Draft Evaluation of Flood Peaks Estimated by USGS

Skagit River Flood Damage Reduction and Ecosystem Restoration Project Feasibility Study
Skagit County Public Works Department

PACIFIC
INTERNATIONAL
ENGINEERING PLLC

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1. Executive Summary

The purpose of this report is to evaluate the use of the James Stewart estimates in identifying peak flows associated with four unrecorded floods on the Skagit River. The report also presents an evaluation based on the use of recorded flood flows that should more accurately identify the peak flows associated with the four unrecorded flood events.

Peak flow estimates for the four floods, which occurred in 1897, 1909, 1917, and 1921, were estimated by Stewart in an unpublished report dated 1923 and documented in U.S. Geological Survey (USGS) Water Supply Paper 1527 (WSP 1527).

Concerns evaluated in the report associated with the estimates of flood peaks for the unrecorded floods include the following:

- Locations of three of the high water marks (HWMs) originally observed by Stewart are not known and the elevations relative to the existing USGS gage near Concrete cannot be accurately determined.

- Location of a hotel used by Stewart as an HWM reference relative to the originally-observed HWM locations and to the existing gage is not known.

- Stage measurements for the 1897 flood have a low level of certainty.

- The effects of the flows in the Baker River on the HWMs observed by Stewart relative to the water surface elevation on the Skagit River were not considered in the flood peak estimates.

- The 1897 and 1909 HWMs identified by Stewart at the hotel in Concrete were all related to flood flows from the Baker River and not directly related to the elevation of flood flows on the Skagit River. There is no documentation as to how this information was transferred to flood flow elevations on the Skagit River.

- There is no documentation as to the location of the HWM recorded by Stewart for the 1917 flood.

- Indirect methods used by Stewart to estimate the flood peaks provide only an approximation.

As an alternative process to estimate flood flows associated with the four unrecorded floods, this report present a methodology using a numerical model calibrated to the October 2003 flood and verified using USGS HWMs from other recent floods.

Skagit County's consultant, Pacific International Engineering (PI Engineering), developed a steady-flow HEC-RAS model for a 7-mile river reach near Concrete that overlaps the area that Stewart analyzed. The model was calibrated for the October 2003 flood HWMs surveyed by USGS (U.S. Geological Survey 2004) in summer 2004 and verified for other recent flood stages observed by USGS at the Concrete gage. Peak stages of the two November 1990 floods, the November 1995 flood, and the October 2003 flood generated by the HEC-RAS model calibration and verification runs appear to match well with the USGS observed HWM data for these floods.

The calibrated and verified HEC-RAS model was then used to run various discharges up to 270,000 cfs, extending the upper end of the discharge rating curve at the Concrete gage, and covering the HWM range of the four unrecorded flood peaks.

The HEC-RAS rating curve was compared with curves produced by linear and log-log extension of the USGS-developed rating curve based on recorded measurements (U.S. Geological Survey 2003).

Stewart's 1923 estimates as published in WSP 1527 are 16 to 20 percent higher than the estimates by the HEC-RAS model results.

PI Engineering also performed a flood frequency sensitivity analysis to evaluate the impact of including and excluding the USGS 1923 estimates for the unrecorded floods in the flood frequency analysis. The differences are significant. Inclusion of the historical flood estimates results in an unregulated flow value of 299,000 cfs for the 100-year event (U.S. Army Corps of Engineers 2004); exclusion of those estimates results in an unregulated flow value of 240,000 cfs, a difference of 59,000 cfs.

2. Introduction

Skagit County and its consultant Pacific International Engineering (PI Engineering) have been working closely with the U.S. Army Corps of Engineers (Corps) and the Washington Department of Ecology (Ecology) to identify measures to reduce public safety hazards and economic losses associated with flooding on the Skagit River below Concrete. The current management plan for the Skagit River Flood Damage Reduction and Ecosystem Restoration Feasibility Study is focused on developing a complete and accurate hydrologic and hydraulic analysis in order to determine the magnitude and frequency of flooding on the Skagit River. The next phase involves using the flood magnitude and frequency information to develop preliminary design of various flood reduction alternatives.

Since the beginning of 2004, the County and PI Engineering have held regular project meetings with the Corps. Topics of discussion during these meetings included the Corps' reevaluation of the Skagit River hydrology and hydraulics. Since May 2004, the Corps' revised hydrology and hydraulics, and related documents, data, and models, have been undergoing Independent Technical Review (ITR).

PI Engineering has identified concerns regarding the technical analysis that supports hydrologic and hydraulic conclusions presented by the Corps. As a result, PI Engineering has held several discussions with Corps staff, and the County has corresponded with the USGS in an effort to resolve questions regarding these issues. This report focuses on the high water mark data and peak flow estimates made by USGS for four historical floods used in the Corps' flood frequency analysis. Section 3 of this report reviews what is known about the historical high water mark data and flow estimates and discusses the level of confidence in those data. Section 4 discusses current methodologies for calculating unrecorded historical flood peaks, and Section 5 describes the significance of using the best available science for flood peak calculation.

3. Stewart's Estimates of Peak Flows for the Floods of 1897, 1909, 1917, and 1921

3.1 Background

Prior to the installation of a gage on the Skagit River at River Mile (RM) 54.15 near Concrete, estimates of peak flows were made for seven large historical floods. Peak estimates for floods that occurred in 1897, 1909, 1917, and 1921 (water years 1898, 1910, 1918, and 1922) are used by the Corps in calculating the flood frequency at the Skagit River gage near Concrete. These four historical flood peaks were estimated by James Stewart in an unpublished report dated 1923 (Stewart 1923) and documented in USGS Water Supply Paper (WSP) 1527 (Stewart and Bodhaine 1961). The reliability of the peak estimates for the remaining three historical floods is considered poor, and those estimates are not used in the Corps' flood frequency analysis (U.S. Army Corps of Engineers 2004).

WSP 1527 provides data for the 1897, 1909, 1917, and 1921 floods as shown in Table 1. Appendix A-1 contains a vicinity map showing the Town of Concrete and the gage location.

Table 1 Peak Stages and Discharges of Skagit River Near Concrete (DA = 2,700 sq. mi.) (Source: WSP 1527)

Flood	Gage Height (ft)*	Stewart's Elevation (ft)**	Discharge (cfs)
1897	51.1	38.4	275,000
1909	49.1	36.4	260,000
1917	45.7	33.0	220,000
1921	47.6	34.9	240,000

*Current gage datum El. 130.00 (NGVD29)
**Prior to Dec. 10, 1924, staff gage located 200 ft upstream and at datum 12.7 ft higher than current gage site (Flynn 1954)

Several parties have questioned the accuracy of the 1897, 1909, 1917, and 1921 flood peak estimates. It is not known if the high water marks (HWMs) used to make these estimates were correctly observed or surveyed, or whether the original HWM data and calculations exist for independent technical review. Sensitivity analysis indicates that inclusion or exclusion of the historical flood peak estimates has a significant effect on the frequency analysis.

Therefore, verification of the HWM data and calculations is essential for evaluation of flood reduction measures.

3.2 Identification and Location of HWMs

3.2.1 Hotel location relative to rated section (gage) and recorded HWMs

Both WSP 1527 and Stewart's 1923 report indicate that the peak stage and discharge estimates for the 1897, 1909, and 1917 floods were based on flood marks as measured by Stewart "about one mile upstream." Neither report provides survey data for the HWM measurements. It is not clear if the phrase "one mile upstream" is used relative to the current gage station or to some other location. Some of the HWM references are one mile upstream of Concrete, some are one mile upstream of The Dalles, and others are simply "one mile upstream." The water surface elevation in this reach of the Skagit River can change by more than 5 feet per mile, so the exact location is important.

For the 1909 flood, WSP 1527 states that Stewart measured a flood mark on "a hotel near the cement plant [that] was just reached by the water." No information is given on the exact location of the hotel, only that it was located somewhere in Concrete. A 1908 roster of the population of Baker (as Concrete was then known) showed two hotels located along the town's main street, along with a number of other structures (Concrete Heritage Museum 2004). It is likely that the hotel footing on which Stewart measured the 1909 HWM was one of these two hotels. However, HWMs on buildings along what is now West Main Street would have been left by Baker River flood flows, and not by flood flows on the Skagit River.

Stewart also referenced HWMs for the 1897 flood to the hotel footing (Stewart 1923). The first 1897 HWM was found "on a barn on the right bank about a mile upstream from Concrete." Later, a second HWM was found on a stump that was reported by Magnus Miller to be "1.5 feet out of the water during the flood of 1897." Exact locations are not given for either the barn or the stump. It is not known if, like the 1909 HWM on the hotel, these HWMs represented flood peak elevations on the Baker River, or if they represented flood peaks on the Skagit River. It is known that the Magnus Miller property was bordered on the east by the Baker River. If the stump was located on Mr. Miller's property, the HWM would have represented Baker River peak flows for the flood of 1897.

Neither WSP 1527 nor Stewart's 1923 report make clear where the HWM for the 1917 flood was measured, only that, like the HWMs for the other floods, it was located "about one mile upstream." It is not known if the 1917 HWM used by Stewart was on the Baker River or the Skagit River.

Given the information available at this time, the locations of the originally-measured HWMs for the 1897, 1909, and 1917 floods cannot be known with any precision. However, it seems likely that the HWM on the hotel measured by Stewart for the 1909 flood recorded peak flows on the Baker River, and not on the Skagit River.

3.2.2 HWMs from flood of 1897

WSP 1527 states "[t]he stage of the 1897 flood is not as certain as the stages for the other two floods." The paper goes on to say "the stage for the 1897 flood was determined from its relation to the 1896 flood about one quarter of a mile upstream." It is not stated how the stage for the 1896 flood was determined. There is no explanation as to what "one quarter of a mile upstream" means – whether the HWM for the 1897 flood was measured 0.25 mile upstream of a HWM for the 1896 flood, 0.25 mile upstream of the gage, or 0.25 mile upstream of some other point. It is not clear how to reconcile this statement with the earlier statement that the stage for the flood of 1897 was estimated from the flood mark on the barn about one mile upstream from Concrete.

In his draft report, Stewart also indicates uncertainty about the stage measurement for the 1897 event, saying, "[t]he stage for flood No. 3 [i.e., the 1897 flood] was rather uncertain at the upstream point. The accuracy for the discharge of that flood has been reduced accordingly." (Stewart 1923). Based on this uncertainty, Stewart assigned an accuracy of 20 percent (i.e., value expected to be within ±20 percent of the real value) to the discharge estimate for the 1897 flood.

As described in the previous section, Stewart used the 1897 flood mark on the barn and transferred this mark by level to the footing of the hotel in Concrete. The difference between the 1897 mark and the 1909 mark was reported to be 5 feet. Stewart allowed 2 feet for the slope of the water surface and estimated that the 1897 flood was 3 feet higher than the 1909 flood at Concrete.

After making his first discharge estimate for the 1897 event, Stewart "ran levels to a stump" that had been reported by Mr. Miller to be 1.5 feet out of water during the 1897 event. From these measurements, Stewart revised his figures upward, estimating that the 1897 flood was 3.5 feet higher than the 1909 flood at Concrete.

However, there is no substantiation for Stewart's original assumption of a 2-foot slope in water surface elevation between the barn and the hotel, and it is not known what slope assumption he made for the second HWM measurement. As discussed in Section 3.2.1, no original survey data have been made available that would allow for verification of the slope assumption. The flood profiles discussed in Section 4 show that the slope of the water surface can be more than 5 feet within the Skagit River reach near Concrete.

Lacking additional location information, it cannot be determined if the HWMs measured for the 1897 event represented Baker River flows or Skagit River flows. If the HWMs were left by Skagit River flows, it is not known how Stewart related these data to the 1909 HWM on the hotel, which would have represented Baker River flood elevations.

Therefore, although Stewart may have been more confident in the later HWM measurement than in his original measurement, the revised figures may be no more accurate than the original estimates.

Finally, it should be noted that the measurements in Table 1 show the elevation of the 1897 flood to be 2 feet higher than the elevation of the 1909 event at the gage near Concrete. Thus, there is an unexplained 1-foot to 1.5-foot discrepancy (depending on which of Stewart's two transferred 1897 HWMs is used) and the published peak stage data.

3.2.3 HWMs from floods of 1909, 1917, and 1921

WSP 1527 indicates that numerous HWMs from the 1909 flood were evident in and near Concrete when Stewart made field measurements in 1918. In addition to the HWM on the hotel footing, flood marks were seen on "an old Washington Cement Plant shop building" and elsewhere. The Washington Cement Plant was located on the east side of the Baker River, and flood marks on that building would have been left by Baker River flows, with significant Skagit River tailwater effects at that location. It is not known if Stewart used HWM measurements at the cement plant and other locations in Concrete for his peak flow estimates, or only the HWM measured at the hotel.

Neither Stewart's 1923 report, nor WSP 1527, provide clear information about the location of the measured HWM for the 1917 flood. Both documents indicate that measurements for this flood, like those for the 1909 and 1897 floods, were made "about one mile upstream." It is not known how Stewart transferred his measurements to the Skagit reach near Concrete. The gaging station at Reflector Bar was in operation during the 1917 flood, but it is not known if or how those gage data were used to estimate the Skagit River flood peak at Concrete.

The peak flow estimate for the 1921 flood was made from HWMs at The Dalles, where the "floodmarks still were so clear that the profile of the flood could be determined within one or two tenths of a foot." These are the only HWMs used by Stewart that are known to represent Skagit River flood flows. However, there are no survey data for verifying where along The Dalles reach the measurements were recorded.

3.3 Potential Calculation and HWM Transfer Problems

The following potential problems with the transfer of HWMs and flow calculations have been identified:

- **Stewart's rated section was not in the same location as the gage**

Note the differences in Table 1 between gage height and Stewart's elevations for the flood peaks. These differences arise from use of an elevation datum and gage location that is different from the existing gage location. This is documented in a USGS memorandum by F.J. Flynn (Flynn 1954) that states: "The statement given under 'Gage' paragraph in recent (since 1951) manuscripts states that the gage used prior to Dec. 10, 1924, was at the same site (present site) and at a different datum (unknown datum implied). Apparently the statement should read: 'Prior to Dec. 10, 1924, staff gage at site 200 ft upstream at datum 12.7 ft higher."

As discussed further in Section 4 of this report, a small change in gage location on the Skagit River may result in a large change in water surface elevation. There is a steep decline in water surface elevation over a short reach near Concrete, with the sharpest drop occurring near The Dalles. A lateral distance as small as 200 feet between gage locations could translate into a significant difference in the measured water surface elevation. This difference is close to two feet for the magnitude of the 1921 flood.

- **The 1897 HWMs may not have been transferred correctly**

As discussed earlier, there is no substantiation for Stewart's original assumption of a 2-foot slope in water surface elevation between the 1897 HWM on the barn and the hotel in Concrete. No survey data have been made available that would allow for verification of the 2-foot slope assumption. As discussed in Section 4, this is significant because of the large changes in water surface profiles seen along the Skagit River reach near Concrete. It is not known if the 1897 HWMs used by Stewart reflected Skagit River peak flows or Baker River peak flows.

Table 2 shows USGS-published figures for Skagit River historical flood peak discharges at gage stations above Concrete. Stewart estimated that the peak flow for the 1897 flood was 3 feet to 3.5 feet higher than the 1909 peak at the hotel in Concrete. However, Table 2 indicates that the Skagit River peak flows for the 1897 flood at Reflector Bar and Newhalem, as well as the Baker River peak flow, were significantly lower than those for the 1909 event. The figures given for the 1897 flood flows on the Skagit River at Reflector Bar and Newhalem, and on the Baker River below Anderson Creek are only slightly larger than those for the 1917 event. Because the peak of the 1917 flood was lower than that of the 1909 flood (which just reached the hotel footing), the HWM for the 1917 flood would have been below the elevation of the hotel footing. Assuming that the published figures shown in Table 2 are correct, it seems unlikely that the peak for the 1897 flood would have exceeded the 1909 peak at Concrete. Both peaks would have been due more to the Baker River flows than the Skagit River flows.

Table 2 Skagit River Historical Flood Peak Discharges (cfs) (Source: WSP 1527)

Flood	Skagit River at Reflector Bar (DA = 1,100 sq. mi.)	Skagit River at Newhalem (DA = 1,160 sq. mi.)	Cascade River near Marblemount (DA = 140/171 sq. mi.)	Sauk River at Darrington (DA = 293 sq. mi.)	Baker River below Anderson Creek (DA = 211 sq. mi.)
1897	48,000	48,000	40,000	44,000	36,700
1909	70,000	63,500	26,000	40,000	46,200
1917	43,000	47,400	32,000	36,000	36,800
1921	63,000	60,000	--	36,000	23,600

- **The effects of the flows in the Baker River on the HWMs observed by Stewart relative to the water surface elevation on the Skagit River were not considered in the flood peak estimates.**

The 1897 and 1909 HWMs measured by Stewart at the hotel in Concrete were related to flood flows from the Baker River and not directly related to the elevation of flood flows on the Skagit River. There is no documentation as to how this information was transferred to flood flow elevations on the Skagit River.

In discussing Stewart's HWM measurements for the 1897 and 1909 floods, WSP 1527 acknowledges that "[t]he flood elevations in Concrete probably were affected to a considerable extent by the flow of Baker River. The relationship between the two floods at that point may have been quite different from the relationship at the gaging station site." These two floods occurred before construction of the Lower and Upper Baker Dams, therefore, Baker River flows were not reduced by dam storage and the effects of the Baker River flows could have been significant.

- **Limitations of indirect methods for calculating flood flows**

In his work on estimating Skagit River flood peak flows, Stewart reportedly collected 1921 flood data at The Dalles that were suitable for flow computations by both the contracted-opening and slope/area methods (Stewart 1923). Both of these are indirect methods that provide only an approximation of flood flows. The estimates produced by the contracted-opening method are very rough and today the method is not generally considered to be valid. Limitations on the slope/area method include the assumption that flow velocity (or velocity head) remains unchanged from section to section.

In his 1923 report, Stewart used both methods to calculate estimates of the 1921 flood. As noted in WSP 1527, the upper end of the rating curve for the gaging station near Concrete was based on Stewart's computations for this flood. The discharges for the 1897, 1909, and 1917 floods were apparently determined by extending the rating at the time through the 1921 flood measurement and calculations.

Stewart also stated in his report that "In this portion of the river [meaning at and near The Dalles], all floods since that of 1856, have been confined within the banks of the main channel." (Stewart 1923). In 1923, the bridge and access road at The Dalles had not yet been built. The access road contains fill to elevation 190 ft. The upstream entrance of a right bank secondary channel through this area is approximately at elevation 180 ft (U.S. Army Corps of Engineers 1976). The WSP 1527 published gage heights shown in Table 1, converted to water surface elevations with a minimum of 3 feet added for backwater effects from the gage to the secondary channel entrance (a distance of approximately 0.5 mile), would indicate flows entering this secondary channel during at least the 1897 and 1909 floods. This is contradictory to Stewart's above statement. This contradiction brings into question the accuracy of the transferred HWMs to the gage for these floods.

However, a review performed by USGS in 1950 indicated "…it appears that the value of n used by Stewart in his 1921 flood flow computation was too low for his upper reach. It was also noted that Stewart did not take into account changes in velocity head in his computations. A re-computation of the 1921 peak by present methods using Stewart's values of A, P, and f, and n =.040 for the upper reach and n = .033 for the lower reach gives 209,000 second-feet. An examination of the plan of the channel (in verification study) shows that the upper reach is considerably larger in the middle than at the ends." (Riggs and Robinson 1950). In Stewart's report, he acknowledged that changes in velocity head "prevent an extremely high degree of accuracy" in flow estimates by either the contracted-opening or slope/area method (Stewart 1923).

The 1950 review recommended downward revision of the historic flood peak values based on logarithmic extension of the rating curve. As shown in Figure 1, Stewart's measurements for the 1897, 1909, 1917, and 1921 peak flows fall well to the right of the logarithmic rating curve extension. The authors of the 1950 review acknowledged that the curve could bend to the right at the upper end because of overflow on the right bank, but noted that at the time Stewart made his calculations, the overflow area was heavily timbered and would have carried little water. It was recommended that the peak flow estimate for the 1921 event be revised downward from 240,000 cfs to 210,000 cfs. Similar downward revisions were recommended for the 1897, 1909, and 1917 flood peaks.

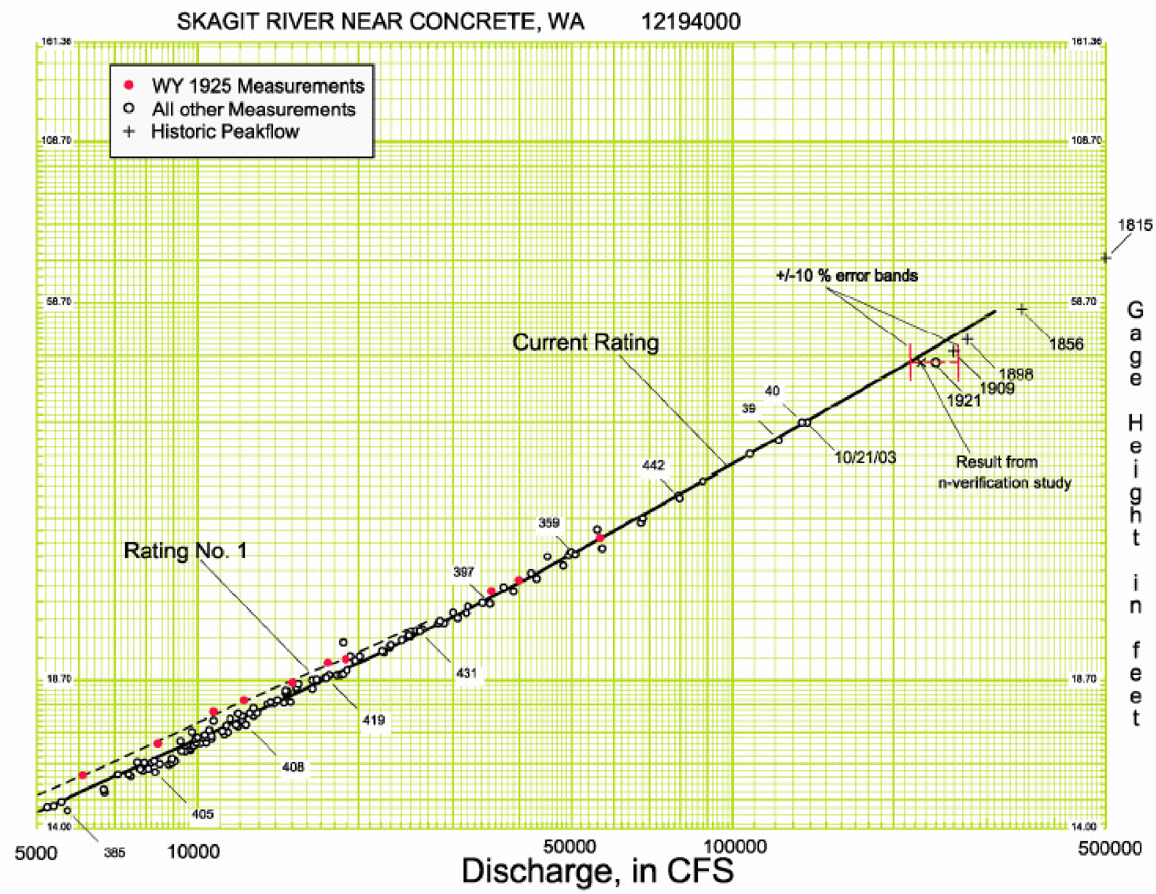

Figure 1 Stage-discharge rating curve for the Skagit River near Concrete
(Provided by U.S. Geological Survey, May 2004)

4. USGS and PI Engineering Recent Methods of Calculating Unrecorded Historic Flood Peaks

PI Engineering developed a steady-flow HEC-RAS model for a 7-mile (RM 48.45-55.35) river reach and the right bank secondary channel (or overflow channel) near Concrete. The model was calibrated for the October 2003 flood HWMs scaled from a profile plot of seven HWMs surveyed by USGS in summer 2004 (U.S. Geological Survey 2004) and verified for other recent flood stages observed by USGS at the Concrete gage. The calibrated and verified HEC-RAS model was then used to run various discharges up to 270,000 cfs, extending the upper end of the discharge rating curve at the Concrete gage, and covering the HWM range of the 1897, 1909, 1917, and 1921 floods reported by USGS in WSP 1527.

Figure 2 shows the layout and location of the Skagit River main channel, and the secondary channel cross sections near Concrete (RM 52.55-55.35) used in the HEC-RAS model. Channel geometric data for most cross sections and all overbank geometric data were obtained from the 1976 Flood Insurance Study (FIS) topographic maps provided by the Corps (U.S. Army Corps of Engineers 1976). PI Engineering surveyed new channel geometric data for 16 cross sections between RM 52.55 and 55.35 in October 2004. Plots for the cross sections are provided in Appendix A-2.

The secondary channel on the right bank between RM 53.94 and RM 54.65 of the Skagit River was modeled as a separate flow conveyance reach from the main channel. Geometric data for this channel were based on the 1976 FIS topographic maps. Prior to construction of The Dalles bridge and access road in 1952, this secondary channel would have conveyed flood flows if the water levels reached above El. 180 at the upstream entrance of the channel (U.S. Army Corps of Engineers 1976). After the 1952 construction of the bridge and road, which contains a 10-foot-high fill, this channel would convey flood flows only if water levels reach above El. 190 (U.S. Army Corps of Engineers 1976). Below El. 190, flood water would only be ponded in this channel.

Manning’s “n” values for the Skagit River main channel and overbanks of the modeled reach vary from 0.028 to 0.038, and from 0.08 to 0.15, respectively, and are shown on the cross section plots in Appendix A-2. These “n” values were originally determined in the FIS study and modified by PI Engineering for use in calibration of the October 2003 flood HWMs. Manning’s "n" values for the right bank secondary channel were assumed to be 0.15 for heavily timbered areas during the time of the 1897, 1909, 1917, and 1921 floods.

Contraction and expansion coefficients are 0.10 and 0.30, respectively, for low transition loss areas of the main channel, but are higher for flow through The Dalles reach (RM 54.05-54.19). Contraction and expansion coefficients were determined from the model calibration and verification runs to vary from 0.3 to 0.8 and from 0.5 to 0.9, respectively, for The Dalles reach. Contraction and expansion coefficients are assumed to be 0.10 to 0.30, and 0.30 to 0.50, respectively, for the secondary channel. Appendix A-3 lists the contraction and expansion coefficients used for the cross sections in the modeled reaches.

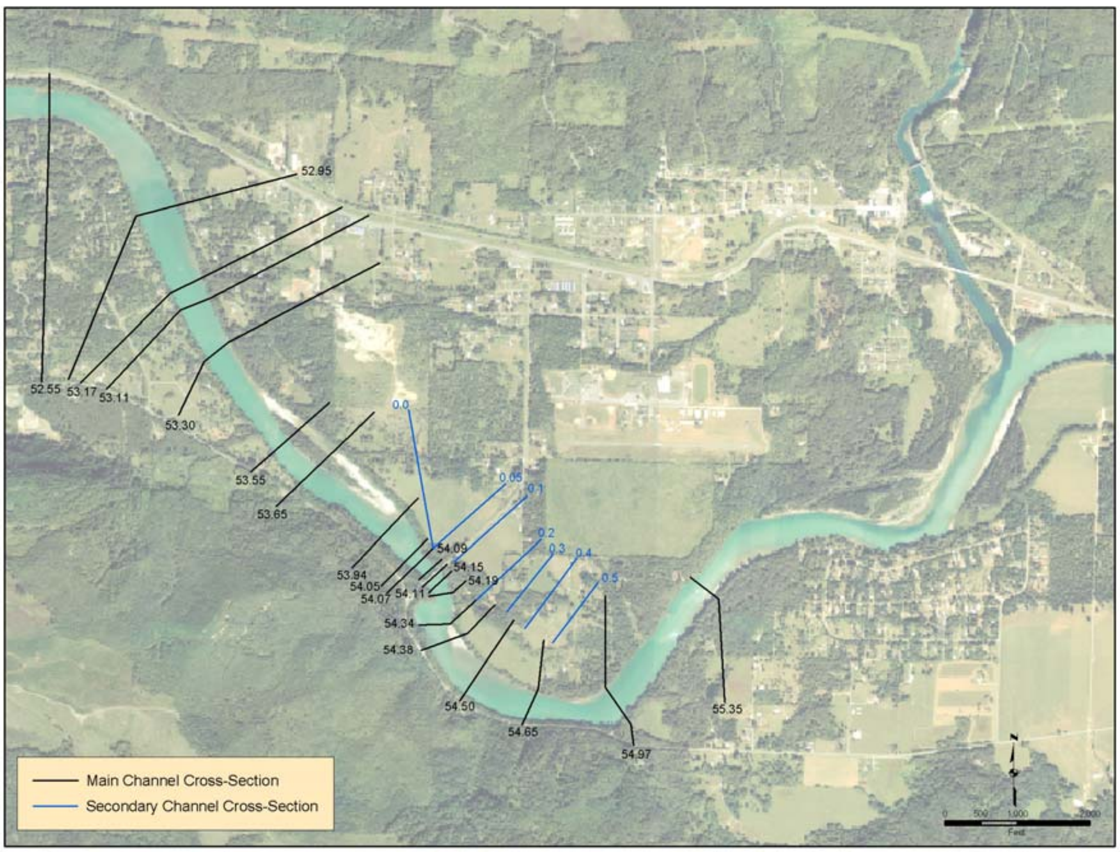

Figure 2 **Skagit River HEC-RAS cross section location map** (Photo dated 2001, provided by Skagit County)

The upstream boundary conditions used for the HEC-RAS model calibration and verification runs were the USGS-observed flood peaks at the Concrete gage. The downstream tailwater boundary conditions for the model were the water surface elevations modeled by PI Engineering using an unsteady-flow HEC-RAS model for the lower Skagit River between Concrete and Skagit Bay. This unsteady-flow model was originally developed by the Corps and refined by PI Engineering in 2004.

Figure 3 shows the Skagit River peak stage profiles of the two November 1990, the November 1995, and the October 2003 floods, resulting from the HEC-RAS model calibration and verification runs. USGS-observed HWMs at the Concrete gage for these floods are also shown in Figure 3 for comparison with the modeled results. The modeled results appear to match well with the actual observed data provided by USGS. The HEC-RAS model output tables for the two 1990, the 1995, and the 2003 floods, plus seven other higher flows for the Concrete gage rating curve extension for the secondary channel conditions prior to the bridge and road construction, are provided in Appendix A-4.

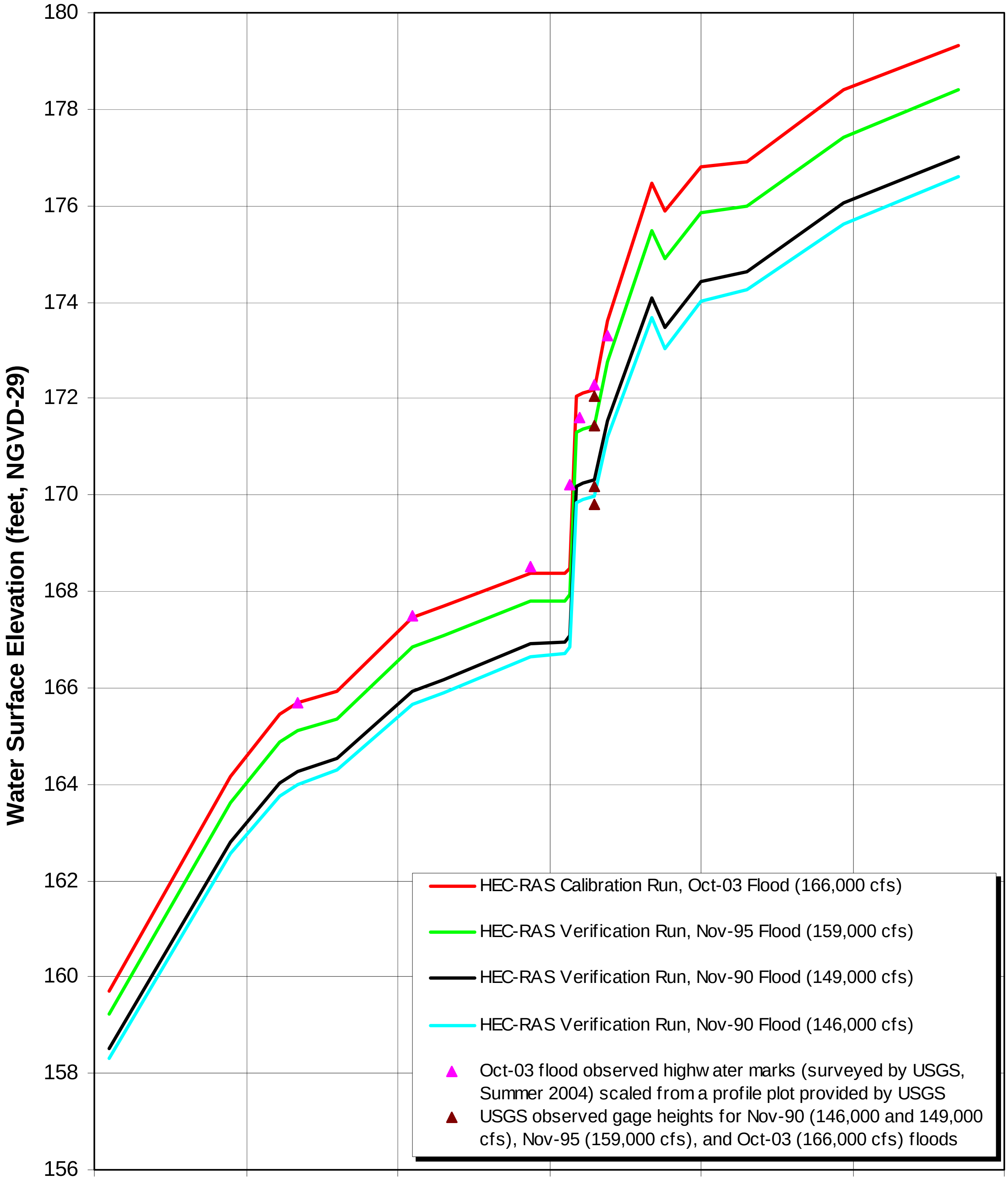

Figure 3 Water surface profiles of the Skagit River near Concrete

As shown in the HEC-RAS model output tables in Appendix A-4, flow area and velocity changes from cross section to cross section. This is contrary to the assumptions inherent in the slope-area method used by Stewart. The calibrated and verified steady-flow HEC-RAS model provides a direct and more accurate method for estimates of the 1897, 1909, 1917, and 1921 floods, assuming the published gage heights as shown in Table 1 are accurate.

Figure 4 shows a plot of four high flow rating curves at the Concrete gage (RM 54.15). Two are provided by USGS and based on extension of the USGS-developed rating curve (one by a linear extension and the other by a log-log extension) (U.S. Geological Survey 2003). The other two rating curves are based on the HEC-RAS model run results, one including the secondary channel as a ponding area for water level below El. 190 after The Dalles bridge and road construction in 1952; and the other including the right bank secondary channel as a flow conveyance prior to The Dalles bridge and road construction. As shown in the figure, the HEC-RAS independently-developed first rating curve matches closely with both of the USGS linear and log-log rating curves, representing the existing secondary channel conditions.

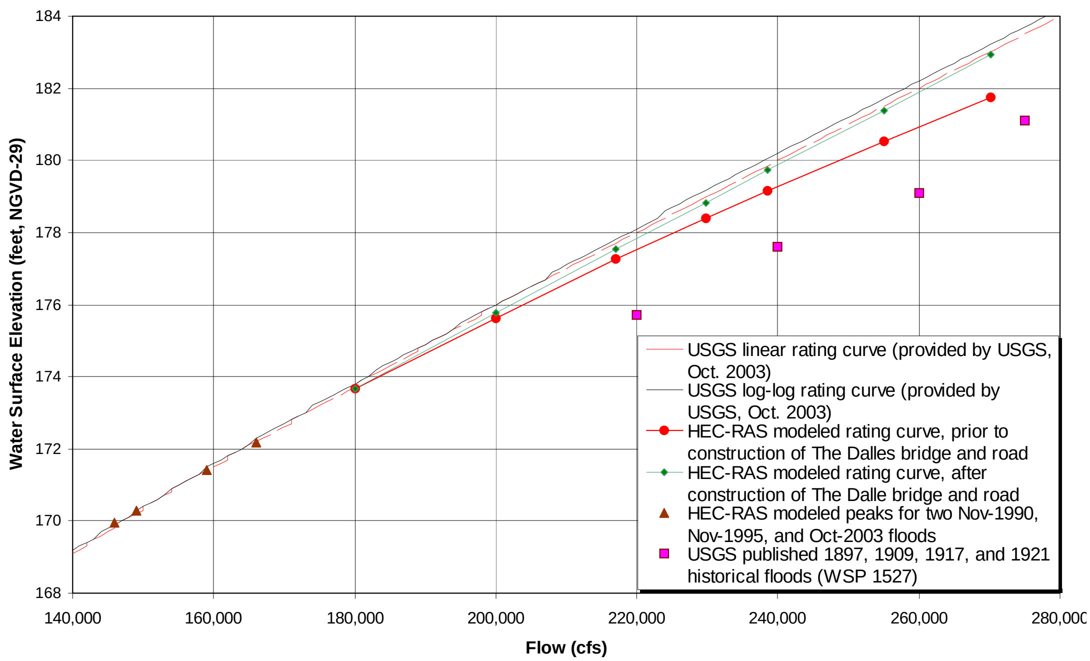

Figure 4 Rating curves of the Skagit River near Concrete (RM 54.15)

Table 3 provides estimates of the 1897, 1909, 1917, and 1921 floods, using USGS published gage heights converted to water surface elevations. These estimates include the USGS 1923 estimates as published in WSP 1527, and the independent estimates based on the calibrated and verified HEC-RAS model discussed above. Figure 4 also shows plotted points of the USGS 1923 estimates for these four historical floods. As shown in Table 3, the estimates based on the HEC-RAS modeled rating curve for the secondary channel conditions prior to 1952 are lower than the USGS 1923 estimates as published in WSP 1527 by 5 to 10 percent. Use of the HEC-RAS-modeled rating curve is considered to be a more accurate method for the historical flood estimates if Stewart's rated section is exactly at the current gage location (RM 54.15).

Table 3 Peak Discharge Estimates for Historical Floods at Skagit River Near Concrete (RM 54.15)

Flood	Water Surface Elevation (ft)	USGS 1923 Estimate (cfs)	HEC-RAS Modeled Rating Curve Estimate (cfs)	Difference	
				(cfs)	(%)
1897	181.1	275,000	262,000	13,000	5
1909	179.1	260,000	238,000	22,000	9
1917	175.7	220,000	201,000	19,000	10
1921	177.6	240,000	221,000	19,000	9

However, if Stewart's rated section is the "staff gage at site 200 ft upstream" (Flynn 1954), the water surface elevation at this staff gage location (RM 54.19) would be 1.6 to 2.0 ft higher than those at the current gage location (RM 54.15) for the flow range of the 1897, 1909, 1917, and 1931 floods. Figure 5 shows the staff gage rating curve based on the pre-1952 conditions HEC-RAS modeling results presented in Appendix A-4. Table 4 shows the revised flow estimates for these four historical floods, using the USGS published gage heights in WSP 1527 converted to water surface elevations, and using the HEC-RAS modeled rating curve shown in Figure 5. The USGS 1923 estimates are 16 to 20 percent higher than the estimates based on the HEC-RAS modeled rating curve for the pre-1952 conditions.

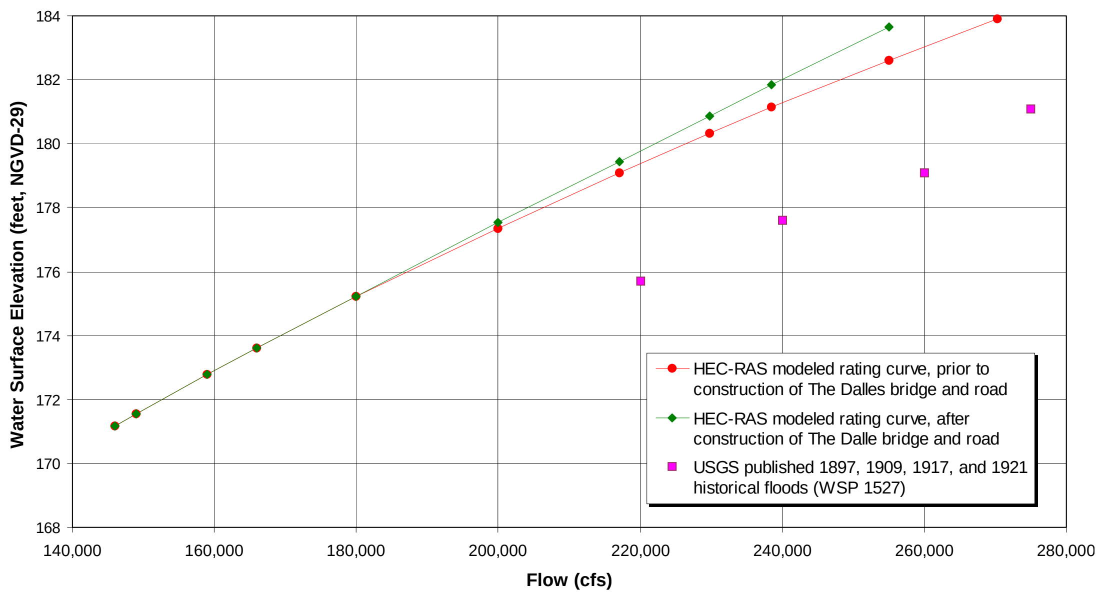

Figure 5 Rating curve of the Skagit River near Concrete (RM 54.19)

Table 4 Peak Discharge Estimates for Historical Floods at Skagit River Staff Gage near Concrete (RM 54.19)

Flood	Water Surface Elevation (ft)	USGS 1923 Estimate (cfs)	HEC-RAS Modeled Rating Curve Estimate (cfs)	Difference	
				(cfs)	(%)
1897	181.1	275,000	238,000	37,000	16
1909	179.1	260,000	217,000	43,000	20
1917	175.7	220,000	184,000	36,000	20
1921	177.6	240,000	202,000	38,000	19

5. Significance of Using Best Science for Flood Peak Calculation

5.1 Use of 1897, 1909, 1917, and 1921 Data in Flood Frequency Analysis

PI Engineering performed a flood frequency sensitivity analysis to evaluate the impact of including and excluding the USGS 1923 estimates for the 1897, 1909, 1917, and 1921 floods in the flood frequency analysis. Results of this analysis using data provided by the Corps in August 2004 (U.S. Army Corps of Engineers 2004) are presented in Table 5. The differences are significant.

Table 5 Flood Frequency at Skagit River Gage Near Concrete – Unregulated Winter Peaks Estimated by the Corps for Water Years 1944-1991, 1994-2002, 2004 (58 Water Years of Recorded Data)

Flood Recurrence Interval (years)	With Four Historical Flood Data (Water Years 1898, 1910, 1918, 1922) USGS 1923 Estimate (cfs)		Without Four Historical Flood Data (cfs)	
	Unregulated*	Regulated*	Unregulated	Regulated
500	437,000	384,312	323,000	260,281
250	373,000	317,550	286,000	220,892
100	299,000	232,778	240,000	181,811
75	278,000	213,586	227,000	171,648
50	251,000	190,687	209,000	157,575
25	209,000	157,032	180,000	134,903
10	160,000	119,600	144,000	106,758
5	127,000	93,410	118,000	86,431

* Source: U.S. Army Corps of Engineers, 2004

The existence and accuracy of the original HWM survey data and flow estimates for the 1897, 1909, 1917, and 1921 floods should be confirmed. Given the significant difference that inclusion or exclusion of these data has on the flood frequency analysis, only the confirmed HWMs and HEC-RAS-modeled rating curve (Figure 5) at RM 54.19 should be used to calculate flood peaks.

6. References

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