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An Independent Technical Review – Comments on Flood Frequency Analyses for the Skagit River, Skagit County, Washington

Our Project No. 10353

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EXECUTIVE SUMMARY

The Skagit River planning process deals with several components, many of which depend on the magnitude of certain regulatory return frequency flood peak flow rates. The 100-year return frequency flood peak flow rate, or "Q100", is currently the subject of considerable scrutiny, the outcome of which impacts the expenditure of tremendous resources.

At the core of this scrutiny, are the values of four historic flood peak flow rates estimated by James E. Stewart based upon his observations following the floods of 1917 and 1921. These four values were estimated (rather than measured by stream gages as are the other 80 or so annual flow rates). These four peak flow estimates all occurred at the turn or beginning of the 20th century. Furthermore, the Stewart flows, if accepted as scientifically valid, would indicate that four extremely rare flow rates (all four being larger in value than any flow rate ever measured in the ensuing 81 years at the relevant stream gages) all occurred in a very limited time-frame of about 25 years in duration, which is an event of even rarer probability than the individual storms themselves.

Because of the overwhelming impact the Stewart flows have on the estimate of Q100 and other hydrologic quantities, the scientific scrutiny of those estimates continues. In the current review of the Skagit River documentation, it is shown that significant evidence exists to question the use of the Stewart flows unless they are adjusted downwards in value. The evidence assembled for the current report is not by any means comprehensive, but may be sufficient to cause re-evaluation of the use of the Stewart flows without further scrutiny. The assembled evidence for the current report includes:

1. The Thomas (2006) report includes in his Table 1 other USGS conclusions that significantly lower the Stewart flow values. In the 1950 USGS restudy of the Stewart flow rates, flow values were adjusted to be significantly less than the Stewart flows and compare very well to the flow rates estimated by the Pacific International Engineering (PIE) studies. In the second USGS restudy of the Stewart flows, as shown in the Thomas Table 1, the USGS second set of estimates are approximately mid-way between the original Stewart flows and the first USGS restudy dated 1950. In all four cases of these historic flows, both USGS re-evaluations resulted in a significant adjustment downwards of the Stewart flow rates.

2. The Thomas (2006) report includes discussion of a recent USGS report dated 2005 that re-evaluates one of the four historic events (the 1921 event). Using friction factors in the range of 0.024 to 0.032, an average flow rate of 240,000 cubic feet/second (cfs) is estimated which matches with the Stewart flow for that event. However, Stewart did not use the range of 0.024 to 0.032 for his friction factors, but apparently used 0.033. And, since an average flow rate produced from a range of friction factors typically corresponds to simply using the average of the friction factor range, that average friction factor would be 0.028 which, when returned to the value used by Stewart of 0.033 reduces the 240,000 cfs value to about 210,000 cfs which compares well with the 1950 USGS restudy value

for the 1921 event (and compares well with the PIE analysis). Furthermore, if that same adjustment is considered for all four Stewart flows, one arrives to a close fit produced from the same 1950 USGS results. Because Stewart was at the scene in 1918 and 1921, nearest to the time of the subject four events, his observations would likely be the most relevant observations for the subject reach of the watercourse under study.

3. The measurements of the historic four events also included flow estimates downstream of the upstream point used for the reporting by Stewart. These downstream flows (near Sedro-Woolley) are significantly less than the upstream flows. Additionally, this particular reach of channel does not appear to demonstrate significant potential for peak flow rate attenuation (i.e., the lowering of peak flow rate value due to the effects of storage and similar effects within the particular reach of study.) For example, other stream gage data indicate negligible attenuation effects. Furthermore, a new study of peak attenuation effects by Northwest Hydraulics Consultants (nhc - 2007), show that for a wide variety of hydrograph shapes and large peak flow rate values, there is negligible attenuation effects. Therefore, if there are negligible attenuation effects, there should be reasonable agreement between upstream and downstream values of the peak flow rate. This is not the case for the subject Stewart flow rates. The Stewart flow rates show very significant attenuation effects. If there are in fact negligible attenuation effects, then the downstream peak flow rates could be evaluated as a substitute for the upstream flow rates of Stewart, in which case those downstream flow rates are seen to be in close agreement with the USGS re-study results of 1950 (and compare well with the PIE analysis).

4. There are several options available to explain these items mentioned above. Some of these are:

a. The Stewart flow rates and the associated downstream flow rates did indeed happen, and the watercourse did indeed experience a sequence of four extraordinary and rare peak flow rates the combined probability of which results in an event of such extreme rareness that it would be difficult to calculate.

b. The Stewart flow estimates are just that: estimates. And, these estimates are subject to measurement error and judgment error in the friction parameter, among others factors. This error in friction factor may possibly be demonstrated by the comparison of the Stewart friction factor of 0.033 being outside of the entire range of friction factors considered by the USGS of 0.024 to 0.032 in their 2005 study. It may be recalled that the Stewart flows are estimates only, based upon a judgment of the friction factor that existed at the study reach in 1918 and in 1921. The Stewart flows can be reduced in value to nearly match the results from the 1950 restudy by the USGS, by adjusting the Stewart friction factor from 0.033 (used by Stewart) to less than 0.037. This is consistent with the PI Engineering approach, confirmed by nhc, to adjust the Stewart staff gage estimates, taking into account that the staff gage readings at the old location were simply transferred downstream with no adjustment (200 feet upstream of the current location, which equates to a hydraulic fall of 1.5-2.0 feet according to the nhc study). This is quite plausible given the documentation of friction factors in the 1918 and 1921 time-frames.

c. There seems to be a paradox along the subject study reach where the Stewart flows are at issue. Namely, the measurements of these historic floods show significant attenuation effects of the peak flow rates along the subject reach yet other data and the 2007 nhc analysis of attenuation indicates there is negligible attenuation effects in the subject reach. If there are no attenuation effects, the upstream and downstream peak flow rates should typically correspond. It is plausible that the downstream flow rates are indeed the true peak flow rate in the subject reach. In fact, the nhc report (2007) points out that nowhere in the record is there any indication that the downstream flow rate estimates were biased low; Bodhaine (1951) believed the 1897 and 1909 estimates at Sedro-Woolley could be adjusted downward by 10 percent. If so, then the downstream peak flow rates are the peak flow rates for the entire subject reach of the watercourse. And, if so, these downstream peak flow rates compare very well with the USGS restudy of 1950 (and compare well with the PIE analysis).

d. There may be other explanations that are far more likely to occur at the subject timeframe than the likelihood of having four such rare and extraordinary storm flows. For example, a debris blockage may have occurred within the study reach such as to cause the appearance of peak flow rate attenuation in the reach whereas negligible attenuation actually occurred. Or, the estimate of the friction factor by Stewart may have been "too low" at the upstream end of the reach for the actual conditions of the watercourse at the time of the storm events. For example, Stewart's first observation of the study reach was in 1918, whereas three of the four extraordinary flows had already occurred. The most extraordinary flow of 275,000 cfs (estimated by Stewart) happened first in that extraordinary storm sequence and occurred in year 1897, about 21 years prior to Stewart's observations. Such massive and rare storm flows would normally be expected to cause changes in the channel reach itself, including a change in the friction factor. Stewart observed the recovery of the study reach after 21 or so years, and with the effects of two other extremely rare storm flows also having passed through the study reach. It is likely that channel cleaning would occur with such extraordinary flows, typically corresponding to a decrease in friction factor. That is, Stewart would be observing the effects of three massive storm events, which typically would correspond to a decrease in friction factor to more efficient channel flow conditions. Consequently, under this concept model, the friction factor corresponding to the 1897 conditions, for example, would be expected to be higher in value than the value corresponding to 1918 or 1921 conditions. Such an increase in friction factor, by even just 10-percent would bring the Stewart flows close to the USGS restudy results of 1950 (and close to the PIE analysis.)

e. A combination of the above considerations is far more probable than the occurrence of such a sequence of rare storm events.

5. The above considerations, and the paradox of peak flow rate attenuation within the study reach, may be tested by additional evidence. Such evidence was recently obtained at the Smith House, located near the study reach. The Smith House can be used to evaluate the history of high-water marks. From that evaluation, only base flooding is found to have occurred, which when analyzed hydraulically, is evidence that the effects of the Stewart flow rates did not manifest themselves in the vicinity of the Smith House (PI Engineering, June 2007).

CONCLUSIONS

Based on the documents reviewed and new analysis from Northwest Hydraulic Consultants and other sources, it may be surmised that good evidence exists to question the applicability of the Stewart peak flow rates. Further work is appropriate to re-examine the veracity of the flow rates before committing to use of them directly, without adjustment, in further planning or design studies.

I. INTRODUCTION

The Skagit River is a large watershed of over 3000 square miles in size that is tributary to Puget Sound near the City of Seattle, Washington. This watershed has recently been the subject of several hydrologic studies, including nearly a dozen studies and analyses conducted by Pacific International Engineering, PLLC (PIE) as a consultant for Skagit County. A focal point of these analyses is the appropriateness of including four particular historic peak flow rates dated November 1897, November 1909, December 1917, and December 1921, all four of which occurred with the river being in an unregulated condition without reservoirs in place. Eight of these reports were reviewed and commented on in a report entitled "An Evaluation of Flood Frequency Analyses for the Skagit River, Skagit County, Washington" prepared by Wilbert O. Thomas, Jr. and made available with date February 9, 2006. Previous analyses by PIE included sensitivity runs of the flood frequency curve with and without various combinations of these four historic flow rates. Subsequent analyses conducted by Northwest Hydraulic Consultants (nhc 2007) to assess and quantify the potential for flood wave storage attenuation along the valley route located between the high water marks used to estimate the subject four historic peak flow rates indicated the river valley attenuation that would be necessary to reconcile the differences in the flow estimates does not exist within any reasonable range of those flow estimates.

A review of the relevant information describing the subject Skagit River watershed and also the history of the estimation of the values for the subject four historic flow rates is contained in several other reports and is not repeated here. The Thomas 2006 report states on page 3 that these subject flow rates were "...determined by James Stewart, U.S. Geological Survey (USGS), from field investigations made in 1918 and 1923 and documented in unpublished reports. The peak discharges were first published in USGS Water Supply Paper 1527 dated 1961 (Stewart and Bodhaine, 1961)." Thomas also describes on page 3 of his report that before publication by the USGS, prior USGS reviews of the flow rate estimates resulted in the subject estimates to be lowered in value. Thomas tabulates a comparison of the USGS published (1961) historic four flow rates versus the revised downward estimates by the USGS in his Table 1 (Thomas, page 4) and includes estimates from PIE (2005). In this tabulation, it can be observed that the Stewart peak flow rates are on the average about 17-percent higher in value than the corresponding peak flow rates estimated by the USGS in 1950. In comparison, another but later USGS study (1951-1952) indicates that the Stewart peak flow rate estimates are on the average about 6.5-percent higher than the second USGS re-assessment study. Finally, the tabulation indicates that the Stewart peak flow rate estimates are on the average about 19-percent higher in value than estimates developed by PIE in year 2005. From the tabulation, it is observed that on the average, the PIE analysis of year 2005 is in substantial agreement with the findings of the USGS re-assessment study of year 1950 (i.e., 19-percent versus 17-percent), and that the second USGS re-assessment study approximately halves the difference between the Stewart study and the original USGS re-assessment study (and also the PIE 2005 assessment), and that all three re-assessment studies agree that the original Stewart study significantly over-estimates the peak flow rate values of the subject four historic flow rates. An independent technical report by nhc (nhc 2007) recently focused again on the historic flood estimates. This effort considered available information (including the citations discussed here) and conducted additional technical analysis. Nhc concluded there was significant uncertainty regarding the magnitude of the historic events. Nhc analyzed the Skagit River reach between Concrete and Sedro-Woolley and stated without equivocation that the amount of hydrologic attenuation necessary to reduce the historic peak estimates between those two locations does not exist. Nhc went on to state that although it has been suggested by many that the Concrete estimates be reduced, no report has ever suggested that the Sedro-Woolley coincident flows be increased. In other words, the Stewart analysis uses a particular model which, when tested four times, (and then a fifth time by the recent nhc study) and compared to corresponding estimates from three other models (of which two of these other models are from the same source, the USGS), in all five cases the Stewart estimate is the highest in value and the difference in value ranges from +4-percent to +20-percent with a mean of +14-percent.

The Thomas (2006) report also summarizes further work prepared by the USGS (Mastin and Kresch, 2005) where hydraulic considerations are examined for the December 1921 historic flood event and particular attention may have been paid regarding the choice of a Mannings friction factor that was used in the Stewart study. Based upon hydraulic considerations and modeling, the conclusion of the new hydraulics analysis was mentioned by Thomas: "Therefore, USGS (Mastin and Kresch, 2005) concluded that the December 1921 peak discharge of 240,000 cfs and the peak discharges for the other three historic floods estimated by Stewart were reasonable." Of possible interest, however, and not mentioned in the report, is justification for the conclusion regarding the other three historic floods that were not modeled hydraulically and, furthermore, there does not appear to be an explanation as to what the USGS did that was perhaps not appropriate in their two re-assessment studies of 1950 and 1951-1952. Finally, it is noted here that nhc recommended the 2005 USGS report not be used to verify possible ranges of friction factors, as “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.”

Because of the continued interest in these four historic flood flows, further examination is warranted in order to help bridge information gaps and to better understand how to deal with these various re-assessment results so that informed decisions can be made involving flood risk and a better evaluation between options can be made versus the risk tolerance of the community.

II. RECENT STUDIES INDICATE THAT THE ORIGINAL 1950 USGS RESTUDY RESULTS ARE CREDIBLE

On his page 4, Thomas (2006) discusses a range of n values proposed in the 2005 USGS study of n = 0.024 to 0.032, and that by using the average of the range of resulting flow rates an estimate can be made of the subject 1921 flood peak flow rate of 240,000 cfs, which is "…essentially the same as estimated by Stewart."

However, also on page 4, Thomas mentions "Stewart used an n value of 0.033 in estimating the December 1921 peak discharge." The average of the above peak flow rates estimated in the friction factor range of 0.024 to 0.032 typically correlates to using the average of the friction factors themselves, or a value of 0.028, which is 16-percent less than Stewart's 0.033. Therefore, had the Stewart's assessed 0.033 friction factor been used, the newly estimated 240,000 cfs value would drop to about 213,000 cfs, which is comparable to the 1950 USGS restudy results as seen in Thomas' Table 1. Because Stewart's observations of 1918 and 1921 are closest in time to the conditions of the subject watercourse at the time of the questioned peak flow rates, it is rational to consider his assessment of the friction factor as being most appropriate. Carrying this consideration further, and assuming that the recent 2005 USGS analysis is the more appropriate handling of the hydraulics (notwithstanding the concerns raised with the USGS friction factor estimates and also considering the possibility that Stewart's evaluation of the friction factor is the more credible), the other three Stewart peak flow values would also decrease by about 16-percent to closely match the values of the 1950 USGS restudy results.

The subject four Stewart flow rates are all estimates made based upon measurements taken in the field and estimates of the Mannings friction n factor.

In Thomas (2006; pages 4 and 5) Thomas mentions the possibility that Stewart "…may have overestimated the n value…" Of course, Stewart was indeed the best observer, being at the site twice, in 1918 and 1921, and his results continue to be heavily weighted in current deliberations. Additionally, overestimating the n value would imply underestimating the peak flow rate and so far no one has suggested there is evidence to increase the Stewart flow rates. Therefore, it is rational to consider that Stewart's assessment of n value is the more appropriate value to use.

III. WHAT KIND OF FLOOD EVENTS WERE THE STEWART EVENTS?

The subject four Stewart flow rates are each significantly larger in value than any of the other annual flow rates being analyzed to date. This somewhat unusual circumstance generally surfaces questions as to what the data or measurements truly mean, whether they are of the same population as the many other annual flows, whether the four subject flow estimates are biased, among other questions typically forwarded. For example, the record does not include the many years of annual flows that are "ordinary" and of much less magnitude which, if available, may significantly impact the flood frequency analysis which likely decreases in the rare storm estimates. (In other words, slipping in four extra aces into a deck of playing cards almost doubles the chance of drawing an ace randomly.) Issues regarding methods of handling possible outliers in data analysis are well known and need not be reviewed here. What may be of possible significance, however, is the nature of these flow events themselves.

More specifically, recent mathematical modeling of the reach between the Concrete gage and the gage at Sedro-Woolley by Northwest Hydraulics Consultants and Pacific International Engineering (PIE) (see Appendix A) shows that for a vast spectrum of hydrograph shapes and large peak flow rates the subject reach shows little peak attenuation. That is, in general, the nature of attenuation is such that the peak flow rates entering the subject reach closely matches in value the peak flow exiting the subject reach.

In contrast, the estimates that form the underpinnings of the Stewart analysis indicate that significant attenuation of the peak flow occurred in the subject events. (See Appendix A.)

Given that the Appendix A analysis shows there is little attenuation potential, this brings into question whether the measurements used in the Stewart analysis are truly indicative of the flow rate processes as understood for the other annual flow rates. In other words, were conditions at the Stewart measurement sites significantly different than the conditions that apply to the other annual flow rates? Were conditions upstream of the Stewart measurement sites significantly different such as to cause water surface effects as observed by Stewart after the storm events?

It is noted that the probability of such large annual flow rates in the limited time frame of occurrence is even more remote than the probability of the individual events themselves. The cause of such a rare occurrence does not appear to be well addressed in the available documents. One possible explanation is that these four events did indeed happen and that this river did indeed experience such an extraordinary event sequence. A second explanation is that conditions of the river were different at that timeframe such as to cause apparent high water marks that are more of a result of river conditions rather than of the flow rates. For example, a debris blockage collapse may cause a flood wave that exhibits the attenuation effects apparent in the data. A river blockage may cause a backwater upstream while allowing lower water surfaces downstream of the blockage. A third explanation is that the Stewart analysis is biased high and, with adjustments, such as worked out by the USGS in their 1950 restudy, the flow rates are brought closer to reality. (It is recalled that the 1951-1952 USGS second restudy positions the flow rates to be in the middle between the Stewart study and 1950 USGS restudy, with the exception of the 1897 event which is still shown to be less than the Stewart study.) A fourth explanation is a combination of explanations two and three. Of course, other explanations may be forwarded but with the information available, the above explanations appear to be the most likely. Furthermore, both USGS restudies show that the USGS evaluated the Stewart values and adjusted all four of them significantly downward in values. This double set of adjustments is consistent with the position that the Stewart values are significantly biased high for all four events.

IV. THE SMITH HOUSE EXAMINATION

A likely illumination to the above paradox may be found in the recent examination of the "Smith" house located in the City of Hamilton. This examination focused on the "Smith" house built in 1908 in an area that would have experienced some flooding in 1909, 1917, and 1921, as well as 1995 and 2003. Witnesses have indicated that the flood of 1995 was the only occurrence where water entered the house. The flood of 1995, with a peak discharge of 160,000 cfs, inundated the house to a depth of 1-2 inches above the floorboards. The peak discharge measured in the 1995 flood is significantly less than the Stewart-estimated 220,000 to 260,000 cfs of water experienced during the three historical floods occurring between 1909 and 1921. A modeled rating curve developed by Pacific International Engineers and using the three historical flooding events (PIE, June 2007,) (concomitantly adjusted to account for the best information available on river conditions at that time) concluded flooding heights in the vicinity of the "Smith" house would have been 3.05, 1.51, and 2.31 feet above the height of the 1995 flood, for the floods of 1909, 1917, and 1921 respectively. A physical examination actually exposed the interior and exterior walls of the Smith home to determine any evidence of high-water marks. The study found evidence of discoloration an inch or two above the floor boards on the interior walls, and clear indication of flooding to the same level on the exterior walls, which could be indicative of flooding observed in the 1995 flood, but did not find any evidence of high-water marks above that point.

These study results show that no flooding occurred in this house higher than the 1995 flood event water level, and that there is no evidence of flooding for the historical events within the walls of the "Smith" house. Using the theoretical flood depths, high water marks should have been found at an approximate height of 1.5 to 3 feet above the floorboard. No evidence found in the "Smith" house suggests this occurrence, thus putting into question the veracity of the historical flood flow estimates.

V. CONCLUSIONS

Based on the documents reviewed and new analysis from PIE, nhc and other sources, it may be surmised that good evidence exists to question the applicability of the Stewart peak flow rates. Further work may be appropriate to re-examine the veracity of the flow rates before committing to use of them directly, without adjustment, in further planning or design studies.

APPENDIX A

Stewart Estimated Peak Flow Data for the Four Unrecorded (Historical) Floods of 1897, 1909, 1917, and 1921.

By Albert Liou
Pacific International Engineering

(Reference: Pacific International Engineering, PLLC., December, 2005. Hydrology and Hydraulics. Skagit River Flood Basin - Existing Conditions. Report prepared for Skagit County.)

Background - Four major floods occurred in 1897, 1909, 1917 and 1921, before installation of the USGS gage at Concrete (RM 54.15) and before construction of any of the five Upper Skagit River dams. These unrecorded flood peaks at Concrete were estimated by James Stewart in 1923. Stewart also estimated the coincident flood peaks at Sedro-Woolley (RM 22.40) and wrote an unpublished draft report in 1923 (Table 1). The accuracy of Stewart's flood peak estimates was questioned by numerous hydrologists, including hydrologists within the USGS (Bodhaine 1954; Riggs & Robinson 1950). In 1961, after James Stewart no longer worked for USGS, USGS published Stewart's 1923 estimates for these historical floods in the Water Supply Paper (WSP) 1527.

Table 1: Comparison of Peak Flows at Concrete and Sedro Wooley

	Peak Flows at Skagit River near Concrete (RM 54.15)			*Peak Flows at Skagit River at Sedro Woolley (RM 22.4)*		
Unrecorded Event	Stewart estimated (cfs)	HEC-RAS model based on 1995 flood hydrograph (cfs)	HEC-RAS model based on 2003 flood hydrograph (cfs)	Stewart estimated (cfs)	HEC-RAS model based on 1995 flood hydrograph (cfs)	HEC-RAS model based on 2003 flood hydrograph (cfs)
1897	275,000	196,000	197,000	190,000	190,000	190,000
1909	260,000	227,000	228,000	220,000	220,000	220,000
1917	220,000	201,000	202,000	195,000	195,000	195,000
1921	240,000	216,000	218,000	210,000	210,000	210,000

Correlation with Sedro-Woolley: Stewart estimated the flood peaks using observed HWMs and the slope-area methodology he applied at both Concrete and Sedro-Woolley. Flood peaks for flood events are expected to be approximately the same (within a few percentage points) at Concrete and Sedro-Woolley. The incremental drainage area between Concrete and Sedro-Woolley is 270 square miles, about 10 percent of the total drainage area of 2,737 square miles above the Concrete gage. There are no large floodplain areas that would add storage between Concrete and Sedro-Woolley that could reduce flood peaks significantly more than increases to the flood peak due to the local inflow in the same reach.

Comparison of flood peaks for recent recorded floods in 1990, 1995 and 2003, demonstrates that flows at the USGS Concrete gage average 1.6% lower than flows at the USGS Sedro-Woolley gage. Assuming that the relationship between Sedro-Woolley and Concrete as discussed above is valid, Stewart's unrecorded flow estimates at Concrete should be approximately 2% lower than his estimates at Sedro-Woolley. In fact, Stewart's estimates at Concrete for the unrecorded floods average 15% higher than his concurrent estimated flood peaks at Sedro-Woolley (the average does not include his estimate for the 1897 flood, which is 45% higher at Concrete than at Sedro-Woolley).

Table 2 below presents a comparison of the coincident peak flows estimated by Stewart at Sedro-Woolley and Concrete for the unrecorded floods.

Table 2: Stewart Estimated peak discharges (cfs) of four unrecorded floods in the Skagit River

Flood Date	*@ Sedro-Woolley*	*@ Concrete*	*% Diff**
Nov. 19, 1897	190,000	275,000	-45%
Nov. 30, 1909	220,000	260,000	-18%
Dec. 30, 1917	195,000	220,000	-13%
Dec. 13, 1921	210,000	240,000	-14%

[* % Diff = (flow @ Concrete - flow @ Sedro-Woolley) / flow @ Sedro-Woolley]

Pacific International Engineering (PIE) performed a HEC-RAS flood routing from Concrete to Sedro-Woolley for these four unrecorded floods.

In this flood routing, two different hydrograph shapes were used for these four events. One used the flatter but more voluminous hydrographs from the PIE modeled 1995 flood event, and the other was based on the flashier 2003 event.

Figure 1 and 2 show flood hydrographs at Concrete and Sedro-Woolley and the HEC-RAS model results showing very little attenuation effects (less than 1%) between Concrete and Sedro-Woolley whether flashy (2003 flood) or voluminous (1995 flood) hydrographs were assumed for the 4 unrecorded events.

Figure 1: November 1995 Flow Hydrographs at Skagit River near Concrete and at Sedro Woolley

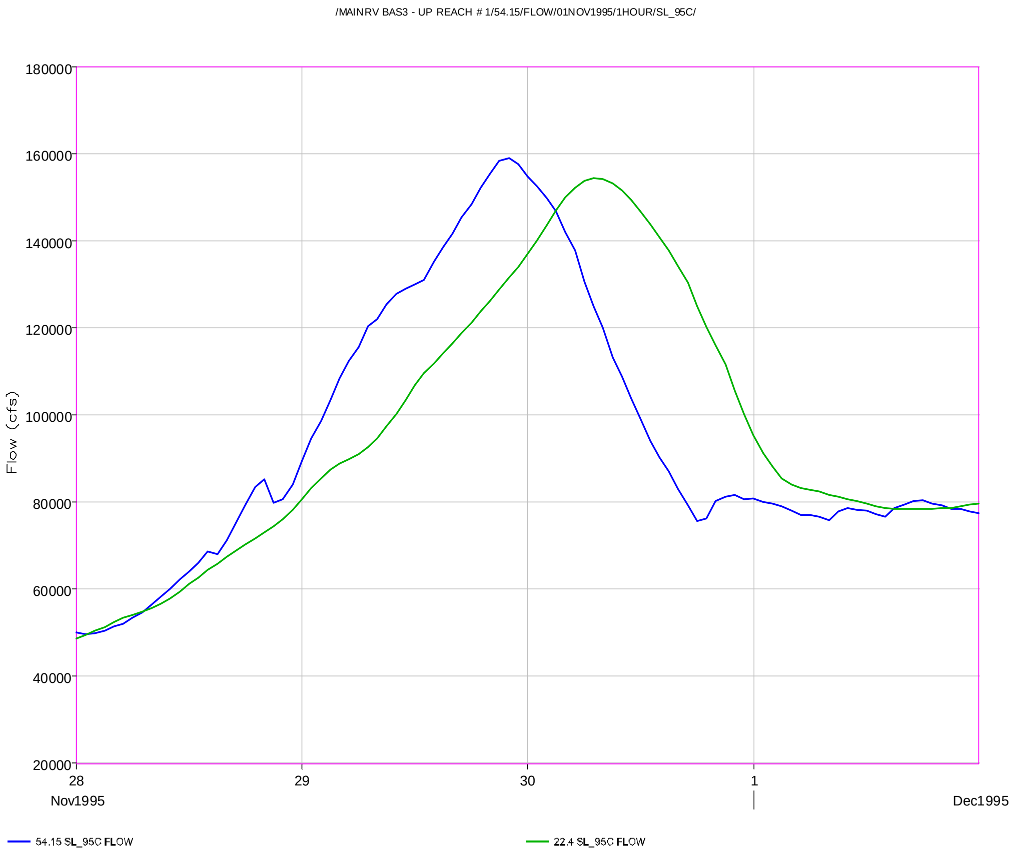
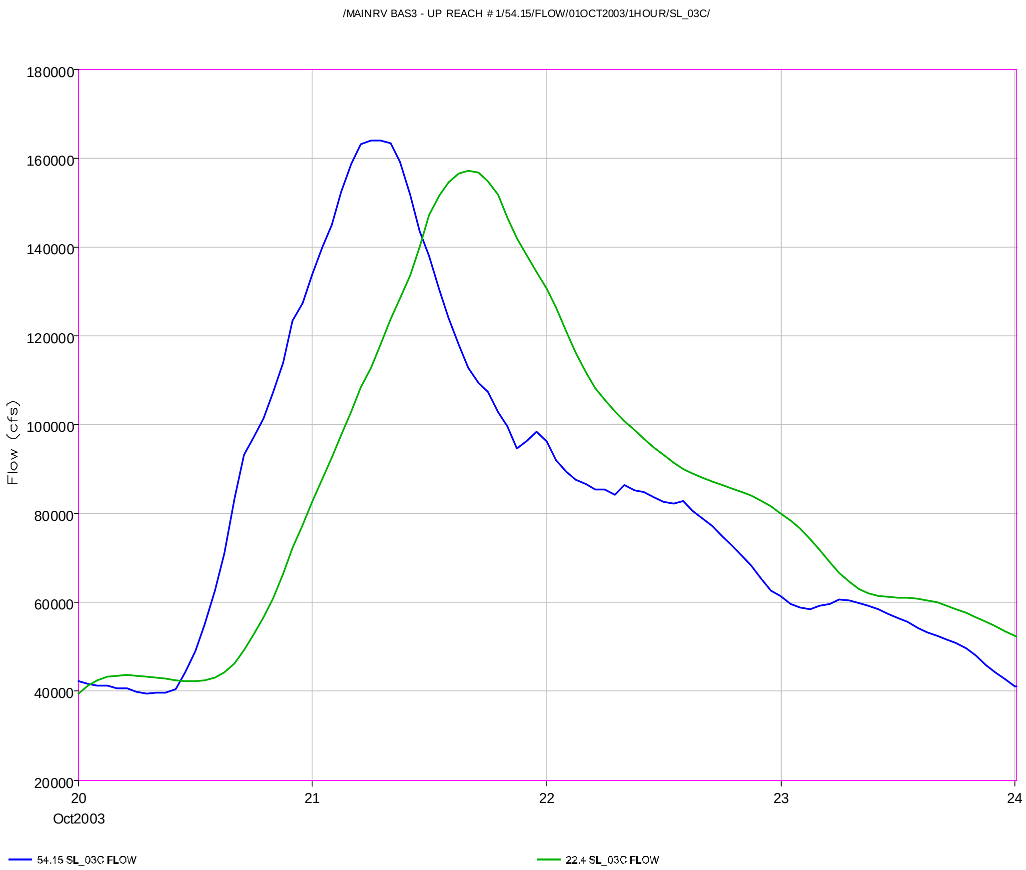


Figure 2: October 2003 Flow Hydrographs at Skagit River near Concrete and at Sedro Woolley



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