# Thompson Falls Hydroelectric Project
# FERC Project No. 1869

## Hydraulic Conditions Study – Final Study Report

Prepared by:
**NorthWestern Energy**
Butte, MT 59701

With Support From:
**GEI Consultants, Inc.**
Portland, OR 97202

May 2023

# Table of Contents



## List of Figures

## List of Tables



## List of Attachments

[This page intentionally left blank]

# List of Abbreviations and Acronyms

| | |
|---|---|
| 2D | two-dimensional |
| 3D | three-dimensional |
| BO | Biological Opinion |
| CAD | Computer Aided Design |
| CFD | computational fluid dynamics |
| cfs | cubic feet per second |
| DEM | digital elevation model |
| FERC | Federal Energy Regulatory Commission |
| FLOW 3D | FLOW-3D HYDRO software |
| fps | feet per second |
| FSR | Final Study Report |
| FWP | Montana Fish, Wildlife and Parks |
| FWS | U.S. Fish and Wildlife Service |
| High Bridge | bridge below the Main Channel Dam |
| HVJ | High Velocity Jet |
| ILP | FERC's Integrated Licensing Process |
| IBM | immersed boundary method |
| ISR | Initial Study Report |
| Ladder | Upstream Fish Passage Facility |
| Licensee | NorthWestern Energy |
| LiDAR | Light Detecting and Ranging |
| Main Dam | Main Channel Dam |
| NorthWestern | NorthWestern Energy |
| Project | Thompson Falls Hydroelectric Project |
| RNG | renormalized group |
| RTK-GPS | Real-Time Kinematic Global Positioning System |
| Scientific Panel | Thompson Falls Scientific Review Panel |
| 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 |

[This page intentionally left blank]

# 1.0 Introduction

The Thompson Falls Hydroelectric Project P-1869 (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) 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.

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[1] 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 Final Study Report (FSR) which is part of the Updated Study Report has been prepared to comply with NorthWestern's Revised Study Plan, filed April 12, 2021 (NorthWestern 2021), as approved in the FERC Study Plan Determination. This FSR provides results from the two-dimensional (2D) and three-dimensional (3D) modeling of the near field downstream of the Thompson Falls Project Main Channel Dam (Main Dam).

## 1.1 Hydraulic Conditions Study Background

Bull Trout (*Salvelinus confluentus*) were federally listed as a threatened species under the Endangered Species Act in 1998. A Biological Evaluation prepared in 2003 concluded the Project was likely adversely affecting Bull Trout. On November 4, 2008, the U.S. Fish and Wildlife (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) and the License amendment approving construction of the upstream fish passage facility (aka 'ladder') (FERC 2009) included a

[1] local, state, and federal governmental agencies, Native American Tribes, local landowners, non-governmental organizations, and other interested parties

requirement for the Licensee to conduct Phase 2 fish passage evaluation studies. At the end of the Phase 2 evaluation period (2011-2019), the Licensee was required to prepare a comprehensive report for filing with FERC. The Comprehensive Phase 2 Fish Passage Report (NorthWestern 2019) 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 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 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 ILP reporting requirements for this study by preparing an Interim Report. The Interim Report Hydraulic Conditions Study Report (NorthWestern 2022c) provided the results from the 2D modeling and made recommendations for the specific scenarios to model with the 3D modeling. The Interim Report was distributed to Montana Fish, Wildlife and Parks (FWP), the U. S. Forest Service (USFS), and the 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 Interim Report, answer questions, and invite comments on the recommendations for Phase 2 of this study. Comments were received from FWP, USFS, and FWS.

NorthWestern filed the Initial Study Report (ISR) with FERC on April 28, 2022 (NorthWestern 2022a). The ISR incorporated the Interim Report including comments received on the Interim Report, and NorthWestern's responses to those comments, which are found in Section 5 – Comments and Responses to Comments of the ISR (NorthWestern 2022a). On May 5, 2022, NorthWestern held an ISR meeting, where there was a presentation on the Hydraulic Conditions Study and an opportunity for Relicensing Participants to comment and ask questions. NorthWestern subsequently filed a study report meeting summary with FERC on July 9, 2022.

Under FERC regulations, 18 CFR[2] § 5.15(c)(4), any participant or FERC staff may file disagreements concerning the applicant's study report meeting summary, modifications to ongoing studies, or propose new studies within 30 days of the study report meeting summary being filed. NorthWestern received comments on several studies from Relicensing Participants, including proposed modifications to the Hydraulic Conditions Study.

On August 8, 2022, NorthWestern filed a response to the comments received on the ISR, proposing to conduct one additional study and modify one study, but declining to adopt the requested modifications to the Hydraulic Conditions Study.

On September 1, 2022, FERC issued its determination on requests for study modifications. Modifications to the Hydraulic Conditions Study requested by Relicensing Participants were not approved.

This FSR includes the results of the Hydraulic Conditions Study, conducted as described in NorthWestern's Revised Study Plan (NorthWestern 2021), as approved in the FERC Study Plan Determinations issued May 10, 2021 and September 1, 2022. This FSR includes the results provided in the ISR, as well as additional modeling results collected in the second year of study using a full 3D model through the dam and downstream channel.

## 1.2 Goals and Objectives of Study

The goals of the Hydraulic Conditions Study were 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.

[2] CFR= Code of Federal Regulations

[This page intentionally left blank]

# 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 (**Figure 2-1)**. The study area for the Hydraulic Conditions Study generally includes a portion of the reservoir immediately upstream of the Main Dam, the Main Dam, and the channel downstream of the Main Dam to 500 feet downstream of the High Bridge (**Figure 2-2)**. Site photographs of the Main Dam and the area immediately downstream are shown in **Figure 2-3**.

## 2.2 Study Methods

The Hydraulics Conditions Study included developing a computational fluid dynamics (CFD) model of the existing Thompson Falls Main Dam and river downstream of the dam. The CFD model included developing a 3D digital terrain of the dam and river using a combination of available digital elevation models (DEMs) and manually collected downstream bathymetric data. The Interim Report Hydraulic Conditions Study Report (NorthWestern 2022c) provided the results from the 2D modeling and made recommendations for the specific flow scenarios to model with the 3D modeling. The 3D modeling flow scenarios proposed in the Interim Report were reviewed and commented on by FWP, the USFS, and the FWS. Based on that consultation, the agreed-upon flow scenarios were set as the simulation inputs and hydraulic conditions to be evaluated. The model configuration and parameters were set up to perform the hydraulic simulations and the results were post processed to evaluate the hydraulic conditions in the downstream channel. Information on fish swimming speeds (reported in the Fish Behavior ISR, NorthWestern 2022b) were used to assess how modeled flows at critical locations in the study area might affect fish passage given fish swimming capability.

The methods used to perform each of these tasks are described in the following sections of the report.

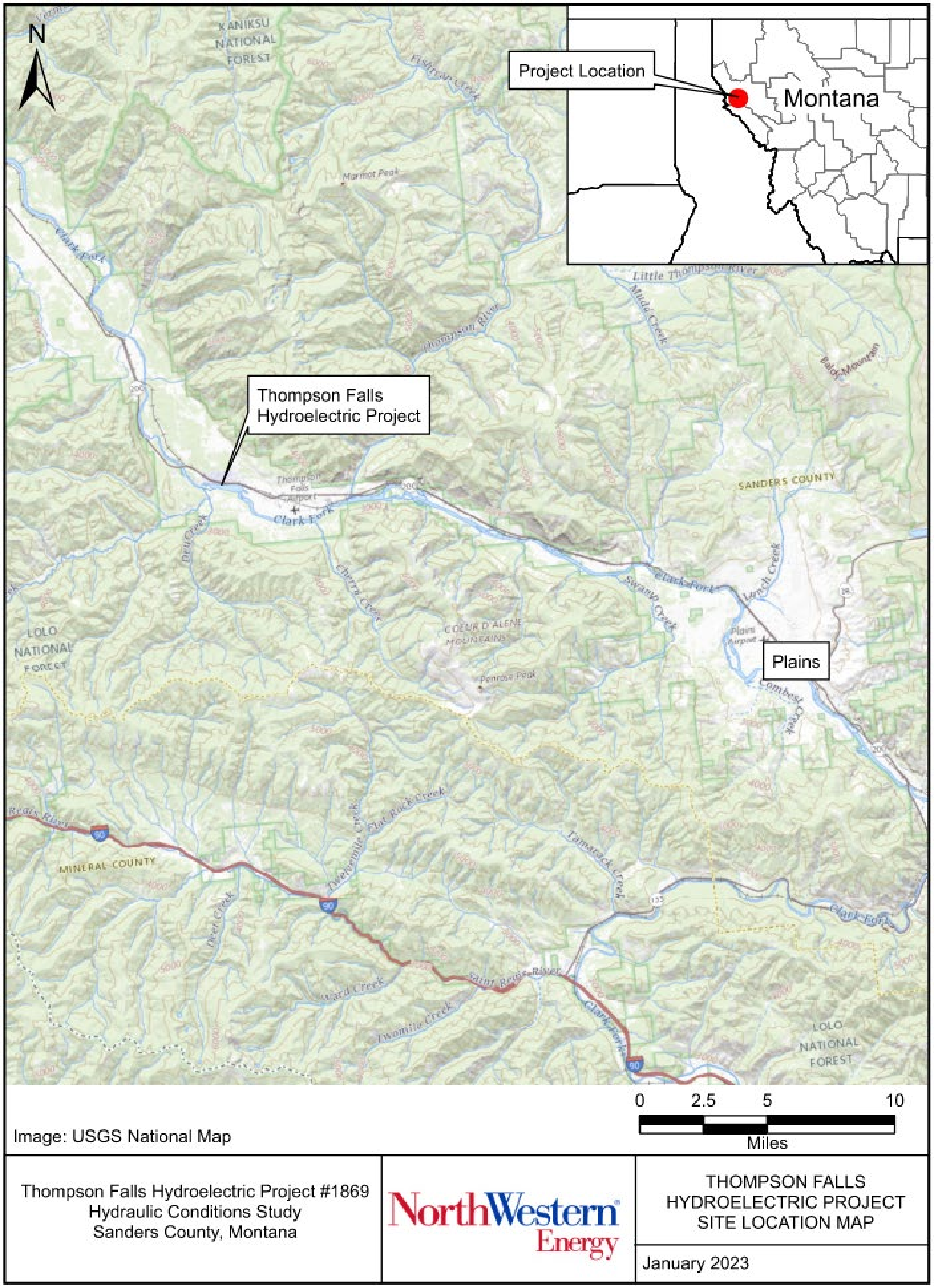
### *2.2.1 Task 1 – Bathymetric Surveying*

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 DEM of the Main 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 using a traditional rod method to supplement the collected data within the pools immediately downstream of the Main 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.). The 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**



[This page intentionally left blank]

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


| | | | |
|---|---|---|---|
| Photo: NorthWestern Energy | Thompson Falls Hydroelectric Project #1869<br>Hydraulic Conditions Study<br>Sanders County, Montana | NorthWestern Energy | THOMPSON FALLS HYDROELECTRIC PROJECT GENERAL SITE PLAN<br>January 2023 |

Document Path: https://geiconsultant-my.sharepoint.com/personal/nmiller_geiconsultants_com/Documents/Desktop/Desktop Files/Thompson Falls/[TFallsFigures.xlsx]Figure2

**Figure 2-3. Thompson Falls Main 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).

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

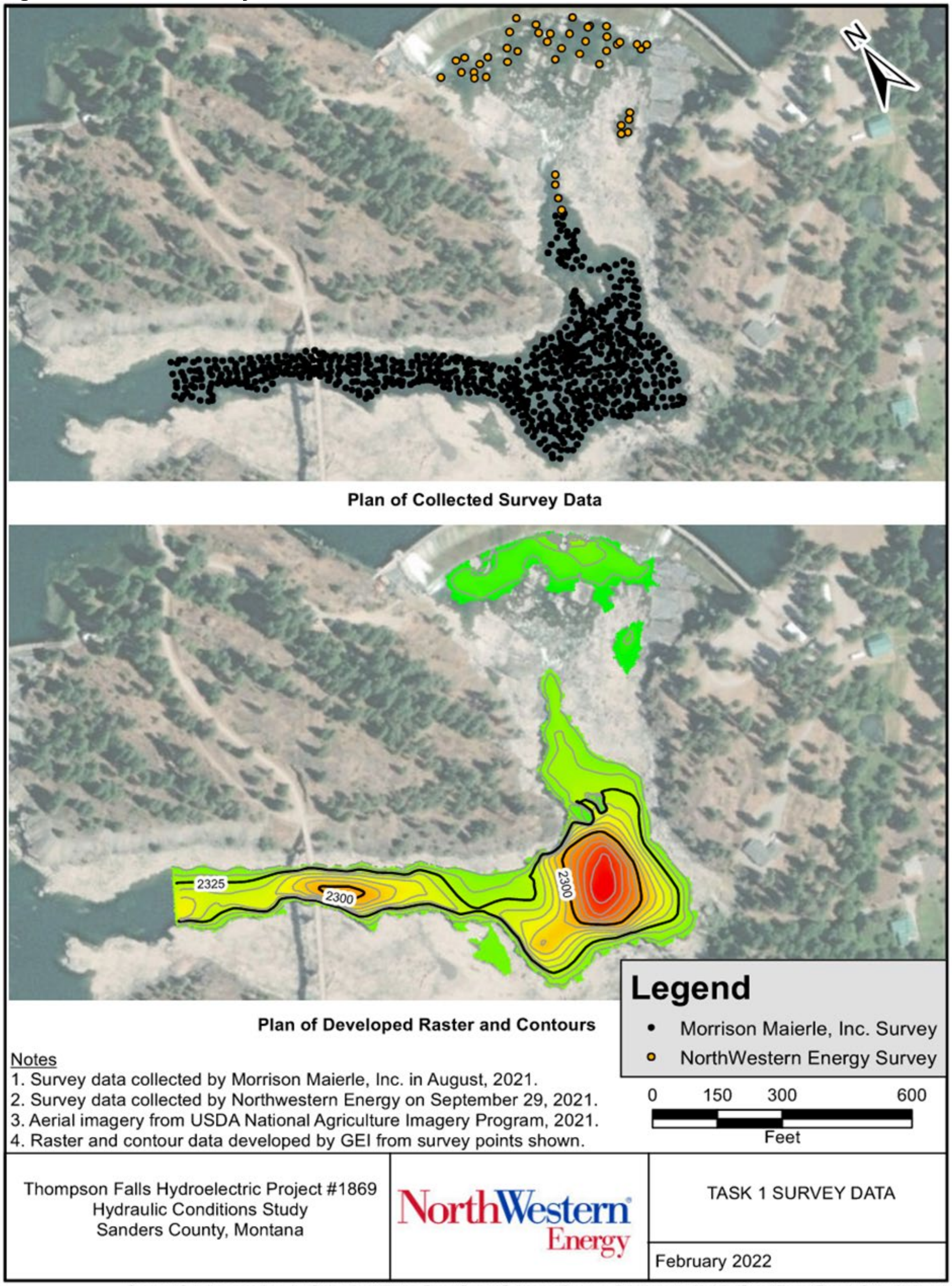
NorthWestern Energy

THOMPSON FALLS
MAIN CHANNEL DAM
SITE PHOTOS

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 2-4. Task 1 Survey Data**




Document Path: \\ore-pzcc-1\ore-data\Projects\NorthWestern Energy\Projects\Relicensing Thompson Falls\Hydraulics Modeling\Report\Figures\Figure4 - Bathy_85x11.mxd

### 2.2.2 Task 2 – Hydraulic Modeling

#### 2.2.2.1 Overview of Modeling Approach

A CFD model was developed of the existing Thompson Falls Main Dam and river downstream of the dam using FLOW-3D HYDRO software (FLOW 3D) (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 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. FLOW-3D solves the Reynolds-Averaged Navier-Stokes equations using a finite volume method and the flow surface is determined using a Volume of Fluid method.

The CFD model included the Main Dam, portions of the reservoir immediately upstream of the Main Dam, and the channel downstream of the Main Dam. The model extended to approximately 500 feet downstream of the High Bridge.

The hydraulic modeling involved two phases. The first phase used 2D simulations to provide depth averaged velocities at four flow scenarios (**Table 2-1**), ranging from 200 to 37,000 cubic feet per second (cfs). The modeling scenarios were developed to determine the flow behavior and resulting downstream flow conditions over the range of operating conditions for the upstream fish passage facility.

The USGS Gage 12389000 Clark Fork Near Plains MT is located approximately 30 river miles upstream of Thompson Falls Dam. This gage provided context for the modeled flows and how they relate to previously observed conditions at the dam. **Figure 2-5**. USGS Gage 12389000 Clark Fork Near Plains MT Flow Exceedance Curve 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.

**Table 2-1. Summary of CFD Modeling Scenarios**

| Run | Modeled Spill over Main 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

These data were then used to identify specific locations in the river channel for the second phase of hydraulic modeling using 3D simulations. During Phase 2, the full model domain was analyzed using 3D modeling to better evaluate the vertical velocity distributions of flow downstream of the Main Dam. Additional evaluations during Phase 2 of the study evaluated 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.

[This page intentionally left blank]

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

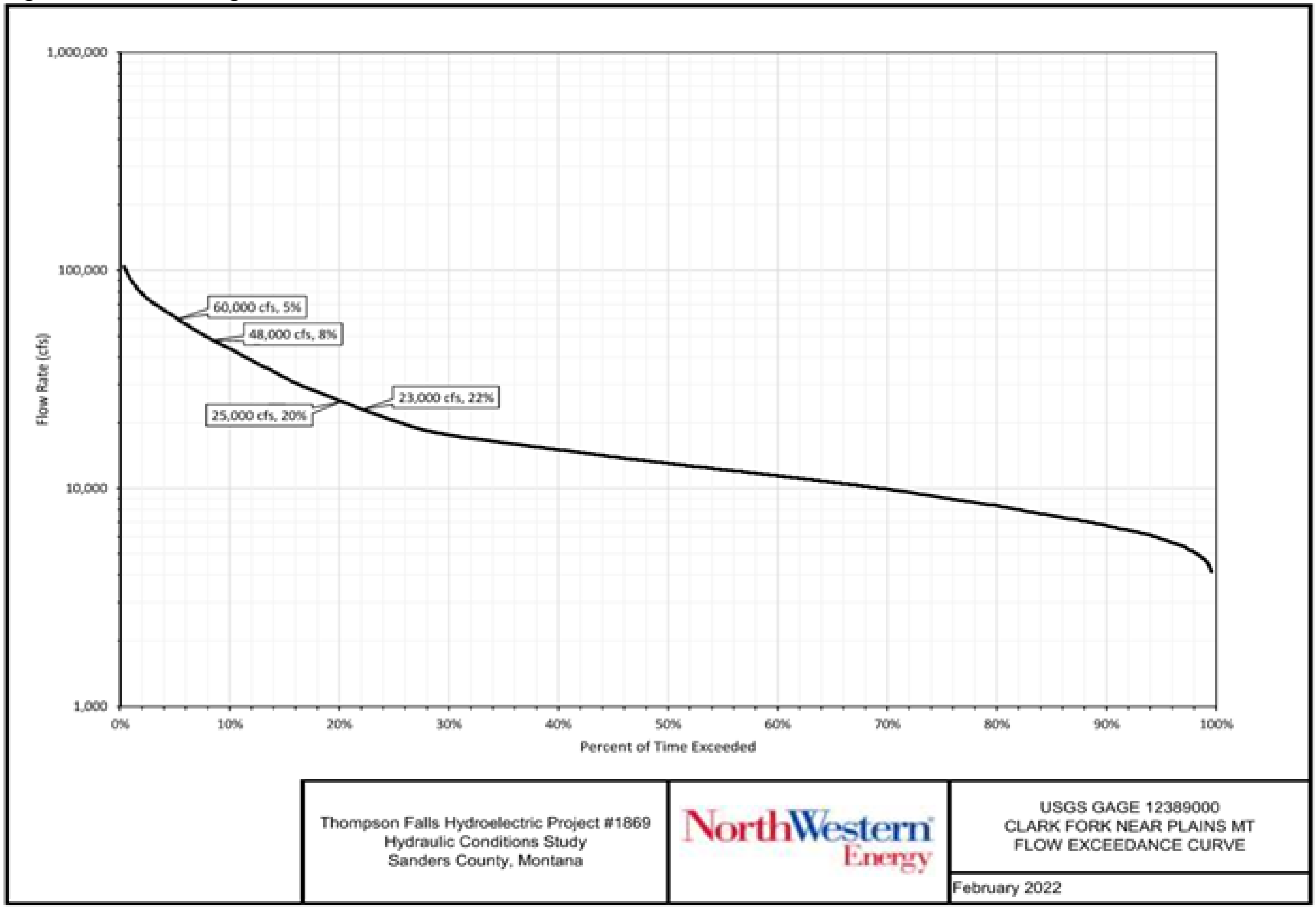
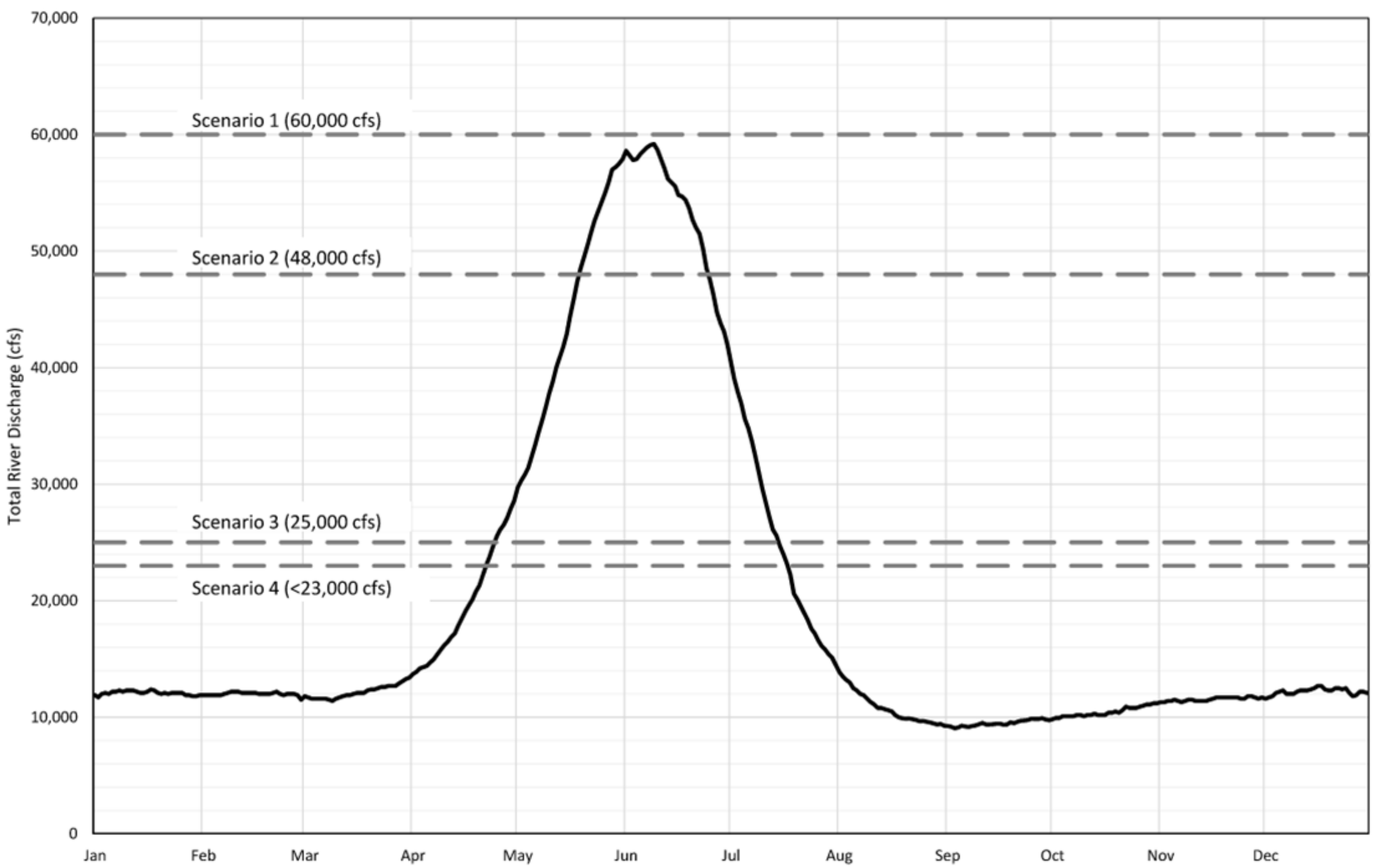


**Figure 2-6. USGS Gage 12389000 Clark Fork Near Plains MT Average Annual Hydrograph**




| Thompson Falls Hydroelectric Project #1869<br>Hydraulic Conditions Study<br>Sanders County, Montana | NorthWestern Energy | USGS GAGE 12389000<br>CLARK FORK NEAR PLAINS MT<br>AVERAGE ANNUAL HYDROGRAPH<br>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)

#### 2.2.2.2 Phase 1 Hydraulic Modeling

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 of the Main Dam were compared to empirical equations and 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. This approach allowed for various model parameters and setup options to be evaluated such as physics modules and boundary conditions before performing the final simulations. The final modeling scenarios described below are the culmination of this model development process.

The results presented in **Section 3 – Results** focus on characterizing the velocity and depth of the resulting flow regimes in those areas considered to be most applicable to fish behavior and passage.

***Development of Terrain for CFD Model***

To develop the terrain for the CFD model, several different sources were used. The bathymetry data collected during Task 1 of this study were supplemented with publicly available LiDAR from the U.S. Army Corps of Engineers and traditionally collected survey data collected by NorthWestern. Additionally, as-built drawings of the Main Dam and Upstream Fish Passage Facility were used to develop geometry for the discharge structures. Additional information regarding the Main Dam is provided in the Supporting Technical Information Document (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 Dam discharge of approximately 26,800 cfs in May 2021. The terrain data and spillway geometries were used to develop the mesh-generated FAVOR[3] geometry in the CFD model. **Figure 2-9** shows a comparison of the terrain data and the CFD geometry.

[3] 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.

### *Model Domains and Mesh Configurations*

Due to the range of flow rates evaluated, 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**.

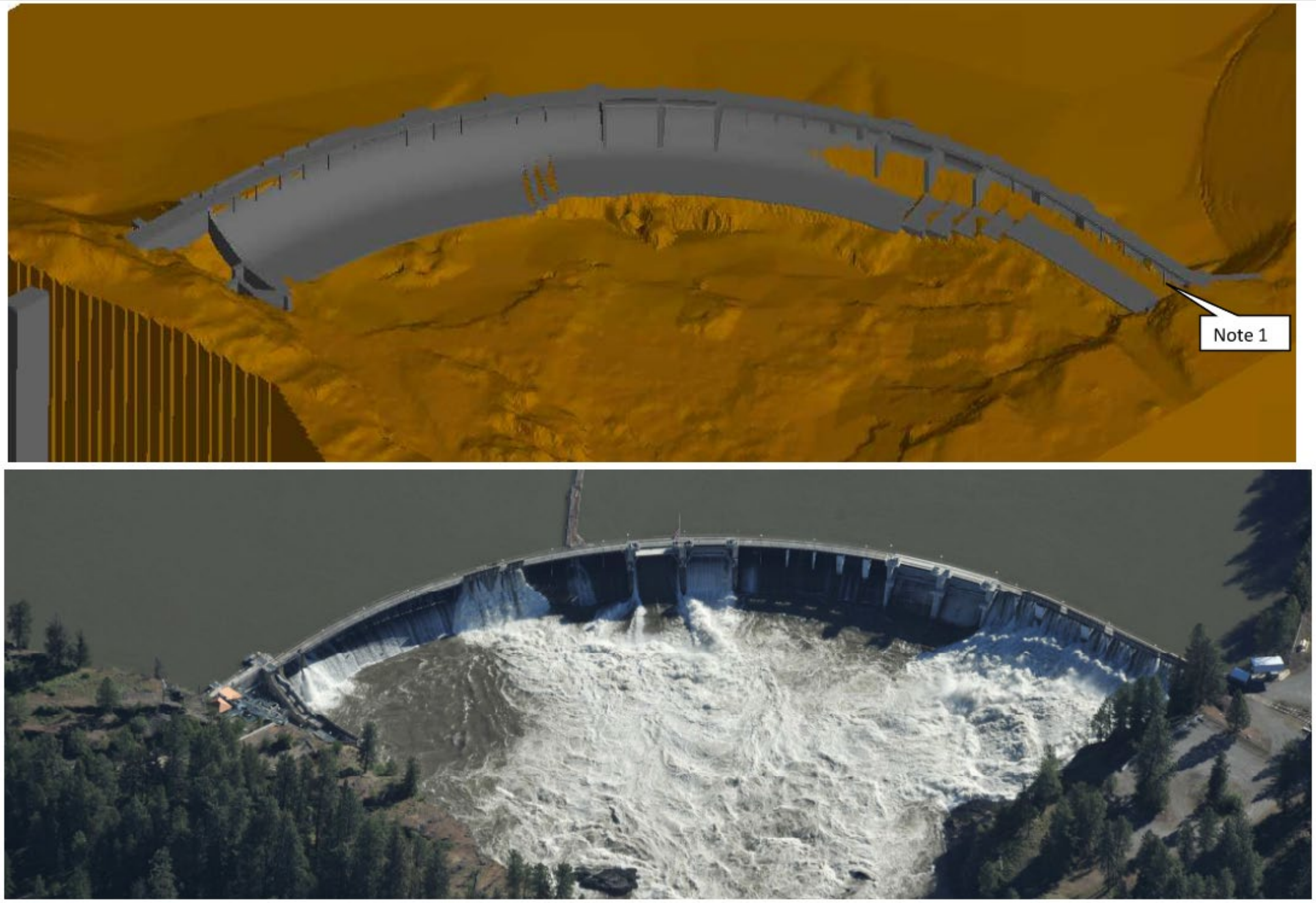
**Table 2-2. Summary of Phase 1 CFD Modeling Domains**

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

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

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 when the fluid depth is much less than the fluid extents in other directions and  for large-scale simulations (Flow Science 2022). The general configuration and spatial extents of the model mesh are 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 improve computation efficiency of the FLOW-3D solver. Additional details of the domain removing blocks and mesh configurations are provided in Attachment B.

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




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

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

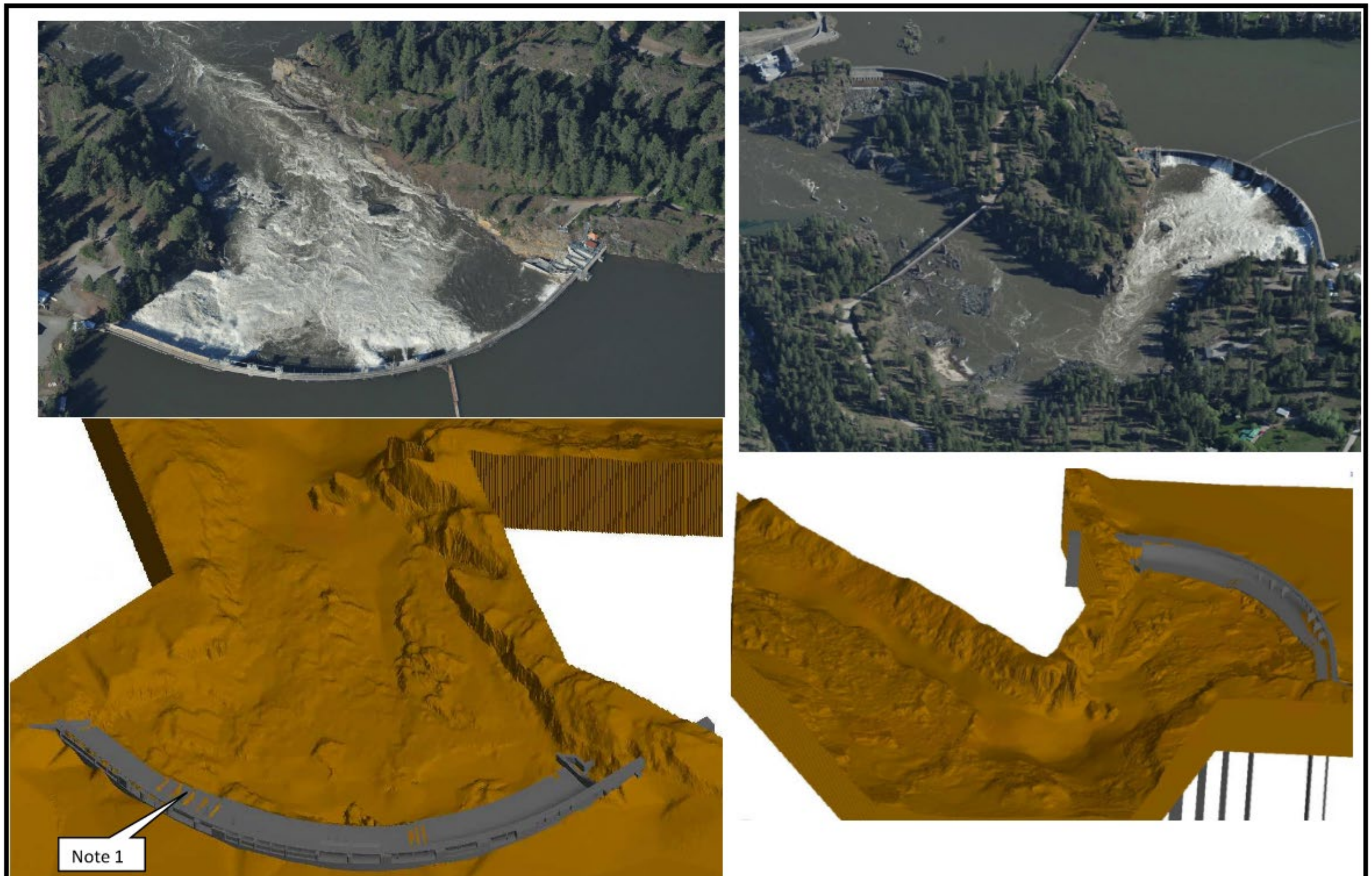
NorthWestern Energy

CFD MODEL - CAD GEOMETRY
(1 OF 2)

February 2022

Document Path: \\ore-pzcc-1\ore-data\Projects\NorthWestern Energy\Projects\Relicensing Thompson Falls\Hydraulics Modeling\Report\Figures\[TFallsFigures.xlsx]Figure 6b

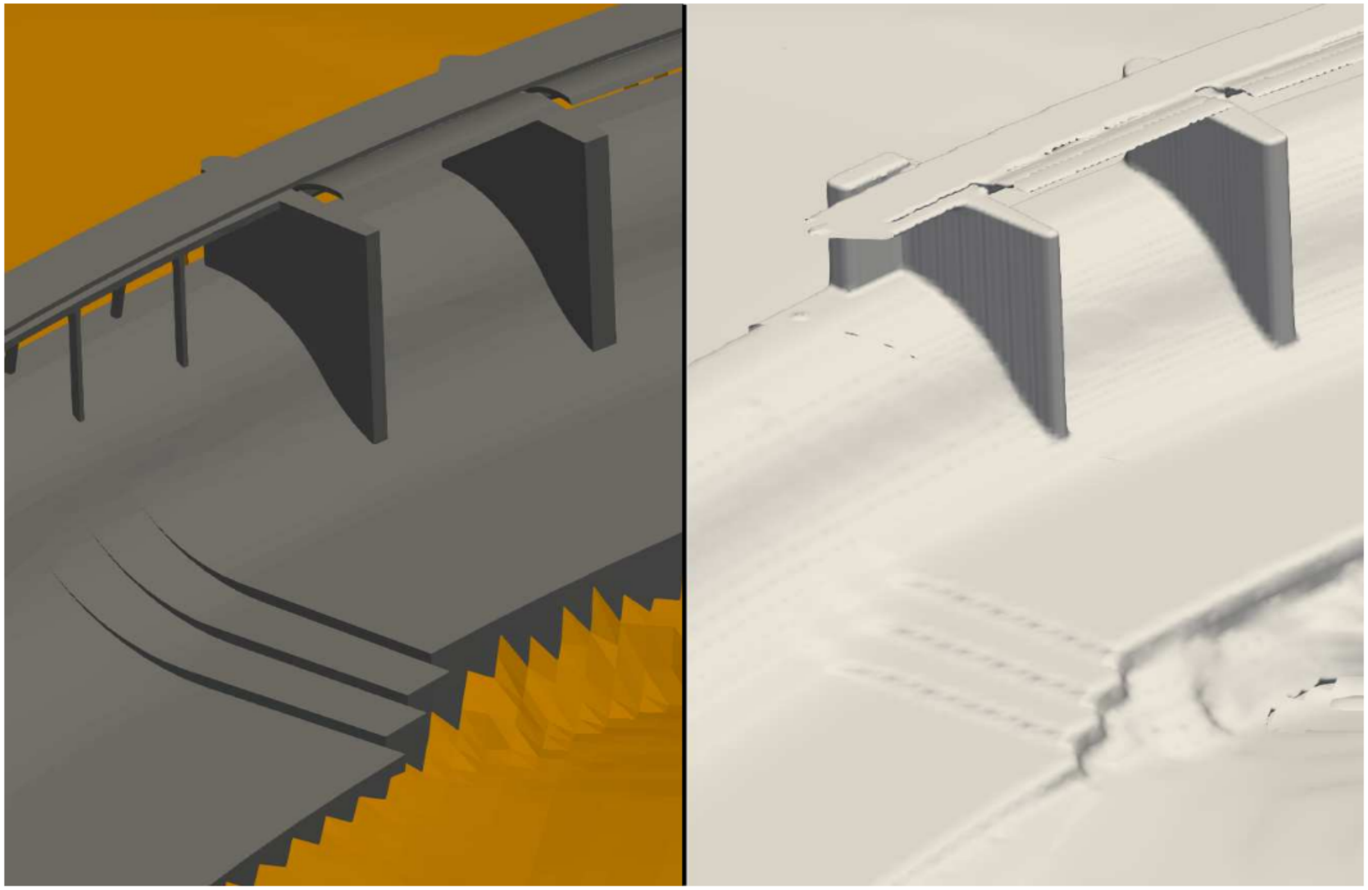
**Figure 2-8. CFD Model – CAD Geometry (2 of 2)**




| Notes<br>1. Terrain edits to remove topography from spillway structure not shown. | Thompson Falls Hydroelectric Project #1869<br>Hydraulic Conditions Study<br>Sanders County, Montana | NorthWestern Energy | CFD MODEL - CAD GEOMETRY<br>(2 OF 2)<br><br>February 2022 |
|---|---|---|---|

Document Path: \\ore-pzcc-1\ore-data\Projects\NorthWestern Energy\Projects\Relicensing Thompson Falls\Hydraulics Modeling\Report\Figures\[TFallsFigures.xlsx]Figure 6b

**Figure 2-9. CFD Model – FAVOR Surface Comparison**



CAD Geometry

FAVOR Surface

Notes

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

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

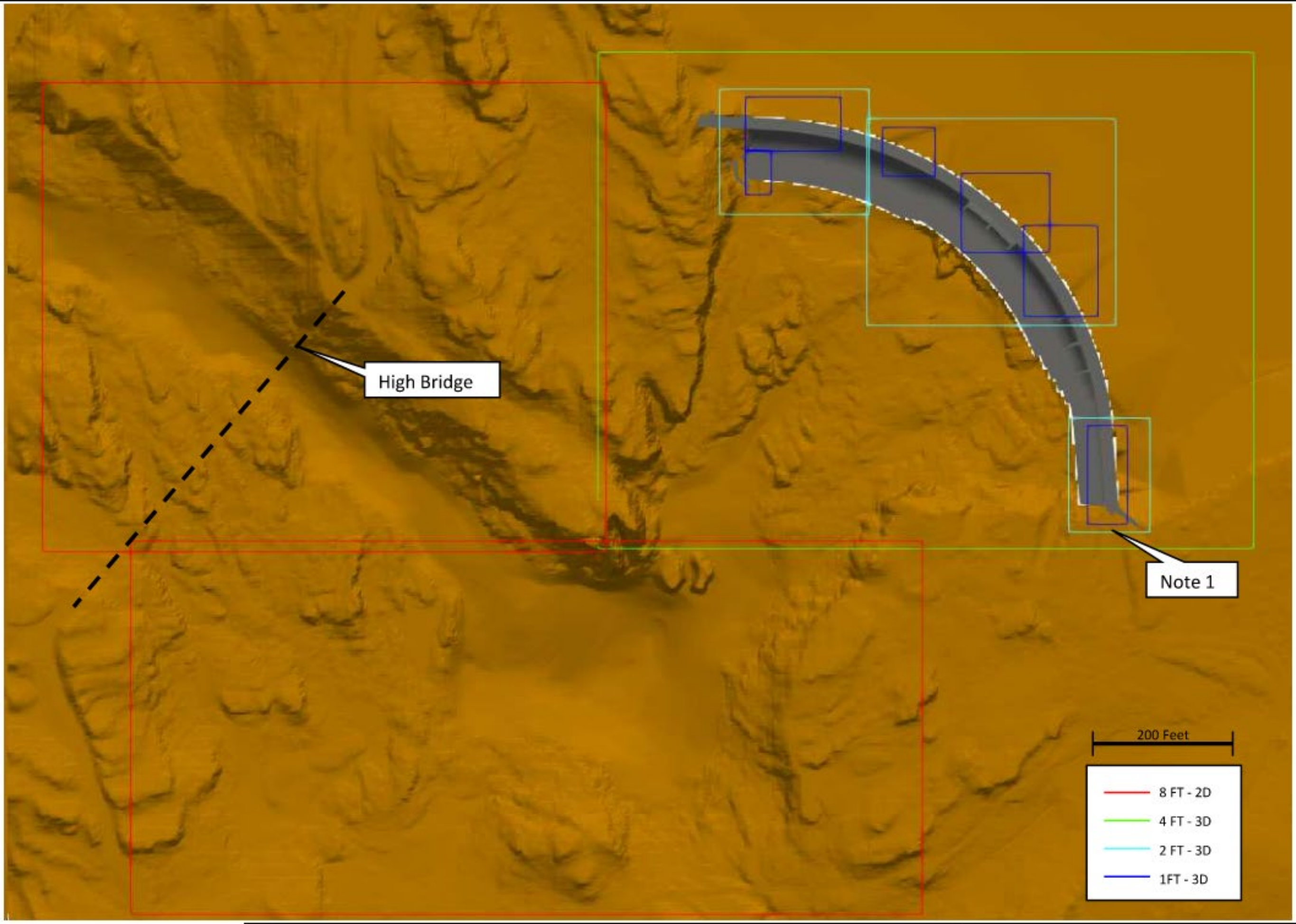
NorthWestern Energy

CFD MODEL - FAVOR SURFACE COMPARISON

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 2-10. Phase 1 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.

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

NorthWestern Energy

CFD MODEL - MESH LAYOUT

February 2022

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

#### *Modeling Parameters*

While developing the model for the Main Dam, parameters within the FLOW-3D software were selected to best suit the high velocity flow through the dam structures and turbulent conditions downstream of the Main 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 can accurately model flows that have strong shear regions (Flow Science 2021).

A sensitivity analysis of the 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 can 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, several solver diagnostic variables were 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 this 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 appropriate for the concrete and natural rock channel surfaces, respectively. 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**.

#### *Modeling Scenarios and Flow Distribution*

To produce each of the target flow rates, different combinations of gate and panel openings on the Main Dam were used for each scenario. In general, these opening configurations were developed in accordance with Project operations as defined in the Total Dissolved Gas (TDG) Plan (PPL Montana 2010). The Upstream Fish Passage Facility is equipped with an auxiliary water system which adds attraction water to the lower ladder, by discharging through one of the fishway entrances into the tailrace (**Figure 2-11**). In addition, the Upstream Fish Passage Facility is equipped with a High Velocity Jet (HVJ) which is designed to discharge 20 cfs through a 14-inch-diameter orifice, producing a discharge jet velocity of approximately 19 feet per second (fps) into the tailrace.

Except for the eight bays which contain the four radial gates, each of the 38 bays at the Main 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 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, a half panel is removed from Bay 1. A half panel is 4 feet wide but is only 4 feet tall.

**Figure 2-11. Looking Downstream from Main Dam, Upstream Fish Passage Facility on Right, With Auxiliary Water Supply and HVJ**

The details of the opening configurations for each scenario are provided in **Table 2-3**. In addition to the flow rates summarized below, the original Powerhouse and new Powerhouse are 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 Dam Flow |
|---|---|---|---|---|---|---|
| 1 | 80 cfs | 1/2 Panel (120 cfs) | Full Open (17,500 cfs) | Closed | 3-5 : 1<br>10, 11 : 6<br>20-25 : 6<br>34 : 5<br>35-38 : 6<br>(19,300 cfs) | 37,000 cfs |
| 2 | 80 cfs | 1/2 Panel (120 cfs) | Full Open (17,500 cfs) | Closed | 3-5 : 1<br>20 : 2<br>35-38 : 6<br>(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). These differences largely can be attributed to variations in panel width due to the locations of the different pier sizes 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.

#### 2.2.2.3 Phase 2 Hydraulic Modeling

The Phase 2 hydraulic modeling was performed with the full model domain evaluated in three dimensions. The hydraulic model included the same 3D mesh blocks as Phase 1 of the study and replaced the 2D modeling meshes in downstream channel with new meshes of 3D cells. The new 3D mesh blocks were made up of 4-foot cells. The general configuration and spatial extents of the model mesh are shown in **Figure 2-12**. All model scenarios began with a 3D mesh volume of approximately 107 million cubic feet. Due to the range of flow rates evaluated, 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 2-4**.

**Table 2-4. Summary of Phase 2 CFD Modeling Domains**

| Run | Target Flow Rate | Mesh Blocks and Cell Spacing | Total Cell Count |
|---|---|---|---|
| 1 | 37,000 cfs | 6 Blocks @ 1 foot<br>3 Blocks @ 2 feet<br>1 Block @ 4 feet<br>2 Blocks @ 4 feet | 7,964,767 |
| 2 | 2,000 cfs | 1 Conforming Block @ 0.5 foot<br>3 Blocks @ 1 foot<br>3 Blocks @ 2 feet (1 conforming)<br>1 Block @ 4 feet<br>2 Blocks @ 4 feet | 8,274,027* |

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

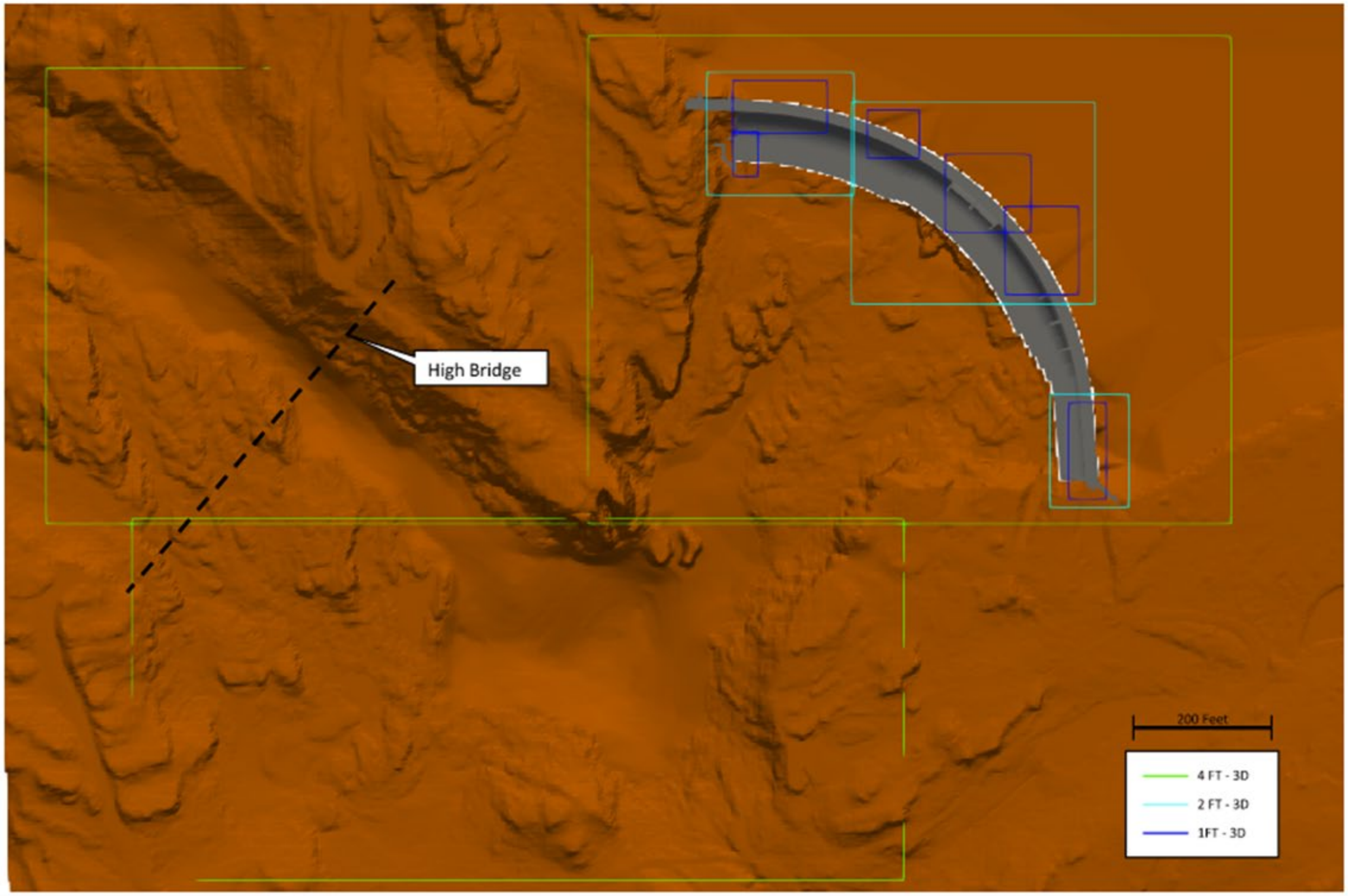
In general, all other modeling parameters were the same as in Phase 1, including surface roughness values, initial conditions, modeling methods, etc. Only the downstream mesh blocks were changed to full 3D meshes.

Use of the full 3D model domain allowed the model to be further refined along the downstream channel and along the margins of the river channel. This helped to evaluate the depth specific velocities and distribution of flow within areas that are critical for movement of salmonids and other fishes. Use of a full 3D model also allowed for several cross sections to be established at specific locations along the flow path to provide a detailed assessment of the vertical distribution of flow velocities at these cross sections. This helped identify areas that may be an obstacle to fish passage or may provide critical resting areas for the fish prior to entering the fish passage facility.

The cross sections were developed for the locations near the fish passage facility entrance, through the falls area, and near High Bridge (*refer to* **Figure 2-2**). These locations for the cross-section output were selected based on review of the 2D modeling results which indicated potential areas that may be an obstacle to upstream fish passage. However, due to limitations with the Flow-3D post processor, the sections are required to be cut parallel to the X and Y planes of the 3D model mesh. This limitation resulted in a series of horizontal cross sections that were cut parallel to the mesh plane to capture the velocity distributions through the falls area at the higher flow rate of 37,000 cfs. At the fish passage facility entrance two cross sections were used, and at High Bridge one cross section was used, to capture the velocity distributions.

[This page intentionally left blank]

**Figure 2-12. Phase 2 CFD Model – Mesh Layout**




Note: Configuration for Run 1 (37,000 cfs) shown. Location of 1 foot and 2 foot blocks varies based on scenario.

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

NorthWestern Energy

CFD MODEL - MESH LAYOUT

January 2023

[This page intentionally left blank]]

***Fish Passage and Behavioral Criteria***

The Fish Behavior Study ISR provided the results of a literature review summarizing the swimming capabilities of Rainbow (*Oncorhynchus mykiss*), Westslope Cutthroat (*Oncorhynchus clarki lewisi*), Brown (*Salmo trutta*), Bull trout and other native fish species (NorthWestern 2022b). The findings of this literature review were used to evaluate the range of flows at which water velocities in the study area are within swimming abilities of fish, allowing for migration upstream to the Upstream Fish Passage Facility.

The Phase 2 modeling evaluated the vertical velocity distributions of flow downstream of the Main Dam for two flow scenarios. The 3D flow velocity modeling output was grouped in relation to fish swimming abilities from available published literature. Details of fish swimming abilities by species are provided in Section 3.4 of the Fish Behavior Report ISR (NorthWestern 2022b).

Velocity gradients were delineated into three categories (**Table 2-5**) to best compile and illustrate fish swimming abilities. The three velocity categories are generalized and not intended to reflect the swim speed capabilities of a specific fish species. The velocity results were categorized into these three groups to identify areas in the downstream reach that could potentially be an obstacle to upstream fish passage. The three groups are:

1. Velocities of 7.0 fps or less, which encompasses the majority of the species swimming abilities for prolonged and burst speeds[4]
2. Velocities between 7.1 and 14.0 fps, the range of burst speeds for all the salmonid species, and
3. Velocities exceeding 14.0 fps, which is greater than all species prolonged and burst swimming abilities.

**Table 2-5. Velocity Categories, Grouped by Fish Swimming Abilities, Used in the 3D Model Scenarios.**

| Velocity Categories | Velocity (fps) |
|---|---|
| Most Species - mix of Prolonged and Burst speeds | 0-7.0 |
| Many Species - Burst Speeds | 7.1-14.0 |
| Exceeds Burst Speeds | >14.0 |

[4] Prolonged swim speeds are those speeds that fish can maintain for 20 seconds to 200 minutes and ends in fatigue. Burst swim speeds are the highest speeds attainable by fish and can be maintained for only short periods of time (<20 seconds) (Beamish 1978).

## 2.3 Modeling Limitations

With all hydraulic models there is some level of uncertainty and modeling error associated with the results. The accuracy of the model depends on the accuracy and resolution of the surveyed surfaces above and below the water in the natural channel and at what resolution that data is rendered in the model. The model calculations may not capture all the details of the underlying rocky terrain surface, particularly overhangs or undercuts that do not show up in a bathymetric survey. The model resolution, extents and simulation time are selected to balance the computational efficiencies and the level of detail in the model, otherwise simulation durations and model output become unreasonable and are not practical for use. Additionally, the CFD model results represent a snapshot in time, once steady state conditions have occurred, and may not account for the dynamics that are a result of constantly changing flow rates in the natural river system.

The flow characteristics presented in this report are based on considerable modeling experience and represent an accurate model with the corresponding limitations. Accordingly, the results of this study are considered approximate, and the flow depths, velocities, and discharges should be used only as guidance for understanding the possible flow conditions in the channel. Actual river flow conditions, depths, velocities, and discharges may vary from the results presented in this 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 Dam structure during the initial hydraulic model study. This is 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 Dam structure.

In addition, the FERC-approved Study Plan described the study area as the Main 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 Dam to 500 feet downstream of the High Bridge, which is an enhancement of the study.

The Interim Report (NorthWestern 2022c) was distributed to FWP, FWS, and USFS on February 15, 2022, with request for comments by March 17, 2022 which was two weeks later than dates specified in the FERC-approved Study Plan. The meeting with FWP, FWS, and USFS was held March 10, 2022, as described in the FERC-approved Revised Study Plan (NorthWestern 2021), and the Interim Report was incorporated into the ISR.

# 3.0 Results

## 3.1 General Observations

Based on the results of CFD modeling, flows immediately downstream of the Thompson Falls Main Dam are very complex, dynamic, and highly turbulent. Due to the curved shape of the Main 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. Downstream of the falls, the river makes a sharp bend to the right, in an area known as the Dollar Hole (**Figure 3-1**). This 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 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 (Figure 3-1). The results of the CFD analyses for each scenario are described in detail in the following sections.

## 3.2 Phase 1 CFD Model Results

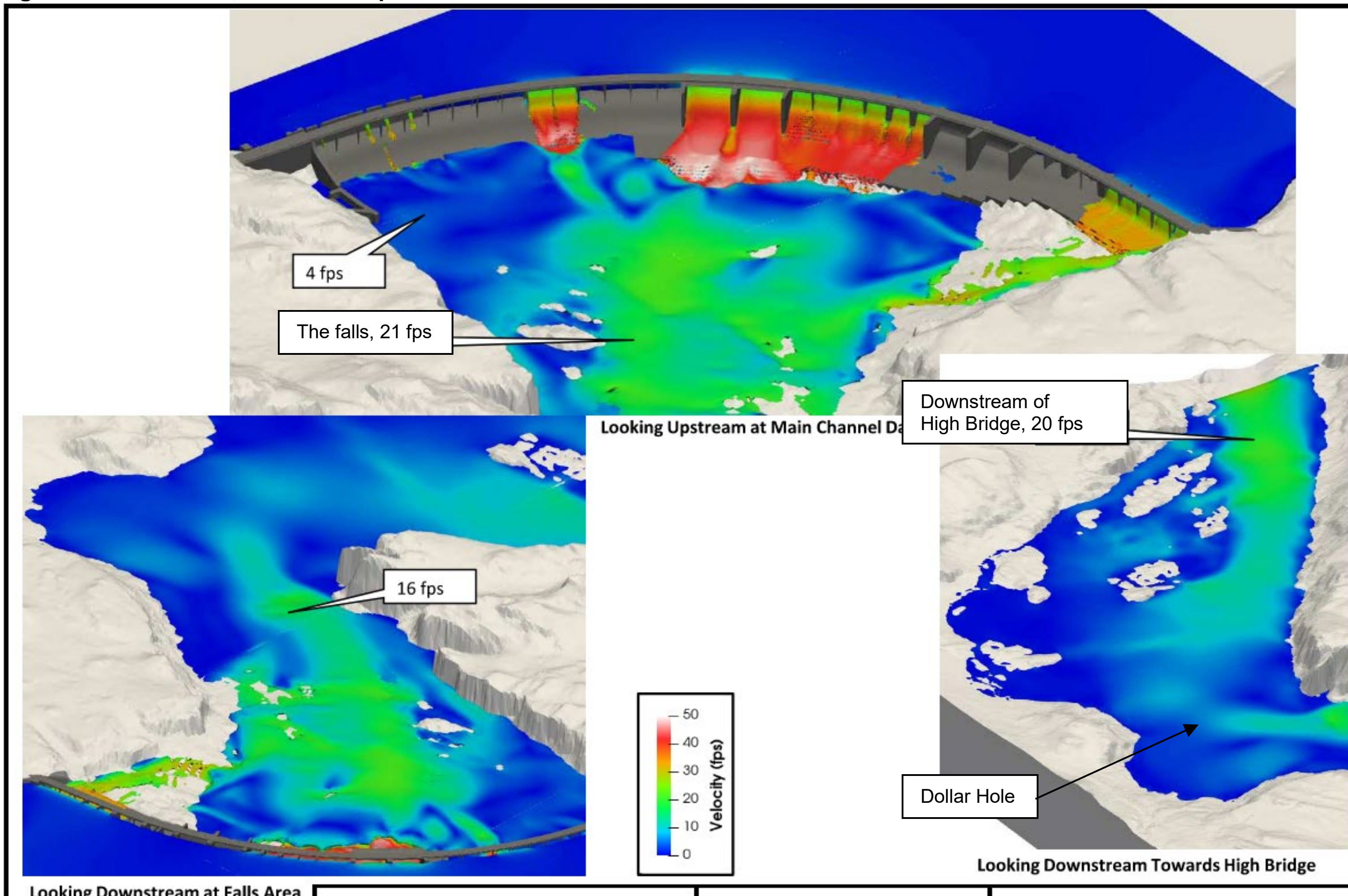
### *3.2.1 Run 1: 37,000 cfs*

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 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 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 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 are shown in **Figure 3-6**.

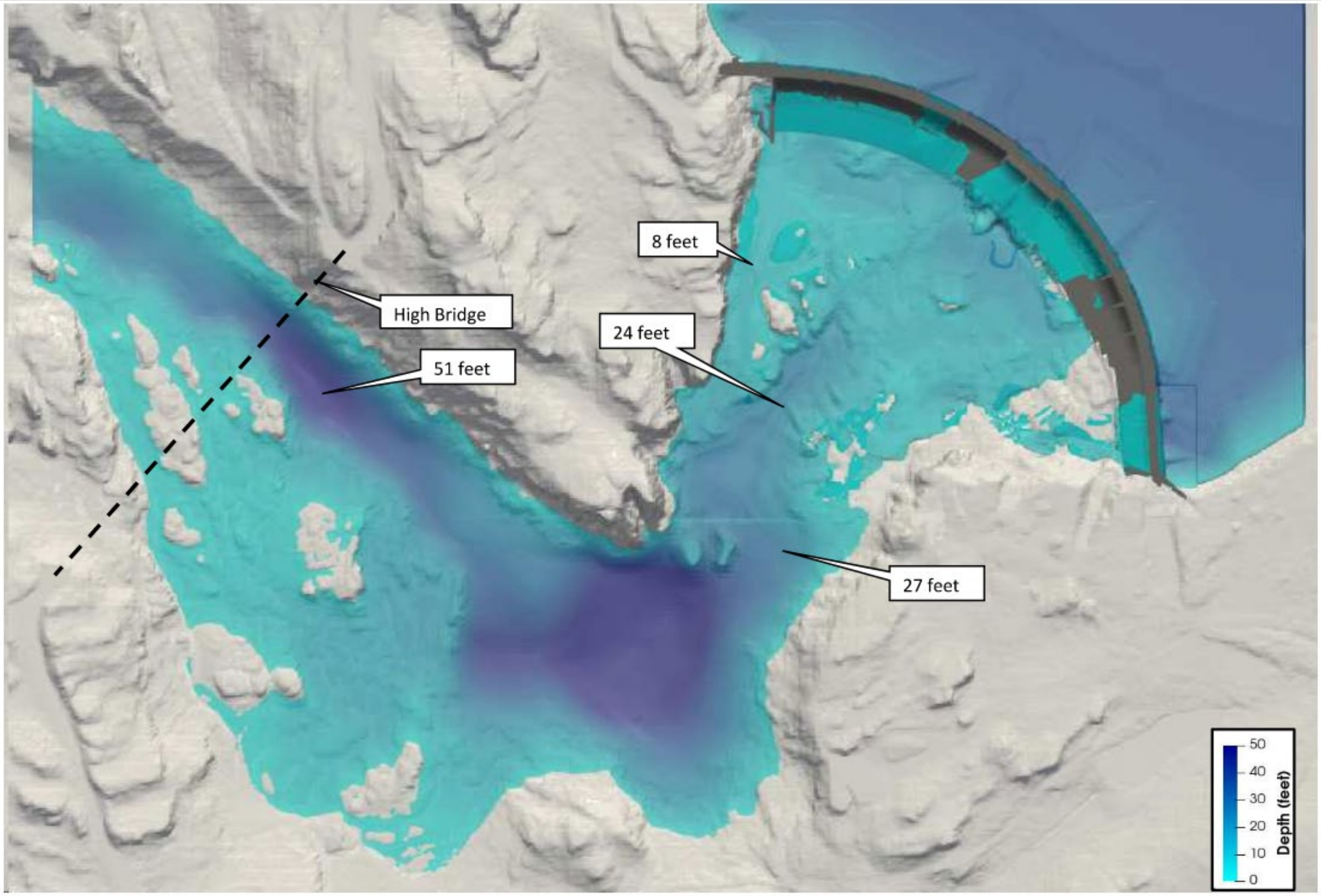
**Figure 3-1. Run 1: 37,000 cfs Perspective Views**




| | | |
|---|---|---|
| Thompson Falls Hydroelectric Project #1869<br>Hydraulic Conditions Study<br>Sanders County, Montana | NorthWestern Energy | RUN 1: 37,000 CFS<br>PERSPECTIVE VIEWS |
| | | February 2022 |

Document Path: B:\Working\BUREAU OF INDIAN AFFAIRS\2200324 Oglala Dam Remediation Design\10_Task 3A 30p Design\05_H&H Design\Background\[10kYrInflowHydrograph_BIA2020.xlsx]Sheet1

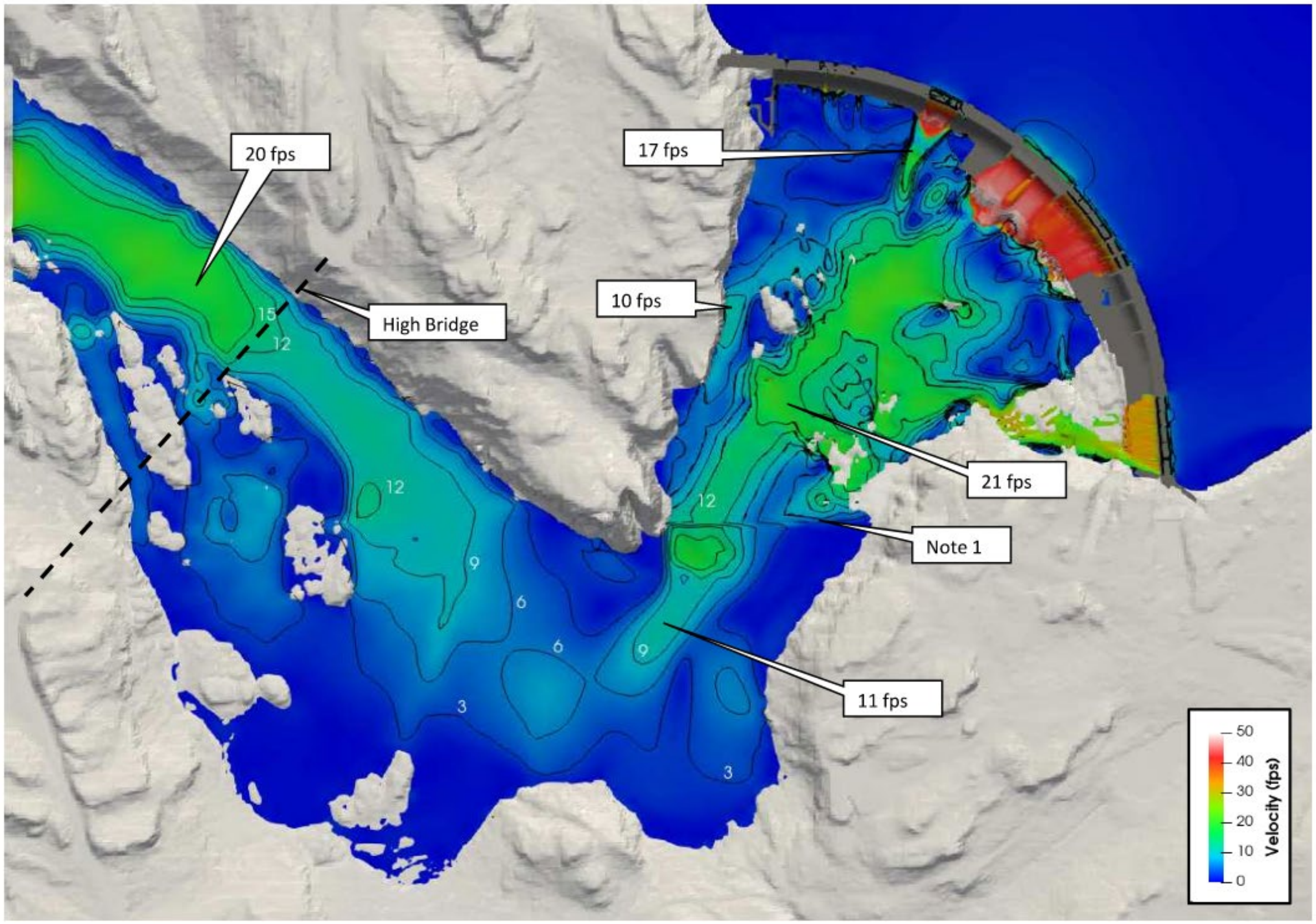
**Figure 3-2. Run 1: 37,000 cfs Plan View of Flow Depths**




| Notes<br>1. Legend shown without transparency. | Thompson Falls Hydroelectric Project #1869<br>Hydraulic Conditions Study<br>Sanders County, Montana | NorthWestern Energy | RUN 1: 37,000 CFS<br>PLAN VIEW OF FLOW DEPTHS<br>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 3-3. 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.

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

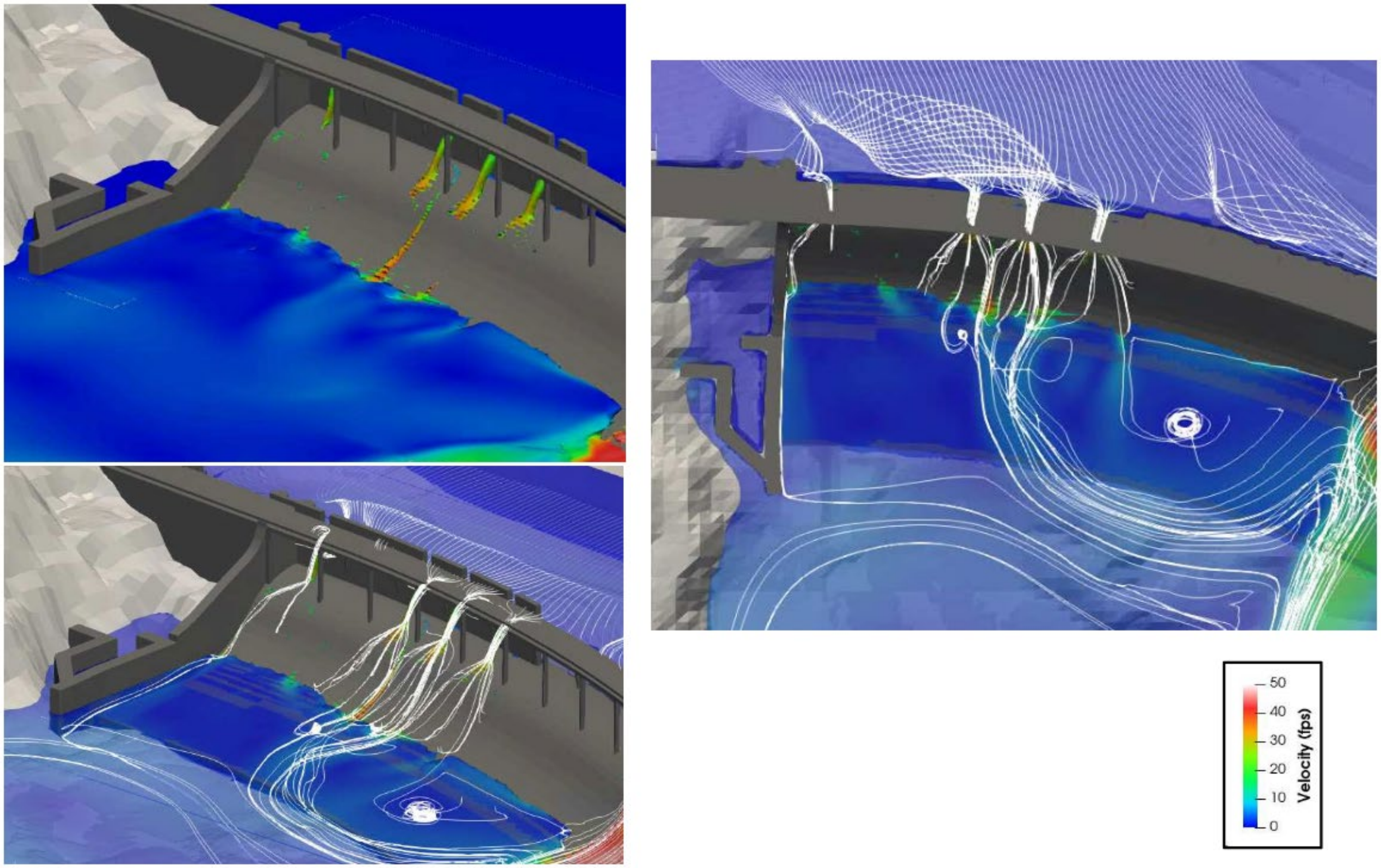
NorthWestern Energy

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




Notes
1. Legend shown without transparency.

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

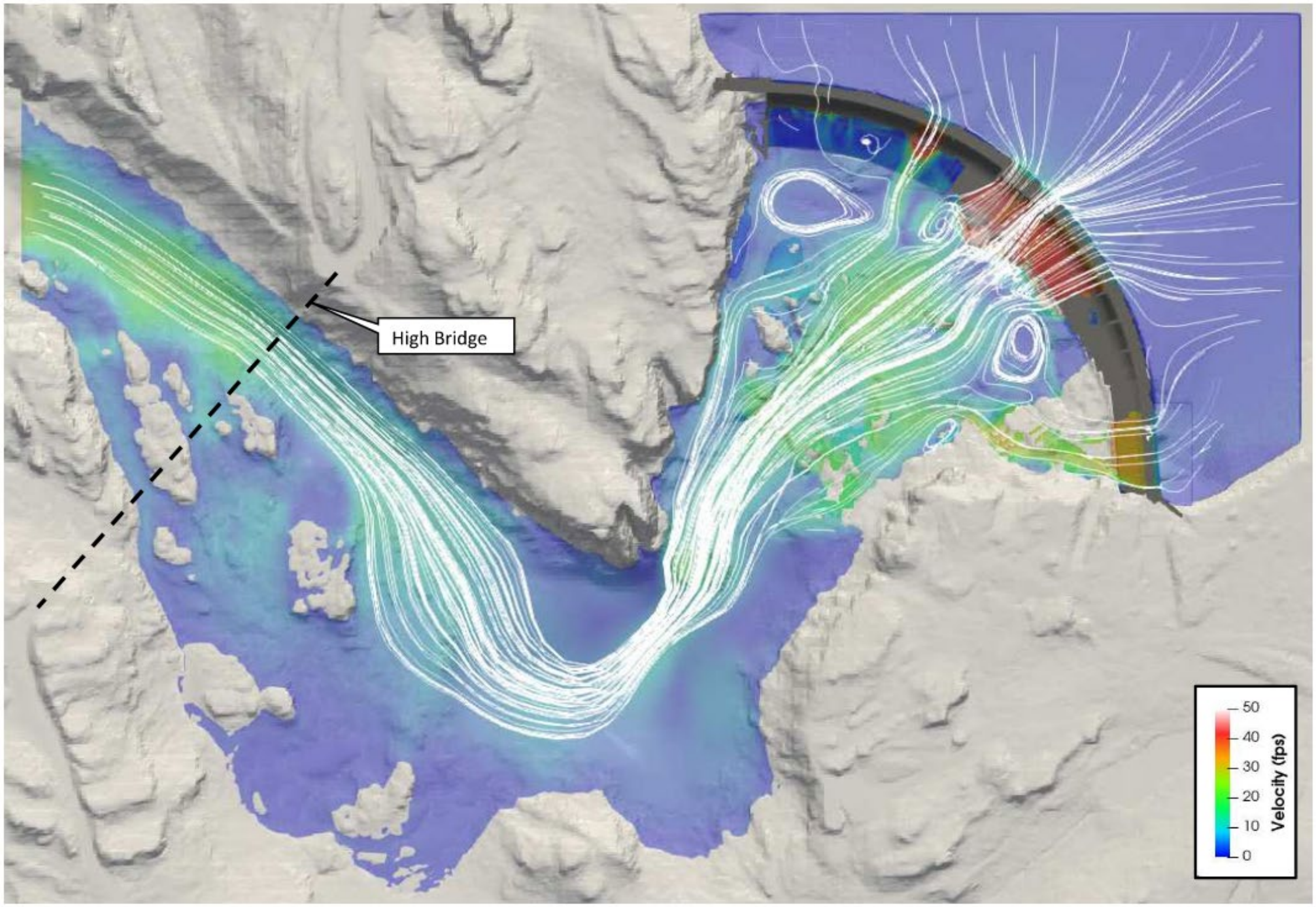
NorthWestern Energy

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




Notes
1. Legend shown without transparency.

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

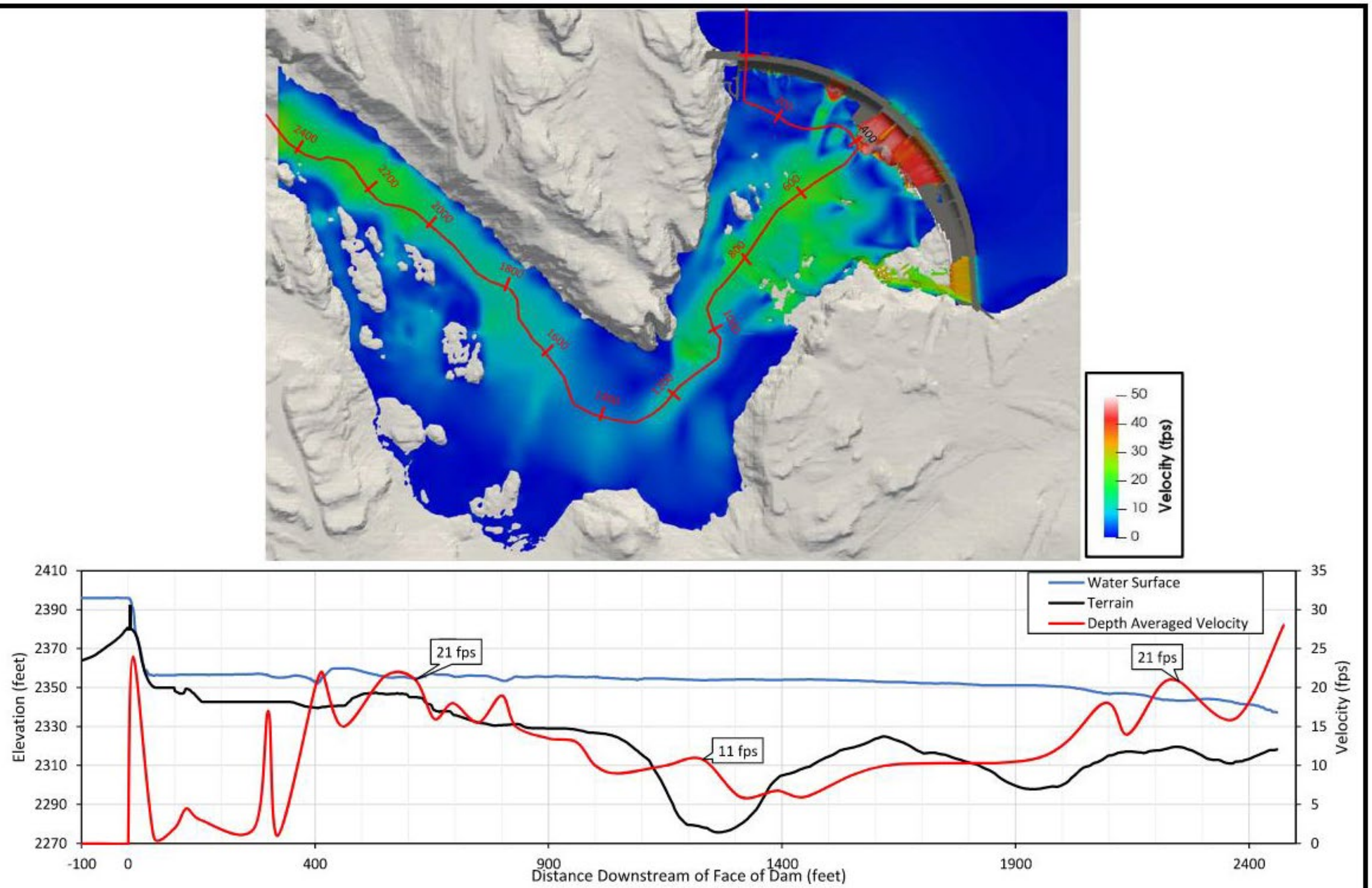
NorthWestern Energy

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




| | | |
|---|---|---|
| Thompson Falls Hydroelectric Project #1869<br>Hydraulic Conditions Study<br>Sanders County, Montana | NorthWestern Energy | RUN 1: 37,000 CFS<br>PLAN AND PROFILE<br><br>February 2022 |

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

### *3.2.2 Run 2: 25,000 cfs*

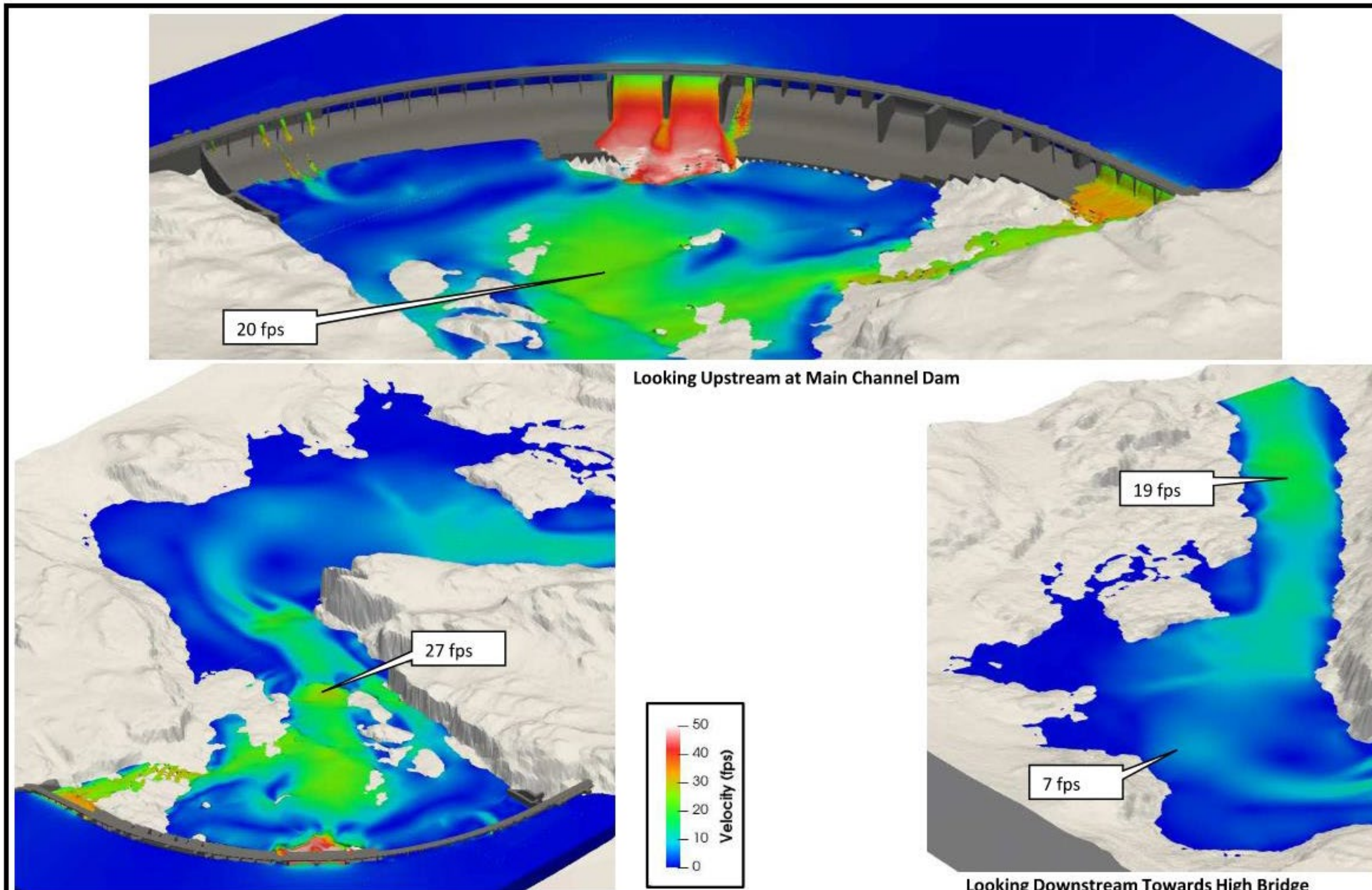
Run 2, with a discharge rate of approximately 25,000 cfs, generally represents the high design flow for the Upstream Fish Passage Facility. Perspective views of the modeled water surface and velocity gradient output at a steady-state flow condition of 25,000 cfs are depicted in **Figure 3-7**. The dam 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 Dam, which are reduced considerably immediately downstream of the Main 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 HVJ at the Upstream Fish Passage Facility. The HVJ has limited influence on the resulting downstream 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 are shown in **Figure 3-12**.

[This page intentionally left blank]

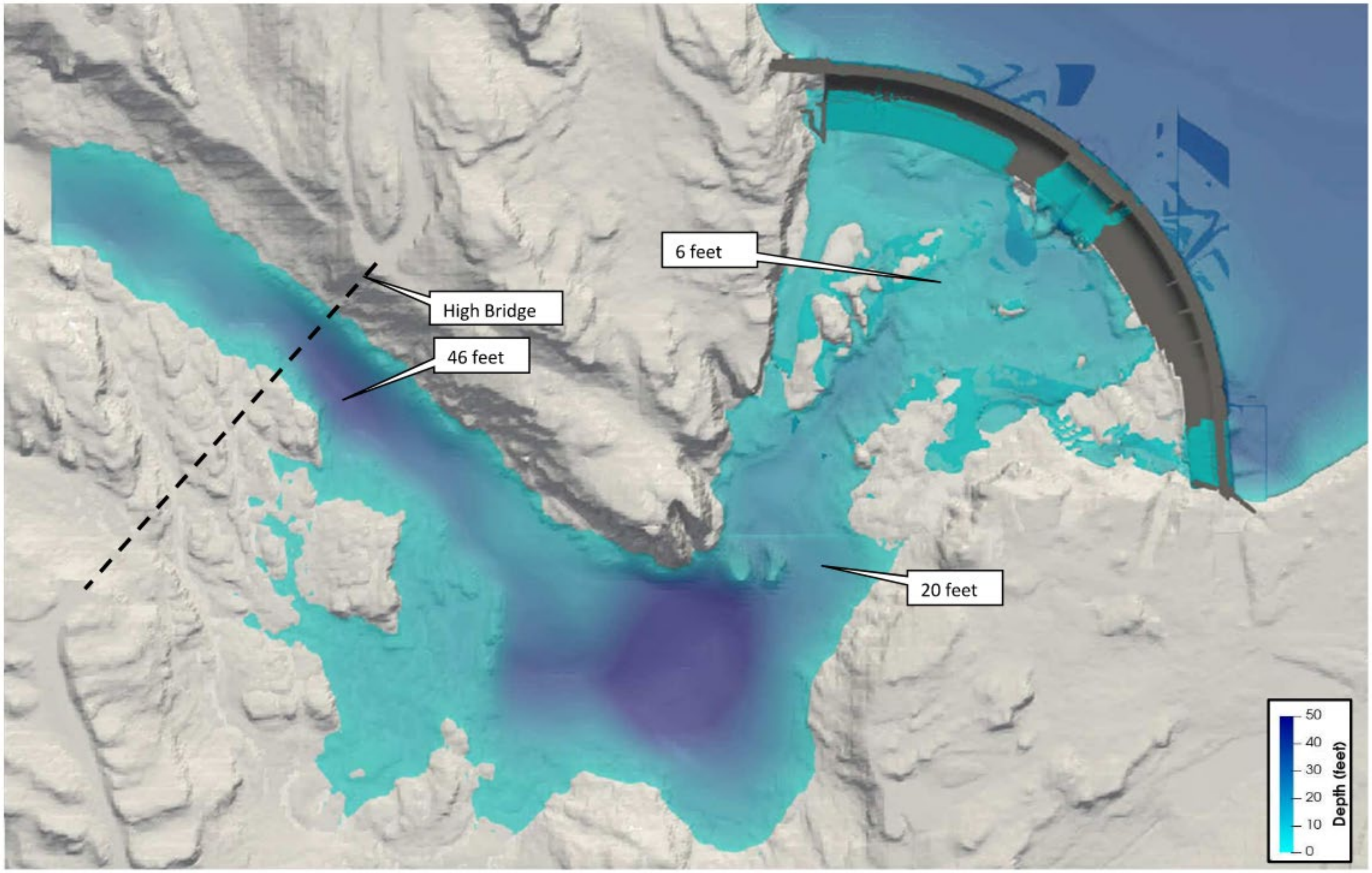
**Figure 3-7. Run 2: 25,000 cfs Perspective Views**




| | | |
|---|---|---|
| Thompson Falls Hydroelectric Project #1869<br>Hydraulic Conditions Study<br>Sanders County, Montana | NorthWestern Energy | RUN 2: 25,000 CFS<br>PERSPECTIVE VIEWS<br>February 2022 |

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

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




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

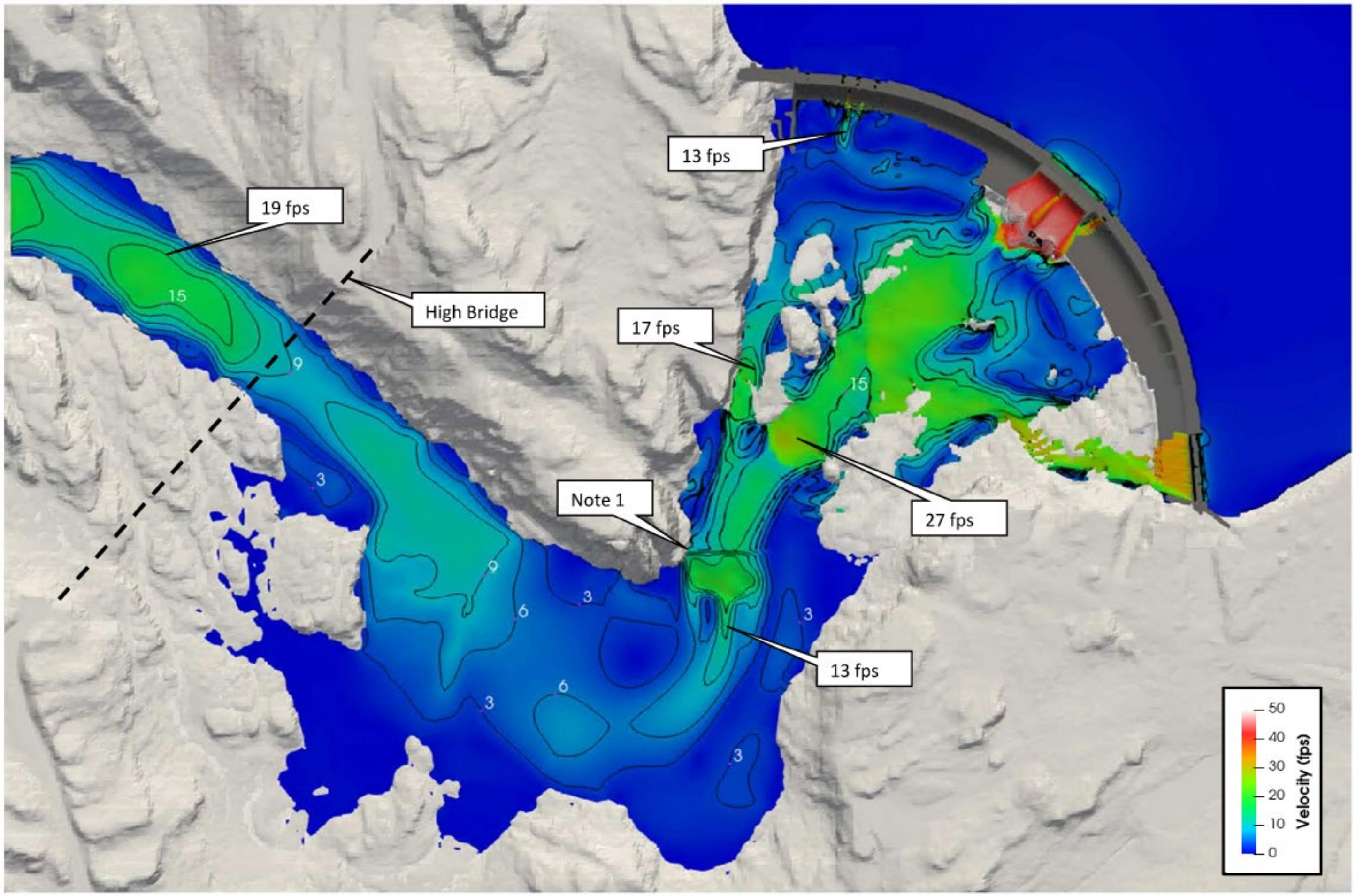
NorthWestern Energy

RUN 2: 25,000 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 3-9. 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.

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

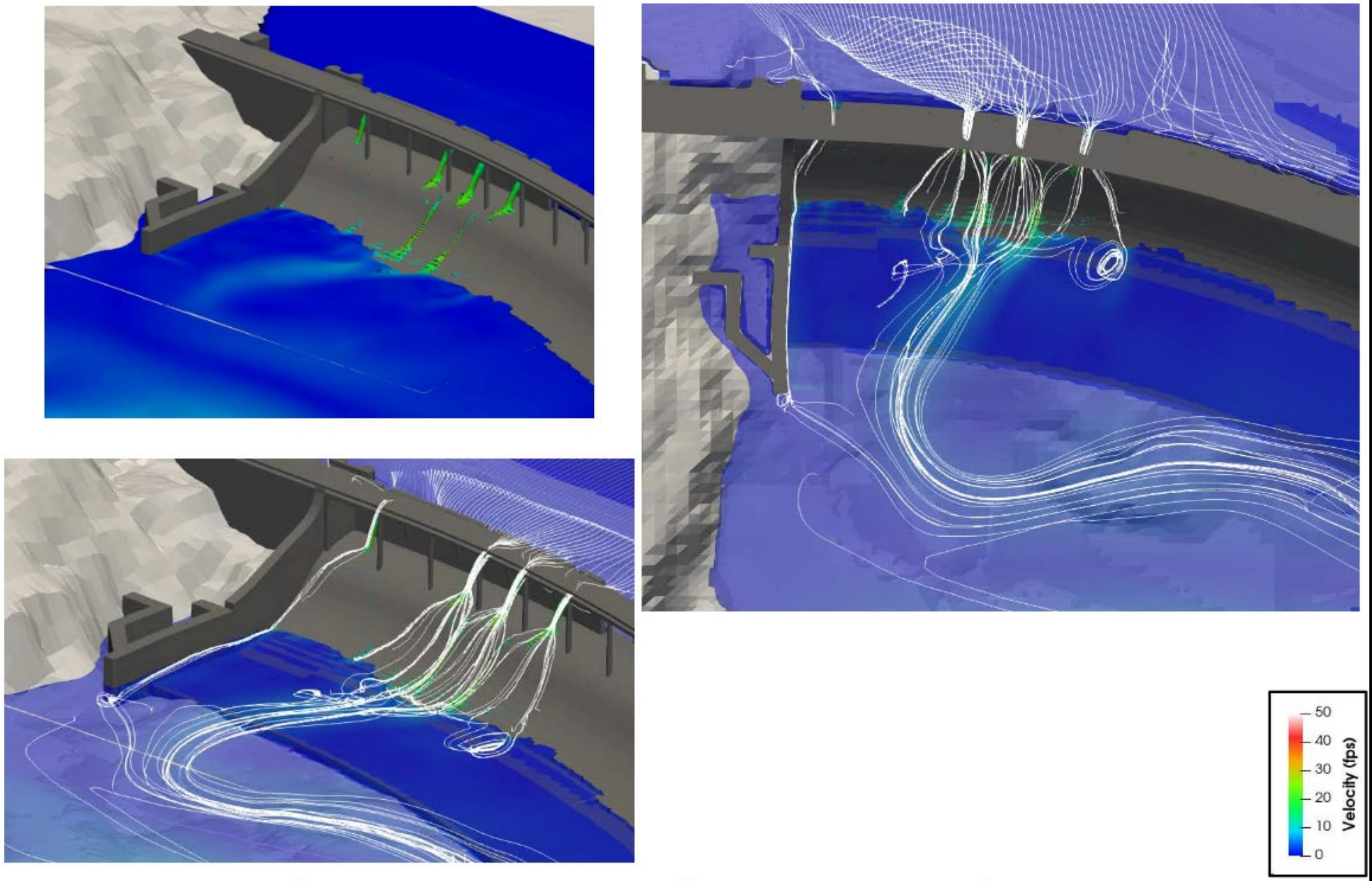
NorthWestern Energy

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




Notes
1. Legend shown without transparency.

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

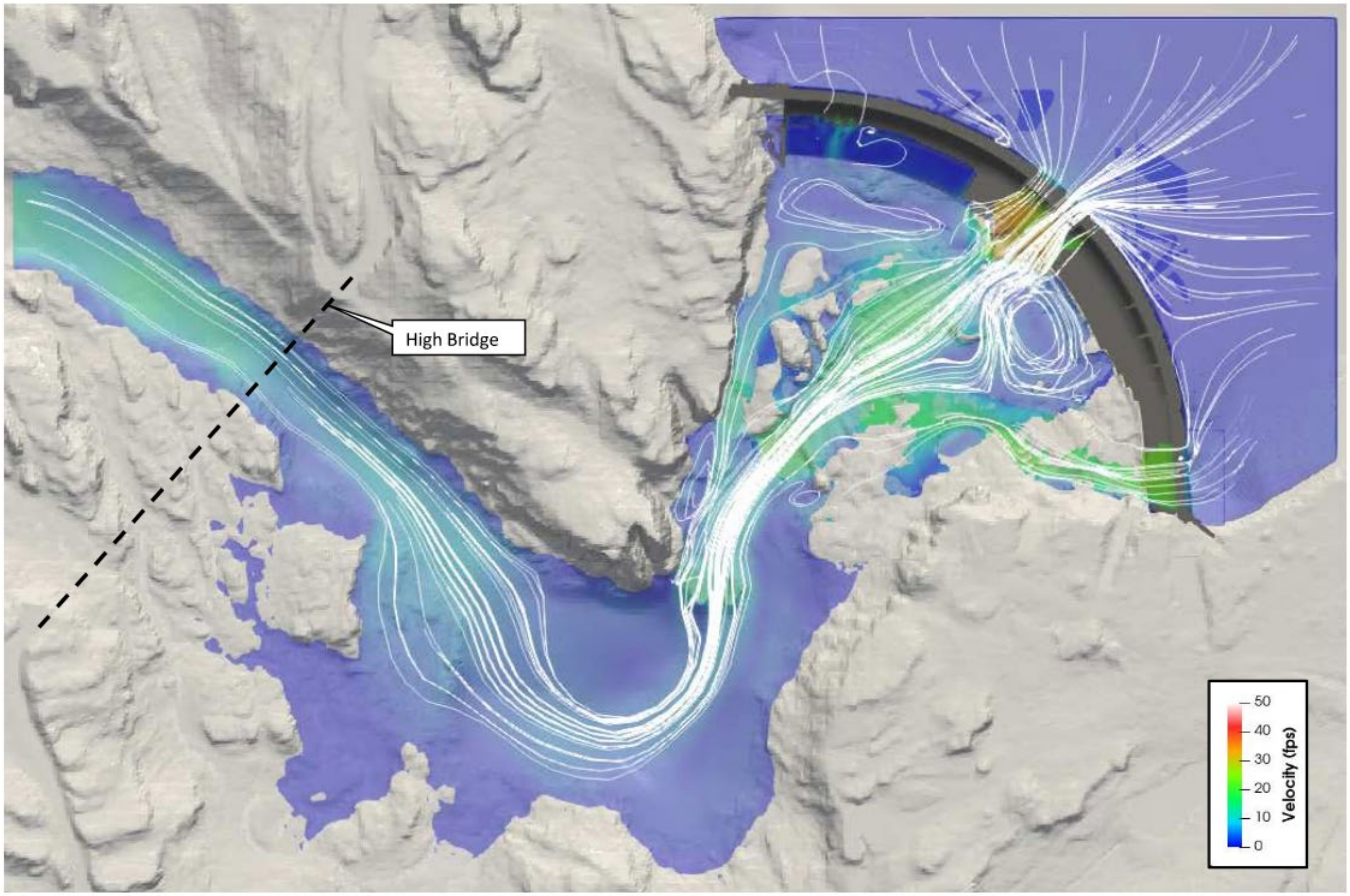
NorthWestern Energy

RUN 2: 25,000 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

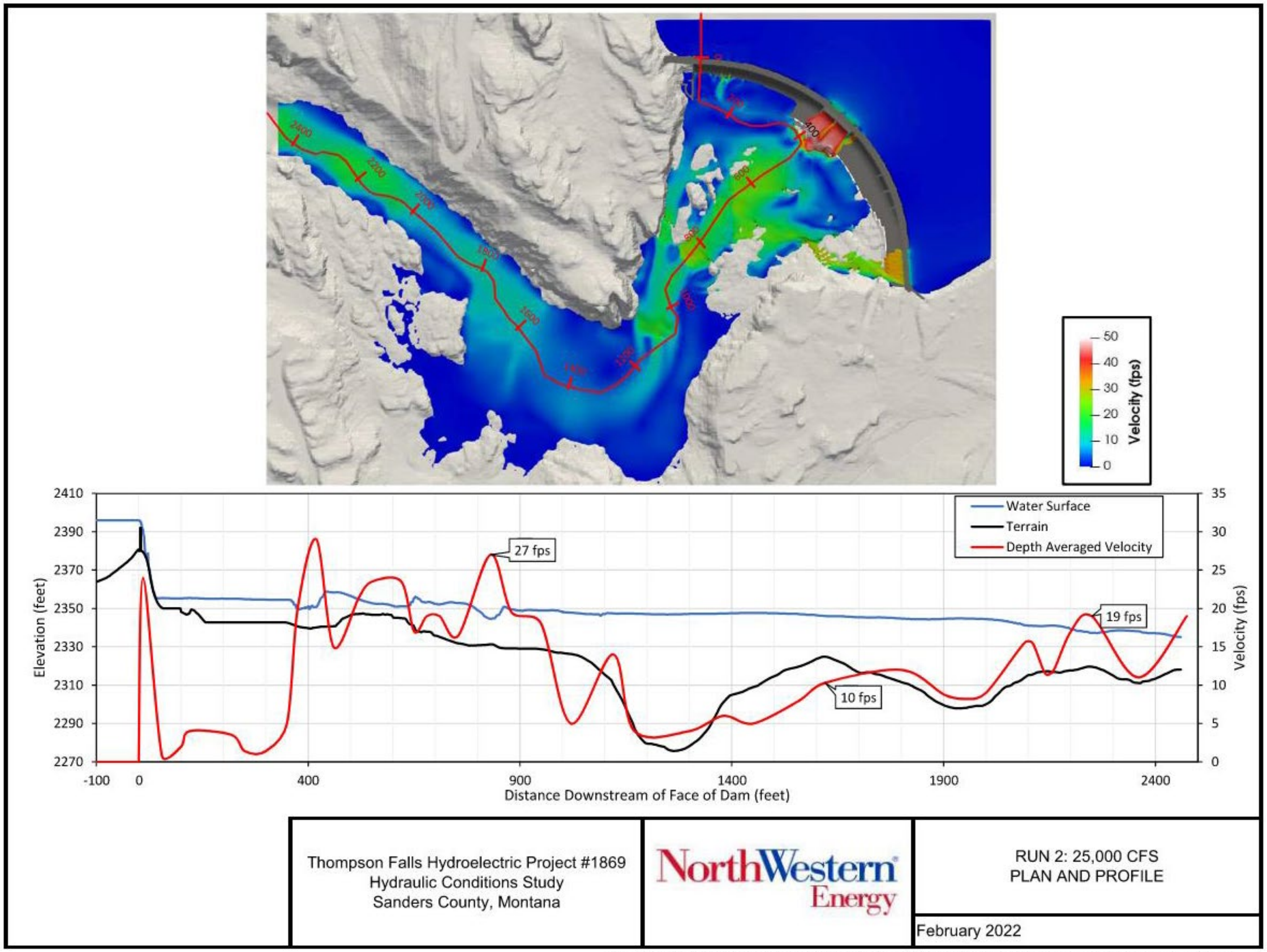
**Figure 3-11. Run 2: 25,000 cfs Flow Path Streamlines**




| Notes<br>1. Legend shown without transparency. | Thompson Falls Hydroelectric Project #1869<br>Hydraulic Conditions Study<br>Sanders County, Montana | NorthWestern Energy | RUN 2: 25,000 CFS<br>FLOW PATH STREAMLINES<br>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 3-12. Run 2: 25,000 cfs Plan and Profile**




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

### *3.2.3 Run 3: 2,000 cfs*

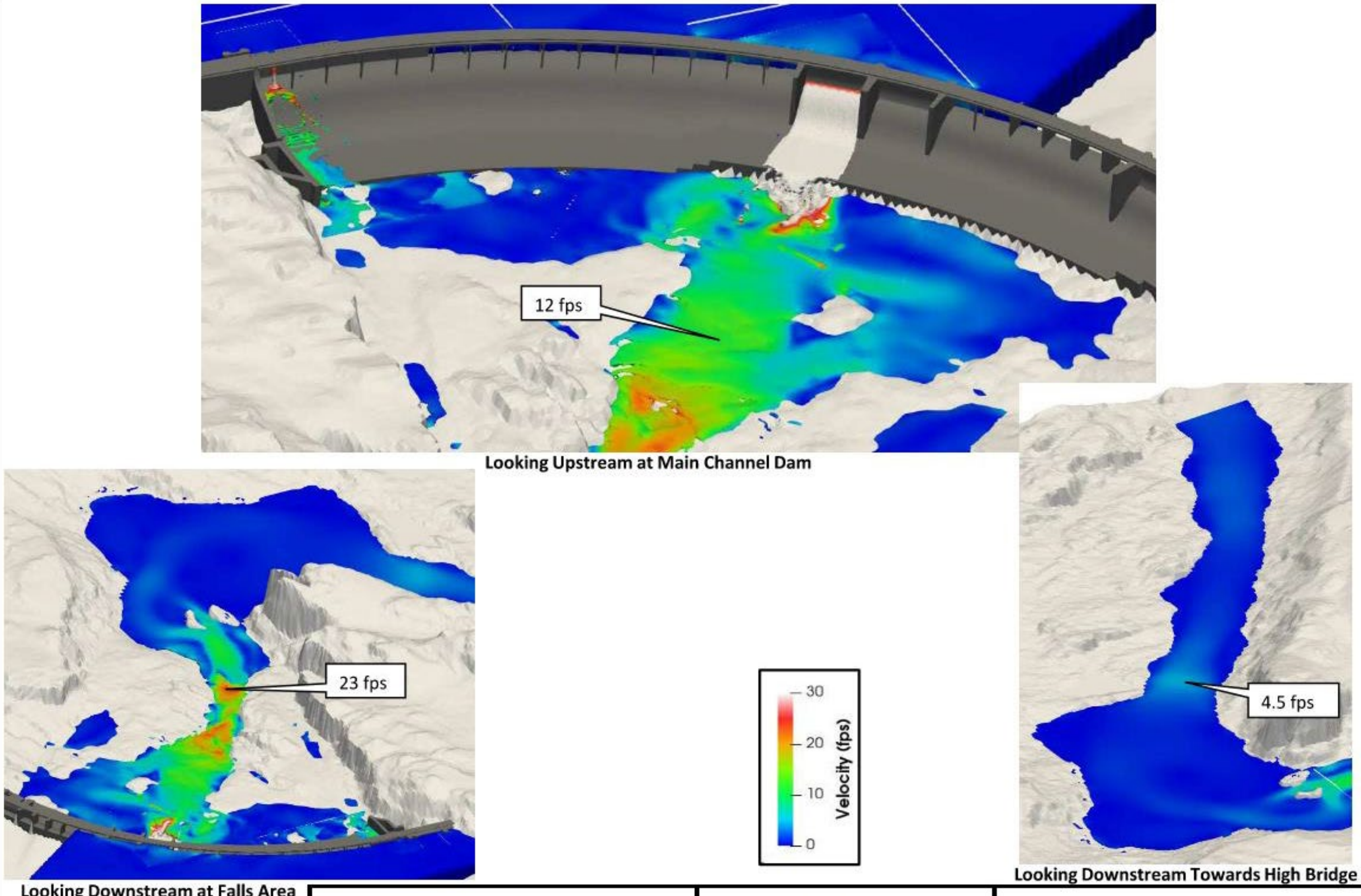
Run 3, with a discharge rate of approximately 2,000 cfs, generally represents an intermediate flow rate. Perspective views of the modeled water surface and velocity gradient output at a steady-state flow condition of 2,000 cfs are depicted in **Figure 3-13**. The dam structures are colored gray for distinction 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 Dam range from approximately 2 to 15 fps. In general, the highest velocities are immediately downstream of the open radial gates. However, these velocities are quickly reduced due to energy dissipation from the turbulent flow in the pool downstream of the Main 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 of the HVJ. 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 are shown in **Figure 3-18**.

[This page intentionally left blank]

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




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

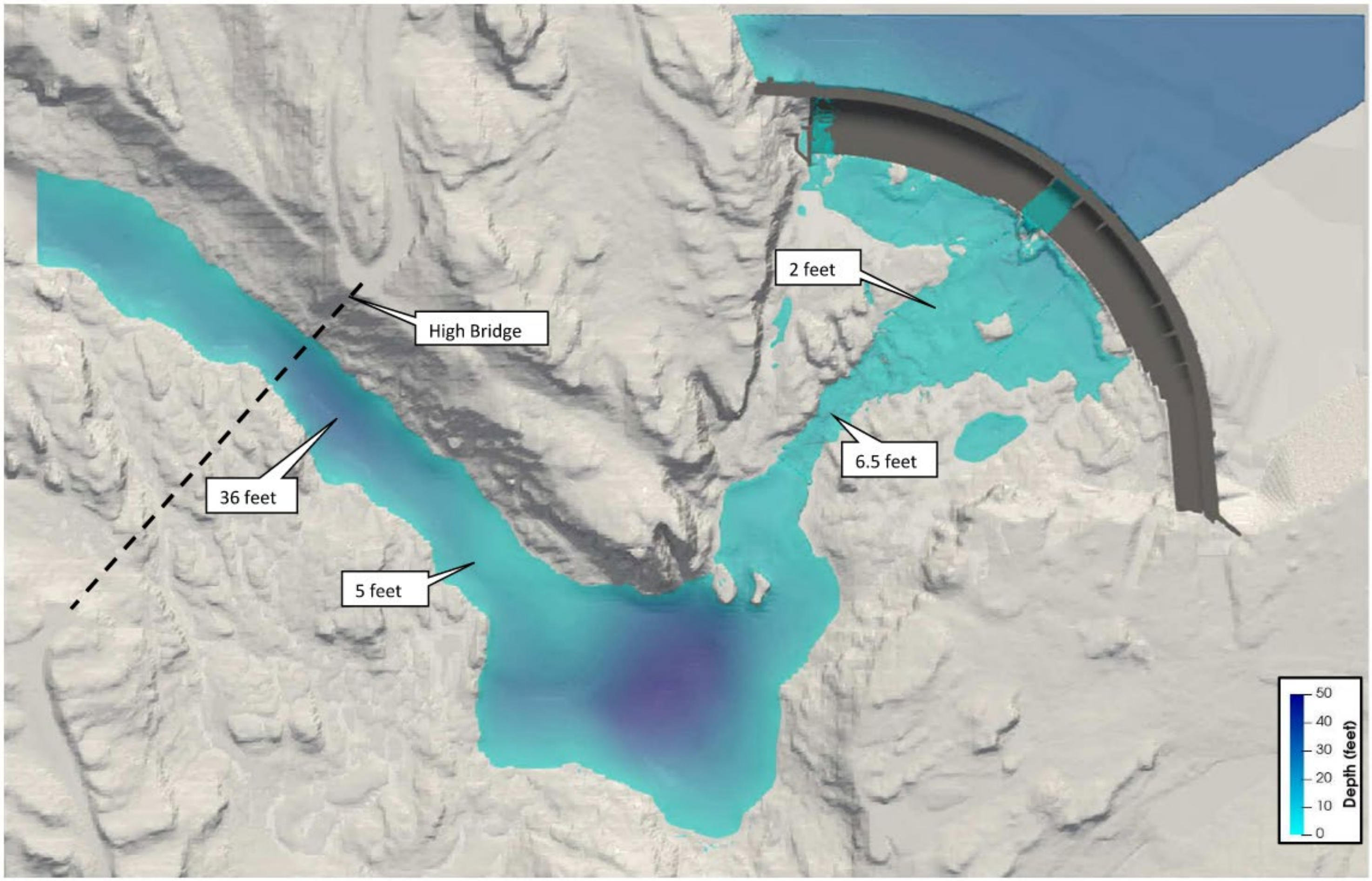
NorthWestern Energy

RUN 3: 2,000 CFS
PERSPECTIVE VIEWS

February 2022

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

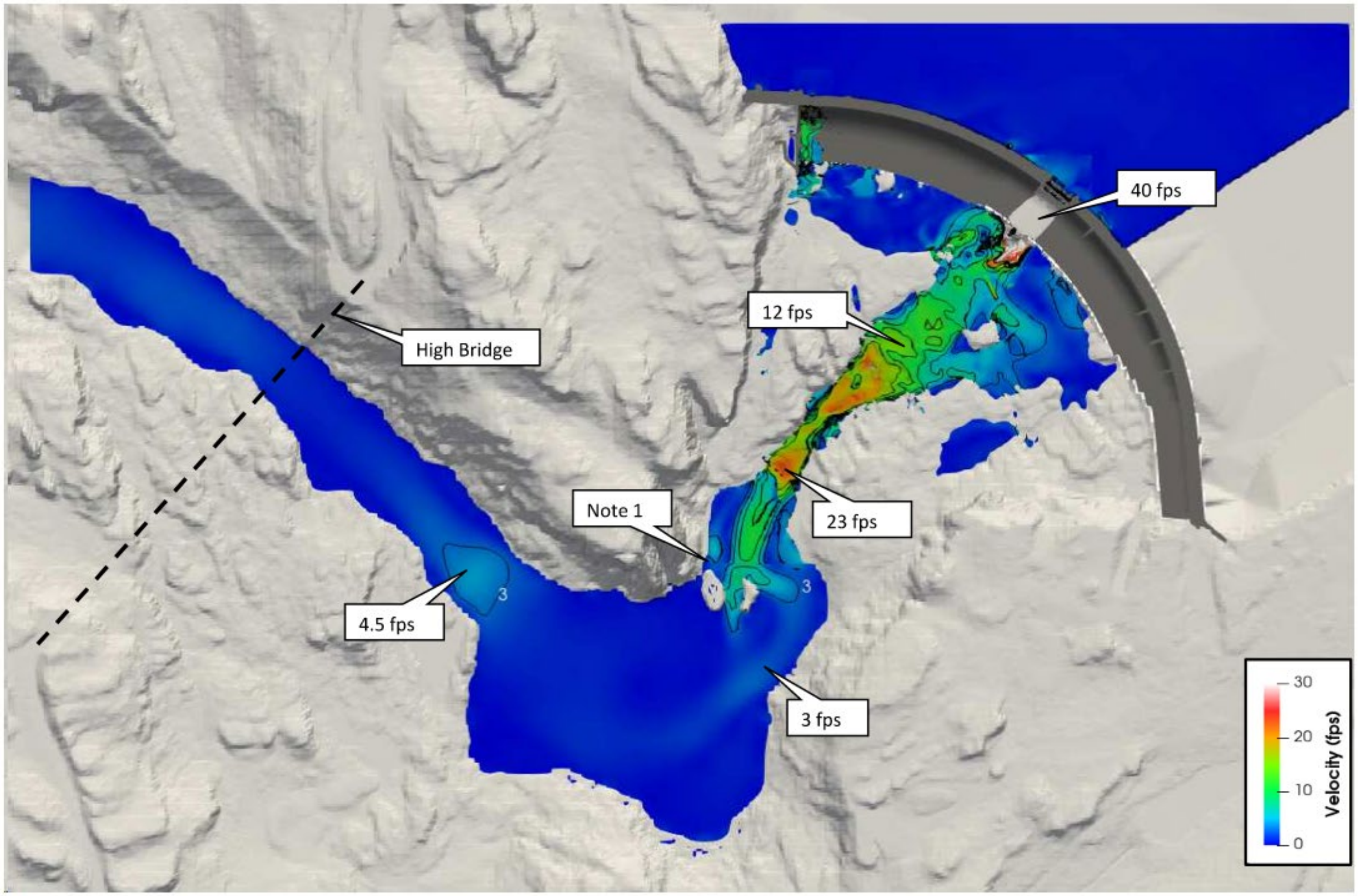
**Figure 3-14. Run 3: 2,000 cfs Plan View of Flow Depths**




| Thompson Falls Hydroelectric Project #1869<br>Hydraulic Conditions Study<br>Sanders County, Montana | NorthWestern Energy | RUN 3: 2,000 CFS<br>PLAN VIEW OF FLOW DEPTHS<br>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 3-15. 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.

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

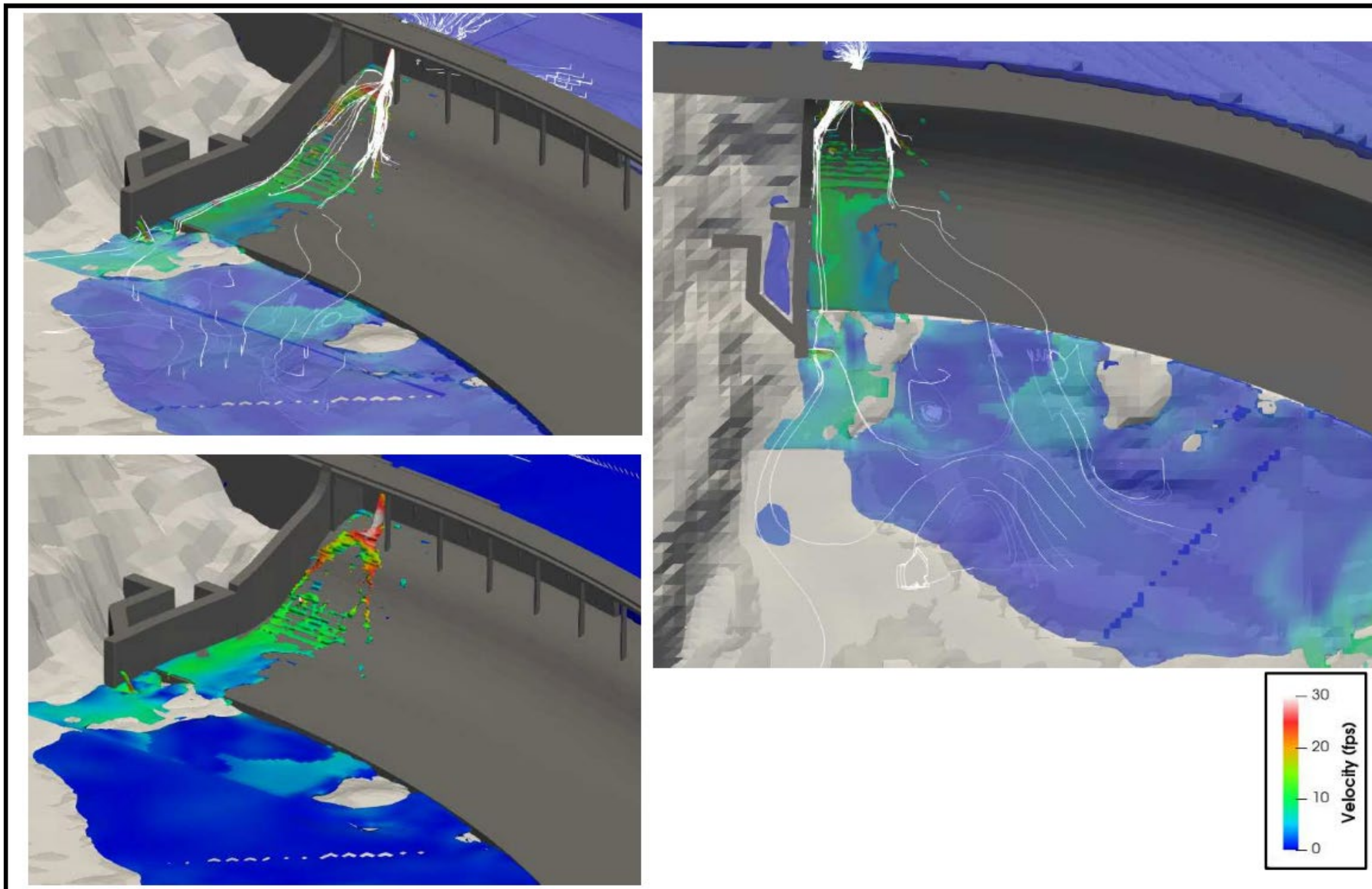
NorthWestern Energy

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




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

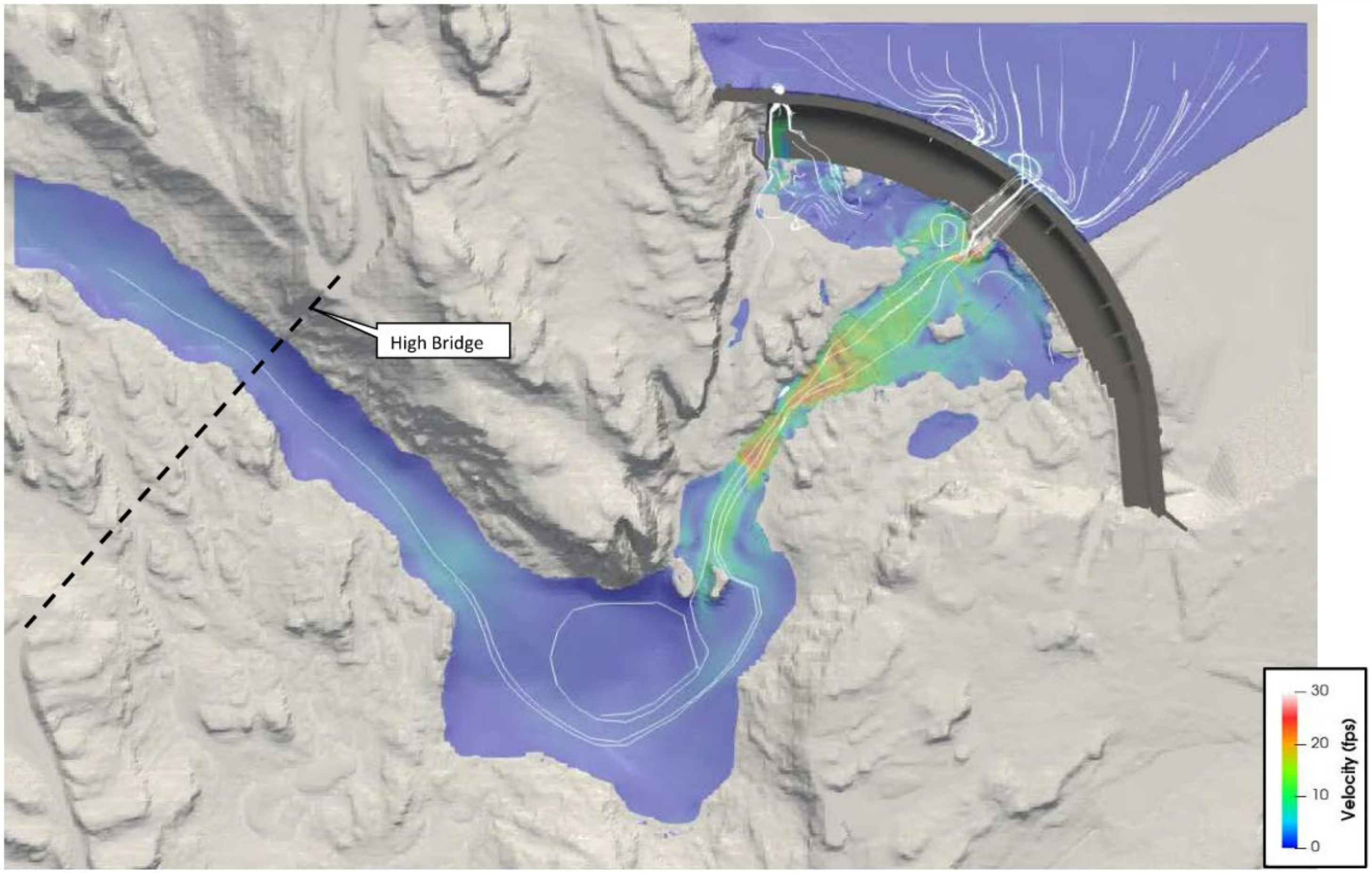
NorthWestern Energy

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




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

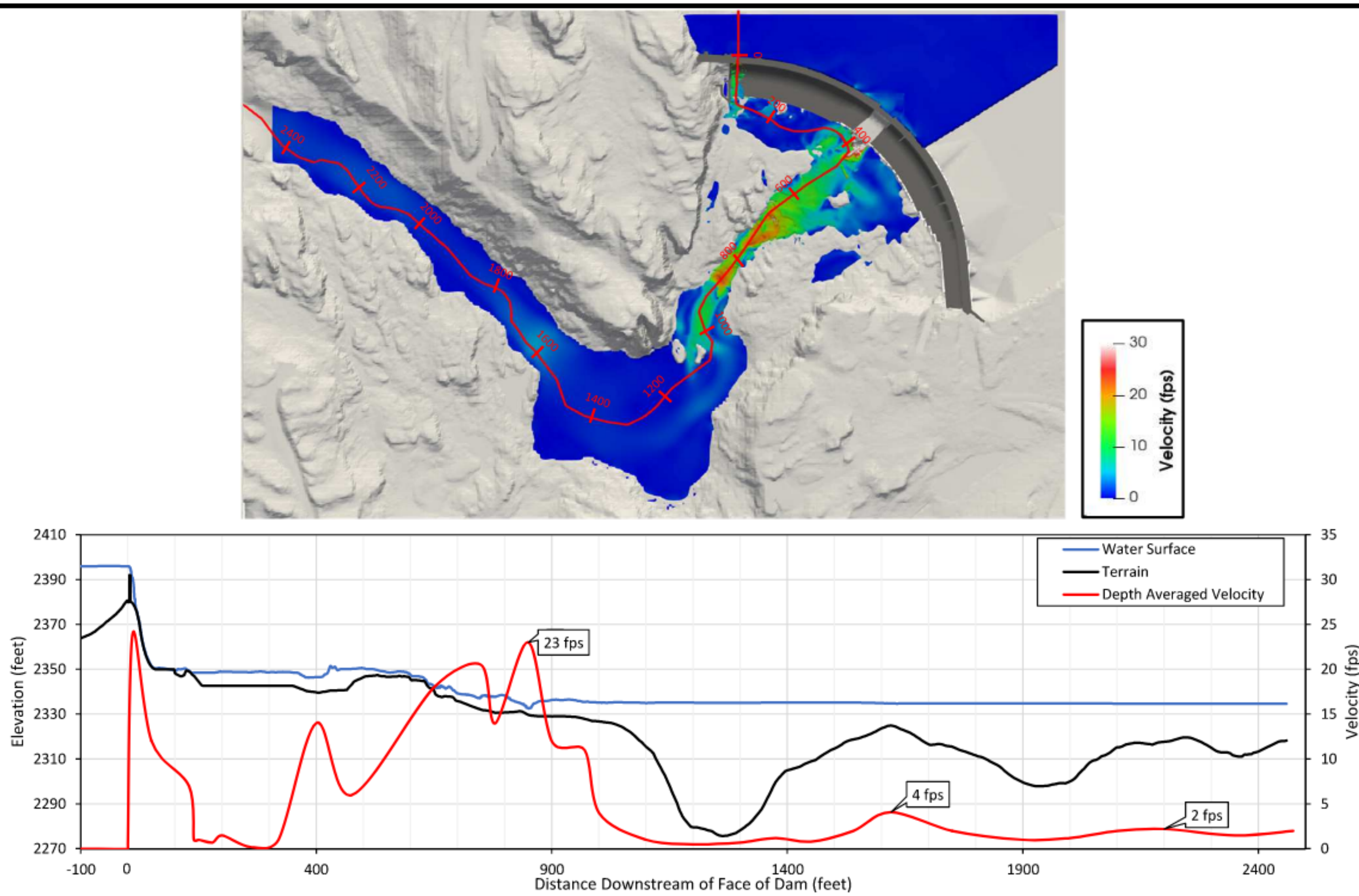
NorthWestern Energy

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




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

NorthWestern Energy

RUN 3: 2,000 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

### *3.2.4 Run 4: 200 cfs*

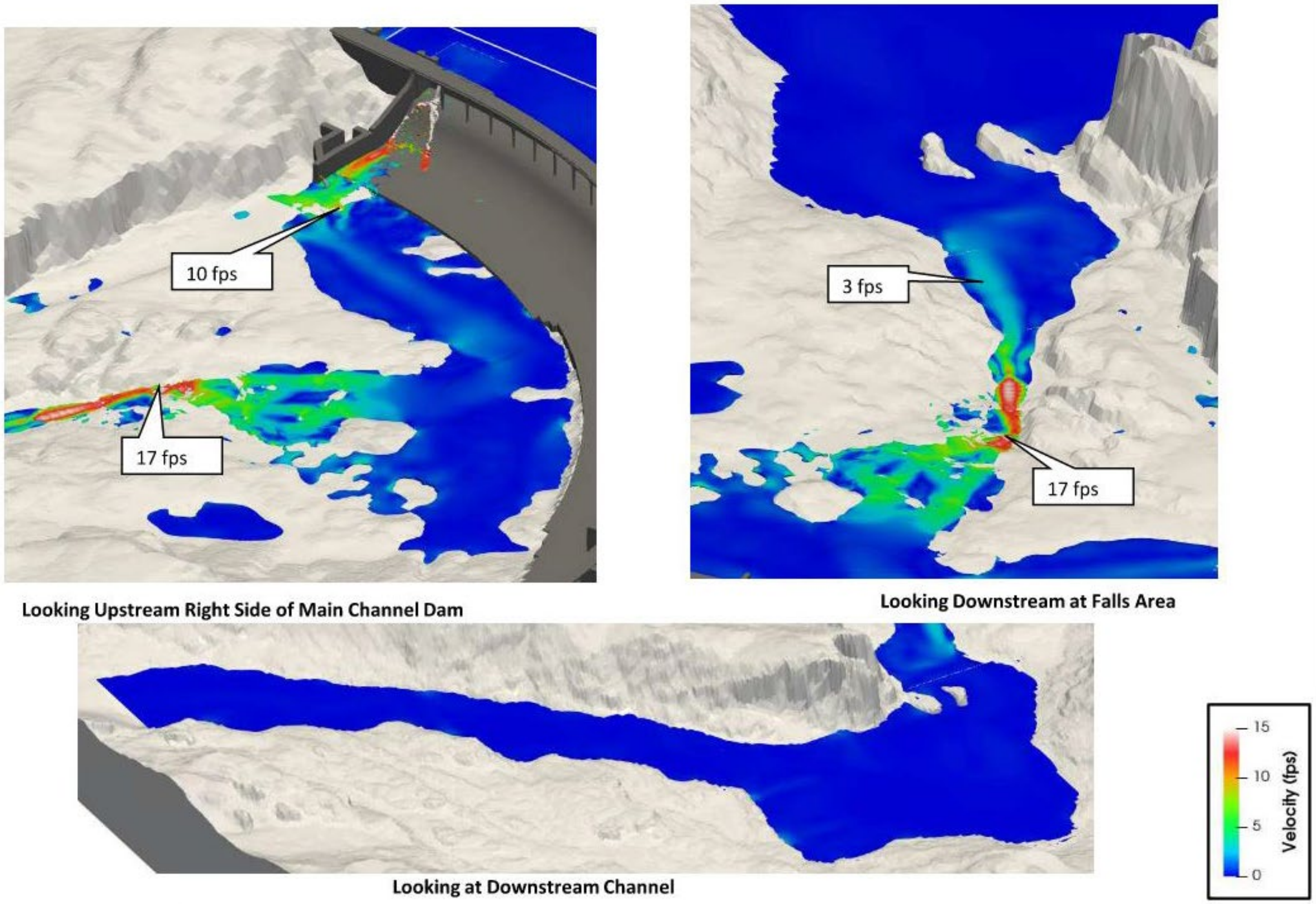
Run 4, with a discharge rate of approximately 200 cfs, generally represents the minimum discharge rate of the Main Dam and Upstream Fish Passage Facility. Perspective views of the modeled water surface and velocity gradient output at a steady-state flow condition of 200 cfs are depicted in **Figure 3-19**. 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 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 322, the local Upstream Fish Passage Facility velocities range from 3 to 8 fps. Higher velocities are most evident where 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 are shown in **Figure 3-24**.

[This page intentionally left blank]

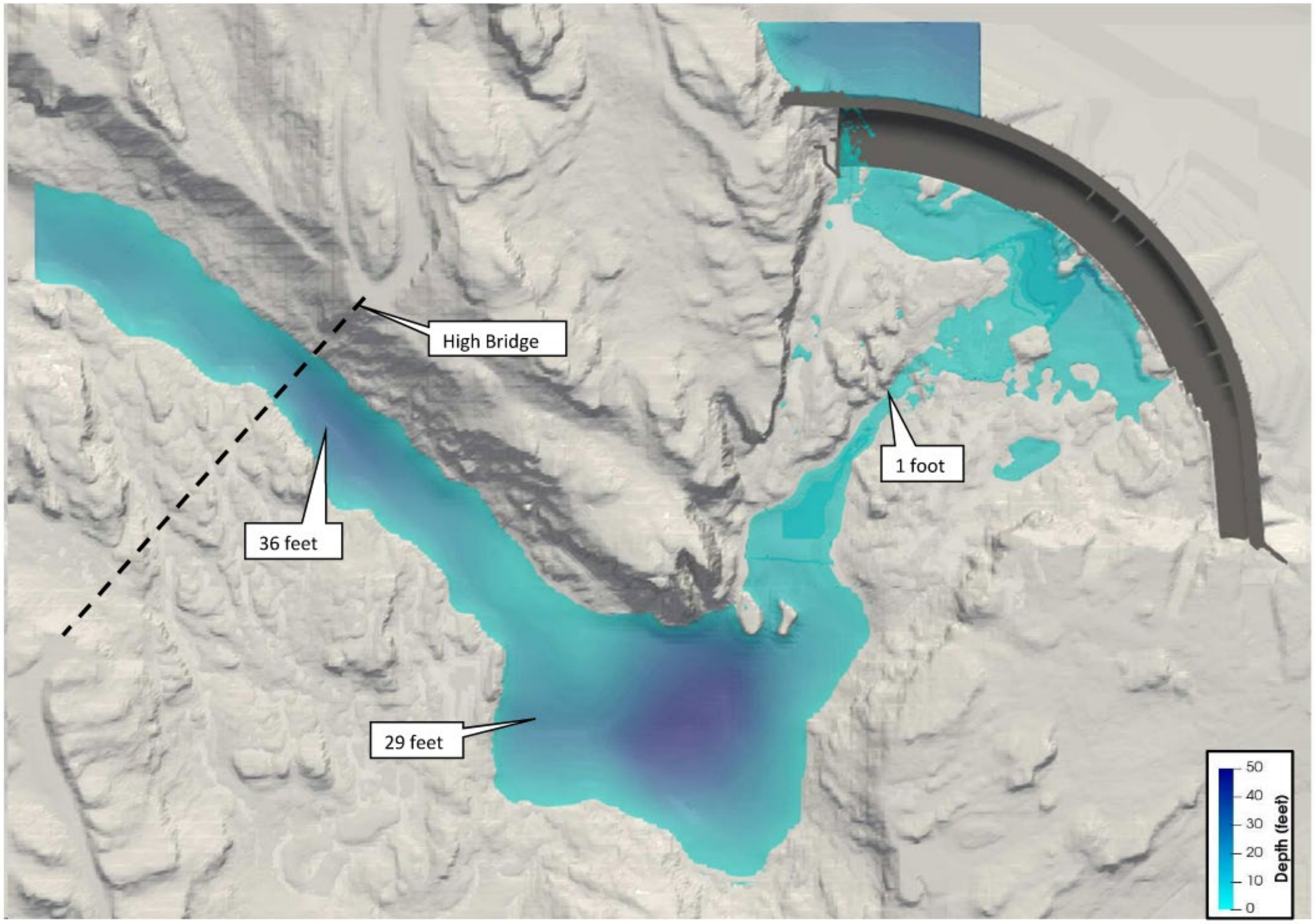
**Figure 3-19. Run 4: 200 cfs Perspective Views**




| Thompson Falls Hydroelectric Project #1869<br>Hydraulic Conditions Study<br>Sanders County, Montana | NorthWestern Energy | RUN 4: 200 CFS<br>PERSPECTIVE VIEWS<br><br>February 2022 |
|---|---|---|

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

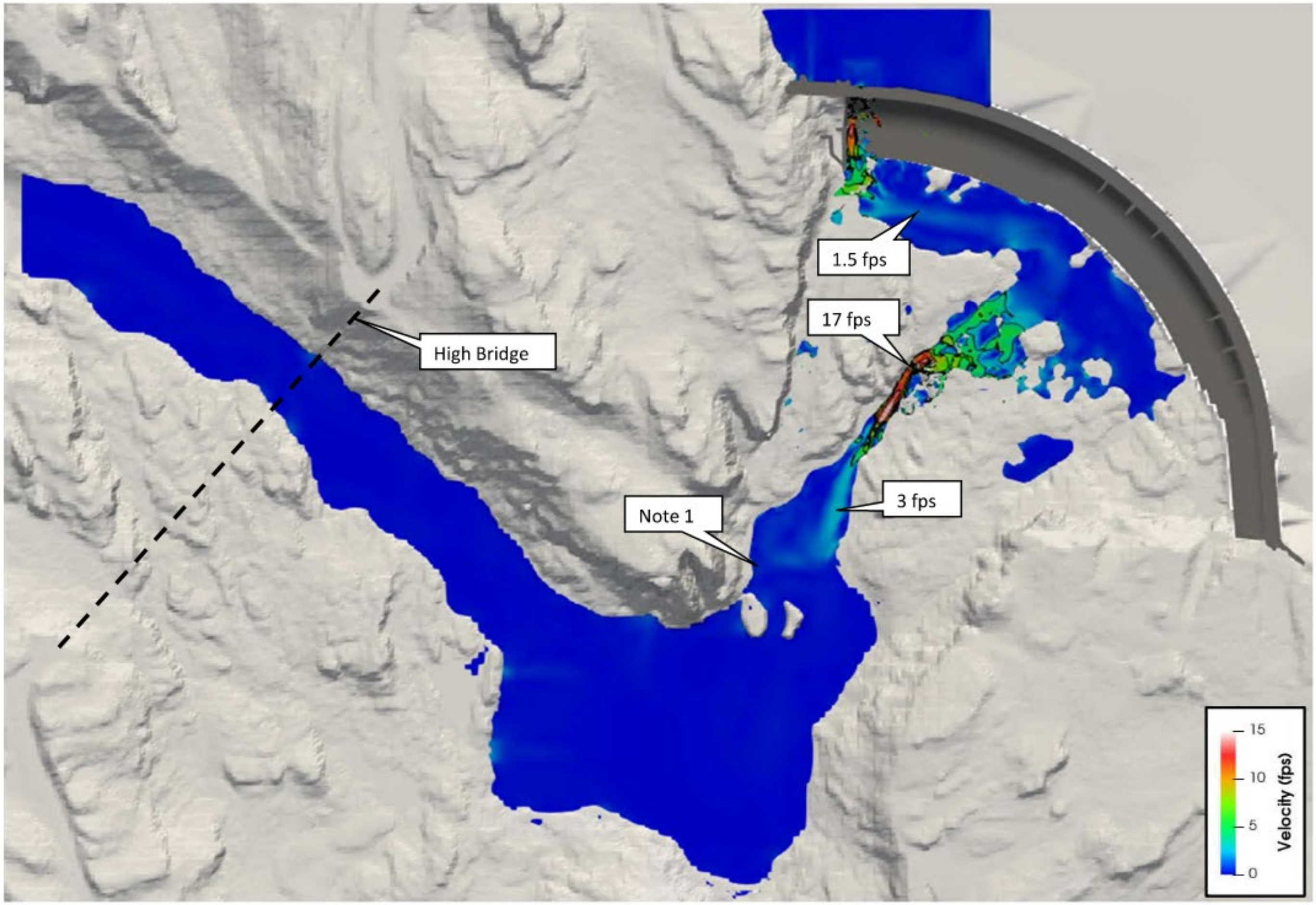
**Figure 3-20. Run 4: 200 cfs Plan View of Flow Depths**




| | | |
|---|---|---|
| Thompson Falls Hydroelectric Project #1869<br>Hydraulic Conditions Study<br>Sanders County, Montana | NorthWestern Energy | RUN 4: 200 CFS<br>PLAN VIEW OF FLOW DEPTHS<br><br>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

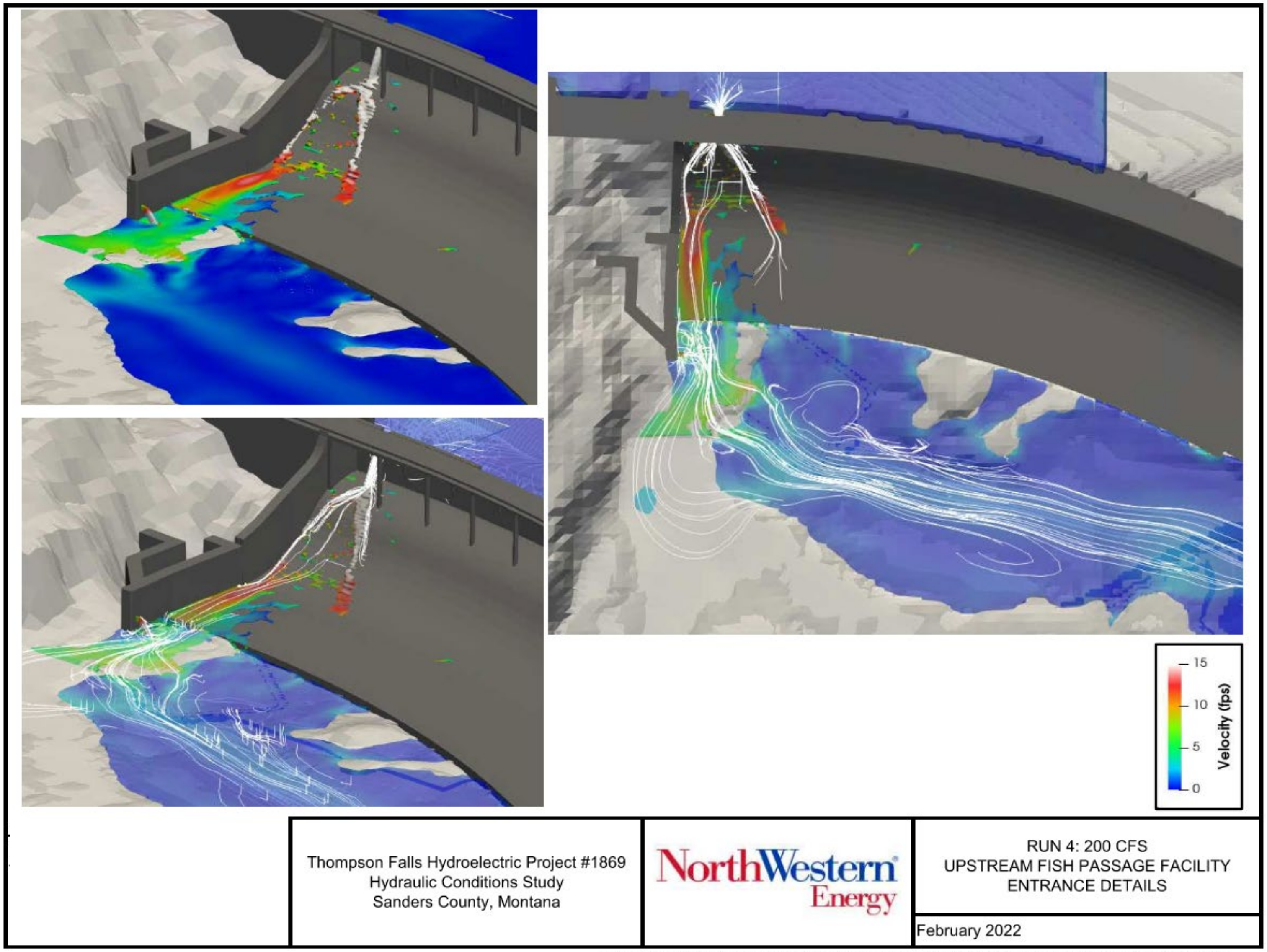
NorthWestern Energy

RUN 4: 200 CFS
PLAN VIEW OF VELOCITIES

February 2022

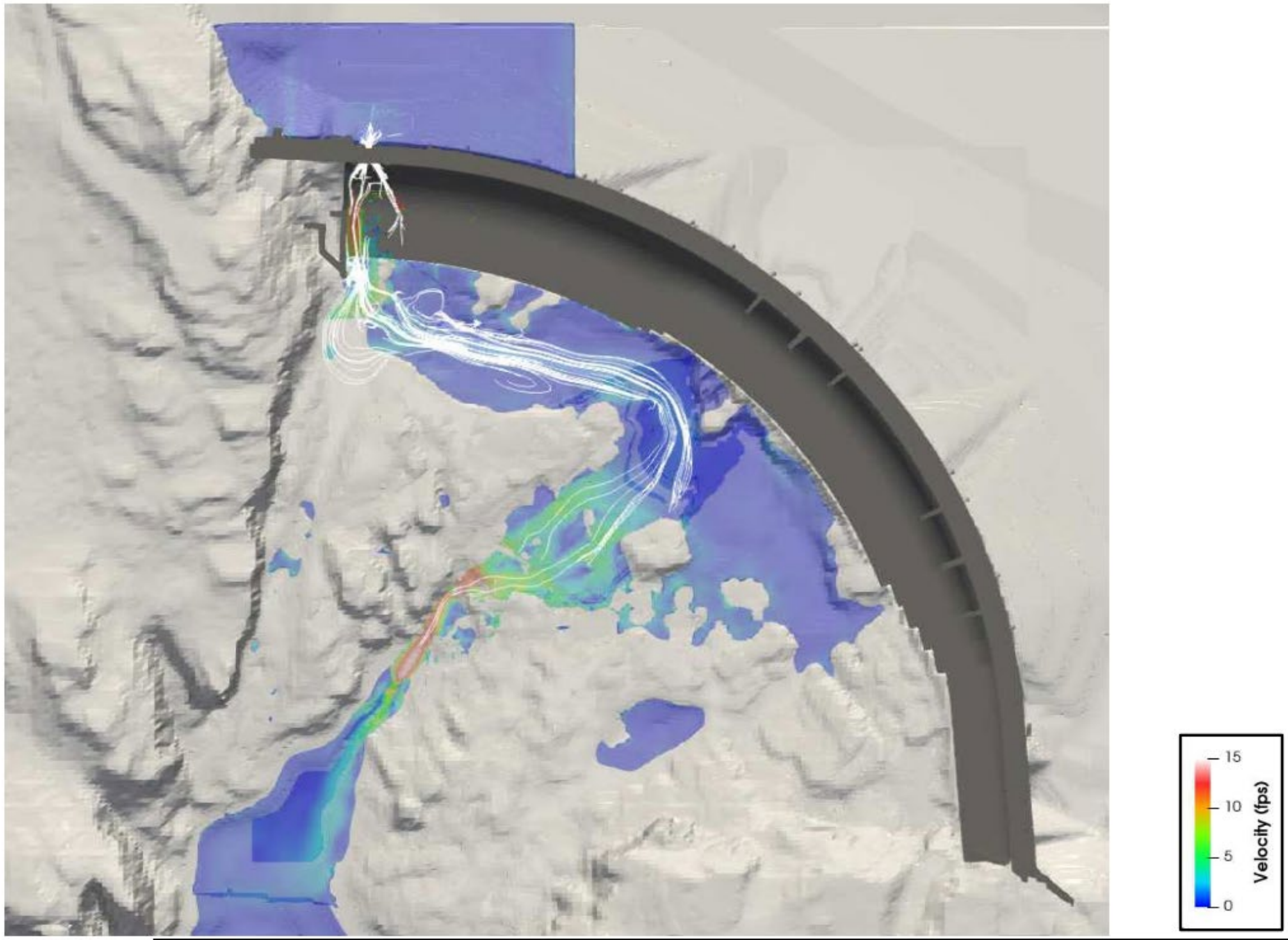
Document Path: \\ore-pzcc-1\ore-data\Projects\NorthWestern Energy\Projects\Relicensing Thompson Falls\Hydraulics Modeling\Report\Figures\[TFallsFigures.xlsx]Figure 8a (3)

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




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

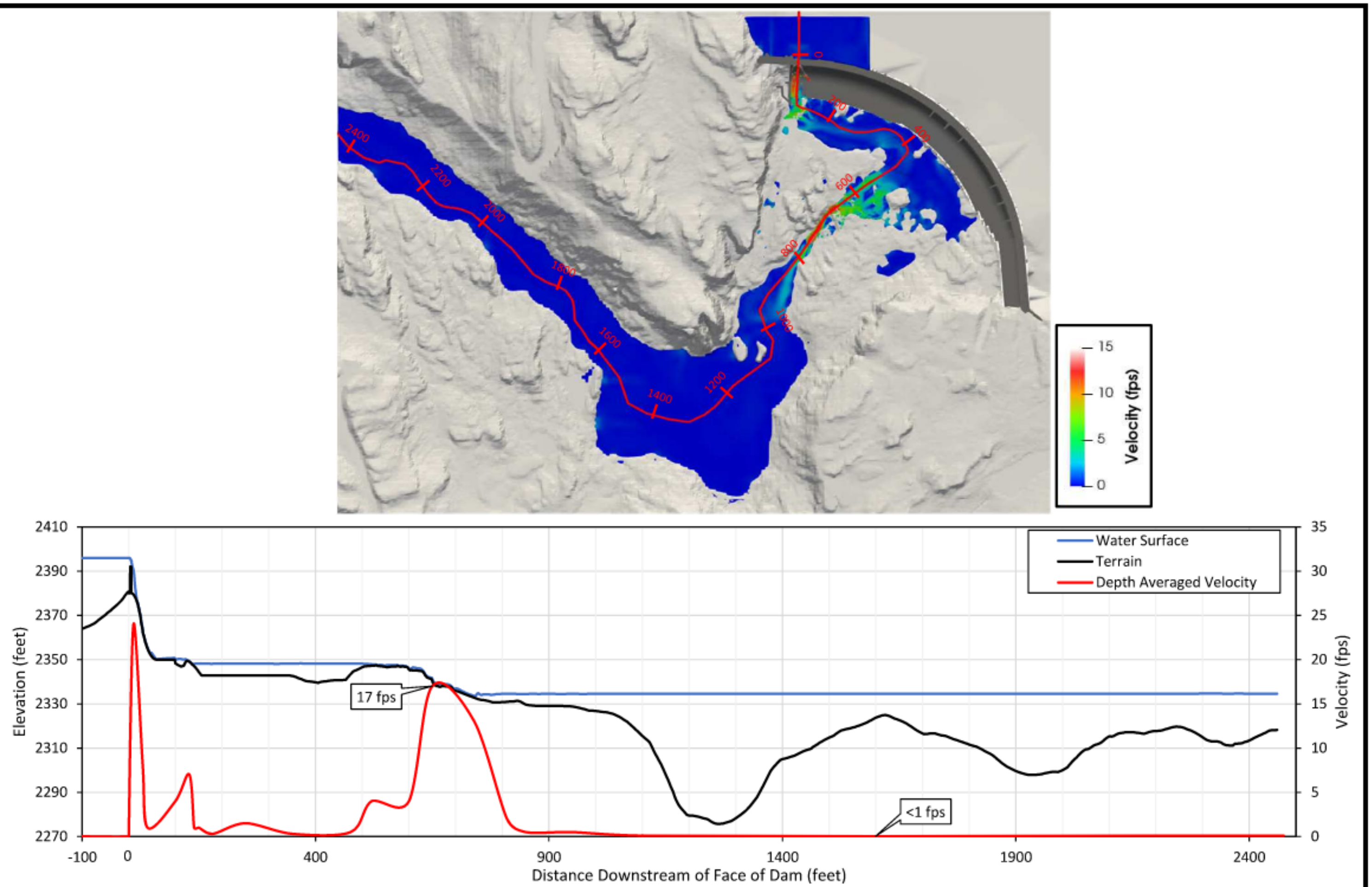
**Figure 3-23. Run 4: 200 cfs Flow Path Streamlines**




| | | |
|---|---|---|
| Thompson Falls Hydroelectric Project #1869<br>Hydraulic Conditions Study<br>Sanders County, Montana | NorthWestern Energy | RUN 4: 200 CFS<br>FLOW PATH STREAMLINES<br><br>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<br>Hydraulic Conditions Study<br>Sanders County, Montana | NorthWestern Energy | RUN 4: 200 CFS<br>PLAN AND PROFILE<br><br>February 2022 |

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

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

**Table 3-1. Results of Thompson Falls Dam Phase 1 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 | 21 | 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

## 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 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 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 Dam. Additional details of the surface roughness sensitivity are provided in Attachment B.

### *3.3.3 Modeling Parameter Sensitivity*

Six different turbulence options are 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 model options are considered to be the most appropriate of the six for the flow conditions at the Main 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 2022). 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 2022). 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 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 Dam.

## 3.4 Phase 2 CFD Model Results

The Phase 2 modeling evaluated conditions at 37,000 and 2,000 cfs. These flows were selected based on an evaluation of historic flow conditions, in coordination with Relicensing Participants, as described in **Section 1.1 – Hydraulic Conditions Study Background** and **Section 2 – Methods**. Results of the modeling at these two flows are as follows.

### *3.4.1 Run 1: 37,000 cfs*

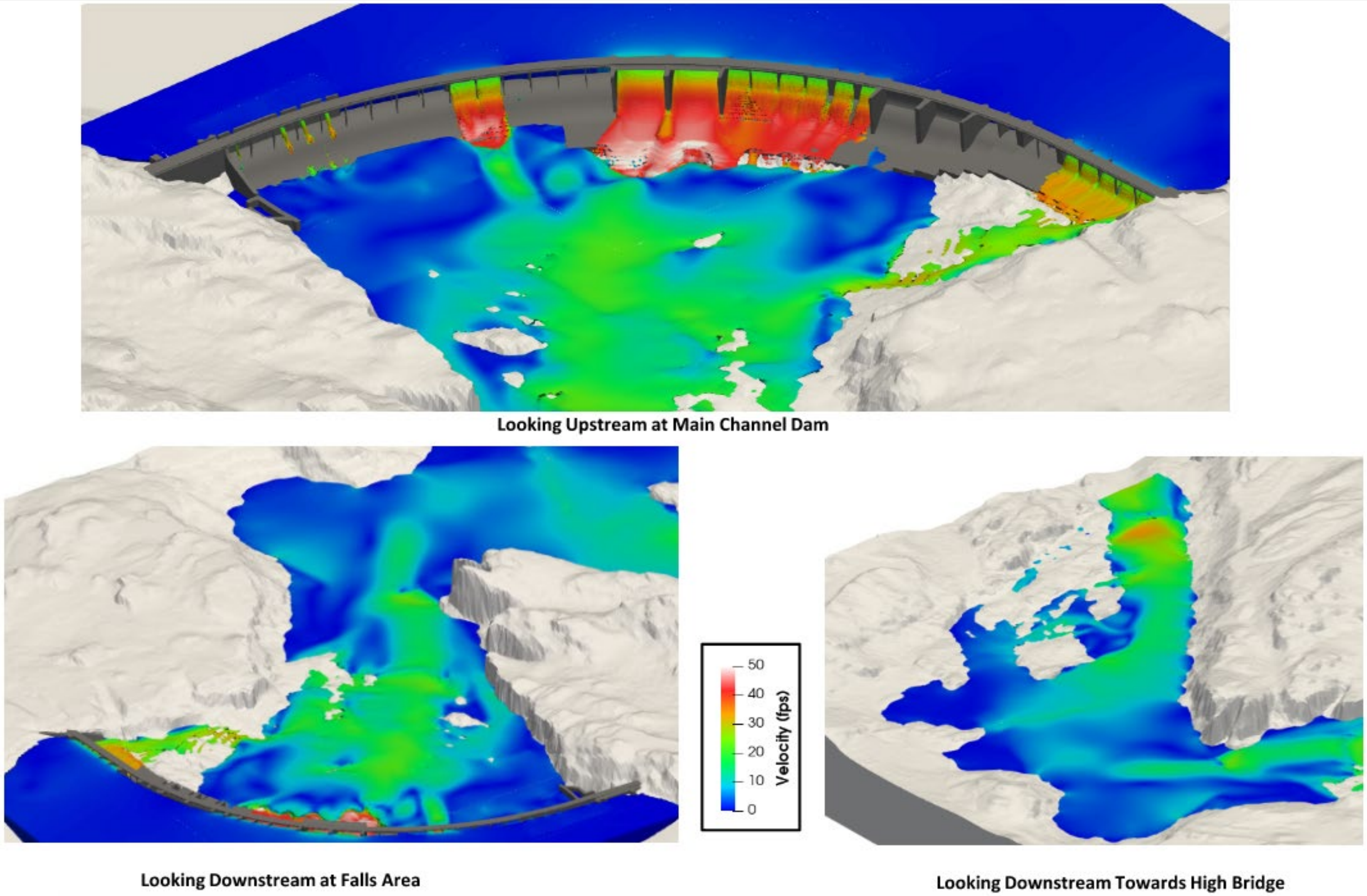
Run 1, with a discharge rate of approximately 37,000 cfs, generally represents the maximum flow rate at which the Upstream Fish Passage Facility is operated. Perspective views of the modeled water surface and velocity gradient output at a steady-state flow condition of 37,000 cfs are depicted in **Figure 3-25**. As shown in Figure 3-25, the flow conditions are generally the same as the Phase 1 study results. In general, the depths and velocities are similar through the downstream reach where the model was refined with a 3D mesh. This is likely due to the relatively deep uniform flow that occurs during the high flow conditions.

Based on a discharge of 37,000 cfs, the CFD model-computed water velocities downstream of the Main Dam generally range from approximately 2 to 21 fps. In general, the highest velocities are on the downstream face of the Main Dam, which are reduced considerably immediately downstream of the Main Dam due to energy dissipation from the highly turbulent flows. A plan view of the categorized water velocities within the model domain are shown in **Figure 3-26**. As indicated in Figure 3-26, the Upstream Fish Passage Facility velocities are relatively low (less than 7 fps) due to the submergence of the HVJ at the Upstream Fish Passage Facility. Within the falls area, water velocities increase, and the majority of the cross-sectional area is above the maximum burst speed (greater than 14 fps) except for isolated locations along the banks of the river. Within the main river channel downstream of the falls, velocities decrease to swimmable velocities 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 above the maximum burst speed (greater than 14 fps), except for along the margins of the downstream river channel. Overall, the 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.

A detailed plan view and cross section views of the categorized water velocity at 37,000 cfs near the Upstream Fish Passage Facility are shown in **Figure 3-27**. As shown in Figure 3-27, the area around the fish ladder entrance and HVJ is generally submerged, resulting in velocities that are below 7 fps, which indicates the areas near the fish ladder entrance are swimmable for most species. In addition, a perspective view of the categorized water velocities at the fish ladder entrance and HVJ at 37,000 cfs is shown in **Figure 3-28**. As shown in Figure 3-28, the HVJ is submerged, and the surrounding velocities generally are below 7 fps.

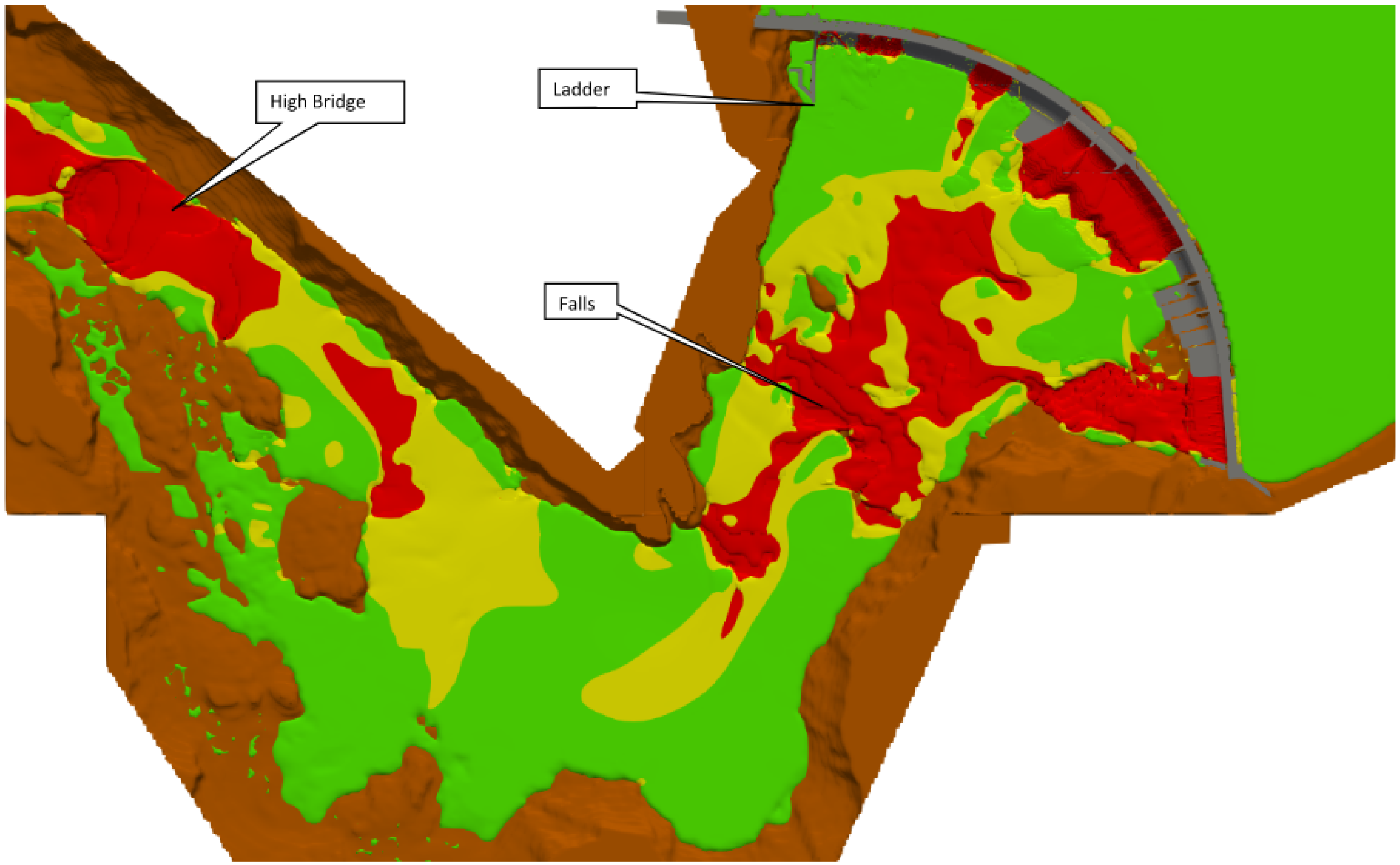
A detailed plan view of the categorized water velocity at 37,000 cfs through the falls area is shown in **Figure 3-29**. Sectional views through the falls area showing the categorized vertical velocity distributions are shown in **Figure 3-30**. As shown in the sectional views, the majority of the cross sections are above 14 fps, except for the areas along the margins of the riverbanks and a couple of isolated areas near the bottom of the channel cross section. This indicates that at a flow rate of 37,000 cfs there are potentially limited areas for the fish to pass through the falls. A detailed plan view and cross section of the categorized water velocities at 37,000 cfs around the High Bridge is shown in **Figure 3-31**. Similar to the falls areas, a flow rate of 37,000 cfs at the High Bridge results in the majority of the river cross section flowing above 14 fps except for the locations along the margins of the river.

**Figure 3-25. Run 1: 37,000 cfs Perspective Views**




| | | | |
|---|---|---|---|
| | Thompson Falls Hydroelectric Project #1869<br>Hydraulic Conditions Study<br>Sanders County, Montana | NorthWestern Energy | RUN 1: 37,000 CFS<br>PERSPECTIVE VIEWS<br>January 2023 |

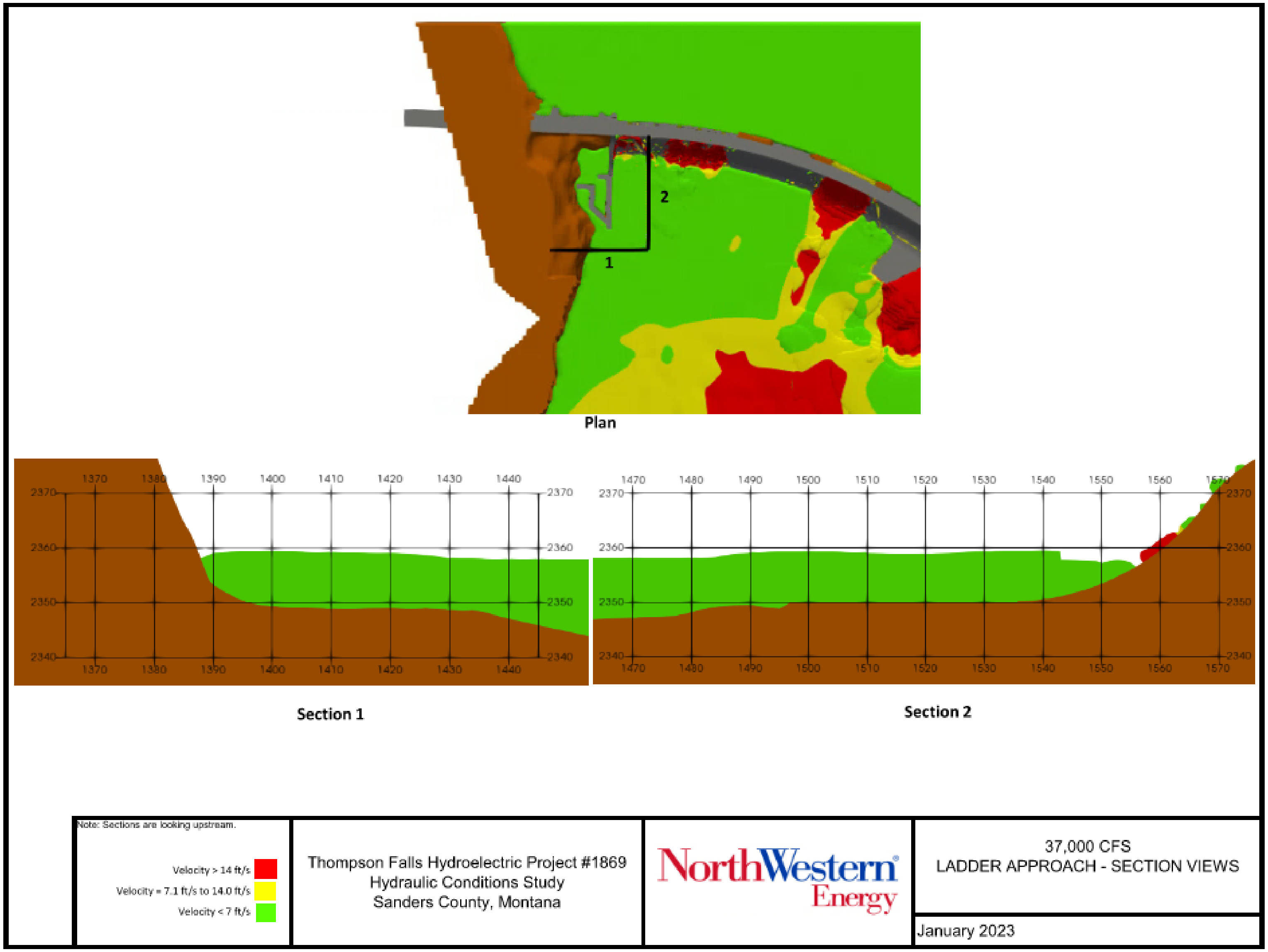
**Figure 3-26. Run 1: 37,000 cfs Overview**




| | | | |
|---|---|---|---|
| Velocity > 14 ft/s<br>Velocity = 7.1 ft/s to 14.0 ft/s<br>Velocity < 7 ft/s | Thompson Falls Hydroelectric Project #1869<br>Hydraulic Conditions Study<br>Sanders County, Montana | NorthWestern Energy | 37,000 CFS<br>OVERVIEW<br>January 2023 |

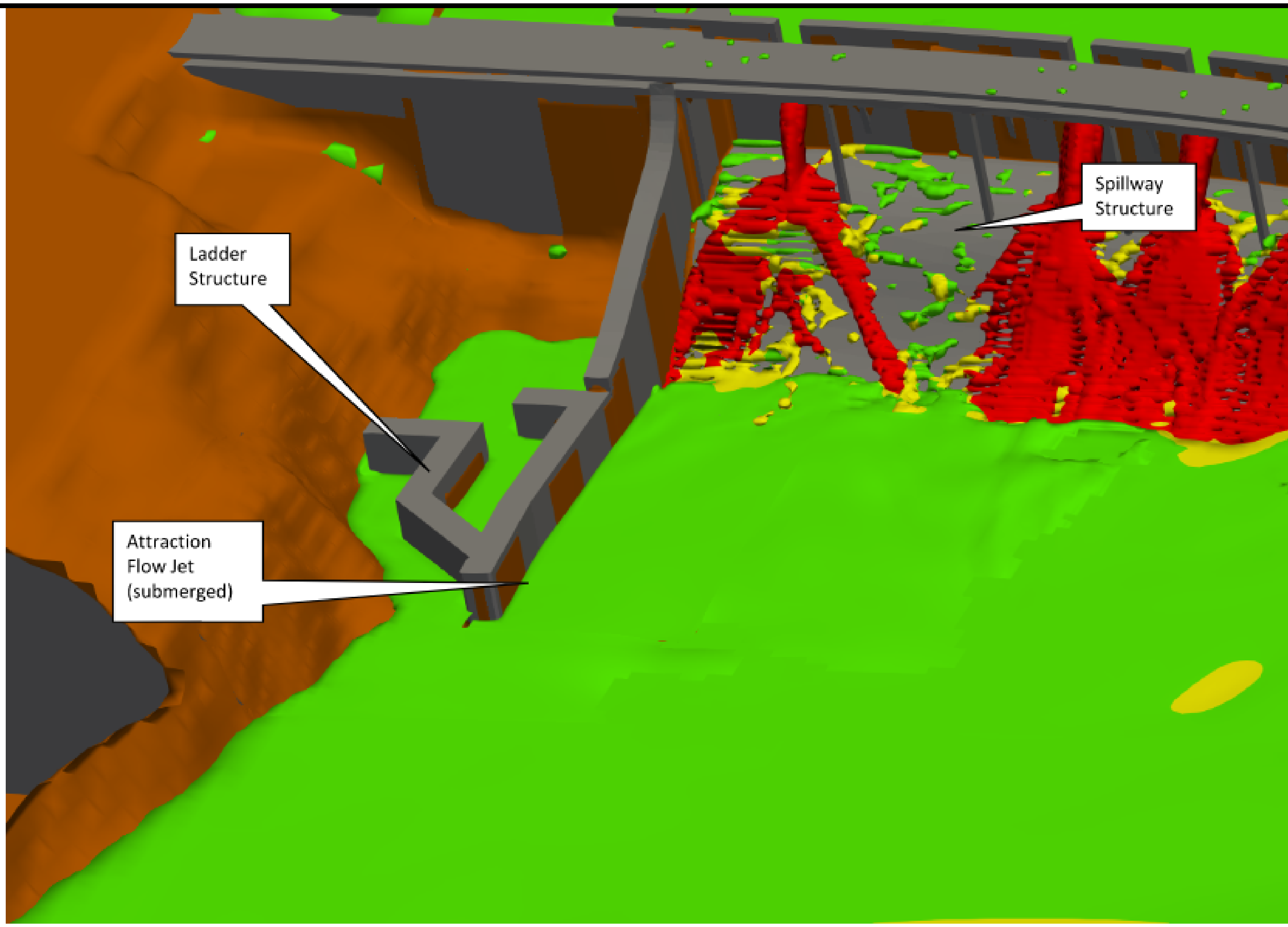
Document Path: \\ORE-pzcc-1\ORE-DATA\Projects\NorthWestern Energy\Projects\Relicensing Thompson Falls\Hydraulics Modeling\Report\Figures\[TFallsFigures2.xlsx]Figure 3-13

**Figure 3-27. Run 1: 37,000 cfs Ladder Approach – Section Views**




Document Path: \\ORE-pzoo-1\ORE-DATA\Projects\NorthWestern Energy\Projects\Relicensing Thompson Falls\Hydraulics Modeling\Report\Figures\[TFallsFigures2.xlsx]Figure 3-13

**Figure 3-28. Run 1: 37,000 cfs Ladder Outlet Isometric View**




Note: Model mesh not optimized to capture attraction flow and ladder apprach area

Velocity > 14 ft/s
Velocity = 7.1 ft/s to 14.0 ft/s
Velocity < 7 ft/s

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

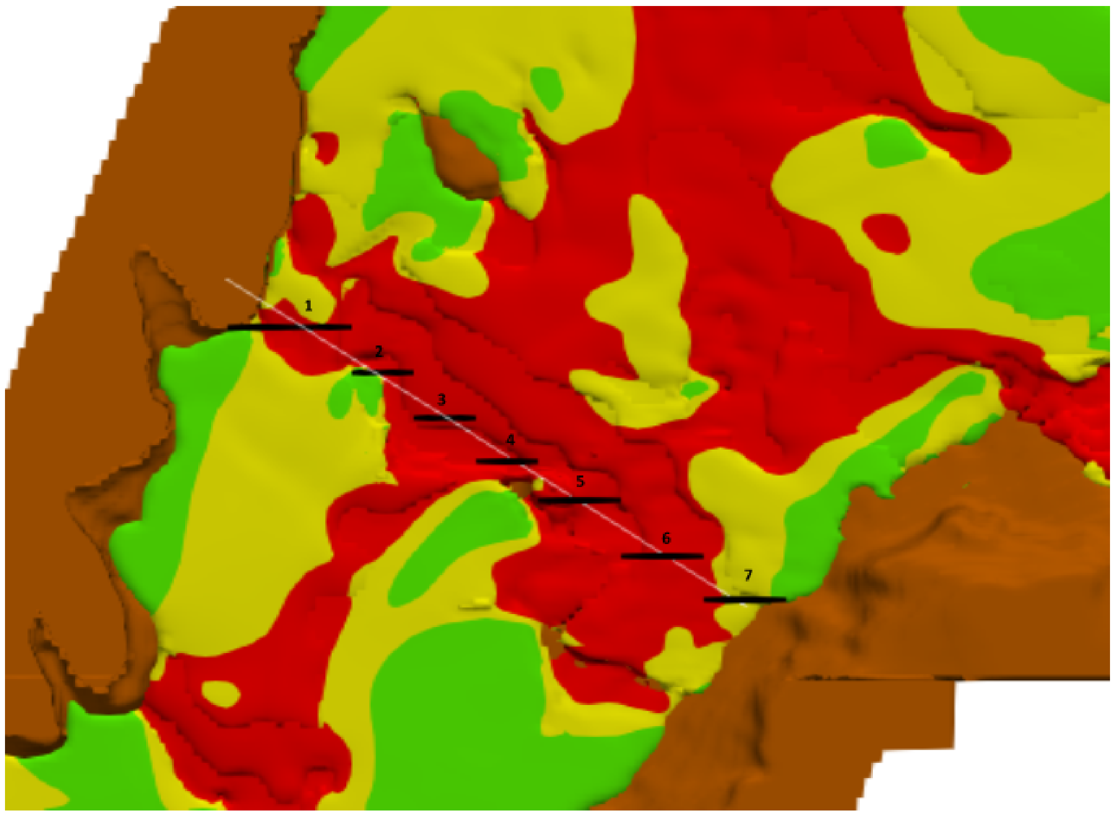
NorthWestern Energy

37,000 CFS
LADDER OUTLET ISOMETRIC VIEW

January 2023

Document Path: \\ORE-pzcc-1\ORE-DATA\Projects\NorthWestern Energy\Projects\Relicensing Thompson Falls\Hydraulics Modeling\Report\Figures\[TFallsFigures2.xlsx]Figure 3-13

**Figure 3-29. Run 1: 37,000 cfs Falls – Plan View**




Note: Sections are looking upstream.

Velocity > 14 ft/s
Velocity = 7.1 ft/s to 14.0 ft/s
Velocity < 7 ft/s

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

NorthWestern Energy

37,000 CFS
FALLS - PLAN VIEW

January 2023

Document Path: \\ORE-pzcc-1\ORE-DATA\Projects\NorthWestern Energy\Projects\Relicensing Thompson Falls\Hydraulics Modeling\Report\Figures\[TFallsFigures2.xlsx]Figure 3-13

Figure 3-30. Run 1: 37,000 cfs Falls Section Views

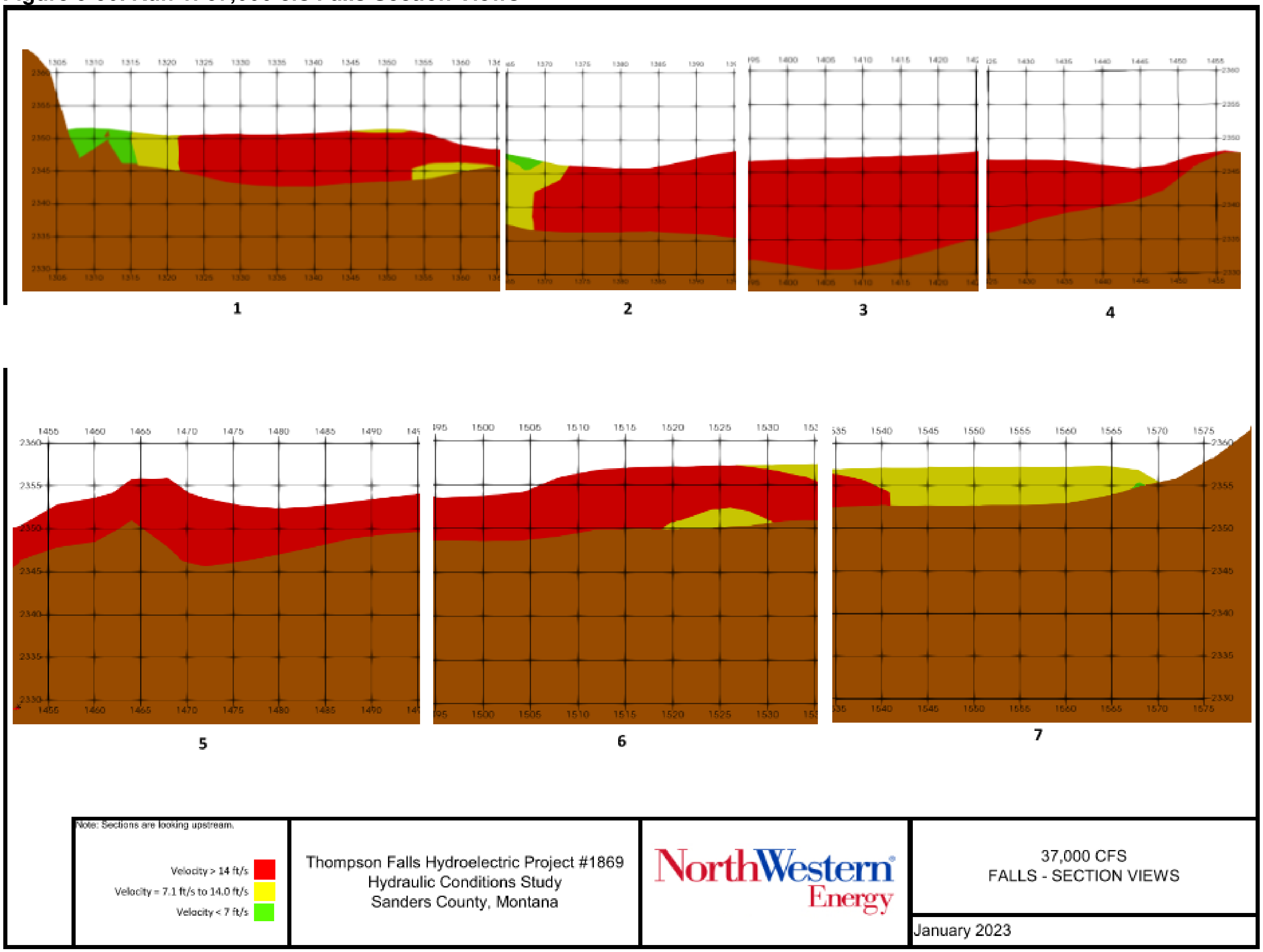
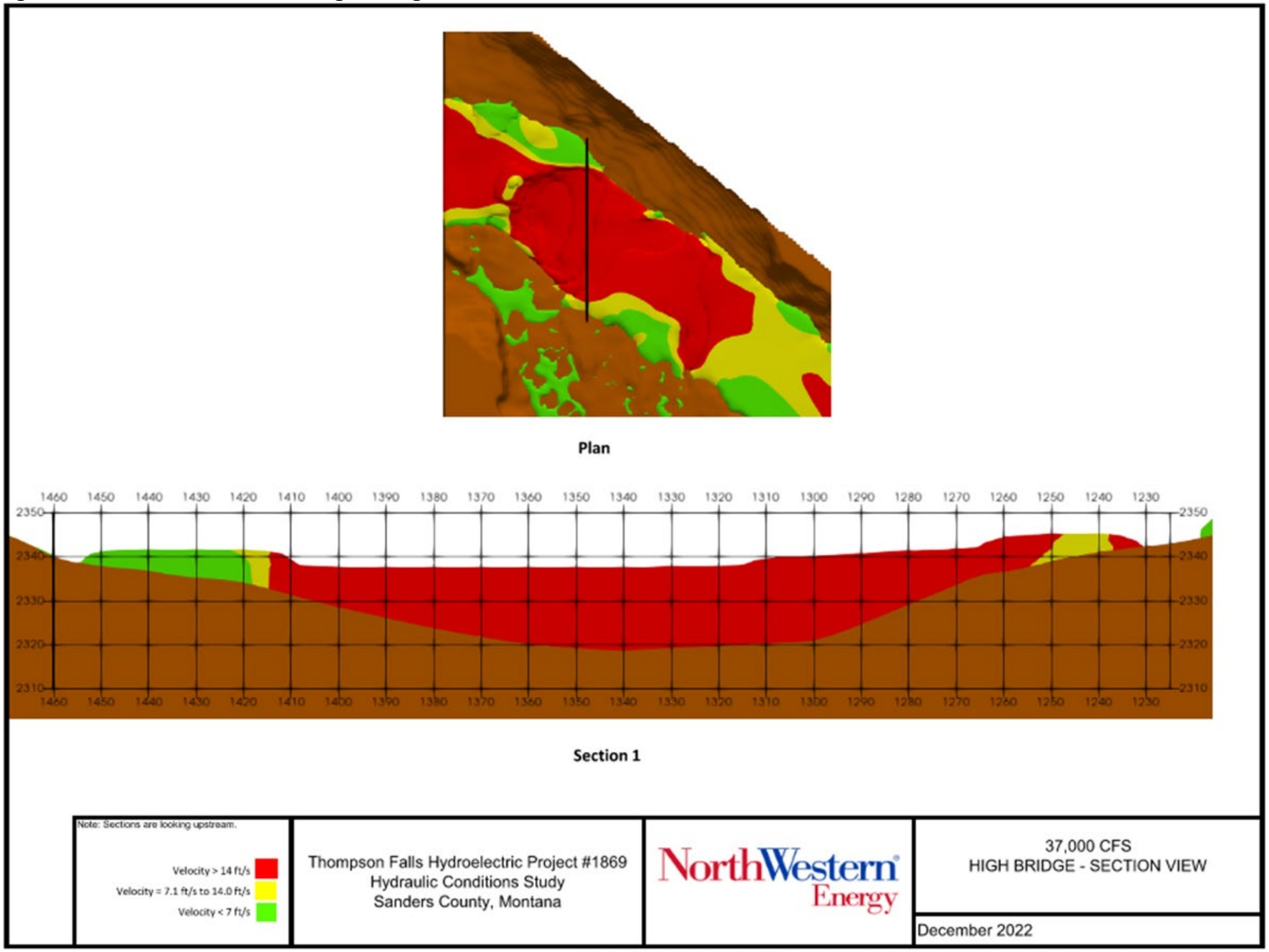


**Figure 3-31. Run 1: 37,000 cfs High Bridge – Section View**




Document Path: \\ORE-pzoo-1\ORE-DATA\Projects\NorthWestern Energy\Projects\Relicensing Thompson Falls\Hydraulics Modeling\Report\Figures\[TFallsFigures2.xlsx]Figure 3-13

[This page intentionally left blank]

### *3.4.2 Run 2: 2,000 cfs*

Run 2, with a discharge rate of approximately 2,000 cfs, generally represents an intermediate flow rate that typically occurs during the ascending and descending limb of the hydrograph each year. 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 3-32**. As shown in Figure 3-32, the flow conditions are generally the same as the Phase 1 study results. In general, the depths and velocities are similar through the downstream reach where the model was refined with a 3D mesh. This is likely due to the relatively deep uniform flow that occurs through the downstream reach under most flow conditions.

Based on a discharge of 2,000 cfs, the CFD model computed water velocities downstream of the Main Dam generally 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 Dam structure. A plan view of the categorized water velocities within the model domain is shown in **Figure 3-33**. As indicated in Figure 3-33, the local Upstream Fish Passage Facility velocities are relatively low (less than 7 fps) with a few isolated areas that are in the intermediate velocity category. Under these flow conditions the Upstream Fish Passage Facility and HVJ are not submerged. Within the falls area, water velocities increase, and the majority of the cross-sectional area is above the maximum burst speed (greater than 14 fps, maximum of 23 fps), except along the banks of the river where velocities are swimmable for fish. Within the main river channel downstream of the falls, velocities decrease to swimmable velocities 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 slightly but the entire cross-sectional area remains below 7 fps. Overall, the 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.

A detailed plan view and cross section views of the categorized water velocity at 2,000 cfs around the Upstream Fish Passage Facility is shown in **Figure 3-34**. As shown in Figure 3-34, the area around the fish ladder entrance is not submerged, resulting in surrounding velocities that are below 7 fps, which indicates the areas near the fish ladder entrance are accessible for most species. In addition, a perspective view of the categorized water velocities at the fish ladder entrance and HVJ at 2,000 cfs is shown in **Figure 3-35**. As shown in Figure 3-35, the HVJ is not submerged, and the HVJ plunges into the downstream areas and the surrounding velocities are generally below 7 fps**.**

A detailed plan view and cross section view of the categorized water velocity at 2,000 cfs through the falls area is shown in **Figure 3-36**. As shown in the sectional view, the majority of the cross section is above 14 fps, except for the areas along the margins of the river. This indicates that at a flow rate of 2,000 cfs there are areas for the fish to pass through the falls. A detailed plan view and cross section of the categorized water velocities at 2,000 cfs around the High Bridge is shown in **Figure 3-37**. As shown in Figure 3-37, a flow rate of 2,000 cfs at the High Bridge results in the entire river cross section flowing below 7 fps.

**Figure 3-32. Run 2: 2,000 cfs Perspective Views**

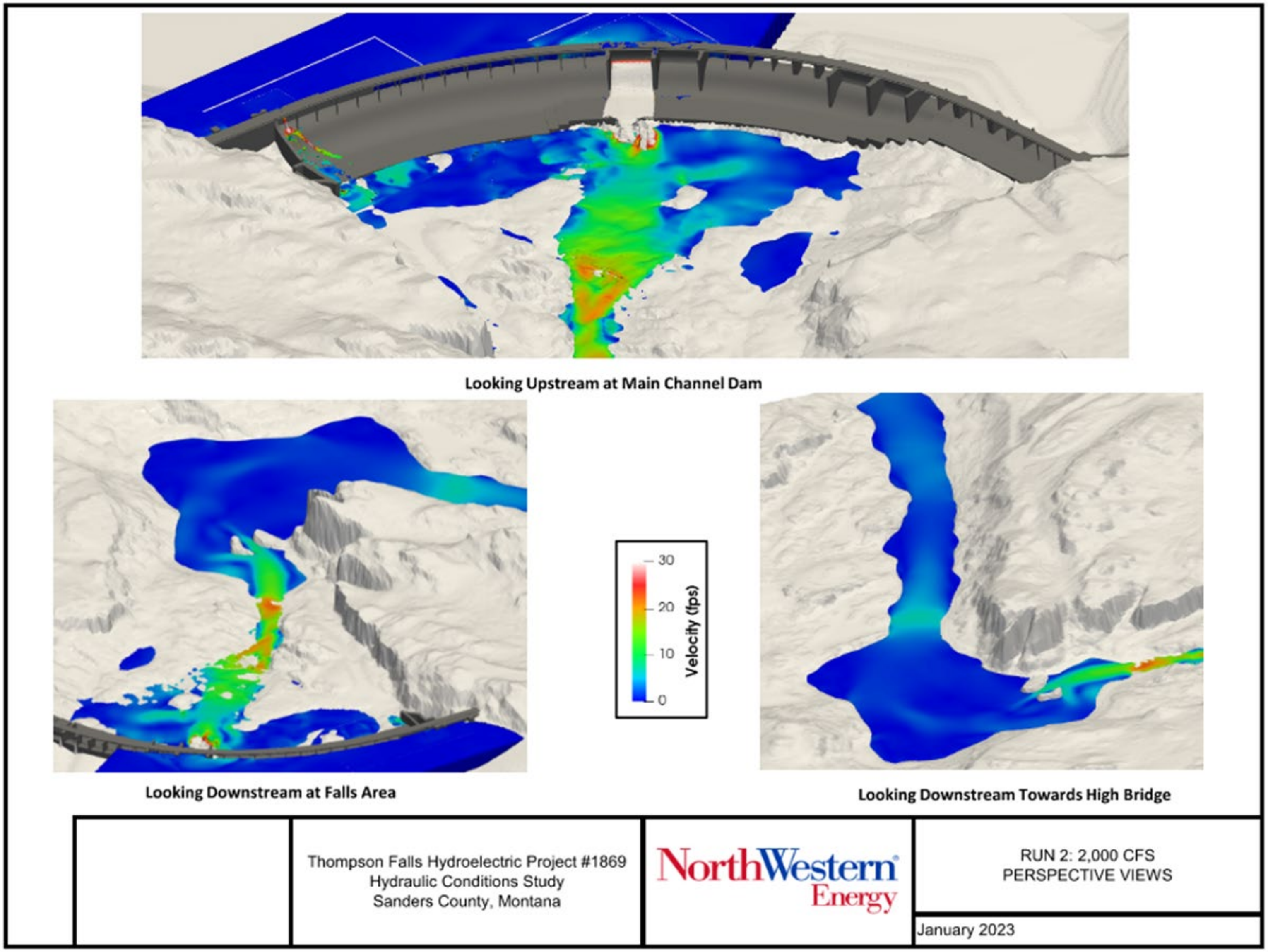
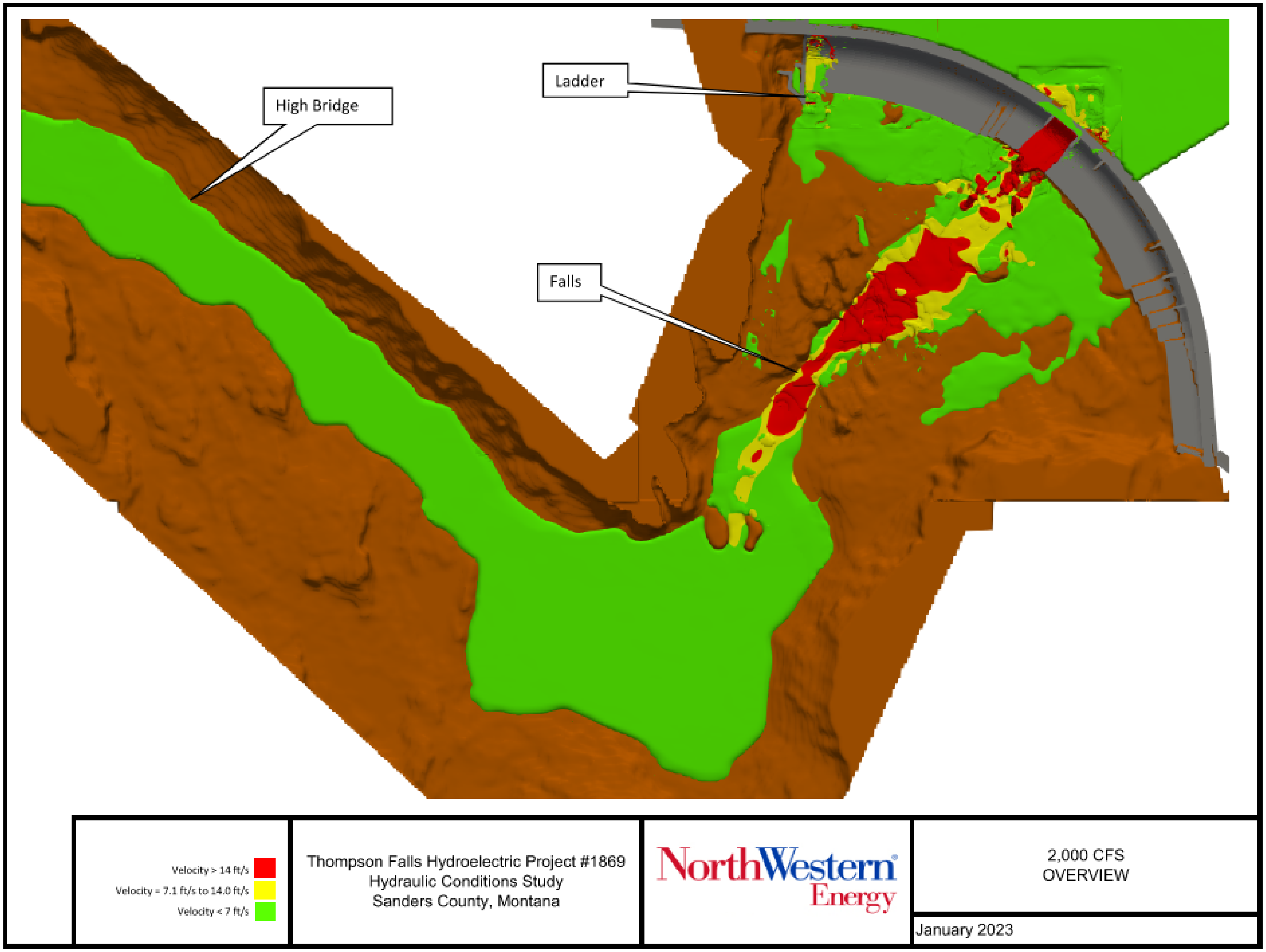
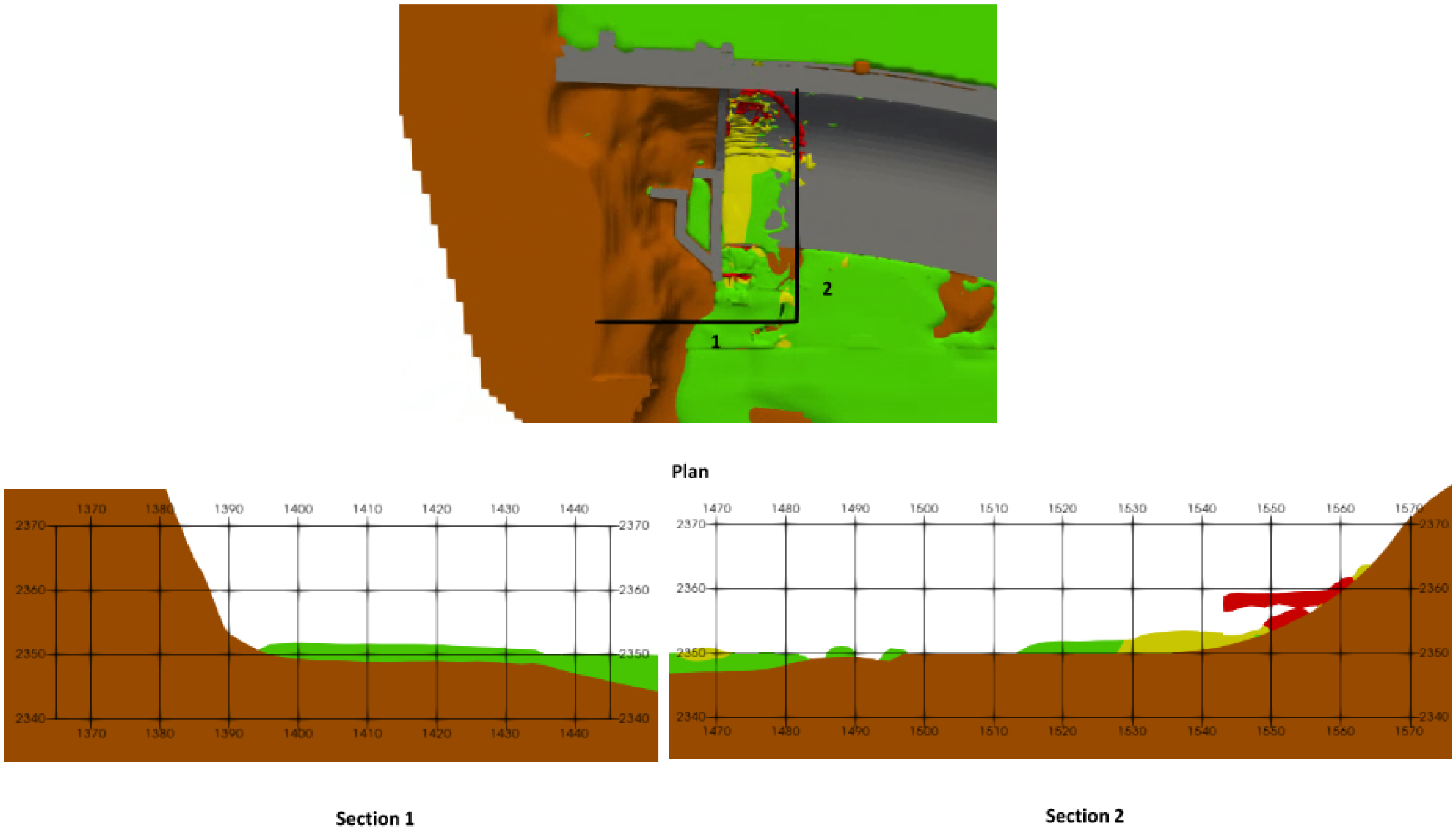


**Figure 3-33. Run 2: 2,000 cfs Overview**




Document Path: \\ORE-pzoo-1\ORE-DATA\Projects\NorthWestern Energy\Projects\Relicensing Thompson Falls\Hydraulics Modeling\Report\Figures\[TFallsFigures2.xlsx]Figure 3-13

**Figure 3-34. Run 2: 2,000 cfs Ladder Approach – Section Views**




Note: Sections are looking upstream.

Velocity > 14 ft/s

Velocity = 7.1 ft/s to 14.0 ft/s

Velocity < 7 ft/s

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

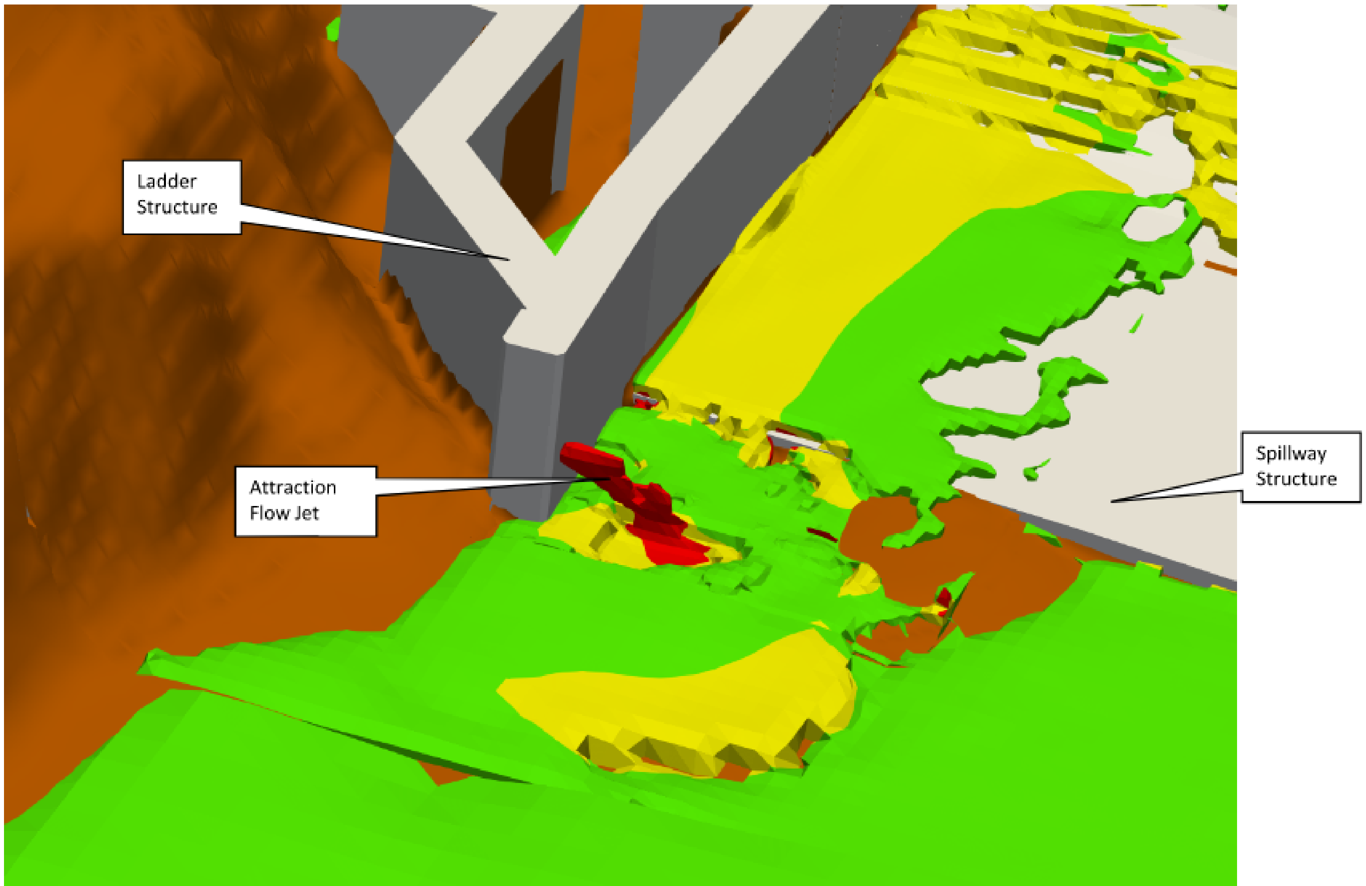
NorthWestern Energy

2,000 CFS
LADDER APPROACH - SECTION VIEWS

January 2023

Document Path: \\ORE-pzcc-1\ORE-DATA\Projects\NorthWestern Energy\Projects\Relicensing Thompson Falls\Hydraulics Modeling\Report\Figures\[TFallsFigures2.xlsx]Figure 3-13

**Figure 3-35. Run 2: 2,000 cfs Ladder Outlet Isometric View**




Note: Model mesh not optimized to capture attraction flow and ladder apprach area

Velocity > 14 ft/s
Velocity = 7.1 ft/s to 14.0 ft/s
Velocity < 7 ft/s

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

NorthWestern Energy

2,000 CFS
LADDER OUTLET ISOMETRIC VIEW

January 2023

Document Path: \\ORE-pzcc-1\ORE-DATA\Projects\NorthWestern Energy\Projects\Relicensing Thompson Falls\Hydraulics Modeling\Report\Figures\[TFallsFigures2.xlsx]Figure 3-13

**Figure 3-36. Run 2: 2,000 cfs Falls – Section Views**

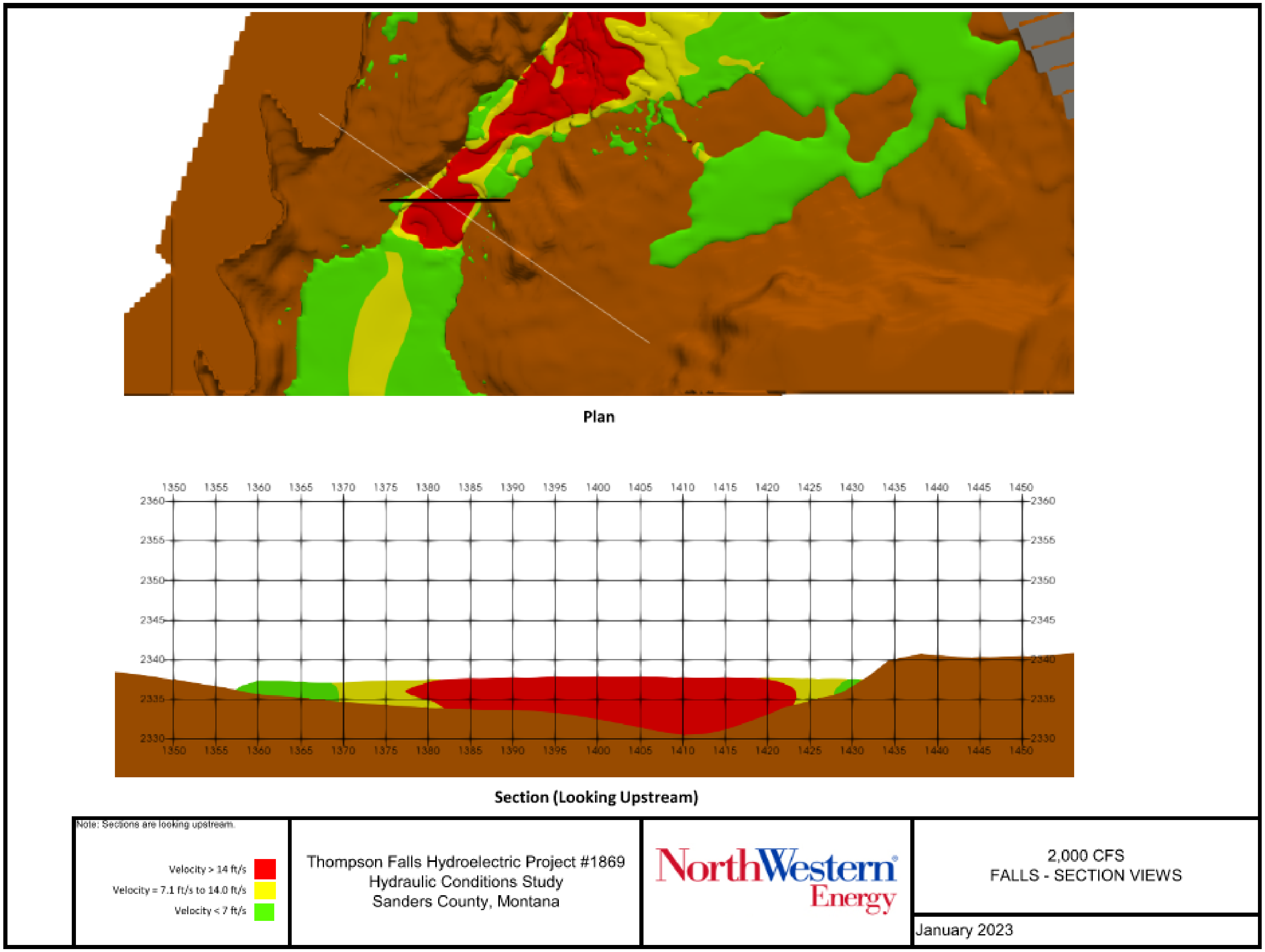
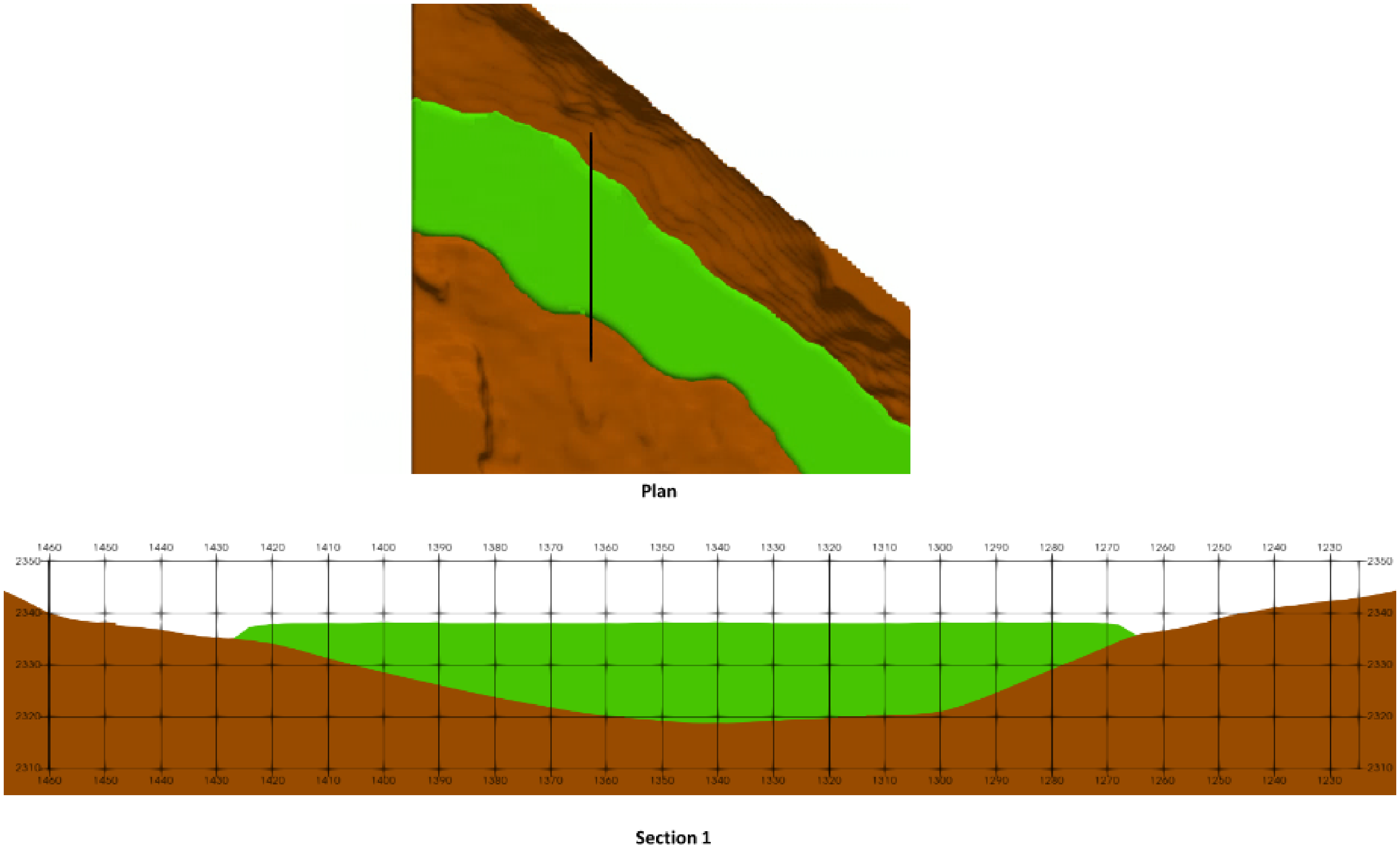


**Figure 3-37. Run 2: 2,000 cfs High Bridge– Section View**




| | | | |
|---|---|---|---|
| Note: Sections are looking upstream.<br>Velocity > 14 ft/s<br>Velocity = 7.1 ft/s to 14.0 ft/s<br>Velocity < 7 ft/s | Thompson Falls Hydroelectric Project #1869<br>Hydraulic Conditions Study<br>Sanders County, Montana | NorthWestern Energy | 2,000 CFS<br>HIGH BRIDGE - SECTION VIEW<br><br>January 2023 |

Document Path: \\ORE-pzcc-1\ORE-DATA\Projects\NorthWestern Energy\Projects\Relicensing Thompson Falls\Hydraulics Modeling\Report\Figures\[TFallsFigures2.xlsx]Figure 3-13

### 3.4.3 Phase 2 Modeling Summary

During Phase 2 of the study, the full model domain was analyzed using 3D modeling to evaluate the vertical velocity distributions of flow downstream of the Main Dam. Additional evaluations during Phase 2 of the study evaluated 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. The Phase 2 portion of the study identified three critical areas in the downstream reach on which to focus the modeling including the area near the ladder entrance, the falls area and the High Bridge area. The results were evaluated based on three categories related to the swimming ability of the fish discussed above. Based on the 3D modeling results, the percent of the cross-sectional area for each velocity category was determined for each of three identified critical areas. The percent of the cross-sectional area for each velocity category at the ladder entrance, falls, and High Bridge areas are summarized in **Table 3-4**.

**Table 3-4. Results of Thompson Falls Dam Phase 2 CFD Modeling**

| Location | | Ladder Entrance | | Falls Area | | High Bridge | |
|---|---|---|---|---|---|---|---|
| Flow Rate (cfs) | | 37,000 | 2,000 | 37,000 | 2,000 | 37,000 | 2,000 |
| Category Description | Velocity Range (ft/sec) | Percent of Cross-Sectional Area (%) | | | | | |
| Maximum Prolonged Swim Speed | 0-7.0 | 100 | 79 | 2 | 8 | 7 | 100 |
| Intermediate Swim Speed Range | 7.1-14.0 | 0 | 21 | 14 | 16 | 4 | 0 |
| Exceeds Maximum Burst Speed | >14.0 | 0 | 0 | 84 | 76 | 89 | 0 |

As shown in Table 3-4, for both flow rates evaluated, the fish passage facility entrance generally has large portions of the cross section that are below 7 fps, with negligible areas that exceed the maximum burst speed of 14 fps. These data indicate no impediments to fish passage in the area surrounding the upstream fish passage facility entrance.

Conversely, for both flow rates evaluated, the falls area has large portions of the cross section that exceed 14 fps, with limited areas that are below 7 fps.

At the High Bridge area, the results vary depending on the flow rate evaluated. At the higher flow, the majority of the cross-section velocity exceeds 14 fps with limited areas that are below 7 fps. At the lower flow rate, the High Bridge velocities are all under 7 fps.

Overall, the CFD modeling results indicate the falls area is the critical area for fish passage upstream and could potentially be an obstacle that limits fish passage.

# 4.0 Discussion

## 4.1 Phase 1: 2D Model

The Phase 1 study results provide an estimate of the hydraulic conditions of the Main Dam and fish passage facility including flow depths, velocities, and patterns in the downstream channel for 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 of the Main Dam vary considerably but present a similar pattern.

In the area immediately downstream of the fish passage facility entrance, two different flow patterns were observed in the four scenarios evaluated. At higher flows (Run 1 and Run 2), the outlet of the fish passage facility and HVJ are submerged, resulting in these structures having minimal influence on the surrounding flow velocities. This is also evident based on the flow path streamlines, which show most of the flow path streamlines concentrated over the Main Dam gates and through the falls area. These modeling results indicate that at higher flows the attraction flow at the fish passage facility may be insufficient to provide efficient fish passage.

During lower flows (Run 3 and Run 4), the HVJ is not submerged and the discharges from the upstream fish passage entrance produce a significant portion of the flow in this area. Therefore, at these lower flow rates, most of the flow path streamlines are concentrated near the entrance of the fish passage facility. These results indicate improved fish attraction to the fish passage facility entrance.

Away from the fish passage entrance, the pools and channel immediately downstream of the Main Dam reduce the velocities and increase flow depths prior to the flow entering the highly turbulent falls area where velocities substantially increase. Velocities generally range from a few feet per second up to 27 fps over the falls area. Even at the lowest flow modeled, 200 cfs, the velocity through the falls is 17 fps, indicating that the falls is a potential obstacle to fish passage at all modeled flows.

Downstream of the falls area, the flow enters the main river channel, where the sharp right bend in the channel at the Dollar Hole has the greatest depths in the modeled reach. In this area, velocities are reduced as the flow turns right toward the High Bridge. Even at the highest flow modeled, 37,000 cfs, the depth averaged velocity in the area of the Dollar Hole was as low as 6 fps.

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. Velocities and depths tend to increase again due to the narrowing of the channel before discharging downstream of the bridge. At the highest flows modeled, depth averaged velocities in the area downstream of the High Bridge were as high as 20 fps. At the lower modeled flows, the area downstream of the High Bridge has moderate velocity and is unlikely to be an obstacle to fish passage.

## 4.2 Phase 2: 3D Model

During Phase 2 of the study, the full model domain was analyzed using 3D modeling to better evaluate the vertical velocity distributions of flow downstream of the Main Dam. Phase 2 evaluated 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 (*refer to* Figure 2-5). During Phase 2 of the study three critical areas in the downstream reach were identified on which to focus the modeling; the area near the ladder entrance, the falls area and the High Bridge area. The 3D model allowed for several cross sections to be established to provide a detailed assessment of the vertical distribution of flow velocities at these cross sections. The results were evaluated based on three categories; velocities below the maximum prolonged swim speed of fish, velocities in the intermediate swim speed range, and velocities that exceed the maximum burst speed of fish. Based on the 3D modeling results, the percent of the cross-sectional area for each velocity category was determined for each of the three identified critical areas.

In general, the 3D cross sections show the greatest velocities in the center of the river channel, with lower velocities along margins of the river channel. These areas along the margins provide more suitable velocities for upstream fish passage.

Under both model scenarios, velocities at the fish passage entrance were below 7 fps, well within the swimming abilities of the native and salmonid fish species of interest. Fish that successfully navigate upstream of the falls can access the fish passage facility without encountering further velocity barriers.

However, as described above, there may be insufficient attraction flow for fish to locate the entrance to the fish passage facility at high flows.

The 3D model results showed a large percentage of the falls transects exceed most fish swimming abilities under both flow scenarios modeled. At the lower flow modeled (2,000 cfs), 24 percent of the cross section of the natural falls was below the maximum burst speed for fish. However, fish are collected at the fish passage facility routinely when flows are 2,000 cfs or higher (NorthWestern 2019), so at least some fish are finding the areas along the margins of the channel or other pathways with suitable velocities for fish passage. In addition, as described above, the model calculations may not capture all the details of the underlying rocky terrain surface, particularly overhangs or undercuts that do not show up in a bathymetric survey. Fish swimming along the bottom of the river channel may successfully navigate upstream by taking advantage of velocity breaks and barriers that are not apparent in the modeling.

The high flow scenario also revealed potential velocity obstacles for fish at the High Bridge, with 89 percent of the cross section having velocities in excess of the maximum burst speed.

The potential fish passage obstacle at the High Bridge does not appear to be present in the low flow scenario, when the entire cross section is below the maximum prolonged swimming speed.

[This page intentionally left blank]

# 5.0 Literature Cited


Beamish, F.W.H. 1978. Swimming capacity. Fish physiology. Academic Press, New York.

Chow, V.T. 1959. Open Channel Hydraulics. McGraw-Hill Book Company, Inc., New York.

Federal Energy Regulatory Commission (FERC). 2009. Order Approving Construction and Operation of Fish Passage Facility. February 12, 2009. 126 FERC 62,105.

Flow Science. 2022. FLOW-3D Hydro 2022R1 Users Manual.

NorthWestern Energy (NorthWestern). 2019. Thompson Falls Hydroelectric Project FERC Project No. 1869, Comprehensive Phase 2 Final Fish Passage Report. Electronically filed with FERC on December 23, 2019. https://www.northwesternenergy.com/docs/default-source/default-document-library/clean-energy/environmental-projects/thompson-falls/2020comprehensivefishladderreport.pdf?sfvrsn=1a815b1a_7. Accessed on March 8, 2023.

NorthWestern Energy (NorthWestern). 2021. Thompson Falls Hydroelectric Project FERC Project No. 1869, Revised Study Plan. https://www.northwesternenergy.com/docs/default-source/default-document-library/clean-energy/environmental-projects/thompson-falls/thompson-falls-relicensing/revised-study-plan-project-no.-1869.pdf

NorthWestern Energy (NorthWestern). 2022a. Thompson Falls Hydroelectric Project FERC Project No. 1869, NorthWestern Energy. Initial Study Report – Hydraulic Conditions Study. April 2022 https://www.northwesternenergy.com/docs/default-source/default-document-library/clean-energy/environmental-projects/thompson-falls/thompson-falls-relicensing/p1869-isr-hydraulic-conditions-study.pdf. Accessed on March 8, 2023.

_____________. 2022b. Thompson Falls Hydroelectric Project FERC Project No. 1869, NorthWestern Energy. Initial Study Report - Fish Behavior Study. April 2022. https://www.northwesternenergy.com/docs/default-source/default-document-library/clean-energy/environmental-projects/thompson-falls/thompson-falls-relicensing/p1869-isr-fish-behavior-study-.pdf. Accessed on March 8, 20223.

_____________. 2022c. Thompson Falls Hydroelectric Project FERC Project No. 1869, NorthWestern Energy. Interim Study Report – Hydraulic Conditions Study. February 2022.

PPL Montana. 2010. Total Dissolved Gas Control Plan: Thompson Falls Hydroelectric Project FERC Project Number 1869. Submitted to: Montana Department of Environmental Quality. Submitted by: PPL Montana. October. https://www.northwesternenergy.com/docs/default-source/default-document-library/clean-energy/environmental-projects/thompson-falls/thompson_falls_total_dissolved_gas_control_plan_2010.pdf?sfvrsn=99d21ecd_7. Accessed on March 8, 20223.

Thompson Falls Scientific Review Panel (Scientific Panel). 2020. Memorandum to NorthWestern Energy and Thompson Falls Technical Advisory Committee. Subject: Thompson Falls Fish Ladder Review. March 27, 2020. (E-Filed with FERC.) https://www.northwesternenergy.com/docs/default-source/default-document-library/clean-energy/environmental-projects/thompson-falls/expert-panel-review-of-fish-passage-2020.pdf?sfvrsn=21d02947_7. Accessed on March 8, 20223.

U.S. Fish and Wildlife Service (FWS). 2008. Biological Opinion for Thompson Falls Hydroelectric Project Bull Trout Consultation. Federal Energy Regulatory Commission Docket No. 1869-048 – Montana. PPL Montana, LLC, Licenses. Prepared by FWS Montana. https://www.northwesternenergy.com/docs/default-source/default-document-library/clean-energy/environmental-projects/thompson-falls/thompson_falls_biological_opinion_2008.pdf?sfvrsn=c55a05c5_7. Accessed on March 8, 20223.

Washington Group International (WGI). 2016. Supporting Technical Information Document: Thompson Falls Hydroelectric Project: Federal Energy Regulatory Commission Licensed Project No. 1869. Prepared for PPL Montana. August.

# Attachment A – Bathymetric Surveying Information

[This page intentionally left blank]

**Table A-1. Area of Bathymetric Survey**


| 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
1055 Mount Avenue
Missoula, MT 59801
406.542.8880
www.m-m.net



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

**Table A-2. LiDar to MMI GNSS Comparison**

| 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

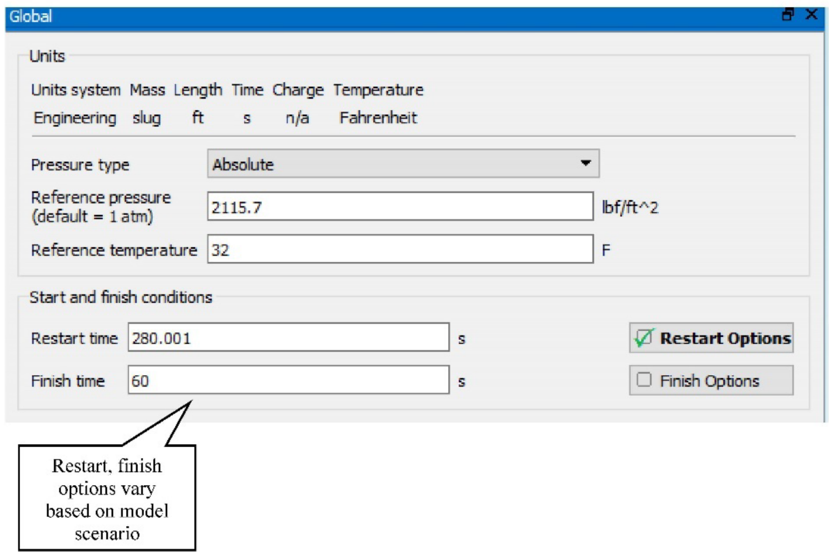
Number Failed: 0

| | 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 |

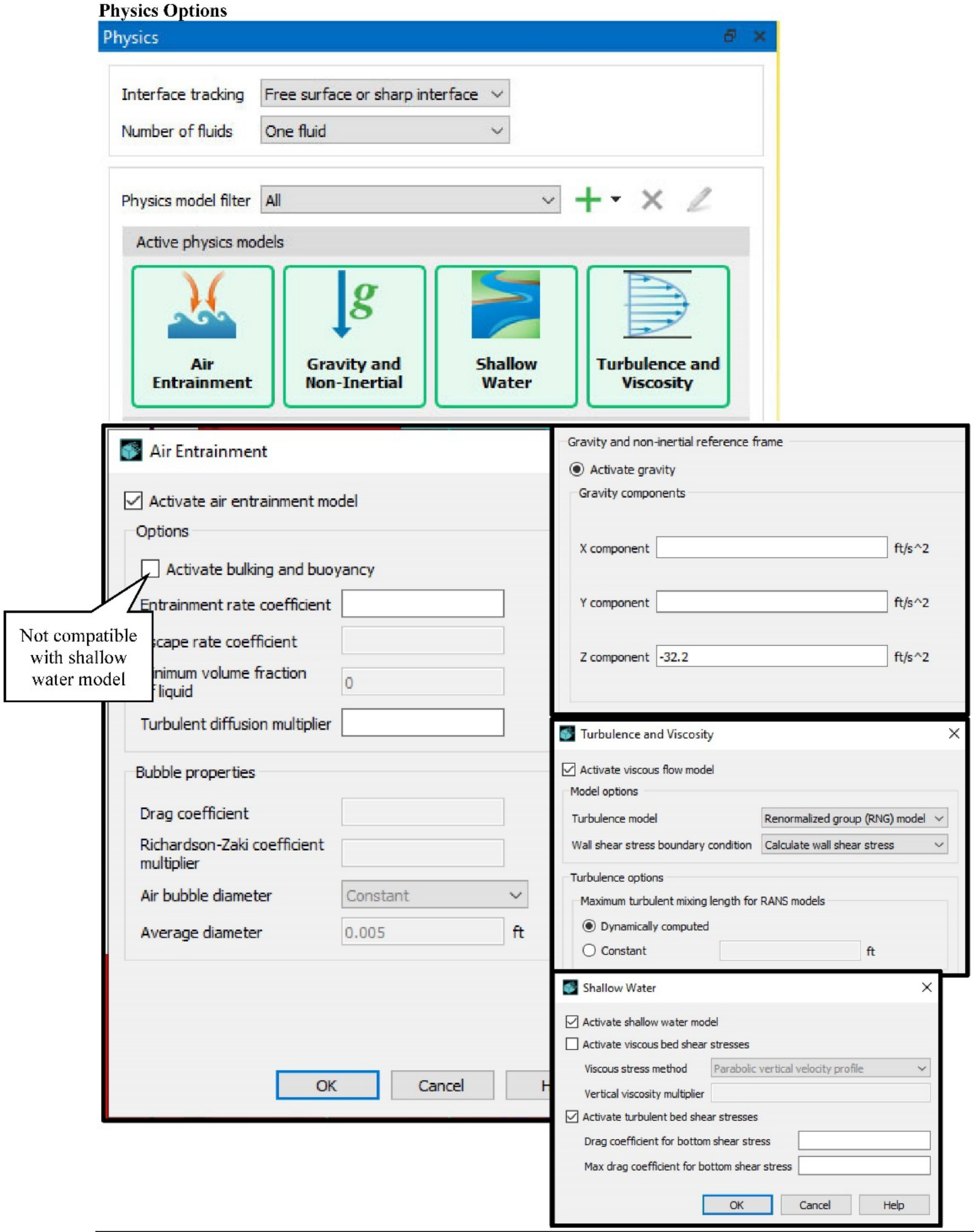
[This page intentionally left blank]

# Attachment B – CFD Model Setup and Results

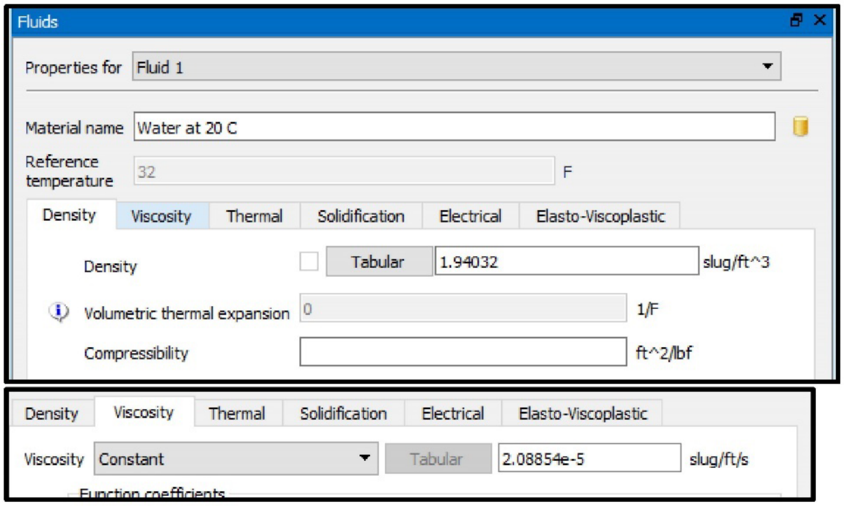
**Global Options**



**Physics Options**



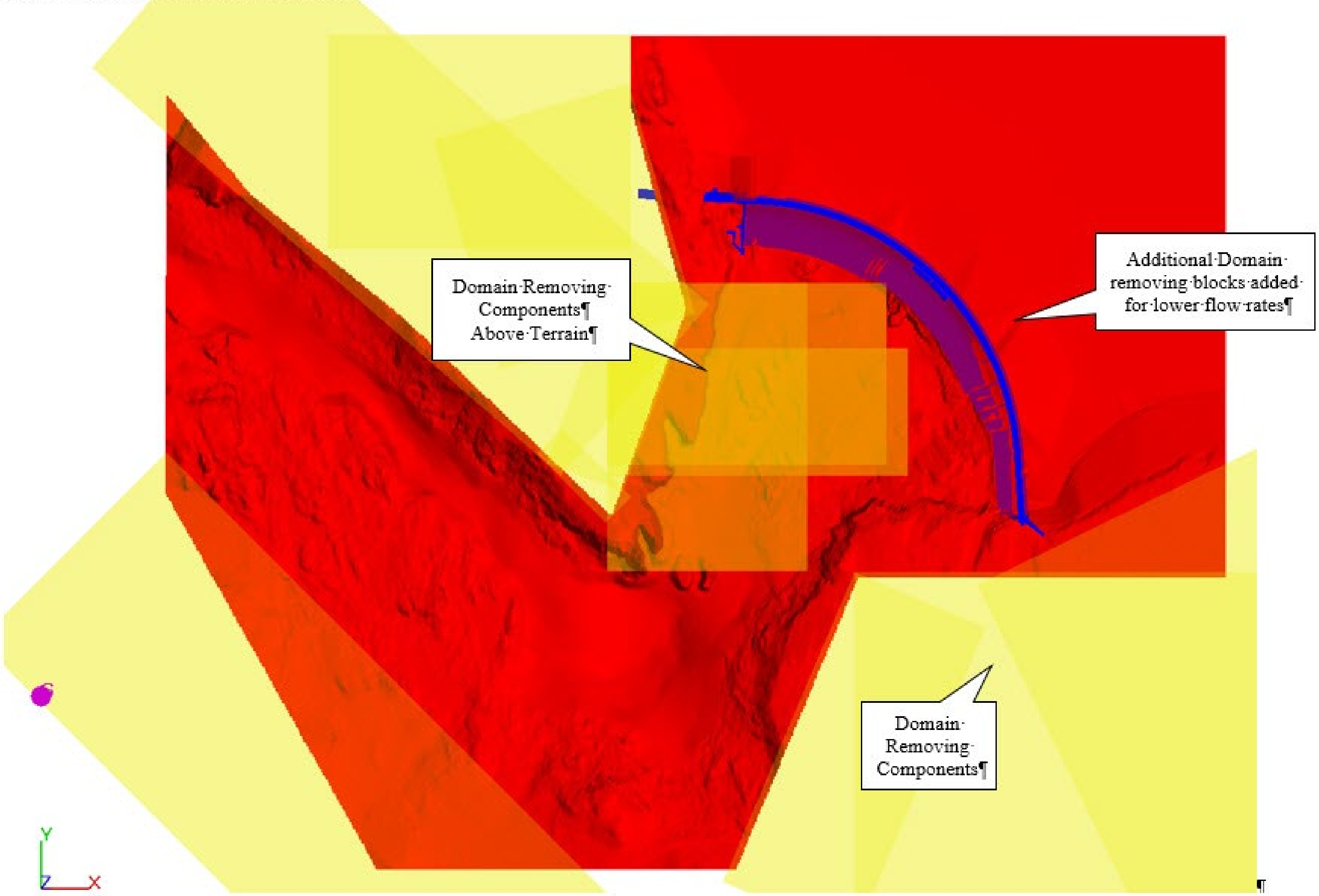
**Fluids**


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

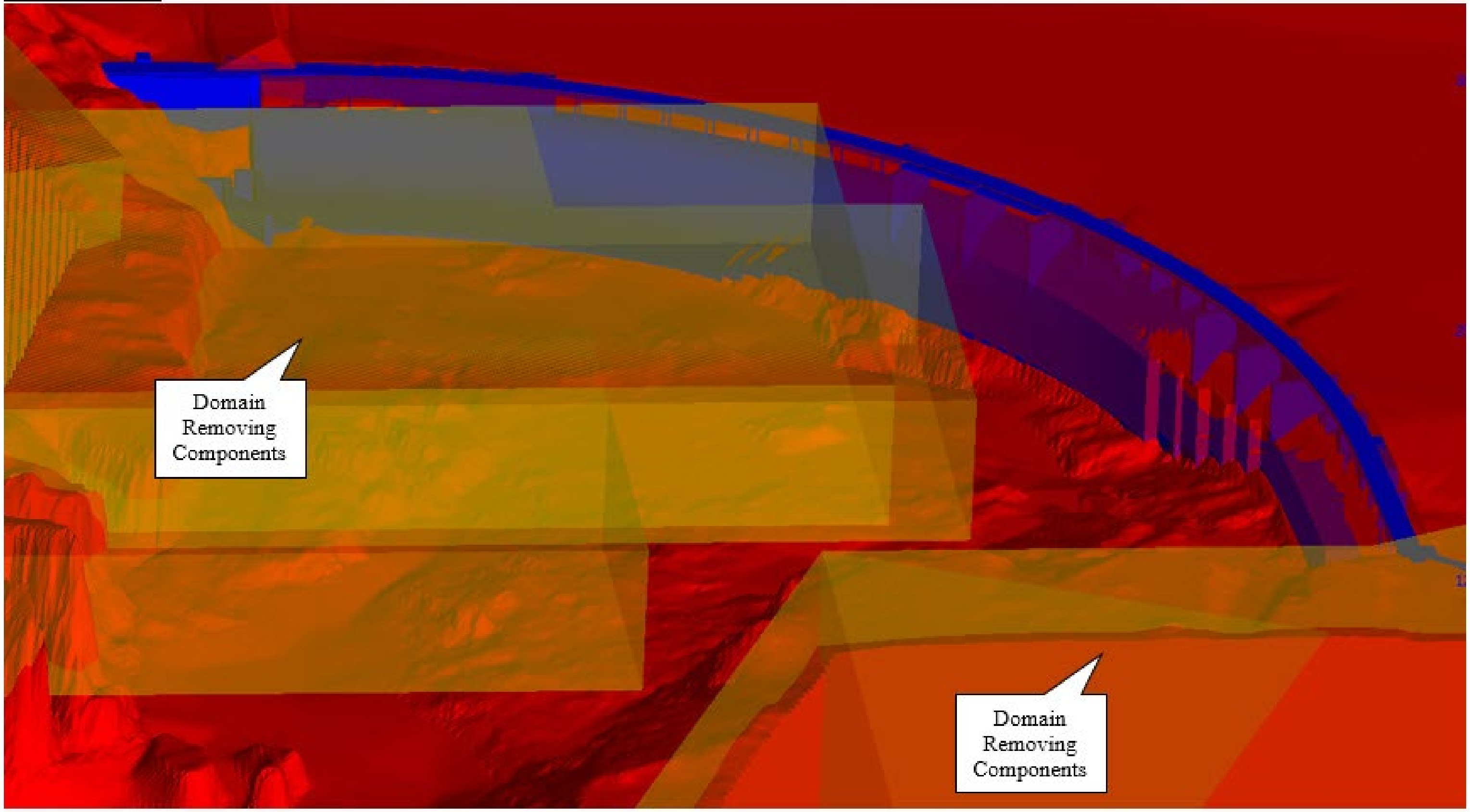
[This page intentionally left blank]

**Geometry**

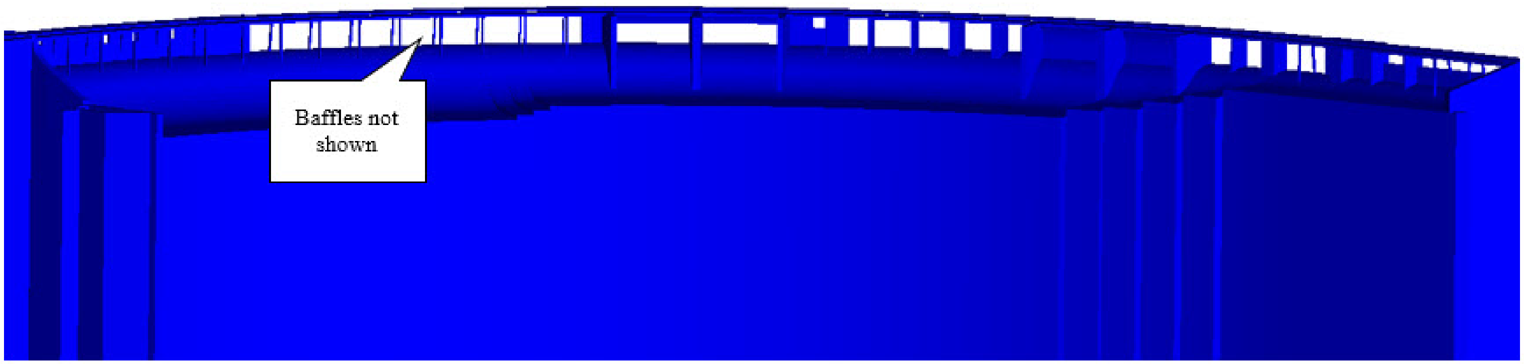
All Components (25,000 cfs and 37,000 cfs)



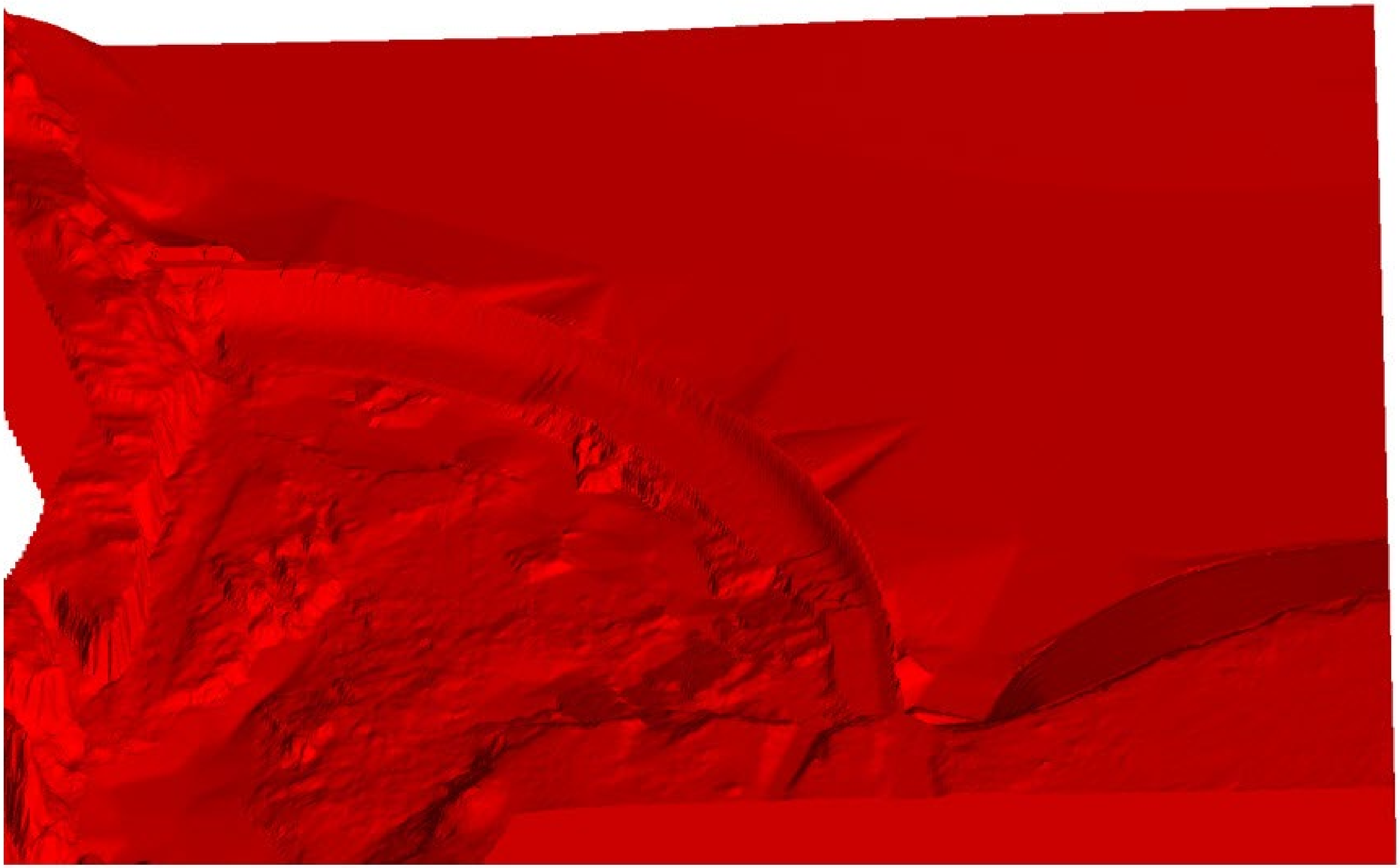
Main Dam Detail

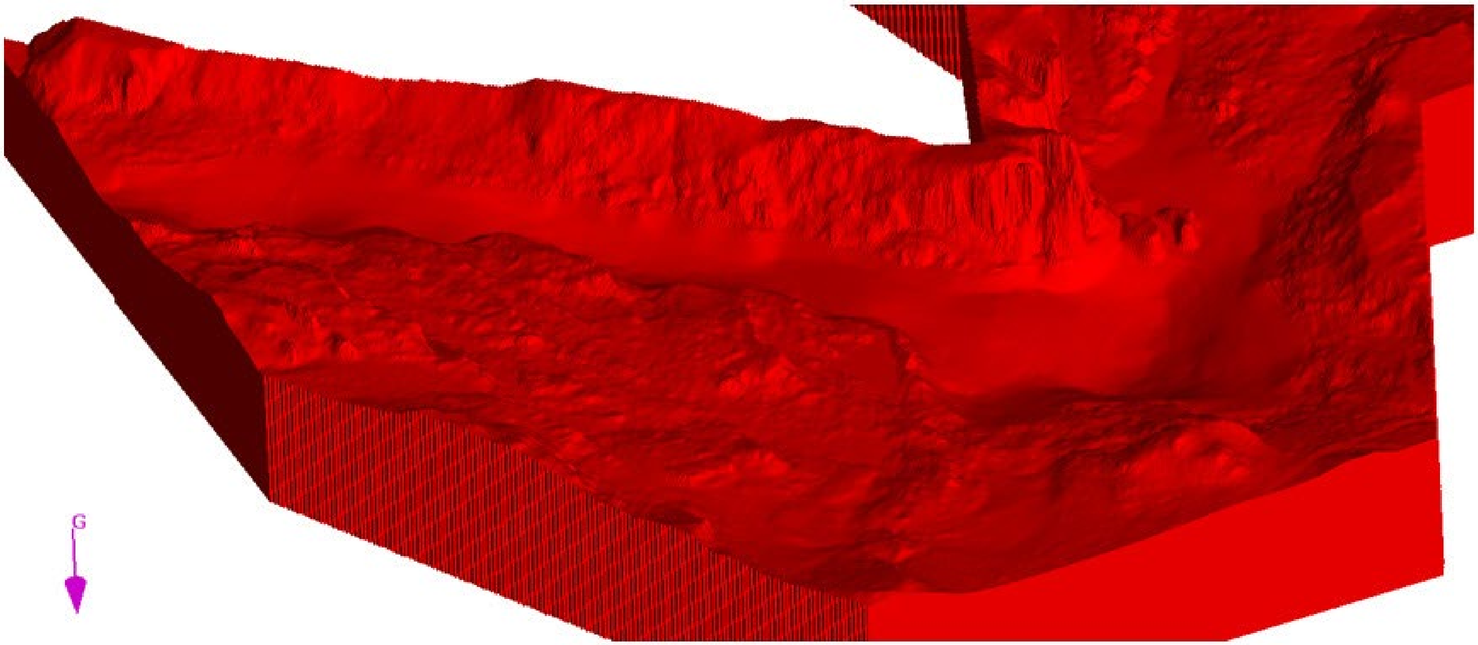


Spillway Chute Component
(25k cfs configuration shown, others similar)

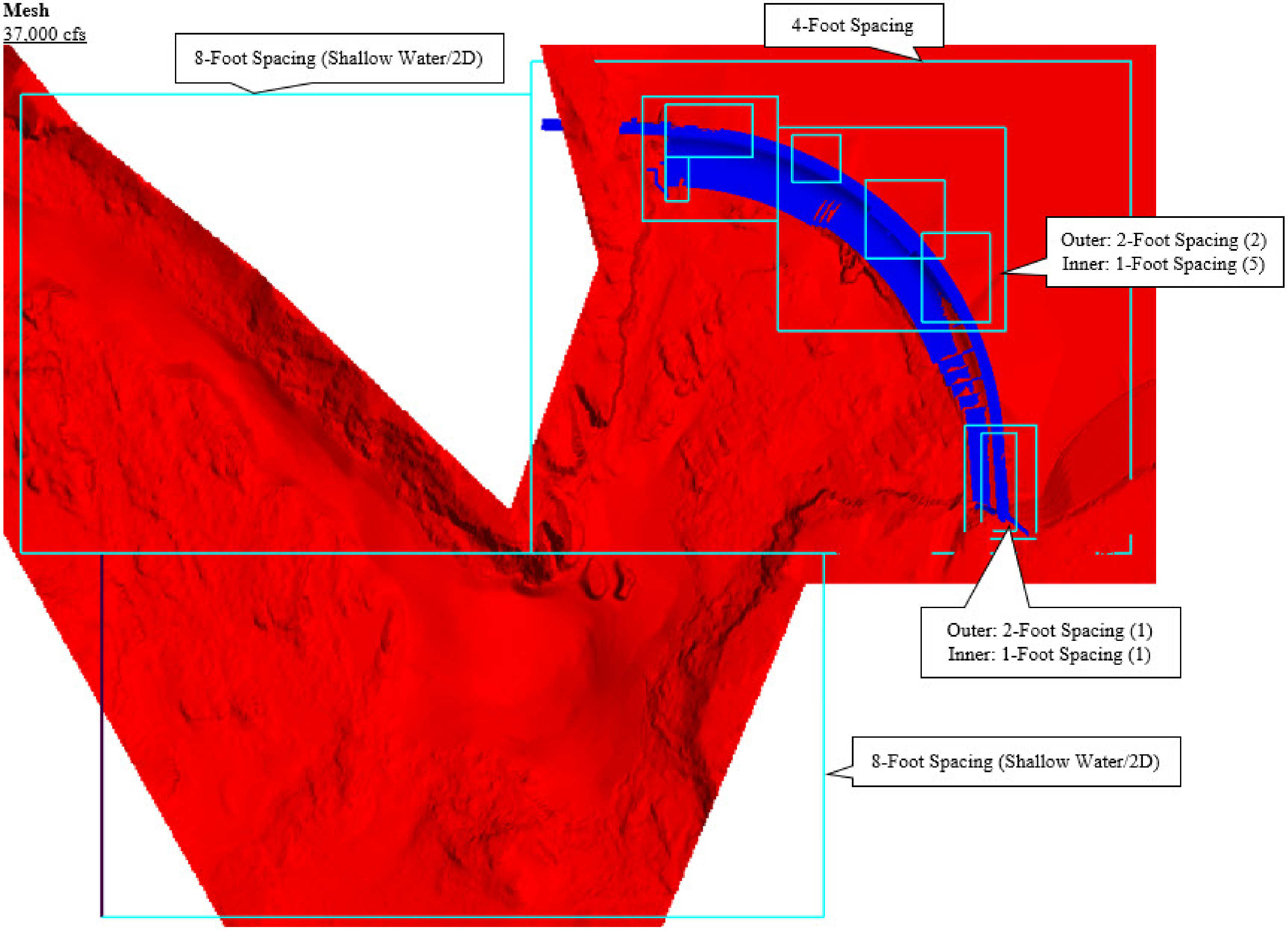


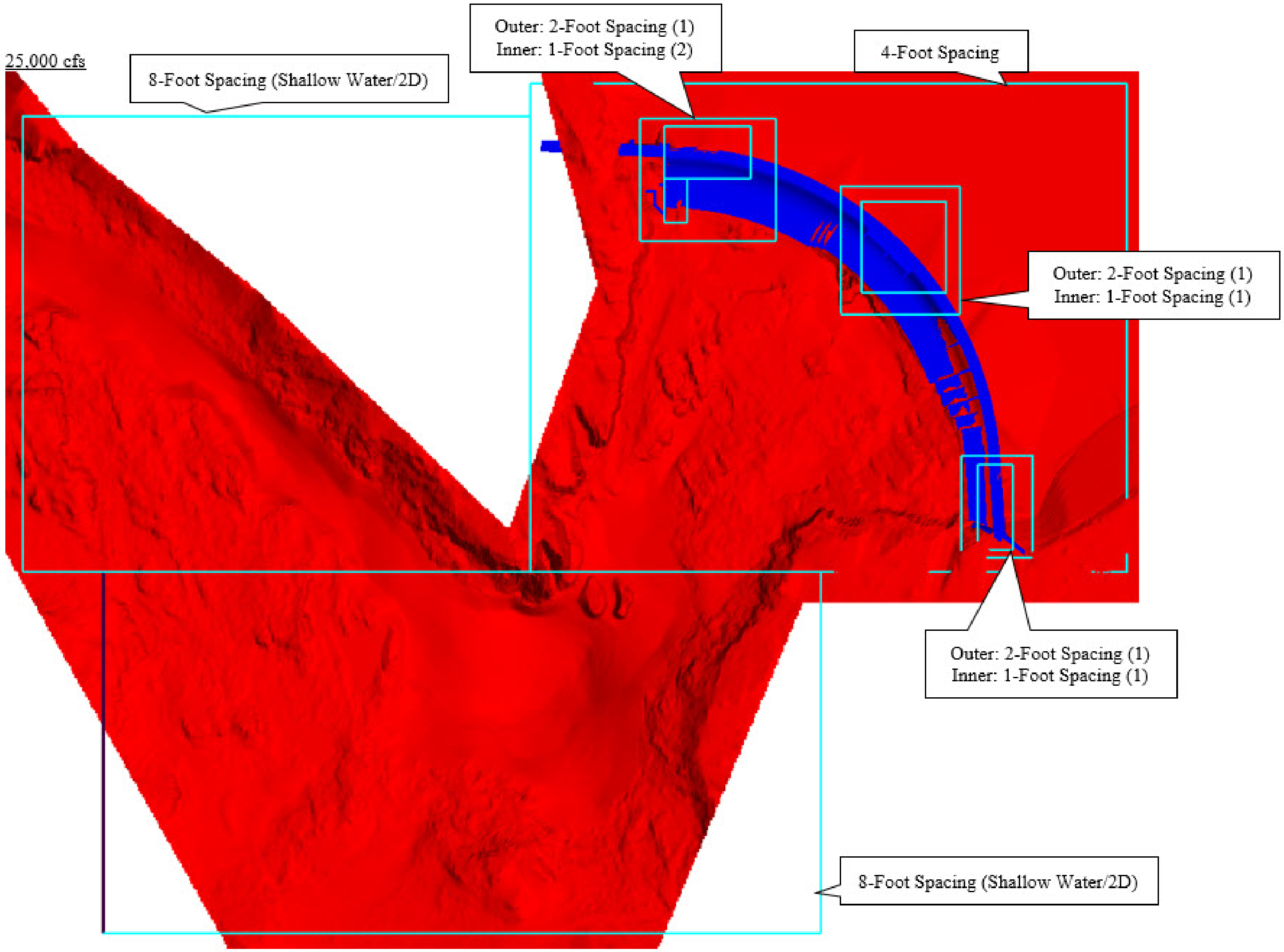
Terrain Component

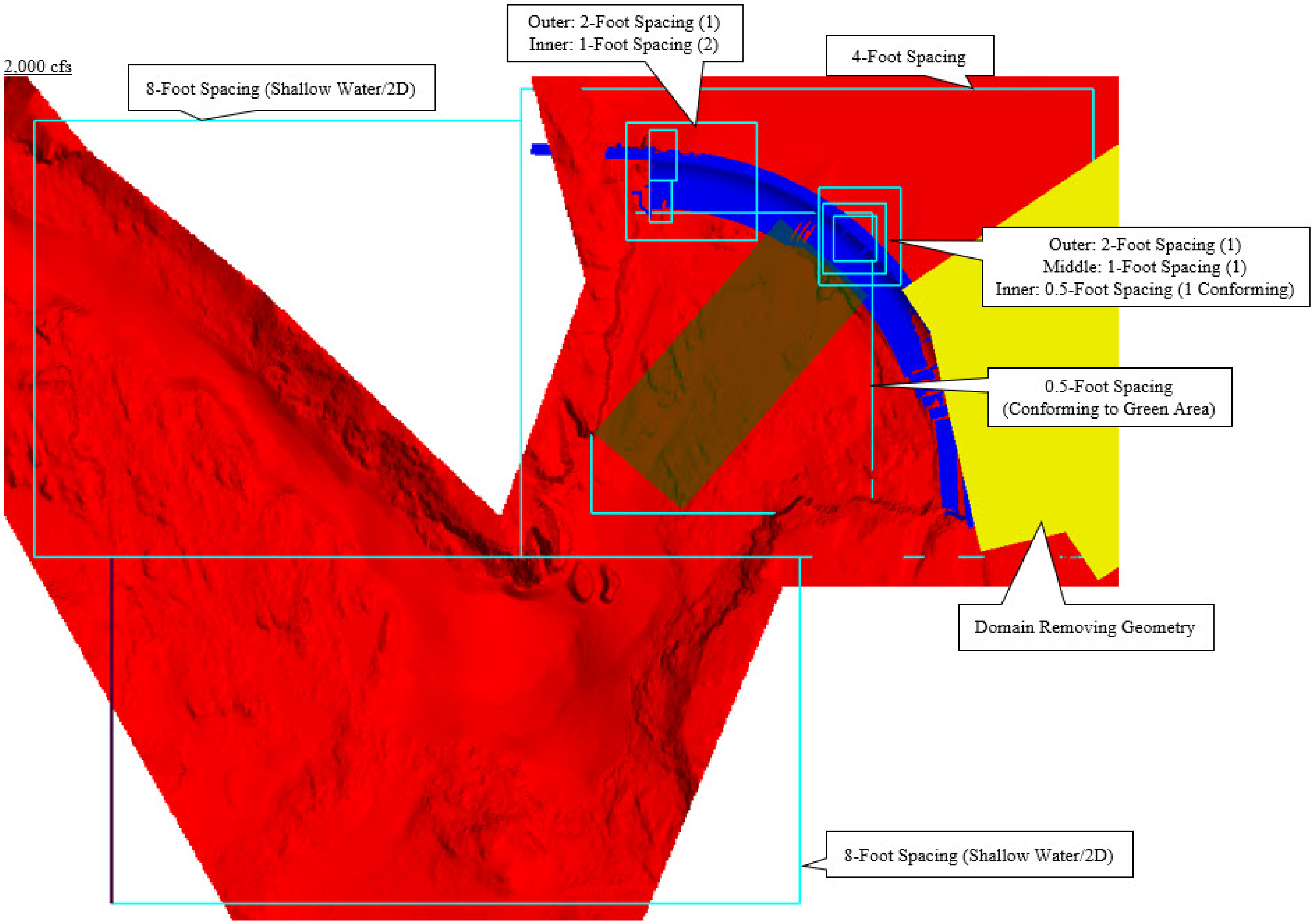



G

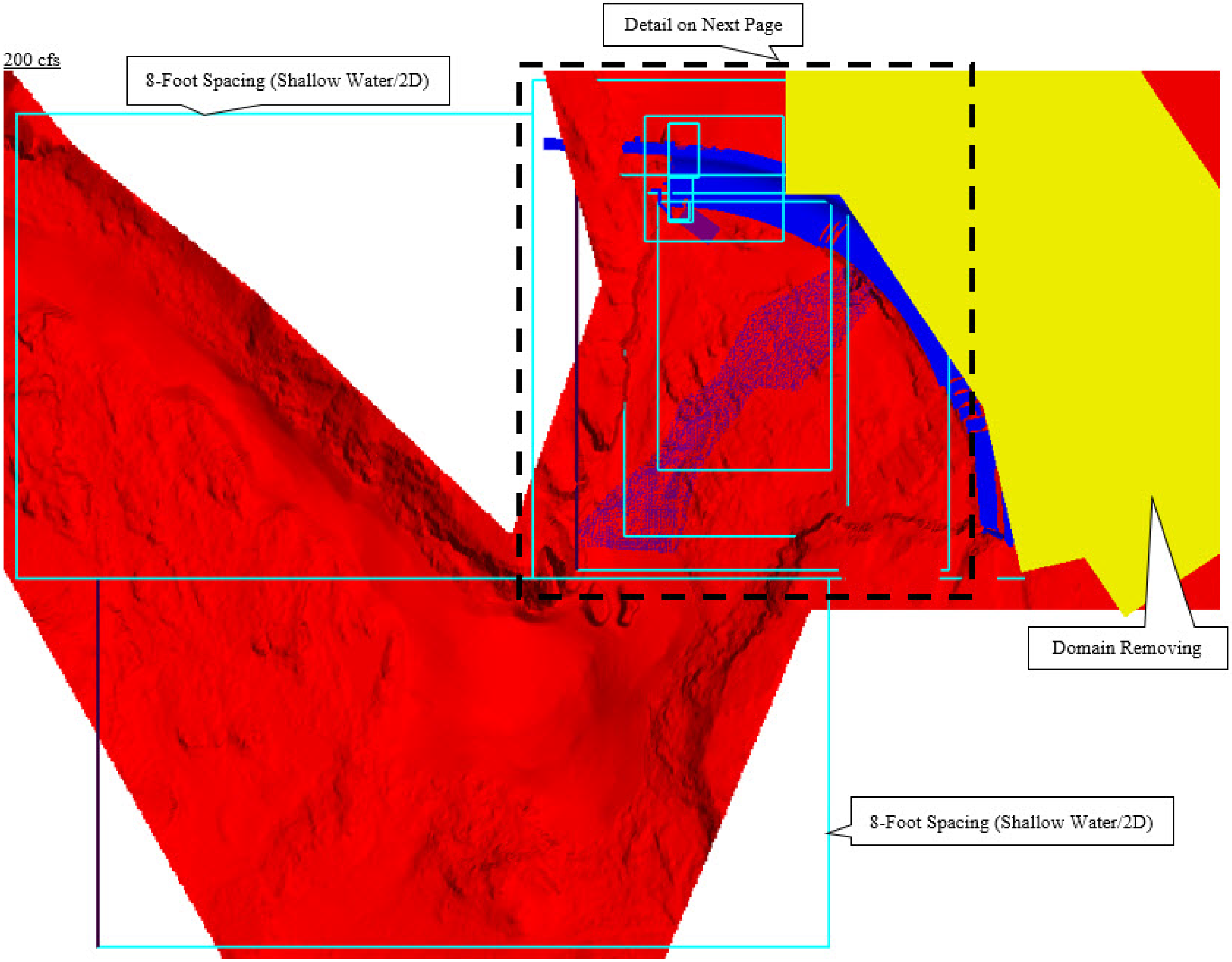
**Mesh**
37,000 cfs



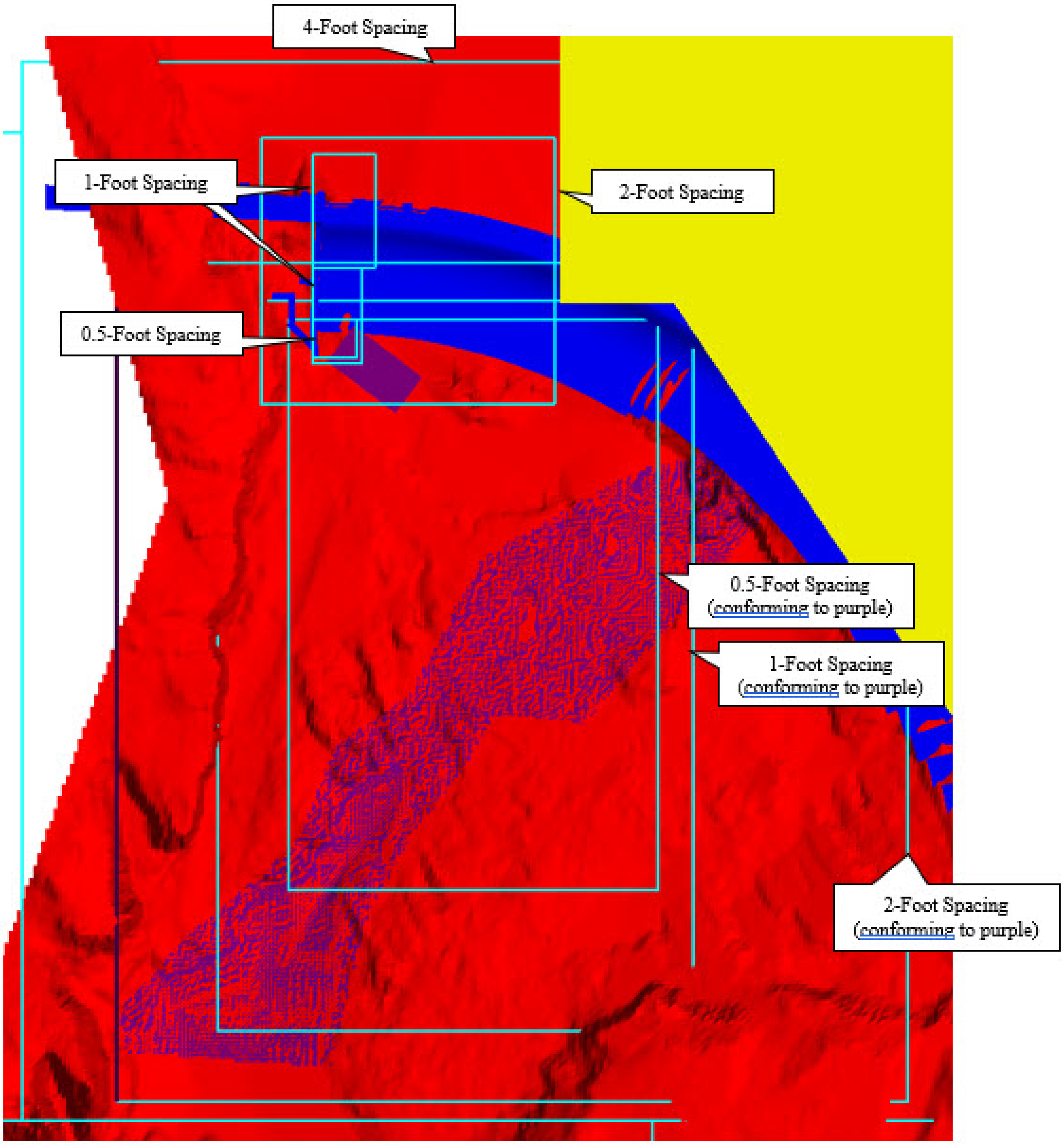

25,000 cfs
8-Foot Spacing (Shallow Water/2D)
Outer: 2-Foot Spacing (1)
Inner: 1-Foot Spacing (2)
4-Foot Spacing
Outer: 2-Foot Spacing (1)
Inner: 1-Foot Spacing (1)
Outer: 2-Foot Spacing (1)
Inner: 1-Foot Spacing (1)
8-Foot Spacing (Shallow Water/2D)


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)

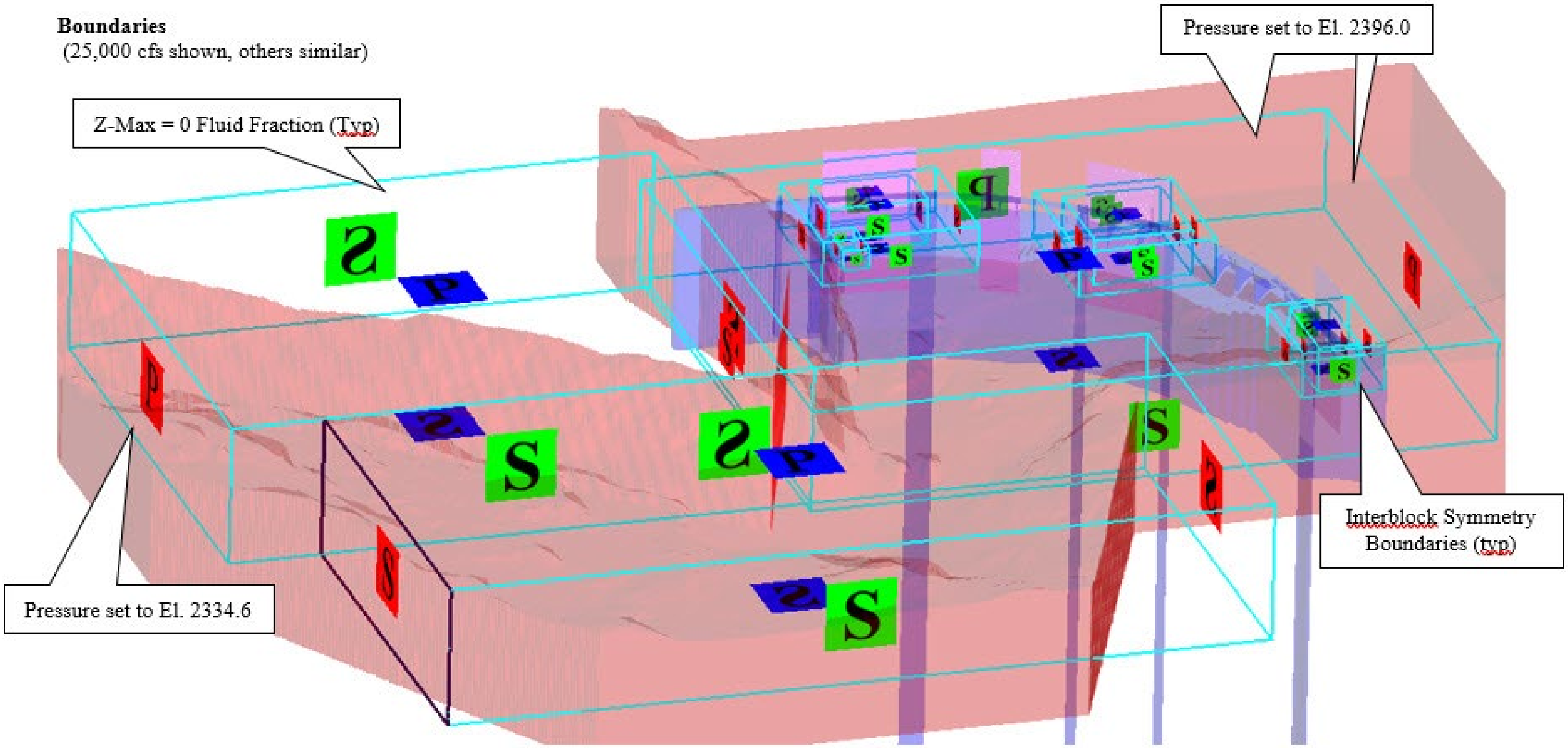
200 cfs


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

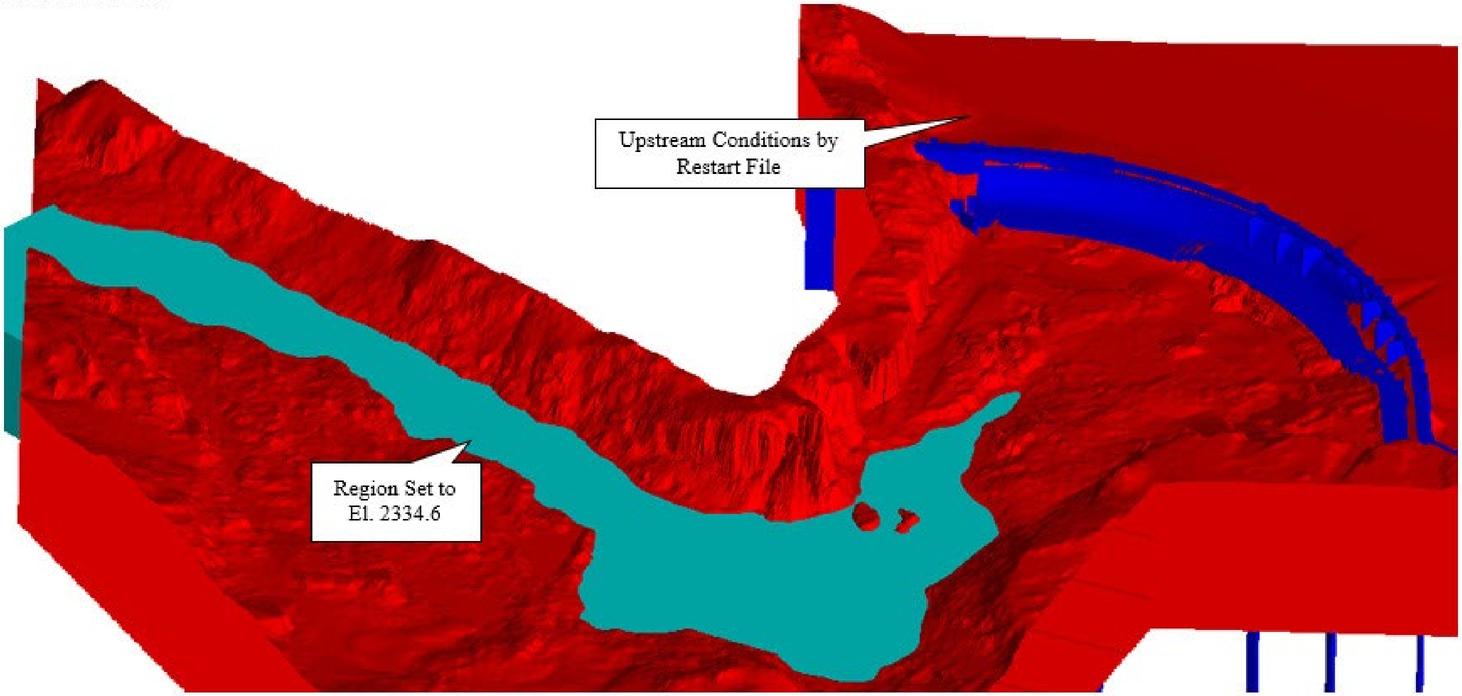
[This page intentionally left blank]


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)

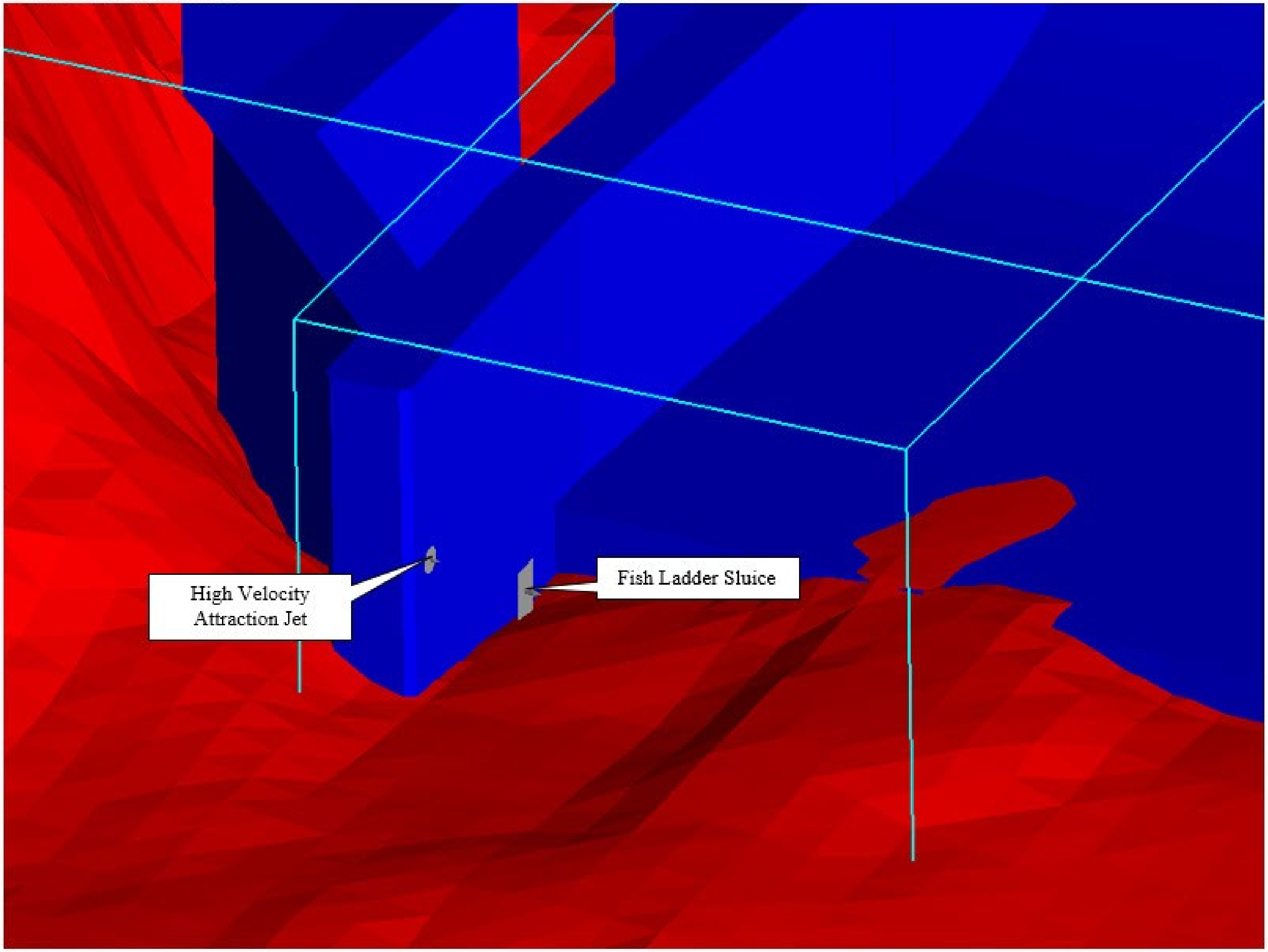
[This page intentionally left blank]


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)

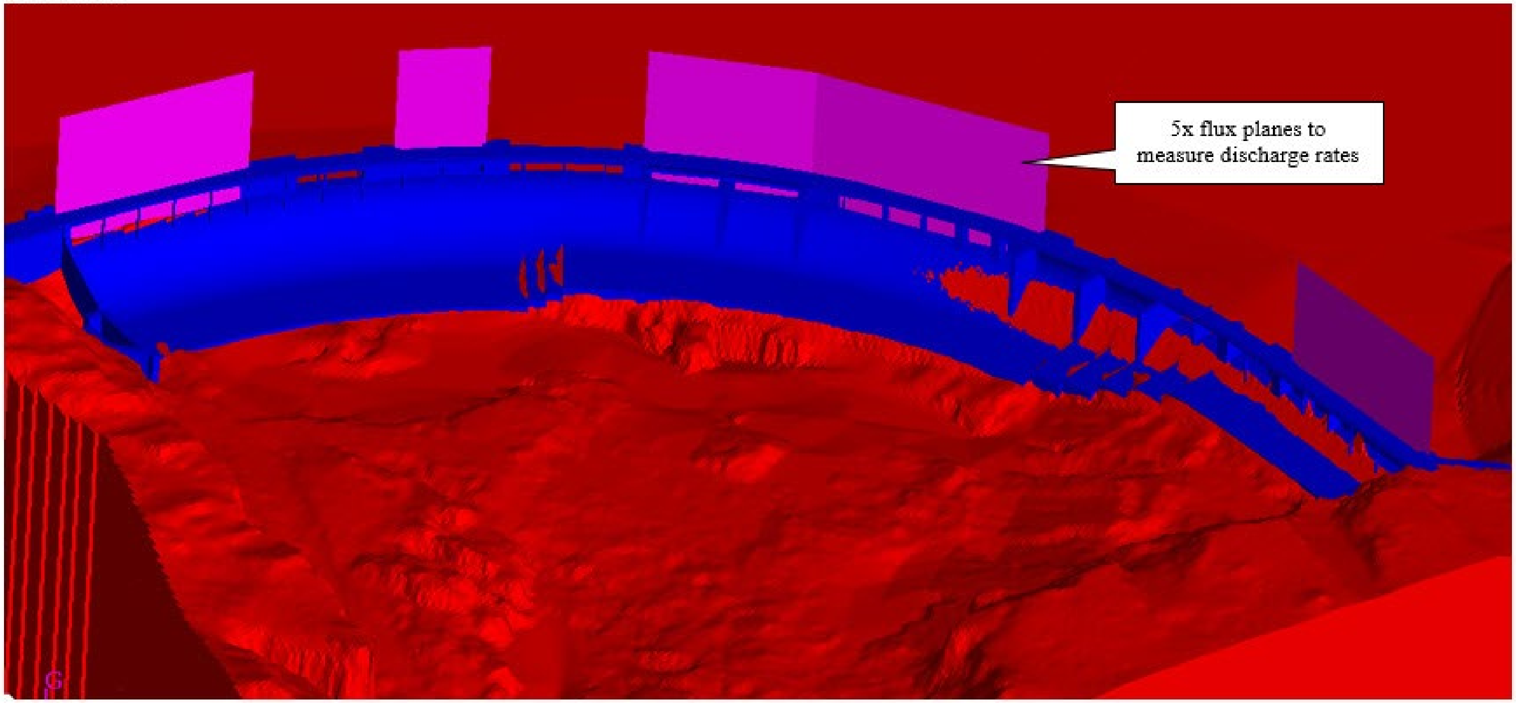
**Initial Conditions**



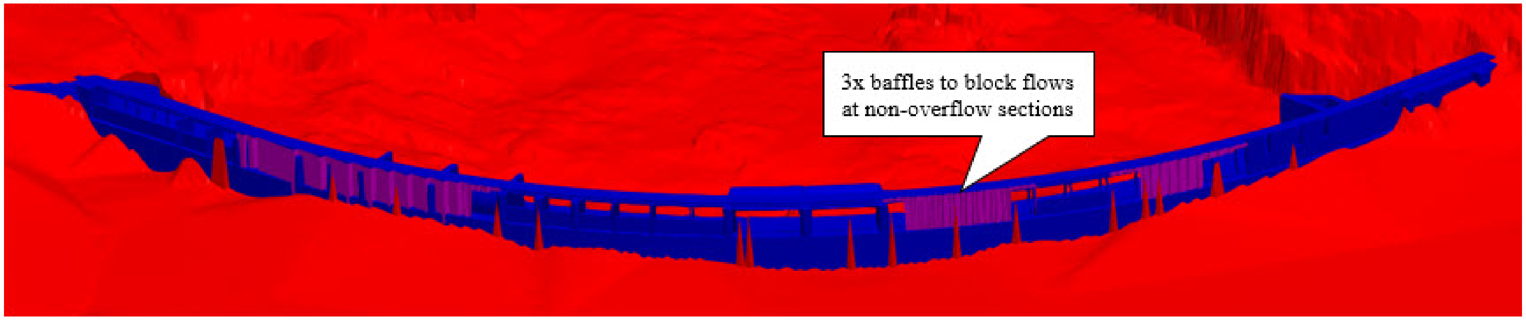
**Mass Momentum Sources**



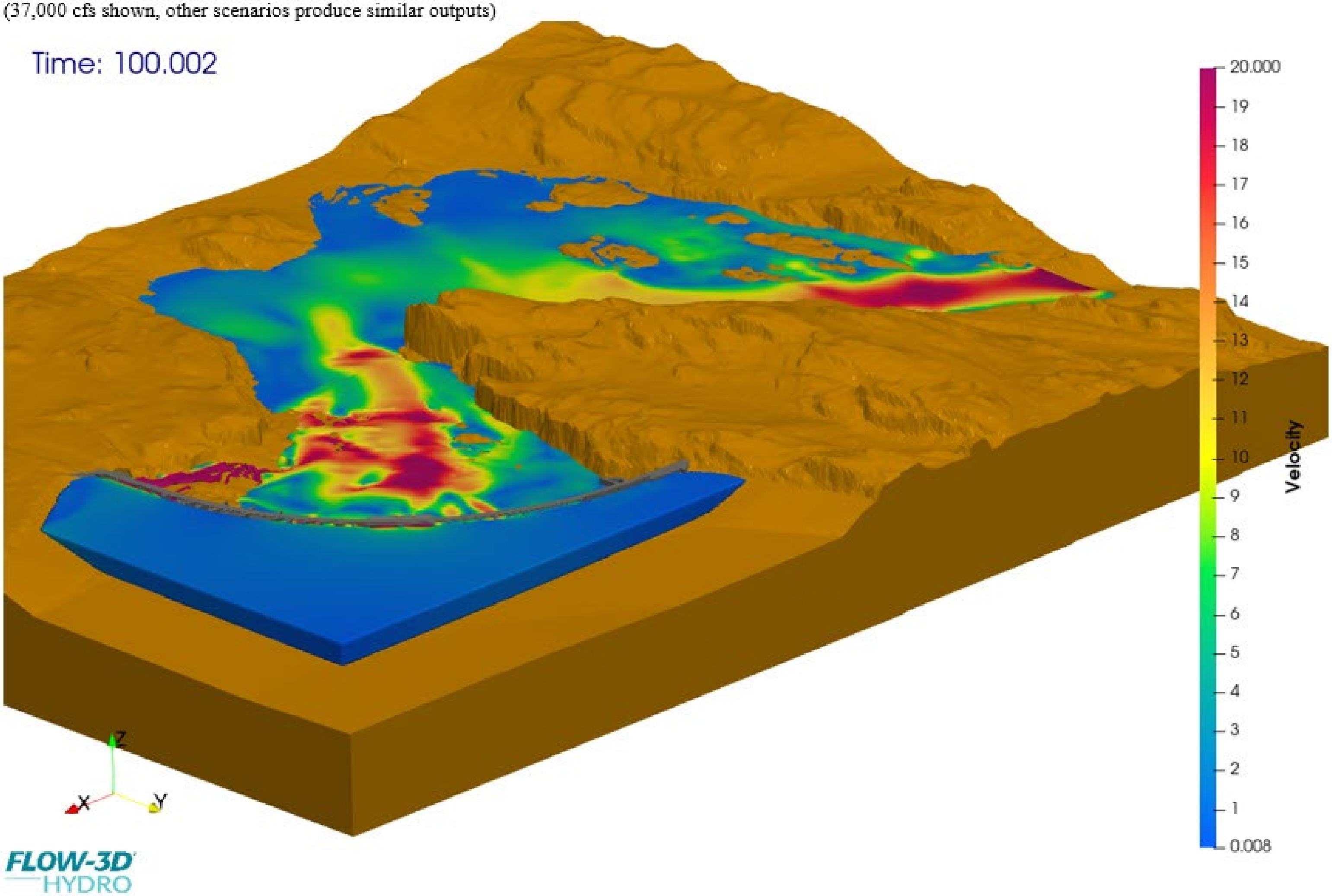
**Flux Planes**



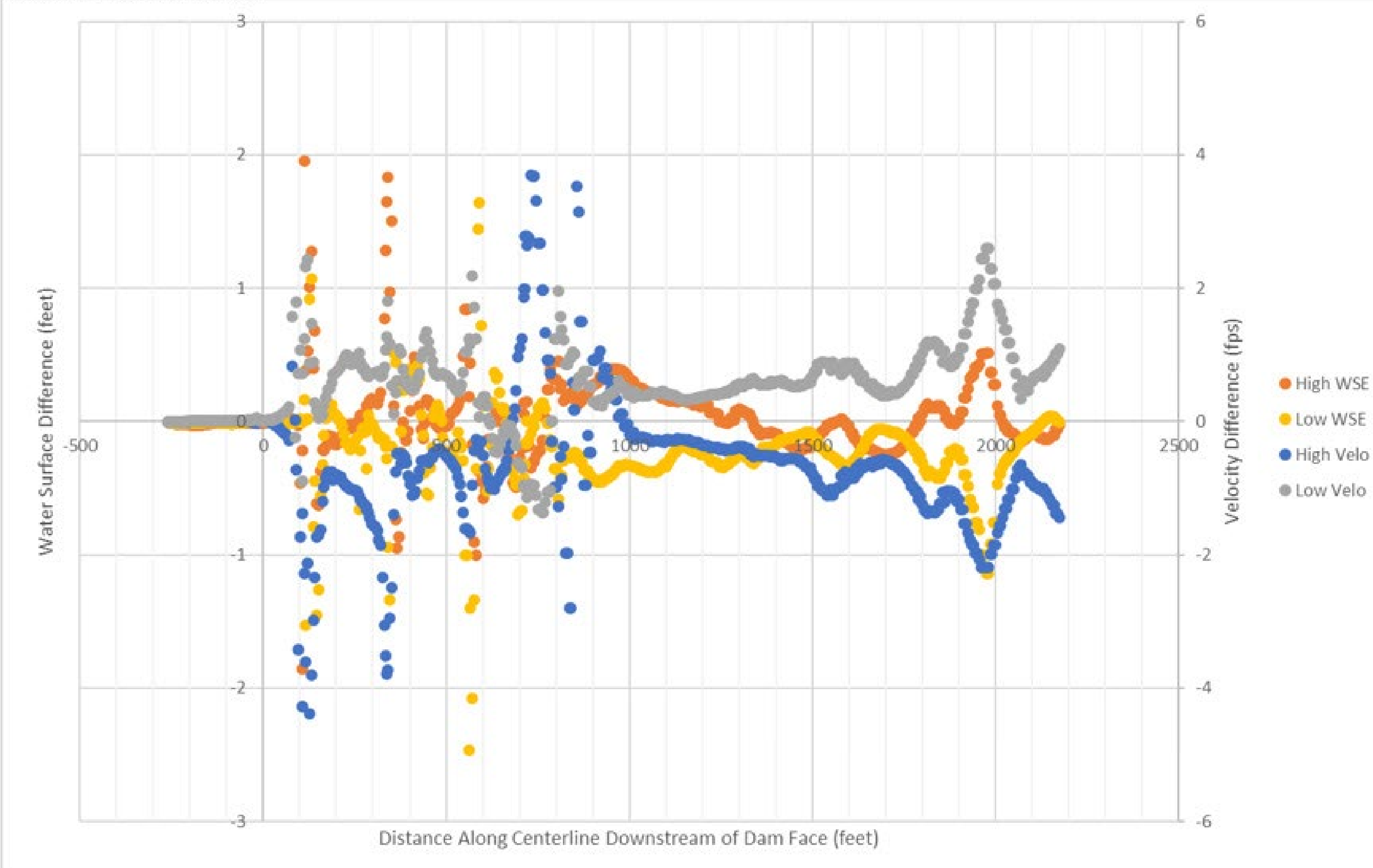
**Flow Baffles**



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



Roughness Sensitivity Results



Turbulence Model Sensitivity