

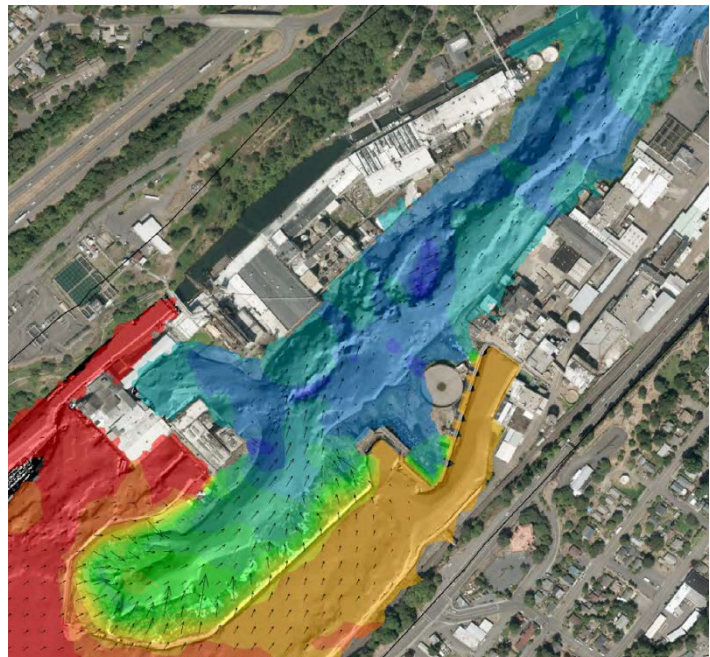
# Riverwalk Project

## Willamette Falls Legacy Site

### *Hydraulic Model Development and Characterization of Existing Conditions*

*Prepared for*  
Metro

*May 2017*



WILLAMETTE FALLS RIVERWALK PROJECT

# HYDRAULIC MODEL DEVELOPMENT AND CHARACTERIZATION OF EXISTING CONDITIONS

PREPARED FOR: Brian Vaughn/Metro  
Alex Gilbertson/Metro  
PREPARED BY: Ryan Mitchell/CH2M  
Tim Bedford/CH2M  
DATE: May 8, 2017  
REVISION NO.: 3  
REVIEWED BY: Paul Burnet/CH2M

## Table of Contents

<b>Introduction .....</b>	<b>3</b>
<b>Existing Conditions.....</b>	<b>3</b>
Hydrology.....	3
Available Stage and Discharge Data.....	4
Flood-Frequency Relationships.....	5
Design Flows .....	6
Design Stages .....	7
Hydraulics.....	9
Existing Flow Controls and Dam Operations .....	9
<b>Hydraulic Model Development.....</b>	<b>10</b>
Hydraulic Modeling Software .....	11
Modeling Approach .....	11
Model Parameterization .....	12
Digital Terrain Model (DTM) Development .....	12
Mesh Development .....	13
Boundary Conditions .....	13
Hydraulic Structures .....	14
Roughness.....	14
Calibration.....	14
Calibration Process and Available Data .....	15
<b>Hydraulic Characterization .....</b>	<b>21</b>
Existing Condition – High Flow (Feb. 1996) .....	22
Existing Condition – 2-year Peak Flow .....	22
10% exceedance of average daily flow, March through June .....	22
<b>Assumptions and Considerations for Conceptual Design Phase.....</b>	<b>22</b>
<b>Conclusions .....</b>	<b>24</b>
<b>References.....</b>	<b>25</b>
<b>Exhibits.....</b>	<b>26</b>

# Introduction

The purpose of this memorandum is to provide information and promote early communication regarding existing hydrologic and associated hydraulic conditions at the Willamette Falls Legacy Project site (Site). In addition, it is intended to document technical details of hydraulic model development, to present graphical hydraulic model results and interpretations of existing conditions, and to communicate key assumptions and considerations for the conceptual design phase of the Riverwalk Project (Project). A companion document titled *Willamette Falls Legacy Site Baseline Habitat Conditions* characterizes the existing aquatic and riparian habitats, discusses conservation priorities and restoration rationale, and summarizes key habitat design assumptions at the Site.

This is the third version (Version 3) of this report. Version 1 focused on characterizing existing site hydrology and physical conditions, model development, model assumptions and limitations, and next steps in the calibration process. Version 1 also presented preliminary result for the 2-year recurrence interval (RI) storm event. Version 2 documented revisions to the model that were described as next steps in Version 1, including revisions to the digital terrain model (DTM) and model-mesh configurations to improve the ability of the model to simulate high-flow conditions – that is, flood events large enough to create overland flow through the site. Version 2 also included a descriptive characterization of the 1996 flood (100-year flood). This version (Version 3) describes additional refinements to the model to improve the model’s resolution and representation of the physical site conditions at the Falls, provides comparison of model results against recently acquired water level data, and includes additional hydraulic characterization results for all 5 design flows.

## Existing Conditions

Hydraulic considerations at the Willamette Falls Legacy Site are important and highly complex. The Site includes many different physical features, both natural and anthropogenic, and accommodates a wide array of uses, including providing critical habitat for unique and threatened species, providing unique cultural and recreational opportunities for the public, and providing economic benefits for the community. An important first step in the Riverwalk Project is to characterize existing hydraulic features and functions of the site, and identify them early in the design process. This document is intended to provide the Design Team with an understanding of the current hydraulic characteristics and constraints for consideration in the conceptual design process.

## Hydrology

Hydrology is the science of characterizing flow - the amount of water (how much), the duration (how long), the timing (when), and the frequency (how often) relationship of river discharges<sup>1</sup> at a given location. In contrast, the science of hydraulics focuses on characterizing the physical parameters associated with a given flow condition, such as the water depth, velocity, shear stress, and water surface elevation at points within a system. The hydrologic characteristics at the site will be essentially unaffected by Riverwalk design elements, whereas the hydraulic conditions are subject to change in response to design elements – thus the need for a predictive hydraulic model (and the absence of need for a predictive hydrologic model).

---

<sup>1</sup> The terms discharge and flow are used interchangeably throughout the report.

The hydrologic conditions described in this report are limited to flows in the Willamette River (local stormwater runoff characteristics are described in a Technical Memorandum titled *Willamette Falls Legacy Project Existing, Hydrological Conditions*) (ESA, 2012). The influence of local stormwater runoff is nominal in terms of site hydraulics and will not be considered or included in this summary of the existing hydraulic conditions at the Site.

The Willamette River at Oregon City is a regulated system, controlled by 13 flood control projects operated by the US Army Corps of Engineers (USACE), which cumulatively controls 27% of the basin’s runoff, mostly in the upper watershed (USACE, 2015). There are numerous river gages, typically operated by the United State Geologic Survey (USGS), located throughout the basin that record the river’s discharge and water levels over time. Several river gages are located close to Willamette Falls which will provide the primary basis for our understanding of river hydrology at the Site. Specifically, historic gage data allow us to quantify important hydrologic conditions such as the flow-frequency relationship and the associated range of water levels (at the gage). Available hydrologic data (i.e., gages and measured parameters), flood-frequency relationships, and selected design flows are described in the sections below.

### Available Stage and Discharge Data

There are 6 gages on the Willamette River within 25 miles of Willamette Falls: four upstream of the falls and two downstream. We are most interested in river discharge data at the upstream locations, as these will serve as the upstream model input. Water level, or stage, data from the downstream gage will serve as the downstream model boundary. The gage locations, period and frequency of record, data type and position relative to the Willamette Falls site are summarized in Table 1.

**Table 1**  
*Summary of USGS gages near Willamette Falls*

GAGE #	Location	DATA	FREQUENCY	RM <sup>1</sup>	BEGIN	END
14207740	UPPER OREGON CITY, OR	STAGE	30 MIN	26.7	10/1/2007	PRESENT
14207700	UPPER OREGON CITY, OR	DISCHARGE	MEAN DAILY	26.7 <sup>2</sup>	10/1/1978	9/30/1979
14207770 <sup>3</sup>	LOWER OREGON CITY, OR	STAGE	30 MIN	25.9	10/1/2007	PRESENT
14198000	WILSONVILLE, OR	DISCHARGE	MEAN DAILY	37.5	10/1/1948	7/31/1973
14197900 <sup>4</sup>	NEWBERG, OR	DISCHARGE	30 MIN	52.3	10/1/2007	PRESENT
14211720	PORTLAND, OR	DISCHARGE	DAILY	12.0	10/1/1972	1/26/2016
		DISCHARGE	ANNUAL PEAK <sup>5</sup>		1973	2016
		DISCHARGE	5 MIN		10/7/2014	2/3/2016
		STAGE	30 MIN		10/1/2007	PRESENT

1: River Mile: Upstream centerline distance from confluence with Columbia River. Willamette Falls is located at River Mile 26.4

2: Exact location of distance upstream of falls is unknown, but is assumed to be at the same location as 14207740

3: Selected downstream gage for water level model boundary condition

4: Selected upstream gage for developing inflow model boundary condition

5: Lower Willamette River Restoration Project, Appendix B: Draft Hydrologic and Hydraulic Technical Memorandum (Tetra Tech, 2014)

The term “stage” refers to a height referenced to a specific local datum. These values must be adjusted to a common vertical datum so they can be directly compared. There are multiple vertical datums in the study reach: the PGE datum, NGVD29, and NAVD 88 (which is the projected). The relation of these three datums are shown in Figure 1.

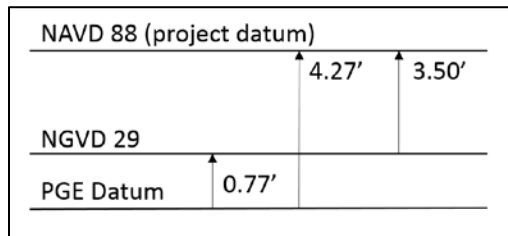


Figure 1. Datum Conversion Factors

For the hydraulic model we need to define the water level (stage) at the downstream boundary of the model and the river discharge at the upstream model boundary. The downstream model boundary will be defined using stage data recorded at USGS gage 14207770 which is located coincident with the hydraulic model boundary (by intention). The period of record for the gage is relatively short with only eight complete waters years of data recorded between 2007 and present. These data will be used to characterize the daily and seasonal variations in stage that will define the downstream boundary of the model; however, the gage record does not include historic data for extreme events such as the 1996 flood so some form of extrapolation will be needed for large flood events. The specific details of how the stage data will be applied is described in the Model Development – Boundary Conditions section of this memorandum.

River discharge at the upstream model boundary will be defined using data recorded at two of the USGS gages: 14211720 (Portland gage) and 14197900 (Newburg gage). The Portland gage has a moderately long period of record (43 years) which is needed to define the statistical flood-frequency analysis. However, the Portland gage is located 14.4 miles downstream of the Site and includes flow contributions from several large tributaries to the Willamette River, including the Clackamas and Tualatin Rivers (which enter the Willamette River downstream from the Newburg gage) – these flow contributions need to be estimated and removed from the flow data recorded at the Portland gage in order to more accurately represent the local discharge at Willamette Falls – the details of this analysis are described in the Model Develop – Boundary Conditions section of this report.

## Flood-Frequency Relationships

The peak discharge recurrence interval (RI) is a useful and commonly used metric for assessing the magnitude-frequency relationship for flood events. Such flows are described in terms of the statistical frequency of occurrence of a given flow rate (i.e., a peak flow that has an annual probability of occurrence of 1/100 is defined as a “100-year” flood). The two most common ways to calculate recurrence intervals for select flood flows are: 1) through use of empirical equations such as those developed regionally by the USGS (Cooper, 2006), and 2) by performing a statistical flood frequency analysis on historic data measured at a given gage. Using statistical analysis of gaged data is always preferred when the data are available because the results are more reliable and scientifically defensible. The closest gage on the Willamette River with a period of record sufficient to perform a flood frequency analysis is located on the Morrison Bridge in Portland (USGS gage 14211720). A recent hydrologic study conducted by The City of Portland’s Bureau of Environmental Services (BES) and the USACE documents a flood-frequency analysis performed on the Portland historic gage record from 1973 to 2013 (*Lower Willamette River Ecosystem Restoration Project, Appendix B, Tetra Tech, 2014*) – the results of that analysis are considered the most recent and reliable for establishing the flow-frequency relationship at the Portland gage.

As noted above, the flows at the Portland gage must be scaled down to more accurately reflect flow rates at Willamette Falls. Flows were down-scaled using the methods described in the Oregon Department of Transportation (ODOT) Hydraulic Manual (ODOT 2014), Section 7.6.3 Statistical Analysis of Stream Gage Data. The scaling method adjusts flows at the ungaged location according to the ratio of the respective drainage areas raised to an alpha-coefficient. The drainage area at the Portland gage is 11,172 square miles compared to drainage area at the site of 10,081 square miles, resulting in a drainage area ratio of 0.90. The resulting flood flows adjusted to the project site at Willamette Falls are shown in Table 2.

**Table 2.**

*Flood Flow Recurrence Intervals for The Willamette River in Portland (USGS gage 14211720)*

Annual Exceedance Probability	Recurrence Interval (years)	Drainage Area Exponent ( $\alpha$ ) <sup>1</sup>	Computed Flood Frequency Curve Ordinate	
			Computed Discharge <sup>2</sup> (cfs), Portland gage (14211720)	Adjusted Discharge <sup>3</sup> (cfs), Willamette Falls
0.2	500	1.023	480,000	432,000
1.0	100	1.023	384,000	346,000
2.0	50	1.022	344,000	310,000
5.0	20	1.021	293,000	264,000
10.0	10	1.021	255,000	230,000
20.0	5	1.020	217,000	196,000
50.0	2	1.021	160,000	144,000

<sup>1</sup> Estimating Peak Discharge in Rural, Unregulated Western Oregon, Table 11. USGS 2005.

<sup>2</sup> Source: Tetra Tech, 2014. Cfs = cubic feet per second.

<sup>3</sup> Computed discharge at Portland gage adjusted by the ratio of respective drainage areas rounded to the nearest 1,000 cfs.

## Design Flows

Design flows are a selected set of flows that are chosen or used by the design team based on specific hydraulic objectives. It is typical to define the hydraulic objectives prior to conducting hydraulic analyses so that the tools and approaches can be structured to meet the defined objectives. Additional objectives and associated design flows can be added later as additional needs arise during the design process.

Design flows for the Riverwalk Project will need to serve a wide range of objectives including:

Aquatic habitat assessments:

- Evaluate habitat suitability for species over a range of flows and life-stages

Regulatory assessments:

- Evaluate impacts to the regulatory FEMA 100-year flood elevations and boundaries for both existing and proposed conditions
- Estimating the Ordinary High Water boundary

Impacts to river infrastructure and public safety:

- Several design flows are needed to evaluate impacts to Riverwalk project elements which may interact with the river at different river stages and flows.

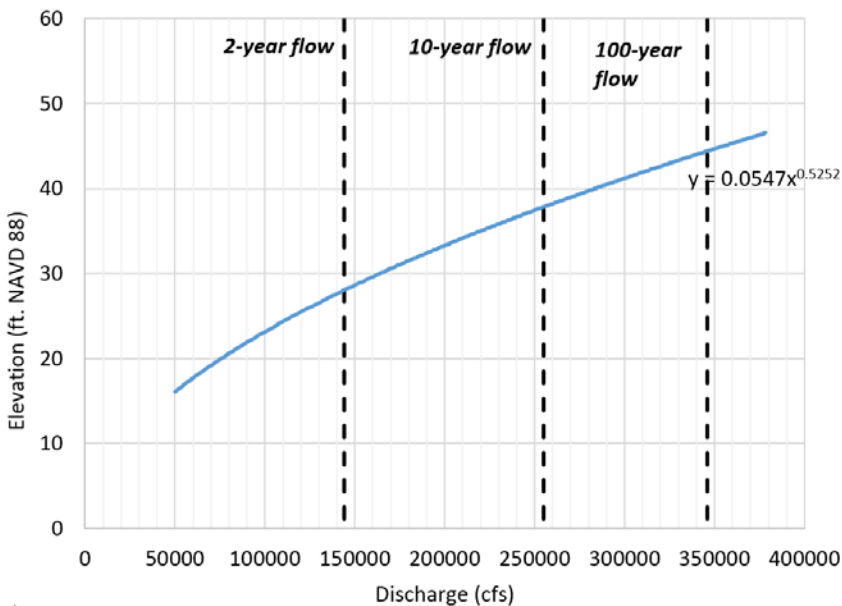
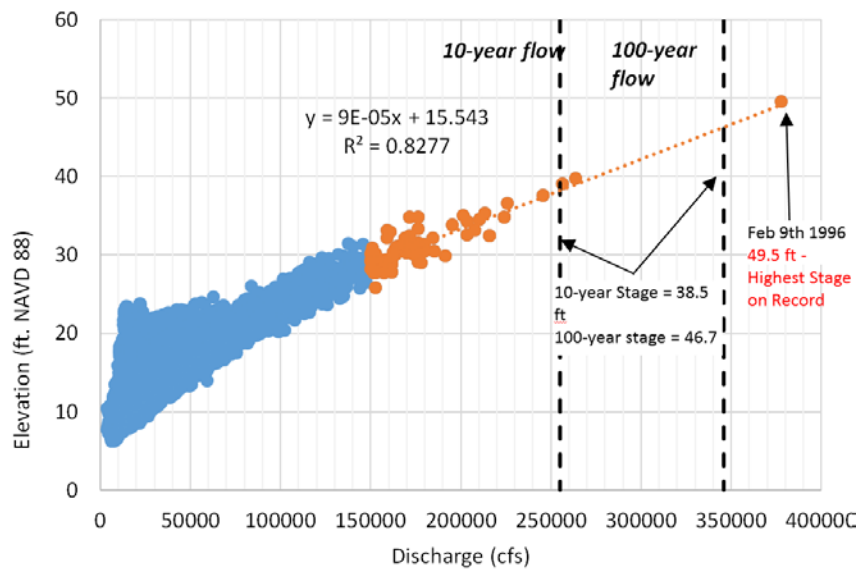
The design flows selected for evaluation of the Riverwalk Project are summarized in Table 3.

**Table 3***Key Design Flows for Modeling*

Design Flow (cfs)	Statistical Definition	Explanation
346,000	100-year	Major flood used to assess impacts to infrastructure and FEMA regulatory floodplain requirements.
144,000	2-year	Approximate flow for estimating Ordinary High Water, a frequent but modest flood.
53,300	10% exceedance of average daily flow, March through June	Typical high flow condition during fish passage period
11,700	90% exceedance of average daily flow, March through June	Typical low flow condition during fish passage period
3,400	Summer low (2015)	Reasonable minimum flows and levels

## Design Stages

Water levels (stages) below the falls are controlled by both discharge and backwater, and therefore these factors need to be reflected in the design stages that will be used to evaluate the Riverwalk design. Low stage issues include water quality, aquatic and riparian habitat, river access, and the interactions with project elements (like restored habitat) during low water level periods in summer and fall. Water levels upstream of the falls are independent of the downstream water levels (except in extreme floods), so there no need for additional consideration of the design stages for high flow scenarios (100-year, 2-year, and 10% exceedance); these will be evaluated using the rating curve from the Lower Oregon City gage to define the downstream water level during flood flows. The rating curve is shown below in Figure 2.



Note:

1. Relationship developed over 40 year overlapping period of record - mean daily discharge/flow .
2. Power Law regression developed from flows exceeding 50,000 cfs.

Figure 2. Stage-Discharge Rating Curve Based on Data Recorded at USGS Gage 14207770 below the Falls.

Two low water levels will be evaluated, each corresponding to one of the low flow design flows. The low water level design stage selected for the 90% exceedance of average daily *flow* in March-June is the corresponding 90% exceedance average daily *stage* for March-June. The design stage selected for the summer low flow of 2015 will be the corresponding lowest recorded stage which is controlled by the lowest tidal cycle during the low flow season. The resulting design stages are shown in Table 4.



**Table 4***Low Water Level Design Stages for Modeling*

Design Stage at Lower Oregon City Gage (feet NAVD88)	Statistical Definition	Explanation
10.1	90% exceedance of average daily stage, March through June	Typical low water level condition during fish passage period
7.3	Summer low (2015)	Reasonable minimum level

## Hydraulics

The river at Willamette Falls is controlled by both natural and anthropogenic features. The basalt rock outcrop that creates the falls has controlled the river hydraulics in this reach for centuries. In recent history the falls have been modified for different purposes including hydro-powered mill operations and hydroelectric power generation. This section of the report documents our understanding of the existing hydraulic controls at the Site, which will inform how the hydraulic model runs are set up and applied.

### Existing Flow Controls and Dam Operations

The current features that control flow over the falls include:

- the concrete dam crest and seasonally-installed wooden flash boards
- the navigation locks
- the Obermeyer weir flow control structures
- the sluice gate
- fish ladders
- penstocks
- debris lodged behind the dam
- buildings and other infrastructure on the Blue Heron paper mill site during flood conditions.

These features are shown on Exhibit 2, and the geometry and hydraulic functions of these features are described below. Portland General Electric (PGE) owns and operates the dam, and uses its own local elevation datum when referencing elevation data. The Site survey data (bathymetric and topographic) and hydraulic modeling are based on the NAVD88 datum – referred to herein as the Project Datum. The PGE datum is 4.27 feet lower than NAVD88. All elevations noted in this memorandum are in NAVD 88, US survey foot, unless otherwise noted.

### PGE Dam Operations

PGE’s Sullivan hydropower facility at Willamette Falls has 13 turbines that are operated with the goal of generating as much power as possible while ensuring that each turbine operates above a specified threshold efficiency. PGE operators take turbines offline when they are all not able to operate within defined efficiency limits. The specified flow rate through each turbine is 465 cubic feet per second (cfs) so with all turbines operating, the maximum flow diverted through the power house is about 6,045 cfs. In general, the operators are able run all 13 turbines during low flow conditions (summer-fall). During high flow conditions plant operators often need to take one or more turbines offline when the available head for power generation is reduced due to elevated tail water conditions, and turbine efficiency drops below threshold values.

In summer months, flashboards are installed on top of the grouted concrete crest of the falls to increase the available head and to help control the upstream water level. The flashboards are installed after spring runoff when flows are approaching summer conditions; they are usually in place by early July. The flashboards raise the headwater by 3.5 feet, but are designed to allow some flow to seep through the

slats to reduce stranding of fish in pools at the base of the falls, and to aide lamprey passage. The flashboards on the crest of the falls are designed to break away in the fall or early winter when the first high flow event occurs.

The section of the wooden flashboard system that runs across the top of the spillway is scheduled to be replaced with adjustable Obermeyer weirs in summer of 2016 or 2017, with the new weirs providing the same function as the wooden flashboards. Only 17 of the 20 dam gate segments are being upgraded, with the remaining three gates, located furthest to the south, being plugged with concrete. There is a sluiceway on the far north side of the concrete dam and spillway that is also being modified in summer of 2016 or 2017. At the time this report was prepared (May 2017), the 3 southern most spillway gates were plugged with concrete but the new Obermeyer gates had not yet been installed.

There are currently three adjustable Obermeyer weirs in the center of the falls, known collectively as the Flow Control Structure (FCS). The weirs are adjusted by PGE operators to help control the headwater elevation for power generation purposes. During high flow events the weirs are typically fully lowered (crest invert elevation = 51.27' NAVD88). In the summer there is at least one weir gate open to facilitate downstream fish passage. At intermediate flows PGE operators adjusts the gates as needed to optimize turbine efficiency.

There are three fish ladders at Willamette Falls that each carry a small amount of flow downstream year-round. The combined by-pass flow for the fish ladders is approximately 600-800 cfs. Another 400-500 cfs is bypassed around the turbines at the Sullivan Plant to facilitate fish passage. The total combined by-pass flow to support fish passage is between 1,000 cfs and 1,300 cfs.

### USACE Navigation Locks

The navigation locks on the north side of the falls were closed in 2011. The lock gates may no longer be operable and there are no current plans to reopen the locks. The head gate on the upper lock is closed, though there is some seepage flow through the gates.

### Blue Heron Paper Mill Site

Under normal conditions the Blue Heron site does not control or significantly affect river hydraulics, although there are seepage flows that emerge under several of the historic buildings. During large floods the river spills over the southeast end of the dam and at points along the railroad alignment allowing floodwaters to inundate portions of the property. The flow paths through (especially beneath) the Blue Heron site are highly complex due to the manner in which the historic structures have been built on top of natural and modified rock features. Many of the buildings are elevated and are somewhat pervious which allows flood waters to follow complex pathways.

## Hydraulic Model Development

Hydraulic models help planners, designers, permitting specialists, and other interested stakeholders understand how water moves through the project site – this is typically referred to as hydraulic characterization of the existing system. The knowledge gained from characterization of the existing system allows planners to develop concepts to meet the design objectives and constraints. As conceptual designs advance the hydraulic models can then be used to evaluate alternative proposed actions to see if the concepts function as intended, from a hydraulic perspective. This section of the report lays out the modeling approach, describes the modeling software being used, details the methods used to parameterize and calibrate the model, and presents preliminary results for the 2-year flood event at the existing site.

# Hydraulic Modeling Software

The selection of a hydraulic model, from the many types available, is typically based on the needs (objectives) of the designers, and constrained by the available data and limitations of computer resources. For the Willamette Falls Legacy Project a 2-dimensional (2D) hydraulic model was recommended, primarily because it is able to simulate and provide visualization of complex flows paths such as those that exist at the project site. In reality, flow characteristics over the falls are 3-dimensional (meaning that they vary vertically [in the z-direction] as well as horizontally), but vertical variations in flow are not currently needed for design purposes, so a 2D model can be used. A 2D model can also simulate some aspects of vertical flow in the x- and y-directions, thereby optimizing computer resources (computation times and file sizes), making the model more practical to use (by shortening run times) relative to a 3-dimensional model.

For this project CH2M recommended using a 2D hydraulic model called MIKE21FM, developed by DHI Water and Environment Inc. This software is widely used, nationally and internationally, and our team has extensive experience in its use. The “FM” acronym stands for Flexible Mesh, meaning the model resolution can be varied within the model boundaries. This flexibility is desirable since we anticipate wanting higher resolution near the Riverwalk compared to other areas.

The model software (MIKE 21FM) is proprietary and requires a license to run simulations but model input and output files can be viewed using free software (available online). The software and supporting documentation can be found at: <https://www.mikepoweredbydhi.com/products/mike-21>.

## Modeling Approach

The approach for developing and applying the 2D hydraulic model involves several sequential steps:

1. Develop existing conditions model
  - a. Model parameterization
  - b. Model calibration and validation
  - c. Hydraulic characterization of the existing system
  - d. Document model development and existing condition model results
2. Alternatives Analysis
  - a. Iterative application of the model to various design alternatives
  - b. Document results

The specific details pertaining to model development, parameterization, calibration and validation are described in the following sections.

Once the model is calibrated and validated (and “ground-truthed” to the best of our ability) the model can then be applied to various design scenarios. In general, this will be done in an iterative fashion with increasing levels of detail as the design progresses. Initial concepts can be evaluated and tested with simple, low-precision, representations of proposed features – for example, evaluating what happens when a building or structure is removed or added to the site. As the design process progresses we will begin using higher precision representations of design features such as those created in AutoCAD or similar software. For preliminary evaluations the modeling team can make manual adjustments in the model based on coarse contours representing the proposed design, with greater resolution added as needed.

After the model has been developed, calibrated, and applied the modeling team will develop the associated documentation in a Hydraulic Modeling Report.

# Model Parameterization

Parameterization is the process of selecting and defining the parameters used to describe specific objects and processes in a model, such as how the terrain is represented in the model mesh, how flow control structures are represented, and how flow resistance is formulated. It also includes the data inputs for the models and the choices related to spatial and temporal scale and resolution. The parameterization described below is preliminary and some aspects may need to be changed as the design advances.

## Digital Terrain Model (DTM) Development

Three data sources were used to develop a seamless terrain surface, which is essential for hydraulic modeling. These data sources, merged into a terrain surface by AKS Engineering, included the following:

- highest hit LiDAR (data including ground objects: trees, rooftops, powerlines, etc.) collected in 2014 to define terrain above the waterline
- supplemental ground survey data of the former Blue Heron Paper mill where available
- bathymetry data collected in 2000.

Since Version 1 of this report, a series of updates and revisions have been made to the existing condition DTM to make it more representative of site conditions. These updates were especially focused on correctly representing flood water flow through the site during major floods. Changes to the DTM were guided by field investigations and anecdotal accounts of flood conditions during the 1996 flood.

Revisions to the DTM include:

- Buildings constructed with corrugated metal walls (vacated 3<sup>rd</sup> Street building, south wall of Mill O), reported to be directly penetrated by floodwater in 1996, were removed from the DTM to allow flood water to enter the buildings as described by anecdotal observations. Flow was allowed to run along the finished floor of these structures before returning to the main channel.
- Concrete walls in inundated building such as Mill H, were left in place, and openings were inserted to represent large roller doors through which flood-waters reportedly flowed during the 1996 flood. Inside the building the floors were removed to allow water to flow downward into Tailrace #2. In actuality water would flow downward through a complex matrix of floor openings and down stairwells, but the 2D model is not able to represent such complex (and three dimensional) flow paths. Water will only be allowed to flow into the buildings through open doors (large roller doors).
- Elevations along the top of the concrete wall that surround the forebay lagoon were reviewed and revised to be consistent with the license drawings of the dam provided by PGE. This wall is a critical feature that control the amount of flood-water that enters the Site during major floods.
- The roof covering the 3<sup>rd</sup> Street access road was removed from the DTM to expose the underlying roadway, along which flood-waters reported flowed during the 1996 flood. Field survey data were used to define the topography of the roadway. The previous DTM showed this roofed area as a solid building (as seen by the LiDAR data), when in fact it is a covered roadway.
- Similar to above, the roof covering the roadway passing between Tank 2 and Building 1 Paper Mill Rewind was also removed to expose the underlying road and associated flow path. The roadway topography was defined using field survey data.

The field observations and anecdotal information describing the flow paths from the 1996 flood, used to revise the DTM, are shown in Exhibits 11A – 11D. The revised DTM is shown in Exhibit 3.

## Mesh Development

Developing the model mesh involves laying out a “flexible” grid over the entire model domain – the model uses the mesh to compute water levels and fluxes between grid cells based on the elevation and roughness data assigned to each grid cell. The elevation data from the terrain model is transferred to the hydraulic model based on the average elevation of the terrain model in each node (corner of a grid cell), which are assigned a single elevation value. Important features such as the dam crest and the “flow control structure” are manually adjusted in the DTM to reflect the precise geometry as defined in the as-built drawings and site survey data.

The resolution (size and spacing) of the grid cells is an important consideration in developing the model. Higher resolution grid cell spacing provides greater resolution in the results (finer detail), but not necessarily greater accuracy. Increasing the spatial resolution is not without consequence – higher resolution means more grid cells (i.e. more computational points) which leads to increased model run-times. In developing the mesh several different resolutions were investigated to help determine an appropriate balance between resolution and run-times, and a variable grid cell spacing developed to help optimize the balance between grid cell spacing and model run times. The current model mesh has an average grid cell spacing of approximately 14 x 25 feet rectangular cells in the channel and triangular cells spaced 10 feet apart on average in the floodplain and the former mill site. The floodplain grid cell resolution of 10 feet, with break lines defining critical features, was determined to be a practical balance between higher resolution and longer model run times. The current model mesh is shown in Exhibit 4.

The mesh used in the near-future to evaluate proposed alternatives, and ultimately the final schematic design, will likely need to use a slightly modified mesh. Critical features will need to be defined with additional breaklines in order to represent the proposed terrain as accurately as possible. However, the mesh will only be modified in select areas where changes are proposed and will leave all other mesh elements unchanged: keeping the same mesh resolution between comparative models is essential when making direct comparisons between model results.

## Boundary Conditions

The model solves the partial differential equations of conservation of mass and momentum (St. Venant equations) which require defined boundary conditions at all exterior open boundaries and initial conditions for all internal elements. The Willamette Falls model has two exterior boundaries, one upstream and one downstream. The upstream boundary condition will be defined by discharge and the downstream boundary will be defined by water level.

The discharge values used to define the upstream boundary are based on Portland USGS gage (14211720), scaled to the Site as described in the Flow-Frequency Relationships Section and presented in Table 2.

The downstream boundary will be defined using water levels recorded at the Oregon City USGS gage (14207770). The water levels at this location are affected by backwater from the Columbia River which means the relationship between discharge and water level is not directly proportional – water levels are influenced by more than just the local discharge. This means we cannot use a fixed rating curve where each discharge has a single water level value. For cases where we’re simulating a historic flood event we will use the gaged water levels corresponding to the time and day of the flood event, when possible. In cases where hypothetical flood events (i.e. 50-year flood, not real historic events) are being simulated, we will use the rating curve and professional judgement to guide the selection of the appropriate downstream boundary condition. There may be some cases where we need to simulate a range of downstream water levels for a single flow to characterize the range of hydraulic conditions associated with a single discharge.

Flows routed through the powerhouse and through the fish ladders are simulated with simple source/sink terms that extract the inflows from above the falls at the approximate locations for the ladders and the powerhouse intake and then re-injects the flows below the falls at their proper locations. The locations for all sources and sinks are shown on Exhibit 4.

## Hydraulic Structures

In the context of this report, hydraulic structures refer to features such as weirs, flashboards, gates, and culverts. These features need special consideration since they can have a strong influence on the hydraulic conditions (and they can sometimes be challenging to represent in a model). As a general rule these features are best defined directly in the mesh geometry whenever possible – this provides the most realistic representation and allows the model to use the full 2D equations of mass and momentum instead of “inserting” a special function (often empirical) to represent a specific situation that cannot be simulated with flow over a free-surface (for example, pressure-flow in a culvert).

The most prominent hydraulic structures at Willamette Falls are those located on the crest of the falls and dam: the concrete sill crest, the Flow Control Structure, sluice gate, Obermeyer weirs, and flashboards. All of these features will be modeled directly in the model mesh with the elevations adjusted specific to each simulation scenario (i.e. grid cell elevation raised and lowered to represent each desired geometric condition).

## Roughness

Water flowing in a riverine environment experiences two forms of flow resistance: form drag and skin friction. Both of these affect hydraulic conditions (such as water level, velocity, and shear stress) and the energy that is available to transport sediment. The software MIKE21FM accounts for flow resistance through a single roughness parameter – the Manning’s n coefficient in this case. Unique roughness values were chosen below, above, and at the falls as well as in floodplain areas to represent different forms of resistance. The primary driver for determining in-channel resistance was the channel bed characteristics present in the bathymetry data, while in the floodplain the relative roughness of the surface over which water was flowing determined resistance values. Flow resistance coefficients were adjusted during calibration. The final roughness values for the existing condition are summarized in Table 5.

**Table 5. Summary of Roughness Values used in Hydraulic Model**

Location	Manning's n	Description
Main Channel	0.034	Flow over non-uniform bedrock surfaces
Flow over falls	0.083	Additional resistance over falls is necessary to maintain realistic velocities
Flow over spillway	0.2	High roughness due to debris restricting flow over the spillway

## Calibration

Model calibration is the iterative process of adjusting isolated model parameters so that simulated results match observed results within a range sufficient for the intended use of the model. Calibration is part of the parameterization process, wherein some of the available data (such as water levels) may be used to guide adjustment of one or more of the model input parameters. The quality of the calibration is a function of the accuracy and reliability of both the measured field data (i.e. water levels) and the

model input data (i.e. boundary conditions), as well as the complexity and scale of the processes being modeled.

This section outlines the calibration process and provides a review of the data that are available for calibration, followed by a description of the flow and water surface elevation calibrations that were performed and their results.

## Calibration Process and Available Data

The model has undergone two rounds of calibration. The first round of calibration was documented in the last version of this report (Version 2, January 2017). A recent high flow event in February of 2017 provided an opportunity to collect additional water level data to support further model calibration. There have also been several refinements to the model mesh aimed at improving the physical representation of the dam and spillway in the model; the concrete piers separating the spillway gates have been added to the model mesh and multiple cells were added across each spillway gate so that the presence of debris can be simulated by blocking select portions of the spillway gate.

There are three sources of data that will guide the calibration process. First, PGE operates two staff gages at Willamette Falls, one upstream of the falls in the forebay and one downstream of the falls in the tailrace. Our understanding is that PGE operators manually record water levels on a daily basis but the timing and frequency of recording may vary day-to-day and may exclude periods of very high flow during large floods where it is unsafe for PGE operators to be on-site. The data recorded from PGE gages is useful in guiding the calibration for smaller, more frequent flows. Metro requested and received stage data from the PGE gages for two relatively recent floods, December 20, 2015 and February 10, 2017, that had flows approximately equal to the 2-year peak flow. The table below summarizes the available data from these events.

The second source of calibration data was obtained by Metro during the February 10, 2017 high flow event. Metro staff marked water levels on the shore at five locations on February 10, 2017 which were later surveyed by CH2M HILL and tied to local on-site survey control, established by AKS. The locations of the water levels marked by Metro and the PGE staff gages are shown in Exhibit 6 and the values are shown in Table 6.

**Table 6. Summary of High Water Elevations Collected by Metro**

<b>Location</b>	<b>Elevation (feet)</b>
ID Location 1	27.94
ID Location 2	27.95
ID Location 3	63.38
ID Location 4	63.30
ID Location 5	63.27
Base of Grotto2	46.50

The third source of calibration data are the high water marks located on some of the historic buildings, including marks from the 1996 flood along with supporting anecdotal accounts of the flood. This flood is of specific interest because it is a relatively recent major flood that occurred at the site and that community members witnessed first-hand. According to historic discharge estimates, the flood flows were larger than a 100-year flood – closer to a 250-year event - but the stage recurrence interval below

the falls is closer to a 100-year recurrence interval (for stage). The high water marks from 1996 have been surveyed by AKS.

### Calibration Parameters

Model calibration requires the accurate definition of enough known parameters such that the unknown parameters can be isolated and adjusted (calibrated) until the model–predicted water levels closely match the observed data. Unfortunately, in the case of Willamette Falls, there are too many unknown parameters (inadequate data) to allow for a direct calibration of the unknown parameters.

The unknown parameters at Willamette Falls include:

- **Discharge:** The Portland and Newberg gages help bound the range of the discharge expected at the site at a given time, but the precise value is unknown because the downstream gage is 15 miles away, with tributaries entering the Willamette River in this reach, and the upstream gage is 26 miles away, also with tributaries contributing to flow in between. The range of uncertainty estimated to be on the order of (+/-) 20%.
- **Floodplain Flow Paths:** Flow paths within the channel are well understood, but during large floods flow paths outside the channel are more uncertain. For example, flow pathways and flow rates through and beneath historic buildings at the Willamette Falls Legacy site are known to be complex but poorly understood or defined (in other words, they are highly uncertain).
- **Channel Roughness:** Riverbed form-drag and skin friction create resistance to flow, and higher resistance results in higher water levels. The roughness parameter is often adjusted during model calibration when the local discharge, velocity profile(s), and water levels are precisely and accurately known (through collection of field data during floods). In the case of Willamette Falls, local discharge, velocity profiles and water levels are not precisely known, limiting the ability to isolate channel roughness as the only calibration parameter.
- **Flow Controls on the Falls and Dam:** The characteristics of flow passing over the crest of the Falls and adjoining spillway are affected by a number of factors such as the height of the adjustable flow control structure and the presence or absence of flashboards (which are designed to break-away during high flows, this process is unpredictable and non-uniform). Flow over the dam crest and spillway during a flood is typically affected by debris snagged on the dam, and may be influenced by other structures such as the elevated walkway above the southeastern portion of the dam. It is therefore not possible to know the precise condition and influence of all controlling elements, at all times, for historic (or future) events.

The water surface elevation profile for the reach below the Falls is controlled by a combination of backwater (from the tidally-influenced Columbia River) and total flow resistance (from form drag and skin friction, which is a function of discharge and roughness height). The backwater effect is inherently accounted for in the model by using measured water level data recorded at the Lower Oregon City USGS gage to define the downstream boundary condition. The local discharge, defining the upstream model boundary condition, is not precisely known at specific times because the USGS gages immediately upstream and downstream of the falls only record stage, not discharge. Therefore, the local discharge is loosely constrained by the upstream gage at Newberg and the downstream gage in Portland.

This uncertainty in the local discharge makes it challenging to isolate other calibration parameters. A typical model calibration process often focuses on adjusting channel roughness to get water levels to match the observations, but to do that properly the local discharge must be accurately known - otherwise, there is a risk of adjusting roughness incorrectly (masking errors in the local discharge, for example). In reality, there is likely some error in the assumed channel roughness and some error in the estimated local discharge, but it is not possible to know which combination of parameter settings is correct. However, it is known that water levels through the study reach during a flood are controlled mostly by the local discharge, backwater, and the position of hydraulic structures on the dam (and the



presence of debris) compared to channel roughness – this can be demonstrated with the model through sensitivity analysis. While backwater is a first-order control on water levels in the reach below the falls, it will not be adjusted during calibration since the water level that creates the backwater effect is gaged (measured) precisely at the models downstream boundary. This provides a defensible rationale for focusing on adjustments to only two parameters (the local discharge and the hydraulic structures, plus any effects from debris that may impede flow over hydraulic structures) to calibrate the water levels, rather than adjusting channel roughness; this is the approach currently used.

## 2-Year Flow Calibration

As described above there are two high-flow events with available calibration data. Both events had recorded flow rates close to the estimated 2-year recurrence interval peak discharge.

A summary of the PGE recorded water levels and the gaged flows and stages at the nearest USGS gages is presented in Table 5. During the December 20, 2015 event there is a 20% increase in the mean daily flow between Newberg and Portland and a 1.0 foot change in the water level at the USGS gage below the falls, with these ranges reflecting the level of uncertainty in boundary conditions. For the February 10, 2017 event the water level variation is only 0.2 foot since we know the exact time that the water levels were recorded, but there is still a 23% increase in flow between Newberg and Portland which adds uncertainty to the upstream boundary condition.

**Table 5**

*Summary of Currently Available Calibration Data for 2-year Storm*

Date and Time	Water Level in Forebay (ft, NAVD 88)	Water Level in Tailrace (ft, NAVD88)	Water Levels at Oregon City D/S gage, max./mean/min. (ft, NAVD 88)	Daily Change in Water Level at Oregon City D/S gage (ft)	Instantaneous Flow / Mean Daily Flow, Newberg gage, (cfs)	Instantaneous Flow / Mean Daily Flow, Portland gage (cfs)
12/20/2015 Exact time unknown	66.0 ft.	30.4 ft.	28.5/28.1/27.5	1.0	N.A. <sup>1</sup> / 129,000	N.A. <sup>1</sup> / 163,000
2/10/2017 14:00	64.7 ft.	28.5 ft.	26.8/26.7/26.6	0.2	107,000 / 105,000	142,000 / 143,000

<sup>1</sup> The instantaneous flow cannot be reported since the time of the water level measurement is not known.

## Calibration for December 20, 2015

For the December 20, 2015 event, the PGE water levels are the only source of calibration data. One of the challenges of calibrating to the PGE water level data for this event is that the time of day when water levels were recorded is unknown. On December 20, 2015 the water levels at the Oregon City gage below the falls fluctuated 1.0 feet; we would expect a similar fluctuation at the PGE tailrace gage. For the purpose of this first model comparison the downstream water level was set at the mean daily value for December 20, 2015, 28.1 feet NAVD88. The local discharge was estimated from the mean daily value at the Portland gage (163,000 cfs) and scaled down based on a ratio of the drainage areas to 144,000 cfs. The initial results showed that modeled water levels were about 1.4 foot low in both the tailrace and the forebay. If all the uncertainty is assumed to be in the local discharge, it would take approximately 8,000 cfs (increasing the local discharge to 152,000 cfs) to increase the tailrace water level by one foot. This value is within the plausible range, given that the average daily value at Portland was 163,000 cfs and the peak instantaneous value was likely higher. The model results for this scenario are included in Exhibit 7A – 7D.

Without more data to better constrain the model inputs (such as a local measurement of discharge) it is not possible to conclusively know if all the uncertainty should be accounted for in the local discharge or if some adjustment to channel bed roughness is also appropriate. Upstream of the falls the water level in the forebay is still 0.9 foot too low even with the additional 8,000 cfs of inflow. As stated above, this value is within the range of water level fluctuations seen on December 20<sup>th</sup> at a discharge estimate at the falls. Water levels upstream of the falls are usually not affected by backwater from the Columbia River (that would occur only during extreme floods); instead they are controlled by local discharge and the invert elevations of the hydraulic controls on the crest of the falls and the adjoining spillway, and by debris that accumulates on the structures. For this calibration event it was assumed that the flashboards were completely gone (as they are designed to break-away during high flows) by the time the 12/20/2015 storm occurred and that all three bays of the adjustable flow control structure were fully lowered. Flow over the spillway in the model includes the 20 pier structures which are an obstruction to high flow, but the effects of the elevated walkway and any local debris build up is assumed and simulated in the model (water levels at the time of the event were high enough that the elevated walkway and railing would likely restrict flow). The increase in flow resistance from the debris that may become snagged on these features, along with the other stated uncertainties, could be enough to explain the 0.9 feet discrepancy.

While results and supporting rationale from this calibration efforts are considered reasonable, they included several potentially significant assumptions. A high flow event in early 2017 provided the opportunity to conduct a second, more accurate, calibration, as described below.

#### **Calibration for February 10, 2017**

For this calibration event there are seven total water levels measurements to consider, two from the PGE staff gages and five marked by Metro on the right shore line (see Exhibit 6 for locations). The time of day associated with all of the water level measurements is also known, which helps constrain the range of downstream water levels - there is only a 0.2 foot range in water levels at the downstream boundary during the period when water levels were marked.

The configuration of the dam crest and spillway during this event was slightly different than it was for the December 20, 2015 calibration event. Three of the spillway gates were permanently blocked-off in the fall of 2016 (the three gates furthest south). Additionally, photos of the site taken on May 1, 2017 show that a significant portion of the dam crest still had flashboards in place, meaning they were in place during the high flow event on February 10, 2017. It is not possible to know exactly which flashboards were still in place but from the photos it appears that most of the flashboards between the flow control structure and the old power house remained in place (see Figure 3). There was also a large amount of accumulated debris behind the dam shown in these photos. The geometry changes were applied to the model mesh for calibration of this event but there is some uncertainty about the number of flashboards that were in place during the event (potentially significant because the flashboards increase the dam crest by approximately 2 feet).



Figure 3. Photo of dam crest on 05/01/2017 showing flashboards in place and debris accumulation.

The calibration approach was to start with a “base” model which reflects our best understanding of the physical geometry of the hydraulic structures on the dam and spillway, and the expected boundary conditions (flow rate and downstream water level) at the time the water levels were recorded. To investigate and quantify the influence of each respective calibration parameter we conducted successive runs which adjusted only one parameter at a time in order to isolate its influence on the resulting water levels. Three primary parameters were examined: local flow rate, roughness, and the effect of debris on the spillway. The adjustments include:

- increasing the flow rate to that measured at the Portland USGS gage which equates to a 16% increase in flow
- increasing by 30 percent the Manning’s n values at all locations
- Increasing the invert elevation of the spillway by 0.7 foot to simulate the potential effect that debris may have had on water levels upstream of the falls.

The water level results and associated residuals for all four scenarios are shown in Table 6.

**Table 6**  
Summary of Model Residuals for the February 10, 2017 event

Location	Measured Water Surface Elevation (ft. NAVD 88)	Base		Increased Roughness 30%		Increased Flow by 16%		Simulated Debris on Spillway	
		Modeled Value (ft)	Residual (ft)	Modeled Value (ft)	Residual (ft)	Modeled Value (ft)	Residual (ft)	Modeled Value (ft)	Residual (ft)
		Q = 122,000 cfs, d/s water level = 26.73 ft (from USGS gage)		A global increase at all locations		Q = 142,000 cfs, the flow recorded at the Portland Gage.		Spillway Crest raised from 63.3' to 64' to simulate blocked flow from debris.	
Metro - Water Mark 1	27.94	26.76	-1.2	26.93	-1.0	27.03	-0.9	26.95	-1.0
Metro - Water Mark 2	27.95	26.97	-1.0	27.00	-1.0	27.20	-0.8	27.02	-0.9
Metro - Water Mark 3	63.38	62.16	-1.2	62.03	-1.3	62.72	-0.7	62.22	-1.2
Metro - Water Mark 4	63.29	62.18	-1.1	62.05	-1.2	62.79	-0.5	62.23	-1.1
Metro - Water Mark 5	63.27	62.18	-1.1	62.03	-1.2	62.84	-0.4	62.21	-1.1
PGE - Upstream Forebay Gage	64.72	63.13	-1.6	63.48	-1.2	63.94	-0.8	63.14	-1.6
PGE - Downstream Tailrace Gage	28.47	26.58	-1.9	26.99	-1.5	27.25	-1.2	27.62	-0.9

Results from the Base scenario show residuals (the difference between modeled and measured water levels) that are all negative (simulated levels are lower than observed) and the magnitude is quite uniform at around 1 foot. Increasing the flow rate has the greatest impact on raising the simulated water levels but the residuals are all still negative. Roughness and debris have a smaller impact on increasing water levels. Having residuals that are uniformly too low, at all locations, is suggestive of one of three typical problems: 1) the local discharge is too low, 2) the roughness is too low, or 3) there is a discrepancy in the elevation data. In this case, a difference in flow and roughness does not appear to be the root cause. There is some supporting evidence for a discrepancy in the surveyed elevation data – the surveyed elevation of Water Mark 1 is reported to be 1.2 ft higher than the elevation at the USGS gage below the falls which is located only 600 ft downstream. The elevations at those two location would be expected to be nearly identical given the low-gradient backwater condition and the close proximity to each other. The survey data suggest a water surface gradient of 0.2 percent between Water Mark 1 and the USGS gage below the falls; that is an order of magnitude higher than both the model and the PGE data show. This observation suggests that there could be a data discrepancy between the surveyed water marks and the USGS gage datum. This could be investigated by surveying the water level at the USGS gage using the survey control network established at the Willamette Falls Legacy Project Site to see if the datums are consistent.

With these findings there are no recommended adjustments to the Base model, as the available data do not definitively support any changes.

### High-Flow Calibration

The flood that occurred in February of 1996 is considered a major flood (approximately equal to a 250-year flood based on flow over the Falls) and an important design event for the project because of the amount of water that could flow through the site during such extreme conditions. There are no measured water level data available for this flood but there are a few high water marks on buildings at the site and anecdotal information describing the primary flow paths through the site which were used to guide high-flow calibration, including the following:

- Aerial photograph taken on February 11, 1996 (2 days after peak flow). See Exhibit 12A.
- High water survey performed by AKS Engineering. See Exhibit 12D.
- The maximum daily average flow rate estimated at the USGS gage on the Morrison Bridge in Portland (420,000 cfs).
- Second-hand anecdotal information from site workers. See Exhibit 12C.

Calibration focused on discharge at the Falls as well as hydraulic structures affecting elevations upstream of the Falls (i.e. flow control structures, debris hindering flow over the falls), and modifications to the DTM to more accurately represent the actual flow paths during the 1996 flood. The aerial image shown in Exhibit 12A was taken on February 11, 1996 and shows water levels in the forebay above the bottom of the elevated walkway, at an elevation of 64.27 feet, but not overtopping the concrete wall at the project site, at an elevation of 67.0'. To replicate this in the model, the spillway invert was raised (along the south spillway section) and roughness was increased to simulate similar elevations in the forebay.

The downstream rating curve for the Lower Oregon City gage suggests that for a river discharge of 378,000 cfs (the flow rate estimated at the Portland gage adjusted to the site) the water level at the gage should have been between 44 feet and 49 feet, which is a large range (high uncertainty). Anecdotal reports from witnesses of the 1996 flood say that floodwaters entering the site from above the falls were routed through the site and flowed back into the river channel downstream of the falls and no flow came into the Site from the river channel below the falls. In other words, no water came into the site from the river channel below the falls, which means the water level in the channel must have been lower than the water levels through the Site. In elevation terms this means that the water level in the

river must have been lower than the wall above the Pipe Chase which was surveyed to be 48.3 feet, providing some constraint as to what the downstream water levels were. An iterative process was used to determine the downstream water level (at the model boundary) that resulted in simulated water levels and flow paths consistent with the anecdotal information. The resulting water level at the model boundary was 44.5 feet which is within the range of values suggested by the rating curve. At this point the model was run and results compared to the surveyed high water marks and best estimated flow paths through the site, both of which had good general agreement, although in this version water did not flow down the vacated 3<sup>rd</sup> street building and through Mill O. In order to get this flow path to activate, the water level upstream of the dam would need to be higher. There are two possible factors that could explain what would cause water levels to be higher: 1) the local discharge could have been greater than 378,000 cfs (an estimated value based on the mean daily value at Portland) and/or 2) the presence of debris and other obstructions such as pipes and railings located above the spillway, and concrete walls that create increased flow resistance, resulting in higher water levels and thus more flow entering the site. While it is not possible to know the exact cause, iterative model runs show that a discharge of 400,000 cfs would be needed to raise the water level enough to activate the flow paths through Mill O and vacated 3<sup>rd</sup> street. For the hydraulic characterization figures included in this report the higher discharge option was used rather than making assumptions about debris accumulations and roughness associated with pipes, railings, and other obstructions. This decision does not affect future model applications – different assumptions can be made based on the objective of runs. For example, there might be a desire for a model run that includes all of the most conservative assumptions to see what the maximum possible water levels could be during an extreme flood. Hydraulic results for the 1996 flood are shown on Exhibits 8A – 8C.

## Hydraulic Characterization

The hydraulic model is a tool that enables us to estimate the hydraulic conditions (WSE, depth, velocity, and shear stress) across the entire study reach over a range of flow conditions. This description is often referred to as hydraulic characterization.

2D hydraulic models compute water levels, water depths, velocities, and shear stress at each grid cell for each time-step of the simulation. Results can be viewed in many different ways and the format is typically adjusted to the needs of the end-user. The most commonly used output format from a 2D model is a color-shaded contour map showing a single hydraulic parameter for a single moment in time (for example, a velocity map at 2-year peak discharge). Color-shaded contour maps show how the results vary spatially across the site and are relatively intuitive and easy to understand. However, a single contour map only depicts a single moment in time. To see how hydraulic results change over time we can either create a series of contour maps (which can become overwhelming and difficult to readily interpret), or time-series graphs which show how the results change at a single location over time; these time-series graphs are generally easier to comprehend. Another common way to review results is with profile plots which extract results along a line and the parameter of interest is plotted as a function of distance along that line (i.e., stationing); multiple profiles can be included on one plot to either show results from different river geometries or different flow rates. For the Riverwalk project we anticipate relying mostly on color-shaded contour map output and extracted profiles. Model results can also be displayed in rendered 3D format which “drapes” the results over a 3D rendering of the terrain – these renderings are often used as visual aids in stakeholder meetings because they give the viewer a more realistic view of the results. Video animations can also be created to show dynamic conditions or fly-overs.

The following results focus on presenting the hydraulic characteristics associated with the five design discharges described in Table 3.

## Existing Condition – High Flow (Feb. 1996)

The February 1996 event is of great interest since it was a major flood that occurred in recent history, witnessed by many community members, and is the highest flow event with sufficient data available for calibration. While the 1996 event was larger than a 100-year event, the calibration process performed on the 1996 event should improve the model's ability to replicate the smaller regulatory "100-year" flood. Results of the February 1996 event can be seen in Exhibits 8A – 8C.

## Existing Condition – 2-year Peak Flow

As described in the Calibration section, the model is currently calibrated to a single flood event (December 2015) which had a magnitude approximately equal to the estimated 2-year peak flow.

The 2-year peak flow condition is important for planners and designers to consider because it approximates the limits of Ordinary High Water (OHW), which is a regulatory boundary. Development actions below (within) the OHW boundary will require more rigorous permitting efforts. Exhibits 7A through 7D show the color-shaded contour maps for water level, depth, velocity, and shear stress for the 2-year peak flow from the preliminary existing condition model.

## 10% exceedance of average daily flow, March through June

This design flow was selected to evaluate "typical" high flows during the fish migration season (March – June). The flow rate of 53,000 cfs is only exceeded 10% of the time. The hydraulic results relating to fish passage and/or refuge habitat are symbolized in a way to highlight the hydraulic conditions that are general suitable for juvenile salmonids (i.e. low enough velocities to hold position and have sufficient flow depths). Results for the 10% exceedance of average daily flows, March – June, are shown on Exhibits 9A – 9B.

## 90% exceedance of average daily flow, March through June

This design flow was selected to evaluate the "typical" low flow during the fish migration season (March – June). The flow rate of 11,700 cfs is exceeded 90% of the time between March and June based on historic flow patterns. Again, the depth and velocity results are symbolized to highlight suitable aquatic conditions for juvenile salmonids. Results for the 90% exceedance of average daily flows, March – June, are shown on Exhibits 10A – 10B.

## Summer low flow (2015)

This design flow was selected to evaluate extreme low flow conditions. The lowest flow in the summer of 2015 was 3,400 cfs. Again, the depth and velocity results are symbolized to highlight suitable aquatic conditions for juvenile salmonids. Results for the summer low flow are shown on Exhibits 11A – 11B.

# Assumptions and Considerations for Conceptual Design Phase

The Design Collective's Pre-Concept Milestone 1 document (March 2016) provides a useful example of reference "language" with which team members can describe and reference areas and features at the project site. Relevant areas for the hydraulic model may be characterized, at this phase of the project, as upstream areas, falls, and downstream areas. Greater resolution, or other categorizations, can be added as Riverwalk features and site designs evolve.

Upstream considerations may include possible impacts along the railroad alignment, habitat and public safety concerns along the shoreline, interactions with the mill site, flow (or lack of flow) in the lagoon area and debris management.

Considerations around the falls may include access and sightlines at low and high water, elevation of walkways and structures relative to the water and the falls, possible issues related to PGE dam operations, flow pathways, fish habitat considerations (both desirable and not), debris pathways, sedimentation concerns, public viewing issues and public safety.

Downstream considerations may include water surface elevations (considering backwater and tidal influences) at high and low water, eddy flows, debris and sedimentation concerns and public safety.

A variety of other topics are directly related and integrated with considerations of hydraulic flow. While not directly addressed in this document, such factors include the following:

- **Public Safety:** While encouraging the public to intimately experience the falls, how can the design provide reasonable protections, especially in a setting that emphasizes wildness and power? How does the design promote access while strategically limiting access to provide the greatest protection to natural resources, and convey to the public the greatest sense of respect of the setting and other users? A range of related issues may warrant consideration.
- **Debris Management:** Flood waters can convey large debris, including trees and unmoored houseboats. Such objects can redirect flow and stress or damage infrastructure. Lower flows typically carry a range of smaller debris that can accumulate as floating or stranded material. Both large and small objects can change the visual appearance of all areas of the falls, and may require regular maintenance to manage. Design elements that reduce the risks to infrastructure and people are desirable, as are making maintenance access and debris removal easier and more efficient.
- **Uncertainty:** While the modeling tool provides a state-of-the-art analytical resource for understanding and simulating site conditions, there is inherent uncertainty in a number of factors related to it, both in existing conditions and simulated future conditions. In addition to those factors discussed above, climate change has the potential to affect future tidally-influenced water levels below the falls, and changes to the hydrologic conditions could change the magnitude and frequency of the flood flows. Limitations of temporal and spatial representativeness of available data create uncertainty with model inputs, as do the accuracy of components of the elevation model. The model itself simulates the complex three dimensional flow as a two dimensional approximation, with additional uncertainty elements. It is important to use the model results with an understanding of these uncertainties, which exist with all simulations of complex natural systems.
- **Flow Pathways:** Restoring former flow pathways at Willamette Falls, notably through one or more “tail races” beneath the former mill site, has been discussed, as has possible removal of the clarifier structure. Similarly, the addition of new structures may be part of future development plans. These and other options may alter the flow of water at high or low stages, and careful evaluation of the effects of such changes should be conducted. Potential effects on fish, habitat and structures, and the potential for sedimentation and debris accumulation, and other factors are likely issues for consideration.

# Conclusions

This report documents the hydrologic and hydraulic characteristics at the site for existing conditions and includes detailed descriptions of the hydrologic analysis, terrain model development, 2D hydraulic model development, and calibration for the 2-Year and 1996 flood events. The 2D hydraulic model has been through a calibration process, but the residuals are still relatively high (around 1 foot on average). Simulated water levels are consistently approximately 1 foot too low, and it's not possible to reasonably increase them enough through calibration adjustments. The fact that all the residuals are nearly the same magnitude, and "out of reach" of model calibration through reasonable parameter adjustment suggests that there may be a discrepancy between one of the vertical datums. This could be investigated with a field survey of datums and water levels. If the discrepancy cannot be resolved, the model can still be used in its current condition, especially in a relative application, but the uncertainty in the model will need to be acknowledge in the design process.

Results for in-channel flows at the 2-year event appear to be reasonable estimates of the general hydraulic conditions, appropriate for use at the conceptual planning level. For the 1996 flood event, the model has been calibrated to observed flow-paths but not precise water levels (which are not available), and the model results closely align with the anecdotal observations. The model can be used as a tool to support continued schematic design. Additional refinements can always be made to the model as new data become available. The most important thing to consider when applying the model is to apply the model consistently between existing condition scenarios and all proposed conditions so that the relative comparison will show only the differences associated with impacts of the proposed design.



# References

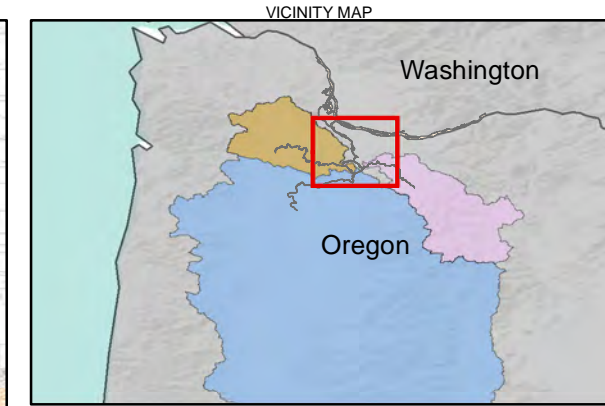
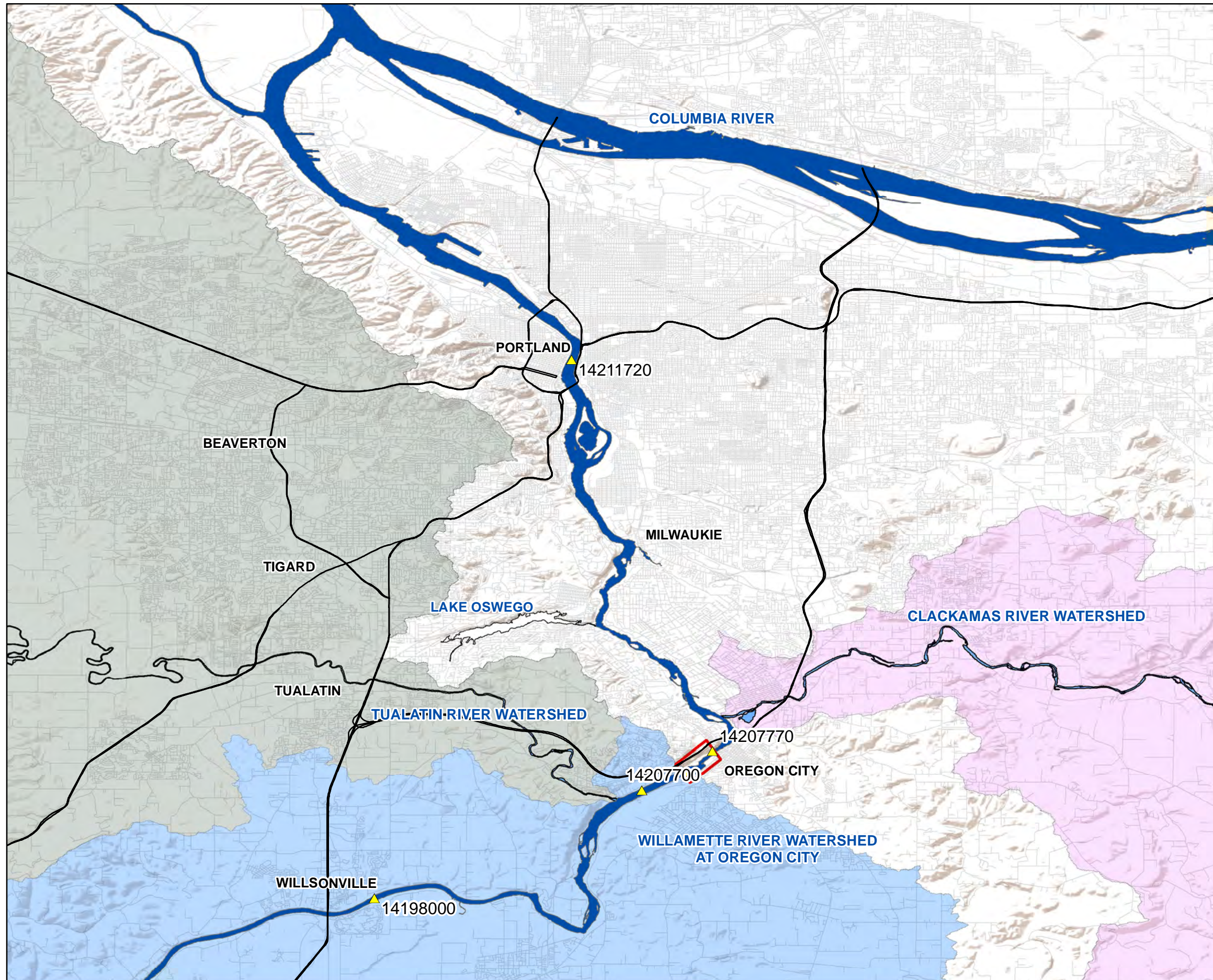
USACE, 2015. A Primer on Flood Risk Management. Retrieved April 07, 2016 from <http://www.nwp.usace.army.mil/Locations/Willamette-Valley/>

Cooper, R.M., 2005. Estimation of peak discharges for rural, unregulated streams in western Oregon: U.S. Geological Survey Scientific Investigations Report 2005-5116, 134 p

Tetra Tech. 2014. Lower Willamette River Ecosystem Restoration Project: Hydrology and Hydraulics Technical Memo. Unpublished report prepared for the U.S. Army Corps of Engineers, Portland, Oregon.

# Exhibits

- Exhibit 1 – Overview Map
- Exhibit 2 – Names and Locations of Important Features at Willamette Falls
- Exhibit 3 – Digital Terrain Model (DTM) Surface
- Exhibit 4 – Computational Mesh and Boundary Conditions
- Exhibit 5 – Preliminary Water level Comparison for 12-20-2015 Flood
- Exhibit 6 – High Water Mark Locations collected by Metro
- Exhibit 7A – Preliminary Results, 2-year Flood Event, Water Surface Elevation Contours
- Exhibit 7B – Preliminary Results, 2-year Flood Event, Velocity Contours and Vectors
- Exhibit 7C – Preliminary Results, 2-year Flood Event, Depth Contours
- Exhibit 7D – Preliminary Results, 2-year Flood Event, Total Bed Shear Stress Contours
- Exhibit 8A – Water Surface Elevation, February 1996
- Exhibit 8B – Annotated Water Surface Elevation, February 1996
- Exhibit 8C – Water Surface Elevation Zoomed into Project Site, February 1996
- Exhibit 9A – Summer 10% Exceedance Flow, 53,300 cfs, Velocity
- Exhibit 9B – Summer 10% Exceedance Flow, 53,300 cfs, Water Depth
- Exhibit 10A – Summer 90% Exceedance Flow, 11,700 cfs, Velocity
- Exhibit 10B – Summer 90% Exceedance Flow, 11,700 cfs, Water Depth
- Exhibit 11A – Summer 2015 Record Low Flow, 3,400 cfs, Velocity
- Exhibit 11B – Summer 2015 Record Low Flow, 3,400 cfs, Water Depth
- Exhibit 12A -8D – High Flow Site Investigation Notes



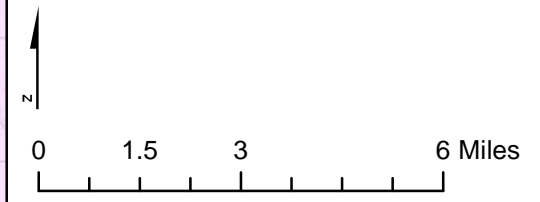
Service Layer Credits: Sources: Esri, DeLorme, USGS, NPS  
Sources: Esri, USGS, NOAA

**LEGEND**

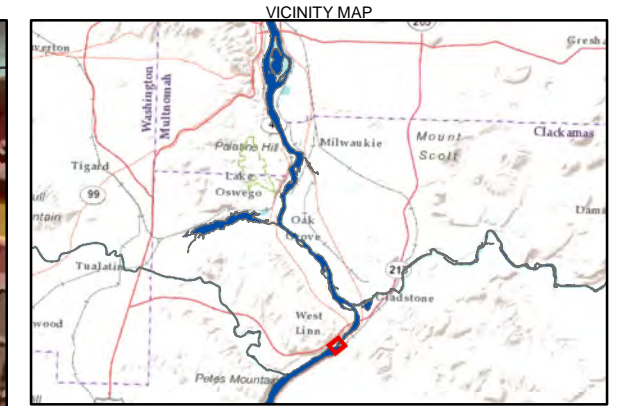
- Major Highways
- Roads
- ▭ Model Domain
- ▭ Clackamas River Watershed
- ▭ Willamette River Watershed
- ▭ Tualatin River Watershed

**Gage Name**

- ▲ Willsonville Gage (14198000)
- ▲ Above Falls Gage (14207700)
- ▲ Below Falls Gage (14207770)
- ▲ Portland Gage (14211720)



**EXHIBIT 1  
OVERVIEW MAP**  
Existing Conditions Hydraulic Model  
Riverwalk Project, Willamette Falls Legacy Site



Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community  
 Sources: Esri, DeLorme, USGS, NPS  
 Sources: Esri, USGS, NOAA

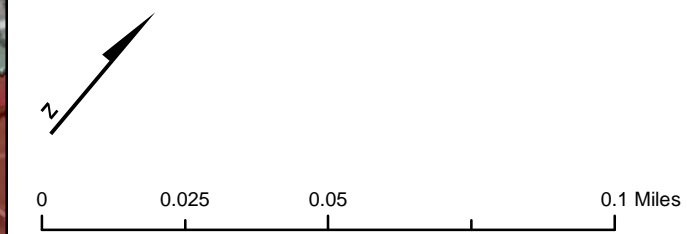
**LEGEND**

**PGE License Drawings**

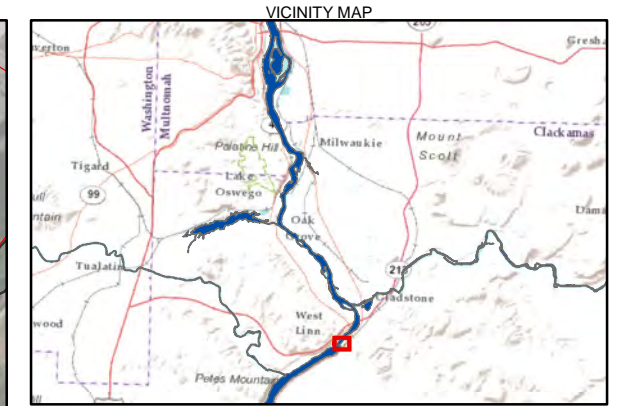
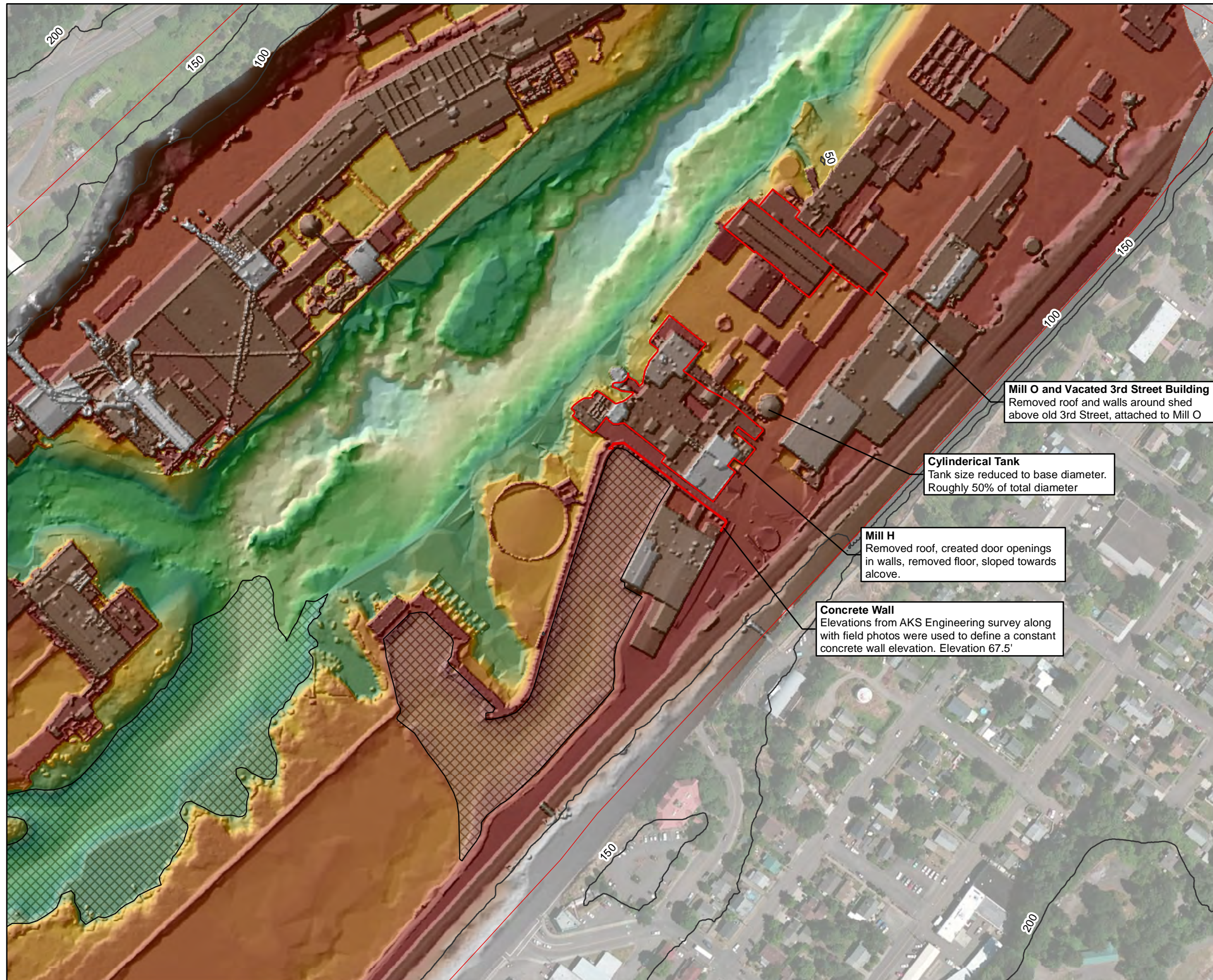
131 - 151	11.0 - 28
113 - 131	-7.0 - 11
98 - 113	-30 - -7
84 - 98	-56 - -30
64 - 84	-81 - -56
45 - 64	-110 - -81
28 - 45	

PGE License Drawings  
 204 - 245  
 172 - 203  
 151 - 172

Notes:  
 1. Area of interest subject to change.  
 2. PGE license drawings provided by PGE, March 2016.  
 Units shown are in NAVD '88 US Survey Foot.  
 PGE Datum = NAVD '88 - 4.14 ft



**EXHIBIT 2**  
**Names and Locations for Important Features at Willamette Falls**  
 Existing Conditions Hydraulic Model  
 Riverwalk Project, Willamette Falls Legacy Site

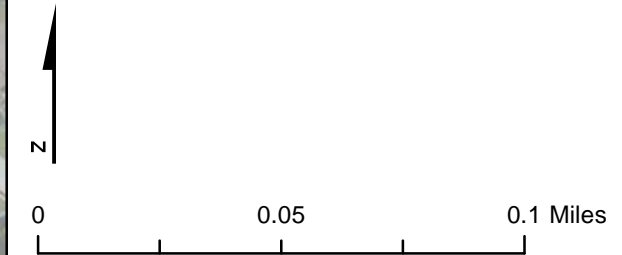


Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community  
 Sources: Esri, DeLorme, USGS, NPS  
 Sources: Esri, USGS, NOAA

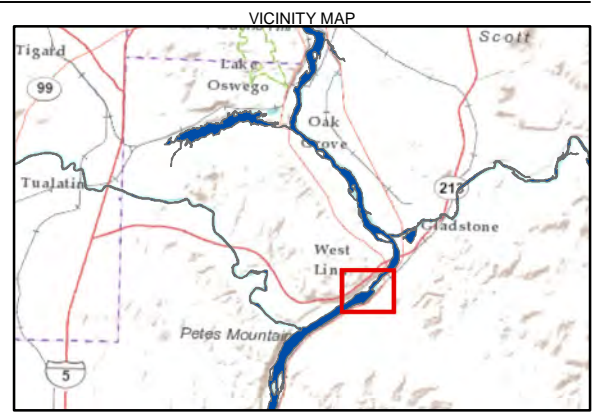
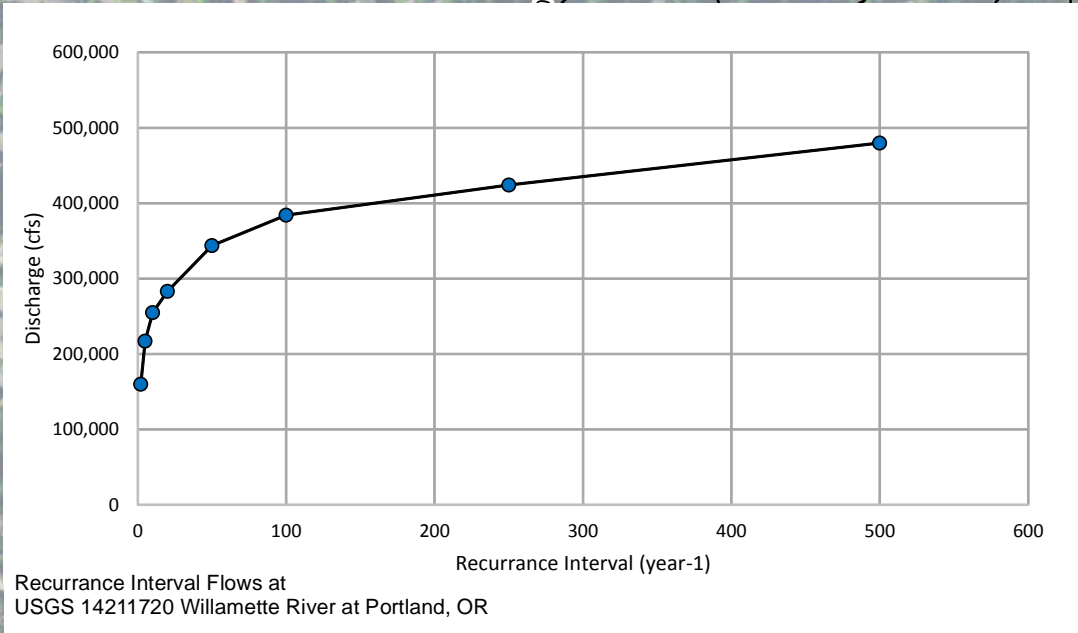
**LEGEND**

	Areas of No Bathymetry Data - Interpolated by AKS		64 - 84
	204 - 245		45 - 64
	172 - 203		28 - 45
	151 - 172		11.0 - 28
	131 - 151		-7.0 - 11
	113 - 131		-30 - -7
	98 - 113		-56 - -30
	84 - 98		-81 - -56
			-110 - -81

Notes:  
 1. Area of interest subject to change.  
 2. Bathymetry Survey performed by David Evans and Associates (DEA, Inc), December 2000



**EXHIBIT 3**  
 Digital Terrain Model (DTM) Surface  
 Existing Conditions Hydraulic Model  
 Riverwalk Project, Willamette Falls Legacy Site

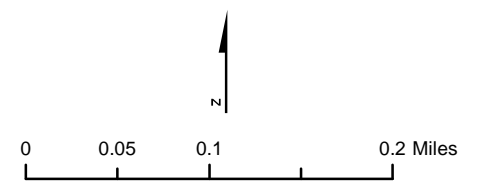


Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community  
 Sources: Esri, DeLorme, USGS, NPS  
 Sources: Esri, USGS, NOAA

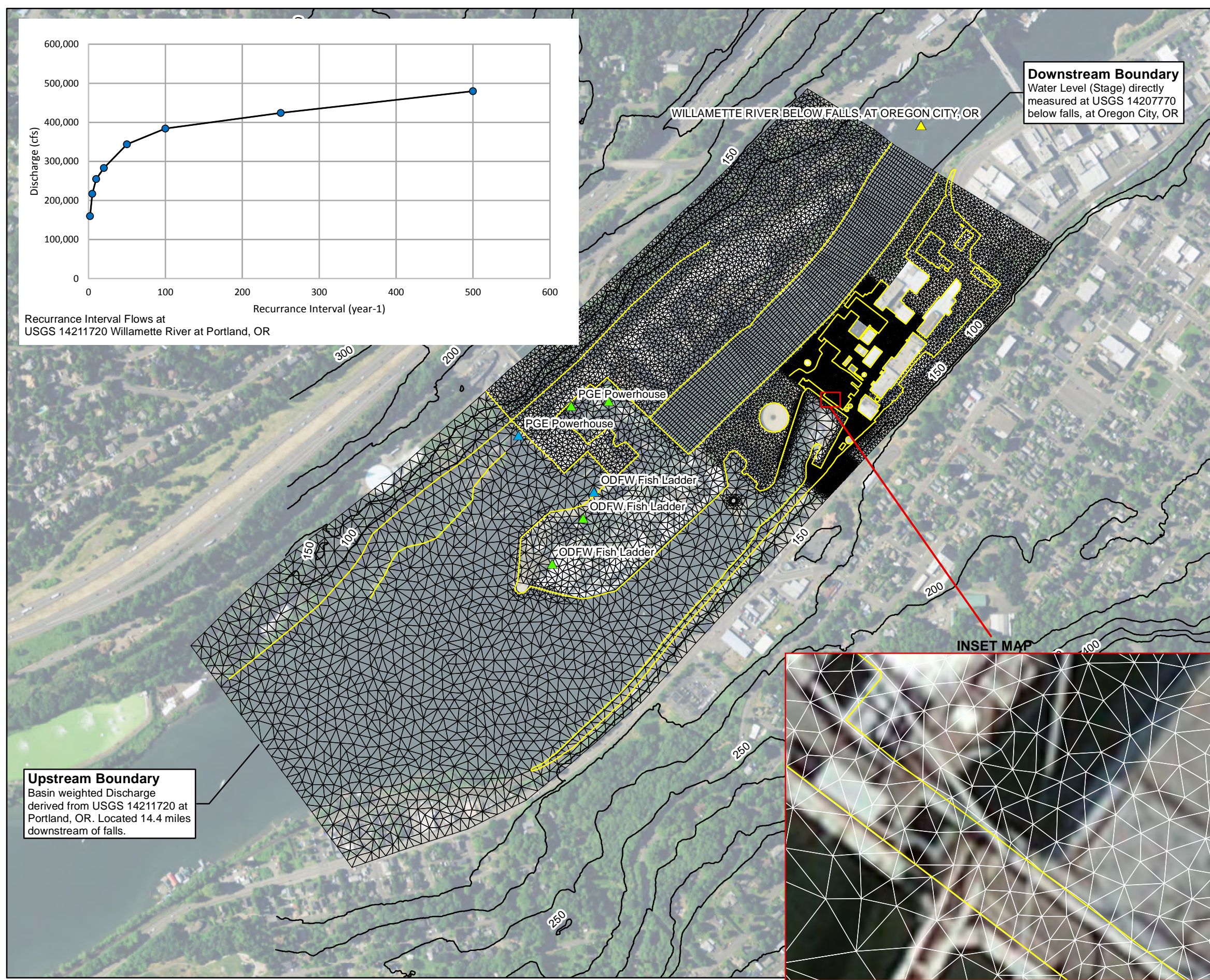
**LEGEND**

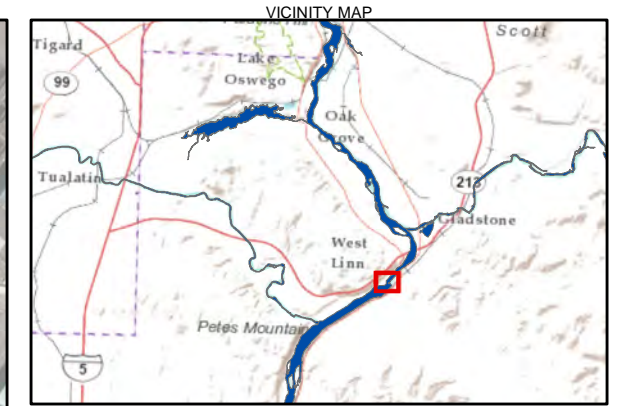
- Source/Sink Terms**
- ▲ Sink
  - ▲ Source
  - ▲ USGS Streamgages
  - Breaklines in Mesh
  - Computational Mesh
  - 50' Contours

Notes:  
 1. Area of interest subject to change.  
 2.



**EXHIBIT 4**  
 Computational Mesh  
 and Boundary Conditions  
 Existing Conditions Hydraulic Model  
 Riverwalk Project, Willamette Falls Legacy Site



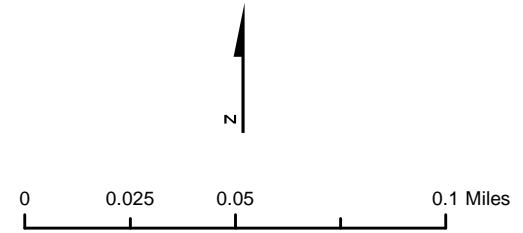


Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community  
 Sources: Esri, DeLorme, USGS, NPS  
 Sources: Esri, USGS, NOAA

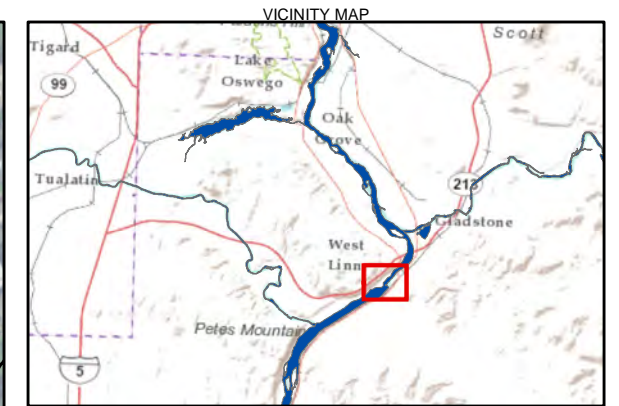
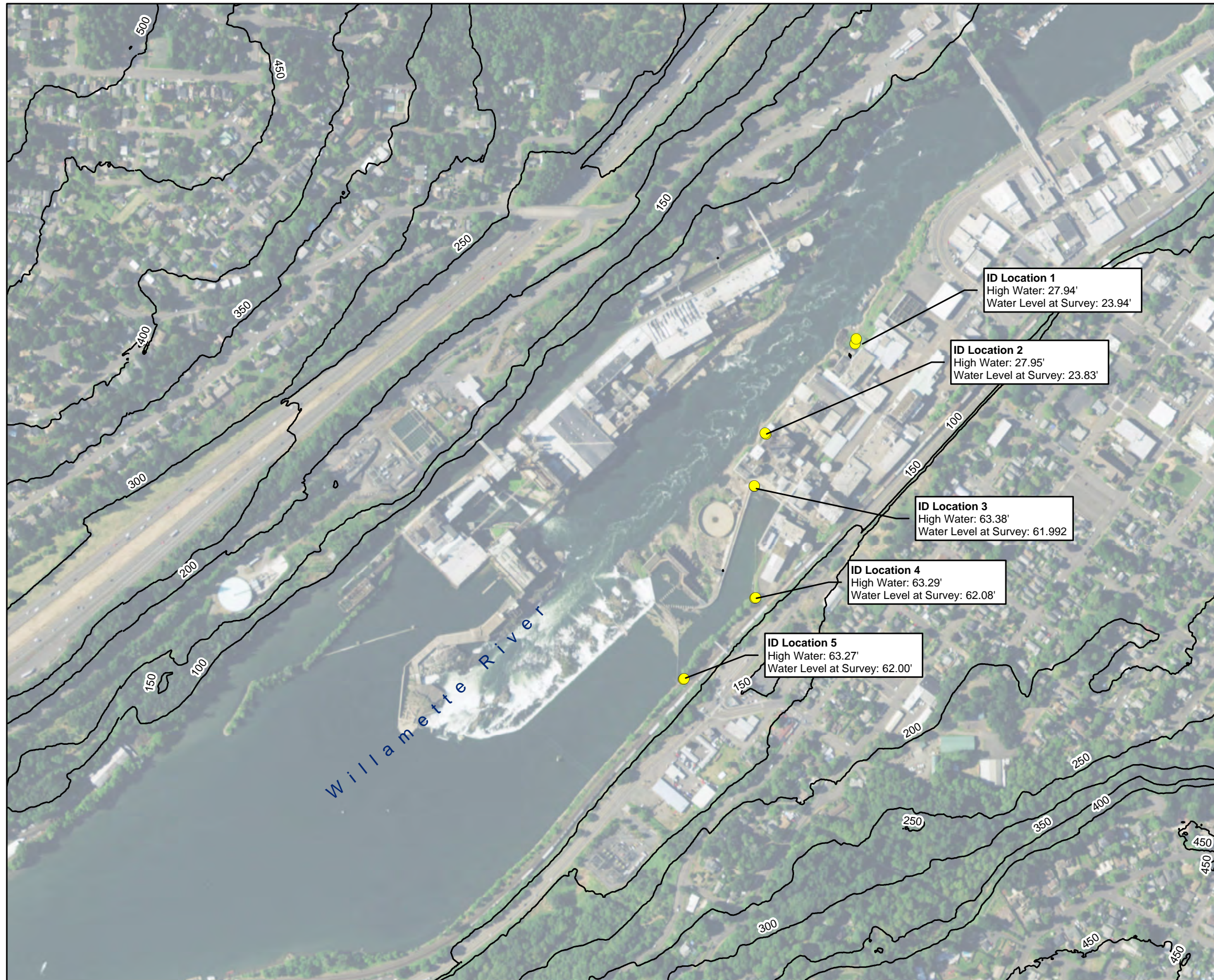
**LEGEND**

- 5' Water Surface Contours
- 1' Water Surface Contours
- Extent of Inundation
- ▲ PGE Gages

- Notes:
1. All elevations are in North American Vertical Datum of 1988 (NAVD '88).
  2. Model calibration was done on the February 2017 event due to more observed data being available. This event is used as a validation.
  2. 5' contour Interval > 35 feet. 1' contour interval < 35 feet.



**EXHIBIT 5**  
 Results from 12/20/2015  
 Approximate 2-year Flood  
 Existing Conditions Hydraulic Model  
 Riverwalk Project, Willamette Falls Legacy Site

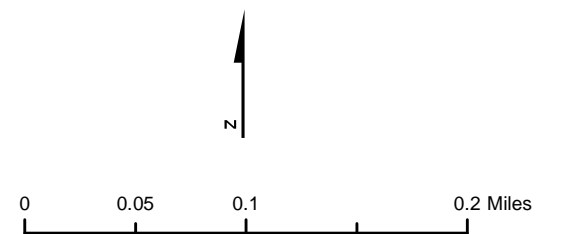


Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community  
 Sources: Esri, DeLorme, USGS, NPS  
 Sources: Esri, USGS, NOAA

**LEGEND**

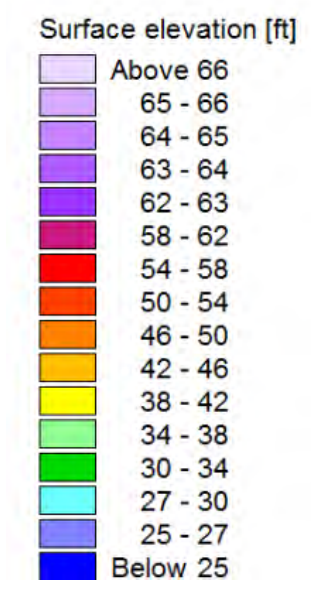
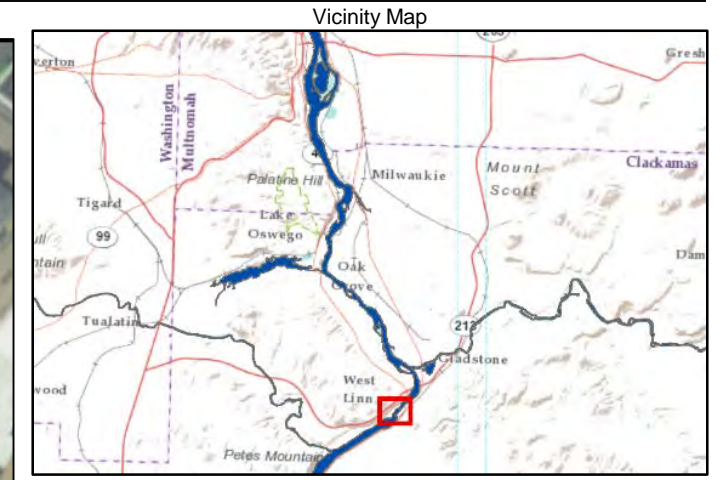
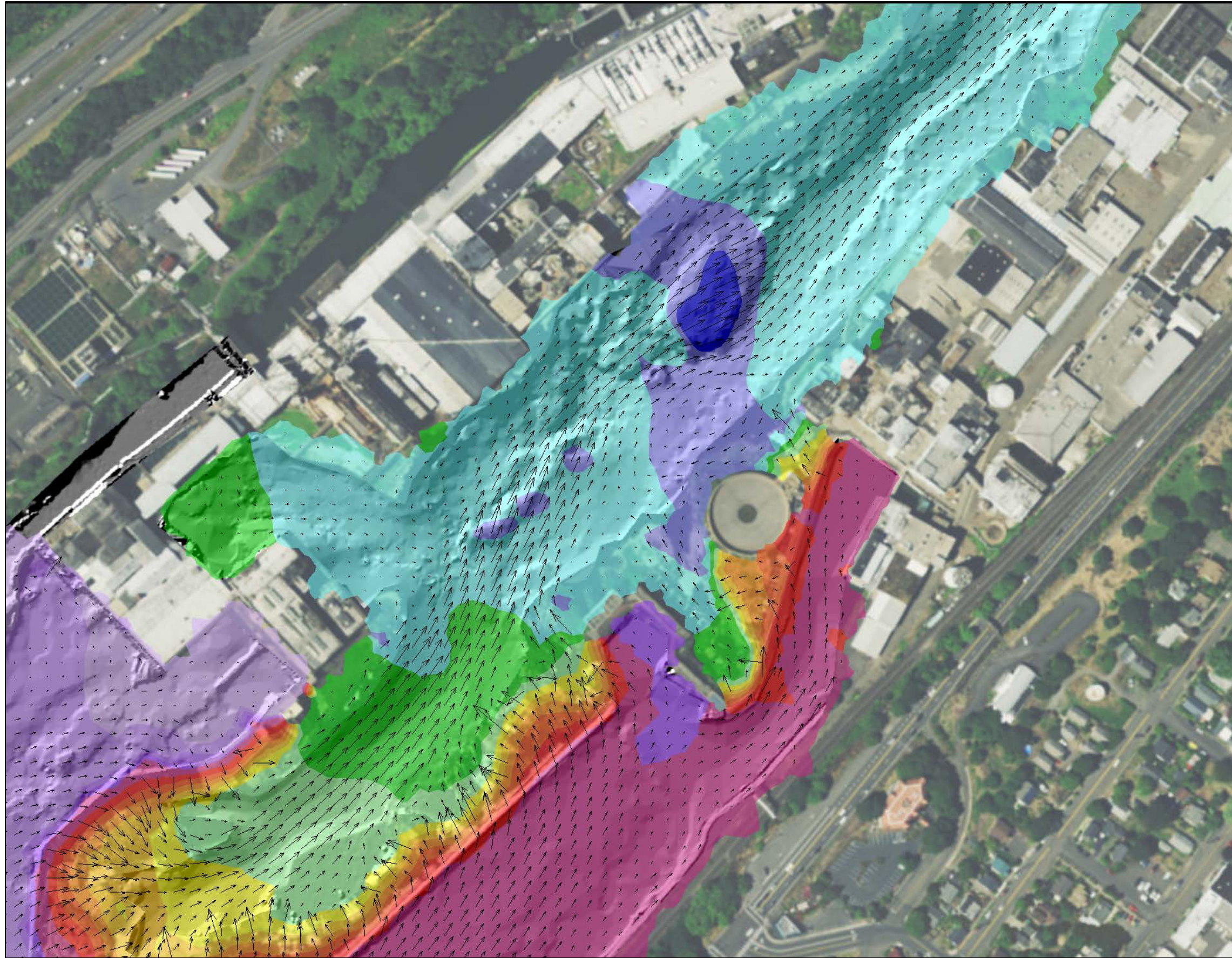
- CH2M-Data
- 50' Contours

- Notes:
1. ID Location 2 - Horizontal GPS signal not available, location was estimated and confirmed by surveyor.
  2. Survey performed on March 14, 2017.

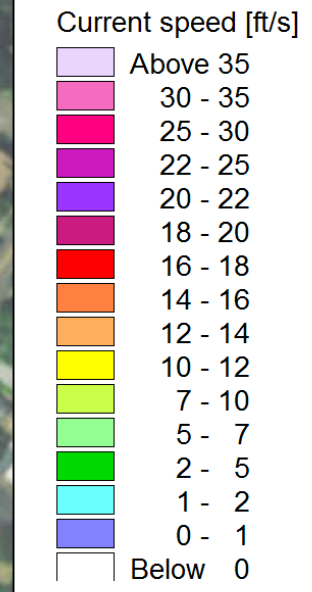
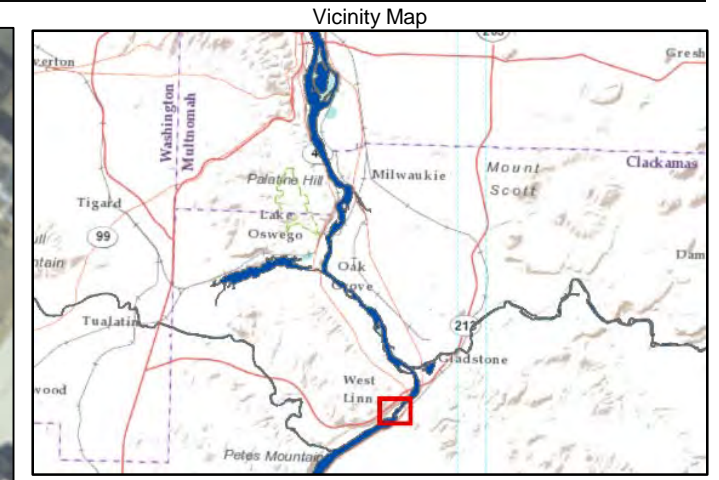
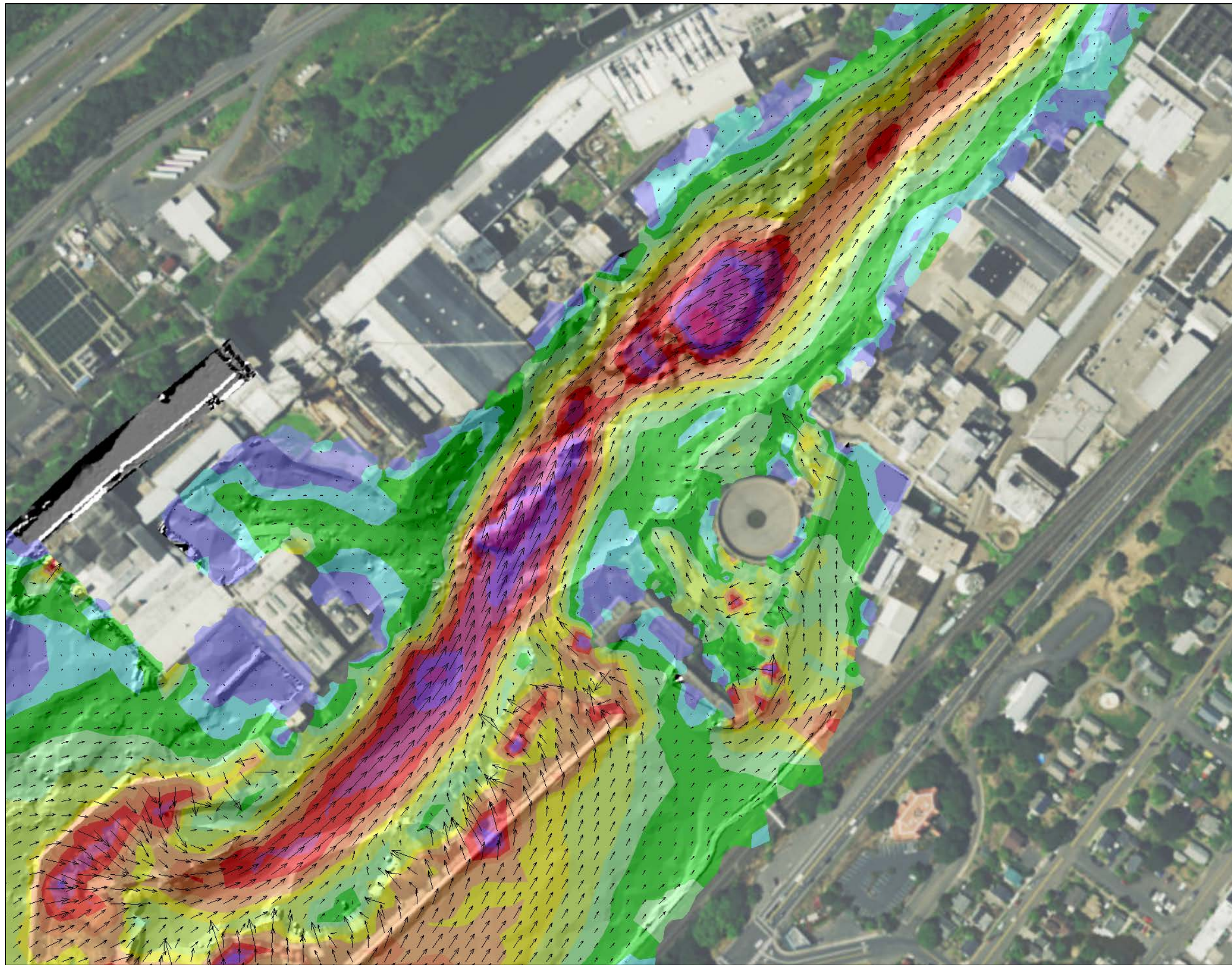


**EXHIBIT 6**  
 February 10, 2017 High Water Marks  
 Location and Elevation  
 Existing Conditions Hydraulic Model  
 Riverwalk Project, Willamette Falls Legacy Site

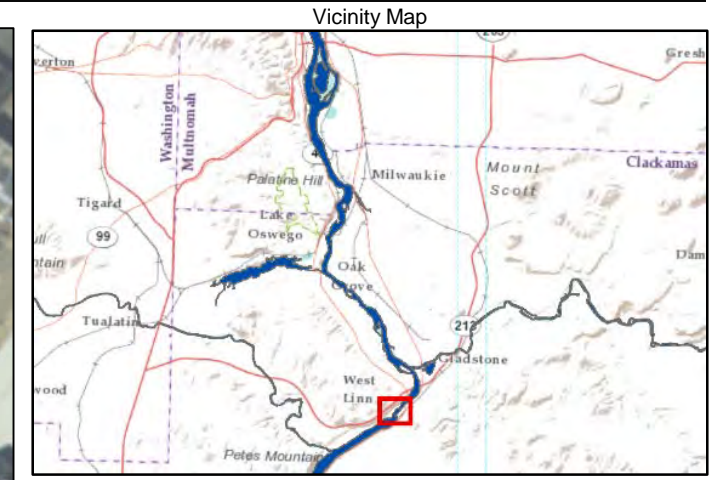
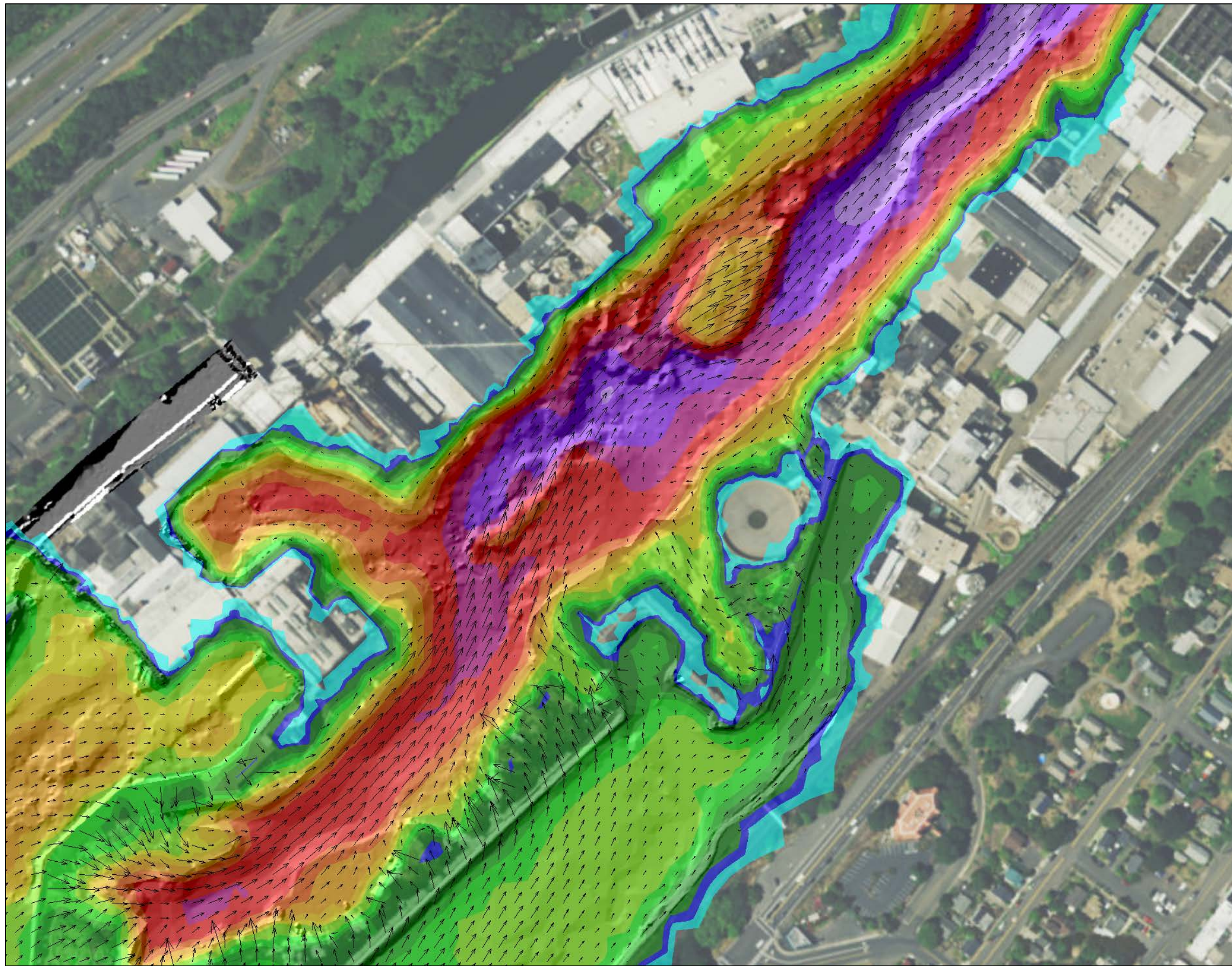




**EXHIBIT 7A**  
 Water Surface Elevation, December 20, 2015  
 Existing Conditions Hydraulic Results  
 Riverwalk Park, Willamette Falls Legacy Site



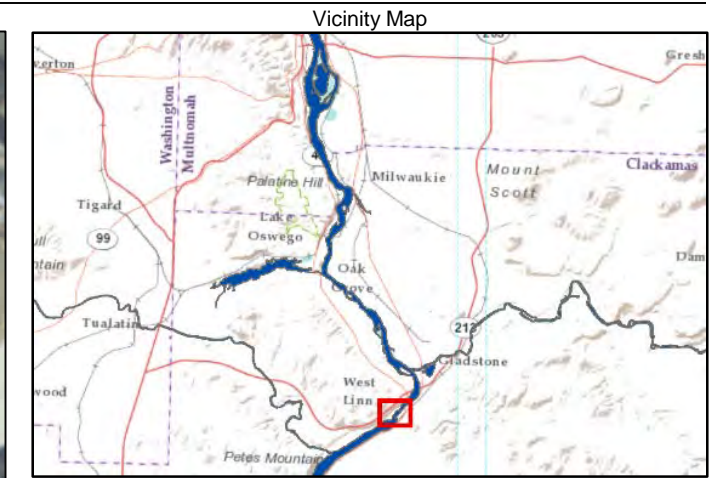
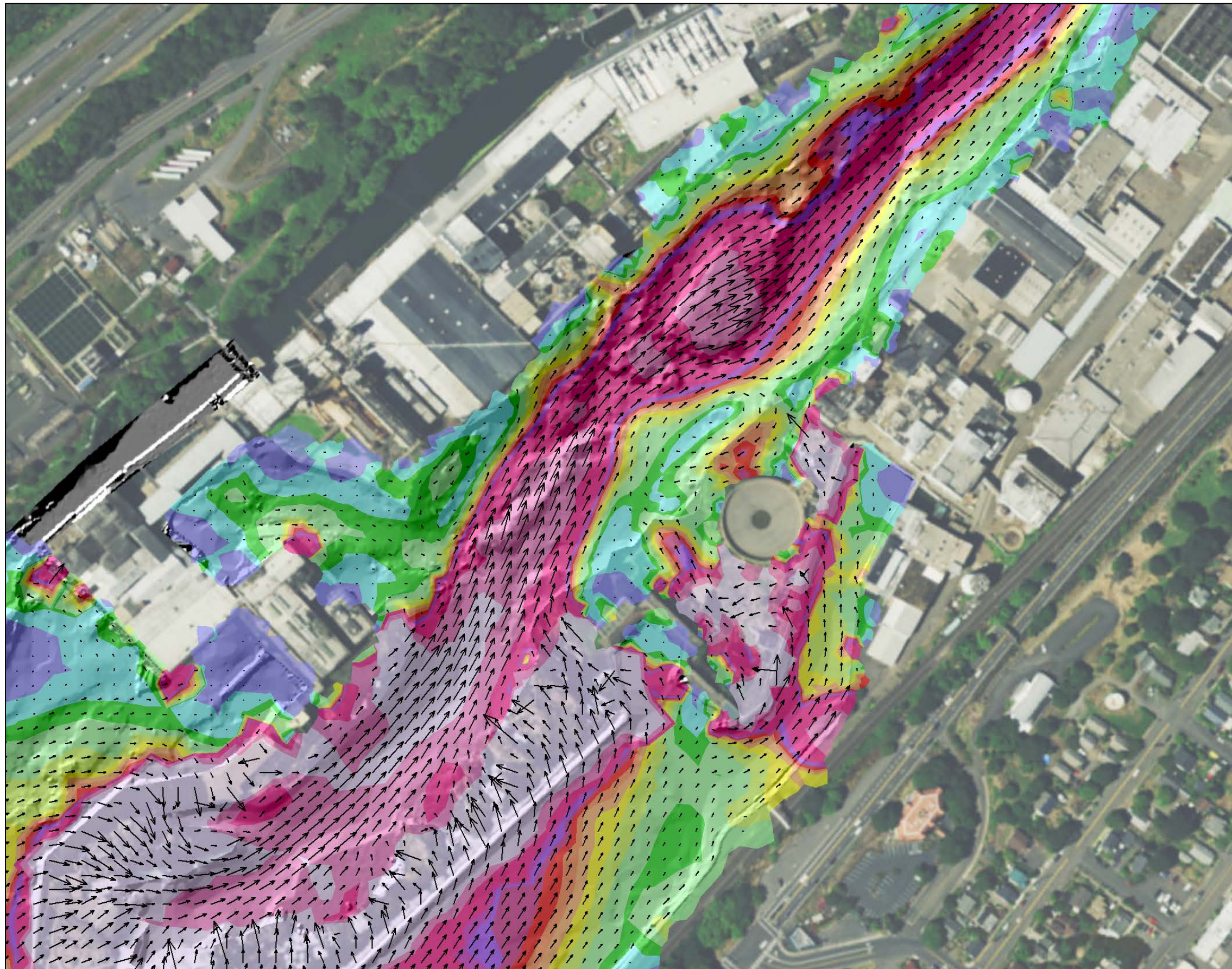
**EXHIBIT 7B**  
 Velocity, December 20, 2015  
 Existing Conditions Hydraulic Results  
 Riverwalk Park, Willamette Falls Legacy Site



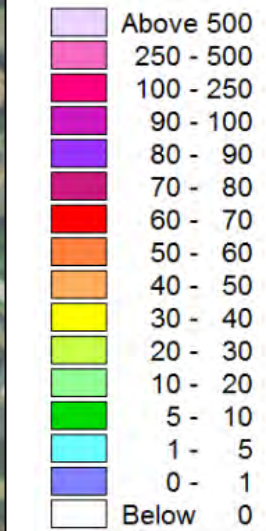
Total water depth [ft]

Light Purple	Above 100
Pink	75 - 100
Magenta	50 - 75
Dark Purple	40 - 50
Red-Orange	30 - 40
Red	25 - 30
Dark Red	20 - 25
Orange	17 - 20
Light Orange	15 - 17
Yellow	10 - 15
Light Green	7 - 10
Green	5 - 7
Light Green	2 - 5
Cyan	1 - 2
Blue	0 - 1
White	Below 0

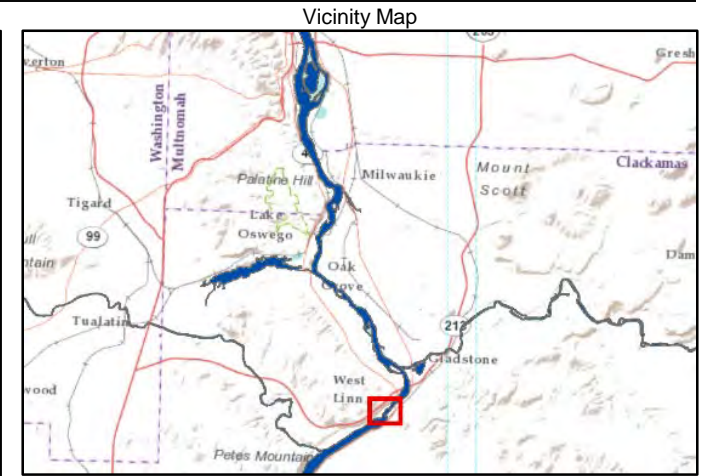
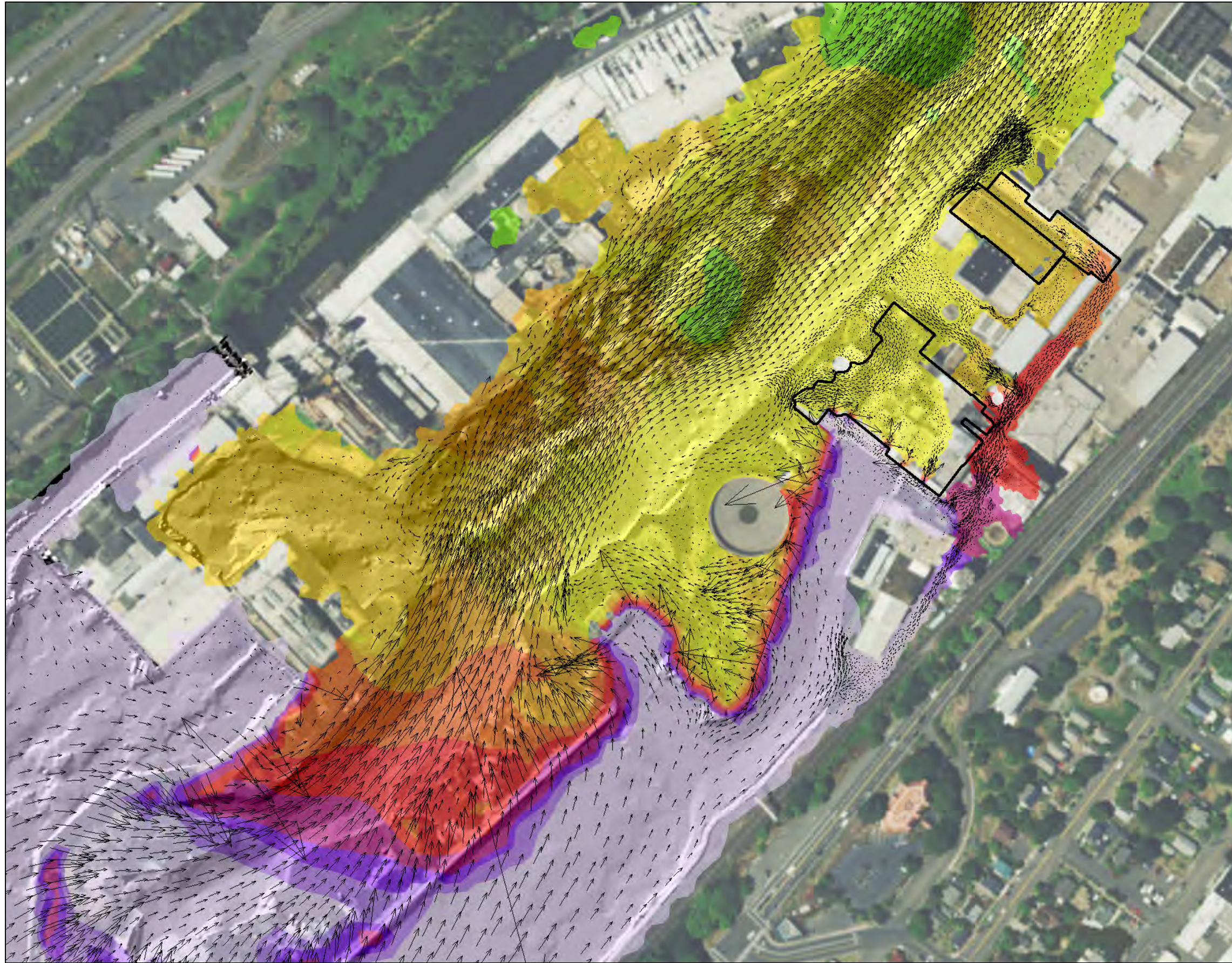
**EXHIBIT 7C**  
 Total Water Depth, December 20, 2015  
 Existing Conditions Hydraulic Results  
 Riverwalk Park, Willamette Falls Legacy Site



Shear Stress (Pa)



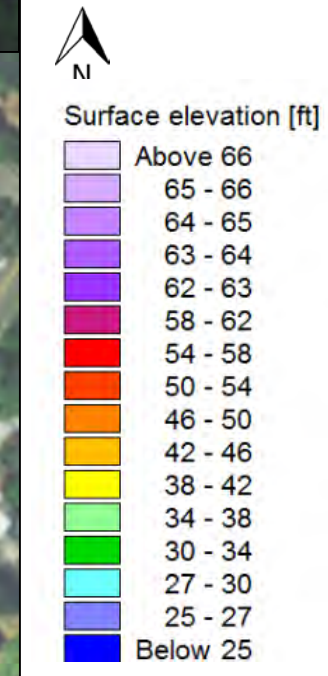
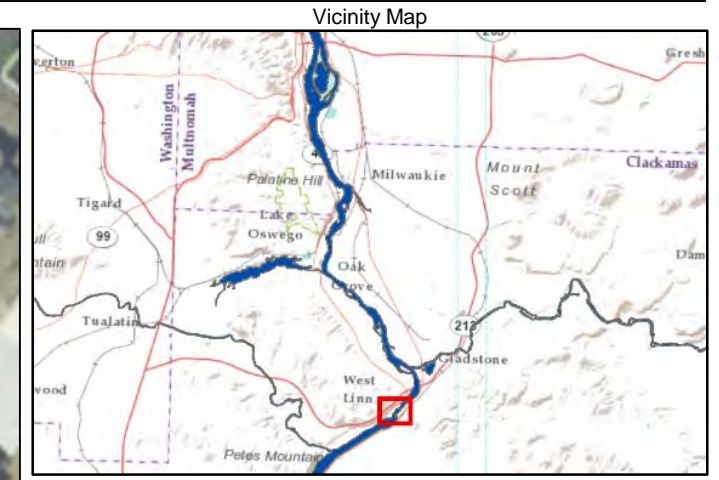
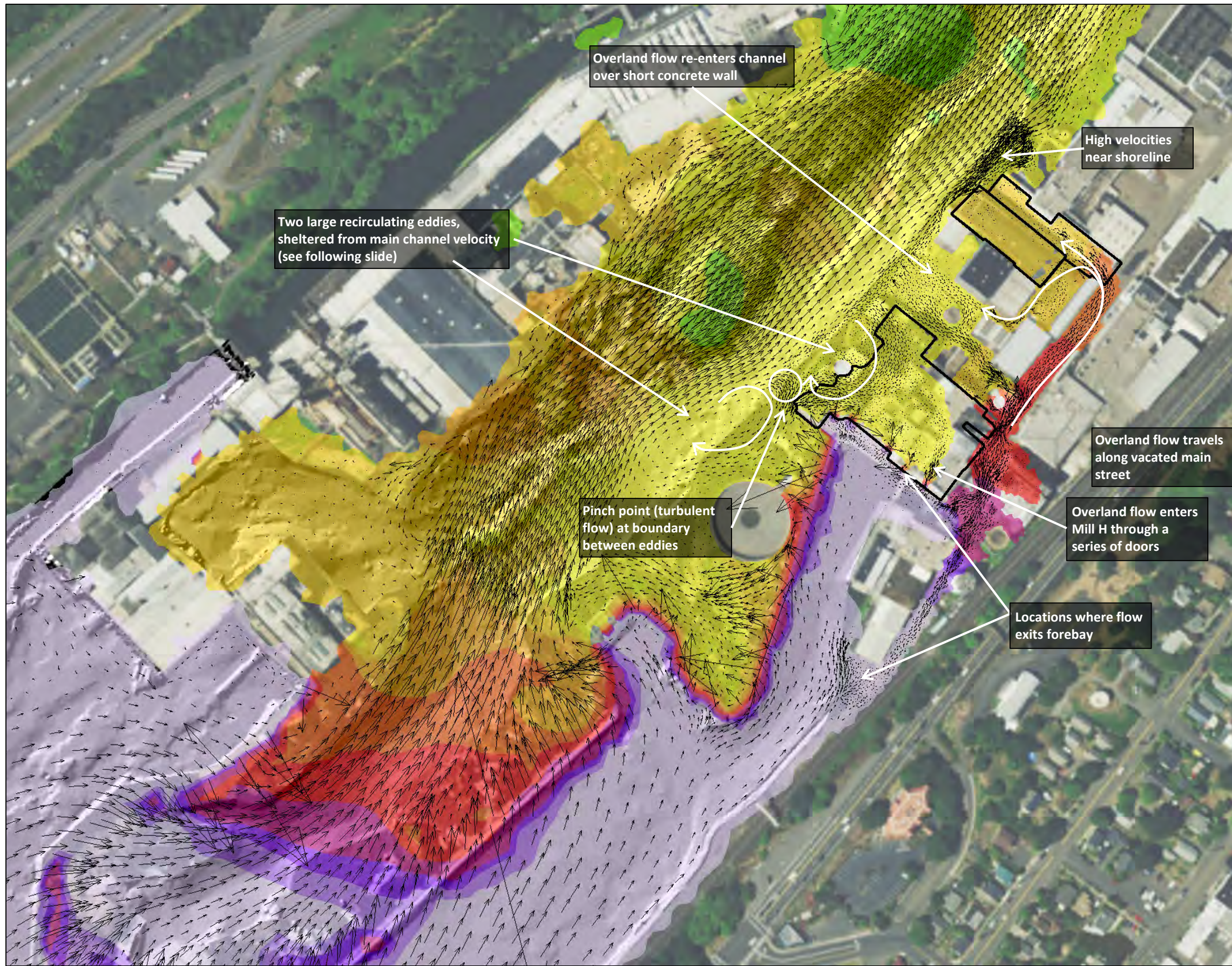
**EXHIBIT 7D**  
 Shear Stress, December 20, 2015  
 Existing Conditions Hydraulic Results  
 Riverwalk Park, Willamette Falls Legacy Site



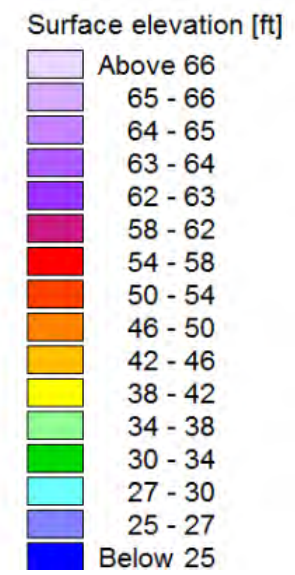
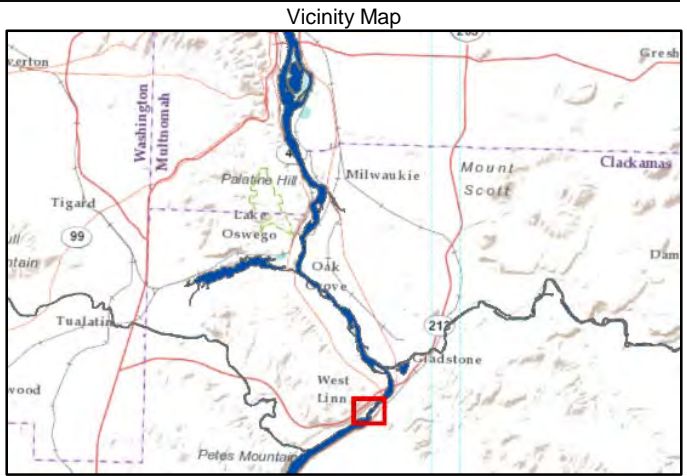
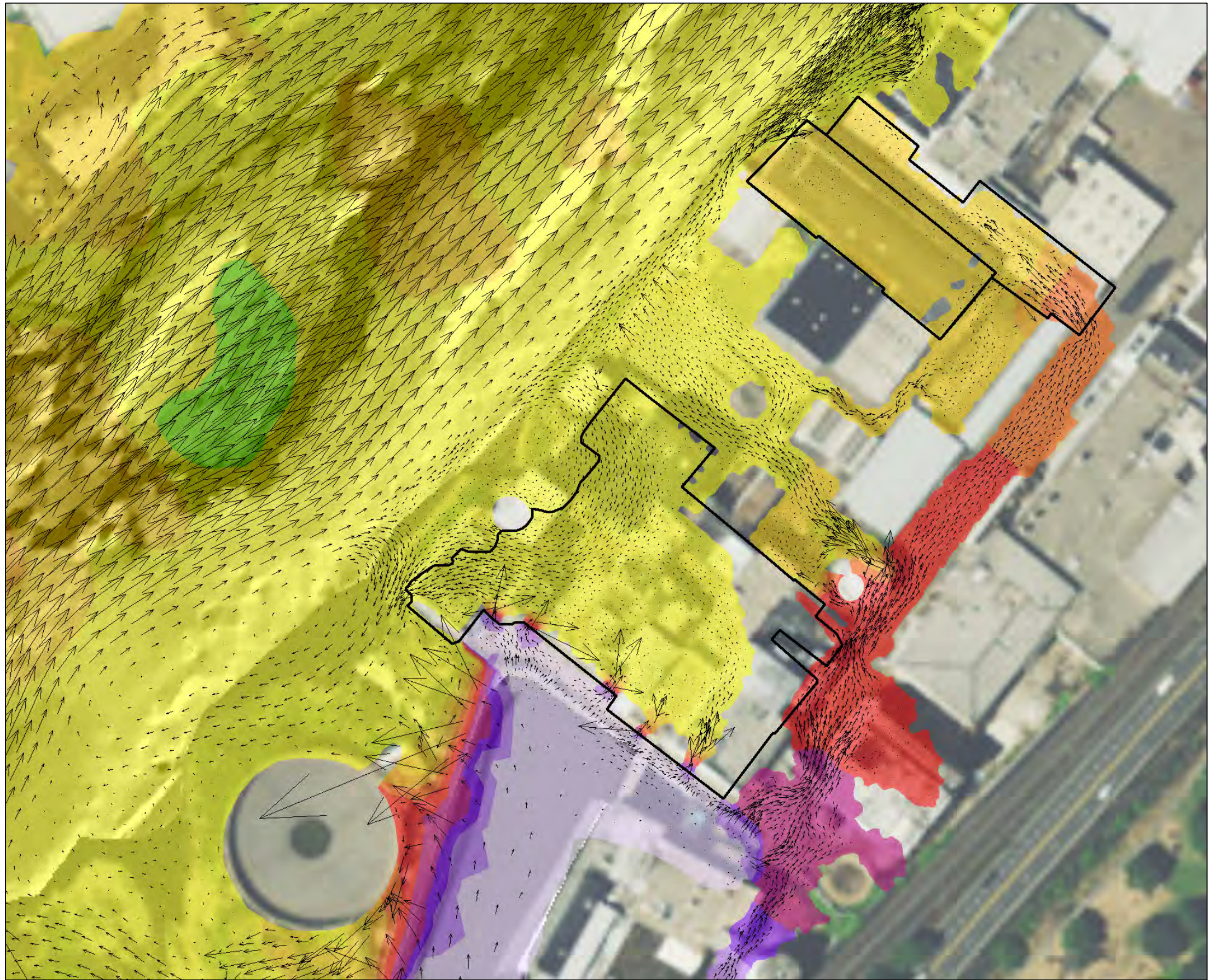
Surface elevation [ft]

Light Purple	Above 66
Purple	65 - 66
Dark Purple	64 - 65
Very Dark Purple	63 - 64
Dark Purple	62 - 63
Red-Orange	58 - 62
Red	54 - 58
Orange	50 - 54
Yellow-Orange	46 - 50
Yellow	42 - 46
Light Green	38 - 42
Green	34 - 38
Light Green	30 - 34
Cyan	27 - 30
Blue	25 - 27
Dark Blue	Below 25

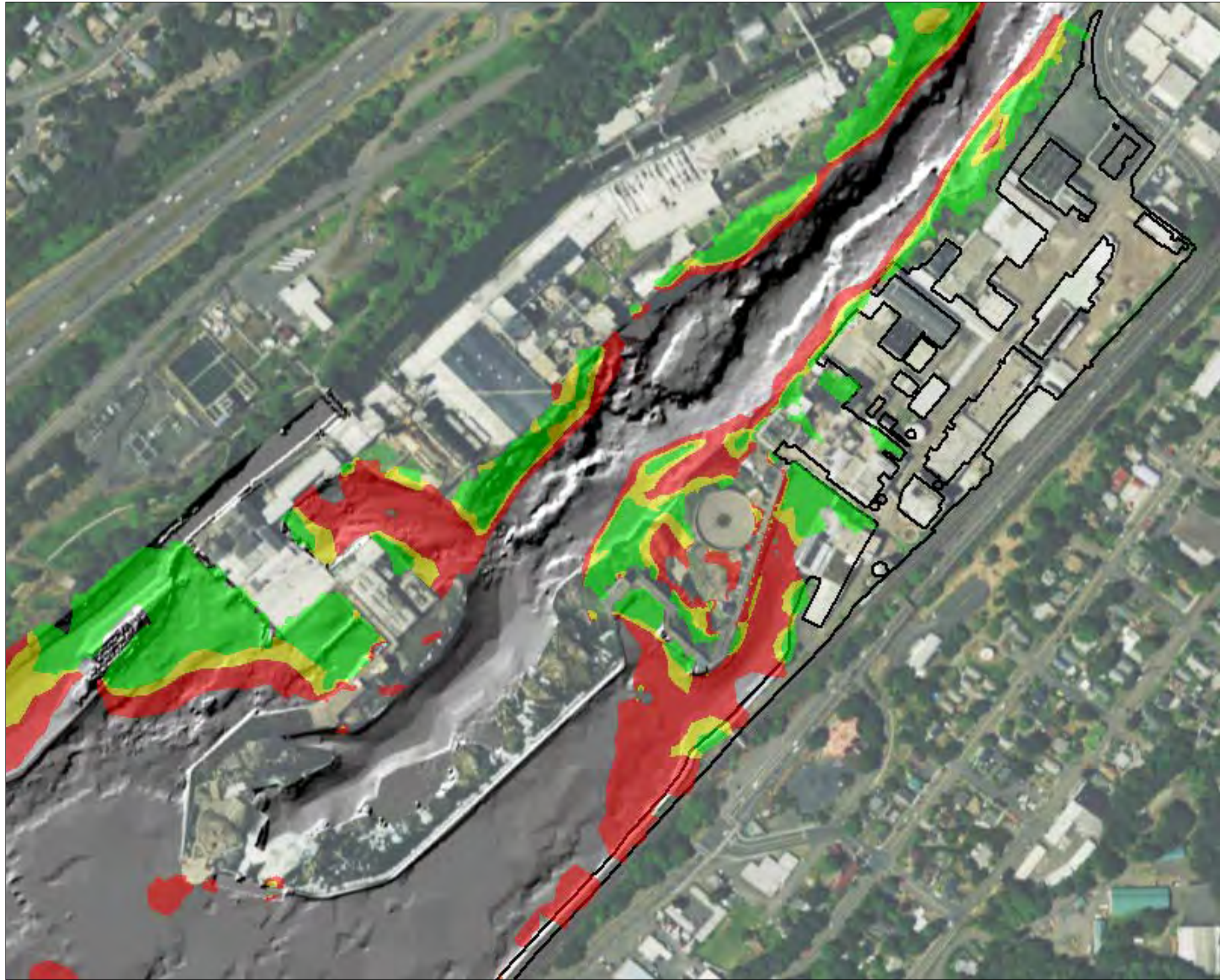
**EXHIBIT 8A**  
 Water Surface Elevation, February 1996  
*Existing Conditions Hydraulic Results*  
 Riverwalk Park, Willamette Falls Legacy Site



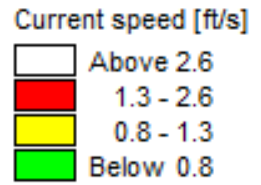
**EXHIBIT 8B**  
 Annotated Water Surface Elevation,  
 February 1996  
*Existing Conditions Hydraulic Results*  
 Riverwalk Park, Willamette Falls Legacy Site



**EXHIBIT 8C**  
 Water Surface Elevation Zoomed into  
 Project Site, February 1996  
*Existing Conditions Hydraulic Results*  
 Riverwalk Park, Willamette Falls Legacy Site

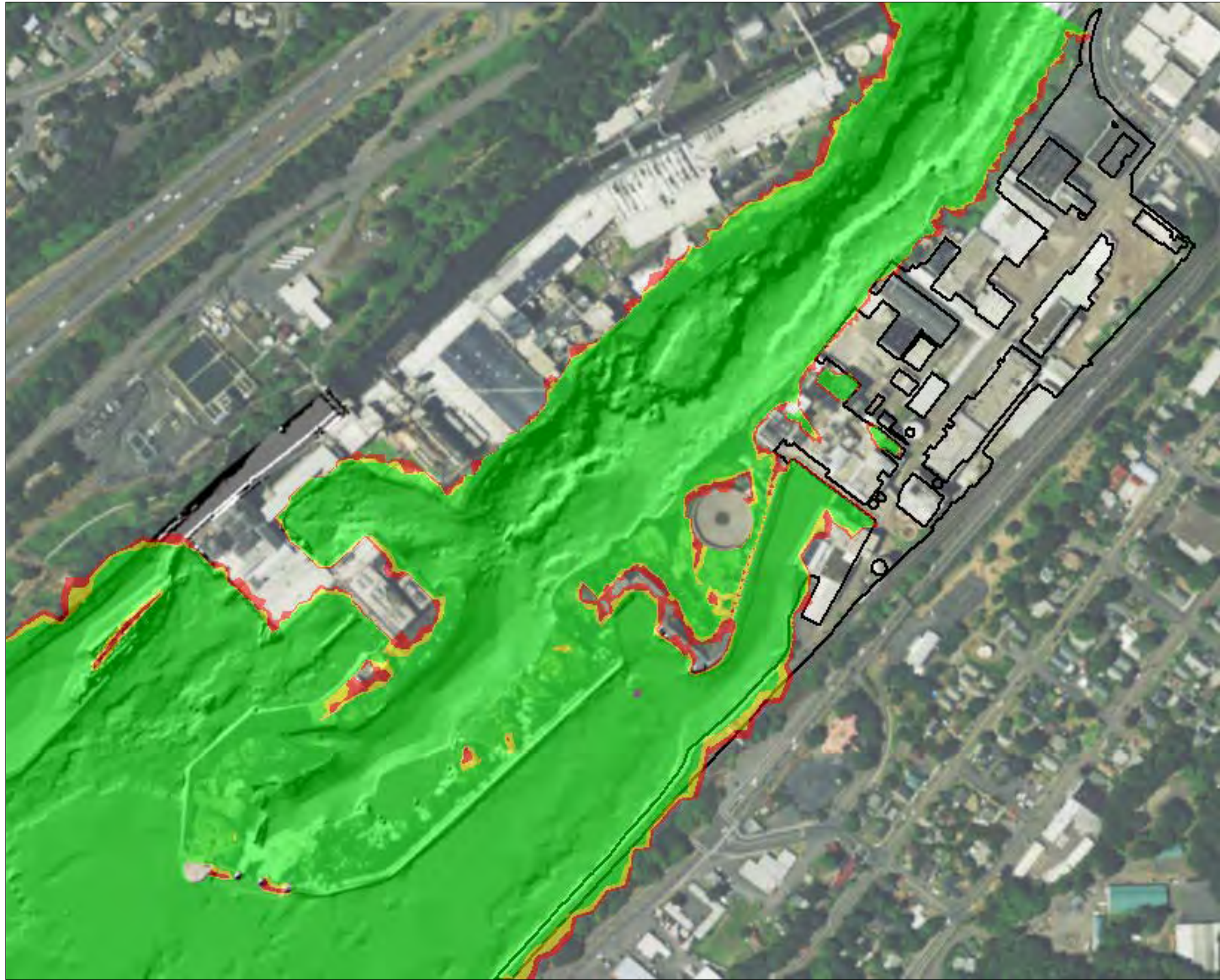


Vicinity Map

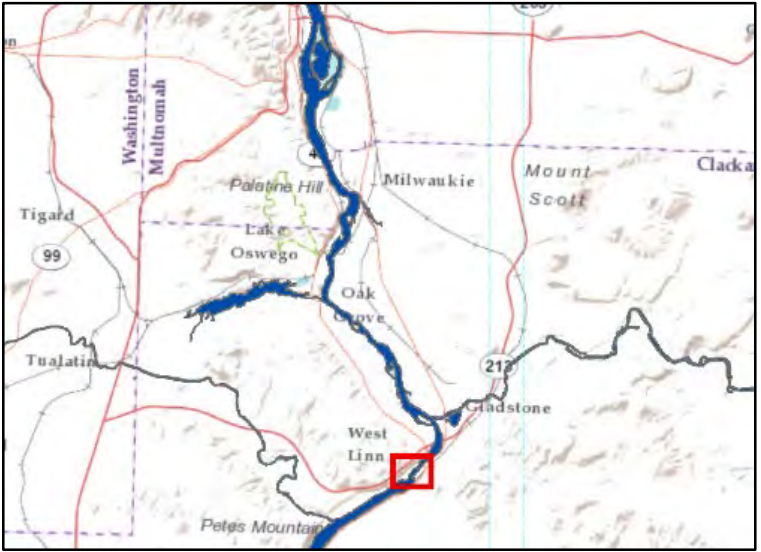


**EXHIBIT 9A**  
 Velocity, Summer 10% Exceedance Flow 53,300 cfs  
 Existing Conditions Hydraulic Results  
 Riverwalk Project, Willamette Falls Legacy Site





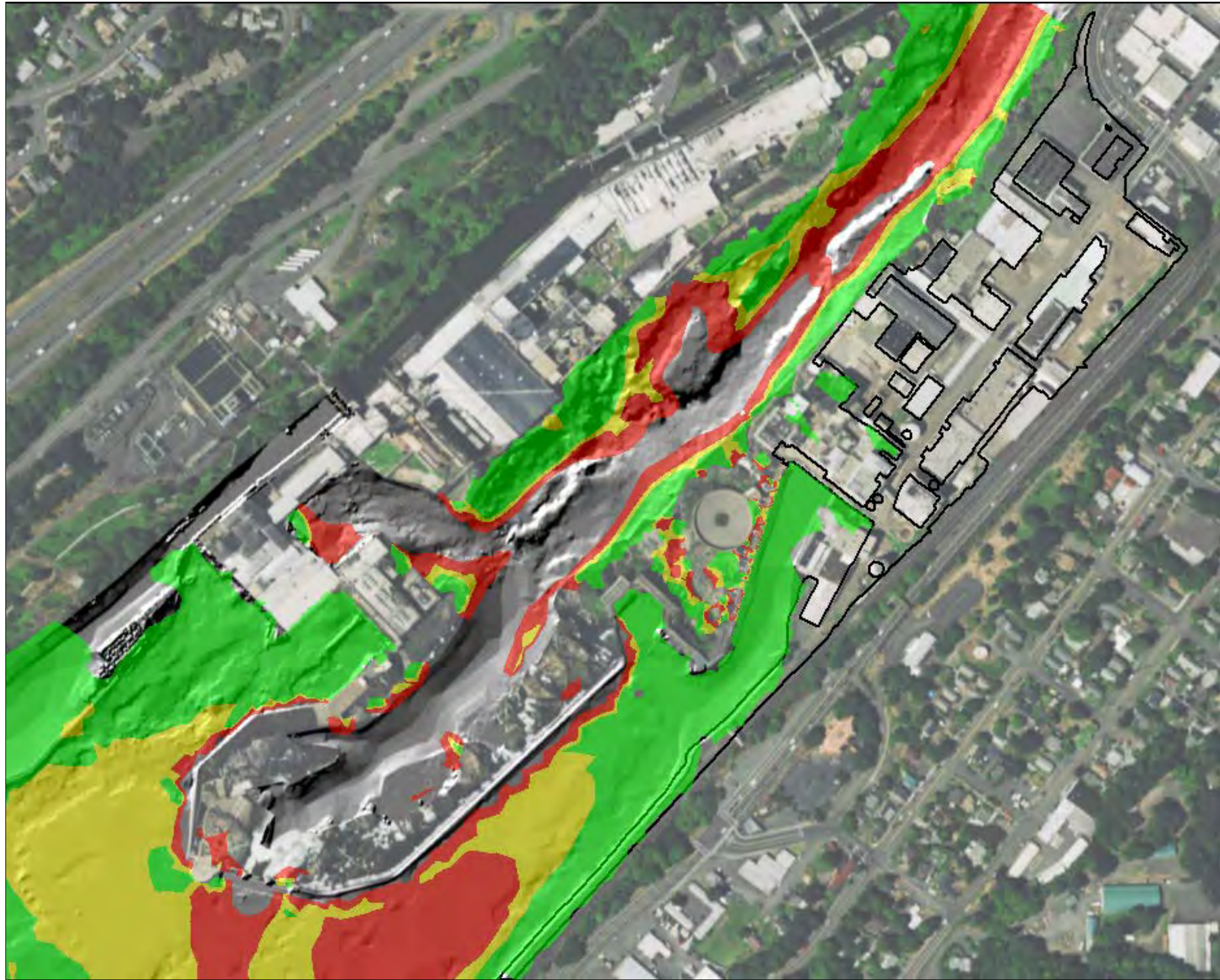
Vicinity Map



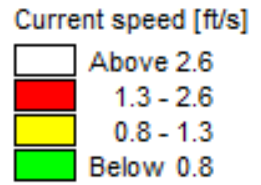
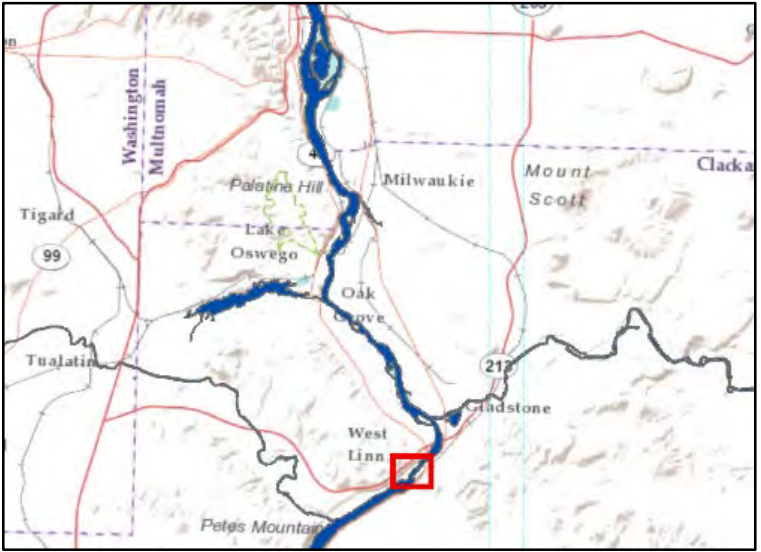
Total water depth [ft]

	Above 1.0
	0.4 - 1.0
	0.0 - 0.4
	Below 0.0

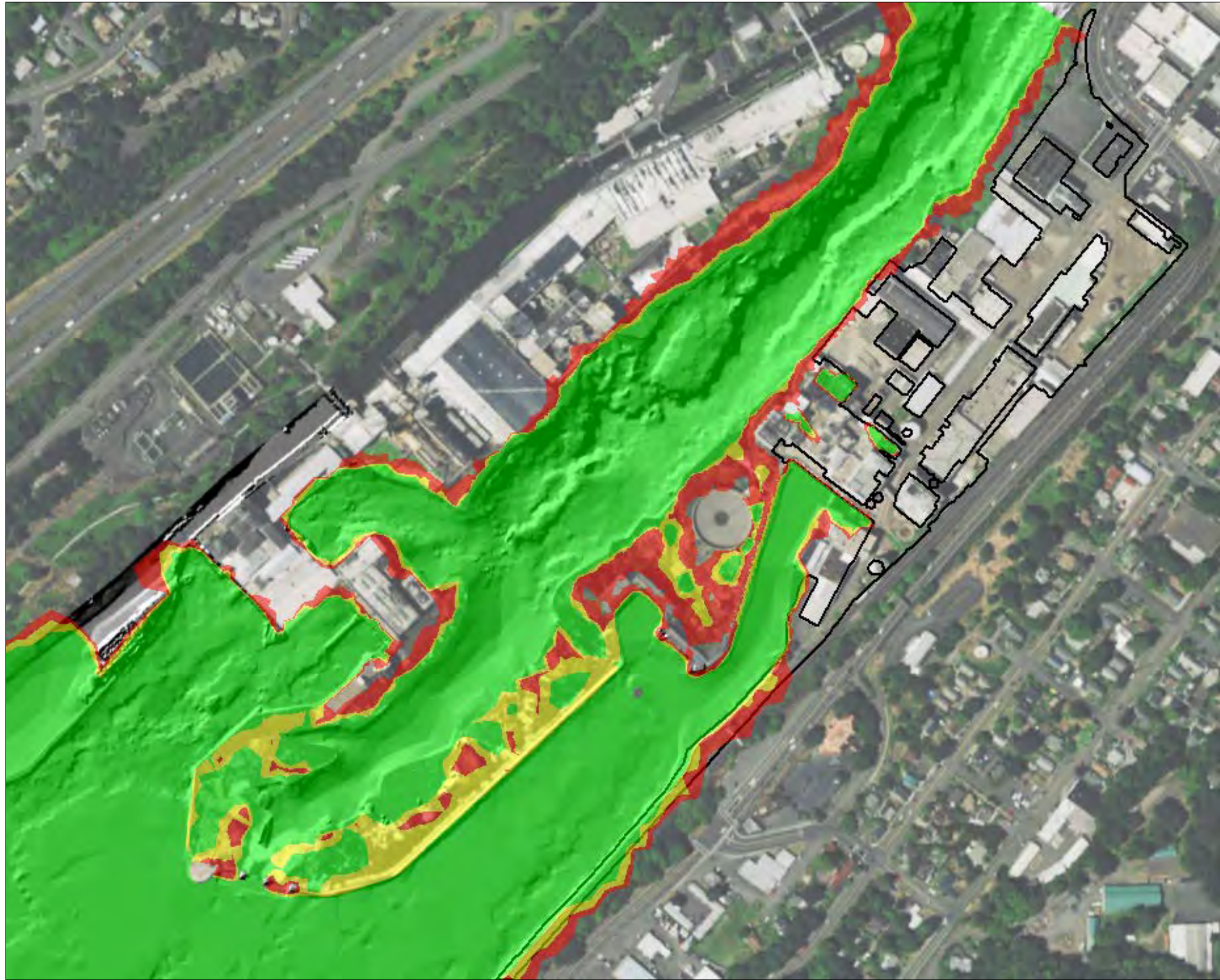
**EXHIBIT 9B**  
 Water Depth , Summer 10% Exceedance Flow 53,300 cfs  
 Existing Conditions Hydraulic Results  
 Riverwalk Project, Willamette Falls Legacy Site



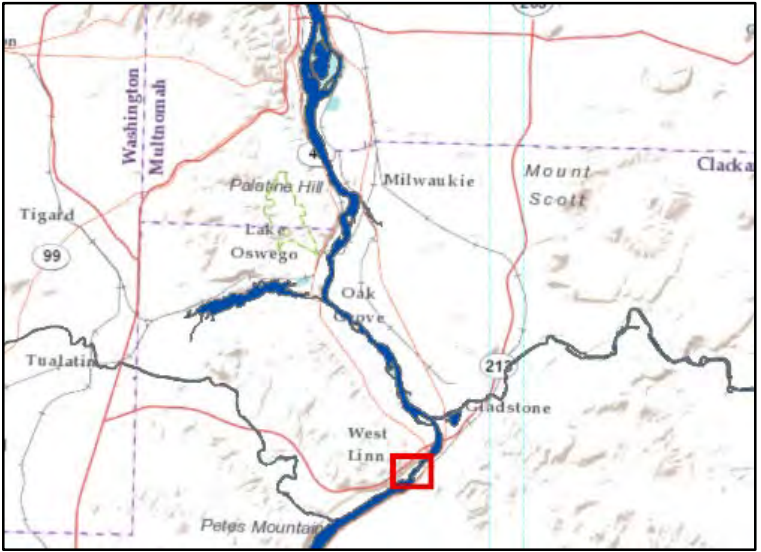
Vicinity Map



**EXHIBIT 10A**  
 Velocity, Summer 90% Exceedance Flow 11,700 cfs  
 Existing Conditions Hydraulic Results  
 Riverwalk Project, Willamette Falls Legacy Site



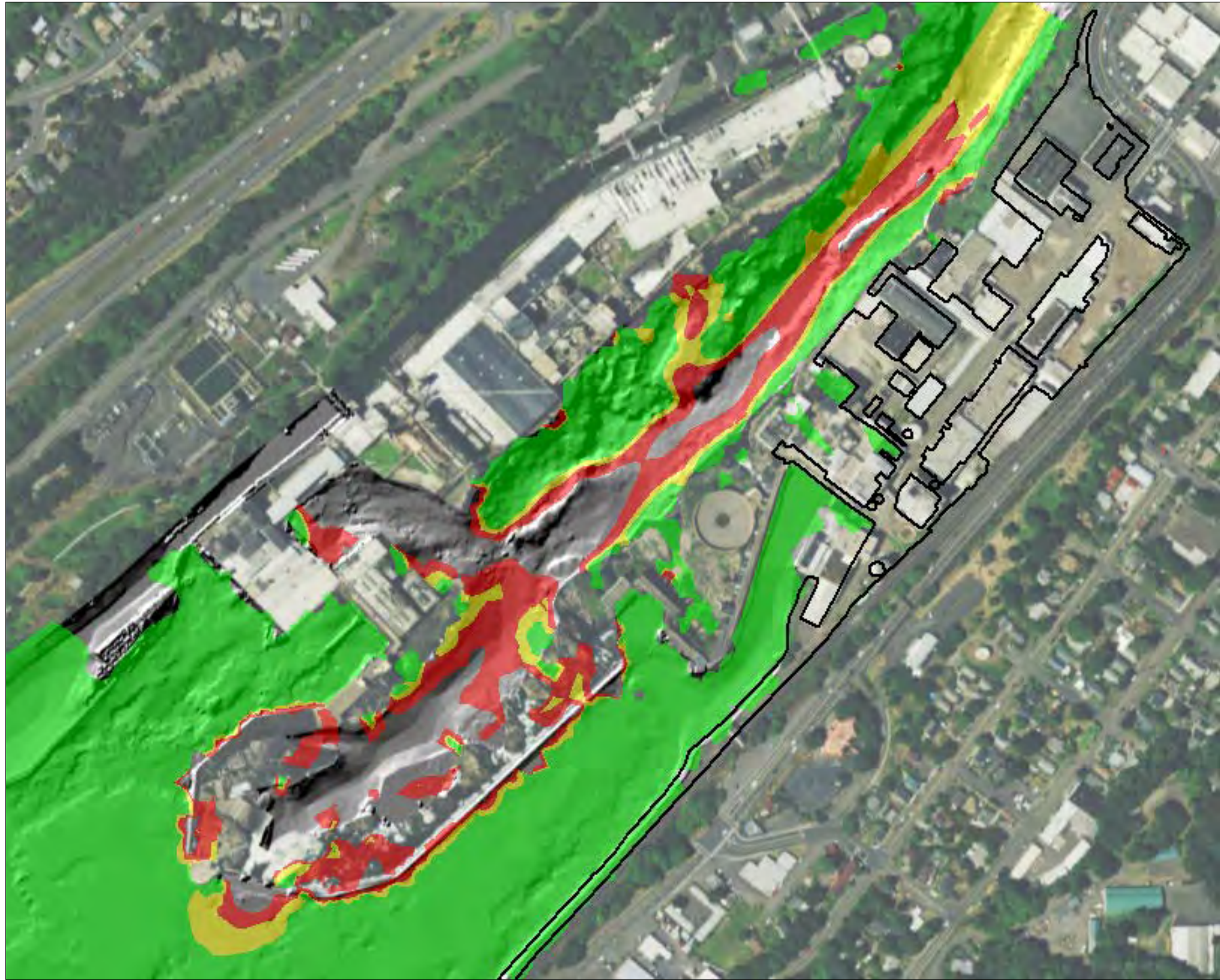
Vicinity Map



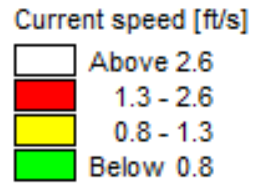
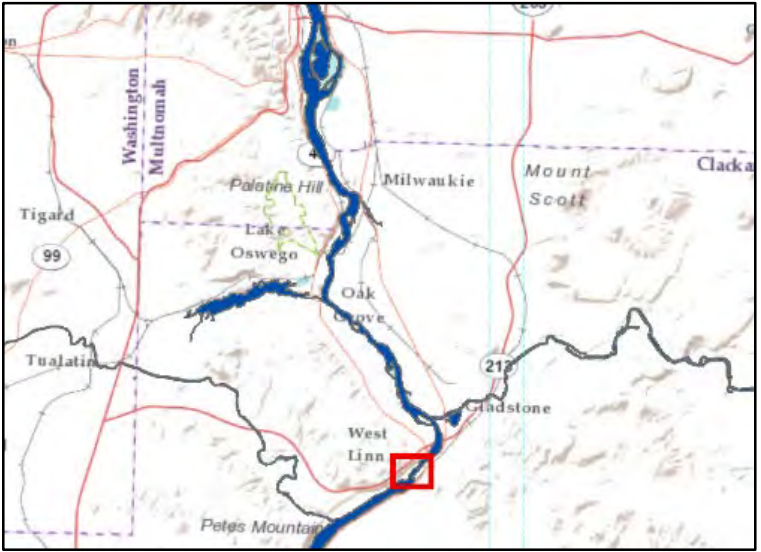
Total water depth [ft]

	Above 1.0
	0.4 - 1.0
	0.0 - 0.4
	Below 0.0

**EXHIBIT 10B**  
 Water Depth, Summer 90% Exceedance Flow 11,700 cfs  
 Existing Conditions Hydraulic Results  
 Riverwalk Project, Willamette Falls Legacy Site



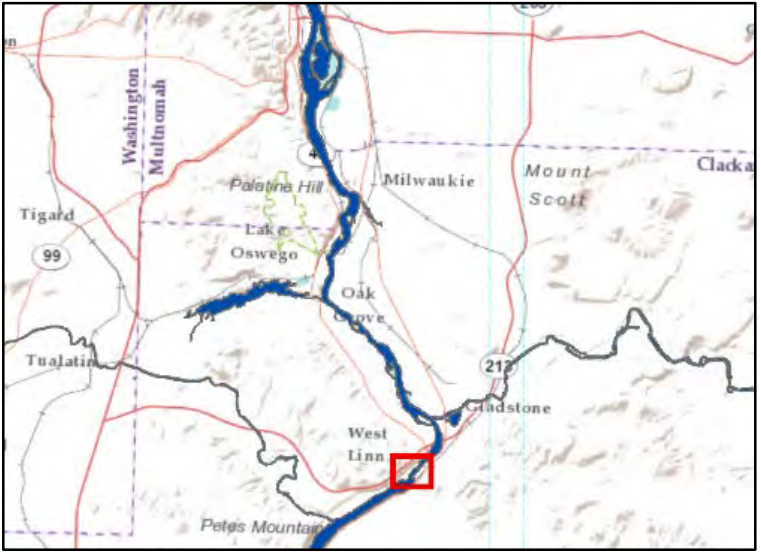
Vicinity Map



**EXHIBIT 11A**  
 Velocity, Summer 2015 Record Low Flow 3,400 cfs  
 Existing Conditions Hydraulic Results  
 Riverwalk Project, Willamette Falls Legacy Site



Vicinity Map



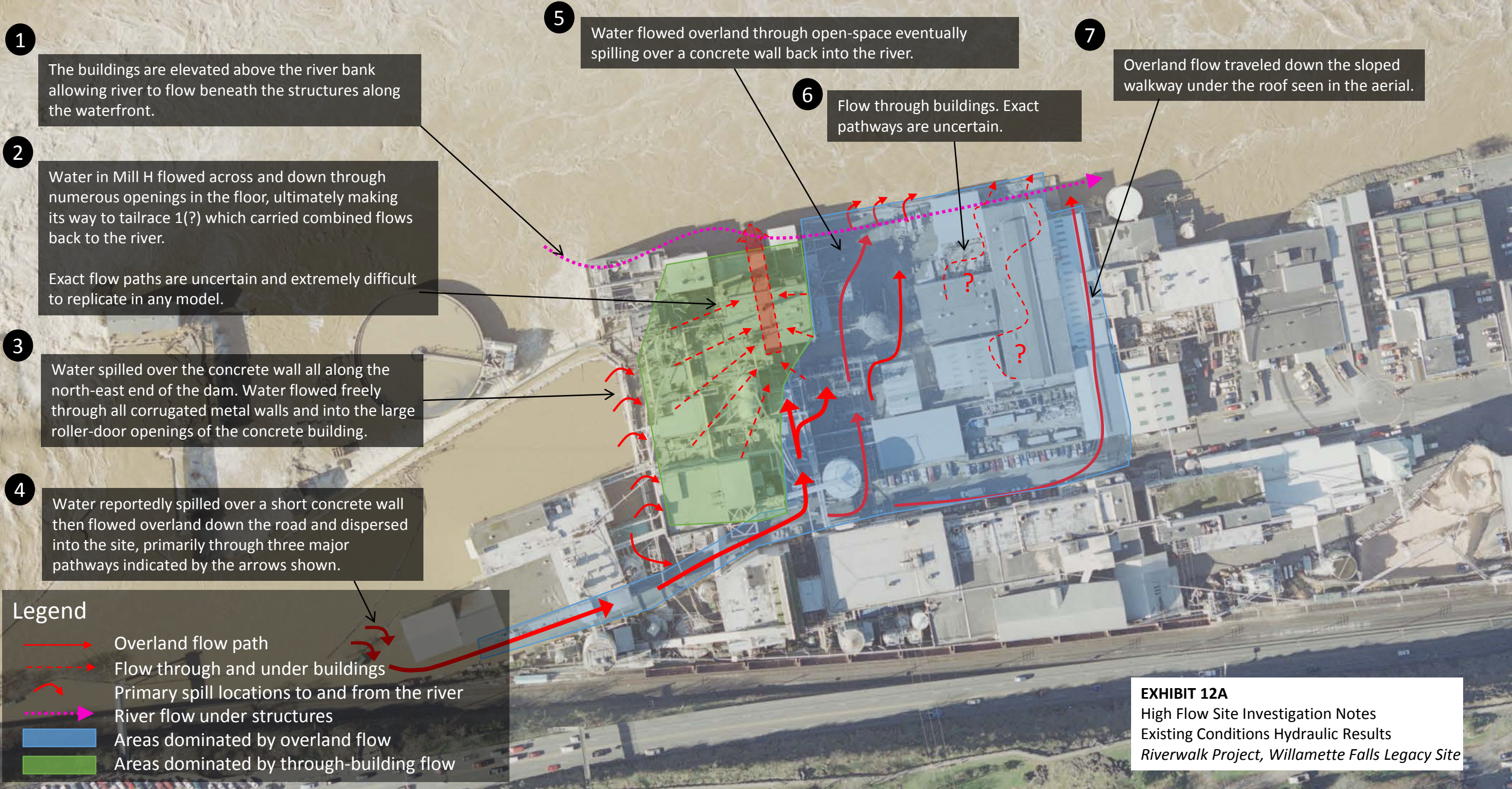
Total water depth [ft]

	Above 1.0
	0.4 - 1.0
	0.0 - 0.4
	Below 0.0

**EXHIBIT 11B**  
 Water Depth, Summer 2015 Record Low Flow 3,400 cfs  
 Existing Conditions Hydraulic Results  
 Riverwalk Project, Willamette Falls Legacy Site

# Flow-paths and general descriptions based on anecdotal information and site visit

Aerial taken 2/11/1996, after peak flow



**EXHIBIT 12A**  
High Flow Site Investigation Notes  
Existing Conditions Hydraulic Results  
Riverwalk Project, Willamette Falls Legacy Site

# Field Photos & Flow Paths

D

Aerial taken 2/11/1996, after peak flow

A



B



E



F



H

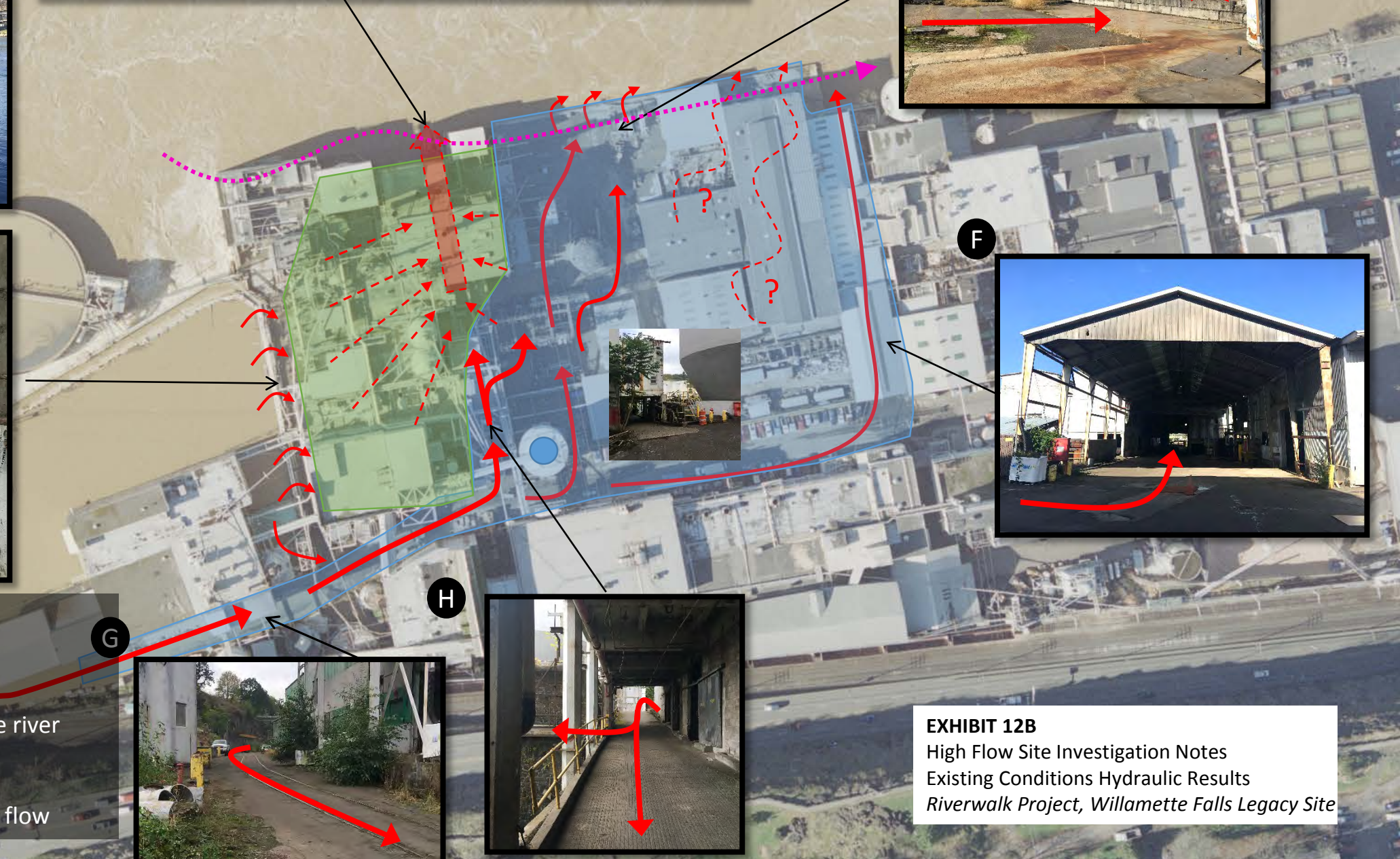


G



**Legend**

- Overland flow path
- Flow through and under buildings
- Primary spill locations to and from the river
- River flow under structures
- Areas dominated by overland flow
- Areas dominated by through-building flow



**EXHIBIT 12B**  
 High Flow Site Investigation Notes  
 Existing Conditions Hydraulic Results  
 Riverwalk Project, Willamette Falls Legacy Site

# Modeling Approach Notes

Aerial taken 2/11/1996, after peak flow

**A**

This in-channel flow path is critically important to the Riverwalk project since this is where the Riverwalk will be exposed to the highest velocities. The bank geometry must be accurately represented in the model. Need to remove the building tops and estimate or survey the underlying river bank.

**B**

Accurately define spill over the concrete wall, remove all corrugated metal walls (assume floods destroyed them as reported), leave concrete walls but add doors, ignore all "vertical" flow through the building, remove building floors, estimate the basalt grotto geometry (or survey it) and add large textural elements like tank 3 and pilings.

**C**

Confirm elevation of the concrete wall. Check LiDAR. Define wall in the mesh.

**D**

Confirm LiDAR excludes are temporary and/or movable features link trash bins, cars, etc. Check wall elevation. Model wall in the mesh.

**E**

Leave concrete walls, open doors, remove the roof so the model sees the floor elevation. Assume no flow below main level.

**F**

Remove roof over the covered walkway, estimate terrain elevation down to river.

**G**

Tapered tank. Shrink tank diameter since the diameter tapers to about half the diameter seem from above.

**Legend**

- Red arrow: Overland flow path
- Dashed red arrow: Flow through and under buildings
- Red curved arrow: Primary spill locations to and from the river
- Pink dotted arrow: River flow under structures
- Blue shaded area: Areas dominated by overland flow
- Green shaded area: Areas dominated by through-building flow

**EXHIBIT 12C**  
High Flow Site Investigation Notes  
Existing Conditions Hydraulic Results  
Riverwalk Project, Willamette Falls Legacy Site



High-water marks from 1996 flood surveyed by AKS.

