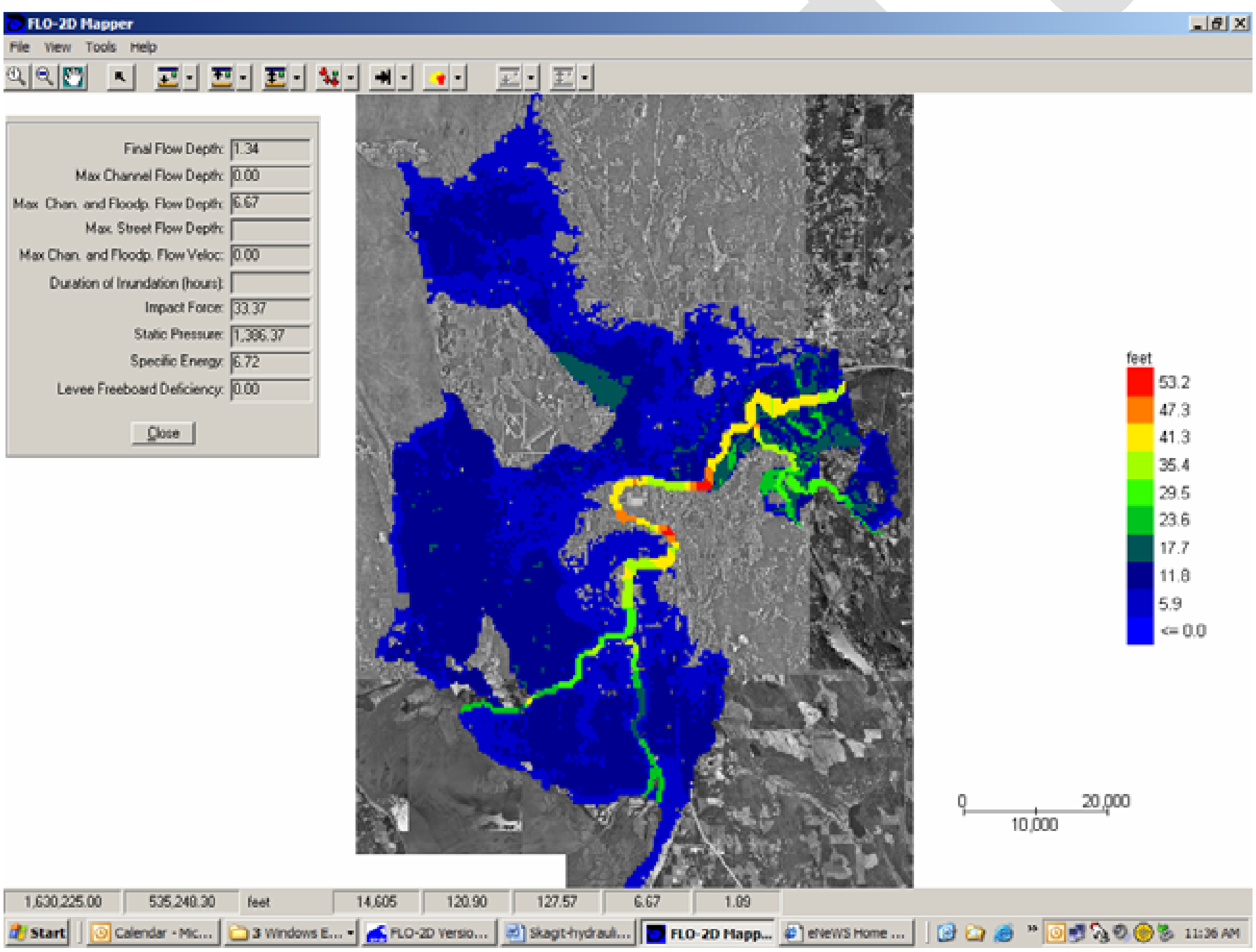
U.S. Army Corps of Engineers
Seattle District

SKAGIT RIVER BASIN, WASHINGTON
REVISED FLOOD INSURANCE STUDY
DRAFT
HYDRAULICS SUMMARY



SKAGIT COUNTY, WA

Prepared For: Federal Emergency Management Agency **22 FEBRUARY 2007**

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Cover photo: Example FLO-2D Output for the Lower Skagit River below Sedro-Woolley.

REVISIONS

This detailed restudy is provided to update the floodplain boundaries and floodway delineations provided in the FEMA report dated October 17, 1984 for Skagit County, Washington and Unincorporated Areas. The study scope called for the determination of the water surface profiles for the 10-, 50-, 100-, and 500-year return frequency floods and delineation of the 100- and 500-year floodplain boundaries from the Skagit River and of the 100-year regulatory floodway. Significant improvements in the modeling capability of complex floodplains such as the lower Skagit River Basin has been made since the previously published FEMA report for Skagit County (1984). The hydraulic model limits extend from river mile (RM) 78.87 on the Skagit River down to the mouths of the North and South Forks of the Skagit River as well as the lower 5.4 miles on the Sauk River and the lower 2.9 miles on the Cascade River. At this time, only the floodplain and base flood elevations for the lower basin below Sedro-Woolley, just downstream of the Highway 9 bridge, to the bays is being updated. A floodway for this lower area and floodplains and floodways for the upper basin will be developed later.

AUTHORITY

The U.S. Army Corps of Engineers, (USACE), Seattle District, performed this restudy for FEMA pursuant to Interagency Agreements EMW-2002-IA-0113 - Project Order No. 5 and EMW01-IA-0244-5.

INTRODUCTION

The hydraulics for this re-study is built off the hydraulic analysis that was developed as part of the Skagit River Flood Damage Reduction (FDR) Study. The following report will detail how this analysis was performed and how it differs from the methodology used for the FDR.

I. BACKGROUND

A. Revised Skagit River Flood Insurance Study Background

In December 2001, FEMA tasked the Corps to perform a revised flood insurance study (RFIS) for the Skagit River downstream of Sedro-Woolley. The original 1984 Flood Insurance Study was limited in its ability to model the lower Skagit Valley floodplain due to the limits of hydraulic computer modeling at the time which required some simplifying assumptions. The Corps has spent considerable effort to accurately model the Skagit River floodplain for the Skagit River Flood Damage Reduction (FDR) Study done in conjunction with Skagit County. This existing analysis uses the latest technology and represented a significant improvement over the methods used for the 1984 Skagit River Flood Insurance Study (FIS).

The RFIS floodplain model is derived from the models built for the Flood Damage Reduction Study. The RFIS model is more complex but is calibrated to the Flood Damage Reduction Study to ensure they perform similarly.

B. Skagit River Flood Damage Reduction Study Background

Authority for the Skagit River, Washington, flood damage reduction feasibility study is derived from Section 209 of the Flood Control Act of 1962 (Public Law 87-874). Section 209 authorized a comprehensive study of Puget Sound and Adjacent Waters, including tributaries such as the Skagit River, in the interest of flood control, navigation, and other water uses and related land resources. The current feasibility study was initiated in 1997 as an interim study under this statutory authority. Skagit County is the local sponsor of the feasibility study and is providing a combination of cash and in-kind services equaling 50 percent of the total study effort. The purpose of the study is to formulate and recommend a comprehensive flood hazard management plan for the Skagit River floodplain that will reduce flood damages downstream of Sedro-Woolley. A secondary purpose is to investigate measures to restore ecosystem functions and processes in the project area to benefit fish and wildlife.

The authorization for the Skagit River Flood Control Feasibility Study necessitated hydrologic and hydraulic analysis of the Skagit River basin. This allows for a basin-wide, systematic evaluation of the Skagit River. These analyses incorporate historic rainfall-runoff, reservoir operations, and flow along the major river systems to effectively evaluate the hydraulic performance of the flood management systems. The models can be used to assess the performance of the current systems or modified systems under a wide range of hydrologic conditions.

The Corps' Flood Damage Reduction Study hydraulic modeling effort was technically reviewed by the Corps' Hydrologic Engineering Center, WEST Consultants, and Tetra Tech for Puget Sound Energy and was developed with significant input from Skagit County.

C. Purpose of Documentation

This report documents the work conducted for the Skagit River RFIS to develop hydraulic computer models, and establish existing hydraulic conditions, floodplains, and a 100-year floodway. The main product components of this effort include:

- Description of the hydraulic analysis methodology
- Development of the models (HEC-RAS and FLO-2D) for the Skagit River Basin
- Modeling and Profiles for the 10-, 50-, 100-, and 500-year events
- Illustration of Base Flood Elevations (BFEs) based on 100-year model results
- Illustration of the 500-year flood extent
- Illustration of a 100-year Floodway based on model results will be done in the next phase

D. Study Area

The hydraulic modeling area encompasses the Skagit River basin from Marblemount, Washington (River Mile (RM) 78.87) to Skagit Bay. It also includes the Sauk River from the confluence with the Skagit to the Sauk River at Sauk gage, and the Cascade River from the confluence of the Skagit to the old Cascade River at Marblemount gage. The Skagit River basin has a drainage area of 3,115 square miles of which 2,737 square miles is above Concrete, Washington. The hydraulic modeling area is illustrated in Figure 1. In this phase, only the floodplain area below the Highway 9 bridge near Sedro-Woolley is being updated with new base flood elevations and extents. The extent of the lower basin is shown by the shaded colored areas in Figure 3. The upper basin will be updated in the next phase.

E. Skagit River Basin

The Skagit River basin is located in the northwest corner of the State of Washington. The Skagit River 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 originates in a network of narrow, precipitous mountain canyons in Canada and flows west and south into the United States where it continues l35 miles to Skagit Bay. Skagit River falls rapidly from its source to an elevation of 1600 ft at the United States-Canadian Border. Stream profiles on Figure 2 show that within the first 40-miles south of the International Border, the River falls 1,100 feet and that the remaining 500 feet fall is distributed along the 95 miles of the lower river.

The Skagit Valley, the 100,000-acre valley area downstream from the town of Concrete, contains the largest residential and farming developments in the basin. The 32-mile long valley between Concrete and Sedro-Woolley is made up of mostly cattle and dairy pasture land and wooded

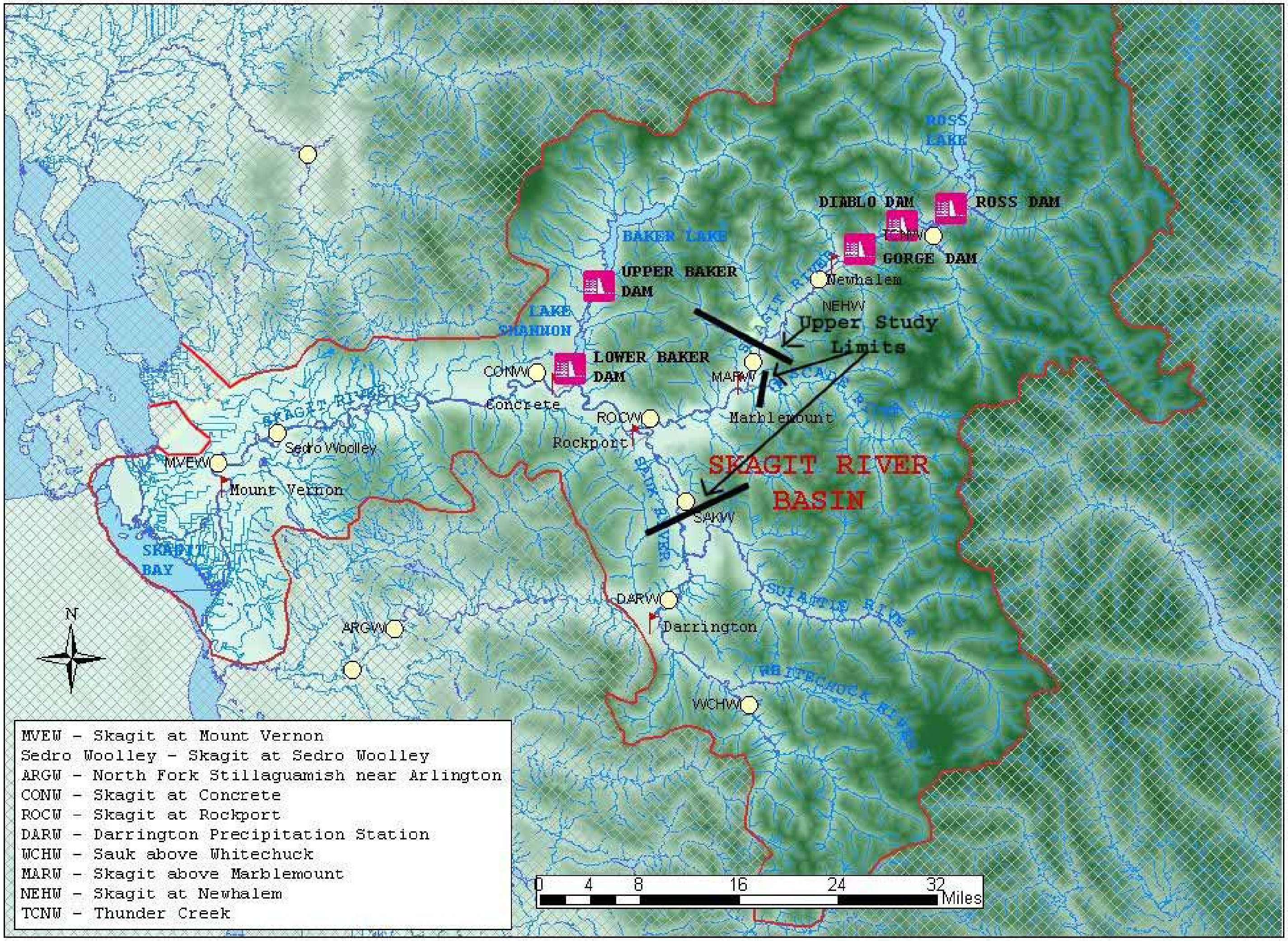

Figure 1 – Skagit River Basin and the Upper Study Boundary

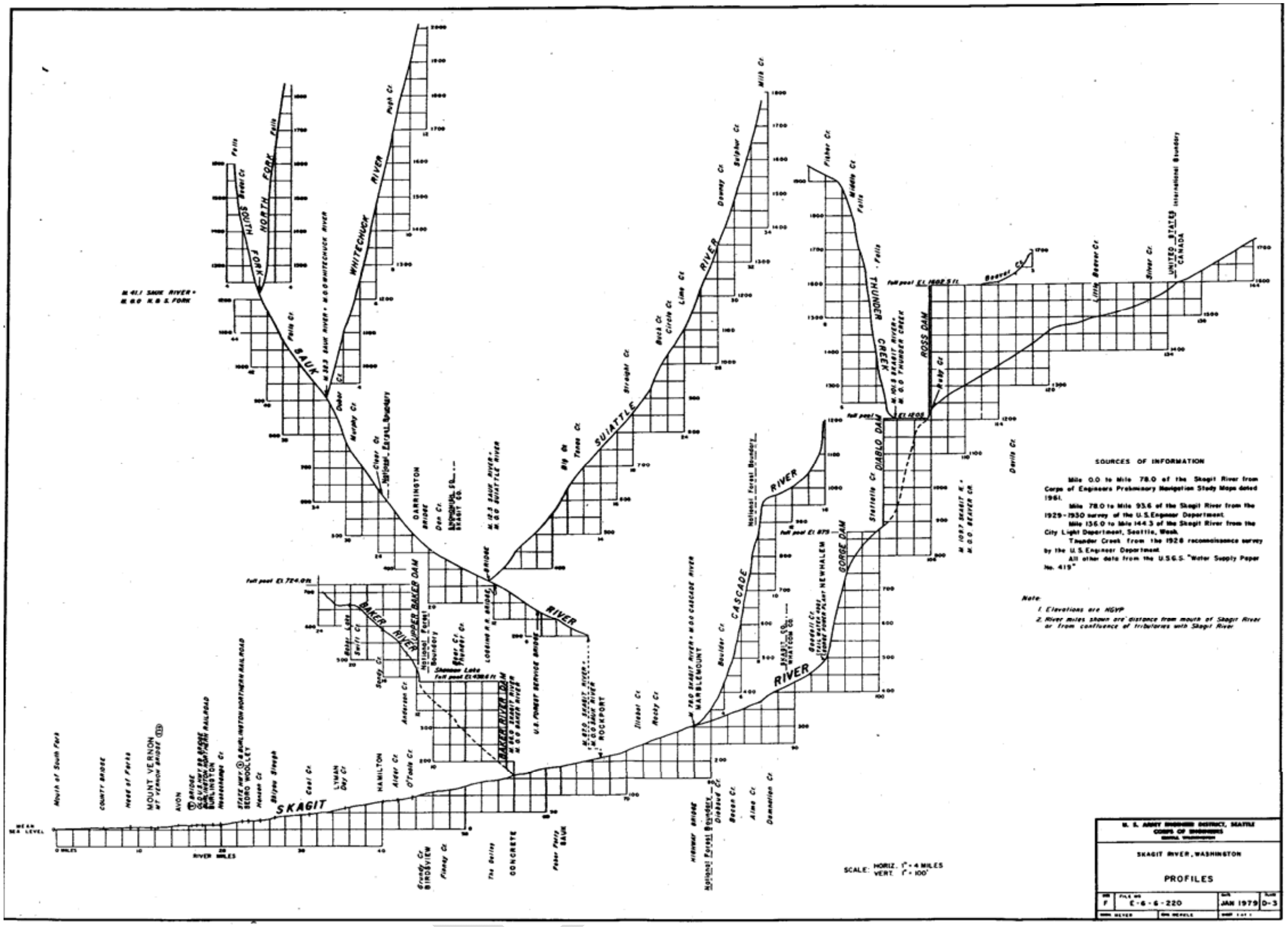

Figure 2- Skagit River Stream Profiles

areas. West of Sedro-Woolley, the flood plain forms a large alluvial fan with an east-west width of about 11 miles and a north-south width of about 19 miles.

The source of the Skagit River starts at 8,000 feet and drops to 1,600 feet at the US border. The average bed slope from Concrete to the mouth is 0.045%. From Concrete to Sedro-Woolley (RM 22.4), the river flows in a valley 1 to 3 miles wide. The valley walls in this section are steeply rising timbered hills. Below Sedro-Woolley, the valley descends to nearly sea level and widens to a flat, fertile outwash plain that joins the Samish Valley to the north and then extends west through Mount Vernon to La Conner and south to the Stillaguamish River. Between Mount Vernon and Sedro-Woolley, a large area is being used as storage, primarily in the Nookachamps Creek Basin along the left overbank of the Skagit River. For high river flows at Mount Vernon, a portion of the Skagit River in this reach can overflow along the right bank and escape out of the system through Burlington via Gages Slough and out to Padilla Bay and out to the Samish River and Samish Bay. This starts at a low spot on Highway 20 in the Sterling area where the road can be overtopped when water reaches an elevation of 39.9 feet NGVD 29. Different preceding flow conditions can produce slightly different model results on when this can exactly occur due to differing backwater affects from Mount Vernon but this overflow can start occurring for flows over 140,000 cfs. The Skagit River continues through a broad outwash plain in the lower reach nearest the river mouth and divides between two principal tributaries, the North Fork and the South Fork, which are 7.3 and 8.1 miles long, respectively. About 60 percent of the discharge is carried by the North Fork and the remainder is carried by the South Fork during lower flows but this split becomes closer to 50-50 in higher flows.

II. HYDRAULIC ANALYSIS METHODOLOGY

A. Model Extent

This section describes the hydraulic analysis methodology, including the development of the HEC-RAS and FLO-2D hydraulic models, the modeling approach, levee methodology, and the development of floodplains. These models will be used to identify current base flood elevations and floodways.

B. Study Approach

For this study, two computer hydraulic models, HEC-RAS Unsteady Flow version 3.1.3 and FLO-2D Version 2006.01, are utilized to represent the hydraulics in the Skagit River Basin. The steps taken to develop these models will be explained. In addition, detailed information about the strengths, applicability, and limitations of each of these analytical tools are presented.

C. Floods Studied

For the hydraulic analysis, hypothetical floods with 10-, 50-, 100-, and 500-year return frequencies are explicitly modeled. The floodway analysis will only utilize the 100-year flood. For information on how the hydrographs are developed for input into the models see the Hydrology Report.

D. Description of Hydraulic Models

Computer-based hydraulic models, such as HEC-RAS and FLO-2D, turn theoretical and empirical equations into useful analytical tools for simulating current, baseline conditions and analyzing alternative flood management scenarios. The two models are used jointly to simulate the channel and overbank hydraulics in the Skagit River system.

The HEC-RAS Unsteady Flow model is built off of the computer program UNET developed by Dr. Robert L. Barkau. HEC-RAS Unsteady Flow and its predecessor, UNET, have been used extensively by Corps of Engineers offices and have been in the public domain since 1990. Over this time, confidence has been built on how this model performs. This model is used and appropriate for the river system upstream of Sedro-Woolley. Its limitation is that it is a 1-dimensional model. It has the ability to store water in the overbanks but if that water can leave the system through other pathways, it becomes more difficult to model correctly. This problem presents itself in the lower Skagit River valley where flow can leave the system towards Samish Bay, Padilla Bay, or Skagit Bay. To model this area accurately, a two-dimensional overbank flow model is necessary.

FLO-2D is a hydraulic model that acts as a 1-dimensional unsteady flow in the channel and a 2-dimensional model for overbank flows. The model has been approved by FEMA for the National Flood Insurance Program (NFIP) for flood insurance studies. For the FDR study, it was necessary to have very precise information on the channel water surface elevations because a number of the proposed solutions involve work near the channel. Because the Corps has more experience and familiarity with the HEC-RAS unsteady flow in-channel model, this channel model was preferred over using the FLO-2D in-channel model. Because the FDR study modeled isolated levee failures, the flows going overbank did not get back to the river. For this reason, it was acceptable to have a separate HEC-RAS in-channel model and overbank FLO-2D models where the output of the HEC-RAS model acted as the input to the FLO-2D models.

For the RFIS study, entire levee systems are removed at once so water can leave the channel and come back to the channel. This makes it necessary to have a model that has both the channel and overbanks connected. To ensure that the FLO-2D model in-channel results mimic the HEC-RAS model results, the FLO-2D model was calibrated to observed gage data and high water marks and compared to the HEC-RAS results. The following sections detail the development of these models for the FDR study and their adaptation for the RFIS study.

1. HEC-RAS Model Development

The computer model, HEC-RAS, developed by the Corps of Engineers Hydrologic Engineering Center, is designed to simulate unsteady flow through a full network of open channels, weirs, bypasses, and storage areas. For this study, use of the HEC-RAS model is utilized primarily for the basin upstream of Sedro-Woolley. Downstream of Sedro-Woolley, the in-channel model developed for the FDR study is utilized to assist in the calibration of the in-channel FLO-2D model. The May 2005 HEC-RAS Version 3.1.3 is used for this study. For more information about the capabilities of this model, refer to the November 2002 HEC-RAS User's Manual.

a. Purpose of Model

The purpose for using HEC-RAS in the RFIS is to provide a means for understanding and representing the channel hydraulics in the Skagit River system. The HEC-RAS models are constructed to allow modeling of flood flow conditions. The HEC-RAS models are used to determine river stage, velocity, and depth. In addition, a 100-year floodway will be modeled upstream of Sedro-Woolley in the next phase.

b. Procedures and Process

Cross sectional data from the upstream boundary to the downstream boundary was developed in 1975 for the Flood Insurance Study (FIS) for Skagit County (FEMA, 1984). This data was collected by Seattle District of the US Army Corps of Engineer's (USACE) Survey Branch. Floodplain geometry was obtained via aerial photogrammetry, while channel cross sections were field surveyed. All of the 52 cross sections from Concrete to Sedro-Woolley (RM 55.35 to RM 22.4) from the 1984 study are used for this study. In addition, 57 cross sections for the Skagit River from Marblemount to Concrete, 10 cross sections for the Cascade River, 13 cross sections on the Sauk River, and 4 cross sections on the Baker River are used from the 1984 study. All of the cross sections from Sedro-Woolley to Skagit Bay were resurveyed in 1999 by Skagit County. Some of these cross sections only included the underwater portions of the cross section so some parts of the 1975 cross sections are used in this reach to provide more detail. These cross section locations can be found in Figure 3.

Supplemental bridge data was field surveyed in 1998 by USACE - Seattle District's Survey Section for the State Route 9 (SR-9) crossing at Sedro-Woolley, while bridge data (station, elevation, and distance to adjacent cross sections) for the former Great Northern Railroad Bridge just upstream of the SR-9 crossing was estimated from field measurement, photographs, USGS topographic maps, and profile point data. Bridge low and high chords are modeled along with bridge piers. For the second railroad bridge at RM 17.56, a significant amount of debris stacks up at the bridge. The debris loading condition used at the RR Bridge assumes that there is debris stacked up on the bridge 20 feet high for a 500-foot width of the channel. This is the condition that was observed in the November 29, 1995 flood. This loading condition is selected as the existing condition because it would be difficult to remove this debris during extreme high flow events.

Overbank and channel distances between cross sections were assigned by scaling the linear channel and overbank distances between sections on a topographic map. Overbank distances were adjusted according to the presumed flow path. Due to the relatively confined nature of the floodplain from Concrete to Sedro-Woolley and the somewhat steep channel gradient, no HEC-RAS defined off-stream storage areas are used for that reach.

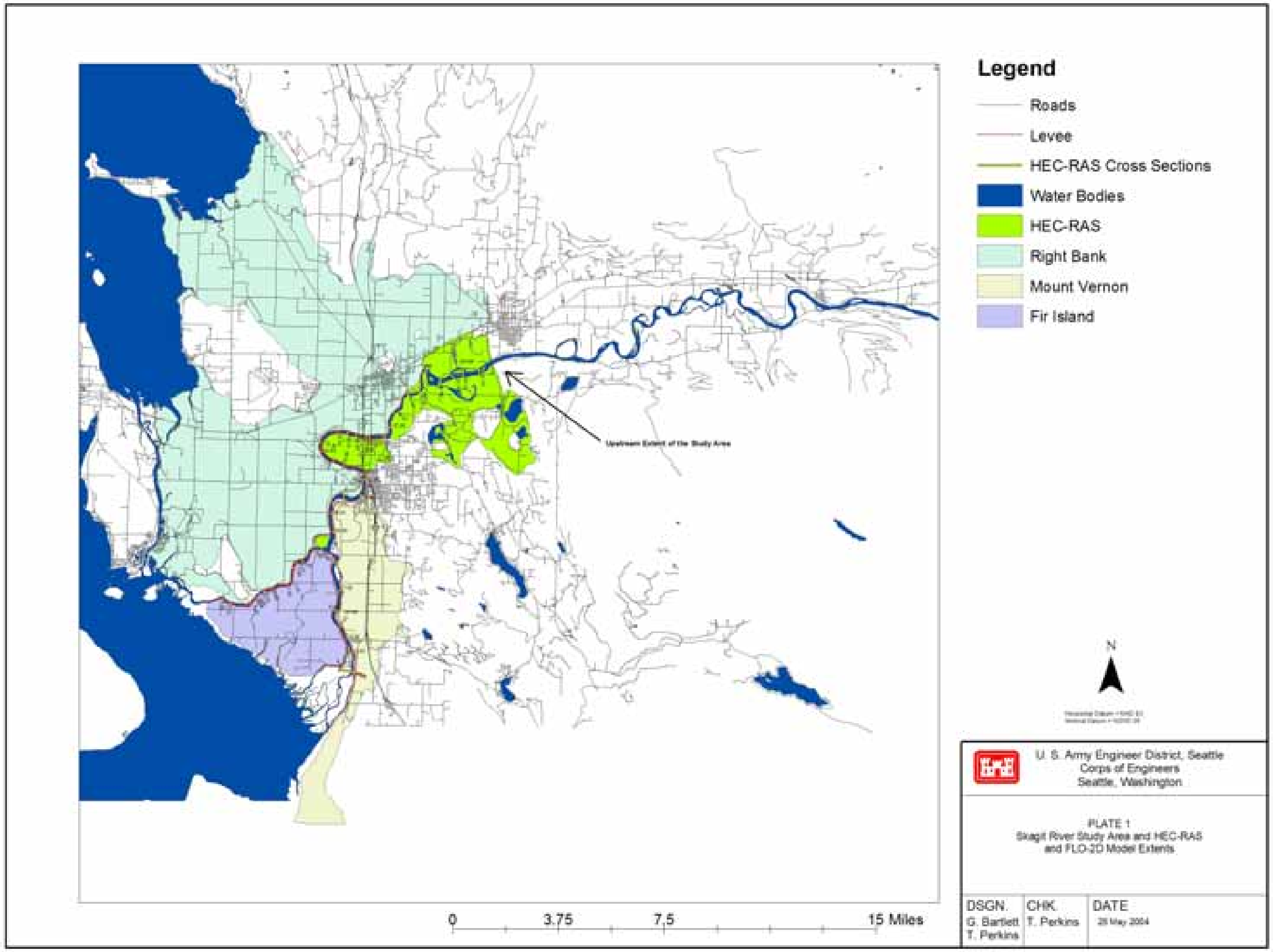

Figure 3 – Map Outlining the Downstream Modeling Efforts in the Flood Damage Reduction Study

Resistance factors are estimated based on engineering judgment from field assessment of the channel and overbanks of the reach and from interpretation of topographic maps. Channel resistance factors of 0.035 and 0.04 are typical, while overbank resistance factors of 0.08 to 0.15 are assigned based on judgment dependant primarily on land use, land cover, topography, and historic and expected depth of flooding.

c. Boundary Conditions

The four primary types of boundary conditions in HEC-RAS are interior, upstream, downstream, and internal. Interior boundary conditions define reach connections and ensure continuity of flow. Upstream boundary conditions are required for all reaches that are not connected to another reach at their upstream end. An upstream boundary condition is a flow hydrograph of discharge versus time for a particular flood event. For this model, an upstream hydrograph is developed for the Skagit River at Marblemount, Cascade River at Marblemount, the Sauk River at Sauk, and the Baker River at Concrete (for methodology, refer to the Hydrology Report).

Downstream boundary conditions are required at the downstream end of all river systems not connected to another reach or river. Downstream boundary conditions consist of stage hydrographs and represent tailwater conditions such as tidal or estuary influences. The downstream boundary condition for both the North and South Forks of the Skagit River is a tidal hydrograph, which has a primary peak at the Mean Higher High Water (4.62 feet NGVD 29), a secondary peak at the Mean High Water (3.72 feet NGVD 29), and a low at the Mean Low Water. This downstream boundary only strongly influences the stages in the immediate vicinity of the boundary (lower couple miles). Various runs were done initially to ensure that this is true. Because of this, timing of the peak in the tidal hydrograph is fairly arbitrary. Internal boundary conditions are coded in HEC-RAS to represent levee failures or storage interactions, spillways or weir overflow/diversion structures, bridge or culvert hydraulics, or pumped diversions.

The stages produced by the lower basin FLO-2D model at the upstream location are then used as the downstream boundary condition on the HEC-RAS model from Concrete to Sedro-Woolley. This modification is made as the FLO-2D water surface elevations developed by a 2-dimensional model below Sedro-Woolley will be more accurate for the 100-year flood than the 1-dimensional model. This also ensures consistency between the stages upstream and downstream of Sedro-Woolley.

Local inflows are distributed evenly from Marblemount to Concrete and from Concrete to Sedro-Woolley. Nookachamps Creek is entered into the system as a lateral flow at River Mile 20.0 (see Hydrology Report for description on the derivation of these flows).

d. Basic Assumptions and Limitations

It is important to note some of the basic capabilities, assumptions, and limitations inherent with the HEC-RAS models. HEC-RAS is used to simulate one-dimensional, unsteady flow. It is a fixed bed analysis and does not account for sediment movement, scour, or deposition. The models assume no exchange with groundwater. The model is intended to simulate channel hydraulics. The spacing of cross sections in the HEC-RAS models also limits the application of these models to problems not requiring finer detail.

2. FLO-2D Model Development

FLO-2D is used to model the lower Skagit River Basin from Sedro-Woolley to Samish, Padilla, and Skagit Bays for this study. Version 2006.01 is used to conduct this effort. More information about FLO-2D can be found in the 2006.01 FLO-2D User's Manual.

a. Purpose of Model

FLO-2D is used in this study to model the lower Skagit River valley, which is comprised of flows that travel out of stream channels and across the topography of the floodplain. FLO-2D has the capability of modeling both one-dimensional channel flow and two-dimensional overbank flow. The Skagit River from Marblemount to Sedro-Woolley is fairly contained so HEC-RAS is exclusively used to model that reach. FLO-2D is necessary to define the routing of overbank flows below Sedro-Woolley.

b. Procedures and Process

Assembling topographic data is the first task in developing the FLO-2D model for the Skagit River Basin. The entire floodplain for the lower Skagit Valley was aerial surveyed in 1999. This information is used to develop new topographic maps of the lower floodplain. A FLO-2D grid of the floodplain has been developed using the information from the aerial flight. This mapping was done to an accuracy that meets ASPRS standards for Class 2 accuracy for 2-foot contours, which means that the topographic feature points are +/- 1.33 feet and the spot or Digital Terrain Model (DTM) elevation points are +/- 0.67 feet. The floodplain model uses a grid system to route the overbank flows. For this study a 400-by-400 foot grid is utilized. This grid size is chosen to provide the necessary detail on the floodplain without burdening the model computationally with excess grids.

The average elevation for each grid cell is coded into the model along with information on the location and size of all structures in the floodplain. All features in the floodplain are noted on the new maps including houses, structures, and roads. Elevated roads are input so that the height of the roads could direct flow. The roads are modeled as levees that direct flow. Sea dikes are modeled the same way. Structures are included in the floodplain model by reducing the flow surface that each grid element can use. Post-processing of the output in conjunction with basin topographic data is performed to generate and define floodplains. The complete model contains 24,295 grids covering 89,238 acres.

The channel portion of the FLO-2D model uses the same cross sections and methodology used for the HEC-RAS channel model (see section 1B) with a few exceptions. FLO-2D does not have capability to model bridges with the same complexity that HEC-RAS does. It uses a rating table that relates the stage upstream of the bridge and the flow making it through the bridge. These bridge rating tables are developed from the relationships observed in the HEC-RAS model for the full range of flows.

FLO-2D allows flow to be routed through the model with either a diffusive wave approximation or with the fully dynamic wave routing technique. Guidelines on which technique should be used can be found in EM 1110-2-1417, Flood Runoff Analysis (USACE, 1994). Due to the channel hydraulics and the complex interaction of overtopping levees and sea dikes, the fully dynamic wave routing method was determined to be appropriate.

c. Boundary Conditions

The types of boundary conditions in the FLO-2D computer model include inflow and outflow boundary nodes, tailwater conditions, and inflow hydrographs. Inflow boundary nodes are identified in the input file and inflow hydrographs are provided from the HEC-RAS model at the Highway 9 bridge near Sedro-Woolley and for the Upper and the East Fork branches of Nookachamps Creek. Outflow boundary nodes are indicated in the input data along with the general direction of the outflow (among the eight possible directions). The downstream boundary condition on the North and South Forks of the Skagit River is a tidal hydrograph, which has a primary peak at the Mean Higher High Water (4.62 feet NGVD 29), a secondary peak at the Mean High Water (3.72 feet NGVD 29), and a low at the Mean Low Water. The model's flow also exits over the sea dikes into the Swinomish Channel and Padilla Bay, Samish Bay, Skagit Bay, and the Stillaguamish River near Stanwood. Tailwater conditions for the outflow nodes are based on normal depth, with the slope computed from adjacent node elevations.

d. Basic Assumptions and Limitations

Several basic assumptions and limitations must be considered with the FLO-2D model. Two-dimensional flow simulation in FLO-2D is limited to the eight directions of the compass (north, northeast, northwest, east, southeast, south, southwest, and west).

The model can route channel and overland flow using the fully dynamic wave or the diffusive wave approximation to the momentum equation. The fully dynamic wave is necessary for this study due to the complexity of the floodplain and channel.

The simulations performed represent a fixed bed analysis so erosion and sedimentation in the floodplain are not modeled. Culverts under roads are also not modeled. The reason that culverts are not modeled for overland flow is that the capacities of the culverts are small compared with the overbank discharge. The FLO-2D model does not contain any sea dike failure scenarios and do not account for pump stations or any other flood fighting techniques to reduce the flood damage.

3. Structures Affecting Flow

a. Levees

The extent of the levee system in the Skagit River system can be seen in Figure 3 in red. Information on levee improvements has been obtained from the diking districts through the improvements made after the October 2003 flood event.

b. Bridges

The bridges in the Skagit River Basin modeled in this study are shown in Table 1. Information regarding bridge geometry, size, and other parameters included in the HEC-RAS model are obtained from bridge as-built drawings and field investigations.

Table 1 – Modeled Bridges on the Skagit River

Bridge Name	**River Mile**
Burlington Northern RR 1	MS 22.4
State Route 9	MS 22.3
Burlington Northern RR 2	MS 17.56
Riverside Drive	MS 17.08
I-5	MS 16.8
Division Street	MS 12.95
Chilberg Road	NF 5.80
Fir Island Road	SF 5.80

MS = Mainstem, NF = North Fork, SF = South Fork

There are three types of hydraulic conditions that could occur at the bridge: free or low flow (when flow is below the bridge deck and only constricted by the piers), pressure flow (when the bridge deck is submerged and the bridge acts as a pressurized conduit or orifice), and weir flow (when flow is overtopping the bridge deck). The free and submerged rating curves are computed for the bridge-weir system for a range of headwater and tailwater elevations.

FLO-2D does not have capability to model bridges with the same complexity that HEC-RAS does. It uses a rating table that relates the stage upstream of the bridge and the flow making it through the bridge. These bridge rating tables are developed from the relationships observed in the HEC-RAS model for the full range of flows. The lower basin FLO-2D model starts immediately downstream of the State Route 9 bridge.

c. Diversion/Impoundment Structures

No diversions or impoundment structures are modeled from Marblemount to the mouth. This is because there are none that significantly impact the flood flows of the Skagit River and the upper basin dams are upstream of the model and are accounted for in the hydrologic analysis.

d. Groundwater Infiltration

FLO-2D allows for flows to be able to infiltrate into the ground. Most of the lower basin is in the Skagit soil series which is described as consisting of very deep, poorly drained soils on floodplains and deltas. The soils are formed in recent alluvium and volcanic ash (Klungland and McArthur, SCS and WADNR, 1989). This soil is a silty loam.

During large floods such as the 100-year flood, there is likely to be heavy rainfall before and during the flood in the lower basin which will fill some of the infiltration storage before the flood arrives. This combined with the general state of the soil is the reason that the soil is given a 90% initial saturation rate. This then has the primary infiltration dependent on the saturated hydraulic conductivity. The average hydraulic conductivity of 0.27 in/hr and average capillary suction head of 6.8 inches for the soil was determined from the references in the FLO-2D user's manual (FLO-2D, 2006) for a silty loam soil.

4. Levee Methodology

The 10-, 50-, 100-, and 500-year frequency discharges were evaluated to determine whether the levee system could be considered to contain those discharges and meet FEMA freeboard criteria (i.e., at least 3 ft freeboard to top of levee). These computations revealed that, of the discharges considered, only the 10-year frequency discharge could be contained below the existing top of the levee and even that flow would not meet FEMA's freeboard criteria. It should be noted that the Corps methodology for levee certification has been adapted from the straight 3 feet of freeboard methodology to one that involves evaluating risk and uncertainty in determining the necessary freeboard on a levee. This requires performing a series of runs to determine what levee elevation will contain a flood 90% of the time. The levees in this basin would not meet this criterion as well for any flood above the 10-year flood.

The methodology for developing the base flood elevations from different levee condition scenarios were derived from Appendix H of the Flood Insurance Study Guidelines and Specifications for Study Contractors (FEMA, 2002). These guidelines state:

"If the subject levee does not meet the requirements stated in 44 CFR 65.10, as verified by the Regional PO, the 100-year flood elevations will be recomputed as if the levee did not exist. None of the subject levee should be recognized as providing 100-year flood protection unless there are portions of the levee system that can meet requirements of 44 CFR 65.10 independent of the remaining levee system. The 100-year flood levels on the unprotected side of the levee will be equal to the 100-year water-surface elevations computed with the levees in place...

The above procedures for the determination of profiles and floodways can also be applied to the conditions where levees exist on both sides of the stream. If levees exist on both sides of a stream, the evaluation of levee systems must consider the possibility of simultaneous levee failure, failure of only the left side, and failure of only the right side. Simultaneous levee failure should be considered for profile and floodway computations…

For levee systems where an area of land may be totally or partially surrounded by levees or where two or more flooding sources join that have levees on both sides of the stream, the SC should contact the Regional PO before proceeding with any analyses for levee failures. For these complex situations, the flood hazard in the area that would have been protected by the non-failed levee(s) should be based on selection of failure scenarios that yield the highest BFE or flood hazard."

The lower Skagit River valley has levees that encompass all of these conditions. There are levees on both sides of the river from the Burlington Northern Railroad Bridge (River Mile 17.5) to the split at Fir Island into the North Fork and South Fork Skagit Rivers. The North and South Forks also have levees on both sides of the river. Fir Island is completely surrounded by two flooding sources (North Fork Skagit River and South Fork Skagit River). The Big Bend area that encompasses North Mount Vernon also is surrounded by levees on the left bank from the Burlington Northern Railroad Bridge (River Mile 17.5) to the Division Street Bridge (River Mile 12.95). After consulting with the Regional PO for FEMA, seven levee removal scenarios were deemed necessary to run to appropriately depict the base flood elevation. These scenarios are shown in Figures 4 through 10. Figure 11 details how the scenarios are used to define the different floodplain areas.

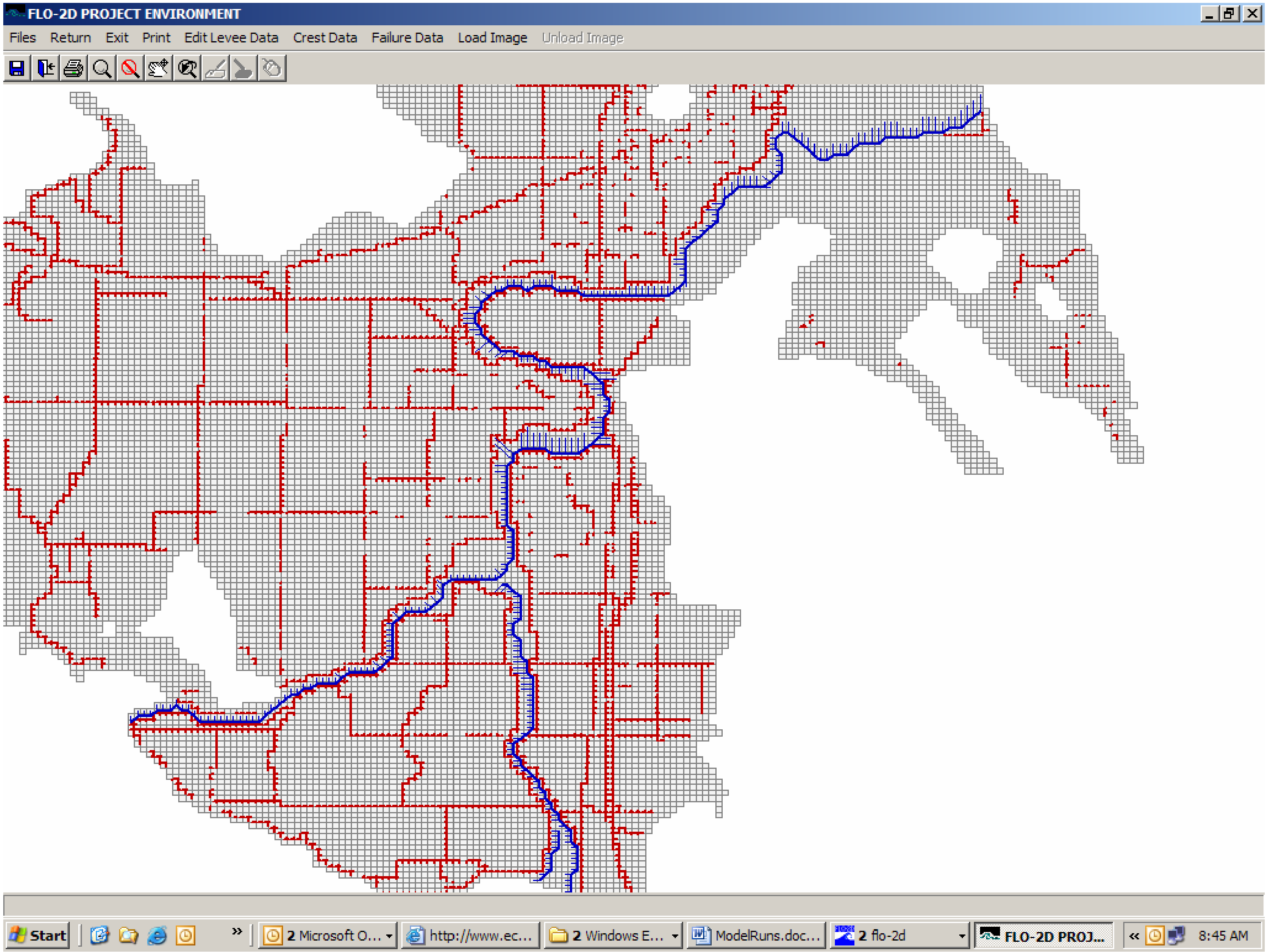

Figure 4 - All Levees Intact

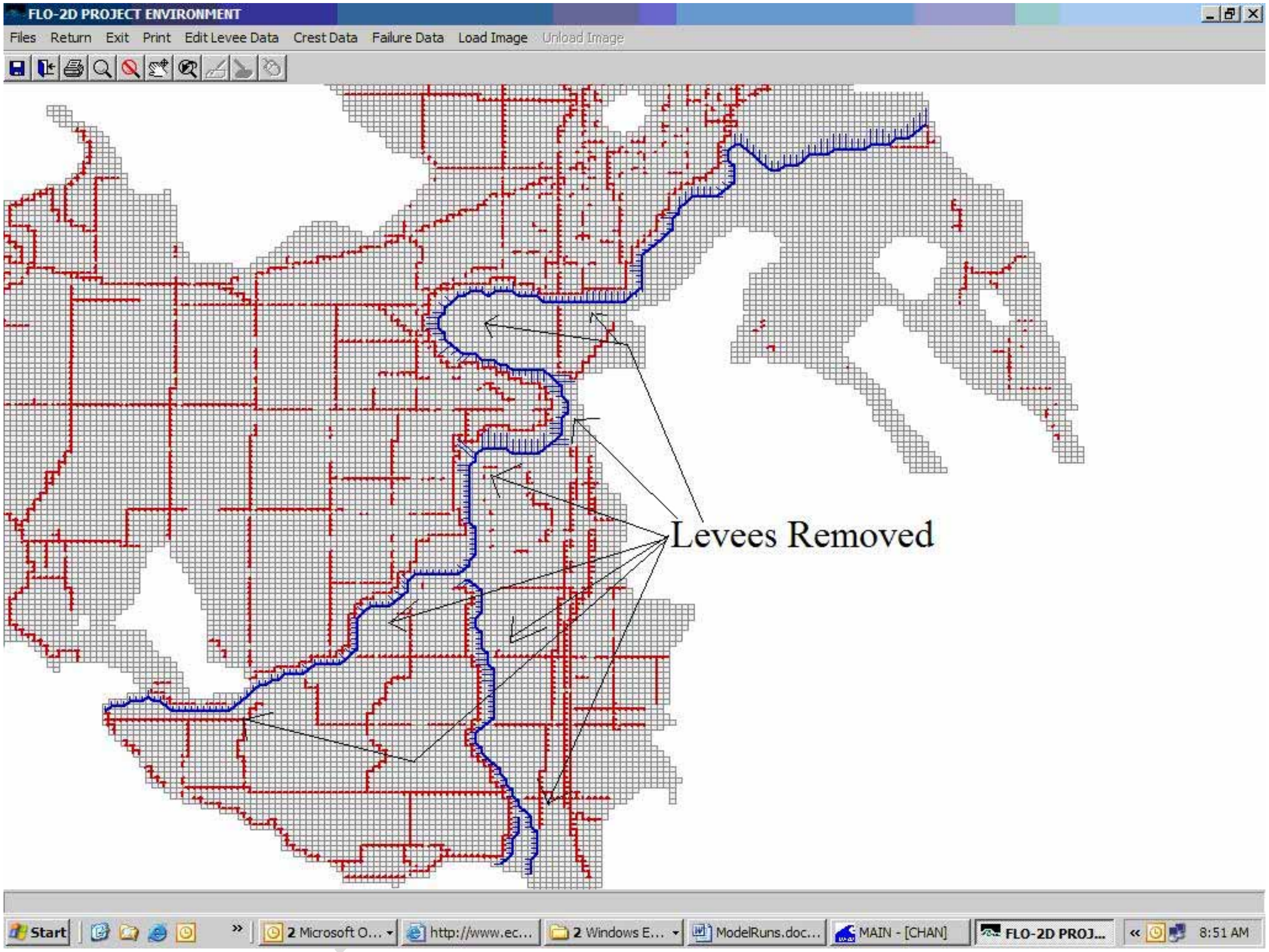

Figure 5 - All Left Bank Levees Removed with Right Bank Levees Intact

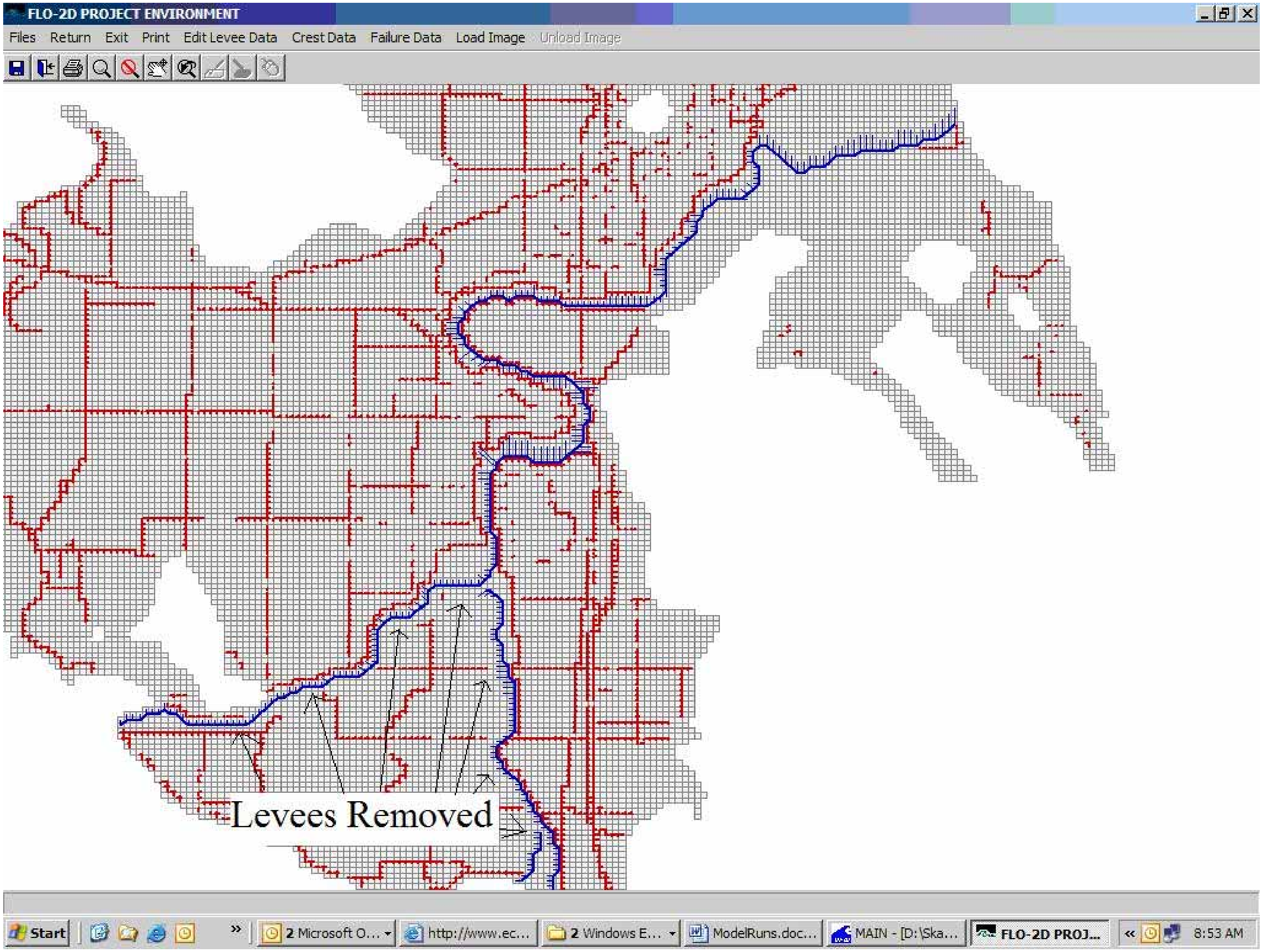

Figure 6 - Fir Island Levees Removed While All Other Levees Remain Intact

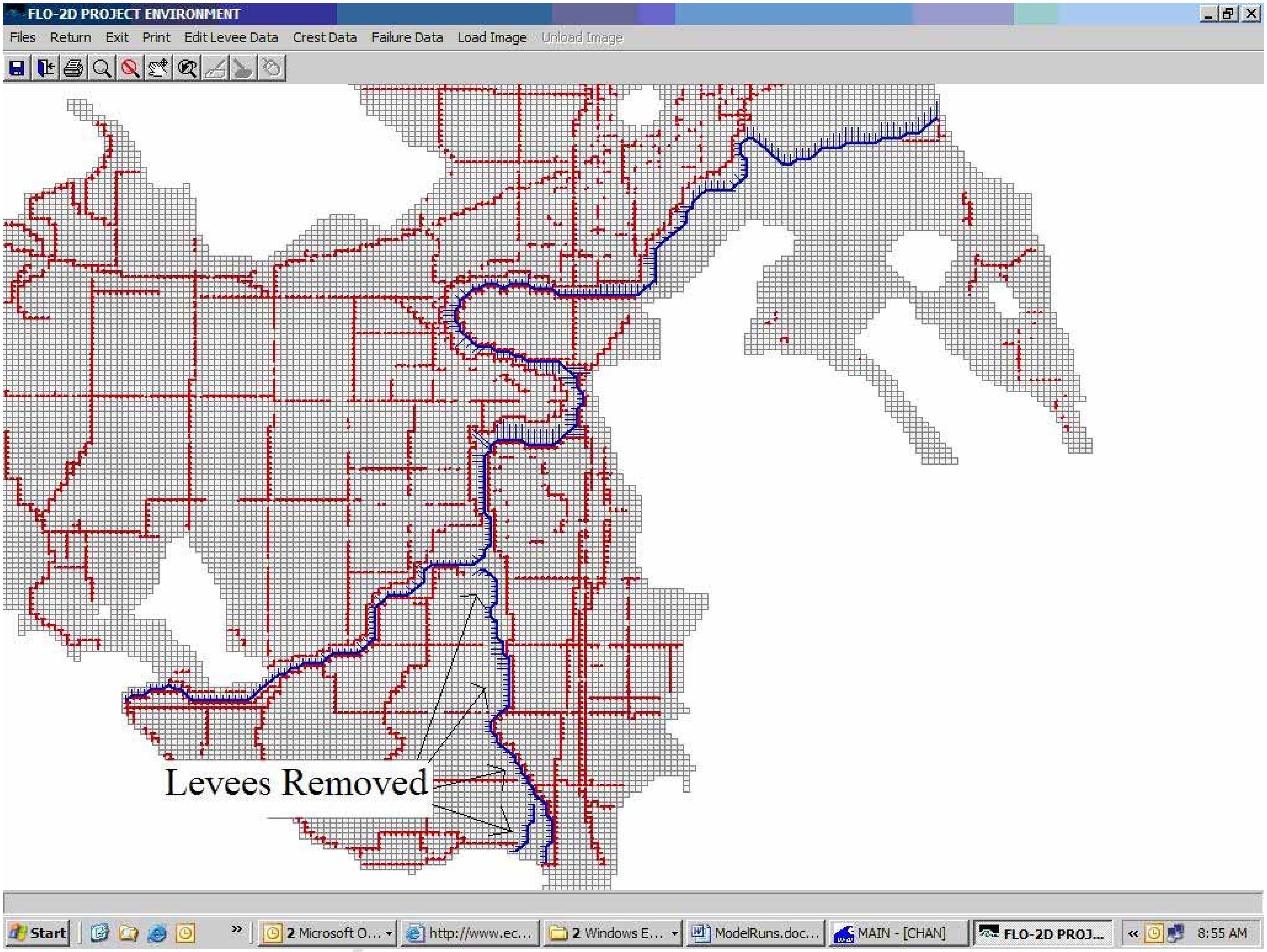

Figure 7 - South Fork Skagit River Right Bank Levee Removed While All Other Levees Remain Intact

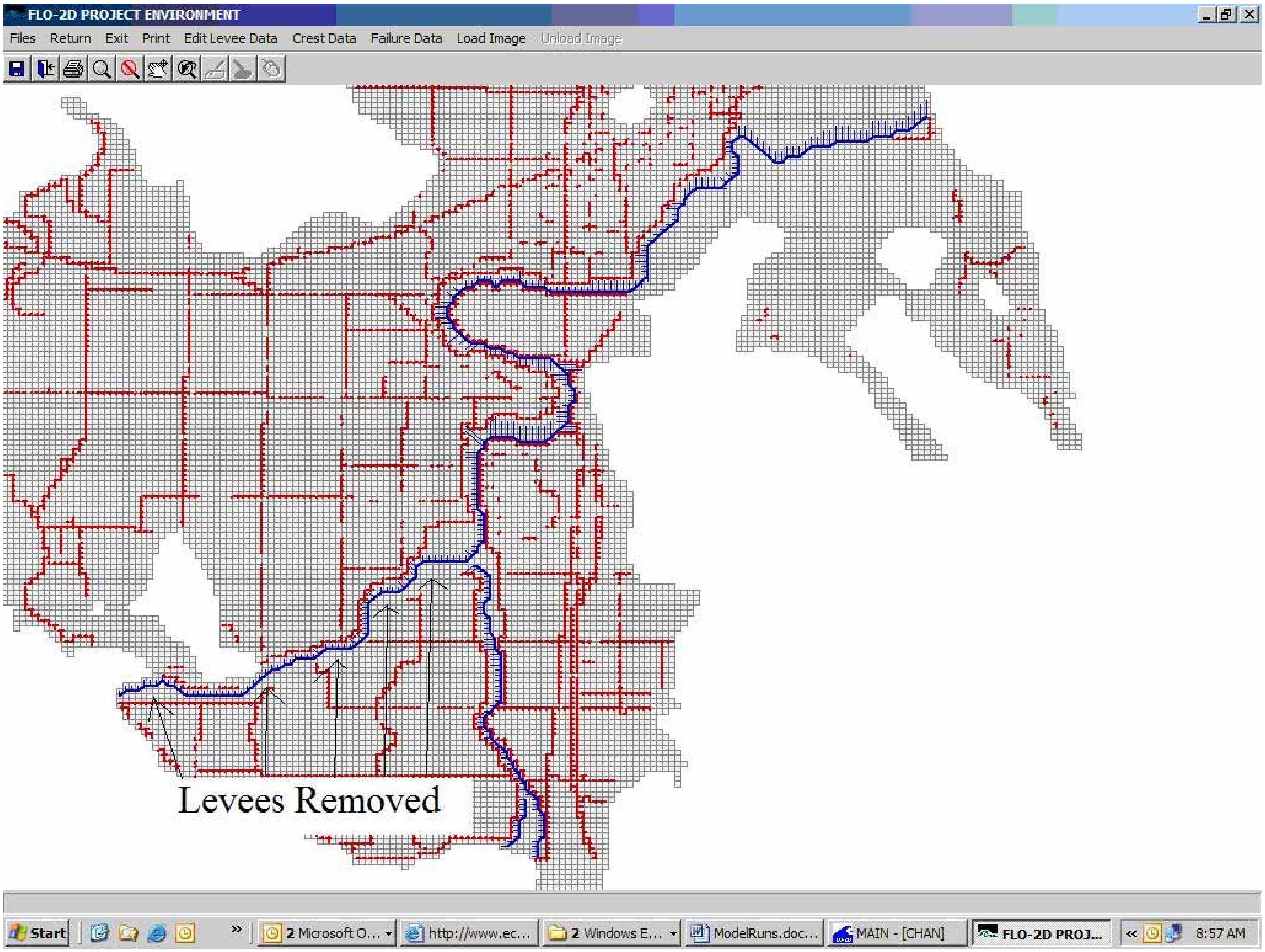

Figure 8 - North Fork Skagit River Left Bank Levees Removed While All Other Levees Remain Intact

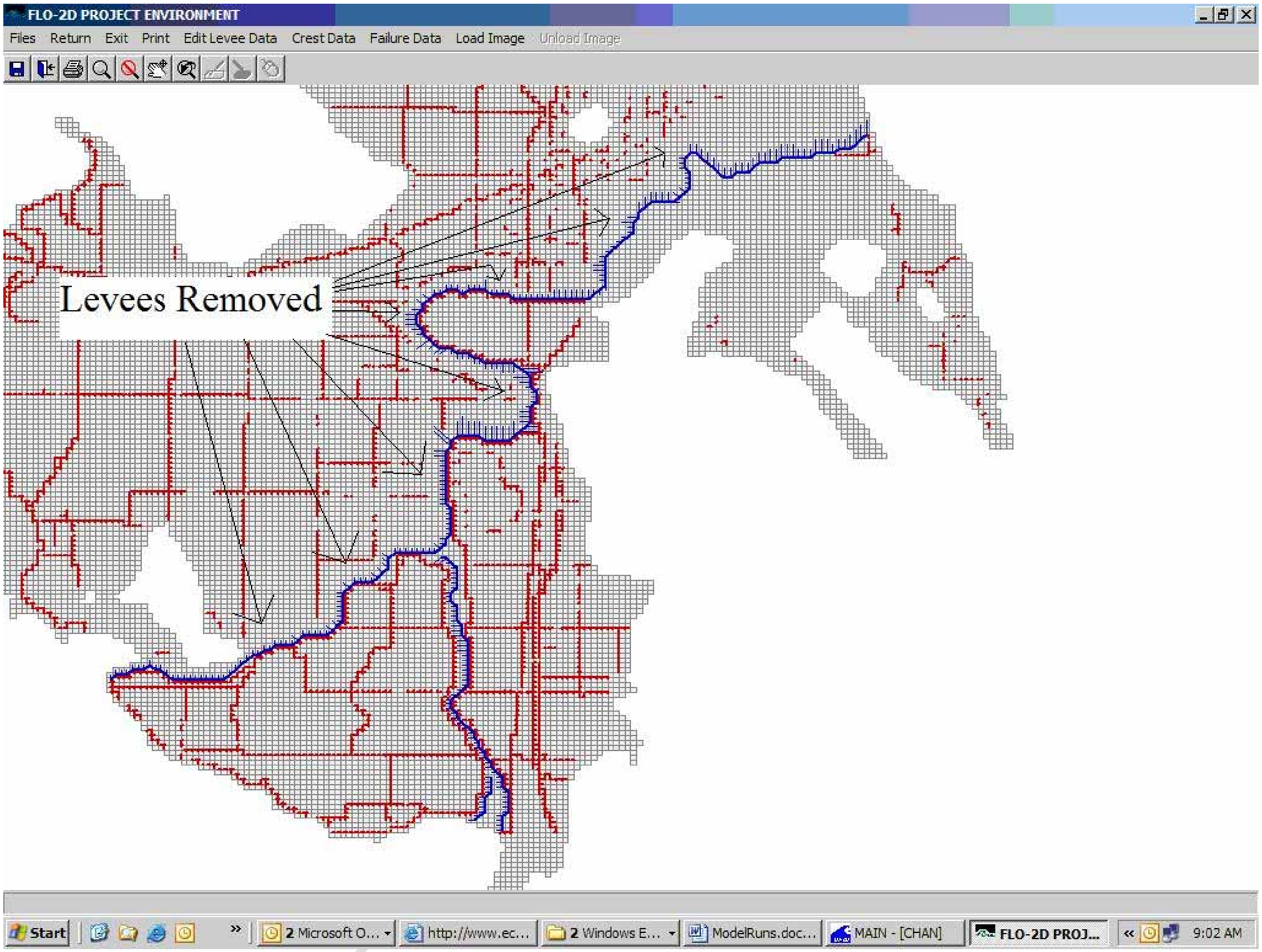

Figure 9 - Right Bank Levees on Mainstem and North Fork Skagit River Removed While All Other Levees Remain Intact

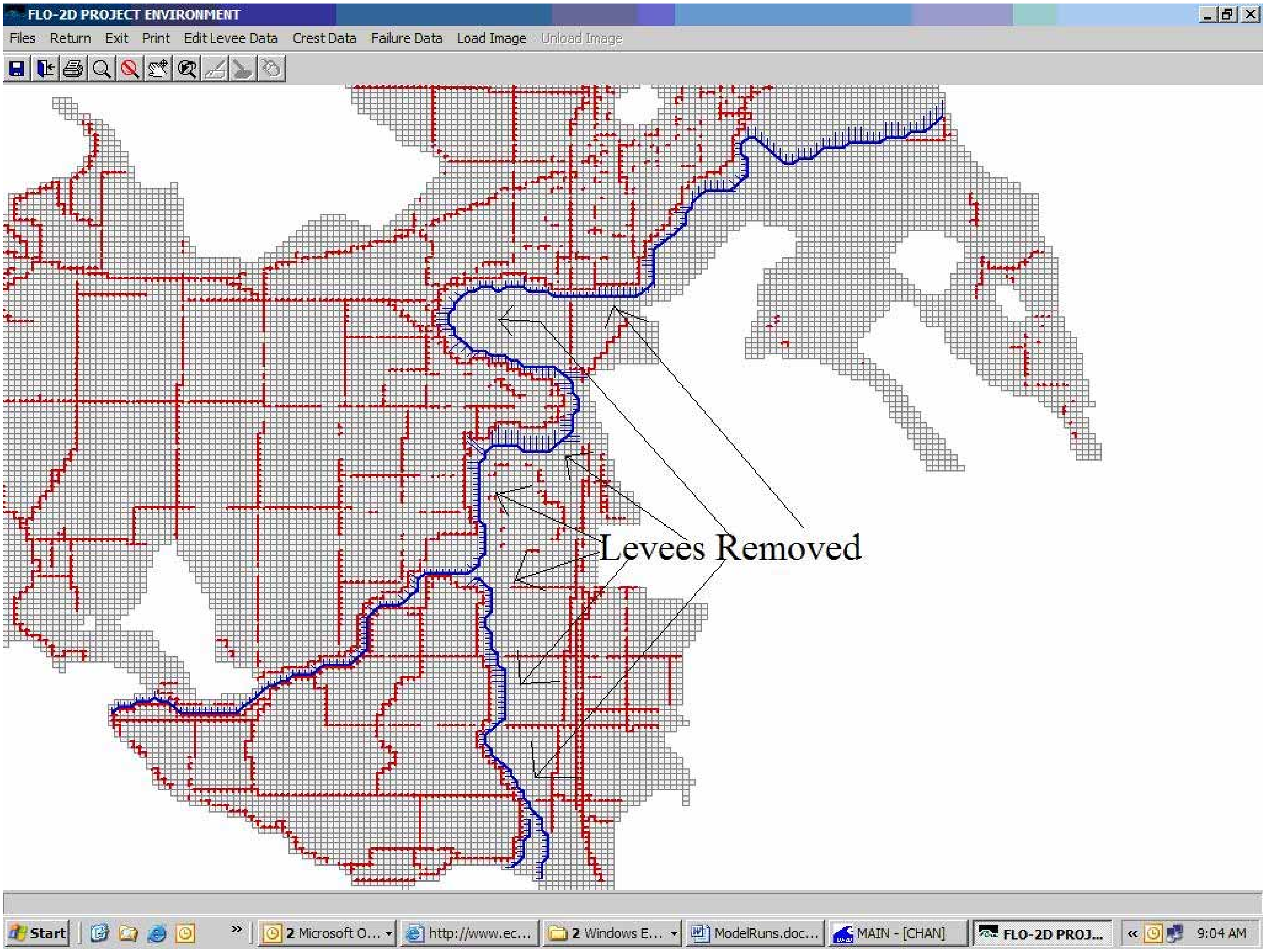

Figure 10 – Left Bank Levees on Mainstem and South Fork Skagit River Removed While All Other Levees Remain Intact

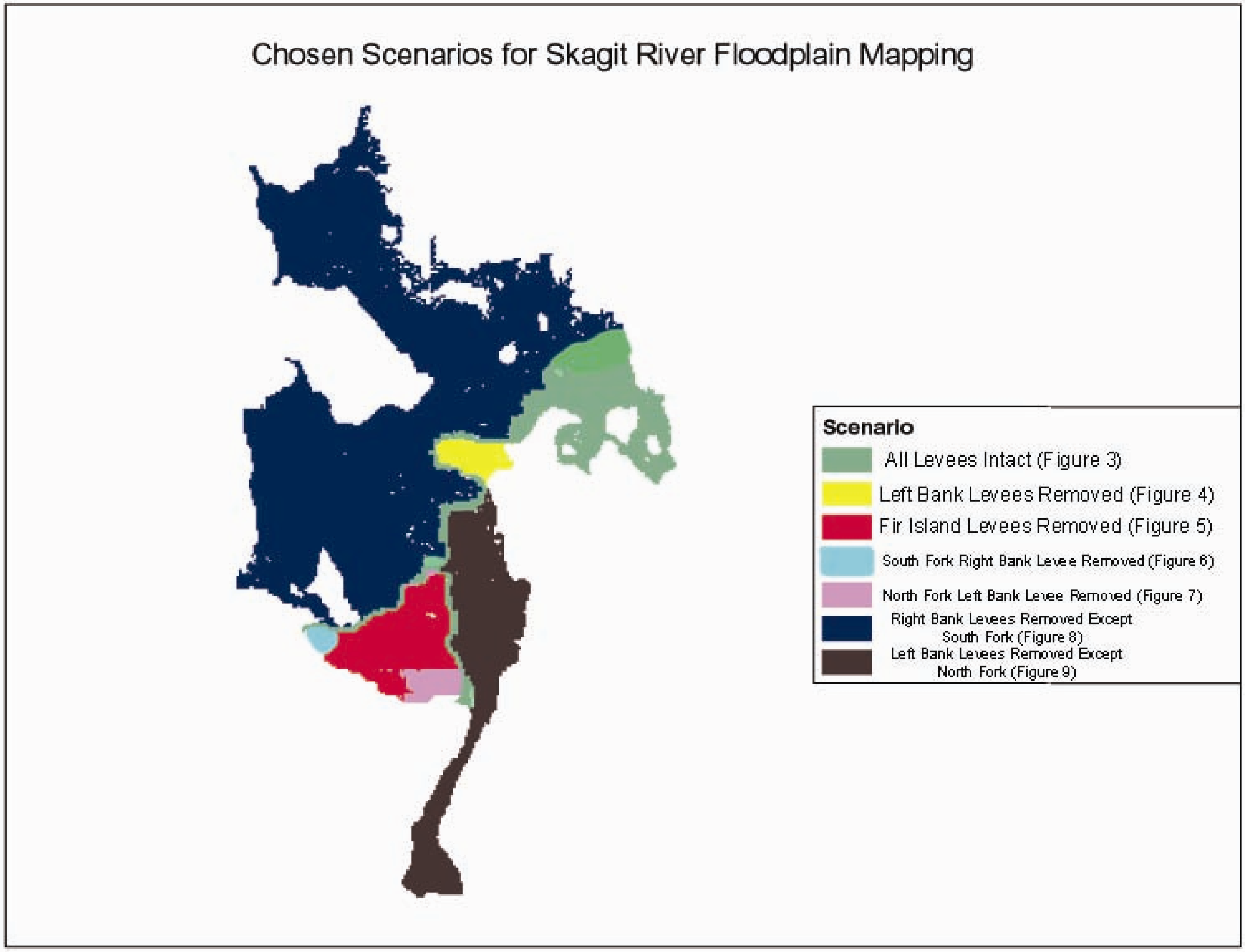

Figure 11 – Depiction of the Floodplain Scenario Location of Implementation

III. MODEL CALIBRATION

A. Sources of Data

Information on flows and high-water marks have been collected for both the October 2003 and November 1995 flood events at a number of locations. Information on some of the local flows coming in below some of the major gages is fairly limited, however. The precipitation also varies from the upper basin to the lower basin and this information is not very detailed around the smaller basins, which limits the ability to use rainfall-runoff models to estimate these flows. High-water marks and limited flow data are also available for the December 1975 and November 1990 floods.

B. Datum

The datum in use for both the FLO-2D and HEC-RAS Models and their output is the Washington State Plane Coordinate System, 1983/91 North American Datum, and Vertical Datum NGVD 29. The Mount Vernon gage datum is sea level (0 feet NGVD 29), Concrete's gage datum is 130 feet above sea level, Rockport's gage datum is 231.8 feet above sea level and the Marblemount gage datum is 305.1 feet above sea level.

C. Hydrology used for Hydraulic Model Calibration

The hydrology is known for the 1995 and 2003 events at the Skagit River near Marblemount (RM 78.8), and the Sauk River at Sauk (Sauk RM 5.4) because there are gages at these locations that has hourly flow data. The outflow records at Lower Baker Dam are used for the Baker River flows in the model. The only unknown flows are the local flows that come in below these gages.

The 2003 event had a very strong orographic nature to the flood event where there was not a lot of rain in the lower basins but, once it got to the higher elevations, the storm did not move over the mountains and continued to dump heavy amounts of precipitation. The local flow from Marblemount to Concrete can be difficult to discern when the Sauk River is high because a lot of the local flow gets caught up in the backwater affect from this river. It does appear to be discernible before the flows get too high (before Skagit River near Concrete reaches roughly 90,000 cfs). Up until this occurs, the Marblemount to Concrete local flow is used for this upper basin local. Above this flow, the hydrograph is expected to be shaped similarly to the Cascade River hydrograph derived from the regression analyses. This upper basin local is assumed to peak roughly 15 hours before Concrete peaks as was determined in the timing analysis. This same approach was used for the 1995 upper basin local.

The North Fork Stillaguamish River gage is used to estimate the lower local flows for these two events (see Section 5 of the Hydrology Report for a more detailed background). For the 2003 event, the regressions developed for determining the lower local for the lower basin hydrology derivation are used to translate the North Fork Stillaguamish flows to Concrete to Sedro-Woolley local and Nookachamps Creek flows. In events where the events are very orographic in nature, however, this relationship overstates the lower local flows. This can be seen with the 1949 event where there was very little rain in the lower basin for that event so not only does the North Fork Stillaguamish River regression with the Skagit River near Concrete overestimate flows by 160% but the lower local regressions with the North Fork Stillaguamish River overestimate flows by 180% for the Concrete to Sedro-Woolley local and by 200% for Nookachamps Creek. Because 2003 was similar to the 1949 event, the flows derived from the North Fork Stillaguamish for the Concrete to Sedro-Woolley local and Nookachamps Creek are scaled down by 100/180 and 100/200.

The 1995 event had a more typical relation between the Upper and Lower Basin for a large flood event and so the North Fork Stillaguamish River regression with the Skagit River near Concrete accurately predicts the actually flow seen on the North Fork Stillaguamish River (predicted 1-day flow is 28,500 cfs, the actual flow 1-day flow is 27,000 cfs). It is for this reason that the lower local flows derived from the regressions used with the North Fork Stillaguamish River are used directly. The routing of the flows did result in a slight overestimation of flows at Mount Vernon so a 20% reduction of local flows from Concrete to Mount Vernon was used to calibrate the lower model with the appropriate flows.

The North Fork Stillaguamish River near Arlington gage tends to peak later than when the lower local tributaries on the Skagit River would peak. In a comparison with the South Fork Nooksack River near Wickersham, which is a smaller basin that also occupies an area on the opposite side of the mountains from the lower local on the Skagit River, the smaller basin peaks 10 hours earlier on average during large events. This 10 hour adjustment is applied to the lower local on the Skagit River from the flows that are derived from the North Fork Stillaguamish River gage.

D. HEC-RAS Calibration and Validation Upstream of Sedro-Woolley

The roughness values of the channel for the HEC-RAS model of the Skagit River Basin is calibrated to the 2003 flood and verified with the 1995 flood. The reason that the effort is focused on these two floods is because they best represent the current channel characteristics. The 1990 event had a levee failure during the event that would affect the calibration and the 1975 flood would not be as representative due to channel aggradation seen over the past 30 years.

Both the 2003 and 1995 events have some strengths and weaknesses in attempting to calibrate to them. The 2003 event was preceded by a fairly dry summer. This set up a condition where the overbank was dry and empty preceding the first storm and allowed for greater losses in the overbank due to factors such as infiltration to the groundwater than a more typical condition such as the 1990 and 1995 floods. Both the 1990 and 1995 floods were preceded by wet months preceding the flood that allows more water to make it downstream to Mount Vernon.

The upstream rating curves and high-water marks can be matched quite well when using the derived coincident local flows in the upper and lower basins with the observed gaged flows for the 2003 event. In-channel and out-of-channel roughness values are fairly consistent for this model run. Calibrating the model to the 1995 event, however, is a lot more difficult and requires more dramatic changes in roughness values from cross section to cross section to match the high water marks. The flow seen at the gages matches up but there is some question about the accuracy of the high water marks. Because there is slightly less confidence in these high water marks, it is decided that the best calibration is to calibrate the roughness values in the upper reach for the 2003 high water marks and ensure that the model reflects the known current rating curves at the gaged locations in the basin.

The HEC-RAS roughness ranges are listed in Table 2.

Table 2 – HEC-RAS Roughness Ranges (Manning's n values)

	Main Channel	Floodplain
Cascade River	0.04	0.12
Sauk River	0.025-0.038	0.04
Baker River	0.04	0.06-0.07
Skagit River from Marblemount to Concrete	0.038-0.040	0.15
Skagit River from Concrete to Sedro-Woolley	0.040-0.045	0.12-0.15
Skagit River from Sedro-Woolley to Skagit Bay	0.03-0.04	0.08-0.12

Figures 12, 13, 14, 15 and 16 show the simulated and observed stage hydrographs for the 2003 event at the upstream locations for the Skagit River at Marblemount, the Sauk River near Sauk, Skagit River near Rockport, the Skagit River near Concrete and Skagit River near Sedro-Woolley gages, respectively. Figures 17, 18, and 19 show the rating curves from the USGS rating and from the model at these locations with the exception of Rockport and Sedro-Woolley, which are not rated. These figures show that the model does a fairly good job with the higher flows. The model has more trouble calibrating with the lower flows that could be caused by aggradation or degradation of the channel since 1975 and/or changing roughness in the channel in lower flows. The change in channel bottom from 1975 would have a lot larger impact on lower flows than higher flows. This study's focus is on defining damages caused by floods so the errors in the lower flows have little impact on the results.

Table 3 shows how the hydraulic model performs in matching high water marks for the 2003 event. Of the 9 high water marks that are above the Highway 9 bridge at Sedro-Woolley, 8

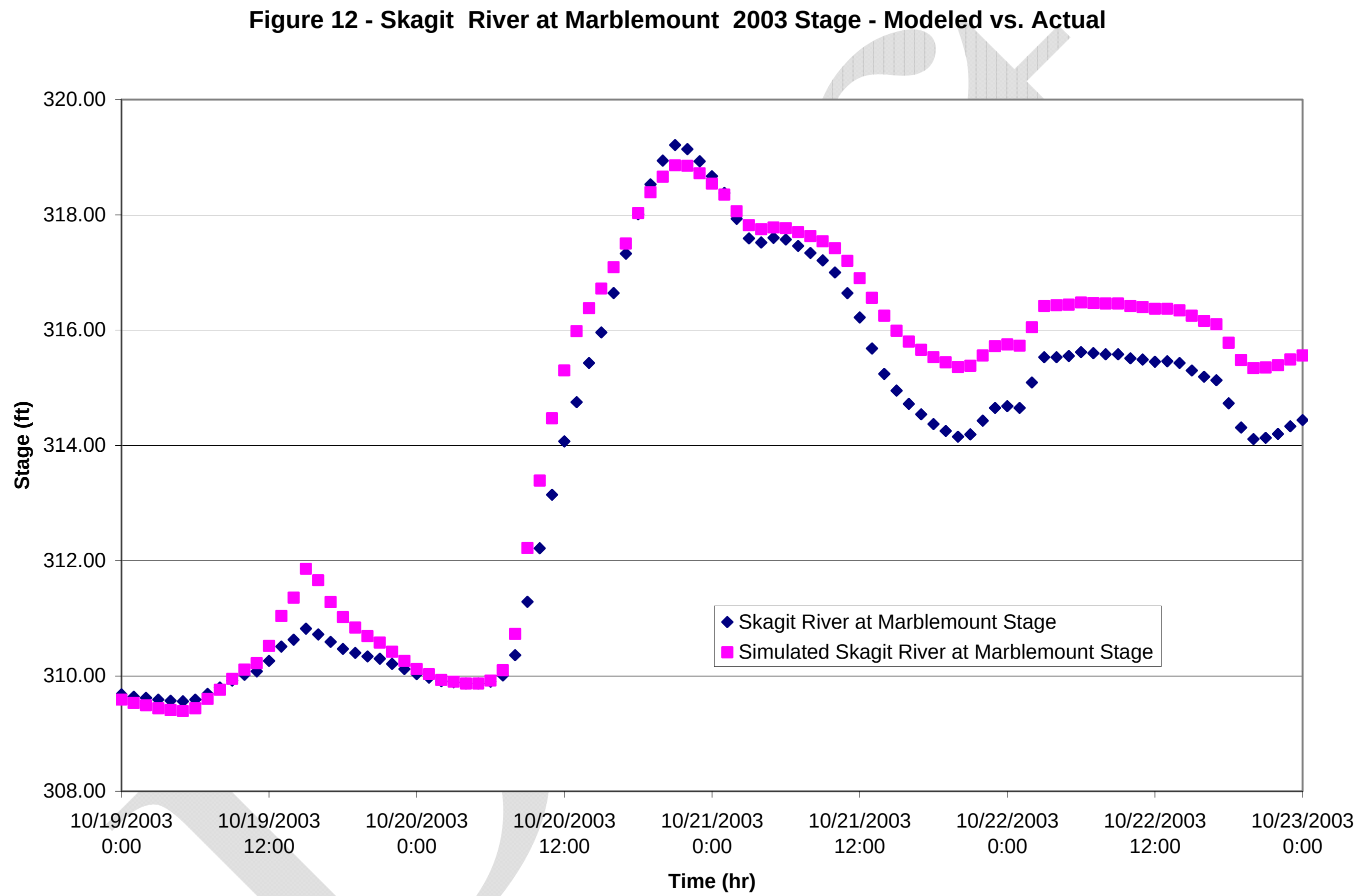

Figure 12 – Skagit River at Marblemount 2003 Stage – Modeled vs. Actual

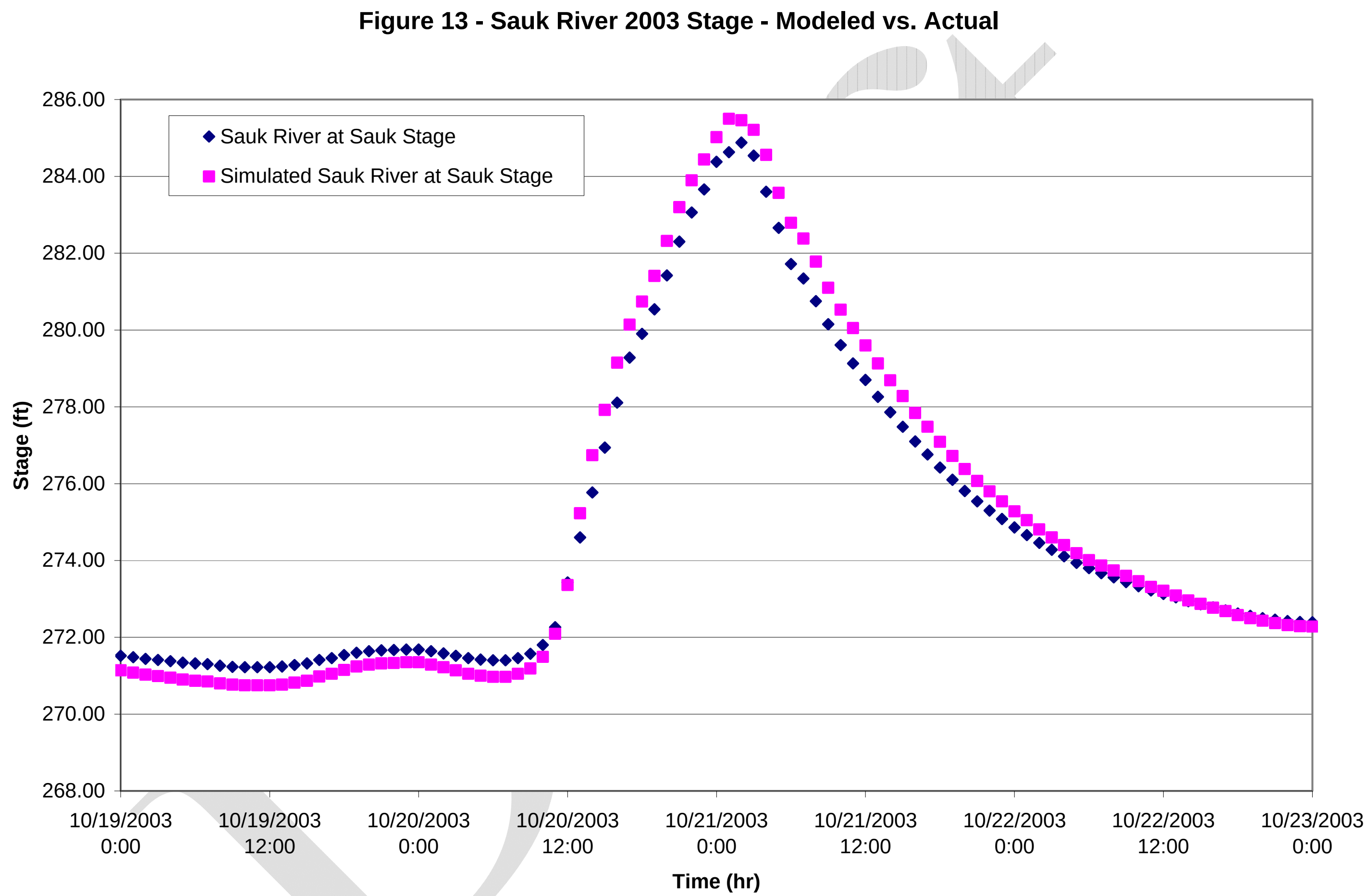

Figure 13 – Sauk River 2003 Stage – Modeled vs. Actual

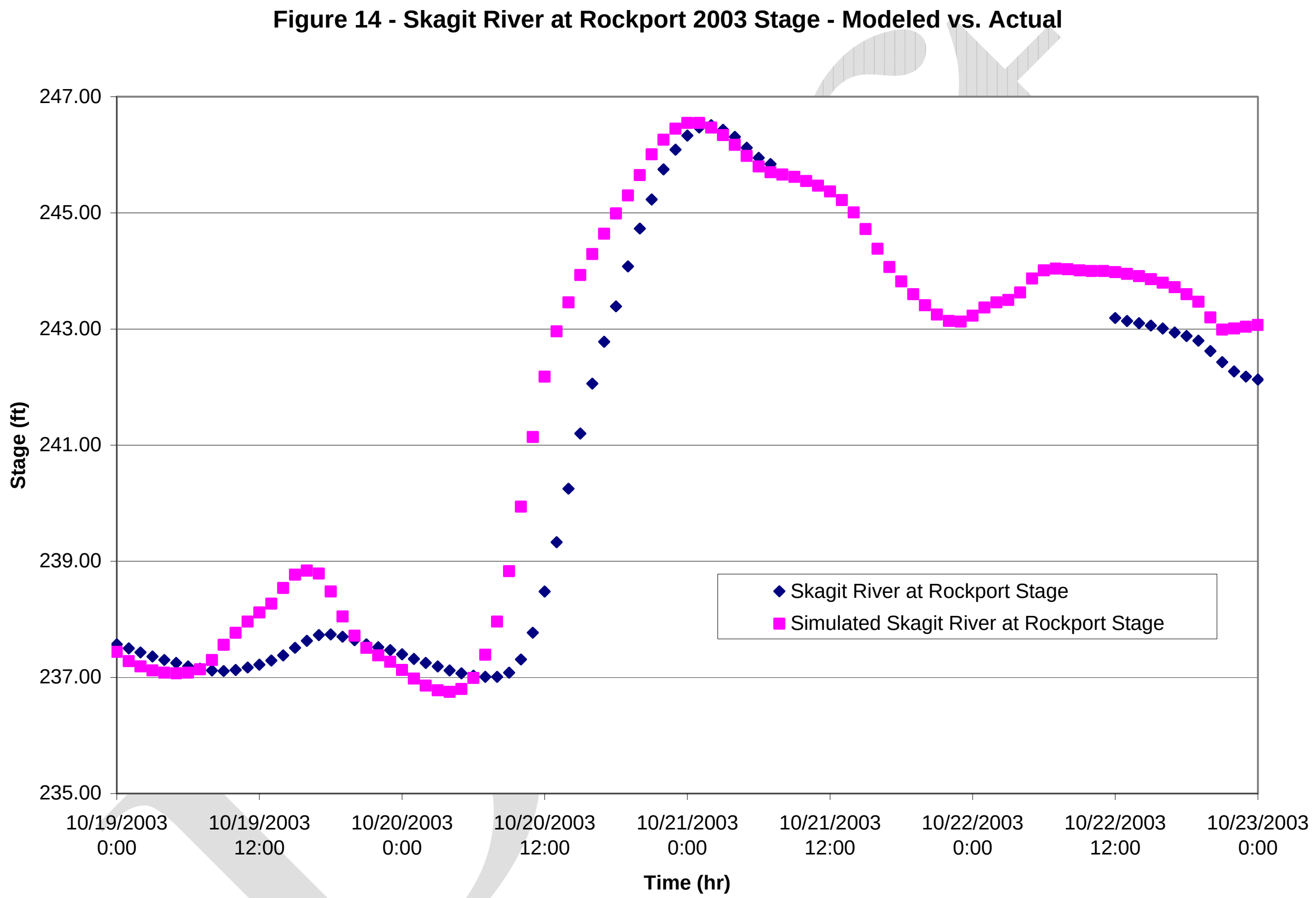

Figure 14 – Skagit River at Rockport 2003 Stage – Modeled vs. Actual

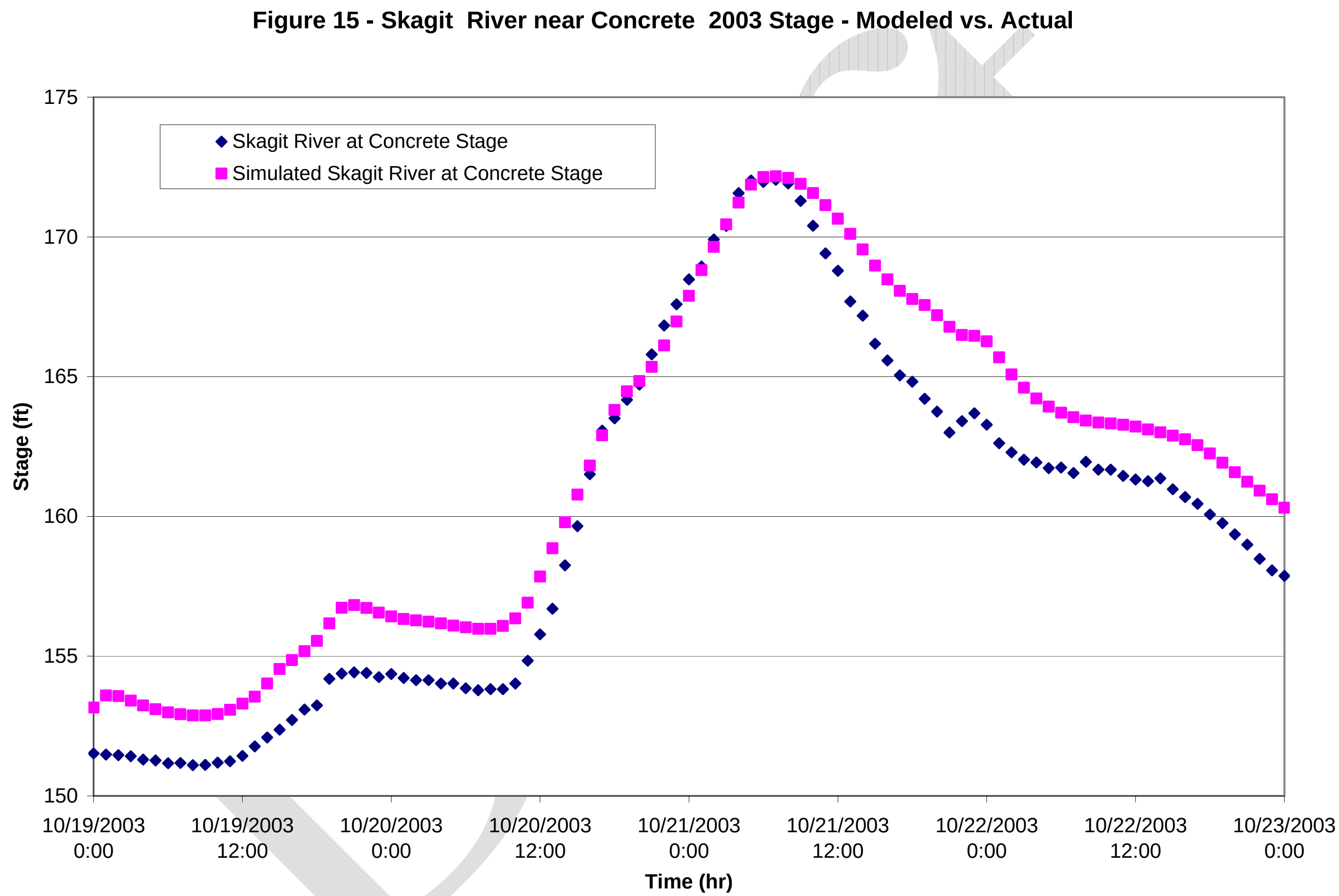

Figure 15 – Skagit River near Concrete 2003 Stage – Modeled vs. Actual

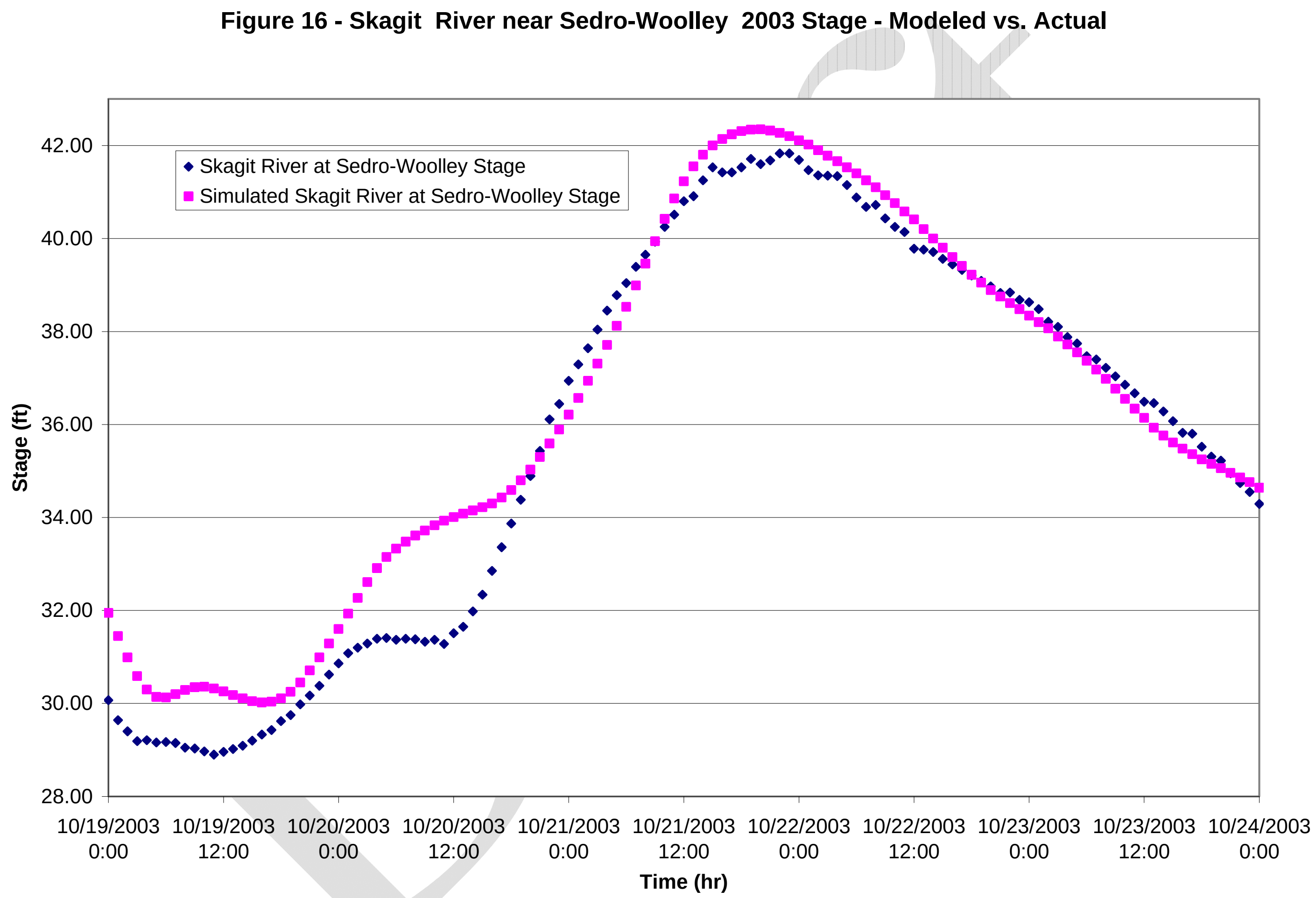

Figure 16 – Skagit River near Sedro-Woolley 2003 Stage – Modeled vs. Actual

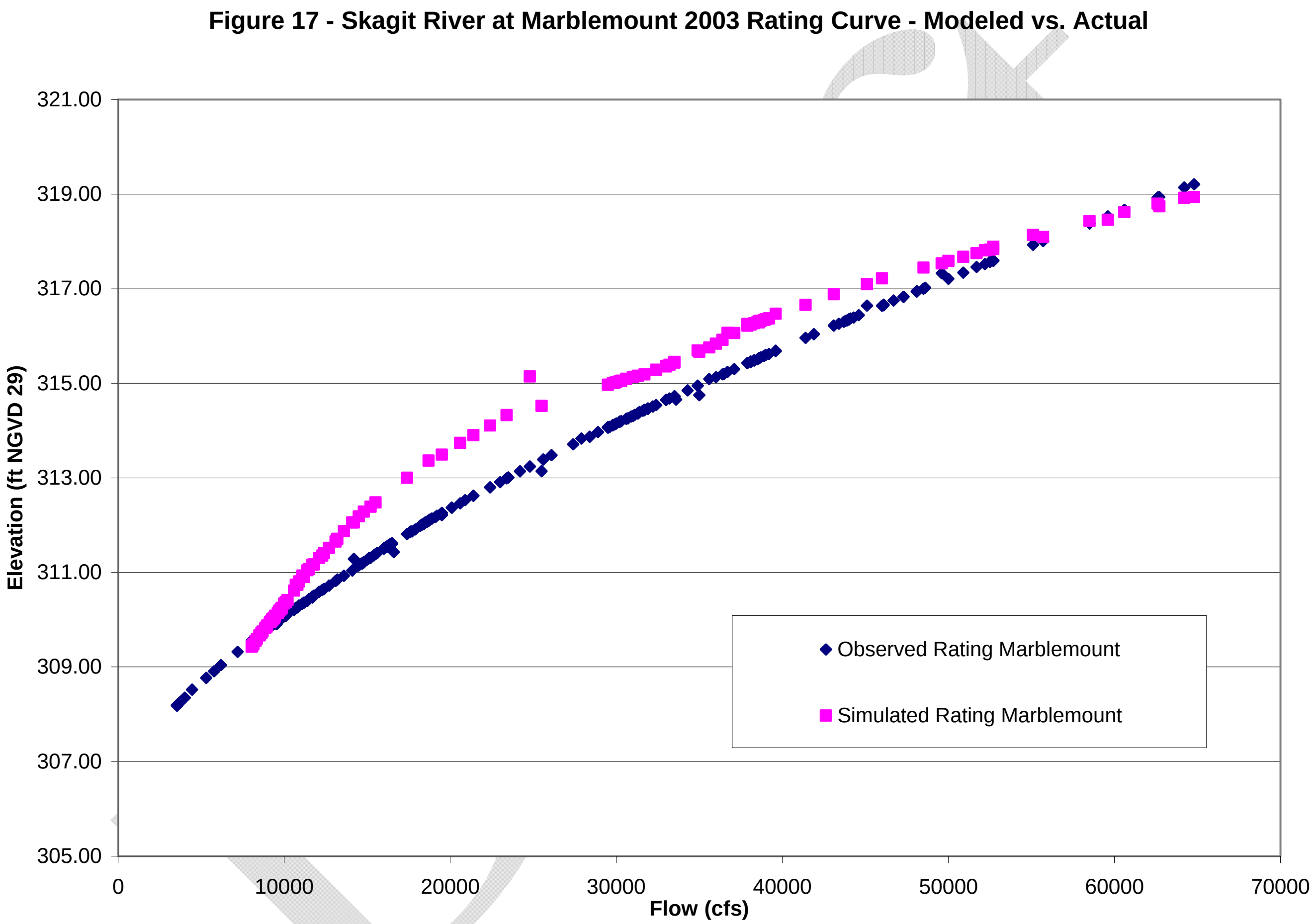

Figure 17 – Skagit River at Marblemount 2003 Rating Curve – Modeled vs. Actual

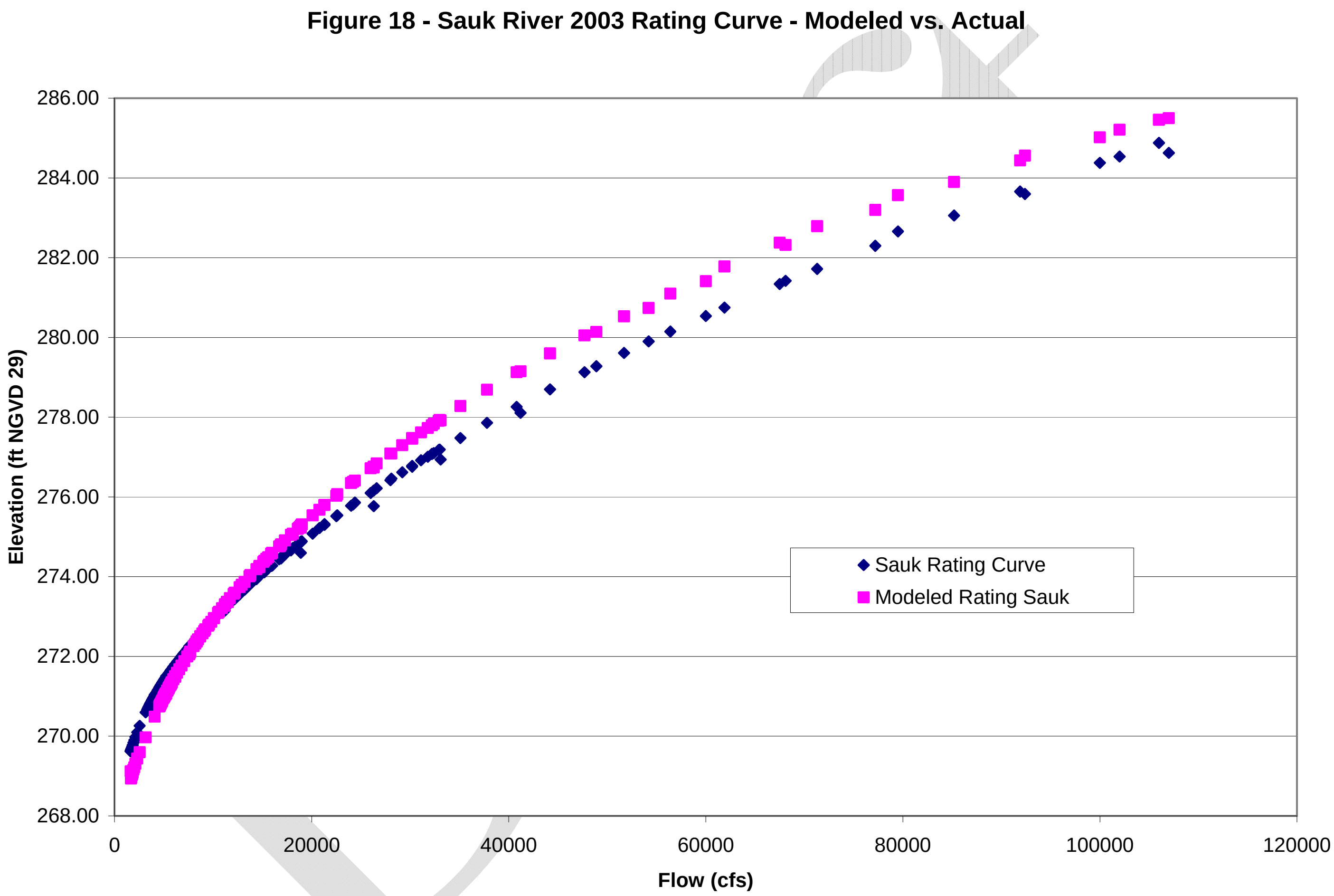

Figure 18 – Sauk River 2003 Rating Curve – Modeled vs. Actual

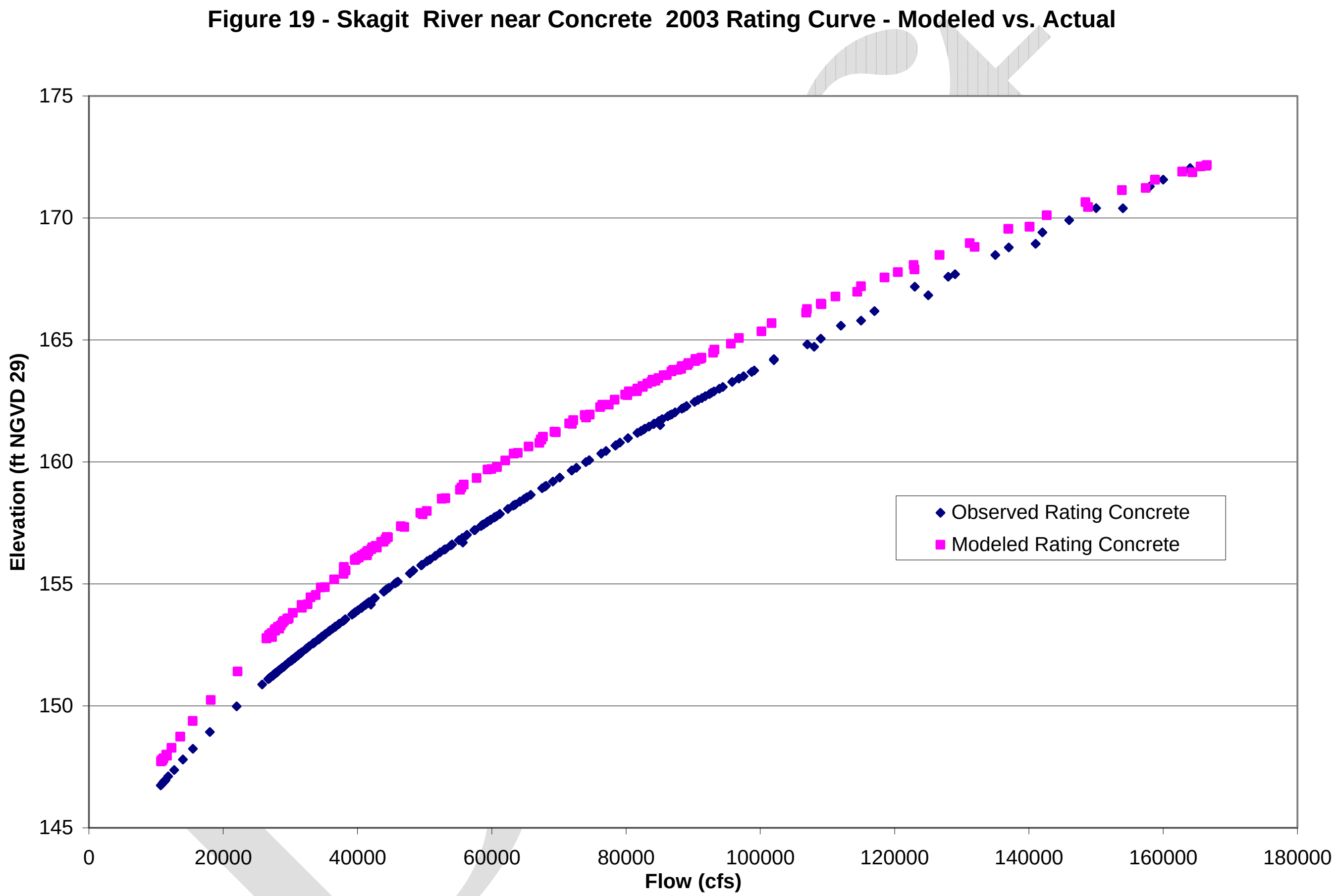

Figure 19 – Skagit River near Concrete 2003 Rating Curve – Modeled vs. Actual

of them are within a half of a foot. There is some uncertainty of the local inflow and high water marks can be slightly affected by waves, wind, and woody debris so increasing this level of accuracy would be quite difficult and not likely to produce a more defensible result.

Table 3 – October 21, 2003 Simulated vs. Observed High Water Marks

Source	River	Location	High Water Mark	Simulated	Difference
		(River Mile)	(Ft NGVD 1929)	(Ft NGVD 1929)	(Ft)
USGS Gage	Mainstem Skagit	78.87	319.21	318.87	-0.34
USGS Gage	Mainstem Skagit	70.8	246.51	246.56	0.05
Skagit County	Mainstem Skagit	59.65	195.48	198.04	2.56
USGS Gage	Mainstem Skagit	54.1	172.19	172.17	-0.02
Skagit County	Mainstem Skagit	49.75	150.01	150.34	0.33
Skagit County	Mainstem Skagit	40.18	100.66	100.99	0.33
Skagit County	Mainstem Skagit	30.20	63.51	63.62	0.11
Skagit County	Mainstem Skagit	22.78	45.17	45.14	-0.03
USGS Gage	Mainstem Skagit	22.3	41.83	42.35	0.52
Average					0.39

Table 4 shows the results of how the simulated 1995 event, using the same geometry and roughnesses that is used for the 2003 simulated event, compares to the observed high water marks for the 1995 flood event.

Table 4 – November 29, 1995 Simulated vs. Observed High Water Marks

Source	Location	High Water Mark	Simulated	Difference
	(River Mile)	(Ft NGVD 1929)	(Ft NGVD 1929)	(Ft)
USGS Gage	78.87	318.83	318.82	-0.01
USGS Gage	70.8	246.9	246.83	-0.07
USACE	54.12	171.6	171.34	-0.26
USGS Gage	54.1	171.57	171.18	-0.39
USACE	52.9	162.8	165.23	2.43
USACE	46.97	138.7	135.11	-3.59
USACE	40.03	103.3	99.91	-3.39
USACE	32.93	71.9	71.63	-0.27
USACE	30.3	61.3	63.53	2.23

USACE	24.7	50.8	52.87	2.07
USACE	22.45	46.18	43.81	-2.37
Average				-0.33

The USACE high water marks appear to be inconsistent and requires significant variation in roughness values to match the marks that would be out of the typical roughness ranges for a river with the characteristics of the Skagit. It is for this reason that there are some concerns with the accuracy of these high water marks and it was decided that the calibration of this upper reach is better represented by the 2003 event. Running the 1995 event with the 2003 roughnesses produces an average difference of -0.33 feet which shows there is no significant bias in the upward or downward direction

E. FLO-2D Channel Calibration Downstream of Sedro-Woolley

The calibration effort downstream of Sedro-Woolley is done in the same manner as the upstream model as it is calibrated to the 2003 flood and verified with the 1995 flood. In this lower reach, the 2003 flood is better representative of the channel conditions because the flow conditions for the 1995 event were complicated by the debris that piled up on the Burlington Northern Railroad Bridge at River Mile 17.56 (grid 18509 in the FLO-2D model). The reason that the effort is focused on these two floods is because they best represent the current channel characteristics. The 1990 event also had a levee failure during the event that would affect the calibration and the 1975 flood would be affected by channel aggradation/degradation that has occurred in the last 30 years.

There are two sets of data that the model is calibrated to. The first is the high water marks taken for the flood and the second is the hydrograph observed at the Mount Vernon gage. The calibration to the high water marks in the 2003 flood can be seen in Table 5.

Table 5 – FLO-2D 2003 Flood Calibration

Source	River	Location	FLO-2D	High Water Mark	FLO-2D Simulated	Difference
		(River Mile)	Grid Number	(ft NGVD 29)	(ft NGVD 29)	(ft)
Skagit County	Skagit	21.6	23252	40.71	40.87	0.16
Skagit County	Skagit	19.48	19544	39.72	39.26	-0.46
Skagit County	Skagit	17.05	17587	36.64	36.98	0.34
USGS Gage	Skagit	17.04	17391	36.18	36.84	0.66
Skagit County	Skagit	15.9	14192	35.21	34.42	-0.79
Skagit County	Skagit	13.1	16542	30.22	30.55	0.33
Skagit County	Skagit	12.4	15713	28.19	28.15	-0.04
Skagit County	North Fork	8.10	9897	21.23	21.16	-0.07
Skagit County	North Fork	5.80	5899	15.89	16.36	0.47
Skagit County	North Fork	4.50	3018	11.74	11.64	-0.10
Average						0.05

Figure 20 details how the FLO-2D model compares to the USGS gage near Mount Vernon on an hour to hour basis and Figure 21 provides a comparison of the respective rating tables.

The hourly data combined with the peak stage data show that the model is working appropriately to match the observed stages for the 2003 flood event. The hourly data includes the HEC-RAS results from the Flood Damage Reduction Study to show that the slightly higher elevations observed in the model are likely due to uncertainty around the local inflows between Concrete and Mount Vernon and not how the hydraulic model is routing these flows. As a final check, the rating table developed for the Mount Vernon gage for computing flow from given stages as shown in Figure 21 confirms the model is matching the correct flows with the appropriate stages.

Because the expected debris condition for the 100-year event is expected to be at least that found on the Burlington Northern Railroad Bridge for the 1995 flood event, it is then necessary to calibrate the bridge loading at this bridge to this event.

Table 6 shows the stage calibration to the 1995 event to the bridge debris condition. The high water marks that were taken are mostly at the outskirts of the floodplain and taken a few hours before the peak flow passed these locations. What is most important in this calibration is that the Burlington Northern Railroad Bridge is metering out the appropriate flow through the leveed in corridor downstream. This is best shown by a comparison to the flow seen at the Mount Vernon gage as is shown in Figure 22.

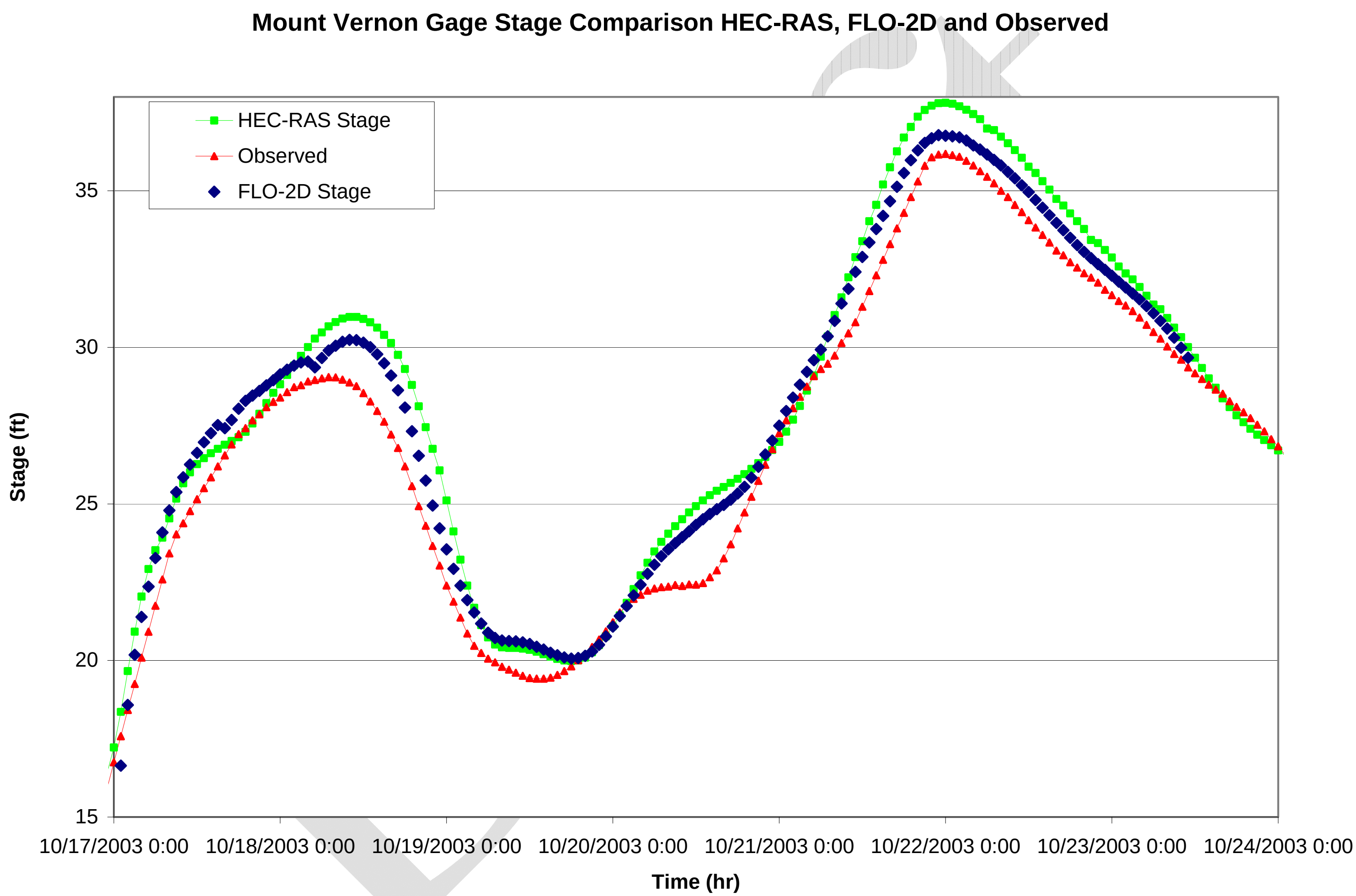

Figure 20 – October 2003 Mount Vernon Gage Stage Comparison between HEC-RAS, FLO-2D, and Observed

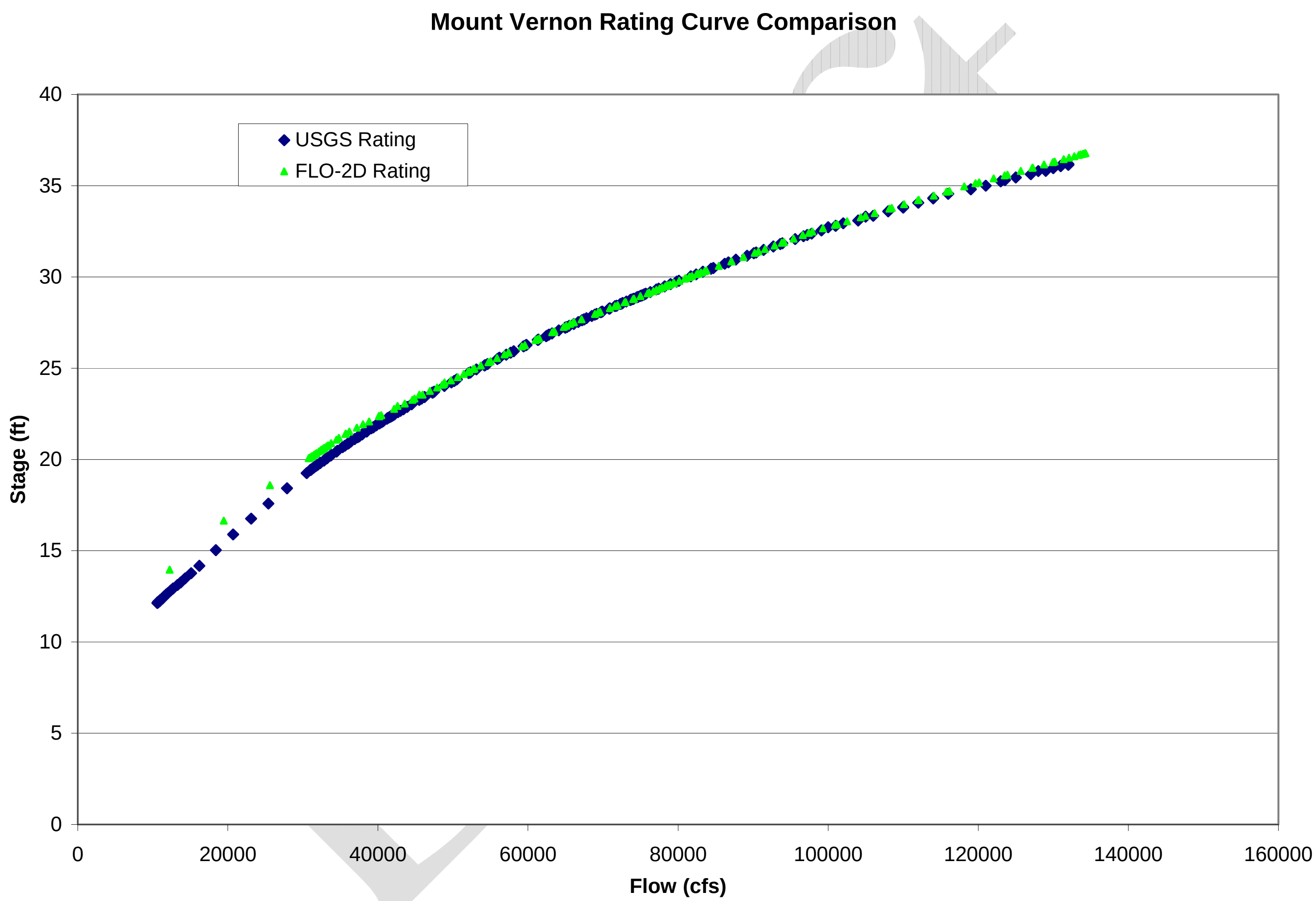

Figure 21 – Mount Vernon Rating Curve Comparison between USGS gage and FLO-2D

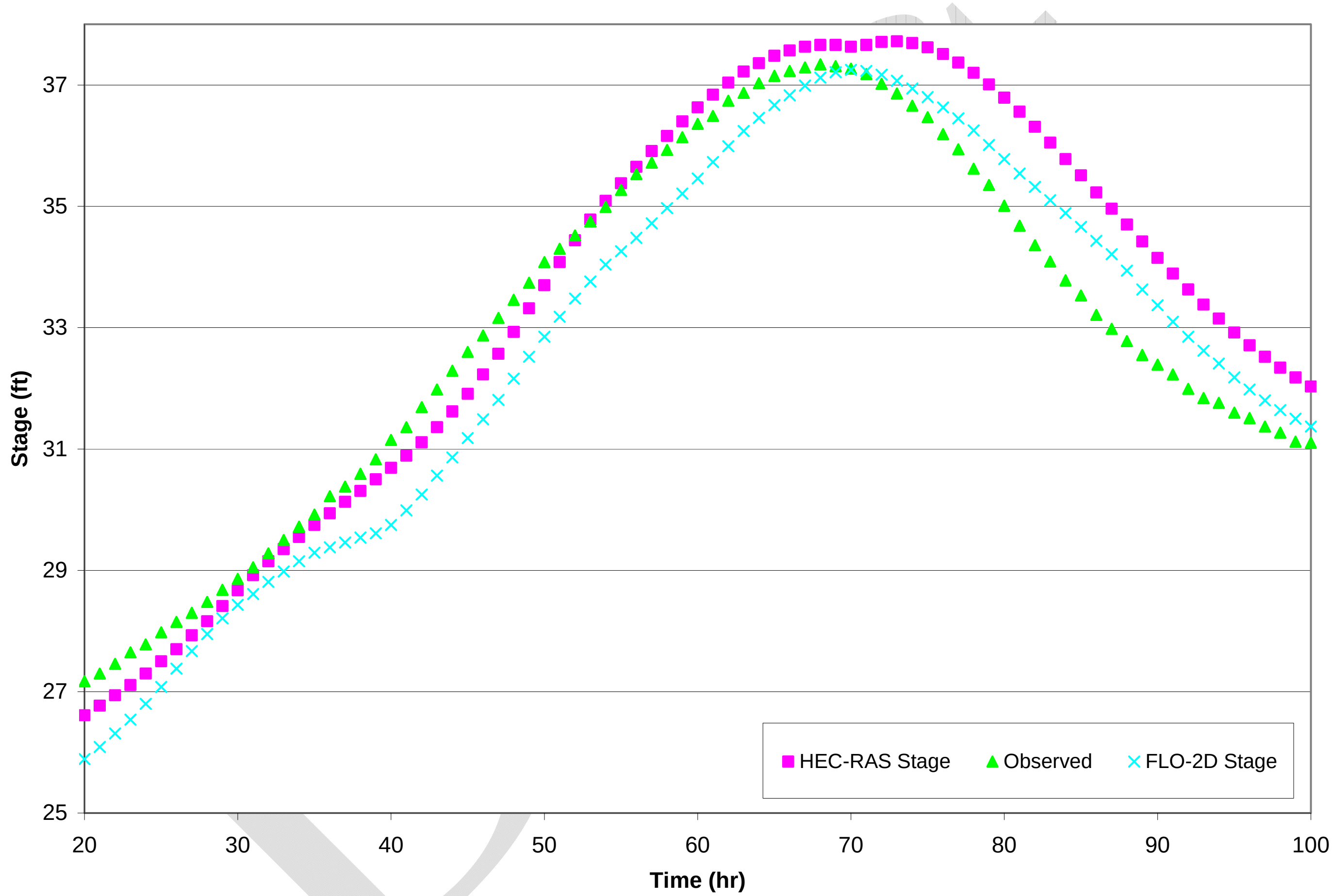

Figure 22 – 1995 Skagit River near Mount Vernon Stage Comparison between USGS gage, HEC-RAS, and FLO-2D

Table 6 – FLO-2D 1995 Flood Calibration

Source	River	Location	FLO-2D	High Water Mark	FLO-2D Simulated	Difference
		(River Mile)	Grid Number	(ft NGVD 29)	(ft NGVD 29)	(ft)
Leonard Halverson	Skagit	22.3	22326	41.9	42.75	0.85
Leonard Halverson	Skagit	22.3	22744	40.9	42.14	1.24
Leonard Halverson	Skagit	21.93	21131	41.3	42.64	1.34
Leonard Halverson	Skagit	21.93	21871	41.1	41.88	0.78
Leonard Halverson	Skagit	21.6	20686	41.4	42.59	1.19
Leonard Halverson	Skagit	18.57	18751	40	39.86	-0.14
Leonard Halverson	Skagit	18.57	19743	39.8	40.75	0.95
Leonard Halverson	Skagit	17.9	18633	40.8	39.71	-1.09
Leonard Halverson	Skagit	17.54	18093	39.2	37.78	-1.42
Leonard Halverson	Skagit	17.08	17587	37.2	37.43	0.23
USGS gage	Skagit	17.04	17391	37.34	37.29	-0.05
Average						0.35

F. FLO-2D Overbank Calibration

The only data on floodplain flows comes from the levee breach at Fir Island in 1990. Calibrating to the high water marks for this floodplain flow, however, would not be representative of the roughness values that can be seen with varying floodplain depths. This event put a large amount of water in the Fir Island area and the high-water marks are more influenced by a backwater situation opposed to floodplain roughness. Most of the hypothetical floodplain flows are affected by the floodplain roughness. It is for this reason that Cowan's (1956) method is used to determine the floodplain roughness values. These are compared to previous studies giving typical roughness values found for certain ranges of depths of flows on specific types of floodplain surfaces to ensure they are appropriate. The derivations of these roughness values are listed in Table 7.

Table 7 – FLO-2D Floodplain Roughness Values

Roughness	Using		Cowan		(1956)				Total	Other Literature
Land Type	Material Type	n_0	Degree of Irregularity	n_1	Effect of Obstructions	n_2	Vegetation	n_3		Ranges
Agriculture	Earth	0.02	Moderate	0.01	Appreciable	0.025	Low	0.01	0.065	0.04-0.08[1]
Forested	Earth	0.02	Moderate	0.01	Appreciable	0.030	High	0.04	0.10	0.07-0.15[1]
Grass	Earth	0.02	Minor	0.005	Severe	0.06	Very High	0.065	0.15	0.15-0.24[2]
Developed	Pavement-Lawn	0-0.02	Smooth	0	Negligible-Appreciable	0 - 0.03	Low	0.01	0.01-0.06	0.011[2]-?

[1]From USACE (1993) EM 1110-2-1416
[2]From Engman (1986)

IV. Floodway Analysis

Encroachment on floodplains, such as structures and fill, reduces flood-carrying capacity, increases flood heights and velocities, and increases flood hazards in areas beyond the encroachment itself. One aspect of floodplain management involves balancing the economic gain from floodplain development against the resulting increase in flood hazard. For purposes of the NFIP and EO 1988, a floodway is used as a tool to assist communities in this aspect of floodplain management. Under this concept, the area of the 100-year floodplain is divided into a floodway and a floodway fringe. The floodway is the channel of a stream, plus any adjacent floodplain areas, that must be kept free of encroachment so that the 100-year flood can be carried without substantial increases in flood heights. Minimum Federal standards limit such increases to 1.0 foot, provided that hazardous velocities are not produced.

The floodway for the Skagit River upstream of Sedro-Woolley, Sauk River and Cascade River will be computed by starting with the floodway that was determined for the 1984 study. If additional conveyance is necessary to stay within the 1 foot criteria, an effort will be made to add conveyance equally to both sides. The floodway will be computed at cross sections using the HEC-RAS model. Between cross sections, the floodway boundaries will be interpolated.

The area between the floodway and the 100-year floodplain boundaries is termed the floodway fringe. The floodway fringe encompasses the portion of the floodplain that could be completely obstructed without increasing the water surface elevation of the 100-year flood more than 1.0 foot at any point. Typical relationships between the floodway and the floodway fringe and their significance to floodplain development are shown in Figure 23.

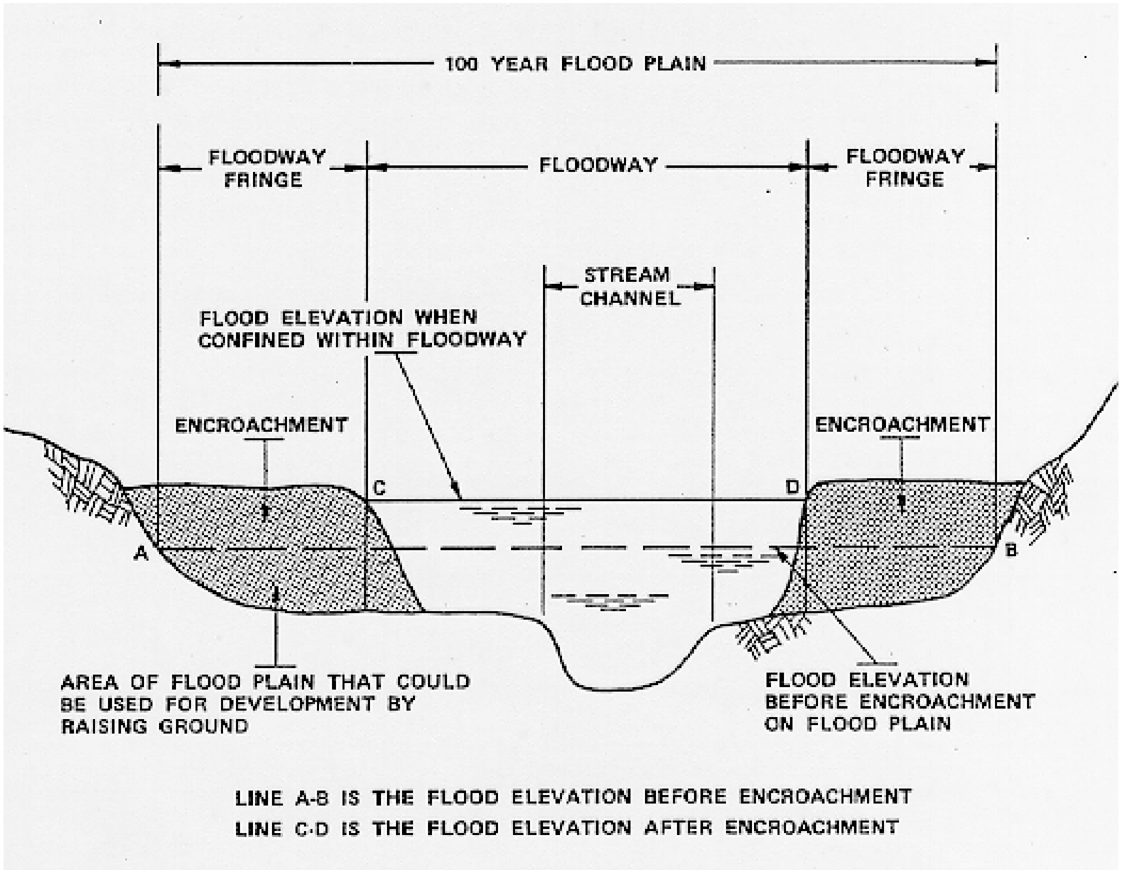

Figure 23 - Floodway Schematic

The 1984 study did not finalize a floodway on the Skagit River downstream of Sedro-Woolley. A reason for this is the complexity in determining the proper positioning and methodology for this downstream floodway when using a one-dimensional model when flows can head north to Samish Bay, south to Skagit Bay and West to Swinomish Slough and Padilla Bay. With the development of the two-dimensional FLO-2D model for this study, a floodway analysis is possible.

There are two approaches that will initially be attempted for the floodway analysis. The first is similar to the upstream methodology where an attempt will be made to do an equal conveyance floodway surrounding the existing river channel. A second approach will look at routing the water through the most logical overbank flow paths and determine the level of encroachments that can be made around these. This work will be done in the next phase and is not a part of this release.

V. HEC-RAS/FLO-2D Model Floodplain Results and Output

HEC-RAS and FLO-2D are used to model the hydraulic conditions in the Skagit River Basin. For the upper basin above Sedro-Woolley, profiles will be developed in the next phase for the 10-, 50-, 100-, and 500-year floods.

Downstream of Sedro-Woolley, profiles are developed for the main channel for the 10-, 50-, 100-, and 500-year floods. The main overbank flow path profiles are developed for the 50-, 100-, and 500-year floods. The lower basin maps detail the 100-year base flood elevation and 500-year floodplain boundaries. The floodway will be developed in the next phase.

A. Mapping Datum

These maps are produced in the North American Vertical Datum of 1988 (NAVD 88) which is the current FEMA mapping standard. Because the hydraulic models are created in the National Geodetic Vertical Datum of 1929 (NGVD 29), the hydraulic results are converted to the NAVD 88 datum before the data is used for the mapping. Elevations in the lower basin below Sedro-Woolley are 3.77 feet higher in the NAVD 88 datum than that in the NGVD 29 datum.

B. Mapping Description

The floodplain maps extents are set to the criteria set by FEMA for Flood Insurance Rate Maps which breaks the floodplain area into panels that roughly mimic the USGS quadrangle format. The 100-year floodplain is shaded in light blue and its extents are delimited by a red line. The 500-year floodplain is shaded in purple. The base flood elevations are in black and the yellow lines detail where these elevations are to be applied across the floodplain.

C. Floodplain Flow Paths

There are 5 floodplain flow paths that are used to develop water surface profiles in the overbank areas in the lower basin below Sedro-Woolley. Figures 24, 25, and 26 show the locations of these flow paths. These flow paths are delineated by attempting to follow the quickest drop to the sea which defines the most likely path the overbank flows will follow.

D. Flood Profiles

Appendix A contains the flood profiles for the Mainstem Skagit River from the Highway 9 bridge to the split into the North and South Forks, the North Fork Skagit River from the split to Skagit Bay, the South Fork Skagit River from the split to Skagit Bay, and the 5 floodplain flow paths.

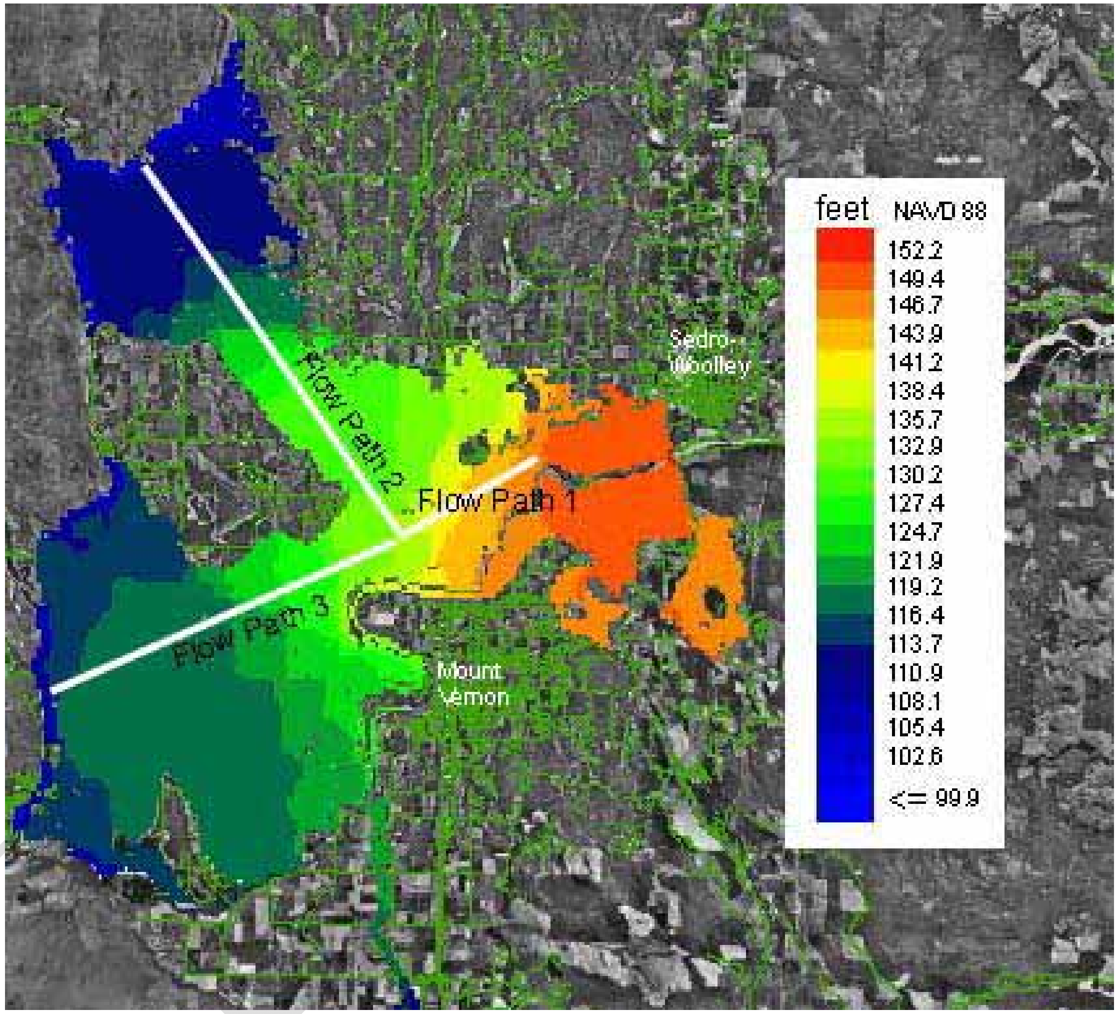

Figure 24 – Floodplain Flow Paths 1, 2 and 3

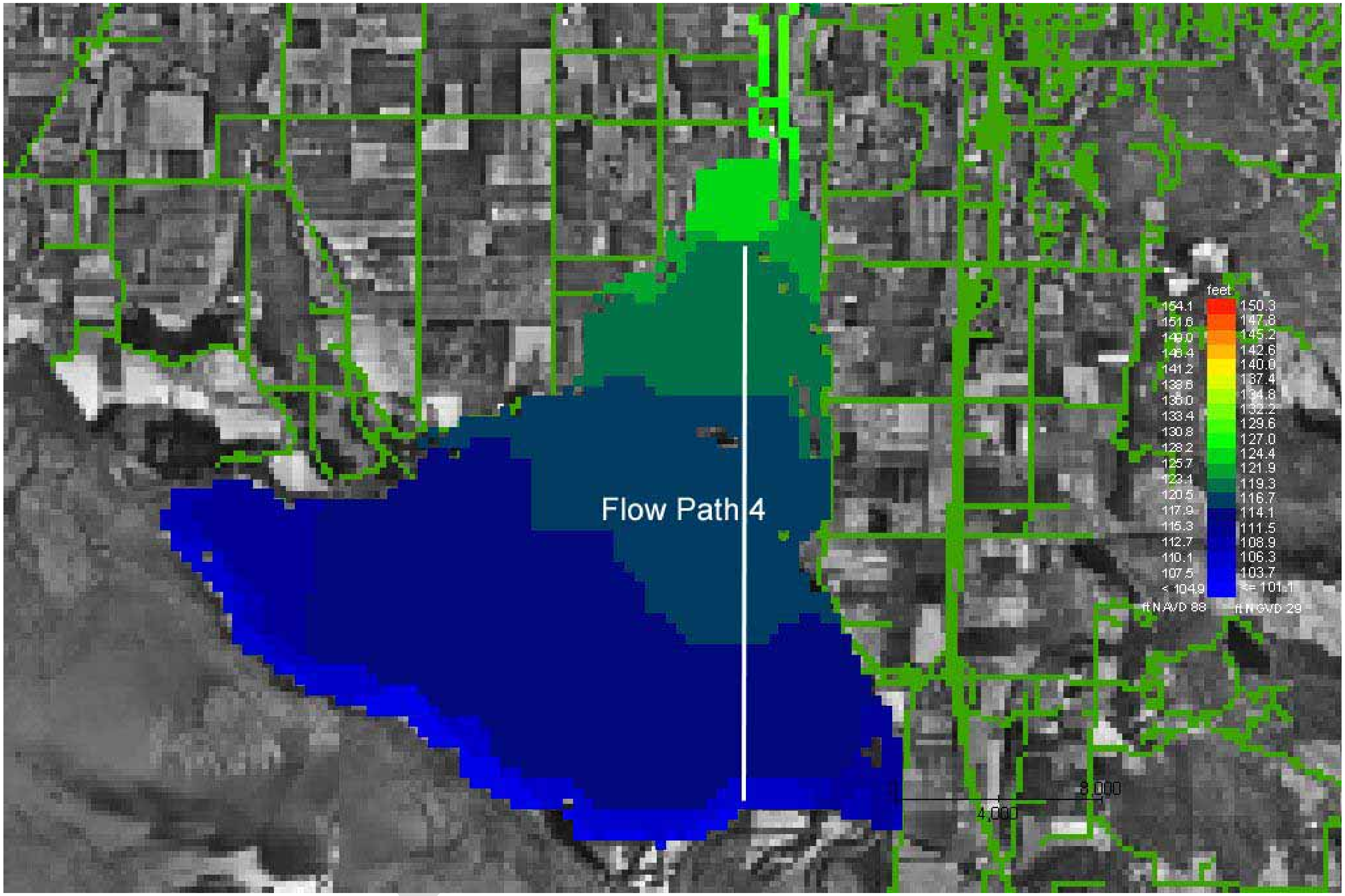

Figure 25 – Floodplain Flow Path 4

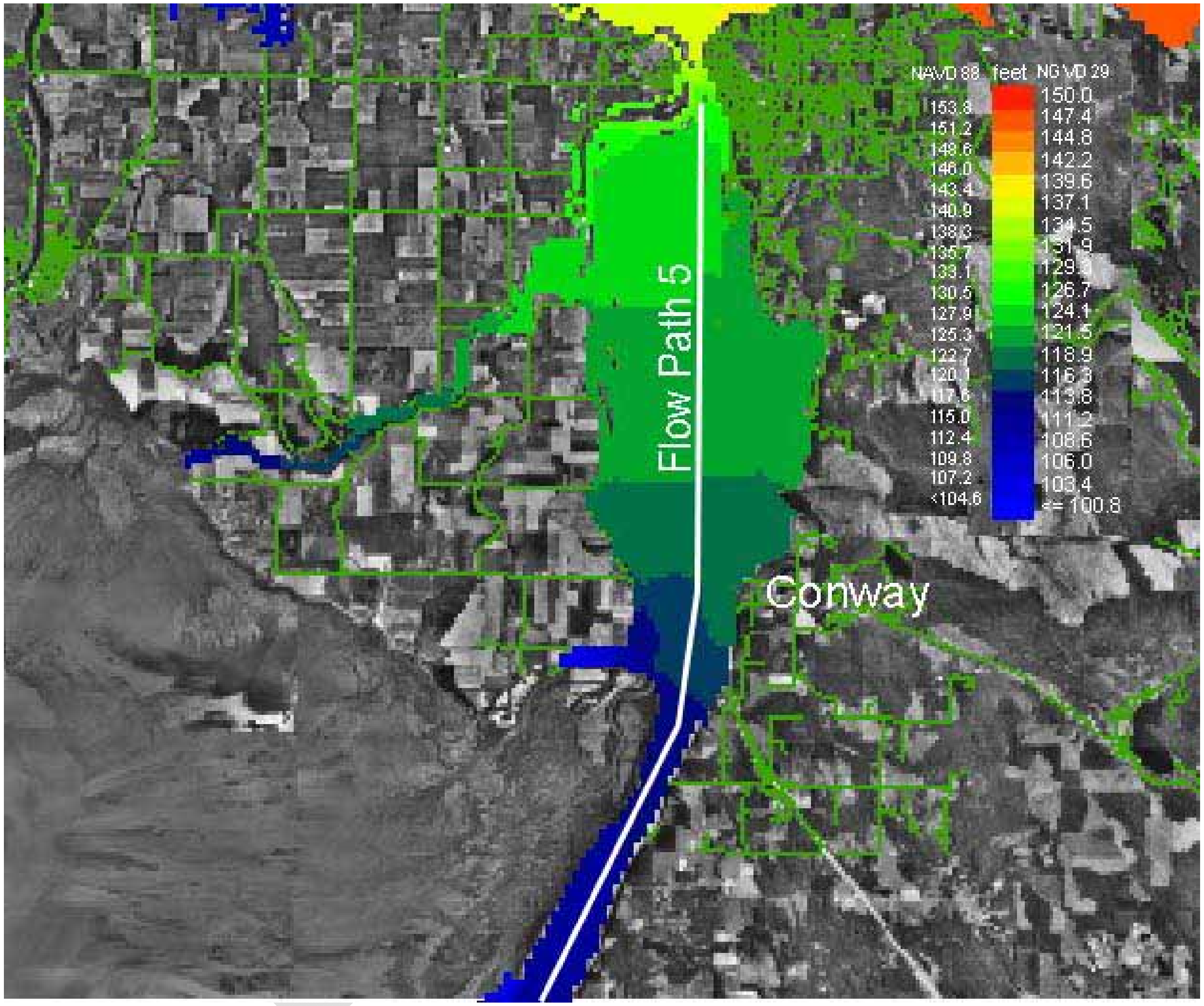

Figure 26 – Floodplain Flow Path 5

E. Comparison of Floodplain Flow Path Profiles to Historic Floods

Although the analysis to develop base flood elevations in the floodplain does not mimic past floods exactly, past information on flood depths in the floodplain give credence to the elevations predicted in the flood profiles. In Appendix A, flood profile 01P, which depicts flow path 1, shows 6 feet of depth for the 100-year flood at Anacortes Street in Burlington. Figure 27 is a picture of the corner of Fairhaven and Anacortes Streets after the December 1921 flood which had roughly the same discharge as the predicted 100-year flood. The Concrete Herald reported on 12/17/21 that “The entire city of Burlington was flooded to a depth of from three to five feet” (Concrete Herald, 12/17/21). In addition, this area has been significantly developed since this flood (see Figures 28 and 29). This reduces the area in which water can flow which can raise the water surface elevation upstream. Roads, such as I-5, have been built as much as 3 to 5 feet above the ground which also forces the water surface up to overtop the roads. It is for these reasons that 6 feet of depth in this area seems reasonable.

Flood profile 02P and 03P depict flow path 2, which is the flow path that runs out to Samish Bay. The Mount Vernon Argus reported on the 1921 flood on 12/15/21, “In some of the houses in the Samish flats water was 6 or 7 feet and the occupants were forced to move to the second story” (Mount Vernon Argus, 12/15/21). The modeling in this area predicts 100-year flood depths of up to 8 feet.

Flood profile 06P depicts flow path 4, which represents Fir Island. It shows a 100-year depth across the floodplain of 8 to 10 feet. On November 11, 1990, the Skagit River near Mount Vernon gage reached 149,000 cfs, which is roughly a 25-year flood event. A levee on the Fir Island side of the North Fork Skagit River (left bank) failed at this time. The Seattle Times in a November 13, 1990 article quoted several farmers in the Fir Island area that the depth of flooding was 7 to 10 feet deep across the entire island (Seattle Times, 11/13/90). The extent of Fir Island flooding after a levee failure is significantly defined by the fact that the area fills up until the water overtops the downstream sea dikes. The area can fill up at even a 25-year flood event so it is consistent that the 100-year flood depths are similar to what was observed in 1990.

Flood profile 07P through 09P depicts flow path 5, which represents the floodplain from West Mount Vernon down to Stanwood. It shows a 100-year depth at the town of Conway of 10 feet. On February 11, 1951, the Skagit River near Mount Vernon gage reached 144,000 cfs, which is roughly a 25-year flood event. The levee system in this reach failed and the flooding in this area can be seen in Figure 30. The Mount Vernon Argus dated 2/15/51 states that “Conway residents declared the 1951 flood was two feet, ten inches below the 1921 inundation in their community.” This would make the 1921 flood similar in depth to the 100-year modeled flood estimate.

Figure 27 – December 1921 Flood at Fairhaven and Anacortes Streets

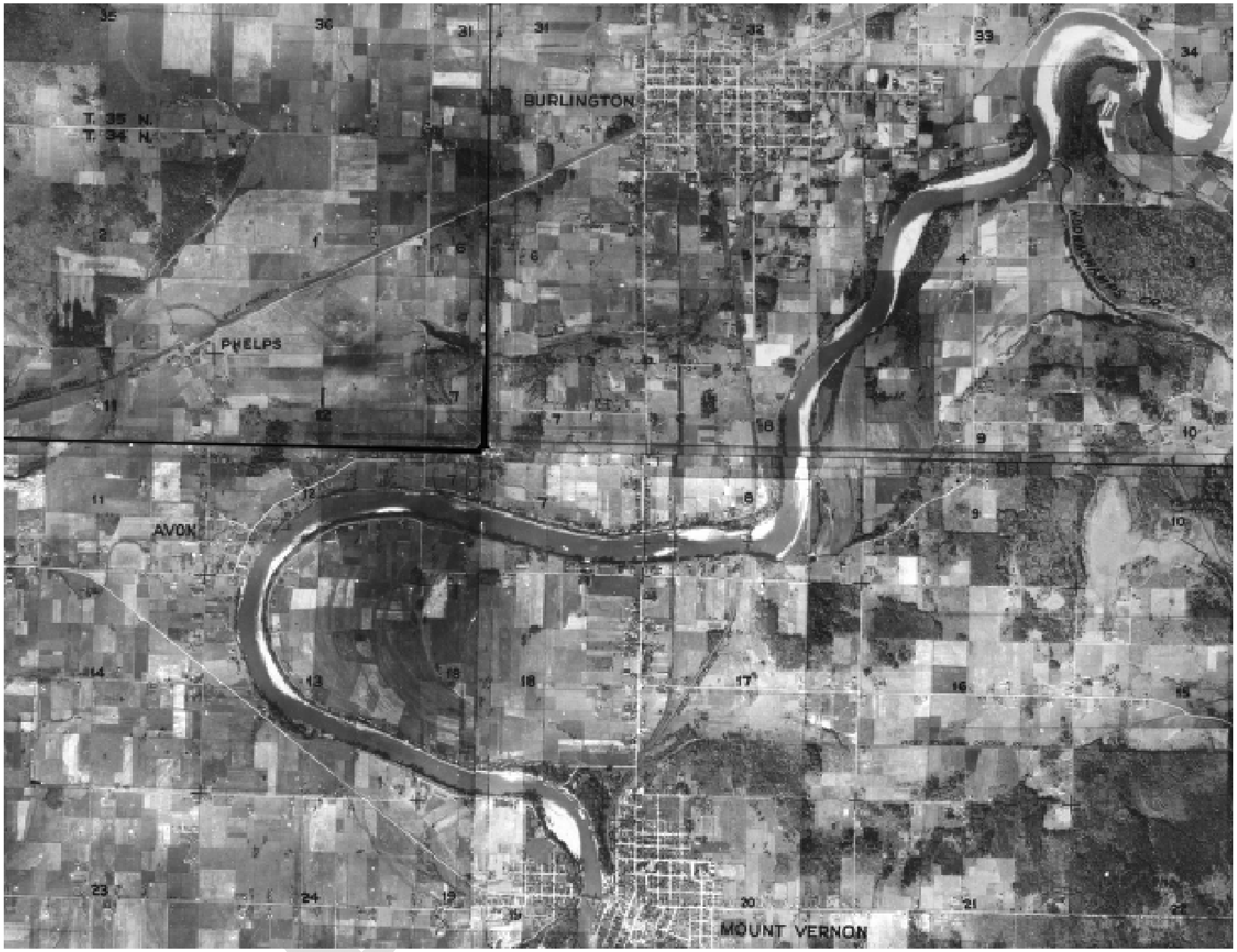

Figure 28 – 1937 Aerial Photo of Mount Vernon and Burlington

Figure 29 – 2001 Aerial Photo of Mount Vernon and Burlington

Figure 30 – Conway Area in February 1951 Flood

REFERENCES

1. The Concrete Herald. 12/17/1921. *HEAVY DAMAGE WAS CAUSED BY FLOODS IN LOWER VALLEY.*

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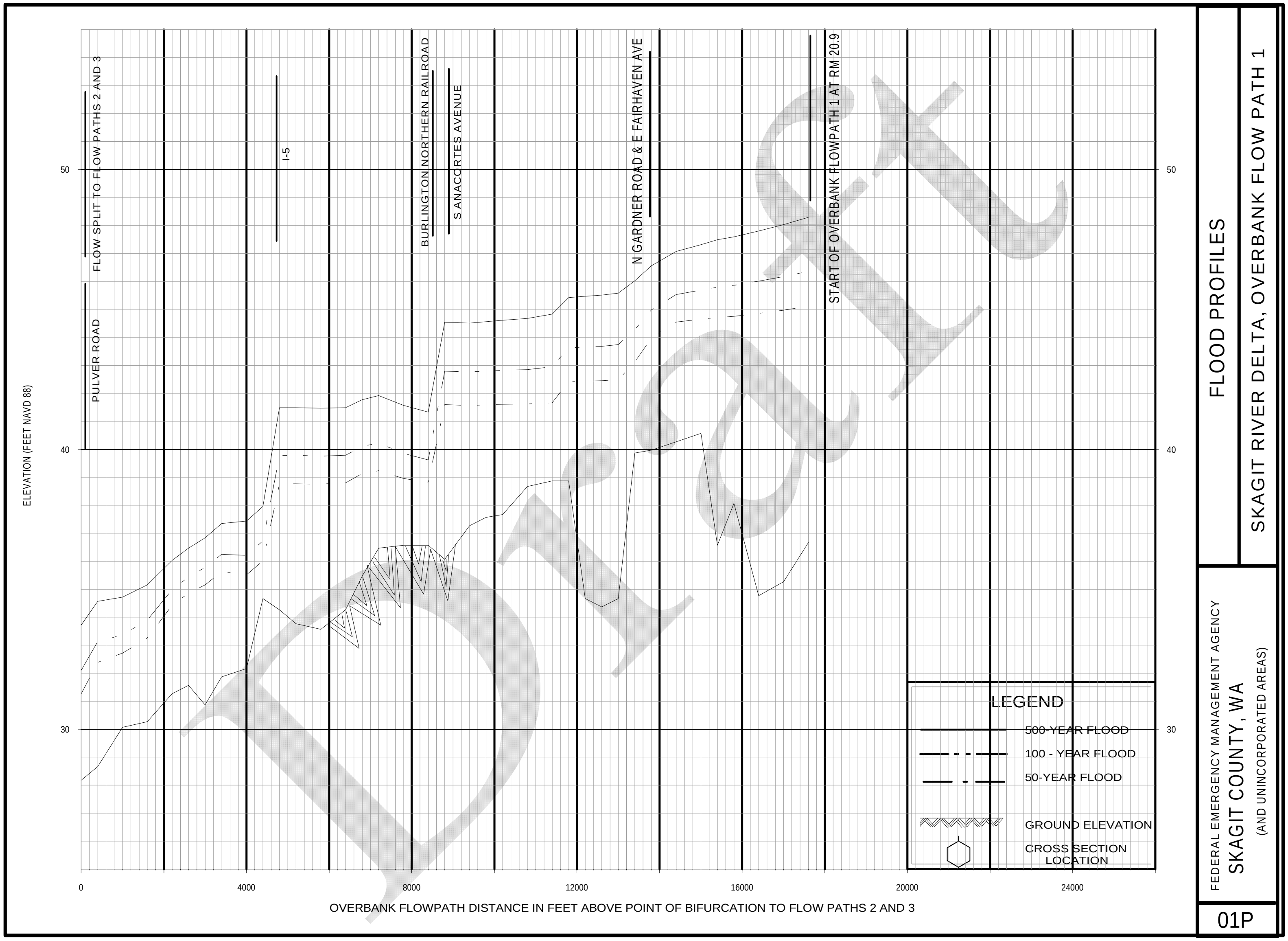
APPENDIX A

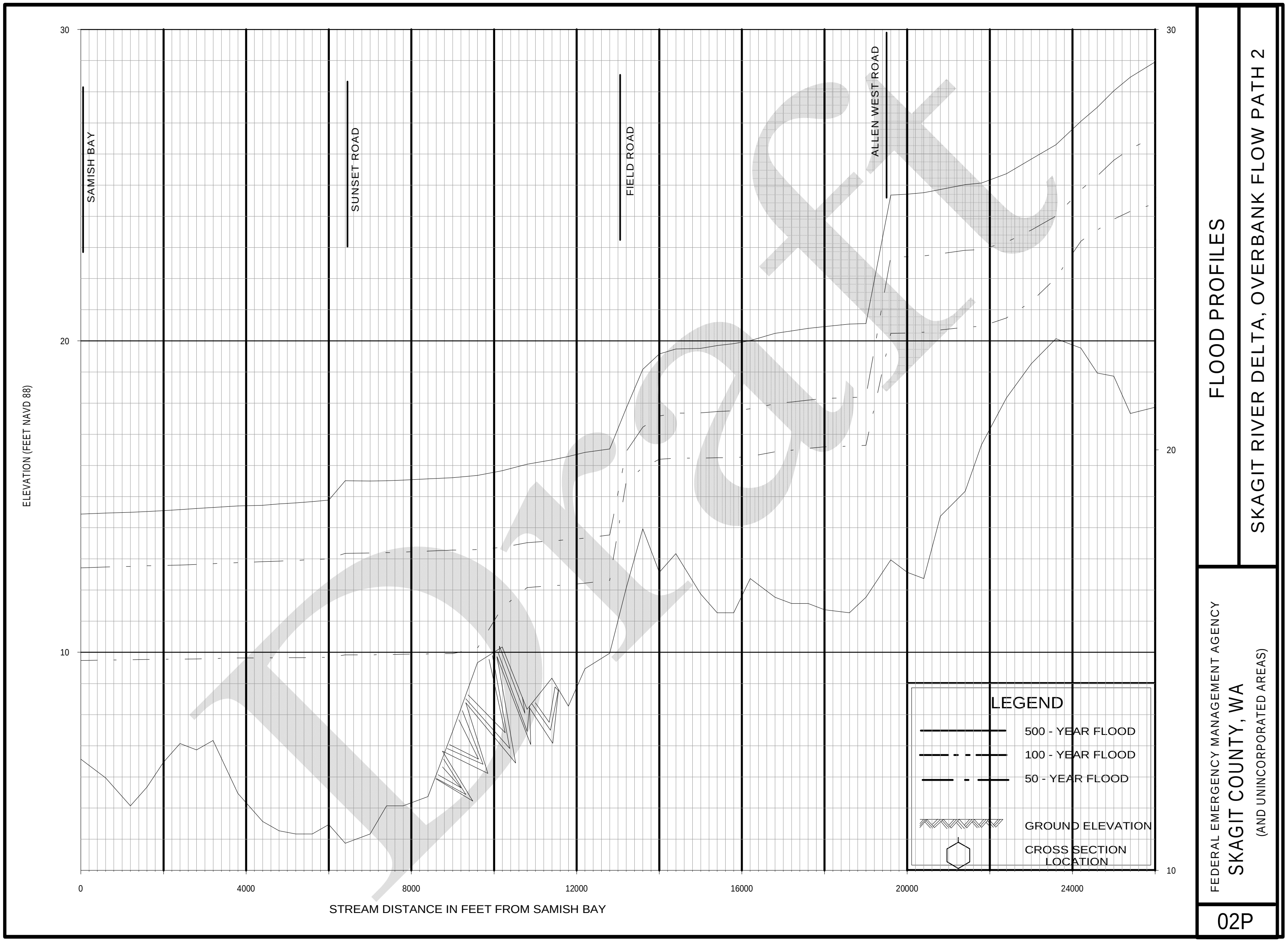
FLOOD PROFILES

FOR THE

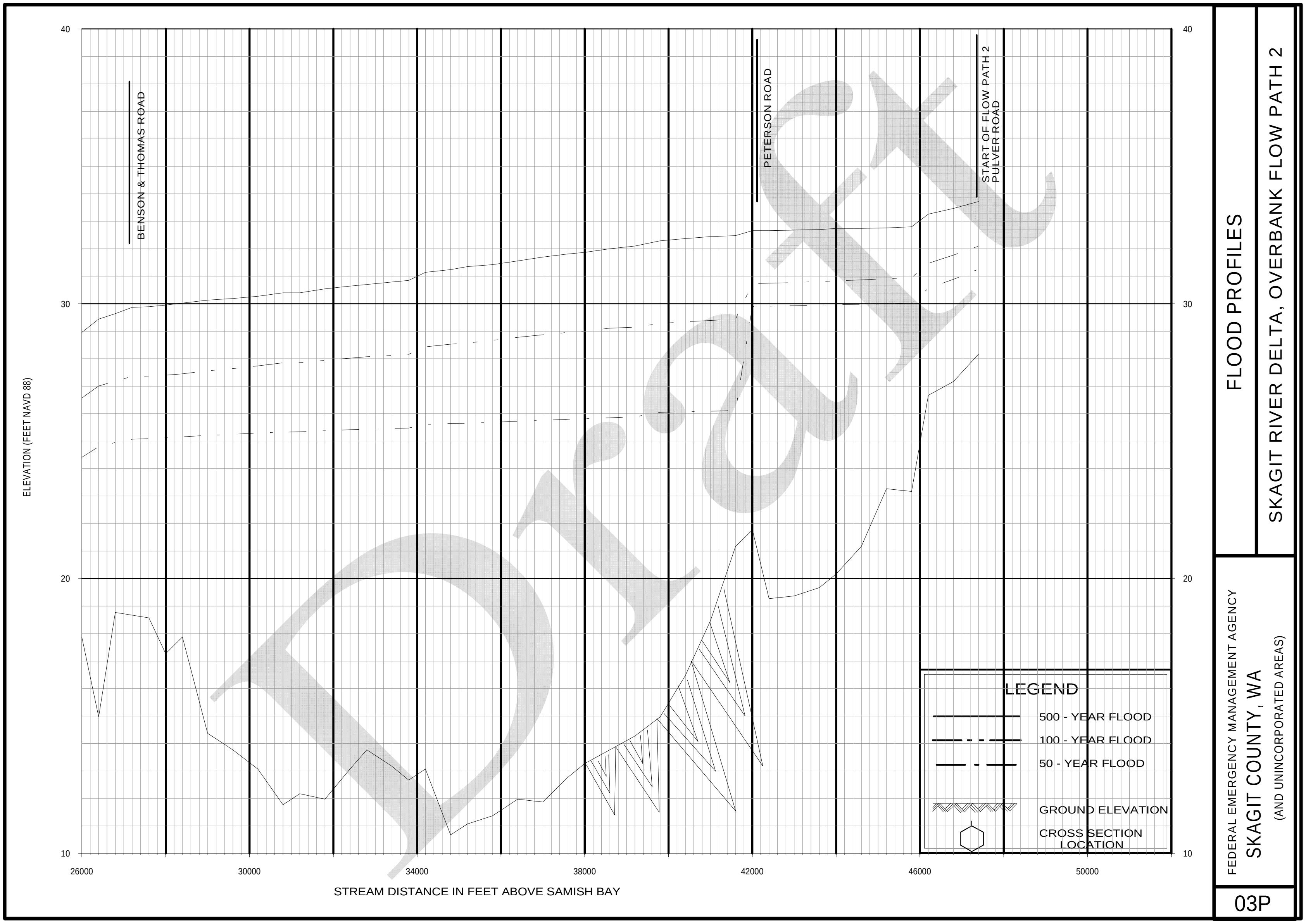
SKAGIT RIVER BASIN

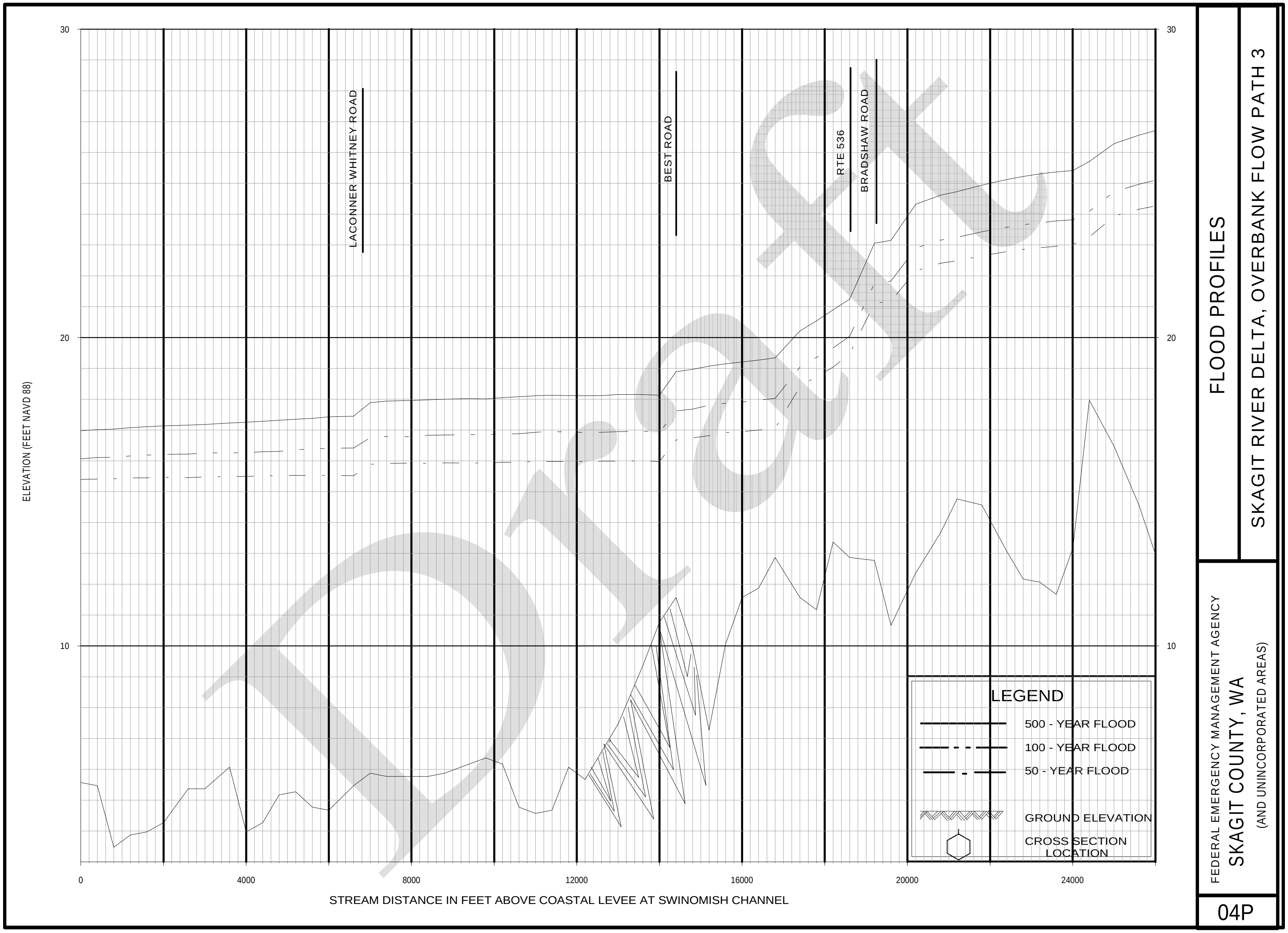


FLOW SPLIT TO FLOW PATHS 2 AND 3
PULVER ROAD
I-5
BURLINGTON NORTHERN RAILROAD
S ANACORTES AVENUE
N GARDNER ROAD & E FAIRHAVEN AVE
START OF OVERBANK FLOWPATH 1 AT RM 20.9
ELEVATION (FEET NAVD 88)
30
40
50
0
4000
8000
12000
16000
20000
24000
OVERBANK FLOWPATH DISTANCE IN FEET ABOVE POINT OF BIFURCATION TO FLOW PATHS 2 AND 3
LEGEND
500-YEAR FLOOD
100 - YEAR FLOOD
50-YEAR FLOOD
GROUND ELEVATION
CROSS SECTION LOCATION
FLOOD PROFILES
SKAGIT RIVER DELTA, OVERBANK FLOW PATH 1
FEDERAL EMERGENCY MANAGEMENT AGENCY
SKAGIT COUNTY, WA
(AND UNINCORPORATED AREAS)
01P

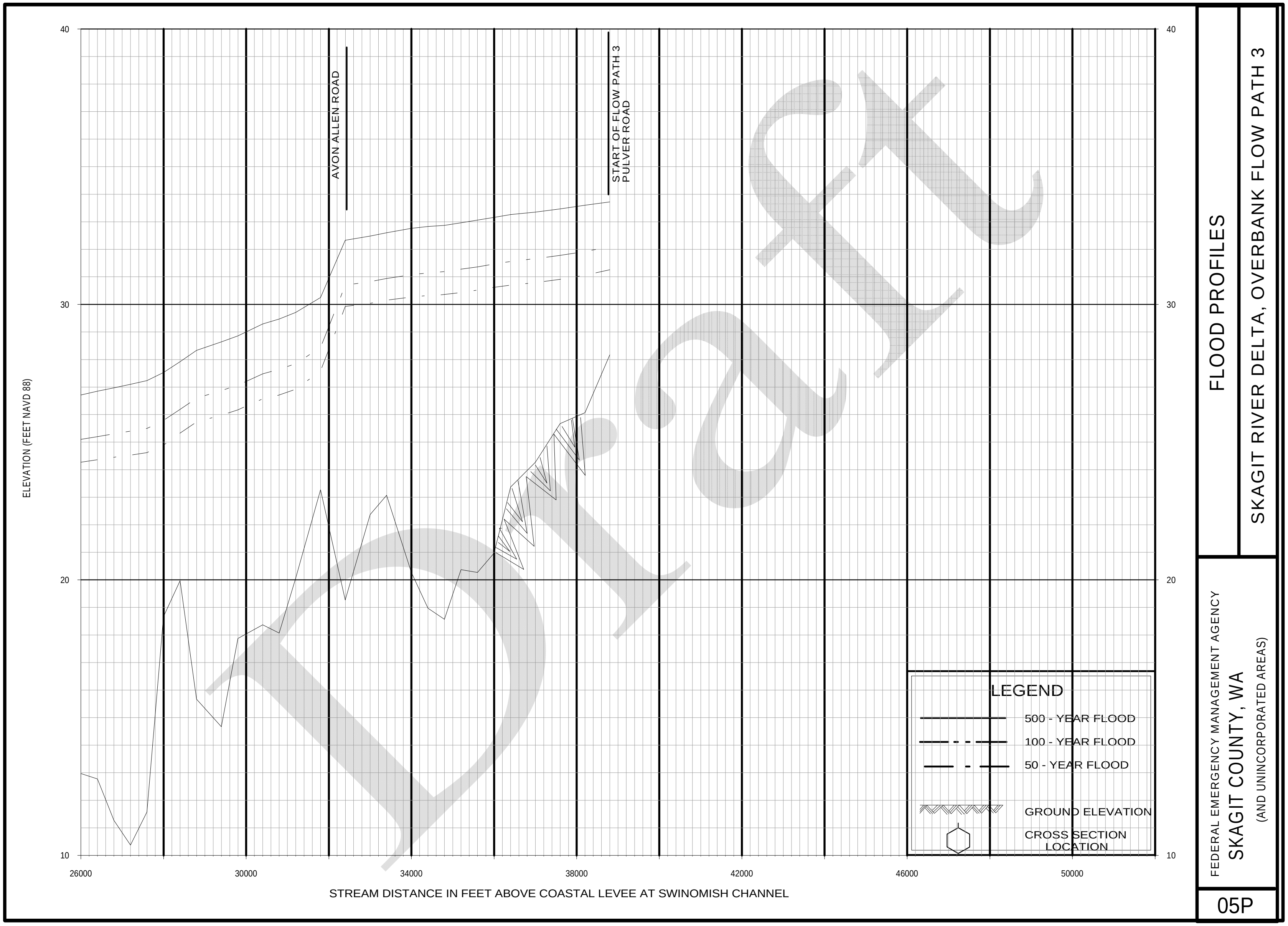


SAMISH BAY
SUNSET ROAD
FIELD ROAD
ALLEN WEST ROAD
30
20
10
ELEVATION (FEET NAVD 88)
0
4000
8000
12000
16000
20000
24000
STREAM DISTANCE IN FEET FROM SAMISH BAY
LEGEND
500 - YEAR FLOOD
100 - YEAR FLOOD
50 - YEAR FLOOD
GROUND ELEVATION
CROSS SECTION LOCATION
FLOOD PROFILES
SKAGIT RIVER DELTA, OVERBANK FLOW PATH 2
FEDERAL EMERGENCY MANAGEMENT AGENCY
SKAGIT COUNTY, WA
(AND UNINCORPORATED AREAS)
02P
Draft

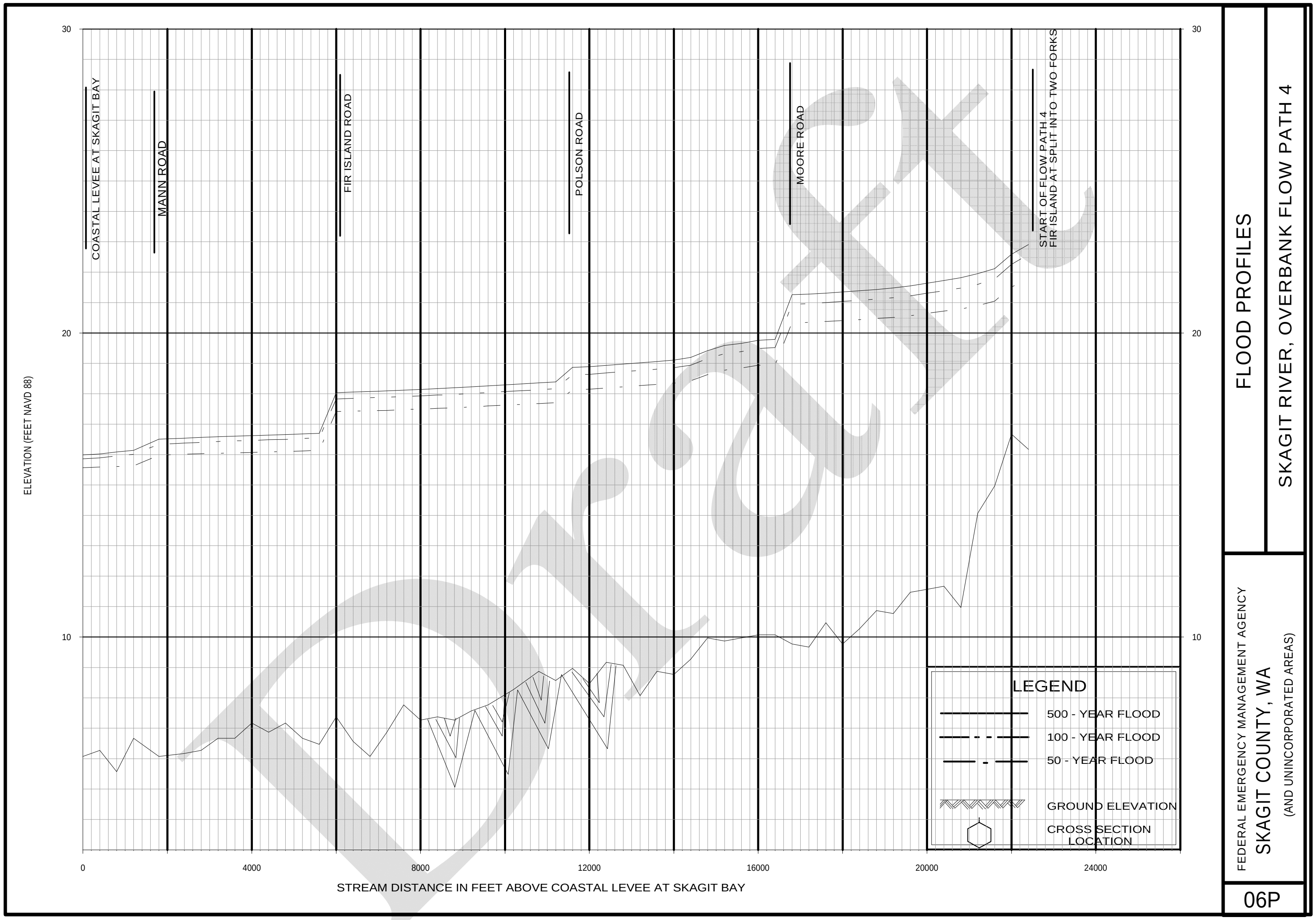

BENSON & THOMAS ROAD
PETERSON ROAD
START OF FLOW PATH 2
PULVER ROAD
ELEVATION (FEET NAVD 88)
40
30
20
10
26000
30000
34000
38000
42000
46000
50000
STREAM DISTANCE IN FEET ABOVE SAMISH BAY
LEGEND
500 - YEAR FLOOD
100 - YEAR FLOOD
50 - YEAR FLOOD
GROUND ELEVATION
CROSS SECTION LOCATION
FLOOD PROFILES
SKAGIT RIVER DELTA, OVERBANK FLOW PATH 2
FEDERAL EMERGENCY MANAGEMENT AGENCY
SKAGIT COUNTY, WA
(AND UNINCORPORATED AREAS)
03P

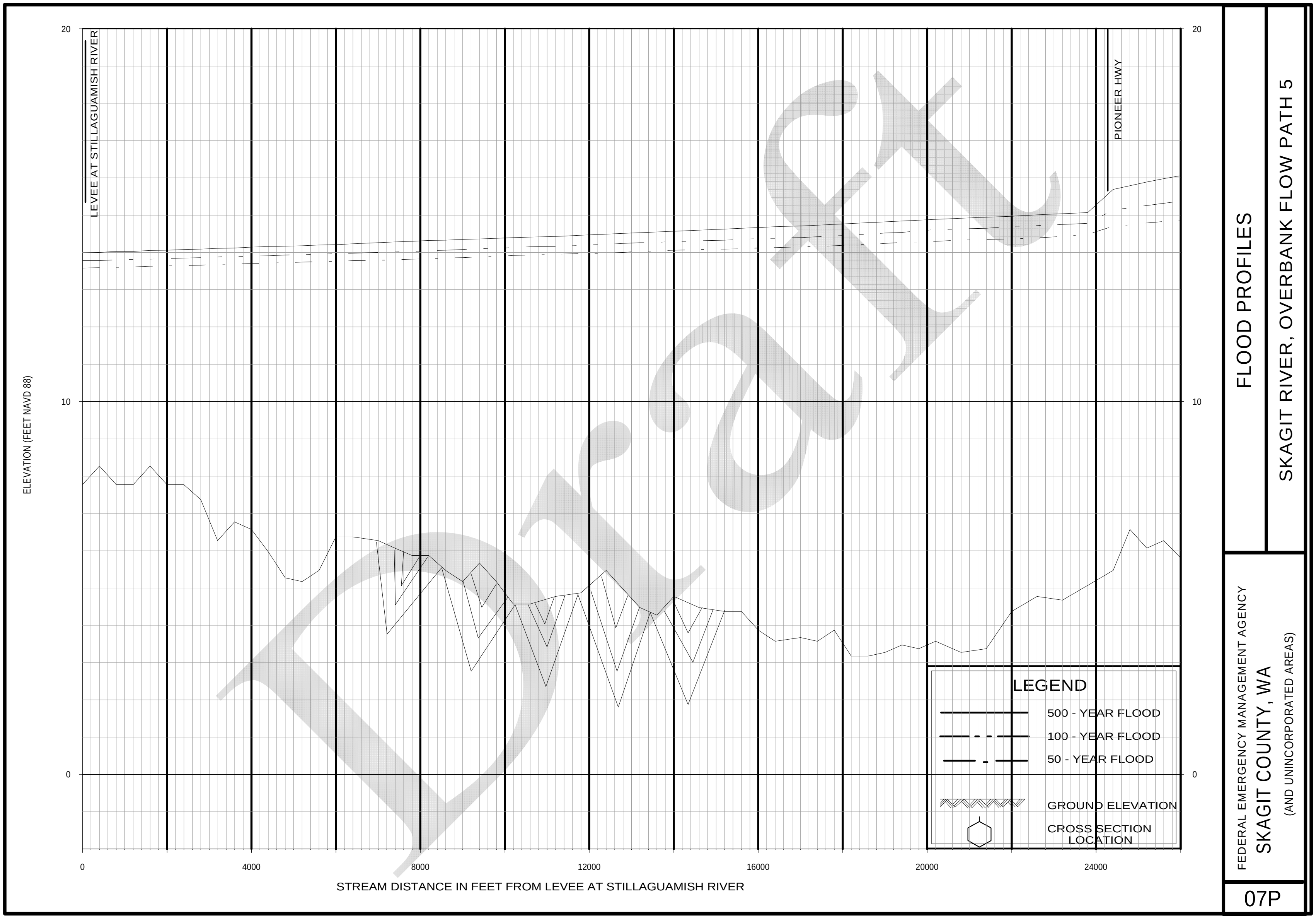


FLOOD PROFILES
SKAGIT RIVER DELTA, OVERBANK FLOW PATH 3
FEDERAL EMERGENCY MANAGEMENT AGENCY
SKAGIT COUNTY, WA
(AND UNINCORPORATED AREAS)
04P
LACONNER WHITNEY ROAD
BEST ROAD
RTE 536
BRADSHAW ROAD
ELEVATION (FEET NAVD 88)
STREAM DISTANCE IN FEET ABOVE COASTAL LEVEE AT SWINOMISH CHANNEL
30
20
10
0
4000
8000
12000
16000
20000
24000
LEGEND
500 - YEAR FLOOD
100 - YEAR FLOOD
50 - YEAR FLOOD
GROUND ELEVATION
CROSS SECTION LOCATION

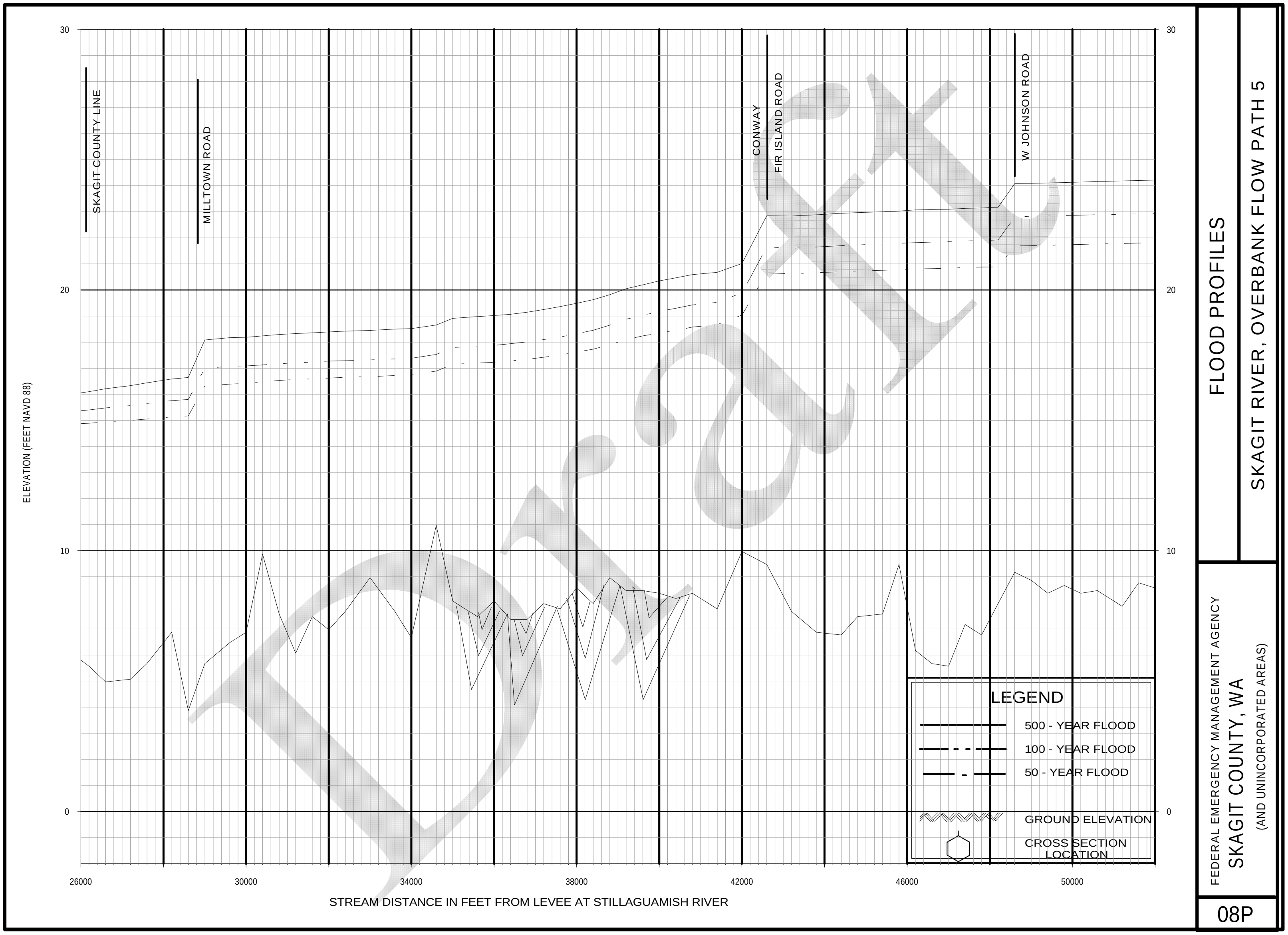


AVON ALLEN ROAD
START OF FLOW PATH 3
PULVER ROAD
ELEVATION (FEET NAVD 88)
STREAM DISTANCE IN FEET ABOVE COASTAL LEVEE AT SWINOMISH CHANNEL
26000
30000
34000
38000
42000
46000
50000
10
20
30
40
LEGEND
500 - YEAR FLOOD
100 - YEAR FLOOD
50 - YEAR FLOOD
GROUND ELEVATION
CROSS SECTION LOCATION
FLOOD PROFILES
SKAGIT RIVER DELTA, OVERBANK FLOW PATH 3
FEDERAL EMERGENCY MANAGEMENT AGENCY
SKAGIT COUNTY, WA
(AND UNINCORPORATED AREAS)
05P

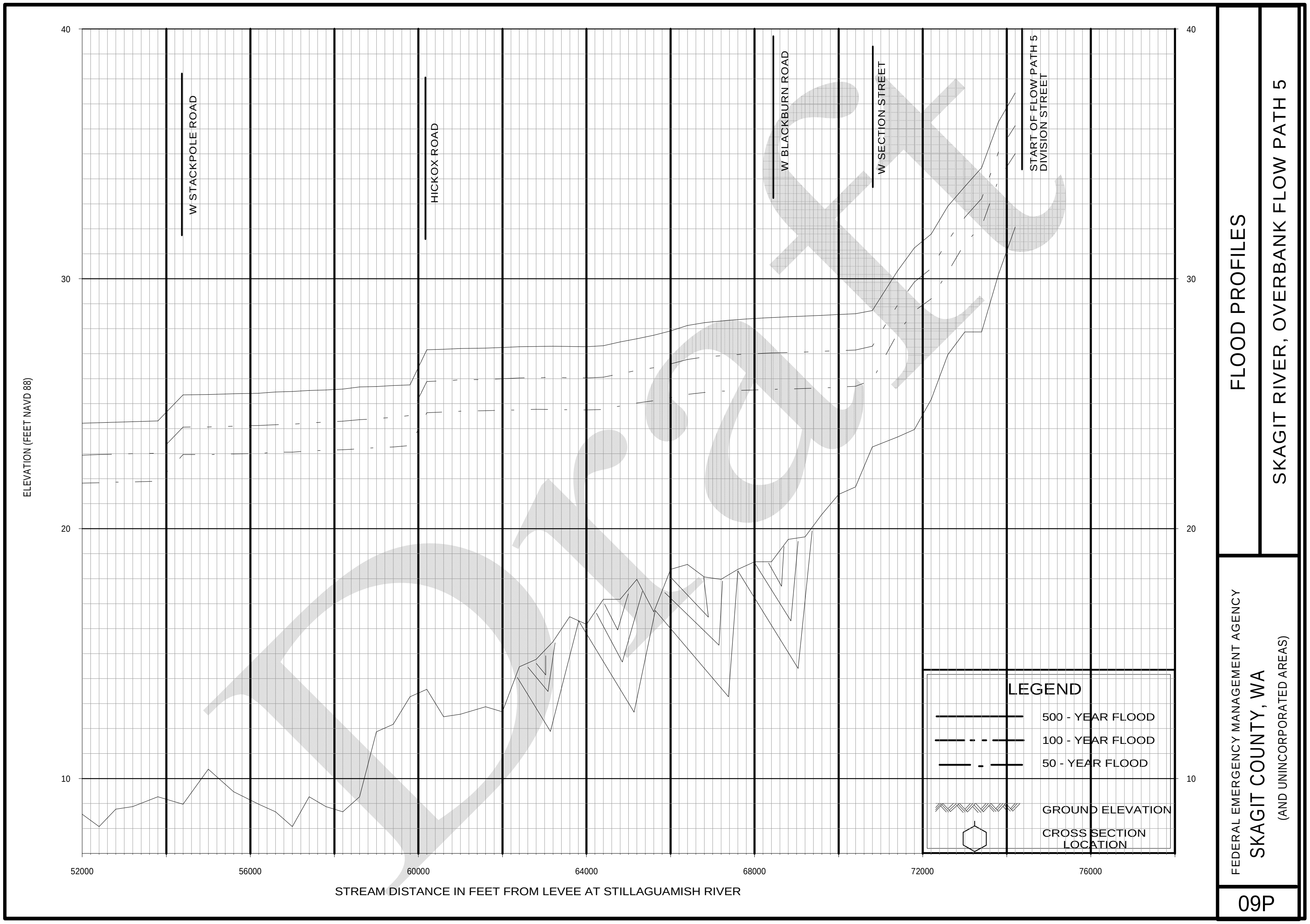

COASTAL LEVEE AT SKAGIT BAY
MANN ROAD
FIR ISLAND ROAD
POLSON ROAD
MOORE ROAD
START OF FLOW PATH 4
FIR ISLAND AT SPLIT INTO TWO FORKS
ELEVATION (FEET NAVD 88)
STREAM DISTANCE IN FEET ABOVE COASTAL LEVEE AT SKAGIT BAY
LEGEND
500 - YEAR FLOOD
100 - YEAR FLOOD
50 - YEAR FLOOD
GROUND ELEVATION
CROSS SECTION LOCATION
FLOOD PROFILES
SKAGIT RIVER, OVERBANK FLOW PATH 4
FEDERAL EMERGENCY MANAGEMENT AGENCY
SKAGIT COUNTY, WA
(AND UNINCORPORATED AREAS)
06P



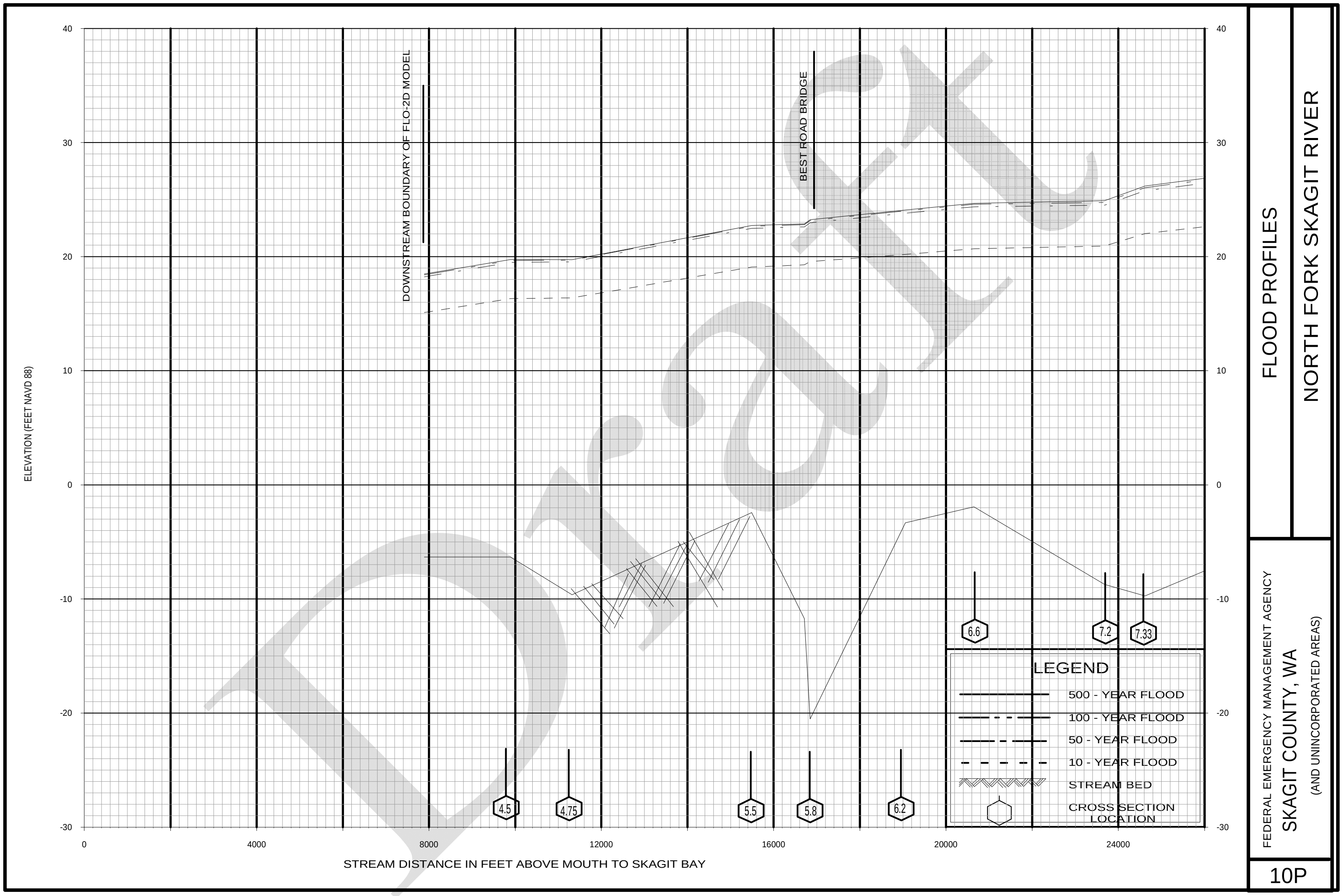
LEVEE AT STILLAGUAMISH RIVER
PIONEER HWY
ELEVATION (FEET NAVD 88)
20
10
0
0
4000
8000
12000
16000
20000
24000
STREAM DISTANCE IN FEET FROM LEVEE AT STILLAGUAMISH RIVER
LEGEND
500 - YEAR FLOOD
100 - YEAR FLOOD
50 - YEAR FLOOD
GROUND ELEVATION
CROSS SECTION LOCATION
FLOOD PROFILES
SKAGIT RIVER, OVERBANK FLOW PATH 5
FEDERAL EMERGENCY MANAGEMENT AGENCY
SKAGIT COUNTY, WA
(AND UNINCORPORATED AREAS)
07P



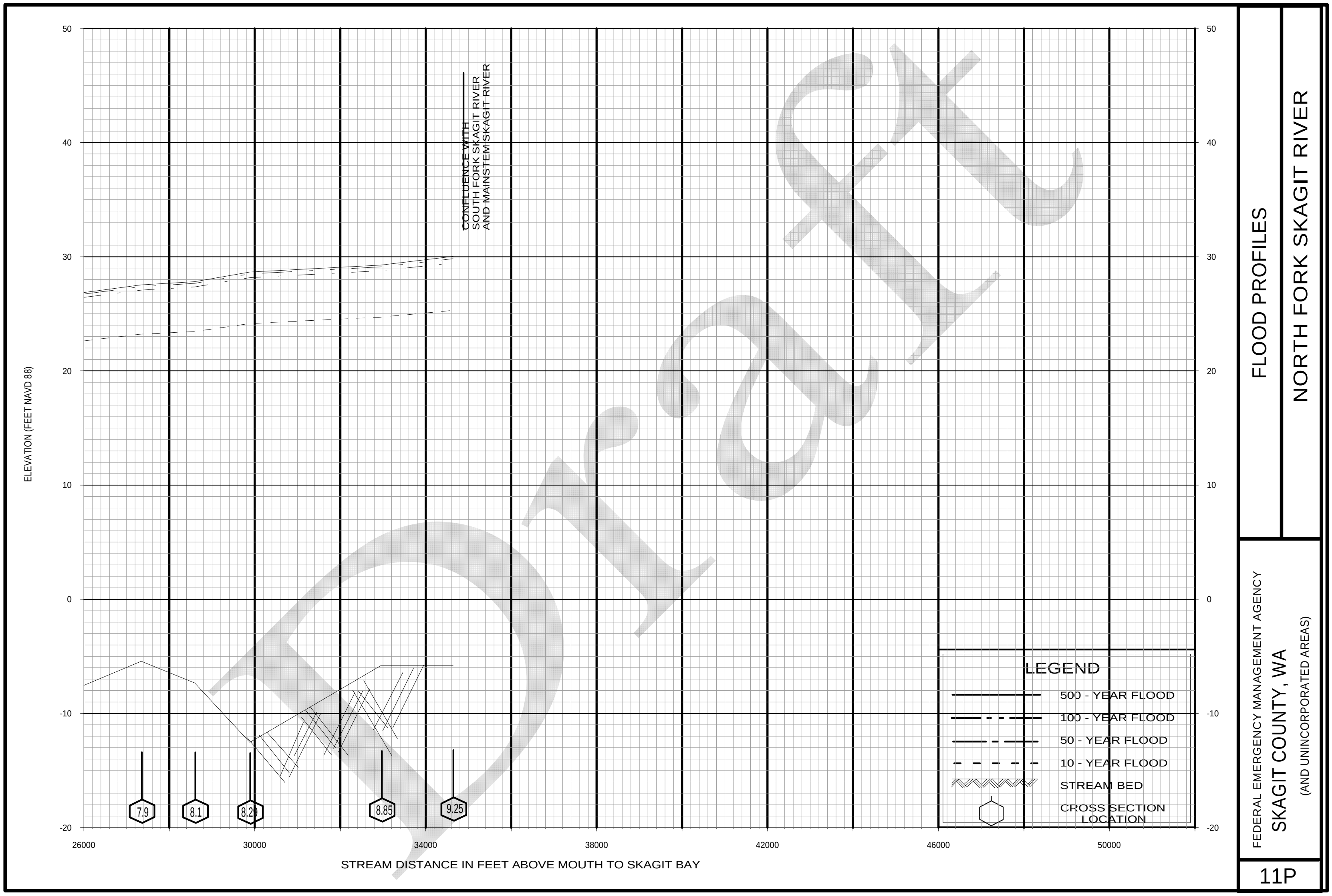
30
20
10
0
ELEVATION (FEET NAVD 88)
SKAGIT COUNTY LINE
MILLTOWN ROAD
CONWAY
FIR ISLAND ROAD
W JOHNSON ROAD
26000
30000
34000
38000
42000
46000
50000
STREAM DISTANCE IN FEET FROM LEVEE AT STILLAGUAMISH RIVER
LEGEND
500 - YEAR FLOOD
100 - YEAR FLOOD
50 - YEAR FLOOD
GROUND ELEVATION
CROSS SECTION LOCATION
FLOOD PROFILES
SKAGIT RIVER, OVERBANK FLOW PATH 5
FEDERAL EMERGENCY MANAGEMENT AGENCY
SKAGIT COUNTY, WA
(AND UNINCORPORATED AREAS)
08P

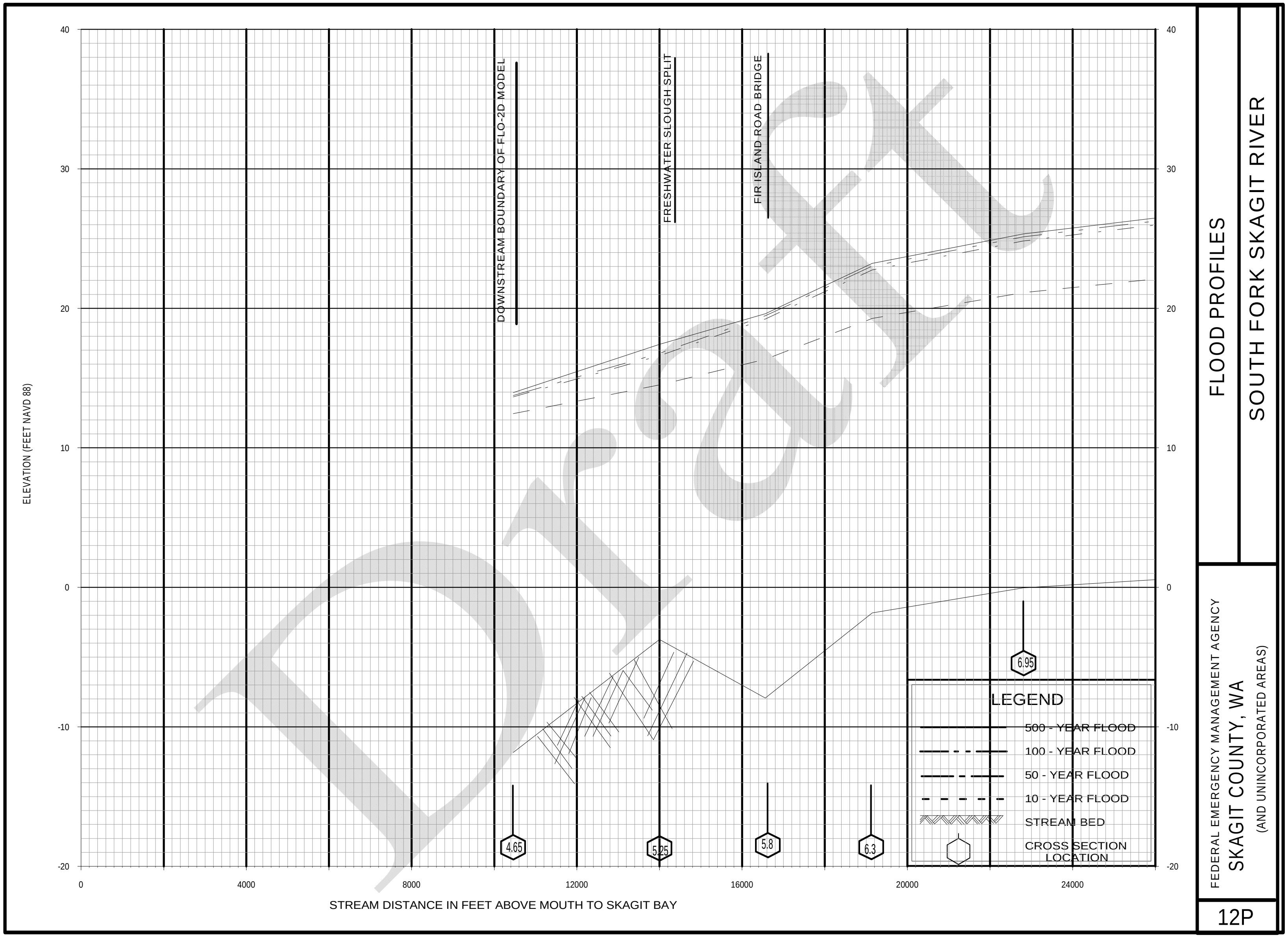


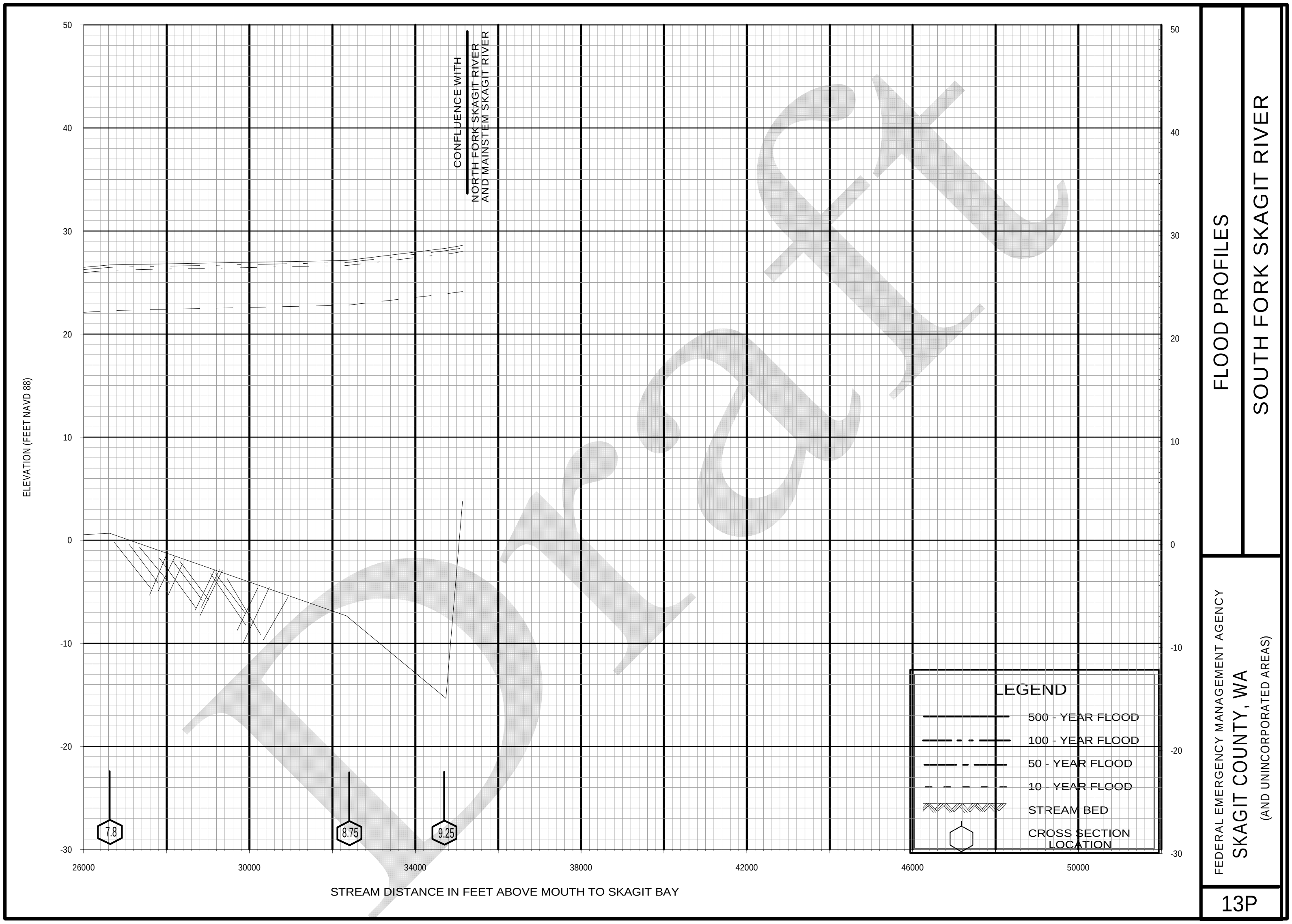
W STACKPOLE ROAD
HICKOX ROAD
W BLACKBURN ROAD
W SECTION STREET
START OF FLOW PATH 5
DIVISION STREET
ELEVATION (FEET NAVD 88)
STREAM DISTANCE IN FEET FROM LEVEE AT STILLAGUAMISH RIVER
LEGEND
500 - YEAR FLOOD
100 - YEAR FLOOD
50 - YEAR FLOOD
GROUND ELEVATION
CROSS SECTION LOCATION
FLOOD PROFILES
SKAGIT RIVER, OVERBANK FLOW PATH 5
FEDERAL EMERGENCY MANAGEMENT AGENCY
SKAGIT COUNTY, WA
(AND UNINCORPORATED AREAS)
09P



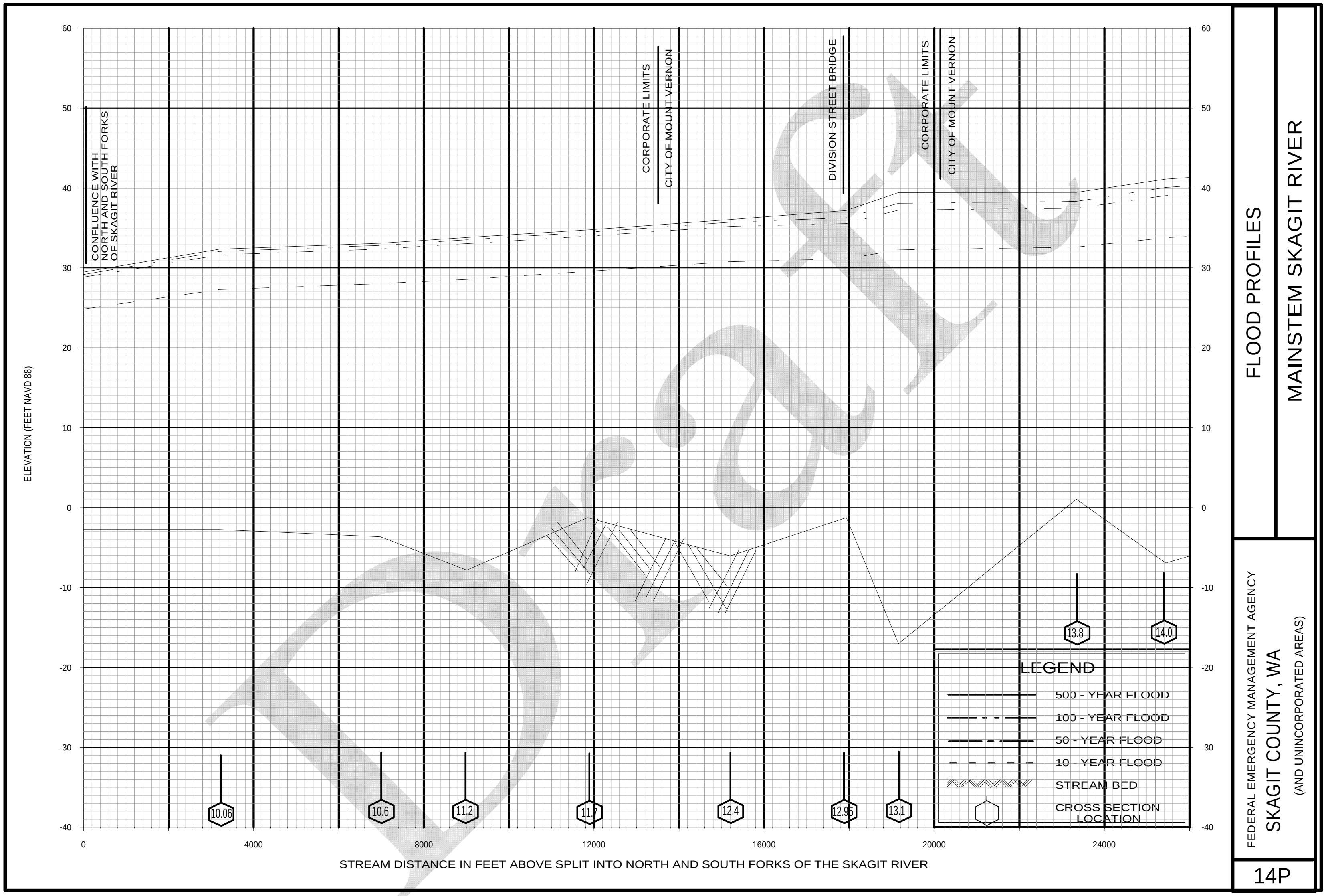
FLOOD PROFILES
NORTH FORK SKAGIT RIVER
FEDERAL EMERGENCY MANAGEMENT AGENCY
SKAGIT COUNTY, WA
(AND UNINCORPORATED AREAS)
10P
ELEVATION (FEET NAVD 88)
STREAM DISTANCE IN FEET ABOVE MOUTH TO SKAGIT BAY
DOWNSTREAM BOUNDARY OF FLO-2D MODEL
BEST ROAD BRIDGE
LEGEND
500 - YEAR FLOOD
100 - YEAR FLOOD
50 - YEAR FLOOD
10 - YEAR FLOOD
STREAM BED
CROSS SECTION LOCATION
4.5
4.75
5.5
5.8
6.2
6.6
7.2
7.33

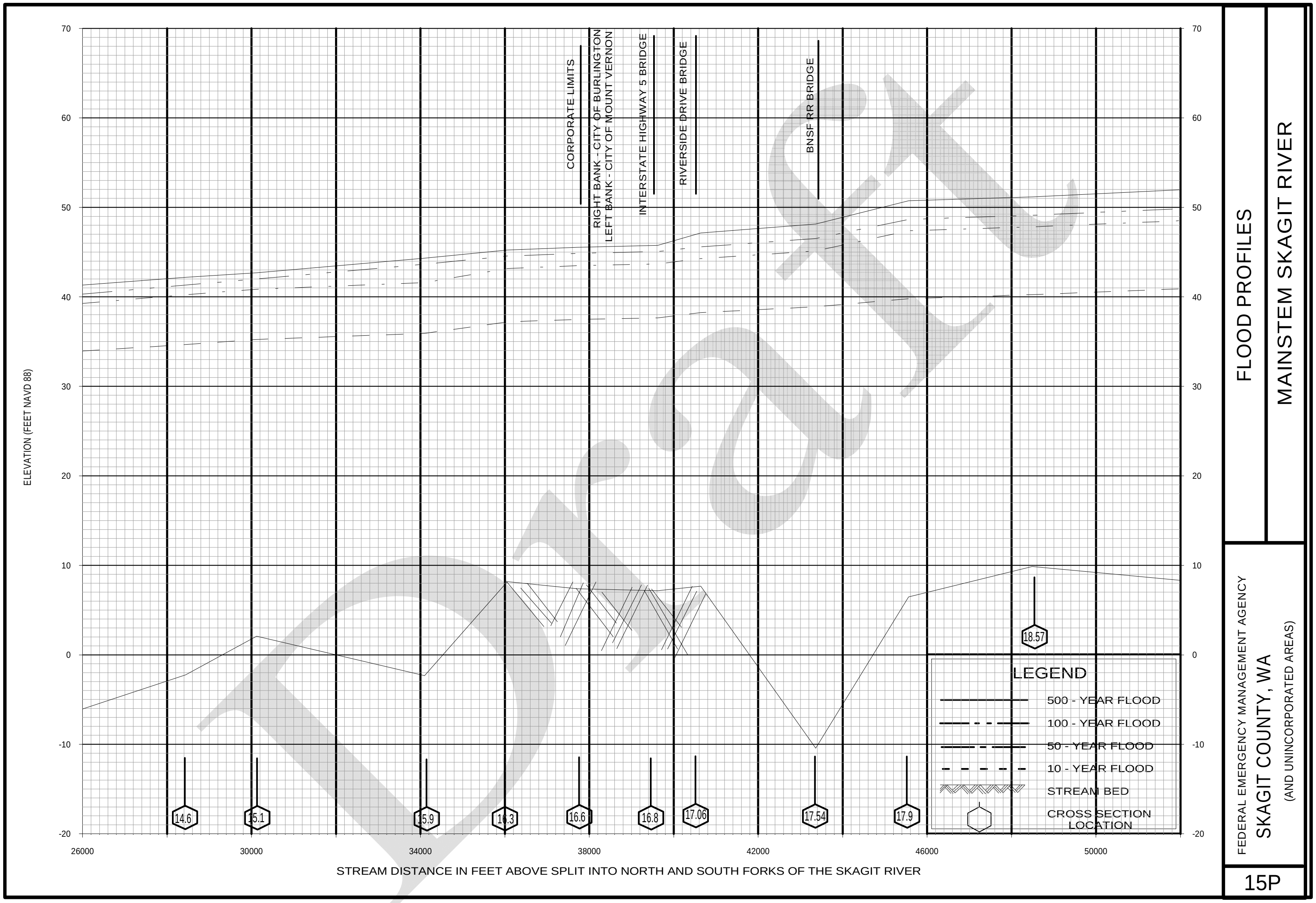

CONFLUENCE WITH
SOUTH FORK SKAGIT RIVER
AND MAINSTEM SKAGIT RIVER
ELEVATION (FEET NAVD 88)
STREAM DISTANCE IN FEET ABOVE MOUTH TO SKAGIT BAY
7.9
8.1
8.29
8.85
9.25
LEGEND
500 - YEAR FLOOD
100 - YEAR FLOOD
50 - YEAR FLOOD
10 - YEAR FLOOD
STREAM BED
CROSS SECTION LOCATION
FLOOD PROFILES
NORTH FORK SKAGIT RIVER
FEDERAL EMERGENCY MANAGEMENT AGENCY
SKAGIT COUNTY, WA
(AND UNINCORPORATED AREAS)
11P


DOWNSTREAM BOUNDARY OF FLO-2D MODEL
FRESHWATER SLOUGH SPLIT
FIR ISLAND ROAD BRIDGE
ELEVATION (FEET NAVD 88)
STREAM DISTANCE IN FEET ABOVE MOUTH TO SKAGIT BAY
40
30
20
10
0
-10
-20
0
4000
8000
12000
16000
20000
24000
4.65
5.25
5.8
6.3
6.95
LEGEND
500 - YEAR FLOOD
100 - YEAR FLOOD
50 - YEAR FLOOD
10 - YEAR FLOOD
STREAM BED
CROSS SECTION LOCATION
FLOOD PROFILES
SOUTH FORK SKAGIT RIVER
FEDERAL EMERGENCY MANAGEMENT AGENCY
SKAGIT COUNTY, WA
(AND UNINCORPORATED AREAS)
12P

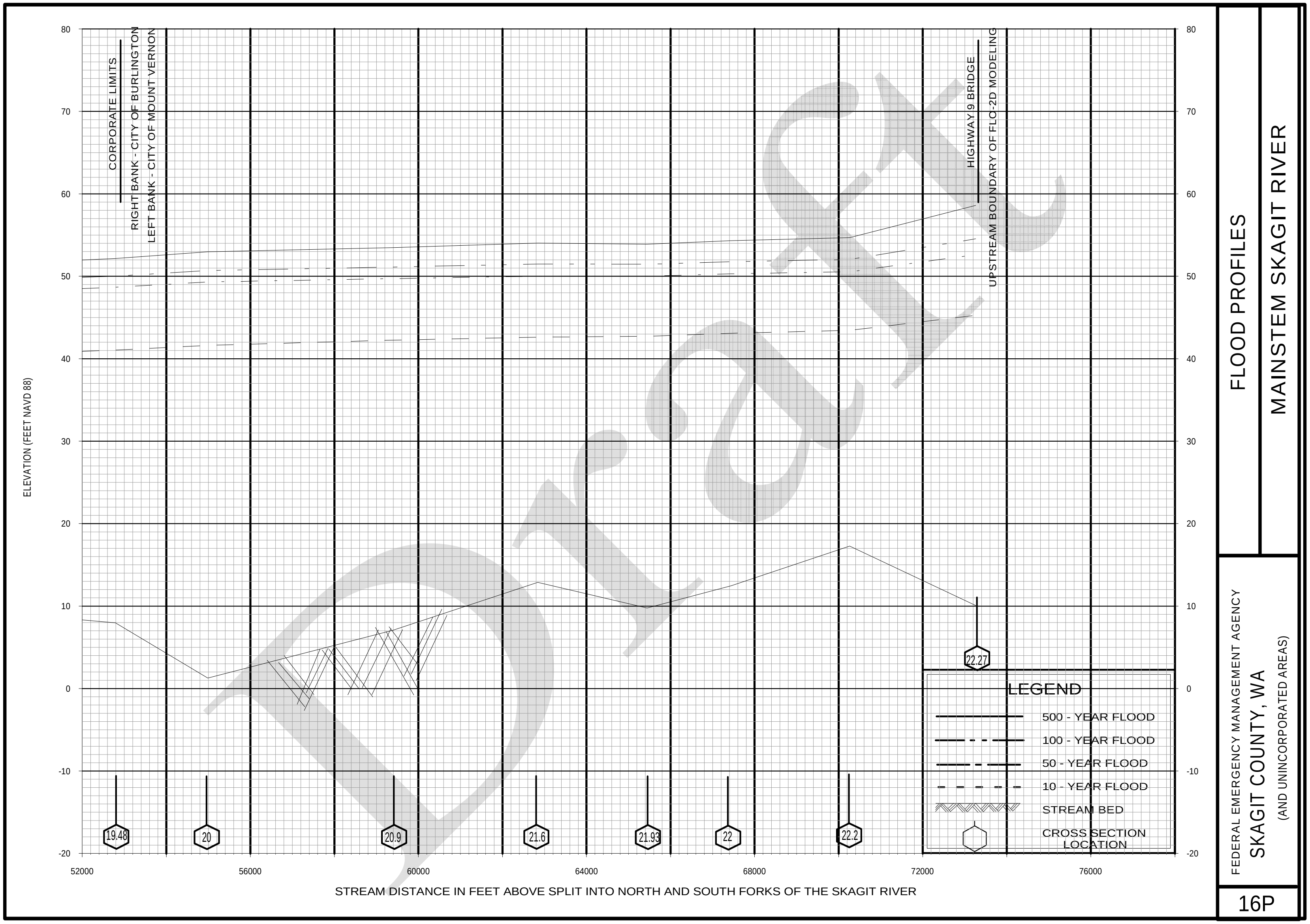


CONFLUENCE WITH
NORTH FORK SKAGIT RIVER
AND MAINSTEM SKAGIT RIVER
ELEVATION (FEET NAVD 88)
STREAM DISTANCE IN FEET ABOVE MOUTH TO SKAGIT BAY
LEGEND
500 - YEAR FLOOD
100 - YEAR FLOOD
50 - YEAR FLOOD
10 - YEAR FLOOD
STREAM BED
CROSS SECTION LOCATION
7.8
8.75
9.25
FLOOD PROFILES
SOUTH FORK SKAGIT RIVER
FEDERAL EMERGENCY MANAGEMENT AGENCY
SKAGIT COUNTY, WA
(AND UNINCORPORATED AREAS)
13P


CONFLUENCE WITH NORTH AND SOUTH FORKS OF SKAGIT RIVER
CORPORATE LIMITS
CITY OF MOUNT VERNON
DIVISION STREET BRIDGE
CORPORATE LIMITS
CITY OF MOUNT VERNON
ELEVATION (FEET NAVD 88)
STREAM DISTANCE IN FEET ABOVE SPLIT INTO NORTH AND SOUTH FORKS OF THE SKAGIT RIVER
LEGEND
500 - YEAR FLOOD
100 - YEAR FLOOD
50 - YEAR FLOOD
10 - YEAR FLOOD
STREAM BED
CROSS SECTION LOCATION
10.06
10.6
11.2
11.7
12.4
12.95
13.1
13.8
14.0
FLOOD PROFILES
MAINSTEM SKAGIT RIVER
FEDERAL EMERGENCY MANAGEMENT AGENCY
SKAGIT COUNTY, WA
(AND UNINCORPORATED AREAS)
14P



ELEVATION (FEET NAVD 88)
STREAM DISTANCE IN FEET ABOVE SPLIT INTO NORTH AND SOUTH FORKS OF THE SKAGIT RIVER
CORPORATE LIMITS
RIGHT BANK - CITY OF BURLINGTON
LEFT BANK - CITY OF MOUNT VERNON
INTERSTATE HIGHWAY 5 BRIDGE
RIVERSIDE DRIVE BRIDGE
BNSF RR BRIDGE
LEGEND
500 - YEAR FLOOD
100 - YEAR FLOOD
50 - YEAR FLOOD
10 - YEAR FLOOD
STREAM BED
CROSS SECTION LOCATION
14.6
15.1
15.9
16.3
16.6
16.8
17.06
17.54
17.9
18.57
FLOOD PROFILES
MAINSTEM SKAGIT RIVER
FEDERAL EMERGENCY MANAGEMENT AGENCY
SKAGIT COUNTY, WA
(AND UNINCORPORATED AREAS)
15P


FLOOD PROFILES
MAINSTEM SKAGIT RIVER
FEDERAL EMERGENCY MANAGEMENT AGENCY
SKAGIT COUNTY, WA
(AND UNINCORPORATED AREAS)
16P
CORPORATE LIMITS
RIGHT BANK - CITY OF BURLINGTON
LEFT BANK - CITY OF MOUNT VERNON
HIGHWAY 9 BRIDGE
UPSTREAM BOUNDARY OF FLO-2D MODELING
ELEVATION (FEET NAVD 88)
STREAM DISTANCE IN FEET ABOVE SPLIT INTO NORTH AND SOUTH FORKS OF THE SKAGIT RIVER
LEGEND
500 - YEAR FLOOD
100 - YEAR FLOOD
50 - YEAR FLOOD
10 - YEAR FLOOD
STREAM BED
CROSS SECTION LOCATION
19.48
20
20.9
21.6
21.93
22
22.2
22.27
80
70
60
50
40
30
20
10
0
-10
-20
52000
56000
60000
64000
68000
72000
76000