Exhibit D to Resolution 17-4824

TECHNICAL MEMORANDUM

Hydraulic Modeling of 90-percent Conceptual Design of the Willamette Falls Riverwalk Project

PREPARED FOR:	Alex Gilbertson/Metro
	Brian Vaughn/Metro
PREPARED BY:	Ryan Mitchell/CH2M
	Tim Bedford/CH2M
DATE:	December 6, 2017
REVISION NO.:	1 (FINAL)
REVIEWED BY:	Paul Burnet/CH2M

Introduction

The purpose of this memorandum is to document the hydraulic modeling analysis performed to support the 90-percent conceptual design of the Riverwalk Project at the Willamette Falls Legacy Site. Hydraulic modeling results are intended to provide members of the internal design and permitting teams with the best available hydraulic information they need to finalize specific elements of the *conceptual design*, specifically those that interact with the river (i.e. river bank and floodplain grading, elevated walkways and their foundations, cantilevered decks, and retaining walls). The results presented here should not be viewed as the final proposed conditions at the site, as the design is expected to evolve throughout the design development process. The model may be reapplied at later design stages to evaluate changes in the design, as needed.

Hydraulic model results also provide the opportunity to better understand the project's impacts on aquatic habitat, with a focus on the impacts to off-channel refugia habitat for juvenile salmonids (spring-run Chinook salmon, coho salmon and Steelhead) and Pacific lamprey. Impacts to riparian habitat, and habitats for other key species (such as white sturgeon, osprey, double-crested cormorants, northern red-legged frog, common nighthawk, common garter snake, green heron, great blue heron, belted kingfisher, and river otter and the California sea lion) are not considered in this analysis due to the nature of the proposed habitat improvements (off-channel alcoves) and hydraulic models can inform conditions related to aquatic habitats (i.e. water depth and velocity).

All hydraulic analysis was performed using a two-dimensional (2D) hydraulic model (MIKE 21 FM). Details of the model development and calibration process, along with associated model results that characterize the existing system, are provided in the report titled *Riverwalk Project - Willamette Falls Legacy Site: Hydraulic Model Development and Characterization of Existing Conditions* (CH2M, 2017).

This memorandum focuses on the hydraulic analysis of the proposed 90-percent Conceptual Design, and specifically describes the modeling approach and key assumptions, and presents the graphical hydraulic results along with a supporting narrative describing key observations for each of the design flows. All graphical results are included in Attachment A.

Modeling Approach

A 2D hydraulic model was initially developed to characterize the existing river system. The model was used to compute water levels, flow depths, velocities, and shear stress throughout the study reach for five flow rates that represent a wide range of flow conditions (summer low-flow to an extreme flood). The existing condition model was calibrated to multiple flood events before being used for hydraulic characterization.

There were two primary objectives for the existing condition model:

1) To characterize the existing hydraulic conditions as they relate to habitat and infrastructure
2) To define baseline hydraulic conditions[1] for use in relative comparisons between existing and proposed conditions.

In contrast to the objectives for the existing condition model, the objectives for the proposed condition modeling effort are focused on evaluating the 90-percent conceptual design condition with the goal of informing the evolution of the design through a iterative feedback process. The *overall* objective is to provide members of the design team the best available hydraulic information that they need to advance the design. The *specific* modeling objectives for the proposed condition simulations are:

1) Identify and quantify impacts to river conditions associated with the proposed design, including but not limited to the following:
    a. Evaluating site conditions during an extreme flood, similar to the flood of February 1996
    b. Estimate hydraulic conditions and forces acting on critical infrastructure, to aid in evaluations of structural integrity (performed by others)
    c. Identify changes to aquatic habitat for juvenile salmonids during fish migration season (March – June)
2) Characterize flow paths and patterns
3) Identify areas with sedimentation or erosion concerns.

The primary difference between the existing and proposed condition models is the definition of the terrain (topography and bathymetry) and the model mesh used to represent the terrain geometry. All other assumptions and components of the model are the same. The following section describes the data sources and details of both the existing and proposed terrain, and their representations in the model mesh.

The terrain data used to define the existing river and floodplain includes bathymetry data collected in 2000, LiDAR data flown in 2014, and supplemental ground survey data of the site collected in 2015. These data sources were merged into a single 1-meter by 1-meter Digital Terrain Model (DTM) surface in ESRI ArcGIS software. The proposed condition for the 90-percent design was inserted into the existing condition DTM to create a single surface that represents the designed condition. The model mesh, which has a coarser spatial resolution than the DTM, is applied (or "draped") over this DTM surface with critical features such as the dam crest, piers, and edges of buildings defined with breaklines for precise and accurate spatial definition. This process includes digitizing hundreds of small relic piers along the right bank adjacent to the site. As a result, the grid spacing was reduced to an average grid size of approximately 2 feet in this region, which increased model runtimes from roughly 12:1 (computational duration time: real flood-duration time) to 6:1 for all runs except the February 1996 event, which

[1] For details describing the existing hydraulic conditions at the site, refer to Technical Memorandum: *Riverwalk Project - Willamette Falls Legacy Site: Hydraulic Model Development and Characterization of Existing Conditions* (CH2M, 2017).

reduced model runtime down to 3:1 due to greater inundation area (more calculations to make) and higher velocities relative to other floods (leading to smaller time steps).

To characterize hydraulic conditions over a wide range of flow conditions the project team identified the same five design flows used to characterize the existing condition. The flow rates and tailwater elevations for the five design flows are summarized in Table 1. The modeling objectives for each design flows are detailed in Figure 1 in Attachment A.

Table 1
Design Flows and Boundary Conditions

Design Flow (cfs)	Stage (ft)	Definition	Explanation
384,000	46.5	February 1996	Extreme flood, >100-year peak flow
122,000	26.7	February 2017	Moderate flood, used for estimating Ordinary High Water
53,300	18.9	10% exceedance of average daily flow, March through June	Typical high flow condition during fish passage period
11,700	10.1	90% exceedance of average daily flow, March through June	Typical low flow condition during fish passage period
3,400	7.3	Summer low (2015)	Extreme low-flow

Proposed Terrain Model

The 90-percent concept design was provided for inclusion in the 2D model in the form of breaklines and 1-foot interval 3D contours in an AutoCAD Civil 3D drawing format. From this format the data were converted to GIS feature class contours, and then converted to a Triangular Irregular Surface (TIN). This process does not always yield a perfectly accurate surface as the automated interpolation between contours assumes a linear variation in elevation between contours. New breaklines were defined in the 90-percent design concept mesh to reflect modifications of terrain features from the existing conditions. The 90-percent concept design is shown in Figure 3, the mesh representation of the design is shown in Figures 4a – 4c, and Figure 5 shows the *difference* in ground elevation between the existing and 90-percent conceptual design to highlight the proposed changes in site grading.

Model Results

Results are presented with color-shaded contour plots showing a given hydraulic parameter (water-surface elevation [WSE], velocity, etc.) for each flow rate and tailwater condition. Results for the flood flows (384,000 cubic feet per second (cfs) and 122,000 cfs) include contour plots for each hydraulic parameter (WSE, depth, velocity, and shear stress); these design flows are intended to guide design of physical infrastructure elements by identifying the hydraulic forces acting on proposed structures.

The three aquatic habitat characterization flows (3,400 cfs, 11,700 cfs, and 53,300 cfs) focus on depth and velocity plots with palette colors selected to highlight threshold habitat suitability conditions for juvenile salmonid habitat. The habitat suitability index ranges from zero to one with one being optimal and zero being unsuitable hydraulic conditions for the respective target species and life-stage (juvenile salmonids in this case). The habitat suitability indices for each hydraulic parameter are summarized in Table 2.

Table 2
Habitat Suitability Index (HSI) Explained

Parameter	Magnitude	Habitat Suitability Index	Color Shading on Results Graphics: Qualitative Habitat Value
Velocity	0 – 0.8 fps	0.8 - 1.0	Green: Valuable Habitat
	0.8 – 1.3 fps	0.8 - 0.4	Yellow: Moderate Habitat Value
	1.3 – 2.6 fps	0.4 – 0.0	Red: Modest Habitat Value
	> 2.6 fps	0.0	Blue/Purple: Unsuitable
Depth	0 – 0.2 ft	0.0	Blue/Purple: Unsuitable
	0.2 – 0.6 ft	0.0 – 0.2	Red: Modest Habitat Value
	0.6 – 1.3 ft	0.2 – 0.8	Yellow: Moderate Habitat Value
	> 1.3 ft	1.0	Green: Valuable Habitat

Observations and interpretations for each of the design flows are summarized below with associated graphics included in Attachment A. Further discussion of key modeling results and observations are included in the Conclusions section.

Extreme Flood Results (February, 1996 Event, 384,000 cfs)

The discussion below summarizes the model results for this event which are shown in Figures 6 through 10 in Attachment A. It should be noted that the modeling effort of the 90-percent concept design did not attempted to characterize or simulate debris buildup, or various PGE spillway configurations during a large flood (such as February 1996). These impedances to flow on the dam crest can greatly affect the flow paths, water surface elevations and potentially the extent of inundation at the project site (for example, overbank flow around Mill E and down Main Street such as occurred during the 1996 flood).

Under this scenario, it was assumed that the primary flow path associate with the buildings located on the river bank (such as Mill H) would be under the building where the only obstructions to flow are the pier foundations (this is the same assumption used for all other design flows). The flow obstruction created by the floor and walls of the first-level of the building is not seen by the model. Actual flow conditions during a large flood would likely experience a combination of these flow paths and associated obstructions.

The exposed alcoves in the 90-percent conceptual design appear to create suitable refugia habitat for juvenile salmonids during large floods, assuming they are able to find and enter the alcove given the challenging approach conditions created by high turbulence and velocities, which could be a limiting factor under these extreme conditions. Modeling results also show suitable refugia habitat zones in the large grotto alcove and behind Mill O, assuming the salmonids can find and access the alcove. There are small refinements that can be made at the entrances to these alcoves to maximize the chance of “capturing” juveniles that are being flushed downstream along the shoreline during large floods – such details can be incorporated at later design stages. As a whole, the 90-percent concept design resulted in increased habitat refugia areas as well as increased flood conveyance due to a net reduction in floodplain obstructions.

There were no apparent impacts to water levels upstream or downstream of the project site (and none were expected given that the proposed alcoves only affect local hydraulics in off-channel areas).

Moderate Flood (February 9th, 2017 Event, 122,000 cfs, ~2-year recurrence interval)

The discussion below summarizes the model results for this event which are shown in Figures 11 through 19 in Attachment A. This event, approximating a river level consistent with the Ordinary High Water Elevation, occurs on average about every-other year. Many of the design features in the North

Riverfront area are above the tailwater elevation at this flow rate. The public yard steps, which taper down to the grotto alcove, are also above the modeled tail water elevation. However, it should be noted that the tailwater elevation is variable (depending on receiving water and tidal conditions) and that under different tailwater conditions (than assumed in the model) the steps could become inundated. The new alcoves represented in the 90-percent concept design creates high quality refugia habitat for juvenile salmonid, as velocities in the main channel are too high for juvenile salmonids to hold position.

Habitat Design Flows (10% and 90% Exceedances of Average Flows for March – June)

The majority of spring runoff flow conditions are characterized between these two flows; the 90% exceedance flow (in other words, exceeded 90% of the time), equal to 11,700 cfs and 10% exceedance flow (exceeded 10% of the time), equal to 53,300 cfs. Habitat suitability and shallow water habitat areas are likely to vary between these conditions as river flows taper off entering into summer months. The discussion below summarizes the model results for these two events which are shown in Figures 20 through 24 in Attachment A.

<u>90% Spring Flow Exceedance, March – June (11,700 cfs)</u>
At this flow rate the grotto alcove provides suitable shelter for juvenile salmonids (adequate depth and low velocity). Downstream along the channel bank, adjacent to the pipe chase and Mill O there is also additional suitable habitat, which is not present in the existing condition. The main channel is unsuitable due to high velocities - however, at this flow rate the main channel flow is primarily near the left bank, and the submerged shelf (elevation -5 to 5 feet) along the right bank provides suitable habitat.

<u>10% Spring Flow Exceedance, March- June (53,300 cfs)</u>
At this flowrate, suitable habitat in terms of depth is limited due to the right bank shelf being fully submerged and now effectively conveying main channel discharge. However, the proposed condition creates localized refugia at the Mill H plant alcove, Grotto alcove and Mill O alcove. These areas are even more important considering the lack of suitable habitat on the left bank, which is characterized by steep banks and high flow velocities.

Summer 2015 Extreme Low Flow, 3,400 cfs

The discussion below summarizes the model results for this event which is shown on Figures 25 in Attachment A. All three of the habitat characterization flows display an increased area of ideal habitat in the grotto alcove, which is the largest alcove directly downstream of legacy Mill H Reject Plant relative to existing conditions. However, the extreme low flow of summer 2015 had the lowest main channel velocity, allowing for the greatest area of suitable habitat (combined depth and velocity) for juvenile salmonids. It should be noted that this analysis does not include evaluations of water quality parameters which are imperative for aquatic health, such as temperature, dissolved oxygen, nutrient concentrations, or cover, or substrate composition; therefore, the HSI scores alone should not be used for assessing the comprehensive aquatic habitat quality. It should be noted that there is a potential fish stranding concern in the alcove by the Yard during extreme low-flow conditions (see Figure 24). Some minor recontouring of the bed may be considered to eliminate the possible stranding risk by providing low-flow continuity.

Conclusions

The 2D hydraulic model was applied to the 90-percent design concept to evaluate how well the design performs relative to the project objectives related to hydraulic conditions (i.e. aquatic habitat goals, flooding impacts to proposed and existing infrastructure, etc.).

Five design flows were selected to investigate the modeling objectives that are stated in Figure 1 of Attachment A. Some of the key findings and observations are summarized below.

Key Findings:

- Observations for the extreme design flood (February 1996, ~250-year peak flow, 100-year downstream water level) include the following:
  - Inundation due to backwater is present in the Mill H and Mill O alcoves, submerging the bulkhead, low pipe chase walkway and public yard deck.
  - Velocities in this scenario are highest beneath the Mill H and low level of the Boiler Plant as high river velocities enter the shallow alcove. Other areas of the site, which are inundated due to backwater, have much lower velocities, including Mill H platform, Boiler Plant, and the Hawley Building.
  - Debris accumulation on the spillway piers can lead to higher water levels in the intake basin, resulting in overtopping of the flood wall and allowing floodwater to flow into the site from upstream, instead of from backwater as is shown in this analysis.
- Results from the 2-year design flood show that the proposed alcoves provide excellent off-channel refugia during this frequent moderate-sized flood event. However, the velocities on the margins of the main channel are at a threshold above which juveniles may not be able to readily access the alcoves due to such high approach velocities. Adding roughness elements along the shoreline would help reduce the velocities on the mainstem margins and enable juveniles to enter the alcoves more easily.
- The model predicts (as expected) that eddies will form at the head of each alcove over the entire range of flows, which creates a hydraulic buffer between the higher mainstem velocities and the quiescent water in the alcove. These eddies will “pull-in” floating woody debris and suspended sediment.
  - Woody debris will likely intermittently accumulate on the concrete piers under Mill H and under the pipe chase – these accumulations will create quality habitat for fish but they may also create safety concerns for boaters.
  - Eddies may accumulate sand; high velocities on the river-side of the eddy may be capable of transporting sand in suspension, and as water flows next to the eddyline it can become entrained in the eddy and subsequently settle-out due to the reduced velocities and turbulence within the eddy formation. To gain an understanding of how much sand may deposit under the eddies, if such an understanding is desired, we recommend field reconnaissance of similar eddy features on the Willamette River, near the site, to observe the sediment characteristics, depth, and expanse. This would ideally be done during late summer when water levels are at their lowest.
- Hydraulic modeling of the habitat design flows shows that the proposed 90-percent conceptual design meets the habitat restoration objectives, specifically to restore habitat health and complexity along shoreline, and increase habitat complexity within the off-channel alcove areas. The overall shoreline complexity is increased for all the flows considered in this analysis, due to the restoration of alcove habitats.
- The micro-complexity, or textural complexity, within the alcove areas was not assessed by the hydraulic model (the scale of the model is too coarse and the small habitat features have yet to be designed). However, there appear to be many opportunities to enhance the micro-complexity within the alcoves by adding basalt boulders and/or woody debris to create more interstitial space, cover, and shading for juvenile salmonids. Boulder clusters, large anchored wood placements, or even piers can also help recruit, or trap, woody debris that enters the alcoves naturally, and such features would enhance the natural processes of debris accumulation. The 2D model can be used in the future to simulate flow patterns and

characteristics around textural habitat elements like boulders and woody debris if the need arises at a later design phase.

- The potential for fish stranding in pools located in the alcoves doesn't appear to be a significant problem but designers should avoid grading plans that create pools that can become hydraulically isolated from the main channel. The alcove in the public yard appears to become isolated during the extreme low-flow condition (3,400 cfs) this could be addressed in the design process by ensuring a low-flow connection (such as a notch in the basalt) for such conditions.

Attachment A

2D Hydraulic Model Results, Willamette Falls Riverwalk - 90% Concept Design

Date: September, 2017

Modeling Objectives:

1. Identify and quantify impacts to river conditions associated with the proposed design, including but not limited to the following:
   a. Evaluating site conditions during an extreme flood similar to the flood of February 1996
   b. Estimate hydraulic conditions and forces acting on critical infrastructure, to aid in evaluations of structural integrity (performed by others)
   c. Identify changes to aquatic habitat for juvenile salmonids during fish migration season (March – June)
2. Characterize flow paths and patterns
3. Identify areas with sedimentation or erosion concerns

Design Flows:

Design Flow (cfs)	Statistical Definition	Purpose/Objectives
384,000	~250-year (estimated upstream conditions for 1996 flood)	Evaluate hydraulic conditions during extreme floods such as the 1996 flood. Assess impacts to infrastructure.
122,000	~2-year (February 2017)	Evaluate hydraulic conditions during a "typical" flood event. Identify availability of refugia habitat for juvenile salmonids. Estimate the Ordinary High Water boundary.
53,300	10% exceedance of average daily flow, March through June	Evaluate refugia habitat for juvenile salmonids during a typical high flow condition during fish migration period
11,700	90% exceedance of average daily flow, March through June	Evaluate refugia habitat for juvenile salmonids during a typical low flow condition during fish migration period
3,400	Extreme low-flow (summer 2015)	Evaluate aquatic habitat conditions during extreme low flow conditions.

FIGURE 1
Modeling Objectives and Design Flows
Riverwalk Project, Willamette Falls Legacy Site

Area 1
North Riverfront

Area 2
South Riverfront

Area 3
PGE Dam and Mill E

Area 4
Canemah

Source: Adapted from 90% Concept Design Package (Snohetta, May 5, 2017)

Willamette Falls
LEGACY PROJECT

Riverwalk - Concept Phase
90% Concept Design - May 5, 2017

Snøhetta Mayer/Reed DIALOG

FIGURE 2
Existing Conditions of Project Site
Riverwalk Project, Willamette Falls Legacy Site

Area 1	Area 2	Area 3	Area 4
North Riverfront	South Riverfront	PGE Dam and Mill E	Canemah

Source: Adapted from 90% Concept Design Package (Snohetta, May 5, 2017)

Willamette Falls
LEGACY PROJECT

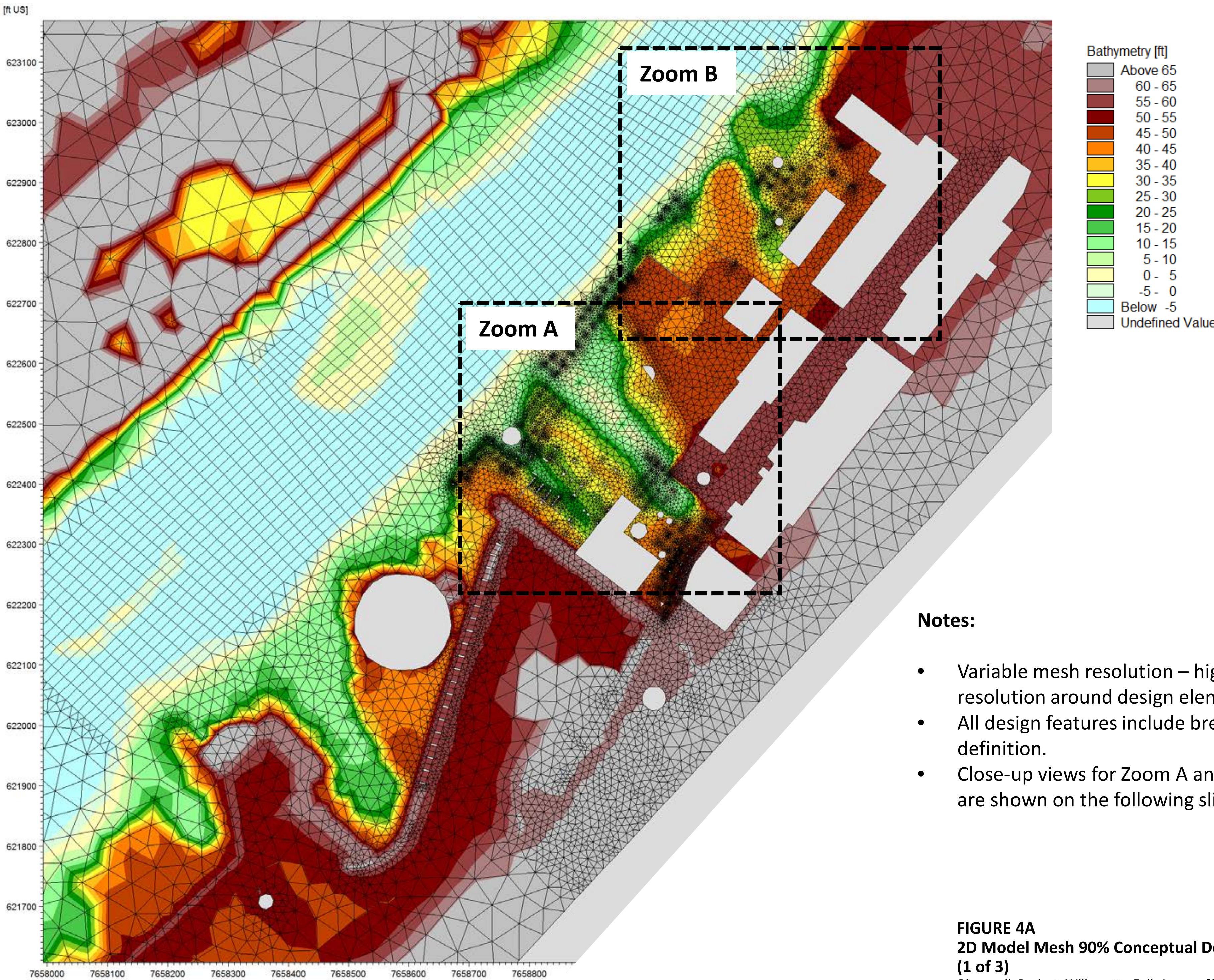
Riverwalk - Concept Phase
90% Concept Design - May 5, 2017

Snøhetta Mayer/Reed DIALOG

- This graphic shows the 90% concept design as modeled.
- The names of features and design areas are referenced on the following hydraulic result graphics.

FIGURE 3
Proposed Conditions- 90% Conceptual Design Surface
Riverwalk Project, Willamette Falls Legacy Site

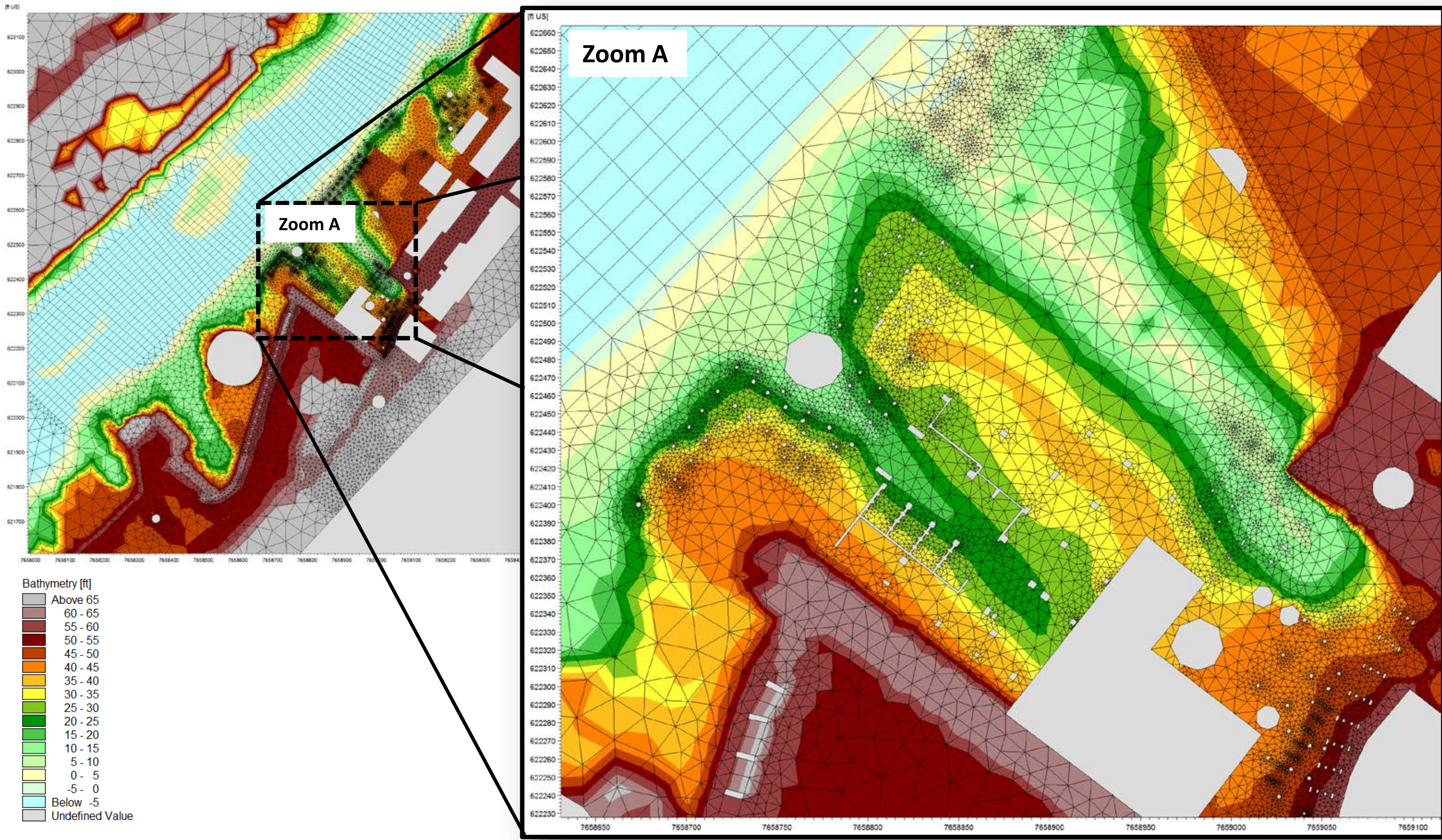
ch2m:



Notes:

- Variable mesh resolution – highest grid resolution around design elements.
- All design features include breakline definition.
- Close-up views for Zoom A and Zoom B are shown on the following slides.

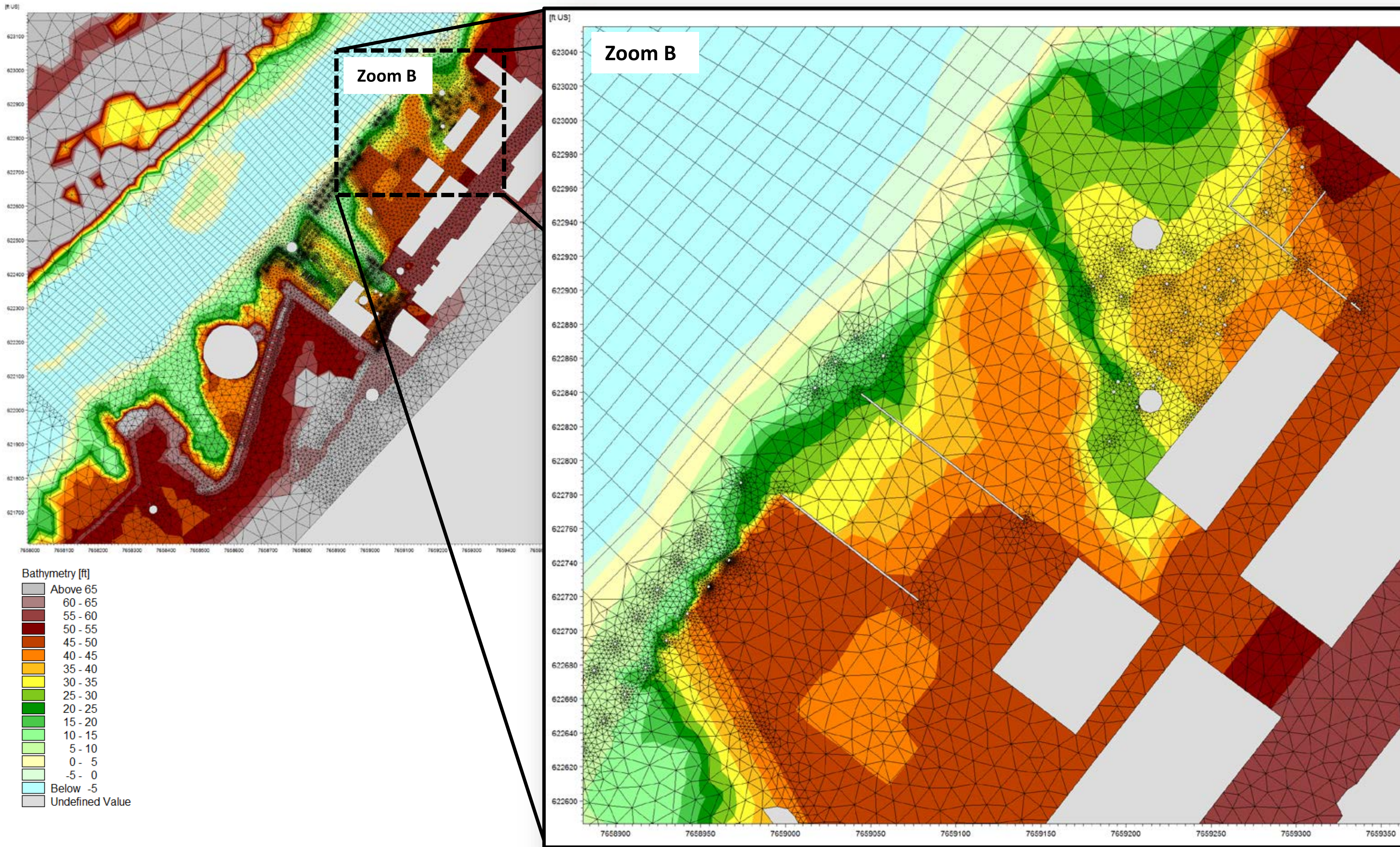
FIGURE 4A
2D Model Mesh 90% Conceptual Design Surface (1 of 3)
Riverwalk Project, Willamette Falls Legacy Site



Notes:

- Piers, tanks, and building walls are defined with breaklines and are seen as solid objects in the 2D hydraulic model.

FIGURE 4B
2D Model Mesh 90% Conceptual Design Surface (2 of 3)
Riverwalk Project, Willamette Falls Legacy Site

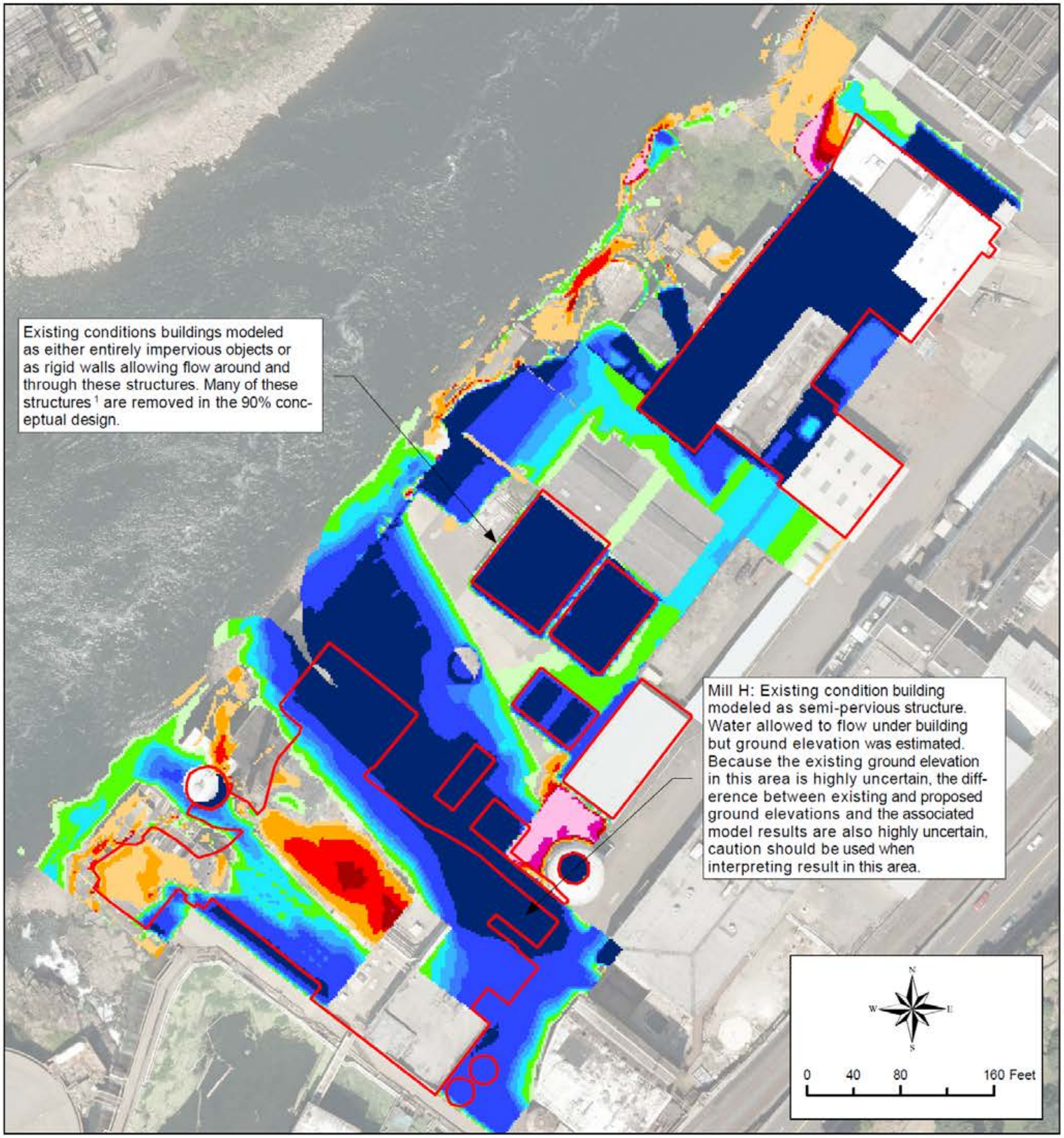


Notes:

- Piers, tanks, and building walls are defined with breaklines and are seen as solid objects in the 2D hydraulic model.

FIGURE 4C
2D Model Mesh 90% Conceptual Design Surface (3 of 3)
Riverwalk Project, Willamette Falls Legacy Site

ch2m:



Notes:
Many buildings[1] in the existing condition which sit on the finished concrete on the mill level deck (elevation roughly 45 feet, AKS Survey, dated Sept 30, 2015) are removed in the 90% conceptual design and the natural basalt exposed.
Buildings in which there is no difference were treated the same in both elevation models. Including: Paper Machine No. 2, Paper Machine No. 1, Hawley Building, and Mill O.

1: Buildings include: Carpentry Shop, Mill Wright Shop, Mill O Covered Storage, South Substation, Paper Machine No. 3, Paper Machine No. 2.

LEGEND

Building outline

Difference Grid: 90% Conceptual Design less Existing Condition

10 - 20	**Fill (ft)**
8 - 10	
6 - 8	
4 - 6	
2 - 4	
1 - 2	
1 - -1	**Neutral**
-2 - -1	
-4 - -2	
-6 - -4	
-8 - -6	
-10 - -8	
-20 - -10	
< -20	**Cut (ft)**

FIGURE 5
Elevation Difference Between Existing and 90-percent Conceptual Design
Riverwalk Project, Willamette Falls Legacy Site

ch2m:

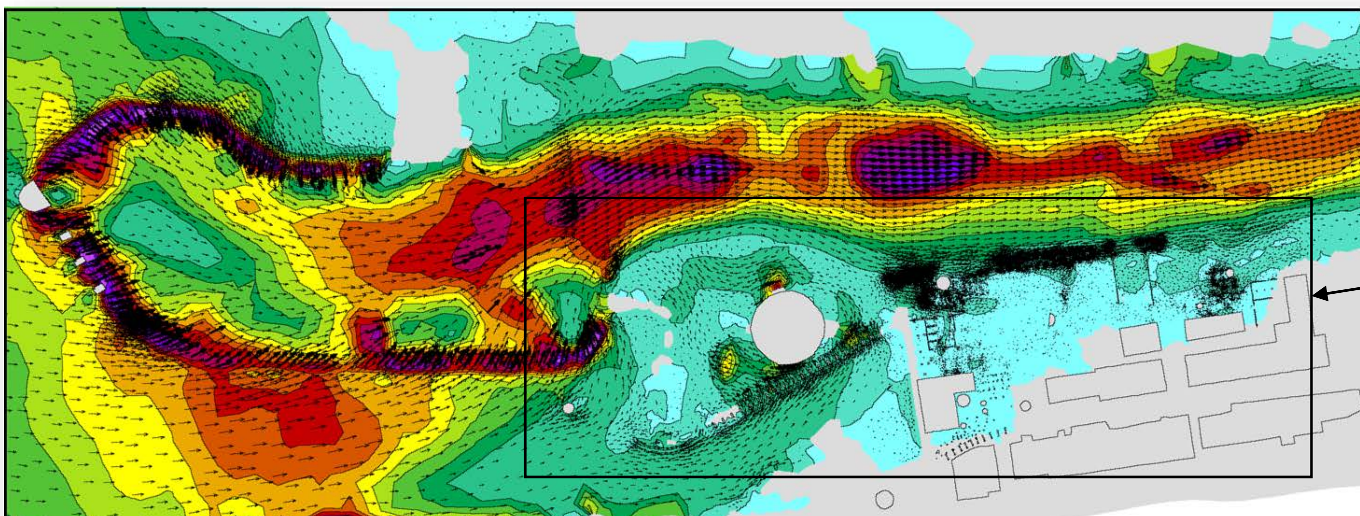
Aerial Image February 1996

Extreme Flood – similar to February 1996

Modeling Objectives:

- Evaluate hydraulic conditions during extreme floods such as the 1996 flood.
- Assess impacts to infrastructure and key design elements.

Flow Rate = 384,000 cfs (estimated)
Tailwater Elevation = 46.5 ft, NAVD 88

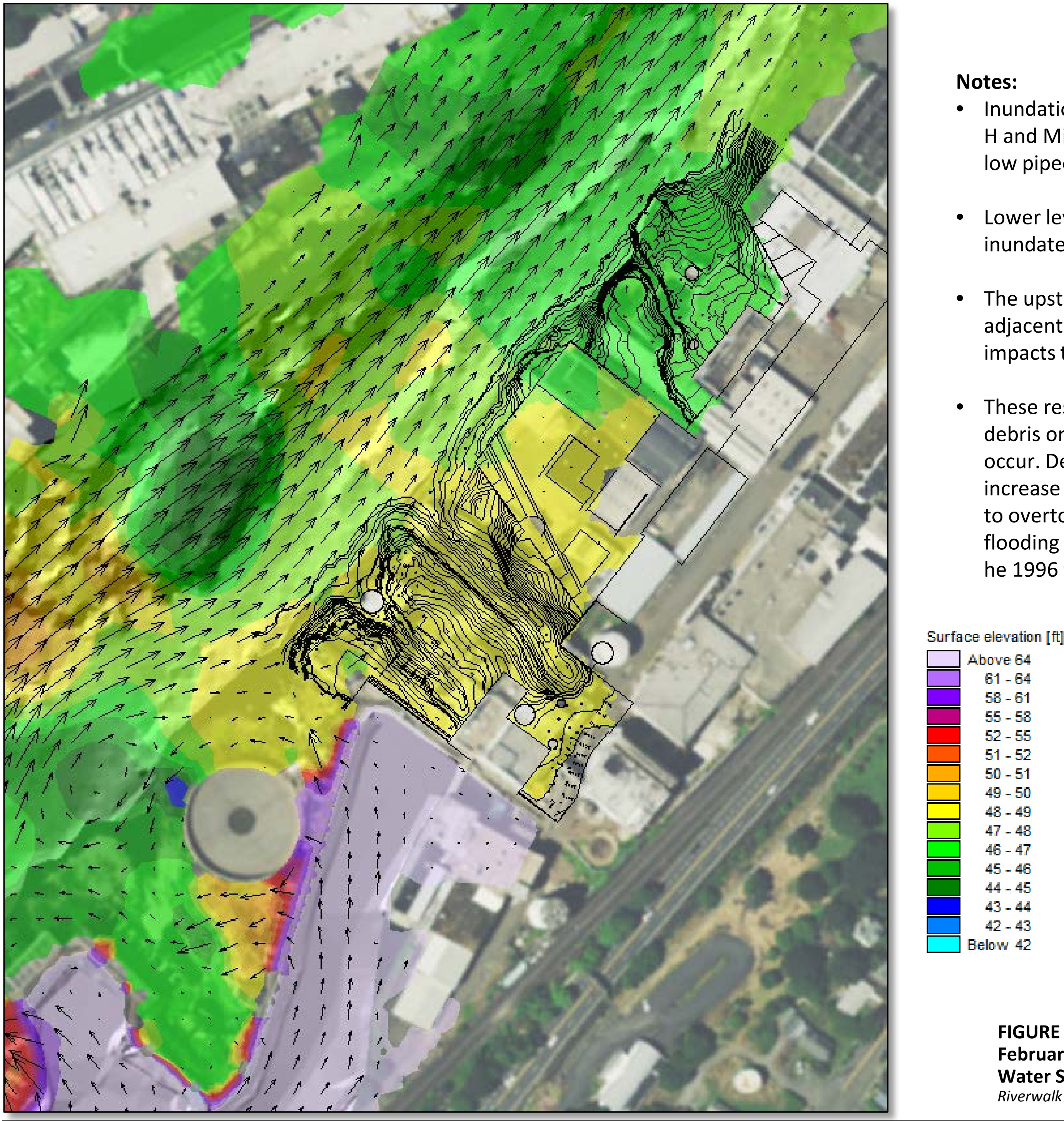


Focus area for results interpretation

2D Model Results for 1996 Flood

FIGURE 6
Introduction to Hydraulic Results for the 1996 Flood
Riverwalk Project, Willamette Falls Legacy Site

ch2m:

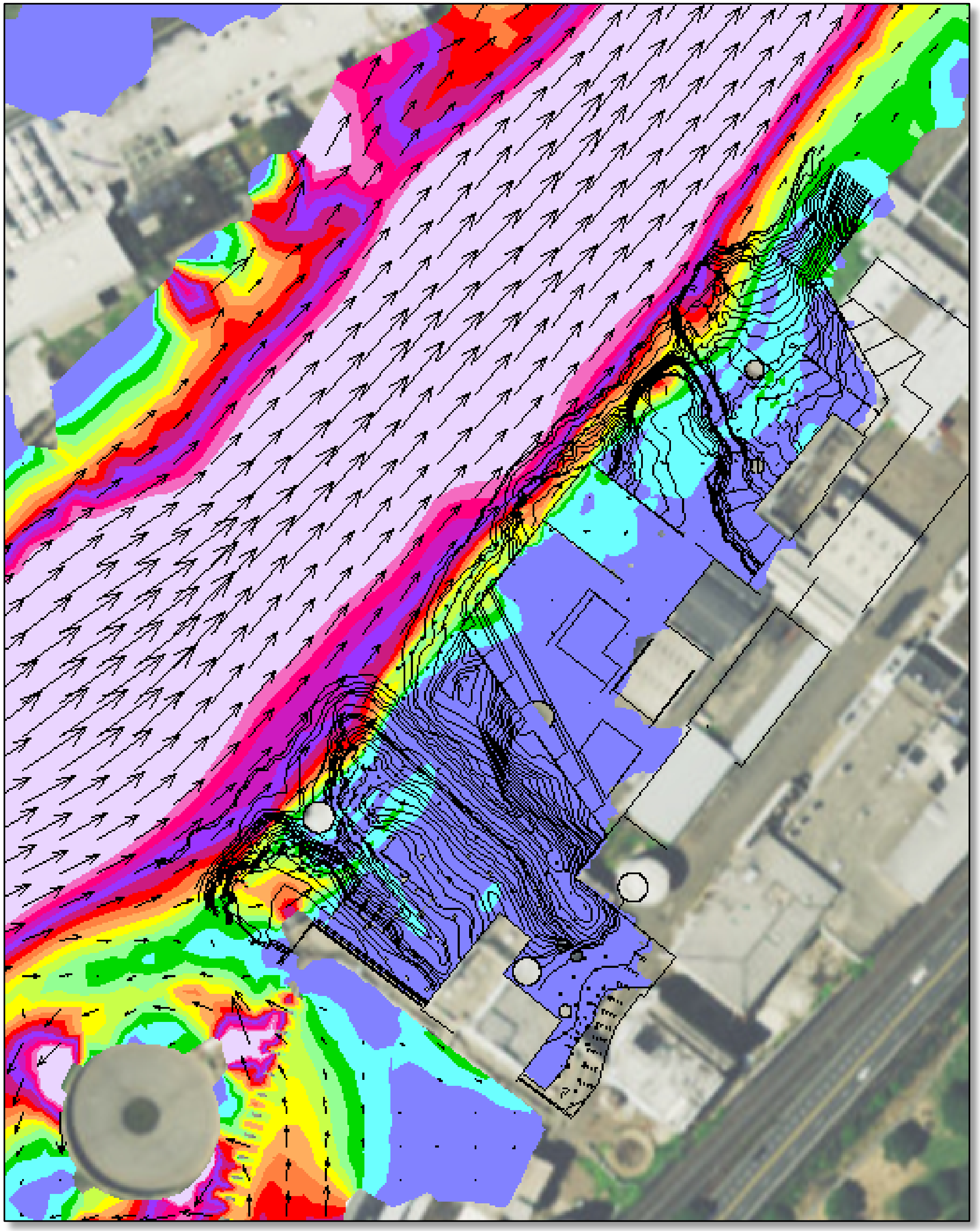


Notes:

- Inundation due to backwater is present in the Mill H and Mill O alcoves, submerging the bulkhead, low pipechase walkway and public yard deck.
- Lower levels of the boiler plant and Mill H are inundated (beneath roughly 49 feet).
- The upstream intake basin does not overtop the adjacent walkway in this scenario, reducing impacts to the site.
- These results do not consider the accumulation of debris on the spillway gates, which is know to occur. Debris accumulation on the gates can increase water levels in the forebay and can lead to overtopping of the dam resulting in greater flooding through the site, as was observed during he 1996 flood.

FIGURE 7
February 1996 Discharge, 384,000 cfs
Water Surface Elevation – 90% concept design
Riverwalk Project, Willamette Falls Legacy Site

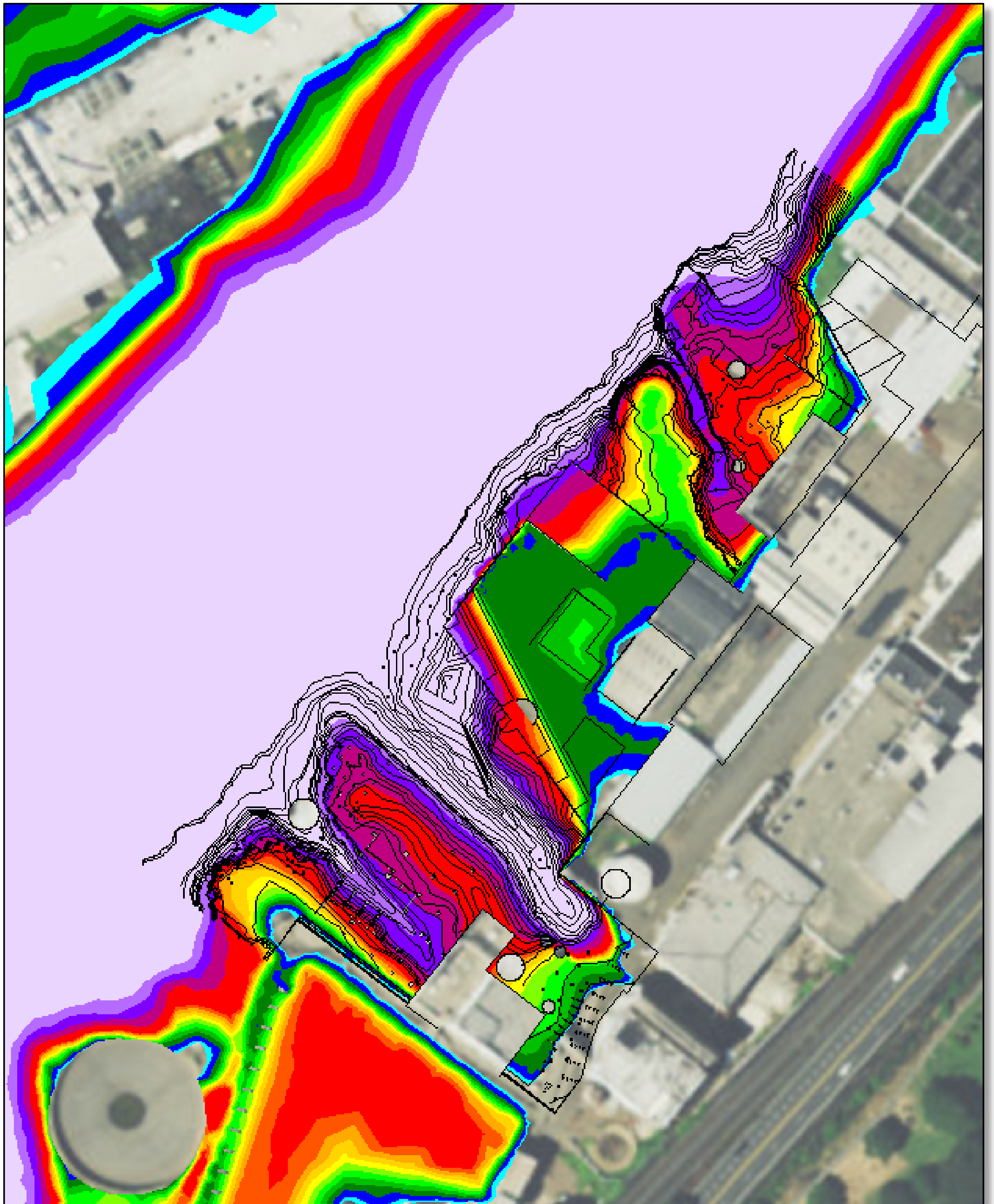
ch2m:



Notes:

- Velocities in this scenario are highest beneath the Mill H and Low level of the Boiler Plant as high river velocities enter the shallow alcove.
- The alcoves near Mill H and the public yard are backwatered. The recirculating eddy velocities are relatively low.
- The alcove near Mill O has velocities up to 5 ft/s with recirculating currents around the bulkhead.

FIGURE 8
February 1996 Discharge, 384,000 cfs
Velocity Characteristics – 90% concept design
Riverwalk Project, Willamette Falls Legacy Site

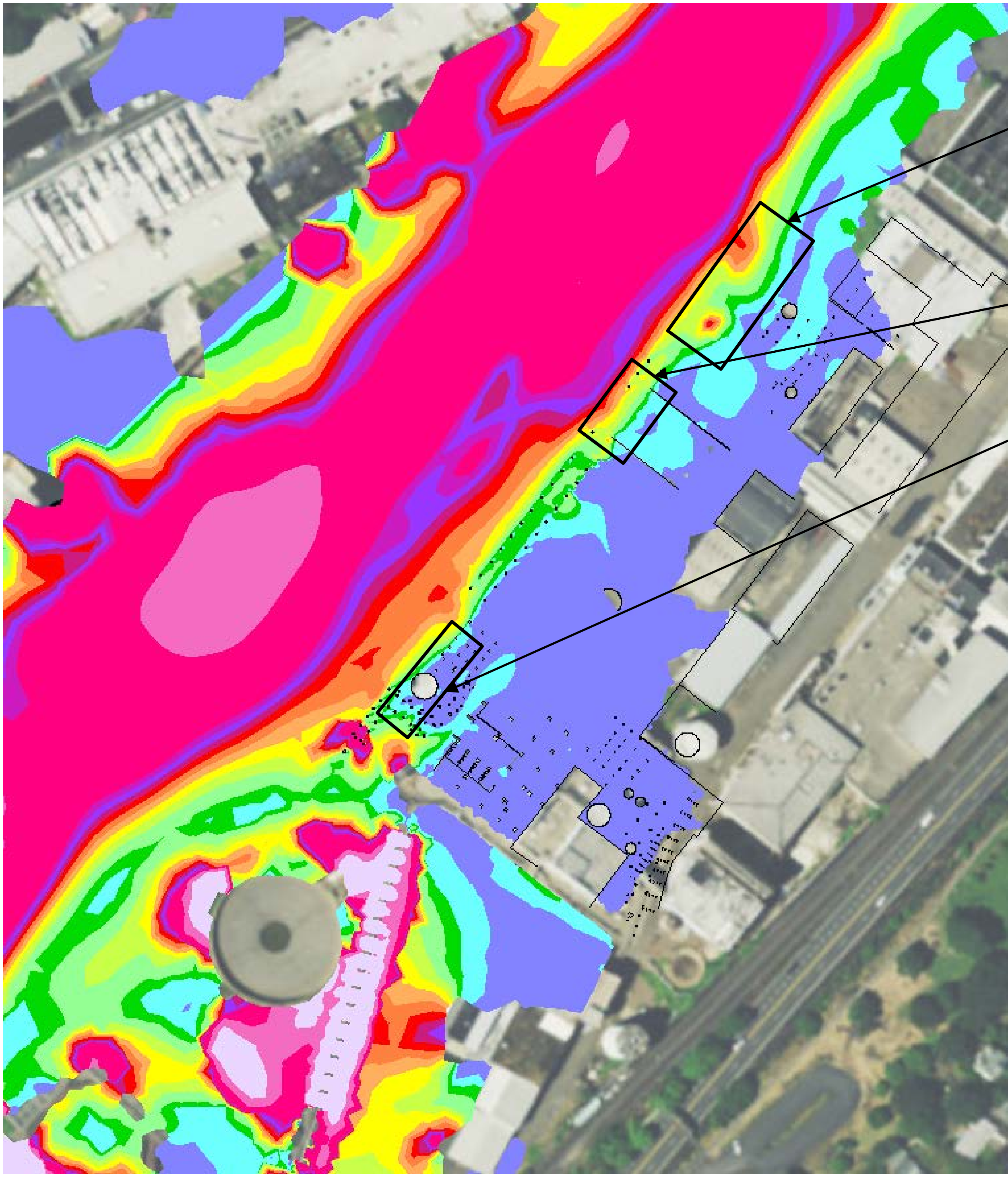


Notes:

- The color ramp is intentionally skewed to highlight the shallow water depths (< 30ft) to focus on the near-shore conditions.

Total water depth [ft]
Above 30.0
25.0 - 30.0
20.0 - 25.0
15.0 - 20.0
10.0 - 15.0
9.0 - 10.0
8.0 - 9.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0.2 - 1.0
Below 0.2

FIGURE 9
February 1996 Discharge, 384,000 cfs
Depth Characteristics – 90% concept design
Riverwalk Project, Willamette Falls Legacy Site



Notes:

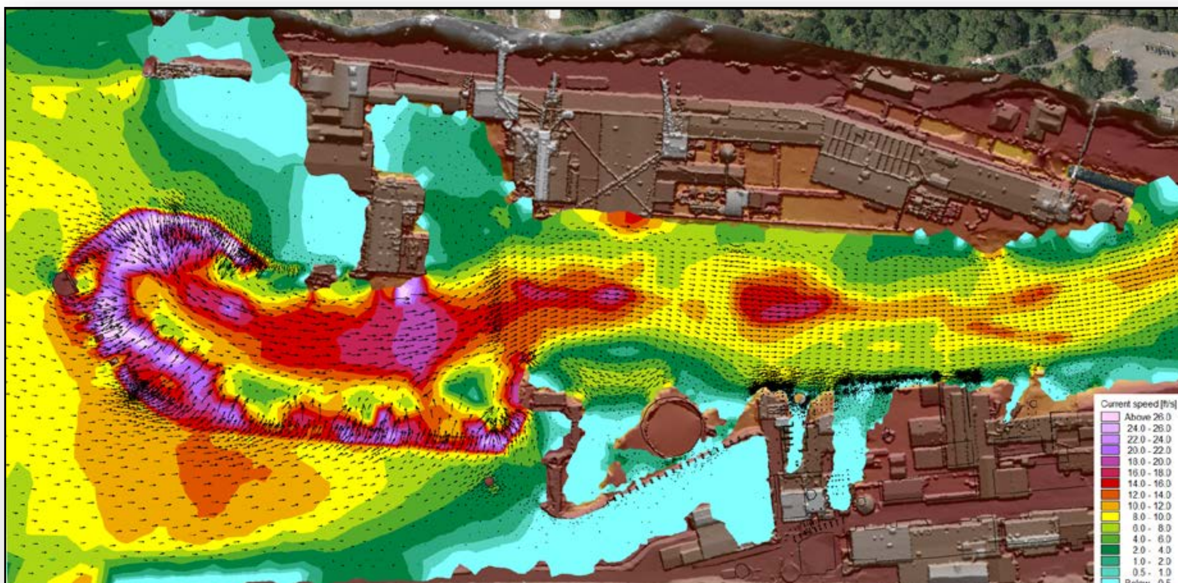
- Shear forces are expected to be highest at the Bulkhead Overlook and No. 3 Paper Machine Buiding, with expected values ranging from 60 - 80 Pa.
- Shear forces acting on the protruding walls of Mill O are expected to reach 30 – 50 Pa.
- In between the relic piers the shear forces are expected to be in the range of 1-40 Pa. The upstream faces of the piers are exposed to the highest velocities with associated shear forces around 40-60 Pa.

Shear Stress (Pa)

- Above 500
- 250 - 500
- 100 - 250
- 90 - 100
- 80 - 90
- 70 - 80
- 60 - 70
- 50 - 60
- 40 - 50
- 30 - 40
- 20 - 30
- 10 - 20
- 5 - 10
- 1 - 5
- 0 - 1
- Below 0

FIGURE 10
February 1996 Discharge, 384,000 cfs
Shear Stress Characteristics –
90% concept Design
Riverwalk Project, Willamette Falls Legacy Site

Field Photos of February 2017 Flood (Source: Metro)



2D Model Results for February 2017

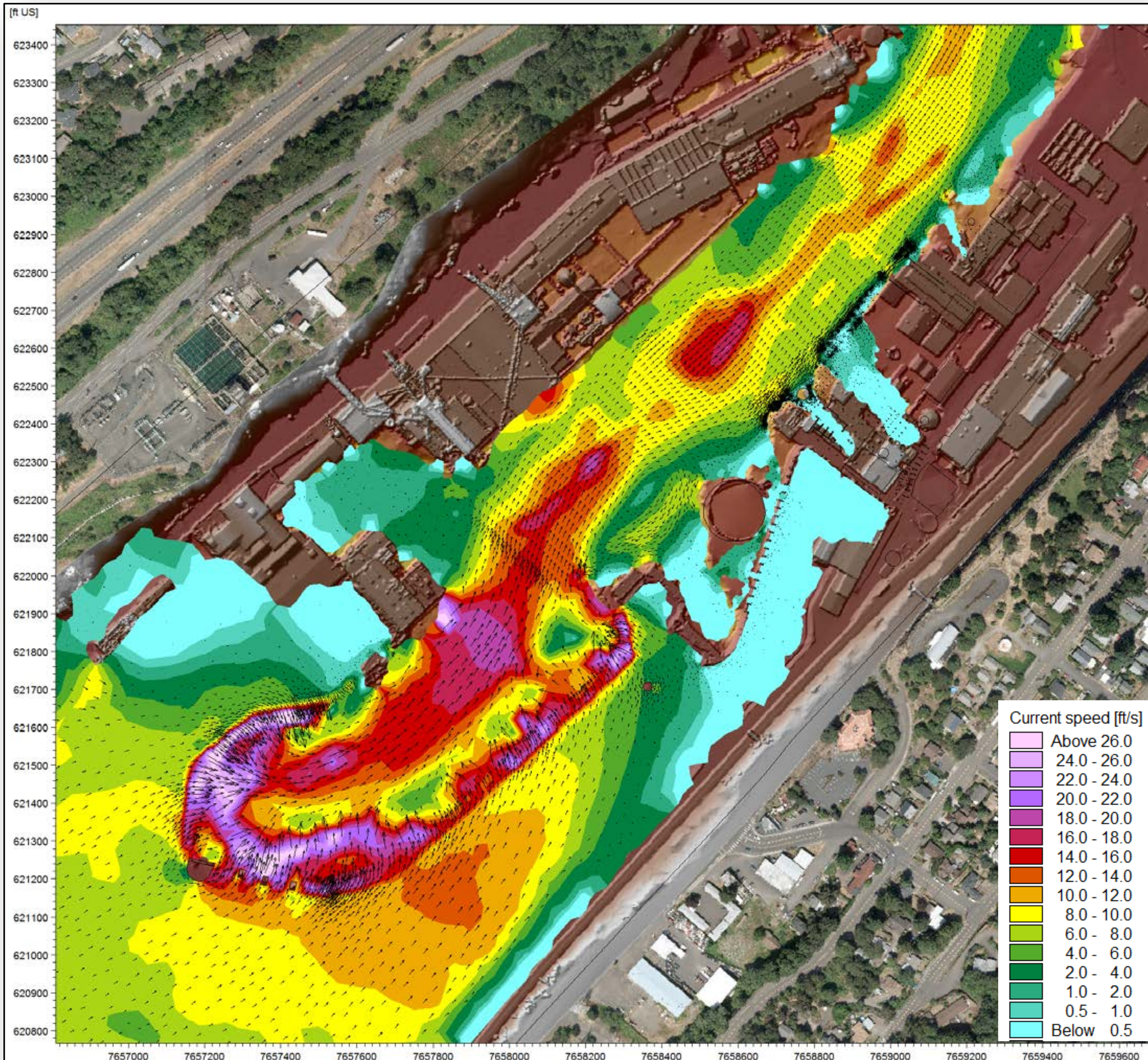
Moderate Flood – Feb. 2017

Modeling Objectives:

- Evaluate hydraulic conditions during a “typical” flood event.
- Identify availability of refugia habitat for juvenile salmonids.
- Estimate the Ordinary High Water boundary.

Flow Rate = 122,000 cfs (estimated)
Tailwater Elevation = 26.7 ft, NAVD 88

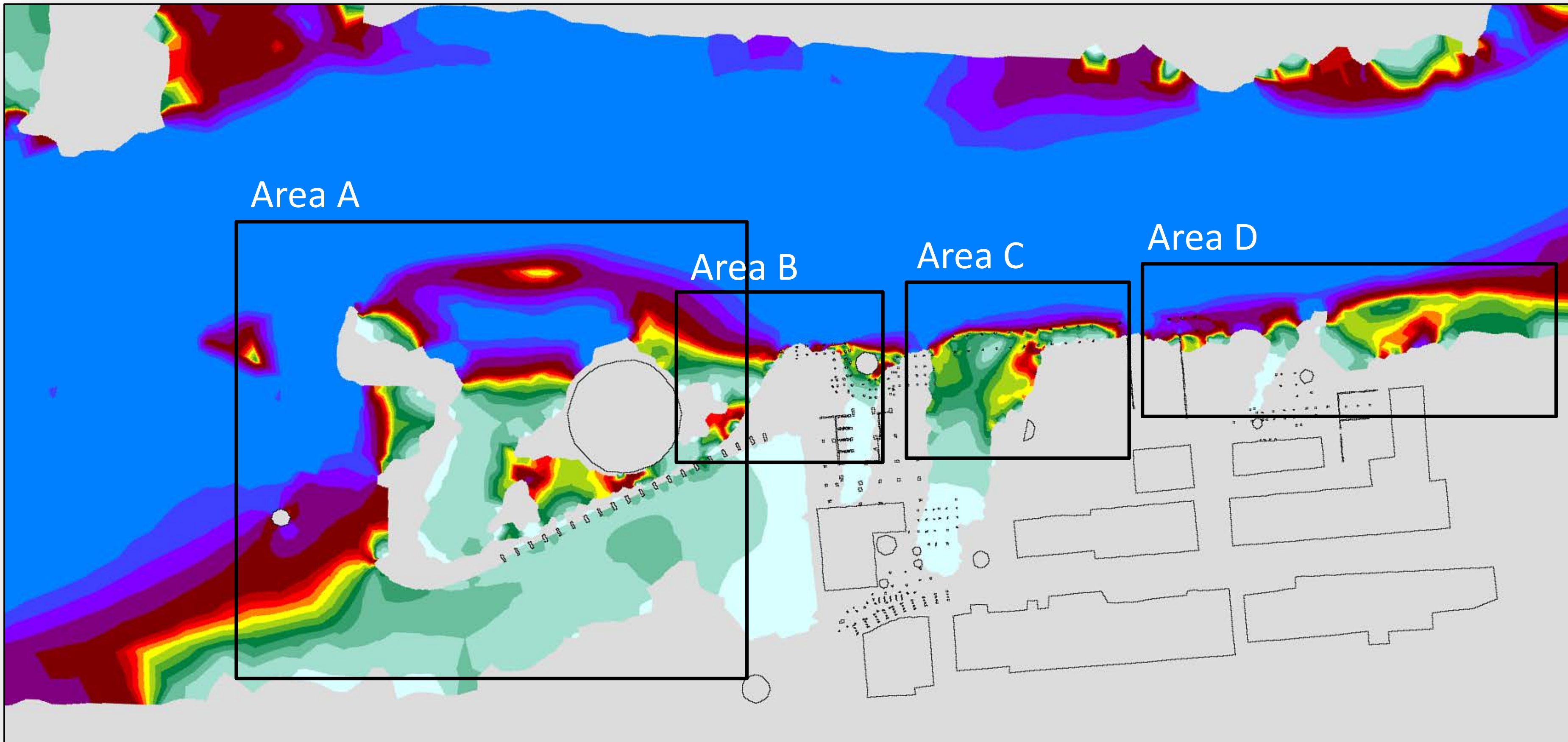
FIGURE 11
Introduction to Hydraulic Results for the February 2017, ~ 2-year flood
Riverwalk Project, Willamette Falls Legacy Site

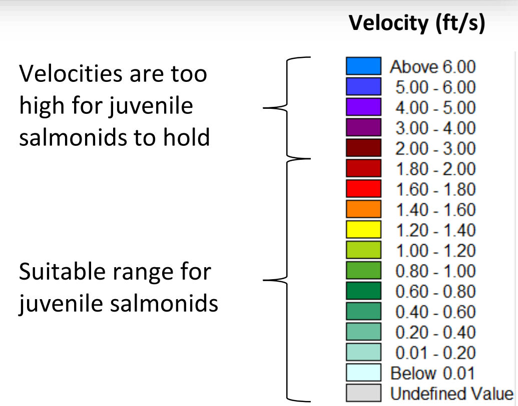


- ❑ Mainstem velocities are generally too high for juvenile salmonids (>2fps in most areas).
- ❑ Low velocity zones exist in the intake basin and in alcoves along the shores of the Willamette Falls Legacy Site.
- ❑ There are eddies at the head of each alcove with quiescent zones on the backside of the eddy.
- ❑ Low velocity zones are good refugia habitat for juvenile salmonids but they may also cause sedimentation.
- ❑ Close-up views of the shoreline in front of the Willamette Falls Legacy Site are shows in Figures 13 – 17.

FIGURE 12
February 2017, ~ 2-year flood, 122,000 cfs
Velocity Characteristics – 90% concept Design
Riverwalk Project, Willamette Falls Legacy Site

ch2m:



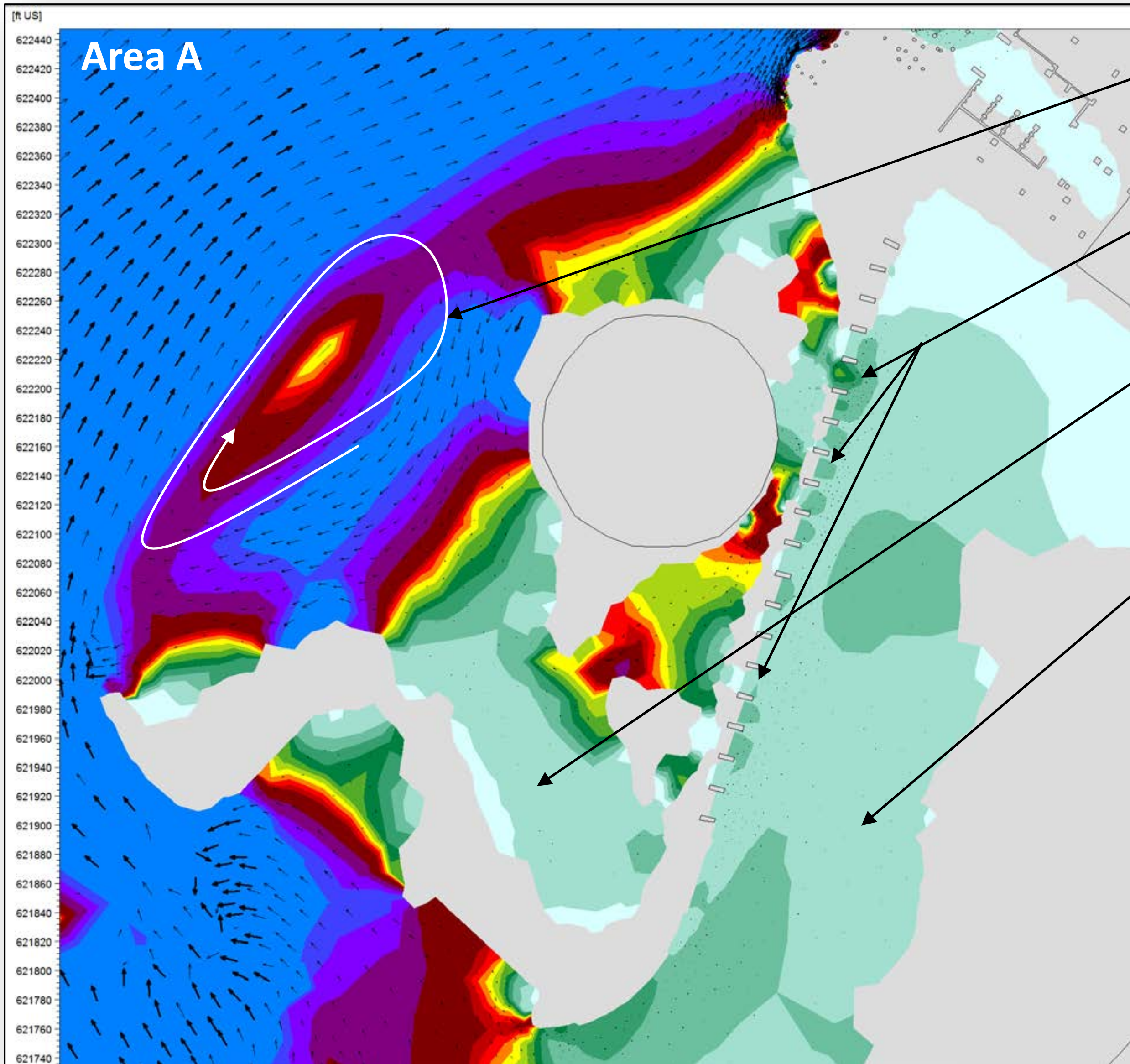


Notes:

- Most of the suitable refugia habitat is on the project side of the river (river-right, looking downstream).
- See the following slides for inset zoom views with detailed interpretations and observations.

FIGURE 13
February 2017, ~ 2-year flood, 122,000 cfs
Shoreline Velocities
Riverwalk Project, Willamette Falls Legacy Site

ch2m:



- This is a large lateral eddy that forms on the northwest side of the clarifier – the recirculating velocities are too high for juvenile salmonids.
- Exact pattern of spill over the dam will depend on the gate settings and debris accumulation on the piers.
- There should be pockets of suitable refugia habitat for salmonids in the alcoves surrounding the clarifier, although high turbulence may make the aquatic conditions less desirable than the model results suggest.
- The low velocities in the intake basin create high quality refugia habitat but they may also encourage sedimentation.

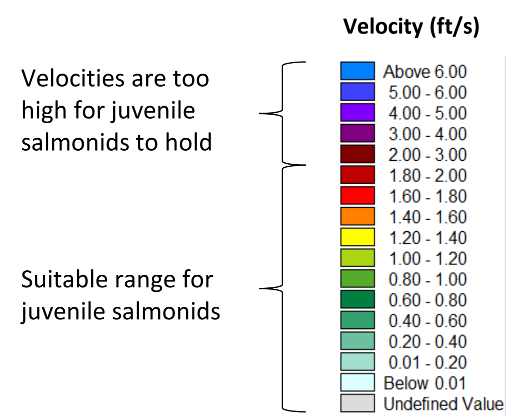
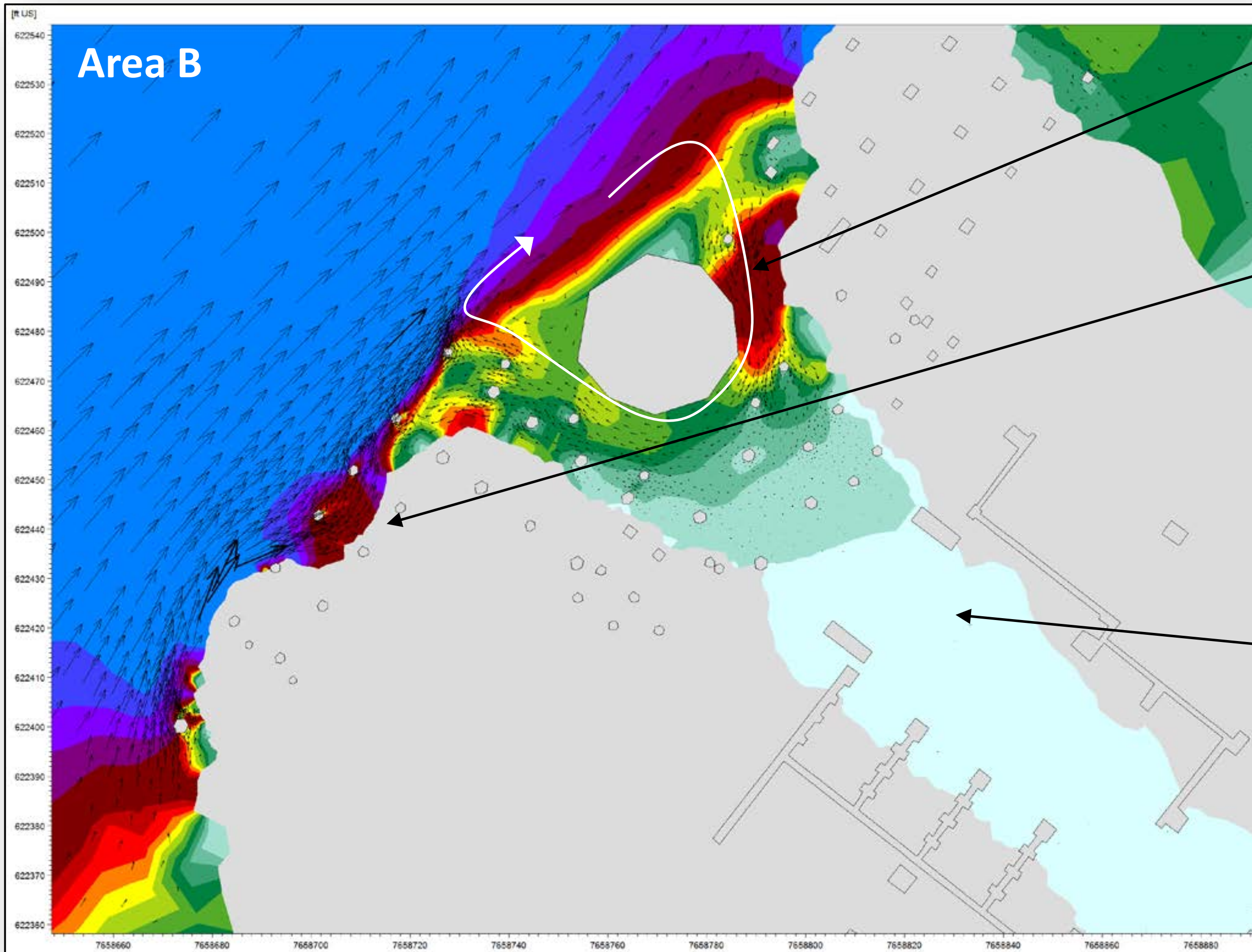


FIGURE 14
February 2017, ~ 2-year flood, 122,000 cfs
Shoreline Velocities – Area A Observations
Riverwalk Project, Willamette Falls Legacy Site



- Clockwise circulation pattern around the tank; some areas may have velocities that are too high for juvenile salmonid refugia habitat but most of the area looks suitable.
- Suitable habitat on the margins of the main channel are quite limited at this flow rate. This could make it challenging for downstream migrating juveniles to be capable of entering the alcoves due to such high approach velocities. Roughness elements could be added to the shoreline to improve habitat on the channel margin and improve approach velocities for the alcove.
- The backwatered alcove should provide excellent refugia habitat for juvenile salmonids. The water in the back of the alcove will have little to no velocity unless seepage enters the head of the alcove to provide a flushing flow.

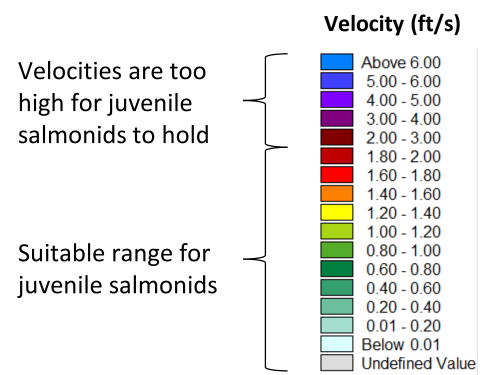
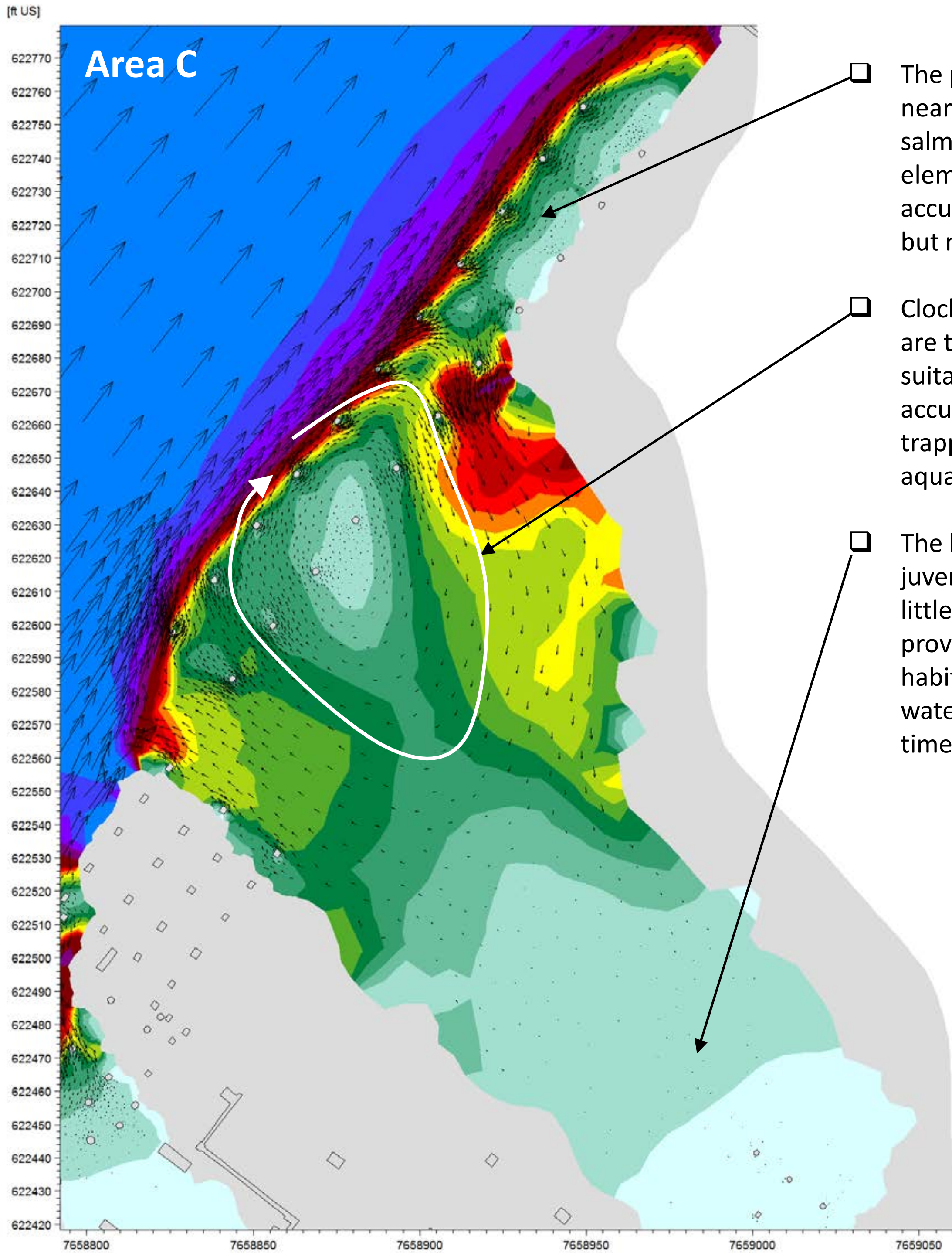


FIGURE 15
February 9, 2017 Discharge, 122,000 cfs
Shoreline Velocities – Area B Observations
Riverwalk Project, Willamette Falls Legacy Site



- The piers under the pipe chase add roughness which help reduce the near-bank velocities, creating creates a refugia zone for juvenile salmonids. This is a good example of how adding roughness elements along the shore can reduce velocities. The piers will likely accumulate woody debris on occasion which is good for fish habitat but may pose a safety concern for boaters.

- Clockwise circulation pattern; some areas may have velocities that are too high for juvenile refugia habitat but most of the area looks suitable. This area could become a trap for woody debris; some will accumulate on the piers and other pieces will become hydraulically trapped due to recirculation. Wood accumulation creates good aquatic habitat but may pose a hazard to boaters.

- The backwatered alcove should provide excellent refugia habitat for juvenile salmonids. The water in the back of the alcove will have little to no velocity unless seepage enters the head of the alcove to provide a flushing flow. While the alcove provides good refugia habitat is will lead to sediment accumulation over time and possible water quality concerns if the stagnation persists for long periods of time.

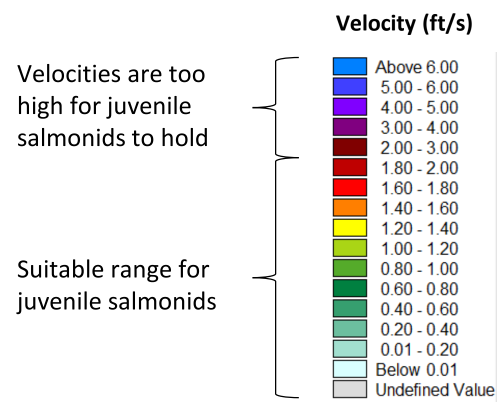
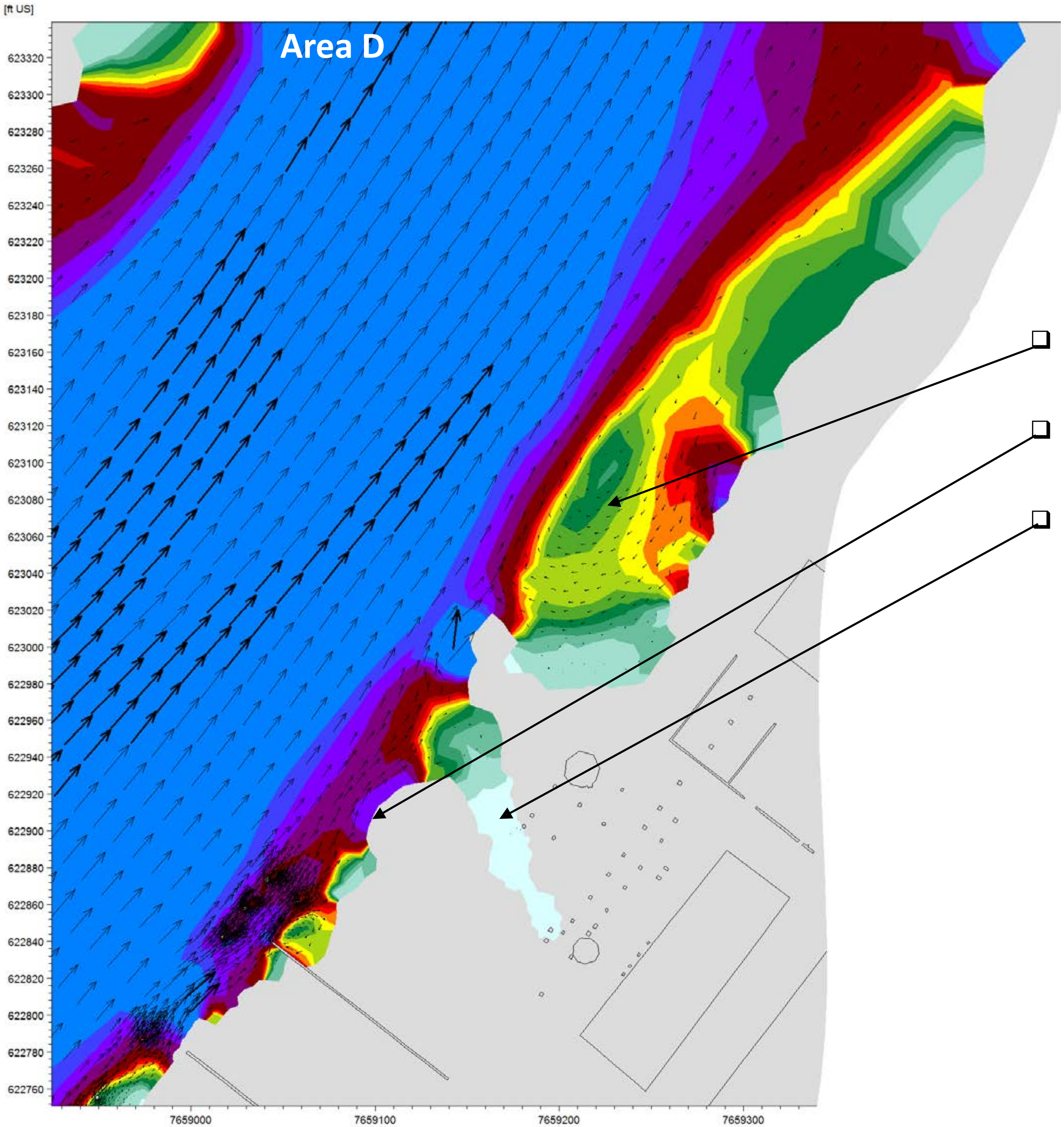


FIGURE 16
February 2017, ~ 2-year flood, 122,000 cfs
Shoreline Velocities – Area C Observations
Riverwalk Project, Willamette Falls Legacy Site



- Clockwise circulation pattern; habitat in the eddy is marginally suitable for refugia.
- The suitable refugia habitat along the channel margin is limited and discontinuous.
- The best refugia habitat in this area, at this flow rate, is the alcove upstream of the fuel bunker.

Velocity (ft/s)

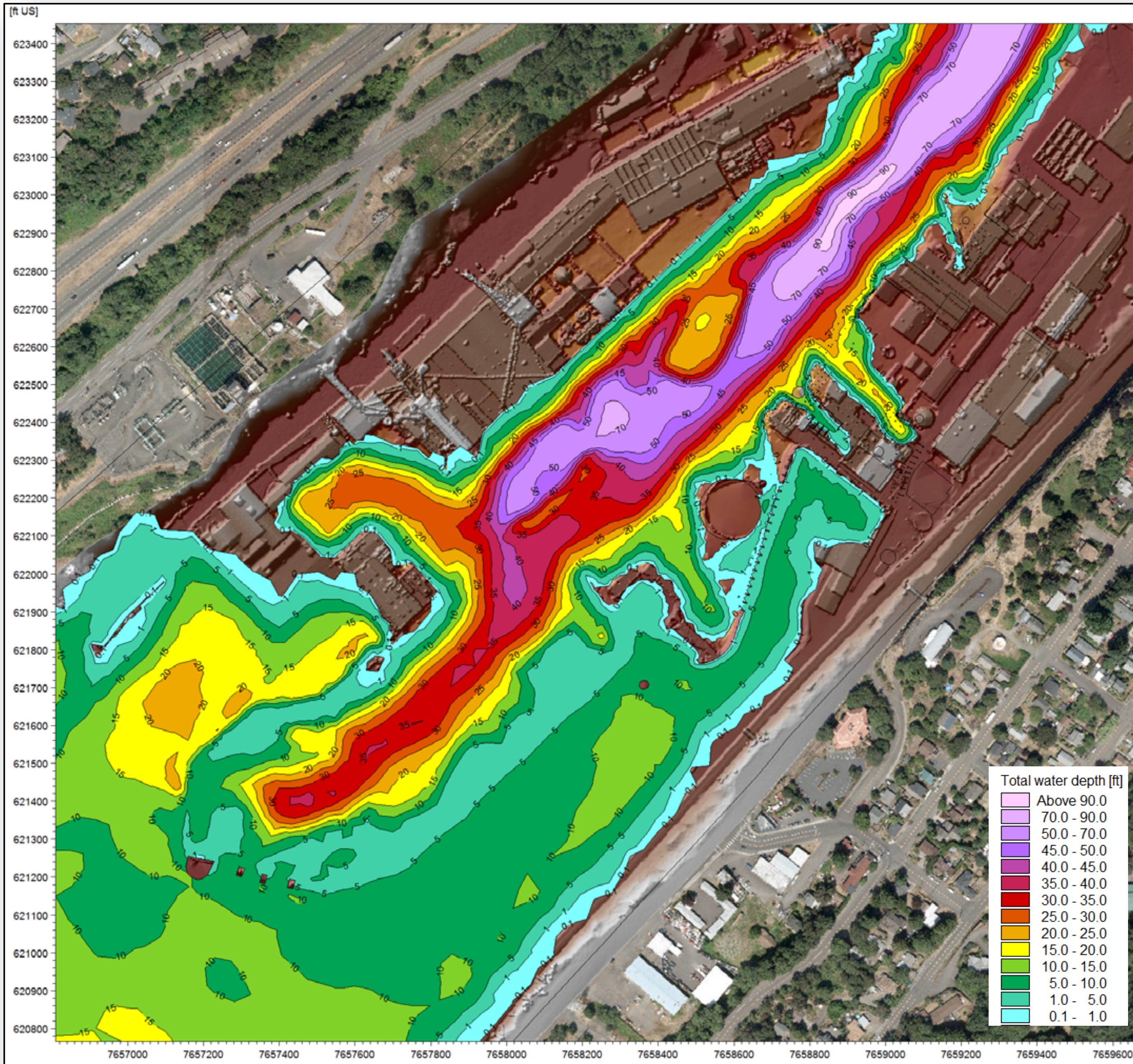
Velocities are too high for juvenile salmonids to hold

- Above 6.00
- 5.00 - 6.00
- 4.00 - 5.00
- 3.00 - 4.00
- 2.00 - 3.00

Suitable range for juvenile salmonids

- 1.80 - 2.00
- 1.60 - 1.80
- 1.40 - 1.60
- 1.20 - 1.40
- 1.00 - 1.20
- 0.80 - 1.00
- 0.60 - 0.80
- 0.40 - 0.60
- 0.20 - 0.40
- 0.01 - 0.20
- Below 0.01
- Undefined Value

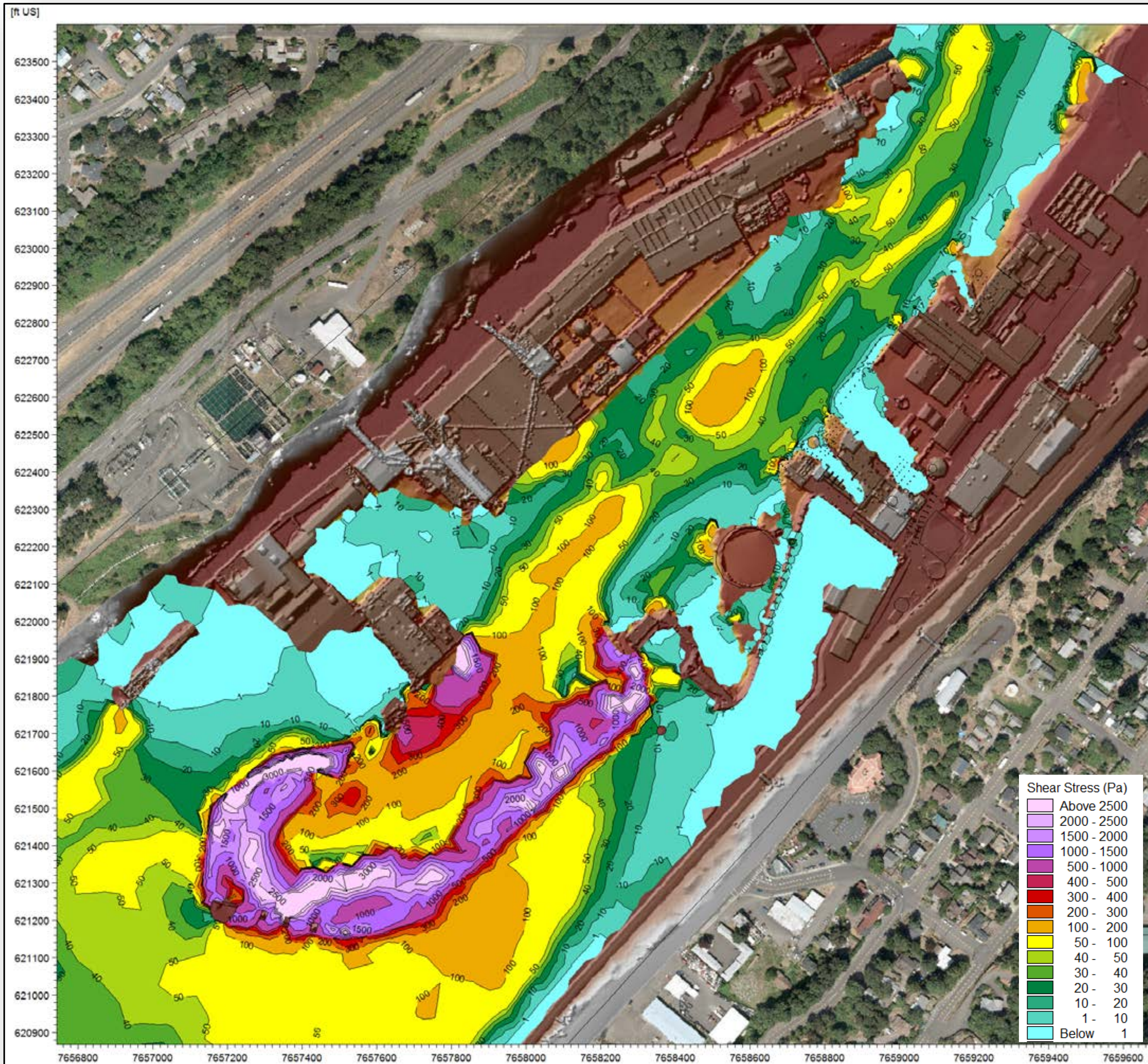
FIGURE 17
February 2017, ~ 2-year flood, 122,000 cfs
Shoreline Velocities – Area D Observations
Riverwalk Project, Willamette Falls Legacy Site



- ❑ Water depths increase rapidly near the shoreline because the river banks are extremely steep.
- ❑ Water depth in the mainstem tailrace are very deep (>90 feet in some areas).
- ❑ Water depths upstream of the falls are much shallower than those in the tailrace. Typical depths upstream of the falls are 5' to 15' during a 2 year flood.

FIGURE 18
February 2017, ~ 2-year flood, 122,000 cfs
Depth Characteristics – 90% concept Design
Riverwalk Project, Willamette Falls Legacy Site

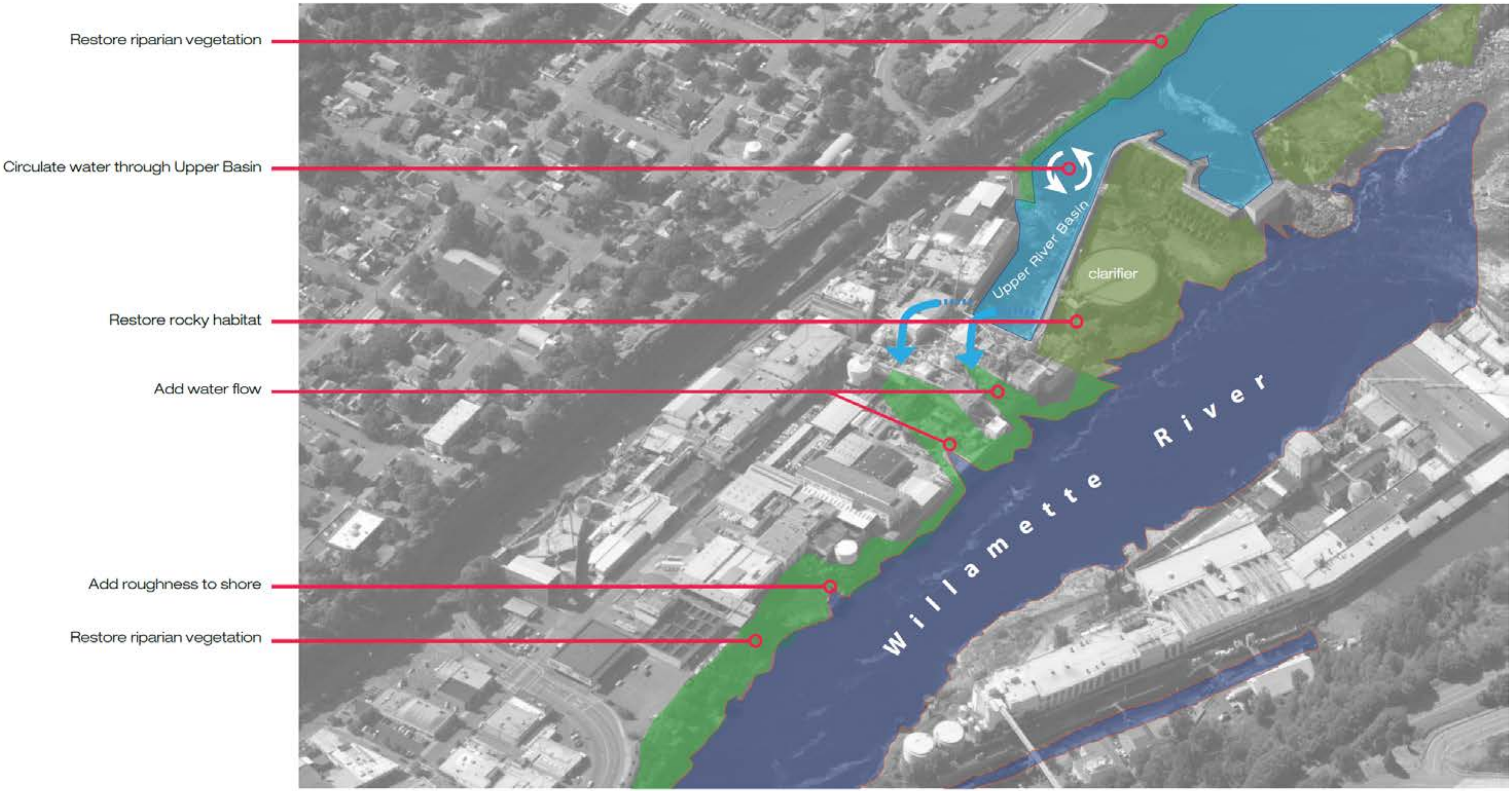
ch2m:



- The spatial distribution of shear stress closely mimics the velocity distribution with the lowest shear stresses coincident with the lowest velocity zones and vice versa (shear and velocity are directly related).
- Typical shear stresses along the shoreline in front of the Willamette Falls Legacy Site are between 1 and 10 Pa.
- The highest shear stresses along the shoreline exist in front of the Mill H Reject Plant where shear stresses are approximately 200 Pa.

FIGURE 19
February 2017, ~ 2-year flood, 122,000 cfs
Shear Stress Characteristics – 90% concept Design
Riverwalk Project, Willamette Falls Legacy Site

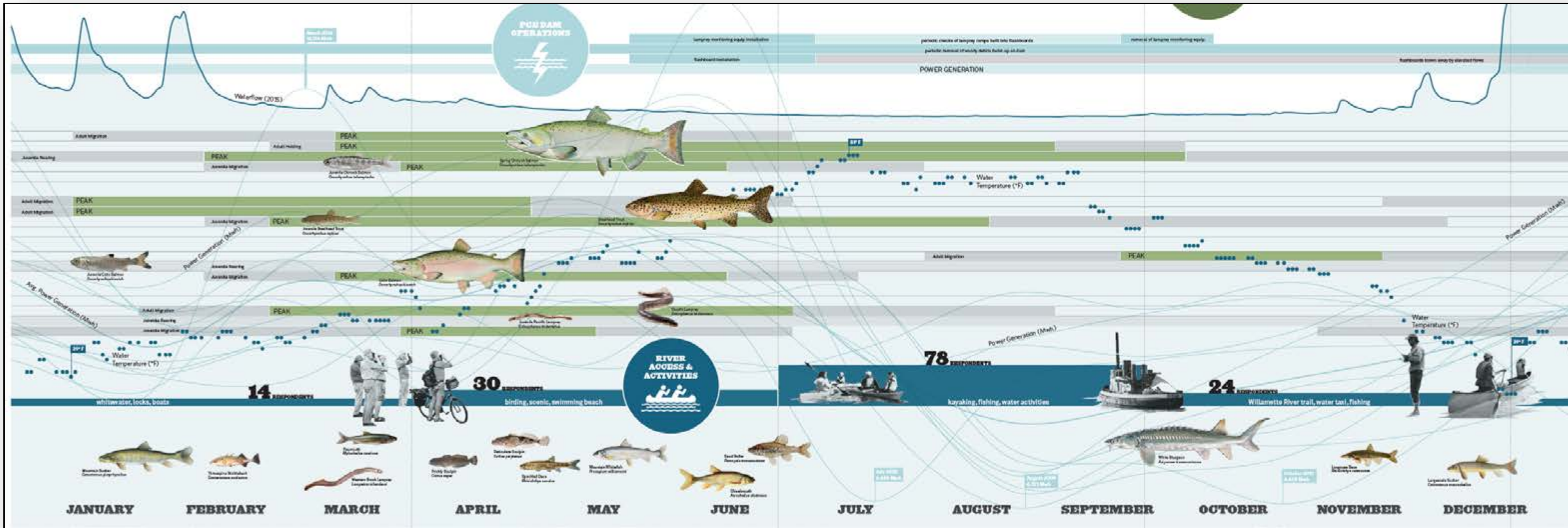
Habitat Opportunities:



Source: Graphic adapted from Willamette Falls Vison Document (2014, pg. 48)

FIGURE 20
Introduction to Hydraulic Results for the Habitat Flows (1 of 2)
Riverwalk Project, Willamette Falls Legacy Site

Aquatic Habitat Design Flows Tied to Migration Seasons

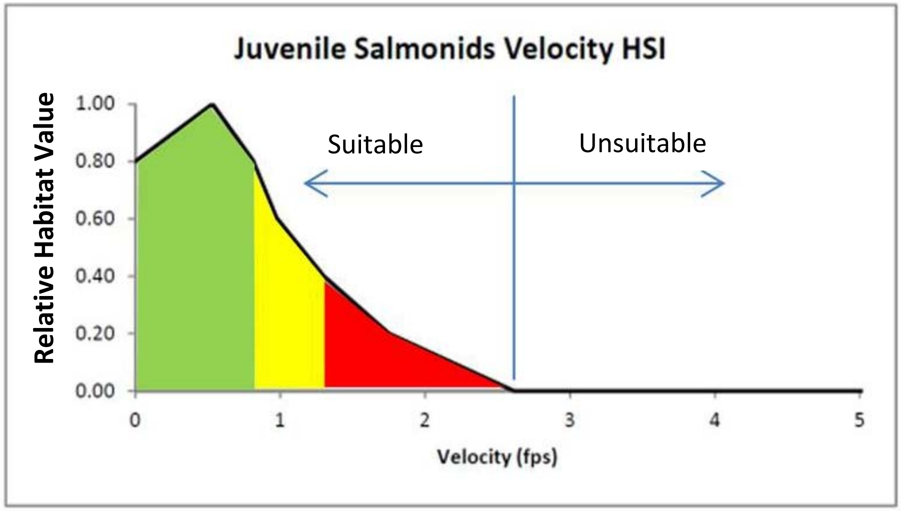


Source: Graphic adapted 90% Concept Design Package (Snohetta 2017)

Two design flows were selected to characterize the typical high and low flow conditions during this season.
10% (53,300 cfs) and 90% (11,700 cfs) exceedances flows for the period between March and June provide the range of flows considered important during migration season for a variety of fish species.

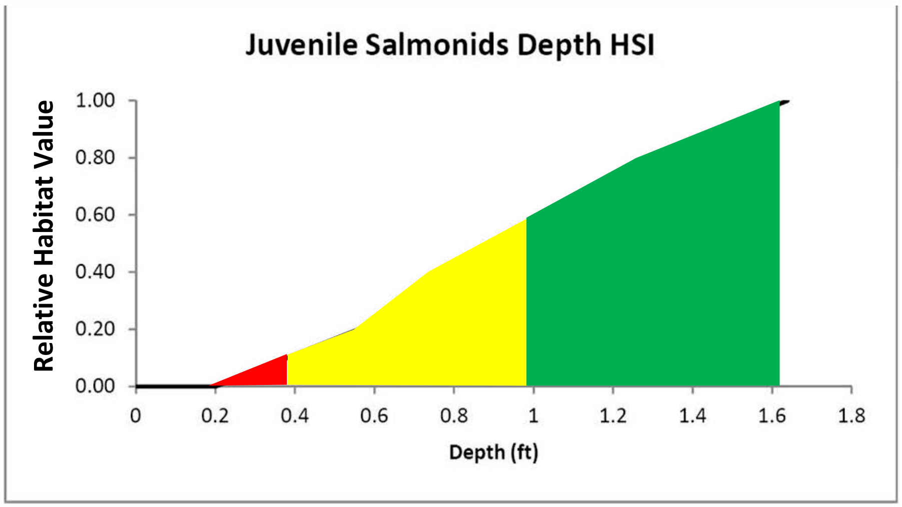
The limiting condition for aquatic habitat in the summer and fall is the extreme low-flow condition. The low flow from the summer of 2015 was used to assess the **extreme low design flow (3,400 cfs).**

FIGURE 21
Introduction to Hydraulic Results for the Habitat Flows (2 of 2)
Riverwalk Project, Willamette Falls Legacy Site



Velocity

Velocity (fps)	SI
0	0.80
0.53	1.00
0.82	0.80
0.98	0.60
1.3	0.40
1.75	0.20
2.61	0.00
50	0.00



Depth

Depth (ft)	SI
0	0.00
0.2	0.00
0.56	0.20
0.75	0.40
1.28	0.80
1.64	1.00

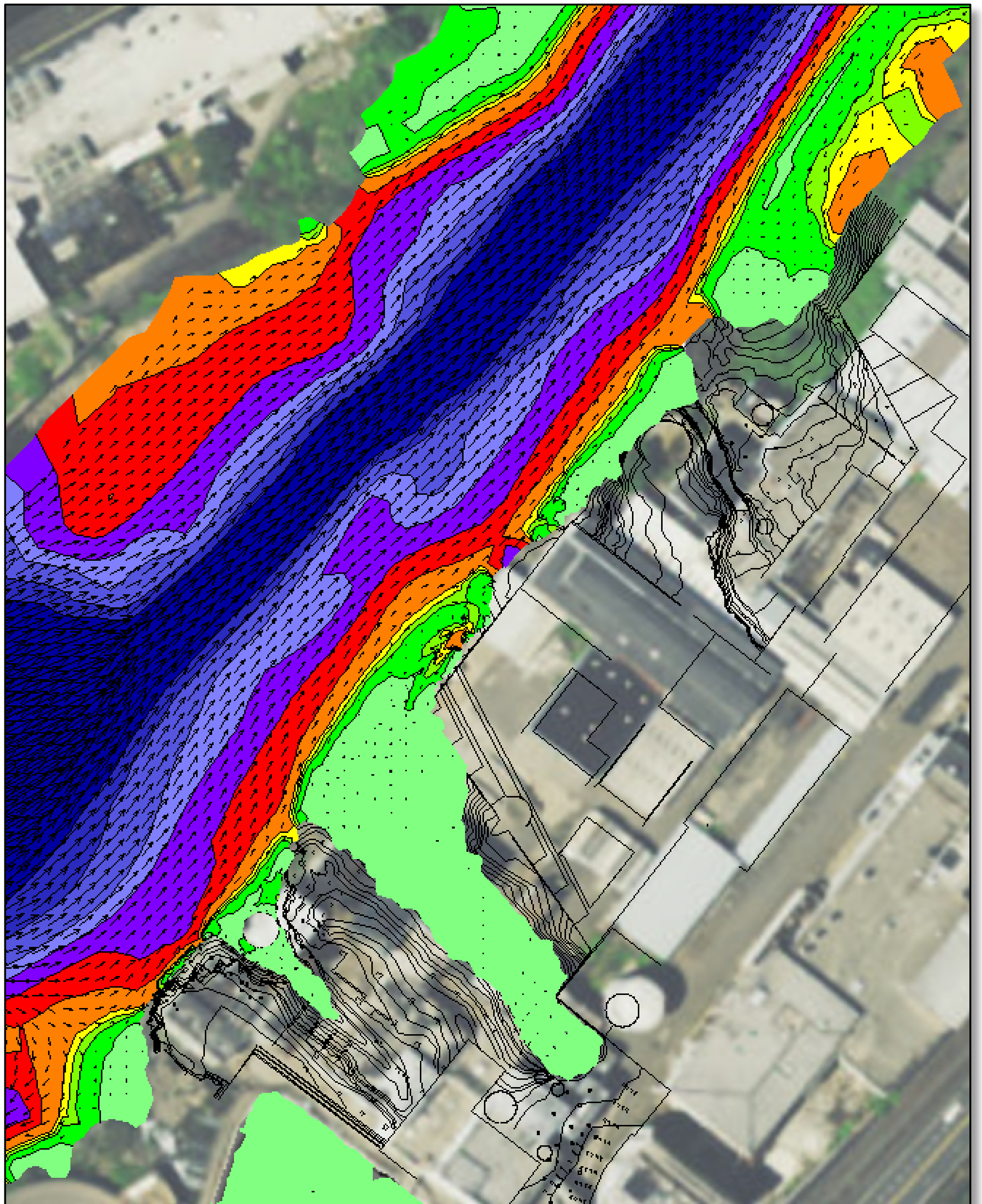
Notes:

- Habitat value refers only to the suitability of hydraulic conditions (depth and velocity); the realized habitat value will also be affected by other factors such as water quality, temperature, cover, and other variables.
- The relative habitat value thresholds were adopted from data collected in the Trinity River, CA. These values are variable from site to site and are a function of species and life-stage; the value used here are for general planning-level use only.

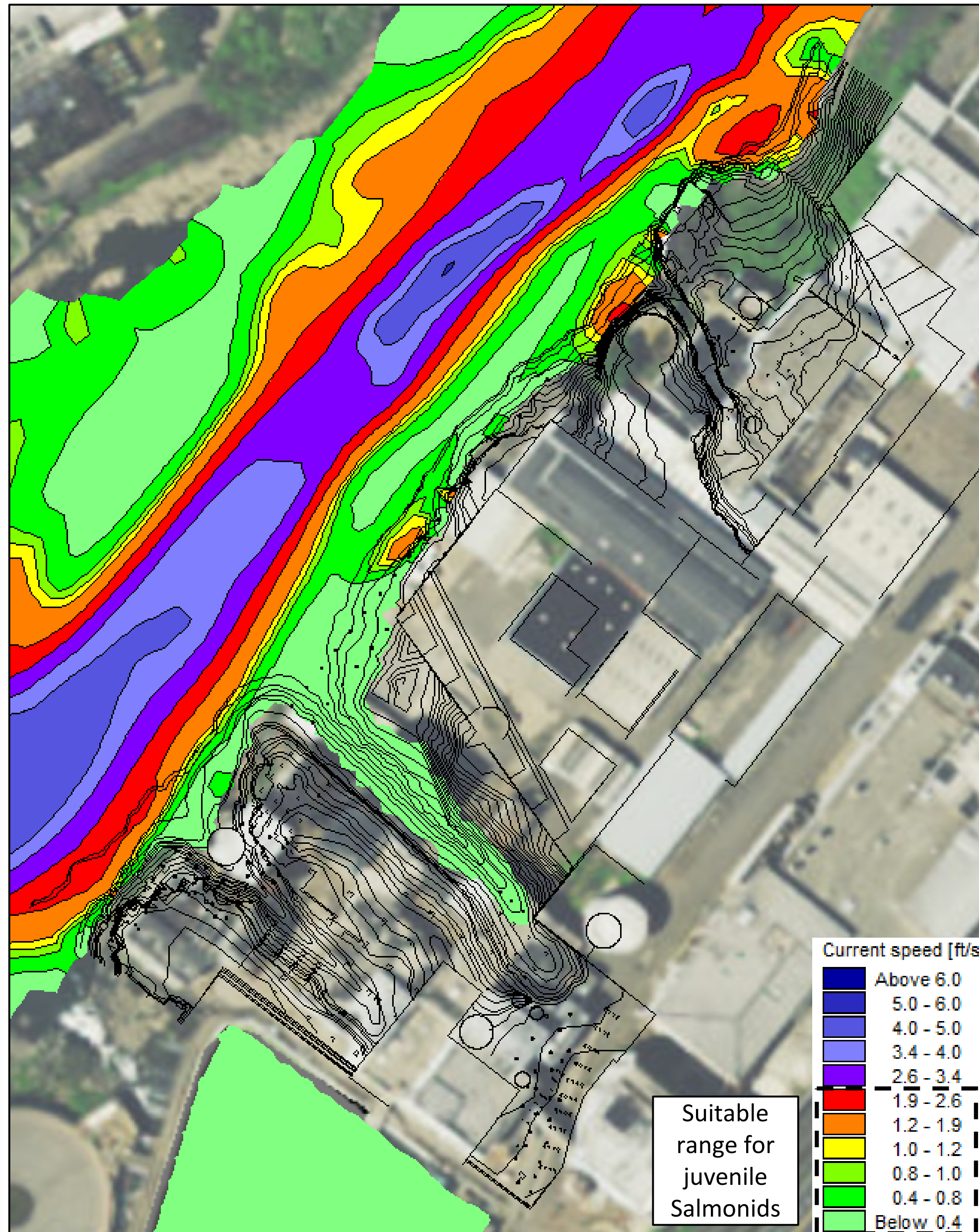
FIGURE 22
Habitat Suitability Index
90% Conceptual Design Surface
Riverwalk Project, Willamette Falls Legacy Site

ch2m:

10% Exceedance Flow (March – June), 53,300 cfs



90% Exceedance Flow (March – June), 11,700 cfs

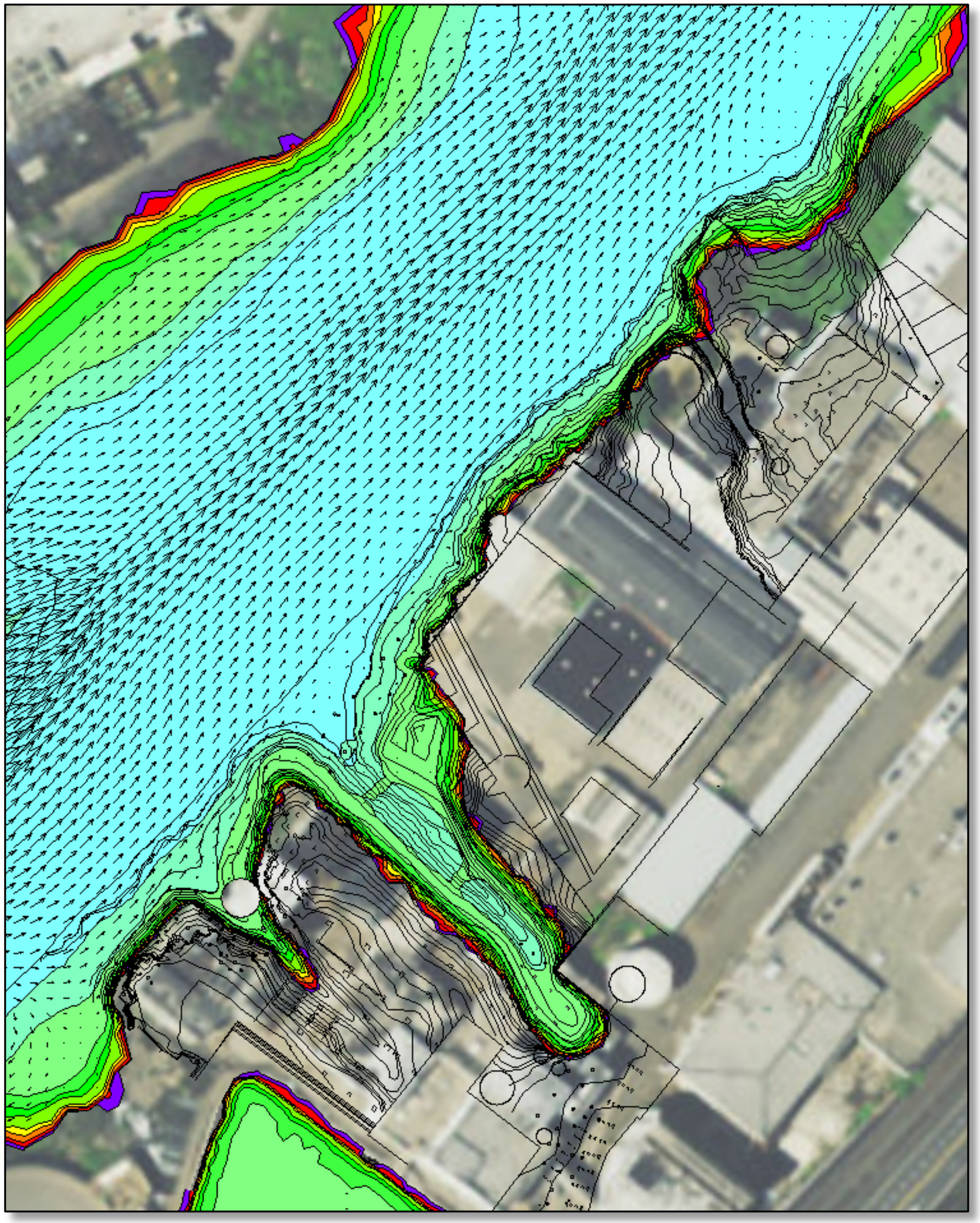


Notes:

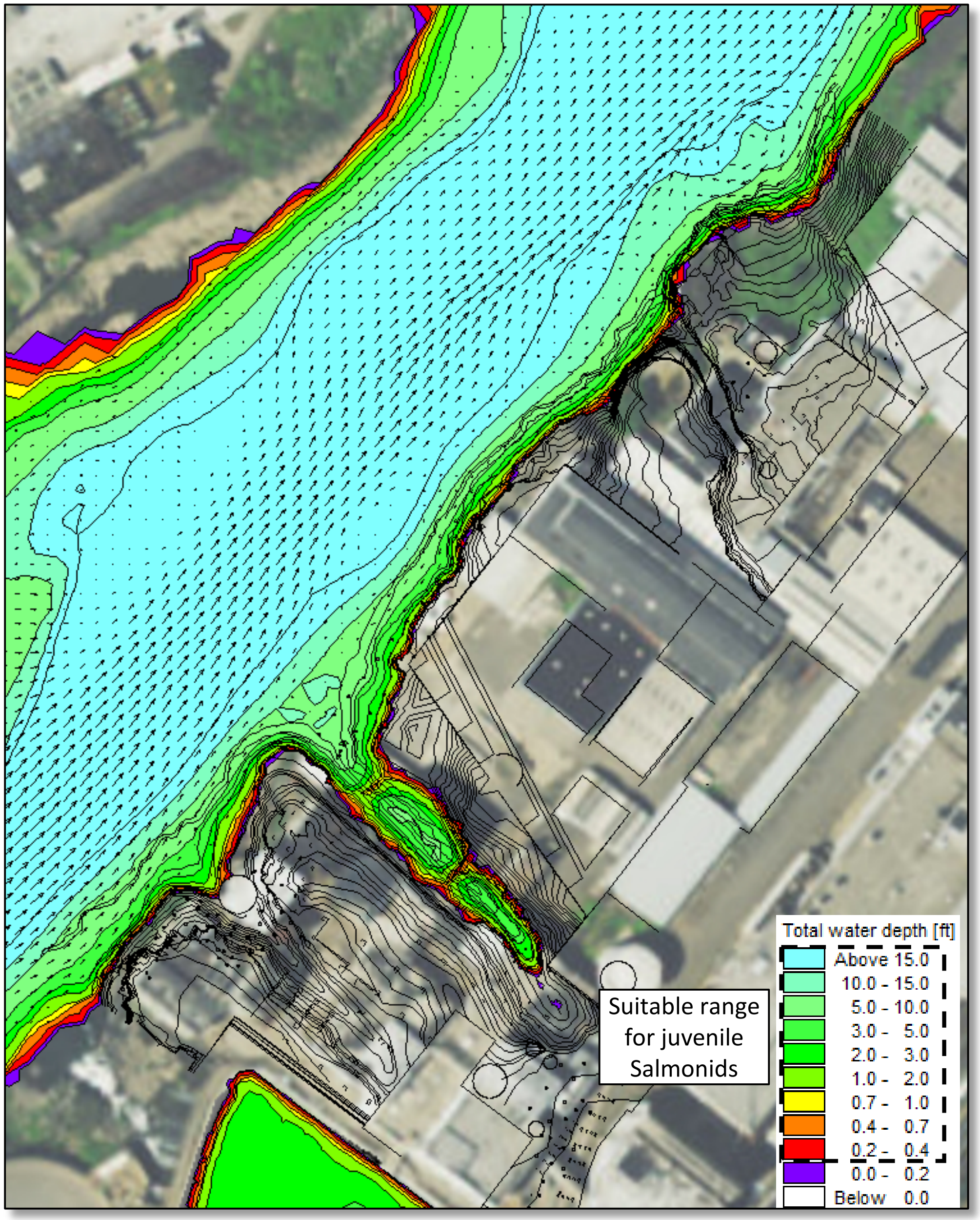
- Along the right bank there is an abundance of suitable habitat for juvenile salmonids with regards to velocity criteria at both 11,700 and 53,300 cfs. Near bank velocities along the left bank are higher.

FIGURE 23
10% and 90% Exceedance Spring Flows
Velocity
90% Conceptual Design Surface
Riverwalk Project, Willamette Falls Legacy Site

10% Exceedance Flow (March – June), 53,300 cfs



90% Exceedance Flow (March – June), 11,700 cfs



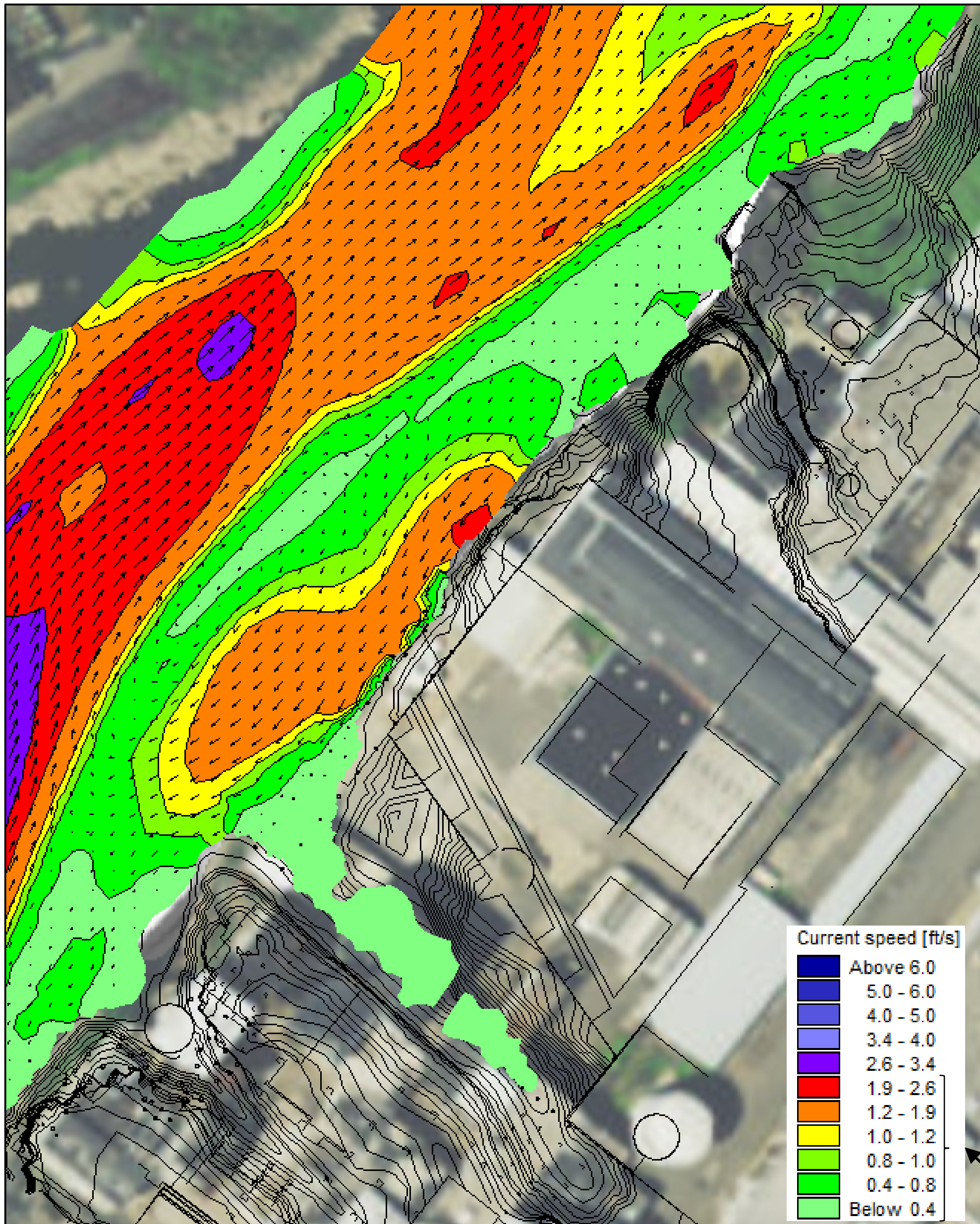
Notes:

- At 11,700 cfs, the right bank adjacent to the pipe chase downstream to Water Street is characterized by depths between 1 – 10 feet, sheltered from the main channel conveyance. This is not true at 53,300 cfs in which depths and velocities are greater until much closer to the right bank.

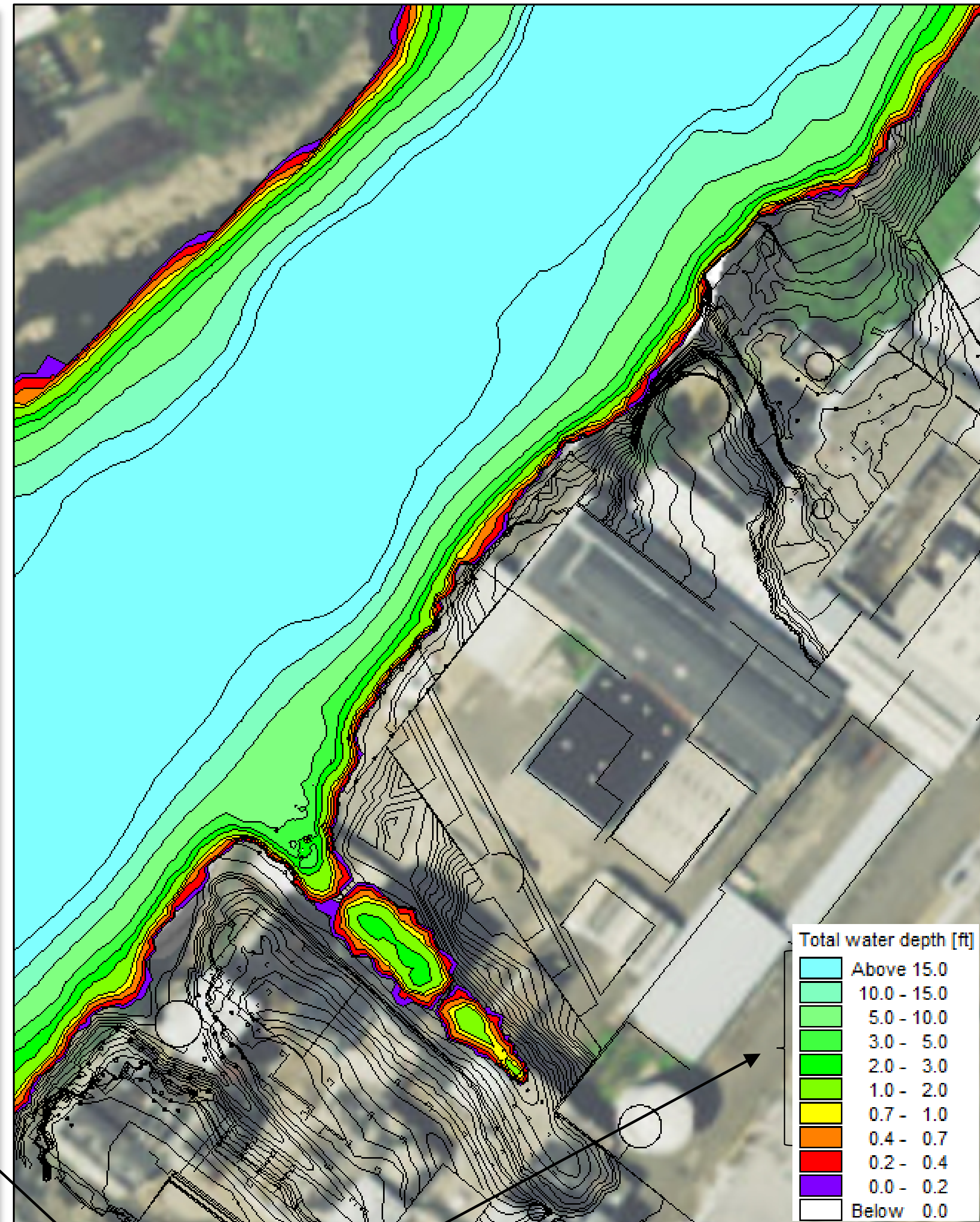
FIGURE 24
10% and 90% Exceedance Spring Flows
Water Depth
90% Conceptual Design Surface
Riverwalk Project, Willamette Falls Legacy Site

ch2m:

Velocity - Extreme Summer Low Flow (3,400 cfs)



Water Depth - Extreme Summer Low Flow (3,400 cfs)



Suitable range for juvenile Salmonids

Notes:

- At this flow rate the Grotto tailrace has isolated ponded areas up to 3 feet deep.
- Main channel velocities are concentrated toward the left bank, while upstream recirculation drives the primary flow velocity near the right bank.

FIGURE 25
Extreme Low Flow
Aquatic Habitat Conditions
90% Conceptual Design Surface
Riverwalk Project, Willamette Falls Legacy Site