RECLAMATION

Managing Water in the West

One-Dimensional Hydraulic Modeling of the Yakima Basin

A component of
Yakima River Basin Water Storage Feasibility Study, Washington

Technical Series No. TS-YSS-14

Naches River

U.S. Department of the Interior
Bureau of Reclamation
Pacific Northwest Region

October 2007

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One-Dimensional Hydraulic Modeling of the Yakima Basin

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INTRODUCTION

Reclamation's Technical Service Center (TSC) was asked to perform one-dimensional (1-D) hydraulic modeling of selected reaches of the Yakima and Naches Rivers in October 2006. This effort is in support of the Yakima River Basin Water Storage Feasibility Study. HEC-RAS (Hydraulic Engineering Center – River Analysis System) is a 1-D step-backwater model that provides flow depth, top width, and cross-section averaged values of velocity (among other parameters) (Brunner, 2002). The primary purpose of the HEC-RAS modeling effort is to define some of the necessary attributes related to the Ecosystem Diagnostics and Treatment (EDT) biological model. EDT is a habitat-based model for anadromous salmonids that develops a working hypothesis to guide restoration efforts and includes an analytical model to quantify the biological potential of stream habitat for salmonid fish species (Greg Blair, Mobrand-Jones and Stokes, written communication). Results from the 1-D model will provide some of the input attributes for the EDT model. The HEC-RAS output will also be used for input to a habitat decision support system (DSS) spreadsheet (U.S. Geological Survey [USGS], Ft. Collins CO), temperature modeling (USGS, Tacoma WA) and provide necessary input to the Sediment Impact and Analysis Model (SIAM), covered in a separate report by Mooney (2007).

Results from the modeling will be shared with the Upper Columbia Area Office (UCAO) and as such, are not contained herein. This report will serve to make the users of the modeling results aware of the details related to the modeling. The HEC-RAS geometry and flow files have been sent electronically to the UCAO should they wish to use the models in the future. Results related to top width vs. stage that are to be input to EDT will be sent electronically to the UCAO along with results from the sediment modeling (SIAM). Other aquatic habitat attributes, such as mesohabitat, and localized values of depth and velocity have been determined with a two-dimensional (2-D) hydraulic model (Hilldale and Mooney, 2007).

DATA SOURCES FOR 1-D MODELING

Bare Earth LiDAR

Bare earth LiDAR (light detection and ranging) was flown in November 2000 for the Yakima River from the headwaters (Kachess, Keechelus, and Cle Elum Reservoirs) to the Columbia River and on the Naches River, from its confluence with the Yakima to the mouth of the Tieton River. These data were used to construct above-water portions of the modeling surface.

Bathymetric Surveys

Bathymetric LiDAR

The primary source of bathymetric data was from airborne LiDAR bathymetry (ALB). ALB works similarly to bare earth LiDAR except that it has the ability to penetrate the water column to measure flow depth. This depth is subtracted from the water surface elevation, also obtained with the ALB, to obtain the riverbed elevation. More details regarding ALB can be found in Hilldale and Raff (2007). The ALB on the Yakima and Naches Rivers was flown at two separate times, September 2004 and April 2005. Reaches where ALB data were collected are shown in Figure 1 and Table 1.

Bathymetric Surveys Using Boat-Mounted Acoustics

Portions of the Yakima River were surveyed in 2004 by the USGS (Tacoma WA) and Reclamation (Ephrata Field Office, [EFO]) using boat-mounted acoustics in conjunction with Real Time Kinematic Global Positioning Satellite (RTK GPS) surveying equipment. Those portions of the Yakima River surveyed by the USGS and the EFO are shown in Figure 1 and Table 1.

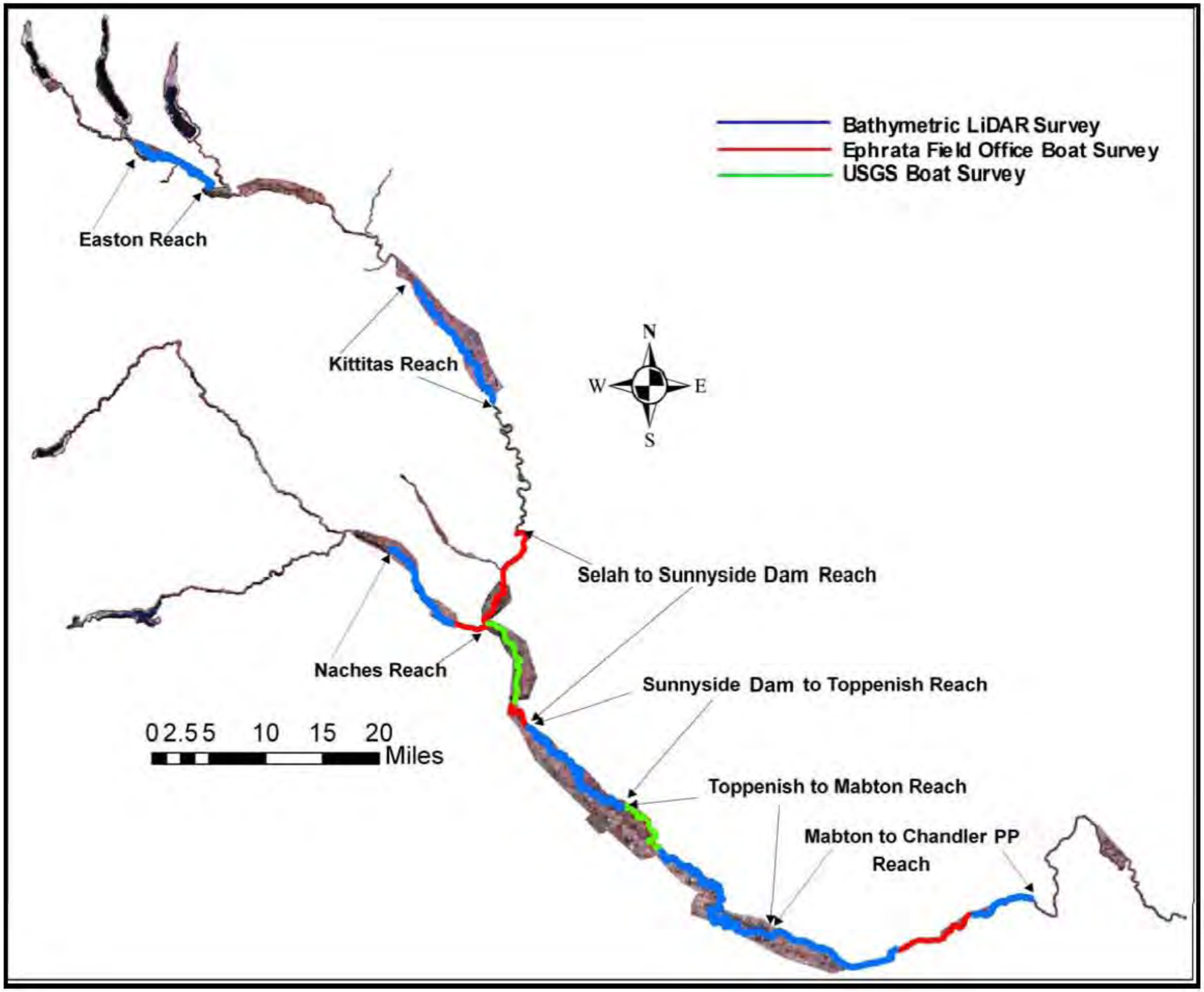

Figure 1: Site map showing modeled reaches and locations of different bathymetric surveys. Blue reaches were surveyed with ALB, red reaches were surveyed by the Ephrata Field Office, and green reaches were surveyed by the USGS.

Table 1: Breakdown of Bathymetric Surveys by Reach and Cross Section.

Reach/Model Name	Cross section ID #	Bathymetric Survey Source
Easton	All cross sections	Bathymetric LiDAR
Kittitas	All cross sections	Bathymetric LiDAR
Roza-to-Selah	N/A (were deleted)	EFO
Selah-to-Sunnyside Dam	113214 -69260	EFO
Selah-to-Sunnyside Dam	67454 - 18179	USGS
Selah-to-Sunnyside Dam	16893 - 333	EFO
Sunnyside Dam-to-Toppenish	All cross sections	Bathymetric LiDAR
Toppenish-to-Mabton	187047 – 171608	Bathymetric LiDAR
Toppenish-to-Mabton	170850 - 152641	USGS
Toppenish-to-Mabton	152115 - 147462	EFO
Toppenish-to-Mabton	147069 - 127172	USGS
Toppenish-to-Mabton	126873 - 120	Bathymetric LiDAR
Mabton-to-Chandler PP	144719 – 73896	Bathymetric LiDAR
Mabton-to-Chandler PP	73535 – 30946	EFO
Mabton-to-Chandler PP	29697 - 30	Bathymetric LiDAR
Naches	173390 – 19794	LiDAR
Naches	19468 - 217	EFO

Notes on Erroneous or Insufficient Bathymetric Surveys

The most critical information for any hydraulic model is the definition of channel and floodplain geometry. No amount of calibration can properly account for poorly represented geometry. Some bathymetric survey data used in this study were discovered to contain large vertical errors, on the order of 7-20 feet. Some bathymetric surveys also suffered from insufficient coverage (i.e., single-line survey). A single-line survey consists of one pass down the center of the channel, resulting in a single point representing the entire channel bottom at a cross section causing an erroneous reduction in computed conveyance (Figure 2). In other words, the triangular cross section has less area to convey flow than the true area of the cross section. The reaches affected by these surveys are shown in Table 2. These cross sections were corrected to the extent possible; however, significant error and uncertainty exists at the indicated locations. Budget and time constraints prevented additional surveys to address problem areas. The red dots on the cross section are coincident with the bank lines.

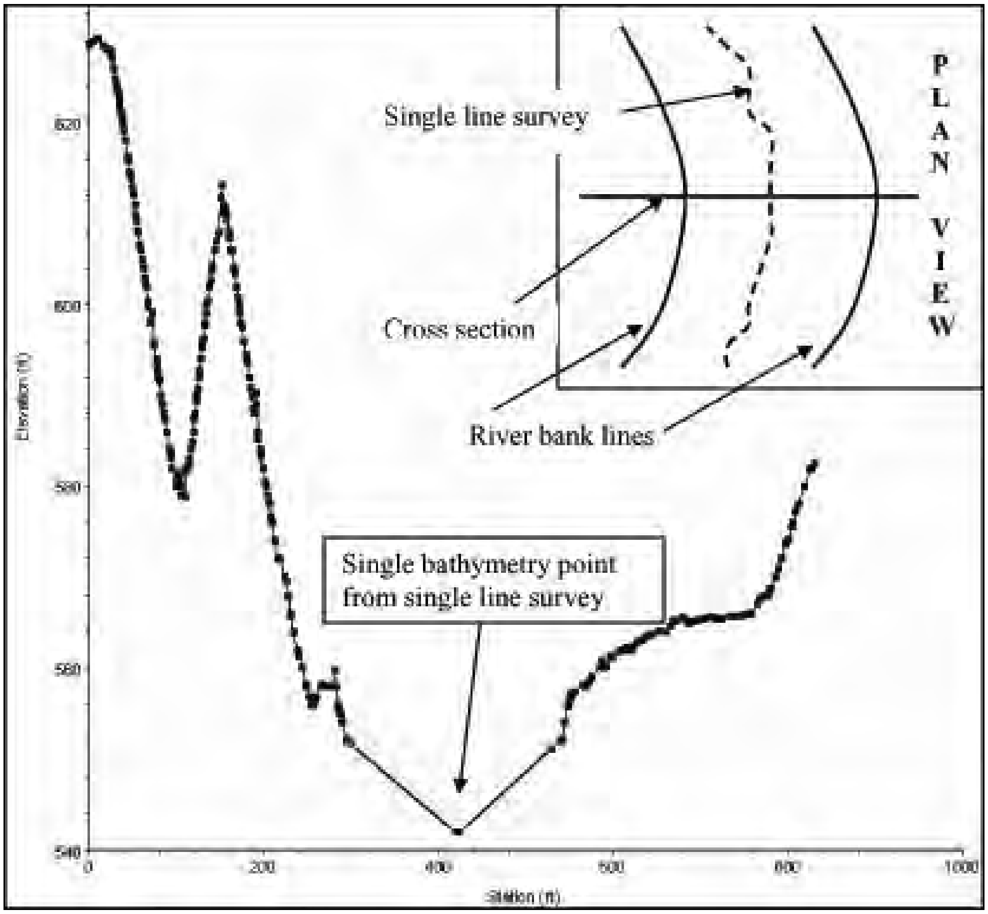

Figure 2: Example of cross section where only a single-line survey was performed.

Table 2: Reaches with known survey errors.

Reach/Model Name	Cross section ID #	Problem description
Selah-to-Sunnyside Dam	113214 - 69260	Bad vertical error, many miles of single-line survey. Some water surface elevation surveys unusable.
Selah-to-Sunnyside Dam	333 - 16893	Water surface elevation surveys unusable.
Naches	19794 - 217	Two path survey that overlapped in many places, large vertical errors in some cross sections. Water surface elevation surveys unusable.
Mabton-to-Chandler Pumping Plant	30946 - 73535	Some single line surveys. Water surface elevation surveys unusable.

The Mabton-to-Chandler Pumping Plant (PP) reach (cross sections 30946-73535) consists mostly of multiline surveys; however, some single-line surveys exist (Figure 3). Many of the single-line surveys in this portion of the reach are short and could thus be avoided during the analysis (i.e., no cross sections were cut). When there was a

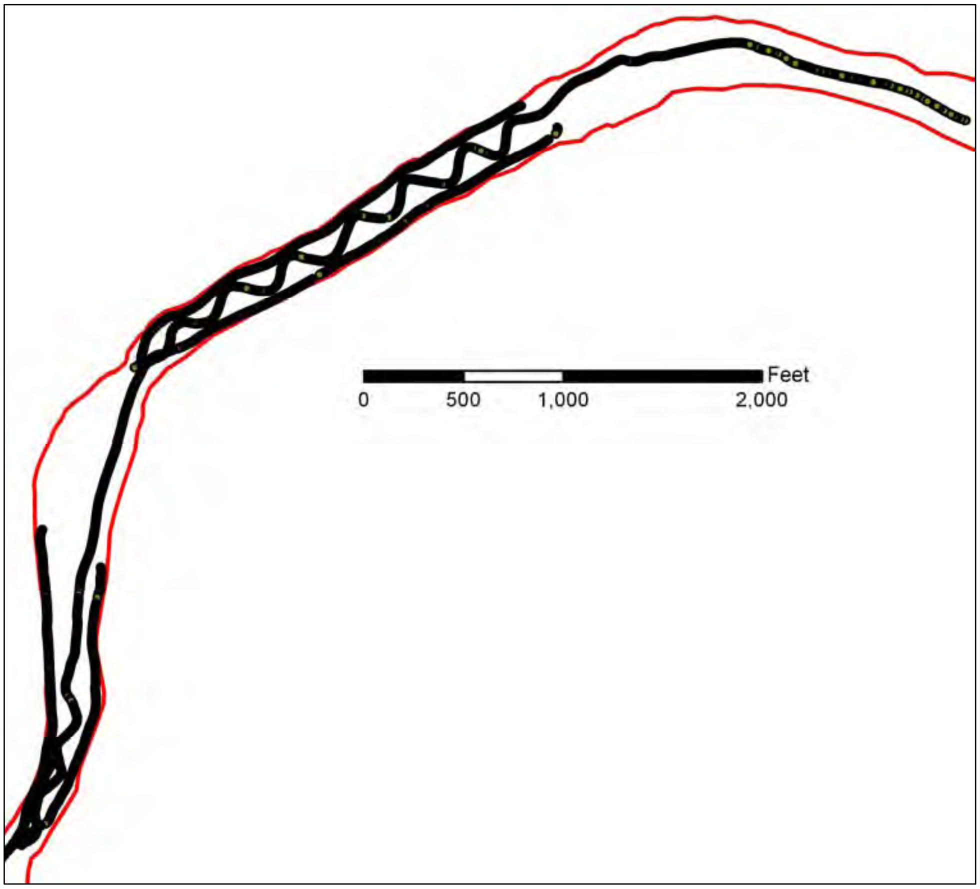

Figure 3: Diagram showing the bathymetric survey.

significant channel length that consisted of a single-line survey, the cross section was made trapezoidal assuming the single-line survey to be the thalweg. Bed elevations provided by these surveys were sometimes off by as much as 20 feet vertically and were inconsistent. The survey lines are in black and the bank lines in red.

Sections of single-line surveys exist in the Selah-to-Sunnyside Dam reach (cross sections 113214-69260) and the same methodology was applied here with single-line surveys. The single-line surveys in this portion of the Selah-to-Sunnyside Dam reach were much longer than in the Mabton-to-Chandler PP reach (cross sections 73535-30946) mentioned previously and could not be avoided. Data outside of the bank lines were generated with bare earth LiDAR. All cross sections in this reach were deleted from the model. The cross sections that were deleted upstream of Selah could not be used to assume a trapezoidal shape because the survey was off vertically by a significant amount, resulting in surveyed bed elevations above the bank/edge of water (Figure 4).

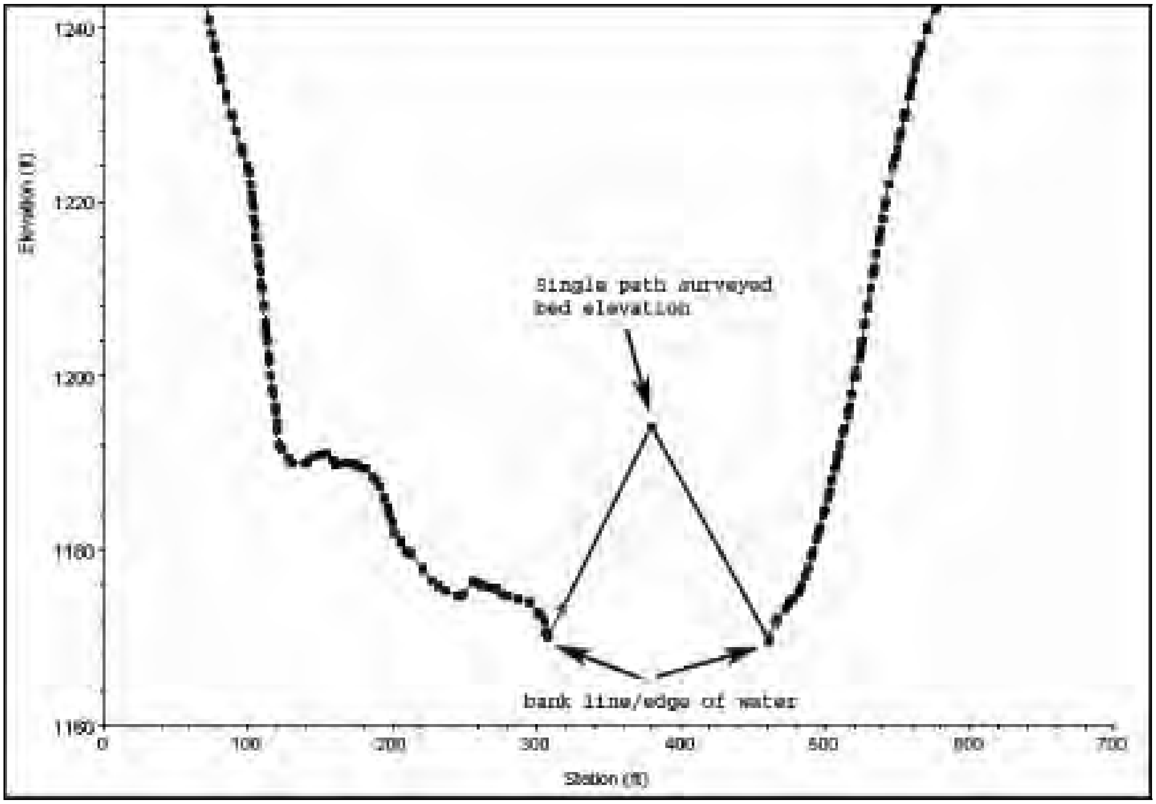

Figure 4: Example of a cross section taken from the Roza-to-Selah reach. This was a single-line survey. Red dots on the cross section are coincident with the bank lines.

In the Naches reach, a single-line survey existed for most of the reach downstream of the bathymetric LiDAR survey to the mouth (cross sections 19468-217). The TSC requested that another survey be performed. Some of the second survey overlapped the initial survey, effectively resulting in the same data coverage as the initial single-line survey. In many locations, the second survey indicated a different bed elevation than the first. Discrepancies appeared random. In some instances, the presumed bad elevation was approximately 15-20 feet too low. In other locations, the presumed bad elevation was approximately 15-20 feet high (Figure 5 and Figure 6).

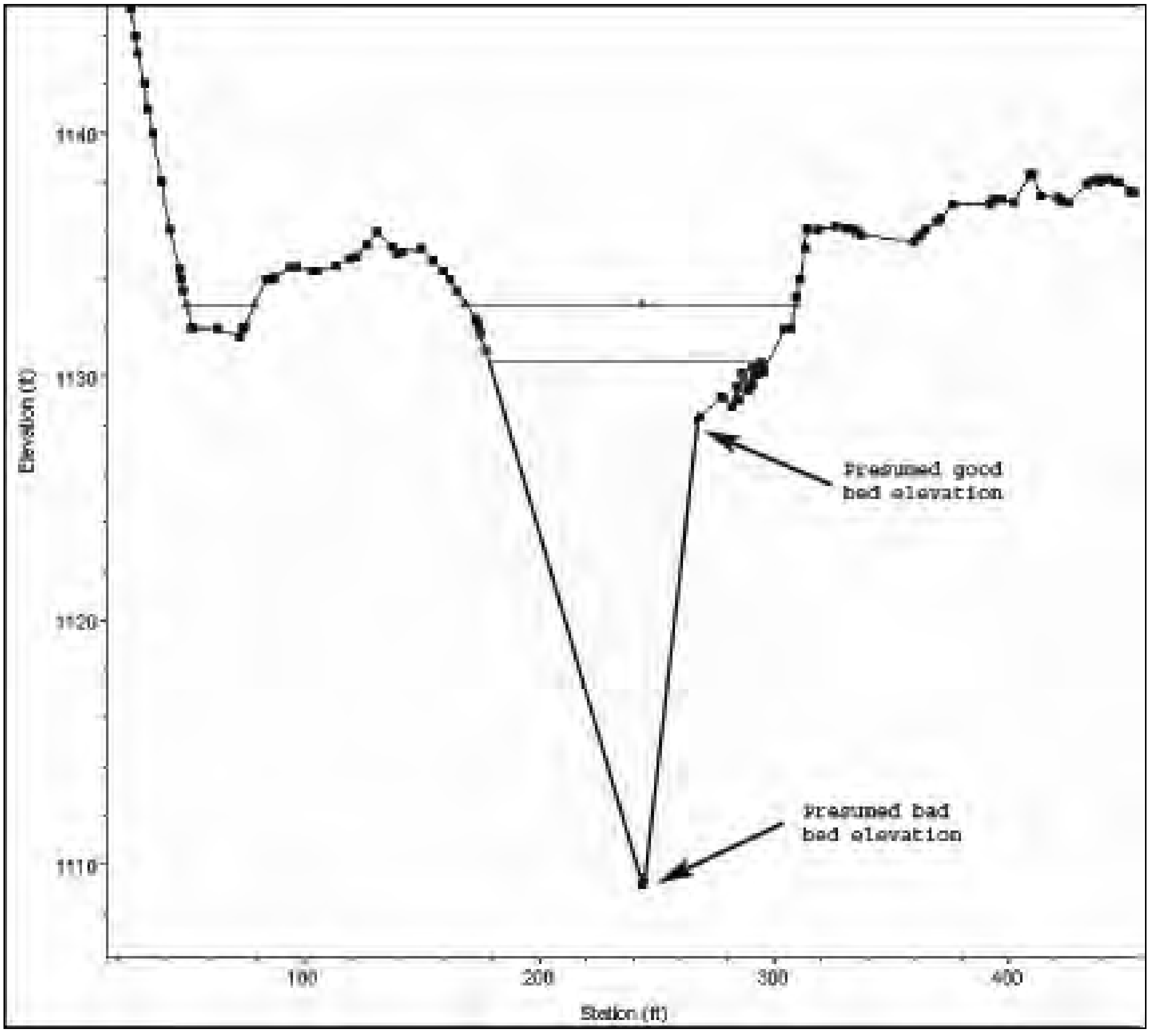

Figure 5: Example of a cross section on the Naches reach (cross sections 19468-217) where there were two survey lines resulting in very different bed elevations. Red dots indicate the bank location. The cross section in Figure 6 is one cross section away from the one shown here.

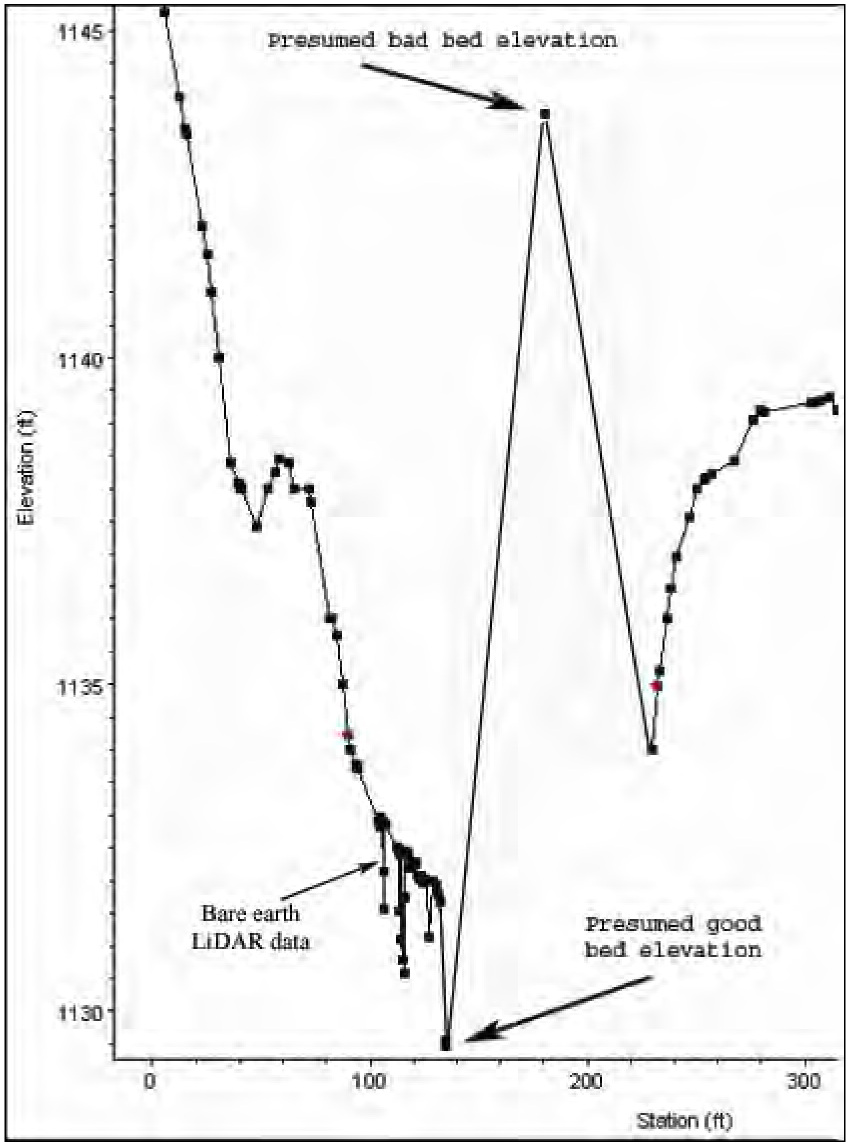

Figure 6: Example of a cross section on the Naches reach (cross sections 19468-217) where there were two survey lines resulting in very different bed elevations. Red dots indicate the bank location.

Water surface elevations were requested from the EFO to be used for model calibration and verification. Many of these surveys indicated unreasonable elevations, e.g. below the thalweg of the channel or 7-15 feet above the modeled water surface. As a result of erroneous survey elevations, some reaches lacked sufficient water surface elevation data with which to verify hydraulic modeling results. The cross section in Figure 5 is one cross section away from the one shown here.

MODELING NOTES FOR INDIVIDUAL REACHES

The following section points out specific assumptions or special considerations for each modeled reach. These details need to be considered when using the results from these models.

Easton Reach

The Easton reach begins downstream of the Easton Dam where the river passes under Interstate 90. The reach ends approximately 11 river miles downstream where the river again passes under Interstate 90 (Figure 1).

The river channel geometry was constructed from ALB data. The upper third of the Easton reach consists of several anastomosed (connected) channels that are active at low discharges. Unless the proportions of each flow split are known and a channel network is created, a 1-D model does not typically divide the discharge properly among the channels. Due to access issues and time constraints, these flow splits were not measured. If detailed information is required, the results from the 2-D model of this reach should be used (Hilldale and Mooney, 2007). The purpose of modeling this reach was to evaluate out-of-bank discharges, which are expected to be modeled more representatively than low discharges. In the vicinity of log jams, it was necessary to increase Manning's *n* (up to 0.9) and assume blocked obstructions to replicate the backwater effects from these structures.

Kittitas Reach

The Kittitas reach begins at Town Dam upstream of Ellensburg and ends approximately 15 river miles downstream at the head of the Yakima Canyon (Figure 1).

The channel geometry was constructed from ALB data. A few ground-surveyed water surface elevations around station 45,000 were significantly different than computed values, but matched water surface elevations at nearby locations. All of the questionable points occur at low flow and movement of a grade controlling riffle in the vicinity likely accounts for the disparity.

Selah-to-Sunnyside Dam Reach

The Selah-to-Sunnyside Dam reach begins approximately 3 miles downstream of Roza Dam and ends at the Sunnyside Dam (Figure 1).

The bathymetry was surveyed with boat-mounted acoustics. This reach was supposed to begin at Roza Dam; however, the bathymetric survey 3 river miles downstream of Roza Dam was insufficient for hydraulic modeling. This model should not be used for any conclusions upstream of cross section 66,140 (near the Naches mouth), as there are significant errors in the survey (see Figure 4). The Wapato Dam is included in the model.

Sunnyside Dam-to-Toppenish Reach

This reach begins just downstream of the Sunnyside Dam and ends approximately 15 miles downstream at the Toppenish Bridge (Figure 1).

The bathymetry was obtained using ALB data. Some water surface elevation surveys in this reach were unusable for calibration/verification due to extreme vertical error. Portions of this reach used interpolated cross sections to prevent the model from passing through critical depth. Critical depth occurs at the lowest energy expenditure for a given unit discharge.

Toppenish-to-Mabton Reach

The Toppenish reach begins at the Toppenish Bridge and extends approximately 32 river miles downstream to the Mabton Bridge (Figure 1).

The channel geometry was constructed from ALB surveys and boat surveys. The boat surveys were primarily done by the USGS; however, some gaps in the survey were resurveyed by the EFO. Four cross sections were skewed to align them perpendicular to the predominant flow direction (cross sections 187,048; 174,559; 174,368). Skewed cross sections are generally corrections to cross sections that are drawn to follow the alignment of a bridge that is not perpendicular to the flow direction.

Mabton-to-Chandler Pumping Plant Reach

This reach begins at the Mabton Bridge and extends approximately 27 river miles downstream to the Chandler Pumping Plant (Figure 1).

The bathymetry from Mabton Bridge to the Prosser Dam was obtained with ALB. The bathymetry downstream of the Prosser Dam to approximately 3 miles upstream of the Chandler Pumping Plant was obtained with boat surveys. The 5 river miles in the vicinity of the pumping plant was obtained with ALB. The Prosser Dam is included in the model. Portions of this reach contained single-line surveys, which are generally not suitable for hydraulic modeling (Figure 3). Most of the portions with a single-line survey were short and could be avoided. In places where the cross section consisted of only a single point and could not be avoided, the elevation of that point was assumed to be the elevation of the entire bed and the cross section was forced to a trapezoidal channel. Much of this reach flows over bedrock, and as such, the channel dimensions do not change significantly from one cross section to the next, making the trapezoidal channel assumption acceptable.

Naches Reach

The Naches reach begins at the Naches Bridge in the town of Naches and ends approximately 14 river miles downstream at the confluence with the Yakima River (Figure 1).

The upstream 10 river miles of this reach (Naches Bridge, station 73,390; to the Highway 12 Bridge, station 19,794) were surveyed with ALB. The downstream 4 river miles were surveyed with boat-mounted acoustics (Highway 12 Bridge, station 19,469 to mouth, station 217). The boat survey in this reach had significant errors, as great as 17 feet vertically. Additionally, the survey in this reach did not have sufficient coverage to properly represent the channel geometry. Water surface elevation surveys in the lower reach were unusable for calibration/verification due to extreme vertical error. Results from the lower reach (station 19,469 to station 217) should not be used.

Four cross sections were skewed to force a perpendicular alignment with the predominant flow direction. These cross sections are at the Powerhouse Road Bridge (20,460 and 20,419), the Highway 12 Bridge (20,142 and 20,079) and the railroad bridge (19,956 and 19,917).

METHODOLOGY

The modeled reaches were chosen based on reports by Stanford et al. (2002) and Snyder and Stanford (2001) that outlined reaches of ecological importance in the Yakima basin. The premise being that the identified reaches, if rehabilitated, could substantially enhance anadromous fish populations. These reports identified the reaches shown in Figure 1 with the exception of the Easton reach, which replaced the Cle Elum reach reported by Snyder and Stanford (2001). The Easton reach was chosen for its habitat quality with respect to spring Chinook spawning and rearing (Joel Hubble, pers. comm.).

Modeling Surface

A series of triangulated irregular networks (TINs), created by Ed Young of the UCAO, were used to represent the terrain for this modeling effort. These TINs were created from the bare earth LiDAR flown in 2000 and the various bathymetric surveys performed between 2004 and 2006.

HEC-GeoRAS

The cross sections for the HEC-RAS model were obtained with an extension for ArcGIS (ESRI, Redlands CA) called HEC-GeoRAS (USACE). Using ArcGIS and HEC-GeoRAS, geometric data are prepared for import to HEC-RAS through the use of a DEM and digitized lines that define the cross sections, channel margins, and flow paths. Additionally, a set of polygons can be used to define flow resistance (Manning's *n*). When the geometric data are imported to HEC-RAS, the model is calibrated and verified (as discussed later) and run over the desired range of discharges. All information is georeferenced so that model results can be exported to ArcGIS.

Boundary Conditions

In the Easton, Kittitas, Naches, and Mabton-to-Chandler PP reaches, a normal depth calculation was used for the downstream boundary condition, calibrated with slope to match measured water surface elevations. The reaches that represent one continuous reach (i.e., the Selah-to-Sunnyside Dam, Sunnyside Dam-to-Toppenish, and Toppenish-to-Mabton reaches) used a rating curve for the downstream boundary condition. This rating curve was developed using the next downstream model, e.g. the Mabton-to-Chandler PP model. This model was used to develop a rating curve for the Toppenish-to-

Mabton model where they had coincident cross sections. This ensured that where the models met, there was no significant change in computed depth and velocity.

Calibration and Verification

The models described in this report were calibrated primarily by adjusting parameters related to the geometry, such as the placement of levees and bank locations, selecting areas of ineffective flow and blocked obstructions, interpolating cross sections where warranted, and accounting for side channel flow as accurately as possible. Adjustments to the roughness only occurred where justifiable by physical changes in the system. Manning's *n* was not varied at each cross section of the model simply to match observed water surface elevations, as this is an improper calibration technique. Error analyses for the models are shown in Figure 7 through Figure 13 for discharges at which there was a water surface elevation surveyed.

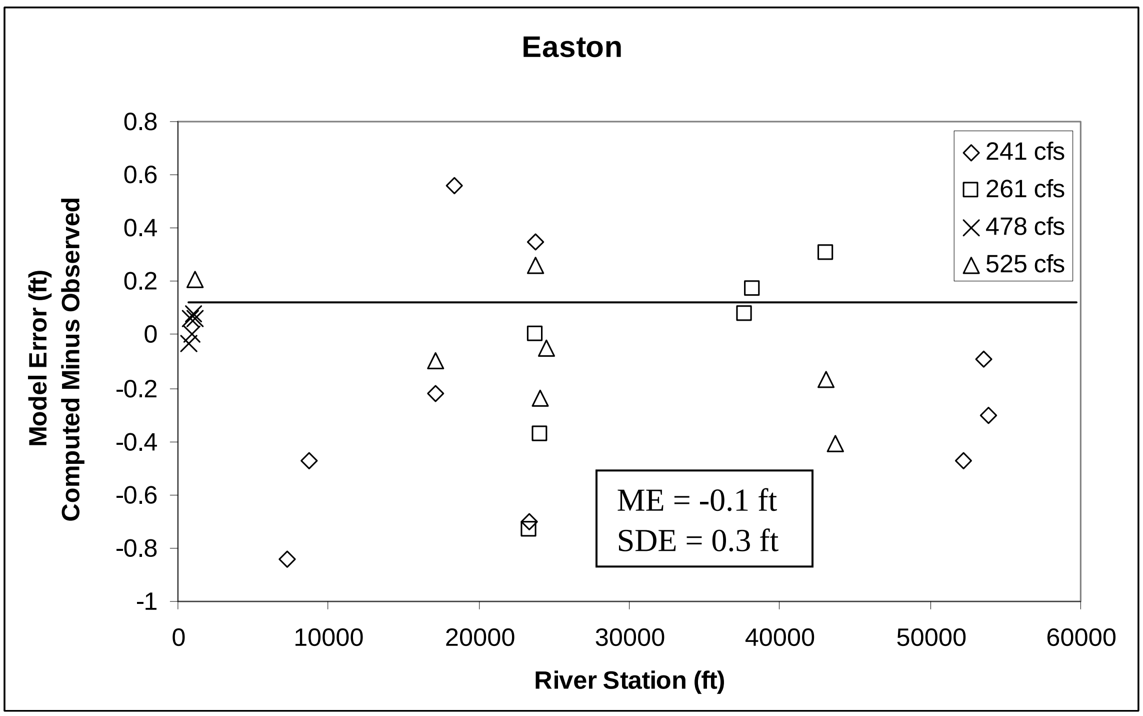

Figure 7: Model error for the Easton reach of the Yakima River. ME is mean error and SDE is the standard deviation.

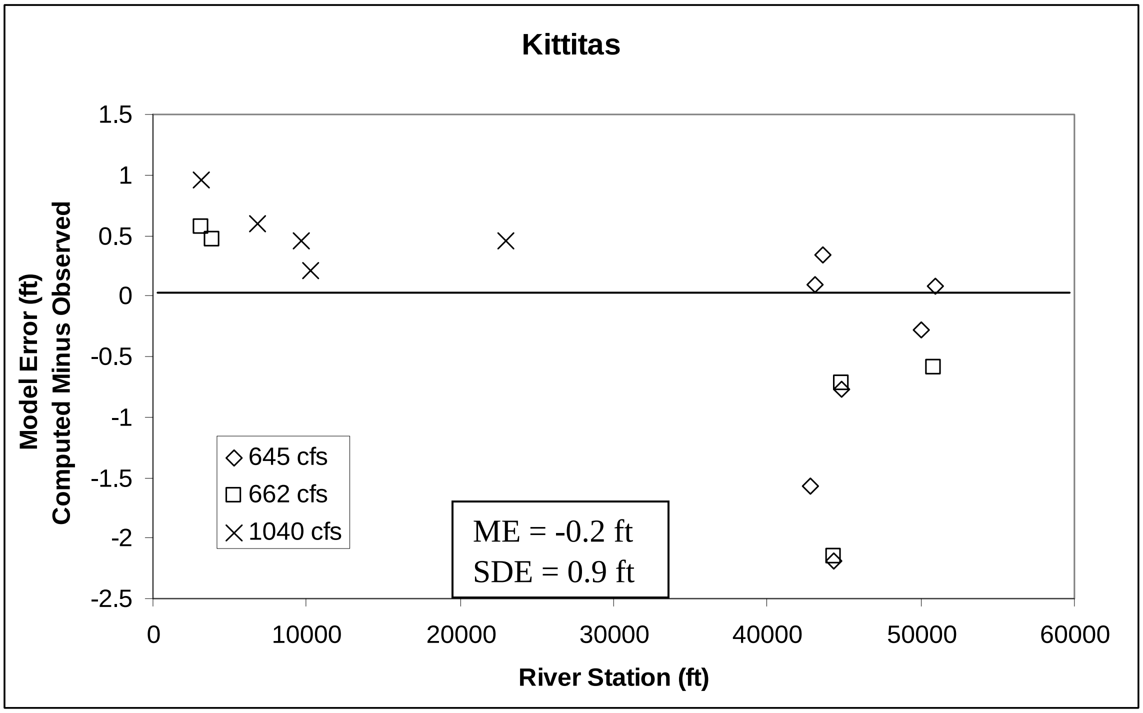

Figure 8: Model error for the Kittitas reach of the Yakima River. ME is mean error and SDE is the standard deviation.

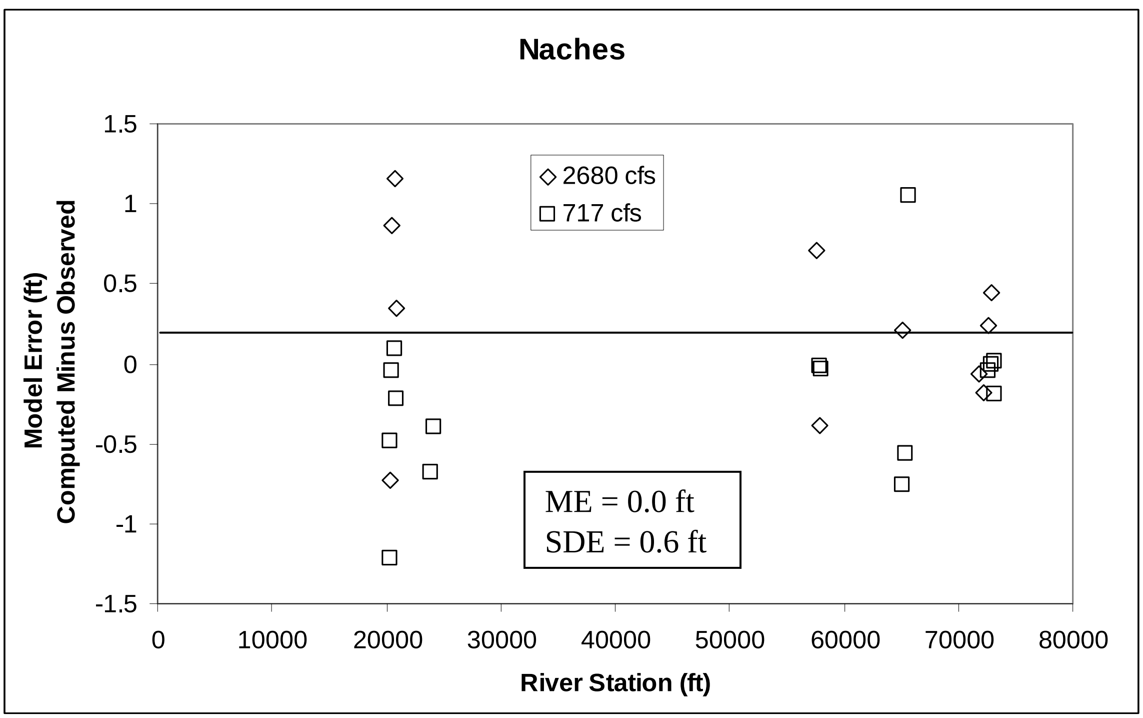

Figure 9: Model error for the Naches reach of the Naches River. ME is mean error and SDE is the standard deviation.

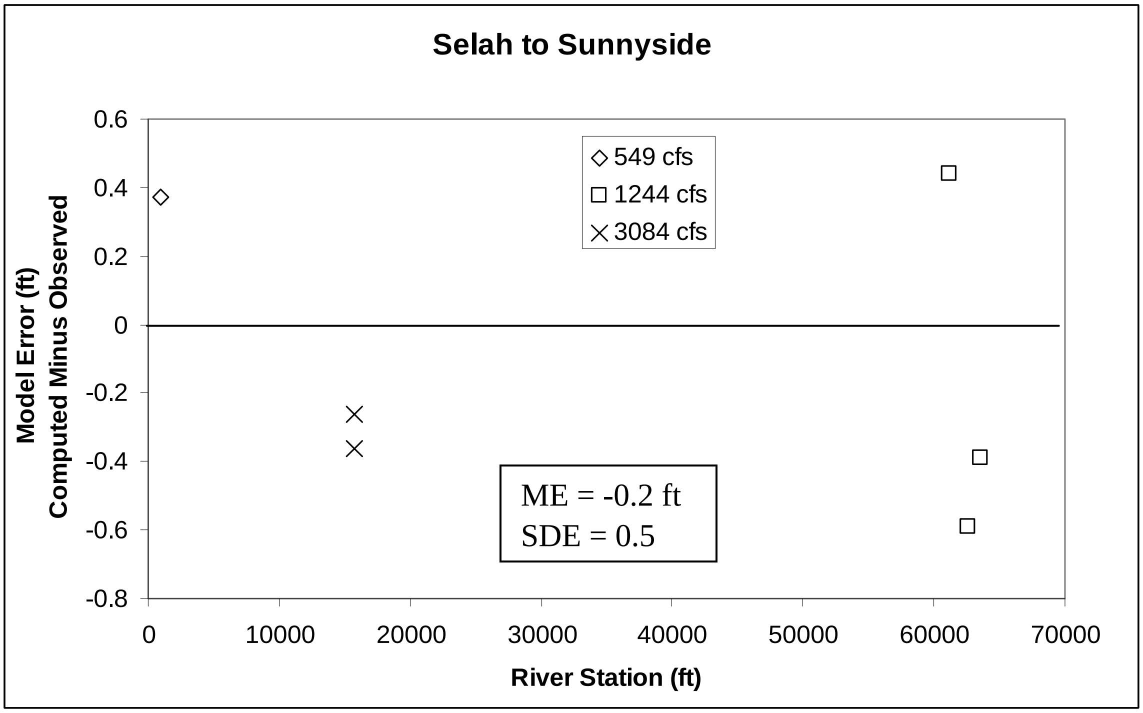

Figure 10: Model error for the Selah-to-Sunnyside Dam reach of the Yakima River. ME is mean error and SDE is the standard deviation.

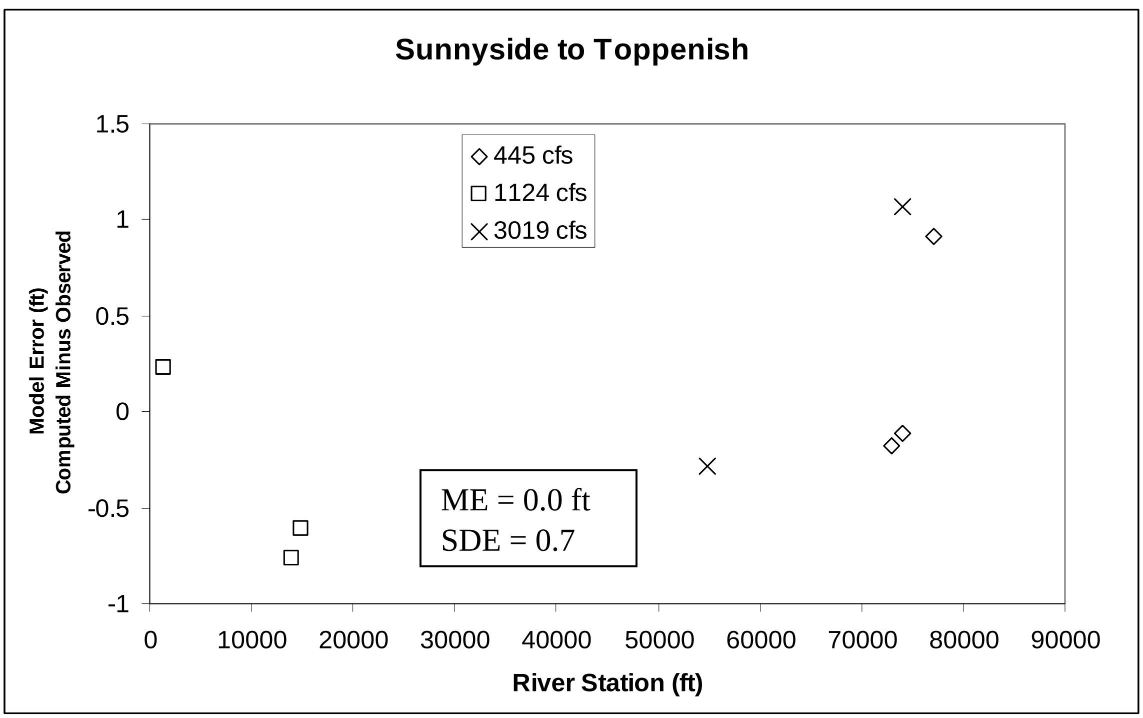

Figure 11: Model error for the Sunnyside Dam-to-Toppenish reach of the Yakima River. ME is mean error and SDE is the standard deviation.

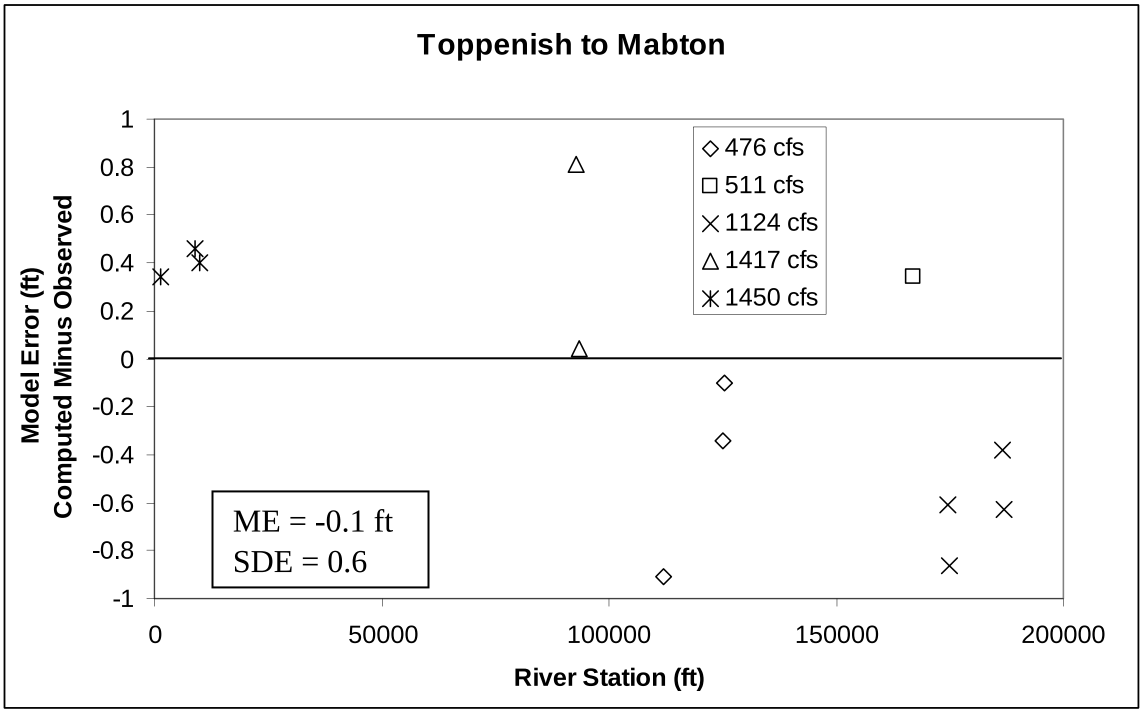

Figure 12: Model error for the Toppenish-to-Mabton reach of the Yakima River. ME is mean error and SDE is the standard deviation.

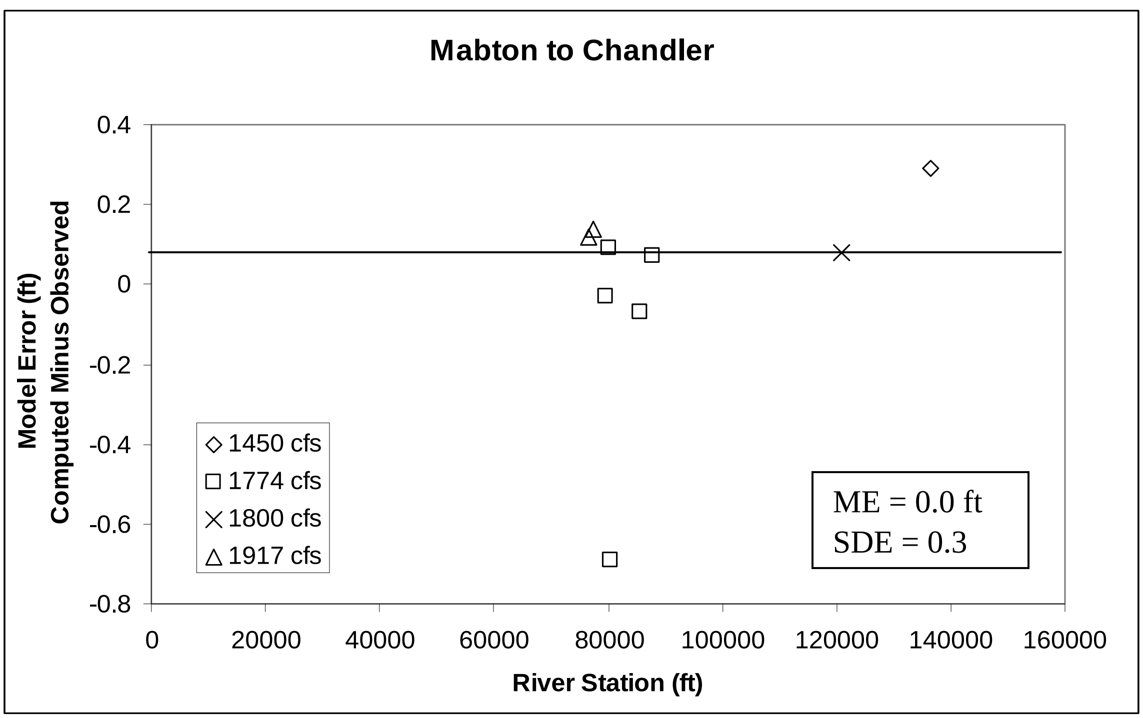

Figure 13: Model error for the Mabton-to-Chandler PP reach of the Yakima River. ME is mean error and SDE is the standard deviation.

Modeled Discharges

The discharges chosen for evaluation ranged from the lowest anticipated discharge to the maximum discharge that could be contained by the geometry (Table 3). These discharges are not meant to match the discharges used by EDT; rather, a rating curve will be made from the modeled discharges for required attributes.

Table 3: Modeled discharges for individual reaches.

Reach	Modeled Discharges (ft3/s)
Easton	200, 250, 300, 400, 500, 600, 800, 1000, 1200, 1400, 1600, 1800, 2000, 2500, 3000, 3500, 4000
Kittitas	300, 500, 750, 1000, 1250, 1500, 2000, 3000, 5000, 7500, 10000, 15000, 20000
Naches	250, 500, 750, 1000, 1250, 1500, 2000, 2500, 3000, 4000, 5000, 6000, 8000
Selah-to-Sunnyside Dam	300, 500, 750, 1000, 1500, 2000, 3000, 5000, 7500, 10000, 12500, 15000, 20000
Sunnyside Dam-to-Toppenish	300, 500, 750, 1000, 1500, 2000, 3000, 5000, 7500, 10000, 12500, 15000, 20000
Toppenish-to-Mabton	300, 500, 750, 1000, 1500, 2000, 3000, 5000, 7500, 10000, 12500, 15000, 20000
Mabton-to-Chandler PP	300, 500, 750, 1000, 1250, 1500, 2000, 3000, 5000, 7500, 10000, 15000, 20000, 30000

CONCLUSIONS

It is important that any users of the HEC-RAS data be informed about the poorly surveyed reaches. Errors in those reaches explained in the "Notes on Erroneous or Insufficient Bathymetric Surveys" section should not be used without understanding the implications of the adaptations developed to create the hydraulic model.

One-dimensional hydraulic models were developed to support habitat modeling on the Yakima River in order to compare the relative differences between restoration flows. Areas with poor bathymetric coverage lead to considerable uncertainty in the results, particularly at flows near bankfull and lower. Single line surveys most likely decrease conveyance and result in overpredicting water surface elevations, consequently creating more flooding, and overpredicting the activation of side channels. At the same time, calibration artificially lowers roughness values in order to match observed water surface elevations using a reduced conveyance area and results reflect higher velocities than likely in the field. At higher flows accessing large portions of the floodplain, in-channel geometry exerts a smaller influence and the introduced errors become smaller. Results in these sections cannot be used for absolute predictions. For comparing relative scenarios, results can provide a reasonable approximation as long as the compared scenarios do not cross any thresholds. An activated side channel with more or less flow is a reasonable comparison, but going from no flow to activation may not be well captured by the model. Similarly, in-channel flow to flooding crosses a threshold and uncertainty in the geometry prevents drawing this conclusion for reaches with unknown geometry. There is no way to interpret or anticipate the computational errors caused by random survey error and these sections cannot be used.

Calibration to observed water surface elevation yielded errors within approximately 1 foot. The spacing of observed locations was greater than intended due to the large vertical error in some of the surveys, which were not able to be used for calibration/verification purposes. This increases the uncertainty of the model. However, it is believed that the results are adequate for the intended purpose, which is to compare hydraulic, temperature, and sediment conditions across various scenarios of reservoir releases. Those reaches with minimal survey error in both water surface elevations and bathymetry have a greater degree of certainty and are wholly adequate for the intended purpose.

ACKNOWLEDGEMENTS

In addition to the author, the modeling was performed by David Mooney and Travis Bauer of the Sedimentation and River Hydraulics Group and John Treacy of the Water Supply, Use and Conservation Group. Peer review provided by Kent Collins, Sedimentation and River Hydraulics Group. Additional comments were provided by Joel Hubble and Lynn Holt.

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