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To: Attendees of the Skagit River flood flow meeting of March 17, 2010

From: Mark Mastin
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Subject: USGS responses to issues raised by the Technical Memorandum, "Review and reevaluation of Skagit River 1921 flood peak discharge."

The following text summaries the USGS responses to specific issues raised by the Technical Memorandum, "Review and reevaluation of Skagit River 1921 flood peak discharge," that was distributed at our March 17 meeting.

1. Incorrect datum used by USGS in Transferring Stewart's HWMs.

   USGS hydrologist Mark Mastin provided a summary of information related to the datum for the Stewart highwater marks and streamgages in his letter of 10/31/08. In brief, Stewart based his highwater mark and streamgage datum surveys on a benchmark in Concrete, Washington, that no longer exists. All the USGS field inspections since 1924 suggest that the gage datum for the highwater marks and streamgages that Stewart installed should be 142.7 or 1.8 feet higher than used by Stewart.

   USGS records demonstrate continuity of datum control at the current streamgage at Skagit River at Concrete from the present time back to the establishment of the gage in 1924. The only area of uncertainty is the linkage of datum from this gage to its predecessor gage, which was established by Stewart and based on the same datum as Stewart's highwater marks. While there are no notes of a direct survey linking the datums of the two gages, there is information indicating that the two datums are the same. It is the standard practice of the USGS to ensure consistency of streamflow records at concurrent downstream and upstream gages by making concurrent flow measurements or rating verification measurements whenever a gage is relocated. Indeed, on the day that the new downstream gage was established (9/16/1924) a streamflow measurement was performed. The field notes for that measurement record simultaneous water-level readings at both gages. The stage readings for both gages agree to within 0.01 feet of one another, suggesting that the two gages reference the same datum. Furthermore, level notes made on that same day at the current streamgage include a conversion equation. The notes include a remark saying: "27 on Gg=169.88". The reference implies that the old datum was 142.88 ft. (169.88-27.00), the same datum as used at the current streamgage at Concrete.

2. Incomplete energy equation used in Stewart's computations.

   This issue was acknowledged and addressed by the USGS in Scientific Investigations Report 2007-5159 in which the complete energy equation was used to revise and lower the Stewart flood estimates.

3. Incorrect flow area used for lower slope section.

   While there are strong similarities between the 2003 Mastin cross-section surveys and the 1921 Stewart surveys, there are clearly significant differences between them, especially near the right bank as indicated in the technical memorandum in figure 3. These differences suggest the very real possibility that the surveys were made at different locations or that the stream cross-sections have changed over the 80 years that have transpired between the surveys.

   The USGS acknowledges that Stewart adjusted the cross-sectional width and area for the upper and lower cross-sections. He did report that he was unsure about the precise correction that should be used and he applied the corrections developed for the upstream cross-section to the downstream cross-section measurements. But Stewart did so having first-hand experience with the survey and knowing whether or not the rope had become wet, stretched, and in need of adjustment. Given that a correction was clearly necessary at the upper section and that the same survey techniques and conditions prevailed at both sections, the USGS sees no compelling reason to nullify Stewart's judgment.

4. Unsupported hydraulic grade line slope used for upper slope-section reach.

   Table 5 of the technical memorandum does not list all of the HWM data available for computing the flood flow estimates. A complete listing is provided below in table 1 and shows 13 HWMs available to Stewart including those surveyed by Wright and/or Thirit in 1923.

Table 1 -Highwater mark data for the 1921 peak flow of Skagit River at Concrete, Washington.

Stationing in feet below Mouth of Dalles Gorge	Elevation, in feet (NGVD '29)	Left Bank (LB) or Right Bank (RB)	Page in field notes
0	172.70	RB	14/14 in loose notes file
525	172.38	RB	14/14 in loose notes file
538	173.49	RB	69
618	172.40	RB	69
618	173.79	RB	69
618	173.75	LB	68
865	171.9	RB	64
985	173.07	RB	14/14 in loose notes file
1525	171.32	RB	14/14 in loose notes file
2090	171.1	RB	14/14 in loose notes file
2470	171.67	RB	14/14 in loose notes file
4655	169.14	RB	78-79
4655	169.1	LB	78-79

Stewart was careful in selecting highwater marks on which to base his water-profile. It is very rare for all high-water mark elevations that are identified in a field survey to be used or considered in determination of a water-profile slope. Some marks are clearer or more vivid and can be more precisely surveyed, because the seedlines, mudlines, or debris that defines them is narrower, more tightly banded, or more continuous than other marks. Even among those marks that are well defined, however, most serve as only low-elevation bounds on the peak high-water elevation simply because they did not occur at the peak flow but AFTER it has occurred. They are more numerous because they occur over a longer period of time, during the flood recession and in generally calmer, relatively low-water flows. Because they do not represent peak flow conditions, the USGS generally disregards the lower highwater marks in favor of the higher marks, particularly when multiple highwater marks provide confirmation of those higher elevations.

This is precisely what Stewart did. He emphasized the highest marks, attributing them to the water levels occurring at peak flow and the lower marks to water levels that occurred after the peak. On p. 25 of Stewart's 1923 report, "Floods in Skagit River Basin, Washington" he writes, "When looking for the 1921 crest, there was danger of obtaining a lower point than the flood crest." As such, the five marks that figure most prominently in the development of his surface-water profile were the most reliable estimates of the water profile during the peak flow. Significantly, two sets of marks (those of cross-sections 1 and 3) are confirmed by independent marks found on the opposite bank. Stewart did not blindly extend the profile from cross-section 2 and 3, he had highwater marks at both locations, and in addition to those he had marks along the reach from cross-section 1 and 2. The result was a single, consistent slope of 0.00119 feet/foot.

This slope has also been confirmed by other flood data. In November 2006, soon after a peak of 145,000 ft^3/s, the USGS surveyed HWMs between locations approximating cross-sections 2 and 3 and defined a peak water slope of 0.00114 (fig. 1, Mastin 2007). This slope matches to within 3 significant figures the surface-water slope computed by Stewart.

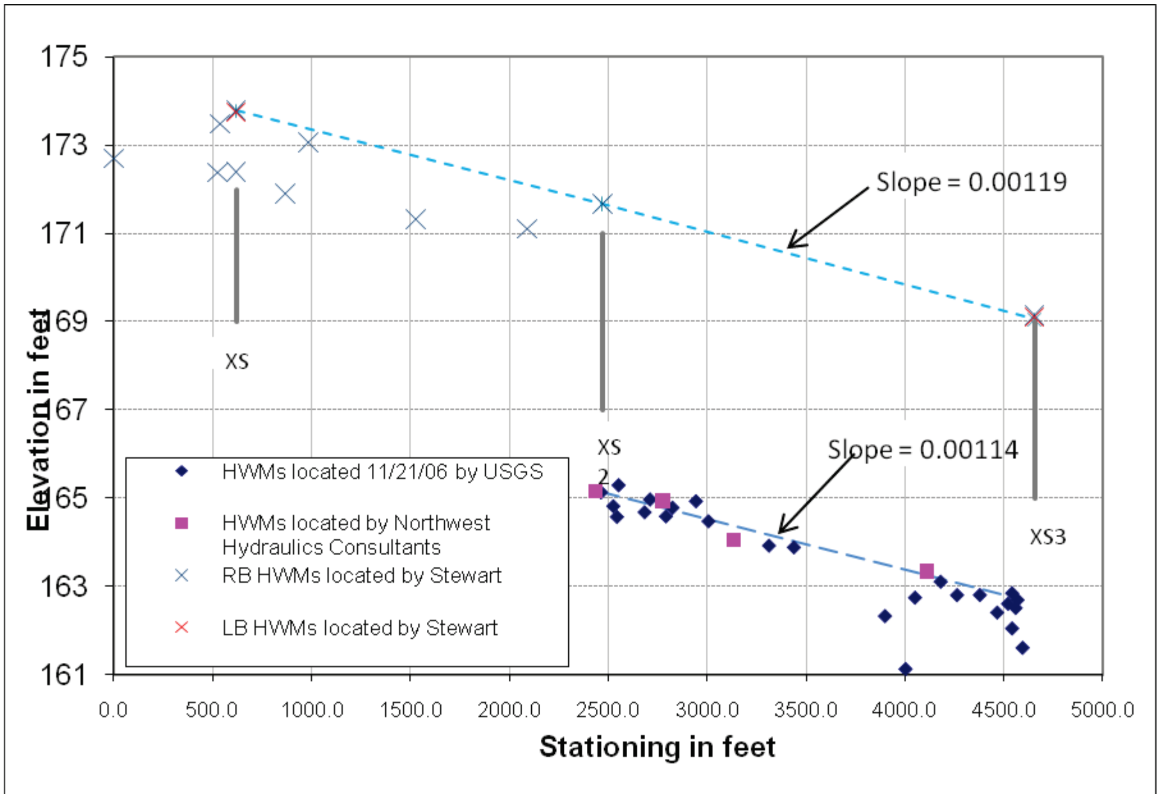

Figure 1 -- High-water marks and peak water-surface profiles in the slope-area reach downstream of USGS streamgage Skagit River near Concrete, WA Station Number 12194000 for the Dec. 1921 and Nov. 2006 floods.

5. Unknown quality of highwater marks; surge effects.

The USGS acknowledges that Stewart did not characterize the quality of his HWMs and surge may have affected some of the marks. However, the technical memorandum greatly over estimates the likely effect of the surge, reporting a surge of 0.6 to 2.1 feet based on the spread between the elevations of the highwater marks and the peak water elevation in the USGS stilling well reported in the 2003 Mastin survey.

There was a lot of vertical variation in the HWMs, but these variations were due as much to the differences in timing and types of HWMs and their resulting quality, as much as to any surge effect. Indeed, most of Stewart's highwater marks are located in low-energy environments on the right back away from the main flow and there the surge should be relatively small.

Regardless, USGS standard practice for computing flow from indirects does not generally include correction for surge effects. As reported by Benson and Dalrymple (1967):

> Observation and photographs of flood flow in natural channels show that, although there may be extensive wave action in the middle of a fast-flowing stream, at the sides, velocities are low and the water surface quiet. Although there undoubtedly is some effect from surge, the high-water marks should be used as found and no adjustments attempted for surge. Any adjustments would necessarily be subjective and would lead to questionable results. This is justified by the fact that roughness values as determined from "verification" studies are determined from high-water marks on the banks, and any effect of surge is

contained in the n values determined; if similar n values are applied for like conditions using the same methods, then the effect of surge would be minimized.

The n-value that Stewart used was based on an n-verification study using a moderately high flow on the Skagit River at Sedro Woolley, though it is not known to what extent the highwater marks (or directly observed water-levels) included surge effects. More importantly, Mastin (2005, 2007) back-computed a new n-value based on directly measured streamflow and the many highwater marks he surveyed in 2003. These marks included surge effects present at that flow. Hence, surge effects are already factored into his n-value and into his revised estimate of the 1921 peak flows. Making additional corrections for surge is not necessary and would unduly bias the results.

6. Reevaluation of the 1921 flood peak discharge using slope-area method

   The flood-peak computations performed by PIE and summarized in table 7 of the technical memo were derived based on fundamentally different input data than that used by Stewart or the USGS. All of these inputs are important, but the over riding input is the water slope and cross-sectional area. As discussed above (item 5), the USGS does not concur in use of a water slope significantly different from that used by Stewart and confirmed by Mastin. Furthermore, the USGS disagrees with altering the cross-sectional areas as described above (item 3). Computations based on other slopes or areas, regardless of similarity of roughness coefficients or treatment of surge effects, will provide different and less reliable peak flow estimates.

7. Reevaluation of the 1921 flood peak discharge using the stage-discharge rating

   The extension of the 1921 high-water marks from their original locations to the current streamgage is ultimately based on assumptions about the location of the marks and past streamgages, and the resulting distances between them. The exact location of the marks or the old streamgages is not well known. While the technical memorandum asserts that the highwater marks were 400 feet upstream of the current gage, USGS survey notes, station descriptions, and published reports, most made prior to 1925 and by persons familiar with the old sites and the area configuration as it existed then, place the upper Dalles gage approximately 200 feet upstream of the current streamgage and in an area where the water slope is much milder than that of the downstream reaches.

   The technical memorandum asserts that the elevation of the Stewart highwater marks was 175.75, 175.18, and 171.04 feet, respectively. These elevations are possible only if one negates the USGS datum correction of 1.8 feet for which there is ample documentation as described in item 1 above. Once the datum correction is made, these elevations become 177.5, 176.0, and 172.8.

   In past USGS publications on the historic floods that show the current stage-discharge rating and the historic flood peaks, the gage height was not corrected for the different locations of the streamgages. It may be more correct to make that correction, but the estimated drop of 1.18 feet shown in the Technical Memorandum between the two gage locations suggests a slope of 0.0059, a much steeper slope than what would be expected and does not agree with levels taken in 1932. Levels dated April 7, 1932 shows an elevation of a HWM at 27.714 feet (gage datum) on the “upper dalles gage” and 27.468 on the “upper section” of the current gage. This is a difference of 0.246 feet or a slope of approximately 0.0012, a more reasonable slope in the backwater of a constriction. At 27.5 feet, the flood that deposited the highwater marks was a minor flood, but there is no reason that the water slope would be much different at higher stages. A correction of -0.25 feet to the gage height of the 1921 flood (based on observations in 1932) would result in reduction of approximately, 2,500 ft^3/s or a revised estimate of 226,500 ft^3/s, about 1 percent below the current estimate of 228,000 ft^3/s.

8. Although not covered in the Technical Memorandum, some of the discussion and presentation at the meeting included the modeling efforts by Pacific International Engineering which was also mimicked by Northwest Hydraulic Consultants (NHC). Both consulting firms used a one-dimensional HEC-RAS hydraulic model and upstream HWMs to estimate the 1921 peak discharge on the Skagit River near Concrete. The USGS has not examined the specific details of either HEC-RAS models. However, the 2010 NHC report, “Re-evaluation of the Magnitude of Historic Floods on the Skagit River near Concrete, Revised Final Report,” provides enough information for the USGS to comment.

   The USGS has concerns with the model construction and calibration. NHC writes in their report (p.17):

   > “Considerable difficulties were encountered in achieving a model calibration which both matched the USGS gage rating over a wide range of flows and which also reasonably matched the HWMs below The Dalles. Emphasis was given to matching the gage stage-discharge rating in preference to the HWMs below The Dalles.”

   This stated approach is not the best way to calibrate the model. The HWMs downstream from the Dalles represent a better dataset to calibrate the main channel roughness values. It is odd that the calibrated model predicts water-surface elevations about 2.5 feet below the excellent-good HWMs surveyed after the 2003 flood. The U.S. Army Corp of Engineer’s model based on 1975 and 2004 data was readily calibrated to these HWMs (Mastin and Kresch, 2005).

   Calibration of a 1-D model should not be made in a bedrock constriction where multi-dimensional flows predominate. It is exceedingly difficult for 1-D models to predict water-surface elevations directly in constrictions, particularly for larger discharges (Magirl and others, 2008). More importantly, it is potentially erroneous to calibrate a 1-D model from a gage located directly in a constriction, as is the case with the Concrete gage. In 1-D modeling, the simultaneous solution of the energy and continuity equations near constrictions often results in numerical artifacts where the predicted water-surface elevation is artificially lower that the actual water surface in the river. At least four water-surface depressions with adverse (negative) slopes are visible for the simulation of 166,000 cfs in figure 7, p. 21 of the NHC report. These numerical artifacts were more severe at larger simulated discharges (figure 14 of the NHC report). More importantly, near the gage within the bedrock constriction, steep drops in the profile are visible with two or three adverse slope sections. The surveyed HWMs of the 2003 flood upstream from the gage indicates that the water-surface profile upstream of the constriction is relatively flat. In contrast, the predicted water-surface profile in the 1-D model upstream from the gage is steep, dropping 5 ft in a distance of about 580 ft. This predicted water-surface profile poorly matched the observed and surveyed water-surface profile. These water-surface artifacts are common in 1-D models of bedrock rivers (Kidson and others, 2006; Magirl and others, 2008). For example, Kidson and others (2006) found similar model behavior in their HEC-RAS simulation of a large flood in a bedrock-confined channel in northern Thailand. In figure 8 of the NHC report, the model shows a close agreement between the stage-discharge rating of the gage and the model. This figure is given as evidence of a calibrated model. However, we suspect that the predicted water-surface profile in the vicinity of the gage suffers from the 1-D numerical artifacts described earlier. Therefore, we are concerned because a match of the model’s stage-discharge rating with the observed stage-discharge rating (fig 8, NHC report) would indicate that the model is poorly calibrated for analysis upstream from the constriction. Without testing the model, it is hard to determine how much this potential error might affect the water-surface profile in the vicinity of the Crofoot's Addition where the 1921 newspaper-account HWM exists.

The roughness values for the upstream portion of the NHC model appear to be overestimated. A calibrated in-channel roughness by Mastin (2007) for the channel below the Dalles Gorge indicated a roughness value of 0.033 for the existing vegetated gravel bar and 0.0305 for the 1949, sparsely-vegetated gravel bar. While not stated in the NHC report, it appears as though n=0.033 was used as the in-channel roughness value upstream of the Dalles for modeling the 1921 flood (Table 3). Aerial imagery (figure 11 in the NHC report) shows most of the river channel in 1937 was bare with large, open areas of unvegetated gravel bars in the main channel, suggesting channel roughness in 1921 would be less than in 2003. In addition, it is widely reported that roughness coefficient decreases with increasing depth in channels as the relative size of the roughness elements on the channel bed decreases (Limerinos, 1970; Jarrett, 1984; Bathurst, 2002; Yen, 2002), suggesting that the channel upstream from the Dalles would have a lower roughness for the 1921 discharge. Also, the right bank from RM 55.5 to RM 56.5 appears different in the 1937 aerial photo (fig. 11, NHC report) than the 2001 aerial photo (fig. 6). A side channel is visible in the 1937 photo that is not seen in the 2001 photo. The right-bank portions of the cross sections in this reach should have roughness values similar to the in-channel values and significantly lower than the roughness values in the current model. The NHC report does state that an n value of 0.06 was used for pastures and 0.20 was used for the forested overbank portions of the channel. The 0.20 roughness value is at the extreme upper end of reported roughness values used for heavy vegetation. While information on verified roughness values for overbank areas is limited, the USGS in Washington has rarely used roughness values larger than 0.10 in forested areas for computations of flood magnitude. In the 1937 photo, the forest in the Crofoot Addition appears to be less dense than it is in the 2001 photo, and though not explicitly stated, it appears an unrealistically large roughness value was applied to the overbank regions in the model.

In summary, after reviewing the material provided at the March 17 meeting, the USGS remains unconvinced that a peak-flow estimate based on a poorly calibrated 1-dimensional model and made 80 years after the event is more reliable than an estimate made using slope area methods made within a year of the event. Hydraulic models have complications in retrodicting past floods stemming from uncertainty of the channel morphology, unknown impacts from dredging, changes to vegetation, reliable HWMs, and other unforeseen influences. When evaluating the discharge of the 1921 peak event, the slope-area computation was made by a competent hydrologist that searched for a uniform reach and surveyed HWMs strictly for the computation of peak discharge. This computation has been reevaluated several times over the years by other USGS hydrologists. Often, the largest unknown in a slope-area computation is the roughness coefficient and several n-verifications have been made to reduce this uncertainty as much as possible. The water-surface slope used in the computation has also been verified with comparisons with a recent surveyed peak water surface from a lesser flood. Also, this method does not depend on knowledge of the correct datum used in the 1921 surveys, whereas the HEC-RAS model does require HWM elevations referenced to a known datum.

References Cited:

Bathurst, J.C., 2002, At-a-site variation and minimum flow resistance from mountain rivers, Journal of Hydrology, Vol. 269, p. 11-26.

Benson, M.A. and Dalrymple, Tate, 1967, General field and office procedures for indirect discharge measurements: U.S. Geological Survey Techniques of Water-Resources Investigations of the United States Geological Survey Bk 3, Chapter A1.

Jarrett, R.D., 1984, Hydraulics of high-gradient streams: Journal of the Hydraulics Division, American Society of Civil Engineers, v. 110, no. 11, p. 1519-1539.

Kidson, R.L., Richards, K.S., Carling, P.A., 2006, Hydraulic model calibration for extreme floods in bedrock-confined channels: case study from northern Thailand, Hydrol. Process. 20, 329-344.

Limerinos, J.T., 1970, Determination of the Manning coefficient from measured bed roughness in natural channels, U.S. Geological Survey Water Supply Paper 1898-B, 47 p.

Magirl. C.S., Breedlove, M.J., Webb R.H., and Griffiths P.G., 2008, Modeling Water-Surface Elevations and Virtual Shorelines for the Colorado River in Grand Canyon, Arizona, U.S. Geological Survey Scientific Investigations Report 2008-5075, 32 p.

Mastin, M.C. and Kresch, D. L., 2005, Verification of the 1921 peak discharge at Skagit River near Concrete, Washington, using 2003 peak-discharge data: U.S. Geological Survey Scientific Investigations Report 2005-5029, 17 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 2007-5159, 12p.

Yen, B.C., 2002, Open channel flow resistance, Journal of Hydraulic Engineering, v. 128, no. 1, p. 20-39, doi:10.1061/(ASCE)0733-9429(2002)128:1(20).