Basis of Design Report

Corte Madera Creek Fish Passage Project

Existing Fish Passage Conditions and Analysis of Resting Pool Performance

Prepared for:

Friends of Corte Madera Creek Watershed

Funded by:

California Coastal Conservancy

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GHD

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The Corte Madera Creek Fish Passage Project is funded by the Coastal Conservancy, a California state agency, established in 1976, to protect and improve natural lands and waterways, to help people get to and enjoy the outdoors, and to sustain local economies along California's coast. It acts with others to protect and restore, and increase public access to, California's coast, ocean, coastal watersheds, and the San Francisco Bay Area. Its vision is of a beautiful, restored, and accessible coast for current and future generations of Californians. More about the Coastal Conservancy's program can be found at the Conservancy's website at scc.ca.gov.

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1. Introduction

1.1 Purpose of the Report

The basis of design report (BODR) provides an overview of the existing passage conditions within Unit 3 of the Corte Madera Creek Flood Control Project in Ross, CA and describes the development and refinement of the proposed passage improvements, which serves as an essential component of the multi-benefit Corte Madera Creek Flood Risk Management Project. The report is intended to provide reviewing agencies a thorough understanding of the proposed fish passage improvements.

The BODR provides background information, including previous studies of existing fish passage conditions in Unit 3 and potential options to improve passage. The BODR then describes fish passage performance objectives, constraints, and results from analyzing various spacings and configurations of resting pools in Unit 3. Lastly, the report summarizes the refinements of the resting pool shape, referred to as pool configuration alternatives, and selection of a preferred alternative. Additionally, anticipated monitoring and maintenance activities are discussed.

1.2 Flood Control Project Background and History

As part of the Flood Control Project, Corte Madera Creek was conceived as six "units". Designed and built by the US Army Corps of Engineers (USACE), Units 1-3 were constructed between 1968 and 1972. Unit 4 was slated to begin construction the following year but was delayed. Unit 4 remains a natural channel. See Figure 1 for an overview map of the Corte Madera Creek Unit 2 through 4.

Corte Madera Creek is designated critical habitat for Central California Coast Steelhead (listed as threatened under the Federal Endangered Species Act) and Central California Coast Coho Salmon, listed by both State and Federal agencies as endangered, yet this system holds significant obstructions from hardscaped water resources infrastructure that prevent passage of these sensitive species. The Unit 3 concrete channel and deficient fish ladder at the upstream end of Unit 3 is a barrier to fish and damaging to natural stream functions.

The USACE proposed a project for Corte Madera Creek in December 2018 to reduce the risk of flooding in the Ross and Kentfield area, but it was not acceptable to the community as a single-purpose, flood control project and the prepared EIS/EIR was deemed inadequate. National Marine Fisheries Service (NMFS) and California Department of Fish and Wildlife (CDFW) reviewers, among others, were also critical that the proposed project did not address fish passage issues in the Unit 3 concrete channel. The Flood Control (FC) District and County Board of Supervisors decided to terminate the Feasibility Cost Share Agreement with the USACE and transition to a locally managed and funded project that better suited local community priorities and could address environmental resource agencies permit requirements for fish passage. The Marin County Flood Control and Water Conservation District (FC District) is currently working with environmental resources agencies, local jurisdictions and stakeholders to design and implement the "Corte Madera Creek Flood Risk Management Project" (CMCRM Project).

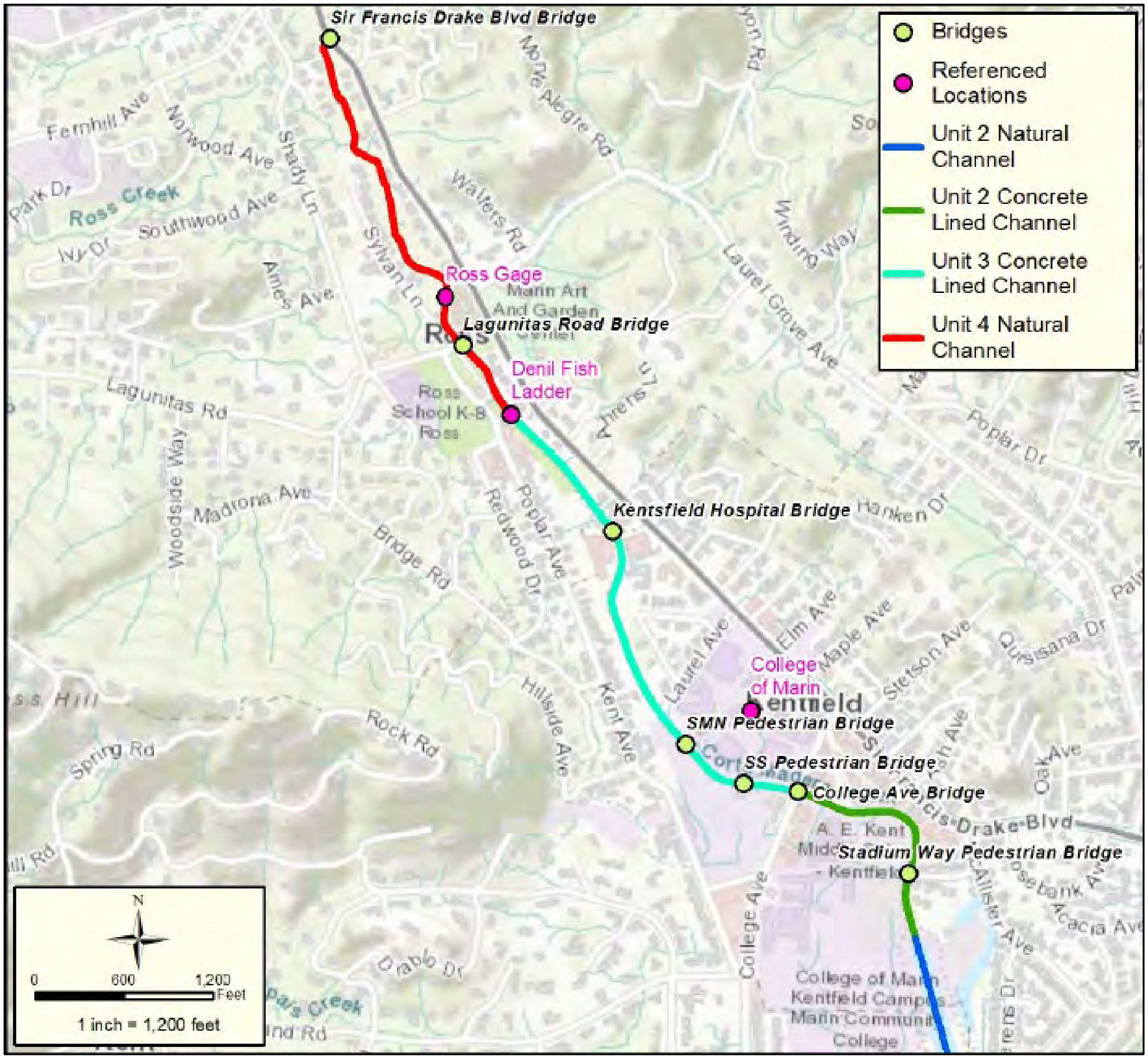


Figure 1. Corte Madera Creek Unit 1 to Unit 4 reaches (USACE, 2018)

1.3 CMCFRM Project Phase 1 Overview

The CMCFRM Project is fully funded by a grant from the Department of Water Resources (DWR) and the local Flood Zone 9, and proposes to reduce flooding while supporting ecological restoration and recreational enhancements that include improvements to fish passage and habitat. The project objectives include the following;

- **Flood Risk Reduction**: Reduce overall flood inundation extent and depth in the Town of Ross and Kentfield areas.
- **Provide Environmental Benefits**: Improve fish passage, natural creek processes, and fish and riparian habitat adjacent to the creek.

- **Enhance Public Access and Recreational Quality**: Maintain public access along the creek via the multi-use path and enhance the recreational experience and amenities along the creek corridor to meet Town of Ross and Kentfield area community needs.

- **Integrate Operational Reliability**: Improve operational reliability and reduce long-term maintenance costs through increasing maintenance access, improving channel stability, and protecting existing utilities.

- **Meet Regulatory Compliance**: Comply with local, state, and federal environmental laws and regulations.

- **Maintain Fiscal Responsibility**: Implement a flood risk reduction project that can be accomplished with currently available local and grant funding and reasonably foreseeable grant funding opportunities.

1.4 Corte Madera Creek Fish Passage Project

While fish passage is considered within the CMCFRM Project, there is not adequate funding to support the full extent of fish passage improvements necessary to restore functional passage. The Corte Madera Creek Fish Passage Project provides support for design of improved fish passage within the Unit 3 concrete channel, a critical component of the CMCFRM Project. The Corte Madera Creek Fish Passage Project is being funded by the California Coastal Conservancy and managed by the grant recipient, Friends of Corte Madera Watershed. Through this effort, Michael Love & Associates, Inc. (MLA) and GHD Inc. (GHD) have been retained to develop the fish passage improvement designs for the Unit 3 concrete channel reach (Project Reach) of the CMCFRM Project. While grant funding supports this current fish passage design effort, an extended search is underway to identify funding for construction of the Unit 3 passage improvements.

1.4.1 Project Objectives

The objective of the Corte Madera Creek Fish Passage Project is to analyze and refine the spacing, location, and shape of new resting pools for fish passage and then develop a preliminary (35%) design drawings and supporting Basis of Design Report (BODR) that, when implemented, will improve passage conditions for adult Steelhead and Coho Salmon (in the event they return to the system) as they move upstream to reach spawning habitat. The design will also be integrated into the CMCFRM Project to ensure the fish passage improvements do not adversely affect flood risk management in the watershed. Alternatives to improve fish passage were developed in 2007 (MLA & JAA 2007). These alternatives involved use of resting pools along Unit 3 to improve passage conditions. This approach will be used as the starting point to refine the proposed fish passage improvement.

1.4.2 Project Activities Summarized in Technical Memorandum

This basis of design report (BODR) summaries findings from the following activities:

- **Review Previous Analysis and Available Data**: Review previous analyses of the concrete channel (MLA 2006, MLA & JAA 2007, MLA 2018), various hydraulic and hydrology models; and results of concrete testing and condition assessment.

- **Establish Baseline Conditions:** Update the fish passage analysis using the latest hydraulic model of the Project Reach and current version of the fish passage routing model.

- **Coordinate with Resource Agencies**: Coordinate with NOAA National Marine Fisheries Service (NMFS) and California Department of Fish and Wildlife (CDFW) to develop design criteria and a range of alternatives for analysis of fish passage consistent with reducing flood risks (including accommodating flows delivered to the Project Reach by improvements in capacity upstream).
- **Evaluate Alternatives**: Analyze various resting pool spacings and shapes and assess their ability to meet project objectives.
- **Select a Preferred Alternative**: Recommend a preferred resting pool configuration based on the analysis and develop preliminary design drawings showing the configuration and locations of the proposed pools.

Based on review comments and guidance from stakeholders, the MLA-GHD design team will continue to refine the design of the preferred pool shape presented in this report, culminating in the preparation of the Basis of Design Report (BODR) and accompanying design drawings for incorporation into the overall CMCFRM Project.

2. Existing Fish Passage Conditions

2.1 History of Fish Passage within the Concrete Channel

Corte Madera Creek and its tributaries support populations of Steelhead Trout (*Oncorhynchus mykiss*), which are part of the Central California Coast Distinct Population Segment (DPS) and listed as threatened under the Federal Endangered Species Act (Federal Register, 2006). The stream also historically supported runs of Coho Salmon (*Oncorhynchus kisutch*), which were observed in Corte Madera Creek and its tributaries until the early 1980s. Since then, they have been extirpated from the watershed, likely in part due to the construction of the USACE flood control channel in lower Corte Madera Creek in the late 1960s and early 1970s.

Unit 3 of the Corte Madera Creek flood control channel is the primary fish passage impediment within lower Corte Madera Creek, making it a keystone barrier for the watershed. Unit 3 consists of a concrete channel completed in 1972 that begins at College Avenue in Kentfield, an unincorporated community, and extends 3,470 feet upstream, ending near the US Post Office in the Town of Ross (Attachment 1). The upstream Unit 4 concrete channel was planned, but never completed due to local opposition. Since 1972, an approximately 5-foot tall wooden bulkhead at the upstream end of Unit 3 has served as a "temporary" grade control structure. The bulkhead includes a wooden Denil fish ladder that was installed to provide interim fish passage. This wooden bulkhead and Denil fish ladder were originally intended to be in service for only one season, with removal as part of the ill-fated Unit 4 construction.

The fish ladder lacks an entrance (downstream) pool, causing adult Steelhead to struggle as they attempt to swim through a fast and shallow jet of water to reach the entrance. The fish ladder has been damaged during floods, including in December 2005, and often has debris caught within it, creating a barrier to fish arriving at the fishway.

The concrete channel has a slope of 0.0038 ft/ft and was designed for supercritical hydraulic conditions during high flows, though tidal conditions cause backwater influences within the lower portions of Unit 3. The lower 1,000 feet of Unit 3 has a channel invert elevation below the Mean Lower Low Water (MLLW) tidal datum, and only the upstream-most 840 feet has a channel invert above Mean Higher High Water (MHHW) tidal datum. The 33-foot-wide Unit 3 concrete channel was designed with a V-shaped bottom that is 3.2 feet deep at the channel centerline, thus concentrating low flows to the benefit of fish passage. The channel was also designed with small, shallow pools intended to serve as fish resting pools.

A total of 24 resting pools are equally spaced approximately 64 feet apart (Attachment 1). The downstream-most pool is located where the channel bottom is at approximately mean tide level (MTL). The upstream most pool is near the head of Unit 3. The pools are 13 feet wide by 4 feet long in the streamwise direction. Each pool bottom is flat across its width and set 0.1 feet below the invert elevation of the V-shaped channel, such that it has only 0.1 feet of residual pool depth. Because the pool bottom is flat and the channel is V-shaped, along the left and right edges of the pool the bottom is recessed approximately 1.5 feet below the adjacent channel floor, providing some velocity shadowing at lower fish passage flows.

Adult anadromous salmonids have occasionally been observed within the Unit 3 concrete channel. MLA-JAA (2007) documented video observations of adult salmonids recorded by volunteers with Friends of Corte Madera Watershed during the fall of 2005 and winter of 2006. This included video documentation of what appeared to be a Chinook Salmon (likely stray from the Sacramento River system) in early December attempting to pass through the Denil fish ladder at a flow of 16.6 cfs. Three separate observations of Steelhead were also made:

- Two observations of Steelhead attempting unsuccessfully to enter the fish ladder at streamflows of 31.7 cfs and 64.8 cfs
- Observation of a Steelhead swimming up the concrete channel and stopping to rest in one of the existing resting pools at a flow of 30.9 cfs

In addition to the four salmonids observed in Unit 3 in 2005-2006, several Steelhead kelts that had apparently spawned were observed holding together in a pool immediately upstream of the fish ladder in February 2006, reluctant to move down the ladder. This observation confirmed that some Steelhead are able to ascend the Denil fish ladder at certain flow conditions.

2.2 Prior Assessments of Fish Passage Conditions in Unit 3

Fish passage through the flood control project was assessed both qualitatively and quantitatively. These assessments focused on passage conditions in the Unit 3 concrete channel upstream of College Avenue, with the channel downstream of this location considered passable due to tidal backwatering at all flows and the persistence of deposited sediment within the bottom of the channel indicating relatively low velocities at higher flows. These assessments are summarized below.

2.2.1 Ross Taylor & Associates (2003) County Assessment

Ross Taylor & Associates (2003) assessed fish passage conditions at road-stream crossings and other sites throughout the Corte Madera Creek watershed as part of a county-wide assessment for passage of anadromous salmonids. The assessment did not analyze the concrete channel but concluded that the Unit 3 channel was likely a barrier to adult salmonids due to excessive velocities over a long distance.

2.2.2 MLA-JAA (2007) Unit 3 Assessment

Michael Love & Associates and Jeff Anderson and Associates (MLA-JAA, 2007) conducted a detailed passage assessment for adult Steelhead in the Unit 3 channel for Friends of Corte Madera Creek Watershed, FC District and the USACE. The assessment did not follow the standard approach that relies on cross-sectional average velocities. Instead, it used depth averaged velocities along an assumed swimming path based on a model that generated a 2-dimenional (2D) flow field with 1-foot grid spacing. Fish swimming through the flow field were analyzed using the Fish Routing, Energetics, and Locomotion Modeling System (Fish-REALMS), which is an individual-base model that samples the size and swimming abilities of each “surrogate” fish from the corresponding population distributions, and runs 1,000 simulations to estimate the percent of the fish population able to ascend through the entire channel.

Assessed fish passage flows were based on flow duration during a migration period assumed to occur from December 1 through March 31. The 50% and 10% exceedance flows during the migration period were selected as the low and high fish passage assessment flows (14 cfs and 177 cfs), respectively. Passage conditions were evaluated at a total of six flows from 14 cfs to 177 cfs. Each flow was analyzed for three tidal conditions: MLLW, MTL, and MHHW.

The results from the assessment are given in Table 1. The results did not account for passage through the existing Denil fish ladder. The assessment found that at lower passage flows the existing resting pools provided ample areas of low velocities suitable for adult Steelhead to hold and recover from fatigue. As flows increase, the effectiveness of these resting pools decreases. Additionally, tidal conditions substantially influenced passage conditions. The lower portion of Unit 3 does not include any resting pools. The analysis found that at low tide nearly all the fish become exhausted attempting to swim through this lower reach due to its lacks resting pools.

Table 1. Estimated portion of Steelhead capable of ascending Unit 3 at various fish passage flows and tidal conditions (from MLA-JAA, 2007).

Tide	Elevation (NAVD88, feet)	Percent Successful					
		14 cfs	23 cfs	40 cfs	77 cfs	113 cfs	177 cfs
MLLW	0.09	7	2	2	2	2	1
MTL	3.32	98	85	51	13	7	1
MHHW	5.89	99	92	97	73	54	4

2.2.3 MLA (2018) Unit 3 Assessment

At the request of FC District, MLA conducted additional analysis of passage conditions for adult Steelhead, with results summarized in a technical memorandum (MLA, 2018). This analysis applied the same 2-D hydraulic model results and Fish-REALMS approach as used by MLA-JAA (2007), but evaluated the frequency and duration fish passage is likely currently provided using historical 15-minute streamflow and tidal stage data.

The 2018 results show opportunities for successful passage through Unit 3 occur for a portion of the fish population (generally the larger fish) at least once per day at most migration flows. These passage opportunities are often associated with occurrence of the daily higher tides and only last for a few hours or less. During most of the time the proportion of fish able to pass through Unit 3 is extremely low.

2.3 Prior Fish Passage Improvement Studies

2.3.1 MLA (2006) Unit 3 – Unit 4 Fishway Replacement Design

During a large flood on December 31st, 2005 the existing wooden Denil fish ladder at the transition between Unit 3 and Unit 4 was damaged. MLA prepared for Friends of Corte Madera Watershed preliminary designs for a replacement fish ladder intended to serve as a long-term structure that would substantially improve passage conditions (MLA, 2006). This was part of a "no-action" alternative being considered for Unit 4. The proposed design was a "hybrid pool-and-chute fish ladder." It used five V-shaped concrete weirs with pools between each weir. Designed drops over the weirs was 1 foot. The proposed fish ladder was channel spanning, with the upstream most weir replacing the existing wooden bulkhead. The fish ladder was designed to meet passage criteria up to a flow of 198 cfs.

2.3.2 MLA-JAA (2007) Unit 3 Alternatives

As part of the 2007 study, MLA-JAA also evaluated the use of new larger resting pools to improve passage success within Unit 3. The analysis focused on three different pool shapes, with the objective of identifying a preferred pool configuration that would provide low velocity zones suitable for Steelhead to hold and rest at all fish passage flows. A competing objective was to develop a pool shape that would produce sufficient shear stress at higher flows to prevent excess sedimentation.

The proposed pools were substantially larger than the existing ones, ranging from 8 feet square to 24 feet long by 11 feet wide. The bottoms of the pools were also recessed below the channel invert by between 1 and 1.5 feet. The project 2D hydraulic model was used to analyze water velocities within each type of pool at each fish passage flow to determine if it could produce a low-velocity zone of sufficient size to allow for fish to hold and rest. The pools were also analyzed at the approximately 1.5-year flow (1,383 cfs) to evaluate the mobility of sediment throughout each pool. The pools were evaluated in both straight channel reaches and within the curved reaches of Unit 3. The report recommended using the Alternative 1 pool configuration for the straight reaches and the Alternative 3 pool configuration for the curved reaches of channel. It also recommended additional studies and refinement of the pool shape.

The study also analyzed the effect of pool spacing on passage success rates. The report recommended pool spacing of 150 feet and placing pools from approximately station 342+00, upstream of the College of Marin pedestrian bridge adjacent to the Science, Math, and Nursing Building, to the upstream end of Unit 3. This pool spacing resulted in passage success rates as high as 99% at the low passage flow of 14 cfs. At the high passage flow of 177 cfs the predicted passage success rate was 65%, regardless of the tidal stage.

2.3.3 MLA (2019) Unit 3 Pool Spacing Assessment

At the request of FC District, MLA conducted additional analysis regarding spacing and location of new resting pools, with the objective of optimizing the placement of pools (MLA, 2018). The study used the same 2D hydraulic model results from the 2007 study and Fish-REALMS model for assessing Steelhead fatigue. It focused on identifying the location that the surrogate fish became exhausted at the established high passage design flow of 177 cfs and used this information to strategically target the placement of each resting pool. Pool placement was aimed at achieving or exceeding a passage success rate of at least 65% at the high passage flow of 177 cfs.

The study found that a total of 16 resting pools were needed in Unit 3. If the upper portions of the Unit 3 channel were restored to natural substrate through Allen Park, as has been considered as an alternative in the CMCFRM Project, then Unit 3 would only require 11 new resting pools downstream of the park to achieve a passage success rate of 64% and higher (depending on tide level) at a flow of 177 cfs.

3. Examples of Fish Passage Improvements in Concrete Channels

Construction of concrete channels by the USACE and other entities for flood control occurred extensively from the 1950's into the 1980's. A number of these have been identified as fish passage impediments for adult salmon and Steelhead, and several of them have been modified in recent years to improve passage conditions. The following are a description of three different projects that improved fish passage conditions within concrete channels while maintaining their flood protection benefit.

3.1 Mission Creek – Santa Barbara, CA

The concrete flood control channel on lower Mission Creek in the City of Santa Barbara was identified as a barrier to Steelhead in the 1990's. The trapezoidal concrete channel had a flat bottom in section and was designed for supercritical flow. The original concept for improving fish passage was to construct an inset boulder channel within the existing concrete channel. Physical modeling of this approach by Northwest Hydraulics Consultants (NHC) in 2007 found that it produced excessive hydraulic roughness, resulting in sediment deposition and excessive loss of flood capacity.

An alternative approach was developed that modified the concrete channel by constructing a rectangular low-flow channel with small "pocket pools" for fish to hold and rest. Depth is controlled by rounded "weirs" within the low-flow channel, as seen in Figure 1. Both scaled physical modeling and 3D (CFD) numerical modeling was used to evaluate the selected alternative (HDR, 2010). The design was developed with a focus on minimizing sedimentation within the channel and pools, maintaining sufficient flood capacity in the channel, and producing sufficiently low velocities and water depths for adult Steelhead passage at migration flows. The design was also required to maintain a corridor with sufficient width to allow service vehicles to drive down the channel for maintenance access, thus limiting the size of the pools.

The project was constructed over two seasons in 2012 and 2013 (Figure 2). The second season the contractor prefabricated a form to cast the concrete channel and pools, substantially accelerating the construction and reducing the project cost. Monitoring following high flow events found the fish passage improvements functioned as intended, with minimal to no sedimentation within the pocket pools. Due to the very few fish that utilize this watershed, there is no biological performance data relative to fish passage.

3.2 Mill Creek – Walla Walla, WA

A USACE concrete channel designed for supercritical flow running through Walla Walla, WA was constructed with a baffled low-flow channel. However, it was identified as a barrier to adult salmonids, including Steelhead Trout, due to the spacing between baffles and high velocities. The selected passage improvements involved use of concrete "roughness panels" along one side of an enlarged low-flow channel (Figure 3). The roughness panels aim to simulate coarse substrate that reduces overall velocities and provides a low-velocity boundary layer near the bottom. The project also included resting pools created by incorporating gaps between panels and replacing the original baffles with closer spaced baffles on the opposite side of the low-flow channel. The project, including roughness panels and baffles, were analyzed in a scaled physical model (NHC, 2011). The model found that high-flow conditions remained supercritical with the improvements and there was no decrease in channel capacity.

The project has been built in phases, and each phase has been modified slightly to improve passage conditions and constructability based in-part on lessons learned from the previous phase. This includes adding sufficiently sized areas downstream of the taller concrete blocks on the roughness panels to provide sufficient area for larger fish to hold and rest. The project is extensively monitored, both physically and biologically. Fish have been documented swimming successfully through the retrofitted channel during high flows, using the larger protrusions as resting areas.

3.3 San Jose Creek - Goleta, CA

A new paved flood control channel was constructed on lower San Jose Creek, in Goleta CA in 2011. It included a bottom consisting of articulated concrete blocks that allowed for groundwater recharge. The bottom had a cross slope, concentrating flow on the left side of the channel. Concrete baffles, resembling speed-humps, were placed along the left edge of the channel to concentrate flow and reduce velocities for passage of adult Steelhead (Figure 4). They included a slot to drain the pools behind the baffles as the stream dries. Downstream of each baffle is a wooden “deflector” to improve the hydraulics on the downstream side of the baffle. There remains a fish barrier at the upstream limit of the project, which is to be replaced in the near future. Therefore, there is no biological monitoring data for this project.

Figure 2. Mission Creek fish passage retrofit with low-flow channel, pocket pools, and rounded weirs to control depth (bottom photo: M. Garello).

Figure 3. Mill Creek flood control channel fish passage modifications, replacing a baffled low-flow channel (top left) with new baffles, roughness panels, and resting pools (top right and bottom) (photos from TriState Steelheaders and Patrick Powers).

Figure 4. San Jose Creek flood control channel with rounded baffles for passage of adult Steelhead (top photos: Ed Zapel; bottom photo: City of Goleta).

4. Fish Passage Project Approach and Methods

4.1 Selected Approach for Improving Fish Passage Conditions

Under the current condition, the existing concrete channel provides sufficient depth at the low passage flow of 14 cfs to fully submerge the body of a large steelhead, thus avoiding passage limitations associated with insufficient depth within the channel. The existing pools provide suitable resting areas for fish for the lower third of fish passage flows but lack suitable areas of low velocity at the higher passage flows.

As the primary means to improve fish passage conditions, the previous MLA-JAA (2007) study proposed larger pools that provide suitable resting areas at flows up to the high passage flow. Other approaches, such as fish baffles or addition of roughness panels, like used in Mill Creek, WA (Figure 3), would substantially increase hydraulic roughness and decrease channel capacity in Unit 3 during flood events. Additionally, using these approaches would require modifying the entire length of Unit 3 rather than at discrete locations which may compromise the structural integrity of the existing concrete channel and may require costly reconstruction. Therefore, the alternatives evaluated as part of this project focused on additional fish resting pools to improve passage conditions, while maintaining the existing resting pools in locations that do not overlap with new pools or degrade structural integrity. This section provided an overview of the analysis approach and methods to define the number of new resting pools, their locations and spacing, performance, and preliminary alternative analysis on the resting pool design geometry.

4.2 Overview of Analysis

Fish passage conditions were analyzed as part of this project using the same approach applied in the MLA-JAA (2007) study. This involved the use of a 2D flow field that calculates depth-averaged velocities from a numerical model specifically developed to evaluate fish passage conditions. The 2D flow field was developed using a HEC-RAS 2D model for the Corte Madera Creek concrete channel. Individual fish were then routed through the 2D flow field using the latest version of the Fish Routing, Energetics, and Locomotion Modeling System (Fish-REALMS) developed by MLA. This was conducted for existing conditions as well as for evaluated resting pool alternatives. To evaluate potential for sedimentation within the resting pools, a sediment mobility analysis was conducted using calculated shear stress from the 2D model. This study also added the use of a computational fluid dynamic (CFD) model to analyze resting pool shapes to evaluate velocities and shear stress (sediment mobility) in 3D. Lastly, particle transport analysis was used in the CFD model to evaluate and refine the resting pool design to reduce sedimentation potential. The following sections describes the methods used to conduct the various analysis.

4.3 HEC-RAS 2D Fish Passage Model Development

4.3.1 Model Domain and Geometry

The fish passage hydraulic model was developed to evaluate the existing and proposed conditions of the concrete channel in Unit 3, which contains the fish pools described previously. The Fish Passage Model is a two-dimensional (2D) HEC-RAS model extending from the earthen channel in the full tidal reach downstream of College Avenue to just downstream of the fish ladder at the upstream limit of Unit 3.

The model domain only included the concrete channel, not the adjacent floodplains. The HEC-RAS model terrain was developed based on the construction drawings for the concrete channel (USACE, 1970) (Figure 5 and Figure 6). The downstream boundary condition was based on tidal stage, as described in subsequent sections.

4.3.2 Fish Passage Model Calibration

The previous fish passage study included the installation of stage gages and monitoring of flow events at five locations within the Unit 3 concrete channel. This effort is documented and described in the Fish Passage Assessment and Alternatives Analysis (MLA-JAA, 2007). Stations 1 (located a short distance downstream of the existing fish ladder) and Station 2 (located upstream of Kentfield Hospital bridge near Station 361+00) were used for the calibration process and are located within upper portions of Unit 3, upstream of tidal influence. The 2D HEC-RAS model was run for a large range of flows to develop rating curves at each of the two monitoring stations. The rating curves were than compared to the observed data and the roughness coefficient of the concrete channel was adjusted to obtain a best fit. Figure 7 displays the resulting rating curves for a roughness coefficient of 0.013, which provides the best fit for the observed water surface elevations at Stations 1 and 2. The roughness coefficient of 0.013 was used to determine depth and velocities for the fish passage flows (14 to 180 cfs) and for sediment transport capacity flows, estimated to be around 500 cfs.

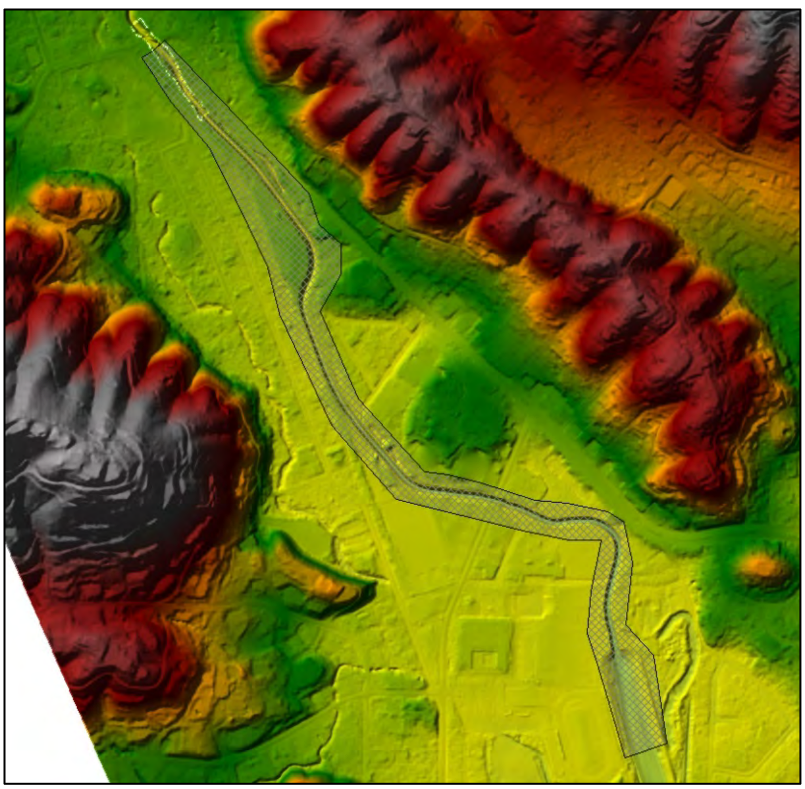


Figure 5. Fish passage model extents and terrain shown in hatched area.

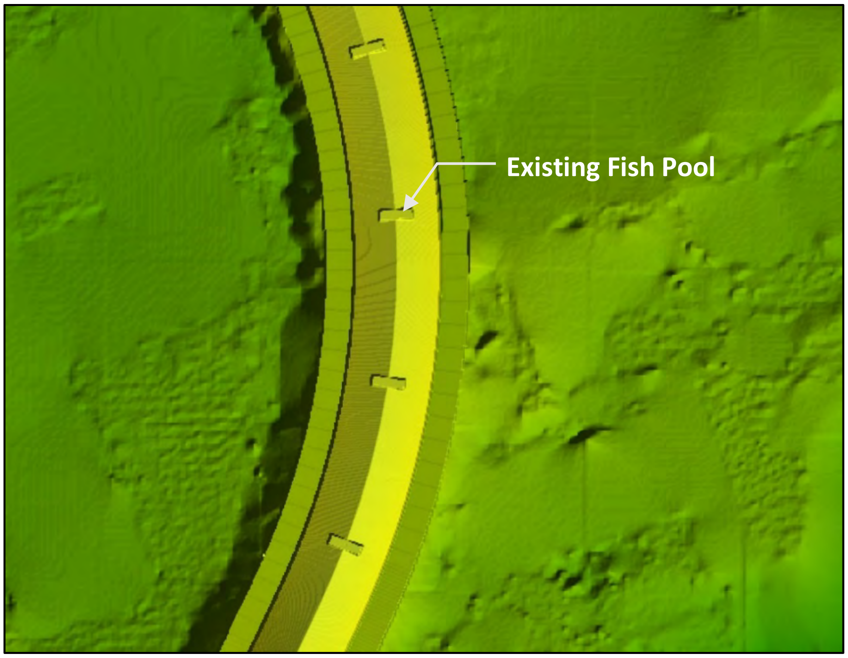


Figure 6. Example of 2D fish passage model terrain with existing fish pool configuration.

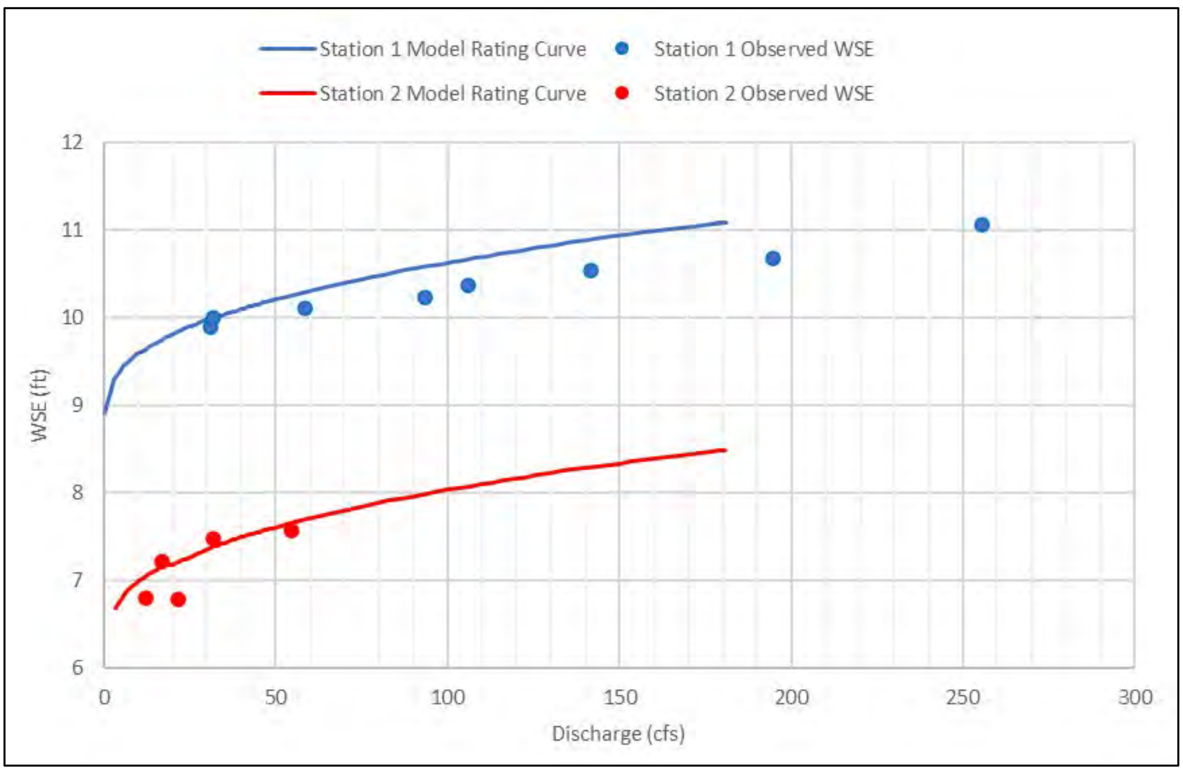


Figure 7. Fish passage model calibration of Manning's roughness coefficient using (n) of 0.013 to observed water surface elevations (WSEs) at two locations in the upper third of the Unit 3 concrete channel.

4.4 Analyzed Fish Passage Flows and Tidal Boundary Conditions

Altogether, 7 flows (Table 2) were analyzed for fish passage. For each analyzed flow, passage conditions for 8 different tidal stages were analyzed (Figure 8). This resulted in a total of 49 different flow-tide combinations that were analyzed for fish passage. The selection of these flows and tides is described in the following sections.

4.4.1 Fish Passage Flows

The low and high fish passage flows bracket the range of streamflows passage should be provided. Steelhead and Coho Salmon typically migrate inland in response to rainfall-runoff events and may not be expected to migrate during low flow conditions. Additionally, during infrequent high flows the fish may not move upstream, but rather shelter in an area of lower velocity until flows recede. Additionally, high flow events in coastal watersheds, such as Corte Madera Creek, are typically short in duration. As such, the delay potentially imposed on upstream fish migration, when streamflows exceed the high passage flow, is relatively short compared to the passage period provided as flows recede.

Fish passage flows were previously developed for this project as part of the MLA-JAA (2007) study based on daily average flows recorded at the USGS Corte Madera Creek at Ross gaging station (Sta. No. 11460000), which was discontinued after water year 1993 but reinstated in water year 2010. Subsequently, an additional 8 years of streamflow data has been collected. Additionally, the previous study used a migration period of December 1 – March 31, while this study has expanded that migration period to April 30. Therefore, the calculated fish passage flows were updated as part of the current project.

For this project, fish passage flows were defined based on daily exceedance flows during the typical Steelhead and Coho Salmon migration period of December 1 through April 30. The previous study used a low and high passage flow equal to the 50% and 10% exceedance flow during the migration period. The additional daily streamflow data collected since the 2007 study causes a slight shift in the flows associated with these exceedance values. Table 2 lists the daily exceedance probabilities and associated streamflows for Corte Madera Creek. The project maintains the same low passage flow used in the previous study, of 14 cfs rather than the updated 50% exceedance flow of 12 cfs. The 14 cfs flow provides sufficient depth within the V-shaped concrete channel for submerging the largest Steelhead while at 12 cfs the depth is insufficient. The high passage flow was increased to 180 cfs, which is the 8% exceedance flow for the period of migration. The 10% exceedance flow was lower than the previous study due to the expansion of the migration period to include April, which tends to be drier than the previous months. The intermediate flows listed between 14 cfs and 180 cfs were also analyzed as part of this project.

Table 2. Daily average exceedance flows during the period of fish migration (December 1 – April 30) based on the 52 years of daily average flows recorded in Corte Madera Creek at Ross (USGS Sta. 11460000). The listed low and high passage flows and intermediate flows were selected for the project's fish passage analysis.

Daily Exceedance Probability during Migration Period	Flow	Description
47%	14 cfs	Low Fish Passage Flow for this Study
40%	20 cfs	
30%	35 cfs	
20%	65 cfs	
15%	100 cfs	
10%	150 cfs	
8%	180 cfs	High Fish Passage Flow for this Study

4.4.2 Tidal Ranges used for Fish Passage Analysis

The tidal ranges experienced at the downstream end of Unit 3 were estimated based on the long-term NOAA tidal station (No. 9414863) located on the Richmond Chevron Oil Pier. The frequency various tidal stages are exceeded were plotted using the station's 2-minute data from 2009 to 2018 (Figure 8). Based in part on this plot, the fish passage analysis was conducted for tidal boundary stages from 0 to 7 feet (NAVD88), at 1-foot increments.

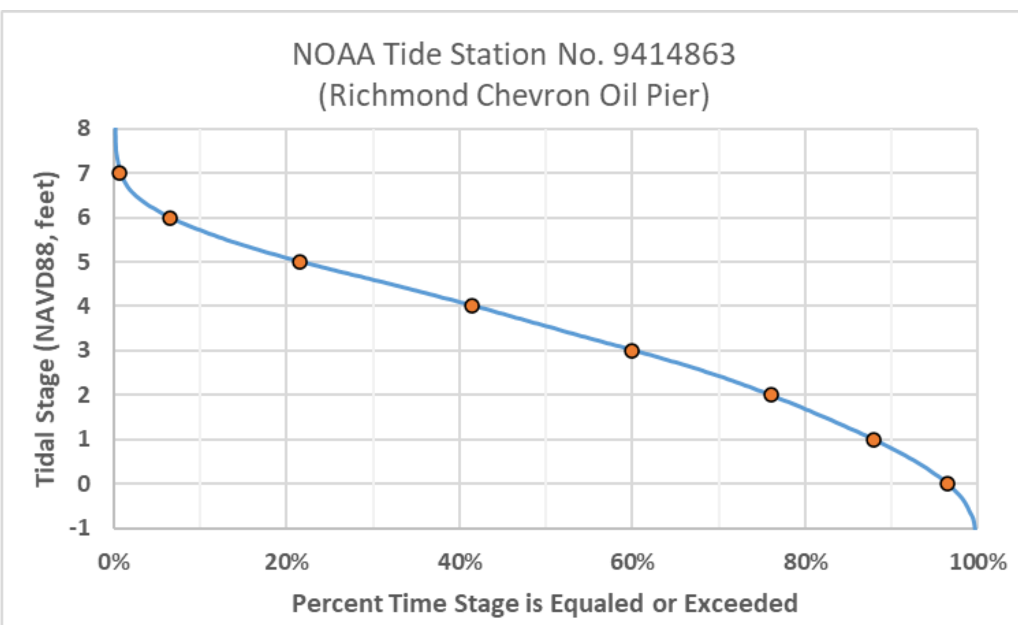


Figure 8. Exceedance frequency of tides applied to Corte Madera Creek. Orange dots represent each tidal boundary condition analyzed.

4.5 Fish-REALMS Model Overview

Fish-REALMS, the Fish Routing, Energetics, and Locomotion Modeling System, is an individual-based model for simulating fish attempting to swim through hydraulically challenging conditions. The model was developed by Michael Love and previously used to evaluate fish passage conditions in San Lorenzo Creek Flood Control Channel in Alameda County, California (MLA, 2006), Corte Madera Creek Flood Control Channel in Marin County, California (MLA-JAA, 2007), and Branciforte Creek Flood Control Channel in Santa Cruz, California (MLA, 2016). All three flood control channels are concrete, similar in size and shape, and designed to produce supercritical flow for flood conveyance.

The Fish-REALMS model was developed based on work by Castro-Santos (2002, 2005, and 2006), among others. The model selects a "surrogate fish" from a fish size distribution and from a distribution of swim speed verses time-to-fatigue relationships. The surrogate fish is routed through the study reach, the Unit 3 concrete channel in this case, based on a numerical model generated depth-averaged 2-D flow field. The model routes the fish along the path with the lowest velocities and sufficient depth to submerge the fish's body. The surrogate fish rests and fully recovers from fatigue when it encounters water velocities low enough to allow holding by maintaining position while swimming at a "sustained" swim speed. Surrogate fish that swim the entire route without becoming fully fatigued (exhausted) are considered successful. If the fish becomes fully fatigued at any location along the route, the fish is considered unable to successfully pass and the location of full fatigue is recorded. For each flow and tidal boundary condition evaluated the model runs 1,000 simulations to characterize the passage conditions for the entire fish population and identifies fatigue locations along the channel.

The Fish-REALMS model was updated as part of the 2016 analysis for Branciforte Creek, with improved regression analysis for the Steelhead swim speed – time to fatigue relationship and addition of Coho Salmon to the model. The following sections provides a brief description of the model setup and assumptions. Refer to the MLA-JAA (2007) and MLA (2016) for a full description of the Fish-REALMS model, and associated assumptions and limitations.

4.5.1 Steelhead Size Distribution

For this project, simulations were performed for adult anadromous Steelhead Trout (*Oncorhynchus mykiss*). The distribution of Steelhead body lengths were derived from Steelhead from the Central California Coast (CCC) Distinct Population Segment (DPS), which includes Corte Madera Creek (Figure 9). The body depth of the fish, used to define the minimum water depth required for routing the fish, is estimated based on a body depth to length ratio of 0.222 for Steelhead, as reported in FishBase (2006). The largest Steelhead in the population is approximately 32 inches in length, which gives a corresponding body depth of 0.60 feet.

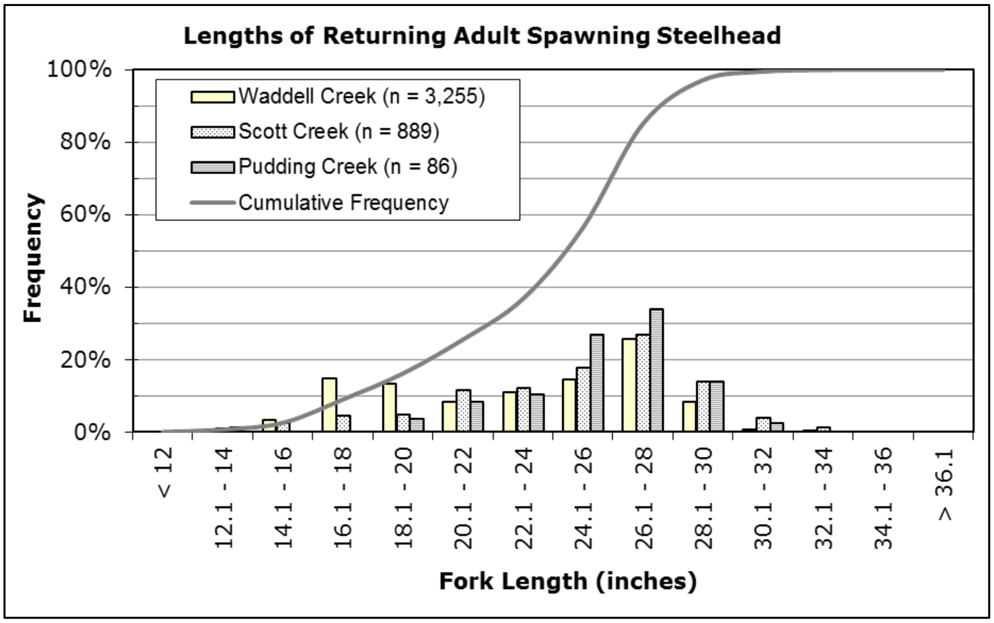


Figure 9. Distribution of fish lengths for sexually mature Steelhead Trout in three streams within the CCC Steelhead DPS. Cumulative frequency distribution of fish lengths normalized by source.

4.5.2 Steelhead Swimming Capabilities

The swim speed - fatigue time data sets were obtained from swim speed tests performed by Paulik and DeLacy (1957) using wild Steelhead sourced from a stream near Seattle, Washington and from tests by Weaver (1963) using Columbia River Steelhead. The swim speed data was divided into the three commonly defined swimming modes, as described by Beamish (1978): (1) sustained, (2) prolonged, and (3) burst (sprint). Swim speeds were normalized by body length, such that swim speeds were reported in body lengths per second (BL/s). Based on the data, swim speeds of 1.5 BL/s and lower were categorized as sustained for Steelhead and can be maintained indefinitely. Swim speeds greater than 7.0 BL/s were categorized as burst swimming, which can only be maintained for less than 30 seconds and is generally not used by the surrogate fish when needing to travel long distance. For prolonged swimming, a generalized mixed log-linear model was fitted to the prolonged swim speed – time to fatigue data set (Figure 10). For each surrogate fish, the intercept of the log- linear model is randomly selected from the probability distribution of that parameter, while the slope remains constant.

The fish was assumed to swim in prolonged mode at the “distance optimizing” ground speed, which results in a constant speed relative to the ground, as defined by Castro-Santos (2005). This is a swim speed that results in the fish traveling the furthest distance before becoming exhausted. Based on the log-linear model provided in Figure 10, the constant ground speed in prolonged mode for Steelhead is 2.05 BL/s. When the optimal ground speed resulted in a swim speed relative to the water greater than 7 BL/s, the fish was assumed to swim in burst mode.

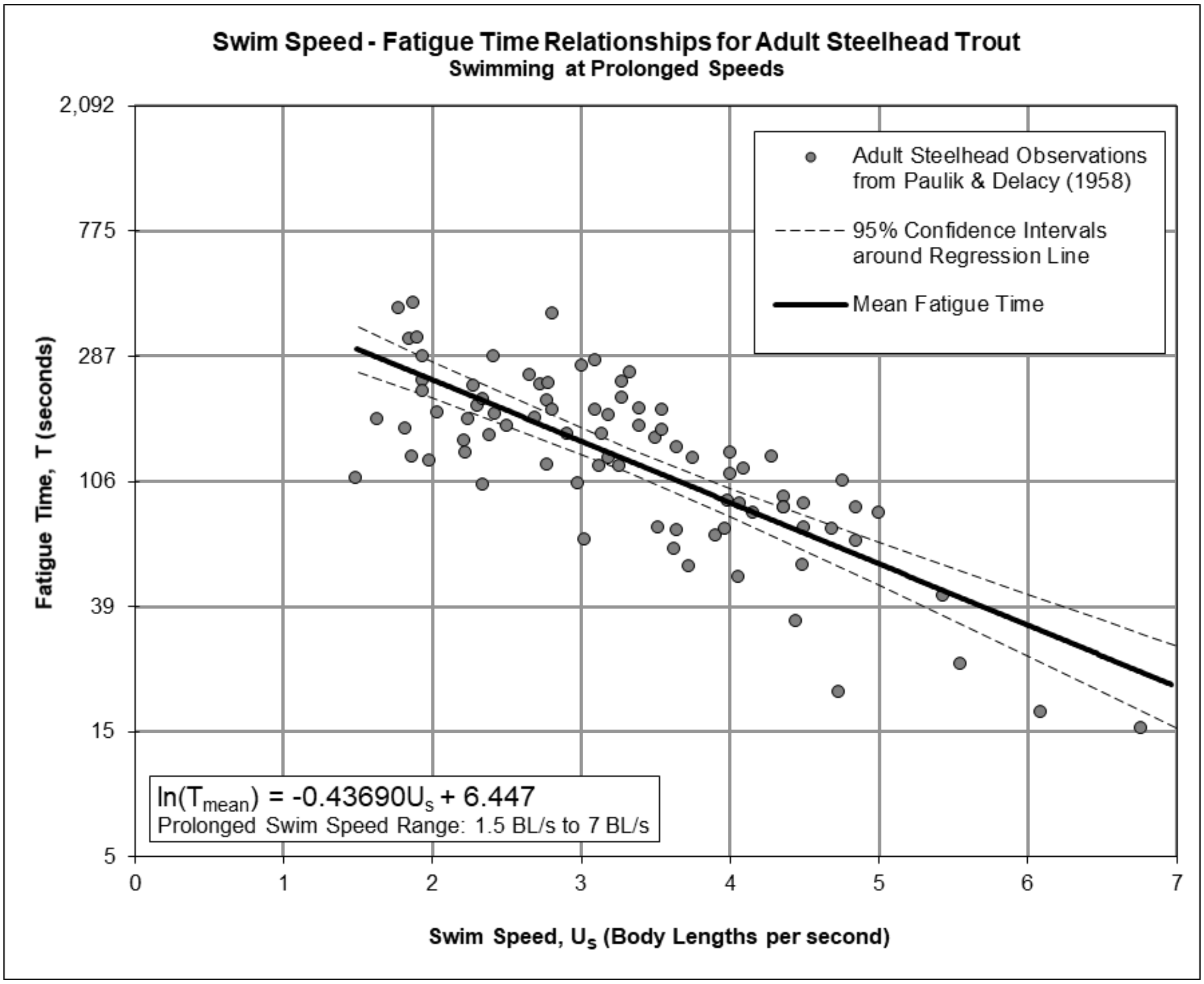


Figure 10. Relationship of swim speed verses time to fatigue for Steelhead Trout swimming at prolonged speeds, developed from data presented in Paulik and Delacy (1958).

For swimming in burst mode, a constant ground speed traveled by the fish was assumed based on an analysis of Steelhead swim speed data provided in Weaver (1963). This data set revealed that at water velocities of 13.4 ft/s (n = 84) and 15.8 ft/s (n = 39), the ground speeds of the fish were grouped tightly around approximately 5 ft/s. Weaver did not provide individual fish lengths but noted the median Steelhead length was approximately 24 inches. Using this length, the dominate Steelhead ground speed was approximately 2.5 BL/s. This burst mode ground speed was applied to the Fish-REALMS simulations for Steelhead.

4.5.3 Fish Routing and Minimum Water Depth

For each analyzed flow and tidal boundary condition, three different preferred fish swimming routes were developed to account for the different water depth requirements associated with small (bottom 25 percentile), average, and large (top 25 percentile) fish (Table 3). The depth must be sufficient to fully submerge the body of the individual fish. The swimming routes assumed a 2-foot wide swimming corridor. The routes were digitized in GIS by identifying the 2-foot wide corridor of lowest water velocity that also provides adequate depth based on the fishes body size. Based on the simplicity of hydraulics within concrete channels, the routes are typically along the outer edge of the wetted channel and involve few or no "cross-overs," where the route crosses from one side of the channel to the other.

Table 3. Steelhead body length ranges and minimum water depth criteria applied to their swimming route.

Range of Fish Lengths	Percentile of Population	Min Water Depth
< 1.62 ft	0 – 25%	0.36 ft
1.62 ft to 2.22 ft	26% - 75%	0.50 ft
> 2.22 ft	76% - 100%	0.64 ft

4.5.4 Application of Steelhead Results to Coho Salmon

Although this analysis is focused on Steelhead Trout, an analysis of passage performance using Fish-REALMS was conducted for both adult Steelhead and Coho Salmon on a similar concrete channel in Branciforte Creek in Santa Cruz CA (MLA, 2016). This included a population distribution of Coho Salmon size and a swim-speed to fatigue-time relationship for the fish. Comparison of results for the two species at the same fish passage flows found passage success rates were similar, with passage success rates generally higher for Coho Salmon. This is primarily due to slightly higher endurance levels for Coho Salmon (swim longer before becoming fatigued) when swimming at low to moderate prolonged speeds. As such, Coho Salmon passage success rates should be similar, or slightly better, than those reported for Steelhead as part of this study.

4.6 Approach to Evaluation of Sedimentation Potential in Resting Pools

As part of evaluating the effectiveness of various fish resting pool configurations, the potential for excessive sedimentation within the pools was evaluated by analyzing sediment mobility. This was conducted based on an estimate of the critical discharge that bedload begins to be transported from upstream into Unit 3. At this critical discharge, the shear stresses within the resting pools were evaluated and compared to commonly applied shear stresses for mobilizing coarse sediment. The presumption is that if adequate shear stress is provided in the resting pools that keeps the dominate sediment size in transport at the critical discharge, then the pools would remain scoured during higher flows, thus less likely to accumulate excess sediment. This analysis required an estimate of the dominate particle size of the streambed being delivered to Unit 3, the critical shear stress for mobilizing the dominate particle size, and the sediment mobility critical discharge that the bed material begins to be transported into Unit 3.

4.6.1 Dominate Particle Size and Critical Shear Stress

Table 4 lists the estimated range of shear stresses that mobilizes different particle sizes based on the listed range of values for the dimensionless Shield parameter given by Julien (1998). The critical shear stress values are categorized as partially mobile, partially-fully mobile, and fully mobile. The particle is considered stable (immobile) at shear stresses lower than these values.

The characteristic particle size (D_{50}) of the bed material in Corte Madera Creek at Ross is 8 mm (Copeland, 2000). Therefore, the mobility analysis focused on the critical shear stresses for fine and medium gravels. Plots of sediment mobility were defined based on fine gravel and used the shear stresses listed in Table 4 for fine gravels:

- Stable $\leq$ 0.0564 psf
- 0.0564 psf < Partially Mobile $\leq$ 0.0877 psf
- 0.0877 psf < Partially-Fully Mobile $\leq$ 0.1191 psf
- Fully Mobile > 0.1191 psf

4.6.2 Sediment Mobility Analysis of Existing Unit 4

The existing condition HEC-RAS model prepared by USACE and Stetson Engineers for the Ross Valley Watershed (Stetson 2017) was used to estimate the channel shear stresses at various flows in the reach upstream of the Lagunitas Road Bridge. The analysis evaluated mobility of fine and medium gravels at each cross section, identifying the cross sections that require the highest flow to produce the critical shear stress. Results suggested that the channel may begin mobilizing fine and medium gravels at a streamflow as low as 350 cfs. Sediment mobilization flow typically is close to the channel bankfull flow, often approximated by the 2-year flow, which is estimated at 2,130 cfs. Since this critical discharge is only 1/6th the magnitude of the 2-year flow, results from the Water Year 2021 bedload sampling were used to reevaluate this critical discharge value.

4.6.3 Water Year 2021 Bedload Sampling to Refine Critical Discharge for Sediment Mobility

The FC District conducted bedload sampling in Corte Madera Creek during the 2021 winter season. The bedload sampling location is at the Lagunitas Road Bridge in the Town of Ross. Lagunitas Road Bridge is located approximately 600 feet upstream of the concrete channel and fish ladder. The sediment mobility analysis and field observations, including gravel deposits, suggested Corte Madera Creek at Lagunitas Road Bridge is prone to sediment deposition. It is a sediment transport bottleneck to the downstream concrete channel in Unit 3.

The plan for bedload sampling involved collecting multiple bedload samples during each major storm event based on USGS sampling protocols using a Helley-Smith bedload sampler. A bridge crane was setup at the downstream face of the bridge to lower the bedload sampler into the stream during high-flow events.

Figure 11 contains a plot of streamflows between October 15, 2020 and April 15, 2021 from the USGS gaging station in Corte Madera Creek at the Town of Ross (USGS Station No. 11460000). The gage is located at approximately 300 feet upstream of Lagunitas Road Bridge, providing a reasonable representation of streamflow at the bridge where bedload sampling occurs.

Table 4. Estimated Shields parameters and critical shear stress for different particle-size classes (adapted from USGS, 2008 and Julien, 1998). Dominate particle size in Corte Madera Creek is fine gravel.

Particle classification	Ranges of particle diameters		Shields parameter	Critical bed shear stress (τc) lb/ft²		
Name	ϕ	mm	(dimensionless)	Low *Partially Mobile*	Average *Partially-Fully Mobile*	High *Fully Mobile*
Coarse cobble	-7 – -8	128 – 256	0.054 – 0.054	2.33916	3.4983	4.65744
Fine cobble	-6 – -7	64 – 128	0.052 – 0.054	1.12363	1.7314	2.33916
Very coarse gravel	-5 – -6	32 – 64	0.050 – 0.052	0.54093	0.8323	1.12363
Coarse gravel	-4 – -5	16 – 32	0.047 – 0.050	0.25480	0.3979	0.54093
Medium gravel	-3 – -4	8 – 16	0.044 – 0.047	0.11905	0.1869	0.25480
Fine gravel	-2 – -3	4 – 8	0.042 – 0.044	0.05639	0.0877	0.11905
Very fine gravel	-1 – -2	2 – 4	0.039 – 0.042	0.02715	0.0418	0.05639
Very coarse sand	0 – -1	1 – 2	0.029 – 0.039	0.00982	0.0185	0.02715
Coarse sand	1 – 0	0.5 – 1	0.033 – 0.029	0.00564	0.0077	0.00982
Medium sand	2 – 1	0.25 – 0.5	0.048 – 0.033	0.00405	0.0048	0.00564
Fine sand	3 – 2	0.125 – 0.25	0.072 – 0.048	0.00303	0.0035	0.00405
Very fine sand	4 – 3	0.0625 – 0.125	0.109 – 0.072	0.00230	0.0027	0.00303

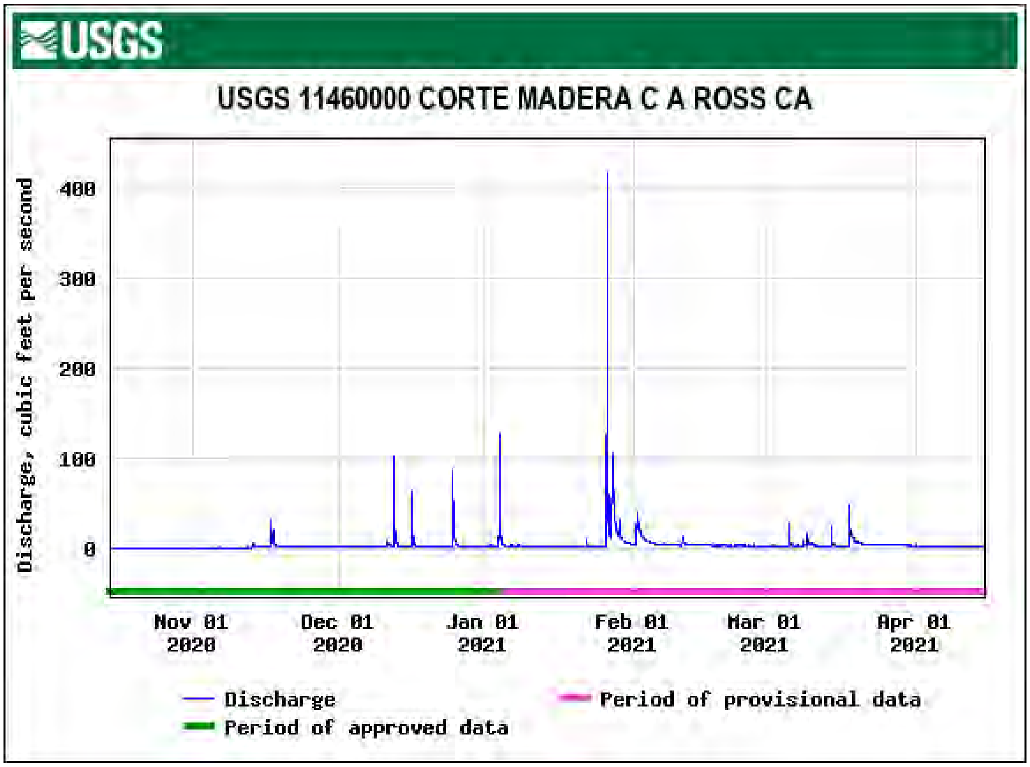


Figure 11. USGS Corte Madera Creek at Ross 15-minute flow data for 10/15/2020 to 4/15/202. Bedload sampling conducted during peak flow on January 27, 2021.

The 2020 winter season was extremely dry. As shown in Figure 11, most of the storm events have peak flow around 100 cfs or less. The largest storm event on January 27, 2021 resulted in a peak flow of 419 cfs. The storm peak was short, with less than two hours of streamflow exceeding 300 cfs. During this storm, the field crew deployed the bedload sampler multiple times, but no bedload was captured. This field data suggests the stream does not transport bedload at the bridge cross section and into downstream Unit 3 at flows of 419 cfs and lower. Additional bedload samplings will be needed to verify the bedload sediment mobility observation.

Based on the bedload sampling, the critical discharge for mobilizing gravels into Unit 3 was assumed to be at least 500 cfs. Therefore, the sediment mobility analysis to evaluate the potential for transported sediment to deposit within the pools focused on shear stress and velocities in the pools at 500 cfs.

4.7 CFD Model Development

Computational fluid dynamics (CFD) modeling was developed to evaluate the hydraulics within a typical proposed fish resting pool and its vicinity. The analysis supports development of the fish resting pool geometry, with the aim of balancing low velocities for fish resting and high sediment mobility potential to minimize sediment deposition. The modeling was undertaken using Siemen's StarCCM+ (Version 2020.3.1) CFD modeling software and used a free-surface model with multi-phase (air and water) flow.

4.7.1 Model Geometry

3-dimensional (3D) models of the existing channel geometry with the various alternatives for the proposed fish resting pools were developed as part of this study. The model geometries were developed in AutoCAD Civil 3D as triangulated irregular network (TIN) surfaces using the record drawings for the channel and the proposed fish pool geometries. The TIN surfaces were exported from AutoCAD Civil 3D as stereolithography (STL) files and then imported into StarCCM+ for CFD modeling.

4.7.2 Large Domain Model

Due to the computational intensity associated with CFD models, a two-step process was used. A model with a larger domain and lower resolution was first used to provide boundary conditions for a model with a smaller domain and smaller cells for higher resolution that focused on the detailed hydraulics of a single resting pool. With that purpose, the larger domain model was developed with a relatively coarse resolution of 1-foot cells to decrease computational run time. The large domain CFD model was developed using the geometric extents from channel station 349+00 to 353+00, which included three proposed fish resting pools based on the Alternative 2 geometry as described in Section6.3, and no existing pools. The model was run with two flow scenarios (1) 180 cfs, which is the high fish passage flow and (2) 500 cfs, which is the estimated flow for mobilizing sediment in the upstream natural-bedded channel.

4.7.3 Single Pool Model

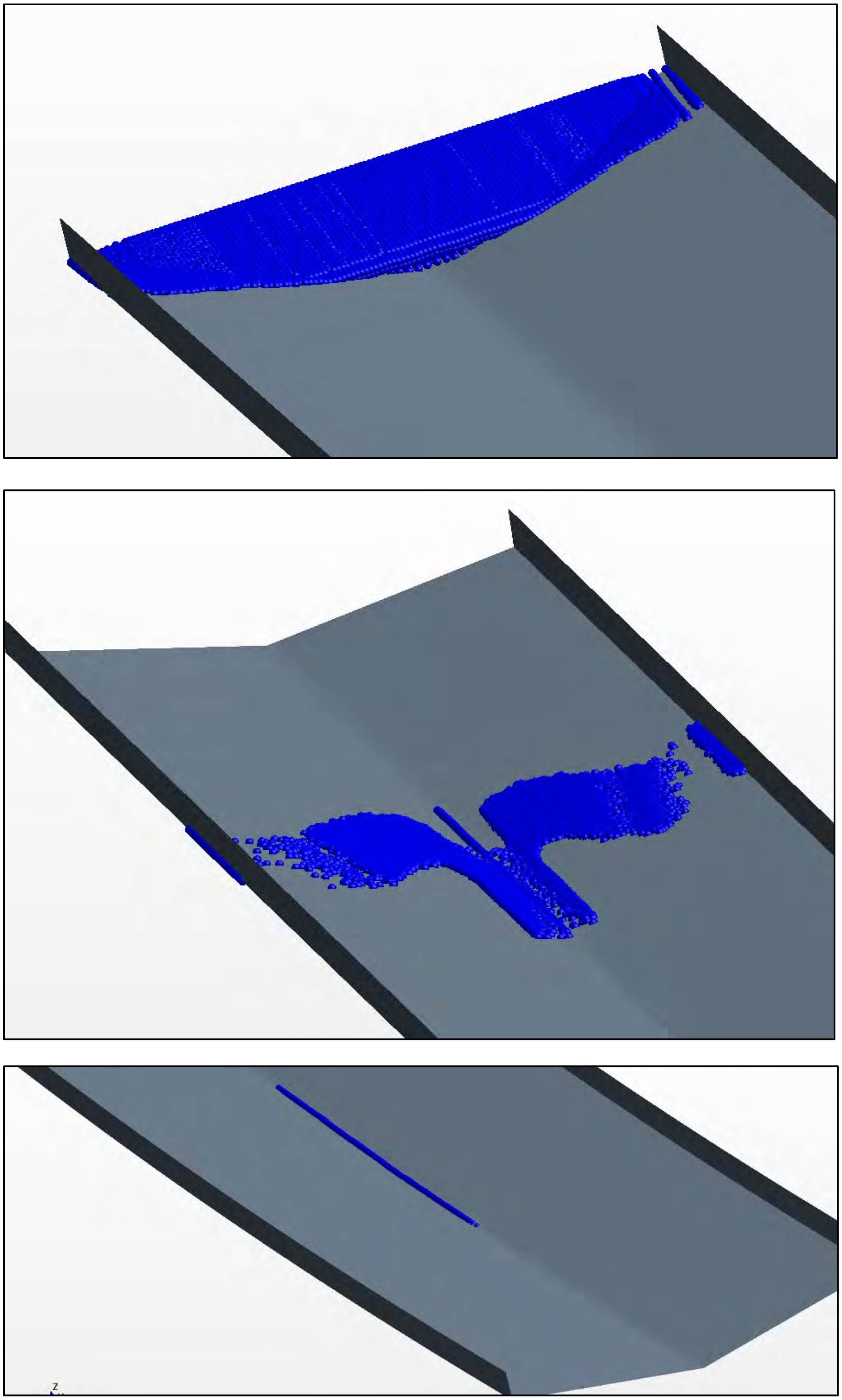
Smaller domain CFD models were developed with the fish resting pool geometries for Alternatives 2, 3 and 4. The models only contained the middle pool that was in the Large Domain Model and extend 25 feet downstream and upstream of the pool from channel station 350+80.00 to 351+42.50. The models were developed with a base cell size of 4 inches and additional refinement within the pools using 2-inch cells. In addition, adaptive mesh refinement was incorporated into the model which provides mesh refinement at the water surface.

Water velocity and depth were obtained from the large domain model and applied as boundary conditions at the upstream and downstream of the single pool models for the two flow scenarios of 180 cfs and 500 cfs.

4.8 Particle Tracking using CFD Model

To help evaluate the potential for sedimentation within the fish resting pools, analyses were conducted using CFD modeling with particle tracking. A Lagrangian multiphase approach was used where spherical particles were injected into the model at the upstream boundary and tracked through the model domain. The particles had a density of 165 lb/ft^3 and a diameter of 8 mm, which is the approximate median diameter, or D_{50}, of bed material samples taken upstream of the concrete channel in 1985 by the USACE Sacramento District (USACE, 1986).

To understand how sediment of this size would be distributed within the channel, a CFD model was developed using the Large Domain Model as described in Section 4.7.2, but with the pools removed so they would not affect the distribution of sediment within the channel. The model was run with a flow of 500 cfs until it reached a steady-state condition, then sediment was injected with an even distribution along the wetted area at the upstream boundary (Figure 12a) at a rate of 0.5 lbs/second for 3 seconds. The modeling showed the sediment particles quickly collecting in a linear arrangement along the channel invert as they moved downstream, as shown in Figure 12b. Based on the results of this model run, sediment was injected near the channel invert for future model runs with proposed fish resting pools, to optimize the model computational efficiency and run time.



(a) (b) (c)

Figure 12 Sediment particles (blue spheres) (a) injection at upstream boundary and subsequently (b and c) distributing toward the channel invert as they move downstream.

Fish resting pool Alternative 4, the preferred alternative as described in Section 6.5, was evaluated using CFD modeling with particle tracking using the Langrangian multiphase approach and sediment particle physics as described above. The single pool model with a flow of 500 cfs served as the basis for the analysis, with sediment particles injected near the channel invert at the upstream boundary at a rate of 0.5 lbs/second for 5 seconds. The results of this modeling effort are discussed in Section 6.5.3.

5. Development and Evaluation of Resting Pools

5.1 Existing Fish Passage Conditions Analysis

5.1.1 Results

Previous fish passage analysis by MLA-JAA (2007) and MLA (2018) documented the partial migration barrier created by the Unit 3 concrete channel. To evaluate passage improvements with different alternatives, the existing fish passage conditions were reassessed using the project's HEC-RAS 2D model (Section 4.3) combined with the current version of Fish-REALMS (Section 4.5). In addition, the passage flows and tidal boundary conditions used for this project were updated from the previous analysis.

The analysis included the seven selected passage flows and the eight corresponding tidal boundary conditions for each flow, for a total of 56 scenarios. The results from the new HEC-RAS 2D model and updated Fish-REALMS model are presented in Table 5. These were similar to the results from the previous MLA-JAA (2007) analysis listed in Table 1.

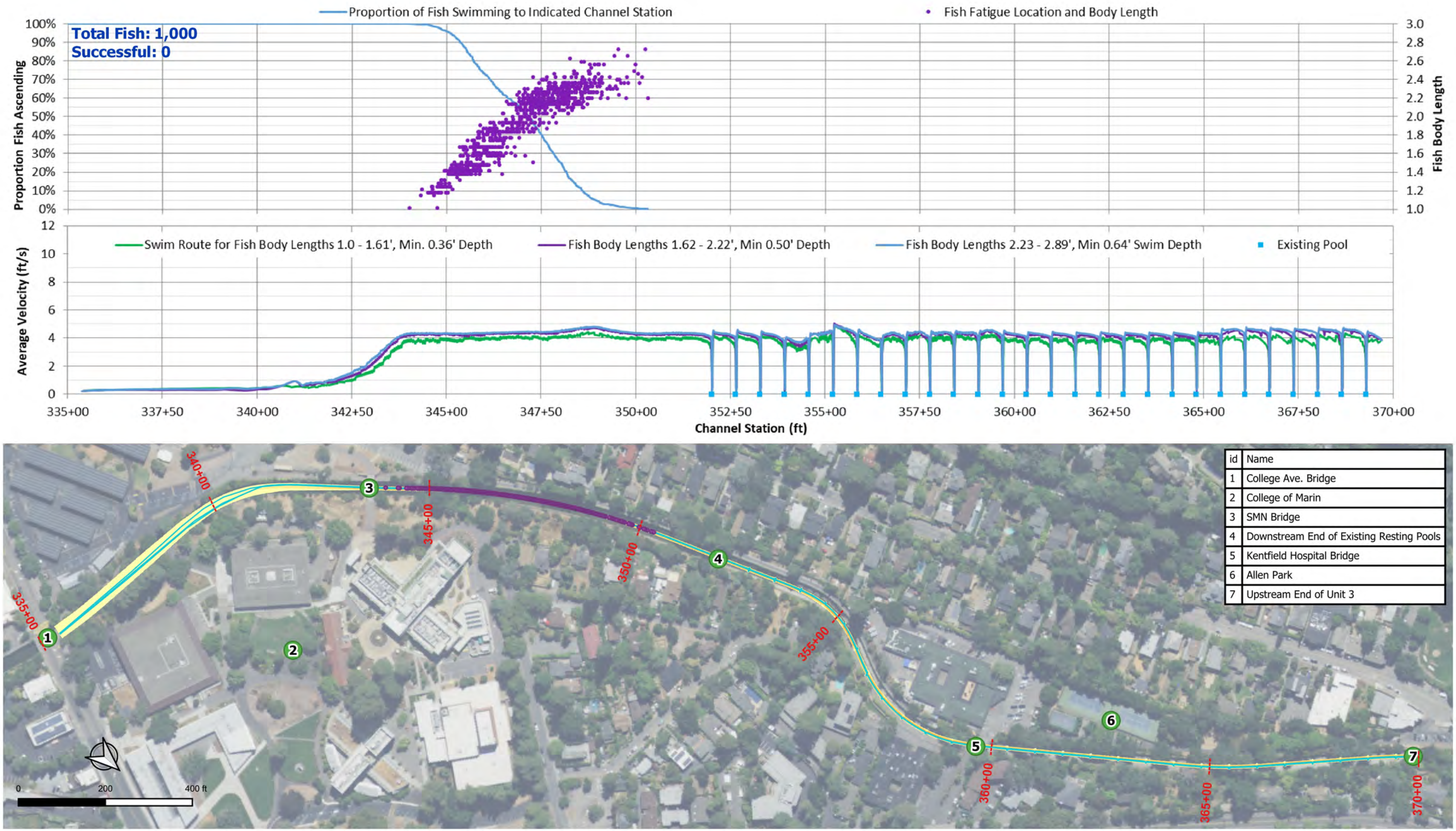
Summary figures for select flows/tidal boundary conditions are presented in Figure 13 through Figure 16 and in Attachment 2. Each of these figures show (1) the location and body length of each surrogate fish that became fatigued within Unit 3, (2) the cumulative percent of the population that successfully swam through the entirety of Unit 3 and the lengths of the successful fish, (3) the three potential swimming routes applied to the analysis (which depended on the body size of the surrogate fish and corresponding minimum water depth for swimming), (4) location of the existing resting pools, and (5) water velocity encountered along each of the three fish routes.

5.1.2 Discussion

As seen in Figure 13, at the low passage flow of 14 cfs with a low tide of 0.0 feet, all of the surrogate fish become exhausted before reaching the location of the downstream-most existing resting pool, thus resulting in 0% success. At the same flow of 14 cfs but at a higher tide of 4.0 feet (Figure 14), the tidal backwater extends upstream of the first resting pool encountered. As such, nearly all the surrogate fish reach the first resting pool without becoming fatigued and successfully pass through Unit 3. The velocities encountered by the fish within the channel are generally between 4.0 and 5.5 ft/s while the velocities in the resting pools are negligible.

These results show that at these lower passage flows the existing pools provide suitable velocities for resting. Velocities in the existing pools remain within the sustained swimming speed range for nearly all surrogate fish at analyzed flows up to 65 cfs, allowing the fish to resting and recover from fatigue.

At 100 cfs the velocities in some of the existing pools increases to magnitudes that prevent resting for the smaller and weaker surrogate fish within the population, causing fatigue and a decrease in overall passage success. At the high passage flow of 180 cfs the velocities in the existing pools are too high for nearly all the surrogate fish (Figure 15 and Figure 16).



Datums:
Horizontal: NAD83 State Plane CA Zone 3
Vertical: NAVD88

Sources:
Aerial Image: 2018 Coastal California NAIP

Prepared for:
- Friends of Corte Madera Creek Watershed
- Marin County Flood Control and Water Conservation District
- California Coastal Conservancy

Map Legend:
Fish Fatigue Location *Fish Swim Path*
Velocity (fps)
<= 1 | 1 - 2 | 2 - 3 | 3 - 4 | 4 - 5 | 5 - 6 | 6 - 7 | 7 - 8 | 8 - 9 | 9 - 10 | > 10

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GHD

FIGURE 13
Ross, CA
Corte Madera Creek, Existing Conditions
Species: Adult Steelhead
Flow: 14 cfs
Boundary Condition: 0 ft Tide

Filepath: Q:\Corte Madera Passage Analysis\7_CAD-GIS\QGIS\Working\CorteMadera_Steelhead_14cfs.qgs

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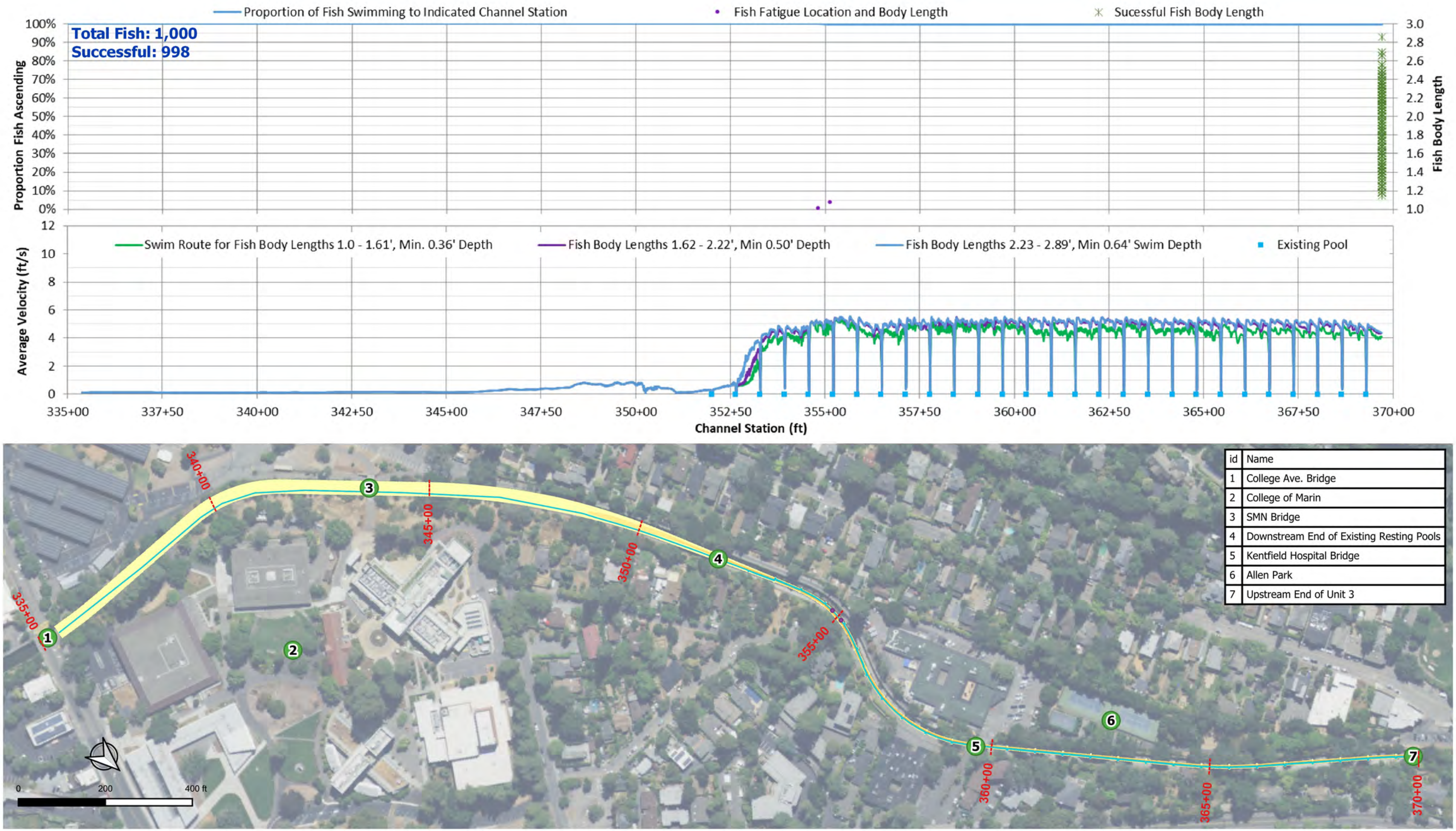

Datums: Horizontal: NAD83 State Plane CA Zone 3 Vertical: NAVD88 Sources: Aerial Image: 2018 Coastal California NAIP	Prepared for: - Friends of Corte Madera Creek Watershed - Marin County Flood Control and Water Conservation District - California Coastal Conservancy	**Map Legend:** • *Fish Fatigue Location* — *Fish Swim Path* *Velocity (fps)* <= 1, 1 - 2, 2 - 3, 3 - 4, 4 - 5, 5 - 6, 6 - 7, 7 - 8, 8 - 9, 9 - 10, > 10	Michael Love & Associates *Hydrologic Solutions* GHD

FIGURE 14
Ross, CA
Corte Madera Creek, Existing Conditions
Species: Adult Steelhead
Flow: 14 cfs
Boundary Condition: 4 ft Tide

Filepath: Q:\Corte Madera Passage Analysis\7 CAD-GIS\QGIS\Working\CorteMadera_Steelhead_14cfs.qgs

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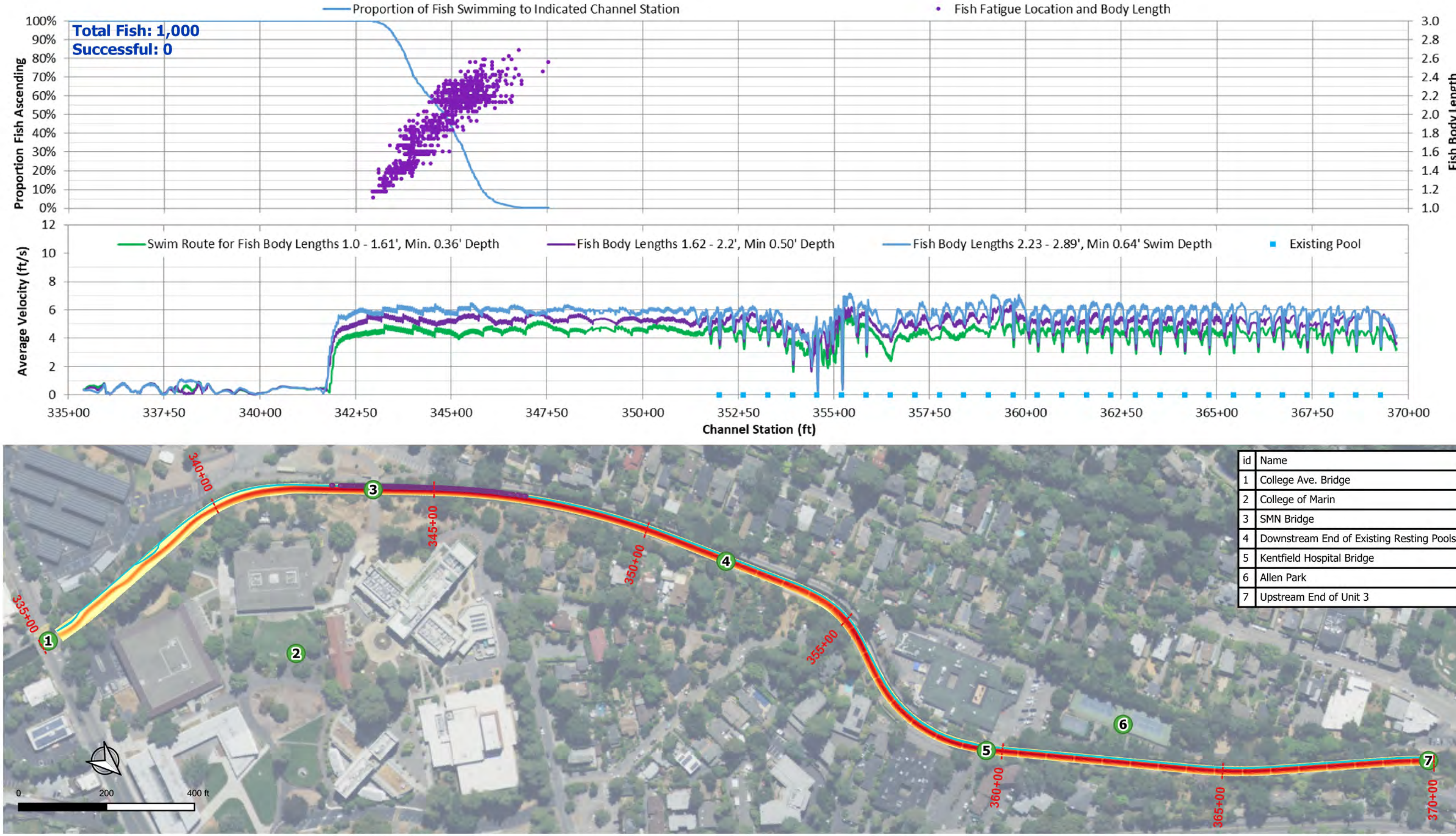

Datums:
Horizontal: NAD83 State Plane CA Zone 3
Vertical: NAVD88

Sources:
Aerial Image: 2018 Coastal California NAIP

Prepared for:
- Friends of Corte Madera Creek Watershed
- Marin County Flood Control and Water Conservation District
- California Coastal Conservancy

Map Legend:
Fish Fatigue Location — Fish Swim Path
Velocity (fps)
<= 1 | 1 - 2 | 2 - 3 | 3 - 4 | 4 - 5 | 5 - 6 | 6 - 7 | 7 - 8 | 8 - 9 | 9 - 10 | > 10

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GHD

FIGURE 15
Ross, CA
Corte Madera Creek, Existing Conditions
Species: Adult Steelhead
Flow: 180 cfs (10% Exceedance)
Boundary Condition: 0 ft Tide

Filepath: Q:\Corte Madera Passage Analysis\7 CAD-GIS\QGIS\Working\CorteMadera Steelhead 180cfs.qgs

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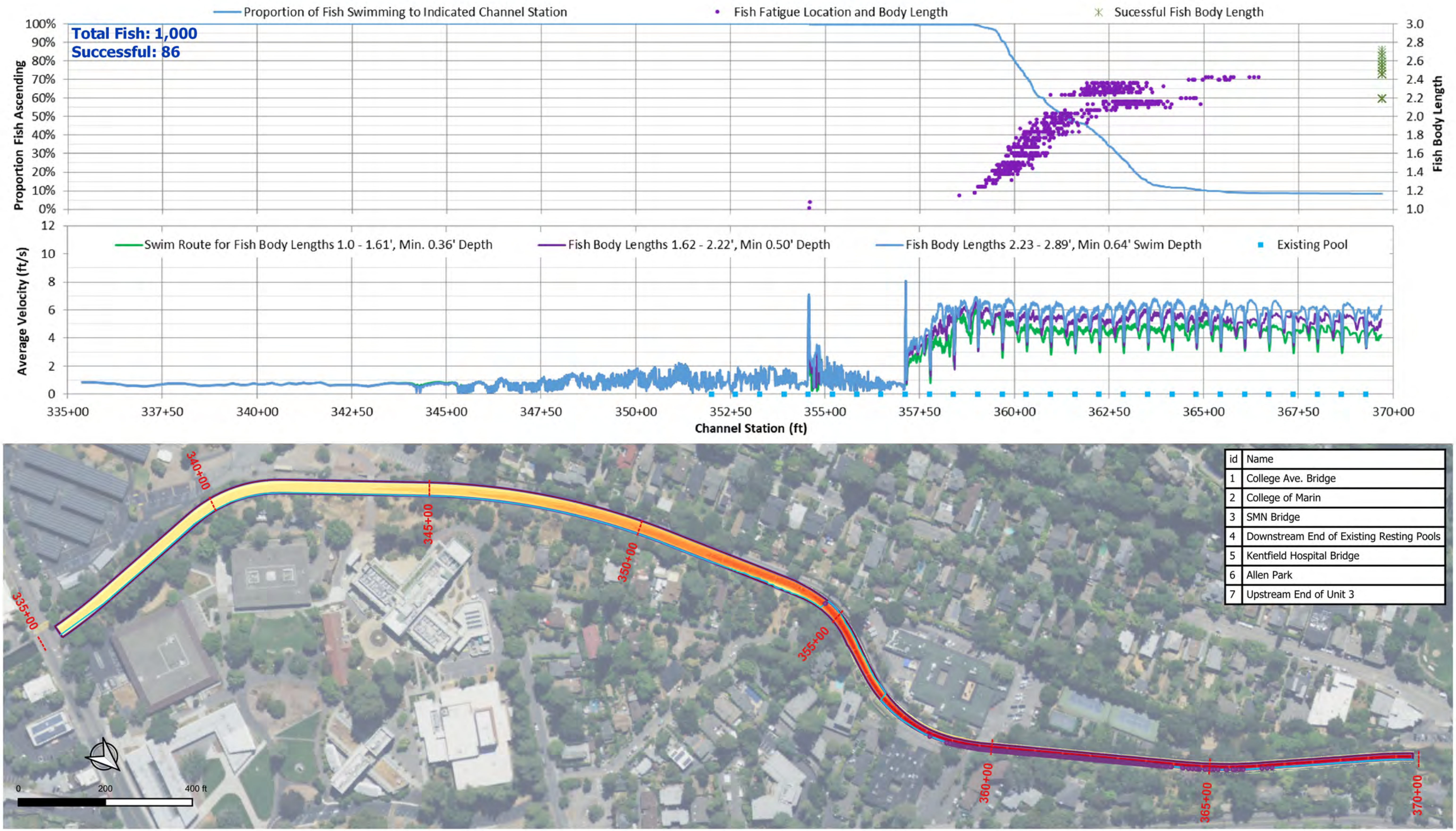

Datums: Horizontal: NAD83 State Plane CA Zone 3 Vertical: NAVD88 Sources: Aerial Image: 2018 Coastal California NAIP	Prepared for: - Friends of Corte Madera Creek Watershed - Marin County Flood Control and Water Conservation District - California Coastal Conservancy	**Map Legend:** • *Fish Fatigue Location* — *Fish Swim Path* *Velocity (fps)* <= 1, 1 - 2, 2 - 3, 3 - 4, 4 - 5, 5 - 6, 6 - 7, 7 - 8, 8 - 9, 9 - 10, > 10	Michael Love & Associates Hydrologic Solutions GHD	**FIGURE 16** Ross, CA Corte Madera Creek, Existing Conditions Species: Adult Steelhead Flow: 180 cfs (10% Exceedance) Boundary Condition: 7 ft Tide

Filepath: Q:\Corte Madera Passage Analysis\7 CAD-GIS\QGIS\Working\CorteMadera_Steelhead_180cfs.qgs

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Table 5. Resulting passage success rates for the adult Steelhead population through the existing Corte Madera Creek Unit 3 channel for each analyzed passage flow and corresponding tidal boundary condition. Analysis does not include passage through the existing Denil fish ladder.

Tide Level, ft (NAVD88)	Passage Successful (%)						
	14 cfs	20cfs	35cfs	65 cfs	100 cfs	150 cfs	180 cfs
0.0	0	0	0	0.1	0	0	0
1.0	0.2	0	0	0	0	0	0
2.0	20.7	5.9	0.4	0.2	0	0	0
3.0	97.3	87.5	33.1	33.1	15	2	0.1
4.0	99.8	99.7	99.9	96.8	74.2	34.2	0.6
5.0	100	99.9	99.6	99.5	80.9	42.3	7.2
6.0	100	99.9	99.7	99.8	80.2	35.7	0.9
7.0	99.9	100	100	99.8	85.2	36.9	8.6

5.2 Resting Pool Design Objectives

The current project is focused on developing and refining the design of fish passage improvements for the Corte Madera Creek Flood Control Channel, Unit 3. Based on the previous studies, passage design objectives and considerations include:

- Provide sufficient opportunities for adult Steelhead Trout and Coho Salmon to successfully pass through Unit 3 at established migration flows by:
  - Providing ample resting areas for fish to recover from fatigue at migration flows,
  - Minimizing frequency and duration of passage delay associated with fluctuations in streamflow and tidal levels, and
  - Considering the migration period for combined Steelhead Trout and Coho Salmon as December 1 through April 30, consistent with other San Francisco Bay Area projects for Steelhead Trout.
- Design to minimize sedimentation and debris accumulation within resting areas.
- Provide for maintenance access along the channel to facilitate removal of debris and sediment in a timely manner.
- Avoid producing excessive head loss at channel capacity flows that decrease the existing level of flood protection provided by the flood control channel.

5.3 Resting Pool Design Guidance and Criteria

The project identified a set of design guidelines and criteria for developing resting pools that aim to meet project objectives, which are described in the following sections and listed in Table 6.

5.3.1 Minimum Width Adjacent to Pools for Maintenance Equipment Access

The Unit 3 concrete channel is V-shaped and 33 feet wide. The CMCFRM Project is proposing to add an access ramp to Unit 3 to allow service vehicles and equipment access to the channel. To allow them to have access to the entire channel length, a service corridor should be maintained that provides sufficient room to drive around the new resting pools. For this project, 12 feet was set as the minimum service corridor width for the resting pools.

5.3.2 Minimum Pool Depth

The new resting pools should provide sufficient depth for fish to hold. This includes adequate depth to submerge the fish's body, but also should consider additional depth to account for behavioral factors that include providing additional "cover" associated with protection from predation. CDFG (2002) recommends a minimum pool depth of 2 feet for jump pools below culvert outlets and Bates (2001) recommends a minimum of 2.5 feet to provide adequate cover for fish. For design of this project's resting pools, the water depth within the pool should be a minimum of 2.5 feet at the low passage flow of 14 cfs and the residual pool depth (depth with no flow) should be 2.0 feet. This requirement provides adequate cover over the fish, while providing adequate pool volume containing suitable resting velocities is covered in 5.3.4.

Table 6. Project guidelines and criteria for new resting pools

<table>
<tr><th>Criteria/Guideline</th><th>Value</th><th>Source</th></tr>
<tr><td>Minimum Service Access Corridor Width around Pools</td><td>12 feet</td><td>Based on width of potential equipment accessing channel to clear debris</td></tr>
<tr><td>Minimum Residual Pool Depth</td><td>2.0 feet</td><td>CDFG (2002)</td></tr>
<tr><td>Minimum Pool Depth at Low Passage Flow</td><td>2.5 feet</td><td>Bates (2001)</td></tr>
<tr><td>Maximum Velocity for Resting</td><td>2.0 ft/s</td><td>Based on sustained swimming speed for 1.3 ft length Steelhead (bottom 3 percentile)</td></tr>
<tr><td colspan="3">Minimum Resting Volume for New Pools</td></tr>
<tr><td>Resting Volume Dimensions per Fish (L x W x H)</td><td>3.0 x 1.5 x 1.5 (feet)</td><td rowspan="4">Developed for this project</td></tr>
<tr><td>Resting Pool Volume per Fish</td><td>6.75 cf</td></tr>
<tr><td>Min. Holding Capacity per Pool</td><td>4 Steelhead</td></tr>
<tr><td>Min. Resting Volume per Pool</td><td>27 cf</td></tr>
</table>

5.3.3 Minimum Pool Resting Velocity

To evaluate the performance of various resting pool configurations, a maximum water velocity at fish passage flows was established. This was set equal to the maximum sustained swim speed of 1.5 body lengths per second (BL/s) for a 1.3 feet long fish. This is the smallest 3 percentile of adult Steelhead within the size distribution used for this project (Figure 9) and represents that smallest fish that various analysis found could pass through Unit 3 with the addition of resting pools. The resulting maximum water velocity for sustained swimming of 2.0 ft/s was then used in identifying areas within proposed pools that provide suitable resting conditions.

5.3.4 Minimum Pool Volume and Dimensions Suitable for Resting

Flows are anticipated to produce a range of water velocities throughout a pool. The pools should provide adequate volume suitable for fish to rest at all fish passage flows. Some of the pool volume will have velocities in excess of those required for the fish to rest and recover from fatigue. Guidance has been developed for providing adequate pool volume based on fish loading rates. Bates (2001) suggests a maximum fish loading factor of 0.4 cubic feet of water per pound of fish (cf/lbs) for salmon within a fishway pool and notes that the Washington Department of Fish and Wildlife used a maximum holding density for Chinook Salmon of 0.5 cf/lbs for long-term holding facilities. A review of the fish length data provided by the NMFS Southwest Fisheries Science Center for adult Steelhead trapped in Scott Creek, Santa Cruz County, CA shows the largest fish (top 95 percentile) are approximately 2.4 feet long and 9.5 pounds. Applying this to the 0.5 cf/lbs guidance results in providing a minimum resting pool volume of 4.75 cubic feet per fish. This volume is equivalent to the following dimensions: L = 2.5 feet, W = 1.4 feet, H = 1.4 feet.

For this project, a larger volume per fish is recommended to account for the uncertainty of the pool hydraulics and potential for complex velocity fields (i.e. eddies) to occur within the resting pools. The adopted project criteria for resting volume of a fish consist of the following dimensions: L = 3.0 feet, Width = 1.5 feet, and Height = 1.5 feet for a volume of 6.75 cubic feet per fish. This is with the understanding that the minimum pool depth is 2.5 feet, so additional water depth will generally be provided above this fish resting volume.

Steelhead are often observed migrating upstream in small groups, such as a female accompanied by one or two males. To ensure that each new pool has adequate resting areas for a small group of fish, the project adopted a minimum holding capacity of four Steelhead per pool. This results in a minimum resting volume per pool of 27 cubic feet, and the volume should have adequate proportions to accommodate the per fish dimensions listed above.

5.4 Optimizing Number and Location of Resting Pools

The number and location of resting pools needed to maximize steelhead passage success at the high passage flow of 180 cfs and a tidal boundary condition of 0.0 feet was developed using the Fish-REALMS model. For this exercise, the locations of potential new pools were inputted into the model and velocities within these pools were assumed to be adequate to allow all fish to rest and fully recover from fatigue. The ability to create pools that provide the required resting area at all passage flows was subsequently validated with the 2D and CFD project models.

The optimal location for each pool was identified by starting at the downstream end of Unit 3 and inserting pools within the model at locations that minimized the number of individual surrogate fish that become fatigued before reaching the next upstream resting pool. Table 7 lists the final location of the 16 proposed new pools. Approximately 5 of the 28 existing pools would be eliminated due to their overlap with the location of the new pools. The resulting passage success rate at the high fish passage flow of 180 cfs and a low tide of 0.0 feet is 90.9% assuming the fish swim along the right side of the channel (looking downstream). The location of these pools is shown in Attachment 3 and 4.

This analysis identified the left bend in the channel (looking downstream) immediately downstream of Kentfield Hospital as having areas of low velocity along the outside of the bend. This is due to the V-shaped channel bottom being superelevated towards the inside of the bend, resulting in deeper and slower water along the outside of the bend at fish passage flows. Videos of higher flows in this reach confirms these results. At 180 cfs the two existing resting pools in this bend, located at stations 354+56 and 355+20, provide low velocity zones suitable for resting of small and weaker swimming surrogate fish. Therefore, no new pools are proposed between stations 352+50 and 356+85, a distance of 435 feet.

5.5 Swimming Routes and Pool Placement

To accommodate access of service equipment throughout Unit 3, the pools will be placed asymmetrically across the channel width, such that a pool will be either predominately on the left or right side of the concrete channel. An analysis was conducted to determine what side of the channel to place each pool to maximize fish passage success. For this discussion, right and left are from the perspective of looking downstream.

Unit 3, within the reach that the new pools would be placed, has a sweeping right and left bend around Kentfield Hospital, and a gentle right bend along Allen Park, near station 365+00. A review of the velocity fields at the high passage flow of 180 cfs reveals that there are limited routes for a fish swimming up the channel, assuming they swim along the path with the lowest velocities. They would likely swim up either the left or right side of the channel for its entire length. The only exception is in the right bend around Kentfield Hospital. This area has slightly slower velocities along the left side of the channel. A fish swimming up the right side could switch over to the left side near station 357+00 and then back to the right side near station 360+00. To determine the best swimming route, and therefore the best side of the channel to place each resting pool, the three different routes were analyzed: (1) right side, (2) left side, and (3) right side except in the right bend between 357+00 and 360+00.

Passage success rates associated with each route, assuming the new resting pools are effective, are listed in Table 8. Results suggest the best passage route is along the right side of the channel (looking downstream). Therefore, all the resting pools should be placed to favor the right side of the channel rather than left. This also avoids requiring the fish to switch sides within the channel bends to utilize the pools.

Table 7. Location of proposed new resting pools within the Unit 3 concrete channel, resulting in a passage success rate of 90.9% at the high passage flow (180 cfs) during low tide (0.0 feet).

Locations of New Pools (Channel Stn)	Distance to next Upstream Pool (feet)	Existing Channel Invert Elev. (feet, NAVD88)	Description
8.69	135	-0.81	Approx. 800 ft upstream of College Ave. Bridge
344+40	135	-0.30	Upstream of SMN Bridge
345+75	135	0.21	
347+10	135	0.70	
348+45	135	1.22	
349+80	135	1.73	
351+15	135	2.24	
352+50	435	2.75	Downstream of S-turns around Kentfield Hospital
356+85	170	4.40	
358+55	145	5.05	
360+00	160	5.60	Near Kentfield Hospital Bridge / Invert at MHHW
361+60	160	6.21	Downstream end of Allen Park
363+20	160	6.83	
364+80	165	7.43	
366+45	165	8.06	
368+10	160	8.69	160 feet downstream of Unit 4 transition

Table 8. Passage success with new resting pools for three different swimming routes at 180 cfs and tide of 0.0 feet.

Fish Swimming Route	Left Side of Channel	Right Side of Channel	Right Side except along Right Bend
Percent Successful	75.8	90.9	90.1

5.6 Anticipated Passage Performance of Selected Resting Pool Spacing and Placement

The proposed addition of 16 new resting pools, placed at the locations listed in Table 7 and all oriented with the pool along the right side of the channel (when looking downstream) is anticipated to dramatically improve passage conditions for Steelhead, as well as Coho Salmon. For these proposed conditions, the Fish-REALMS model predicts a passage success rate of 90.9 percent for adult Steelhead at the high passage flow of 180 cfs and a low tide of 0.0 feet. At this same flow and tide, the existing conditions analysis found a passage success rate of zero. At lower fish passage flows and at higher tides the passage success rate will increase to 100 percent, meaning that even the smallest and weakest swimming fish within the adult Steelhead population are predicted to successfully swim through Unit 3.

6. Refinement of Resting Pool Configuration

6.1 Objectives of Preliminary Resting Pool Refinements

This section summarizes the analysis and refinement of pool configurations to optimize the fish resting pool design geometry. The intent of these analysis is to inform design regarding:

1) Ability of new resting pools to provide suitable resting area at all fish passage flows,
2) Inform the design process regarding influence pool shape has on:
   a. Hydraulics within the pools and the adjacent channel
   b. Sediment transport mobility and potential for sedimentation within the pools
3) Resulting head loss at channel capacity flows associated with adding new pools
4) Structural viability and constructability of new resting pools within the existing channel

The pool geometry was refined multiple times based on the understandings gained from the analyses presented in this section, resulting in a total of four individual alternatives. The first two alternatives focused on refinement of hydraulics to provide suitable resting habitat. Additional analysis was conducted for Alternatives 3 and 4, focusing using the CFD model to analyze transport of individual sediment particles and potential for deposition within the pool. Through the refinement process, Alternative 4 was selected as the preferred pool geometry and forwarded to final design.

6.2 Alternative 1 Resting Pool Geometry

The shape of potential resting pools was initially developed and analyzed as part of the MLA-JAA (2007) study. The study investigated three pool shapes in terms of their ability to provide adequate resting areas while minimizing sedimentation risk. The study was limited to using a 2D hydraulic model to analyze the hydraulics of a single pool within a short select segment of channel. Two representative channel segments were analyzed: a straight section and a bend. Based on these results, the study found the "Alternative 1" pool shape performed the best in the straight section, and nearly equally to, or as good as, the other two alternatives for the bend section. Therefore, this study chose to conduct additional analysis of Alternative 1 to evaluate its overall effectiveness at improving fish passage conditions and serve as a starting point for refinement of the pool geometry.

6.2.1 Alternative 1 Pool Description

The geometry of Alternative 1 is shown in isometric view in Figure 17 and plan, profile, and section in Figure 19. The pool is asymmetric with the channel centerline; 3 feet to the left of the centerline and 8 feet to the right. This provides sufficient corridor along the left side of the channel for maintenance access. The residual pool depth is 1.5 feet, which is shallower than the project guidance given in Table 6 but provides a good starting point for analysis and refinement of the pool geometry. Additionally, on the right shoulder (looking downstream) the pool bottom is 3.1 feet below the existing channel. The upstream face of the pool is vertical, intended to create an abrupt discontinuity in velocities to provide a resting shadow for fish. The pool is relatively long, with a flat bottom length of 8 feet and a "tailout" sloping gently back up at a slope of 5.3H:1V, resulting in an overall footprint of 24 feet long and 11 feet wide. The gentle slope of the tailout is intended to provide a gradual hydraulic transition to avoid excessive headloss and an abrupt hydraulic jump at flood flows. It is also intended to assist with keeping sediment in transport.

6.2.2 Alternative 1 Fish Passage Results

The Alternative 1 pool shape was graded into the existing channel DEM in CAD at the 16 locations listed Table 7. The updated DEM was then inputted in the project's HEC-RAS 2D model (Figure 18) and analyzed at the high passage flow of 180 cfs and a tidal boundary condition of 0.0 feet. This represents the most challenging fish passage flow/tide scenario, with both lower flows and higher tides scenarios would have higher passage success rates. The swimming routes, encountered velocities, and passage results are presented in Figure 20.

The passage assessment results in a 90.9 percent success rate. The hydraulic model results show all of the 16 new pools provide adequate low velocity zones for resting nearly for all of the surrogate fish. Surrogate fish smaller than approximately 1.37 feet, representing the bottom 4 percentile of fish within the population, were unable to successfully reach the upstream end of Unit 3. There were also approximately 1.2% of the surrogate fish that became fatigued within a few feet of the upstream end of Unit 3.

6.2.3 Alternative 1 Pool Sedimentation Potential

The potential for sedimentation within the pools was evaluated using the 2D model results and the approach outlined in section 4.6. A single typical pool in a straight channel segment and another in the channel bend segment were selected. The area of the pool providing depth-averaged water velocities less than 2.0 ft/s at 180 cfs was mapped. This mapped "resting area" was overlayed onto the shear stresses within the pool at the estimated critical discharge for sediment mobility of 500 cfs to provide insight into whether sediment may deposit within this resting area, which could further reduce or eliminate the available area for resting at the high fish passage flow. The results are provided in Figure 21 and Figure 22, and in Attachment 3.

Results indicate that the high passage flow resting area also contains lower shear stresses than the remaining pool at 500 cfs. In the straight segment the pool bottom in the mapped resting area has sediment mobility for the dominate particle size of 8 mm defined as partially to partially-full mobile. The pool in the channel bend segment has even higher shear stresses and sediment mobility. The results suggests that sediment is likely to remain in transport and not deposit in the pools at this and higher flows.

To help interpret the results, plots showing the flow state in terms of the dimensionless Froude number (super- verses subcritical flow) were also plotted for 500 cfs, and are included in Attachment 3. The wetted width of the channel between the pools is primarily supercritical, with subcritical conditions along the shallower margins. Within the pool the flow is nearly entirely subcritical. Based on the change in flow regime and water surface elevations through the pool, there is a small hydraulic jump within the sloping "tailout" at the downstream end of the pool.

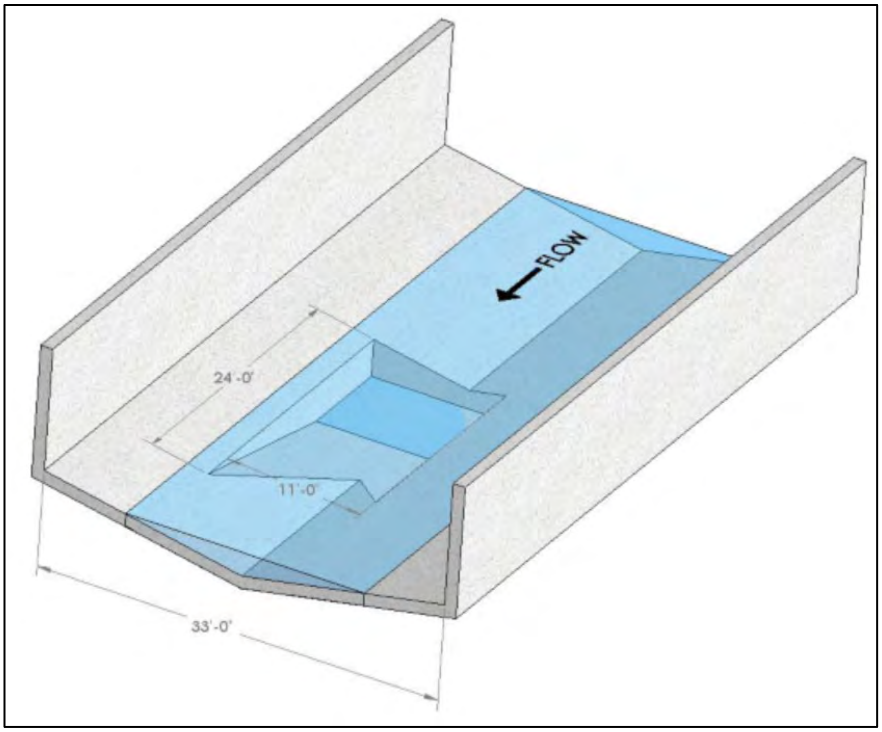


Figure 17. Isometric drawings of Alternative 1 resting pool (from MLA-JAA, 2007)

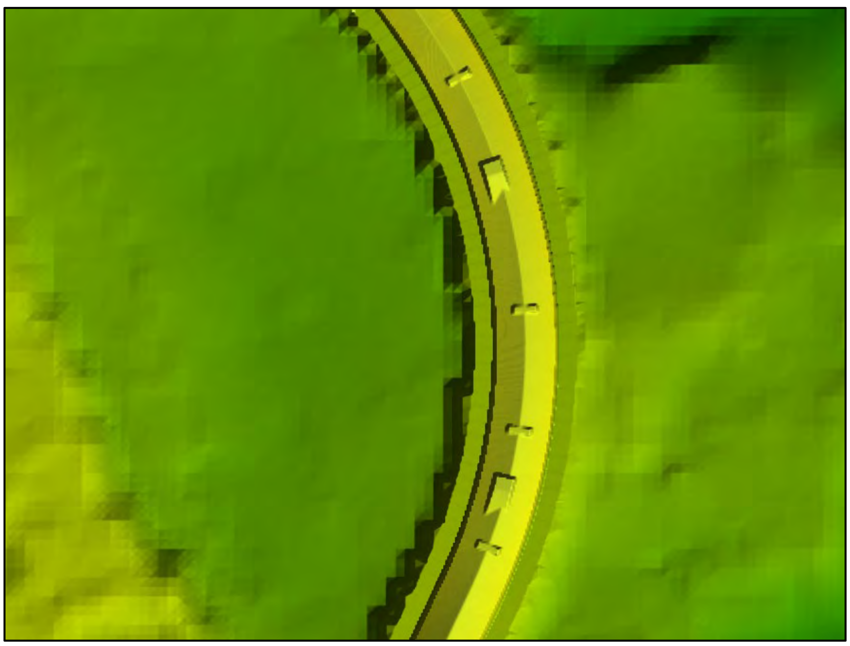


Figure 18. Concrete channel surface with proposed fish passage pool locations

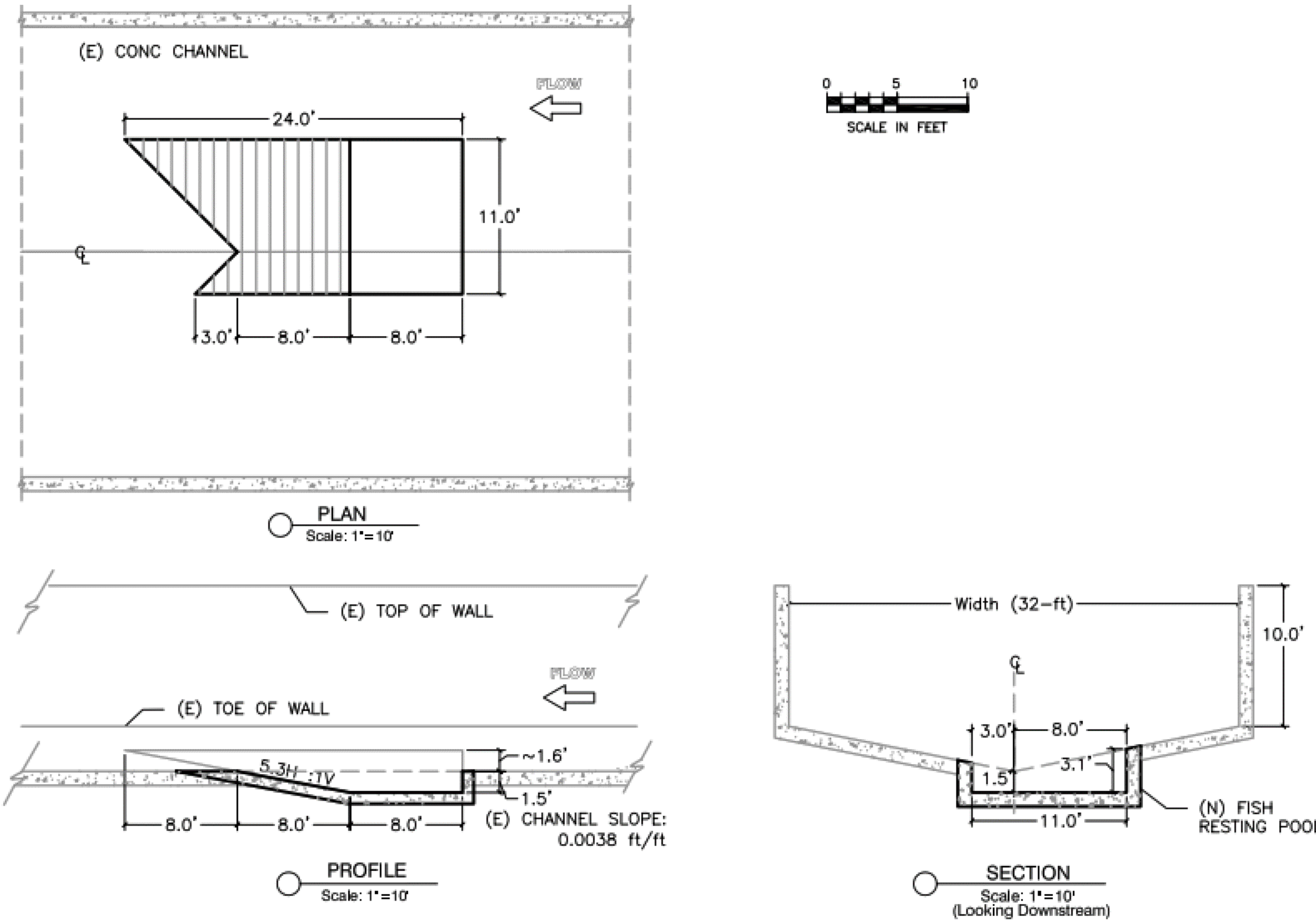
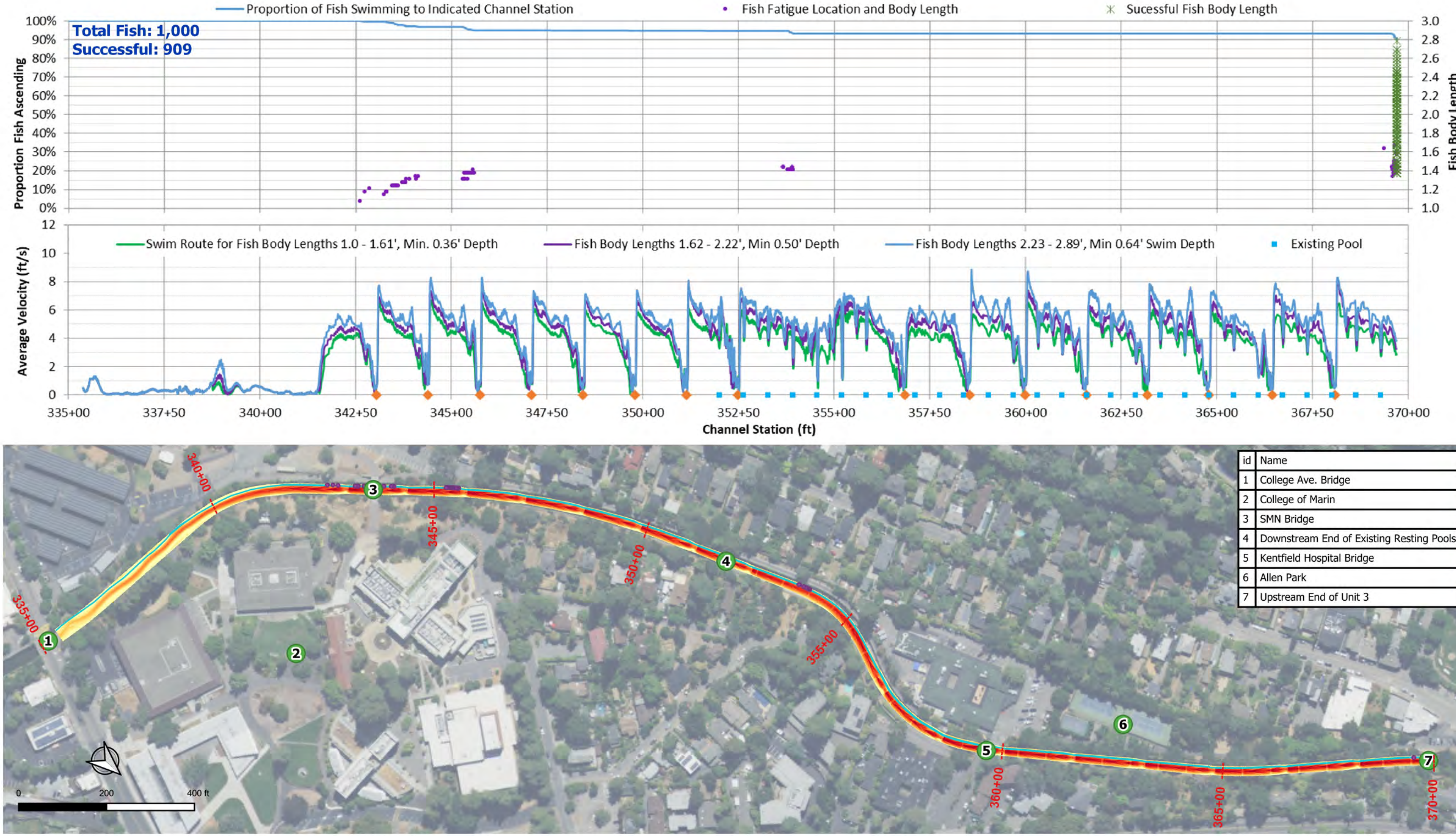


Figure 19. Plan, profile, and section of Alternative 1 pool configuration (from MLA-JAA, 2007).



Datums:
Horizontal: NAD83 State Plane CA Zone 3
Vertical: NAVD88

Sources:
Aerial Image: 2018 Coastal California NAIP

Prepared for:
- Friends of Corte Madera Creek Watershed
- Marin County Flood Control and Water Conservation District
- California Coastal Conservancy

Map Legend:
• *Fish Fatigue Location* — *Fish Swim Path*
Velocity (fps)
<= 1 | 1 - 2 | 2 - 3 | 3 - 4 | 4 - 5 | 5 - 6 | 6 - 7 | 7 - 8 | 8 - 9 | 9 - 10 | > 10

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Hydrologic Solutions
GHD

FIGURE 20
Alternative 2 Resting Pools
Corte Madera Creek, Proposed Conditions
Species: Adult Steelhead
Flow: 180 cfs (10% Exceedance)
Boundary Condition: 0 ft Tide

Filepath: Q:\Corte Madera Passage Analysis\7_CAD-GIS\QGIS\Working\CorteMadera_Steelhead_180cfs.qgs

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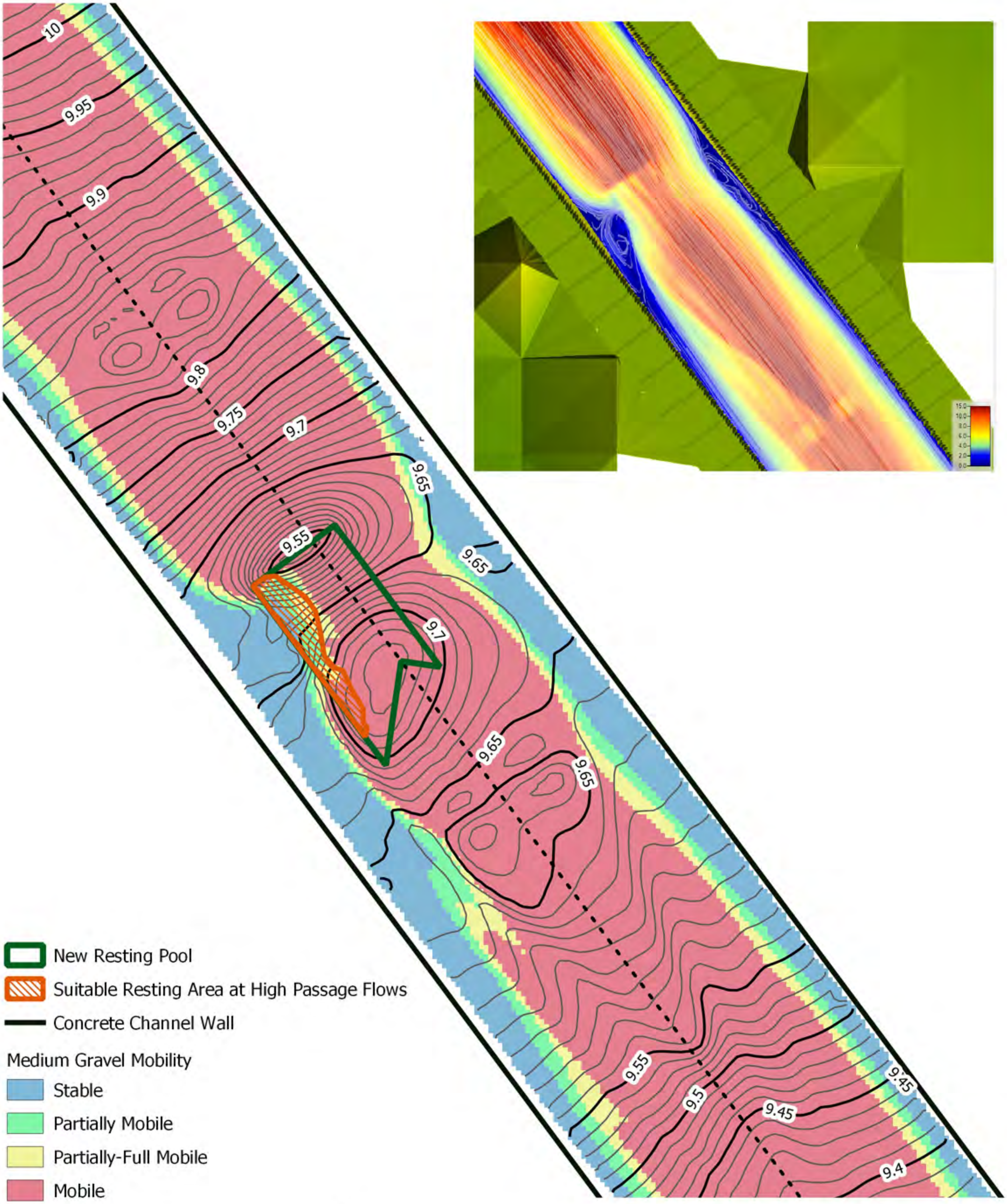

Datums:
Horizontal: NAD83 State Plane CA Zone 1
Vertical: NAVD88

Sources:
NA

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Hydrologic Solutions

GHD

0 10 20 ft

FIGURE 21 - 500 cfs - Shear

Alternative 1
Ross, CA
Corte Madera Creek, Proposed Conditions
Species: Adult Steelhead
Flow: 500 cfs
Boundary Condition: 0 ft Tide

Filepath: Q:\Corte Madera Passage Analysis\7 CAD-GIS\QGIS\Working\CorteMadera Steelhead 500cfs.qgs

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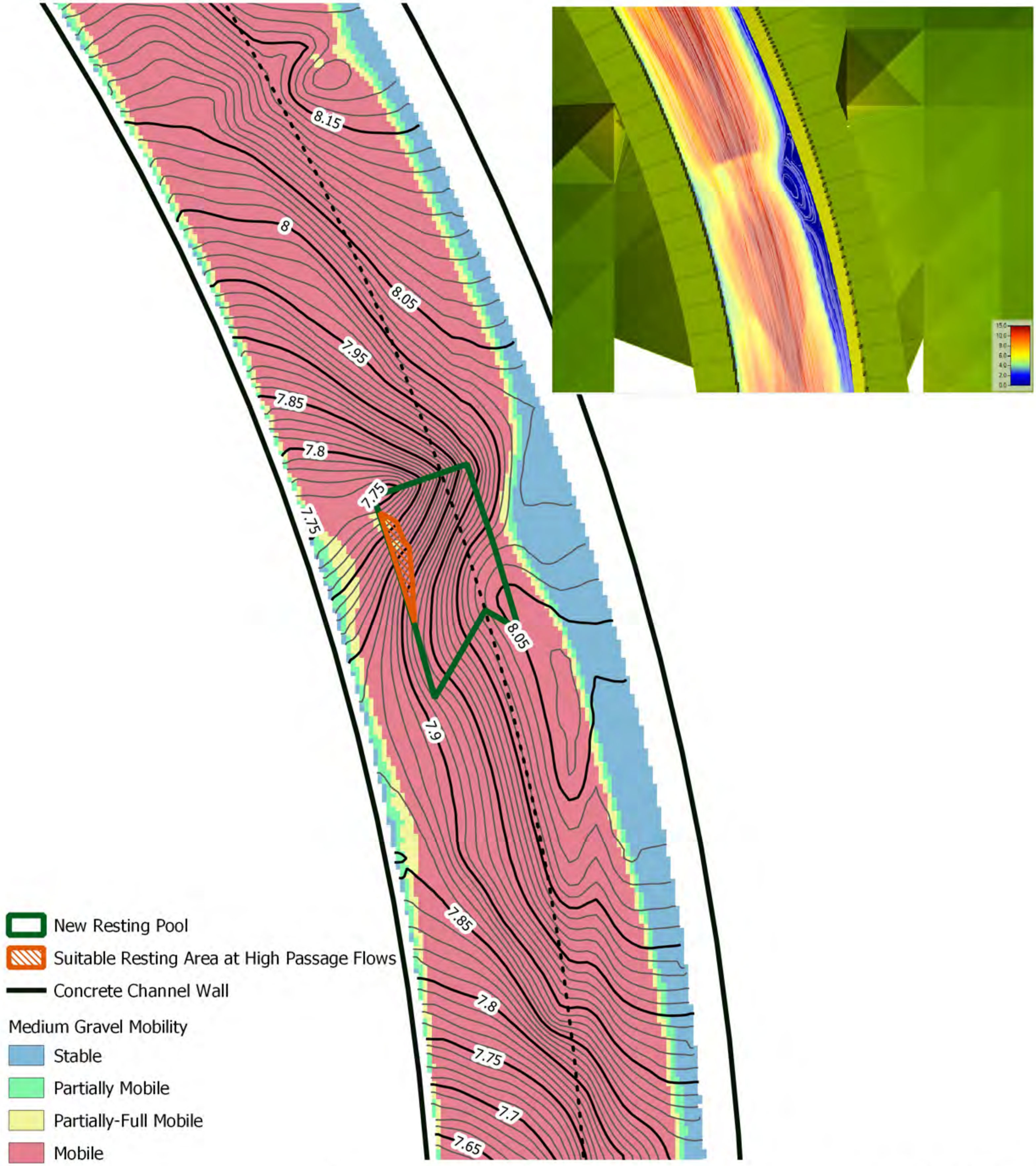

Datums:
Horizontal: NAD83 State Plane CA Zone 1
Vertical: NAVD88

Sources:
NA

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GHD

0 10 20 ft

FIGURE 22 - 500 cfs - Shear

Alternative 1
Ross, CA
Corte Madera Creek, Proposed Conditions
Species: Adult Steelhead
Flow: 500 cfs
Boundary Condition: 0 ft Tide

Filepath: Q:\Corte Madera Passage Analysis\7 CAD-GIS\QGIS\Working\CorteMadera Steelhead 500cfs.qgs

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Arcata, CA 95521 (707) 822-2411

6.2.4 Headloss from Alternative 1 Resting Pools

The proposed fish resting pools are anticipated to influence the hydraulic grade line through the concrete channel. As such, the headloss associated with the addition of 16 new resting pools during the 25-year storm event was determined using the HEC-RAS 2D project model and the Alternative 1 resting pool configuration. The analysis focused on using the 2D model results to estimate the increase in Manning's roughness value (n), which can be applied to the Ross Valley Watershed HEC-RAS 1D/2D combined model and used for analyzing flood conveyance for the overall CMCFRM Project.

To determine the increase in the WSE from the new resting pools, the hydraulic grade line was plotted for existing and proposed conditions through the project reach for the 25-year storm event (Figure 23). The results from the 2-D model predicted an increase of approximately 0.3 feet in water surface elevations (WSEs) in the Allen Park area of the Unit 3 concrete channel. Downstream of Allen Park there was no significant impact on the WSE in the concrete channel. The Ross Valley Watershed model has a calibrated existing condition roughness coefficient through Allen Park of 0.018 (Stetson, 2017). To approximate the impact of the proposed fish pools on the WSE, the roughness was increased from 0.018 to 0.025 and 0.022 through this upper section of Unit 3 between Stations 36950 to 35943

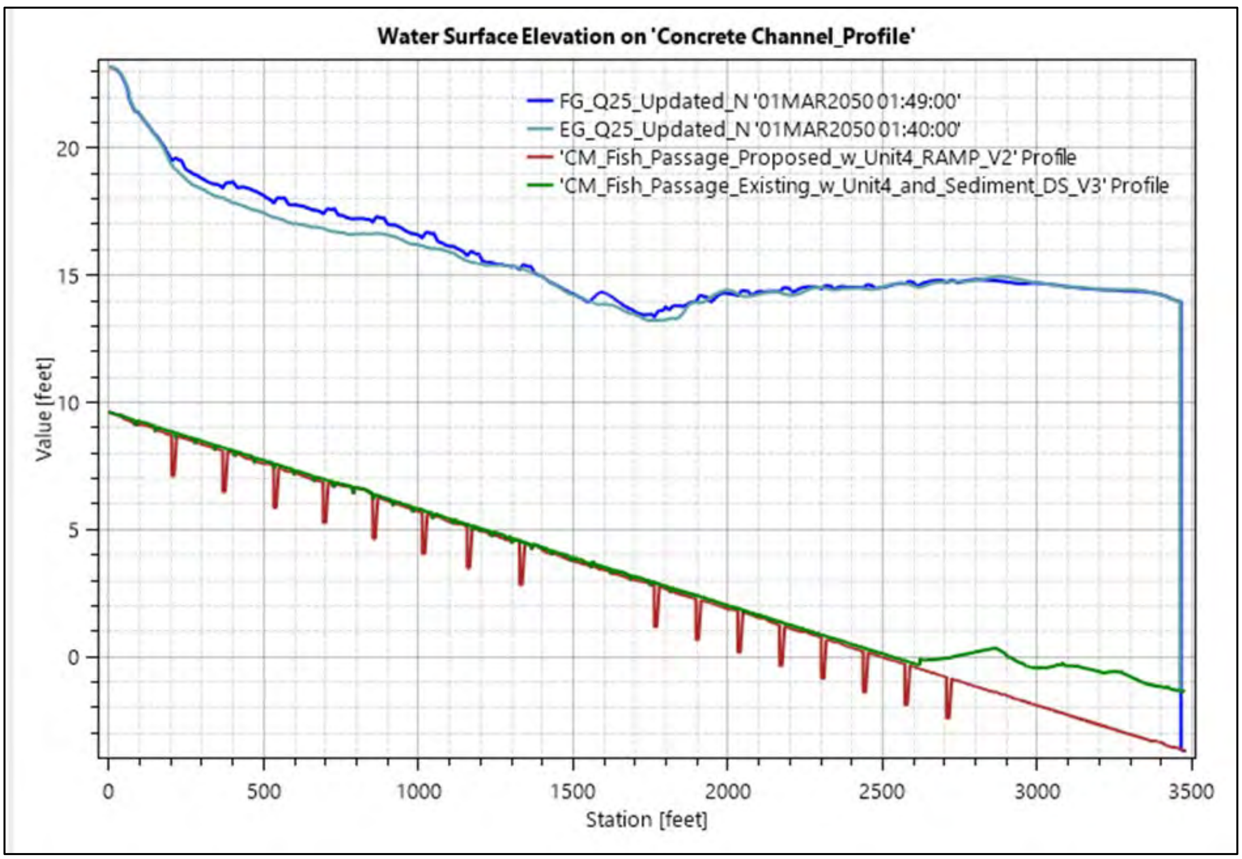

Figure 23. Unit 3 concrete channel water surface profile from the project HEC-RAS 2D model for existing conditions (EG) and with addition of the Alternative 1 fish pool (FG) at the 25-year flow event.

6.2.5 Alternative 1 Pool Conclusions

The Alternative 1 pool shape is effective at providing resting velocities and relatively effective at producing sufficient shear stress at the estimated critical discharge to minimize sedimentation within the pool. However, the pool is much larger than needed, providing resting volume sufficient for at least 9 fish at the high passage flow. Additionally, the pool depth is only 1.5 feet, which is shallower than the 2.0 minimum pool depth recommended in Table 6. Therefore, the alternative was refined to make the pool deeper but its overall size smaller. This refinement was referred to as Alternative 2.

6.3 Alternative 2 Resting Pool Geometry

The Alternative 2 resting pool configuration is based on findings from the Alternative 1 pool evaluation. The Alternative 2 pool is one foot deeper, but with a smaller footprint.

6.3.1 Alternative 2 Pool Description

The Alternative 2 pool configuration and dimensions is shown in Figure 24. The pool bottom is recessed 2.5 feet below the existing channel bed, such that the pool bottom has a 5.5H:1V cross-slope that matches the existing channel cross-slope. The bottom of the pool is 5 feet long streamwise and 10 feet wide, and has a vertical upstream face intended to create a velocity shadow that allows the faster velocities to skim over the top of the pool while velocities within the bottom 2 feet or more of the pool remain relatively slow. The left edge of the pool (looking downstream) runs along the channel centerline and the right side of the pool was set to extend to the approximate wetted edge of the channel at the high passage flow of 180 cfs. The upstream outer edge of the pool is beveled, with the intent of turning the flow to help break up the eddying within the pool at higher flows to reduce sedimentation potential. The pool ramps back up to the existing channel bottom at a 3H:1V slope, resulting in an overall pool length of 12.5 feet.

6.3.2 Alternative 2 Pool Fish Resting Velocities

The Alternative 2 pool shape was graded into the existing channel DEM in CAD at the 16 locations listed in Table 7. The updated DEM was then inputted in the project's HEC-RAS 2D model. Each pool was found to provide adequate volume of low velocities for fish to rest at the high passage flow of 180 cfs, such that the passage success through Unit 3 should be identical to Alternative 1, at 90.9 percent of the population at 180 cfs and a tide of 0.0 feet (NAVD88). At the high passage flow the resting area in the straight sections (Figure 25) was larger than in Alternative 1, while in the bends it was smaller (Figure 26).

6.3.3 Alternative 2 Pool Sedimentation Potential

Using the 2D model results, the potential for sedimentation within the pool at the estimated critical discharge of 500 cfs was evaluated by examining the bed shear stress within the pools in the straight channel segments (Figure 25) and within the channel bends (Figure 26). The suitable fish resting area at 180 cfs was mapped and shear stresses at 500 cfs within this area were examined to estimate potential for sedimentation within the resting area. The results show that the Alternative 2 pool has relatively low shear stress, such that bed material within the mapped resting area of the pool would not be mobilized at 500 cfs. Based on the 2D model results, the sedimentation potential of the Alternative 2 pool configuration appears more prone to sedimentation than Alternative 1.

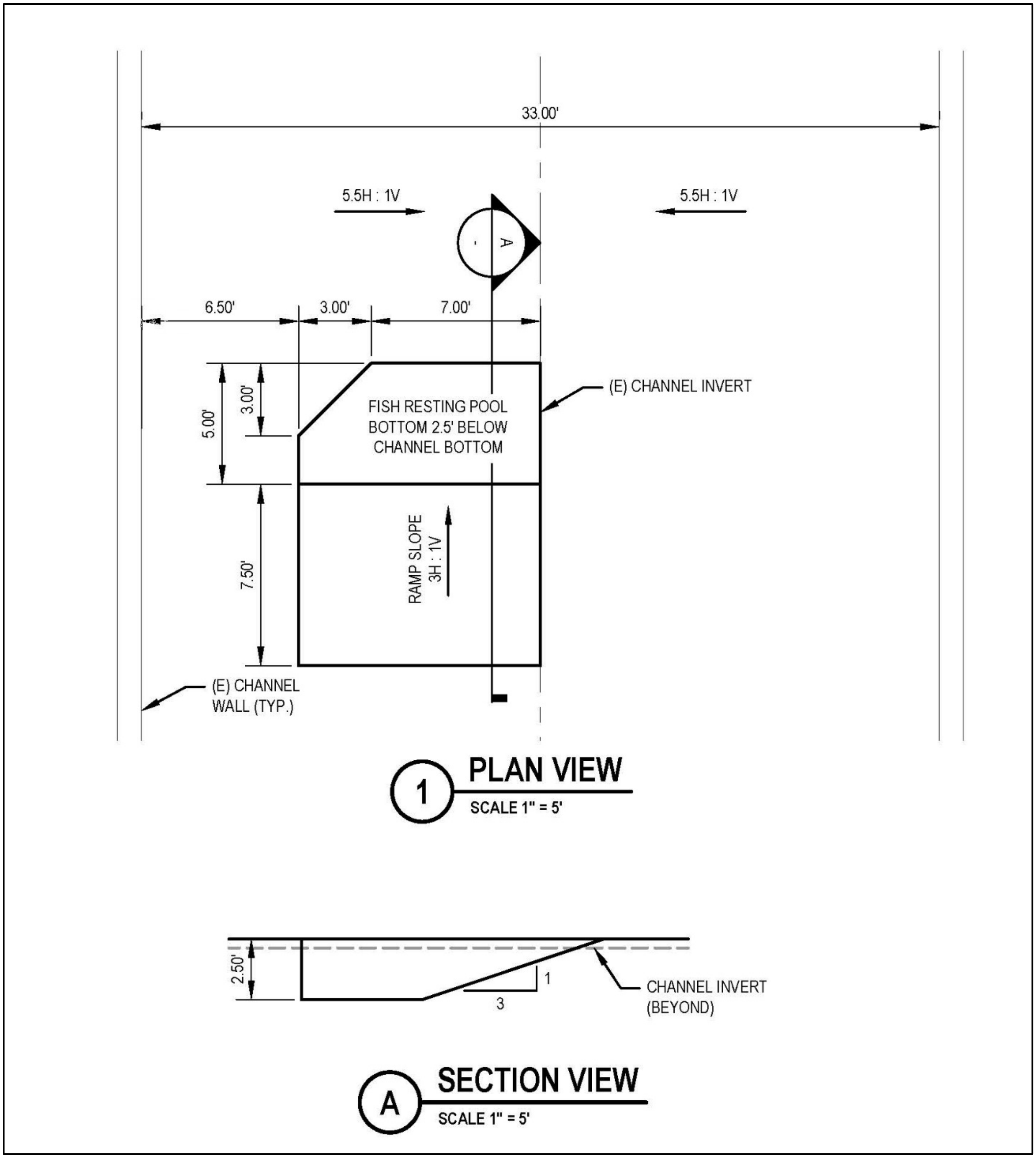

Figure 24. Alternative 2 pool configuration in plan and section, with flow from top to bottom and left to right respectively.

Datums:
Horizontal: NAD83 State Plane CA Zone 1
Vertical: NAVD88

Sources:
NA

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0 10 20 ft

FIGURE 25 - 500 cfs - Shear

Alternative 2
Ross, CA
Corte Madera Creek, Proposed Conditions
Species: Adult Steelhead
Flow: 500 cfs
Boundary Condition: 0 ft Tide

Filepath: Q:\Corte Madera Passage Analysis\7_CAD-GIS\QGIS\Working\CorteMadera_Steelhead_500cfs.qgs

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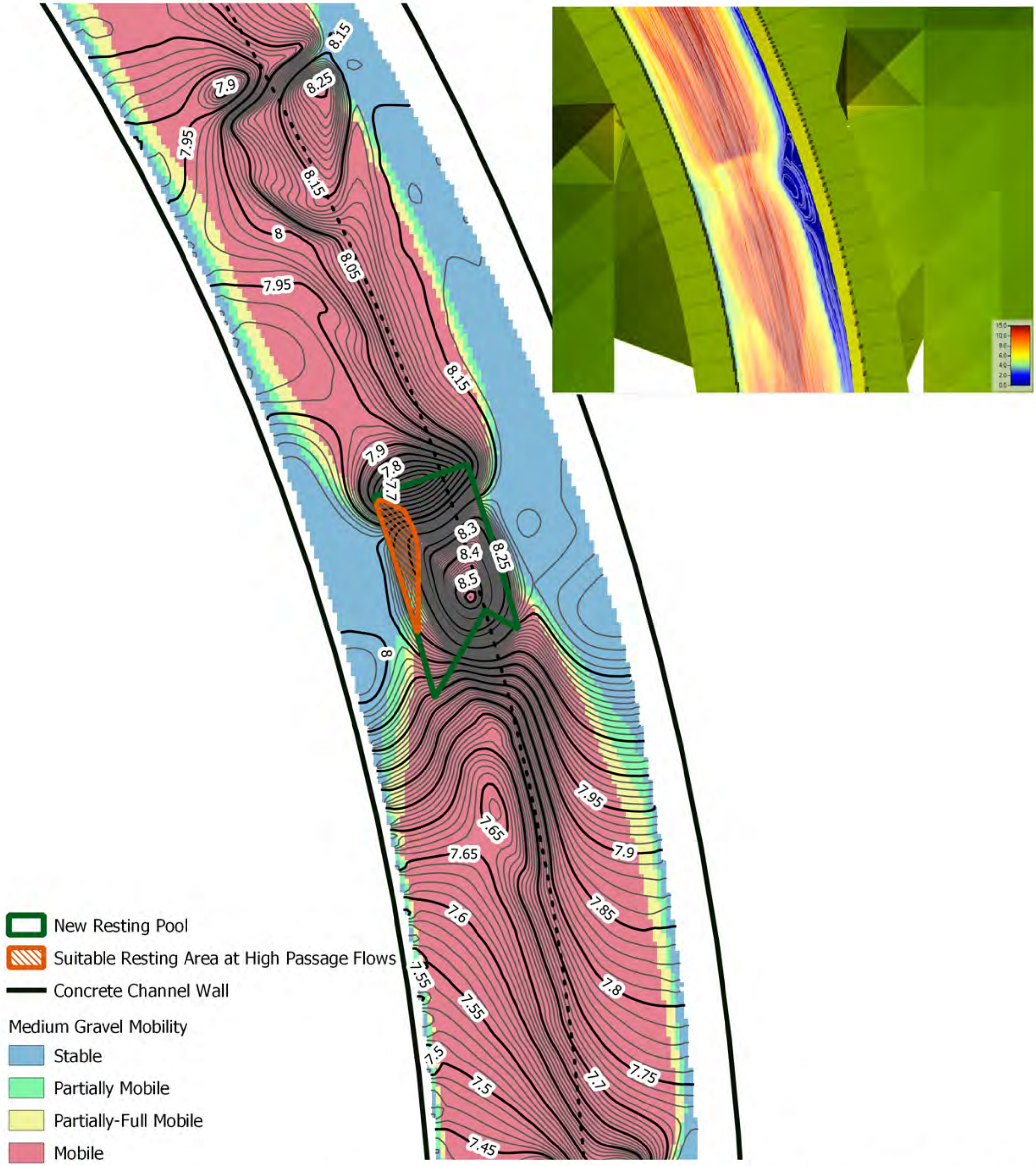

Datums:
Horizontal: NAD83 State Plane CA Zone 1
Vertical: NAVD88

Sources:
NA

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Hydrologic Solutions

GHD

0 10 20 ft

FIGURE 26 - 500 cfs - Shear

Alternative 2
Ross, CA
Corte Madera Creek, Proposed Conditions
Species: Adult Steelhead
Flow: 500 cfs
Boundary Condition: 0 ft Tide

Filepath: Q:\Corte Madera Passage Analysis\7_CAD-GIS\QGIS\Working\CorteMadera_Steelhead_500cfs.qgs

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To help interpret the results, plots showing the flow state in terms of the dimensionless Froude number (super- verses subcritical flow) were also plotted for 500 cfs and are included in Attachment 4. These plots show that between pools flow is supercritical down the center of the wetted channel and subcritical along the shallower margins. Alternative 2 pool at 500 cfs has subcritical flow in the mapped resting area while remaining supercriticial closer to the channel centerline. The water surface elevations show a dip and rise in the water surface through the pool, but no change in flow state, and thus no hydraulic jump.

6.3.4 Alternative 2 CFD Model Results

Due to the complexity of the flow hydraulics and the inability of the 2D model to simulate vertical variation in velocity within the pools, a 3D CFD model was developed for the Alternative 2 resting pool within a straight section of channel. The model was executed at the high passage flow of 180 cfs and at the estimated critical discharge of 500 cfs. Figure 27 shows the terrain for the small-scale model that focused on the hydraulics of a single pool within a straight channel section. Results are presented in the following sections and provided in Attachment 4.

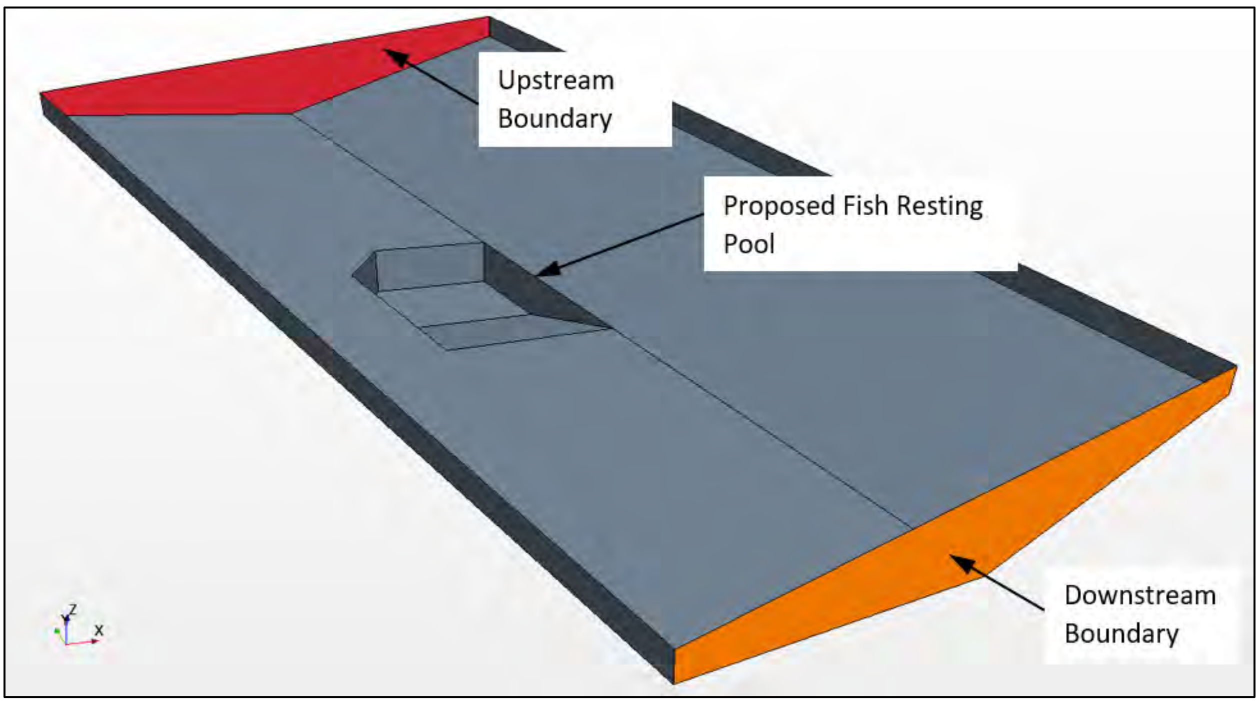
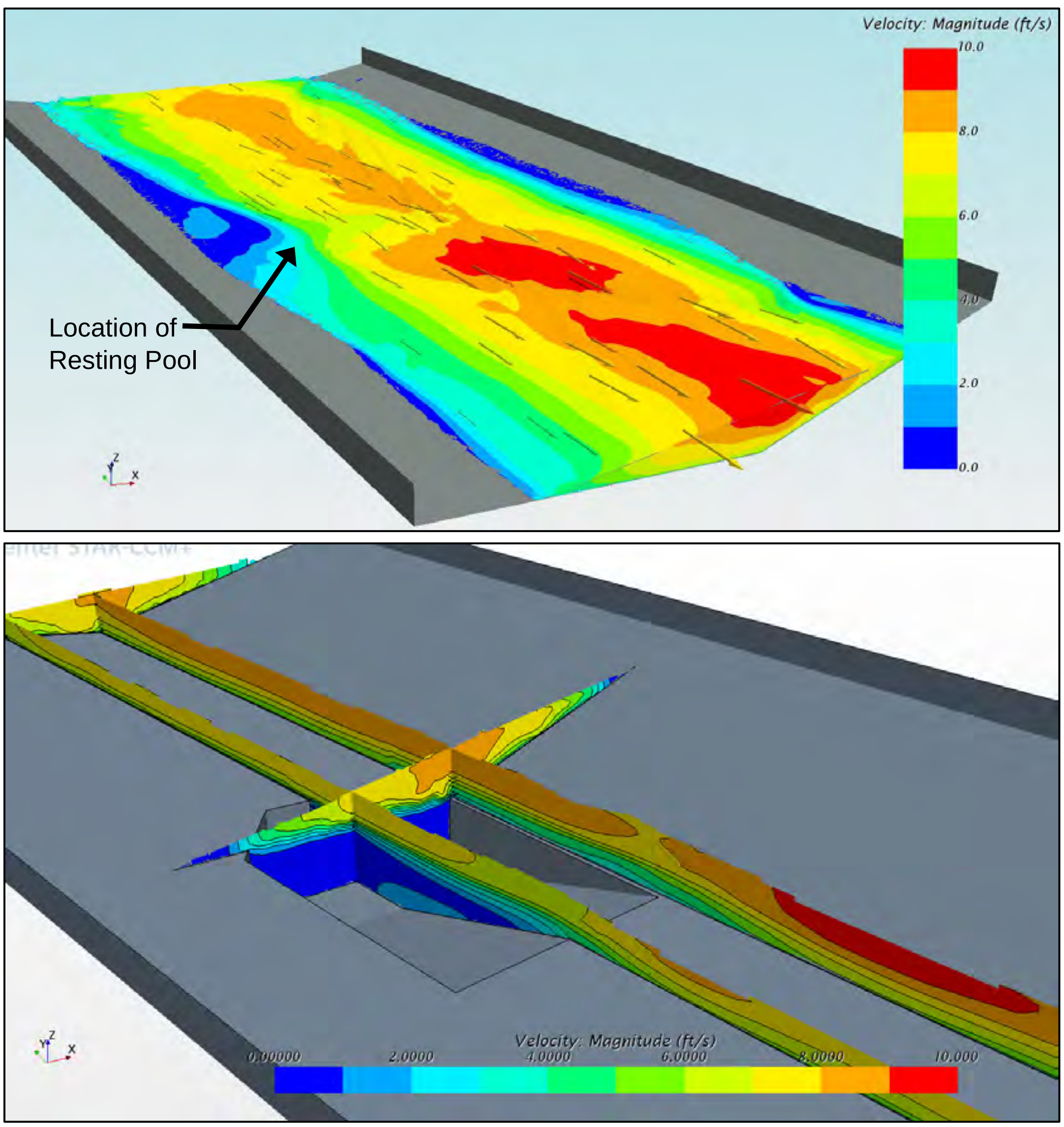


Figure 27. CFD model terrain for the Alternative 2 small-scale model.

High Fish Passage Flow (180 cfs)

At the high passage flow the CFD model results show surface velocities through the pool vary widely, with surface velocities below 2 ft/s in the outer portions of the pool and exceeding 7 ft/s closer to the channel centerline (Figure 28a). Comparing to upstream and downstream, the resting pool has an influence on the overall pattern of surface velocities within the channel.

The select cross sections through the pool shown in Figure 28b confirms that the velocities are highly variable within the water column, with high velocities skimming over the pool surface while lower down they are below 1 ft/s. There is both vertical and horizontal circulation (eddy) patterns occurring within the pool, as would be anticipated. This low velocity zone persists partway down the pool “tailout,” indicating that the Alternative 2 pool provides ample pool volume for fish to hold and recover from fatigue. Attachment 4 provides additional figures from the CFD model results for 180 cfs.



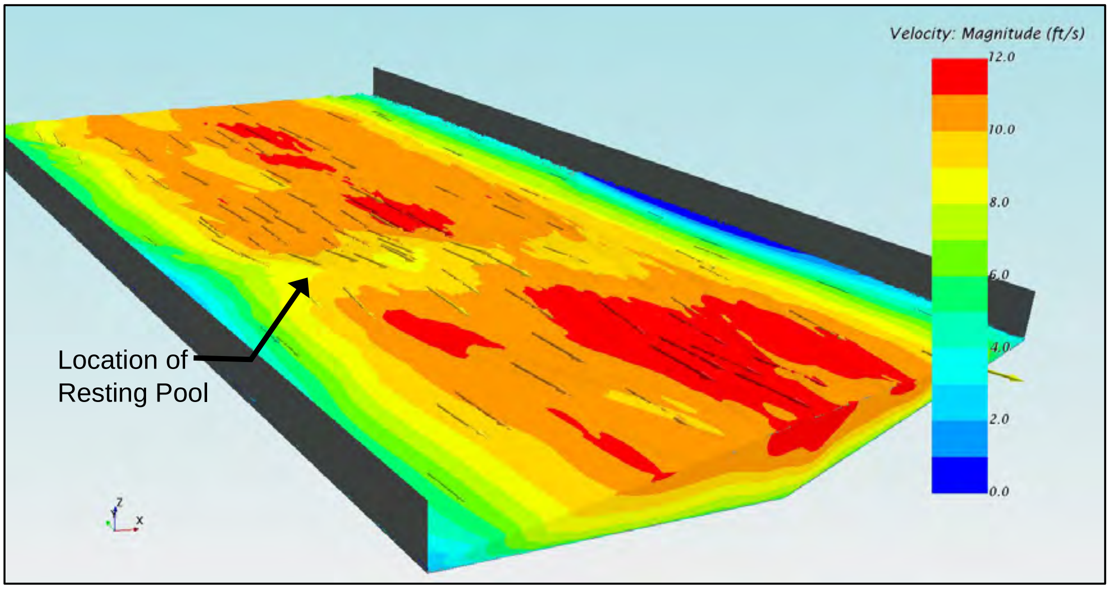
(a)

(b)

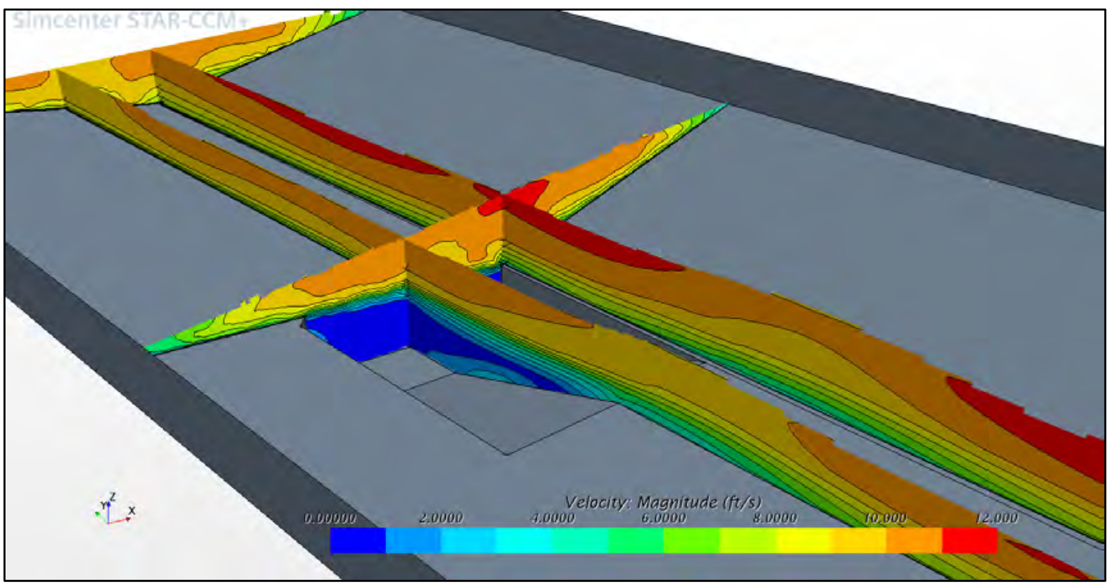
Figure 28. CFD model predicted water velocities (a) on the surface and (b) at select sections for Alternative 2 pool configuration at the high passage flow of 180 cfs.

Sediment Mobility at Critical Discharge (500 cfs)

The streambed material within the upstream sediment delivery channel is estimated to mobilize at approximately 500 cfs. The CFD model results at this flow were used to evaluate flow patterns within the Alternative 2 resting pool, including water velocities (Figure 29), shear stresses applied to the bed of the pool (Figure 30), and turbulence kinetic energy (TKE), which is the mean kinetic energy per unit mass of water associated with eddies in turbulent flow (Attachment 4). The velocity patterns resemble those occurring at 180 cfs, with streaming velocities across the surface of the pool and low velocities within the lower 2 feet of the pool that results in recirculation pattern occurring both vertically and horizontally.



(a)



(b)

Figure 29. CFD model predicted water velocities (a) on the surface and (b) at select sections for Alternative 2 pool configuration at the estimated sediment mobility critical discharge of 500 cfs.

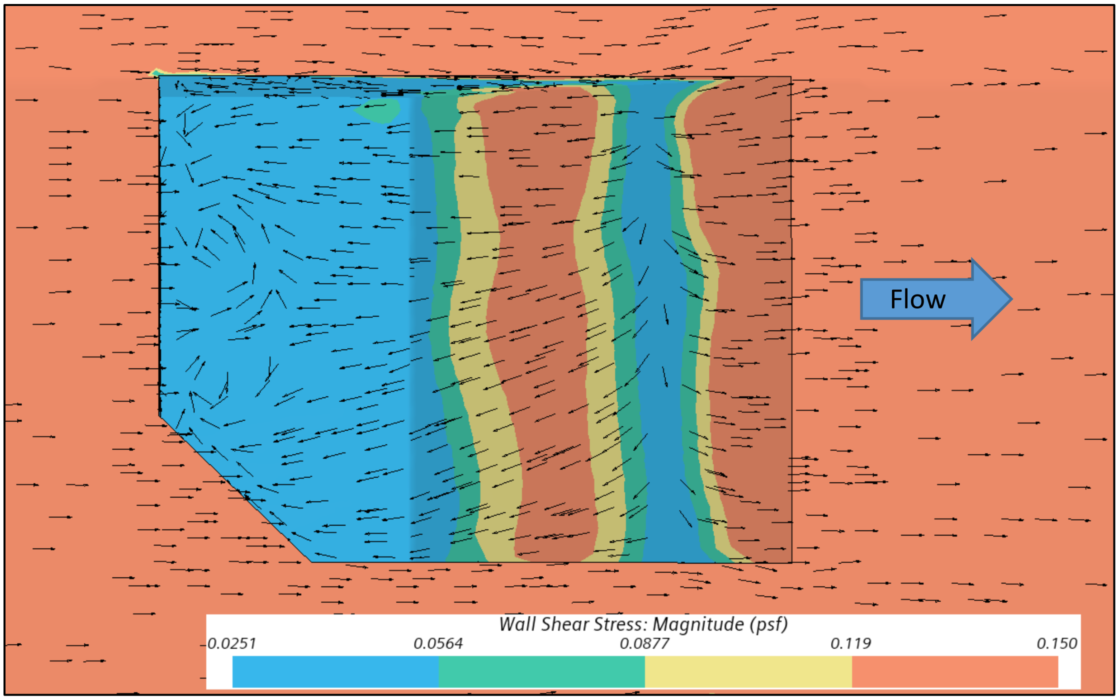


Figure 30. Shear stress applied to the channel bed and Alternative 2 pool bottom at 500 cfs. Orange represents shear stress sufficient to fully mobilize the dominate particle size of 8 mm, while yellows are partially-fully mobile, greens are partially mobile, and blues represents stable.

The shear stress magnitudes are relatively low in the pool but substantially greater across the pool tailout. The pool bottom appears potentially prone to sedimentation due to the low shear stress. A vertical eddy from the flow separation at the head of the pool causes a flow reversal along the bottom of the pool. This results in the direction of shear stresses to be reversed, with them going in the upstream direction. This may tend to mobilize deposited sediment towards the bottom of the pool rather than downstream. Given the complex interaction of the shear and water velocities near the bottom, the likely extents and patterns of sedimentation within the pool are difficult to predict.

6.3.5 Alternative 2 Pool Conclusions

The 2D and CFD model results suggest that the Alternative 2 pool configuration provides adequate resting areas for fish at the high passage flow but may be more prone to sedimentation than the Alternative 1 configuration. A substantial factor may be the increased depth of the pool between the alternatives. Given that Alternative 1 pool velocities were sufficiently low enough for fish resting and both provided more than ample resting area, a slightly shallower and smaller version of the Alternative 2 pool may strike a balance between providing sufficient resting area while reducing sedimentation potential.

6.4 Alternative 3 Resting Pool Geometry

Alternative 3 pool geometry was developed as a refinement of Alternative 2 with the intent of reducing the potential for sedimentation within the pools while maintaining suitable resting areas at fish passage flow flows. This involved reducing the pool depth and size to increase water velocities and reduce eddies in the pool during sediment transport flows.

6.4.1 Alternative 3 Pool Configuration

Compared to Alternative 2, the Alternative 3 pool geometry has the pool depth reduced to 2.0 feet, maintaining the 5.5H:1V cross-slope, and a reduced pool bottom length of 3.0 feet (Figure 31). The pool remains 10 feet wide, which is the approximate wetted width of the concrete channel at the high fish passage flow, with the upstream outer edge of the pool remaining beveled, with the intent of turning the flow to help break up the eddying within the pool at higher flows to reduce sedimentation potential. The “tailout” transition on the downstream side of the pool remained at a 3H:1V slope. The reduced pool depth also reduces the length of the tailout to 6.0 feet, resulting in an overall pool length of 9.0 feet.

6.4.2 Alternative 3 Pool Velocities from CFD Model

A 3D CFD model was developed for the Alternative 3 resting pool within a straight section of channel. The model was executed at the high passage flow of 180 cfs and at the estimated sediment mobility critical discharge of 500 cfs. Results are presented in the following sections and provided in Attachment 5.

High Fish Passage Flow (180 cfs)

At the high passage flow the CFD model results show surface velocities through the pool vary widely, with surface velocities below 2 ft/s in the outer portions of the pool and 8- 9 ft/s closer to the channel centerline (Figure 32a). Comparing to upstream and downstream, the resting pool has an influence on the overall pattern of surface velocities within the channel. Compared to Alternative 2 (Figure 28a), Alternative 3 maintains higher surface velocities down the channel centerline.

The select cross section through the pool shown in Figure 32b confirms that velocities are highly variable within the water column, with high velocities skimming over the pool surface while lower down they are below 1 ft/s. There is both vertical and horizontal circulation (eddy) patterns occurring within the pool (Attachment 5), as would be anticipated. This low velocity zone persists partway down the pool “tailout.”

Figure 33 shows the entire 100 ft^3 of the pool volume that maintains velocities less than 2 ft/s at 180 cfs, indicating that the Alternative 3 pool provides ample pool volume for fish to hold and recover from fatigue. Based on the project’s pool resting volume criteria (Section 5.3.4), the Alternative 3 pool should provide ample volume at the high fish passage flow for a minimum of six adult steelhead to hold in the pool and rest at a given time. Attachment 5 provides additional figures from the CFD model results for 180 cfs.

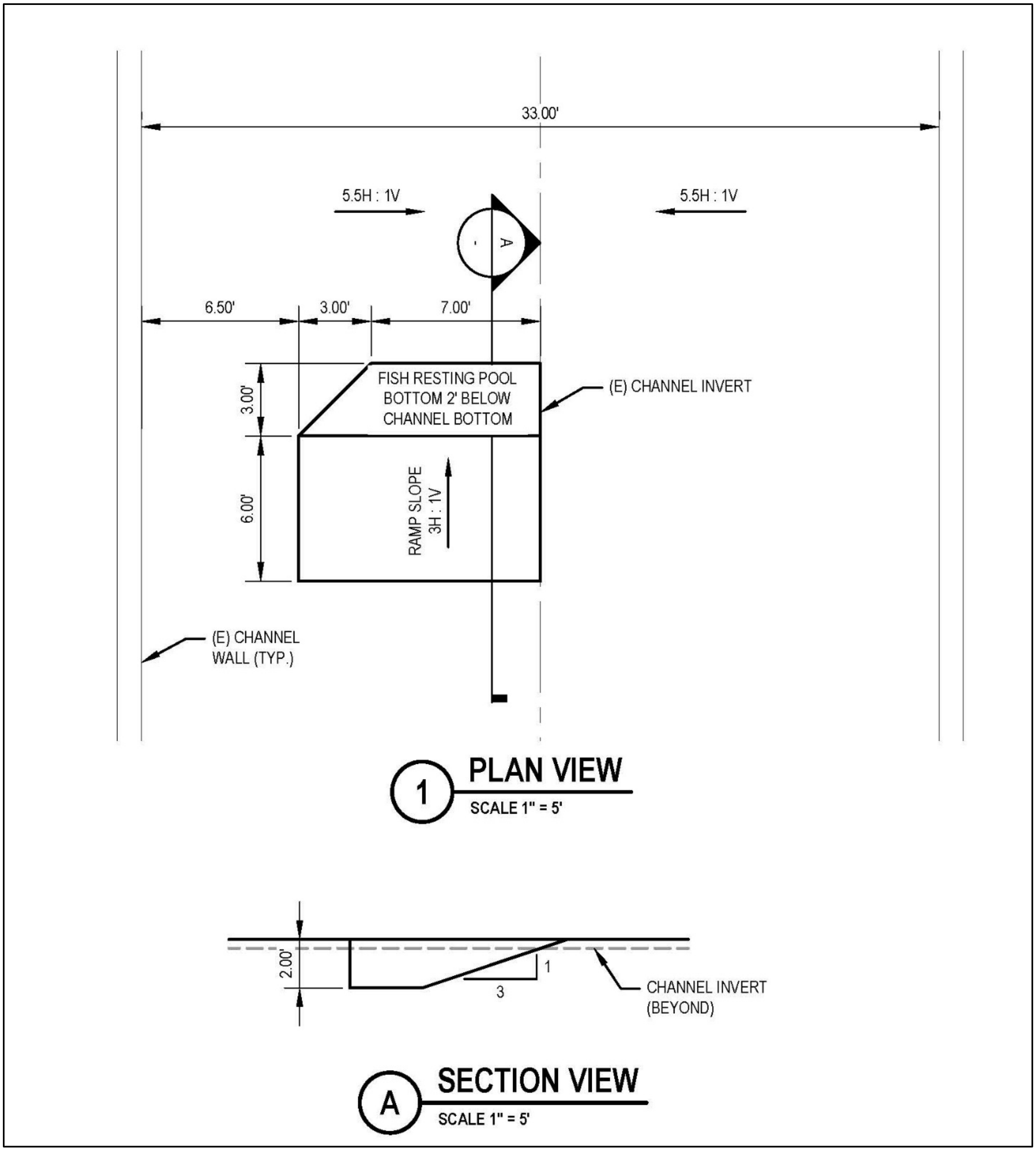
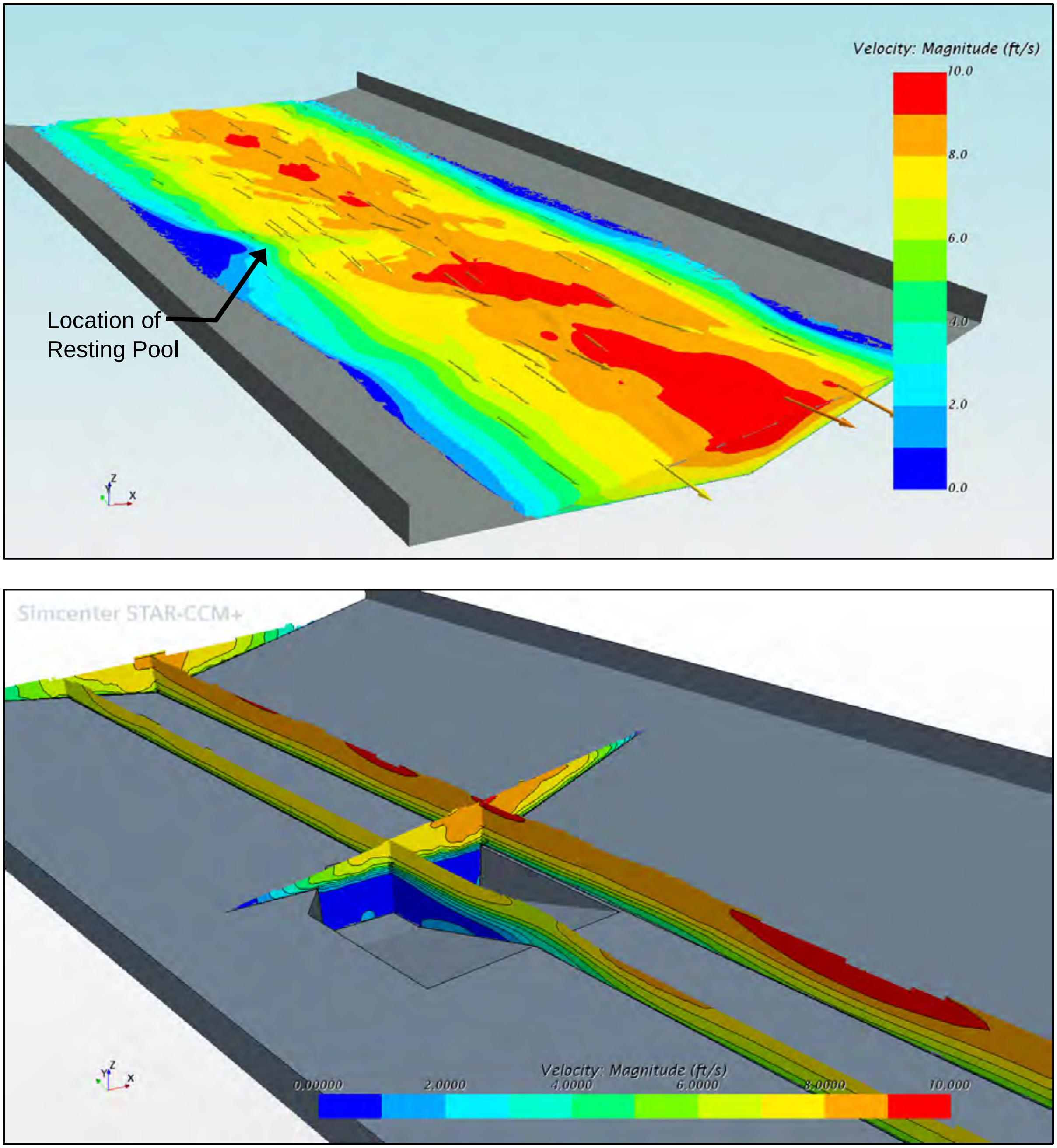


Figure 31. Alternative 3 pool configuration in plan and section, with flow from top to bottom and left to right respectively.



(a)

(b)

Figure 32. CFD model predicted water velocities (a) on the surface and (b) at select sections for Alternative 3 pool configuration at the high passage flow of 180 cfs.

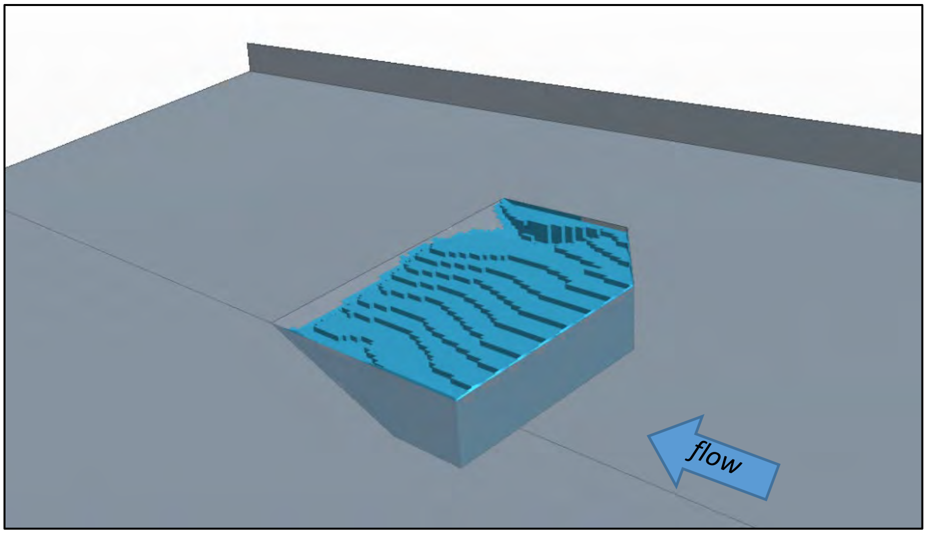


Figure 33. Volume of Alternative 3 pool (100 ft^3) with velocities below 2 ft/s at 180 cfs, and suitable for fish resting (volume below the blue contours).

Sediment Mobility at Critical Discharge (500 cfs)

The streambed material within the upstream sediment delivery channel is estimated to mobilize at approximately 500 cfs. The CFD model results at this flow were used to evaluate flow patterns within the Alternative 3 resting pool, including water velocities (Figure 34), shear stresses applied to the bed of the pool (Figure 35) and turbulence kinetic energy (TKE), which is the mean kinetic energy per unit mass of water associated with eddies in turbulent flow (Attachment 5). The velocity patterns resemble those occurring at 180 cfs, with streaming velocities across the surface of the pool and low velocities within the lower 2 feet of the pool that results in recirculation pattern occurring both vertically and horizontally.

The shear stress magnitudes are relatively low along the pool bottom but substantially greater across the pool tailout. A vertical eddy from the flow separation at the head of the pool causes a flow reversal along the bottom of the pool. This results in the direction of shear stresses to be reversed, with them going in the upstream direction. This may tend to mobilize deposited sediment towards the bottom of the pool rather than downstream.

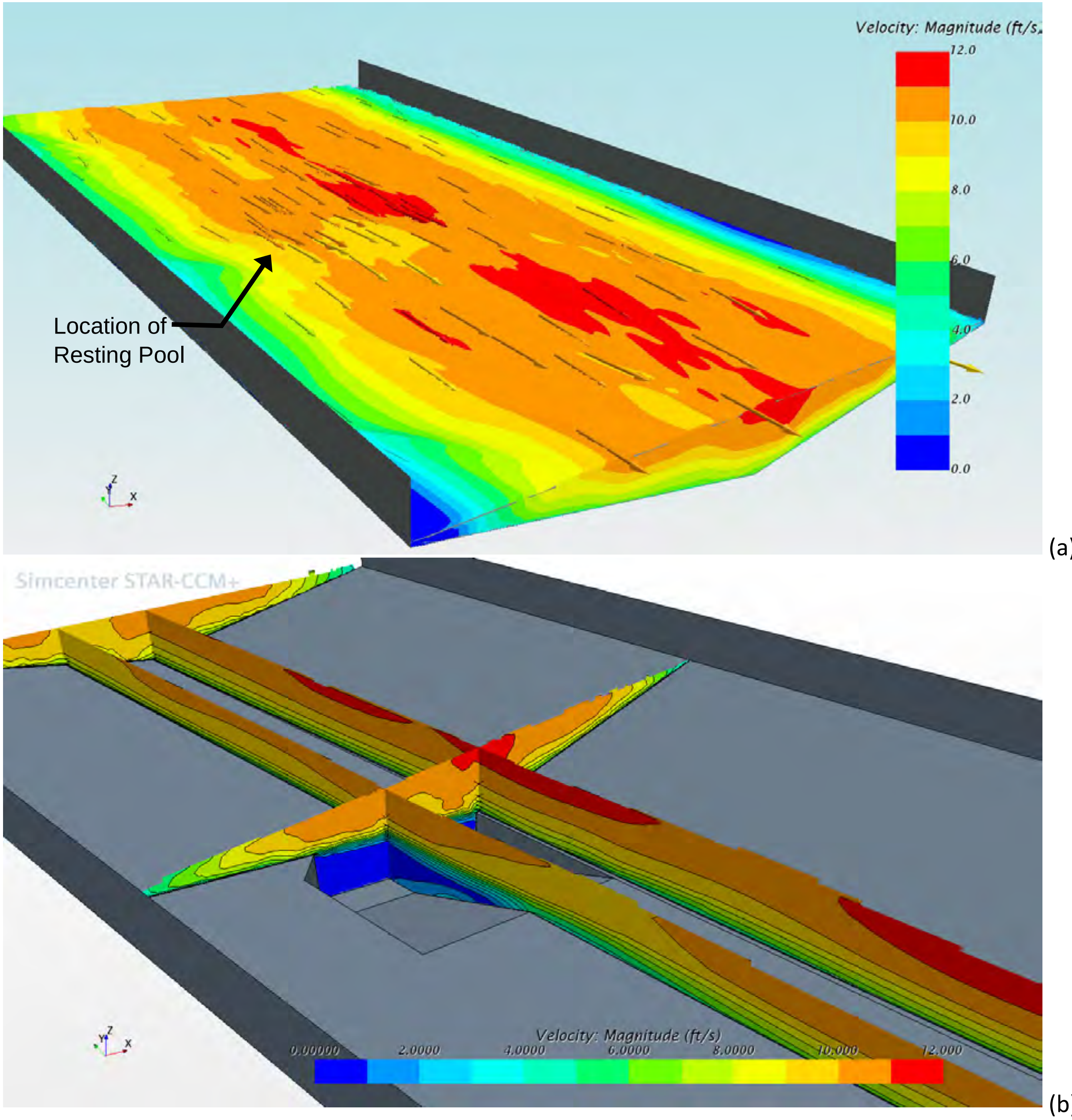


Figure 34. CFD model predicted water velocities (a) on the surface and (b) at select sections for Alternative 3 pool configuration at the estimated sediment mobility critical discharge of 500 cfs.

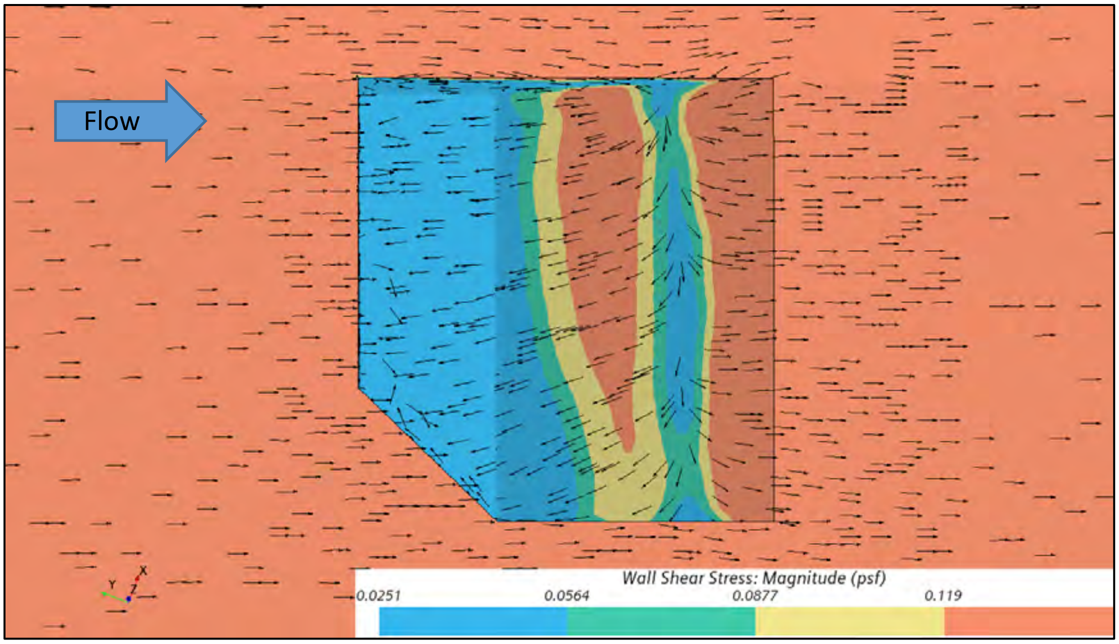


Figure 35. Shear stress applied to the channel bed and Alternative 3 pool bottom at 500 cfs. Orange represents shear stress sufficient to fully mobilize the dominate particle size of 8 mm, while yellows are partially-fully mobile, greens are partially mobile, and blues represents stable.

6.4.3 Alternative 3 Tracking Sediment Particles through Alternative 3 Pool

To help evaluate the potential for sedimentation within the fish resting pools, analyses were conducted using CFD modeling with particle tracking, as discussed in Section 4.8. The Alternative 3 pool configuration was not modeled with particle tracking, however, the modeling conducted with no fish pools in the channel showed the sediment particles collecting along the channel invert as they moved downstream (Section 4.8). Based on this, and the findings from the sediment mobility analysis, it was expected the Alternative 3 configuration with the fish resting pool adjacent to the channel invert would be susceptible to intercepting and accumulating sediment that was traveling along the channel invert.

6.4.4 Alternative 3 Pool Conclusions

Alternative 3 pool geometry provided more than adequate resting areas for fish at the high passage flow of 180 cfs. However, the sediment mobility analysis and particle tracking analysis at the approximate sediment transport critical discharge of 500 cfs suggests that sediment is prone to deposit in the channel. The analysis showed that at 500 cfs most of the coarse sediment delivered from the upstream into Unit 3 will be transported down the invert of the channel given its cross-sectional v-shape. This sediment is shown dropping into the pool and depositing along the bottom. Based on these findings, the pool shape was refined as part of Alternative 4 to reduce entrainment of coarse sediment into the pool, where it has a tendency to deposit.

6.5 Alternative 4 (Final) Resting Pool Geometry

Alternative 4 pool geometry was developed as a refinement of Alternative 3 and serves as the preferred alternative that was forwarded to final design. This alternative modifies Alternative 3 pool geometry to reduce the potential for sediment that is in transported along the channel invert to become entrained within the pool and thus deposit.

6.5.1 Alternative 4 Pool Configuration

Alternative 4 pool bottom is 2 feet deep and 3 feet long with a pool tailout that is 6 feet long at a slope of 3H:1V. Compared to Alternative 3, Alternative 4 moves the pool 2 feet away from the channel centerline (Figure 36). Because of the channel's 5.5H:1V cross-slope, moving the pool over places the inside edge of the pool 0.36 feet higher than the adjacent channel invert. This results in insufficient depth for fish to swim from the channel centerline into the pool at the low passage flow of 14 cfs. To maintain sufficient water depth for fish to use the pool at 14 cfs, a 3-foot long flat section of channel is included between the channel centerline and the pool.

6.5.2 Alternative 4 Pool Velocities from CFD Model

A 3D CFD model was developed for the Alternative 3 resting pool within a straight section of channel. The model was executed at the high passage flow of 180 cfs and at the estimated sediment mobility critical discharge of 500 cfs. Results are presented in the following sections and provided in Attachment 6.

High Fish Passage Flow (180 cfs)

At the high passage flow the CFD model results show surface velocities through the pool vary, but to a lesser degree than Alternative 3. Comparing to upstream and downstream, the resting pool has a relatively minor influence on the overall pattern of surface velocities within the channel. A small area of the surface flow is below 2 ft/s along the outer edge of the pool, and between 7 and 8 ft/s over the center of the pool (Figure 37a).

The select cross section through the pool shown in Figure 37b confirms that velocities are highly variable within the water column, with high velocities skimming over the pool surface while lower down they are below 1 ft/s. There is both vertical and horizontal circulation (eddy) patterns occurring within the pool (Attachment 6), as would be anticipated. This low velocity zone persists partway down the pool "tailout." The section view also shows that the outer edge of the pool is at the approximate edge of the wetted channel at this flow.

Figure 38 shows the entire 108 ft^3 of the pool volume that maintains velocities less than 2 ft/s at 180 cfs, indicating that the Alternative 4 pool provides similar resting volume as Alternative 3. Based on the project's pool resting volume criteria (Section 5.3.4), the Alternative 4 pool should provide ample volume at the high fish passage flow for a minimum of six adult steelhead to hold in the pool and rest at a given time. Attachment 6 provides additional figures from the CFD model results for 180 cfs.

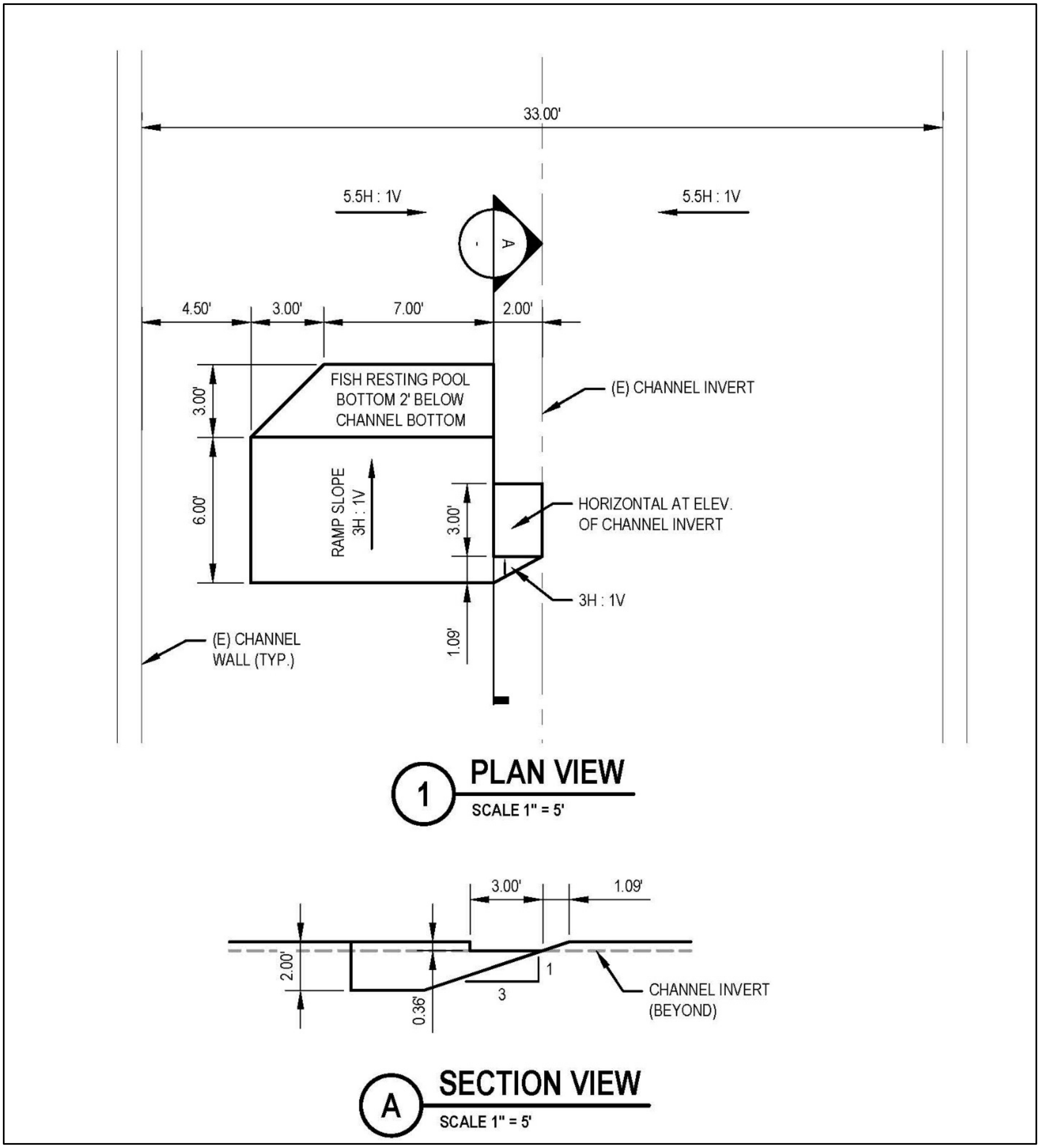
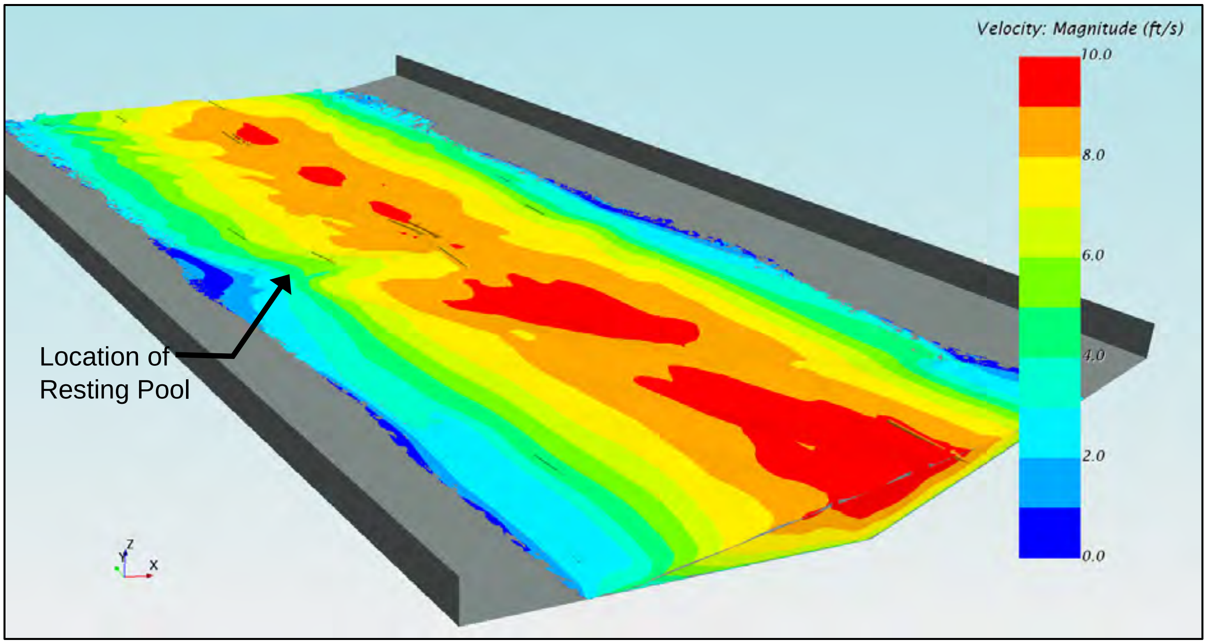
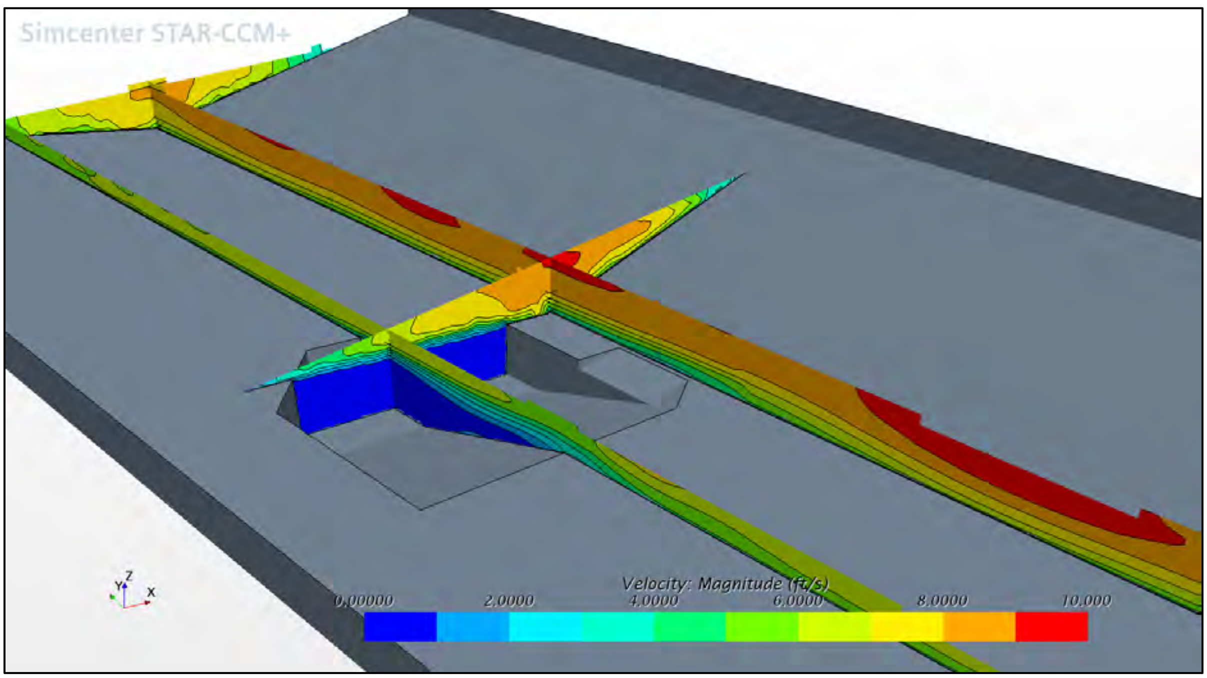


Figure 36. Alternative 4 pool configuration in plan and section, with flow from top to bottom and left to right respectively.



(a)



(b)

Figure 37. CFD model predicted water velocities (a) on the surface and (b) at select sections for Alternative 4 pool configuration at the high passage flow of 180 cfs.

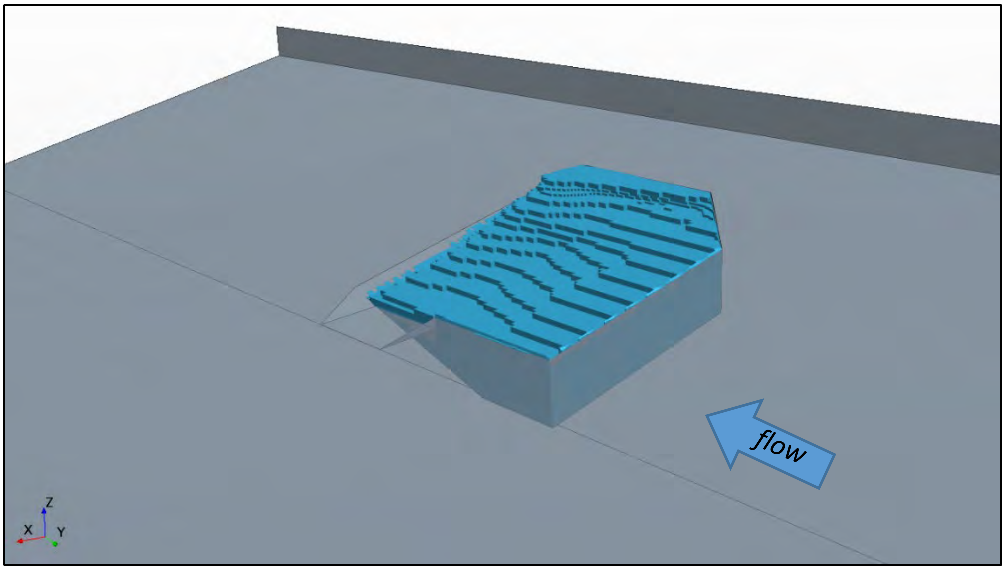


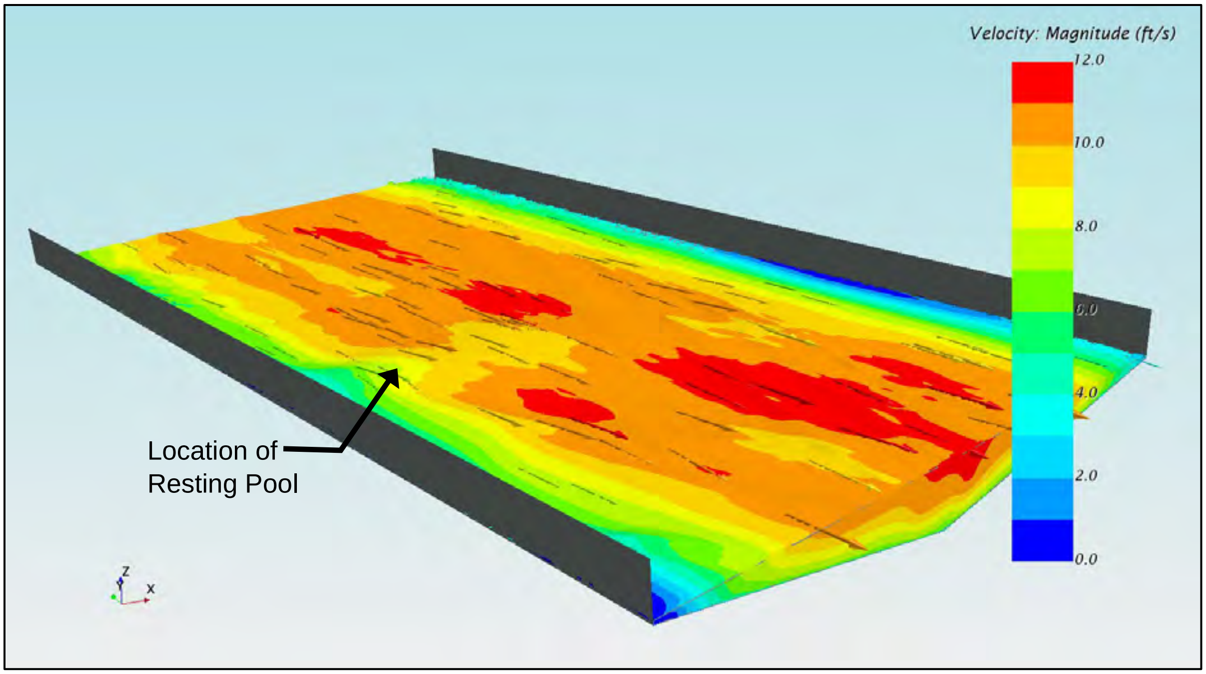
Figure 38. Volume of Alternative 3 pool (108 ft^3) with velocities below 2 ft/s at 180 cfs, and suitable for fish resting (volume below the blue contours).

Sediment Mobility at Critical Discharge (500 cfs)

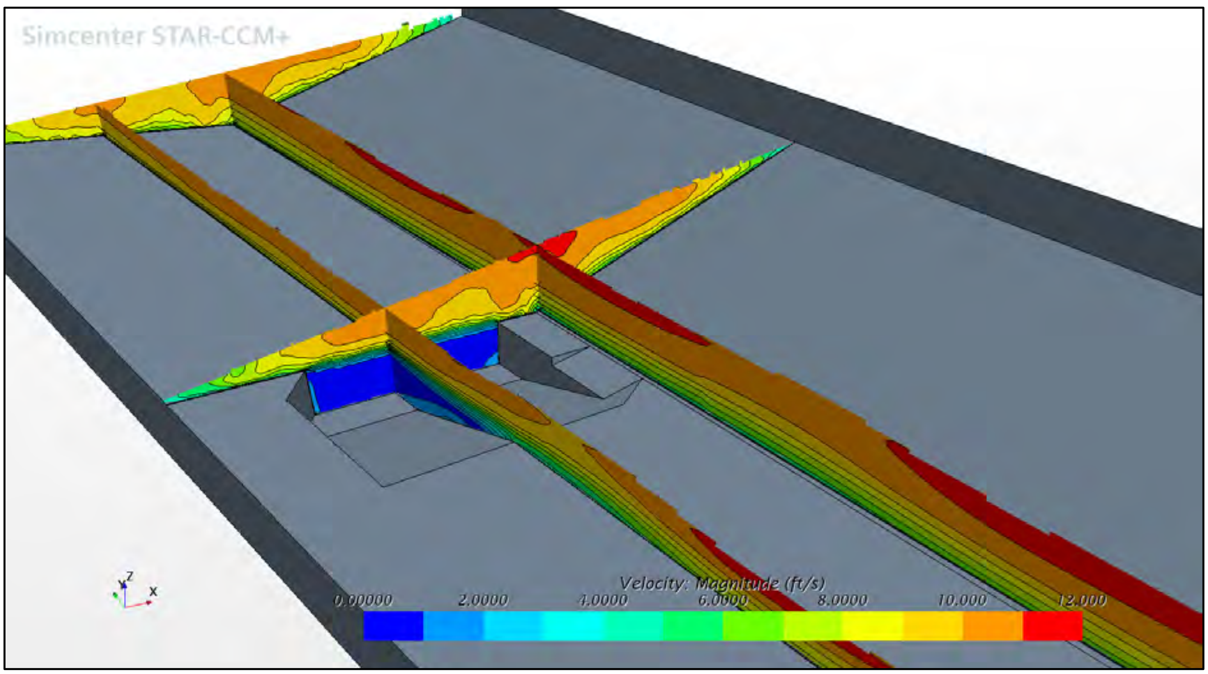
The streambed material within the upstream sediment delivery channel is estimated to mobilize at approximately 500 cfs. The CFD model results at this flow were used to evaluate flow patterns within the Alternative 4 resting pool, including water velocities (Figure 39), shear stresses applied to the bed of the pool (Figure 40) and turbulence kinetic energy (TKE), which is the mean kinetic energy per unit mass of water associated with eddies in turbulent flow (Attachment 6). The velocity patterns resemble those occurring at 180 cfs, with streaming velocities across the surface of the pool and low velocities within the lower 2 feet of the pool that results in recirculation pattern occurring both vertically and horizontally.

The shear stress magnitudes are relatively low along the pool bottom but substantially greater across the pool tailout. The flat section connecting the channel invert to the resting pool shows shear stress directions and magnitudes sufficient to keep the sediment conveyed down the channel invert from being swept into the pool. This suggests that the Alternative 4 pool will be less likely to entrain sediment than the other analyzed pools. However, coarse sediment that does enter the pool will likely deposit at this flow due to the overall low shear stress and velocities in the pool bottom.

Additional CFD analysis was conducted using sediment particle tracking as described in the following section to further evaluate the ability of sediment to be transported past the pool.



(a)



(b)

Figure 39. CFD model predicted water velocities (a) on the surface and (b) at select sections for Alternative 4 pool configuration at the estimated sediment mobility critical discharge of 500 cfs.

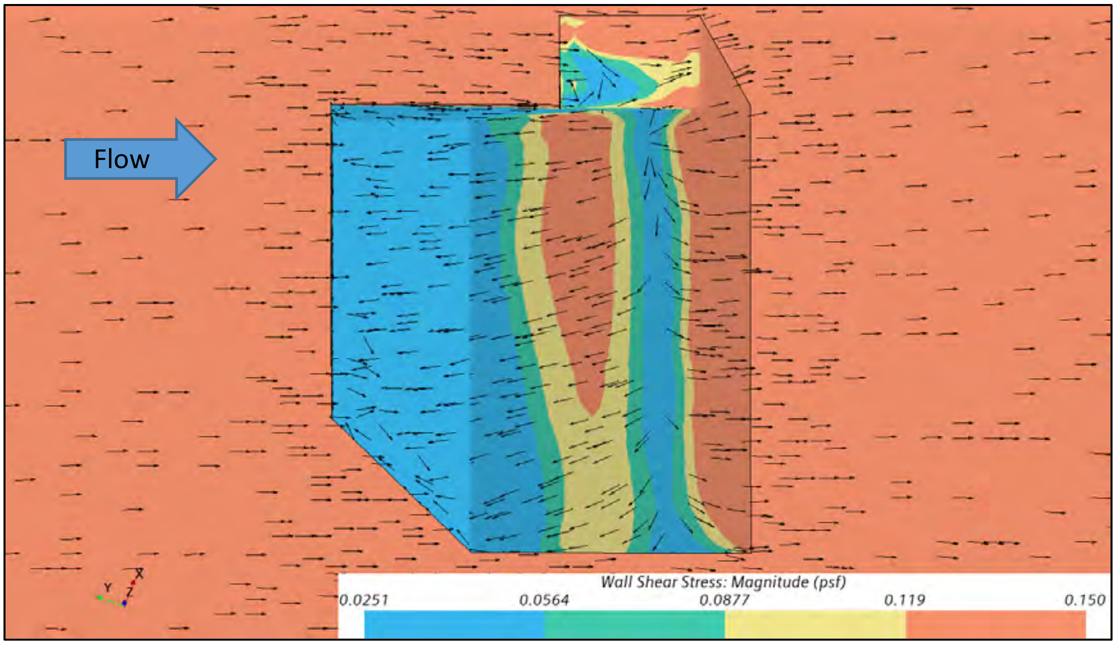


Figure 40. Shear stress applied to the channel bed and Alternative 4 pool bottom at 500 cfs. Orange represents shear stress sufficient to fully mobilize the dominate particle size of 8 mm, while yellows are partially-fully mobile, greens are partially mobile, and blues represents stable.

6.5.3 Alternative 4 Tracking Sediment Particles through Pool

To help evaluate the potential for sedimentation within the fish resting pools, analyses were conducted using CFD modeling with particle tracking, as discussed in Section 4.8. Alternative 4 was modeled with particle tracking with the model setup described in Section 4.8. The modeling showed the particles (shown as the blue spheres along the channel invert) bypassing the pool and remaining within the channel invert, as shown in Figure 41. These model results indicate that offsetting the pool from the channel invert reduces the likeliness of it intercepting and accumulating sediment that is traveling along the channel invert.

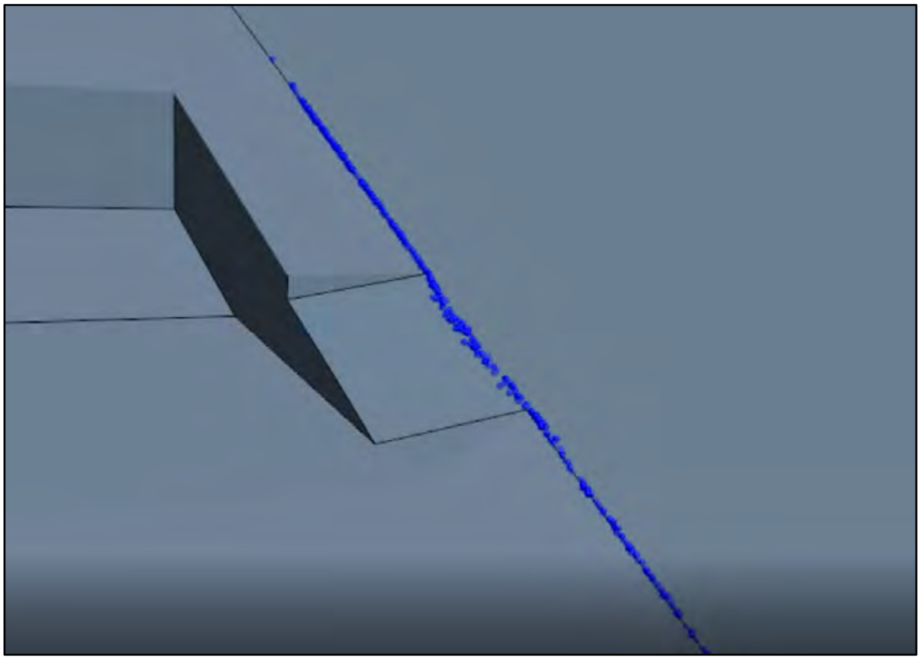


Figure 41 Sediment particles (blue spheres) bypassing Alternative 4 pool.

6.5.4 Alternative 4 Fish Passage Performance

The fish passage conditions through the entire Unit 3 channel were evaluated in HEC-RAS 2D and Fish-REALMS using the Alternative 4 pool shape placed at the stationing listed Table 7. The Alternative 4 pool shape was graded into the existing channel DEM in CAD at the 16 locations. The updated DEM was then inputted in the project's HEC-RAS 2D model.

Each of the 16 pools were found to provide adequate resting volume at the high passage flow of 180 cfs and a low tide of 0.0 feet (Figure 42). The fish passage analysis resulted in 99.0% of the surrogate fish able to pass successfully through the Unit 3 channel at the 180 cfs flow and zero tide and 99.3% passage at the low passage flow of 14 cfs and zero tide. In both situations, only the smallest and weakest swimming individuals in the population were unable to succeed. Therefore, using Alternative 4 resting pool geometry and placing the 16 pools at their indicated locations, passage success rates equal or exceed 99% for all fish passage flows and tides.

6.5.5 Alternative 4 Analysis of Resting Velocities with Pool Sediment Deposition

Sediment deposition within some or all the pools is inherent given that they are designed to produce low velocities for fish resting. The impact of pool sedimentation on fish resting velocities was evaluated to help inform the potential need for sediment removal activities as part of project maintenance. Two different sedimentation depths were evaluated: one with up to 6 inches of sediment and the other with 12 inches of sediment (Figure 43). The analysis was conducted for the high fish passage flow of 180 cfs using the CFD model.

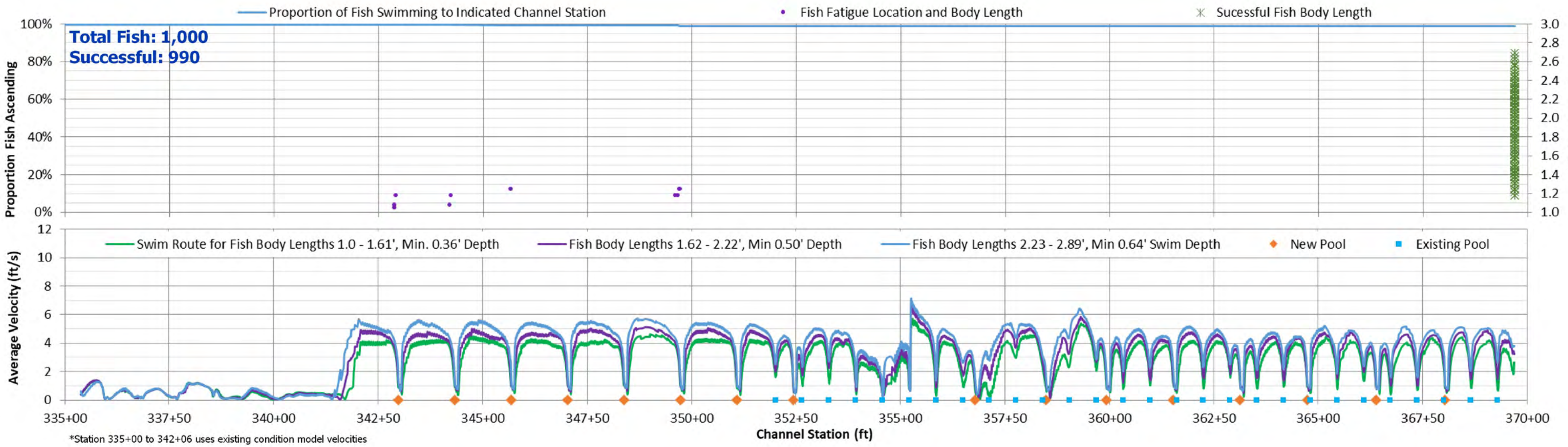
The CFD model results found the two analyzed levels of sediment deposition caused only minor reduction in the pool volume maintaining less than 2 ft/s velocities for resting. For Alternative 4, without sedimentation the suitable pool volume at 180 cfs is 108 ft^3. This is reduced to 104 ft^3 with 6 inches of sediment and 96 ft^3 with 12 inches of sediment.

The main constraint associated with sedimentation is the loss of pool depth at low flows. The design criterion for minimum pool depth is 2.5 feet (Section 5.3.2) at the low fish passage flow of 14 cfs. With no sedimentation, the Alternative 4 pool depth at this flow is approximately 2.7 feet. Therefore, even minimal sedimentation will reduce the pool depth to less that 2.5 feet at 14 cfs.

The minimum pool depth criterion is relatively conservative. This should be accounted for when considering the amount of sedimentation necessitating pool clean-out. It may not be necessary to remove all sediment to maintain this depth. At higher passage flows, the pool provides ample area that meet fish resting requirements, even with 12 inches of sediment deposition.

6.5.6 Alternative 4 Pool Conclusions

The Alternative 4 pool geometry was found to provide suitable fish resting conditions at all passage flows and is less prone to sediment entrainment and resulting deposition than the other alternatives. The analysis of Unit 3 with the Alternative 4 resting pool placed at the 16 designated locations found passage success rates of 99.0% and higher at all fish passage flows and tides. An evaluation of pool performance with sediment deposition up to 12 inches thick also found that the pool continues to provide ample resting volume for multiple steelhead at the high fish passage flow. Therefore, the Alternative 4 pool configuration was selected for final design.



Datums:
Horizontal: NAD83 State Plane CA Zone 3
Vertical: NAVD88

Sources:
Aerial Image: 2018 Coastal California NAIP

Prepared for:
- Friends of Corte Madera Creek Watershed
- Marin County Flood Control and Water Conservation District
- California Coastal Conservancy

Map Legend:
Fish Fatigue Location — Fish Swim Path
Velocity (fps)
<= 1, 1 - 2, 2 - 3, 3 - 4, 4 - 5, 5 - 6, 6 - 7, 7 - 8, 8 - 9, 9 - 10, > 10

Michael Love & Associates
Hydrologic Solutions
GHD

FIGURE 42
Alternative 4 Resting Pools
Corte Madera Creek, Final Proposed Conditions
Species: Adult Steelhead
Flow: 180 cfs (10% Exceedance)
Boundary Condition: 0 ft Tide

Filepath: Q:\Corte Madera Passage Analysis\7_CAD-GIS\QGIS\Working\CorteMadera_Steelhead_180cfs.qgs

Michael Love & Associates, Inc. P.O. Box 4477, Arcata, CA 95521 (707) 822-2411

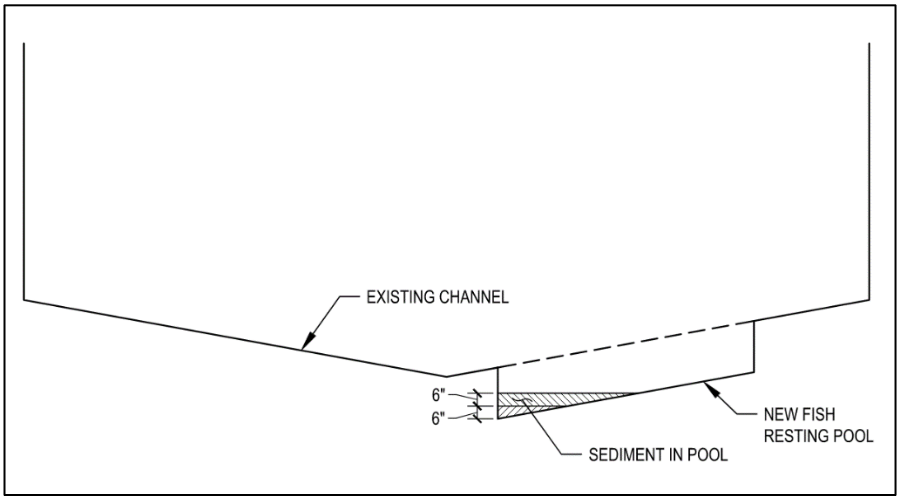
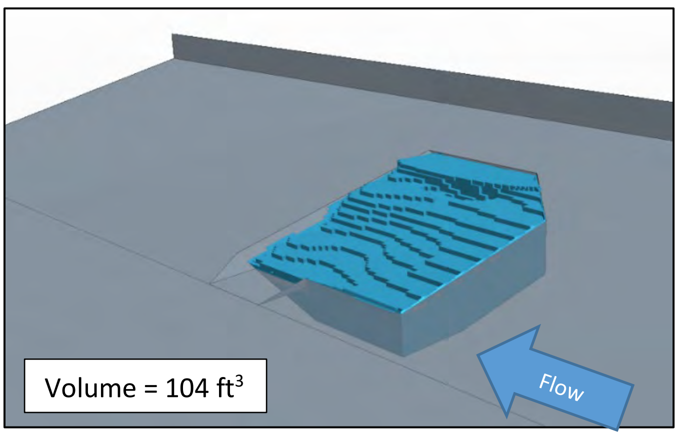
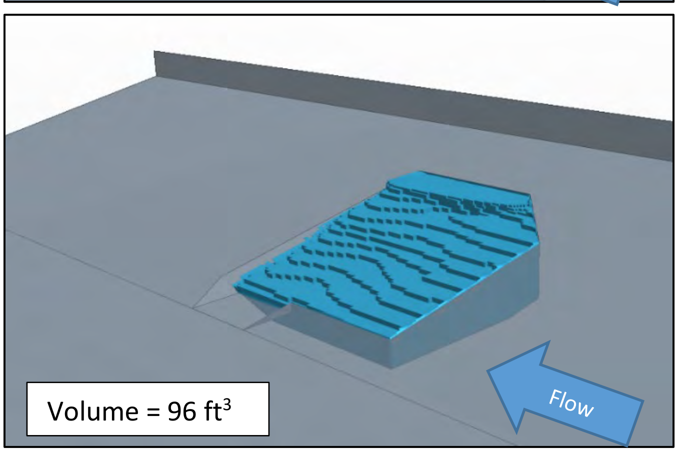


Figure 43. Cross section through Alternative 4 pool showing two sedimentation conditions (6 inches and 12 inches thick) evaluated for influence on fish resting velocities.



(a)



(b)

Figure 44. Volume of pool with water velocities less than 2 ft/s at high fish passage flow of 180 cfs with (a) 6 inches and (b) 12 inches of sediment in the pool bottom.

7. Final Resting Pool Configuration, Passage Performance, and Maintenance

7.1 Project Description

A total of 16 new resting pools are proposed for Unit 3 to improve passage conditions for Steelhead Trout and Coho Salmon. The pools will be constructed of concrete recessed into the existing concrete channel. The location of each pool is listed in Table 7. The downstream-most 11 pools will be constructed in the intertidal portion of Unit 3. Pool spacing ranges between 135 feet and 165 feet, with the exception of a section of channel near Kentfield Hospital. In this section the channel makes an s-turn that produces lower water velocities with ample areas for fish to hold and rest without additional pools. Therefore, the distance between pools in this section of channel is 435 feet.

The project will use the pool geometry associated with Alternative 4, as shown in Figure 36. The pool is offset from the channel centerline by 2 feet to reduce the potential for sediment to become entrained and deposit within the pool. A 3 feet long flat section of concrete formed at the channel invert elevation connects the pool to the channel centerline, providing ample depth for fish to swim from the center of the channel into the pool at the low passage flow. The floor of the pool is set 2 feet below the existing concrete channel bottom. The pool bottom is 3 feet long and 10 feet wide. The upstream face of the pool is vertical, with the upstream outer edge of the pool beveled in plan view. The bevel is included to turn the flow and help reduce the strength of the eddy that forms within the pool at higher flows, thus reducing the potential for pool sedimentation. The downstream end of the pool ramps back up to the existing channel bottom at a 3H:1V slope. The overall pool length 9 feet.

7.2 Anticipated Passage Performance

The proposed project is anticipated to dramatically improve passage conditions. At the high fish passage flow and a tide of 0.0 feet (NAVD88), the project is anticipated passage for up to 99% of the Steelhead population based on results from the 2D hydraulic model and Fish-REALMS analysis (Figure 42). The passage rate is anticipated to be equal or greater than 99.0% at lower flows and higher tides.

7.3 Influence of Sedimentation on Resting Pool Performance

An analysis of the proposed pools with up to 12 inches of sediment deposited across the lower portion of the pool bottom (Figure 43) found that they continue to provide more than ample resting volume at the high fish passage flow. However, sediment deposition more than approximately 0.3 feet thick in the lowest portion of the pool bottom will results in the pool depth being less than the 2.5-foot depth criterion at the low fish passage flow. The minimum pool depth criterion is relatively conservative, this should be considered when determining the action level for removing sediment from pools as part of ongoing project maintenance.

7.4 Project Inspection and Maintenance

7.4.1 Establishing Inspection and Maintenance Procedures

It is recommended that robust inspection and maintenance procedures be established and followed once the project is implemented to ensure suitable fish passage conditions are maintained and any issues arising from debris and sedimentation are addressed in a timely manner. Establishing appropriate thresholds for taking action based on inspection reports may require some initial monitoring. This monitoring should aim at characterizing the impacts sedimentation has on the effectiveness of fish resting pools and also the potential impacts of debris within the channel on water velocities.

7.4.2 Recommended Inspection Procedures

The project is intended to require minimal maintenance, but uncertainty persists regarding the potential for excessive sedimentation within the pools that could make them inoperable. Maintenance may also be needed if debris becomes hung-up within the pools or elsewhere within the Unit 3 channel. Ongoing visual inspection of the project is needed to identify if maintenance activities may be required. Two types of visual inspection are recommended. The first would be following each large flow event to inspect the Unit 3 channel for debris accumulations. This would be conducted from top of bank. Any debris in or around a resting pool should be removed as soon as it is reasonably safe for maintenance staff. Because the fish swimming route is typically near the margins of the wetted channel where velocities are slow enough for the fish, and the location of the wetted margin changes with changing flow, most debris can be problematic for fish passage and should be removed if it is unlikely to be easily swept away by rising flows.

The second type of inspection would be annually to assess sediment deposition conditions within the pools. The annual pool sedimentation inspection should be done during summer low-flow conditions, when it is safe to enter the channel and the water is clear enough to see accumulated sediments within the pools. Tides should be considered when conducting the inspection. The inspector should walk the entire length of the channel, from the downstream to upstream most pool and record the depth of sediment within each pool. The pool number should be noted on or adjacent to the pool (such as on the channel wall) to allow for ease of identification. A stage plate should be stenciled onto the upstream face of each pool to allow for direct reading of depth of sediment.

Action level sedimentation is not yet defined, and will be established in part from findings associated with the physical performance monitoring of the pools (Section7.4.3). Initially, it is recommended that sedimentation depths of 6 inches or greater should trigger a review process involving qualified fisheries biologist and fish passage engineers, including staff from the fisheries resource agencies, to discuss the potential need for sediment removal and/or additional monitoring of the pool. Through this process, final thresholds for sediment removal can be established.

7.4.3 Project Physical Performance Monitoring

Performance of the resting pools should be evaluated at fish passage flows to verify that they provide suitable resting conditions for fish. The monitoring should be conducted in pools that are experiencing various levels of sediment deposition to assess their performance as well as pools that are not experiencing sedimentation. The monitoring would provide valuable insights regarding fish resting conditions provided with various degrees of sedimentation, thus helping identify an appropriate sedimentation threshold for triggering pool cleanout. At the lower end of passage flows this could be done by physically measuring water depths with a wading rod. At higher flows, when water velocities are unsafe for wading, alternative monitoring methods should be used. This may include the use of an acoustic doppler current profiler (ADCP) mounted on a float attached to taglines leading to both sides of the channel. The ADCP measures depth and water velocities throughout the water column, identifying areas within the pool suitable for fish to hold and rest.

Monitoring should also involve documenting debris within the channel and its local effects on water velocities. This can be captured through video taken at a range of fish passage flows. The focus of this monitoring is to characterize the size and type of debris that disrupts the slower velocities along the channel margins that fish may use to swim upstream.

7.4.4 Sediment Removal Activities

If sediment removal is deemed necessary, this activity should occur during the summer/early fall, when stream flows are at their lowest. Removal should be conducted in accordance with the permit requirements, but is envisioned to involve either hand removal of sediment or mechanical removal. Given the water quality conditions and complete lack of cover within the concrete pools during summer low-flows, it is not anticipated fish would be present. However, a qualified fisheries biologist should be present to inspect the pools and relocate any fish within them prior to cleanout activities. A fish screen should be installed upstream and downstream of the maintenance activities to ensure no fish reenter the work area. Water quality BMPs should also be implemented to control downstream turbidity. Sediment removed from the pools should be taken out of the channel and disposed of properly. Hand shovels may be adequate for this. Alternatively, a vacuum pump could be used.

8. Structural and Constructability Considerations for Resting Pools

An evaluation of the existing structural condition of the Unit 3 concrete channel was conducted by the project team at the initiation of this current project to identify any design constraints and constructability challenges associated with new fish resting pools. This helped ensure that the resting pool approach and configurations being proposed are feasible to construct.

8.1 Existing Structural Condition of the Concrete Channel

Unit 3 of the Corte Madera Creek is an open top reinforced concrete channel. It was constructed in the early 1970s by the U.S. Army Corps of Engineers and appears to be the original construction, without any major repairs or modifications.

Within Unit 3, the channel cross section is consistent, with vertical retaining walls approximately 10 feet high and a channel base width of approximately 33 feet wide. Embedded in the top of both walls are 6 feet high chain link fences and both banks are level with the top of concrete wall. The right bank, or west side of the channel, consists of a paved pedestrian path, and the left bank, or east side of the channel, consist of a packed dirt trail. There are mature shrubs and trees growing directly against the back face of the channel walls on both banks.

In general, the concrete channel does not require major repairs. The walls are in fair condition with some signs of cracks or open spalls at the base. The channel base slab cover is in moderate to poor condition with significant delamination and spalls. It appears to be primarily the concrete cover that is wearing away and thus may not be reducing the structural capacity of the concrete. However, repairs are recommended to curtail further deterioration (GHD, 2019(a)).

8.2 Structural Design Considerations for Fish Passage Improvements

The base of the channel appears to be primarily in compression where the lateral soil load from one wall is transferred through the base and into the opposing wall to bear against the soil. Enlarging the fish pools are not anticipated to be detrimental to the stability of the existing channel structure. To establish the load path around the opening in the base due to the fish pool, it will be cut in a larger rectangular shape with perpendicular walls and base. The perimeter of the opening will be doweled into the existing concrete and reinforced as a grade beam to distribute the load at the opening. The interior will then be shaped using non-shrink grout to form the desired geometry per the hydraulic analysis.

8.3 Constructability Design Considerations for Fish Passage Improvements

The Fish Pool Construction memo (GHD, 2019(b)) identifies several design considerations for the constructability of the fish pools within Unit 3, including construction equipment access, groundwater, and tidal influence within the work area. The construction methods will depend on the size and type of construction equipment that can access the site. It is possible that large construction equipment will not have direct access to the project site, in which case the design should allow for construction methods that use small equipment and long concrete pump runs. The Fish Pool Construction memo (GHD, 2019(b)) recommends that the Flood Control (FC) District consider the construction of a permanent access ramp into the channel at the FC District-owned property located at Locust Ave. and Cedar Ave. which would allow for large construction equipment and concrete trucks to access the site, which would provide more flexibility in the construction methods and design considerations. The permanent access ramp could also provide access for future maintenance and monitoring activities. The access ramp is currently planned as a part of the CMCFRM Project, to be constructed before the fish pool construction in the channel.

The Fish Pool Construction memo (GHD, 2019(b)) notes that groundwater is expected to be encountered in the excavations for the fish pools, especially those lower in the channel. The design should take into account the likely presence of groundwater and the limitation of materials and/or construction methods that can be used in those conditions.

The Fish Pool Construction memo (GHD, 2019(b)) notes that the majority of the fish pool construction area is within a tidally-influenced zone and subject to inundation. The design should include a temporary cofferdam downstream of the work area and an upstream diversion to direct nuisance flow around the project site. Note that the fish passage improvements may coincide with the USACE *Corte Madera Creek, Lower College of Marin Reach Concrete Channel Removal Project*, which includes the installation of a temporary cofferdam downstream of the fish passage improvements. There could be cost and constructability benefits if the two projects can be scheduled to coincide.

Construction within the channel is only permitted between June 15 and October 15. To construct all of the fish pools in the required timeframe may require multiple construction crews and phased construction. The Fish Pool Construction memo (GHD, 2019(b)) outlines a number of scenarios for construction of the fish pools in different reaches, i.e. all reaches constructed in a single phase, or individual reaches constructed individually or in combination. The design should consider accelerated construction if needed.

9. References

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Attachment 1

Layout of Existing Unit 3 Channel

Datums:
Horizontal: NAD83 State Plane CA Zone 3
Vertical: NAVD88

Sources:
Aerial Image: 2018 Coastal California NAIP

Prepared for:
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- California Coastal Conservancy

Unit 3 Resting Pools Existing Conditions

0 50 100 ft

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FIGURE 1
Ross, CA
Corte Madera Creek
Unit 3 Resting Pools
Existing Conditions

Filepath: Q:\Corte Madera Passage Analysis\7 CAD-GIS\QGIS\Working\CorteMadera_Steelhead_Stationing.qgs

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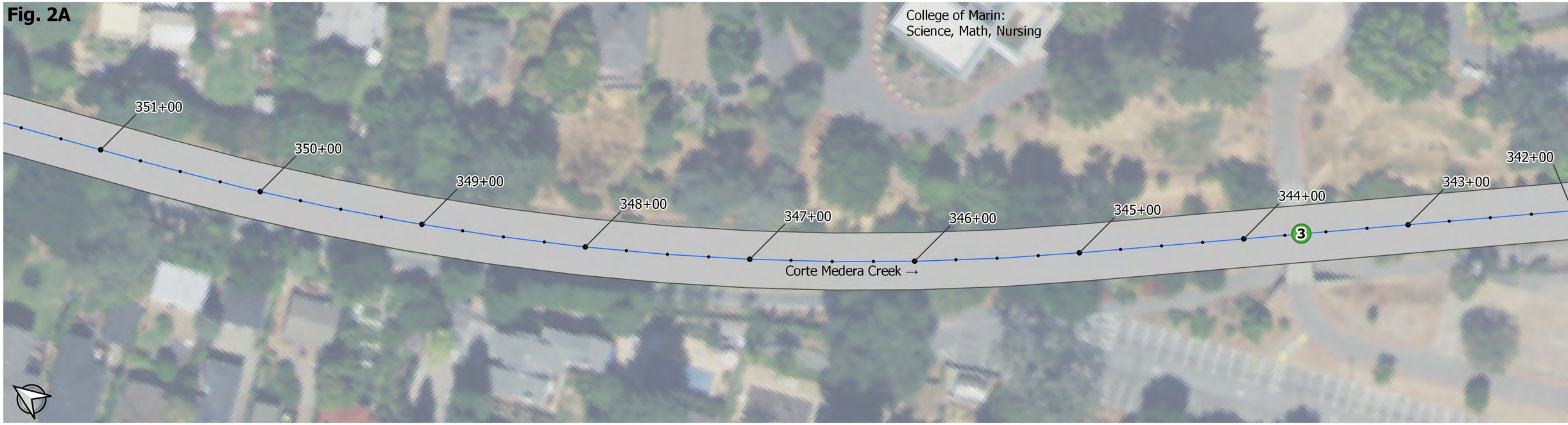

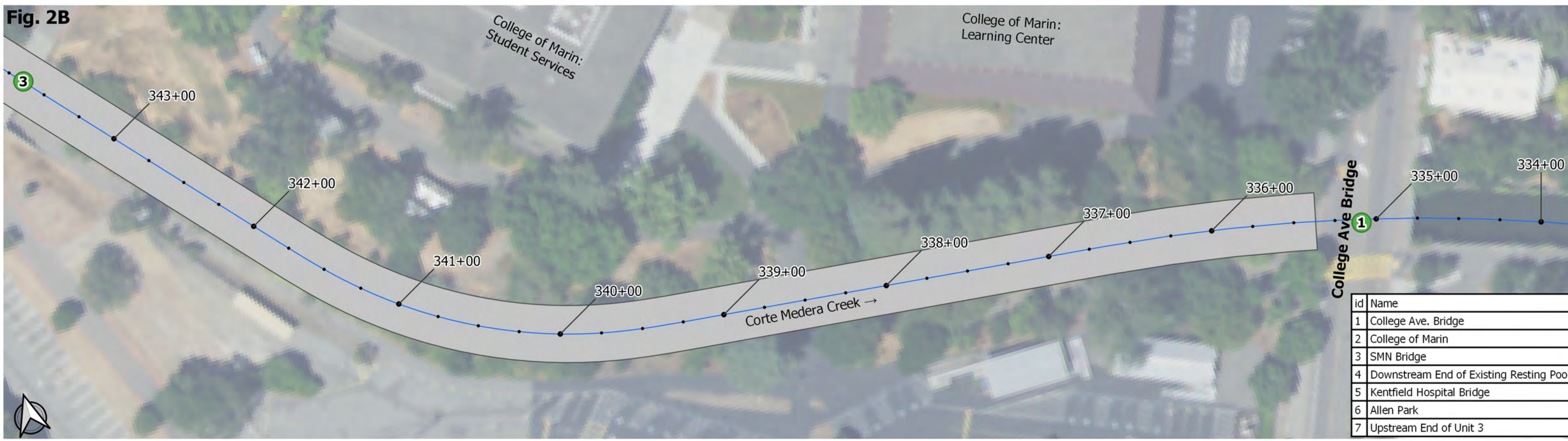

id	Name
1	College Ave. Bridge
2	College of Marin
3	SMN Bridge
4	Downstream End of Existing Resting Pools
5	Kentfield Hospital Bridge
6	Allen Park
7	Upstream End of Unit 3

Datums:
Horizontal: NAD83 State Plane CA Zone 3
Vertical: NAVD88

Sources:
Aerial Image: 2018 Coastal California NAIP

Prepared for:
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- **Marin County Flood Control and Water Conservation District**
- **California Coastal Conservancy**

Unit 3 Resting Pools Existing Conditions

0 50 100 ft

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FIGURE 2
Ross, CA
Corte Madera Creek
Unit 3 Resting Pools
Existing Conditions

Filepath: Q:\Corte Madera Passage Analysis\7_CAD-GIS\QGIS\Working\CorteMadera_Steelhead_Stationing.qgs

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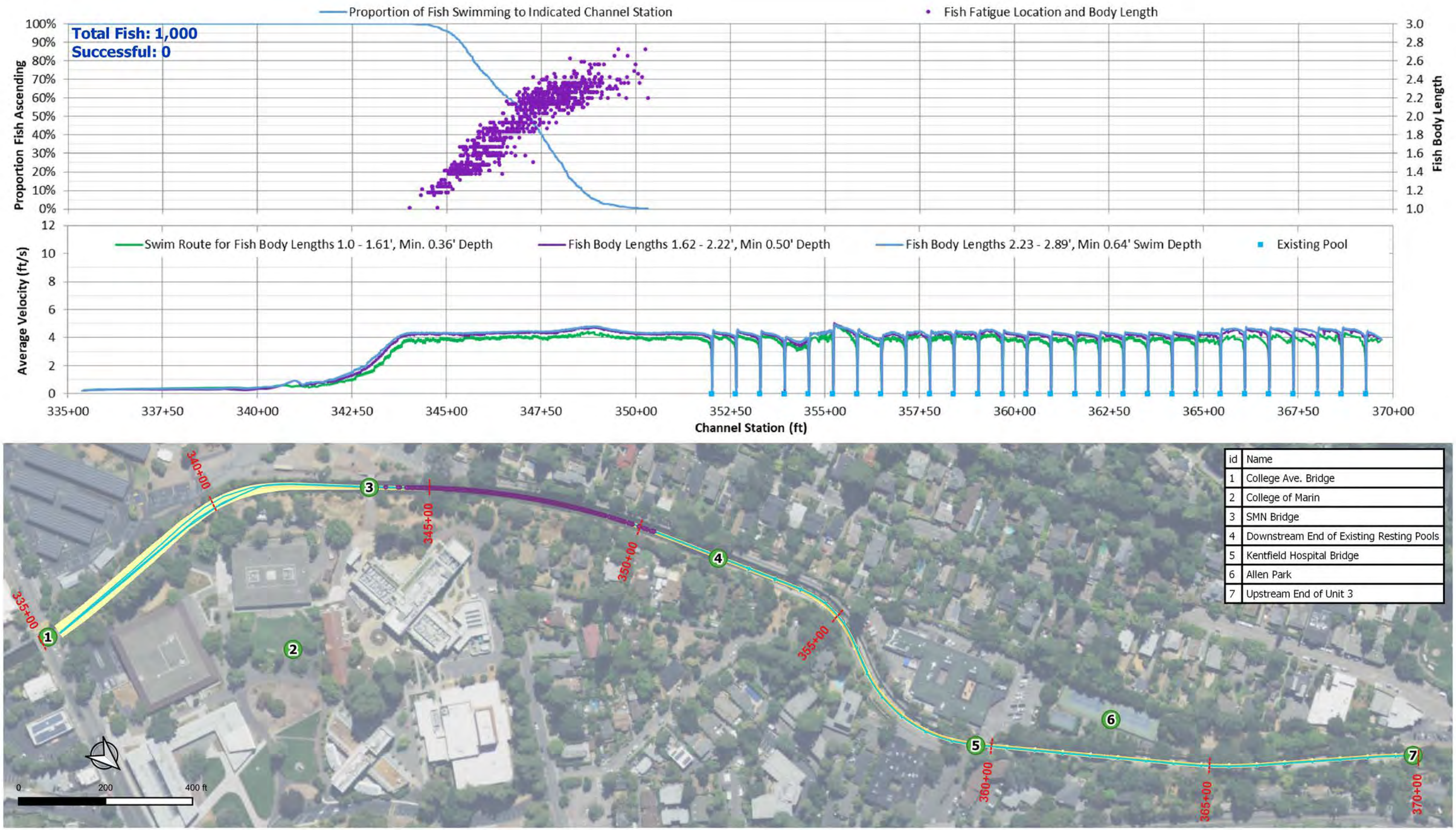
Attachment 2

Existing Conditions Fish Passage Results for Select Flows/Tides



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Vertical: NAVD88

Sources:
Aerial Image: 2018 Coastal California NAIP

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Map Legend:
Fish Fatigue Location — *Fish Swim Path*
Velocity (fps)
<= 1 | 1 - 2 | 2 - 3 | 3 - 4 | 4 - 5 | 5 - 6 | 6 - 7 | 7 - 8 | 8 - 9 | 9 - 10 | > 10

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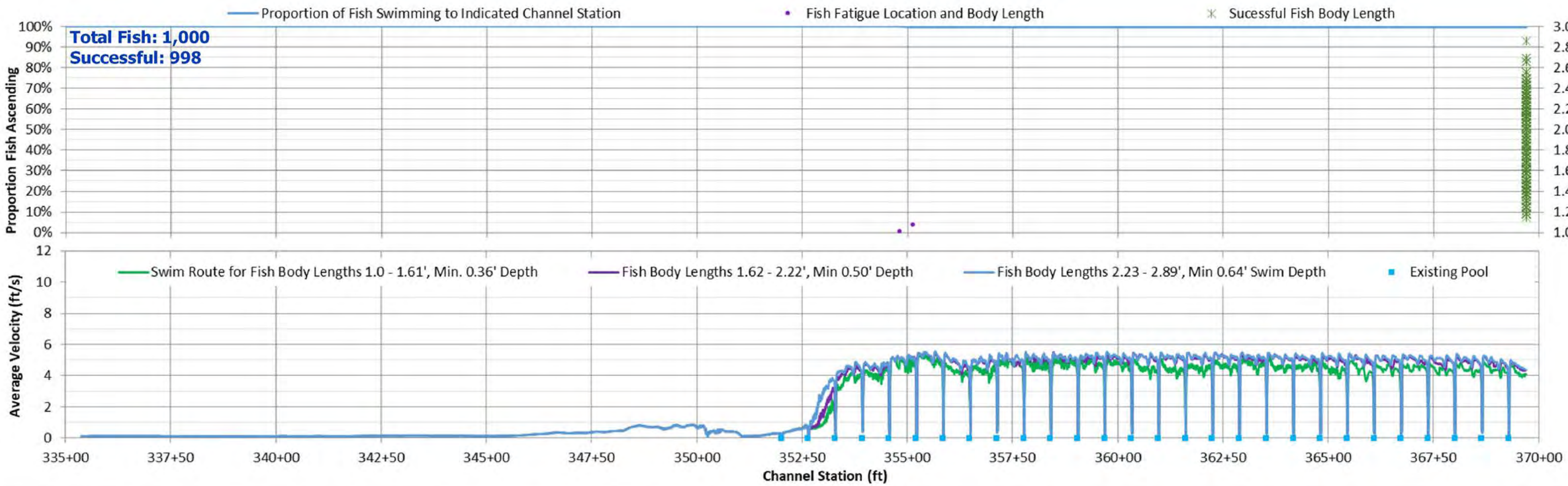
FIGURE 1
Ross, CA
Corte Madera Creek, Existing Conditions
Species: Adult Steelhead
Flow: 14 cfs
Boundary Condition: 0 ft Tide



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Vertical: NAVD88

Sources:
Aerial Image: 2018 Coastal California NAIP

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- Marin County Flood Control and Water Conservation District
- California Coastal Conservancy

Map Legend:
- *Fish Fatigue Location*
- *Fish Swim Path*

Velocity (fps)
<= 1 | 1 - 2 | 2 - 3 | 3 - 4 | 4 - 5 | 5 - 6 | 6 - 7 | 7 - 8 | 8 - 9 | 9 - 10 | > 10

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FIGURE 2
Ross, CA
Corte Madera Creek, Existing Conditions
Species: Adult Steelhead
Flow: 14 cfs
Boundary Condition: 4 ft Tide

Filepath: Q:\Corte Madera Passage Analysis\7 CAD-GIS\QGIS\Working\CorteMadera_Steelhead_14cfs.qgs

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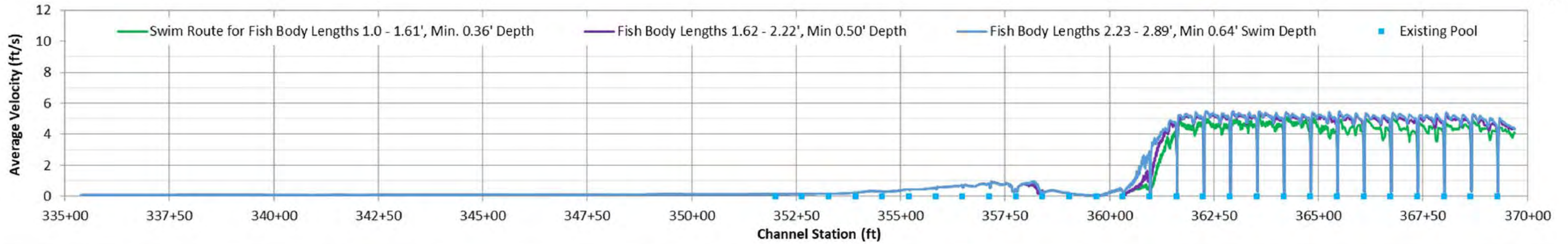

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Sources:
Aerial Image: 2018 Coastal California NAIP

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- California Coastal Conservancy

Map Legend:
Fish Fatigue Location *Fish Swim Path*
Velocity (fps)
<= 1 | 1 - 2 | 2 - 3 | 3 - 4 | 4 - 5 | 5 - 6 | 6 - 7 | 7 - 8 | 8 - 9 | 9 - 10 | > 10

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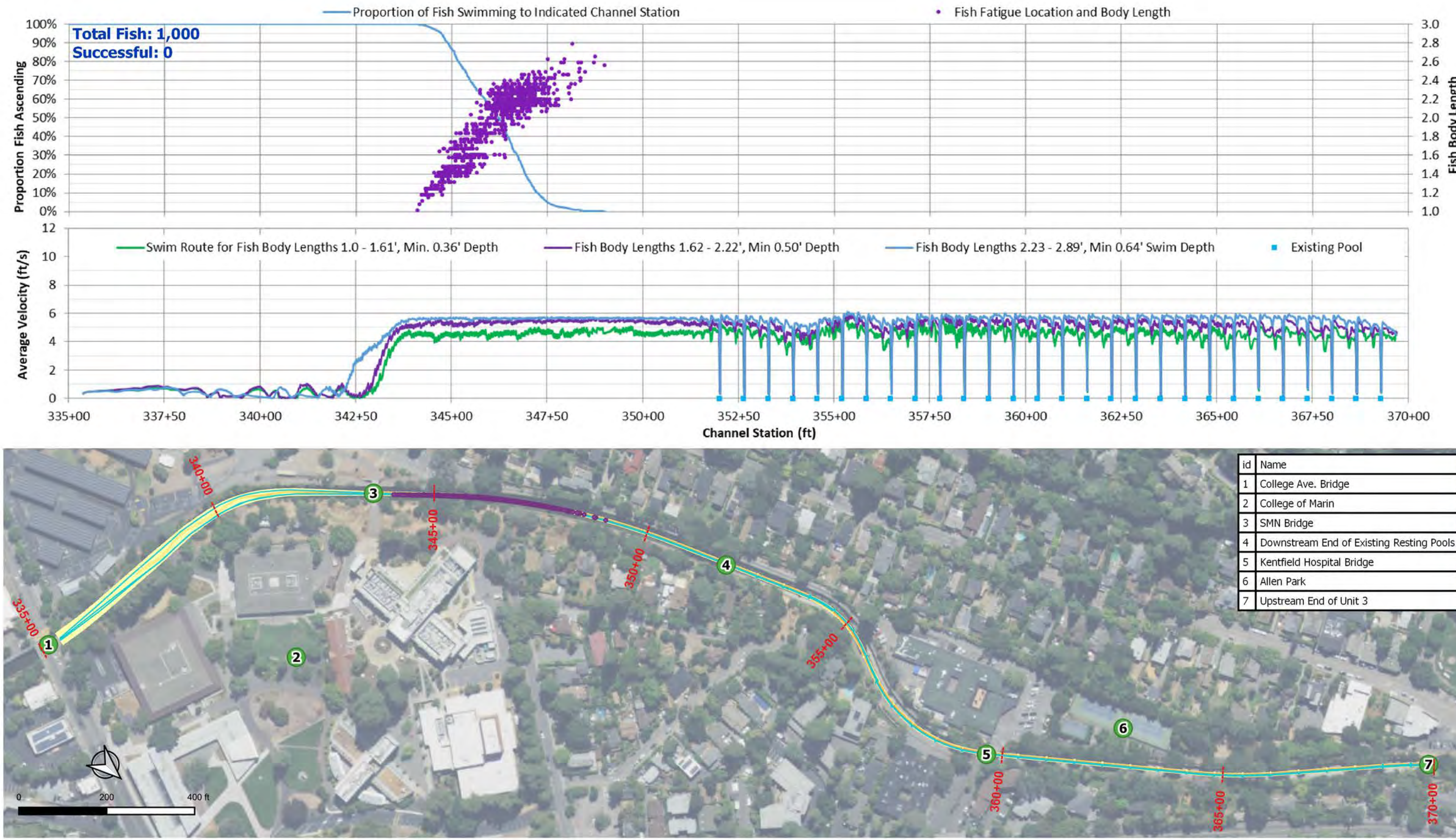
FIGURE 3
Ross, CA
Corte Madera Creek, Existing Conditions
Species: Adult Steelhead
Flow: 14 cfs
Boundary Condition: 7 ft Tide



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Sources:
Aerial Image: 2018 Coastal California NAIP

Prepared for:
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- California Coastal Conservancy

Map Legend:
Fish Fatigue Location *Fish Swim Path*
Velocity (fps)
<= 1 | 1 - 2 | 2 - 3 | 3 - 4 | 4 - 5 | 5 - 6 | 6 - 7 | 7 - 8 | 8 - 9 | 9 - 10 | > 10

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FIGURE 4
Ross, CA
Corte Madera Creek, Existing Conditions
Species: Adult Steelhead
Flow: 20 cfs
Boundary Condition: 0 ft Tide

Filepath: Q:\Corte Madera Passage Analysis\7_CAD-GIS\QGIS\Working\CorteMadera_Steelhead_20cfs.qgs

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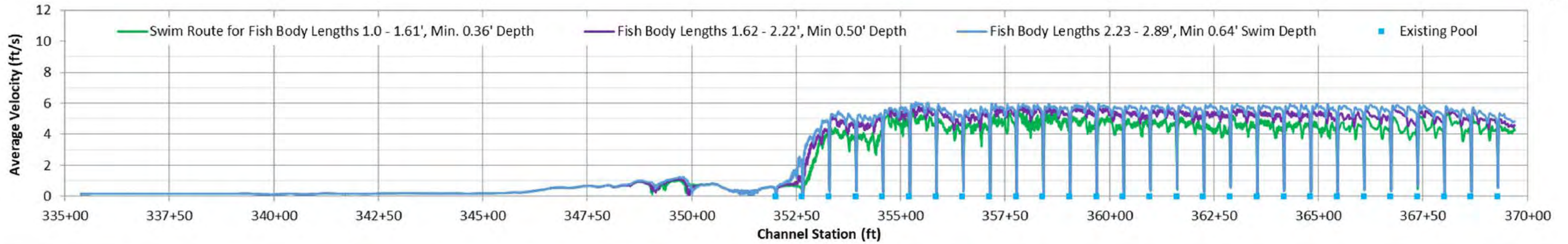

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Vertical: NAVD88

Sources:
Aerial Image: 2018 Coastal California NAIP

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- California Coastal Conservancy

Map Legend:
• Fish Fatigue Location — Fish Swim Path
Velocity (fps)
<= 1 | 1 - 2 | 2 - 3 | 3 - 4 | 4 - 5 | 5 - 6 | 6 - 7 | 7 - 8 | 8 - 9 | 9 - 10 | > 10

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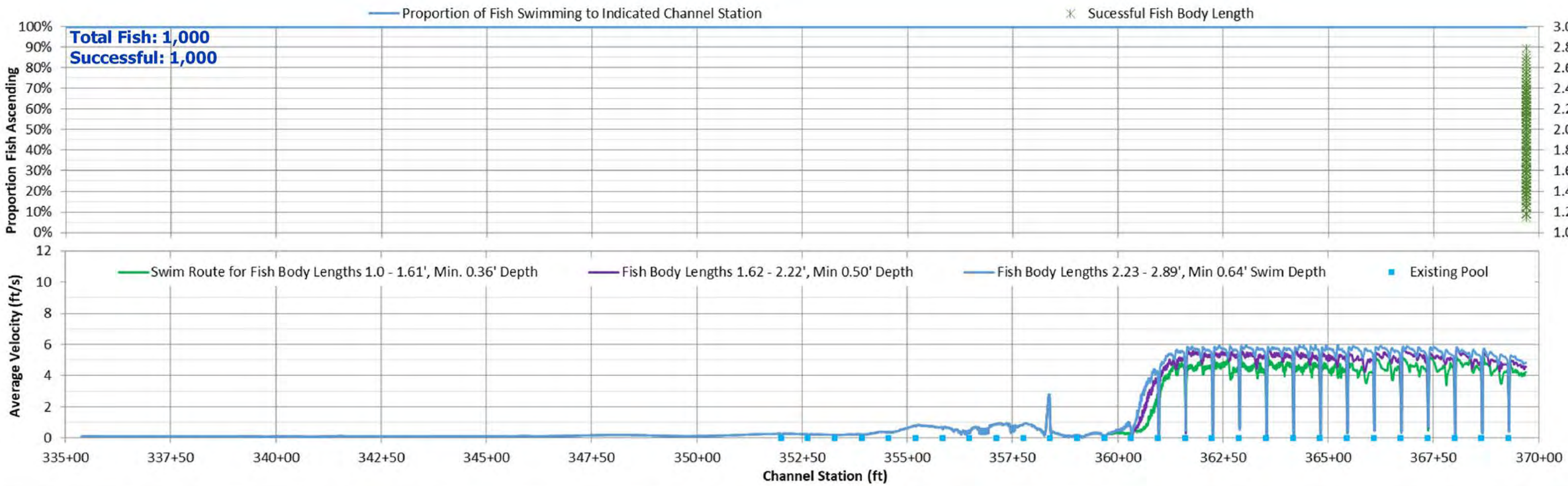
FIGURE 5
Ross, CA
Corte Madera Creek, Existing Conditions
Species: Adult Steelhead
Flow: 20 cfs
Boundary Condition: 4 ft Tide



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Sources:
Aerial Image: 2018 Coastal California NAIP

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Map Legend:
Fish Fatigue Location — *Fish Swim Path*
Velocity (fps)
<= 1 | 1 - 2 | 2 - 3 | 3 - 4 | 4 - 5 | 5 - 6 | 6 - 7 | 7 - 8 | 8 - 9 | 9 - 10 | > 10

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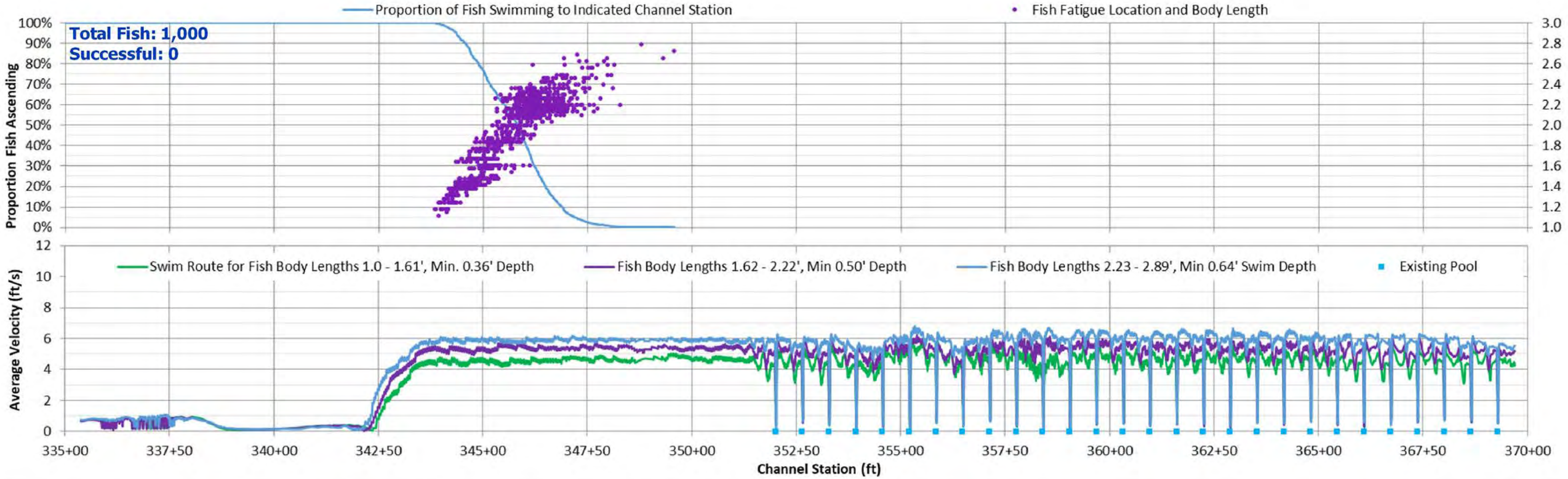
FIGURE 6
Ross, CA
Corte Madera Creek, Existing Conditions
Species: Adult Steelhead
Flow: 20 cfs
Boundary Condition: 7 ft Tide



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1	College Ave. Bridge
2	College of Marin
3	SMN Bridge
4	Downstream End of Existing Resting Pools
5	Kentfield Hospital Bridge
6	Allen Park
7	Upstream End of Unit 3

Datums:
Horizontal: NAD83 State Plane CA Zone 3
Vertical: NAVD88

Sources:
Aerial Image: 2018 Coastal California NAIP

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- California Coastal Conservancy

Map Legend:

Fish Fatigue Location — *Fish Swim Path*

Velocity (fps)

<= 1 | 1 - 2 | 2 - 3 | 3 - 4 | 4 - 5 | 5 - 6 | 6 - 7 | 7 - 8 | 8 - 9 | 9 - 10 | > 10

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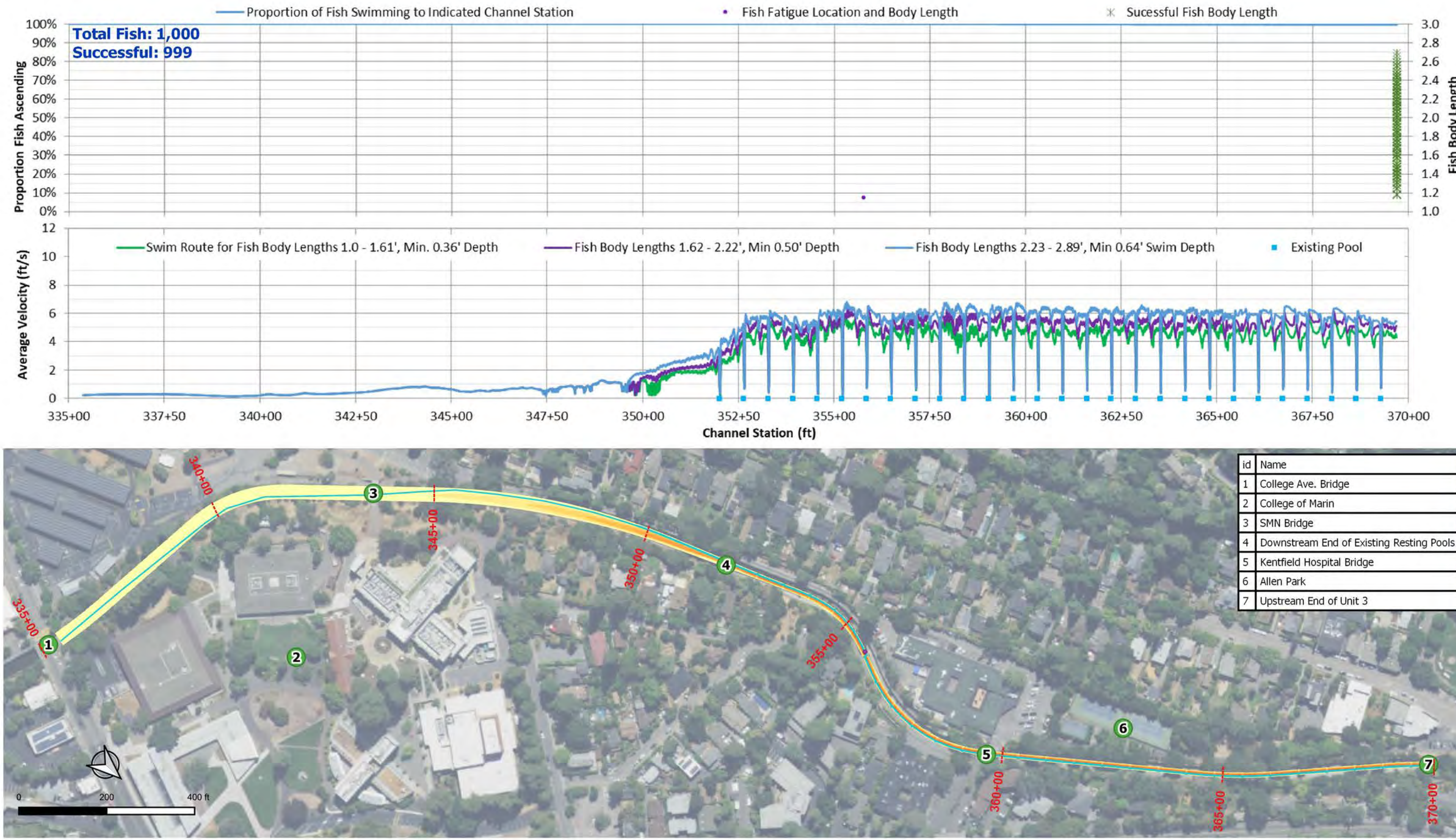
FIGURE 7
Ross, CA
Corte Madera Creek, Existing Conditions
Species: Adult Steelhead
Flow: 35 cfs
Boundary Condition: 0 ft Tide



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Vertical: NAVD88

Sources:
Aerial Image: 2018 Coastal California NAIP

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- California Coastal Conservancy

Map Legend:
• Fish Fatigue Location — Fish Swim Path
Velocity (fps)
<= 1 | 1 - 2 | 2 - 3 | 3 - 4 | 4 - 5 | 5 - 6 | 6 - 7 | 7 - 8 | 8 - 9 | 9 - 10 | > 10

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FIGURE 8
Ross, CA
Corte Madera Creek, Existing Conditions
Species: Adult Steelhead
Flow: 35 cfs
Boundary Condition: 4 ft Tide

Filepath: Q:\Corte Madera Passage Analysis\7 CAD-GIS\QGIS\Working\CorteMadera_Steelhead_35cfs.qgs

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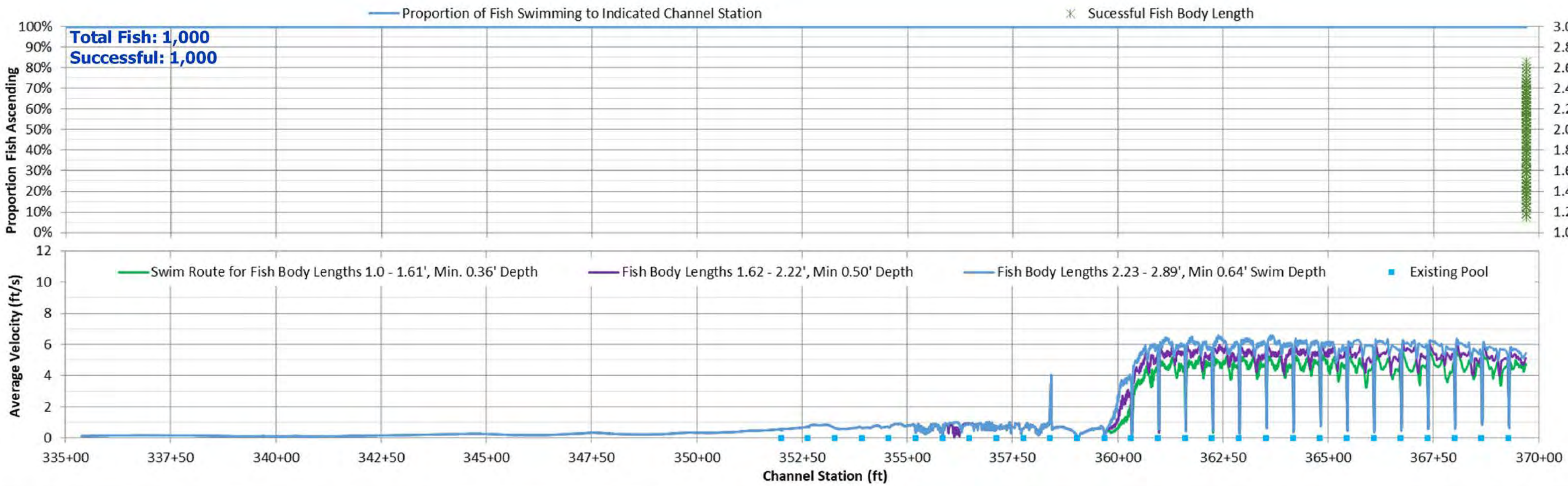

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Horizontal: NAD83 State Plane CA Zone 3
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Sources:
Aerial Image: 2018 Coastal California NAIP

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Map Legend:
Fish Fatigue Location *Fish Swim Path*
Velocity (fps)
<= 1 | 1 - 2 | 2 - 3 | 3 - 4 | 4 - 5 | 5 - 6 | 6 - 7 | 7 - 8 | 8 - 9 | 9 - 10 | > 10

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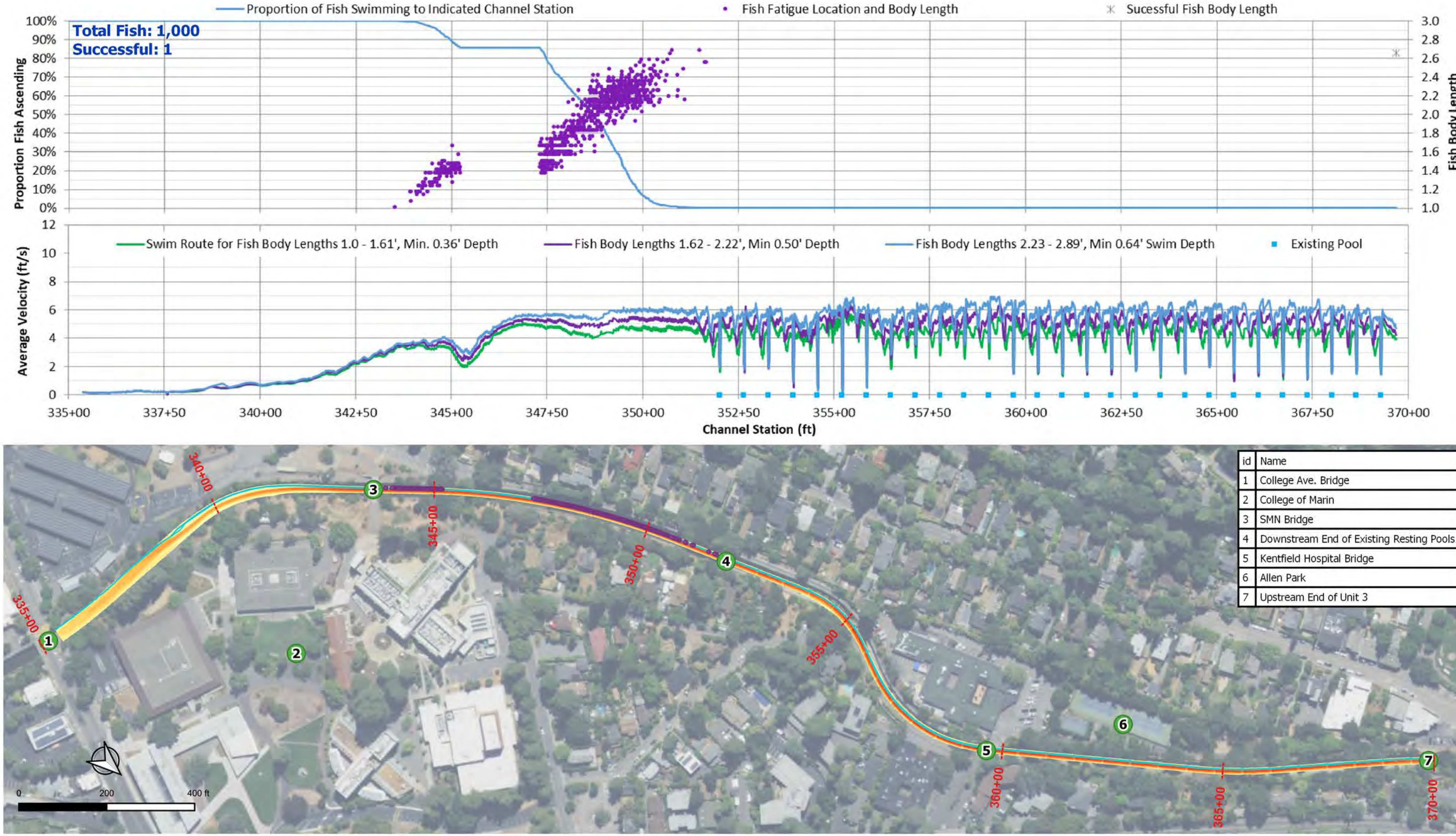
FIGURE 9
Ross, CA
Corte Madera Creek, Existing Conditions
Species: Adult Steelhead
Flow: 35 cfs
Boundary Condition: 7 ft Tide



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Sources:
Aerial Image: 2018 Coastal California NAIP

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Map Legend:
Fish Fatigue Location — Fish Swim Path
Velocity (fps)
<= 1 | 1 - 2 | 2 - 3 | 3 - 4 | 4 - 5 | 5 - 6 | 6 - 7 | 7 - 8 | 8 - 9 | 9 - 10 | > 10

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FIGURE 10
Ross, CA
Corte Madera Creek, Existing Conditions
Species: Adult Steelhead
Flow: 65 cfs
Boundary Condition: 0 ft Tide

Filepath: Q:\Corte Madera Passage Analysis\7 CAD-GIS\QGIS\Working\CorteMadera_Steelhead_65cfs.qgs

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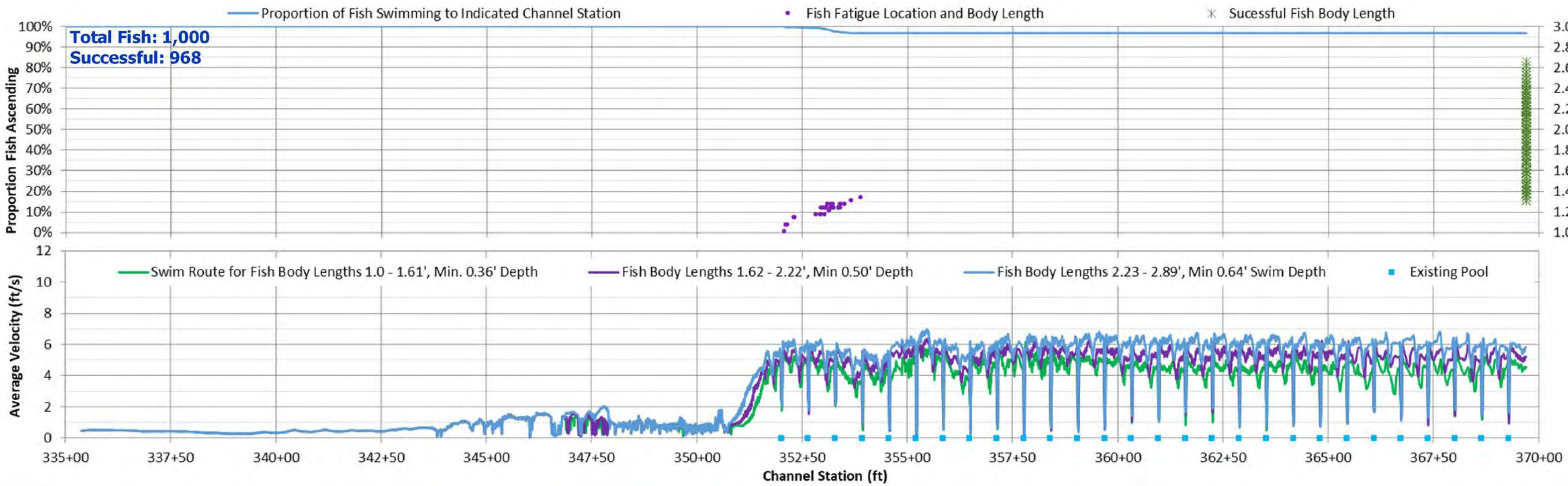

id	Name
1	College Ave. Bridge
2	College of Marin
3	SMN Bridge
4	Downstream End of Existing Resting Pools
5	Kentfield Hospital Bridge
6	Allen Park
7	Upstream End of Unit 3

Datums:
Horizontal: NAD83 State Plane CA Zone 3
Vertical: NAVD88

Sources:
Aerial Image: 2018 Coastal California NAIP

Prepared for:
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- Marin County Flood Control and Water Conservation District
- California Coastal Conservancy

Map Legend:
Fish Fatigue Location
Fish Swim Path
Velocity (fps)
<= 1 | 1 - 2 | 2 - 3 | 3 - 4 | 4 - 5 | 5 - 6 | 6 - 7 | 7 - 8 | 8 - 9 | 9 - 10 | > 10

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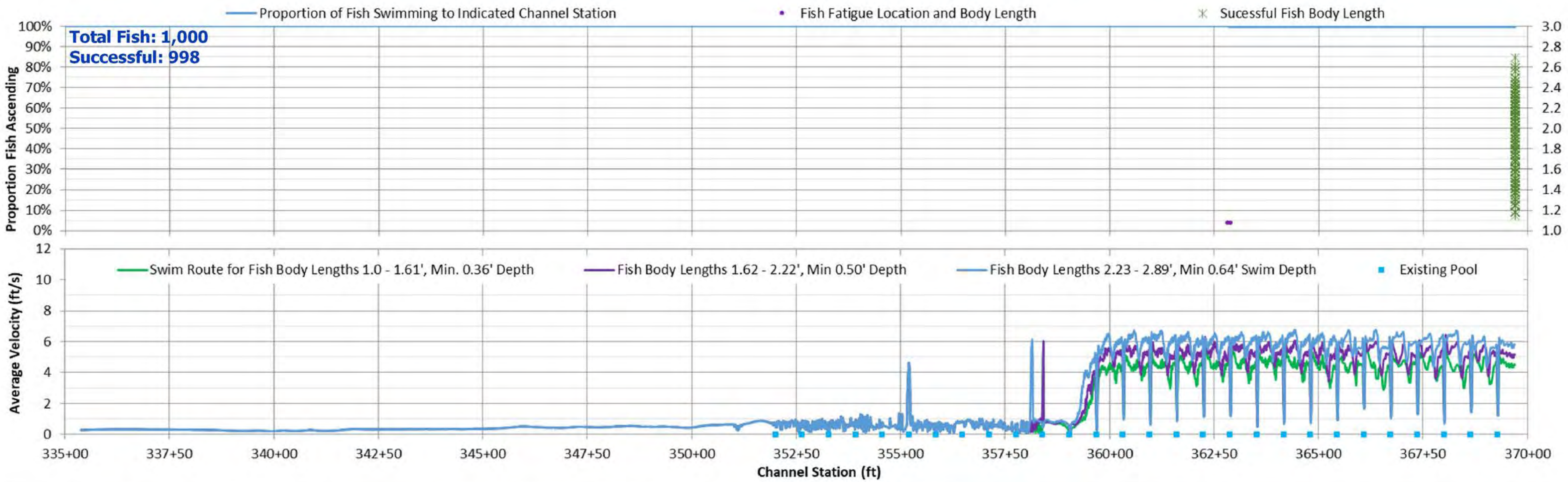
FIGURE 11
Ross, CA
Corte Madera Creek, Existing Conditions
Species: Adult Steelhead
Flow: 65 cfs
Boundary Condition: 4 ft Tide

Filepath: Q:\Corte Madera Passage Analysis\7 CAD-GIS\QGIS\Working\CorteMadera_Steelhead_65cfs.qgs



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Sources:
Aerial Image: 2018 Coastal California NAIP

Prepared for:
- Friends of Corte Madera Creek Watershed
- Marin County Flood Control and Water Conservation District
- California Coastal Conservancy

Map Legend:
Fish Fatigue Location *Fish Swim Path*
Velocity (fps)
<= 1 | 1 - 2 | 2 - 3 | 3 - 4 | 4 - 5 | 5 - 6 | 6 - 7 | 7 - 8 | 8 - 9 | 9 - 10 | > 10

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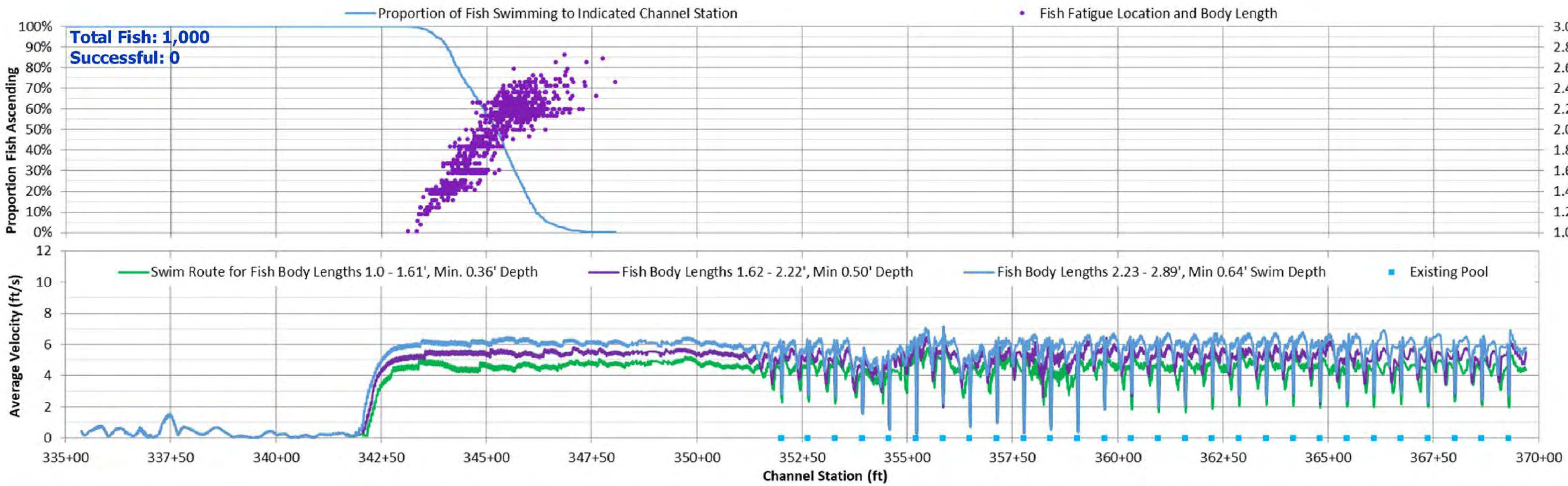
FIGURE 12
Ross, CA
Corte Madera Creek, Existing Conditions
Species: Adult Steelhead
Flow: 65 cfs
Boundary Condition: 7 ft Tide

Filepath: Q:\Corte Madera Passage Analysis\7_CAD-GIS\QGIS\Working\CorteMadera_Steelhead_65cfs.qgs

Michael Love & Associates, Inc. P.O. Box 4477, Arcata, CA 95521 (707) 822-2411



Datums: Horizontal: NAD83 State Plane CA Zone 3 Vertical: NAVD88	Prepared for:	Map Legend:	Michael Love & Associates Hydrologic Solutions	**FIGURE 13**
Sources: Aerial Image: 2018 Coastal California NAIP	- Friends of Corte Madera Creek Watershed - Marin County Flood Control and Water Conservation District - California Coastal Conservancy	• Fish Fatigue Location — Fish Swim Path *Velocity (fps)* <= 1, 1 - 2, 2 - 3, 3 - 4, 4 - 5, 5 - 6, 6 - 7, 7 - 8, 8 - 9, 9 - 10, > 10	GHD	Ross, CA Corte Madera Creek, Existing Conditions Species: Adult Steelhead Flow: 100 cfs Boundary Condition: 0 ft Tide

Filepath: Q:\Corte Madera Passage Analysis\7_CAD-GIS\QGIS\Working\CorteMadera_Steelhead_100cfs.qgs

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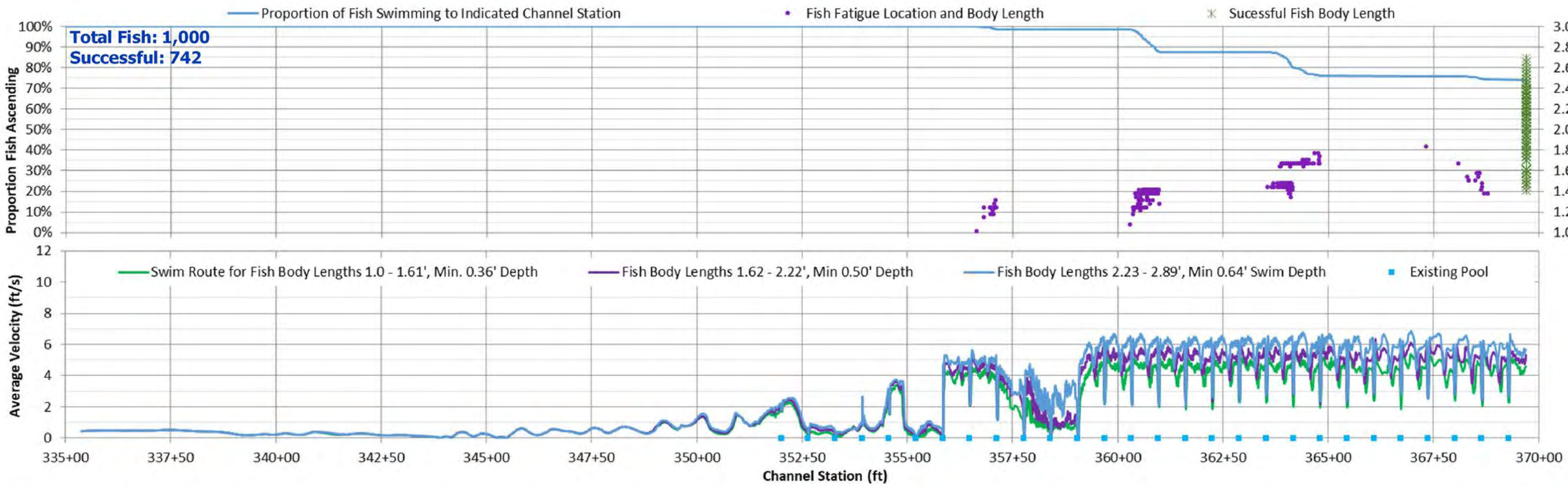

Datums:
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Sources:
Aerial Image: 2018 Coastal California NAIP

Prepared for:
- Friends of Corte Madera Creek Watershed
- Marin County Flood Control and Water Conservation District
- California Coastal Conservancy

Map Legend:
Fish Fatigue Location *Fish Swim Path*
Velocity (fps)
<= 1 | 1 - 2 | 2 - 3 | 3 - 4 | 4 - 5 | 5 - 6 | 6 - 7 | 7 - 8 | 8 - 9 | 9 - 10 | > 10

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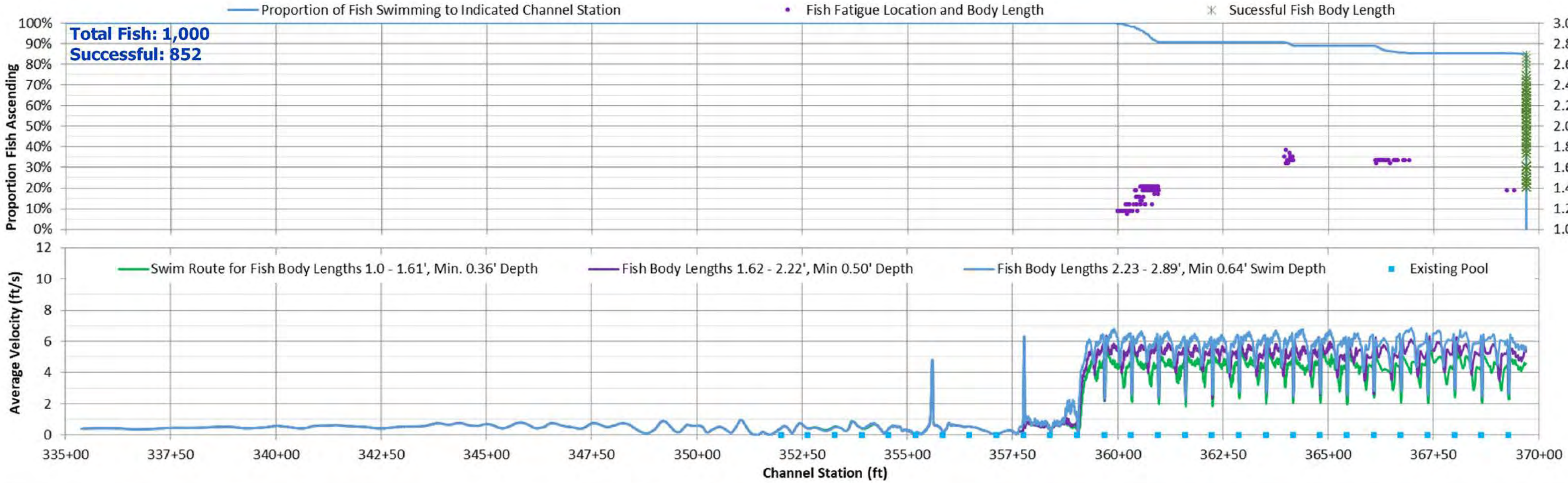
FIGURE 14
Ross, CA
Corte Madera Creek, Existing Conditions
Species: Adult Steelhead
Flow: 100 cfs
Boundary Condition: 4 ft Tide

Filepath: Q:\Corte Madera Passage Analysis\7_CAD-GIS\QGIS\Working\CorteMadera_Steelhead_100cfs.qgs

Michael Love & Associates, Inc. P.O. Box 4477, Arcata, CA 95521 (707) 822-2411



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Vertical: NAVD88

Sources:
Aerial Image: 2018 Coastal California NAIP

Prepared for:
- Friends of Corte Madera Creek Watershed
- Marin County Flood Control and Water Conservation District
- California Coastal Conservancy

Map Legend:
Fish Fatigue Location *Fish Swim Path*
Velocity (fps)
<= 1 | 1 - 2 | 2 - 3 | 3 - 4 | 4 - 5 | 5 - 6 | 6 - 7 | 7 - 8 | 8 - 9 | 9 - 10 | > 10

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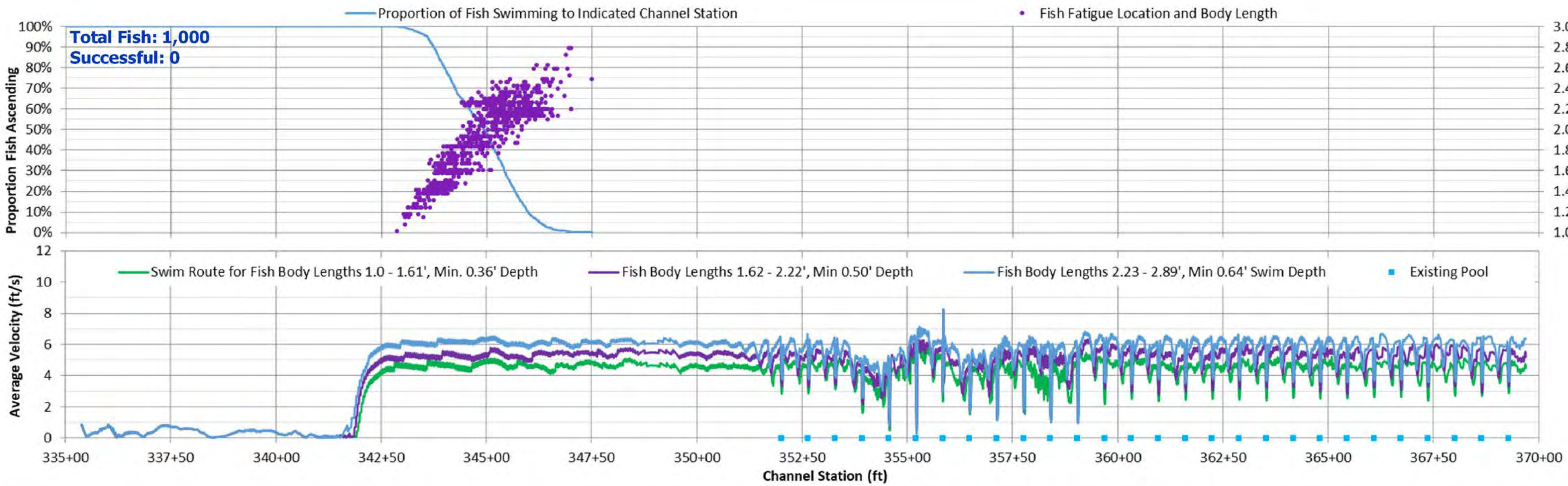
FIGURE 15
Ross, CA
Corte Madera Creek, Existing Conditions
Species: Adult Steelhead
Flow: 100 cfs
Boundary Condition: 7 ft Tide

Filepath: Q:\Corte Madera Passage Analysis\7_CAD-GIS\QGIS\Working\CorteMadera_Steelhead_100cfs.qgs



id	Name
1	College Ave. Bridge
2	College of Marin
3	SMN Bridge
4	Downstream End of Existing Resting Pools
5	Kentfield Hospital Bridge
6	Allen Park
7	Upstream End of Unit 3

Datums:
Horizontal: NAD83 State Plane CA Zone 3
Vertical: NAVD88

Sources:
Aerial Image: 2018 Coastal California NAIP

Prepared for:
- Friends of Corte Madera Creek Watershed
- Marin County Flood Control and Water Conservation District
- California Coastal Conservancy

Map Legend:
Fish Fatigue Location *Fish Swim Path*
Velocity (fps)
<= 1 | 1 - 2 | 2 - 3 | 3 - 4 | 4 - 5 | 5 - 6 | 6 - 7 | 7 - 8 | 8 - 9 | 9 - 10 | > 10

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FIGURE 16
Ross, CA
Corte Madera Creek, Existing Conditions
Species: Adult Steelhead
Flow: 150 cfs
Boundary Condition: 0 ft Tide

Filepath: Q:\Corte Madera Passage Analysis\7 CAD-GIS\QGIS\Working\CorteMadera Steelhead 150cfs.qgs

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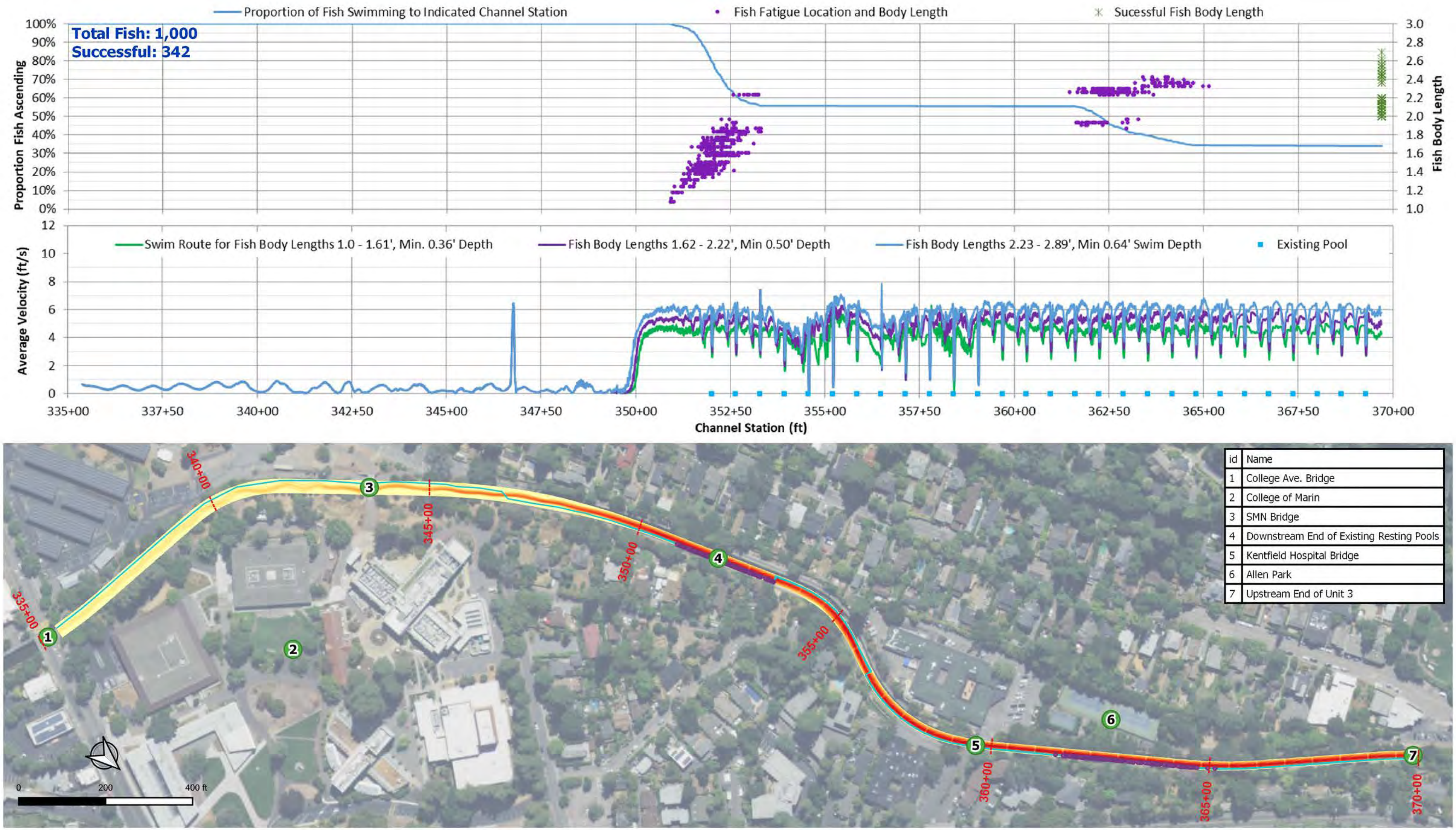

Datums:
Horizontal: NAD83 State Plane CA Zone 3
Vertical: NAVD88

Sources:
Aerial Image: 2018 Coastal California NAIP

Prepared for:
- Friends of Corte Madera Creek Watershed
- Marin County Flood Control and Water Conservation District
- California Coastal Conservancy

Map Legend:
Fish Fatigue Location *Fish Swim Path*
Velocity (fps)
<= 1 | 1 - 2 | 2 - 3 | 3 - 4 | 4 - 5 | 5 - 6 | 6 - 7 | 7 - 8 | 8 - 9 | 9 - 10 | > 10

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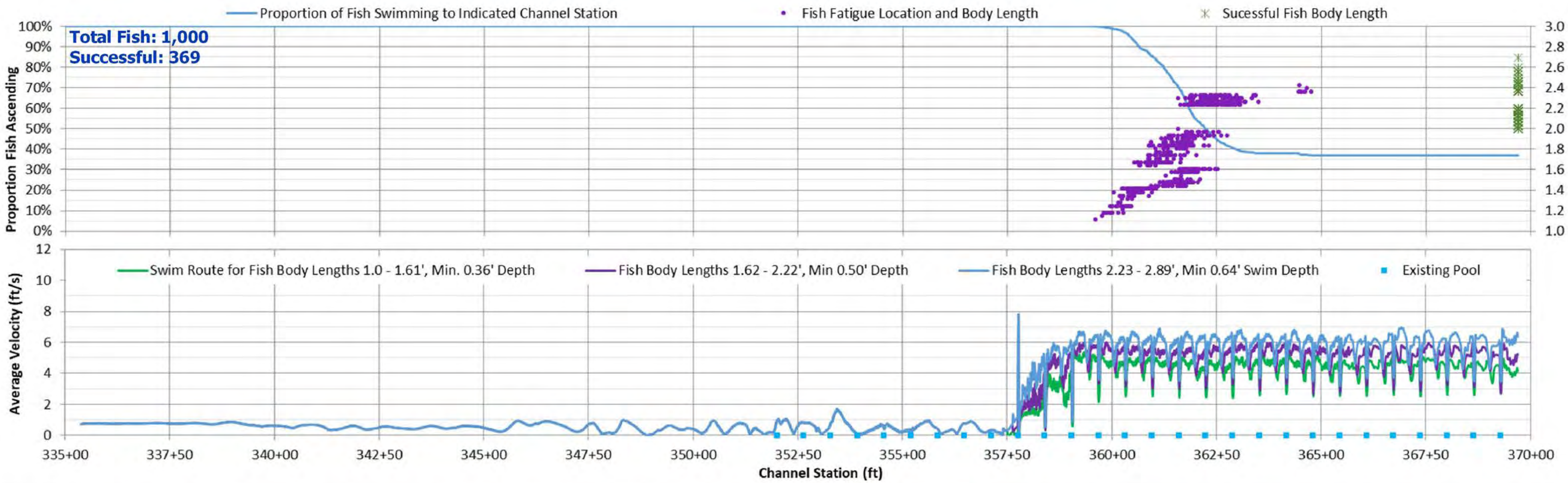
GHD

FIGURE 17
Ross, CA
Corte Madera Creek, Existing Conditions
Species: Adult Steelhead
Flow: 150 cfs
Boundary Condition: 4 ft Tide

Filepath: Q:\Corte Madera Passage Analysis\7_CAD-GIS\QGIS\Working\CorteMadera_Steelhead_150cfs.qgs

Michael Love & Associates, Inc. P.O. Box 4477, Arcata, CA 95521 (707) 822-2411



id	Name
1	College Ave. Bridge
2	College of Marin
3	SMN Bridge
4	Downstream End of Existing Resting Pools
5	Kentfield Hospital Bridge
6	Allen Park
7	Upstream End of Unit 3

Datums:
Horizontal: NAD83 State Plane CA Zone 3
Vertical: NAVD88

Sources:
Aerial Image: 2018 Coastal California NAIP

Prepared for:
- Friends of Corte Madera Creek Watershed
- Marin County Flood Control and Water Conservation District
- California Coastal Conservancy

Map Legend:
Fish Fatigue Location *Fish Swim Path*
Velocity (fps)
<= 1, 1 - 2, 2 - 3, 3 - 4, 4 - 5, 5 - 6, 6 - 7, 7 - 8, 8 - 9, 9 - 10, > 10

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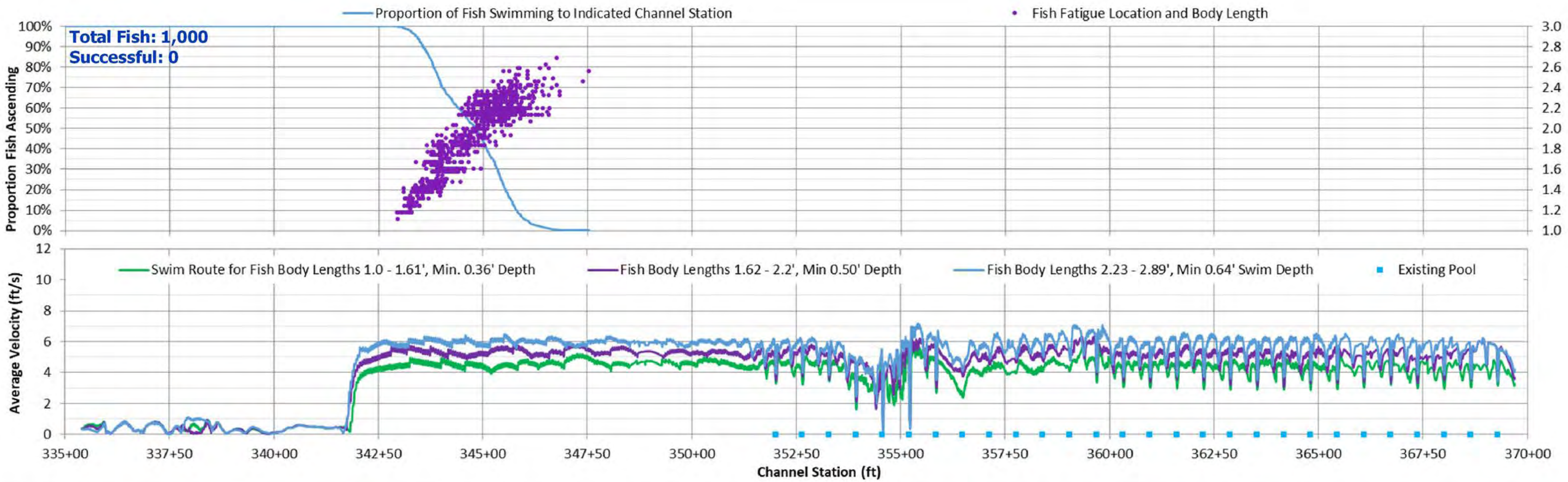
FIGURE 18
Ross, CA
Corte Madera Creek, Existing Conditions
Species: Adult Steelhead
Flow: 150 cfs
Boundary Condition: 7 ft Tide

Filepath: Q:\Corte Madera Passage Analysis\7 CAD-GIS\QGIS\Working\CorteMadera_Steelhead_150cfs.qgs

Michael Love & Associates, Inc. P.O. Box 4477, Arcata, CA 95521 (707) 822-2411



id	Name
1	College Ave. Bridge
2	College of Marin
3	SMN Bridge
4	Downstream End of Existing Resting Pools
5	Kentfield Hospital Bridge
6	Allen Park
7	Upstream End of Unit 3

Datums:
Horizontal: NAD83 State Plane CA Zone 3
Vertical: NAVD88

Sources:
Aerial Image: 2018 Coastal California NAIP

Prepared for:
- Friends of Corte Madera Creek Watershed
- Marin County Flood Control and Water Conservation District
- California Coastal Conservancy

Map Legend:
Fish Fatigue Location *Fish Swim Path*
Velocity (fps)
<= 1 | 1 - 2 | 2 - 3 | 3 - 4 | 4 - 5 | 5 - 6 | 6 - 7 | 7 - 8 | 8 - 9 | 9 - 10 | > 10

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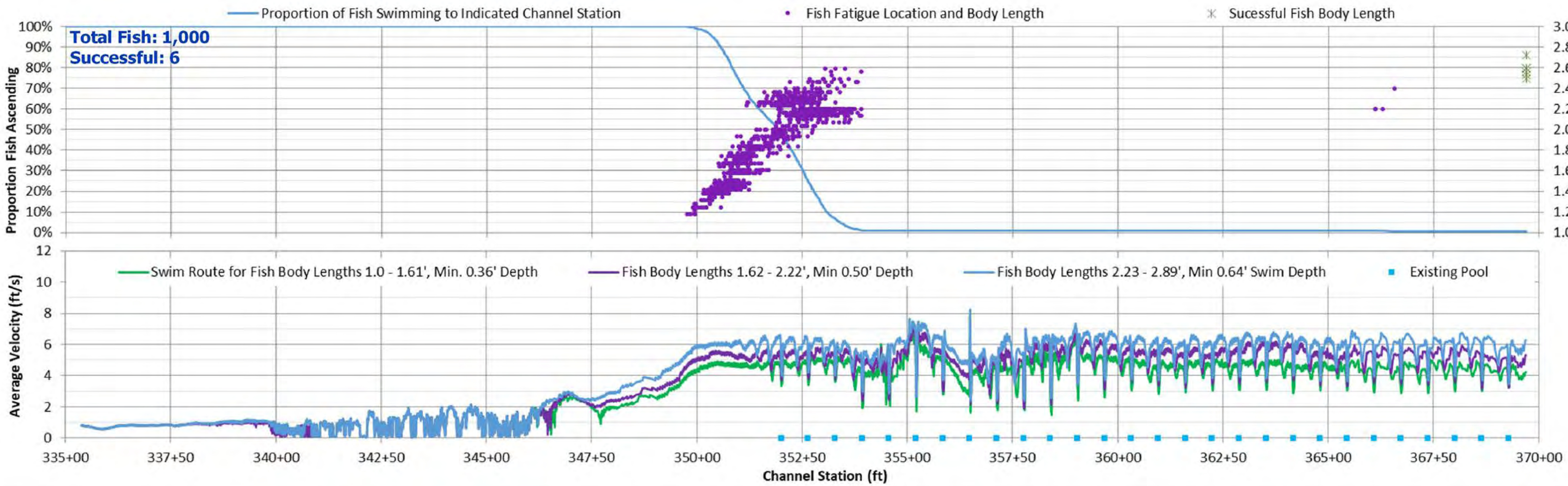
FIGURE 19
Ross, CA
Corte Madera Creek, Existing Conditions
Species: Adult Steelhead
Flow: 180 cfs (10% Exceedance)
Boundary Condition: 0 ft Tide

Filepath: Q:\Corte Madera Passage Analysis\7 CAD-GIS\QGIS\Working\CorteMadera_Steelhead_180cfs.qgs



Datums:
Horizontal: NAD83 State Plane CA Zone 3
Vertical: NAVD88

Sources:
Aerial Image: 2018 Coastal California NAIP

Prepared for:
- Friends of Corte Madera Creek Watershed
- Marin County Flood Control and Water Conservation District
- California Coastal Conservancy

Map Legend:
Fish Fatigue Location *Fish Swim Path*
Velocity (fps)
<= 1 | 1 - 2 | 2 - 3 | 3 - 4 | 4 - 5 | 5 - 6 | 6 - 7 | 7 - 8 | 8 - 9 | 9 - 10 | > 10

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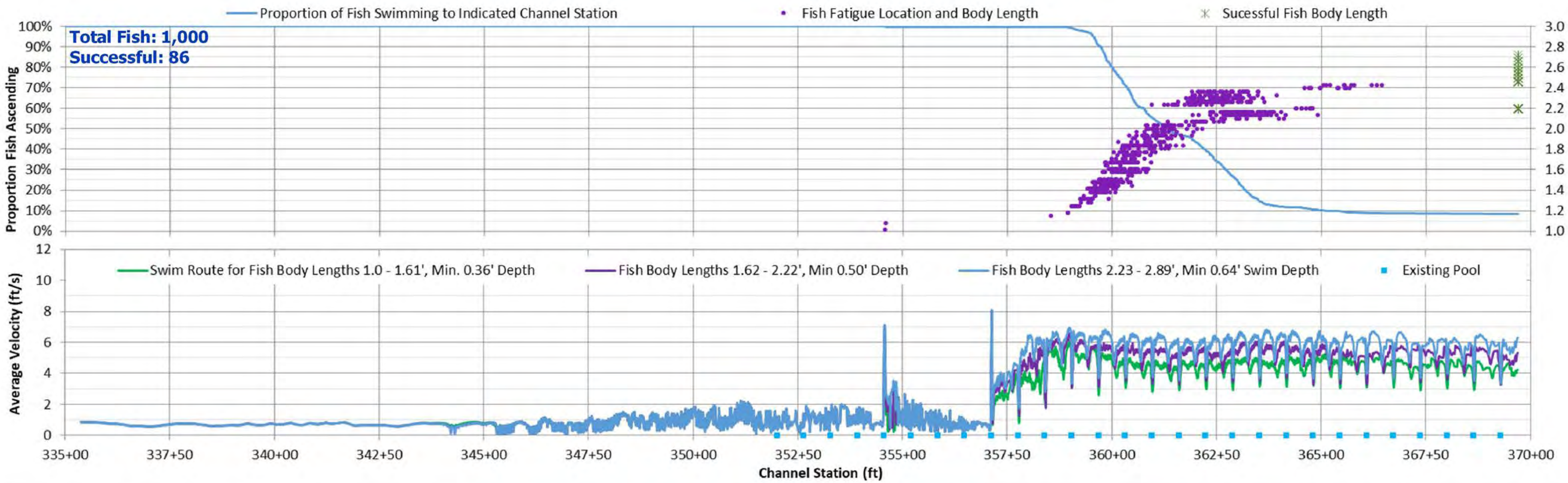
FIGURE 20
Ross, CA
Corte Madera Creek, Existing Conditions
Species: Adult Steelhead
Flow: 180 cfs (10% Exceedance)
Boundary Condition: 4 ft Tide

Filepath: Q:\Corte Madera Passage Analysis\7 CAD-GIS\QGIS\Working\CorteMadera_Steelhead_180cfs.qgs

Michael Love & Associates, Inc. P.O. Box 4477, Arcata, CA 95521 (707) 822-2411



Datums:
Horizontal: NAD83 State Plane CA Zone 3
Vertical: NAVD88

Sources:
Aerial Image: 2018 Coastal California NAIP

Prepared for:
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- California Coastal Conservancy

Map Legend:
Fish Fatigue Location — Fish Swim Path
Velocity (fps)
<= 1 | 1 - 2 | 2 - 3 | 3 - 4 | 4 - 5 | 5 - 6 | 6 - 7 | 7 - 8 | 8 - 9 | 9 - 10 | > 10

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FIGURE 21
Ross, CA
Corte Madera Creek, Existing Conditions
Species: Adult Steelhead
Flow: 180 cfs (10% Exceedance)
Boundary Condition: 7 ft Tide

Filepath: Q:\Corte Madera Passage Analysis\7 CAD-GIS\QGIS\Working\CorteMadera Steelhead 180cfs.qgs

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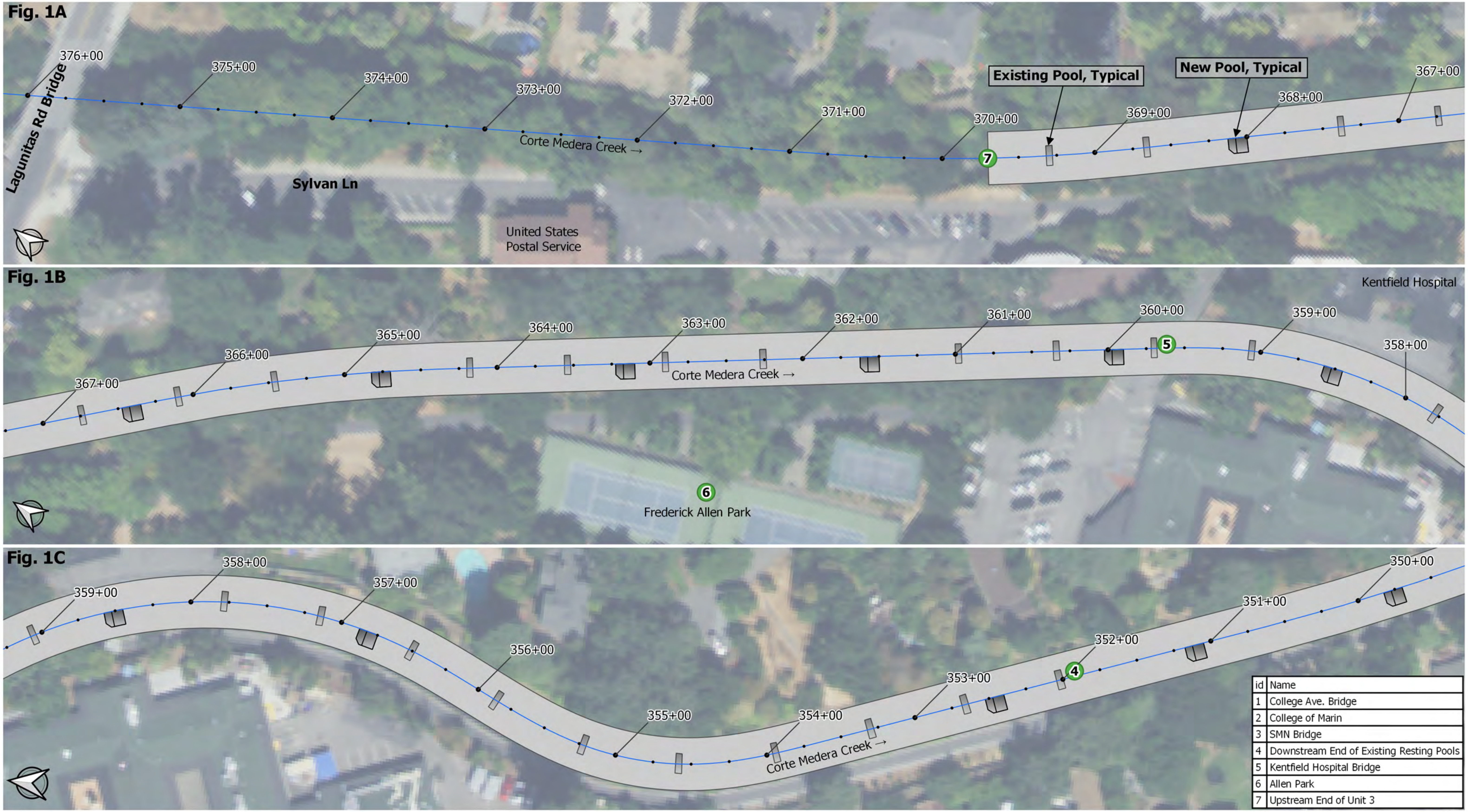
Attachment 3

Analysis of Alternative 1
Resting Pool Configuration



id	Name
1	College Ave. Bridge
2	College of Marin
3	SMN Bridge
4	Downstream End of Existing Resting Pools
5	Kentfield Hospital Bridge
6	Allen Park
7	Upstream End of Unit 3

Datums:
Horizontal: NAD83 State Plane CA Zone 3
Vertical: NAVD88

Sources:
Aerial Image: 2018 Coastal California NAIP

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Unit 3 Proposed Resting Pools Alternative 2

0 50 100 ft

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FIGURE 1
Ross, CA
Corte Madera Creek
Unit 3 Proposed Resting Pools
Alternative 2

Filepath: Q:\Corte Madera Passage Analysis\7 CAD-GIS\QGIS\Working\CorteMadera_Steelhead_Stationing.qgs

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Fig. 2A

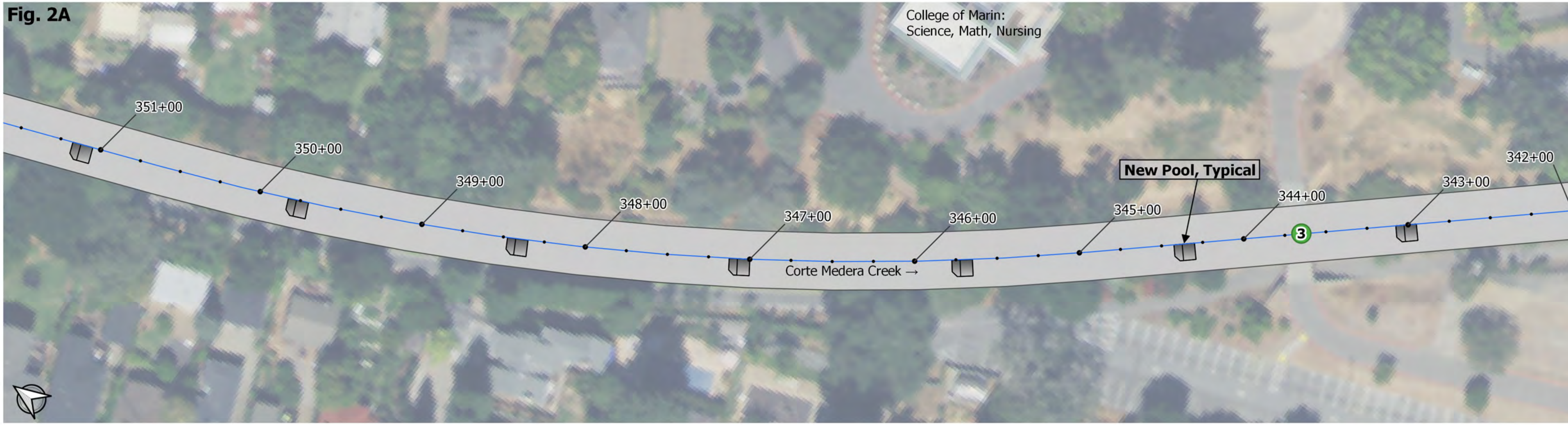
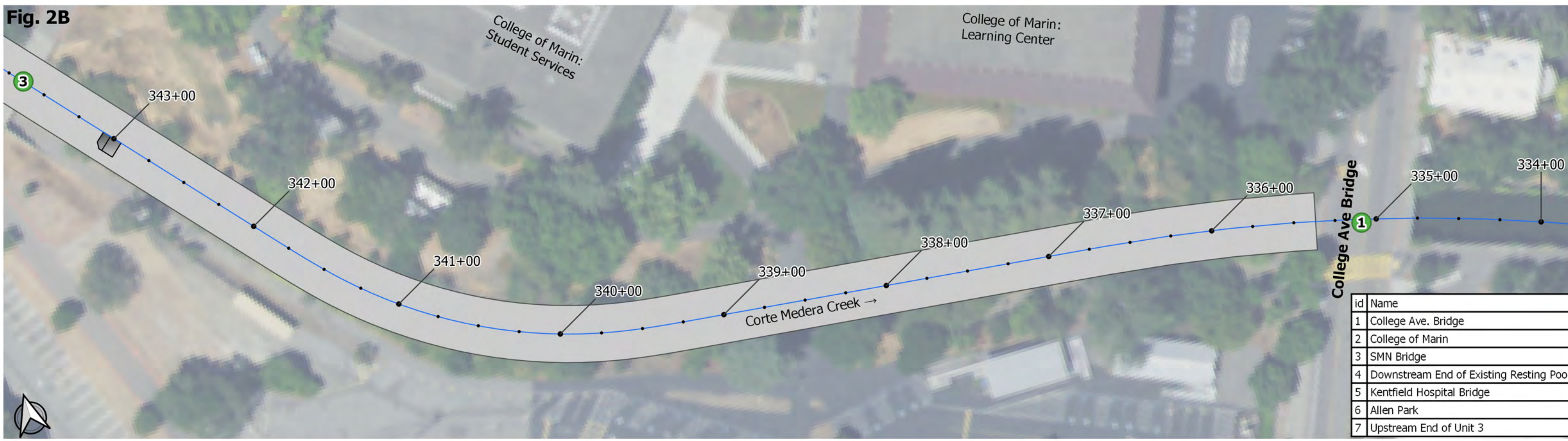


Fig. 2B



id	Name
1	College Ave. Bridge
2	College of Marin
3	SMN Bridge
4	Downstream End of Existing Resting Pools
5	Kentfield Hospital Bridge
6	Allen Park
7	Upstream End of Unit 3

Datums:
Horizontal: NAD83 State Plane CA Zone 3
Vertical: NAVD88

Sources:
Aerial Image: 2018 Coastal California NAIP

Prepared for:
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- California Coastal Conservancy

Unit 3 Proposed Resting Pools Alternative 2

0 50 100 ft

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FIGURE 2
Ross, CA
Corte Madera Creek
Unit 3 Proposed Resting Pools
Alternative 2

Filepath: Q:\Corte Madera Passage Analysis\7_CAD-GIS\QGIS\Working\CorteMadera_Steelhead_Stationing.qgs

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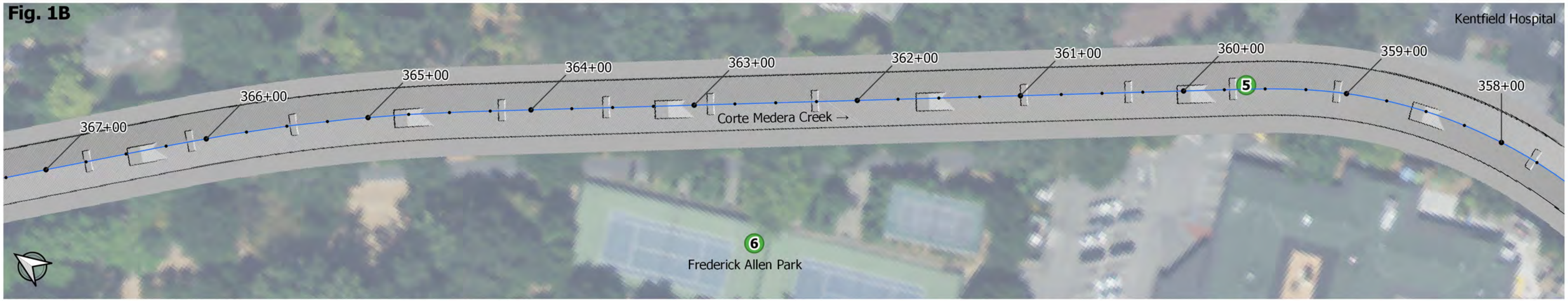

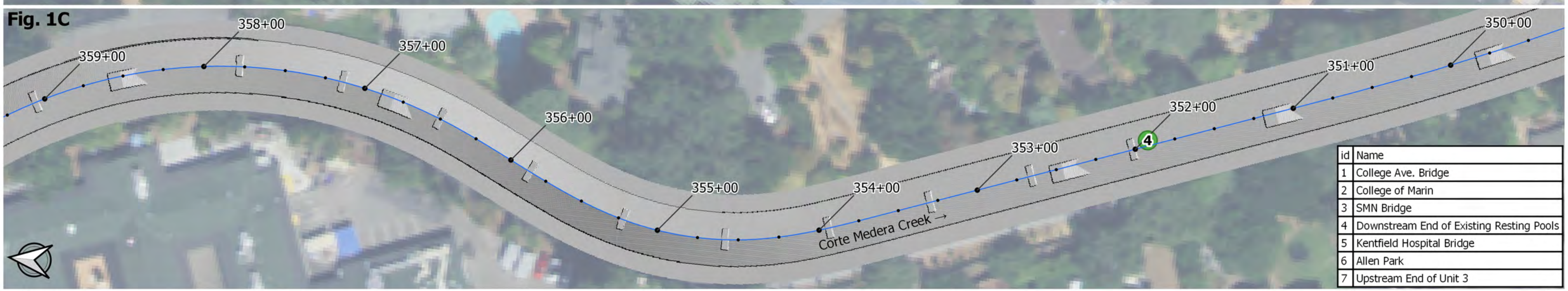

id	Name
1	College Ave. Bridge
2	College of Marin
3	SMN Bridge
4	Downstream End of Existing Resting Pools
5	Kentfield Hospital Bridge
6	Allen Park
7	Upstream End of Unit 3

Datums:
Horizontal: NAD83 State Plane CA Zone 3
Vertical: NAVD88

Sources:
Aerial Image: 2018 Coastal California NAIP

Prepared for:
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- Marin County Flood Control and Water Conservation District
- California Coastal Conservancy

Unit 3 Proposed Resting Pools Alternative 1

0 50 100 ft

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FIGURE 1
Ross, CA
Corte Madera Creek
Unit 3 Proposed Resting Pools
Alternative 1

Filepath: Q:\Corte Madera Passage Analysis\7 CAD-GIS\QGIS\Working\CorteMadera Steelhead Stationing.qgs

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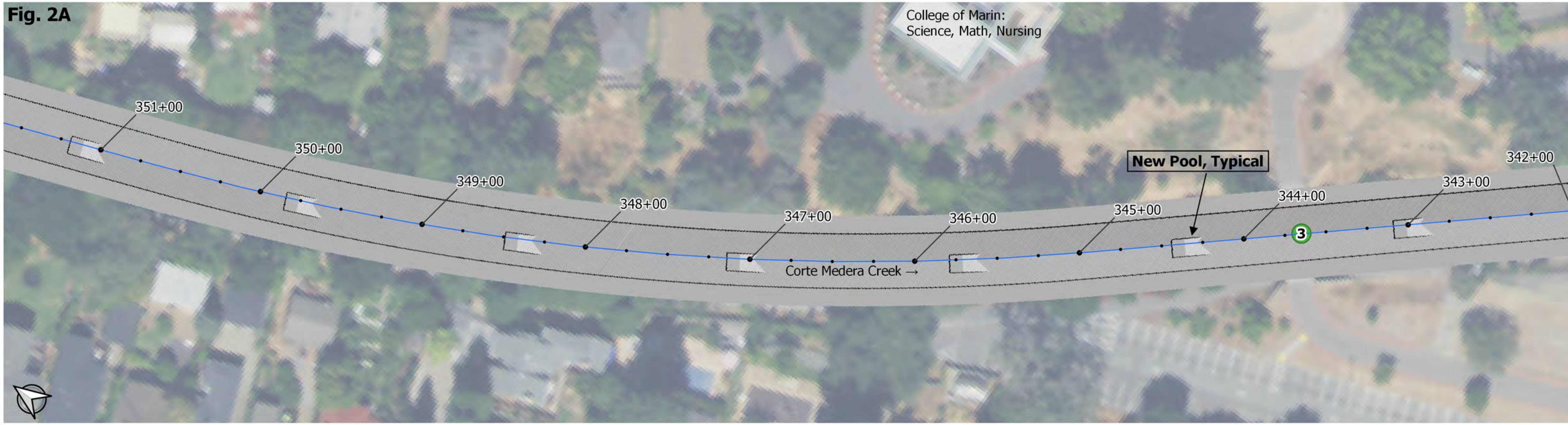

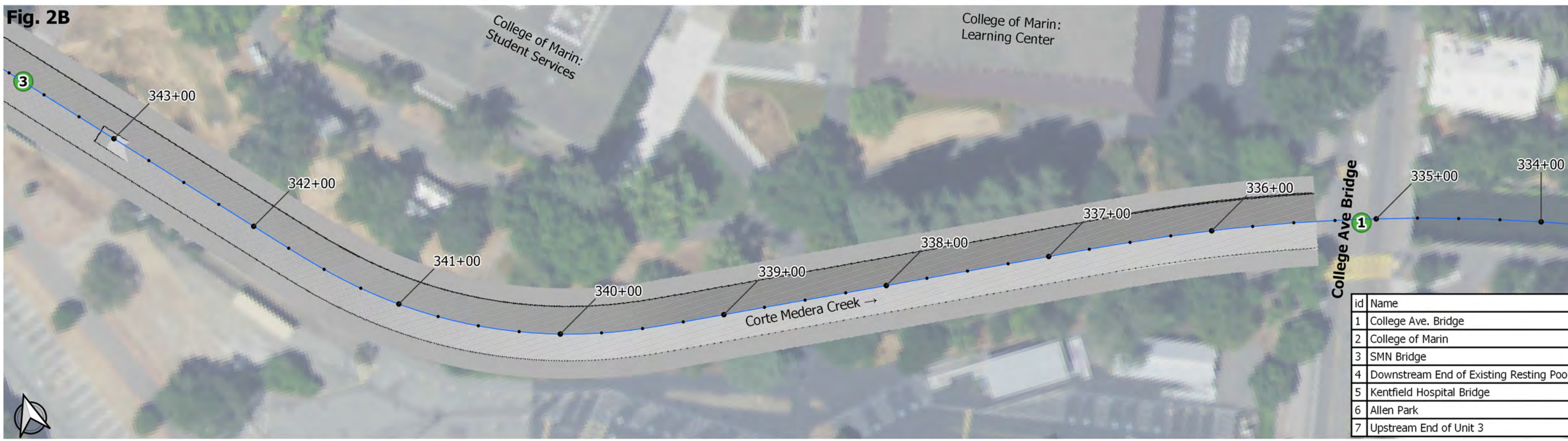

id	Name
1	College Ave. Bridge
2	College of Marin
3	SMN Bridge
4	Downstream End of Existing Resting Pools
5	Kentfield Hospital Bridge
6	Allen Park
7	Upstream End of Unit 3

Datums:
Horizontal: NAD83 State Plane CA Zone 3
Vertical: NAVD88

Sources:
Aerial Image: 2018 Coastal California NAIP

Prepared for:
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- California Coastal Conservancy

Unit 3 Proposed Resting Pools Alternative 1

0 50 100 ft

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FIGURE 2
Ross, CA
Corte Madera Creek
Unit 3 Proposed Resting Pools
Alternative 1

Filepath: Q:\Corte Madera Passage Analysis\7 CAD-GIS\QGIS\Working\CorteMadera Steelhead Stationing.qgs

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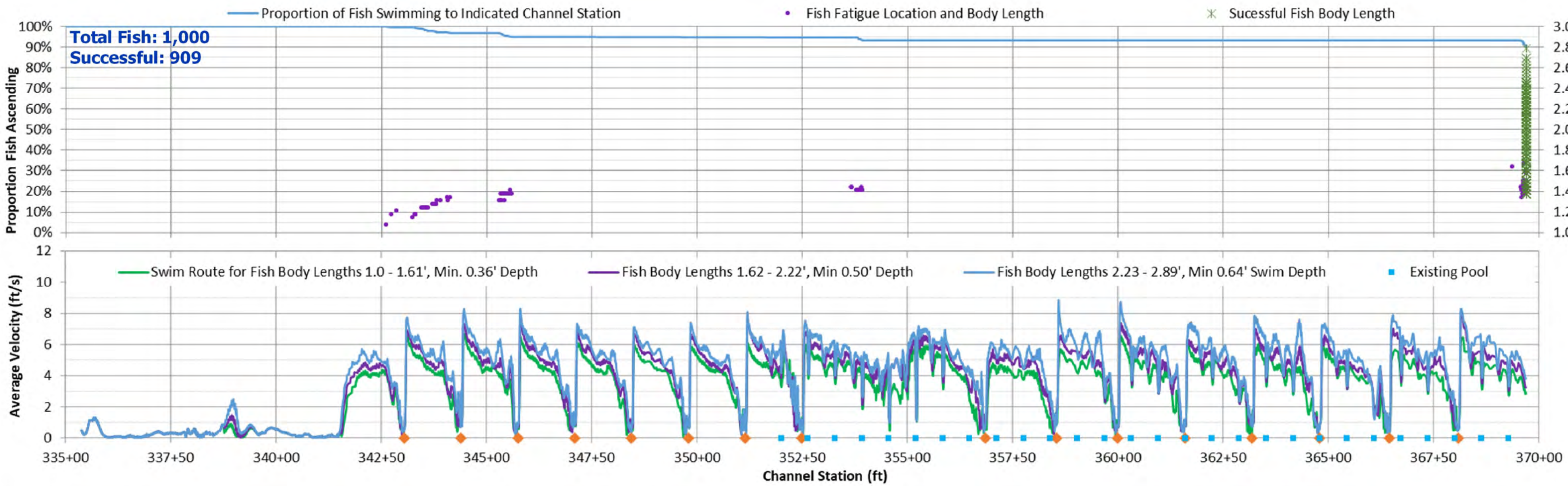

Datums:
Horizontal: NAD83 State Plane CA Zone 3
Vertical: NAVD88

Sources:
Aerial Image: 2018 Coastal California NAIP

Prepared for:
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- Marin County Flood Control and Water Conservation District
- California Coastal Conservancy

Map Legend:
Fish Fatigue Location *Fish Swim Path*
Velocity (fps)
<= 1 | 1 - 2 | 2 - 3 | 3 - 4 | 4 - 5 | 5 - 6 | 6 - 7 | 7 - 8 | 8 - 9 | 9 - 10 | > 10

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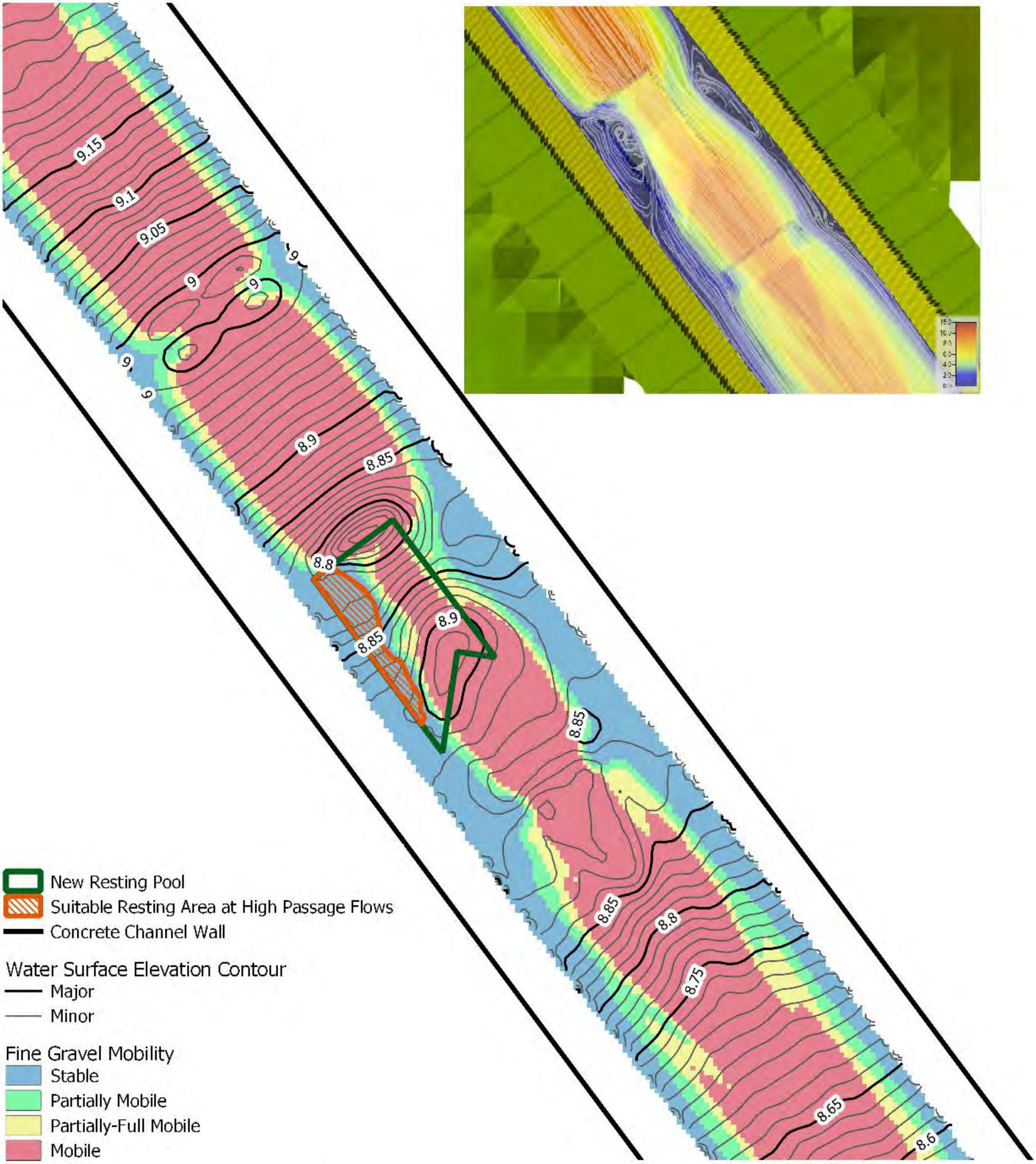
FIGURE 1
Ross, CA
Corte Madera Creek, Proposed Conditions
Species: Adult Steelhead
Flow: 180 cfs (10% Exceedance)
Boundary Condition: 0 ft Tide

Filepath: Q:\Corte Madera Passage Analysis\7_CAD-GIS\QGIS\Working\CorteMadera_Steelhead_180cfs.qgs

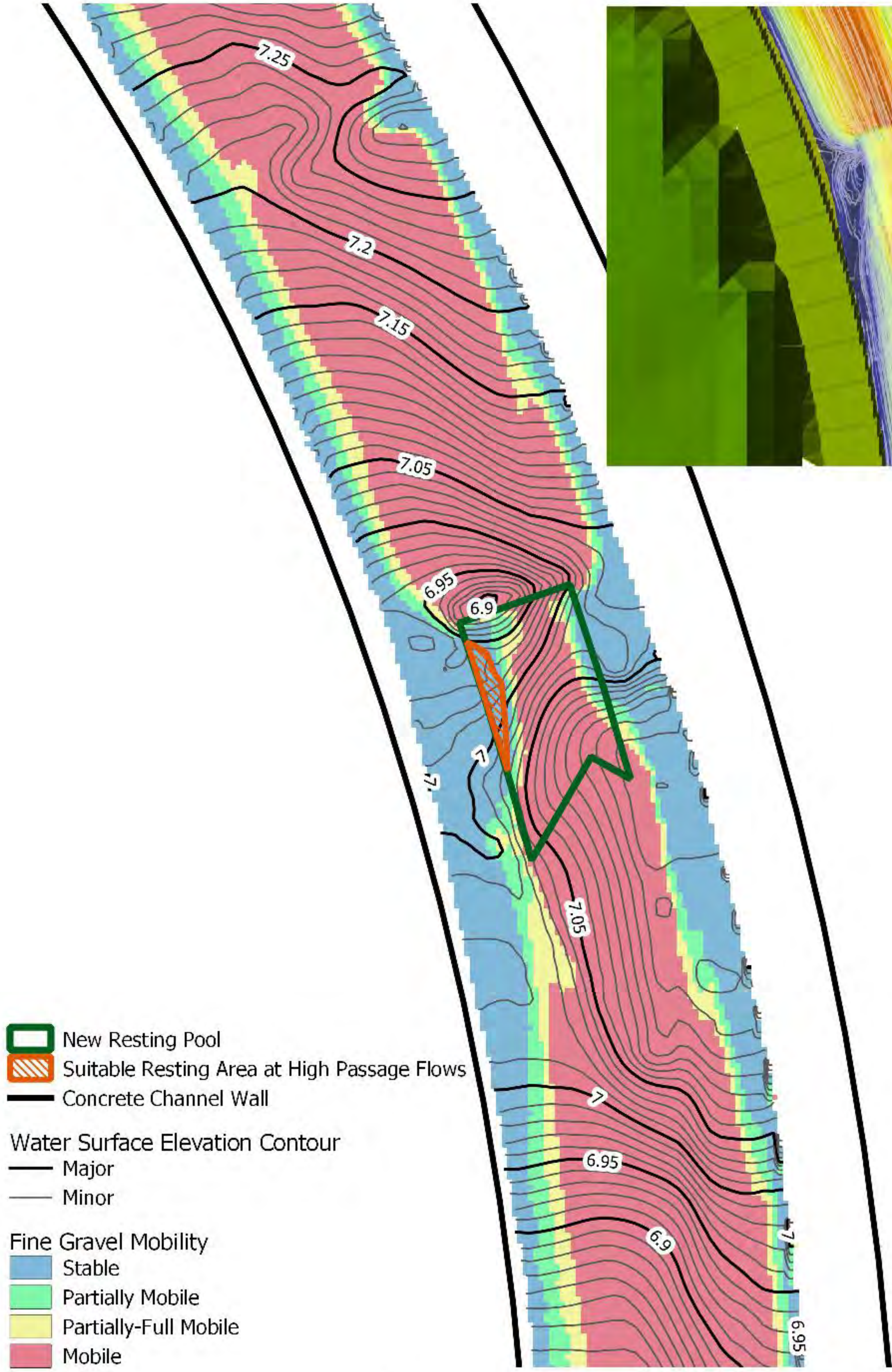
Michael Love & Associates, Inc. P.O. Box 4477, Arcata, CA 95521 (707) 822-2411

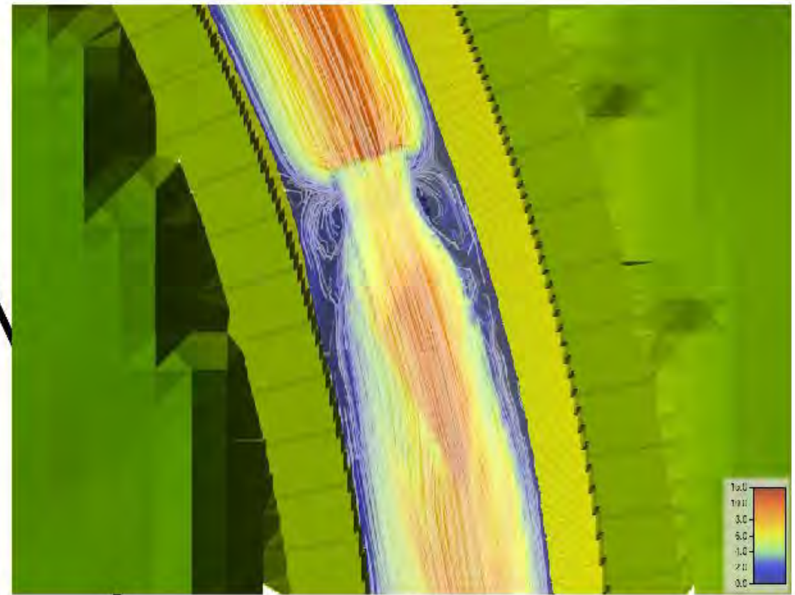


Datums: **Horizontal: NAD83 State Plane CA Zone 1** **Vertical: NAVD88** **Sources:** **NA** Michael Love & Associates *Hydrologic Solutions* GHD	0 10 20 ft	**FIGURE 1.A - 200 cfs - Shear** Ross, CA Corte Madera Creek, Proposed Conditions Species: Adult Steelhead Flow: 200 cfs Boundary Condition: 0 ft Tide

Filepath: Q:\Corte Madera Passage Analysis\7 CAD-GIS\QGIS\Working\CorteMadera Steelhead 200cfs.qgs

Michael Love & Associates, Inc. P.O. Box 4477,
Arcata, CA 95521 (707) 822-2411





Datums:
Horizontal: NAD83 State Plane CA Zone 1
Vertical: NAVD88

Sources:
NA

Michael Love & Associates
Hydrologic Solutions

GHD

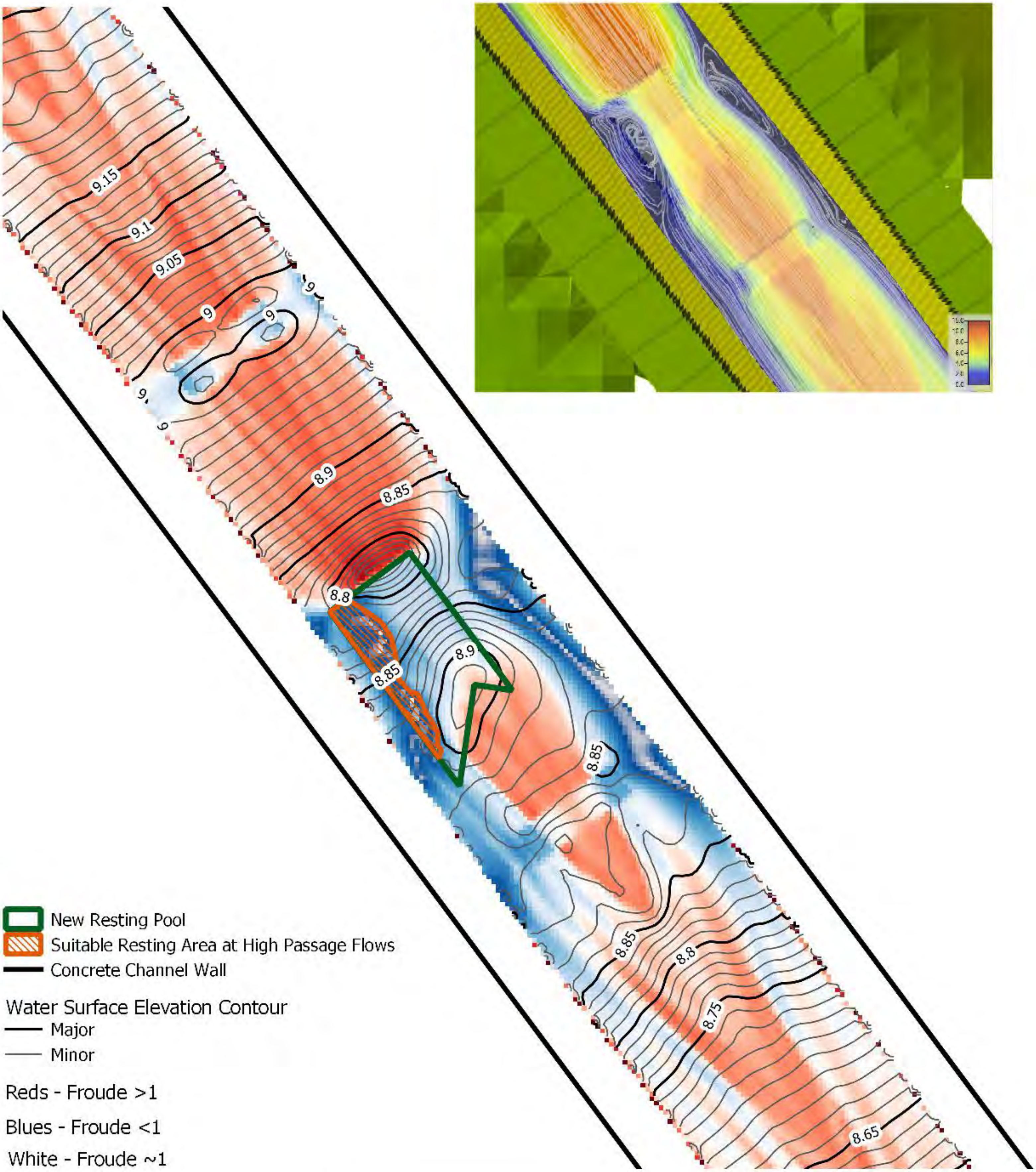
0 10 20 ft

FIGURE 1.B - 200 cfs - Shear

Ross, CA
Corte Madera Creek, Proposed Conditions
Species: Adult Steelhead
Flow: 200 cfs
Boundary Condition: 0 ft Tide

Filepath: Q:\Corte Madera Passage Analysis\7 CAD-GIS\QGIS\Working\CorteMadera Steelhead 200cfs.qgs

Michael Love & Associates, Inc. P.O. Box 4477,
Arcata, CA 95521 (707) 822-2411



Datums:
Horizontal: NAD83 State Plane CA Zone 1
Vertical: NAVD88

Sources:
NA

Michael Love & Associates
Hydrologic Solutions

GHD

0 10 20 ft

FIGURE 1.C - 200 cfs - Froude

Ross, CA
Corte Madera Creek, Proposed Conditions
Species: Adult Steelhead
Flow: 200 cfs
Boundary Condition: 0 ft Tide

Filepath: Q:\Corte Madera Passage Analysis\7 CAD-GIS\QGIS\Working\CorteMadera Steelhead 200cfs.qgs

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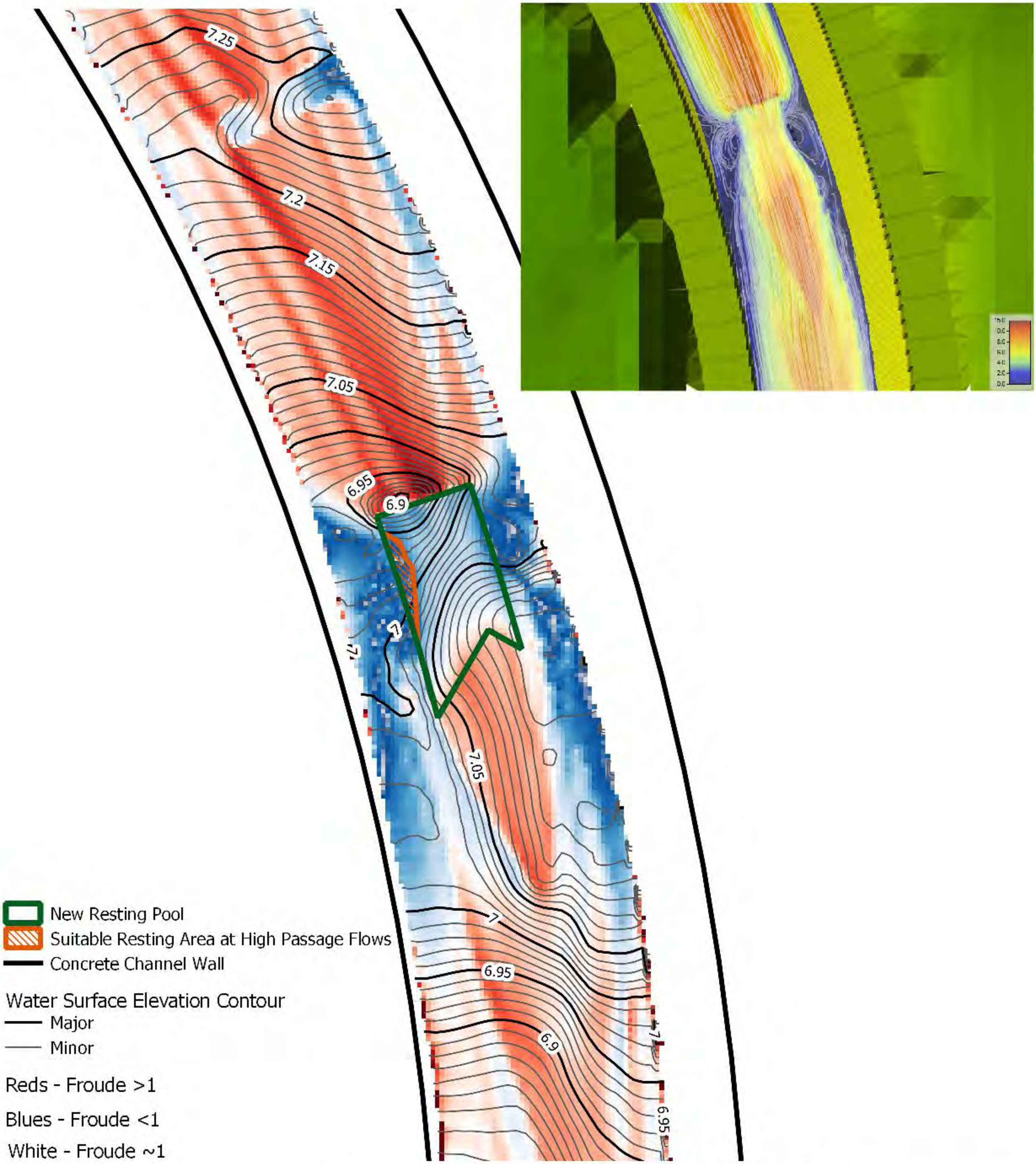

Datums:
Horizontal: NAD83 State Plane CA Zone 1
Vertical: NAVD88

Sources:
NA

Michael Love & Associates
Hydrologic Solutions

GHD

0 10 20 ft

FIGURE 1.D - 200 cfs - Froude

Ross, CA
Corte Madera Creek, Proposed Conditions
Species: Adult Steelhead
Flow: 200 cfs
Boundary Condition: 0 ft Tide

Filepath: Q:\Corte Madera Passage Analysis\7 CAD-GIS\QGIS\Working\CorteMadera Steelhead 200cfs.qgs

Michael Love & Associates, Inc. P.O. Box 4477,
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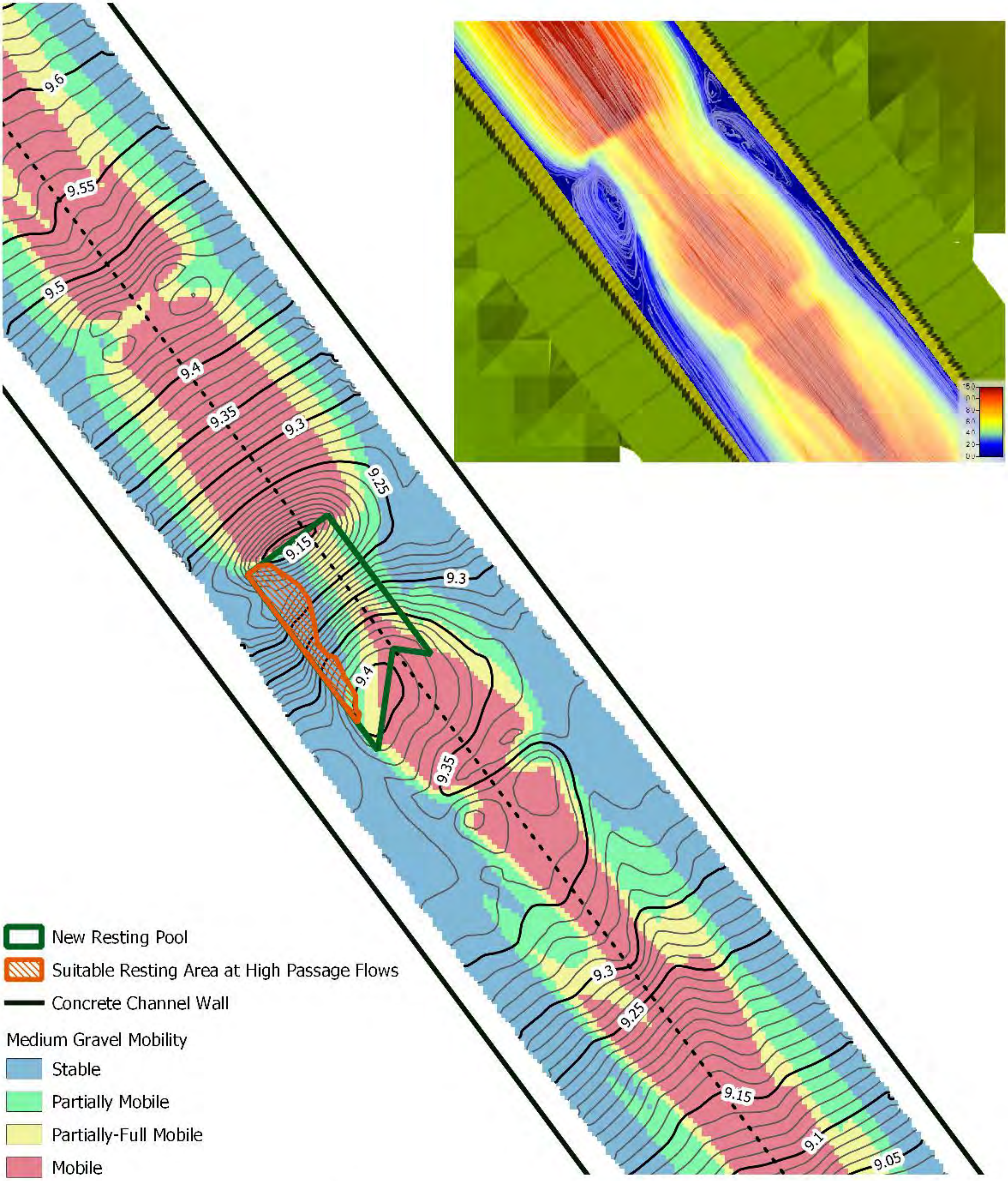

Datums:
Horizontal: NAD83 State Plane CA Zone 1
Vertical: NAVD88

Sources:
NA

Michael Love & Associates
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GHD

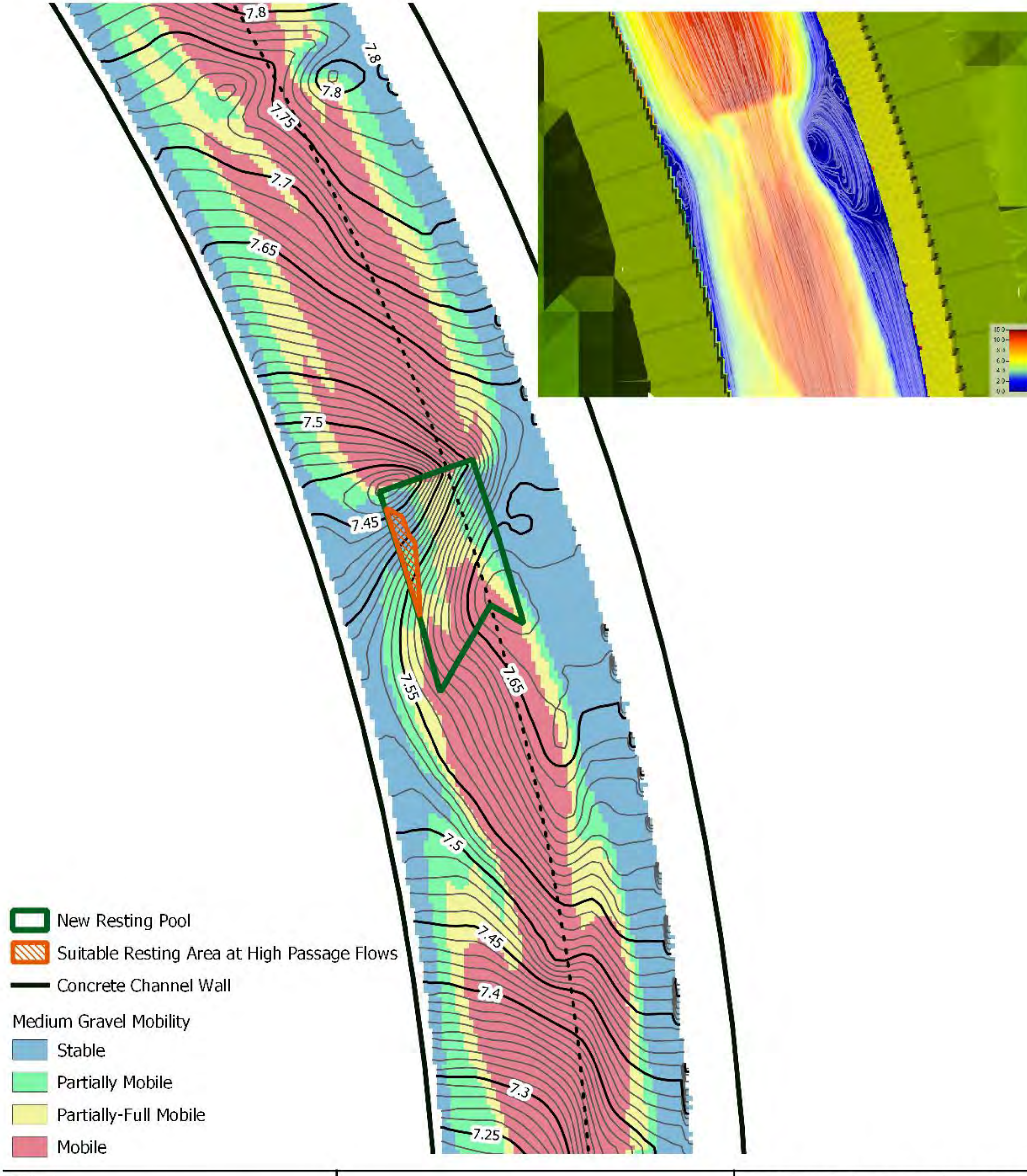
0 10 20 ft

FIGURE 2.A - 350 cfs - Shear

Ross, CA
Corte Madera Creek, Proposed Conditions
Species: Adult Steelhead
Flow: 350 cfs
Boundary Condition: 0 ft Tide

Filepath: Q:\Corte Madera Passage Analysis\7 CAD-GIS\QGIS\Working\CorteMadera Steelhead 350cfs.qgs

Michael Love & Associates, Inc. P.O. Box 4477, Arcata, CA 95521 (707) 822-2411



Datums:
Horizontal: NAD83 State Plane CA Zone 1
Vertical: NAVD88

Sources:
NA

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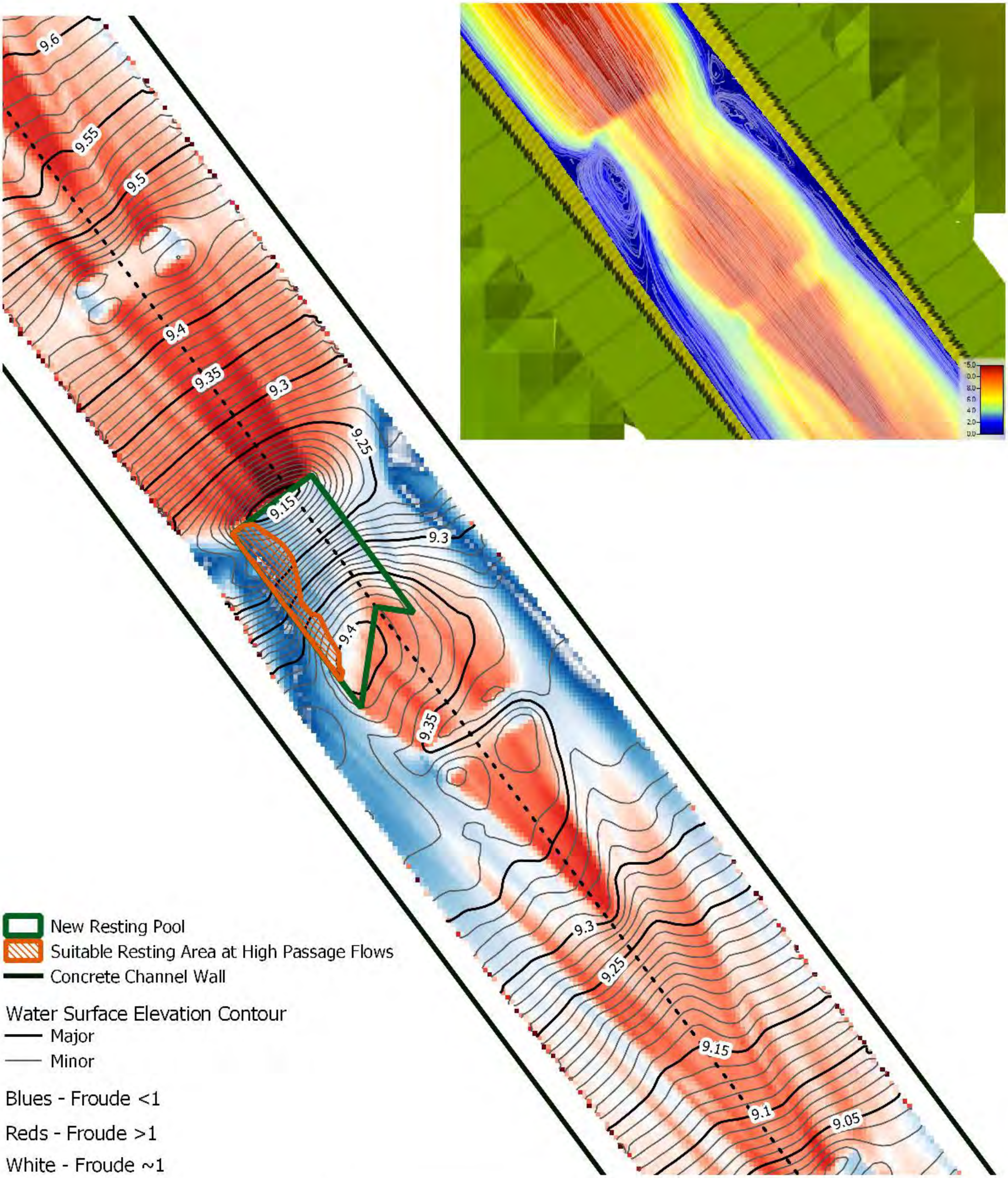
FIGURE 2.B - 350 cfs - Shear

Ross, CA
Corte Madera Creek, Proposed Conditions
Species: Adult Steelhead
Flow: 350 cfs
Boundary Condition: 0 ft Tide

Filepath: Q:\Corte Madera Passage Analysis\7 CAD-GIS\QGIS\Working\CorteMadera Steelhead 350cfs.qgs

Michael Love & Associates, Inc. P.O. Box 4477, Arcata, CA 95521 (707) 822-2411



Datums:
Horizontal: NAD83 State Plane CA Zone 1
Vertical: NAVD88

Sources:
NA

Michael Love & Associates
Hydrologic Solutions

GHD

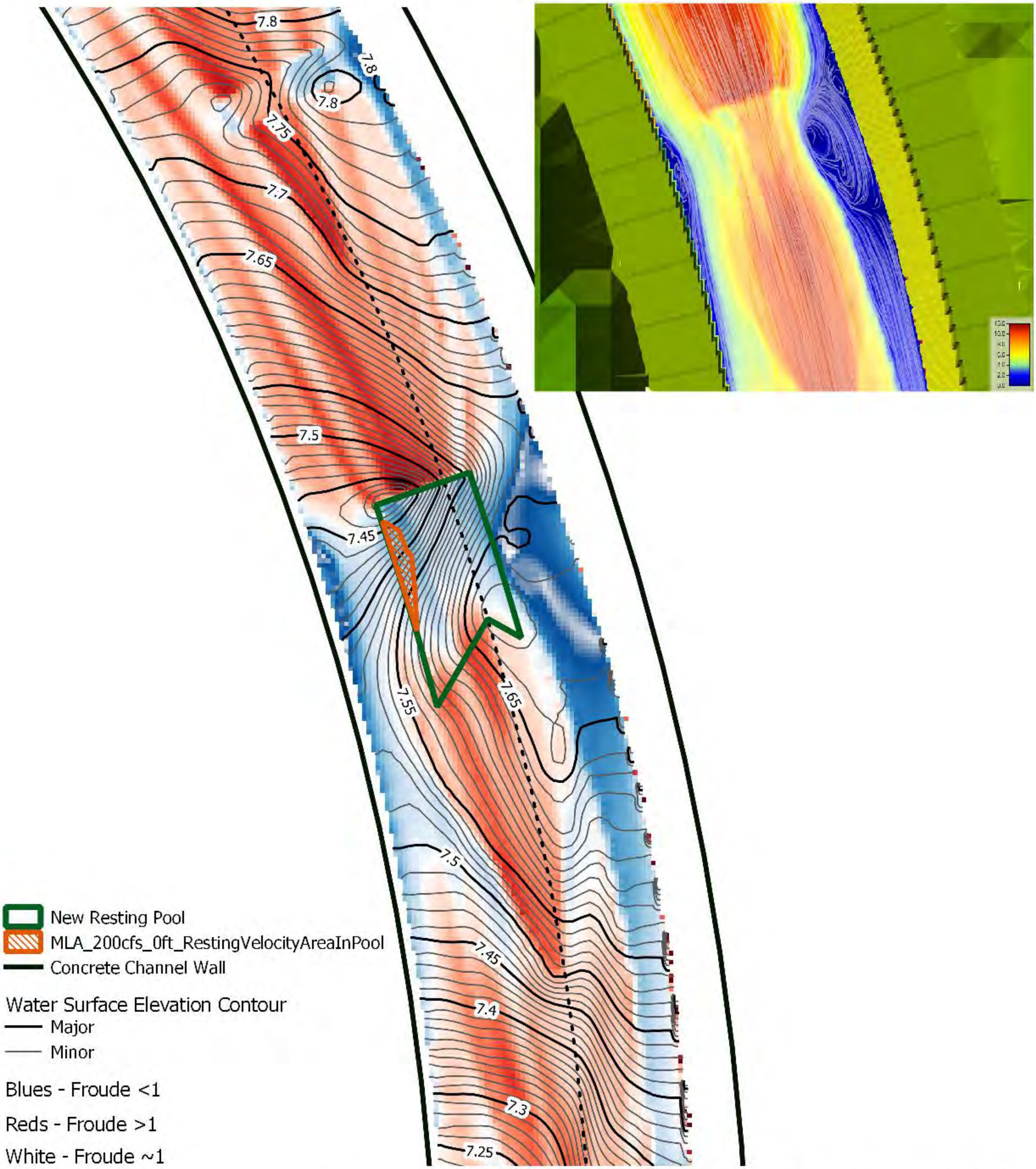
0 10 20 ft

FIGURE 2.C - 350 cfs - Froude

Ross, CA
Corte Madera Creek, Proposed Conditions
Species: Adult Steelhead
Flow: 350 cfs
Boundary Condition: 0 ft Tide

Filepath: Q:\Corte Madera Passage Analysis\7 CAD-GIS\QGIS\Working\CorteMadera Steelhead 350cfs.qgs

Michael Love & Associates, Inc. P.O. Box 4477,
Arcata, CA 95521 (707) 822-2411



Datums:
Horizontal: NAD83 State Plane CA Zone 1
Vertical: NAVD88

Sources:
NA

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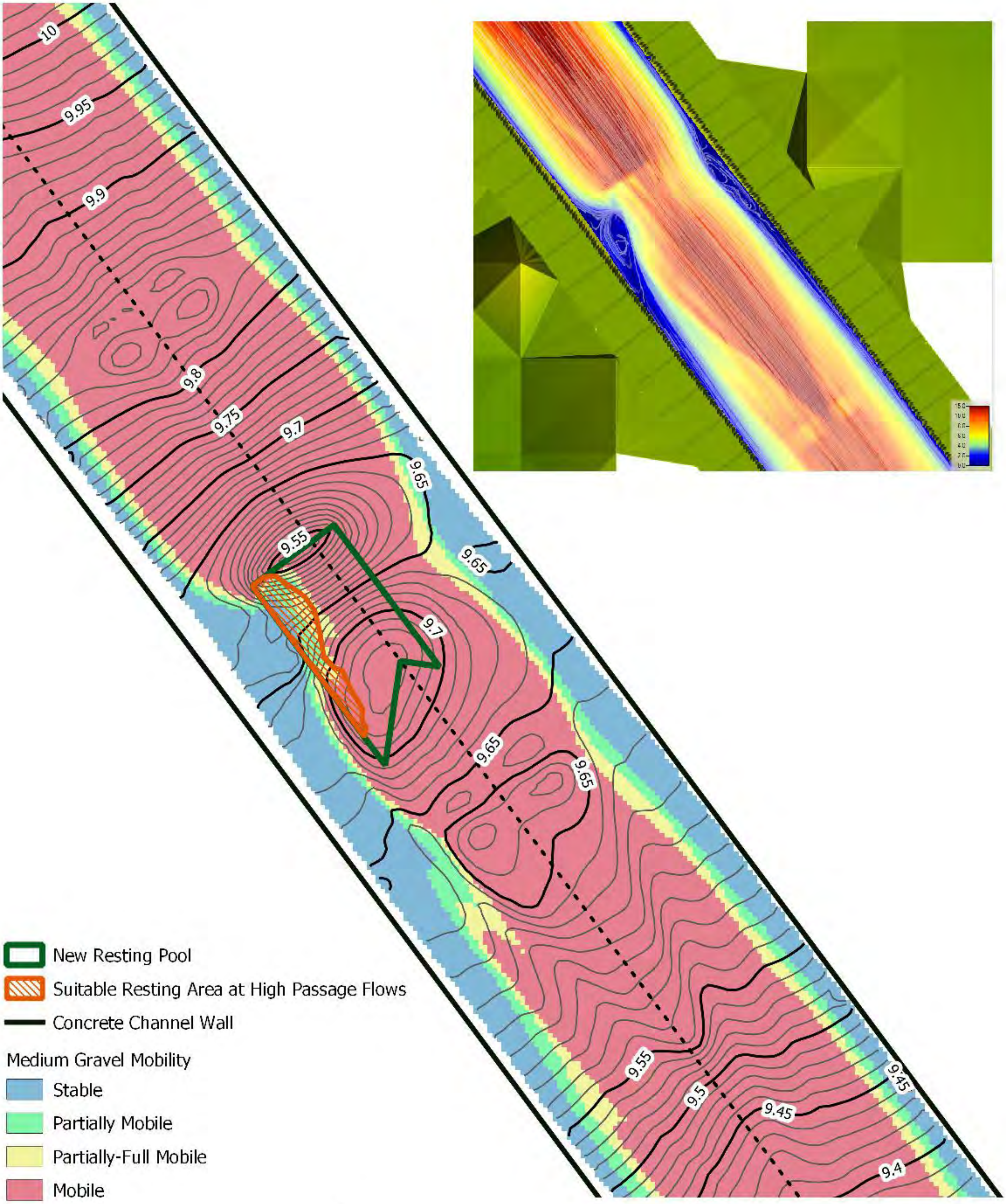
0 10 20 ft

FIGURE 2.D - 350 cfs - Froude

Ross, CA
Corte Madera Creek, Proposed Conditions
Species: Adult Steelhead
Flow: 350 cfs
Boundary Condition: 0 ft Tide

Filepath: Q:\Corte Madera Passage Analysis\7 CAD-GIS\QGIS\Working\CorteMadera Steelhead 350cfs.qgs

Michael Love & Associates, Inc. P.O. Box 4477,
Arcata, CA 95521 (707) 822-2411



Datums:
Horizontal: NAD83 State Plane CA Zone 1
Vertical: NAVD88

Sources:
NA

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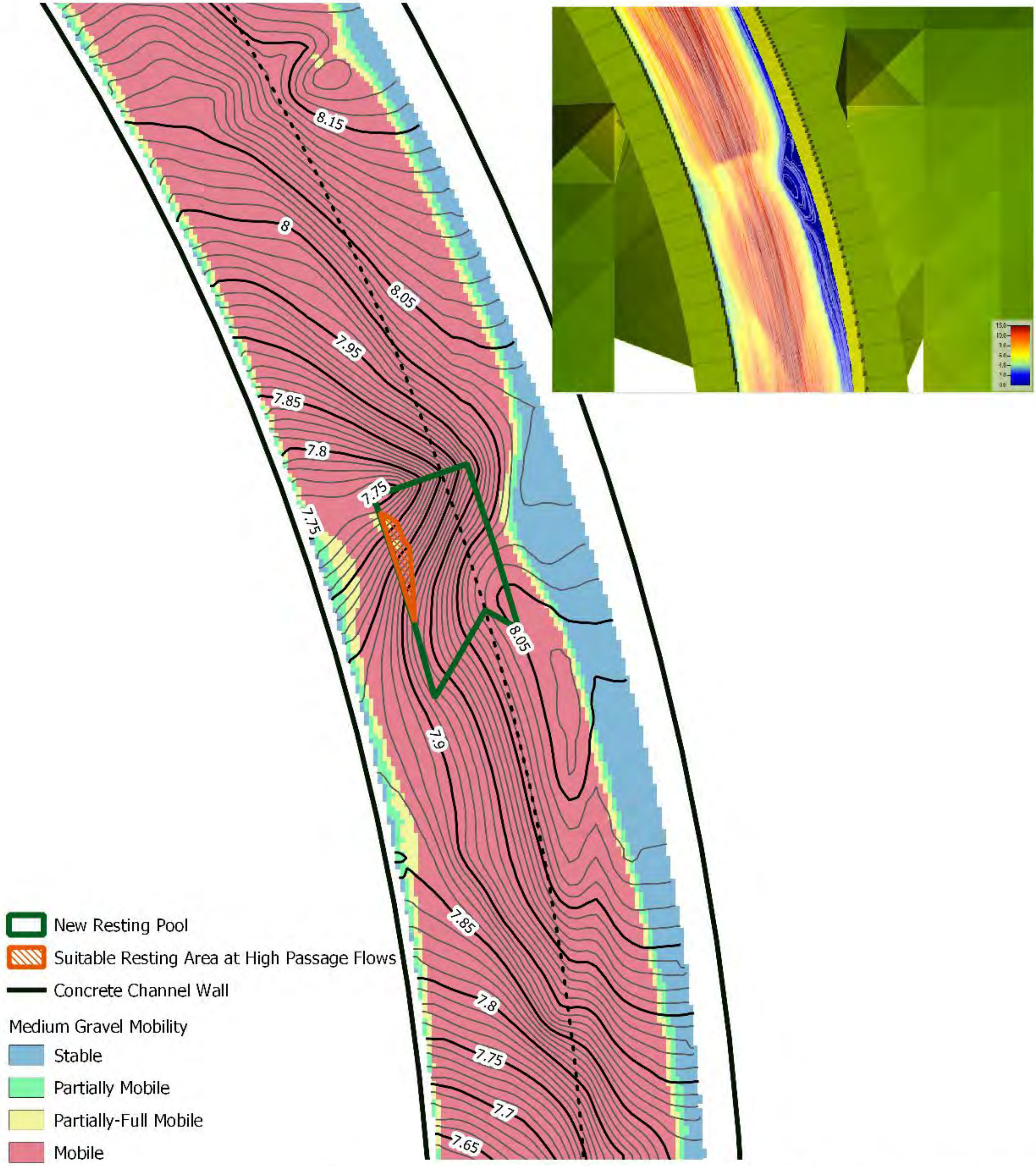
0 10 20 ft

FIGURE 3.A - 500 cfs - Shear

Alternative 1
Ross, CA
Corte Madera Creek, Proposed Conditions
Species: Adult Steelhead
Flow: 500 cfs
Boundary Condition: 0 ft Tide

Filepath: Q:\Corte Madera Passage Analysis\7 CAD-GIS\QGIS\Working\CorteMadera Steelhead 500cfs.qgs

Michael Love & Associates, Inc. P.O. Box 4477,
Arcata, CA 95521 (707) 822-2411



Datums:
Horizontal: NAD83 State Plane CA Zone 1
Vertical: NAVD88

Sources:
NA

Michael Love & Associates
Hydrologic Solutions

GHD

0 10 20 ft

FIGURE 3.B - 500 cfs - Shear

Alternative 1
Ross, CA
Corte Madera Creek, Proposed Conditions
Species: Adult Steelhead
Flow: 500 cfs
Boundary Condition: 0 ft Tide

Filepath: Q:\Corte Madera Passage Analysis\7 CAD-GIS\QGIS\Working\CorteMadera Steelhead 500cfs.qgs

Michael Love & Associates, Inc. P.O. Box 4477,
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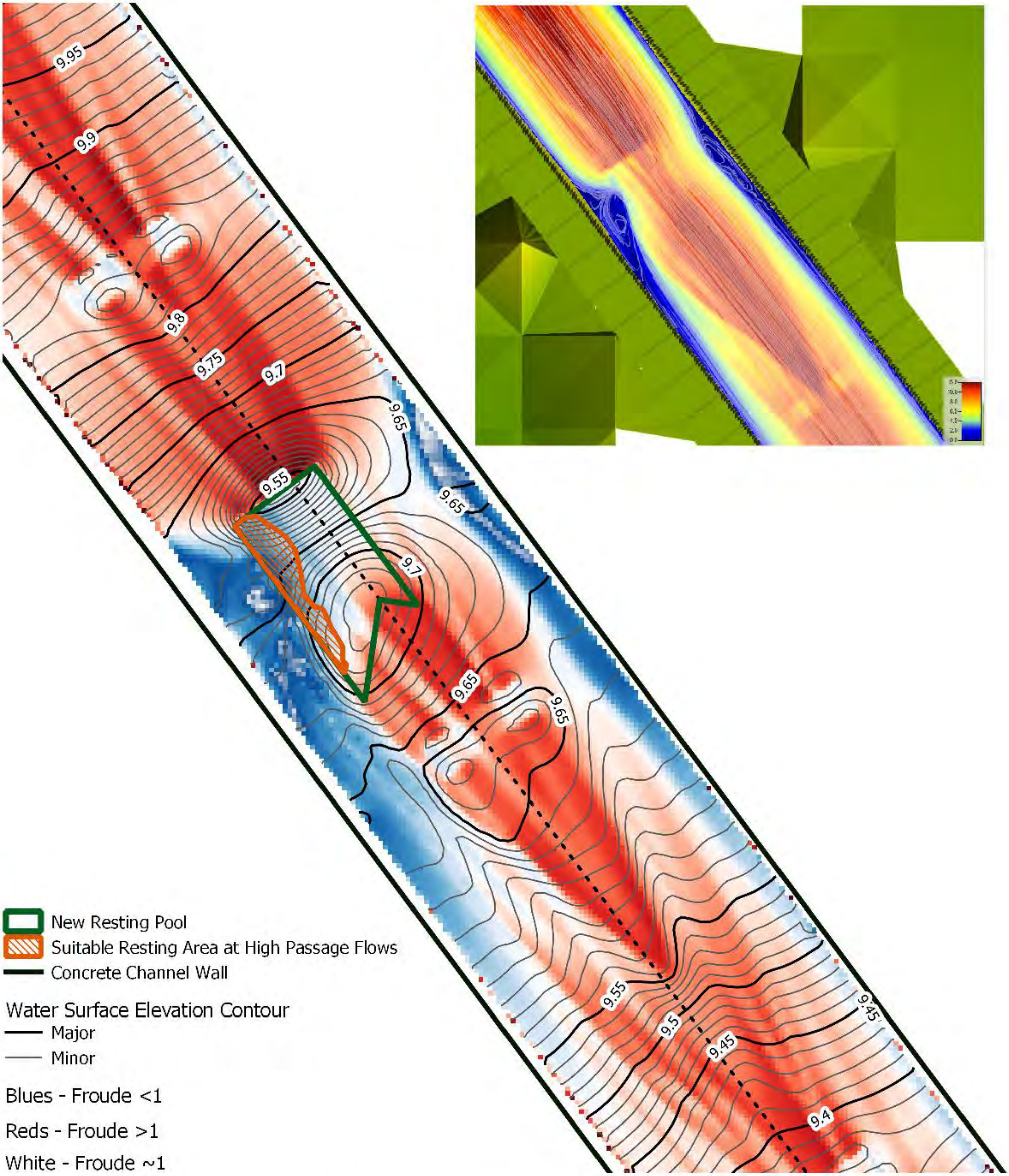


Datums:
Horizontal: NAD83 State Plane CA Zone 1
Vertical: NAVD88

Sources:
NA

Michael Love & Associates
Hydrologic Solutions

GHD

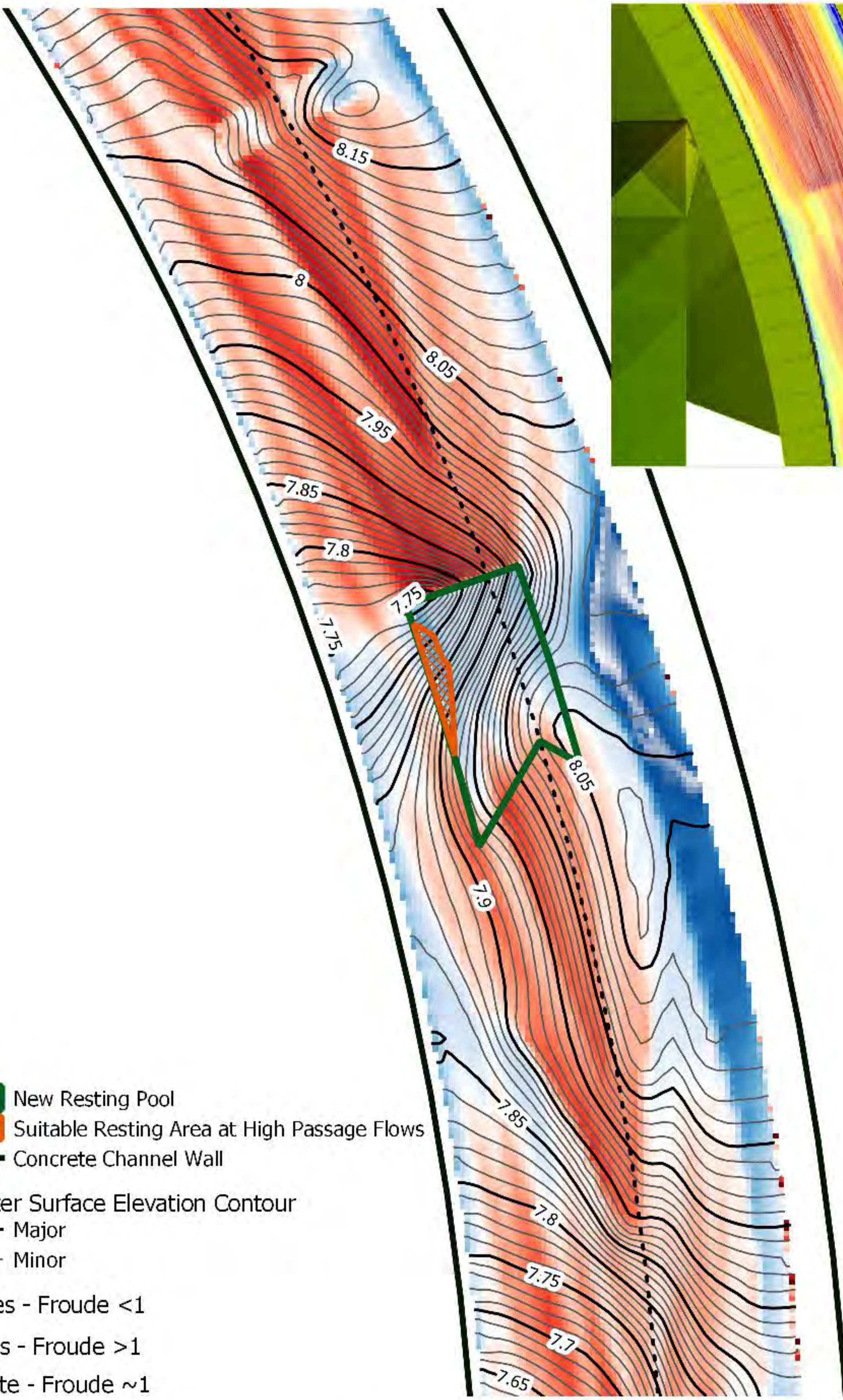
0 10 20 ft

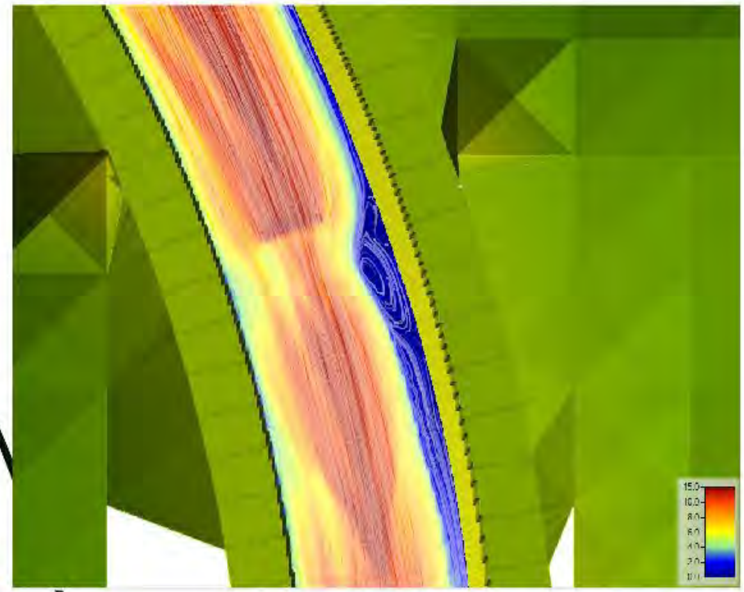
FIGURE 3.C - 500 cfs - Froude

Alternative 1
Ross, CA
Corte Madera Creek, Proposed Conditions
Species: Adult Steelhead
Flow: 500 cfs
Boundary Condition: 0 ft Tide

Filepath: Q:\Corte Madera Passage Analysis\7 CAD-GIS\QGIS\Working\CorteMadera Steelhead 500cfs.qgs

Michael Love & Associates, Inc. P.O. Box 4477,
Arcata, CA 95521 (707) 822-2411





New Resting Pool
Suitable Resting Area at High Passage Flows
Concrete Channel Wall

Water Surface Elevation Contour
Major
Minor

Blues - Froude <1

Reds - Froude >1

White - Froude ~1

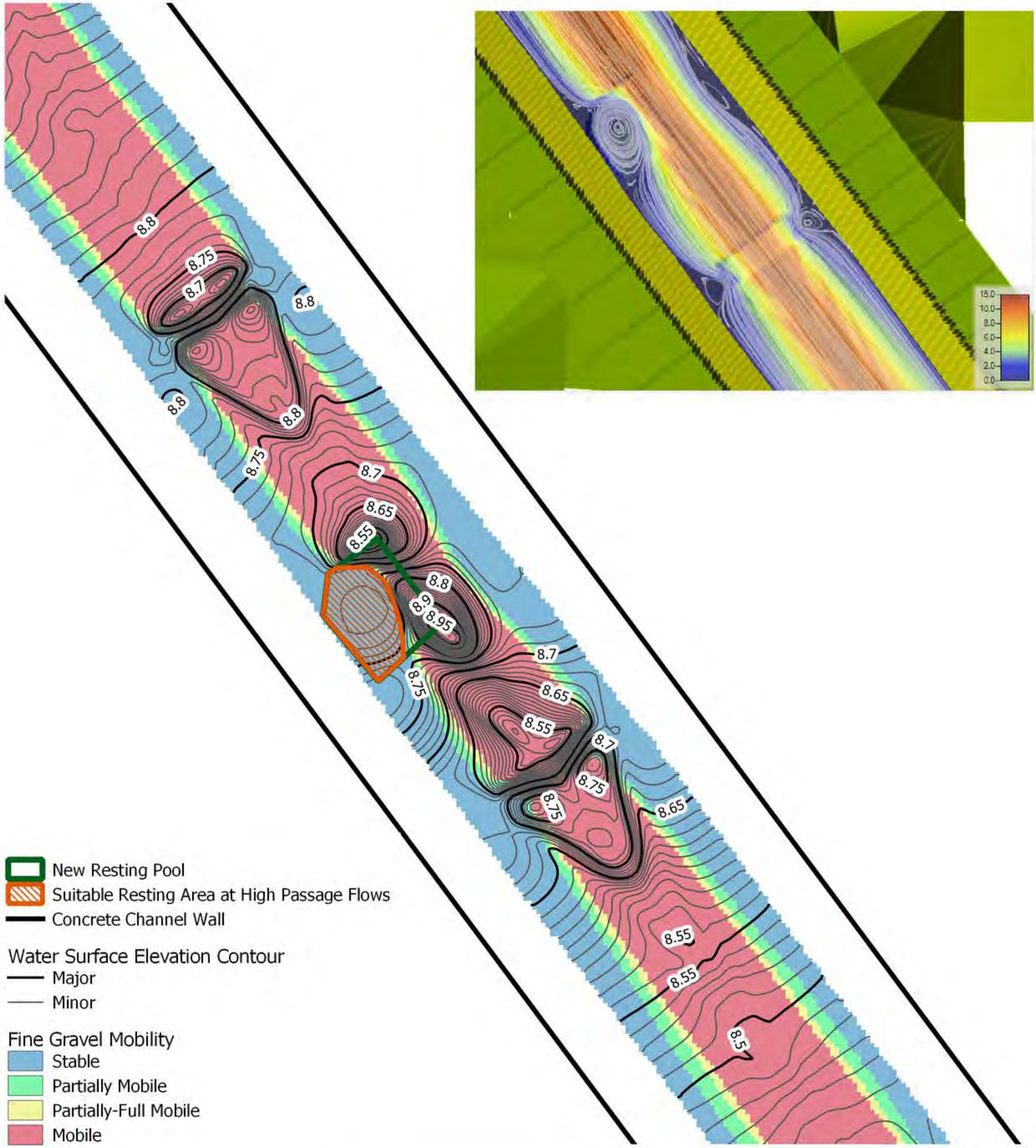
Datums: **Horizontal: NAD83 State Plane CA Zone 1** **Vertical: NAVD88**		**FIGURE 3.D - 500 cfs - Froude**
Sources: **NA**	0 10 20 ft	**Alternative 1** Ross, CA Corte Madera Creek, Proposed Conditions Species: Adult Steelhead Flow: 500 cfs Boundary Condition: 0 ft Tide
Michael Love & Associates *Hydrologic Solutions*		

Filepath: Q:\Corte Madera Passage Analysis\7 CAD-GIS\QGIS\Working\CorteMadera Steelhead 500cfs.qgs

Michael Love & Associates, Inc. P.O. Box 4477,
Arcata, CA 95521 (707) 822-2411

Attachment 4

Analysis of Alternative 2 Resting Pool Configuration



Datums:
Horizontal: NAD83 State Plane CA Zone 1
Vertical: NAVD88

Sources:
NA

Michael Love & Associates
Hydrologic Solutions

GHD

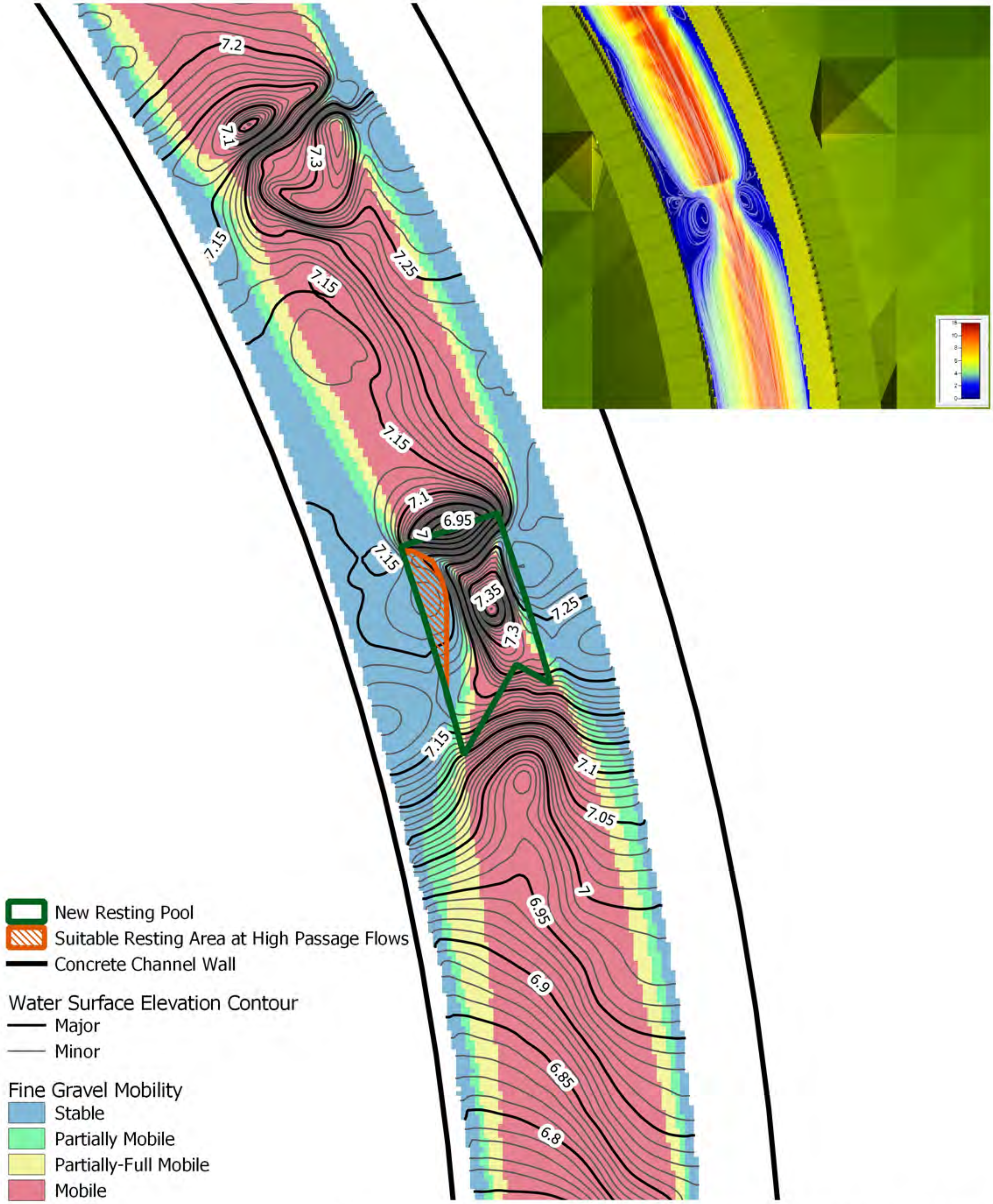
0 10 20 ft

FIGURE 1.A - 200 cfs - Shear

Alternative 2
Ross, CA
Corte Madera Creek, Proposed Conditions
Species: Adult Steelhead
Flow: 200 cfs
Boundary Condition: 0 ft Tide

Filepath: Q:\Corte Madera Passage Analysis\7 CAD-GIS\QGIS\Working\CorteMadera Steelhead 200cfs.qgs

Michael Love & Associates, Inc. P.O. Box 4477,
Arcata, CA 95521 (707) 822-2411



Datums:
Horizontal: NAD83 State Plane CA Zone 1
Vertical: NAVD88

Sources:
NA

Michael Love & Associates
Hydrologic Solutions

GHD

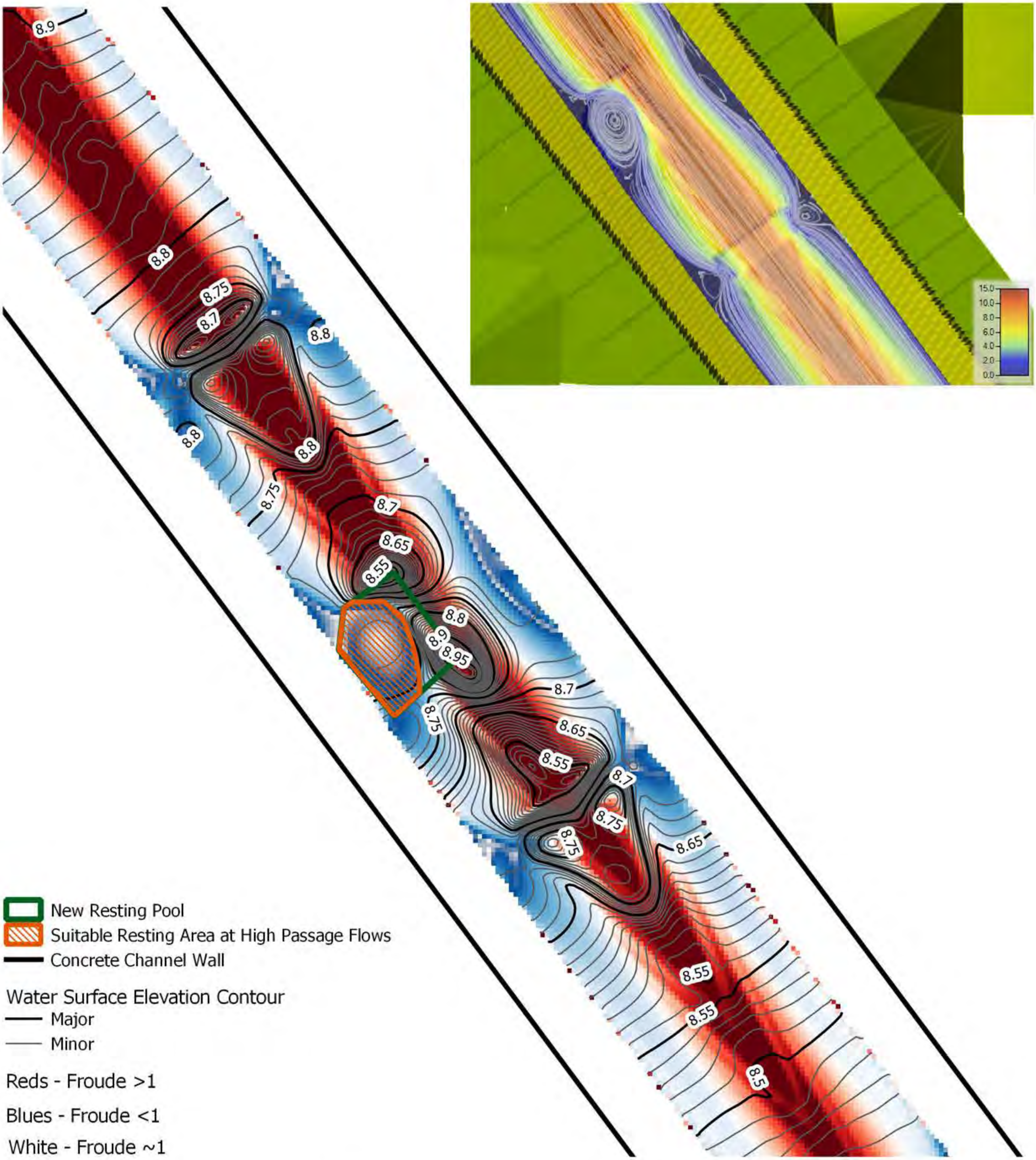
0 10 20 ft

FIGURE 1.B - 200 cfs - Shear

Alternative 2
Ross, CA
Corte Madera Creek, Proposed Conditions
Species: Adult Steelhead
Flow: 200 cfs
Boundary Condition: 0 ft Tide

Filepath: Q:\Corte Madera Passage Analysis\7_CAD-GIS\QGIS\Working\CorteMadera_Steelhead_200cfs.qgs

Michael Love & Associates, Inc. P.O. Box 4477,
Arcata, CA 95521 (707) 822-2411



Datums:
Horizontal: NAD83 State Plane CA Zone 1
Vertical: NAVD88

Sources:
NA

Michael Love & Associates
Hydrologic Solutions

GHD

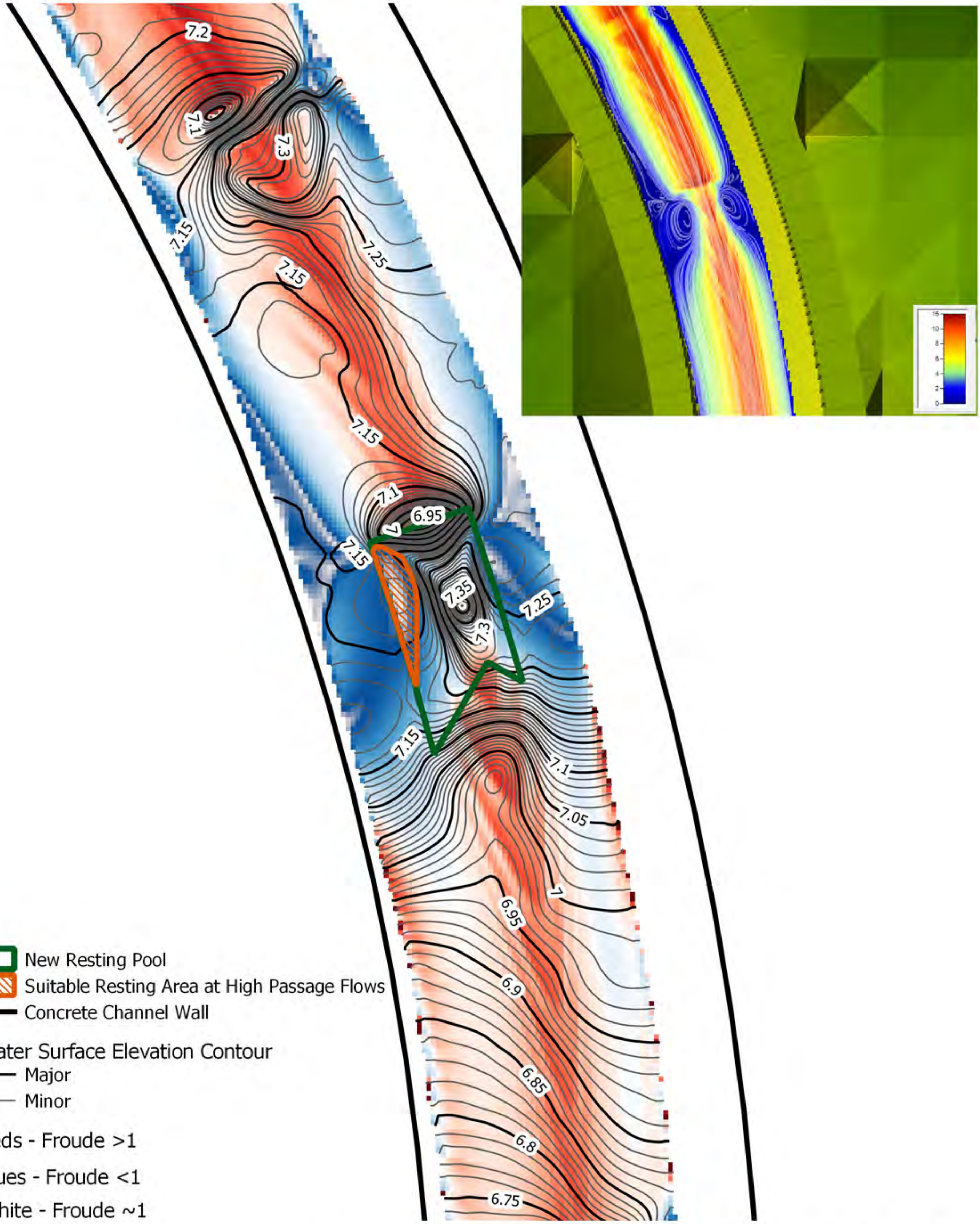
0 10 20 ft

FIGURE 1.C - 200 cfs - Froude

Alternative 2
Ross, CA
Corte Madera Creek, Proposed Conditions
Species: Adult Steelhead
Flow: 200 cfs
Boundary Condition: 0 ft Tide

Filepath: Q:\Corte Madera Passage Analysis\7 CAD-GIS\QGIS\Working\CorteMadera Steelhead 200cfs.qgs

Michael Love & Associates, Inc. P.O. Box 4477,
Arcata, CA 95521 (707) 822-2411



Datums:
Horizontal: NAD83 State Plane CA Zone 1
Vertical: NAVD88

Sources:
NA

Michael Love & Associates
Hydrologic Solutions
GHD

0 10 20 ft

FIGURE 1.D - 200 cfs - Froude

Alternative 2
Ross, CA
Corte Madera Creek, Proposed Conditions
Species: Adult Steelhead
Flow: 200 cfs
Boundary Condition: 0 ft Tide

Filepath: Q:\Corte Madera Passage Analysis\7 CAD-GIS\QGIS\Working\CorteMadera Steelhead 200cfs.qgs

Michael Love & Associates, Inc. P.O. Box 4477,
Arcata, CA 95521 (707) 822-2411

Datums:
Horizontal: NAD83 State Plane CA Zone 1
Vertical: NAVD88

Sources:
NA

Michael Love & Associates
Hydrologic Solutions
GHD

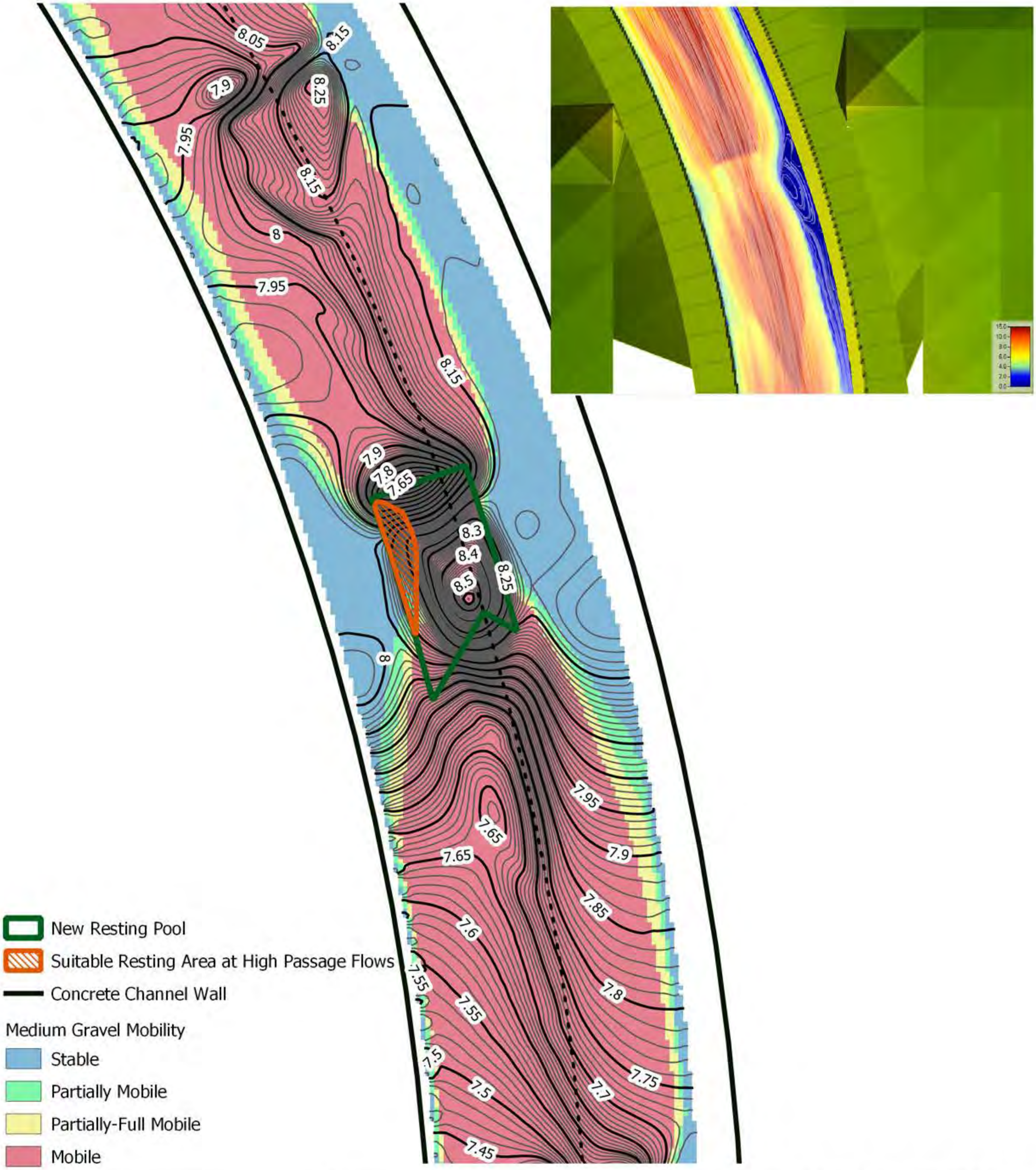
0 10 20 ft

FIGURE 3.A - 500 cfs - Shear

Alternative 2
Ross, CA
Corte Madera Creek, Proposed Conditions
Species: Adult Steelhead
Flow: 500 cfs
Boundary Condition: 0 ft Tide

Filepath: Q:\Corte Madera Passage Analysis\7 CAD-GIS\QGIS\Working\CorteMadera Steelhead 500cfs.qgs

Michael Love & Associates, Inc. P.O. Box 4477, Arcata, CA 95521 (707) 822-2411



Datums:
Horizontal: NAD83 State Plane CA Zone 1
Vertical: NAVD88

Sources:
NA

Michael Love & Associates
Hydrologic Solutions

GHD

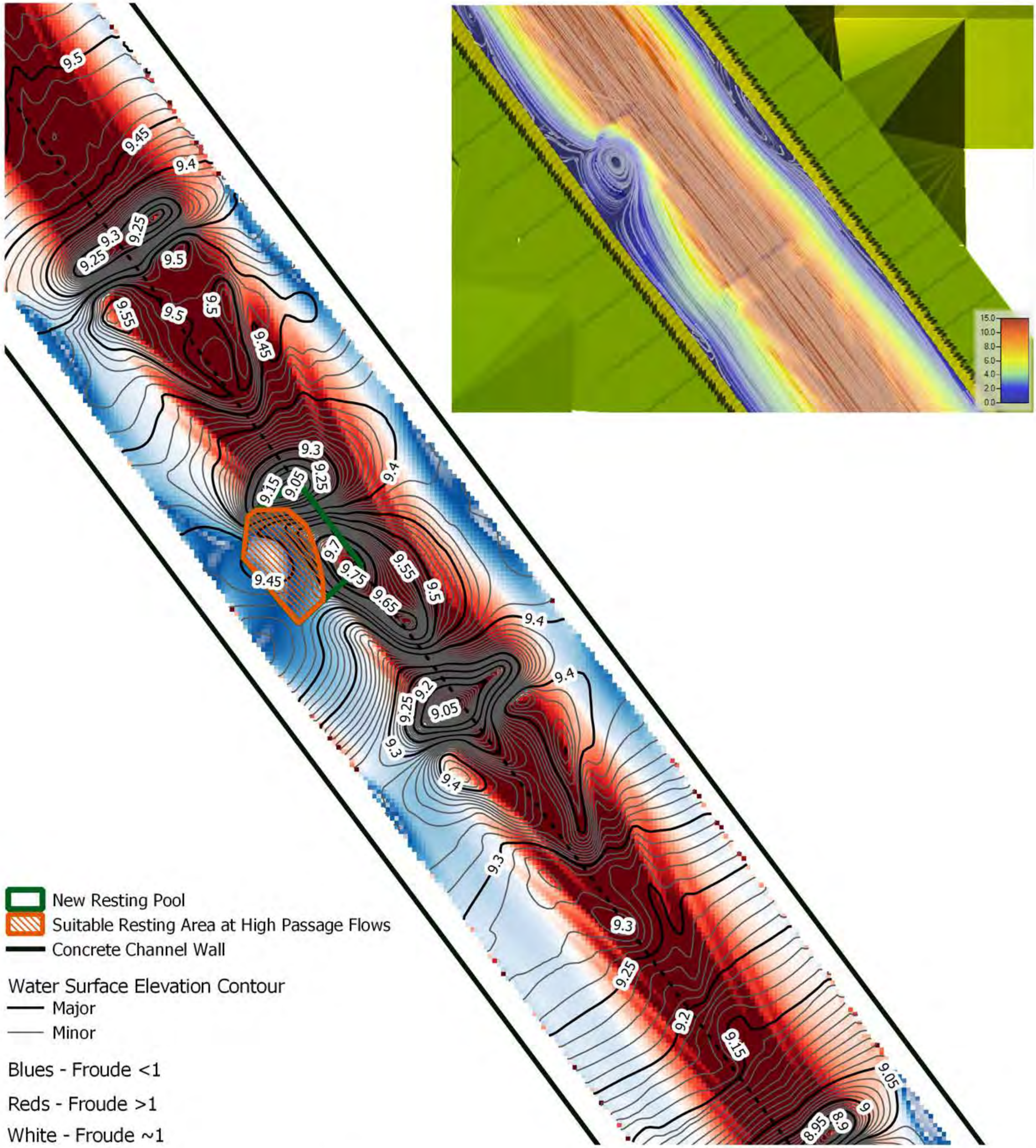
0 10 20 ft

FIGURE 3.B - 500 cfs - Shear

Alternative 2
Ross, CA
Corte Madera Creek, Proposed Conditions
Species: Adult Steelhead
Flow: 500 cfs
Boundary Condition: 0 ft Tide

Filepath: Q:\Corte Madera Passage Analysis\7 CAD-GIS\QGIS\Working\CorteMadera Steelhead 500cfs.qgs

Michael Love & Associates, Inc. P.O. Box 4477,
Arcata, CA 95521 (707) 822-2411



Datums:
Horizontal: NAD83 State Plane CA Zone 1
Vertical: NAVD88

Sources:
NA

Michael Love & Associates
Hydrologic Solutions

0 10 20 ft

FIGURE 3.C - 500 cfs - Froude

Alternative 2

Ross, CA

Corte Madera Creek, Proposed Conditions

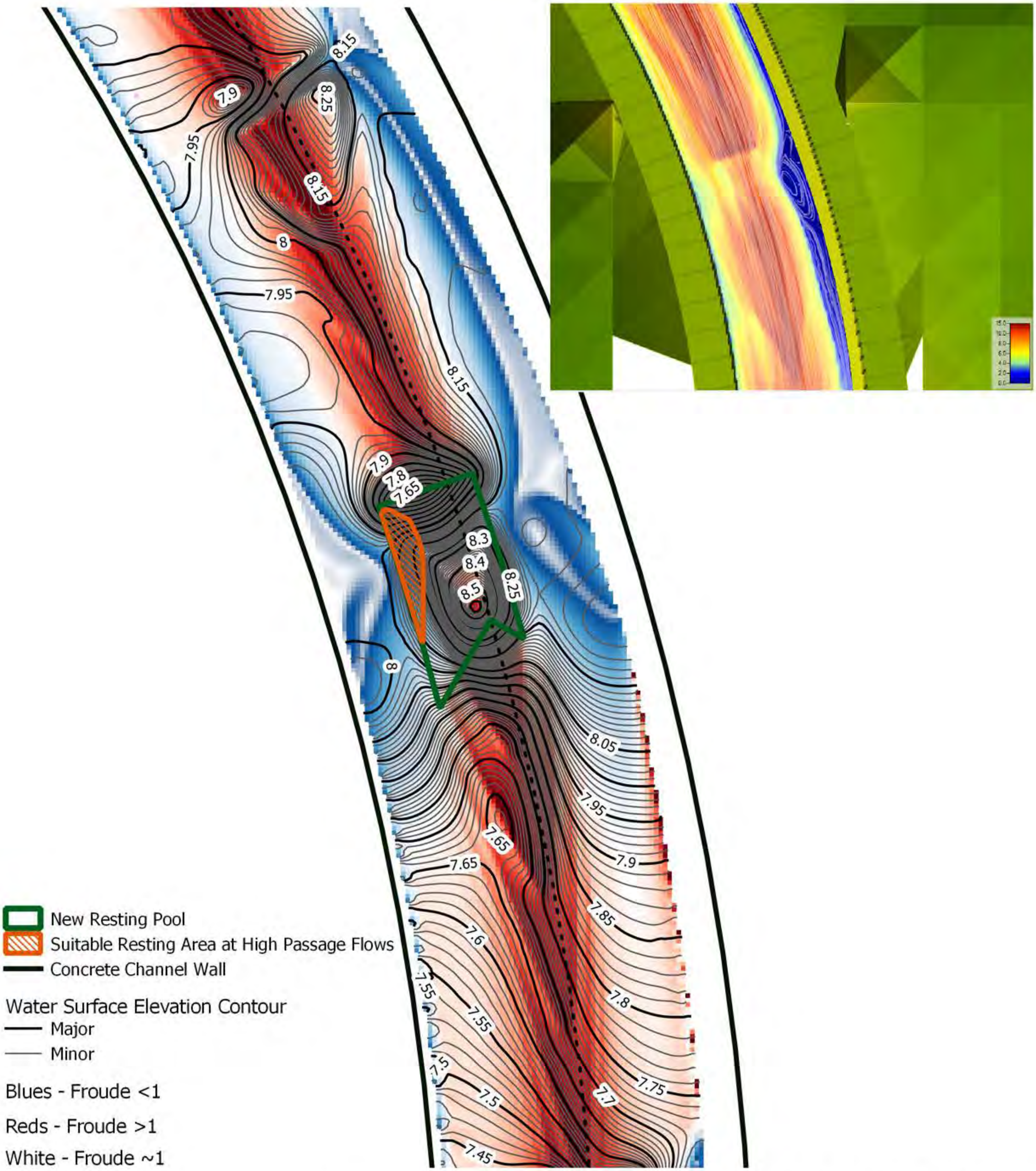
Species: Adult Steelhead

Flow: 500 cfs

Boundary Condition: 0 ft Tide

Filepath: Q:\Corte Madera Passage Analysis\7 CAD-GIS\QGIS\Working\CorteMadera Steelhead 500cfs.qgs

Michael Love & Associates, Inc. P.O. Box 4477, Arcata, CA 95521 (707) 822-2411



Datums:
Horizontal: NAD83 State Plane CA Zone 1
Vertical: NAVD88

Sources:
NA

Michael Love & Associates
Hydrologic Solutions

GHD

0 10 20 ft

FIGURE 3.D - 500 cfs - Froude

Alternative 2

Ross, CA

Corte Madera Creek, Proposed Conditions

Species: Adult Steelhead

Flow: 500 cfs

Boundary Condition: 0 ft Tide

Filepath: Q:\Corte Madera Passage Analysis\7 CAD-GIS\QGIS\Working\CorteMadera Steelhead 500cfs.qgs

Michael Love & Associates, Inc. P.O. Box 4477,
Arcata, CA 95521 (707) 822-2411

CFD Model Results for Alternative 2 Resting Pool

Model Domain and Resting Pool Shape

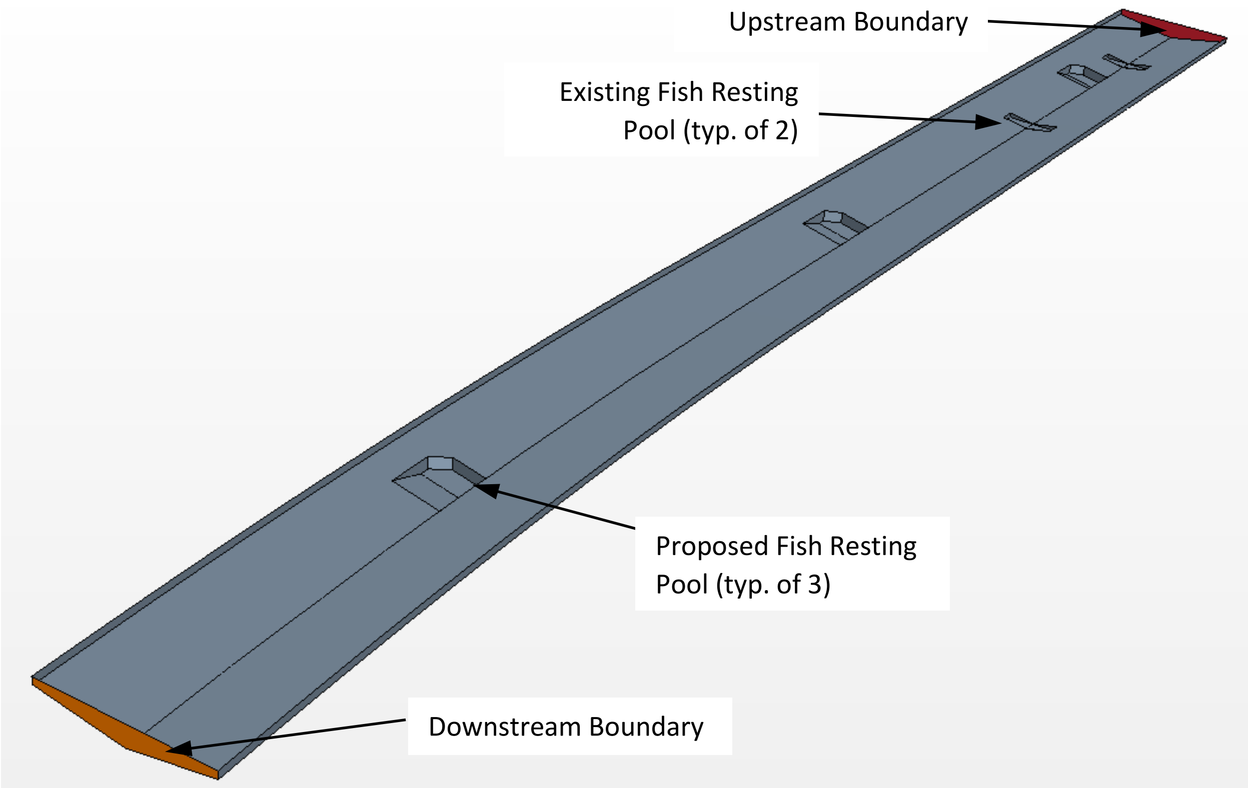


Figure 1 Overall geometry for large domain model.

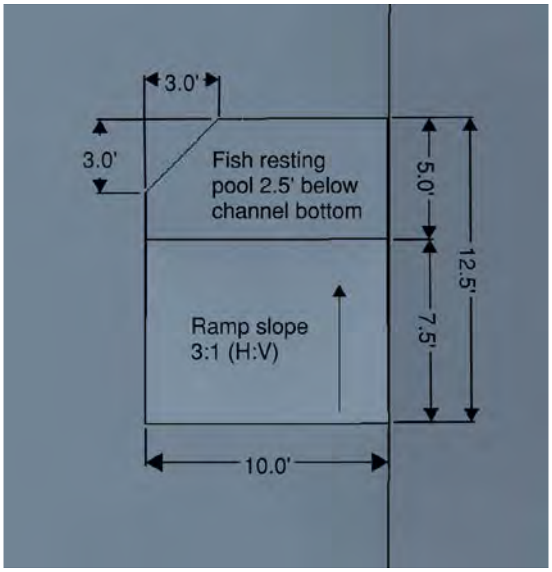


Figure 2 Proposed fish resting pool layout

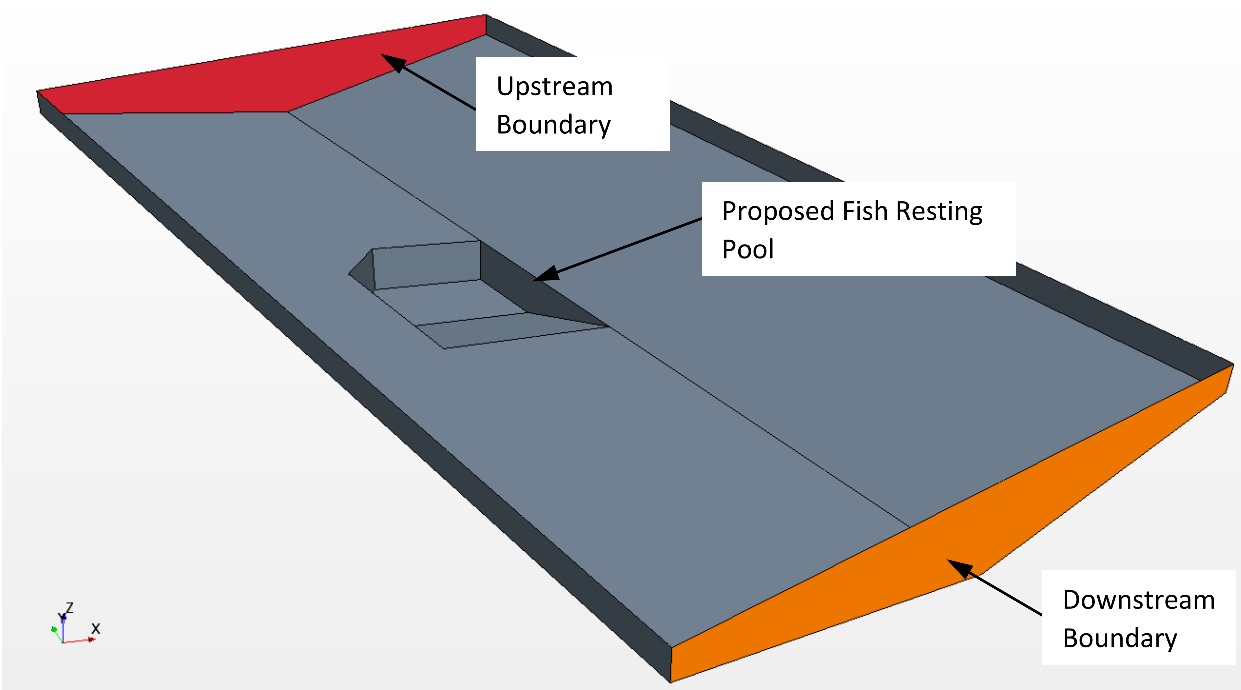


Figure 3 Single pool model geometry

180 cfs Scenario (High Fish Passage Flow)

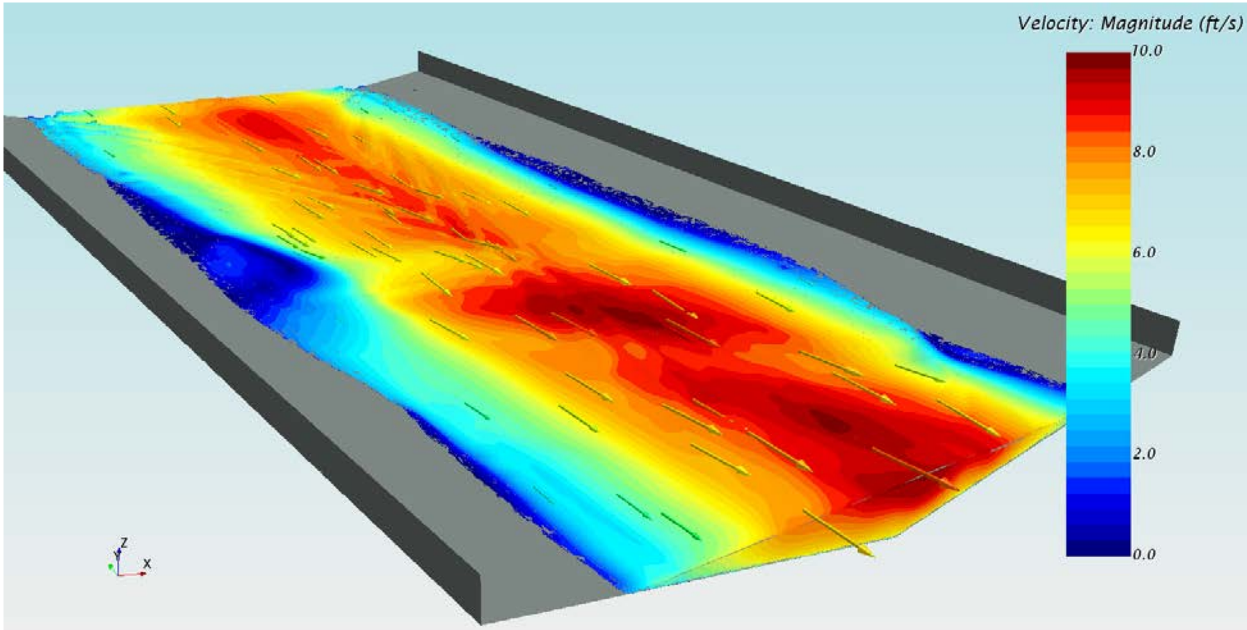


Figure 4 Velocity magnitude at water surface at 180 cfs.

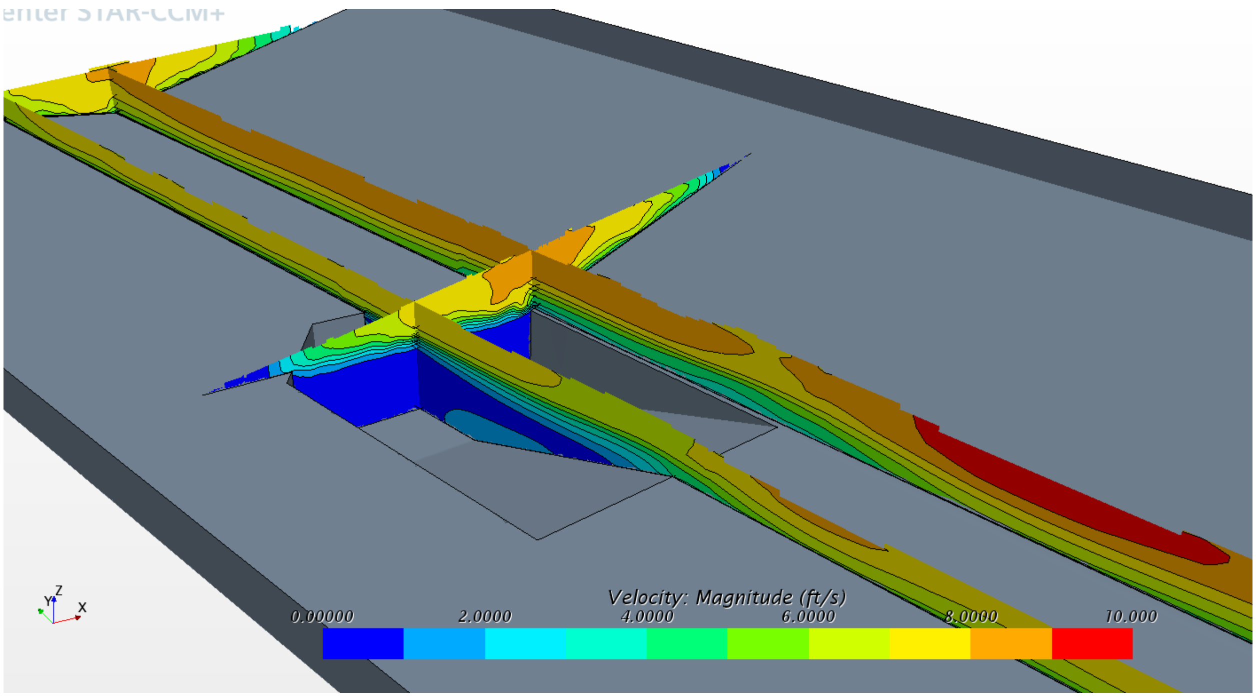


Figure 5 Velocity magnitude at sections at 180 cfs.

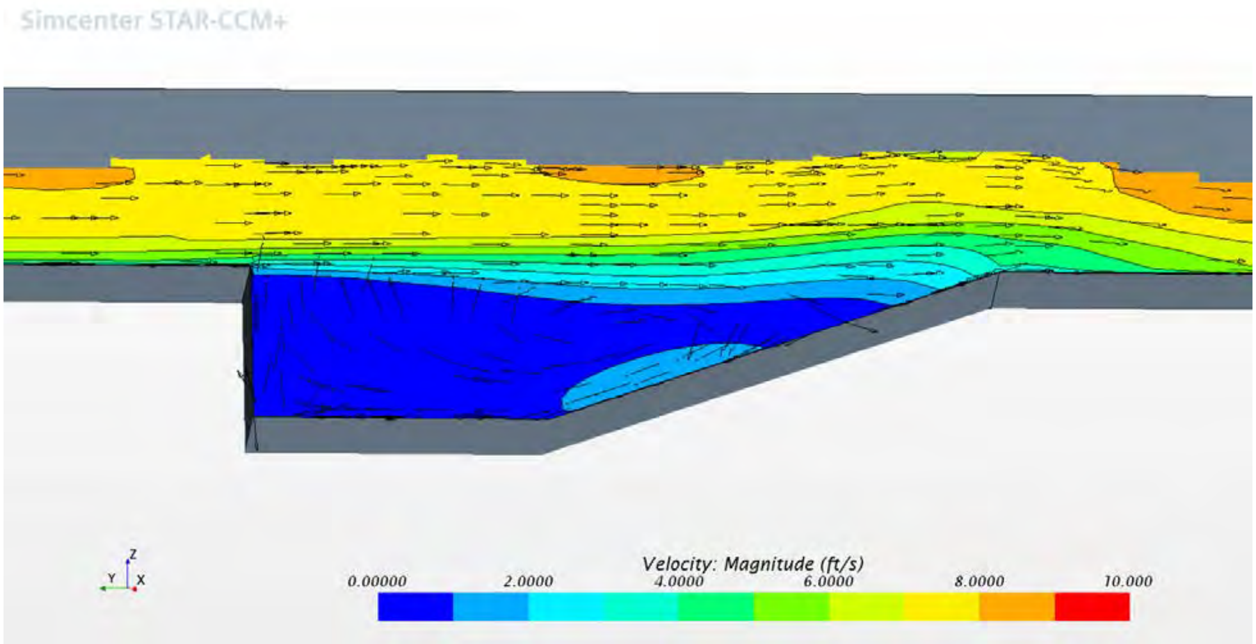


Figure 6 Velocity magnitude and direction at Longitudinal Section 1 (2.5 ft from channel invert) at 180 cfs.

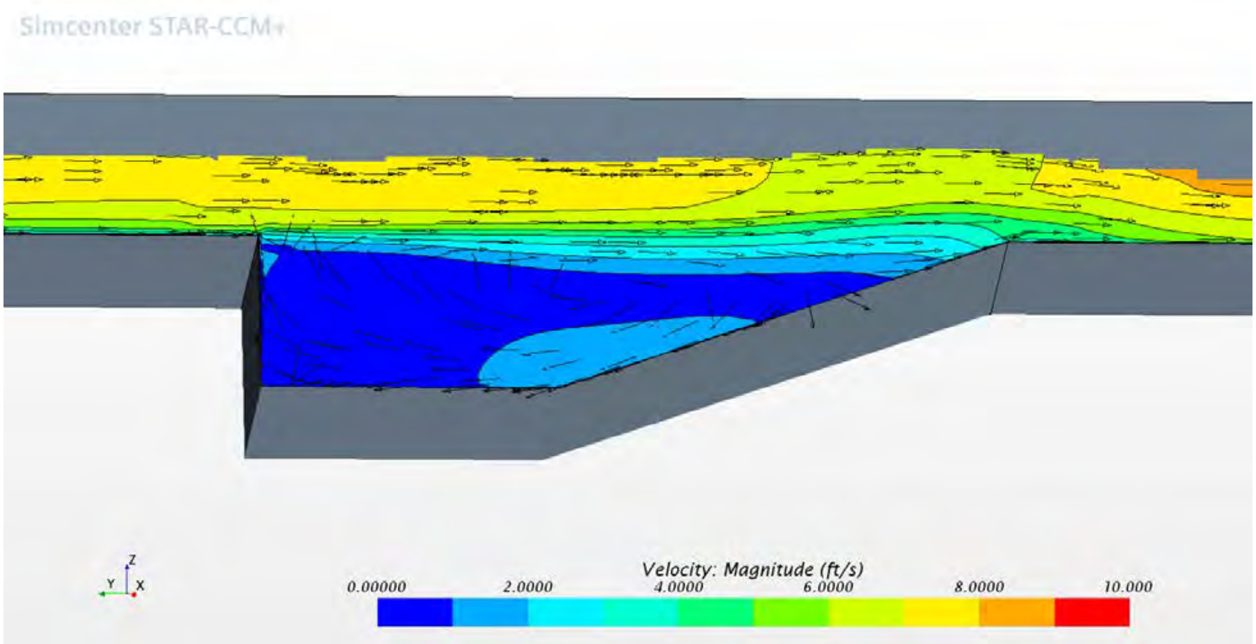


Figure 7 Velocity magnitude and direction at Longitudinal Section 2 (5 ft from channel invert) at 180 cfs.

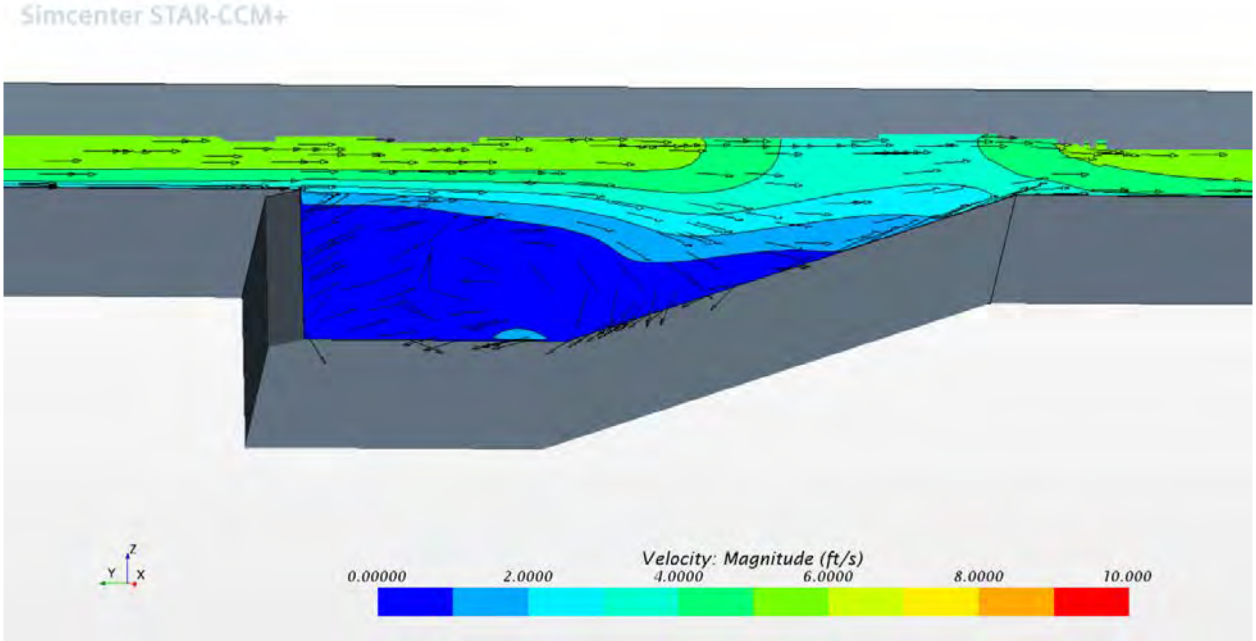


Figure 8 Velocity magnitude and direction at Longitudinal Section 3 (7.5 ft from channel invert) at 180 cfs.

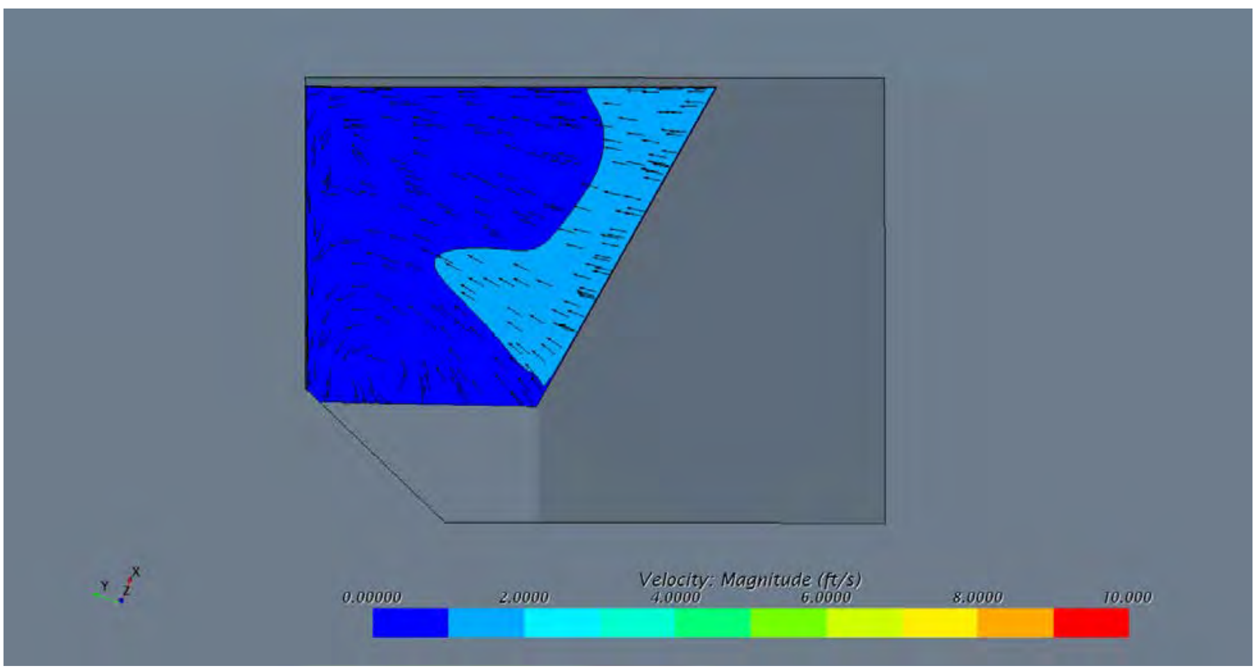


Figure 9 Velocity magnitude and direction at Horizontal Section 1 (Elev. 1 ft) at 180 cfs.

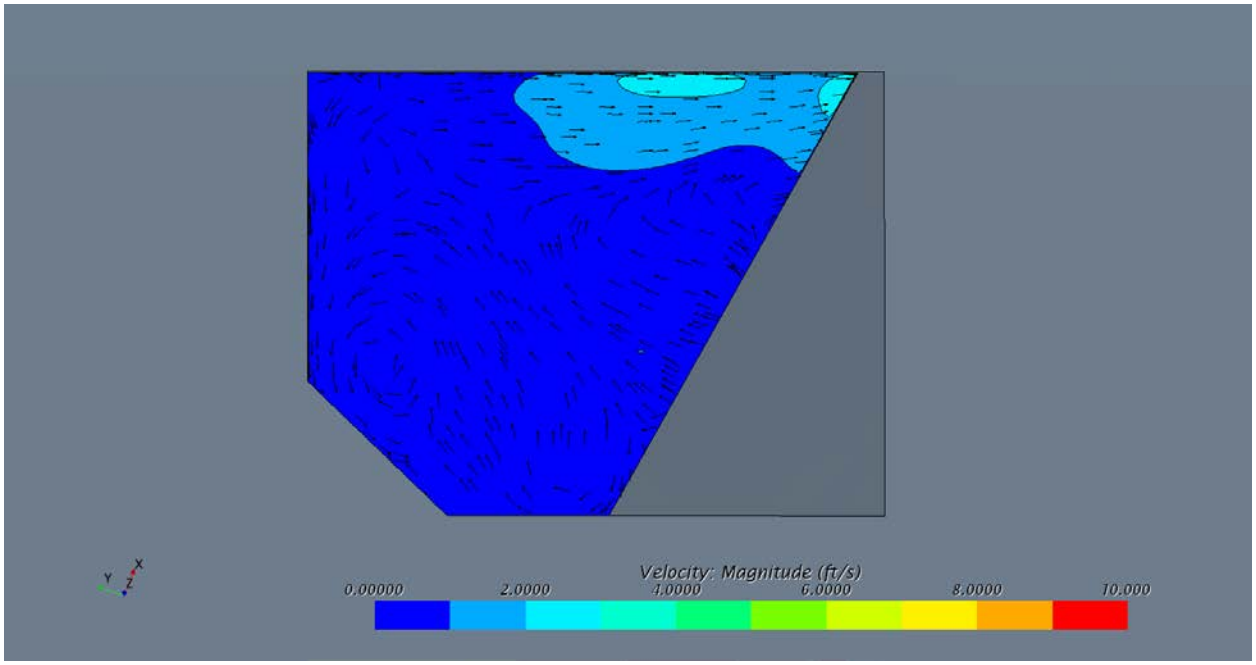


Figure 10 Velocity magnitude and direction at Horizontal Section 2 (Elev. 2 ft) at 180 cfs.

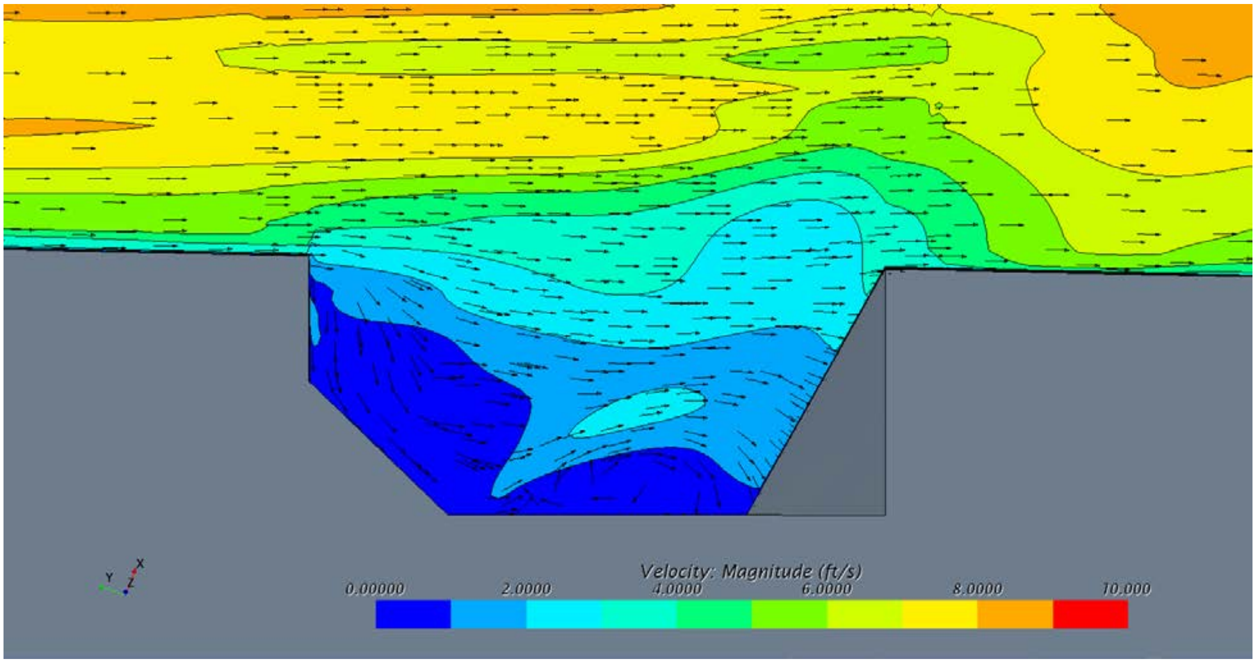


Figure 11 Velocity magnitude and direction at Horizontal Section 3 (Elev. 3 ft) at 180 cfs.

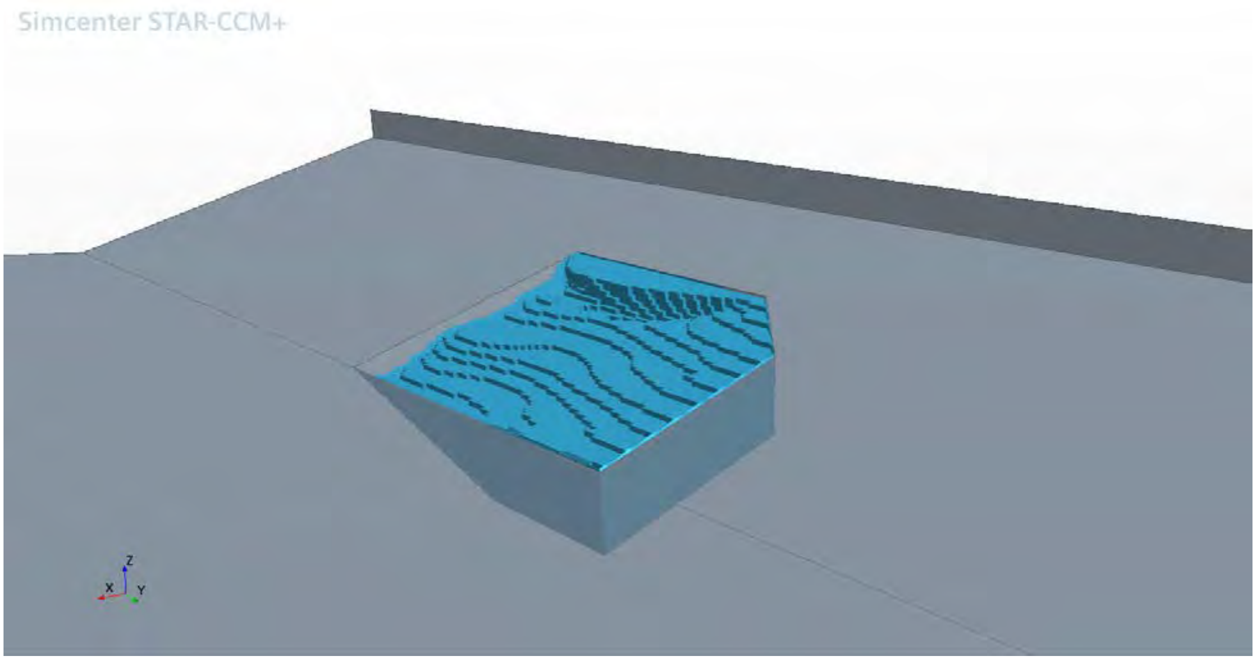


Figure 12 Region in fish pool with velocity < 2 ft/s (volume = 187 ft^3) at 180 cfs.

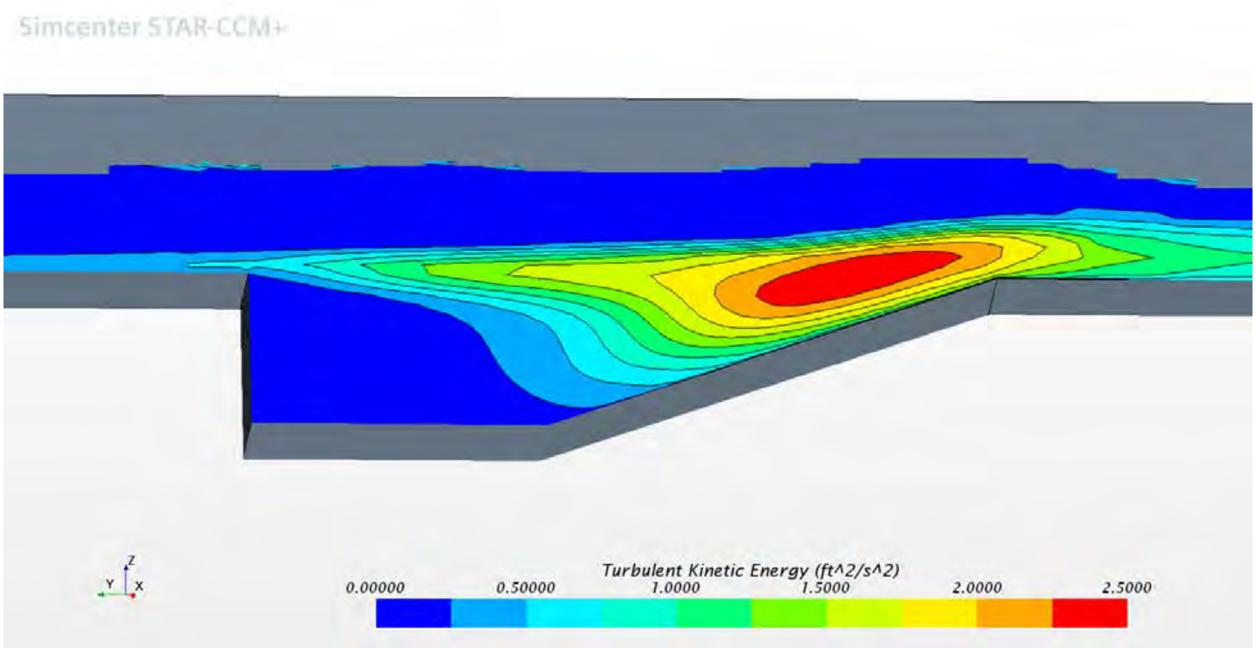


Figure 13 TKE magnitude at Longitudinal Section 1 (2.5 ft from channel invert) at 180 cfs.

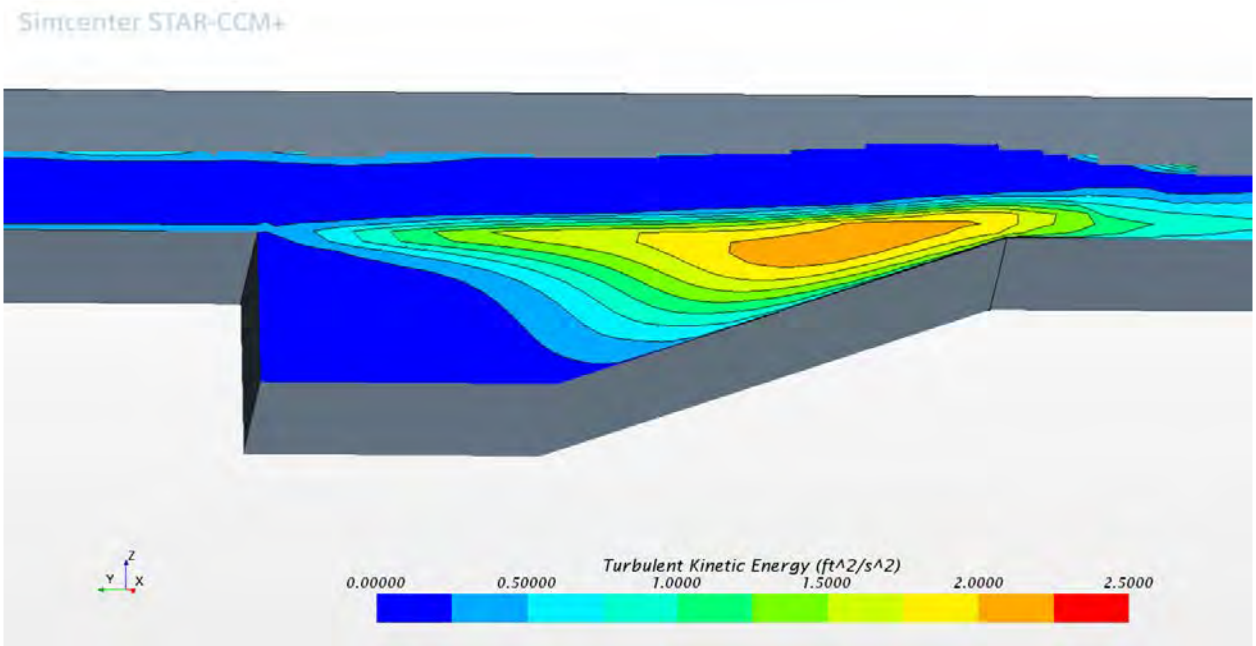


Figure 14 TKE magnitude at Longitudinal Section 2 (5 ft from channel invert) at 180 cfs.

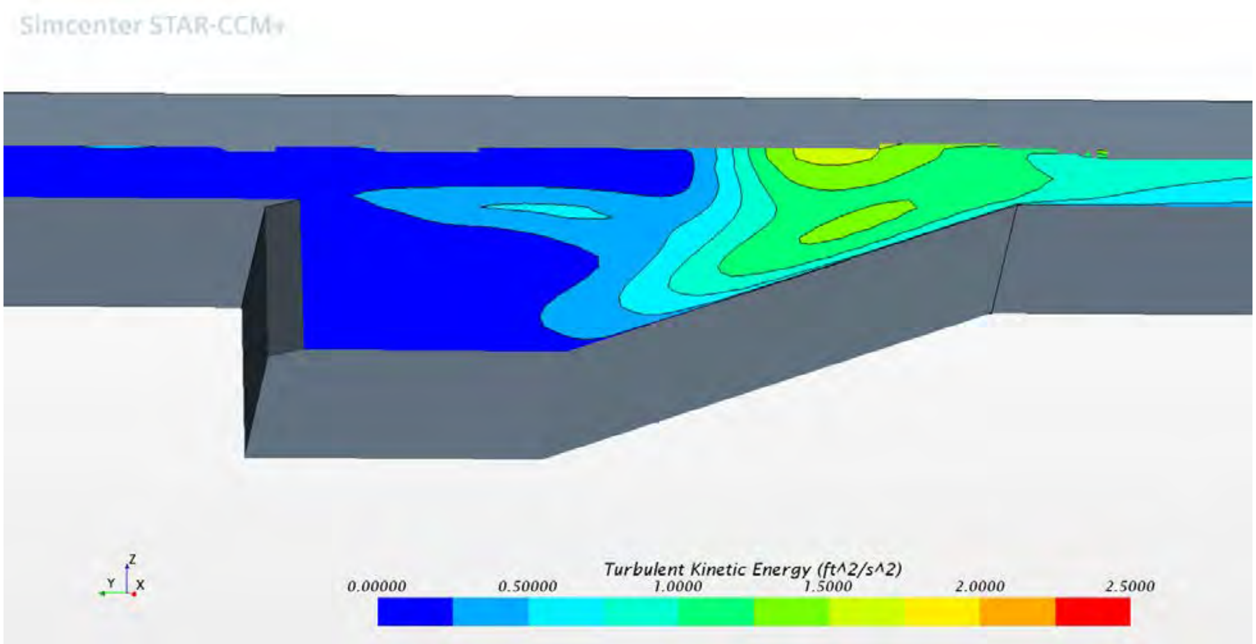


Figure 15 TKE magnitude at Longitudinal Section 3 (7.5 ft from channel invert) at 180 cfs.

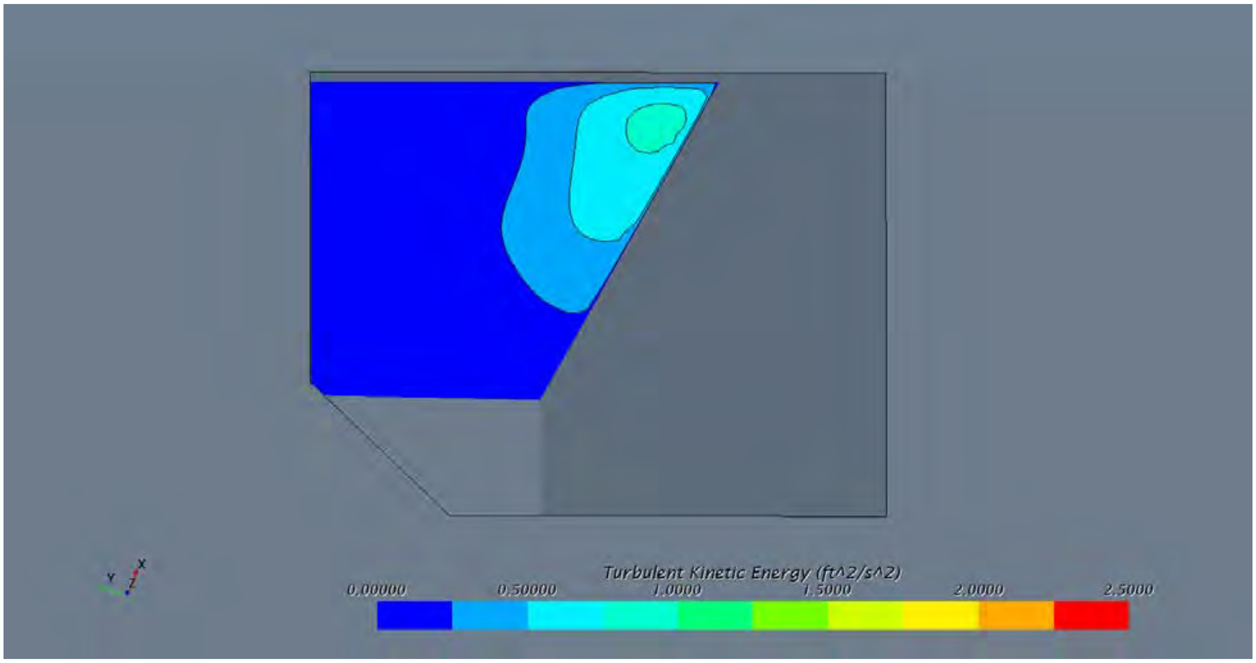


Figure 16 TKE magnitude at Horizontal Section 1 (Elev. 1 ft) at 180 cfs.

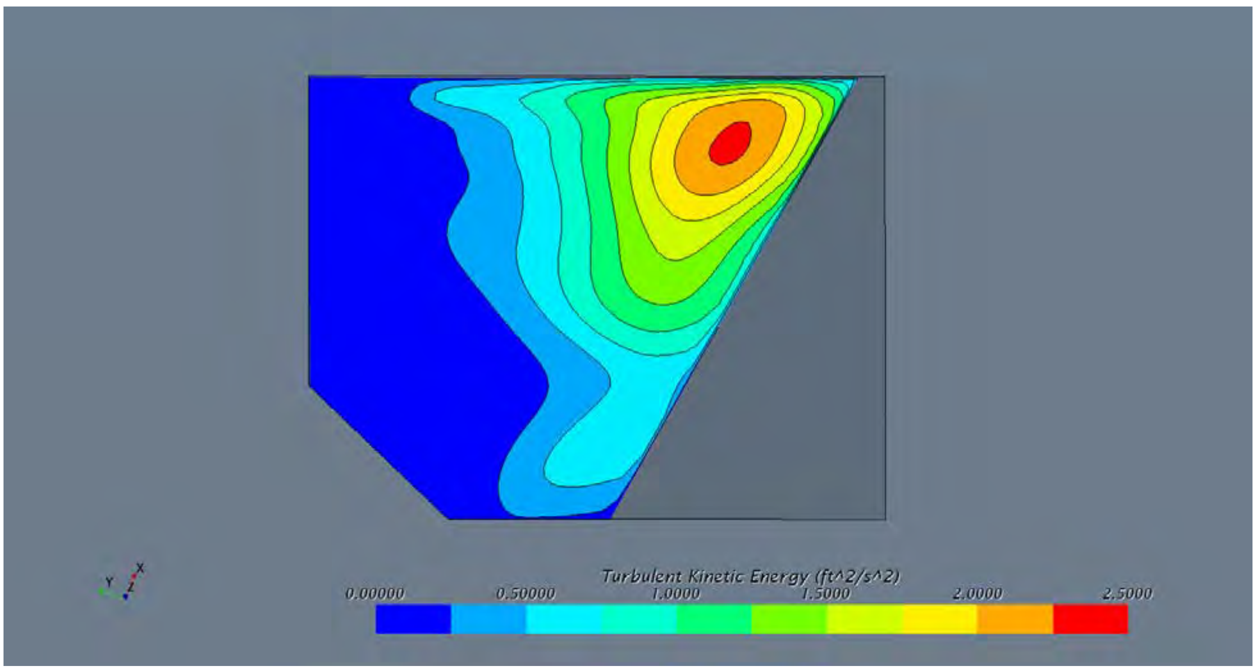


Figure 17 TKE magnitude at Horizontal Section 2 (Elev. 2 ft) at 180 cfs.

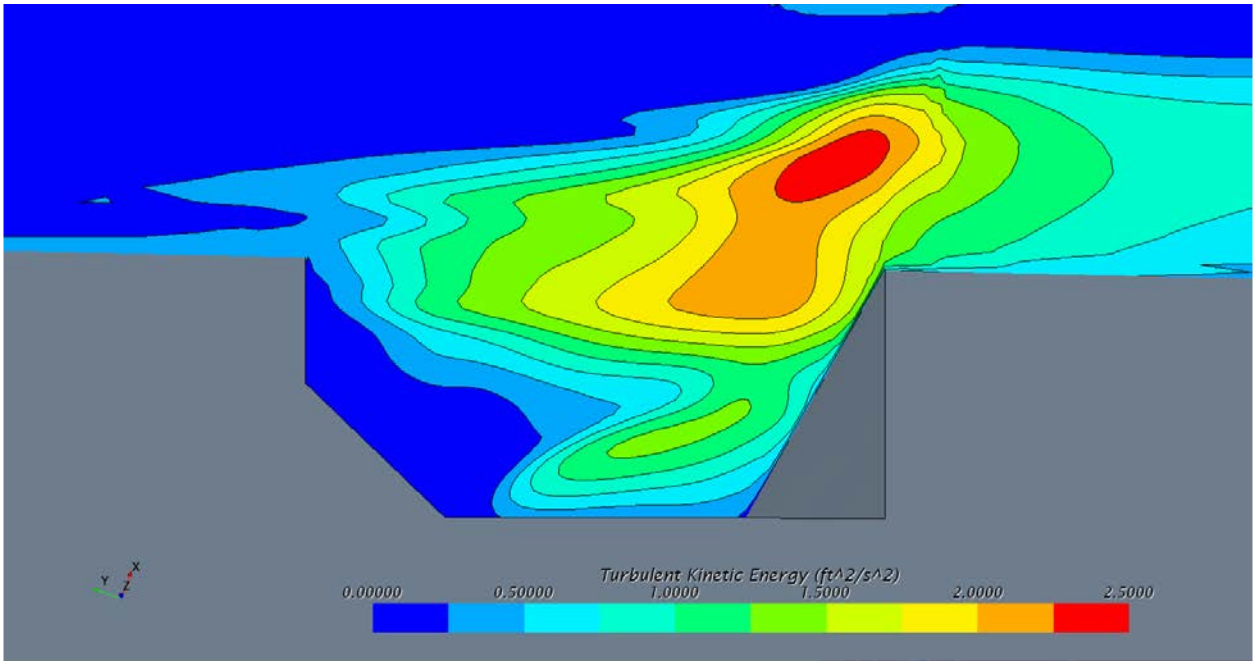


Figure 18 TKE magnitude at Horizontal Section 3 (Elev. 3 ft) at 180 cfs.

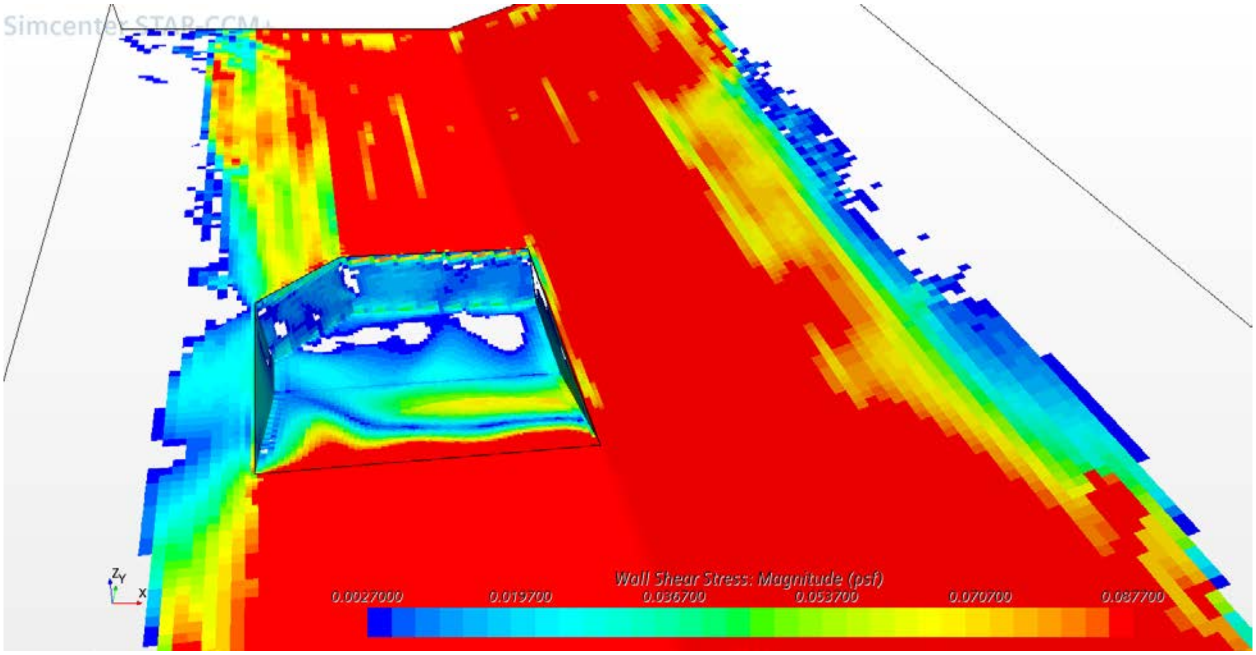


Figure 19 Shear stress magnitude on channel bottom at 180 cfs.

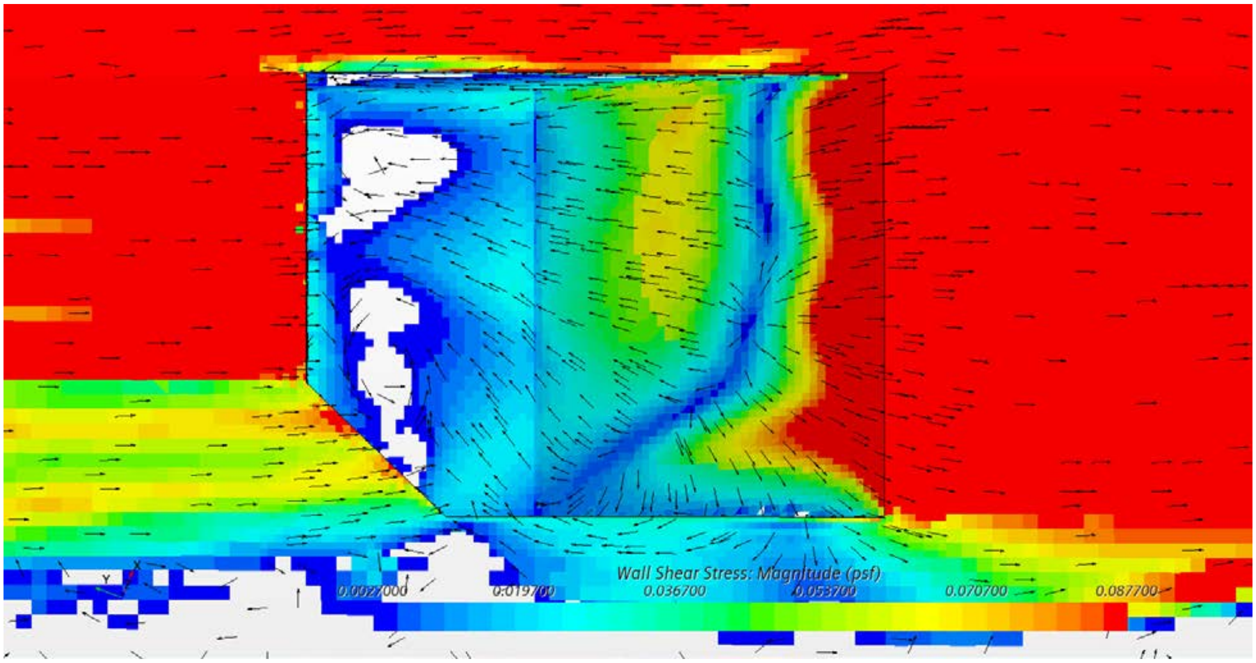


Figure 20 Shear stress magnitude and direction at fish pool at 180 cfs.

500 cfs Scenario
(Estimated Delivery Reach Critical Discharge for Sediment Transport)

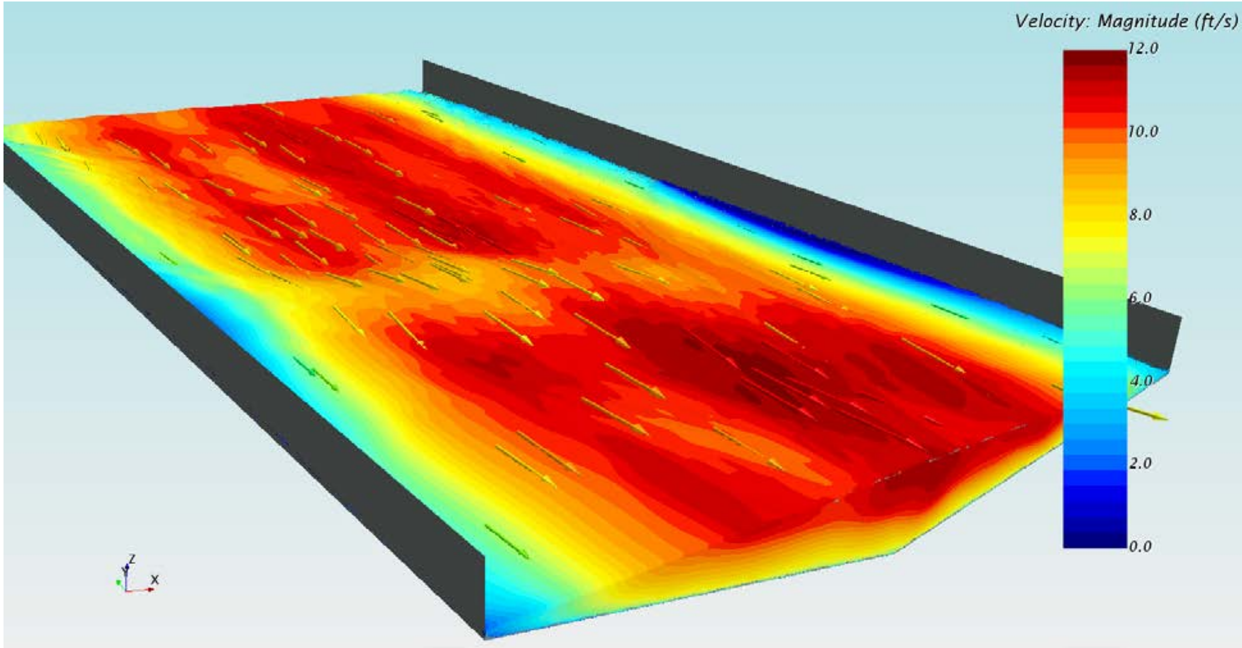


Figure 21 Velocity magnitude at water surface at 500 cfs.

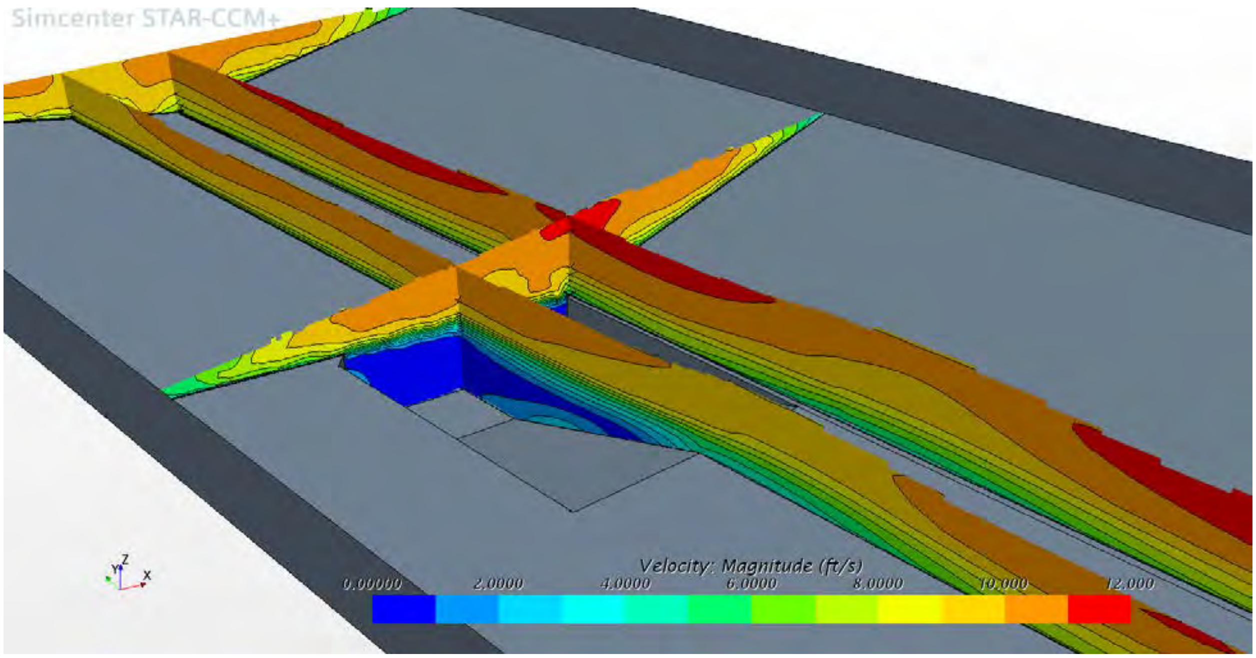


Figure 22 Velocity magnitude at sections at 500 cfs.

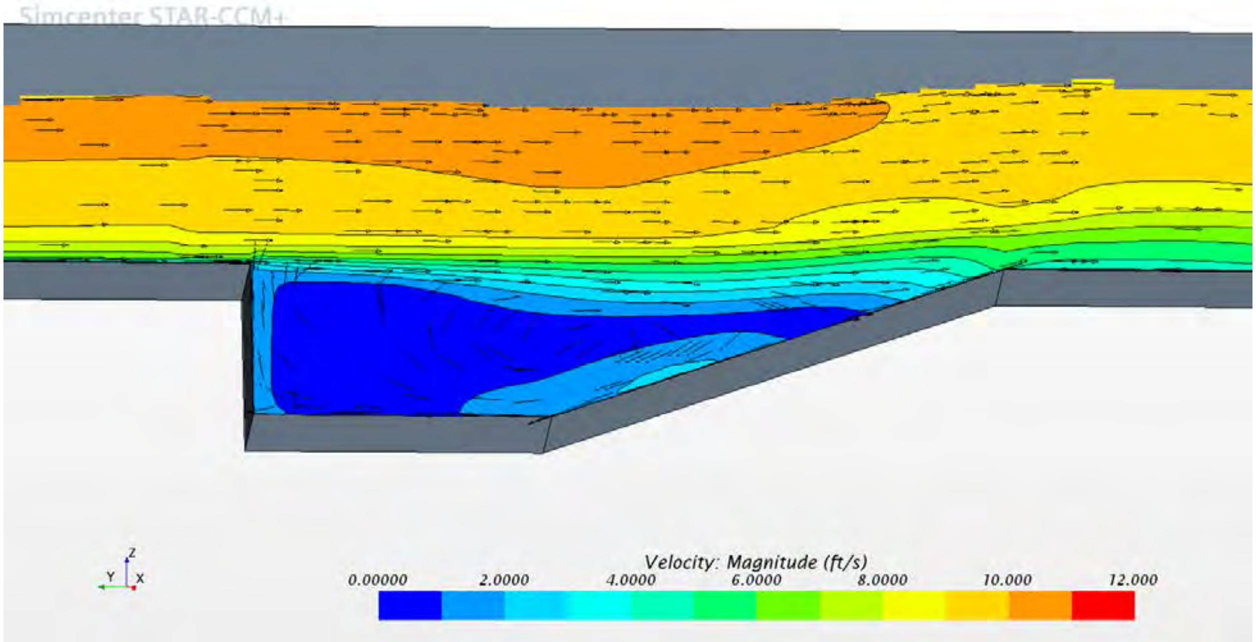


Figure 23 Velocity magnitude and direction at Longitudinal Section 1 (2.5 ft from channel invert) at 500 cfs.

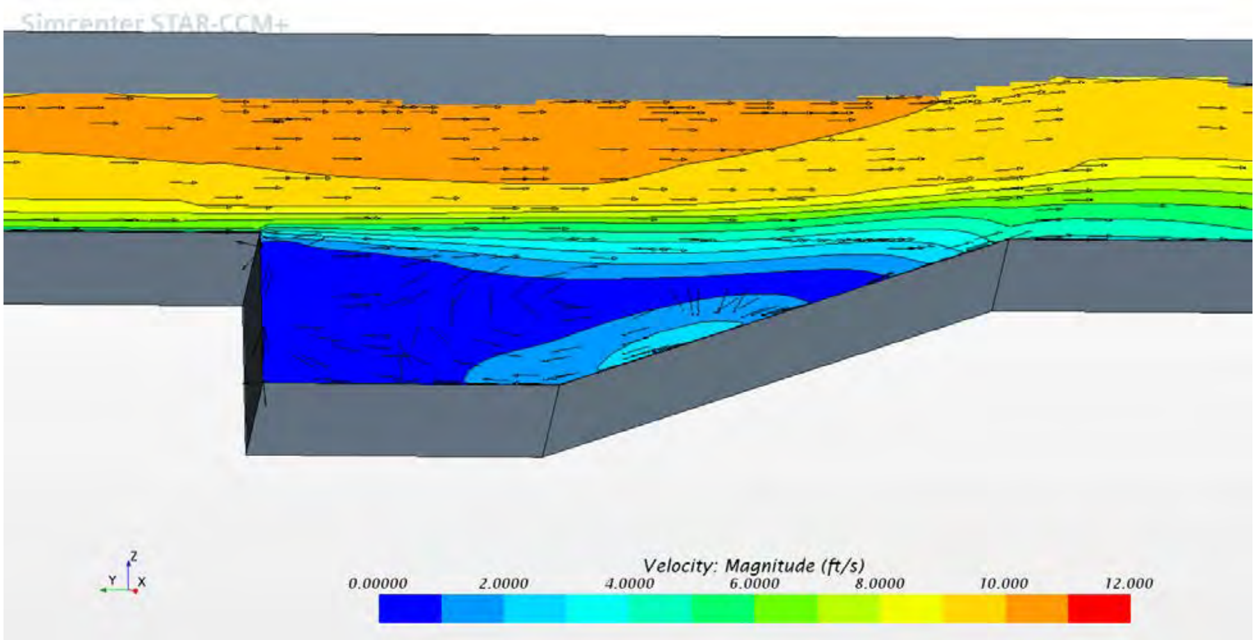


Figure 24 Velocity magnitude and direction at Longitudinal Section 2 (5 ft from channel invert) at 500 cfs.

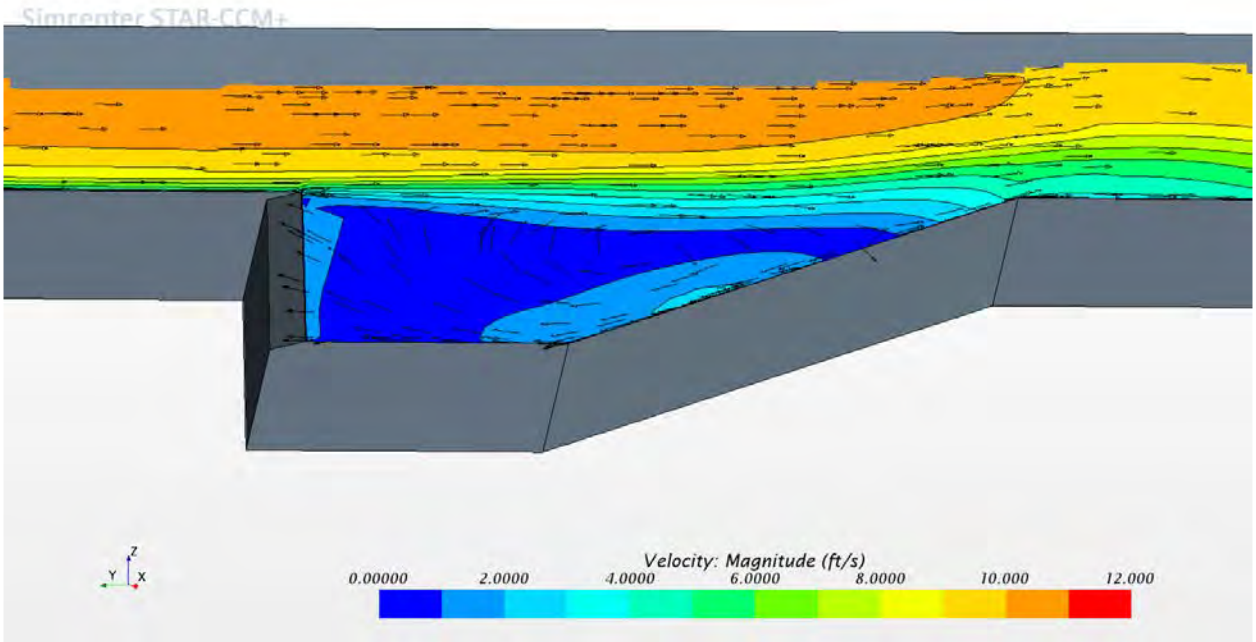


Figure 25 Velocity magnitude and direction at Longitudinal Section 3 (7.5 ft from channel invert) at 500 cfs.

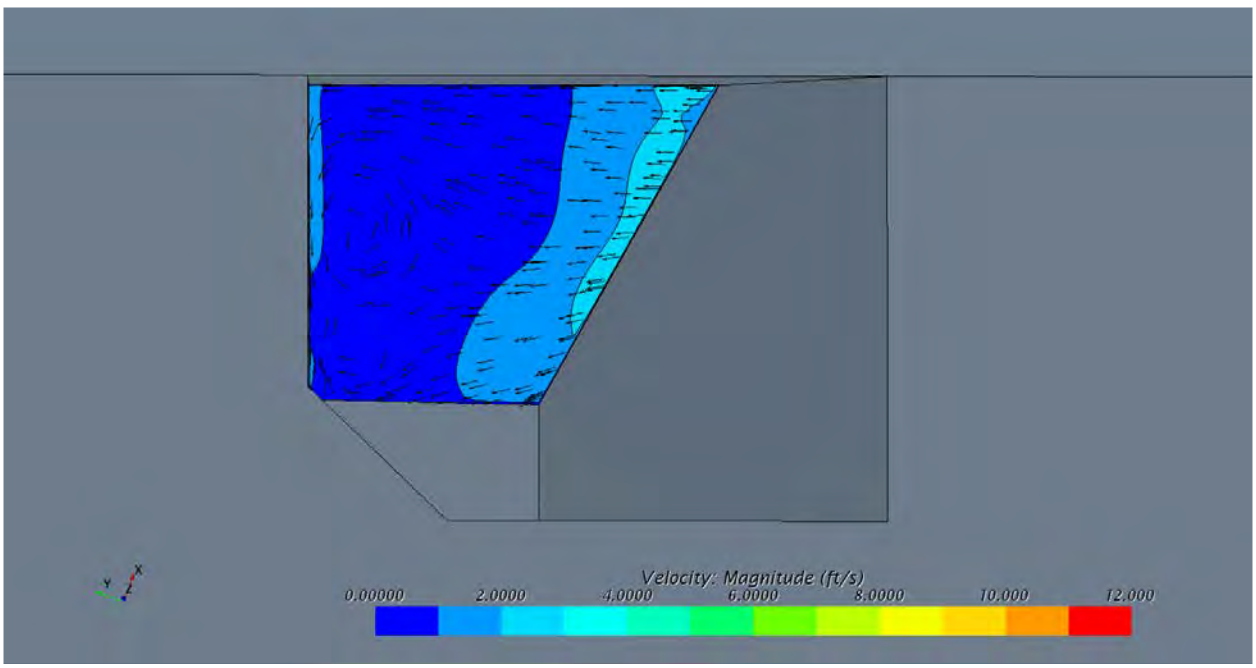


Figure 26 Velocity magnitude and direction at Horizontal Section 1 (Elev. 1 ft) at 500 cfs.

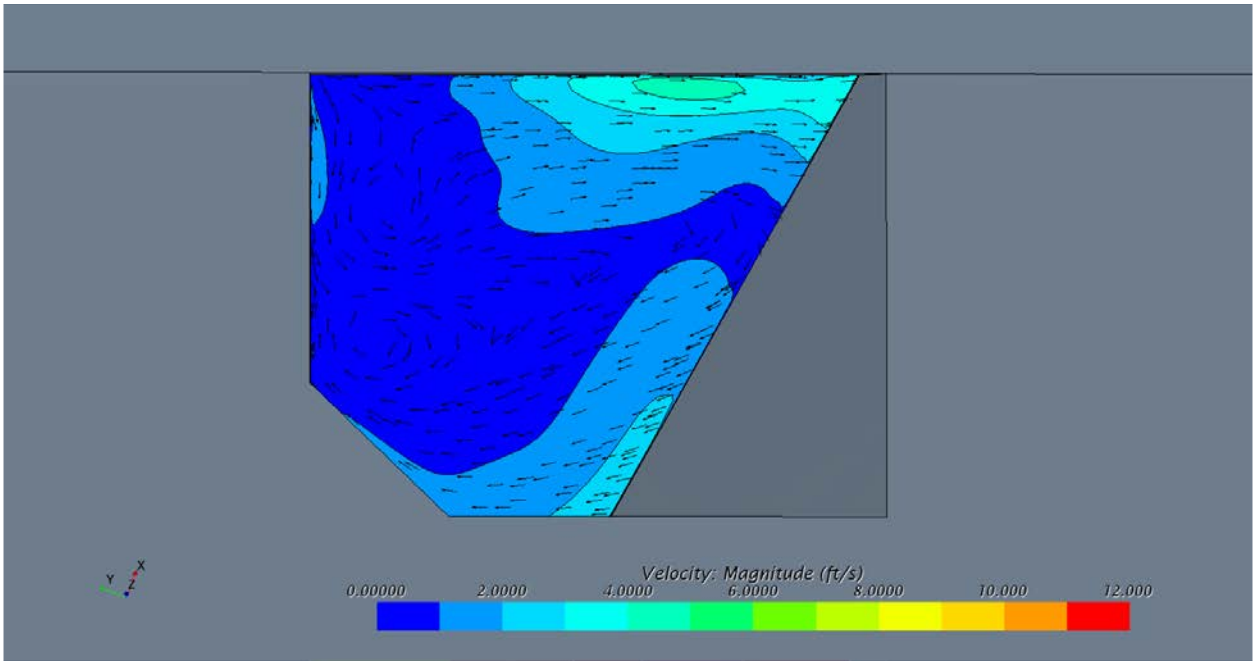


Figure 27 Velocity magnitude and direction at Horizontal Section 2 (Elev. 2 ft) at 500 cfs.

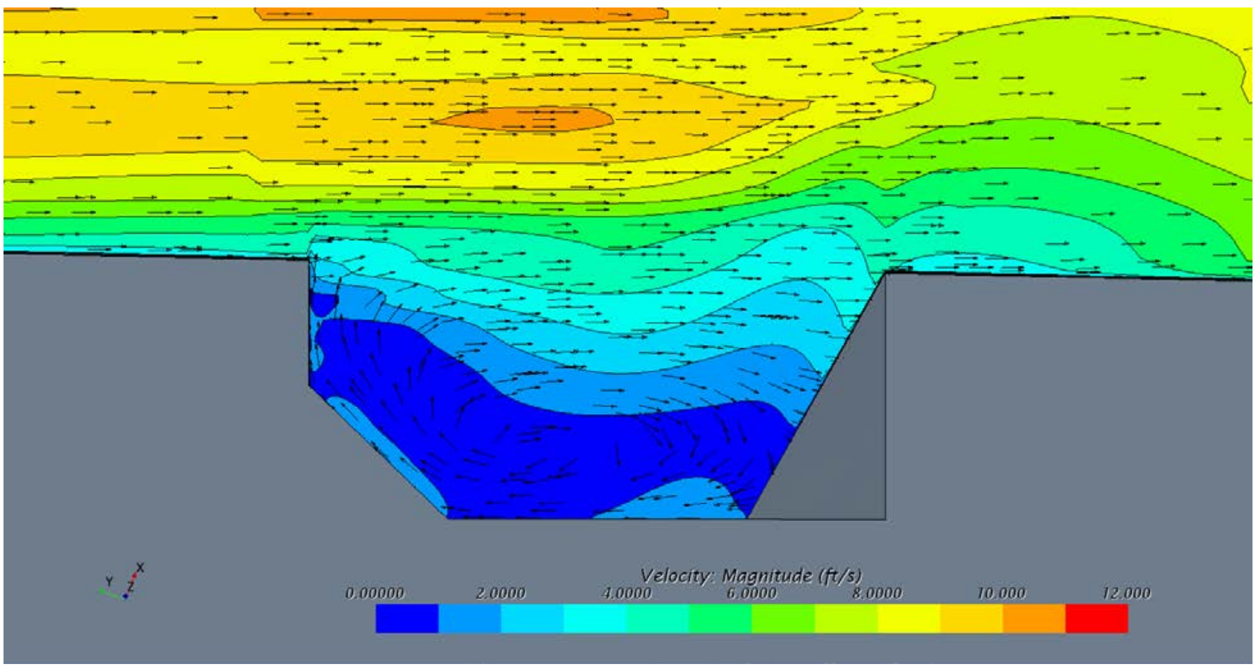


Figure 28 Velocity magnitude and direction at Horizontal Section 3 (Elev. 3 ft) at 500 cfs.

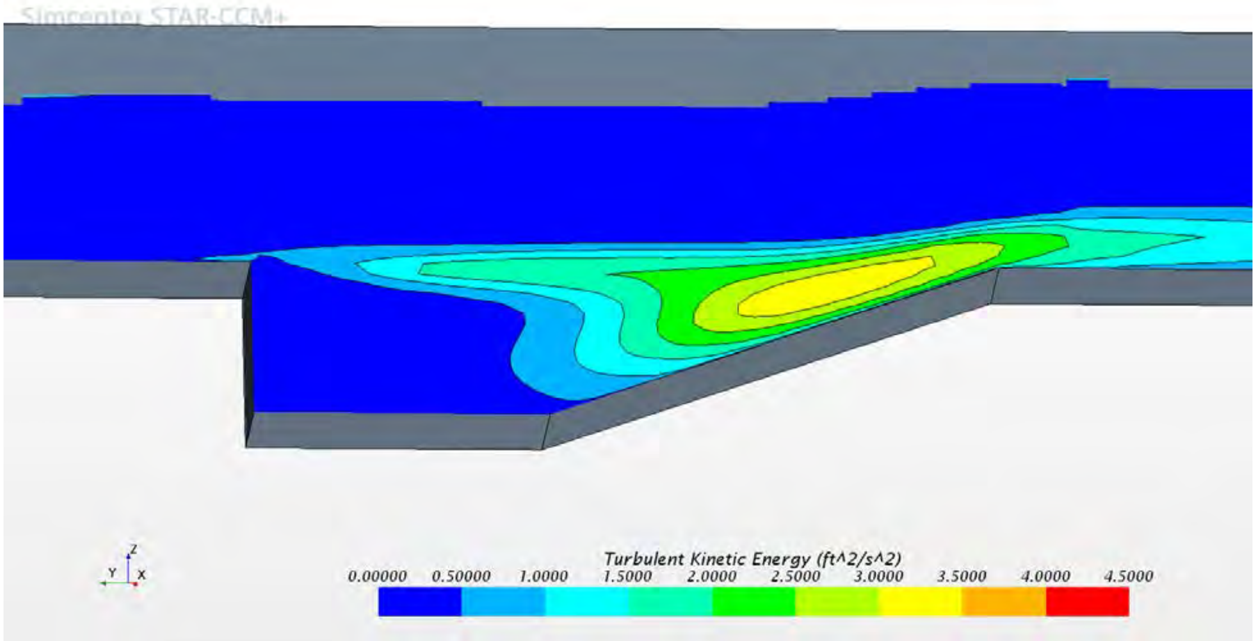


Figure 29 TKE magnitude at Longitudinal Section 1 (2.5 ft from channel invert) at 500 cfs.

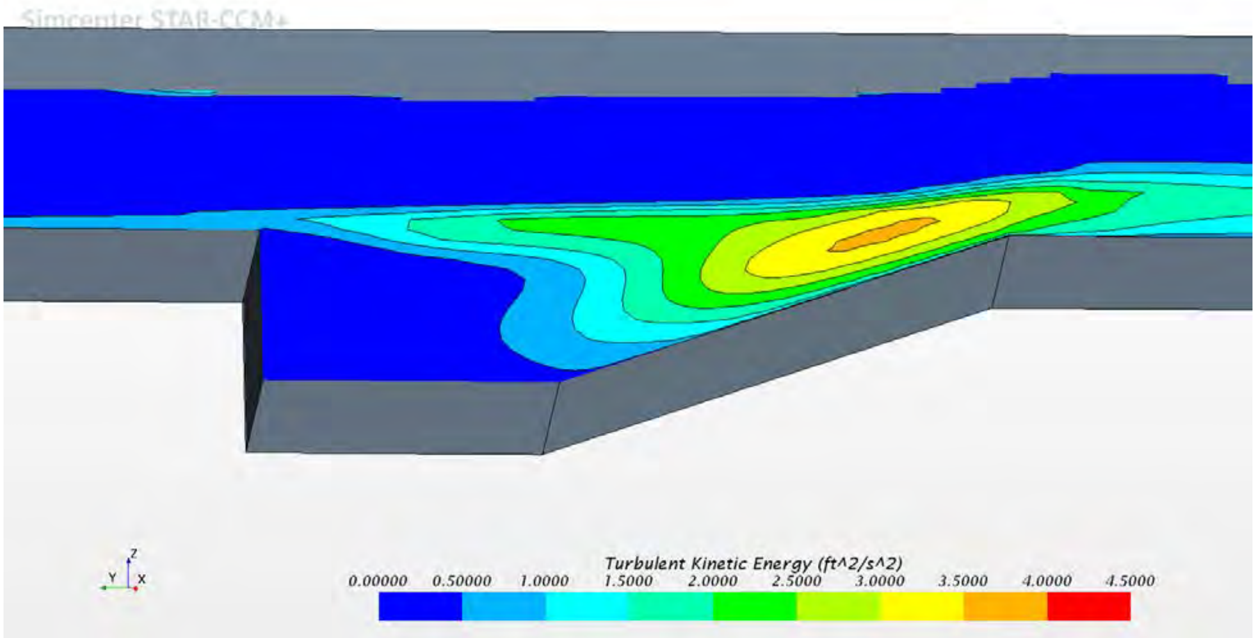


Figure 30 TKE magnitude at Longitudinal Section 2 (5 ft from channel invert) at 500 cfs.

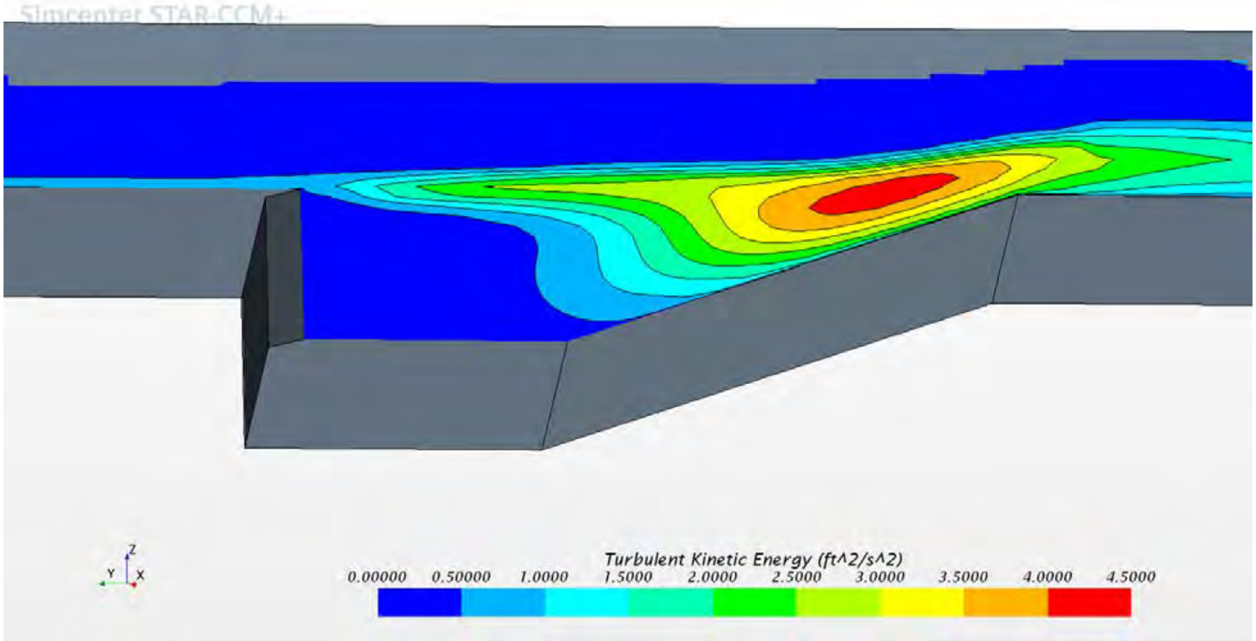


Figure 31 TKE magnitude at Longitudinal Section 3 (7.5 ft from channel invert) at 500 cfs.

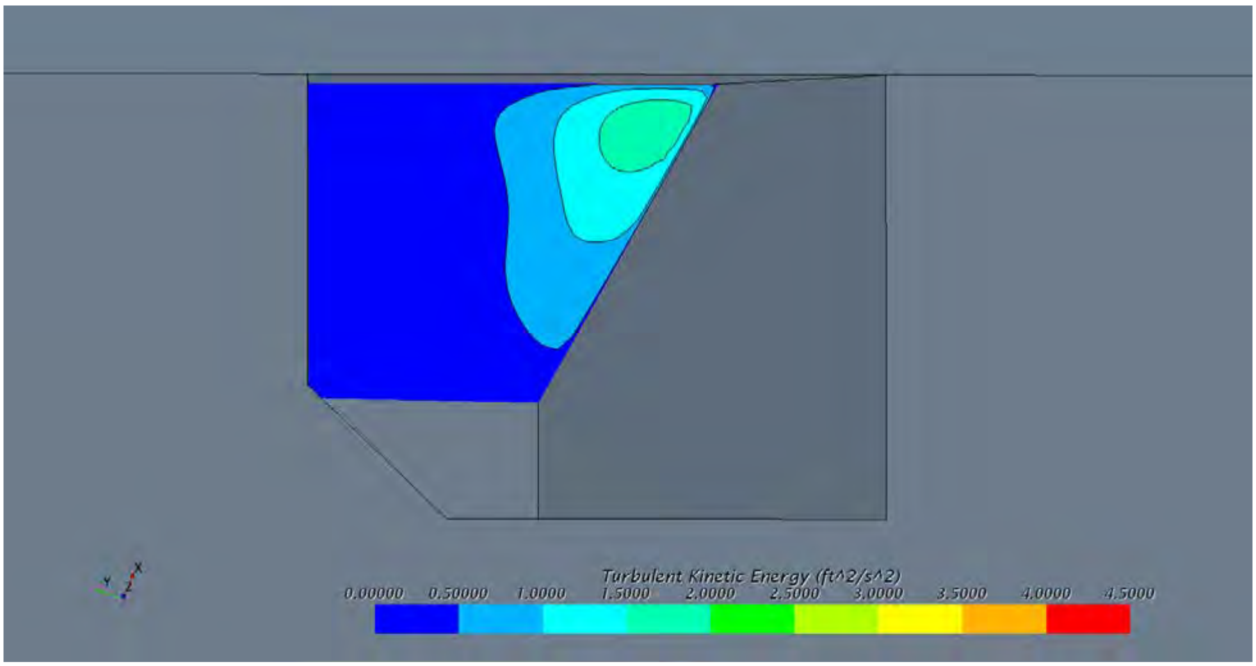


Figure 32 TKE magnitude at Horizontal Section 1 (Elev. 1 ft) at 500 cfs.

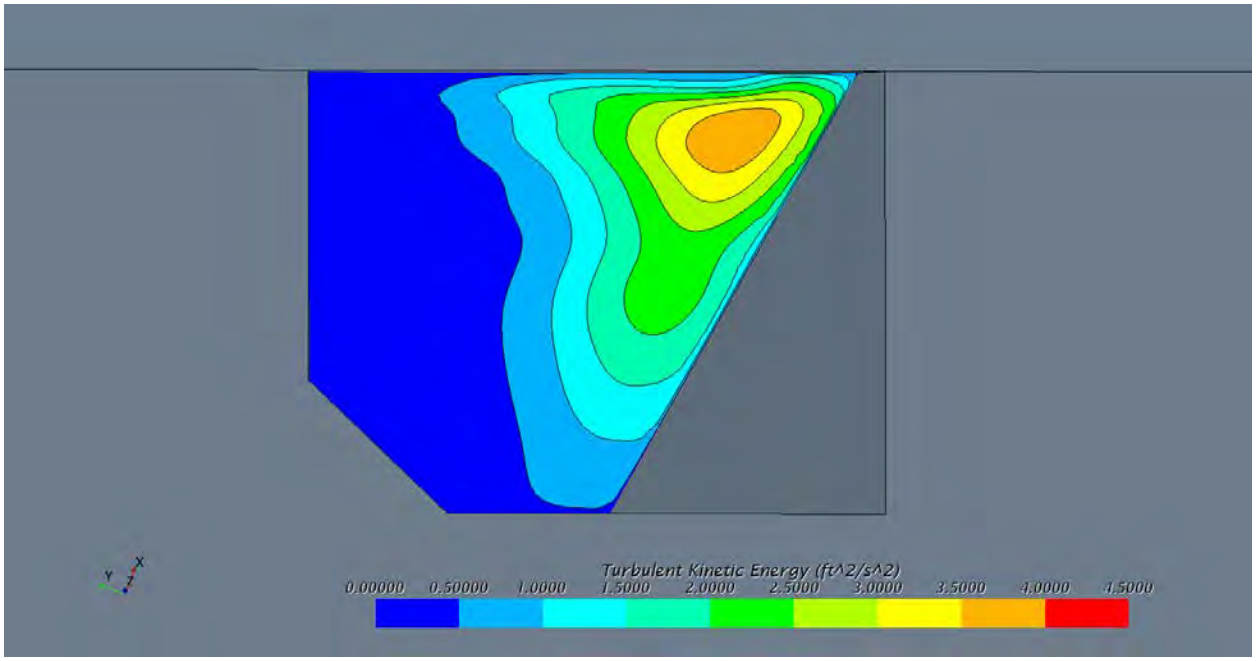


Figure 33 TKE magnitude at Horizontal Section 2 (Elev. 2 ft) at 500 cfs.

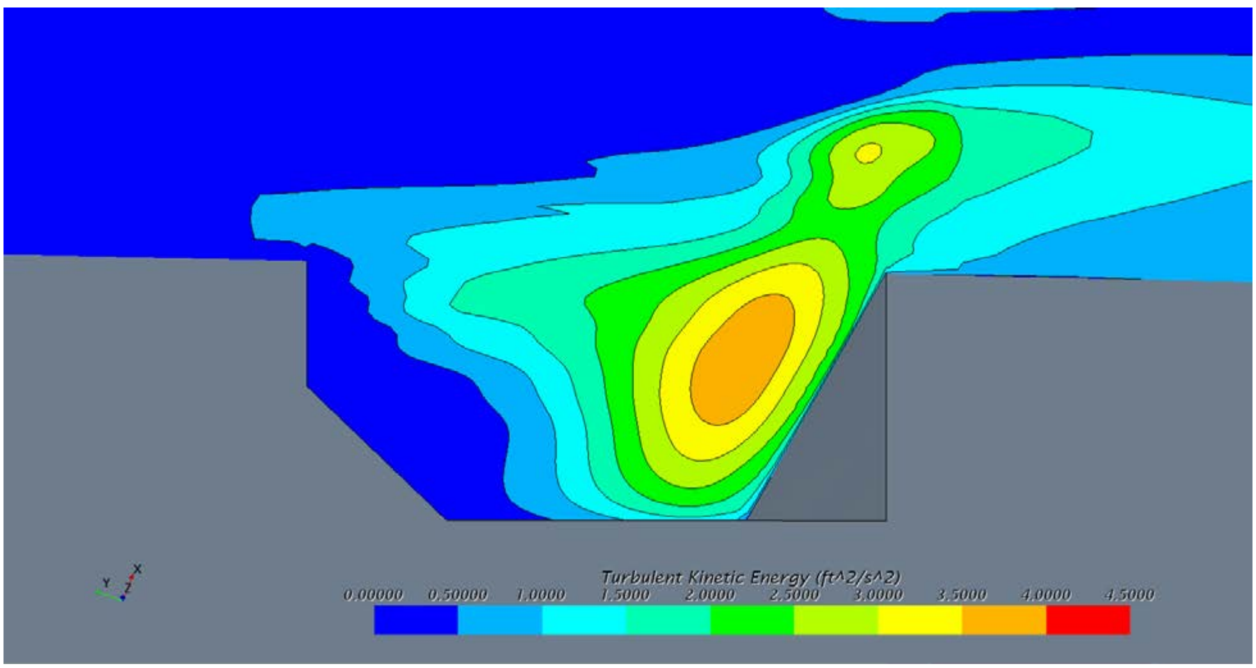


Figure 34 TKE magnitude at Horizontal Section 3 (Elev. 3 ft) at 500 cfs.

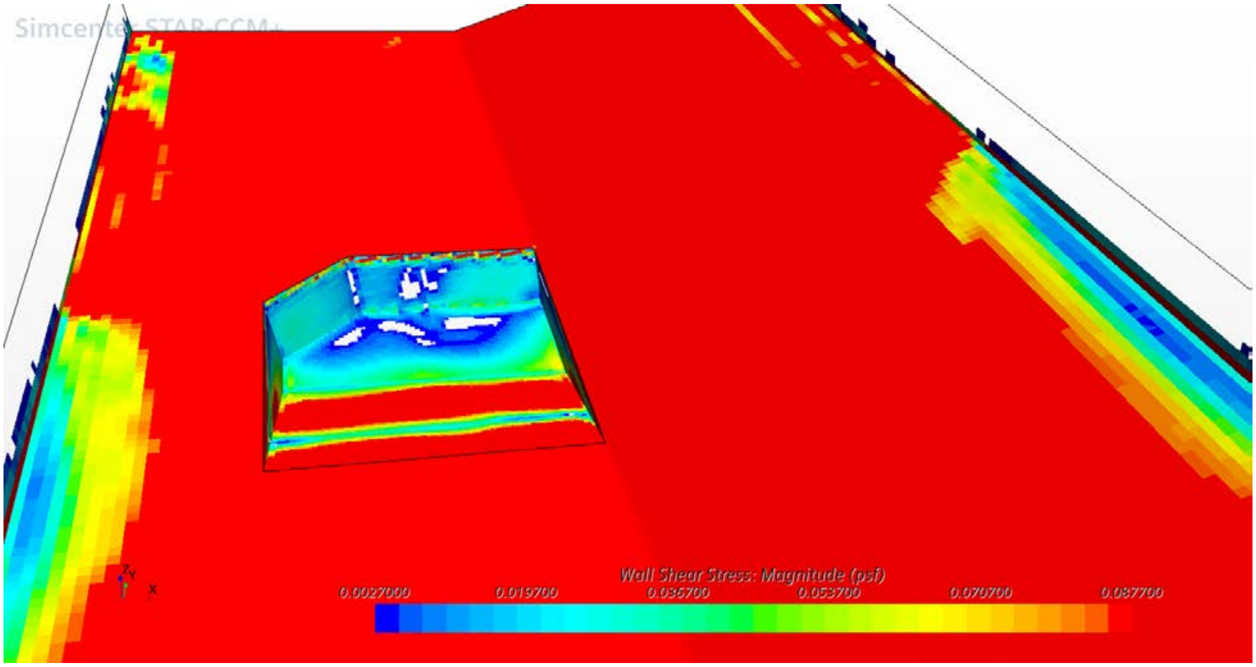


Figure 35 Shear stress magnitude on channel bottom at 500 cfs.

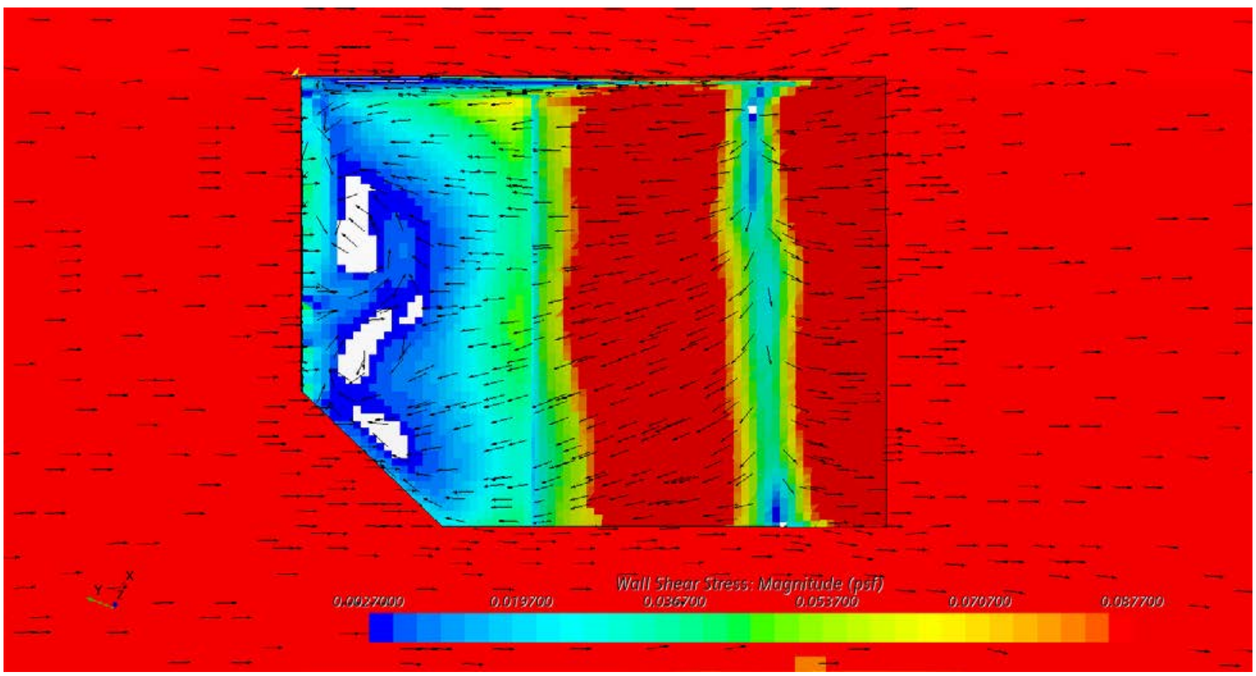


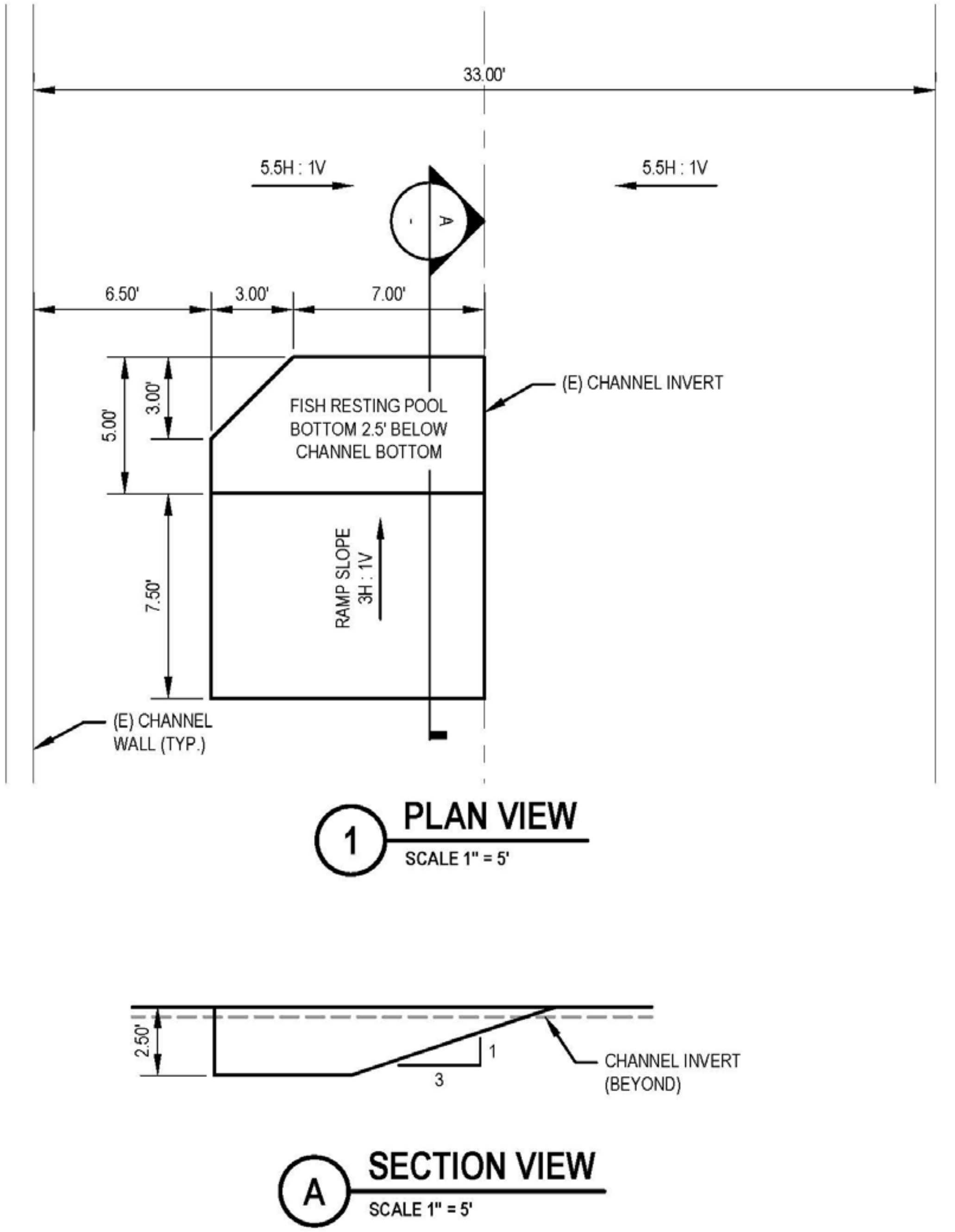
Figure 36 Shear stress magnitude and direction at fish pool at 500 cfs.

Attachment 5

Analysis of Alternative 3
Resting Pool Configuration

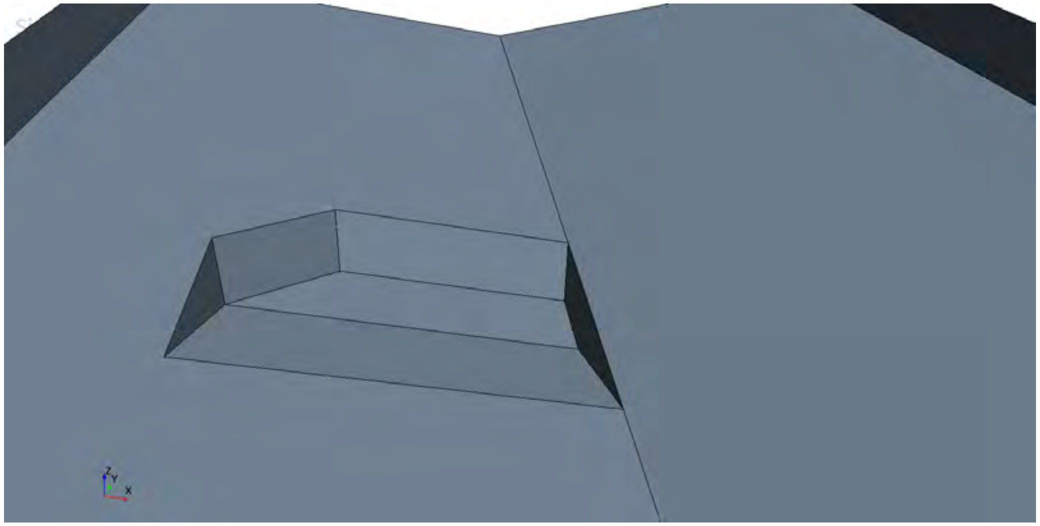
Alternative 3 Fish Pool Geometry

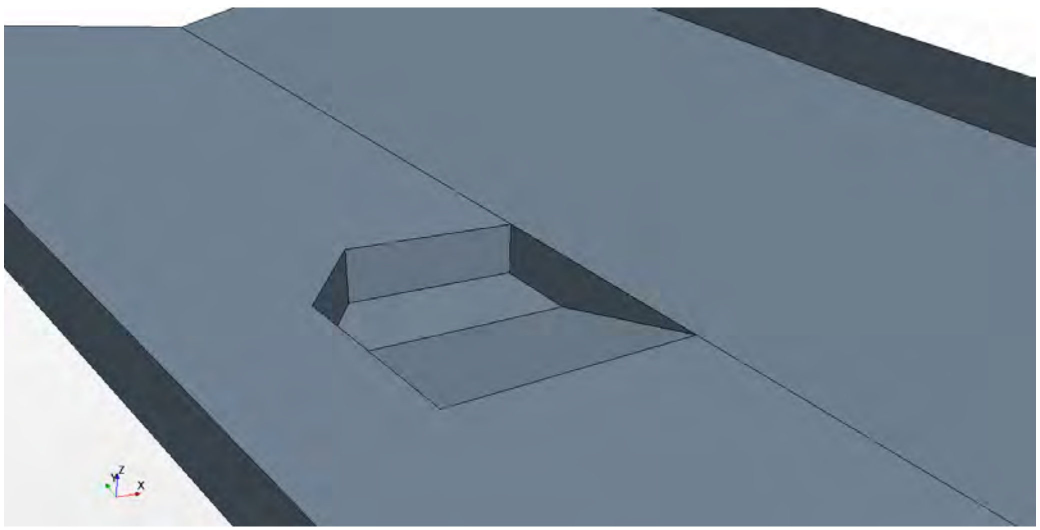
Figure 1: Alternative 3 fish pool layout in plan and profile.



Alternative 3 Fish Pool Geometry

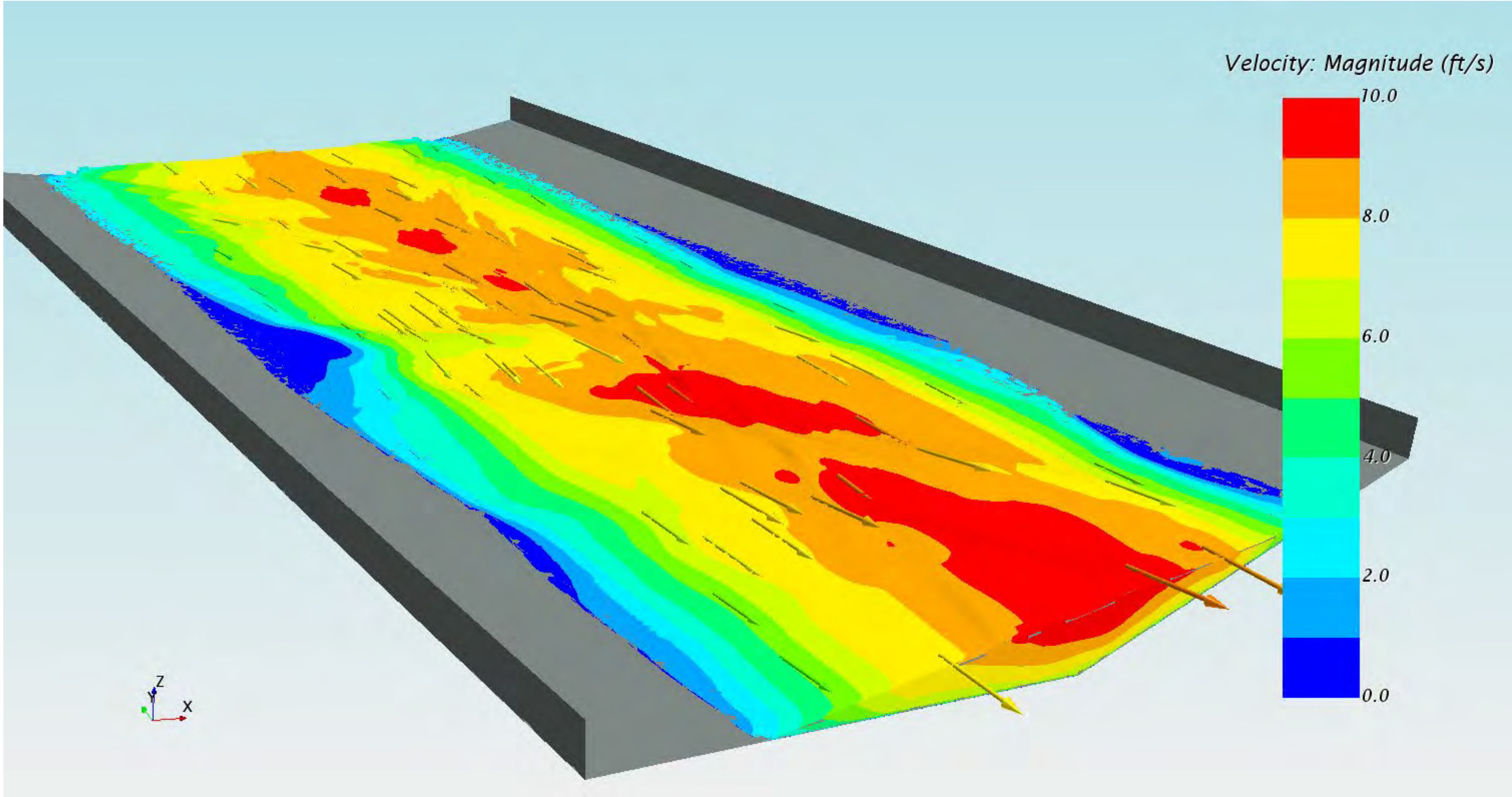
Figure 2: Front view looking upstream and angled view looking upstream





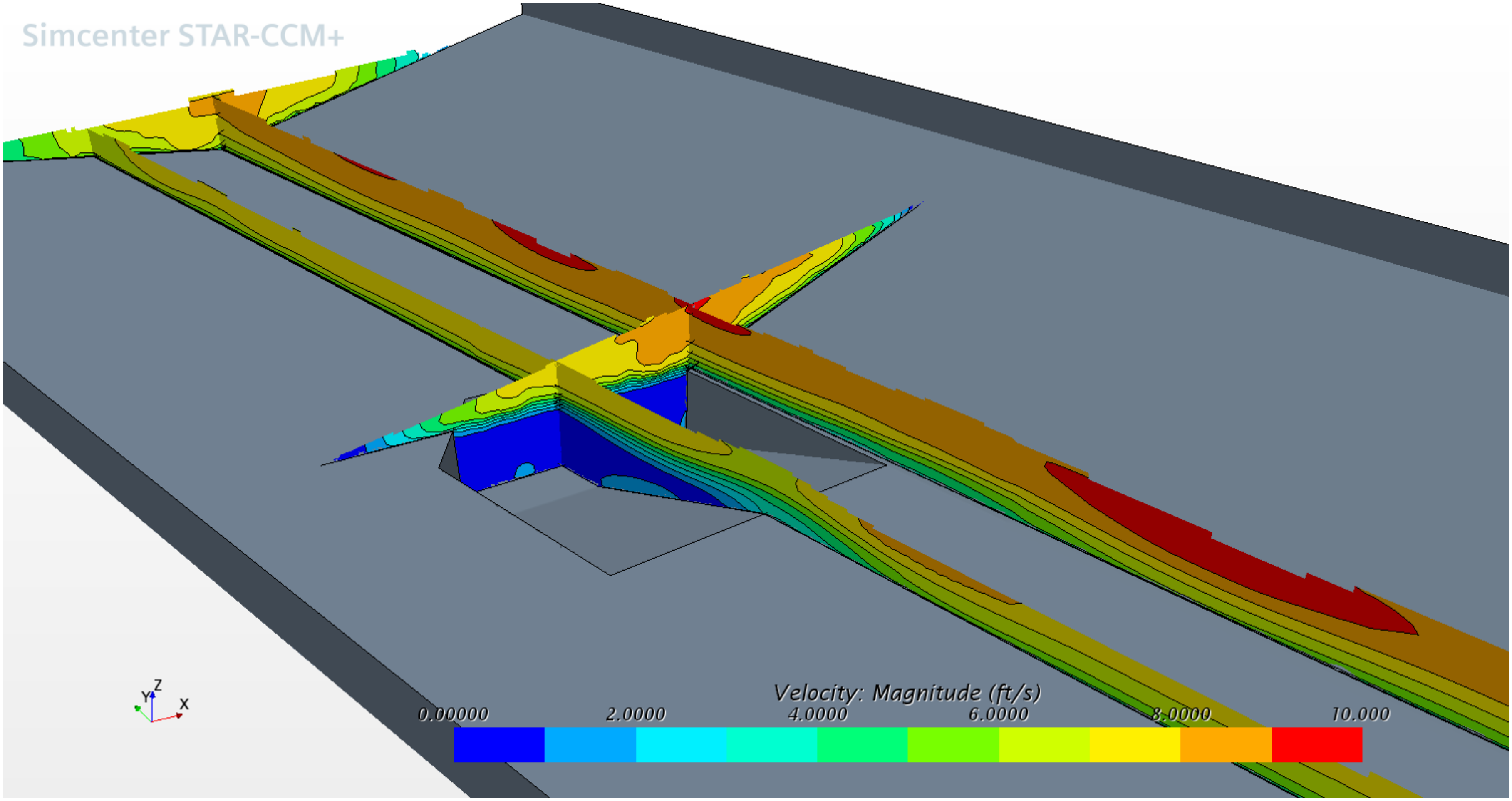
Velocity (Q = 180 cfs)

Figure 3: Velocity magnitude at water surface



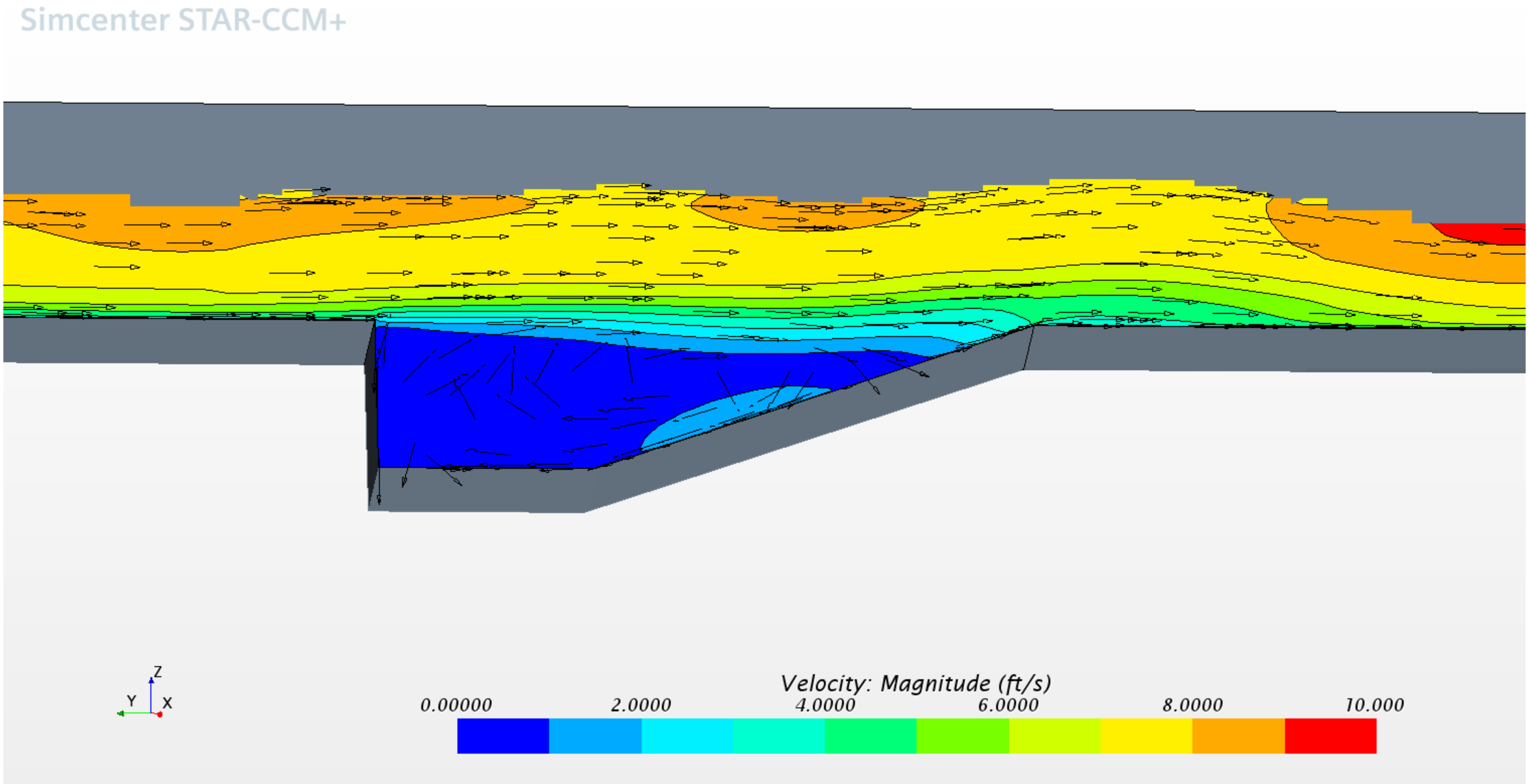
Velocity (Q = 180 cfs)

Figure 4: Velocity magnitude at sections



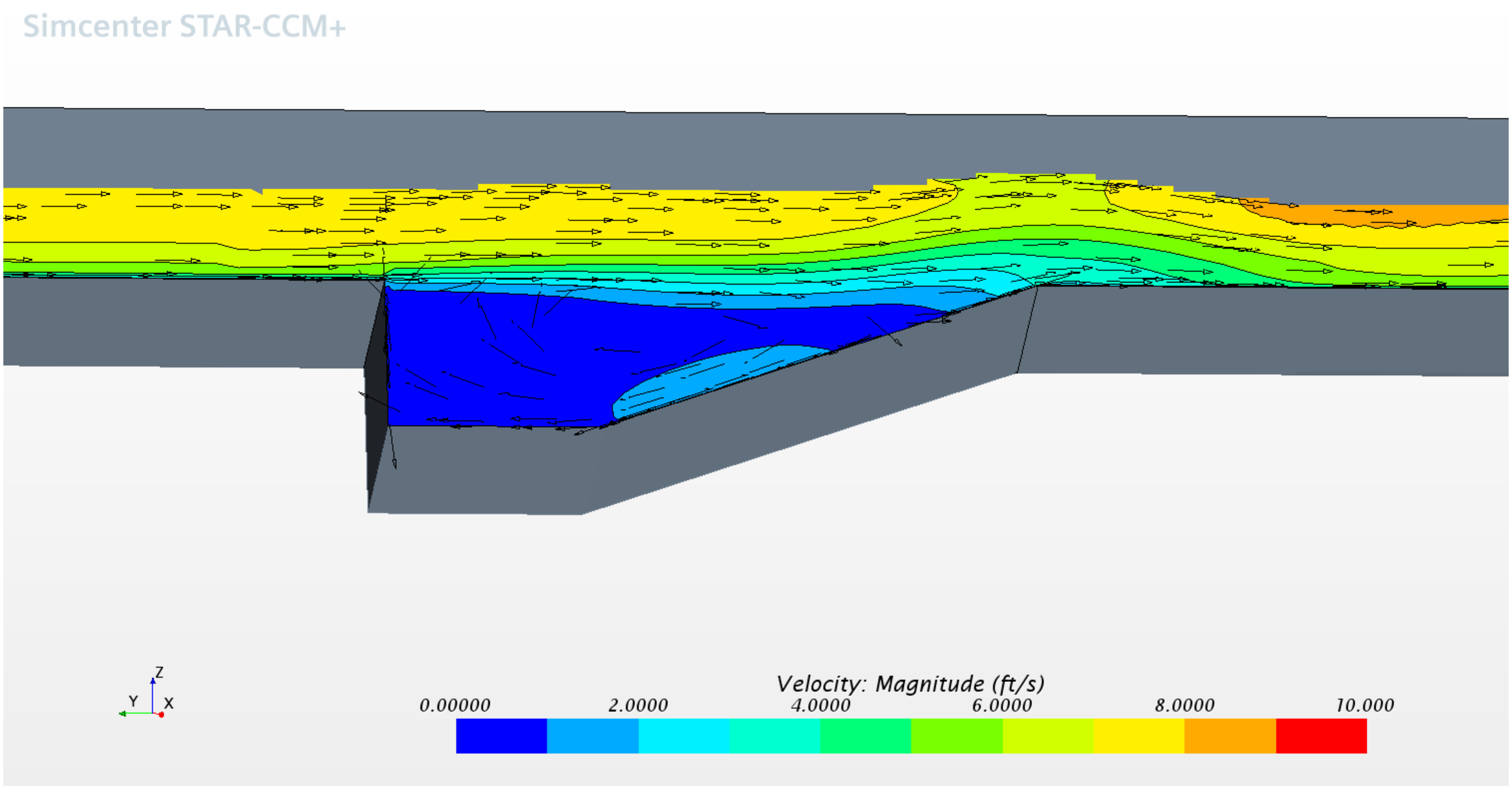
Velocity (Q = 180 cfs)

Figure 5: Velocity magnitude and direction at Longitudinal Section 1 (2.5 ft from channel invert)



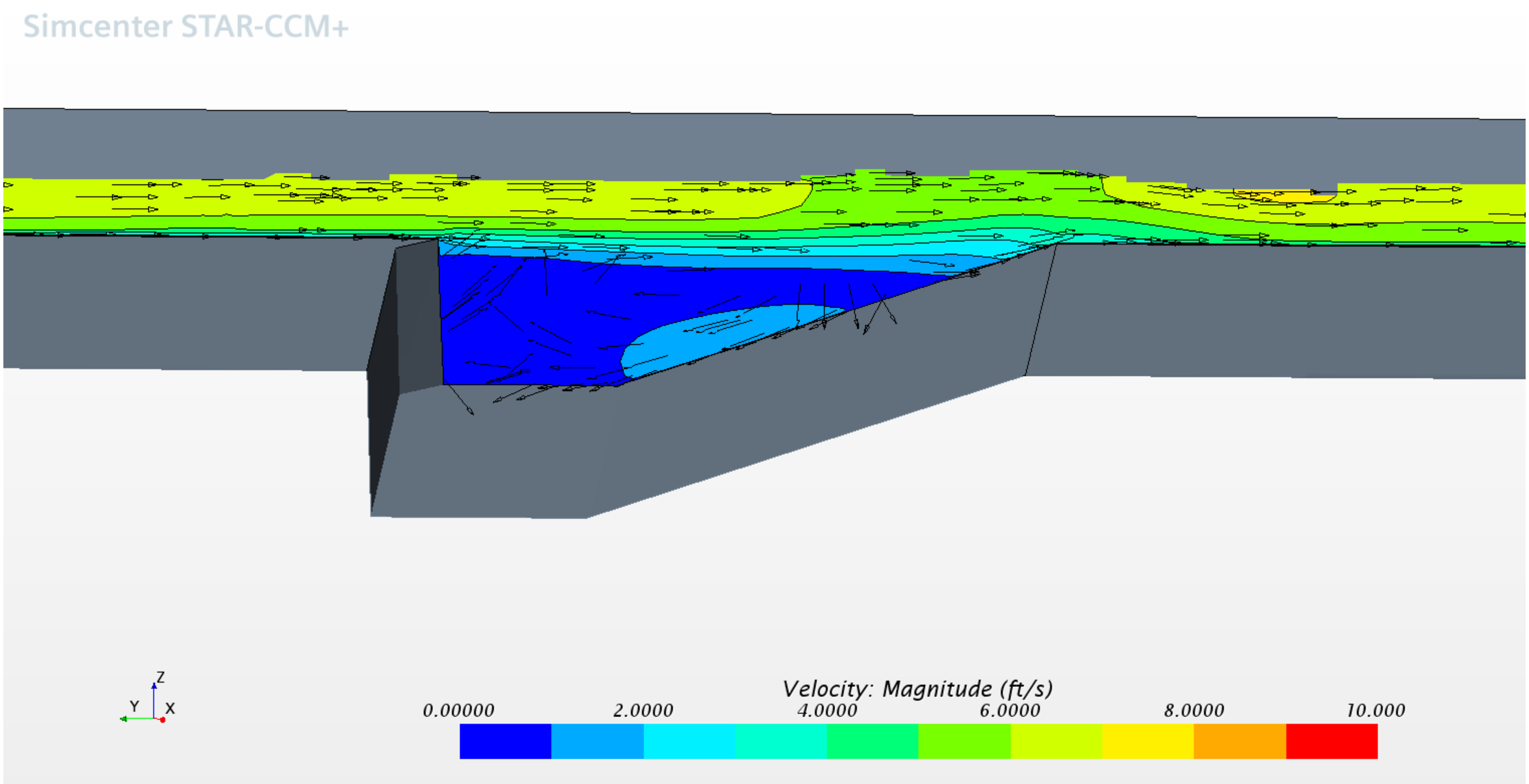
Velocity (Q = 180 cfs)

Figure 6: Velocity magnitude and direction at Longitudinal Section 2 (5 ft from channel invert)



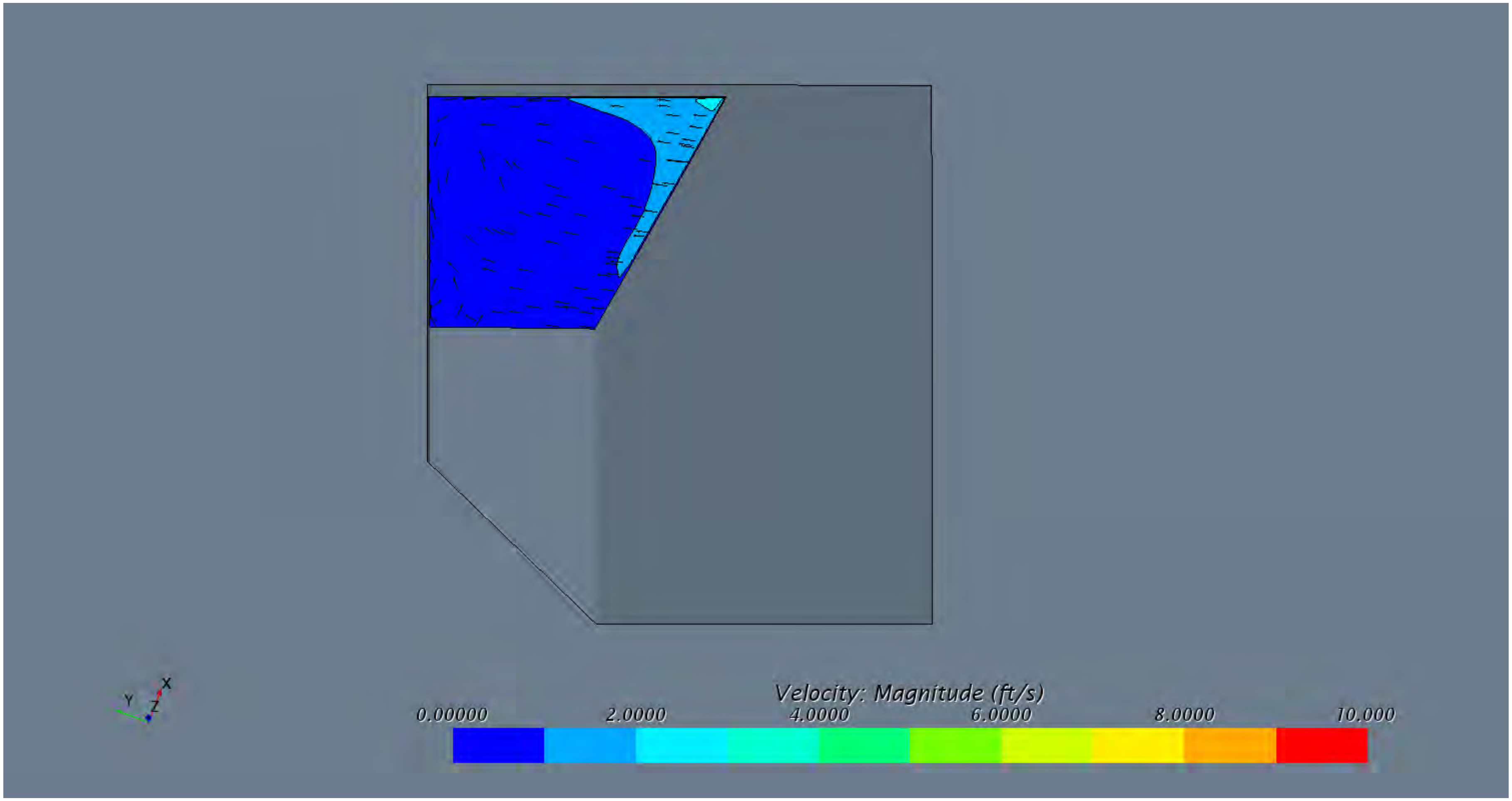
Velocity (Q = 180 cfs)

Figure 7: Velocity magnitude and direction at Longitudinal Section 3 (7.5 ft from channel invert)



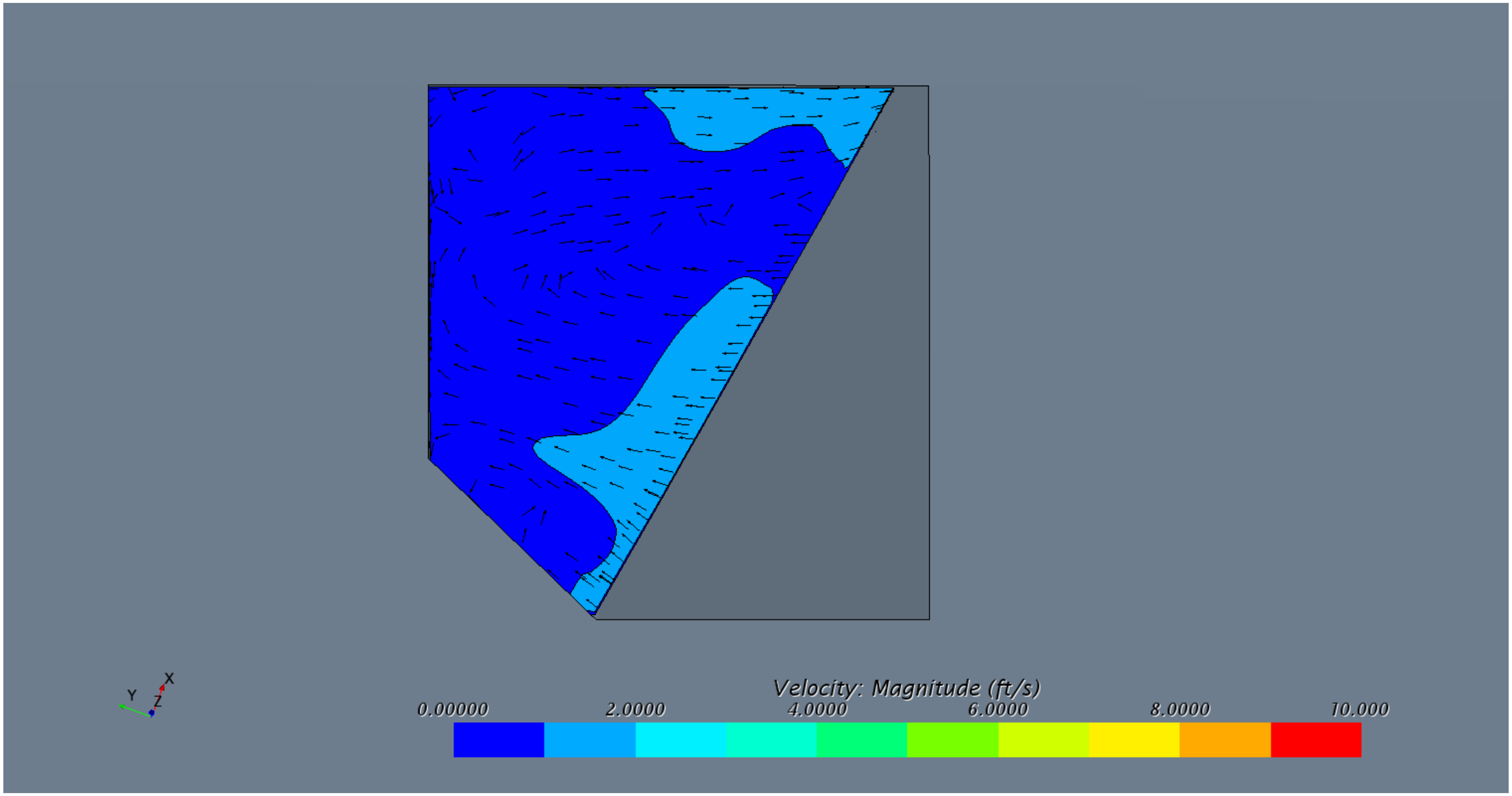
Velocity (Q = 180 cfs)

Figure 8: Velocity magnitude and direction at Horizontal Section 1 (Elev. 1 ft)



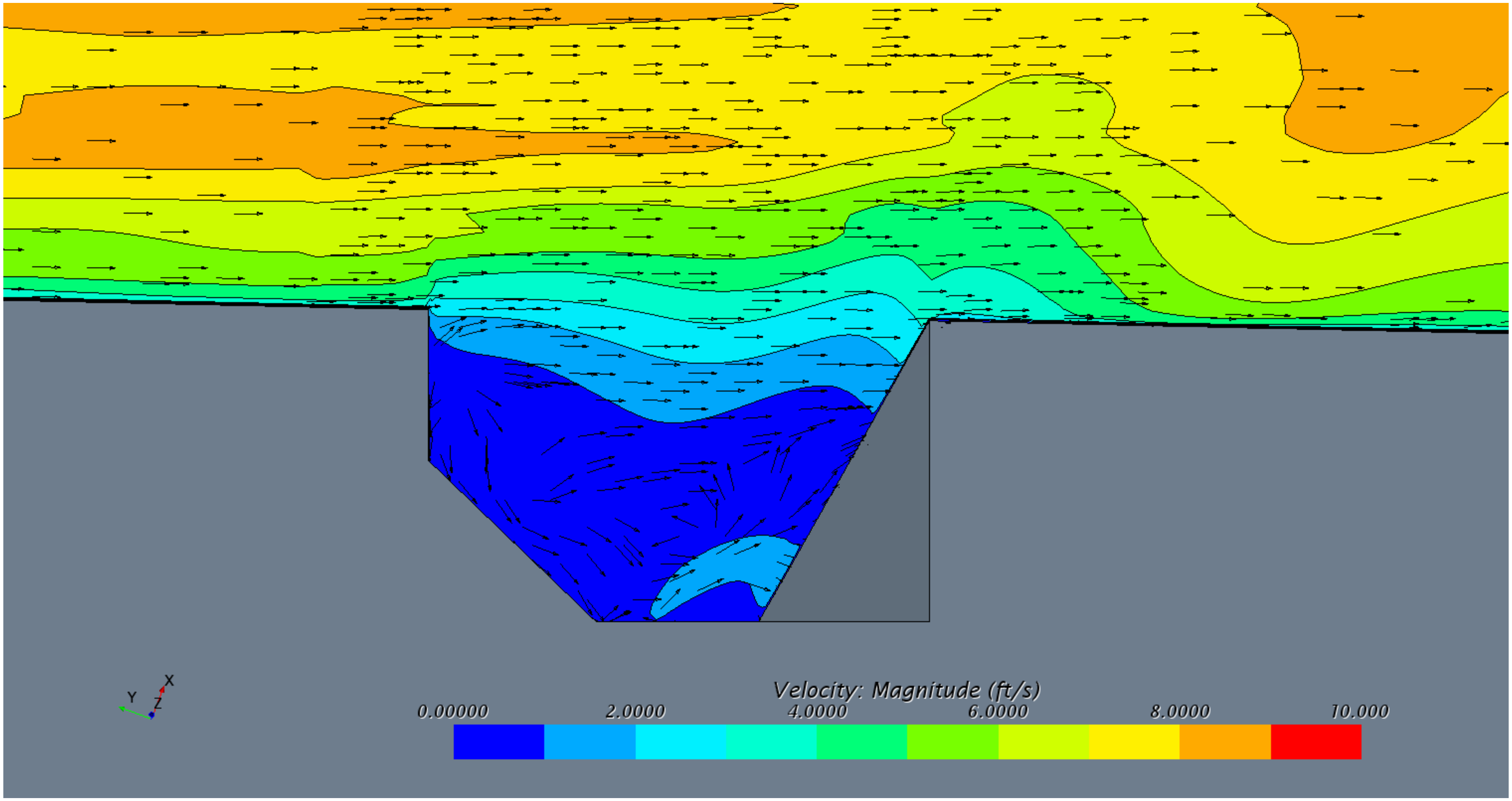
Velocity (Q = 180 cfs)

Figure 9: Velocity magnitude and direction at Horizontal Section 2 (Elev. 2 ft)



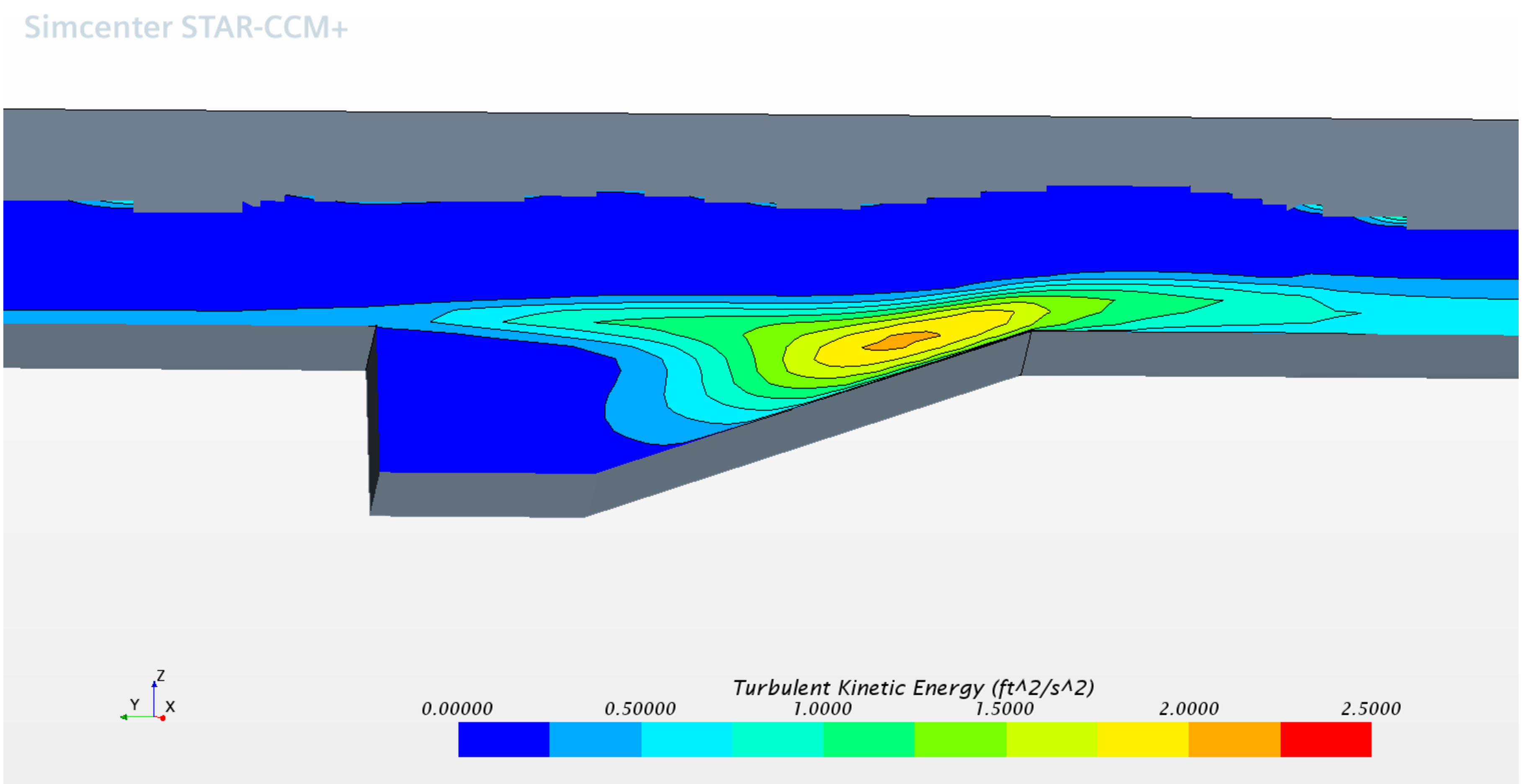
Velocity (Q = 180 cfs)

Figure 10: Velocity magnitude and direction at Horizontal Section 3 (Elev. 3 ft)



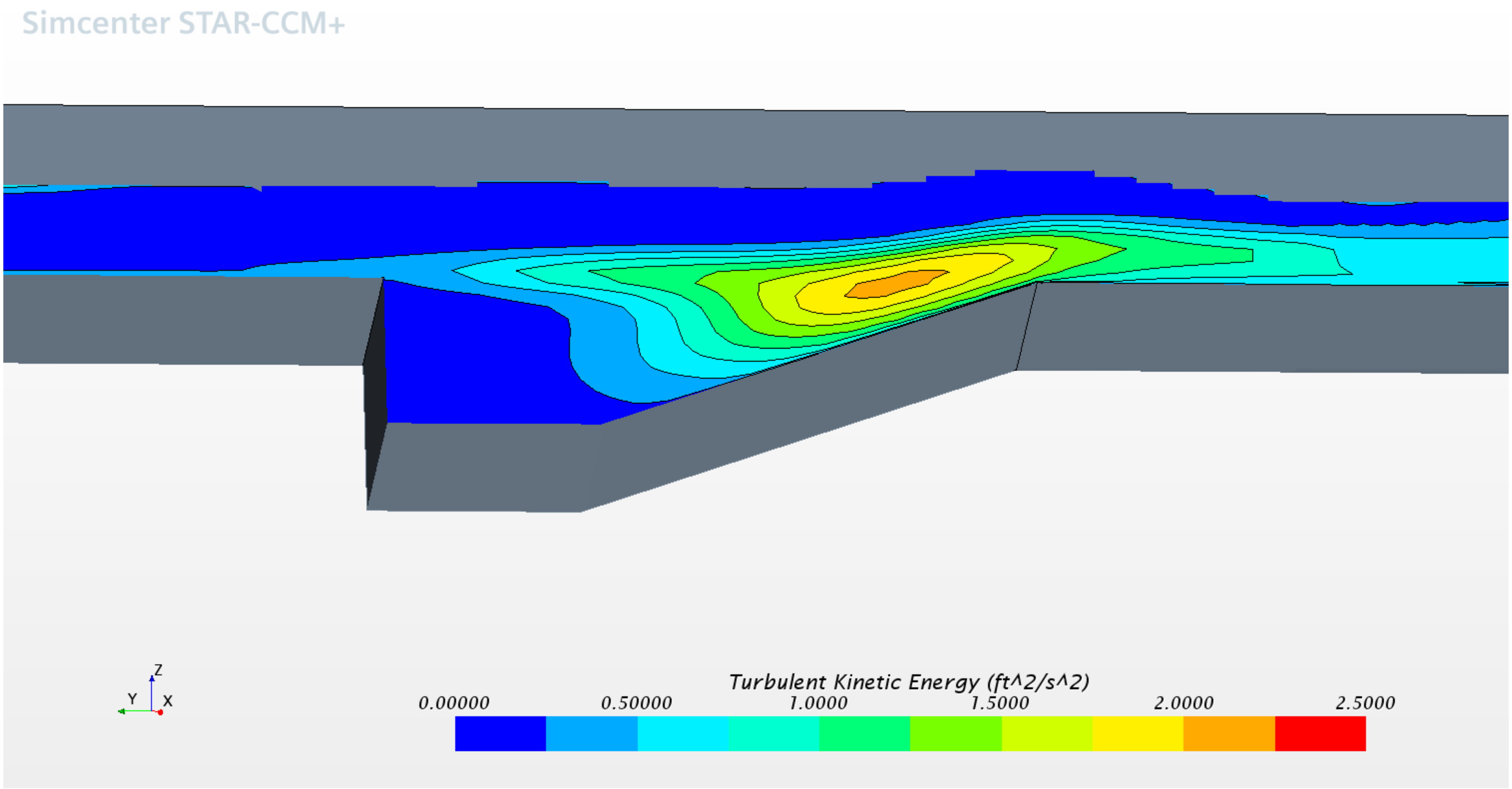
Turbulent Kinetic Energy (Q = 180 cfs)

Figure 11: TKE magnitude at Longitudinal Section 1 (2.5 ft from channel invert)



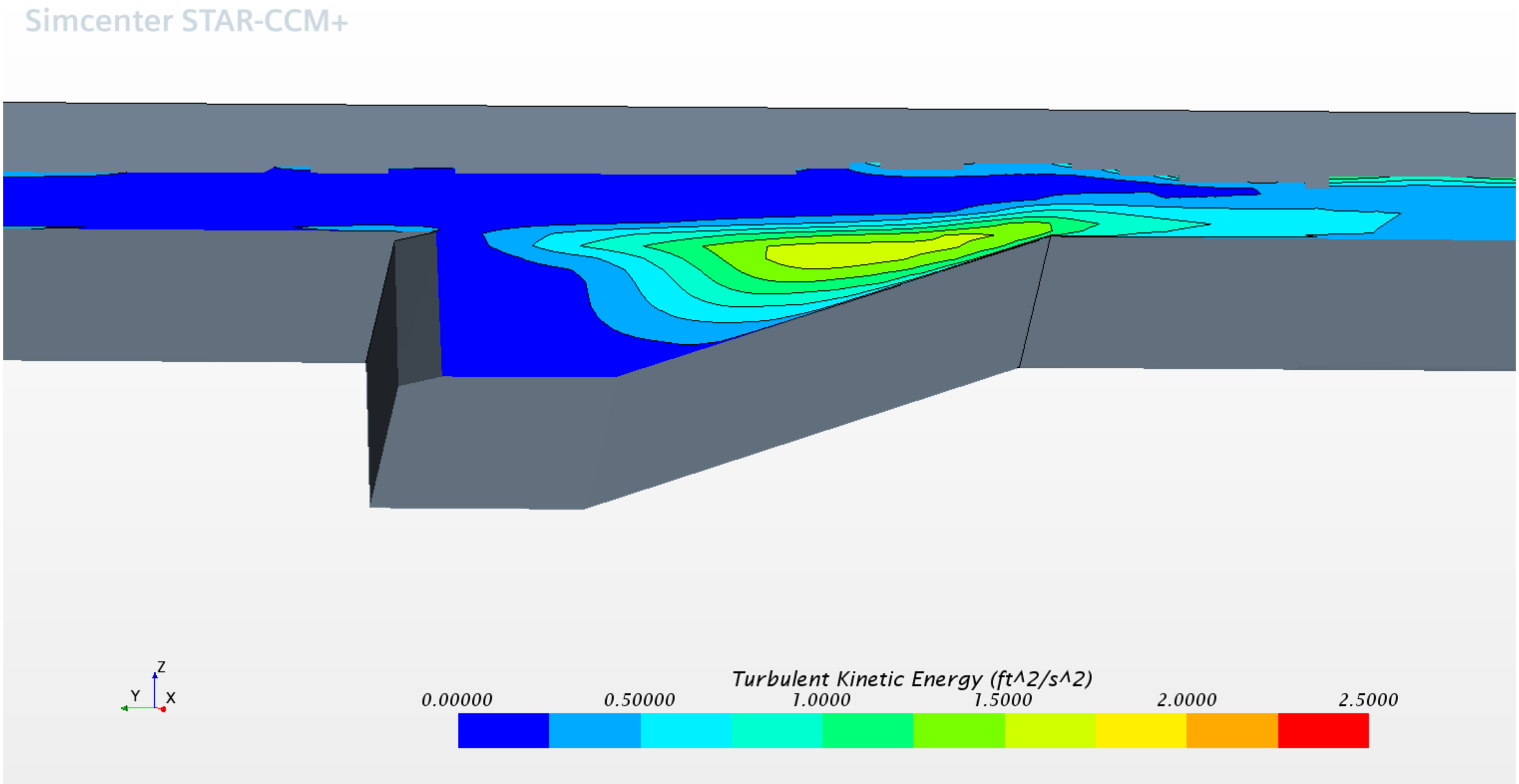
Velocity (Q = 180 cfs)

Figure 12: TKE magnitude at Longitudinal Section 2 (5 ft from channel invert)



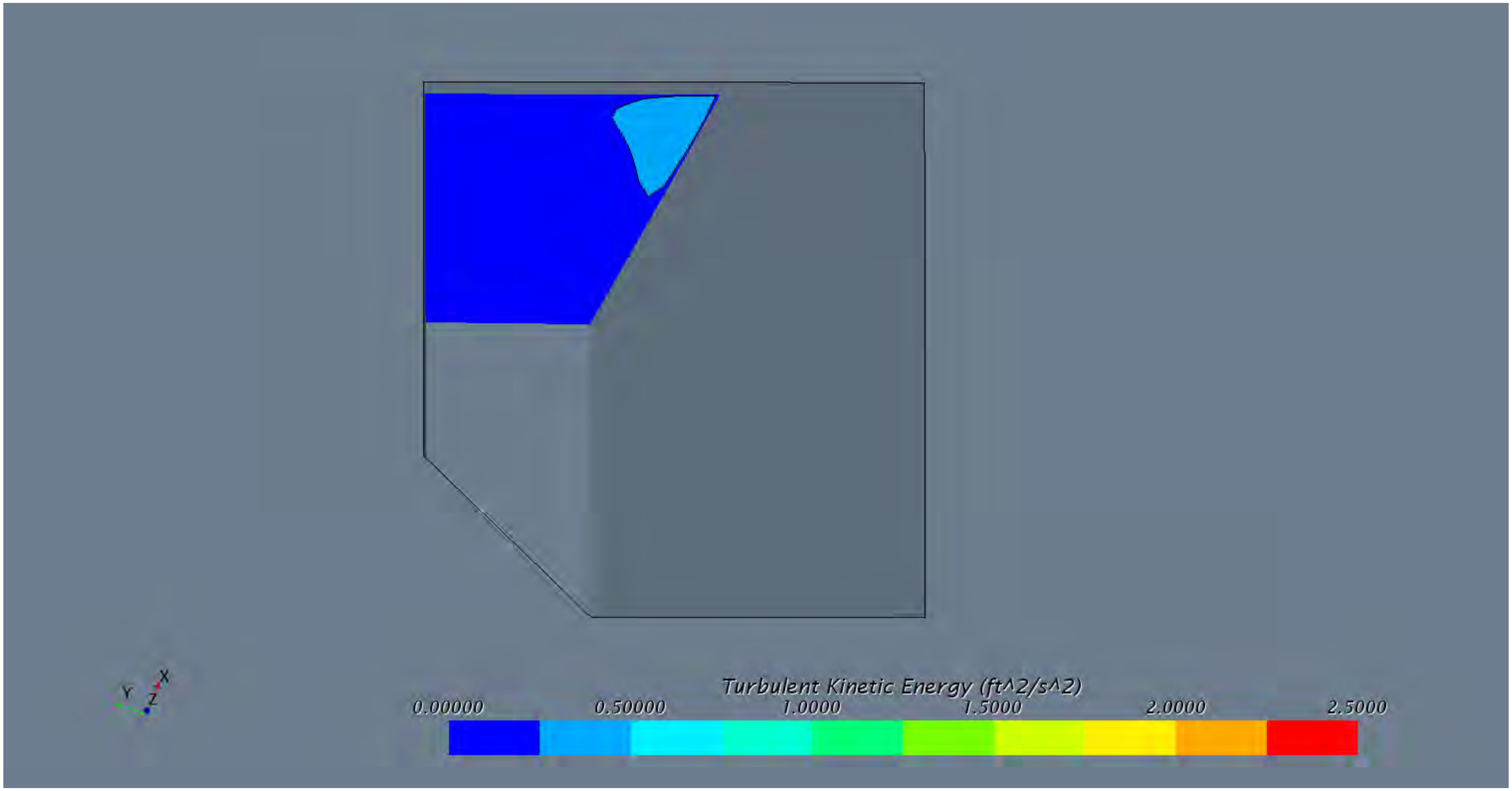
Velocity (Q = 180 cfs)

Figure 13: TKE magnitude at Longitudinal Section 3 (7.5 ft from channel invert)



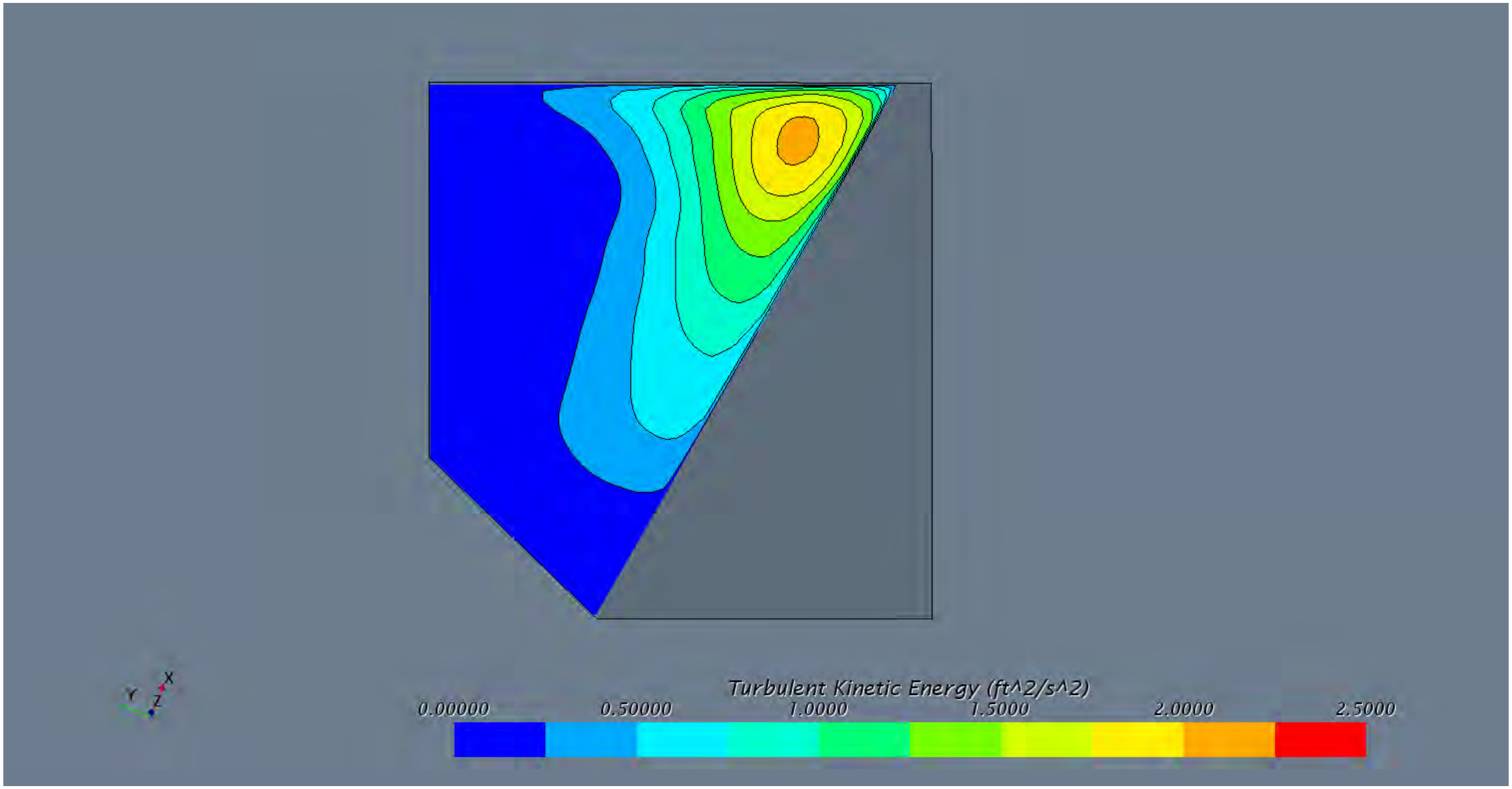
Velocity (Q = 180 cfs)

Figure 14: TKE magnitude at Horizontal Section 1 (Elev. 1 ft)



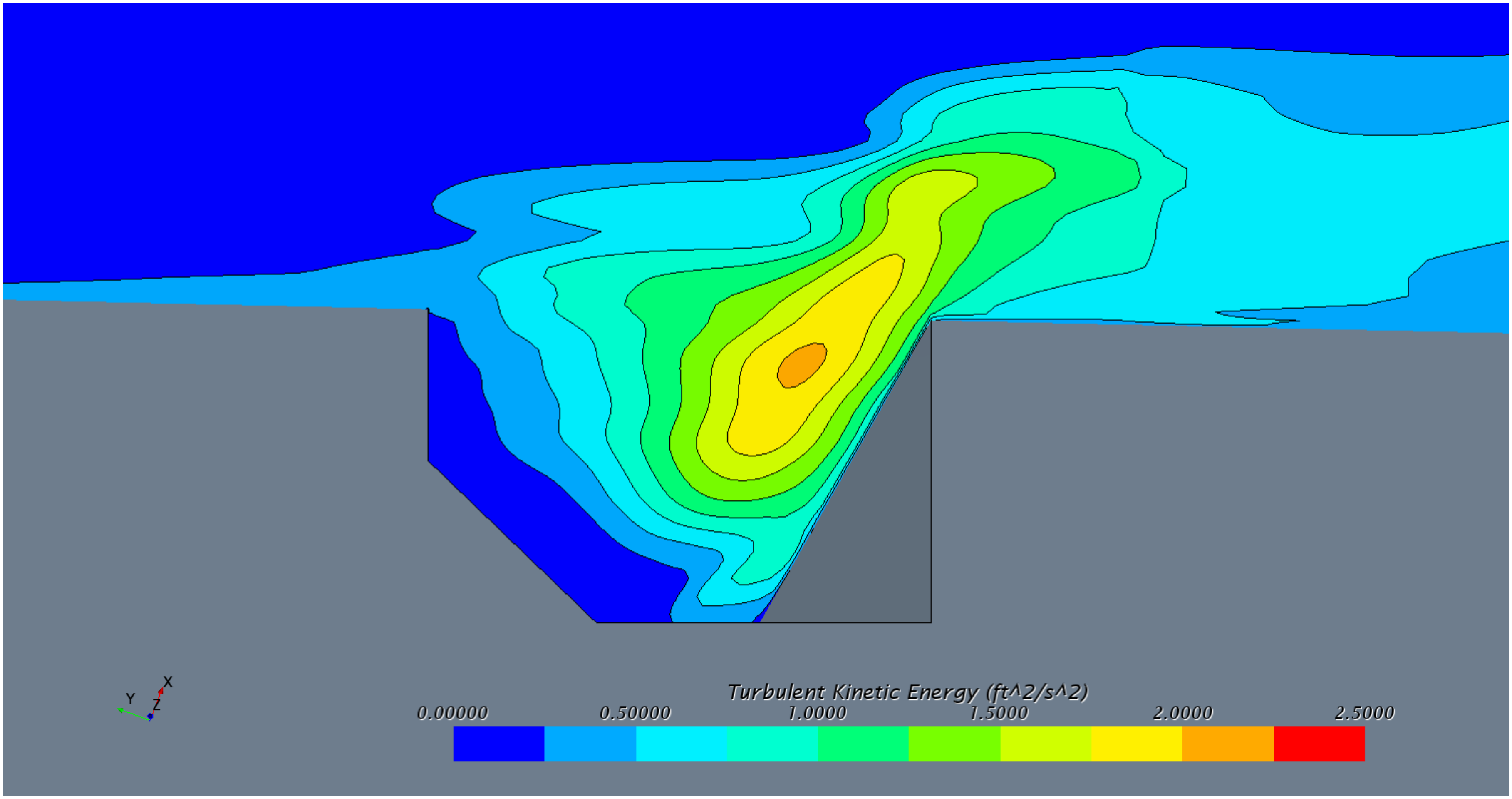
Velocity (Q = 180 cfs)

Figure 15: TKE magnitude at Horizontal Section 2 (Elev. 2 ft)



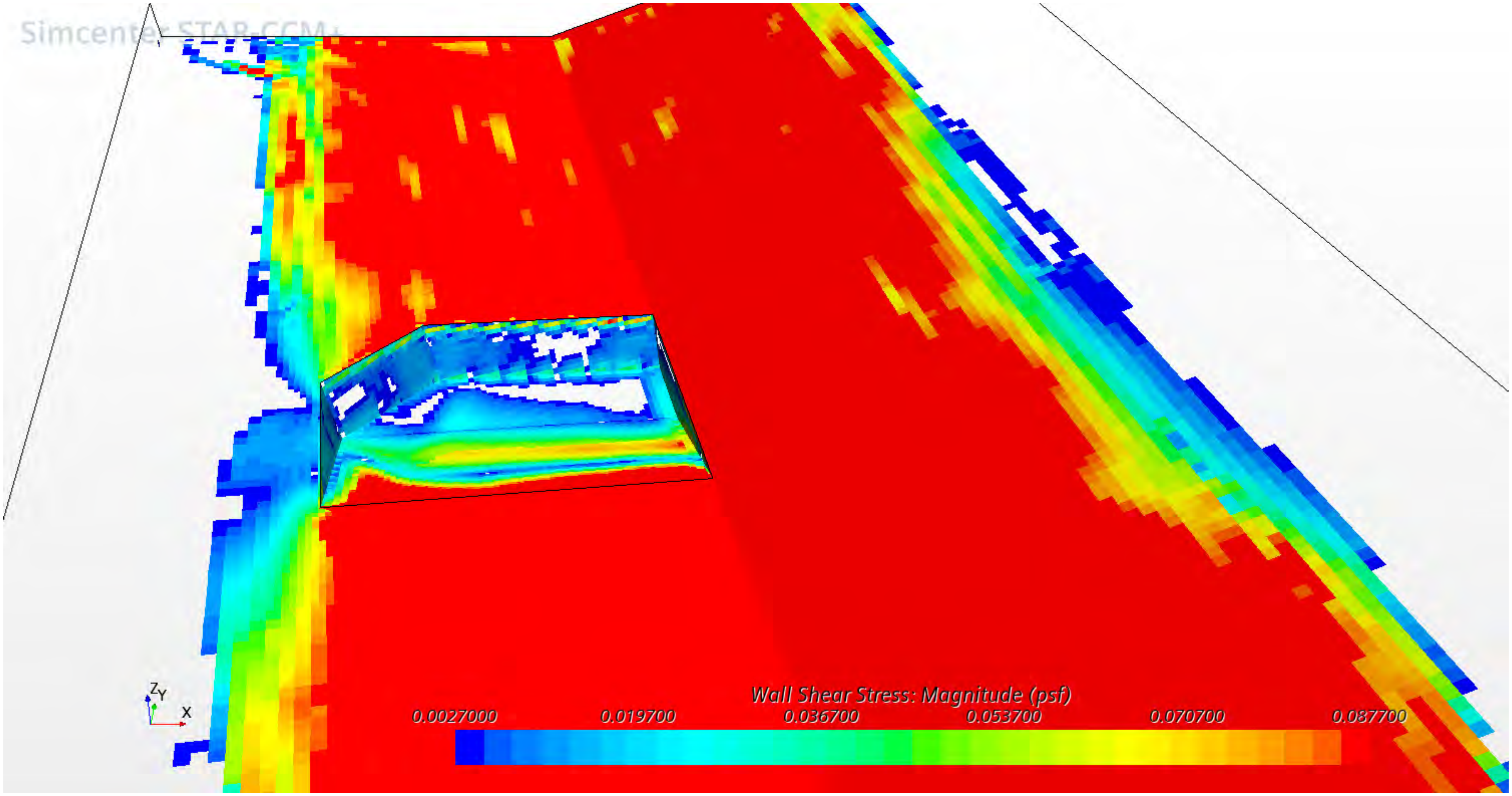
Velocity (Q = 180 cfs)

Figure 16: TKE magnitude at Horizontal Section 3 (Elev. 3 ft)



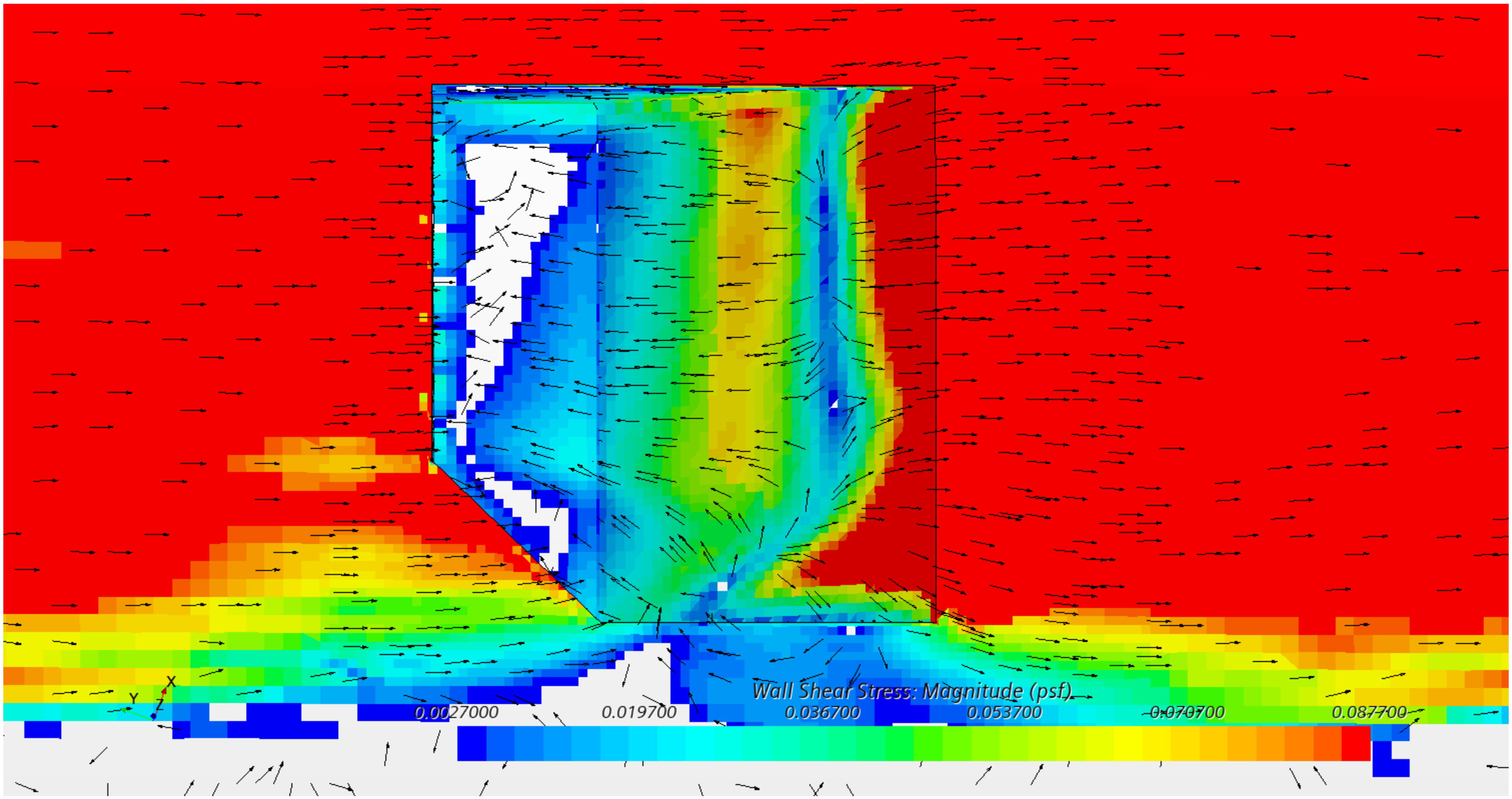
Shear Stress (Q = 180 cfs)

Figure 17: Shear stress magnitude on channel bottom
White areas < 0.0027 psf (critical shear for very fine sand)
Red areas >= 0.0877 psf (critical shear for fine gravel)



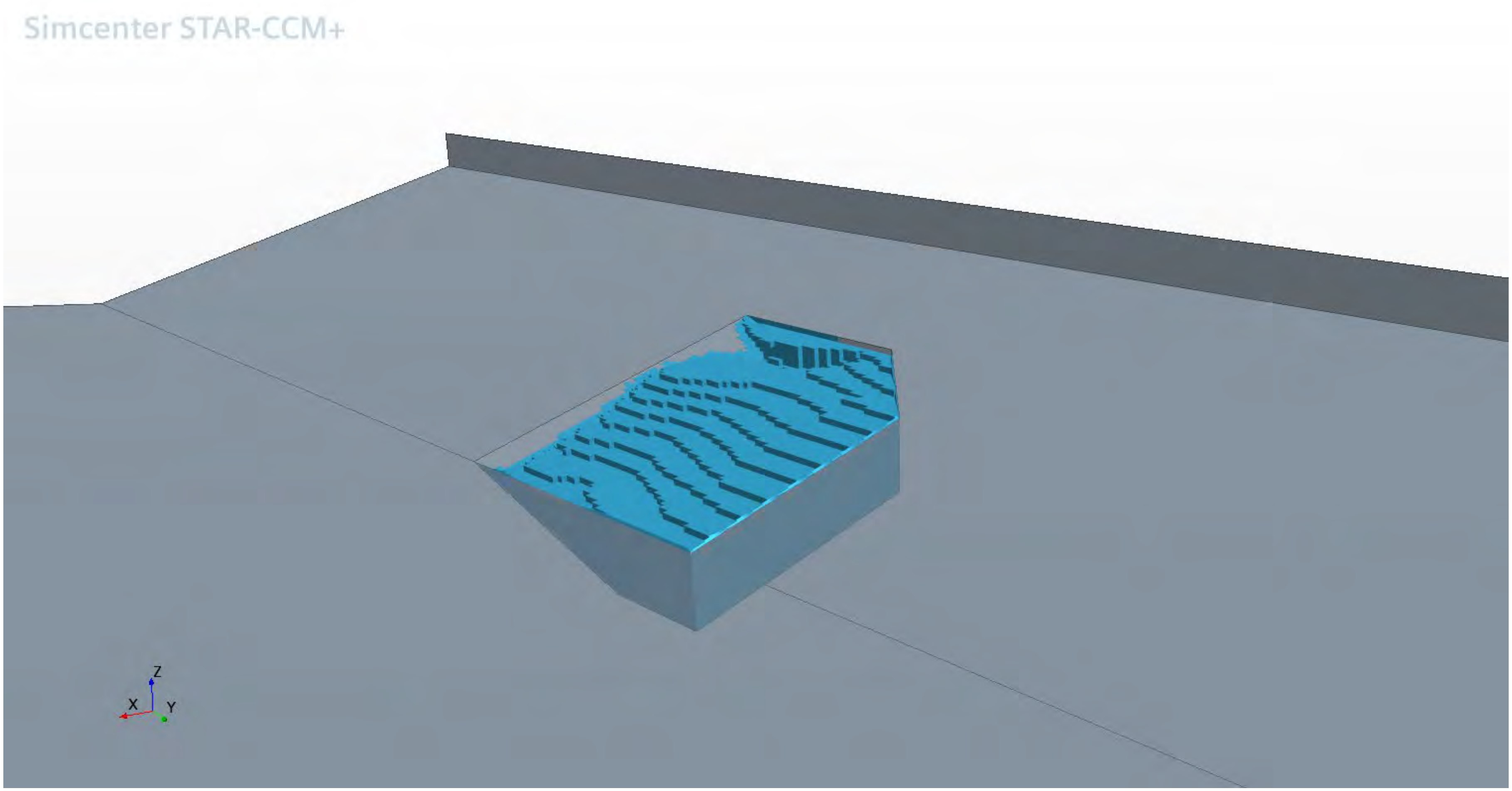
Shear Stress (Q = 180 cfs)

Figure 18: Shear stress magnitude and direction at fish pool
White areas < 0.0027 psf (critical shear for very fine sand)
Red areas >= 0.0877 psf (critical shear for fine gravel)



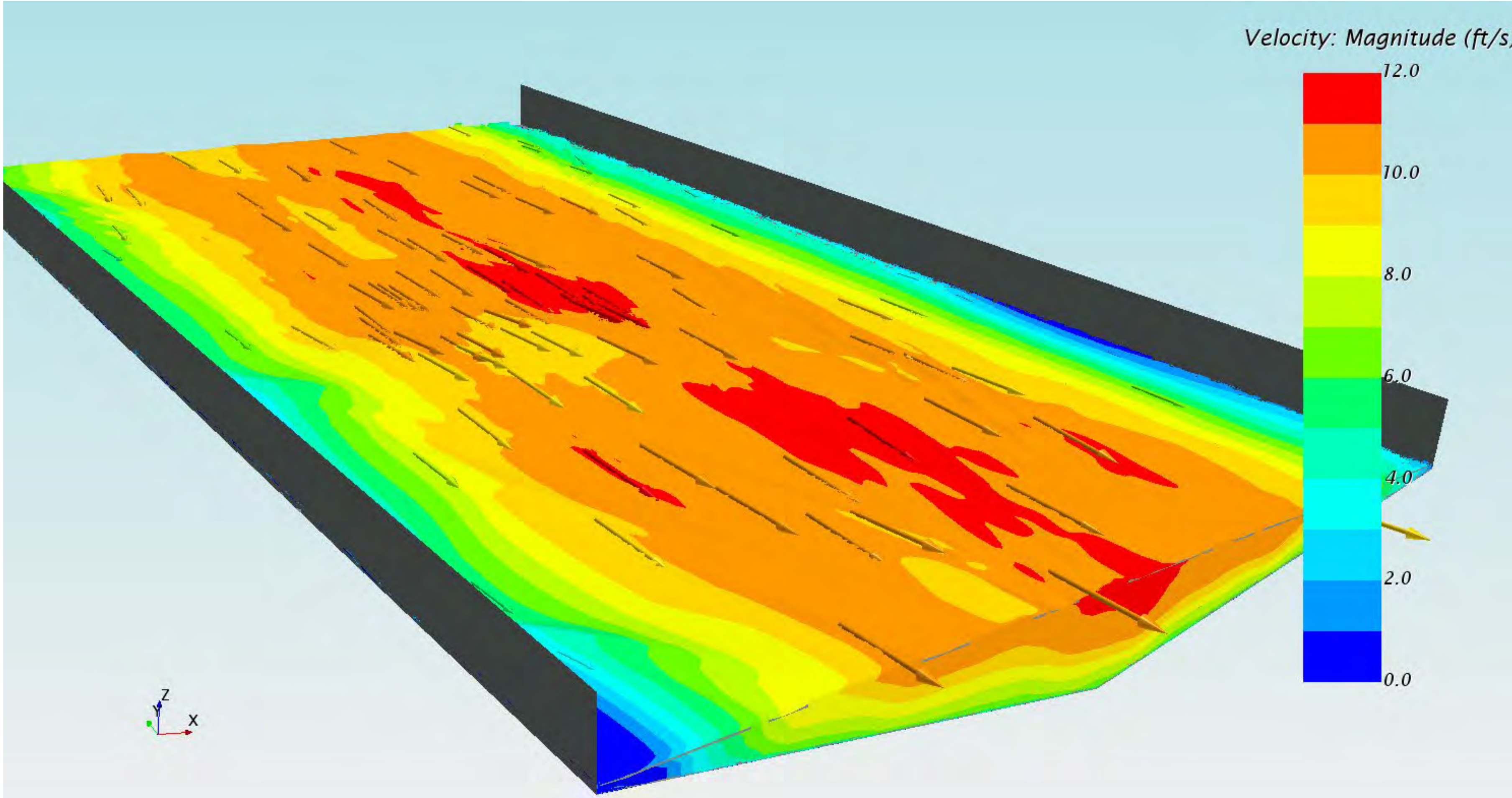
Velocity < 2 ft/s (Q = 180 cfs)

Figure 19: Region in fish pool with velocity < 2 ft/s
Volume = 100 ft^3



Velocity (Q = 500 cfs)

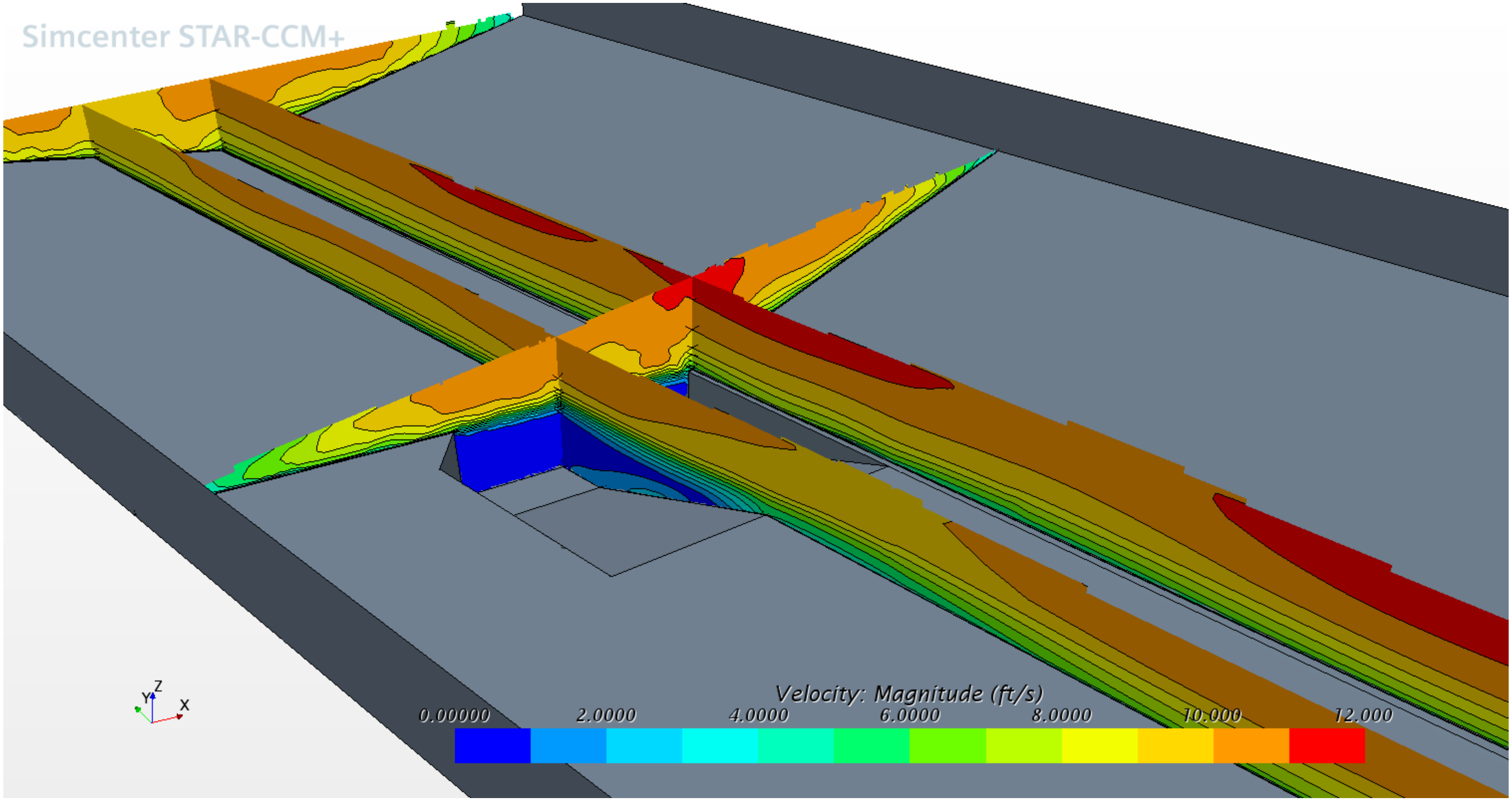
Figure 3: Velocity magnitude at water surface



Velocity: Magnitude (ft/s)
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Z
Y
X

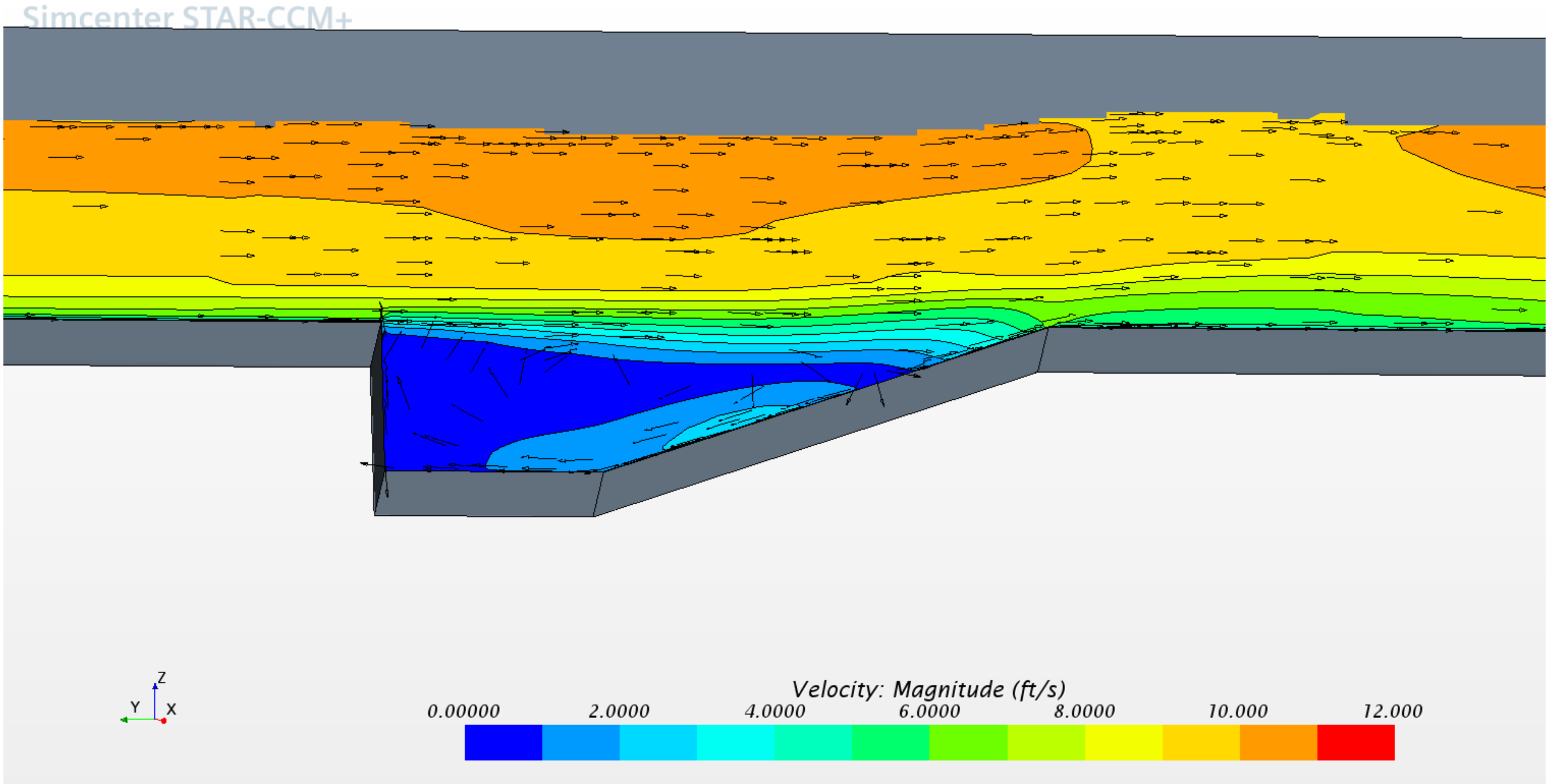
Velocity (Q = 500 cfs)

Figure 4: Velocity magnitude at sections



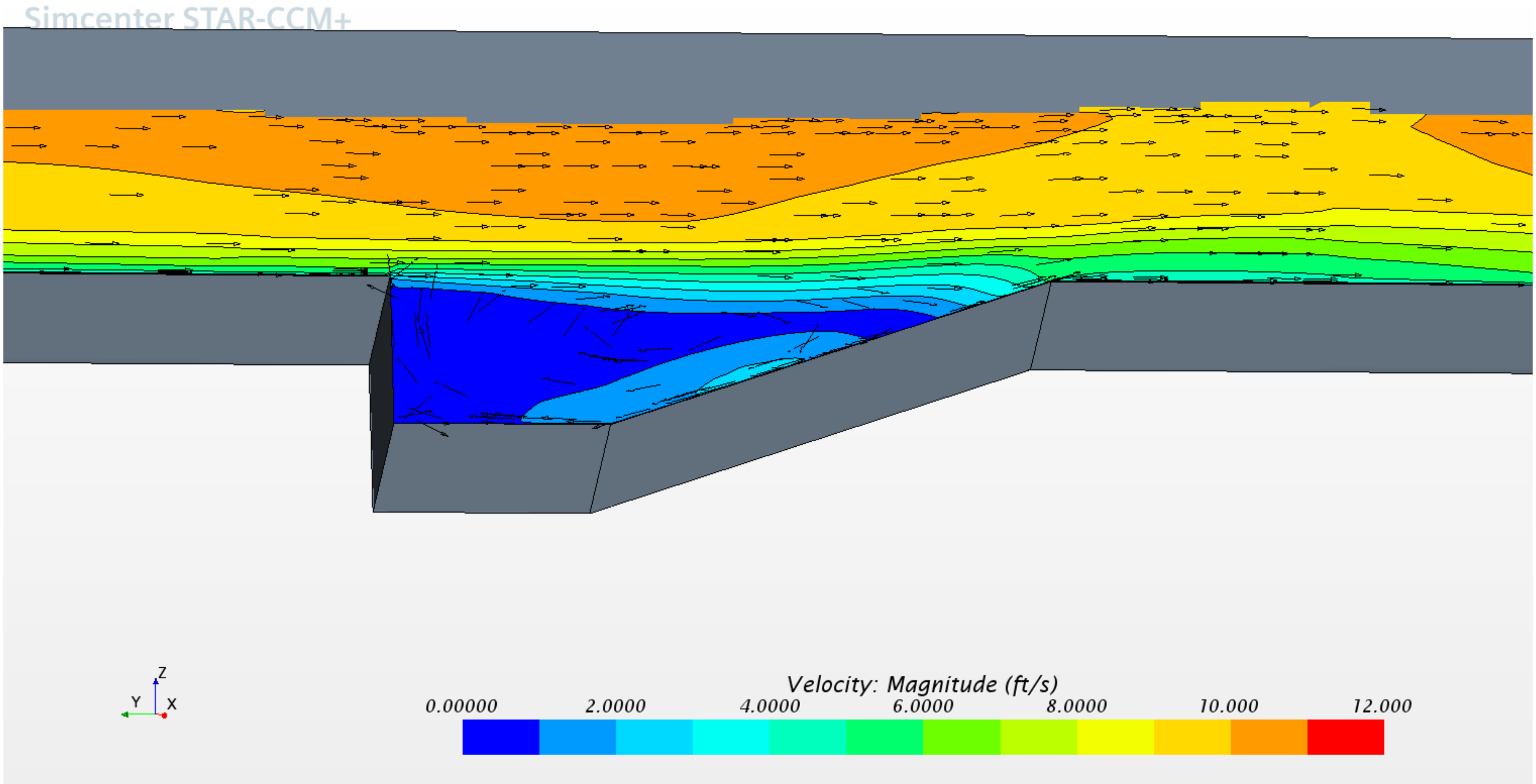
Velocity (Q = 500 cfs)

Figure 5: Velocity magnitude and direction at Longitudinal Section 1 (2.5 ft from channel invert)



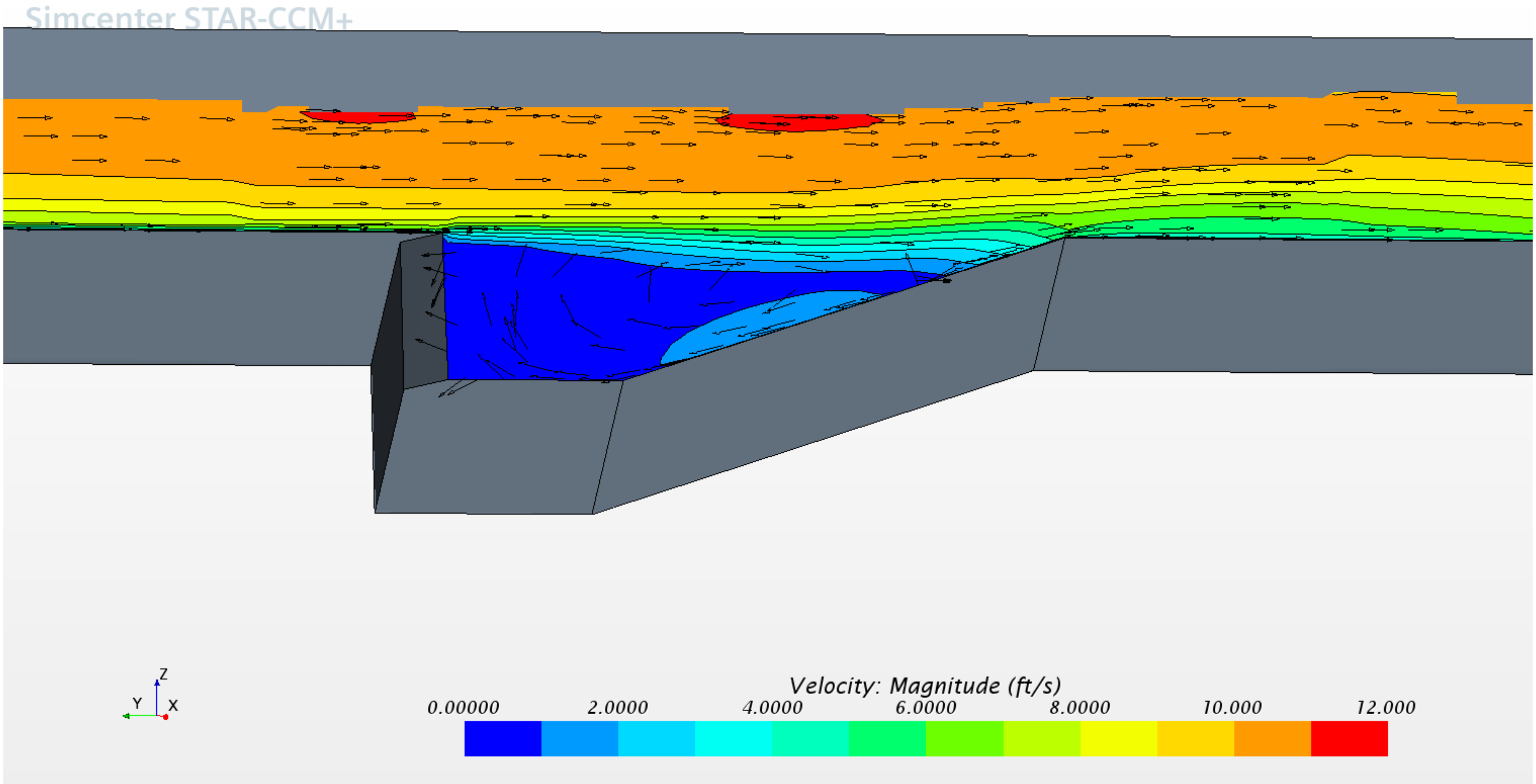
Velocity (Q = 500 cfs)

Figure 6: Velocity magnitude and direction at Longitudinal Section 2 (5 ft from channel invert)



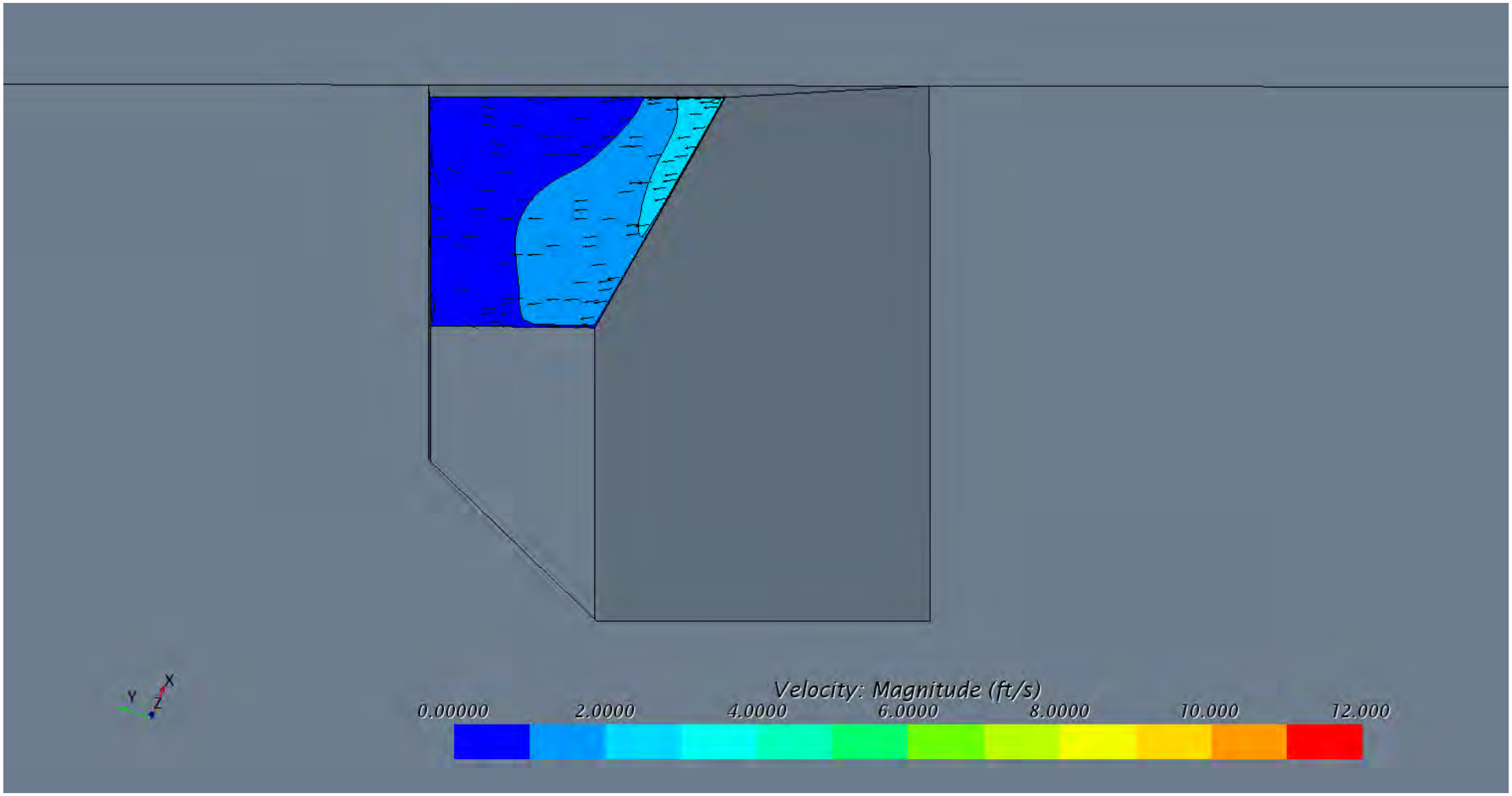
Velocity (Q = 500 cfs)

Figure 7: Velocity magnitude and direction at Longitudinal Section 3 (7.5 ft from channel invert)



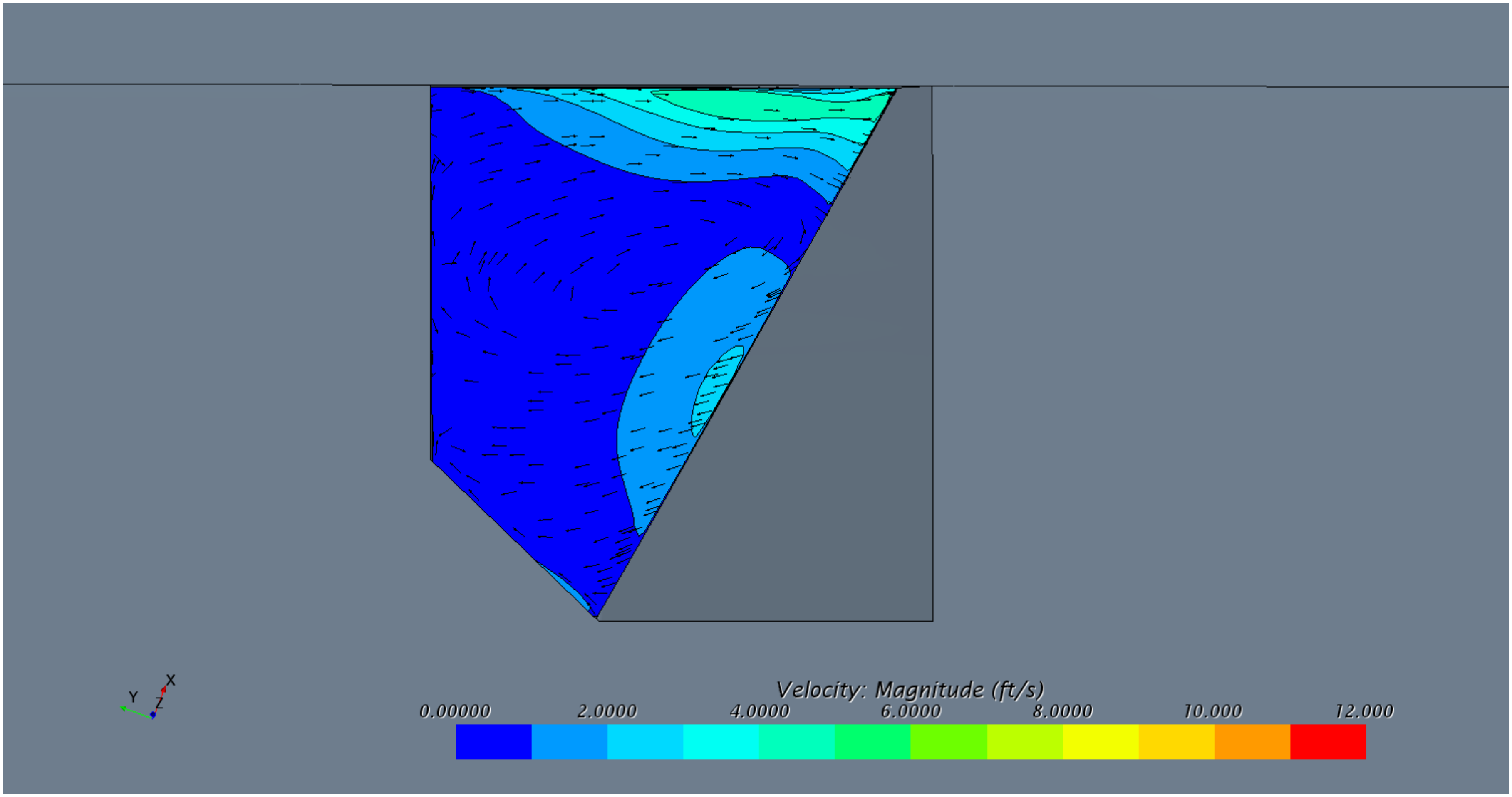
Velocity (Q = 500 cfs)

Figure 8: Velocity magnitude and direction at Horizontal Section 1 (Elev. 1 ft)



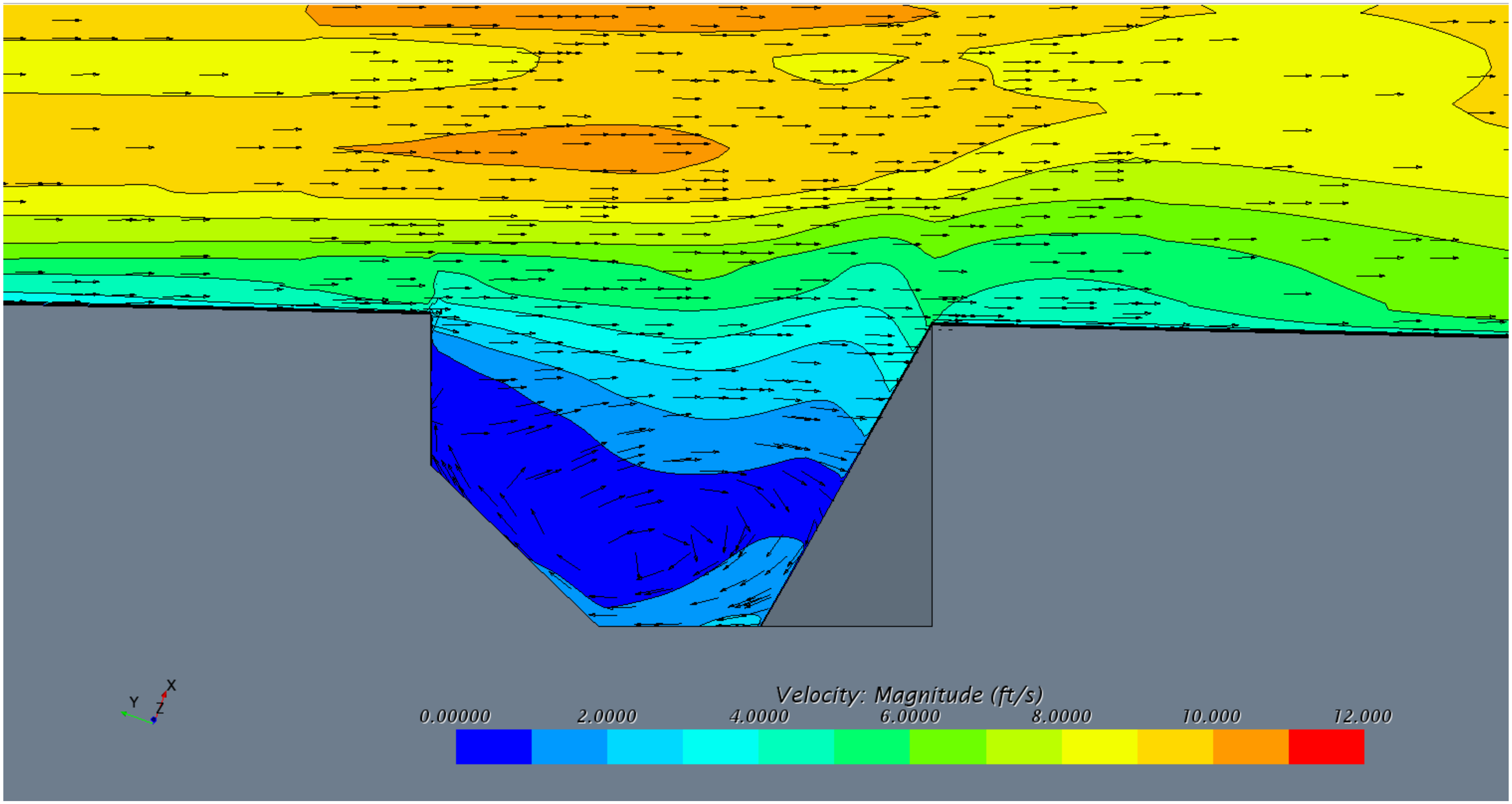
Velocity (Q = 500 cfs)

Figure 9: Velocity magnitude and direction at Horizontal Section 2 (Elev. 2 ft)



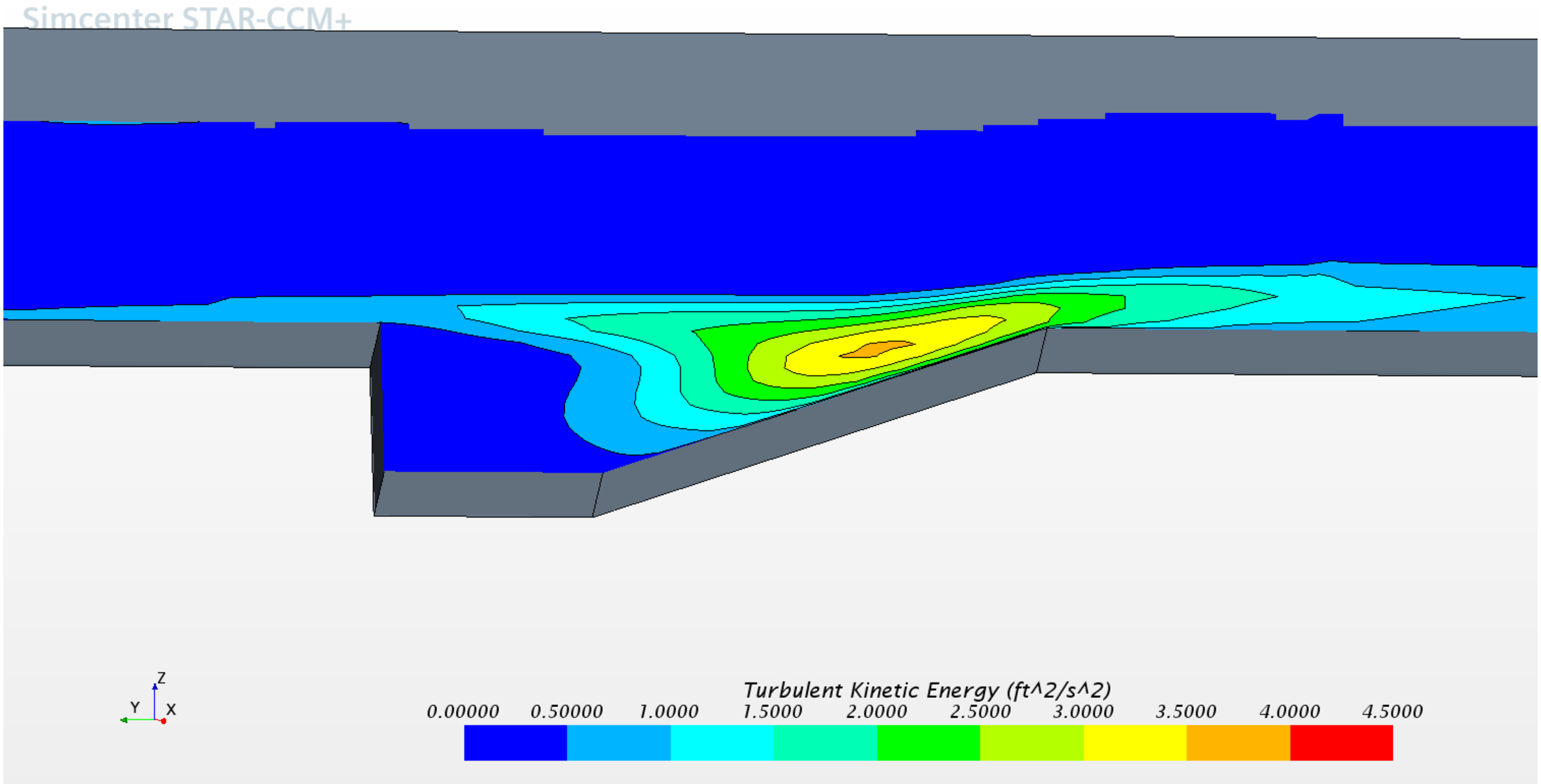
Velocity (Q = 500 cfs)

Figure 10: Velocity magnitude and direction at Horizontal Section 3 (Elev. 3 ft)



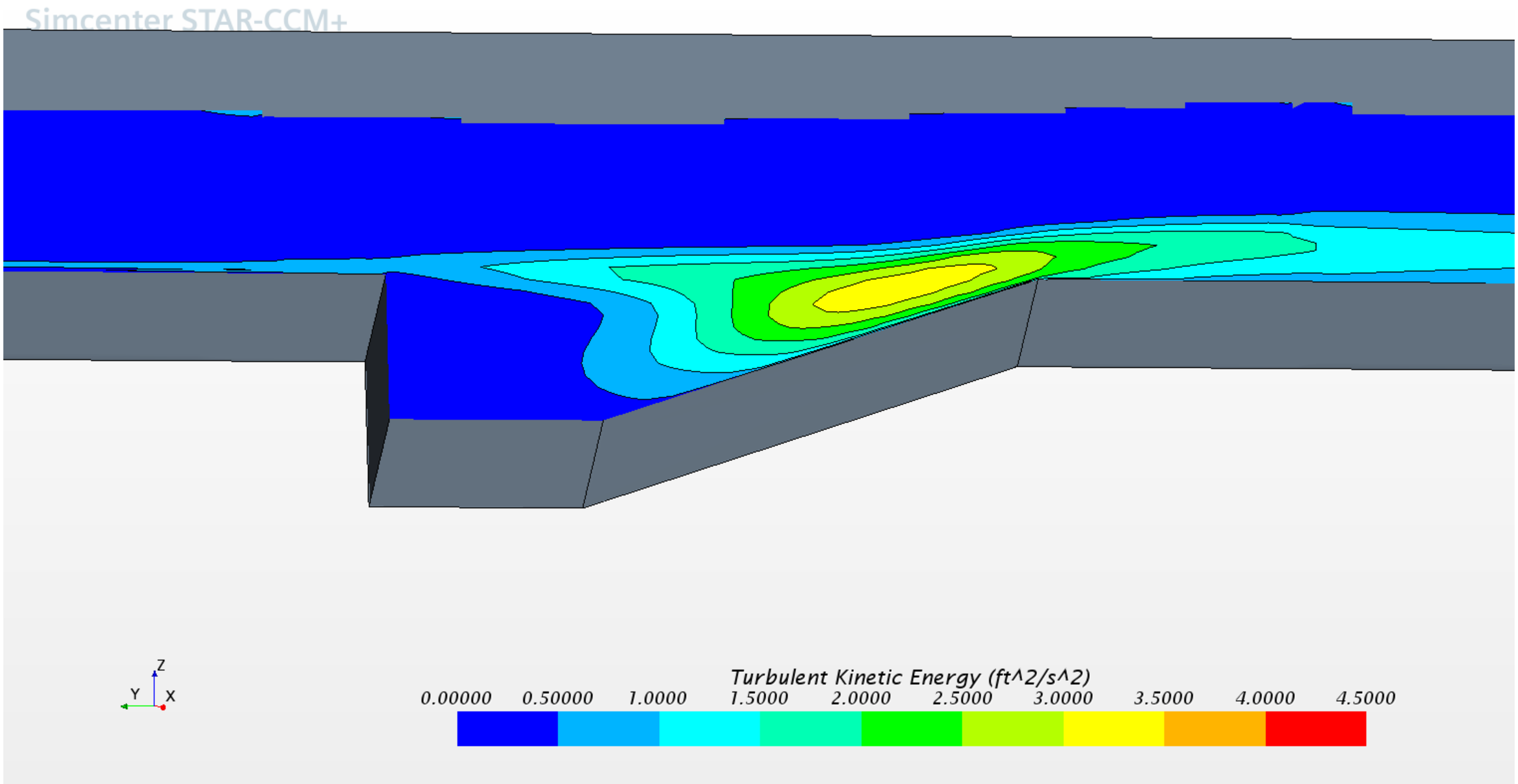
Turbulent Kinetic Energy (Q = 500 cfs)

Figure 11: TKE magnitude at Longitudinal Section 1 (2.5 ft from channel invert)



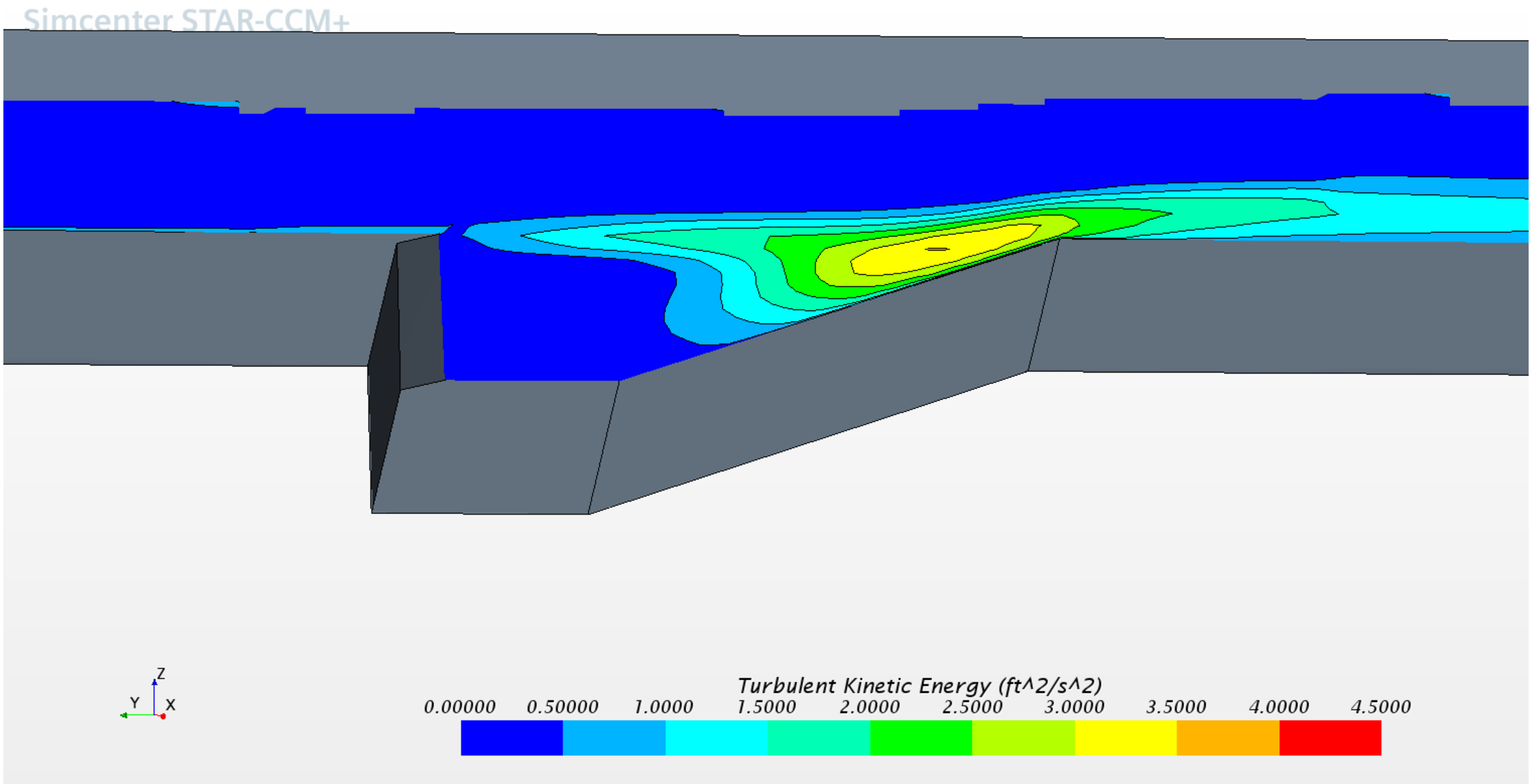
Velocity (Q = 500 cfs)

Figure 12: TKE magnitude at Longitudinal Section 2 (5 ft from channel invert)



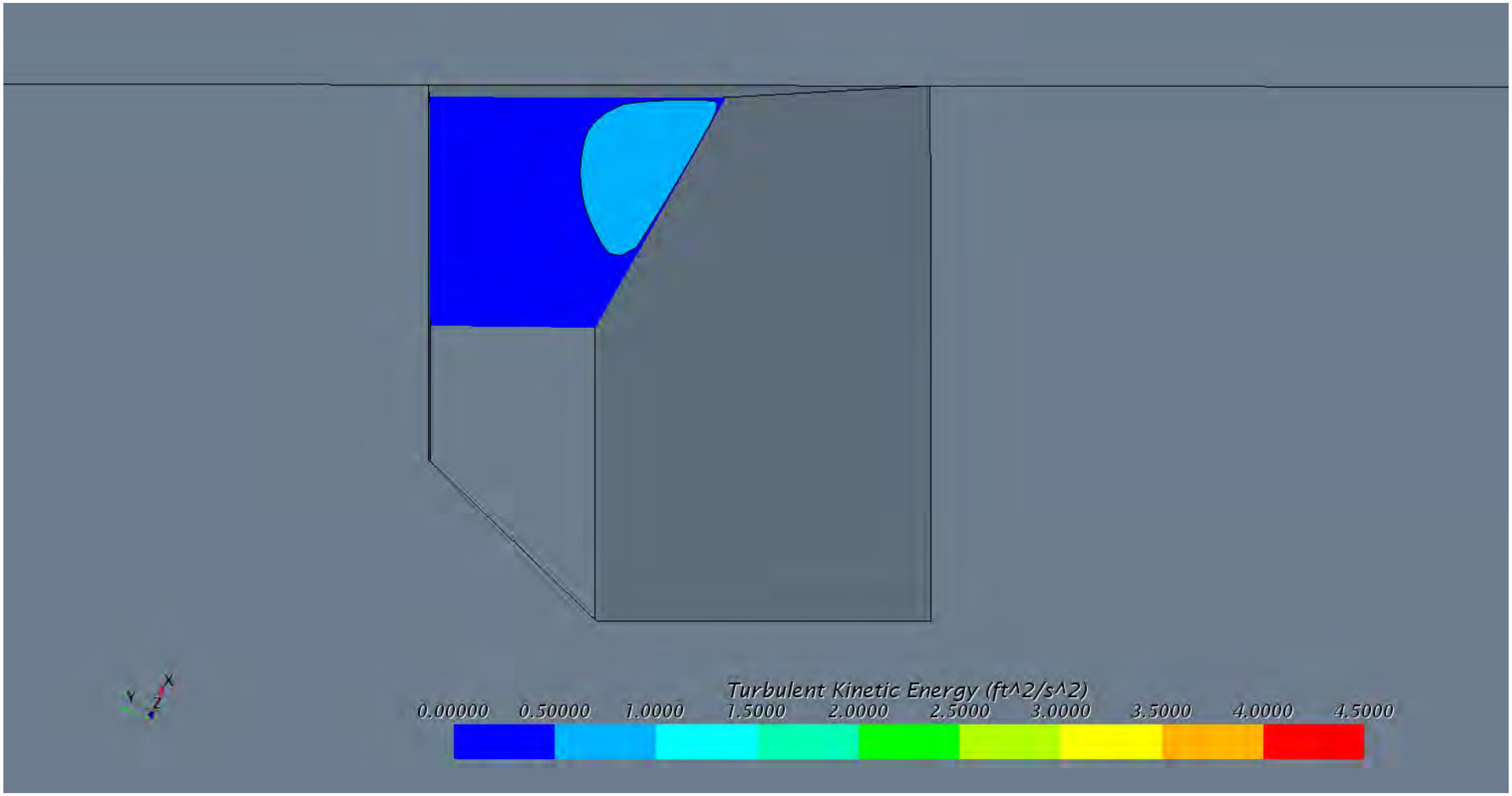
Velocity (Q = 500 cfs)

Figure 13: TKE magnitude at Longitudinal Section 3 (7.5 ft from channel invert)



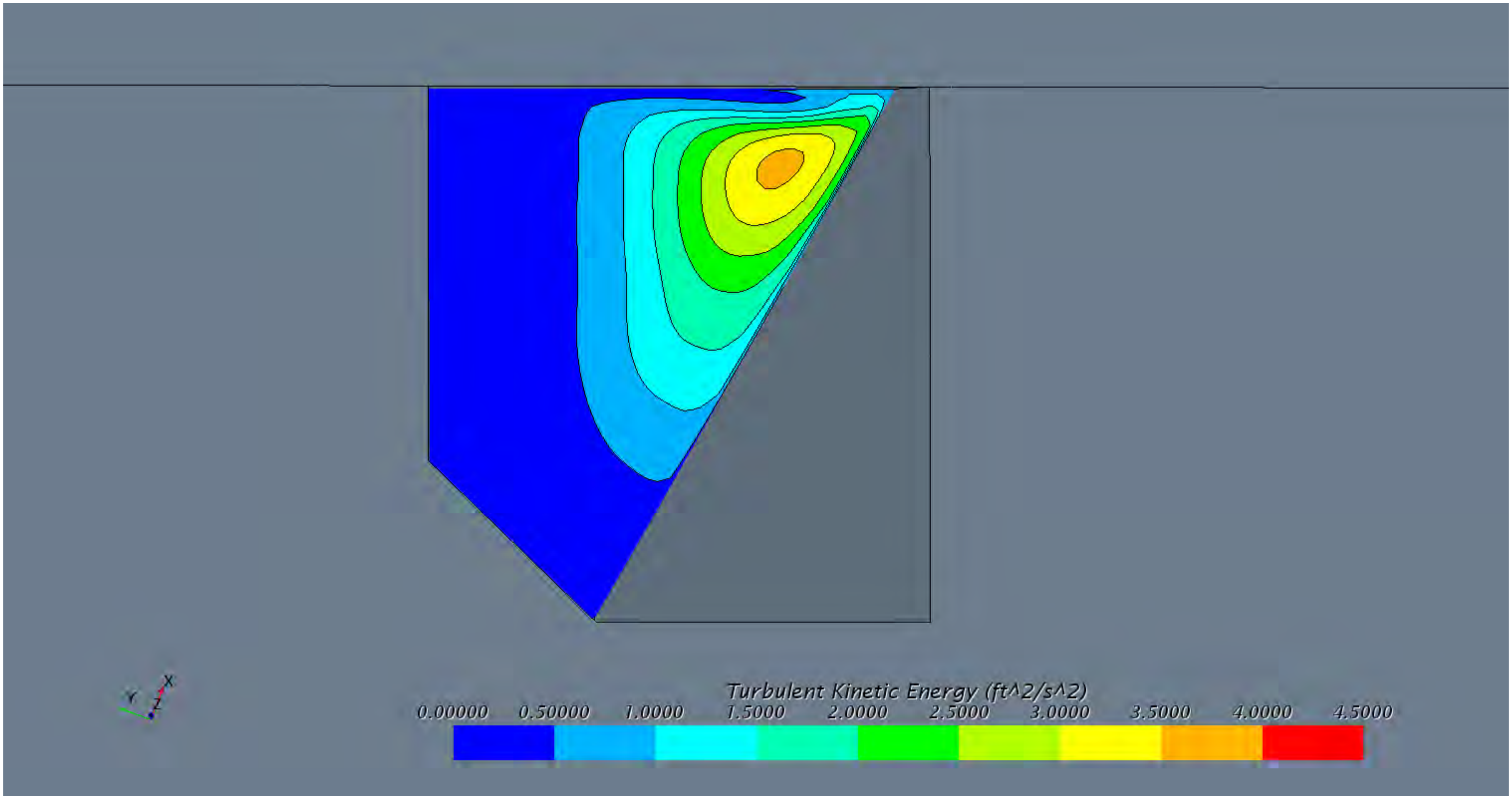
Velocity (Q = 500 cfs)

Figure 14: TKE magnitude at Horizontal Section 1 (Elev. 1 ft)



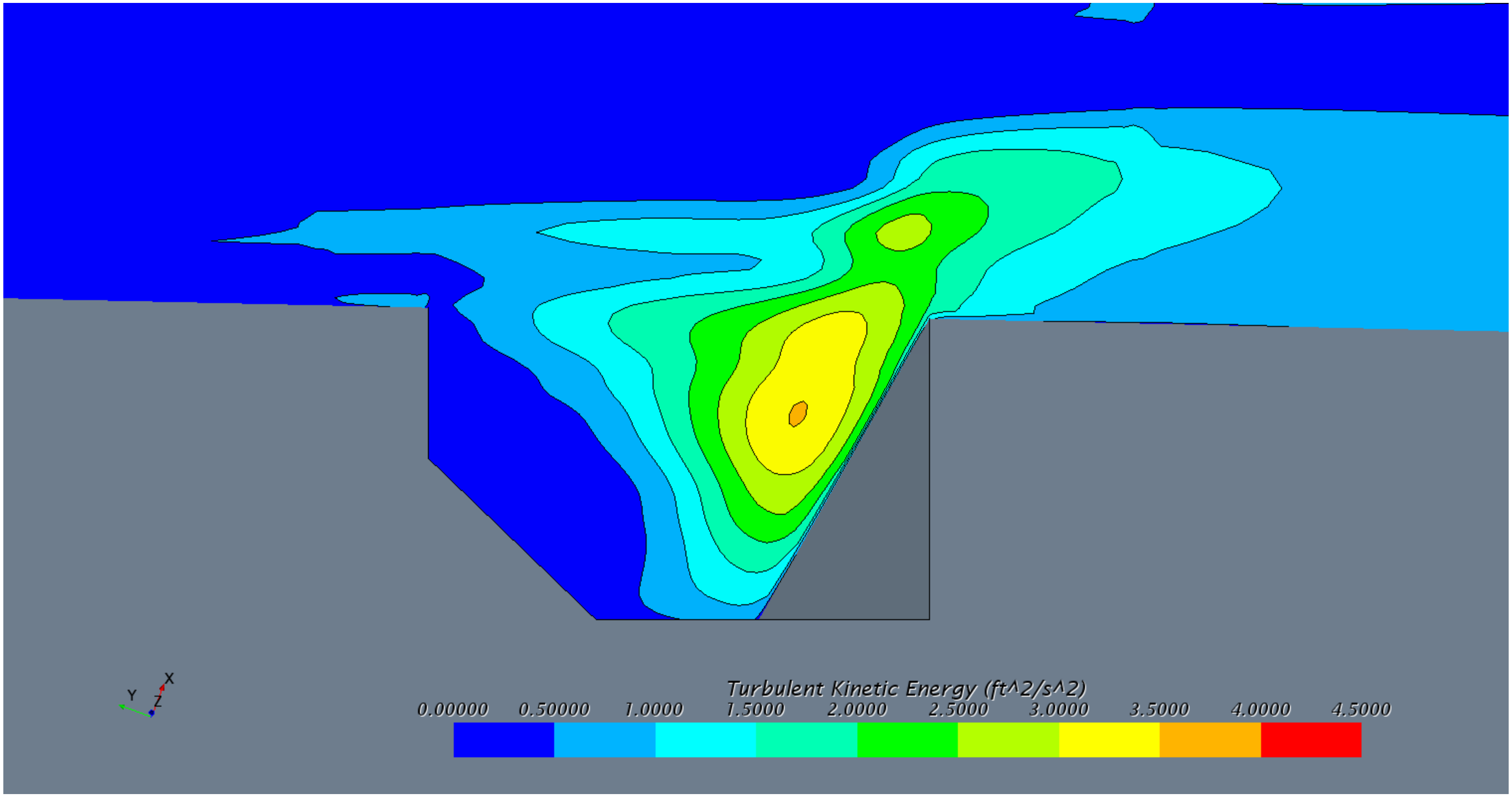
Velocity (Q = 500 cfs)

Figure 15: TKE magnitude at Horizontal Section 2 (Elev. 2 ft)



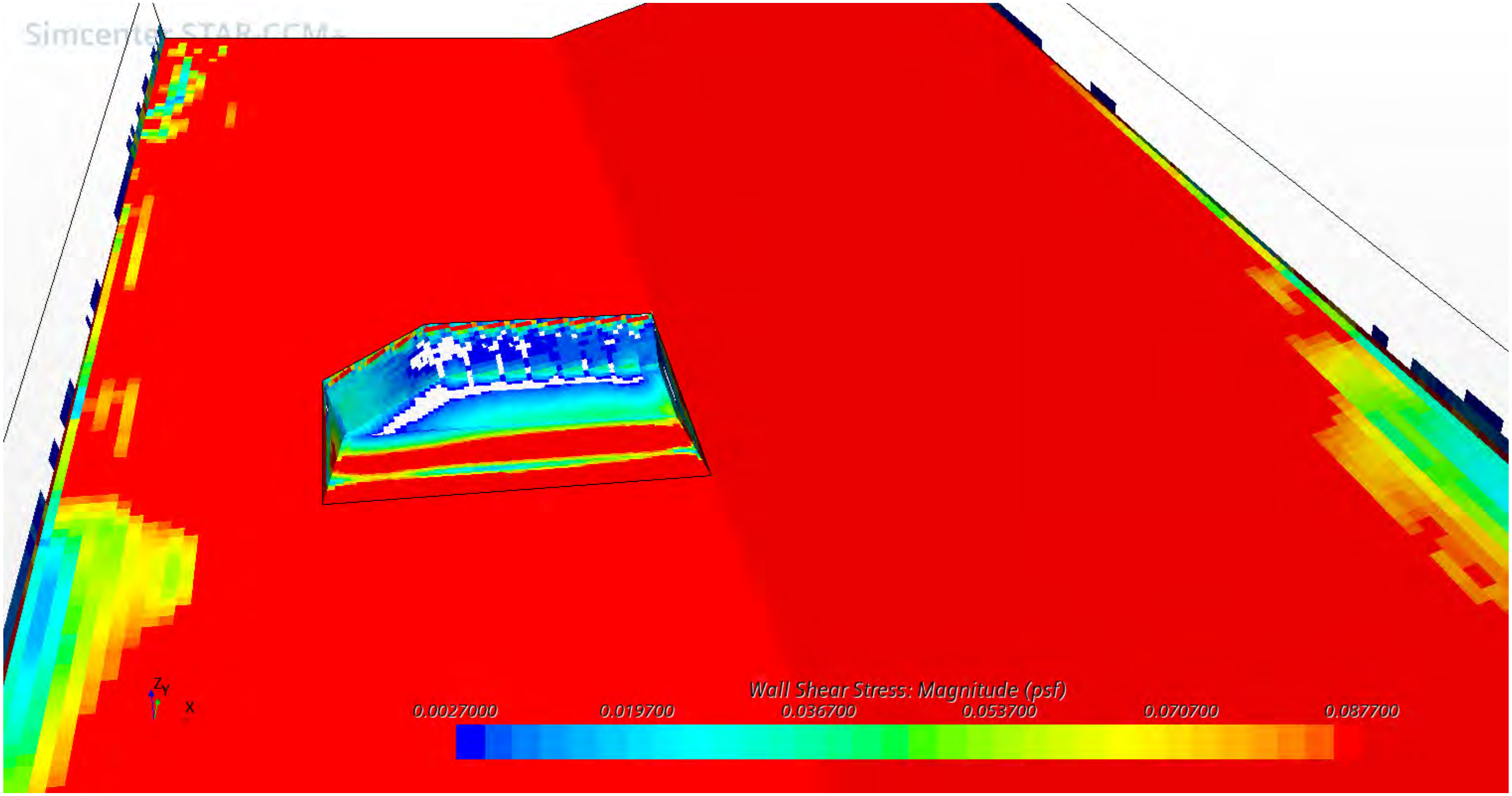
Velocity (Q = 500 cfs)

Figure 16: TKE magnitude at Horizontal Section 3 (Elev. 3 ft)



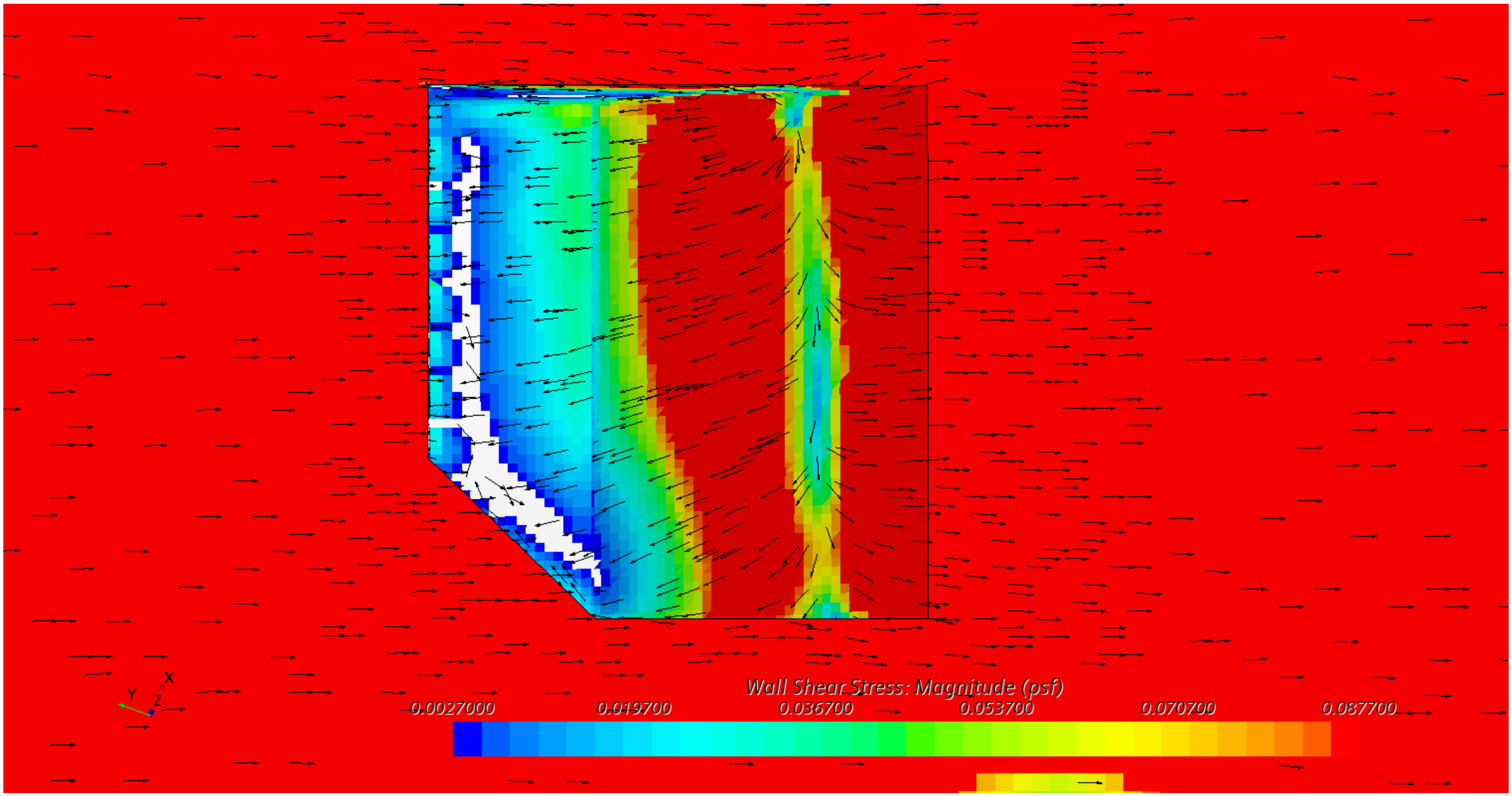
Shear Stress (Q = 500 cfs)

Figure 17: Shear stress magnitude on channel bottom
White areas < 0.0027 psf (critical shear for very fine sand)
Red areas >= 0.0877 psf (critical shear for fine gravel)



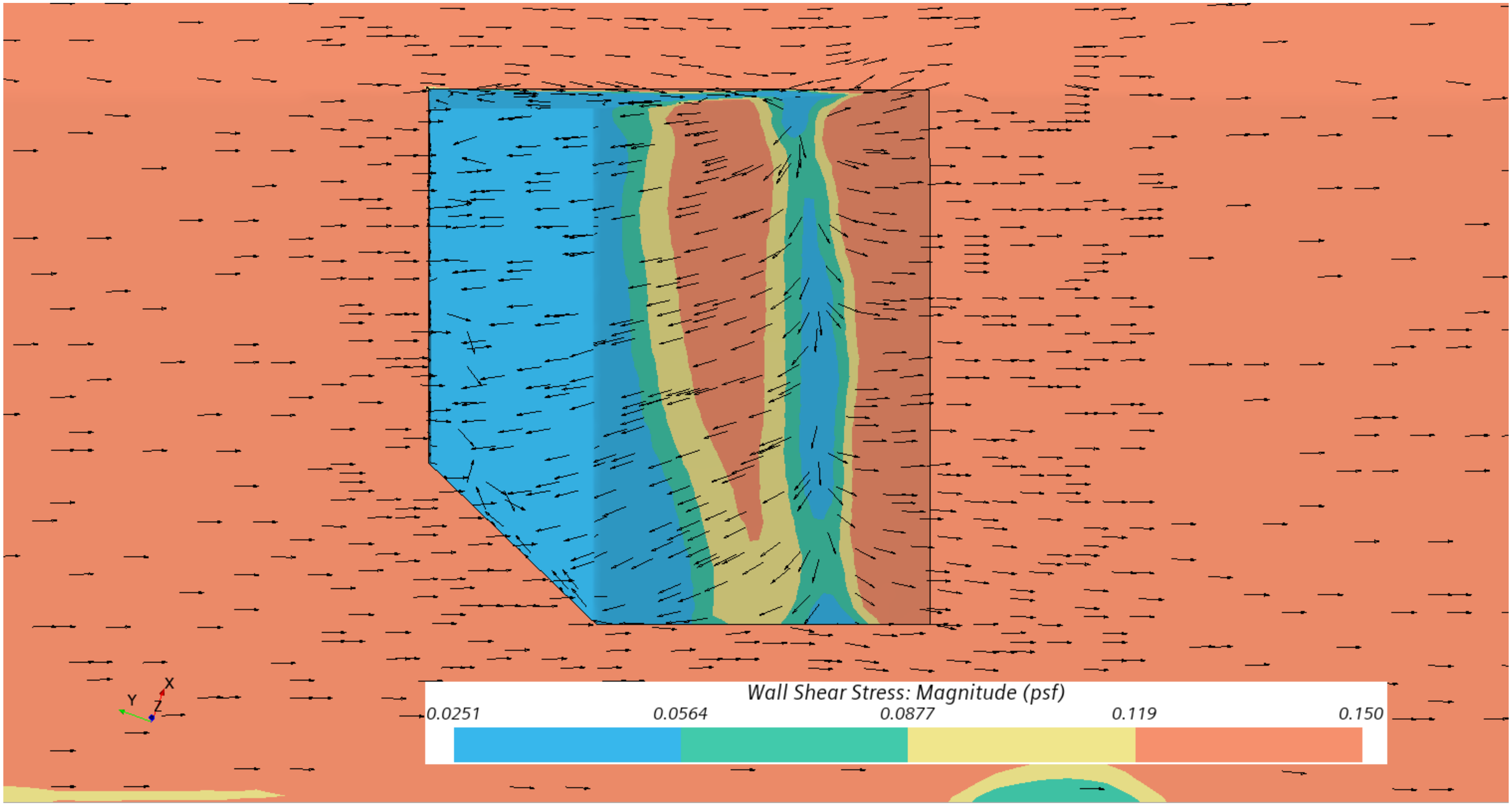
Shear Stress (Q = 500 cfs)

Figure 18: Shear stress magnitude and direction at fish pool
White areas < 0.0027 psf (critical shear for very fine sand)
Red areas >= 0.0877 psf (critical shear for fine gravel)



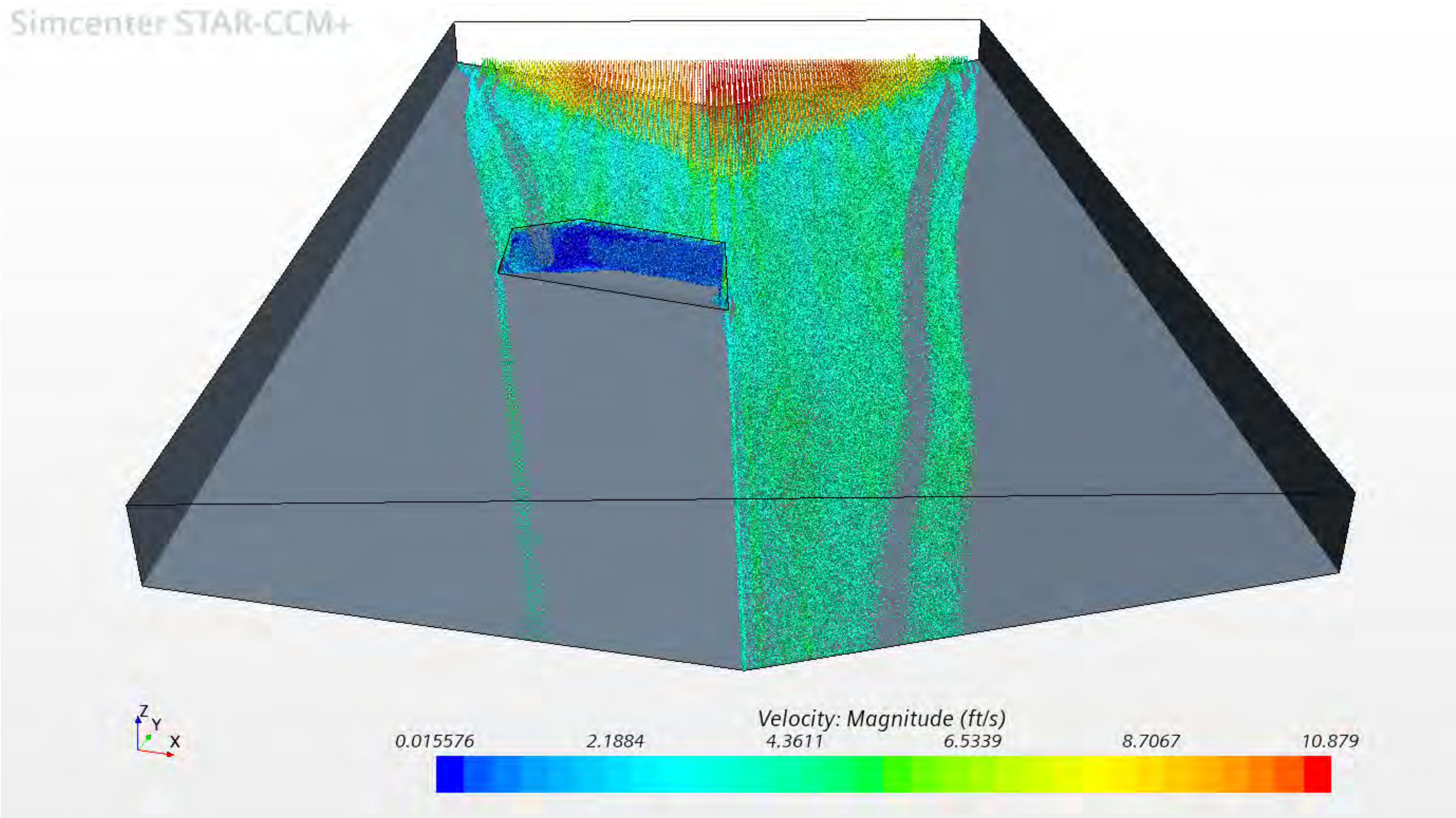
Shear Stress (Q = 500 cfs)

Figure 19: Shear stress magnitude and direction at fish pool



Particle Tracking (Q = 500 cfs)

Figure 20: CFD modeling with particles injected across the entire wetted cross section.



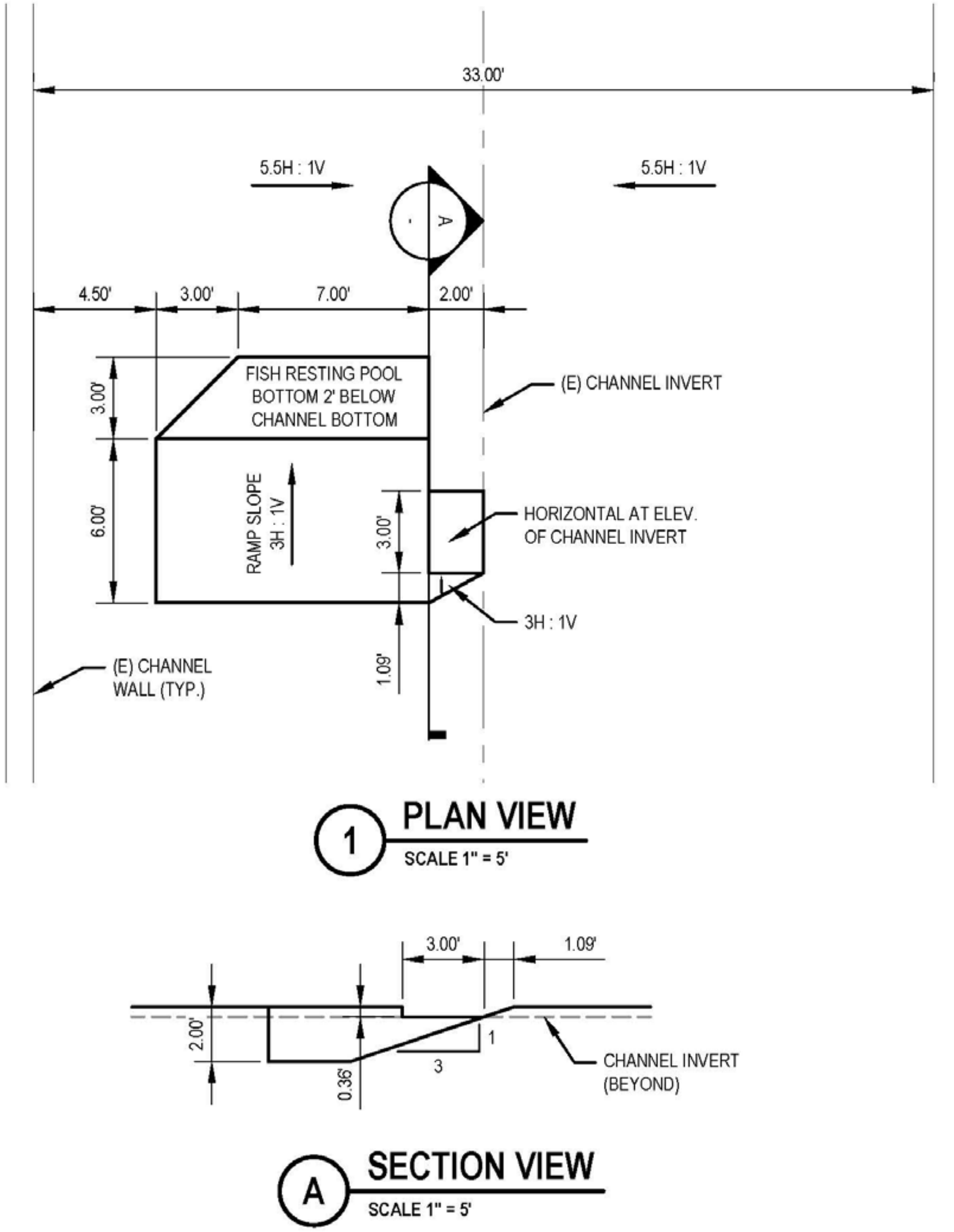
Attachment 6

Analysis of Alternative 4
Resting Pool Configuration

Alternative 4 Fish Resting Pool

Figure 1: Alternative 4 resting pool layout in plan and profile

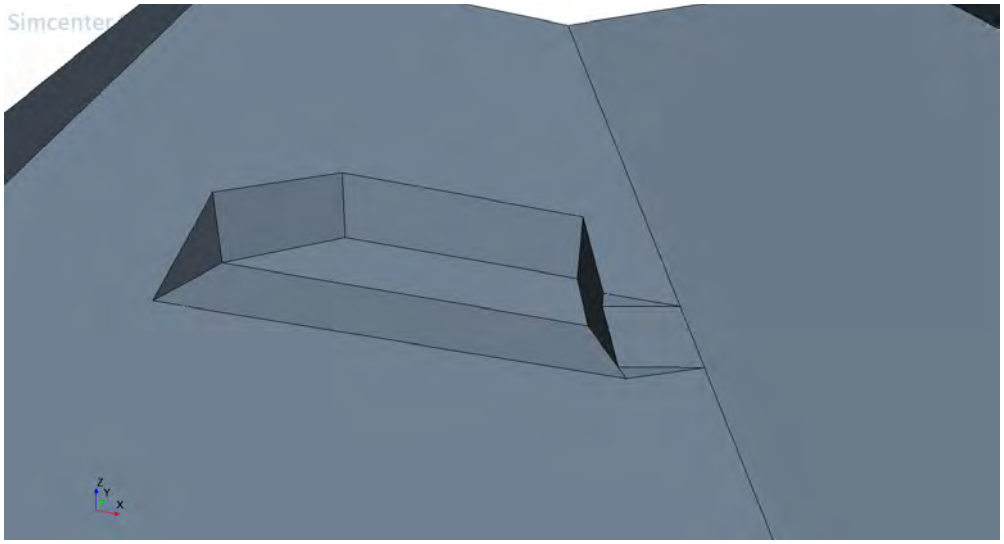
.

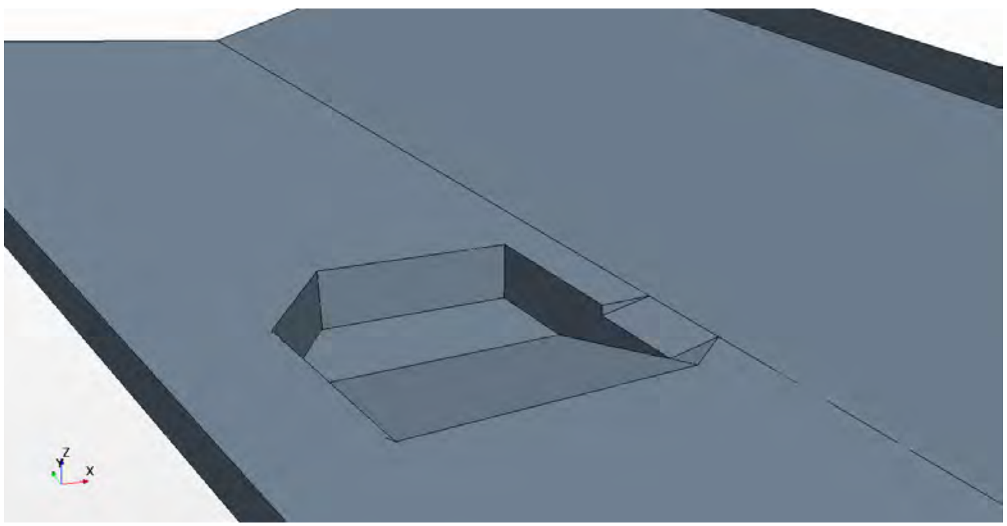


Fish Pool Alternative 4

Fish Pool Geometry

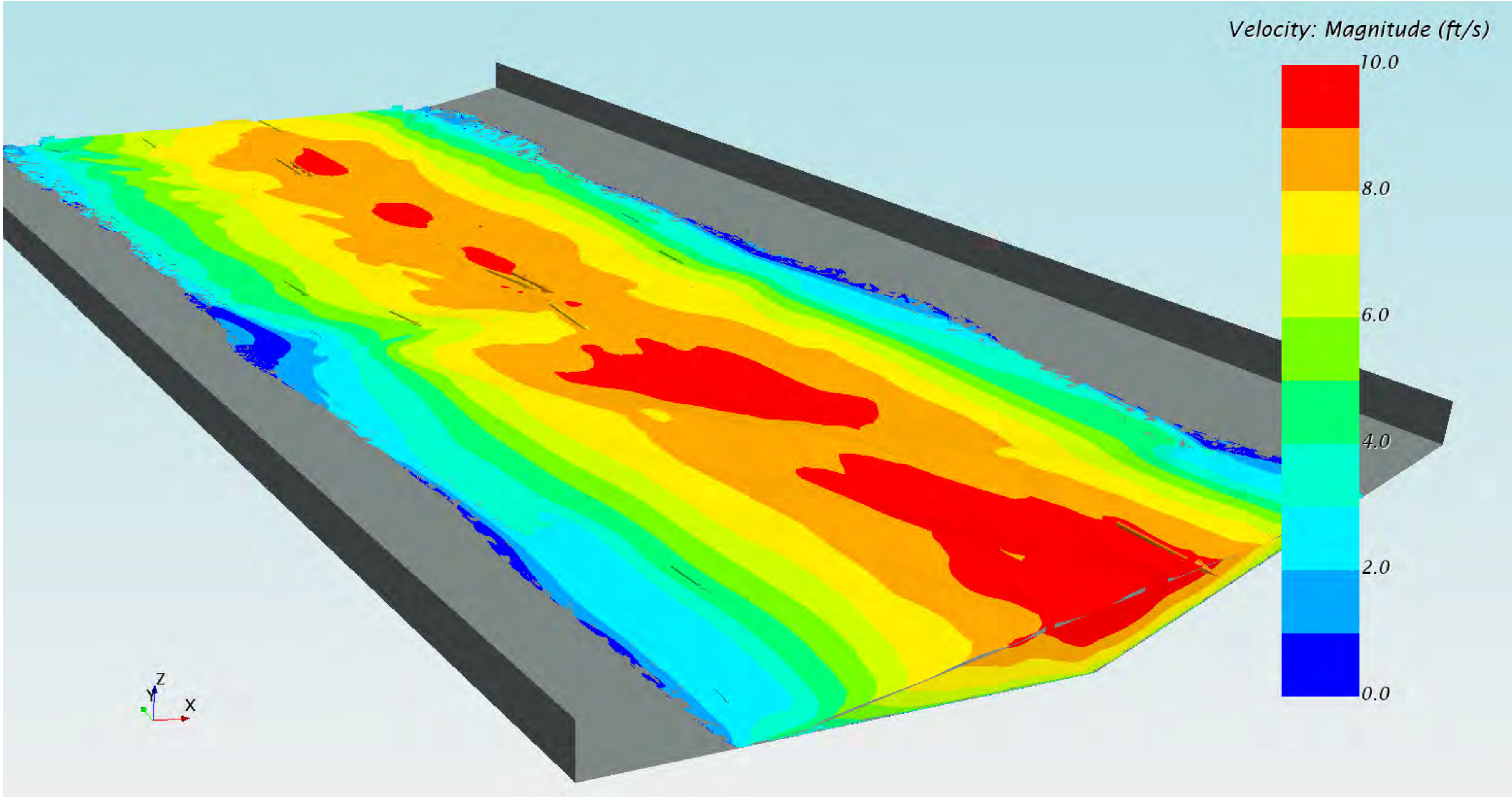
Figure 2: Front view looking upstream and angled view looking upstream





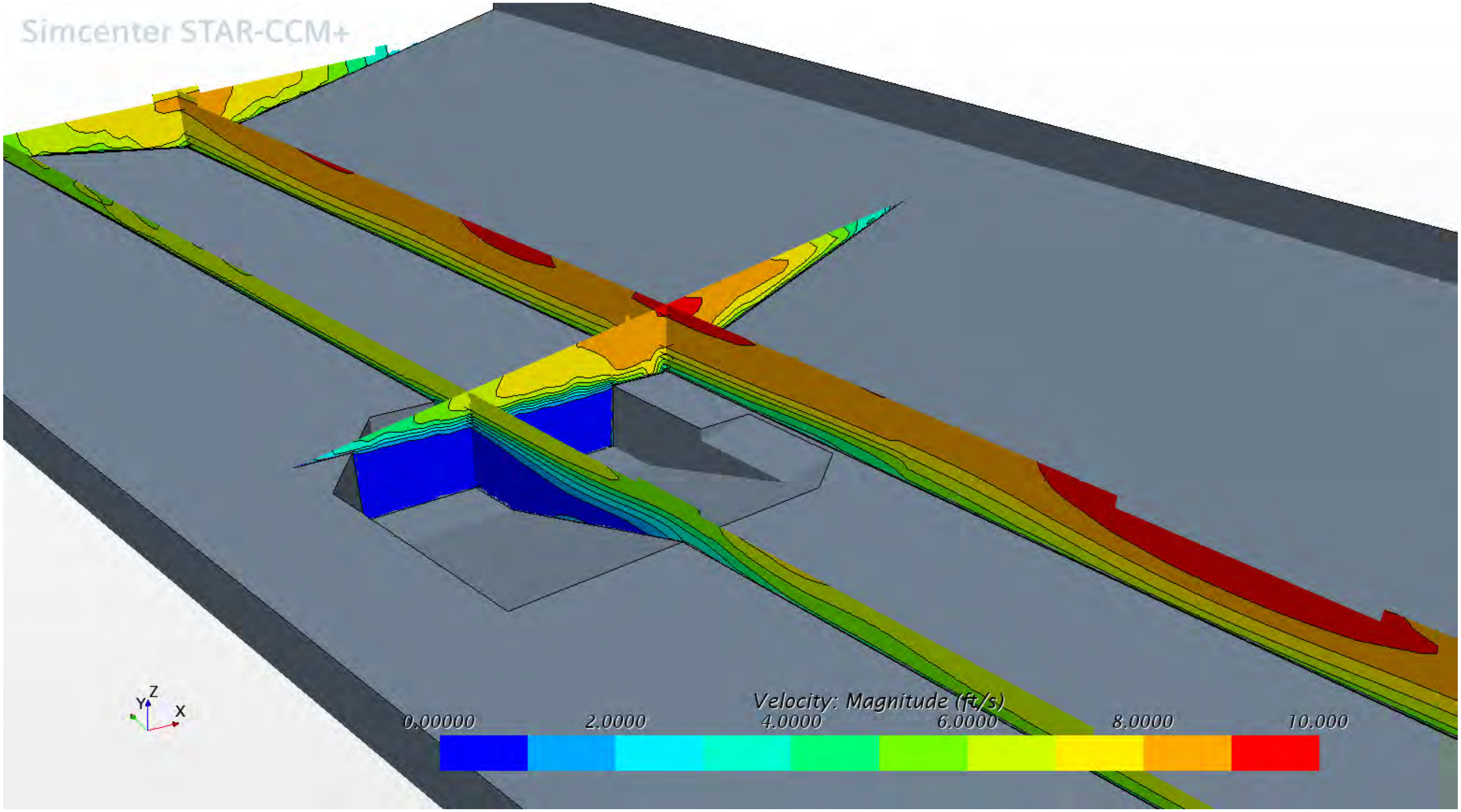
Velocity (Q = 180 cfs)

Figure 3: Velocity magnitude at water surface



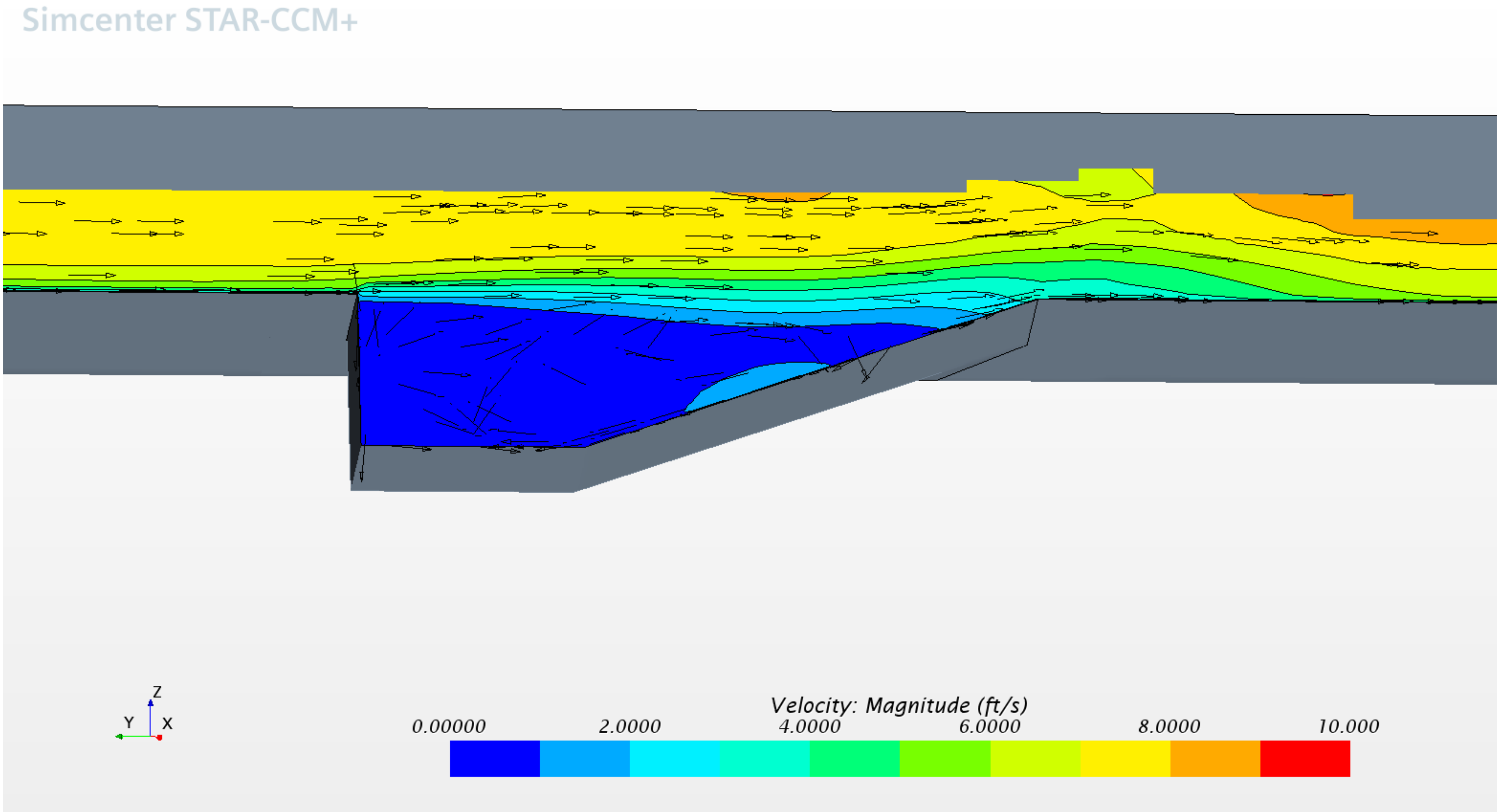
Velocity (Q = 180 cfs)

Figure 4: Velocity magnitude at sections



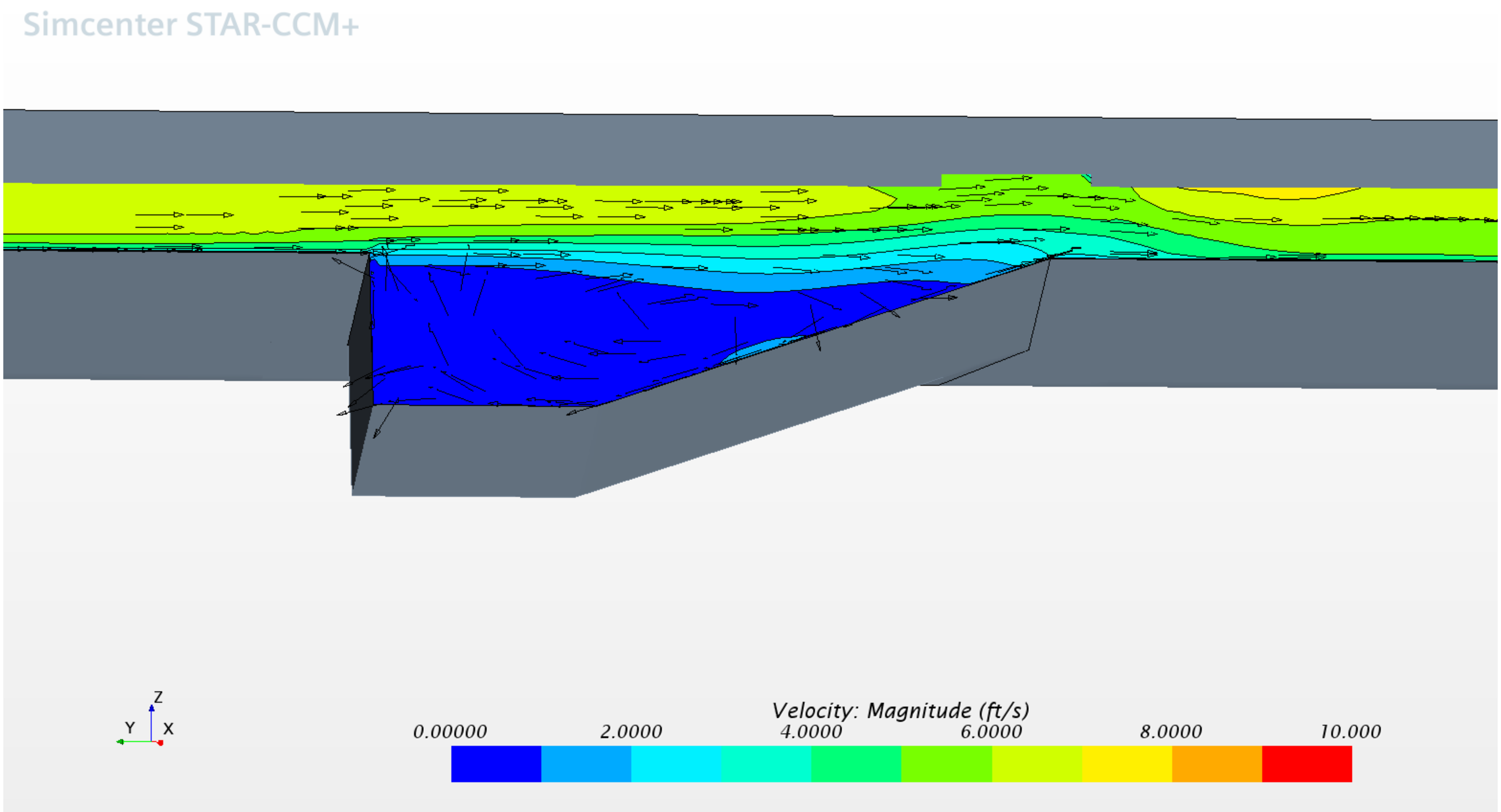
Velocity (Q = 180 cfs)

Figure 5: Velocity magnitude and direction at Longitudinal Section 1 (4.5 ft from channel invert)



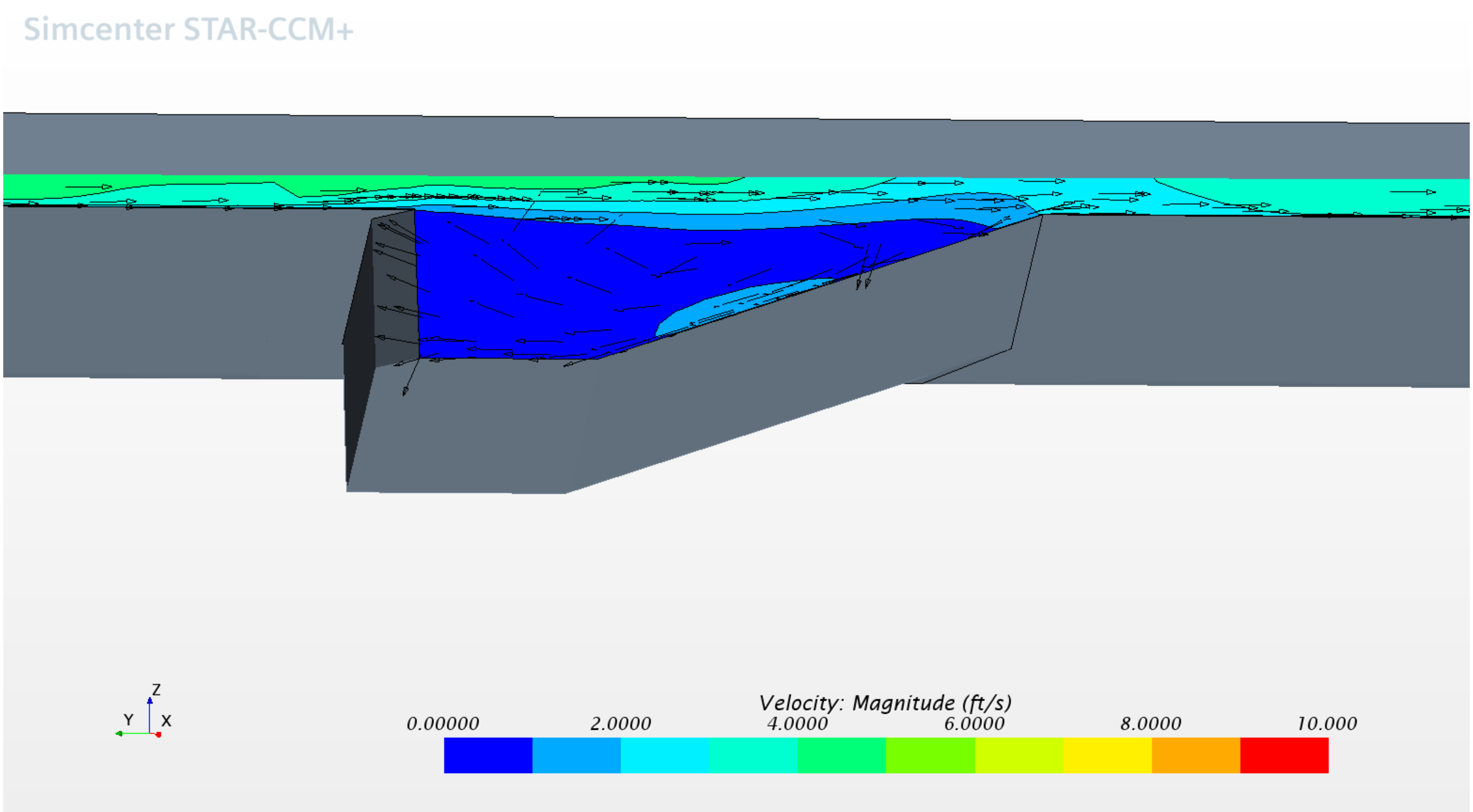
Velocity (Q = 180 cfs)

Figure 6: Velocity magnitude and direction at Longitudinal Section 2 (7 ft from channel invert)



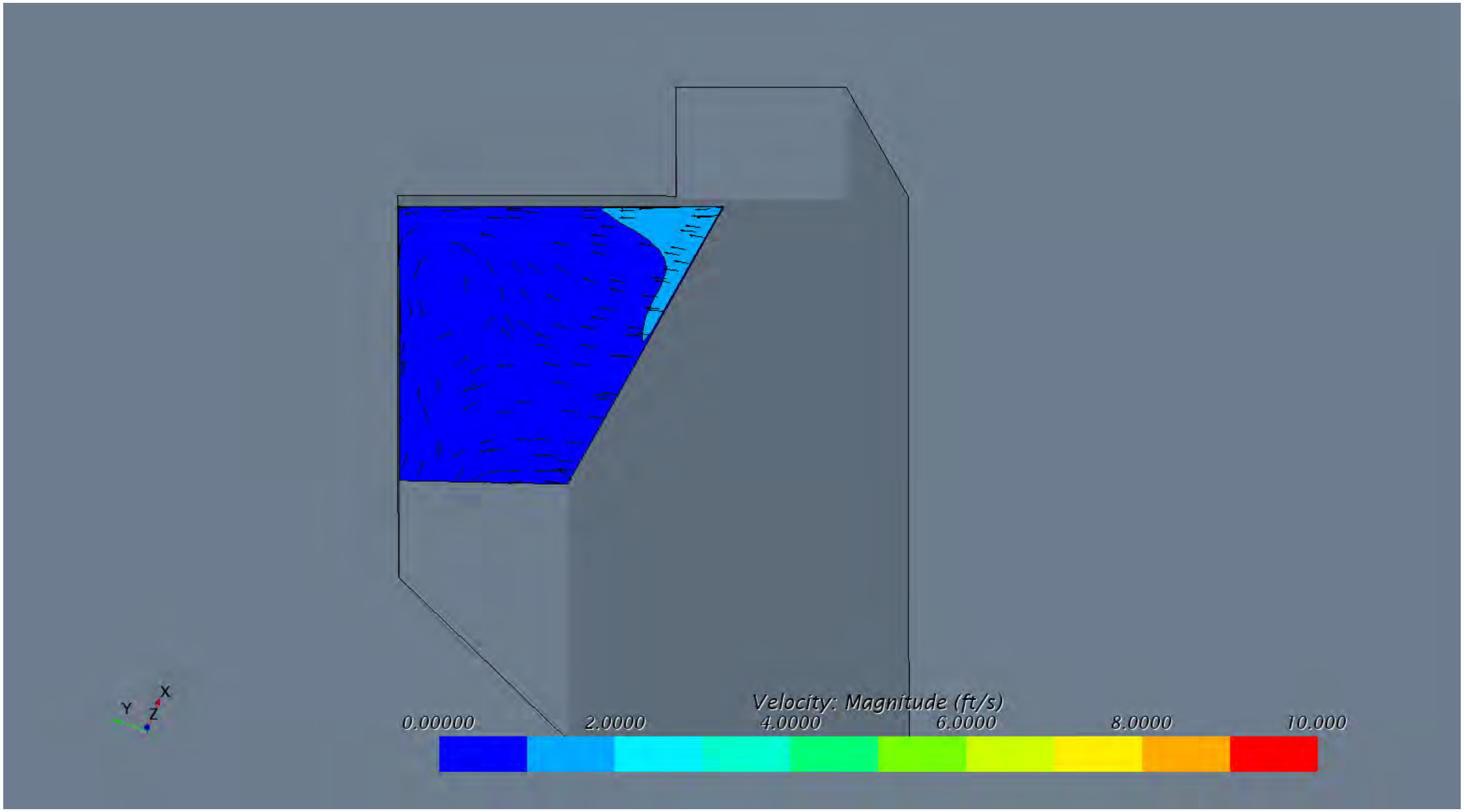
Velocity (Q = 180 cfs)

Figure 7: Velocity magnitude and direction at Longitudinal Section 3 (9.5 ft from channel invert)



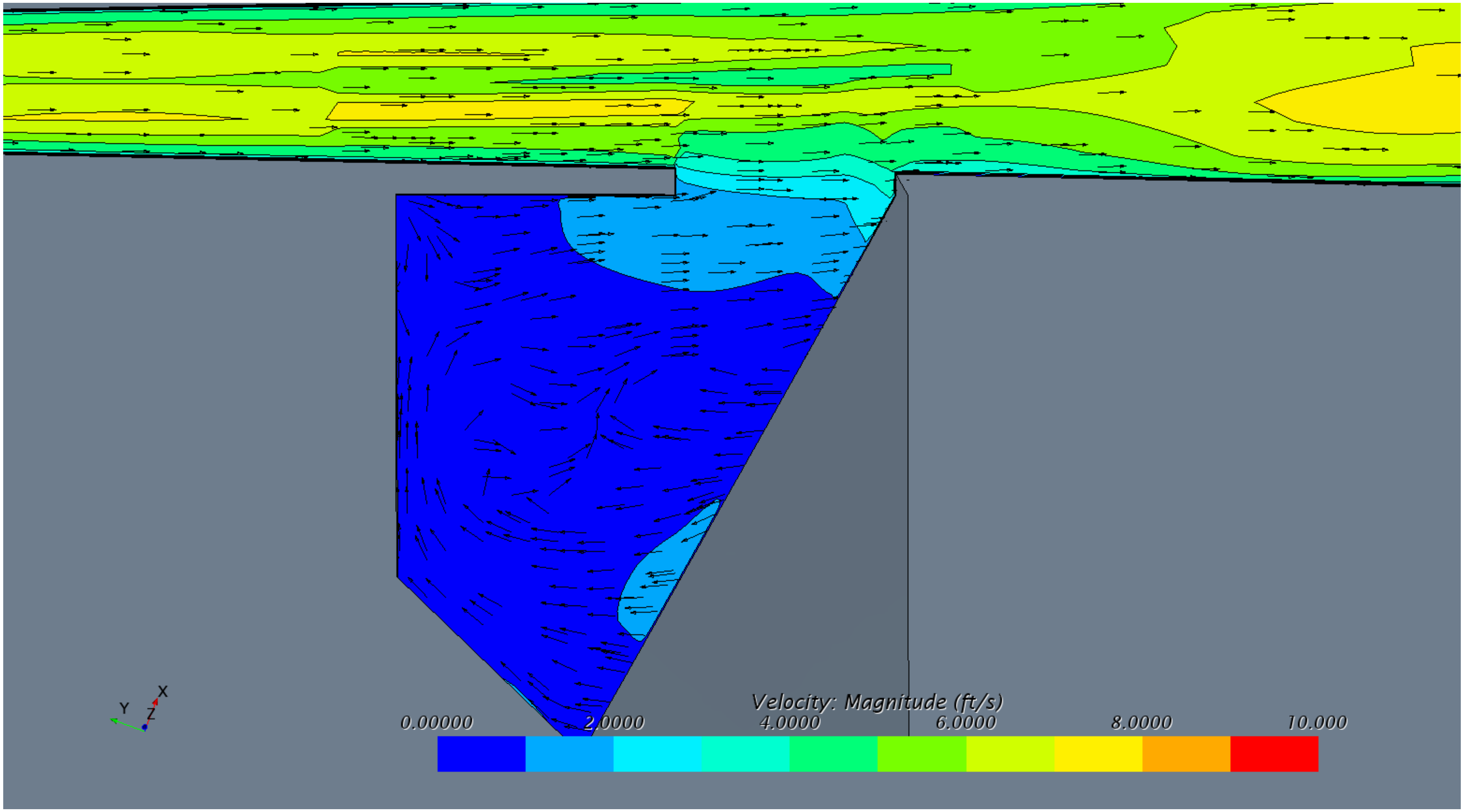
Velocity (Q = 180 cfs)

Figure 8: Velocity magnitude and direction at Horizontal Section 1 (Elev. 1.5 ft)



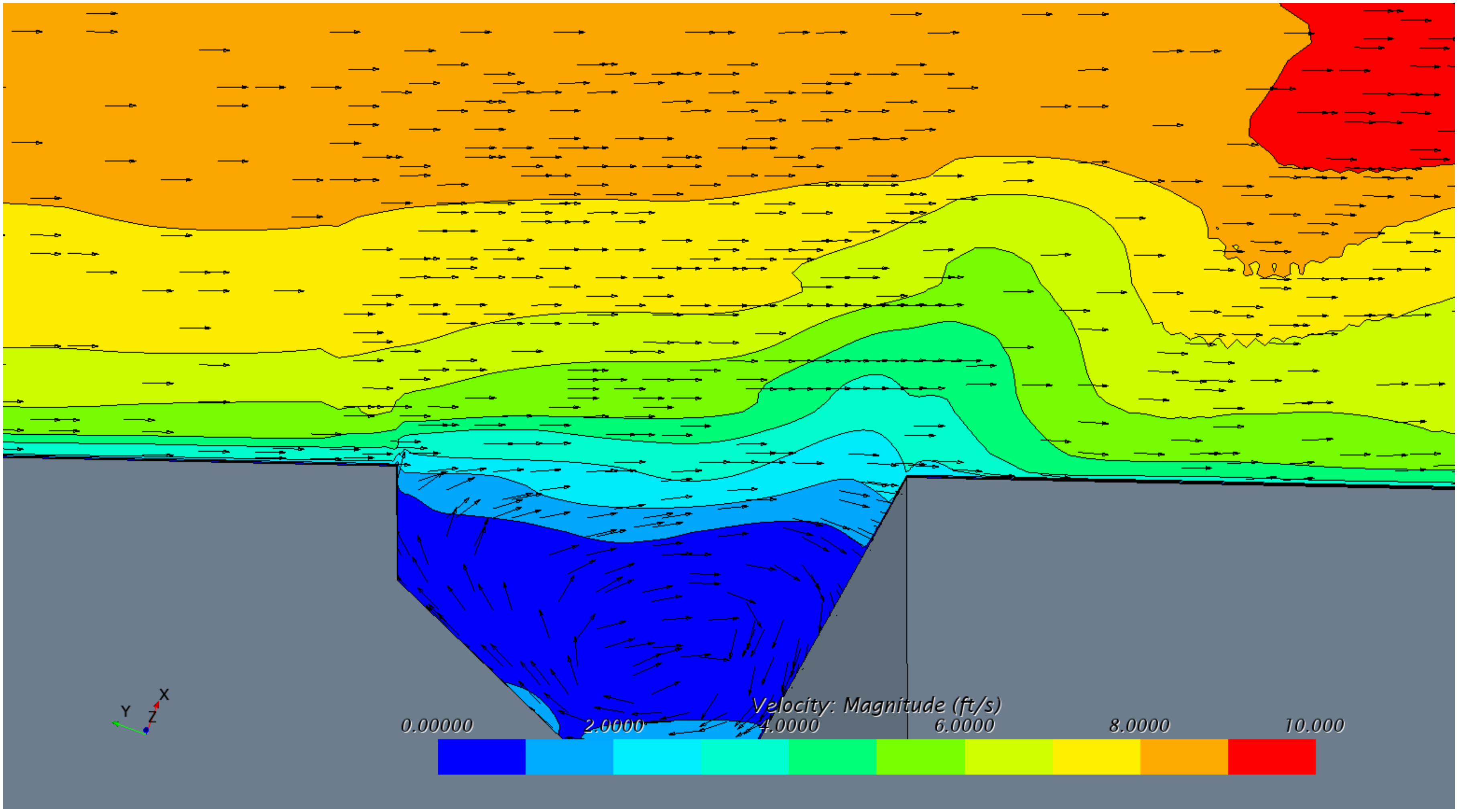
Velocity (Q = 180 cfs)

Figure 9: Velocity magnitude and direction at Horizontal Section 2 (Elev. 2.5 ft)



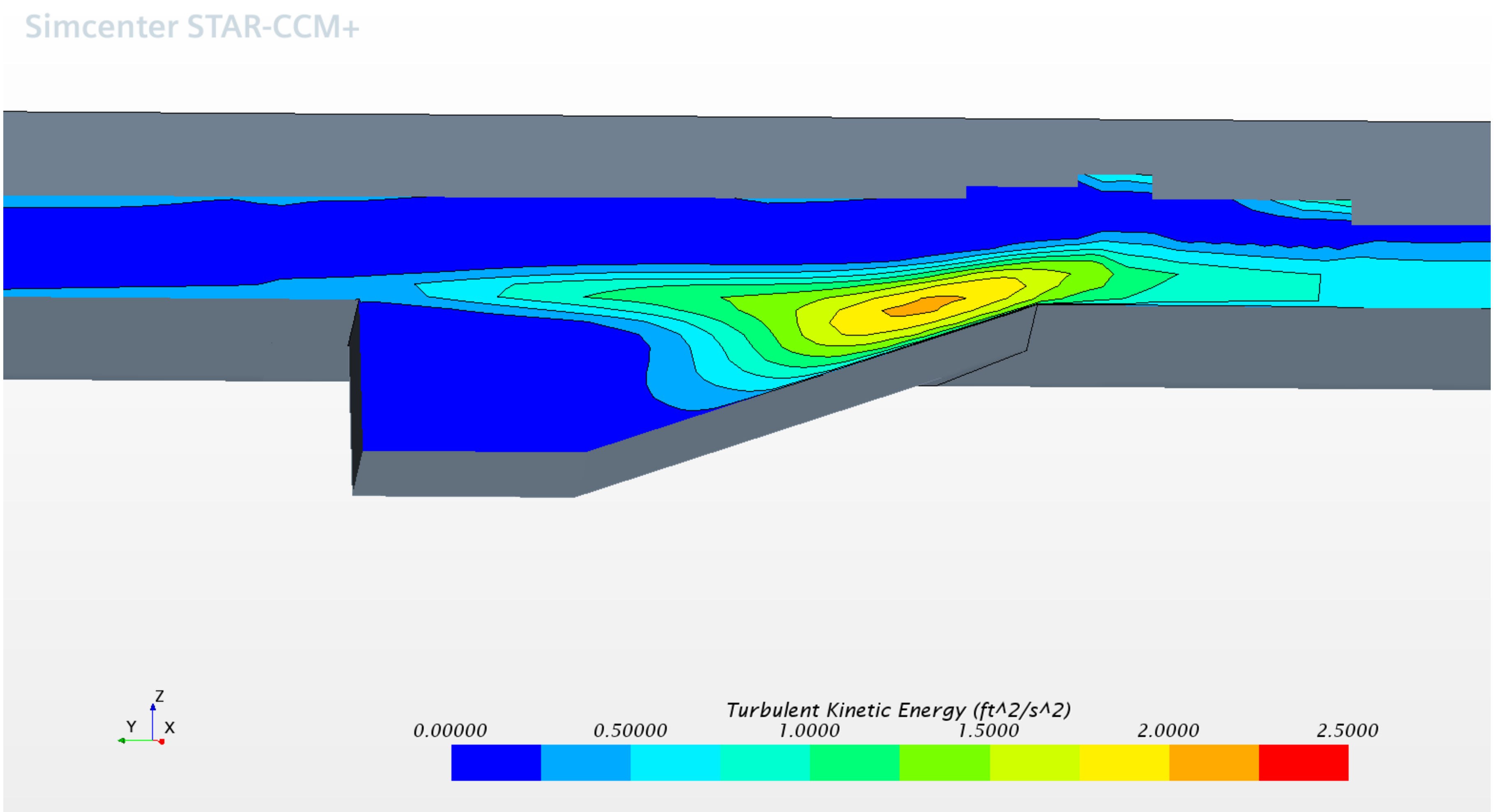
Velocity (Q = 180 cfs)

Figure 10: Velocity magnitude and direction at Horizontal Section 3 (Elev. 3.5 ft)



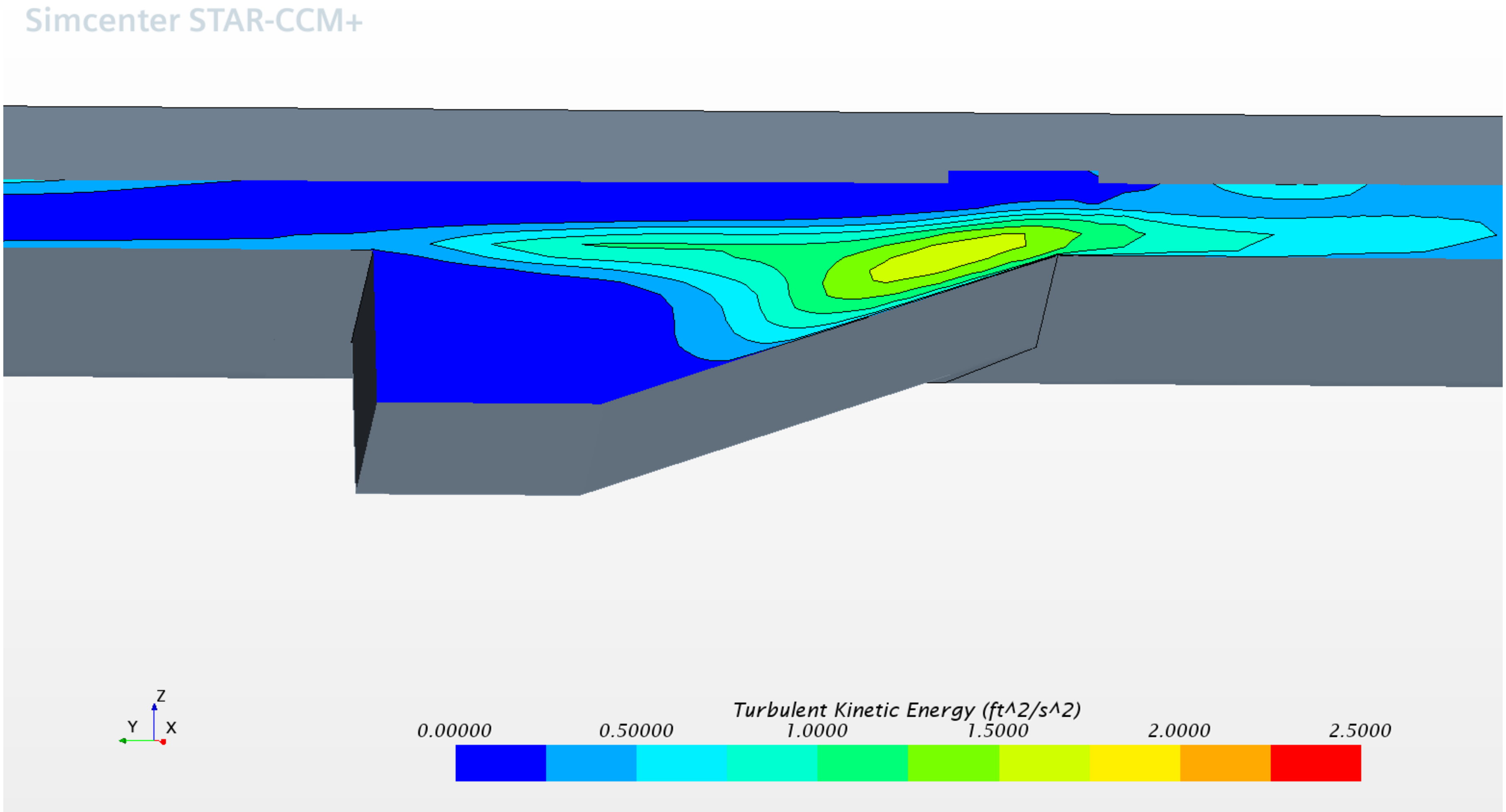
Turbulent Kinetic Energy (Q = 180 cfs)

Figure 11: TKE magnitude at Longitudinal Section 1 (4.5 ft from channel invert)



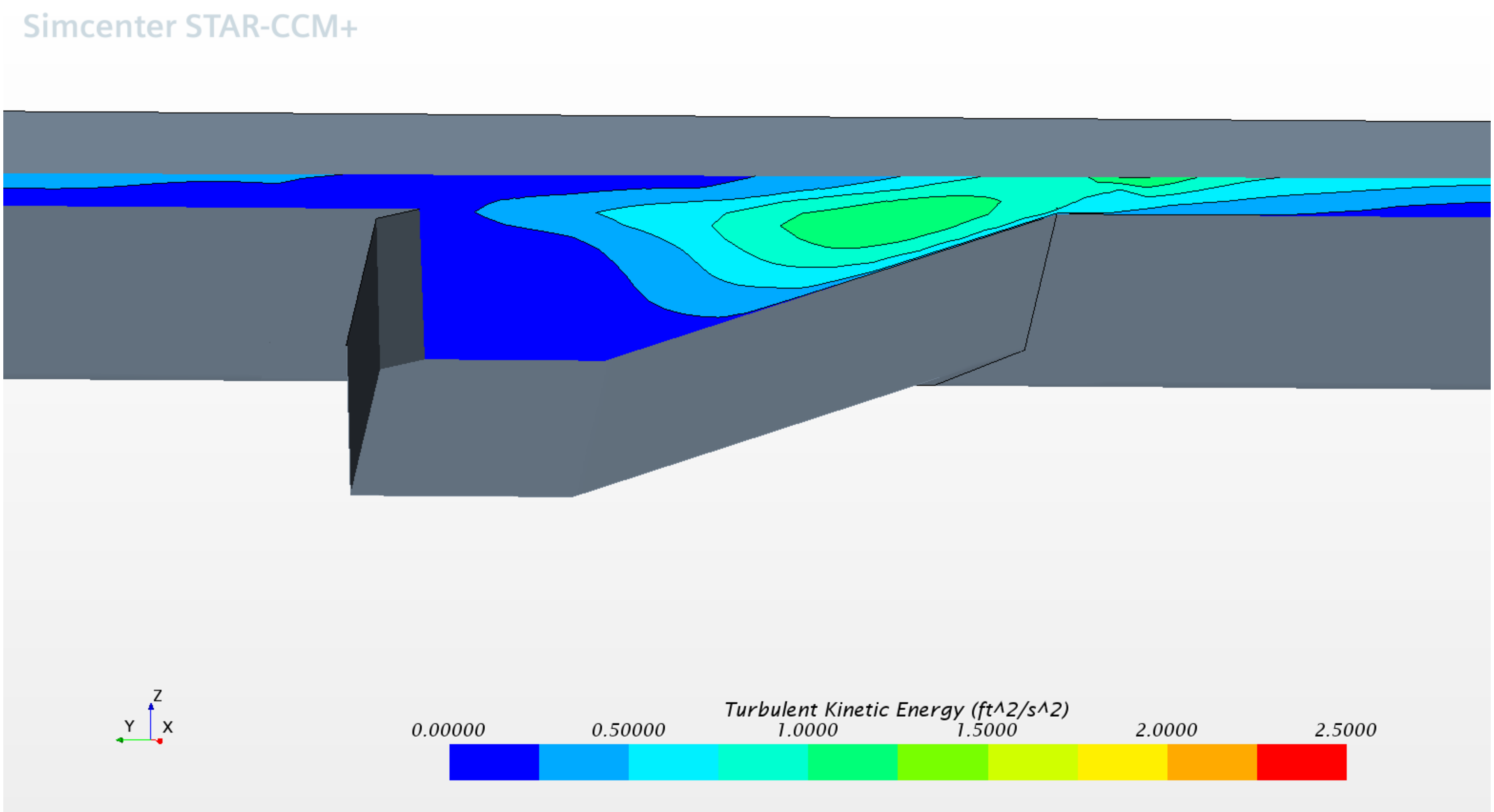
Velocity (Q = 180 cfs)

Figure 12: TKE magnitude at Longitudinal Section 2 (7 ft from channel invert)



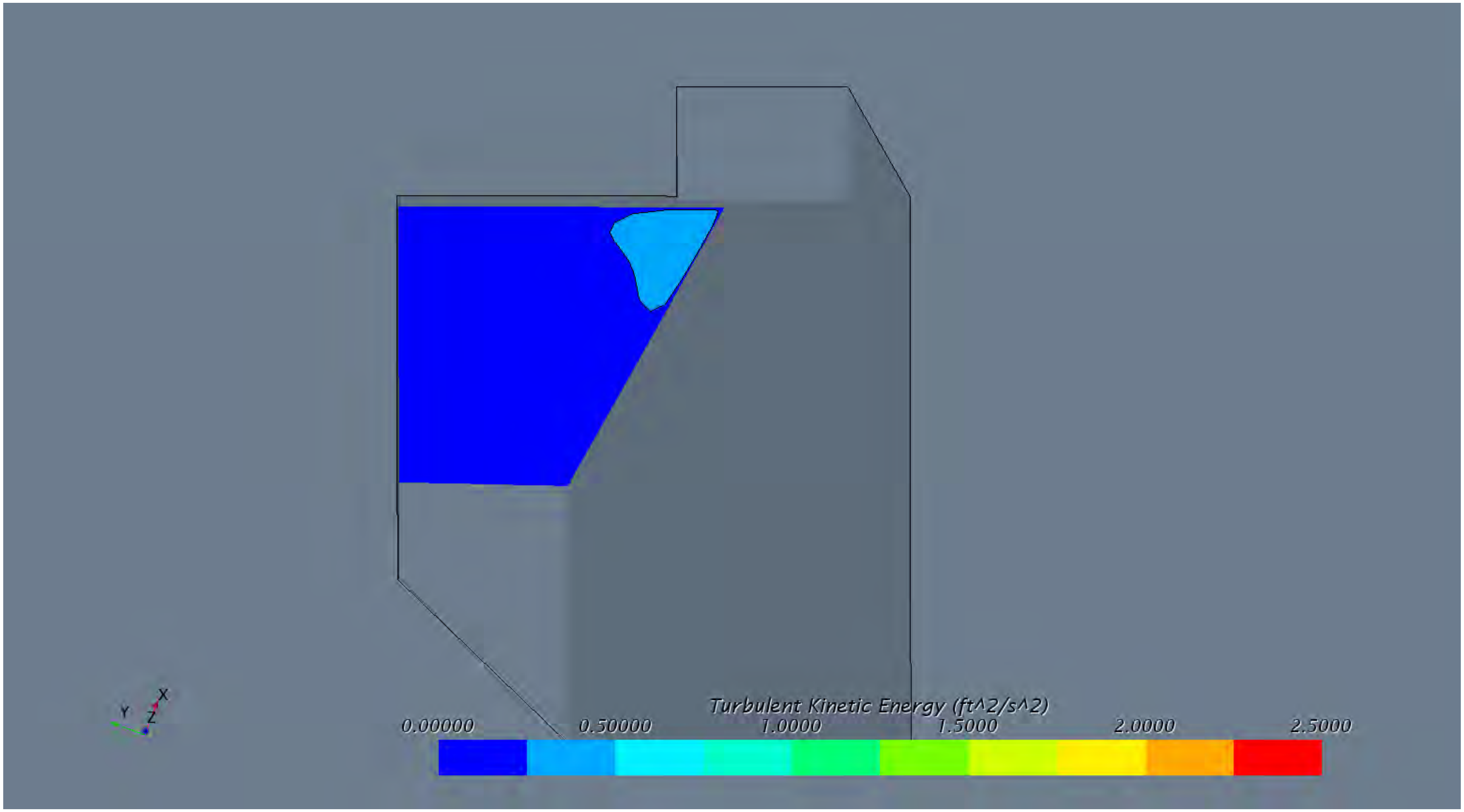
Velocity (Q = 180 cfs)

Figure 13: TKE magnitude at Longitudinal Section 3 (9.5 ft from channel invert)



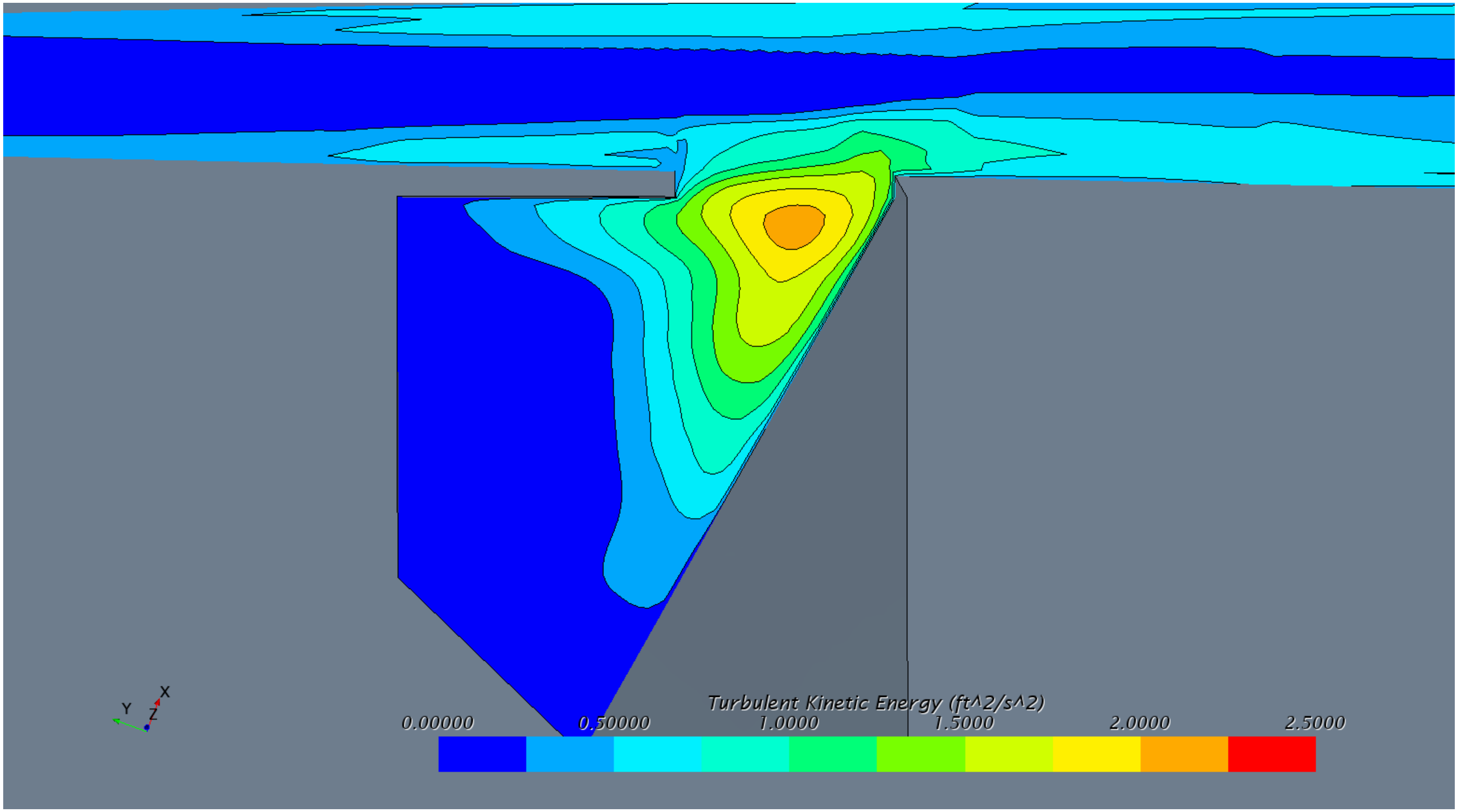
Velocity (Q = 180 cfs)

Figure 14: TKE magnitude at Horizontal Section 1 (Elev. 1.5 ft)



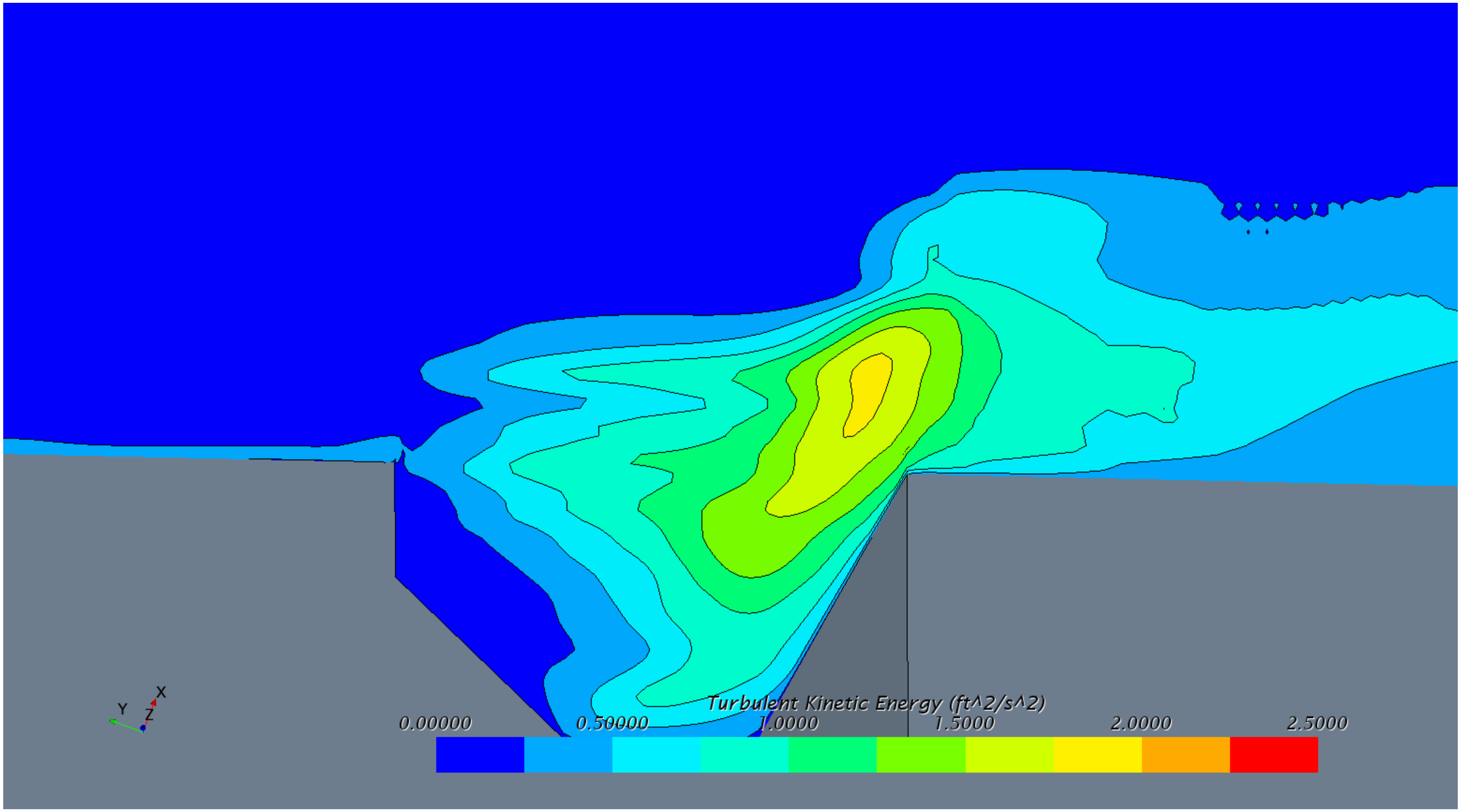
Velocity (Q = 180 cfs)

Figure 15: TKE magnitude at Horizontal Section 2 (Elev. 2.5 ft)



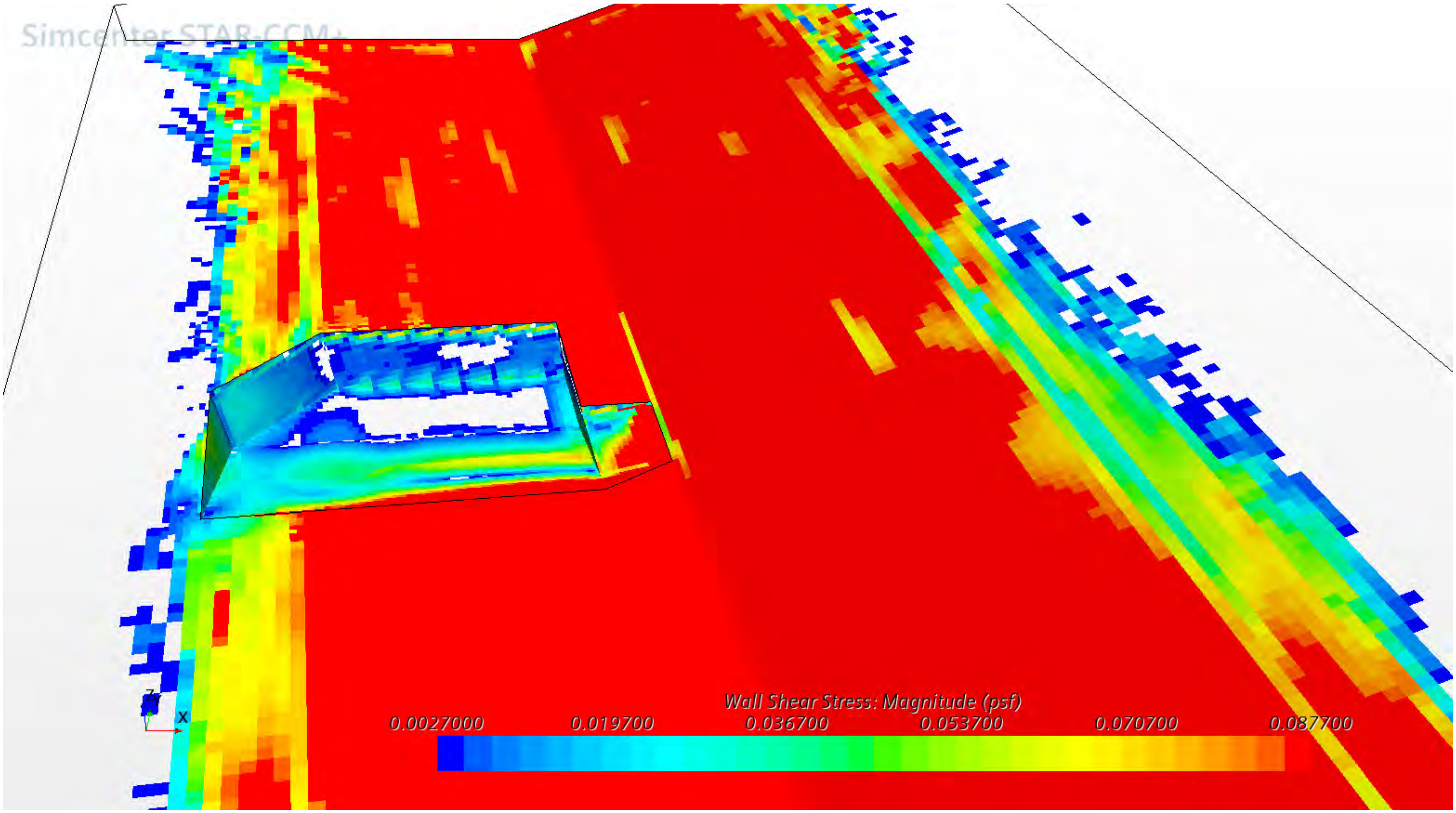
Velocity (Q = 180 cfs)

Figure 16: TKE magnitude at Horizontal Section 3 (Elev. 3.5 ft)



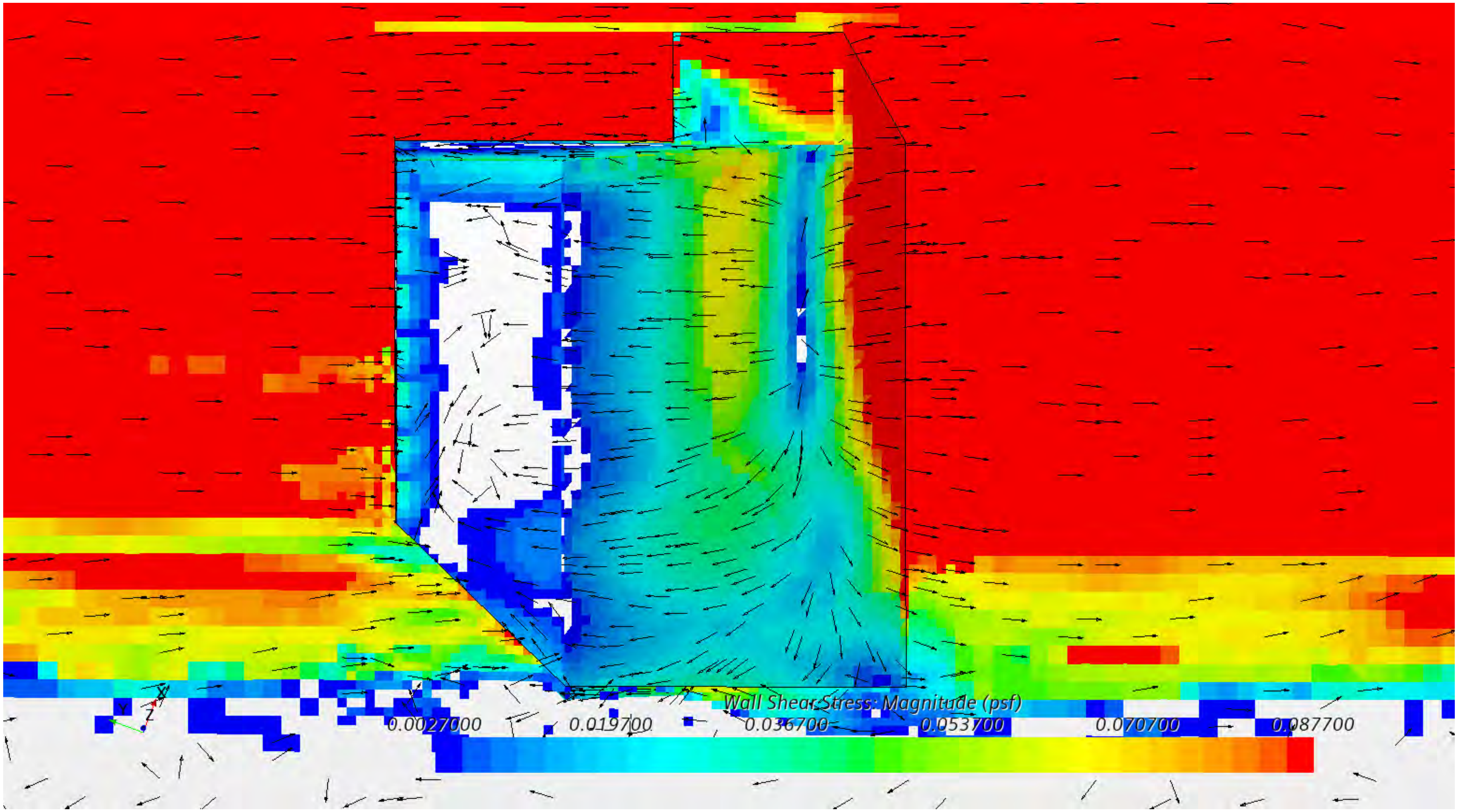
Shear Stress (Q = 180 cfs)

Figure 17: Shear stress magnitude on channel bottom
White areas < 0.0027 psf (critical shear for very fine sand)
Red areas >= 0.0877 psf (critical shear for fine gravel)



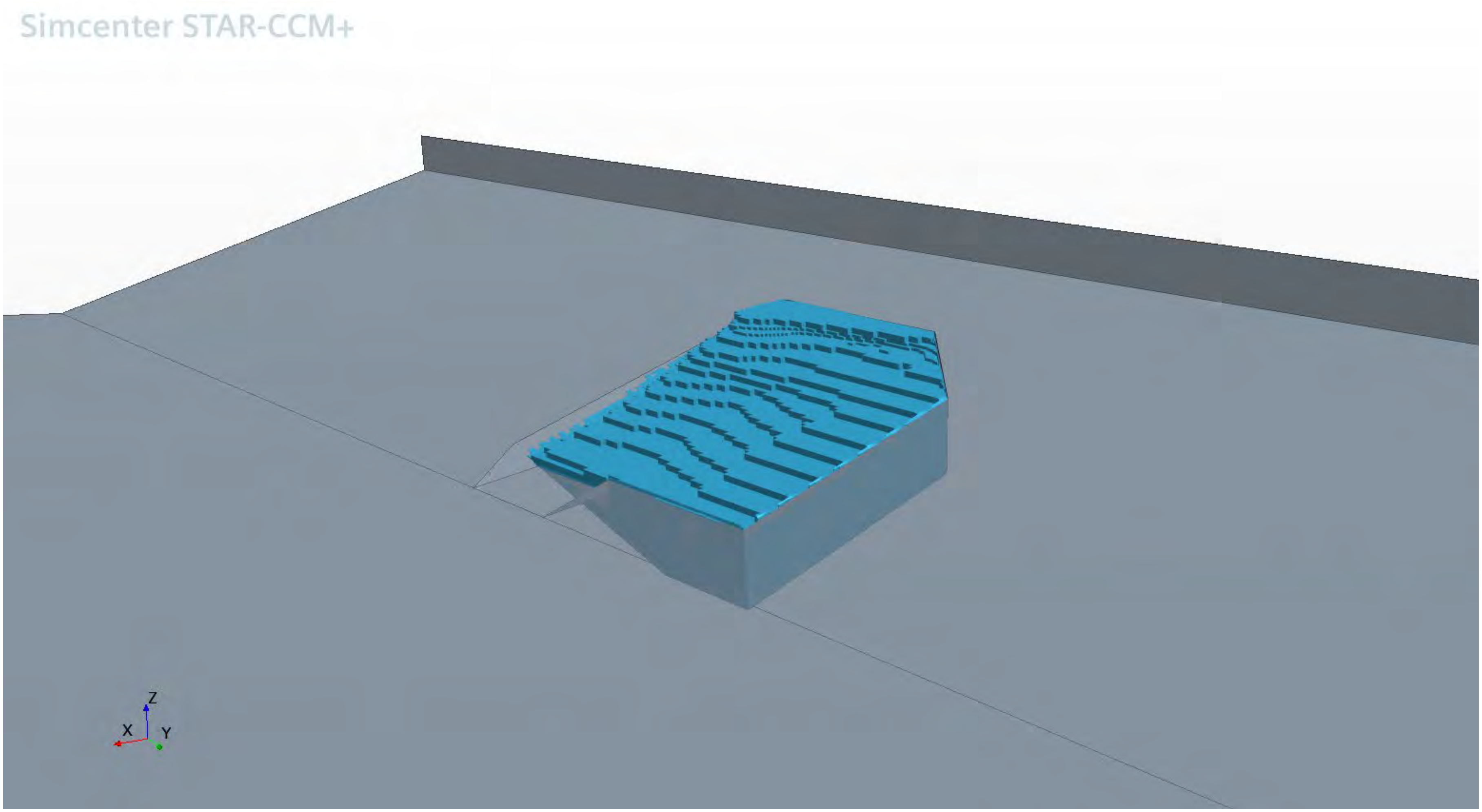
Shear Stress (Q = 180 cfs)

Figure 18: Shear stress magnitude and direction at fish pool
White areas < 0.0027 psf (critical shear for very fine sand)
Red areas >= 0.0877 psf (critical shear for fine gravel)



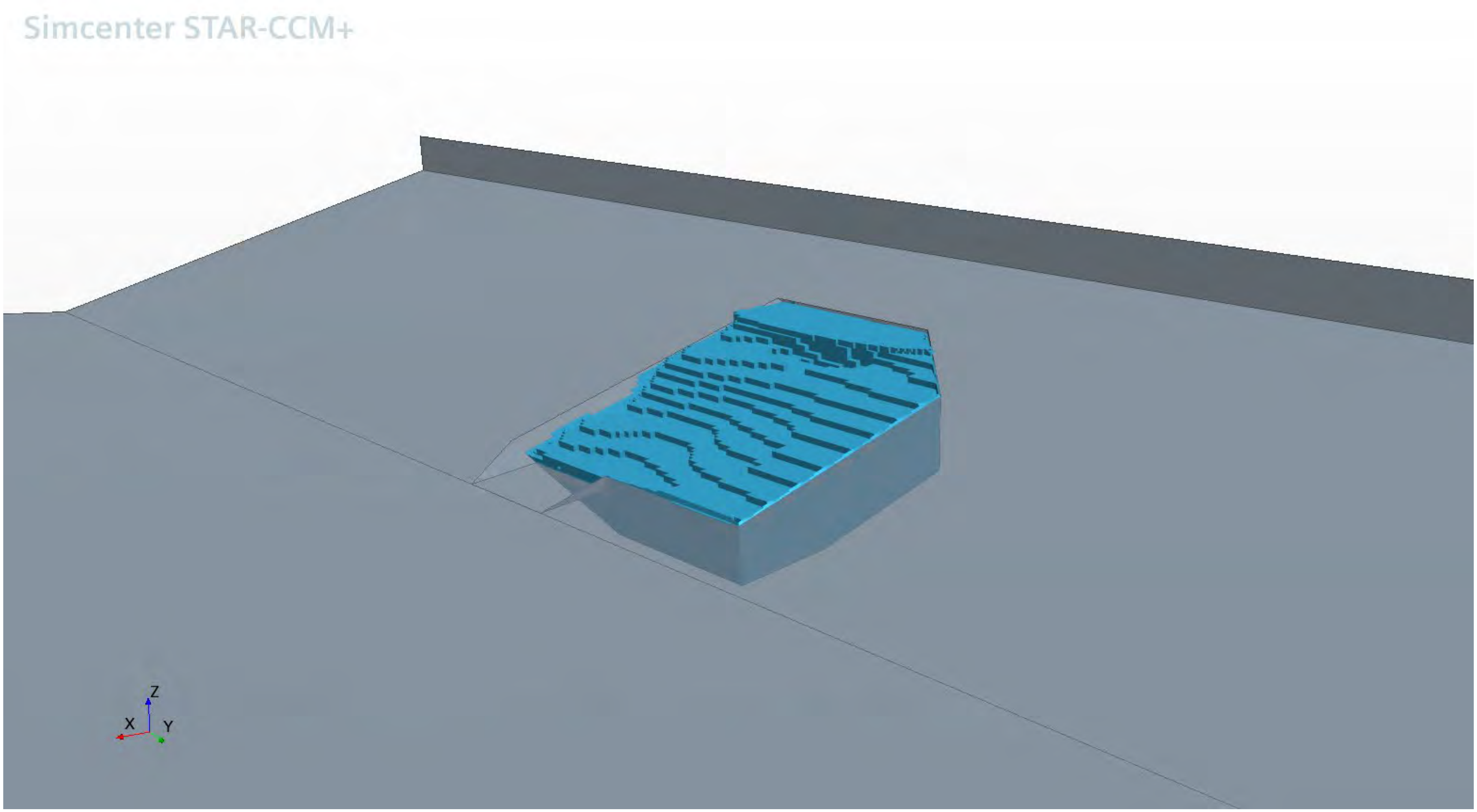
Velocity < 2 ft/s (Q = 180 cfs)

Figure 19: Region in fish pool with velocity < 2 ft/s
Volume = 108 ft^3



<u>Fish Pool Alternative 4 – 180 cfs with 6" of Sediment in Pool</u>
Velocity < 2 ft/s (Q = 180 cfs)

Figure 20: Region in fish pool with velocity < 2 ft/s
Volume = 104 ft^3



<u>Fish Pool Alternative 4 – 180 cfs with 12” of Sediment in Pool</u>
Velocity < 2 ft/s (Q = 180 cfs)

Figure 21: Region in fish pool with velocity < 2 ft/s
Volume = 96 ft^3