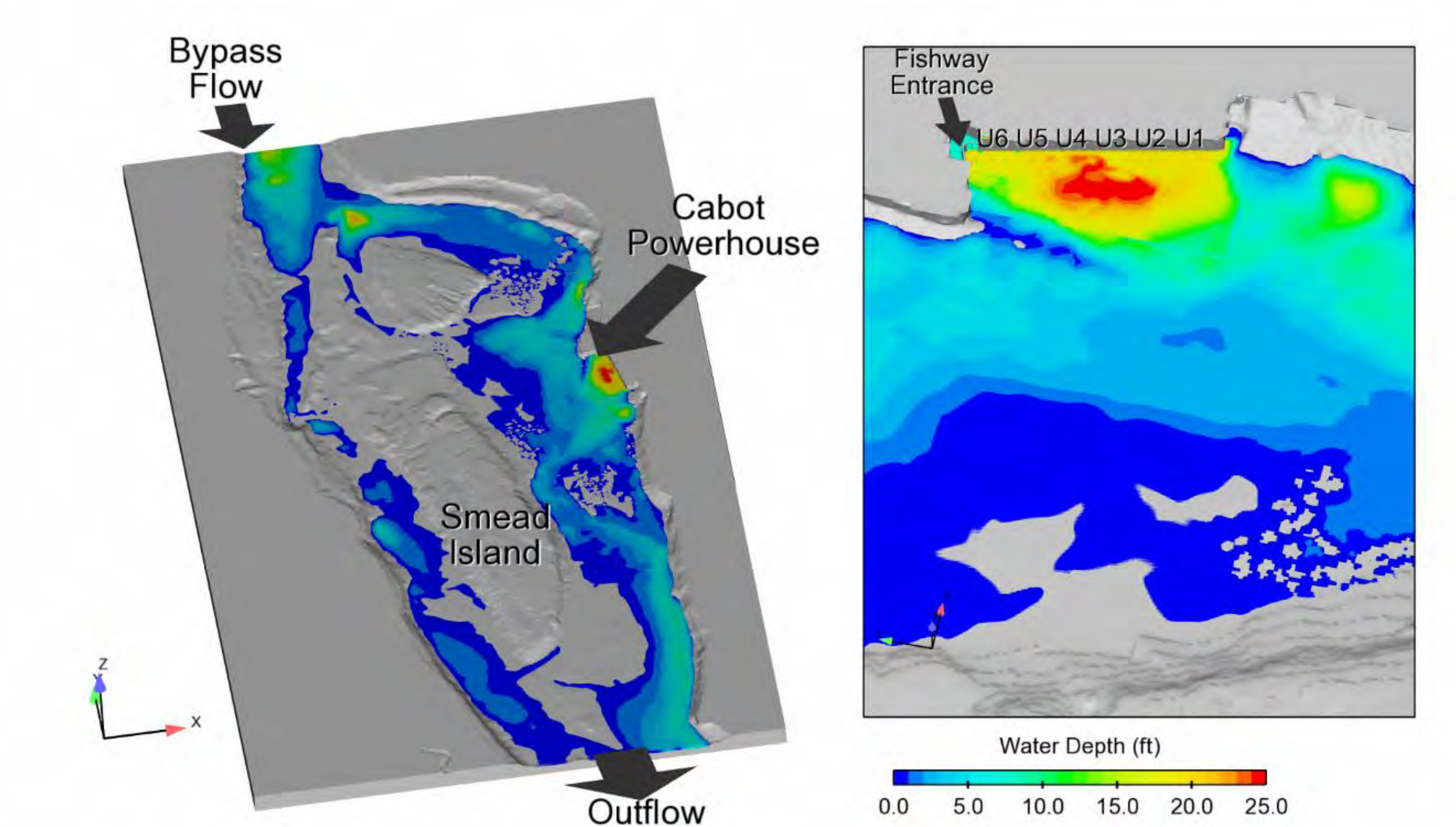


Figure 8.4.1-3: PR 5-1 modeled water depths. Total model flow is 2,468 cfs.

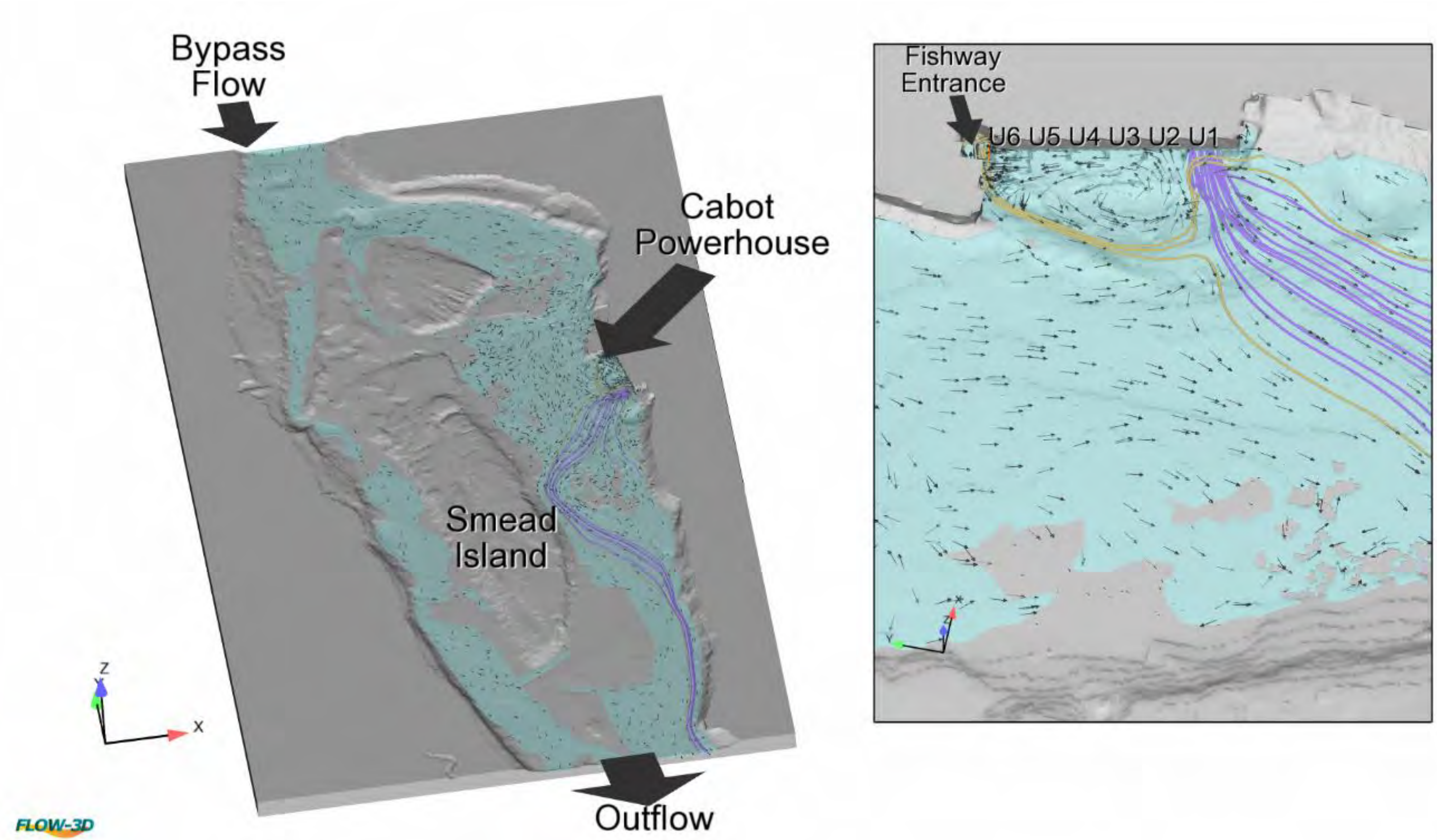
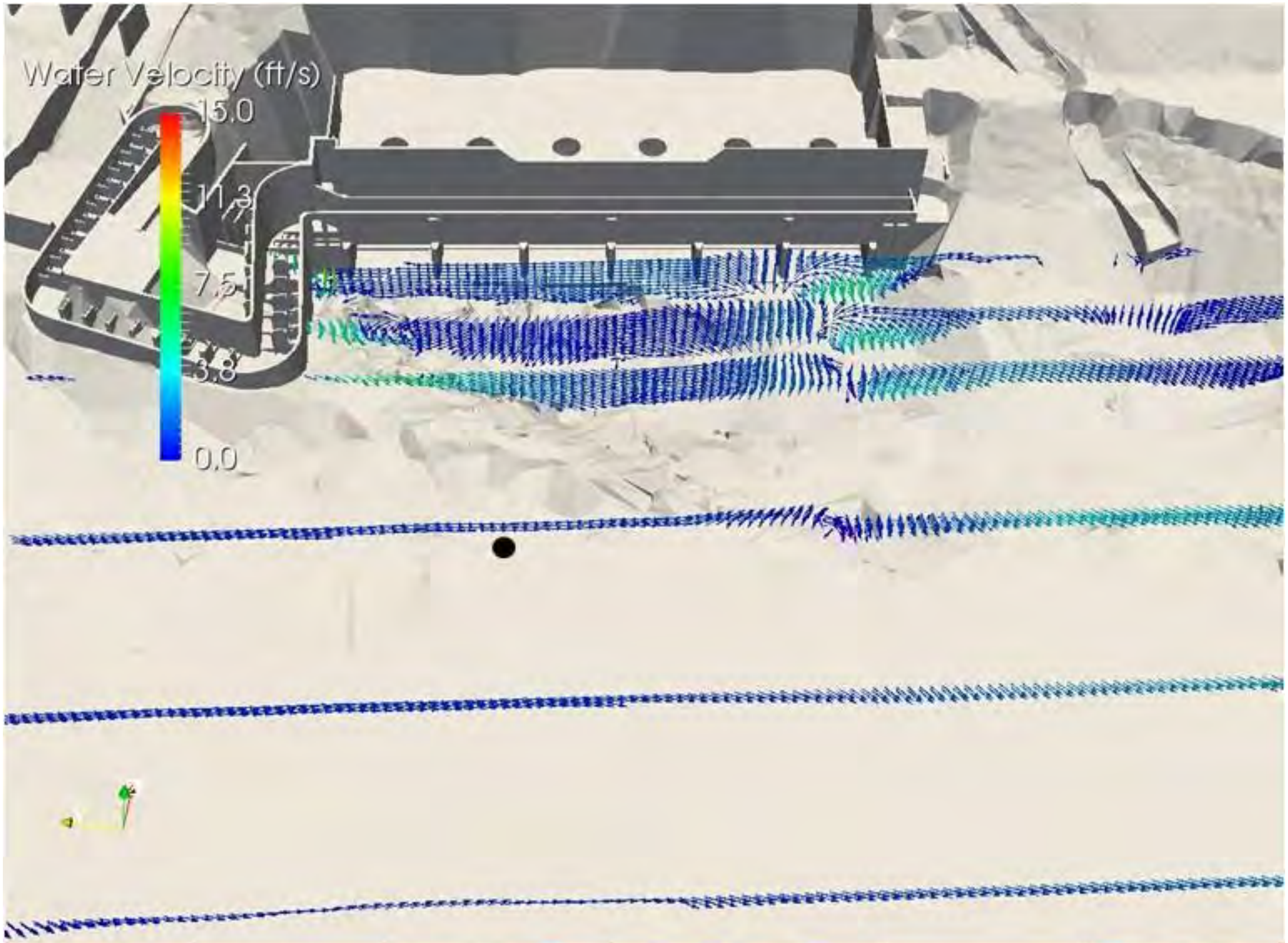
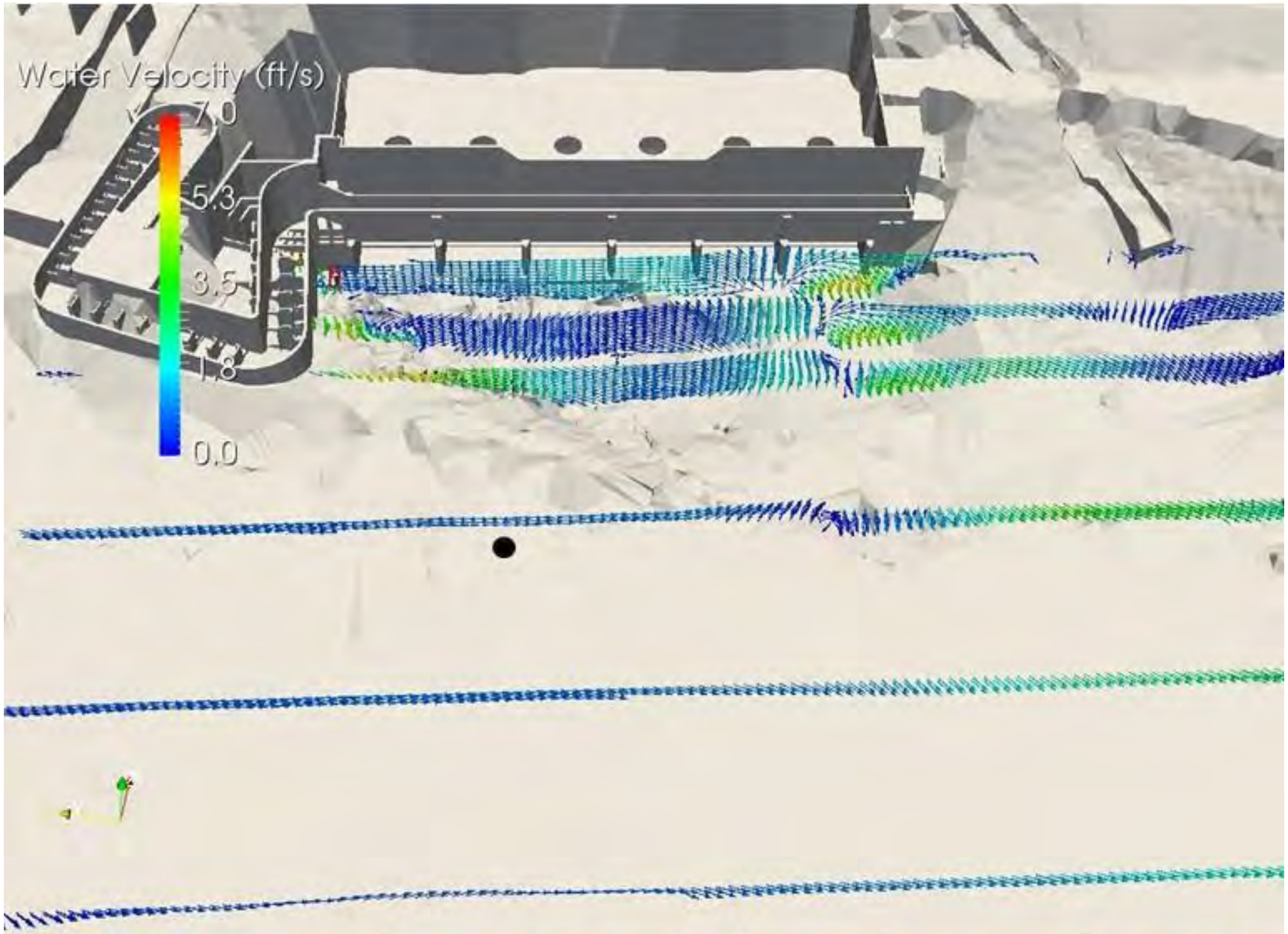


Figure 8.4.1-4: PR 5-1 Modeled Streamlines and Velocity Vectors
The black arrows indicate flow direction. The streamlines represent the path of water released from the Spillway fishway (orange) or Cabot Station (purple). Total model flow is 2,468 cfs.



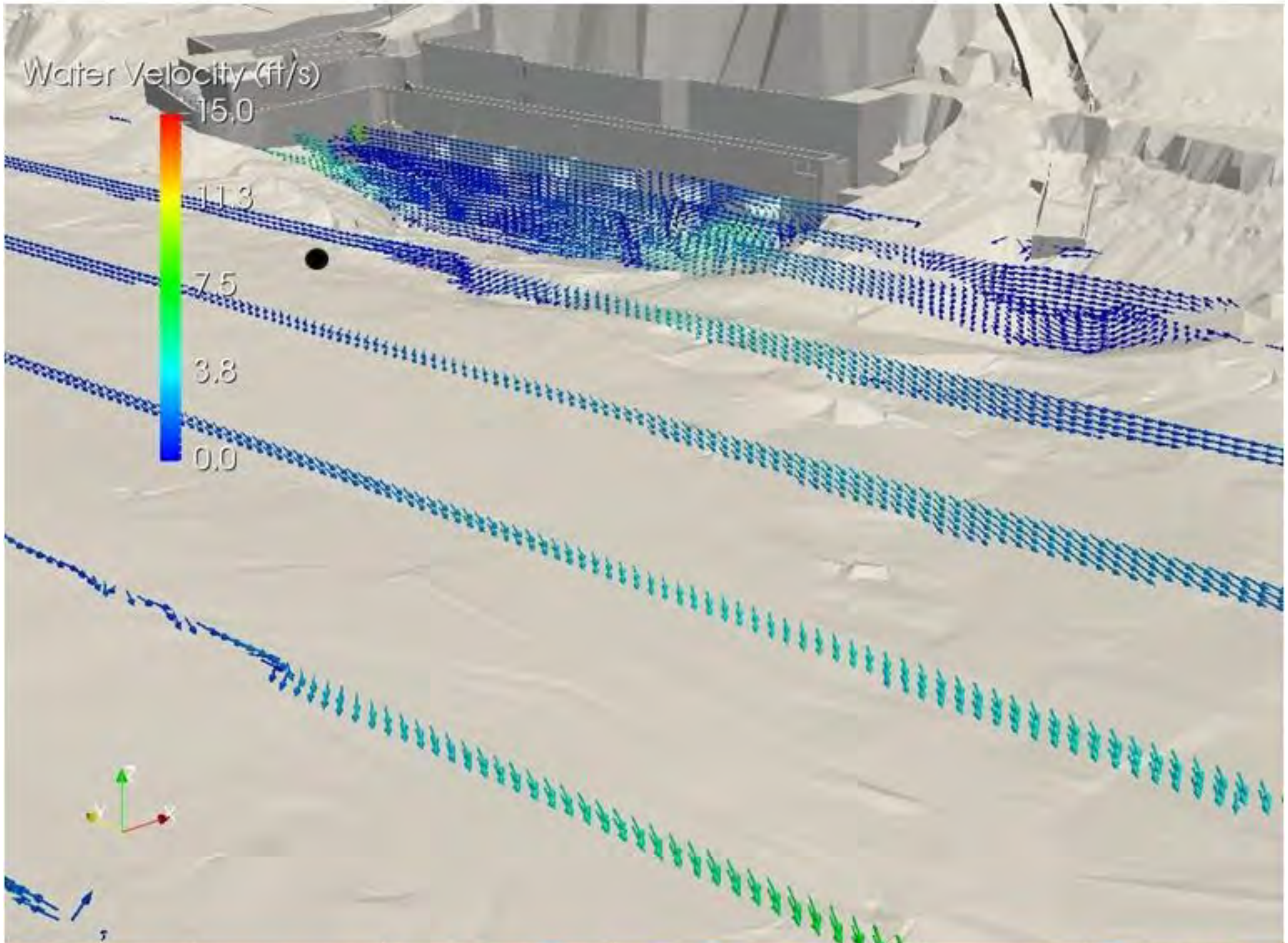
Scenario Number	Cabot Flow (cfs)	Bypass Reach Flow (cfs)	Cabot Fishway Flow (cfs)	Total Flow (cfs)	Water Surface Elevation (ft)
5-1	1,700	400	368	2,468	109.0 ●

Figure 8.4.1-5: PR 5-1 Water Velocity Vector Plots for Cross-Sections Parallel to Cabot Station, Looking from the Center of the River
Total model flow is 2,468 cfs. Scaled from 0-15 fps.



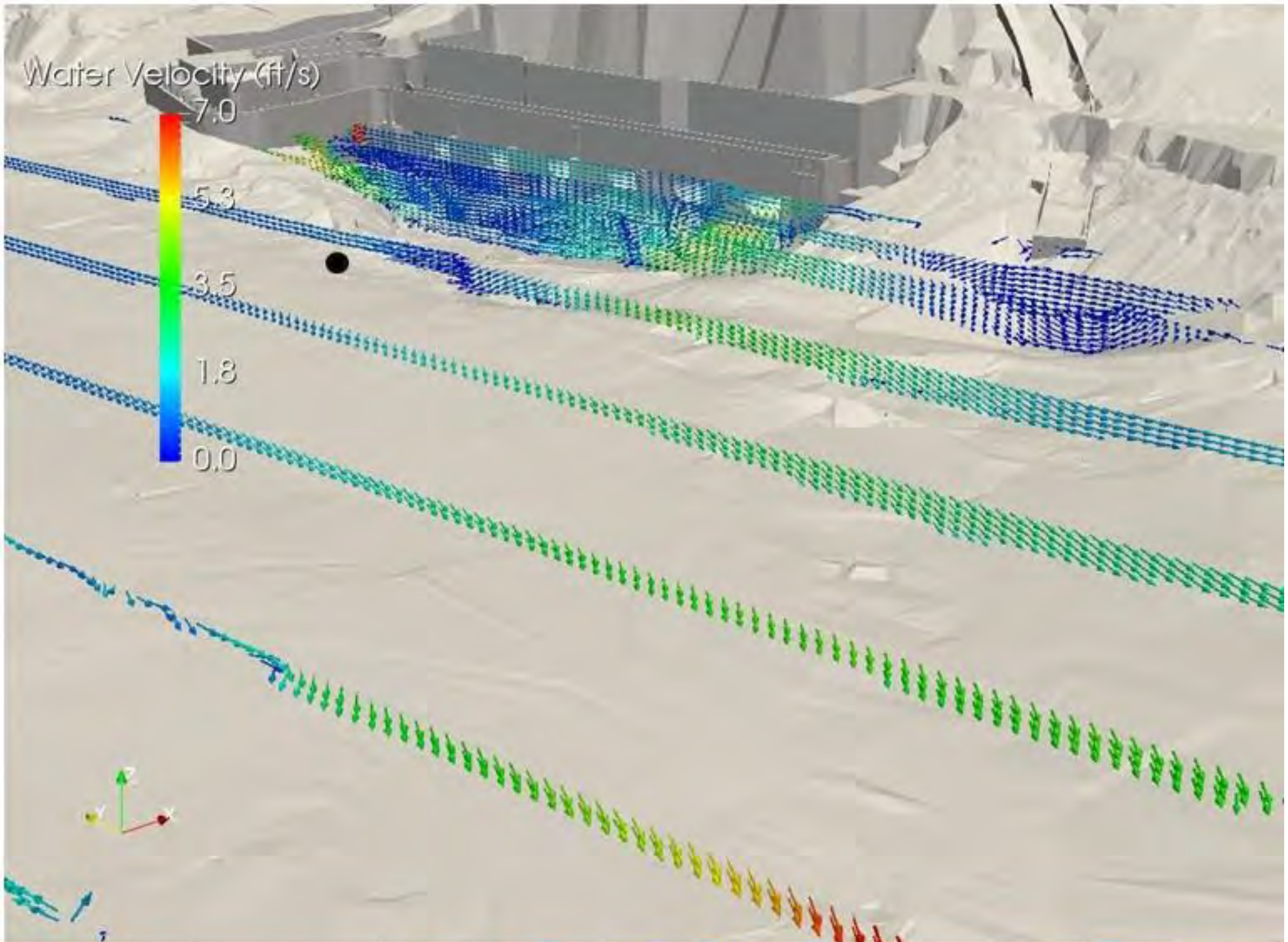
Scenario Number	Cabot Flow (cfs)	Bypass Reach Flow (cfs)	Cabot Fishway Flow (cfs)	Total Flow (cfs)	Water Surface Elevation (ft)
5-1	1,700	400	368	2,468	109.0 ●

Figure 8.4.1-6: PR 5-1 Water Velocity Vector Plots for Cross-Sections Parallel to Cabot Station, Looking From the Center of the River
Total model flow is 2,468 cfs. Scaled from 0-7 fps.



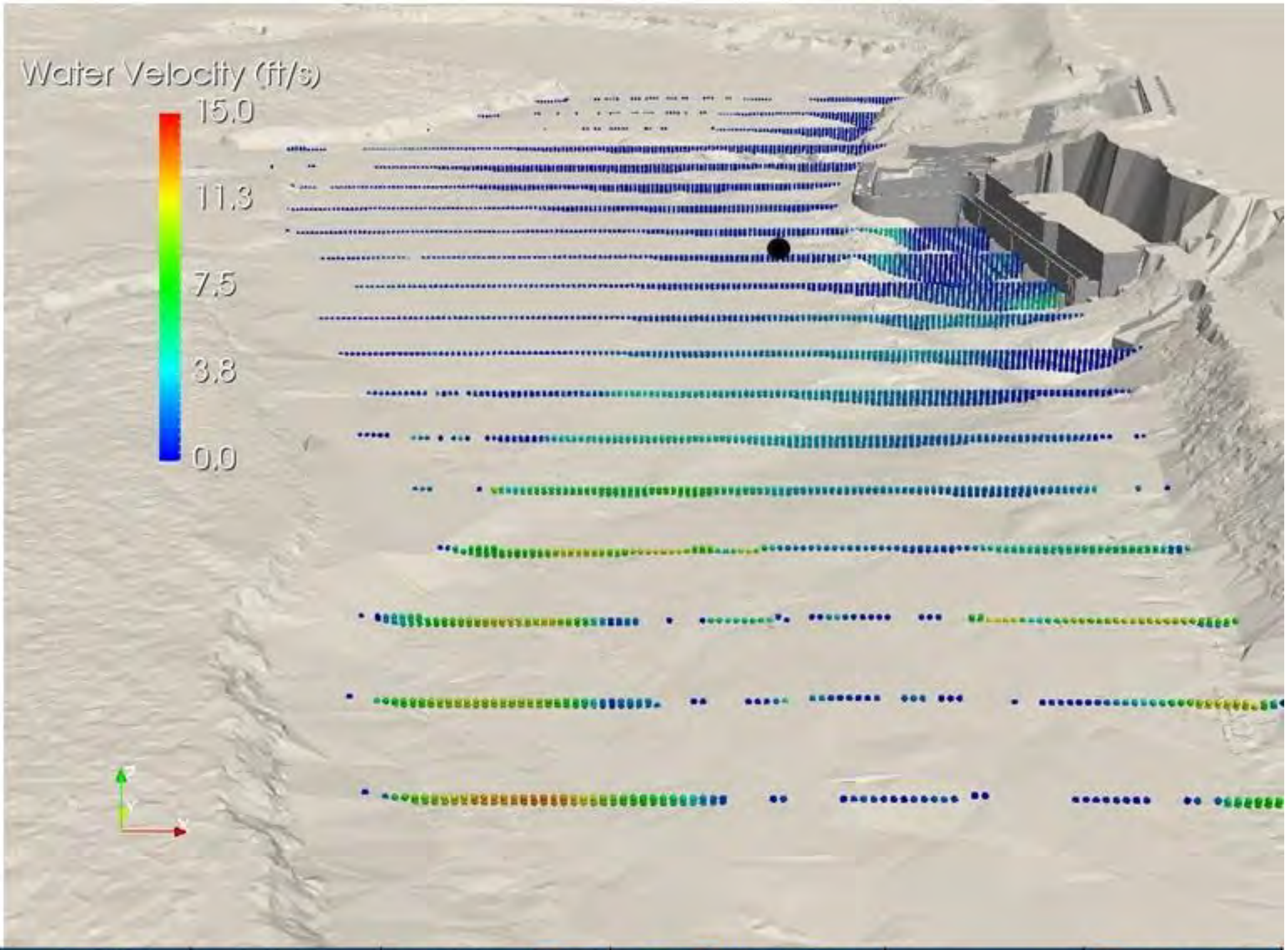
Scenario Number	Cabot Flow (cfs)	Bypass Reach Flow (cfs)	Cabot Fishway Flow (cfs)	Total Flow (cfs)	Water Surface Elevation (ft)
5-1	1,700	400	368	2,468	109.0 ●

Figure 8.4.1-7: PR 5-1 Water Velocity Vector Plots for Cross-Sections Parallel to Cabot Station, Looking Upstream toward the Cabot Powerhouse
Total model flow is 2,468 cfs. Scaled from 0-15 fps.



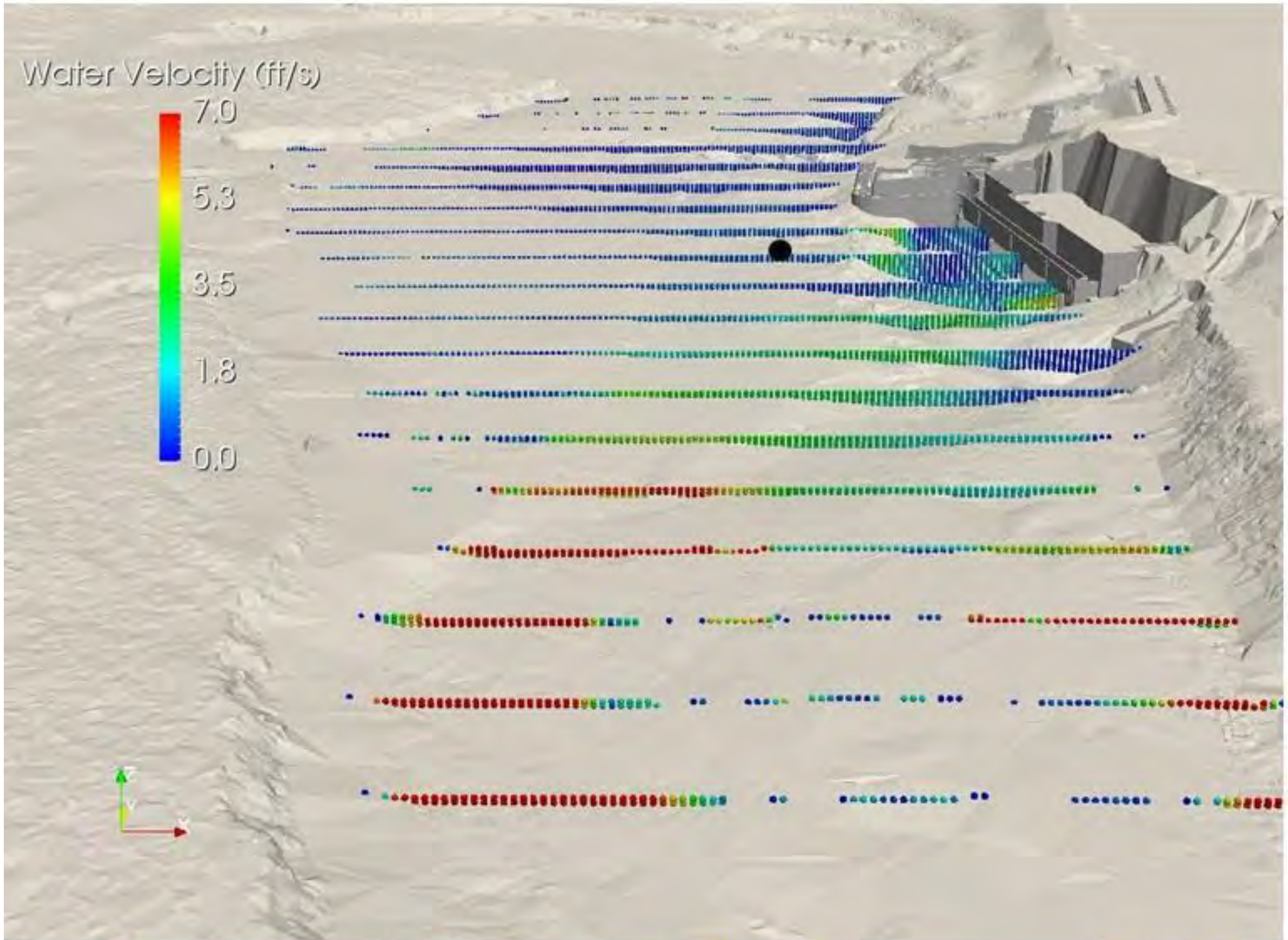
Scenario Number	Cabot Flow (cfs)	Bypass Reach Flow (cfs)	Cabot Fishway Flow (cfs)	Total Flow (cfs)	Water Surface Elevation (ft)
5-1	1,700	400	368	2,468	109.0 ●

Figure 8.4.1-8: PR 5-1 Water Velocity Vector Plots for Cross-Sections Parallel to Cabot Station, Looking Upstream toward the Cabot Powerhouse
Total model flow is 2,468 cfs. Scaled from 0-7 fps.



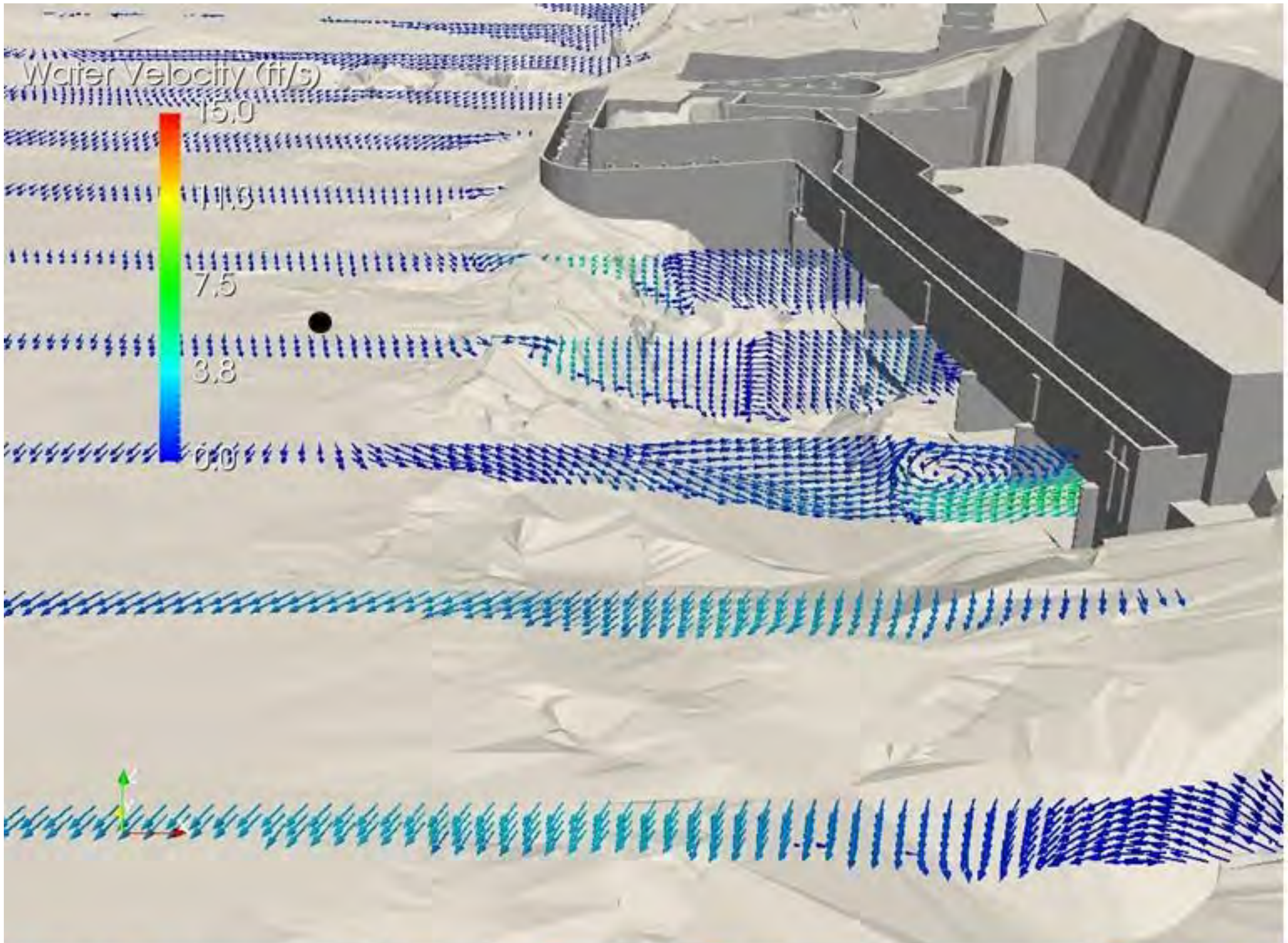
Scenario Number	Cabot Flow (cfs)	Bypass Reach Flow (cfs)	Cabot Fishway Flow (cfs)	Total Flow (cfs)	Water Surface Elevation (ft)
5-1	1,700	400	368	2,468	109.0 ●

Figure 8.4.1-9: PR 5-1 Cross-Sections Showing Water Velocity Across the River's Left Channel
Total model flow is 2,468 cfs. Scaled from 0-15 fps.



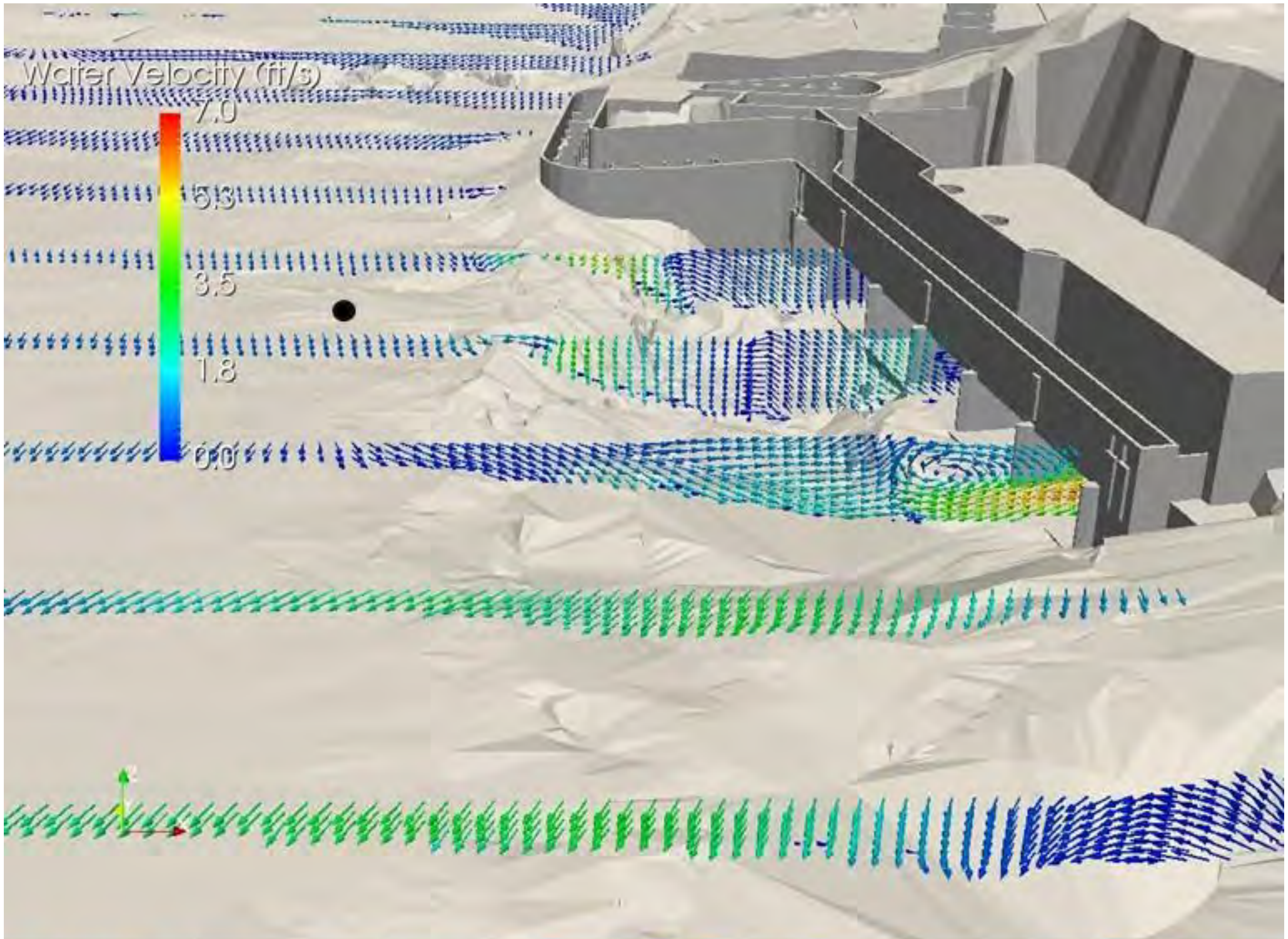
Scenario Number	Cabot Flow (cfs)	Bypass Reach Flow (cfs)	Cabot Fishway Flow (cfs)	Total Flow (cfs)	Water Surface Elevation (ft)
5-1	1,700	400	368	2,468	109.0 ●

Figure 8.4.1-10: PR 5-1 Cross-Sections Showing Water Velocity Across the River's Left Channel
Total model flow is 2,468 cfs. Scaled from 0-7 fps.



Scenario Number	Cabot Flow (cfs)	Bypass Reach Flow (cfs)	Cabot Fishway Flow (cfs)	Total Flow (cfs)	Water Surface Elevation (ft)
5-1	1,700	400	368	2,468	109.0 ●

Figure 8.4.1-11: PR 5-1 Cross-Sections Showing Water Velocity Near the Cabot Station Draft Tubes
Total model flow is 2,468 cfs. Scaled from 0-15 fps.



Scenario Number	Cabot Flow (cfs)	Bypass Reach Flow (cfs)	Cabot Fishway Flow (cfs)	Total Flow (cfs)	Water Surface Elevation (ft)
5-1	1,700	400	368	2,468	109.0 ●

Figure 8.4.1-12: PR 5-1 Cross-Sections Showing Water Velocity Near the Cabot Station Draft Tubes
Total model flow is 2,468 cfs. Scaled from 0-7 fps

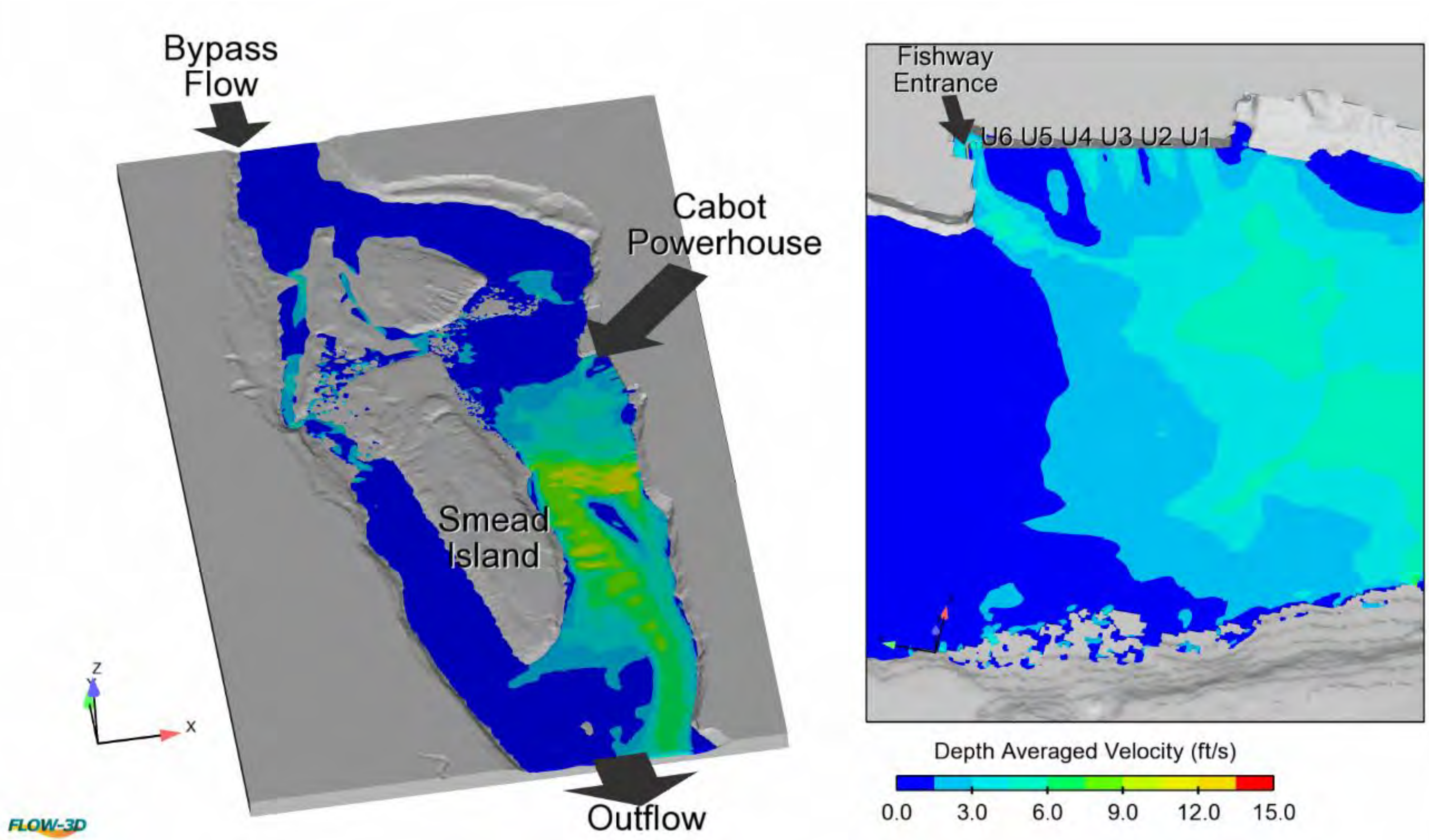


Figure 8.4.2-1: Depth-Averaged Water Velocities for the Full Study Area (left) and Near Cabot Station (Right) for PR 5-2
Total model flow is 8,268 cfs. Scaled from 0-15 fps.

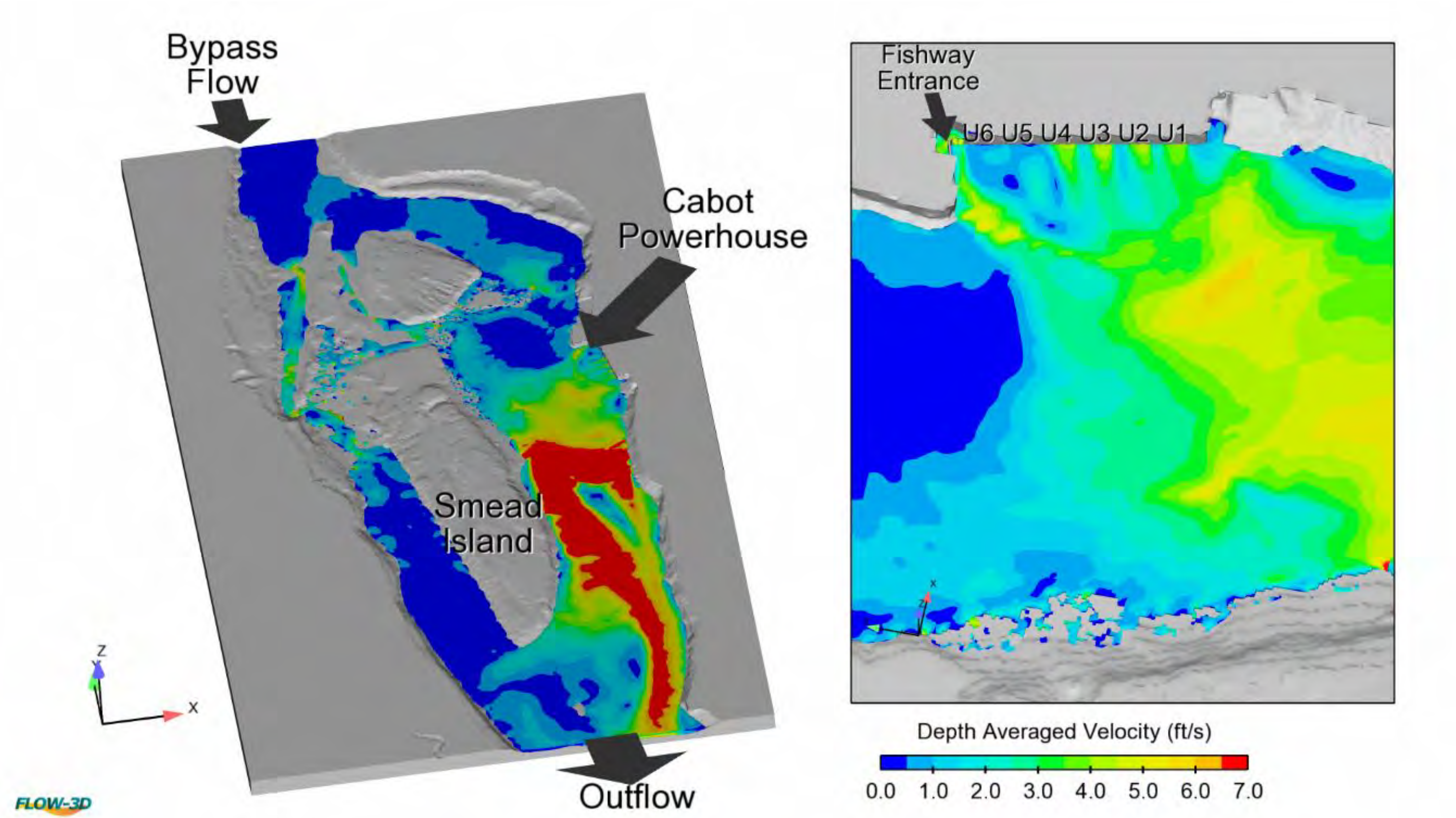


Figure 8.4.2-2: Depth-Averaged Water Velocities for the Full Study Area (Left) and Near Cabot Station (Right) for PR 5-2
Total model flow is 8,268 cfs. Scaled from 0-7 fps.

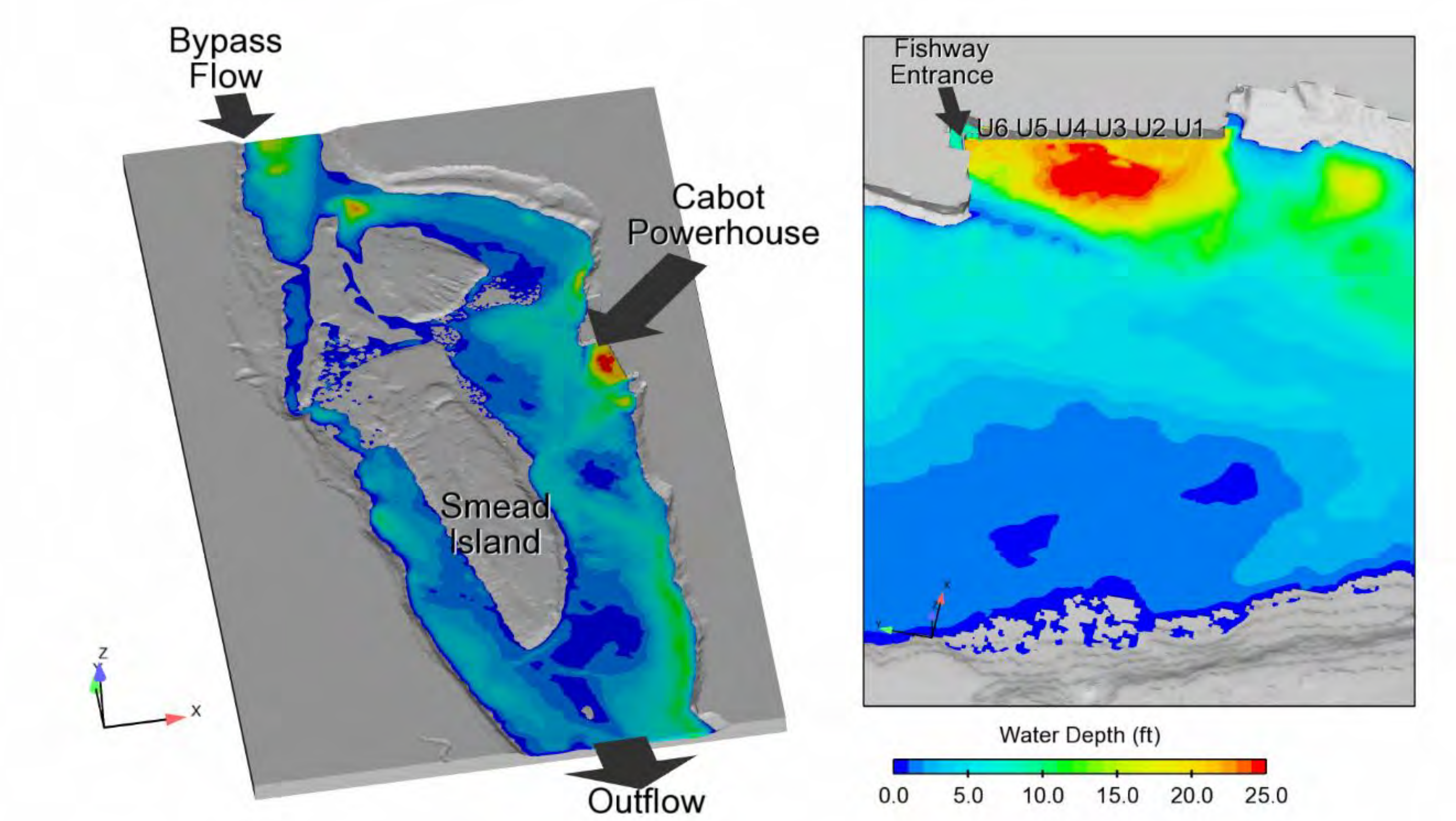


Figure 8.4.2-3: PR 5-2 Modeled Water Depths
Total model flow is 8,268 cfs.

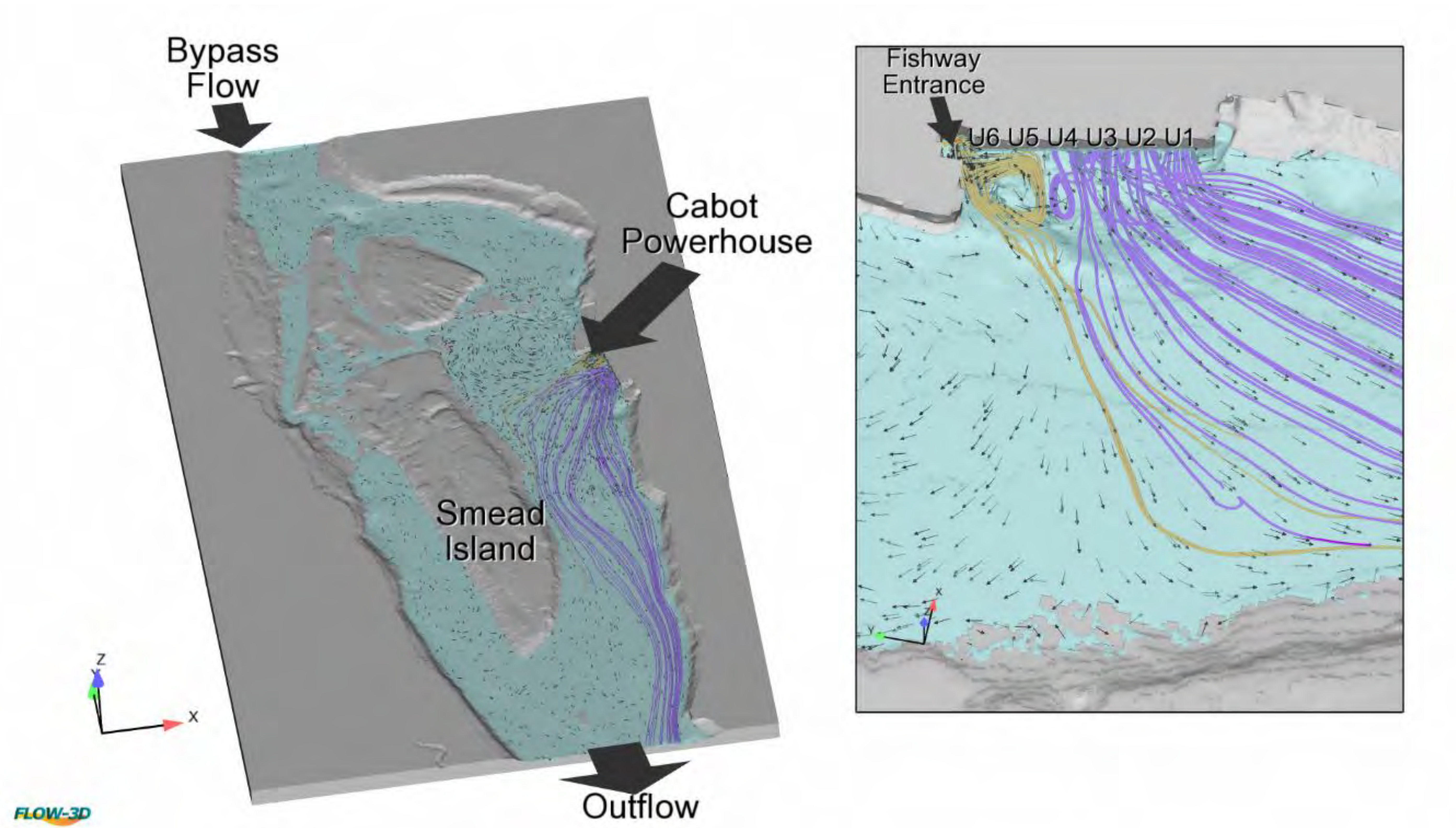
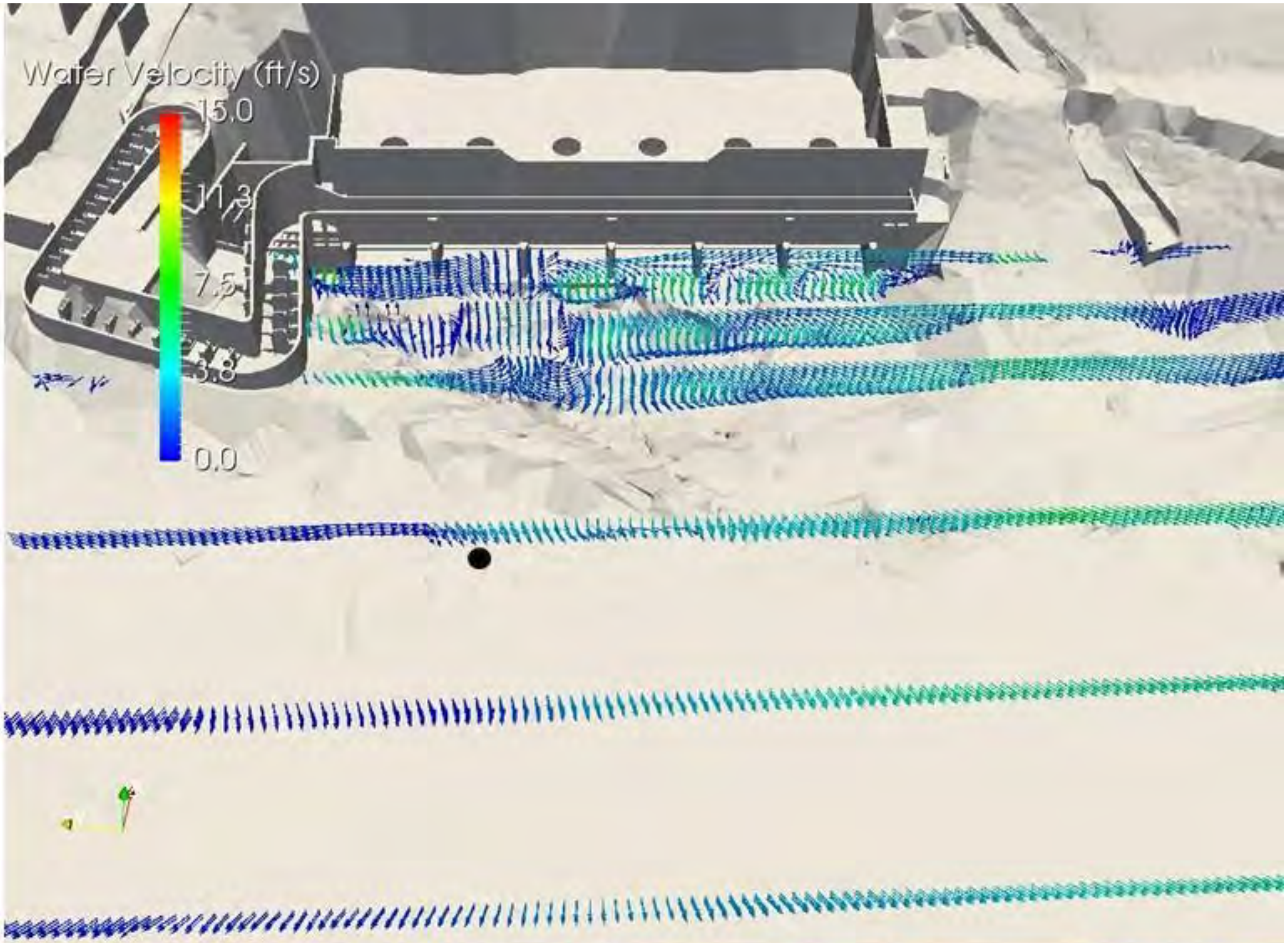


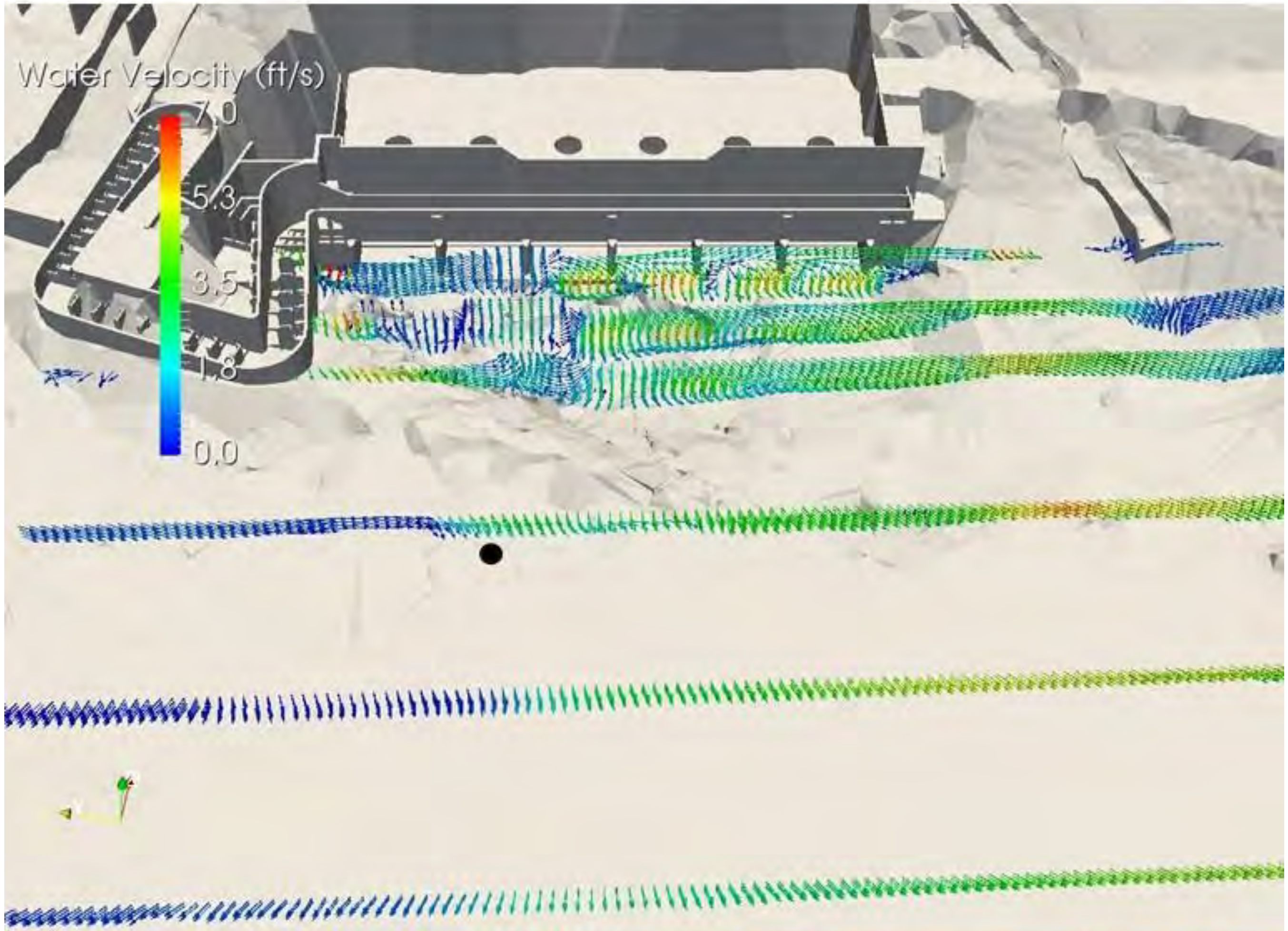
Figure 8.4.2-4: PR 5-2 Modeled Streamlines and Velocity Vectors

The black arrows indicate flow direction. The streamlines represent the path of water released from the Spillway fishway (orange) or Cabot Station (purple). Total model flow is 8,268 cfs



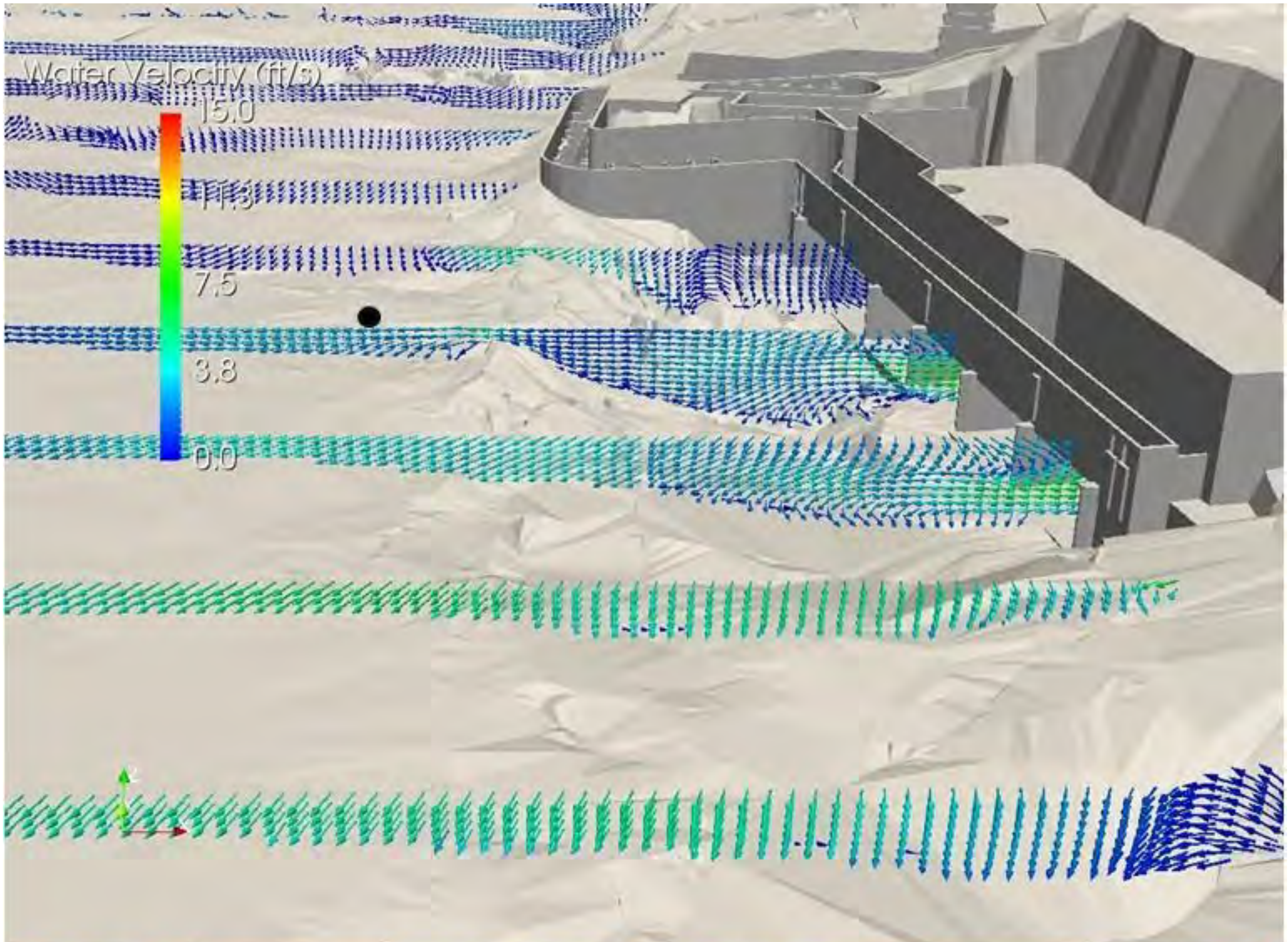
Scenario Number	Cabot Flow (cfs)	Bypass Reach Flow (cfs)	Cabot Fishway Flow (cfs)	Total Flow (cfs)	Water Surface Elevation (ft)
5-2	7,500	400	368	8,268	111.0 ●

Figure 8.4.2-5: PR 5-2 Water Velocity Vector Plots for Cross-Sections Parallel to Cabot Station, Looking from the Center of the River
Total model flow is 8,268 cfs. Scaled from 0-15 fps.



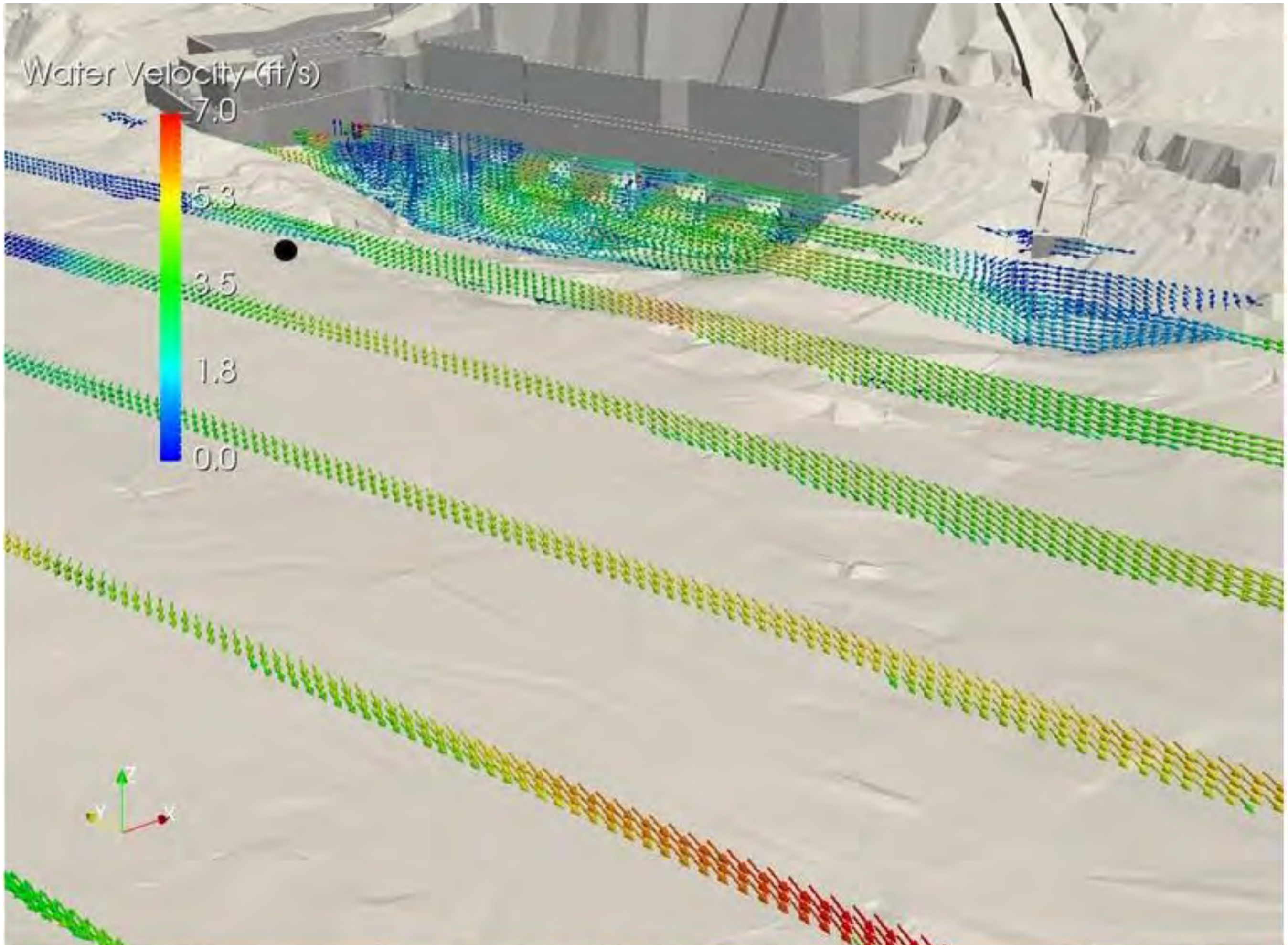
Scenario Number	Cabot Flow (cfs)	Bypass Reach Flow (cfs)	Cabot Fishway Flow (cfs)	Total Flow (cfs)	Water Surface Elevation (ft)
5-2	7,500	400	368	8,268	111.0 ●

Figure 8.4.2-6: PR 5-2 Water Velocity Vector Plots for Cross-Sections Parallel to Cabot Station, Looking from the Center of the River
Total model flow is 8,268 cfs. Scaled from 0-7 fps.



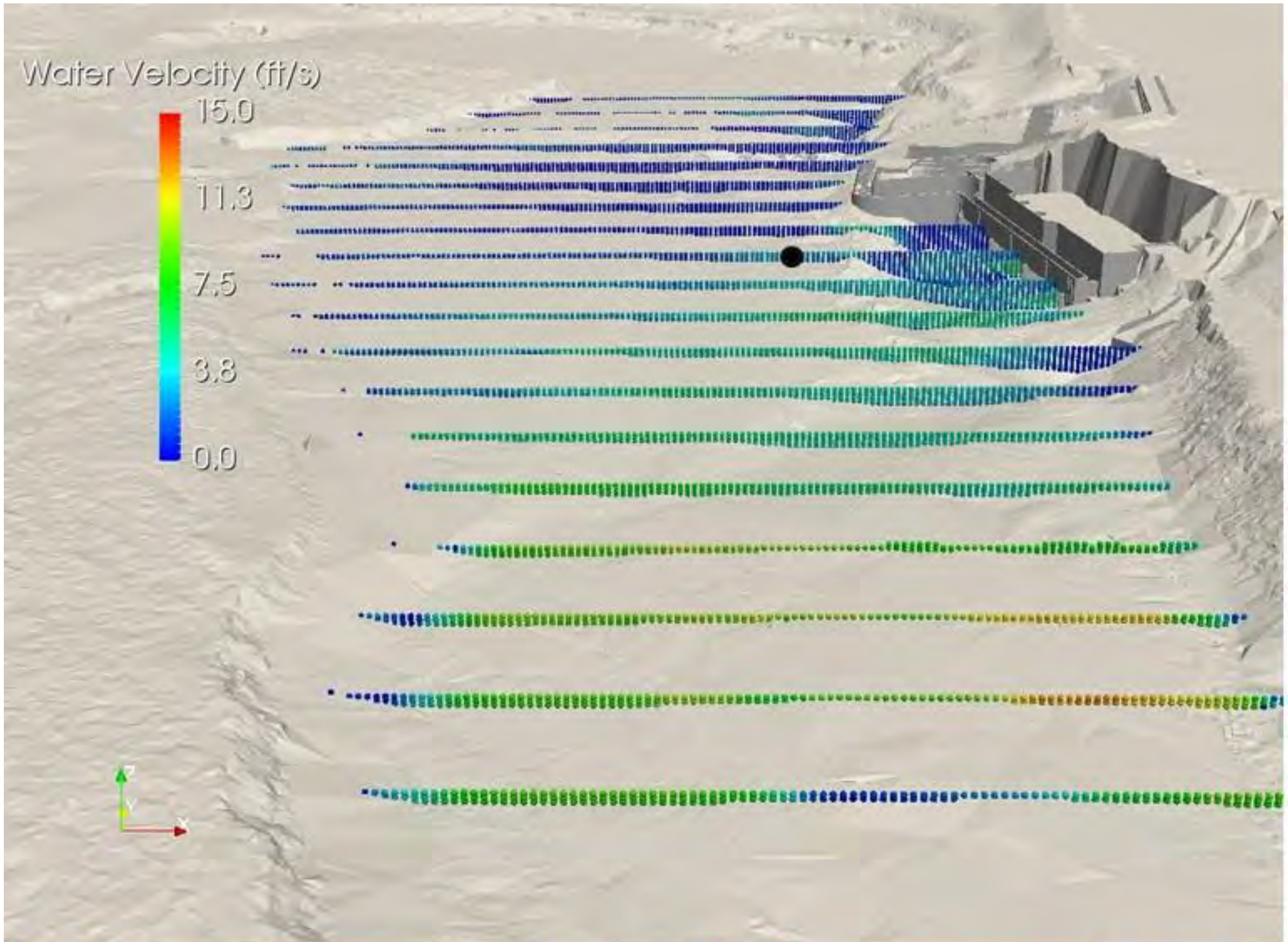
Scenario Number	Cabot Flow (cfs)	Bypass Reach Flow (cfs)	Cabot Fishway Flow (cfs)	Total Flow (cfs)	Water Surface Elevation (ft)
5-2	7,500	400	368	8,268	111.0 ●

Figure 8.4.2-7: PR 5-2 Water Velocity Vector Plots for Cross-Sections Parallel to Cabot Station, Looking Upstream Toward the Cabot Powerhouse
Total model flow is 8,268 cfs. Scaled from 0-15 fps.



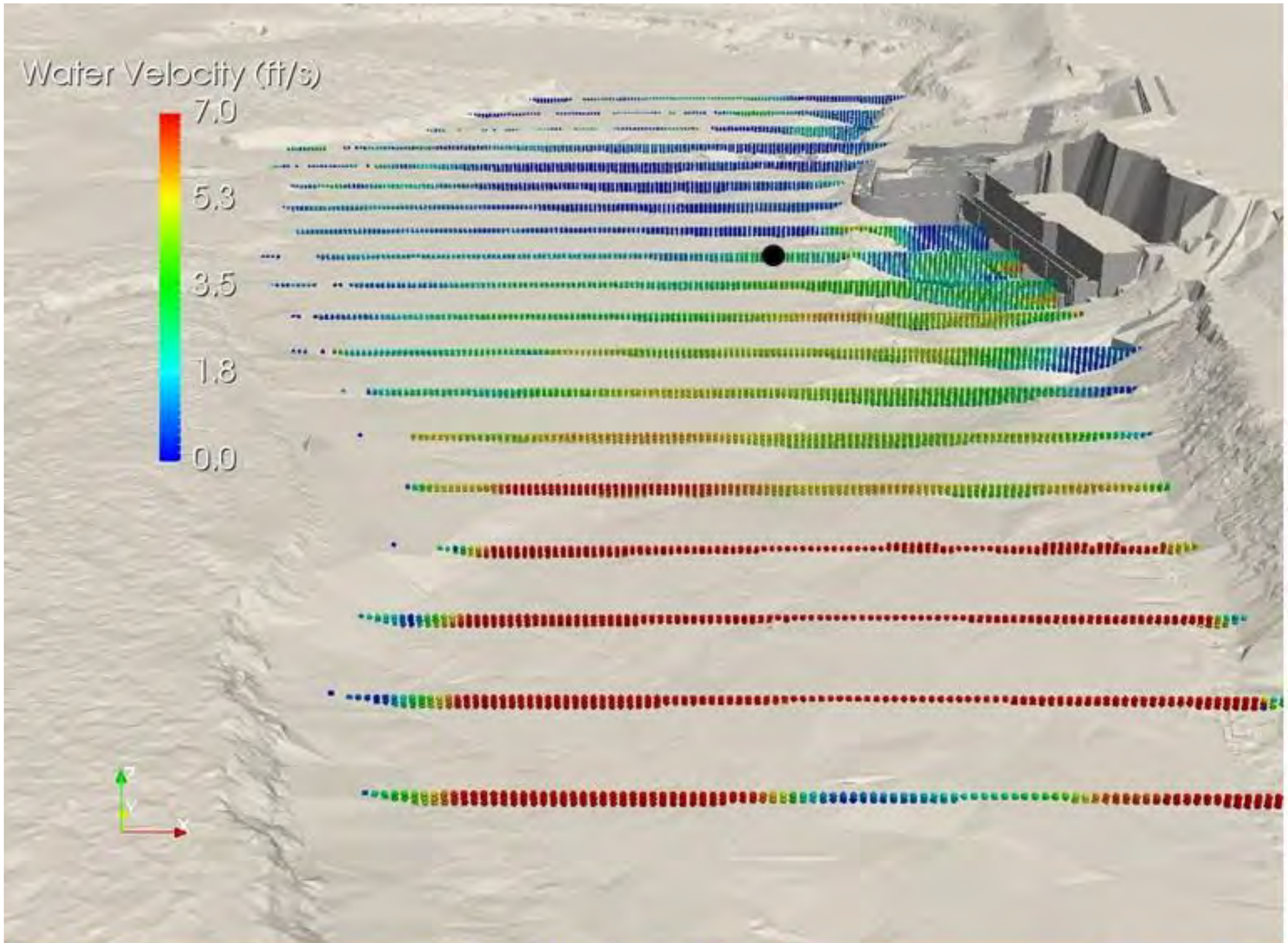
Scenario Number	Cabot Flow (cfs)	Bypass Reach Flow (cfs)	Cabot Fishway Flow (cfs)	Total Flow (cfs)	Water Surface Elevation (ft)
5-2	7,500	400	368	8,268	111.0 ●

Figure 8.4.2-8: PR 5-2 Water Velocity Vector Plots for Cross-Sections Parallel to Cabot Station, Looking Upstream Toward the Cabot Powerhouse
Total model flow is 8,268 cfs. Scaled from 0-7 fps.



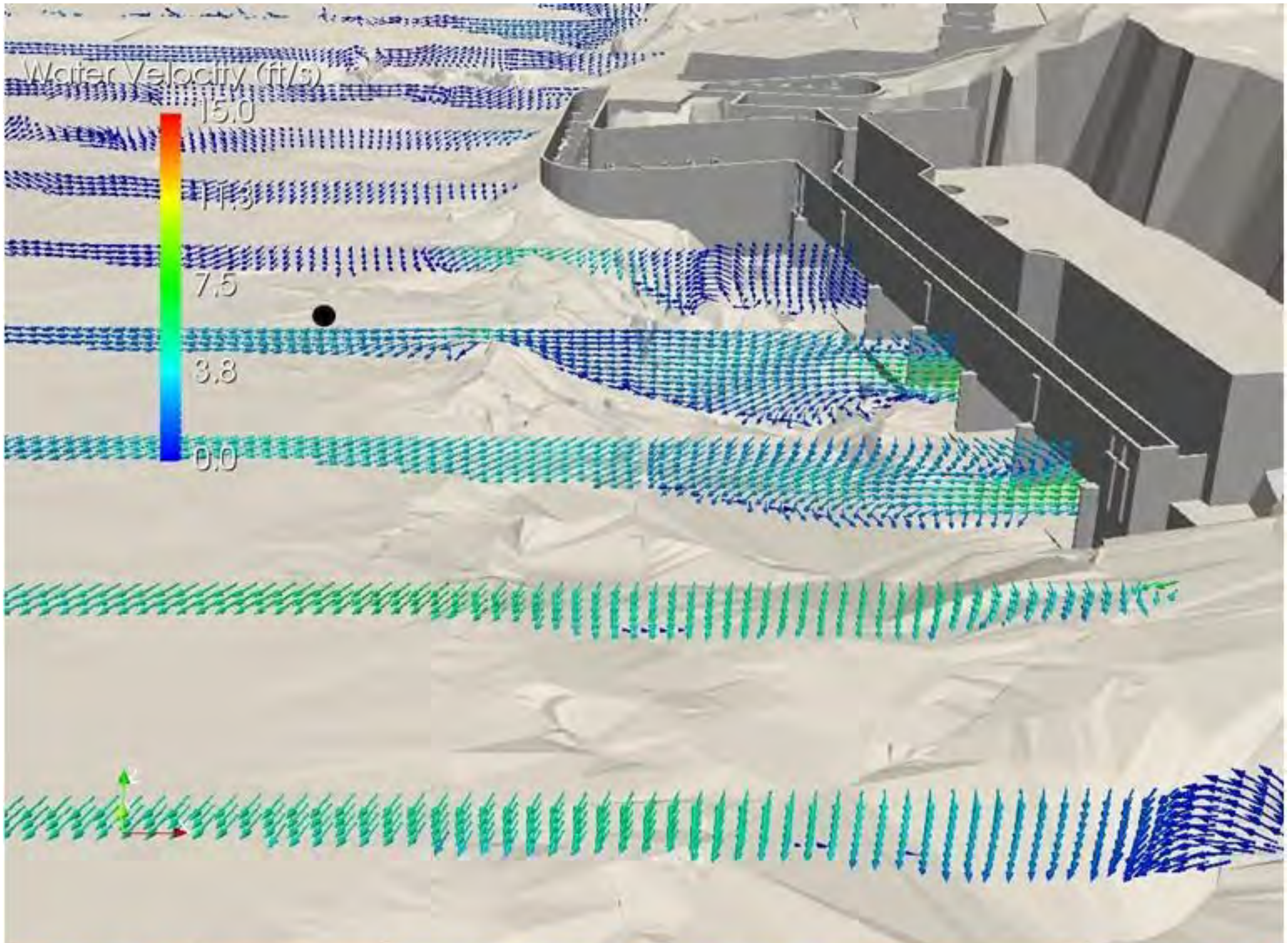
Scenario Number	Cabot Flow (cfs)	Bypass Reach Flow (cfs)	Cabot Fishway Flow (cfs)	Total Flow (cfs)	Water Surface Elevation (ft)
5-2	7,500	400	368	8,268	111.0 ●

Figure 8.4.2-9: PR 5-2 Cross-Sections Showing Water Velocity Across the River's Left Channel
Total model flow is 8,268 cfs. Scaled from 0-15 fps.



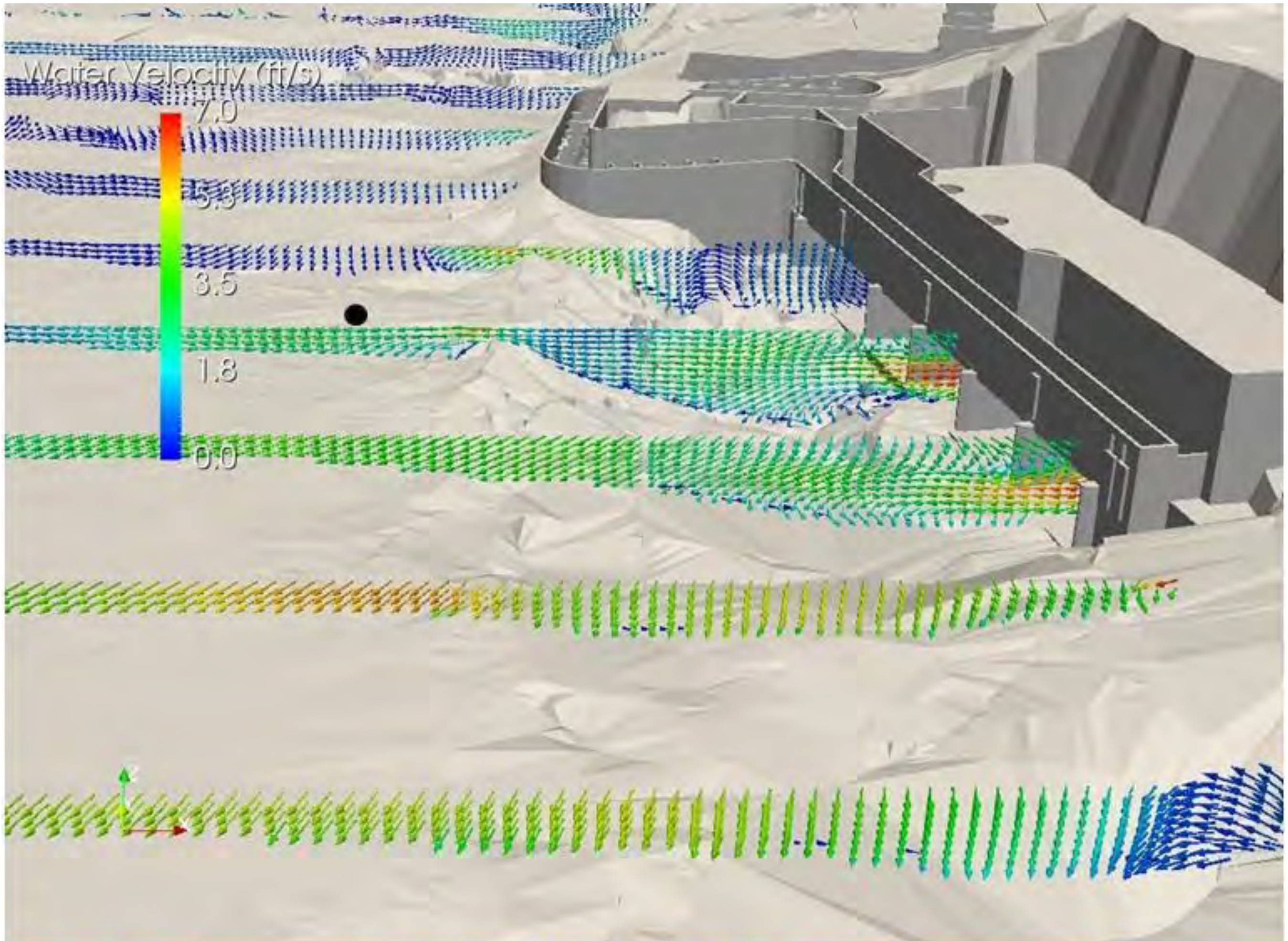
Scenario Number	Cabot Flow (cfs)	Bypass Reach Flow (cfs)	Cabot Fishway Flow (cfs)	Total Flow (cfs)	Water Surface Elevation (ft)
5-2	7,500	400	368	8,268	111.0 ●

Figure 8.4.2-10: PR 5-2 Cross-Sections Showing Water Velocity Across the River's Left Channel
Total model flow is 8,268 cfs. Scaled from 0-7 fps.



Scenario Number	Cabot Flow (cfs)	Bypass Reach Flow (cfs)	Cabot Fishway Flow (cfs)	Total Flow (cfs)	Water Surface Elevation (ft)
5-2	7,500	400	368	8,268	111.0 ●

Figure 8.4.2-11: PR 5-2 Cross-Sections Showing Water Velocity near the Cabot Station Draft Tubes
Total model flow is 8,268 cfs. Scaled from 0-15 fps.



Scenario Number	Cabot Flow (cfs)	Bypass Reach Flow (cfs)	Cabot Fishway Flow (cfs)	Total Flow (cfs)	Water Surface Elevation (ft)
5-2	7,500	400	368	8,268	111.0 ●

Figure 8.4.2-12: PR 5-2 Cross-Sections Showing Water Velocity Near the Cabot Station Draft Tubes
Total model flow is 8,268 cfs. Scaled from 0-7 fps

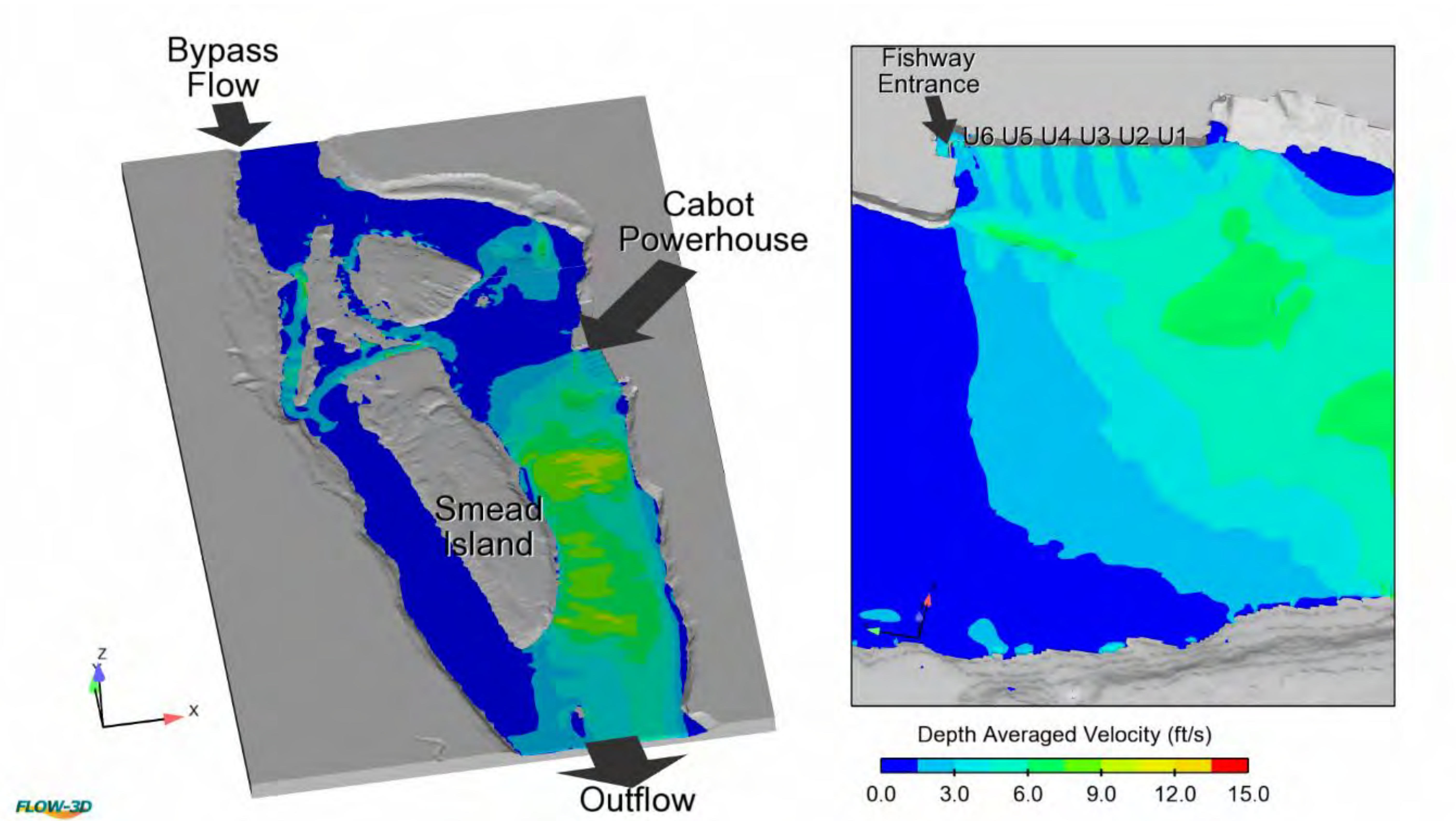


Figure 8.4.3-1: Depth-Averaged Water Velocities for the Full Study Area (Left) and Near Cabot Station (Right) for PR 5-3
Total model flow is 14,496 cfs. Scaled from 0-15 fps.

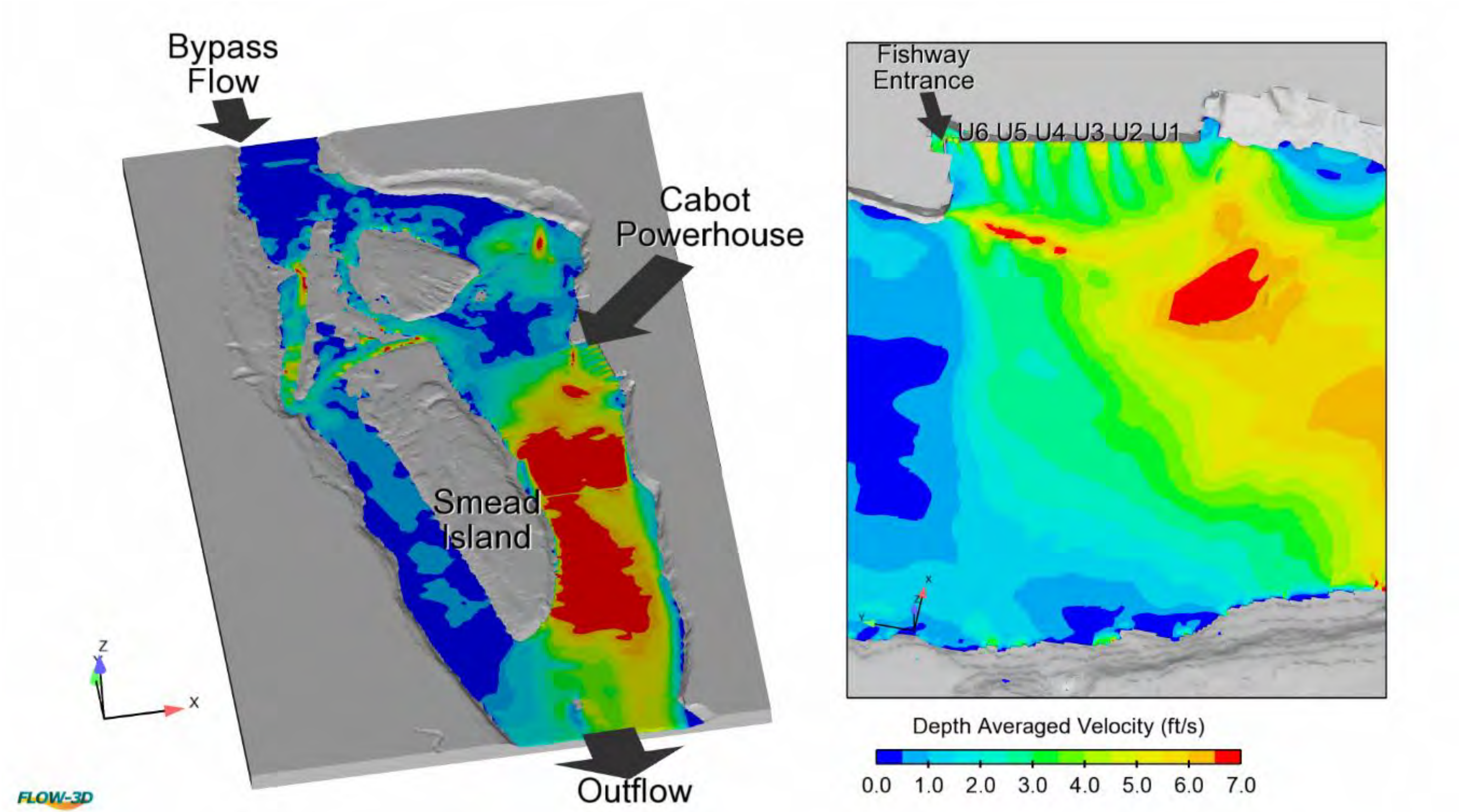


Figure 8.4.3-2: Depth-Averaged Water Velocities for the Full Study Area (Left) and Near Cabot Station (Right) for PR 5-3
Total model flow is 14,496 cfs. Scaled from 0-7 fps.

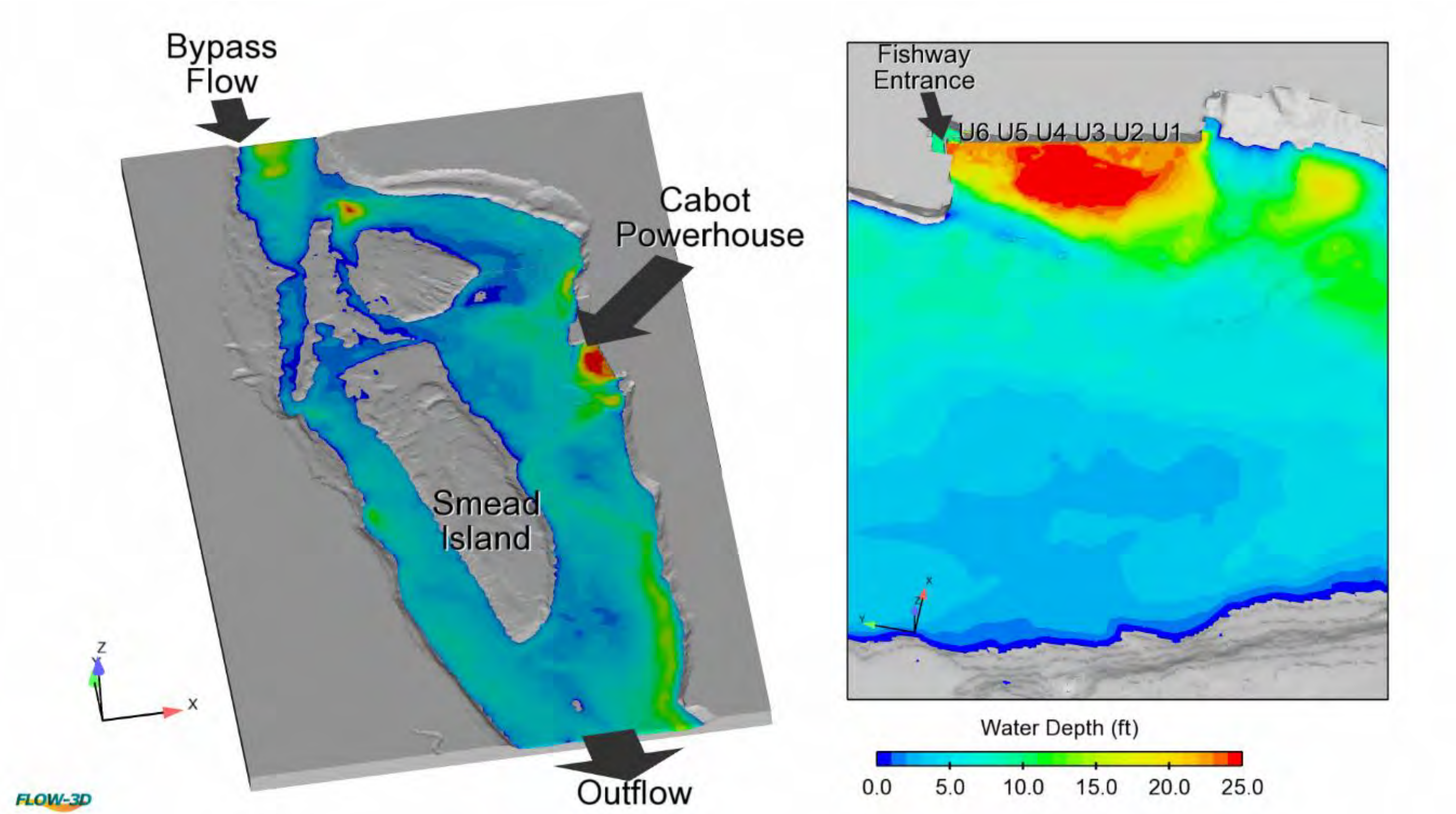


Figure 8.4.3-3: PR 5-3 Modeled Water Depths
Total model flow is 14,496 cfs.

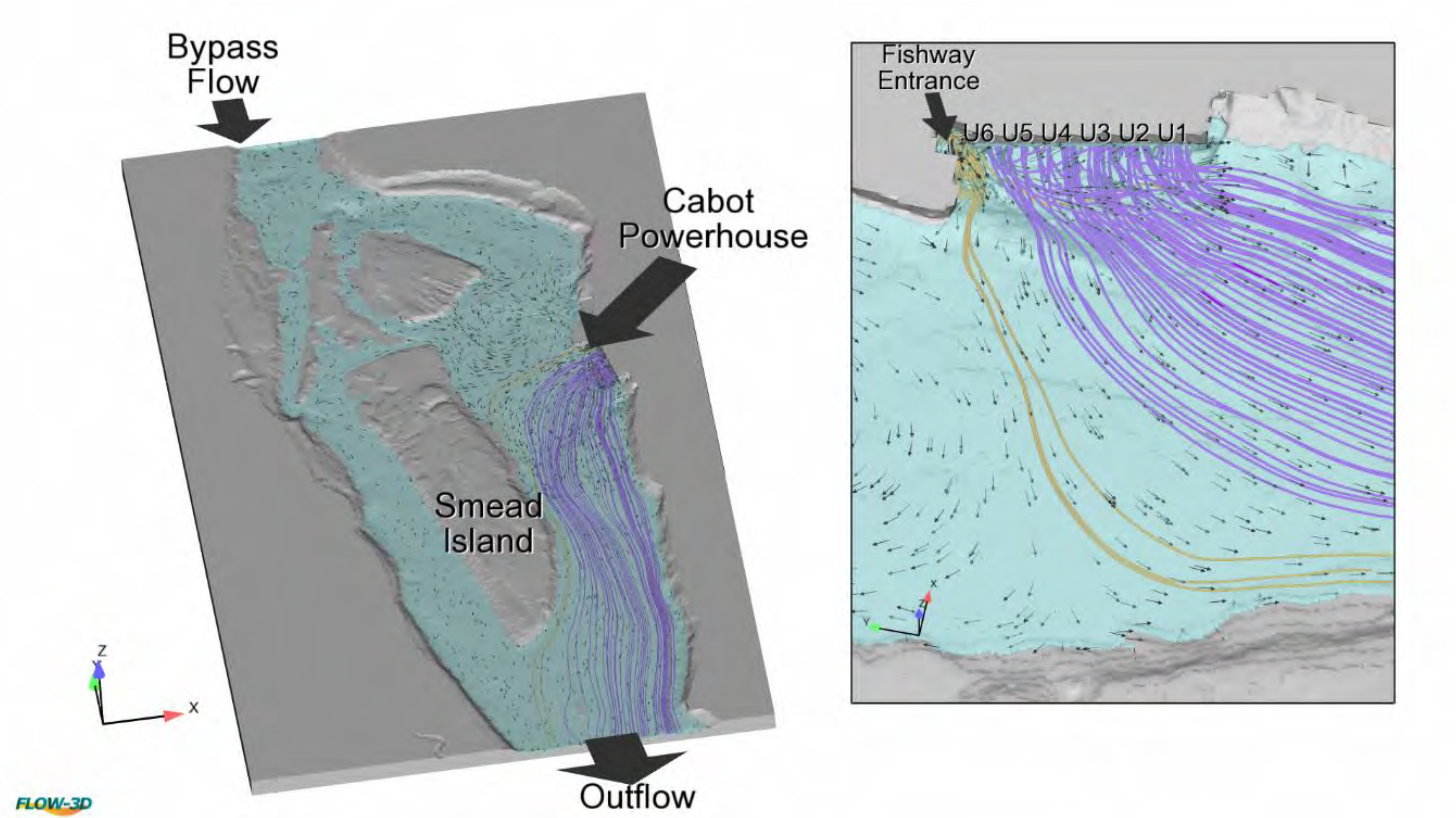
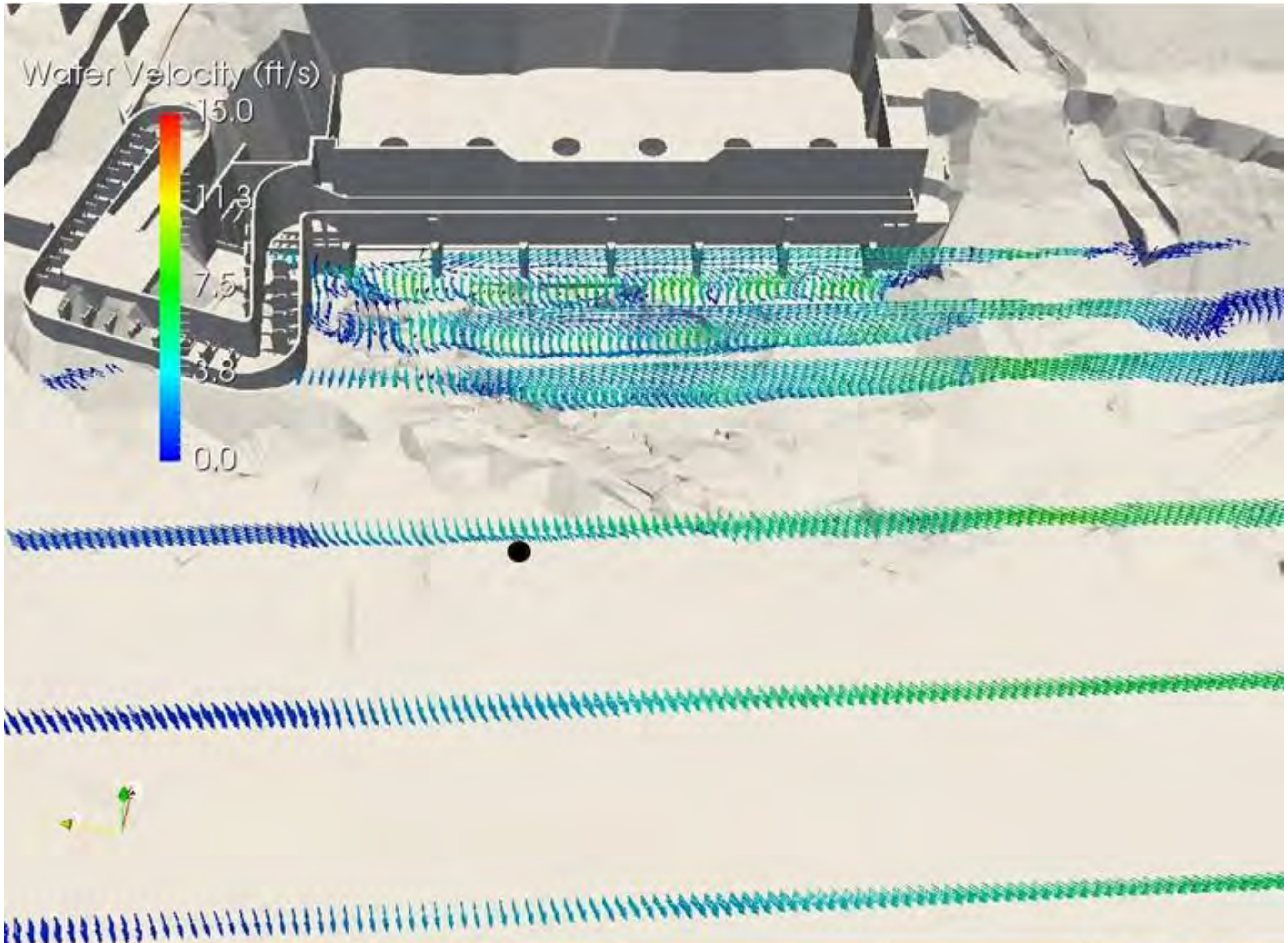
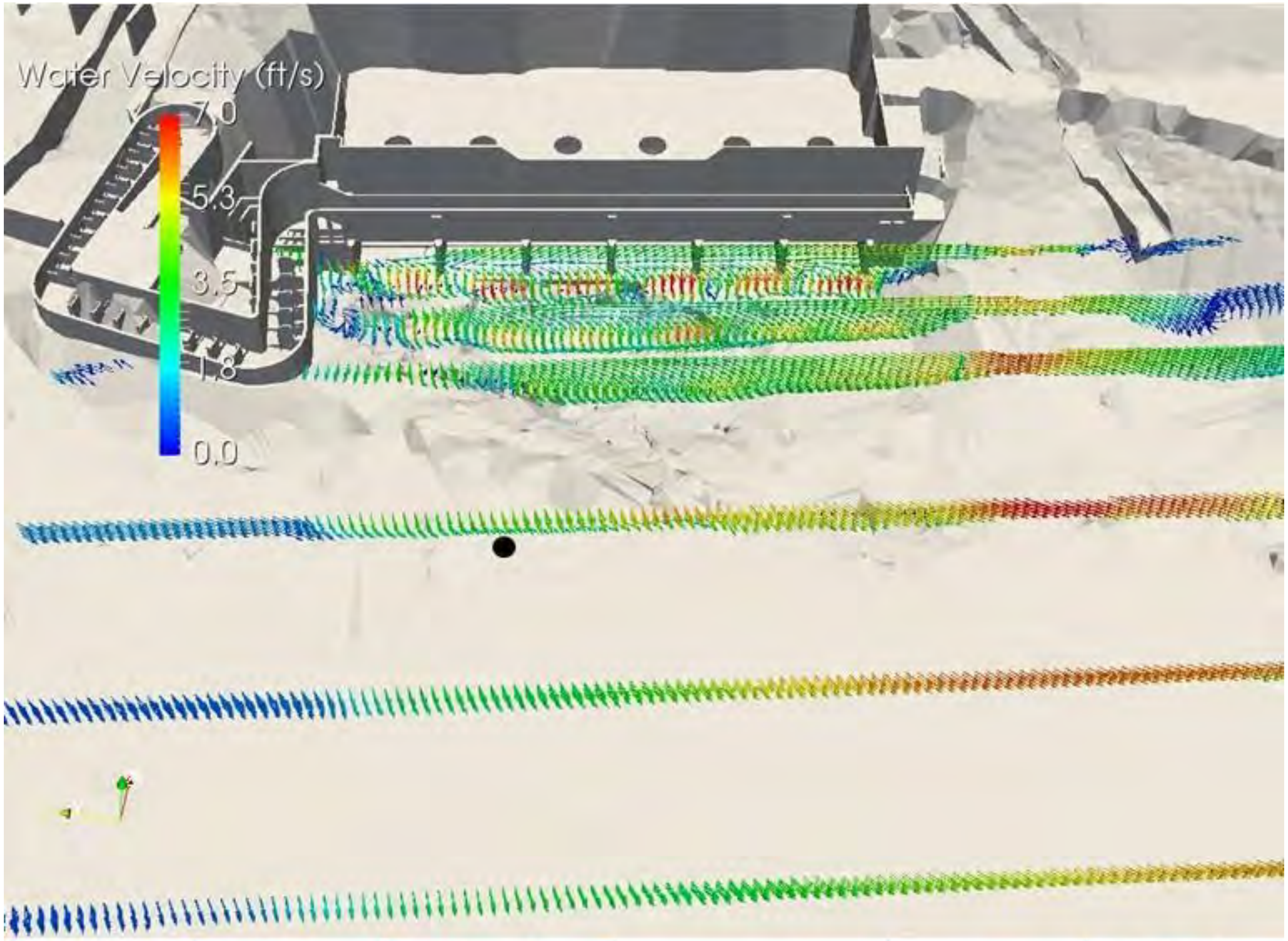


Figure 8.4.3-4: PR 5-3 Modeled Streamlines and Velocity Vectors
The black arrows indicate flow direction. The streamlines represent the path of water released from the Spillway fishway (orange) or Cabot Station (purple). Total model flow is 14,496 cfs.



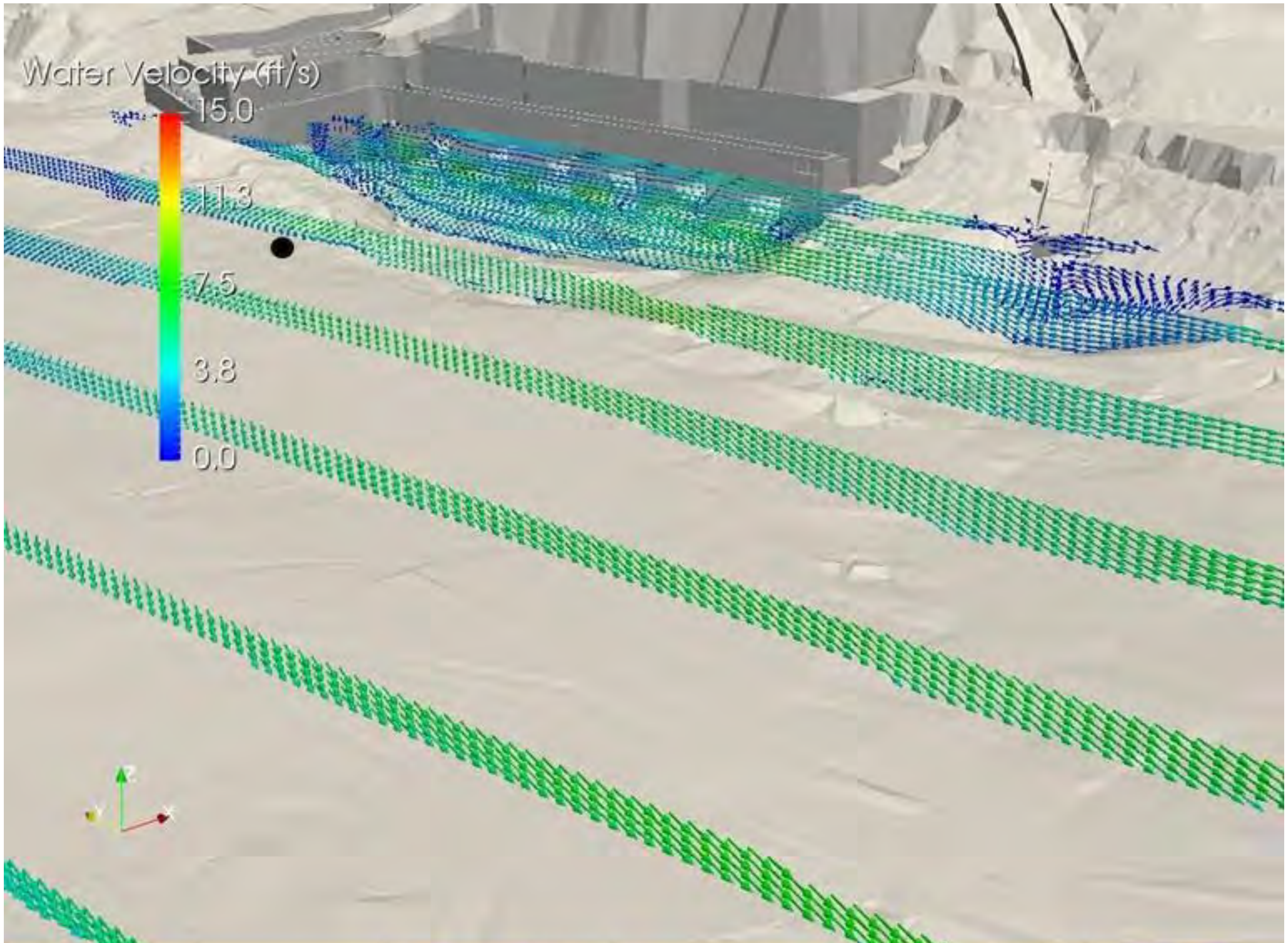
Scenario Number	Cabot Flow (cfs)	Bypass Reach Flow (cfs)	Cabot Fishway Flow (cfs)	Total Flow (cfs)	Water Surface Elevation (ft)
5-3	13,728	400	368	14,496	112.8 ●

Figure 8.4.3-5: PR 5-3 Water Velocity Vector Plots for Cross-Sections Parallel to Cabot Station, Looking from the Center of the River
Total model flow is 14,496 cfs. Scaled from 0-15 fps.



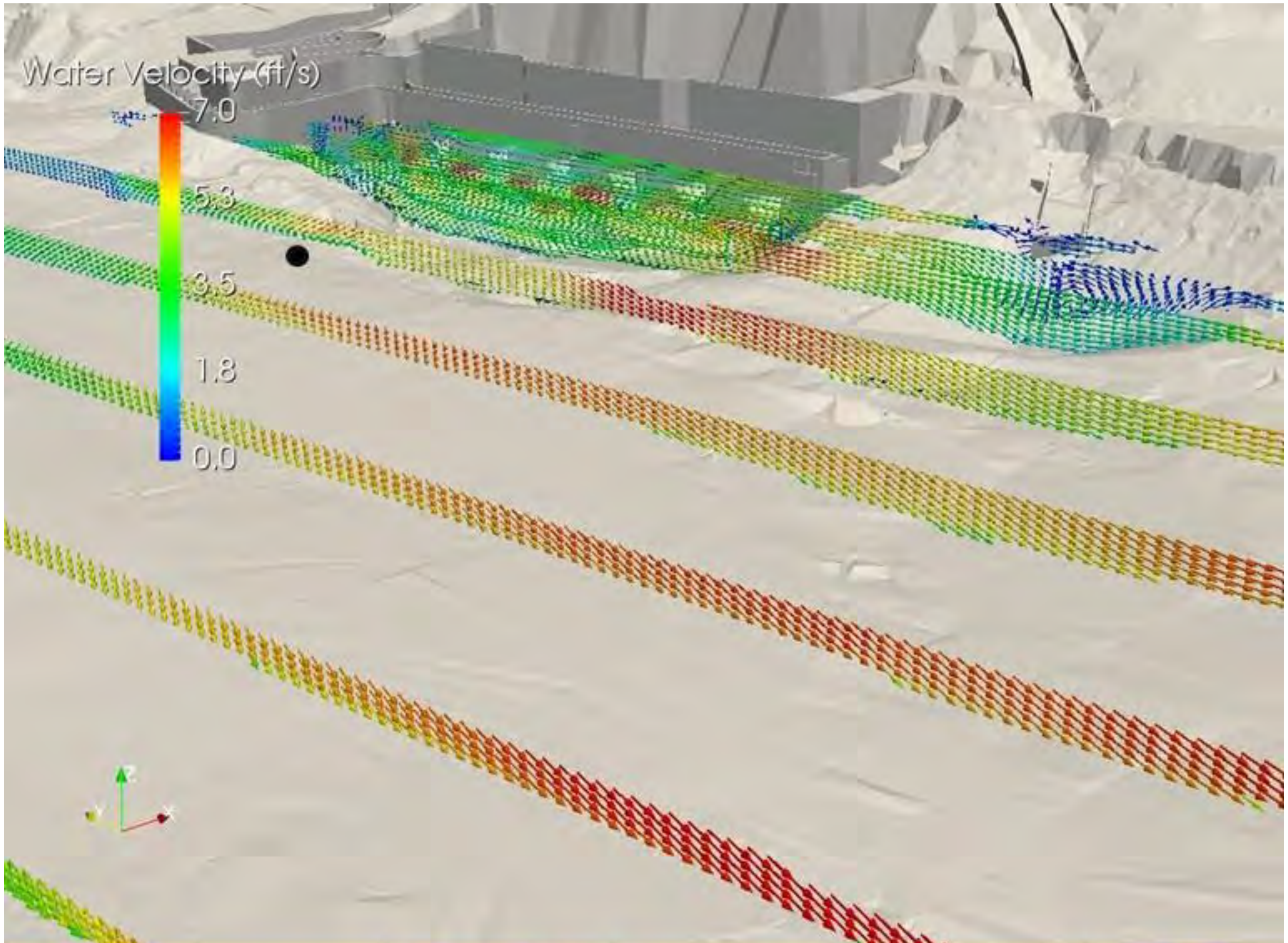
Scenario Number	Cabot Flow (cfs)	Bypass Reach Flow (cfs)	Cabot Fishway Flow (cfs)	Total Flow (cfs)	Water Surface Elevation (ft)
5-3	13,728	400	368	14,496	112.8 ●

Figure 8.4.3-6: PR 5-3 Water Velocity Vector Plots for Cross-Sections Parallel to Cabot Station, Looking from the Center of the River
Total model flow is 14,496 cfs. Scaled from 0-7 fps.



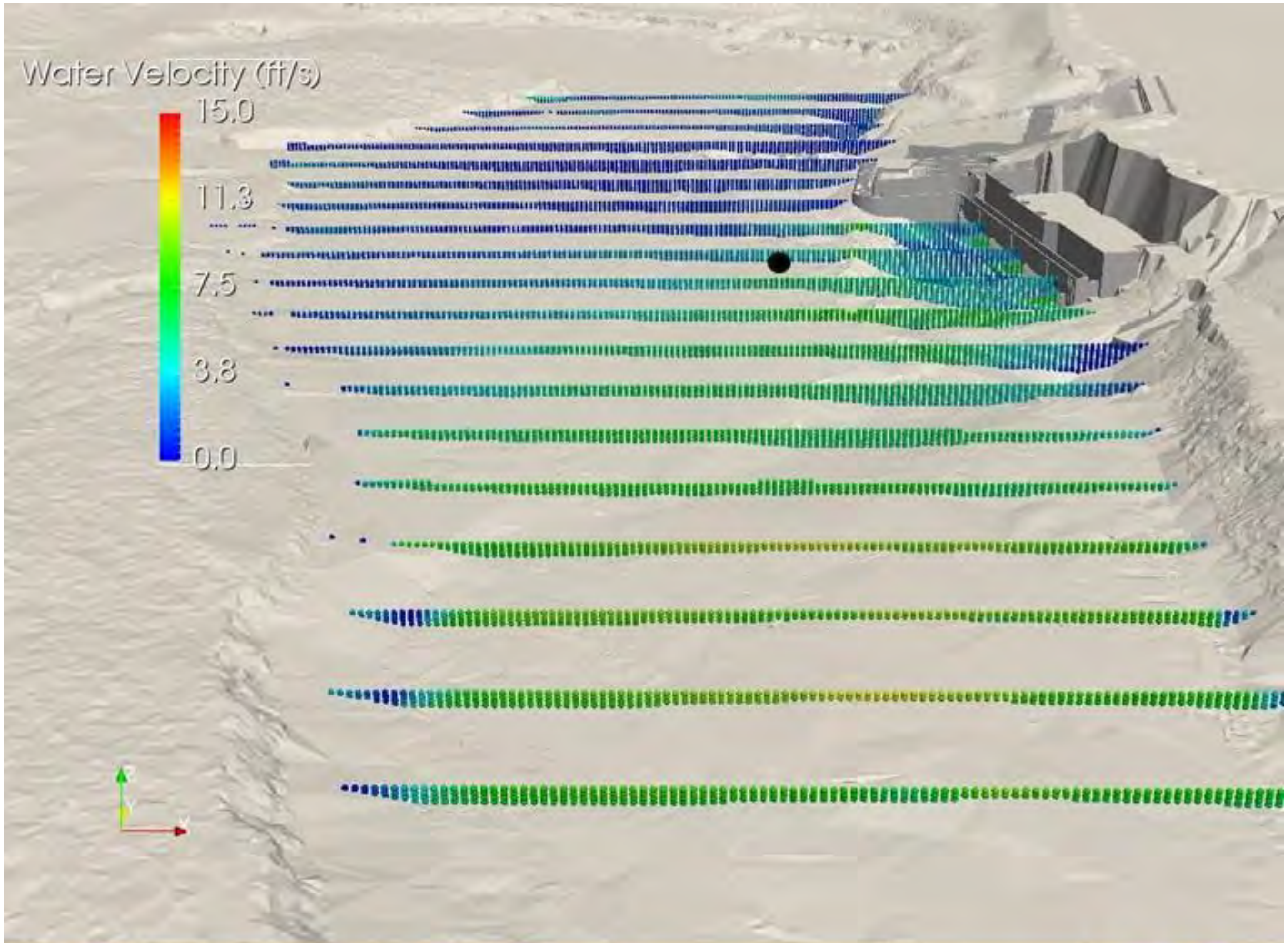
Scenario Number	Cabot Flow (cfs)	Bypass Reach Flow (cfs)	Cabot Fishway Flow (cfs)	Total Flow (cfs)	Water Surface Elevation (ft)
5-3	13,728	400	368	14,496	112.8 ●

Figure 8.4.3-7: PR 5-3 Water Velocity Vector Plots for Cross-Sections Parallel to Cabot Station, Looking Upstream Toward the Cabot Powerhouse
Total model flow is 14,496 cfs. Scaled from 0-15 fps.



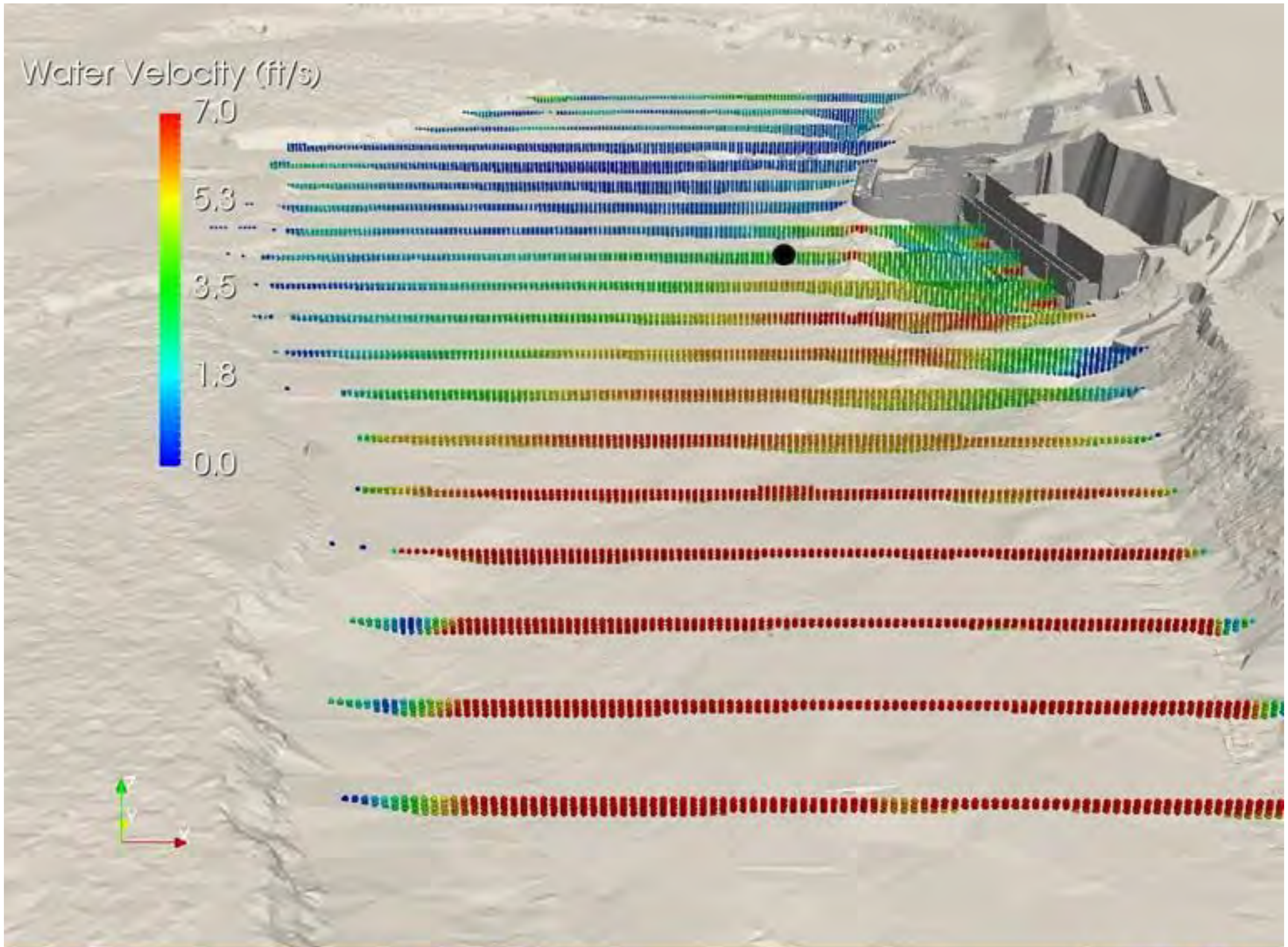
Scenario Number	Cabot Flow (cfs)	Bypass Reach Flow (cfs)	Cabot Fishway Flow (cfs)	Total Flow (cfs)	Water Surface Elevation (ft)
5-3	13,728	400	368	14,496	112.8 ●

Figure 8.4.3-8: PR 5-3 Water Velocity Vector Plots for Cross-Sections Parallel to Cabot Station, Looking Upstream toward the Cabot Powerhouse
Total model flow is 14,496 cfs. Scaled from 0-7 fps.



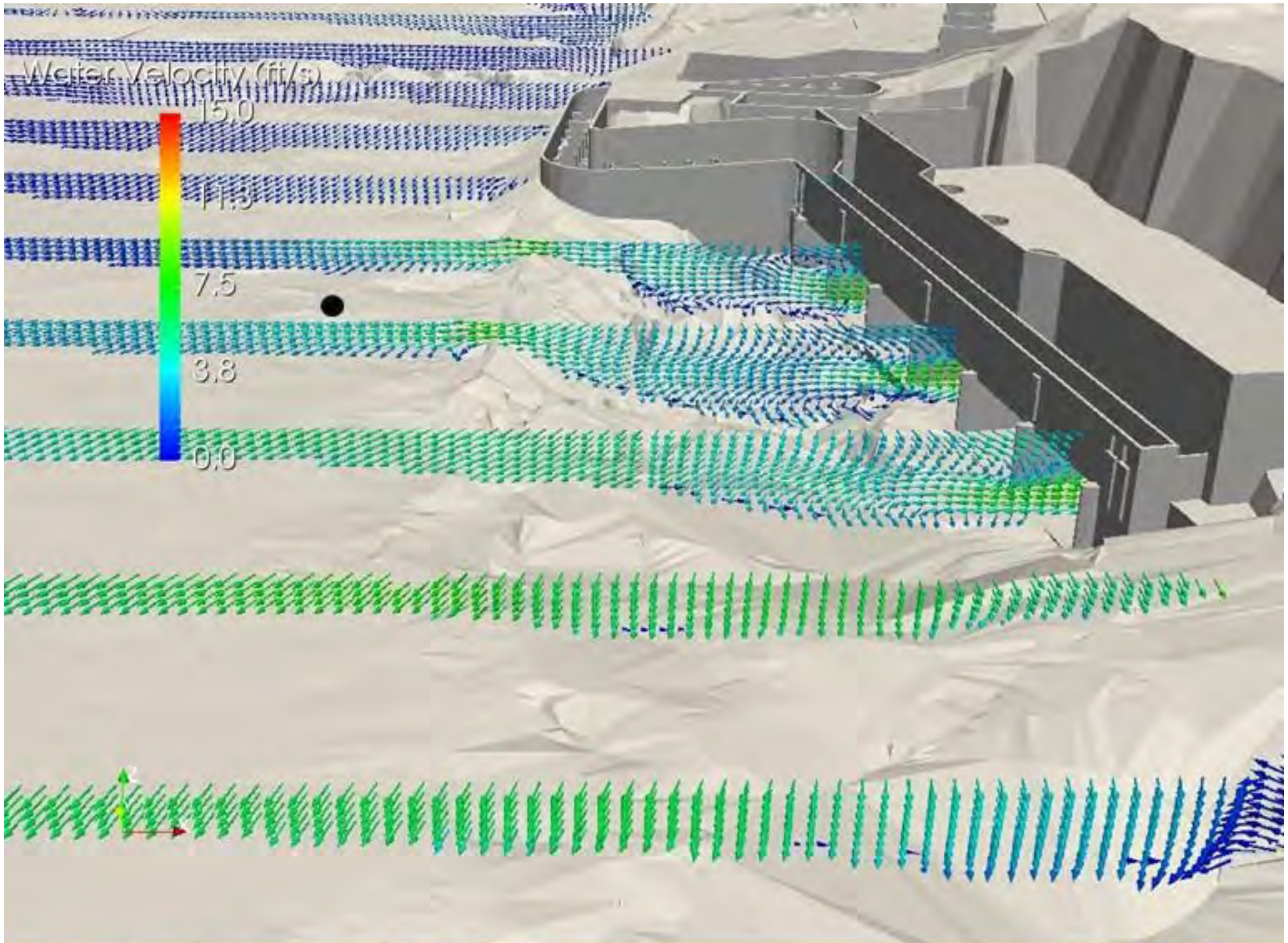
Scenario Number	Cabot Flow (cfs)	Bypass Reach Flow (cfs)	Cabot Fishway Flow (cfs)	Total Flow (cfs)	Water Surface Elevation (ft)
5-3	13,728	400	368	14,496	112.8 ●

Figure 8.4.3-9: PR 5-3 Cross-Sections Showing Water Velocity Across the River's Left Channel
Total model flow is 14,496 cfs. Scaled from 0-15 fps.



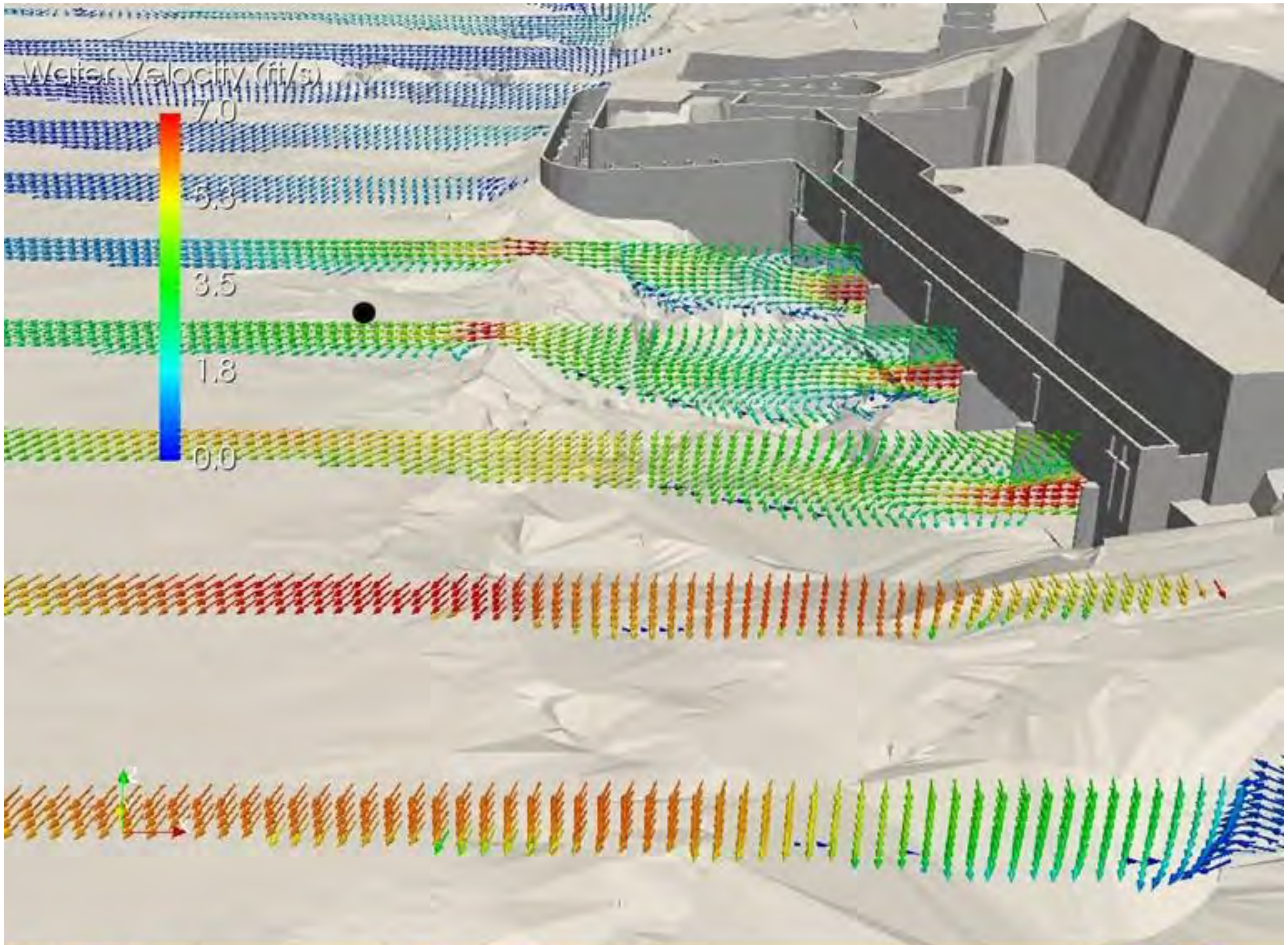
Scenario Number	Cabot Flow (cfs)	Bypass Reach Flow (cfs)	Cabot Fishway Flow (cfs)	Total Flow (cfs)	Water Surface Elevation (ft)
5-3	13,728	400	368	14,496	112.8 ●

Figure 8.4.3-10: PR 5-3 Cross-Sections Showing Water Velocity Across the River's Left Channel
Total model flow is 14,496 cfs. Scaled from 0-7 fps.



Scenario Number	Cabot Flow (cfs)	Bypass Reach Flow (cfs)	Cabot Fishway Flow (cfs)	Total Flow (cfs)	Water Surface Elevation (ft)
5-3	13,728	400	368	14,496	112.8 ●

Figure 8.4.3-11: PR 5-3 Cross-Sections Showing Water Velocity Near the Cabot Station Draft Tubes
Total model flow is 14,496 cfs. Scaled from 0-15 fps.



Scenario Number	Cabot Flow (cfs)	Bypass Reach Flow (cfs)	Cabot Fishway Flow (cfs)	Total Flow (cfs)	Water Surface Elevation (ft)
5-3	13,728	400	368	14,496	112.8 ●

Figure 8.4.3-12: PR 5-3 Cross-Sections Showing Water Velocity Near the Cabot Station Draft Tubes
Total model flow is 14,496 cfs. Scaled from 0-7 fps.

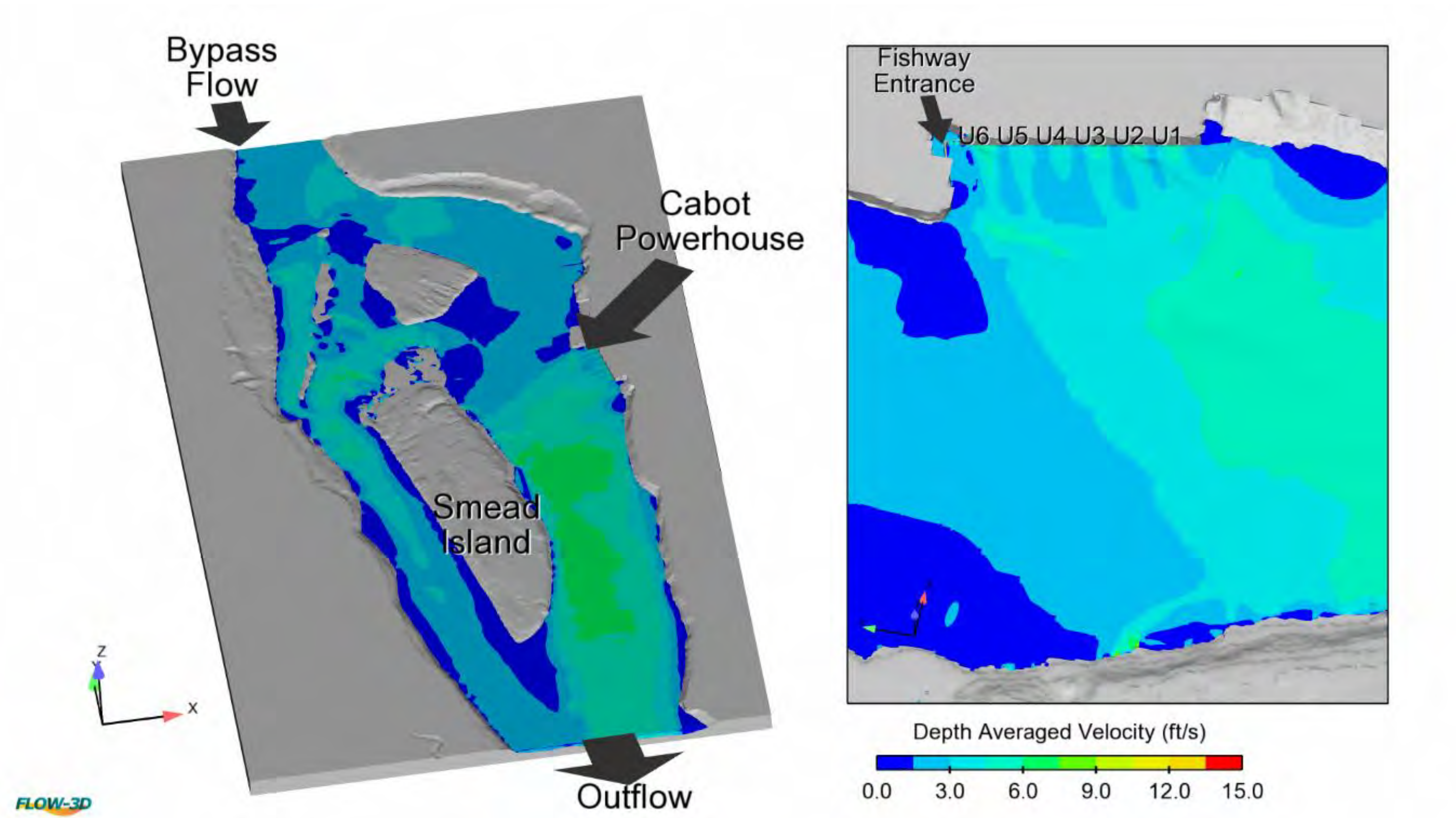


Figure 8.4.4-1: Depth-Averaged Water Velocities for the Full Study Area (Left) and Near Cabot Station (Right) for PR 5-4
Total model flow is 20,597 cfs. Scaled from 0-15 fps.

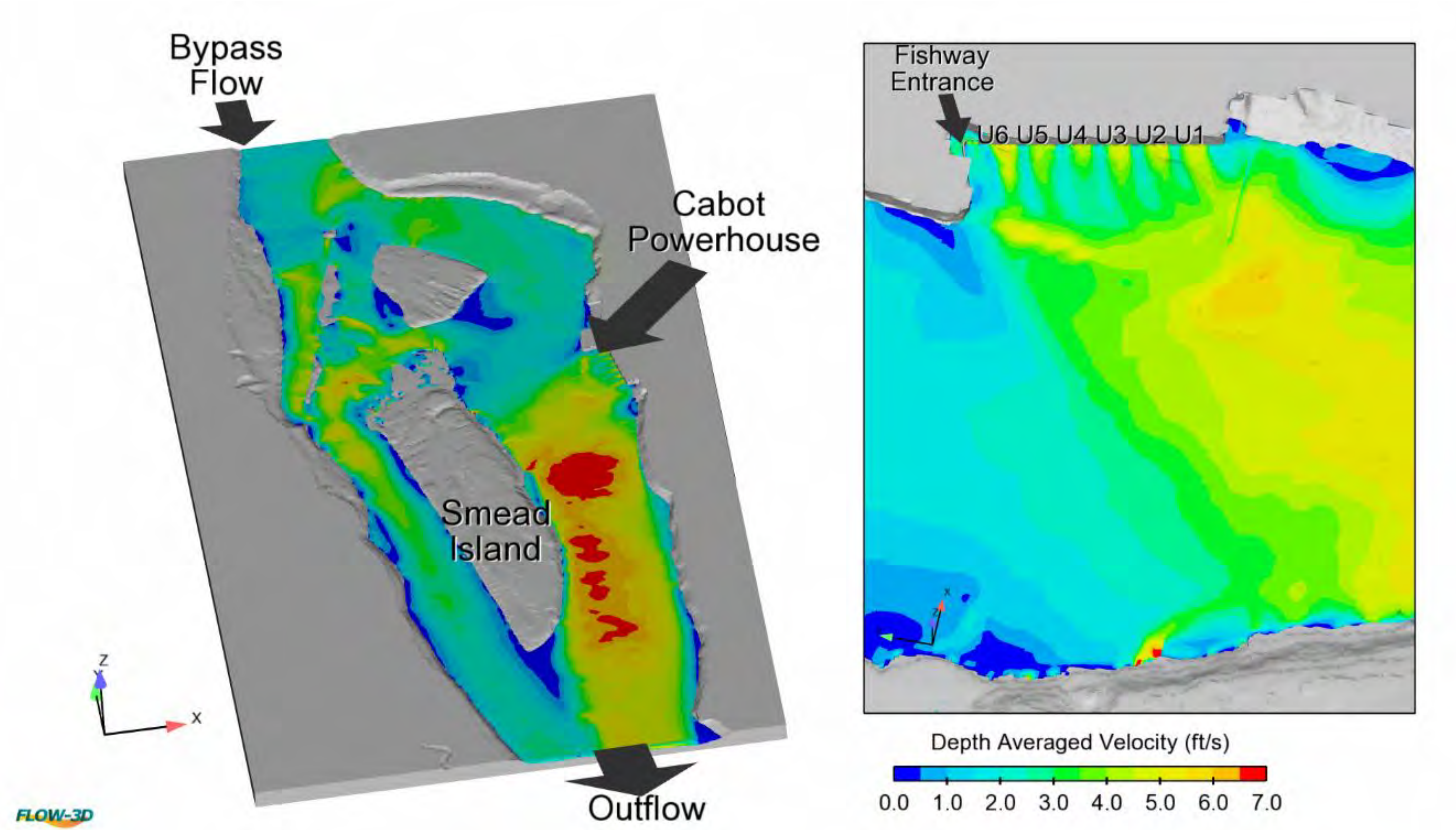


Figure 8.4.4-2: Depth-Averaged Water Velocities for the Full Study Area (Left) and Near Cabot Station (Right) for PR 5-4
Total model flow is 20,597 cfs. Scaled from 0-7 fps.

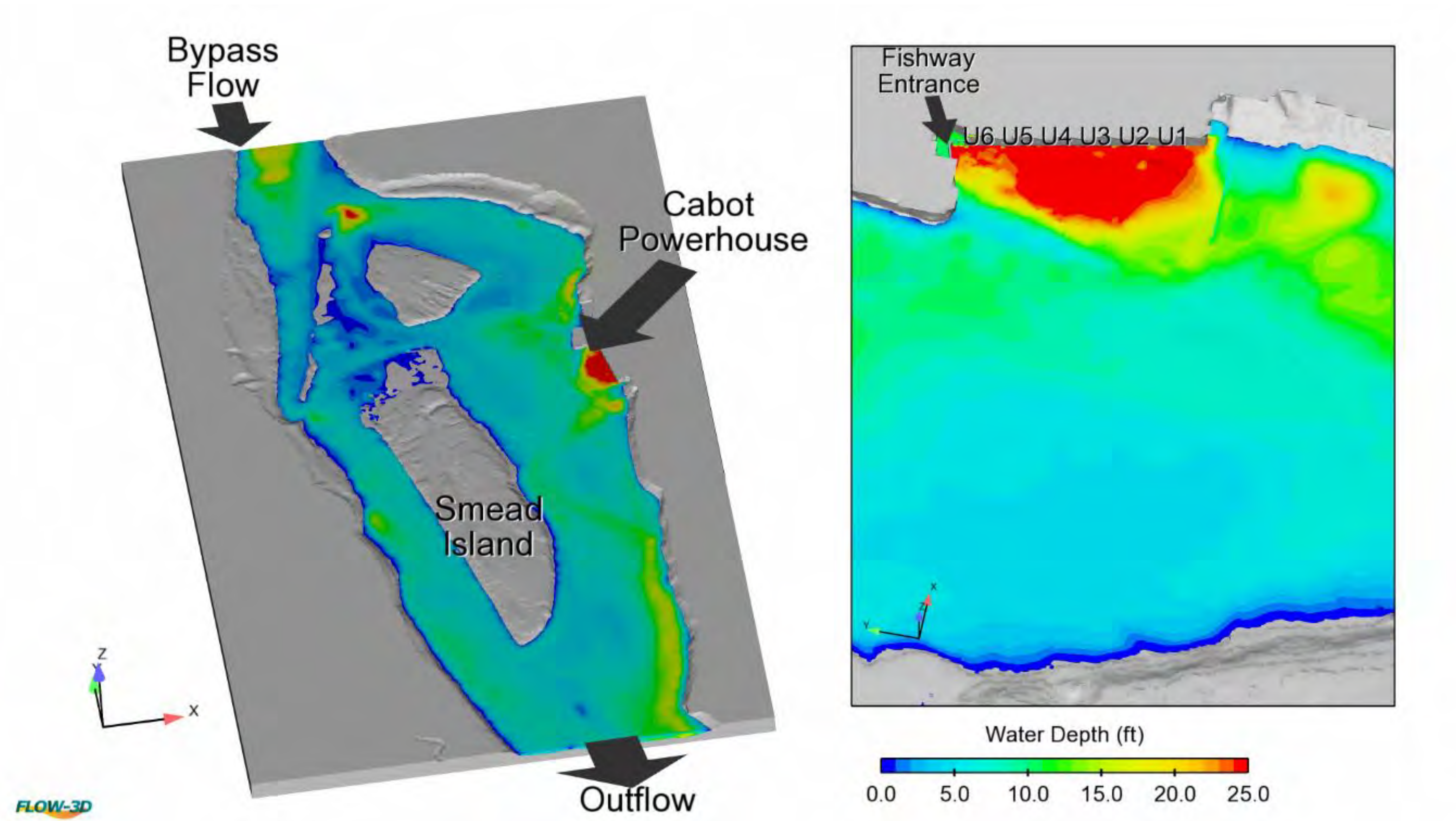


Figure 8.4.4-3: PR 5-4 Modeled Water Depths
Total model flow is 20,597 cfs.

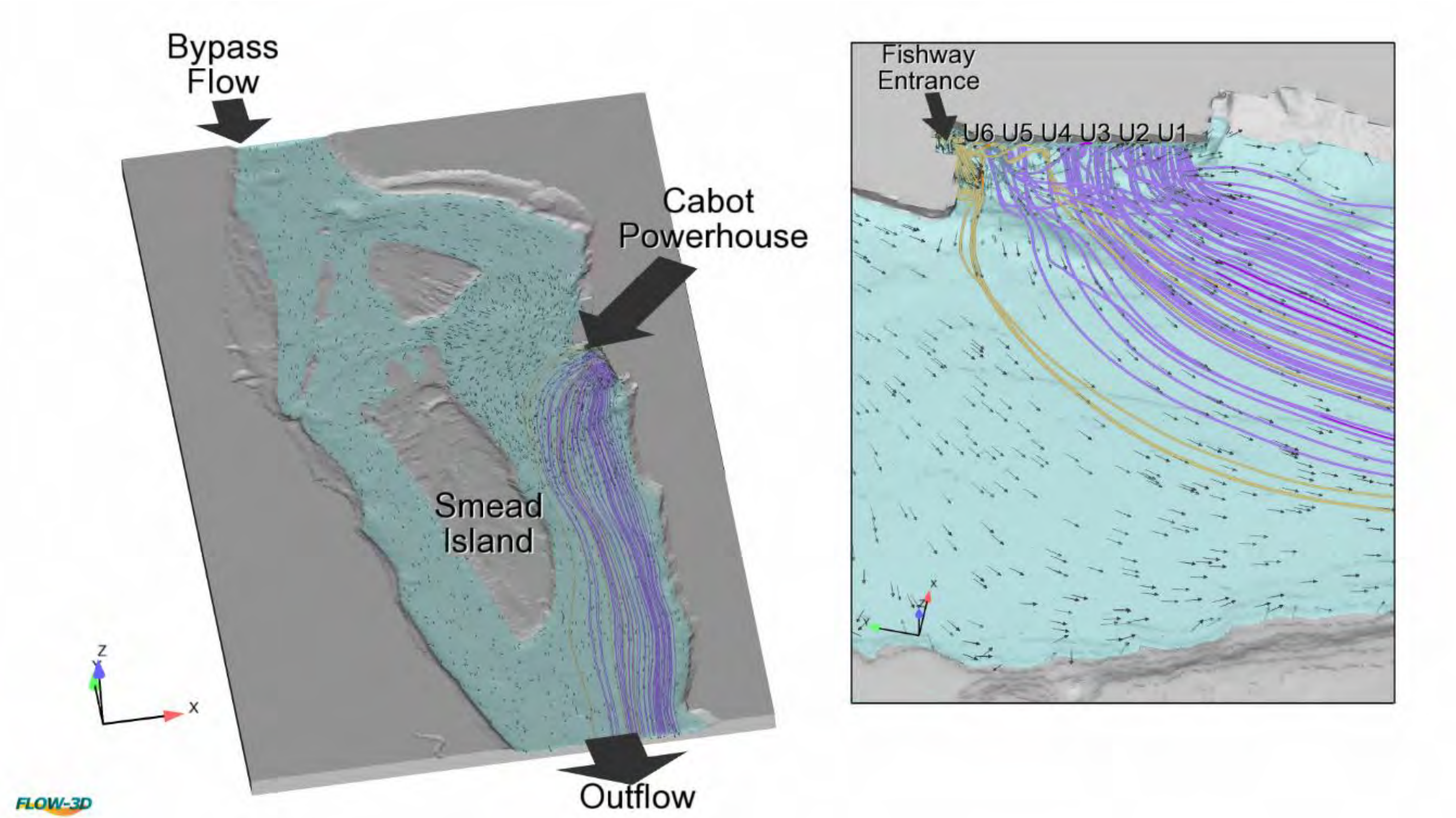
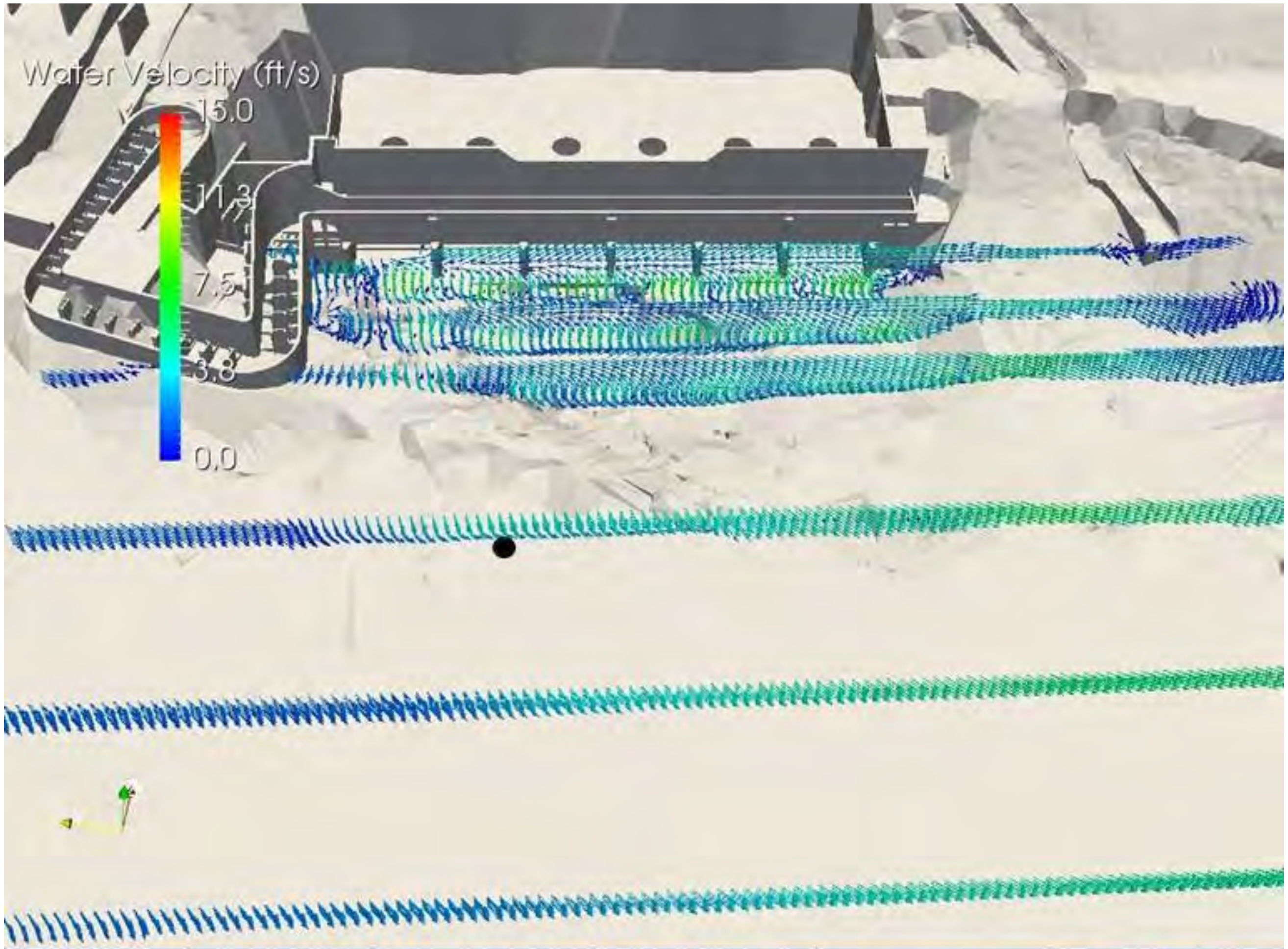


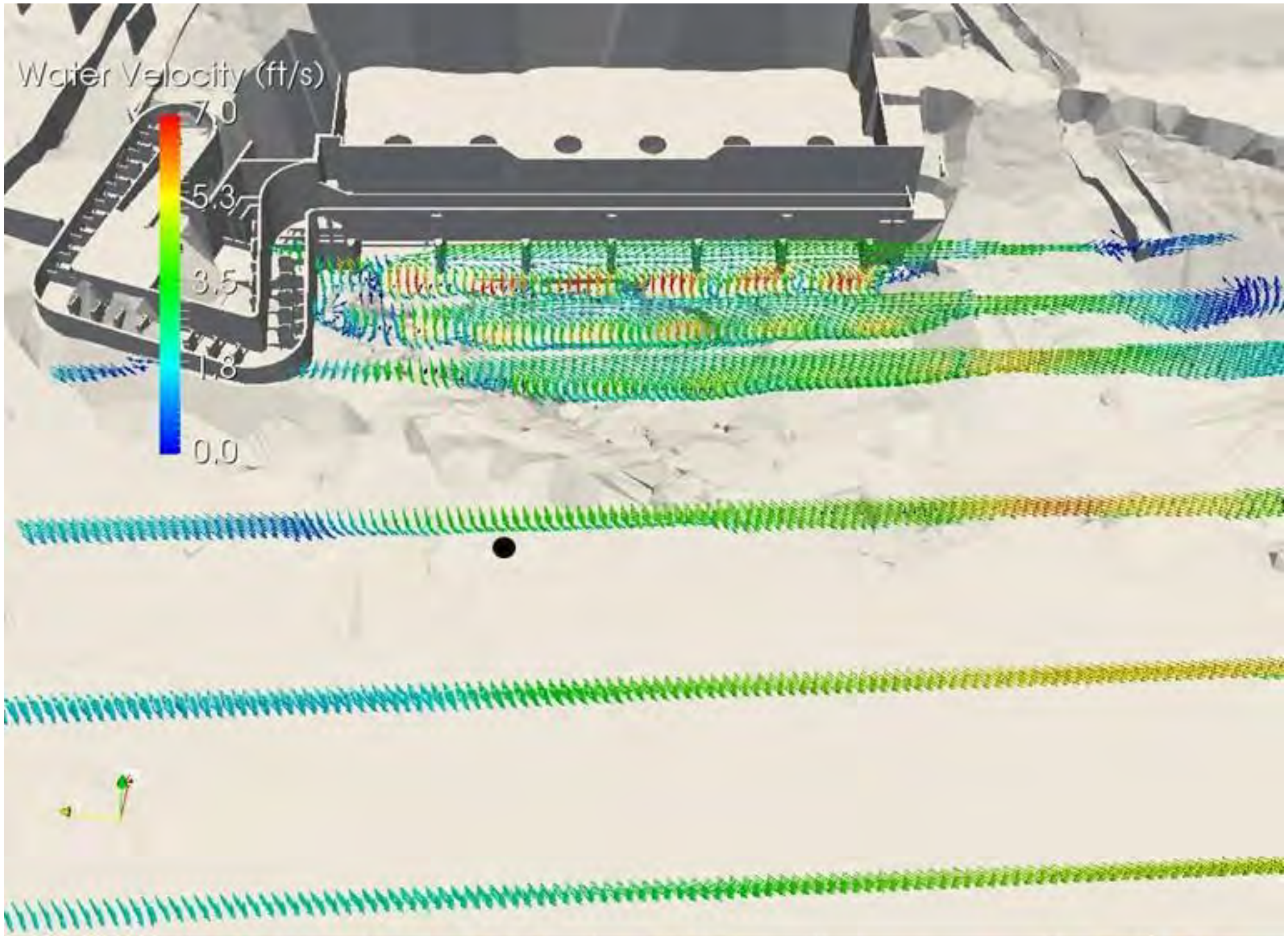
Figure 8.4.4-4: PR 5-4 Modeled Streamlines and Velocity Vectors

The black arrows indicate flow direction. The streamlines represent the path of water released from the Spillway fishway (orange) or Cabot Station (purple). Total model flow is 20,597 cfs.



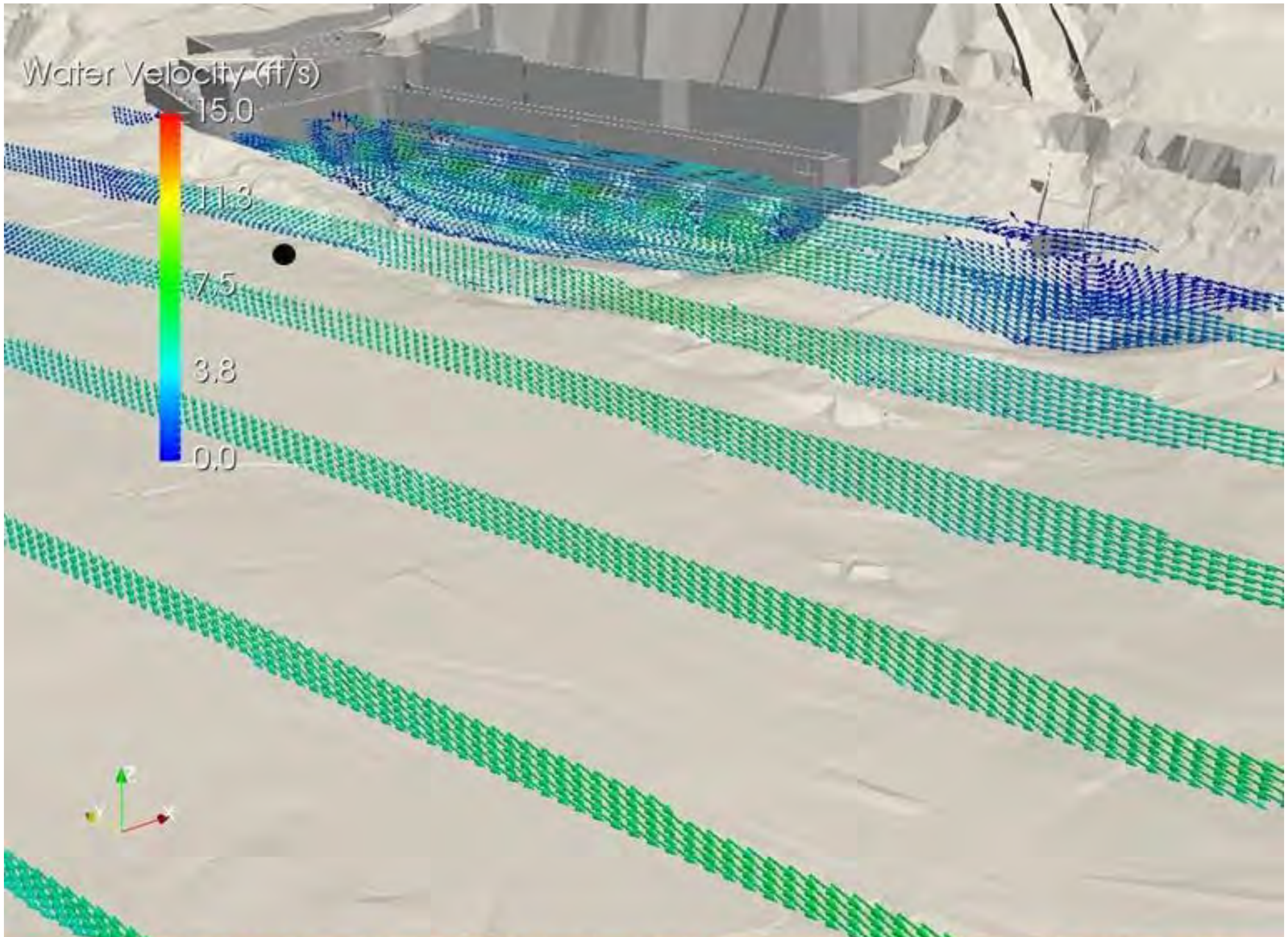
Scenario Number	Cabot Flow (cfs)	Bypass Reach Flow (cfs)	Cabot Fishway Flow (cfs)	Total Flow (cfs)	Water Surface Elevation (ft)
5-4	13,728	6,501	368	20,597 (April 75% exc.)	114.5 ●

Figure 8.4.4-5: PR 5-4 Water Velocity Vector Plots for Cross-Sections Parallel to Cabot Station, Looking from the Center of the River
Total model flow is 20,597 cfs. Scaled from 0-15 fps.



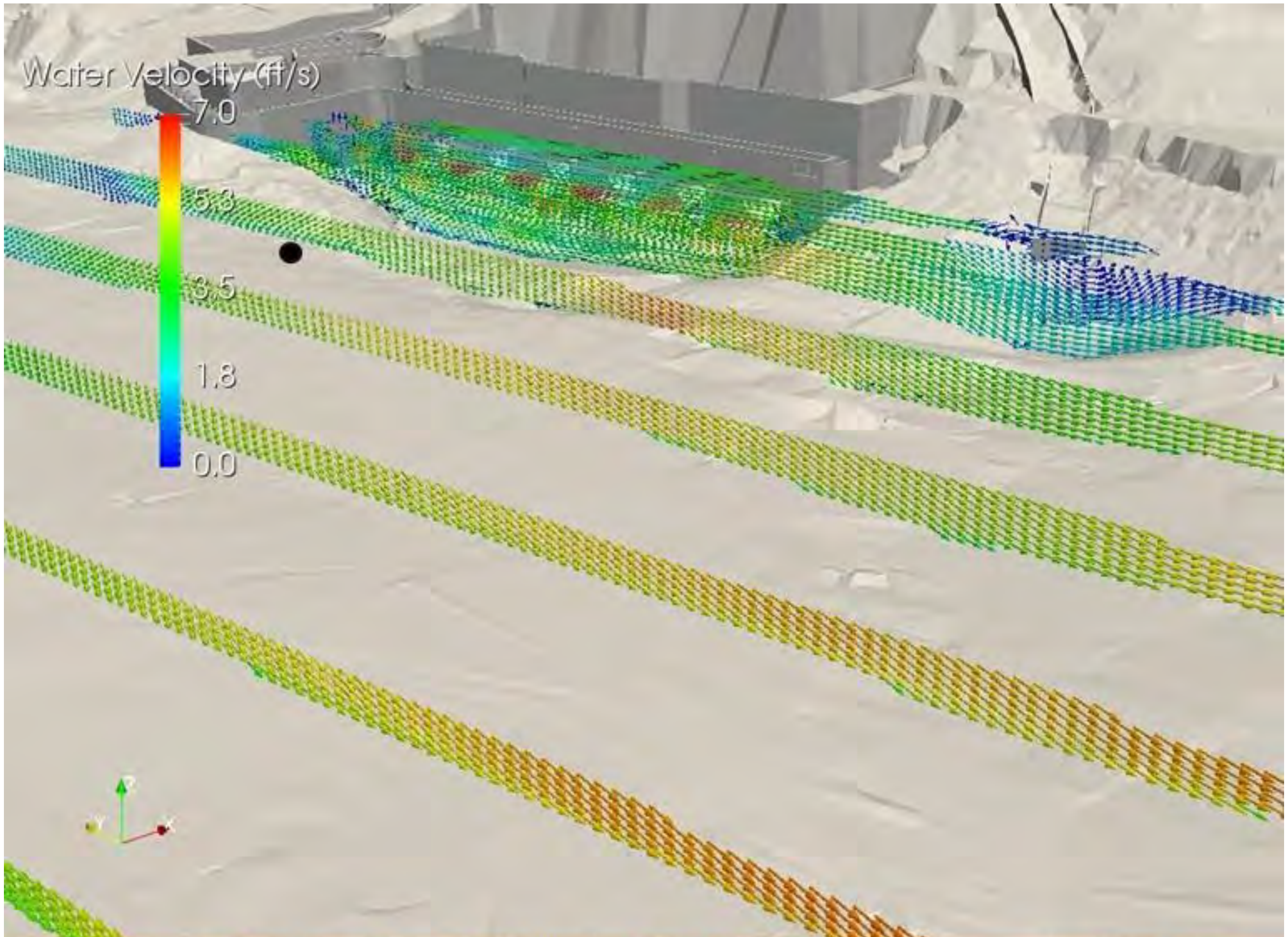
Scenario Number	Cabot Flow (cfs)	Bypass Reach Flow (cfs)	Cabot Fishway Flow (cfs)	Total Flow (cfs)	Water Surface Elevation (ft)
5-4	13,728	6,501	368	20,597 (April 75% exc.)	114.5 ●

Figure 8.4.4-6: PR 5-4 Water Velocity Vector Plots for Cross-Sections Parallel to Cabot Station, Looking from the Center of the River
Total model flow is 20,597 cfs. Scaled from 0-7 fps.



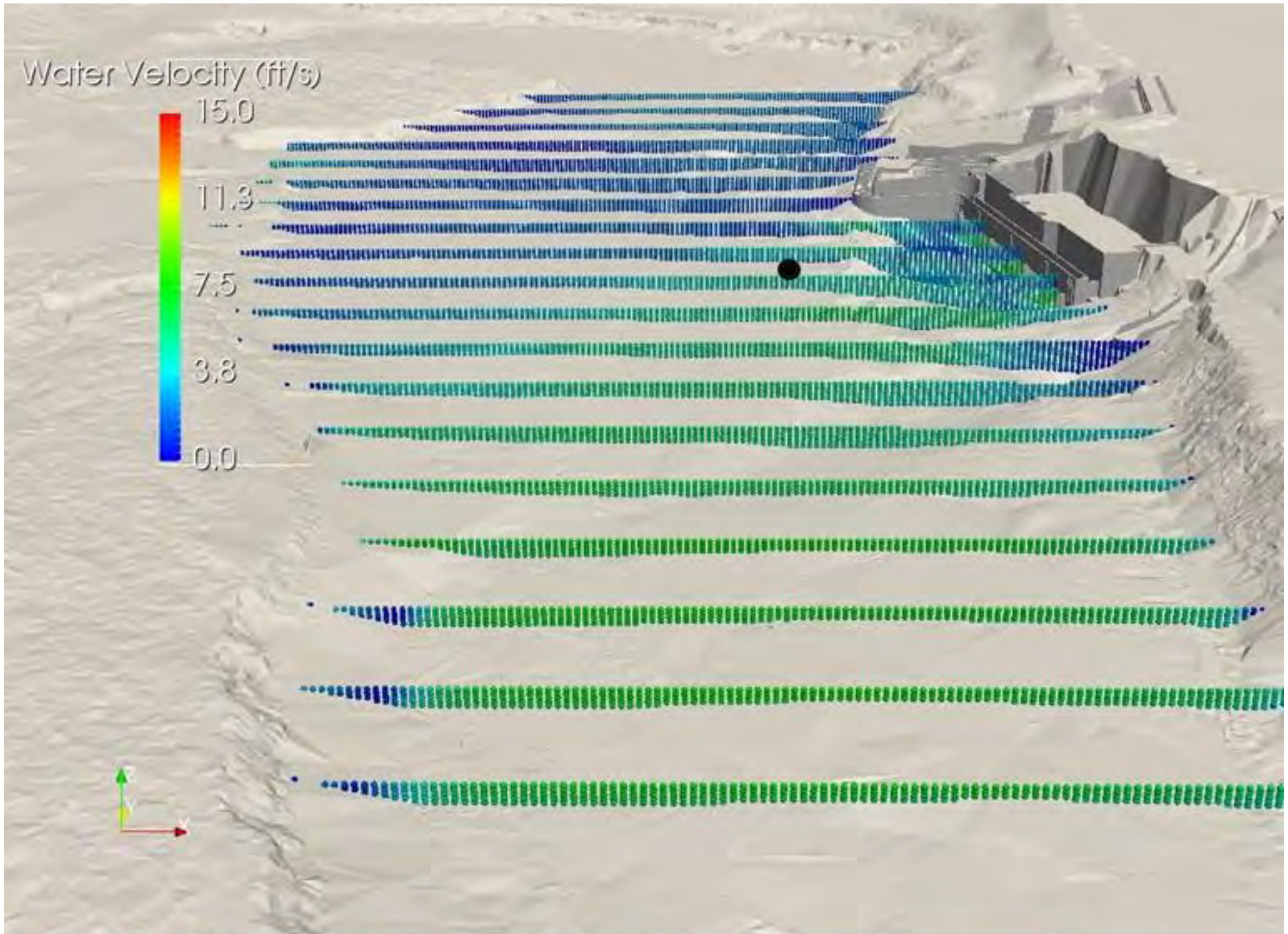
Scenario Number	Cabot Flow (cfs)	Bypass Reach Flow (cfs)	Cabot Fishway Flow (cfs)	Total Flow (cfs)	Water Surface Elevation (ft)
5-4	13,728	6,501	368	20,597 (April 75% exc.)	114.5 ●

Figure 8.4.4-7: PR 5-4 Water Velocity Vector Plots for Cross-Sections Parallel to Cabot Station, Looking Upstream Toward the Cabot Powerhouse
Total model flow is 20,597 cfs. Scaled from 0-15 fps.



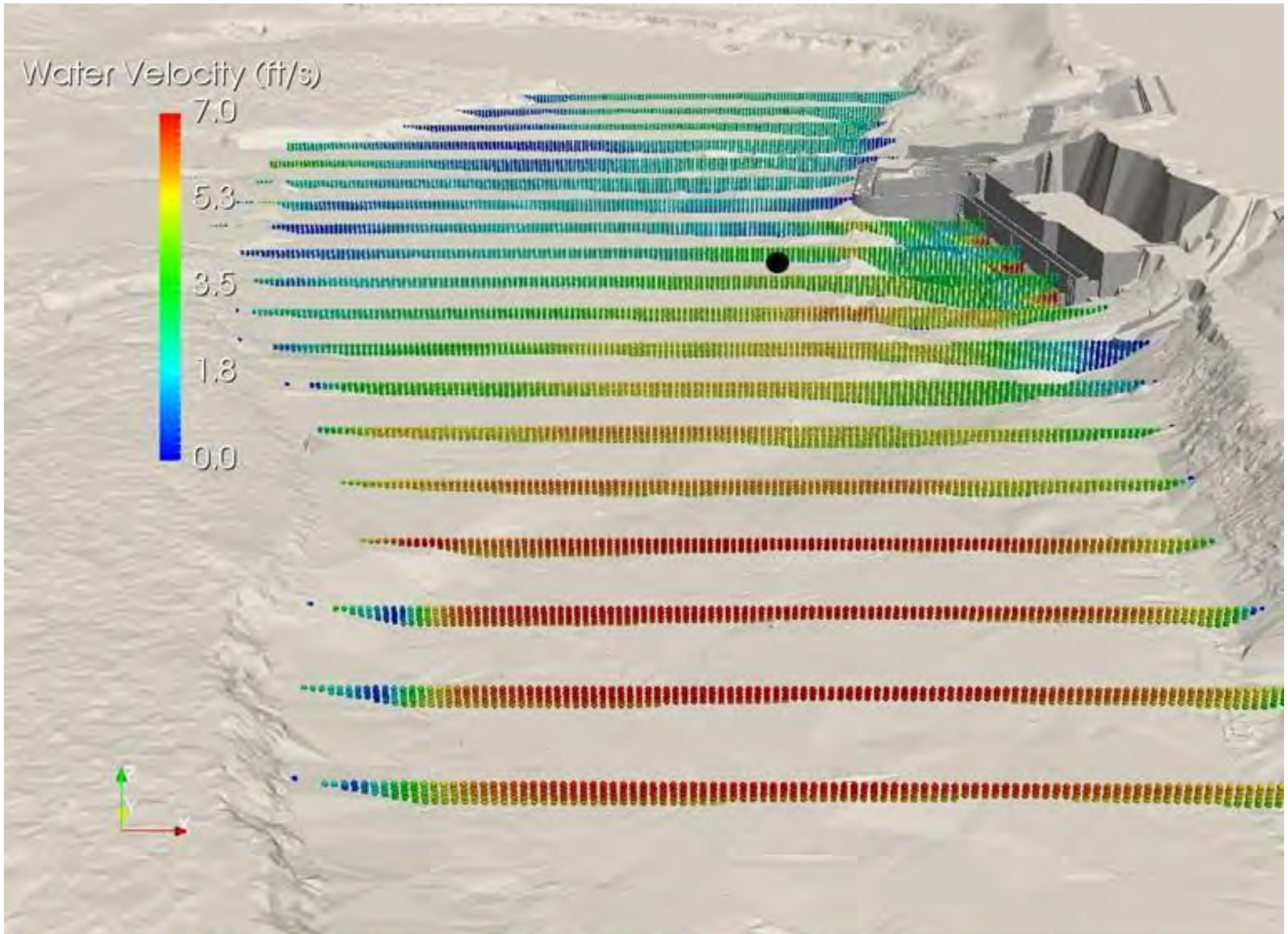
Scenario Number	Cabot Flow (cfs)	Bypass Reach Flow (cfs)	Cabot Fishway Flow (cfs)	Total Flow (cfs)	Water Surface Elevation (ft)
5-4	13,728	6,501	368	20,597 (April 75% exc.)	114.5 ●

Figure 8.4.4-8: PR 5-4 Water Velocity Vector Plots for Cross-Sections Parallel to Cabot Station, Looking Upstream Toward the Cabot Powerhouse
Total model flow is 20,597 cfs. Scaled from 0-7 fps.



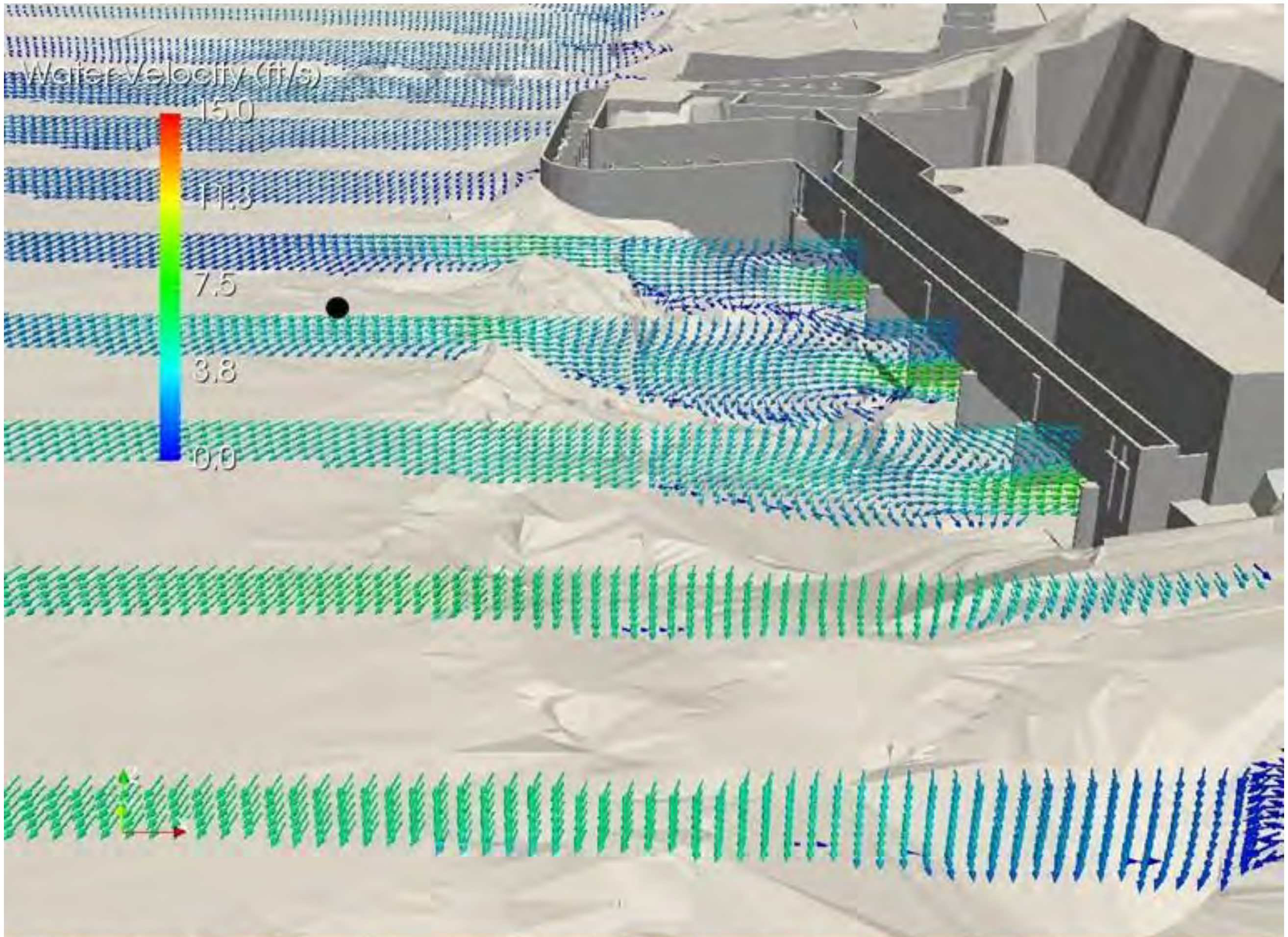
Scenario Number	Cabot Flow (cfs)	Bypass Reach Flow (cfs)	Cabot Fishway Flow (cfs)	Total Flow (cfs)	Water Surface Elevation (ft)
5-4	13,728	6,501	368	20,597 (April 75% exc.)	114.5 ●

Figure 8.4.4-9: PR 5-4 Cross-Sections Showing Water Velocity Across the River's Left Channel
Total model flow is 20,597 cfs. Scaled from 0-15 fps.



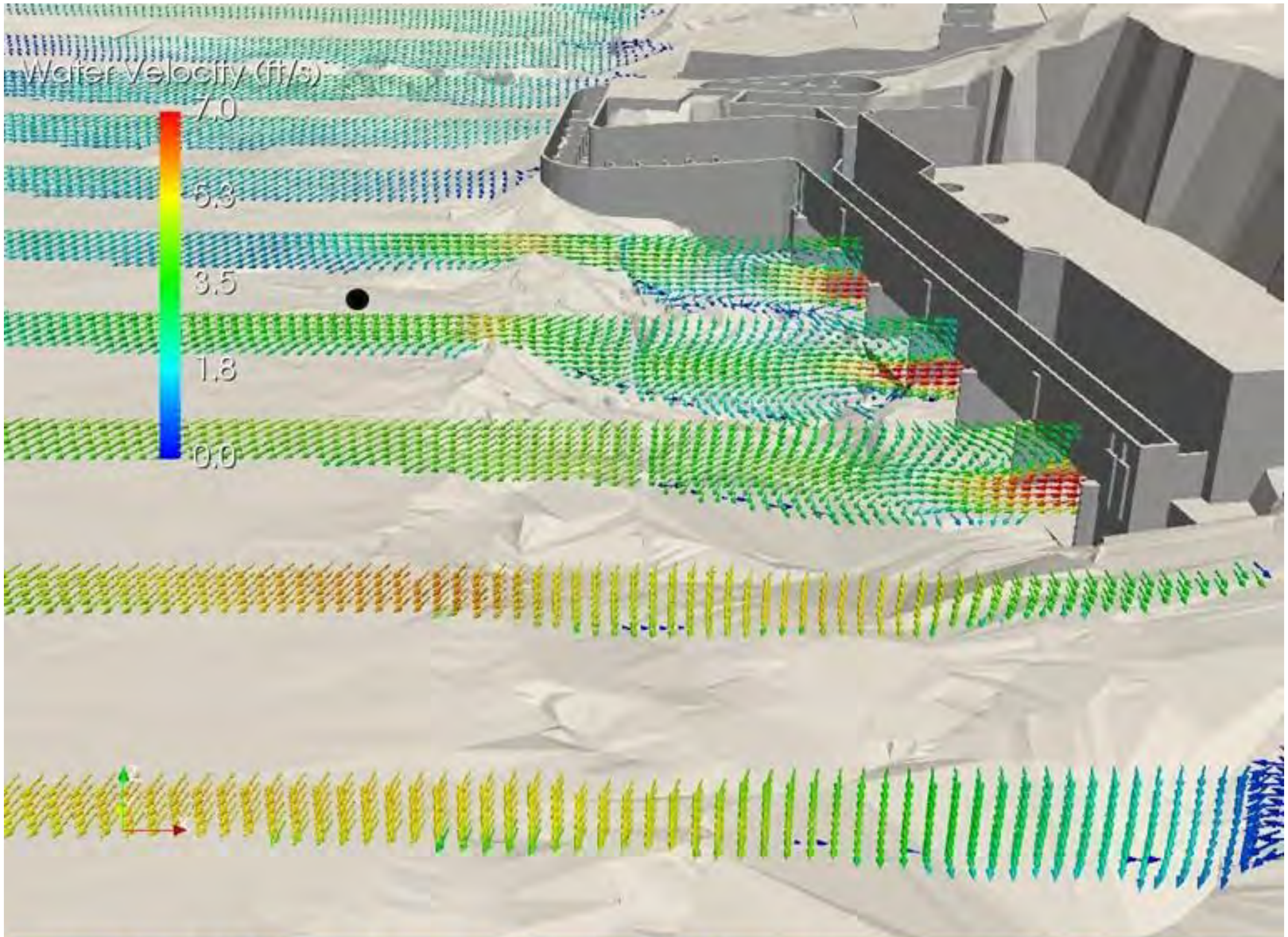
Scenario Number	Cabot Flow (cfs)	Bypass Reach Flow (cfs)	Cabot Fishway Flow (cfs)	Total Flow (cfs)	Water Surface Elevation (ft)
5-4	13,728	6,501	368	20,597 (April 75% exc.)	114.5 ●

Figure 8.4.4-10: PR 5-4 Cross-Sections Showing Water Velocity Across the River's Left Channel
Total model flow is 20,597 cfs. Scaled from 0-7 fps.



Scenario Number	Cabot Flow (cfs)	Bypass Reach Flow (cfs)	Cabot Fishway Flow (cfs)	Total Flow (cfs)	Water Surface Elevation (ft)
5-4	13,728	6,501	368	20,597 (April 75% exc.)	114.5 ●

Figure 8.4.4-11: PR 5-4 Cross-Sections Showing Water Velocity Near the Cabot Station Draft Tubes
Total model flow is 20,597 cfs. Scaled from 0-15 fps.



Scenario Number	Cabot Flow (cfs)	Bypass Reach Flow (cfs)	Cabot Fishway Flow (cfs)	Total Flow (cfs)	Water Surface Elevation (ft)
5-4	13,728	6,501	368	20,597 (April 75% exc.)	114.5 ●

Figure 8.4.4-12: PR 5-4 Cross-Sections Showing Water Velocity near the Cabot Station Draft Tubes
Total model flow is 20,597 cfs. Scaled from 0-7 fps.

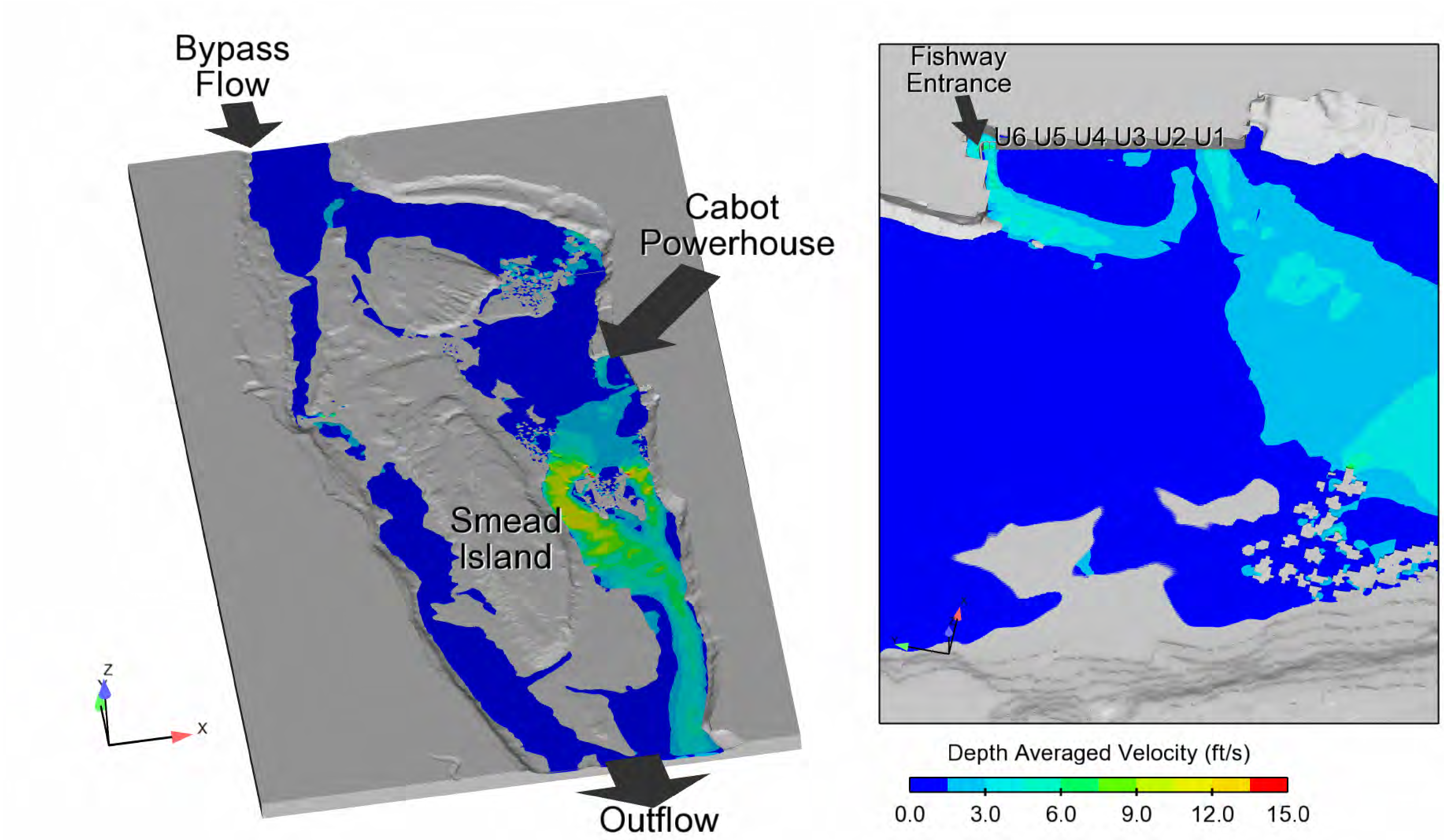


Figure 8.4.5-1: Depth-Averaged Water Velocities for the Full Study Area (Left) and Near Cabot Station (Right) for PR 5-5
Total model flow is 30,336 cfs. Scaled from 0-15 fps.

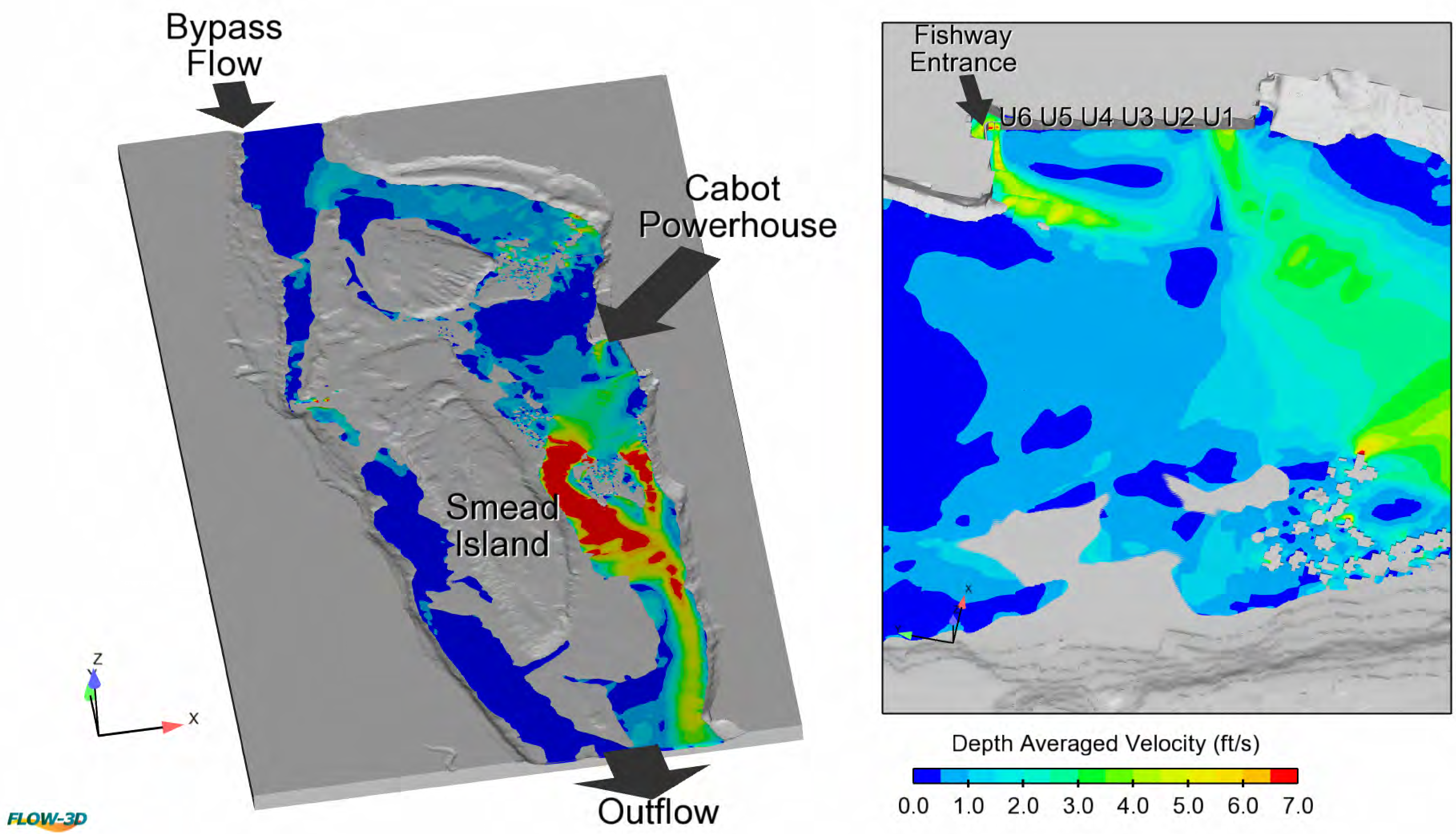


Figure 8.4.5-2: Depth-averaged water velocities for the full study area (left) and near Cabot Station (right) for PR 5-5
Total model flow is 30,336 cfs. Scaled from 0-7 fps.

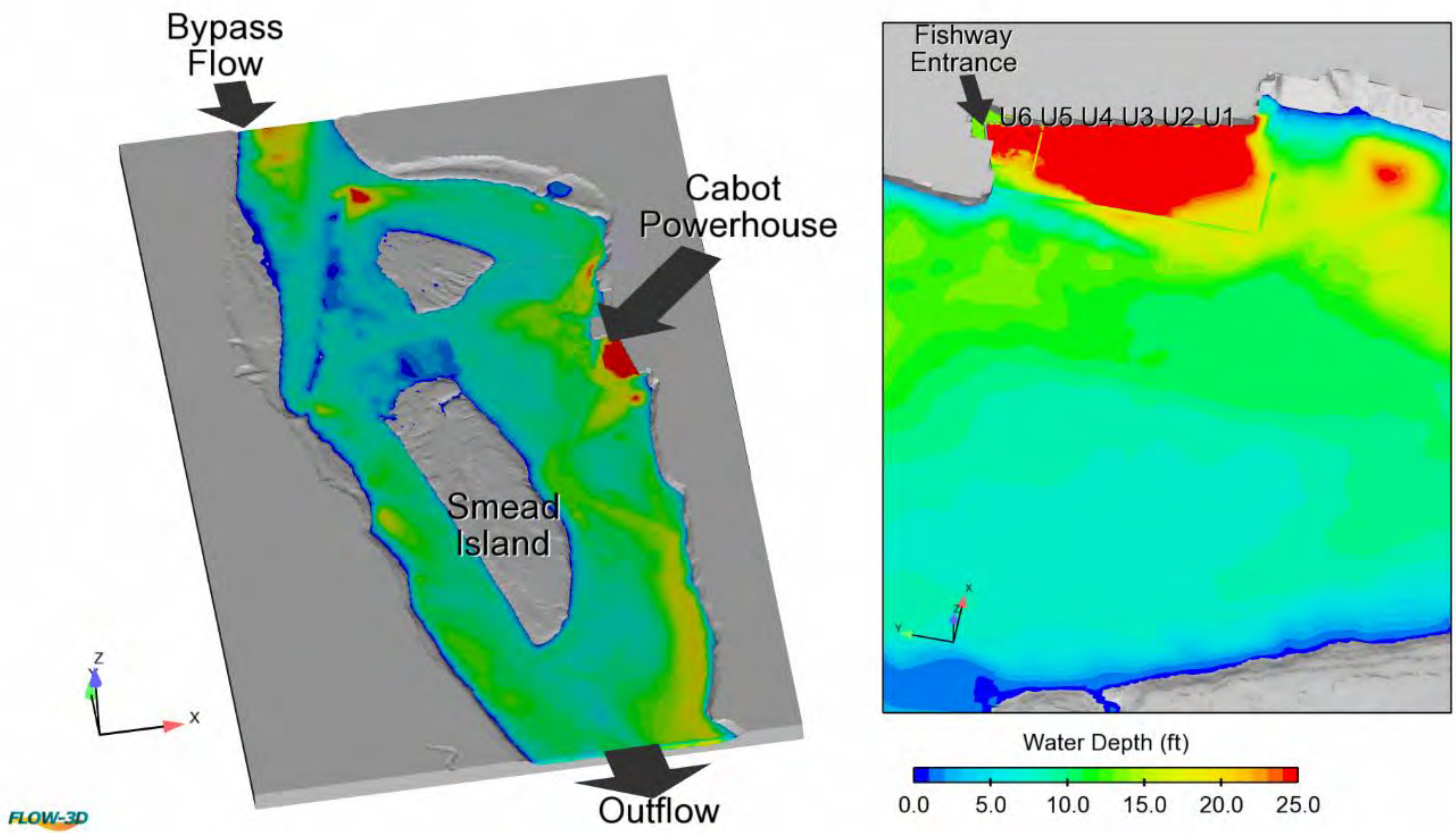


Figure 8.4.5-3: PR 5-5 Modeled Water Depths
Total model flow is 30,336 cfs.

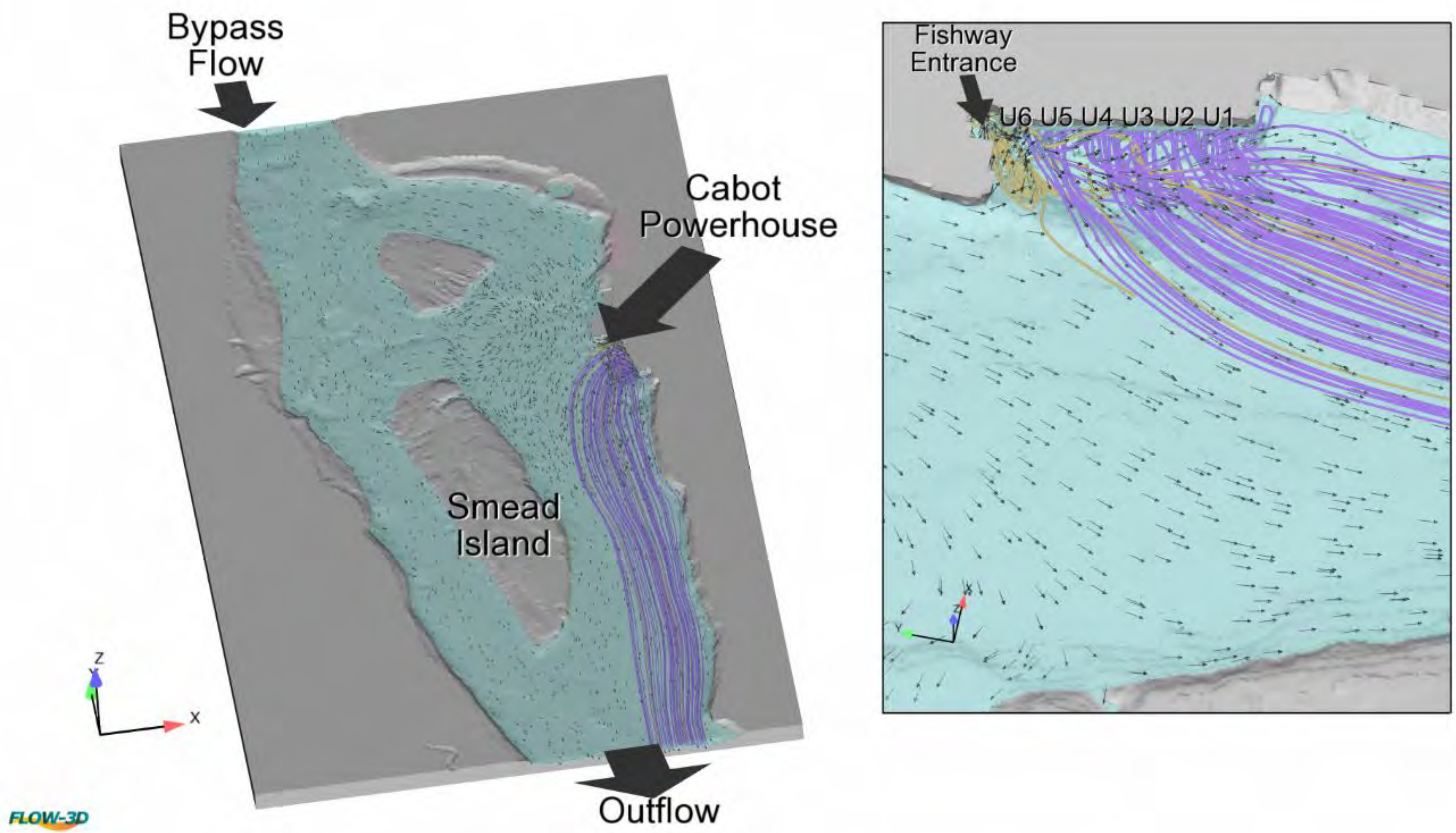
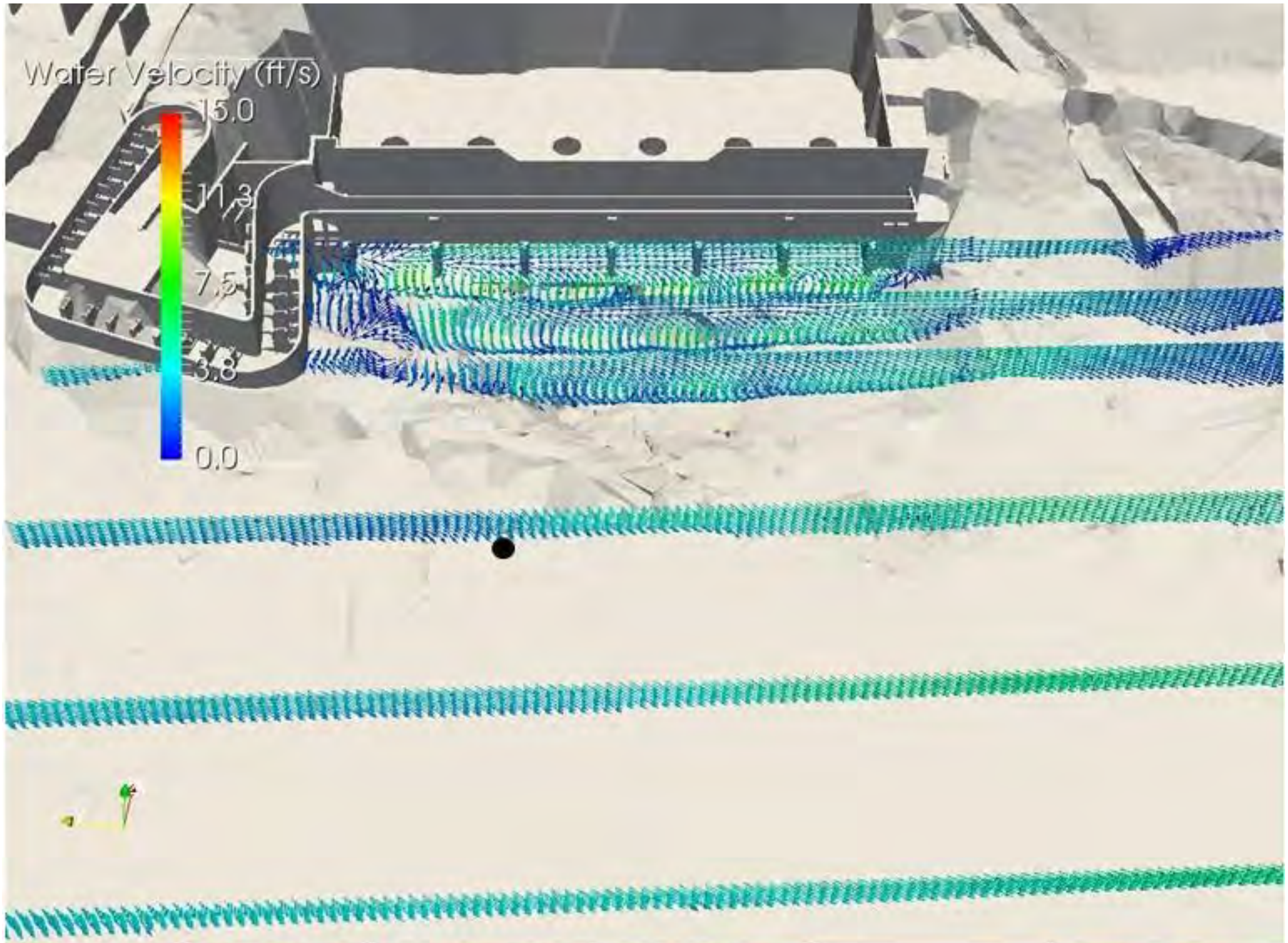


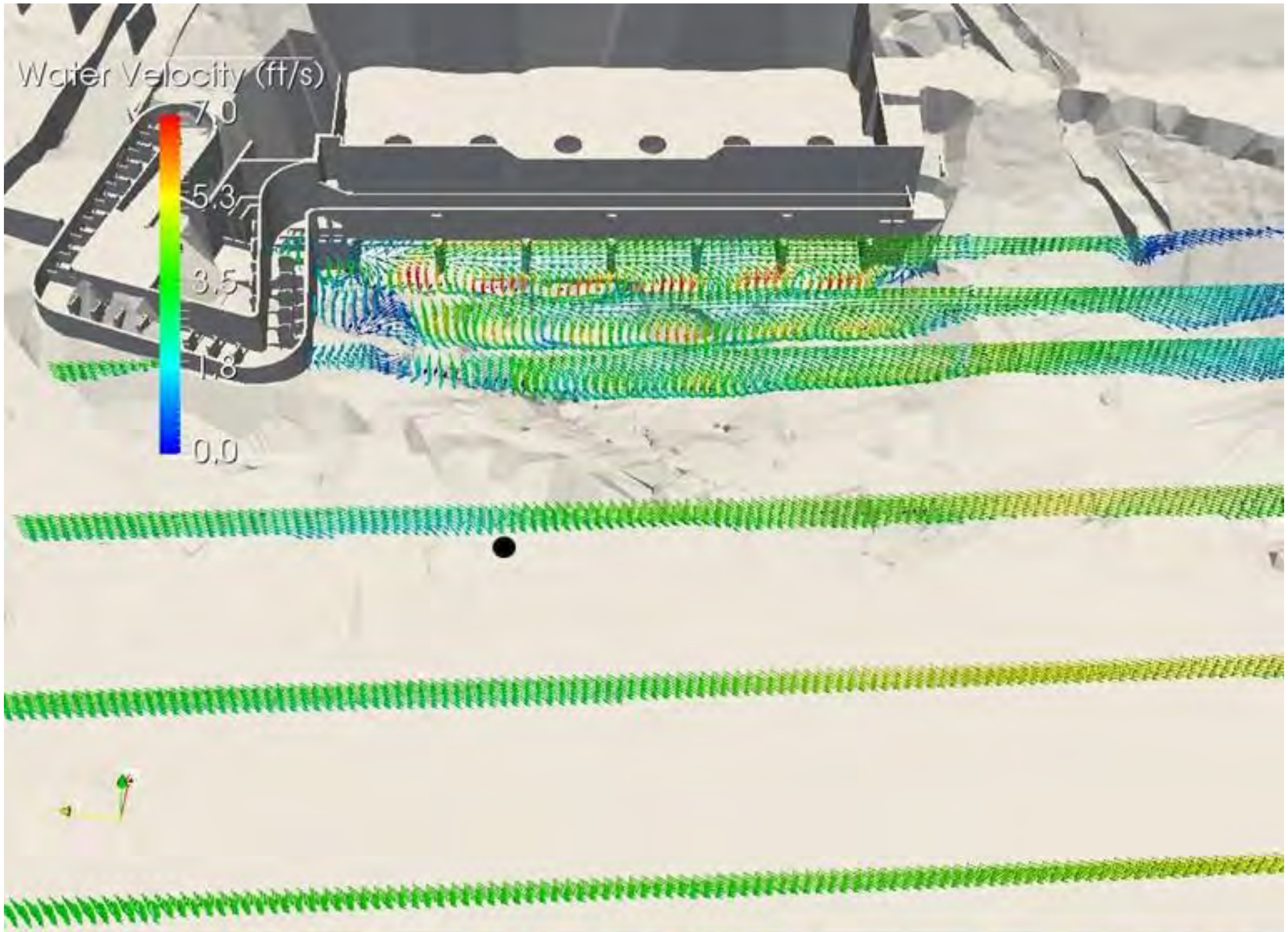
Figure 8.4.5-4: PR 5-5 Modeled Streamlines and Velocity Vectors

The black arrows indicate flow direction. The streamlines represent the path of water released from the Spillway fishway (orange) or Cabot Station (purple). Total model flow is 30,336 cfs.



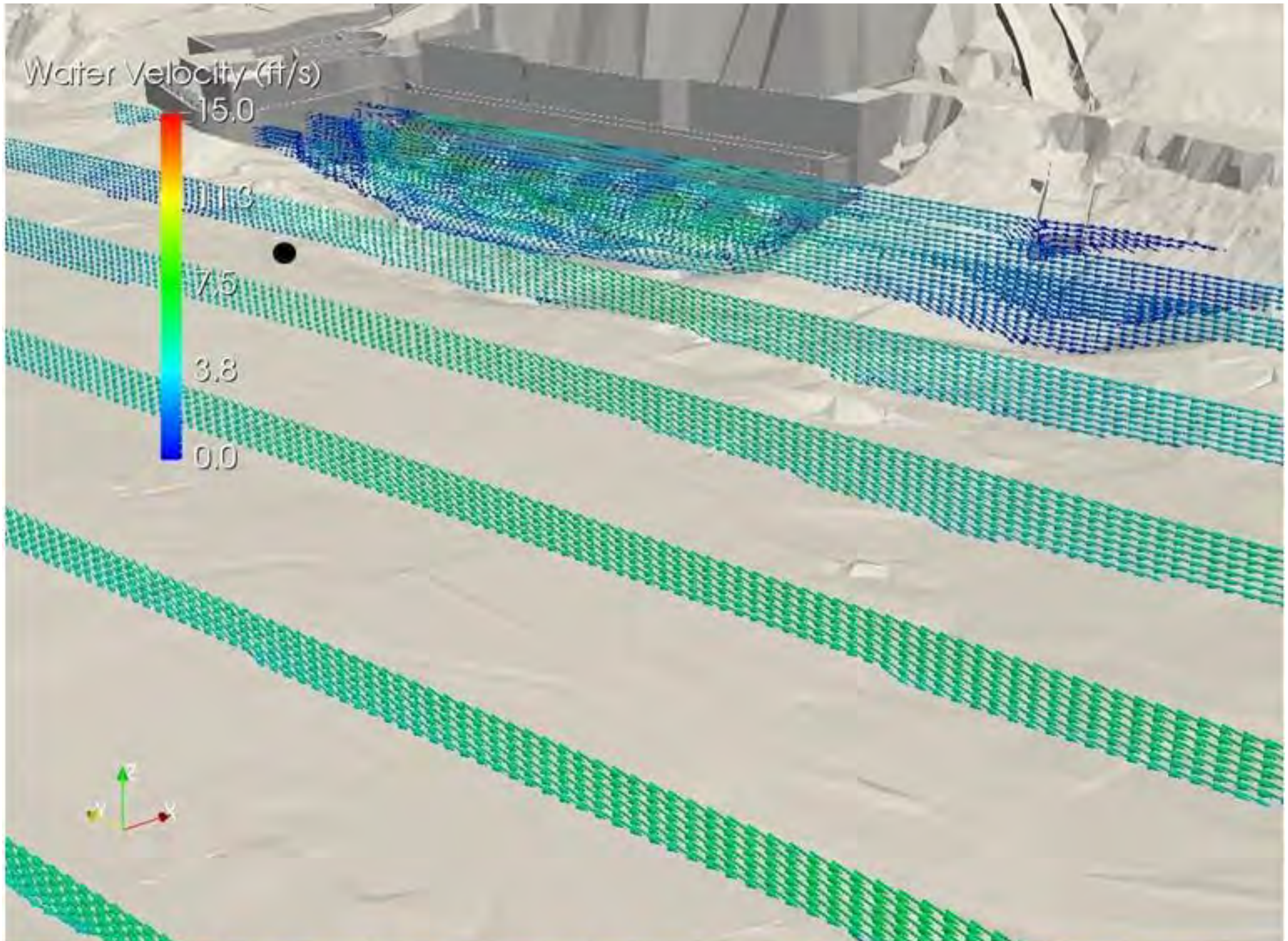
Scenario Number	Cabot Flow (cfs)	Bypass Reach Flow (cfs)	Cabot Fishway Flow (cfs)	Total Flow (cfs)	Water Surface Elevation (ft)
5-5	13,728	16,240	368	30,336 (April 50% exc.)	117.5 ●

Figure 8.4.5-5: PR 5-5 Water Velocity Vector Plots for Cross-Sections Parallel to Cabot Station, Looking From the Center of the River
Total model flow is 30,336 cfs. Scaled from 0-15 fps.



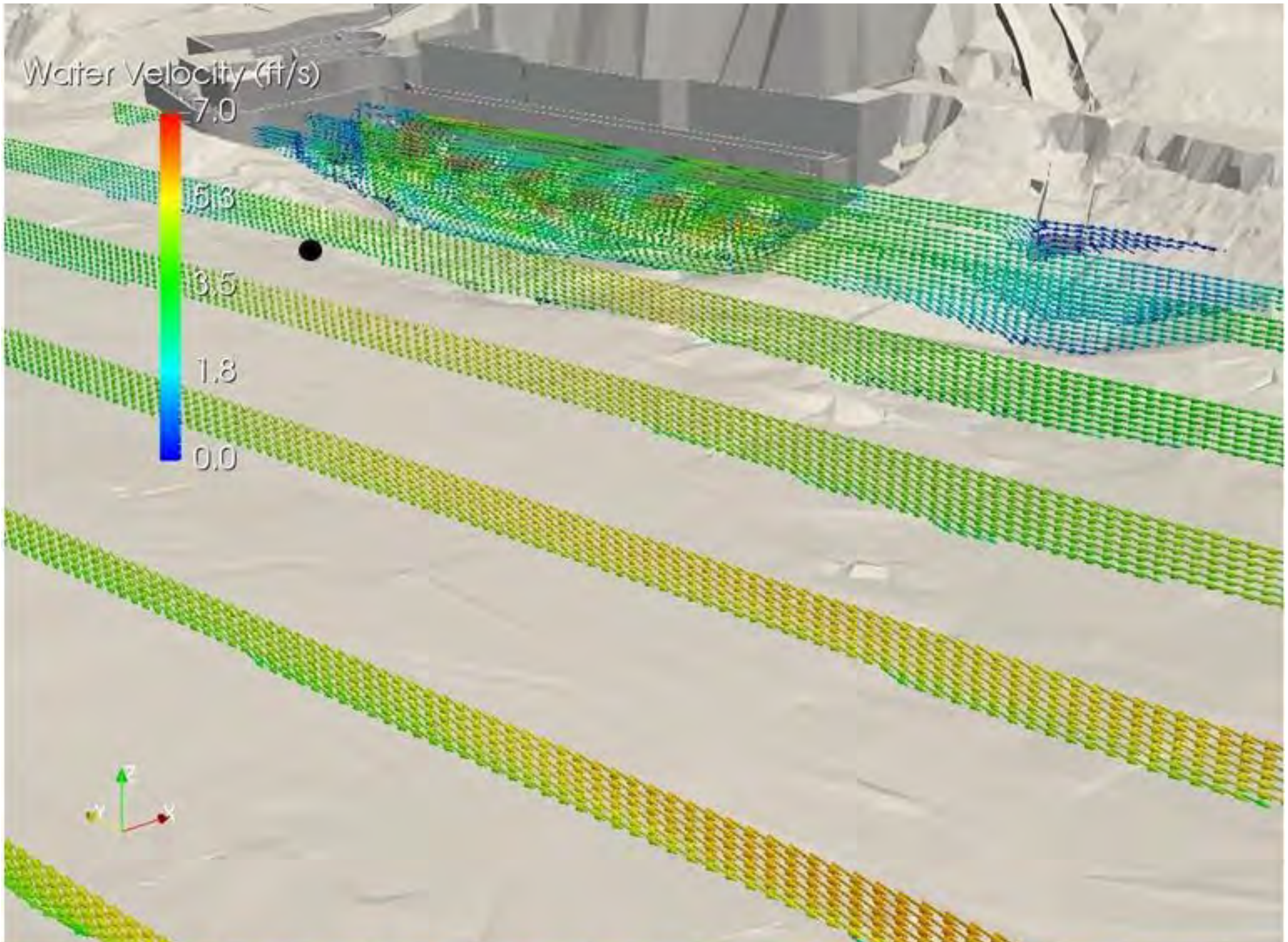
Scenario Number	Cabot Flow (cfs)	Bypass Reach Flow (cfs)	Cabot Fishway Flow (cfs)	Total Flow (cfs)	Water Surface Elevation (ft)
5-5	13,728	16,240	368	30,336 (April 50% exc.)	117.5 ●

Figure 8.4.5-6: PR 5-5 Water Velocity Vector Plots for Cross-Sections Parallel to Cabot Station, Looking from the Center of the River.
Total model flow is 30,336 cfs. Scaled from 0-7 fps.



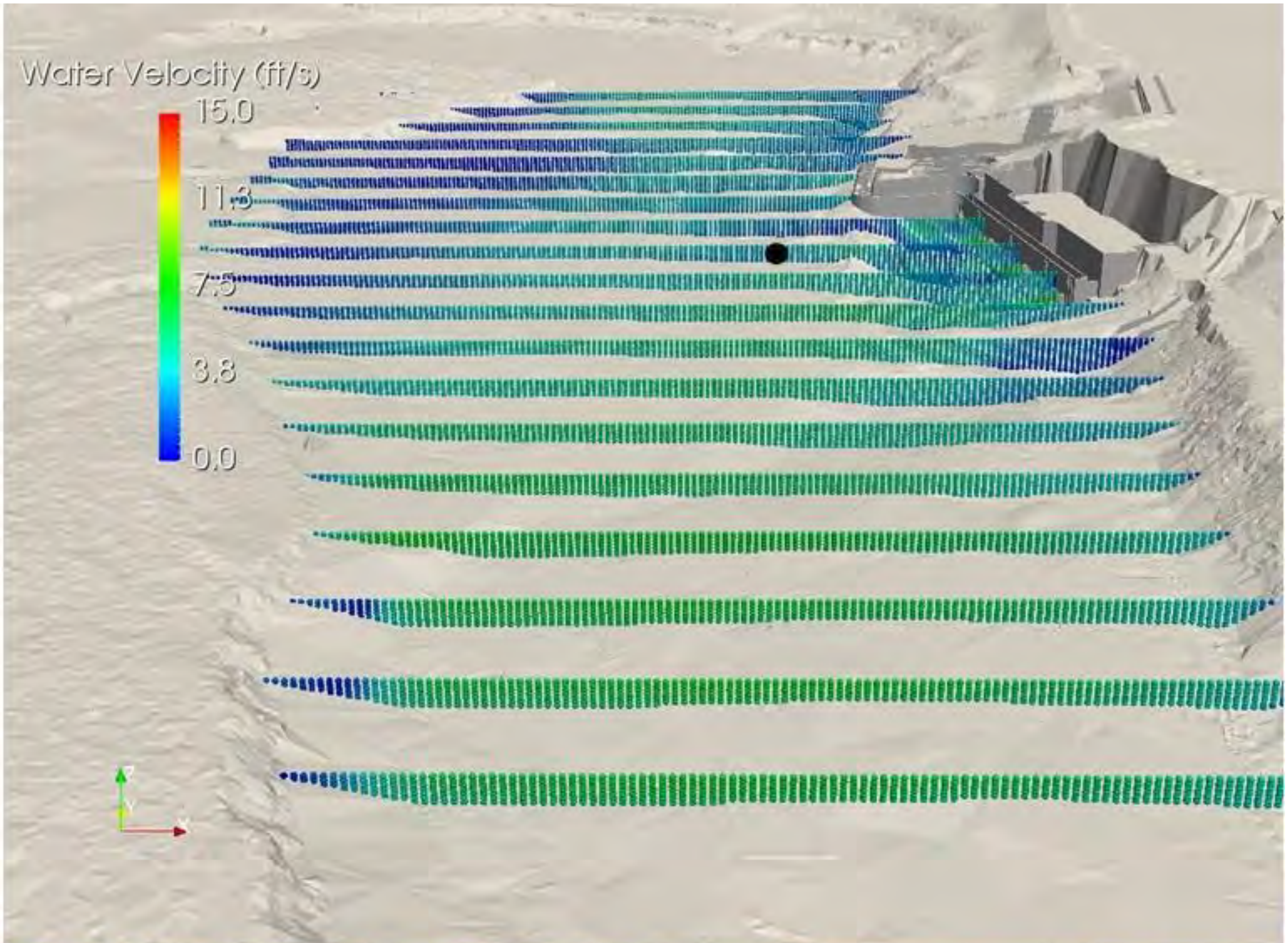
Scenario Number	Cabot Flow (cfs)	Bypass Reach Flow (cfs)	Cabot Fishway Flow (cfs)	Total Flow (cfs)	Water Surface Elevation (ft)
5-5	13,728	16,240	368	30,336 (April 50% exc.)	117.5 ●

Figure 8.4.5-7: PR 5-5 Water Velocity Vector Plots for Cross-Sections Parallel to Cabot Station, Looking Upstream toward the Cabot Powerhouse
Total model flow is 30,336 cfs. Scaled from 0-15 fps.



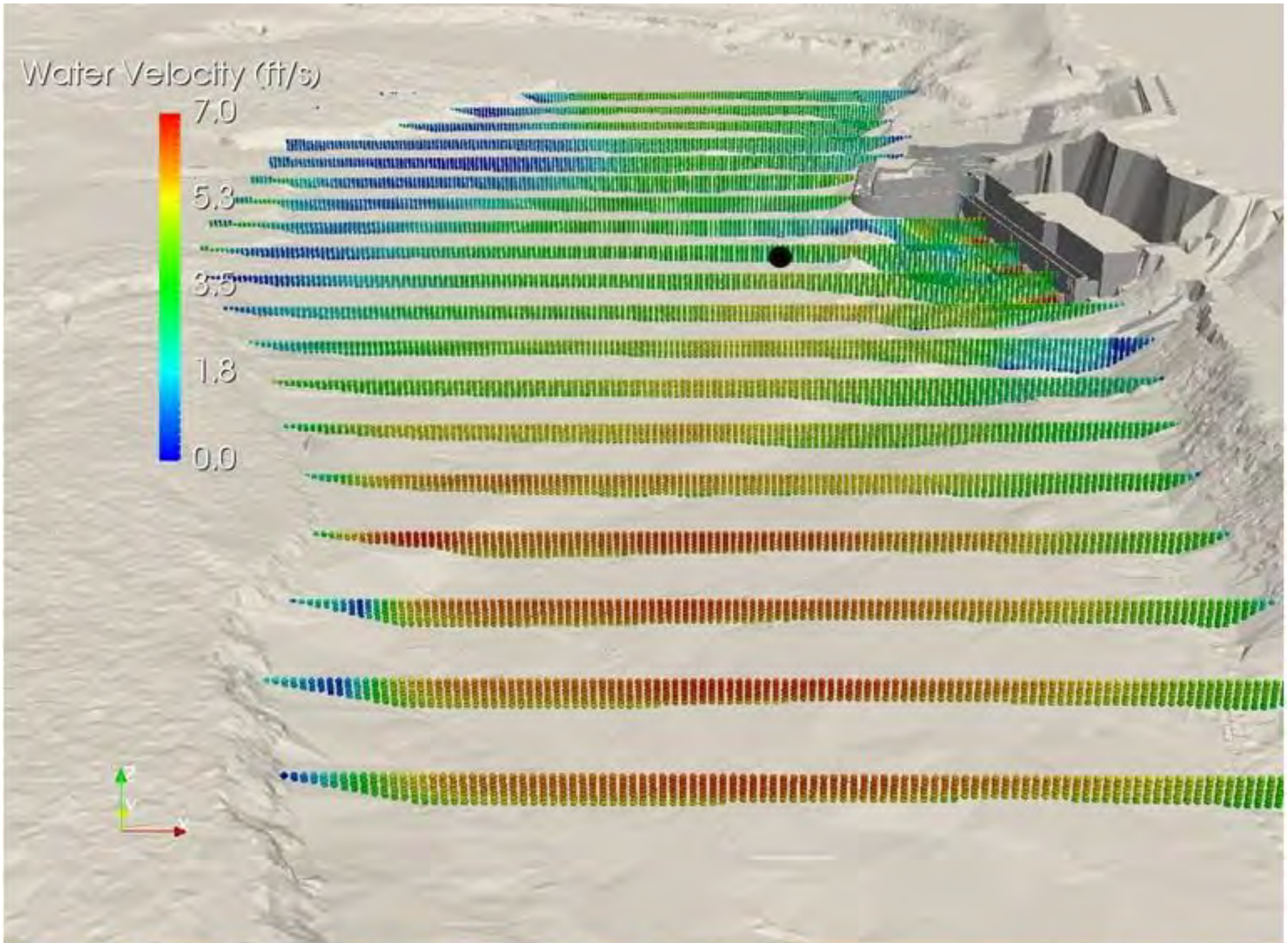
Scenario Number	Cabot Flow (cfs)	Bypass Reach Flow (cfs)	Cabot Fishway Flow (cfs)	Total Flow (cfs)	Water Surface Elevation (ft)
5-5	13,728	16,240	368	30,336 (April 50% exc.)	117.5 ●

Figure 8.4.5-8: PR 5-5 Water Velocity Vector Plots for Cross-Sections Parallel to Cabot Station, Looking Upstream toward the Cabot Powerhouse Total Model Flow is 30,336 cfs. Scaled from 0-7 fps.



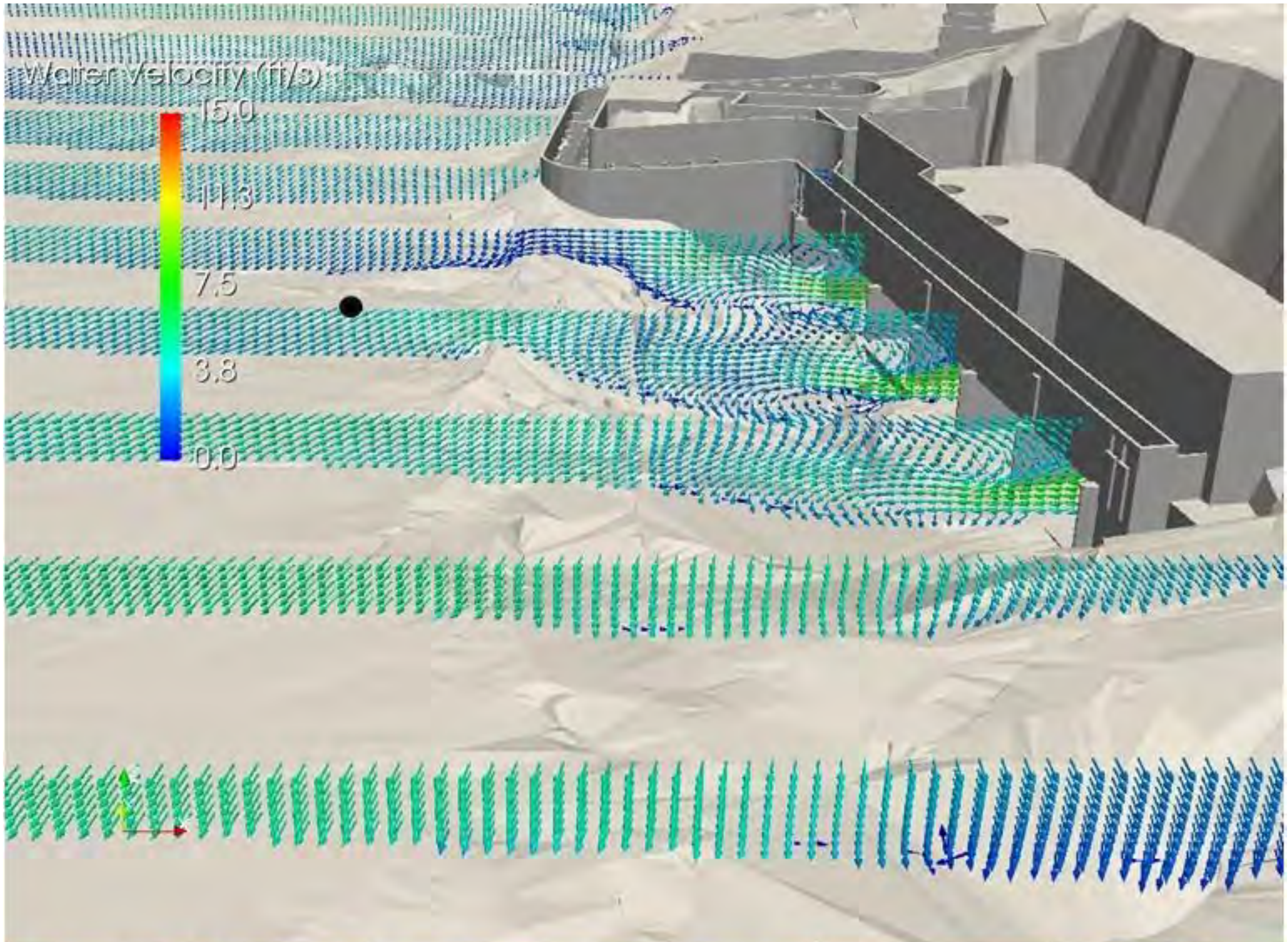
Scenario Number	Cabot Flow (cfs)	Bypass Reach Flow (cfs)	Cabot Fishway Flow (cfs)	Total Flow (cfs)	Water Surface Elevation (ft)
5-5	13,728	16,240	368	30,336 (April 50% exc.)	117.5 ●

Figure 8.4.5-9: PR 5-5 Cross-Sections Showing Water Velocity Across the River's Left Channel
Total model flow is 30,336 cfs. Scaled from 0-15 fps.



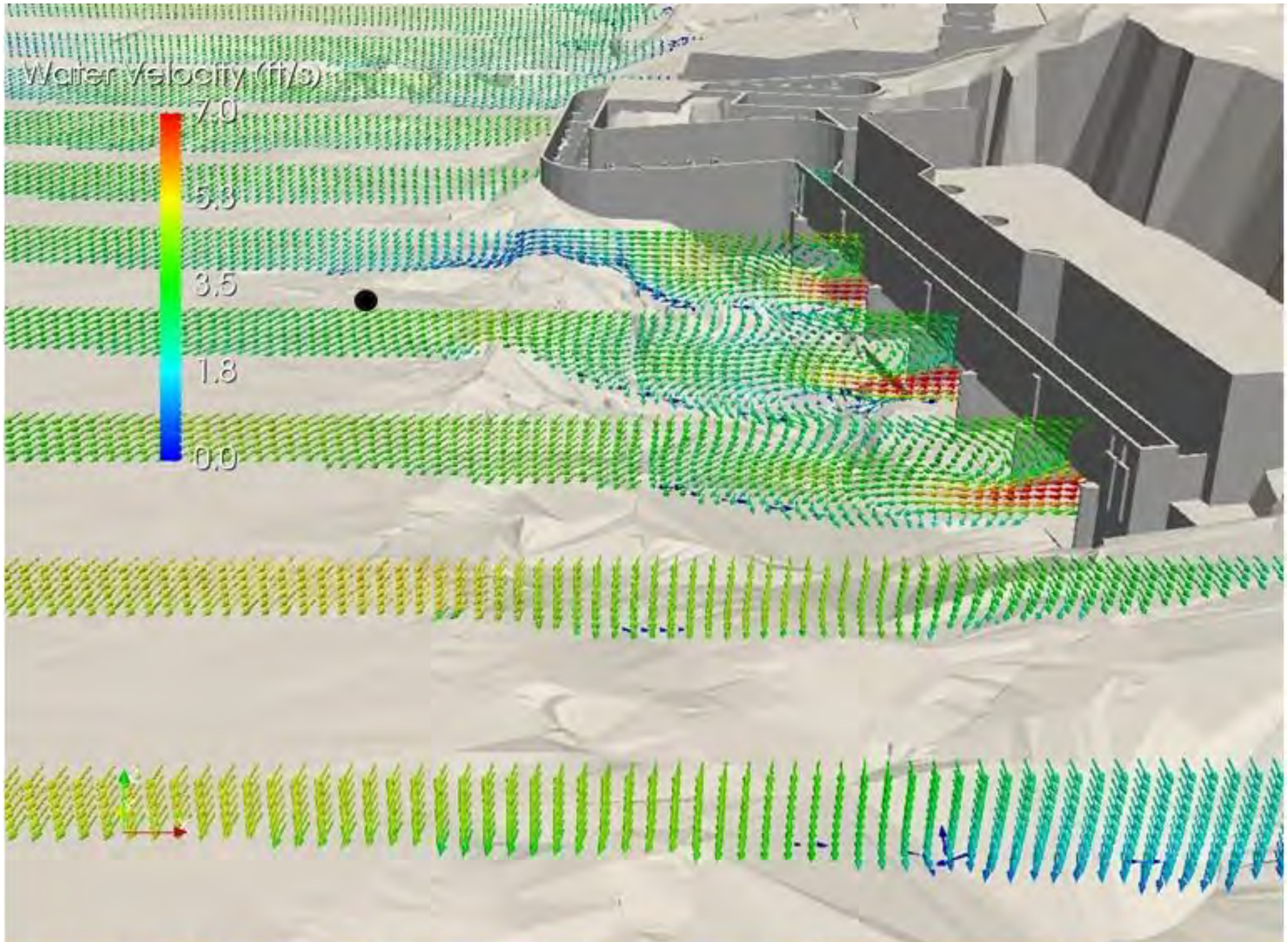
Scenario Number	Cabot Flow (cfs)	Bypass Reach Flow (cfs)	Cabot Fishway Flow (cfs)	Total Flow (cfs)	Water Surface Elevation (ft)
5-5	13,728	16,240	368	30,336 (April 50% exc.)	117.5 ●

Figure 8.4.5-10: PR 5-5 Cross-Sections Showing Water Velocity Across the River's Left Channel
Total model flow is 30,336 cfs. Scaled from 0-7 fps.



Scenario Number	Cabot Flow (cfs)	Bypass Reach Flow (cfs)	Cabot Fishway Flow (cfs)	Total Flow (cfs)	Water Surface Elevation (ft)
5-5	13,728	16,240	368	30,336 (April 50% exc.)	117.5 ●

Figure 8.4.5-11: PR 5-5 Cross-Sections Showing Water Velocity near the Cabot Station Draft Tubes
Total model flow is 30,336 cfs. Scaled from 0-15 fps.



Scenario Number	Cabot Flow (cfs)	Bypass Reach Flow (cfs)	Cabot Fishway Flow (cfs)	Total Flow (cfs)	Water Surface Elevation (ft)
5-5	13,728	16,240	368	30,336 (April 50% exc.)	117.5 ●

Figure 8.4.5-12: PR 5-5 Cross-Sections Showing Water Velocity Near the Cabot Station Draft Tubes
Total model flow is 30,336 cfs. Scaled from 0-7 fps.

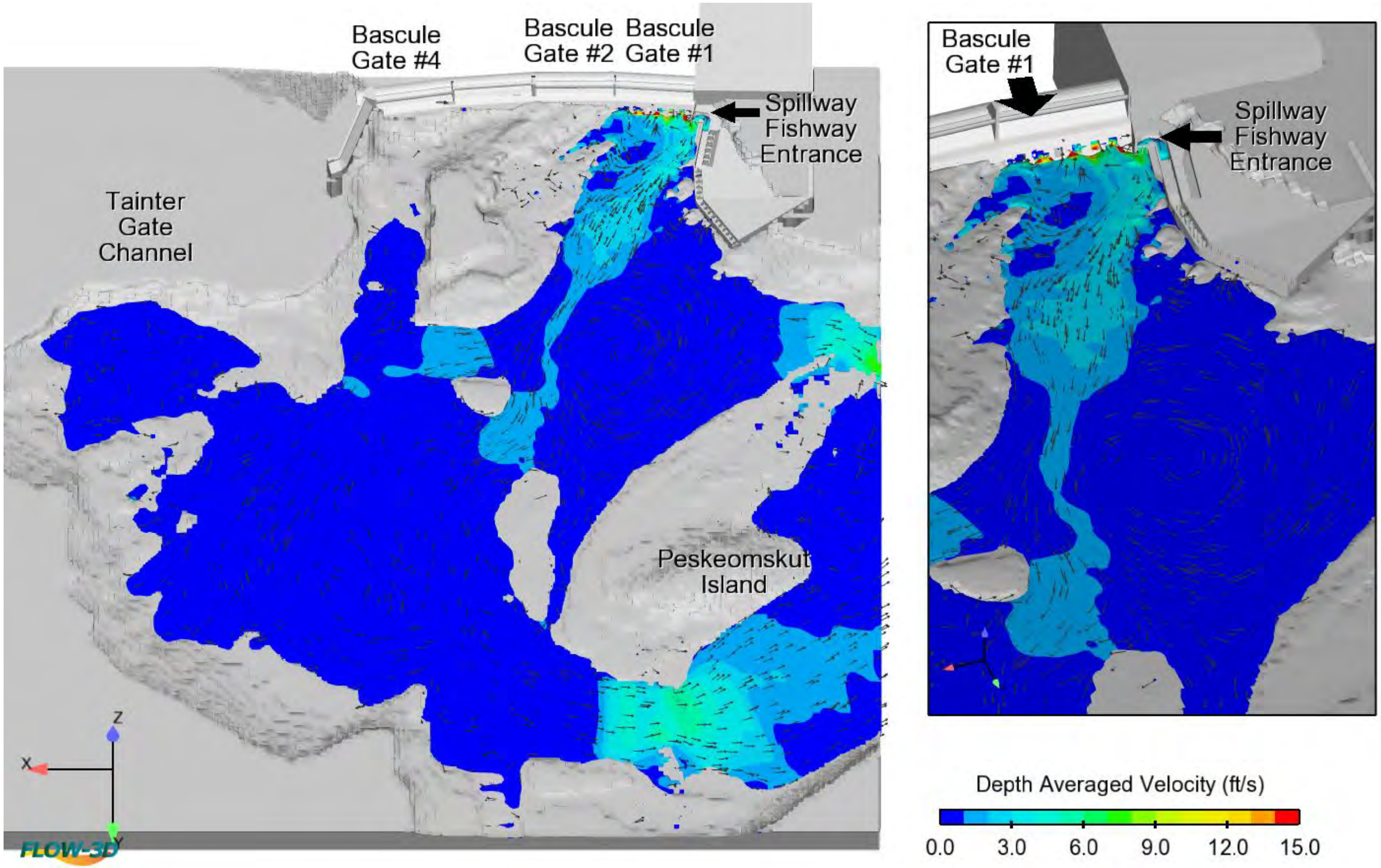


Figure 8.5.1-1: PR 6-1 Depth-Averaged Water Velocities in the Turners Falls Spillway Area
Total flow is 718 cfs. Scaled from 0-15 fps.

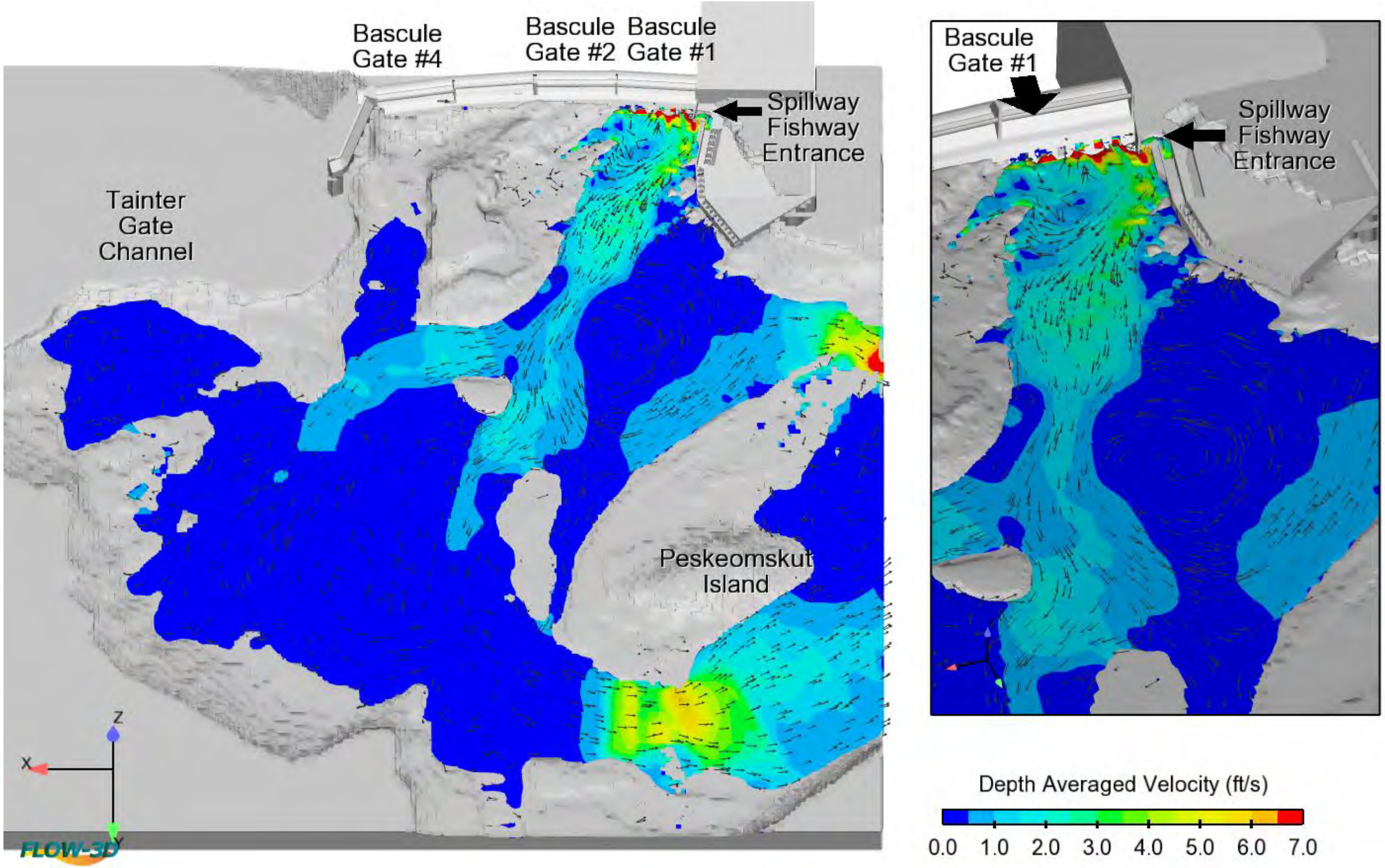


Figure 8.5.1-2: PR 6-1 Depth-Averaged Water Velocities in the Turners Falls Spillway Area
Total flow is 718 cfs. Scaled from 0-7 fps.

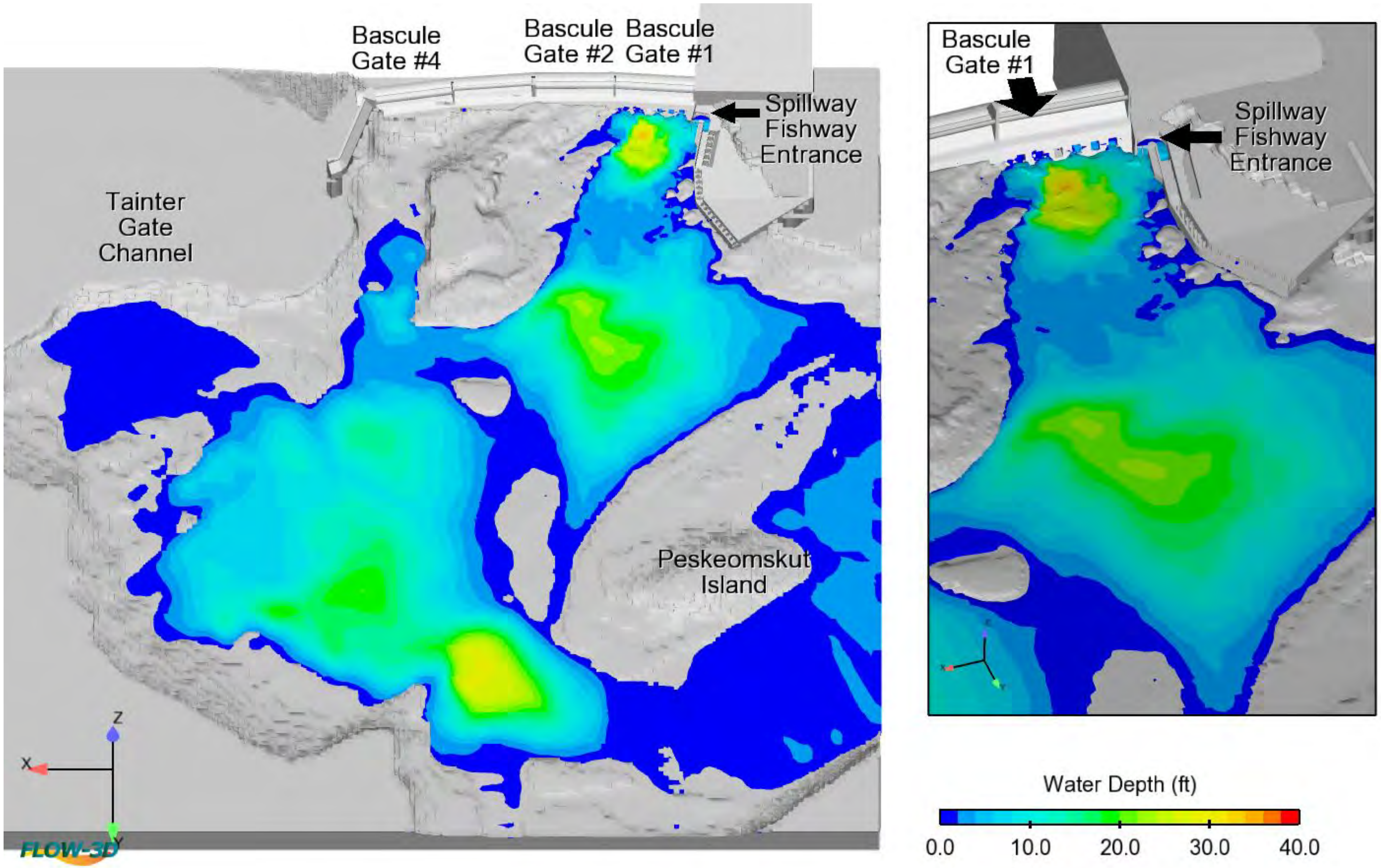


Figure 8.5.1-3: PR 6-1 Water Depths in the Turners Falls Spillway Area
Total flow is 718 cfs. Scaled from 0-40 ft.

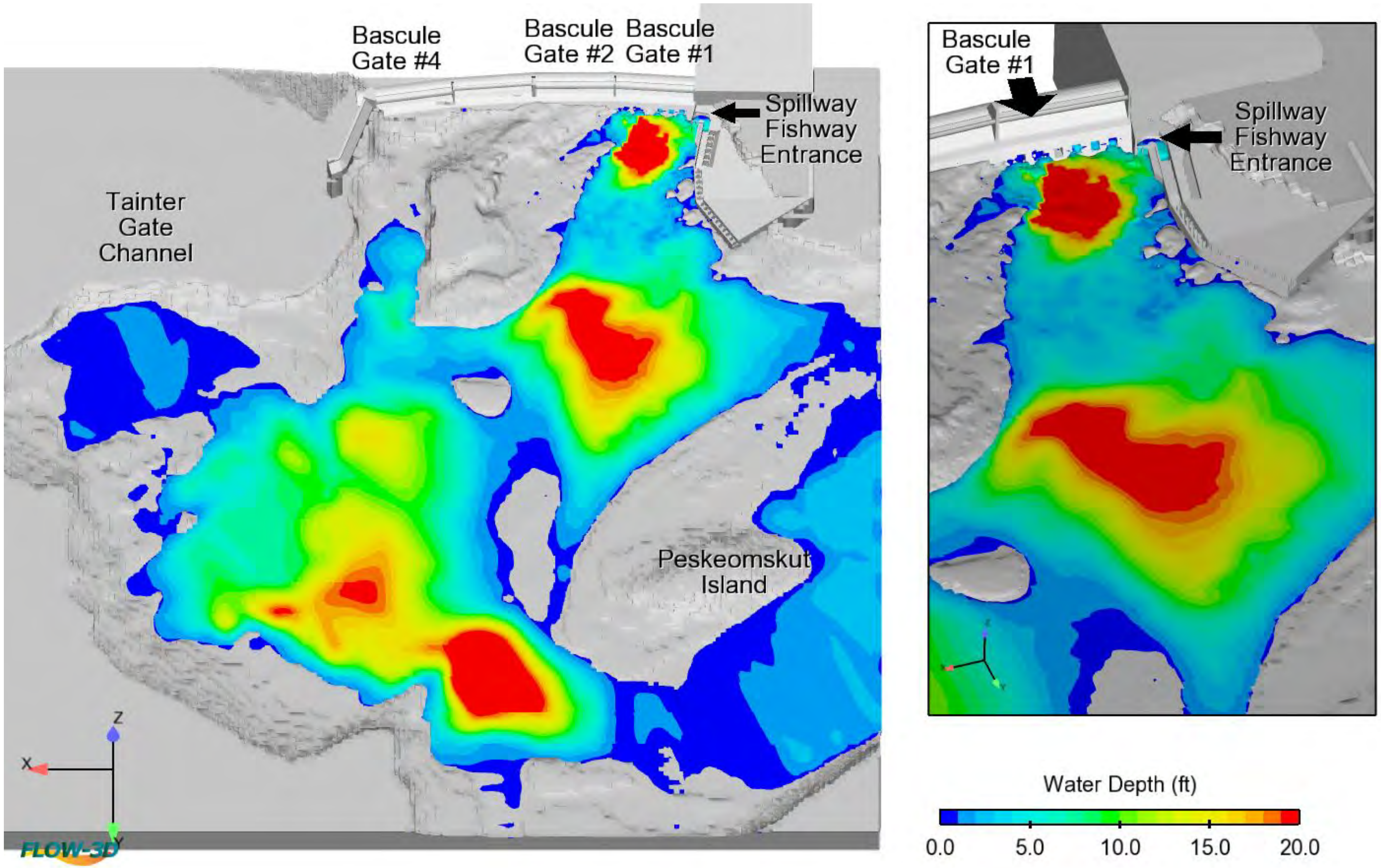


Figure 8.5.1-4: PR 6-1 Water Depths in the Turners Falls Spillway Area
Total flow is 718 cfs. Scaled from 0-20 ft.

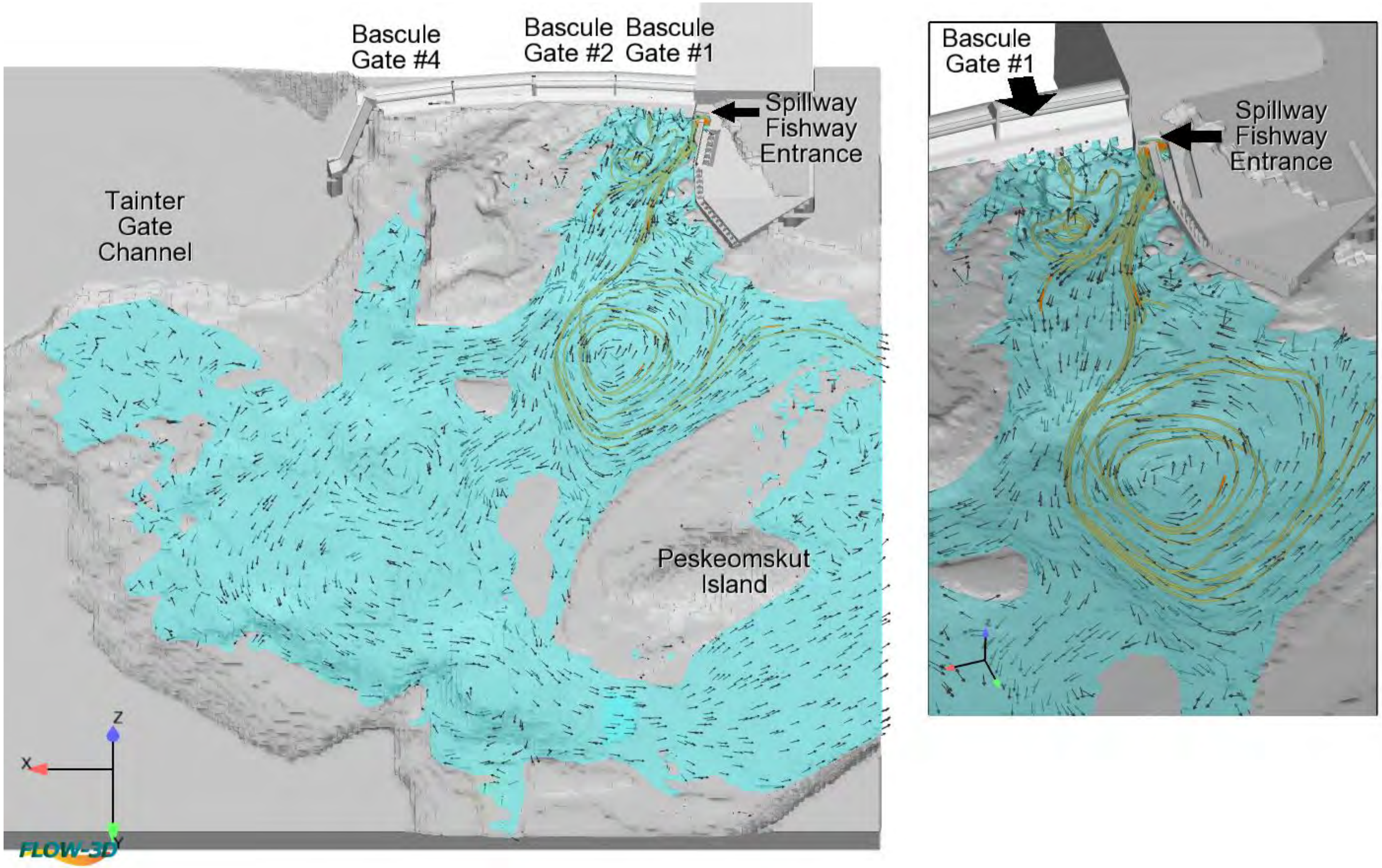
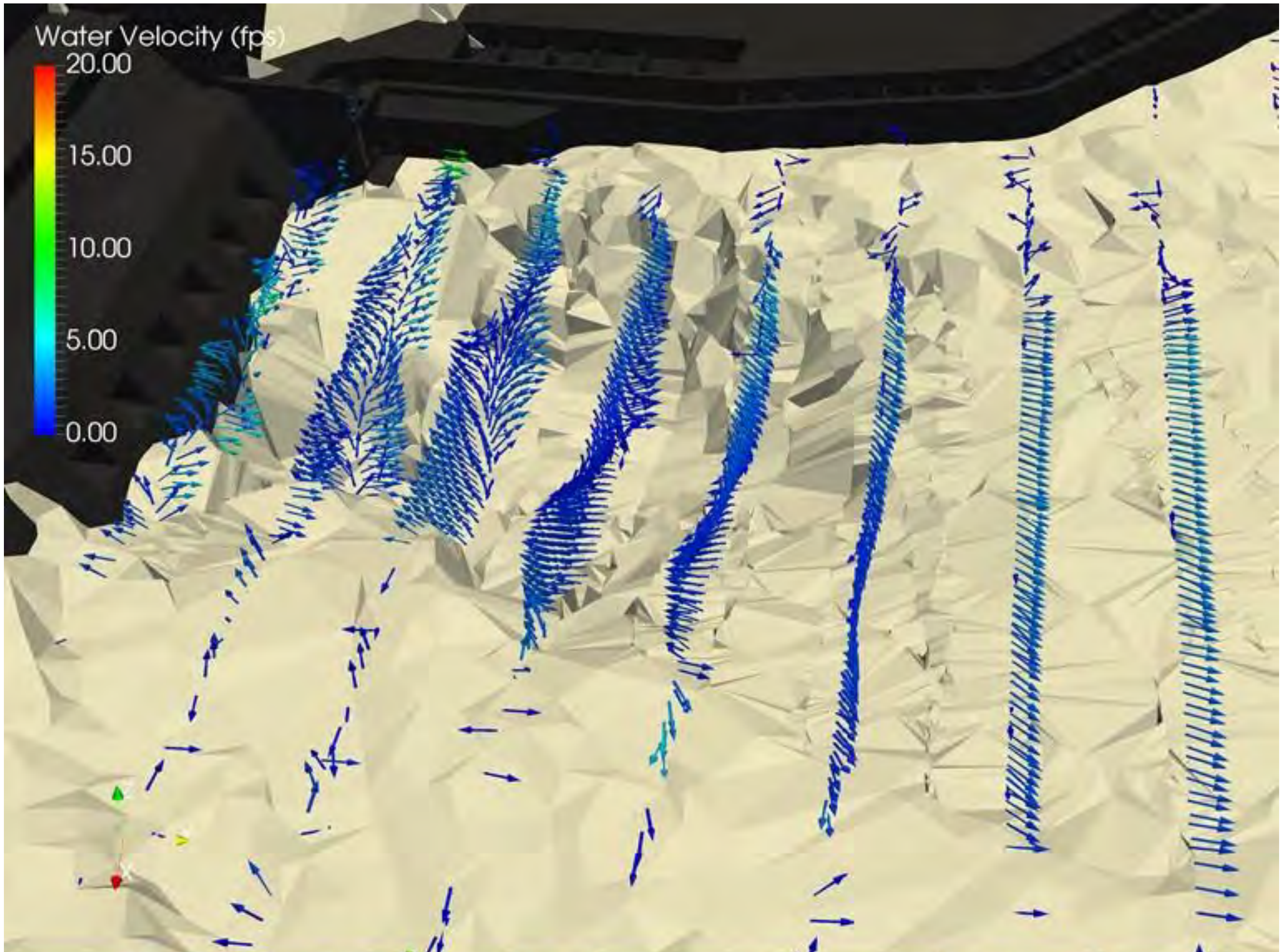
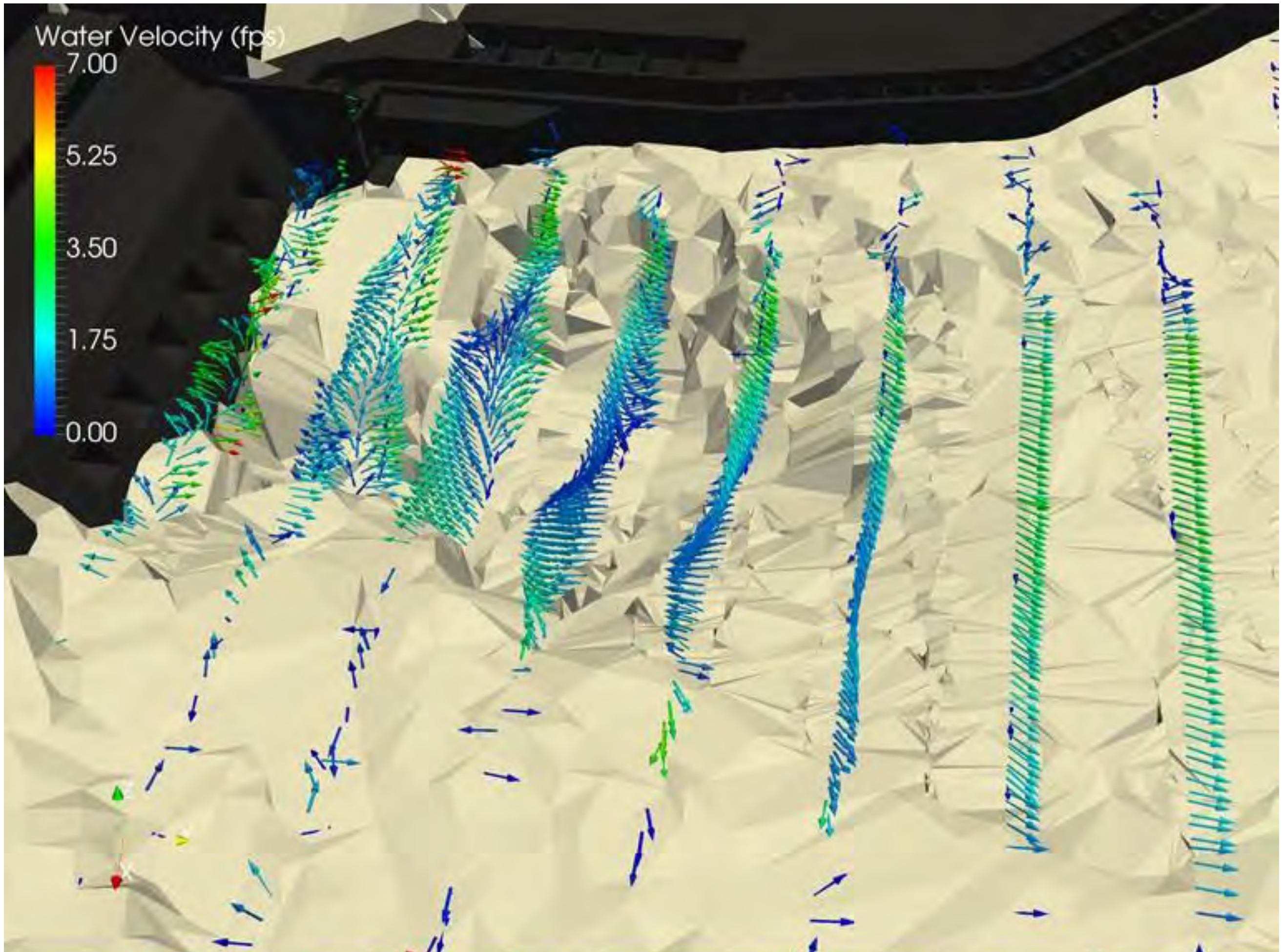


Figure 8.5.1-5: PR 6-1 Modeled Streamlines and Velocity Vectors
The black arrows indicate flow direction. The orange streamlines represent the path of water released from the Spillway fishway. Total model flow is 718 cfs.



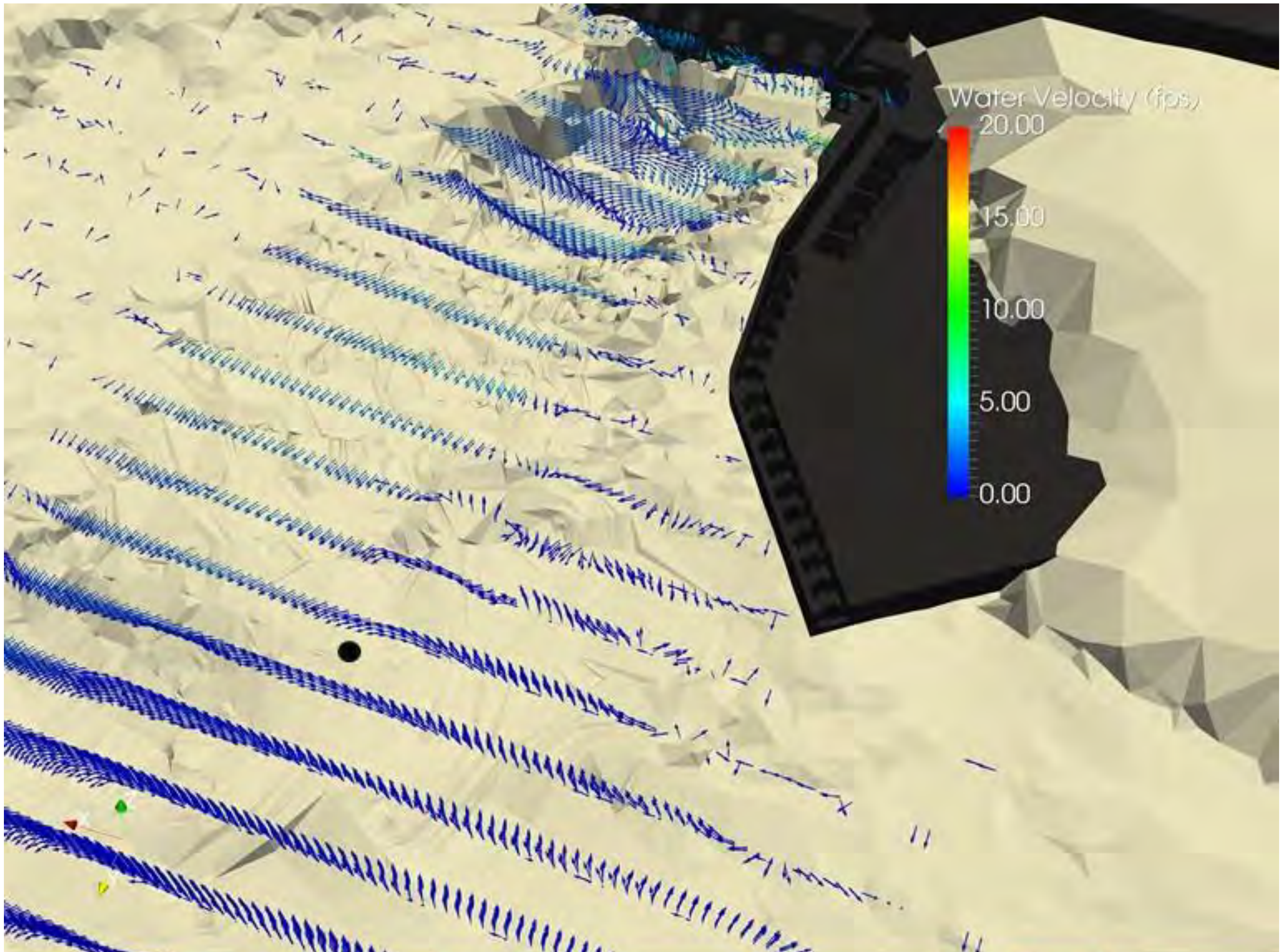
Scenario Number	Power Canal Flow (cfs)	Spillway Ladder Flow (cfs)	Bascule Gate No. 1 Flow (cfs)	Other Bascule Gate Spill (cfs)	Tainter Gate Spill (cfs)	Total Turners Falls Flow (cfs)	Water Surface Elevation (ft)
6-1	7,282	318	400	0	0	8,000	135.4

Figure 8.5.1-6: PR 6-1 Cross-Sections Showing Water Velocity Near the Spillway Fishway
Total model flow is 718 cfs. Scaled from 0-20 fps.



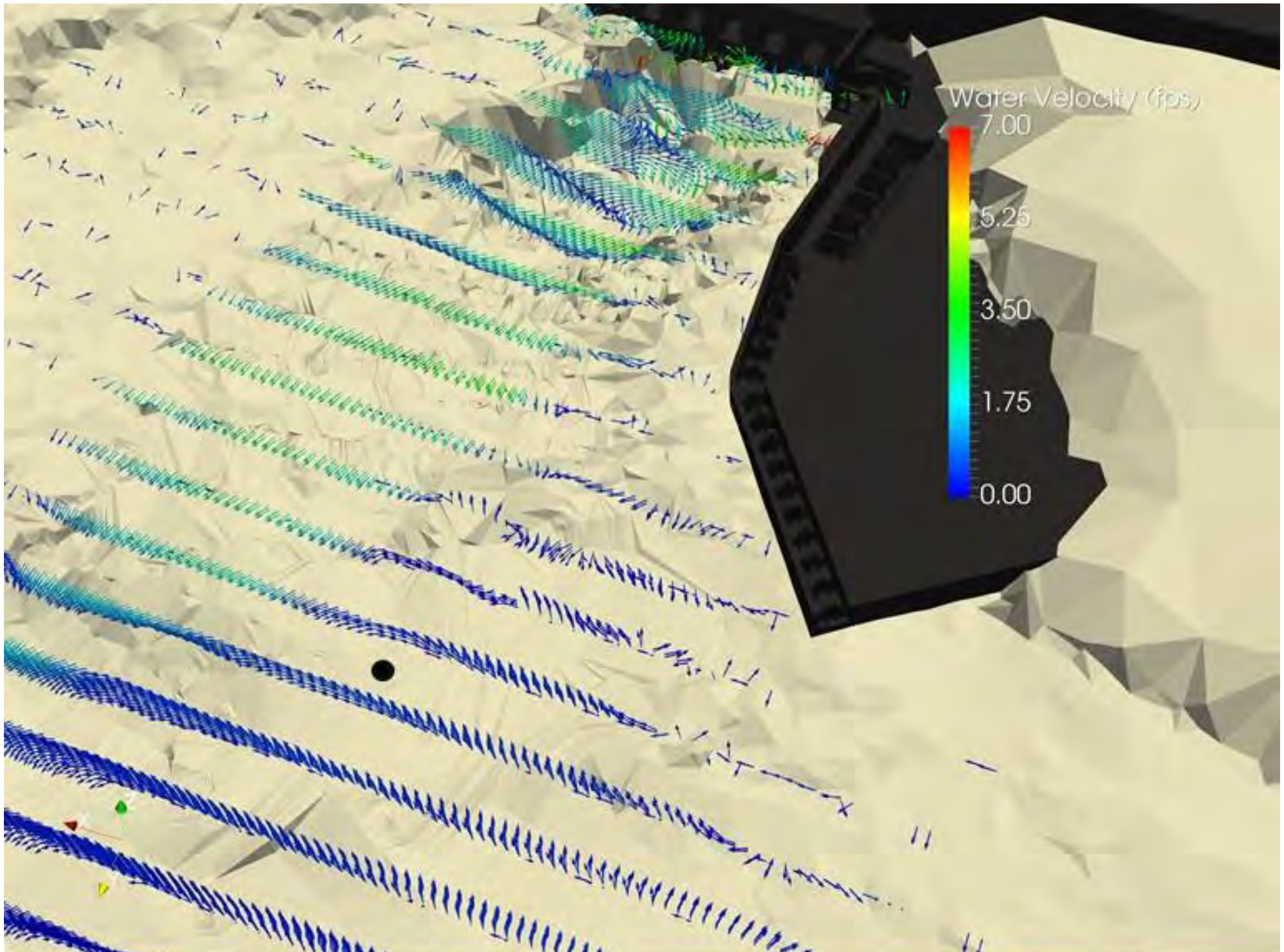
Scenario Number	Power Canal Flow (cfs)	Spillway Ladder Flow (cfs)	Bascule Gate No. 1 Flow (cfs)	Other Bascule Gate Spill (cfs)	Tainter Gate Spill (cfs)	Total Turners Falls Flow (cfs)	Water Surface Elevation (ft)
6-1	7,282	318	400	0	0	8,000	135.4

Figure 8.5.1-7: PR 6-1 Cross-Sections Showing Water Velocity near the Spillway Fishway
Total model flow is 718 cfs. Scaled from 0-7 fps.



Scenario Number	Power Canal Flow (cfs)	Spillway Ladder Flow (cfs)	Bascule Gate No. 1 Flow (cfs)	Other Bascule Gate Spill (cfs)	Tainter Gate Spill (cfs)	Total Turners Falls Flow (cfs)	Water Surface Elevation (ft)
6-1	7,282	318	400	0	0	8,000	135.4 ●

Figure 8.5.1-8: PR 6-1 Cross-Sections Showing Water Velocity near the Spillway Fishway, Looking Upstream
Total model flow is 718 cfs. Scaled from 0-20 fps.



Scenario Number	Power Canal Flow (cfs)	Spillway Ladder Flow (cfs)	Bascule Gate No. 1 Flow (cfs)	Other Bascule Gate Spill (cfs)	Tainter Gate Spill (cfs)	Total Turners Falls Flow (cfs)	Water Surface Elevation (ft)
6-1	7,282	318	400	0	0	8,000	135.4 ●

Figure 8.5.1-9: PR 6-1 Cross-Sections Showing Water Velocity near the Spillway Fishway, Looking Upstream
Total model flow is 718 cfs. Scaled from 0-7 fps.

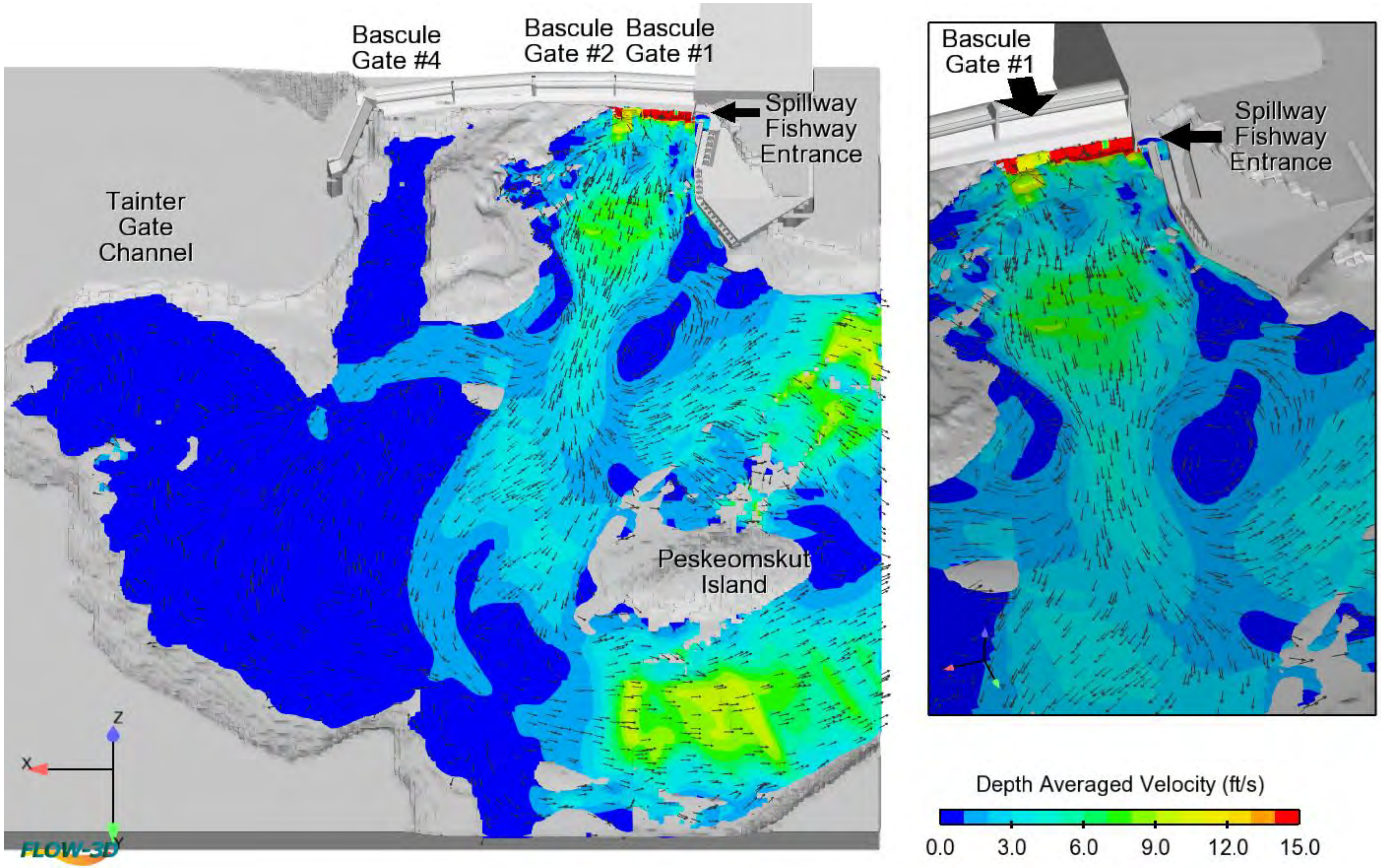


Figure 8.5.2-1: PR 6-2 Depth-Averaged Water Velocities in the Turners Falls Spillway Area
Total flow is 4,659 cfs. Scaled from 0-15 fps.

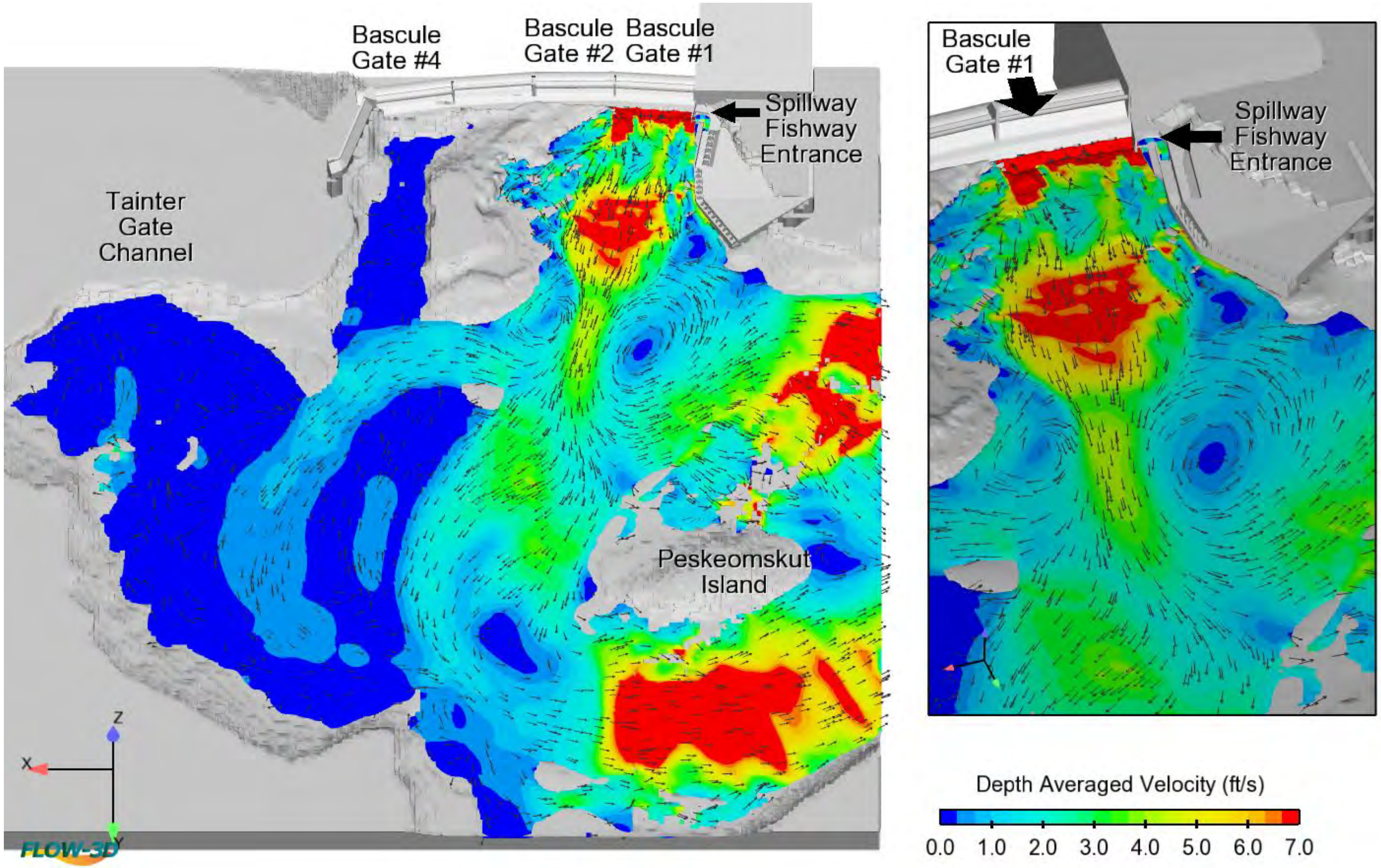


Figure 8.5.2-2: PR 6-2 Depth-Averaged Water Velocities in the Turners Falls Spillway Area
Total flow is 4,659 cfs. Scaled from 0-7 fps.

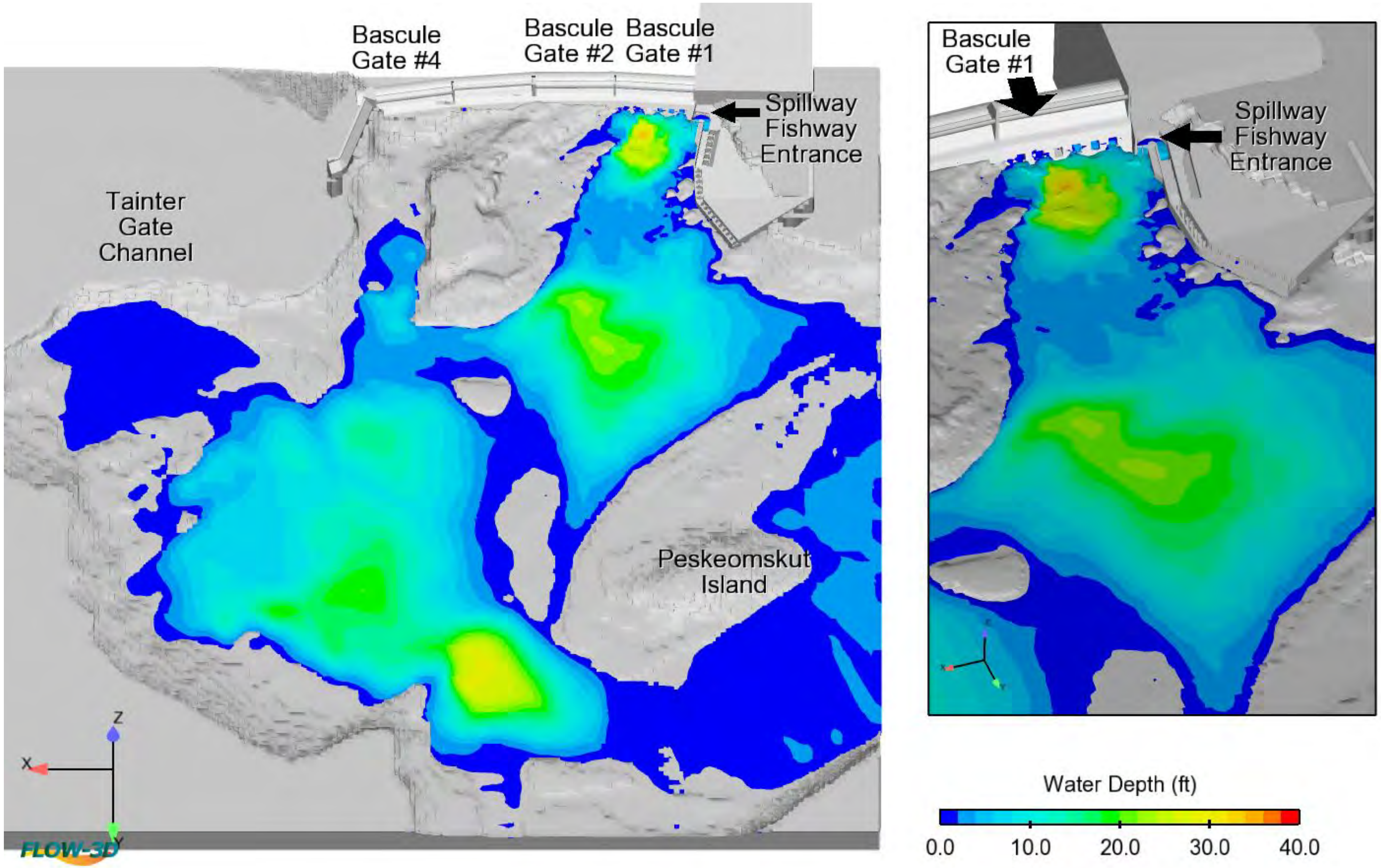


Figure 8.5.2-3: PR 6-2 Water Depths in the Turners Falls Spillway Area
Total flow is 4,659 cfs. Scaled from 0-40 ft.

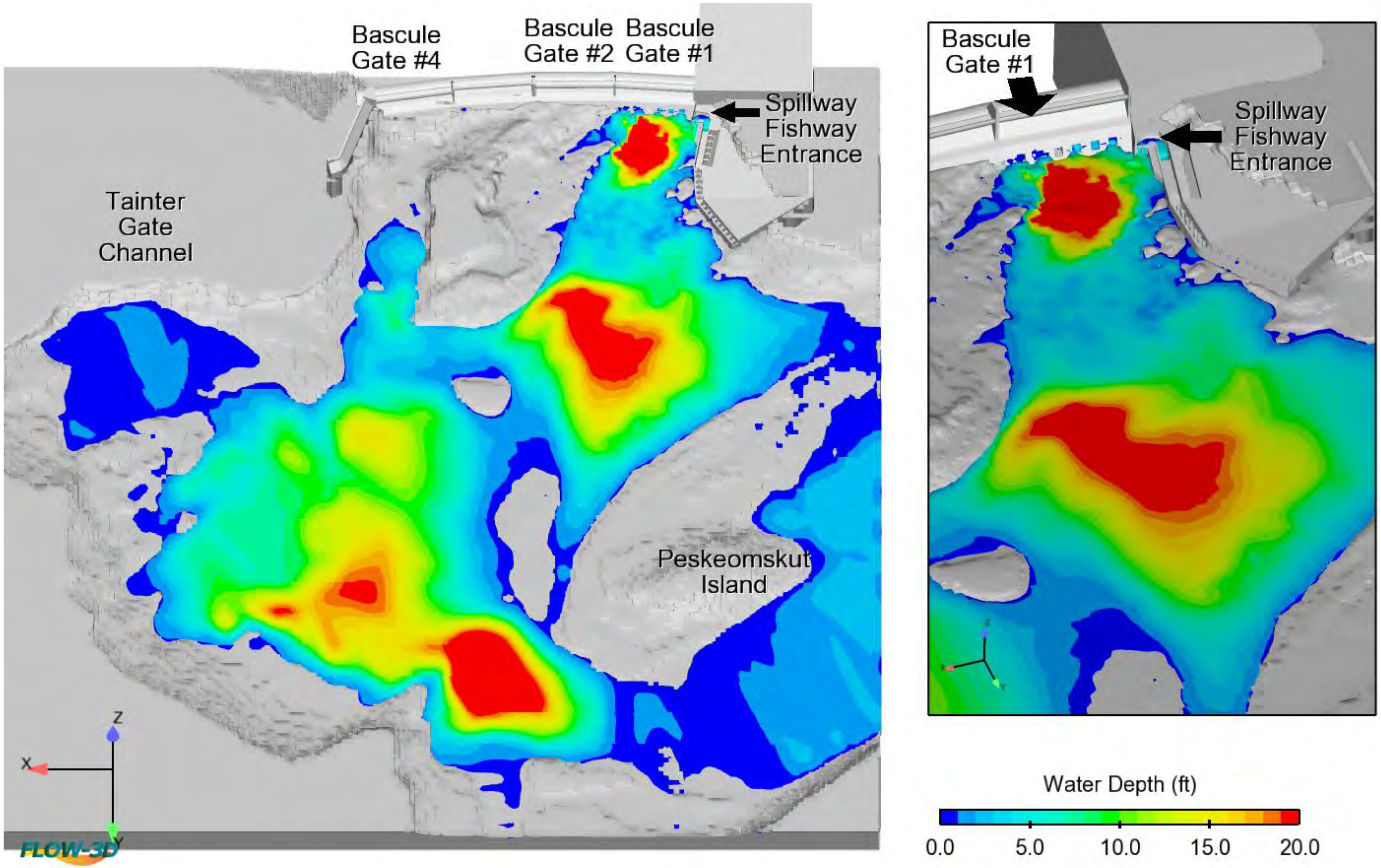


Figure 8.5.2-4: PR 6-2 Water Depths in the Turners Falls Spillway Area
Total flow is 4,659 cfs. Scaled from 0-20 ft.

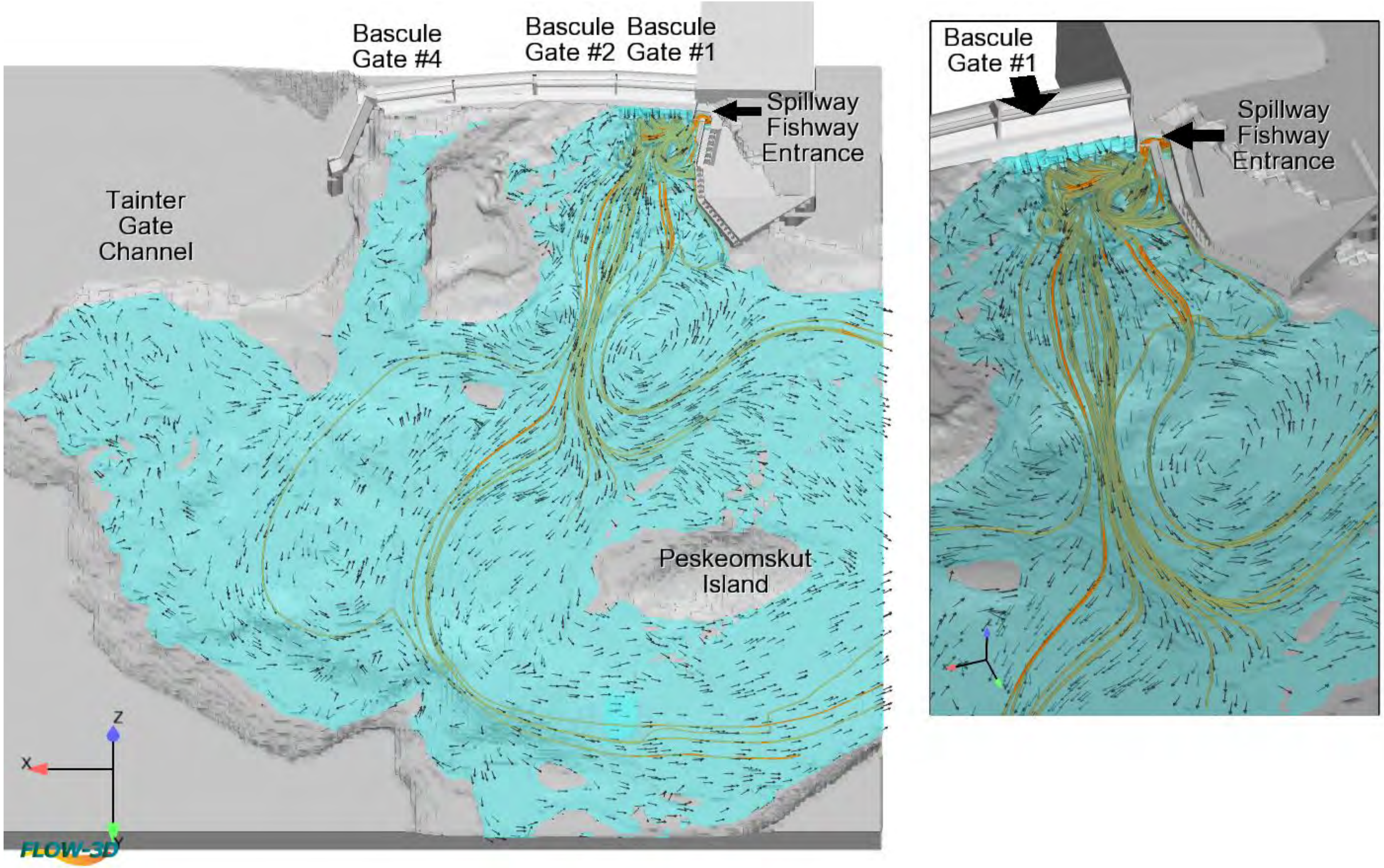
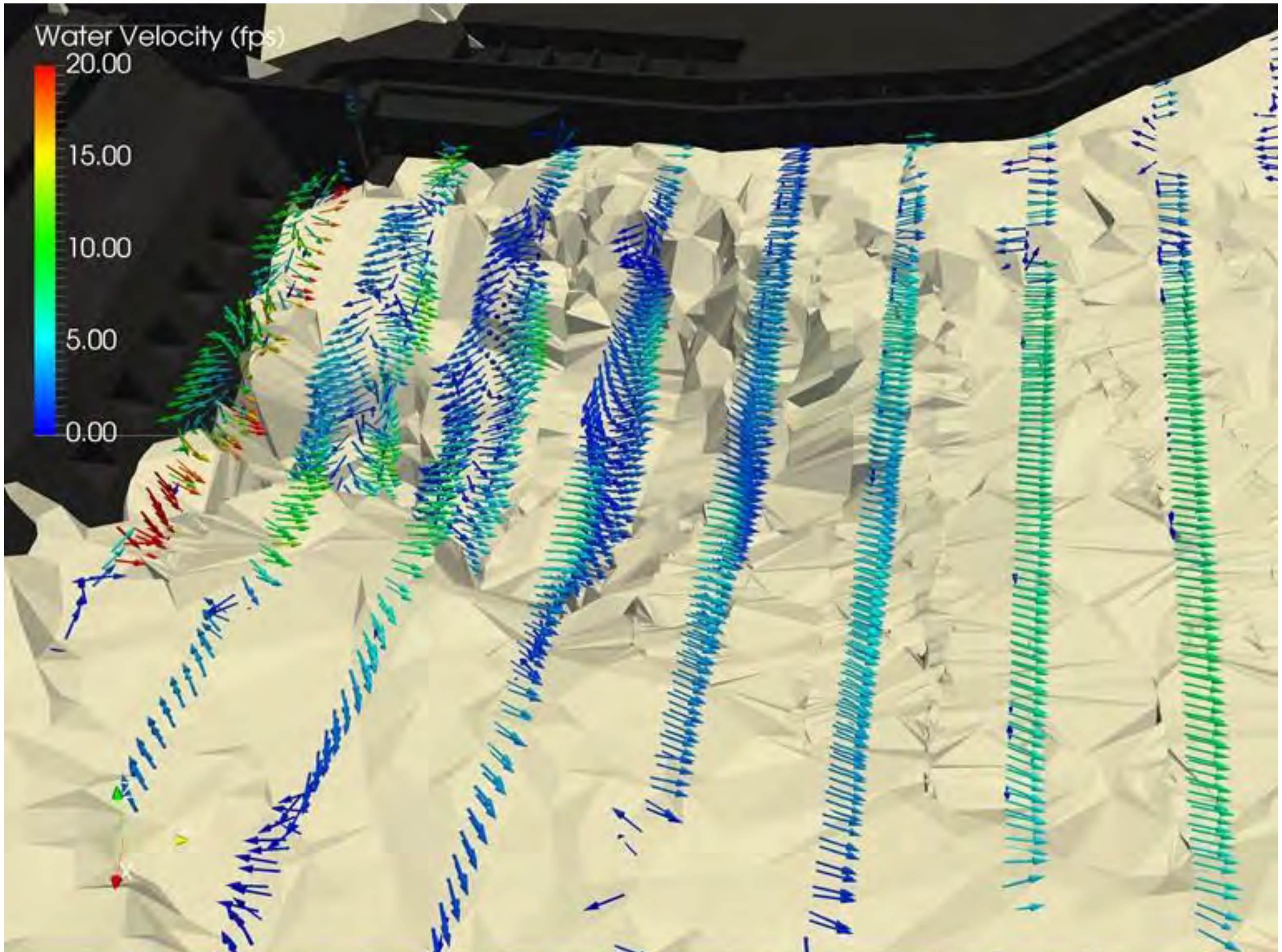
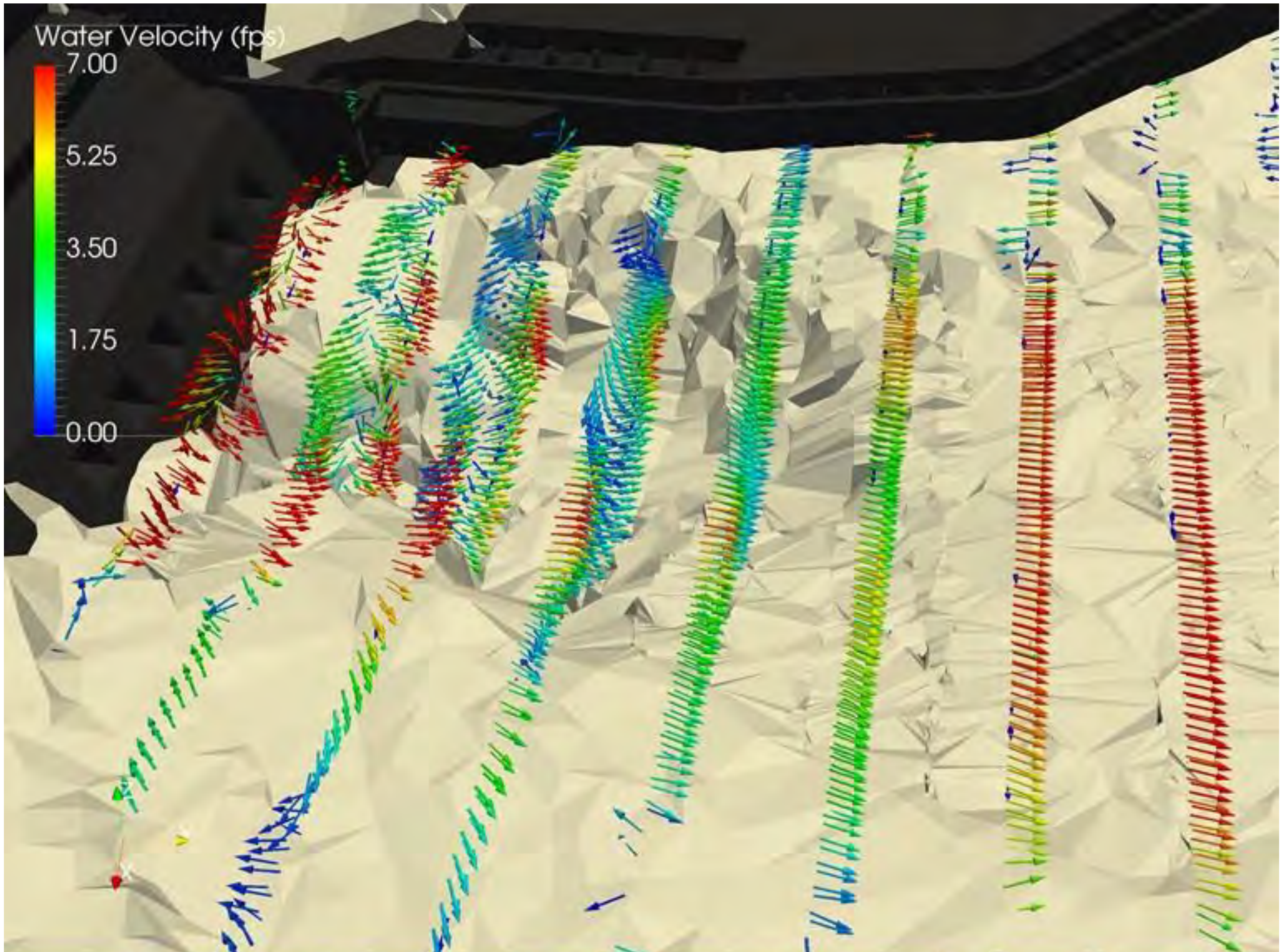


Figure 8.5.2-5: PR 6-2 Modeled Streamlines and Velocity Vectors
The black arrows indicate flow direction. The orange streamlines represent the path of water released from the Spillway fishway. Total model flow is 4,659 cfs.



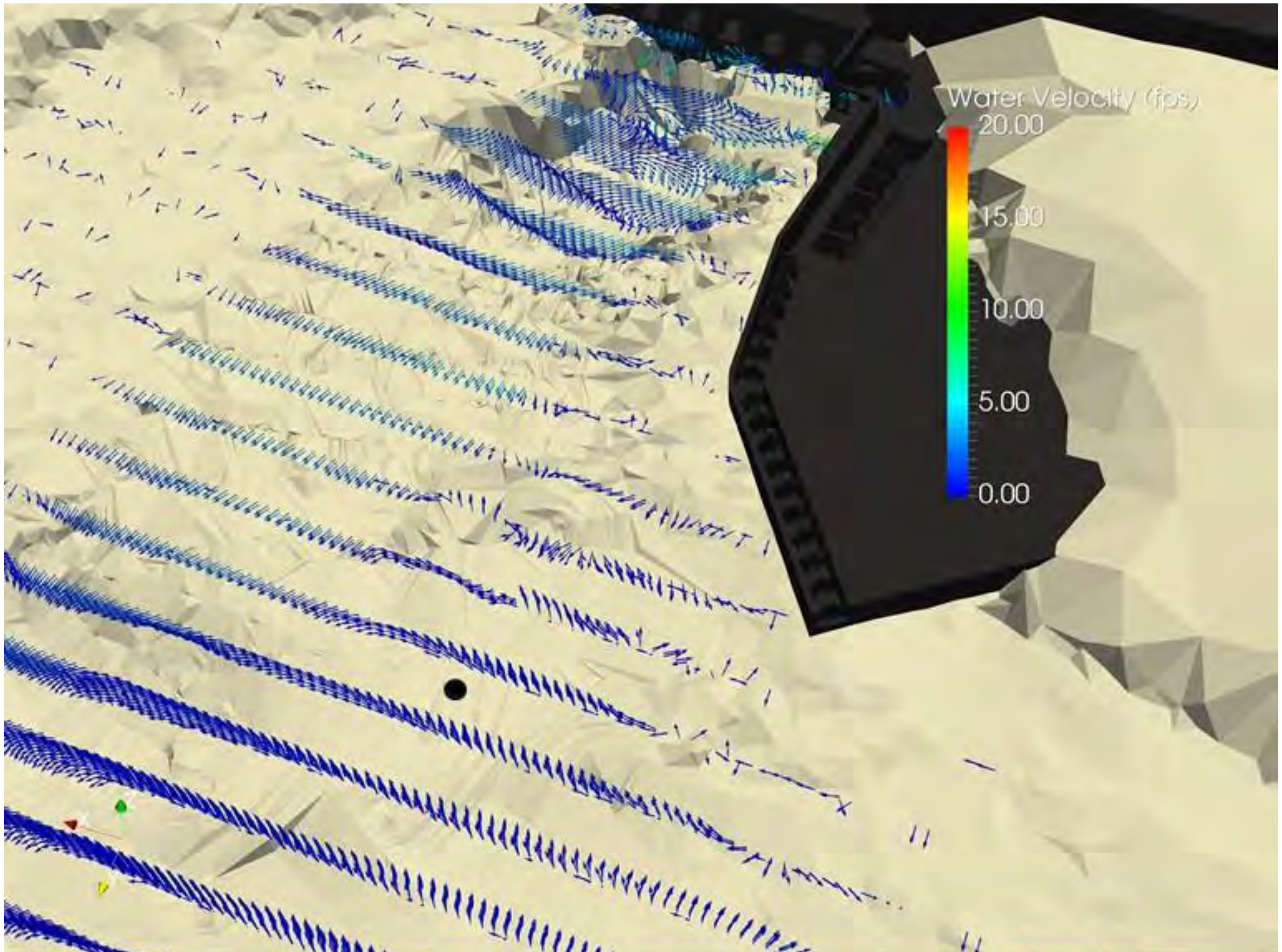
Scenario Number	Power Canal Flow (cfs)	Spillway Ladder Flow (cfs)	Bascule Gate No. 1 Flow (cfs)	Other Bascule Gate Spill (cfs)	Tainter Gate Spill (cfs)	Total Turners Falls Flow (cfs)	Water Surface Elevation (ft)
6-2	15,938	318	4,341	0	0	20,597	137.0

Figure 8.5.2-6: PR 6-2 Cross-Sections Showing Water Velocity Near the Spillway Fishway
Total model flow is 4,659 cfs. Scaled from 0-20 fps.



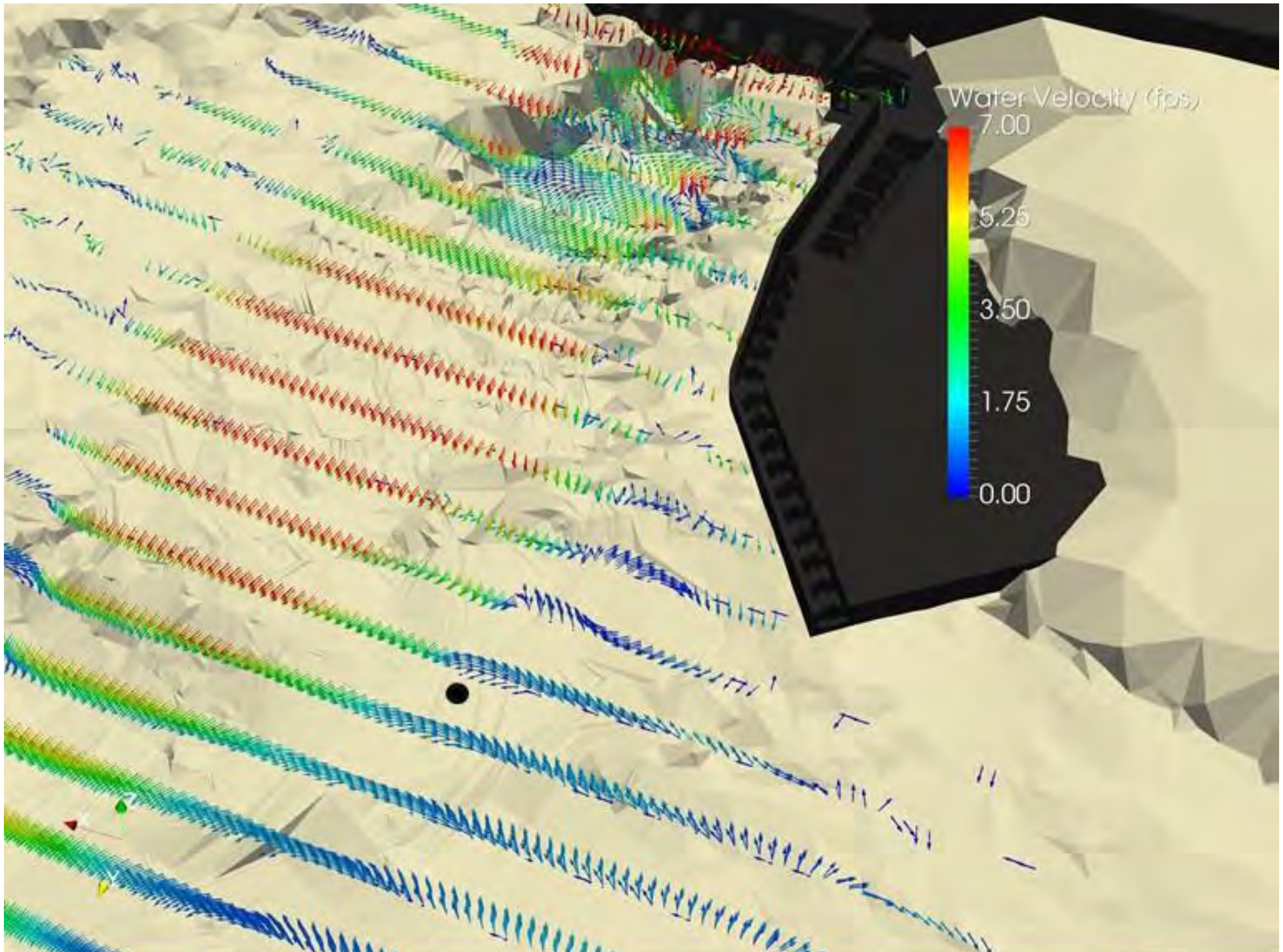
Scenario Number	Power Canal Flow (cfs)	Spillway Ladder Flow (cfs)	Bascule Gate No. 1 Flow (cfs)	Other Bascule Gate Spill (cfs)	Tainter Gate Spill (cfs)	Total Turners Falls Flow (cfs)	Water Surface Elevation (ft)
6-2	15,938	318	4,341	0	0	20,597	137.0

Figure 8.5.2-7: PR 6-2 Cross-Sections Showing Water Velocity Near the Spillway Fishway
Total model flow is 4,659 cfs. Scaled from 0-7 fps.



Scenario Number	Power Canal Flow (cfs)	Spillway Ladder Flow (cfs)	Bascule Gate No. 1 Flow (cfs)	Other Bascule Gate Spill (cfs)	Tainter Gate Spill (cfs)	Total Turners Falls Flow (cfs)	Water Surface Elevation (ft)
6-2	15,938	318	4,341	0	0	20,597	137.0 ●

Figure 8.5.2-8: PR 6-2 Cross-Sections Showing Water Velocity Near the Spillway Fishway, Looking Upstream
Total model flow is 4,659 cfs. Scaled from 0-20 fps.



Scenario Number	Power Canal Flow (cfs)	Spillway Ladder Flow (cfs)	Bascule Gate No. 1 Flow (cfs)	Other Bascule Gate Spill (cfs)	Tainter Gate Spill (cfs)	Total Turners Falls Flow (cfs)	Water Surface Elevation (ft)
6-2	15,938	318	4,341	0	0	20,597	137.0 ●

Figure 8.5.2-9: PR 6-2 Cross-Sections Showing Water Velocity Near the Spillway Fishway, Looking Upstream
Total model flow is 4,659 cfs. Scaled from 0-7 fps.

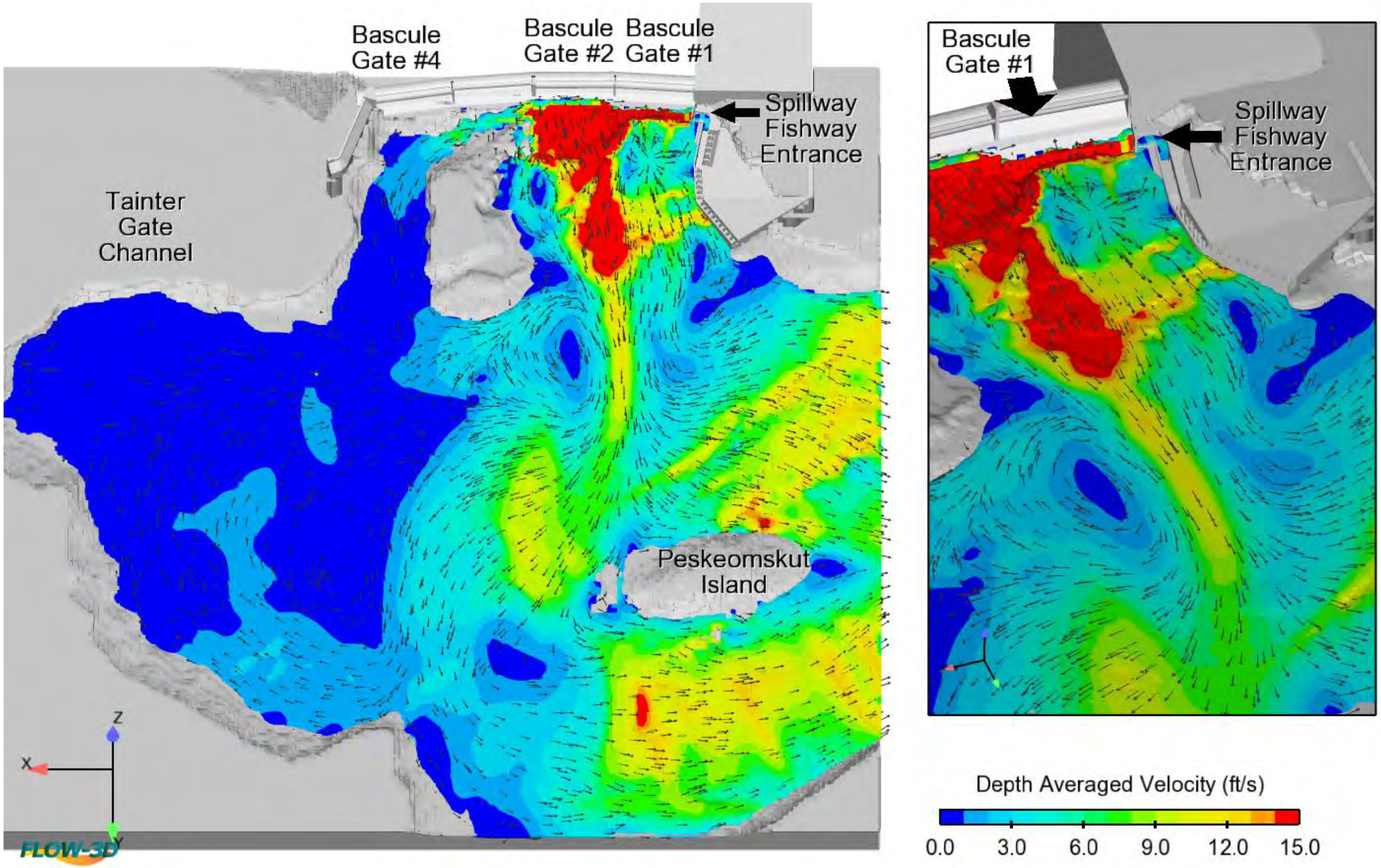


Figure 8.5.3-1: PR 6-3 Depth-Averaged Water Velocities in the Turners Falls Spillway Area
Total flow is 14,398 cfs. Scaled from 0-15 fps.

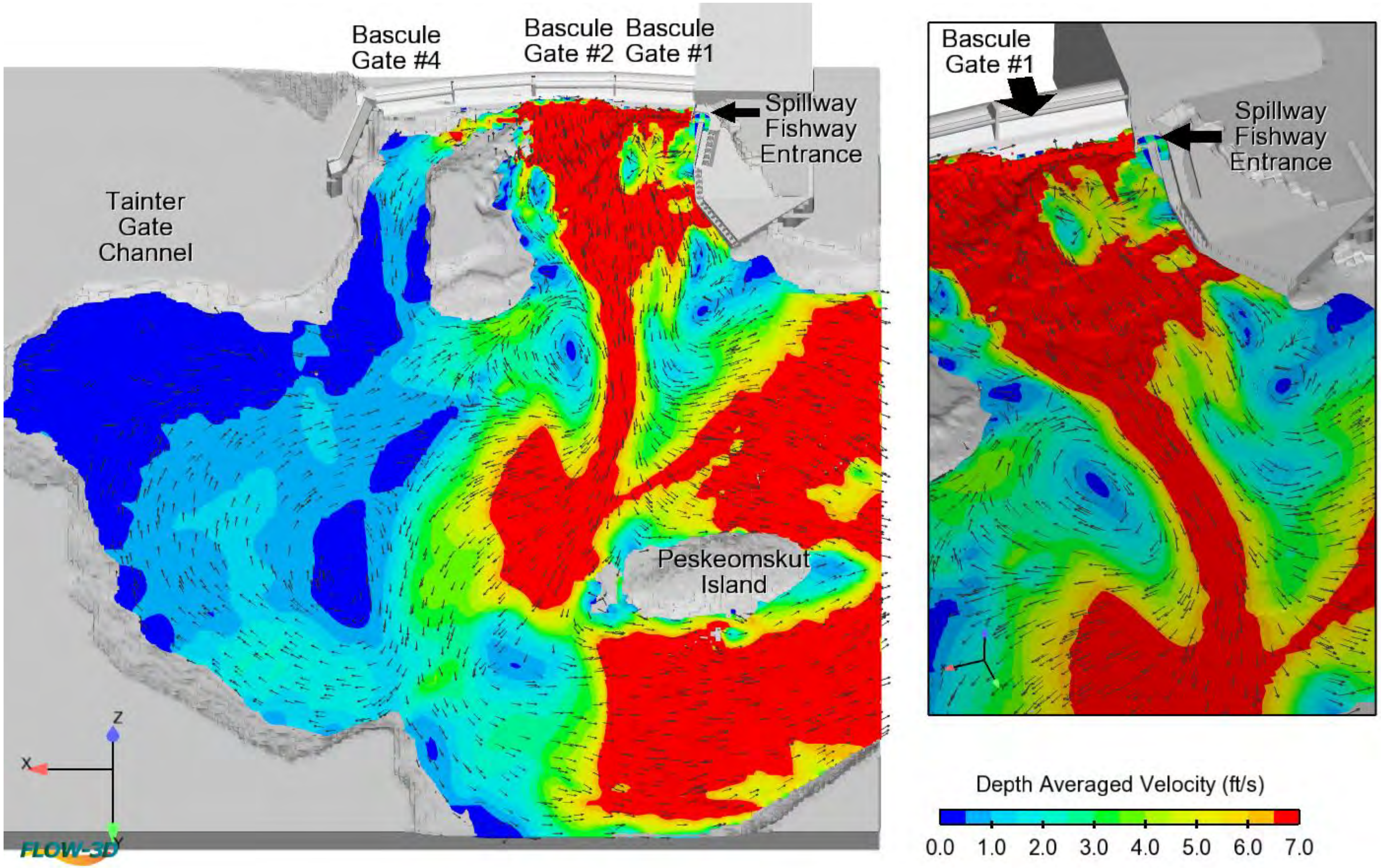


Figure 8.5.3-2: PR 6-3 Depth-Averaged Water Velocities in the Turners Falls Spillway Area
Total flow is 14,398 cfs. Scaled from 0-7 fps.

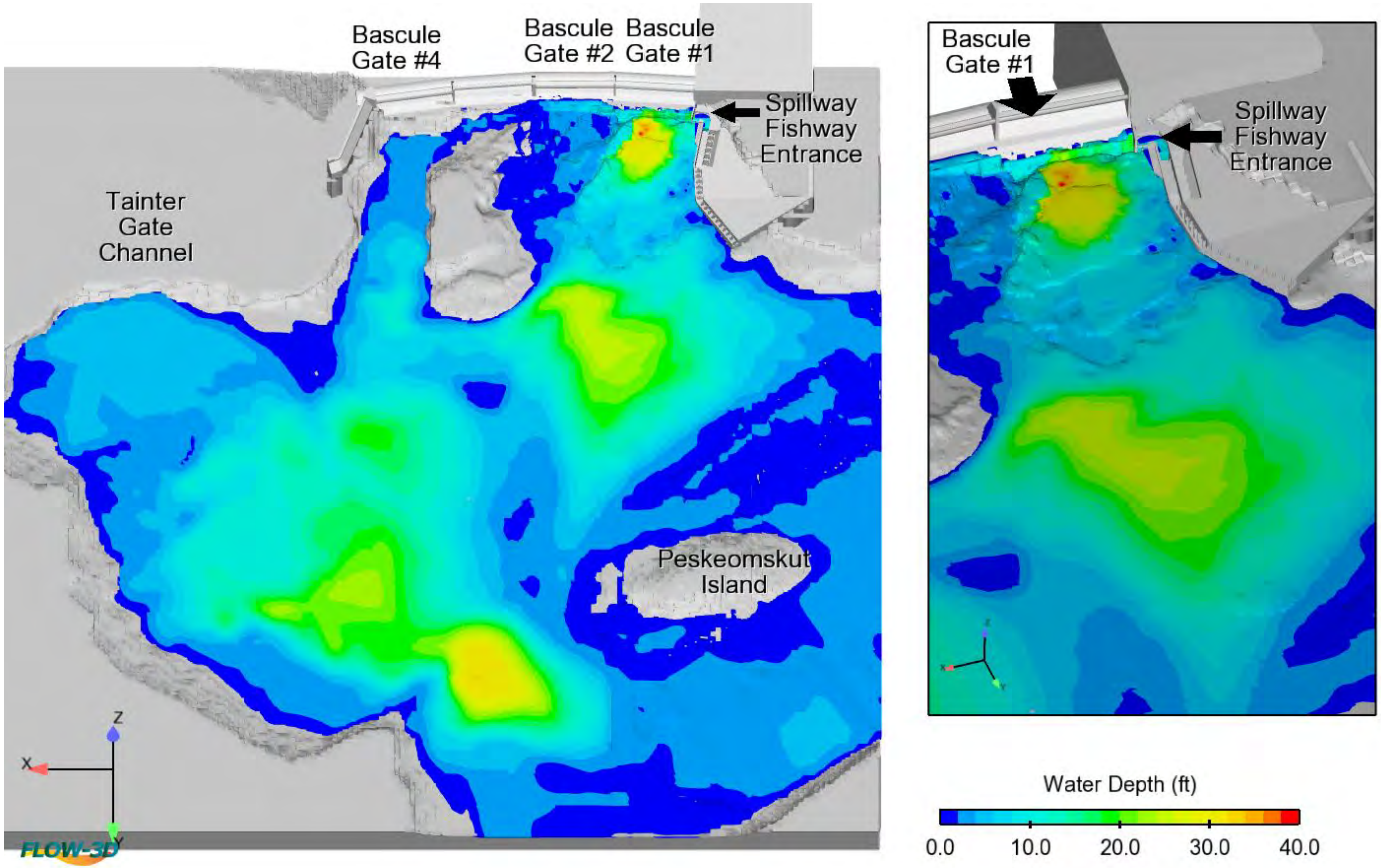


Figure 8.5.3-3: PR 6-3 Water Depths in the Turners Falls Spillway Area
Total flow is 14,398 cfs. Scaled from 0-40 ft.

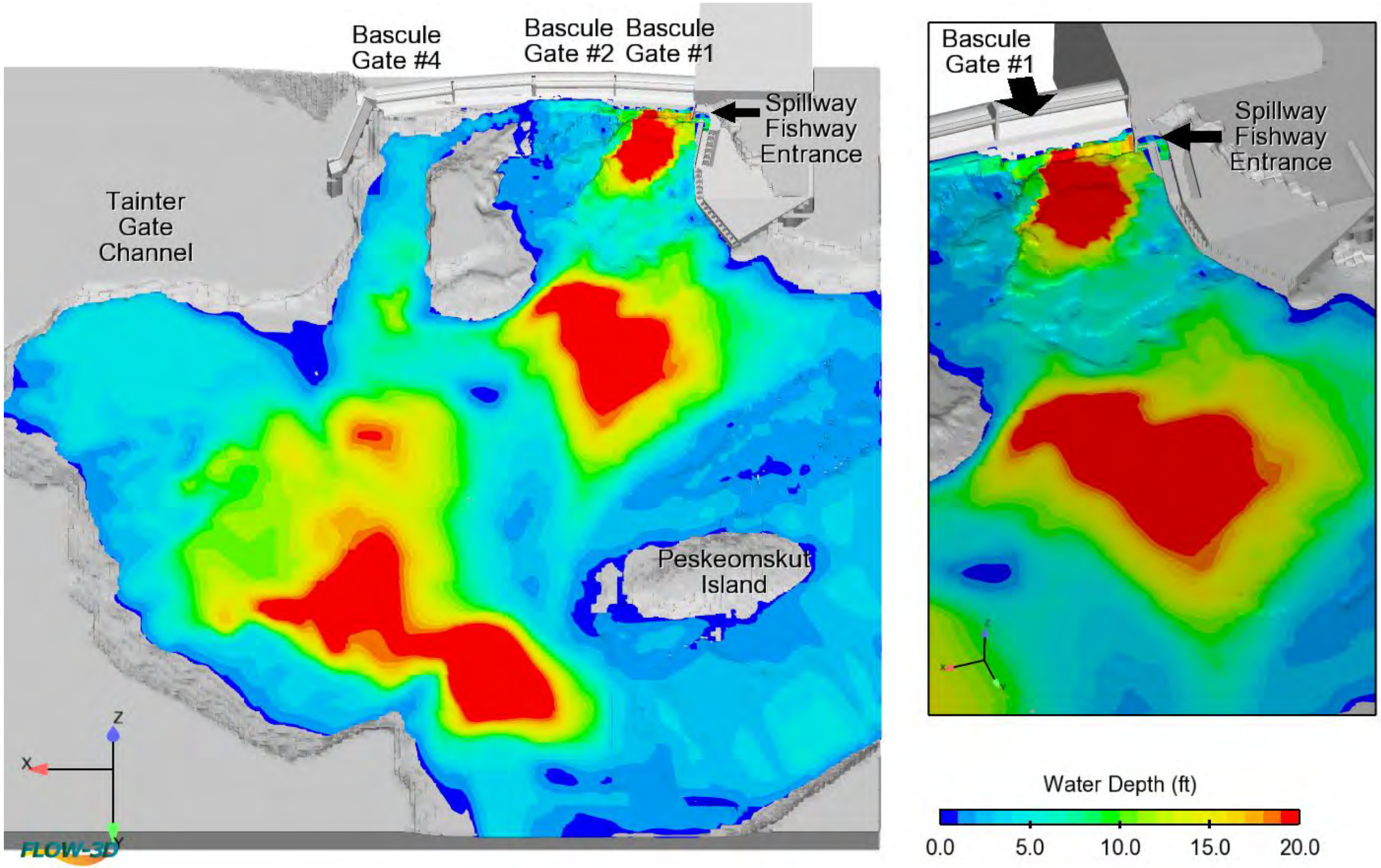


Figure 8.5.3-4: PR 6-3 Water Depths in the Turners Falls Spillway Area
Total flow is 14,398 cfs. Scaled from 0-20 ft.

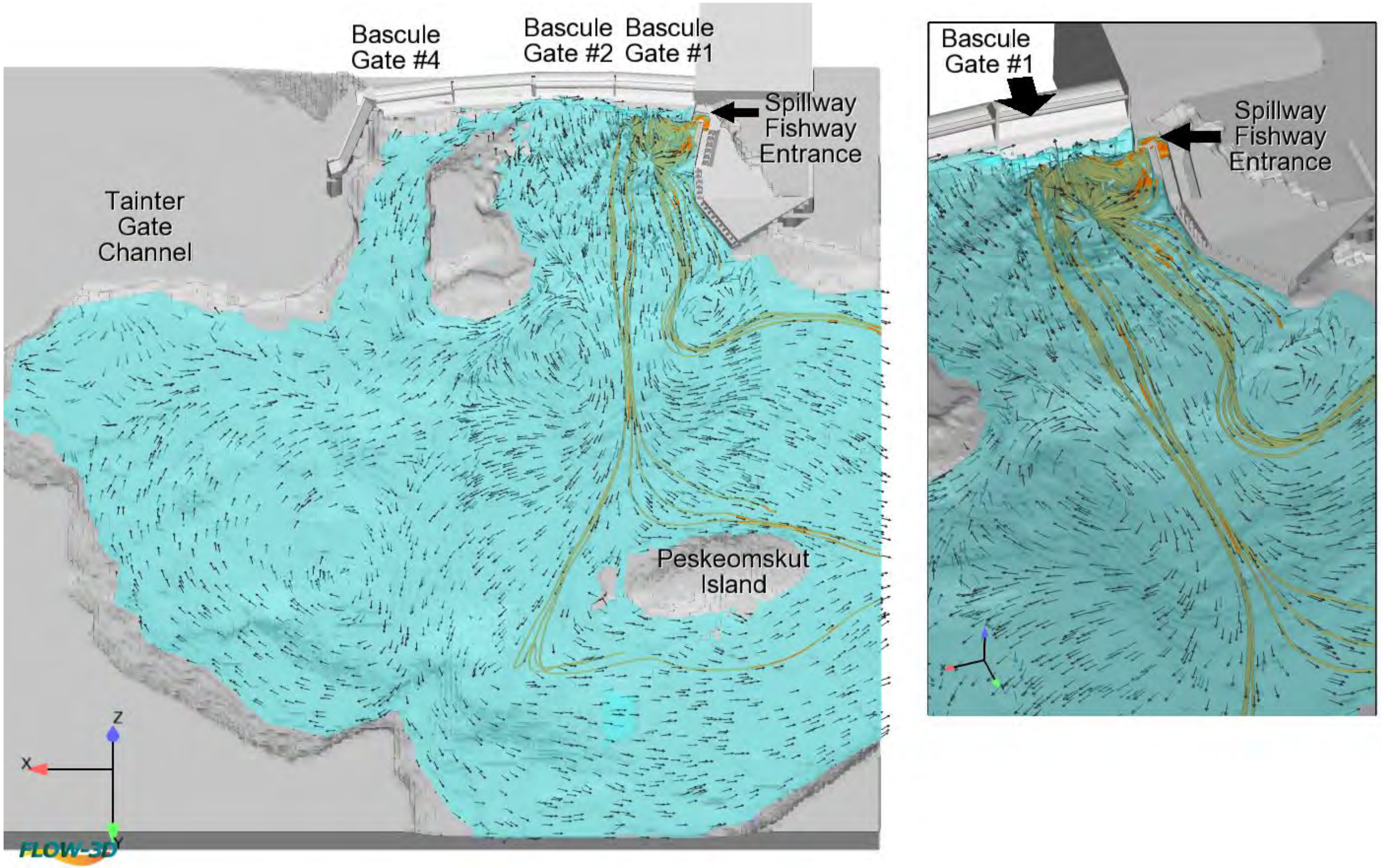
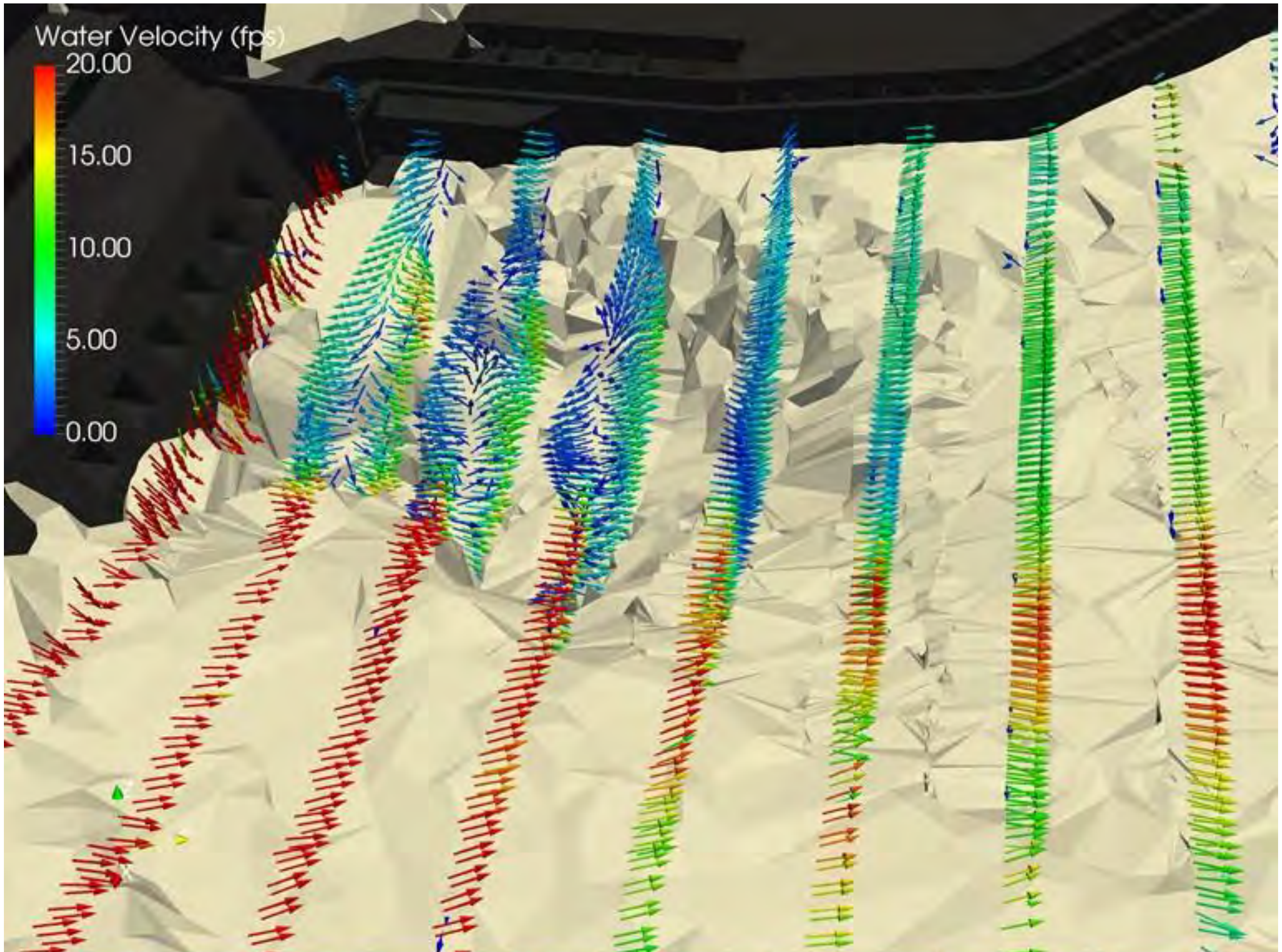
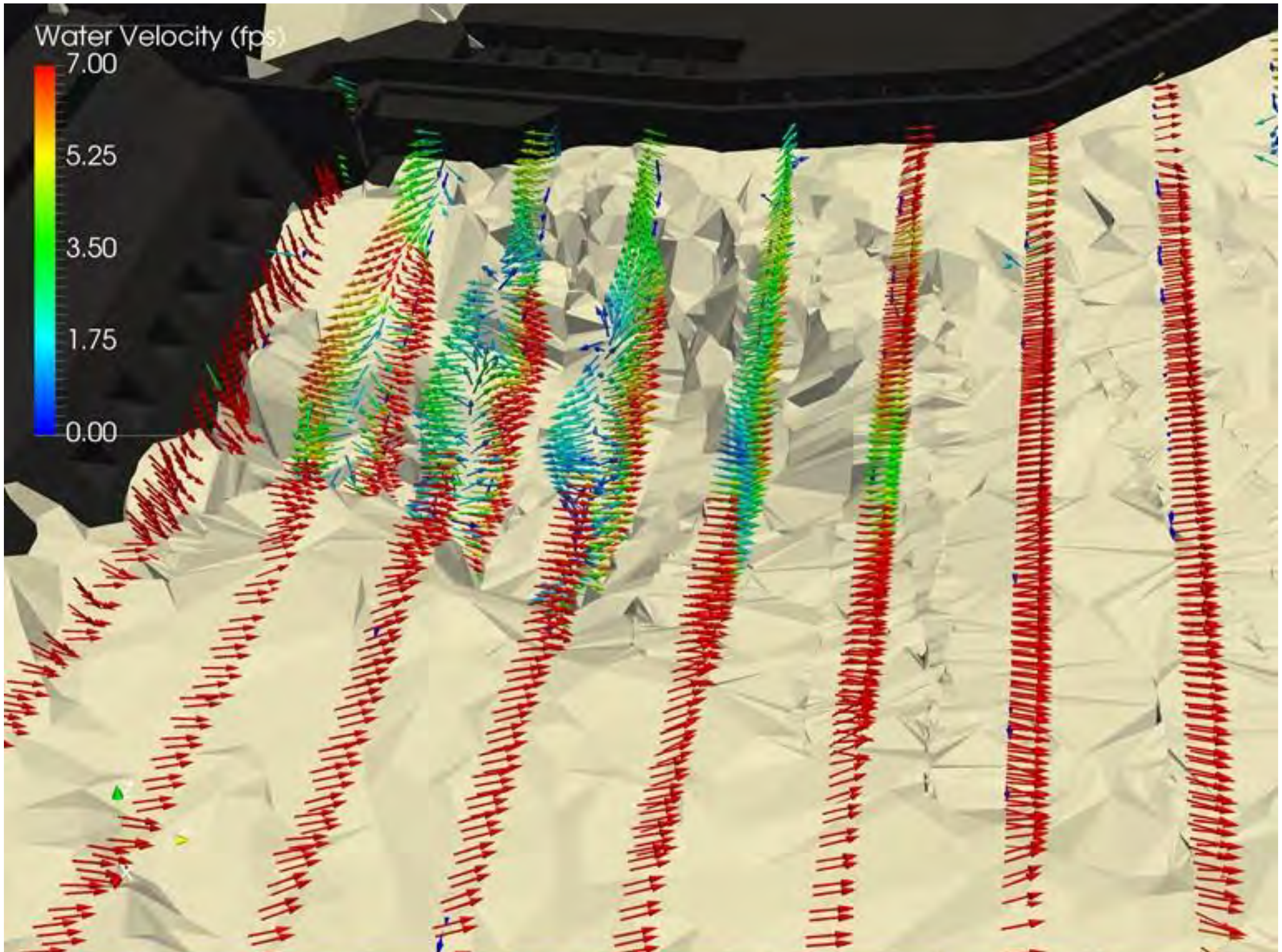


Figure 8.5.3-5: PR 6-3 Modeled Streamlines and Velocity Vectors
The black arrows indicate flow direction. The orange streamlines represent the path of water released from the Spillway fishway. Total model flow is 14,398 cfs.



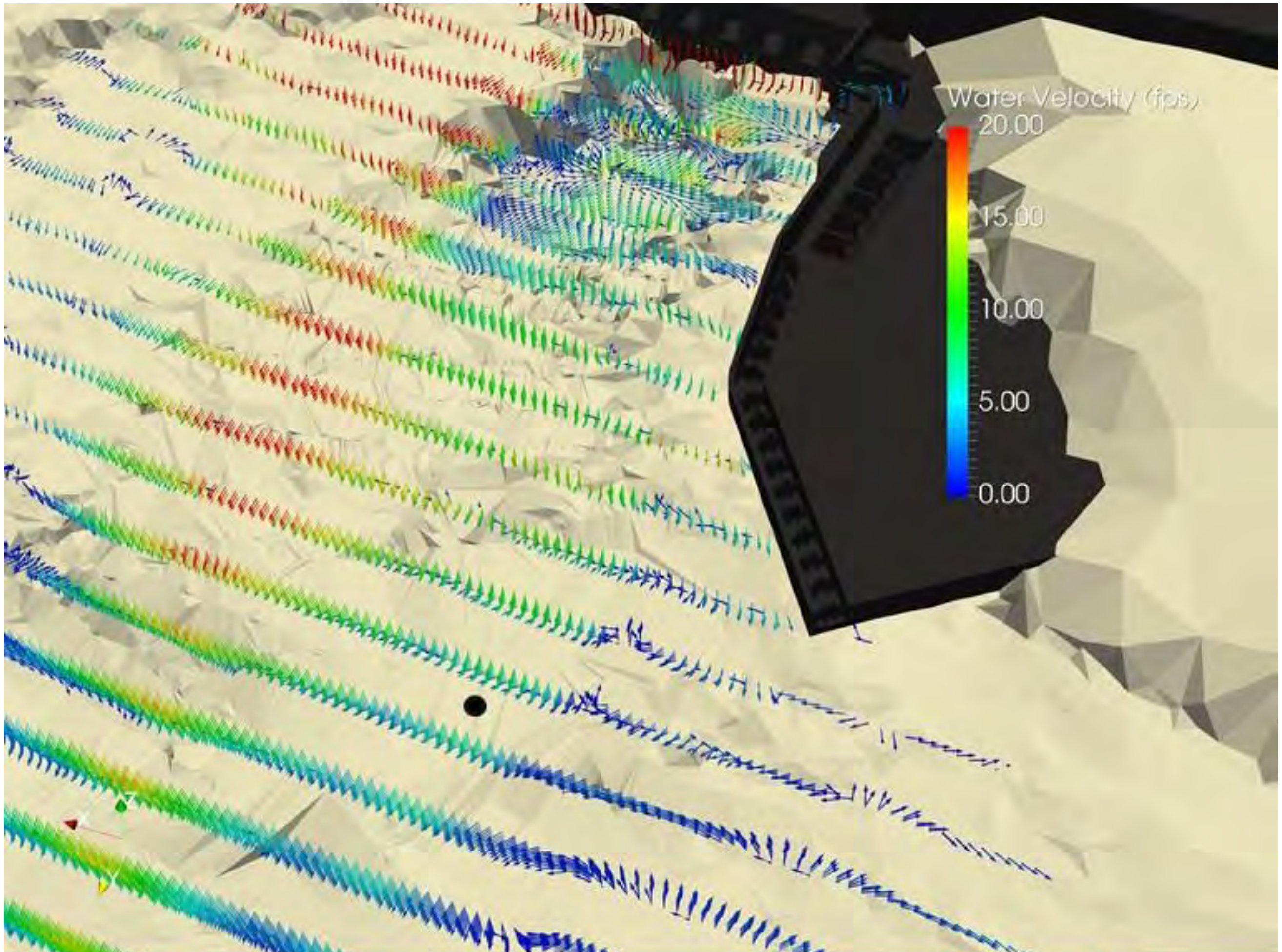
Scenario Number	Power Canal Flow (cfs)	Spillway Ladder Flow (cfs)	Bascule Gate No. 1 Flow (cfs)	Other Bascule Gate Spill (cfs)	Tainter Gate Spill (cfs)	Total Turners Falls Flow (cfs)	Water Surface Elevation (ft)
6-3	15,938	318	7,500	6,580	0	30,336	138.7

Figure 8.5.3-6: PR 6-3 Cross-Sections Showing Water Velocity Near the Spillway Fishway
Total model flow is 14,398 cfs. Scaled from 0-20 fps.



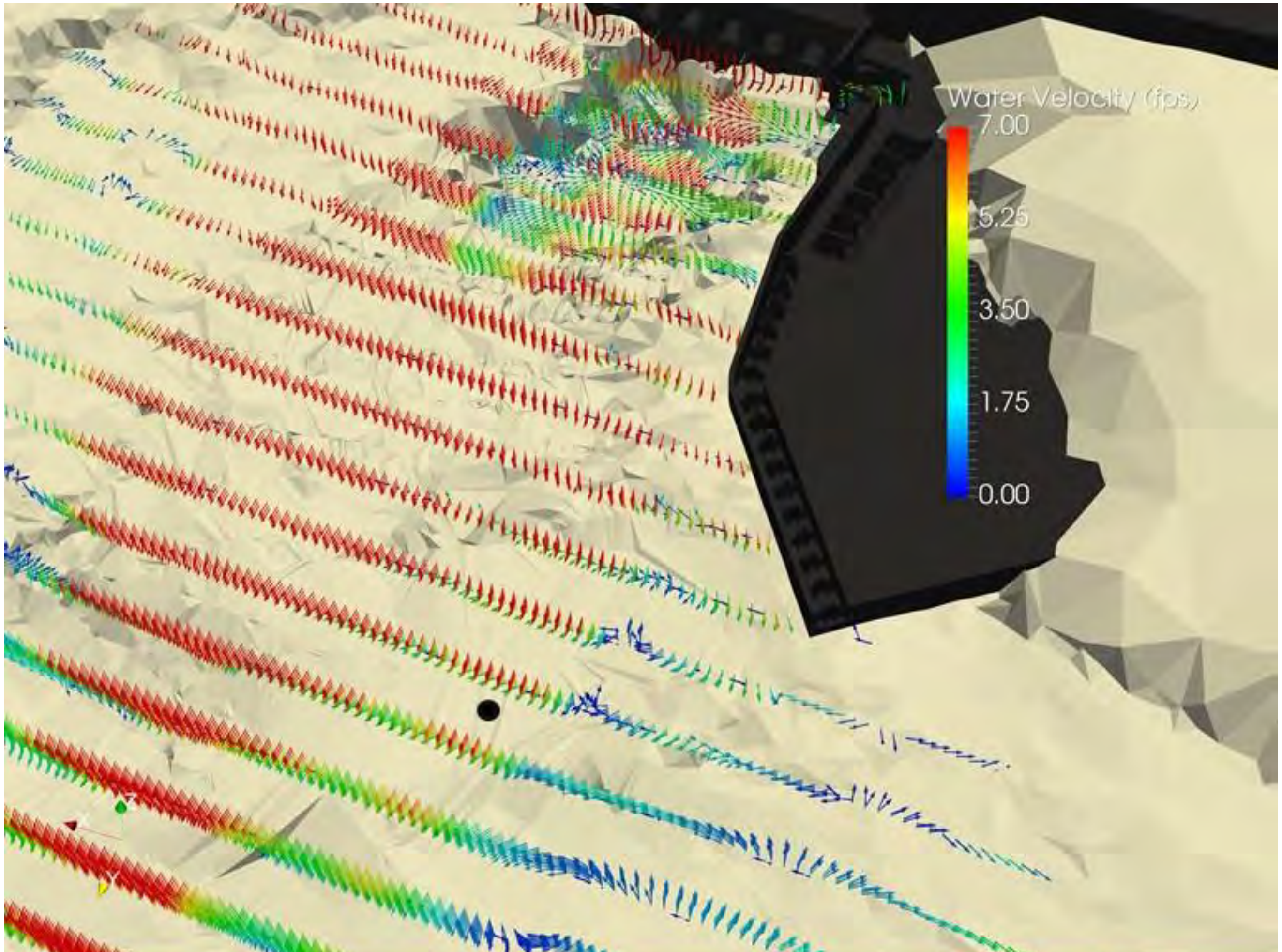
Scenario Number	Power Canal Flow (cfs)	Spillway Ladder Flow (cfs)	Bascule Gate No. 1 Flow (cfs)	Other Bascule Gate Spill (cfs)	Tainter Gate Spill (cfs)	Total Turners Falls Flow (cfs)	Water Surface Elevation (ft)
6-3	15,938	318	7,500	6,580	0	30,336	138.7

Figure 8.5.3-7: PR 6-3 Cross-Sections Showing Water Velocity Near the Spillway Fishway, Looking Upstream
Total model flow is 14,398 cfs. Scaled from 0-7 fps.



Scenario Number	Power Canal Flow (cfs)	Spillway Ladder Flow (cfs)	Bascule Gate No. 1 Flow (cfs)	Other Bascule Gate Spill (cfs)	Tainter Gate Spill (cfs)	Total Turners Falls Flow (cfs)	Water Surface Elevation (ft)
6-3	15,938	318	7,500	6,580	0	30,336	138.7 ●

Figure 8.5.3-8: PR 6-3 Cross-Sections Showing Water Velocity Near the Spillway Fishway
Total model flow is 14,398 cfs. Scaled from 0-20 fps.



Scenario Number	Power Canal Flow (cfs)	Spillway Ladder Flow (cfs)	Bascule Gate No. 1 Flow (cfs)	Other Bascule Gate Spill (cfs)	Tainter Gate Spill (cfs)	Total Turners Falls Flow (cfs)	Water Surface Elevation (ft)
6-3	15,938	318	7,500	6,580	0	30,336	138.7 ●

Figure 8.5.3-9: PR 6-3 Cross-Sections Showing water velocity near the Spillway Fishway, Looking Upstream
Total model flow is 14,398 cfs. Scaled from 0-7 fps.

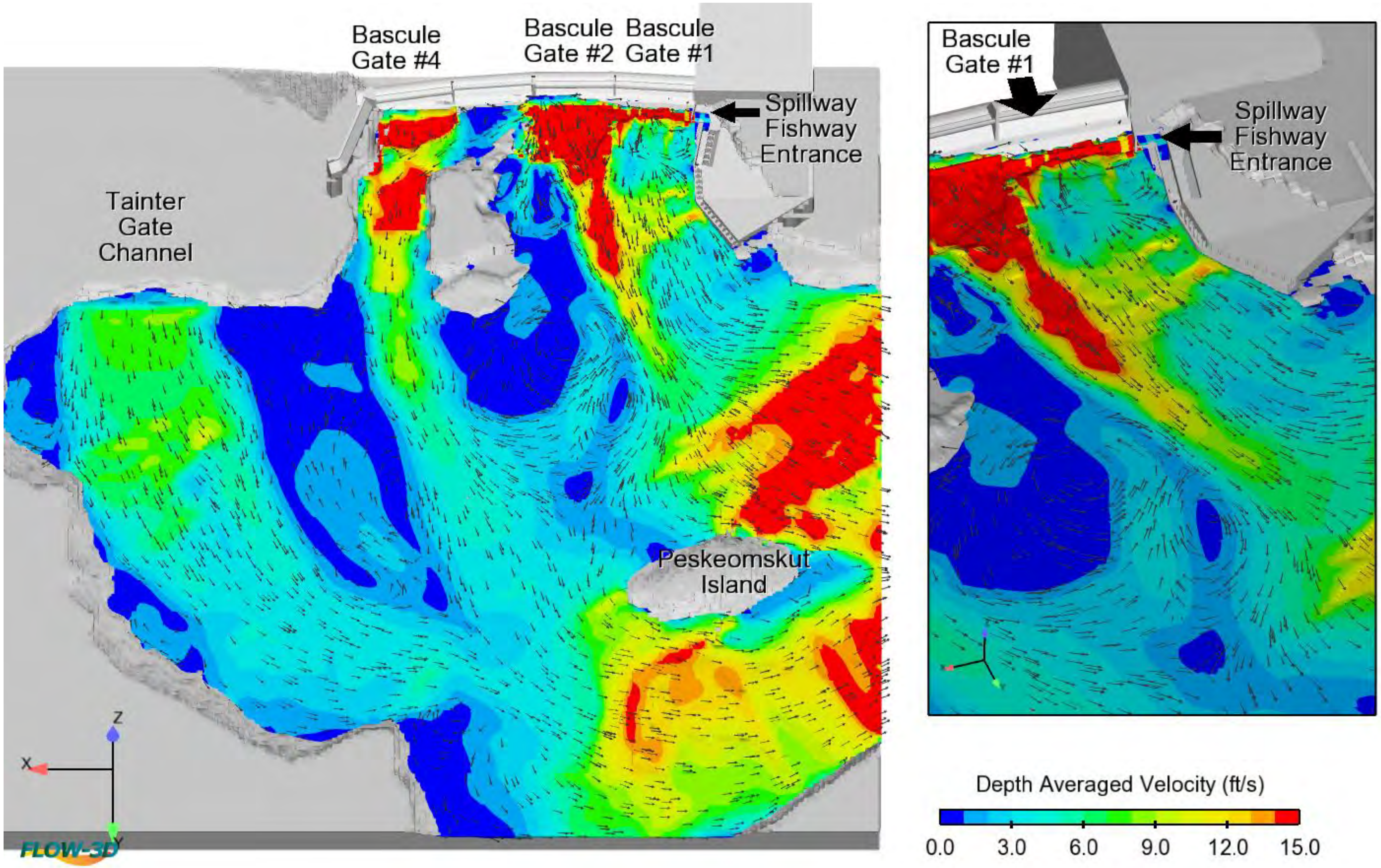


Figure 8.5.4-1: PR 6-4 Depth-Averaged Water Velocities in the Turners Falls Spillway Area
Total flow is 30,278 cfs. Scaled from 0-15 fps.

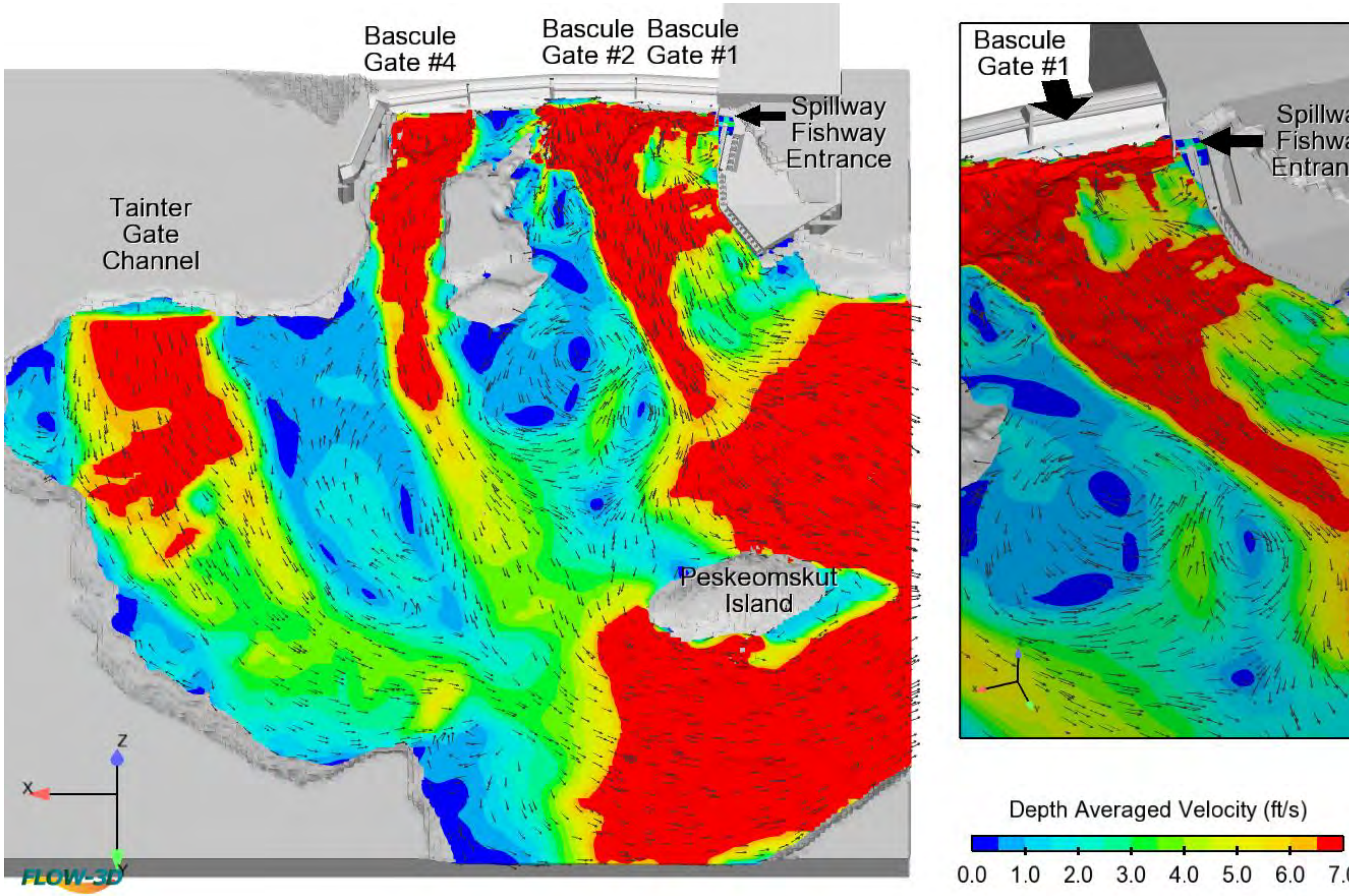


Figure 8.5.4-2: PR 6-4 Depth-Averaged Water Velocities in the Turners Falls Spillway Area
Total flow is 30,278 cfs. Scaled from 0-7 fps.

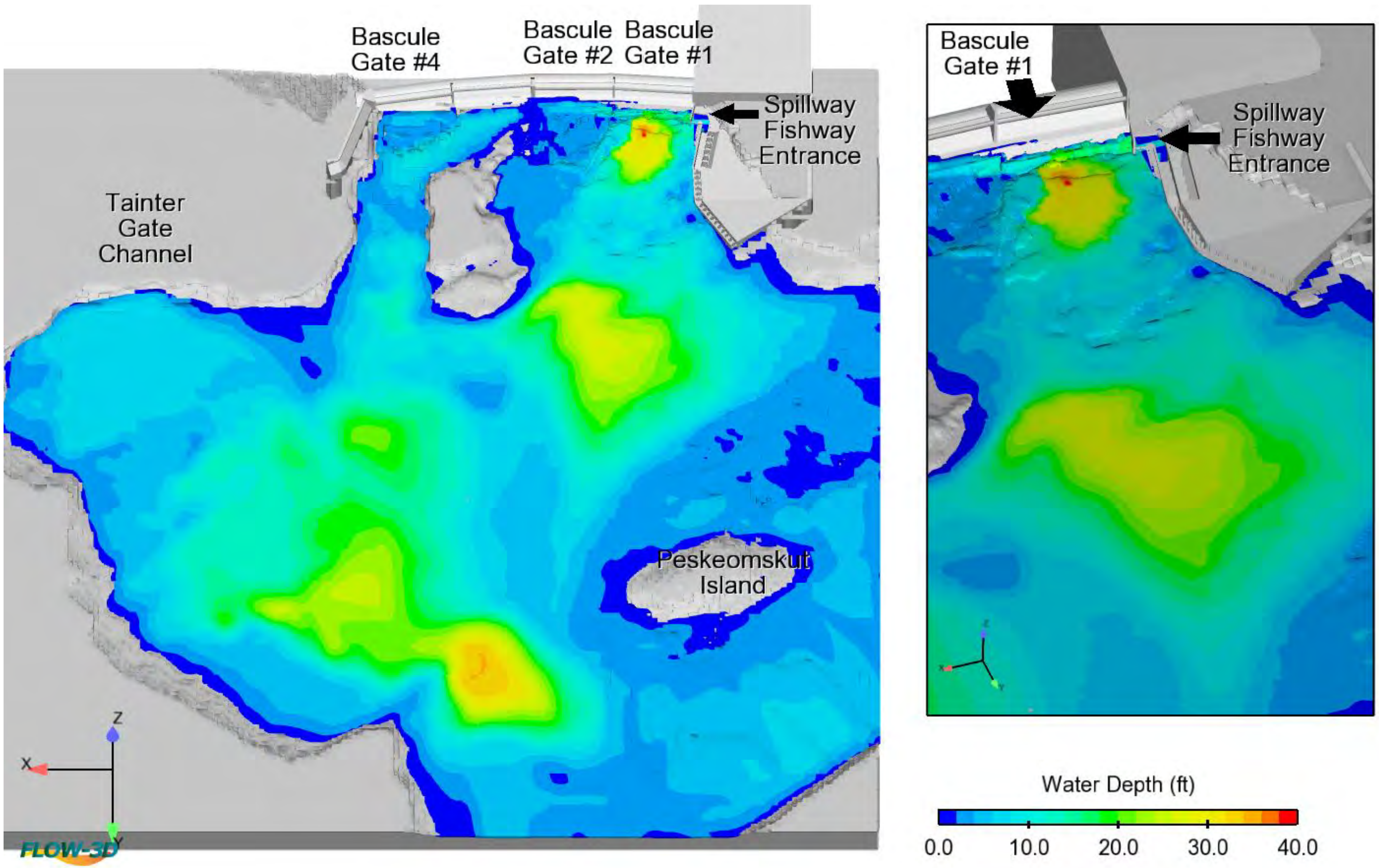


Figure 8.5.4-3: PR 6-4 Water Depths in the Turners Falls Spillway Area
Total flow is 30,278 cfs. Scaled from 0-40 ft.

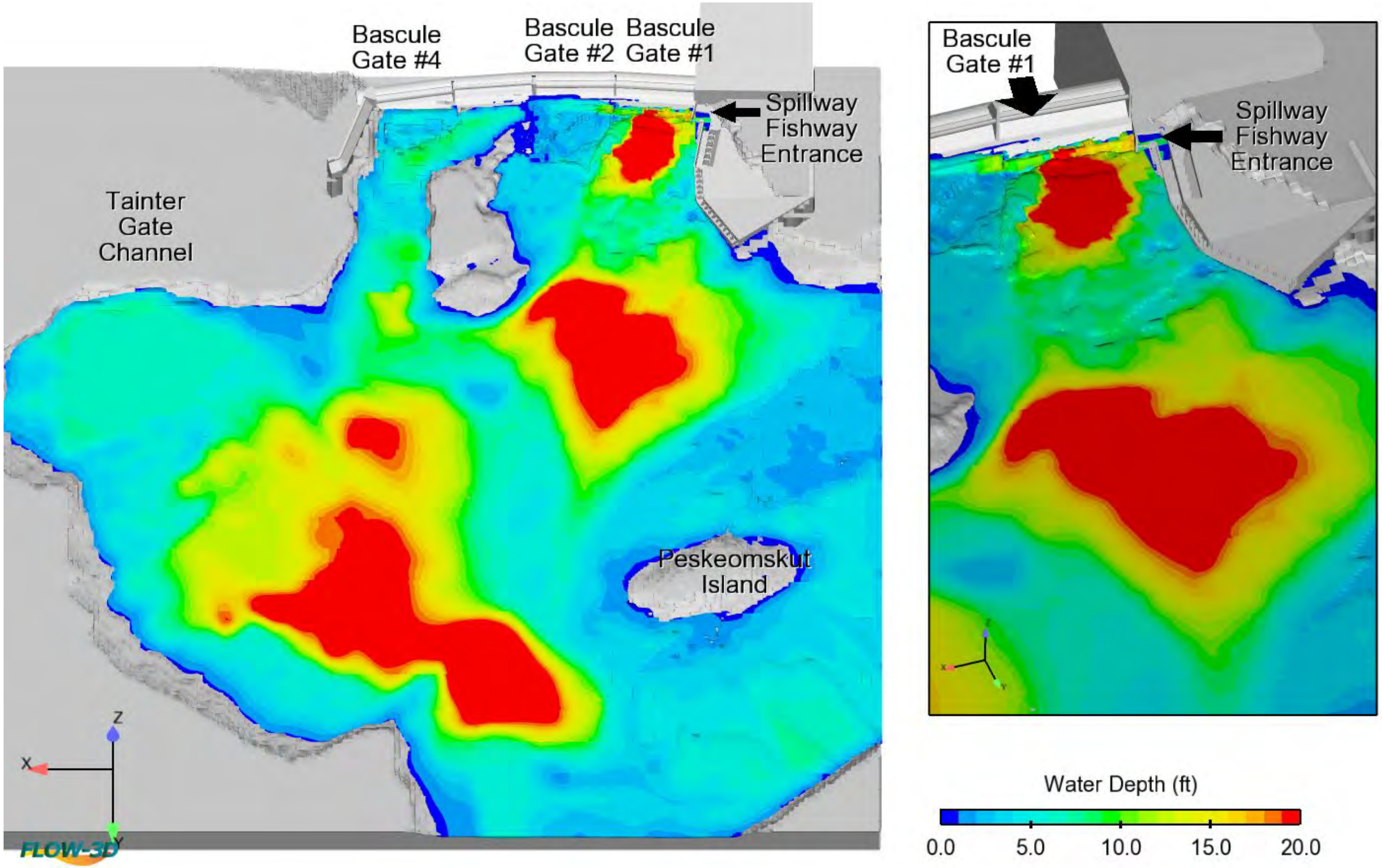


Figure 8.5.4-4: PR 6-4 Water Depths in the Turners Falls Spillway Area
Total flow is 30,278 cfs. Scaled from 0-20 ft.

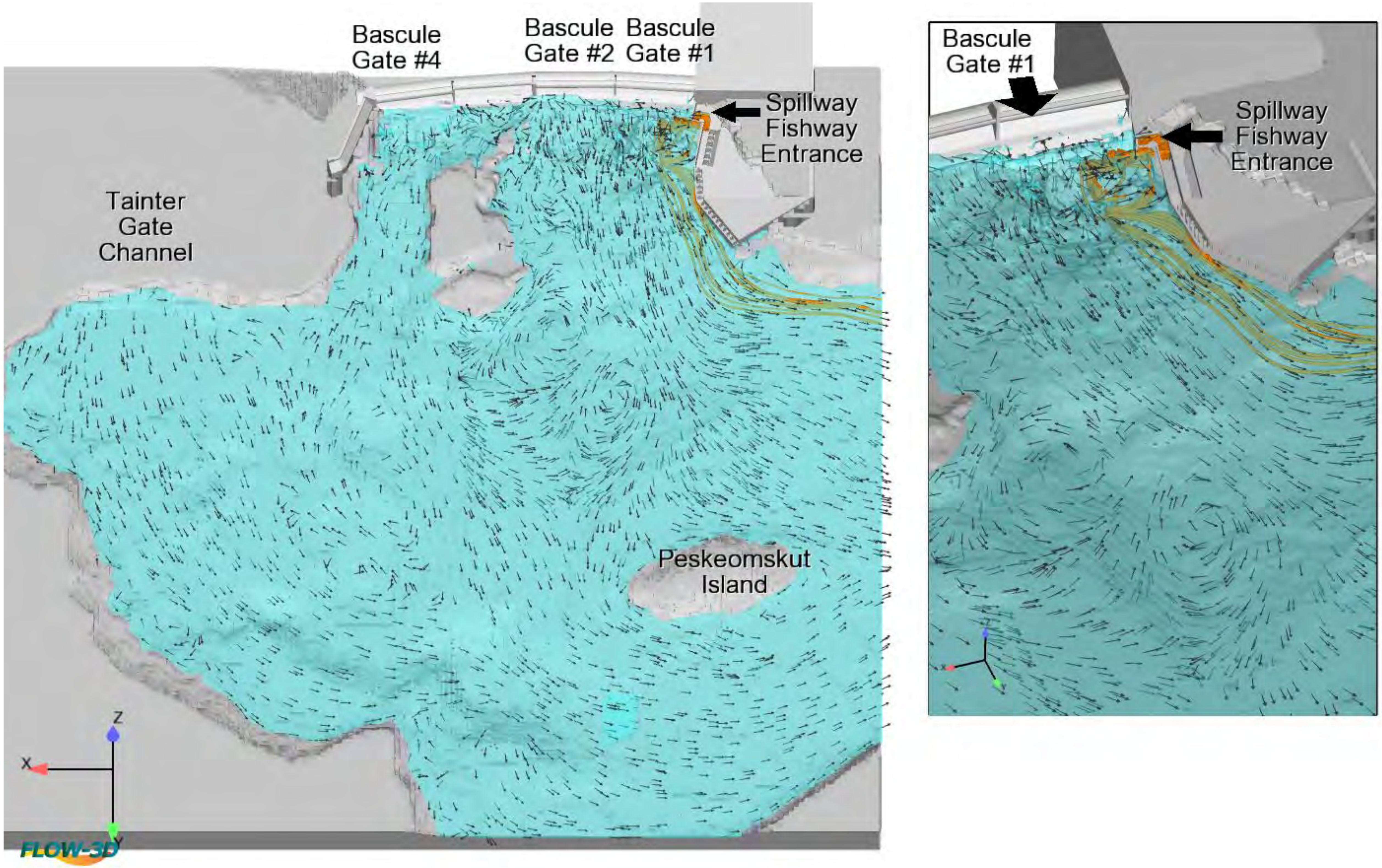
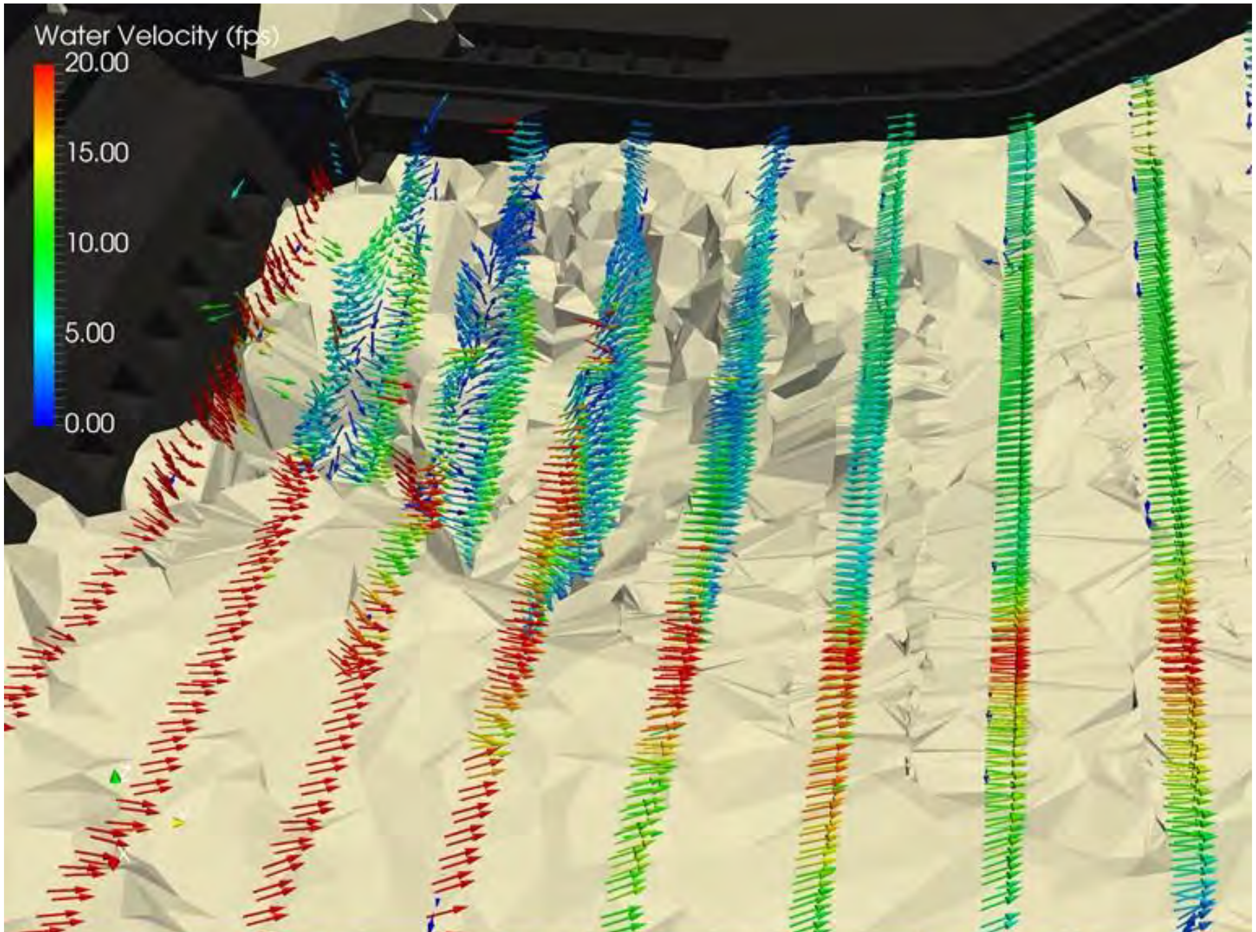
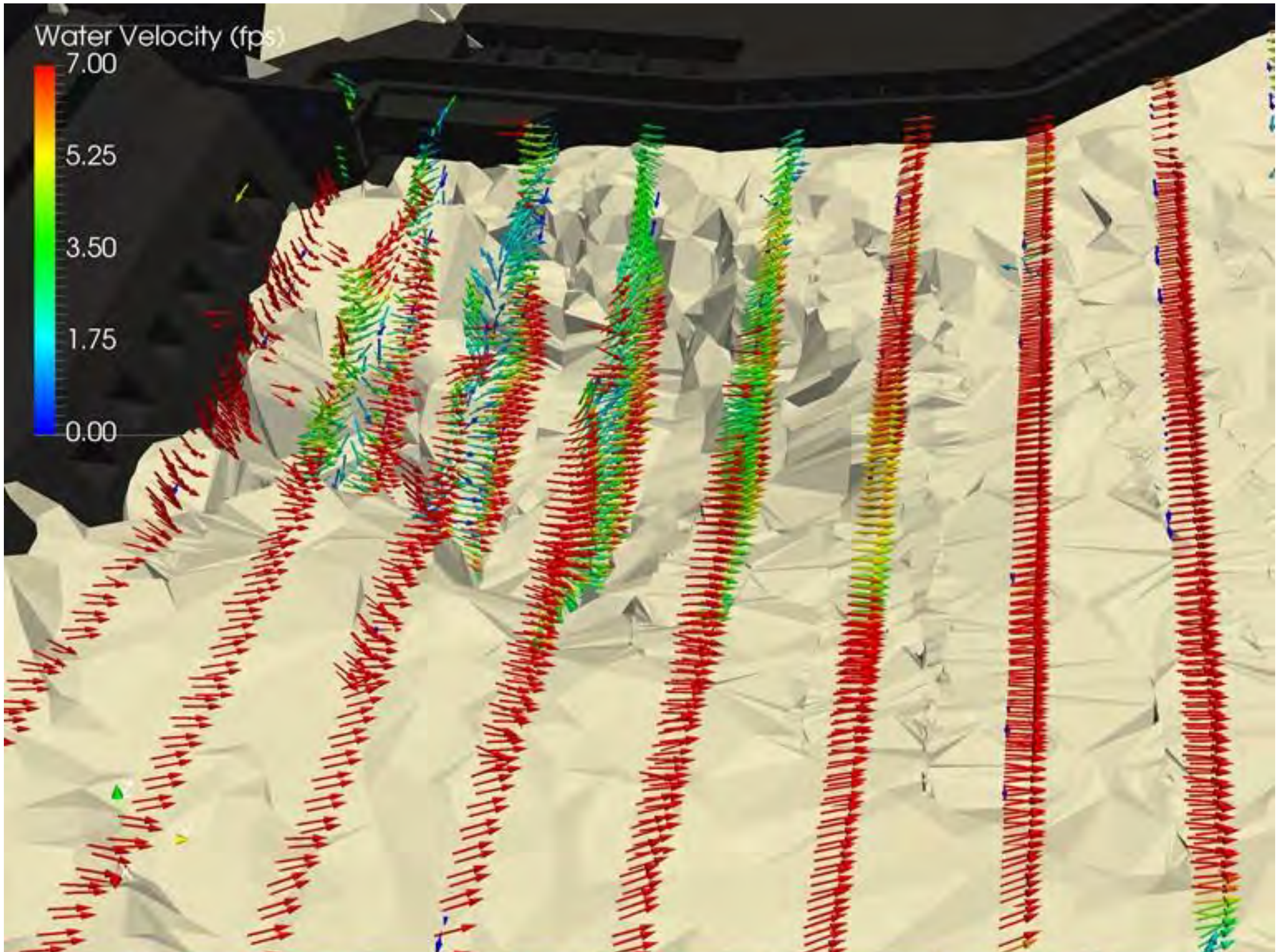


Figure 8.5.4-5: PR 6-4 Modeled Streamlines and Velocity Vectors
The black arrows indicate flow direction. The orange streamlines represent the path of water released from the Spillway fishway. Total model flow is 30,278 cfs.



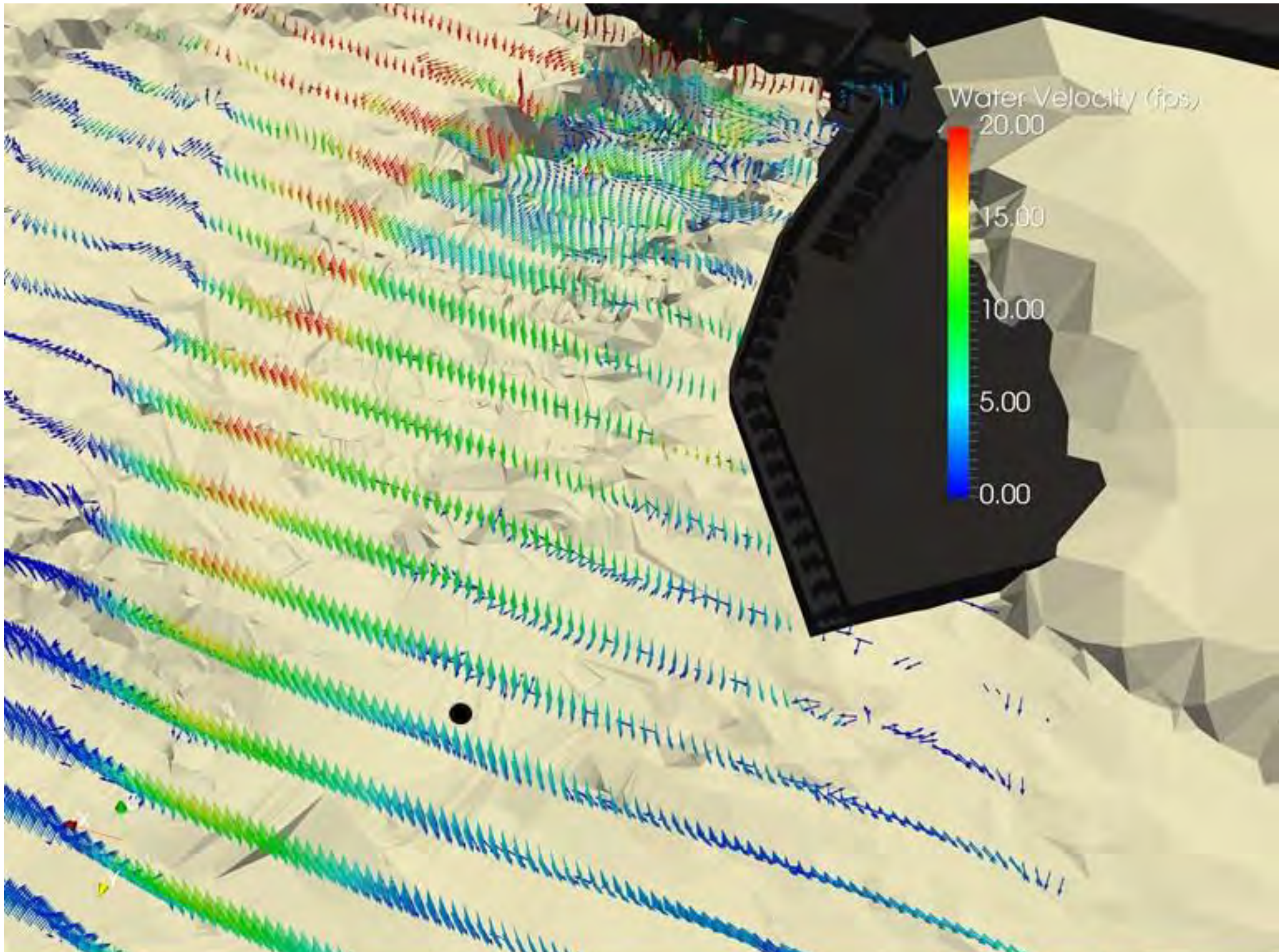
Scenario Number	Power Canal Flow (cfs)	Spillway Ladder Flow (cfs)	Bascule Gate No. 1 Flow (cfs)	Other Bascule Gate Spill (cfs)	Tainter Gate Spill (cfs)	Total Turners Falls Flow (cfs)	Water Surface Elevation (ft)
6-4	15,938	318	7,500	12,460	10,000	46,216	140.6

Figure 8.5.4-6: PR 6-4 Cross-Sections Showing Water Velocity Near the Spillway Fishway
Total model flow is 30,278 cfs. Scaled from 0-20 fps.



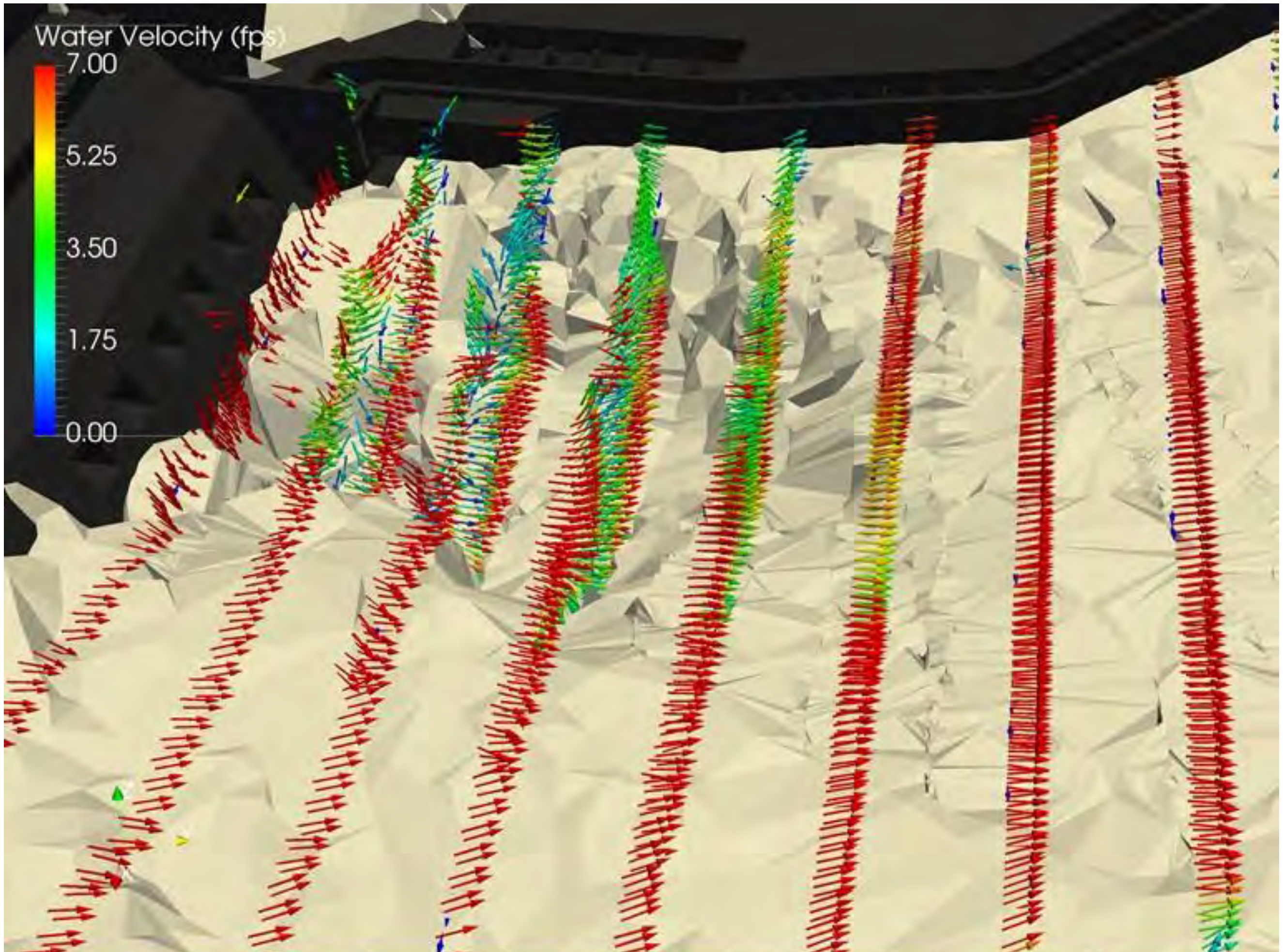
Scenario Number	Power Canal Flow (cfs)	Spillway Ladder Flow (cfs)	Bascule Gate No. 1 Flow (cfs)	Other Bascule Gate Spill (cfs)	Tainter Gate Spill (cfs)	Total Turners Falls Flow (cfs)	Water Surface Elevation (ft)
6-4	15,938	318	7,500	12,460	10,000	46,216	140.6

Figure 8.5.4-7: PR 6-4 Cross-Sections Showing Water Velocity Near the Spillway Fishway, Looking Upstream
Total model flow is 30,278 cfs. Scaled from 0-7 fps.



Scenario Number	Power Canal Flow (cfs)	Spillway Ladder Flow (cfs)	Bascule Gate No. 1 Flow (cfs)	Other Bascule Gate Spill (cfs)	Tainter Gate Spill (cfs)	Total Turners Falls Flow (cfs)	Water Surface Elevation (ft)
6-4	15,938	318	7,500	12,460	10,000	46,216	140.6 ●

Figure 8.5.4-8: PR 6-4 Cross-Sections Showing Water Velocity Near the Spillway Fishway
Total model flow is 30,278 cfs. Scaled from 0-20 fps.



Scenario Number	Power Canal Flow (cfs)	Spillway Ladder Flow (cfs)	Bascule Gate No. 1 Flow (cfs)	Other Bascule Gate Spill (cfs)	Tainter Gate Spill (cfs)	Total Turners Falls Flow (cfs)	Water Surface Elevation (ft)
6-4	15,938	318	7,500	12,460	10,000	46,216	140.6

Figure 8.5.4-9: PR 6-4 Cross-Sections Showing Water Velocity Near the Spillway Fishway, Looking Upstream
Total model flow is 30,278 cfs. Scaled from 0-7 fps.

9 REFERENCES

Federal Energy Regulatory Commission. (2013) "Study Plan Determination Letter for the Turners Falls Hydroelectric Project and the Northfield Mountain Pumped Storage Project." Letter to FirstLight. 13 Sept. 2014.

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Songheng, L., Hecker, G., & Johannson, A. (2013) Turners Falls Upstream Fish Passage CFD Modeling of Gatehouse Entrance. Hartford, Ct: Alden Research Laboratory, Inc.