U.S. Department of Homeland Security
Region X
130 228th Street, SW
Bothell, WA 98021-9796

FEMA

February 10, 2006

Skagit County Commissioners
1800 Continental Place
Suite 100
Mount Vernon, Washington 98273

Dear Skagit County Commissioners:

The purpose of this letter is to transmit an evaluation of flood frequency analyses for the Skagit River. During the process of undertaking a Flood Insurance Study (FIS) for Skagit County and the cities along the Skagit River, The U.S. Department of Homeland Security's Federal Emergency Management Agency (FEMA) Region X was asked by the Skagit County Commissioners to review a hydrologic analysis done for them by Pacific International Engineering (PIE). To fulfill this request, the region asked Will Thomas of Michael Baker, Jr. Engineers to evaluate PIE's hydrology and that of the U.S. Army Corps of Engineers who is conducting the FIS. That evaluation is enclosed.

The county's request did not constitute a formal appeal of proposed flood elevation determinations as described in 44 CRF, Chapter 1, Part 67, and the enclosed evaluation is simply a response to the county's request. When the FIS is submitted to FEMA by the U.S. Army Corps of Engineers, FEMA will establish an appeal period pursuant to Part 67. The enclosed evaluation in no way diminishes a community's appeal options under that part.

FEMA has worked for years in partnership with the Skagit County communities to address flooding issues. We will continue to do that and hope that this evaluation will resolve concerns regarding hydrology.

Comments or questions regarding this evaluation should be addressed to Ryan Ike at the address above, or (425) 487-4767.

Sincerely,

Carl L. Cook, Jr.

Carl L. Cook, Jr., Director
Mitigation Division

Enclosure

Distribution

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

Review comments by Wilbert O. Thomas, Jr.
Michael Baker, Jr.
Alexandria, Virginia

On behalf of the Federal Emergency Management Agency
Region X
Bothell, Washington

February 9, 2006

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

Background

The Seattle District of the U.S. Army Corps of Engineers (USACE) is conducting a flood damage reduction feasibility study for the Skagit River in cooperation with Skagit County, Washington. The purpose of the study is to formulate and recommend a comprehensive flood hazard management plan for the Skagit River floodplain that will reduce flood damages in Skagit County. The results of this study will also be used to revise the Flood Insurance Study and Flood Insurance Rate Map for Skagit County.

The Skagit River is a 3,115 square mile watershed that originates in British Columbia, Canada and drains in a southwestern direction into Puget Sound north of Seattle, Washington. The hydrologic analyses for the USACE study is documented in a report entitled "Draft Skagit River Basin, Washington, Revised Flood Insurance Study, Hydrologic Summary", dated November 10, 2005 (USACE, 2005). Figure 1, taken from USACE (2005), is a schematic of the Skagit River watershed showing location of dams and important gaging stations.

Pacific International Engineering (PIE), working as a consultant for Skagit County, has performed independent hydrologic and hydraulic analyses for the Skagit River and their work is summarized in a report entitled "Hydrology and Hydraulics, Skagit River Flood Basin – Existing Conditions" dated December 2005 (PIE, 2005). This report actually summarizes the results of eight different reports prepared by PIE.

The flood discharges estimated by PIE are different than those developed by USACE and this review was undertaken to determine which results are most reasonable. The review and analyses focus primarily on the gaging station near Concrete, Washington (station 12194000, drainage area of 2,737 square miles) that has the longest record of annual peak flows in the Skagit River watershed including four historic floods whose values have been questioned by PIE (2005).

Flood frequency analyses for the Skagit River are complicated by the fact that five hydroelectric power reservoirs with flood-control capabilities have been constructed on the Skagit River or a major tributary from 1924 to 1961 plus the regulation procedures have changed over time (see Figure 1 for locations of the dams). The general modeling approach used for such a regulated watershed was to develop unregulated flows, perform frequency analyses on the unregulated flows, route the unregulated flood hydrographs through the current reservoir system, and then perform frequency analyses on the regulated peak flows. USACE (2005) performed the reservoir routings using a series of spreadsheets while PIE (2005) used the HEC-5 model.

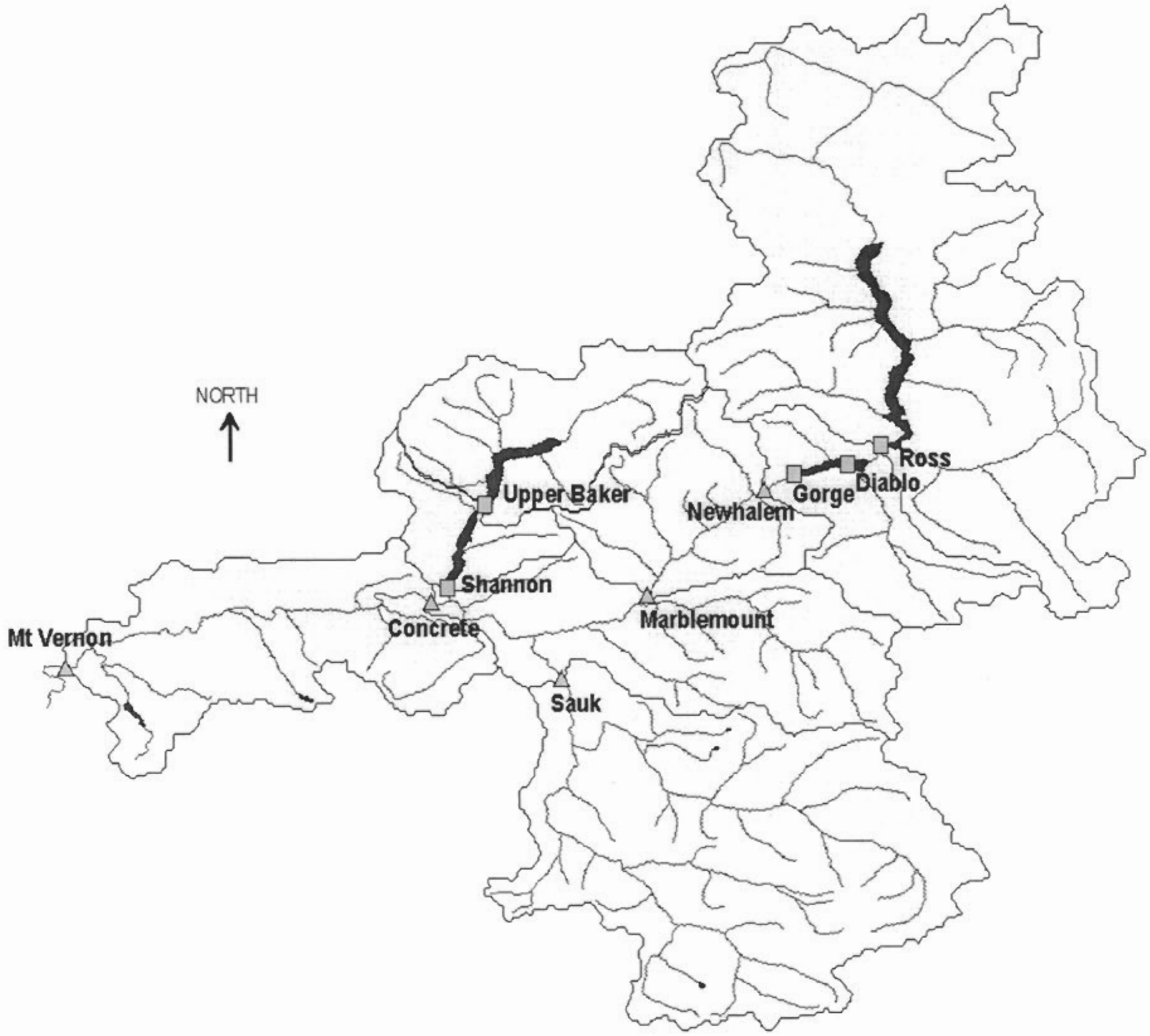

Figure 1. A map of the Skagit River watershed showing the location of dams (squares) and important gaging stations (triangles).

Peak Discharges for Four Historic Floods

A major issue associated with the unregulated frequency analysis is the peak discharge of four historic floods that occurred in November 1897, November 1909, December 1917, and December 1921 prior to construction of the reservoirs. The peak discharges for these floods were determined 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). Before the peak discharges were published for these four historic floods in 1961, the USGS performed two technical reviews of Stewart's analyses in the 1950 to 1952 time period. These subsequent analyses resulted in different and lower peak discharges. Recent HEC-RAS analyses by PIE have provided another set of estimates of the peak discharges for the November 1897, November 1909, December 1917, and December 1921 floods. All estimates are summarized in Table 1.

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

Date of flood	USGS published peaks (1961)	USGS (1950)	USGS (1951-52)	PIE HEC-RAS (2005)
November 1897	275,000	230,000	265,000	238,000
November 1909	260,000	220,000	240,000	217,000
December 1909	220,000	190,000	205,000	184,000
December 1921	240,000	210,000	225,000	202,000

The variability of estimates in Table 1 indicate there is uncertainty associated with the determination of peak discharges for these historic floods as reflected by the location and quality of the high water marks, cross-sectional data, and Manning's n values. However, all subsequent estimates are generally within 20 percent of the USGS published values and within the uncertainty of peak discharges determined by indirect methods (slope areas and contracted-opening measurements). The analyses and reports prepared by Stewart in 1918 and 1923 in determining the historic peak discharges were more detailed than the documentation generally available for historic floods at most gaging stations although his procedures were not as detailed and thorough as those used by USGS today.

<u>USGS Analyses Using Data for the October 2003 Flood</u>

Recently, USGS has reevaluated the discharge of the December 1921 flood (Mastin and Kresch, 2005) by using high water marks and a measured peak discharge for the October 2003 flood (166,000 cfs) to verify n values in the reach that James Stewart used in estimating the December 1921 flood. The USGS concluded that the n values in this reach downstream of the Concrete gaging station ranged from 0.024 to 0.032 using profiles of the October 2003 flood based on the flattest and steepest plausible profiles, respectively. Using these n values and high water marks for the December 1921 flood, the average peak discharge was estimated as 240,500 cfs, essentially the same as estimated by Stewart. 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. Mastin and Kresch (2005) also demonstrated that using the USGS 1950 and 1951-52 peak discharges from Table 1 resulted in a 1-percent annual chance (base or 100-year) flood that was 8.4 and 2.8 percent less than the base flood discharge using Stewart's (1961 published) peak discharges.

Stewart used an n value of 0.033 in estimating the December 1921 peak discharge. Mastin and Kresch (2005) provided pictures that illustrate the island downstream of the gaging station was more heavily vegetated in 1921 than today. This implies that Stewart may have overestimated the n value for the 1921 flood and underestimated the peak discharge. However, it is not possible to estimate the change in n value given the visual change in vegetation on the downstream island.

PIE HEC-RAS Model

PIE estimated their discharges for the four historic floods using a HEC-RAS model and cross sectional data upstream and downstream of the Concrete gaging station. A review of this HEC-RAS model indicated that some cross sections were subdivided in places they should not have been, that high n values were used in the main channel for some cross sections, and that n values increased with elevation at a few cross sections around the Dalles Bridge. The peak discharges estimated by PIE for the four historic floods (Table 1) also assume that the peak stages reported by Stewart are applicable to a location 200 feet upstream of the present gage location and that there is up to 2 feet in fall in water surface elevation between these two locations for major floods. These issues decrease the credibility of the PIE estimated discharges for the four historic floods.

Conclusions

The recent USGS analyses (Mastin and Kresch, 2005) support the peak discharge of 240,000 cfs estimated by Stewart for the December 1921 flood and hence the other historic floods. Analyses by USGS in the 1950 to 1952 period provided lower peak discharges for the four historic floods but flood frequency analyses based on these discharges provide estimates of the base flood discharge that are within 8.4 percent of estimates based on Stewart's historic discharges. The subdivision of some cross sections and the high n values used by PIE in their analyses are inappropriate. Given all this information, the historic peak discharges published by USGS in 1961 should not be revised. USACE (2005) used the USGS published values in their unregulated frequency analyses and this is a reasonable approach. The impacts of using the USGS 1961 published discharges versus those estimated by PIE (2005) are discussed later.

Unregulated Frequency Analyses

Use of data for the period 1925 to 1943

For their unregulated frequency analyses for the Skagit River near Concrete, USACE (2005) used the four historic floods as published by Stewart and Bodhaine (1961) and estimates of unregulated peak flows from 1944 to 2004. They did not attempt to convert the observed annual peak flows from 1925 to 1943 to unregulated conditions because of lack of data to estimate the effects of regulation. PIE (2005) believes the effects of regulation are minimal during the period 1925 to 1943 and chose to use the observed peak flows for this period in their unregulated frequency analyses.

An assessment of the effects of regulation for the Skagit River near Concrete for the two periods 1928 to 1943 and 1944 to 2004 was undertaken by plotting the annual peak flows near Concrete versus the concurrent peak flows for the Sauk River near Sauk (station 12189500). The Sauk River is the largest tributary (714 square miles) to the Skagit River (see Figure 1) and has unregulated peak flow data from 1928 to present. A comparison of the concurrent annual peak flows for the two gaging stations for the periods 1928 to 1943 and 1944 to 2004 is shown in Figure 2.

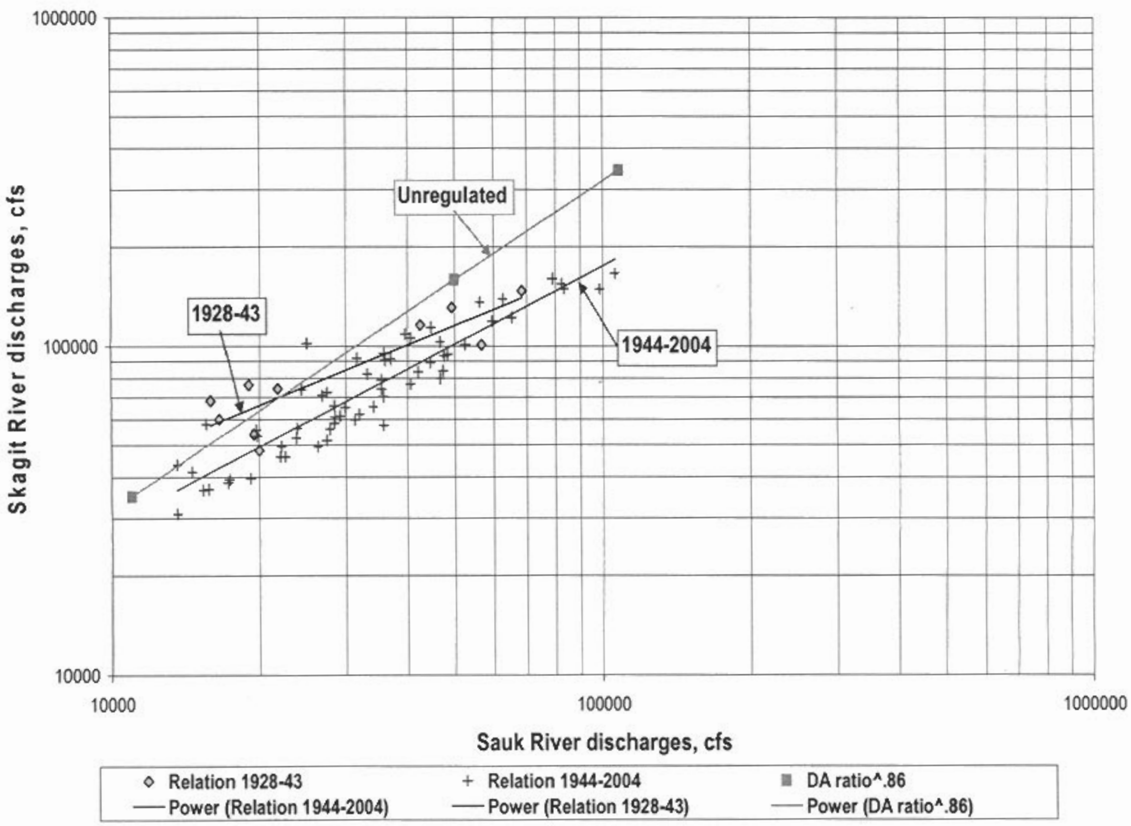

Figure 2. Comparison of concurrent annual peak discharges for Skagit River near Concrete (2,737 square miles) and Sauk River near Sauk (714 square miles).

As shown in Figure 2, the peak flows for the two periods define two different relations. That is, the peak flows for the Skagit River prior to 1944 are larger with respect to the unregulated peak flows for the Sauk River than the peak flows after 1944. This indicates that there was less regulation on the Skagit River during 1928 to 1943. The orange line shown in Figure 1 is based on a drainage area ratio (2,737 / 714) raised to the 0.86 power. The exponent of 0.86 was taken from USGS Water-Resources Investigation Report 97-4277 for Region 2 (Sumioka and others, 1998). If the Skagit River were unregulated, then the orange line in Figure 2 would be a reasonable estimate of the unregulated peak flows based on the Sauk River peak flows. As shown in Figure 2, the annual peak flows for the period 1928 to 1943 less than 80,000 cfs tend to cluster around the orange line indicating minimal regulation. However, the annual peak flows greater than 100,000 cfs indicate a greater effect of regulation. For example, the observed value of 147,000 cfs for the February 1932 flood would be about 218,000 cfs for unregulated conditions if estimated from the orange line.

Analyses in USGS Water Supply Paper 1527 (Stewart and Bodhaine, 1961) are similar indicating that the reservoirs in place in 1932 reduced the February flood from 182,000 cfs to 147,000 cfs. It appears that the larger floods in the period 1928 to 1943 were sufficiently affected by regulation and should not be included in an **unregulated** frequency analysis. USACE (2005) did not include the data for the period 1925 to 1943 in their unregulated frequency analysis and this is a reasonable approach. However, PIE (2005) did include the "regulated" peak flows for the period 1925 to 1943 in their unregulated analysis. However, this is not a major issue as the inclusion of the annual peak flows from 1925 to 1943 by PIE only reduces the 1-percent annual chance flood discharge by 3.2 percent.

Comparison of USACE (2005) and PIE (2005) unregulated analyses

The major differences between the USACE and PIE unregulated frequency analyses are the use of different peak discharges for the November 1897, November 1909, December 1917, and December 1923 floods and PIE's use of the observed annual peaks for the period 1925 to 1943. The base flood discharge as estimated by USACE was 284,000 cfs and by PIE 246,300 cfs. The PIE estimate is 13.3 percent lower than USACE. As noted above, 3.2 percent of the difference is attributed to PIE's use of the peak flows from 1925 to 1943 leaving about 10 percent to the different values for the four historic floods.

FEMA uses the 50-percent confidence limits to determine if flood discharges are statistically different (Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix C: Guidance for Riverine Flooding Analyses and Mapping, page C-8). The 50-percent confidence limits for the base flood discharge for the USACE analysis were estimated using procedures in Kite (1988) that include the uncertainty in the skew coefficient. The computation of confidence limits in Bulletin 17B (Interagency Advisory Committee on Water Data (IACWD), 1982) assumes no uncertainty in the skew coefficient and underestimates the confidence limits. The lower and upper 50-percent confidence limits for the USACE base flood estimate of 284,000 cfs are 249,000 cfs and 324,000 cfs, respectively. The PIE base flood estimate of 246,300 cfs is only slightly below the lower 50-percent limit.

Regulated Frequency Analyses

The regulated frequency analysis by PIE for the Skagit River near Concrete involved analyzing the regulated annual peak flows from 1956 to 2004. They then routed six synthetic flood hydrographs (10-, 25-, 50-, 100-, 200- and 500-year events determined from the unregulated frequency analyses) to Concrete and plotted them on the regulated frequency curve. The PIE regulated frequency curve (Figure 9 from their 2005 report) for the Skagit River near Concrete is given in Figure 3.

PIE (2005) indicated that the six routed synthetic events match closely with the statistically-derived frequency curve. The Bulletin 17B (IACWD, 1982) analysis for the statistically-derived regulated frequency curve was given in Appendix F1 of the PIE 2005 report. This analysis only used the 49 observed regulated peak flows from 1956 to 2004 and provided a base flood discharge of 198,500 cfs. That is, the six synthetic events that were originally derived from the unregulated frequency analysis were not actually used in shaping or defining the upper end of the regulated frequency curve. This is surprising given all the discussion and analyses related to the four historic floods. The six routed synthetic events up to the 100-year event plot below the frequency curve in Figure 3 indicating that they are on the low side. (Note that Figure 3 is a scanned pdf file and the synthetic events for the 2-, 1- and 0.2 percent chance events should be orange.)

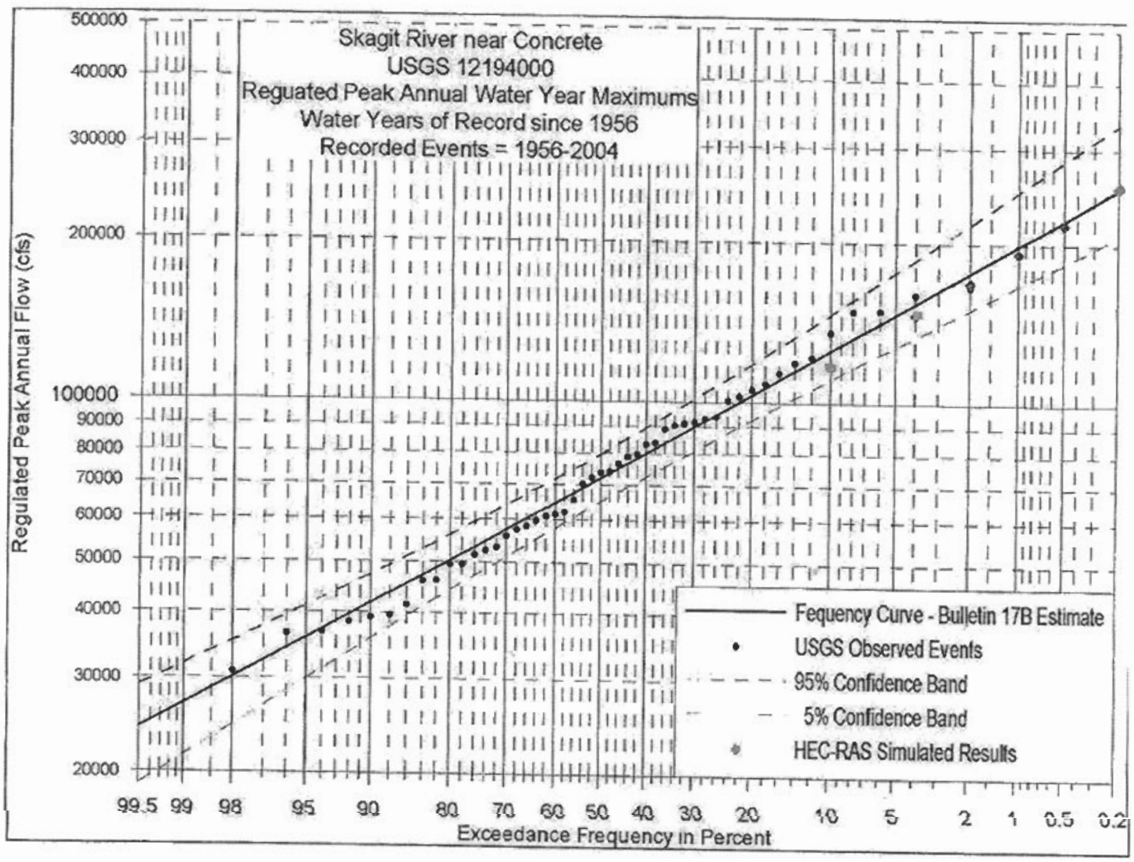

Figure 3. PIE regulated frequency curve for Skagit River near Concrete.

USACE (2005) used the same observed regulated annual peak flows for the period 1956 to 2004 to shape the lower end of their regulated frequency curve. They also routed six synthetic events to Concrete and then used these synthetic events to shape the upper end of their regulated frequency curve. The USACE regulated frequency curve for Concrete is given in Figure 4 (UASCE, 2005).

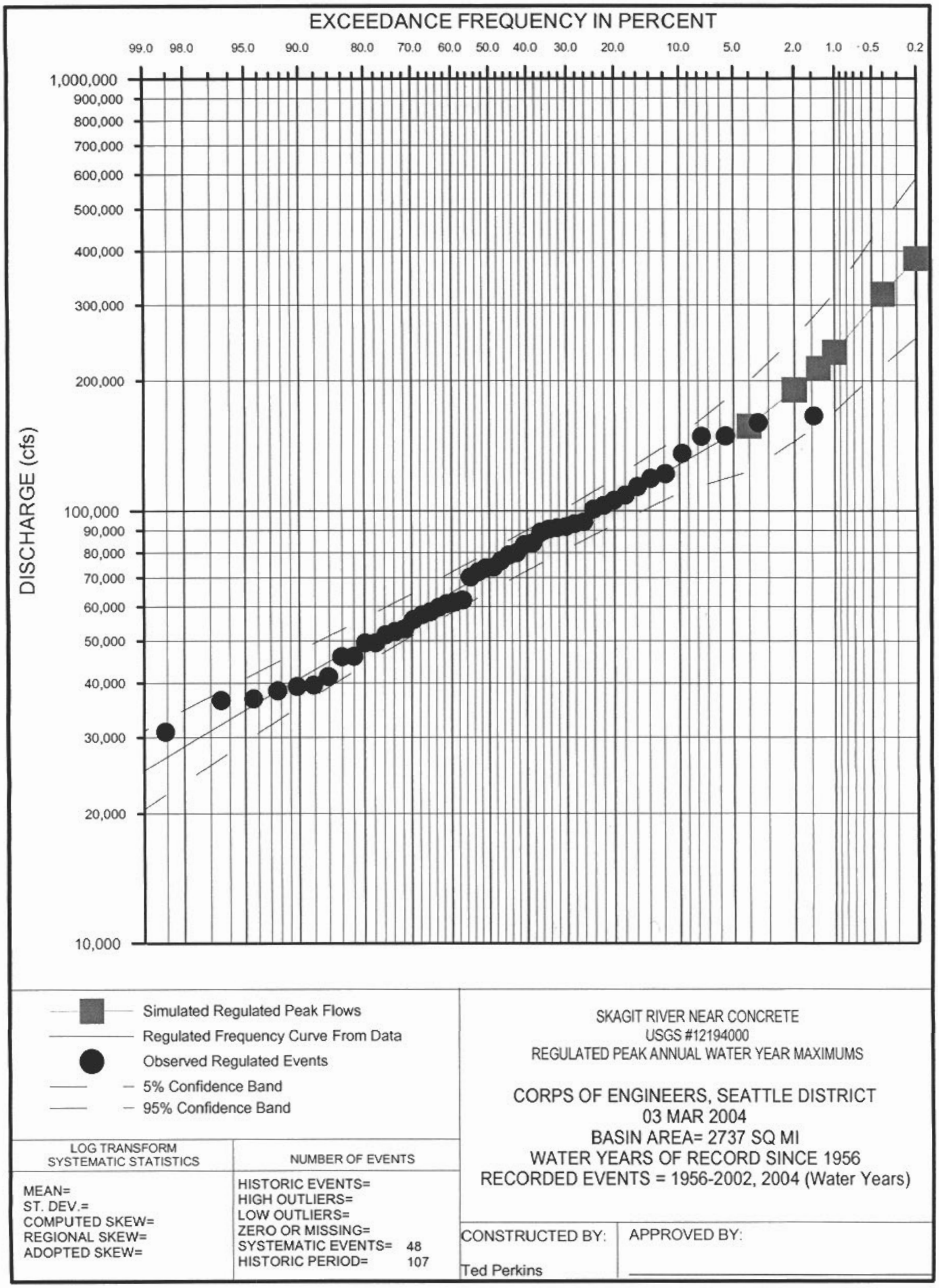

Figure 4. USACE regulated frequency curve for Skagit River near Concrete.

The USACE frequency curve is drawn through the synthetic (design) events and they are used to shape the upper end of the regulated frequency curve while the PIE curve is not based on the synthetic events. The PIE curve in Figure 3 has a skew of about zero and is basically a straight line on lognormal probability paper. This is unreasonable for a regulated frequency curve. As the flood event becomes more extreme, the reservoir system has less ability to store and regulate the event so that the regulated frequency curve should become concave upward (positive skew) and tend to converge with the unregulated frequency curve when reservoir capacity is exceeded.

A comparison was made of the regulated-unregulated relations for the USACE and PIE relations by plotting the regulated 10-, 50-, 100- and 500-year events versus the corresponding unregulated events. These data are plotted in Figure 5.

Note that the exponent on the USACE relation is greater than 1 while the PIE exponent is less than 1. This implies that the PIE regulated frequency curve will never converge to the unregulated frequency curve no matter how large the event. This is not reasonable. The data used in plotting Figure 5 are given in Table 2 which includes the ratio of regulated to unregulated flood discharges.

Table 2. Summary of regulated and unregulated flood discharges in cubic feet per second (cfs) and their ratios for the USACE and PIE analyses.

Event	USACE regulated	USACE unregulated	USACE ratio	PIE regulated	PIE unregulated	PIE ratio
10-year	117,430	158,000	0.743	125,400	145,700	0.861
50-year	185,650	242,000	0.767	176,000	214,100	0.822
100-year	226,400	284,000	0.797	198,500	246,300	0.806
500-year	345,630	398,000	0.868	253,600	329,400	0.770

As shown in Table 2, the ratio of the regulated to unregulated flood discharges for the PIE analysis is actually decreasing as the flood event becomes more extreme while the USACE ratio increases as it should. Therefore, the USACE regulated frequency analysis is more reasonable than the PIE analysis.

As shown in Table 2, the regulated 100-year or base flood discharge from the PIE analysis is 198,500 cfs while it is 226,400 cfs from the USACE analysis. The PIE base flood discharge is 12.3 percent less than USACE. USACE (2005) provided confidence limits for their regulated frequency curve in terms of one and two standard deviations. Assuming that the 50-percent confidence limits are two thirds of a standard deviation, the lower and upper 50-percent confidence limits for the USACE (2005) regulated frequency curve are estimated as 204,000 cfs and 252,000 cfs, respectively. The PIE regulated estimate of 198,500 cfs is only slightly below the lower 50-percent limit. Given the uncertainty in the historic and observed flood data, the uncertainty in converting the unregulated flows to regulated conditions, and the uncertainty of the regulated frequency analysis, a difference of 12.3 percent in the regulated base flood discharges estimates as determined by PIE and USACE is not significant from a hydrologic viewpoint.

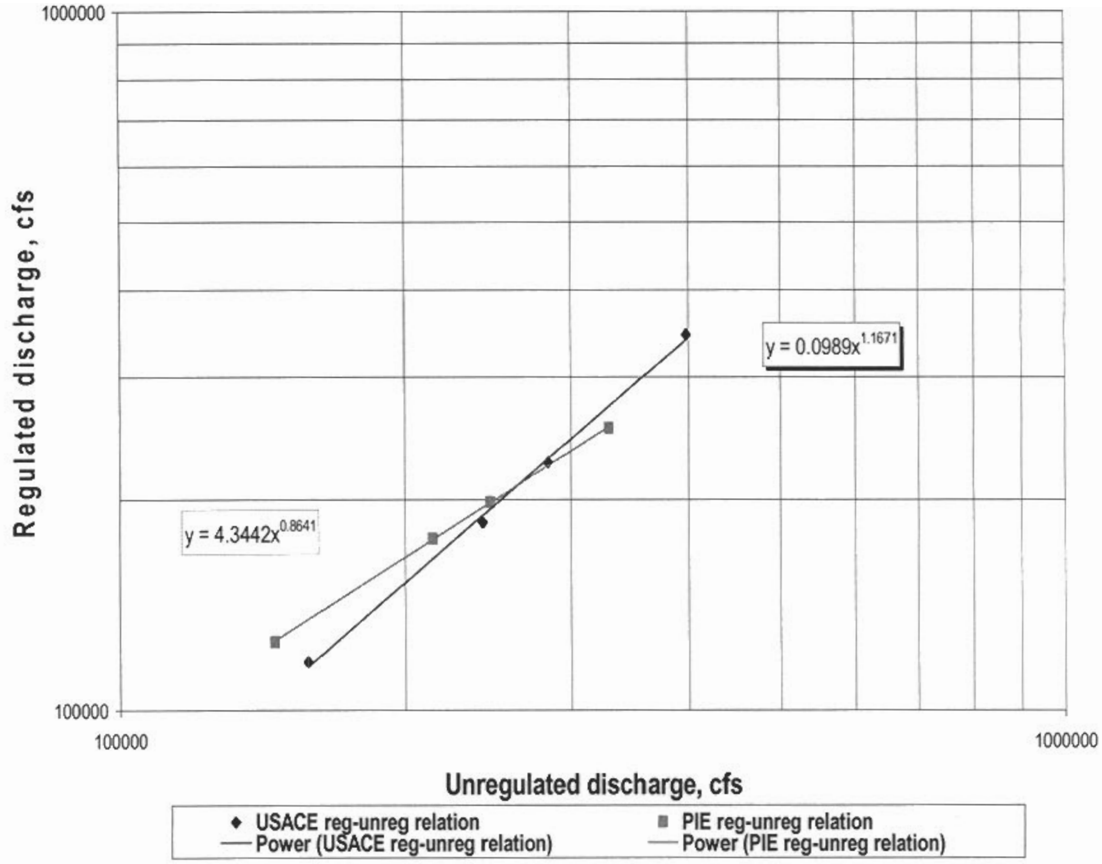

Figure 5. Comparison of regulated–unregulated relations for the USACE and PIE analyses.

Conclusions

The USACE (2005) regulated frequency analysis is more reasonable than the PIE (2005) analysis for the following reasons:

- The historic peak flows used by USACE (2005) are based on published USGS estimates that have recently been verified by USGS (Mastin and Kresch, 2005). The PIE estimated historic flood discharges are based on a HEC-RAS model that used inappropriate subdivision of the cross sections and high n values.
- The use of the PIE historic peak flows only decreases the unregulated base flood discharge estimate by 10 percent, well within the uncertainty of the historic peak discharges.
- PIE used observed annual peak flows during the period 1925 to 1943 for their unregulated frequency analysis and the larger peak flows in this period are

considered regulated. USACE did not use these data and that is a more reasonable approach.

- The PIE unregulated base flood discharge estimate is only 13.3 percent lower than the USACE estimate and only slightly outside the 50-percent confidence limits of the USACE estimate. The difference in the two estimates is not statistically significant.
- The historic peak flows, converted to regulated conditions, were not used by PIE in their regulated frequency analysis. This is not a defensible approach.
- The slope of the PIE regulated frequency curve is such that it will never converge with the unregulated frequency curve. This is not a reasonable result.
- From a hydrologic viewpoint, a difference of 12.3 percent in regulated base flood estimates is not significant. The PIE regulated base flood discharge estimate is only slightly outside the 50-percent confidence limits of the USACE (2005) estimate.

References

Federal Emergency Management Agency, 2003, *Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix C: Guidance for Riverine Flooding Analyses and Mapping*: Washington, DC, April 2003 (http://www.fema.gov/fhm/dl_cgs.shtm).

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

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

Mastin, M. C., and Kresch, D. L., 2005, *Verification of 1921 Peak Discharge at Skagit River near Concrete, Washington, Using 2003 Peak-Discharge Data*: U.S. Geological Survey Scientific Investigations Report 2005-5029, 17 p.

Pacific International Engineering, 2005, *Hydrology and Hydraulics, Skagit River Flood Basin – Existing Conditions*: Pacific International Engineering, Edmonds, Washington, December 2005.

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

Sumioka, S. S., Kresch, D. L., and Kasnick, K. D., 1998, *Magnitude and Frequency of Floods in Washington*: U.S. Geological Survey Water-Resources Investigations Report 97-4277, 91 p.

U.S. Army Corps of Engineers, 2005, *Draft Skagit River Basin, Washington, Revised Flood Insurance Study, Hydrology Summary*: Seattle District, U.S. Army Corps of Engineers, November 2005, 62 p.