Thompson Falls Hydroelectric Project
FERC Project No. 1869

NorthWestern Energy Initial Study Report Hydraulic Conditions Study

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April 2022

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List of Abbreviations and Acronyms

2D	two-dimensional
3D	three-dimensional
BO	Biological Opinion
CAD	Computer Aided Design
CFD	computational fluid dynamics
CFR	Code of Federal Regulations
cfs	cubic feet per second
DEM	digital elevation model
DEQ	Montana Department of Environmental Quality
ESA	Endangered Species Act
FERC	Federal Energy Regulatory Commission
fps	feet per second
FWP	Montana Fish, Wildlife and Parks
FWS	U.S. Fish and Wildlife Service
High Bridge	below the Main Channel Dam
HVJ	High Velocity Jet
ILP	FERC's Integrated Licensing Process
IBM	immersed boundary method
Licensee	NorthWestern Energy
LiDAR	Light Detecting and Ranging
Literature Review	Literature Review of Downstream Fish Passage Issues at Thompson Falls Hydroelectric Project (GEI, 2007)
NorthWestern	NorthWestern Energy
Project	Thompson Falls Hydroelectric Project
RANS	Reynolds Averaged Navier Stokes
Relicensing Participants	local, state, and federal governmental agencies, Native American Tribes, local landowners, non-governmental organizations, and other interested parties.
RNG	renormalized group
RTK-GPS	Real-Time Kinematic Global Positioning System
Scientific Panel	Thompson Falls Scientific Review Panel
STID	Supporting Technical Information Document
TAC	Technical Advisory Committee
TDG	total dissolved gas

TDG Plan	Total Dissolved Gas Control Plan
Thompson Falls Project	Thompson Falls Hydroelectric Project
TIN	Triangular Irregular Networks
U.S.	United States
USFS	United States Forest Service
VOF	Volume of Fluid

1.0 Introduction

The Thompson Falls Hydroelectric Project (Thompson Falls Project or Project) is located on the Clark Fork River in Sanders County, Montana. Non-federal hydropower projects in the United States (U.S.) are regulated by the Federal Energy Regulatory Commission (FERC) under the authority of the Federal Power Act. The current FERC License expires December 31, 2025. As required by the Federal Power Act and FERC's regulations, on July 1, 2020 NorthWestern Energy (NorthWestern), the current licensee, filed a Notice of Intent to relicense the Thompson Falls Project using FERC's Integrated Licensing Process (ILP). Concurrently, NorthWestern filed a Pre-Application Document (PAD).

The ILP is FERC's default licensing process which evaluates effects of a project based on a nexus to continuing Project operations. In general, the purpose of the pre-filing stage of the ILP is to inform Relicensing Participants about relicensing, to identify issues and study needs (based on a project nexus and established FERC criteria), to conduct those studies per specific FERC requirements which are included in the FERC Study Plan Determination, issued May 10, 2021, and to prepare the Final License Application.

This Initial Study Report has been prepared to comply with NorthWestern's Revised Study Plan, filed April 12, 2021, as approved in the FERC Study Plan Determination. This Initial Study Report provides results from the two-dimensional (2D) modeling of the near field downstream of Thompson Falls Main Channel Dam and recommendations for the specific scenarios to model with the three-dimensional (3D) modeling.

1.1 Hydraulic Conditions Study Background

Bull Trout (*Salvelinus confluentus*) were federally listed as a threatened species under the Endangered Species Act in 1998. The prior Licensee-prepared 2003 Biological Evaluation concluded that the Project was likely adversely affecting Bull Trout. On November 4, 2008, the FWS filed a Biological Opinion (BO) (FWS 2008) with FERC, concluding that continuing operations of the Project is likely to result in incidental 'take' of the Bull Trout in the form of harm and harassment, including mortality. The FWS further concluded that the level of anticipated incidental 'take' is not likely to result in jeopardy to the species or destruction or adverse modification of critical habitat. The BO included 'reasonable and prudent measures' which were deemed appropriate to minimize 'take', as well as terms and conditions for implementation of the reasonable and prudent measures.

The terms and conditions in the BO (FWS 2008) included a requirement for the Licensee to conduct Phase 2 fish passage evaluation studies. At the end of the Phase 2 evaluation period, the Licensee was required to prepare a comprehensive report for filing with FERC. The

Comprehensive Phase 2 Fish Passage Report was prepared with guidance from the Thompson Falls Technical Advisory Committee and filed with FERC on December 20, 2019.

The BO (FWS 2008) also required that the Licensee conduct a scientific review to determine if the Thompson Falls fish passage facility is functioning as intended, and whether operational or structural modifications are needed. The scientific review convened in January 2020, with the formation of the Thompson Falls Scientific Review Panel (Scientific Panel). On March 27, 2020, the Scientific Panel issued a memo (Scientific Panel 2020) summarizing its evaluation of the fish passage facility and providing recommendations on how to better evaluate the facility in the future. The Scientific Panel suggested NorthWestern initiate two parallel studies to assist in the determination of the fish passage facility's attraction and entrance efficiency:

- 2D hydraulics study that incorporates measured or approximated bathymetry to determine, at a minimum, a depth-averaged velocity field and water depths in the near field downstream of the dam/Project.
- Telemetry (radio-tag) study using sufficient sample sizes of surrogates to posit movement paths/rates and behavior in response to hydraulic conditions in the near field (areas immediately downstream of the Main Channel Dam, to approximately the High Bridge); the telemetry should be augmented by a literature review of the relative swimming capacities and behaviors of Rainbow, Westslope Cutthroat, Brown and Bull trout.

NorthWestern supplemented the Integrated Licensing Process (ILP) reporting requirements for this study by preparing an Interim Report. The Interim Report provided results from the 2D modeling and recommendations for the specific scenarios to model with the 3D modeling. The Interim Study Report was distributed to Montana Fish, Wildlife and Parks (FWP), the U. S. Forest Service (USFS), and the U.S. Fish and Wildlife Service (FWS) on February 15, 2022 for a 30-day review and comment period. A meeting was held on March 10, 2022 with representatives of FWP, the FWS, and the USFS to discuss the report, answer questions, and invite comments on the recommendations for Phase 2 of this study. Comments were received from FWP, USFS, and FWS. The Interim Report was revised based on comments received. The comments received on the Interim Study Report and NorthWestern's responses to those comments are found in **Section 5 – Comments and Responses to Comments**.

The goal of the hydraulic modeling study is to assess the velocity field downstream of the fish passage facility to understand if the flow field created by discharge from the fish passage facility provides a sufficient behavioral cue (attraction flow) to Bull Trout and other species, and whether velocities are low enough as to not fatigue fish attempting to approach the fish passage facility entrance.

1.2 Goals and Objectives of Study

The goal of the hydraulic modeling study is to assess the velocity field downstream of the fish passage facility to understand if the flow field created by discharge from the fish passage facility provides a sufficient behavioral cue (attraction flow) to Bull Trout and other species, and whether velocities are low enough as to not fatigue fish attempting to approach the fish passage facility entrance.

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2.0 Methods

2.1 Study Area

The Thompson Falls Hydroelectric Project is located in Thompson Falls, Montana on the Clark Fork River approximately 24 miles northwest of Plains, Montana. The general project location is shown in **Figure 2-1**. The study area for this Study generally includes a portion of the reservoir, the Main Channel Dam, and the channel downstream of the Main Channel Dam to the High Bridge. This area is shown in **Figure 2-2**. Site photographs of the Main Channel Dam and the area immediately downstream are shown in **Figure 2-3**.

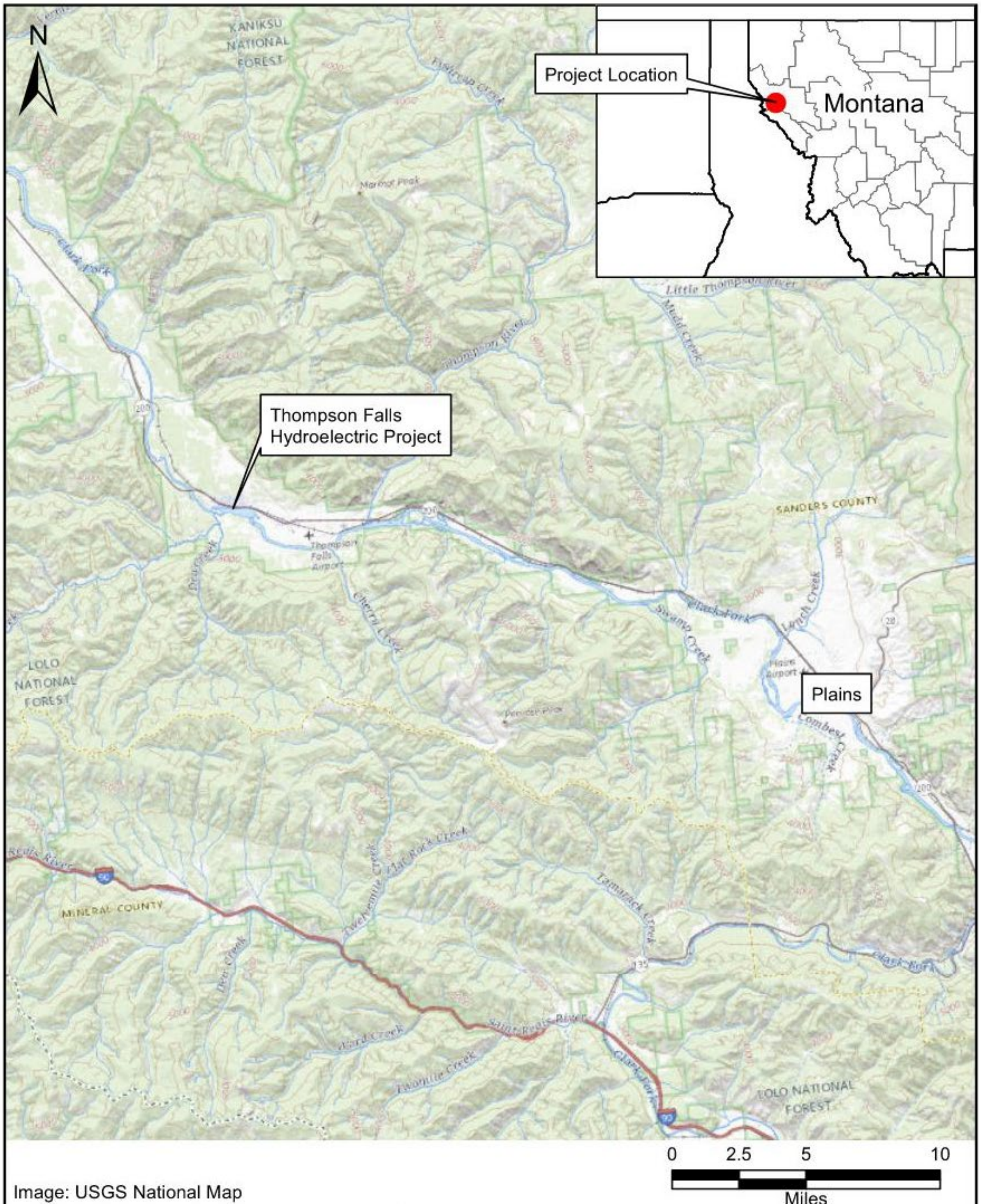
2.2 Study Methods

2.2.1 Task 1 – Bathymetric Surveying

The initial task (Task 1) for developing an understanding of the hydraulic conditions downstream of the fish passage facility included developing a 3D terrain model. The 3D model development included performing a bathymetric survey of the downstream channel. The bathymetric survey data was combined with publicly available Light Detecting and Ranging (LiDAR) data to develop a digital elevation model (DEM) of the Main Channel Dam, downstream river channel, and surrounding terrain.

Task 1 was accomplished by establishing ground control points and conducting the bathymetric survey with a single beam echo-sounder that was configured with a Real-Time Kinematic Global Positioning System (RTK-GPS). This provided data in XYZ format of riverbed elevations at accuracies limited by the equipment (e.g., 1-centimeter accuracy of echo-sounder and 3-centimeter accuracy of RTK-GPS). Additional information related to the survey resolution and accuracy is provided in Attachment A. To efficiently capture a complete bathymetric coverage of the riverbed, the RTK-GPS equipped echo-sounder was attached to a motorized boat that circled the river channel at approximately 25-foot spacings at survey speed (i.e., 2-4 kilometers per hour). To ensure an accurate bathymetric survey, the echo-sounder data was compared against multiple RTK-GPS depths taken from the traditional rod method. Additional survey information was also collected by Northwestern using a traditional rod method to supplement the collected data within the pools immediately downstream of the Main Channel Dam. The land and bathymetric surveys were combined into a single DEM. This was accomplished by merging the datasets into a single-point cloud and creating a surface using a Triangular Irregular Network (TIN) and breaklines (spillway structure, water surface elevations, etc.). This TIN was converted into raster format (also known as geoTIFF) and 1-foot contours for use in this study. The terrain data developed as part of Task 1 are shown in **Figure 2-4**.

Figure 2-1. Thompson Falls Hydroelectric Project Site Location Map



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THOMPSON FALLS
HYDROELECTRIC PROJECT
SITE LOCATION MAP

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Figure 2-2. Thompson Falls Hydroelectric Project General Site Plan

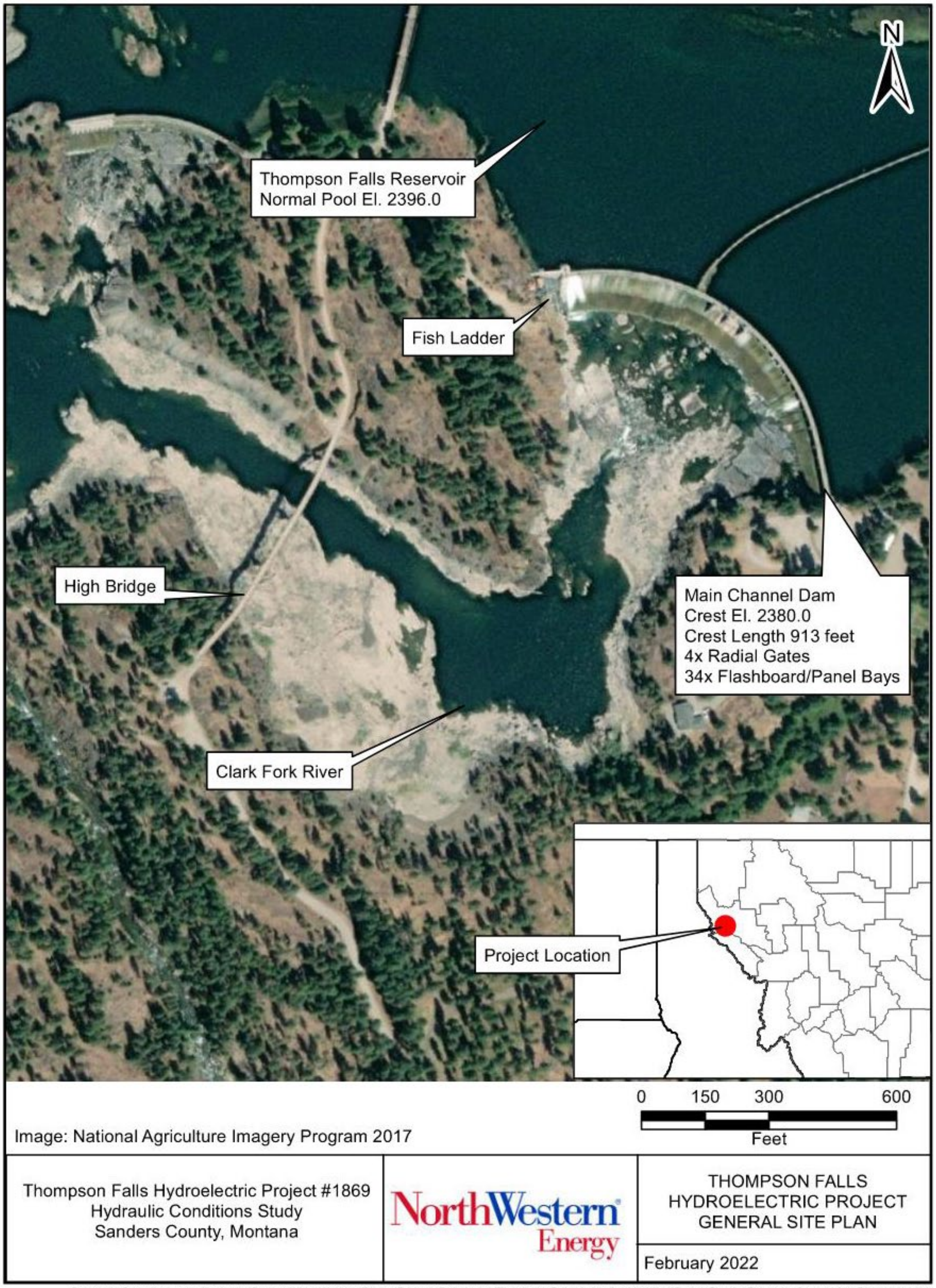

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Figure 2-3. Thompson Falls Main Channel Dam Site Photos

Looking Upstream Towards Dam

Right Side of Dam

Typical Bay and Panel Configuration

Left Side of Dam

Notes
1. Photos excerpted from 2016 Part 12D inspection report (AECOM, 2016).

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THOMPSON FALLS
MAIN CHANNEL DAM
SITE PHOTOS

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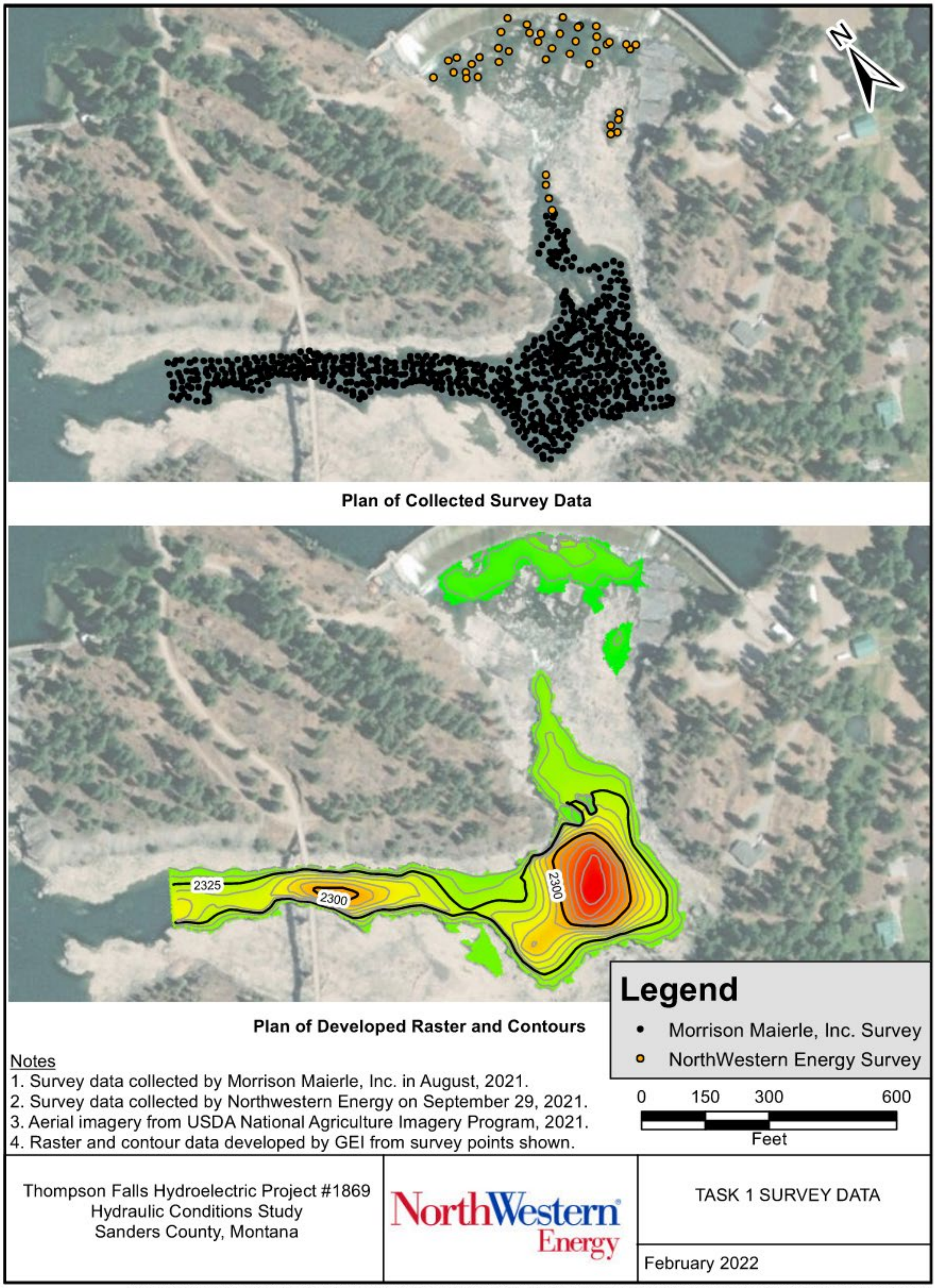
Figure 2-4. Task 1 Survey Data



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2.2.2 Task 2 – Hydraulic Modeling

A computational fluid dynamics (CFD) model was developed of the existing Thompson Falls Main Channel Dam and river downstream of the dam using FLOW-3D software. FLOW-3D can perform both Shallow Water methods (a sophisticated 2D modeling method) and highly resolved 3D modeling of the river flow, using 3D topography, bathymetry, structures geometry, and the surrounding terrain. FLOW-3D can simulate fully 3D and transient flow to examine important parameters like velocity, mixing, pressure, turbulence intensity and dissipation, and free water surface profiles.

NorthWestern is using a two-phase approach to the hydraulic modeling. The first phase was performed using 2D simulations to provide an overview of the river channel hydraulics and evaluate a wider range of flow rates to identify areas in the river channel to focus and refine the hydraulic modeling and to identify the critical flow rates. The CFD model was used to simulate 2D flow with depth averaged velocities. Model results were reviewed and compared with available operational data to validate the model results with known flow rates and depths. Model adjustments were performed as necessary to calibrate the model to observed initial conditions and flow rates.

A total of four scenarios were developed and evaluated for the first phase of the CFD modeling. The modeling scenarios were developed to determine the flow behavior and resulting downstream flow conditions. The four modeling scenarios are presented in **Table 2-1.**

Table 2-1. Summary of CFD Modeling Scenarios

Run	Modeled Spill over Main Channel Dam	Total River Discharge	Key Output Goals
1	37,000 cfs	60,000 cfs	Assess downstream flow conditions during the upper limit of Upstream Fish Passage Facility operations
2	25,000 cfs	48,000 cfs	Assess downstream flow conditions at the high design flow of the Upstream Fish Passage Facility
3	2,000 cfs	25,000 cfs	Assess downstream flow conditions at an intermediate typical flow rate
4	200 cfs	<23,000 cfs	Assess downstream flow conditions near the minimum operating conditions of the Upstream Fish Passage Facility

Note: cfs = cubic feet per second

In general, these discharge scenarios were selected to evaluate a wide range of potential flow scenarios at Thompson Falls Dam. The USGS Gage number 12389000 Clark Fork Near Plains MT is located approximately 30 river miles upstream of Thompson Falls Dam can be used to provide some context for these flows and how they relate to previously observed conditions at the dam. **Figure 2-5** shows a daily maximum flow exceedance curve developed from this gage with a period of record from October 1, 1910. As indicated in **Figure 2-5**, Scenario 4 represents approximately 78 percent of the observed flows in the Clark Fork River. For further reference,

Figure 2-6 shows the average annual hydrograph at this USGS gage. As can be seen in this figure, the average annual hydrograph peaks in early June at approximately 59,000 cfs. This is approximately 98 percent of the flow evaluated in analysis Scenario 1.

Prior to development of the CFD model, preliminary analyses were performed using spreadsheet tools to evaluate initial and boundary conditions that could be used for modeling the hydraulic conditions at the Main Channel Dam. These analyses were guided by a review of relevant background information including rating curves and discharge information provided by dam operators. The empirical analyses performed helped to provide a starting point for the CFD analyses described in the following sections.

CFD simulations were performed using FLOW-3D HYDRO software (version 22.1.0.16). The FLOW-3D model is a robust CFD program capable of modeling a wide variety of hydraulics problems. FLOW-3D solves the Reynolds-Averaged Navier-Stokes (RANS) equations using a finite volume method and the flow surface is determined using a volume of fluid (VOF) method. The CFD model included the Main Channel Dam, portions of the reservoir immediately upstream of the Main Channel Dam, and the channel downstream of the Main Channel Dam. The model extended to approximately 500 feet downstream of the High Bridge.

To develop the terrain for the CFD model, a number of different sources were used. The bathymetry data collected during Task 1 of this study was supplemented with publicly available LiDAR from the U.S. Army Corps of Engineers and traditionally collected survey data performed by NorthWestern. Additionally, as-built drawings of the Main Channel Dam and Upstream Fish Passage Facility were used to develop geometry for the discharge structures. Additional information regarding the Main Channel Dam is provided in the Supporting Technical Information Document (STID) (WGI 2016). The supporting piers for the High Bridge were not included in the model but are not expected to have a significant impact on the flow regimes within the model. This assumption is considered to be reasonable given the narrow profile of the bridge piers and placement outside of the main river channel.

Figure 2-7 and **Figure 2-8** show the terrain used in the CFD model. The terrain information shown in these figures generally represents the areas shown in the aerial photographs. These photographs were taken during a Main Channel Dam discharge of approximately 26,800 cfs in May 2021. The terrain data and spillway geometries were used to develop the mesh-generated FAVOR[1] geometry in the CFD model. **Figure 2-9** shows a comparison of the terrain data and the CFD geometry.

Due to the range of flow rates evaluated as this part of the project, different model domains and mesh configurations were developed for each scenario. The details of the model domains for each of these scenarios is provided in **Table 2-2**.

[1] FAVOR means "Fractional Area Volume Obstacle Representation." The FAVOR method is used by FLOW-3D to represent geometry by smoothly blocking out fractional portions of the grid cells filled with the solid geometry.

Table 2-2. Summary of CFD Modeling Domains

Run	Target Flow Rate	Mesh Blocks and Cell Spacing	Total Cell Count
1	37,000 cfs	6 Blocks @ 1 foot 3 Blocks @ 2 foot 1 Blocks @ 4 foot 2 Shallow Water Blocks @ 8 foot	7,964,767
2	25,000 cfs	4 Blocks @ 1 foot 3 Blocks @ 2 foot 1 Blocks @ 4 foot 2 Shallow Water Blocks @ 8 foot	5,901,293
3	2,000 cfs	1 Conforming Block @ 0.5 foot 3 Blocks @ 1 foot 3 Blocks @ 2 foot (1 conforming) 1 Blocks @ 4 foot 2 Shallow Water Blocks @ 8 foot	8,274,027*
4	200 cfs	2 Blocks @ 0.5 foot (1 conforming) 3 Blocks @ 1 foot (1 conforming) 2 Blocks @ 2 foot (1 conforming) 1 Blocks @ 4 foot 2 Shallow Water Blocks @ 8 foot	63,382,692*

* This does not account for reduced cell counts due to conforming blocks.

Figure 2-5. USGS Gage 12389000 Clark Fork Near Plains MT Flow Exceedance Curve

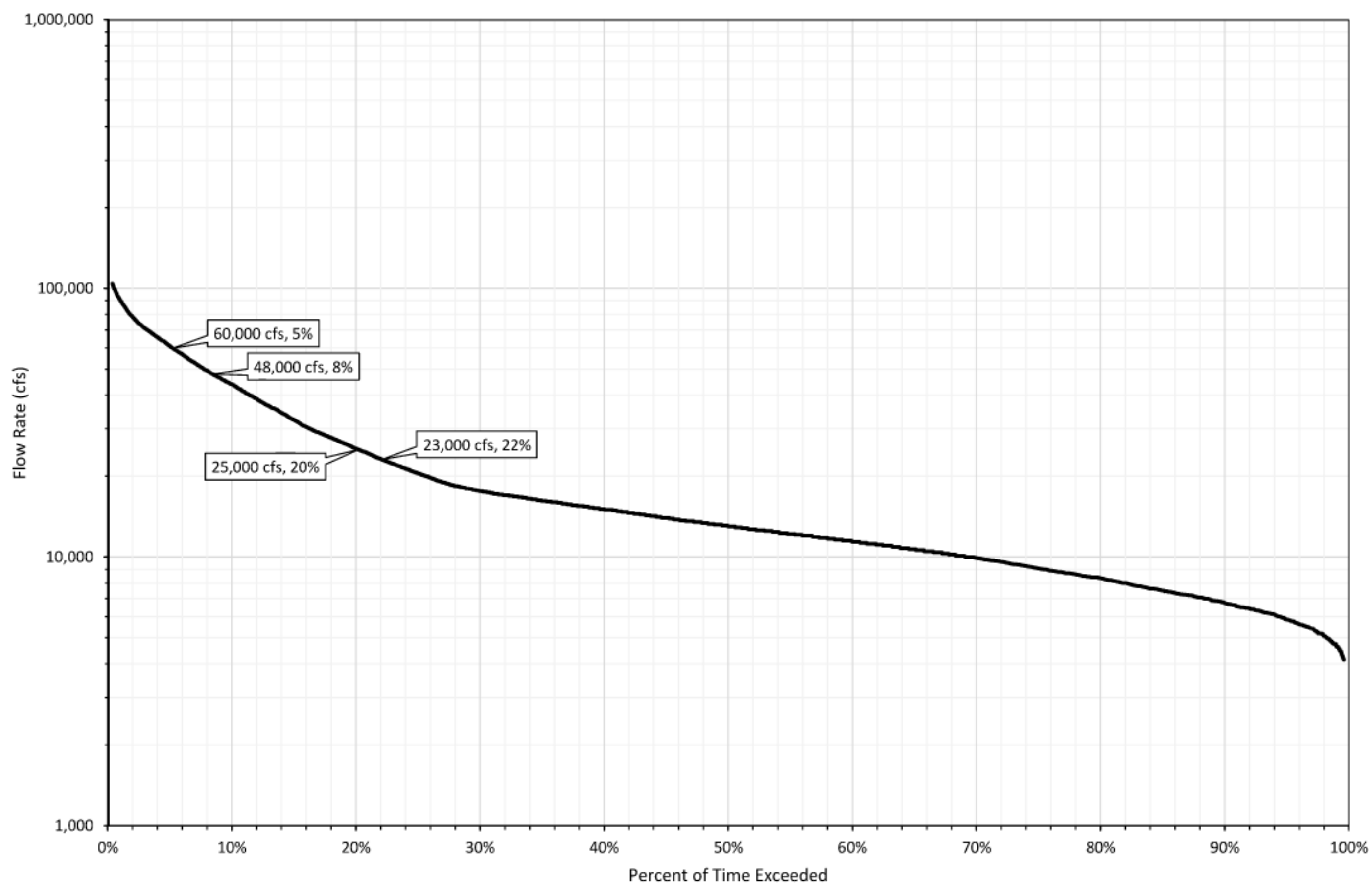

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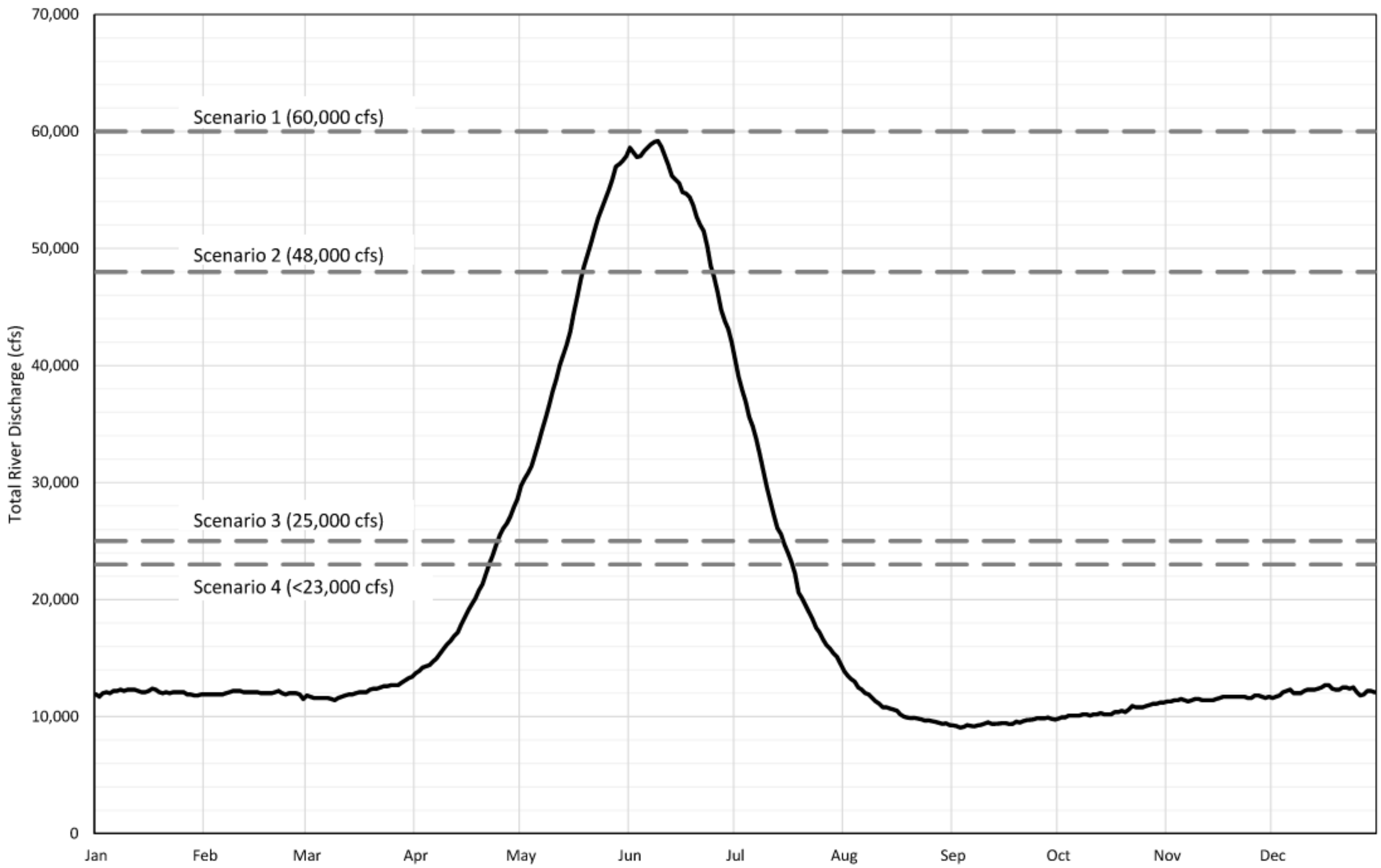
Figure 2-6. USGS Gage 12389000 Clark Fork Near Plains MT Average Annual Hydrograph



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USGS GAGE 12389000
CLARK FORK NEAR PLAINS MT
AVERAGE ANNUAL HYDROGRAPH

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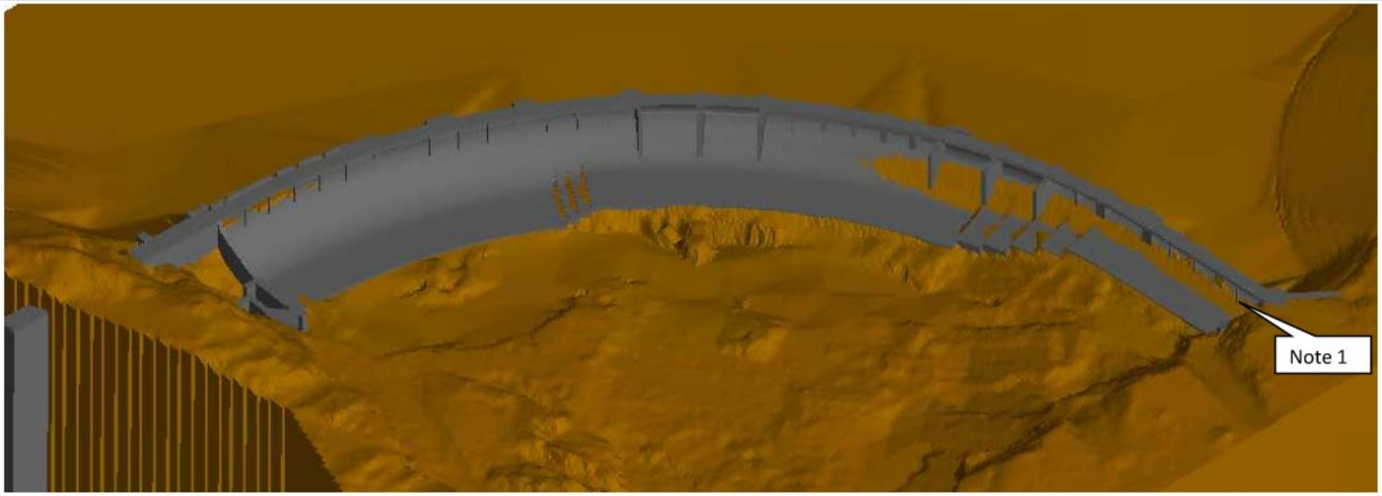
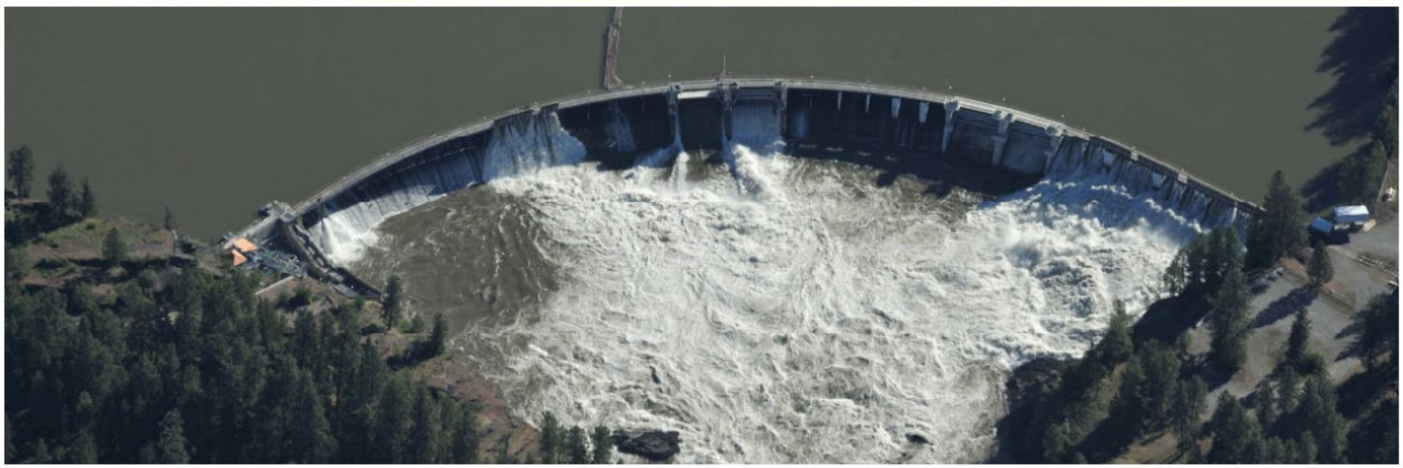
Figure 2-7. CFD Model – CAD Geometry (1 of 2)





Notes
1. Terrain edits to remove topography from spillway structure not shown.

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CFD MODEL - CAD GEOMETRY
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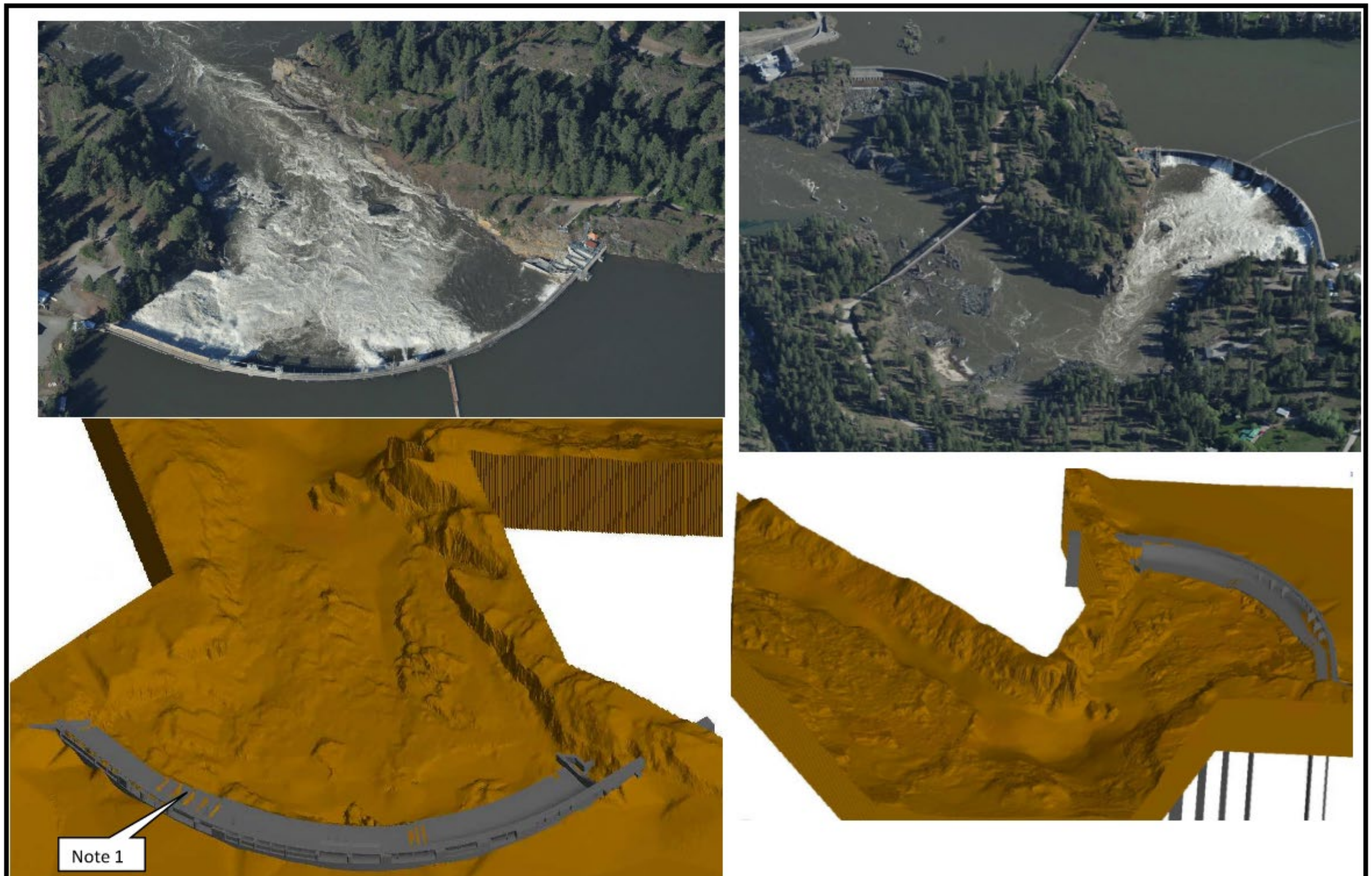
Figure 2-8. CFD Model – CAD Geometry (2 of 2)



Notes
1. Terrain edits to remove topography from spillway structure not shown.

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CFD MODEL - CAD GEOMETRY
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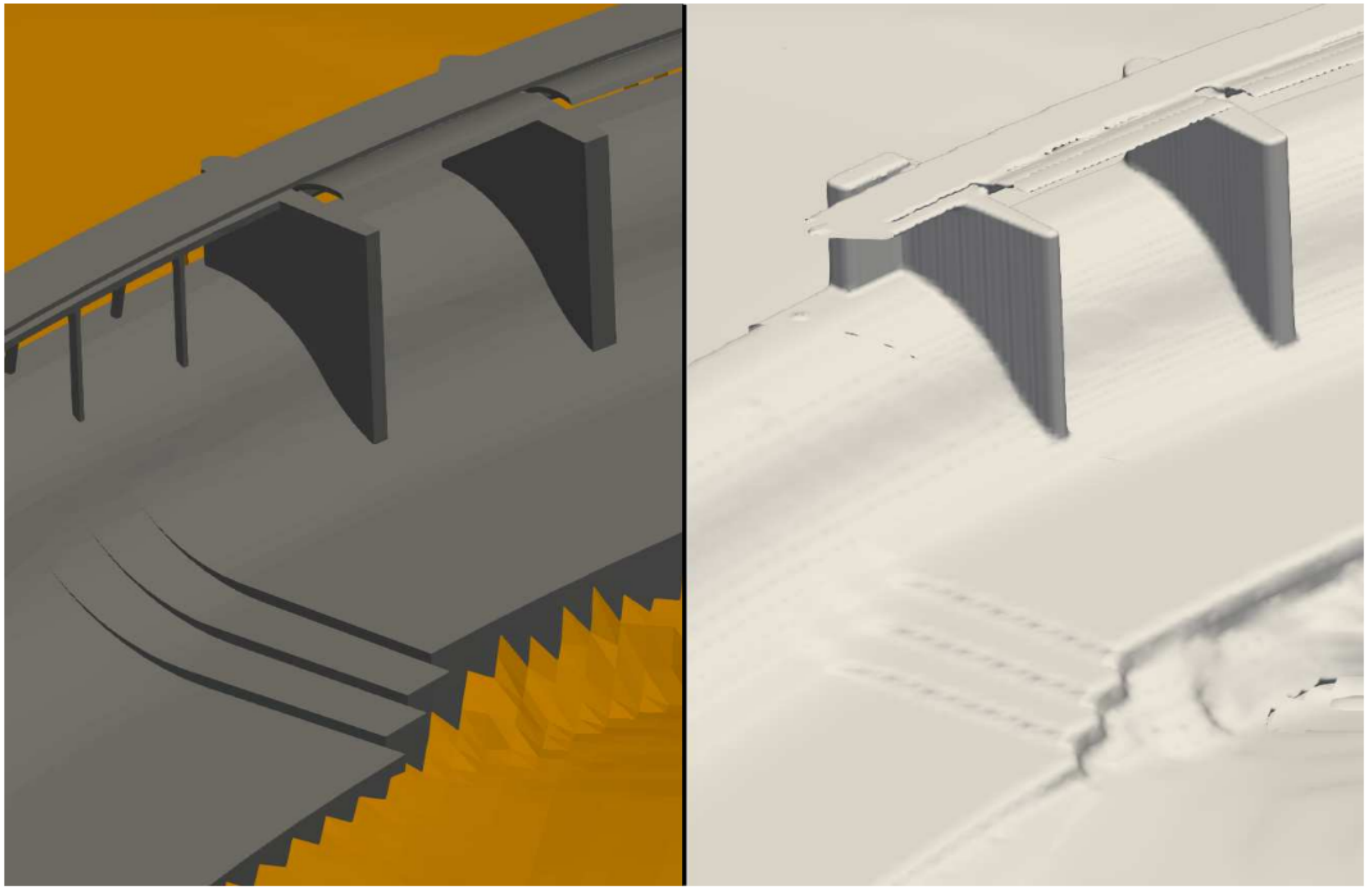
Figure 2-9. CFD Model – FAVOR Surface Comparison



CAD Geometry

FAVOR Surface

Notes
1. Terrain edits to remove topography from spillway structure not shown.

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CFD MODEL - FAVOR SURFACE COMPARISON

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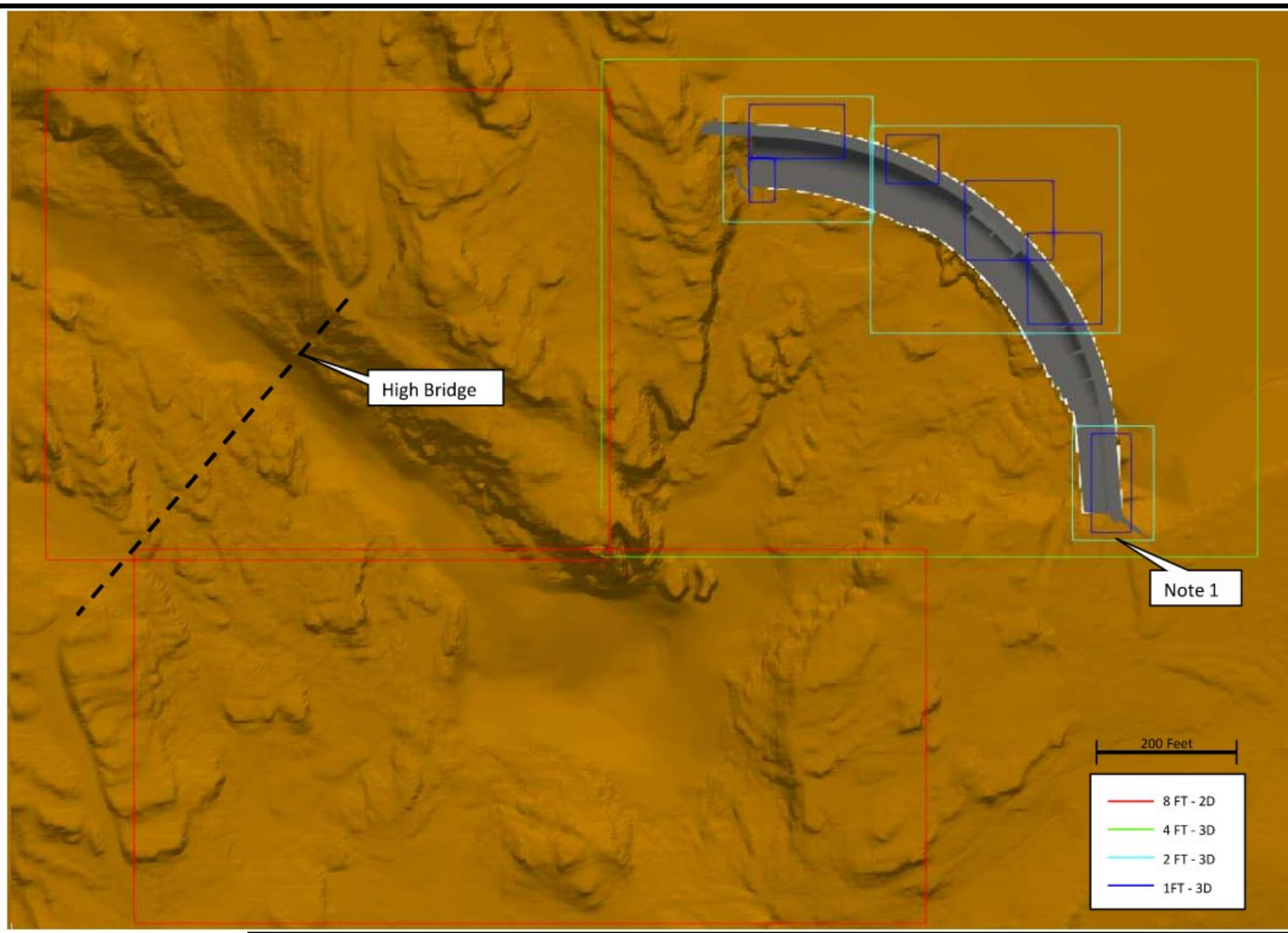
The 2D blocks had a spacing of 8 feet and were added to the CFD model using the shallow water physics module. FLOW-3D documentation indicates that using this module is appropriate for when the fluid depth is much less than the fluid extents in other directions and is useful for large-scale simulations (Flow Science 2021). The general configuration and spatial extents of the model mesh is shown in **Figure 2-10**. All model scenarios began with a 3D mesh volume of approximately 107 million cubic feet and a 2D mesh area of approximately 1.3 million square feet. Both the 3D and 2D mesh portions were additionally reduced in size for each scenario using domain removing blocks. The removal of cells that are not wetted during the entire model runtime help to improve computation efficiency of the FLOW-3D solver. Additional details of the domain removing blocks and mesh configurations are provided in Attachment B.

A vast number of modeling parameter options are available within the FLOW-3D software for users to adjust to better fit the modeling needs and scenarios. While developing the model for the Main Channel Dam, parameters were selected to best suit the high velocity flow through the dam structures and turbulent conditions downstream of the Main Channel Dam. To model the turbulent flow, the Renormalized Group (RNG) turbulence model was used. The RNG model is similar to k-ε model with the modification that a number of numerical constants are derived explicitly. Additionally, the RNG model uses a dynamically computed mixing length. This turbulence model is generally recommended for turbulent flows because it is able to accurately model flows that have strong shear regions (Flow Science 2021). A sensitivity analysis of this turbulence model selection was performed and is documented in **Section 3.3 – CFD Model Sensitivity Analysis**. At the upstream end of the model, a constant pressure boundary condition was used to set a steady reservoir water surface corresponding to the normal reservoir water surface elevation. At the downstream end of the model, a pressure boundary was used to allow water to maintain a tailwater elevation in the model and allow flow to freely exit from the model domain. To model the forces and energy losses along solid objects, the immersed boundary method (IBM) option was selected (Flow Science 2021). The IBM option simulates "ghost cells" within the solid boundary layer to resolve numerical errors that occur at the boundary layer in fractional area cells (Flow Science 2021).

In numerical modeling, the selected timestep can have an impact on model accuracy as well as calculation runtimes. The computational timestep within the FLOW-3D model is dynamically computed during the model simulation and cannot be manually controlled by the user. In general, the timestep is adjusted by the solver to produce a stable model result and to meet convergence criteria, generally pressure residuals, at each mesh cell within the model domain. While the timestep is able to be reduced as small as 1x10-7 seconds, the Thompson Falls model generally utilized a timestep of approximately 5x10-3 seconds, which provided a stable model result and allowed for convergence criteria to be met. During the simulation runtime, a number of solver diagnostic variables can be monitored to assess and confirm model stability. The model scenarios generally used a simulation duration of approximately 600 seconds (10 minutes). This simulation duration allowed for flows to reach steady-state throughout the model domain.

The FLOW-3D model allows the user to assign surface roughness values to the various geometry components within the domain. These values are designated based on absolute roughness values, also referred to as Nikuradse roughness. These values can be estimated from more typical Manning's n-values through the Manning-Strickler equation (Chow 1959). For the Thompson Falls model, absolute roughness values of 2.1x10-3 and 0.14 were used for the concrete and natural surfaces, respectively. These values correspond to manning's n-values of 0.015 and 0.03 which are considered to be appropriate for the concrete and natural rock channel surfaces, respectively. It is important to note that these roughness values are primarily used within the FLOW-3D model to account for skin friction. Other losses due to momentum and impacts with the rocky and uneven channel topography (form losses) are accounted for in the numerical solver directly. The FLOW-3D hydraulic model summary and input and output files are provided in Attachment B. A sensitivity analysis for these roughness values is included in **Section 3.3 – CFD Model Sensitivity Analysis**.

Figure 2-10. CFD Model – Mesh Layout



Notes
1. Configuration for Run 1 (37,000 cfs) shown. Location of 1 foot and 2 foot blocks varies depending on model scenario.

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CFD MODEL - MESH LAYOUT

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During development of the FLOW-3D model, a traditional hydraulic modeling approach was utilized. In general, preliminary models were simple, with just a few components included (i.e., the reservoir and a singular bay opening). As the hydraulic flow conditions were reviewed and validated against available data, the complexity of the model was gradually increased to encompass the final model domain and all flow structures. Additionally, as these preliminary model runs were performed, discharge rates for the various control structures including the gated and paneled sections were compared to empirical equations and results of previous studies. This approach allowed for various model parameters and setup options to be evaluated such as physics modules and boundary conditions without being computationally expensive. In general, the final modeling scenarios described below are the culmination of this model development process. The results presented in **Section 3 – Results** generally focus on characterizing the velocity and depth of the resulting flow regimes as those are considered to be most applicable to fish behavior and passage. The details of some of these sensitivity analyses are additionally included in Section 3.

To produce each of the target flow rates, different combinations of gate and panel openings were used along with discharges from the High Velocity Jet (HVJ) and entrance to the Upstream Fish Passage Facility for each scenario. In general, these opening configurations were developed in accordance with historical operations and the Total Dissolved Gas (TDG) Plan (PPL Montana 2010).

Except for the 8 bays which contain the four radial gates, each of the 38 bays at the Main Channel Dam have 8-foot-high fixed wheel panels atop 8-foot-high flashboards. Each of these panels is approximately 4 feet wide and can generally be removed individually to produce the desired outflow rate at the Main Channel Dam. Each bay contains approximately six panels. This number varies between bays which have wider dividing piers. Additionally, to provide additional attraction flows near the Upstream Fish Passage Facility, half panels are able to be removed from Bay 1. A half panel has the same 4 feet wide but is only 4 feet tall instead of the 8 feet of a full panel.

The details of the opening configurations for each scenario are provided in **Table 2-3** below. In addition to the flow rates summarized below, the original Powerhouse and new Powerhouse located farther downstream is assumed to be passing 23,000 cfs.

Table 2-3. Summary of CFD Modeling Scenarios and Flow Distribution

Run	Fish Passage and HVJ	Bay 1 Attraction Flows	Radial Gates (Bays 16-19)	Radial Gates (Bays 26-29)	Panels (Bays 2-15, 20-25, 30-38)*	Main Channel Dam Flow
1	80 cfs	1/2 Panel (120 cfs)	Full Open (17,500 cfs)	Closed	3-5 : 1 10, 11 : 6 20-25 : 6 34 : 5 35-38 : 6 (19,300 cfs)	37,000 cfs
2	80 cfs	1/2 Panel (120 cfs)	Full Open (17,500 cfs)	Closed	3-5 : 1 20 : 2 35-38 : 6 (7,300 cfs)	25,000 cfs
3	80 cfs	1/2 Panel (120 cfs)	2.2 feet Open (1,800 cfs)	Closed	-	2,000 cfs
4	80 cfs	1/2 Panel (120 cfs)	Closed	Closed	-	200 cfs

* Bay Number(s) : Panels Opened

Based on the preliminary CFD model simulation results, minor differences in the discharge capacity for each panel were identified compared to the discharge capacity of 235 cfs per panel reported in the TDG Plan (PPL Montana 2010). Through discussion with the dam operations staff, it was determined that this 235 cfs capacity is based on previous operation history. Further review indicates that these differences can be attributed to variations in panel width due to the locations of the different pier sizes relative to the panel openings that may not have been accounted for in the previous study and differences of less than 5 percent in the estimated discharge capacity of the radial gate openings. To account for the minor differences in discharge capacity, additional flow panels were opened for model simulations 1 and 2 to achieve the target flow rates.

2.3 Fish Passage and Behavioral Criteria

As part of the Fish Behavior Study, a literature review is being conducted to increase understanding of the relative swimming capacities and behaviors of Rainbow, Westslope Cutthroat, Brown, Bull trout and other native fish species. The findings of this literature review will be used to evaluate the range of flows at which passage is feasible and if velocities at the Upstream Fish Passage Facility provide a sufficient attractant flow. A detailed description of these criteria and the literature review will be provided as part of the Initial Study Report on the Fish Behavior Study which will be filed with FERC by May 2022. This Initial Study Report represents the initial 2D hydraulic modeling results that will be tied to biological criteria in the Final Study Report.

2.4 Variances from the FERC-approved Study Plan

A variance from the FERC-approved Study Plan is the inclusion of 3D modeling blocks for portions of the Main Channel Dam structure. This is considered to be an enhancement to the study. The 3D modeling blocks were necessary to allow the CFD model to better capture the dynamic 3D flow conditions that occur at, and immediately downstream of, the Main Channel Dam structure.

In addition, the FERC-approved Study Plan described the study area as the Main Channel Dam downstream to the High Bridge. Specifically, the Study Plan stated that, "Based on available Project information and collected survey data, a 3D Computer Aided Design (CAD) model will be created of the spillway, downstream river channel and surrounding terrain. The downstream river channel will extend to just upstream of the High Bridge, or approximately 1,500 feet downstream of the dam." The study was conducted over a longer reach of river, from the Main Channel Dam to 500 feet downstream of the High Bridge, which is an enhancement of the study.

The FERC-approved Study Plan included a delivery date of February 1, 2022 for the Interim Report to be distributed to Relicensing Participants and a date of March 1, 2022 for comments being due to NorthWestern, with a meeting with Relicensing Participants to discuss Interim Report to be held in March 2022. The Interim Report was distributed to FWP, the FWS, and the USFS on February 15, 2022, with request for comments by a March 17, 2022 to allow more time to complete the Interim Report. The meeting with FWP, the FWS, and the USFS and was held in March (March 10, 2022) as described in the FERC-approved Revised Study Plan.

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3.0 Results

3.1 General Observations

Based on the results of CFD modeling, flows immediately downstream of the Thompson Falls Main Channel Dam are very complex, dynamic, and highly turbulent. Due to the curved shape of the Main Channel Dam, the flow jets through the panel and gate openings collide downstream of the structure causing significant mixing, turbulence, and energy dissipation. As flows pass downstream through the rocky falls area, velocities generally increase but are quickly dissipated by the main channel. The relatively sharp bend in the river alignment further dissipates velocities. As flows proceed farther downstream to the High Bridge, approximately 2,200 feet downstream of the Main Channel Dam, flows are relatively calm and uniform. Velocities increase again as the river narrows and depths decrease at the downstream boundary of the model domain approximately 500 feet downstream of the High Bridge. The results of the CFD analyses for each scenario are described in detail in the following sections.

3.2 CFD Model Results

3.2.1 Run 1: 37,000 cfs

Run 1, with a discharge rate of approximately 37,000 cfs, generally represents the maximum flow rate at which the Upstream Fish Passage Facility is operated. Perspective views of the modeled water surface and velocity gradient output at a steady-state flow condition of 37,000 cfs are depicted in **Figure 3-1**. The dam structures are colored gray for distinction from the terrain. Based on a discharge of 37,000 cfs, the CFD model computed general depths of approximately 5 to 8 feet within areas upstream of the falls. Some isolated locations are deeper in areas with localized pooling. Within the falls area, the river is approximately 25 feet deep. Downstream of the falls, depths exceed 50 feet at the right turn in the river channel and again near High Bridge. A plan view of depths within the model domain is shown in **Figure 3-2.**

Water velocities downstream of the Main Channel Dam generally range from approximately 2 to 21 feet per second (fps). In general, the highest velocities are on the downstream face of the Main Dam, which are reduced considerably immediately downstream of the Main Channel Dam due to energy dissipation from the highly turbulent flows. A plan view of water velocities within the model domain are shown in **Figure 3-3**. As indicated in **Figure 3-4**, the local Upstream Fish Passage Facility velocities are relatively low (less than 5 fps) due to the submergence of the Upstream Fish Passage Facility. Within the falls area, water velocities increase to a maximum of approximately 21 fps. Within the main river channel downstream of the falls, velocities decrease to approximately 11 fps as the channel widens and turns right. As the channel narrows again and flows pass under the High Bridge near the downstream end of the model, velocities increase to approximately 20 fps. The margins of the downstream river channel generally exhibit velocities of approximately 3 fps. However, along the left bank of the main channel there are a number of small side channels which locally increase the velocities. These generally reenter the main river channel near or just downstream of the High Bridge. Overall, the depth-averaged velocities from the Upstream Fish Passage Facility, through the channel downstream of High Bridge range from about 3 to 20 fps, with the higher velocities in the main channel path and lower velocities along the edges of the channel banks.

The flow path streamlines for Run 1, with a discharge rate of approximately 37,000 cfs, are shown in **Figure 3-5**. As indicated in **Figure 3-5**, the majority of the flow is concentrated towards and over the falls area, and then downstream and to the right before passing below the High Bridge. Velocity and water surface profiles along the centerline of the main flow path of the downstream channel is shown in **Figure 3-6**.

Figure 3-1. Run 1: 37,000 cfs Perspective Views

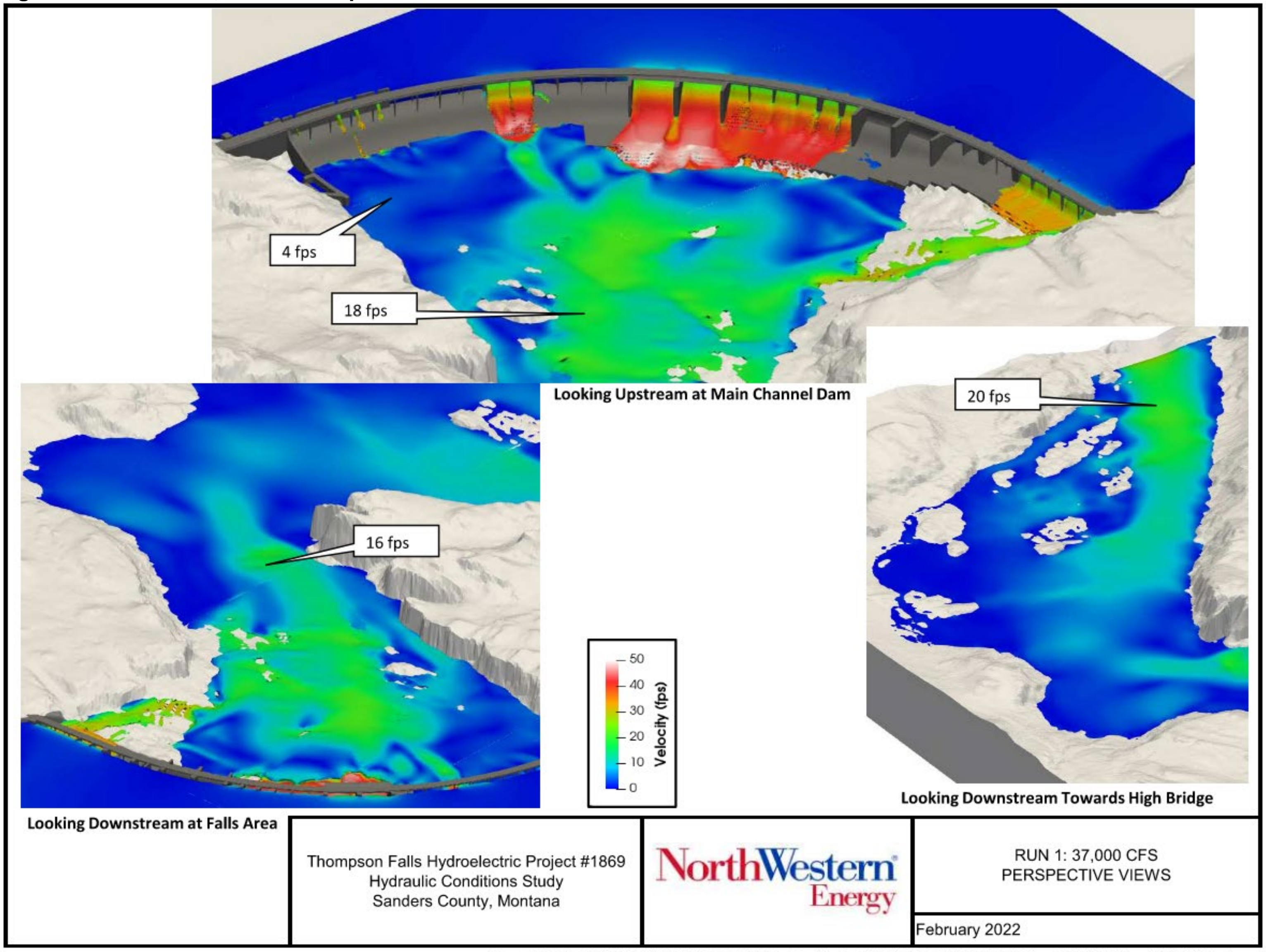
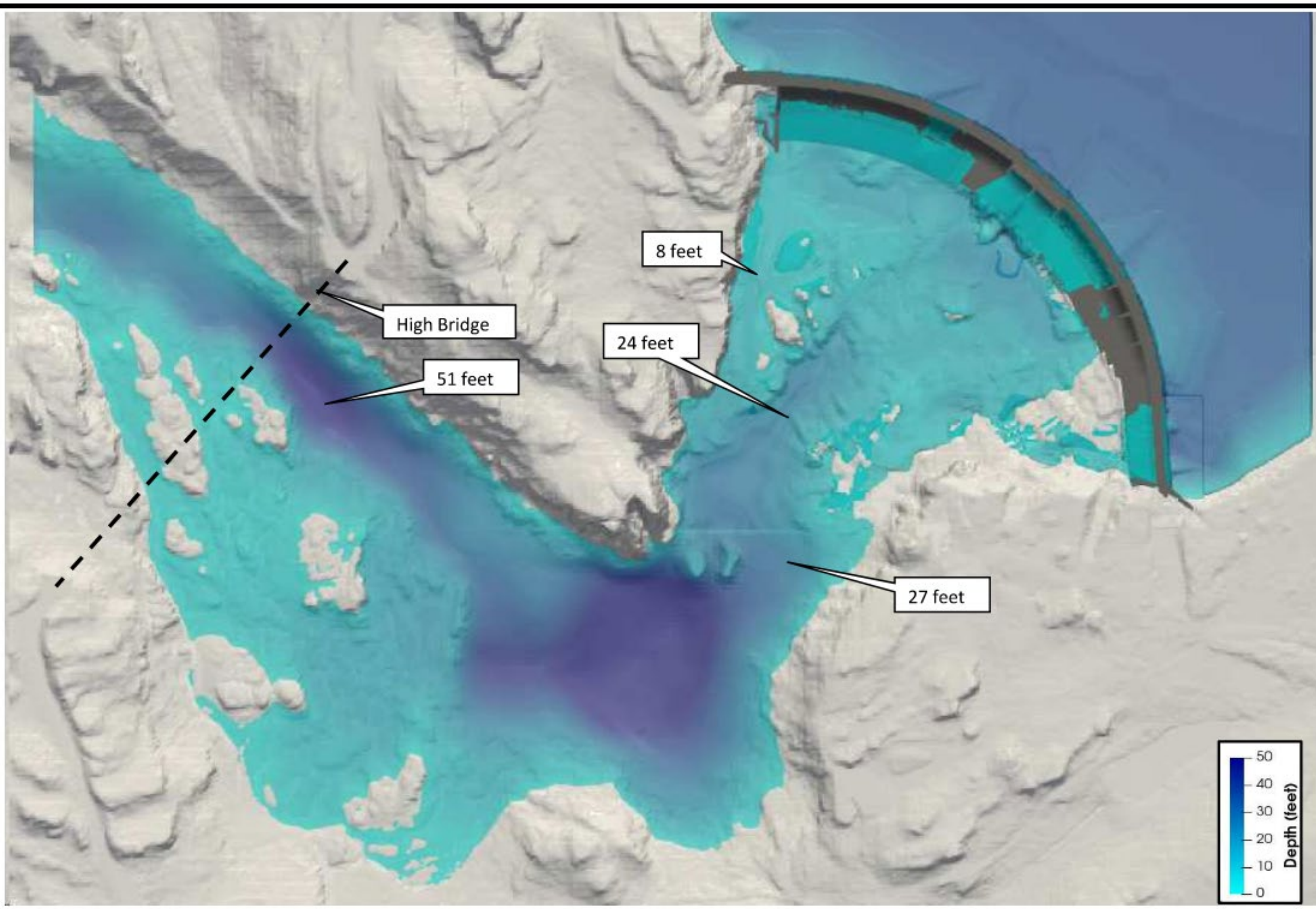


Figure 3-2. Run 1: 37,000 cfs Plan View of Flow Depths



Notes
1. Legend shown without transparency.

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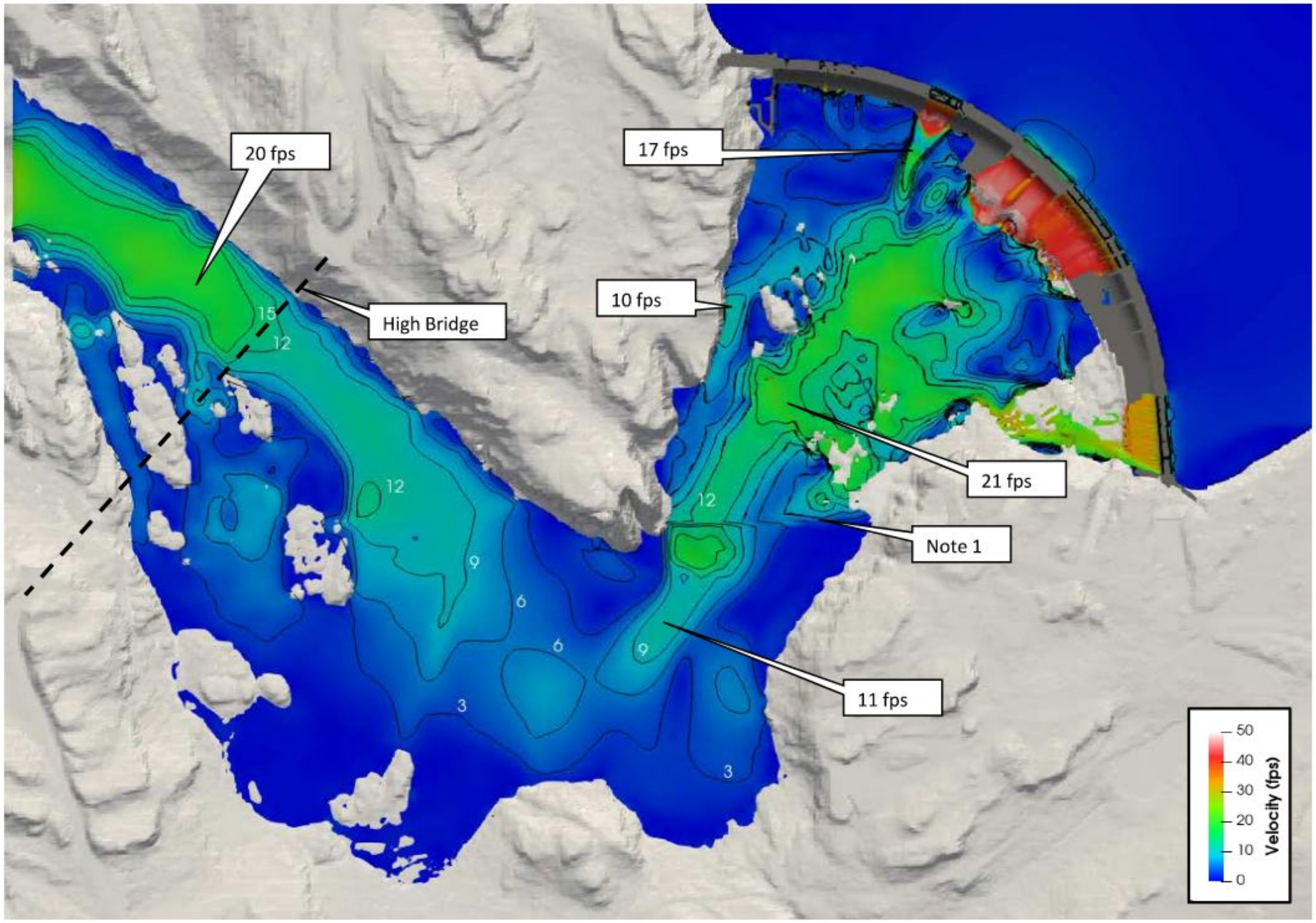
Figure 3-3. Run 1: 37,000 cfs Plan View of Velocities



Notes:
1. 2D/3D mesh block boundary.
2. Contour interval of 3 fps shown from 0-15 fps.

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Figure 3-4. Run 1: 37,000 cfs Upstream Fish Passage Facility Entrance Details

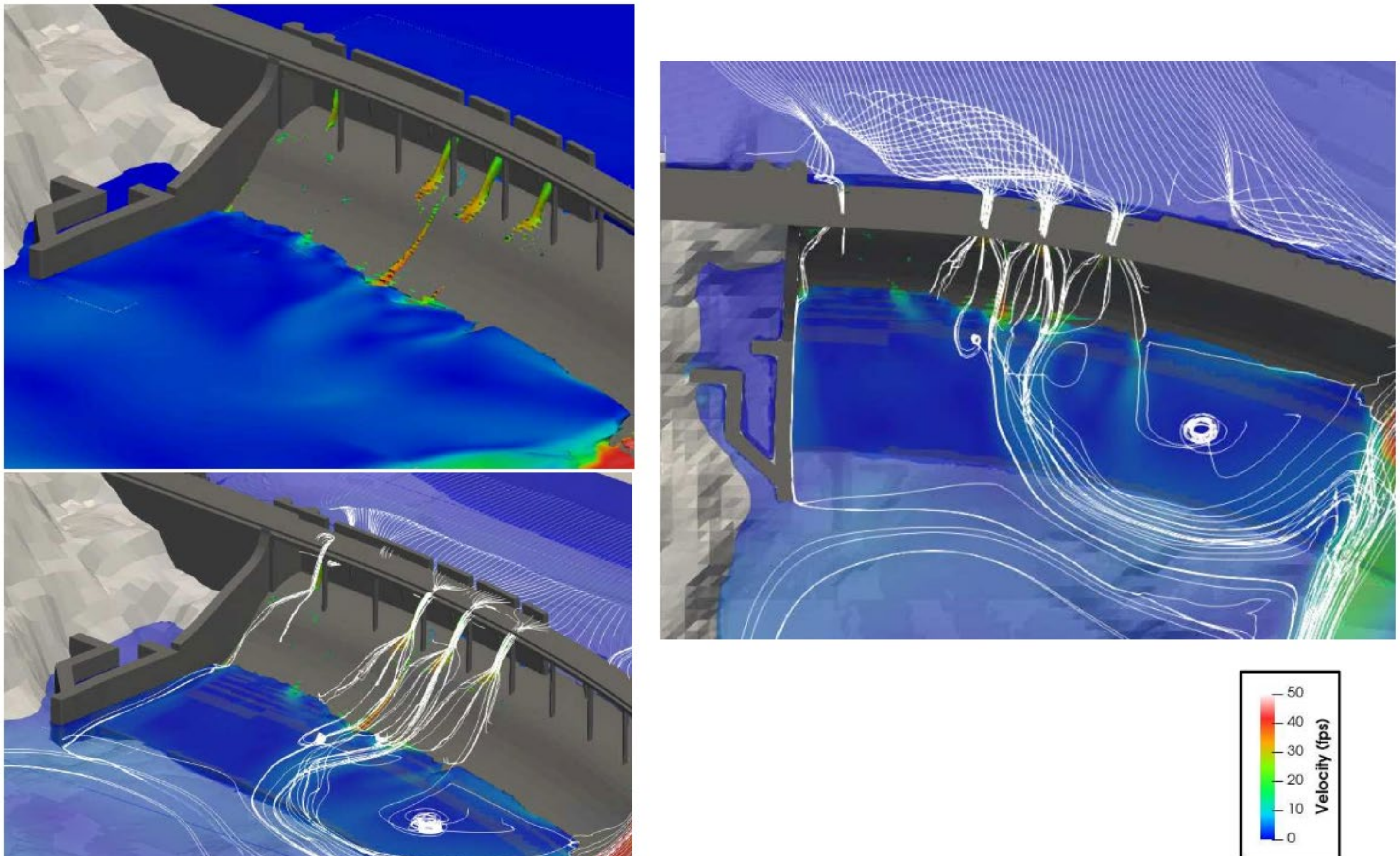

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Figure 3-5. Run 1: 37,000 cfs Flow Path Streamlines

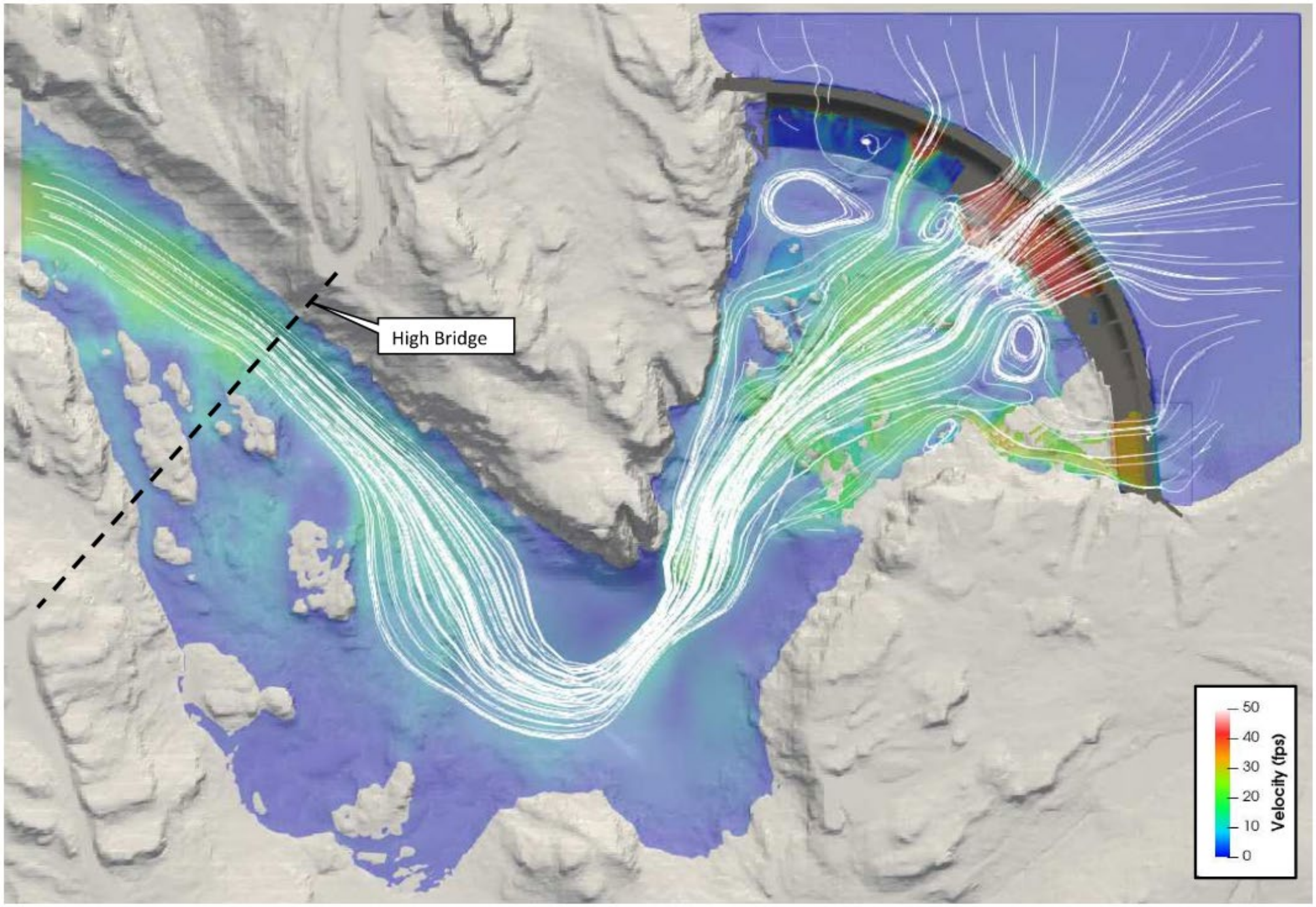

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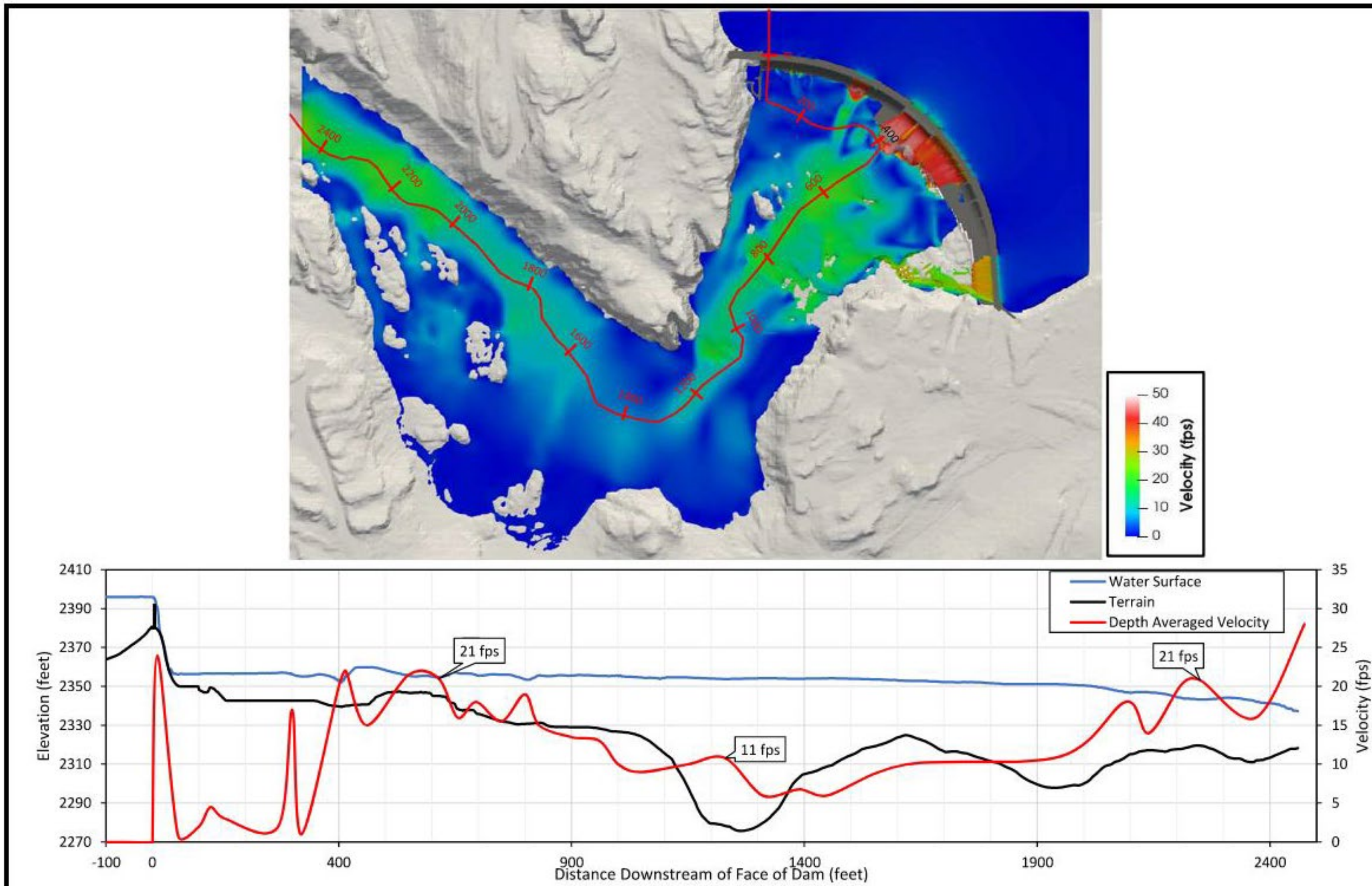
Figure 3-6. Run 1: 37,000 cfs Plan and Profile



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3.2.2 Run 2: 25,000 cfs

Run 2, with a discharge rate of approximately 25,000 cfs, generally represents the high design flow for the Upstream Fish Passage Facility. Perspective views of the modeled water surface and velocity gradient output at a steady-state flow condition of 25,000 cfs are depicted in **Figure 3-7**. The dam structures are colored gray for distinction from the terrain. The model results at this flow rate are very similar to those estimated for Run 1. Based on a discharge of 25,000 cfs, the CFD model computed general flow depths of approximately 5 to 8 feet within areas upstream of the falls. Some isolated locations are deeper in areas with localized pooling. Within the falls, the river is approximately 21 feet deep. Downstream of the falls, the river is approximately 50 feet deep at the right turn in the river channel and again near High Bridge. A plan view of water depth within the model domain is shown in **Figure 3-8**.

The velocities downstream of the Main Dam generally range from approximately 2 to 20 fps. In general, the highest velocities are on the downstream face of the Main Channel Dam, which are reduced considerably immediately downstream of the Main Channel Dam due to energy dissipation from the highly turbulent flows. A plan view of flow velocities within the model domain is shown in **Figure 3-9**. A detailed view of the velocities in the vicinity of the Upstream Fish Passage Facility is shown in **Figure 3-10**. As indicated in **Figure 3-10**, the local Upstream Fish Passage Facility velocities are relatively low (less than 5 fps) due to the submergence of the Upstream Fish Passage Facility. Some impacts from the HVJ can be seen within the resulting velocity field. Within the falls area, velocities increase to a maximum of approximately 27 fps. These velocities are slightly higher than those modeled at 37,000 cfs due to less submergence and a larger drop across the falls. Within the main river channel downstream of the falls, flow velocities decrease to approximately 13 fps as the channel widens and turns right. As the channel narrows again and flows pass under the High Bridge near the end of the model, velocities increase to approximately 19 fps. The margins of the downstream river channel generally exhibit velocities of approximately 1 to 5 fps. Overall, the depth-averaged velocities from the Upstream Fish Passage Facility, through the channel downstream of High Bridge range from about 2 to 27 fps, with the high velocities in the main channel path and lower velocities along the edges of the channel banks.

The flow path streamlines for Run 2, with a discharge rate of approximately 25,000 cfs, are shown in **Figure 3-11**. As indicated in **Figure 3-11**, the majority of the flow is concentrated towards and over the falls area, and then downstream and to the right before passing below the High Bridge. Velocity and water surface profiles along the centerline of the main flow path of the downstream channel is shown in **Figure 3-12**.

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Figure 3-7. Run 2: 25,000 cfs Perspective Views

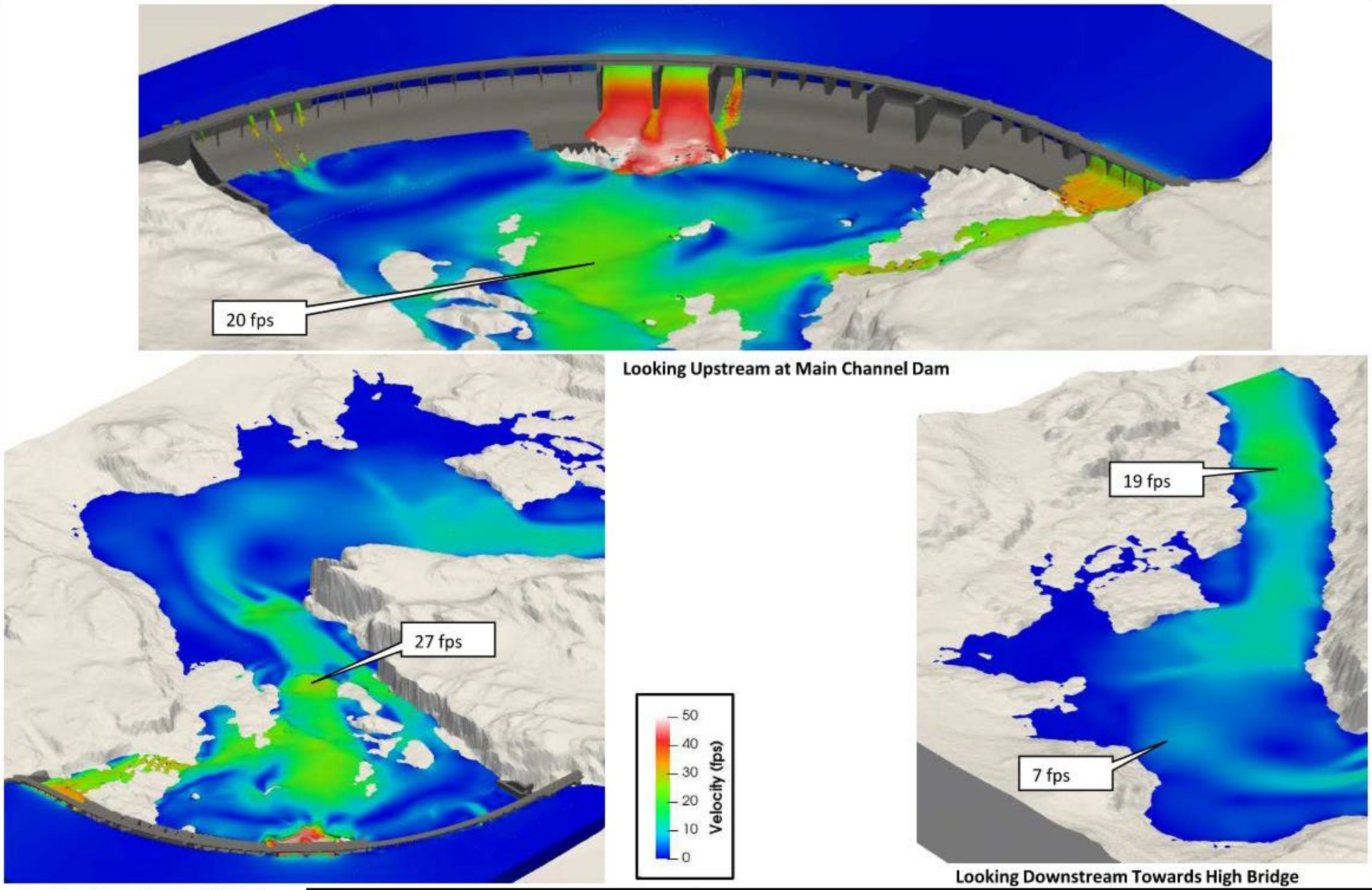

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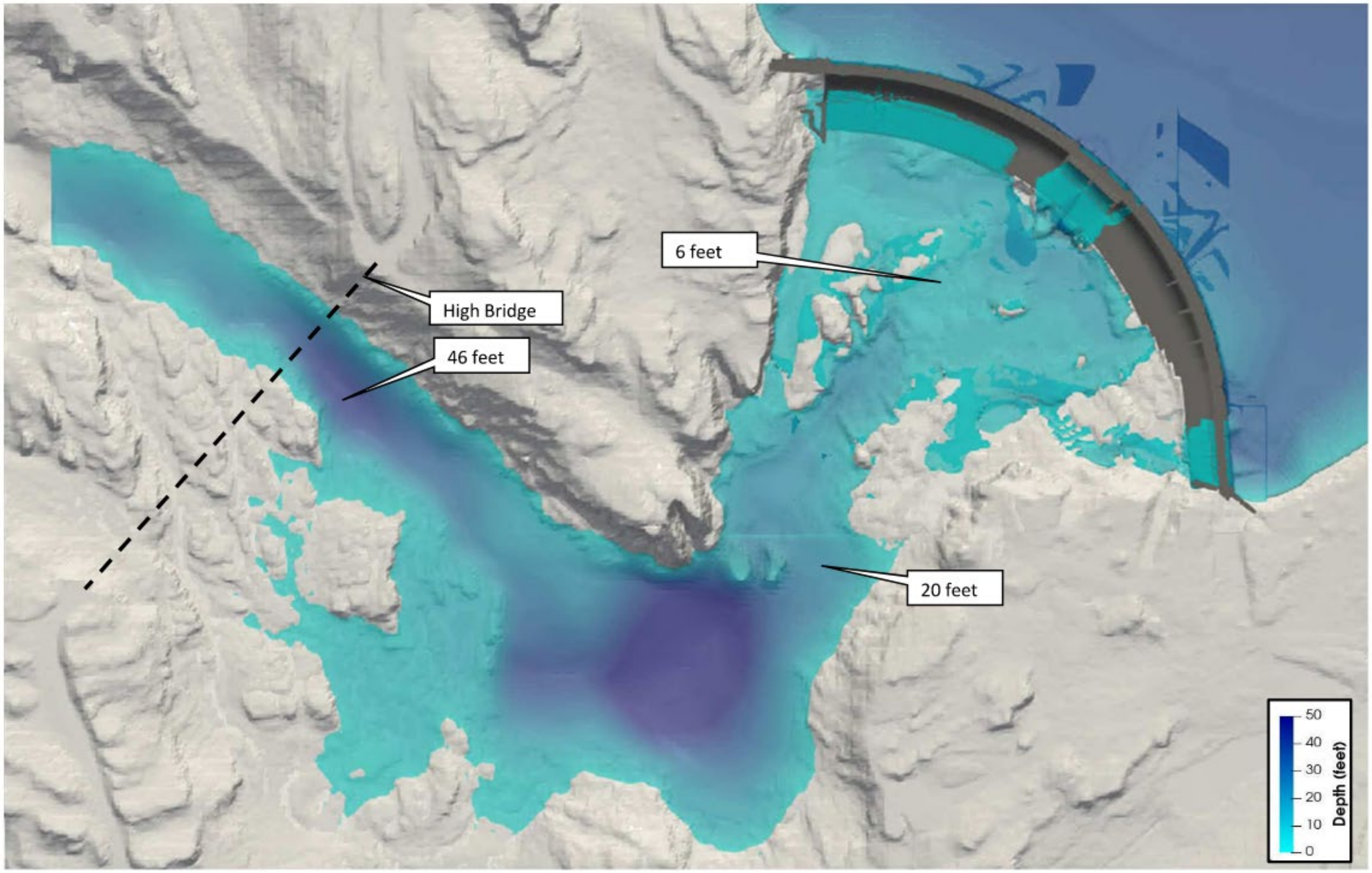
Figure 3-8. Run 2: 25,000 cfs Plan View of Flow Depths



Notes
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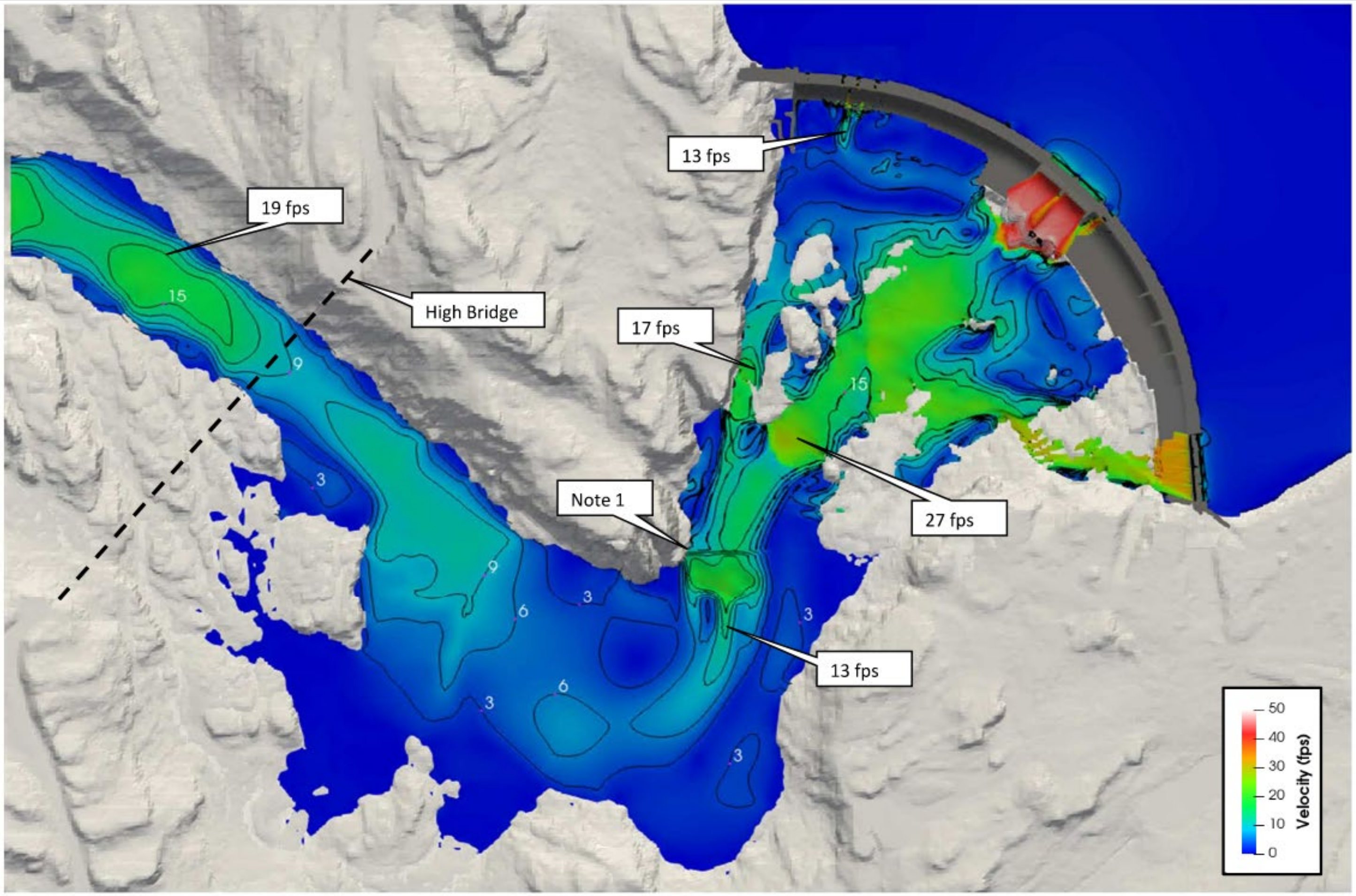
Figure 3-9. Run 2: 25,000 cfs Plan View of Velocities



Notes:
1. 2D/3D mesh block boundary.
2. Contour interval of 3 fps shown from 0-15 fps.

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Figure 3-10. Run 2: 25,000 cfs Upstream Fish Passage Facility Entrance Details

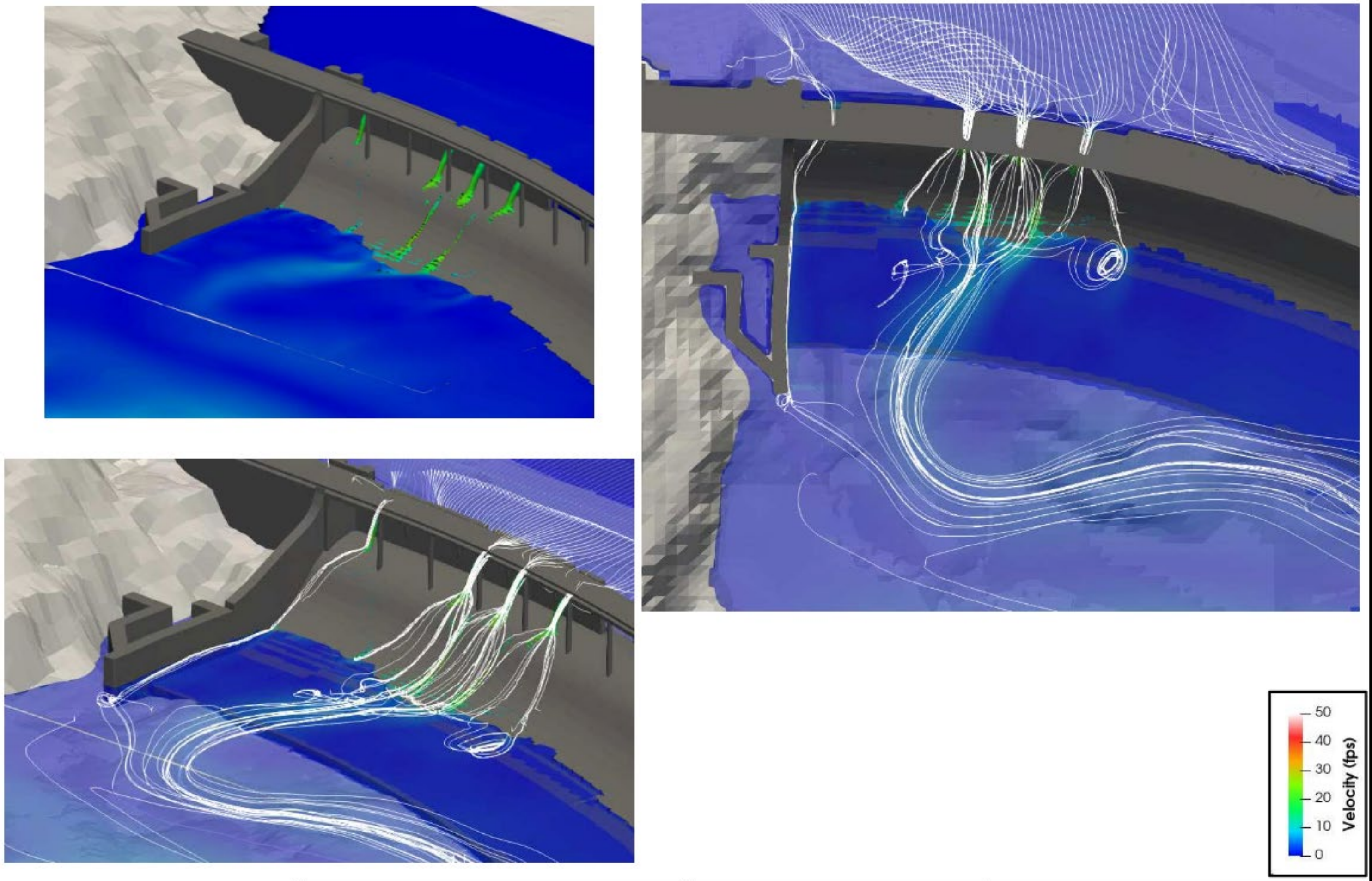

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Figure 3-11. Run 2: 25,000 cfs Flow Path Streamlines

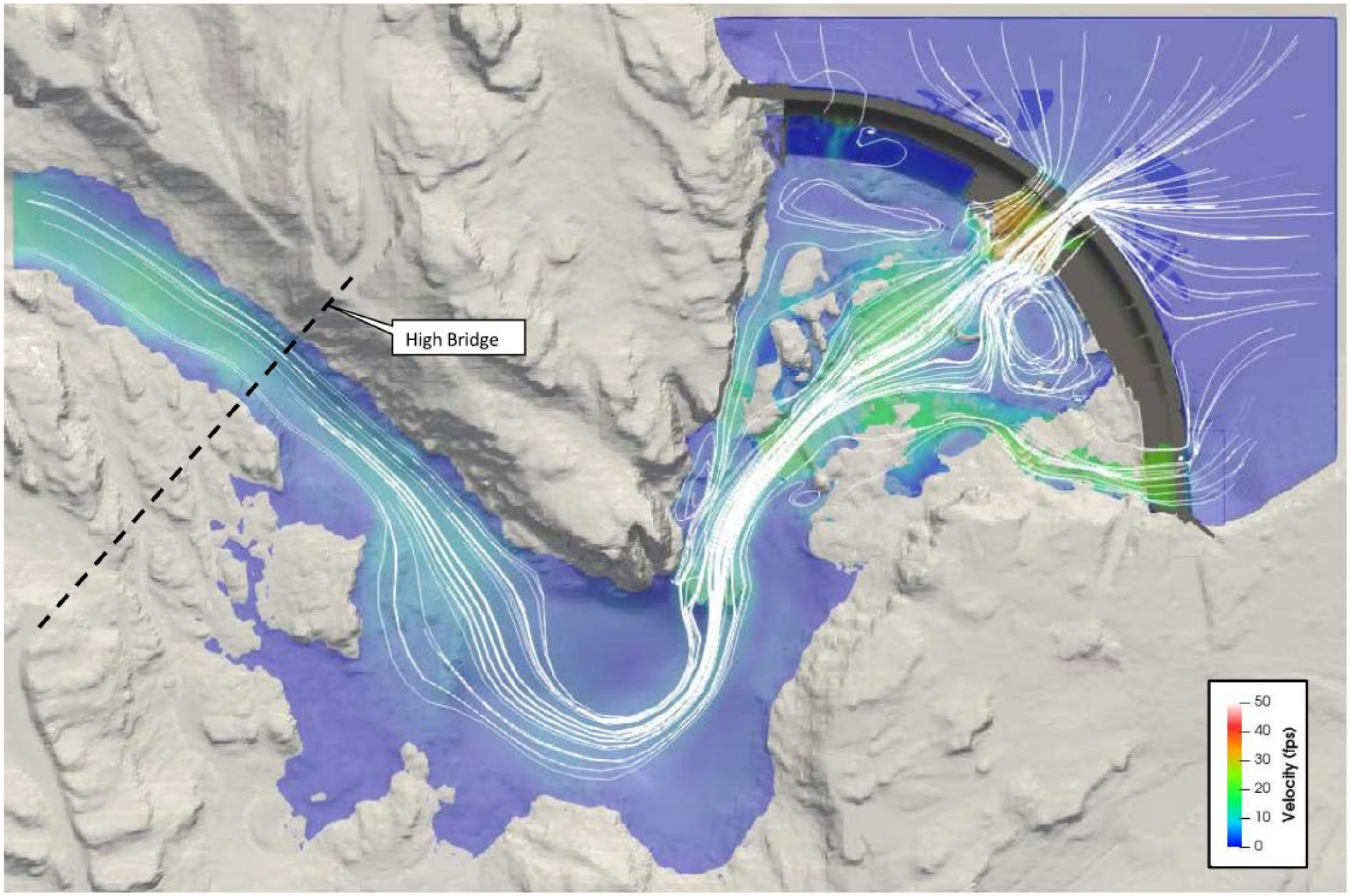

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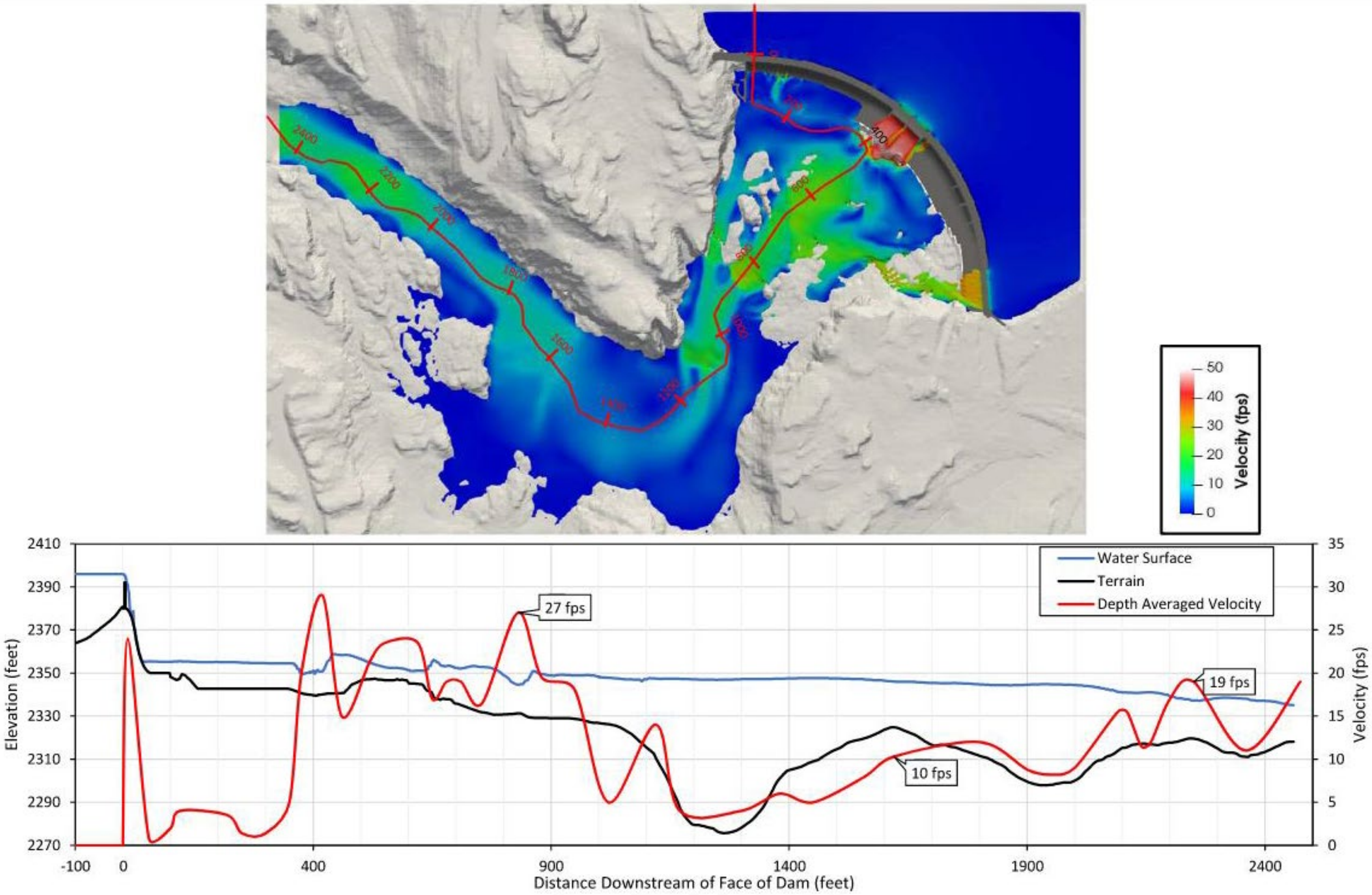
Figure 3-12. Run 2: 25,000 cfs Plan and Profile



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3.2.3 Run 3: 2,000 cfs

Run 3, with a discharge rate of approximately 2,000 cfs, generally represents an intermediate flow rate. Perspective views of the modeled water surface and velocity gradient output at a steady-state flow condition of 2,000 cfs are depicted in **Figure 3-13**. The dam structures are colored gray for distinction from the terrain. Based on a discharge of 2,000 cfs, the CFD model computed flow general depths of approximately 2 to 6 feet within areas upstream of the falls. Some isolated locations are deeper in areas with localized pooling. Within the falls, flows deepen to approximately 7 feet deep. Downstream of the falls, flow depths are about 50 feet at the right turn in the river channel and are about 36 feet deep near High Bridge. A plan view of flow depths within the model domain is shown in **Figure 3-14**.

The velocities downstream of the Main Channel Dam range from approximately 2 to 15 fps. In general, the highest velocities are immediately downstream of the open radial gate. However, these velocities are quickly reduced due to energy dissipation from the turbulent flow in the pool downstream of the Main Channel Dam structure. A plan view of flow velocities within the model domain is shown in **Figure 3-15**. The velocities from the open radial gate generally carry flow directly towards the falls. The pools to the left and right of this main flow path generally have limited flow and are relatively calm. A detailed view of the velocities in the vicinity of the Upstream Fish Passage Facility is shown in **Figure 3-16**. As indicated in **Figure 3-16**, the local Upstream Fish Passage Facility velocities are about 3 to 12 fps, which is noticeably higher than the previous two simulations due to the lower submergence. Additionally, the impacts of the HVJ and Upstream Fish Passage Facility entrance flows are much more evident. Within the falls area, the flow velocities increase to a maximum of approximately 23 fps. Within the main river channel downstream of the falls, peak flow velocities decrease to about 3 to 5 fps as the channel widens and turns right. As the channel narrows again and flows pass under the High Bridge near the end of the model, velocities increase to slightly greater than 2 fps. The margins of the downstream river channel generally exhibit velocities less than 1 fps. Overall, the depth-averaged velocities from the Upstream Fish Passage Facility, through the channel downstream of High Bridge range from about 3 to 23 fps, with the higher velocities in the main channel path and lower velocities along the edges of the channel banks.

The flow path streamlines for Run 3, with a discharge rate of approximately 2,000 cfs, are shown in **Figure 3-17**. As indicated in **Figure 3-17**, the majority of the flow is concentrated towards and over the falls area, and then downstream and to the right before passing below the High Bridge. Velocity and water surface profiles along the centerline of the main flow path of the downstream channel is shown in **Figure 3-18**.

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Figure 3-13. Run 3: 2,000 cfs Perspective Views

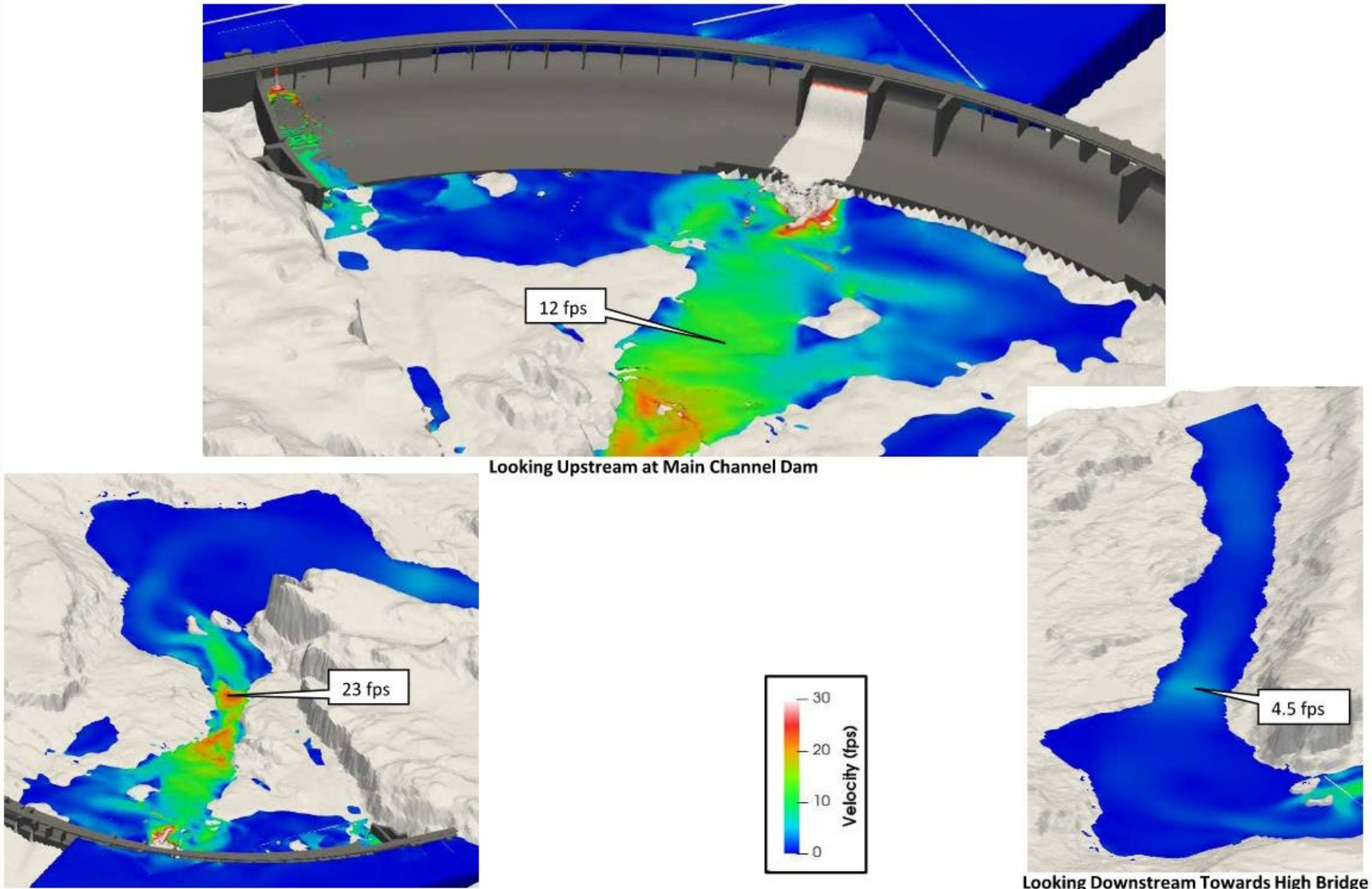

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Figure 3-14. Run 3: 2,000 cfs Plan View of Flow Depths

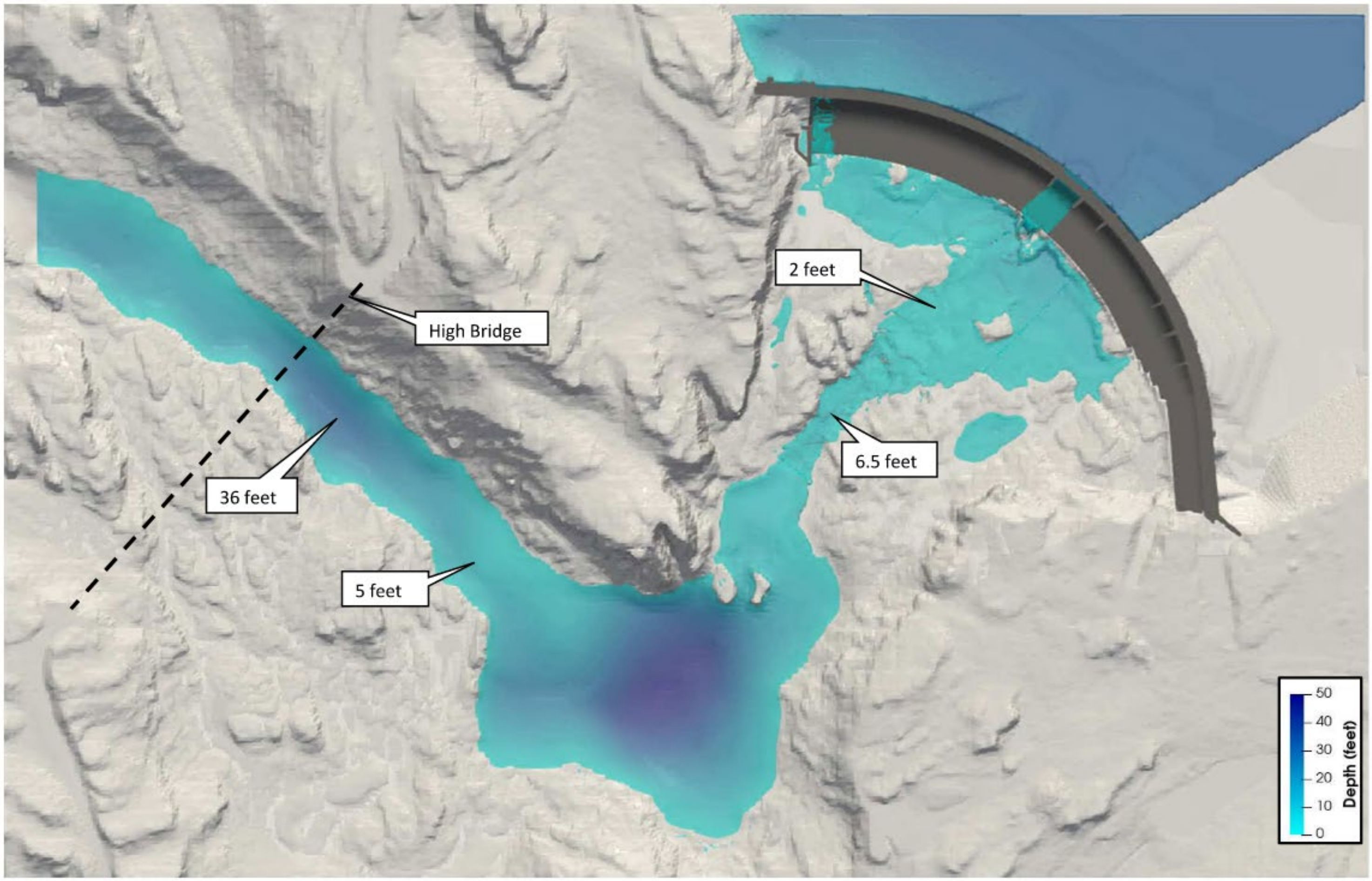

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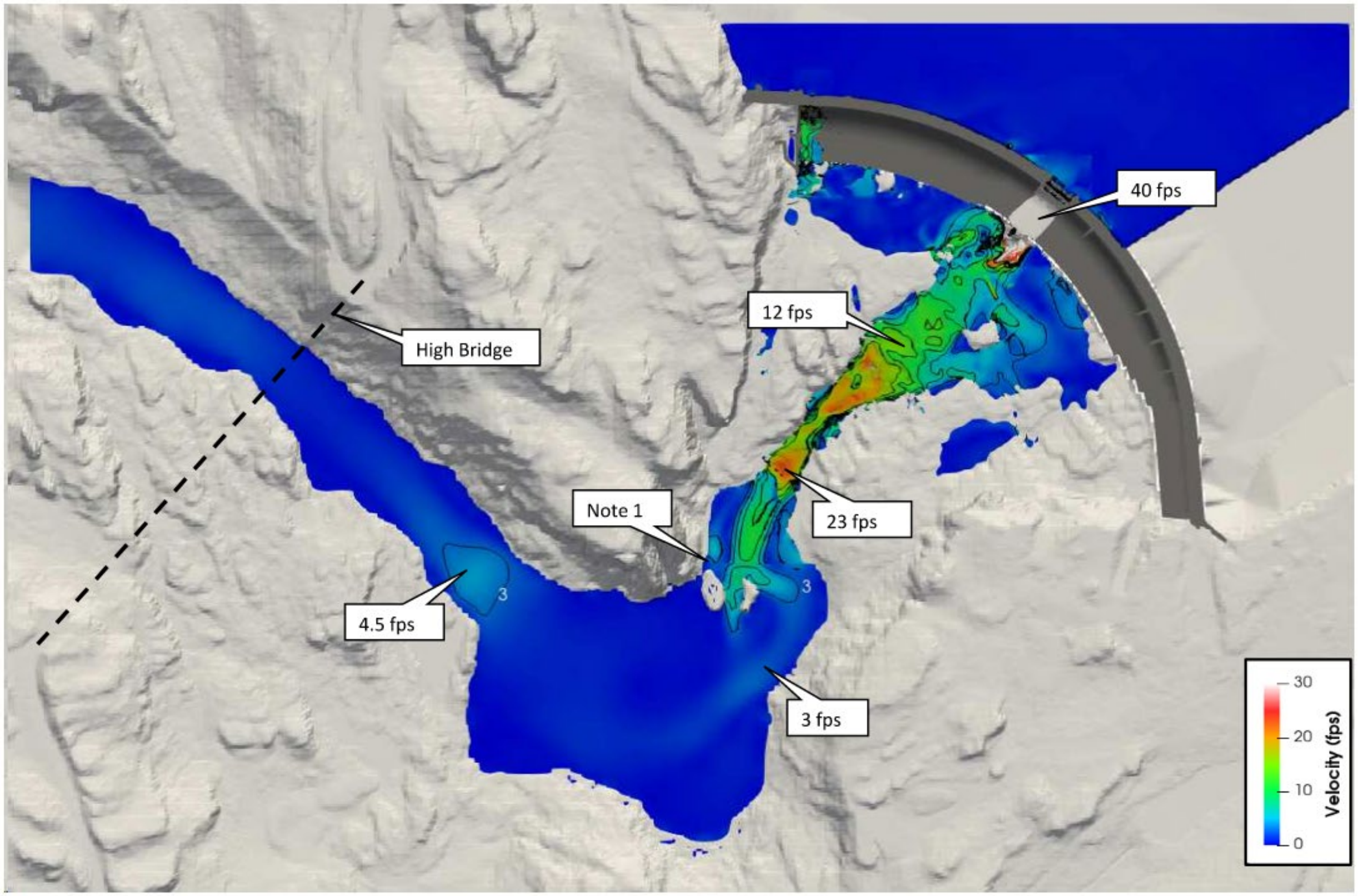
Figure 3-15. Run 3: 2,000 cfs Plan View of Velocities



Notes:
1. 2D/3D mesh block boundary.
2. Contour interval of 3 fps shown from 0-15 fps.

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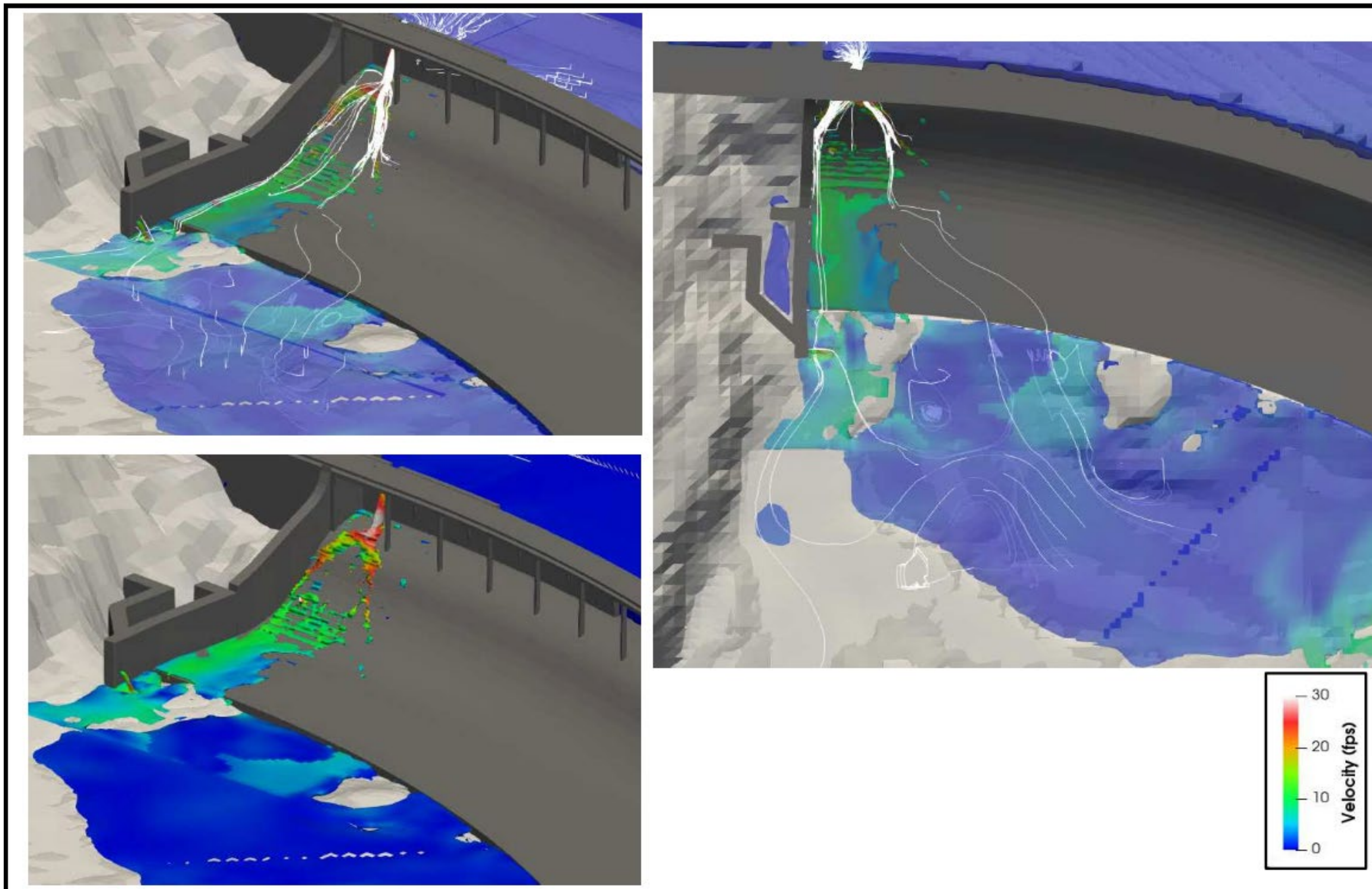
Figure 3-16. Run 3: 2,000 cfs Upstream Fish Passage Facility Entrance Details



Notes
1. Legend shown without transparency.

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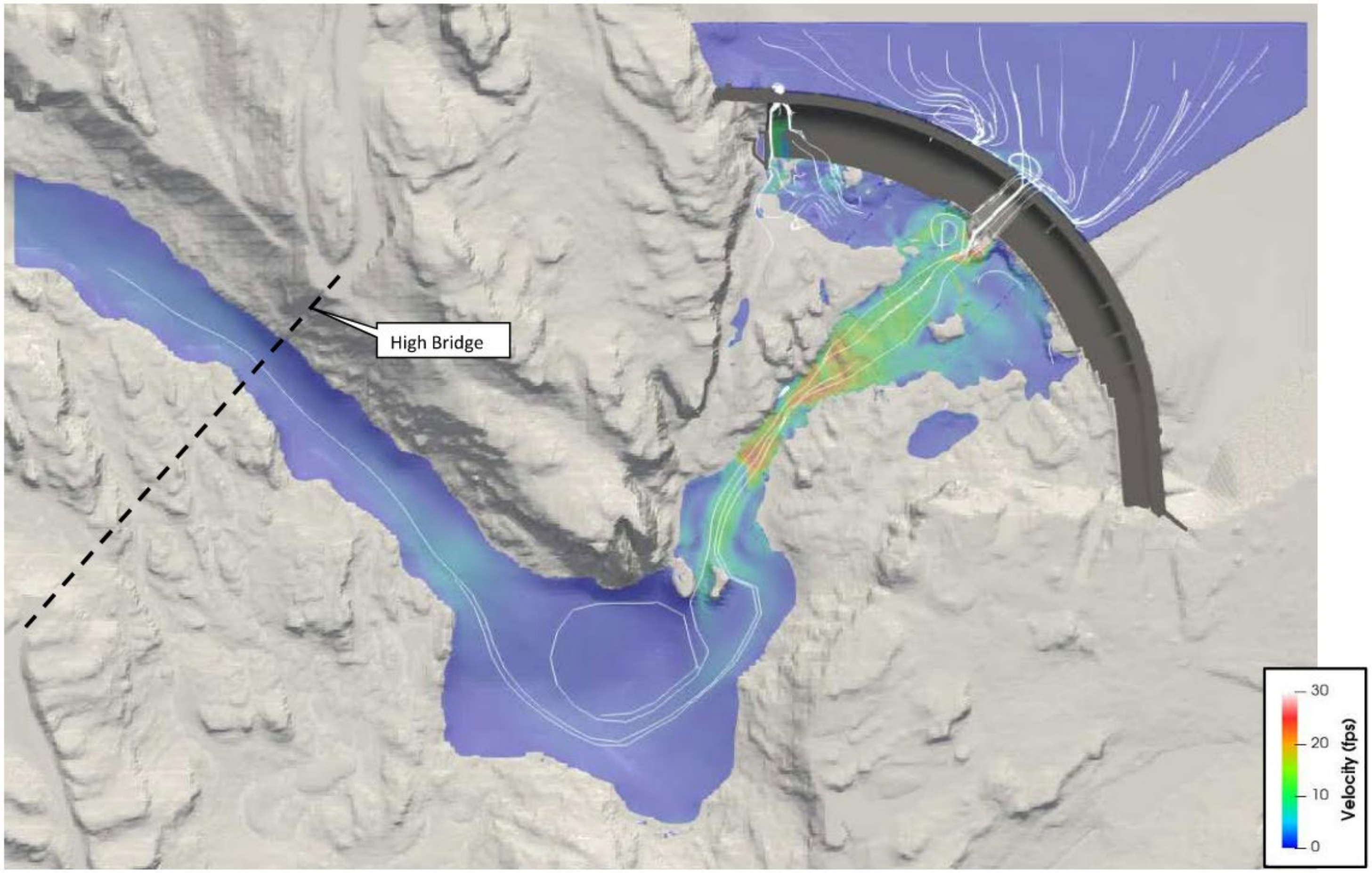
Figure 3-17. Run 3: 2,000 cfs Flow Path Streamlines



Notes
1. Legend shown without transparency.

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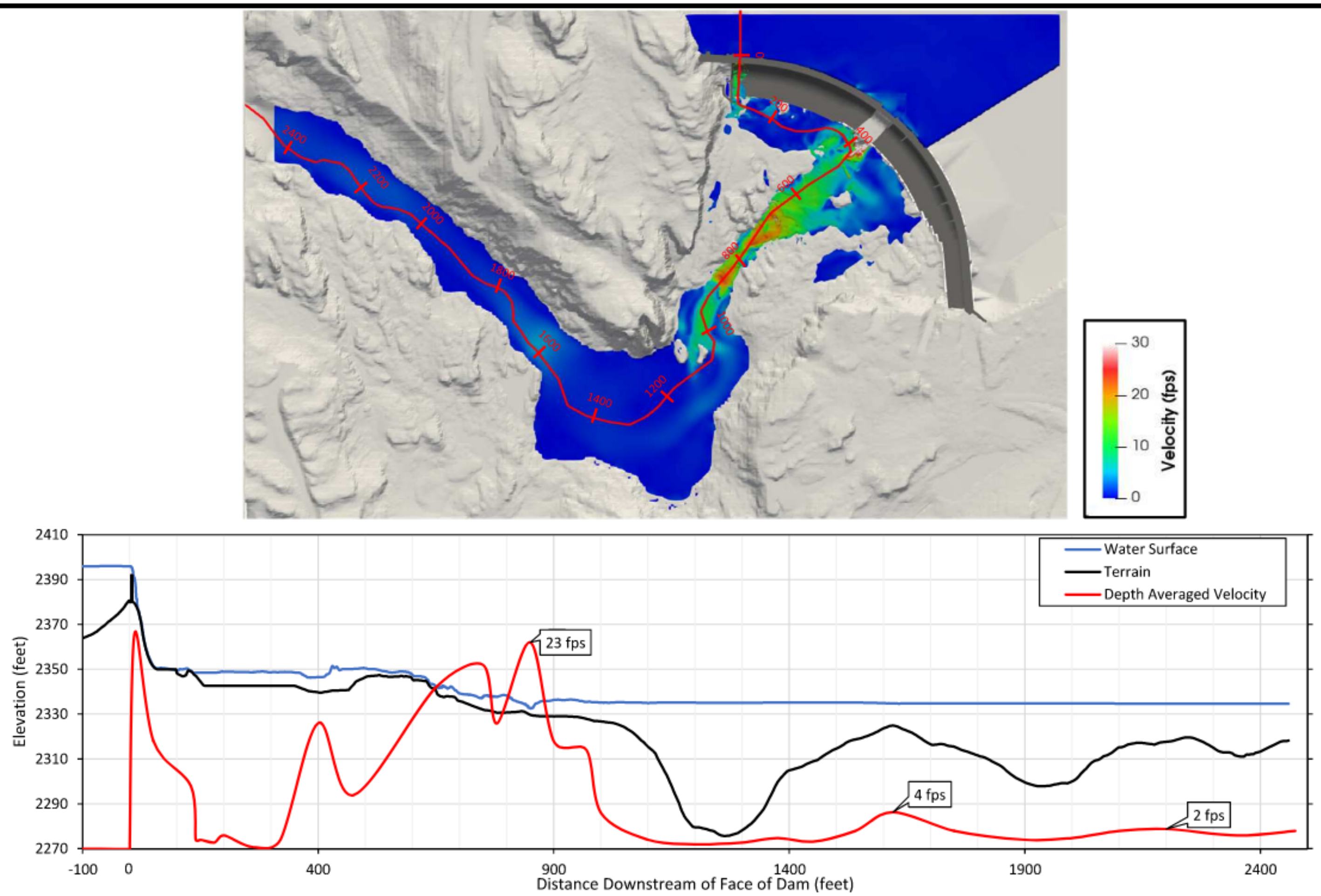
Figure 3-18. Run 3: 2,000 cfs Plan and Profile



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3.2.4 Run 4: 200 cfs

Run 4, with a discharge rate of approximately 200 cfs, generally represents the minimum discharge rate of the Main Channel Dam and Upstream Fish Passage Facility. Perspective views of the modeled water surface and velocity gradient output at a steady-state flow condition of 200 cfs are depicted in **Figure 3-19**. The dam structures are colored gray for distinction from the terrain. Based on a discharge of 200 cfs, the CFD model computed general flow depths of approximately 1 to 5 feet within areas upstream of the falls. Some isolated locations are deeper in areas with localized pooling. Within the falls, flows are generally less than 3 feet deep. Downstream of the falls, flow depths are about 50 feet at the right turn in the river channel and are about 36 feet deep near High Bridge. A plan view of flow depths within the model domain is shown in **Figure 3-20**. In general, the majority of flows aside from some splash and spray is contained within the main path of the falls.

The velocities downstream of the Main Channel Dam generally are less than 2 fps. Velocities are higher immediately downstream of bay 1. However, these velocities are quickly dissipated within the pool in front of the Upstream Fish Passage Facility entrance. A plan view of flow velocities within the model domain is shown in **Figure 3-21**. A detailed view of the velocities in the vicinity of the Upstream Fish Passage Facility is shown in **Figure 3-22**. As indicated in **Figure 3-22**, the local Upstream Fish Passage Facility velocities range from 3 to 8 fps. Higher velocities are most evident where shallow flows pass from the HVJ and Upstream Fish Passage Facility entrance into the neighboring pool. Within the falls, flow velocities increase to a maximum of approximately 17 fps. As flows exit the falls and enter the main river channel, the velocities are quickly dissipated to 3 fps or less. As the river channel widens flows pass through the righthand bend, velocities are less than 2 fps. The remainder of the modeled river channel also exhibits flow velocities less than 1 to 2 fps across the full cross section of the channel. Overall, the depth-averaged velocities from the Upstream Fish Passage Facility, through the channel downstream of High Bridge range from about 3 to 17 fps, with the higher velocities isolated to the falls area and downstream of the Upstream Fish Passage Facility.

The flow path streamlines for Run 4, with a discharge rate of approximately 200 cfs, are shown in **Figure 3-23**. As indicated in **Figure 3-23**, all flow is concentrated towards and over the falls area, and then downstream and to the right before passing below the High Bridge. Velocity and water surface profiles along the centerline of the main flow path of the downstream channel is shown in **Figure 3-24**.

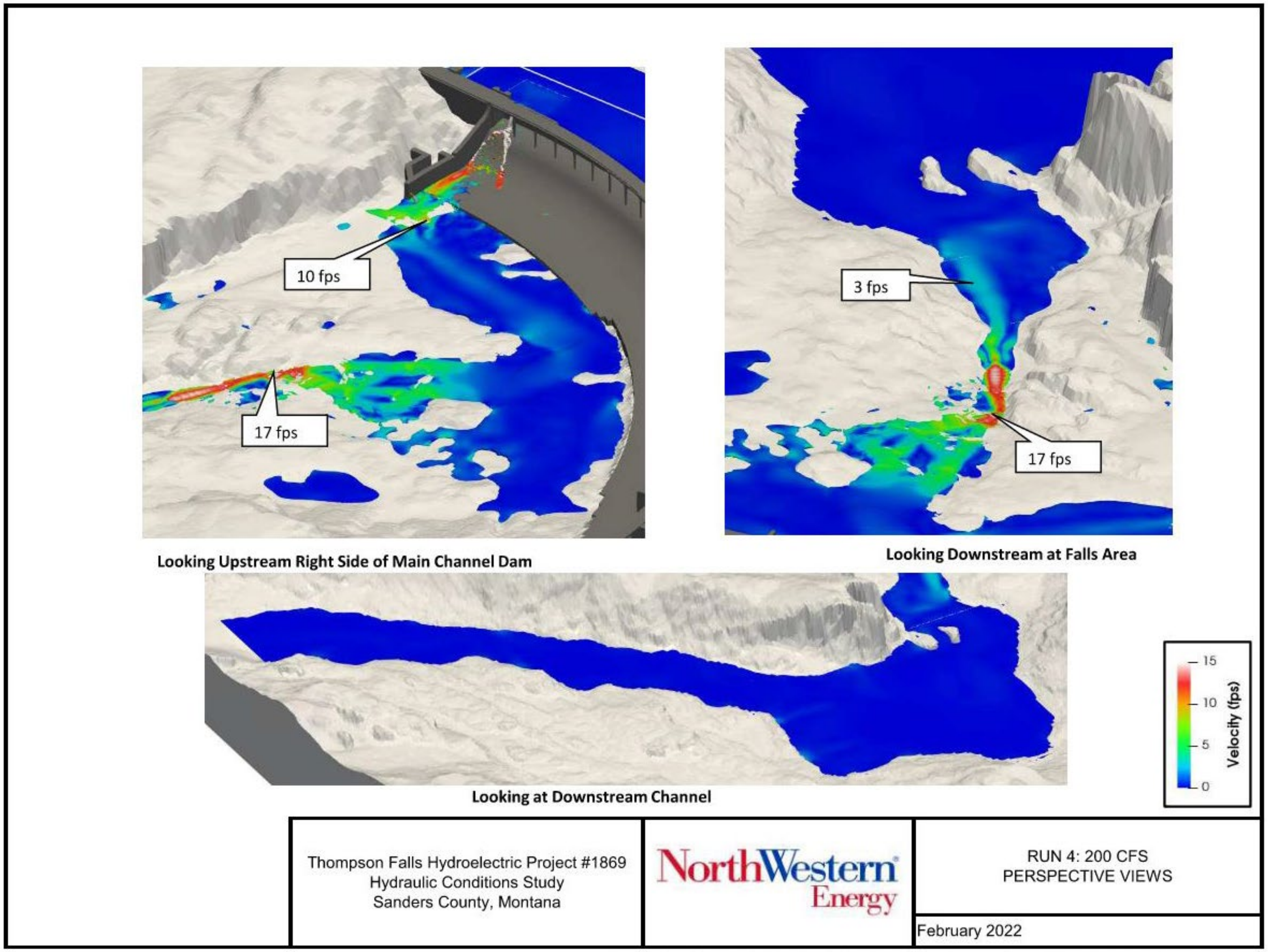
Results of hydraulic analyses for CFD modeling of the Thompson Falls Main Channel Dam and downstream channel are summarized in **Table 3-1** below.

Table 3-1. Results of Thompson Falls Dam CFD Modeling

Run	Flow Rate (cfs)	Typical Flow Depth Below Dam* (feet)	Maximum Velocity Below Dam* (fps)	Typical Velocity Near Upstream Fish Passage Facility Entrance (fps)	Maximum Velocity Through Falls (fps)	Downstream Channel Margin Velocities (fps)	Maximum Velocity Near High Bridge (fps)
1	37,000	5-8	20	1-5	20	3	20
2	25,000	5-8	20	1-5	27	1-5	19
3	2,000	2-6	15	3-12	23	<1	2
4	200	1-5	10	3-8	14	<1	<1

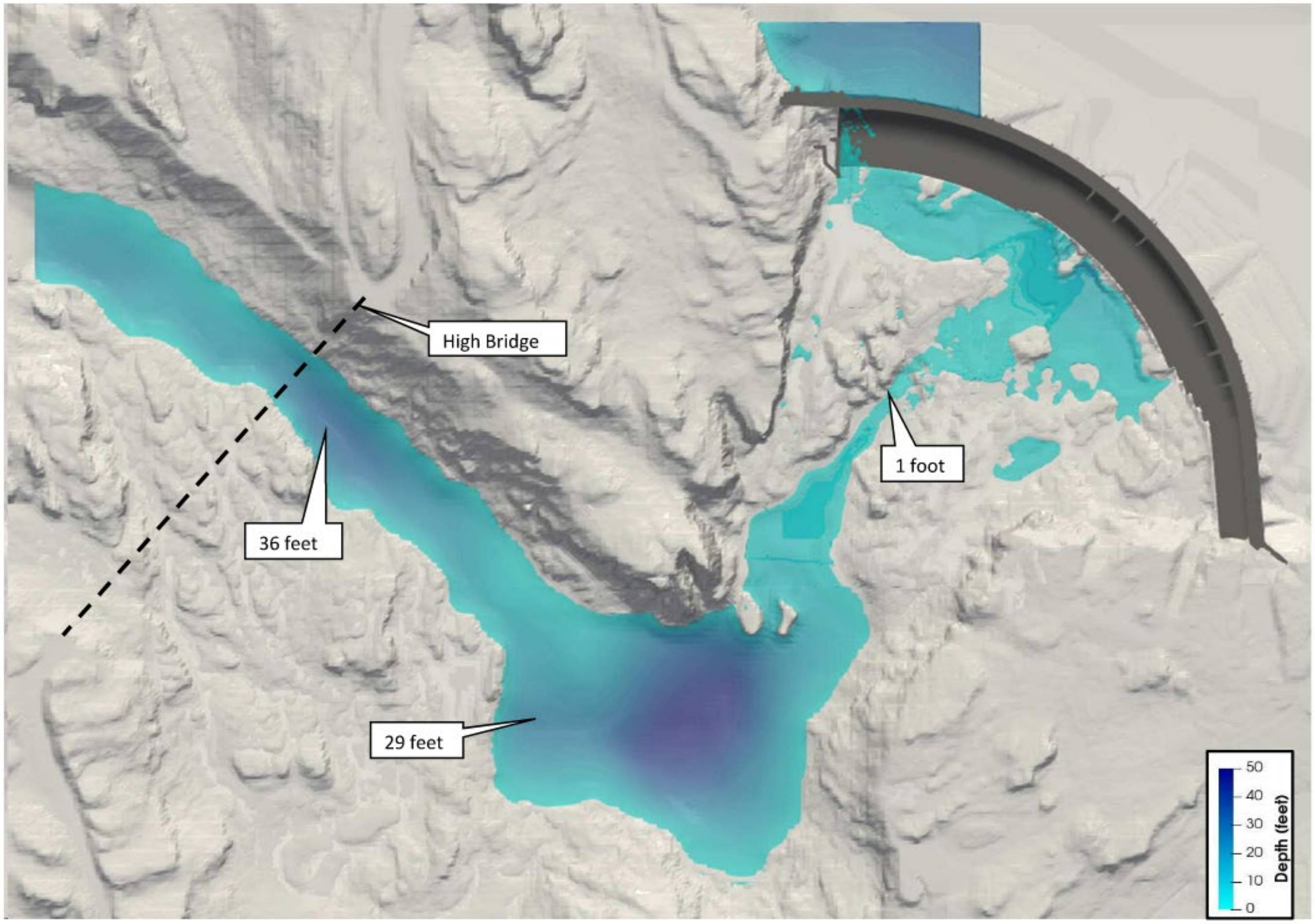
***** These columns refer to the area below the main channel dam but above the falls.

Figure 3-19. Run 4: 200 cfs Perspective Views



Document Path: \\ore-pzcc-1\ore-data\Projects\NorthWestern Energy\Projects\Relicensing Thompson Falls\Hydraulics Modeling\Report\Figures\[TFallsFigures.xlsx]Figure3a

Figure 3-20. Run 4: 200 cfs Plan View of Flow Depths



Notes
1. Legend shown without transparency.

Thompson Falls Hydroelectric Project #1869
Hydraulic Conditions Study
Sanders County, Montana

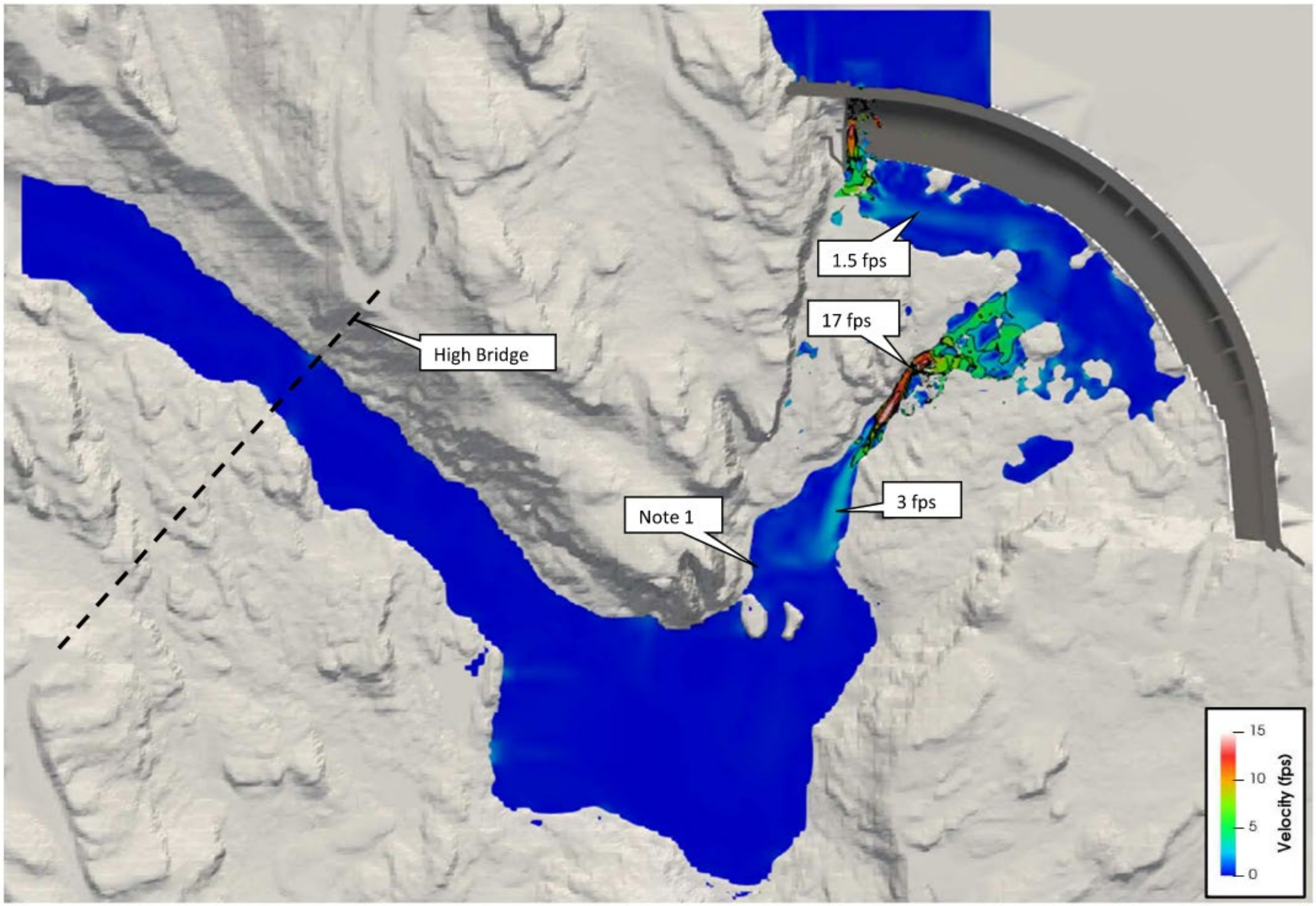
NorthWestern Energy

RUN 4: 200 CFS
PLAN VIEW OF FLOW DEPTHS

February 2022

Document Path: \\ore-pzcc-1\ore-data\Projects\NorthWestern Energy\Projects\Relicensing Thompson Falls\Hydraulics Modeling\Report\Figures\[TFallsFigures.xlsx]Figure 31a

Figure 3-21. Run 4: 200 cfs Plan View of Velocities



Notes:
1. 2D/3D mesh block boundary.
2. Contour interval of 3 fps shown from 0-15 fps.

Thompson Falls Hydroelectric Project #1869
Hydraulic Conditions Study
Sanders County, Montana

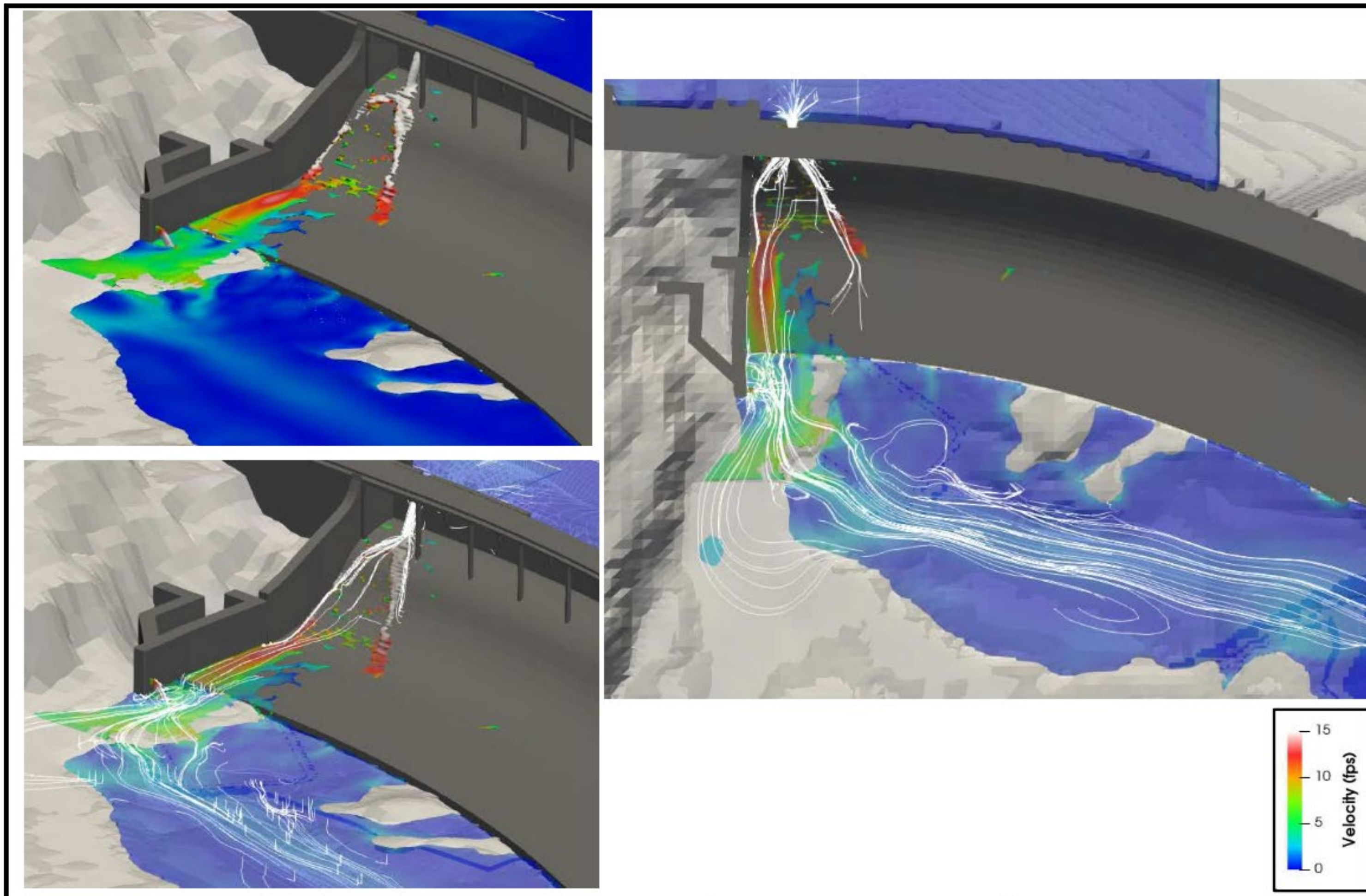
NorthWestern Energy

RUN 4: 200 CFS
PLAN VIEW OF VELOCITIES

February 2022

Document Path: \\ore-pzcc-1\ore-data\Projects\NorthWestern Energy\Projects\Relicensing Thompson Falls\Hydraulics Modeling\Report\Figures\[TFallsFigures.xlsx]Figure 8a (3)

Figure 3-22. Run 4: 200 cfs Upstream Fish Passage Facility Entrance Details



Notes
1. Legend shown without transparency.

Thompson Falls Hydroelectric Project #1869
Hydraulic Conditions Study
Sanders County, Montana

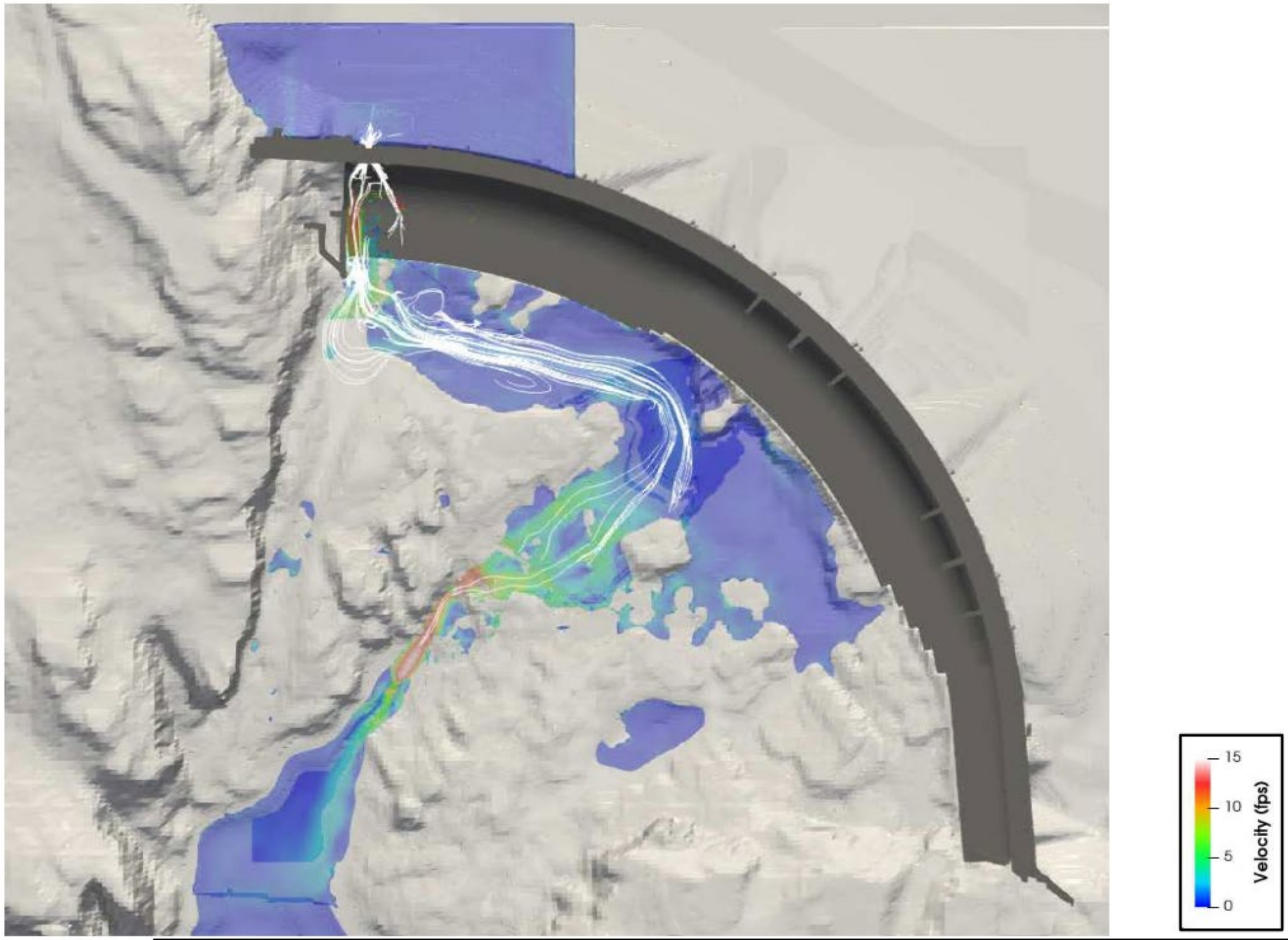
NorthWestern Energy

RUN 4: 200 CFS
UPSTREAM FISH PASSAGE FACILITY
ENTRANCE DETAILS

February 2022

Document Path: \\ore-pzcc-1\ore-data\Projects\NorthWestern Energy\Projects\Relicensing Thompson Falls\Hydraulics Modeling\Report\Figures\[TFallsFigures.xlsx]Figure 31a

Figure 3-23. Run 4: 200 cfs Flow Path Streamlines

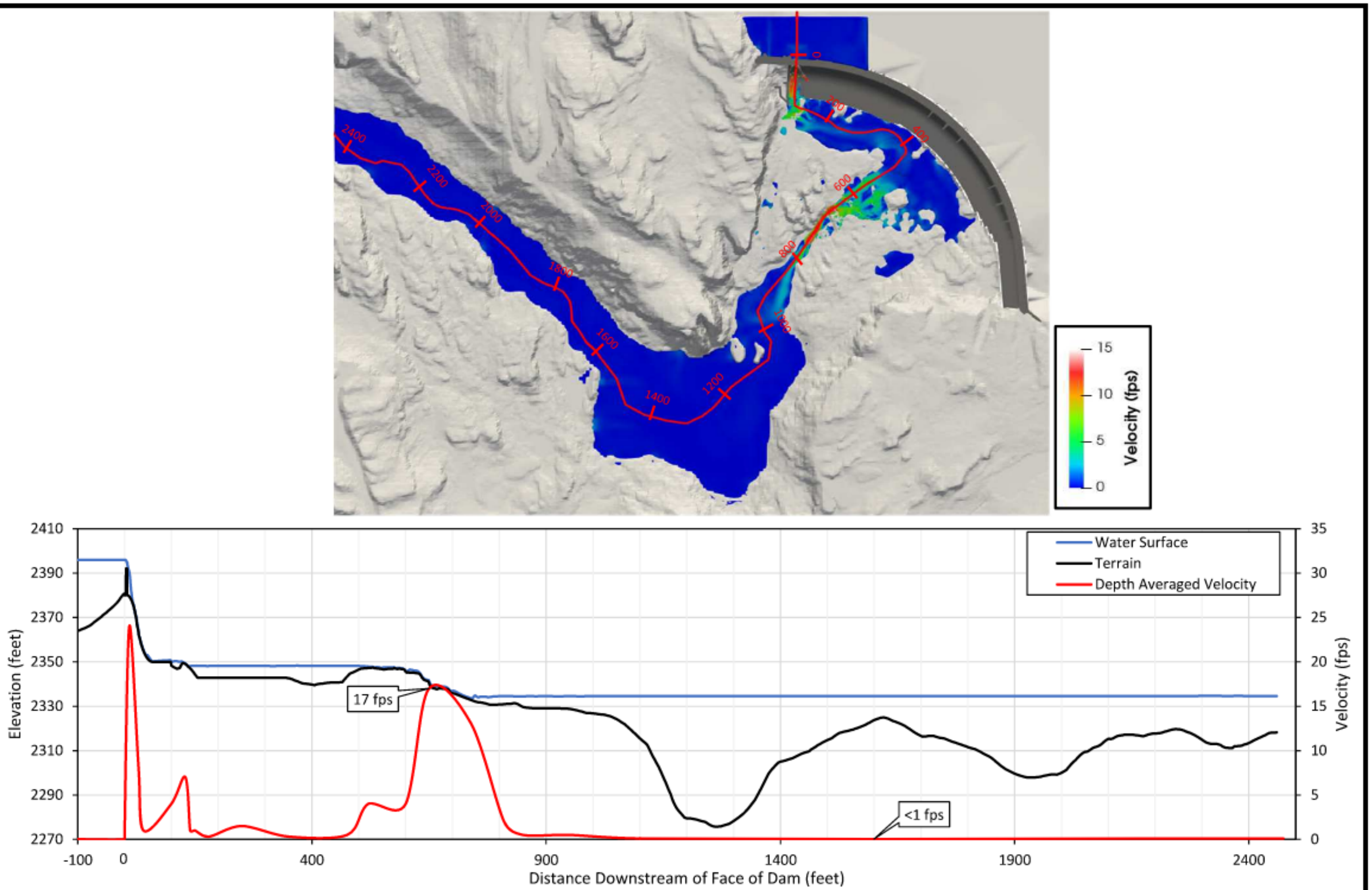


Notes
1. Legend shown without transparency.

Thompson Falls Hydroelectric Project #1869 Hydraulic Conditions Study Sanders County, Montana	NorthWestern Energy	RUN 4: 200 CFS FLOW PATH STREAMLINES February 2022

Document Path: \\ore-pzcc-1\ore-data\Projects\NorthWestern Energy\Projects\Relicensing Thompson Falls\Hydraulics Modeling\Report\Figures\[TFallsFigures.xlsx]Figure 31a

Figure 3-24. Run 4: 200 cfs Plan and Profile



Thompson Falls Hydroelectric Project #1869 Hydraulic Conditions Study Sanders County, Montana	NorthWestern Energy	RUN 4: 200 CFS PLAN AND PROFILE February 2022

Document Path: \\ore-pzcc-1\ore-data\Projects\NorthWestern Energy\Projects\Relicensing Thompson Falls\Hydraulics Modeling\Report\Figures\[TFallsFigures.xlsx]Figure 31a

3.3 CFD Model Sensitivity Analysis

3.3.1 General

Sensitivity analyses of the hydraulic modeling parameters used in the CFD model were performed to test the influence of the selected values. A surface friction sensitivity analysis was performed to evaluate the influence of the assumed surface friction values. In addition, an analysis of the selected turbulence model used in the CFD model was performed. The sensitivity analyses are discussed below.

3.3.2 Surface Roughness Sensitivity Analysis Results

To evaluate the effects of surface friction and account for uncertainty in the selected values, the geometry surface roughness values were adjusted from the base values. This sensitivity analysis is especially valuable as there is no measured data available at the high flow rates evaluated to calibrate the selection of surface roughness values. The model was evaluated using Run 2 with a steady-state flow rate of approximately 25,000 cfs.

The CFD model uses a surface absolute roughness value in feet, which is usually a very small number, so adjusting these values directly has very minimal impact on the hydraulic modeling results. However, the surface roughness values can be converted to an equivalent Manning's n-value, which when adjusted has a larger potential to influence the hydraulic modeling results. The CFD base model simulations have assumed an equivalent Manning's n-value of 0.015 for the concrete surfaces and 0.03 for the natural rocky surfaces. This value was converted to a surface roughness value using the Strickler Equation (Chow 1959), which uses a non-linear function to convert the n-values into an equivalent surface roughness depth in feet for the CFD model. The concrete and natural surface Manning's n-values were adjusted by ±20-percent. The resulting roughness values are provided in **Table 3-2** below. These values are beyond the typical limits used for concrete and natural surfaces but were selected to show the possible range of changes in results that could occur from variations in surface roughness.

Table 3-2. Surface Roughness Sensitivity Values

Material	Base Case Surface Roughness Values		High Surface Roughness (+20%)		Low Surface Roughness (-20%)	
	Manning's n	Absolute Roughness	Manning's n	Absolute Roughness	Manning's n	Absolute Roughness
Concrete	0.015	2.16e-3	.018	6.48e-3	.012	5.68e-4
Natural	0.03	1.39e-1	.036	4.15e-1	.024	3.64e-2

The surface roughness sensitivity analysis results are summarized in **Table 3-3**.

Table 3-3. Surface Roughness Sensitivity Analysis Results

Base Case Surface Roughness		High Surface Roughness		Low Surface Roughness	
Falls Velocity (fps)	Downstream Channel Margin Velocity (fps)	Falls Velocity (fps)	Downstream Channel Margin Velocity (fps)	Falls Velocity (fps)	Downstream Channel Margin Velocity (fps)
27	1-5	25	1-5	29	2-6

Overall, the results of the CFD model with adjusted surface roughness values were similar to base case results for the flow scenario evaluated. The model showed relatively low sensitivity to the surface roughness adjustments. The estimated velocities through the falls varied by a maximum of approximately 2 fps. The estimated downstream channel margin velocities varied only a minor amount. Based on the results of the surface roughness sensitivity analyses, the selected surface roughness values are considered adequate to model the hydraulic conditions at the Main Channel Dam. Additional details of the surface roughness sensitivity are provided in Attachment B.

3.3.3 Modeling Parameter Sensitivity

There are six different turbulence options available within the FLOW-3D model for modeling turbulent conditions. This sensitivity analysis has evaluated both the RNG k-ε and k- ω models. In general, these two models are considered to be the most appropriate of the six for the flow conditions at the Main Channel Dam.

The FLOW-3D documentation shows that generally the RNG k-ε model has a wide applicability and is known to "describe low intensity flows and flows having strong shear regions more accurately," (Flow Science, 2021). The FLOW-3D documentation explains that the k-ω model "is superior," to the RNG model "near wall boundaries and in flows with streamwise pressure gradients," (Flow Science, 2021). To evaluate the impact of selecting different turbulence modules, separate simulations for Run 2 with a steady-state flow rate of 25,000 cfs were evaluated. Quantitatively, the results of both models showed similar results. The most significant difference between the results was that the k-ω model showed slightly lower (less than 0.5 feet) water surfaces within the main river channel downstream of the falls. Velocities were generally the same with minor variations generally limited to the locations with slightly different water surface elevations. Discharge rates through the Main Channel Dam varied by less than 1 percent due to the different turbulence models. Additional details of the turbulence model sensitivity are provided in Attachment B. In general, the RNG k-ε turbulence model is considered to be appropriate for modeling the Main Channel Dam.

4.0 Discussion

The Phase 1 study results provide an estimate of the hydraulic performance of the Main Channel Dam and fish passage facility and the resulting flow depths, velocities, and flow patterns in the downstream channel for various flow rates ranging from 200 cfs up to about 37,000 cfs. Over this wide range of flow rates, the hydraulic characteristics of the flow downstream vary considerably but have a similar pattern. In the area directly downstream of the fish passage facility entrance there are generally two different flow patterns observed between the four scenarios evaluated. At higher flows (Run 1 and Run 2), the outlet of the fish passage facility and high velocity jet are submerged and limited impacts from these structures is observed. During lower flows (Run 3 and Run 4), the high velocity jet is unsubmerged and the discharges from the upstream fish passage entrance represent a significant portion of the flow in this area. At the lower flow rates, the streamlines in this area are well concentrated from the fish passage entrance. Away from the fish passage entrance, the pools and channel immediately downstream of the Main Channel Dam reduces the velocities and increases flow depths prior to the flow entering the highly turbulent falls area where velocities increase noticeably. Downstream of the falls area, the flow enters the main river channel, depths increase considerably, and velocities are reduced as the flow turns right toward High Bridge. As the flow approaches the High Bridge, depths are reduced slightly, increasing the velocity just before entering the narrow and deep section under the High Bridge where the velocities and depths tend to increase again before discharging downstream of the bridge. Overall, the velocities generally range from a few feet per second up to almost 30 feet per second over the falls area.

During Phase 2 of the study, the full model domain will be analyzed using 3D modeling to better evaluate the vertical velocity distributions of flow downstream of the Main Channel Dam. Additional evaluations during Phase 2 of the study will evaluate flows of 37,000 and 2,000 cfs. These flow rates bracket the range of possible flow conditions that are likely to occur during operation of the Upstream Fish Passage Facility.

In addition to modeling the full model domain in three dimensions, it will be valuable to further refine the model mesh along the downstream channel and along the margins. This will help to better evaluate the depth specific velocities and distribution of flow within these areas that are critical for trout movement. Use of a full 3D model will also allow for a number of cross sections to be cut along the model channel flow paths to provide a detailed assessment of the vertical distribution of flow velocities at these cross sections. These cross sections will also be useful for gaining a better understanding of velocities along the margins of the downstream channel. This will help identify areas that may be a barrier to fish passage or to identify critical resting areas for the fish prior to entering the fish passage facility.

The results of the river channel hydraulic performance will be used to provide a more comprehensive understanding of how the flow conditions influence fish behavior and operation of the fish passage facility. These results will be reported in the Final Study Report, which will be filed with FERC by May 10, 2023.

5.0 Comments and Responses to Comments

The comment period on the Interim Report closed on March 17, 2022. NorthWestern received written comments from FWP, the FWS, and USFS.

5.1 Comments Received

Montana Fish, Wildlife & Parks

FWP.MT.GOV

THE **OUTSIDE** IS IN US ALL.

Fisheries Division
PO Box 200701
Helena, MT 59620-0701
(406) 444-2449
March 14, 2022

Ms. Mary Gail
Director, Environmental and Lands
NorthWestern Energy

Re: Thompson Falls Hydroelectric Project P-1869-060 Interim Report, Hydraulic Conditions Response.

Dear Mary Gail,

Thank you for the opportunity to provide input on the Hydraulic Conditions Interim Report (Report) relating to the relicensing of the Thompson Falls Hydroelectric Project (Project; P-1869).

FWP supports the 3-D modeling at the two discharges recommended by Northwestern Energy (NWE) in their Report. If only two discharges are to be chosen from the four evaluated, we support 37,000 and 2,000 CFS of discharge over or through the main channel dam. However, we again emphasize the need for additional investigations using flow modeling throughout the project area below the dam. 1

FWP has emphasized the importance of evaluating additional passage facilities or capture options that may increase passage effectiveness at the Project beyond potential improvements to the current fish ladder. We outlined the need for these additional fish evaluations in our response letter on August 28, 2020, to the Scoping Document 1 solicitation for comments (pgs. 1-2, 25-27), as well as, in our March 10, 2021, comments (pgs. 2-3) that provided input on NWE's proposed studies relating to the Project. Understanding the hydraulics at other locations associated with the Project's large footprint would be helpful to better inform what is learned from the other studies currently being conducted in association with the licensing process. 2

There are at least three other potential trapping or capture locations associated with the Project that FWP requests should be evaluated using hydraulic modeling. This could help improve fish passage at flows beyond the capacity at which the ladder was built to function, especially with some of the higher velocities identified in this report. Site one is located on river right on the right side of the old powerhouse. Site two is located on the left side of the new turbine. Site three is located on the dry channel dam.

During high flows we know many riverine species seek refuge or choose to migrate through side-channels or floodplain habitat to bypass high flow velocities associated with run-off conditions in large mainstem rivers. It is very likely that prior to impoundment, fish would have naturally used these types of habitats in such a large river system as the natural "falls" on the river were located where the current main channel dam was built. Therefore, this area was probably always a velocity barrier at high flows to upstream migrating fish and they would have likely used other portions of the river which are now also blocked by the Project. 2 (cont.)

Thank you for your consideration of these comments.

Sincerely,

Eileen Ryce
Fisheries Division Administrator

Task 2 – Hydraulic Modeling

A computational fluid dynamics (CFD) model was developed of the existing Thompson Falls Main Channel Dam and river downstream of the dam using FLOW-3D software. FLOW-3D can perform both Shallow Water methods (a sophisticated 2D modeling method) and highly resolved three-dimensional (3D) modeling of the river flow, using 3D topography, bathymetry, structures geometry, and the surrounding terrain. FLOW-3D can simulate fully 3D and transient flow to examine important parameters like velocity, mixing, pressure, turbulence intensity and dissipation, and free water surface profiles.

NorthWestern is using a two-phase approach to the hydraulic modeling. The first phase was performed using 2D simulations to provide an overview of the river channel hydraulics and evaluate a wider range of flow rates to identify areas in the river channel to focus and refine the hydraulic modeling and to identify the critical flow rates. The CFD model was used to simulate 2D flow with depth averaged velocities. Model results were reviewed and compared with available operational data to validate the model results with known flow rates and depths. Model adjustments were performed as necessary to calibrate the model to observed initial conditions and flow rates.

A total of four scenarios were developed and evaluated for the first phase of the CFD modeling. The modeling scenarios were developed to determine the flow behavior and resulting downstream flow conditions. The four modeling scenarios are presented in **Table 2-1.**

Table 2-1. Summary of CFD Modeling Scenarios

Run	Modeled Spill over Main Channel Dam	Total River Discharge	Key Output Goals
1	37,000 cfs	60,000 cfs	Assess downstream flow conditions during the upper limit of Upstream Fish Passage Facility operations
2	25,000 cfs	48,000 cfs	Assess downstream flow conditions at the high design flow of the Upstream Fish Passage Facility
3	2,000 cfs	25,000 cfs	Assess downstream flow conditions at an intermediate typical flow rate
4	200 cfs	<23,000 cfs	Assess downstream flow conditions near the minimum operating conditions of the Upstream Fish Passage Facility

CFD simulations were performed using FLOW-3D HYDRO software (version 22.1.0.16). The CFD model included the Main Channel Dam, portions of the reservoir immediately upstream of the Main Channel Dam, and the channel downstream of the Main Channel Dam. The model extended to approximately 500 feet downstream of the High Bridge.

To develop the terrain for the CFD model, a number of different sources were used. The bathymetry data collected during Task 1 of this study was supplemented with publicly available LiDAR from the U.S. Army Corps of Engineers and traditionally collected survey

Summary of Comments on Eco Report Template I

Page: 1

Number: 1 Author: kaceituno Subject: Sticky Note Date: 3/14/2022 8:54:01 AM

This is helpful information since it relates flow through the dam to river conditions (e.g., stages run-off). Is it possible to provide information on when these river discharge conditions typically occur and for how long? This is valuable information when trying to put these conditions in a biological context, like when we would expect fish to be migrating.

Number: 2 Author: kaceituno Subject: Highlight Date: 3/14/2022 8:51:42 AM

4. Discussion and Recommendations

The Phase 1 study results provide an estimate of the hydraulic performance of the Main Channel Dam and fish passage facility and the resulting flow depths, velocities, and flow patterns in the downstream channel for various flow rates ranging from 200 cfs up to about 37,000 cfs. Over this wide range of flow rates, the hydraulic characteristics of the flow downstream vary considerably but have a similar pattern. In general, the channel immediately downstream of the Main Channel Dam reduces the velocities and increases flow depths prior to the flow entering the highly turbulent falls area where velocities increase noticeably. Downstream of the falls area, the flow enters the main river channel, depths increase considerably, and velocities are reduced as the flow turns right toward High Bridge. As the flow approaches the High Bridge, depths are reduced slightly, increasing the velocity just before entering the narrow and deep section under the High Bridge where the velocities and depths tend to increase again before discharging downstream of the bridge. Overall, the velocities generally range from a few feet per second up to almost 30 feet per second over the falls area.

During Phase 2 of the study, the full model domain will be analyzed using 3-dimensional modeling to better evaluate the vertical velocity distributions of flow downstream of the Main Channel Dam. It is recommended that additional evaluations during Phase 2 of the study evaluate flows of 37,000 cfs and 2,000 cfs. These flow rates bracket the range of possible flow conditions that are likely to occur during operation of the Upstream Fish Passage Facility. In addition to modeling the full model domain in three dimensions, it will be valuable to further refine the model mesh along the downstream channel and along the margins. This will help to better evaluate the depth specific velocities and distribution of flow within these areas that are critical for trout movement. Use of a full 3-dimensional model will also allow for a number of cross sections to be cut along the model channel flow paths to provide a detailed assessment of the vertical distribution of flow velocities at these cross sections. This will help identify areas that may be a barrier to fish passage or to identify critical resting areas for the fish prior to entering the fish passage facility.

The results of the river channel hydraulic performance will be used to provide a more comprehensive understanding of how the flow conditions influence fish behavior and operation of the fish passage facility. These results will be reported in the Final Study Report, which will be filed with FERC in May 2023.

Summary of Comments on Eco Report Template I

Page: 1

Number: 1 Author: kaceituno Subject: Sticky Note Date: 3/15/2022 1:58:56 PM

The USFWS supports the recommendation of running the 3D analysis with the 37,000 and 2,000 cfs dam discharge scenarios.

If resources allow, the USFWS would also recommend running the 3D analysis with the 25,000 cfs discharge scenario. In addition to the 37,000 cfs scenario, this also corresponds to periods in total river discharge when catch rates in the ladder are very low.

Number: 2 Author: kaceituno Subject: Highlight Date: 3/15/2022 1:54:24 PM

USFS

USDA United States Department of Agriculture | Forest Service | Lolo National Forest | Building 24, Fort Missoula
Missoula, MT 59804-7297
406 329-3750

March 16, 2022

To: Mary Gail Sullivan - Director, Environmental and Lands, NorthWestern Energy

From: Traci Sylte - Soil, Water, & Fisheries Program Manager, Lolo National Forest

Re: Review and Comments on Interim Hydraulic Conditions Study Report – Thompson Falls Hydroelectric Project – P-1869-060

Dear Ms. Sullivan,

Thank you for the opportunity to review and comment on the interim hydraulics conditions report. We also appreciate the presentation last week to assist with our review. We have reviewed the report and provide the following comments for your consideration towards revisions as noted in your cover letter.

Overview:

We thoroughly reviewed the interim report and had some concerns, so we contacted a colleague with substantive experience to obtain objective input. His review reinforced our concerns. Accordingly, and if possible, we request that NWE provide a response to our comments below, or update to the interim report to address the concerns. This request is made in the spirit of cooperation and ensuring the project's success, as will be clearer in the specific comment below, which briefly highlight items sequentially through the interim report.

Essential Components for Modeling – To Facilitate Sound Review and Assurance of Effective Outputs

More information and clarification are needed to determine with certainty that the purposes are achieved. Specifically, and as noted below, additional information on the modeling approach and its results are necessary. We believe that the following information is fundamental to this effort and should be thoroughly addressed:

- Clearly state the model purpose and the questions that the model outputs are to address. What specifically needs to be quantified to support needed decisions related to fish passage and behaviors, and how is the model addressing this? Describe the needed spatial and temporal scale for the model and identify accuracy requirements or levels of acceptable uncertainty. How do the model results relate to specific performance criteria for the project? 1
- Clearly identify the state variables of interest to the modeling exercise (e.g., water surface elevation, velocity magnitude and direction, etc.). These should relate closely to fish behavior and successful passage. Identify the range of conditions over which these variables are of interest (e.g. expected flow range during spawning migrations and fishway use). 2
- Describe the selected model and its limitations with respect to the model purposes. Describe the necessary model domain and identify relevant trade-offs. This discussion should address the spatial extents, boundary conditions, spatial and temporal fidelity, solution schemes, tolerances, and other material model characterizations. 3
- Clearly describe the model parameterization, calibration, and validation. This must include a comparison of predicted state variables with field measurements of those variables for the 4

calibration conditions. Describe the differences and their implications. If a validation data set is
available, conduct a model validation within the range of interest. Describe the model behavior 4, con't
relative to observed system behavior through a comparison of predicted and measured conditions.

- Model performance should be assessed in the context of the variables of interest. In this case,
  those should be hydraulic variables correlated to fish passage. This aspect of the report, in
  particular, needs more development. The safety concerns cited during the presentation are noted; 5
  however, with no validation of model performance, the results are best used qualitatively and
  mainly reinforce conditions that are generally already understood.
- Sensitivity analysis is appreciated. However, the results should be structured so as to quantify 6
  uncertainty.
- Provide reference materials not otherwise generally available or describe the input data and
  solution schemes in greater detail (e.g., the Flow-3D manual does not appear to be available 7
  online without a subscription, so we can't assess some aspects of the modeling).

Specific Comments/Findings:

- On the goal, consider adding the full context of hydraulics that are being assessed in the near-
  field across the dam face in addition to the "entrance of the fish passage facility." Our
  understanding is that the full extent of the dam face is within the study domain based on agency 8
  requests. A more comprehensive understanding of hydrodynamics in the vicinity of the dam will
  enhance the assessment of the existing fishway and permit the assessment of alternatives.
- Table 2-2: Should include an assessment and quantification of vertical and horizontal accuracies 9
  of the DTMs.
- Page 16:
  - RNG Turbulence Model: Don't know what this is. Is it a k-e model with variable
    turbulence length? More generally, we need to have access to the reference materials for 10
    Flow 3D in order to independently assess the modeling approach, or the authors need to
    describe these issues in more detail.
  - Pressure boundary condition: Assume the "pressure boundary" is the static head for a 11
    given water surface?
  - IMB - need to describe generically or, if using terminology specific to Flow 3D, provide 12
    the documentation.
  - Stable model result – need to describe how this is determined. We have concerns that the
    model may be unstable given the very short simulation time. We'd like to see more 13
    discussion regarding the model time-steps, how it performs with increased steps, and how
    you assure it is stable.
  - Identify the convergence criteria and tolerances for mesh cells and boundaries. 14
  - This simulation allowed for flows to reach a steady-state throughout the model domain" - 15
    Were the flows unsteady for a time then became steady?
  - Surface roughness coefficients: It may be valuable to provide a bit more focus here - We
    believe this is likely not correct in the present application. They can be related with 16
    caution for pipes and very small-form ("skin friction") cases, but not where larger-scale
    roughness elements, form losses, momentum losses at fluid interfaces, etc., occur.
  - Lots to be said on the Manning's n value here too. The Manning's n-value for natural
    surfaces is low even when adjusted higher for the 20% sensitivity assessment and given
    what the terrain model and site conditions appear to present. There's mention that the 17
    value is beyond the range of typical natural channel values; however, in our experience, it
    is very typical to have roughness coefficients of 0.04 to 0.07 (or even higher) when back-
    calculating Manning's n-values from measured flow velocities.

- As such, velocity and turbulence outcomes could significantly differ from reality. It would be helpful to provide additional rationale for the selection of Manning's n values and validate them using measured flow conditions. (However, it's also good to fully recognize that it may not be critical to have roughness coefficients entirely accurate if the model has been validated and there is reasonable certainty with predictions) 18
- There's mention that the model showed relatively little sensitivity to surface roughness adjustments. Perhaps describe in terms of relative roughness? 19

- Page 18
  - Validation of the model using available data is a form of calibration rather than validation of accuracy to address parameters of interest. The model needs to be calibrated then demonstrate predictability through validation of model behavior relative to measured system behavior 20
    - It's typical to validate the model by comparing calibrated results to measured water surface elevations (at flows that are safe). Once the model is known to be accurate then flows and conditions between the validated predictions can be extrapolated for best usage with fish behavioral data 21
    - Also need to validate velocity in the near-field to meaningfully understand fish behaviors affected by structure, velocity, turbulence, etc. 22
  - Not sure why there is a need to add complexity as the model is not truly validated yet. The model is capable of reflecting measured conditions, but there is high uncertainty on if it actually is unless validation truly occurs. 23
  - Comparison of discharges at structures and empirical equations and results of previous studies: we question doing this as preliminary model runs are performed versus conducting it prior to modeling to use the relations to help parameterize the models 24
  - The model development process needs additional explanation 25
  - Why just "in general"? It's expected that the simulations will "precisely" follow the master operating manual for the dam. Where were there deviations? 26
  - Target flow rates – need more explanation; why just "in general"? one may expect the simulations to "precisely" follow the master operating manual for the dam. Why and where were there deviations? More development needed and also to assure that scenarios are representative of true operating conditions. 27
- Page 19 – explain what "minor" discharge deviations are for the panels to provide assurance that values are insignificant 28
- Page 20
  - Inclusion of 3D modeling blocks: Although we look forward to the 3D modeling, we question the reliability until there's assurance that the current 2D outputs are reliable and provide the needed information for specifically identified fisheries behavior questions/performance parameters of interest. The velocity field and depths are what is most important and without assurance of accuracy, then maybe a time-step is not going to be as useful/meaningful? 29
- Page 21 Results:
  - General observations – what is stated is already understood without the modeling, so it'll be important to address everything mentioned herein to assure that the model is presenting helpful, quantitative information, that is reliable and contributing quantitatively to the fisheries behavior study 30
  - CFD Model Results (all sections): Respectfully and with eye towards best results and cost efficiencies, the observations in this section could have been made without a single model run. What is really needed in the assessment and final report is 1) how the model was calibrated and validated, 2) how the model results compare with measured data, and 31

3) what observations can be made about the flow field that are relevant to fish passage and behaviors? A good fourth discussion (hopefully later) would be sources of uncertainty, their magnitude, and implications. 31, con't

- Page 23 and other: Provide more refined/broader colors that clearly illustrate ranges under 15 fps, as it would help refine interpretation of velocities that matter to the fish. Fish are generally present near boundary conditions that are 0-3 fps. When moving, average bankfull (~Q2) velocities in natural channels range 3-5 fps. 32
- Page 25 - Show velocity vectors when displaying velocities 33
- Page 36, Figure 3-16 discussion: This is the first really meaningful relevant observation from the model runs and is good; How does this compare with measurements? 34
- Page 44. Table 3-1: There is 80 cfs in the fishway for moth these runs, and both have limited tailwater. If anything, the tailwater elevation for 3 should be less than 4. So why did you achieve higher velocities for 3? 35
- Page 51:
    - surface absolute roughness coefficient in feet and having "little impact on modeling results": Please develop this more because this is very questionable. The water surface elevation and velocity may be relatively insensitive to the expected range of resistance for this reach, but that is not because of the absolute magnitude of the resistance. 36
    - 20% is too small of a range for a reasonable sensitivity analysis. Resistance likely varies by more than this as a function of depth over the modeled range of flows. 37
- Page 52:
    - Table 3-3: Water surface elevation is likely more sensitive to roughness than is velocity. In the falls, roughness should be MUCH higher, and you should expect multiple zones of alternate critical/subcritical flow (with lots of associated energy loss to account for with your roughness value. 38
    - "Qualitatively" – this is probably meant as Quantitatively? 39
    - Which model was more accurate (i.e. better matched measured values)? 40
    - The general information isn't that informative, what is needed is addressing which model performs better (as determined through validation of a calibrated model against measured values that differ from the calibration set) for the model parameters important to the task (evaluating fish passage and behavior)? 41
- Page 53 Discussions and Recommendations:
    - Stated previously, but most of this information describes known conditions and suggests that an initial model setup was conducted and run for a few flows, but much more information is needed to verify model calibration and reliability/model validation. 42
    - There is little to no discussion of velocity fields and turbulence structure in the immediate vicinity of the fish passage facilities, which is likely anticipate to be the analysis need (specific characterization of modeling need and parameters of interest are extremely critical and for which the results specifically need to address, in addition to reliability and uncertainty). 43
    - The 3-D model may provide some reliable insights into vertical velocity distributions provided the modeling is done correctly; more work and validation work and/or clarification is needed for confidence that 3D will be informative/useful (compelling evidence that vertical velocity distributions matter to fish passage here hasn't been provided but we all know it… would be good to present) 44
- Page 54 – References – can these be made available? 45
- Finally, we'll respectfully continue to voice our requests that were not considered and within context of said future considerations. As such, the bathymetric results immediately downstream of the dam are very useful, and this type of result is what we requested for the entire reservoir during the study proposal process. Understanding the reservoir bathymetry to this degree has the 46

potential to greatly inform dam discharge/operational changes that could assist in non-native fish population reductions, reduce native fish mortality, and various erosion and sedimentation issues. 46, con't

We are grateful for this process and opportunity to engage as a stakeholder. Overall, we are pleased with the efforts so far and look forward to the next steps. We especially look forward to the integration of reliable modeling outcomes and what can be learned when combined with the fisheries telemetry data.

Sincerely,

/s/ Traci Sylte

Traci Sylte
Soil, Water, and Fisheries Program Manager
Lolo National Forest

5.2 NorthWestern Responses to Comments

Agency	Comment Number	Comment and NorthWestern response
FWP	1	FWP supports the 3-D modeling at the two discharges recommended by Northwestern. If only two discharges are to be chosen from the four evaluated, we support 37,000 and 2,000 CFS of discharge over or through the main channel dam.
		NorthWestern response: Thank you for your comment, NorthWestern intends to conduct Phase 2 of the hydraulic modeling with a 3-D model of flows of 37,000 and 2,000 cfs over the Main Channel Dam.
FWP	2	FWP has emphasized the importance of evaluating additional passage facilities or capture options that may increase passage effectiveness at the Project beyond potential improvements to the current fish ladder. There are at least three other potential trapping or capture locations associated with the Project that FWP requests should be evaluated using hydraulic modeling. Site one is located on river right on the right side of the old powerhouse. Site two is located on the left side of the new turbine. Site three is located on the dry channel dam.
		NorthWestern response: The FERC-approved Study Plan specifies the study area for the Hydraulic Modeling to extend from the Main Channel Dam to the High Bridge. NorthWestern has already extended the study area further downstream to include the area immediately downstream of the High Bridge, an enhancement to the FERC-approved Study Plan. However, the areas FWP is requesting modeling are significantly downstream from the existing range of the model. A significant effort would be required to extend the modeling to cover such an extensive area of the river. Therefore, conducting 3-D hydraulic modeling downstream of the powerhouses and in the Dry Channel is the equivalent of an entirely new study. NorthWestern does not agree that this new study is warranted and has made no changes to this study report based on this comment. Any requests for a new study filed in response to the ISR will be evaluated by FERC in a study plan determination.
FWS	1	This is helpful information since it relates flow through the dam to river conditions (e.g., stages run-off). Is it possible to provide information on when these river discharge conditions typically occur and for how long? This is valuable information when trying to put these conditions in a biological context, like when we would expect fish to be migrating.
		NorthWestern response: Additional flow exceedance and annual hydrograph information has been added following Table 2.1.
FWS	2	The USFWS supports the recommendation of running the 3D analysis with the 37,000 and 2,000 cfs dam discharge scenarios.
		NorthWestern response: Thank you for your comment. NorthWestern intends to conduct Phase 2 of the hydraulic modeling with a 3-D model of flows of 37,000 and 2,000 cfs over the Main Channel Dam.
FWS	3	If resources allow, the USFWS would also recommend running the 3D analysis with the 25,000 cfs discharge scenario. In addition to the 37,000 cfs scenario, this also corresponds to periods in total river discharge when catch rates in the ladder are very low.
		NorthWestern response: The FERC-approved Study Plan for the Hydraulic Modeling Study states that, "The 3D CFD modeling will be performed for two

		identified flow conditions to be determined after review of the 2D CFD modeling results." NorthWestern proposes to complete the Hydraulic Modeling Study as described in the FERC-approved Study Plan, modeling flows of 37,000 cfs and 2,000 cfs. NorthWestern does not propose to adopt this addition to the study. No change to the report has been made in response to this comment.
USFS	1	More information and clarification are needed to determine with certainty that the purposes are achieved. Specifically, and as noted below, additional information on the modeling approach and its results are necessary. We believe that the following information is fundamental to this effort and should be thoroughly addressed: Clearly state the model purpose and the questions that the model outputs are to address. What specifically needs to be quantified to support needed decisions related to fish passage and behaviors, and how is the model addressing this? Describe the needed spatial and temporal scale for the model and identify accuracy requirements or levels of acceptable uncertainty. How do the model results relate to specific performance criteria for the project?
		NorthWestern response: As described in Section 1.1 and 1.2, the purpose of this report is to inform the 3D modeling in the following phase. The goals of this study are those outlined by the Scientific Review Panel and described in Section 1.1. No change to the report has been made in response to this comment.
USFS	2	Clearly identify the state variables of interest to the modeling exercise (e.g., water surface elevation, velocity magnitude and direction, etc.). These should relate closely to fish behavior and successful passage. Identify the range of conditions over which these variables are of interest (e.g. expected flow range during spawning migrations and fishway use).
		NorthWestern response: Information on the specific variables of interest has been added to Section 2.2, Task 2. The variables of interest and those discussed throughout Section 3.2 are velocity and depth as they are most relevant to fish behavior and passage. Additional information related to the ranges of conditions evaluated has been added following Table 2.1.
USFS	3	Describe the selected model and its limitations with respect to the model purposes. Describe the necessary model domain and identify relevant trade-offs. This discussion should address the spatial extents, boundary conditions, spatial and temporal fidelity, solution schemes, tolerances, and other material model characterizations.
		NorthWestern response: Discussion of the spatial extents, boundary conditions, mesh resolution, modeling time steps, physics modules, and selected material properties are included in Section 2.2 Task 2. Additional information has been added as appropriate.
USFS	4	Clearly describe the model parameterization, calibration, and validation. This must include a comparison of predicted state variables with field measurements of those variables for the calibration conditions. Describe the differences and their implications. If a validation data set is available, conduct a model validation within the range of interest. Describe the model behavior relative to observed system behavior through a comparison of predicted and measured conditions.
		NorthWestern response: Due to the nature of the downstream channel and its hazards during even low flow conditions, validation data cannot be safely collected (See Figures 2-3, 2-5, and 2-6). This was taken into consideration during study planning and is one reason this study was designed to provide an

		estimate of downstream channel flow conditions in the absence of observed data. NorthWestern does not propose to adopt this addition to the study. No change to the report has been made in response to this comment.
USFS	5	Model performance should be assessed in the context of the variables of interest. In this case, those should be hydraulic variables correlated to fish passage. This aspect of the report, in particular, needs more development. The safety concerns cited during the presentation are noted; however, with no validation of model performance, the results are best used qualitatively and mainly reinforce conditions that are generally already understood.
		NorthWestern response: In the absence of measured field data no comparisons are drawn between model performance and variables of interest. See response to USFS comment number 4. NorthWestern does not propose to adopt this addition to the study. No change to the report has been made in response to this comment.
USFS	6	Sensitivity analysis is appreciated. However, the results should be structured so as to quantify uncertainty.
		NorthWestern response: Additional information related to uncertainty in the selected Manning's N values has been added to Section 3.3.
USFS	7	Provide reference materials not otherwise generally available or describe the input data and solution schemes in greater detail (e.g., the Flow-3D manual does not appear to be available online without a subscription, so we can't assess some aspects of the modeling).
		NorthWestern response: Additional information has been added to Section 2.2 Task 2 related to the solution schemes used by FLOW-3D.
USFS	8	On the goal, consider adding the full context of hydraulics that are being assessed in the near-field across the dam face in addition to the "entrance of the fish passage facility." Our understanding is that the full extent of the dam face is within the study domain based on agency requests. A more comprehensive understanding of hydrodynamics in the vicinity of the dam will enhance the assessment of the existing fishway and permit the assessment of alternatives.
		NorthWestern response: As shown in Figure 2.8 the full extent of the Main Channel Dam is included within this study as appropriate for each scenario. In general, the results presented in the report are most applicable to fish passage.
USFS	9	Table 2-2: Should include an assessment and quantification of vertical and horizontal accuracies of the DTMs
		NorthWestern response: Additional data related to the accuracy of the survey data collected in Task 1 has been added to Appendix A and the CFD information shifted to Appendix B. However, this information is not specifically relevant to Table 2-2.
USFS	10	RNG Turbulence Model: Don't know what this is. Is it a k-e model with variable turbulence length? More generally, we need to have access to the reference materials for Flow 3D in order to independently assess the modeling approach, or the authors need to describe these issues in more detail.
		NorthWestern response: Additional information on the turbulence model has been added to Section 2.2 Task 2. See USFS Comment 7 for information on the reference materials.
USFS	11	Pressure boundary condition: Assume the "pressure boundary" is the static head for a given water surface?
		NorthWestern response: Correct. As described in section 2.2 Task 2, the pressure boundary is used to set the reservoir water surface elevation.
USFS	12	IMB - need to describe generically or, if using terminology specific to Flow 3D, provide the documentation.

		NorthWestern response: Additional information has been added to Section 2.2 Task 2 related to the Immersed Boundary Method. See USFS Comment 7 for information on the requested reference materials.
USFS	13	Stable model result – need to describe how this is determined. We have concerns that the model may be unstable given the very short simulation time. We'd like to see more discussion regarding the model time-steps, how it performs with increased steps, and how you assure it is stable.
		NorthWestern response: To monitor for stability, flow rates through the model are monitored for convergence. As described in Section 2.2 Task 2, time steps within FLOW-3D cannot be manually controlled. Additional information has been added to this section for clarification.
USFS	14	Identify the convergence criteria and tolerances for mesh cells and boundaries.
		NorthWestern response: Additional information on convergence criteria and tolerances has been added to Section 2.2 Task 2.
USFS	15	This simulation allowed for flows to reach a steady-state throughout the model domain" - Were the flows unsteady for a time then became steady?
		NorthWestern response: From the initial conditions it takes the model time for the flow to pass over the dam and through the downstream channel before reaching the end of the model domain. The model reaches steady-state conditions when the outflow from the Main Channel Dam equals the outflow of the model domain.
USFS	16	Surface roughness coefficients: It may be valuable to provide a bit more focus here - We believe this is likely not correct in the present application. They can be related with caution for pipes and very small-form ("skin friction") cases, but not where larger-scale roughness elements, form losses, momentum losses at fluid interfaces, etc., occur.
		NorthWestern response: The geometry development process and hydrodynamic calculations within the model account for form losses, momentum losses, etc. The absolute roughness values provide additional losses at the geometry surfaces. Sensitivity analyses were performed to understand the impact on results from the selected surface roughness coefficients and generally show low sensitivity to the surface roughness values. Additional discussion of this has been added to Section 2.2 Task 2.
USFS	17	Lots to be said on the Manning's n value here too. The Manning's n-value for natural surfaces is low even when adjusted higher for the 20% sensitivity assessment and given what the terrain model and site conditions appear to present. There's mention that the value is beyond the range of typical natural channel values; however, in our experience, it is very typical to have roughness coefficients of 0.04 to 0.07 (or even higher) when back-calculating Manning's n-values from measured flow velocities.
		NorthWestern response: In general, surface roughness within Flow-3D does not perform the same as it would in a more simplified 1D or 2D model. Because the 3D model is capable of resolving the model geometry and accounting for momentum and other losses, the surface roughness values are only responsible for skin friction losses. Manning's N is presented in Section 2.2 to provide a frame of reference for the values input into Flow-3D. Additional information has been added to clarify this section.
USFS	18	As such, velocity and turbulence outcomes could significantly differ from reality. It would be helpful to provide additional rationale for the selection of Manning's n values and validate them using measured flow conditions. (However, it's also good to fully recognize that it may not be critical to have roughness coefficients entirely accurate if the model has been validated and there is reasonable certainty with predictions)

		NorthWestern response: Additional information has been added to this section. See USFS Comment 4, 16 and 17.
USFS	19	There's mention that the model showed relatively little sensitivity to surface roughness adjustments. Perhaps describe in terms of relative roughness?
		NorthWestern response: The sensitivity analyses for roughness present the differences based on percentage, manning's n, and absolute roughness. This is considered sufficient to present the roughness. NorthWestern does not propose to adopt this addition to the study. No change to the report has been made in response to this comment.
USFS	20	Validation of the model using available data is a form of calibration rather than validation of accuracy to address parameters of interest. The model needs to be calibrated then demonstrate predictability through validation of model behavior relative to measured system behavior.
		NorthWestern response: See response to USFS comment number 4. NorthWestern does not propose to adopt this addition to the study. No change to the report has been made in response to this comment.
USFS	21	It's typical to validate the model by comparing calibrated results to measured water surface elevations (at flows that are safe). Once the model is known to be accurate then flows and conditions between the validated predictions can be extrapolated for best usage with fish behavioral data. Also need to validate velocity in the near-field to meaningfully understand fish behaviors affected by structure, velocity, turbulence, etc.
		NorthWestern response: Given the dynamic nature of the downstream channel it is unlikely that lower flows would provide a correlation to higher flows. See response to USFS comment number 4. NorthWestern does not propose to adopt this addition to the study. No change to the report has been made in response to this comment.
USFS	22	Not sure why there is a need to add complexity as the model is not truly validated yet. The model is capable of reflecting measured conditions, but there is high uncertainty on if it actually is unless validation truly occurs.
		NorthWestern response: See response to USFS comment number 4 for discussion of validation data. NorthWestern does not propose to adopt this addition to the study. No change to the report has been made in response to this comment.
USFS	23	Comparison of discharges at structures and empirical equations and results of previous studies: we question doing this as preliminary model runs are performed versus conducting it prior to modeling to use the relations to help parameterize the models
		NorthWestern response: Preliminary analysis was performed prior to use of the Flow-3D model to evaluate initial conditions and boundary conditions. Information on these has been added to Section 2.2 Task 2. Comparison of discharges was additionally performed to assess model performance after model development.
USFS	24	The model development process needs additional explanation.
		NorthWestern response: Additional information on the model development process has been added to Section 2.2 Task 2.
USFS	25	Why just "in general"? It's expected that the simulations will "precisely" follow the master operating manual for the dam. Where were there deviations?
		NorthWestern response: As described following Table 2-3, differences between the model and the operating plan included in the Total Dissolved Gas Control Plan are related to the fact that the operating plan is based on an average panel discharge which does not account for the varying width of panels and spillway piers. NorthWestern does not propose to adopt this

		addition to the study. No change to the report has been made in response to this comment.
USFS	26	Target flow rates – need more explanation; why just "in general"? one may expect the simulations to "precisely" follow the master operating manual for the dam. Why and where were there deviations? More development needed and also to assure that scenarios are representative of true operating conditions.
		NorthWestern response: See response to USFS comment number 25.
USFS	27	Page 19 – explain what "minor" discharge deviations are for the panels to provide assurance that values are insignificant
		NorthWestern response: This information has been added following Table 2-3.
USFS	28	Page 20, Inclusion of 3D modeling blocks: Although we look forward to the 3D modeling, we question the reliability until there's assurance that the current 2D outputs are reliable and provide the needed information for specifically identified fisheries behavior questions/performance parameters of interest. The velocity field and depths are what is most important and without assurance of accuracy, then maybe a time-step is not going to be as useful/meaningful?
		NorthWestern response: As described in this section, the 3D blocks were included to facilitate modeling of the dam crest. Without the inclusion of these blocks, evaluation of the flow field near the dam and fish passage facility would be incredibly difficult and overly simplified due to the complexity of the dam bay panels and vertical acceleration of flows down the face of the dam. NorthWestern does not propose to adopt this addition to the study. No change to the report has been made in response to this comment.
USFS	29	Page 21 Results: General observations – what is stated is already understood without the modeling, so it'll be important to address everything mentioned herein to assure that the model is presenting helpful, quantitative information, that is reliable and contributing quantitatively to the fisheries behavior study
		NorthWestern response: This section is an introduction to the technical results presented in Section 3.2. NorthWestern does not propose to adopt this addition to the study. No change to the report has been made in response to this comment.
USFS	30	CFD Model Results (all sections): Respectfully and with eye towards best results and cost efficiencies, the observations in this section could have been made without a single model run. What is really needed in the assessment and final report is 1) how the model was calibrated and validated, 2) how the model results compare with measured data
		NorthWestern response: It would be extremely difficult to estimate the velocities and flow depths in the highly turbulent falls area and other locations solely by observation. The model was calibrated to previously established rating curves and operational data as described in Section 2.2 Task 2. For information on validation data see response to USFS comment number 4. NorthWestern does not propose to adopt this addition to the study. No change to the report has been made in response to this comment.
USFS	31	What observations can be made about the flow field that are relevant to fish passage and behaviors? A good fourth discussion (hopefully later) would be sources of uncertainty, their magnitude, and implications.
		NorthWestern response: Discussions relevant to fish passage are included when discussing velocities at river margins and results immediately downstream of the fish passage entrance within Section 3.2. Additionally, all general discussion about velocities through the falls and other portions of the channel are relevant to fish passage. Further conclusions related to fish passage and hydraulic results will be included in the final study report. This study provides a reasonable estimate of the downstream flow patterns and

		conditions. NorthWestern does not propose to adopt this addition to the study. No change to the report has been made in response to this comment.
USFS	32	Provide more refined/broader colors that clearly illustrate ranges under 15 fps, as it would help refine interpretation of velocities that matter to the fish. Fish are generally present near boundary conditions that are 0-3 fps. When moving, average bankfull (~Q2) velocities in natural channels range 3-5 fps.
		NorthWestern response: Contours for velocities below 15 fps have been added to figures 3.3, 3.9, 3.15, 3.21.
USFS	33	Page 25 - Show velocity vectors when displaying velocities
		NorthWestern response: Velocity vectors are provided for all runs in Figures 3.5, 3.11, 3.17, and 3.23 respectively. The results are shown as opaque with no vectors in the referenced figure to better depict velocities.
USFS	34	Page 36, Figure 3-16 discussion: This is the first really meaningful relevant observation from the model runs and is good; How does this compare with measurements?
		NorthWestern response: Discussion similar to that of Figure 3-16 is provided for each run. See response to USFS comment number 4 for discussion of validation data. No change to the report has been made in response to this comment.
USFS	35	Page 44. Table 3-1: There is 80 cfs in the fishway for moth these runs, and both have limited tailwater. If anything, the tailwater elevation for 3 should be less than 4. So why did you achieve higher velocities for 3?
		NorthWestern response: As described in Section 3.2, Run 2, Paragraph 2, this is due to decreased submergence in the areas measured.
USFS	36	Page 51: surface absolute roughness coefficient in feet and having "little impact on modeling results": Please develop this more because this is very questionable. The water surface elevation and velocity may be relatively insensitive to the expected range of resistance for this reach, but that is not because of the absolute magnitude of the resistance. 20% is too small of a range for a reasonable sensitivity analysis. Resistance likely varies by more than this as a function of depth over the modeled range of flows
		NorthWestern response: The selected roughness values are based on previous studies and professional engineering judgment. In general, absolute roughness does not have the same depth variable characteristics as an empirical Manning's n value would have in a traditional 1D or fully 2D model. A range of 20% is considered to be reasonable to vary the Manning's n values over as this varies the absolute roughness values by approximately +200% and -75%. See response to USFS comment 17 for additional discussion of roughness values. NorthWestern does not propose to adopt this addition to the study. No change to the report has been made in response to this comment.
USFS	37	Page 52: Table 3-3: Water surface elevation is likely more sensitive to roughness than is velocity. In the falls, roughness should be MUCH higher, and you should expect multiple zones of alternate critical/subcritical flow (with lots of associated energy loss to account for with your roughness value.
		NorthWestern response: Roughness sensitivity analyses were performed as described in Section 3.3 and are considered sufficient for modeling purposes. Velocity is more critical to this fish passage evaluation. See response to USFS comment 17 for discussion of roughness values. No change to the report has been made in response to this comment.
USFS	38	"Qualitatively" – this is probably meant as Quantitatively?
		NorthWestern response: Concur. Change made in the last paragraph of Section 3.3.
USFS		Which model was more accurate (i.e., better matched measured values)?

	39	**NorthWestern response:** There are no measured values for comparison. See response to USFS Comment number 4. No change to the report has been made in response to this comment.
USFS	40	The general information isn't that informative, what is needed is addressing which model performs better (as determined through validation of a calibrated model against measured values that differ from the calibration set) for the model parameters important to the task (evaluating fish passage and behavior)?
		NorthWestern response: See response to USFS comment number 4. No change to the report has been made in response to this comment.
USFS	41	Page 53 Discussions and Recommendations: Stated previously, but most of this information describes known conditions and suggests that an initial model setup was conducted and run for a few flows, but much more information is needed to verify model calibration and reliability/model validation.
		NorthWestern response: See response to USFS comment number 4. NorthWestern does not propose to adopt this addition to the study. No change to the report has been made in response to this comment.
USFS	42	There is little to no discussion of velocity fields and turbulence structure in the immediate vicinity of the fish passage facilities, which is likely anticipate to be the analysis need (specific characterization of modeling need and parameters of interest are extremely critical and for which the results specifically need to address, in addition to reliability and uncertainty).
		NorthWestern response: Additional discussion of the results near the fish passage facility has been added to Section 4 in addition to the results presented in section 3.2.
USFS	43	The 3-D model may provide some reliable insights into vertical velocity distributions provided the modeling is done correctly; more work and validation work and/or clarification is needed for confidence that 3D will be informative/useful (compelling evidence that vertical velocity distributions matter to fish passage here hasn't been provided but we all know it… would be good to present)
		NorthWestern response: Additional information related to what can be expected from the 3D analyses has been added to Section 4. Vertical velocity distributions will be assessed along with the 3D analyses as described in Section 4.
USFS	44	Page 54 – References – can these be made available?
		NorthWestern response: Links to references have been added to the citations when available. The Supporting Technical Information Document: Thompson Falls Hydroelectric Project is classified as Critical Energy Infrastructure Information by FERC and is not publicly available. The Flow 3D Users Manual is a proprietary document, only available from the software vendor.
USFS	45	Finally, we'll respectfully continue to voice our requests that were not considered and within context of said future considerations. As such, the bathymetric results immediately downstream of the dam are very useful, and this type of result is what we requested for the entire reservoir during the study proposal process. Understanding the reservoir bathymetry to this degree has the potential to greatly inform dam discharge/operational changes that could assist in non-native fish population reductions, reduce native fish mortality, and various erosion and sedimentation issues.
		NorthWestern response: The FERC-approved study plan does not include gathering bathymetric data in the Thompson Falls Reservoir. NorthWestern does not propose to adopt this addition to the study. No change to the report has been made in response to this comment.

USFS	46	We are grateful for this process and opportunity to engage as a stakeholder. Overall, we are pleased with the efforts so far and look forward to the next steps. We especially look forward to the integration of reliable modeling outcomes and what can be learned when combined with the fisheries telemetry data.
		NorthWestern response: Noted.

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6.0 Literature Cited

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Attachment A – Bathymetric Surveying Information

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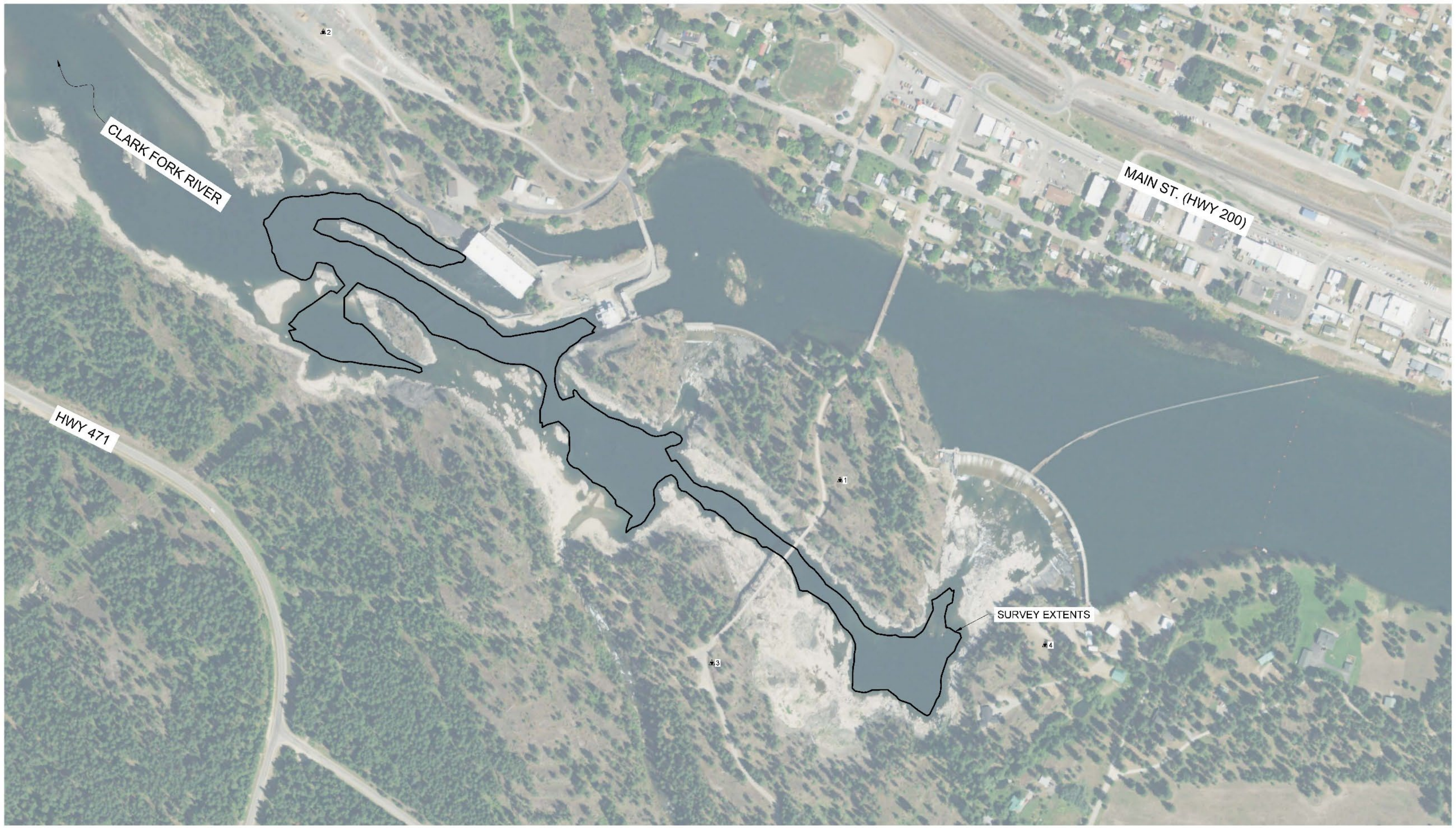

CONTROL POINT TABLE				
Point #	Raw Description	Northing	Easting	Elevation
1	AC	1272102.74	526035.18	2438.51
2	AC	1273918.56	523936.86	2419.80
3	AC	1271361.82	525514.71	2420.28
4	AC	1271434.38	526867.00	2401.49

HORIZONTAL DATUM

BEARINGS, COORDINATES, AND DISTANCES ARE STATE PLANE GRID, DERIVED FROM GPS OBSERVATIONS WITH SURVEY-GRADE RECEIVERS AND REFERENCED TO THE MONTANA COORDINATE SYSTEM, SINGLE ZONE, NAD 83 (CORS) AT CONTROL POINT NO. 1 DEPICTED HEREON. HORIZONTAL UNITS ARE INTERNATIONAL FEET. COMBINED SCALE FACTOR FOR THIS PROJECT IS 0.9993297791.

VERTICAL DATUM

ELEVATIONS ARE NAVD88, BASED ON MSOL AND COMPUTED USING GEOID 18. VERTICAL UNITS ARE US SURVEY FEET.

200 100 0 200 400

SCALE IN FEET

#
#

VERIFY SCALE!

THESE PRINTS MAY BE REDUCED. LINE BELOW MEASURES ONE INCH ON ORIGINAL DRAWING.

MODIFY SCALE ACCORDINGLY!

REVISIONS			
NO.	DESCRIPTION	BY	DATE

M:\1051\080.14 - NWE THOMPSON FALLS BATHYMETRIC SURVEY\ACAD\EXHIBITS\CONTROL MAP.DWG PLOTTED BY:DAVID SIMS ON Sep/17/2021

Morrison Maierle
engineers • surveyors • planners • scientists

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Missoula, MT 59801
406.542.8880
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DRAWN BY: DCS
DSGN. BY:
APPR. BY: CAS
DATE: 09/21
Q.C. REVIEW
BY:
DATE:

NORTHWESTERN ENERGY BATHYMETRIC SURVEY

THOMPSON FALLS MT

CONTROL EXHIBIT

PROJECT NUMBER 1051.080.14
SHEET NUMBER 1
DRAWING NUMBER EX.1

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Morrison Maierle
engineers • surveyors • planners • scientists

Vertical Comparison

Project: Thompson Falls Bathy
Project #: 1051.080.14
Date: 8/5/2021
Field Technician: Sims/ Stubblefield

2010 Lidar to MMI GNSS comparison

Point number	Point description	z (MMI GNSS)	z (2010 LIDAR)	diff in z	(diff in z)^2
60001	SE	2348.841	2348.384	0.4568	0.209
60002	SE	2350.019	2349.924	0.095	0.009
60003	SE	2351.112	2350.323	0.7889	0.622
60005	SE	2346.856	2345.977	0.8786	0.772
60007	SE	2348.681	2348.172	0.5089	0.259
60009	SE	2340.577	2340.507	0.0703	0.005
60011	SE	2351.411	2349.916	1.4949	2.235
60012	SE	2355.269	2355.146	0.1233	0.015
60013	SE	2343.537	2343.001	0.5362	0.288
60024	SE	2355.142	2355.096	0.046	0.002
60027	SE	2339.093	2339.0173	0.0757	0.006
60036	SE	2342.161	2342.0882	0.0728	0.005
60038	SE	2354.092	2353.9199	0.1721	0.030
60039	SE	2355.525	2354.6865	0.8385	0.703
60040	SE	2345.369	2344.9821	0.3869	0.150
60041	SE	2349.719	2349.6297	0.0893	0.008
60042	SE	2349.001	2348.9384	0.0626	0.004
60043	SE	2352.076	2351.9125	0.1635	0.027
60044	SE	2350.632	2349.1451	1.4869	2.211
60045	SE	2351.902	2352.1894	-0.2874	0.083
60046	SE	2359.715	2358.6956	1.0194	1.039
60047	SE	2355.558	2355.8299	-0.2719	0.074
60051	SE	2354.949	2355.4501	-0.5011	0.251
60052	SE	2353.952	2353.6963	0.2557	0.065
60053	SE	2358.978	2358.1118	0.8662	0.750
60054	SE	2356.211	2354.8264	1.3846	1.917
60064	SE	2342.625	2341.5966	1.0284	1.058
60072	SE	2344.468	2344.3931	0.0749	0.006
60073	SE	2342.82	2343.1698	-0.3498	0.122
60076	SE	2354.771	2354.6169	0.1541	0.024
60077	SE	2351.989	2350.7523	1.2367	1.529
60111	SE	2339.327	2339.5845	-0.2575	0.066
60124	SE	2347.244	2347.0634	0.1806	0.033
60125	SE	2361.965	2361.731	0.234	0.055
60126	SE	2363.744	2362.6234	1.1206	1.256
60127	SE	2351.516	2351.1499	0.3661	0.134
60128	SE	2356.558	2356.0342	0.5238	0.274
60129	SE	2355.702	2355.144	0.558	0.311
60130	SE	2352.54	2352.6183	-0.0783	0.006

60149	SE	2338.249	2337.6763	0.5727	0.328
60153	SE	2350.28	2348.8679	1.4121	1.994
60154	SE	2350.768	2350.2345	0.5335	0.285
60156	SE	2355.086	2353.9598	1.1262	1.268
60157	SE	2347.733	2347.8274	-0.0944	0.009
60158	SE	2342.662	2342.7122	-0.0502	0.003
60159	SE	2343.709	2343.8518	-0.1428	0.020
60163	SE	2342.778	2342.9097	-0.1317	0.017
60164	SE	2369.643	2369.4567	0.1863	0.035
60167	SE	2348.039	2348.4926	-0.4536	0.206
				sum	20.777
				average	0.42401326
				RMSE	0.65116301
				NSSDA	1.27627949

The relationship of the RMSE values and the 95 percent confidence intervals is as follows:
Vertical Accuracy = 1.9600 x RMSEz
Where RMSEz is the RMSE of the vertical differences

USE THE APPROPRIATE TITLE & TABLE BELOW AS NEEDED

NSSDA 2-Foot Contour - Vertical Accuracy Assessment

2-Foot Contour Vertical Accuracy Acceptance Criteria

RMSEz should = 0.6 ft or less

NSSDA ACCURACYr must = 1.2 ft or less at 95% confidence level

Project File Data		Coordinate System	
Name:	M:\1051\080.14 - NWE Thompson Falls Bathymetric Survey\Survey Data\TBC Process\BASELINE PROCESSING.vce	Name:	United States/State Plane 1983
Size:	70 KB	Datum:	NAD 1983 (Conus)
Modified:	8/19/2021 11:35:02 AM (UTC:-6)	Zone:	Montana 2500
Time zone:	Mountain Standard Time	Geoid:	GEOID18 (Conus)
Reference number:		Vertical datum:	
Description:		Calibrated site:	
Comment 1:			
Comment 2:			
Comment 3:			

1 Network Adjustment Report

2 Adjustment Settings

Set-Up Errors

GNSS

Error in Height of Antenna: 0.002 ft

Centering Error: 0.002 ft

Covariance Display

Horizontal:

Propagated Linear Error [E]: U.S.

Constant Term [C]: 0.000 ft

Scale on Linear Error [S]: 1.000

Three-Dimensional

Propagated Linear Error [E]: U.S.

Constant Term [C]: 0.000 ft

Scale on Linear Error [S]: 1.000

3 Adjustment Statistics

Number of Iterations for Successful Adjustment: 2

Network Reference Factor: 1.00

Chi Square Test (95%): Passed

Precision Confidence Level: DRMS
Degrees of Freedom: 32

Post Processed Vector Statistics

Reference Factor: 1.00
Redundancy Number: 32.00
A Priori Scalar: 1.64

---

4 Control Point Constraints

Point ID	Type	North σ (International foot)	East σ (International foot)	Height σ (International foot)	Elevation σ (International foot)
MSOL	Global	Fixed	Fixed	Fixed	
MTFV	Global	Fixed	Fixed	Fixed	
WASK	Global	Fixed	Fixed	Fixed	
Fixed = 0.000003(International foot)					

5 Adjusted Grid Coordinates

Point ID	Northing (International foot)	Northing Error (International foot)	Easting (International foot)	Easting Error (International foot)	Elevation (International foot)	Elevation Error (International foot)	Constraint
1	1272102.747	0.010	526035.180	0.009	2438.514	0.046	
2	1273918.569	0.011	523936.858	0.010	2419.808	0.047	
3	1271361.825	0.011	525514.709	0.010	2420.293	0.047	
4	1271434.382	0.011	526866.996	0.010	2401.495	0.048	
A378	1271467.010	0.016	525522.281	0.013	2407.904	0.051	
MSOL	1010665.209	?	818318.100	?	3200.724	?	LLh
MTFV	1486287.066	?	793133.376	?	3024.306	?	LLh
WASK	1343776.344	?	21169.836	?	1941.359	?	LLh

6 Adjusted Geodetic Coordinates

Point ID	Latitude	Longitude	Height (International foot)	Height Error (International foot)	Constraint

1	N47°35'29.36080"	W115°21'15.57879"	2385.519	0.046	
2	N47°35'45.69287"	W115°21'48.10491"	2366.803	0.047	
3	N47°35'21.68101"	W115°21'22.34710"	2367.301	0.047	
4	N47°35'23.39249"	W115°21'02.74241"	2348.506	0.048	
A378	N47°35'22.72237"	W115°21'22.35157"	2354.912	0.051	
MSOL	N46°55'45.83763"	W114°06'31.84491"	3151.610	?	LLh
MTFV	N48°13'38.89086"	W114°19'36.54278"	2971.361	?	LLh
WASK	N47°39'56.58453"	W117°25'14.01624"	1881.313	?	LLh

7 Adjusted ECEF Coordinates

Point ID	X (International foot)	X Error (International foot)	Y (International foot)	Y Error (International foot)	Z (International foot)	Z Error (International foot)	3D Error (International foot)	Constraint
1	-6054933.337	0.016	-12777937.768	0.029	15376970.638	0.034	0.048	
2	-6056419.346	0.017	-12775867.135	0.030	15378072.951	0.035	0.049	
3	-6055593.438	0.017	-12778247.229	0.030	15376432.318	0.035	0.049	
4	-6054318.632	0.017	-12778695.555	0.030	15376535.412	0.036	0.050	
A378	-6055556.770	0.020	-12778169.139	0.034	15376494.342	0.039	0.055	
MSOL	-5848431.903	?	-13068919.738	?	15213616.145	?	?	LLh
MTFV	-5754051.125	?	-12727923.369	?	15532935.344	?	?	LLh
WASK	-6502332.156	?	-12533260.620	?	15394847.920	?	?	LLh

8 Error Ellipse Components

Point ID	Semi-major axis (International foot)	Semi-minor axis (International foot)	Azimuth
1	0.014	0.013	177°
2	0.015	0.014	179°
3	0.015	0.014	176°
4	0.016	0.014	174°
A378	0.022	0.018	5°

9 Adjusted GNSS Observations

Transformation Parameters

Deflection in Latitude: 0.025 sec **(DRMS)** 0.027 sec
Deflection in Longitude: -0.023 sec **(DRMS)** 0.045 sec
Azimuth Rotation: 0.010 sec **(DRMS)** 0.004 sec
Scale Factor: 1.00000002 **(DRMS)** 0.00000003

Observation ID		Observation	A-posteriori Error	Residual	Standardized Residual
1 --> 3 (PV18)	**Az.**	210°48'15.2"	0.881 sec	0.962 sec	0.739
	ΔHt.	-18.218 ft	0.010 ft	0.036 ft	2.122
	Ellip Dist.	905.964 ft	0.004 ft	-0.007 ft	-1.109
1 --> 3 (PV17)	**Az.**	210°48'15.2"	0.881 sec	-0.638 sec	-0.433
	ΔHt.	-18.218 ft	0.010 ft	-0.032 ft	-1.975
	Ellip Dist.	905.964 ft	0.004 ft	0.003 ft	0.514
1 --> 2 (PV28)	**Az.**	306°35'22.0"	0.273 sec	0.060 sec	0.122
	ΔHt.	-18.716 ft	0.007 ft	0.025 ft	1.800
	Ellip Dist.	2776.461 ft	0.003 ft	0.007 ft	1.325
1 --> 4 (PV19)	**Az.**	124°29'58.0"	0.877 sec	-2.630 sec	-1.668
	ΔHt.	-37.013 ft	0.013 ft	0.030 ft	1.079
	Ellip Dist.	1067.660 ft	0.005 ft	0.009 ft	1.117
MTFV --> 1 (PV61)	**Az.**	227°44'57.7"	0.006 sec	-0.003 sec	-0.816
	ΔHt.	-585.785 ft	0.067 ft	0.005 ft	1.222
	Ellip Dist.	342532.892 ft	0.012 ft	0.022 ft	1.623

3 --> 4 (PV24)	**Az.**	82°38'41.6"	0.818 sec	-0.483 sec	-0.319
	ΔHt.	-18.795 ft	0.014 ft	-0.002 ft	-0.081
	Ellip Dist.	1354.987 ft	0.004 ft	-0.011 ft	-1.465
WASK --> 1 (PV75)	**Az.**	92°16'42.3"	0.007 sec	-0.004 sec	-1.416
	ΔHt.	504.154 ft	0.089 ft	0.003 ft	0.668
	Ellip Dist.	510207.615 ft	0.019 ft	-0.010 ft	-0.952
1 --> 2 (PV37)	**Az.**	306°35'22.0"	0.273 sec	-0.129 sec	-0.457
	ΔHt.	-18.716 ft	0.007 ft	-0.007 ft	-1.165
	Ellip Dist.	2776.461 ft	0.003 ft	-0.005 ft	-1.342
2 --> 3 (PV40)	**Az.**	144°01'50.9"	0.293 sec	0.862 sec	1.218
	ΔHt.	0.499 ft	0.011 ft	0.005 ft	0.216
	Ellip Dist.	3006.094 ft	0.005 ft	-0.003 ft	-0.206
3 --> 4 (PV21)	**Az.**	82°38'41.6"	0.818 sec	-0.348 sec	-0.228
	ΔHt.	-18.795 ft	0.014 ft	0.026 ft	0.821
	Ellip Dist.	1354.987 ft	0.004 ft	0.011 ft	1.189
1 --> A378 (PV15)	**Az.**	214°36'48.3"	2.458 sec	2.371 sec	0.958
	ΔHt.	-30.607 ft	0.022 ft	0.001 ft	0.042
	Ellip Dist.	817.295 ft	0.012 ft	-0.014 ft	-1.114
1 --> 4 (PV22)	**Az.**	124°29'58.0"	0.877 sec	1.061 sec	0.806
	ΔHt.	-37.013 ft	0.013 ft	-0.018 ft	-1.093
	Ellip Dist.	1067.660 ft	0.005 ft	-0.007 ft	-0.949
MSOL --> 1 (PV48)	**Az.**	308°26'28.4"	0.006 sec	0.004 sec	1.085
	ΔHt.	-766.087 ft	0.077 ft	0.001 ft	1.049
	Ellip Dist.	392378.946 ft	0.014 ft	-0.009 ft	-0.595
1 --> A378 (PV14)	**Az.**	214°36'48.3"	2.458 sec	-2.072 sec	-0.841
	ΔHt.	-30.607 ft	0.022 ft	-0.003 ft	-0.108
	Ellip Dist.	817.295 ft	0.012 ft	0.012 ft	1.072
2 --> 4 (PV30)	**Az.**	126°00'08.5"	0.273 sec	0.646 sec	0.977
	ΔHt.	-18.297 ft	0.013 ft	-0.007 ft	-0.199

	Ellip Dist.	3843.607 ft	0.005 ft	0.002 ft	0.157
2 --> 3 (PV29)	**Az.**	144°01'50.9"	0.293 sec	-0.471 sec	-0.898
	ΔHt.	0.499 ft	0.011 ft	0.016 ft	0.794
	Ellip Dist.	3006.094 ft	0.005 ft	0.000 ft	-0.048
2 --> 4 (PV27)	**Az.**	126°00'08.5"	0.273 sec	-0.413 sec	-0.559
	ΔHt.	-18.297 ft	0.013 ft	0.019 ft	0.423
	Ellip Dist.	3843.607 ft	0.005 ft	0.006 ft	0.517

10 Histogram of Standardized Residuals

Critical Tau Value: 3.4

Observations Failing the Tau Test: 0

11 Covariance Terms

From Point	To Point		Components	A-posteriori Error	Horiz. Precision (Ratio)	3D Precision (Ratio)
1	2	**Az.**	306°35'22.0"	0.270 sec	1 : 805946	1 : 815885
		ΔHt.	-18.716 ft	0.007 ft		
		ΔElev.	-18.705 ft	0.007 ft		
		Ellip Dist.	2776.461 ft	0.003 ft		
1	4	**Az.**	124°29'58.0"	0.864 sec	1 : 229220	1 : 234637
		ΔHt.	-37.013 ft	0.013 ft		
		ΔElev.	-37.018 ft	0.013 ft		
		Ellip Dist.	1067.660 ft	0.005 ft		
1	MSOL	**Az.**	127°31'35.2"	0.005 sec	1 : 41268304	1 : 41498070
		ΔHt.	766.091 ft	0.046 ft		
		ΔElev.	762.210 ft	0.046 ft		
		Ellip Dist.	392378.953 ft	0.010 ft		
1	MTFV	**Az.**	46°59'12.7"	0.006 sec	1 : 36443194	1 : 36257551
		ΔHt.	585.842 ft	0.046 ft		
		ΔElev.	585.792 ft	0.046 ft		

		Ellip Dist.	342532.898 ft	0.009 ft		
1	WASK	**Az.**	273°48'18.0"	0.004 sec	1 : 55569665	1 : 55677948
		ΔHt.	-504.206 ft	0.046 ft		
		ΔElev.	-497.155 ft	0.046 ft		
		Ellip Dist.	510207.623 ft	0.009 ft		
3	1	**Az.**	30°48'10.2"	0.892 sec	1 : 228858	1 : 226782
		ΔHt.	18.218 ft	0.010 ft		
		ΔElev.	18.221 ft	0.010 ft		
		Ellip Dist.	905.964 ft	0.004 ft		
3	2	**Az.**	324°02'09.9"	0.289 sec	1 : 649475	1 : 656806
		ΔHt.	-0.498 ft	0.011 ft		
		ΔElev.	-0.485 ft	0.011 ft		
		Ellip Dist.	3006.094 ft	0.005 ft		
3	4	**Az.**	82°38'41.6"	0.816 sec	1 : 303647	1 : 305494
		ΔHt.	-18.795 ft	0.014 ft		
		ΔElev.	-18.798 ft	0.014 ft		
		Ellip Dist.	1354.987 ft	0.004 ft		
4	2	**Az.**	306°00'41.9"	0.269 sec	1 : 749716	1 : 761330
		ΔHt.	18.297 ft	0.013 ft		
		ΔElev.	18.313 ft	0.013 ft		
		Ellip Dist.	3843.608 ft	0.005 ft		
A378	1	**Az.**	34°36'43.3"	2.519 sec	1 : 70966	1 : 69567
		ΔHt.	30.607 ft	0.022 ft		
		ΔElev.	30.610 ft	0.022 ft		
		Ellip Dist.	817.295 ft	0.012 ft		

Project File Data		Coordinate System	
Name:	M:\1051\080.14 - NWE Thompson Falls Bathymetric Survey\Survey Data\TBC Process\BASELINE PROCESSING.vce	Name:	United States/State Plane 1983
Size:	102 KB	Datum:	NAD 1983 (Conus)
Modified:	8/20/2021 4:25:35 PM (UTC:-6)	Zone:	Montana 2500
Time zone:	Mountain Standard Time	Geoid:	GEOID18 (Conus)
Reference number:		Vertical datum:	
Description:		Calibrated site:	
Comment 1:			
Comment 2:			
Comment 3:			

1 GNSS Loop Closure Results

2 Summary

Legs in loop: 3
Number of Loops: 32
Number Passed: 32
Number Failed: 0

	Length (International foot)	Δ3D (International foot)	ΔHoriz (International foot)	ΔVert (International foot)	PPM
Pass/Fail Criteria			0.082	0.115	
Best		0.006	0.002	0.003	0.916
Worst		0.085	0.035	0.081	25.470
Average Loop	6478.648	0.037	0.016	0.031	6.790
Standard Error	1897.866	0.042	0.018	0.038	5.377

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Attachment B – CFD Model Setup and Results

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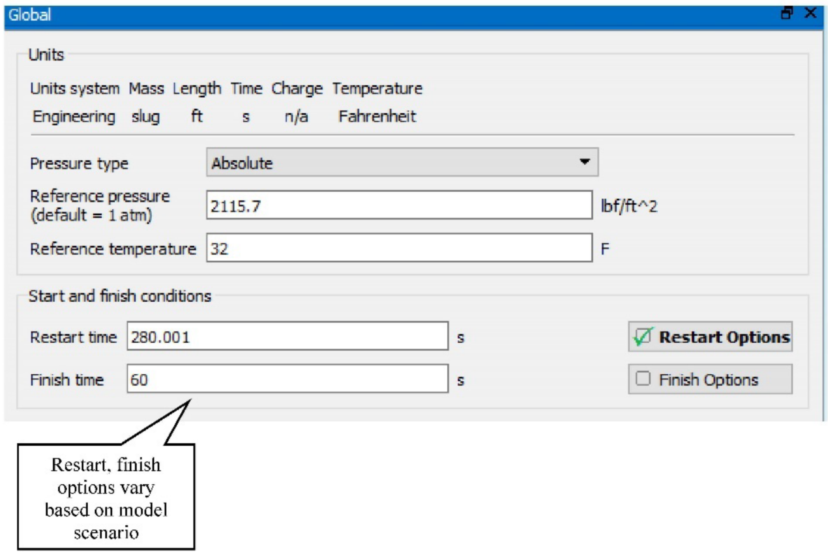
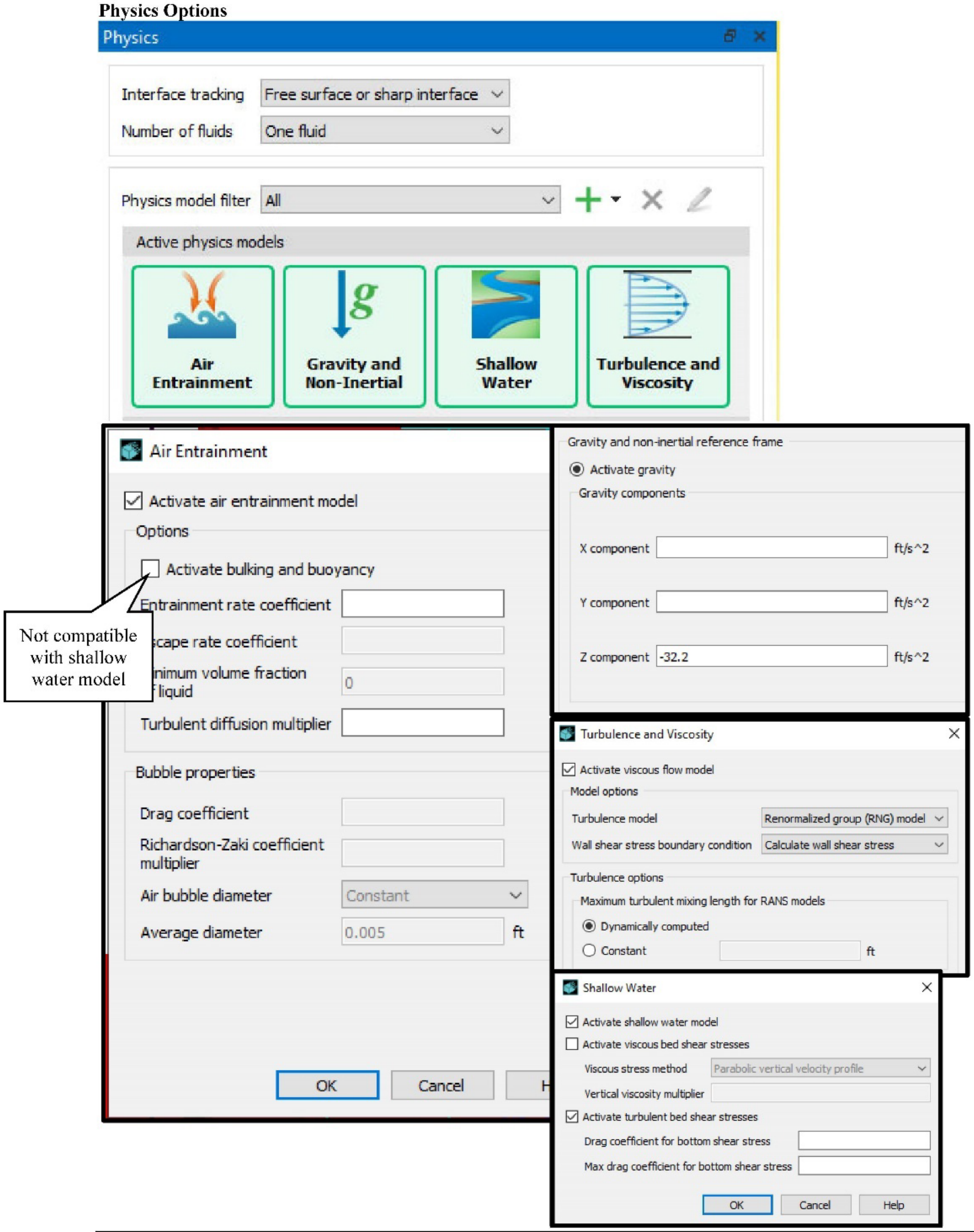
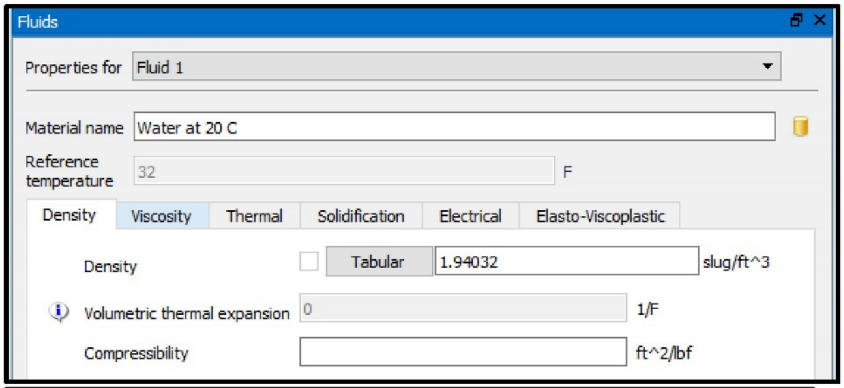
Global Options



Physics Options



Fluids


Fluids
Properties for
Fluid 1
Material name
Water at 20 C
Reference temperature
32
F
Density
Viscosity
Thermal
Solidification
Electrical
Elasto-Viscoplastic
Density
Tabular
1.94032
slug/ft^3
Volumetric thermal expansion
0
1/F
Compressibility
ft^2/lbf


Density
Viscosity
Thermal
Solidification
Electrical
Elasto-Viscoplastic
Viscosity
Constant
Tabular
2.08854e-5
slug/ft/s
Function coefficients

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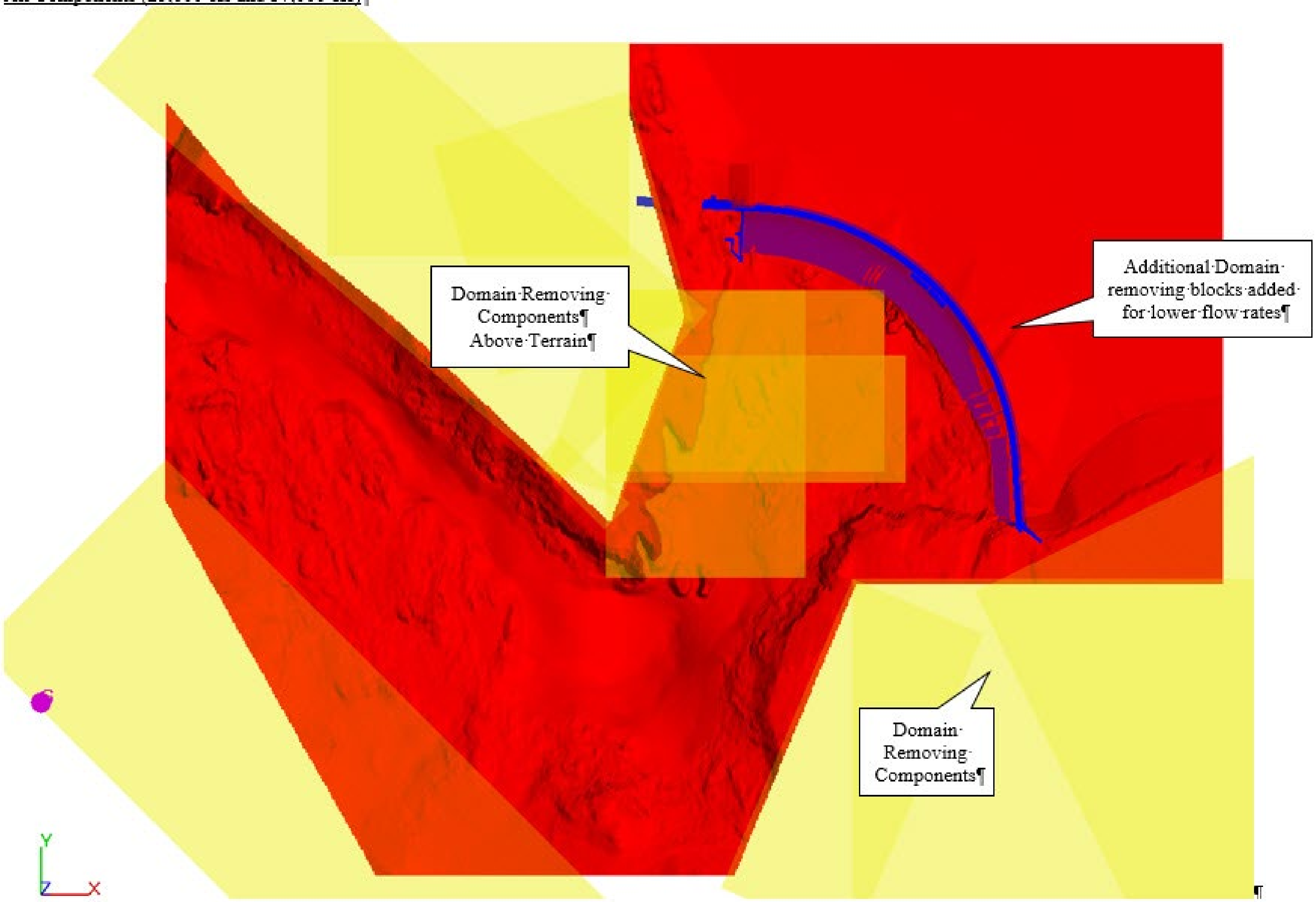
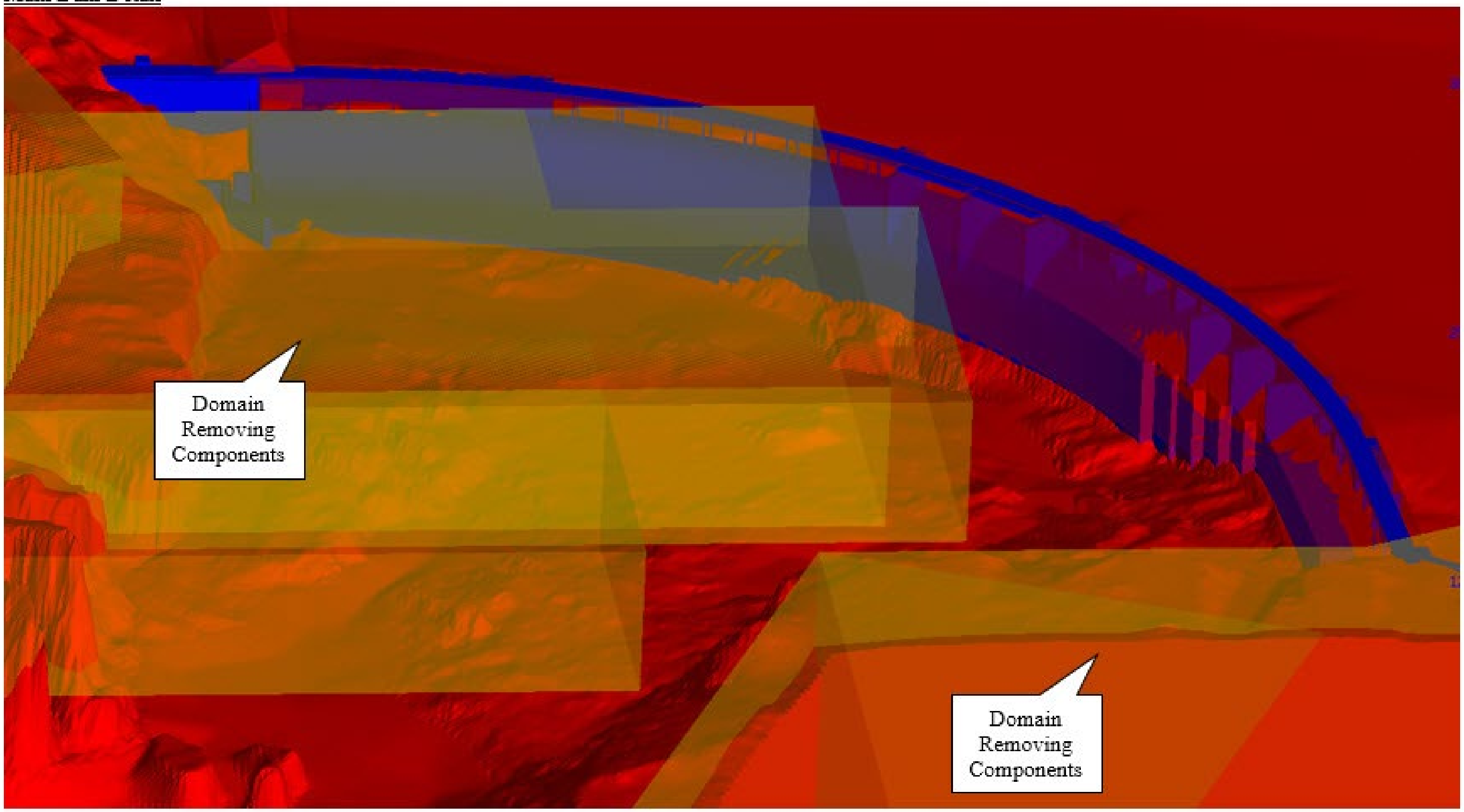
Geometry

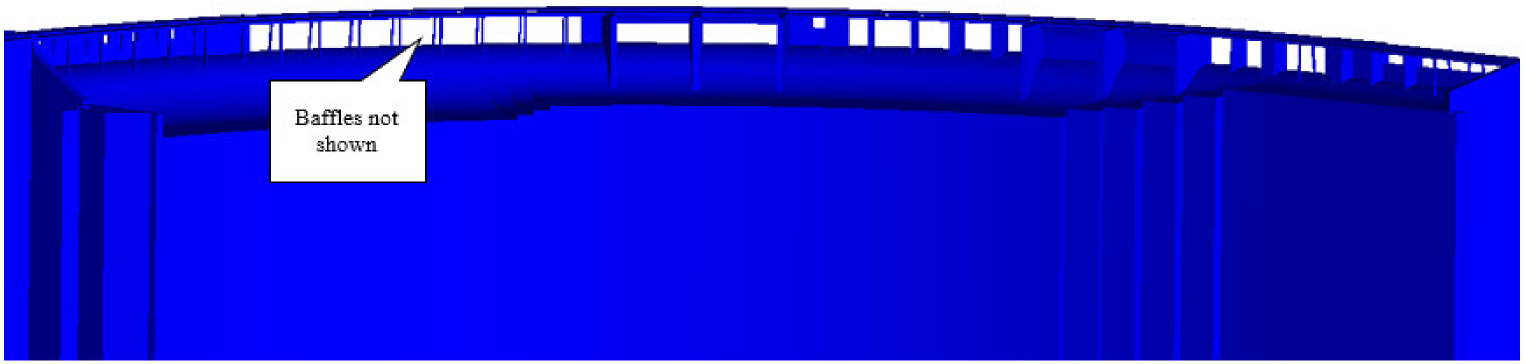
All Components (25,000 cfs and 37,000 cfs)



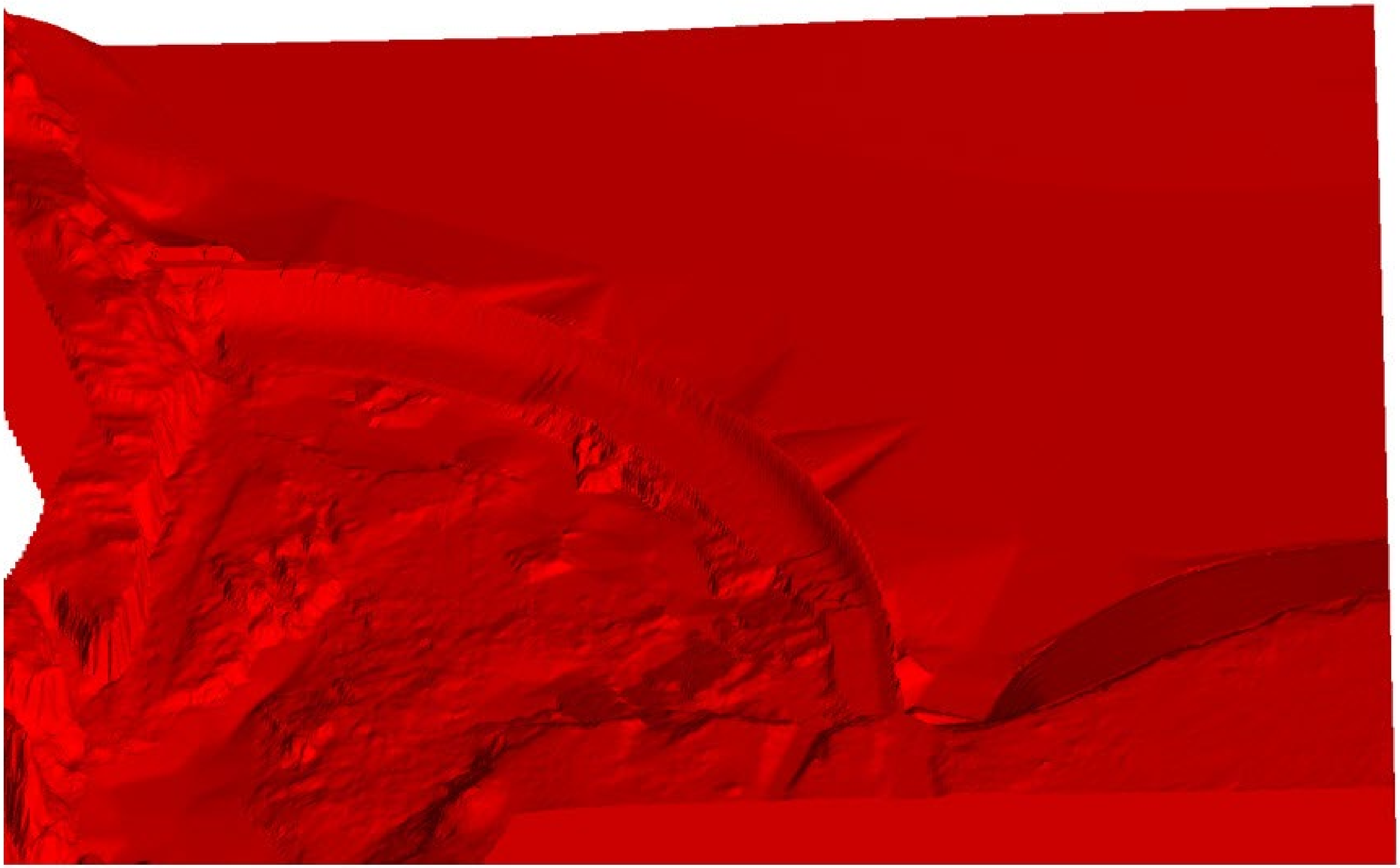
Main Dam Detail

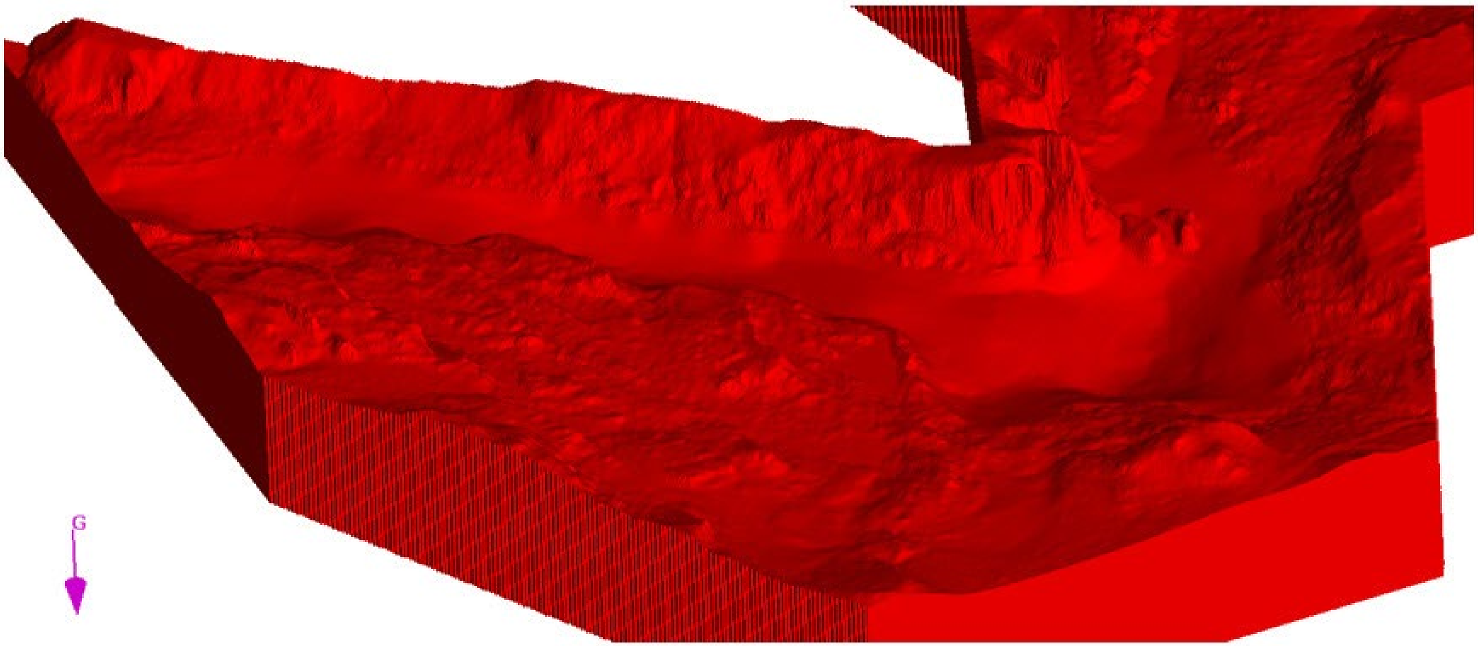


Spillway Chute Component
(25k cfs configuration shown, others similar)

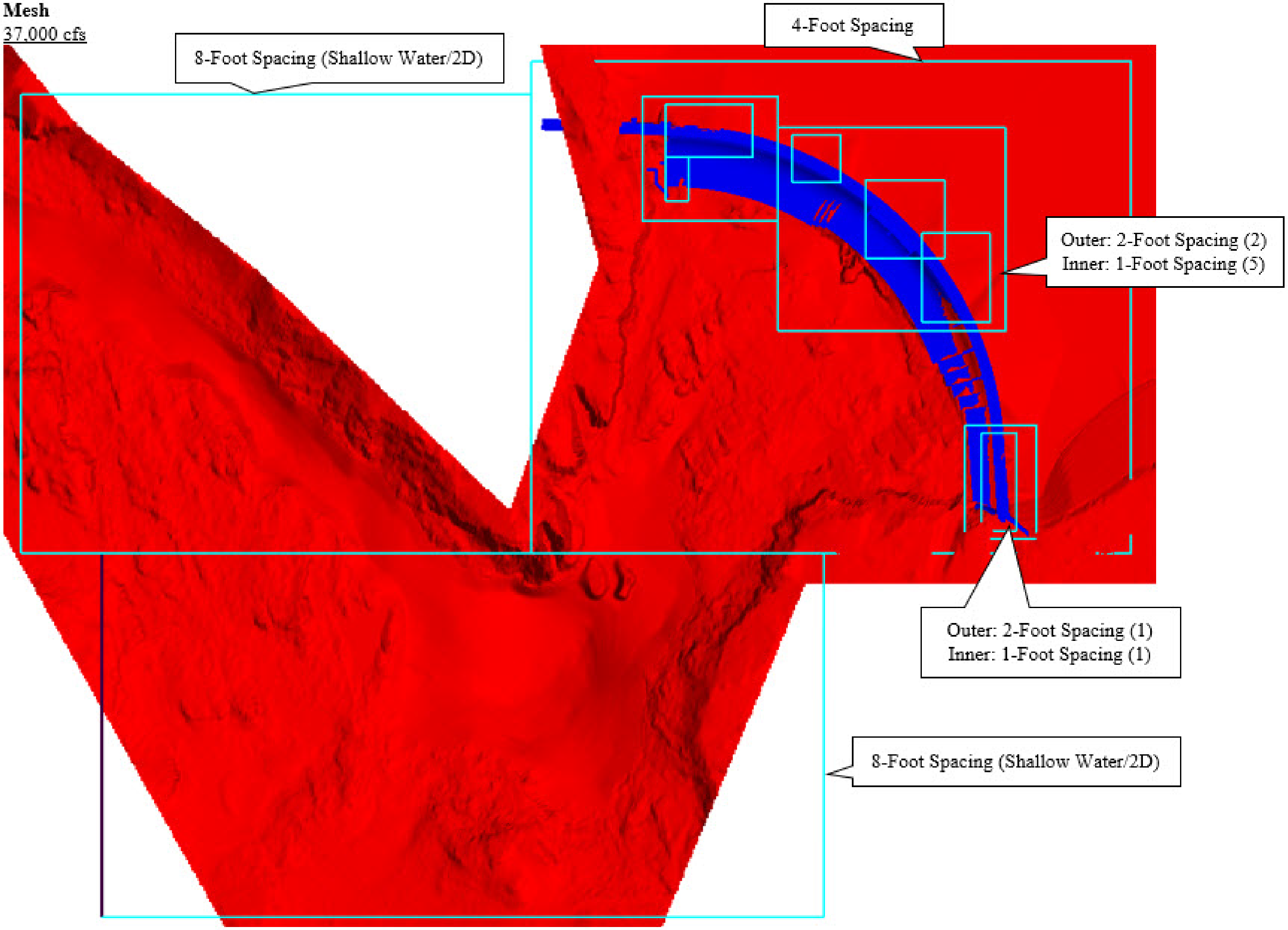


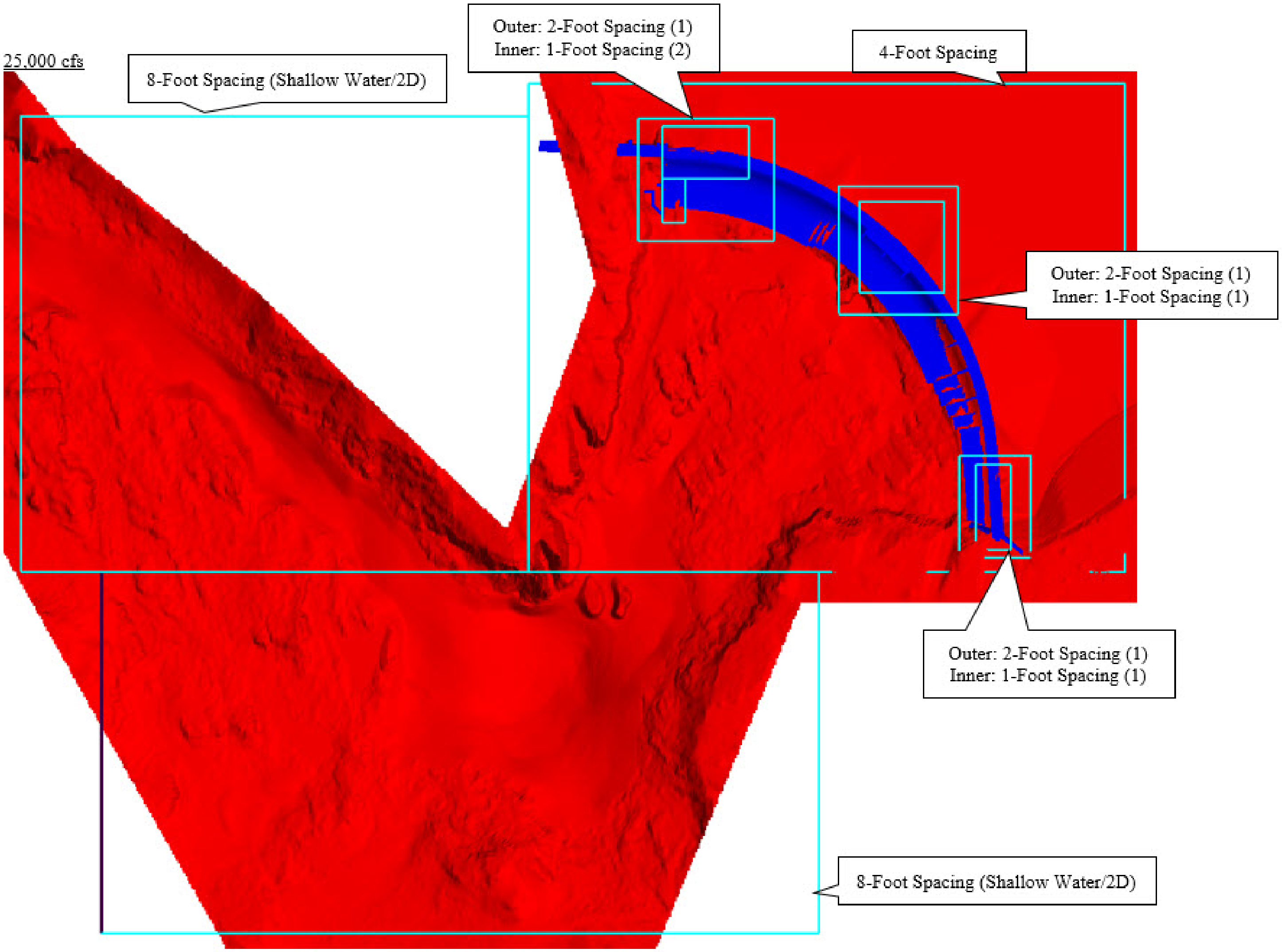
Terrain Component

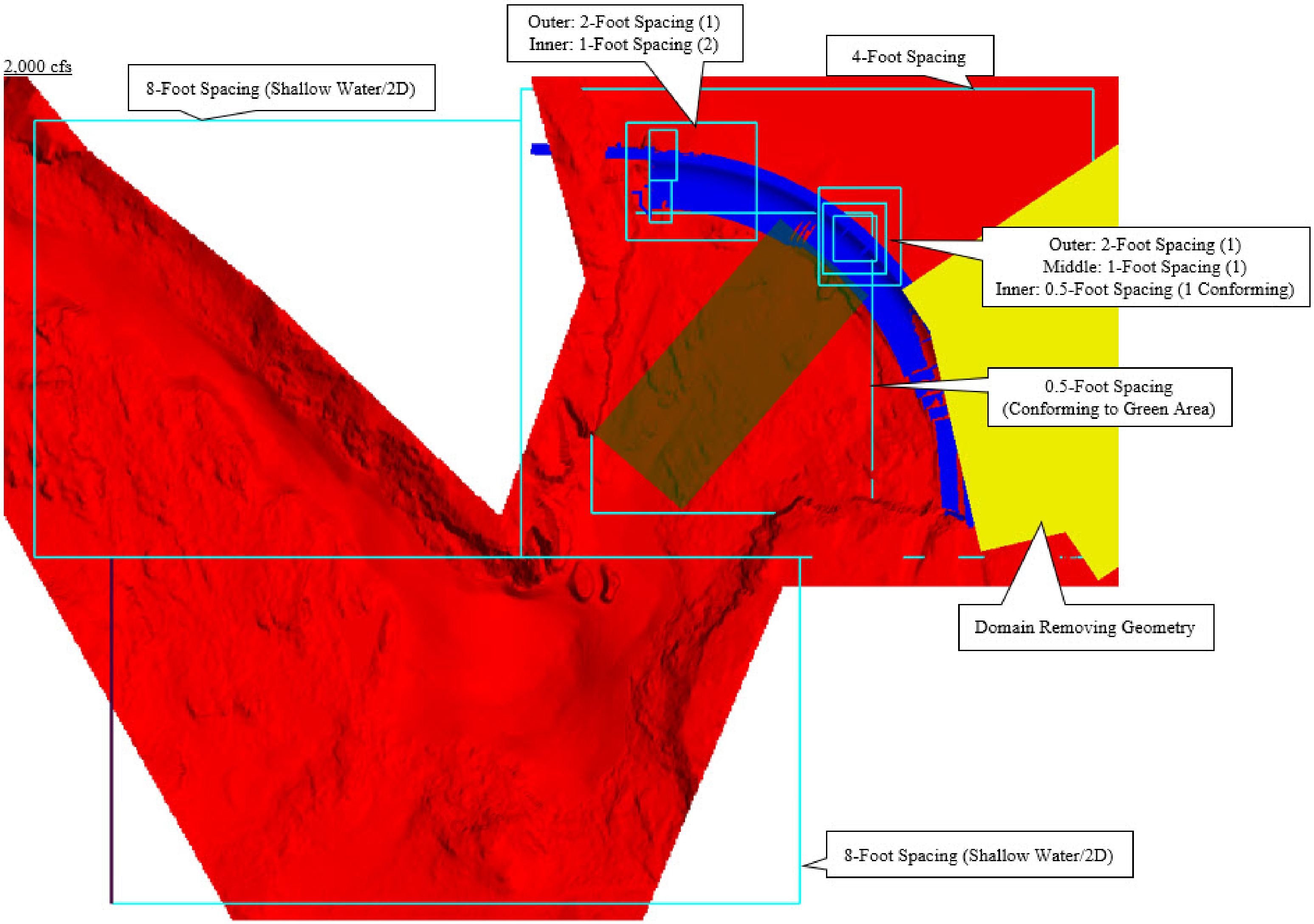


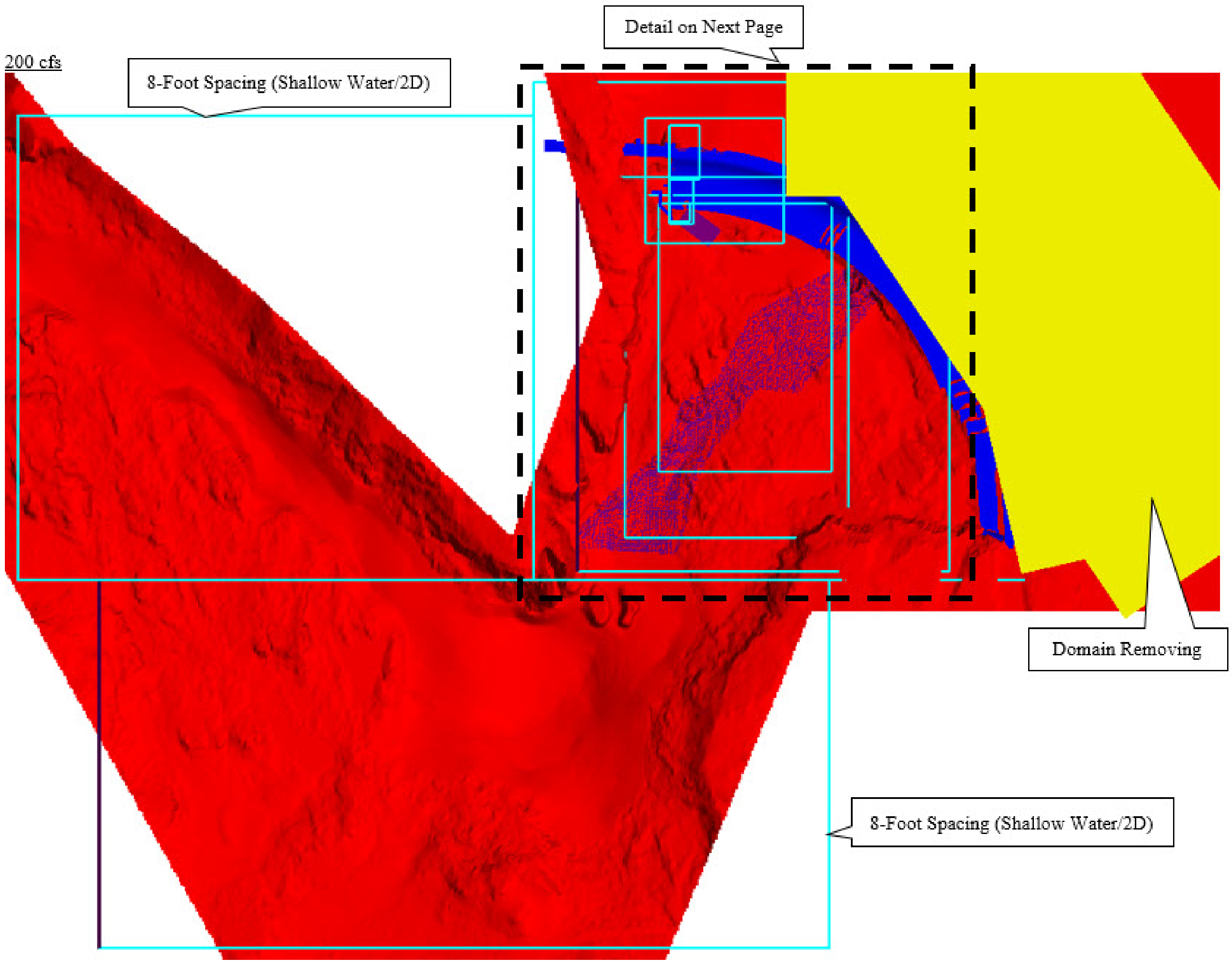

G

Mesh
37,000 cfs




25,000 cfs
8-Foot Spacing (Shallow Water/2D)
Outer: 2-Foot Spacing (1)
Inner: 1-Foot Spacing (2)
4-Foot Spacing
Outer: 2-Foot Spacing (1)
Inner: 1-Foot Spacing (1)
Outer: 2-Foot Spacing (1)
Inner: 1-Foot Spacing (1)
8-Foot Spacing (Shallow Water/2D)


2,000 cfs
8-Foot Spacing (Shallow Water/2D)
Outer: 2-Foot Spacing (1)
Inner: 1-Foot Spacing (2)
4-Foot Spacing
Outer: 2-Foot Spacing (1)
Middle: 1-Foot Spacing (1)
Inner: 0.5-Foot Spacing (1 Conforming)
0.5-Foot Spacing
(Conforming to Green Area)
Domain Removing Geometry
8-Foot Spacing (Shallow Water/2D)


200 cfs
8-Foot Spacing (Shallow Water/2D)
Detail on Next Page
Domain Removing
8-Foot Spacing (Shallow Water/2D)

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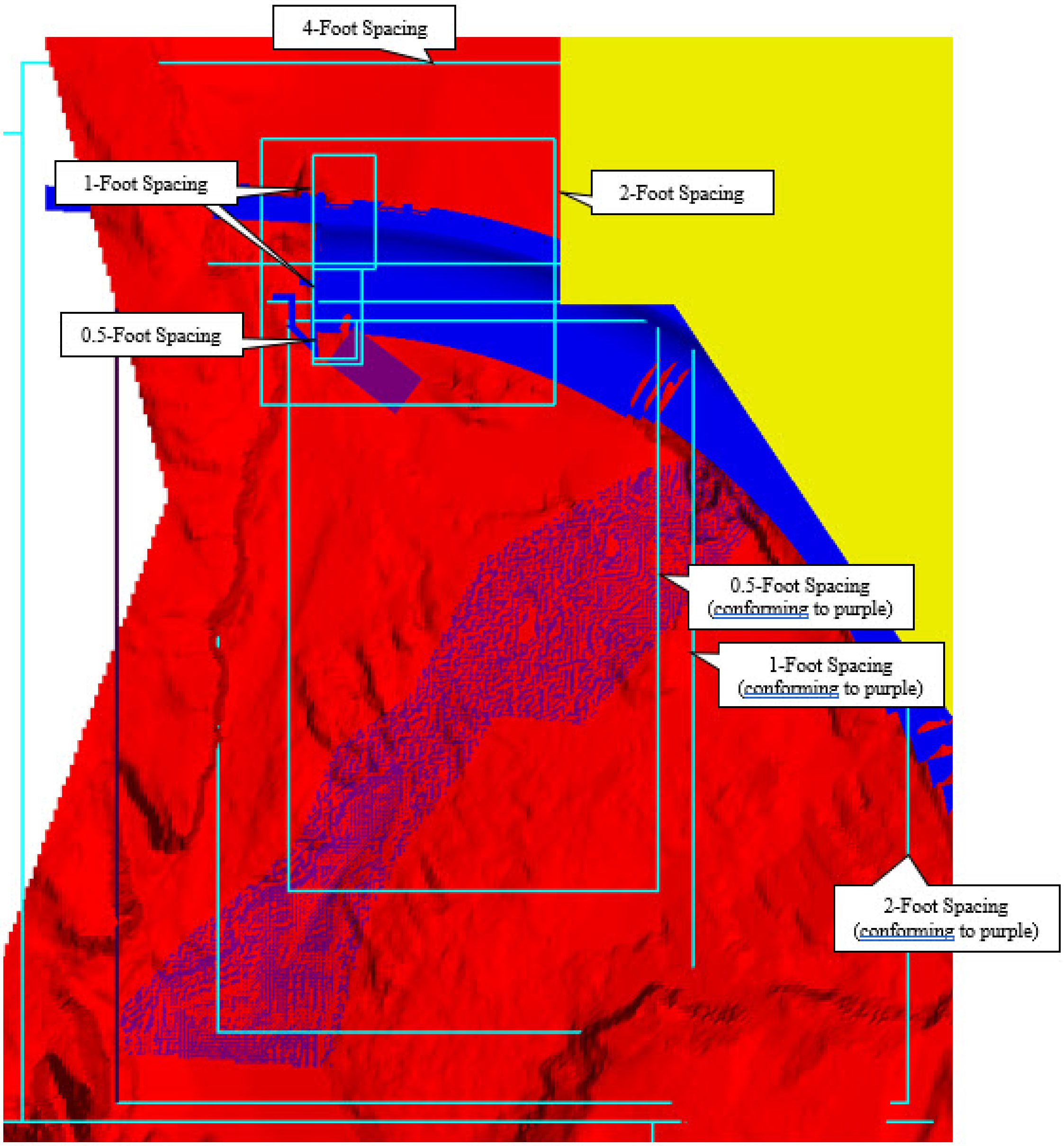
4-Foot Spacing
1-Foot Spacing
2-Foot Spacing
0.5-Foot Spacing
0.5-Foot Spacing (conforming to purple)
1-Foot Spacing (conforming to purple)
2-Foot Spacing (conforming to purple)

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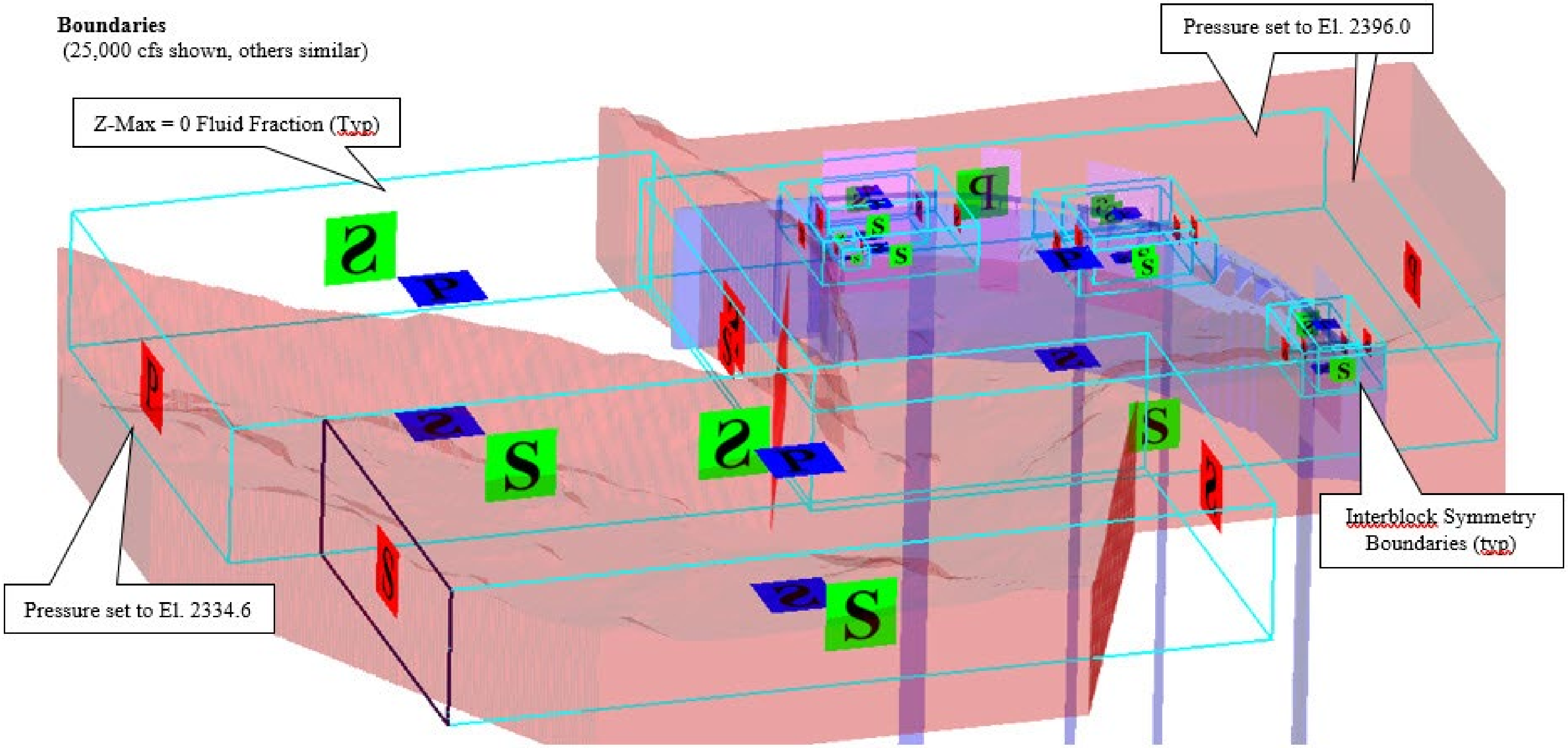
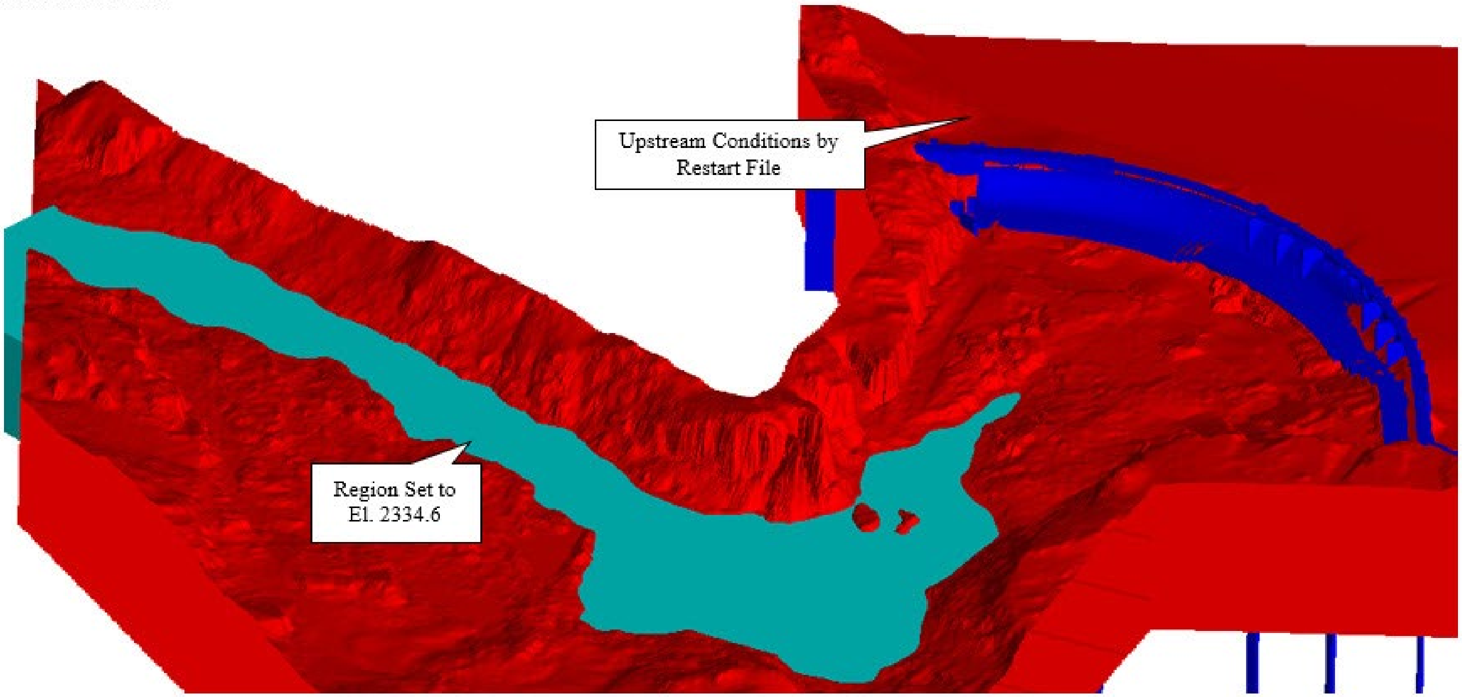
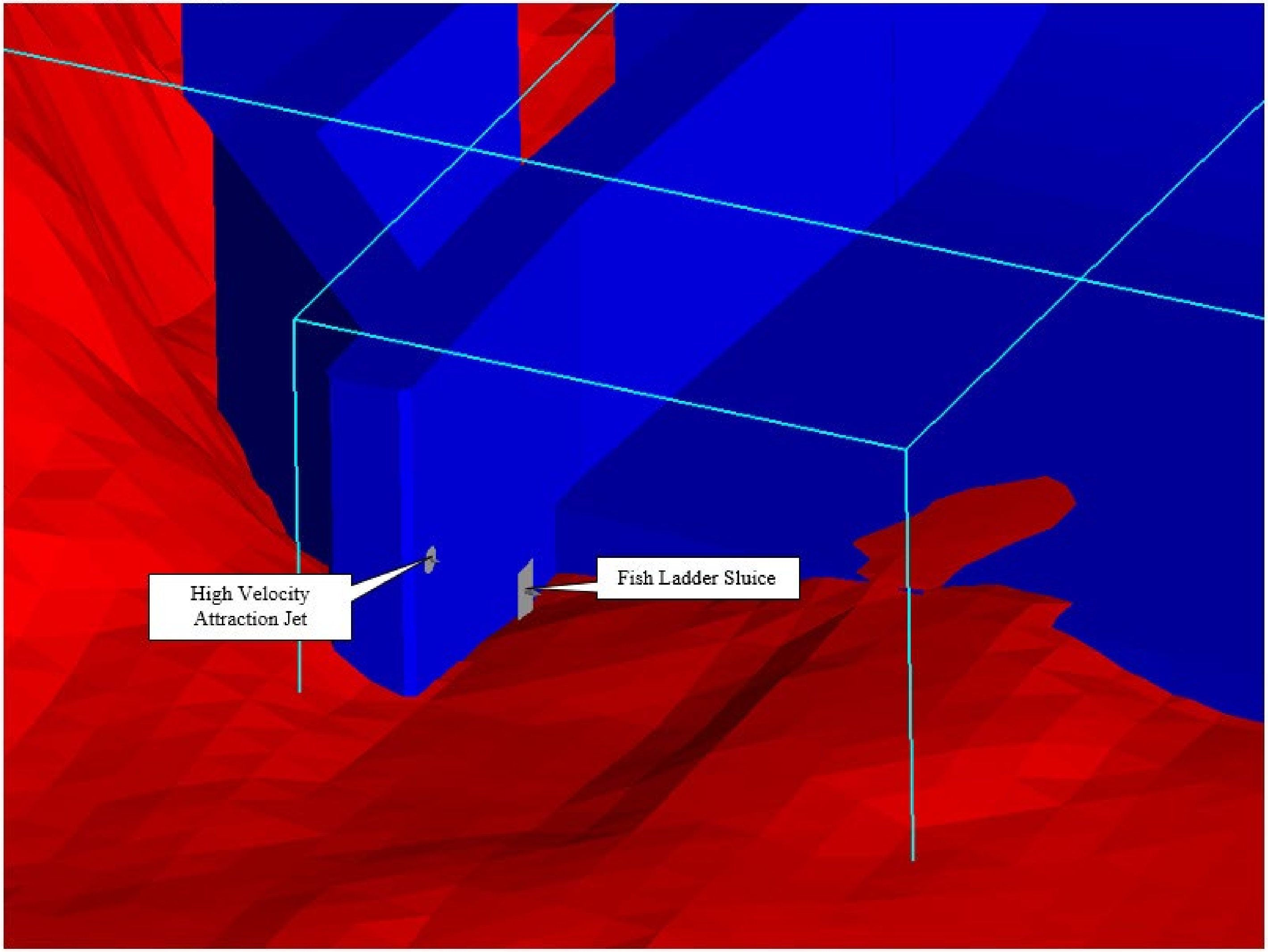


Boundaries
(25,000 cfs shown, others similar)
Z-Max = 0 Fluid Fraction (Typ)
Pressure set to El. 2396.0
Pressure set to El. 2334.6
Interblock Symmetry Boundaries (typ)

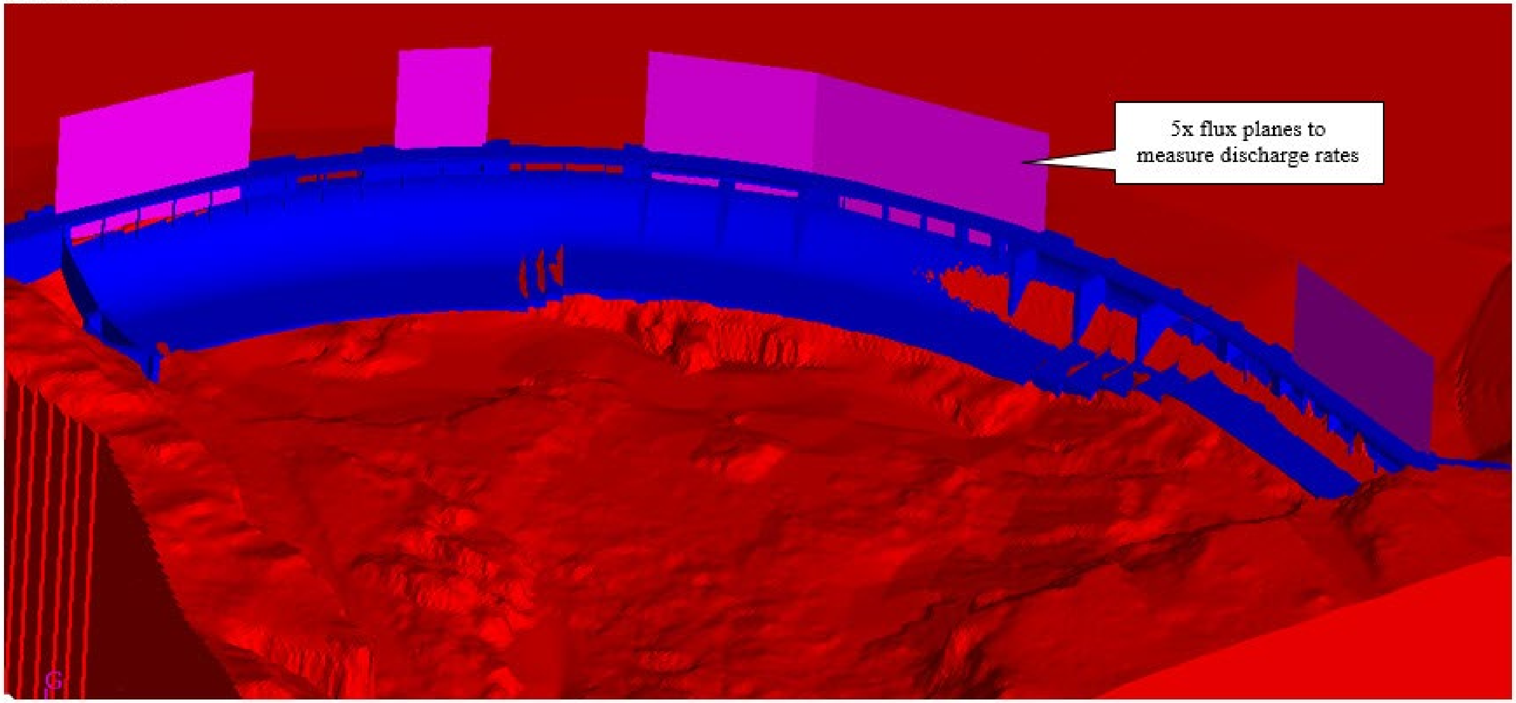
Initial Conditions



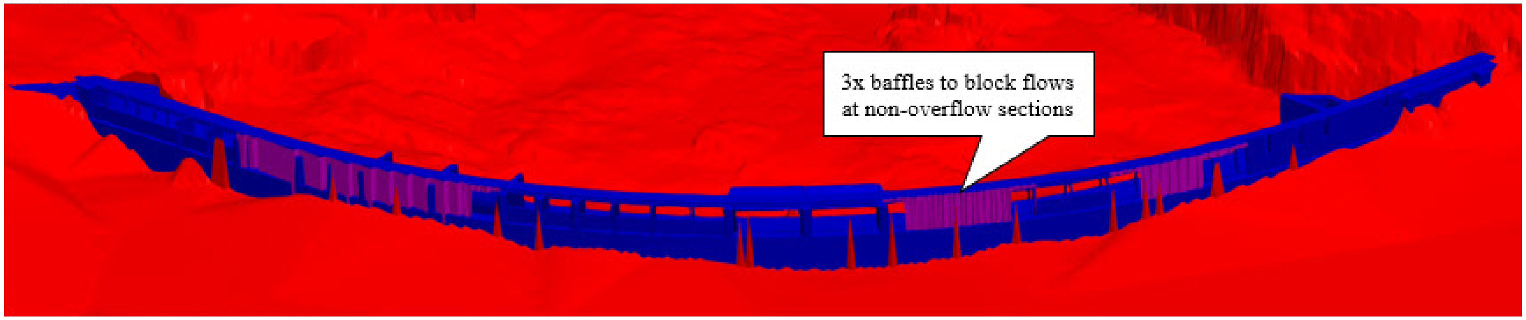
Mass Momentum Sources



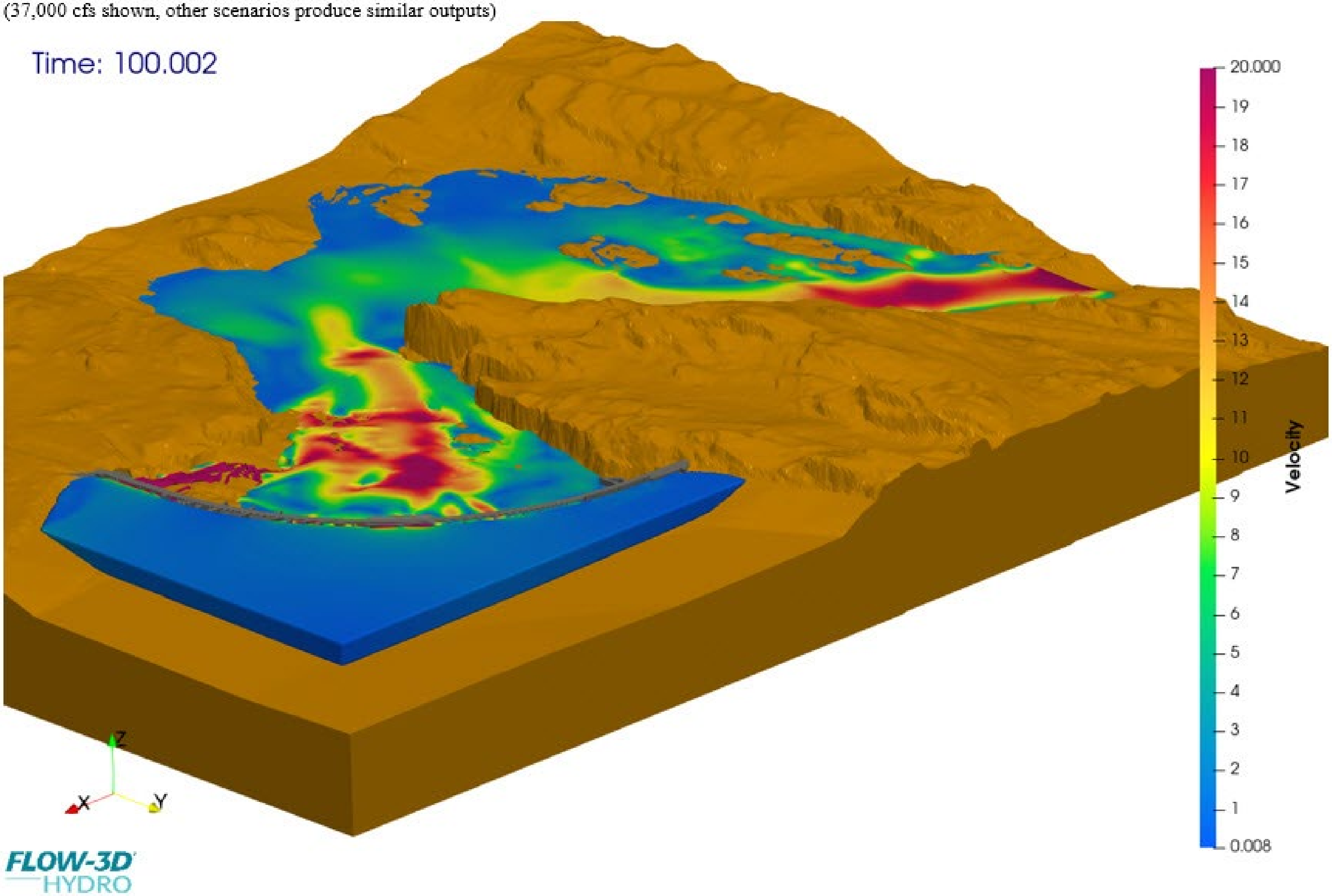
Flux Planes



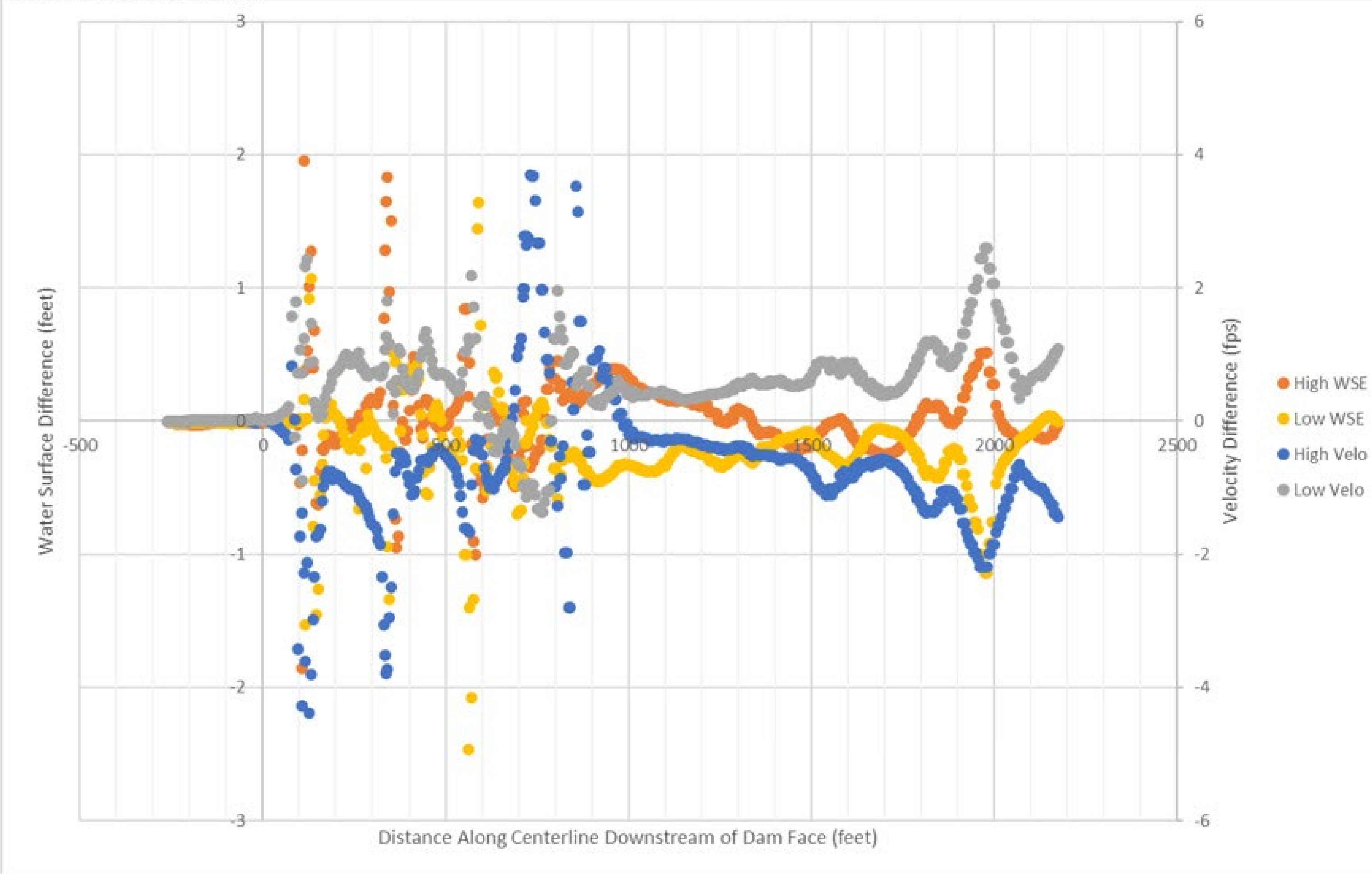
Flow Baffles



Isosurface Results
(37,000 cfs shown, other scenarios produce similar outputs)



Roughness Sensitivity Results



Turbulence Model Sensitivity