Review and Comments of “Draft Evaluation of Flood Peaks Estimated by USGS,” by Pacific International Engineering, dated November 16, 2004.

Reviewed by Robert D. Jarrett, Ph.D., USGS, National Research Program, Paleohydrology and Climate Change Project, Lakewood, Colorado, February 14, 2005.

As requested, I have reviewed the subject draft report as requested by the Washington District. Below are my main review comments for the subject draft report.

Page 1. Paragraph 1. In two places here (and in the main text), the historical floods are termed “unrecorded.” These historical floods (and floods in 1815 and 1856) have physical documentation for their occurrence and age. Every effort needs to be made to learn more about these floods and incorporate them in the flood-frequency analysis (see discussion of paleoflood techniques in a later comment).

Page 2. Paragraphs 1 and 2. Indirect methods to estimate peak discharges are standard practice and widely used by the U.S. Geological Survey (USGS) and other water-data organizations. These methods continue to receive validation and improvements, and, thus, are viewed (with few exceptions, such as extremely complex hydraulic conditions) as significantly more than an “approximation.” The report needs to provide the discharges used for calibration and validation of U.S Army Corps of Engineering (Corps) Hydrologic Engineering Center - River Analysis System (HEC-RAS) models. The report should comment here and elsewhere on the range of these discharges regarding extrapolation to historical flood estimates beyond the range of validation runs. Also, the report needs to clarify why a seven-mile reach was modeled? For example, was PI Engineering attempting to estimate historical flood discharges elsewhere in the reach from available high-water marks (HWMs) for the historical floods? Also, below the gorge, the floodplain widens; thus, a given discharge would likely have substantial attenuation due to floodplain dynamics. Should this be included in the HEC-RAS analyses? Flow hydraulics in the bedrock canyon reach is extremely complex and may justify use of a multi-dimensional (multi-D) flow model. Both one dimensional (1-D) and multi-D models have uncertainties. The report should explain some of the assumptions made in using the HEC-RAS and uncertainties for peak discharge estimation. The report needs to explain if multi-D flow models need to be used for developing a rating curve in the hydraulically complex Dalles section of the Skagit River near the Concrete streamflow-gaging station. The report should provide details here and elsewhere on the flood-frequency analyses model, assumptions, and limitations. Excluding historical peaks in a flood-frequency analysis is not standard or acceptable practice in flood hydrology. The comparison of flood-frequency analyses with and without historical floods in the report have no practical meaning. The large historical floods have occurred, and while their magnitude and stage may have unknown uncertainties, it is critical that the estimated discharges and their estimated uncertainties be evaluated in the flood-frequency analyses by using more robust frequency models that better incorporate historical (and paleoflood) data. A more meaningful comparison would be to compare the USGS results with their historical flood estimates against PI Engineering’s analysis with their revised historical flood discharge estimates in the flood-frequency results. Differences would be much smaller, more objective, and more useful for managers and decision makers, without discarding critical flood data. The National Academy of Sciences (NAS), National Research Council (NRC, 1999) recommended use of the Expected Moments Algorithm (EMA) (e.g., England and others, 2003a and 2003b). In addition, a flood-frequency analysis can be made by using ranges of flood estimates for 1815 and 1856, because these exceptional floods were documented as the largest known since the early 1800s. The level of flood documentation is different (improved) in recent decades, but robust flood-frequency methods have been developed to improve frequency estimates not only for incorporating historical flood data, but also for historical or paleoflood data without definitive knowledge of actual stage or discharge (O'Connell, 1999; O'Connell and others, 2002; Levish, 2002). These frequency models also better estimate uncertainties (confidence intervals) that are critical for decision makers. The need for such analyses is demonstrated by concern for public safety and potential economic loss as related to the proper evaluation of flood reduction alternatives discussed on page 3 of the subject report. While working on the NAS review of the American River flood hydrology near Sacramento, California, the Corps of Engineers provided the NAS review team with documentation of methods used to convert regulated flow discharges to unregulated flow. I would suggest PI Engineering provide a brief summary of methods used to estimate unregulated flows and their associated uncertainties and effects on flood-frequency analysis in their report.

Page 3. Paragraph 1. The PI Engineering report states "… the feasibility study is focused on developing a complete and accurate hydrologic and hydraulic analysis in order to determine the magnitude and frequency of flooding in the Skagit River." In the 3rd paragraph, PI Engineering also notes that section 5 "… describes the significance of using the best available science for flood peak calculation." Paragraph 2. The report needs to include a summary of how "best science" was determined at stakeholder meetings. For example, who are the participants and how are consensus decisions made? Elsewhere in my review, I will suggest a few ideas that, if included, would enhance the science of the Skagit River study.

Page 6. Section 3.2. I believe Mark Mastin's (USGS) responses to specific questions concerning high-water marks (HWMs) and gage heights of historical floods raised by Mr. Chal Martins' letter of December 13, 2004 are appropriate for section 3.2. [Mark also compared channel geometry for three cross sections in the subject reach (email dated February 10, 2005), which shows only minor total change in channel geometry from Stewart's January 31, 1923 surveys to geometry surveyed on July 28, 2004. The February 10th email also provides documentation that much less vegetation was on the island downstream from the Concrete gage, and thus, is further support that vegetation may be the primary factor in the modest differences in the historical and present rating curves.] Uncertainty in estimates of peak discharges due to channel changes would not substantially have changed peak discharge estimates. Mark Mastin's review comments are provided separately. However, I do have a few comments. One issue relates to confusion on location of HWMs and whether they represent Baker Creek or Skagit River water levels. The Skagit River appears to have substantial backwater in the Baker River. For example, the attached Federal Emergency Management Agency (FEMA), floodinsurance study water-surface profiles (attached at end of review) are essentially flat through the entire Baker River study reach. Although some of the HWMs may have been interpreted (by PI engineers and in the NARA summary provided by Mr. Larry Kunzler, dated January 31, 2004) as being from the Baker River, the FEMA profiles support Stewart's claim that HWMs were emplaced by floods in the Skagit River. Extension of the Baker Creek FIS study reach with cross sections farther upstream would be needed to ascertain the upstream extent of the backwater from Skagit River floods. Extending the study reach farther upstream could be done concurrently with a paleoflood study to determine maximum flood stages (termed paleostage indicators, PSIs) in the Skagit and Baker Rivers to determine historical and paleoflood depths and peak discharges, particularly for the largest flood in the Skagit and Baker Rivers. Such studies would help reduce the uncertainties of flood discharges and speculation of HWMs and flood stages for historical floods. Thus, I would recommend the Corps' flood-frequency analysis include all historical flood data, including floods in 1815 and 1856, with respective uncertainties included in the analysis. In addition, because flood hazard mitigation involves both instantaneous peak discharge and flood volume, I suggest the frequency analyses include flood volumes such as the 1-, 3-, 7-, and 15-day values.

Pages 7, 8, 9. Sections 3.1 to 3.2.3, paragraph 1. I believe that much of the uncertainty in the historical flood estimates that can be evaluated now resides in factors that likely may remain unknown (unless someone can find newspaper records, diaries, or other historical documents) and need to be evaluated. For example, roughness coefficients and other energy losses associated with unknown historical vegetation density and woody debris dams (e.g., as noted by Mr. Kunzler) and land-use changes are problematic, but need to be incorporated in the analyses. Although historical data (generically speaking) may have substantial uncertainties in magnitude and/or age, their use in flood-frequency analysis is as valuable as recent flood data. These uncertainties are incorporated into the frequency analysis because they provide more realistic flood-frequency relations and confidence limits. After reading the quality of Mr. Stewart's flood documentation (although containing some uncertainties) made following the 1921 flood, I believe he was a very experienced flood specialist. Stewart did substantial flood documentation in the Skagit River basin, particularly at the Concrete gage and lacking evidence to the contrary, it seems prudent to believe his statements that the HWMs documented were for the Skagit River. He also involved many local ranchers and lay people in his work to document flooding. They would have been alert to the fact that Stewart's conclusions about the occurrence or origins of floods were reasonable. Similarly, subsequent reviews were made by USGS hydraulic engineers with much experience. It appears there is a bias in attempting to discredit Mr. Stewart's work and all historical data (re: February 9, 2005, email from Mr. Kunzler), but more so a bias in only looking to reduce flood stages and discharges (unscientific). For example, it has been documented that large flood flows have resulted in use of the secondary channel (bypassing the gage) when the Skagit River stage is greater than about 180 feet (page 11, 4^{th} paragraph). HEC-RAS modeling by PI Engineering demonstrated that up to 16,800 ft^3/s could bypass the Skagit River streamflow-gaging station at Concrete. Thus, to be fair (unbiased), Stewart's historical flood estimates could be larger than the current published flood values by similar or large amounts of flow that bypassed the gage. On page 7, section 3.2.1, last paragraph, PI

Engineering states that: "However, it seems likely that the HWM on the hotel… were from the Baker River." Yet, later in the report (page 8, section 3.2.2, paragraph 2), PI Engineering claims that the HWMs on the hotel "…would have represented Baker River flood elevations." Clarify how you concluded certainty of this, particularly without acknowledging the Skagit River flood backwater (level water surface) in the Baker River (FEMA, attachment). On page 8, section 3.2.2, paragraph 1, PI Engineering states: "The flood profiles discussed in Section 4 show the slope of the water surface can be more than 5 feet within the Skagit River reach near Concrete." Water-surface slope is a dimensionless value; clarify the meaning of the sentence.

Page 9. Section 3.2.3, 1st paragraph. Stewart clearly stated that all documented 1921 HWMs represented flood heights for the Skagit River (rather than only those in the Dalles). Rephrase to state this is your interpretation/speculation, not as Stewart documented. Section 3.3 (and table 1, page 10). PI Engineering attempts to help answer questions about flood magnitude at the Concrete gage on the Skagit River by comparing four historical floods (1897, 1909, 1917, and 1921) with two other locations on the Skagit River and three tributaries. For completeness, I would suggest a basin-wide paleoflood study (Jarrett and England, 2002) be conducted that would include paleoflood estimates for more locations along the Skagit River and all significant tributaries. Dendrochronological studies (Yanosky and Jarrett, 2002) also may provide additional paleoflood evidence of historical flood stages, particularly near the Concrete gage site. In addition to providing a more complete flood history for the Skagit River basin, the data could be used to help ascertain the effects of debris dams on historical peak discharges from flood evidence (PSIs) preserved in channels and on floodplains. Section 3.3 (1897 HWMs discussions, last sentence). Stewart stated the 1897 HWMs were for the Skagit River. Rephrase that this is your speculation/interpretation or provide evidence they were Baker River HWMs. It seems a detailed step-backwater (HEC-RAS) analysis of the Skagit and Baker Rivers would help validate the relation of flood stages from the Skagit and Baker Rivers.

Page 11. Section 3.3, 1st paragraph. Paleoflood studies would help determine the effects of flood control (or water storage) reservoirs on flood magnitude upstream as compared with peak discharge downstream from a structure, and for flooding before and after construction of the reservoir. 2nd paragraph. "Both of these [Stewart's contracted-opening and slope/area methods] are indirect methods that provide only an approximation of flood flows. These estimates produced by the contracted-opening method are very rough, and today the method is not generally considered to be valid." Actually, the contracted-opening method is widely used to estimate peak discharges and has been validated (by subsequent current-meter discharge measurements) as being accurate when applied properly. Similarly, PI Engineering noted limitations in Stewart's slope-area computations. However, given the fall (e.g., see your figure 3, page 18) of about 8 feet over a very short distance (4 feet near vertical drop for the October 2003 flood), it is most likely that flow went through critical depth in the most constricted part of the Dalles. For critical flow, discharge is a function of channel geometry and only minimally from roughness. Certainly, other energy losses from sharp bends in the Dalles canyon may be significant. Not surprising is that flood discharges computed for the 1921 flood by different investigators and at different times have been fairly consistent. For normal hydraulic conditions of critical flow, Jarrett and England (2002) validate that critical-depth methods can match current-meter discharge measurements within +/-15 percent. Uncertainties for large flood estimates in complex channels are likely on the order of +/-20 to +/-25 percent (for the 1921 flood at the Concrete gage, a discharge uncertainty of over +/-40,000 ft^3/s). This is true for USGS indirect methods, 1-D models such as HEC-RAS, and definitely for multi-dimensional flow models, which essentially have not undergone validation, particularly, and unfortunately, for modeling large floods. A range of peak discharges for historical floods may be the best hydraulic engineers can estimate until more research is done to validate total energy losses and develop improved models. The uncertainties are why more emphasis is needed in the flood-frequency analyses.

Page 13. Figure 1, USGS provided rating curve of May 2004. It is unclear why the rating curve for the Skagit River near Concrete above the October 2003 flood does not better fit the historical floods. The USGS suggests the dense trees on the island downstream from the Concrete gage may have been removed by large historical floods and would have had a slightly different rating, but there is limited photographic or other supportive evidence. Subsequent to the historical floods, trees could have reestablished on the island and the rating would shift to the left (present rating).

Page 15. Section 4. Paragraph 1. It is unclear why the HEC-RAS model (rating curve) was not extended to the stage of the 1815 flood. I'd recommend rerunning the model so the rating curve could be evaluated when extended to the stage of the 1815 flood with an uncertainty analysis of factors affecting the flood discharge. These results (1815 and 1856 floods and their uncertainties) could then be used in the subsequent flood-frequency analysis. Paragraph 2. As I view the cross sections used in the model, all but a few are incorrectly subdivided. Cross sections are subdivided based on main channel breaks in slope, then sub-divided for relatively uniform over-bank areas based on geometry and changes in flow resistance. In the PI Engineering report, it appears the cross sections were subdivided by channel roughness, probably associated with bank vegetation; some sections, those without defined breaks in bank slope, do not need to be subdivided. The main channel n values (defined at the top of the break in slope) need to be assigned, by using standard hydraulic methods, as a weighted n based on channel roughness and vegetation roughness such as by conveyance, area, or top width. The analysis needs to be rerun with proper subdivision according to standard hydraulic practice. Paragraph 3. Please clarify how the secondary channel was modeled. Were the computations made independent of the main channel or by the standard method of divided flow (often termed "island flow") and balancing the energy equation at the upper end of the "island" where the flow enters the secondary channel? Preferably, Manning's n values for the secondary channel need to vary over a reasonable range to account for the uncertainty in estimated roughness. Paragraph 4. Manning's n values above the calibrated/validated discharge for the 2003 flood need to be varied according to reasonable variation for the range of historical flood stages. This will help ascertain approximate uncertainties of flood discharge for each historical flood.

Page 16. 1st Paragraph. Contraction and expansion (C/E) coefficients in the Dalles constriction are unknown because there has been very limited validation, particularly in complex, bedrock constrictions. Given the uncertainty in the 1921 flood estimates due to many factors, varying these coefficients is little more than a meaningless exercise to tweak the 1921 flood discharge estimate. In the PI Engineering report, all modifications appear to be biased towards decreasing the peak discharge – and eliminating historical flood data. Quantifying energy losses due to contraction and expansion, particularly for expanding reaches, is poorly understood. To my knowledge, there are no comprehensive scientific/engineering studies that provide guidelines for varying C/E coefficients. Recently, HEC-RAS model analyses are being made where C/E coefficients are increased according to guidelines provided by the Corps' Hydrologic Engineering Center. The guidelines are based on anecdotal studies and attempts to model complex hydraulic conditions that are beyond model validation and, perhaps, the actual capabilities of the 1-D model. Because much more documentation and guidelines on the selection of Manning's n values are available (and all this work was done using C/E coefficients set to 0.0 and 0.5, respectively), the USGS prefers not to use these poorly understood coefficients to calibrate models. For those models where C/E coefficients are increased, then uncertainties are introduced in selected n values by using standard guidelines. The HEC-RAS model calibrations certainly help validate the model, but the historical floods have substantially higher stages/discharges than used in the calibration/validation, which introduce uncertainties. However, I believe that because the Dalles constriction forces the flow (and rating curve) to be controlled by channel geometry, varying n values and other energy losses will have minimal effect on computed discharges (given the overall uncertainty of at least +/-20 percent). I also am surprised the HEC-RAS results do not show critical flow in the constriction (re: Figure 3, water-surface profiles). It may be the use of such large contraction and expansion coefficients in the HEC-RAS model may incorrectly preclude modeling the flow as "critical" in the Dalles constriction.

Page 18. Figure 3 has no scale for the x-axis, but the profiles (essentially vertical) strongly suggest: 1) flow is critical, and; 2) the Concrete gaging station may be in the drawdown zone, particularly for large floods, which adds to the uncertainty in the rating curve. Given the extreme importance of these gage records and after revised HEC-RAS analysis results are available, it may be best to consider relocating the gage (although I have not seen the site).

Page 19. Figure 4. The difference in the HEC-RAS rating curves and historical data can not be evaluated until the HEC-RAS modeling is redone properly using standard hydraulic practices.

Pages 19 and 20 (Regarding the location of Stewart's measurement for the 1921 flood and PI Engineering's suggestion for an earlier gage location and revised peak discharges.) The material provided and the HEC-RAS modeling results suggest lower historical discharges, assuming PI Engineering's interpretations of gage height and slope (corrections) between gages are correct. At this point, knowing the exact location of Stewart's gage heights may be beyond current documentation to clearly identify the actual historical stages. However, though Stewart's stages may not be known precisely (or there may have been slight rating shifts pre- and post-1921), the exact gage location likely would not have affected Stewart's 1921 peak discharge estimate. The important issues pertaining to the differences in historical peak discharges include: 1) to recognize that under the best of circumstances the original 1921 flood computation has an uncertainty of at least +/-20 percent, which is larger than uncertainties of any subsequent computations of the 1921 flood; 2) to consider incorporating a basin-wide paleoflood study, and; 3) to incorporate such uncertainties in the historical and paleoflood data in a more robust flood-frequency analyses, particularly the 1815 and 1856 historical floods. The apparent large differences in the HEC-RAS model runs, without the bridge and historical flood stages, could be explained by several unknown factors such as modest debris jams in or downstream from the control, possible fracturing of canyon bedrock and removal by subsequent flooding sometime during the time of the historical floods, which were much larger than present day floods, or other explanations. HEC-RAS modeling of such complex reaches also have limitations and infallibilities that are not being acknowledged, but need to be discussed.

Page 23. Section 5. Significance of Using Best Science. Using the best science is a goal of all involved with the flood hydrology for the Skagit River near Concrete, the difficulty is how and who defines "best science." Most reasonable hydrologists and engineers would question the flood-frequency analysis in Table 5 because of the decision to discard the historical data, including the two known largest floods in 1815 and 1856. It would not take much effort to extend the HEC-RAS rating curve to the 1815 flood stages and estimate ranges of peak discharge for each historical flood and associated uncertainties. Although discarding large flood data (outliers) was sometimes done decades ago (based on unscientific reasoning), it is not standard practice to delete data for large floods as newer methods to estimate peak discharge with more robust hydraulic models and flood-frequency analysis methods are available and recommended by the NAS (1999). Given the critical importance to obtain the best hydrology for this gage (and other sites along the Skagit River and its tributaries) and the serious consequences to the goal of flood-damage reduction and ecosystem restoration by using flood hydrology that has not undergone a fair, unbiased and incomplete analysis (e.g., discrediting Stewart's data and abilities and only evaluating factors that reduce peak historical discharges), it seems prudent to expand the flood study to a multi-disciplinary, basin-wide approach to meet the stated goals of the study. The public will be ill-served with the present study and is at a greater risk from flooding given the incomplete analyses to date. I find it difficult to agree with the conclusions in the last paragraph on page 23. This further emphasizes the need to enhance the current PI Engineering study, which will add minor (say 1-3 percent) costs to the total study cost and provide greater confidence to the public that the best hydrology is used.

Summary

Stewart's study of historical floods in the Skagit River basin had, by today's standards short-comings, simplifications, incomplete documentation, no known photographic documentation, and took decades to review and complete the evaluation of flood hydrology for the Skagit River near Concrete. Similarly, there are shortcomings, some lack of documentation, and questionable HEC-RAS hydraulic analyses in the PI Engineering preliminary report. None of the proposed alternatives in the PI Engineering report are outside the possible error of the original USGS 1921 peak discharge; thus the USGS has every reason to believe that the 1921 value is as good as could be obtained.

Major points of my review include:

1) Flow is complex through the Concrete gage site and may not be best modeled with 1-D hydraulics. Peak discharge measurement uncertainties for large floods likely are +/-20 to +/-25 percent;
2) Skagit River HWMs can extend substantially up the Baker River (attached figure 1);
3) The USGS and PI Engineering (HEC-RAS) 1921 peak discharge estimates likely differ by less than the estimated measurement uncertainty;
4) The HEC-RAS model inconsistencies need to be fixed and the model rerun. I suggest extending the HEC-RAS model to estimate the peak discharges (and uncertainties) for the 1815 and 1856 floods;
5) Consider conducting at-site or basin-wide paleoflood studies to provide a more complete flood history of the site/basin;
6) Consider using EMA or other robust flood-frequency methods to better incorporate all historical (and paleoflood) flood data and determine more reliable confidence intervals. I also suggest the frequency analyses include flood volumes such as the 1-, 3-, 7-, and 15-day values, and;
7) Most importantly, not using any of the historical flood data will underestimate flood frequency, and thus, put residents, visitors, and structures at greater risk to future flooding.

References

England, J.F. Jr., Salas, J.D., and Jarrett, R.D., 2003a, Comparisons of two moments-based estimators that utilize historical and paleoflood data for the log-Pearson Type III distribution: Water Resources Research, v. 39, no. 9, pp. 5-1 to 5-16, doi:10.1029/2002WR001791.

England, J.F. Jr., Jarrett, R.D., and Salas, J.D., 2003b, Data-based comparisons of moments estimators that use historical and paleoflood data: Journal of Hydrology, v. 278, nos. 1-4, pp. 170-194.

Jarrett, R.D., and Tomlinson, E.M., 2000, Regional interdisciplinary paleoflood approach to assess extreme flood potential: Water Resources Research, v. 36, no. 10, p. 2957-2984.

Jarrett, R. D., and England, J. F., Jr., 2002, Reliability of paleostage indicators for paleoflood studies, in P.K. House and others, eds., Ancient Floods, Modern Hazards: Principles and Applications of Paleoflood Hydrology: American Geophysical Union Water Science and Application Series, v. 5, p. 91-109, with additional supporting data and information on cd-rom.

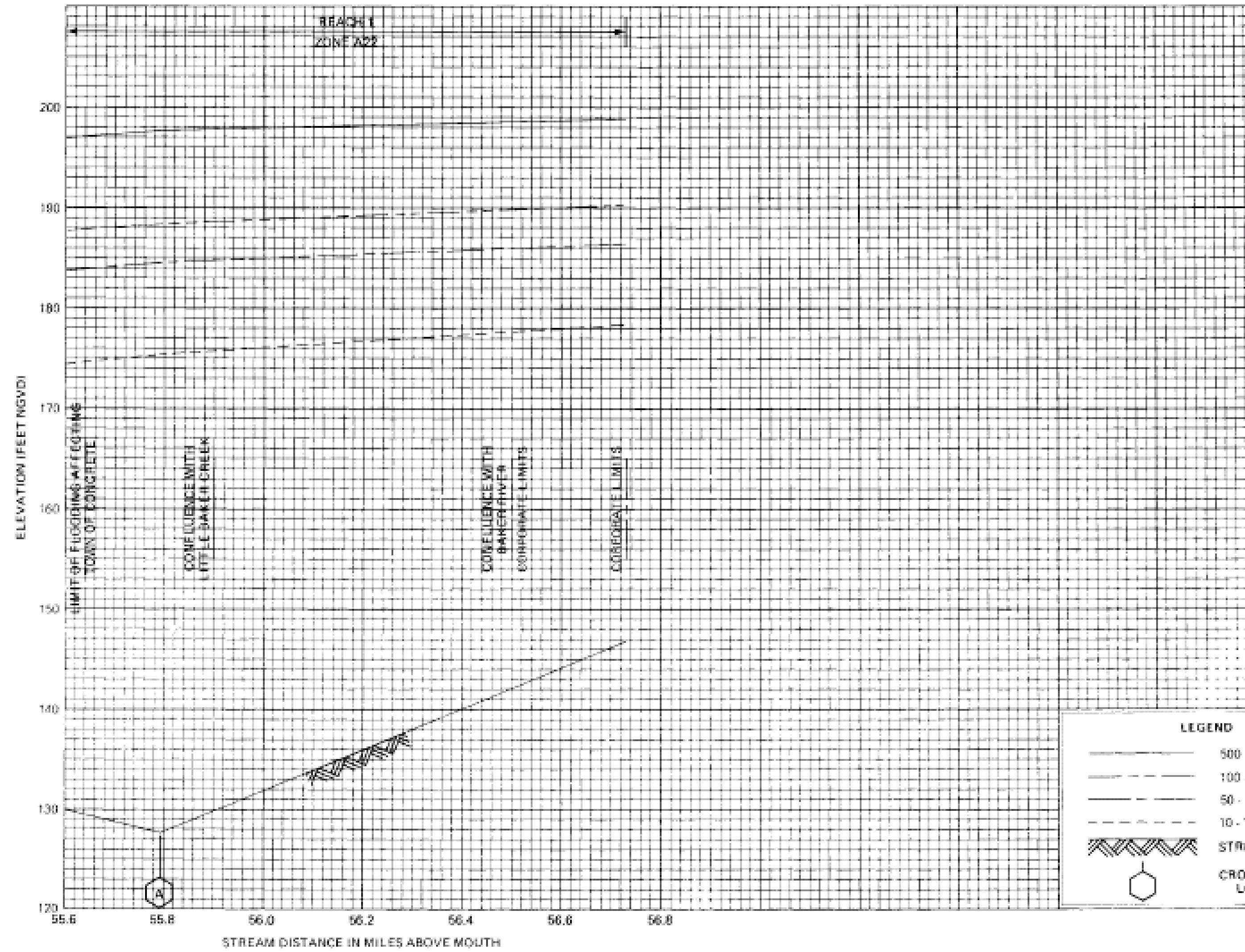
National Research Council (NRC), 1999, Improving American River flood frequency analyses, Committee on American River Flood Frequencies: Washington, D.C., National Academy Press, 120 p.

Levish, D.R., 2002, Paleohydrologic Bounds—Non-Exceedance Information for Flood Hazard Assessment, in P.K. House and others, eds., Ancient Floods, Modern Hazards: Principles and Applications of Paleoflood Hydrology, Water Science and Application Series, v. 5, pp. 175-190, American Geophysical Union, Washington, D.C..

O’Connell, D. R. H., 1999, FLDFRQ3, Three-parameter maximum likelihood flood-frequency estimation with optional probability regions using parameter grid integration. User’s Guide (Release 1.1), February 24, 1999: Denver, Colorado, U.S. Bureau of Reclamation, 19 p.

O'Connell, D.R.H., Ostenaa, D.A., Levish, D.R., Klinger, R.E., 2002, Bayesian flood frequency analysis with paleohydrologic bound data: Water Resources Research, v. 38, no. 5, DOI 10.1029/2000WR000028, 14 p.

Yanosky, T. M. and Jarrett, R. D., 2002, Dendrochronologic evidence for the frequency and magnitude of paleofloods, in P.K. House and others, eds., Ancient Floods, Modern Hazards: Principles and Applications of Paleoflood Hydrology, American Geophysical Union Water Science and Application Series, v. 5, p. 77-89.


REACH 1
ZONE A22
200
190
180
170
160
150
140
130
120
ELEVATION (FEET NGVD)
LIMIT OF FLOODING AFFECTING TOWN OF CONCRETE
CONFLUENCE WITH LITTLE BAKER CREEK
CONFLUENCE WITH BAKER RIVER
CORPORATE LIMITS
CORPORATE LIMITS
A
55.6
55.8
56.0
56.2
56.4
56.6
56.8
STREAM DISTANCE IN MILES ABOVE MOUTH
LEGEND
500
100
50
10