Lower Willamette River
Unsteady HEC-RAS Model

May 2022

USACE Portland District, ENC-HY

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Introduction

Overview

The U.S. Army Corps of Engineers (USACE) Portland District has developed a one-dimensional (1D) unsteady-flow hydraulic model of the Lower Willamette River in collaboration with the City of Portland and other local stakeholders. The project was initiated under the Oregon Silver Jackets programs, which aids efforts that benefit floodplain management and awareness throughout the state. The model was developed considering feedback from the stakeholder group via working meetings and review of a detailed model planning document.

This report documents the model and model building process in detail. It also discusses intended uses of the model and recommendations for future development.

The model and documentation will be shared directly with the City of Portland and made available for other local, state, and federal agencies. The report is to be fully public, meaning the report and documentation can be shared with contractors and made available to private consultants and interested parties. The final product will likely be made available be via download site on either USACE or City of Portland websites. The final product will be a package including the following:

- a general purpose (high and low flows), calibrated, 1D unsteady HEC-RAS hydraulic model of the Lower Willamette River complete with model files from calibration events,
- a hydraulic modeling report including flow and stage determination details,
- boundary condition dss files used to drive the model,
- the digital elevation model (DEM) with documentation

The City of Portland and EPA have expressed the need for a steady state model with which simple no-rise analyses can be performed. The Corps built a simple, truncated, steady-state model that utilizes existing FEMA flows and can be used as a draft “Duplicate Effective Model”. The construction of this product is described in Appendix C.

Applications

The primary function of the model is to estimate water levels along the lower Willamette River that occur during various flow conditions. As part of the full suite of HEC-RAS output, the model produces water surface profiles and hydrographs, as well as inundation polygons and depth grids used for mapping products. The model is intended to simulate historic flood events, hypothetical floods, or typical flow conditions

The primary application of the model will be for using model output for floodplain mapping and regulation. For example, the City of Portland plans to use inundation mapping from a simulation of the February 1996 flood event to update regulatory maps based on that historic event. Other applications indicated by the stakeholder group included various no-rise analyses, habitat analyses for restoration studies, climate change impact studies, and assessment of Superfund remediation projects in the lower river.

The model was developed with the array of potential applications in mind. For example, the model boundaries were set such that the downstream control on the Willamette River is determined hydraulically, allowing for no-rise analyses to be performed in the lower river. Including the Columbia River flow as input allows for modeling unlimited flow combinations in the confluence area, allowing for flow reversal modeling during Columbia-driven floods. If finer resolution is needed, the model is suitable for adaptation to 2D modeling in the overbanks and channel. The model is also calibrated to simulate both flood flow and general flow conditions.

Future FEMA flood map and floodway updates were also considered when building the model. While further hydrologic analysis required to develop boundary conditions needed for traditionally-mapped FEMA flood zones (e.g. Zone AE, Zone X, etc.), the model is configured to support that analysis with only minor modifications.

Model Limitations

The hydraulic model is built to support for the applications stated above. Modification to the model would be required for several applications.

The model has specific limitation related to boundary conditions and the challenges with establishing flow data for historic events. This is largely because the Lower Columbia River HEC-RAS model used to develop boundary conditions in some years is owned by USACE and is not publicly available. Simulating other historic events using the same methodology employed for calibration of the model will not be possible for the public.

Simulating recent and future observed flow conditions can be done using the measured flows at Vancouver, the measured stage at St Helens, and the measured flows at the other USGS gages used to develop local inflows including inflow at Willamette Falls. Using measured Vancouver flow at USGS gage 14144700 instead of the methods used in this report would likely be acceptable for most applications.

For simulating hypothetical events, generating downstream stage conditions that might coincide with the defined flow conditions upstream would be slightly challenging, but it should be possible considering general flow-stage trends at St Helens and the uncertainty about that relationship.

The model is not developed to simulate flood risk in leveed areas. Additional work would be required to assess levee fragility, interior hydrology, and drainage.

Similarly, this model and report does not directly provide any information on peak flow or stage frequency. New flood frequency work is underway, and this model will be useful in applying the updated hydrology and hydrologic methods developed for assessing specific probability conditions, such as the 1% annual chance event or stage with a predicted recurrence interval of 1 in 100 years, but the present model is intended to capture reach hydraulics based on observed conditions. Any attempt to generate boundary conditions intended to define stages or flood conditions associated with a given probability should be done at the user’s risk.

Existing Models and Datasets

Several existing models and studies were used as reference or directly to develop boundary conditions for the present model. These include the following:

- Current Effective FEMA HEC-RAS Model – The City of Portland provided the “current effective” FEMA model that has previously been the best, publicly-available hydraulic model of the Lower

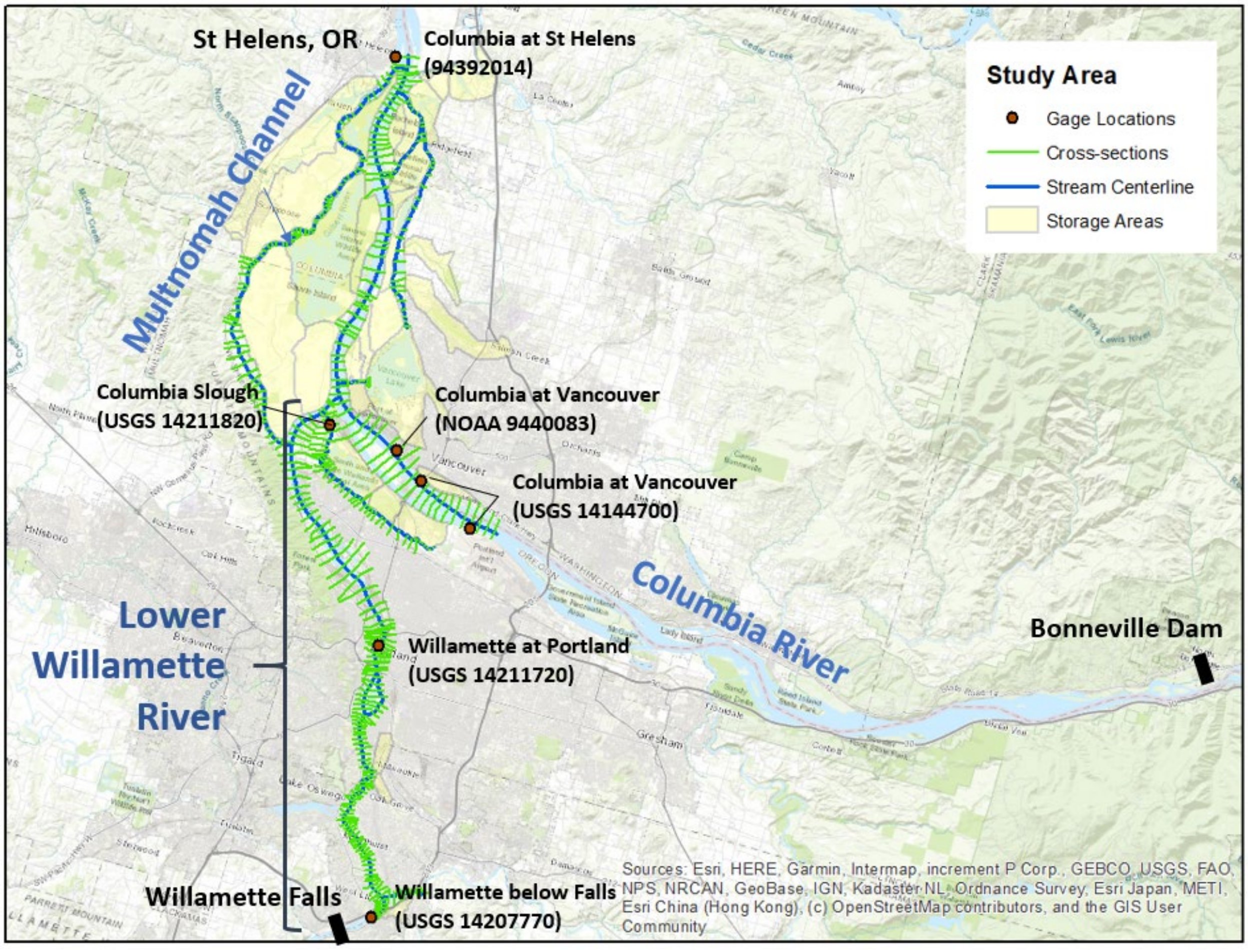
Willamette River. This is a working, georeferenced version of the original HEC2 FEMA model from 1980.
- USACE Lower Columbia River HEC-RAS Model (2019) – The Portland District Corps of Engineers developed a 1D unsteady HEC-RAS model of the Lower Columbia River (LCR) from Bonneville Dam downstream to the Tongue Point gage near Astoria and including the downstream portions of major tributaries including the Willamette, Lewis, Cowlitz, Coweeman, Sandy, Clatskanie, and several other smaller rivers. The model is currently not publicly available but it can be used to generate publicly available results.
- USACE Long Term Run (2015) – The Portland District Corps of Engineers simulated 40 years from the observed record to develop a publicly available "long term" dataset of flows and stages throughout the Lower Columbia River. The simulation was run using an earlier version of the LCR HEC-RAS model.
- 2021 USGS Open File Report 2020-1138 – To support Portland District USACE flood profile modeling of the Lower Columbia River (LCR), the USGS compiled robust dataset of available stage and flow data from various sources covering the basin.
- February 1996 High Water Mark Survey (1997) – Under contract with Portland District USACE, CH2MHill compiled information from multiple high water mark survey efforts following the February 1996 flood event.
- February 1996 inundated area polygon developed by the City of Portland's Bureau of Environmental Services.

Background

Study Reach Description

The study area is focused on the Willamette River downstream of Willamette Falls at Oregon City to the confluence with the Columbia River, flowing through the densely populated heart of Portland and the industrial areas north of downtown including the Portland Harbor. The study area spans the highly channelized river and includes overbank areas potentially inundated during the largest floods.

To provide an adequate downstream boundary for the Willamette River, the entire Multnomah Channel west of Sauvie Island and a 25-mile stretch of the Columbia River from the NOAA tide gage at St Helens, OR upstream past the USGS flow measurement station at Vancouver is included in the model. Within this reach, the model extends laterally to include all major features potentially engaged during extreme flood conditions. This includes floodplain lakes such as Sturgeon Lake and Vancouver Lake, and leveed areas such as those on Sauvie Island, Bachelor Island, and several of the Multnomah County Drainage District (MCDD) levees. The approximate model extents are shown in Figure 1.



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

Figure 1. Study area and hydraulic model extents.

Gages and Observed Data

At a glance, the NOAA gages on the Columbia River at Vancouver (9440083) and St Helens (9439201), and the USGS gages at Vancouver (14144700), Portland at Morrison Street Bridge (14211720), and Willamette River below Falls at Oregon City (14207770) all play a large role in calibration of the hydraulic model. See Figure 1. Flow data from the Willamette River at Morrison Street Bridge are directly used to develop inflow data on the Willamette River, and flow data from the USGS flow gage at Vancouver is important for Columbia River flow validation. The stage record at the USGS gage at Columbia Slough (14211820) provides additional data used in calibration, and several other USGS gages (not shown in Figure 1) are directly used to develop flow estimates for local subbasins, including Clackamas River at Oregon City (USGS 14211010), Johnson Creek at Milwaukie (14211550), Johnson Creek at Sycamore (14211500), and the East Fork Lewis River nr Heisson (14222500). Gages from the broader Lower Columbia River area, and up to The Dalles Dam, are used indirectly in this study for the creation of modeled-observed flows at Vancouver and stage at St Helens during the February 1996 event.

Measured stage and flow data from these gages were gathered from the compilation performed by USGS for streamflow evaluation of the Lower Columbia River (USGS 2020), and then supplemented with data downloaded from USGS and NOAA online resources for years 2018 and 2019. Detailed descriptions of record construction for each gage site including period of record and strategies for addressing data gaps are compiled in the table in Appendix A. Datum conversion used to shift stage data to NAVD88 are discussed in the Datums section. Applications of these measured data to determine inflows in the model are discussed in the Boundary Conditions section, and additional discussion on the accuracy and precision of measured data and the limitations of estimated data through gaps is included in the Calibration section.

High water marks (HWM) from the February 1996 flood event are used in calibration. These data are documented in a memo dated January 27, 1997 by CH2MHILL, under contract with USACE. The location of the HWM surveys in HEC-RAS were ascertained via import into RASMapper via a GIS shapefile. Elevation data for all points in the Lower Columbia River reach were converted from NGVD29 to NAVD88 by adding +3.27 feet.

In addition to these HWM data, hydrograph data were collected for the February 1996 flood wave at the amphitheater near Oswego Point Drive around RM 20. These data were provided by the City of Lake Oswego. These data were converted from NGVD29 to NAVD88 by a more localized conversion of +3.40 feet.

Hydrologic and Hydraulic Setting

Flood conditions typically occur during the winter period from November through March. They are caused by intense rains augmented by lower elevation snowmelt in the west Cascade Mountains and Coast Range. Major winter storms are typically large-scale atmospheric-river events that are fed by moist air from the west. The winter floods are characterized by sharp high peaks and are usually of shorter duration. These basin-wide winter storms generate snow in the higher elevations and do not immediately contribute to high Columbia River flows at The Dalles.

Spring snowmelt in the Willamette basin and other drainages west of the Cascades can contribute to elevated flow levels in the Willamette, Columbia, and other rivers in the LCR, but they typically do not result in flood conditions.

Historically, the largest floods in the LCR would occur in early summer as snow melts from the greater Columbia River Basin in large snow years. Large storage projects since built in the Columbia River Basin reduce the risk of these large snowmelt floods, but Columbia-driven spring and early summer floods can still occur, causing elevated water levels in the LCR.

Having two fundamentally different types of floods results in very different possibilities for flood hydraulics near the Willamette-Columbia confluence. Winter events will typically be Willamette-driven and result in relatively steep hydraulics through the lower Willamette. Large Columbia-driven events typically occur in the early summer when Willamette flows are low. This creates a backwater effect through most of the Willamette River, and a flow reversal often occurs in the lower 3 miles as the Multnomah Channel conveys a considerable fraction of the Columbia River flows.

The lower Columbia River basin is also tidal, with tidal effect evident throughout most of the study area at all but the highest flow conditions. During low flow periods, daily water fluctuations driven by the tide can been all the way up to the Willamette Falls at Oregon City and Bonneville Dam.

The bedform in the lower Willamette River and the entire Lower Columbia River is sand and sand waves. It is understood that sand wave formation processes occur during high flow conditions, changing the bathymetry and roughening the channel. Regular maintenance dredging of the Federal Navigation Channel will flatten sand waves and deepen the channel in aggrading zones, resulting in yearly or every-other-year bathymetry changes in most shoaling reaches.

The Columbia River is also heavily leveed. This results in flow confined to the main channel in most flow conditions. Some floodplain lakes and sloughs exist and provide valuable wetland habitats in the area during typical flow conditions. Some smaller/lower levees may overtop and create considerable floodplain storage at moderate and major flood stages. Some overbank flow does occur across inundated leveed areas, activating the larger, historic floodplain during extremely high flows.

The lower stretch of the Willamette River study area is highly channelized with urban flood walls often clearly defining the break between channel and overbank. The reach has numerous bridges. Evident in the multibeam bathymetry, the bridge piers cause local scour and channel roughening. With the exception of the Steel Bridge, all of the bridges are relatively high with low cords, well above the overbank elevations, and do not come into contact with flood waters.

The upper stretch of the Willamette River study area is relatively confined due to the natural topography. Bedrock ledges are common in much of the reach, as are huge holes in the channel with depths over one hundred feet. During higher flow events, near-shore slack water and large eddies form through much of the reach, and flow is concentrated in an often clearly delineated area in the middle of the channel, evident by high velocities, standing waves and sharp eddy lines.

Event history

The February 1996 flood is one of the largest Willamette River floods in recorded history, certainly the largest in the post-dam construction era starting in the mid-1970’s. The event produced the highest stages at Portland and Vancouver, as well as further upstream on the Willamette River at Oregon City. The high stages were a result of both high flows on the Willamette River at Portland (420 kcfs, daily average) and the Columbia River at Vancouver (500 kcfs). This event produced the highest stage in Portland (32.7 feet NAVD88) since the Christmas Day flood in 1965.

The January 1997 event (293 kcfs) is also noteworthy as the second largest Willamette flow in the post-dam period. This event coincided with a Columbia flow of 400 kcfs and produced the second largest peak at Portland (27.8 feet NAVD88) since 1965.

There have been several high flow and stage events on the Lower Willamette River over the past 20 years in which there is better gage coverage of the study area with observed stage records at the St Helens and Vancouver NOAA gages. The highest three based on measured peak flow at the Morrison Bridge gage include January 2012 (211 kcfs), January 2006 (191 kcfs), and January 2009 (188 kcfs).

The relatively large 2017 freshet is notable as the combination of high Columbia and Willamette flows resulted in the highest Columbia stages since the large flow events in the late 1990’s, and it is within the period of complete gage record in the study area.

Model Setup

General

USACE’s Hydraulic Engineering Center River Analysis System (HEC-RAS) modeling platform, version 6.1. This platform is used for this model for several reasons including the following:

- It is the industry standard hydraulic modeling tool used in a wide range of applications.
- It is versatile, free software with user-friendly interface, support manuals, etc.
- It is used for 80% of FEMA floodplain mapping projects.
- It has 2D and 1D-2D combination modeling options.
- It has built-in GIS capabilities with RASMapper.

Datums

The model is developed in “USA Contiguous Albers Equal Area Conic USGS Version” horizontal coordinate system. The horizontal datum for the final model is the North American Datum of 1983 (NAD83). Units are in U.S. feet. All vertical data and results in this study are referenced to the North American Vertical Datum of 1988 (NAVD88).

Many of the gages report data in the Columbia River Datum (CRD) or stations datums and need to be converted to NAVD88 for use in the model or comparison to model results. While many National Weather Service (NWS) gage sites included datum conversions, conversions to NAVD88 are often lacking. Conversion factors used in the present analysis are from the USGS’s 2021 record compilation effort (USGS 2021).

Terrain

Terrain throughout the study area is mostly represented by a clipped version of USACE’s Willamette CWMS digital elevation model (DEM). Queries about specific datasets contained in the 2020 CWMS dataset can be directed to Gregg Bertrand in the NWP GIS department.

Recent detailed survey efforts were compiled by Gregg Savage at the City of Portland are used to create a separate DEM comprised of the most recent and best available data. The City’s DEM was used to supplement the CWMS DEM in areas lacking data or showing considerable change. These included areas around Ross Island in South Portland, the Willamette River at Tryon Creek near Lake Oswego, and the Willamette River at Abernathy Creek in Oregon City. The updated LiDAR dataset was used to identify and update overbank terrain on Sauvie Island at the Willamette-Multnomah Channel confluence.

River Mile

The downstream boundary at St. Helens is defined according to the NOAA description referenced to RM 86 (RM 86.1 for the Lower Willamette RAS model), and Columbia River stationing upstream is calculated using cumulative reach lengths as calculated in RAS based on the revised stream centerline. River stationing for the Willamette River is calculated similarly starting at RM 0 at the intersection of stream centerlines at the Willamette-Columbia confluence. All reference to river miles in this report are based on the stationing defined in this model geometry. This will differ slightly from USACE Navigational River Miles and USGS River Miles.

Geometry construction

Overview

The Lower Willamette HEC-RAS model includes a fully georeferenced, 1D geometry. The model build is focused on the Willamette River from just below Willamette Falls through Portland to the Columbia River confluence; however, the model extends beyond the Willamette River to adequately capture hydraulics in the lower river about confluences with the Multnomah Channel and Columbia River.

The layout is based on that in the USACE Lower Columbia River HEC-RAS model through the Columbia reach from Vancouver down to St Helens, although some simplifications have been made. The major channels, levees, and leveed areas from Vancouver to St Helens are reflected in the model to enable modeling of major flood hydraulics at the reach scale.

The fully georeferenced geometry leans on the DEM for elevation and volume data integral to the unsteady flow calculations.

Geometry Elements

Stream centerline and flow paths

Stream centerline is adopted from the USACE model. Minor refinements were made in the Willamette River and around Hayden Island where a flow split was previously modelled.

While most river reaches are highly channelized, overbank flow paths are added to the model and used to calculate overbank reach lengths used in flow calculations.

Cross-sections

The model has 368 cross-sections. Cross-section in conjunction with storage areas are used to cover the entire floodplain beyond the 500-year floodplain. Cross-section spacing ranges from about 300 feet to 4000 feet across the model. On the Willamette River, cross-section spacing is about 1500 to 2500 feet in the lower 12 miles of the river, and then typically 600 to 1400 feet from RM 12 to the top of the model just below Willamette Falls. Cross-sections were drawn to overlap with existing FEMA lettered cross-sections where possible.

Profile data for most cross-sections are cut directly from the 3-foot DEM. Most of the DEM contains elevation data reflecting bathymetric surveys, but some areas lack bathymetry. For cross-sections in areas lacking bathymetry, cross-section profiles are manually adjusted by adding trapezoidal sections to reflect an assumed ground surface underneath the returned water surface from the LiDAR. Areas without bathymetry represented in the DEM include Columbia Slough, Lake River, and smaller side channel areas.

Storage areas

One-dimensional storage areas are used to model leveed areas, floodplain lakes and wetlands, and off-channel storage areas that do not convey water during all but the most extreme flooding conditions. Storage areas are also used to capture storage that occurs within tributary that would be backwatered by high water conditions in the adjacent main channel. Along the upper portion of the Willamette River, storage areas are used to capture off channel storage in Abernathy Creek, Kellogg Creek, and Johnson Creek areas. Near the confluence and downstream, storage areas are used to model leveed areas such as the MCDD levees, Smith and Bybee Lakes, Sauvie Island, Vancouver Lake, and the Lewis River.

To model storage capacity, elevation-storage relationships are obtained from the DEM via built-in terrain interrogation features in HEC-RAS. Minor adjustments are made to the bottom end of the curves in some leveed areas for model stability.

Lateral structures

Lateral structures are used to connect storage areas to river channels. Lateral structures are drawn to capture terrain features that limit hydraulic connectivity to a storage area, typically following high ground. In the case of storage areas representing leveed areas, lateral structures are used to simulate levees and flow across overtopped levees. Profile data for a lateral structure simulating the top of the levee are cut from the DEM. Manual adjustments to the profile are occasionally warranted as the DEM can contain data gaps that do not reflect the actual terrain. Similarly, closures structures about Pen1 and Pen2 are assumed to be operational during flooding conditions and need to be manually added to the levee profile.

With non-leveed storage areas, the primary hydraulic connection often exists via small channel or culvert. In both cases, the relevant information is not available in the DEM but must be added to the lateral structure manually. In the case of creeks and rivers within a lateral structure, depth below the LiDAR's returned water surface in the DEM is added to the lateral structure profile assuming a reasonable trapezoidal channel geometry. In absence of field measurements, culvert dimensions and construction details are assumed to provide a reasonable connection that allows uninhibited backwatering of a storage area to occur.

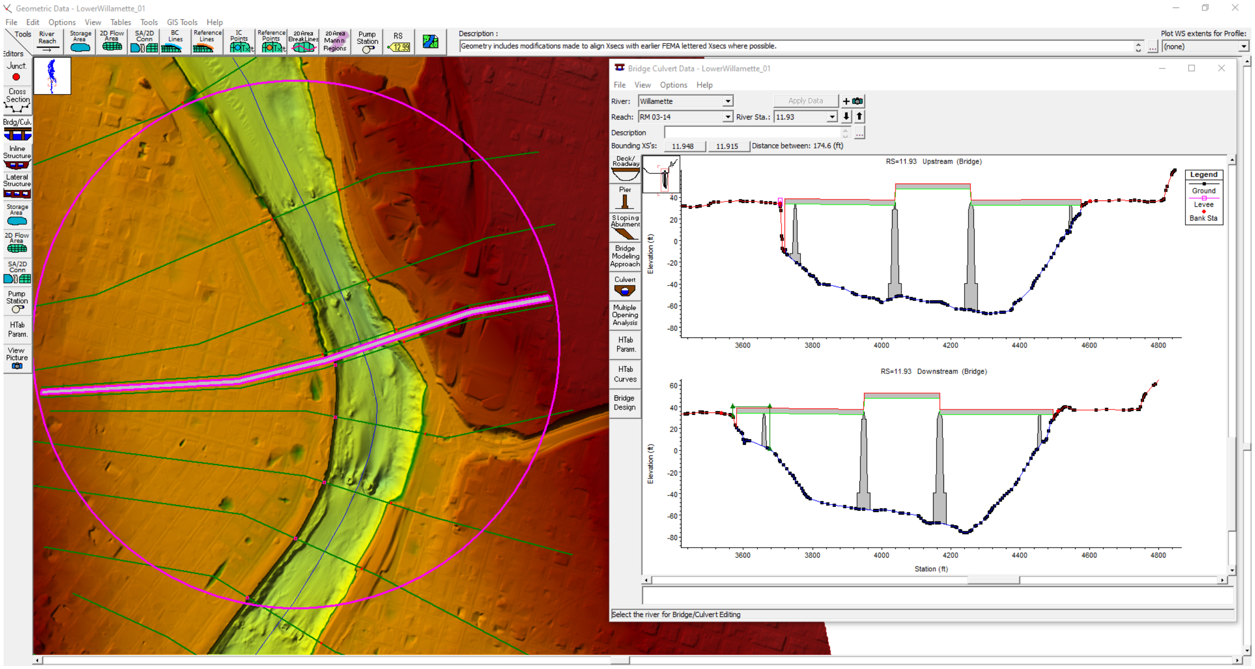
Weir coefficients for lateral structures are typically between 0.5 and 1.5, which is lower than those associated with conventional weirs. This is due to the width of the levee represented by the lateral structure and the orientation of the lateral structure, which in most cases is parallel to the main flow direction.

Storage area connections

Storage area connections connect adjacent storage areas in model geometry. The typically are representing cross-levees or other high ground separating two leveed areas or a leveed area and another storage area. The same principle applied to lateral structure profile creations are used with storage area connections.

Bridges

While there 15 bridges on the Willamette River below Willamette Falls, nine of which are in a stretch of 3 miles through downtown Portland, only the Steel Bridge is modeled as a bridge in the HEC-RAS geometry. The three bridges on the Columbia River near Vancouver are not modeled either. The Steel bridge is the only bridge with low cord low enough to impact flows, which was the case in both the Dec 1964 and February 1996 flood events. The Steel Bridge is modeled using plans obtained from the City of Portland. The general profile drawing shows deck and abutment elevations along with pier shape and elevation data. See Figure 2 for visual of the bridge peir and deck geometry as entered in the bridge editor with HEC-RAS.


Geometric Data - LowerWillamette_01

Description : Geometry includes modifications made to align Xsecs with earlier FEMA lettered Xsecs where possible.

Plot WS extents for Profile: (none)

Bridge Culvert Data - LowerWillamette_01

River: Willamette

Reach: RM 03-14

River Sta.: 11.93

Description

Bounding XS's: 11.948 11.915 Distance between: 174.6 (ft)

Select the river for Bridge/Culvert Editing

Figure 2. Steel bridge geometry in HEC-RAS.

The bridge piers of the numerous other bridges certainly impact flow locally and cumulatively, but the current model addresses bridges in a reach using channel roughness. This is due to a lack of readily available bridge pier geometry data, and because reach-scale hydraulics are adequate for this modeling effort. Adding bridges to the model would also decrease model stability and complicate any 2D overbank modeling options.

Bridges could be added to the model if needed. For example, bridges may be warranted if simulating extreme events (beyond the 500-year flow) with substantial out-of-bank flow and potential flow constrictions caused by roadways approaching bridges, or if simulating partial flow obstructions due to racked debris. Bridge piers may also be built into the terrain and included in full 2D flow explorations.

The three bridges on the Columbia River near Vancouver are not modeled either. The bridge decks of all bridges are well above possible high water levels, and it is assumed the bridge piers do not substantially impact river hydraulics on the reach scale relevant to flood modeling.

Levee Tool

While providing some functionality with conveyance area and overbank storage calculations within a reach, the levee tool is generally used to improve inundation mapping. The “levee” can be placed along a cross-section at high ground or levees to essentially confine the wetted area to the channel until water levels exceed the elevation at the high ground or levee. In this model, the levee tool is also used to improve mapping along Columbia Slough and to simulate the flood protection provided by the Willamette seawall.

The Willamette seawall extends approximately 1.0 miles from approximately 240 feet south of the Hawthorne Bridge downstream to the Steel Bridge. The seawall adds flood protection to a considerable area in downtown SW Portland. Terrain interrogation suggests the ground surface at the seawall is only at 33.5’ in some places toward the upstream end. This is 0.4’ lower than the reported average ground elevation of 33.9 feet reported in the 2012 USACE condition assessment of the seawall (USACE 2012). Conservatively, the entire floodwall is set at 33.5' + 43".

Roughness and Ineffective Flow

A detailed roughness analysis for this reach was not available, though the "Roughness Characteristics of Natural Channels" paper (USGS 1967) suggests using a Manning's *n* value of 0.030 for the Columbia River near The Dalles. When no detailed roughness study is available, the HEC-RAS Hydraulic Reference Manual (USACE 2001 and 2008) and the FHWA report FHWA-TS-84-202 (1984) are often used to provide justification for roughness parameter selections. Water-Supply Papers 1849 and 2339, published by the USGS (1967, 1989), are also applicable and dedicated specifically to guidance on selecting "n" values in natural channels and floodplains.

Initial estimates of Manning's n values for the main channels were estimated from previously developed HEC-RAS models, visualization of the river using Google earth, and hydraulic modeling experience gained from other studies. Main channel Manning's n values were estimated for the channel as a whole, rather than separate values for the channel bottom and the channel banks. A large portion of the river corridor has extensive and thick brush and trees on the banks of the main channel. Channel Manning's n values were estimated by weighting the base n value of the bottom with larger n values for the channel banks. Overbank Manning's n values were initially estimated using aerial images to identify areas of similar land use, then assigning an n value for that land use type. For example, thick forested areas were assigned an n value of 0.10, urban areas with high densities of building were assigned a value of 0.15, and open fields with grass was assigned values of 0.05. After all of the cross sections were assigned initial Manning's n value estimates, and further refinement of the Manning's n values was made during the model calibration process.

To simulate the highly concentrated flow in the deeper portions of the Willamette River and the widespread occurrence of large eddies and slack water over the shallower shelves along the riverbanks, a "high velocity channel" was established with a polygon in RASMapper to demarcate a zone of lower Manning's n compared to relatively high Manning's n along banks and in overbank areas. By creating a landcover layer using this polygon, manning's n values were burned into the cross-sections. Ineffective areas polygons were also used to further constrict conveyance area where large eddies have been observed or are likely. All ineffective flow areas are permanent. Extents of ineffective flow areas is based on topography and preliminary flows and inundation results. The calibration process involved refining the horizontal extents and top elevation of ineffective areas. High velocity channel n was set to achieve low-flow calibration, and the residual n (outside the high velocity zone) was increased to achieve calibration at higher flows. Table 1 shows the range of Manning's n values for the major rivers.

Table 1: Manning's n Value Ranges for Main Channels and Overbank Areas

River Name	Main Channel Manning's n	Overbank Manning's n
Willamette River	0.025 - 0.029	0.07 - 0.10
Columbia River	0.027 - 0.034	0.10 - 0.12
Multnomah Channel	0.028 – 0.035	0.06 - 0.15
All Other Channels	0.030 – 0.031	0.09 – 0.10

A flow-roughness scheme was implemented for the main channel of the Columbia River. Initial calibration showed results being compressed with higher modeled stages at low flow, and lower modeled stages at higher flows. The calibration strategy was adjusted by setting channel n to achieve low flow conditions, increasing overbank n to the upper end of reasonable values, and then adding flow roughness factors to achieve a better calibration during flood peaks. The flow-roughness factors are between 0.95 and 1.20, with the lower flow corrected down and higher flows corrected up. The table below shows the flow-roughness factors used.

Table 2. Flow roughness factors for the Columbia River reaches.

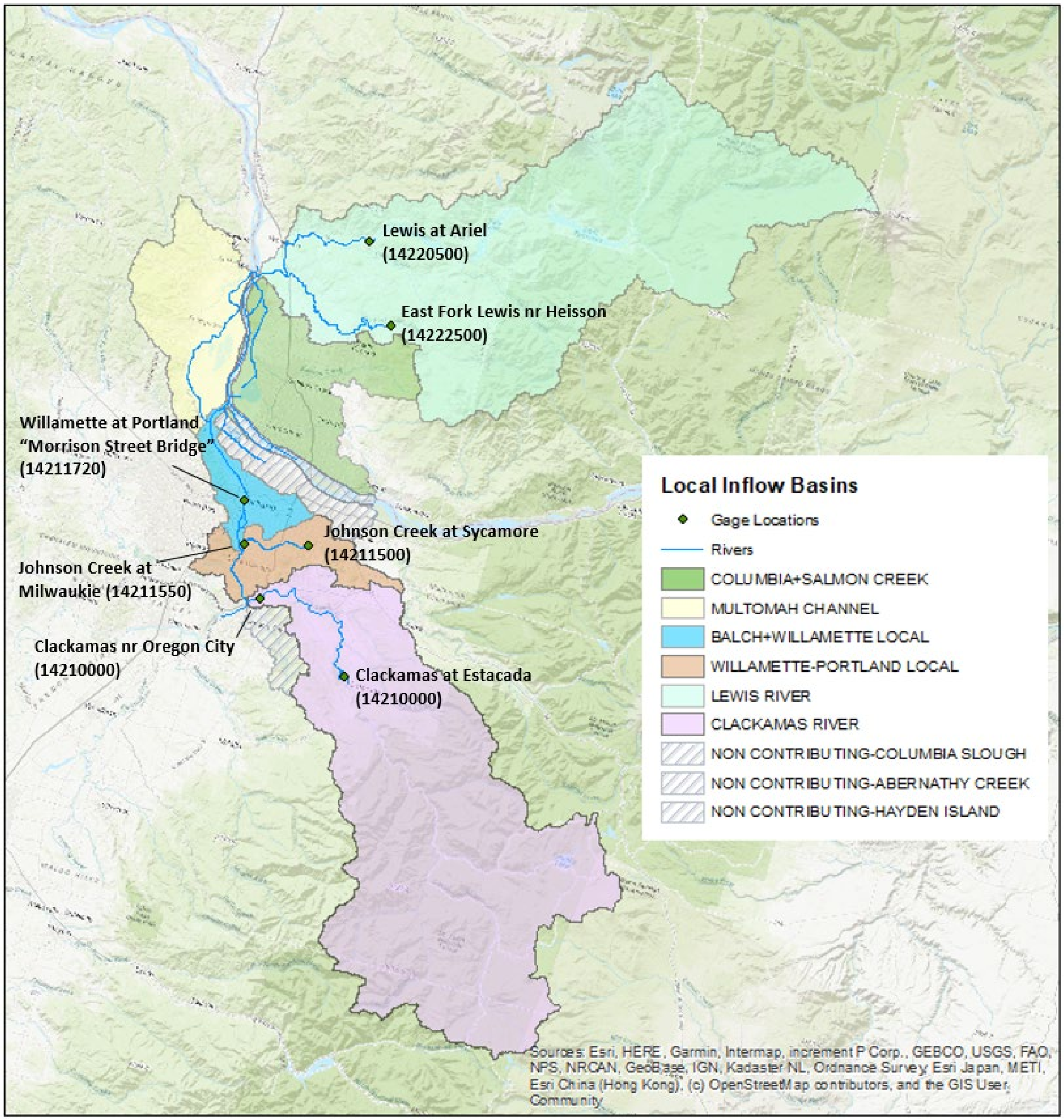
Flow	below Willamette confluence	above Willamette confluence
0	0.95	0.95
200,000	0.96	0.98
300,000	0.97	1.00
400,000	0.98	1.05
500,000	0.99	1.10
550,000	1.05	1.15
600,000	1.10	1.20
650,000	1.15	1.20
700,000	1.20	1.20

Flow-roughness is physically justifiable for the Columbia River. While there is some additional roughness added by bank vegetation at higher stages, the most significant factor increasing roughness is sand-wave formation on the riverbed. They tend to increase in height with velocity and flow and require significant energy to move downstream upon formation.

Boundary Conditions

Flow Record Construction

Continuous time series data are required at all inflow boundaries in the unsteady HEC-RAS model for any simulation. The following subsections describes the specific methods used for flow record construction for the major inflow locations on the Willamette and Columbia Rivers, and the local subbasins within the study area. Figure 3 shows the different contributing locals flow subbasins within the study area. Detailed notes on record construction including process dealing with data gaps are described in Appendix A.



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

Figure 3. Local inflow basins and key flow gages.

Columbia River

Data for the upstream inflow boundary on the Columbia River are modeled-observed results from USACE's LCR HEC-RAS model. These simulations include flow estimation through the LCR HEC-RAS model which extends from Bonneville to the Tongue Point gage near Astoria, OR. Hourly Bonneville outflow records are estimated using the measured flow data from the USGS gage below The Dalles Dam (14105700), adding daily average flow estimates of local tributary inflows between Bonneville and The Dalles, and then shaping the combined daily flow volumes to hourly pattern that includes power peaking at Bonneville.Flow record construction methods for all local flow estimates used in the model from The Dalles Dam to Astoria can be found in the Lower Columbia River Hydrology Update [USACE 2018].

Publicly available data were available from the Long Term Run study for years prior to 2016; however, the flow estimation methods in this older study did not include hourly shaping at Bonneville. Also, local flow estimation techniques were improved from that study to the present methods. A comparison of the LTR results and those from the updated model (not included in this report) show much improved flow and stage calibration, particularly with hourly stage dynamics.

Measured hourly flow data are available from the USGS gage at Vancouver starting in March 2016 through the present. The gage is located on the left bank about 1.3 miles upstream of Hayden Island, at RM 109.196 in the LW model. The gage obtains velocity measurements to estimate flow. Data are available in tidally filtered and unfiltered. The unfiltered data are compared to the modeled-observed flow results from the LCR model to validate the Columbia River flow inputs in the present model.

The figures below compare the hourly modeled-observed flow results from the LCR model at the cross-section closest to the top of the LW model (RM 110.196) and the hourly unfiltered USGS-measured flows at Vancouver. Both the measured USGS flows and modeled-observed results reflect the influence of the downstream tidal boundary, even at higher flows. They also show the impact of hourly releases at Bonneville related to load shaping related to hydropower operations. The modeled flows trend higher than measured flows, particularly with higher flow conditions (above 300 kcfs).

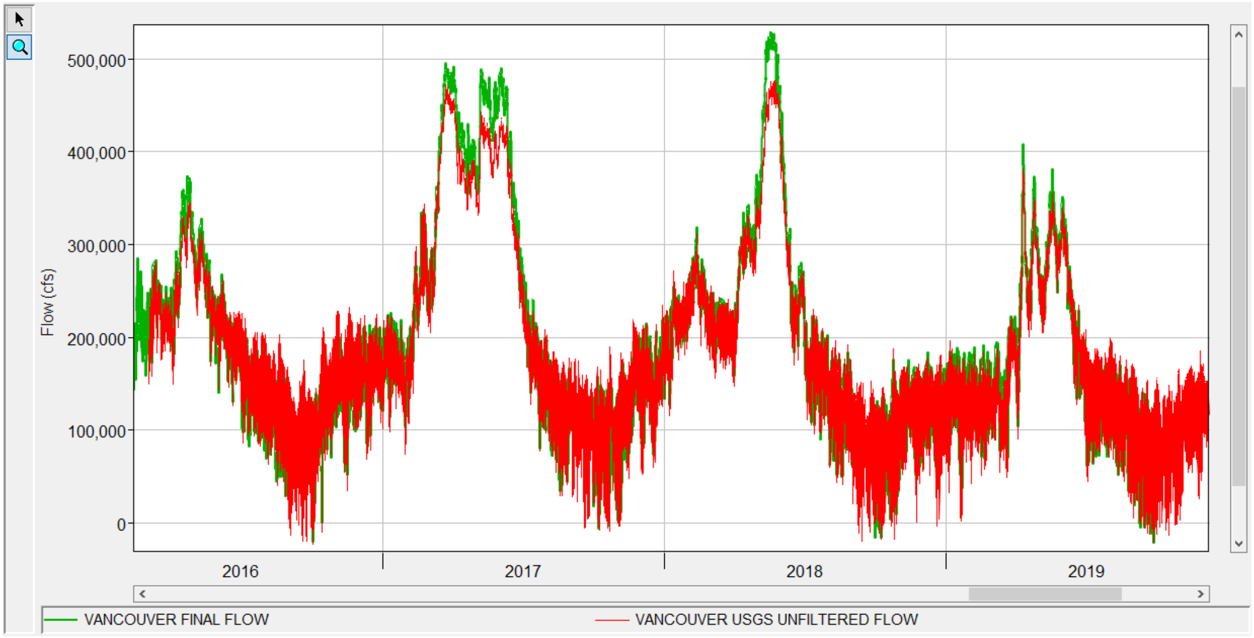


Figure 4. Comparison to hourly, modeled-observed flows (green) to USGS-measured flows (red) at Vancouver.

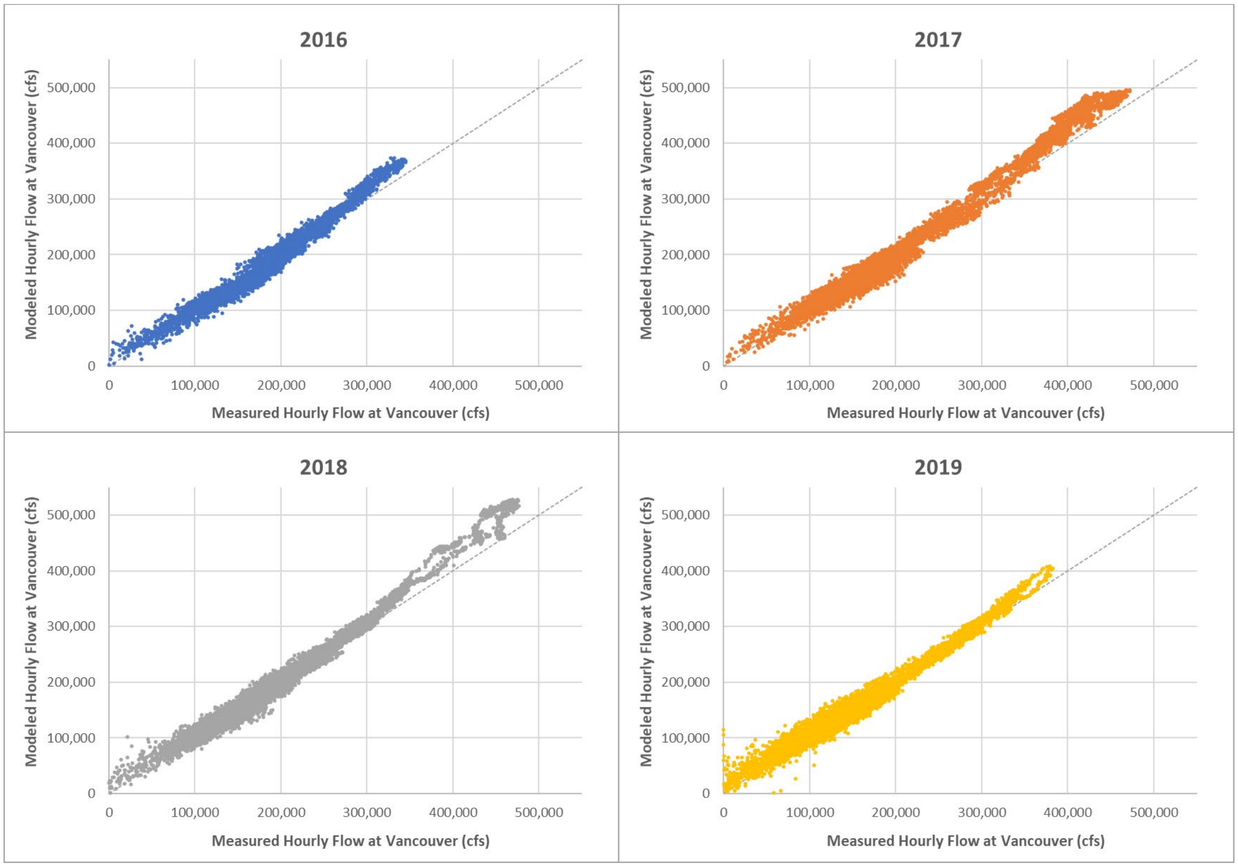


Figure 5. Scatter plots of modeled-observed flows vs USGS-measured flows at Vancouver.

The modeled flows would presumably be less accurate because of the gross assumptions required in the flow determination methods, most notably those around estimating flows for ungauged locals. Additionally, the modeled flows at Vancouver do not consider changes in storage behind Bonneville dam and other potential losses such as evaporation and groundwater recharge. There is also some error associated with the flow measurement method at The Dalles. Both the USGS flow gages at Vancouver and below The Dalles Dam use the velocity-index method. While all flow measurements have some error, the flow estimates at The Dalles tend to be very low, often less than 2% (personal communication with Adam Stonewall at USGS). Due to the tidal influence, the flow measurement errors at Vancouver are suspected to be greater than those at The Dalles.

See Figure 6 and Figure 7 for comparisons of the daily measured flow at Vancouver and The Dalles Dam and the modeled flow at Vancouver. It is worth noting that measured flows at Vancouver are similar to or often lower than the measured flows at The Dalles, particularly during high freshet flows, indicating a net loss of volume from The Dalles to Vancouver. It is conceivable that the drainage area ratio method used to estimate flow for the ungauged areas downstream are overestimating flows in the spring, since snowmelt would typically only be occurring at the higher elevations; however, the decrease in measured flow from The Dalles to Vancouver suggest other, more impactful issues, such as measured gage error (at one of both of the gages) and/or significant losses across the reach.

A detailed investigation could be done to improve understanding of flow accuracy in the lower Columbia River, but this is outside the scope of the current effort. The implication of overestimated Columbia flows on the hydraulic model are discussed in the Calibration section.

Figure 6. Comparison of measured daily average flows at Vancouver (yellow) and below The Dalles Dam (green), and modeled flow at Vancouver (red).

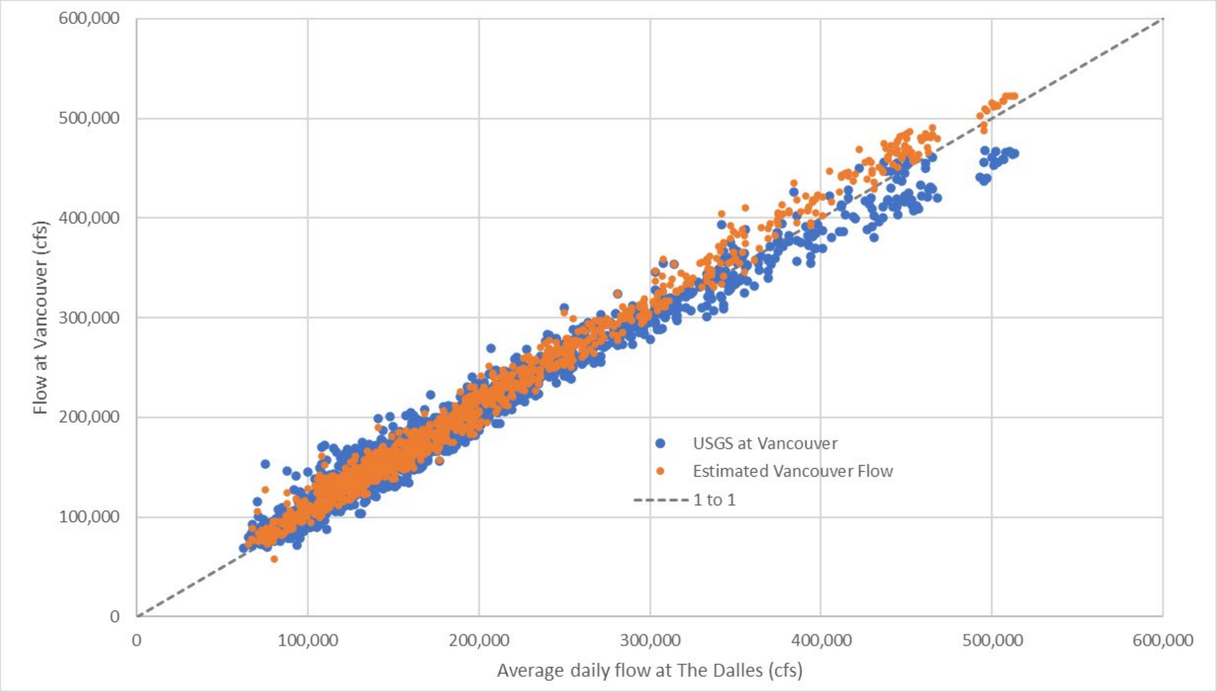


Figure 7. Scatter plot of measured (blue) and modeled (orange) daily flows vs. measured daily flow at The Dalles Dam.

Willamette River

Flow inputs to the Willamette River are comprised of the estimated Willamette River flows at Willamette Falls and the three major drainage areas downstream. These three drainage areas are shown in Figure 10 and summarized below:

- Clackamas River, to include the entire Clackamas River drainage area (HUC 8-17090011)
- Willamette-Portland Local, to include Johnson Creek and the local runoff between the Clackamas River and Johnson Creek confluences (HUC 10-1709001201)
- Balch+Willamette Local, to include the contributing drainage area to the Willamette downstream of the Johnson Creek confluence (HUC 12-170900120202). Columbia Slough is considered noncontributing and not included in hydrology calculation since most drainage area flows into the interior of leveed areas and is pumped out with different timing.

The only reliable long-term flow gage on the Willamette downstream of Salem is at Morrison Bridge in downtown Portland (USGS 14211720), which has recorded flow data from WY1973 to the present. The general approach to develop inflow data at the upstream end of the model at Willamette Falls is to apply the measured flow at Morrison Bridge (RM12) adjusted to the represent Falls at Oregon City (RM26). Because local inflow estimates are needed to calculate the estimated flow at Willamette Falls, they are presented first in the following subsections.

Clackamas River

The upstream boundary on the Clackamas River (RM 1.938) is located just upstream of the USGS gage "Clackamas nr Oregon City" (14211010), located at RM 1.677. Hourly flow data are available at this gage from June 2001 to the present. Located less than 2 miles upstream of the confluence, the measured flow at the gage is assumed to represent flows from the entire Clackamas River basin, so no adjustments were made based on drainage area.

For events before 2001, the closest gage on the Clackamas is the long-term gage at Estacada (USGS 14210000), which is about 23 miles upstream of the mouth. Hourly flow data at this gage, adjusted for ungagged locals downstream using a drainage area ratio of 1.4 (940/671),was used to estimate flow for the Clackamas basin for 1996 and 1997. No routing was applied to the data.

Willamette- Portland Locals

Representing the local flow input from the ungauged area between downtown Portland and the Clackamas River confluence, the "Willamette-Portland" series is estimated using the Johnson Creek Gage at Milwaukie gage (USGS 14211550). The ungauged area downstream of the confluence was included by applying a drainage area ratio of 1.77 (94/53). No lag, peaking factors, or smoothing was applied to the data.

Balch and Willamette

The Balch+Willamette local contributing flows is based on the extents of the Balch Creek-Willamette River HUC10 boundary (170900120202). This HUC10 is divided into two HUC12 areas, the Columbia Slough (57 square miles) and Willamette River locals (65 square miles), which largely consist of the west hills of Portland.

Flows for the 65 square miles of the Balch+Willamette basin that flows directly to the Willamette River (as opposed to toward the Columbia and Columbia Slough) are estimated using the Johnson Creek at

Sycamore gage (USGS 14211500). The data were multiplied by a drainage area ratio of 2.42 (65/27). This method may bias the estimated flows high considering the high urbanized of the basin downstream of the Sycamore gage compared to the unurbanized fraction upstream of the gage; however, the error is negligible when considering the flow volumes in the Willamette and Columbia Rivers.

Willamette River at Willamette Falls

As mentioned earlier, flow is not measured at Willamette Falls at the upstream model boundary condition. Inflow estimates are derived from the next best available data, with are the measured flow at the USGS gage at Morrison Bridge (14211720) about 14 miles downstream of the falls. Flow data at the falls is calculated by subtracting Willamette-Portland locals from the Morrison Bridge data, shifting the time series for the estimated one-hour travel time from Willamette Falls to downtown, and then subtracting the Clackamas inflows.

The flow at Portland is constructed using the hourly filtered data when available. For 1996 and 1997, flow at Portland is based on the daily average data that is available. The daily data are converted to instantaneous data and centered at noon. No manual adjustments were made to the estimated hourly flow series to adjust for the underestimated instantaneous peak or maximum daily volume, or the likely early timing of the peak. The reported peak annual peak on the USGS website is equal to the daily average flow (420 kcfs).

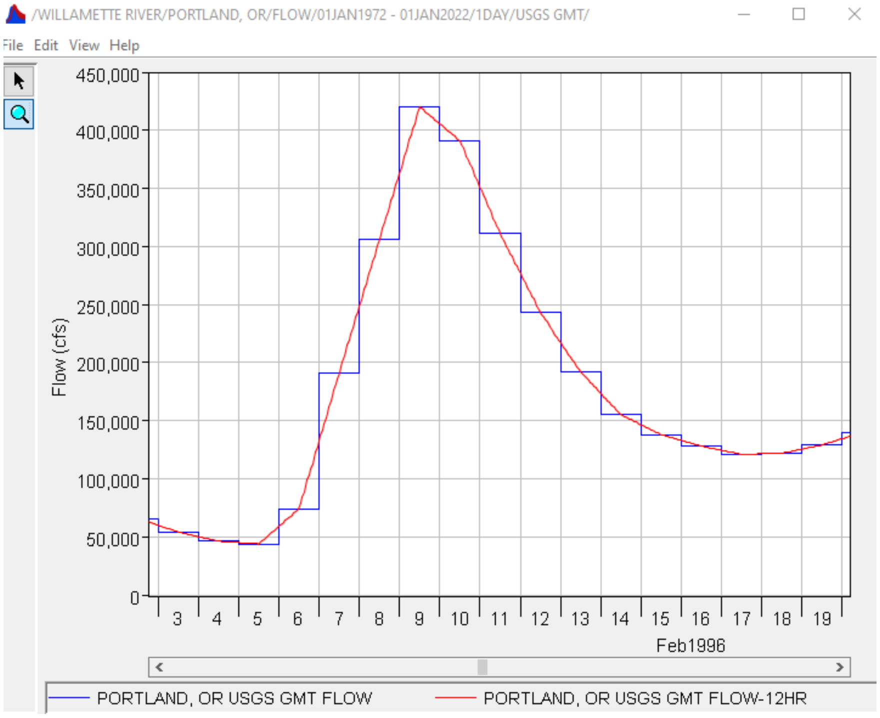


Figure 8. Daily average flow data (blue) and assumed hourly hydrograph (red) at Willamette at Portland for February 1996.

Other Local Inflows

Columbia Slough

The Columbia Slough basin (a portion of the Balch+Willamette HUC10) is 57 square miles, but the Columbia Slough itself receives very little natural inflow. MCDD pump stations may pump water into the slough during heavy rain periods but modeling this flow input is unnecessary for determining hydraulics on the Willamette River. The maximum capacity of all pump stations combined is about 600 cfs. USGS gage 14211820 (Columbia Slough at Portland, OR) has intermittent flow records from 1988 to present, but due to the relatively little inflow and the proximity to the Willamette-Columbia confluence, this gage is nearly in constant backwater conditions and measures flow only of the tidal flux in and out of the slough. Considering the relative size of this local drainage basin and its location, Columbia Slough flow is not estimated but assumed to be insignificant. A constant flow of 50 cfs is applied to the model only for stability.

Multnomah Channel

The Multnomah Channel watershed is based on the HUC10 drainage area of 191 square miles and is comprised of the west hills of Portland to Scappoose and Sauvie Island between the Multnomah Channel and the Columbia River. There are no representative streamflow gages in the Multnomah Channel watershed. The nearest and most similar gage is the East Fork Lewis River near Heisson gage (USGS 14222500) across the river in Washington. Flow data from the East Fork Lewis River gage were multiplied by a drainage area ratio of 1.53 (191/125) to estimate flows for this drainage area. Partitioning of this HUC into inflow locations is described in Boundary Condition Linking section.

Salmon Creek and Burnt Bridge

The Salmon+Burnt Creek local contributing flows is based on the on the Salmon Creek-Frontal Columbia River HUC10 boundary (1708000301). Like the Multnomah Channel watershed, there are no reliable streamflow gages within the Salmon+Burnt Creek watershed, and the most appropriate nearby gage available for flow estimation is the East Fork Lewis River at Heisson (USGS 14222500). This dataset was multiplied by a drainage area ratio of 1.67 (209/125) to develop the flows for this area. The final East Fork Lewis River at Heisson flows were multiplied by a DA ratio of 1.67 (209/125) to develop the flows for this area.

Lewis River

Lewis River inflows to the Columbia River are estimated as the sum of Lewis River at Ariel (USGS 14220500), East Fork Lewis River near Heisson (14222500), and ungauged locals between the two gages and the terminus at the Columbia River. Local inflows for the downstream area are accounted for via application of a drainage area ratio of 1.7 (212/125) using the East Fork gage. Routing was considered negligible, so no lag was added when combining the data. The individual and combined datasets are compiled in regular 30-minute data intervals. Daily data were used to fill gaps during the WY1997.

Stage Record Construction

Columbia River at St Helens

Measured, hourly stage data at the NOAA Columbia River at St Helens gage (9439201) are available starting in March 1986, but data are missing for the February 1996 flood event. These observed data are used as the downstream stage boundary conditions in the model for all simulations except February 1996. For the February 1996 event, modeled-observed output from the LCR RAS model, adjusted slightly based on other observed peak elevation data, are used as the downstream boundary in the present model.

The LCR model and inflow hydrology methods have been reviewed and show very good calibration against observed data, matching both timing and magnitude at low and high flows. Below are two plots from the LCR RAS documentation that describe modeled accuracy at St Helens and one plot comparing modeled and observed hydrographs for the January 1997 event, which is the next largest flood simulated and the highest with observed data available for comparison.

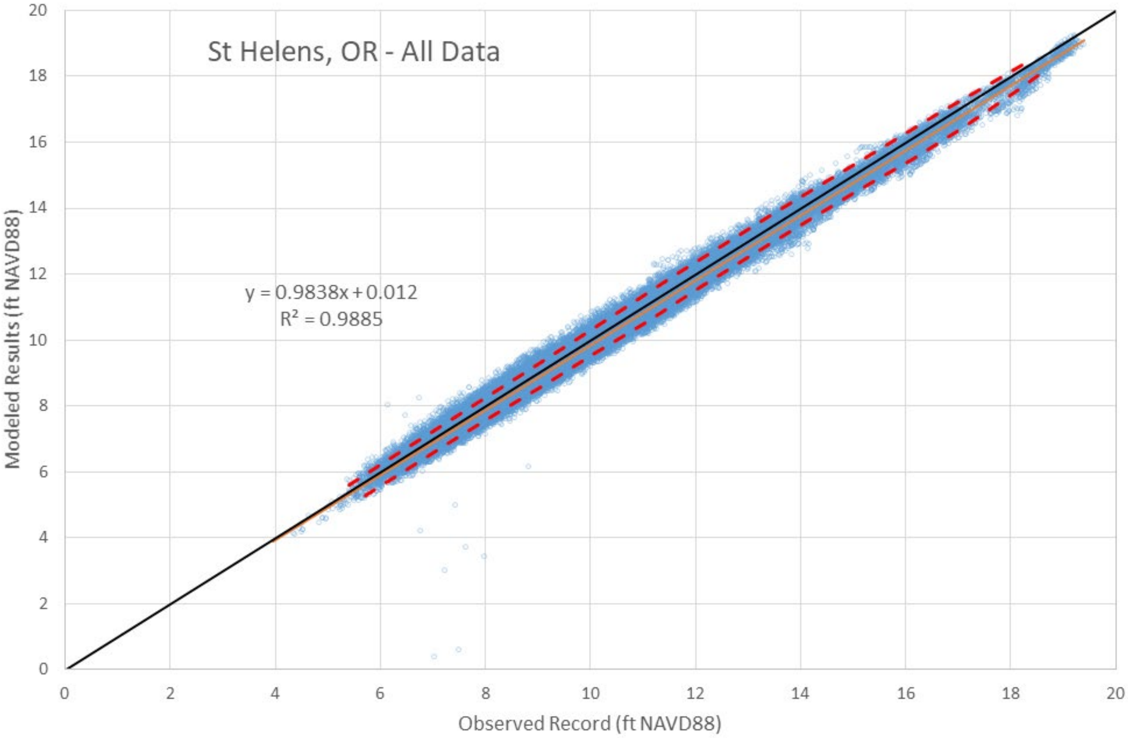


Figure 9. Hourly comparison of observed and modeled results at St Helens for years 2002 to 2017.

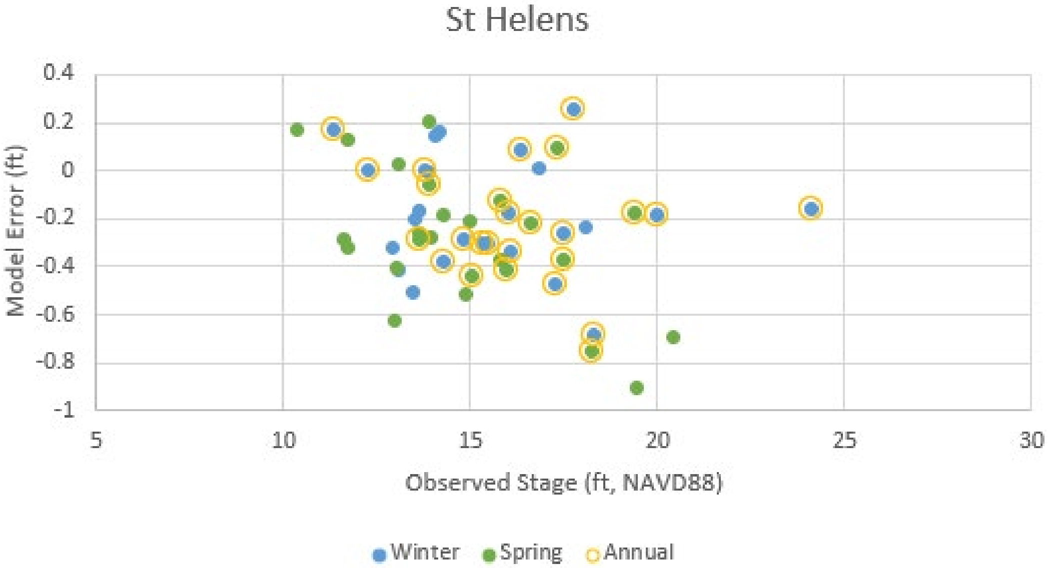


Figure 10. Peak stage model error (modeled minus observed) at St Helens for year 1990 to 2017.

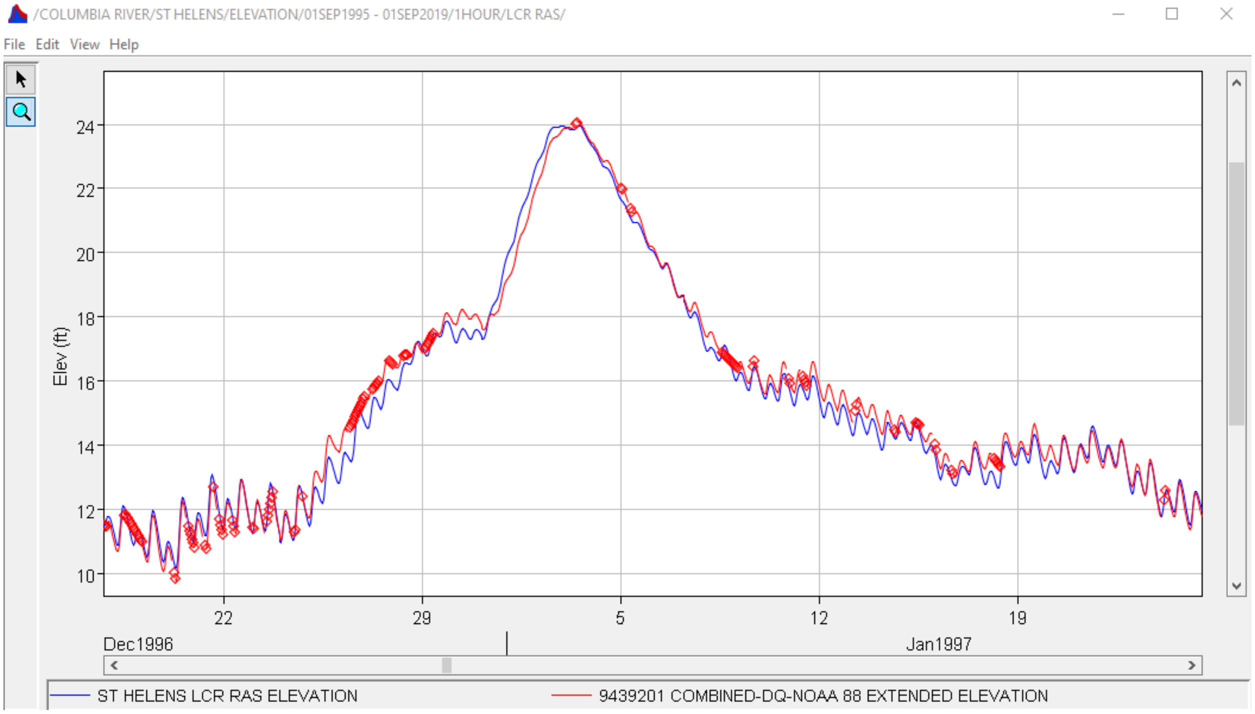


Figure 11. LCR RAS Modeled and measured flow at St Helens for January 1997 flood event.

Despite good calibration for most events, the modeled results for this largest flood in recent record are higher than observed data through much of the Columbia River. The unadjusted stage hydrograph from the LCR RAS model at St Helens peaks at 28.95 feet NAVD88. This is 0.9 feet higher than the elevation of 28.02 feet published in CH2MHILL February 1996 flood event high water mark survey compilation (CH2MHILL 1997), and 1.8 feet higher than the peak elevation of 27.13 feet NAVD88 reported for the event on the NOAA site (station elevation is 23.00 feet.) Overestimated water level at St Helens is consistent with over-estimated water levels downstream at Longview (over 2 feet higher than observed peaks) and generally compared to the suite of highwater marks along the Columbia River.

Because this event is so important for calibration, it is prudent to adjust the hydrograph so the peak stage is closer to the observed high water marks that are expected to better reflect the actual peak water surface. Figure 12 shows the unadjusted LCR RAS model results and the adjusted hydrograph used for the downstream boundary in the February 1996 simulation for calibration of the present model. Note that the adjustments only occur above 24 feet NAVD88 since the LCR RAS model has shown good calibration to peaks at and below this elevation.

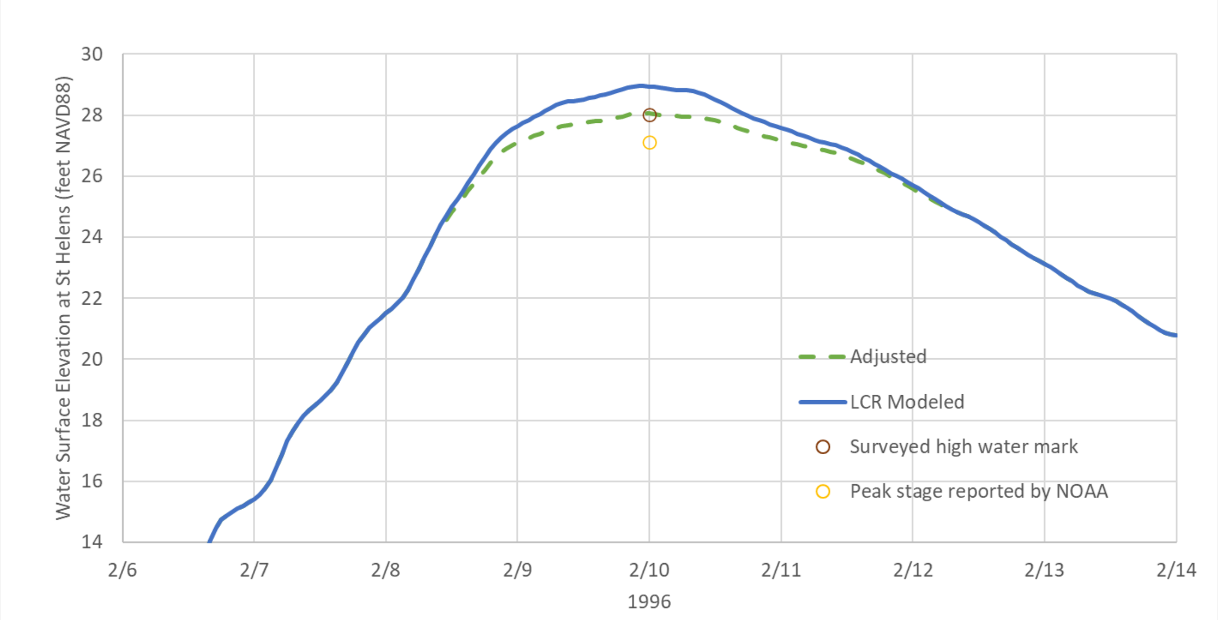


Figure 12. Comparison of February 1996 unadjusted modeled stage at St Helens, observed data points from different sources, and the adjusted stage hydrograph used as downstream boundary for the current model.

Boundary Condition Linking

The HEC-RAS model is comprised of multiple boundary conditions in the unsteady flow file. Table 3 and Table 4 below provide a summary of the data used for the model and each location the flow or stage data is applied.

Table 3. Reach boundary conditions.

River	Reach	River Station	Boundary Condition	Flow Input	Factor
Clackamas	Clackamas	1.938	Flow Hydrograph	Oregon City Local	1
Columbia	RM 101-110	110.288	Flow Hydrograph	Vancouver	1
Columbia	RM 086-86.5	86.1	Stage Hydrograph	St Helens	1
Columbia Slough	Reach 1	8.748	Flow Hydrograph	Constant Flow 50 cfs	1
Lake	Reach 2b	7.969	Uniform Lateral Flow	Columbia+Salmon Creek Local	0.11
Multnomah	Reach 1	12.926	Uniform Lateral Flow	Multnomah Channel Local	0.19
Multnomah	Reach 1	1.533	Lateral Inflow Hydrograph	Multnomah Channel Local	0.17
Willamette	RM 25-Falls	25.913	Flow Hydrograph	Blw Willamette Falls	1
Willamette	RM 16-25	20.792	Lateral Inflow Hydrograph	Portland Local Milwaukie	0.44
Willamette	RM 16-25	16.054	Lateral Inflow Hydrograph	Balch + Willamette Local	0.27
Willamette	RM 03-14	13.276	Uniform Lateral Flow	Balch + Willamette Local	0.73

Table 4. Storage area boundary conditions.

Storage Areas	Boundary Condition	Flow Input	Factor
Johnson Creek	Lateral Inflow Hydrograph	Portland Local Milwaukie	0.56
Lewis River	Lateral Inflow Hydrograph	EF Lewis + Lewis Local	0.38
Ridgefield Refug	Lateral Inflow Hydrograph	Columbia + Salmon Creek Local	0.07
Salmon Creek	Lateral Inflow Hydrograph	Columbia + Salmon Creek Local	0.44
Scappoose Bay	Lateral Inflow Hydrograph	Multnomah Channel Local	0.48
Sturgeon Lake	Lateral Inflow Hydrograph	Multnomah Channel Local	0.16
Vancouver Lake	Lateral Inflow Hydrograph	Columbia + Salmon Creek Local	0.38

The flow and stage hydrographs for the upstream and downstream boundary conditions were based on the compiled data for specific gage locations. The remaining flow locations and flow multiplication factors were chosen based on the HUC 12 boundaries, topography, and aerial imagery.

The Portland Local Milwaukie flows were divided between two locations, the Johnson Creek Storage area and RM 20.792. The location at RM 20.792 was chosen to simulated flows from Tryon Creek as well as some other local area flows in Lake Oswego. The Johnson Creek at Milwaukie gage was used for the flows into the Johnson Creek storage area. The HUC 12 boundaries were used to divide up the flows between the two flow locations.

The Balch + Willamette Local represents the HUC 12 Balch Creek Willamette River area that begins downstream of the Confluence with Johnson Creek downstream to the confluence with the Columbia River. The complied flow data were divided between two areas, one at a large culvert at the upstream end of Will-Ross Island Reach on the east side and the second near the Ross Island Bridge. Most of the flow is applied as a uniform lateral flow from approximately the Ross Island Bridge to just upstream of the Multnomah Channel.

The Multnomah Channel Local was split up into four locations. Figure 20 below shows the HUC 10 for the Multnomah Channel and the HUC 12 boundaries within that area. The drainage area for Milton Creek is applied as a lateral flow at RM 1.533 on the Multnomah Reach. The combined drainage area for the North Scappoose, South Scappoose, and Scappoose Creek was used as the factor for the flows assigned to Scappoose Bay. The drainage area for the HUC 12 Multnomah Channel was split between the east and west side of the reach. The eastern portion was applied to Sturgeon Lake and the longer western portion was applied as a uniform lateral flow along the Multnomah Reach.

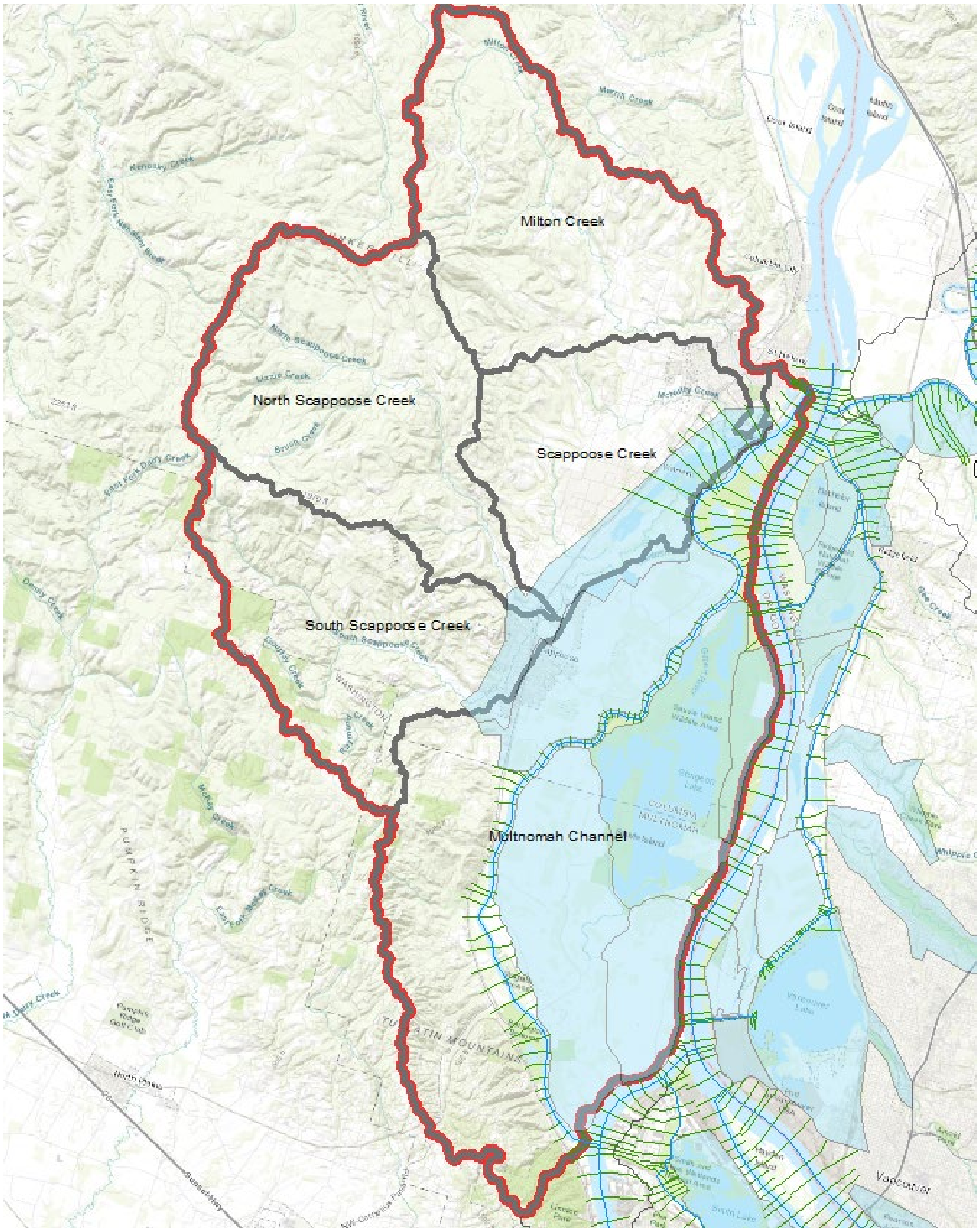


Figure 13. HUC 10 and HUC 12 Drainage Areas for the Multnomah Reach.

The Columbia + Salmon Creek Local split up into four locations. Figure 21 below shows the HUC 10 for the Salmon Creek-Frontal Columbia River HUC 10 and the HUC 12 boundaries within that area. The contributing flows from the combined Upper and Lower Salmon Creek drainage areas were assigned to the Salmon Creek storage area. The drainage area for Gee Creek was assigned to the Ridgefield Wildlife Refuge storage area. The combined drainage area for the Burnt Bridge Creek boundary and the area upstream of the Salmon Creek confluence was applied to the Vancouver Lake storage area. The remaining flows were applied to the model as a uniform lateral flow along Lake Reach 2b.

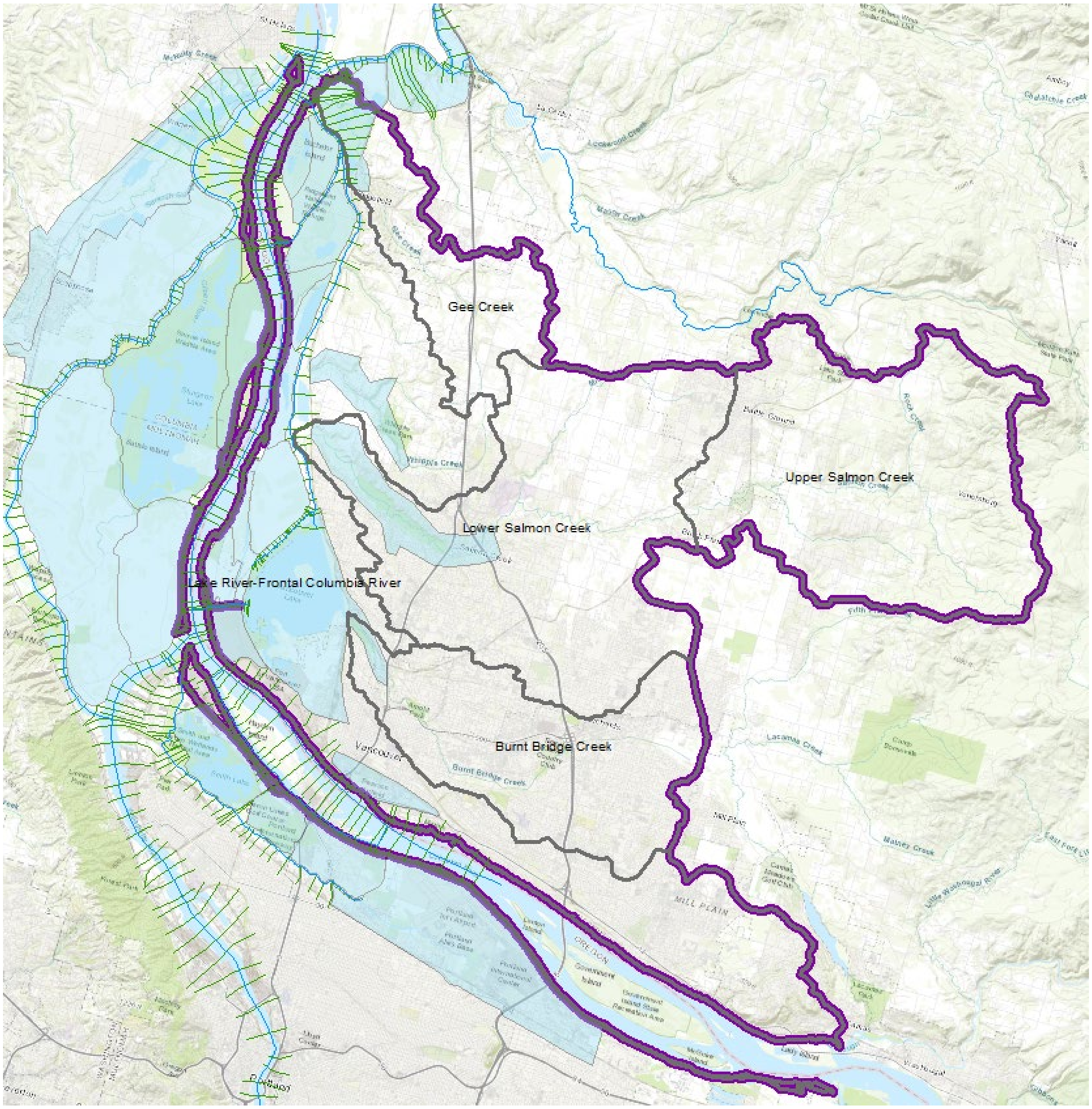


Figure 14. HUC 10 and HUC 12 Drainage Areas for the Columbia + Salmon Creek flows.

Calibration

Calibration and Validation Events

The February 1996 event is a landmark event which is often used the design event for planning studies in the regions. There are numerous high water marks available that allow for a good peak flood profile calibration throughout the Willamette reach. There is also a GIS shapefile generated by the City of Portland's Bureau of Environmental Services (BES) that demarks the maximum inundation boundaries of the flooding.

Other more recent events, including 1997, have better observed flow and stage records. Table 6 lists several high flow and stage events that are used in calibration. All are useful for calibration as they represent a range of high flow combinations on the Willamette, Columbia, or both.

Table 5. Measured peak stage and flow data for historic events used for calibration.

	Peak stage (feet NAVD)		Peak flow (kcfs)	
Event	Morrison St Bridge	blw Willamette Falls	Willamette flow	Columbia flow
Feb-96	32.6	43.0	420	543
Jan-97	27.8	40.2	293	425
Jun-97	23.4	23.5	17	590
Jan-11	18.8	27.5	149	338
Jun-11	**22.0**	22.7	50	**550**
Jan-12	17.8	**32.1**	**211**	215
Apr-12	**20.7**	**29.4**	158	**485**
Mar-17	**22.2**	25.8	125	**495**
May-18	**20.5**	20.3	15	**505**
Apr-19	**20.5**	**29.6**	**181**	390

Simulation periods are set wide enough to include typical and low water periods in most years. While flood profiles are the main focus of the model, the model is calibrated to all water level conditions.

Calibration challenges

Measured stage data accuracy

Accuracy and precision of measured stage and flow data can create calibration challenges. Whether there are shifts or slow drifts in elevation data (not evident in a nearby gage) or uncertainty with station datum survey accuracy, time issues where one series obviously shifts from standard time to daylight savings time, or uncertainty in instrument calibration for velocity measurement, the observed gage records are known to be imperfect. A series of investigations were done to try to establish an understanding of which gages might be out of vertical control, when, and by how much. All of these can be demonstrated in a number of ways. Simply looking at multiple time series data together often highlights incongruities and provides a sense of the precision of the data.

Using model results to establish a physics-based picture of what relative water level heights about the confluence area should be during different flow conditions, and then comparing that to what the observed records show is useful in identify when a gage might be out of vertical control and by how much. A basic comparison of modeled water surface at gage locations yield the following conclusions:

- Vancouver USGS, which is located about 2 miles upstream, is always higher than Vancouver NOAA in the model. The difference tends to be linked to Columbia flow, with higher spring flows linked to greater differences in water levels between the two gages. The differences range from 0.1 feet to 0.3 feet.
    - The observed difference between in water levels between the two Vancouver gages shows a completely different pattern in all year except 1997. Vancouver NOAA is consistently higher than Vancouver USGS by about 0.2-0.5 feet, with smaller difference typically occurring in the spring.

  - Figure below shows the difference in stage from Vancouver USGS to Vancouver NOAA about 2 miles downstream. The modeled difference (red) is consistently positive reflecting a downward slope in the river, and slightly larger difference during the spring than winter. The observed difference (green) shows consistently negative (river flowing uphill), some years show consistently larger differences than others with some shifts and drifts apparent. The observed also shows the large fluctuations starting in 2018 that can be attributed to the two datasets being out of phase (likely PST vs. PDT).

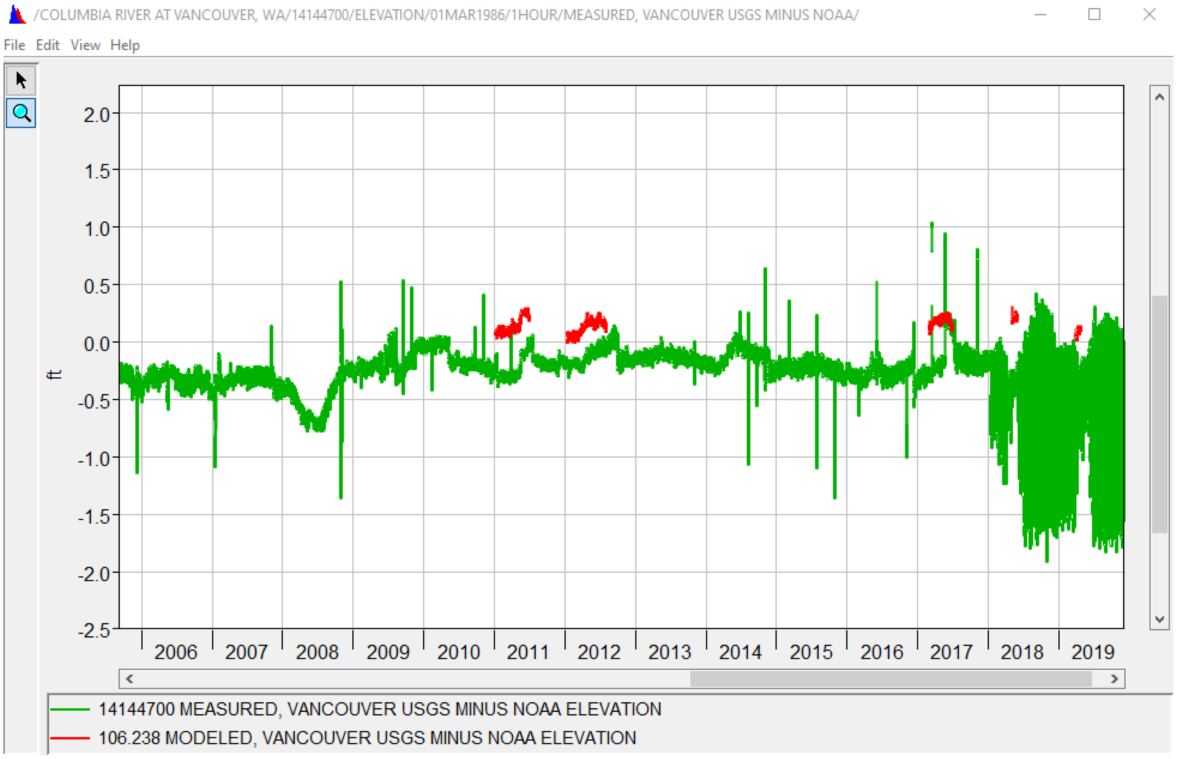


Figure 15. Comparison of the decrease in stage from the USGS gage at Vancouver and the NOAA gage at Vancouver between modeled results and measured data.

- During low flow conditions on both rivers, the Vancouver NOAA and Morrison Street gages are within 0.1 feet of each other in the model. Vancouver NOAA is never more than 0.2 feet higher than Morrison Street, but during high Willamette flows, it is not uncommon for the Morrison Street bridge to be several tenths of a foot higher than Vancouver NOAA, exceeding 0.5 to 1.0 feet higher with some events.
  - This is seldom the case with the measured data. The Vancouver NOAA gage is consistently 0.5 feet higher than Morrison Street, and Morrison is very seldom above Vancouver NOAA. At low flows, the gages are similar but Vancouver NOAA is consistently a couple tenths of a foot higher than Morrison Street.
- Columbia Slough is always the lowest of the four gages in the model, except when the Willamette River is flowing very high relative to the Columbia River. In such circumstances, water levels at Columbia Slough gage can be higher than the Vancouver at NOAA gage, but not by more than 0.1 feet. The Willamette River water level at Morrison Street is always equal to or higher than the Columbia Slough water level.

- The observed Columbia Slough water levels are consistently 0.1 to 0.2 feet higher than Morrison Bridge, and never higher than the Vancouver NOAA gage.

It should be noted that USGS revised the gage zero elevation for the Willamette at Portland gage in 2018 upwards by 0.25 feet based on a new survey, and this modification is included in the dataset (USGS 2019). It is unknown whether a comprehensive gage comparison was done looking at the other confluence-area gages. It is also understood that Columbia Slough gage has not been surveyed in some years and is generally understood to be of poor vertical control.

Given the quality of the underlying bathymetry and established physics of hydraulic modeling, the modeled relationships between observed stage datasets indicate that vertical control for the confluence gages as a set is in question and absolute vertical accuracy of the calibration and results reflects that uncertainty. Attempting to tightly match all observed data (at all gages for all events) forces unrealistic calibration parameters or is simply not possible. Calibration within a few tenths of a foot for any given year should be considered as good as possible. The strategy for calibration is to split the difference and try to achieve a reasonable calibration for all years, knowing that modeled results will be high one year and low the next.

Measured flow data accuracy

Comparison of the modeled-observed Columbia River flows and the measured flows at Vancouver was presented in the Flow Record Construction section. The question of which method is more accurate is not yet answered.

To address the Vancouver flow uncertainty, simulations were developed to determine the sensitivity of Vancouver flow error on Willamette River stages. Results were compared using estimated and USGS-measured flow at Vancouver for 2016 through 2019 as inflow to the Lower Willamette HEC-RAS model. The data suggest a 10% difference in flow can result in a 0.30- to 0.45-foot change in water level at Morrison Bridge. The data also suggest that Vancouver flow error is less impactful during period of high Willamette flow, where a 10% change in Vancouver flow may change water levels less than 0.2 feet.

Changing channel conditions

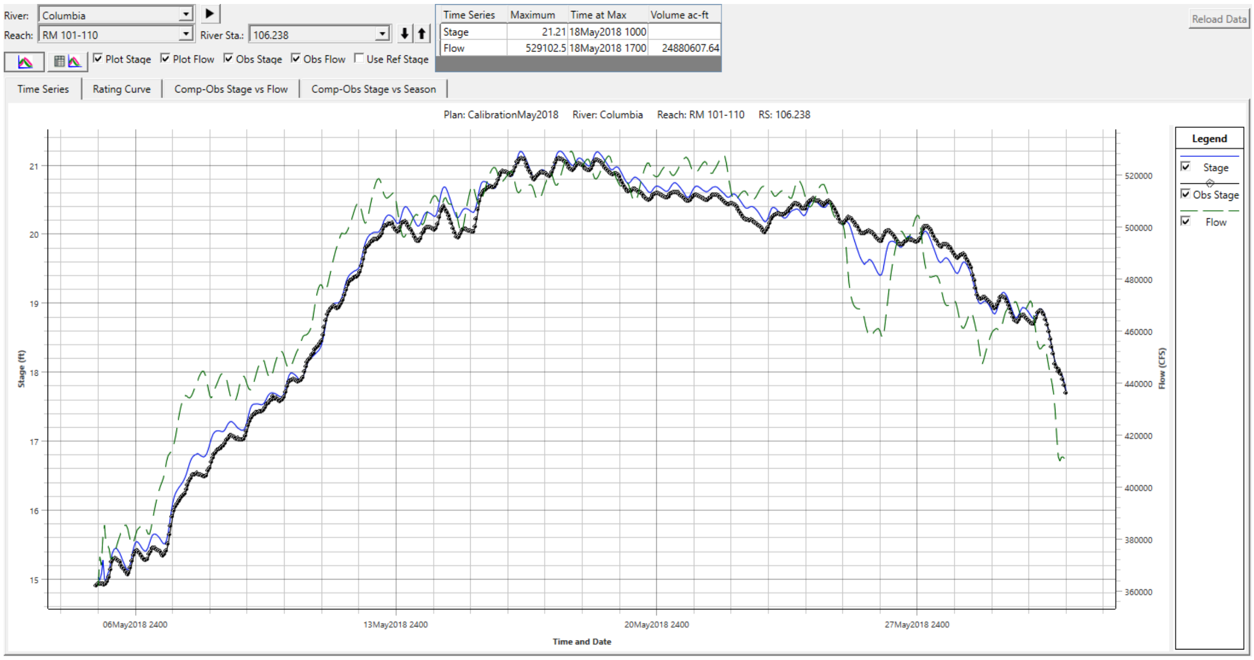
It should be noted that the river channel has been consistently changing over the past century. A USACE investigation has identified increased model error with historic events and a significant trend from more to less error throughout the measured period, suggesting that conveyance has increased over time. The implications of this phenomenon would be lower peak water levels occurring today compared to those that occurred historically under the same flow conditions. The trend is more pronounced in the spring than in the winter, likely due to increase uncertainty with local inflow estimation during winter rainflood events. For more discussion on this, see Appendix A of the Portland Metro Levee Study (https://www.nwp.usace.army.mil/Missions/Projects-and-Plans/Portland-Metro-Levee-System/)

Because the model is intended to represent current conditions, calibration of recent events is prioritized. However, the February 1996 event provides the only simulation with a robust high water survey dataset with which to calibrate the water surface profile away from gages. Also, the 1996 flood is a benchmark event used directly for floodplain management by the City of Portland.

This phenomenon may not have much significance for the present calibration effort, other than to perhaps err toward underestimating water levels during 1996 instead of overestimating them, but it may have larger implication for future studies related to stage-frequency statistics and more comprehensive studies on flood risk in the Lower Columbia River if the trend continues.

Calibration Results

Calibration results are voluminous considering that seven different simulations were evaluated, some of which containing both winter and spring events, and that there are five gages available for comparison. Generalized results are provided in this section. Hydrograph comparisons and modeled vs. measured water level scatter plots are available in Appendix B. Examples of both are provided below. A summary of the modeled error (modeled minus measured) about event peaks is presented in the table below.



River: Columbia
Reach: RM 101-110 River Sta.: 106.238
☑ Plot Stage ☑ Plot Flow ☑ Obs Stage ☑ Obs Flow ☐ Use Ref Stage

Time Series	Maximum	Time at Max	Volume ac-ft
Stage	21.21	18May2018 1000	
Flow	529102.5	18May2018 1700	24880607.64

Figure 16. Example hydrographs from HEC-RAS comparing modeled (blue) with measured (black) water surface at the USGS Vancouver gage for the May 2018 event. Modeled flow (green) is also shown.

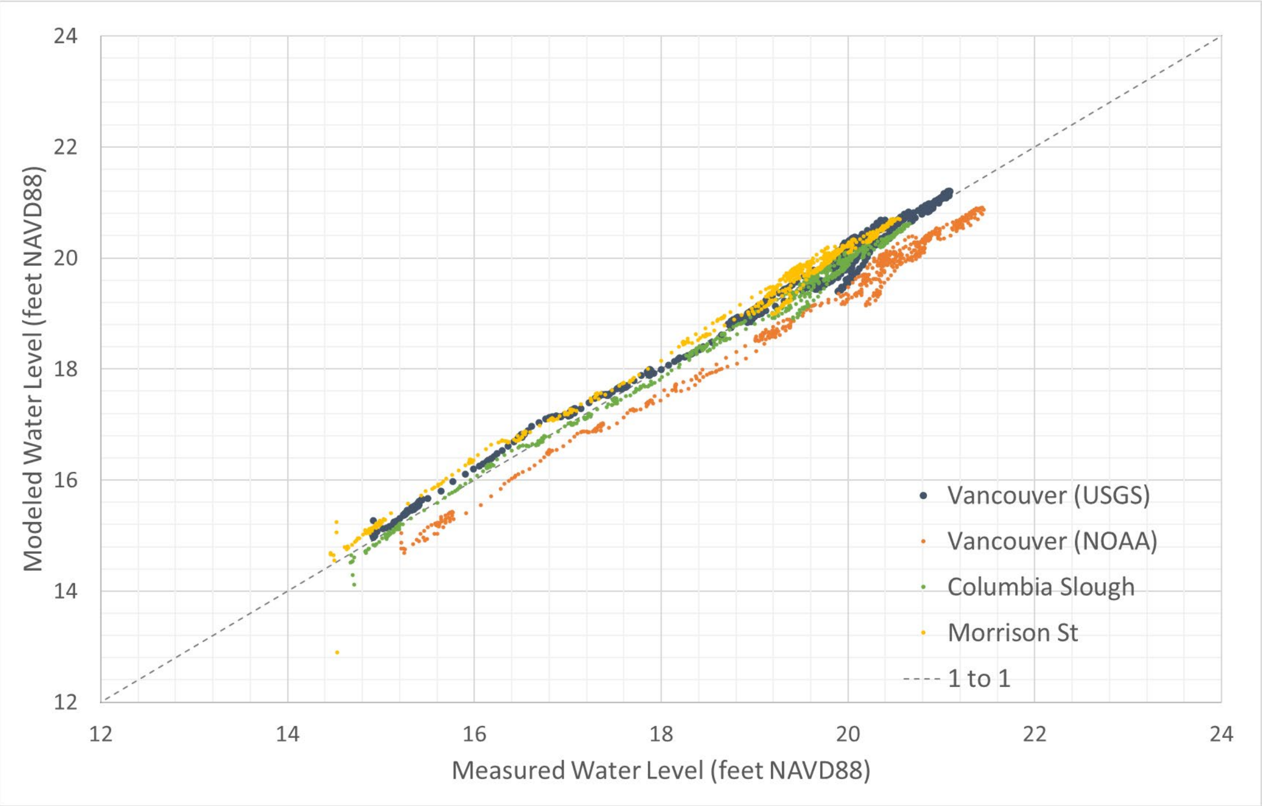


Figure 17. Example modeled vs. measured water surface scatter plot for the May 2018 event.

A summary of the modeled error (modeled minus measured) about event peaks is presented in the table below. The model predicts peak water surface elevations within a foot for all scenarios and at all gages. Average differences are in the order of tenths of a foot. Water levels at Vancouver NOAA gage tends to be underestimated and water levels at Morrison Street tend to be consistently overestimated. The differences between modeled and measured peaks suggests that the model might be calibrated slightly high, although it certainly is not the case in all years. Spring events might tend to be calibrated lower than winter events, but this is not always the case. The modeled water levels in the spring of 1997 are consistently low. This could at least partially be attributed to the USGS flow data for this event being actually sourced from the USACE at-site estimates, which are known to be generally lower than the USGS measured flow. Channel changes following the February 1996 and January 1997 floods may have occurred and contributed to a modeled versus measured difference for the June 1997 event.

Table 6. Differences (modeled minus observed) in peak stages for simulated events.

	Feb-96	Jan-97	Jun-97	Jan-11	Jun-11	Jan-12	Apr-12	Mar-17	May-17	May-18	Apr-19
Vancouver (USGS)	-0.4	NA	-0.8	0.3	0.2	0	0	0.2	0	0.1	0.2
Vancouver (NOAA)	NA	-0.4	-0.8	-0.2	-0.3	-0.2	-0.3	-0.3	-0.3	-0.5	-0.4
Columbia Slough	NA	-0.7	-1	NA	-0.1	NA	NA	-0.1	-0.1	0	0
Morrison Street	0.3	0	-0.6	0.3	0.2	0.5	0.3	0.4	0.2	0.2	0.3
Willamette Falls	NA	1	-0.7	-0.2	0.3	-0.7	-0.3	0	0.2	0.2	0.7

Looking specifically at the February 1996 event, calibration to high water marks is very good. Figures 18 through 20 shows the peak modeled water surface profile and surveyed high water marks through the major river reaches in the model. Note that some error with high water mark survey is not uncommon. For example, the two high water marks at the upper end of Multnomah Channel (about RM 20 in the figure) can be disregarded due to being obviously incongruous with the other high water marks. Similarly, the two high water marks in the lower third of the Columbia River profile should be disregarded due to being obviously high. (This is more apparent when looking at the entire Columbia profile of surveyed high water.)

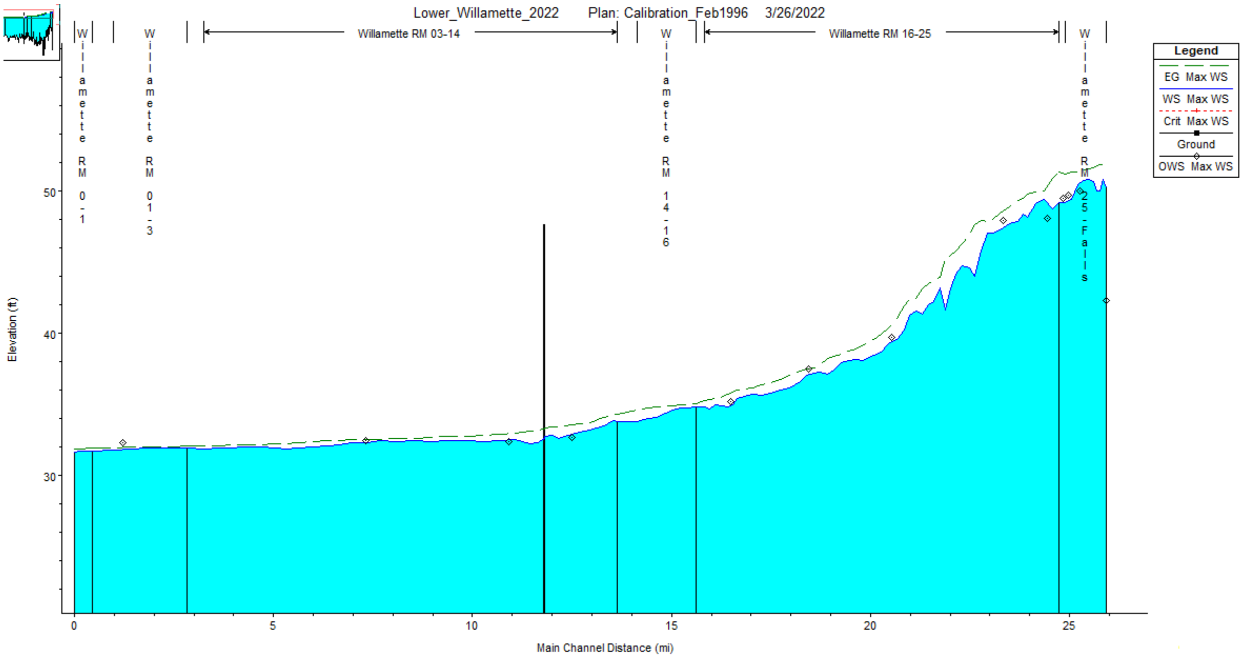


Figure 18. Maximum water surface profile and observed high water marks on Willamette River from the Columbia River to Oregon City.

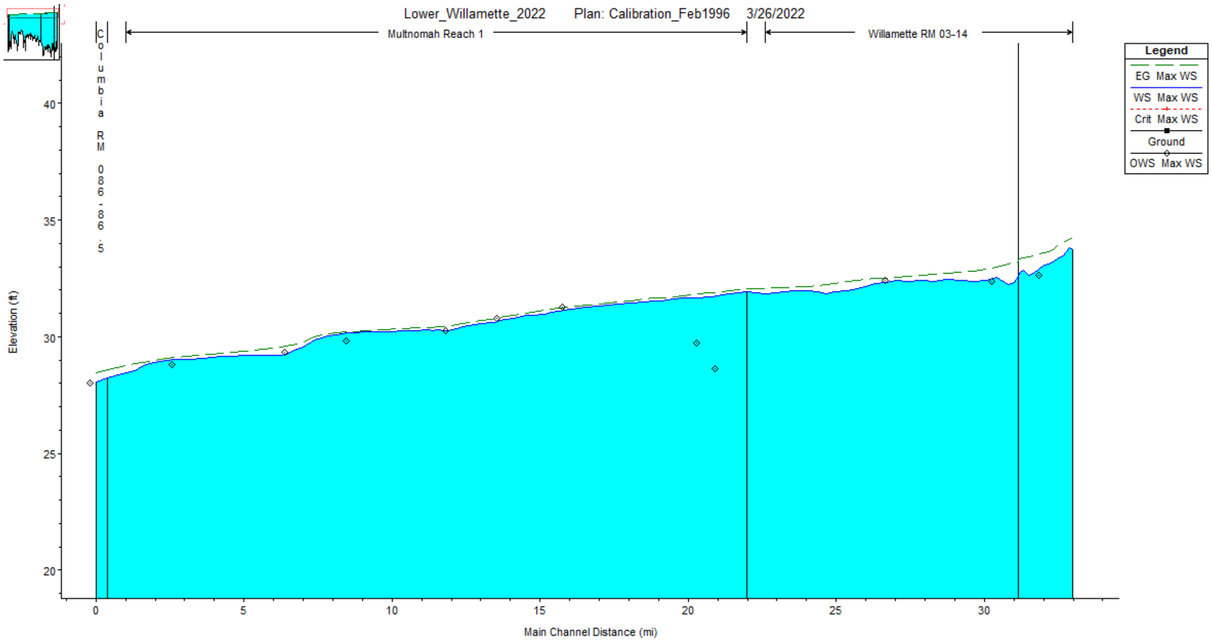


Figure 19. Maximum water surface profile and observed high water marks on Multnomah Channel and the Willamette River from the Multnomah Channel confluence through downtown to RM 14.

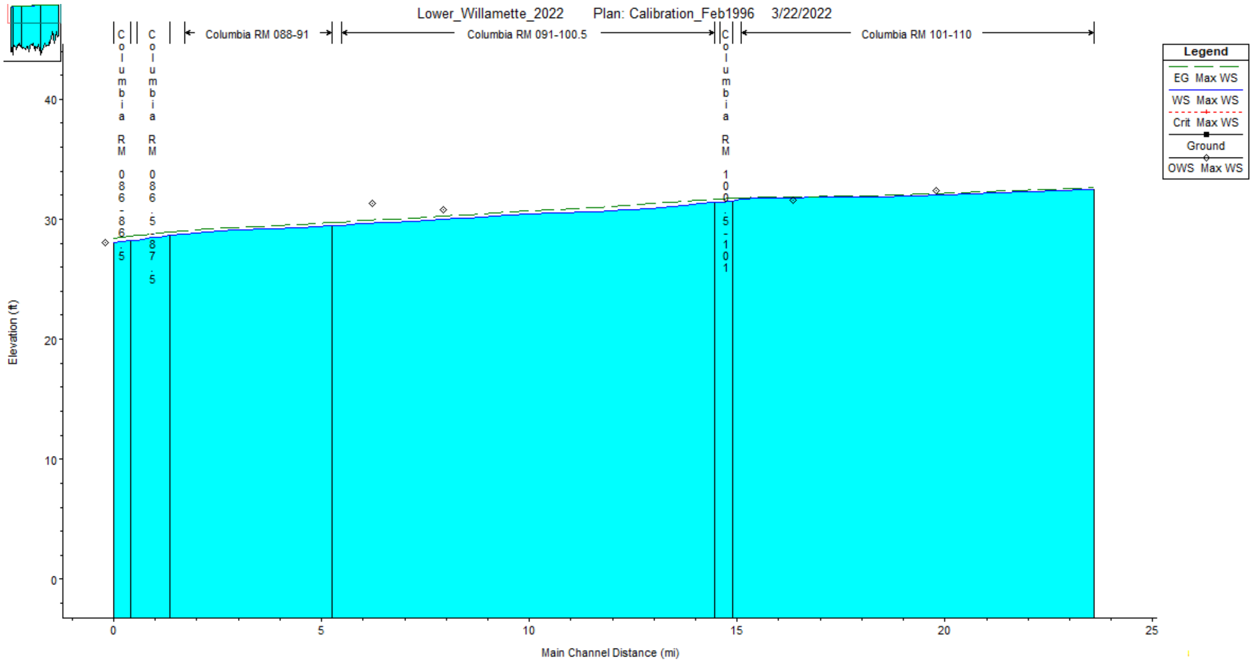


Figure 20. Maximum water surface profile and observed high water marks on the Columbia River from St Helens to Vancouver.

Mapped results comparing modeled peak water surface depth grids with observed maximum inundation extents for the February 1996 event show very good calibration. See screen captures from RASMapper in Figure 21.

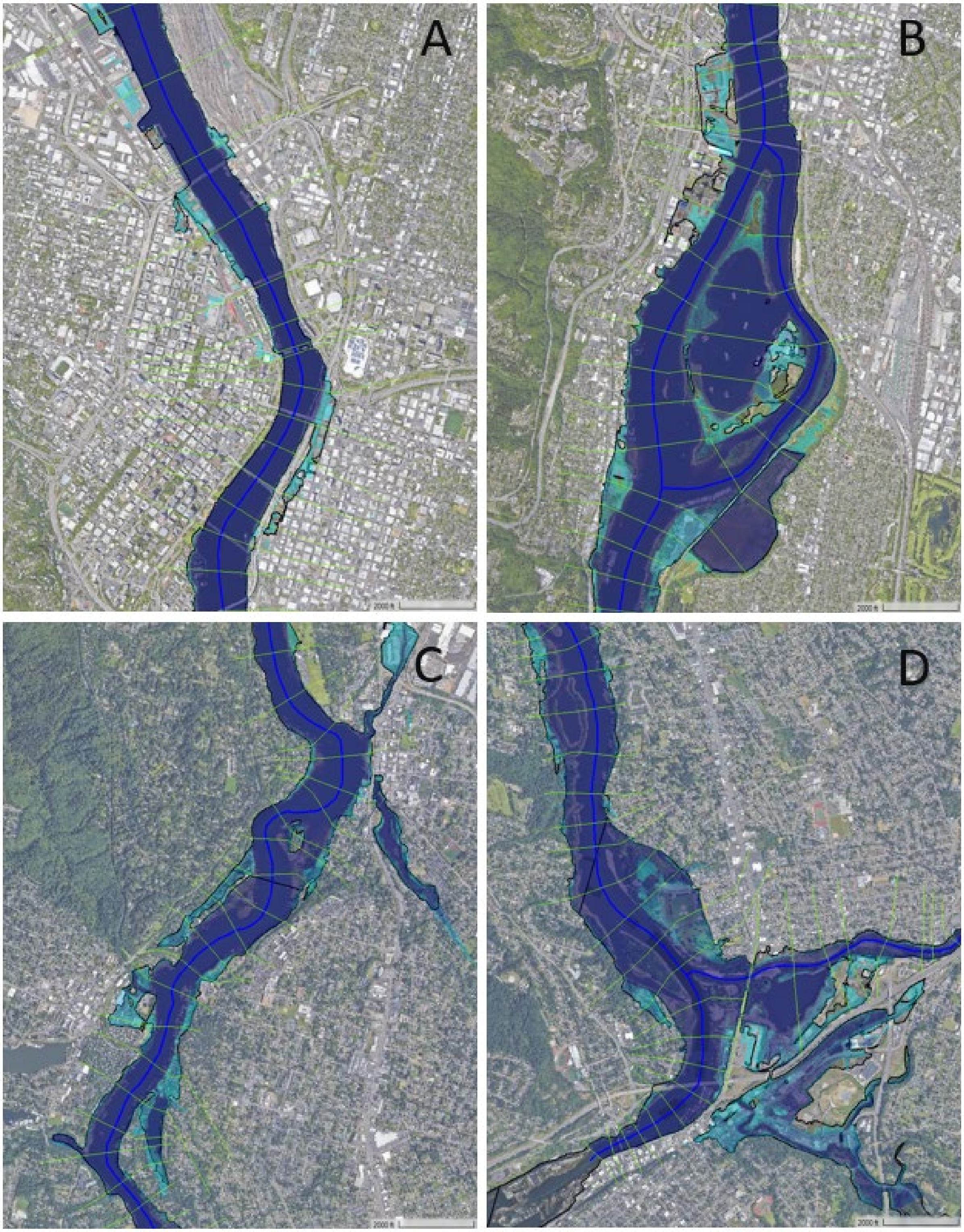


Figure 21. Comparison of modeled and observed inundation extents along the Willamette River for the February 1996 event.

Conclusions and Future Work

This model represents the best available hydraulic model of the Lower Willamette River through the Portland area. The model is calibrated to within a few tenths of a foot to the set of USGS and NOAA gages about the confluence area for a range of flow conditions in most years. The model produces water surface profiles and inundation extents for the February 1996 event that closely match observed data.

Boundary conditions data from the calibration simulations are included with the model for simulation of typical and high flow conditions. Simulation of other events not included in the calibration events could performed using the flow record construction methods described in this report; however, because the LCR RAS model is not publicly available, inflow estimates at Vancouver would need to be developed using other methods, or by using measured flow data from the UGSG flow gage at Vancouver, and downstream stage boundary data would not be available for years prior to 1986.

Model improvements could still be made to the hydraulics in the upper portion of the Willamette reach if new bathymetric data were available. The current DEM relies on single beam crosslines in the main channel. The hydraulics through this reach warrant 2D modeling for better understanding of ineffective flow areas. An updated DEM would allow for 2D modeling, which would allow for refinement of the 1D model, helping validate or refine assumptions about ineffective flow areas and likely producing a smoother water surface profile.

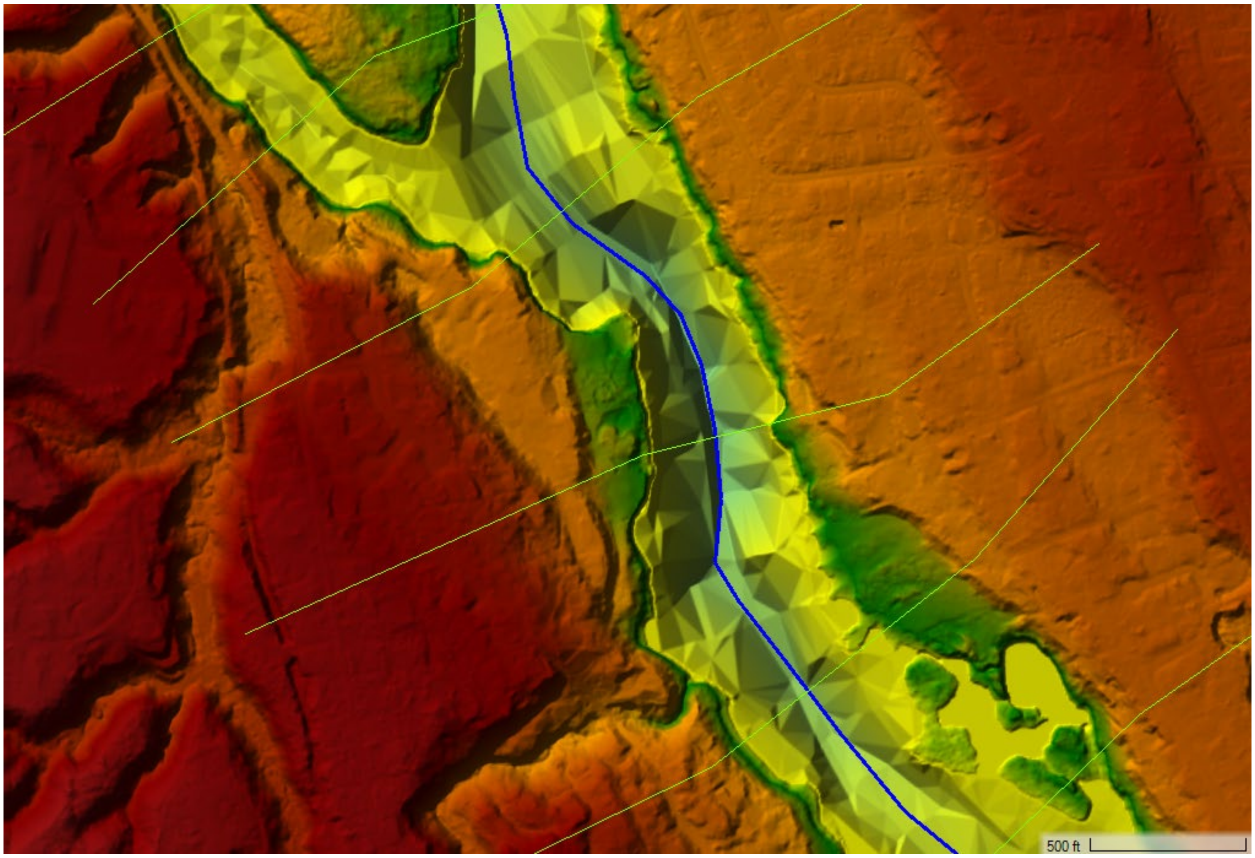


Figure 22. CWMS DEM channel developed from single beam crossline bathymetry.

Bathymetry does exist for Columbia Slough but it has not been incorporated into the model due to the backwater conditions that exist during flooding. The lack of bathymetric data on the lower Clackamas

River reach limits the ability to model this reach. These reaches were not calibrated but modeled purely for reasonable backwater profiles and exchanges with the mainstem rivers. If bathymetric data were available for the Clackamas, the DEM and cross-sections could be updated and the reaches could be calibrated.

The need to run specific design events has been stated as an immediate need. The February 1996 event can directly be used to simulate that historic flood. Additional work is required to develop boundary conditions to simulate a specific AEP flood condition, for example the 1% AEP condition. The effective FEMA model assumes a downstream boundary at the Willamette-Columbia confluence of 30.8 feet NAVD88 and simulates a peak flow of 375 kcfs on the Willamette River through most of the reach and an assumed 112 kcfs leaving at the Multnomah Channel. The provided February 1996 inflow data could be scaled to achieve the Willamette peak flows, and the Columbia inflow time series could be scaled up or down to achieve the design water surface at the Willamette-Columbia confluence.

A duplicate effective steady-state model could also be created from the present unsteady model using the same boundary conditions from the effective FEMA model. Channel roughness would likely need to be adjusted to ensure the modeled water surface profile is within 0.5 feet at every letter FEMA cross-section.

An update of Willamette River flood frequency data is underway at USACE. This study would provide peak flow frequency results on the Willamette River but may not provide coincident flow frequency information for the Columbia River. It is still undetermined how stage-frequency information will be developed.

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Arcement, G. and Schneider, V. 1989. Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Floodplains. USGS Water Supply Paper 2339.

CH2MHILL 1997. High Water Mark Survey – Contract No. DACW57-95-D-0002, Delivery Order No. 7. January 27, 1997.

USACE 2017. Water Years 1966 to 2015 Lower Columbia River HEC-RAS Results – Observed Record. February 22, 2017. Prepared by CENWP-ENC-HY.

USACE 2019. Lower Columbia River Flood Profile Data Compilation and Analysis Support. Carrie Boudreau. Draft Open File Report.

USGS 2021. Historical Streamflow and Stage Data Compilation for the Lower Columbia River, Pacific Northwest. Prepared by Boudreau CL, Stewart MA, and Stonewall AJ. Open-File Report 2020-1138.

Appendix A. Gage Record Construction

Overview

Measured stage and flow data are critical pieces of a calibrated hydraulic model. Continuous inflow data are required for all boundaries in the HEC-RAS model, as well as at the downstream stage boundary. These inflow data are constructed using the best available measured data from USGS and NOAA sites in the area. This appendix describes data sources and modifications required to create continuous datasets needed for modeling. It also describes the available data for measured stage gages used for model calibration.

All of the final inflow datasets are included in the “LowerWillamette.dss” file included with the HEC-RAS model package. Additional datasets including raw and intermediate datasets are archived in “LowerWillaemtte_full.dss”.

General Methods

The USGS’s Open File Report (OFR) 2020-1138, titled “Historical Streamflow and Stage Data Compilation for the Lower Columbia River, Pacific Northwest” was used as a primary source for gage data. This study includes detailed description of the archive sources, QA/QC procedures used in the compilation, datum conversion information, etc. The actual flow and stage records are compiled in the HEC-DSSVue file “LCR_FinalDataset.dss”.

Although published in 2021, the USGS-compiled datasets are only complete through water year 2018 in most cases. For the May 2018 and April 2019 simulations, gage data were obtained directly from USGS and NOAA online resources.

Hourly data are desirable for the precision of modeling in the present study. Processing was required to convert the often irregular and/or intermittent data to continuous datasets. Irregular data was converted to either 1-hour or 30-minute regular data using HEC-DSSVue.

For flow datasets, gaps in the hourly or sub-hourly datasets were either filled using linear interpolation (for short or non-critical periods) or supplemented with daily average data. Where daily average data were used to create hourly data, the period average, daily data were converted to instantaneous data and then shifted minus 12 hours from day-end (24:00) to noon (12:00). These data then converted from daily to hourly data and then merged with the hourly dataset created from instantaneous data to fill the gaps. All these steps were performed using HEC-DSSVue.

In some cases, additional steps were taken to create hourly flow data through a critical event peak. This was common for the February 1996 event. Record construction for these occurrences are discussed in the following section.

The data also all needed to be processed in the same time zone (Pacific standard) and vertical datum (NAVD88). The USGS-compiled data were already in these time datums and vertical datums, but online resources needed to be converted. Datum conversion information supplied in the OFR was used for this.

Detailed Notes

Columbia River Vancouver - 14144700

The irregular, unfiltered flow data were downloaded from the USGS website and converted to regularly hourly data. There were no notable gaps in the record.

Irregular water level data were obtained from the USGS-compiled record and then supplemented with irregular data from the USGS website from March 2018 to the present. The data from the USGS website were converted from station datum to NAVD88 by adding 5.26 feet.

Columbia River Vancouver - 940083

Irregular water level data were obtained from the USGS-compiled record and then supplemented with irregular data from NOAA's "Tides and Currents" website from March 2018 to the present. These data from the Tides and Currents website were converted to NAVD88 from NGVD29 by adding 3.45 feet.

Columbia River St Helens – 94392014

Irregular water level data were obtained from the USGS-compiled record and then supplemented with irregular data from the USGS website from March 2018 to the present. The data from the Tides and Current website were converted from station datum to NAVD88 by adding 4.13 feet.

There are notable gaps in the dataset from January 1996 through May 1996 and sporadic data for the remainder of the calendar year. Due to a lack of data and the challenges estimating Columbia River water levels in this reach, modeled-observed results from USACE's Lower Columbia River HEC-RAS model were used for the February 1996 simulation.

Columbia Slough – 4211820

Similar methods were used to create continuous hourly water level data at the Columbia Slough gage. Downloaded data from the USGS website from October 2017 to the present were converted to NAVD88 by adding 4.92 feet. Some large gaps were present in the dataset, but a continuous dataset is not required for this stage gage.

Lewis River at Ariel – 14220500

Irregular, sub-daily flow and regular daily average flow data were downloaded from the USGS website. Sub-daily data were available from October 1999 and July 2021, but daily average flow data were present for the 1996 and 1997 simulation periods. Daily average flow data was used to supplement both small, non-critical gaps as well as the entire period including event peaks in 1996 and 1997. Daily average flow data were converted from period-average to instantaneous, then shifted minus 12 hours from day-end (24:00) to noon (12:00). This method will slightly underestimate daily volume and peak flow at an event peak, but it deemed accessible considering application of these data in the model (a local inflow basin far removed from the Willamette River).

East Fork Lewis River near Heisson - 14222500

The irregular time interval data was taken from the USGS website. There are large gaps in the instantaneous dataset during the February 1996 events and the January 1997 event; however, daily average flow data were available throughout both events.

For the gap in the February 1996 event continuous hourly flow data were developed from daily average flow data, peak flow statistics from the USGS glow statistics page (28.6 kcfs), and limited hourly data present in the USGS-compiled record. For the gap in the February 1996 event (2/1-2/7), 2/1-2/5 used continuous hourly flow data developed from daily average flow data and 2/6-2/7 used the available 30-minute data. The flow on 2/8 was shaped manually to both contain the estimated peak flow (assumed at noon) and match the daily average flow. The gaps in the January 1997 dataset (1/8-3/9) were filled using daily average data.

Willamette River below Willamette Falls – 14207770

Irregular water level data were obtained from the USGS-compiled record and then supplemented with irregular data from the USGS website from June 2018 to the present. The irregular data were converted to regular, hourly data. The data from the USGS website were converted from station datum to NAVD88 by adding 3.49 feet.

Willamette at Portland – 14211720

Both tidally filtered and unfiltered flow, sub-daily, irregular data are available back to September 2007 and were downloaded from the USGS website. Continuous daily average data were available from the USGS website back to 1972. The missing data for 1996 and 1997 for the filtered dataset were filled using daily average data. As discussed in the main report, adjustments were not made to adjust for underestimated peak flow or daily volume at an event peak.

Clackamas River Oregon City – 14211010

This gage was installed in 2001. Irregular sub-daily and regular daily flow data from 2001 to the present were downloaded from the USGS website.

To estimate Clackamas River flows during the 1996 and 1997 simulation periods, flow data from the upstream gage near at Estacada (14210000) were used. Irregular, 30-minute data was available from the USGS-compiled record through both periods without notable gaps.

Johnson Creek Sycamore - 14211500

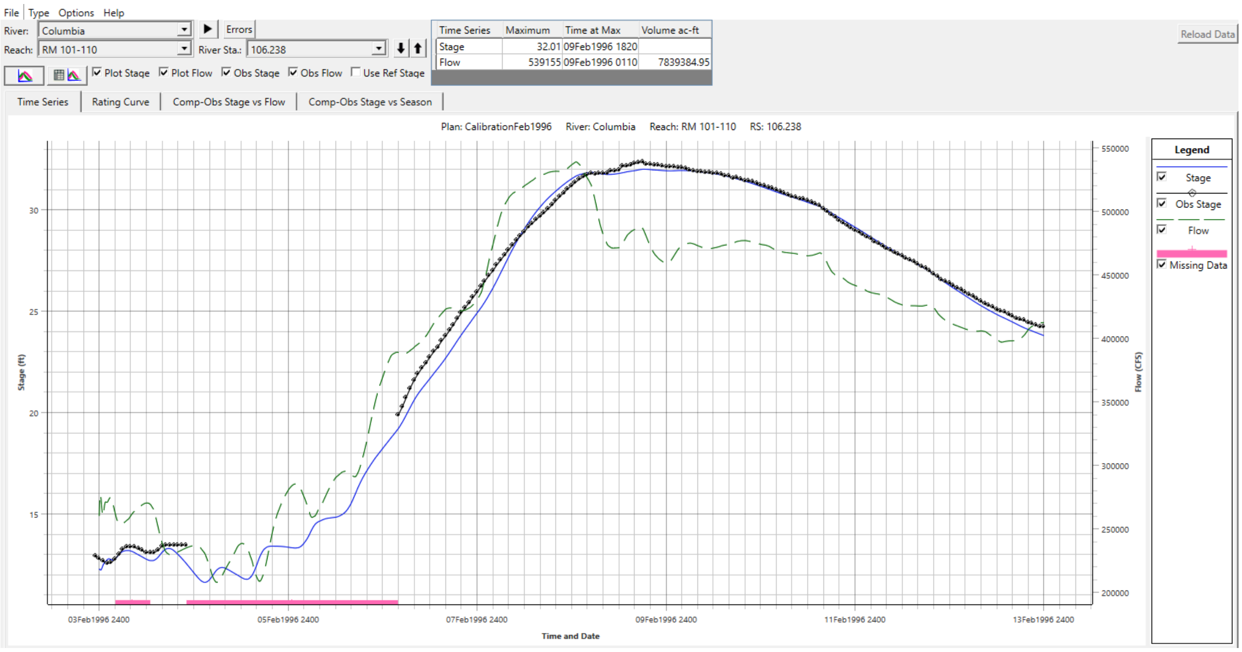
The irregular sub-daily and regular daily flow data were downloaded from the USGS website. The sub-daily data are available back to 1992 and the daily data are available back to 1940. Some 30-minute data was available from the USGS-compiled record for a portion of the 1996 (Feb) and for all of the 1997 events (Dec96/Jan97)

There are large gaps in the sub-daily record during the February 1996 events and the January 1997 event; however, daily average flow data were available throughout both events.

Appendix B. Calibration Results

February 1996 Hydrographs

Columbia River at Vancouver USGS



River: Columbia

Reach: RM 101-110

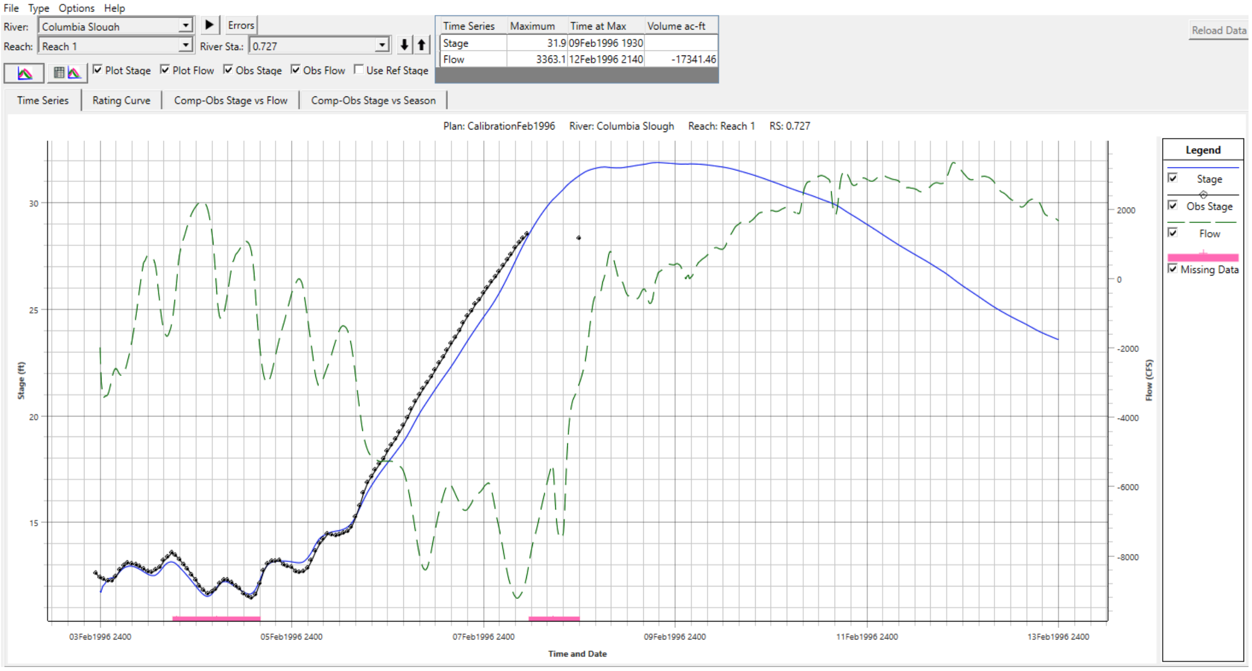
River Sta.: 106.238

☑ Plot Stage ☑ Plot Flow ☑ Obs Stage ☑ Obs Flow ☐ Use Ref Stage

Time Series	Maximum	Time at Max	Volume ac-ft
Stage	32.01	09Feb1996 1820	
Flow	539155	09Feb1996 0110	7839384.95

Plan: CalibrationFeb1996 River: Columbia Reach: RM 101-110 RS: 106.238

Columbia Slough



River: Columbia Slough

Reach: Reach 1

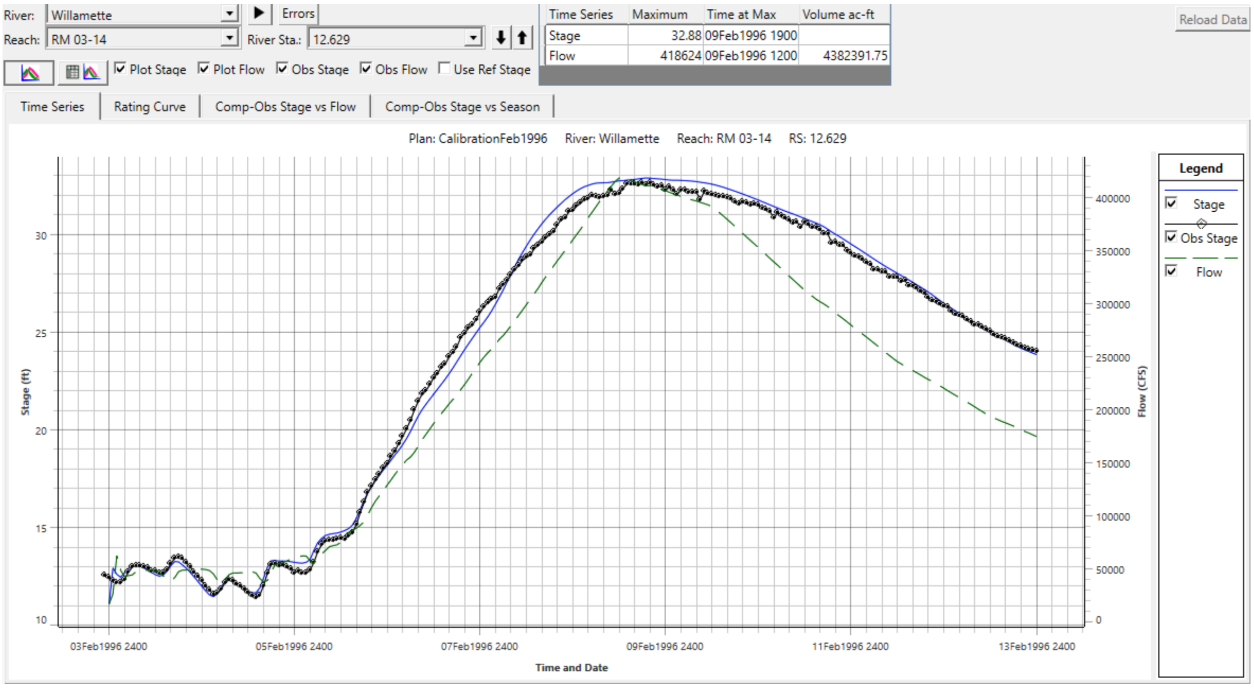
River Sta.: 0.727

☑ Plot Stage ☑ Plot Flow ☑ Obs Stage ☑ Obs Flow ☐ Use Ref Stage

Time Series	Maximum	Time at Max	Volume ac-ft
Stage	31.9	09Feb1996 1930	
Flow	3363.1	12Feb1996 2140	-17341.46

Plan: CalibrationFeb1996 River: Columbia Slough Reach: Reach 1 RS: 0.727

Willamette River at Morrison Street Bridge



River: Willamette

Reach: RM 03-14

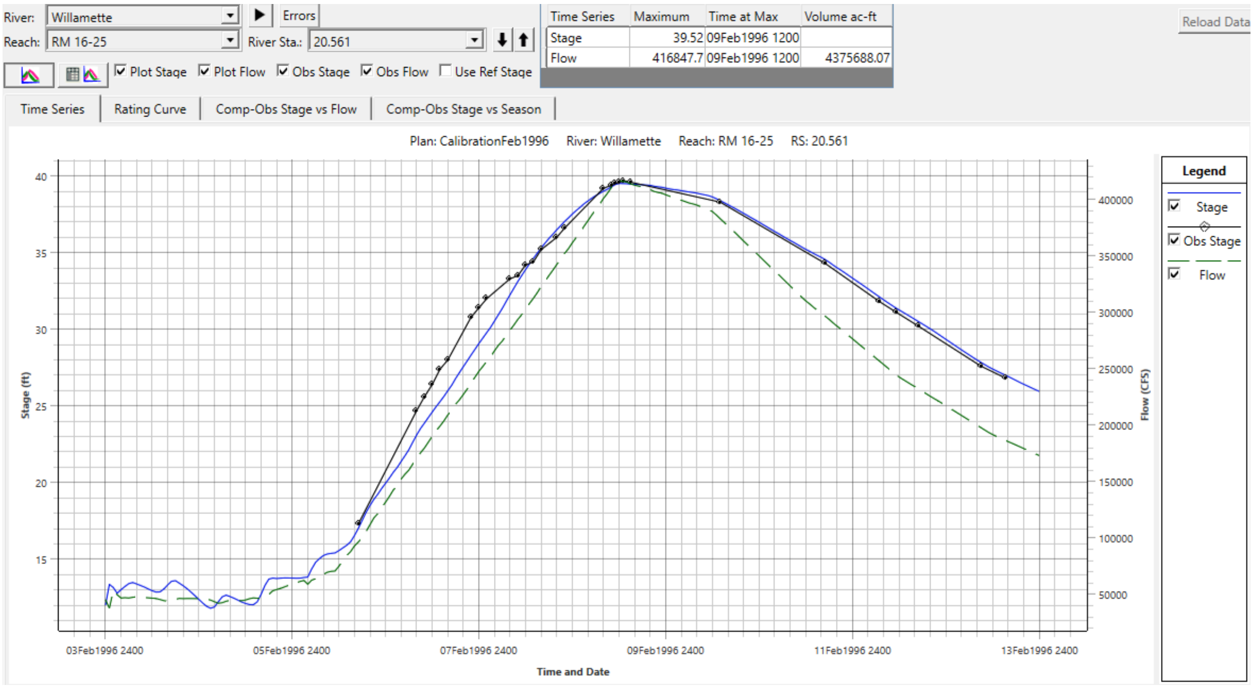
River Sta.: 12.629

☑ Plot Stage ☑ Plot Flow ☑ Obs Stage ☑ Obs Flow ☐ Use Ref Stage

Time Series	Maximum	Time at Max	Volume ac-ft
Stage	32.88	09Feb1996 1900	
Flow	418624	09Feb1996 1200	4382391.75

Plan: CalibrationFeb1996 River: Willamette Reach: RM 03-14 RS: 12.629

Willamette River at amphitheater near Oswego Pointe Drive



River: Willamette

Reach: RM 16-25

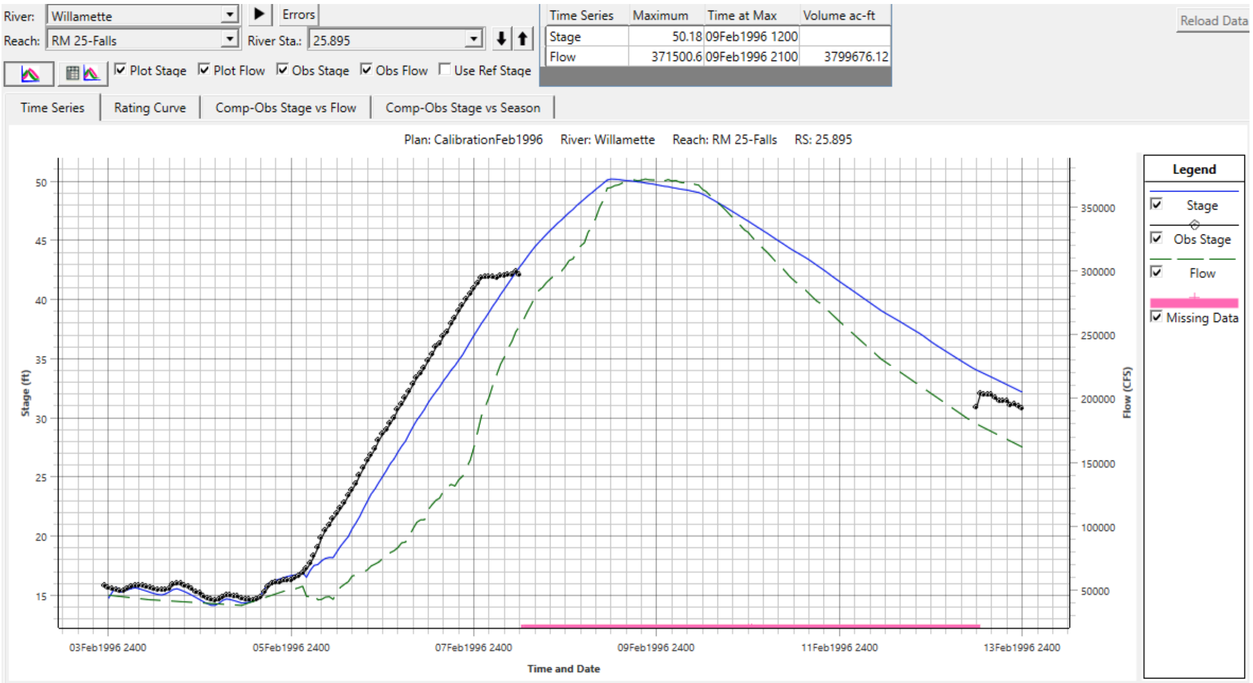
River Sta.: 20.561

☑ Plot Stage ☑ Plot Flow ☑ Obs Stage ☑ Obs Flow ☐ Use Ref Stage

Time Series	Maximum	Time at Max	Volume ac-ft
Stage	39.52	09Feb1996 1200	
Flow	416847.7	09Feb1996 1200	4375688.07

Plan: CalibrationFeb1996 River: Willamette Reach: RM 16-25 RS: 20.561

Willamette River below Willamette Falls at Oregon City



River: Willamette
Reach: RM 25-Falls
River Sta.: 25.895

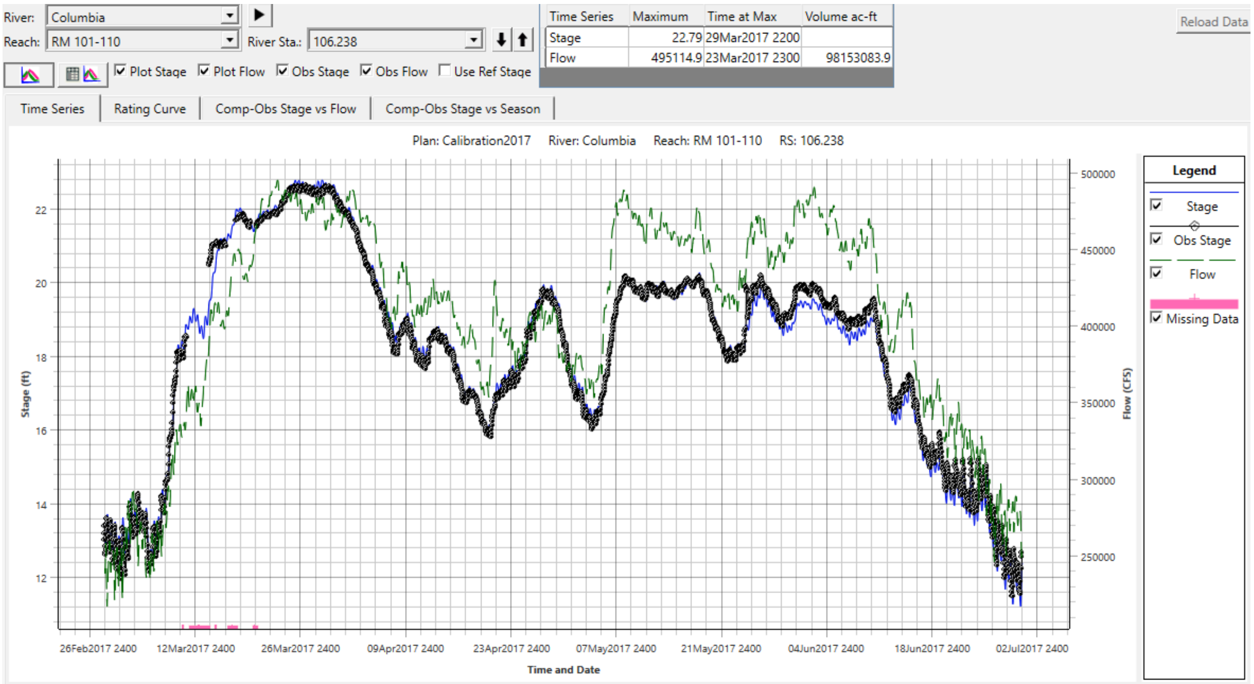
☑ Plot Stage ☑ Plot Flow ☑ Obs Stage ☑ Obs Flow ☐ Use Ref Stage

Time Series	Maximum	Time at Max	Volume ac-ft
Stage	50.18	09Feb1996 1200	
Flow	371500.6	09Feb1996 2100	3799676.12

Plan: CalibrationFeb1996 River: Willamette Reach: RM 25-Falls RS: 25.895

2017 Hydrographs

Columbia River at Vancouver USGS



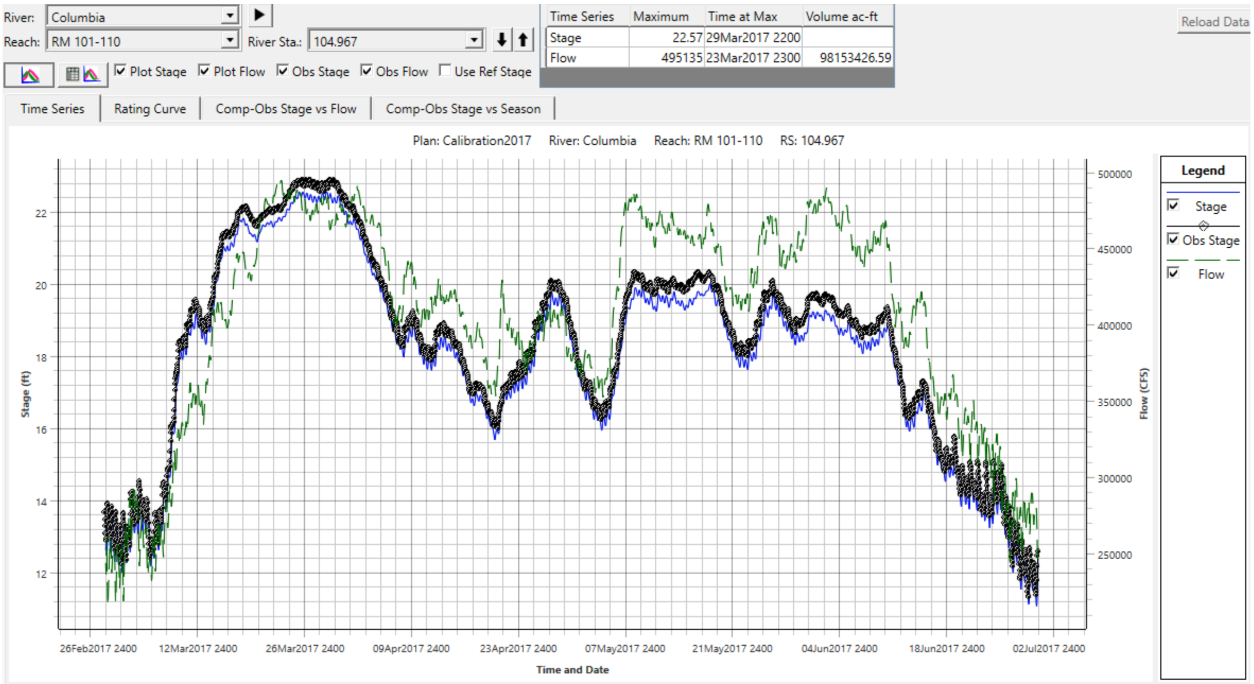
River: Columbia
Reach: RM 101-110
River Sta.: 106.238

☑ Plot Stage ☑ Plot Flow ☑ Obs Stage ☑ Obs Flow ☐ Use Ref Stage

Time Series	Maximum	Time at Max	Volume ac-ft
Stage	22.79	29Mar2017 2200	
Flow	495114.9	23Mar2017 2300	98153083.9

Plan: Calibration2017 River: Columbia Reach: RM 101-110 RS: 106.238

Columbia River at Vancouver NOAA

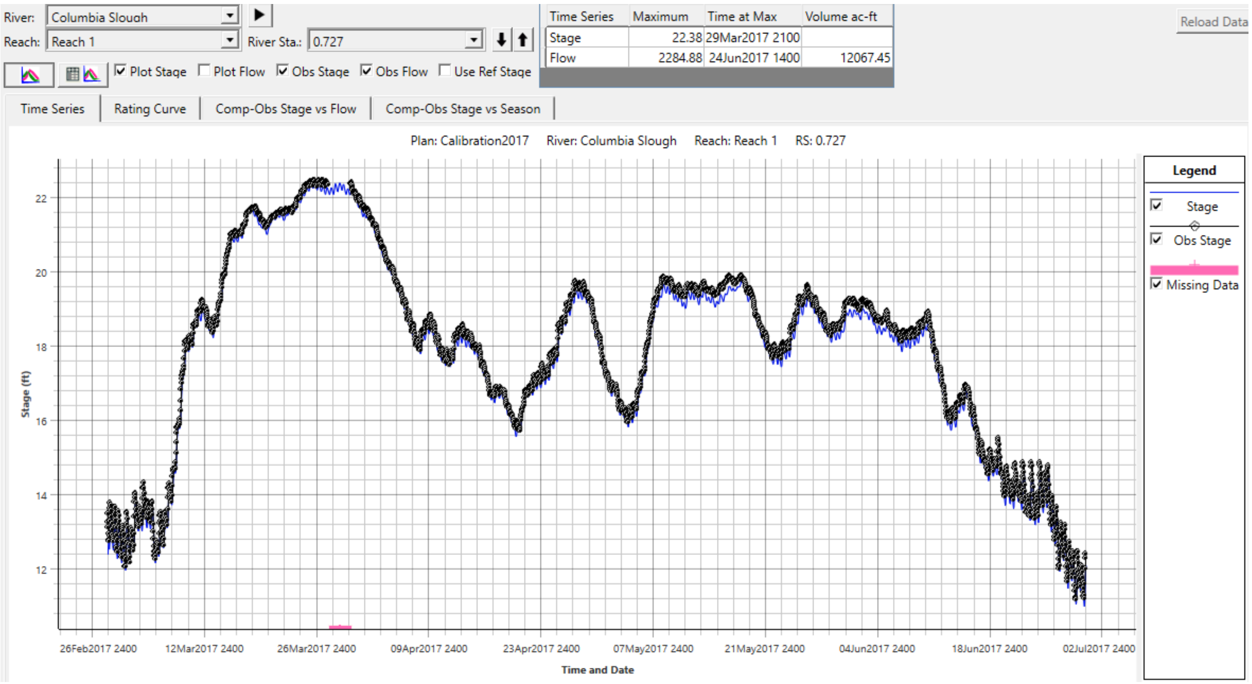


River: Columbia
Reach: RM 101-110
River Sta.: 104.967

☑ Plot Stage ☑ Plot Flow ☑ Obs Stage ☑ Obs Flow ☐ Use Ref Stage

Time Series	Maximum	Time at Max	Volume ac-ft
Stage	22.57	29Mar2017 2200	
Flow	495135	23Mar2017 2300	98153426.59

Columbia Slough

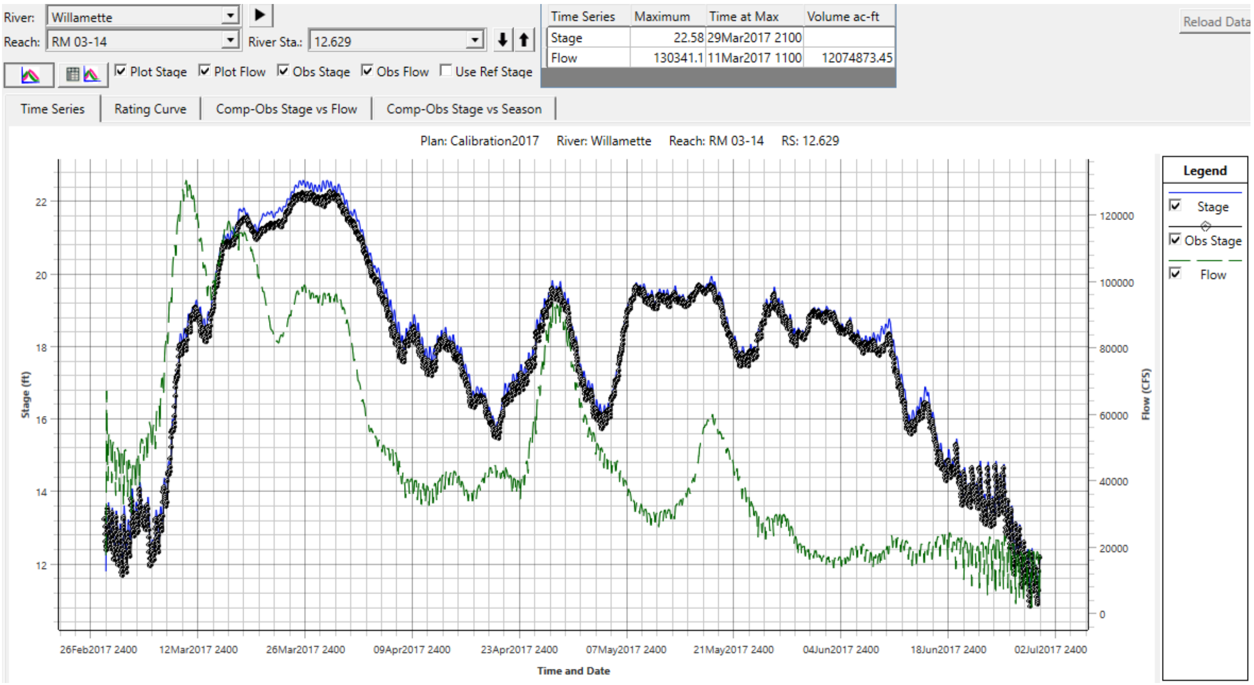


River: Columbia Slough
Reach: Reach 1
River Sta.: 0.727

☑ Plot Stage ☐ Plot Flow ☑ Obs Stage ☑ Obs Flow ☐ Use Ref Stage

Time Series	Maximum	Time at Max	Volume ac-ft
Stage	22.38	29Mar2017 2100	
Flow	2284.88	24Jun2017 1400	12067.45

Willamette River at Morrison Street Bridge



River: Willamette

Reach: RM 03-14

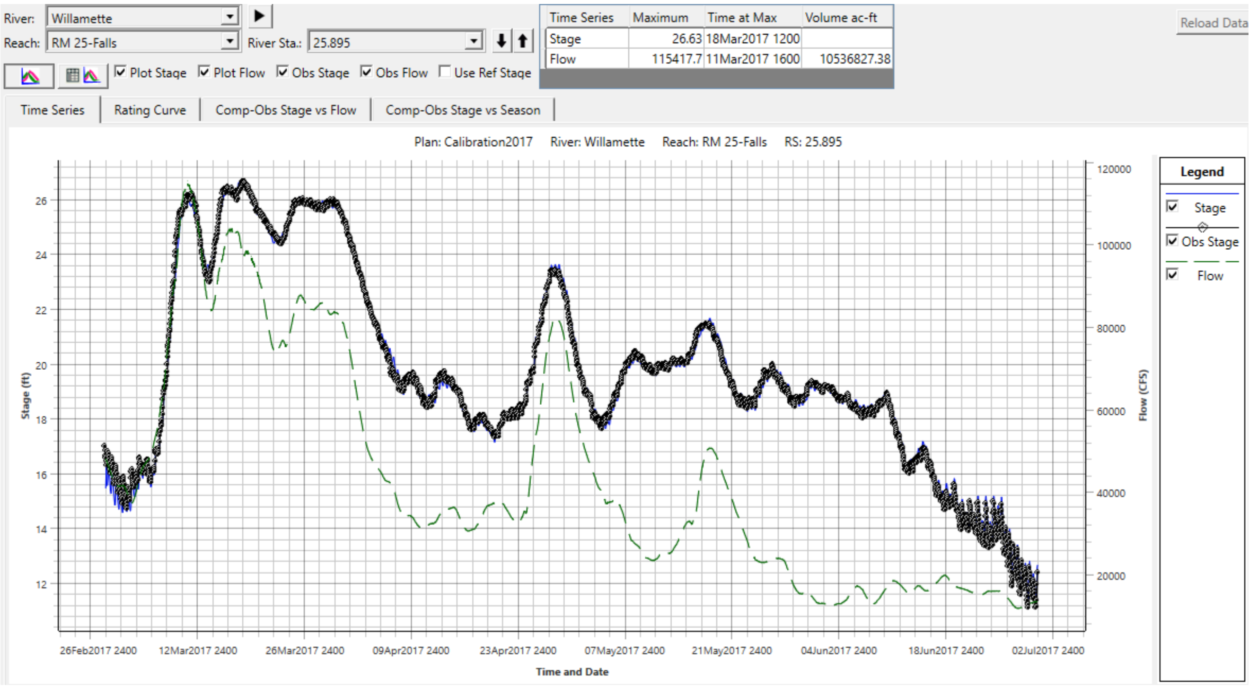
River Sta.: 12.629

Time Series	Maximum	Time at Max	Volume ac-ft
Stage	22.58	29Mar2017 2100	
Flow	130341.1	11Mar2017 1100	12074873.45

☑ Plot Stage ☑ Plot Flow ☑ Obs Stage ☑ Obs Flow ☐ Use Ref Stage

Plan: Calibration2017 River: Willamette Reach: RM 03-14 RS: 12.629

Willamette River below Willamette Falls at Oregon City



River: Willamette

Reach: RM 25-Falls

River Sta.: 25.895

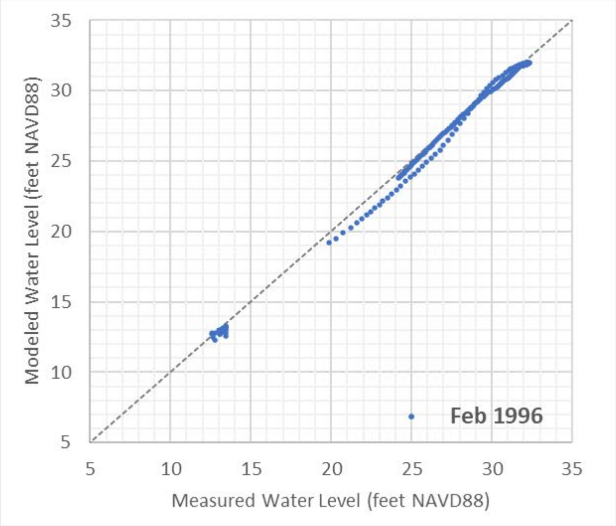
Time Series	Maximum	Time at Max	Volume ac-ft
Stage	26.63	18Mar2017 1200	
Flow	115417.7	11Mar2017 1600	10536827.38

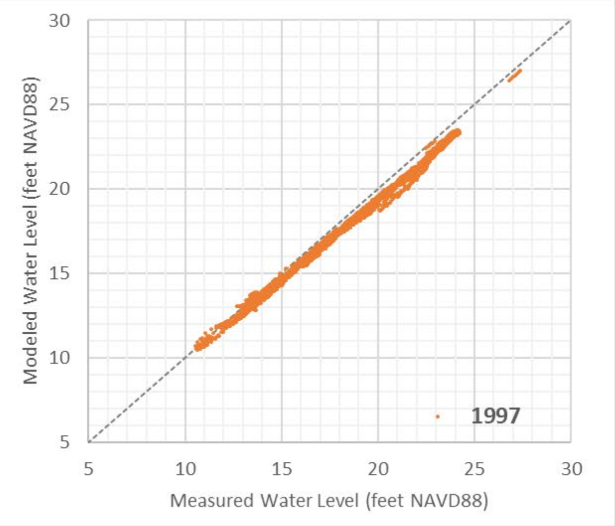
☑ Plot Stage ☑ Plot Flow ☑ Obs Stage ☑ Obs Flow ☐ Use Ref Stage

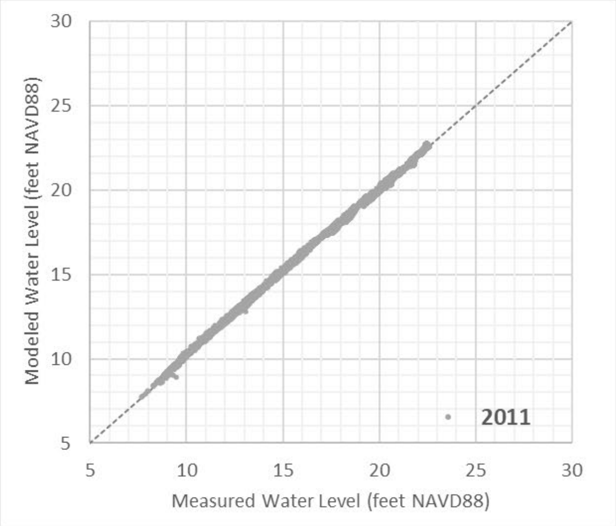
Plan: Calibration2017 River: Willamette Reach: RM 25-Falls RS: 25.895

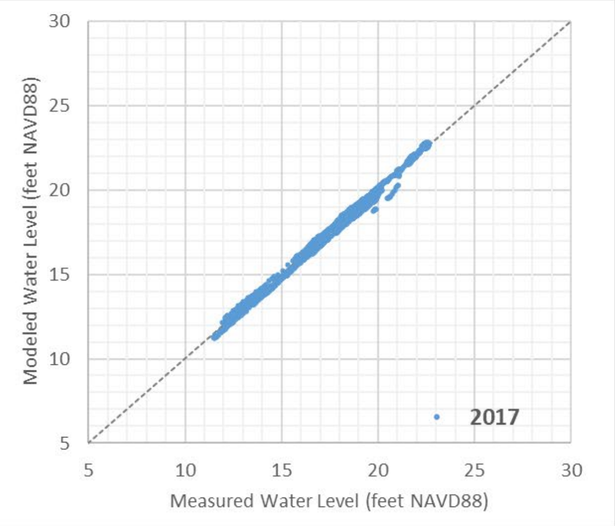
Scatter Plots

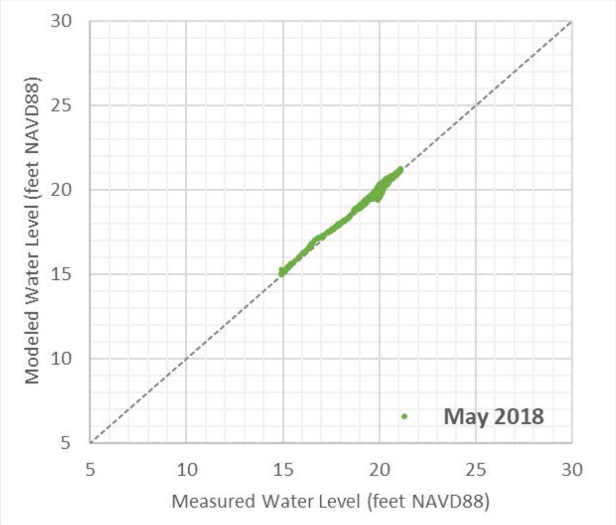
Columbia River at Vancouver USGS

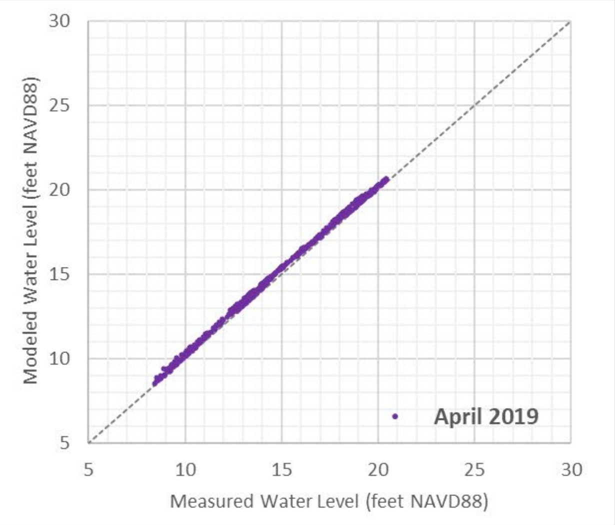




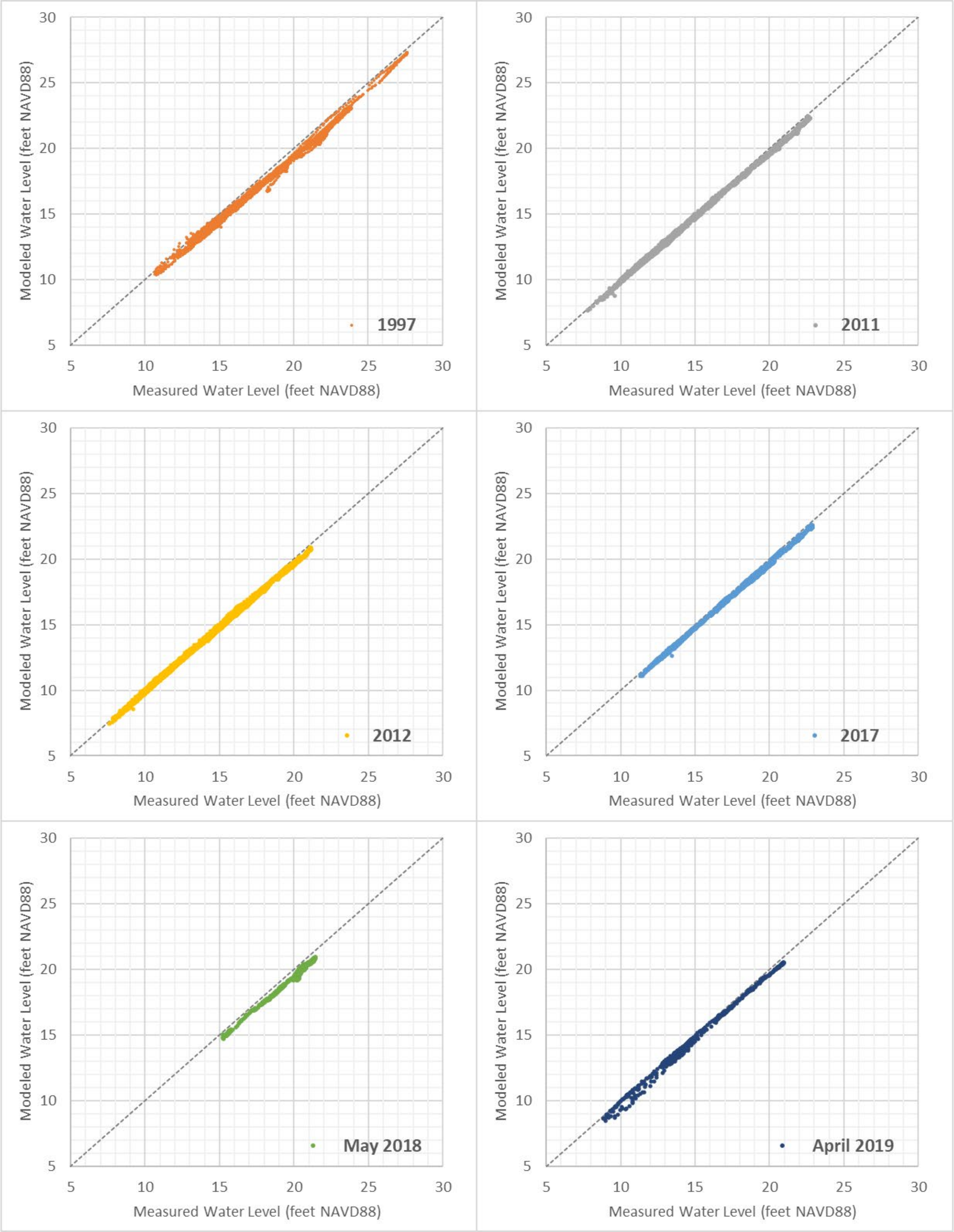




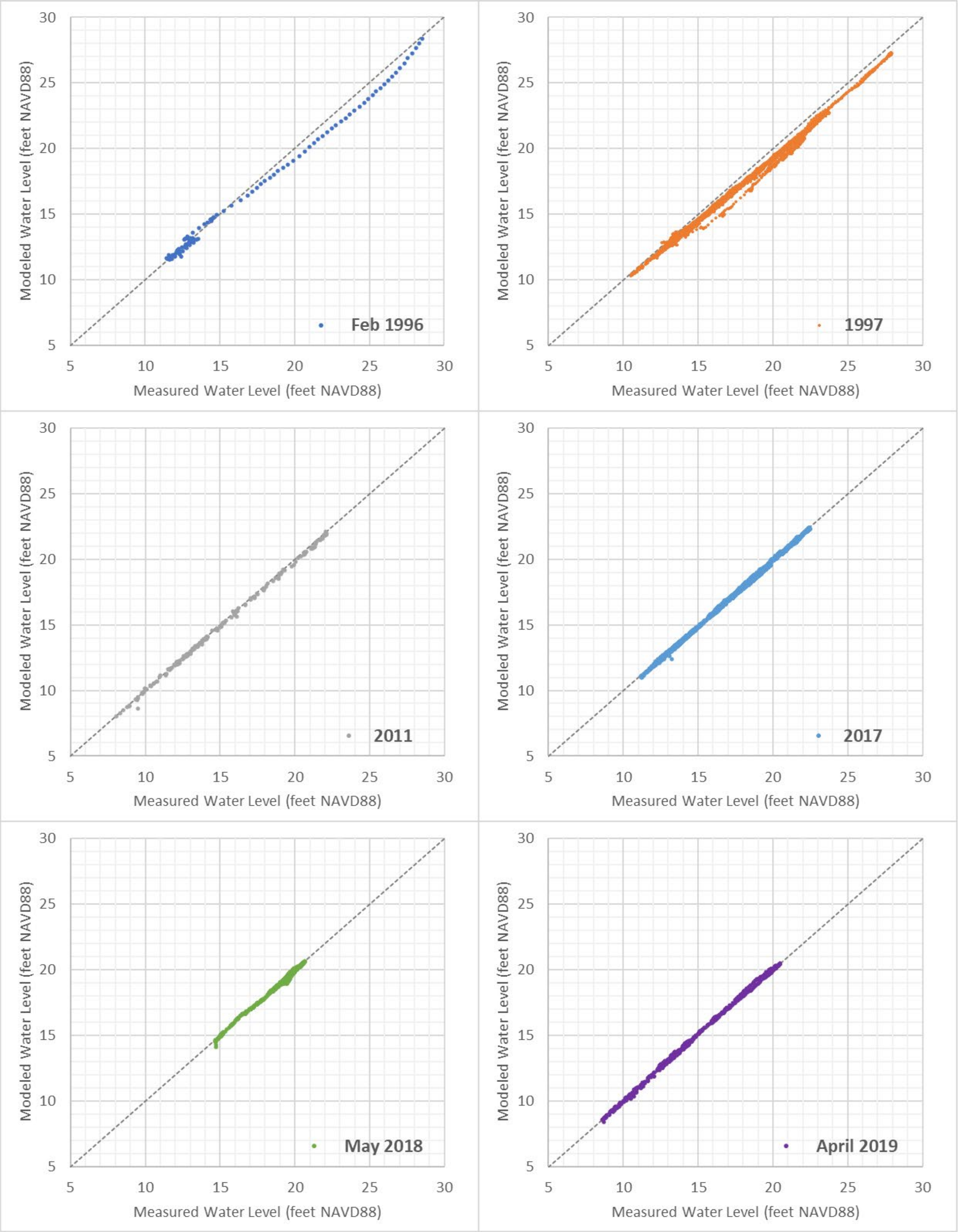




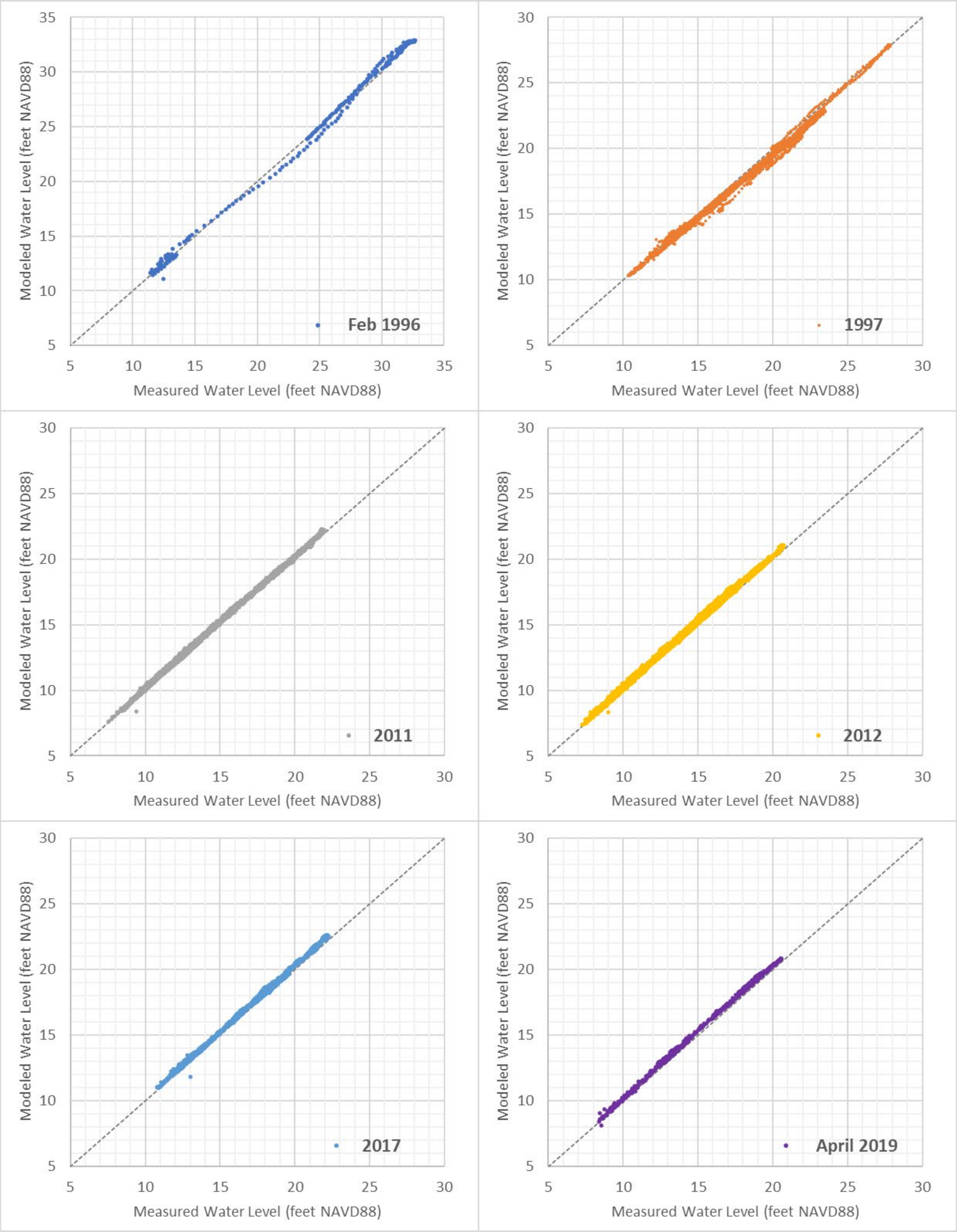
Columbia River at Vancouver NOAA



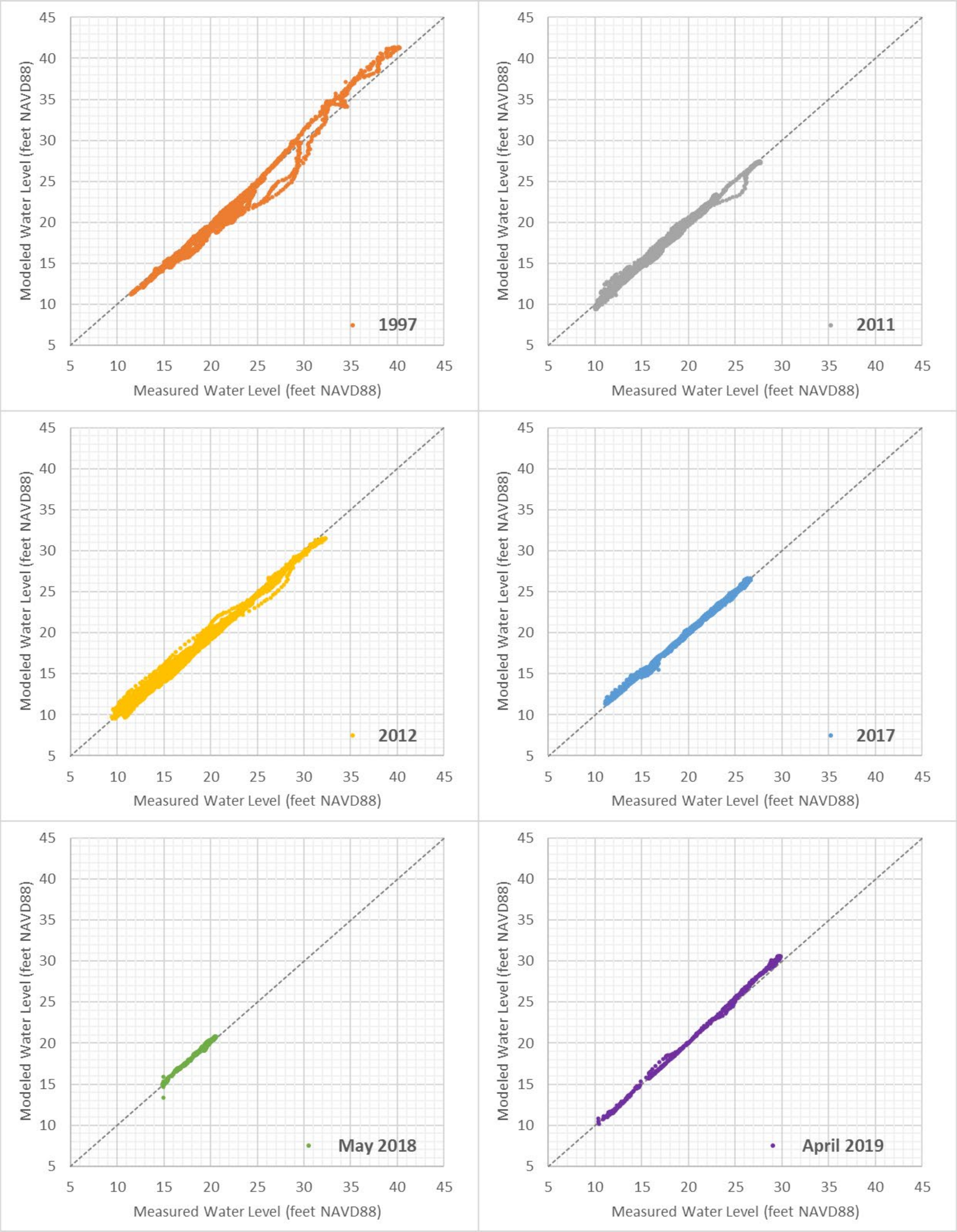
Columbia Slough



Willamette River at Morrison Street Bridge



Willamette River below Willamette Falls at Oregon City



Appendix C. Duplicate Effective Model

Introduction

From the 1D unsteady model described in the main report, a truncated steady-state model was assembled for eventual application as an updated effective model. The short-term need was stated by EPA where the added complexity of the unsteady model is unnecessary and developing a duplicate effective model (steady state) was determined to be the best solution for their needs in assessing water level impacts in their required “no-rise” analyses. This path was supported by the City of Portland and the Corps developed a draft duplicate effective model in a day for trial application with the EPA and the City. This appendix describes the methods used to develop that model.

Geometry

A duplicate of the calibrated 1D geometry was created and use as the base for truncated, “LowerWillamette_only” geometry. As implied, all reaches and geometric components outside of the Willamette River were deleted including the Clackamas River, Multnomah Channel, and Columbia Slough reaches. Although they have a negligible influence in the steady state environment, new storage areas were created to represent the Clackamas River and Columbia Slough/Bybee Lakes area. The Sauvie Island levees on the left bank of the lower 3 miles were left in along with the associated storage areas. The lower 3 reaches from the unsteady model were combined into a single reach after removing the junctions at Multnomah Channel and Columbia Slough.

Roughness values and ineffective flow area assumptions were varied during the calibration process in order to achieve a modeled water surface profile that closely matches the effective water surface profile. More discussion on changes to roughness values and ineffective flow assumptions is included in the Calibration section.

Boundary Conditions

The flow inputs and downstream boundary from the current effective model were applied in the existing model. The only modification to the flow file was to partition flow about Ross Island. This was done by assuming a constant 74.1% of flow is contained in the main channel and 25.9% of flow is in the side channel. This number is based on an early investigation of the unsteady flow hydraulics for large flow conditions. Profiles were developed for the 10-, 50-, 100-, and 500-year recurrence interval flows, or 10%, 2%, 1%, and 0.2% AEP conditions, respectively.

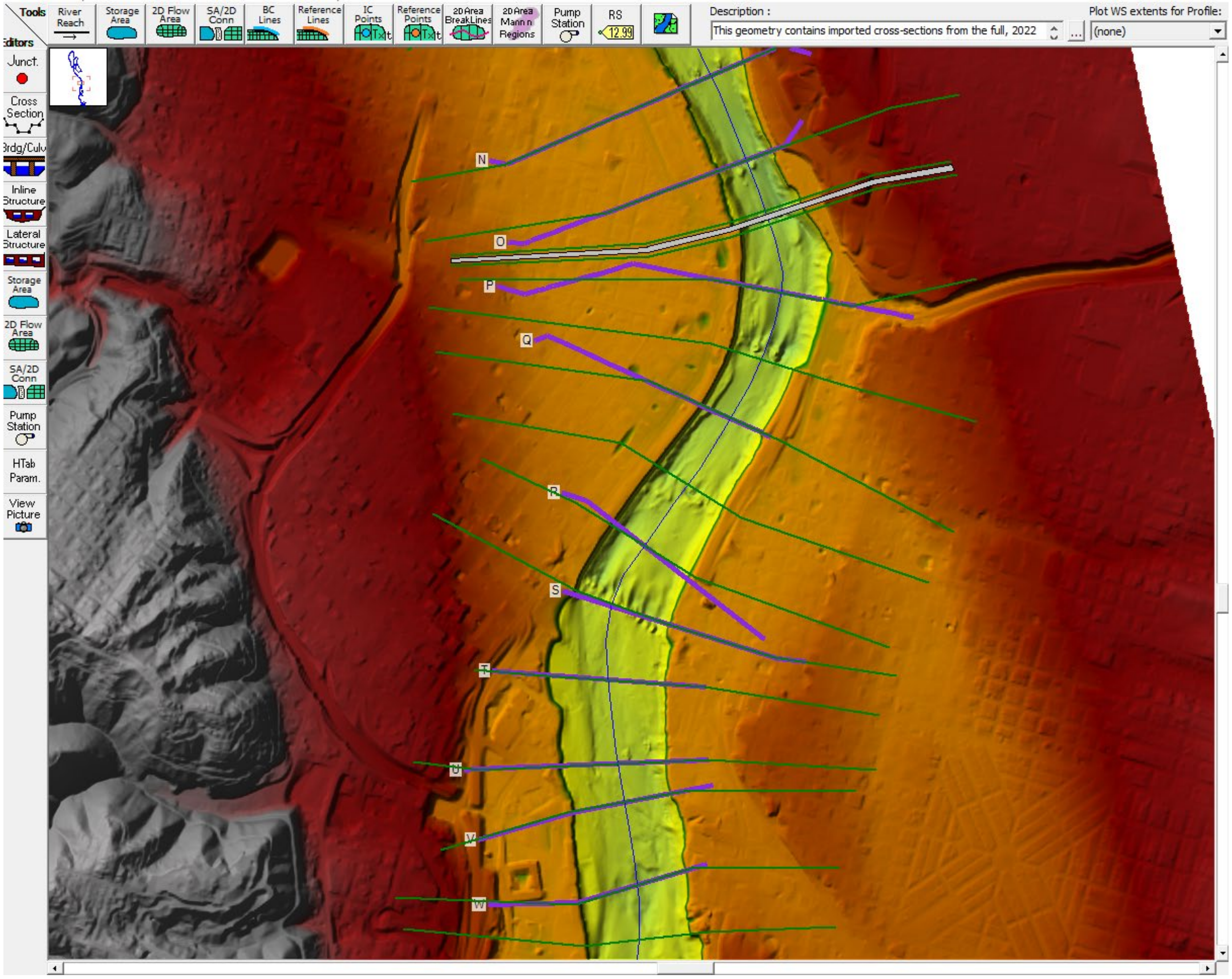
Table 7. Flow and stage boundary conditions for the steady-state model.

Reach	10-yr	50-yr	100-yr	500-yr
Willamette abv Ross Island	251,000	329,000	375,000	495,000
Willamette at Ross Island	186,000	244,000	278,000	367,000
Ross Island side channel	65,000	85,000	97,000	128,000
Willamette blw Ross Island	251,000	329,000	375,000	495,000
Willamette blw Multnomah Ch	200,800	246,750	263,000	346,500
DS stage boundary (feet NAVD88)	24.7	29.1	30.8	35.1

Calibration

Calibration of the steady state model is entirely based on the 1% AEP FEMA profile as defined in the 2010 Multnomah County and 2019 Clackamas County Flood Insurance Studies (FIS) and associated GIS data downloaded from FEMA's flood map products website (https://www.fema.gov/flood-maps/products-tools/products). The lettered cross-section shapefiles were imported into RASMapper as part of the unsteady model build process. Anticipating future comparison with the effective FEMA model and existing FEMA profiles, cross-sections for the unsteady model were drawn on top of existing FEMA lettered cross-sections. Figure X shows an example of the imported FEMA lettered sections and the model cross-sections.

Specifically for creation of the duplicate effective model, the effective 1% FEMA profile as reported in the effective FIS tables was imported into the HEC-RAS steady flow file as observed high water marks.



Description : This geometry contains imported cross-sections from the full, 2022

Plot WS extents for Profile: (none)

Figure 23. Alignment of updated model cross-sections compared to existing FEMA lettered sections.

Changes were made to both channel roughness and ineffective flow areas to achieve the FEMA standard of maximum 0.50-foot difference between the computed profile and the effective profile at each letter cross-section. Calibration started at the downstream end and worked upstream. No consideration was given to the FEMA floodway or profiles other than the 1% AEP.

Figure X graphically depicts the channel and overbank n values for both the unsteady and the steady state models for the Willamette River. In the lower 15 miles, from Ross Island down to the Columbia confluence, only a slight increase to channel roughness through downtown was required to match the effective profile. This is likely due to the proximity to the fixed downstream boundary and the relatively low gradient hydraulics through the reach.

Upstream of Ross Island, larger changes were required to match the effective profile. In this reach, the water surface profile is steeper, hydraulics are more complicated, and the available bathymetry is of poorer quality. The duplicate effective model required a step increased step in roughness around RM 16-17 and again at RM 21, and a decrease elsewhere. The increase in RM 16-17 coincided with a decrease in extents of ineffective flow areas, but the large step at the channel constriction at RM 21 required more aggressive ineffective flow area usage.

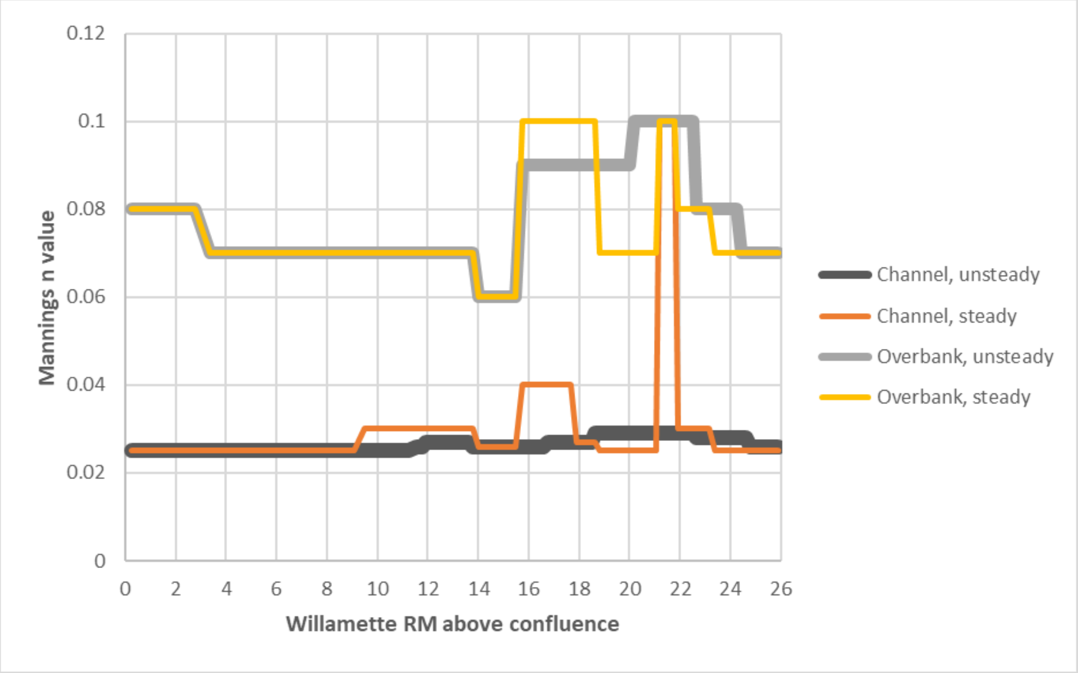


Figure 24. Comparison of Manning's n values for the unsteady and steady models.

Results

Figure X shows calibrated 1% AEP water surface profile along with the effective FEMA water surface elevations as HWM's. Table X aligns the effective lettered cross-sections with the updated RAS cross-sections. It also shows the effective and modeled 1% AEP water surface at each section along with the calculated difference.

All cross-sections except for 24.255 (Clackamas County section Q) are under the 0.50-foot maximum difference standard required by FEMA.

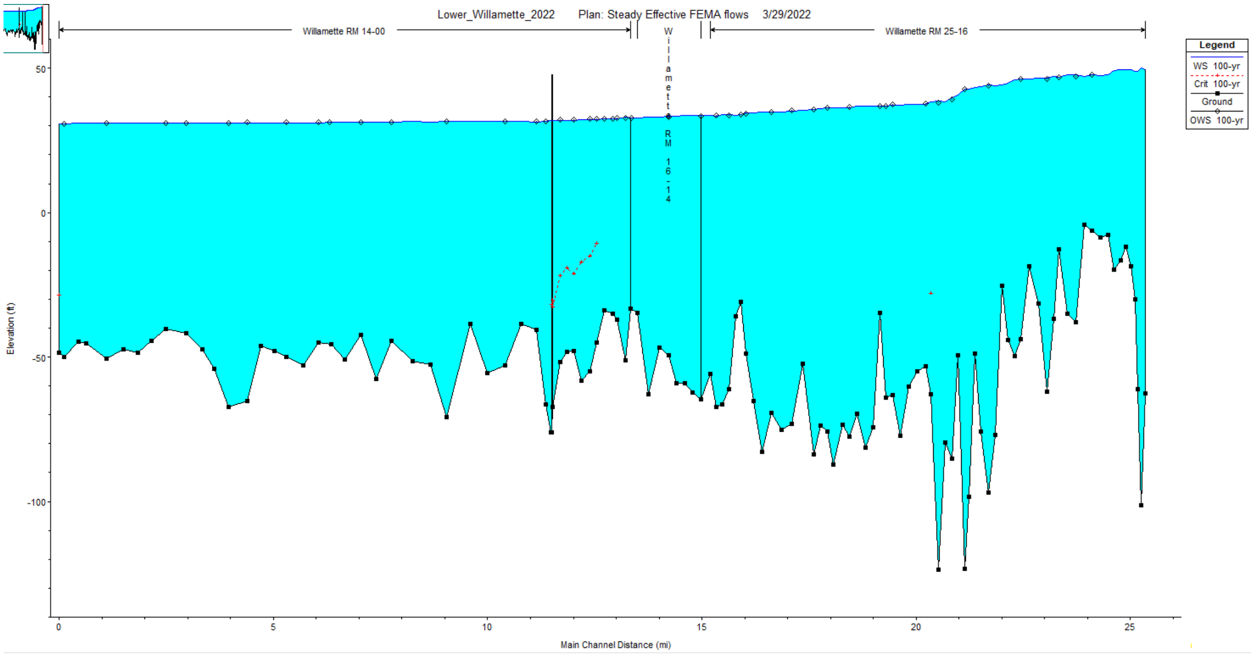


Figure 25. Modeled 1% AEP water surface compared to effective 1% AEP water levels at FEMA lettered sections (shown as observed water surface points).

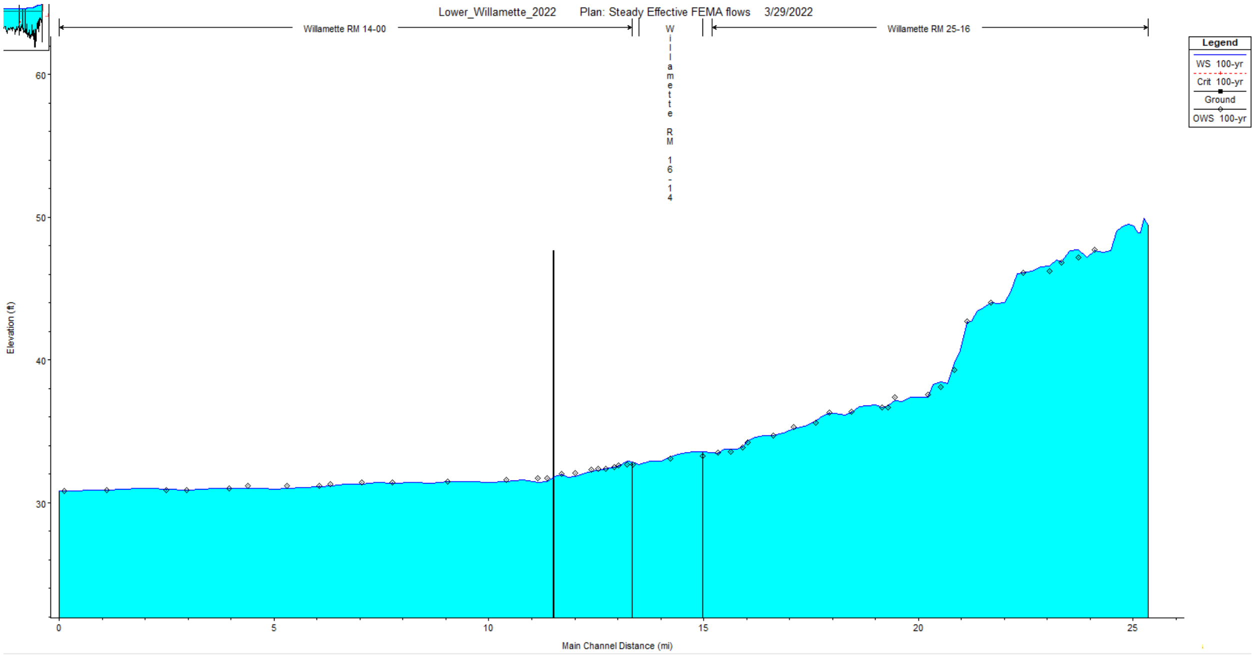


Figure 26. Comparison of modeled and effective 1% AEP water surface profiles with greater vertical scale.

Table 8. Comparison of 1% AEP modeled and effective water levels.

	Cross section	RAS Xsec (2022)	1% AEP water surface elevation (feet NAVD88)		Difference (feet)
			Effective	**Modeled**	
FEMA effective profile, Multnomah Co, 2010	A	0.375	30.8	30.8	0.00
	B	1.388	30.9	30.91	0.01
	C	2.769	30.9	30.98	0.08
	D	3.387	30.9	30.91	0.01
	E	4.397	31	31.02	0.02
	F	4.819	31.2	31.01	-0.19
	G	5.274	31.2	30.98	-0.22
	H	6.483	31.2	31.1	-0.10
	I	6.784	31.3	31.19	-0.11
	J	7.468	31.4	31.33	-0.07
	K	8.816	31.4	31.42	0.02
	L	9.472	31.5	31.46	-0.04
	M	10.841	31.6	31.5	-0.10
	N	11.568	31.7	31.4	-0.30
	O	11.786	31.7	31.5	-0.20
	P	12.116	32	31.94	-0.06
	Q	12.442	32.1	31.85	-0.25
	R	12.808	32.3	32.2	-0.10
	S	12.975	32.4	32.26	-0.14
	T	13.152	32.4	32.37	-0.03
	U	13.352	32.5	32.51	0.01
	V	13.444	32.6	32.57	-0.03
	W	13.645	32.7	32.9	0.20
	X	14.001	32.7	32.67	-0.03
	Y	14.728	33.1	33.22	0.12
	Z	15.487	33.3	33.59	0.29
	AA	15.895	33.5	33.46	-0.04
	AB	16.195	33.6	33.78	0.18
	AC	16.476	33.9	33.94	0.04
	AD	16.598	34.2	34.35	0.15
FEMA effective profile, Clackamas Co, 2019	A	17.186	34.7	34.68	-0.02
	B	17.663	35.3	35.18	-0.12
	C	18.159	35.6	35.71	0.11
	D	18.488	36.3	36.23	-0.07
	E	18.995	36.4	36.33	-0.07
	F	19.699	36.7	36.7	0.00
	G	19.841	36.7	36.78	0.08
	H	19.984	37.4	37.14	-0.26
	I	20.75	37.6	37.39	-0.21
	J	21.053	38.1	38.46	0.36
	K	21.359	39.3	39.79	0.49
	L	21.655	42.7	42.62	-0.08
	M	22.207	44	44.03	0.03
	N	22.959	46.1	46.09	-0.01
	O	23.581	46.2	46.56	0.36
	P	23.845	46.8	46.88	0.08
	Q	24.255	47.2	47.71	0.51
	R	24.621	47.7	47.64	-0.06

Future Work

While the steady state model here creates a water surface profile that closely matches the effective profile, there is still work that could be done to improve understanding and modeling of hydraulics in the upper reach between Johnson Creek and the Willamette Falls. The available data and modeling capabilities today are vastly improved over what was available for the prior modeling efforts decades ago, and a fresh evaluation of hydraulics and the 1% profile (either new or old hydrology) should be done. To this end, there are improvements that could be made to the available data and modeling. These are discussed below:

- Improved bathymetry – The current "best available data" for bathymetry in this reach are single beam cross-section surveys from 1990 and 1991. While some small areas have undergone detailed survey for specific projects, obtaining detailed multibeam bathymetry for the entire reach would be a great asset for understanding and modeling hydraulics in the reach.

- Two-dimensional modeling – While any effective model needed for no-rise analyses through this reach will likely be 1D and steady state, a 2D model of the reach could be done to improve understanding of ineffective flow area assumptions.

- Comprehensive review – Only the 1% AEP profile was considered for the present effort. Calibration could be done looking at additional profiles to ensure consistent hydraulic assumptions across the range of flows potentially used for no-rise analyses and for updated FEMA profiles. The 2D modeling effort would greatly support this review of all profiles in conjunction.

To be officially approved as the new duplicate effective model, the draft model created by NWP would need to undergo FEMA review. To support that review, official documentation may need to be compiled by the City of Portland and others compiling the necessary information from the main, unsteady model report and any additional information requested by FEMA.