An Evaluation of Flood Frequency Analyses for the Skagit River, Skagit County, Washington

(Responses from the Cities of Burlington and Mount Vernon shown in italicized blue font)

Federal Emergency Management Agency
Region X
Bothell, Washington

February 26, 2010
Revised May 19, 2010

Responses provided in conjunction with Appeal of the Revised Digital Flood Insurance Rate Map (rDFIRM) and Revised Flood Insurance Study (rFIS)

Submitted March 30, 2011

An Evaluation of Flood Frequency Analyses for the Skagit River, Skagit County, Washington

Background

The Federal Emergency Management Agency (FEMA) is conducting a Flood Insurance Study (FIS) for Skagit County, Washington and Incorporated Areas. The Seattle District of the U.S. Army Corps of Engineers (USACE) is the study contractor. The results of this study will be used to revise the Flood Insurance Rate Map for Skagit County.

The Skagit River is a 3,115 square mile watershed that originates in British Columbia, Canada and drains in a southwestern direction into Puget Sound north of Seattle, Washington. The hydrologic analyses for the FEMA study is documented in a report entitled "Draft Skagit River Basin, Washington, Revised Flood Insurance Study, Hydrologic Summary", dated May 1, 2008 (USACE, 2008). Figure 1, taken from the USACE (2008) report, is a schematic of the Skagit River watershed showing location of dams and important gaging stations. The critical gaging station is the Skagit River near Concrete, Washington (station 12194000), drainage area of 2,737 square miles, that has long-term record from 1924 to present including four historic floods whose values have been the subject of much discussion. These historic floods occurred in November 1897, November 1909, December 1917, and December 1921 before the gaging station was established near Concrete and are the largest floods used in the USACE (2008) unregulated frequency analysis.

The USACE (2008) report is an update of a November 10, 2005 report by the same title. USACE updated their hydrologic analysis in May 2008 for the Skagit River because:

- the U.S. Geological Survey (USGS) revised the annual peak discharges for the four historic floods (Mastin, 2007) for the gaging station near Concrete, and
- regulated flow data from a previous USACE analysis were found for the period 1924-43 and were incorporated into the analysis.

Cities' comment: *an additional significant factor is that the USACE increased its peak to one-day and peak to three-day flow ratio, resulting in a reduction in flood volumes. (See USACE 10 Nov 2005 Hydrology Summary compared to USACE 1 May 2008 Hydrology Summary).*

The impact of the historic peak discharge revisions and new data resulted in the regulated 1-percent annual chance (base) discharge decreasing from 226,400 cfs to 209,500 cfs.

Flood frequency analyses for the Skagit River are complicated by the fact that five hydroelectric power reservoirs with flood-control capabilities have been constructed on the Skagit River or a major tributary from 1924 to 1961 plus the regulation procedures have changed over time (see Figure 1 for locations of the dams). The general modeling approach used by USACE (2008) for such a regulated watershed was to develop unregulated flows, perform frequency analyses on the unregulated flows, route the unregulated flood hydrographs through the current reservoir system, and then perform frequency analyses on the regulated peak flows.

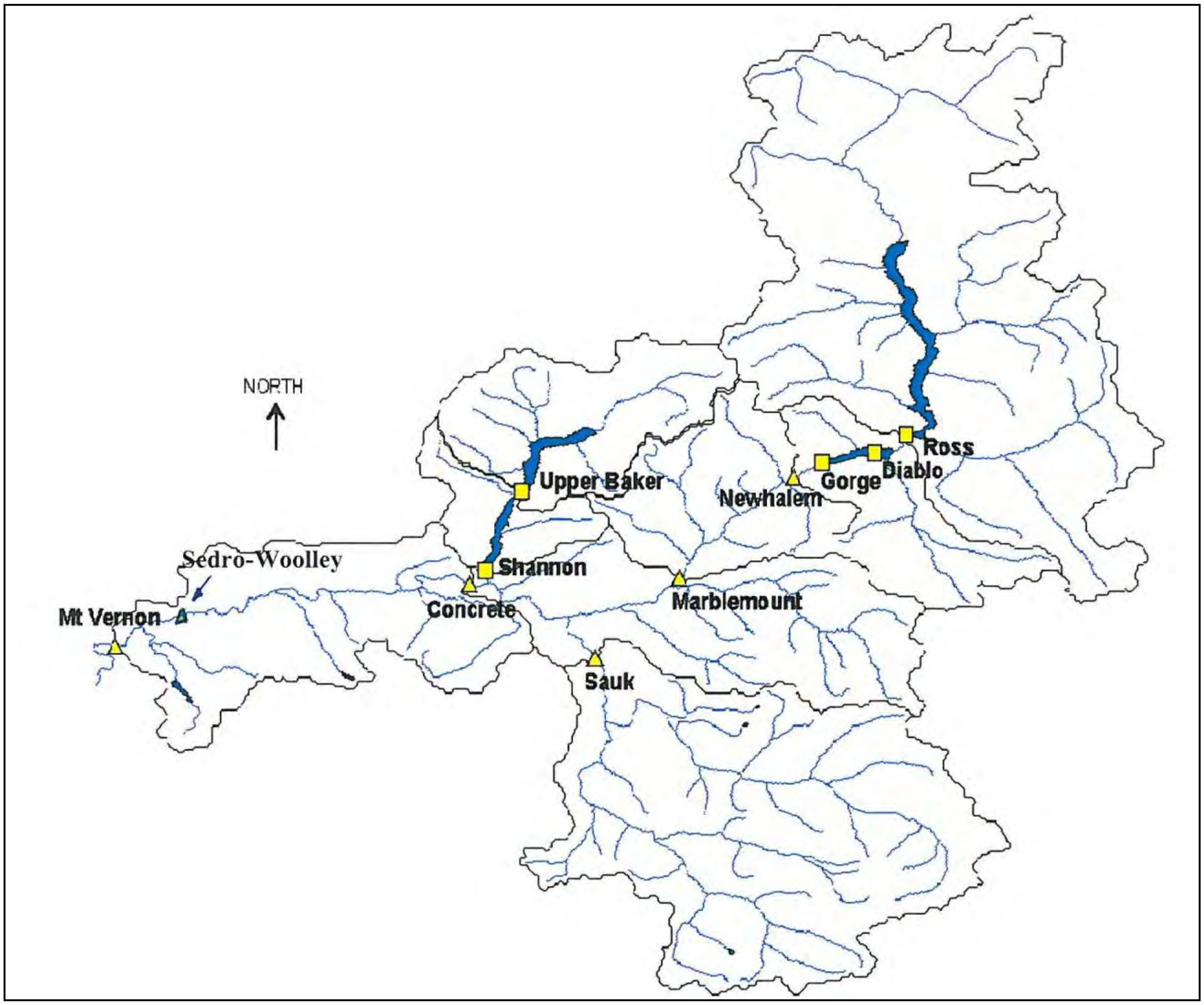


Figure 1. A map of the Skagit River watershed showing the location of dams (squares) and important gaging stations (triangles). ***(Cities' comment:** Location of Sedro-Woolley USGS gage added)*

Purpose of this Review

Even though the USGS revised the peak discharges for the four historic floods in 2007, some local communities believe the revised discharges are still too high. Because the four historic floods are higher than any estimated unregulated peaks in the systematic record, they collectively have some influence on the magnitude of the 1-percent annual chance flood discharge. Pacific International Engineering (PIE), working as a consultant for the Cities of Burlington and Mount Vernon, and Dike Districts 1 and 12, performed independent hydrologic and hydraulic analyses for the Skagit River and estimated different peak discharges for the four historic floods. Using their revised historic peak flows, PIE (2008) performed unregulated and regulated frequency analyses for the Skagit River. Their work is summarized in a report entitled "Skagit River Basin Hydrology - Existing Conditions" dated October 2008 (PIE, 2008).

Northwest Hydraulic Consultants (NHC), working as a consultant for Skagit County, performed independent hydrologic and hydraulic analyses and estimated different peak discharges for the four historic floods. Using their revised historic peak flows, NHC (2008) performed unregulated frequency analyses for the Skagit River near Concrete. Their analyses are described in a report entitled

“Re-evaluation of the Magnitude of Historic Floods on the Skagit River near Concrete – Final Report”, dated October 2008 (NHC, 2008).

On March 17, 2010, FEMA had a meeting with Skagit County, the City of Burlington and their consultants (NHC and PIE) and the USGS and USACE to discuss issues related to the estimation of peak discharges for the four historic floods. Prior to this meeting NHC and PIE provided the following documents:

- “Re-evaluation of the Magnitude of Historic Floods on the Skagit River near Concrete – Revised Final Report”, dated March 2010, NHC,
- “Technical Memorandum – Review and Reevaluation of Skagit River 1921 Flood Peak Discharge”, dated March 2010, PIE.

The information and analyses discussed in the October 2008 reports by PIE and NHC and the information in the documents distributed for the March 17, 2010 meeting are discussed below.

Peak Discharges for Four Historic Floods

A major issue associated with the frequency analysis for the Skagit River near Concrete is the peak discharge of four historic floods that occurred in November 1897, November 1909, December 1917, and December 1921 prior to construction of the reservoirs. The peak discharges for these floods were determined originally by James Stewart, USGS, from field investigations made in 1918 and 1922-23 and documented in unpublished reports. The peak discharges were first published in USGS Water Supply Paper 1527 dated 1961 (Stewart and Bodhaine, 1961). Before the peak discharges were published for these four historic floods in 1961, the USGS performed at least two technical reviews of Stewart’s analyses in the 1950 to 1952 time period. These subsequent analyses resulted in different and lower peak discharges. However, USGS made the decision in 1961 to publish the peak discharges as originally estimated by Stewart because the differences in the peak discharges from the various analyses were less than 10 percent. Recently, PIE (2008) and NHC (2008) have estimated revised values for the four floods. The peak discharges for the November 1897, November 1909, December 1917, and December 1921 floods estimated by different analysts are summarized in Table 1.

Table 1. Summary of four historic peak discharges, in cubic feet per second (cfs), for the Skagit River near Concrete, Washington.

Source	**November 1897**	**November 1909**	**December 1917**	**December 1921**
USGS (1950)	230,000	220,000	190,000	210,000
USGS (1951-52)	265,000	240,000	205,000	225,000
USGS (1961)	275,000	260,000	220,000	240,000
USGS (2007)	265,000	245,000	210,000	228,000
PIE (2008)	181,200	179,000	158,700	169,700
NHC (2008)	220,000	205,000	185,000	195,000

The variability of estimates in Table 1 indicates there is uncertainty associated with the determination of peak discharges for these historic floods as reflected by the location and quality of the high water marks, cross-sectional data, and Manning’s n values. The analyses and reports prepared by Stewart in 1918 and 1922-23 in determining the historic peak discharges were more detailed than the documentation generally available for historic floods at most gaging stations although his procedures were not as detailed and thorough as those used by USGS today.

Cities' comment: *A point we would emphasize here is that taken in totality, additional USGS gaging station data from other locations infers errors in the USGS estimated historic peak discharges; further, the 85-year continuous gage record at Concrete provides valuable and substantive context related to Skagit peak flows that Stewart did not have access to.*

The USGS also published estimated peak flows at the site of the USGS gage location at Sedro-Woolley for the four historic flood events. A gage has been in place at Sedro-Woolley since 1908. The Sedro-Woolley flood peaks were estimated by Stewart at the same time he estimated the flood peaks at Concrete and are published by the USGS in Water Supply Paper 1527 (USGS 1961). Stewart had also made earlier estimates in 1918. In subsequent USGS studies, Bodhaine (1954) suggested values for the four floods; other estimates were made by Riggs & Robinson in 1950, and by Hidaka in 1954 for the 1897 and 1909 events. These estimates are significant because hydraulic modeling by both the USACE and PI Engineering indicate that in general, peak flow of the Skagit River at Sedro-Woolley, which is downriver from Concrete, will be a few percentage points higher than the peak at Concrete. There is very little off-channel storage between Concrete and Sedro-Woolley (USACE Draft Skagit River Basin Hydrology Summary 1 May 2008, p.52) . Therefore, if the peak flow estimates for Sedro-Woolley are accurate, these peak flow estimates strongly infer the much higher peak flow estimates for Concrete are implausible. See table below:

Stewart and USGS peak discharge estimates for historical floods at Sedro-Woolley

	Stewart			USGS	
Flood	**1918**	**1923**	**Rigg & Robinson**	**Hidaka**	**Bodhaine**
1897	171,000	190,000	170,000	145,000	170,000
1909	169,000	220,000	190,000	175,000	200,000
1917	157,000	195,000	160,000	----	195,000
1921	----	210,000	170,000	----	210,000

(Source: Stewart 1918 & 1923 Reports; Proposed Revision of Skagit River Peaks, H.C. Riggs & W.H. Robinson, 11/16/50; Skagit River near Sedro-Woolley, Wash., Proposed revisions of historical flood peaks, F. L. Hidaka, 1/12/54; Skagit River Flood Peaks, Memorandum of Review by G.L. Bodhaine, USGS, 5/13/54). Available at www.skagitriverhistory.com

USGS (2007) Re-evaluation of the Four Historic Floods

The peak discharge for the December 1921 flood was estimated by Stewart in 1923 with a slope-area computation and is the basis for estimating the other three earlier historic floods. The USGS re-evaluated and revised the peak discharge for the December 1921 flood in 2007 from 240,000 cfs as originally published by Stewart and Bodhaine (1961) to 228,000 cfs (Mastin, 2007). The revision was based on:

- Manning's n value of 0.0315 verified using data collected during the November 1949 flood,
- Cross sections 2 and 3 as surveyed by Stewart,
- Cross section 2 was subdivided but the same n value (0.0315) was used for both subareas, and
- Water surface slope of 0.00120 as determined by Stewart.

The revisions to Stewart's original computations include a Manning's n value of 0.0315 rather than 0.033 as used by Stewart, use of two cross sections (2 and 3) rather than all three cross sections surveyed by Stewart, and subdivision of cross section 2 for channel roughness. Mastin (2007) rated the re-computation of the December 1921 peak discharge as a "fair" measurement implying that the peak discharge of 228,000 cfs was within 15 percent of the actual value.

The USGS also recomputed the December 1921 peak discharge using Manning's n value of 0.033 estimated from the October 2003 flood and the water-surface slope from the November 2006 flood (0.00114). Again cross section 2 as surveyed by Stewart was subdivided. This computation resulted in a peak discharge of 219,000 cfs for the December 1921 flood.

The USGS decided to use the n value as verified using data for the November 1949 flood because channel conditions in 1949 were likely more similar to conditions in 1921. Mastin (2007) provides 1932 and 1948 photographs showing the island/sand bar downstream of the gaging station as mostly bare of vegetation. When the October 2003 and November 2006 floods occurred, this sand bar was densely forested.

Cities' comment: *The USGS has documented the reasons it changed Stewart's n-value estimate in its 2007 report. It has been a recurring issue in USGS discussions about the slope/area sections downstream of the Dalles that the island located just downstream of XS1 and at XS2 was virtually bare of vegetation in December 1921; whereas today, the island is highly vegetated; therefore, in 1921 the Manning's n-value should be lower than the 0.33 Stewart estimated. However, Stewart made his judgment on site in 1923; also, the USGS did not use the upper cross section in its reevaluation of the slope/area sections. Further, in its 2005 study, the USGS did not change Stewart's discharge estimates. Most importantly, the USGS has incorrectly applied all HWMs in all of its calculations, assuming these HWMs at the slope sections represented the mean water surface elevations. This assumption is incorrect as we have found out that these HWMs are more representative of the energy grade line elevations, based on the USGS velocity measurements at the cableway located upstream of XS3. The USGS has made this incorrect assumption in all of its studies in the slope sections, including the 2005 and 2007 reevaluation studies, and the 1949 n-value verification study. For discussion of this incorrect application of HWMs, see PI Engineering's March 2011 report entitled "Technical Report – Supporting Data and Analysis for Skagit River RFIS Appeal," Section 2.1.4 and 2.2.6.*

The historic floods of November 1897, November 1909, and December 1917 were estimated from a revised rating curve that included the 1925 water year discharge measurements, the highest current-meter measurements and constraining the rating curve to pass through the recomputed December 1921 peak discharge of 228,000 cfs. The USGS (2007) revised values for the other three historic floods are given in Table 1.

Cities' comment: *Because the USGS made errors in setting the stage elevation of the 1921 flood event at the current gage location, estimating the discharge of the previous historical flood events by extending the rating curve at the current gage location produces significant overestimates of the prior historic floods. See PI Engineering's March 2011 report, Section 2.2.6.*

On May 6, 2010, USGS sent out a letter to all attendees of the March 17, 2010 meeting commenting on information presented at that meeting and reiterating that no revisions are warranted in the four historic peak discharges. This document is referenced in subsequent discussions.

***Cities' comment**: Following the October 2003 flood of record on the Skagit River, and prior to publication of its 2007 study, the USGS published an antecedent report entitled "Verification of 1921 Peak Discharge at Skagit River near Concrete, Washington, Using 2003 Peak-Discharge Data," (Scientific Investigations report 2005-5029). The following are links to this report and the revision sheet:*

http://pubs.usgs.gov/sir/2005/5029/pdf/sir20055029rev2.pdf
http://pubs.usgs.gov/sir/2005/5029/sir20055029_Revision_History.htm.

The 2005 report was based on high water mark data gathered by USGS approximately 10 months after the 2003 flood. Part of this data is shown below in a figure from the 2005 USGS report. On the following page, a profile of the Dalles gorge shows all of the USGS HWM data of the October 2003 flood event, gathered in 2004, as well as Stewart's 1921 peak flow stage data from his field notes (not adjusted with USGS-asserted 1.8 foot datum shift).

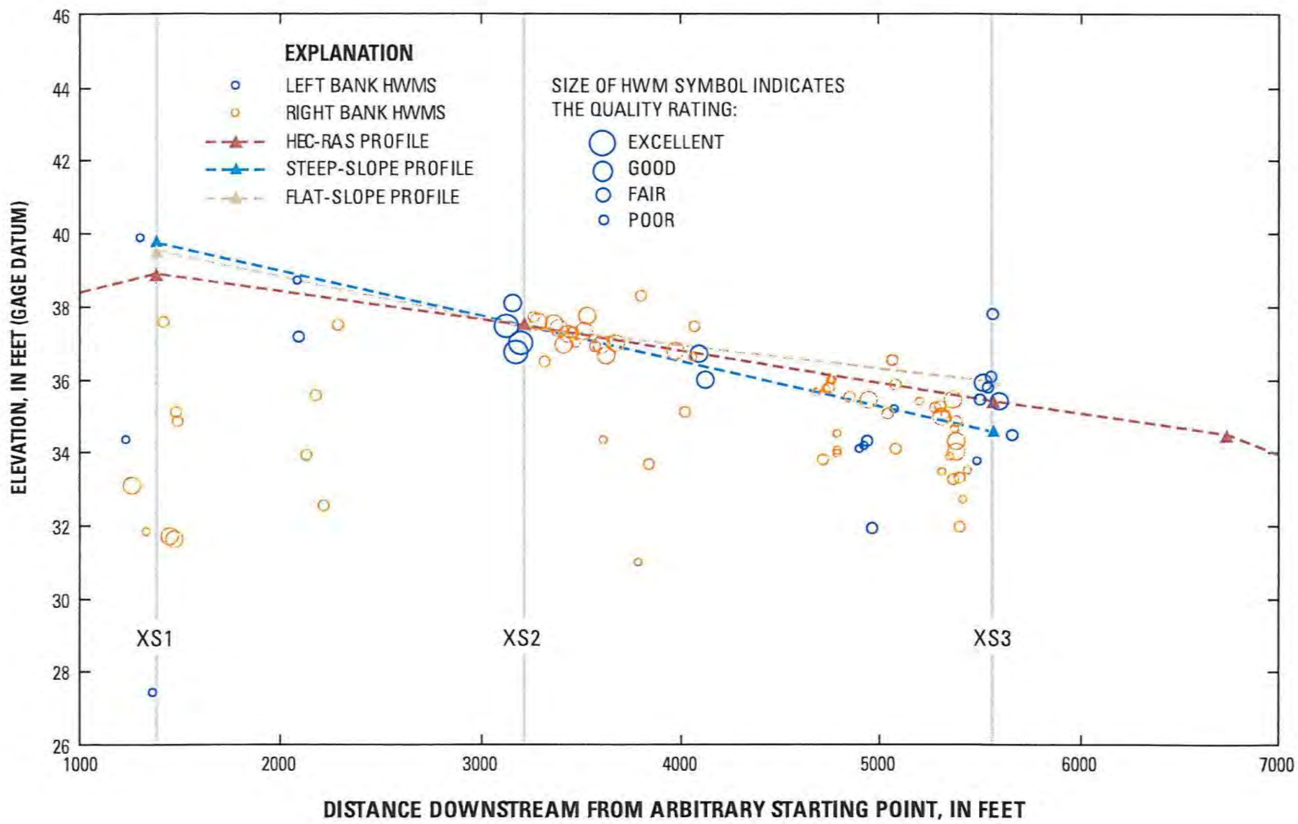
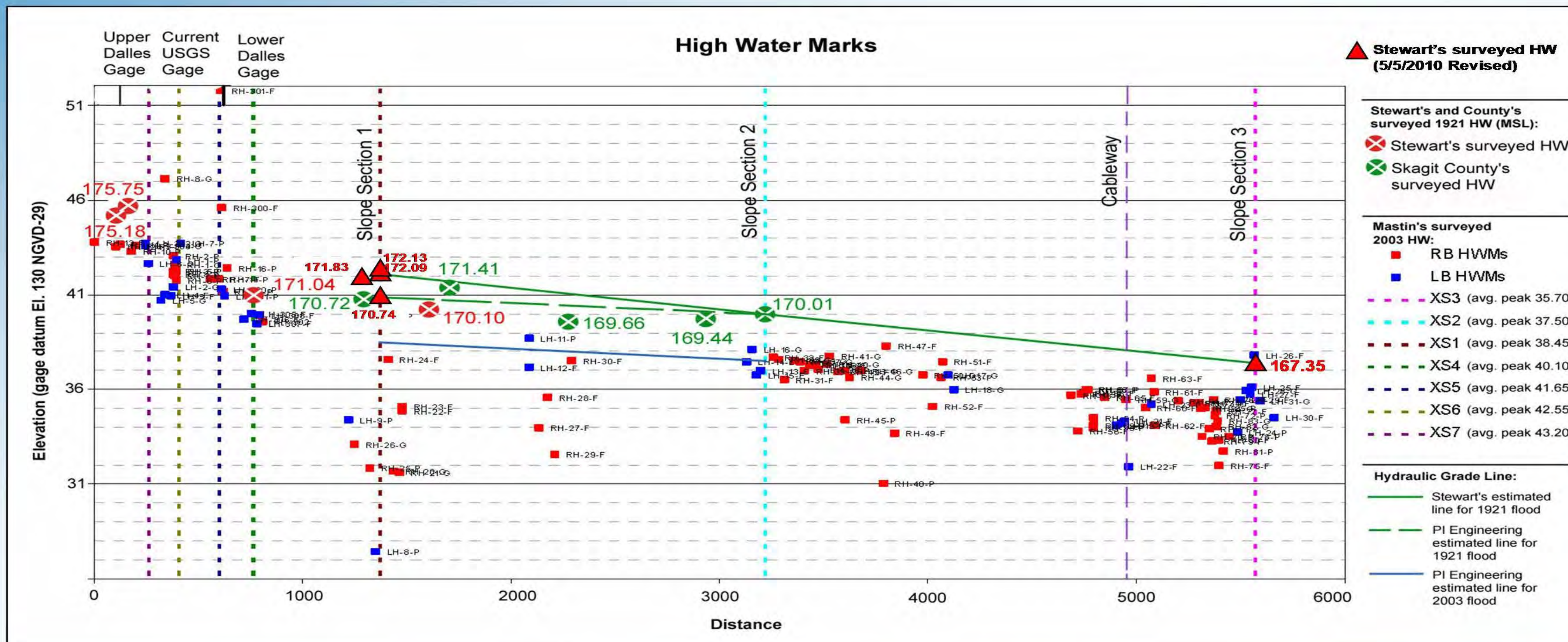


Figure 4. High-water marks (HWMs), flattest- and steepest-sloped water-surface profiles, and a HEC-RAS water-surface profile near cross sections XS1, XS2, and XS3, at Skagit River near Concrete, Washington.

1921 and 2003 flood high water marks surveyed by Stewart (in 1922-23) and USGS (in summer 2004)

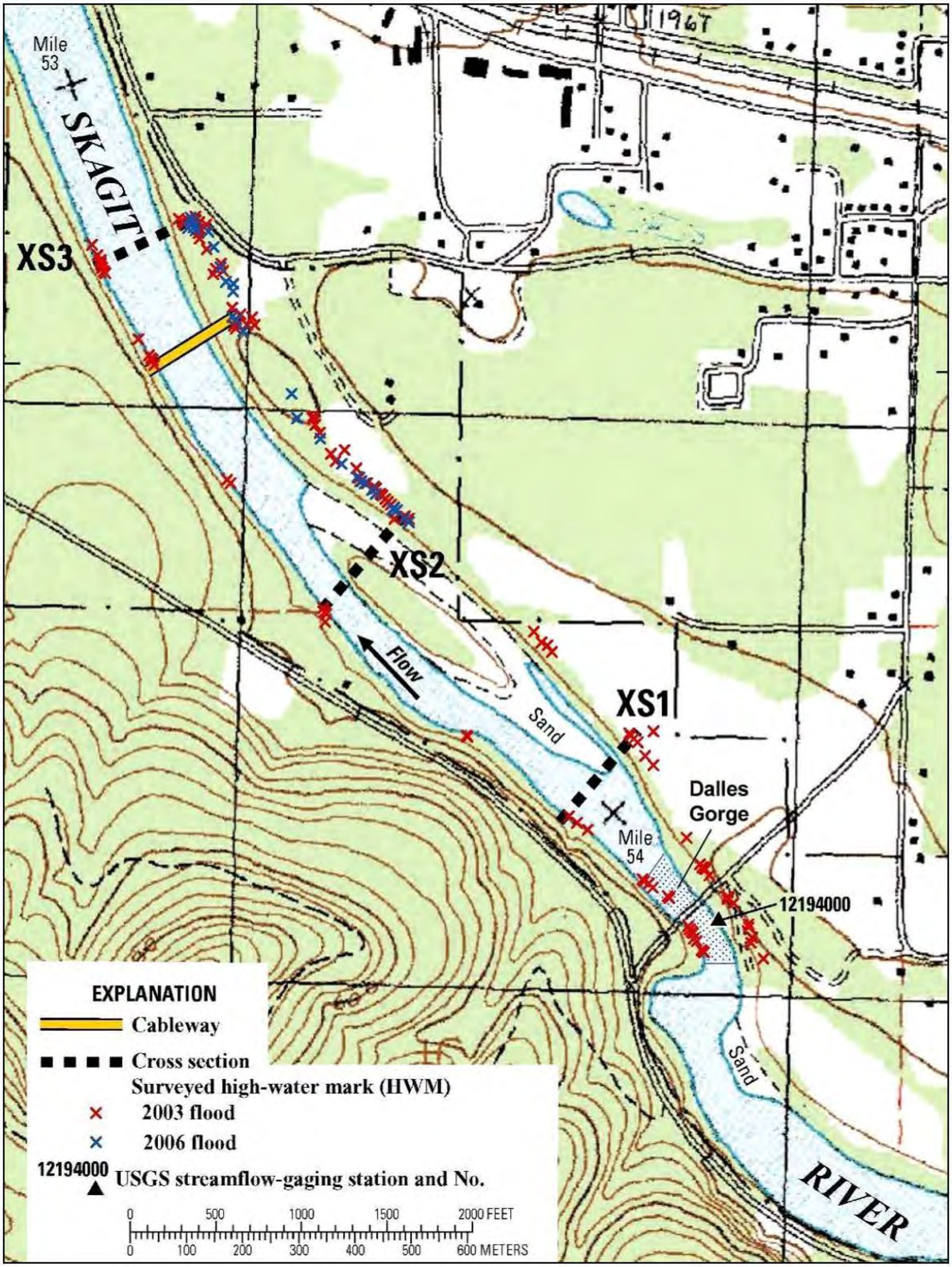


Cities' comment: *Of note is the significant variation in high water marks – as much as several feet to over 10 feet. The report authors attempted to determine a slope from the data gathered, and ultimately decided not to change the previous USGS estimate from this study (240,000 cfs), apparently because of the extreme variation in the high water marks surveyed in 2004. This USGS study demonstrates the difficulty in obtaining accurate high water mark information in the Dalles reach of the Skagit River, where the Concrete gage is located (see map, next page, from USGS SIR 2007.)*

The USGS field data collection effort took place in the summer of 2004. The 2003 flood of record at this location occurred about 9 months previously, in late October 2003. Stewart's work in this reach began in late November 1922, about 11 months after the flood of 1921. The experience of the USGS gathering high water marks in the spring of 2004 highlights the fundamental question of whether Stewart's high water marks were accurate. The Cities addressed this fundamental issue by developing different methodologies that relied on modern hydraulic modeling techniques, as well as inherently more certain data. However, we have studied Stewart's work in detail. His field notes provide a picture of an experienced field person who was methodical and carefully thinking through his study effort. It continues to be the position of the cities that Stewart's high water marks were accurate. Where the cities differ from the USGS is the way the high water mark data provided by Stewart is modified and processed – two key areas in particular involve changing the datum and the manner of transferring Stewart's high water marks from his upstream gage location to the present gage location.

The USGS stage elevation estimate for the 1921 flood at the Concrete gage is 177.6 feet. This stage estimate, as can be seen from the figure on page 8, is arrived at by transferring Stewart's high water marks from his upper Dalles gage (175.75 feet), adding 1.8 feet for what the USGS believes is a datum correction (we disagree there is any evidence to support this datum correction) to arrive at 177.55 feet, rounding that to 177.6 feet, and then transferring that high water mark downstream 300 feet to the current gage location without accounting for hydraulic drop through the Dalles gorge, which is on the order of 1 to 2 feet for a flood the size of the 1921 event. A more accurate stage elevation of the 1921 flood would be obtained by using Stewart's upper Dalles Gage high water mark of 175.75 feet, then transcribing that high water mark downstream by conservatively reducing it by 1.2 feet for head loss in the 300 feet to the existing gage site, and then reducing this further by 1.3 feet for surge effects (see PI Engineering's March 2011 Report, Section 2.3.2, "Transferring of Stewart's 1921 HWMs to Current Gage Site."

The following page shows a plan view of the Dalles reach, from the USGS 2007 study.



Plan view of the Dalles showing location of the Dalles gorge, Stewart's slope-arch cross-sections, the USGS cableway and the USGS gage.

NHC (2008) Re-evaluation of the Four Historic Floods

NHC (2008) Approach

NHC (2008) estimated the December 1921 peak discharge using a different approach than USGS. The NHC (2008) analysis of the 1921 flood relies heavily on a description of this flood in the December 17, 1921 issue of *The Concrete Herald* newspaper that indicated flood depths were an inch to 14 inches deep in residences in the Crofoot Addition. The Crofoot Addition is that area of Concrete just west of the confluence of the Baker and Skagit Rivers. The finished floor elevation of the lowest existing residence dating from 1921 in the Crofoot Addition at 45956 Albert Street was determined to be 184.93 feet NGVD 1929. A flood depth of 14 inches was added to the finished floor elevation to get a flood elevation of 186.1 feet NGVD 1929 for the 1921 flood. A HECRAS model was developed for the Skagit River from River Mile (RM) 51.1 to RM 56.77. The gaging station near Concrete (station 12194000) is located at RM 54.1. The peak discharge that gave an elevation of 186.1 feet at the residence in the Crofoot Addition (RM 56.35) was 195,000 cfs and was recommended by NHC (2008) as the revised value for the December 1921 flood.

Cities' comment: *The cities believe NHC used a reasonable approach, but likely too conservative because the newspaper report at the time may very well have been referring to a house closer to the river with a lower first floor elevation that no longer exists today; further, the newspaper report was somewhat ambiguous about whether the water was above the first floor level or merely into the crawl space. For these reasons, we believe the better high water mark is the 184.55 feet taken from p.22 of Stewart's field notes.*

Briefly the steps and assumptions in the NHC (2008) analysis are as follows:

- Develop a 1D steady-state HEC-RAS model using cross-sectional data from in- channel and overbank sections from the 1976 FIS, in-channel sections surveyed in October 2004, and in-channel and overbank sections surveyed in 2008.
- Calibrate the HEC-RAS model using discharge data for the October 21, 2003 flood and peak elevations at the USGS gaging station, a residence in the Crofoot Addition and the current rating curve at the USGS gaging station.
- Vary the expansion/contraction coefficients in the HEC-RAS model, use ineffective flow areas and high channel roughness for the left bank of The Dalles gorge to calibrate to the 2003 high water marks. NHC (2008) points out that field conditions in The Dalles gorge deviate considerably from one-dimensional flow assumptions of the HEC-RAS model so adjustments to the model were needed.
- Compare current (1976 to 2008) cross sections to those surveyed in 1911 by USACE. NHC (2008) concluded that channel conditions had not changed significantly since 1911, thus justifying the use of recent cross-sectional data to estimate the 1921 flood.
- Estimate the 1921 peak discharge as the discharge corresponding to an elevation of 186.1 feet at the Crofoot Addition residence at 45956 Albert Street.

NHC (2008) estimated a peak discharge of 195,000 cfs for the December 1921 flood using the HEC-RAS model with high expansion/contraction coefficients. This value is 14.5 percent less than the USGS published value of 228,000 cfs. NHC (2008) developed a rating curve at the Crofoot Addition residence at 45956 Albert Street by running the HEC-RAS model for various flow values. The high water data collected and discussed by Stewart in his field notes were used to estimate elevations for the November

1897, November 1909 and December 1917 floods. The elevations for the historic floods differed somewhat from those published by USGS but the relative ranking of the floods remained the same. NHC (2008) used the flood elevations and the rating curve at the Crofoot Addition residence to estimate flood discharges for the 1897, 1909 and 1917 floods. The revised flood discharges estimated by NHC (2008) for all four historic floods are given in Table 1.

NHC (2008) used their revised estimates of the four historic floods and the USACE estimates of unregulated peak flows from 1924 to 2007 in a Bulletin 17B analysis (Interagency Advisory Committee on Water Data (IACWD), 1982). These analyses were performed with and without the 1897 flood because it has the most uncertainty. The estimate of the 1-percent annual chance flood discharge decreased less than 2 percent by omitting the 1897 flood. NHC (2008) estimate of the unregulated 1-percent annual chance flood including the 1897 flood is 254,000 cfs as compared to 278,000 cfs from the USACE (2008), a difference of about 9 percent.

<u>Comments on the NHC (2008) Analysis</u>

The following comments are pertinent to the NHC (2008) analysis:

- The re-computation of the December 1921 peak discharge is based primarily on flood depths in residences reported in a newspaper article. The assumption is made that the 14-inch flood depth is applicable to an existing residence at 45956 Albert Street. This elevation data is considered less credible than multiple high water marks surveyed in the field by James Stewart 11 months after the flood.
- As pointed out by NHC (2008), the modeling of the flow through The Dalles gorge is difficult and subject to several uncertainties such as the applicable expansion/contraction coefficients and the applicability of the cross-sectional data. The slope-area reach as used by USGS was based on a uniform (contracting) reach downstream of The Dallas Gorge and based on cross-sectional data collected in 1923 for the purpose of indirectly estimating the December 1921 peak discharge and was not subject to the uncertainties of modeling flow through the Dalles Gorge.

Cities' comment: *At the same time, the USGS 2007 study did not use most of Stewart's surveyed HWMs in the Dalles vicinity. The USGS study only used high water marks from cross sections 2 and 3.*

- NHC (2008) maintains that 1911 cross-sectional data are similar to data collected in the 1976 to 2008 time period and therefore it is appropriate to use the recent cross-sectional data to estimate the December 1921 flood. However, Figure 6 in the NHC report indicates that the streambed elevation in 1911 differed by more than 5 feet in some places and was more than 10 feet higher than current data through the Dalles Gorge. Since NHC (2008) did not use the 1911 data, this does not impact their analyses but does raise questions about the accuracy (or datum) of the 1911 data and whether the Skagit River channel has changed over time.

Cities' comment: *Questions about the 1911 survey data are speculative. We have seen no evidence to suggest that the 1911 streambed survey is inaccurate. The documentation indicates this streambed survey was a substantial undertaking and was promulgated in a professional manner by the Corps of Engineers.*

- Although NHC was able to match the current USGS rating, the HEC-RAS models underestimated the high water mark elevation for the 1921 flood at the upper Dalles gage. This is likely due to the complexities of modeling the flow through The Dalles Gorge and differences in cross-sectional data and n values from 1921 to current conditions.

Cities' comment: *NHC used the 177.6 foot high water mark at the upper Dalles location. As previously stated, we believe the high water mark at the upper Dalles should be 175.75 feet, as documented in Stewart's notes.*

NHC (2010) Additional Information

For the March 17, 2010 meeting, NHC provided a March 2010 revised version of their report that included a new section titled "Uncertainty in Slope-Area Measurements for the December 1921 Flood". This new section described the sources of uncertainty in the USGS slope-area measurement. The major concerns expressed by NHC were:

- There are only seven high water marks to support the Stewart's slope-area measurement for the December 1921 flood and there were no high water marks between cross sections 2 and 3,
- A plot of the seven high water marks does not support the water-surface slope used by Stewart for his slope-area measurement,
- Based on high water marks surveyed by NHC and Skagit County for the November 2006 flood, there appears to be a break in water surface between cross sections 2 and 3.

In the May 6, 2010 letter sent out by Mark Mastin, USGS, he identified 13 high water marks surveyed by Stewart for the December 1921 flood and pointed out that five high water marks support the water-surface slope of 0.00119 used by Stewart for the slope- area computation. In addition, Mastin plotted high water marks surveyed by USGS and NHC for the November 2006 and these high water marks define a water-surface slope of 0.00114, very similar to the slope used by Stewart. This new information provided by USGS provides support for the slope-area measurement for the December 1921 flood.

Cities' comment*: The figure on the next page shows NHC's plot of all 13 of the high water marks. Although we cannot speak for NHC, we understand the point NHC was making is that there are alternative slopes which are equally as plausible, from the 13 data points provided by Stewart and the supplemental high water mark survey. NHC states in its March 2010 Re-evaluation of the Magnitude of Historic Floods on the Skagit River Near Concrete Revised Final Report, "While the water surface profile for the November 2006 flood is well defined, it provides little guidance for interpretation of the 1921 HWMs. Stewart's slope-area calculations for reach XS2-XS3 assume a water surface slope of 0.0012 compared with a slope of 0.00076 from the November 2006 data downstream from the gravel bar. USGS interpretation of its 2006 data (relying only on HWMs between XS2 and XS3) shows a slope of 0.00114. There is clearly considerable scope for uncertainty in the slope area measurements which strongly suggest that alternative approaches to estimation of the peak should be considered."*

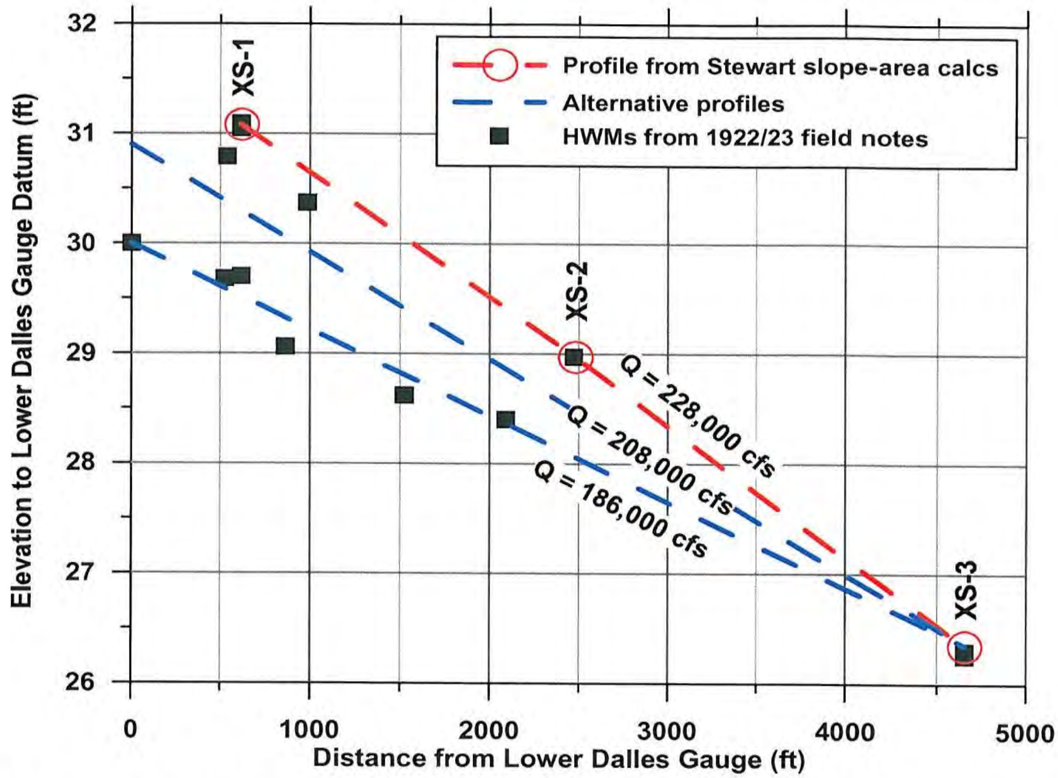


Figure 1: Stewart's 1921 HWMs and water surface profile used in slope area calculations. (Revised from Figure 3 of NHC, March 2010)

The figure on the next page is from page 4 of USGS SIR 2007-5159 and shows the high water marks collected by the USGS within two weeks of the 2006 Skagit flood event. Note that the high water marks collected were limited to the vicinity of XS2 and XS3. At issue is whether this high water mark information, collected only on the lower part of Stewart's slope-area reach, should be used to infer the hydraulic slope for the entire reach.

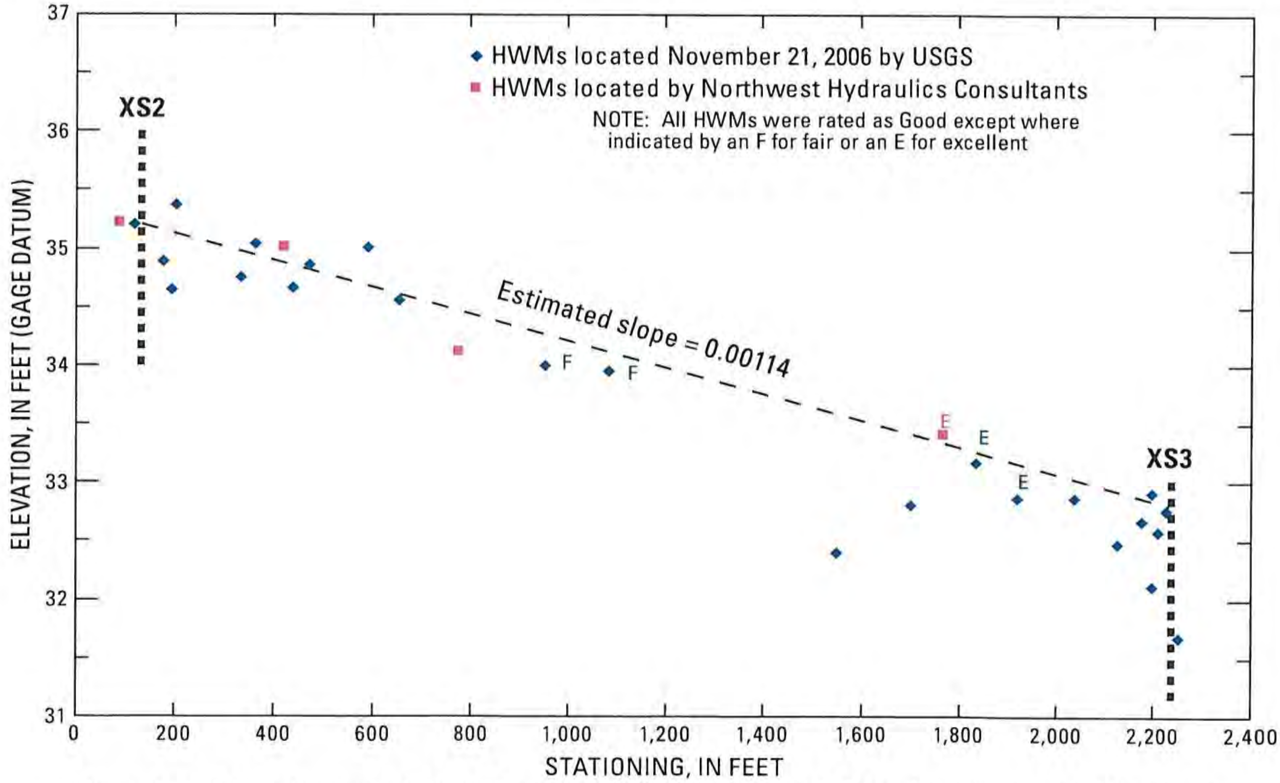


Figure 2. High-water marks (HWMs) from peak flow of November 6, 2006, that was surveyed November 21, 2006, by the U.S. Geological Survey on the right bank between cross sections 2 (XS2) and 3 (XS3) on the Skagit River about 3,000–5,000 feet downstream of the streamflow-gaging station, Skagit River near Concrete, Washington (station No. 12194000).

FEMA infers that the additional high water marks it provided from the supplemental survey performed by Skagit County in March, 1923 provide more and better information to support the slope Stewart calculated. But in fact the additional high water marks from the supplemental survey provide at least as much additional information that would support a much lower slope, as can be seen from NHC's alternate profile plots. It is Pacific International Engineering's opinion that a different slope should be estimated for XS1 to XS2; XS2 to XS3; and XS1 to XS3 and that the slopes should then be averaged.

Summary Comments on the NHC analyses

In summary, the USGS peak discharge for the 1921 flood is considered more reasonable than the NHC (2008) estimated value because:

- It is based on a slope-area measurement made downstream of the Dalles Gorge that is not subject to the HEC-RAS modeling uncertainties.

Cities' comment: *The author of this memorandum overstates the uncertainty of the hydraulic models – both the NHC model and especially the PI Engineering hydraulic model, which will be addressed later. While stressing uncertainties in the hydraulic models, FEMA fails to mention the uncertainties associated with the high water marks themselves, the uncertainty involved with the slope/area methodology in the reach below the Dalles, and the uncertainty associated with the USGS unsupported datum change.*

- The cross-sectional data and high water marks were surveyed in the field by James Stewart approximately 11 months after the 1921 flood.

Cities' comment: *Stewart surveyed the high water marks 11-13 months after the 1921 flood event, starting in late November and continuing through late January 1922-23. Later, a survey crew from Skagit County surveyed additional high water marks in early March 1923 (such marks presumably marked by Stewart to be surveyed later.) We note that the USGS-surveyed high water marks following the flood of record in October 2003 were surveyed in July-August of 2004, about 10 months following the flood. Shown below is a profile of the high water marks collected and surveyed by USGS in the summer of 2004 following the October 2003 flood of record (USGS SIR 2005-5029, p.8). As can be seen from the plot below, the high water marks in the vicinity of cross section XS2 are well clustered. However, the range of high water marks in the vicinity of XS3 indicate that gathering high water marks in this area was a more difficult task than at XS2. And, in the case of XS1, it is clear the difficulty of gathering accurate high water marks is very challenging, likely due to surge effects during the flood itself, and also due to the time interval between the flood and the data collection. We observe that the right bank marks rated "good" are 5-8 feet below the expected water surface elevation. Two left bank marks, both rated "poor," are over 5 feet different.*

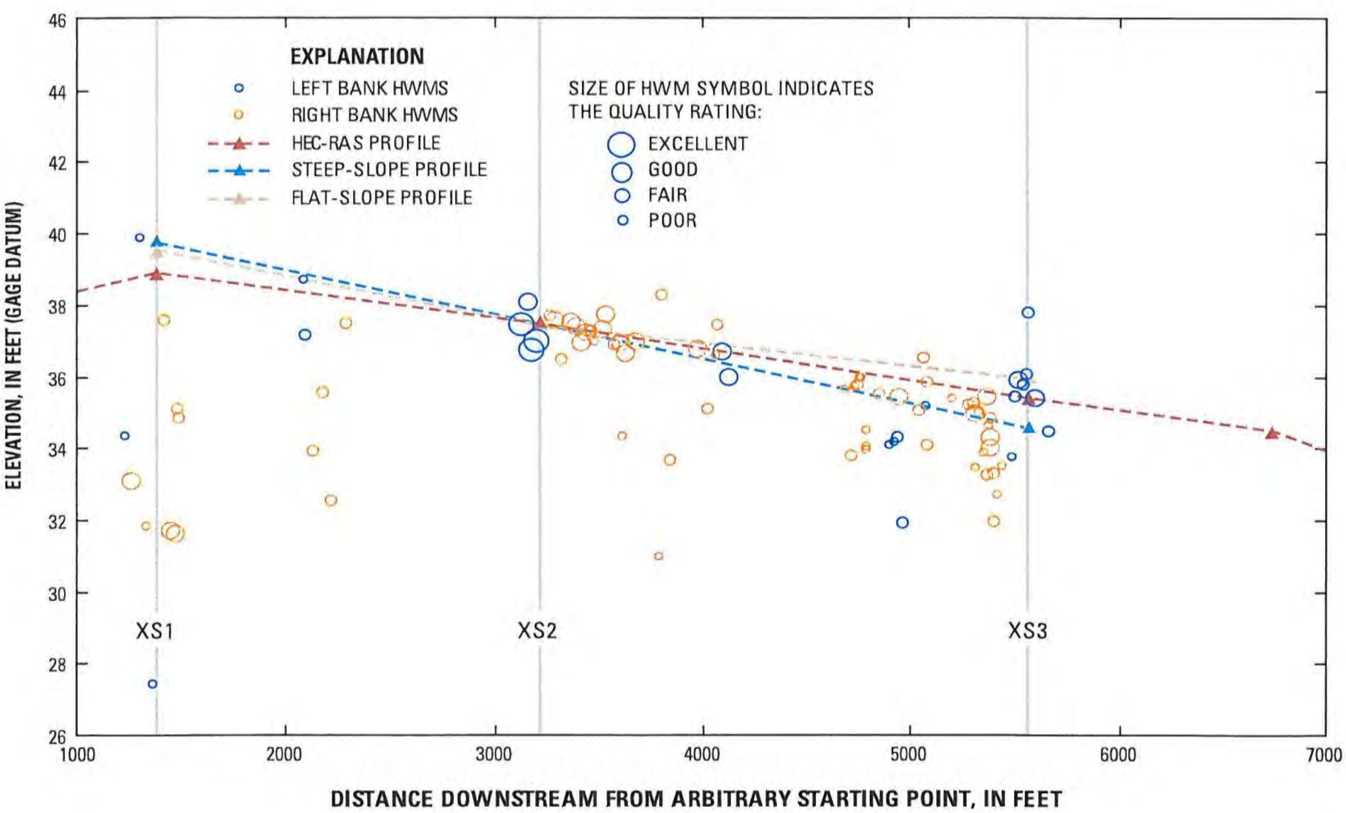


Figure 4. High-water marks (HWMs), flattest- and steepest-sloped water-surface profiles, and a HEC-RAS water-surface profile near cross sections XS1, XS2, and XS3, at Skagit River near Concrete, Washington.

The peak discharge for the October, 2003 flood event at the Concrete gage was 166,000 cfs, which is very similar to PI Engineering's estimate for the peak flow of the 1921 event. Despite the obvious challenge of obtaining accurate high water marks, it has been the position of the cities that Stewart's work should be given deference unless it can be clearly demonstrated that newer methodologies or demonstrated inconsistencies require modification.

- Manning's n values were verified by USGS using data for the November 1949 flood.

Cities' comment: *As commented previously, the USGS has incorrectly applied all HWMs in all of its calculations, by incorrectly assuming these HWMs at the slope sections represented the mean water surface elevations. This assumption is incorrect. We have determined these HWMs are more representative of the energy grade line elevations, based on the USGS velocity measurements at the cableway located upstream of XS3. The USGS has made this incorrect assumption in all of its studies in the slope sections, including the 2005 and 2007 reevaluation studies, and the 1949 n-value verification study. This incorrect HWM application invalidates the USGS 1949 n-value verification study. For discussion of this incorrect application of HWMs, see PI Engineering's March 2011 report, section 2.1.4 and 2.2.6.*

- At least five high water marks surveyed by Stewart and others in 1922-23 support the water-surface profile used in the 1923 slope-area computation and these high water marks are considered more appropriate for estimating the 1921 peak discharge than a high water mark determined from a newspaper article.

Cities' comment: *It is important to note here that none of the high water marks used by the USGS come straight from Stewart's field notes or the subsequent high water mark survey conducted by Skagit County. The table on page 18 summarizes the raw data from Stewart's notes, the subsequent high water marks surveyed by Skagit County, and the changes made to the raw data by USGS.*

Compendium of Stewart's high water marks below the Dalles, 1922-23

Station	Bank	Comment	Source Document and Source Document Explanatory Comment	Survey Elev from source document	Datum Adjustment from Source Document	Datum Elev from source document	msl/NGVD29 from source documents	USGS Datum Adjustment	USGS msl/ NGVD29 Assertion
0+00	R	Site of "Lower Dalles" Gage	3/8/23 supplemental survey notes at the lower Dalles -- "On rotten stump 25' N guage"	30	0	Page 67 Stewart's notes: "datum of lower Dalles gage 141.04"	171.04	1.66	172.7
5+25	R		Supplemental survey notes 3/8/23: "H.W. - Mapletree 60' L. of Line"	29.68	0	141.04	170.72	1.66	172.38
5+38	R		Stewart's notes p.68; 1/31/23: "1921 HW sand in stump 80' upstream from cross section"	27.9	2.89 (see bottom right corner Stewart's notes p. 69)	141.04	171.83	1.66	173.49
6+18	L	Upper slope section XS-1	Stewart's notes, p. 68: "1921 HW mark on tree at L end of cross section"	28.16	2.89	141.04	172.09	1.66	173.75
6+18	R		Stewart's notes, p. 68: "1921 drift"	26.81	2.89	141.04	170.74	1.66	172.4
6+18	R		Stewart's notes, p. 68: "1921 HW mk about OK I think use this"	28.2	2.89	141.04	172.13	1.66	173.79
8+65	unk	High water mark is likely on the right bank	Stewart's notes p. 64-65, 1/30/23: "1921 HW at cedar tree Note Levels of cross sections above and below indicate this probably is in error"	170.1	0	0	170.1	1.8	171.9
9+85	R		Supplemental survey notes 3/8/23: "10" Alder - 50' Left H.W."	30.37	0	141.04	171.41	1.66	173.07
15+25	R		Supplemental survey notes 3/8/23: "H.W. - 30" Hemlock 30' Left"	28.62	0	141.04	169.66	1.66	171.32
20+90	R		Supplemental survey notes 3/8/23: "H.W. 10' Left Line - Moss on Vine Maple - Poorest Evidence"	28.4?*	0	141.04	169.4?	1.66	171.1
24+70	R	Middle slope section XS2 at 2479 feet below lower gauge at the Dalles	Supplemental survey notes 3/8/23: "H.W. 12" Alder 10' L."	28.97	0	141.04	170.01	1.66	171.67
46+55	L	This is the lower slope section, XS-3. Stewart recommended using 24.75 (bottom of pg. 79).	Stewart's notes p. 78-79 1/29/23: "1921 flood mk 1.45' above this TP = Elev 24.74"	24.75**	1.51***	141.04	167.3	1.8	169.1
46+55	R	Stewart recommended using 24.79 (bottom of pg. 79)	Stewart's notes p. 78-79 1/29/23: "about .25 above HI looks like 1921 HW, moss scoured off of tree"	24.79**	1.51	141.04	167.34	1.8	169.14

* The last digit cannot be read from the supplemental survey notes

** Stewart also recommended using 24.80 as the 1921 HWM for both sides of the river at this cross section

*** Water surface 30 Jan 142.35 (pg 64/65). WS 30 Jan 0.2 feet below WS of 29 Jan (p. 65), or 142.55. Lower Dalles gage datum is 141.04. 142.55-141.04=1.51 feet. 1.51+24.79+141.04=167.34

FEMA (2009) is now using one standard error (comparable to a 68-percent confidence interval) to determine if flood discharges are statistically different (November 2009 version of Appendix C: *Guidance for Riverine Flooding Analyses and Mapping*, http://www.fema.gov/library/viewRecord.do?id=2206.) The USACE (2008) unregulated frequency analysis was based on 79 years of systematic record with a historic period of 110 years (1897 to 2007) to include the four historic floods. Assuming the "effective" record length is 95 years (an average of the systematic and historic record lengths), the standard error of the USACE 1-percent annual chance unregulated discharge of 278,000 cfs is +15.5 and -13.4 percent (321,000 cfs and 240,700 cfs, respectively) (Kite, 1988). The NHC (2008) estimate of 254,000 cfs differs from the USACE estimate by about 9 percent, is within one standard error and not statistically different from the USACE estimate using FEMA (2009) criteria.

The NHC (2008) analysis does not warrant revising the USACE (2008) estimate of the 1- percent annual chance unregulated flood discharge. Performing a regulated frequency analysis was apparently not in the scope of work for the NHC study.

Cities' comment: *FEMA could elect to make a change if compelling evidence is provided, even if that change is not required due to policy. The argument that a change in the frequency analysis is not warranted strictly because the recommended changes fall within a very large error range is not in the best interests of the Public due to the long term public safety and economic consequences of an inaccurate analysis. Further, according to FEMA guidelines, if the revised hydrology would affect the base flood elevations significantly, (or more than one foot as is the case here,) the hydrology should be revised.*

PIE (2008) Re-evaluation of the Four Historic Floods

PIE (2008) Approach

PIE (2008) estimated the revised peak discharges for the four historic floods using a different approach than USGS or NHC. The PIE (2008) analysis for the December 1917 and December 1921 floods relies on high water marks surveyed by James Stewart, USGS, at the Wolfe Residence about 2 miles upstream of the Concrete gaging station (RM 54.1) and at the confluence with the Baker River. The PIE (2008) analysis for the November 1897 and November 1909 floods relies on high water marks determined by James Stewart at Savage Ranch (about RM 45.2) and Kemmerick Ranch (about RM 45.2) which are upstream of the Town of Hamilton.

The approach taken for the 1917 and 1921 floods included:

- Develop a 1D steady-state HEC-RAS model for the Skagit River and Baker River using cross sections from the 1976 FIS, cross sections surveyed by Skagit County in 2008 and by PIE in 2004 and with supplemental ground elevations from 2007 Lidar data. PIE developed a second model with revised in-channel sections using data from the 1911 USACE survey.
- Calibrate the HEC-RAS models to high water marks from the October 2003 flood using high water marks at the gaging stations and the Jenkins House in the Crofoot Addition. The downstream starting elevation for the models was provided by USGS for the Concrete gaging station.

Cities' comment: *PI Engineering's model was also calibrated utilizing data from the USGS Baker River gage, which is located just a few hundred yards away from Stewart's high water marks (see hydraulic model cross-section aerial photo schematic, below), as well as the Jenkins residence. These exceedingly unusual circumstances are fortuitous, and enable development of an extremely accurate hydraulic model, because of the proximity of the USGS gage and the stage data provided by this gage.*

- Assume high expansion and contraction losses for the sections in the Dalles Gorge due to two 90-degree turns of the river channel.

Cities' comment: *This comment seems to suggest that head loss through the Dalles gorge must be known exactly in order for the hydraulic model to return accurate estimates for Concrete. This suggestion is in error. We again point out that the hydraulic model utilizes the data from two USGS gages. Any uncertainty about head loss through the Dalles gorge have very little impact on determining water surface elevations at the upstream end of the hydraulic model, because the area of interest is so close to the USGS Baker River gage. The purpose of the model is to estimate the discharge for a backwater stage elevation in the Concrete Crofoot's Addition in order to estimate the discharge for Stewart's Wolf residence high water mark.*

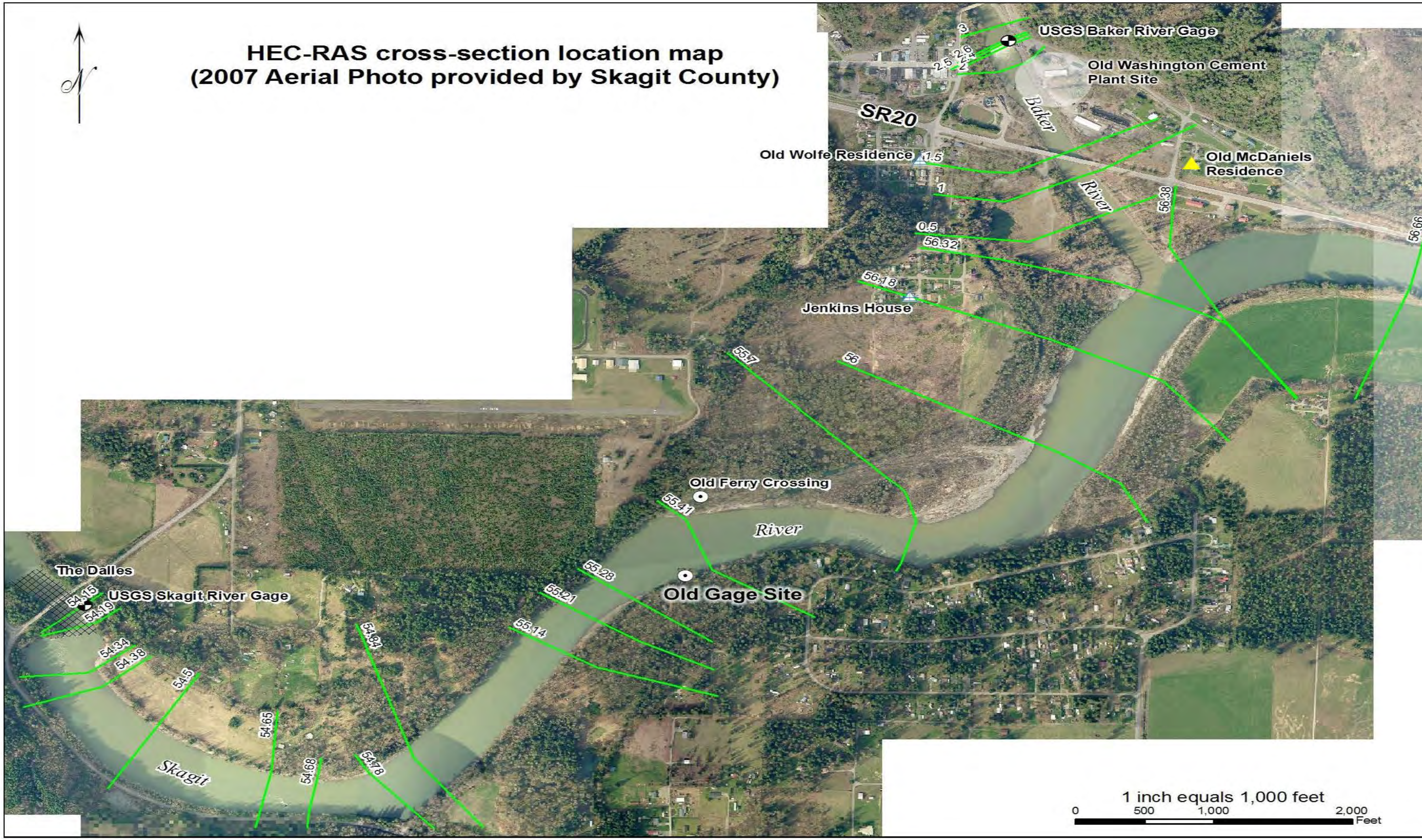
- Develop stage-discharge relations at the Wolfe Residence for the two HEC-RAS models using a range of discharges and estimate peak discharges for the December 1917 and December 1921 floods based on Stewart's high water marks.

PIE (2008) estimated the peak discharges for the 1917 and 1921 floods as 158,700 cfs and 169700 cfs, respectively. These values are shown in Table 1. The HEC-RAS model with cross sections modified from the 1911 USACE was used to estimate the final discharges because it was assumed the 1911 channel conditions were more indicative of conditions during these floods.

The approach taken for estimating the peak discharges for the November 1897 and November 1909 floods included:

- Utilize a modified version of an unsteady HEC-RAS model originally developed by USACE.
- Develop stage-discharge relations at Kemmerick Ranch and Savage Ranch using a range of discharges.
- Utilize the difference in elevation between the 1921 flood and the 1897 and 1909 floods to estimate peak discharges for the 1897 and 1909 floods. The discharge of 169,700 cfs for the 1921 flood, as determined at the Wolfe Residence, was used in these computations.

PIE (2008) estimated the peak discharges for the 1897 and 1909 floods as 181,200 cfs and 179,000 cfs, respectively. These values are shown in Table 1.



HEC-RAS cross-section location map
(2007 Aerial Photo provided by Skagit County)
N
USGS Baker River Gage
Old Washington Cement Plant Site
SR20
Baker
River
Old Wolfe Residence
Old McDaniels Residence
Jenkins House
Old Ferry Crossing
River
Old Gage Site
The Dalles
USGS Skagit River Gage
Skagit
3
2.6
2.5
2.4
2
1.5
1
0.5
56.66
56.38
56.32
56.18
56
55.7
55.41
55.28
55.21
55.14
54.94
54.78
54.68
54.65
54.5
54.38
54.34
54.19
54.15
1 inch equals 1,000 feet
0
500
1,000
2,000
Feet

Comments on the PIE (2008) Approach

For estimating the peak discharges for the December 1917 and December 1921 floods, PIE (2008) used the high water elevations as surveyed by Stewart. There has been much discussion of the datum used by Stewart in determining the elevations of his high water marks. Stewart did most of his field work in 1922-23 before the NGVD 1929 datum was established. However, based on investigations by USGS, PIE and NHC, it appears that the pre-1929 elevations based on mean sea level were close to the NGVD 1929 datum.

Cities' comment: *plus or minus 0.119 feet; see table below.*

HEIGHT DIFFERENCES IN SKAGIT COUNTY, WASHINGTON

Source 1909 Heights		U.S. Geological Survey, Bulletin 674 "Spirit Leveling in the State of Washington"		
Source 1912 Heights		National Geodetic Survey Integrated Database		
Source NAVD 88 Heights		National Geodetic Survey Integrated Database		
USGS to NAVD 88 Average			3.87	All values shown in feet.
Standard Deviation			0.12	

PID	DESIGNATION	NAVD 88	USGS 1909	DIFFERENCE
TR0071	19 B	23.84	19.668	4.172
TR0230	3	7.25	3.339	3.911
TR0232	4	8.18	4.304	3.876
TR0102	9	12.86	8.978	3.882
TR0094	PTS 17	27.58	23.669	3.911
TR0210	D 13	40.31	36.545	3.765
TR0243	E 13	37.54	33.773	3.767
TR0087	F 13	24.91	21.145	3.765
TR0217	G 13	17.32	13.537	3.783
TR0536	K 13	48.15	44.314	3.836
TR0059	S 6	18.73	14.783	3.947

Computed by David Doye, National Geodetic Survey, 10/06/2008

3.874090909
0.119111254

There was no gaging station on the Skagit River when Stewart was conducting his 1922- 23 field investigations so he established an inclined staff gage (called the upper Dalles Gage) about 200 feet upstream of the location of the existing recording stations.

Cities' comment: *The location of this gage was actually 300 feet upstream of the location of today's USGS station (see previous discussion at page 9). This is important because Stewart surveyed 1921 high water marks at the upper Dalles gage, and these high water marks were later transferred directly to the current gage location without any adjustment for head loss through this gorge, which is significant through the gorge in this area and would amount to 1 – 2 feet in a flood of the magnitude of 1921.*

Recent new data collected by Skagit County strongly supports our assertion that these high water marks should have been adjusted for the head loss that is occurring, and did occur in 1921 in this 300-foot reach. Pursuant to suggestions by the USGS to obtain head loss data through the Dalles gorge, Skagit County in November, 2010 installed several crest stage gages upstream and downstream of the current USGS gage location. As it happened, a minor Skagit flood occurred on December 12, 2010, triggering a reading on one of the crest stage gages 200 feet upstream from the current USGS gage. The USGS stage elevation for this minor flood, with a discharge of 81,900 cfs at the Concrete gage, was 161.22 feet NGVD 29. The crest stage gage reading 200 feet upstream was 162.27 feet, for a difference of 1.05 feet in a 200-foot distance. This data strongly infers an estimate of a 2-foot drop between Stewart's upper Dalles gage, located 300 feet upstream of the current USGS gage for the 1921 flood is very reasonable and probably too conservative for a flood discharge in the neighborhood of 170,000 cfs.

(continued) Documentation provided by the USGS indicates that the upper Dalles Gage and the existing recording station are at the same datum.

Cities' comment: *This is not correct. The USGS has no evidence that the datum was properly reconciled between the upper Dalles gage and the current gage location. The direct evidence (Stewart's field notes), points the other way. See also the memo submitted with these materials by PSE Surveyors that addresses the datum issue.*

Information on the datum issue includes the following facts:

- The USGS used a datum of 142.7 ft for the upper Dalles Gage to convert the elevations of the historic floods as surveyed by Stewart to NGVD 1929. This yields an elevation of 177.6 ft for the December 1921 flood at the current gaging station at Concrete (12194000).

  Cities' comment: *See discussion above at page 9 regarding the direct shift of high water marks downstream 300 feet through a river gorge without consideration given for the hydraulic grade line.*

- PIE (2008) has pointed out information in Stewart's field notes that indicates the datum used by Stewart was actually 140.9 ft which gives an elevation of 175.8 ft for the December 1921 flood at the Concrete gaging station.

  Cities' comment: *Stage elevation of the 1921 flood at the current gage location should conservatively be estimated no higher than 174 feet to account for hydraulic fall and surge – see previous discussion).*

- PIE (2008) used the lower elevations for the gaging station and high water marks as reported in Stewart's draft report in their HEC-RAS model.

Cities' comment: *This statement is in error. The high water information used by PI Engineering did not come from a "draft report," but directly from Stewart's field notes. Later, the USGS provided additional high water mark survey information detailed in the field notes of a Skagit County survey performed in March, 1923. All of this survey data was tied to the datum of either the upper Dalles or lower Dalles gages, set by Stewart, with the datum for each annotated in Stewart's field notes. Stewart was experienced in field work and understood the importance of establishing an accurate datum for each of these gages (refer to the "Height Difference in Skagit County, Washington" table on p.22 above.*

In addition, PIE used the 1911 USACE in-channel data which contributes to lower discharges because the in-channel elevations for the 1911 data are higher (less cross sectional area) than the current cross-sectional data.

- A November 5, 2008 letter from Mark Mastin, USGS, Tacoma, to representatives of PIE, NHC and Skagit County, summarizes the available information on the datum issue. When the recording station was established in 1924, it was set to the same datum as the inclined staff gage (upper Dalles Gage) upstream. The datum of the recording station was later determined to be 142.7 ft NGVD.
- The evidence provided in the November 5, 2008 USGS letter is not conclusive but the preponderance of information indicates that the datum of the upper Dalles Gage (inclined staff gage) is likely 142.7 ft NGVD.

Cities' comment: *Gage historical information provided by the USGS indicates the new gage was set to the same datum as the upper Dalles gage. But Stewart's field notes p.89 clearly indicate the datum of the upper Dalles gage was 140.89 feet, not 142.7 feet. We are aware of no documentation explaining how the datum was changed to 142.7 feet. The cities therefore question how and why the datum was changed from Stewart's field notes. See memorandum on the datum issue provided by PSE surveyors.*

- This implies that 1.8 ft should be added to the high water marks for the 1917 and 1921 floods as reported by Stewart and used in the PIE (2008) HEC-RAS analysis.

Cities' comment: *We are aware of no evidence to support this conclusion.*

If a high water mark of 186.35 ft is used at the Wolfe Residence rather than 184.55 ft (as reported by Stewart), then PIE's estimate of the December 1921 flood becomes about 183,000 cfs using the 1911 cross-sectional data and about 188,000 cfs using the current cross-sectional data. PIE's estimates of the December 1921 flood ranged from 169,700 cfs to 173,900 cfs.

Cities' comment: *In the vicinity of the Wolf residence in the Crofoot's Addition to Concrete, Stewart surveyed this high water mark directly from a USGS benchmark located in Concrete (the survey is annotated in Stewart's field notes (pp.22-23) and was not difficult to establish, with just seven turning points.) In addition, Stewart surveyed the high water mark twice, coming within 2/100's of a foot (see Stewart's field notes, pp.30-33). The bench mark used by Stewart (see field notes p.22, "230.51 BM USGS") has been verified from the USGS publication, "Bulletin 674, Spirit Leveling in the State of Washington, 1897 to 1917, Inclusive", p.78:*

Baker, 0.25 mile west of, at bottom of hill, 40 feet north of fence corner, 50 feet north of road, in granite boulder; copper bolt stamped "231 T. U. L.".. 230.506

Although this benchmark no longer exists, it is difficult to make the case that Stewart did not accurately perform the survey (and no evidence has been uncovered to suggest that Stewart's survey was in error.) It has been suggested that the USGS benchmark may have been moved or adjusted in some way. But given that Stewart was a competent surveyor, it seems unlikely he would have used the benchmark if he had suspected it had been moved or altered in some way, especially by nearly two feet.

One would think that the 1911 cross-sectional data is more representative of conditions in 1917 and 1921 than more recent cross sections surveyed since 1976 but there may be accuracy or datum issues with the 1911 data. In places the 1911 streambed elevations differ by several feet from the current cross-sectional data and through the Dalles Gorge, the 1911 streambed elevation is more than 10 feet higher than the current elevation.

Cities' comment: *By this comment, FEMA suggests that there are accuracy or datum issues with the 1911 data; however, there is no evidence upon which to base this assertion. If it were an objective of the hydrologic study to develop a conservative estimate of the 1921 historic flood event, then one could argue that using the current cross-sectional data is more conservative in light of the information provided by the 1911 streambed elevation survey. But that argument would have no factual support, and it would be inconsistent with determining the most accurate estimate of the 1921 flood event. Therefore, we believe it is best to use the 1911 cross-sectional information. We have no reason to question the accuracy of this information.*

In summary, the USGS peak discharge for the December 1921 flood and the other three floods are considered more reasonable than the PIE (2008) estimated discharges for the following reasons:

- The PIE (2008) revised peak discharges for the four historic floods were based on elevations that are likely 1.8 ft too low. If the elevations of the four historic floods are increased by 1.8 ft, then the historic peak discharges will increase by about 10 percent.

Cities' comment: *We observe that the written record, including Stewart's field notes, not only supports the use of the high water marks used in the PI Engineering analysis, but also brings into question the use of ay historic flood stage information that is tied to a different datum than that of Stewart's upper Dalles gage.*

- The 1911 cross-sectional data as used by PIE differs in places by several feet with the current data and raises questions about the accuracy or datum of the 1911 data.

Cities' comment: *This cross-sectional data from the 1911 survey exists, was completed by the US Army Corps of Engineers, and was completed with a substantial effort. In sum, this data is credible and should be used.*

- The PIE (2008) HEC-RAS steady state analysis is subject to the same uncertainties of using the high expansion/contraction coefficients in the Dalles Gorge as discussed for the NHC (2008) analysis.

Cities' comment: *This is not correct. See previous discussion at p.20 explaining why the PI Engineering hydraulic model is accurate; notably, because it is tied at its upstream end, to a USGS gage only a few hundred yards away from the 1921 and 1917 high water marks surveyed by Stewart.*

- The USGS slope-area measurement made downstream of the Dalles Gorge is not subject to the HEC-RAS modeling uncertainties.

Cities' comment: *The USGS slope-area measurement made downstream of the Dalles gorge is subject to the accuracy of the high water marks, including USGS' unsupported datum assertion. Conversely, the HEC-RAS modeling approach does not depend on resolving the datum issue at the Dalles, relies on high water marks that are very high quality (both in 1922 and the high water marks available for the 2003 flood event), and is very accurate due to the proximity to the USGS Baker River gage.*

- The cross-sectional data collected for the slope-area measurement were obtained approximately 11 months after the flood and should be more pertinent to channel conditions during the 1921 flood.

Cities' comment: *Although the cities concur, the bottom slope section should be modified to account for rope stretch, as Stewart indicated.*

- Manning's n values were verified by USGS using data for the November 1949 flood.

Cities' comment: *The cities observe that the USGS determined the 1949 information was compelling enough to override Stewart's on-site judgment that he made based on his observations of the Dalles area less than a year after the 1921 flood event.*

- Thirteen high water marks were surveyed by Stewart and others in 1922-23 for the slope-area reach downstream of the Concrete gaging station for the December 1921 flood. At least five of these high water marks support the water-surface slope used in Stewart's slope-area computation.

Cities' comment: *At least six others support using a lower slope.*

PIE (2008) used their revised estimates of the four historic floods and unregulated peaks for the observed record in a Bulletin 17B analysis (IACWD, 1982) to obtain a 1-percent annual chance unregulated discharge of 240,800 cfs. The PIE (2008) estimate is about 13 percent less than the USACE estimate of 278,000 cfs. As discussed earlier, plus and minus one standard error about the USACE estimate is 321,000 cfs and 240,700 cfs, respectively, so the PIE estimate is within this error band and not statistically different based on FEMA (2009) criteria.

Cities' comment: *A policy argument such as that advanced here is not relevant to a technical analysis. To illustrate further, FEMA would not revise its hydrologic analysis even if it agreed with every point made by PI Engineering and NHC.*

PIE (2010) Additional Information

For the March 17, 2010 meeting, PIE provided a "Technical Memorandum – Review and Reevaluation of Skagit River 1921 Flood Peak Discharge", dated March 2010. This memorandum discussed the datum issue for the Stewart high water marks, deficiencies in the Stewart's slope-area computation, reevaluation of the December 1921 peak discharge using revised data for the slope-area measurement, and using the stage-discharge relation at the Concrete gaging station.

The **new** information and data summarized in the PIE (2010) Technical Memorandum are briefly described as follows:

- Low-flow water surface elevations surveyed by Stewart in December 1922 and January 1923 were compared to those surveyed by USACE in 1911 and PIE and Skagit County in 2004 and 2008. The discharges at the time of the surveys were estimated primarily using daily flows recorded downstream at the Sedro Woolley gaging station (12199000). The comparisons provided by PIE indicated that the low-flow elevations surveyed by Stewart agreed more closely with elevations surveyed by others using Stewart's datum of 140.9 ft NGVD rather than 142.7 ft NGVD as used by USGS.
- PIE's issues with Stewart's slope-area measurement included use of the incomplete energy equation, possible incorrect flow area for cross section 3, unsupported water-surface slope for the upper slope-area reach (cross section 1 to 2), and the effect of surging on the high water marks.
- PIE made revisions in the slope-area measurement and did some sensitivity tests with different n values and revised the high water mark elevations for the December 1921 flood by subtracting -0.5 to 2.0 feet of surge.
- PIE also estimated a revised peak discharge for the December 1921 flood by transferring Stewart's high water marks to the current gaging station and using the current stage-discharge relation.

As described in the PIE (2010) Technical Memo, "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". The low-flow elevations obtained by Stewart in 1922-23 were compared to USACE elevations surveyed in 1911 and those by PIE and Skagit County in 2004 and 2008, respectively. It is likely that the low-water channel did change over time as significant floods occurred between the different surveys. Additionally is not clear that the low-water elevations obtained by the different parties were in the same location. For these reasons, the low-flow elevation comparisons made by PIE are not a compelling reason to conclude that the USGS datum of 142.7 ft NGVD is incorrect.

Cities' comment: *The data we have presented speaks for itself. We believe it provides relevant supplemental information which adds to the discussion on the datum issue.*

PIE made several revisions to the input data for the slope-area measurement and determined lower peak discharges for the December 1921 flood than published by USGS. The use of the incomplete energy equation by Stewart is not a factor because Mastin (2007) recomputed this measurement using the complete energy equation. With regard to the incorrect flow area for cross section 3, Stewart's judgment and decisions at the time of the measurement should be more reliable than making judgments over 80 years later. The water-surface slope used by Stewart in the slope-area measurement is supported in the upper slope-area reach by high water marks documented in Mastin's May 6, 2010 letter. Lastly, reducing the high water mark elevations for surge is highly subjective and, as discussed in Mastin's May 6, 2010 letter, the variation in the elevations of the high water marks was due as much to differences in timing and types of marks and their resulting quality than to any surge effect. PIE's revised estimates of the December 1921peak discharge ranging from 177,000 to 184,000 cfs are not considered as reasonable as the USGS published value of 228,000 cfs.

Cities' comment: *After PI Engineering completed its HEC-RAS modeling of the Dalles-to-Concrete reach of the Skagit River, and used that model to estimate the 1921 flood discharge, it became apparent a substantial discrepancy existed. In subsequent meetings with the USGS, USGS staff members were also surprised the two methodologies produced such significant variation. PI Engineering's re-analysis using the slope/area method and data from below the Dalles shows how the data also supports a much lower discharge estimate. There is certainly much room for uncertainty in this reach and that is the reason PI Engineering developed a better methodology for estimating the 1921 flood's peak discharge. PI Engineering's approach eliminates questions about the datum issue in the Dalles; eliminates questions about the accuracy of the high water marks in the Dalles slope sections; eliminates questions about the furthest downstream cross section; reduces uncertainty about the correct n-value to use, and eliminates the uncertainty regarding the correct slope (or slopes) to be applied to the sections below the Dalles.*

PIE's use of the current stage-discharge relation at the Concrete gaging station involves assumptions about the locations of the high water marks, and locations of the old gages and the slope of the water surface between them.

Cities' comment: *PI Engineering made no assumptions about the locations of high water marks or the locations of the old gages. The high water mark information and the gage locations were taken directly from Stewart's notes and are well-documented. Similarly, PI Engineering made no assumptions about the slope of the water surface between the upper Dalles gage and the lower Dalles gage. The datum for both of these gages is clearly documented in Stewart's notes (pp. 67 and 87). Further, the high water marks surveyed by Stewart and the County's survey team are also clearly documented for those gage locations (see previous table, page 18).*

(continued) These assumptions are not consistent with information provided by USGS. A further assumption is that the datum of 140.9 ft NGVD is applicable for the Stewart high water marks. As discussed above, the preponderance of information provided by USGS indicates the datum for the Stewart high water marks was 142.7 ft NGVD.

Cities' comment: *PI Engineering's use of Stewart's 140.89 NGVD datum (p. 89 of Stewart's field notes) is not an assumption. This information came directly from Stewart's field notes, based on calculations shown in his notes. Stewart was a competent hydraulic engineer and surveyor, and a competent field person. That competence is reflected in his notes. One must presume Stewart understood the importance of accurately determining the datum of the Dalles gages. This was documented in his field notes. PI Engineering used those exact figures. On the other hand, the USGS can produce no documentation showing how the datum for the new gage, which is located between the upper Dalles and lower Dalles gages, was set to an elevation approximately 1.8 feet higher than Stewart's upper Dalles gage. One set of gage statiion notes indicates that the datum of the new gage was set to Stewart's upper Dalles gage (140.89 feet msl (same as NGVD; subsequent gage notes indicate a datum of the gage to be 142.7 feet. Lacking any documentation about how or why this datum change was made, we assert that the datum for Stewart's high water marks must be 140.89 feet, and not 142.7 feet. Stewart's datum is the only datum for which there is written documentation.*

(continued) PIE's revised estimate of 178,000 cfs for the December 1921 peak discharge using the current stage-discharge relation is not considered as reasonable as the USGS published value of 228,000 cfs.

Cities' comment: We respectfully disagree and we believe that our technical analysis significantly reduces the uncertainty surrounding the USGS methodology.

Unregulated Frequency Analyses

The unregulated flood frequency estimates developed by USACE, NHC and PIE for the Skagit River near Concrete, WA are summarized in Table 2. The differences are primarily related to the different estimates of the four historic floods.

Table 2. Summary of unregulated flood discharges for the Skagit River near Concrete, WA (12194000).

Source	10-percent discharge (cfs)	2-percent discharge (cfs)	1-percent discharge (cfs)	0.2-percent discharge (cfs)
USACE (2008)	159,000	241,000	278,000+	373,000
NHC (2008)	153,000	222,000	254,000	325,000
PIE (2008)	146,800	212,100	240,800	309,500

+ Plus and minus one standard error 321,000 cfs and 240,700 cfs, respectively.

Regulated Frequency Analyses

USACE (2008) developed unregulated mean daily flow data for the Skagit River using natural flow data for major tributaries like Thunder River, Sauk River, Cascade River and Baker River. The unregulated mean daily flows and regression equations were used to estimate peak unregulated flow and 3-day flows. These data were used to develop balanced flood hydrographs for several frequencies including the 10-, 2-, 1- and 0.2- percent annual chance floods using the October 2003 flood to shape the hydrographs. The unregulated hydrographs were then routed through the reservoirs to produce a consistent set of regulated data.

PIE (2008) used the USACE unregulated flood hydrographs and HEC-5 and HEC-RAS models to develop their own regulated flow estimates for the 10-, 2-, 1- and 0.2-percent annual chance floods at the Concrete gaging station. PIE first performed a frequency analysis using the observed regulated record from 1956 to 2007 at the Concrete gaging station. The regulated routed flows for the 10-, 2-, 1- and 0.2-percent annual chance events were then compared to the observed frequency curve for the period 1956 to 2007. The data are compared in Figure 2 which is Figure 21 in the PIE (2008) report.

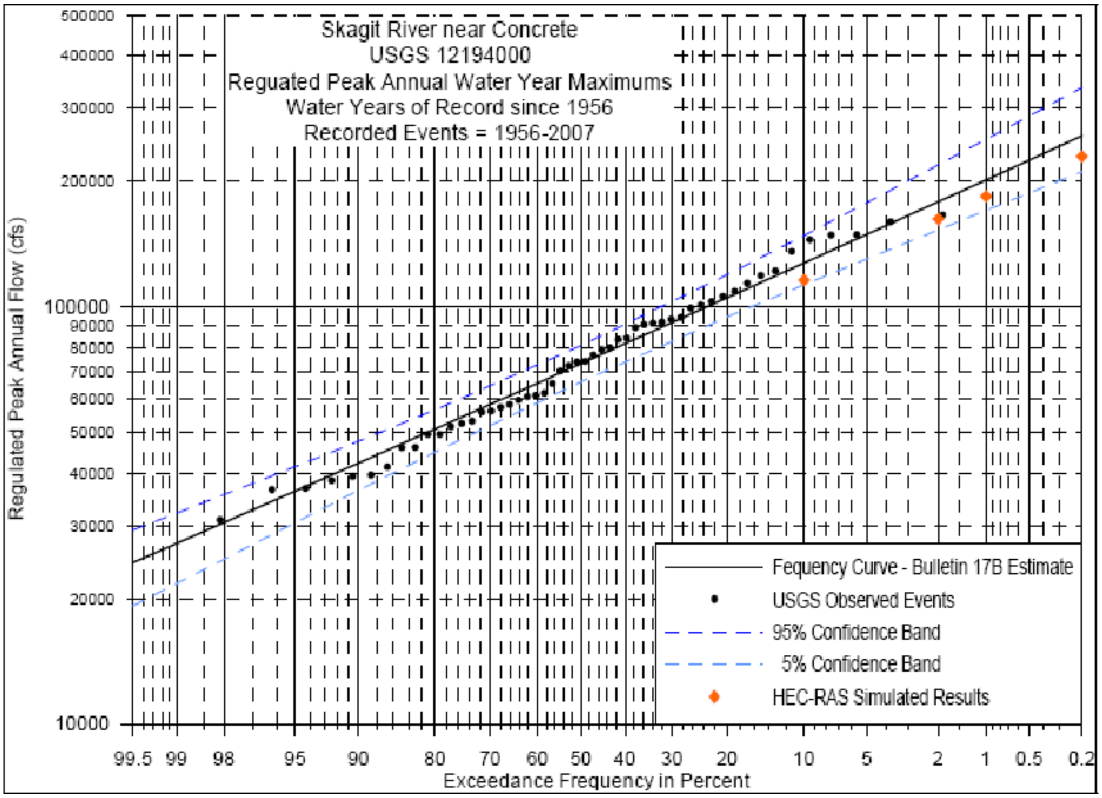


Figure 2. Flood frequency curve for regulated peak discharges observed by USGS at Concrete compared with the HEC-RAS simulated regulated peak flows at Concrete (Figure 21 from PIE (2008)).

The HEC-RAS routed flows in Figure 2 for the 10-, 2-, 1- and 0.2-percent chance floods are less than the regulated frequency curve based on the observed record from 1956 to 2007. The unregulated flood hydrographs that were routed to give the HEC-RAS simulated results in Figure 2 were based on the four historic floods and other unregulated peak data from 1925 to 1955. The PIE (2008) estimates of the four historic floods have been significantly reduced from those published by USGS and their impact on the regulated frequency curve is now minimal.

The USACE (2008) and PIE (2008) regulated and unregulated flood discharges and their ratios are summarized in Table 3 (on the following page). A confidence limits analysis for the USACE (2008) regulated frequency curve indicates that plus and minus one standard deviation for the 1- percent annual chance flood of 209,490 cfs are 244,300 cfs and 179,600 cfs, respectively. The PIE (2008) 1-percent annual chance discharge of 184,400 cfs falls within one standard deviation and is not statistically different from the USACE estimate according to FEMA (2009) criteria.

Table 3. Summary of regulated and unregulated flood discharges in cubic feet per second (cfs) and their ratios for the USACE (2008) and PIE (2008) analyses.

Event	USACE regulated	USACE unregulated	USACE ratio	PIE regulated	PIE unregulated	PIE ratio
10-percent	116,300	159,000	0.731	116,100	146,800	0.791
2-percent	180,260	241,000	0.748	162,600	212,100	0.767
1-percent	209,490	278,000	0.754	184,400	240,800	0.766
0.2-percent	316,530	373,000	0.849	229,400	309,500	0.741

As shown in Table 3, the ratio of the regulated to unregulated flood discharges for the PIE analysis is actually decreasing as the flood event becomes more extreme while the USACE ratio increases as it should. As the magnitude of the flood event increases and the flood storage in the reservoirs decreases, the regulated and unregulated flood discharges should converge. At the 0.2-percent annual chance event, the PIE (2008) unregulated and regulated frequency curves are still diverging. This is illustrated in Figure 3. The skew for the PIE (2008) regulated frequency curve is about -0.35 and -0.142 for the unregulated curve implying they are diverging.

The available flood storage in the Skagit River reservoirs includes 74,000 acre-feet for Upper Baker Reservoir and 120,000 acre-feet for Ross Reservoir for a total of 194,000 acre-feet. This amounts to 71 acre-feet of storage per square mile for the 2,737-squaremile watershed upstream of Concrete. The dedicated flood storage is not a significant amount and one would expect to see the 1- and 0.2-percent annual chance regulated flood discharges converging with the unregulated values.

This is the case for the USACE (2008) analyses as shown in Table 3 (above) and in Figure 4 (p.33). The skew for the USACE (2008) regulated frequency is about 2.0 and 0.0 for the unregulated curve implying the frequency curves are converging.

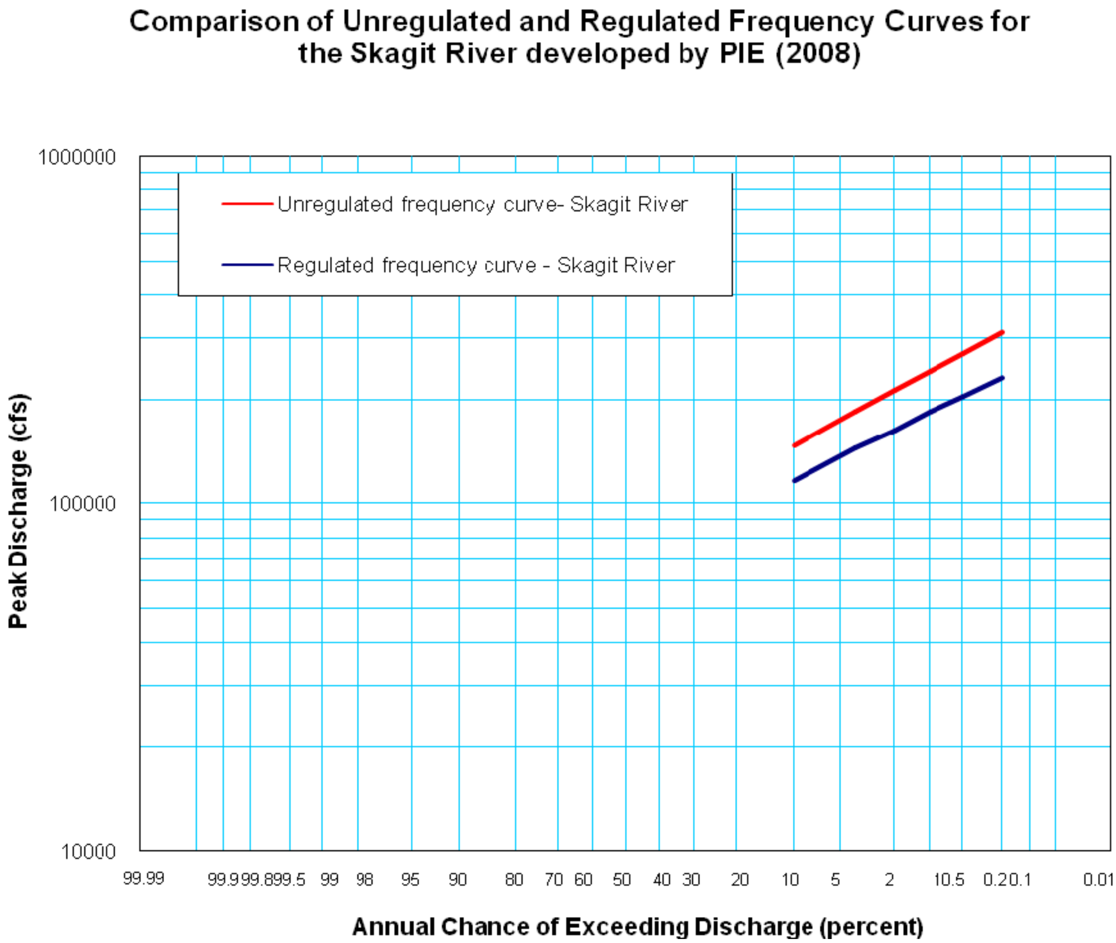


Figure 3. Comparison of unregulated and regulated frequency curves for the Skagit River near Concrete, WA as develeped by PIE (2008).

The diverging of the regulated and unregulated frequency curves was prevalent in an earlier 2005 analysis performed by PIE. This issue was discussed in a February 2006 review by FEMA. In response to the FEMA 2006 review, PIE pointed out that their 2005 frequency curves would converge at about 4 times the 1-percent annual chance flood discharge. This may also be the case for the PIE (2008) analysis that the frequency curves will converge for some very large flood event. However, it seems the PIE (2008) regulated and unregulated frequency curves should be converging for a large flood like the 0.2-percent chance flood given the dedicated flood storage (71 acre-feet per square mile) in the Skagit River watershed.

Cities' comment: *The above simplistic analysis is inaccurate. See PI Engineering's March 2011 report, section 2.6.*

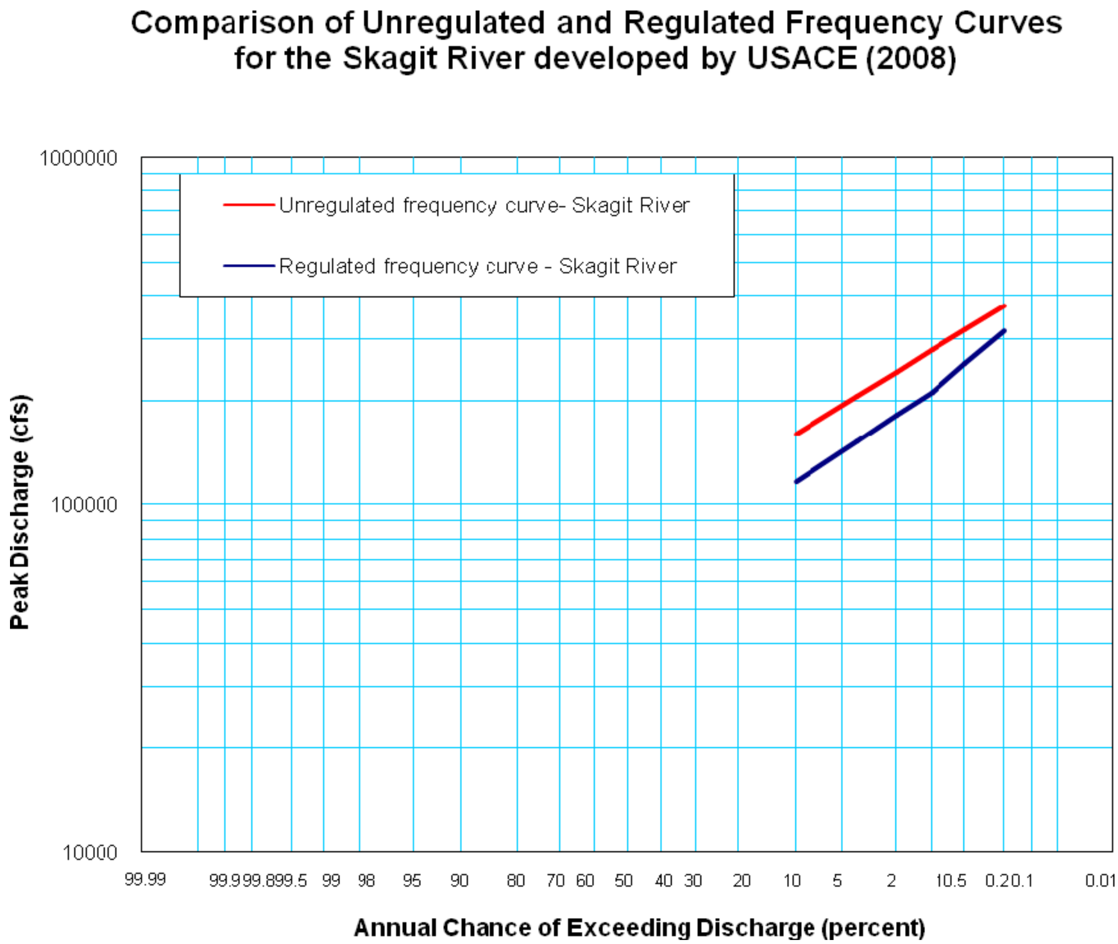


Figure 4. Comparison of unregulated and regulated frequency curves for the Skagit River near Concrete, WA as develeped by USACE (2008).

Summary

A major issue with flood frequency analyses for the Skagit River near Concrete is the magnitude of the peak discharges for four historic floods that occurred in November 1897, November 1909, December 1917, and December 1921. The values for these floods were originally published by USGS in 1961 and recently revised by Mastin (2007). However, some local communities believe the revised values are still too high. The magnitudes of the four historic floods as published by USGS are larger than any estimated unregulated peaks in the observed record since 1925. USACE (2008) used the USGS published discharges in flood frequency analyses in support of a Flood Insurance Study for FEMA.

Analyses by NHC (2008) and PIE (2008) resulted in different estimates of the four historic floods. These analyses were reviewed to determine if different values should be adopted for the Flood Insurance Study.

Based on this review, it was concluded that the USGS estimated peak discharges for the four historical floods were more reasonable because:

- The NHC (2008) and PIE (2008) HEC-RAS steady state analyses are subject to the uncertainties of using the high expansion/contraction coefficients in the Dalles Gorge.

Cities' comment: *FEMA's inference that PI Engineering's hydraulic model contains uncertainty due to unknown expansion/contraction coefficients in the Dalles is misleading and unsupported. The model is very accurate due to its upstream proximity to a USGS gage. Further, sensitivity runs of the model demonstrated that varying the expansion/contraction coefficients in the Dalles vicinity had almost no impact on the results returned by the model 2 miles upstream which was linked to the USGS gage data only a few hundred yards away from the point of interest. We consider this hydraulic model to be much more accurate than the USGS slope/area methodology below the Dalles gorge, and contrary to FEMA's assertions here, much less subject to uncertainty. See PI Engineering's March 2011 report, section 2.3.3.*

- The USGS estimates were based on a slope-area measurement made downstream of the Dalles Gorge that is not subject to the HEC-RAS modeling uncertainties.

Cities' comment: *FEMA fails to mention the significant uncertainty surrounding the slope/area methodology in the slope sections below the Dalles, including:*

- *Whether the slope used by USGS is supported by the high water marks*
- *Whether the USGS change to Stewart's n-value was defensible*
- *Whether the lower slope section should be modified to account for rope stretch as PI Engineering demonstrated*
- *Whether the high water marks noted by Stewart had factored in surge. A letter written by Stewart in 1950 noted that this was a concern*
- *The USGS unsupported upward datum adjustment of 1.8 feet*
- *The accuracy, overall, of the high water marks in light of the difficulty the USGS experienced attempting to gather high water marks in the same reach following the 2003 flood of record 10 months after that flood; and less than two weeks following a smaller flood that occurred in 2006.*

See PI Engineering's March 2011 report, sections 2.1.4 and 2.2.6.

- The cross-sectional data and high water marks were surveyed in the field by James Stewart, USGS, approximately 11 months after the 1921 flood.
- Thirteen high water marks were surveyed by Stewart and others in the slope-area reach downstream of the Concrete gaging station for the December 1921 flood. At least five of these high water marks support the water-surface slope used in the slope-area computation.

Cities' comment: *FEMA fails to mention that the USGS adjusted all of Stewart's high water marks upward by 1.66 or 1.8 feet (see table at page 18). Additionally, the set of 13 high water marks can also be used to support an argument for a lower slope. The USGS chose to use the highest plausible slope. See PI Engineering's March 2011 report, sections 2.2.5 and 2.2.6.*

- Manning's n values were verified by USGS using data for the November 1949 flood.

Cities' comment: *As commented previously, the USGS has incorrectly applied all HWMs in all of its calculations, by incorrectly assuming these HWMs at the slope sections represented the mean water surface elevations. This assumption is incorrect.*

We have determined these HWMs are more representative of the energy grade line elevations, based on the USGS velocity measurements at the cableway located upstream of XS3. The USGS has made this incorrect assumption in all of its studies in the slope sections, including the 2005 and 2007 reevaluation studies, and the 1949 n-value verification study. This incorrect HWM application invalidates the USGS 1949 n-value verification study. For discussion of this incorrect application of HWMs, see PI Engineering's March 2011 report, section 2.1.4 and 2.2.6.

- The PIE (2008) revised peak discharges for the four historic floods were based on elevations that are likely 1.8 ft too low.

Cities' comment: *This comment is incorrect. Based on research of the source documents, PI Engineering has determined there is no basis for applying Stewart's historic flood high water marks to a datum of 142.7 feet. The gage datum should be 140.89 feet (mean sea level, which is very close to NGVD29), as indicated in Stewart's field notes, p.87. The high water information used by PI Engineering source directly from Stewart's field notes and a subsequent Skagit County survey performed after Stewart had left the area. All of this survey data was tied to the datum of either the upper Dalles or lower Dalles gages, set by Stewart, with the datum for each annotated in Stewart's field notes. Stewart was experienced in field work and understood the importance of establishing an accurate datum for each of these gages. For additional information about the incorrect 1.8 foot datum shift applied to Stewart's high water marks by the USGS, see PI Engineering's March 2011 report, section 2.2.2, and also March 29, 2011 letter from PSE surveyors, both under separate cover.*

(continued) If the elevations of the four historic floods are increased by 1.8 ft, then the PIE (2008) historic peak discharges will increase by about 10 percent.

- The 1911 cross-sectional data as used by PIE differs in places by several feet with the current data and raises questions about the accuracy or datum of the 1911 data.

Cities' comment: *This comment is speculative and incorrect. No questions have been raised about the datum of the 1911 channel survey. The differences in river bed elevations are expected, and due to river hydraulic forces. The largest river bed change has occurred in the lower Dalles, where the river bed materials are sand and gravel, and where flow velocity can reach as high as 15-20 feet per second during the peak of a major flood, and as low as 2-3 feet per second during low flow periods. Several feet of river bed elevation change is not unusual in this case. There are many places where river bed elevations have changed from time to time. This comment attempts to cast doubt generally on PI Engineering's technical study without any supporting arguments based on specific information – i.e., the Corps of Engineers data compared to more recent cross-sectional data. PI Engineering has made these specific comparisons and has reasonably concluded that the Corps of Engineers 1911 cross-sectional information should be used.*

Because the USGS estimated historic flood discharges are considered more reasonable, they should be used in the USACE (2008) analyses. The unregulated flood discharges as estimated by USACE (2008) are considered more reasonable than those from the PIE (2008) and NHC (2008) analyses. However, as shown in Table 2 (p.29)` the NHC (2008) and PIE (2008) estimates of the unregulated 1-percent annual chance flood are within one standard error of the USACE (2008) estimate and are not considered statistically different from a hydrologic perspective using FEMA criteria (2009).

For the USACE (2008) regulated 1-percent annual chance flood of 209,490 cfs, plus and minus one standard deviation are 244,300 cfs and 179,600 cfs, respectively (+16.6 and -14.3 percent). The PIE (2008) regulated estimate of 184,400 cfs falls within this interval and is not considered statistically different from a hydrologic perspective using FEMA (2009) criteria. However, it is recognized that differences of about 15 percent in the 1- percent annual chance discharge represents about 30,000 cfs and could mean a difference of approximately 2 feet in the water-surface elevation for the with-levees condition.

Based on this review, it was concluded that no changes are warranted in the USACE (2008) hydrologic analysis.

References

Federal Emergency Management Agency, 2009, *Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix C: Guidance for Riverine Flooding Analyses and Mapping*: Washington, DC, November 2009 (http://www.fema.gov/library/viewRecord.do?id=2206).

Interagency Advisory Committee on Water Data, 1982, *Guidelines For Determining Flood Flow Frequency*: Bulletin 17B of the Hydrology Subcommittee, Office of Water Data Coordination, U.S. Geological Survey, Reston, Virginia, 183 p.

Kite, G.W., 1988, *Frequency and Risk Analyses in Hydrology*, Water Resources Publications, Littleton, Colorado, 257 p.

Mastin, M. C., 2007, *Re-evaluation of the 1921 Peak Discharge at Skagit River near Concrete, Washington*: U.S. Geological Survey Scientific Investigations Report 2007- 5 159, Tacoma, Washington, 12 p.

Northwest Hydraulic Consultants, 2008, Re-evaluation of the Magnitude of Historic Floods on the Skagit River near Concrete – Final Report: Prepared for the Skagit County Department of Public Works by Northwest Hydraulic Consultants, Seattle Washington, October 2008.

Pacific International Engineering, 2008, *Skagit River Basin Hydrology Report – Existing Conditions*: Prepared for the City of Burlington, City of Mount Vernon, Dike, Drainage and Irrigation District 12, and Dike District 1 by Pacific International Engineering, Edmonds, Washington, October 2008.

Stewart, J. E. and Bodhaine, G. L., 1961, *Floods in the Skagit River Basin Washington*: U.S. Geological Survey Water-Supply Paper 1527, Washington, DC.

U.S. Army Corps of Engineers, 2008, *Draft Skagit River Basin, Washington, Revised Flood Insurance Study, Hydrology Summary*: Seattle District, U.S. Army Corps of Engineers, May 2008, 64 p.