Technical Memorandum

Review and Reevaluation of Skagit River 1921 Flood Peak Discharge

Introduction

Pacific International Engineering (PI Engineering) performed a review of Stewart's data and computations at the Dalles slope sections for the 1921 peak discharge estimate and found problematic use of data in his slope-area computations. In addition, PI Engineering found errors associated with the transferring of Stewart's high water mark data to the official gage record of USGS 12194000, Skagit River Near Concrete, WA. A reevaluation of the 1921 flood peak discharge was conducted using our revised data and two different methods, one by the slope-area computations and the other by the stage-discharge rating at the current gage. This Technical Memorandum documents results and conclusions of the review and the reevaluation of the 1921 flood peak discharge.

Background

In 1923, following a field investigation conducted in late 1922 and early 1923, U.S. Geological Survey (USGS) hydrologist James Stewart estimated a peak discharge of 240,000 cfs for the historical flood that occurred on December 13, 1921 (USGS 1961). Stewart applied the slope-area method to estimate the discharge by averaging the results of three slope-area reaches (XS1–XS2, XS2–XS3, and XS1–XS3) using surveyed HWMs and three cross sections (XS1, XS2, and XS3) of the Skagit River below the Dalles near Concrete, Washington (Stewart 1923). The estimated slope-area peak discharge of the 1921 flood was then used by Stewart to extend a stage-discharge rating for determining three other large historical flood peak discharges at the Dalles occurring in 1897, 1909, and 1917 (USGS 1961). Figure 1 shows the location of the slope-area cross sections, the Dalles (or Dalles Gorge), and the USGS gaging station.

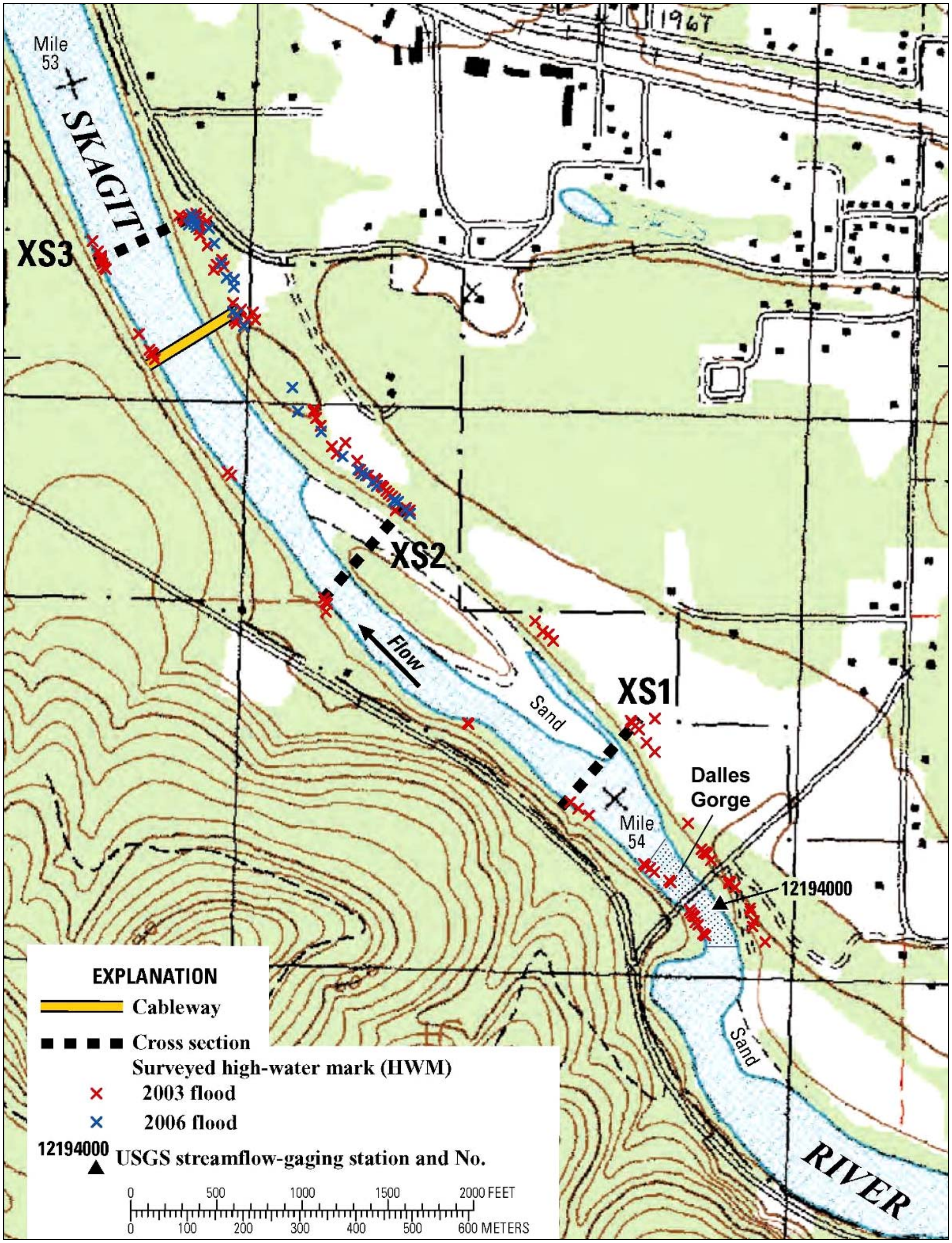

Figure 1. Topographic map of the slope-area measurement reach on the Skagit River near Concrete showing the three cross sections (XS1, XS2, and XS3), the streamflow-gaging station, and HWMs from the 2003 flood and the 2006 flood surveyed by the U.S. Geological Survey (source of data: Scientific Investigation Report 2007-5159, USGS)

The accuracy of the Stewart-estimated peak discharge of the 1921 flood has been widely questioned, thus bringing into question the accuracies of the peak discharges of the other three historical floods as well as the USACE-developed synthetic floods. In 2007, USGS hydrologist Mark Mastin reevaluated the 1921 peak discharge, applying a lower Manning's "n" value and an improved computation approach to Stewart's data at the lower slope-area reach (XS2–XS3), and slightly revised Stewart-estimated historical flood discharges (USGS 2007). The USGS-revised historical flood peak discharges are used, in conjunction with the systematic annual peak discharge record observed since 1924 at the USGS gaging station Skagit River near Concrete (12194000), by the U.S. Army Corps of Engineers (USACE) to determine the discharges of the 10-, 50-, 100-, and 500-year synthetic floods for this station (USACE 2008).

In 2008, PI Engineering used Stewart-surveyed HWMs in the Concrete to Hamilton area (outside the Dalles slope sections) in conjunction with the use of the HEC-RAS model to provide an alternative methodology to estimate the peak discharges of the 1897, 1909, 1917, and 1921 historical floods (PI Engineering 2008). Table 1 lists the peak discharges of the four historical floods estimated or revised by Stewart, USGS, and PI Engineering.

Table 1. Historical flood peak discharges of Skagit River near Concrete

	Peak Discharge (cfs)		
Flood	**1923 Estimated by Stewart**	**2007 Revised by USGS**	**2008 Estimated by PI Engineering**
1897	275,000	265,000	181,200
1909	260,000	245,000	179,000
1917	220,000	210,000	158,700
1921	240,000	228,000	169,700

As shown in this table, the peak discharges originally estimated by Stewart in 1923 and revised by USGS in 2007 are significantly higher than the peak discharges estimated by PI Engineering in 2008. PI Engineering undertook a review of Stewart's and the USGS' slope-area data and computations in an attempt to determine the reasons the slope-area metholology was returning peak flow estimates so much different than the HEC-RAS modeling. Results follow.

Incorrect Gage Datum Used by USGS in Transferring Stewart's HWMs

Subsequent to PI Engineering publishing new estimates of the historical flood peak discharges in 2008 (shown in Table 1), USGS asserted that *"the gage datum of Stewart's historical HWM elevations was likely to be 142.7 ft NGVD-29 and not 140.9 ft,"* (Mastin's November 5, 2008 letter (USGS 2008)). This statement indicates there is a 1.8-ft gage datum discrepancy (142.7 – 140.9 = 1.8 ft).

However, in Stewart's survey notes, Stewart clearly noted his survey benchmark and elevations of HWMs, low-flow water surface, and gage datum based on the use of the Mean Sea Level (MSL) which is approximately the same as the use of NGVD-29 datum, and estimated by National Geodetic Survey (NGS) to be within 0.12 (+/-) feet for the average of height shifts (ranging zero to +0.4 ft) from a sample of 1909/1912 benchmarks to NAVD 88 elevations (see email from Malcolm Leytham, 10/16/2008, including NGS spreadsheet: Height Differences in Skagit Co, WA.xls (Leytham 2008)). Stewart set up an upper Dalles gage during his 1922–23 field survey of the 1921 HWMs. Stewart's survey for elevations of the gage datum and HWMs (as well as low-flow water surface) starts at a USGS benchmark in Concrete (PI Engineering 2008, Section 3.2.6 - Datum of Stewart-surveyed HWMs) (Note: the Concrete benchmark was probably established in 1898. We don't know the height difference of MSL between 1898 and 1909, but assume the difference is small). Stewart's surveyed upper Dalles gage datum is 140.89 as noted in his survey notes (Stewart's survey notes, pp. 86-87), not 142.7, which is a rounded elevation of an old Skagit County gage datum of 142.69 (=130+12.69, see USGS 1961, p. 50, "Gage" paragraph for gage datum)[1].

During the 1924–37 period, Skagit County operated a gage at the Dalles with the gage datum of 142.69, or 1.8 ft higher than Stewart's upper Dalles gage datum of 140.89. (See footnote 1 and USGS 1961, P 50, "Gage" paragraph).

The USGS-published Water Supply Paper 612 (USGS 1925, p. 62) describes that: "*Gage – Since December 10, 1924, Stevens continuous recorder in concrete shelter, on right bank at the Dalles. Gage used prior to December 10, 1924, was vertical and inclined staff on right bank about 200 feet above present gage. Both gage readings refer to same datum, 163 feet above sea level*." The referenced vertical and inclined staff gage was Stewart's upper Dalles gage (Stewart's survey notes, pp. 86-87). The referenced gage datum 163 feet above sea level is incorrect for both Stewart's and the County's gages (USGS 2008, p. 2). We believe the above statement that "*Both gage readings refer to same datum*" is incorrect. (Note: notwithstanding the incorrect reference to a gage datum of 163 feet, the USGS has not been able to provide direct evidence relating to the gage-datum conversion to support the statement that "Both gage readings refer to same datum." The USGS does, however, point to indirect evidence to support a hypothesis that Stewart's Upper Dalles gage datum was wrong, and subsequently corrected when the new gage datum was established (See Mastin's November 5, 2008 letter, USGS 2008 and attachments)).

In 1937, the current gage was established by USGS (see USGS 1936 letter for an agreement of cooperation between USGS and Skagit County, and USGS 1961,

---

[1] For the County's gage installation, see the October 21, 1936 letter from G.L. Parker, District Engineer, USGS, to Hugo Baumen, Chairman, Skagit County Commissioners (USGS 1936). The letter states that "*You will recall that Mr. Knapp explained to you that records at the Skagit River gaging station near Concrete were essential in preparing any sort of plan for flood prevention and control.* **He built the gaging station from Skagit County funds in the fall of 1924** *as a consequence of studies made of flood damage and plans for protection undertaken after the disastrous flood of 1921*. --- *For a number of years the gaging station was financed entirely from Skagit County funds because the Federal appropriation did not provide for corporation*." Mr. Knapp was the County Engineer, in accordance with the September 6th 1923 letter from Mr. Knapp, County Engineer, to Mr. D.J.F. Calkins, Acting District Engineer, USGS.

p. 25, for gage history). The USGS has since published all pre-1937 HWM elevation data based on the County's gage datum of 142.69, as the USGS was not aware of Stewart's original gage datum of 140.89 until 2008 (see Mastin's November 5, 2008 letter, 2nd paragraph, USGS 2008). The USGS-published HWM elevations based on the county gage datum, including Stewart's historical HWM elevations, are therefore 1.8 ft higher than Stewart's surveyed historical HWM elevations based on Stewart's gage datum.

<u>Low-flow Water Surface Elevations Surveyed by Stewart and Others</u>

In an effort to provide additional information for use in objectively analyzing this 1.8-ft gage datum discrepancy, PI Engineering reviewed all low-flow water surface elevations in Concrete and the Dalles, which are available from Stewart's survey notes and are also available from other sources for the same locations and flow conditions.

It is not expected that Stewart's surveyed low-flow water surface elevation would be exactly the same as others' survey for the same location and flow conditions. Factors that could affect low-flow water surface elevations surveyed by different parties include change in channel bottom geometry due to sediment degradation/aggradation, temporary debris deposition, slight flow variation, and survey accuracy. These factors may significantly affect low-flow water surface elevations. However, we would still expect that the majority of Stewart's surveyed elevations would be close to 1.8 feet lower than others' surveyed elevations if the USGS-asserted gage datum is accurate.

Table 2 lists the low-flow water surface elevations surveyed by Stewart in comparison with those surveyed by USACE (in 1911), Skagit County (in 2008), and PI Engineering (in 2004), for approximately the same survey locations and similar low-flow conditions. Two sets of Stewart's surveyed elevations, one based on his original survey gage datum of 140.89 and the other based on the USGS-asserted 1.8-ft higher datum (142.69), are listed in the table for comparison. All elevations shown in the table are based on the same elevation datum (either MSL or NGVD-29). Figure 2 is a USACE 1911 river survey map of the area on which the survey points, elevations, and notes by various parties shown in Table 2 are annotated.

If the gage datum of Stewart's surveyed elevations were to be 142.7 (rounded from 142.69) or 1.8-ft higher than Stewart's noted 140.89 datum, all of Stewart's elevations (including not only HWM elevations but also low-flow water surface elevations based on Stewart's gage datum 140.89) would have had a difference of approximately 1.8 ft from other parties' surveyed elevations. More specifically, if Stewart's datum were wrong, the low-flow water elevations from his field notes would all be approximately 1.8-ft lower than other data.

Table 2. Comparison of low-flow water surface elevations surveyed by Stewart and others using NGVD-29 datum

Location	Stewart 1922–23 Survey: Based on 140.89 Datum	Stewart 1922–23 Survey: Based on 142.69 Datum	USACE 1911 Survey*	Recent Survey	Difference Between Stewart and Other Surveys (ft): Based on 140.89 Datum	Difference Between Stewart and Other Surveys (ft): Based on 142.69 Datum
Near old Concrete Ferry Site	**151.92** (01/27/23 – Stewart notes, p. 84, flow 9,740 cfs at Sedro-Woolley)	**153.72** (01/27/23 – Stewart notes, p. 84, flow 9,740 cfs at Sedro-Woolley)	**151.1** (8,570–9,980 cfs at Sedro-Woolley)	**152.1** (Skagit County 04/28/08 – 9,420 cfs at Mt. Vernon and 7,680 cfs at Concrete, surveyed 152.32/150.84 at LB Pt. # 1365/1366)	**0.82 and –0.18**	**2.62 and 1.62**
Upper Dalles Gage	**144.58** (01/27/23 – Stewart's Notes, p. 86, flow 9,740 cfs at Sedro-Woolley)	**146.38** (01/27/23 – Stewart's Notes, p. 86, flow 9,740 cfs at Sedro-Woolley)	**144.5** (8,570–9,980 cfs at Sedro-Woolley)		**0.08**	**1.88**
	147.55 (12/23/22 – Stewart's Notes, p. 34, 6.66+140.89, flow 14,200 cfs at Sedro-Woolley)	**149.35** (12/23/22 – Stewart's Notes, p. 34, 6.66+140.89, flow 14,200 cfs at Sedro-Woolley)		**147.4** (PIE 9/30/04 – flow 13,300 cfs at Mt. Vernon and 12,500 cfs at Concrete)	**0.15**	**1.95**
Lower Dalles Gage	**144.95** (01/25/23 – Stewart's notes, p. 54, 3.91+141.04, flow 10,100 cfs at Sedro-Woolley)	**146.75** (01/25/23 – Stewart's notes, p. 54, 3.91+141.04, flow 10,100 cfs at Sedro-Woolley)	**144.3** (8,570–9,980 cfs at Sedro-Woolley)		**0.65**	**2.45**
Upper Slope Section	**144.12** (01/30/23 – Stewart's notes, p. 64, flow 7,660 cfs at Sedro-Woolley)	**145.92** (01/30/23 – Stewart's notes, p. 64, flow 7,660 cfs at Sedro-Woolley)	**143.7** (8,570–9,980 cfs at Sedro-Woolley)		**0.42**	**2.22**
Lower Slope Section	**142.35** (01/30/23 – Stewart's notes, p. 64, flow 7,660 cfs at Sedro-Woolley)	**144.15** (01/30/23 – Stewart's notes, p. 64, flow 7,660 cfs at Sedro-Woolley)	**142.1** (8,570–9,980 cfs at Sedro-Woolley)		**0.25**	**2.05**
				Range of Difference =	**–0.18 to 0.82**	**1.62 to 2.62**

* Elevations based on extreme low water of Puget Sound were adjusted by –8.93 ft to NGVD-29 (see USGS 1961, p. 52, "Gage" description). The Skagit River survey was conducted between August 24 and September 19, 1911 by USACE from Baker River to Sedro-Woolley (see the title and notes of the original USACE surveyed map on lower right corner of Figure 4). We assume the survey in Concrete area was conducted in August 1911 for conservatism, as the Sedro-Woolley gage data indicate that the Skagit River flows in August 1911 were lower than those in September 1911.

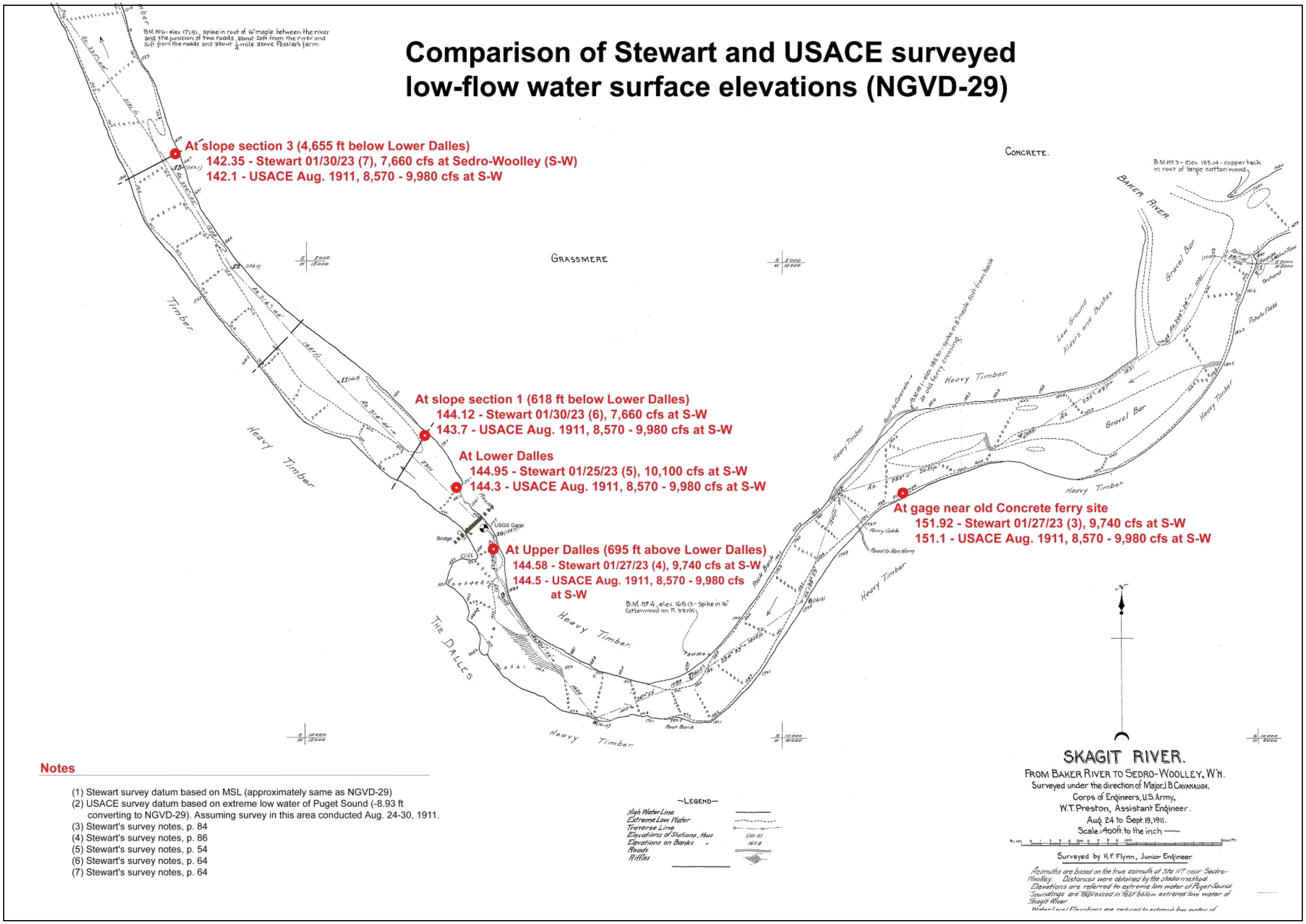

Figure 2. Comparison of Stewart and USACE surveyed low-flow water surface elevations (NGVD-29)

As shown in Table 2, Stewart's surveyed low-flow water elevations (based on his gage datum of 140.89) are between 0.18 feet lower and 0.82 feet higher than those surveyed by other parties.[2] Stewart's data are mostly higher, not lower. None of Stewart's surveyed elevations are near the 1.8-ft difference they should have been, if the USGS-asserted datum were correct. And as shown in Table 2, if using the USGS-asserted 1.8-ft higher gage datum of 142.69, Stewart's surveyed low-flow water surface elevations are between 1.62 and 2.62 feet higher than those surveyed by other parties, which is not reasonable.

<u>Converting Stewart's 1921 HWMs to Others' Survey Datum</u>

Assuming Stewart's gage datum is incorrect, an alternative approach to estimating the 1921 flood peak discharge is not to use directly Stewart-surveyed HWM elevations that are based on his survey datum, but to use his HWM data after converting to others' survey datum (based on NGVD-29). The procedure for converting Stewart's HWMs to others' survey datum is described below.

At several locations as documented in his 1922-23 survey notes, Stewart surveyed the elevations (or gage heights) based on his gage datum for both 1921 HWM and low-flow water surface on his noted field date. At each of these survey locations, a relative gage height of Stewart's surveyed 1921 HWM can be calculated in relation to his surveyed low-flow water surface level. The calculated relative gage height equals the surveyed HWM elevation subtracting the surveyed low-flow water surface elevation. This relative gage height is no longer associated with Stewart's gage datum (or the benchmark used by Stewart). This relative gage height is also not affected by any carried-over errors potentially accumulated during his survey. A converted 1921 HWM elevation can then be obtained by adding this relative gage height to others' surveyed low-flow water surface elevation, so long as both Stewart's and others' survey locations and low-flow conditions are approximately similar. The converted 1921 HWM would be slightly affected by the low-flow water level difference between Stewart's and others' surveys.

[2] General Notes for Table 2: the stream flow at the Dalles is approximately 90% of the stream flow at Sedro-Woolley based on the ratio of the drainage area; and the flow-stage rating at the Dalles is approximately 2,000 cfs (+/-) per one-foot stage increase during low flows. It is also noted that Stewart's surveyed low-flow water surface elevations at slope sections are higher than the USACE surveyed elevations even though the stream flow was lower during Stewart's survey. This adds evidence that the datum used by Stewart is rather on a high side than on a low side.

Table 3 shows the conversion of four Stewart-surveyed 1921 HWMs, one at the old Concrete ferry site located approximately one mile upstream of the upper Dalles, two at Stewart's upper Dalles gage site, and one at Stewart's lower Dalles gage site (see Figure 4 for these locations and Stewart's surveyed HWM elevations based on his gage datum). The low-flow water surface elevations surveyed by Stewart based on his gage datum, and by others based on NGVD-29 at these sites, are listed in Table 2. A comparison between Stewart's HWM elevations based on his gage datum and the converted HWM elevations based on others' survey datum is also provided in the table. This comparison indicates that the differences between Stewart's surveyed HWM based on his gage datum and the converted HWM based on others' survey datum are not significant, within a range between –0.18 and +0.65 ft, which is within the data accuracy. This indicates that Stewart's gage datum and his surveyed HWM elevations are consistent with those based on the use of the NGVD-29 datum.

We have used these four Stewart's surveyed HWMs to estimate the 1921 flood peak discharge by two different methods. These two methods are one using the HEC-RAS modeling and Stewart's HWM at the Concrete ferry site (see PI Engineering 2008, Section 3.2.5), and the other using the stage-discharge rating at the current gage and Stewart's HWMs at the upper and lower Dalles gages (see discussion provided later in this Technical Memorandum). Alternatively, the four converted HWMs shown in Table 3 could be used to replace Stewart's original elevation data to estimate the 1921 flood peak discharge. We would not expect any significant difference of the estimates between uses of Stewart's data and the converted data, since the data difference as shown in Table 3 is not significant.

<u>Summary of Gage Datum Issue</u>

A careful reading of Stewart's field notes of 1922-23 leads us to conclude Stewart was not confused about his established gage datum. This present-day comparison demonstrates that Stewart's gage datum and HWM elevations are consistent with those based on the use of the NGVD-29 datum. Therefore, we believe the USGS-published historical HWM elevations based on the use of the County's gage datum, instead of Stewart's gage datum, are incorrect and should be lowered by 1.8 ft. (See PI Engineering 2008, p. 23, Table 2, for USGS-published and Stewart-surveyed historical flood gage heights.)

As a result of this 1.8-ft gage datum downward correction, both the Stewart-estimated and the USGS-revised 1921 flood peak discharges (see Table 1) would also need to be revised downward based on the stage-discharge rating at the current gage. (It is noted here that Stewart did not have any of the 1897, 1909, and 1917 flood HWMs observed or surveyed in the Dalles. See PI Engineering 2008, p. 24.) More discussion on the reevaluation of the 1921 flood peak discharge using the stage-discharge rating is provided later in this Technical Memorandum.

Table 3. Comparison of 1921 HWMs independent of datum difference

Location	Stewart 1922–23 Surveyed Elevation (ft) Based on 140.89 Gage Datum at Upper Dalles		Relative Gage Height (ft) 1921 HWM Above Low-Flow Water Level	Similar Low-Flow Water Level (NGVD-29) Surveyed by Other**	Converted 1921 HWM Elevation (NGVD-29) Not Associated w/ Stewart's Gage Datum	Difference between Stewart's and Converted 1921 HWM Elevations (ft)
	1921 HWM*	Low-Flow Water Level**				
Near old Concrete Ferry Site	182.58[a]	151.92	30.66	152.1 (Skagit County, 2008)	182.76	–0.18
Upper Dalles Gage	175.75[b]	144.58	31.17	144.5 (USACE, 1911)	175.67	0.08
	175.18[c]	147.55	27.63	147.4 (PIE, 2004)	175.03	0.15
Lower Dalles Gage	171.04[d]	144.95	26.09	144.3 (USACE, 1911)	170.39	0.65
					Range of Difference =	**–0.18 to 0.65**

* See Figure 5 for Stewart's HWM elevations

** See Table 2 for Stewart's and others' low-flow water surface elevations

Notes: a. 182.58 = 32.0 (gage height) + 150.58 (gage datum), Stewart's survey notes, p. 85

b. 175.75 = 34.86 (gage height) + 140.89 (gage datum), Stewart's survey notes, p. 87

c. 175.18 = 34.29 (gage height) + 140.89 (gage datum), Stewart's survey notes, p. 87

d. 171.04 = 30.0 (gage height) + 141.04 (gage datum), Stewart's survey notes, pp. 54-55 & p. 67

Stewart's Slope-Area Computations

The data used and the 1921 flood computations performed by Stewart for the slope sections below the Dalles are provided in Exhibit B of Stewart's unpublished report (Stewart 1923). Table 4 summarizes the slope-section hydraulic parameters used in Stewart's computations and the 1921 flood peak discharges computed by Stewart.

Table 4. Slope-section hydraulic parameters and 1921 flood peak discharges computed by Stewart

Slope-Area Reach	Mean Flow Area (sq. ft)	Mean Hydraulic Radius (ft)	Water Surface Fall (ft)	Reach Length (ft)	Slope of Hydraulic Grade Line	Manning's "n" Value	Computed 1921 Peak Discharge (cfs)
XS1-XS2	18,500	26.1	2.11	1,860	0.00113	0.033	244,000
XS2-XS3	18,000	24.2	2.62	2,190	0.00120	0.033	234,000
XS1-XS3	18,200	25.1	4.73	4,050	0.00117	0.033	240,000

Note: Flow area = 18,000, 19,000, and 16,900 for XS1, XS2, and XS3, respectively

A discussion of Stewart's slope-area computations is provided below.

<u>Incomplete Energy Equation used in Stewart's Computations</u>

Stewart assumed a uniform flow (Chow 1959, Chapter 5) (meaning flow velocity remains constant from section to section). Stewart therefore used the incomplete energy equation which ignores variation of velocity head between slope sections when applying the slope-area method. The flow in the slope-area reaches is a gradually varied flow (Chow 1959, Chapter 9), not a uniform flow. The full energy equation that includes the velocity head variation should be used in this case when applying the slope-area method.

The uniform flow assumption made by Stewart was probably necessary and likely due to limited application of the slope-area computation method to only situations involving uniform flow in Stewart's time. Stewart, in a memorandum enclosed in his June 1, 1950 letter to USGS stated that, "*In choosing a slope section, the most important feature is the selection of one where the stream is neither gaining or losing velocity; i.e., selecting a section where the average velocity at the upper end of it (and throughout) is the same as for the lower end. If this is not done, there is a gain or loss in velocity head which cannot be taken care of in the regular formula. In practice, the ideal cannot be attained, but it should be approached as closely as possible.*" After Stewart's time, the slope-area computation method was improved and expanded to enable application to situations involving gradually varied flow (Chow 1959, pp. 147–148).

<u>Incorrect Flow Area used for Lower Slope Section (XS3)</u>

Stewart surveyed the lower slope section (XS3) on January 29, 1923 (see Stewart's survey notes, p. 78) (Stewart 1922–23). On January 31, 1923, while surveying the upper slope section (XS1), Stewart checked the graduations on rope he used for the survey and noted this: *"Checked graduations on rope as follows. Markers 80 to 160, 84 1/2 on steel tape = 80 on rope 0 - 320 portion of rope. Taped dry and before stretching, 41.2 on steel tape = 40 on rope. This will apply from graduation 320 on. Checks on rope graduation were made while rope was still stretched across river. It is not certain that these checks are applicable to the lower cross section also but probably will have to be assumed so"* (see Stewart survey notes, p. 69). This meant that Stewart assumed his survey rope was also stretched by approximately 5% when he was surveying the lower slope section (XS3) and went ahead to modify his originally surveyed lower slope section without an actual verification of his assumption. (For Stewart's originally surveyed and modified data, see Stewart's survey notes, p. 78.)

Figure 3 shows plots of Stewart's originally surveyed and later-modified lower slope section. In 2004, Mastin and his field crew surveyed this section. The 2004-surveyed lower slope section is also shown in the figure for a comparison. This comparison indicates that Stewart's originally surveyed section appears accurate, matching the channel width and bottom elevations with the 2004-surveyed section better than his modified section. This comparison assumes that the 1923 and 2004 surveys are approximately at the same location, and that the change in cross section from 1923 to 2004 at this location is not significant.

<u>Unsupported Hydraulic Grade Line Slope Used for Upper Slope-Section Reach (XS1–XS2)</u>

Stewart used 2.11 ft for the 1921 water surface fall between the upper and middle slope sections (XS1–XS2). This fall is not supported by the surveyed HWMs. The 1921 HWMs in the upper slope-area reach between XS1 and XS2 were surveyed by Skagit County staff on March 7–8, 1923, after Stewart left the area, and are documented on unpaged loose note sheets as a part of Stewart's survey notes. Since Stewart's 1922–23 study was performed for Skagit County in accordance with an agreement between the County and the USGS (see Stewart's 1923 unpublished report, p. 1 (Stewart 1923)), these HWMs were probably field-marked by Stewart and then surveyed by the County under Stewart's direction. Table 5 lists the County's surveyed 1921 HWMs from the "Summary of H.W. Marks" on the last loose note sheet provided by USGS, as well as the HWMs surveyed under Stewart's direct control. The survey reference station (0+00) and elevation (lower Dalles gage datum El. 141.04, Stewart's survey notes, p. 67) are based on the location and gage datum of the lower Dalles gage set up by Stewart. The converted HWM elevations above NGVD-29 and above the current gage datum El. 130 are also listed in the table.

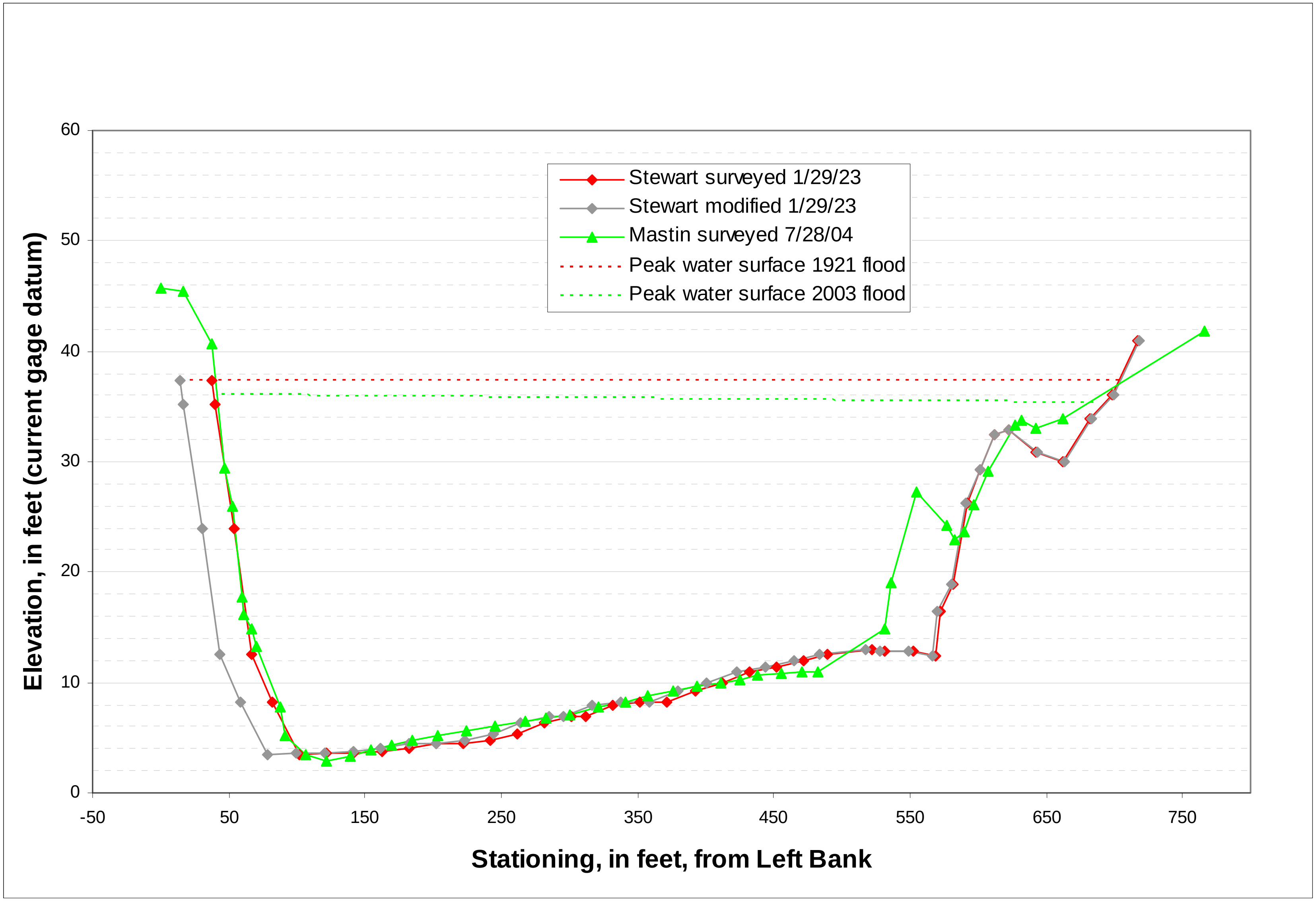

Figure 3. Slope Section XS3 – Skagit River near Concrete, WA

Table 5. Summary of 1921 H.W. Marks (surveyed 3/7– 8/1923 by Skagit County staff under Stewart's direction, unless noted otherwise)

Station (ft)	HWM (ft)	Elevation (NGVD-29)	Above Current Gage* Datum (ft)
0+00	30.00**	171.04	41.04
5+25	29.68	170.72	40.72
8+65	29.06***	170.10	40.10
9+85	30.37	171.41	41.41
15+25	28.62	169.66	39.66
20+90	28.40	169.44	39.44
24+70	28.97	170.01	40.01

Notes:

* Current gage datum El. 130.00 above NGVD-29

** Also surveyed by Stewart 1/25–30/1923 (see Stewart's survey notes, pp. 54–55)

*** Only surveyed by Stewart 1/25–30/1923 (see Stewart's survey notes, p. 64, "170.10 1921 HW" at 865' below lower Dalles gage)

The slope sections XS1 and XS2 are located at 6+18 and 24+79, respectively (Stewart 1923, Exhibit B, p. 2). The corresponding 1921 HWMs at XS1 and XS2 are thus estimated to be approximately 40.86 (interpolating between County survey points 5+65 and 9+85, and ignoring Stewart's survey point 8+65 for conservatism) and 40.01, respectively, above the current gage datum elevation of 130.00. The 1921 water surface fall between XS1 and XS2 is therefore 0.85 ft, not 2.11 ft used by Stewart. The corresponding slope of our estimated hydraulic grade line between XS1 and XS2 is therefore 0.000457 (= 0.85/1860), not 0.00113 used by Stewart (see Table 3).

As the flow is expanding from XS1 to XS2 and contracting from XS2 to XS3, the slope of hydraulic grade line should be flatter between XS1 and XS2 than between XS2 and XS3. Stewart's calculation used a water surface fall value corresponding to a hydraulic grade line slope of 0.00113 between XS1 and XS2, which is not reasonable since this is very similar to the slope of 0.00120 between XS2 and XS3 (Table 3).

Figure 4 shows elevation plots of Stewart-surveyed 1921 HWMs and USGS-surveyed 2003 HWMs (surveyed in summer 2004 and provided in the spreadsheet Concrete_03_SAM.xls) in the Dalles and slope-area reaches. As shown in the figure, the 2003 flood HWMs also support the flatter hydraulic grade line slope between XS1 and XS2. Using the USGS-estimated average peak elevations 38.45 and 37.50 provided in the spreadsheet and listed in Figure 4, we estimate the hydraulic grade line slope between XS1 and XS2 for the 2003 flood to be 0.000511 (= (38.45 – 37.50) / 1860), which is very similar to our above-estimated slope of 0.000457 for the 1921 flood. The hydraulic grade lines used by Stewart for the upper and lower slope-section reaches (XS1–XS2 and XS2-XS3) are plotted on Figure 4, as well as those estimated by PI Engineering for the upper slope-section reach (XS1–XS2). Our comparison assumes no revision to Stewart-used lower reach hydraulic grade line. Figure 5 shows the location and elevations of Stewart's surveyed 1921 HWMs in the Dalles and Concrete area.

Unknown Quality of High Water Marks; Surge Effects

Stewart's HWMs in the slope-area reaches are based on natural indicators such as sand deposited in moss on trees, moss scoured from trees, mud marks, and drift along bank lines. Stewart did not attempt to characterize the quality of his observed HWMs (as a general practice today, each observed HWM should be assigned to one of these four categories: poor, fair, good, or excellent—P, F, G, or E—based on the condition, type, and accuracy of the HWM). Therefore, there is no way to know the quality of Stewart's HWMs in the slope-area reaches. And we would not be able to characterize the accuracy of the 1921 peak discharge estimate if we were to rely only on these HWMs.

Regarding surge effects on the slope-section HWMs, Stewart, in his memorandum enclosed in his June 1, 1950 letter to USGS stated that, *"Another feature of some importance, although how much is uncertain, is the amount of surging in the stream at the ends of the sections during the crest of the flood. Manifestly the only elevations available, when the flood crest is based on high water marks, is the crest of the surges, whereas what is needed is the mean level of the water at the time of the flood crest. Information as to this feature can be obtained by determining the amount of surging at the cross-sections for a lower flood, and then by means of the relation of the surging at the water stage records for both floods, determine the surging for the higher flood at the cross-sections."* These statements indicate that, first, Stewart's surveyed 1921 HWMs at the slope sections were the crest of the surges and that, second, Stewart suggested these HWMs be adjusted for the amount of surging observed during other flood events at these slope sections so that the mean water level at the time of the 1921 flood crest could be determined for use to more accurately estimate the peak discharge of the 1921 flood.

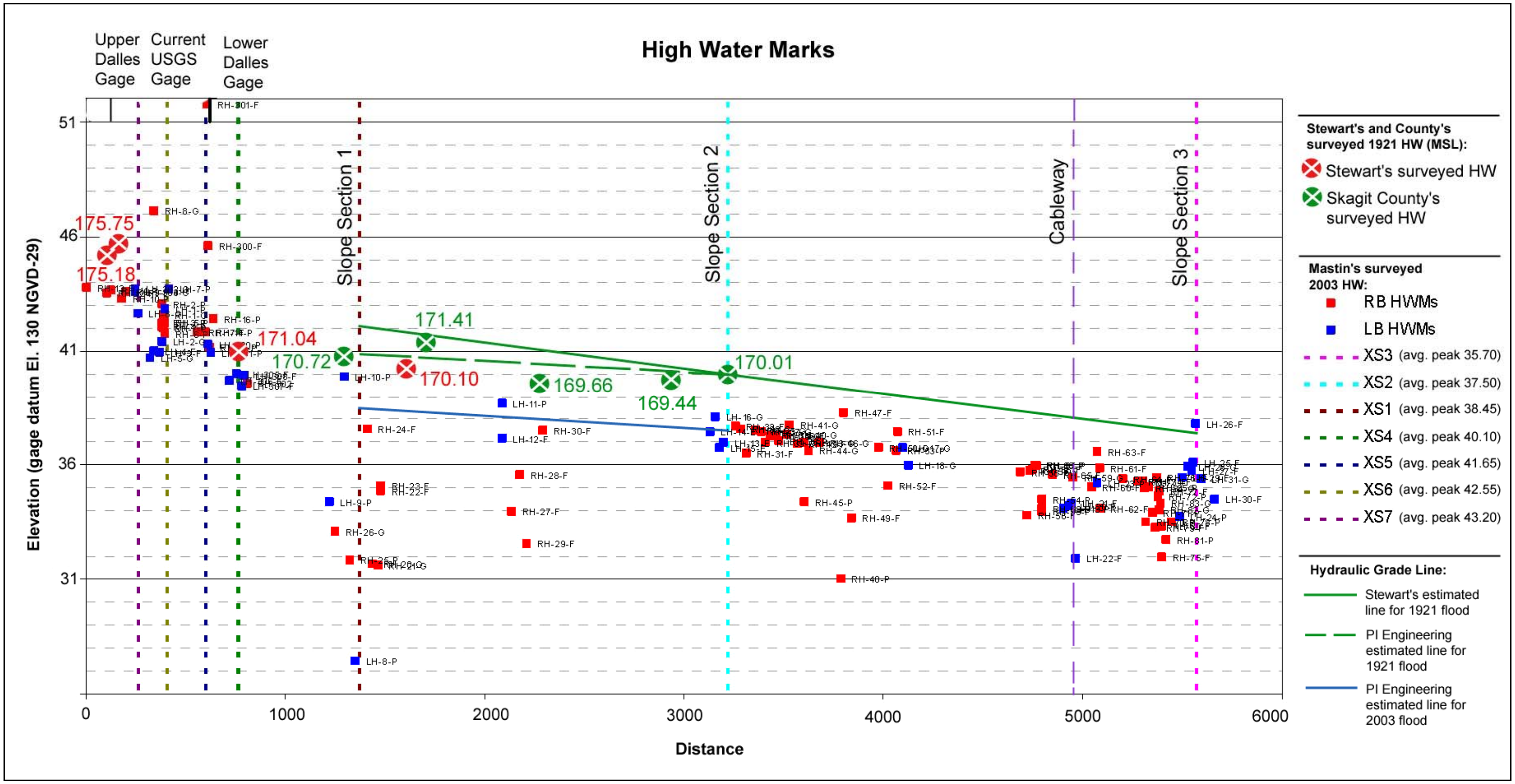

Figure 4. 1921 and 2003 flood high water marks surveyed by Stewart (in 1922–23) and USGS (in summer 2004)

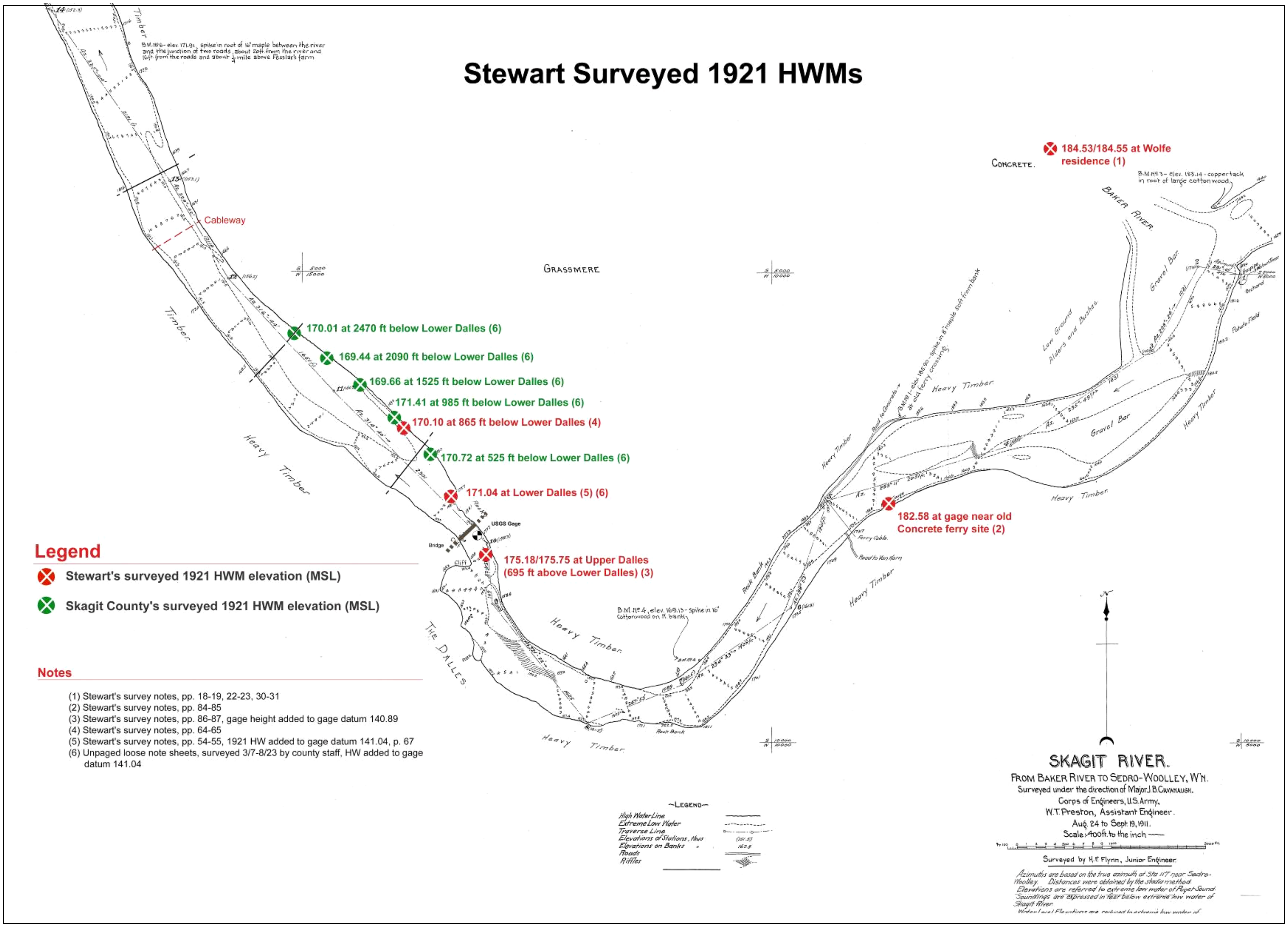

Figure 5. Stewart Surveyed 1921 HWMs

Following Stewart's suggestion, we reviewed USGS-surveyed 2003 HWMs at the slope sections to see what the data might indicate regarding the amount of surging for the 2003 flood (flood of record for this gage station). USGS-surveyed HWMs were provided to us in a spreadsheet (Concrete_03_SAM.xls) that contains all surveyed 2003 HWMs as plotted in Figure 4. This spreadsheet also provided the USGS-estimated average peak water levels of the 2003 flood at all cross sections (total seven sections) as listed in Figure 4. The 2003 flood is the largest flood recorded at the current gage, and has the most extensive HWMs surveyed by USGS in the Dalles as provided in the spreadsheet and plotted in Figure 4. Our approach to estimating surge effects was to assume the USGS-estimated average peak water levels corresponded to the mean water levels of the 2003 flood crest, and the USGS-surveyed highest HWMs corresponded to the crests of surges. The USGS-published peak discharge of the 2003 flood at the current Concrete gage is 166,000 cfs, which is very close to the 1921 peak discharge of 169,700 cfs estimated by PI Engineering (see Table 1).

Table 6 lists this information. A weakness of this approach is that there is only one HWM for the upper slope section (XS1) that is higher than the USGS-estimated average peak water levels. Although it gives an indication of the magnitude of the surge effects that Stewart recognized should be accounted for, it is inconclusive, as surge effects may be very different for the 1921 flood, for which we have no information to draw an estimate.

Table 6. Indication of surging for 2003 flood at slope sections

Slope-section	Highest HWM (ft)*	Average Peak Water Level (ft)*	Indication of Surging (ft)
XS1	39.87	38.45	1.4
XS2	38.08	37.50	0.6
XS3	37.79	35.70	2.1

* Source of data: USGS-provided spreadsheet – Concrete_03_SAM.xls

We also note here that the estimated average peak level at the current gage site is 42.55 (see Figure 4, XS6 avg. peak 42.55), which is 0.34 ft higher than the USGS published peak stage of 42.21, the true mean water level of the flood crest. This indicates that using surveyed HWMs to draw a peak water surface generally results in a flood level with a bias to be above the true mean water level of the flood crest.

Wind and wave actions can cause the debris lines to be higher than the actual water surface. Floating debris can cause large surges. (As an example, a 7-ft surge of water was reported during the December 2007 flood in the Chehalis River, resulting from forming and bursting of large woody debris jams.) The Skagit River is known to carry heavy floating debris during large flood events (As an example, Stewart's survey notes, p. 23, state *"Leonard Everett says 1897 flood about 9" lower than 1909. He says that log jam in Dalles raised water 10 ft in 2 hrs."*). High water marks in (or near) the overbank area are often higher than in the channel. The overbank water is moving slower and may be closer to the energy grade line, which is higher than the water surface elevation by an amount of the velocity head. The 2003 flood peak velocities in the slope section reaches are high, approximately in the 10 to 12 ft/sec range (cross section average, and equivalent to a velocity head range of 1.6 to 2.3 ft). All of these factors could contribute to the amounts of surging indicated in Table 6. We note the 2003 USGS-surveyed high water marks near XS5, XS6, and XS7 indicate such an effect.

It is not possible to determine the exact amounts of surging for the 1921 flood at the slope sections since we do not have a sufficient number of 1921 HWMs similar to those collected for the 2003 flood. But we can reasonably assume, based on the HWM information from the 2003 flood and likelihood of periodic debris blockages and other factors at flood flows in the range of the 2003 flood event, that the approximate amounts of surging on the reach-average basis for the 1921 flood at the slope sections are likely between 1.0 and 1.5 ft. For conservatism, we have used 0.5 feet of surge in our conclusions.

Reevaluation of 1921 Flood Peak Discharge Using Slope-Area Method

A thorough reading of Stewart's field notes and written reports and correspondence regarding the Skagit basin, including his 1917 report, illustrates to us that Stewart's work was competent, conscientious, and exceptional for the time. But it must be remembered Stewart did not have access to the significantly improved hydraulic analytical techniques we now use routinely, nor did he have the benefit of an 85-year gage history for the Skagit River at the Dalles. PI Engineering performed a reevaluation of the 1921 flood using the slope-area method, and incorporating corrections as described above. The reevaluation uses: (1) the complete energy equation for the slope-area method applicable to the gradually varied flow observed in the slope-area reaches; (2) the revised flow area based on Stewart's originally surveyed lower slope section (XS3); (3) the revised hydraulic grade line slope of the upper slope-section reach supported by Stewart-surveyed HWMs at the upper slope section (XS1); and (4) all associated computational revisions. The reevaluation also includes the use of five various adjustments for surge between 0.0 and 2.0 ft, as well as the use of Manning's "n" value of 0.0033 originally used by Stewart and a lower "n" value of 0.0315 suggested in the USGS-revised estimate. The slope-area reevaluation was conducted following the procedure of computation (involving six computation steps) outlined in Chow's Open-Channel Hydraulics, pp. 147–148 (Chow 1959).

Table 7 presents a summary of the reevaluation results. Stewart's original estimates for all three slope-area reaches and the USGS-revised estimate for the lower slope-area reach are also shown in the table for comparison. Figure 6 shows the plots of the estimated 1921 flood peak versus surge adjustment with Manning's "n" values of 0.0315 and 0.033.

Table 7. Summary of 1921 flood peak estimates using slope-area method and Stewart-surveyed data

	Surge Adjustment (ft)	Manning's "n" value	Reach XS1–XS2	Reach XS2–XS3	Reach XS1–XS3	Average
	0.0	0.0330	163,600	198,000	185,800	182,467
	-0.5	0.0330	158,300	192,100	180,100	176,833
	-1.0	0.0330	153,200	186,300	174,500	171,333
	-1.5	0.0330	148,100	180,500	169,000	165,867
	-2.0	0.0330	143,300	174,800	163,600	160,567
	0.0	0.0315	172,000	205,000	193,500	190,167
	-0.5	0.0315	166,400	199,000	187,600	184,333
	-1.0	0.0315	161,000	193,000	181,800	178,600
	-1.5	0.0315	155,500	186,900	176,100	172,833
	-2.0	0.0315	150,500	181,100	170,400	167,333
Stewart's original estimates (1923)	0.0	0.0330	244,000	234,000	240,000	**240,000**
USGS revised estimate (2007)	0.0	0.0315	N/A	228,000	N/A	**228,000**

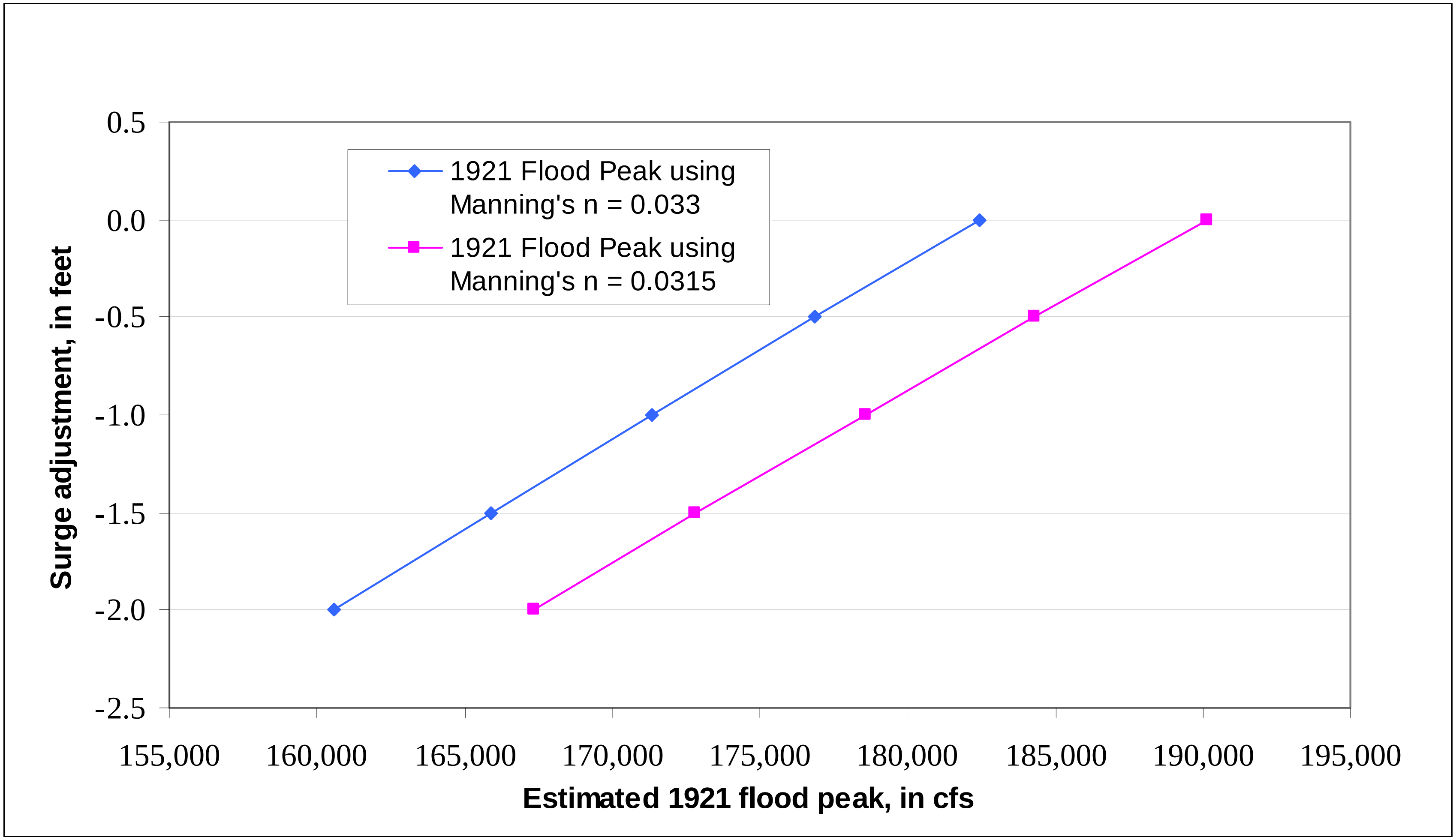

Figure 6. Estimated 1921 flood peak vs. surge adjustment using slope-area method

As shown in Table 7, results of the reevaluation of the 1921 flood peak discharge using the slope-area method are summarized below.

- All of the ten 1921 flood peak discharge estimates using Stewart's surveyed HWMs with five varying surge adjustments between 0.0 and 2.0 ft, and two varying Manning's "n" values between 0.0315 and 0.033, are substantially lower than both Stewart's original estimates in 1923 and the USGS-revised estimate in 2007.
- For each of the five varying surge adjustments, varying Manning's "n" values between 0.0315 and 0.033 would not result in a significant difference in the 1921 flood peak estimates. All of the differences due to these two "n" values are approximately 4%, which is within the expected accuracy of this reevaluation.
- The 1921 flood peak discharge would be between 172,000 and 205,000 cfs, averaging 190,167 cfs, if using Stewart's surveyed HWMs with a zero surge adjustment (which is too conservative) and using Manning's "n" value of 0.0315.
- The 1921 flood peak discharge would be between 143,300 and 174,800 cfs, averaging 160,567 cfs, if using Stewart's surveyed HWMs with a 2.0-ft surge adjustment (which is too aggressive) and using Manning's "n" value of 0.033.
- The average 1921 flood peak discharge would be 176,833 and 184,333 cfs if using Stewart's surveyed HWMs with a surge adjustment of 0.5 ft (which is conservative) and using Manning's "n" value of 0.033 and 0.0315, respectively.

Reevaluation of 1921 Flood Peak Discharge Using Stage-discharge Rating

The stage-discharge rating at the current gage has been stable over the last 80 years. The USGS states that "The channel geometry does not substantially change at the highest stages, which indicates that a straight-line extension of the rating beyond the highest current-meter measurement is a reasonable method to estimate high flows" (see USGS 2007, p. 10). The highest two discharges based on the USGS-published streamflow measurements are 135,000 cfs on 2/27/1932 and 138,000 cfs on 10/21/2003, with a gage height of 38.68 above the current gage datum 130.00 for both discharges (data available at http://waterdata.usgs.gov/wa/nwis/measurements/?site_no=12194000&agency_cd=USGS). Using Stewart-surveyed HWMs at the Dalles and the extended stage-discharge rating provides another method to estimate the 1921 flood peak discharge.

Transferring of Stewart's HWMs to Current Gage Site

Three Stewart-surveyed 1921 HWMs (expressed in MSL) are shown in Figure 7 (an enlarged plot of Figure 4 showing only HWMs in the Dalles gorge), including 175.18 and 175.75 at his upper Dalles gage and 171.04 at his lower Dalles gage. Stewart noted that the upper Dalles is 695 ft above the lower end of the Dalles (Stewart's survey notes, p. 62). Figure 7 shows that the current gage (XS6) is located approximately 365 ft above the lower Dalles (XS4). This leads to an estimated distance of 330 ft between Stewart's upper Dalles gage and the current gage (which is more than "*about 200 feet above present gage*" stated by the USGS-published Water Supply Paper 612 (USGS 1925, p. 62)).

Since the current gage is located approximately in the middle of Stewart's upper and lower Dalles gages, all of his 1921 HWMs at both gages are used (in order to avoid a biased estimate) to estimate the 1921 HWM at the current gage.

To transfer Stewart's HWMs from the upper and lower Dalles to the current gage site, we first estimate two hydraulic grade lines between the upper Dalles and the current gage, and between the current gage and the lower Dalles, using the USGS-surveyed 2003 HWMs. These two hydraulic grade lines are plotted in Figure 7 (green lines 1 and 2). The 1921 flood hydraulic grade lines are expected to be closely parallel to the estimated 2003 flood hydraulic lines, as the channel geometry through the Dalles did not substantially change at high flood stages over the last 80 years, and the difference between the USGS-published 2003 and PI Engineering-estimated 1921 flood peak discharges is not substantial. As shown in Figure 7, parallel lines (red lines 3, 4 and 5) are drawn to connect each of the three Stewart-surveyed 1921 HWMs to the current gage site. The estimated 1921 HWMs at the current gage site are thus determined by the elevation points where the hydraulic grade lines intersect the XS6 vertical line. Table 8 lists Stewart's HWMs at the Dalles and the estimated 1921 HWMs at the current gage site. As shown in the table, the estimated 1921 HWMs at the current gage are between 174.00 and 174.57, averaging 174.19 (or 44.19, rounded to 44.2, above the current gage datum 130.00).

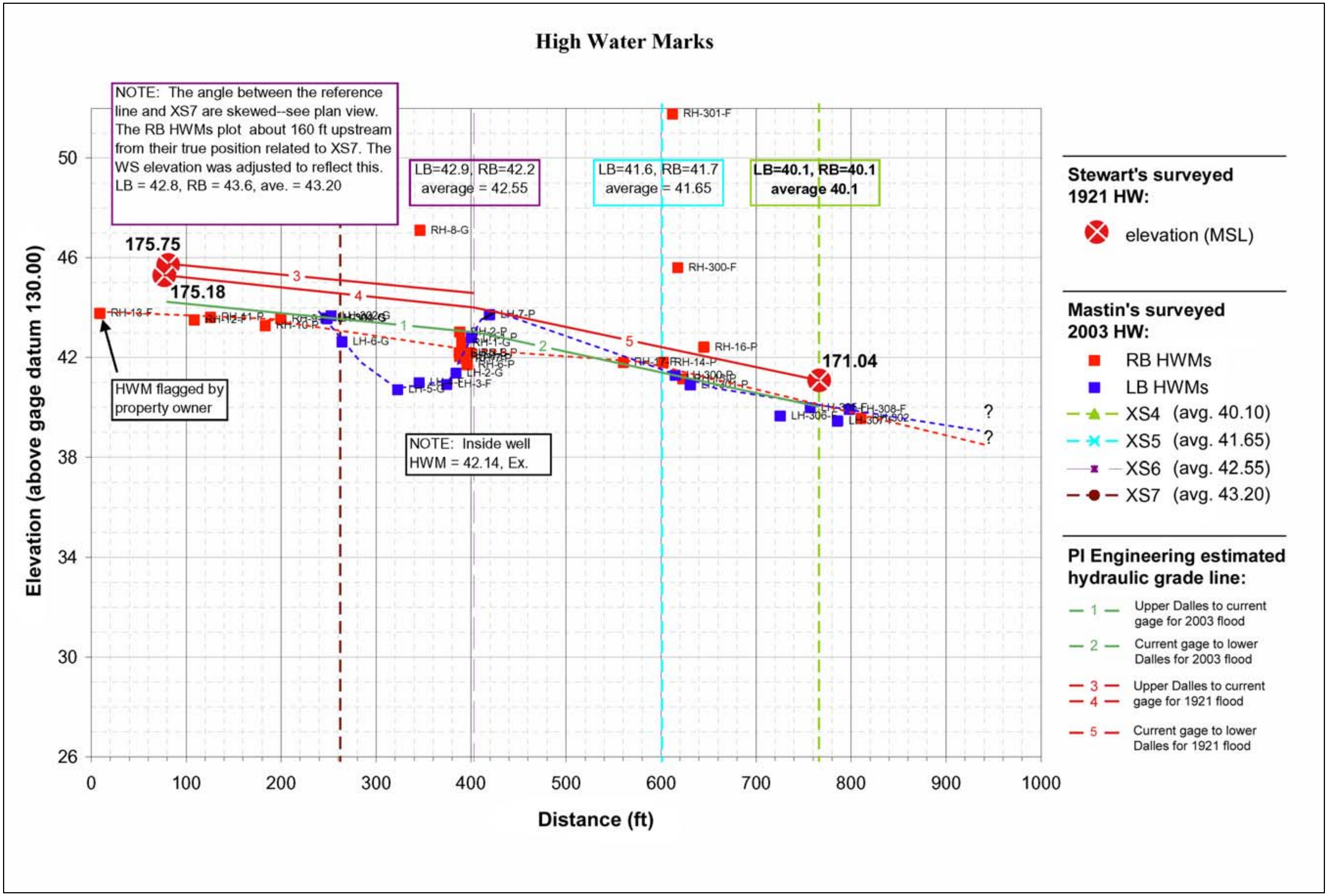

Figure 7. 1921 and 2003 HWMs in the Dalles gorge (original source of data: USGS-provided spreadsheet – Concrete_03_SAM.xls)

Table 8. Transferring of Stewart's HWMs to current gage site

Stewart-surveyed 1921 HWM (MSL)		Estimated Water Surface Drop (ft) to current gage	PI Engineering – Estimated 1921 HWM (MSL) at current gage
Upper Dalles	175.75	1.18	174.57
	175.18	1.18	174.00
Lower Dalles	171.04	–2.96	174.00
			Average = 174.19

Determination of 1921 Flood Stage Inside the Gage

The above-estimated 1921 average HWM elevation of 174.2 (rounded from 174.19) cannot be used directly on the current gage stage-discharge rating to estimate the 1921 flood peak discharge. The current gage stage-discharge rating is based on the stage readings inside the gage, while the estimated HWM is outside the gage. The flood stages inside and outside the gage can be significantly different due to surge effects.

The amount of surging for the 2003 flood is estimated to be 0.9 to 1.6 ft at the gage site, based on the USGS-surveyed HWMs (see Figure 7, the 0.9 to 1.6 range calculated between HWMs inside well HWM = 42.14 and outside well HWMs = 43.021 and 43.715 for surveyed points RH-2 LH-7, respectively). This estimated range of surges is probably reasonable as the flow velocity is very high, estimated to be approximately 15 ft/sec (cross section average, and equivalent to a velocity head of 3.5 ft, at the current gage site) based on a HEC-RAS model (PI Engineering 2008, Section 3.2.5). Conservatively using 0.5 ft for the estimated amount of surging for the 1921 flood at the current gage site, the 1921 flood stage inside the gage would be 173.7, or 43.7 above the current gage datum of 130.00.

1921 Flood Peak Discharge Based on the Stage-Discharge Rating

Figure 8 shows the stage-discharge rating curve for the current gage. Based on the estimated 1921 gage height of 43.7 at the gage, the 1921 flood peak discharge is estimated to be 178,000 cfs, which is 8,300 cfs above 169,700 cfs estimated in 2008 by PI Engineering (see Table 1), or a difference of less than 5 %, which is within the accuracy of this reevaluation.

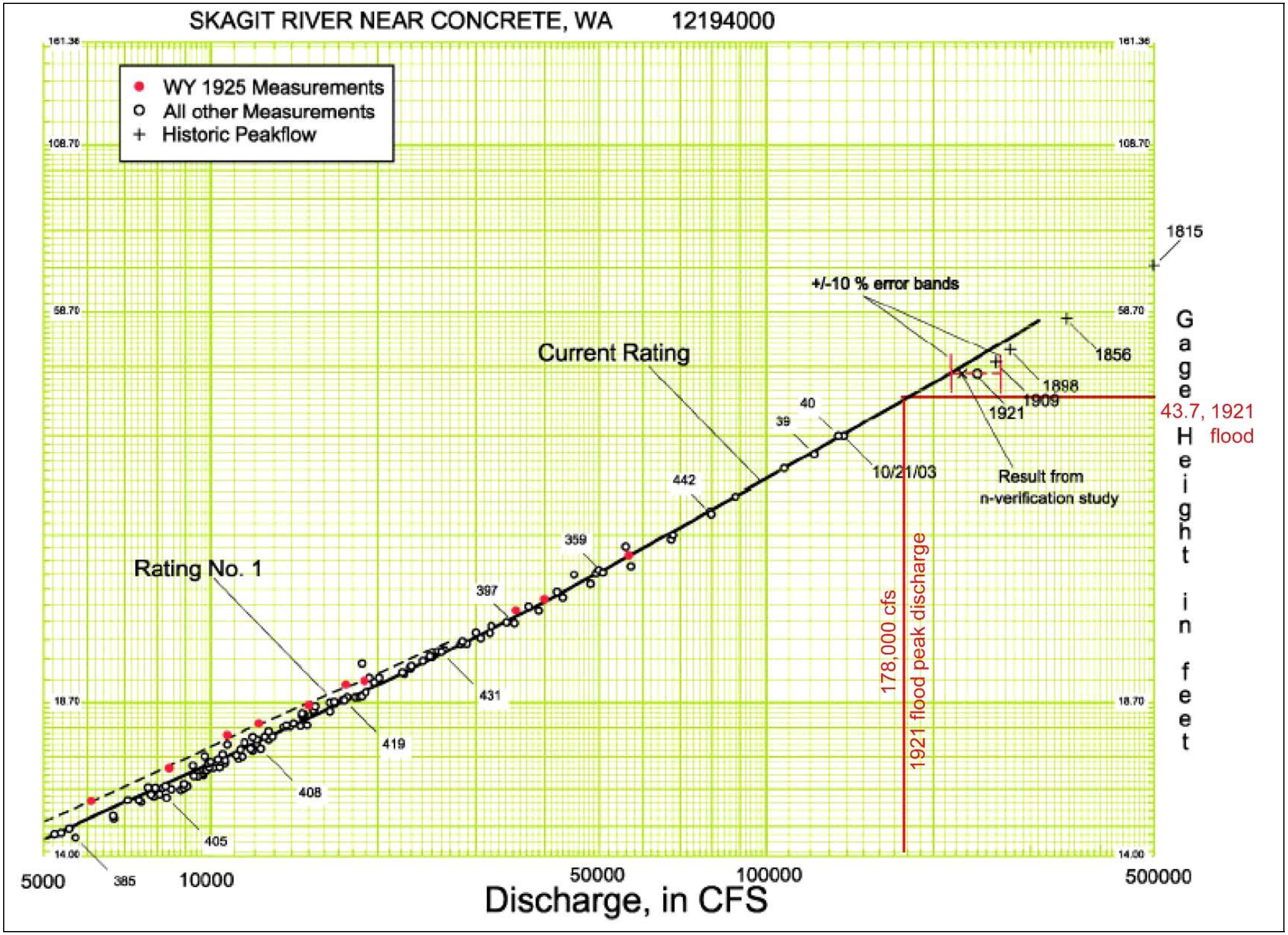

Figure 8. Stage-discharge Rating Curve for the Skagit River near Concrete (provided by USGS, May 2004)

Conclusions of the 1921 Flood Reevaluation

Based on the findings of our review and results of our reevaluation of the 1921 flood peak discharge, we conclude the following:

- Stewart’s original slope-area computations conducted in 1923 for the 1921 flood peak discharge contain use of an incomplete energy equation and can be improved based on analytical techniques and data available to us today. Stewart’s estimated 240,000 cfs for the 1921 flood peak discharge was incorrect.
- It is our opinion that the unknown amount of surging associated with Stewart’s 1921 HWMs in the slope-section reaches makes it extremely difficult to use these HWM data and the slope-area method to estimate with confidence the 1921 flood peak discharge. In our opinion, a reasonable and conservative 1921 flood peak discharge estimate based on our slope-area reevaluation would be in the range of 177,000 to 184,000 cfs (rounded from 176,833 to 184,333 cfs), based on the corrected application of the slope-area method to Stewart’s surveyed HWMs at the slope sections, using a conservative surge adjustment of 0.5 ft, and Manning’s “n” values between 0.0315 and 0.033. This range of estimates, from 177,000 cfs to 184,000 cfs, is close to 169,700 cfs estimated by PI Engineering in 2008 using a different methodology. The difference can be attributed to the additional uncertainty associated with the data used as the basis of the slope-area study in this case.
- Based on the current gage stage-discharge rating and the estimated 1921 flood gage height transferred from Stewart’s surveyed HWMs at the upper and lower Dalles gage sites, the 1921 flood peak discharge would be 178,000 cfs using a conservative surge adjustment of 0.5 ft between HWMs inside and outside the gage well.
- In our opinion, the reevaluation techniques presented in this Technical Memorandum return a conservative result (177,000 – 184,000 cfs peak discharge estimate for the 1921 flood). We believe the methodology undertaken by PI Engineering in 2008 to evaluate the historic flood peaks through modern hydraulic modeling methods is superior to the methodologies employed in this technical memorandum, due to the uncertainty of the data used. Therefore, it is our conclusion that the 1897, 1909, 1917, and 1921 historical flood peak discharges should be those estimated by PI Engineering in 2008, as shown in Table 1. We believe the methodologies documented in that study are more accurate than those either originally estimated by Stewart in 1923 or later revised by Mastin in 2007. Details of the estimates for the other three historical flood peak discharges based on relation with the estimated 1921 flood discharge are provided in the PI Engineering 2008 report (PI Engineering 2008, Sections 3.2.5 and 3.2.9). This estimated discharge is also consistent with 1921 HWMs observed or stated by all parties including Stewart, Skagit County, Great Northern Railroad (GNRR), Smith, and Slipper, in the Concrete–Hamilton

area as described in the PI Engineering 2008 report (PI Engineering 2008, Sections 3.2.3 to 3.2.5).

- The USGS-revised data are currently used by USACE for estimates of the 10-, 50-, 100-, and 500-year synthetic flood peak discharges, which are listed in Table 9. Use of the new data estimated by PI Engineering will improve the accuracy of the synthetic flood estimates, and will result in significantly lower estimates of the three larger synthetic flood peak discharges with exception of the 10-year flood peak discharge, which are also listed in Table 9. Details of these estimates are provided in the USACE report (USACE 2008) and PI Engineering report (PI Engineering 2008) for the USACE and PI Engineering estimates, respectively.

Table 9. Comparison of 10-, 50-, 100-, and 500-year flood peak discharges at Concrete and Sedro-Woolley for existing basin conditions with upstream dam storage regulation

Flood	Concrete (RM 54.15)		Sedro-Woolley (RM 22.40)	
	USACE developed Peak (cfs)	PI Eng. developed Peak (cfs)	USACE developed Peak (cfs)	PI Eng. developed Peak (cfs)
10-year	116,300	116,100	123,610	117,200
50-year	180,260	162,600	183,780	161,900
100-year	209,490	184,400	215,270	184,700
500-year	316,530	229,400	322,900	231,700

Sources of Data

Sources of data, including Stewart's 1922–23 field survey notes, Stewart's unpublished 1923 report (including Exhibit B), and Stewart's 1950 letter to the USGS District Engineer (including his memorandum), are provided in a CD which is attached to this Technical Memorandum. Mastin's 2007 report for reevaluation of the 1921 flood peak discharge is also included in the CD. In addition, an excel spreadsheet (Slope_Sections.xls) containing the slope section data and PI Engineering's slope-area computations using the complete energy equation for the 1921 flood peak discharge is included in the CD.

References

Chow, V.T. 1959. Open-Channel Hydraulics. McGraw-Hill Book Company.

Leytham, M. 2008. Leytham's 10/16/2008 email Re: Burlington BM including spreadsheet: Height Differences in Skagit Co, WA.xls, from NGS.

PI Engineering, 2008. Skagit River Basin Hydrology Report – Existing Conditions.

Stewart, J.E. 1922–23. Stewart’s survey notes handwritten when he was performing a field flood investigation during the winter of 1922-23. Available from USGS and at www.skagitriverhistory.com.

Stewart, J.E. 1923. Stage and Volume of Past Floods in Skagit Valley and Advisable Protective Measures prior to the construction of Permanent Flood Controlling Works. Unpublished report.

Stewart, J.E. 1950. Letter dated June 1, 1950 from James E. Stewart to F.M Veatch, District Engineer of USGS at Tacoma, Washington.

U.S. Army Corps of Engineers. 2008. Draft Report—Skagit River Basin, Washington, Revised Flood Insurance Study, Hydrology Summary.

U.S. Geological Survey. 1925. Water Supply Paper 612 “Part XII. North Pacific Slope Drainage Basins. A. Pacific Basins in Washington and Upper Columbia River Basin.”

U.S. Geological Survey. 1936. October 21, 1936 letter from G.L. Parker, District Engineer, USGS, to Hugo Baumen, Chairman, Skagit County Commissioners.

U.S. Geological Survey. 1961. Water Supply Paper 1527 “Floods in the Skagit River Basin, Washington,” by James E. Stewart and G. Lawrence Bodhaine.

U.S. Geological Survey. 2007. Scientific Investigations Report 2007-5159 “Re-evaluation of the 1921 Peak Discharge at Skagit River near Concrete, Washington,” by M. C. Mastin.

U.S. Geological Survey. 2008. Letter dated and emailed November 5, 2008 from M.C. Mastin to a list of recipients.