Skagit River Basin Hydrology Report
Existing Conditions

October 2008

Prepared For:

City of Burlington
City of Mount Vernon
Dike, Drainage and Irrigation District 12
Dike District 1

By:

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INTERNATIONAL
ENGINEERING PLLC

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1.0 Summary

This report presents an update of Skagit River hydrology conducted by Pacific International Engineering (PI Engineering) under an Agreement for Engineering Services authorized in June 2007 by the City of Burlington. The technical work pursuant to this Agreement is funded through a cost-share partnership between the City of Burlington, the City of Mount Vernon, Dike, Drainage, and Irrigation District 12, and Dike District 1. The City of Burlington is administrative lead agency. The information and results of the analyses presented herein are intended for use in the Federal Emergency Management Agency (FEMA) Flood Insurance Study (FIS).

The hydrology presented in this report updates the Skagit River flood hydrology contained in the December 2005 report prepared by PI Engineering for Skagit County, entitled "Hydrology and Hydraulics, Skagit River Flood Basin – Existing Conditions" (PI Engineering 2005). The river's hydrology has been the subject of measurement and study for over 85 years, and predictions of flood behavior have been revisited periodically in the light of a growing body of recorded data. PI Engineering has, over the last six years, conducted analyses of the available data, and has been actively in discussion with other consultants and the agencies involved.

The purpose of this report is to determine the flood frequency and synthetic flood hydrographs for the highly developed floodplain areas of the Skagit River basin from Sedro-Woolley downstream to the confluences of the North and South Forks of the Skagit River with Puget Sound (Figure 1). This report describes the analyses performed to make those determinations with the highest degree of confidence and presents peak flows and flood hydrographs for the 10-, 50-, 100-, and 500-year events that meet the requirements for the Skagit River FIS in accordance with the current FEMA guidelines (FEMA 2003).

Hydrologic studies have covered the entire Skagit River basin with an emphasis given to the lower basin from Concrete downstream to Puget Sound. Above this stretch of river are the Ross, Gorge and Diablo Dams and Seattle City Light hydroelectric plants on the main stem of the Skagit, and Puget Sound Energy's hydroelectric development on the Baker River, a tributary of the Skagit with its confluence at Concrete. Since their completion, these hydroelectric facilities have provided regulation to the flow in the Skagit in accordance with agreements since 1954 and 1980 respectively. Prior to these dates, the presence of the facilities contributed to some regulation of the flows, the extent of which cannot be determined with exactitude.

Prior to 1925, there are no stream gage records on the Skagit River at Concrete. Earlier records are available for gages at Sedro-Woolley, and on tributary streams including the Sauk River and Baker River, as well as stage readings and anecdotal reports of high water observed during high-flow events. In the three decades before the Concrete gage was installed, and before the construction of the hydroelectric developments, high flows caused flooding on the Skagit, notably in 1897, 1909, 1917, and 1921. James E. Stewart, of the U.S. Geological Survey, set out to collect and analyze observations of these major flood events and used two engineering methods available at the time to estimate discharges of these events (Stewart 1923).

Stewart's early work was not revisited until the 1950s, documented in USGS memoranda, and was finally published as USGS Water Supply Paper 1527 in 1961. In spite of the fact that Stewart had access only to limited amounts of historical data and could only roughly estimate the flood discharges, his study was a valuable contribution to codifying flood expectations for the Skagit River. Recent high-flow events in 1990, 1995, 2003, and 2006, have lent urgency to the need for refinement of hydrologic studies of the Skagit River, particularly as they affect development and investment in the region's urbanizing areas.

It is consistent with FEMA's *Guidelines and Specifications for Flood Hazard Mapping* to update estimates of flood discharge frequency as the length of gage records increases. There are now over 80 years of records at the Concrete gage, supplemented by the limited observations and estimates of the "historical" floods.

The four historical floods included in Stewart's study have very significant effects on the FIS and the flood maps. Consistent with FEMA guidelines to use the best quality data possible, PI Engineering for the 2005 flood hydrology study used the most up-to-date HEC-RAS modeling method, in conjunction with the use of the USGS published water surface elevations at Concrete, to estimate these four historical flood discharges. Recent detailed review of Stewart's 1922-23 field survey notes revealed that there is no scientific evidence to support the published flood elevations at the current gage. This finding invalidates the historical flood estimates based on the published flood elevations. Also, this review further revealed that useful historical flood elevations in the Concrete to Hamilton area are available from Stewart's survey notes. Additional new data, including flood marks along the old road and railroad in the Hamilton-Lyman floodplain, and a finding of the location of the old Wolfe residence in Concrete where Stewart surveyed the 1917 and 1921 flood elevations, lent further support to use Stewart's highwater marks in conjunction with the use of the HEC-RAS model to provide the best scientific estimates for the 1897, 1909, 1917, and 1921 floods.

Data for these historic events are combined with data sets developed by the Corps and PI Engineering to compile a record covering 84 years of unregulated systematic peaks and 4 years of unregulated historical peaks for frequency analysis. The analysis results in a prediction of 240,800 cfs as the unregulated peak flow at the Concrete gage for a 100-year flood. Using similar data sets, values are also derived for unregulated one-day flows at Concrete. Using synthetic hydrographs originally developed by the Corps, and the HEC-RAS and HEC-5 models originally developed by the Corps, runs were conducted routing the floods through the Ross/Diablo/Gorge and Baker Dams storage regulation and downstream Skagit Valley to Puget Sound. This enabled regulated flood peaks and hydrographs reflecting the existing basin conditions, to be developed at the location of the highly developed floodplain areas downstream of Sedro-Woolley.

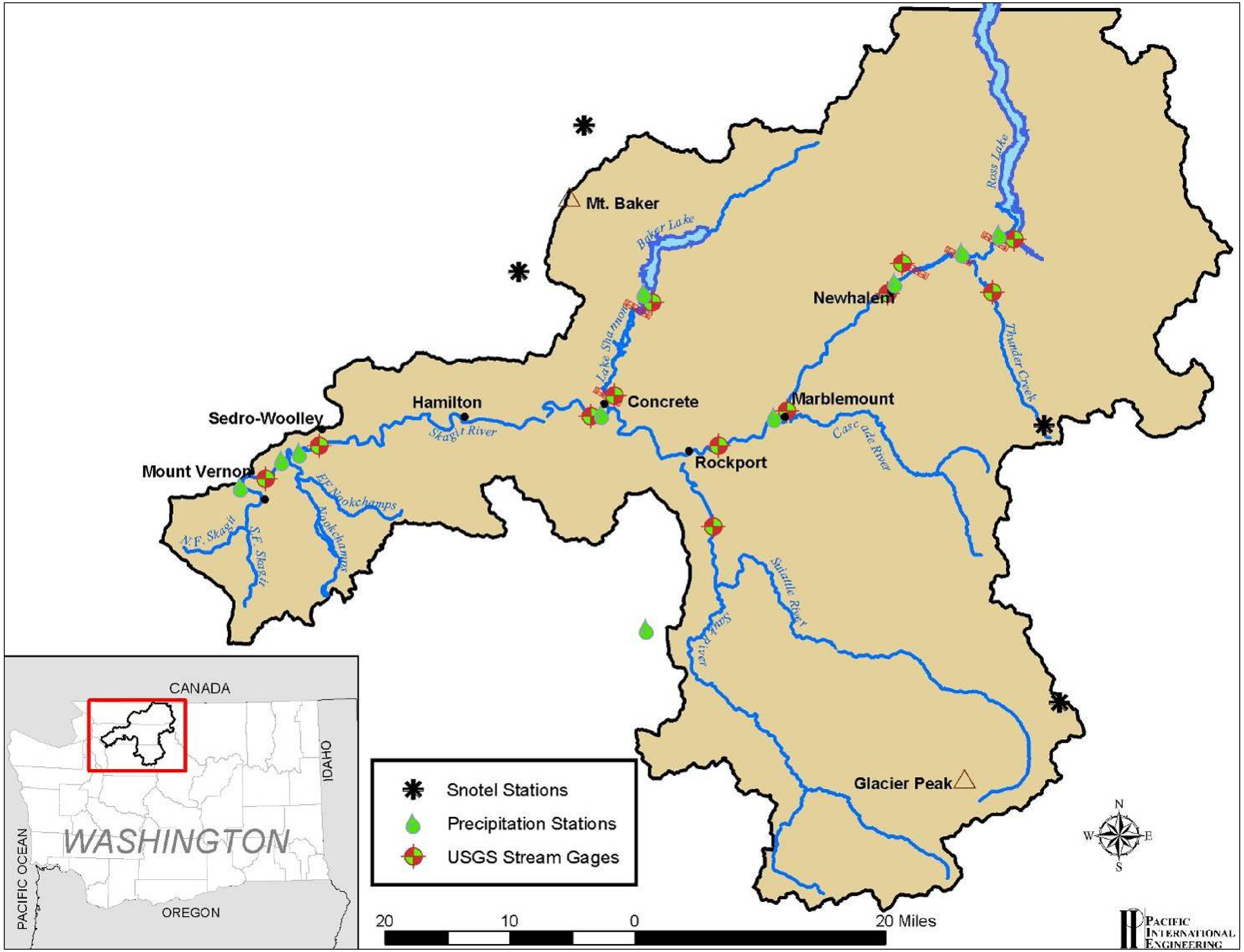

Figure 1. Skagit River Basin

2.0 Skagit River Watershed Characteristics

The Skagit River basin, located in the northwest corner of the State of Washington (Figure 1) is a regulated watershed. It includes three dams located on the mainstem Skagit River (Gorge, Diablo and Ross), and two dams located on the Baker River (Lower Baker and Upper Baker). Gorge Dam was completed as a wooden structure in 1924, and replaced with a concrete dam in 1950. Diablo Dam was completed in 1931, at the time the tallest dam in the world at 389 feet. The first level of Ross Dam (300 feet tall) was completed in 1940, and the second and third levels were both completed in 1949 bringing the dam's total height to 540 feet. Lower Baker Dam was completed in 1925, creating Lake Shannon. Upper Baker Dam was completed in 1959, increasing the size of the naturally occurring Baker Lake. Regulation of the Skagit River using 120,000 acre-feet of flood control storage at Ross Dam began in 1954, and regulation of the Baker River using 74,000 acre-feet of flood control storage at Upper Baker Dam began in 1980 (information in this paragraph sourced from publicly available hydroelectric licenses, other public records/studies, and Corps of Engineer documents).

The Skagit River basin has a total drainage area of 3,115 square miles, originating near the Cascade Mountains in British Columbia, Canada. The basin extends about 110 miles in the north-south direction, and about 90 miles in the east-west direction between the crest of the Cascade Range and Puget Sound. The northern end of the basin extends 28 miles into Canada.

The Skagit River falls rapidly from its source at elevation 8,000 feet to an elevation of 1,600 feet at the United States-Canadian border. Within the first 40 miles south of the international border, the river falls 1,100-feet, and the remaining 500-foot fall is distributed along the 95 miles of the lower river.

Immediately downstream from Mount Vernon, the river divides into two principal distributaries, the North Fork and the South Fork. These two distributaries carry about 60 percent and 40 percent, respectively, of the normal flows of the Skagit River into Puget Sound, although these ratios change during a large flood event (U.S. Army Corps of Engineers 2008).

The Skagit Valley, the 100,000-acre, 54-mile-long valley between Concrete and the river mouths, contains the largest residential and farming developments in the basin. It is made up of cattle and dairy pastureland, agricultural areas, the urban areas of Sedro-Woolley, Mount Vernon, Burlington and La Conner (all located in the flood plain), and wooded areas. West of Sedro-Woolley, a large alluvial fan floodplain (east-west width of about 11 miles and a north-south width of about l9 miles) had its origin about 5,900 years ago from a series of lahars (or a single event) originating from Glacier Peak (Beget, Dragovich and others, 1982 – 2006). Prior to 5,900 years ago, the floodplain terminated near the present-day location of Burlington, and the sea level was about 20 feet lower than today (Dragovich and McKay; Dethier, Beget and others, 1982-2000). Subsequent lahars as recent as 1,800 years ago may have added material to the flood plain, either directly or through sediment transport over time (Washington Department of Natural Resources, Open File Report 2000-6).

2.1 Topography

A major portion of the Skagit River basin lies on the western slopes of the Cascade Range. Most of the eastern portion of the basin is mountainous land above an elevation of 6,000 feet. The two most prominent topographical features in the basin are Mount Baker on the northern side of the basin at an elevation of 10,778 feet, and Glacier Peak in the southern portion of the basin at an elevation of 10,568 feet. In the eastern portion of the basin, 22 peaks are above an elevation of 8,000 feet. The upper reaches of nearly all tributaries are situated in precipitous steep-walled mountain valleys.

The Skagit River flows in a l-mile- to 3-mile-wide valley from Rockport to Sedro-Woolley. In this section, the valley walls are moderately steep timbered hillsides with few developments. Below Sedro-Woolley, the valley falls to nearly sea level and widens to a flat, fertile floodplain formed by continual river sediment transport and also by significant volcanic activity from Glacier Peak, most notably from a catastrophic lahar event about 5,900 years ago that deposited between 0.5 and 0.7 cubic miles of sediment extending to the present location of Samish Bay to the northeast, and La Conner and Stanwood to the southeast (Beget, 1982; Dragovich, Grisamer and others, see Washington State Department of Natural Resources, Open File Report 98-8). Additional more recent Glacier Peak volcanic activity from about 1,800 years ago may have added lahar material to the lower valley (Dragovich and Grisamer, Dec 1998). The lahar/flood plain joins the Samish valley along the northeast side of the valley and extends west through Mount Vernon to La Conner and south to the Stillaguamish River.

2.2 Geology

The eastern mountainous region of the upper Skagit River basin consists of ancient metamorphic rocks, largely phyllites, slates, shales, schists, and gneisses together with intrusive granitic rocks and later andesitic lavas and pyroclastic deposits associated with Mount Baker and Glacier Peak (U.S. Army Corps of Engineers 2008). The valleys are generally steep-sided and frequently flat-floored. Valley walls are generally mantled with a mixture of rocky colluvium, and, to a considerable elevation, by deposits of continental and alpine glaciation (U.S. Army Corps of Engineers 2008). These deposits are a heterogeneous mixture of sand and gravel together with variable quantities of silt and clay depending on the mode of deposition (U.S. Army Corps of Engineers 2008). Some of these deposits are susceptible to land sliding when saturated.

The floodplain of the Skagit River below Concrete is composed of sands and gravels that diminish to sands, silts, and some clays further downstream. Below Hamilton, fine-grained floodplain sediments predominate. The Baker River valley in the vicinity of Baker Lake is geologically quite different from most of the other Skagit tributaries. This is largely due to the influence of Mount Baker, a volcanic cone rising to an elevation of 10,778 feet, that sets astride the western boundary of the Baker River basin.

Present bedrock exposures adjacent to Ross Lake consist of Chilliwack sediments, volcanics and granitics, Skagit gneiss, and Nooksack group phyllite (Corps 2008). The continental ice movement and mountain glaciers sculpted the basic geological forms and rock types into the major landforms that are recognizable today. A large mass of metamorphic rock, known as the Skagit gneiss, forms the foundation rock for all three of the Skagit River Project plants (Corps 2008). The age of its parent strata is presumed to be Paleozoic. The resistance to erosion provided by the massive gneiss is undoubtedly the reason for the narrow gorge of the Skagit River where the dams are located. Alpine glaciers have contributed to the steepness of the valley sides and to the depth of the valley bottoms. Over ten thousand years ago, the upper Skagit Valley and the peaks were severely glaciated, removing not only the soil but much of the loose rock (Corps 2008). Many river channels created during the glacial melt have continued to aggrade, and as a result of that glacial action, the bedrock bottoms of most canyons are covered with glacial alluvium (Corps 2008).

2.3 Sediment

Predicted rates of bed accumulation for 100 years in the Skagit River system vary in depth from 4 feet at the mouth of the 2 distributaries, the North and South Forks of the Skagit River, to 2 feet at Mount Vernon (Corps 2008). The 2 feet of depth continues upstream to Burlington (Corps 2008). The river annually transports about 3,000,000 tons of sediment of mostly glacial origin (Mastin, Schwartzenberger and Perry, 2008). Size of bed material, as determined by field observations and samples, varies from 1/4-inch to 3/4-inch gravel and coarse sand at Mount Vernon to medium and fine sand near the river mouths. From Burlington to Concrete, channel sediments are predominantly fine-to-coarse sands, gravels, and cobbles together with small quantities of silt and clay (Corps 2008).

2.4 Climate

The major factors influencing the climate of the Skagit River basin are terrain, proximity of the Pacific Ocean, and the position and intensity of the semi-permanent high and low pressure centers over the north Pacific Ocean. The basin lies about 100 miles inland from the moisture supply of the Pacific Ocean. Westerly air currents from the ocean prevail in these latitudes bringing the region considerable moisture, cool summers, and comparatively mild winters. Annual precipitation throughout the basin varies markedly due to elevation and topography. Major storm activity occurs during the winter when the basin is subject to rather frequent ocean storms that include heavy frontal rains associated with cyclonic disturbances generated by the semi-permanent Aleutian Low. During the summer months, the weather is relatively warm and dry due to increased influence of the semi-permanent Hawaiian high pressure system.

2.4.1 Temperature

The mean annual temperature for stations in or near the basin varies from 40.l degrees Fahrenheit (°F) at Mount Baker Lodge to 50.7°F at Concrete. Normal monthly temperatures vary in January from a low of 26.9°F at Mount Baker Lodge to a high of 39.1°F at Anacortes, and in August from a low of 56.7°F at Mount Baker Lodge to a high of 64.7°F at Diablo Dam. The temperature extremes recorded in the basin are 109°F at Newhalem and -14°F at Darrington Ranger Station. A phenomenon known as the Pineapple Express can cause Pacific Northwest wintertime temperatures to rise to the upper 50s or warmer, such as happened in December 1990 when temperatures in the Seattle area reached 63 degrees. A Pineapple Express occurs when the jet stream dips into the tropics and then carries a large batch of tropical (Hawaiian) moisture northeast into the Pacific Northwest during the winter. This causes wet and warm weather, a common cause of lowland flooding episodes.

2.4.2 Precipitation

The locations of precipitation stations in the Skagit River basin are shown on Figure 1. Average annual precipitation over the Skagit basin varies by about 150 inches. Mean annual precipitation is 40 inches or less near the mouth of the Skagit River and in the portion of the basin in Canada that lies in topographic rain shadows. Average precipitation of l80 inches or more falls on the higher elevations of the Cascade Range in the southern end of the basin and over the higher slopes of Mount Baker. The annual precipitation over the basin above the town of Mount Vernon, as recorded at Ross Dam, Diablo Dam, Newhalem, Upper Baker Dam, Concrete, and Sedro-Woolley, averages 71 inches with approximately 75 percent of this amount falling during the 6-month period of October-March. The mean monthly precipitation at stations in or near the basin ranges from 0.96 of an inch in July at Anacortes to 17 inches in December at Mount Baker Lodge. The mean annual precipitation at Baker Lake and Diablo Dam is 102.88 inches and 77.07 inches, respectively. The maximum recorded precipitation for one month was 4l.95 inches at Silverton (south of Darrington) in January 1953. Storm studies indicate that 5 to 6 inches of rainfall in a 24-hour period have occurred over much of the basin. Information on storms and flooding in the basin is discussed in Section 2.7.

2.4.3 Snowfall

Snowfall in the Skagit River basin is dependent upon elevation and proximity to the moisture supply of the ocean. The mean annual snowfall at stations in the vicinity of the basin varies from 6.2 inches at Anacortes to 525.3 inches at Mount Baker Lodge; with a maximum recorded value of 1,140 inches at Mount Baker Lodge during the July

1998 through June 1999 season. Snow surveys have been made in the vicinity of the Skagit River basin since 1943. Locations of Snotel snow measuring stations in the vicinity of the basin are shown on Figure 1.

2.4.4 Wind

Surface wind speeds in the basin are the result of the pressure gradient between high and low pressure cells, storm intensity, and topographic effects. Prevailing winds in the lower basin are generally from the southerly quadrant from September through May, and from the northerly quadrant from June through August. In the upper valleys above Concrete, the airflow is subject to a topographic funneling effect and is generally up the valley in winter and down slope in summer. A diurnal change in direction often occurs in the summer. Occasionally in the winter, cold continental air from eastern Washington or eastern British Columbia will flow through mountain passes creating cold east winds down the valley. In the winter season, storm winds will vary from 20 to 30 miles per hour (mph). During extreme events, winds will exceed 60 mph for short durations with 100 mph gusts occurring over mountain peaks. A common producer of high winds in this area is the Pacific Northwest chinook, which results from high and low pressure areas colliding overhead. Two notable chinook wind storms of recent history hit northwest Washington in December 1996 and in December 2003. The 1996 chinook brought winds up to 60 to 70 mph, with gusts to 80 mph. Trees were blown onto power lines causing extensive power outages, and in some cases trees were snapped off at the ground. The 2003 chinook sustained winds of 45 to 50 mph, with gusts to 65 mph.

2.5 Channel Characteristics

2.5.1 International Border to Gorge Dam

The Skagit River from the United States-Canadian Border to Gorge Dam flows through the three Skagit River hydroelectric plants (Ross, Diablo and Gorge) in a hydraulically-connected reservoir waterway.

2.5.2 Gorge Dam to Newhalem

The 15,000-foot-long reach from Gorge Dam to the Gorge Powerhouse is usually dry during normal hydropower operations. During even small flooding events, however, local runoff generally fills the limited storage space in Gorge Lake prior to the flood peak, causing Gorge to spill into the normally dry channel between the dam and Gorge Powerhouse. When the channel is filled below Gorge, releases from Ross can be routed to Newhalem in a half hour or less provided the spill gates at Diablo and Gorge are opened when the release is made at Ross.

2.5.3 Newhalem to Concrete

The 39.6-mile-long Skagit River reach from Newhalem to Concrete falls approximately 8 feet per mile. The upper half of the reach contains a steep rugged channel located between narrow rock canyon walls in many places, with evidence of past slides, some of which were large enough to block the river channel for a time. Most of the channel bed is composed of large irregular-shaped boulders, rocks, and cobbles. The river flows in a series of water drops and deep pools. The lower half of the reach is much more placid with a wider flatter channel with smaller rocks and gravel materials. Hydraulic travel time from Newhalem to Concrete is approximately eight hours at the higher range of flows that occur during flood conditions.

2.5.4 Concrete to Mount Vernon

The 38.4-mile-long reach from Concrete to Mount Vernon falls approximately 150 feet (an average of about 3.9 feet per mile). River gradients range from 5.3 feet per mile near Concrete to l.5 feet per mile below Sedro-Woolley. Hydraulic velocities vary according to the location along the river, ranging from 5 feet per second to 10 feet per second. This reach is comparatively placid with a wide, gravel-lined channel with mostly small cobbles and gravels, soil embankments, and numerous side channels, oxbows and overbank erosion scars created during large floods of the past. Travel time through this reach varies with the rate of discharge, decreasing from between 15 and 20 hours at low flow to between 10 and 15 hours at higher discharges. There is a wide range of hydraulic travel times between Concrete and Mount Vernon, and the above values are occasionally exceeded.

2.6 Streamflow Characteristics

The Skagit River basin is subject to rain and snowmelt runoff during the fall, winter, and spring. Spring snowmelt runoff is caused predominantly by melting of the winter snowpack, and is characterized by a relatively slow rise and long duration evidenced by the higher mean high flows for the months of April through June. Some minor contribution to the rate and peak of the snowmelt is occasionally provided by warm spring rains, but the spring rain-on-snow impact is usually not significant. Highest mean monthly snowmelt discharges are usually reached in June. The resulting runoff occasionally inundates low areas adjacent to the river but rarely reaches the major damage stage. The maximum-recorded spring snowmelt discharge at Mount Vernon was 92,300 cubic feet per second (cfs) in April of 1959.

Power reservoirs are normally refilled during the annual spring snowmelt runoff; and as a result, the spring peak discharges are generally reduced. The Skagit River and all of its major tributaries usually have low flows during August and September after the high elevation snowpack has melted and the baseflow has partially receded, even though operation of the upper basin reservoirs increases flows over historic numbers.

With the advent of heavy precipitation in the fall and winter, the Skagit River experiences a significant flow increase. Floods and the highest daily and highest instantaneous peak discharge of the year usually occur during this period. Heavy rainfall and warm winds during typical 1- to 3-day winter storms cause streamflows to rise rapidly in a matter of hours to flood levels. Streamflows recede rapidly within hours after the storms have moved eastward through the region, although base flows and basin soil moistures usually remain high for several days. Several minor rises usually occur each winter, while major floods are more intermittent.

The Skagit River, which receives the effect of the initial lifting of Pacific Ocean air over the Cascade Range, varies in seasonal streamflow throughout the basin, generally due to the basin's heavy winter precipitation, spring snowmelt runoff, dry summers and topographical and elevation differences. The average annual runoff at the following stations reflects the runoff variation throughout the basin: Skagit River at the Newhalem stream gage - 51.1 inches, Sauk River near Sauk stream gage - 83.0 inches, Baker River at Upper Baker - 131.0 inches, Baker River at Concrete stream gage - 121.8 inches, and Skagit River near Mount Vernon - 73.2 inches. The 999-square-mile watershed above Ross Dam, located in the lee of western mountains that shield the basin from winter storms, has an annual runoff of only 45.6 inches.

Maximum and minimum extremes in recorded annual runoff at Mount Vernon during the 1941-1999 period are 16,752,595 acre-feet (in l991) and 7,608,893 acre-feet (in l944) or 101.6 and 46.1 inches, respectively, for the 3,093 square-mile basin. The locations of U.S. Geological Survey stream gaging stations in the Skagit River basin are shown on Figure 1.

2.7 Floods

Major floods on the Skagit River are the result of winter storms moving eastward across the basin with heavy precipitation and warm snow-melting temperatures. Several storms may occur in rapid succession, raising antecedent runoff conditions and filling various stream and river storage areas. Frequently, a low-elevation snowpack forms over large parts of the basin. Heavy rainfall and warm snow-melting complete the flood producing sequence. Minor floods usually last about three days, rising to major damage proportions in a day or less, reaching a flood crest in the next several hours, and receding rapidly in 24 hours or less. Floods of this variety have flood peaks less than 120,000 cfs below Concrete and are expected every 10 years or so. Minor floods become major floods when the intense storm rainfall is extended for a longer period of time, or multiple storm systems occur in rapid succession. Several minor rises usually occur every year, but major floods occur with less regularity. For example, two major floods have occurred in a single season, while several years have passed without a significant flood event. Winter rain-type floods usually occur in November or December but may occur as early as October or as late as February.

Flood volume, channel storage, and Concrete to Mount Vernon local inflow have a marked effect on the routing and attenuation of flood peaks between Concrete and Mount Vernon. For example, during the two large floods in November 1990 (see Section 2.7.4 below), the first flood peak attenuated between Concrete and Mount Vernon while the second flood increased in the same reach.

Skagit River flood peaks usually attenuate between Concrete and Mount Vernon. However, floods with high peaks and large volumes will generally fill the channel storage; and, combined with runoff from the 356-square-mile local area between Concrete and Mount Vernon will cause the peak discharge to increase as it moves downstream.

During dry summer weather, soil moistures in the Skagit River basin become substantially depleted. With the beginning of fall and winter rainfall, soil moistures are recharged; however, there is often a noticeable loss of runoff volume during the initial floods of the season until the various loss parameters are fully satisfied.

The Nookachamps Creek area on the south bank of the Skagit River, between Mount Vernon and Sedro-Woolley, is a major source of valley storage. Storage in this area can reduce major flows by 15,000 cfs to 25,000 cfs downstream from Sedro-Woolley during high-peak/low-volume floods. Larger floods with greater volume will fill the Nookachamps storage prior to the flood crest and offset most of the storage benefit.

2.7.1 Flood Runoff from Uncontrolled Watersheds

Runoff from the uncontrolled watersheds in the Skagit River basin has a major effect on flooding in the lower Skagit Valley. Flood control at Ross and Upper Baker dams is sufficient to control floods in the lower valley (within the levee system from Burlington to the mouths) with exceedance frequencies of approximately two percent; but flood runoff from the Skagit’s uncontrolled watersheds during events greater than approximately two percent exceedance frequency at Mount Vernon is sufficient to produce major flooding in the valley regardless of the flood control regulation at Ross and Upper Baker dams. The floods of November 1990 and November 1995 (see Sections 2.7.4 and 2.7.5 below) were approximately two percent exceedance frequency events that raised the river to the tops of the main levees.

Authorized flood control storage at Ross and Upper Baker dams is sufficient to store inflow while releasing only the minimum outflow for most recent floods. The contribution from the uncontrolled watersheds for a major event, however, is still large enough to exceed the current levee capacity at Mount Vernon. This will likely mean that the lower Skagit Valley will have flooded due to levee failures as a result of runoff from the uncontrolled watersheds during larger floods. The magnitude of the uncontrolled watershed runoff is implied by the following runoff data for the river: Ross and Upper Baker reservoir watersheds are 39 percent of the total Skagit River drainage area at Mount Vernon (the remaining 61 percent of the total area is uncontrolled), and their combined annual runoff is 32 percent of the average annual runoff of the Skagit River at Mount Vernon. Uncontrolled runoff is 68 percent of the average annual runoff at Mount Vernon.

2.7.2 November 1949 Flood

The flood of November l949 is a good example of a flood crest flattening while moving downstream. The peak discharge of 154,000 cfs at Concrete was reduced to 114,000 cfs at Mount Vernon. Whereas channel storage had a marked effect on the sharpness of the peak between Concrete and Mount Vernon, an absence of precipitation in the lower basin at the time of this flood partially explains the reduction in crest in the lower reaches of the channel. The Sedro-Woolley precipitation gage indicated that very little rain fell in the lower part of the basin.

2.7.3 February 1951 Flood

The February 1951 flood had a peak discharge of l39,000 cfs at Concrete, a peak of l50,000 cfs at Sedro-Woolley, and a peak of l44,000 cfs at Mount Vernon. Reservoir storage reduced the peak discharge at Concrete about 13,000 cfs. However, due to the long duration of the peak discharge between Concrete and Mount Vernon, channel storage and attenuation had little effect on reducing the peak stage in the lower reaches. The flood remained near its peak for 6 hours at Mount Vernon. The duration of this peak was more significant than its magnitude because it minimized the effectiveness of natural storage in the Nookachamps Creek area, and dikes failed because they lacked sufficient cross-sectional dimensions to withstand a long period of high water.

2.7.4 November 1990 Floods

The month of November 1990 included significant floods on November 9-11 (the first flood) and November 24-25 (the second flood). The first flood was slightly larger in volume than the second flood, but peak discharges were similar during both floods at the Concrete stream gage. The two November 1990 floods broke through the Fir Island levee, and inundated most of the interior farmland in this major farming region between the North and South Forks of the Skagit River, about 3 miles downstream from Mount Vernon. Both events required extensive flood fighting in the vicinity of Mount Vernon.

The major levee failure at Fir Island during the November 1990 floods increased the river slope and velocity below Mount Vernon, causing an artificially low crest stage at the Mount Vernon gage. During the November 1990 flood events, the peak discharge of 149,000 cfs at Concrete increased to 152,000 cfs at Mount Vernon, while the discharge of 160,000 cfs at Concrete during the November 1995 flood was reduced to 141,000 cfs at Mount Vernon. During the 1990 and 1995 floods, the stages at Mount Vernon were nearly equal, 37.34 feet and 37.37 feet, respectively.

Total flood storage used at both Ross and Upper Baker projects amounted to approximately 194,000 acre-feet during the first flood, and approximately 153,900 acre-feet during the second flood. The above volumes include 112,000 acre-feet stored in Ross reservoir, and 82,000 acre-feet stored in Upper Baker reservoir during the first November 1990 flood; and 100,000 acre-feet stored in Ross, and 53,900 acre-feet stored in Upper Baker during the second November 1990 flood. Inflow to both projects peaked on November 10, 1990 (first flood) as follows: 46,000 cfs at Ross, and 33,000 cfs at Upper Baker. Outflows at both projects were regulated to a minimum of 5,000 cfs through the main part of the flood.

The Fir Island levee failure caused the Skagit River to fall abruptly. The hydraulic relief provided by the Fir Island levee failure was probably instrumental in preventing failure of other major levees in the vicinity. Emergency repairs to the Fir Island levee were made between the first and second floods, but time was insufficient to fully stabilize the levee and the levee failed again during the second flood. Flood peaks between Concrete and Mount Vernon are normally reduced by attenuation and limited local inflow. This relation was reversed during the second flood due to significant local inflow, saturated soil conditions, and remaining pondage from the first flood.

2.7.5 November 1995 Flood

Flows on the Skagit River reached 160,000 cfs at Concrete and 141,000 cfs at Mount Vernon during the November 28-30, 1995 flood. Concrete was above zero damage stage for four days and above major damage (90,000 cfs) for one and a half days. Mount Vernon was above zero damage stage for approximately 4 days and above major damage for approximately 3 days. As a result of the reservoir regulation and sandbagging efforts, levees at Mount Vernon and Fir Island were able to withstand the flood without failing. Runoff stored at Ross and Upper Baker reservoirs are estimated to have reduced flood levels by about 5 feet and 2 feet at Concrete and Mount Vernon, respectively.

This flood set a new crest-stage record at the Concrete gage despite the regulation at Ross and Upper Baker. The Concrete gage reached a crest of 41.57 feet. The Mount Vernon gage reached a crest of 37.34 feet, approximately equal to the record stage of 37.37 feet during the November 25, 1990 flood.

Reservoir inflow caused Ross Lake to fill to elevation 1602.38 feet, which is within 0.12 feet of the maximum full flood control pool. Upper Baker started to evacuate storage at 6 p.m. on November 30, nearly a day after the river crested at Concrete.

2.7.6 October 2003 Floods

The floods of October 2003 started with a smaller peak followed by a larger peak. The first flood peaked at 94,700 cfs at Concrete and 73,500 cfs at Mount Vernon on October 17th and 18th. This exceeded the major damage stage for 6 hours at Concrete but did not get above major damage at Mount Vernon. The second flood was significantly larger and spread more completely across the upper basin. It peaked at 166,000 cfs at Concrete and 135,000 cfs at Mount Vernon on October 21st. Concrete was above zero damage stage for 57 hours and above major damage (90,000 cfs) for 33 hours. Mount Vernon was above zero damage stage for 64 hours and above major damage for 47 hours. As a result of the reservoir regulation and sandbagging efforts, levees at Mount Vernon and Fir Island were able to withstand the flood without failing.

This flood set a new crest-stage record at the Concrete gage despite the regulation at Ross and Upper Baker. The Concrete gage reached a crest of 42.21 feet, about 0.6 feet greater than the flood of November 1995. The Mount Vernon gage reached a crest of 36.2 feet, which is a foot lower than the peaks seen for the November 1995 and November 25, 1990 flood.

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3.0 Flood Frequency Analysis for Unregulated Flows at Concrete

This section presents the results of a flood frequency analysis for unregulated flows at Concrete. The report is prepared in accordance with FEMA Guidelines and Specifications for Flood Mapping Partners (FEMA 2003) for regulated watersheds, and the guidelines for determining floodflow frequency presented in Bulletin 17B (Interagency Advisory Committee on Water Data 1982) and subsequent modifications. The USGS-developed, FEMA-approved, computer program "PEAKFQ, Annual Flood Frequency Analysis following Bulletin 17B Guidelines" (version 5.0, May 6, 2005) was used for performing this Skagit River flood frequency analysis (USGS 1998). In accordance with the FEMA guidelines (Section c.2.1) (FEMA 2003), the Skagit River flood frequency curves for this analysis were developed for unregulated conditions, and subsequently converted to regulated conditions using the current reservoir operation criteria.

The unregulated flow data considered for the Skagit River flood frequency analysis include 84 systematic peaks for water years (WY)1925 through 2008, and 4 historical peaks for 1897, 1909, 1917, and 1921 (WY 1898, 1910, 1918, and 1922). (As defined in Bulletin 17B Guidelines, systematic records are the annual peak discharge information collected systematically by a federal or state agency, or a private enterprise; and historical data are the information about major floods which occurred either before or after the period of systematic data collection.)

3.1 Unregulated Systematic Flow Data (WY 1925–2008) in the Skagit River at Concrete

Table 1 presents the systematic annual peak and one-day discharge data observed at the USGS gage 12194000 – Skagit River near Concrete for WY 1925–2008. Also included in the table are unregulated flows estimated mostly by the Corps with some estimated by PI Engineering. Discussion of the source and any adjustments made to the data are provided below.

Table 1 Annual peak and one-day discharge data at the USGS Gage 12194000 - Skagit River near Concrete

Water Year	USGS Observed Annual Peak Flows (cfs)	Winter Unregulated Annual Peak Flows	USGS Observed Winter One-Day Flows	Winter Unregulated One-Day Flows
1925	92,500	100,721	85,400	85,400
1926	51,600	48,591	42,100	41,200
1927	88,900	66,754	56,700	56,600
1928	95,500	94,812	81,200	80,390
1929	74,300	83,631	62,200	70,910
1930	*32,200	41,937	29,200	35,558

Water Year	USGS Observed Annual Peak Flows (cfs)	Winter Unregulated Annual Peak Flows	USGS Observed Winter One-Day Flows	Winter Unregulated One-Day Flows
1931	*60,600	58,770	48,900	48,900
1932	147,000	165,000	129,000	151,945
1933	116,000	115,519	97,800	97,947
1934	101,000	97,733	85,000	82,867
1935	131,000	143,702	120,000	121,843
1936	*60,000	18,000	14,300	14,480
1937	*68,300	25,767	21,500	21,500
1938	89,600	88,484	63,500	75,025
1939	*79,600	64,203	55,200	54,437
1940	48,200	45,280	38,900	38,392
1941	51,000	46,471	42,200	39,402
1942	76,300	67,515	56,100	57,245
1943	54,000	55,529	45,000	47,082
1944	65,200	61,643	49,000	52,266
1945	70,800	64,412	61,200	54,614
1946	102,000	108,451	87,500	91,954
1947	82,200	77,377	62,000	65,607
1948	95,200	81,409	69,000	69,026
1949	*55,700	36,127	52,100	30,632
1950	154,000	170,342	123,000	144,431
1951	139,000	157,098	128,000	133,202
1952	*43,500	32,094	36,700	27,212
1953	66,000	75,243	60,700	63,798
1954	58,000	54,313	46,900	46,051
1955	*56,300	56,676	51,200	48,055
1956	106,000	125,871	94,100	106,725
1957	61,000	60,813	49,700	51,563
1958	41,400	40,293	34,600	34,164
1959	*90,700	79,089	58,200	67,059
1960	89,300	99,673	77,500	84,512
1961	79,000	89,468	60,300	75,859
1962	56,000	68,720	48,900	58,267
1963	114,000	106,674	81,700	90,448
1964	73,800	78,105	58,600	66,224

Water Year	USGS Observed Annual Peak Flows (cfs)	Winter Unregulated Annual Peak Flows	USGS Observed Winter One-Day Flows	Winter Unregulated One-Day Flows
1965	52,600	58,788	49,500	49,846
1966	*36,800	35,738	29,000	30,302
1967	*72,300	78,247	53,900	66,345
1968	84,200	83,101	60,200	70,460
1969	49,500	59,240	44,100	50,229
1970	38,400	34,032	29,000	28,855
1971	62,200	79,312	54,700	67,248
1972	*91,900	57,099	40,400	48,414
1973	49,500	50,781	43,100	43,057
1974	79,900	123,434	73,400	104,658
1975	57,500	57,427	42,500	48,692
1976	122,000	155,281	108,200	131,661
1977	58,400	65,441	45,800	55,487
1978	70,300	69,589	57,800	59,004
1979	46,000	52,015	35,300	44,103
1980	135,800	149,079	113,700	126,402
1981	148,700	170,470	104,900	144,540
1982	*51,700	61,885	49,000	52,472
1983	101,000	79,992	61,500	67,824
1984	109,000	111,556	79,600	94,587
1985	*46,100	32,515	23,900	27,569
1986	93,400	103,347	70,100	87,627
1987	83,500	74,104	60,300	62,832
1988	39,600	35,801	29,000	30,355
1989	74,100	86,250	55,900	73,130
1990	119,000	141,277	86,100	119,787
1991	149,000	199,017	135,000	172,979
1992	*53,300	47,389	35,300	39,459
1993	*39,300	31,490	25,300	26,257
1994	36,500	50,609	31,400	42,911
1995	59,800	74,313	51,800	63,009
1996	160,000	187,982	131,000	156,645
1997	*91,400	103,692	63,000	87,919
1998	76,700	70,049	61,400	59,394

Water Year	USGS Observed Annual Peak Flows (cfs)	Winter Unregulated Annual Peak Flows	USGS Observed Winter One-Day Flows	Winter Unregulated One-Day Flows
1999	61,400	76,869	45,100	65,176
2000	103,000	138,206	86,000	117,183
2001	30,900	33,277	22,800	28,215
2002	94,300	127,137	79,700	107,798
2003	65,500	72,461	43,200	61,439
2004	166,000	205,651	131,000	171,364
2005	99,400	111,118	74,700	94,216
2006	56,300	66,893	47,700	56,718
2007	145,000	173,974	118,000	153,886
2008	77,900	106,503	72,400	88,439

* Non-winter event

3.1.1 Unregulated Flow Data for WY 1944–2007 Estimated by the Corps

A synthetic record of the mean daily unregulated discharge in the Skagit River at the Concrete gaging site was constructed by the Corps for the period including water years 1944 through 2007 (excluding WY 1992 and 1993). The Corps constructed this record by adjusting the observed mean daily flows to include estimated effects of the regulation operations occurring at the three Seattle City Light (SCL) dams on the Upper Skagit and two Puget Sound Energy (PSE) dams on the Baker River. The unregulated annual winter peak one-day flows in the Skagit River at Concrete for these water years were selected from the mean daily unregulated discharges estimated by the Corps.

The Corps also developed the unregulated annual peak flows for this period based on a regression of the winter peak to one-day flows from water years 1925 through 1953 for the Skagit River near Concrete. The Corps assumed that the regression closely mimicked unregulated basin conditions, as no storage occurred at any of the dams for flood control during this time period. Details of the Corps-developed unregulated annual peak and one-day discharges are documented in the Corps' "Draft Report – Skagit River Basin, Washington, Revised Flood Insurance Study, Hydrology Summary" (Corps 2005). This draft report was recently revised by the Corps (Corps 2008).

3.1.2 Unregulated Flow Data for WY 1925–1943 Estimated by the Corps

The period of record of stream flow data at the USGS gage 12194000 – Skagit River near Concrete – includes the period 1924 to present.

Data collected at this gage includes the effects of regulation at upstream reservoirs. Flow data measured by USGS at the Concrete gage during the period between 1924 and 1943 comprised lower annual flood peaks, in general, than the flood peaks measured outside of this period. Prior to 1943, two dams were in operation in the Skagit watershed, Lower Baker Dam and Diablo Dam. (Construction of Ross Dam was completed in 1949, and regulation of Ross Dam for winter flood control storage was initiated in 1954). Prior to 1943, construction and operation of Lower Baker Dam and Diablo Dam had only incidental regulation effects on the flood flows in the Skagit River.

Diablo Dam – Construction of the dam was completed in 1930, and the power plant began operation in 1936. The dam has never been operated for flood control purposes. During construction, all flows were routed through construction bypass tunnels with no provision for storage during the fall and winter periods.

Lower Baker Dam – Construction of Lower Baker Dam was completed in 1925. Operation of Lake Shannon, the reservoir created by Lower Baker Dam, for flood control has never been part of the purpose of the dam. Hydrologically, storms arrive at the Baker system early in the event and the peak flood outflow from the Baker River passes the Concrete gage about 10 hours in advance of the peak flow coming from the Skagit River upstream of the Concrete gage.

The Corps in 1965 performed calculations of the one-day peak flows and reservoir storage changes to unregulate the observed annual winter peak one-day discharges at the Skagit River gage near Concrete. These unregulated one-day flow discharges estimated by the Corps include data for WY 1925 through 1943 (excluding WY 1931 and 1937). By applying the unregulated peak to one-day flow correlation, the corresponding annual winter peak discharges for this period were estimated by the Corps.

3.1.3 Unregulated Flow Data Estimated by PI Engineering

PI Engineering estimated the winter unregulated one-day flows for WY 1931, 1937, 1992, 1993, and 2008 by adjusting the USGS observed one-day flows with the regression of regulated and unregulated flows developed by the Corps. The annual peak discharges for these five water years were estimated by using the peak to one-day flow regression developed by the Corps. For those water years when the annual peak flows observed by USGS were non-winter events, USGS-observed one-day flow data were used and the corresponding winter peak flows were estimated by using the same peak to one-day flow regression discussed above.

PI Engineering also modified the unregulated peak flow for WY 1932 provided by the Corps. The peak flow actually recorded by USGS is

147,000 cfs at about 8 PM on February 27, 1932 at the Skagit River gage near Concrete. As published in the Water Supply Paper 1527 (USGS 1961, Figure 4), the USGS estimated the unregulated peak discharge to be 182,000 cfs, which is the same as the Corps provided. The USGS estimated the effects of Diablo and Lake Shannon storage to be 26,400 and 35,100 cfs, respectively, on reduction of the peak flows occurring at the same time, approximately 5 AM on February 27, 1932. These estimates ignore the flow travel time difference between Diablo reservoir to Concrete and Lake Shannon to Concrete. The travel time from Diablo reservoir to Concrete is about nine hours and from Lake Shannon to Concrete is about one hour. The 8-hour time difference between these two reservoirs is significant and should be considered in estimating the unregulated peak disharge. PI Engineering estimated the unregulated peak to be 165,000 cfs based on an 8-hour adjustment for the travel time difference between these two reservoirs to Concrete.

3.2 Peak Flow Data for the Four Historical Floods of 1897, 1909, 1917, and 1921

3.2.1 Background

Four major historical floods occurred before installation of the USGS gage at Concrete and before construction of any of the five Upper Skagit River dams. These historical floods were estimated by James Stewart in 1923 (Stewart 1923). The accuracy of Stewart's flood peak estimates was questioned by numerous hydrologists, including hydrologists within the USGS (Bodhaine 1954; Riggs & Robinson 1950). Despite the questions raised regarding Stewart's 1923 estimates, USGS published them in 1961 as Water Supply Paper (WSP) 1527. Table 2 shows the USGS published gage heights and estimated peak discharges for the four historical floods.

Table 2 USGS estimated peak stages and discharges of Skagit River near Concrete for four historical floods (Drainage Area = 2,700 sq. mi.)

Flood	Gage Height at Current Gage* as Published in 1961 (ft)	Gage Height** Estimated by Stewart in 1923*** (ft)	Discharge Estimated by Stewart in 1923*** (cfs)	Discharge Revised by USGS in 2007**** (cfs)
1897	51.1	38.4	275,000	265,000
1909	49.1	36.4	260,000	245,000
1917	45.7	33.0	220,000	210,000
1921	47.6	34.9	240,000	228,000

* Current gage datum El. 130.00 (NGVD29) at RM 54.15.

** At the Upper Dalles gage installed by Stewart for his flood investigation during the winter of 1922-23. Gage Datum El. 140.89 surveyed by Stewart (Stewart's survey notes, pp. 86-87).

*** These unpublished 1923 estimates by James Stewart were documented in the 1961 U.S. Geological Survey Water Supply Paper (WSP) 1527 (USGS 1961).

**** Revised due to Manning's "n" verification in Scientific Investigations Report 2007-5159 (USGS 2007)

It is important to note that the 1921 flood stages using Stewart-surveyed two gage heights of 34.29 and 34.86 at his upper Dalles gage (Stewart's survey notes, p. 87), are El. 175.18 and El. 175.75 (NGVD-29), and using the USGS published 1921 flood gage height of 47.6 and gage datum El. 130.00 at the current gage is El. 177.6 (NGVD-29), approximately 2.4 to 1.8 feet higher than Stewart-surveyed elevations upstream, which is not reasonable. In Stewart's 1923 report (Stewart 1923, Exhibit B, p. 2) he described his No. 1 cross section as about 560 feet above the mouth of the Dalles and about 100 feet below the upper end of the Dalles. The current USGS gage is located on the right bank about 50 feet upstream of the Dalles Bridge, or about 200 feet upstream of the mouth of the Dalles. The Stewart installed gage at the upper Dalles is therefore estimated about 460 feet upstream of the current USGS gage site. Stewart stated that the drop at the crest of the 1921 flood amounted to over four feet in a distance of 560 feet through the Dalles (Stewart 1923, Exhibit B, p. 1). The water surface drop between these two gage sites is probably about 3 feet for the 1921 flood. Using Stewart-surveyed 1921 flood El. 175.18 and El. 175.75 at the upper Dalles gage, the corresponding 1921 flood stage at the current USGS gage should be below El. 173, or about 5 feet lower than the USGS published 1921 flood El. 177.6. Based on our review of and discussion with USGS on available data, we could not find any explanation for this discrepancy and there is no scientific evidence to support the USGS-published 1921 flood stage.

The other three flood gage heights published were based on the relation of the Stewart-surveyed high water marks (HWMs) located on the east bank of the Baker River near the old Washington Cement Plant. These HWMs were due to the Baker River flows and not due to the Skagit River flows (as Stewart noted in his survey notes, p. 0, p. 19, and p. 23 and also as PI Engineering observed during our recent flood modeling experience). Stewart directly transformed the relationship of these Baker River HWMs to his upper Dalles gage and then estimated the 1897, 1909, and 1917 flood discharges using his gage rating from the 1921 flood estimate. This approach was state-of-the-art at the time; now, it is possible to further refine these estimates using Stewart's well-documented field observations, surveys and interviews of 1922-1923, combined with modern hydraulic modeling techniques. Stewart's work in the early part of the last century was all the more remarkable in that he did not have access to any consistent stream gage data. Today we have the benefit of 84 years of continuous stream flow data from the Dalles gage, as well as access to a significant additional body of research and data, and the availability of modern hydraulic modeling programs and techniques. This hydrology report would not be possible without Stewart's work and the gage data resulting from his recommendation to install a river gage at The Dalles location.

Stewart collected extensive 1921 flood data in the vicinity of the Dalles and estimated the 1921 flood peak discharge to be 240,000 cfs by two different engineering methods available at the time, the contracted-opening and the slope-area methods (Stewart 1923, Exhibit B). Both of these are indirect, older methods that provide only approximate flow estimates. Today, the contracted-opening method is no longer used. The slope-area method is still used. Limitations on the slope-area method include the assumption that flow velocity remains unchanged from section to section. The estimates produced by the slope-area method are sensitive to flow velocity and velocity changes. The application of this method to a slow moving stream generally produces better results than its application to a fast moving stream. The slope-area sections of the Skagit River below the Dalles selected by Stewart for his 1921 flood estimate are in a high velocity reach of the river (with section-average velocity varying 10 to 14 ft/sec). The river channel in this reach curves and has produced different water surface elevations between right and left banks during floods. In addition, the velocities vary between sections. These factors, and maybe others like surging effects, make the application of this method to estimate the 1921 flood discharge at Stewart's slope sections uncertain. Other than the Manning's "n" value verification performed by other USGS reviewers and the original contracted-opening method used by Stewart, there has never been any attempt by the USGS to validate the applicability of the slope-area method to the 1921 flood estimate or to verify the slope-area estimate by use of more advanced, accurate methods at other locations where Stewart-surveyed 1921 flood elevations are available.

More review discussion of the historical flood discharges estimated by Stewart in correlation with flows in Sedro-Woolley and in conflict with available flood marks in Hamilton and Concrete is presented below. Also presented are the results of using the best scientific method available today to estimate the 1897, 1909, 1917, and 1921 flood discharges. This method uses the HEC-RAS hydraulic modeling technique and Stewart's originally surveyed HWMs in the Hamilton-Concrete area.

3.2.2 Correlation with Flows in Sedro-Woolley

The USGS also published estimated peak flows at the site of the USGS gage location at Sedro-Woolley for the four historic flood events. A gage has been in place at Sedro-Woolley since 1908. The flood peaks were estimated by Stewart at the same time he estimated the flood peaks at Concrete and are published by the USGS in Water Supply Paper 1527 (USGS 1961). Stewart had also made earlier estimates in 1918. In subsequent USGS studies, Bodhaine (1954) suggested values for the four floods; other estimates were made by Riggs & Robinson in 1950, and by Hidaka in 1954 for the 1897 and 1909 events (Table 3).

Table 3 Stewart and USGS peak discharge estimates for historical floods at Sedro-Woolley

	Stewart		USGS		
Flood	1918	1923	Rigg & Robinson	Hidaka	Bodhaine
1897	171,000	190,000	170,000	145,000	170,000
1909	169,000	220,000	190,000	175,000	200,000
1917	157,000	195,000	160,000	----	195,000
1921	----	210,000	170,000	----	210,000

(Source: Stewart 1918 & 1923 Reports; Proposed Revision of Skagit River Peaks, H.C. Riggs & W.H. Robinson, 11/16/50; Skagit River near Sedro-Woolley, Wash., Proposed revisions of historical flood_peaks, F. L. Hidaka, 1/12/54; Skagit River Flood Peaks, Memorandum of Review by G.L. Bodhaine, USGS, 5/13/54). Available at www.skagitriverhistory.com

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 ten 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 floods in 1990, 1995, and 2003, demonstrates that flows recorded at the USGS Concrete gage average 1.6% lower than flows modeled by PI Engineering at the USGS Sedro-Woolley gage. Recent studies analyzed by the Corps (2005) and Northwest Hydraulic Consultants (2007) also arrived at similar results.

Assuming that the relationship between flows at Sedro-Woolley and Concrete as discussed above is valid, Stewart's flow estimates at Concrete should be approximately 2% lower than his estimates at Sedro-Woolley. In fact, Stewart's estimates at Concrete for the historical floods average 15% higher than his concurrent estimated flood peaks at Sedro-Woolley for the years during which USGS gage records are available at Sedro-Woolley. For the 1897 flood, Stewart's flow estimate is 45% higher at Concrete than at Sedro-Woolley.

Table 4 presents a comparison of the peak flows estimated by Stewart at Sedro-Woolley and Concrete for the historic flood events. The magnitude of the difference between Sedro-Woolley and Concrete for the 1897 flood is not consistent with any of the other flood events. This observation indicates that the HWM for the 1897 event at Concrete may have been inaccurately observed or recorded; or, this could have been the result of debris blockage at the Dalles, according to Stewart's interview with Leonard Everett (Stewart's Notes, p. 23) who stated that in 1897, the "log jam in the Dalles raised water 10 ft in 2 hrs." HWMs of other three events at Sedro-Woolley are based upon records of the USGS gage installed in 1908.

Table 4 Comparison of Stewart's peak discharge estimates (cfs) for four historical floods in the Skagit River at Concrete and Sedro-Woolley

Flood Date	Stewart Estimates @ Sedro- Woolley	Stewart Estimates @ 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%

Although reliable stage records at Sedro-Woolley are available for the period starting in 1908, it has always been difficult to establish a rating curve at that location. At this time, it is impossible to develop a rating curve that would reflect the river channel characteristics current at the time of the four historical floods. Part of this difficulty arises from the effect of debris blockage of the SR-9 Bridge and the abandoned railroad bridge at the gage, and a significant factor is the changes in river bank levee and channel geometry that have occurred in the course of nearly a century, particularly immediately downstream of Sedro-Woolley (cutting off the Sterling Bend). These uncertainties preclude an accurate estimate of river flows based upon the stage records.

3.2.3 Historical Flood Marks in Lyman – Hamilton Area

The towns of Lyman and Hamilton are located on the right bank floodplain of the Skagit River between RM 34 and 41. Both towns have historically experienced extensive flooding. Available flood marks in the area were recently collected and are described later in this section and plotted on Figure 2.

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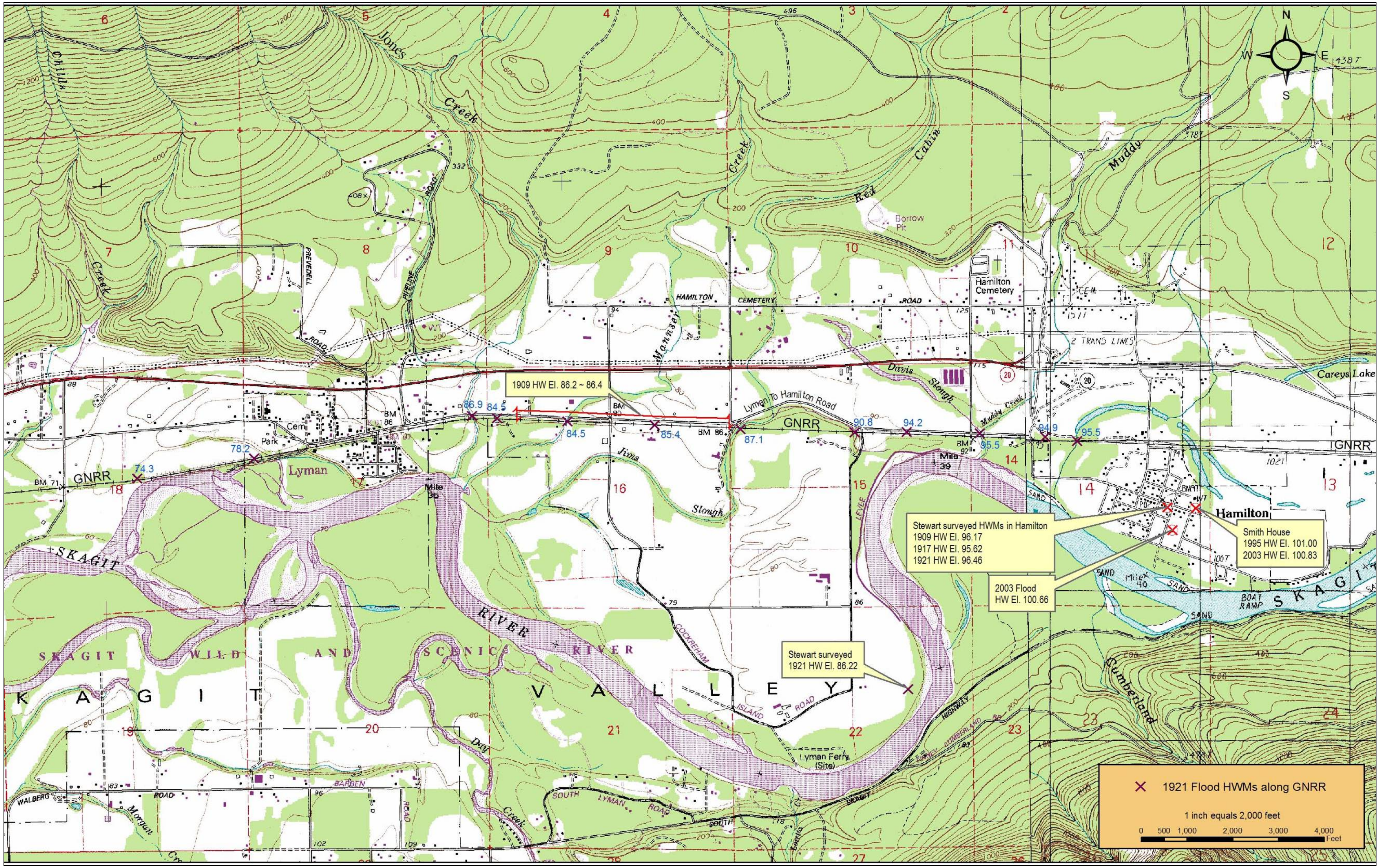

Figure 2. **Historical Flood Marks in Lyman-Hamilton Area**

- *1909 Flood Marks along Lyman-Hamilton Road*

  A 5,700-foot long profile of Lyman-Hamilton road that extends east from Jones Creek to Jims Slough was recently discovered at the County Public Works Department. Jones Creek joins the Skagit River at RM 35.1 on the east side of Lyman. The Lyman-Hamilton Road crosses the north side of Cockreham Island and is on the Skagit River floodplain. The discovered road profile presents a flood water line from a high point about 700 feet east of Jones Creek and continuing east about 5,000 feet. This flood water line is at El. 86.2 to El. 86.4, entitled "H.W. of flood 1909".

- *1921 Flood Marks along old GNRR*

  The removed Great Northern Railroad (GNRR) used to run parallel to Lyman-Hamilton Road through the area. PI Engineering recently obtained a GNRR profile from BNSF Company, on which many 1921 flood marks were annotated, as well as finished track elevations. The 1921 flood marks range between El. 74.3 at RM 33.4, one half mile downstream of Lyman, and El. 95.5 at RM 39.5 in Hamilton. The 1921 flood marks vary between El. 84.5 and El. 85.4, along the reach of Lyman-Hamilton Road west of Jims Slough on the north side of Cockreham Island. Caution is required to interpret the plotted flood marks. For example, the flood mark El. 86.9 shown at the Jones Creek crossing was probably due to Jones Creek flows and not Skagit River flows. Similar situations probably occurred at the Muddy Creek crossing.

  Stewart's notes (p. 13-14) indicate he surveyed an elevation of 93.9 at "Top of GN rail in front of Hamilton Depot." The City of Burlington recently verified the site of the old Depot, based on field observations of the old standard-type sign posts, which still exist along the old railroad right of way. The old sign posts are located about 90 yards east of Pettit Street, indicating the Depot building itself was nearby. This was confirmed by interviews with long-time Town residents (personal interview with Jim and Carol Bates, January 2008 by Chal Martin, Burlington Public Works Director). This Stewart-surveyed elevation of 93.9 correlates closely (an identical rail top El. 93.9 is shown approximately 200 feet east of Pettit Street on the railroad profile) with the old Great Northern railroad profile in the possession of PI Engineering. At issue here, and throughout this study, is the datum used by Stewart for his observations in 1922-23. This independent correlation between Stewart's surveyed GNRR track elevation in 1922, and the Great Northern profile obtained by PI Engineering, is compelling evidence that the datum used by Stewart was, in fact, NGVD 29. This benchmark El. 93.9, "at top of rail in front of Hamilton station," is listed in the USGS published Bulletin 674 (USGS 1918, p. 78).

- *Stewart-Surveyed Flood Marks*

  Stewart surveyed several flood marks in the Hamilton-Lyman area during the winter of 1922-23. These include the 1909 flood El. 96.17, the 1917 flood El. 95.62 and the 1921 flood El. 96.46 at a cigar store building in Hamilton (Stewart's notes, pp. 13-14), (about RM 39.9), and the 1921 flood El. 86.22 at the old Lyman ferry site (Stewart's notes, pp. 132-133) (about three quarter mile upstream from then new Lyman ferry site, or about RM. 37.9). These flood elevations compare reasonably well with the flood marks shown on the Lyman-Hamilton Road and the old GNRR profiles.

The above described historical flood marks in the Lyman-Hamilton area appear lower than the 1995 and 2003 high water marks surveyed by the County. For example, the County surveyed HWMs show the 1995 flood El. 101.00 and the 2003 flood El. 100.83 at the Smith house in Hamilton (about RM 40.0), the 2003 flood El. 100.66 about 500 feet southwest of the Smith house (about RM 40.0). There are many other specific road overtopping locations and times observed by the County field crew during the 1995 and 2003 flood events. All appear to indicate that the above historical flood marks are of similar magnitude if not lower than those observed during these recent two floods.

3.2.4 Hydraulic Analysis Using Smith House Flood Marks

The Smith house is located at 307 Maple Street in the City of Hamilton, (about RM 40.0). The Smith house (Figure 3) was built in 1908 and therefore experienced three of the four historical floods estimated by Stewart. However, only one flood in the last 100 years, the November 1995 flood, has left a water mark above the level of the main floor.

Figure 3. **Smith House in Hamilton, undated photograph of the 1909, 1917, or 1921 flood event (Hamilton Museum archives)**

Note that in Figure 3 the first floor elevation of the house is 100.83 ft NGVD 29 and the ground elevation is approximately 98 ft at the base of the front porch. It is unknown whether this photograph was taken during the flood peak but we note the water surface level shown here would not be inconsistent with Stewart-surveyed high water marks, which were taken near the furthest building visible, down Maple street in this photograph (Stewart pp. 13-14).

Two separate inspections of the house recently conducted by the City of Burlington (2007) confirmed the reported 1995 flood water mark on the exterior wall, verified by interior wall inspection at four locations (Figure 4). The conclusions from the inspections are that water from the 1995 flood just barely covered the main floor and that water from the 2003 event came up into the crawl space just below the level of the sub-floor. There was no evidence of any higher water marks above the observed 1995 flood mark. Supporting evidence that this was representative of high water experienced was obtained in discussion with the owner of the Fred Slipper house in Hamilton (see Declaration of Fred W. Slipper, April 29, 2006. Available at www.skagitriverhistory.com).

Figure 4. Interior wall cavity, Smith House, 2006.

Figure 4 shows that no lath or plaster has been disturbed and there is no lath discoloration from flooding. The wall cavity of the Smith house, constructed in 1908, was pristine. Stain on bottom of upright member could indicate wicking of floor-level flood water from 1995 flood event, or may not be flood-related.

PI Engineering performed an unsteady flow HEC-RAS modeling to estimate the potential 1909, 1917, and 1921 flood stages at the Smith house based on Stewart's estimated peak flows at Concrete. The model was calibrated for the 1995 and 2003 high water marks at the Smith house. The model was further modified to incorporate the Corps 1911 surveyed river channel and banklines in the Hamilton area, reasonably reflecting the conditions of the river that existed during the Stewart estimated flood events. Details of the new analysis for the Smith House are presented in Appendix A, "Technical Memorandum, Hydraulic Analysis – Smith House Flood Stages" (PI Engineering, 2007).

The Seattle District, Corps of Engineers, has questioned Stewart's 1922 surveyed high water marks in Hamilton, citing the small range of elevation differences between the Stewart-surveyed HWMs and a more recently surveyed river cross section just downstream of Hamilton, as well as newspaper articles and citizen recollections about the 1897 flood event. The Seattle District believes this apparent discrepancy involves a datum conversion issue. However, PI Engineering believes the datum of the Stewart-surveyed HWMs in Hamilton is consistent with the NGVD-29 datum as previously discussed under the subsection 1921 Flood Marks along old GNRR**.** This issue of the datum in use by Stewart in 1922-23 will be addressed again later in this report.

The HEC-RAS modeled flood stages at the Smith house are El. 104.05, El. 102.51, and El. 103.31 for Stewart estimated peak discharges of 260,000, 220,000, and 240,000 at Concrete for the 1909, 1917, and 1921 floods, respectively. These modeled flood stages are about 7 feet higher than Stewart-surveyed flood stages at an old cigar store building about two blocks west on Maple Street (see Figure 2). Nevertheless, we have no reason to discount the accuracy of Stewart's high water marks, which are based on his observations on scene in 1922, and on his interviews with residents of Hamilton. What Stewart lacked at the time were the tools and data we have available to us today to translate his high water marks into peak discharge estimates. While recognizing the uncertainty of our estimates of the peak discharge of the historic flood events based solely on the Hamilton investigation, this investigation nevertheless provided significant additional objective and tangible evidence that the historic floods had been mischaracterized and were very likely, much smaller than previously thought. Next we will describe additional technical work in the Concrete vicinity which enables us to estimate the historic flood peaks with more certainty.

3.2.5 Hydraulic Analysis using Stewart Surveyed Flood Marks in Concrete to Estimate 1917 and 1921 Flood Peak Discharges

Stewart collected extensive field data in the vicinity of Concrete during the winter of 1922-23 as a part of his study of flooding in the Skagit River basin. These field data presented in his hand written survey notes (Stewart 1922-23) include one each of the 1917 and 1921 flood HWMs at old Wolfe residence in Concrete (Stewart's notes spelled Wolfe as "Wolf", pp. 18-19, 22-23, 30-31), one 1921 HWM at a gage installed by Stewart upstream of the old ferry site near Concrete (Stewart's notes, pp. 84-85), and two 1921 HWMs near a gage installed by Stewart at the upper end of the Dalles (Stewart's notes, pp. 58-59, 86-87). Stewart surveyed these HWMs starting at a USGS benchmark (BM) in Concrete, consistent with the NGVD-29 datum (USGS 1918, p. 78). The water surface levels corresponding to these HWMs using the gage heights and gage datum surveyed by Stewart are El. 184.55, El. 182.58 and El. 175.75 (and El. 175.18) for the 1921 flood at the old Wolfe residence, upstream of the old ferry site near Concrete, and at the upper end of the Dalles, respectively, and El. 183.03 for the 1917 flood at the old Wolfe residence. In combination with data gained during recent flooding in the Crowfoot Addition, these flood elevations are very useful for estimating the Skagit River flood peak discharges.

Stewart's survey notes presented more 1921 HWMs in the area through and below the Dalles. But these were surveyed by Stewart for relative stage heights locally and were not tied to a known BM so that these HWMs could be converted to the elevations of NGVD-29. Stewart's notes also contained relative stage heights for the 1897 and the 1909 (as well as the 1921) flood HWMs in the vicinity of the Washington Cement Plant on the east bank of the Baker River. But these HWMs were due to Baker River flows and not Skagit River flows. These HWMs are not useful for estimating the Skagit River flood discharges.

The likely location of the old Wolfe residence was recently discovered by the City of Burlington from the "1921 Tax Roll and Assessment, State Archives", files stored in Bellingham. The old Wolfe residence was located about one quarter mile above the Baker River mouth, but is within the Skagit River backwater area. The flood stages there have been governed by Skagit River, not Baker River, flood discharges. For all moderate to major historical flood events, the Skagit River peak reaches Concrete approximately ten hours after the Baker River peak passes. When the Skagit River stage peaks, the Baker River natural flow contribution usually reduces substantially from its peak, such that it would not add any significant stage rise from its mouth to the Wolfe residence area.

PI Engineering recently performed steady flow HEC-RAS modeling to estimate the 1917 and 1921 flood peak discharges using Stewart-surveyed HWMs at the old Wolfe residence in Concrete. A new HEC-RAS model was developed for a 2-mile reach of the Skagit River and 0.5-mile reach of the Baker River, from the USGS Skagit River gage (RM 54.15) near Concrete to upstream of the USGS Baker River gage at Concrete. The model incorporates ten new Skagit River cross sections surveyed in April 2008 by Skagit County, seven Skagit River channel sections surveyed in 2004 by PI Engineering, and remaining sections of Skagit and Baker Rivers surveyed in 1977 for the FEMA FIS study. Supplemental ground elevation data for the section overbank areas were obtained from the FIS survey topographic maps and the 2007 Lidar data provided by Skagit County.

Figure 5 shows locations of the model cross sections, the location of the old Wolfe residence, the old ferry crossing site near Concrete, the Dalles, and the USGS gage sites.

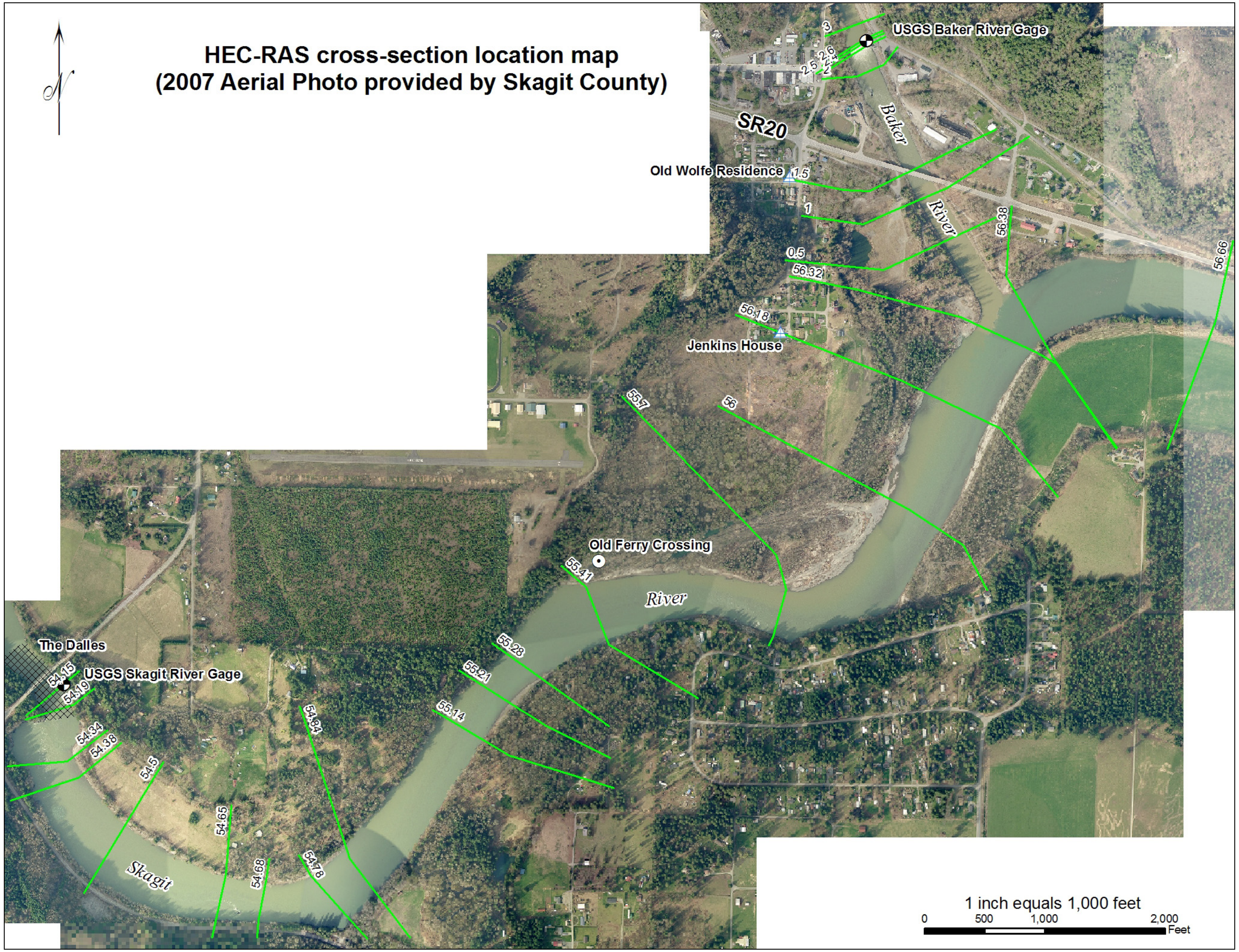

Figure 5. HEC-RAS cross-section location map for Concrete reach of the Skagit and Baker Rivers

The HEC-RAS model was calibrated for the 2003 flood HWMs observed at 1) the Baker River gage, 2) the Jenkins house (RM 56.18), and 3) at the old staff gage site (RM 54.19), using discharges observed during flood peak hours between 150,956 and 165,655 cfs of the Skagit River (provided by USGS) and concurrent discharges between 4,647 and 4,822 cfs of the Baker River (provided by Puget Sound Energy). The downstream starting water surface elevations at the Skagit River gage (RM 54.15) used in the model were also provided by USGS. Figure 6 is a picture of the Jenkins house taken by Mr. Allen Jenkins at 9:36 AM on October 21, 2003, approximately 3 hours after the Skagit River flood peak. The two 2003 flood elevations, one at 9:36 AM and the other at approximately 6:15 AM, were estimated from this picture, as shown on the figure. Figure 7 shows the 2003 flood HWMs surveyed in summer 2004 by the USGS along the Dalles and downstream reach.

Table 5 shows the model calibration results, which are considered good. The Manning's "n" values determined for the calibrated model are 0.031-0.032 for the Skagit River channel, 0.030 for the Baker River channel, and 0.06-0.15 for the overbank areas. High transition loss factors by assigning 0.8 and 0.6 to the expansion and contraction coefficients, respectively, were assumed for sections in the Dalles due to the two 90-degree turns of the river channel, which could cause significant head losses during floods. This assumption is based on our engineering judgment and no observed data is available to verify this assumption. However, the model accuracy due to this assumption would only affect the flood profiles locally and would not significantly affect the model results at the Wolfe residence, two miles upstream, where a flood stage-discharge rating curve is to be determined by the model in order to estimate the 1917 and 1921 flood discharges using Stewart-surveyed HWMs.

Figure 6. October 2003 Flood – Jenkins House at 7752 South Dillard (RM. 56.18) in Concrete. Photo provided by Allen Jenkins

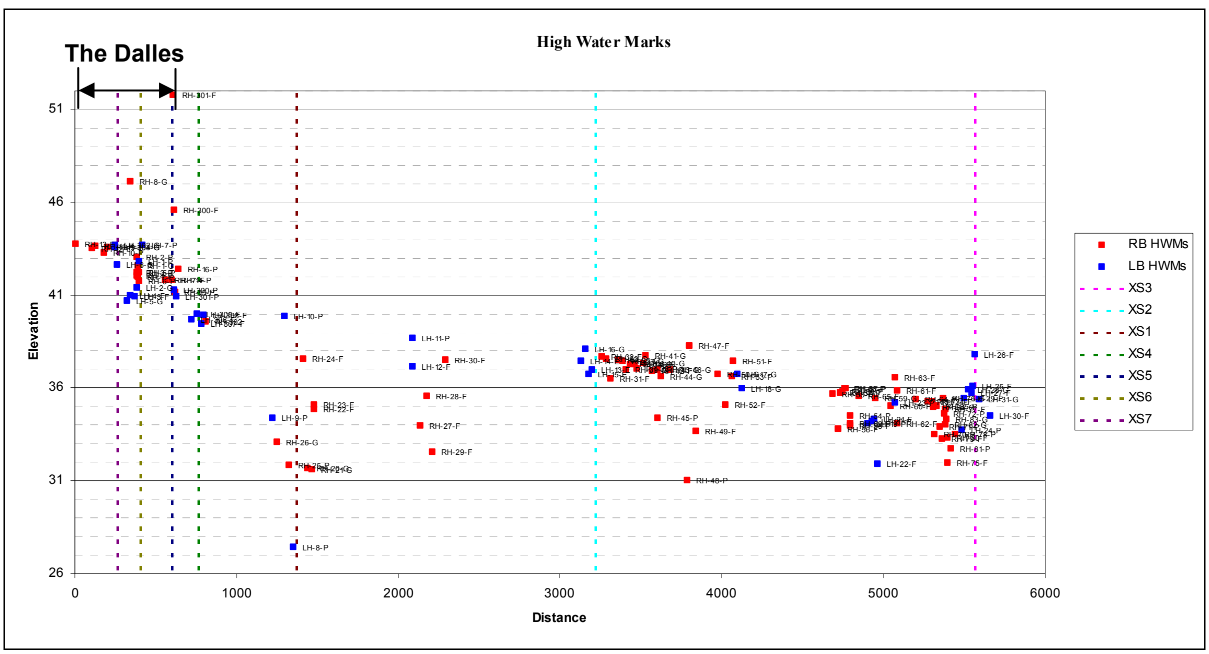

Figure 7. Skagit River 2003 flood high water marks near Concrete surveyed in summer 2004 by USGS. Notes: XS6 (RM 54.15) is the current gage site. Data provided by USGS

Table 5 Comparison of Modeled and Observed 2003 Flood Elevations (NGVD-29) in Concrete

Date of Flood	Time	Skagit River Flow* (cfs)	Baker River Flow** (cfs)	High Water Mark Location	Source of Data	Flood Elevation (NGVD-29) Observed (ft)	Flood Elevation (NGVD-29) Modeled (ft)	Difference (ft) btw. Modeled and observed flood elev.
21-Oct-03	6:15 AM	165,655	4,647	Baker River gage	USGS gage record	183.49	183.70	0.21
21-Oct-03	6:30 AM	164,169	4,655	Baker River gage	USGS gage record	183.48	183.50	0.02
21-Oct-03	7:15 AM	162,602	4,710	Baker River gage	USGS gage record	183.32	183.29	-0.03
21-Oct-03	7:30 AM	162,342	4,747	Baker River gage	USGS gage record	183.22	183.25	0.03
21-Oct-03	9:30 AM	150,956	4,822	Baker River gage	USGS gage record	181.77	181.70	-0.07
21-Oct-03	9:45 AM	151,538	4,822	Baker River gage	USGS gage record	181.54	181.78	0.24
21-Oct-03	6:15 AM	165,655	4,647	Jenkins House	Resident provided photo	182.75	182.78	0.03
21-Oct-03	6:30 AM	164,169	4,655	Jenkins House	Resident provided photo	182.75	182.57	-0.18
21-Oct-03	9:30 AM	150,956	4,822	Jenkins House	Resident provided photo	181.15	180.74	-0.41
21-Oct-03	9:45 AM	151,538	4,822	Jenkins House	Resident provided photo	181.15	180.82	-0.33
21-Oct-03	6:15 AM	165,655	4,647	Old staff gage at the Dalles	USGS 2004 Survey	173.30	173.39	0.09
21-Oct-03	6:30 MA	164,169	4,655	Old staff gage at the Dalles	USGS 2004 Survey	173.30	173.21	-0.09

***USGS provided flow data (15-minute interval) at the Skagit River gage near Concrete**
****PSE provided hourly flow data (interpolated for 15-minute interval) below Lower Baker Dam and powerhouse**

Upon calibration of the model based on the 2008 surveyed Skagit River channel sections, the model was modified using the Corps 1911 surveyed low-flow channel sections. The Corps 1911 surveyed sections most closely represent the Skagit River channel bottom geometry present during the 1917 and 1921 flood events. Figure 8 is the Corps 1911 survey map showing locations of the surveyed low-flow channel sections of the Skagit River from the Baker River mouth to downstream of the Dalles. A review of the 1911 and the 2008 channel sections indicates that the channel bottom has experienced scouring throughout the years. Figure 9 shows a comparison of the 1911 and 2008 channel bottom profiles.

After revisions of the Skagit River low-flow channel sections, the model was run for a range of flows between 155,000 and 190,000 cfs to cover the flood stages of Stewart-surveyed 1917 and 1921 HWMs at the old Wolfe residence in Concrete. The downstream starting water surface elevations at the Skagit River gage (RM 54.15) were based on an extension of the current gage rating curve provided by USGS. The concurrent Baker River flows were assumed to be 7.61% of the Skagit River flows, which would have insignificant effects on the modeled flood elevations at the Wolfe residence.

Figure 10 shows the flood stage-discharge rating curves at the Wolfe residence from the model runs for both 1911 and 2008 channel sections. The Stewart-surveyed 1921 flood stage El. 184.55 at the Wolfe residence corresponds to a Skagit River peak discharge of 173,900 cfs using 2008 channel sections, and 169,700 cfs using 1911 channel sections. The difference is 4,000 cfs less, or a little over two percent, when using the 1911 channel section instead of the 2008 channel section for estimating the 1921 flood peak discharge. Since the use of the 1911 channel section is more representative of conditions in 1917 and 1921, 169,700 cfs is the estimated 1921 flood peak discharge of the Skagit River.

The Stewart-surveyed 1917 flood stage at the Wolfe residence is 1.52 ft below the 1921 flood stage, or at El. 183.03. From the flood stage discharge curve shown in Figure 10 for the 1911 channel sections, 158,700 cfs is the estimated 1917 flood peak discharge of the Skagit River.

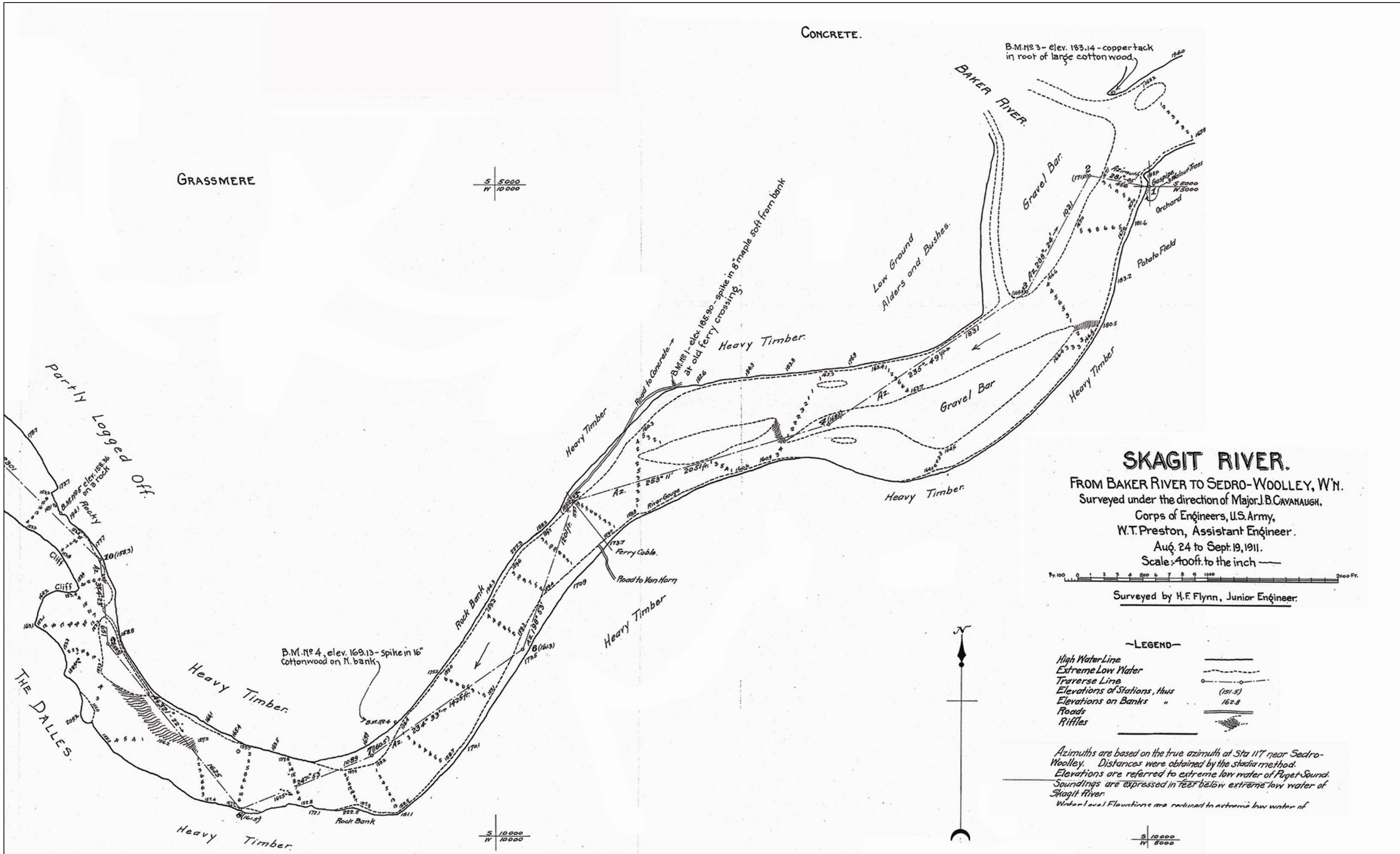

Figure 8. Corps 1911 survey map in Concrete area

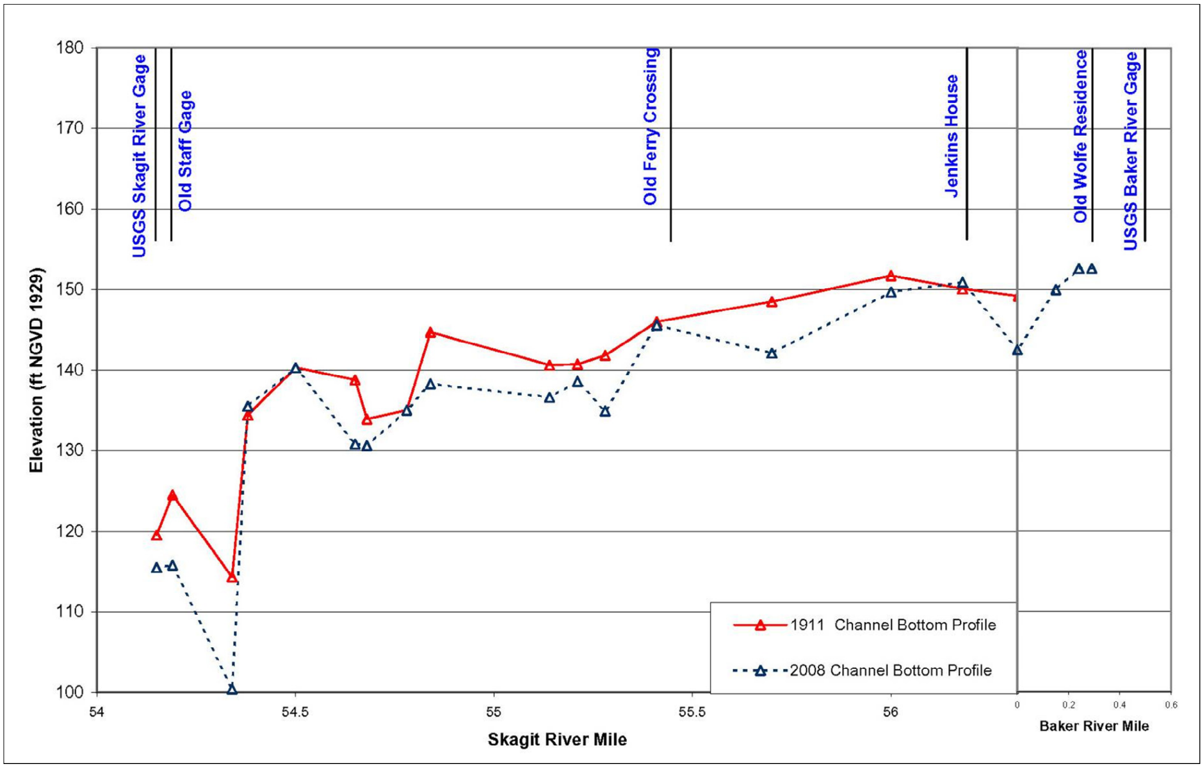

Figure 9. **Comparison of 1911 and 2008 surveyed Skagit River channel bottom profiles in Concrete reach**

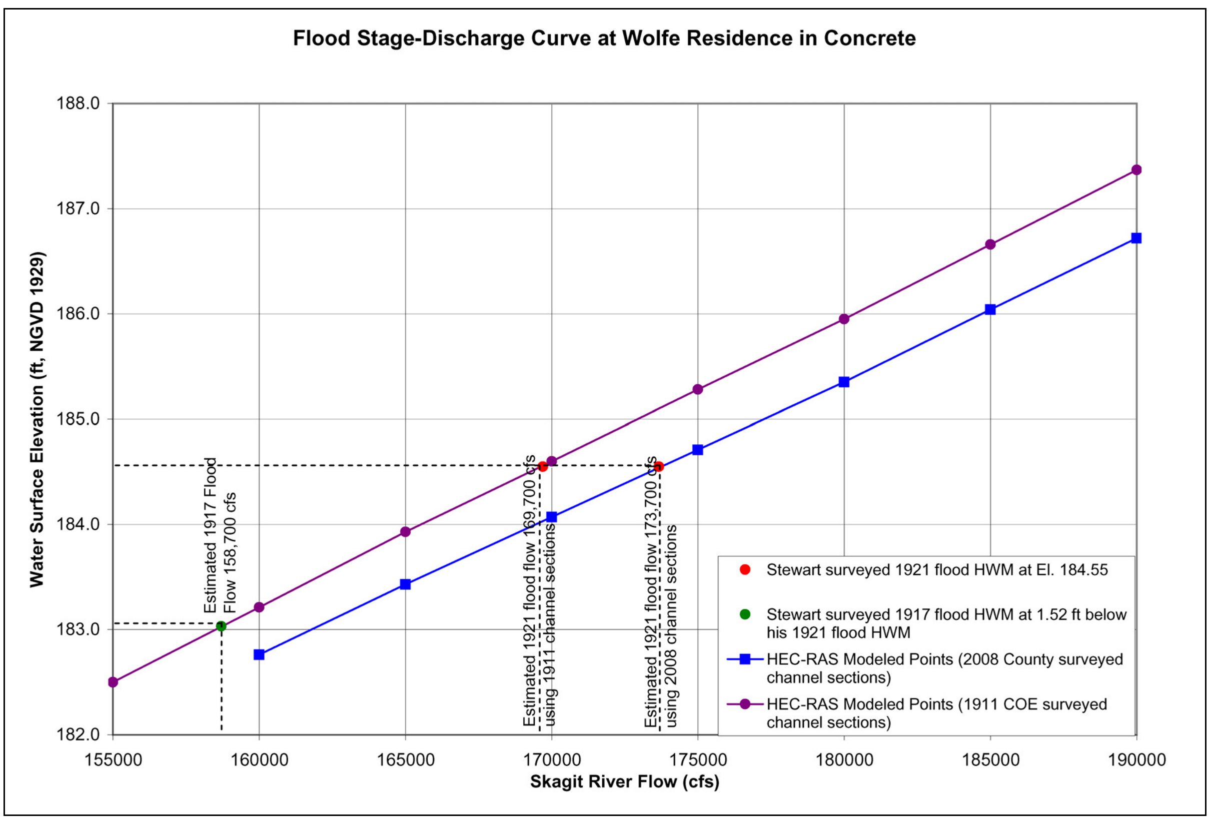

Figure 10. **Skagit River flood stage-discharge curves at old Wolfe residence in Concrete**

Figure 11 presents the flood profiles from HEC-RAS run results of the 2003 flood calibration and the estimated 1921 flood peak discharges of 169,700 cfs and 173,700 cfs for the 2008 and 1911 surveyed Skagit River low-flow channel sections, respectively. Modeled energy gradient lines for the two estimated 1921 flood peak discharges were also plotted on Figure 11. The selected estimate of the 1921 flood peak discharge is 169,700 cfs based on the Corps 1911 surveyed channel sections. The Stewart-surveyed 1917 and 1921 HWMs are also plotted on the figure, comparing well with the modeled flood profiles.

The Stewart-estimated peak discharges of 220,000 and 240,000 cfs for the 1917 and 1921 floods, respectively, were also modeled. The model results show the flood stages at the Wolfe residence are El. 191.37 and El. 194.03 for these two floods estimated by Stewart, respectively. These modeled flood stages are 8 and 9 feet above Stewart-surveyed flood elevations at the Wolfe residence.

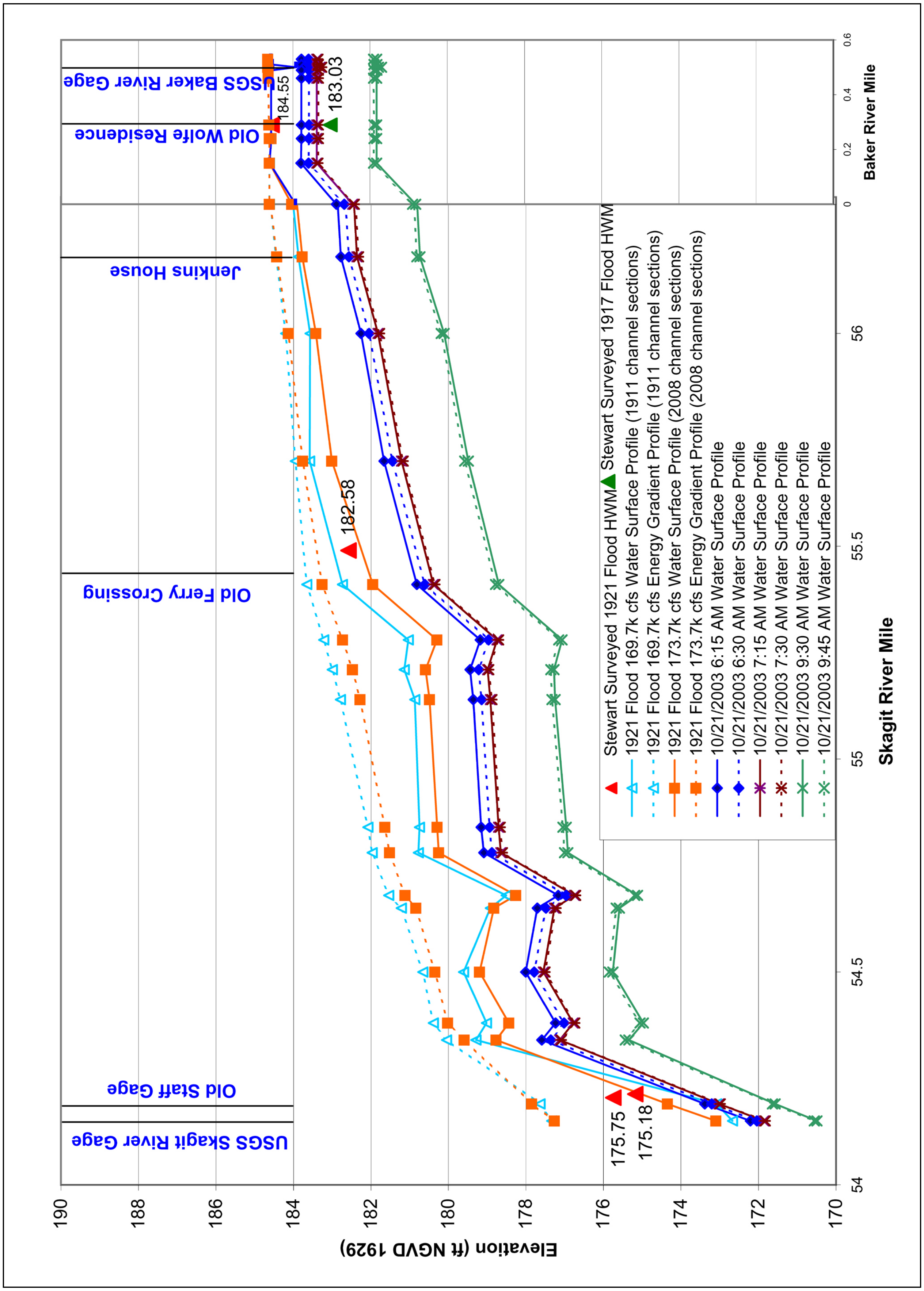

Figure 11. HEC-RAS modeled flood profiles in Concrete reach of the Skagit and Baker Rivers

3.2.6 Datum of Stewart-surveyed HWMs

Stewart's survey of flood marks in Concrete that include the 1917 and 1921 flood HWMs at the old Wolfe residence, and the 1921 flood HWMs near the old Concrete ferry site and at the upper Dalles gage, starts at a USGS benchmark elevation of 230.51 in Concrete (Stewart's notes, p. 22 and p. 30). This USGS benchmark is listed in the USGS published Bulletin 674 (USGS 1918, pp. 78-79) as elevation of 230.506. Stewart twice surveyed the 1921 flood HWM at the Wolfe residence (Stewart's notes, pp. 22-23 and pp. 30-31). In his first survey of the Wolfe residence HWM, his survey turning points include one at El. 214.33 on the rail about 300 feet below the depot in Concrete (Stewart's notes, p. 22-23). This Stewart-surveyed elevation of 214.33 correlates well with the old Great Northern railroad profile in the possession of PI Engineering. All elevations at the USGS benchmarks used in the Stewart's surveys of the flood marks in Concrete and in Hamilton (see Section 3.2.3, 1921 Flood Marks along old GNRR) and on the old GNRR profile are based on mean sea level datum of the early 1900s, which were not significantly different from the NGVD-29 datum.

We believe this analysis significantly reduces the uncertainty of Stewart's peak discharge estimates of the historic floods. That James Stewart was a competent hydraulic engineer and surveyor is apparent from his field notes, the volume of the work he produced, and the pace of field activity, all documented by his notes and other work products. We believe Stewart's surveyed high water mark information, documented in his field notes and often double and triple-checked, is reliable, the best objective information describing the historic floods, and should be used in the current analysis. But it is important to note that Stewart was essentially working in the blind, without access to modern hydraulic modeling methods, and even more importantly, without access to the robust volume of objective data and additional reporting produced over the past 84 years. In particular, given 84 years of continuous stream gage data at the Dalles, and given the known stage/discharge information of recent Skagit floods at the Dalles, and given sets of Skagit River cross sections and Baker River cross sections, PI Engineering extended a HEC-RAS hydraulic model from the Dalles to Concrete. The model, essentially based on known stage/discharge relationships from the flood of record at the Dalles gage and Stewart's surveyed and documented historic flood data, connects together for the first time, Stewart's objective observations of the historic flood high water marks surveyed in 1922-23, with confirmed stage/discharge information from the Dalles gage.

Although Stewart ultimately estimated the peak flows of the historic flood events much higher than we believe the objective evidence points to, Stewart did not have access to the considerable data, additional independent study and field investigation that has since become part of the record. The difficulty of using the slope-area or contracted-opening methodology to estimate the flood discharges based on the minimal stage information available to Stewart at the time cannot be overstated and is illustrated by recent studies. In 2004, less than a year after the October 2003 flood of record on the Skagit River (similar to the time frame following a major flood event that Stewart was challenged with), the USGS undertook a study to verify historic flood discharges utilizing the slope-area methodology using Stewart's cross section locations he originally established downstream of the Dalles. The USGS had considerable difficulty in establishing river water surface levels based upon the HWMs surveyed in this area (see Figure 7). In some cases, and especially at cross section XS1 (one of the slope-area sections shown in Figure 7), surveyed HWMs varied by six feet or more, indicating uneven velocities and unsuitability of this section for using the slope-area method to estimate flood discharges. Stewart had no access to information of this type and the nature and extent of his calculations is not available. Given the much more objective, quantifiable, and modern methodologies presented here, we believe this new information must now be used as the basis for establishing the peak discharges of the historic Skagit floods.

3.2.7 Forensic Investigation of Crofoot Residences for Historical Flood Marks

Coincident with the work to survey additional river cross sections for the purpose of extending the hydraulic model from the Dalles to Concrete, the City of Burlington undertook a forensic investigation of residences in the Crofoot Addition to Concrete (now often called "Crofoot;" however, the original plat was named "Crofoot's First Addition to Concrete") (Martin, 2008) that were built prior to 1921, in an attempt to ascertain whether evidence of historic flooding existed in these residences and if so, what that information might tell us about the nature and effect of the historic floods. This investigation was prompted when local historian Larry Kunzler reviewed existing literature and pointed out that similar to the Hamilton "Smith" house, several residences in the Crowfoot Addition to Concrete were also built prior to 1921 and might provide information about that event. Mr. Kunzler pointed to a 1921 article in the Concrete Herald stating that, "In Crofoot Addition only three residences remained above the high water mark, the water being to a depth of an inch to 14 inches in the others. No particular damage was done, except for small articles outside being washed away, and the job of cleaning out the mud left by the flood." (From "Historical Newspaper Articles, Skagit River Floods, Volume IV, Concrete Herald, 1920 – 1970. Researched and Transcribed by Larry Kunzler and Dan Berentson. Skagit County

Public Works Department, 2005. See additional information in Appendix I.)

The investigation focused on four properties which, according to Skagit County real property records, had been constructed prior to 1921. Two of the residences were located on adjacent lots and were owned by the same property owner, who gave permission to the City to conduct a forensic investigation. One of the houses was constructed in 1900 (Skagit County real property records, parcel #P70749) (Figure 12), and the other house was constructed in 1912 (Parcel #P70748) (Figure 13). Although there was no conclusive evidence of flooding above the first floor elevation of any of the four houses, it was apparent from the field work that these two properties on Albert Street showed the least evidence of having been disturbed and became the main focus of the forensic investigation.

a.

Ripple House #1, 45968 Albert Street, Crofoot Addition, Concrete

b.

Ripple House #1 with exterior siding removed for inspection of interior wall cavity. First floor elevation 185.51

Figure 12. Ripple House #1, parcel #70749

Figure 13. Ripple House #2, parcel #P70748. First floor elevation 184.96. Annotated photo showing with exterior siding removed for inspection of interior wall cavity

Figure 13 is annotated with water surface elevations from HEC-RAS models of various Skagit River flood peak discharges. It should be noted that the Stewart-surveyed 1921 HWM was directly taken from Stewart's notes and has not been adjusted according to the output of the HEC-RAS model. Since Stewart's mark was north of this location about 250 yards, the HEC-RAS modeled 1921 flood elevation at this location would have been about 0.7 ft lower than the 1921 HWM at the Wolfe residence.

Microscopic examination of samples taken from both houses indicated that it was unlikely the house built in 1912 was ever flooded above the first floor level. For the oldest house, the microscopic examination of the samples could not be used to preclude with certainty that the house had not been flooded above the first floor level at some time in the past; however, the results indicated with reasonable certainty that the house was never flooded more than 10 inches above the first floor, if at all.

Notable in this forensic investigation is the argument of why a person in 1912 would build a house with a first floor elevation a half foot lower than the house next door that presumably was flooded to the rafters by the flood just three years earlier (i.e., previous peak flow estimate of the 1909 flood was 260,000 cfs; current USGS estimate is 245,000 cfs). There are at least one half dozen houses built in 1911-1915 within two blocks in this neighborhood, all with the first floor elevation finished below El. 186 as recently surveyed by Skagit County. We believe this is an anecdotal but nonetheless compelling and common-sense argument that supports the results of our technical investigation. In summary, the City's substantial forensic investigation found no evidence of significant flooding (above the first floor level) to these two houses.

3.2.8 Selected Literature Review

Due to substantial and ongoing historical research (Kunzler, www.skagitriverhistory.com and Kunzler, Berentson, "Skagit River Floods, Volumes I-IV," 2004-2005), numerous newspaper articles, photographs, letters and other historical information is available regarding the nature of the historic flood events. A discussion of this information is included in Appendix I.

3.2.9 Estimates of 1897 and 1909 Flood Peak Discharges Using Stewart's Flood Marks Downstream of the Dalles

The USGS suggests and we concur that downstream of the stream gage at the Dalles where there is no question of whether the flood marks are more representative of flooding on the Baker River or flooding of the Skagit River, Stewart found several sets of HWMs that could only represent the water surfaces of the Skagit River (see the October 26, 2006 letter to Mr. Daniel O'Donnell of LaConner, WA from Matthew C. Larsen, Chief Scientist for Hydrology, USGS, in response to Representative Rick Larsen's request).

In the town of Hamilton, approximately at RM 39.9, Stewart found a 1917 HWM 0.55 feet below a 1909 HWM and 0.84 feet below a 1921 HWM (Stewart's notes, pp. 13-14). These HWMs surveyed by Stewart are at El. 96.17, 95.62, and 96.46, respectively. Stewart-surveyed HWMs were located at the A.J. Jacobin cigar store building which no longer exists today. Based on 1918 historical maps available in the Skagit County Historical Museum, the old Jacobin cigar store was located on Maple Street and east of Cumberland Street, or approximately 200 yards west of the Smith house, also located on Maple Street. The 1995 and 2003 flood HWMs at the Smith house surveyed by the County are at El. 101.00 and 100.83, respectively. A comparison of the 1995 and 2003 flood stages at the Smith house and the 1909, 1917, and 1921 flood stages at the old Jacobin cigar store building appear to indicate that the peak discharges of the recent two floods are greater than the peak discharges of the three historical floods. The 1995 and 2003 flood peak discharges recorded at the USGS gage near Concrete are 160,000 and 166,000 cfs, respectively. However, due to the complexity of flood hydraulics on the Hamilton floodplain and the historical migration of the Skagit River channel alignment in the vicinity, it is difficult to use Stewart-surveyed HWMs at the old Jacobin cigar store building to estimate the flood peak discharges with certainty.

At Kemmerick Ranch (about RM 44.5), Stewart found HWMs that showed the 1897 peak was about the same as the 1909 peak and 0.78 feet above the 1921 peak (Stewart's notes, pp. 26-27). At Savage Ranch, across from Old Birdsview School (about RM 45.2), Stewart's notes show the 1909 flood to be 0.51 and 0.67 feet higher than the 1921 flood and the 1917 flood to be 0.68 feet below the 1921 flood (Stewart's notes, pp. 26-27). Stewart did not survey to tie these HWMs to any known benchmark. However, these relative HWMs provide a reasonable basis to estimate the differential quantities of the 1897 and 1909 peak discharges in relation to the 1921 peak discharge estimated previously using Stewart surveyed HWMs at the Wolfe residence in Concrete. The relative HWMs between the 1917 and 1921 floods found by Stewart at the Savage Ranch also compare well with Stewart-surveyed HWMs at the Wolfe residence.

Figure 14 presents the flood stage-discharge rating curves at the Kemmerick and Savage Ranches near Birdsview, approximately at RM 44.5 and 45.2, respectively. These curves were plotted for the Skagit River flood peak discharges between 160,000 and 190,000 cfs from results of an unsteady HEC-RAS model originally developed by the Seattle District, Corps of Engineers and improved in 2004 by PI Engineering for the Skagit River Basin. Using Stewart-surveyed differential HWMs, the 1897 and 1909 flood peak discharges were estimated to be 181,200 and 179,000 cfs, respectively. It is further noted that the 1897 flood may well have been a debris-blockage event as noted by Stewart (Stewart notes, p. 23).

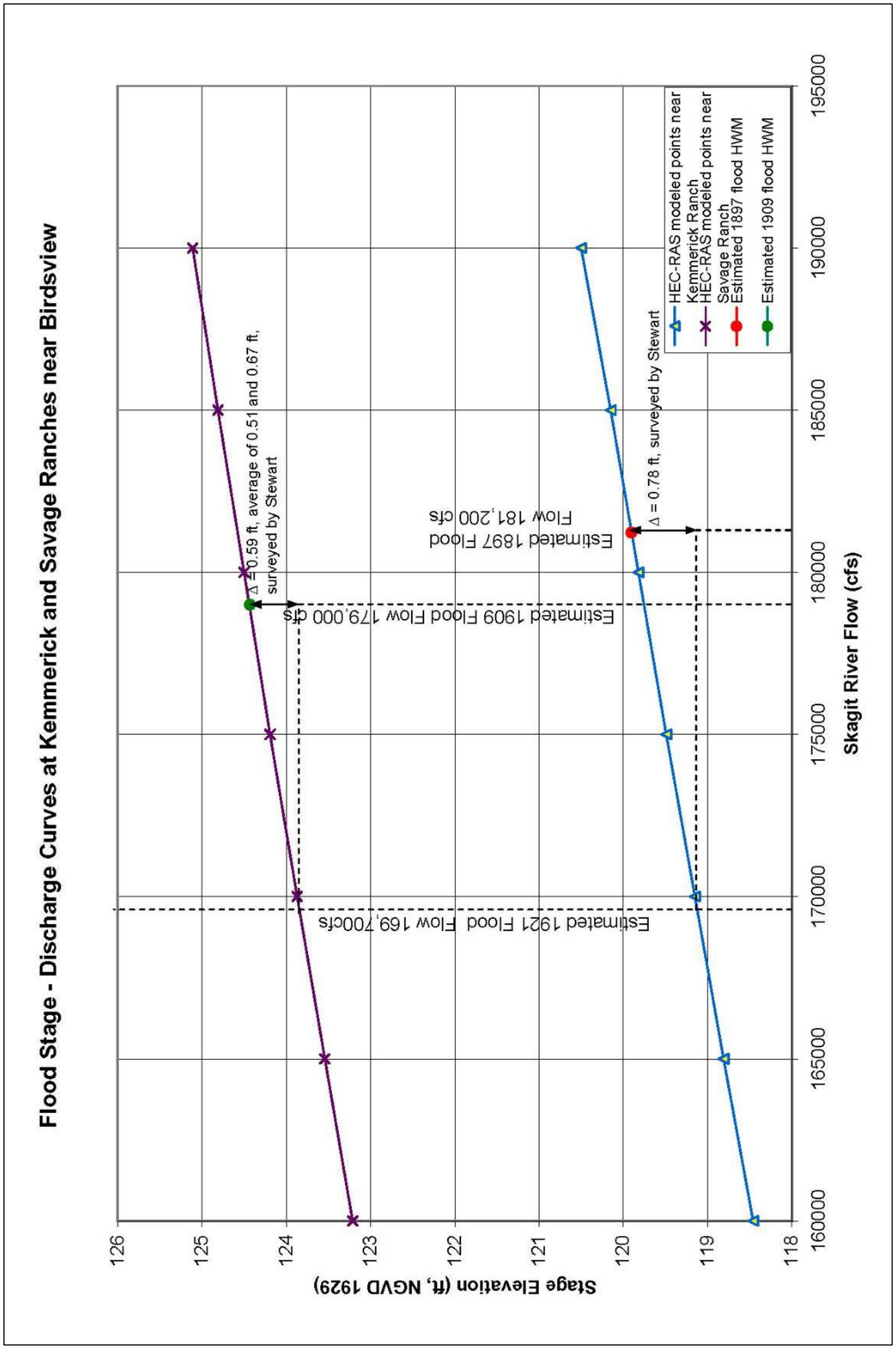

Figure 14. Skagit River flood stage-discharge curves at Kemmerick and Savage Ranches near Birdsview

3.2.10 Estimates of Unregulated One-Day Flows for the Four Historical Floods

The one-day flows represent the most critical flood volumes determining the lower Skagit River floodplain flooding conditions after routing through dams and floodplain storages in the Skagit River system. The winter unregulated one-day flow data for water years 1925 through 2008 are provided in Table 1.

The four historical floods estimated by Stewart and other USGS reviewers, as well as by PI Engineering, have only the unregulated peak discharges estimated. To estimate the corresponding unregulated one-day discharges for these four events, a regression of selected flood events unregulated by the Corps was applied. Figure 15 below shows the Corps' unregulated floods and the regression curve. The estimated one-day discharges of the four historical events are listed in Table 6 together with the estimated peak discharges of these four events as discussed in Sections 3.2.5 and 3.2.6.

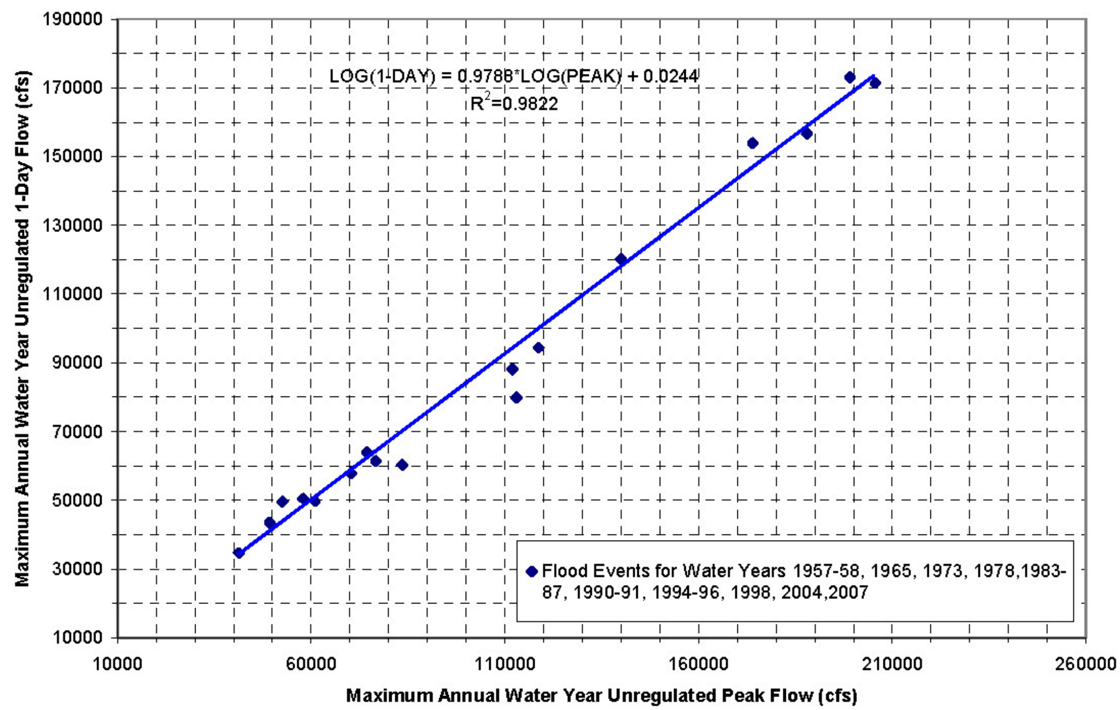

Figure 15. Regression curve of peak to one-day flow for the flood events unregulated by the Corps

Table 6 Estimated unregulated peak and one-day discharges for four historical floods in the Skagit River near Concrete

Water Year	Date	Peak Discharges (cfs) Estimated by model and Stewart's HWMs	One-Day Discharges (cfs) Estimated by Regression
1898	Nov. 19, 1897	181,200	148,300
1910	Nov. 30, 1909	179,000	146,500
1918	Dec. 30, 1917	158,700	130,200
1922	Dec. 13, 1921	169,700	139,100

3.3 Flood Frequency Analysis for Unregulated Annual Peak and One-Day Flows in the Skagit River near Concrete

A flood frequency analysis for unregulated peak and one-day flows in the Skagit River near Concrete was performed, using PEAKFQ software (USGS 2005). The unregulated peak flow frequency curve and the confidence band from the result of the PEAKFQ run using 84 water years of data (Table 1) and the four historical events (Table 6) are shown on Figure 16. Output from the PEAKFQ run is presented in Appendix B. The unregulated peak flows at Concrete would have values of 146,800, 212,100, 240,800, and 309,500 cfs, for the 10-, 50-, 100- , and 500-year floods, respectively.

The unregulated one-day flow frequency curve and the confidence band, together with all data used in the frequency analysis, are plotted in Figure 17. The output of the PEAKFQ run for the one-day flood frequency analysis is also presented in Appendix B.

The unregulated one-day flows at Concrete would have values of 123,700, 177,900, 201,400, and 257,500 cfs, for the 10-, 50-, 100-, and 500-year floods, respectively. A generalized skew of 0 and –0.04 was used for the analysis of the peak and one-day flows, respectively, as adopted by the Corps [(Section 4.2 of the Corps Draft Report – Skagit River Basin, Washington, Revised Flood Insurance Study, Hydrology Summary (Corps 2005 and 2008)].

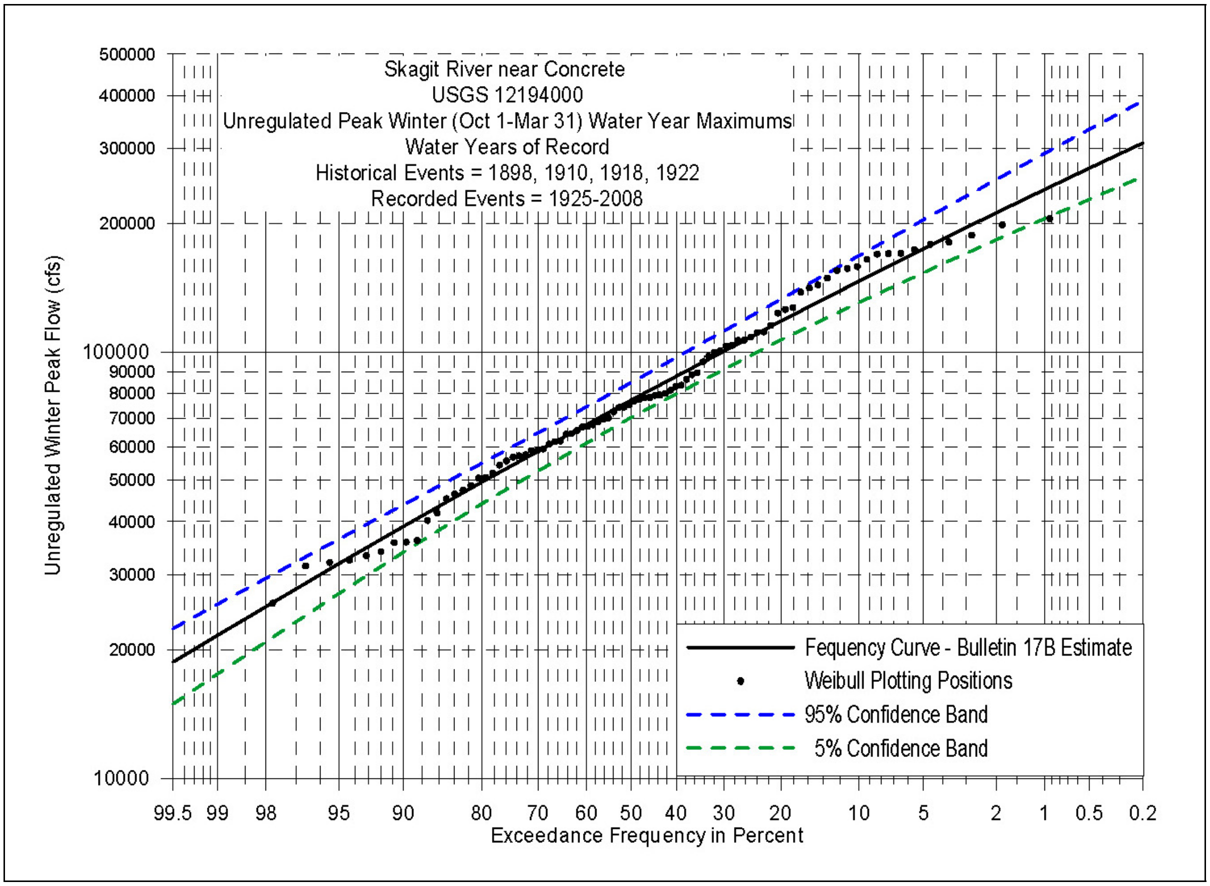

Figure 16. **The unregulated peak flow frequency curve for the Skagit River near Concrete, and the confidence band together with all data used in the frequency analysis at Concrete**

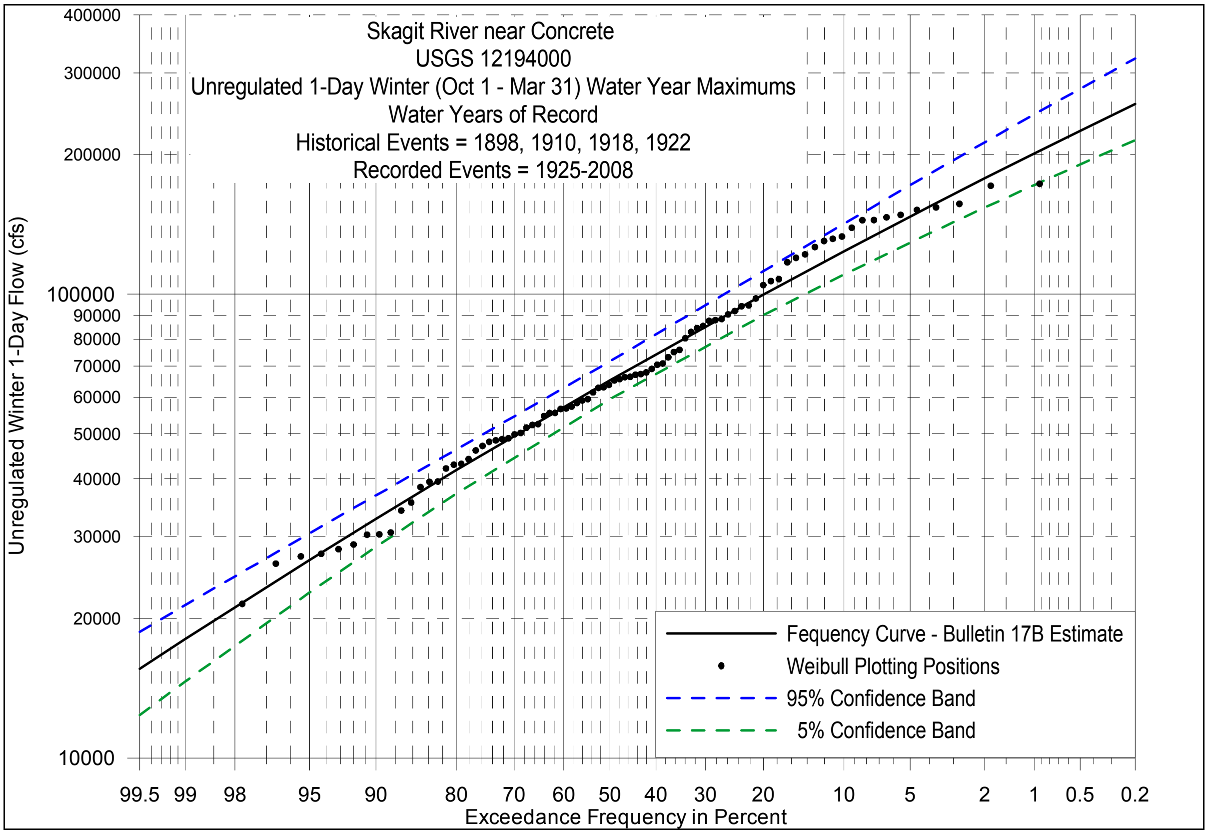

Figure 17. **The unregulated one-day flow frequency curve and the confidence band together with all data used in the frequency analysis at Concrete**

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4.0 Synthetic Flood Hydrographs at Concrete

This section presents information on development of the synthetic flood hydrographs for the Skagit River at Concrete. The HEC-5 and HEC-RAS models originally developed by the Corps and subsequently improved by PI Engineering were used to route the coincident synthetic flood hydrographs. The hydrograph routing was performed for the area of the Skagit River above Concrete (see Figure 18), first for unregulated conditions, and then for regulated conditions.

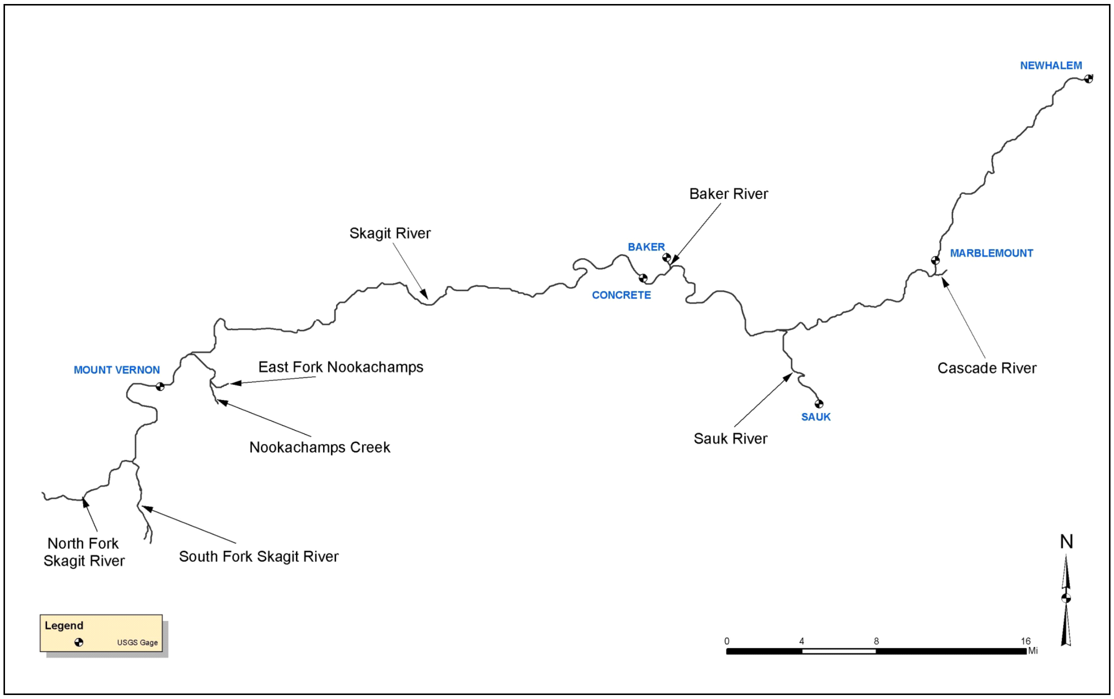

Figure 18. Skagit River HEC-RAS model routing reaches

4.1 Development of Unregulated Synthetic Flood Hydrographs

Based primarily on the unregulated peak one-day flow data and various regressions, the Corps developed coincident flood hydrographs for nine upper Skagit River subbasins above Concrete. A total of nine synthetic flood hydrographs for each subbasin was constructed by the Corps. Details of the Corps-developed synthetic flood hydrographs for these subbasins are presented in the Corps' Draft Report – Skagit River Basin, Washington, Revised Flood Insurance Study, Hydrology Summary (Corps 2005 and 2008).

PI Engineering applied the improved HEC-5 and HEC-RAS models to route the unregulated flood hydrographs for the FEMA FIS-required 10-, 50-, 100-, and 500-year synthetic flood events along the Skagit River from Ross Dam to Concrete including Cascade, Sauk and Baker River tributaries. Details of the HEC-5 (without flood control storage operation) and HEC-RAS models are provided in the Draft Technical Memorandum – Skagit River Basin Historical

Flood Modeling – Hydrology (Appendix C) and the Draft Technical Memorandum – Skagit River Basin Historical Flood Modeling – Hydraulics (Appendix D).

The peak and one-day flows of the synthetic flood hydrographs routed to Concrete were compared with the corresponding unregulated events statistically developed for Concrete. These flows and subbasin hydrographs were then scaled and routed again as necessary until the routed flows matched the unregulated peak and one-day flows that were derived as described in Section 3.3. The one-day scaled flows are listed in Table 7.

Figure 19 and Figure 20 show the plots of the peak and the one-day flows, respectively, at Concrete for the four HEC-RAS simulated unregulated synthetic flood events, in comparison with the corresponding flood frequency curves developed as described in Section 3.3. This comparison indicates that the unregulated peak and one-day flows resulting from the HEC-5 and HEC-RAS routing of the constructed synthetic flood hydrographs for each of the 10-, 50-, 100-, and 500-year events match very well with the statistically-derived unregulated peak and one-day flows at Concrete.

Table 7 Unregulated synthetic flood one-day coincident flows (cfs) for upper Skagit River subbasins

	Flood Event			
Location	**10-year**	**50-year**	**100-year**	**500-year**
Unregulated Skagit River Near Concrete	123,700	177,900	201,400	257,500
Ross Dam Inflow	23,700	34,100	39,100	49,300
Thunder Creek and Ross Dam to Newhalem Local	8,500	12,300	14,000	17,700
Newhalem to Marblemount Local	17,600	25,400	29,000	36,700
Cascade River at Marblemount	8,100	11,600	13,300	16,800
Marblemount to Sauk Local	4,800	6,900	7,900	10,000
Sauk to Concrete Local	3,300	4,800	5,500	6,900
Sauk River at Sauk	39,800	57,300	65,600	82,800
Upper Baker Dam Inflow	17,000	24,500	28,100	35,400
Lower Baker Dam Inflow	4,800	7,000	8,000	10,100

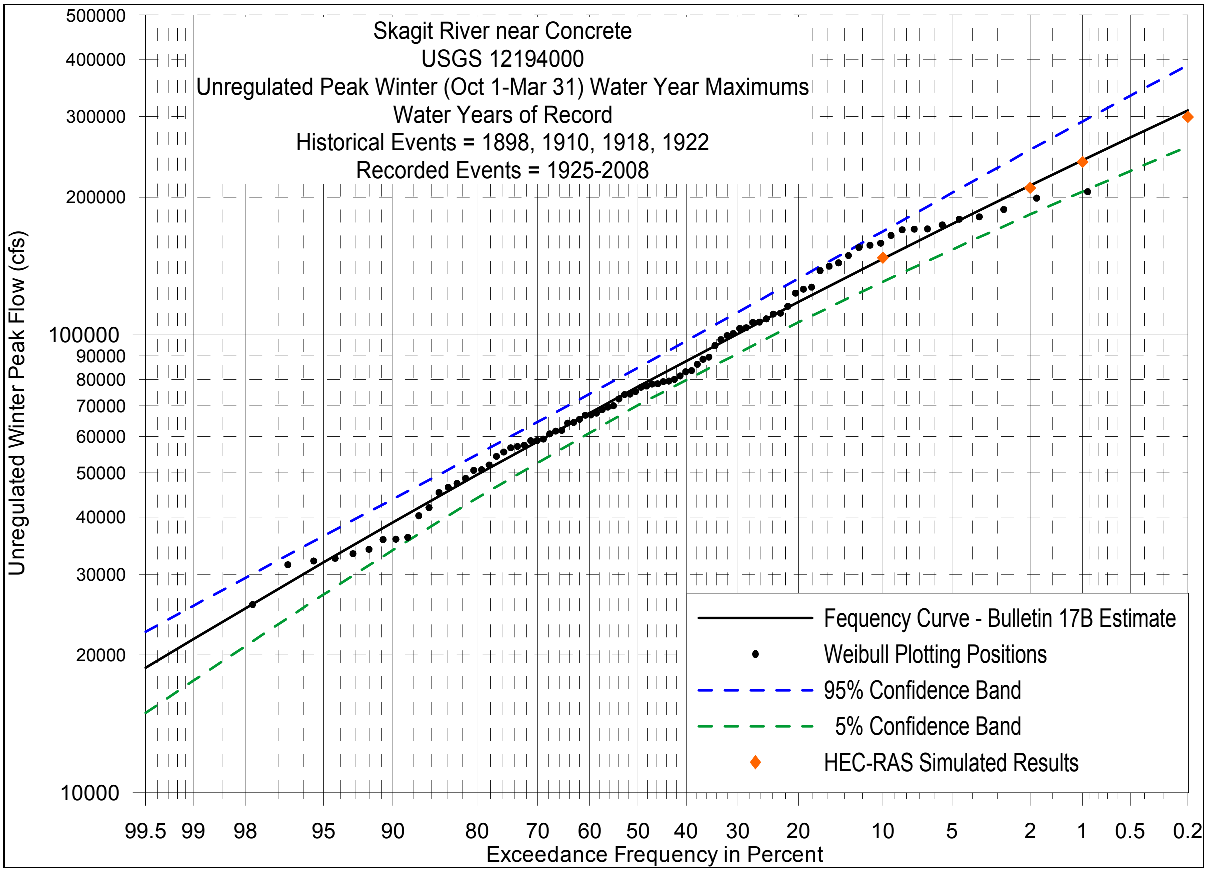

Figure 19. **Flood frequency curve for unregulated peak discharges at Concrete, compared with the HEC-RAS simulated peak flows at Concrete for the 10-, 50-, 100-, and 500-year synthetic events**

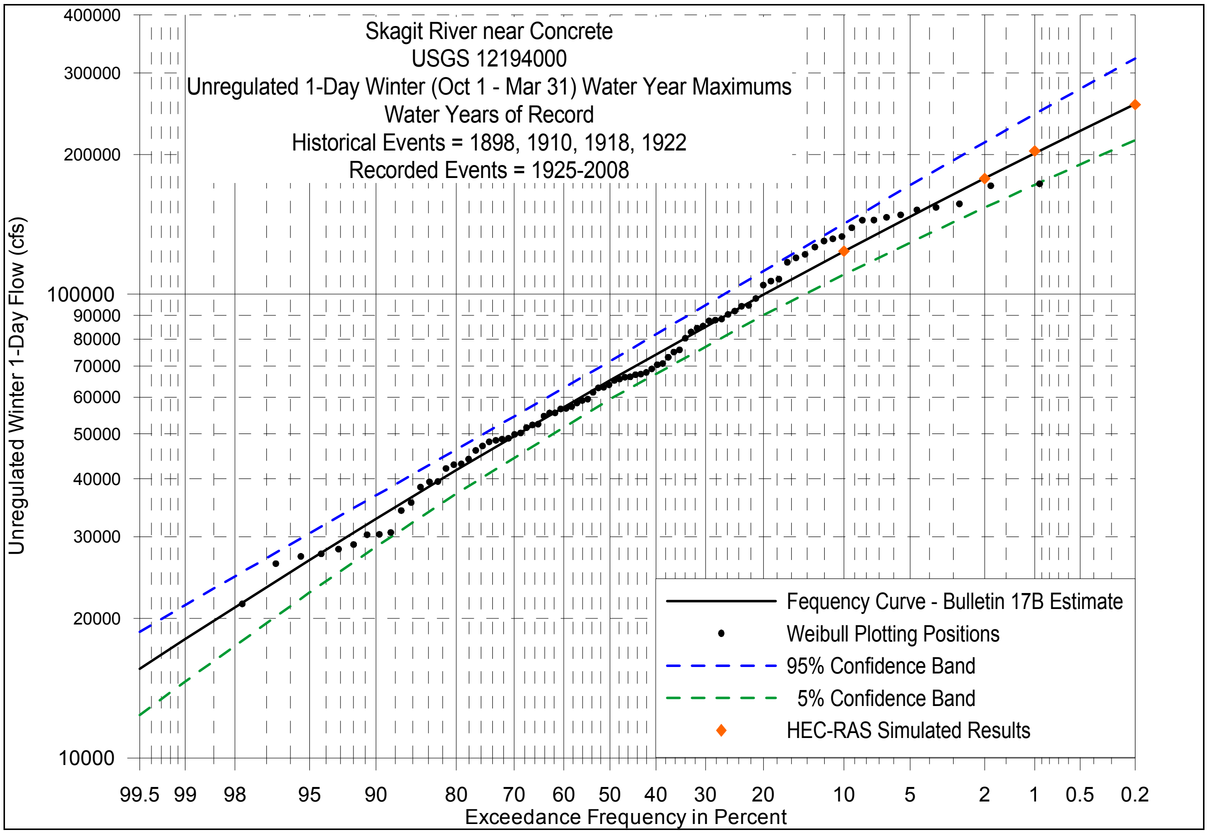

Figure 20. Flood frequency curve for unregulated one-day discharges at Concrete, compared with the HEC-RAS simulated one-day flows at Concrete for the 10-, 50-, 100-, and 500-year synthetic events

4.2 Development of Regulated Synthetic Flood Hydrographs

The coincident unregulated hydrographs of all subbasins above Concrete for each of the 10-, 50-, 100-, and 500-year synthetic flood events derived as discussed above in Section 4.1 were then routed by the HEC-5 model with the existing flood control storage of 120,000 and 74,000 acre-feet provided at Ross Dam and Upper Baker Dam, respectively. The regulated outflow hydrographs at these two dams and local inflow hydrographs representing subsequent flow contribution from subbasins were routed by the HEC-RAS model along the Skagit River and main tributary routing reaches to Concrete. Development and details of the HEC-5 and HEC-RAS routing models are discussed in the Draft Technical Memorandum – Skagit River Basin Historical Flood Modeling – Hydrology (Appendix C) and the Draft Technical Memorandum – Skagit River Basin Historical Flood Modeling –Hydraulics (Appendix D).

Figure 21 and Figure 22 show the plots of the annual peak and one-day flows, respectively, at Concrete for the four routed regulated synthetic flood events, in comparison with the corresponding flood frequency curves based on PEAKFQ modeling of the USGS observed regulated flow data at Concrete for the time period from 1955 through 2006 (water years 1956-2007). Output of the PEAKFQ runs for the observed regulated peak and one-day flows in the Skagit River near Concrete are provided in Appendix E. Appendix F presents the regulated and unregulated hydrographs for the HEC-5 and HEC-RAS routed four synthetic flood events at selected locations in the Upper Skagit River Basin.

The comparison shown in Figure 21 and Figure 22 indicates that the regulated annual peak and one-day flows resulting from the HEC-5 and HEC-RAS routing of the synthetic flood hydrographs for each of the 10-, 50-, 100-, and 500-year events match reasonably well with the projection and within the confidence band of the frequency curves based on USGS observed regulated data at Concrete. It is noted that since the actually observed regulated data do not include the low-flow hydrological years preceding 1956, it is reasonable to expect that the frequency curves plotted from these observed regulated data are shown in the figures above the plotted points of the modeled four synthetic floods.

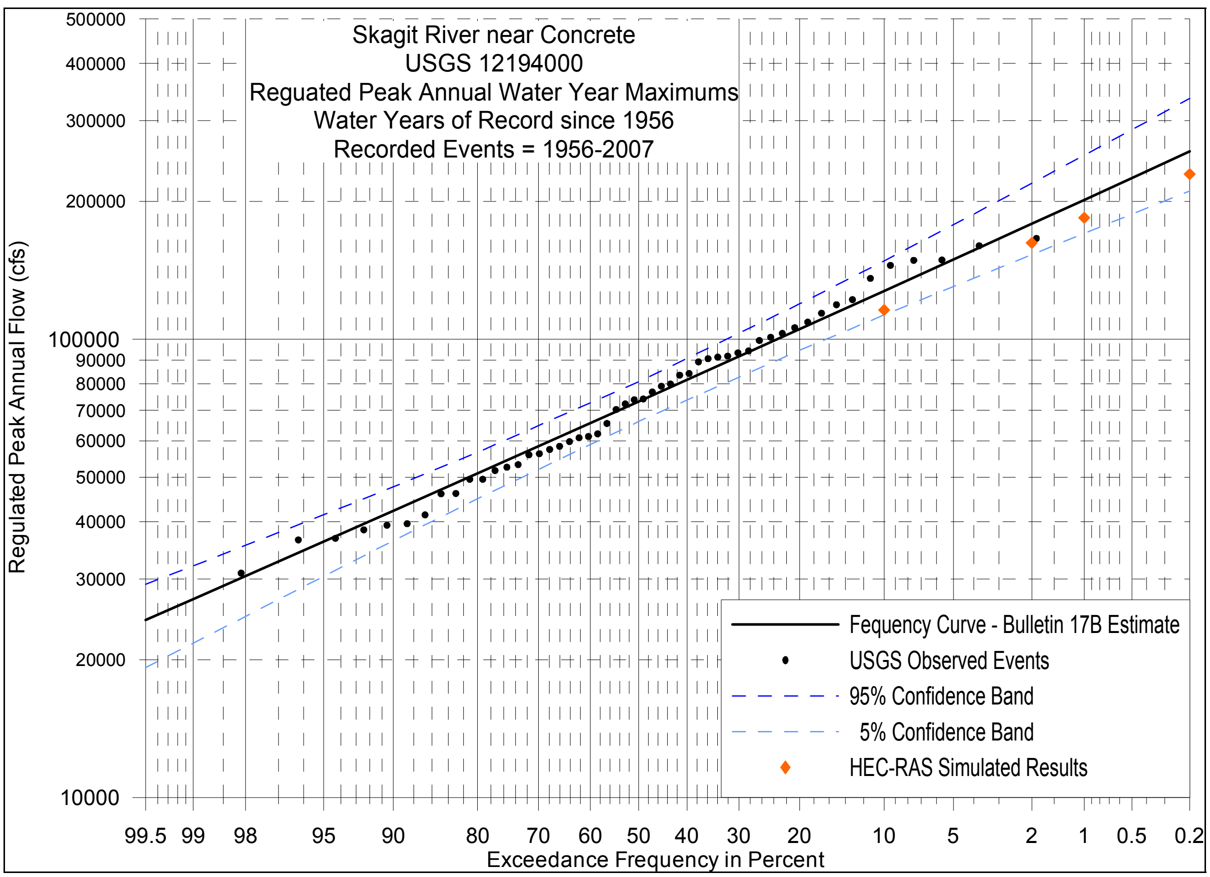

Figure 21. Flood frequency curve for regulated peak discharges observed by USGS at Concrete, compared with the HEC-RAS simulated regulated peak flows at Concrete for the 10-, 50-, 100-, and 500-year synthetic events

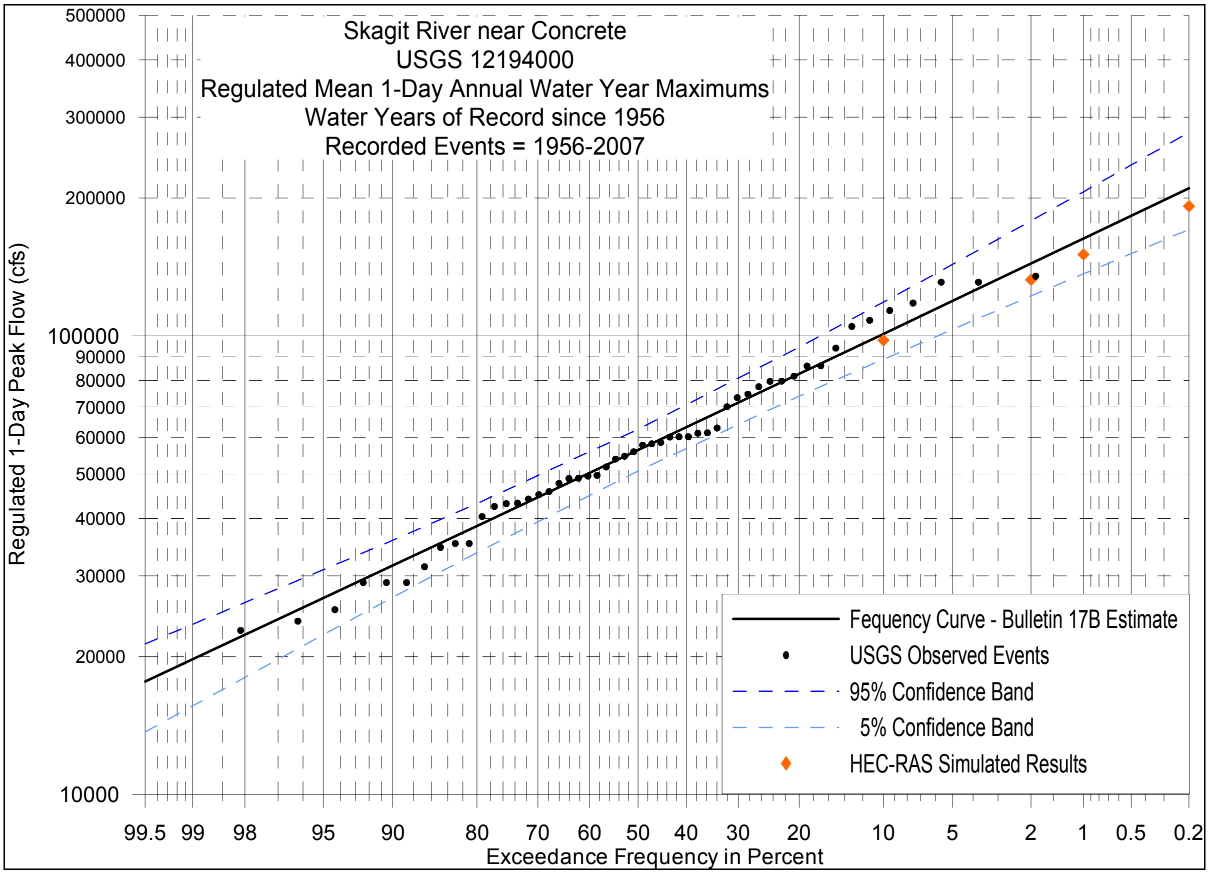

Figure 22. Flood frequency curve for regulated one-day discharges observed by USGS at Concrete, compared with the HEC-RAS simulated regulated one-day flows at Concrete for the 10-, 50-, 100-, and 500-year synthetic events

5.0 Synthetic Flood Hydrographs at Mount Vernon

This section presents information on development of the regulated synthetic flood hydrographs routed by the HEC-RAS model originally developed by the Corps and later improved by PI Engineering along the Skagit River system from Concrete to Mount Vernon. Local coincident inflow hydrographs developed by the Corps were adjusted and used in the flood routing. A flood frequency based on USGS observed regulated events at Mount Vernon was developed and compared with HEC-RAS modeled results.

The majority of flood damages in the Skagit River floodplain occur below Concrete, primarily from Sedro-Woolley to the mouths of the North and South Forks of the Skagit River. It is, therefore, important that the flood modeled results match reasonably well with flood projections based on observed flood records available from USGS at the Mount Vernon gage. The Mount Vernon gage, USGS Station No. 12200500, provides the longest systematic flow record below Concrete (1941 to present).

5.1 Local Inflows below Concrete

The coincident local inflow hydrographs developed by the Corps for synthetic flood events from Concrete to Sedro-Woolley [see Section 5.1 of the Corps' Draft Report – Skagit River Basin, Washington, Revised Flood Insurance Study, Hydrology Summary (Corps 2005 and 2008)] were used in development of the synthetic flood hydrographs at Mount Vernon. This data represents flow contribution from the intermediate drainage area of 278 square miles between Concrete and Sedro-Woolley.

The coincident local inflow hydrographs developed by the Corps for the 71.6-square-mile Nookachamps Creek [see Section 5.2 of the Corps' Draft Report – Skagit River Basin, Washington, Revised Flood Insurance Study, Hydrology Summary (Corps 2005 and 2008)] were not used. Instead, the coincident local inflow hydrographs developed by the Corps for the 51.6-square-mile Finney Creek [see Section 5.1 of the Corps' Draft Report – Skagit River Basin, Washington, Revised Flood Insurance Study, Hydrology Summary (Corps 2005 and 2008)] were used with a direct proportional adjustment of the drainage area to represent the flow contribution from Nookachamps Creek. The Corps-developed regression for the Nookachamps Creek drainage area is a weak correlation, while the Corps-developed flow regression for Finney Creek is a better correlation. Finney Creek is located on the left bank of the Skagit River, the same side as Nookachamps Creek; and, the size and location of Finney and Nookachamps Creeks are similar.

Table 8 lists the one-day coincident flows for the local drainage areas below Concrete, and the unregulated one-day flows at Concrete for the 10-, 50-, 100-, and 500-year synthetic floods analyzed.

Table 8 Unregulated synthetic flood one-day coincident flows (cfs) for lower Skagit River subbasins

Location	Flood Event			
	10-year	50-year	100-year	500-year
Unregulated Skagit River Near Concrete	123,700	177,900	201,400	257,500
Concrete to Sedro-Woolley Local	11,700	16,800	19,200	24,300
Nookachamps Creek	2,800	4,000	4,600	5,800

5.2 Routing of Regulated Flood Hydrographs below Concrete

The regulated flood hydrographs at Concrete for the 10-, 50-, 100-, and 500-year synthetic events, derived as described above in Section 4.2, were routed downstream along the Skagit River to the mouths of the North and South Forks of the Skagit River, using the PI Engineering improved HEC-RAS model. Local inflows as discussed above in Section 5.1 were added to the routing as necessary. It was assumed that there was no levee failure below Concrete, and no levee overtopping below Sedro-Woolley. Details of the HEC-RAS improvements are discussed in the Draft Technical Memorandum – Skagit River Basin Historical Flood Modeling – Hydraulics (Appendix D).

The HEC-RAS routed peak and one-day flows for the 10-, 50-, 100-, and 500-year floods at Sedro-Woolley (RM 22.40) and Mount Vernon (RM 17.05) are listed in Table 9. The regulated peak and one-day values at Concrete (RM 54.15) are also listed in Table 9 for a comparison. The HEC-RAS modeled flood hydrographs for the regulated four synthetic floods at these three locations are presented in Appendix G.

Table 9 Peak and one-day flows (cfs) at Concrete, Sedro-Woolley and Mount Vernon for regulated synthetic floods

Flood	Concrete (RM 54.15)		Sedro-Woolley (RM 22.40)		Mount Vernon (RM 17.05)	
	Peak	One-Day	Peak	One-Day	Peak	One-Day
10-year	116,100	98,200	117,200	105,500	108,200	103,400
50-year	162,600	133,000	161,900	141,400	143,500	135,100
100-year	184,400	151,000	184,700	160,000	162,200	152,400
500-year	229,400	192,500	231,700	203,200	195,700	184,500

Figure 23 and Figure 24 present regressions of the USGS observed peak and one-day flows, respectively, at Concrete and Mount Vernon for the time period from 1955 through 2006 (water years 1956-2007), representing regulated conditions of the Skagit River. The HEC-RAS modeled peak and one-day values for the 10-, 50-, 100-, and 500-year events are also shown in these two figures, indicating a reasonable match of the HEC-RAS modeled results and the USGS observed data. The modeled values appear to be slightly conservative.

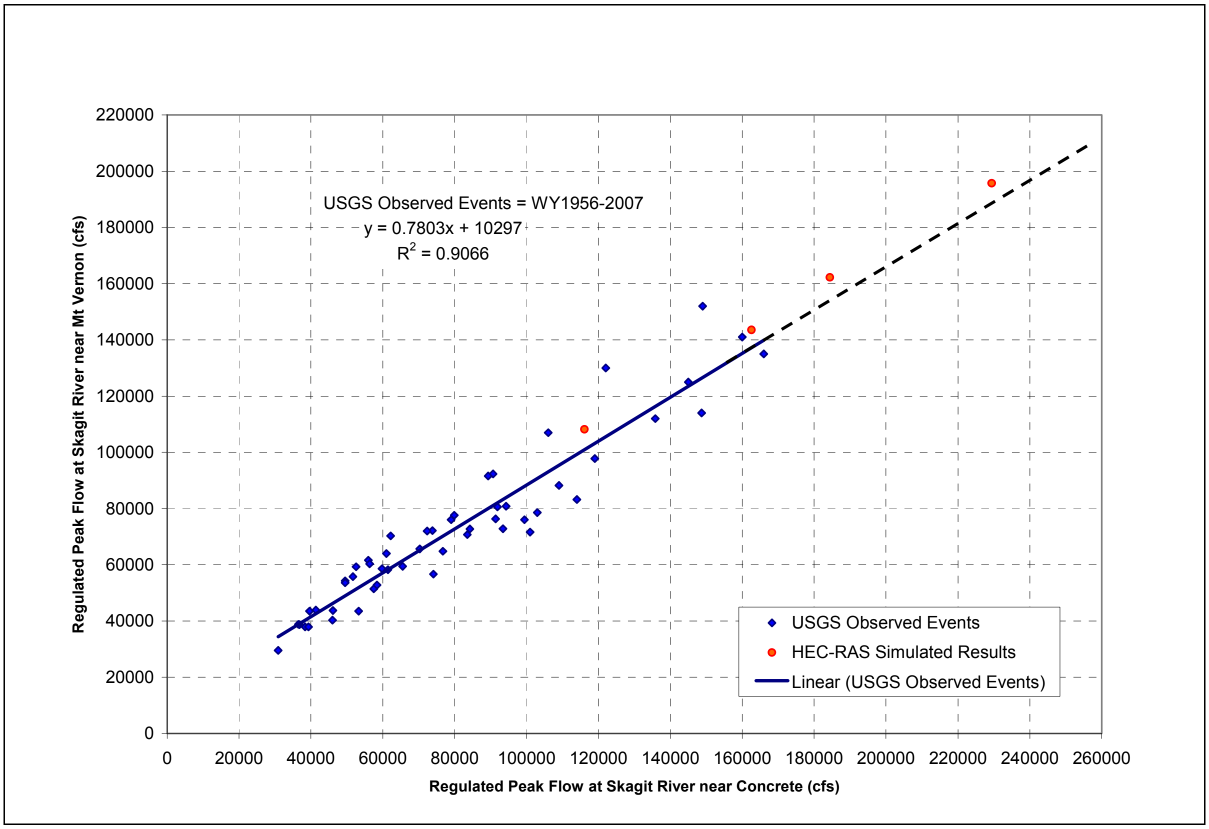

Figure 23. Regression of regulated peak flows observed by USGS at Concrete and Mount Vernon, compared with the HEC-RAS simulated peak values for the 10-, 50-, 100-, and 500-year synthetic events

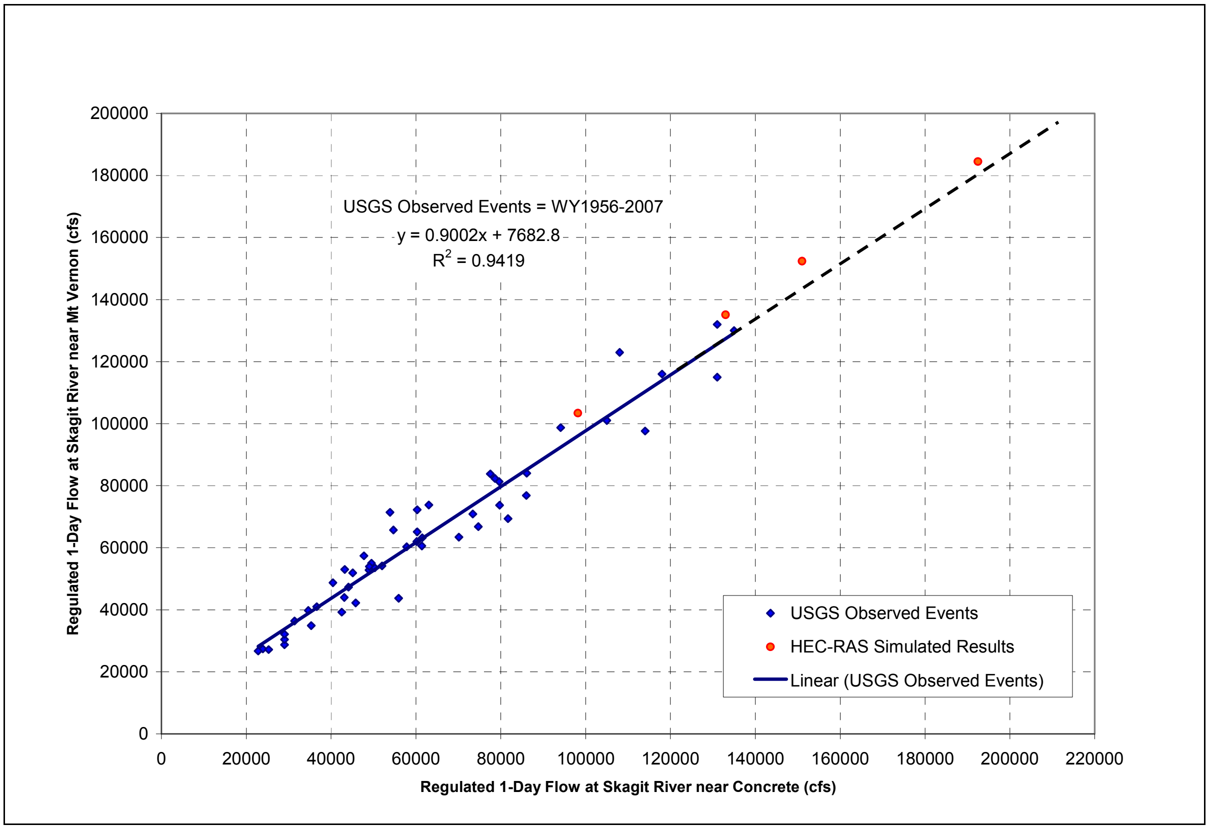

Figure 24. **Regression of the regulated one-day flows observed by USGS at Concrete and Mount Vernon, compared with the HEC-RAS simulated one-day values for the 10-, 50-, 100-, and 500-year synthetic events**

5.3 Flood Frequency Curves at Mount Vernon

Figure 25 and Figure 26 show the annual peak and one-day flood frequency curves, respectively, at Mount Vernon. These frequency curves were based on the USGS observed flow data at the Mount Vernon gage for the time period from 1955 through 2006 (water years 1956-2007), representing regulated conditions of the Skagit River system. The HEC-RAS modeled peak and one-day flows at Mount Vernon for the 10-, 50-, 100-, and 500-year events were also plotted in Figure 25 and Figure 26 for a comparison with the USGS observed annual flood data and the calculated flood frequency curves. The comparison indicates that the modeled synthetic floods compare well with projection of the frequency curves based on the observed events at Mount Vernon.

The PEAKFQ software was used for the flood frequency analysis. Output of the PEAKFQ runs for the peak and one-day flows at Mount Vernon are provided in Appendix H.

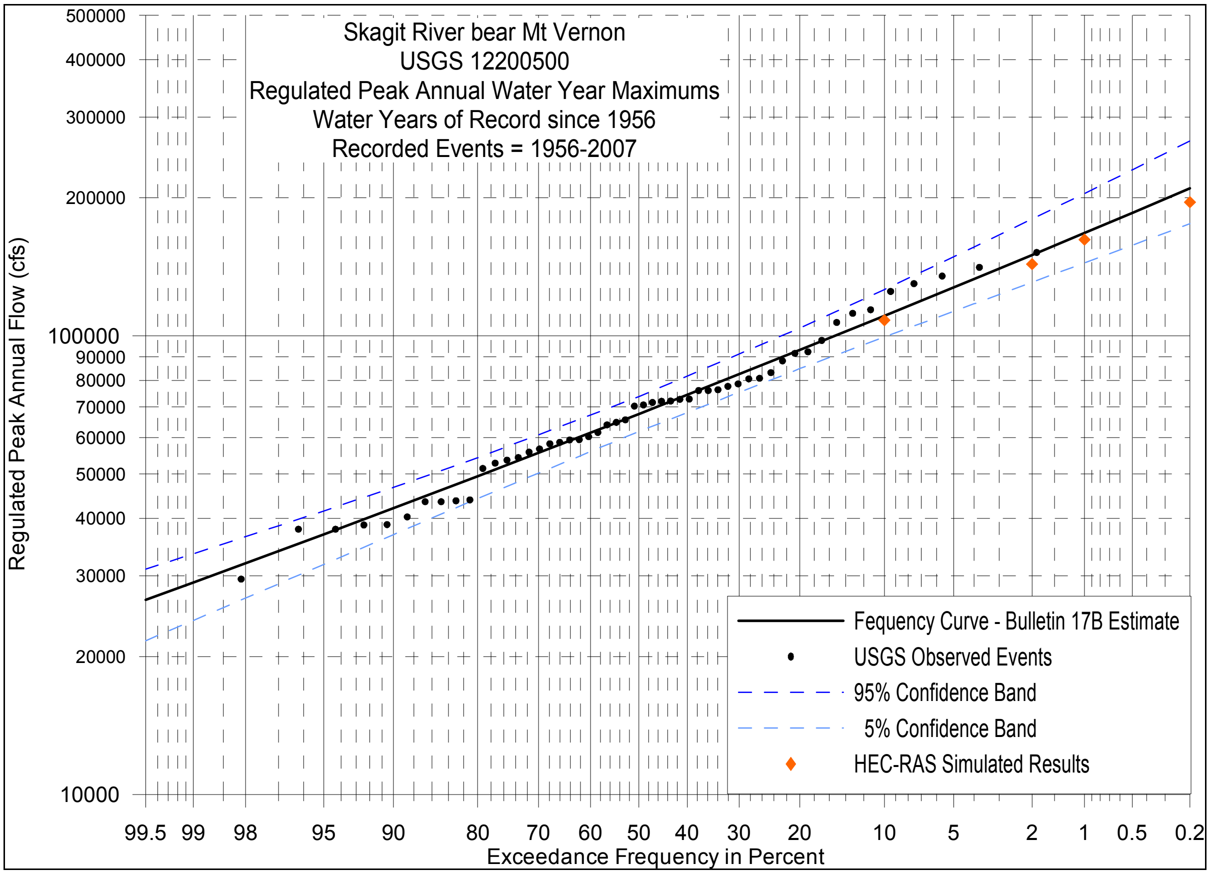

Figure 25. Flood frequency curve for regulated peak discharges observed by USGS at Mount Vernon, compared with the HEC-RAS simulated peak flows at Mount Vernon for the 10-, 50-, 100-, and 500-year synthetic events

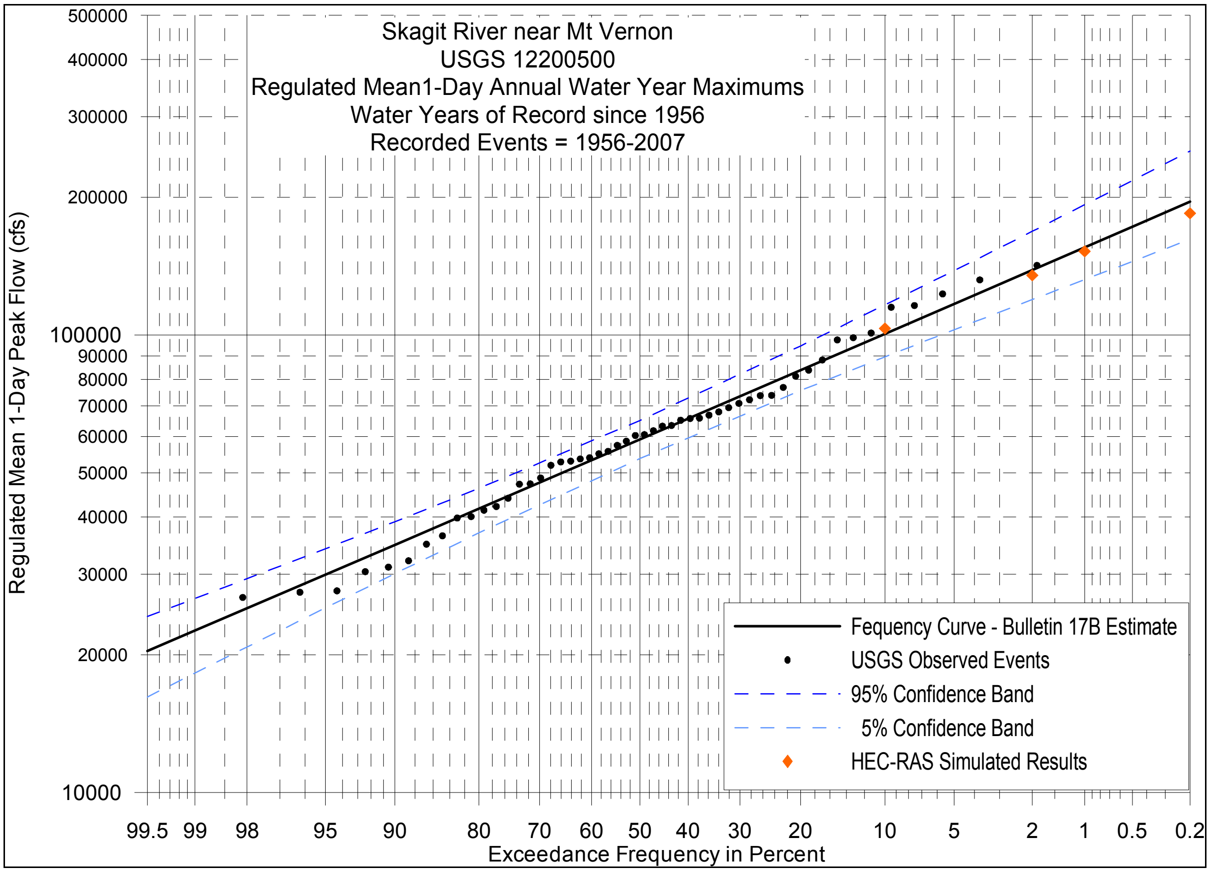

Figure 26. Flood frequency curves for regulated one-day discharges observed by USGS at Mount Vernon, compared with the HEC-RAS simulated one-day flows at Mount Vernon for the 10-, 50-, 100-, and 500-year synthetic events

6.0 List of References

Beget, J.E. "Postglacial volcanic deposits at Glacier Peak, Washington, and potential hazards from future eruptions: U.S. Geological Survey Open File Report 82-830.

Bodhaine, G.L. 1954. Skagit River Flood Peaks, Memorandum of Review. U.S. Geological Survey. May 13, 1954

Burlington, City of, 2007. Preliminary Investigation into Historic Flood Marks in the "Smith" House, Hamilton, Washington. Undated report.

Dragovich, Joe E. and Grisamer, Carly L. "Quaternary Stratigrapphy, Cross Sections, and general Geohydrologic Potential of the Bow and alger 7.5-minute Quadrangles, Western Skagit County, Washington. Open File report 98-8, Washington State Department of Natural Resources, December 1998.

Dragovich, Joe E.; McKay, Donald T. Jr.; Dethier, David P. and Beget, James E. "Holocene Glacier Peak Lahar Deposits in the Lower Skagit River Valley, Washington." Washington Geology, vol. 28, no.1/2, September 2000 with references.

Federal Emergency Management Agency 2003. Guidelines and Specifications for Flood Hazard Mapping Partners. May 19, 2003. Available at www.fema.gov/fhm/dl_cgs.shtm

Flynn, F.J. 1954. Memorandum titled Skagit River Near Concrete, Washington, Historic Flood Peaks. U.S. Geological Survey. July 16, 1954

Hidaka, F.L. 1954. Proposed revisions of historical flood peaks, Skagit River near Sedro-Woolly, Washington. U.S. Geological Survey. January 12, 1954

Interagency Advisory Committee on Water Data 1982. Bulletin No. 17B, Guidelines for Determining Flood Flow Frequency. Office of Water Data Coordination, Hydrology subcommittee. September 1981, Revised March 1982

Kunzler, L.J. 2006. James E. Stewart Skagit River Flood Reports and Assorted Documents, A Citizen Critical Review Whitepaper. Available at www.skagitriverhistory.com, July 11, 2006

Mastin, M.C. 2008 Coastal Habitats in Puget Sound (CHIPS) Poster: New measures of Skagit River sediment load into Skagit Bay-Whidbey Basin, 2006-2007 (PDF, 2.1 MB) Northwest Hydraulic Consultants, 2007. Skagit River Hydrology Independent Technical Review. Final report prepared for Skagit County. April 2007

Open File Report 2000-6, Washington State Department of Natural Resources, Washington Division of Geology and Earth Resources; in cooperation with USGS, Plate 3, "Lahar Inundation of the Lower Skagit River Valley."

Pacific International Engineering, 2004. Evaluation of Flood Peaks Estimated by USGS. Draft report prepared for Skagit County. November 16, 2004

Pacific International Engineering, 2005. Hydrology and Hydraulics, Skagit River Flood Basin – Existing Conditions. Report prepared for Skagit County. December 2005

Pacific International Engineering, 2007. Technical Memorandum, Hydraulic Analysis – Smith House Flood Stages. June 2007

Riggs, H.C. and Robinson, W.H. 1950. Proposed Revision of Skagit River Flood Peaks. U. S. Geological Survey. November 11, 1950

Stewart, J.E. 1922-23. Stewart's survey notes handwritten when he was performing a field flood investigation during the winter of 1922-23. Available from USGS and at www.skagitriverhistory.com.

Stewart, J.E. 1923. Stage and Volume of Past Floods in Skagit Valley and Advisable Protective Measures prior to the Construction of Permanent Flood Controlling Works, 1923. Unpublished report.

U.S. Army Corps of Engineers 1992. Generalized Computer Program HEC-FFA Flood Frequency Analysis User's Manual. U.S. Army Corps of Engineers Hydrologic Engineering Center. May 1992.

U.S. Army Corps of Engineers 2001. Skagit River Basin Draft Hydrology Investigation Report. Technical Services Branch, Hydraulics and Hydrology Section. August 9, 2001

U.S. Army Corps of Engineers 2004. Draft Report – Hydraulic Technical Documentation, Skagit River Basin, Skagit River Flood Damage Reduction Feasibility Study. August 2004

U.S. Army Corps of Engineers 2005. Draft Report –Skagit River Basin, Washington, Revised Flood Insurance Study, Hydrology Summary. November 10, 2005

U.S. Army Corps of Engineers 2008. Draft Report – Skagit River Basin, Washington, Revised Flood Insurance Study, Hydrology Summary. May 1, 2008

United States Geological Survey 1918. Bulletin 674. Spirit Leveling in the State of Washington, 1896 to 1917, Inclusive, by R.B. Marshall, Chief Geographer, 1918.

United States Geological Survey 1961. Water Supply Paper 1527. Floods in the Skagit River Basin Washington, by James E. Stewart and G. Lawrence Bodhaine. U.S. Geological Survey. 1961

United States Geological Survey 1998. Users Manual for Program PEAKFQ, Annual Flood Frequency Analysis Using Bulletin 17B Guidelines. U.S. Geological Survey Water-Resources Investigations Draft Report. January 30, 1998

United States Geological Survey 2005. Computer Software Program PEAKFQ, Annual Flood Frequency Analysis following Bulletin 17B Guidelines. U.S. Geological Survey Water-Resources Investigations. Version 5.0, May 6, 2005

United State Geological Survey 2005. Scientific Investigations Report 2007-5029, Verification of 1921 Peak Discharge at Skagit River near Concrete, Washington, Using 2003 Peak Discharge Data.

United States Geological Survey 2007. Scientific Investigations Report 2007-5159, Re-Evaluation of the 1921 Peak Discharge at Skagit River near Concrete, Washington.