SKAGIT RIVER HYDROLOGY INDEPENDENT TECHNICAL REVIEW FINAL REPORT

Prepared for: Skagit County Department of Public Works

Skagit River at The Dalles
Photo courtesy of Larry Kunzler

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nhc

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CREDITS AND ACKNOWLEDGEMENTS

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GLOSSARY OF HYDROLOGIC TERMS

Definitions for a small selection of the technical terms as used in this report are provided in the following list:

Manning's Roughness: A measure of roughness commonly used to describe the roughness of natural river channels and usually referred to as Manning's "n". Photographs and descriptive data for a variety of river channels for which Manning's roughness has been determined are provided by Barnes (1967).

Rating Curve: *See* **Stage-Discharge Rating**

Stage-Discharge Rating: A graph showing the relationship between the stage or gage height and the discharge in a river channel.

Water Year: The twelve-month period used as the basis for analysis of surface-water records and commonly defined in the USA, as in this report, as the period 1 October through 30 September. The water year is designated by the calendar year in which it ends. Thus the year ended 30 September 1995 is referred to as "water year 1995", and the flood of December 1921 occurred in water year 1922.

1.0 INTRODUCTION

Northwest Hydraulic Consultants (**nhc**) was retained by Skagit County to provide an independent technical review of hydrologic and hydraulic analyses either relied upon by or conducted by the US Army Corps of Engineers (Corps) in the preparation of its flood damage reduction feasibility study and its flood insurance study for the Skagit River.

The hydrologic and hydraulic analyses of flood flows on the Skagit and the baseline data for those analyses have been subject to extensive previous review by others. Our purpose here is not to go over old ground. Many aspects of Skagit River flood hydrology, such as the reliability of high water marks from historic flood events, have been subjected to detailed review and re-review by others and we see no merit in yet another exhaustive review of those data. The work documented in this brief report provides additional focused review of topics which, in our opinion, merited additional consideration and which may lead to improved confidence in the characterization of the Skagit River flood hydrology. We have also identified a small number of issues that have not been previously raised but which may need to be considered in finalization of the Corps study reports.

2.0 THE FLOOD OF DECEMBER 1921

The estimate of the peak discharge for the flood of December 1921 on the Skagit River is crucial to the determination of the 100-year discharge, which in turn is the single most important hydrologic parameter for the flood damage reduction feasibility study and the flood insurance study. The peak discharge for the December 1921 flood was determined by J.E. Stewart at the location of the Skagit River near Concrete gage on the basis of indirect discharge measurements. Peak discharge estimates for the other historic floods at issue (in water years 1898, 1910, and 1918) rely on a stage-discharge rating drawn through the December 1921 data point together with the elevation of high water marks from those events relative to high water marks from the December 1921 flood.

The following specific aspects of peak flow estimates from the December 1921 flood were subject to additional review:

- verification of Manning's roughness
- consistency of historic data with the stage-discharge rating
- consistency of historic data with evidence of non-inundation

2.1 Verification of Manning's Roughness

Stewart's 1923 estimate of the December 1921 peak discharge of 240,000 cfs was made using indirect measurement techniques. Three slope-area measurements were made using high water mark information for a reach of the Skagit immediately below The Dalles and one contracted-opening estimate was made at The Dalles. The average of those four measurements was published as the peak discharge for December 1921. Stewart's slope-area calculations relied on an estimate of Manning's roughness "n" for a reach of the Skagit near Sedro-Woolley. Stewart recognized that hydraulic conditions at Sedro-Woolley could be different from conditions at The Dalles and recommended that his assumed value for "n" be verified.

To date, two "n" verification studies have been completed for the reach of the Skagit below The Dalles used by Stewart for his slope-area measurements. These studies were conducted in the early 1950s, using data from the flood of 27 November 1949 (peak discharge at Concrete of 153,000 cfs) and in 2004, using data from the flood of 21 October 2003 (peak discharge 166,000 cfs).

High water marks for the flood of 7 November 2006 (peak discharge 145,000 cfs) have also been identified in the field by **nhc** and surveyed by Skagit County. High water marks for this event have also been independently identified and surveyed by the USGS. **nhc** has completed an analysis of the November 2006 data, as discussed later in this section, to provide a further check on channel roughness "n".

Estimates of "n" from data obtained after the 27 November 1949 flood and recalculation of the peak discharge for the December 1921 flood are discussed in a series of brief memos by USGS staff between 1950 and 1954 (Riggs and Robinson 1950, Benson and

Flynn 1952, Bodhaine 1954, and Flynn 1954b). The outcome was an “n” value of 0.030 and a recomputed peak discharge for the December 1921 flood of 225,000 cfs that was believed to be “the most logical answer based on the latest methods of computing peak flow” (Bodhaine 1954). The memos recommended that “the highwater rating be extended through a discharge of 225,000 cfs (as computed by Benson) for the stage of the 1921 flood …” (Flynn 1954b). However it was recommended that the published value for the 1921 flood be kept at 240,000 cfs as determined by Stewart “because of the small percentage differences and the fact that these figures have been published in Water Supply Papers” (Bodhaine 1954). The hydraulic conditions during the December 1949 flood are closer to those of December 1921 than current conditions, particularly with respect to the large right-bank gravel/cobble bar below The Dalles, which is discussed in more detail below.

Verification of “n” using data from the flood of October 2003 is discussed by Mastin and Kresch (2005). High water mark (HWM) data from the October 2003 flood were apparently difficult to identify in the field and show a substantial scatter. It was perhaps unfortunate that the USGS chose to publish this “n” verification work since the scatter in the data have been used by some parties in an attempt to call into doubt the applicability of slope-area techniques on this reach of the river. The slope-area measurement is a well established technique for estimating river discharges and in our opinion is reasonably well-suited to this reach, provided reliable water level data are available. The USGS used the HWMs from the October 2003 flood to determine a range of “n” values from a low of 0.024 to a high of 0.032. When applied to the HWMs from the December 1921 flood, these “n” values in turn result in a peak discharge for December 1921 in the range 215,000 cfs (“n” of 0.032) to 266,000 cfs (“n” of 0.024). The range of “n” values determined by the USGS is, in our opinion, so large as to be of little value in verifying Manning’s roughness and does not contribute to improving confidence in the reliability of the 1921 peak discharge estimate.

A water surface profile for the 7 November 2006 flood was staked by **nhc** for the reach in question approximately 10 hours after the peak discharge at Concrete, and high water marks for the event were staked by **nhc** a week later, on 14 November 2006. The staked points were subsequently surveyed by Skagit County. This work was restricted to the right bank because of difficulty accessing the left bank. The HWMs for this event were very obvious, identified primarily by strand lines of light debris at the edge of high water, and are considered to be accurate to within about 0.2 ft. HWMs for this event were also identified and surveyed by the USGS. The **nhc** and USGS data are plotted on Figure 1. Also shown on Figure 1 are the locations of USGS cross-sections 2 and 3, which define the reach used by the USGS in their 2004 “n” verification, along with a best estimate high water profile for the event.

The high water profile data of Figure 1 were used, with cross-section data from 2004 provided by the USGS, to estimate channel roughness for reach 2-3, following the procedures used by Mastin and Kresch (2005). The data were analyzed using the USGS NCALC software (Jarrett and Petsch, 1985) to produce an estimate of “n” for reach 2-3 of 0.030.

The primary problem in use of data from November 2006 to verify roughness for the purposes of recomputing the December 1921 peak discharge is the effect of changed channel conditions between 1921 and present. Two specific concerns arise; possible changes in channel cross-section, and changes in the large right-bank gravel/cobble bar about 2000 ft below the Dalles which is now well vegetated with trees and shrubs but which is believed to have been clear of any significant vegetation in 1921. While there is no direct evidence of the condition of this bar in 1921, an aerial photograph of 1937 shows the bar to be bare, and it would be reasonable to expect that Stewart would have commented if the bar had been vegetated in 1921.

Mastin and Kresch (2005) compare surveyed cross-sections from 1923 and 2004 and showed differences in channel geometry to be relatively small. The effect of vegetation growth on the gravel/cobble bar is more difficult to deal with.

During the November 2006 event, the entire bar was submerged. Section 2 cuts across the downstream end of the bar, while Section 3 is a further 2100 ft downstream (a location map is provided in Figure 1 of Mastin and Kresch). The high water data show that the bar was under about 8 feet of water at Section 2. Growth of vegetation on the bar can be expected to have some impact on water levels at Section 2. This impact cannot be reliably quantified, but with Section 2 located close to the downstream end of the bar the effects are probably quite small. Vegetation on the bar would increase water levels at Section 2 by some small amount, resulting in a slight increase in the average water surface slope between Sections 2 and 3, and an estimate of Manning's roughness slightly higher than if the bar had been free of vegetation, as it is assumed to have been in1921.

nhc's estimate of "n" from analysis of the November 2006 flood data is consistent with Benson's determination of "n" based on data from the November 1949 flood and his recomputation of the peak discharge for the December 1921 flood of 225,000 cfs. Since this estimate was only 6% lower than Stewart's original estimate, no change was made to the then-published value of 240,000 cfs. Nevertheless, the USGS n-verification for the November 1949 flood, under conditions closer to the those of 1921 than today's conditions, together with supporting evidence from the November 2006 event, indicate that the 240,000 cfs published value for December 1921 is conservatively high, other possible sources of uncertainty notwithstanding.

2.2 Consistency of December 1921 Data with Published Rating Curve

The Skagit River near Concrete gage has a well defined and stable stage-discharge rating which has been established through a comprehensive long-term program of discharge measurements. The current rating curve (Rating No. 6) is plotted in Figure 2 along with a selection of stage-discharge measurements. The discharge measurement for December 1921 is for the indirect measurement reported by Stewart. The corresponding gage height(s) shown in the figure for the December 1921 measurement are discussed below. All other measurements on Figure 2 are direct measurements (e.g. with a Price meter or more recently by ADCP) as reported by the USGS.

The top end of the stage-discharge rating (from around 80,000 cfs to 150,000 cfs is defined by a set of measurements taken during the flood of February 1932 (highest measured discharge 135,000 cfs, gage height 38.68 ft). A measurement taken in October 2003 (discharge 138,000 cfs, gage height 38.68 ft) agrees very closely with those of February 1932, confirming and validating the rating at least up to about 150,000 cfs. The close agreement between the highest measured discharge in February 1932 and the October 2003 measurement suggests that changed channel conditions downstream of the gage site (primarily changes in vegetation on the right bank gravel/cobble bar) have had no discernible impact on the stage-discharge rating at the gage site, at least for discharges up to 150,000 cfs. At this discharge, we estimate the bar to be covered by from 5 ft to 8 ft of water. The effect of the gravel/cobble bar on upstream conditions at the gage site can be expected to decrease at higher discharges because of the hydraulic control imposed by the contraction at The Dalles. Given the stability of the channel at the gage site, there is no reason to expect a material change in the high water rating between 1921 and present at this location.

The indirect measurement for the December 1921 event is plotted on Figure 2 using Stewart's discharge estimate but with two alternate "estimates" of gage height. The higher of the two gage heights shown for December 1921 is as published by the USGS and as determined by Stewart for the original site of the Concrete gage (reported to be 200 feet upstream from its current location) adjusted for the difference in datum between the original and current gage sites. The lower of the two gage heights shown for December 1921 reflects a further hypothesized adjustment of 2 feet to account for the water surface slope between the old and new gage sites. All other data shown on Figure 2 are taken from the current gage which was established in 1924.

No attempt has been made in the data published by the USGS to adjust the reported December 1921 gage height for difference in water level between the old and new gage locations. (Gage heights published for the other historic events are, similarly, referenced to the old gage site.) The magnitude of those differences has been the subject of limited discussion. Flynn (memo 16 July 1954), in a discussion of the historic flood peaks, states "from the falls measured in the slope-area determination[1], the fall between the two gage sites is probably on the order of 0.2 ft". Mastin (letter to C. Martin, 10 February 2005) states that "As the flows increase, the draw down through the gorge seems to begin further upstream somewhere upstream of the current gage location. The HWMs from the October 2004[2] peak flow, gage height of 42.14, showed a drop of 0.5 to 1.5 feet from the old site to the current gage site depending on which HWMs are chosen to represent the slope".

Given the hydraulic conditions at The Dalles, the fall in water level between the two gage sites can be expected to increase with increasing discharge. The fall in water level between the old and new gage sites for floods of the magnitude of the 1921 event could thus be in the range 0.5 to 2 feet. (A drop of 2 ft. is consistent with estimates by Pacific International Engineering Ltd. based on a HEC-RAS model. However, given the complexity of hydraulic conditions at The Dalles, we would not rely on a HEC-RAS

[1] This refers to the slope-area measurement for the 1949 flood
[2] This is a typographical error – the event referred to is October 2003

model to either determine or validate estimates of water surface slopes at this location.) Based on the slope of the published stage-discharge rating, at a discharge of 240,000 cfs a reduction in gage height of 2 feet corresponds to a reduction in discharge of 20,000 cfs.

Rating curves are typically extrapolated beyond the range of direct measurements as a straight line in log-log space. The exact basis for extrapolation of the rating for the Concrete gage is unknown. As noted in Section 2.1 above, it had been recommended (Flynn 1954) that the highwater rating be drawn through a discharge of 225,000 cfs for the reported stage of the December 1921 flood (47.6 ft at the current gage datum). This recommendation was apparently never adopted since the current rating does not pass through that point. As with the discharge measurements themselves, there is uncertainty associated with the extrapolation of rating curves. A slight variation of the top end of the published rating, as a straight line extrapolation in log-log space, is plotted in Figure 2. This illustrates how a modest adjustment could result in a rating which provides a better fit to the published (higher gage height) December 1921 indirect discharge measurement. The top end of the current rating will only be known with more certainty if measurements of stage and discharge are obtained under those extreme conditions.

Mastin's 10 February 2005 letter to Martin, which deals primarily with issues surrounding the reliability of HWMs, points out that Stewart's estimate of the December 1921 peak discharge was made independently of estimates of the gage height at the (old) Concrete gage. Nevertheless, it is clear there are unresolved (and probably unresolvable) inconsistencies between several of Stewart's data and the stage-discharge rating established for this site. The range of magnitude of the December 1921 peak discharge for various assumptions regarding the stage-discharge rating and gage height estimates are summarized below (refer also to Figure 2):

Assumptions	**Peak Gage Height or Discharge (December 1921)**	
	Gage Height[3] (feet)	**Discharge (cfs)**
Gage height reported by Stewart with discharge from the current Rating 6	47.6	215,000
Gage height adjusted for 0.5 ft fall to new gage site with discharge from Rating 6	47.1	210,000
Gage height adjusted for 1.5 ft fall to new gage site with discharge from Rating 6	46.1	201,000
Gage height adjusted for 2 ft fall to new gage site with discharge from Rating 6	45.6	196,000
Gage height reported by Stewart with discharge from straight line log-log extension of Rating 6 above 140,000 cfs	47.6	222,000
Discharge reported by Stewart with gage height from Rating 6	50.2	240,000

[3] Gage height is with reference to current gage.

2.3 Consistency of December 1921 Data with Evidence of Non-Inundation

According to research by Kunzler (2006), the Smith House in Hamilton (307 Maple Street, Hamilton) was built in 1908 and anecdotal reports indicate that it has only once been flooded above its main floor level. The house is reported to have had 2 inches of water above the main floor level during the flood of November 1995 (peak discharge at Concrete 160,000 cfs). Anecdotal reports suggest that the house was **not** flooded in earlier and much larger flood events (1910 – 260,000 cfs, 1918 – 220,000 cfs, 1922 – 240,000 cfs). If flows of the magnitude of these historic events had occurred under **current** river channel conditions, then the water levels should have been several feet above the main floor level. These apparent inconsistencies have a number of possible explanations:

- the anecdotal reports are incorrect and the house was in fact flooded above the main floor level in the earlier floods,
- the peak discharge estimates for water years 1910, 1918, and 1922 are incorrect and are too large, or,
- the hydraulic conveyance capacity of the river channel and/or floodplain in and around Hamilton was historically significantly greater than at present and was able to carry greater flows at lower water levels.

Preliminary work has been undertaken (City of Burlington, 2007) to determine whether or not the Smith House was flooded prior to 1995. The work undertaken involved cutting out two sections of wall covering (one of original lath and plaster and one of gypsum sheetrock) on the main floor level of the house and inspecting the interior of the wall for signs of flood damage or water marks. No flood marks were found. Some discoloration of plaster was evident at the base of the wall, possibly indicating water damage during very shallow flooding of the main floor in 1995.

Although no sign of water damage from large historic floods was evident, it is our present opinion that this does not provide **conclusive** evidence that flooding did **not** occur. Any flood marks from December 1921 would now be 85 years old. From our limited experience with flooding of buildings, we would expect flood marks to fade with age. At the present time, we simply do not know whether a flood mark on the interior of a wall would still be visible after 85 years.

Historic maps and aerial photographs were inspected to assess changes in channel and flood plain conditions since the 1900s. Bank lines of the river were determined from Government Land Office (GLO) maps from about 1886, from a Corps survey of 1911, and from aerial photographs from 1937 and 2001. The changes in channel bank lines with time are shown in the immediate vicinity of Hamilton in Figure 3. Also shown on Figure 3 are the Cockreham Levee and the Great Northern Railway Line, the only man-made features on the flood plain that might affect flood levels in Hamilton in any significant way.

Figure 3 clearly shows a significant shift in channel planform between 1886 and 1937 downstream from Hamilton. The shift between 1937 and 2001 is much less pronounced. It is presumed that movement of the meander bend downstream from Hamilton was arrested in the 1950's with the construction of the Cockreham Levee.

Figure 3 also shows a substantial narrowing of the river channel downstream from Hamilton between 1937 and 2001. The average channel width for the approximately two-mile reach through the first meander bend below Hamilton was about 750 ft in 1886, 1000 ft in 1911, and 900 ft in 1937 compared with only 600 ft in 2001. These estimates should be used with some caution since the basis for delineation of bank lines from the various maps may not be entirely consistent, considering that: (1) we do not know with certainty how the river channel was delineated on the GLO maps, (2) the bank line from the Corps 1911 map is taken from the mapped high water line, and (3) bank lines from the 1937 and 2001 aerials were drawn, in the absence of stereographic coverage, as the edge of continuous vegetation. Difficulties were encountered in geo-referencing the 1911 map and the exact spatial location of the 1911 bank lines relative to the underlying aerial photograph may not be quite correct, especially east of Hamilton. The greater width in 1937 is due mostly to inclusion within the defined channel of a broad left-bank sand or gravel bar. Despite these uncertainties, the river channel in 1886, 1911 and 1937, the period spanning the historical floods of interest, was clearly much wider than at present and would have had a correspondingly greater conveyance capacity. Just how much greater is not possible to determine with any accuracy since detailed channel surveys from the period are not available.

With regard to man-made features, the Seattle and Northern Railway line (later part of the Great Northern system) up the Skagit valley was completed to Hamilton by 1891 and to Rockport by 1901, i.e. before construction of the Smith House. The line has long been abandoned and was converted to a multi-use trail under the Rails-to-Trails program in the 1990s. We are of the opinion that any changes in flood conveyance capacity due to either the presence of the rail line or its conversion to a trail would be minimal.

The Cockreham Levee (see Figure 4) is hydraulically a much more significant man-made feature than the rail line. A representative cross-section through the levee is shown in Figure 4. The levee confines flows downstream from Hamilton and prevents spill over the right-bank floodplain until the levee is overtopped or is otherwise breached, as appears to have been the case on a number of occasions in the past (most recently in November 2006). As far as we are aware, no hydraulic modeling or analyses have previously been performed to assess the impact of the levee on upstream water levels. Since the levee is not certified, it is not included in the hydraulic models developed by the Corps for the current flood insurance study. An approximate analysis of the impact of the levee on water levels in Hamilton at RM 39.8 was undertaken as part of this review. A simple representation of the levee was included in the Corps' final HEC-RAS model and the model was then run with and without the levee for a flow of 160,000 cfs, as reported at Concrete for the November 1995 flood, and for a flow of 240,000 cfs, as published for the December 1921 flood and also, coincidentally, the current estimate of the 100-year regulated discharge at Hamilton. The results are summarized below:

Flood	Discharge (cfs)	Water Surface Elevation in Hamilton (ft)*	
		Without Levee	With Levee
December 1921	240,000	102.7	103.9
November 1995	160,000	99.1	99.7

* Water levels estimated using 1975 hydraulic geometry data.

Note that the Corps' model uses cross-section data from 1975. A limited amount of more recent cross-section data from 1999 is presented by Pentec (2000) for the reach immediately below Hamilton. Comparison of the 1975 and the 1999 data by Pentec shows that since 1975 the river channel has deepened by scour on the outside of the meander bend below Hamilton (i.e. along the toe of the Cockreham Levee) and narrowed through continuing accumulation of sediment on the opposite bank. A similar situation has occurred at the South Skagit Highway along the south side of the river opposite the southern end of Cockreham Island. Detailed comparisons of the 1975 and 1999 data are possible for only two cross-sections. The available data show that the deepening and narrowing of the river has resulted in no net change in cross-sectional average bank-full channel depth at one location and a modest (about 10%) reduction in the average channel depth at the second location. The planform geometry of the river has not changed materially since 1975 and, in the absence of more comprehensive recent cross-section data, it is assumed that the 1975 cross-section data are reasonably representative of hydraulic conditions from 1975 to present.

An assessment of the geomorphology of the Skagit River below the Baker River confluence was conducted in support of the FERC relicensing of the Baker River Hydroelectric Project (R2 Resource Consultants Inc., 2004). This work notes (pg. 4-13) that the Skagit River downstream from Sedro-Woolley has aggraded by about 1.5 feet since the mid-1960s. It also notes (pg 4-14) that the overall channel length between Sedro-Woolley and Hamilton has decreased since the early 20th century and that such changes are typically associated with an aggrading channel. This, in conjunction with the limited survey data reported by Pentec (2000), thus provides some indication of possible on-going channel aggradation below Hamilton, local deepening of the channel on the outside of the meander bends, as discussed above, not withstanding. A more detailed program of channel cross-section surveys would be required for a more definitive evaluation of recent channel changes.

The approximate analysis conducted for this review indicates that the Cockreham Levee raises water levels in Hamilton by about one foot for flows in the range of 240,000 cfs. With the levee in place and assuming that the Smith House was just flooded to the level of the main floor at a discharge of 160,000 cfs in November 1995, then a discharge of 240,000 cfs **with the present channel conditions**[4] would have flooded the house to a depth of about four feet. Without the levee but **with present channel conditions**, the depth of flooding would have been about three feet. However, as discussed earlier, the river below Hamilton was considerably wider in the early part of the 20th century than it

[4] Strictly speaking, 1975 channel conditions, since the hydraulic model uses channel cross-section data from 1975.

is today, and, in our opinion, it is possible that the river could have carried 240,000 cfs in December 1921(or even 260,000 cfs in November 1909) without flooding the main floor of the Smith House. Limited sensitivity studies using the Corps' hydraulic model (without the Cockreham Levee in place) showed that widening the 1975 channel cross-sections by 50% for a two-mile reach below Hamilton resulted in about a 2 foot reduction in the water level in Hamilton for a flow of 240,000 cfs. Further reductions in water level would be produced with a wider channel (the 1911 channel was approximately 60% wider on average than present and in places immediately below Hamilton as much as 100% wider). Definitive estimates of water levels at the Smith House during the December 1921 flood, or other historic floods, are not possible given the lack of channel geometry data from that period and related uncertainty in hydraulic modeling. It is simply not possible to state with confidence that the Smith House would or would not have flooded in December 1921 at a flow of 240,000 cfs or in November 1909 at a flow of 260,000 cfs.

3.0 COINCIDENT FLOWS AT CONCRETE AND SEDRO-WOOLLEY

The adequacy of hydraulic modeling between Concrete and Sedro-Woolley has been questioned because of differences between the attenuation of peak flows indicated by the Corp's hydraulic model and the attenuation indicated by the reported peak flows for the historic events.

Reported peak flows for the historic floods at Sedro-Woolley and Concrete (from USGS Water Supply Paper 1527) together with the Corp's modeled 100-year regulated peak flows are as follows:

Date	Peak Discharge (cfs)		Difference	
	Concrete	Sedro-Woolley	(cfs)	(%)
Historic Events (WSP 1527)				
19 November 1897	275,000	190,000	-85,000	-31
30 November 1909	260,000	220,000	-40,000	-15
30 December 1917	220,000	195,000	-25,000	-11
13 December 1921	240,000	210,000	-30,000	-13
Modeled Event				
100-yr regulated	235,400	242,000	+6,600	+3

The historic data show attenuation (reduction) in peak flows between Concrete and Sedro-Woolley ranging from 11% to 31% while the hydraulic modeling results for the 100-year regulated event show a 3% increase. The apparent discrepancy between historic data and model results may be due to one or more of the following factors:

- the hydraulic model may be unreliable
- modeled "local" inflows between Concrete and Sedro-Woolley may be too high
- differences between regulated and unregulated hydrology (i.e. unregulated historic flows would have likely been more peaked and thus more likely to show attenuation when compared to regulated flows which are already somewhat attenuated, with drawn out peaks)
- historic peak flows reported at Concrete may be too high
- historic peak flows reported at Sedro-Woolley may be too low

3.1 Hydraulic Modeling

nhc reviewed the Corps' HEC-RAS unsteady-flow hydraulic model of the Skagit system and accompanying hydraulic report (USACE, 2004a). While the hydraulic report focuses primarily on the lower Skagit River downstream of Sedro-Woolley (River Mile [RM] 22.4), the model actually extends upstream to Marblemount (RM 78.87) and includes the lower ends of major tributaries, including 5.4 miles of the largest tributary, the Sauk River. The primary focus of **nhc**'s review was flow attenuation within the reach from Sedro-Woolley upstream to the Baker River confluence at Concrete (RM 55.35). All cross-section data upstream from Sedro-Woolley are taken from 1975 surveys from the effective FIS (published in 1984), and are spaced on the order of 0.5 to 1.0 mile apart (excepting interpolated sections added for model stability). Downstream cross-sections within the area of greater interest to the Corps study were resurveyed in 1999 by Skagit County.

The floods of October 2003 and November 1995, both large events with a decent number of recorded high water marks, were used by the Corps in an attempt to calibrate and verify the hydraulic model. Gaged streamflow data and regression relationships with the North Fork Stillaguamish River (to estimate local inflows between Concrete and Sedro-Woolley) provided the inflow hydrographs required by the model. Calibration was performed for the 2003 event resulting in reasonable n-value roughness coefficients, ranging from 0.04 to 0.045 in the channel and 0.12 to 0.15 on the overbank along the Concrete to Sedro-Woolley reach (and beyond to the railroad bridge by Mount Vernon). Independent verification using the same set of n-values could not, however, be achieved for the 1995 event. In order to reasonably match high water marks for this event, significant changes in n-values were made. Within the first 8 miles or so downstream from Concrete, n-values are about the same as for the 2003 calibration. Continuing downstream from about RM 47.55 to RM 31.45, n-values are increased to 0.05 to 0.06 in the channel and remain 0.12 to 0.15 on the overbank. Along the lowest 8 miles of this reach (upstream from Sedro-Woolley) n-values were decreased to 0.03 to 0.035 in the channel and 0.08 on the overbank (n-values were also decreased downstream of Sedro-Woolley). Possible reasons cited for the difficulty in calibration and independent verification include differences in antecedent conditions and groundwater infiltration (October 2003 was preceded by a dry season whereas November 1995 was more typically wet), as well as questionable accuracy of the older 1995 high water marks. The final model relies upon the October 2003 calibrated n-values which appear more appropriate for the Concrete to Sedro-Woolley reach.

A review of the cross-sections from Concrete to Sedro-Woolley, based on the original FIS work maps and the HEC-RAS model itself, indicates that the cross-sections are representatively located with appropriate alignment and lateral extent. There were no significant areas of off-channel storage beyond the limits of the cross-sections (and therefore not represented in the model), which might act to attenuate flood peaks. Given the age of the cross-section surveys, their rather wide spacing, and the uncertainty in calibration and n-values, the localized accuracy of computed water levels at specific locations within this reach may be questionable. The larger question, as pertains to this review, is how these uncertainties in the hydraulic modeling in the upper reach between Concrete and Sedro-Woolley translate to uncertainties in the lower reach, below Sedro-Woolley. In other words, how sensitive is the computed discharge at Sedro-Woolley to the uncertain model inputs within the upper reach, such as n-values and cross-section data as well as upstream hydrologic inputs?

The following sensitivity tests were conducted using the HEC-RAS unsteady model to help answer these questions:

1) Using the final 2003 geometry file, all n-values (channel and overbank) were increased by 50% from Concrete to Sedro-Woolley. Such n-values would be considered unusually high for this reach of river, but it provides for a useful "what-if" scenario. The increased n-values result in greater flow depths and therefore greater storage of water, both in-channel and on the floodplain. Even with such an extreme modification to n-values, the reduction in 100-year peak flow at Sedro-Woolley (due to increased storage attenuation) is only about 3,000 cfs.

2) The time base of the 100-year inflow hydrographs to the model was halved to investigate the effect of uncertainty in the duration or "peakedness" of those input hydrographs. Longer duration, larger volume floods result in less flow attenuation. Increasing the peakedness (reducing the volume) of the inflow hydrographs should result in greater storage attenuation. Halving the time base of the inflow hydrographs resulted in a 12,000 cfs reduction in the 100-year peak flow at Sedro-Woolley compared to the baseline run.

3) The modeled 100-year local inflow between Concrete and Sedro-Woolley consists of a hydrograph with a peak discharge of 30,000 cfs (see Figure 5), evenly distributed along the reach. For test 3 the local inflows between Concrete and Sedro-Woolley were eliminated to determine their effect on flows at Sedro-Woolley. Eliminating local inflows resulted in the 100-year peak flow at Sedro-Woolley being reduced by 17,000 cfs relative to the baseline run. Since peak flow attenuation between Concrete and Sedro-Woolley is masked by local inflows, this run also demonstrates that floodplain storage is, in fact, causing attenuation in the modeled flows. As shown in Figure 6, the peak flow in this sensitivity run was reduced by approximately 6,000 cfs (2.5%) between Concrete and Sedro-Woolley.

4) Local inflows between Concrete and Sedro-Woolley were eliminated **and** the time base of the other 100-year inflow hydrographs to the model was halved to estimate the peak flow attenuation under the most favorable conditions. The resulting 100-year peak flow at Sedro-Woolley was reduced by 26,000 cfs relative to the baseline run, with the peak flow between Concrete and Sedro-Woolley for this run being attenuated by about 16,000 cfs (7%).

The results of the sensitivity runs are summarized in the peak discharge profile plot of Figure 6.

Even with the most extreme of the above scenarios (no local inflow between Concrete and Sedro-Woolley and the time base of the hydrographs halved) it is not possible for the hydraulic model to reproduce the attenuation implied by the historic flood data from

Concrete and Sedro-Woolley, which strongly suggests that either the historic peak discharges reported for Concrete are too high or the corresponding discharges reported at Sedro-Woolley are too low.

3.2 Estimation of Historical Peak Flows at Sedro-Woolley

By all accounts, estimation of peak flows for the Skagit River at Sedro-Woolley is fraught with difficulty. Stage-discharge ratings for the site have proven to be unstable and extension of the ratings to high discharges is subject to significant uncertainty. Stewart (1923) states (pg 12) "…this is an exceedingly poor station, so far as rating is concerned, and should be abandoned." The principal issues as they affect estimation of peak flows for the floods of water years 1898, 1910, 1918, and 1922 have been identified as follows:

- Difficulty in estimating overbank flows during large floods (Stewart [1923] provides a lengthy discussion of these difficulties and estimates that overbank flow during the 1922 flood amounted to about 25% of the total discharge).
- Changes in channel conditions downstream from the gage, most significantly the Sterling bend cut-off of 1911.
- The effect of downstream levee failures on water surface slope and discharge rate at the gage site.
- Varying backwater effects as a result of varying water levels in the Nookachamps area.
- Lack of a quantitative basis for extension of the rating curve to high discharges, especially for the 1898 and 1910 floods which occurred prior to the Sterling bend cut-off.

A staff gage at Sedro-Woolley was first installed at the Northern Pacific railroad bridge about 1 May 1908. Water levels were recorded at or close to this location for the 1910, 1918, and 1922 floods. The water level for the 1898 flood was presumably based on a local highwater mark (possibly from the Hart Ranch) transferred to the gage site. However, available information on the determination of the 1898 water level is unclear.

Stage-discharge ratings at Sedro-Woolley were established through a program of direct discharge measurements. Stewart reports a total of 81 discharge measurements between 12 June 1908 and 22 January 1923. The highest discharge measurement appears to have been about 90,000 cfs (Measurement 45). The ratings show significant shifts, are apparently dependent on whether the river is rising or falling, and extrapolation to flows of the magnitude of the historic events is subject to considerable uncertainty. The difficulty of estimating peak flows for large events is compounded by the need to measure or estimate overbank discharges. It appears that Stewart estimated the peak discharge for the December 1921 flood from the stage-discharge rating and then added 50,000 cfs to account for overbank flow. This latter figure, which represents about 25% of the estimated total discharge, was calculated from the hydraulic characteristics of the three "slough openings" in the Northern Pacific embankment through which all overbank flow would have had to pass. It is not clear how overbank flow was determined for the other historic floods since the stage-discharge rating appears to provide an estimate of discharge in the main channel only.

The peak discharges for the historic floods estimated by Stewart were reviewed by USGS staff in the early 1950s (Riggs and Robinson 1950, Flynn 1951, Bodhaine 1954, Flynn 1954a). All the reviews recommend various levels of reduction in the peak flows for Sedro-Woolley; however, there does not appear to have been consensus on what level of reduction was appropriate. The final and apparently overriding review by Bodhaine (1954) concluded, on the basis of very little quantitative data, that peak discharges estimated by Stewart for 1918 and 1922 were probably "quite reliable" but that peak flows for the earlier events in 1898 and 1910 were probably about 10% high. Bodhaine points out that the "maximum change of 10.8% seems small when all of the possible sources of errors are considered", and recommends that Stewart's values continue to be used. Bodhaine also notes that "the peaks near Concrete probably should be revised if those near Sedro-Woolley are changed."

Given the poorly defined stage-discharge ratings at Sedro-Woolley together with the uncertainty regarding overbank flows, we have little confidence in the magnitude of the published Sedro-Woolley discharges. We do note however, that nowhere in the available documents is there any indication that the estimates of the historic peak discharges may be low at Sedro-Woolley.

As discussed in Section 3.1 above, the attenuation in historic peak flows between Concrete and Sedro-Woolley suggested by the published data appears unreasonably large. From the point of view of hydraulic conditions, the gage site at Concrete is greatly superior to the site at Sedro-Woolley and given the poor quality of the rating at Sedro-Woolley it is not possible to say with certainty whether peak flows reported for Sedro-Woolley are high or low. Nevertheless, the consensus amongst the USGS reviewers of the 1950s was that the published Sedro-Woolley peak flows were high and if that is the case then peak flow estimates at Concrete must also be high.

4.0 FLOOD FREQUENCY ANALYSES

A key step in estimating the design discharge for flood hazard management on the Skagit is flood frequency analysis of unregulated peak discharges for the Skagit River near Concrete. Two particular aspects of the flood frequency analyses conducted by the Corps were investigated as part of this review: the period of unregulated record used for analysis; and the treatment of historic events.

4.1 Period of Record Used in Frequency Analysis

The Corps' frequency analysis of unregulated peak discharges makes use of data from the four historic floods and a 58-year systematic record from water year 1944 through water year 2004, excluding water years 1992, 1993, and 2003. The period of systematic record used by the Corps was governed by the availability of data to estimate the effects of upstream reservoir regulation.

In review of the Corps' work by Pacific International Engineering (PIE), it was suggested that the effects of reservoir regulation prior to 1944 would be minimal and that the record of unregulated peak flows at Concrete should be extended back to water year 1925 by simply using the observed (regulated) peak flow data. PIE's argument was essentially that in the period 1925 through 1944, there were no requirements for flood control storage at the projects then in place (Lower Baker, Diablo, and Gorge), and that peak flows would be passed through those facilities without attenuation. PIE's position implies that there would be no incidental flood control storage, e.g. as a result of reservoir drawdown due to hydropower operations.

The observed record of annual peak discharges at the Concrete gage, the record of unregulated winter (October-March) peak discharges used by the Corps in their frequency analysis, and the record of unregulated winter peak discharges used by PIE are listed in Table 1. Although PIE assumed that the then-existing projects had no impact on peak flows from 1925 through 1944, USGS Water Supply Paper 1527 contains an estimate of the unregulated peak flow for water year 1932 of 182,000 cfs, compared with an observed peak discharge of 147,000 cfs. No other information has been located on unregulated flows in the 1925 through 1944 time period, however, the data from 1932 indicate potential for incidental storage in that period to have a significant affect on peak discharges. A final column of data is included in Table 1 showing two changes to the data series – replacement of the 1932 data with the estimated unregulated value of 182,000 cfs and addition of an estimated unregulated discharge for the November 2006 (water year 2007) flood of 185,000 cfs (Perkins, personal communication, 2007).

Table 1: Peak Discharge Data, Skagit River near Concrete

	Observed Data		Unregulated Winter Data			
Water Year	Date	Annual Peak Discharge (cfs)	Date	USACE Peak Discharge (cfs)	PIE Peak Discharge (cfs)	Changes to Data Series (cfs)
1898	19-Nov-1897	275,000	19-Nov-1897	275,000		
1910	30-Nov-1909	260,000	30-Nov-1909	260,000		
1918	30-Dec-1917	220,000	30-Dec-1917	220,000		
1922	13-Dec-1921	240,000	13-Dec-1921	240,000		
1925	12-Dec-1924	92,500	12-Dec-1924	m	92,500	
1926	23-Dec-1925	51,600	23-Dec-1925	m	51,600	
1927	16-Oct-1926	88,900	16-Oct-1926	m	88,900	
1928	12-Jan-1928	95,500	12-Jan-1928	m	95,500	
1929	09-Oct-1928	74,300	09-Oct-1928	m	74,300	
1930	07-Jun-1930	32,200	20-Feb-1930	m	43,692	
1931	26-Jun-1931	60,600	28-Jan-1931	m	64,145	
1932	27-Feb-1932	147,000	27-Feb-1932	m	147,000	182,000
1933	13-Nov-1932	116,000	13-Nov-1932	m	116,000	
1934	22-Dec-1933	101,000	22-Dec-1933	m	101,000	
1935	25-Jan-1935	131,000	25-Jan-1935	m	131,000	
1936	03-Jun-1936	60,000	05-Jan-1936	m	28,223	
1937	19-Jun-1937	68,300	23-Dec-1936	m	35,698	
1938	28-Oct-1937	89,600	28-Oct-1937	m	89,600	
1939	29-May-1939	79,600	02-Jan-1939	m	70,686	
1940	15-Dec-1939	48,200	15-Dec-1939	m	48,200	
1941	19-Oct-1940	51,000	19-Oct-1940	m	51,000	
1942	02-Dec-1941	76,300	02-Dec-1941	m	76,300	
1943	23-Nov-1942	54,000	23-Nov-1942	m	54,000	
1944	03-Dec-1943	65,200	03-Dec-1943	67,639	67,639	
1945	08-Feb-1945	70,800	08-Feb-1945	70,077	70,077	
1946	25-Oct-1945	102,000	25-Oct-1945	108,844	108,844	
1947	25-Oct-1946	82,200	25-Oct-1946	81,490	81,490	
1948	19-Oct-1947	95,200	19-Oct-1947	85,040	85,040	
1949	13-May-1949	55,700	07-Oct-1948	45,180	45,180	
1950	27-Nov-1949	154,000	27-Nov-1949	163,325	163,325	
1951	10-Feb-1951	139,000	10-Feb-1951	151,668	151,668	
1952	05-Jun-1952	43,500	20-Oct-1951	41,628	41,628	
1953	01-Feb-1953	66,000	12-Jan-1953	79,612	79,612	
1954	31-Oct-1953	58,000	01-Nov-1953	61,187	61,187	
1955	11-Jun-1955	56,300	19-Nov-1954	63,268	63,268	
1956	03-Nov-1955	106,000	04-Nov-1955	124,179	124,179	
1957	20-Oct-1956	61,000	20-Oct-1956	66,910	66,910	
1958	17-Jan-1958	41,400	17-Jan-1958	48,846	48,846	
1959	30-Apr-1959	90,700	03-Dec-1958	82,998	82,998	
1960	23-Nov-1959	89,300	23-Nov-1959	101,118	101,118	
1961	16-Jan-1961	79,000	15-Jan-1961	92,134	92,134	
1962	03-Jan-1962	56,000	03-Jan-1962	73,870	73,870	
1963	20-Nov-1962	114,000	20-Nov-1962	107,280	107,280	
1964	22-Oct-1963	73,800	22-Oct-1963	82,130	82,130	

Table 1 (continued).

Water Year	Observed Data: Date	Observed Data: Annual Peak Discharge (cfs)	Unregulated Winter Data: Date	USACE Peak Discharge (cfs)	PIE Peak Discharge (cfs)	Changes to Data Series (cfs)
1965	01-Dec-1964	52,600	01-Dec-1964	65,127	65,127	
1966	06-May-1966	36,800	06-Oct-1965	44,836	44,836	
1967	21-Jun-1967	72,300	16-Dec-1966	82,256	82,256	
1968	28-Oct-1967	84,200	28-Oct-1967	86,529	86,529	
1969	05-Jan-1969	49,500	05-Jan-1969	65,525	65,525	
1970	04-Nov-1969	38,400	23-Jan-1970	43,335	43,335	
1971	31-Jan-1971	62,200	31-Jan-1971	83,194	83,194	
1972	13-Jul-1972	91,900	13-Mar-1972	63,640	63,640	
1973	26-Dec-1972	49,500	26-Dec-1972	58,079	58,079	
1974	16-Jan-1974	79,900	16-Jan-1974	122,033	122,033	
1975	21-Dec-1974	57,500	21-Dec-1974	63,929	63,929	
1976	04-Dec-1975	122,000	03-Dec-1975	150,068	150,068	
1977	18-Jan-1977	58,400	18-Jan-1977	70,984	70,984	
1978	02-Dec-1977	70,300	02-Dec-1977	74,635	74,635	
1979	08-Nov-1978	46,000	08-Nov-1978	59,164	59,164	
1980	18-Dec-1979	135,800	18-Dec-1979	144,608	144,608	
1981	26-Dec-1980	148,700	26-Dec-1980	163,438	163,438	
1982	21-Jun-1982	51,700	15-Feb-1982	67,853	67,853	
1983	04-Dec-1982	101,000	04-Dec-1982	83,792	83,792	
1984	05-Jan-1984	109,000	04-Jan-1984	111,577	111,577	
1985	07-Jun-1985	46,100	03-Nov-1984	42,000	42,000	
1986	19-Jan-1986	93,400	19-Jan-1986	104,351	104,351	
1987	24-Nov-1986	83,500	24-Nov-1986	78,609	78,609	
1988	24-Nov-1987	39,600	10-Dec-1987	44,891	44,891	
1989	16-Oct-1988	74,100	16-Oct-1988	89,300	89,300	
1990	04-Dec-1989	119,000	10-Nov-1989	137,739	137,739	
1991	10-Nov-1990	149,000	10-Nov-1990	200,072	200,072	
1992	29-Apr-1992	53,300	01-Feb-1992	m	54,343	
1993	13-May-1993	39,300	23-Mar-1993	m	40,637	
1994	03-Mar-1994	36,500	02-Mar-1994	57,927	57,927	
1995	20-Dec-1994	59,800	20-Dec-1994	78,793	78,793	
1996	29-Nov-1995	160,000	29-Nov-1995	185,733	185,733	
1997	09-Jul-1997	91,400	19-Mar-1997	104,655	104,655	
1998	05-Oct-1997	76,700	05-Oct-1997	75,040	75,040	
1999	13-Dec-1998	61,400	13-Dec-1998	81,043	81,043	
2000	12-Nov-1999	103,000	12-Nov-1999	135,037	135,037	
2001	20-Oct-2000	30,900	20-Oct-2000	42,670	42,670	
2002	08-Jan-2002	94,300	08-Jan-2002	125,293	125,293	
2003	26-Jan-2003	65,500	26-Jan-2003	m	65,171	
2004	21-Oct-2003	166,000	21-Oct-2003	185,685	185,685	
2005	11-Dec-2004	99,400	m	m	m	
2006	m	m	m	m	m	
2007	07-Nov-2006	145,000	06-Nov-2006	m	m	185,000

Frequency analyses were conducted on the unregulated winter peak discharge data of Table 1 using the Corps' HEC-FFA software following the guidelines of Bulletin 17B (U.S. Water Resources Council 1982). Results for winter floods with return period from 2- to 100-years are provided below along with: 1) analysis of the PIE data with adjustment to the 1932 data and addition of the 2007 data, and 2) analysis of the Corps' data with the addition of the 2007 data. The differences between the various analyses are minimal. In our opinion, the Corps' approach of discounting the systematic record prior to 1944, is acceptable and has only minor impact on the results of the frequency analyses.

Run	Data Series	Peak Discharge by Return Period (cfs)				
		2-year	10-year	25-year	50-year	100-year
1	USACE: 4 historic events + 58-yr systematic record	84,400	158,000	203,000	242,000	284,000
2	PIE: 4 historic events + 80-yr systematic record	80,300	152,000	196,000	232,000	272,000
3	PIE Adjusted: As Run 2 with 1932 adjusted and 2007 added	81,200	156,000	201,000	239,000	281,000
4	USACE Adjusted: As Run 1 with 2007 added	86,000	160,000	205,000	242,000	282,000

4.2 Treatment of Historic Data

The flood frequency analyses conducted by the Corps follow the guidelines of USWRC Bulletin 17B. This is the widely accepted standard approach to flood frequency analysis. However, as pointed out by several researchers (e.g. Stedinger and Cohn 1986), the Bulletin's approach to treatment of historic data is inefficient and Bulletin 17B itself (page 28) acknowledges the need for "Alternative procedures for treating historic data".

More comprehensive treatment of historic data is available through the EMA (Expected Moments Algorithm) software package developed by the US Bureau of Reclamation (England 1999). This package was developed specifically to make better use of the information typically available for historical or paleofloods. EMA supports more efficient statistical parameter estimation procedures than Bulletin 17B, allows analysis of historic data with multiple thresholds for multiple historical periods, and allows for the explicit incorporation of uncertainty in historical flood estimates through specification of a range of discharges for those estimates. It also provides for considerably greater flexibility in terms of the type of historical or paleoflood data that can be incorporated into flood frequency analyses. For example, in addition to the ability to specify a range for flood magnitude, EMA can incorporate information that no floods exceeded some specified level, or that a flood exceeded some level but its magnitude is unknown. None of this type of information can be used in the Bulletin 17B procedures.

Improvements in Bulletin 17B are being actively considered by the Hydrologic Frequency Analysis Work Group. This is a work group of the Hydrology Subcommittee of the Advisory Committee on Water Information (ACWI), for which the USGS is the lead agency (see http://acwi.gov/aboutus.html). The Hydrologic Frequency Analysis Work Group (HFAWG) was formed in December 1999 to recommend improvements or alternatives to the Bulletin 17B procedures. The work program of the HFAWG specifically includes evaluation of EMA and comparison of EMA against Bulletin 17B. The HFAWG includes members from Federal agencies, academia, consultants, and several special interest groups. Members include representatives from FEMA, US Army Corps of Engineers, USGS, and Michael Baker amongst others.

A number of exploratory flood frequency analyses were performed using EMA on the Corps' record of unregulated instantaneous peak flows for the Skagit River near Concrete. These analyses, and the resultant 100-yr peak flow estimates, are summarized in Table 2. The following points should be noted:

- The 100-year discharge for Run 1 (Base Case with published data) agrees exactly with the Corps analysis performed using the HEC-FFA software for the flood insurance study. The Corps analysis for the flood insurance study provides computed probabilities and does not include the expected probability adjustments applied for the flood damage reduction feasibility study (see Bulletin 17B [USWRC 1982] for details).
- Runs 2 and 4 use estimates of peak discharges for the historic events summarized by Bodhaine (1954) and resulting from the "n" verification study of the early 1950's discussed in Section 2.1. These discharges, and the comparable published discharges, are:

Water Year	**Published Peak Discharge (cfs)**	**Peak Discharge from Bodhaine (1954) (cfs)**
1898	275,000	265,000
1910	260,000	240,000
1918	220,000	205,000
1922	240,000	225,000

It will be recalled from Section 2.1 that the peak discharge for water year 1922 as recomputed by Bodhaine was believed to be "the most logical answer based on the latest methods of computing peak flow". Peak discharges for the other historic events as reported by Bodhaine are based on a high flow rating drawn through the water year 1922 value of 225,000 cfs.

Table 2: Summary of EMA flood frequency analyses for unregulated peak annual flows, Skagit River near Concrete

Run	Assumptions	Q_{100} (cfs)
1	Base Case with published data: 107-yr period 1898 – 2004 46-yr historic record 1898 – 1943 4 historic peaks 1898, 1910, 1918, 1922 61-yr systematic record 1944 – 2004 3 yrs missing in systematic period (1991, 1992, 2003)	284,000
2	Base Case with historic data from Bodhaine (1954): 107-yr period 1898 – 2004 46-yr historic record 1898 – 1943 4 historic peaks 1898, 1910, 1918, 1922 61-yr systematic record 1944 – 2004 3 yrs missing in systematic period (1991, 1992, 2003)	270,000
3	Extend Period back to 1870 with published data: 135-yr period 1870 – 2004 29-yr first historic period 1870 – 1898 1 historic peak above first threshold 1898 45-yr second historic period 1899 – 1943 3 historic peaks above second threshold 1910, 1918, 1922 61-yr systematic record 1944-2004 3 yrs missing in systematic record (1991, 1992, 2003)	276,000
4	Extend Period back to 1870 with historic data from Bodhaine (1954): 135-yr period 1870 – 2004 29-yr first historic period 1870 – 1898 1 historic peak above first threshold 1898 45-yr second historic period 1899 – 1943 3 historic peaks above second threshold 1910, 1918, 1922 61-yr systematic record 1944-2004 3 yrs missing in systematic record (1991, 1992, 2003)	263,000
5	Eliminate 1898: As Run 1 but 106-yr period 1899 – 2004 (eliminate 1898)	266,000
6	Uncertain Gage Heights: As Run 3 but with range of values for historic data reflecting uncertain gage height (see Section 5.0 for details).	248,000
7	Uncertain Gage Heights, Uncertain Roughness: As Run 3 but with range of values for historic data reflecting uncertain gage height and uncertain roughness (see Section 5.0 for details).	241,000

Note: All years are given as water years.

- Run 3 and Run 4 rely on extending the period of historic information for the Concrete gage back to 1870. Reports from the time of the 1898 flood (compiled by Kunzler 2006) seem to be reasonably consistent in claiming this to be the largest flood since settlement of the valley around 1870. However, it is not known whether the period 1870 – 1897 included flood events larger than the other historic floods in the record (i.e. 1910, 1918, and 1922). Since EMA can handle multiple historical periods with multiple flood thresholds, it is now possible to analyze the situation where the 1898 flood is the largest in the period 1870 – 1898, and the 1910, 1918, and 1922 floods are the largest in the period 1899 – 1943. This type of analysis is not possible under the Bulletin 17B procedures of HEC-FFA.
- Run 5 is the same as Run 1 (Base Case with published data) except that data for the historic flood of water year 1898 was dropped. The high water mark(s) for this event (and hence the gauge height and discharge estimate) was reported by Stewart as being the most uncertain of the four historic events considered here.
- Runs 6 and 7 incorporate uncertainty into the analysis of the historic data and are discussed in more detail in Section 5.0.

5.0 UNCERTAINTY

USGS staff have repeatedly stressed that all discharge measurements are uncertain and, depending on circumstances, may be good to only within ±25%. Furthermore, upon review, the USGS has taken the position that measurements of peak discharges for the historic floods of 1898, 1910, 1918, and 1922 for the Skagit River near Concrete should not be downgraded and will remain part of the official record. The US Army Corps of Engineers has in turn accepted the USGS position and has determined that the historic events be incorporated into its analysis of flood risk in the Skagit Valley.

We agree with the USGS and the US Army Corps of Engineers basic positions with respect to the historic events for the following rather simple reasons:

- there is convincing evidence that significant floods occurred in those years
- exclusion of those data from the analyses could result in an understatement of flood risk

We are also of the opinion that uncertainty should be incorporated into the analysis of flood risk in the Skagit Valley and that planning for flood hazard management, including the current flood damage reduction study, should incorporate safe-fail features.

The principal challenge to incorporating uncertainty into the analyses is characterizing that uncertainty. Incorporation of uncertainty into flood frequency analyses can be achieved using the EMA software by specifying a range of values for the historic flood events. The pre-settlement floods of 1815 and 1856 could also be included in analyses with EMA provided a suitable range of values for those events could be agreed on and provided that the historical time period for which the 1815 flood was the largest could be established.

Our review of the historic data has identified or confirmed a number of indications that the discharge estimate for the December 1921 flood is likely high. Given the manner in which the discharge estimates for other historic events are dependent on the December 1921 estimate, this would imply that discharge estimates for the historic events of water years 1898, 1910, and 1918 are also high. The various indications that the December 1921 peak flow estimate is likely high include the following:

- the discharge estimate is inconsistent with extrapolation of the established stage-discharge rating and plots to the right of the curve (i.e. the discharge is higher than would be expected from the rating for the reported gage height).
- no account has been made for the drop in water level between the old and new gage sites.
- the "n" verification study of 1950 indicates that the published peak discharge is high.

- the reported attenuation in peak discharges between Concrete and Sedro-Woolley appears to be excessive.

(Evidence that the Smith House in Hamilton did not flood in 1921 when it was flooded at an appreciably lower discharge in 1995 has been cited by others as a further indication that the published peak discharge for December 1921 is high. However, as discussed in Section 2.3 above, changes in hydraulic conditions downstream from Hamilton appear to have significantly reduced the channel conveyance capacity between 1921 and present. With the information currently available it is not possible to say with certainty whether the Smith House would or would not have been flooded in 1921 at a discharge of 240,000 cfs).

While each of the above points could be argued, the preponderance of the evidence suggests that the current estimate for the December 1921 peak discharge is toward the high end of the range of uncertainty.

We have attempted to identify specific indications that the December 1921 peak discharge estimate may be low. The only specific source of understatement appears to be the possibility of flow bypassing the gage site at Concrete on the right overbank and being unrecorded. However, there is no known evidence of bypassed flows and it could (and has) been argued that reported water levels or mainstem discharges that imply bypassed flows are, in the absence of evidence of such bypass, simply another indication that those water levels or discharges are overestimated. Given the published gage heights, a bypass is obviously most likely to have occurred in the water year 1898 flood.

The “n” verification studies notwithstanding, uncertainty also remains in the roughness at the higher discharges experienced in 1921 and earlier historic events. The value of 0.030 determined in 1950 is, at best, probably good to within ±0.002, corresponding to uncertainty in the computed discharge of ± 7%.

Exploratory frequency analyses were conducted with EMA using a range of values for the historic floods to reflect uncertainty. Two alternative analyses were carried out: 1) with uncertain gage height and fixed roughness, and 2) with uncertain gage height and uncertain roughness. The results of those analyses are summarized in Table 2 (Section 4.2). It should be stressed that at this point, these analyses are primarily for illustrative purposes. Further work would be required to establish defensible flow ranges for the historic events.

Uncertain gage height and fixed roughness

For the floods of 1910, 1918, and 1922, the top of the range was taken as the published discharge values, and the bottom end of the range was taken as the discharge values indicated by the current rating for the published gage height less 2 ft to account for the fall in water level between the old and new gage sites at Concrete. A similar approach was used for the 1898 flood except that a nominal 15,000 cfs was added to the top end of the range to account for flows possibly bypassing the gage site. Note that the various estimates of the fall in water level between the two gage sites varies from about 0.2 ft to 2 ft (see Section 2.2). The 2 ft fall adopted here is thus probably the largest fall that could be reasonably assumed. The range of discharge values assumed for historic events is thus as follows:

Flood Event	Range of Peak Flow (cfs)	
November 1897	229,000	290,000
November 1909	210,000	260,000
December 1917	179,000	220,000
December 1921	196,000	240,000

The frequency curve as estimated by EMA with uncertain historic data values is shown, together with the discharge data, in Figure 7. With the above range of discharges for the historic floods and assuming that the 1898 flood is the largest in the period 1870 to 1898, the estimate of the 100-year unregulated discharge is reduced from 284,000 cfs to 248,000 cfs.

Uncertain gage height and uncertain roughness

The effects of uncertain roughness were approximately accounted for by widening the above range of historic discharges by ±7%, representing uncertainty in Manning's roughness of ±0.002. The discharge values for the historic events were assumed as follows:

Flood Event	Range of Peak Flow (cfs)	
November 1897	213,000	310,000
November 1909	195,000	278,000
December 1917	166,000	235,000
December 1921	182,000	257,000

With the above range of discharges for the historic floods and assuming the 1898 flood is the largest in the period 1870 to 1898, the estimate of the 100-year unregulated discharge is reduced from 284,000 cfs to 241,000 cfs.

6.0 OTHER CONSIDERATIONS

6.1 Reservoir Regulation

The usual practice amongst the various regulatory agencies involved in flood hazard management is to assume that only dedicated or mandatory flood control storage should be considered when analyzing the effects of reservoir regulation on downstream flood flows.

The Corps hydrologic analyses (USACE 2004b, Section 4.4) assumes the availability of 120,000 acre ft of flood control storage at Ross Dam and 74,000 acre ft of flood control storage at Upper Baker Dam. It is assumed that no flood control storage is available at other projects. Required flood control storage at Ross and Upper Baker varies seasonally as follows:

Date	Required Flood Control Storage (acre ft)	
	Upper Baker	Ross
October 1	0	0
October 15	8,000	20,000
November 1	16,000	43,000
November 15	74,000	60,000
December 1	74,000	120,000
March 1	74,000	120,000

Note that the full amount of flood control storage assumed in the Corps analysis is not actually required until December 1 of each flood control season. Many of the large floods in the historical record have however occurred in November or even October (e.g. the flood of October 2003) when required flood control is substantially less than that assumed by the Corps.

If the Corps analyses were intended to rely only on required flood control storage, then the analyses to date would overstate the degree of flood control regulation afforded by the upstream reservoirs and by Ross in particular. In practice, we expect that normal power generation practices would result in the Ross and Baker reservoirs being drawn down more than required under the current flood control operating curves prior to the start of the flood control season. However, such “incidental” flood control storage is typically not relied on in either delineation of flood hazards or in design of flood control projects.

It should also be noted that the Baker River Project is currently undergoing relicensing by FERC. Modifications to the flood storage requirements at the Baker River Project (including the amounts of flood storage and the dates on which such storage should be available) are under consideration as part of the relicensing process. Modification to flood storage requirements are also being examined under the Corps Skagit River Flood Control General Investigation.

6.2 Hypothetical Flood Events

The Corps' hydrologic and hydraulic analyses rely on a series of hypothetical flood hydrographs for future regulated conditions for a range of return periods from 25- to 500-years. These hydrographs were developed by means of a complex chain of regression and flood frequency analyses, the details of which are described in the Corps' Hydrology Technical Documentation (USACEb, 2004). The approach requires development of hypothetical flood hydrographs for the various sub-basins of the system, routing of hydrographs through the system's reservoirs consistent with flood control operating policies, addition of inflows downstream of the system reservoirs and then routing to Concrete and Sedro-Woolley.

Development of the hypothetical hydrographs relied heavily on regression relationships between peak instantaneous, peak one-day, and peak three-day discharges. The Corps analyses show high degrees of correlation between the instantaneous peak and one-day values and between the one-day and three-day values which are somewhat misleading.

Taking regression between one-day and three-day values as an example, in most of the basic data analyzed by the Corps, the annual one-day peak is embedded in the annual three-day peak. Regression between one- and three-day values is thus effectively a regression of the one-day peak against itself plus flows for two adjacent days, a procedure which leads to a spuriously high correlation coefficient. Data for the Sauk River near Sauk (USGS gage 121895000, period of record water years 1930 – 2005) were analyzed to assess the effects of this shortcoming. Regression of the one-day winter peak flow against the three-day winter peak flow resulted in a correlation coefficient of 0.92. Regression of the one-day peak flow against the flows for the adjacent two days gave a correlation coefficient of 0.75. Similar results would be expected from analysis of data from other gage sites. A similar issue also arises in regression between one-day peak and instantaneous peak discharges.

The Corps' hypothetical hydrographs assume a nested construction with the T-year instantaneous, one-day and three-day peak discharges all contained within the same event. As a result of overstatement of the regression coefficients, the Corps' hydrographs appear to exhibit a somewhat conservative combination of high peak and high volume which will result in some overestimation of routed peak discharges. This overestimation is likely small compared with other sources of uncertainty, and in our opinion the Corps' approach to synthesis of hypothetical events is appropriate given the practical difficulties of alternatives techniques, such as generation of hydrographs by rainfall-runoff modeling.

7.0 CONCLUSIONS AND RECOMMENDATIONS

Based on a focused review of the large body of information on the hydrology and hydraulics of the Skagit River, we are of the opinion that estimates of the peak discharges for the historic flood events of water years 1898, 1910, 1918, and 1922 should continue to be incorporated in analyses of flood hazard and flood hazard management in the Skagit Valley. We are also of the opinion that uncertainty in the magnitude of the historic floods should be accounted for in future hydrologic analyses.

The estimated peak discharge for the 1922 flood is of critical importance to flood hazard management since estimates of the peak discharges for the other historic events are directly dependent on the estimate for the 1922 event. The peak discharge estimates for the historic events collectively determine the magnitude of the 100-year discharge, which in turn is the single most important hydrologic parameter for the flood damage reduction feasibility study and the flood insurance study.

It is widely recognized that the peak discharge estimates for the historic events are uncertain. Review of various factors affecting the discharge estimates indicates that the published peak discharge for the 1922 flood of 240,000 cfs at the Concrete gage is most likely toward the high end of the range of uncertainty. We tentatively estimate that the peak discharge for the 1922 flood falls in the range of 180,000 cfs to 260,000 cfs. This is between 75% and 108% of the published value of 240,000 cfs, and between 80% and 116% of the best estimate of the peak discharge for this event of 225,000 cfs as determined by Benson in 1952. Similar tentative ranges have been estimated for the other historic events. Further work is required to establish agreement on defensible flow ranges in consultation with the USGS and US Army Corps of Engineers.

Exploratory frequency analyses of the instantaneous unregulated peak flows at Concrete have been conducted with the EMA (Expected Moment Algorithm) software package. EMA supports more comprehensive and more flexible frequency analysis of historic and paleo flood data than is available in the standard approach to flood frequency analysis using the procedures of USWRC Bulletin 17B. The exploratory analyses with EMA indicate that more rigorous frequency analyses, incorporating uncertainty in the historic peak discharge estimates and taking advantage of EMA's ability to handle multiple historic periods with multiple flood thresholds, could result in a 10% to 15% reduction in the estimate of the 100-year peak **unregulated** discharge. With our current estimates for the range of uncertainty of the historic flood magnitudes, EMA analysis would result in an estimated 100-year peak unregulated discharge for the Skagit River near Concrete of between approximately 240,000 and 250,000 cfs, compared with the current estimate of 284,000 cfs.

Recommendations arising from this review are as follows:

1) Given the past occurrence of major storms early in the flood control season, agreements should be negotiated with Seattle City Light and with Puget Sound

Energy to ensure the availability of 120,000 acre-ft of flood control storage at Ross Dam and 74,000 acre-ft of flood control storage at Upper Baker Dam by no later than November 1 of each flood control season. Consideration should also be given to conditioning flood control storage requirements in the early part of the flood control season, starting on October 1 of each year, on watershed moisture conditions and intermediate term weather forecasts. Note that modifications to the current flood storage requirements are under consideration as part of the FERC relicensing process for the Baker River Project and also under the Corps Skagit River Flood Control General Investigation.

2) The County should seek clarification from the USGS regarding the potential for proposed paleoflood studies to contribute to a more reliable characterization of flood risk. The USGS has previously proposed a paleoflood study which targets the pre-settlements floods of around 1856 and 1815. From currently available information, it is not clear whether the proposed work can be expected to both produce estimates of the magnitude of these events **and** establish a time period within which the 1815 flood was the largest such event. Information on both magnitude and time frame are necessary for risk-based analysis.

3) The County should determine whether potential reduction in the 100-year peak **unregulated** discharge, based on more rigorous flood frequency analysis, warrants additional investment in hydrologic and hydraulic studies.

4) More rigorous flood frequency analysis using the EMA software holds the potential for producing more defensible flood quantile estimates by accounting for uncertainty in the magnitude of historic flood discharges. Should the County decide to proceed with additional hydrologic and hydraulic studies (see Recommendation #3 above), discussions should be initiated with the USGS, the US Army Corps of Engineers, and FEMA to explore the technical and institutional feasibility of using EMA to refine the current estimates of the design flood quantiles for the Skagit River near Concrete. Initial discussions should focus on:

   - the merits of using EMA as opposed to Bulletin 17B,
   - the acceptability of EMA to the three agencies,
   - institutional issues resulting from possible revisions to the current estimates of flood quantiles, including scheduling and budgetary considerations,
   - the process for review and acceptance of revised flood quantiles, and,
   - characterization of the range of uncertainty in historic peak flow

5) Uncertainty in the fall in water level between the original and current locations of the Skagit River near Concrete gage is one of several factors contributing to uncertainty in the historic discharges. A staff gage should be installed at the original site of the Concrete gage and arrangements made to read gage heights at both the current and original locations during future flood events.

While the above recommendations are under consideration, we believe it appropriate for the County to continue development of flood hazard management projects on the basis of the Corps' current hydrologic analyses. Our review indicates that Corps estimates of design discharges are conservatively high. Modification to the Corps' design or inundation mapping work to accommodate a possible reduction in design discharge should be relatively straightforward from a technical point of view.

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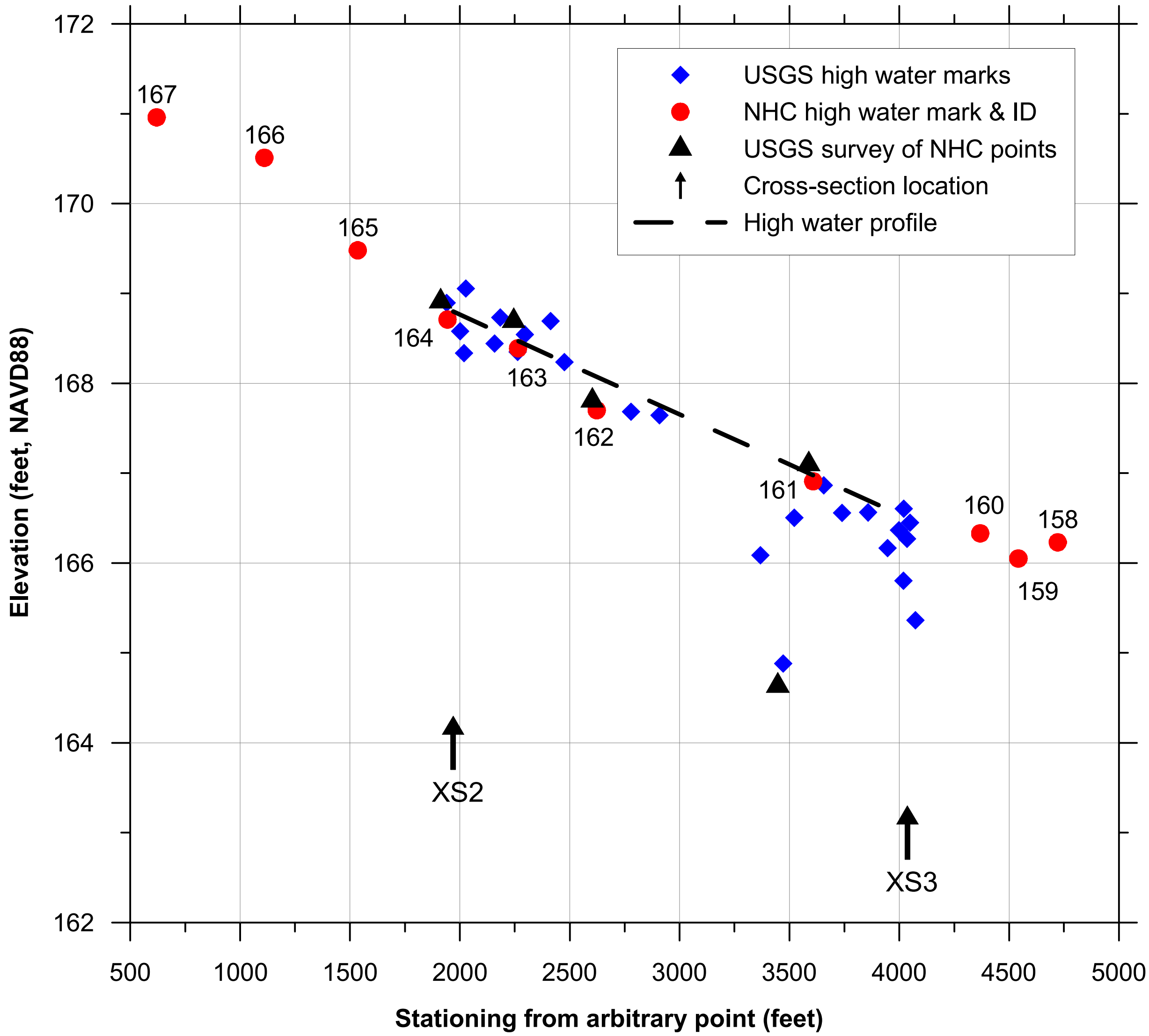


Figure 1: High water marks and water surface profile for flood of 7 November 2006, Skagit River near Concrete

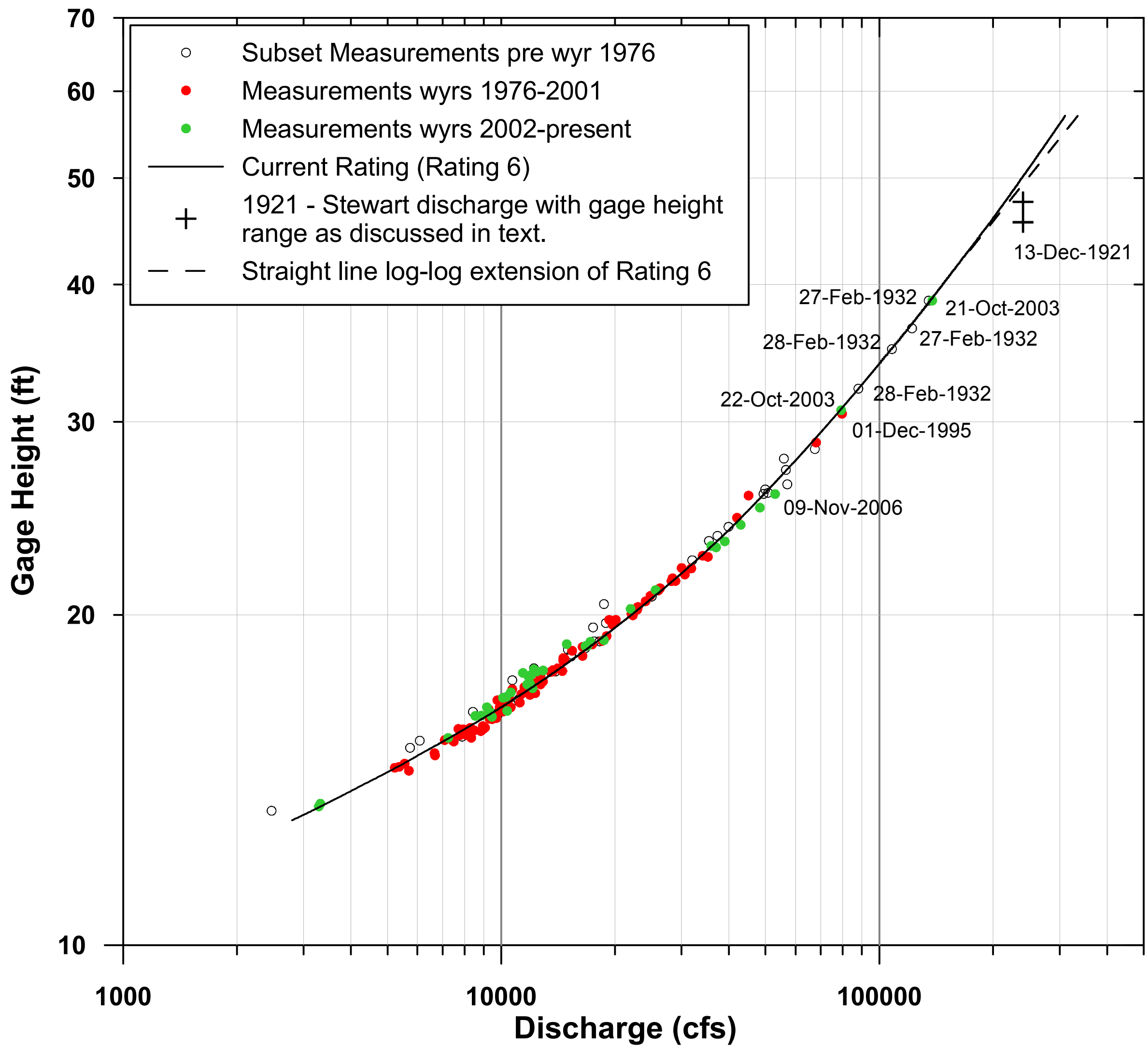
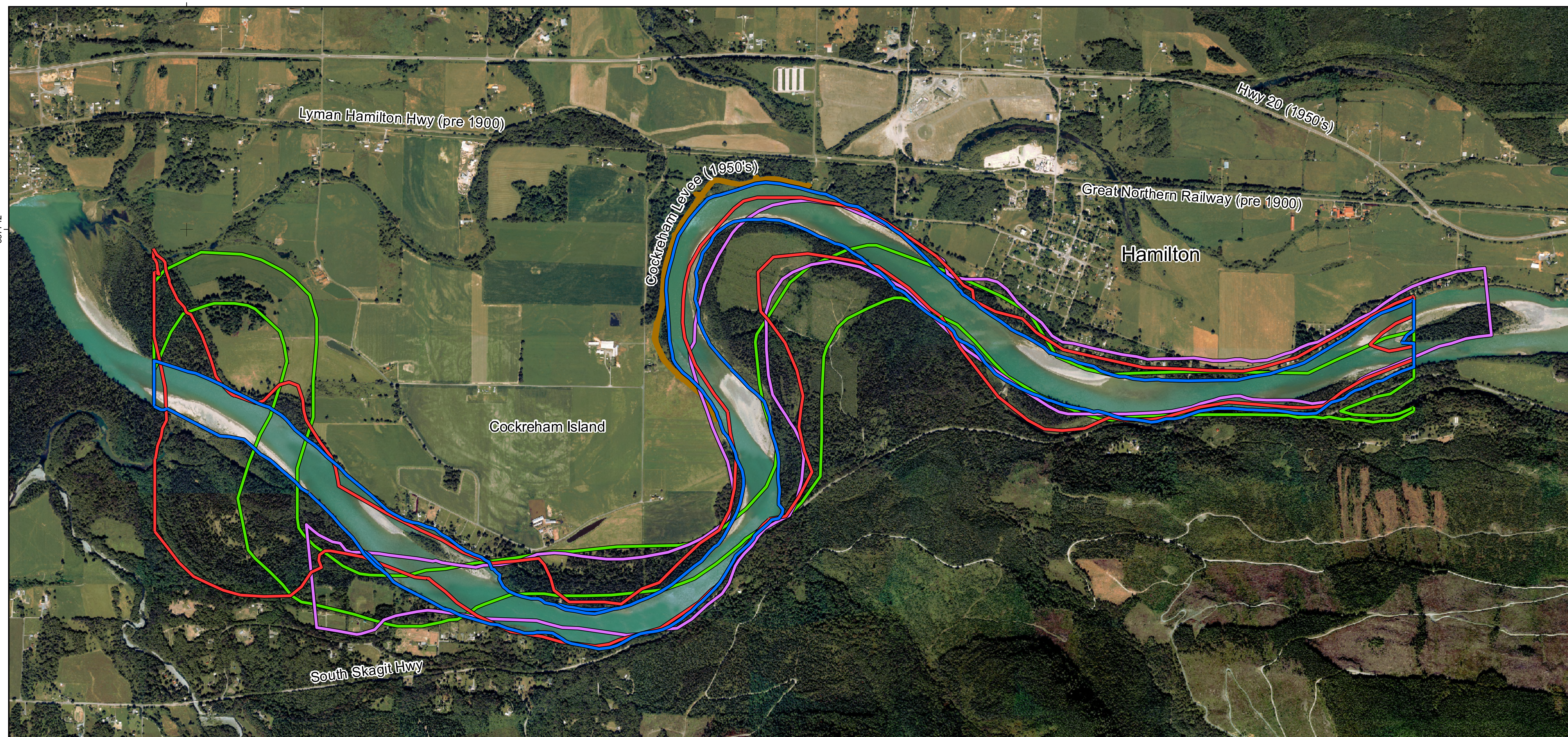


Figure 2: Stage-discharge rating, Skagit River near Concrete



Legend

- 2001 bank line
- 1937 bank line
- 1911 bank line
- 1886 bank line
- levee

SKAGIT RIVER

Skagit River Channel Change Over Time

0 500 1,000 2,000 3,000 4,000 5,000 Feet

coord. syst.: State Plane Wash N	horz. datum: NAD 27	horz. units: Foot
northwest hydraulic consultants	project no. 21487	26-Apr-2007

nhc, G:_proj\21487_Skagit\Skagit_Final.mxd

Figure 3

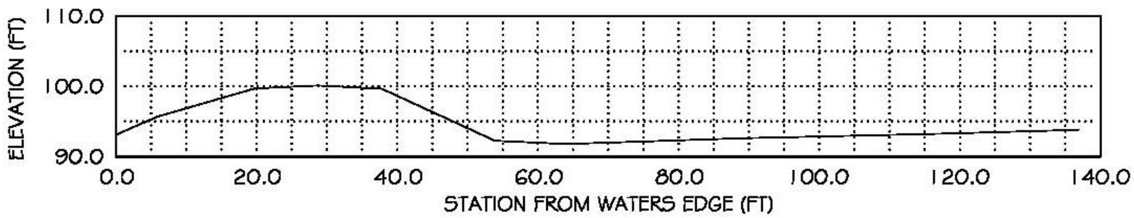


Figure 4: Representative Section through Cockreham Levee (looking d/s)

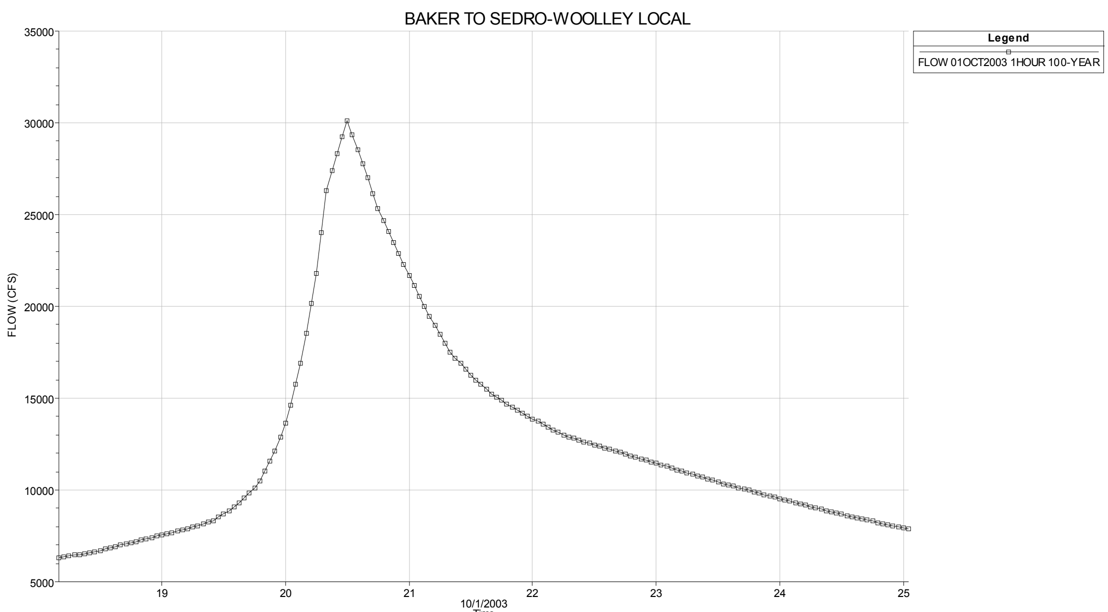


Figure 5: 100-year Local Inflow Hydrograph Concrete to Sedro-Woolley

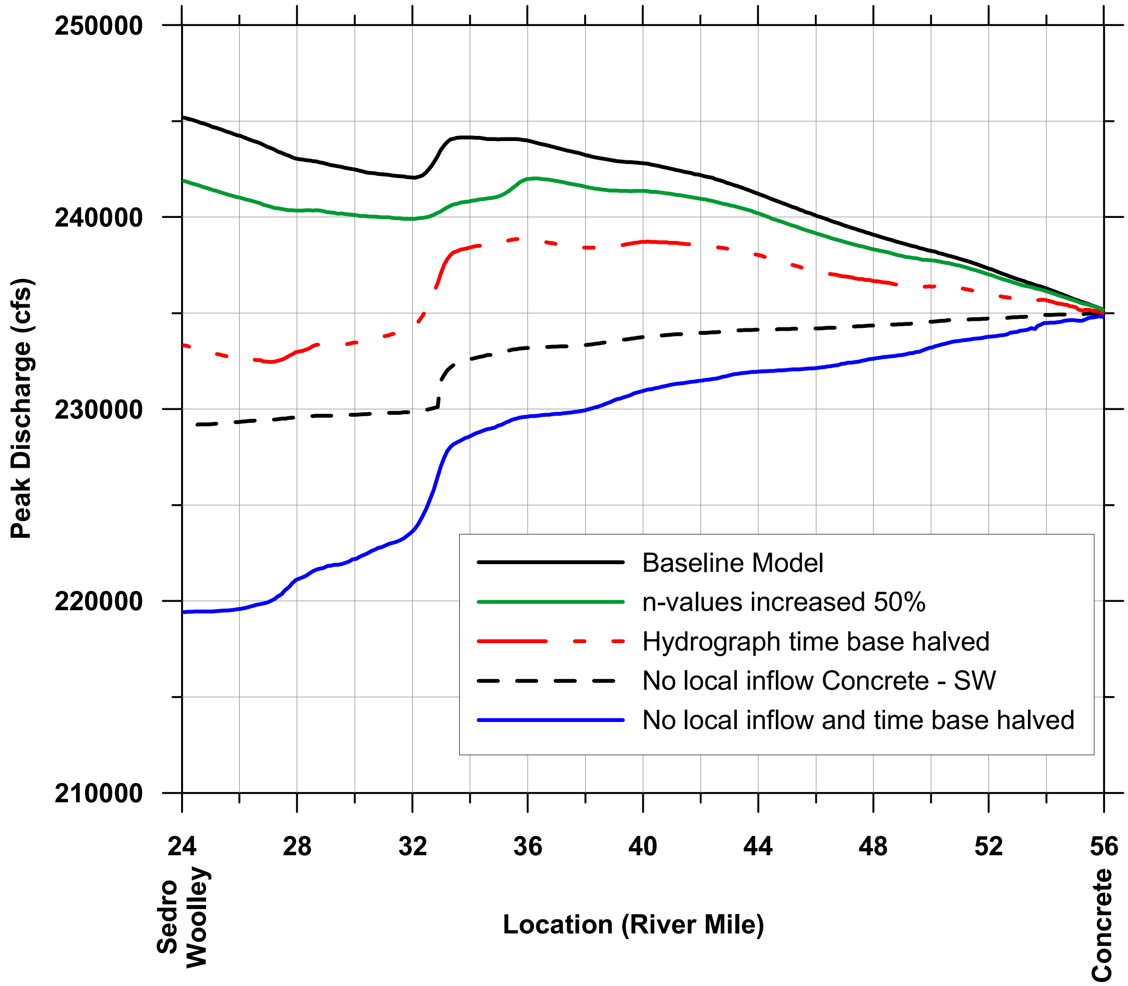


Figure 6: 100-year Regulated Peak Discharge Profiles

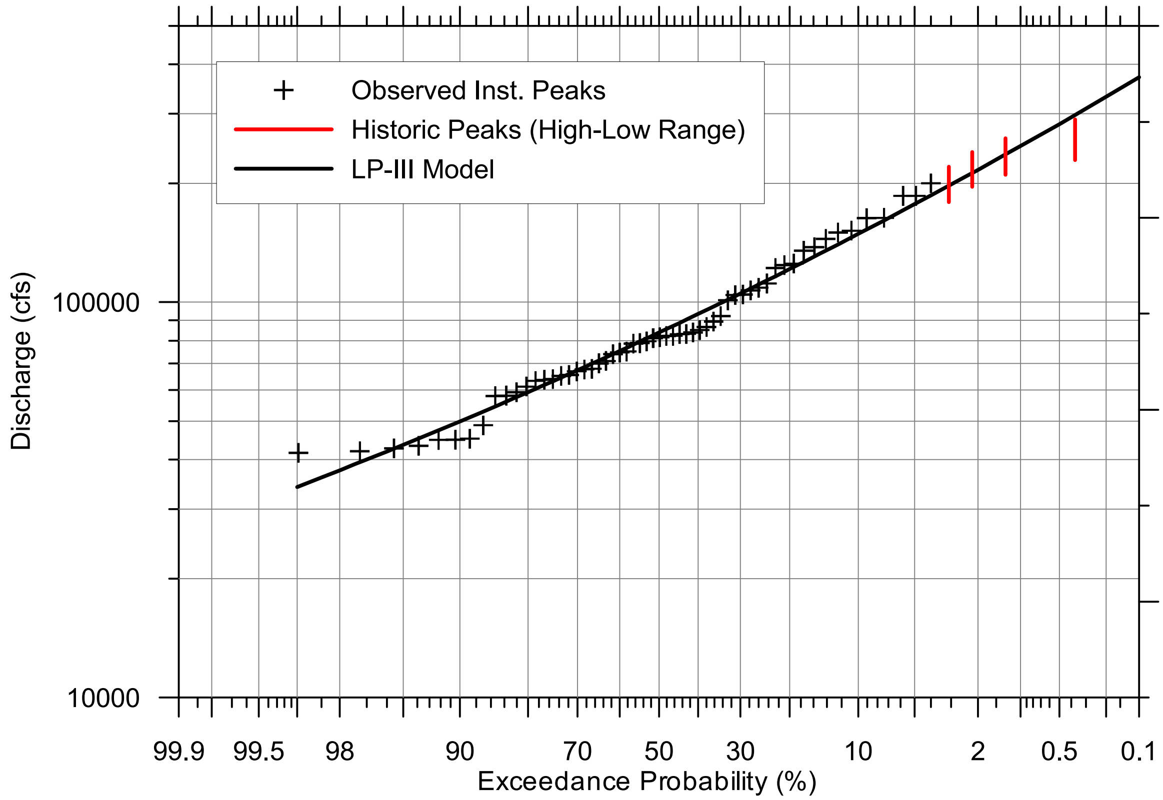


Figure 7: Annual Frequency Analysis, Skagit River near Concrete Unregulated Instantaneous Peak Discharge – Run 6

APPENDIX

COMMENTS ON FEBRUARY 2007 DRAFT REPORT
WITH
RESPONSES

Comments by:

Chal A. Martin
Public Works Director/City Engineer
City of Burlington

From: Martin, Chal [mailto:cmartin@ci.burlington.wa.us]
Sent: Tuesday, April 03, 2007 12:04 PM
To: rboge RicBoge
Cc: Bell, Esco; Rick Blair; Harmon, Mike; Fleek, Margaret; Hanson, Jana; DaveBrookings; dolson@clearwire.net; dkdist12@cnw.com; NEIL HAMBURG; Hanson, Jana
Subject: nhc report comments

Ric, per your request last night. Thanks for the opportunity to respond.

My overall impression is that this is a thoughtful and well-written report that contains valuable data and concise summary information of the relevant issues related to the historic flood estimates. I appreciate the obvious effort that went into the study. Here are my comments:

1. page 3, last word in the second paragraph: consider replacing “measurement” with “estimate.” **Agreed - report changed.**
2. page 4, 3rd full paragraph: “This impact cannot be reliably quantified, but with Section 2 located close to the downsteam end of the bar the effects are probably quite small.” Could a sentence be added that states something like “But in theory, the effect would be______________________.” **Text added as requested.**
3. page 6, top sentence: not sure if “Ased” is supposed to be “used.” **Report fixed - word should have been "based".**
4. page 7 and subsequent: I think “Cockerham” should be spelled “Cockreham.” **Report fixed.**
5. page 8: I will attach the pdf file of the COE 1911 map of the Hamilton reach. Maybe that could be incorporated into the migration map on figure 3. **The 1911 banklines have been added to Figure 3 and the text modified. The 1911 bank lines are similar to or wider than those of 1937 and if anything reinforce our conclusions that the river could have carried appreciably more water at the time of the historic floods.**
6. page 9, conclusion: “More definitive estimates of water levels at the Smith House during the December 1921 flood are not possible given the lack of detailed channel geometry data from the period.” But isn’t it possible to artificially insert a range of channel configurations into the model, and see what affect that has on water surface levels at the Smith house location? For example, the report speaks of 1.5 feet of aggradation in that area since the mid-sixties, as well as channel width decreases. Couldn’t an estimate of the appropriate cross sections be made and modeled, bookending the worst and best cases? There is evidence that the flood of 1932 did put water into Hamilton, with a discharge of 147,000 cfs. Seems like that bit of information might be dialed into the assumptions made on the cross sections. (see attached Concrete Herald news article of the time – “nearly the whole of Hamilton was covered at the height of the flood). In addition, it must be remembered that the Smith house was also subjected to a 1909 flood discharge of 260,000 cfs, as well as a 1917 discharge of 220,000cfs. Finally, in the same Concrete Herald news article of March 3, 1932, the statement “Hamilton and Lyman suffered only the usual damage, with no buildings washed away” is intriguing. Does this statement imply that some houses were washed away in the floods of 1921 or 1917, those events still relatively fresh in peoples’ minds in 1932? If so, the Smith house was not. Or does this statement imply that the minor floods of 1928, 1926, and 1924 also flooded Hamilton with a much lower discharge? (see page 16). **Given the lack of survey data, we don't see much point in detailed modeling of hypothetical scenarios. We have however done some sensitivty runs which demonstrate, at least to our satisfaction, that given the magnitude of channel changes from past to present, the river could well have carried 240,000 cfs in 1921 without flooding the Smith House. As stated in the report, it is not possible to say with certainty whether the house would or**

would not have flooded in either 1921 or 1909. The report text will be modified to refer to the sensitivity runs.

7. page 15: the report accepts the 1932 unregulated value of 182,000 cfs published by USGS; however, I wonder what really happened back then. See several 1932 articles, attached. There seem to be conflicting reports, but I would submit it is quite plausible that the dams were not operated at that time in a way that would have effectively reduced the peak flow by 35,000 cfs at the peak of the flood – J.D. Ross' protestations to the contrary notwithstanding. Seems like maybe this is an area that could be explored further, with a range of assumptions about precedent reservoir levels, etc. My impression from the newspaper articles is that most likely these dams were operating as run of the river facilities at the times that would have reduced the flood peak. 35,000 cfs reduction is quite a lot, given only Baker and Diablo had flood control capability at the time. **Figure 4 in USGS Water Supply Paper 1527 shows the regulated and unregulated hydrograph for the February 1932 flood at Concrete and implies regulation by about 100,000 acre-ft of upstream storage. The Courier Times article on the flood states "At Baker River before the flood, water was 36 feet below the top, and at the peak of high water flowed nine feet deep over the top of the dam". This 45 ft range would account for about 84,000 acre ft of storage. Diablo was not generating power in 1932 so I suspect Diablo was operated prior to the flood with gates open. At the start of the flood, the water level would likely have been at the gate sill level. The Courier Times refers to the gates being operated during the flood and the elevation-storage curve for Diablo shows that there could very easily have been 16,000 acre ft of storage change as a result. We don't see any reason to challenge the USGS estimate for the unregulated peak for 1932. No changes will be made to the report.**
8. page 22, 3rd sentence from bottom: change "expect" to "except" **Report fixed.**
9. page 25, 2nd paragraph, last sentence: replace "vales" with "values" **Report fixed.**
10. again, nice report **Thanks.**

Thanks Chal

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Comments by:

Larry. J. Kunzler

LJK COMMENTS ON NHC DRAFT FEB 2007 REPORT RE SKAGIT HYDROLOGY

NHC response in red text after each comment.

2.1 Verification of Manning's Roughness

Verification of "n" using data from the flood of October 2003 is discussed by Mastin and Kresch (2005). High water mark (HWM) data from the October 2003 flood were apparently difficult to identify in the field and show a substantial scatter. It was perhaps unfortunate that the USGS chose to publish this "n" verification work since the scatter in the data have been used by some parties in an attempt to call into doubt the applicability of slope-area techniques on this reach of the river. The slope-area measurement is a well established technique for estimating river discharges and in our opinion is reasonably well-suited to this reach, provided reliable water level data are available. The USGS used the HWMs from the October 2003 flood to determine a range of "n" values from a low of 0.024 to a high of 0.032. When applied to the HWMs from the December 1921 flood, these "n" values in turn result in a peak discharge for December 1921 in the range 215,000 cfs ("n" of 0.032) to 266,000 cfs ("n" of 0.024). The range of "n" values determined by the USGS is, in our opinion, so large as to be of little value in verifying Manning's roughness and does not contribute to improving confidence in the reliability of the 1921 peak discharge measurement. (Page 3)

LJK COMMENTS: The comments highlighted above give credence to the lack of confidence in the USGS "rush to judgment" Mastin Report and more importantly show the unreliability of taking "flood marks" (i.e. mud on trees and rocks) months after a flood event let alone what Stewart tried to do attributing mud marks to floods 4 years to 102 years preceding his investigation. MOST importantly is that once again it shows us the importance of the "n" value and how just tweaking the figure .008 can influence the flood flows from 266,000 cfs to 215,000 cfs or a difference of 51,000 cfs. This difference seemingly means little to USGS or the Corps but results in multiple millions of dollars in additional flood control project costs.

NHC RESPONSE: No edits will be made to report. Note however that a change in "n" of 0.008 is a large change - it can hardly be called "tweaking". Also, note that Stewart's work to identify high water marks from the December 1921 flood was based on much more than "mud on trees and rocks" and the field work to establish high water marks was done mostly in late 1922 and early 1923 – about a year after the December 1921 flood. The observation and use of flood high water marks, while never exact, is a widely accepted component of hydrologic engineering practice.

. . .

nhc's estimate of "n" from analysis of the November 2006 flood data is consistent with Benson's estimate of "n" based on data from the November 1949 flood and his recomputation of the peak

discharge for the December 1921 flood of 225,000 cfs. Since this estimate was only 6% lower than Stewart's original estimate, no change was made to the then-published value of 240,000 cfs. Nevertheless, the USGS n-verification for the November 1949 flood, under conditions closer to the those of 1921 than today's conditions, together with supporting evidence from the November 2006 event, indicate that the 240,000 cfs published value for December 1921 is conservatively high, other possible sources of uncertainty notwithstanding. (Page 4)

LJK COMMENTS: Does the above highlighted text imply that only one "n" value should be used for the entire reach above and below The Dalles? What was wrong with the way Riggs and Robinson computed the flows using different "n" values in 1950?

NHC RESPONSE: "n" can be expected to vary from one reach of the river to another and some river reaches are more suitable for determining "n" than others. The "n" estimated by nhc is for the reach between USGS 2003 sections 2 and 3 as stated in our report at the bottom of page 3. Problems with the Riggs and Robinson calculation are discussed in the August 1952 memo of Benson and Flynn.

2.2 Consistency of December 1921 Data with Published Rating Curve

. . .

A measurement taken in October 2003 (discharge 138,000 cfs, gage height 38.68 ft) agrees very closely with those of February 1932, confirming and validating the rating at least up to about 150,000 cfs. The close agreement between the highest measured discharge in February 1932 and the October 2003 measurement suggests that changed channel conditions downstream of the gage site (primarily changes in vegetation on the right bank gravel/cobble bar) have had no discernible impact on the stage-discharge rating at the gage site, at least for discharges up to 150,000 cfs. At this discharge, we estimate the bar to be covered by from 5 ft to 8 ft of water. The effect of the gravel/cobble bar on upstream conditions at the gage site can be expected to decrease at higher discharges because of the hydraulic control imposed by the contraction at The Dalles. Given the stability of the channel at the gage site, there is no reason to expect a material change in the high water rating between 1921 and present at this location. (Page 5)

LJK COMMENTS: So one can infer from the above verbiage that the gravel bar/island downstream of The Dalles is not a serious player in determining flood flows which I have no problem with I just want to make sure that I am understanding what **nhc** is stating. What about "changed channel conditions" upstream of the gage as described by Riggs and Robinson and later Benson.

> "On the basis of a slope-area study made in the reach below the gage for the flood of November 27, 1949[1], it appears that the value of "n" used by Stewart in his 1921 flood flow computation was too low for his upper reach. It was also noted that Stewart did not

[1] The gage in The Dalles was installed in 1924, three years after the last flood "estimated" by Stewart.

take into account changes in velocity head in his computations. A recomputation of the 1921 peak by present methods using Stewart's values of A, P, and f, and "N" = .040 for the upper reach and "N" = .033 for the lower reach gives 209,000 cfs." … "I can find no data on which to base an estimate of the percentage of energy recovery for various conditions, but it might be that much of this energy is lost in moving the gravel bottom of the stream." … "The need for revision of the historic flood peaks is supported by the logarithmic extension of the present rating curve. … at those times the overflow area was heavily timbered and would carry little water. In addition, the possibility of a reduction in slope **due to log jams** downstream is to be considered. The recomputed value of 209,000 cfs mentioned above checks this logarithmic extension within 2%. The flood frequency curve shows a sharp offset to the right between recorded and historic floods and **casts further doubt on the published values for the historic floods.** ***(Source: Proposed Revision of Skagit River Flood Peaks, H.C. Riggs & W.H. Robinson, 11/16/50)***

"Only reach B-C used. Reach A-B is expanding and "n" for that portion of the channel is not well verified. Value of "n" for reach B-C is from verification using data from flood of November 27, 1949. ***(Source: Slope area measurement of Skagit River near Concrete for the flood of December 13, 1921, M. A. Benson, 5/5/52)***

They also feel that only the reach 2-3 of Stewart's 1921 determination should be used in computing the discharge because reach 1-2 is expanding and the "N" for that reach may be questionable. ***(Source: Skagit River near Concrete, Wash. – Verification Study by F.J. Flynn and M.A. Benson, 8/52)***

NHC RESPONSE: As far as we can tell, the growth of vegetation on the gravel bar has had no effect on the stage-discharge rating at the gage site. We feel that this is adequately covered in our report and do not propose to make any changes. Again as far as we can determine, neither Riggs & Robinson nor Benson discuss channel changes upstream from the gage site. The reference to the "great overflow area on the right bank" by Riggs & Robinson is too vague to comment on. No edits will be made to nhc's report.

. . .

Assumptions	Peak Gage Height or Discharge (December 1921)	
	Gage Height (feet)	Discharge (cfs)
Gage height reported by Stewart with discharge from Rating 6	47.6	215,000
Gage height adjusted for 0.5 ft fall to new gage site with discharge from Rating 6	47.1	210,000
Gage height adjusted for 1.5 ft fall to new gage site with discharge from Rating 6	46.1	201,000
Gage height adjusted for 2 ft fall to new gage site with discharge from Rating 6	45.6	196,000

Gage height reported by Stewart with discharge from straight line log-log extension of Rating 6 above 140,000 cfs	47.6	222,000
Discharge reported by Stewart with gage height from Rating 6	50.2	240,000

(Page 6)

LJK COMMENTS: I'm not sure how to interpret the above table. What is Rating 6? Does the last entry suggest that in order to reach 240,000 cfs that would mean that the gage would have had to read 50.2 on the new gage instead of the USGS reported 47.6 and visa vie if the gage height was 47.6 then the Skagit would have only carried 215,000 cfs not the reported 240,000 cfs? The second entry is interesting in that it is exactly the same discharge as Riggs and Robinson came up with in 1950. ***(Source: Proposed Revision of Skagit River Flood Peaks, H.C. Riggs & W.H. Robinson, 11/16/50)***

What the above chart does show us is that Stewart could have been off by as much as 44,000 cfs which equates to approximately 4.5 feet of water which further equates to hundreds of millions of dollars in questionable flood control project costs.

NHC RESPONSE: Rating 6 is the current USGS stage-discharge rating at Concrete. LJK's interpretation of the last entry in the table is correct. We will add text to assist in interpretation of the table.

2.3 Consistency of December 1921 Data with Evidence of Non-Inundation

. . .

According to research by Kunzler (2006), the Smith House in Hamilton (307 Maple Street, Hamilton) was built in 1908 and anecdotal reports indicate that it has only once been flooded above its main floor level. The house is reported to have had 2 inches of water above the main floor level during the flood of November 1995 (peak discharge at Concrete 160,000 cfs). Anecdotal reports suggest that the house was **not** flooded in earlier and much larger flood events (1910 – 260,000 cfs, 1918 – 220,000 cfs, 1922 – 240,000 cfs). If flows of the magnitude of these historic events had occurred under **current** river channel conditions, then the water levels should have been several feet above the main floor level. These apparent inconsistencies have a number of possible explanations:

- the anecdotal reports are incorrect and the house was in fact flooded above the main floor level in the earlier floods,
- the peak discharge estimates for water years 1910, 1918, and 1922 are incorrect and are too large, or,
- the hydraulic conveyance capacity of the river channel and/or floodplain in and around Hamilton was historically significantly greater than at present and was

able to carry greater flows at lower water levels.

. . .

Although no sign of water damage from large historic floods was evident, it is our present opinion that this does not provide **conclusive** evidence that flooding did **not** occur. Any flood marks from December 1921 would now be 85 years old. **From our limited experience with flooding of buildings, we would expect flood marks to fade with age.** At the present time, we simply do not know whether a flood mark on the interior of a wall would still be visible after 85 years. (Page 7)

. . .

Figure 3 also shows a substantial narrowing of the river channel downstream from Hamilton between 1937 and 2001. The average channel width for the approximately 1.5 mile reach through the first meander bend below Hamilton was about 750 ft in 1886 and 900 ft in 1937 compared with only 600 ft in 2001. These estimates should be used with some caution since: (1) we do not know with certainty how the river channel was delineated on the GLO maps, and (2) bank lines from the 1937 and 2001 aerials were drawn, in the absence of stereographic coverage, as the edge of continuous vegetation. The greater width in 1937 is due mostly to inclusion within the defined channel of a broad left-bank sand or gravel bar. Nevertheless the river channel in 1937 (and presumably also at the time of the historic floods) was clearly wider than at present and would have had a correspondingly greater conveyance capacity. Just how much greater is not possible to determine with any accuracy since detailed channel surveys from 1937 are not available. (Page 8)

The approximate analysis conducted for this review indicates that the Cockerham Levee raises water levels in Hamilton by about 1.2 ft for flows in the range of 240,000 cfs. With the levee in place and assuming that the Smith House was just flooded to the level of the main floor at a discharge of 160,000 cfs in November 1995, then a discharge of 240,000 cfs **with the present channel conditions**[3] would have flooded the house to a depth of about 4.2 ft. Without the levee but **with present channel conditions,** the depth of flooding would have been about 3.0 ft. **Given that the river below Hamilton was considerably wider in 1937 than today, it is possible that the river could have carried 240,000 cfs in 1921 without flooding the main floor of the Smith House.** More definitive estimates of water levels at the Smith House during the December 1921 flood are not possible given the lack of detailed channel geometry data from that period. **(Emphasis added)** (Page 9)

<u>LJK COMMENTS:</u> This section of the report is perhaps the most inconsistent with otherwise a great work product of documentation and research. **nhc** has concluded that because the river was wider in 1937 then it is today that it could have carried the flows in 1921 and not flooded the Smith House. Based on the following local history I would have to respectfully disagree with **nhc**.

After the 1921 flood the local newspapers reported the following:

> *At Hamilton the entire town was covered with water to a depth of from three to seven feet, the water entering every business house in town. Sidewalks were washed away and considerable inconvenience and small damage caused the residents, but no heavy losses are reported. (Source: **12/17/21 C.H.**)* **(Emphasis added)**
>
> *The flood of 1921 is the biggest flood in the history of the Skagit, according to old timers, who recall the floods of 1879, 1888, 1897 and on up to the big flood of 1909 and the 1917 freshet. Mrs. Dreyer, who lives west of town, tells of the big flood of 1888, when in some places the river backed up higher than this year. She says that not so much damage was done then because there were practically no dikes and the water spread over the lowlands more gradually.* ***Measurements at the Dalles, near Concrete, show that the flood water this year reached a point two feet higher than at any previous time in the memory of the oldest settler****. Charley Moses says that it was the biggest flood, with the biggest volume of water ever carried in the Skagit. At Van Horn the water was 14½ inches higher than it had ever been.* ***In 1909 the river in the upper valley was only about two-thirds as wide as it is now.*** *Hundreds of acres of land are being washed away every year, by both Skagit and Sauk rivers. W. A. Ellison says he has been on the upper river for 21 years and this is the biggest flood he has seen or heard old timers tell about. (Source: **12/22/21 CT**)* **(Emphasis added)**
>
> **Old timers in the Skagit valley, who have seen all the floods in the Skagit valley since the early 80's say that the recent flood carried a greater volume of water than any previous flood since the county was settled, surpassing even the famous high water of 1897. The fact that the river did not reach marks set in former years at some points in the upper valley is accounted for by the widening of the river since that time.** In all places where the banks of the river have remained unchanged the **1921 mark is considerably above that of any previous flood known to settlers.** *(Source: **12/31/21 C.H.**)* **(Emphasis added)**

The reports are very consistent with what Mr. Slipper testified to about his house having 1-2 inches of water in it as at that time the house sat about 3 feet off the ground. (See **Declaration of Fred W. Slipper**)

According to USGS, the Corps and Stewart, the 1921 flood (240,000 cfs) was the third highest with the 1897 and 1909 floods (Stewart 275,000 cfs and 260,000 cfs respectively) being higher which would mean that the three foot depth put forth by **nhc** would have been much greater for the 1897 and 1909 flood events. Based on the local history presented herein not only are the depths of the flood events not consistent with local history neither are their order of magnitudes.

Further credence to the articles mentioned above is given by the "sounding map" performed by the Corps of Engineers in 1911. *(See **Corps Map of Hamilton Vicinity**)* The map appears to show the Skagit River in a position much more closely aligned to where the river is today then where it was in 1937. What I believe it shows us is that the river was in the process of widening itself after the 1897 and 1909 flood events, or more likely then not, due to the log rafts being floated down the Skagit during that time, the log rafts played a substantial part in erosion of the Skagit banks and the widening of the Skagit River.

One other item of interest worth mentioning is that the whole exercise with the Smith house is not to establish a "flood mark" such as a "stain" as referenced by **nhc**. Given the fact that the Skagit River has as its two main contributor's volcanic rivers (The Baker and The Sauk) and as such both, but especially the Sauk, put a tremendous amount of volcanic material into the Skagit River system. The locals refer to this material as "silt" however when the "silt" is analyzed it shows a very heavy concentration of volcanic material. Most older homes like the Smith House were constructed with "ship lathe". If the Smith House had in fact had several feet of water in it in any of the 3 historical floods (especially the 1909 flood event when the river had not widen) the ship lathe should show signs of the volcanic dust (i.e. silt). To date none has been found.

NHC RESPONSE: Bank lines from the COE map of 1911 will be added to Figure 3 of our report and text will be modified accordingly. The 1911 bank lines are similar to or wider than those of 1937 and our opinion remains that because of channel changes between 1886 and present, it is not possible to demonstrate that the Smith House would (or would not) have flooded at a discharge of 240,000 cfs in 1921. Fundamentally, information is not available to the necessary standard to reach a definitive conclusion on this issue. Prompted by a comment from Chal Martin we have done some sensitivity runs with the hydraulic model which demonstrate that with the magnitude of channel changes from past to present, it is quite possible that the river could have carried 240,000 cfs or more in 1921 without flooding the Smith House. The text will be modified to make reference to the sensitivity runs.

We note that the preliminary report on the Smith House investigations repeatedly refers to flood marks. Even the title of the preliminary report refers to flood marks. Only in one location of that report, in the section on Additional Investigations, is silt mentioned. Specifically, the Smith House report states that additional future investigations could "Perform microscopic examination of the cutout wall sections …. to determine the presence or absence of flood silt."

3.0 COINCIDENT FLOWS AT CONCRETE AND SEDRO-WOOLLEY

LJK COMMENTS ON NHC DRAFT FEB 2007 REPORT RE SKAGIT HYDROLOGY

. . .

The historic data show attenuation (reduction) in peak flows between Concrete and Sedro-Woolley ranging from 11% to 31% while the hydraulic modeling results for the 100-year regulated event show a 3% increase. The apparent discrepancy between historic data and model results may be due to one or more of the following factors:

- the hydraulic model may be unreliable
- modeled "local" inflows between Concrete and Sedro-Woolley may be too high
- differences between regulated and unregulated hydrology (i.e. unregulated historic flows would have likely been more peaked and thus more likely to show attenuation when compared to regulated flows which are already somewhat attenuated, with drawn out peaks)
- historic peak flows reported at Concrete may be too high
- historic peak flows reported at Sedro-Woolley may be too low (Page 10)

3.1 Hydraulic Modeling

. . . The primary focus of **nhc**'s review was flow attenuation within the reach from Sedro-Woolley upstream to the Baker River confluence at Concrete (RM 55.35). All cross-section data upstream from Sedro-Woolley are taken from 1975 surveys from the effective FIS (published in 1984), and are spaced on the order of 0.5 to 1.0 mile apart (excepting interpolated sections added for model stability). Downstream cross-sections within the area of greater interest to the Corps study were resurveyed in 1999 by Skagit County. . . . (Page 11)

Given the age of the cross-section surveys, their rather wide spacing, and the uncertainty in calibration and n-values, the localized accuracy of computed water levels at specific locations within this reach may be questionable. (Page 11)

. . .

Even with the most extreme of the above scenarios (no local inflow between Concrete and Sedro-Woolley and the time base of the hydrographs halved) it is not possible for the hydraulic model to reproduce the attenuation implied by the historic flood data from Concrete and Sedro-Woolley, which strongly suggests that either the historic peak discharges reported for Concrete are too high or the corresponding discharges reported at Sedro-Woolley are too low. (Page 12)

. . .

. . . The final and apparently overriding review by Bodhaine (1954) concluded, on the basis of very little quantitative data, that peak discharges estimated by Stewart for 1918 and 1922 were probably "quite reliable" but that peak flows for the earlier events in 1898 and 1910 were probably about 10% high. Bodhaine points out that the "maximum change of 10.8% seems small when all of the possible sources of errors are considered", and recommends that Stewart's values continue to be used. Bodhaine also notes that "the peaks near Concrete probably should be revised if those near Sedro-Woolley are changed." . . . Nevertheless, the consensus amongst the USGS reviewers of the 1950s was that the published **Sedro-Woolley peak flows were high and if that is the case then peak flow estimates at Concrete must also be high.** (Page 14) ***(Emphasis added.)***

LJK COMMENTS: The first thing this lengthy and in-depth section reveals to us is that as a lot of us suspected, nothing has been "studied" between Concrete and Sedro-Woolley since 1975 and that work is at best questionable. However with respect to the 4 historic floods it might not matter as I couldn't have said it better then **nhc** did:

> *Even with the most extreme of the above scenarios (no local inflow between Concrete and Sedro-Woolley and the time base of the hydrographs halved) it is not possible for the hydraulic model to reproduce the attenuation implied by the historic flood data from Concrete and Sedro-Woolley, which strongly suggests that either the historic peak discharges reported for Concrete are too high or the corresponding discharges reported at Sedro-Woolley are too low.* (Page 15) . . . . . . the consensus amongst the USGS reviewers of the 1950s was that the published **Sedro-Woolley peak flows were high and if that is the case then peak flow estimates at Concrete must also be high.** (Page 14)

NHC RESPONSE: No response needed.

4.2 Treatment of Historic Data

The flood frequency analyses conducted by the Corps follow the guidelines of USWRC Bulletin 17B. This is the widely accepted standard approach to flood frequency analysis. However, as pointed out by several researchers (e.g. Stedinger and Cohn 1986), the Bulletin's approach to treatment of historic data is inefficient and Bulletin 17B itself (page 28) acknowledges the need for "Alternative procedures for treating historic data". (Page 18)

LJK COMMENTS: I'm glad to see **nhc** have this discussion. It has been my position for some time now that use of the 4 historic floods actually violates the spirit and intent of 17B which by the way is the only thing that the Corps of Engineers has to rely on for usage of the USGS data. (See **17B Analysis**) Contrary to what we were told by the former Colonel of the Seattle District, there is no regulation that requires the Corps of Engineers to use USGS data.

NHC RESPONSE: No response needed. However LJK's conclusion that the Corps analysis "violates the spirit and intent of 17B" is not our position. We simply believe that alternative approaches now available better utilize the available data and can provide a better estimate of flood quantiles.

5.0 UNCERTAINTY

USGS staff have repeatedly stressed that all discharge measurements are uncertain and, depending on circumstances, may be good to only within ±25%. Furthermore, upon review, the USGS has taken the position that measurements of peak discharges for the historic floods of 1898, 1910, 1918, and 1922 for the Skagit River near Concrete should not be downgraded and will remain part of the official record. The US Army Corps of Engineers has in turn accepted the USGS position and has determined that the historic events be incorporated into its analysis of flood risk in the Skagit Valley.

We agree with the USGS and the US Army Corps of Engineers basic positions with respect to the historic events for the following rather simple reasons:

- there is convincing evidence that significant floods occurred in those years
- exclusion of those data from the analyses could result in an understatement of flood risk

We are also of the opinion that uncertainty should be incorporated into the analysis of flood risk in the Skagit Valley and that planning for flood hazard management, including the current flood damage reduction study, should incorporate safe-fail features.

. . .

Our review of the historic data has identified or confirmed a number of indications that the discharge estimate for the December 1921 flood is likely high. Given the manner in which the discharge estimates for other historic events are dependent on the December 1921 estimate, this would imply that discharge estimates for the historic events of water years 1898, 1910, and 1918 are also high. The various indications that the December 1921 peak flow estimate is likely high include the following:

- the discharge estimate is inconsistent with extrapolation of the established stage-discharge rating and plots to the right of the curve (i.e. the discharge is higher than would be expected from the rating for the reported gage height).

- no account has been made for the drop in water level between the old and new gage sites.
- the "n" verification study of 1950 indicates that the published peak discharge is high.
- the reported attenuation in peak discharges between Concrete and Sedro-Woolley appears to be excessive. (Pages 21 and 22)

(Evidence that the Smith House in Hamilton did not flood in 1921 when it was flooded at an appreciably lower discharge in 1995 has been cited by others as a further indication that the published peak discharge for 1921 is high. However, as discussed in Section 2.3 above, changes in hydraulic conditions downstream from Hamilton appear to have significantly reduced the channel conveyance capacity between 1921 and present. With the information currently available it is not possible to say with certainty whether the Smith House would or would not have been flooded in 1921 at a discharge of 240,000 cfs).

While each of the above points could be argued, the preponderance of the evidence suggests that the current estimate for the December 1921 peak discharge is toward the high end of the range of plausibility.
(Pages 21 and 22)

Uncertain gage height and fixed roughness

Flood Event	**Range of Peak Flow (cfs)**	
November 1897	229,000	290,000
November 1909	210,000	260,000
December 1917	179,000	220,000
December 1921	196,000	240,000

With the above range of discharges for the historic floods and assuming that the 1898 flood is the largest in the period 1870 to 1898, the estimate of the 100-year unregulated discharge is reduced from 284,000 cfs to 248,000 cfs. (Pages 22 and 23)

Uncertain gage height and uncertain roughness

The effects of uncertain roughness were approximately accounted for by widening the above range of historic discharges by ±7%, representing uncertainty in Manning's roughness of ±0.002. The discharge values for the historic events were assumed as follows:

Flood Event	**Range of Peak Flow (cfs)**

November 1897	213,000	310,000
November 1909	195,000	278,000
December 1917	166,000	235,000
December 1921	182,000	257,000

With the above range of discharges for the historic floods and assuming the 1898 flood is the largest in the period 1870 to 1898, the estimate of the 100-year unregulated discharge is reduced from 284,000 cfs to 241,000 cfs.
(Page 23)

LJK COMMENTS: I am sure that Commissioners' Dahlstedt and Munks will remember that during my James E Stewart Goes To Washington DC presentation (*See James E. Stewart Work Product Goes to D.C.),* I made the remark several times that one of the things that bothered me was one figure kept coming up no matter whose hydrology you were using. That figure was **around 40,000 cfs** at The Dalles. Riggs and Robinson in 1950 wanted to reduce Stewarts flows for the 1909 flood by **40,000 cfs** and the 1921 flood by **50,000 cfs**. ***(Source: Proposed Revision of Skagit River Flood Peaks, H.C. Riggs & W.H. Robinson, 11/16/50)*** The Corps of Engineers hypothetical 100 year flood difference between using Stewarts figures and not using Stewarts figures for regulated flows is approximately **40,000 cfs. nhc** as previously discussed herein using a Gage height adjusted for 2 ft fall to new gage site with discharge from Rating 6 results in a **44,000 cfs** reduction to Stewarts 1921 flow. And now we have **nhc**, world renown and well respected engineering company stating that the estimate of the 100 year unregulated discharge could be reduced between **36,000 and 43,000 cfs.**

The USGS, FEMA and the Corps might be comfortable with their + or – 25% and 40,000 cfs might mean nothing to them with respect to accuracy in their "in-exact" science of hydrology, but to the taxpayers of Skagit County, indeed the taxpayers of our country, this could be the difference of 100 to 200 million dollars in tax money for a flood control project. 4 feet of water is significant and + or – 25% is unacceptable. Accuracy should not be allowed to be replaced with bureaucratic obstinance.

With respect to the above comments on the Smith House, please see the previous section titled 2.3 Consistency of December 1921 Data with Evidence of Non-Inundation. I do believe that **nhc** needs to revisit this section before this report is finalized. While I am willing to accept **nhc**'s statement that the Smith House is not "conclusive" evidence I think that given the historical documents presented herein that it is at least "suggestive" evidence that the Stewart flows are too high and in fact support the rest of the **nhc** report.

NHC RESPONSE: The thrust of our work has been to try to understand and explicitly recognize the uncertainty in the historic peak discharge values. Hydrology is and always will be an inexact science. We think it counter productive to continually criticize the federal agencies on the issue of the accuracy of the discharge estimates.

We are uncomfortable with the focus on the two foot fall in water surface we assumed between the old and new gage sites. The text of our report will be modified to stress the uncertain nature of this estimate and to recommend that attempts be made to monitor the water level difference between the two gage sites in future high flow events. As indicated in our report, the 2 ft fall we have assumed results in discharge estimates at the low end of what we have characterized as the range of uncertainty, and should not be taken to imply that Stewart's estimate for Dec 1921 is 44,000 cfs too high. Note also that the reduction in the 100-yr discharge presented in our report comes from two sources: 1) uncertainty in the peak discharge estimates for the historic events, and 2) extension of the historic period back to 1870.

With regard to the Smith House, we have modified the report section at issue to incorporate data from surveys conducted in 1911, which, if anything, reinforces our opinion that evidence of non-inundation of the Smith House cannot be used to support the position that historic peak discharge estimates are too high.

7.0 CONCLUSIONS AND RECOMMENDATIONS

. . .

. . .we are of the opinion that estimates of the peak discharges for the historic flood events of water years 1898, 1910, 1918, and 1922 should continue to be incorporated in analyses of flood hazard and flood hazard management in the Skagit Valley. We are also of the opinion that uncertainty in the magnitude of the historic floods should be accounted for in future hydrologic analyses.

The estimated peak discharge for the 1922 flood is of critical importance to flood hazard management since estimates of the peak discharges for the other historic events are directly dependent on the estimate for the 1922 event. **The peak discharge estimates for the historic events collectively determine the magnitude of the 100-year discharge, which in turn is the single most important hydrologic parameter for the flood damage reduction feasibility study and the flood insurance study.** ***(Emphasis added)***

It is widely recognized that the peak discharge estimates for the historic events are uncertain. Review of various factors affecting the discharge estimates indicates that the published peak discharge for the 1922 flood of 240,000 cfs at the Concrete gage is most likely toward the high end of the range of uncertainty. . . . Further work is required to establish **agreement on defensible flow ranges** in consultation with the USGS and US Army Corps of Engineers.
(Emphasis added)

. . .

The exploratory analyses with EMA indicate that more rigorous frequency analyses, incorporating uncertainty in the historic peak discharge estimates and taking advantage of EMA's ability to handle multiple historic periods with multiple flood thresholds, could result in a 10% to 15% reduction in the estimate of the 100-year peak **unregulated** discharge. (Page 26)

. . .

Recommendations arising from this review are as follows:

1) Given the past occurrence of major storms early in the flood control season, agreements should be negotiated with Seattle City Light and with Puget Sound Energy to ensure the availability of 120,000 acre-ft of flood control storage at Ross Dam and 74,000 acre-ft of flood control storage at Upper Baker Dam by no later than November 1 of each flood control season. Consideration should be given to conditioning flood control storage requirements in the early part of the flood control season on watershed moisture conditions and intermediate term weather forecasts.

2) The County should seek clarification from the USGS regarding the potential for proposed paleoflood studies to contribute to a more reliable characterization of flood risk. The USGS has previously proposed a paleoflood study which targets the pre-settlements floods of around 1856 and 1815. From currently available information, it is not clear whether the proposed work can be expected to both produce estimates of the magnitude of these events **and** establish a time period within which the 1815 flood was the largest such event. Information on both magnitude and time frame are necessary for risk-based analysis.

3) The County should determine whether the potential for a 10% to 15% reduction in the 100-year peak **unregulated** discharge, based on more rigorous flood frequency analysis, warrants additional investment in hydrologic and hydraulic studies. (Pages 26 and 27)

LJK COMMENTS: For the most part I am in complete agreement with **nhc**'s conclusions and recommendations and feel completely vindicated on the work product that I have produced as a layperson over the last several years with respect to questioning the accuracy of Mr. Stewarts work product. **nhc** has stated without equivocation that there is a "uncertainty in the magnitude of the historic floods should be accounted for in future hydrologic analyses", that the 4 historic floods are what is driving the outcome of the flood insurance study and the flood reduction study, and that "**It is widely recognized that the peak discharge estimates for the historic events are uncertain.**"

Their first recommendation that additional storage be negotiated with PSE and SCL I could not be more in agreement with and would support a .005% increase in the sales tax to help pay for additional storage. As one PSE official told me in Washington DC he didn't have a problem providing additional storage so long as the utility got paid for it.

So pay them for it. Given the total lack of protecting the general safety health and welfare demonstrated by FERC in not requiring additional storage, paying for it is our next best option. I think we should also consider additional storage beginning on October 1^{st} not November 1^{st}.

The second recommendation I'm not too keen on given how I recently began to feel about the competency of federal employees to get anything right. Having reviewed the USGS proposal I feel it raises more questions than answers.

The third recommendation should be a no-brainer for the County. A reduction of 15% to the Corps hypothetical 100 year flood would be a reduction of around **40,000 cfs** or 4 feet of flood waters. While that might not equate to a very large reduction in base flood elevations in the lower valley it certainly would make it a lot more achievable to protect our urban areas by modifying the 3 bridge corridor and our current levee system.

NHC RESPONSE: We were not retained to review the flood insurance study. However, it is our current understanding that it is FEMA's levee analysis policy (i.e. multiple levee failure analyses including separate analyses for left bank and right bank failures) that is driving the dramatic differences between the current and previous FIS and that the change in hydrology is only a small part of the water level differences being reported.

Report recommendation 1) will be clarified to indicate that agreements should be pursued to condition flood control requirements at Upper Baker and Ross on watershed moisture and weather forecasts starting on 1 October of each year. This may be a more cost effective approach to enhancing flood protection in the early part of the flood control season than simply mandating additional flood control storage.

It should be understood that report recommendation 2) refers to potential 10% to 15% reductions in **unregulated** 100-year discharges and that these reductions may not translate to 10 to 15% reductions in **regulated** discharges, particularly if early season flood control storage at Upper Baker and Ross is not addressed.