
Draft Hydraulic Report

Howard Street South Channel Bridge Replacement

Prepared for:



Prepared by



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Abbreviations

BFE	Base Flood Elevation
cfs	cubic feet per second
CEM	Corrected Effective Model
CMP	Corrugated Metal Pipe
DEM	Duplicate Effective Model
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
FIS	Flood Insurance Study
fps	feet per second
HEC-RAS	Hydrologic Engineering Center River Analysis System
NRCS	Natural Resources Conservation Service
OHW	Ordinary High Water
ROW	Right-of-Way
RCP	Reinforced Concrete Pipe
SVRP	Spokane-Valley Rathdrum Prairie
SCS	Soil Conservation Service
SFHA	Special Flood Hazard Area
USACE	U.S. Army Corps of Engineers
USCG	United States Coast Guard
UTM	Universal Transverse Mercator
WSE	Water Surface Elevation



Introduction

1.1 Report Purpose

This hydraulic report presents a hydraulic analysis of the South Channel Howard Street Bridge replacement project. The analysis demonstrates that the proposed bridge design would not cause a significant rise in the South Channel water surface elevation during construction or following bridge replacement during ordinary flow conditions and the 100-year base flood.

1.2 Project Location

The South Channel Howard Street Bridge is located within Riverfront Park in Downtown Spokane, Washington. As shown on the Figure 1-1 *Vicinity Map*, the Spokane River is split into three channels where Howard Street crosses the river with three bridges. About 1300 feet upstream of Howard Street, the Spokane River is a single channel that is impounded by the Upper Falls Diversion Dam at the head of Riverfront Park. Water spilling over the diversion dam curves around the north side of Riverfront Park and continues downstream in a semi-natural channel. As it passes Riverfront Park on the north, the Spokane River splits around an island at Howard Street to form the North Channel and the Middle Channel before coming together again as the main channel. The South Channel begins just upstream of the Upper Falls Diversion Dam and functions as an extension of the impoundment that passes Riverfront Park on its south side.

The South Channel impoundment functions as a hydropower forebay that extends from the Upper Falls Diversion Dam to roughly 300 feet beyond the South Channel Howard Street Bridge, where water enters an 18-foot-diameter penstock intake for the Avista Corporation Upper Falls Hydroelectric Facility (Staff Report, 2015). The Upper Falls Diversion Dam (Division Street Control Works) was completed in 1922 and diverts water through the South Channel forebay past the Spokane Convention Center and Red Wagon Park, and into the powerhouse intake structure. From the powerhouse, water is discharged to the main Spokane River channel downstream of where the North and Middle channels come back together. See Figure 1-2 *Location Map* for an illustration of the project location.

1.3 Project Context

Replacement of the South Channel Howard Street Bridge has been scheduled as one of the first in a series of significant investments and physical changes to Riverfront Park to be funded by the 2014 Riverfront Park Bond and guided by the 2014 Riverfront Park Master Plan.

In the fall of 2014, the City of Spokane with the participation of the Riverfront Park Citizen Advisory Committee, City Staff, the Spokane Park Board, the City Council and the Mayor's Office completed the Riverfront Park Master Plan 2014. This master plan identifies multiple phases that will "bring people to the center" and outlines multiple infrastructure upgrades and analysis to be completed prior to implementation of adjacent phases. This master plan seeks to make Howard Street the "string" that links the "pearls" of downtown, including the North Bank, Arena, Riverfront Park, Downtown retail core, Medical District, and South Hill. Howard Street will be a pedestrian corridor, with amenities such as landscaping, wide sidewalks, street furniture, public art, outdoor restaurants, and improved sidewalk/building interfaces (Master Plan, 2014).

The Howard Street Bridge was constructed in 1931. At the time of construction, this area was an active rail yard area and industrial in nature. The bridge has been repurposed as this area has undergone its well-known and historic changes from industrial area to a regional park. In 2009, the center of the bridge was cordoned off from pedestrians, to prevent bridge collapse while people gather on the bridge. The structural integrity of the bridge is a significant issue and the replacement of this bridge has been identified as essential.

In short, the authors of the Riverfront Park Master Plan, with the support of the Downtown Spokane Streetcar Alternative Analysis, have prioritized the Howard Street Bridge replacement with some urgency. Intermediate steps have been taken to limit pedestrian and light vehicle traffic in the interim.

1.4 Proposed Bridge Replacement

There are existing ineffective flow areas in the channel due to encroachments: on the northern slope there is an existing rock outcropping that encroaches into the channel just downstream of the third pier on the downstream face of the existing structure (see Photo 5 in **Appendix C** and Figure 1-2 *Location Map*). The southern abutment block of the bridge also encroaches at the south shore.

The new bridge configuration encroaches slightly less than the existing configuration. The proposed layout and typical section of the new South Channel Howard Street Bridge are shown in **Appendix A**. The new bridge will use two piers, instead of the three piers of the existing bridge, to improve hydraulic efficiency and reduce costs. The proposed bridge will span bank to bank and will modify the upstream retaining wall on the north side with a 2:1 vegetated slope. The proposed bridge will also eliminate the existing offsetting southern abutment and will improve continuity by matching the proposed southern abutment with the existing retaining wall. It was agreed with Avista and the City of Spokane that the proposed modifications would have negligible impact on forebay storage and hydropower operations.

The proposed replacement bridge is 50 feet wide (clear width between rails) to accommodate pedestrian use. The piers of the new bridge will be skewed parallel to the natural water flow path to match the orientation of the existing bridge piers and avoid unnecessarily hindering water movement.

Communications with Avista are copied in **Appendix A**.

This drainage report presents hydraulic analysis of the existing bridge to establish existing conditions, and hydraulic analysis of the proposed design to demonstrate acceptably low hydraulic impacts.

Spokane Falls Hydroelectric Project, Final EIS, Appendix C, Figure C-1, Spokane River, 10/20/2015

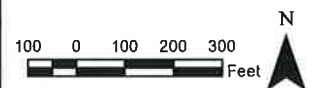


City of Spokane
Howard Street Bridge
South Channel

ch2m:

Legend

— Roadway



**Figure 1-2
Location Map**

City of Spokane
Howard Street Bridge Hydraulic Analysis

SECTION 2

Existing Conditions and Hydraulic Models

2.1 Existing Bridge Structure

Existing South Howard Street Bridge as-builts from the City of Spokane are in **Appendix A**. The existing bridge, constructed in 1931, is a 4-span cast-in-place concrete beam/slab structure. The bridge is approximately 68 feet wide and consists of spans measuring 45.5 feet and 48 feet for a total approximate length of 187 feet. The bridge framing consists of four primary longitudinal girders spanning between piers that support secondary transverse beams and a concrete deck slab. The longitudinal girders frame into single span transverse cross beams at each interior pier that are supported by short columns on spread-footing foundations (CH2M HILL, 2009).

The current topographic survey was used to establish elevations for the existing bridge superstructure. The surveyed low chord elevation at the front (upstream) face of the bridge is 1874.13 feet. The high chord elevation was obtained from the top of the rail along the front (upstream) face of the bridge as 1880.13 feet. The bridge deck has an elevation of 1877.02 feet on the front (upstream) face of the bridge.

2.2 Existing Channel

There were repairs and periphery upgrades to the South Channel Forebay prior to the World's Fair in 1974. Channel as-builts obtained from Avista are in **Appendix A**. As it stands today, the South Channel has multiple developments along its shores between the penstock intake and Upper Falls Diversion Dam. These developments and shoreline conditions are shown on Figure 1-2 *Location Map*. Selected photos of the channel and banks are in Appendix C.

Beginning at the intake, a trash rack filters floating debris prior to flows entering the 18-foot penstock. The bank slope is paved along the western wall next to the intake structure. There are three 8-inch steel pipes that provide flow for downstream surface-water features within the western portion of Riverfront Park.

Moving upstream from the intake toward the diversion dam along the south shore of the South Channel, the southern shoreline is a mixture of stepped concrete and vertical retaining walls. Directly upstream of the channel terminus, the south shoreline is a vertical retaining wall that curves to mimic the natural shoreline. The south abutment for the existing structure is offset approximately 6 feet into the channel from this retaining wall at the downstream southern edge creating a minor encroachment into the channel. The retaining wall then continues upstream where it bumps out into the channel approximately 50 feet upstream of the Howard Street Bridge (see Photo 8 and Figure 1-2 *Location Map*). The southern shoreline then becomes stepped banks for approximately 250 feet upstream until transitioning into a vertical retaining wall near the existing pedestrian bridge. Through the

remaining reach included in this analysis, the southern channel becomes a mixture of vertical retaining walls, aesthetic bumps near existing bridges and stepped shorelines for approximately 200 feet at the most upstream limit (see Figure 1-2 *Location Map*).

Moving upstream from the intake toward the diversion dam along the north shore of the South Channel, vertical retaining walls extend from the intake to the existing concrete abutment and gage station, located 80 feet upstream of the intake. Natural shoreline façade built with heavy rock and planted with trees and shrubs makes up the northern shoreline for approximately 120 feet upstream until it meets up with the downstream face of the Howard Street Bridge (see Photo 5). The northern shoreline upstream of the Howard Street Bridge includes approximately 50 feet of abutment retaining wall that is angled to improve hydraulic efficiency through the bridge (See Photo 7 and Figure 1-2 *Location Map*). Upstream of this abutment is natural channel banks that include trees and shrubs with heavy rock through the remaining portion through the upstream limit of this analysis (see Photo 9).

2.3 Existing Hydraulic Models

2.3.1 West Consultants (2014) Model

Two existing hydraulic models of the Spokane River at Howard Street have been identified, but neither model is considered adequate for modeling the South Channel Howard Street Bridge and its replacement. The more robust model was a HEC-RAS model developed by West Consultants, Inc. (West Consultants, Inc. 2014) for the City of Spokane of the entire Spokane River from Long Lake Dam, located near where Spring Creek Road crosses the Spokane River, to Upriver Dam, located at river mile 8.2, approximately 5 miles upstream of downtown Spokane. This study included a dam breach analysis to evaluate failure of Upriver Dam using gradually varied flow, and included geometry for 15 bridges along the Spokane River within downtown.

Although the model by West Consultants, Inc., includes local geometries, the South Channel of the Spokane River is treated exclusively as storage adjacent to the Spokane River Floodway at Upper Falls Diversion Dam. Flows through the South Channel and powerhouse are neglected. Documentation for the West Consultants, Inc., model indicate that as larger flows increase within the main channel of the Spokane River, those larger flows are not diverted down the South Channel towards the Upper Falls Intake but are accommodated through the Upper Falls Diversion Dam gates. Documented results indicate that larger flood events cause the water surface elevation of the South Channel to rise, but the modeling is not detailed enough to calculate conveyance characteristics through the South Channel as it relates to Avista flow demands during these large flood events.

2.3.1 FEMA (2010) Model

The second available model supported the current FEMA study for the Spokane River, and is described in the Flood Insurance Study (FIS) for Spokane County, Washington, effective July 2010. The FIS identifies the calculated water surface profiles for return-period floods along the Spokane River channels within downtown portions of the City of Spokane.

Originally, hydrologic and hydraulic backwater analysis of the Spokane River was completed in May 1986 using what was formally known as the Soil Conservation Service's (SCS's) WSP-2 computer program, which has since been phased out by the same agency, now named the National Resource Conservation Service (NRCS). When the FEMA FIS was updated in 2010, the model was not revised or upgraded to a HEC-RAS model.

CH2M obtained a hardcopy of the WSP-2 model inputs and results from the NRCS during development of the HEC-RAS model, including original model files (data cards) and output files. This model did not consider conveyance in the South Channel and did not include cross-sections for the South Channel. This model only assumed the South Channel provides storage. This model information was used to calibrate the water surface elevation in the new model for this study at the upstream Upper Falls Diversion Dam.

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SECTION 3

Hydrologic Design Criteria

3.1 Low Flows

The Spokane Valley-Rathdrum Prairie (SVRP) aquifer serves nearly 600,000 people in the Coeur d' Alene and Spokane areas in Washington State (Barber et al., 2011). The areal extent of the SVRP aquifer includes sections of the Spokane and Pend Oreille Rivers. The Spokane River is a losing stream between Post Falls, Idaho, and Trentwood, Washington, and a gaining stream from Trentwood to Spokane, Washington (Jehn, 1988). Large variations in the directions as well as amounts of flow between the Spokane River and the aquifer along various stretches of the river have been noted (Jehn, 1988). It is generally recognized that in the vicinity of downtown Spokane, the river is gaining flows from the aquifer. This helps support a dependable minimum baseflow in the study reach. However, there are no specific hydrologic design criteria associated with low flows.

3.2 Maximum Operational Flows

Apart from diversion backwater effects, flow only passes down the South Channel when it is diverted through the Avista hydropower facilities. Maximum operational flows under the South Channel Howard Street Bridge are therefore the maximum allowable flow capacity to the Avista penstock. According to Avista, this maximum flow rate is 2500 cfs (see communication in **Appendix A**). Flow rate demands change over the course of the seasons, so normal operations may require lower flow rates.

3.3 Maximum Flood Flows

In addition to operational flows, the water surface elevation in the South Channel is also affected by impounded depths upstream of the Upper Falls Diversion Dam. When flow rates increase in the Spokane River, if diversion gate operations allow more water to be impounded by the diversion, the water surface elevation in the South Channel increases, regardless of operational releases through the Avista power plant.

Peak flows for the Spokane River are experienced during spring snowmelt and winter rain events. Upstream flow is regulated by the Post Falls Dam, located in Idaho approximately 27 miles upstream of the Upper Falls Diversion Dam. Taking into account river operations, FEMA has identified within the FIS for this location a regulatory 100-year base flood and associated floodplain. FEMA has indicated that the 100-year base flood for the Spokane River at the Upper Falls Diversion Dam is 52,000 cfs with a BFE of 1875.0 feet (FEMA 2010). Pertinent pages from the current FEMA FIS can be found in **Appendix A**.

In this case, the South Channel Howard Street Bridge should be conservatively designed for the BFE at the Upper Falls Diversion Dam, and not for any 100-year flow rate under the

bridge. For FEMA 100-year flow conditions, the maximum active flow through the South Channel remains unchanged at the maximum operational flow rate of 2500 cfs. All additional rise in the South Channel water surface elevation is caused by backwater from the Upper Falls Diversion, and is therefore independent of the South Channel Howard Street Bridge. Since there is no flow into the downstream end of the South Channel, the maximum water surface elevation in the channel is determined by the water surface impounded just upstream of the diversion dam. This water surface will increase upstream of the diversion dam in the main Spokane River channel, but will not exceed the water surface at the head of the South Channel anywhere *downstream* in the direction of the bridge.

3.4 Other Flows

The West Consultants (2014) dam breach study evaluated dam breach for three Spokane River flow conditions: 8,000 cfs, 40,000 cfs, and 85,000 cfs. These flows do not specifically pertain to design criteria for the South Channel Howard Street Bridge.

3.5 Summary

The conclusion from the hydrologic design criteria evaluated above is that the following hydrologic criteria pertain to the South Channel bridge design:

- Maximum Operation Flow rate of 2500 cfs.
- Maximum FEMA BFE of 1875.0 (no 100-year flow routing required). This elevation is pertinent to freeboard design, but does not need to be tested by a model because the BFE will not be increased by any bridge design.

SECTION 4

Hydraulic Analysis

4.1 Overview

The two existing Spokane River models (Section 2.3) were found to fall short of the modeling needs to evaluate hydraulic impacts from the South Channel Howard Street Bridge. The West Consultants (2014) model assumes storage within the South Channel Forebay with a normal pool elevation of 1870.8 to match the Avista as-builts. This model does not include conveyance calculations or detailed cross sections for the Spokane River South Channel.

The available FEMA hydraulic model was completed in WSP2. This hydraulic study assumed storage within the South Channel and a water surface elevation of 1875.0 to match the 100-year base flood water surface elevation (BFE) within the impoundment upstream of the Upper Falls Diversion Dam. The FEMA BFE is therefore independent of the South Channel bridges and omits conveyance through the South Channel and Avista power plant.

To overcome the limitations of the existing models, CH2M developed a site-specific conveyance model for the South Channel to evaluate the maximum operational flow rate (2500 cfs; Section 3) in the South Channel and the 100-year flow rate (52,000 cfs; Section 3) through the multichannel Spokane River system. The following sections summarize additional design criteria that were evaluated, development of the hydraulic model, specific model parameters and model results to support the proposed design.

4.2 Design Criteria

4.2.1 Spokane Valley Municipal Code

The FEMA Flood Insurance Rate Map (FIRM) is shown in Appendix A. It shows that the impoundment upstream of the Upper Falls Diversion Dam has been classified as Zone AE, which means the BFE has been determined by or for FEMA using a detailed hydraulic model adequate to define inundation elevations. The Spokane Municipal Code (SMC) 17E.030 conforms to the FIRM and designates Zone AE on the FIRMette as “areas of special flood hazard.” A regulatory floodway, which has a zero-rise criteria for new encroachments, has not been established in this reach. FEMA guidelines and SMC 17E.030.150 mandates that the proposed bridge encroachment cannot raise the BFE greater than 1.0 feet at any point within the City.

4.2.2 Fish Passage

The Washington Department of Natural Resources states the South Channel water type is “S,” denoting it is a fish bearing water. Acceptable rise in the backwater elevation is 0.2 feet above the BFE, as referenced in WAC 220-110-070 (1) (h) for fish bearing waters.

Large Woody Debris (LWD) components or other in-stream long-term improvements to the habitat are not currently planned as part of this project.

Fish passage during construction shall be ensured through adherence to conservation measures described in work plans and other terms and conditions of environmental permits and approvals.

4.2.3 Navigational Clearance

The stream is not considered navigable in the vicinity of the project location by the United States Coast Guard (USCG). A Section 9 permit for "Bridge Work in Navigable Waters" will not be required.

4.3 Topographic and Bathymetric Data

Topographic data was collected by Coffman Engineers in May of 2015. Strategic cross-sections of the channel were also obtained by Coffman Engineers at the same time, including channel cross-sections immediately upstream (east) and downstream (west) of the existing bridge. An additional channel cross-section was obtained approximately 150 feet upstream of the existing bridge. Using the survey data, CH2M developed an approximate bathymetric surface and interpolated two additional channel cross-sections from this surface.

4.4 Freeboard for Ice and Debris

Ice has not been reported to accumulate to any significant degree on bridge piers or abutments of the existing bridge at this crossing. Avista has indicated that the South Channel does not freeze due to the constant movement of required flows through their hydropower facility. Avista has also indicated that they have not had ice accumulation adjacent to their intake facility in the past. Correspondence regarding this information is located in **Appendix A**.

Since the location of the bridge is removed from the main channel, traditional freeboard criteria for fast-moving floods do not apply. Instead, it was decided that the freeboard for the new bridge may approximately match or exceed the freeboard for the existing bridge, with the intent to approximately maintain or improve existing hydraulic conditions. Currently, the bottom of the existing bridge superstructure at elevation 1874.13 feet provides 3.35 feet of freeboard above the maximum 2500 cfs design WSE of 1870.78 feet at the upstream edge of the bridge (see Table 4-1, below). The top of the existing bridge deck at elevation 1877.0 feet provides 2.0 feet of freeboard above the current FEMA BFE of 1875.0 feet.

Based on model results below in Table 4-1, the proposed new bridge encroachment would cause no rise or change in the maximum normal operating WSE in the South Channel. The existing and proposed freeboard of 3.35 feet during maximum normal operations should be adequate to pass ice, debris and waves, but is somewhat limiting for inspection by boat. It should also be noted that the WSE will typically rise during floods, reducing operational freeboard.

As indicated above, the FEMA BFE will not be affected by the bridge design. It is considered prudent to design the bridge deck at elevation 1877.0 or higher to provide at least 2 feet of freeboard above the 100-year flood. The purpose of this freeboard is to provide safety to pedestrians during a 100-year flood against waves, wind-driven debris, and a potentially elevated WSE due to unforeseen operational restrictions at the Upper Falls Diversion Dam or potential errors in 100-year flood estimation.

Final freeboard elevations will be selected during design in consultation with the City. The final design freeboard is not critical to the hydraulic modeling described below, since the bridge superstructure will remain above the maximum 2500 cfs design WSE.

4.5 Model Development

4.5.1 Methodology

CH2M followed the FEMA Region X guidelines and developed a new South Channel hydraulic model using the U.S. Army Corps of Engineers Hydraulic Engineering Center's River Analysis System (HEC-RAS) software, version 4.1. The resulting model was used to evaluate encroachment of the South Channel Howard Street Bridge. The model was developed for the vicinity of the bridge and calibrated throughout the South Channel reach limits to the data in the South Channel as-builts obtained from Avista (Avista 1991; see Appendix A).

4.5.2 Current Effective Model

The current FEMA Effective Model was described in Section 2.3.

4.5.3 Duplicate Effective Model

CH2M was not able to develop a Duplicate Effective Model (DEM) because the current FEMA Effective Model did not include South Channel bathymetry or cross sections. Instead, CH2M developed a Corrected Effective Model (CEM).

4.5.4 Corrected Effective Model

CH2M developed a CEM to establish baseline existing hydraulic conditions, using the new topographic and bathymetric cross-section data from the surveyed cross sections and subsequent interpolated cross sections.

4.5.5 Proposed Condition Model

The CEM was updated with the geometry of the proposed bridge and its northern encroachment to represent the proposed conditions. Changes to the channel are reflected in modified cross sections and bridge geometry.

4.6 Model Parameters

4.6.1 Cross Sections

Cross-section survey data were described above. The HEC-RAS model CH2M built for this analysis uses the following cross-sections, which are located on Exhibit A *Cross Section Map* in **Appendix B**:

- Three surveyed cross-sections (XS-1.0, XS-2.0 and XS-3.0).
- Two cross-sections built from HEC-RAS interpolation between the surveyed cross-sections (XS-2.3 and XS-2.6).
- Six cross-sections created from the Avista South Channel as-built drawings (XS-0.1, XS-0.5, XS-4.0, XS-5.0, XS-7.0 and XS-8.0).
- Assumed cross-sections that take on the features of the intake and outfall structures (XS- "-1.0" and XS-0.0).

Cross-sections begin at and downstream of the Avista Hydropower Outfall facility to model flow through the South Channel and Avista penstock.

4.6.2 Boundary Conditions

Boundary conditions are necessary to establish the water surface for the hydraulic calculations. In a subcritical flow regime, boundary conditions are required at the downstream end of the river system, which in this case is located at Cross-section -1.0 near Avista's outfall structure. For maximum operational flows, the water surface elevation at Cross-section -1.0 was set at elevation 1838 feet to represent a submerged outfall condition. By setting the downstream boundary condition beyond the South Channel, it helps ensure that modeled water surface elevations within the South Channel, and especially at the South Channel Howard Street Bridge, are not overly sensitive to the selected boundary conditions.

The project bathymetric survey previously described showed that the existing bottom of the South Channel is nearly flat, so for the purposes of modeling these conditions, a slope of 0.001% was used as the upstream boundary condition for normal-depth calculations through the South Channel¹.

The FEMA 100-year flood was not modeled in the South Channel for the reasons previously stated.

¹ It should be noted that the actual water surface in the South Channel will vary depending on the flow rate in the Spokane River and operation of the gates at the Upper Falls Diversion Dam. The water surface elevation in the South Channel produced by the described set of boundary conditions was used to approximate the South Channel impoundment by calibrating its flow depths to match the operational water surface elevations previously modeled by Avista for their penstock and powerhouse designs and shown on their design drawings (Avista 1991). If the Spokane River flow rate and diversion dam combine to raise the South Channel water surface elevation *higher* than Avista used in design, any incremental changes in flow depth shown in Table 4-1 (there are none) would be *smaller* due to additional conveyance width and depth in the channel. The analysis used is therefore both consistent with Avista's previous design and conservative.

4.6.3 Channel Roughness and Loss Coefficient

The water surface elevation (WSE) in the South Channel is primarily controlled by the upstream diversion, flow rate through the Avista penstock, channel cross-sections, channel roughness, bridge hydraulics and losses through the penstock and powerhouse. The upstream diversion was not modeled directly, but was modeled indirectly by calibrating the South Channel WSE to the design water surface profile shown on the Avista drawings (Avista 1991). The geometry of the cross-sections and bridge were entered in the model as described above. Channel roughness and the penstock entrance loss coefficient were used as calibration parameters to fine-tune the WSE for existing conditions. Of these two, the WSE was most sensitive to the penstock loss coefficient.

Channel roughness is specified within HEC-RAS with Manning's n Coefficients that account for resistance to flow from surface roughness, turbulence and other sources at a given cross section. The selected Manning's n values for overbank areas were 0.013 where concrete was present and 0.08 where trees were present. As shown in the photographs in **Appendix C**, concrete retaining walls and other developed banks extend below the water surface elevation under ordinary operating conditions. An initial estimate of 0.03 was used for all channel Manning's n based on multiple field visits and bathymetric information about the channel bottom. After initializing the model, the channel Manning's n values were adjusted during the calibration process until the existing water surface profile matched the profile on the Avista drawings (Avista 1991). Overall, because velocities are relatively low, the WSE profile showed low sensitivity to the choice of Manning's " n ".

The WSE profile was more sensitive to the penstock entrance loss coefficient because it determines how much head is required to push 2500 cfs through the powerhouse, and therefore determines the WSE at the downstream (western) end of the South Channel at the intake. After calibration, a penstock entrance loss coefficient of 0.04 was selected.

4.6.4 Existing and Proposed Bridge Structure

As described in Section 2, the geometry of the existing bridge was obtained from the City of Spokane as-builts available in **Appendix A** and the current topographic survey was used to establish bridge elevations. The current topographic survey was also used to locate the existing bridge deck and horizontal pier locations within the surveyed model cross sections.

As described in Section 1, the general approach for this bridge replacement is to approximately mimic the existing conditions with concessions regarding bridge span, length and minor changes in freeboard. The geometries and parameters used to model the proposed bridge incorporate these proposed changes. With regard to freeboard, the modeled low chord and high chord elevations match those of the existing structure, although these remain above the WSE and therefore do not affect the model hydraulics. The proposed layout and typical section of the new South Channel Howard Street Bridge are shown in **Appendix A**.

4.7 Model Scenarios

The following model scenarios were created and used to compare the river hydraulics at the project site for the maximum operational design flow rate:

- No bridge (natural condition)
- Existing bridge
- Proposed bridge
- Construction phase (with sheet pile walls)

4.8 Operational Model Results

Table 4-1 summarizes the resulting water surface elevation calculations completed in HEC-RAS for the maximum operational flow rate of 2500 cfs following construction.

Table 4-1
Summary of HEC RAS modeling results – 2500 cfs Maximum Avista Operations

Cross Section	Natural Conditions		Existing Conditions		Proposed Conditions		WSE Difference between Existing and Proposed Conditions
	Water Surface Elevation (ft)	Channel Velocity (ft/s)	Water Surface Elevation (ft)	Channel Velocity (ft/s)	Water Surface Elevation (ft)	Channel Velocity (ft/s)	(ft)
<i>Just upstream of the Spokane Convention Center</i>							
8.0	1864.76	2.03	1870.83	1.15	1870.83	1.15	0.00
7.0	1864.61	3.07	1870.81	1.34	1870.81	1.34	0.00
5.0	1864.55	2.63	1870.80	1.42	1870.80	1.42	0.00
4.0	1864.41	3.54	1870.79	1.53	1870.79	1.53	0.00
3.0	1864.31	4.19	1870.78	1.60	1870.78	1.60	0.00
2.6	1864.21	4.14	1870.78	1.56	1870.78	1.56	0.00
2.3	1864.19	4.07	1870.78	1.55	1870.78	1.55	0.00
2.0	1864.18	4.02	1870.78	1.54	1870.78	1.52	0.00
<i>Howard Street Bridge</i>							
1.0	1864.02	4.62	1870.74	1.97	1870.74	1.93	0.00
0.5	1863.68	5.53	1870.73	1.94	1870.73	1.94	0.00
0.1	1863.77	3.41	1870.71	2.10	1870.71	2.10	0.00
0.0	1861.12	12.90	1870.37	4.95	1870.37	4.95	0.00
<i>Avista Penstock</i>							
-1.0	1838.00	3.64	1838.00	3.64	1838.00	3.64	0.00
<i>Just downstream of Avista Hydroelectric Outfall</i>							

NOTE: "Natural Conditions" refers to an undeveloped state prior to all of the bridges in the South Channel, and prior to damming the channel in 1906. In the natural condition, there was river flow through the South Channel. Results for the Natural Channel are approximate, and do not directly impact the analyses in this report.

4.8.1 Operational Water Surface Elevations

Results of the analysis indicate that the operational WSE will not be impacted by the new bridge and its in-water structural members. If the proposed bridge low chord elevation is not lowered from the existing conditions, then the proposed freeboard from the Avista maximum operational flows would remain at approximately 3.3 feet.

4.8.2 FEMA Floodplain Impacts

As explained in Section 3.3 and the project overview, the South Channel acts as a Forebay for Avista hydropower facilities, and should not exceed the FEMA BFE just upstream of the Upper Falls Diversion Dam during the 100-year flood. Consistent with this, the South Channel is not modeled for conveyance in any current FEMA or City hydraulic model. The current BFE should remain unchanged as a result of the bridge replacement project. The current FEMA BFE of 1875.0 rises above the bottom of the existing and proposed bridge superstructures, but the bridge decks would not be overtopped without waves.

4.9 Hydraulic Effects during Construction

4.9.1 Construction Approaches and Conditions

Access for equipment and materials in the channel will be needed for drilled shaft and pier construction, and for demolition of the existing bridge. The bridge construction contractor will be responsible for determining what temporary facilities, means, and methods will be used to demolish the existing bridge and construct the new bridge. However, it is anticipated that access will be provided by temporary work pads installed in the river. This approach has the added benefit of being quick to construct and remove with conventional earth moving equipment.

The work pads would be installed during the in-water work period and removed prior to the end of the same in-water work period. The work pads would be constructed of clean native rock materials and would be completely removed after construction. The contractor may elect to support the rock dikes with steel sheet piling, although the shallow depth of granular material over the basalt bedrock will limit the use of sheet piles.

The new bridge abutments will use spread footings founded on basalt bedrock. The construction areas will be dewatered by constructing cofferdams and concrete seals. Cofferdam construction may require drilling soldier piles into the basalt bedrock.

Near-shore bridge construction activity (above the ordinary high water elevation) will consist of overburden excavation, existing bridge demolition, concrete bridge abutment, installation and removal of work pads, and minor grading and planting to restore the disturbed river embankments to the pre-construction condition.

4.9.2 Construction Phase Hydraulic Modeling

An individual hydraulic model was created to analyze activities that will be present during construction of the proposed facility, which would include but are not limited to the construction of rock pads, work trestles and coffer dams. The construction-phase hydraulic model was developed in parallel with the operational hydraulic analysis of the proposed Howard Street Bridge within HEC RAS 4.1.

Proposed cross-sections were modified to impede as much as 50% of the river channel during construction, which included 50 feet of abutment on the north bank and 40 feet of abutment on the south bank. Conservative estimations included the vertical impediment at these locations to simulate sheet pile restrictions in the river channel. This was assumed to represent a "worst case" construction condition. Ineffective flow areas were adjusted accordingly.

4.9.3 Construction Phase Hydraulic Modeling Results

Table 5-2 illustrates the modeled hydraulic impacts from the proposed construction activities.

Table 4-2
Summary of HEC RAS modeling results – 2500 cfs during construction

Cross Section	Existing Conditions		Construction Conditions		WSE Difference
	Water Surface Elevation (ft)	Channel Velocity (ft/s)	Water Surface Elevation (ft)	Channel Velocity (ft/s)	(ft)
<i>Just upstream of the Spokane Convention Center</i>					
8.0	1870.83	1.15	1871.46	1.09	0.63
7.0	1870.81	1.34	1871.44	1.26	0.63
5.0	1870.80	1.42	1871.43	1.35	0.63
4.0	1870.79	1.53	1871.42	1.43	0.63
3.0	1870.78	1.60	1871.42	1.49	0.64
2.6	1870.78	1.56	1871.41	1.58	0.63
2.3	1870.78	1.55	1871.38	2.01	0.60
2.0	1870.78	1.54	1871.34	2.49	0.56
<i>Howard Street Bridge</i>					
1.0	1870.74	1.97	1870.71	2.69	-0.03
0.5	1870.73	1.94	1870.73	1.94	0.00
0.1	1870.71	2.10	1870.71	2.10	0.00
0.0	1870.37	4.95	1870.37	4.95	0.00
<i>Avista Penstock</i>					
-1.0	1838.00	3.64	1838.00	3.64	0.00
<i>Just downstream of Avista Hydroelectric Outfall</i>					

Table 4-2 shows that the operating WSE downstream of the bridge during construction encroachment of about 50% of the channel would remain unchanged at the intake and might slightly decrease immediately downstream of the bridge due to removal of the encroachment at the southern bridge abutment 1. The WSE increase upstream of the bridge of 0.46 to 0.64 feet represents the driving head needed to provide the intake with an operational flow of 2500 cfs when channel capacity at the bridge is restricted as described during construction. If the proposed low chord elevation is not lowered from the existing bridge low chord elevation, there will be approximately 2.8 feet of freeboard over the Avista maximum operating conditions during construction. This should be adequate for a short-term condition in the absence of flooding.

During construction, alternative flow requirements may be identified as Avista fluctuates demand throughout the course of the construction season. Close coordination will be important to identify whether required flows will be met. For purposes of this analysis, the maximum design flows identified by Avista have been incorporated in the existing, proposed and construction hydraulic modeling.

4.9 Bank Stabilization and Scour

Visual inspection of the channel bottom has identified a large number of various objects and soil/rock types. These include historic concrete spalls, railroad ties, rebar and cobbles. No soil samples or gradation is available to further represent the South Channel bottom material.

Hydraulic modeling shows average existing channel velocities of 1.59 feet per second (at Cross-Section 3.0 in Tables 4-1 and 4-2) or less, except where local velocities are elevated at the intake. Proposed channel velocities are similar. For proposed operations, the maximum average channel velocities are slightly reduced to 1.55 feet per second; and during temporary construction, maximum average channel velocities may be increased slightly to 2.48 feet per second at Cross-Section 2.0 and 2.69 at Cross-Section 1.0 in Table 4-2. None of the modeled velocity changes were considered significant or sufficiently large to warrant the use of permanent erosion revetment, especially in light of concrete armoring of the banks and visible rubble on the channel bottom. Patterns of long-term scour and deposition within the channel is expected to continue much as it does today.

4.10 Conclusions

The proposed Howard Street South Channel Bridge Replacement Project will require structures to be placed within the floodplain of the Spokane River. A HEC-RAS backwater analysis was not required to evaluate floodplain impacts by the proposed bridge replacement because backwater is controlled upstream at the Upper Falls Diversion Dam and cannot increase in the downstream direction of the bridge and Avista intake; at most a flatwater condition would persist if flow through the Avista Power House were temporarily discontinued. Therefore, assuming that FEMA's modeling is correct, neither the proposed bridge nor any alternative new bridge will cause a rise in the currently accepted FEMA BFE.

A HEC-RAS backwater model was developed to compare pre- and post-project water surface elevations and to determine the driving head needed to maintain the conveyance of 2500 cfs through the proposed bridge structure during normal operations and during construction.

A corrected effective model was developed to determine the hydraulic characteristics of the system as it currently operates. This model was then revised to evaluate the proposed bridge configuration. These two models were compared to analyze the hydraulic effects of the proposed project under maximum operational flows, both for Avista design conditions and construction-phase conditions. The proposed bridge causes no rise of the design water surface elevation during normal operations. During construction, a 50% encroachment of the existing channel will cause an incremental rise in the design water surface elevation of about 0.6 feet. Average velocities through the bridge section do not change significantly under any of the evaluated conditions.

The number and size of temporary obstructions allowed in the channel during construction must be carefully evaluated. This analysis presents impacts to the water surface elevation due to a reduction in channel cross-sectional area of approximately 50%.

There appears to be capacity for minor changes in the existing freeboard. Final freeboard will be determined in design in consultation with the City, but existing freeboard should generally be approximated. At least 3.0 feet of normal operational freeboard to the bottom of the superstructure and about 2.0 feet of freeboard to the bridge deck above the BFE is desirable.

Optional future model evaluations may include:

- Modification to the City's HEC-RAS model to include operational conveyance down the South Channel to assess impacts in conjunction with FEMA flood events. This would effectively revise and update the FEMA BFE to account for operational flows down the South Channel and allow for refined evaluation of floodplain impacts. However, it is reasonably likely that Avista will reserve the right to discontinue hydropower operations during a 100-year flood to limit intake of sediment and debris, in which case there would be no South Channel flow and the current model assumption of a flatwater backwater in the South Channel would remain valid.
- Analysis of multiple construction scenarios to obtain a range of acceptable temporary channel encroachments. This should only be needed if additional construction encroachment is proposed, or if a lower rise in the WSE during construction is desired.

SECTION 5

References

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Barber et al., *Spokane-Valley Rathdrum Prairie Aquifer Optimized Recharge for Summer Flow Augmentation of the Columbia River*. April 2011

The City of Spokane. *Riverfront Park Master Plan 2014*. Fall 2014.

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Jehn et al., *The Rathdrum Prairie Aquifer Technical Report*. August 1988.

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Appendix A

Pertinent Design Data

Correspondence with Avista

Existing Channel As-Builts

Existing Bridge As-Builts

FEMA FIS

Proposed Bridge Plan & Elevation

Proposed Bridge Typical Section



Meeting Title/Date

ATTENDEES: Cynthia Oestreich/Avista; Iosefa Matagi/CH2M HILL
COPY TO: Mark Brower/CH2M HILL
PREPARED BY: Iosefa Matagi
DATE: September 22, 2015
PROJECT: Howard Street South Channel Bridge Replacement

Objectives

This meeting was created to:

- Orient all participants with the current level of design for the Howard Street South Channel Bridge.
- Identify any concerns Avista may have regarding the ability of the South Channel Forebay to convey required and maximum flows for their facility given the conceptual parameters of the proposed bridge.
- Identify any concerns that Avista may have regarding the available volume of water present in the South Channel Forebay given the conceptual parameters of the proposed bridge.
- Discuss questions concerning the conceptual design of the proposed bridge as it pertains to the hydraulic capacity of the South Channel Forebay.

Summary

Avista has addressed the need for the current water surface elevations to remain unchanged with any proposed final bridge design. This would include the current operating conditions as well as the maximum flow conditions of 2500 cfs (WSE = 1870.8). All elevations presented here are referenced to the North American Vertical Datum of 1988. CH2M HILL has confirmed this need and will actively ensure that this need is met.

Avista has identified that the Upper Falls currently has reservoir storage of approximately 800 acre-ft. This is matched and verified with the current Spokane River Dam Breach HEC RAS modeling efforts completed by West Consultants Inc. Avista has acknowledged that a proposed concept to reduce the current bridge from three (3) spans to two (2) spans which will include placing the proposed northern abutment further south will be adequate and will not result in a significant loss of storage volume in the Upper Falls reservoir.

Action Items

CH2M HILL will communicate with Avista regarding any major changes with the proposed bridge design as it progresses through final design.

Matagi, Iosefa/BOI

From: Oestreich, Cynthia <Cynthia.Oestreich@avistacorp.com>
Sent: Wednesday, December 02, 2015 8:46 AM
To: Matagi, Iosefa/BOI
Subject: RE: Avista Hydraulic/Topographic Data - Spokane River - South Channel

Hi Sefa,

No the water never freezes because it is always moving and the same goes for the intake. The unit is always running so no ice builds up. Not sure about the bridges if ice builds up against any. Do you want a contact that I have with the City bridge engineers and maintenance crews?

Take care,
Cynthia

From: Iosefa.Matagi@CH2M.com [mailto:Iosefa.Matagi@CH2M.com]
Sent: Tuesday, December 01, 2015 1:27 PM
To: Oestreich, Cynthia
Subject: RE: Avista Hydraulic/Topographic Data - Spokane River - South Channel

Hey Cynthia,

One more quick question:

Does the South Channel freeze on the surface during the winter or would you say the water is moving enough that it does not freeze? If it does freeze, have you noticed ice gathering up against the intake or up against any of the bridges across the South Channel?

Just finishing up my report to turn in and have this basic question to figure out..

Thanks again.

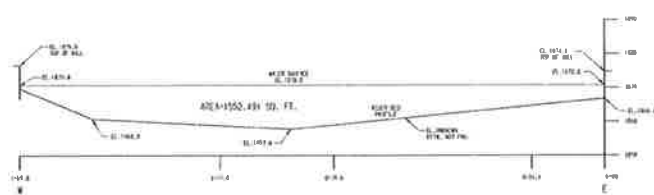
Sefa

From: Oestreich, Cynthia [mailto:Cynthia.Oestreich@avistacorp.com]
Sent: Wednesday, November 18, 2015 4:33 PM
To: Matagi, Iosefa/BOI <Iosefa.Matagi@CH2M.com>
Subject: RE: Avista Hydraulic/Topographic Data - Spokane River - South Channel

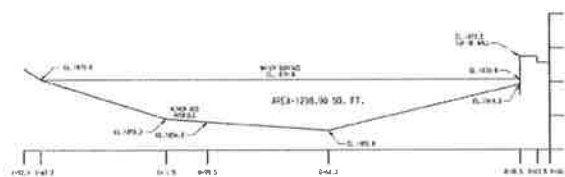
Hi Sefa,

No snow here yet, but we just had a crazy storm go through Spokane yesterday with peak winds in the evening close to hurricane gusts. We have lots of power outages. Thankfully my power stayed on.

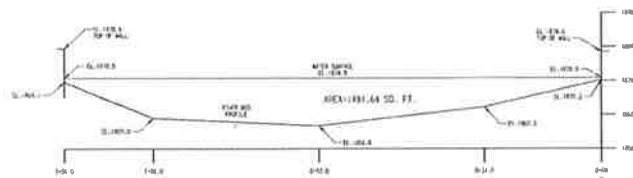
I looked at your previous mtg minutes and what you just sent. The reservoir normal full pool elevation is 1870.5'. The maximum flow or hydraulic capacity through our turbine at Upper Falls is 2,500 cfs. Upper Falls and Monroe St plants have very little storage capacity and are operated as run-of-river facilities. Operations at Upper Falls and Monroe St HED's are responsive to operations in the watersheds feeding the Spokane River. The excerpt below describes our "operations".



SECTION I
GRADE 1-4



SECTION 2
實地工作訓練



SECTION 3
第 3 部分



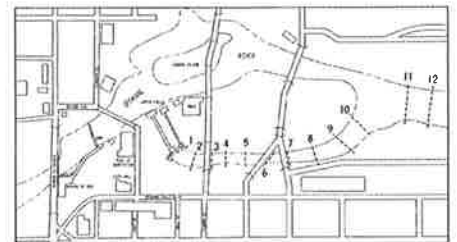
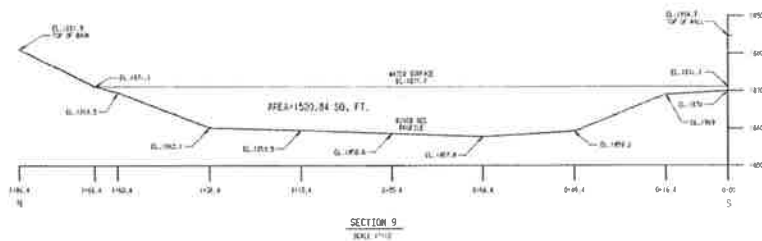
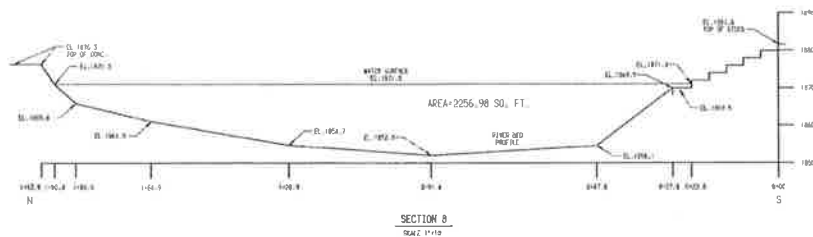
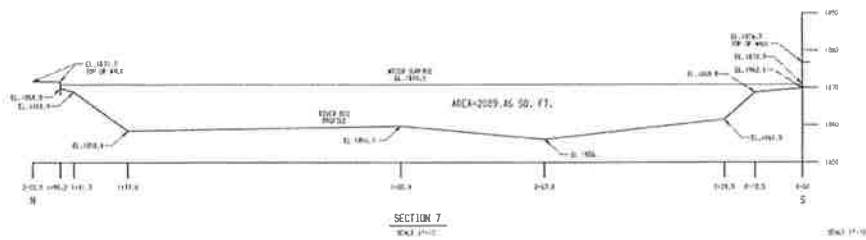
KEY MAP
SCALE: NONE

2025
 2025 JUL 26 AM 2:00 EDT. 047.0 - 10 PM

DEFENSE DRAWINGS

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140. (790001). 00000 05/11/85 01-2540

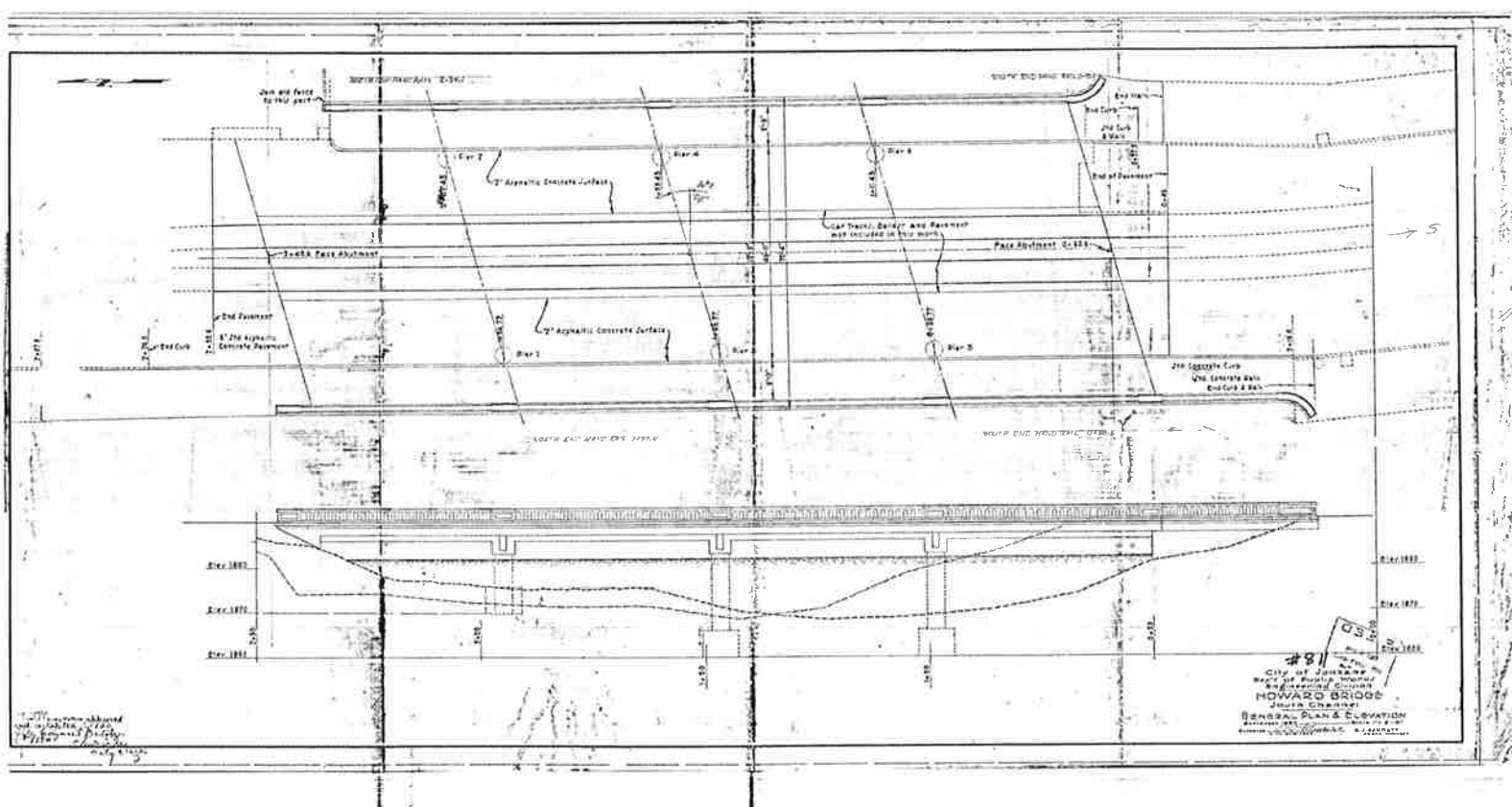
MONROE STREET I.L.E.O.
1990 INSTALLATION
SPOKANE RIVER & CHANAMONT
SOUTH CHANNEL CROSS SECTIONS
THE WASHINGTON WATER POWER COMPANY
SPokane, Washington

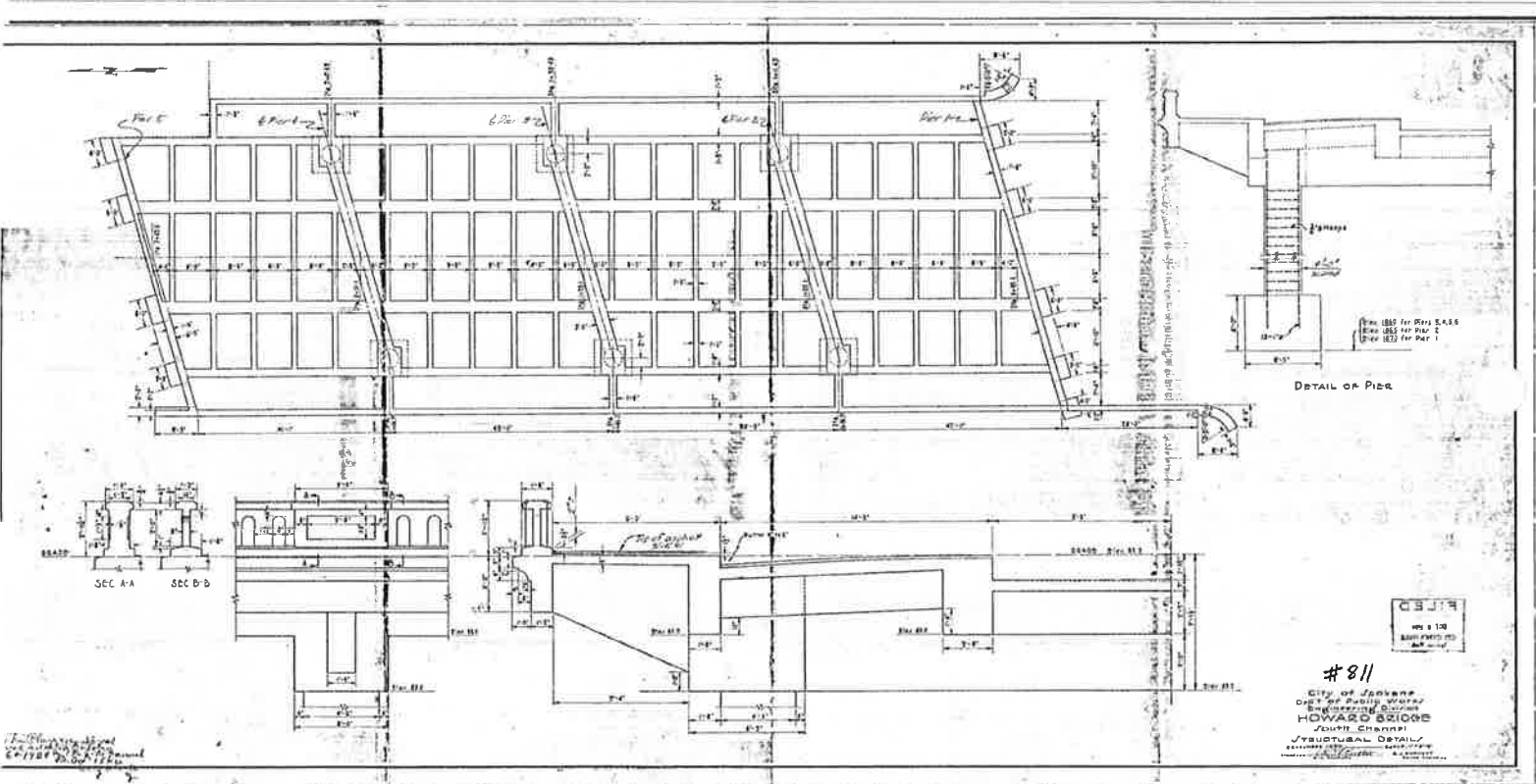


NOTES:
RIVER ELEV. AT 2000 FT. (2000 + 17.00)

REFERENCE DRAWINGS:
CROSS-SECTION OF RIVER BED AND CHANNEL 1-2001
1:11 CHANNEL CROSS-SECTION 1-2002

WYOMING STREET H.E.D.
1990 INSTALLATION
SPOKANE RIVER & EMBANKMENT
SOUTH CHANNEL CROSS SECTIONS
THE WASHINGTON WATER POWER COMPANY
SPOKANE, WASHINGTON





FLOOD INSURANCE STUDY



SPOKANE COUNTY, WASHINGTON

AND INCORPORATED AREAS



Community

Name

*AIRWAY HEIGHTS, CITY OF
CHENEY, CITY OF
DEER PARK, CITY OF
FAIRFIELD, TOWN OF
LATAH, TOWN OF
LIBERTY LAKE, CITY OF
MEDICAL LAKE, CITY OF
MILLWOOD, TOWN OF
ROCKFORD, TOWN OF
SPANGLE, CITY OF
SPOKANE COUNTY UNINCORPORATED AREAS
SPOKANE VALLEY, CITY OF
SPOKANE, CITY OF
WAVERLY, TOWN OF

*NON-FLOODPRONE

Community

Number

530270
530175
530176
530177
530178
530162
530179
530180
530181
530182
530174
530342
530183
530184



Effective: July 6, 2010

Federal Emergency Management Agency

Flood Insurance Study Number

53063CV000A

Table 3 - Historic Floods

Hangman Creek ¹ (Date)	Peak Discharge (cfs)	Recurrence Interval (Years)
February 1963	20,600	37
January 1974	17,700	21
January 1959	16,200	15
December 1965	14,500	10
May 1948	11,900	6
Predicted 100-Year Flood	26,000	100
Spokane River ² (Date)	Peak Discharge (cfs)	Recurrence Interval (Years)
May 1894	49,000	62
December 1933	47,800	50
January 21 1974	45,600	36
May 1917	41,900	20
January 1918	39,600	14
Predicted 100-Year Flood	52,000	100

¹ U.S. Geological Survey (USGS) Stream Gage, Hangman Creek at Spokane

² U.S. Geological Survey (USGS) Stream Gage, Spokane River at Spokane

No long-term gage records exist for Chester Creek. Limited gage measurements of the flow along Chester Creek were made as part of a previous hydrology investigation (HYDMET, 1977). The gage data were collected near the Dishman-Mica Road crossing of Chester Creek from December 1994 through March 1995 and November 1995 through February 1996. No significant flood events occurred during the period of record.

City of Spokane

The Spokane River is generally contained in its channel, with substantial freeboard even at the 1% annual chance flood, except for a few areas as described below.

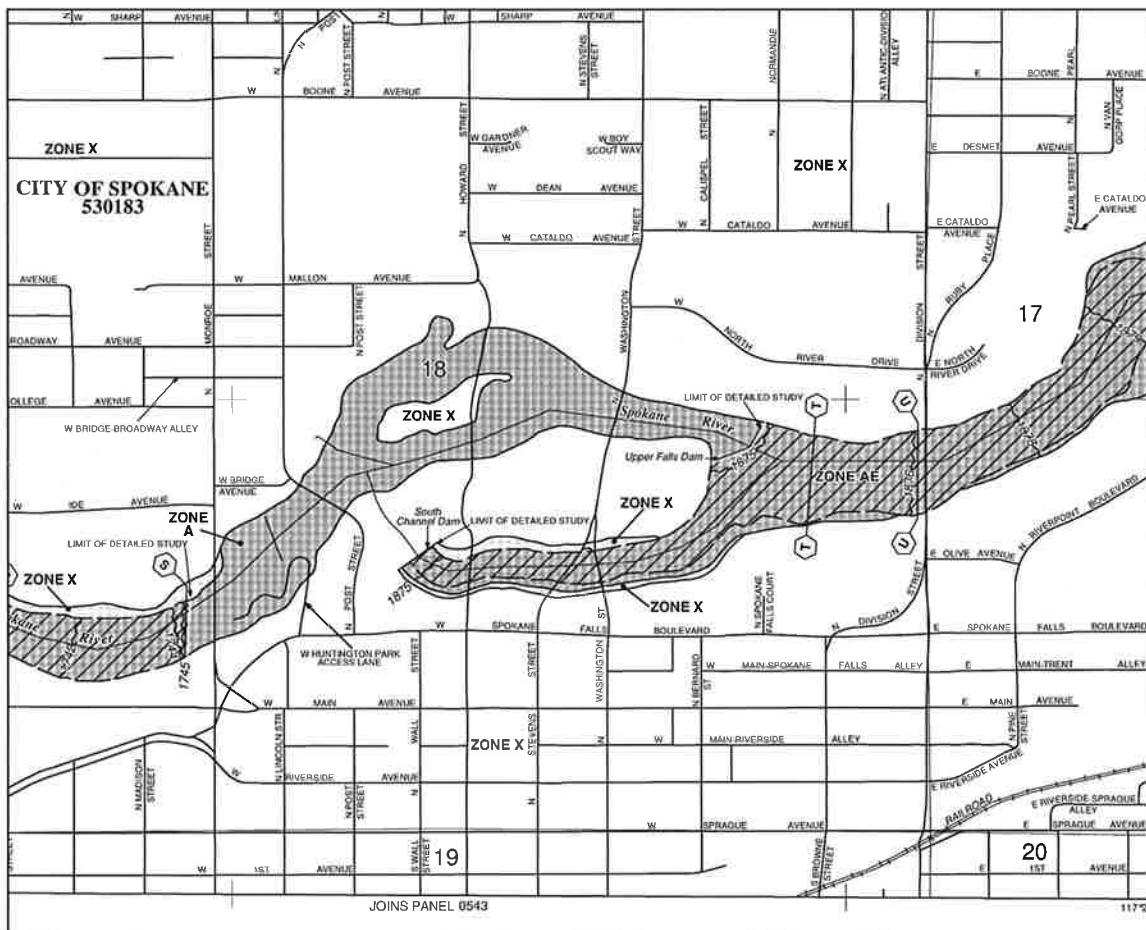
In Peaceful Valley (River Mile 73.6), the total area potentially affected is approximately 11.7 acres, containing 20 single-family residences and 1 industrial structure. The estimated potential damage resulting from the 1% annual chance flood and the failure of temporary sandbag dikes is street, yard, and basement flooding involving 20 homes, some of which experience first floor damage. The single industrial facility in the area is a casket factory whose concrete floor is above the flood plain, the flood potential being confined primarily to the storage yard. The residences in the area are single-family wood structures, mostly over 40 years old. The 1974 flood, classified as a 36-year event, caused some damage, mainly basement and street flooding.

Table 4 - Summary of Discharges (Cont'd)

Flooding Source and Location	Drainage Area (square miles)	Peak Discharges (cubic feet per second)			
		10-Percent- Annual- Chance	2-Percent- Annual- Chance	1-Percent- Annual- Chance	0.2-Percent- Annual- Chance
Hangman Creek / Little Spokane River Near Mouth – cont'd					
Above Confluence with Deep Creek	638	2,545	3,761	4,194	5,454
Below Confluence with Dragoon Creek	490	2,054	3,011	3,372	4,452
Below Chatteroy	312	1,001	1,436	1,611	2,166
Below Confluence with Eloika Lake	281	892	1,260	1,415	1,917
At Milan	255	727	1,006	1,137	1,590
Saltese Creek					
At Steen Road	24.2	65	215		531
At Baker Road	21.8	31	66		101
Spokane River					
At USGS Gage Near Otis Orchard	3,880	37,500	47,000		65,000
Forker Draw					
At Bigelow Gulch Road	-- ¹	49	88	109	135
Below East Jacob Road	-- ¹	60	108	134	166
At Chursh Driveway	-- ¹	117	209	259	321
Rock Creek					
Below Confluence with Mica Creek	128.8	5,190	9,590	11,500	15,590
Above Confluence with Mica Creek	106.2	4,410	8,060	9,640	12,990
Mica Creek					
At its mouth	22.6	1,190	2,290		3,840

Unnamed Tributary to Chester Creek (see next page)

--¹ Not Available



See Flood Insurance Study report for this jurisdiction.
 Flood insurance is available in this community, contact your insurance agent or the National Flood Insurance Program at 1-800-636-6620.



MAP SCALE 1" = 500'

PANEL 0541D

**FIRM
 FLOOD INSURANCE RATE MAP
 SPOKANE COUNTY,
 WASHINGTON
 AND INCORPORATED AREAS**

PANEL 541 OF 1150
 SEE MAP INDEX FOR FIRM PANEL LAYOUT
 CONTAINS:
 COMMUNITY: SPOKANE, CITY OF
 NUMBER: 530183
 PANEL: 0541
 SHEET: 1 OF 1

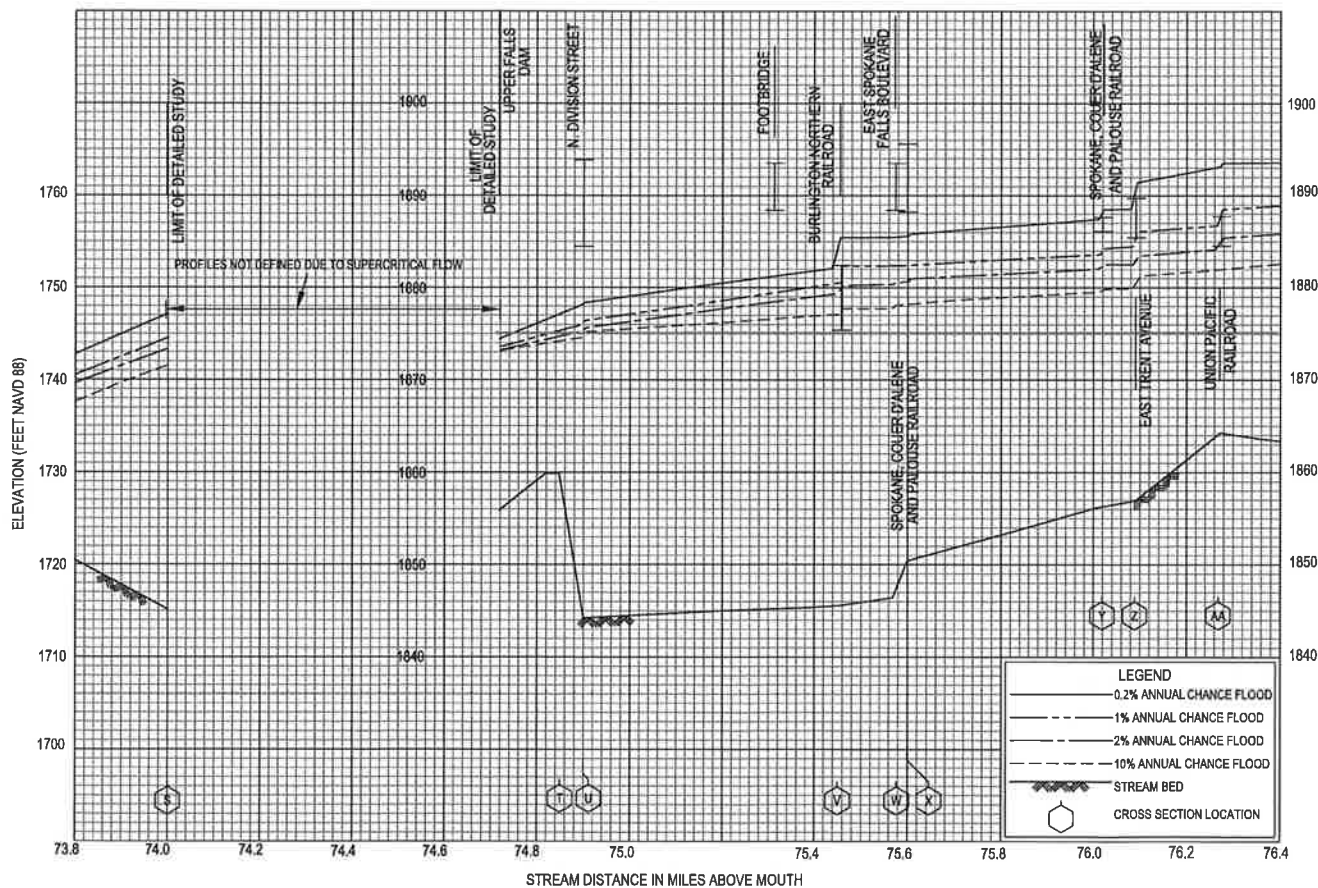
Notes to User: The map boundary shown below should be used for determining flood insurance coverage. The Community Name shown above should be used on insurance applications for the subject community.

**MAP NUMBER
 53063C0541D**
**EFFECTIVE DATE
 JULY 6, 2010**
 Federal Emergency Management Agency

JOINS PANEL 0543

47 0922 117 2422 50'

This is an official copy of a portion of the above referenced flood map. It was extracted using FIRM 24/24. This map does not reflect changes or amendments which may have been made subsequent to the date on the title block. For the latest product information about National Flood Insurance Program flood maps, check the FEMA Flood Map Store at www.msc.fema.gov

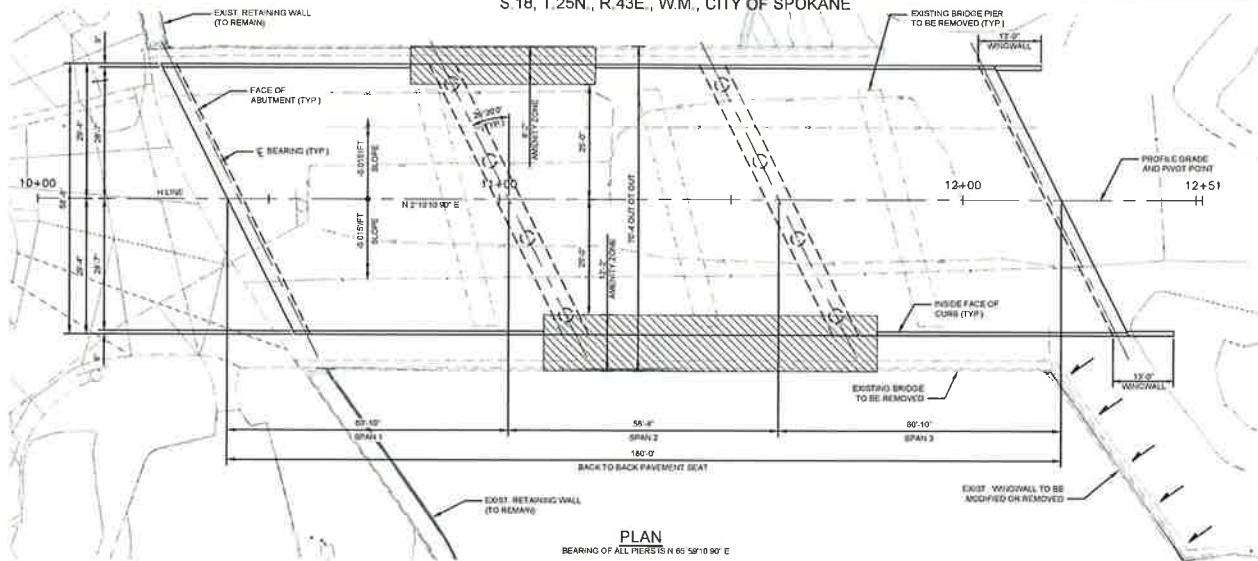


FLOOD PROFILES

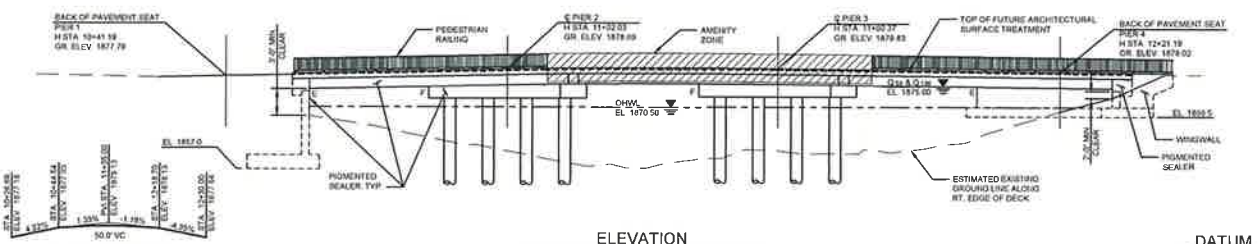
SPOKANE RIVER

FEDERAL EMERGENCY MANAGEMENT AGENCY
SPOKANE COUNTY, WA
AND INCORPORATED AREAS

S 18, T.25N, R.43E., W.M., CITY OF SPOKANE



PLAN
BEARING OF ALL PIERS IS N 65° 58' 18" 00" E

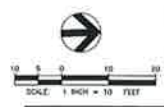


ELEVATION

GRADE ELEVATIONS SHOWN ARE FINISH GRADE AT TOP OF ARCHITECTURAL TREATMENT ON H LINE AND EQUAL TO PROFILE GRADE

DATUM
NAVD 1988

H LINE PROFILE



PRELIMINARY
DESIGN
FOR REVIEW ONLY
10 DEC 2015

<div>ch2m</div>			<div>CITY OF SPOKANE, WASHINGTON DEPARTMENT OF PARKS AND RECREATION 1000000000 SPOKANE, WASHINGTON 99201-1000</div>		<div>1000000000 BRIDGE PLAN & ELEVATION</div>		<div>DISTRICT ENGINEER STREET 2009xxx BR-1</div>	
NO.	REVISIONS	DATE	CITY DATUM SCALE		BRIDGE PLAN & ELEVATION		DISTRICT ENGINEER	

Appendix B

Hydraulics

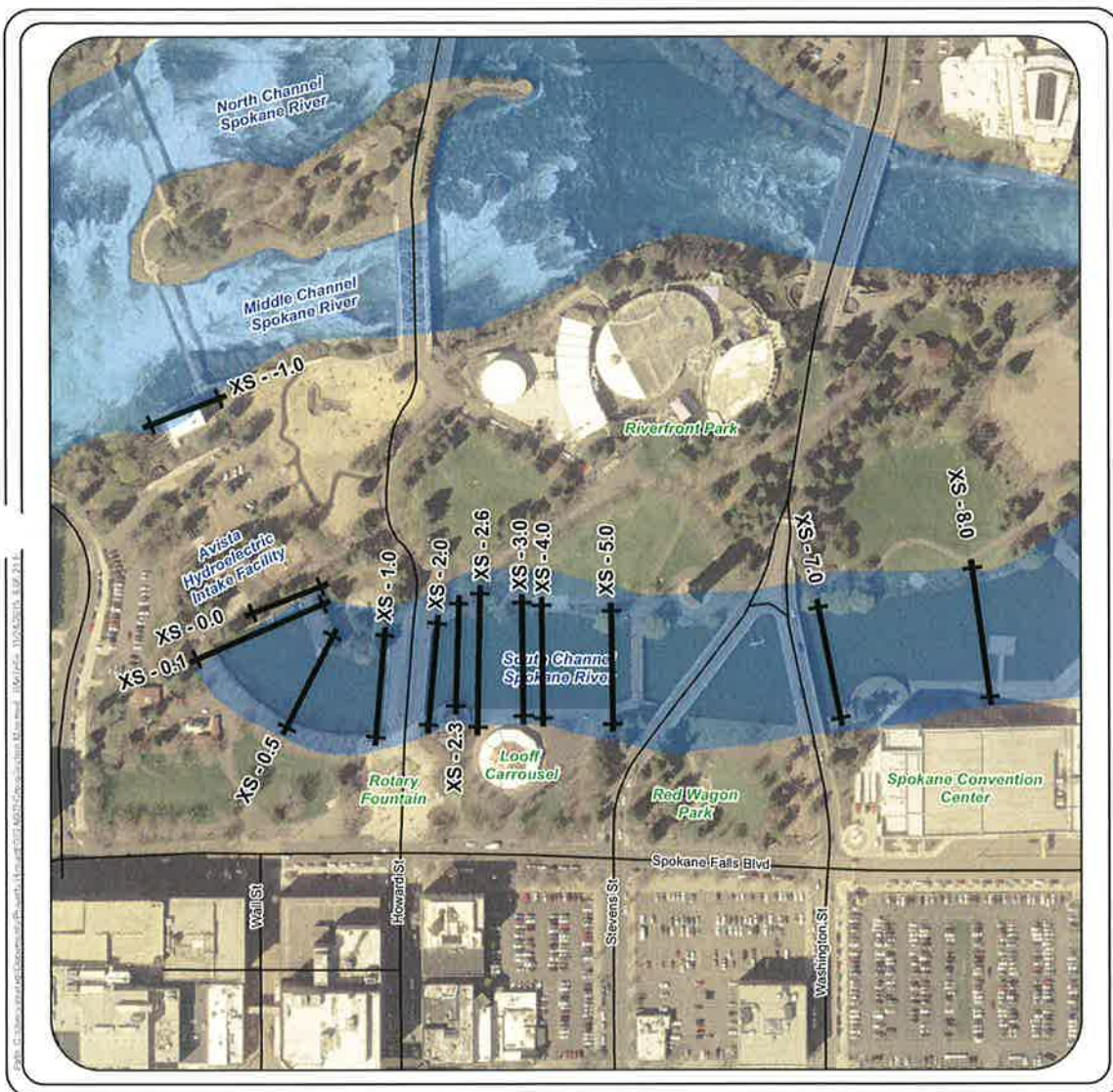
Location Map

HEC RAS Output (Natural Conditions)

HEC RAS Output (Existing Conditions)

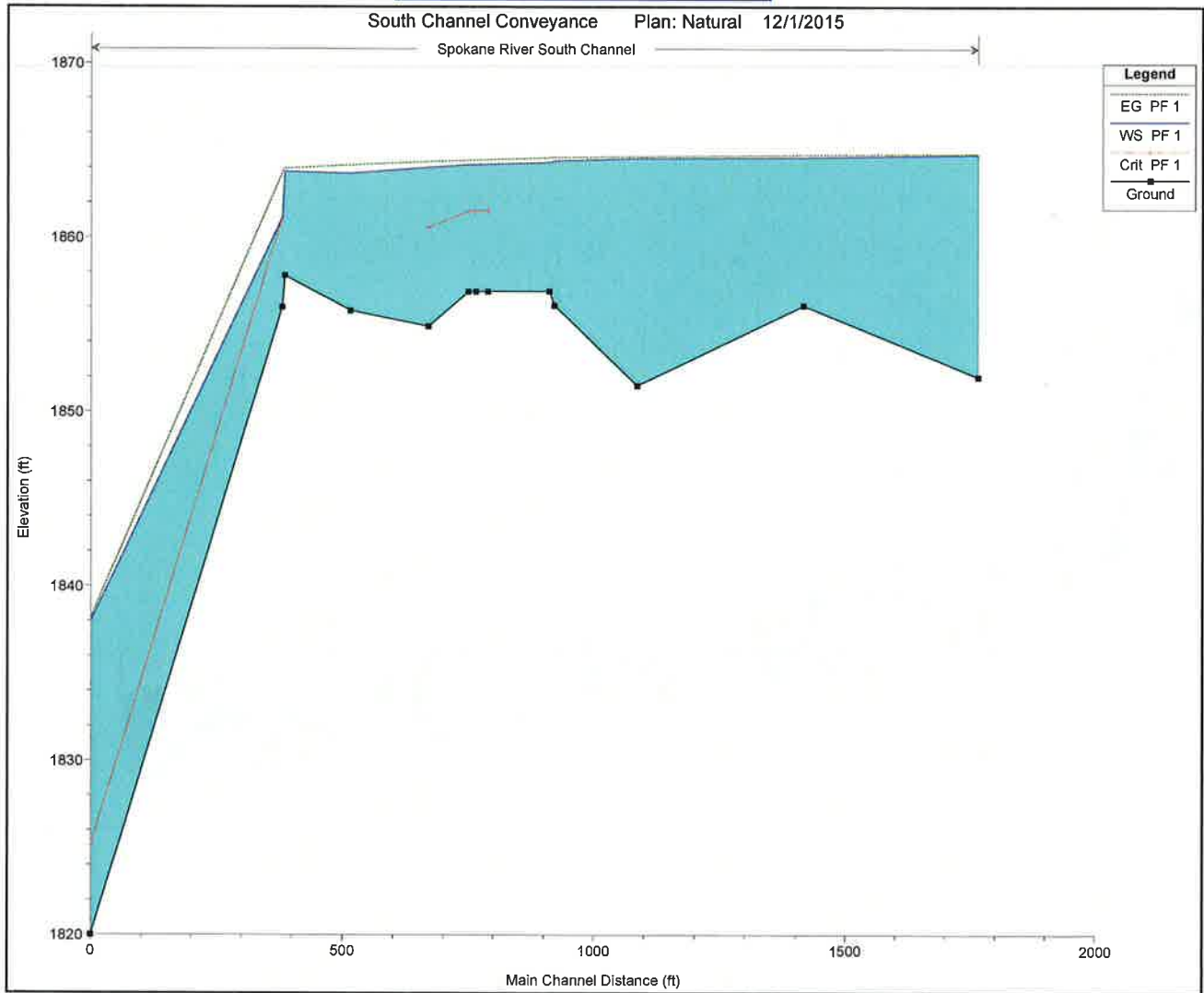
HEC RAS Output (Proposed Conditions)

HEC RAS Output (Construction Condition)

City of Spokane
Howard Street Bridge Hydraulic Analysis

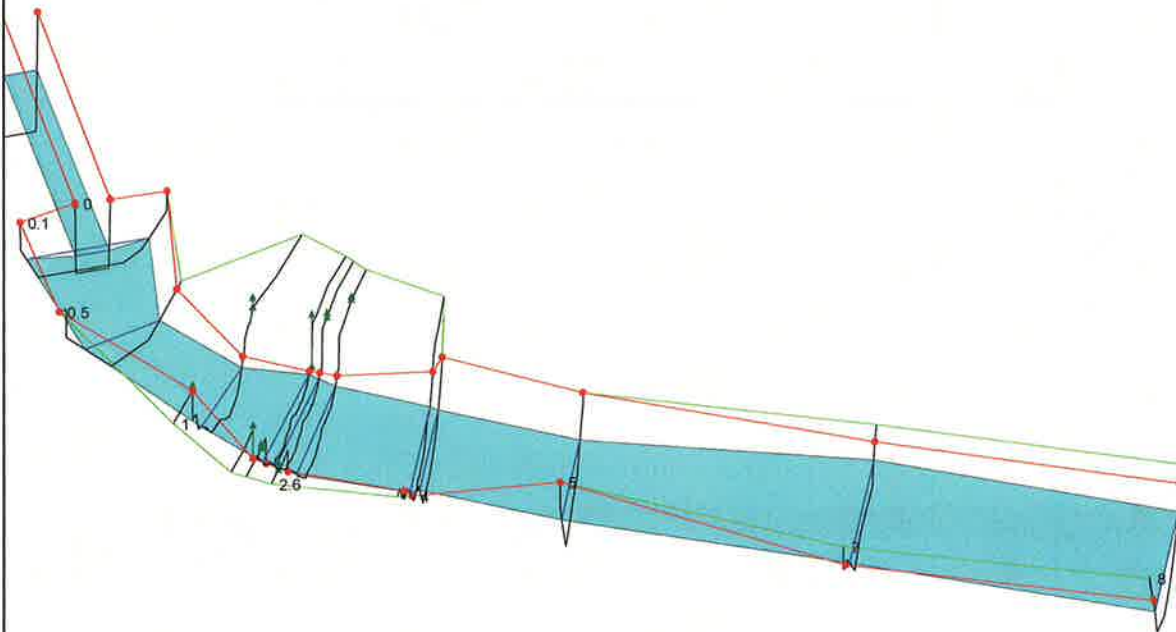


NATURAL CHANNEL CONDITIONS



South Channel Conveyance Plan: Natural 12/1/2015

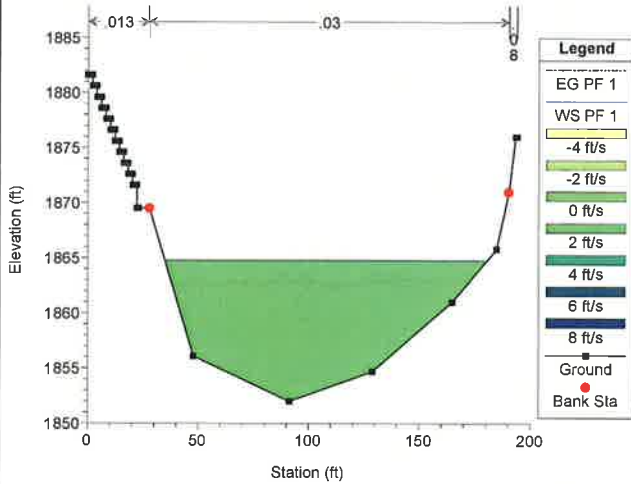
Legend	
WS PF 1	
Ground	
Bank Sta	
Ineff	



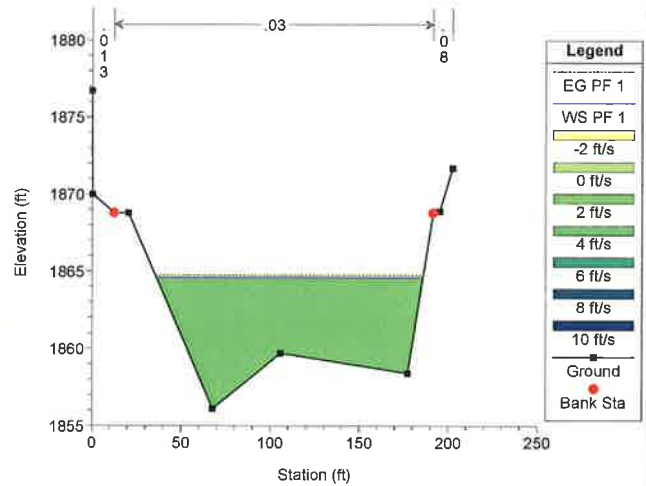
HEC-RAS Plan: Natural River: Spokane River Reach: South Channel Profile: PF 1

Reach	River Sta	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl
South Channel	8	2500.00	1852.00	1864.76		1864.83	0.000102	2.03	1229.10	145.70	0.12
South Channel	7	2500.00	1856.10	1864.61		1864.75	0.000414	3.07	814.42	149.86	0.23
South Channel	5	2500.00	1851.50	1864.55		1864.66	0.000181	2.63	949.43	116.02	0.16
South Channel	4	2500.00	1856.10	1864.41		1864.60	0.000475	3.54	706.09	116.59	0.25
South Channel	3	2500.00	1856.91	1864.31		1864.59	0.000907	4.19	597.21	124.50	0.34
South Channel	2.6	2500.00	1856.90	1864.21	1861.53	1864.47	0.000955	4.14	604.24	133.79	0.34
South Channel	2.3	2500.00	1856.90	1864.19	1861.52	1864.45	0.000919	4.07	614.34	134.99	0.34
South Channel	2	2500.00	1856.89	1864.18	1861.49	1864.43	0.000889	4.02	622.44	135.76	0.33
South Channel	1	2500.00	1854.90	1864.02	1860.56	1864.35	0.000909	4.62	541.17	96.28	0.34
South Channel	0.5	2500.00	1855.80	1863.68		1864.15	0.001570	5.53	451.82	93.68	0.44
South Channel	0.1	2500.00	1857.80	1863.77		1863.95	0.000539	3.41	733.25	141.70	0.26
South Channel	0	2500.00	1856.00	1861.12	1861.12	1863.71	0.001969	12.90	193.79	38.14	1.01
South Channel	-1	2500.00	1820.00	1838.00	1825.15	1838.21	0.000275	3.64	686.57	38.79	0.15

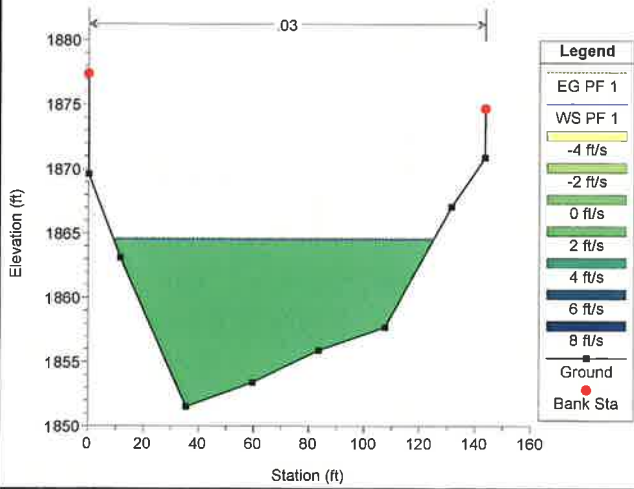
South Channel Conveyance Plan: Natural 12/1/2015



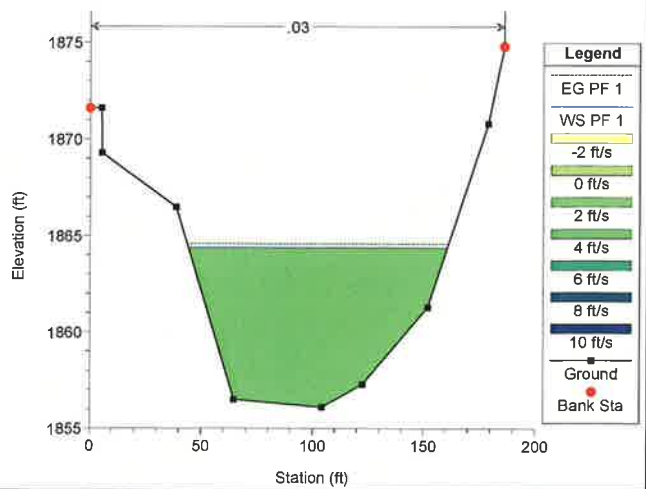
South Channel Conveyance Plan: Natural 12/1/2015

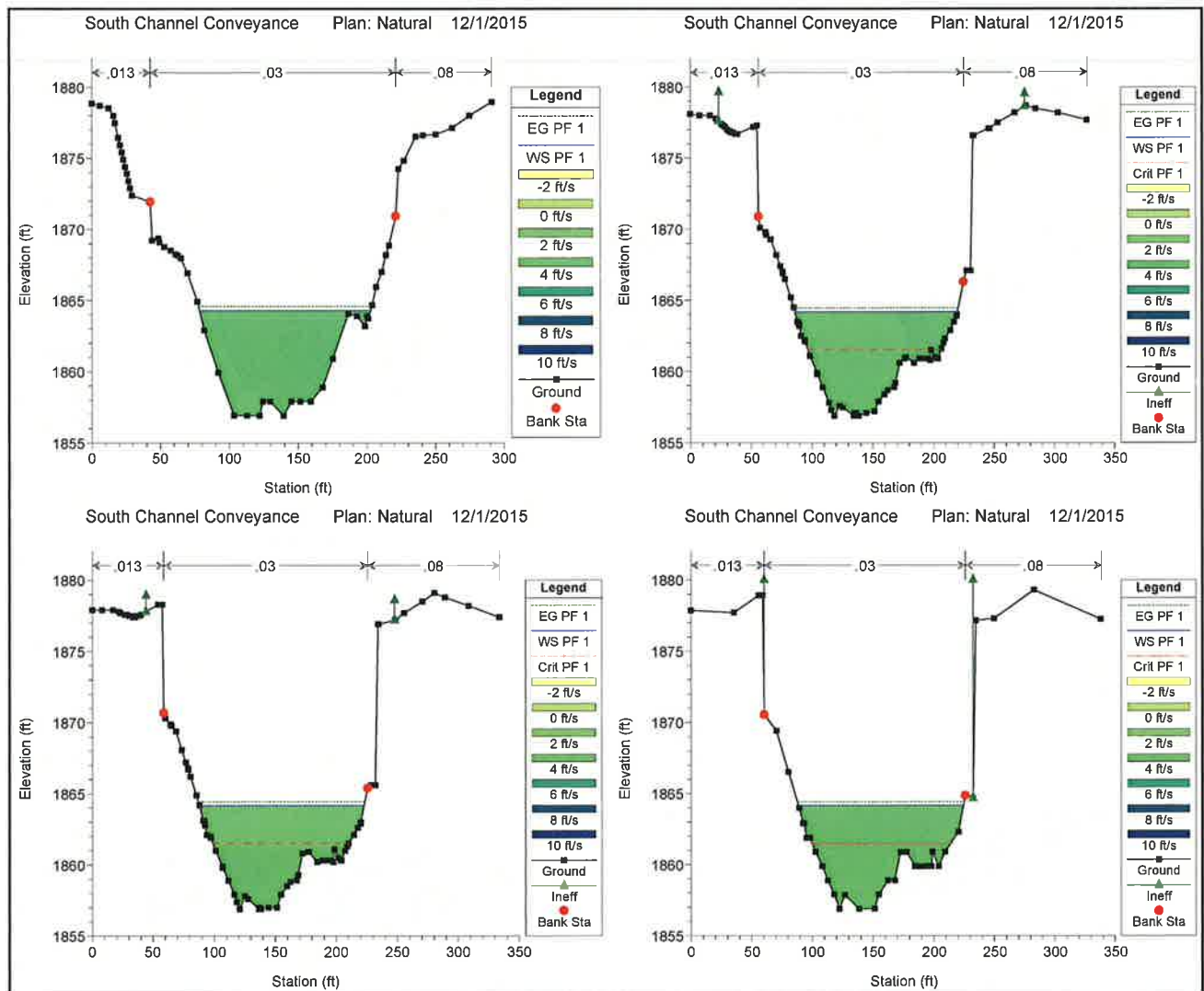


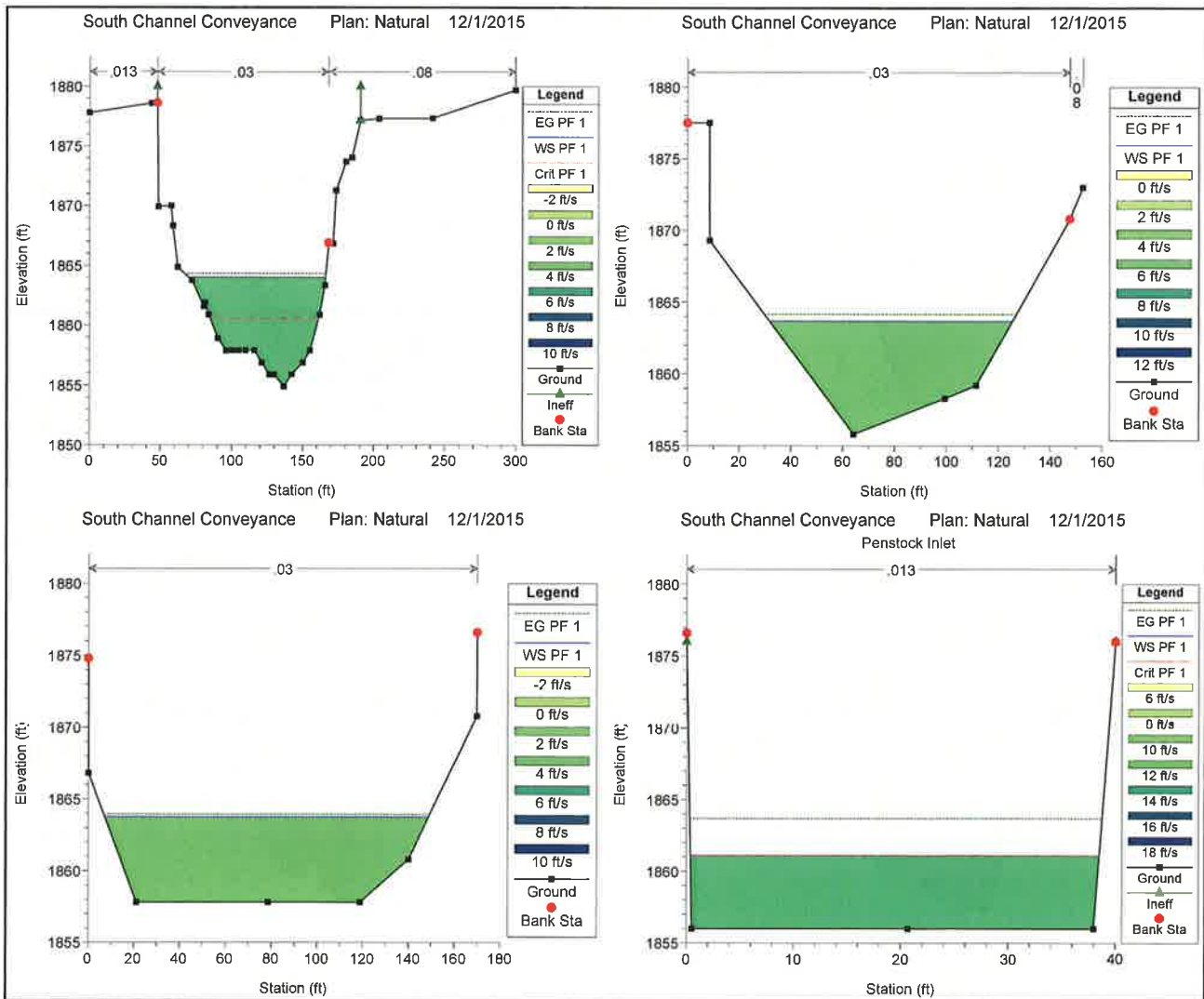
South Channel Conveyance Plan: Natural 12/1/2015



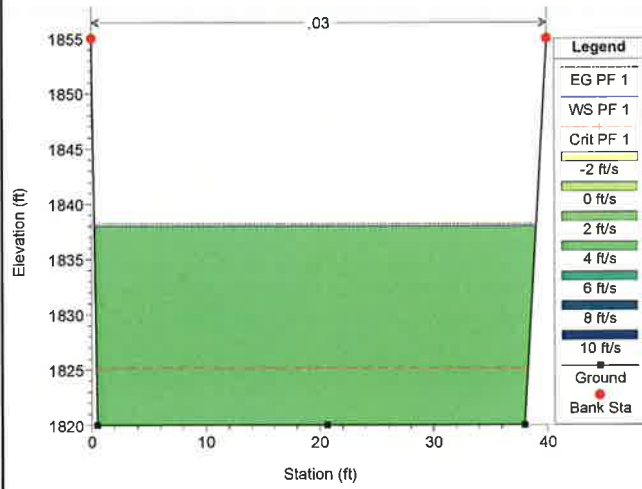
South Channel Conveyance Plan: Natural 12/1/2015

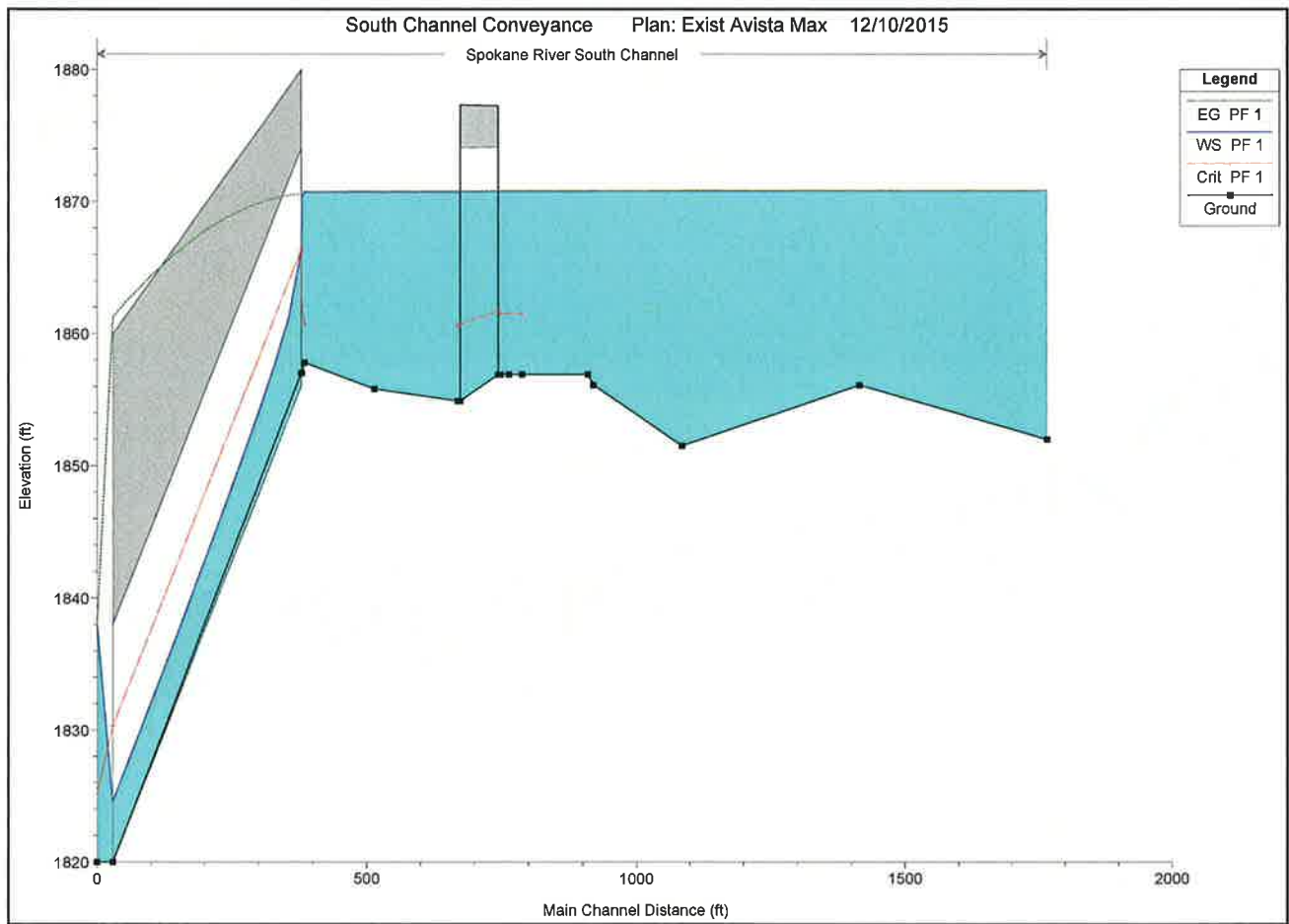






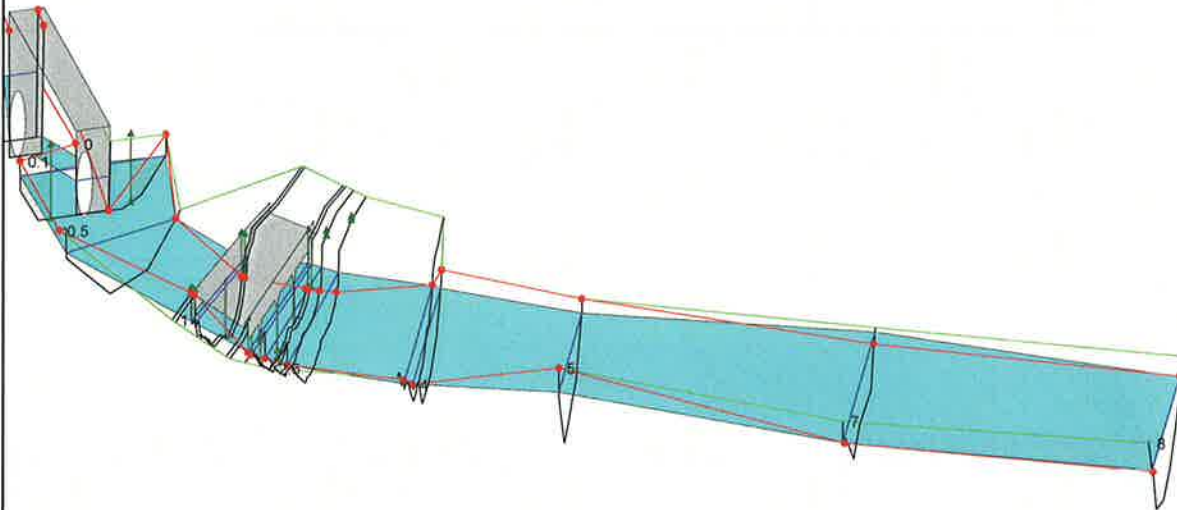
South Channel Conveyance Plan: Natural 12/1/2015





South Channel Conveyance Plan: Exist Avista Max 12/10/2015

Legend	
WS PF 1	
Ground	
Bank Sta	
Ineff	

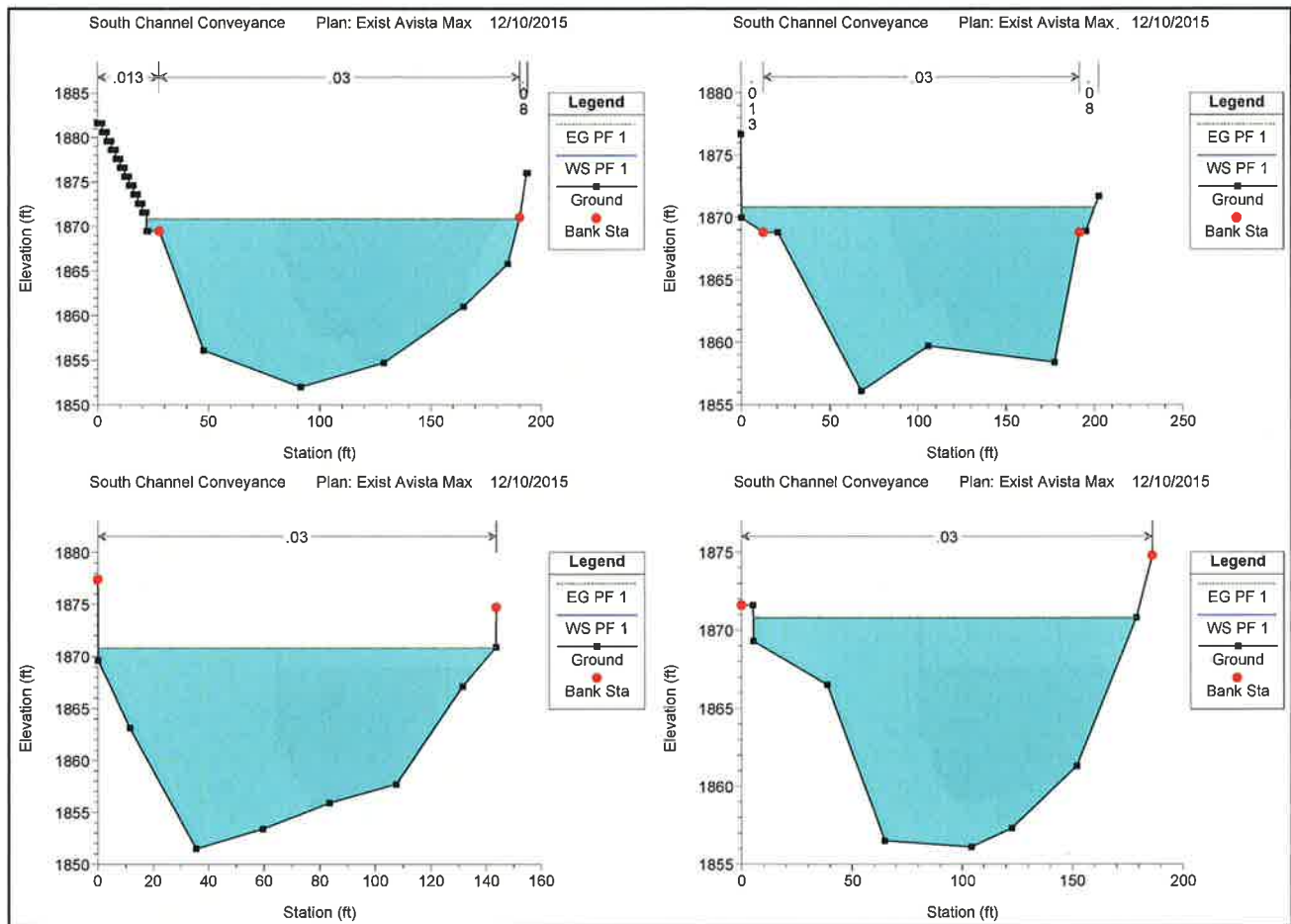


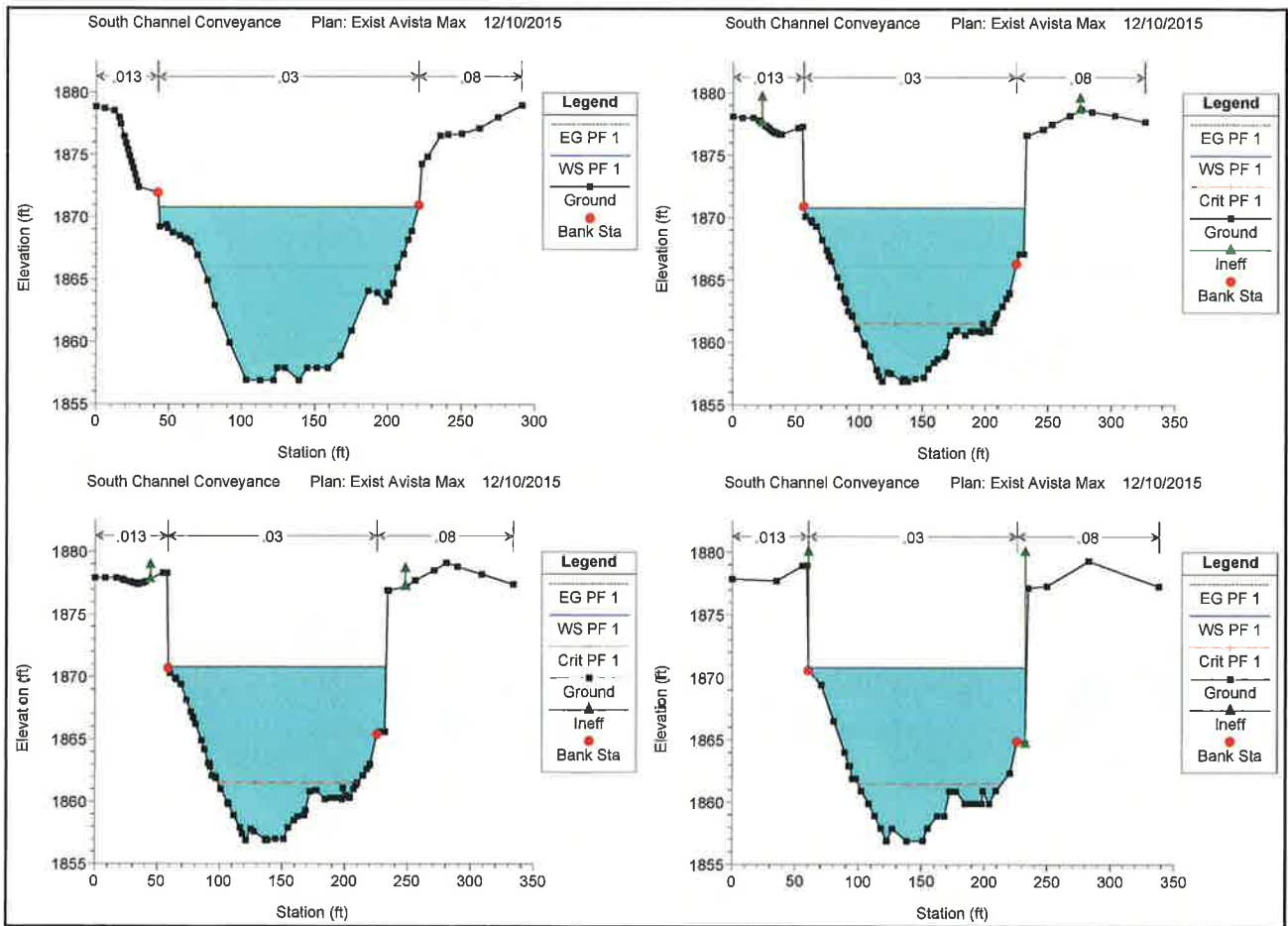
Plan: Exist Avista Spokane River South Channel RS: 1.5 Profile: PF 1

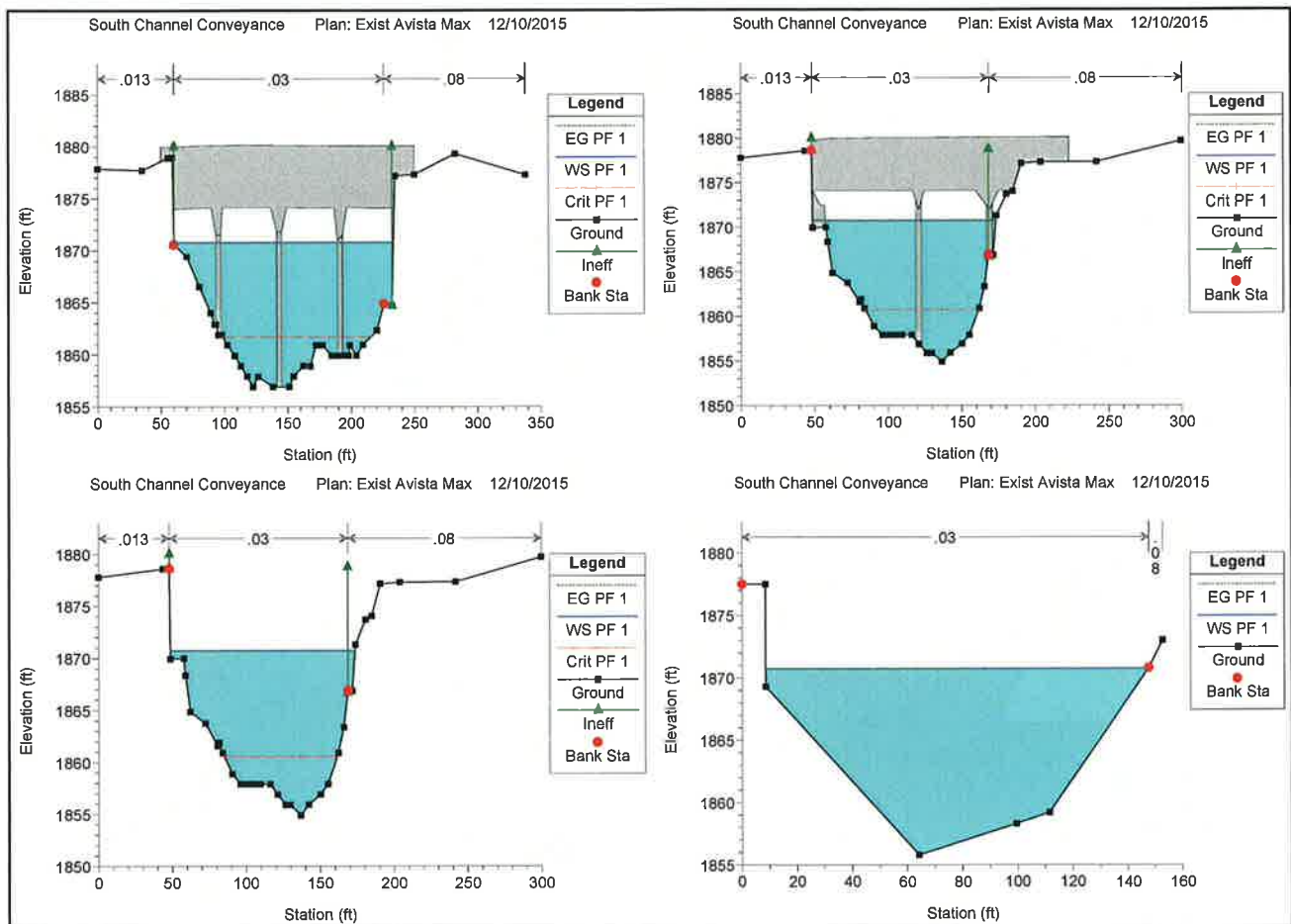
E.G. US. (ft)	1870.81	Element	Inside BR US	Inside BR DS
W.S. US. (ft)	1870.78	E.G. Elev (ft)	1870.81	1870.80
Q Total (cfs)	2500.00	W.S. Elev (ft)	1870.77	1870.74
Q Bridge (cfs)	2500.00	Crit W.S. (ft)	1861.69	1860.72
Q Weir (cfs)		Max Chl Dpth (ft)	13.88	15.83
Weir Sta Lft (ft)		Vel Total (ft/s)	1.65	2.08
Weir Sta Rgt (ft)		Flow Area (sq ft)	1512.33	1201.70
Weir Submerg		Froude # Chl	0.10	0.11
Weir Max Depth (ft)		Specif Force (cu ft)	8390.75	7585.59
Min El Weir Flow (ft)	1880.01	Hydr Depth (ft)	9.45	11.38
Min El Prs (ft)	1874.13	W.P. Total (ft)	229.99	147.00
Delta EG (ft)	0.01	Conv. Total (cfs)	259010.3	241540.8
Delta WS (ft)	0.04	Top Width (ft)	161.18	107.95
BR Open Area (sq ft)	1557.47	Frctn Loss (ft)	0.01	0.00
BR Open Vel (ft/s)	2.08	C & E Loss (ft)	0.00	0.00
Coef of Q		Shear Total (lb/sq ft)	0.04	0.05
Br Sel Method	Energy only	Power Total (lb/ft s)	0.00	0.00

HEC-RAS Plan: Exist Avista River: Spokane River Reach: South Channel Profile: PF 1

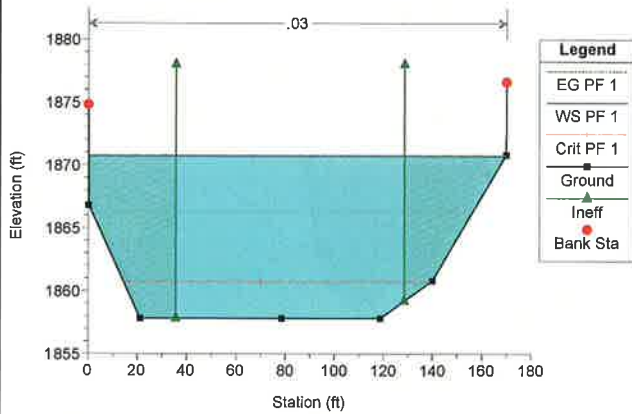
Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
South Channel	8	PF 1	2500.00	1852.00	1870.83		1870.85	0.000018	1.15	2184.59	168.18	0.06
South Channel	7	PF 1	2500.00	1856.10	1870.81		1870.84	0.000034	1.34	1877.66	200.13	0.07
South Channel	5	PF 1	2500.00	1851.50	1870.80		1870.83	0.000031	1.42	1761.79	143.10	0.07
South Channel	4	PF 1	2500.00	1856.10	1870.79		1870.82	0.000050	1.53	1633.75	173.73	0.09
South Channel	3	PF 1	2500.00	1856.91	1870.78		1870.82	0.000059	1.60	1564.53	177.53	0.09
South Channel	2.6	PF 1	2500.00	1856.90	1870.78	1861.53	1870.82	0.000051	1.56	1622.43	175.17	0.09
South Channel	2.3	PF 1	2500.00	1856.90	1870.78	1861.52	1870.81	0.000049	1.55	1639.17	174.02	0.09
South Channel	2	PF 1	2500.00	1856.89	1870.78	1861.49	1870.81	0.000048	1.54	1647.15	173.18	0.09
South Channel	1.5		Bridge									
South Channel	1	PF 1	2500.00	1854.90	1870.74	1860.56	1870.80	0.000073	1.97	1270.89	124.78	0.11
South Channel	0.5	PF 1	2500.00	1855.80	1870.73		1870.79	0.000083	1.94	1288.16	138.89	0.11
South Channel	0.1	PF 1	2500.00	1857.80	1870.71	1860.71	1870.78	0.000060	2.10	1192.98	169.48	0.10
South Channel	0	PF 1	2500.00	1857.00	1870.37	1862.16	1870.75	0.000088	4.95	512.92	39.25	0.24
South Channel	-0.5		Culvert									
South Channel	-1	PF 1	2500.00	1820.00	1838.00	1825.15	1838.21	0.000275	3.64	686.57	38.79	0.15





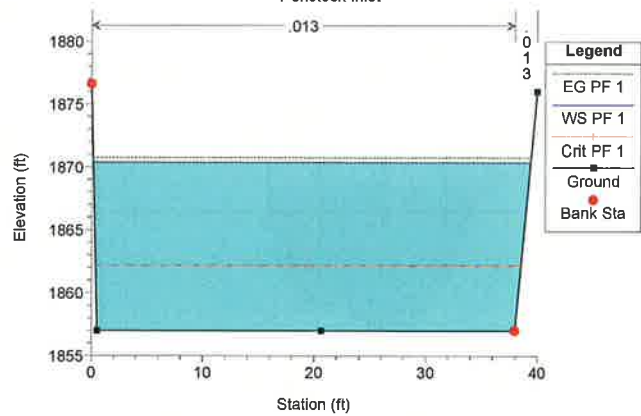


South Channel Conveyance Plan: Exist Avista Max 12/10/2015

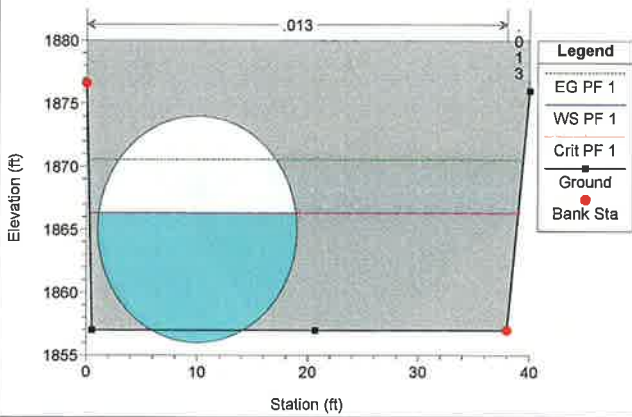


South Channel Conveyance Plan: Exist Avista Max 12/10/2015

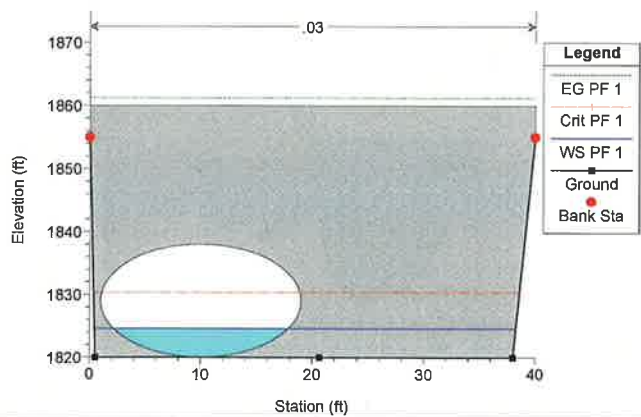
Penstock Inlet



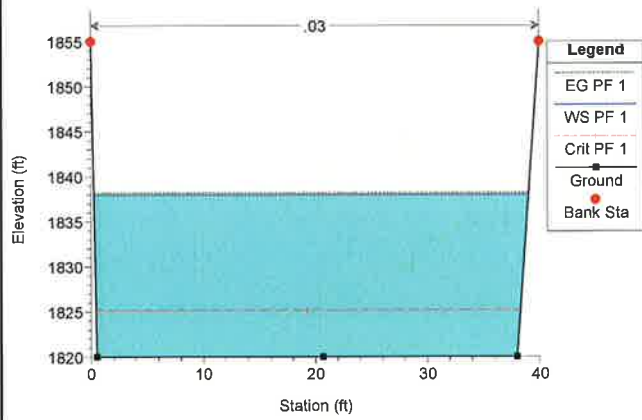
South Channel Conveyance Plan: Exist Avista Max 12/10/2015



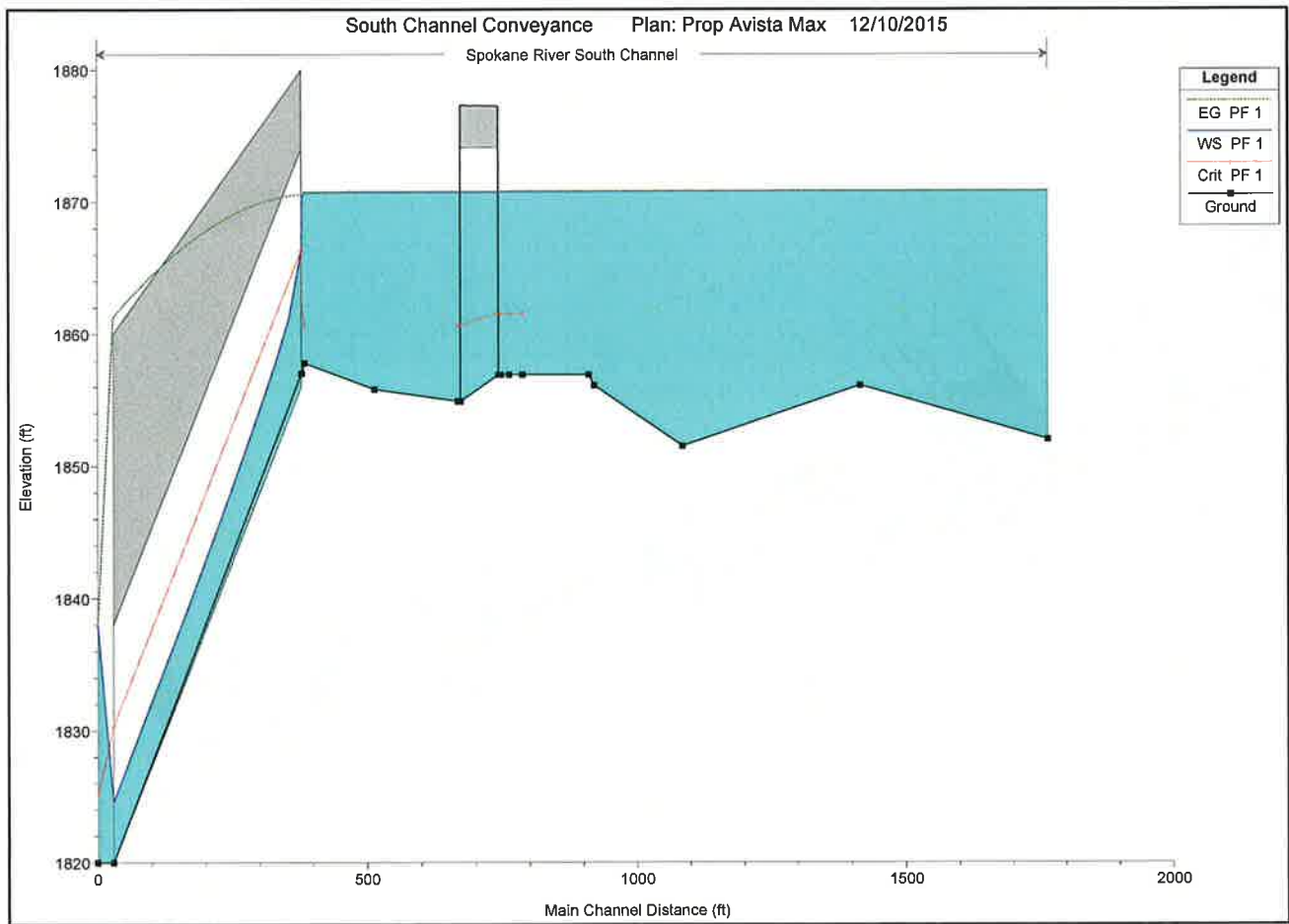
South Channel Conveyance Plan: Exist Avista Max 12/10/2015







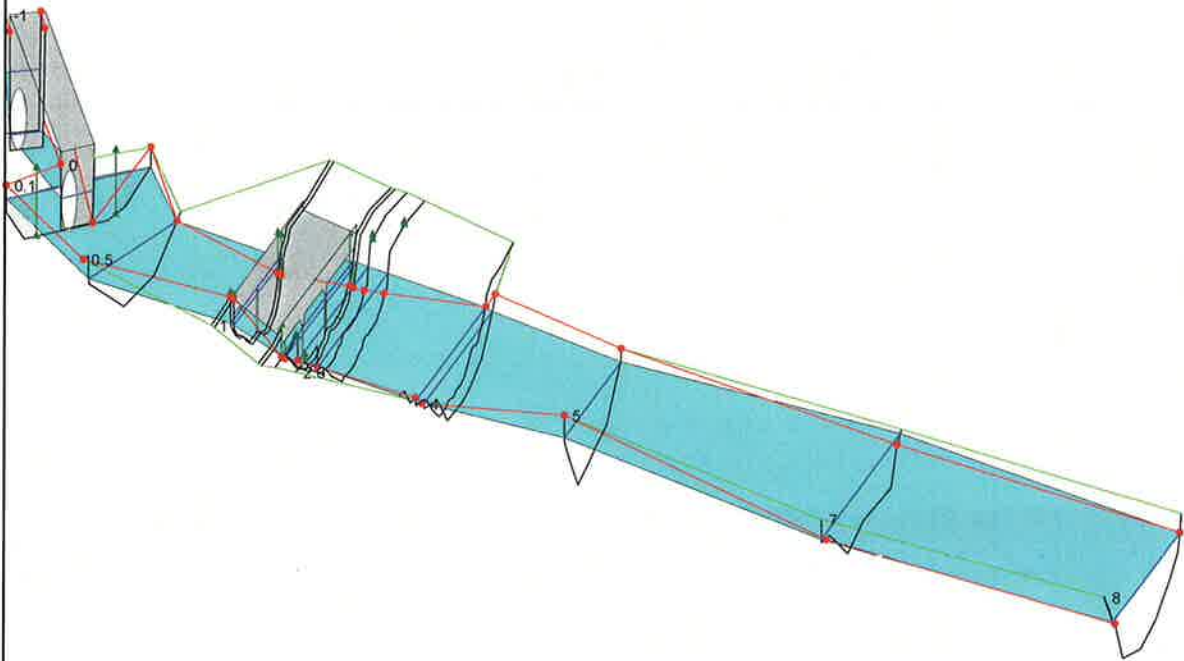
South Channel Conveyance Plan: Exist Avista Max 12/10/2015







Legend	
	WS PF 1
	Ground
	Bank Sta
	Ineff

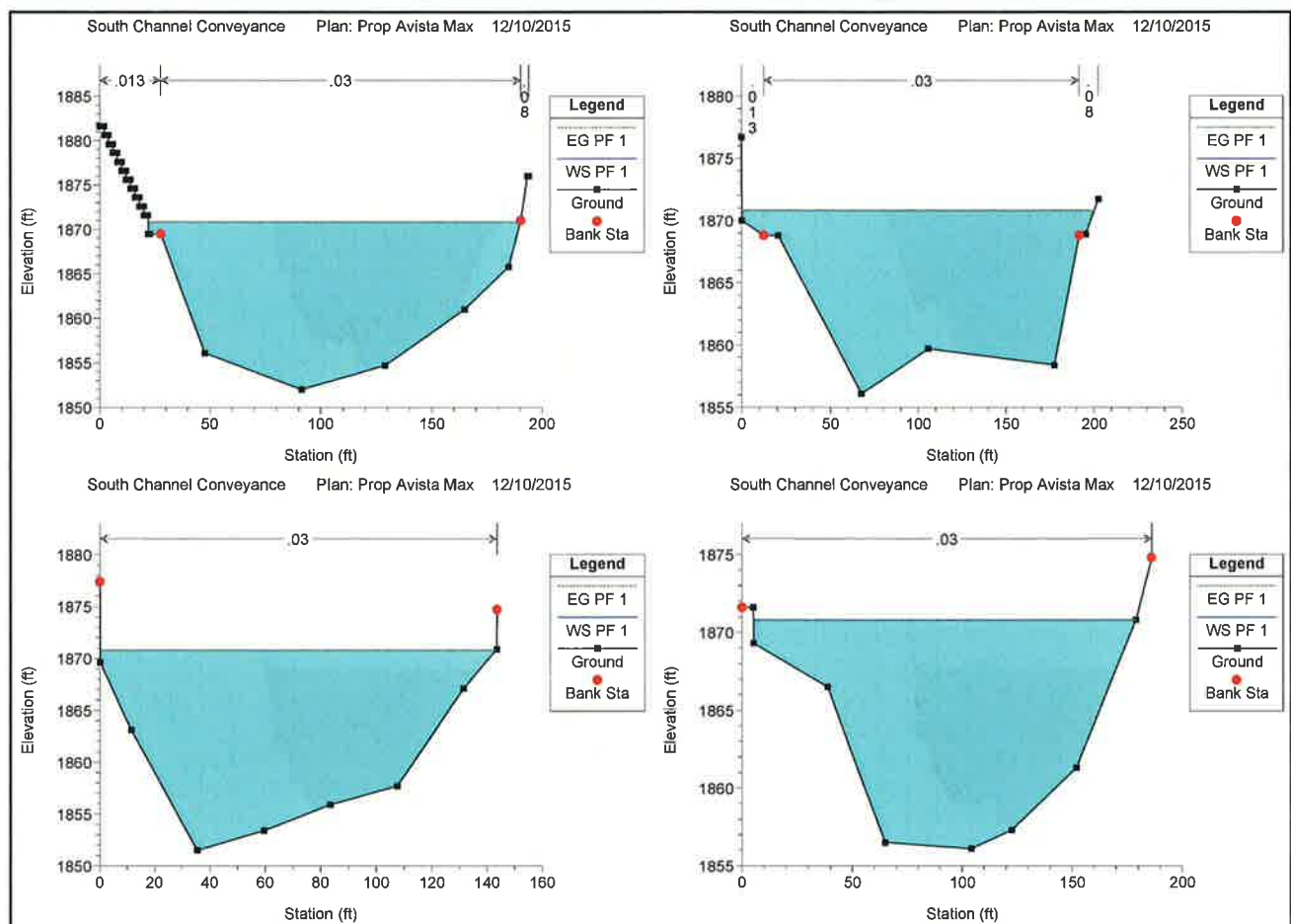


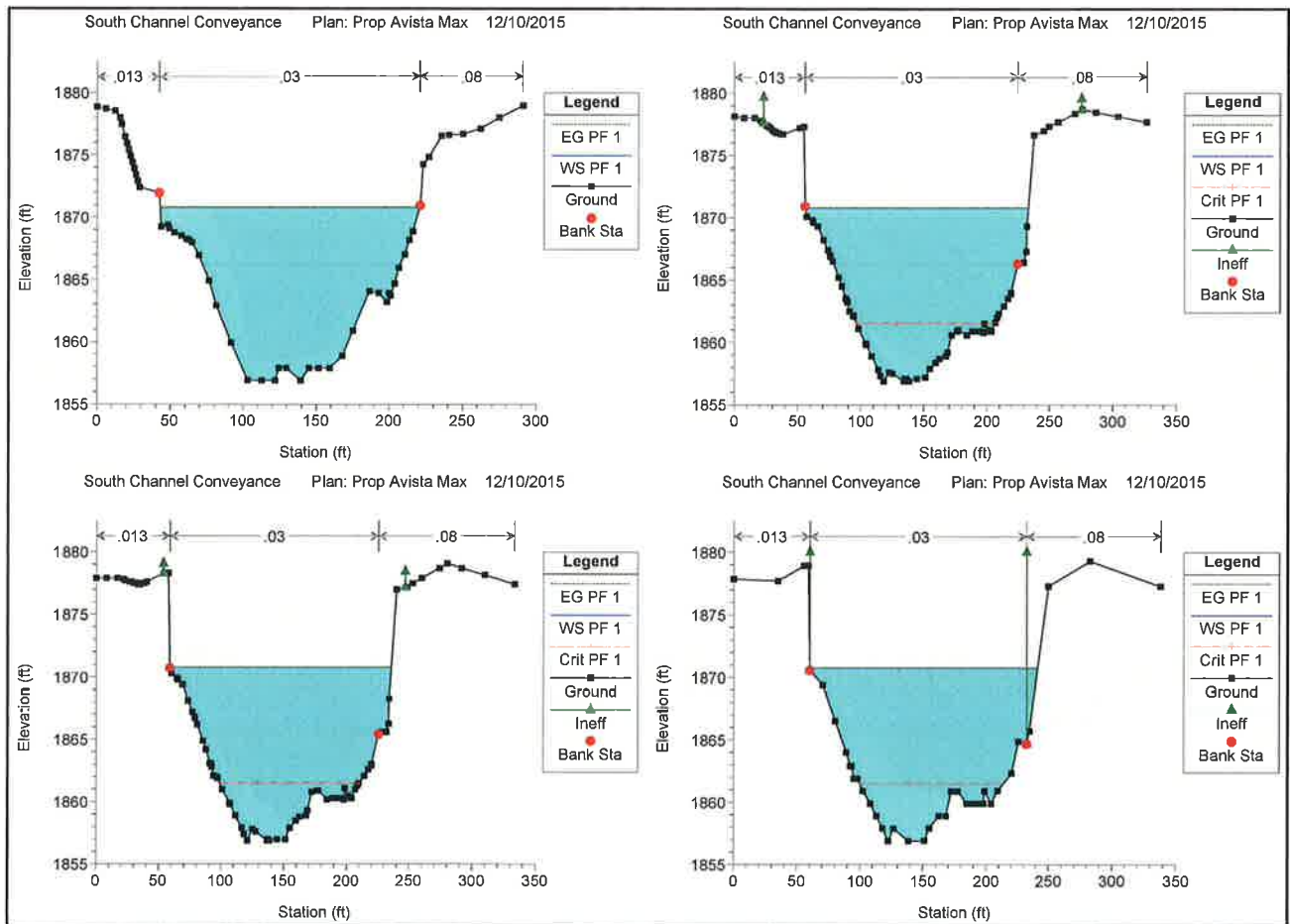
Plan: Prop Avista Max Spokane River South Channel RS: 1.5 Profile: PF 1

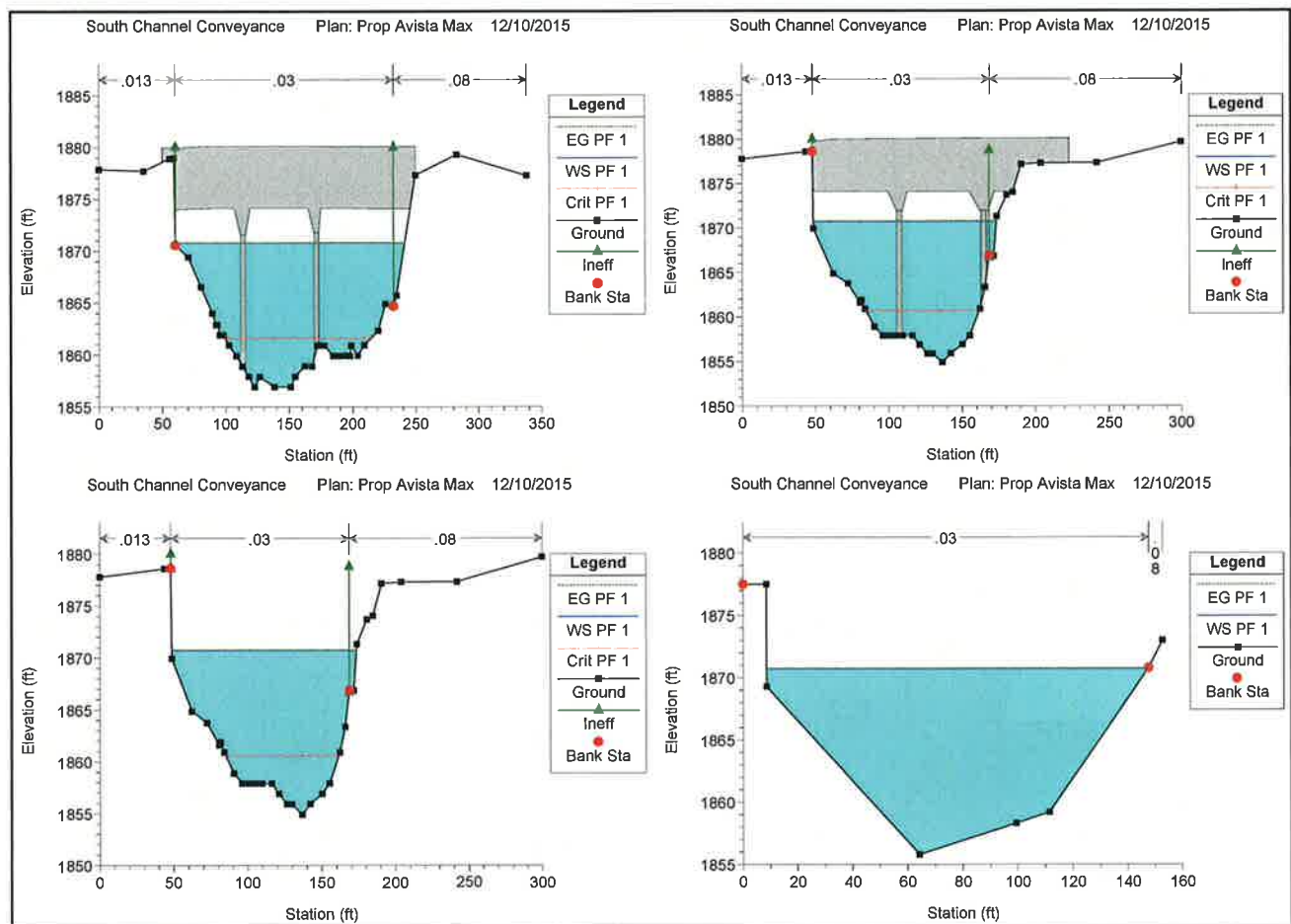
E.G. US. (ft)	1870.81	Element	Inside BR US	Inside BR DS
W.S. US. (ft)	1870.78	E.G. Elev (ft)	1870.81	1870.80
Q Total (cfs)	2500.00	W.S. Elev (ft)	1870.77	1870.74
Q Bridge (cfs)	2500.00	Crit W.S. (ft)	1861.59	1860.67
Q Weir (cfs)		Max Chl Dpth (ft)	13.88	15.84
Weir Sta Lft (ft)		Vel Total (ft/s)	1.61	2.07
Weir Sta Rgt (ft)		Flow Area (sq ft)	1556.92	1209.96
Weir Submerg		Froude # Chl	0.09	0.11
Weir Max Depth (ft)		Specif Force (cu ft)	8658.20	7585.15
Min El Weir Flow (ft)	1880.01	Hydr Depth (ft)	9.49	10.83
Min El Prs (ft)	1874.13	W.P. Total (ft)	212.64	157.73
Delta EG (ft)	0.01	Conv. Total (cfs)	290768.2	233107.4
Delta WS (ft)	0.03	Top Width (ft)	172.95	116.78
BR Open Area (sq ft)	1561.90	Frctn Loss (ft)	0.01	0.00
BR Open Vel (ft/s)	2.07	C & E Loss (ft)	0.00	0.00
Coef of Q		Shear Total (lb/sq ft)	0.03	0.06
Br Sel Method	Energy only	Power Total (lb/ft s)	0.00	0.00

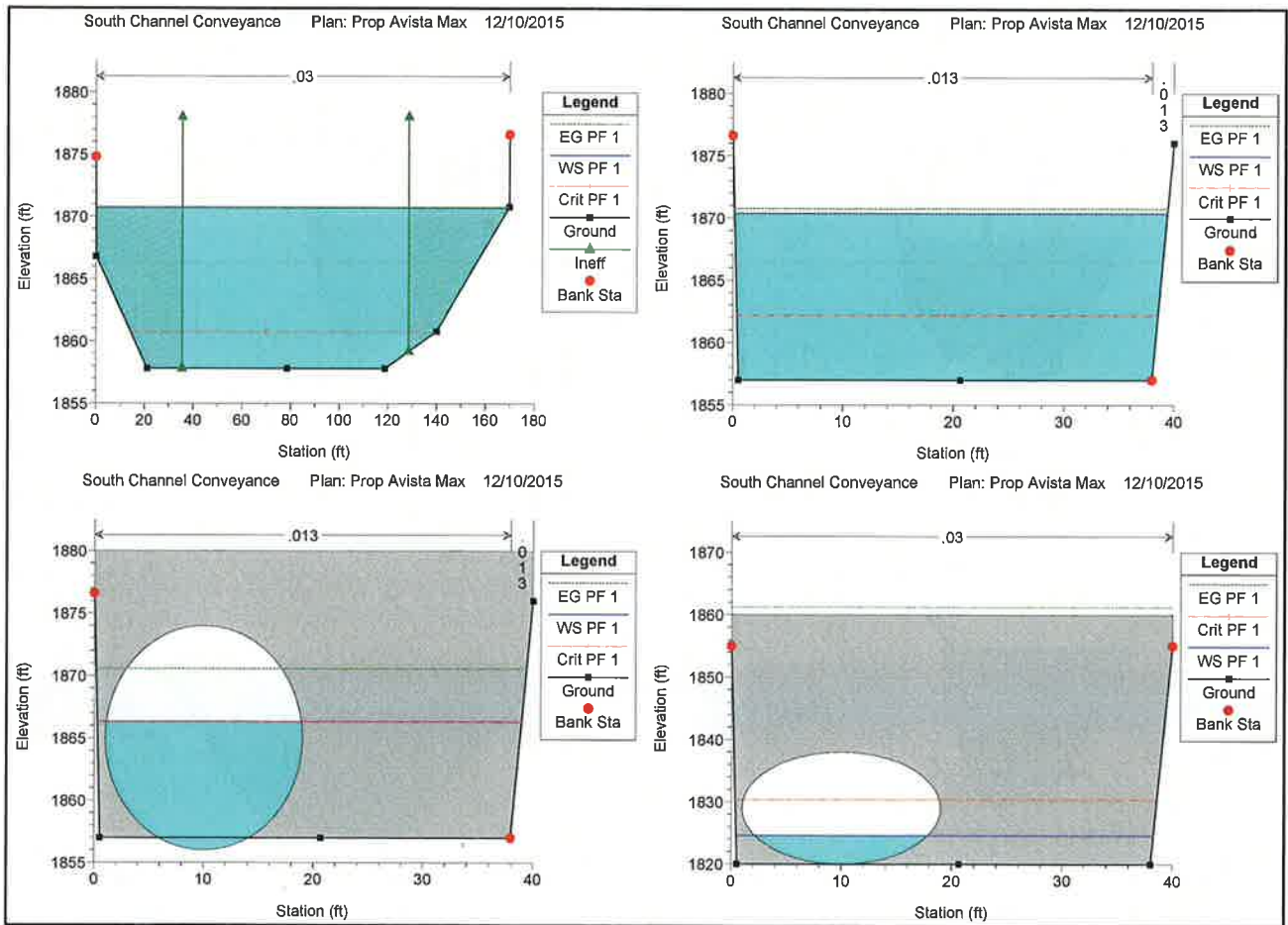
HEC-RAS Plan: Prop Avista Max River: Spokane River Reach: South Channel Profile: PF 1

Reach	River Sta	Profile	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl
South Channel	8	PF 1	2500.00	1852.00	1870.83		1870.85	0.000018	1.15	2184.38	168.18	0.06
South Channel	7	PF 1	2500.00	1856.10	1870.81		1870.84	0.000034	1.34	1877.41	200.13	0.07
South Channel	5	PF 1	2500.00	1851.50	1870.80		1870.83	0.000031	1.42	1761.61	143.09	0.07
South Channel	4	PF 1	2500.00	1856.10	1870.79		1870.82	0.000050	1.53	1833.54	173.72	0.09
South Channel	3	PF 1	2500.00	1856.91	1870.78		1870.82	0.000059	1.60	1564.31	177.53	0.09
South Channel	2.6	PF 1	2500.00	1856.90	1870.78	1861.53	1870.81	0.000051	1.56	1629.83	177.06	0.09
South Channel	2.3	PF 1	2500.00	1856.90	1870.78	1861.52	1870.81	0.000049	1.55	1648.94	177.00	0.09
South Channel	2	PF 1	2500.00	1856.89	1870.78	1861.49	1870.81	0.000048	1.52	1647.09	180.96	0.09
South Channel	1.5		Bridge									
South Channel	1	PF 1	2500.00	1854.90	1870.74	1860.56	1870.80	0.000068	1.93	1293.73	124.78	0.10
South Channel	0.5	PF 1	2500.00	1855.80	1870.73		1870.79	0.000083	1.94	1288.16	138.89	0.11
South Channel	0.1	PF 1	2500.00	1857.80	1870.71	1860.71	1870.78	0.000060	2.10	1192.98	169.48	0.10
South Channel	0	PF 1	2500.00	1857.00	1870.37	1862.16	1870.75	0.000088	4.95	512.92	39.25	0.24
South Channel	-0.5		Culvert									
South Channel	-1	PF 1	2500.00	1820.00	1838.00	1825.15	1838.21	0.000275	3.64	686.57	38.79	0.15

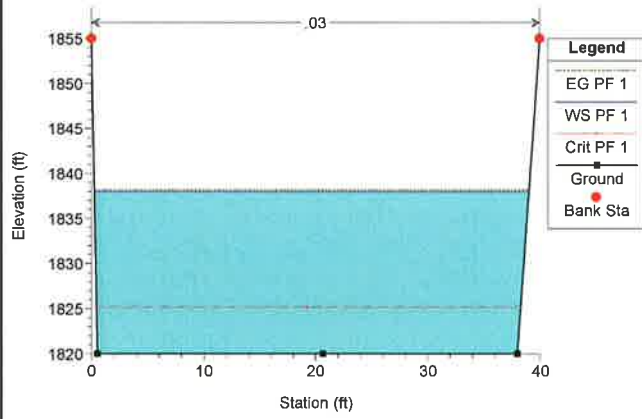


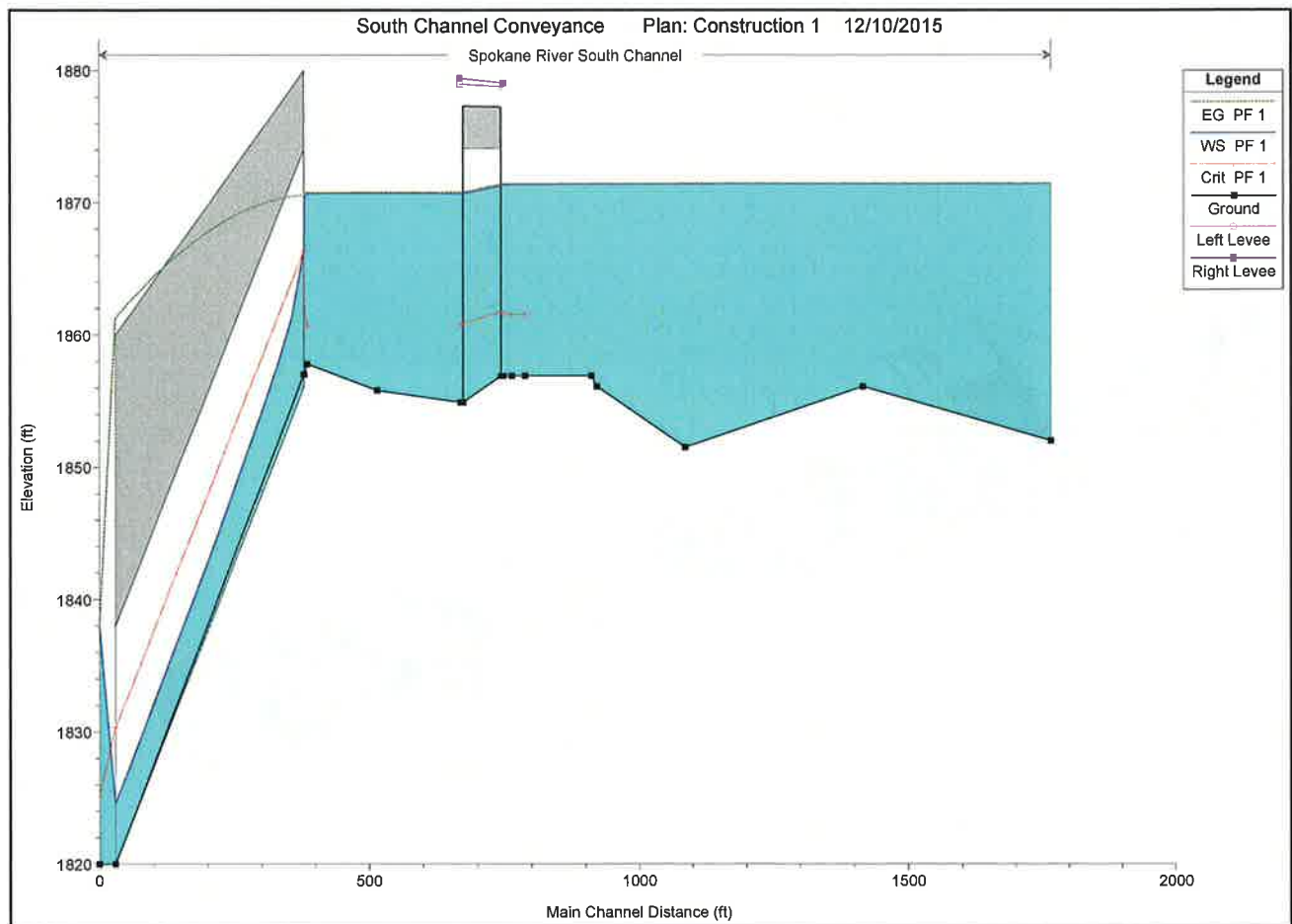






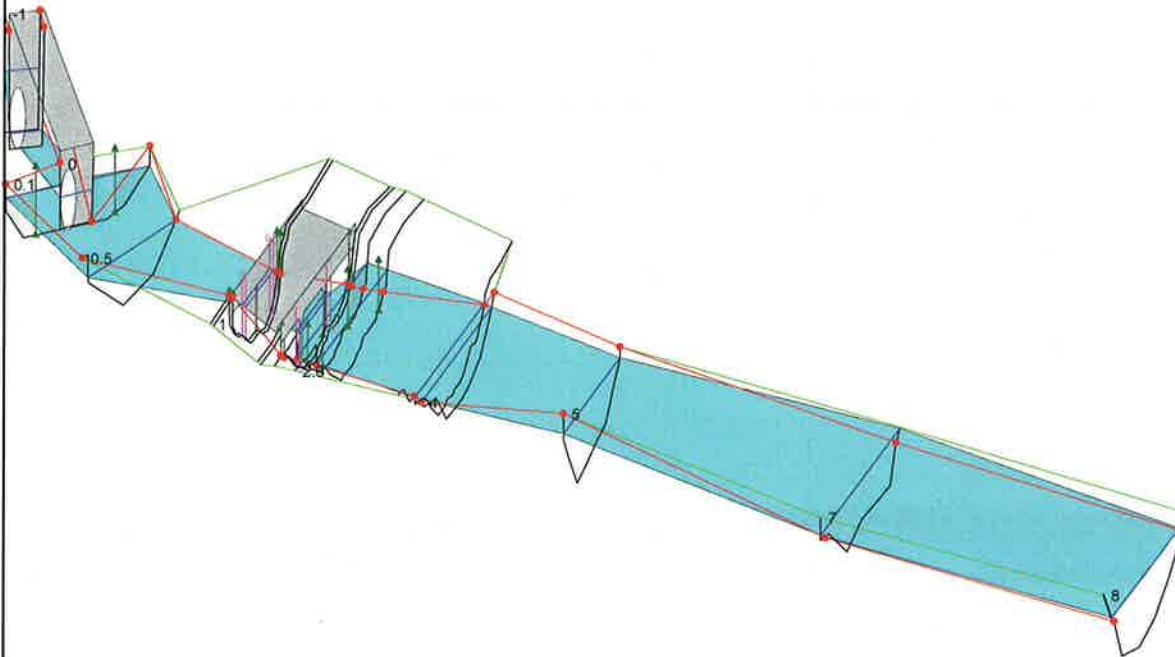
South Channel Conveyance Plan: Prop Avista Max 12/10/2015





South Channel Conveyance Plan: Construction 1 12/10/2015

Legend	
WS PF 1	
Ground	
Bank Sta	
Ineff	
Levee	

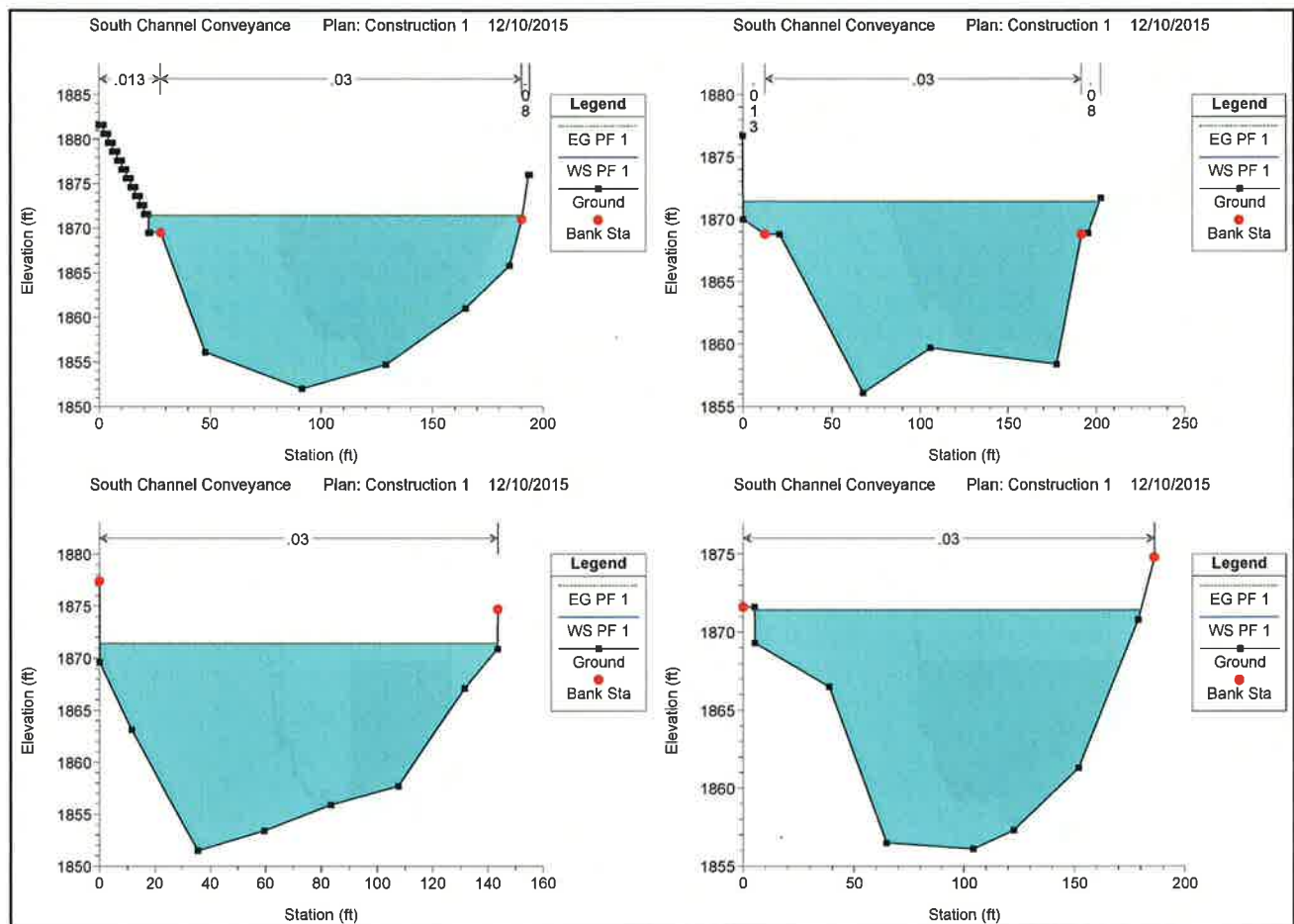


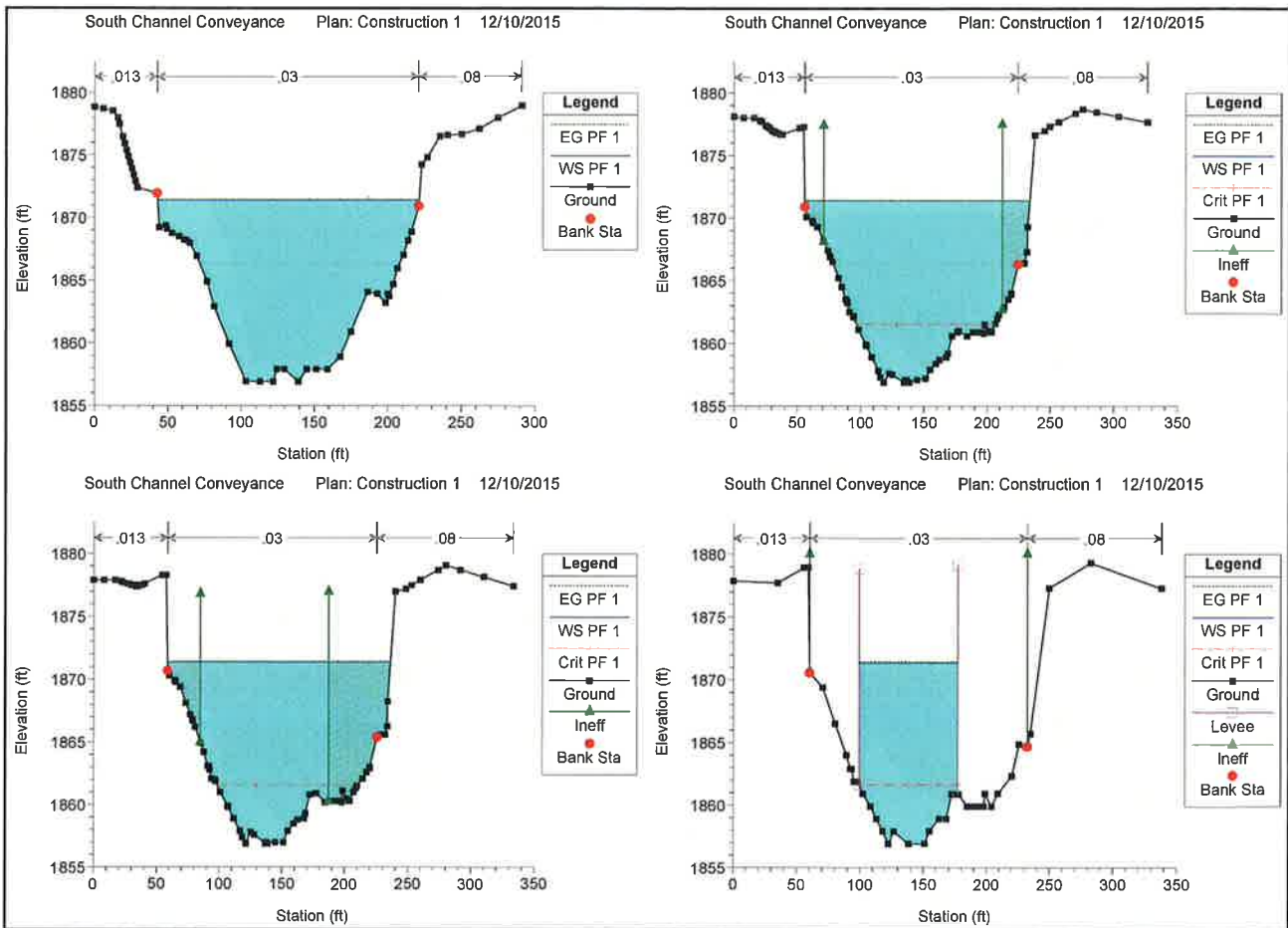
Plan: Construction Spokane River South Channel RS: 1.5 Profile: PF 1

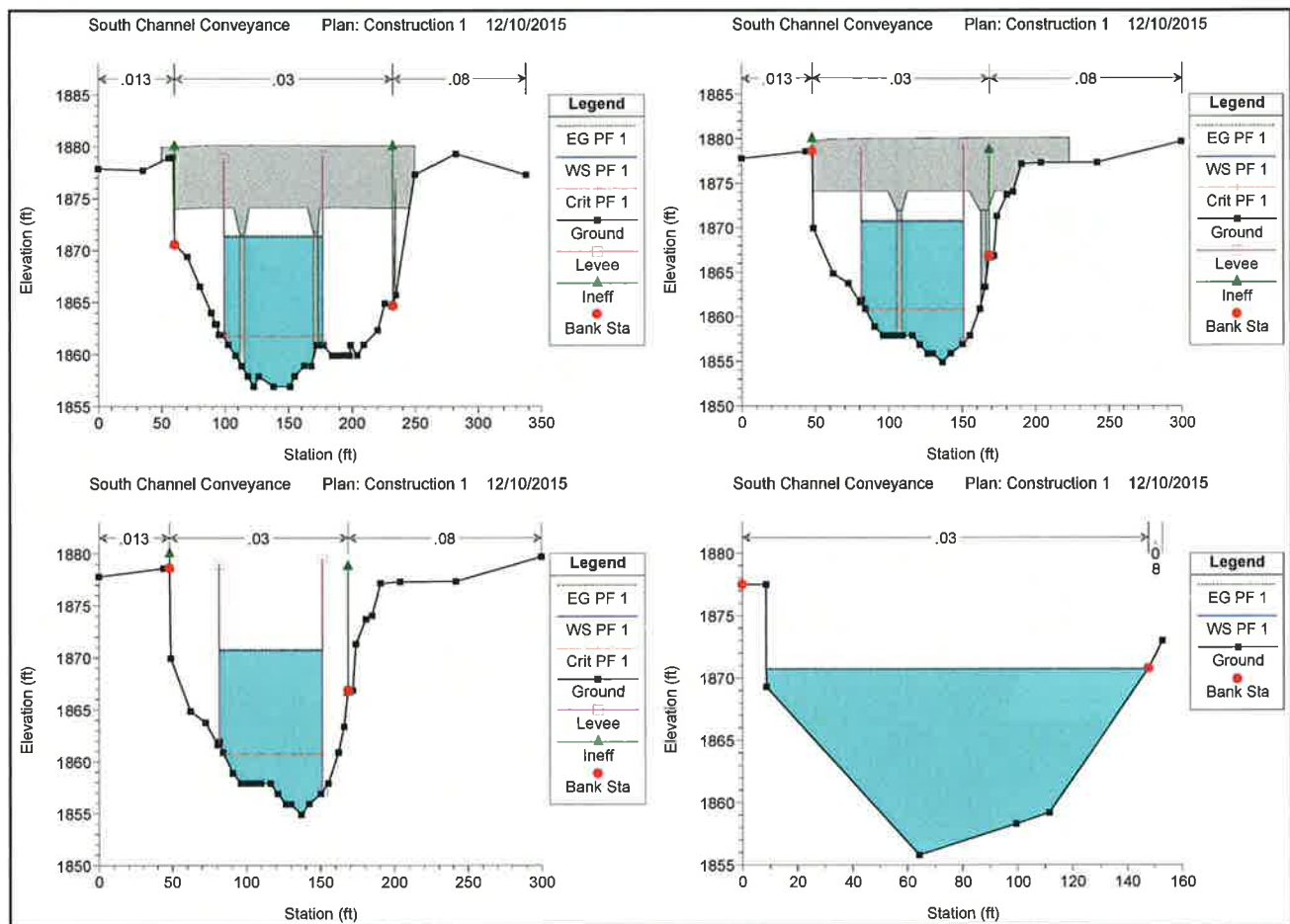
E.G. US. (ft)	1871.44	Element	Inside BR US	Inside BR DS
W.S. US. (ft)	1871.34	E.G. Elev (ft)	1871.42	1870.82
Q Total (cfs)	2500.00	W.S. Elev (ft)	1871.30	1870.69
Q Bridge (cfs)	2500.00	Crit W.S. (ft)	1861.74	1860.84
Q Weir (cfs)		Max Chl Dpth (ft)	14.41	15.79
Weir Sta Lft (ft)		Vel Total (ft/s)	2.76	2.85
Weir Sta Rgt (ft)		Flow Area (sq ft)	906.98	877.58
Weir Submerg		Froude # Chl	0.13	0.14
Weir Max Depth (ft)		Specif Force (cu ft)	6170.20	6158.74
Min El Weir Flow (ft)	1880.01	Hydr Depth (ft)	12.98	13.34
Min El Prs (ft)	1874.13	W.P. Total (ft)	117.87	92.42
Delta EG (ft)	0.62	Conv. Total (cfs)	175095.6	194916.4
Delta WS (ft)	0.63	Top Width (ft)	69.85	65.79
BR Open Area (sq ft)	1086.39	Frctn Loss (ft)		
BR Open Vel (ft/s)	2.85	C & E Loss (ft)		
Coef of Q		Shear Total (lb/sq ft)	0.10	0.10
Br Sel Method	Momentum	Power Total (lb/ft s)	0.00	0.00

HEC-RAS Plan: Construction River: Spokane River Reach: South Channel Profile: PF 1

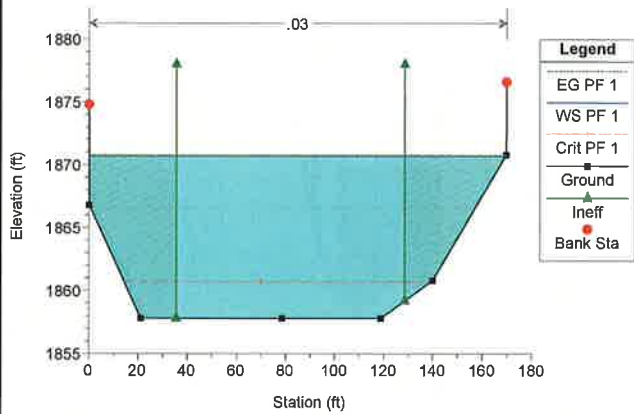
Reach	River Sta	Profile	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl
South Channel	8	PF 1	2500.00	1852.00	1871.46		1871.47	0.000015	1.09	2289.99	168.67	0.05
South Channel	7	PF 1	2500.00	1856.10	1871.44		1871.47	0.000028	1.26	2004.01	201.76	0.07
South Channel	5	PF 1	2500.00	1851.50	1871.43		1871.46	0.000027	1.35	1852.13	143.44	0.07
South Channel	4	PF 1	2500.00	1856.10	1871.42		1871.45	0.000041	1.43	1744.06	174.91	0.08
South Channel	3	PF 1	2500.00	1856.91	1871.42		1871.45	0.000048	1.49	1677.38	178.48	0.09
South Channel	2.6	PF 1	2500.00	1856.90	1871.41	1861.54	1871.45	0.000041	1.58	1582.27	177.83	0.08
South Channel	2.3	PF 1	2500.00	1856.90	1871.38	1861.55	1871.44	0.000060	2.01	1242.78	177.51	0.10
South Channel	2	PF 1	2500.00	1856.89	1871.34	1861.61	1871.44	0.000116	2.49	1003.72	77.85	0.12
South Channel	1.5		Bridge									
South Channel	1	PF 1	2500.00	1854.90	1870.71	1860.73	1870.82	0.000137	2.69	929.82	69.79	0.13
South Channel	0.5	PF 1	2500.00	1855.80	1870.73		1870.79	0.000083	1.94	1288.16	138.89	0.11
South Channel	0.1	PF 1	2500.00	1857.80	1870.71	1860.71	1870.78	0.000060	2.10	1192.98	169.48	0.10
South Channel	0	PF 1	2500.00	1857.00	1870.37	1862.16	1870.75	0.000088	4.95	512.92	39.25	0.24
South Channel	-0.5		Culvert									
South Channel	-1	PF 1	2500.00	1820.00	1838.00	1825.15	1838.21	0.000275	3.64	686.57	38.79	0.15



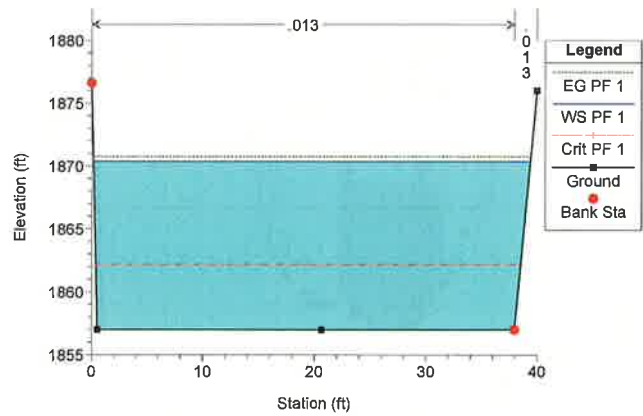




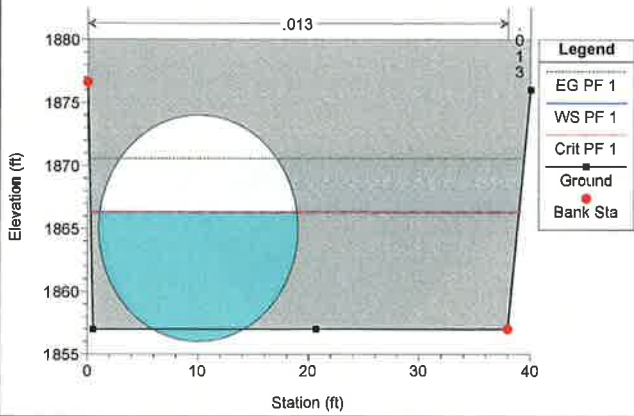
South Channel Conveyance Plan: Construction 1 12/10/2015



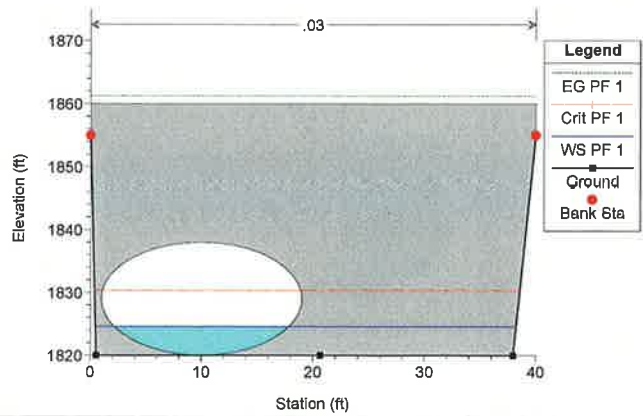
South Channel Conveyance Plan: Construction 1 12/10/2015



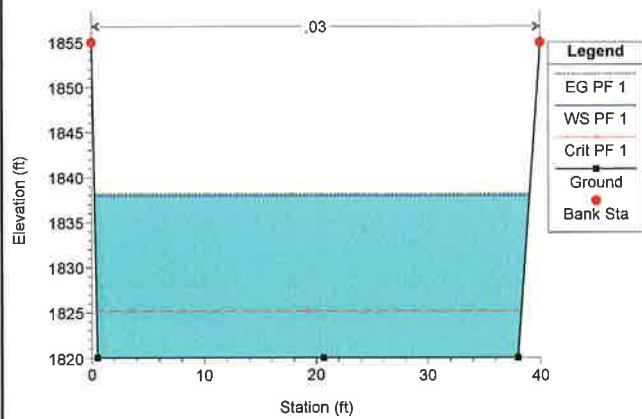
South Channel Conveyance Plan: Construction 1 12/10/2015



South Channel Conveyance Plan: Construction 1 12/10/2015



South Channel Conveyance Plan: Construction 1 12/10/2015





Appendix C

Photographs



Photo 1 - Standing on the Gage House looking Northwest toward the Avista Hydroelectric Intake



Photo 2 - Standing on the Southwesterly corner of the Channel Looking Northeast along Cross-Section 0.1

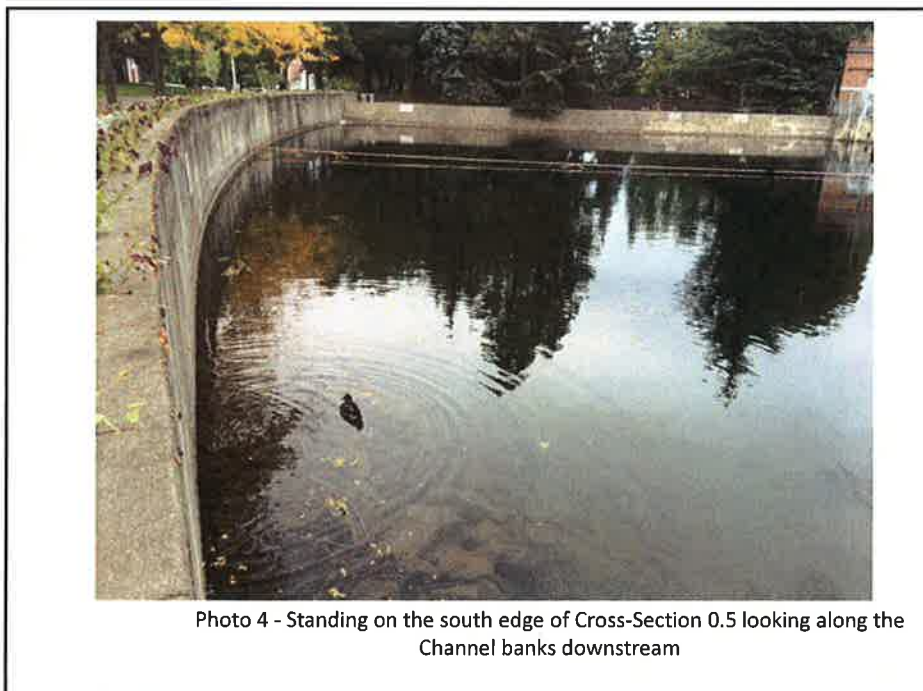
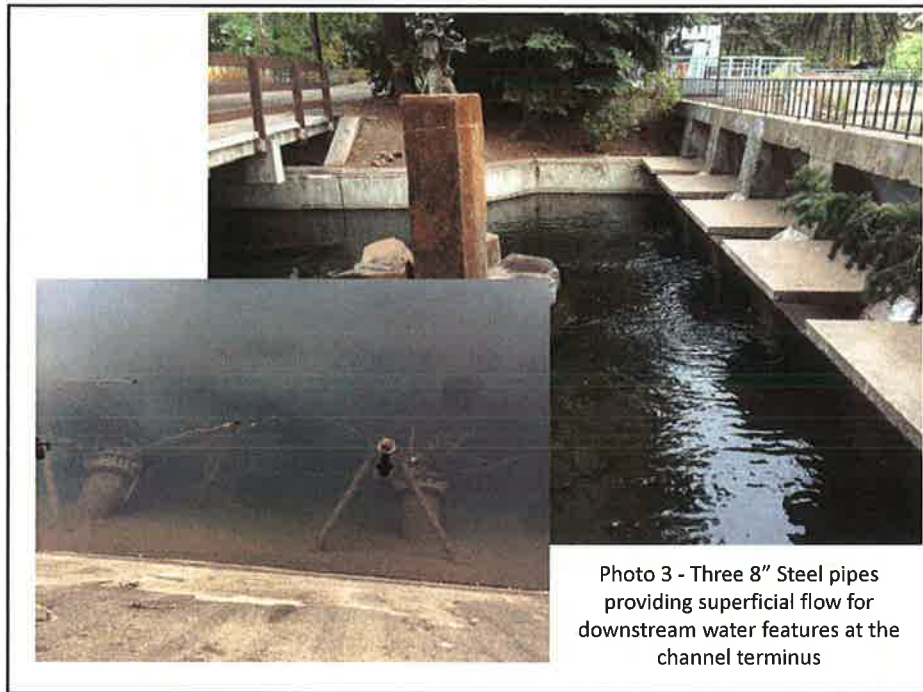




Photo 5 - Standing on the north edge of Cross-Section 1.0 looking along the Channel banks downstream

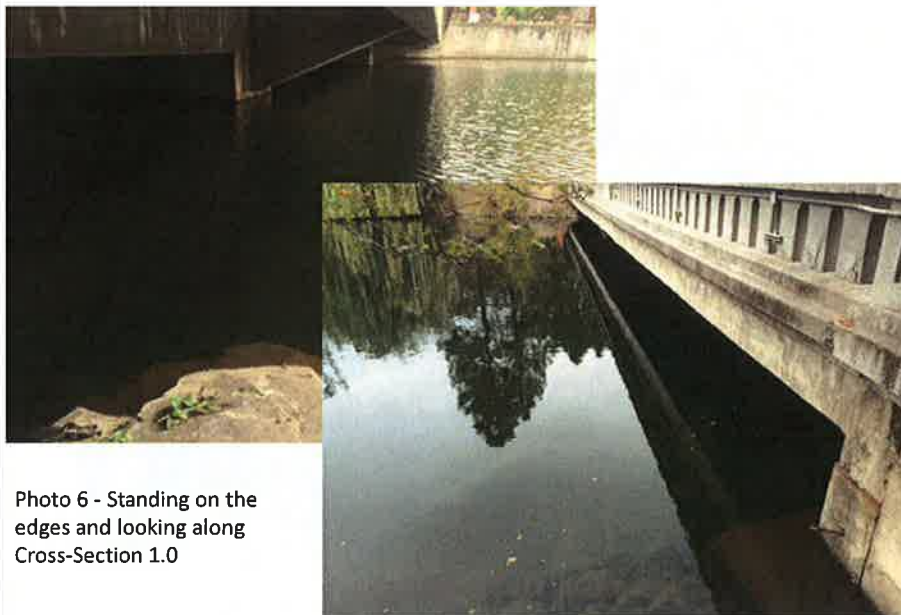


Photo 6 - Standing on the edges and looking along Cross-Section 1.0



Photo 7 - Standing on the south edge and looking along Cross-Section 2.0



Photo 8 - Standing on the south edge of Cross-Section 2.6 and looking along the banks downstream



Photo 9 - Standing on the north edge of Cross-Section 3.0 and looking along the banks downstream



Photo 10 - Standing on the south edge of Cross-Section 3.0 and looking along the banks downstream

