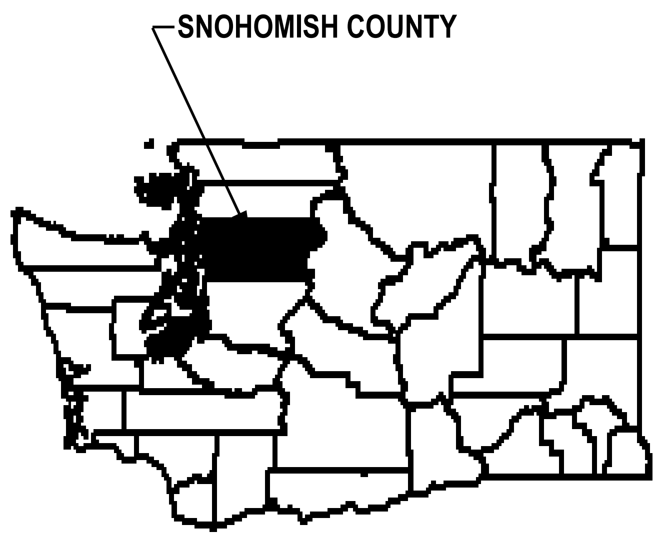
FLOOD INSURANCE STUDY

Volume 2 of 3

SNOHOMISH COUNTY, WASHINGTON

AND INCORPORATED AREAS



Community Name	Community Number
ARLINGTON, CITY OF	530271
BOTHELL, CITY OF	530075
BRIER, CITY OF	530276
DARRINGTON, TOWN OF	530233
EDMONDS, CITY OF	530163
EVERETT, CITY OF	530164
GOLD BAR, CITY OF	530285
GRANITE FALLS, TOWN OF	530287
INDEX, TOWN OF	530166
LAKE STEVENS, CITY OF	530291
LYNNWOOD, CITY OF	530167
MARYSVILLE, CITY OF	530168
MILL CREEK, CITY OF	530330
MONROE, CITY OF	530169
MOUNTLAKE TERRACE, CITY OF	530170
MUKILTEO, CITY OF	530235
SNOHOMISH, CITY OF	530171
SNOHOMISH COUNTY, UNINCORPORATED AREAS	535534
STANWOOD, CITY OF	530172
SULTAN, CITY OF	530173
WOODWAY, TOWN OF	530308

PRELIMINARY

Federal Emergency Management Agency

FLOOD INSURANCE STUDY NUMBER
53061CV002B

NOTICE TO
FLOOD INSURANCE STUDY USERS

Communities participating in the National Flood Insurance Program have established repositories of flood hazard data for floodplain management and flood insurance purposes. This Flood Insurance Study (FIS) report may not contain all data available within the Community Map Repository. Please contact the Community Map Repository for any additional data.

The Federal Emergency Management Agency (FEMA) may revise and republish part or all of this FIS report at any time. In addition, FEMA may revise part of this FIS report by the Letter of Map Revision process, which does not involve republication or redistribution of the FIS report. Therefore, users should consult with community officials and check the Community Map Repository to obtain the most current FIS report components.

This FIS report was revised on _________. Users should refer to Section 10.0, Revisions Description, for further information. Section 10.0 is intended to present the most up-to-date information for specific portions of this FIS report. Therefore, users of this report should be aware that the information presented in Section 10.0 supersedes information in Sections 1.0 through 9.0 of this FIS report.

Initial Countywide FIS effective date: November 8, 1999
Revised Countywide FIS effective date: September 16, 2005

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Volume 3

Exhibit 1 - Flood Profiles (Cont'd)

10.0 REVISION DESCRIPTIONS

This section has been added to provide information regarding significant revisions made since the original FIS was printed. Future revisions may be made that do not result in the republishing of the FIS report. To assure that any user is aware of all revisions, it is advisable to contact the community repository of flood-hazard data.

10.1 First Revision

Countywide Update

This update combined the FIRMs and FIS reports for Snohomish County and incorporated communities into the countywide format. Under the countywide format, FIRM panels have been produced using a single-layout format for the entire area within the county instead of separate layout formats for each community. The single-layout format facilitates the matching of adjacent panels and depicts the flood-hazard area within the entire panel border, even in areas beyond a community's corporate boundary line. In addition, under the countywide format, this single FIS report provides all FIS information and data for the entire County area.

As part of this update, the format of the map panels for most of the communities within Snohomish County, including the unincorporated areas, has changed. Previously, flood-hazard information was shown on both the FIRM and Flood Boundary and Floodway Map. In the new format, all BFEs, cross sections, zone designations, and floodplain and floodway boundary delineations are shown on the FIRM and the Flood Boundary and Floodway Map has been eliminated. Some of the flood insurance zone designations were changed to reflect the new format. Areas previously shown as numbered Zone A were changed to Zone AE. Areas previously shown as Zone B were changed to Zone X (shaded). Areas previously shown as Zone C were changed to Zone X (unshaded). In addition, all Flood Insurance Zone Data Tables were removed from the FIS report and all zone designations and reach determinations were removed from the profile panels.

The mapping for the countywide conversion has been prepared using digital data. Previously published FIRM data produced manually have been converted to vector digital data by a digitizing process. These vector data were fit to raster digital images of the USGS quadrangle maps of the county area to provide horizontal positioning.

Locally owned digital base map data have been provided by the City of Everett. For all remaining communities, road and highway name and centerline data were obtained from the Snohomish County Geographic Information Systems Department. The centerline data were computer plotted with the digitized floodplain data to produce the countywide FIRM.

This restudy incorporates the determinations of mappable Letters of Map Revision (LOMRs) and Letters of Map Amendment (LOMAs) issued by FEMA for the projects listed by community in Table 12, "Letters of Map Change." Changes established by those LOMRs and LOMAs have been incorporated into the tables and onto the FIRM and profile panels where applicable.

This study was revised to incorporate the results of detailed hydrologic and hydraulic analyses of North Creek affecting the City of Bothell. The analyses were performed by Northwest Hydraulic Consultants, Inc., for FEMA, under Contract No. EMW-93-C-4152. This work was completed in April 1994.

Table 12. Letters of Map Change

Community	Type	Case No.	Project/Flooding Source	Letter Date
Snohomish County (Unincorporated Areas)	LOMR	96-10-022P	Tributary to Swamp Creek (Poplar Creek)	May 10, 1996

The initial CCO meeting was held on September 21, 1993, and attended by representatives of FEMA and Northwest Hydraulic Consultants, Inc. To acquire information for this revision, Northwest Hydraulic Consultants, Inc., contacted the Public Works Department of the City of Bothell; the Surface Water Management Division of Snohomish County; Montgomery Water Group, Inc.; Quadrant Company; Alderwood Water District; Bush, Roed and Hitchings; and the USACE.

The reach of North Creek that was studied for this revision extends upstream from the King-Snohomish County line to the City of Bothell corporate limits at 208th Street. Prior to this revision, the majority of this reach had not been studied in detail.

Peak discharge-frequency relationships for the revised reach of North Creek were determined from the hydrologic computer model developed for the original study of North Creek using the EPA HSPF model (Reference 98). For the original study, the North Creek HSPF model was run with 39 years of 15-minute rainfall and daily evaporation to develop flood-frequency curves. The resulting 39-year time series of simulated North Creek stream flows were used to create 39 years of annual instantaneous peak flow data at four locations along the study reach. A log-Pearson Type III distribution was fitted to the annual peaks using the procedures of Water Resources Council Bulletin 17B, and the magnitudes of flows with return periods of 10, 50, 100, and 500 years were determined.

The hydraulic analyses for the revised study were performed using the USACE HEC-2 computer program (Reference 68). The physical geometry of the North Creek channel was represented by 39 cross sections surveyed by Northwest Hydraulic Consultants, Inc., between December 1993 and February 1994. Only the channel portion of each section was surveyed. The cross sections were extended to include the floodplain using 2-foot-contour-interval mapping provided by the City of Bothell Department of Public Works (Reference 6) and the Quadrant Company. The HEC-2 model contains the surveyed sections as well as sections synthesized from the survey data to define the characteristics of bridges and complex study areas.

The starting WSELs were determined from the flood profiles computed for the original study for the 10-, 50-, and 1-percent-annual-chance events. The 0.2-percent-annual-chance flood profile was not computed for the previous study due to complex hydraulic conditions downstream of the county line. Therefore, the starting WSEL for the 0.2-percent-annual-chance event was determined based on normal depth.

Channel roughness coefficients (Manning's "n" values) used in the HEC-2 model were determined by calibrating the model to conditions observed in the field on December 10, 1993. The December 10 calibration event generally stayed within the channel banks. Therefore, floodplain "n" values were estimated using engineering judgment and reference to classical publications (References 5 and 94). The final calibrated "n" values for North Creek are shown in Table 9, "Manning's "n" Values."

Twelve bridges are represented in the HEC-2 model for the revised reach of North Creek. The data used to define these structures were obtained during Northwest Hydraulic Consultants, Inc., field surveys. No other permanent structures were identified that would significantly affect flood levels.

Downstream of the King-Snohomish County line, North Creek is confined between levees. At the county line, tieback levees have been constructed across both the left and right floodplains to direct upstream flow into the North Creek channel. Just upstream of the county line, in the Monte Villa Center development, a setback levee parallels the channel to the east. At the county line, it connects to the downstream levee. At its upstream end, it tapers into higher ground near 240th Street Southeast.

The water-surface profiles for the areas affected by the east setback levee, which did not meet FEMA's freeboard requirements, from Monte Villa Parkway to 240th Street Southeast, were computed as follows:

1. For the levee area between the west overbank and east setback levee, the profiles were determined considering that the levee would remain in place.

2. For the east overbank, the profiles and floodplain boundary were determined without considering the effects of the east setback levee.

The 1- and 0.2-percent-annual-chance floodplain boundaries were delineated using the flood elevations determined at each cross section. Between cross sections, the boundaries were interpolated using topographic maps at a scale of 1"=200', with a contour interval of 2 feet (Reference 39).

The floodway determined for the revised reach of North Creek from 240th Street Southeast to the upstream limit of detailed study at the north Bothell corporate limits was computed based on equal conveyance reduction from each side of the floodplain. The floodway for the reach of North Creek from I-405 to 240th Street Southeast was computed based on incorporating the credited levee system and equal conveyance reduction from each side of the flooding.

Table 1, "CCO Meetings"; Table 2, "Streams and Tidal Areas Studied by Detailed Methods"; Table 3, "Streams Studied by Approximate Methods"; Table 7, "Summary of Discharges"; Table 8, "Manning's "n" Values"; Table 10, "Floodway Data"; Table 12, "Letters of Map Change"; and Exhibit 1, "Flood Profiles," were revised to reflect changes as a result of this restudy.

10.2 Second Revision

Introduction

This FIS Report was revised on September 16, 2005, to incorporate the effects of flooding along the Snohomish River. The hydrologic and hydraulic analyses for this restudy were performed by WEST Consultants Inc., for the USACE, Seattle District, under Contract No. DACW67-97-D-1016 (Reference 107). This work, performed for FEMA, was completed in April 2001.

The purpose of this restudy was to develop flood hazard information for flood insurance purposes for the Snohomish River from the City of Monroe to the City of Everett. The need for a detailed study of flooding on the Snohomish River was identified at a meeting attended by representatives of WEST Consultants Inc., the USACE, FEMA, and Snohomish County on February 22, 1999.

The results of the restudy were reviewed at the final CCO meeting held on September 4, 2003. All problems raised at that meeting have been addressed in this restudy.

Area Studied

The study reach extends from the mouth of the Snohomish River to the confluence of the Snoqualmie, Skykomish, and Snohomish Rivers, a distance of approximately 20 RM.

This restudy covered the Snohomish River and connected side channels including Ebey Slough, Ebey-Steamboat Slough Connector, Steamboat Slough, and Union Slough.

Principal Flood Problems

Snohomish River - November 1990 Flood Event

The Thanksgiving weekend flood of November 1990 was preceded by a rain-on-snow event, a common denominator with most large floods along rivers in the western Cascade Mountains. Two large cold fronts led to 3 feet of snow in the mountains during the week preceding the flood, then two large back-to-back warm fronts generated 25 inches of rain that melted the snow. The coincident flood peaks of the upstream Skykomish and Snoqualmie Rivers also contributed to the Snohomish River flooding. Peak flow for this event was estimated at 150,000 cfs.

Hydrologic Analyses

Hydrographs were generated to simulate the hydraulic response of the 10-, 2-, 1- and 0.2-percent-annual-chance flows for the Snohomish River and the channels. However, for an unsteady flow model, the upstream flood hydrograph must consider not only peak discharge but also volume. One method to develop an appropriate synthetic hydrograph is the "balanced hydrograph" approach. In this approach, flood frequency analyses (Reference 69) were conducted for instantaneous peak flows, and average 1-, 3-, 5-, and 7-day flows for the continuous period of record, after removing the hysteresis effect at the gage. For this restudy, synthetic hydrographs for the 10-, 2-, 1- and 0.2-percent-annual-chance events were created by ensuring that the hydrograph ordinates preserved the peak discharge and the average 1-, 3-, 5-, and 7-day flows. Then, historical flood events were examined, and a skew was specified that placed the flood peak at day 3 of the 7-day event.

Based on a flood frequency analysis from the 1964-99 record at the Monroe gage (Reference 91), the November 1990 peak flow was approximately a 1-percent-annual-chance event. However, numerous historic events, measured or inferred at nearby gages and streams, revealed that this event had been exceeded several times since the late 1800s. When these flows, which were reported only as peak flows, were included in the analysis of peak values, the November 1990 peak flow was closer to the 30-year event, a finding that is consistent with nearby rivers with longer gage records. This information was used to increase the 1-day average flow (volume) of the synthetic hydrographs by multiplying those values by the ratio of the peak with historical flows to the peak without historical flows, to account for the absence of historical volume data.

Peak discharge-drainage area relationships for the detailed study streams are shown in Table 7, "Summary of Discharges."

Hydraulic Analyses

Analyses of the hydraulic characteristics of flooding from the sources studied were carried out to provide estimates of the elevations of floods with 10-, 2-, 1-, and 0.2-percent-annual-chance recurrence intervals. Users should be aware that flood elevations shown on the FIRM represent rounded whole-foot elevations and may not exactly reflect the elevations shown on the Flood Profiles (Exhibit 1) or in the Floodway Data Table in the FIS report. Flood elevations shown on the FIRM are primarily intended for flood insurance rating purposes. For construction and/or floodplain management purposes, users are cautioned to use the flood elevation data presented in this FIS in conjunction with the data shown on the FIRM.

Snohomish County representatives provided cross-section data from their Full Equations (FEQ) model of the system (References 50 and 90). To provide better channel definition where necessary, cross-section information was supplemented with cross-section data from the original USACE hydraulic model (Reference 81), bridge cross sections from the Washington Department of Transportation (DOT) and the Burlington Northern Santa Fe Railroad (BNSFRR), and various additional surveys throughout the study area.

Snohomish County, the Washington DOT, and the BNSFRR provided construction information for defining bridge structures (Reference 50).

An unsteady flow model of the system was developed using UNET (References 33 and 53). The UNET model consists of 13 separate reaches with a total of almost 270 cross sections and 12 storage areas. The most significant overbank areas are the Fryelands area, which was modeled as a storage area, and Marshland, which was modeled as a conveyance area because it ties into the Snohomish River at the upstream and downstream ends.

Fairly extensive sets of observations along the main stem of the Snohomish River were available to calibrate the UNET model for the floods of 1989 and 1990. The December 1989 event was essentially a bank-full event, and it was used to calibrate Manning's "n" roughness values in the main channel. The November 1990 event caused significant overbank flooding. Numerous high-water marks were surveyed throughout the system, and continuous stages were recorded at the Monroe and Snohomish gages. The 1990 event was used, without changing the calibrated main channel "n" values, to calibrate the overbank (including storage areas and the Marshland area) "n" values. Manning's "n" values in the sloughs were determined during calibration of the main stem, although calibration was limited because of the limited number of observed WSELs in these areas. No further "validation" was conducted beyond these events because of the lack of data during other overbank flood events. The calibrated "n" values used for the Snohomish River range from 0.035 to 0.045 for the channel and from 0.050 to 0.070 for the overbank areas. The Manning's "n" values used for the sloughs and the Marshland area range from 0.036 to 0.070 for the channel and from 0.050 to 0.070 for the overbank areas. The roughness coefficients were revised for this restudy and are shown in Table 9, entitled "Manning's "n" Values."

The downstream boundary condition in an unsteady flow model may be time-dependent, whereas a normal-depth condition or fixed stage is usually specified in a steady flow model. Puget Sound is tidal, and there are tide gages at Everett and Seattle with long periods of record. These data were used as downstream boundary conditions for model calibration.

An FIS with a tidal downstream limit usually considers both a river flood and a tidal surge in establishing flood elevations. However, as these events rarely occur at the same time, they may be considered to be independent events. A fixed downstream stage equal to mean higher high water (MHHW) plus 1 foot was used for the river flood stages, based on recommendations by the USACE, Seattle District. (Reference 31). The USACE, Seattle District, had previously conducted a tidal surge analysis and established tidal surge elevations at the mouth of the Snohomish River for the 10-, 2-, 1-, and 0.2-percent-annual-chance events (Reference 31).

<u>Floodplain Management Application</u>

The regulatory floodway (See Section 4.2) is defined as the portion of the river and adjacent land area that must remain unobstructed to ensure that the WSEL does not cumulatively increase more than 1 foot above the Base (1-percent-annual-chance) Flood Elevation (BFE). Typically, an encroachment analysis is computed from both the left and right channel banks toward the center of the river channel using an equal conveyance reduction method. Development of a floodway becomes more complicated when multiple channels and split flows are involved and when an unsteady flow model is used.

Multiple channel bifurcations and junctions occur in the downstream reaches of the Snohomish network, especially near the downstream sloughs, and major storage areas exist upstream. Performing an encroachment analysis in such a system becomes extremely complex, as each reach must be individually modeled, and changes between reaches are dependent on one another, making determination of the 1-foot increase even more difficult.

Because of these complexities, a series of meetings was held between February 22, 1999, and April 9, 2001 (Reference 107), with representatives of FEMA and the local communities to identify options and priorities for development in the Snohomish River floodplain. The downstream Cities of Everett and Marysville had specific encroachment goals, whereas the county has an existing ordinance based on the density of development for the upstream detailed reaches in the unincorporated county areas. The result was a floodplain analysis where encroachment and storage-volume reduction were specified in locations of zoned development. This consensus among the local communities also removed the need for a traditional equal conveyance reduction floodway.

For this restudy, the area downstream of Snohomish River RM 15.7 (Section AH) was analyzed using a density fringe analyses. The reach upstream of Section AH was determined using the standard equal conveyance floodway.

For the downstream reach, the density fringe areas are based on a hydraulic analyses that takes into account a density fringe criteria (15 percent reduction of conveyance) based on the existing Snohomish County Code; see Table 13, "Density Fringe Area" (Reference 34). For this reach, the areas outside the density fringe area shown on the FIRM were defined in most locations by the existing Snohomish County fringe boundary (Reference 105). These areas generally are areas that would not contribute to 1-percent-annual-chance flow conveyance.

Representatives of the City of Everett requested additional floodway fringe near the downstream end of the Snohomish River, near RM 0.5. Everett representatives also requested that an area called a Special Development Area be identified for the zoned area near the downstream end of the Marshland area and Storage Area No. 6. These areas were labeled as "Special Development Area" on the FIRM. Storage Area No. 6 is located in the left overbank of the Snohomish River from RM 7.2 to RM 8.8, just east of the BNSFRR, as described in the report entitled "Flood Insurance Restudy Snohomish County, Washington," (Reference 107). In addition, the downstream Marshland area is located in the left overbank of the Snohomish River from RM 7.2 to RM 9.4, west of the railroad (Reference 107). Both areas were analyzed in the hydraulic models assuming a maximum fill of 3 feet on top of the existing grade.

FLOODING SOURCE		FLOODWAY			1-PERCENT ANNUAL CHANCE FLOOD WATER SURFACE ELEVATION			
CROSS SECTION	**DISTANCE [1]**	**WIDTH [2] (FEET)**	**SECTION AREA (SQUARE FEET)**	**MEAN VELOCITY (FEET PER SECOND)**	**REGULATORY (FEET NAVD)**	**WITHOUT FLOODWAY (FEET NAVD)**	**WITH FLOODWAY (FEET NAVD)**	**INCREASE (FEET)**
Ebey Slough								
A[4]								
B	1.65	422	6,973	2.9	12.1 [3]	11.7	11.8	0.1
C	1.83	373	5,928	3.6	12.1 [3]	11.8	11.9	0.1
D	2.40	420	6,488	3.2	12.3	12.3	12.6	0.3
E	2.87	1,214	9,589	3.7	12.5	12.5	13.1	0.6
F	3.19	5,113	29,486	3.4	12.7	12.7	13.6	0.9
G	4.24	900	7,861	3.5	14.0	14.0	14.6	0.6
H	5.54	2,055	21,310	3.5	15.3	15.3	15.7	0.4
I	6.21	2,256	17,790	3.9	15.7	15.7	16.2	0.5
J	6.72	3,080	33,618	2.7	16.1	16.1	16.6	0.5
K	6.85	2,916	36,389	2.6	16.1	16.1	16.6	0.5
L	7.37	345	7,971	4.2	16.2	16.2	16.8	0.6
M	8.75	1,454	19,353	4.4	16.7	16.7	17.3	.0.6
N	9.12	1,082	15,311	4.6	16.9	16.9	17.3	0.4
O	9.32	1,218	15,282	5.0	16.9	16.9	17.3	0.4
P	9.40	1,083	14,007	5.3	16.9	16.9	17.3	0.4
Q	10.95	1,648	21,971	7.3	18.9	18.9	18.9	0.0
R	11.46	1,750	27,045	6.0	20.1	20.1	20.2	0.1
S	13.08	2,377	35,749	5.6	22.8	22.8	23.1	0.3

(1) Stream distance in miles above mouth
(2) Widths take into account floodway fringe and density fringe
(3) Tidal surge elevation from Possession Sound
(4) No density fringe or floodway computed

TABLE 13

FEDERAL EMERGENCY MANAGEMENT AGENCY
SNOHOMISH COUNTY, WA
AND INCORPORATED AREAS

DENSITY FRINGE AREA DATA

EBEY SLOUGH

FLOODING SOURCE		FLOODWAY			1-PERCENT ANNUAL CHANCE FLOOD WATER SURFACE ELEVATION			
CROSS SECTION	**DISTANCE [1]**	**WIDTH [2] (FEET)**	**SECTION AREA (SQUARE FEET)**	**MEAN VELOCITY (FEET PER SECOND)**	**REGULATORY (FEET NAVD)**	**WITHOUT FLOODWAY (FEET NAVD)**	**WITH FLOODWAY (FEET NAVD)**	**INCREASE (FEET)**
Ebey-Steamboat Slough Connector								
A	0.00	407	5,237	4.1	15.5	15.5	16.1	0.6
B	0.25	250	5,157	3.5	15.8	15.8	16.4	0.6
C	0.60	272	5,205	3.3	16.1	16.1	16.6	0.5

(1) Stream distance in miles above confluence with Steamboat Slough

(2) Widths take into account floodway fringe and density fringe

TABLE 13

FEDERAL EMERGENCY MANAGEMENT AGENCY

SNOHOMISH COUNTY, WA

AND INCORPORATED AREAS

DENSITY FRINGE AREA DATA

EBEY-STEAMBOAT SLOUGH CONNECTOR

FLOODING SOURCE		FLOODWAY			1-PERCENT ANNUAL CHANCE FLOOD WATER SURFACE ELEVATION			
CROSS SECTION	**DISTANCE [1]**	**WIDTH [2] (FEET)**	**SECTION AREA (SQUARE FEET)**	**MEAN VELOCITY (FEET PER SECOND)**	**REGULATORY (FEET NAVD)**	**WITHOUT FLOODWAY (FEET NAVD)**	**WITH FLOODWAY (FEET NAVD)**	**INCREASE (FEET)**
Marshland								
A	0.00	8,540	19,109	1.0	23.9	23.9	24.2	0.3
B	0.76	3,314	46,938	3.1	24.2	24.2	24.6	0.4
C	1.65	4,690	91,868	1.5	25.0	25.0	25.6	0.6
D	2.06	6,340	130,368	1.0	25.1	25.1	25.7	0.6
E	2.68	6,910	135,254	1.0	25.2	25.2	25.8	0.6
F	3.16	7,487	126,411	1.5	25.3	25.3	25.9	0.6
G	3.65	7,565	114,236	2.3	25.4	25.4	26.0	0.6
H	4.05	9,145	131,146	2.6	25.5	25.5	26.1	0.6
I	4.67	5,050	47,238	3.9	25.7	25.7	26.5	0.8
J	5.19	3,960	40,187	2.1	26.1	26.1	27.0	0.9
K	5.63	3,050	30,009	2.7	26.4	26.4	27.4	1.0
L	6.04	2,040	3,835	7.0	26.8	26.8	27.8	1.0

(1) Stream distance in miles above mouth

(2) Width takes into account floodway fringe and density fringe

TABLE 13

FEDERAL EMERGENCY MANAGEMENT AGENCY

SNOHOMISH COUNTY, WA

AND INCORPORATED AREAS

DENSITY FRINGE AREA DATA

MARSHLAND

FLOODING SOURCE		FLOODWAY			1-PERCENT ANNUAL CHANCE FLOOD WATER SURFACE ELEVATION			
CROSS SECTION	DISTANCE [1]	WIDTH (FEET)	SECTION AREA (SQUARE FEET)	MEAN VELOCITY (FEET PER SECOND)	REGULATORY (FEET NAVD)	WITHOUT FLOODWAY (FEET NAVD)	WITH FLOODWAY (FEET NAVD)	INCREASE (FEET)
Snohomish River								
A[2]								
B	0.50	1,171	18,260	4.9	12.1 [3]	9.9	9.9	0.0
C	2.02	766	12,298	7.3	12.7	12.7	13.0	0.3
D	2.60	1,227	21,123	4.2	14.3	14.3	14.9	0.6
E	2.90	581	10,504	8.5	14.3	14.3	14.9	0.6
F	3.30	703	22,351	4.0	15.4	15.4	16.1	0.7
G	3.68	390	11,748	7.6	15.4	15.4	16.1	0.7
H	3.86	750	11,890	7.5	15.7	15.7	16.3	0.6
I	4.40	1,549	15,115	6.8	16.6	16.6	17.0	0.4
J	4.65	1,004	14,690	7.0	17.0	17.0	17.3	0.3
K	4.84	467	11,220	7.8	17.1	17.1	17.4	0.3
L	5.00	522	11,669	7.4	17.4	17.4	17.6	0.2
M	5.59	546	13,088	7.1	18.3	18.3	18.3	0.0
N	6.25	534	11,654	8.3	19.9	19.9	19.9	0.0
O	6.77	1,557	19,236	7.7	20.9	20.9	21.3	0.4
P	7.31	1,630	20,540	5.6	22.3	22.3	22.7	0.4
Q	7.66	432	11,799	7.7	22.6	22.6	22.9	0.3
R	7.92	590	14,029	6.6	22.8	22.8	23.1	0.3
S	8.08	721	14,071	6.7	22.8	22.8	23.2	0.4
T	8.40	465	36,660	8.8	23.0	23.0	23.4	0.4
U	8.87	449	52,800	7.6	23.7	23.7	24.1	0.4
V	9.93	503	24,582	8.5	24.9	24.9	25.5	0.6
W	11.02	1,392	16,252	8.7	26.4	26.4	26.7	0.3
X	12.23	388	14,725	9.3	29.0	29.0	29.1	0.1
Y	12.70	344	12,558	10.5	30.7	30.7	30.8	0.1
Z	13.01	454	16,589	8.4	32.2	32.2	32.2	0.0

(1) Stream distance in miles above mouth

(2) No density fringe or floodway computed

(3) Tidal surge elevation at the mouth of Snohomish River

TABLE 13

FEDERAL EMERGENCY MANAGEMENT AGENCY

SNOHOMISH COUNTY, WA

AND INCORPORATED AREAS

DENSITY FRINGE AREA DATA

SNOHOMISH RIVER

FLOODING SOURCE		FLOODWAY			1-PERCENT ANNUAL CHANCE FLOOD WATER SURFACE ELEVATION			
CROSS SECTION	**DISTANCE [1]**	**WIDTH (FEET)**	**SECTION AREA (SQUARE FEET)**	**MEAN VELOCITY (FEET PER SECOND)**	**REGULATORY (FEET NAVD)**	**WITHOUT FLOODWAY (FEET NAVD)**	**WITH FLOODWAY (FEET NAVD)**	**INCREASE (FEET)**
Snohomish River (continued)								
AA	13.60	1,729	27,636	4.5	34.0	34.0	34.1	0.1
AB	13.94	617	18,353	6.9	34.0	34.0	34.1	0.1
AC	14.15	594	15,742	8.1	34.4	34.4	34.4	0.0
AD	14.57	917	18,301	7.4	35.0	35.0	35.0	0.0
AE	14.85	1,041	20,328	7.0	35.2	35.2	35.2	0.0
AF	15.20	1,187	23,450	6.7	35.6	35.6	35.6	0.0
AG	15.42	1,480	29,130	5.7	35.9	35.9	35.9	0.0
AH	15.68	1,450	39,835	4.3	36.5	36.5	36.5	0.0

(1) Stream distance in miles above mouth

TABLE 13

FEDERAL EMERGENCY MANAGEMENT AGENCY

SNOHOMISH COUNTY, WA

AND INCORPORATED AREAS

DENSITY FRINGE AREA DATA

SNOHOMISH RIVER

FLOODING SOURCE		FLOODWAY			1-PERCENT ANNUAL CHANCE FLOOD WATER SURFACE ELEVATION			
CROSS SECTION	DISTANCE [1]	WIDTH (FEET)	SECTION AREA (SQUARE FEET)	MEAN VELOCITY (FEET PER SECOND)	REGULATORY (FEET NAVD)	WITHOUT FLOODWAY (FEET NAVD)	WITH FLOODWAY (FEET NAVD)	INCREASE (FEET)
Steamboat Slough								
A	0.16	2,917	30,510	3.9	12.1 [2]	9.9	9.9	0.0
B	0.80	1,353	21,730	4.7	12.1 [2]	10.9	10.9	0.0
C	1.12	2,889	17,842	4.4	12.1 [2]	11.6	11.9	0.3
D	1.49	1,368	19,526	5.3	12.1 [2]	12.0	12.3	0.3
E	1.62	596	12,265	5.9	12.1	12.1	12.6	0.5
F	1.72	626	12,730	5.1	12.4	12.4	12.9	0.5
G	2.15	1,309	17,342	4.8	13.1	13.1	13.8	0.7
H	2.60	1,148	13,451	5.6	13.8	13.8	14.5	0.7
I	3.30	1,150	16,315	4.5	15.0	15.0	15.5	0.5
J	3.76	2,145	22,823	4.5	15.3	15.3	15.9	0.6
K	4.04	2,772	26,253	4.9	15.5	15.5	16.1	0.6
L	4.20	350	6,490	3.5	16.0	16.0	16.6	0.6
M	4.96	349	5,844	2.9	16.7	16.7	17.2	0.5
N	5.70	240	4,566	3.4	16.7	16.7	17.2	0.5
O	6.23	742	10,093	1.6	16.7	16.7	17.2	0.5

(1) Stream distance in miles above mouth

(2) Tidal surge at the mouth of Snohomish River

TABLE 13

FEDERAL EMERGENCY MANAGEMENT AGENCY

SNOHOMISH COUNTY, WA

AND INCORPORATED AREAS

DENSITY FRINGE AREA DATA

STEAMBOAT SLOUGH

FLOODING SOURCE		FLOODWAY			1-PERCENT ANNUAL CHANCE FLOOD WATER SURFACE ELEVATION			
CROSS SECTION	**DISTANCE [1]**	**WIDTH[2] (FEET)**	**SECTION AREA (SQUARE FEET)**	**MEAN VELOCITY (FEET PER SECOND)**	**REGULATORY (FEET NAVD)**	**WITHOUT FLOODWAY (FEET NAVD)**	**WITH FLOODWAY (FEET NAVD)**	**INCREASE (FEET)**
Union Slough								
A	0.17	610	7,084	3.6	12.1 [3]	10.9	10.9	0.0
B	0.23	505	4,798	5.3	12.1 [3]	11.5	11.6	0.1
C	0.88	278	4,356	5.8	12.5	12.5	13.2	0.7
D	1.08	382	4,948	3.8	13.8	13.8	14.8	1.0
E	1.35	207	3,281	4.9	14.4	14.4	15.0	0.6
F	2.49	309	4,189	4.5	15.2	15.2	15.7	0.5
G	2.91	260	3,250	2.1	15.5	15.5	16.1	0.6
H	3.24	259	3,086	2.1	15.5	15.5	16.1	0.6
I	3.79	272	2,925	2.7	15.5	15.5	16.1	0.6
J	4.50	364	3,413	2.2	15.7	15.7	16.3	0.6

(1) Stream distance in miles above mouth

(2) Widths take into account floodway fringe and density fringe

(3) Tidal surge elevation at the mouth of Snohomish River

TABLE 13

FEDERAL EMERGENCY MANAGEMENT AGENCY

SNOHOMISH COUNTY, WA

AND INCORPORATED AREAS

DENSITY FRINGE AREA DATA

UNION SLOUGH

The study contractor delineated the floodway upstream of Snohomish RM 15.7 starting with the floodway established in the prior FIS and then reducing the encroachment as necessary to attain the maximum 1-foot rise; see Table 8, “Floodway Data.” There is no density fringe upstream of this location. Base maps from the original FIS (Reference 22) were used to delineate cross sections, floodplains, and floodways, projecting this information onto USGS quad maps to generate work maps. The boundaries for the area inundated by the 1-percent-annual-chance flood were plotted on USGS 1:24,000-scale topographic maps (Reference 74). Topographic data, roads, and canals on digital raster graphics and recent aerial photographs and field observations were reviewed for assistance in plotting the flood boundaries between cross sections. Inundated areas with little or no flow were identified.

More precise determination of the extent of inundation may be determined at any given location using the computed WSEL and detailed field surveys of the land surface.

For this restudy, all elevations are referenced to the NGVD29. To obtain up-to-date elevation information, please contact the Information Services Branch of the NGS at (301) 713-3242, or visit its website at www.ngs.noaa.gov. Map users should seek verification of non-NGS ERM monument elevations when using these elevations for construction or floodplain management purposes.

The NFIP encourages State and local governments to adopt sound floodplain management programs. To assist in this endeavor, each FIS provides 1-percent-annual-chance floodplain data, which may include a combination of the following: 10-, 2-, 1-, and 0.2-percent-annual-chance flood elevations; delineations of the 1-percent-annual-chance and 500-year floodplains; and a 1-percent-annual-chance floodway. This information is presented on the FIRM and in many components of the FIS, including the Flood Profiles, the Floodway Data Table, and the Summary of Discharges Table. Users should reference the data presented in the FIS as well as additional information that may be available at the local community map repository before making flood elevation and/or floodplain boundary determinations.

10.3 Third Revision

Introduction

This FIS Report was revised on _________, 2010, to incorporate the results of the Lower Snoqualmie River, the Lower Skykomish River and the Upper Skykomish River studies in Snohomish County, to convert the Snohomish County and Incorporated Areas FIRM to the digital format that meets *2005 FEMA Map Modernization Guidelines and Specifications*, and to incorporate changes from the redelineation of 10 streams, a total of 183 miles of stream. All of the previous studies have been included in this work and all stream information has been referenced to NAVD88.

The hydrologic and hydraulic analyses for Lower Snoqualmie and Lower Skykomish Rivers were performed by Northwest Hydraulic Consultants, Inc. (SC), for FEMA. This work was completed in April 2006. The Snohomish and King Counties served as Cooperating Technical Partners (CTP), providing relevant study data, first-hand information on the watersheds and associated flooding issues, and technical review of all study products. King County also served in the role of Project Manager.

The government agencies and consulting firms contacted for information relevant to this study include:

Table 14. Data Providing Agencies or Firms

Agency/Consulting Firm	Information Provided
U.S. Geological Survey (USGS)	Gaged flow data throughout the Snohomish River watershed (including the Snoqualmie and Skykomish River basins)
U.S. Army Corps of Engineers (USACE), Seattle District	High-water mark surveys, previous hydrologic reports within the Snohomish River watershed
King County	Background information, high-water mark surveys, aerial photos of historic flooding, GIS shapefiles and LIDAR data
Snohomish County	Background information, high-water mark surveys, aerial photos of historic flooding, GIS shapefiles and LIDAR data
Trout Unlimited (and R2 Resource Consultants)	Hydraulic model of Cherry Valley
West Consultants	Information from 2001 Snohomish River FIS Update

Area Studied

The downstream mapping limit of the study reach in Snohomish County is the State Route 522 Bridge, crossing over the Snohomish River, approximately 1 RM downstream of the confluence of the Snoqualmie and Skykomish Rivers. The upstream mapping limit on the Snoqualmie River is the county boundary between Snohomish and King Counties, approximately 5.5 RMs upstream of the confluence with the Skykomish River. On the Skykomish River, the upstream mapping limit is approximately 9 RMs upstream of the confluence with the Snoqualmie River at a location between the cities of Monroe and Sultan, in Snohomish County.

The Snoqualmie and Skykomish Rivers drain adjacent watersheds of similar size and mean annual discharge. Headwaters of both rivers are at the crest of the Cascade Mountains, and land cover in both watersheds is dominated by coniferous forest cover. The primary distinction between the two rivers is that the Snoqualmie River, below Snoqualmie Falls, occupies a relatively broad, alluvial valley and has a much lower gradient than the mainstem Skykomish River, which is generally steeper and more confined. The hydrologic response, therefore, on the Snoqualmie River is generally more delayed and flows are often attenuated relative to the Skykomish River which is flashier with typically higher peak discharges.

Principal Flood Problems

Flood problems in the Lower Skykomish River are concentrated in the Tualco Valley area south of Monroe. The highest concentrations of development in the City of Monroe are generally on high ground above flood levels. Skykomish floodwaters do, however, back up Woods Creek and also inundate the Cadman gravel pit, both within the Monroe city limits.

The principal infrastructure affected by flooding includes State Route 203, which stretches south from Monroe across the Skykomish River and through the lowermost portion of the Snoqualmie Valley, and the Burlington Northern Santa Fe Railroad (BNSFRR), which parallels the river and is near the main channel at several points where it must be protected from bank erosion. Haskel Slough, a major floodplain overflow path, is blocked at its head by the Haskel Slough dike, a Snohomish County maintained structure. This dike, and the lands adjacent, has sustained significant damages in past floods and the river has exhibited behaviors indicating a possibility of avulsion through the slough.

In the lower end of the Tualco Valley, the flows of the Snoqualmie and Skykomish Rivers merge. Flood flows here are slower, but depths of flooding are greater and durations are longer. Throughout the Lower Skykomish Valley localized bank erosion is common, putting structures near the channel at risk.

The Snoqualmie Valley is a wide, low gradient floodplain mostly comprised of agricultural lands with a few relatively small residential communities. Flooding is most commonly associated with inundation of farm houses and barns, and the valley roads that parallel or cross the mainstem Snoqualmie River. Damage is often due to large areas of inundation along with localized erosion of outer river banks and revetments, overtopping of flood protection levees, and road embankments.

Although the mainstem Snoqualmie is characterized by relatively low velocities and a mild gradient, flooding can cause substantial localized erosion. Problems generally relate to constrictions, where flow energies become concentrated.

In addition to this erosion damage, the deep, broad flooding of the Snoqualmie River valley brings other damages. The Thanksgiving 1990 flood killed hundreds of cows on the lower valley's dairy farms. Rising flood waters damaged homes at scattered locations throughout the valley. In two separate incidents (January 1990 and November 1990), motorists drowned when they attempted to drive across flooded valley roads.

<u>Flood Protection Measures</u>

There are no FEMA accredited levees on either the Snoqualmie or Skykomish Rivers. There are dams on two tributaries (Tolt River, Sultan River); however, these dams do not have significant dedicated flood control storage and do not provide significant flood flow reduction on the Snoqualmie or Skykomish Rivers.

<u>Hydrologic Analyses</u>

The objective of the hydrologic analysis in this study was to develop 10-, 2-, 1-, and 0.2-percent-annual-chance (i.e. "N"-year) design flood hydrographs for input to the HEC-RAS unsteady hydraulic model at all model inflow points. Design flood hydrographs were developed for eleven inflow locations along the Snoqualmie River portion of the study area and seven locations along the Skykomish River portion. Inflow points include the upstream boundaries of each river, major tributaries, and areas contributing significant direct discharge to the rivers.

Design event inflow hydrographs were developed using a process that included model calibration, application of the model to simulate a wide range of historic flood events, stage frequency analysis on the resultant historic flood stages at key locations, and then refinement of the N-year design event hydrologic inputs to achieve reasonable concurrence with the corresponding N-year stages at the key locations.

Inflow hydrographs from sixteen of the largest flood events that occurred between water years 1966 and 2003 were synthesized for input to the hydraulic model. The primary source of these flow data were USGS observed flow records. Where USGS data was not available, a range of methods were utilized to estimate historical flood hydrographs at the hydraulic model inflow points including gage data transposition, rainfall-runoff modeling, and reservoir operations modeling.

Each of the sixteen historic floods was then simulated using the HEC-RAS unsteady hydraulic model. For water years in which two significant flood events occurred, both were simulated and the highest stage at each key location was retained. The resultant peak stages were then plotted on frequency paper and stage frequency curves were drawn through the data.

Of all of the floods simulated with the hydraulic model, two were found to produce stages that most closely corresponded to certain N-year stages at key locations throughout the study area. Peak stages produced by the December 1977 flood simulations most closely approximated 1-percent-annual-chance flood stages in the study area while the November 1990 flood simulations resulted in river stages that most closely matched 2- and 1-percent-annual-chance conditions. November 1990 is also the largest flood within the USGS's systematic gage record, and best suited for developing 0.2-percent-annual-chance design hydrographs. Consequently, historical inflow hydrographs for these two historic floods with relatively small adjustments were used to produce the N-year design input hydrographs for floodplain mapping, floodway analysis, and discharge quantile estimation. The resultant discharge quantiles in the Snohomish County are summarized in Table 7, "Summary of Discharges".

Hydraulic Analyses

An HEC-RAS unsteady flow hydraulic model was created to simulate the hydraulic characteristics of the study reach. The model was used to compute water surface profiles corresponding to the 10-, 2-, 1-, and 0.2-percent-annual-chance floods, floodplain inundation limits for the 1- and 0.2-percent annual chance events, and floodway boundaries for the 1-percent-annual-chance flood.

All of the mainstem cross sections were surveyed in March 2004 by bathymetric techniques. The surveyed transects included only the wetted river channel from the water's edge, bank to bank. Topographic data for the overbank portions of each cross section was derived from digital topographic data. The topographic data was created using a combination of photogrammetric techniques and Light Detection And Ranging (LiDAR) data. Aerial photographs of the study reach were taken in March 2004.

The bridges which have potential to significantly affect hydraulic conditions within Snohomish County are High Bridge (Crescent Lake Road) on the Snoqualmie River and State Route 203 Bridge at Monroe (12th Street Bridge) and the old BNSFRR Bridge, located 3,600 feet upstream of the 12th Street Bridge on the Skykomish River. Bridge dimensions were obtained from as-built drawings and were supplemented with field survey as necessary.

The general approach applied in this study was to characterize the probability of flooding based on an evaluation of annual peak stages rather than annual peak flows. Because of numerous complicating factors including dynamic interaction at the confluence of the Snoqualmie and Skykomish Rivers (including flow reversals), significant differences in floodplain storage in the two study reaches, and historically observed variations in the concurrence of high flows on the two rivers, the only reliable approach to estimate flood inundation frequency was to apply an unsteady flow hydraulic model (HEC-RAS) to estimate 10-, 2-, 1-, and 0.2-percent-annual-chance (N-year) flood profiles throughout the study reach.

The following steps were executed to develop the N-year, unsteady hydraulic models:

1. Reviewed USGS gage records in the Snohomish River basin and selected 16 large historic flood events to model.

2. Developed inflow hydrographs to the unsteady HEC-RAS model for the historic events. These hydrographs utilized available 15-minute and/or hourly USGS flow data, correlation coefficients, rainfall-runoff modeling, and information about reservoir operations on the Tolt and Sultan Rivers.

3. Performed hydraulic modeling of the selected flood events, including calibration/verification historic events, and extracted peak stages at 20 key locations throughout the study reach.

4. Estimated plotting positions associated with the 16 selected flood events.

5. Manually fit non-parametric frequency curves to the peak stages obtained from step 3 using plotting positions from step 4.

6. Used the curves developed in step 5 to provide estimates of the 10-, 2-, 1-, and 0.2-percent-annual-chance stages at each key location.

7. Developed the N-year HEC-RAS models. Used a trial-and-error method to adjust historic flood inflows so that the peak stage at all key locations match the N-year stage developed in step 6.

8. Applied N-year unsteady HEC-RAS models to estimate the 10-, 2-, 1-, and 0.2-percent-annual-chance profiles throughout the study reach.

Channel and overbank roughness factors (Manning's "n" values) used in the hydraulic computations were chosen using engineering judgment and were based on field observations, orthophotos, and published data. Within the study reach, in-channel roughness values on the Skykomish River range from 0.03 to 0.05 and on the Snoqualmie River from 0.03 to 0.055. Overbank roughness values for both rivers range from 0.02 to 0.15.

The hydraulic model was calibrated and verified to high-water marks and/or aerial photography from seven recorded events. The USACE Seattle District provided high-water marks for the following flood events: January 5, 1969; December 3, 1975; December 26, 1980; and November 23, 1986. King and Snohomish Counties and several long time valley residents provided high-water marks for the November 24, 1990 storm. King County also provided oblique aerial photos of the storms on November 24, 1990, November 29, 1995, and February 9, 1996.

A significant effort was made to match each of the high-water marks through refinement of the model parameters and structure. Calibration efforts included changes to the delineations of overflow reaches, adjustment of roughness and contraction and expansion coefficients, and modifications to model inputs that govern breakout flows. In some cases, the model simulated water surfaces that were higher than reported high-water marks for one event while in other events the simulations yielded lower than reported peak WSELs. Where conflicting information was found, an effort was made to split the difference, giving more weight to the recent and larger flood events. The final calibration/verification is felt to be adequate given the complexities of the system and the limitations of a one-dimensional hydraulic model.

The downstream limit of this Snoqualmie and Skykomish hydraulic model was the State Route 522 Bridge crossing over the Snohomish River. FEMA recently reviewed and approved a flood study by the USACE the Snohomish River from Possession Sound to the State Route 522 Bridge. The Snohomish River transition was discussed in detail with representatives from King County, Snohomish County, FEMA Region X, and FEMA's technical review contractor at the Regional Management Center 10 (RMC10). Based on those discussions, adjustments were made to the hydrologic data for the design events on the Skykomish River to reflect historic flood data from the early 1900's as reported by the USGS. Those adjustments also brought the design event flows at the downstream boundary closer to those previously estimated by the USACE. Furthermore, since the transition reach on the Snohomish River is characterized by a narrow and relatively steep channel, the floodplain and floodway delineations at this location blend appropriately.

The upstream study limit on the Skykomish River occurs at RM 8.95. The effective floodplain and floodway at this location are very similar in width to the revised mapping generated by this study. Blending of the floodplain and floodway boundaries here also are very closely matched.

In general, the estimated 1-percent-annual-chance floodplain limits within the Snoqualmie Valley extend from the west valley wall to the east valley wall. The flattest portion of the flood profile on the lower Snoqualmie River occurs between the High Bridge (Crescent Lake Road) and the Woodinville-Duvall Road Bridge. The 1-percent-annual-chance water surface rises less than 2 feet across this span of 7 RMs.

The channel slope of the Lower Skykomish River is significantly steeper though the floodplain is not significantly more confined than the lower Snoqualmie. For comparison, the lower 7 miles of the Skykomish River drops 33 feet, compared to the 2 foot drop on the lower 7 miles of the Snoqualmie River. In general, however, the 1-percent-annual-chance floodplain of the Skykomish River still extends from the south valley wall to either the north valley wall or State Highway 2.

A regulatory floodway was delineated for the Lower Snoqualmie and Lower Skykomish Rivers using the unsteady HEC-RAS model and following the FEMA Guidelines and Specifications for Flood Hazard Mapping Partners. The hydraulic model for the baseline floodplain included eight distinct secondary flow branches in addition to the main channel reaches on the Snoqualmie and Skykomish Rivers. These secondary flow branches were added to improve the model's simulation of complex floodplain hydraulic conditions including breakout flows, topographic divides, overflow channels, and storage areas. For the floodway analysis, the baseline model was modified to reflect floodplain encroachments as could be made while maintaining a flow corridor that could pass the 1-percent-annual-chance exceedence event without exceeding a 1.0 foot surcharge at any point in the main channel. The process of developing the floodway model comprised the following steps:

1. Begin with the 1-percent-annual-chance exceedence event (base flood) floodplain model.

2. Transfer the floodway limits from the effective FIS to the new hydraulic model.

3. Evaluate the surcharge of the effective floodway encroachments on WSELs in the new model. Like the base flood model, the floodway model is run using unsteady HEC-RAS.

   Thus the surcharge reflects both a loss of conveyance capacity and a reduction in flood storage.

4. Make adjustments to the effective floodplain encroachments to the extent necessary to pass the base flood without exceeding a 1.0 foot surcharge at any point in the main channel. To the extent possible, encroachment adjustments were made to provide an equal conveyance reduction on the left and right overbanks.

5. The modeled floodway encroachments at each cross section were plotted on the project work maps and floodway encroachments were adjusted to provide smooth transitioning floodway delineation and to account for any areas of high ground between model cross sections.

6. The adjusted floodway encroachments from Step 5 were then reinserted in the HEC-RAS model and final floodway simulations were conducted to ensure that the surcharge criteria for the main channel were achieved.

The floodway analysis focused on achieving a 1 foot surcharge in the main channel. It should be noted that there are areas where the newly estimated BFEs in the overbank are not at the same level as the newly estimated main channel BFEs on the adjacent reach. This is because discharge to overflow reaches is affected by hydraulic controls in the floodplain, such as roads or high ground. Comparing the BFEs for the main channel with the BFEs in the adjacent overflow reaches shows that elevation differences of greater than 1 foot occur in several locations. In these locations, and throughout the study area, the analysis focused on maintaining floodway surcharges in the main channel within the allowable 1 foot limit.

The extents of the floodway were extracted from the final floodway model at each modeled cross section. Between sections, the floodway boundary was interpolated based on topographic information and to reflect general hydraulic principles.

The results of the floodway computations for the Lower Snoqualmie and Lower Skykomish Rivers study are tabulated for selected cross sections (see Table 10, Floodway Data).

The Digital Flood Insurance Rate Map (DFIRM) was produced directly from the effective Flood Insurance Rate Map (FIRM) for the county and incorporated areas using a process that involves converting the hard-copy data to a digital (computer-readable) format and applying specialized computer technology to plot map panels. As part of the process of producing the DFIRM, all essential information was incorporated from the effective FIRMs.

Base map information shown on this FIRM is from 1:12,000 USGS Digital Orthophoto Quadrangles, dated 1989 or later and from Snohomish County orthophotos, produced at a 1 foot pixel resolution and dated 2002 or later. New, 2 foot contour interval, topographical data was also provided by Snohomish County. Non-revised floodplains were compared to this new base map data and adjusted where appropriate.

In accordance with FEMA Procedure Memo 36 (Reference 28), profile base lines have been included in all areas of detailed study. Profile base lines are shown in the location of the original stream centerline or original profile base line without regard to the adjusted floodplain position on the new base map. This was done to maintain the relationship of distances between cross sections along the profile base line between the hydraulic models, profiles, and floodway data tables.

French Slough Area

In June 2006, Snohomish County held a meeting to discuss the French Slough Diking District's concerns about the base flood profile in their area. (Reference 106) The meeting was attended by people from the French Slough Flood Control District, FEMA, WEST and Snohomish County staff. It was concluded at the meeting that WEST conduct a thorough review of (1) the levee elevations along the French Slough and Marshlands reach of the Snohomish River (roughly River Miles RM 13-16.5), and (2) considered the Diking District's concern that some levees along the lower Pilchuck River should have been included in the FIS as they potentially represented a longer length of relatively lower levees for flood waters to exit the French Slough area. The original FIS study used the Corps of Engineers' one-dimensional unsteady hydraulic model, UNET (Reference 33), and modeled conveying reaches and "Storage Areas".

During this investigation, an error related to a levee elevation was discovered in the calibration of the UNET hydraulic model for the November 1990 overbank flooding event. After this was corrected and the models re-run, it was concluded that adding some of the Lower Pilchuck River levees, to extend the levees bounding the French Slough storage area, would allow more flood waters to over flow back to the Snohomish River. The result of this was (1) the BFE in the French Slough storage area #1 would decrease from 32 ft to 31 ft NGVD, (2) and the BFEs along the adjacent reach of the Snohomish River would increase.

Changes to the November 1990 UNET Model Calibration

When the original UNET hydraulic model development was reviewed, specifically the levee elevations along the French Slough and upper Marshlands reach of the Snohomish River (RM 13-16.5), an error was discovered in the model calibration. This had no effect on the final model results, as will be describe below. The error was an incorrect levee elevation along the French Slough portion of the Snohomish River levees, and was discovered when the levee elevations in the UNET model were compared to the levee drawings from 1987 provided by Snohomish County. When the error was corrected, the UNET model calibration was re-examined to the November 1990 flood, which inundated both storage areas. The only additional model adjustment was to re-define the elevation at which the Marshlands levee would begin to breach. This shows that the revised model actually results in an improved simulation of the timing and of the levee breach and shape of the hydrograph peak.

The reason that this error does not affect the original model study is that after the November 1990 flood, parts of the French Slough and Marshlands levees along the Snohomish River were modified. These modifications were reflected the effective FIS UNET model used to simulate the 10%-Annual Chance Flood through-0.2-Annual Chance Flood flows. No changes were made to model sections or hydraulic parameters.

Changes to the Effective FIS Hydraulic Model

After the November 1990 flood, changes to the previous effective were made to the Marshland and French Slough levees along the Snohomish River. In 2000, Snohomish County surveyed the top-on-levees along the Snohomish River. As the 2000 survey was compared with the elevations in the effective UNET model, two changes were incorporated:

1. The levee information was refined in UNET, to improve the model representation of the French Slough and Marshland levees along the Snohomish River between RM 13.94-16.53

2. 4,200 feet of the Lower Pilchuck River levee was added (essentially the northwest boundary of French Slough), and connected French Slough ("Fryelands #1"), to the Snohomish River at RM 13.6 and 13.2.

A sensitivity analysis was conducted to include a portion of the lower Pilchuck River levee along the northwest side of the French Slough storage area. With the Lower Pilchuck levee included in the model, the BFE in the French Slough storage area decreases from 32 ft to 31 ft NGVD29, and there is an associated rise where the flow re-enters the Snohomish River over the Pilchuck levee. Snohomish County concluded that this would more appropriately model the dynamics of the interaction of French Slough and the Snohomish River.

With the Lower Pilchuck levees included in the FIS hydraulic model, the BFE in Storage Area #1 will be established at 31 ft NGVD29 (previous effective 32 ft NGVD29), and the BFE in Storage Area #3 be established at 27 ft NGVD29 (previous effective 26 ft NGVD29). The remaining Storage Areas would be not be altered.

Stream Redelineation Summary

183 miles of streams were redelienated by Snohomish County and their contractor WEST. The 1% annual chance floodplain was redelienated onto 2 foot contours. The elevations used for redelienation originate from cross sections and BFE attributes in the effective Geodatabase. The floodway have been aligned to agree with the current channel location using newly developed floodways aerial imagery and LIDAR topography provided by Snohomish County.

The redelienation included the following flooding sources: North Creek, the North Fork Stillaguamish River, Pilchuck River, Sauk River, Snohomish River, South Fork Stillaguamish River, Stillaguamish River, Swamp Creek, Canyon Creek, and Scriber Creek.

During the redelienation, it was noticed that the new floodplain was smaller than the previous effective floodway width in some locations. To correct this, the floodway has been redrawn on the DFIRM panels to coincide with the new 1% annual chance floodplain. Floodway widths are maintained wherever possible. The 1% annual chance floodplain is only mapped when located more than 5 feet horizontally from the 1% annual chance floodway. Otherwise, it is considered coincident with the 1% annual chance floodplain. If the width has changed at any cross section, The Floodway Data Tables have been modified for these streams noting the effective floodway width and the modified map width.

10.3.1 Upper Skykomish River Study

Introduction

The Upper Skykomish River study measured the effects of flooding along the upper Skykomish River and its tributaries. This work was performed for FEMA under Project Number 07-10-0034S. The hydrologic and hydraulic analyses, floodplain mapping, and DFIRM database production for this restudy were performed by Snohomish County and contractors including Northwest Hydraulic Consultants, Inc. (NHC) and L3 Stratis.

The purpose of this restudy was to develop updated flood hazard information for flood insurance purposes for the upper Skykomish River and tributaries affecting unincorporated Snohomish County, the City of Sultan, City of Gold Bar, and Town of Index. The need for revised study of this area was identified at a scoping meeting attended by representatives of Snohomish County and FEMA on September 29, 2005.

Area Studied

The study reach for the upper Skykomish River begins at RM 8.95 and continues upstream to the confluence of the North and South Fork Skykomish Rivers at RM 29.0. The lower Skykomish River from RM 0 to 8.95 was re-mapped as part of the Lower Skykomish Flood Study completed by NHC in 2005. The upper Skykomish River study is sub-divided into a detailed study reach (RM 8.95 to 26.10) and a limited detail study reach (RM 26.10 to 29.00). The study reach for the North Fork Skykomish River begins at RM 0.0 at the confluence of the North Fork and South Fork Skykomish Rivers and continues upstream to the RM 11.3. The North Fork Skykomish River is sub-divided into a detailed study reach (RM 0.0 to RM 4.2) and a limited detail study reach (RM 4.2 to RM 11.3 at the confluence). The South Fork Skykomish River study reach begins at the confluence with the North Fork Skykomish River, near the City of Index and continues upstream approximately 7 miles. This reach was studied using limited detail study methods. The Sultan River study reach begins at the confluence with the Skykomish River, in the City of Sultan and continues upstream approximately 3.3 miles.

Principal Flood Problems

In November 2006 an extreme peak discharge occurred on the Skykomish River. The USGS investigated and determined that the peak flow was 129,000 cfs at the USGS Skykomish River near Gold Bar gage (12134500), the primary gage record on the main stem of the Skykomish River. This gage is currently operating and has been in operation since water year 1929. There are 79 years of published peak streamflow data for this gage making it an ideal gage for performing a flood-frequency analysis.

Hydrologic Analyses

NHC developed peak discharge quantiles for use in the Upper Skykomish River Flood Insurance Re-Study being performed by the Snohomish County Surface Water Management Division. The hydrologic data that was analyzed included frequency analysis of gage data, transposition of frequency analyses, USGS regional regression equations and two-station comparisons. The resultant peak flow values and drainage areas for the detailed study streams are shown in Table 7, "Summary of Discharges." Results of the hydrologic analyses are summarized in a technical memorandum. These results were presented to the City of Sultan's City Council and Planning board at a meeting on November 18, 2008.

Hydraulic Analyses

Upper Skykomish River, North Fork Skykomish River, Sultan River - The cross section data for the study along the upper Skykomish River, North Fork Skykomish River, and the Sultan River were taken from field surveys and topographic mapping prepared by Snohomish County Public Works. The water-surface elevations of the floods for selected recurrence intervals were computed using HEC-RAS 4.0. Channel and overbank roughness factors (Manning's "n") used in the hydraulic analyses were based on engineering judgment.

For the upper Skykomish River, the range of channel roughness factors of 0.028 to 0.1 and overbank roughness factors of 0.05 to 0.1 were used for the model.

For the North Fork Skykomish River, the range of channel roughness factors of 0.028 to 0.1 and overbank roughness factors of 0.05 to 0.1 were used for the model.

For the Sultan River, the range of channel roughness factors of 0.03 to 0.071 and overbank roughness factors of 0.044 to 0.07 were used for the model.

The South Fork Skykomish River was studied using limited detail study methods. Because the 1-percent-annual-chance water-surface elevations are determined using approximate methods, BFEs will not be shown on the FIRM and only the 1-Percent-Annual-Chance profile will be shown on the profile sheets. The cross-section data for the study along the South Fork Skykomish River was taken from field surveys and topographic mapping prepared by Snohomish County Public Works. The water-surface elevations were computed using HEC-RAS 4.0. Channel and overbank roughness factors (Manning's "n") used in the hydraulic analyses were based on engineering judgment. The range of channel roughness factors of 0.038 to 0.048 and overbank roughness factors of 0.080 to 0.120 were used to model the South Fork Skykomish River.

Floodplain Management Application

The NFIP encourages State and local governments to adopt sound floodplain management programs. To assist in this endeavor, each FIS provides 1-percent-annual chance floodplain data, which may include a combination of the following: 10-, 2-, 1-, and 0.2-percent-annual-chance flood elevations; delineations of the 1- and 0.2-percent-annual-chance floodplains; and a 1-percent-annual-chance floodway. This information is presented on the FIRM and in many components of the FIS, including the Flood Profiles, the Floodway Data Table, and the Summary of Discharges Table. Users should reference the data presented in the FIS as well as additional information that may be available at the local community map repository before making flood elevation and/or floodplain boundary determinations.

For this restudy, all elevations are referenced to the North American Vertical Datum of 1988 (NAVD88). To obtain up-to-date elevation information on NGS shown on this map, please visit the NGS website at www.ngs.noaa.gov. Map users should seek verification of non-NGS EMS elevations when using these elevations for construction or floodplain management purposes.

Upper Skykomish River - The 1-percent floodplain boundary was delineated using water-surface elevation determined at each cross section. Between cross sections, the 1-Percent-Annual-Chance floodplain was interpolated using topographic mapping at a scale of 1:2,400, with contour intervals of 4 feet. In the reach between cross sections DX and EC connectivity is limited thus channel BFEs are unrealistic and it was removed from Zone

AE. Alternatively, the area was mapped as Zone AO with flood depths of 2-3 feet. It should be noted that existing conveyance features across the highway and railroad are unknown, but flooding from the Skykomish is likely minimal to the north. Average whole-foot flood depths derived from the detailed hydraulic analyses are shown within this zone on the FIRM. For the portions of the study completed using limited detail methods (RM 26.10 to 29.00), BFE lines are not shown on the FIRM as this area is shown as Zone A

North Fork Skykomish River - The 1 percent floodplain boundary was delineated using water-surface elevation determined at each cross section. Between cross sections, the 1 percent floodplain was interpolated using topographic mapping at a scale of 1:2,400, with contour intervals of 4 feet. For the portions of the study completed using limited detail methods, Base Flood Elevation lines will not be shown on the FIRM and only the 1-Percent-Annual-Chance profile will be shown on the profile sheets because the 1-percent-annual-chance water surface elevations for the North Fork Skykomish River were determined using approximate methods.

South Fork Skykomish River - The 1 percent floodplain boundary was delineated using water-surface elevation determined at each cross section. Between cross sections, the 1 percent floodplain was interpolated using topographic mapping at a scale of 1:2,400, with contour intervals of 2 feet. Base Flood Elevation lines are not shown on the FIRM as this area is shown as Zone A.

Sultan River - The 1-Percent-Annual-Chance floodplain boundary was delineated using water-surface elevation determined at each cross section. Between cross sections, the 1-Percent-Annual-Chance floodplain was interpolated using topographic mapping at a scale of 1:2,400, with contour intervals of 4 feet.

May Creek - May Creek was re-delineated using the previous effective flood elevations that were mapped to new topographic data. The 1-Percent-Annual-Chance floodplain boundary was delineated using water-surface elevation determined at each cross section. Between cross sections, the 1-Percent-Annual-Chance floodplain was interpolated using topographic mapping at a scale of 1:2,400, with contour intervals of 4 feet. Shallow flooding occurs between cross sections M and P. The Zone AE delineation on the right overbank was removed because connectivity is limited and channel BFEs are unrealistic and replaced with a small Zone AO with flood depths of 2-3 ft. The terrain in this area slopes away from the channel, thus flooding is expected to be shallow. Furthermore, the channel is steep in this reach and the majority of flow is likely to remain within the main corridor. Average whole-foot flood depths are shown within this zone on the FIRM.

Wallace River - The Wallace River was scoped for re-delineation. The 1-Percent-Annual-Chance discharge computed by NHC is approximately 21% lower than the effective FIS (Reference 109). In light of this difference FEMA recommended that a new study of the Wallace river be undertaken. As a new study was beyond the scope of the project, the Wallace River was not re-delineated. Some adjustment of the Wallace River flood data was necessary to ensure continuity with the upper Skykomish River study data.

All of the above work was completed by updating the existing 2006 Preliminary DFIRM to produce a 2010 Revised Preliminary DFIRM. A datum conversion was completed from NGVD29 to NAVD88 as part of the production of the 2006 Preliminary DFIRM.

The results of the restudy were reviewed at the final CCO meeting held on ________________and attended by________________. All problems raised at that meeting have been addressed in this restudy.