Skagit River Flood Risk Management Study
Hydraulic Effectiveness of Measures
FINAL DRAFT

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Executive Summary

This report describes analysis of the hydraulic effectiveness of various measures proposed for management of floods in the lower Skagit River basin, focusing on conditions at and downstream from Sedro-Woolley. The intent of the work is to identify those measures which hold promise for improving flood management and for which additional more detailed analysis is warranted. Hydraulic effectiveness is defined for current purposes as the impact of the proposed measure on flows and water levels in the Skagit River (including the North and South Forks) upstream and downstream from the measure location, and the impact on spill from the river channel onto the floodplain. No analyses are provided in this report of the costs or environmental or cultural impacts of measures. Such analyses will be undertaken in a later study phase.

The measures considered in this report were defined in a series of meetings of the Skagit River Flood Risk Management General Investigation Study (Skagit GI) Project Delivery Team (PDT)[1], and refined in subsequent discussion with several of the project stakeholders. The measures considered reflect screening and rationalization by the PDT of a larger list of measures identified earlier in the Skagit GI process. The list of measures considered is not complete; it is anticipated that additional measures will be developed and analyzed as the project proceeds.

Measures considered in this report are as follows:

- Increased flood control storage and/or modification of flood control operations at Upper Baker
- Increased early flood control season storage at Upper Baker and Ross
- Mount Vernon Flood Wall
- Burlington Urban Levee
- Three Bridge Corridor Improvements with and without bridge modifications
- Flood control storage in the lower Nookachamps basin
- North Mount Vernon (Riverbend) Levee
- Sterling Levee
- Improve Existing Levees
- Levee Setbacks from the Three Bridge Corridor downstream
- Fir Island and Mount Vernon Bypasses
- Swinomish Bypass
- Improvement of outlet structures (these manage discharge from floodplain sloughs to Skagit Bay and Padilla Bay)
- Other facility and community levees.

The performance of the majority of the measures (the levee, bypass, Three Bridge Corridor and Nookachamps basin measures) was determined for 50- and 100-year flood events only using a one-dimensional (HEC-RAS) hydraulic model of the river system developed in previous work on the Skagit GI. Hydraulic analysis of these measures was restricted to the areas represented within the HEC-RAS model, that is within the mainstem channel of the Skagit River, the North and South Forks of the Skagit River,

[1]The Skagit GI PDT comprises representatives from the Seattle District US Army Corps of Engineers and Skagit County as the local sponsor

and within the Nookachamps and Riverbend floodplain storage areas. No analysis was performed for this report to determine the impact of measures on floodplain flows or extent of floodplain inundation other than in the Nookachamps and Riverbend areas. The performance of these measures is documented in spreadsheet-based performance matrices which are included with the report in digital form. The performance matrices provide comprehensive information on the impact of the measures on discharge rates and water levels at key locations on the Skagit River, along with spill rates and volumes from the Skagit River onto the flood plain, and water levels in the Nookachamps basin.

The Upper Baker and Ross flood control storage measures were investigated using a spreadsheet-based reservoir routing model also developed in previous work on the Skagit GI. The hydraulic effectiveness of these measures was determined as the reduction in regulated peak discharge on the Skagit River near Concrete compared to existing flood control operations. The performance of the Upper Baker and Ross storage measures is documented in tables provided in the main body of the report.

The Improve Outlet Structure measure differs from other measures examined in this report in that it has no impact on Skagit River flows or water levels but is intended to facilitate drainage of floodplain flows into Padilla Bay or Skagit Bay. Analysis in this report addresses outlet structure improvements at the outlet of Joe Leary Slough to Padilla Bay only. Similar improvements would be considered at other locations. The performance of this measure was determined as the time required to draw down flood water stored behind the sea dike.

1.0 Introduction

This report describes analysis of the hydraulic effectiveness of various measures proposed for management of floods in the lower Skagit River basin, focusing on conditions at and downstream from Sedro-Woolley. Several measures involving improved flood management at upstream reservoirs also provide some degree of flood reduction upstream from Sedro-Woolley however the primary concern for this work is at and downstream from Sedro-Woolley.

The intent of this work is to identify those measures which hold promise for improving flood management and for which additional more detailed analysis is warranted. Hydraulic effectiveness is defined for current purposes as the impact of the proposed measure on flows and water levels in the Skagit River (including the North and South Forks) upstream and downstream from the measure location, and the impact on spill from the river channel onto the floodplain.

The report builds, to the extent possible, on previous work on the analysis of measures conducted by both Pacific International Engineering (PIE) and the Seattle District US Army Corps of Engineers (USACE). Analysis of measures is based on the most recent characterization of Skagit River hydrology and hydraulics (USACE, 2011a, 2011b).

2.0 Measures Considered

Measures considered in this report are listed below in the order discussed. These measures were defined in a series of meetings of the Skagit River Flood Risk Management General Investigation Study (Skagit River GI) Project Delivery Team (PDT)[2], and refined in subsequent discussion with several of the project's stakeholders. The measures below reflect screening and rationalization by the PDT of a larger list of measures identified earlier in the GI process. Screening of measures included elimination, by the PDT, of some measures which were deemed to be clearly infeasible because of environmental impact, cost or lack of flood control benefit. The list of measures considered here is not complete; it is anticipated that additional measures will be developed and analyzed as the project proceeds. The measure code, where provided in the table below, is used to identify the measure in the performance matrices accompanying the report.

Measure Code	Measure	
	Increased Upper Baker Storage	
	a.	74,000 acre-ft Upper Baker flood control storage, 0 cfs minimum release
	b.	85,000 acre-ft Upper Baker flood control storage, 0 cfs minimum release
	c.	100,000 acre-ft Upper Baker flood control storage, 0 cfs minimum release
	d.	110,000 acre-ft Upper Baker flood control storage, 0 cfs minimum release
	Increased Early Flood Control Season Storage at Upper Baker	
	Increased Early Flood Control Season Storage at Upper Baker and Ross	
MVFW	Mount Vernon Flood Wall	
BURL	Burlington Urban Levee	
	Three Bridge Corridor Improvements	
3 BRD w mods	a.	With levee setbacks and bridge modifications ("with bridge modifications")
3 BRD w/o mods	b.	With levee setbacks only ("without bridge modifications")
BASE	Base Condition Measures (includes MVFW, BURL and 3 BRD w and w/o mods)	
	Nookachamps Storage	
NKCHMPS1	a.	Nookachamps Low Storage option
NkCHMPS2	b.	Nookachamps High Storage option
RIVERBND	North Mount Vernon (Riverbend) Levee	
STERL	Sterling Levee	
	East Mount Vernon Levee	

[2] The Skagit GI PDT comprises representatives from the Seattle District US Army Corps of Engineers and Skagit County as the local sponsor

	Improve Existing Levees	
LEVSETBK	Levee Setbacks	
	Fir Island and Mount Vernon Bypasses	
FIR BPS	a.	Fir Island Bypass (diversion at North Fork RM 7.0)
FIR + MTV BPS	b.	Fir Island Bypass + Mount Vernon Bypass
SWIN BPS	Swinomish Bypass	
	Improve Outlet Structures	
	a.	Joe Leary Slough Outlet Structure
	Other Facility and Community Levees	
	a.	United General Hospital
	b.	Clear Lake
	c.	West Mount Vernon
	d.	La Conner
	e.	Sedro-Woolley

3.0 Methodology

The performance of measures was determined for the 50- and 100-year flood events only, except for the Upper Baker and Ross storage measures. For the Increased Upper Baker Storage measure, a full suite of design floods was considered from the 5-year to the 500-year event, while performance of the Increased Early Flood Control Season Storage measures considered the 10- and 100-year flood events only.

The Upper Baker and Ross storage measures were investigated by means of the spreadsheet reservoir routing model originally developed by the USACE and modified by NHC for use in basin hydrology studies (USACE, 2011a). All other measures, with the exception of the Improve Outlet Structures measure, were analyzed using the existing condition HEC-RAS model of the lower Skagit River (USACE, 2011b) modified as appropriate to represent the measure or measures in question. Hydraulic analyses of these measures were restricted to the areas represented within the HEC-RAS model, i.e. within the mainstem channel of the Skagit River, the North and South Forks of the Skagit River, and within the Nookachamps and Riverbend floodplain storage areas. No FLO-2D analysis was performed for this work[3], and hence no information is provided on the impact of measures on floodplain flows or extent of floodplain inundation other than in the Nookachamps and Riverbend areas. The Improve Outlet Structures measure was investigated using a stand-alone HEC-RAS model developed specifically to estimate the time required to drain flood waters accumulated behind the sea dikes at the outlet of Joe Leary Slough to Padilla Bay.

For current purposes, the measures analysis assumes average-case flood regulation at Upper Baker and Ross Reservoirs and average debris loads at the BNSF and Great Northern Railroad bridges. No other debris loads are considered. Debris assumptions are described in detail in the existing conditions hydraulics report (USACE, 2011b) and are further discussed in a memorandum reviewing bridge debris loading assumptions (NHC, 2011). Debris assumptions at the BNSF bridge have a significant impact on flows and water levels both upstream and downstream from the bridge; future analyses must consider the effects of uncertainty in those debris loads.

Except in one case, the analysis performed for this work allowed for overtopping of levees but did not consider breaches of either existing or improved levees. As discussed later, a single left bank levee breach was assumed in the Riverbend area at RM 16.6 for the purpose of analyzing the performance of the North Mount Vernon Levee measure.

The impacts of flood fighting on flows in the system, including levee overtopping and spill into the floodplain, are not considered.

In a simpler system than the Skagit, flood management measures would typically be analyzed independently of one another and the most promising individual measures would then be assembled

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[3] FLO-2D is a complex two-dimensional hydraulic modeling code which is used in the Skagit River GI to model overbank flows in areas where the complexity of the floodplain is such that accurate results cannot be obtained using a one-dimensional HEC-RAS model. Details of the FLO-2D model are provided in the Hydraulic Technical Documentation (USACE, 2011b).

into flood management alternatives to provide a basis for a comprehensive flood management plan. On the Skagit, there is a strong interrelationship between measures such that it does not make sense to consider measures in isolation. For example, constructing a levee to reduce spill from the system at Sterling has a direct impact on downstream flows and the performance of downstream measures.

The analysis presented here considers that there is much greater likelihood of some measures being constructed than others. For example, the Mount Vernon Flood Wall is considered here as a measure rather than an existing condition. The flood wall is partly completed and there is a high likelihood that it will be completed in the future. Similarly, the Burlington Urban Levee and the Three Bridge Corridor Improvements are considered to have a relatively high probability of being implemented, although their exact configurations are still uncertain. The Mount Vernon Flood Wall, Burlington Urban Levee, Three Bridge Corridor Improvements, Upper Baker and Ross storage measures, and Improve Outlet Structures measure, are all modeled as individual stand-alone measures. Most other measures are modeled in conjunction with the Mount Vernon Flood Wall, Burlington Urban Levee Project and Three Bridge Corridor measures. As discussed below, two alternative versions of the Three Bridge Corridor measure were analyzed – one version with levee setbacks but no bridge improvements, and the second with both levee setbacks and bridge improvements.

The performance of all measures expect the Upper Baker and Ross storage measures and the Improve Outlet Structures measure is described in terms of their impact (in isolation or in conjunction with other measures depending on the measure) on flows, water levels and spills at key points throughout the river system. As noted above, no FLO-2D modeling was done for this report and hence no information is provided on floodplain inundation except for the Nookachamps and Riverbend areas, both of which are represented within the existing condition HEC-RAS model. The performance of measures is summarized in the large matrices accompanying this report in digital form. These matrices are intended to facilitate examination of the system-wide impacts of measures and cross-comparison of the effectiveness of various measures.

The performance of the Upper Baker and Ross storage measures is described only in terms of their impact on regulated peak flow on the Skagit River near Concrete. The performance of the Upper Baker and Ross storage measures is summarized in Tables 1 through 3, as described in further detail in Sections 4.1 and 4.2 below.

The performance of the Improve Outlet Structures measures is described in terms of the time required to drain flood water accumulated behind the sea dikes.

4.0 Analysis of Measures

4.1 Increased Upper Baker Storage

The Increased Upper Baker Storage measures provide additional flood control storage at Upper Baker reservoir and/or a reduction in the minimum release from Upper Baker from 5,000 cfs, as currently required, to 0 cfs. Lower Baker is assumed to provide no flood control; Lower Baker is assumed to be at full pool and operated to pass inflows.

The following scenarios were analyzed:

a) 74,000 acre-ft of flood control storage at Upper Baker (as currently required), with 0 cfs minimum release.

b) 85,000 acre-ft of flood control storage at Upper Baker, with 0 cfs minimum release.

c) 100,000 acre-ft of flood control storage at Upper Baker, with 0 cfs minimum release.

d) 110,000 acre-ft of flood control storage at Upper Baker, with 0 cfs minimum release.

In accordance with advice from staff with the Seattle District USACE Reservoir Control Center, the release from Upper Baker was assumed to be reduced to zero cfs four hours before the peak flow occurs at the Skagit River near Concrete gauge and held at zero until three hours after the peak. This release policy is overridden by the Spillway Gate Regulation Schedule.

The performance of the Upper Baker Storage measures was analyzed to determine effects on peak flows for the Skagit River near Concrete (below the confluence with the Baker River) for design floods with return periods of 5-, 10-, 25-, 50-, 75-, 100-, 250- and 500-years. Upper Baker provides no flood control regulation for the 2-year event. The analysis assumed the average-case regulation scenario as described in the basin hydrology study Hydrology Technical Documentation (Section 4.4.2.4.3). The analysis was conducted in two steps: flood control operations at Upper Baker and Ross reservoirs were modeled using the spreadsheet reservoir routing model used in the basin hydrology study; modeled releases from Upper Baker and Ross were then routed to the Skagit River near Concrete using the HEC-RAS model of the Upper Skagit River as also used in the basin hydrology study.

The peak flows on the Skagit River near Concrete for the Upper Baker Storage measures are summarized in Table 1 along with the peak Upper Baker reservoir elevations. Also shown in Table 1 are the existing condition peak flows and the unregulated peak flows. Compared with existing conditions, peak flows for the Skagit River near Concrete are reduced by a little under 5,000 cfs for each measure for return periods from 5- to 50-years as a direct result of reducing the minimum release from Upper Baker to zero. For larger events (from 100- to 500-years), releases from Upper Baker are dictated by the Spillway Gate Regulation Schedule (SGRS) which specifies release as a function of pool elevation and project inflow. Near full pool, the specified releases are quite sensitive to small changes in pool elevation and inflow. As the flood control storage is increased for the various measures, maximum Upper Baker pool levels decrease slightly resulting in a reduction in releases required under the SGRS, and a corresponding reduction in peak flows on the Skagit River near Concrete as shown in Table 1.

Table 1: Performance of Increased Upper Baker Storage Measures

Measure	Peak Discharge, Skagit River near Concrete (cfs)									Impact on Peak Flow: Difference from Existing Conditions (cfs)							
	2-Year	5-Year	10-Year	25-Year	50-Year	75-Year	100-Year	250-Year	500-Year	5-Year	10-Year	25-Year	50-Year	75-Year	100-Year	250-Year	500-Year
Unregulated:	77,300	120,500	153,300	210,200	229,300	255,500	272,400	325,400	363,600	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Existing: Upper Baker 74,000 ac-ft Flood Control and 5000 cfs Minimum Release	77,300	100,700	125,500	159,300	180,300	200,700	214,200	267,400	313,300	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Measure: Upper Baker 74,000 ac-ft Flood Control and 0 cfs Minimum Release	77,300	96,350	120,700	154,500	175,600	200,400	214,200	267,400	313,300	(4,350)	(4,800)	(4,800)	(4,700)	(300)	0	0	0
Measure: Upper Baker 85,000 ac-ft Flood Control and 0 cfs Minimum Release	77,300	96,350	120,700	154,500	175,600	195,500	207,500	261,600	304,900	(4,350)	(4,800)	(4,800)	(4,700)	(5,200)	(6,700)	(5,800)	(8,400)
Measure: Upper Baker 100,000 ac-ft Flood Control and 0 cfs Minimum Release	77,300	96,350	120,700	154,500	175,600	195,500	207,400	255,900	296,000	(4,350)	(4,800)	(4,800)	(4,700)	(5,200)	(6,800)	(11,500)	(17,300)
Measure: Upper Baker 110,000 ac-ft Flood Control and 0 cfs Minimum Release	77,300	96,350	120,700	154,500	175,600	195,500	207,400	250,400	290,900	(4,350)	(4,800)	(4,800)	(4,700)	(5,200)	(6,800)	(17,000)	(22,400)

Measure	Peak Reservoir Elevation, Upper Baker (ft., NAVD88)								
	2-Year	5-Year	10-Year	25-Year	50-Year	75-Year	100-Year	250-Year	500-Year
Existing: Upper Baker 74,000 ac-ft Flood Control and 5000 cfs Minimum Release	n/a	712.1	715.3	719.8	722.8	724.4	725.0	726.4	726.8
Measure: Upper Baker 74,000 ac-ft Flood Control and 0 cfs Minimum Release	n/a	713.1	716.3	720.8	723.8	724.6	725.0	726.4	726.8
Measure: Upper Baker 85,000 ac-ft Flood Control and 0 cfs Minimum Release	n/a	710.5	713.9	718.4	721.6	723.4	724.1	726.0	726.6
Measure: Upper Baker 100,000 ac-ft Flood Control and 0 cfs Minimum Release	n/a	706.8	710.3	715.2	718.5	720.5	721.6	724.8	726.3
Measure: Upper Baker 110,000 ac-ft Flood Control and 0 cfs Minimum Release	n/a	704.3	708.0	713.0	716.4	718.4	719.6	723.8	725.6

Note: Assumes average-case reservoir regulation.

4.2 Increased Early Flood Control Season Storage at Upper Baker and Ross

These measures consider the benefit of increased flood control storage early in the flood control season. Under existing operating policies, flood control storage is increased from 0 acre-ft on October 1, to 16,000 acre-ft on October 15, and 74,000 acre-ft by November 15 of each flood control season at Upper Baker and from 0 acre-ft on October 1 to 120,000 acre-ft on December 1 at Ross. Providing increased early flood control season storage at Upper Baker and/or Ross would reduce flood risk in October and November.

Two scenarios were considered:

a) Modify project operations at Upper Baker only to provide 74,000 acre-ft of flood control storage starting on October1. Operating policies at Ross would be unchanged, with flood control storage there increasing from 0 acre-ft on October 1 to 120,000 acre-ft on December 1.

b) Modify project operations at both Upper Baker and Ross to provide 74,000 acre-ft of flood control storage at Upper Baker and 120,000 acre-ft of flood control storage at Ross starting on October 1.

No original analysis was undertaken for these measures. Rather, the effect of providing increased early flood control season storage was estimated from earlier work by NHC assessing the impact of seasonal variation in flood storage on regulated peak flows for the Skagit River near Concrete. This work, described in a 15 June 2010 memorandum provided in Appendix A, was restricted to analysis of 10- and 100-year floods and was performed before the most recent update (2011) to the hydrology study for the Skagit River basin was completed. Results presented here have been adjusted for consistency with the 2011 hydrology study update but no new analysis has been performed. The results should therefore be regarded as approximate.

It should also be noted that the 15 June 2010 memorandum assumed that the seasonal variation in flood control storage provided at Upper Baker follows the requirements of the Upper Baker Water Control Manual (WCM) whereas in practice the seasonal operation follows slightly different requirements contained in the project's current FERC license. Under the FERC license, flood control storage at Upper Baker is increased from 0 acre-feet on October 1 to 16,000 acre-feet on October 15 and 74,000 acre-feet on November 15. Under the WCM, flood control storage would be increased from 0 acre-feet on October 1 to 16,000 acre-feet on November 1and 74,000 acre-feet on November 15.

Estimated peak flows on the Skagit River near Concrete with and without increased early flood control season storage at Upper Baker are provided for 10- and 100-year events at approximately two-week intervals for the early part of the flood control season in Table 2. It can be seen in Table 2 for example, that providing 74,000 acre-ft of flood control storage at Upper Baker by October 8, would reduce the regulated peak discharge at Concrete in a 100-year event by about 23,000 cfs, from an estimated 259,000 cfs under current operating policies to about 236,000 cfs. Similar results for increased early flood control season storage at both Upper Baker and Ross are provided in Table 3.

It is important to note that the regulated peak discharges presented in Tables 2 and 3 are **NOT** 10- or 100-year flows but the regulated peak flows that would be produced if a 10- or 100-year event occurred at a specific date early in the flood control season with a specified amount of flood control storage. It should also be noted that this analysis does not consider incidental flood control storage. As noted in the memo in Appendix A, Ross Reservoir in particular often provides significantly greater storage early in the flood control season than is required under the terms of its operating license as a result of normal power operations.

Table 2: Impact on Regulated Peak Discharge of Increased Early Flood Control Season Storage at Upper Baker

Date	Regulated Peak Discharge, Skagit River near Concrete (cfs)						Starting Flood Storage per WCM (acre-ft)	
	10-year Event			100-year Event				
	Upper Baker and Ross Starting Flood Storage per WCM	Upper Baker Starting Flood Storage Increased to 74,000 acre-ft	Change in Regulated Peak Discharge	Upper Baker and Ross Starting Flood Storage per WCM	Upper Baker Starting Flood Storage Increased to 74,000 acre-ft	Change in Regulated Peak Discharge	Upper Baker	Ross
October 8	150,500	138,500	-12,000	259,200	236,200	-23,000	3,700	10,100
October 23	145,500	135,500	-10,000	253,200	230,200	-23,000	11,700	31,600
November 8	132,500	132,500	0	248,200	230,200	-18,000	46,100	51,500
November 23	125,500	125,500	0	223,200	223,200	0	74,000	90,100
After December 1	125,500	125,500	0	214,200	214,200	0	74,000	120,000

Table 3: Impact on Regulated Peak Discharge of Increased Early Flood Control Season Storage at Upper Baker and Ross

Date	Regulated Peak Discharge, Skagit River near Concrete (cfs)						Starting Flood Storage per WCM (acre-ft)	
	10-year Event			100-year Event				
	Upper Baker and Ross Starting Flood Storage per WCM	Upper Baker and Ross Starting Flood Storages Increased to 74,000 acre-ft and 120,000 acre-ft	Change in Regulated Peak Discharge	Upper Baker and Ross Starting Flood Storage per WCM	Upper Baker and Ross Starting Flood Storages Increased to 74,000 acre-ft and 120,000 acre-ft	Change in Regulated Peak Discharge	Upper Baker	Ross
October 8	150,500	125,500	-25,000	259,200	214,200	-45,000	3,700	10,100
October 23	145,500	125,500	-20,000	253,200	214,200	-39,000	11,700	31,600
November 8	132,500	125,500	-7,000	248,200	214,200	-34,000	46,100	51,500
November 23	125,500	125,500	0	223,200	214,200	-9,000	74,000	90,100
After December 1	125,500	125,500	0	214,200	214,200	0	74,000	120,000

4.3 Mount Vernon Flood Wall (MVFW)

The Mount Vernon Flood Wall is intended to provide 100-year protection from flooding for downtown Mount Vernon. It would prevent spill from the Skagit into and through downtown Mount Vernon downstream from Lion's Park. The measure comprises an 8,600 ft long flood wall and levee that would extend along the left bank of the Skagit River from approximately RM 13.0 to RM 11.8, wrapping around the downstream end of the Mount Vernon Wastewater Treatment facility (Figure 1). The modeled flood wall and levee geometry (top elevations and alignment) were taken from plans by Pacific International Engineering dated 01/30/2009.

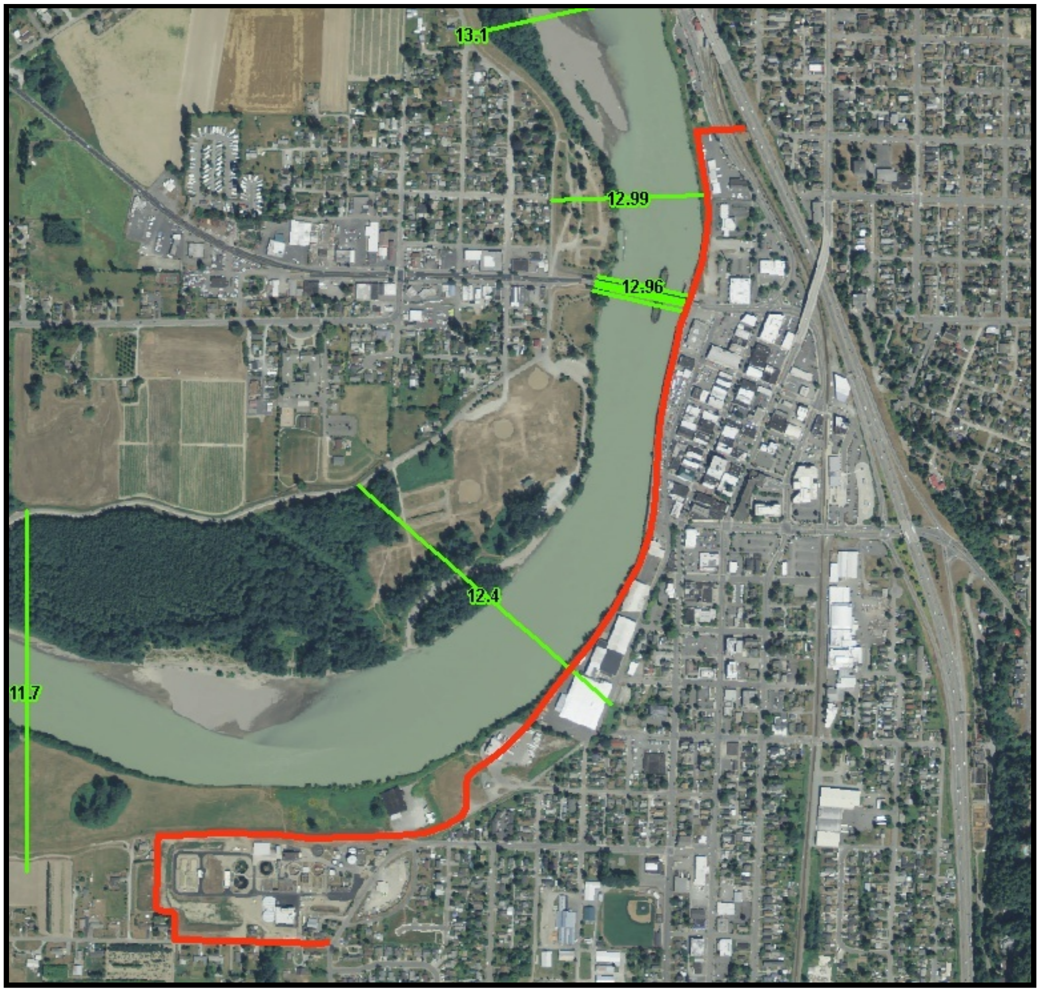

Figure 1: Mount Vernon Flood Wall approximate alignment

At the time of writing (July 2011), the flood wall was complete upstream from Division Street, except for closure structures across Freeway Drive and the railway lines at the north end of the wall. The modeled **existing** condition assumes no flood wall in place.

Downstream from Division Street, much of the proposed flood wall comprises a concrete wall with top elevation at the current (July 2011) regulatory 100-year water surface elevation, corresponding to a 100-year peak flow of 229,000 cfs at Sedro-Woolley and about 185,000 to 190,000 cfs at Division Street

(Albert Liou, PIE, personal communication, 2011), with 3-ft of freeboard being provided by stoplogs. The top of wall is represented in the hydraulic model as including the stoplogs, where proposed. The hydraulic model also assumes that all proposed closures are effective.

Current hydraulic modeling with the Mount Vernon Flood Wall in place and relying on the most recent project hydrologic analysis (USACE, 2011a) produces 50- and 100-year peak discharges at Division Street of 146,400 cfs and 153,500 cfs respectively. The difference between these values and those used in design of the flood wall is believed to be due to a combination of factors including different hydrologic analysis (resulting in different peak flows at Sedro -Woolley) and, more significantly, different assumptions regarding accumulation of debris on the BNSF bridge and upstream spill of flow out of the channel system. The analysis presented here assumed an average debris load on the BNSF bridge (see Section 4.5) and accounts for upstream spill both over the right bank Dike District 12 (DD12) levees upstream from the BNSF bridge (see Section 4.4) and at Sterling (see Section 4.9). Analysis for the design of the flood wall assumes no debris blockage on the BNSF bridge and makes different assumptions regarding spill, however information on those spill assumptions is not readily available. The existing capacity of the Skagit River channel between the BNSF and Division Street bridges before overtopping of levees, and ignoring flood fighting, is approximately 147,000 cfs. A top of wall profile along with water surface profiles for the 50- and 100-year events, as defined in this study, is shown in Figure 2.

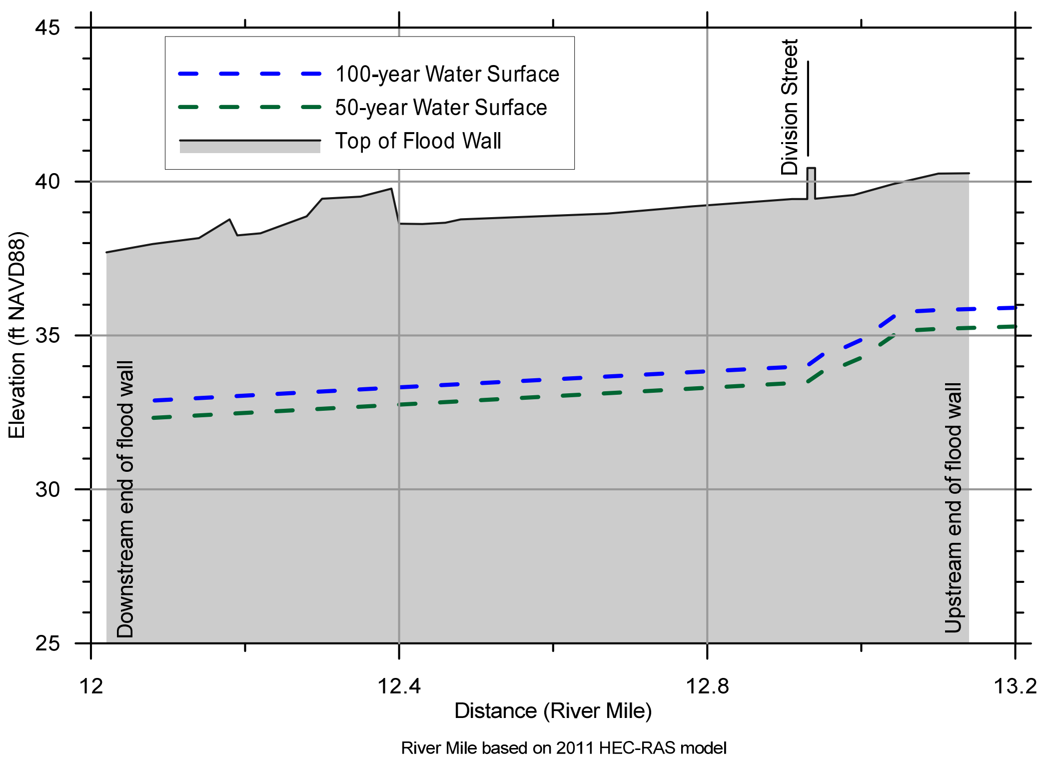

Figure 2: Mount Vernon Flood Wall with 50-year and 100-year Water Surface Profiles

50-year Results:

Relative to existing conditions, the flood wall prevents about 1,500 cfs from spilling into Mount Vernon during the 50-year event.

The flood wall tends to slightly increase peak water surface elevations upstream of Mount Vernon; this increase is greatest at the upstream end of the wall, where the rise is 0.1 ft. The rise gradually diminishes in the upstream direction through the Three Bridge Corridor.

Downstream from Mount Vernon, increased Skagit River flow resulting from the reduction in spill into Mount Vernon, causes an approximately 0.1 foot rise in peak water surface elevations in both the mainstem Skagit and the North and South Forks.

100-year Results:

Relative to existing conditions, the flood wall prevents about 3,300 cfs from spilling into Mount Vernon during the 100-year event.

The flood wall tends to slightly increase peak water surface elevations upstream of Mount Vernon; this increase is greatest at the upstream end of the wall, where the rise is 0.2 ft. The rise gradually diminishes in the upstream direction through the Three Bridge Corridor.

Downstream from Mount Vernon, increased Skagit River flow resulting from the reduction in spill into Mount Vernon, causes an approximately 0.2 foot rise in peak water surface elevations in both the mainstem Skagit and the North and South Forks.

4.4 Burlington Urban Levee (BURL)

The Burlington Urban Levee measure is intended to protect the City of Burlington from flooding. The measure considered here would improve the existing right bank DD12 levee from about RM 17.9 upstream to about RM 20.9 by increasing top width and height as necessary. Setback levees would be constructed from about RM 17.9 downstream to about RM 16.5 consistent with the right bank levee setback proposed for the Three Bridge Corridor Improvements (Figure 3). Plans developed by Golder Associates and dated 08/2009 were used to define the top-of-levee profile and levee alignment for modeling purposes.

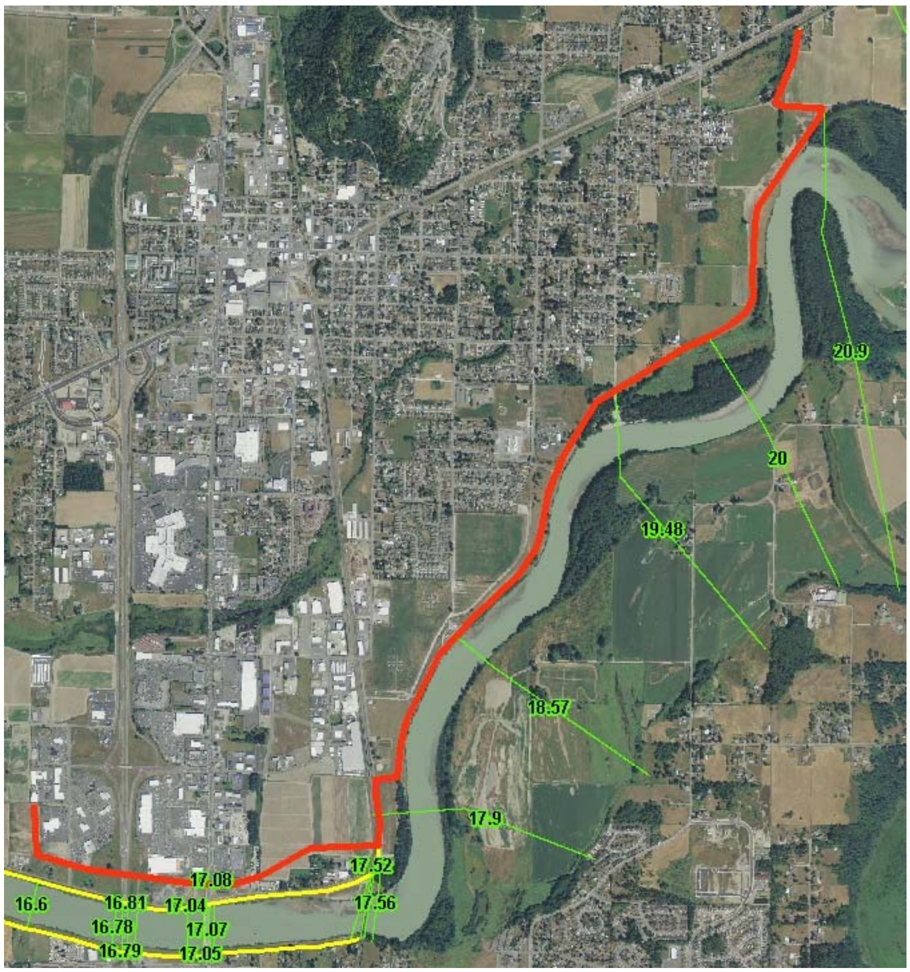

Figure 3: Burlington Urban Levee approximate alignment.

(Orange line shows proposed extent of levee improvements and alignment of proposed setbacks through the Three Bridge Corridor; yellow line shows existing alignment.)

At the time of writing (July 2011) the proposed alignment for the upstream end of the Burlington Urban Levee was uncertain. For current modeling purposes, the Burlington Urban Levee was assumed to terminate at SR-20 as shown in Figure 3. A number of alternatives have been put forward to tie the levee into high ground at its upstream end to prevent floodplain flows from entering Burlington from the northeast, along the general alignment of Gages Slough. These alternatives include, amongst others: extending the levee north of SR-20 to tie into Sterling Hill; or extending the levee east to tie into high ground in Sedro-Woolley. An extension to Sterling Hill would have no impact on flows and water levels in the mainstem Skagit and would thus have no impact on hydraulic effectiveness as defined for this work; however it would likely have a significant impact on flooding in Burlington. A levee extension to Sedro-Woolley would have impacts on mainstem flows and water levels similar to those for the Sterling Levee measure which is discussed in Section 4.9.

50-year Results:

The Burlington Urban Levee will prevent spill of about 6,300 cfs[4] into the City of Burlington just upstream from the BNSF bridge during the 50-year event. This measure results in an approximately 0.1 ft increase in the peak upstream water level in the Sterling area and an approximately 2,500 cfs increase in maximum spill discharge from the right bank of the Skagit River at Sterling. The principal locations of spill over the DD12 levees and at Sterling are shown in Figure 4. Downstream from the Burlington Urban Levee, the peak discharge is increased by about 2,400 cfs. The peak water level is increased by about 0.2 ft at the Anacortes WTP, with similar increases throughout the downstream system.

100-year Results:

The Burlington Urban Levee will prevent spill of about 18,600 cfs into the City of Burlington upstream from the BNSF bridge during the 100-year event. This measure results in an approximately 0.4 ft increase in the peak upstream water level in the Sterling area and an approximately 9,500 cfs increase in maximum spill discharge from the right bank of the Skagit River at Sterling. Downstream from the Burlington Urban Levee, the peak discharge is increased by about 6,600 cfs. The peak water level is increased by about 0.5 ft at the Anacortes WTP, with somewhat lesser increases throughout the downstream system.

The spill hydrographs over the DD12 levees for 50- and 100-year events under existing conditions are shown in Figure 5. It is again important to note that, for the purposes of this report, only spill due to overtopping of the DD12 levee is shown. It is assumed that there is no levee breach. The Burlington Urban Levee would eliminate the existing condition spill over the DD12 levee for both the 50- and 100-year events.

Spill hydrographs at Sterling for 50- and 100-year events for the existing condition and with the Burlington Urban Levee measure are shown in Figure 6. As noted above, the increased spill at Sterling with the Burlington Urban Levee in place is due to the elimination of spill over the DD12 levees just upstream from the BNSF bridge, which results in an increase in upstream water level.

[4] Unless otherwise noted, all spill estimates provided in this report are for levee overtopping only and do not consider levee breaches.

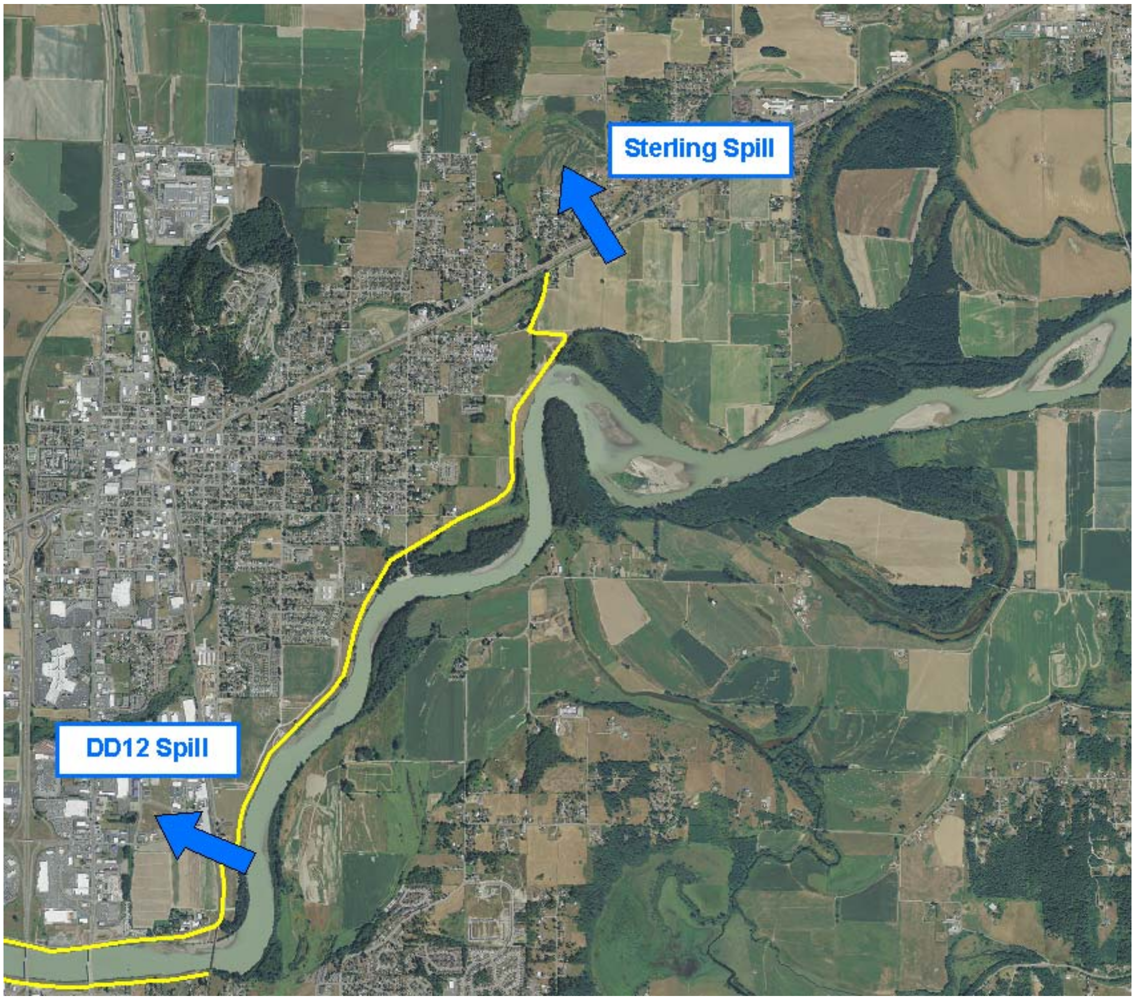

Figure 4: Principal locations of Skagit River right bank spill upstream from the BNSF bridge under Existing Conditions

(Yellow line shows existing levee alignment)

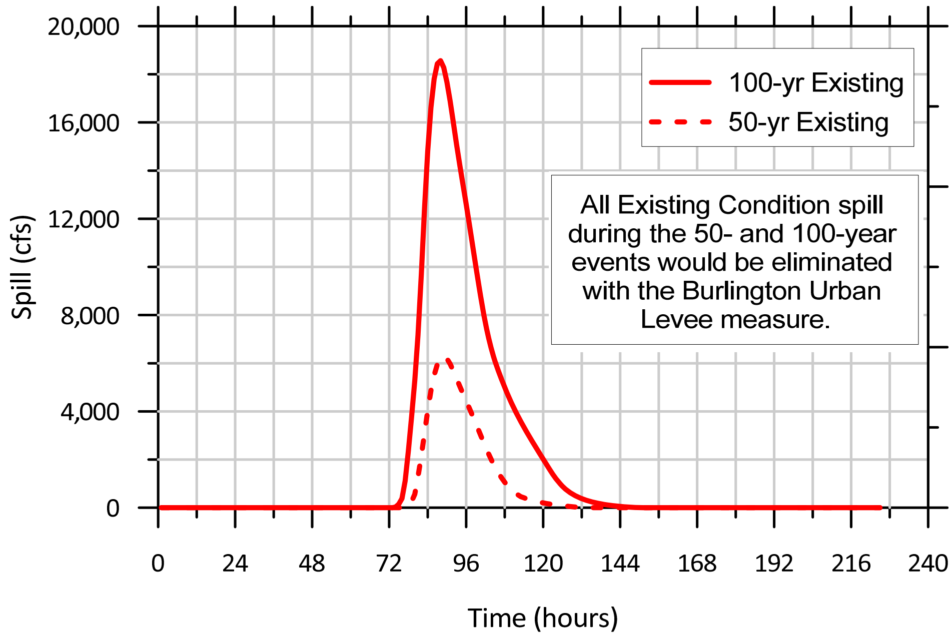

Figure 5: Spill Hydrographs at DD12 Levees Upstream from the BNSF Bridge for Existing Condition

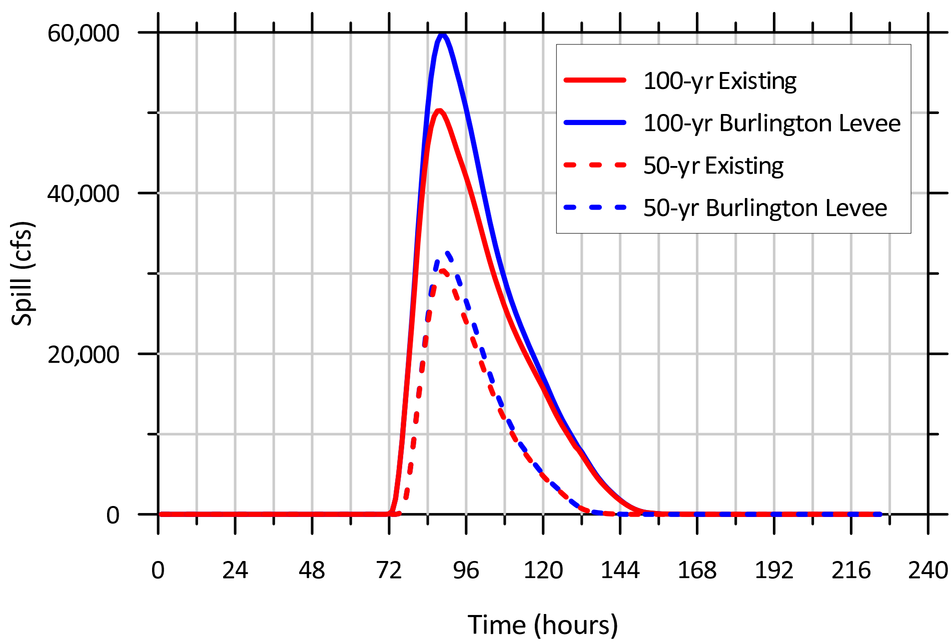

Figure 6: Spill Hydrographs at Sterling for Existing Condition and Burlington Urban Levee measure

4.5 Three Bridge Corridor Improvements (3 BRD w mods, 3 BRD w/o mods)

The objective of this measure is to improve conveyance through the Three Bridge Corridor, where bridge abutments and levees encroach on the Skagit River channel, limiting the river to a channel width of 800 to 900 ft. The measure calls for pulling the levees back from the river by between about 100 and 300 ft on the left bank and between 300 and 400 ft on the right bank (Figure 7), and raising the levee crest elevation. The right bank levee setback forms part of the Burlington Urban Levee measure (see Section 4.4). Crest elevations and alignment for the right bank levee come from the Golder Associates study of the Burlington Urban Levee. Top elevations for the left bank levees are unchanged from existing conditions; the alignment comes from a report by Anchor QEA dated 08/03/2009. Two variations of this measure were analyzed: levee setbacks only, without modifications to the bridges or their abutments; and levee setbacks with bridge modifications.

The “without modifications” measure pulls back the levees between the bridges, but leaves the current bridges and their abutments in place. The reaches between the bridges are modeled with ineffective flow areas to account for expansion and contraction of flow between each abutment. Bridge geometries and debris loading on the BNSF bridge are as in the existing conditions analysis.

The “with modifications” measure assumes that all bridge abutments are pulled back the same distance as the levee setbacks and that the BNSF bridge is replaced. The main hydraulic difference is that the replacement bridge is assumed to be a cable-stayed structure with only one large pier in the channel instead of the 12 piers that support the current bridge. This would significantly reduce debris loads and increase downstream flows. The size of the debris blockage at the BNSF bridge for the 50- and 100-year floods is assumed to be reduced from 500 wide by 20 ft deep “without modifications” to 120 ft wide by 20 ft deep “with modifications”.

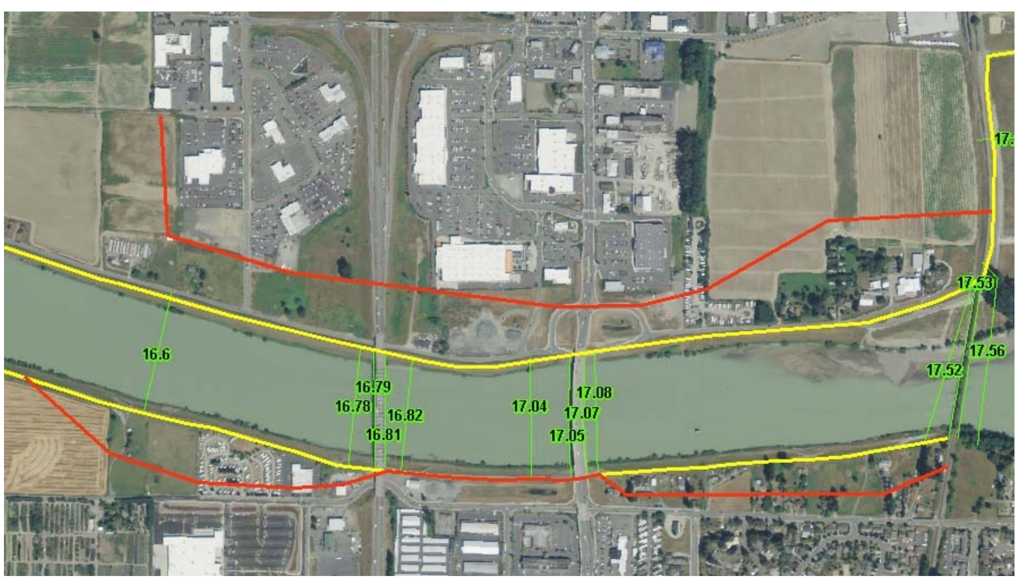

Figure 7: Alignment of the Three Bridge Corridor levees.
(Orange line shows proposed alignment; yellow line is existing alignment.)

It is likely that improvements in the ability to pass debris at the BNSF bridge will increase the risk of debris blockages developing at downstream bridges, however this effect is not considered in this report.

50-year Results:

For the "without modifications" measure, the improved conveyance in the Three Bridge Corridor results in an approximately 1,300 cfs increase in downstream peak flows on the mainstem Skagit and a corresponding minor increase in water levels. Upstream from the Three Bridge Corridor, there would be a slight decrease in water levels and a net reduction in spill from the system upstream from the BNSF bridge of about 1,600 cfs.

Impacts of the "with modification" measure are much more dramatic, with an approximately 13,300 cfs increase in downstream peak flow in the Three Bridge Corridor and a corresponding increase in peak water level in the Three Bridge Corridor of about 1.3 ft. The increased flow and water level results in an increase in spill from the system downstream from the Three Bridge Corridor, primarily a 3,500 cfs increase in left bank spill into Mount Vernon below Division Street and an approximately 1,800 cfs increase in left bank spill from the South Fork near Fisher Slough. The improved conveyance results in a reduction in upstream peak water levels in the vicinity of Sterling of about 0.8 ft and a net reduction in spill upstream from the BNSF bridge of close to 20,000 cfs.

100-year Results:

For the "without modifications" measure, the improved conveyance in the Three Bridge Corridor results in an approximately 1,900 cfs increase in downstream peak flows on the mainstem Skagit and a corresponding minor increase in water levels. Upstream from the Three Bridge Corridor, there would be a slight decrease in water levels and a net reduction in spill from the system upstream from the BNSF bridge of about 2,100 cfs.

Impacts of the "with modification" measure are much more dramatic, with an approximately 19,000 cfs increase in downstream peak flow in the Three Bridge Corridor and a corresponding increase in peak water levels in the Three Bridge Corridor of about 1.7 ft. The increased flow and water level results in an increase in spill from the system downstream from the Three Bridge Corridor, primarily a 6,900 cfs increase in left bank spill into Mount Vernon below Division Street and an approximately 2,700 cfs increase in total spill from the South Fork. The improved conveyance results in a reduction in upstream peak water levels in the vicinity of Sterling of about 0.4 ft and a net reduction in spill upstream from the BNSF bridge of about 22,600 cfs.

The construction of the Mount Vernon Flood Wall (Section 4.3) would prevent spill into Mount Vernon below Division Street for both the 50-year and 100-year events even under the "with modification" scenario, as can be seen from the Base Case (Section 4.6) simulation results presented in the performance matrices. Similarly, proposed setback levee crest elevations in the Three Bridge Corridor are sufficient to accommodate the increased flows downstream from the BNSF bridge under the "with modifications" measure for both the 50-year and 100-year events.

4.6 Base Condition Measures (BASE)

The Mount Vernon Floodwall, Burlington Urban Levee, and Three Bridge Corridor measure without bridge modifications are considered to have the greatest likelihood of implementation in the near to intermediate term. These three measures were assumed to define one of two “base conditions” for analysis of other measures (Figure 8). Note that the right bank levee setback under the Three Bridge Corridor measure forms part of the Burlington Urban Levee measure. For convenience of presentation, a second “base condition” was also assumed incorporating the Three Bridge Corridor measure **with** bridge modifications. However, it is recognized that bridge modifications are unlikely to be implemented in the near to intermediate term.

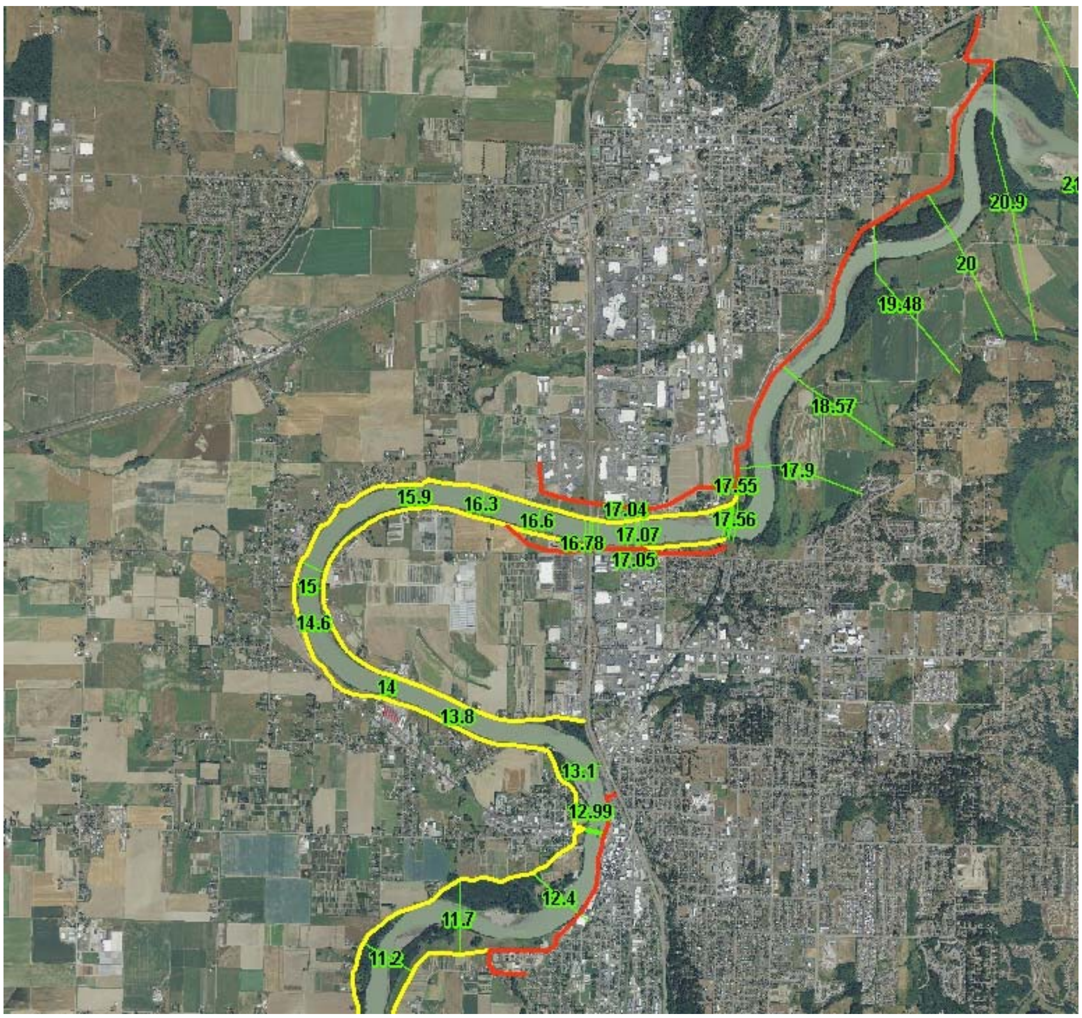

Figure 8: Base Condition measures.

(Orange line shows proposed alignment of new or improved levee; yellow line is existing alignment.)

The principal hydraulic impacts of implementing the Base Condition measures are due to elimination of spill from the right bank of the Skagit above the BNSF bridge into Burlington at about RM 18 and the conveyance improvements associated with replacement of the BNSF Bridge (and the reduction in bridge debris load) under the “with modifications” variant of the Three Bridge Corridor measure.

50-year Results:

The “without modifications” base condition results in an approximately 4,700 cfs increase in peak flows on the mainstem Skagit downstream from Mount Vernon and an increase in water levels of about 0.4 ft. Upstream from Burlington, there would be a slight increase in water levels and an increase in spill at Sterling of the order of 1,200 cfs.

The “with modification” base condition results in an approximately 12,000 cfs increase in peak flows on the mainstem Skagit downstream from Mount Vernon and an increase in water levels of about 0.9 ft. Upstream from Burlington, there would be a decrease in water levels around Sterling of about 0.5 ft and a decrease in spill at Sterling of the order of 10,000cfs.

100-year Results:

The “without modifications” base condition results in an approximately 10,500 cfs increase in peak flows on the mainstem Skagit downstream from Mount Vernon and an increase in water levels of about 0.8 ft. Upstream from Burlington, there would be a increase in water levels of about 0.3 ft in the Sterling area and an increase in spill at Sterling of the order of 8,400 cfs.

The “with modification” base condition results in an approximately 19,000 cfs increase in peak flows on the mainstem Skagit downstream from Mount Vernon and an increase in water levels of about 1.3 ft. Upstream from Burlington, there would be a slight decrease in water levels and a decrease in spill at Sterling of the order of 3,300cfs.

Spill hydrographs at Sterling for the existing and base conditions are shown in Figure 9.

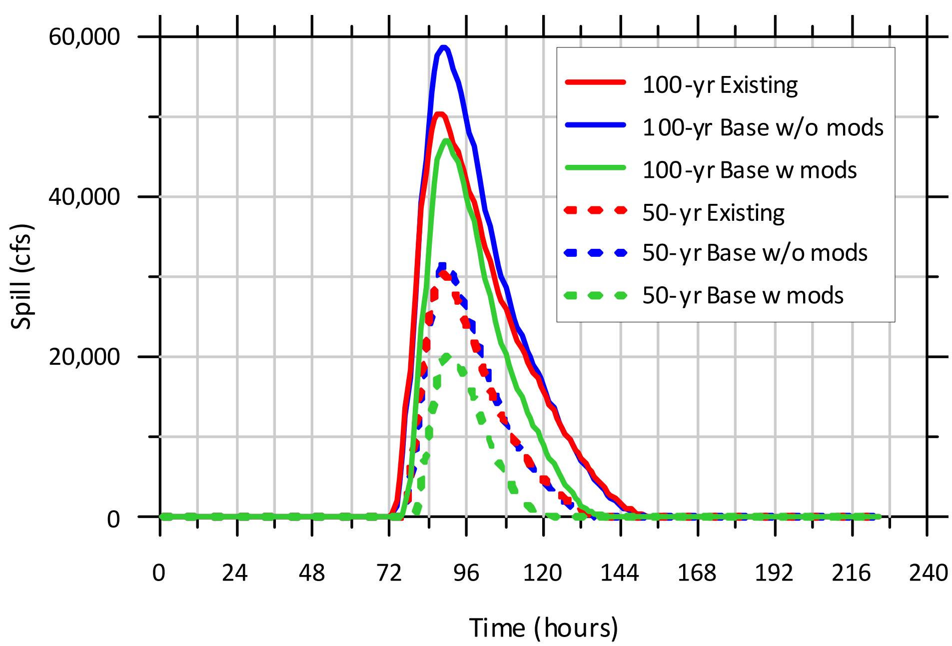

Figure 9: Spill Hydrographs at Sterling for Existing and Base Conditions

4.7 Nookachamps Storage (NKCHMPs)

The Nookachamps Storage measure would regulate use of the flood storage available in the Nookachamps basin in a manner that provides greater flood reduction benefits than under current conditions. The measure consists of a levee with inlet and outlet control structures on the left bank floodplain of the Skagit River extending downstream from SR-9. The levee would prevent rising limb flood flows from entering the Nookachamps basin, thereby reserving flood storage until nearer to the peak of the flood. At that point a gate structure would open and begin to divert flow from the river into the Nookachamps area, in effect clipping off the peak of the flood.

Two levee alignments were evaluated that result in different (low and high) flood storage volumes (Figure 10). Flood storage available below elevation 50 ft NAVD88 is 51,300 acre feet and 79,200 acre feet for the low and high storage alignments respectively. Levee crest elevations were set to ensure no overtopping occurred; all flow into and out of the Nookachamps basin was through gates. The high storage volume alignment assumes a levee built from near the BNSF bridge upstream to the SR-9 bridge. The levee is set back 500 feet from the river to allow for a riparian buffer and to reduce the risk of channel migration and erosion forces on the levee. The low storage volume levee is set farther back and excludes the area downstream of the confluence of Nookachamps Creek and the Skagit River.

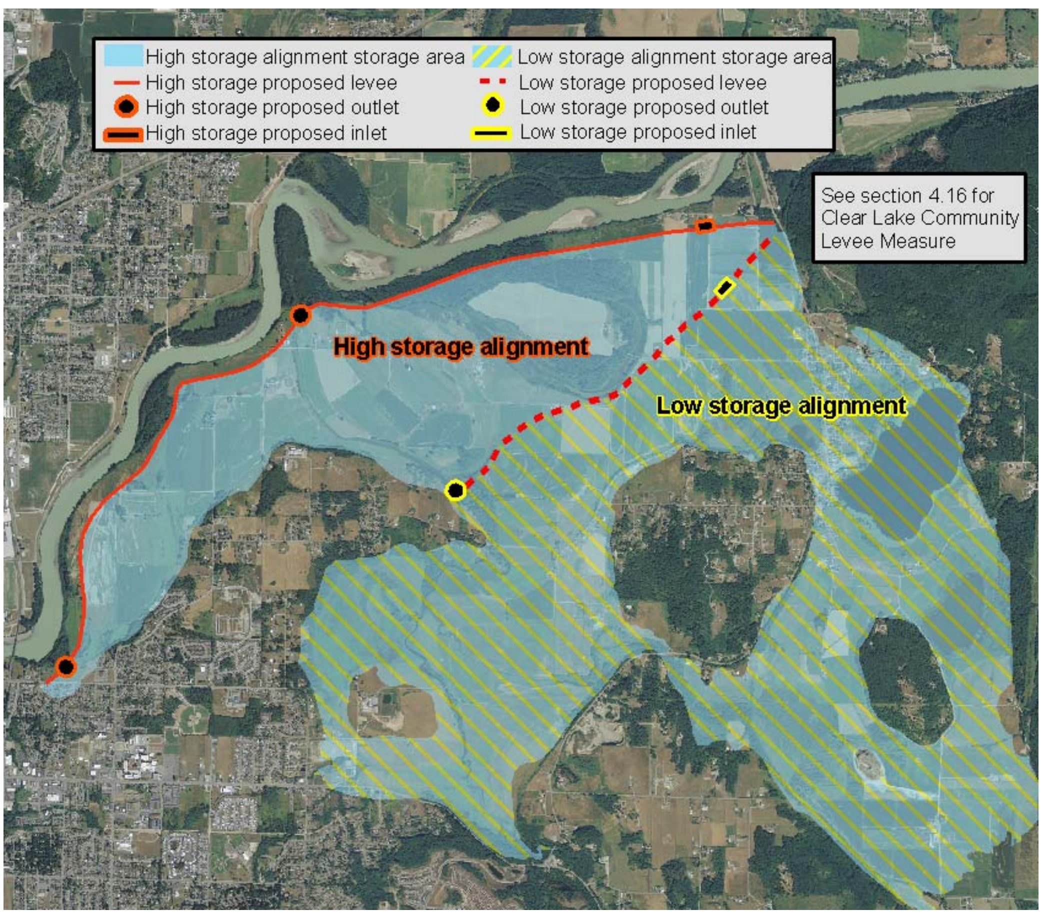

Figure 10: Nookachamps storage areas.

For each levee alignment, three different inlet gate structure configurations were evaluated, with small, medium and large gate openings. The mid range gate configuration was taken from previous work by PIE and consisted of 11 fuse gates with a total width of 550 feet and height of 10 feet. The gate inverts were set at 27 feet. The gates were set to open when riverside water surface elevations reached 49 feet, which corresponds to a flow at Sedro-Woolley ranging from about 167,000 cfs for the high storage option to 181,000 cfs for the low storage option. The lower threshold flow for storage with the high storage option arises because under that option, the levee alignment confines flows in the mainstem channel resulting in an increased stage for a given mainstem discharge; hence spill into the Nookachamps occurs for a lower mainstem discharge. Total gate widths 50% larger and smaller were also simulated with the same invert and gate opening elevation.

Outlet structures with a total opening of 100 by 20 feet were assumed for each levee alignment. To simplify modeling, a single outlet structure was assumed for each alignment however in practice multiple outlets would likely be required for the high storage alignment as shown in Figure 10. The outlet structures were modeled with flap gates to prevent reverse flow into the Nookachamps area when the Skagit River was higher than the Nookachamps. All variants were modeled with the "Base Conditions" measures, with and without bridge modifications.

Results:

Table 4 shows the performance of the Nookachamps Storage measures in term of change in water surface elevation at various locations relative to the Base Conditions for the 100-year flood for all combinations of levee alignments and gate sizes. The following conclusions are drawn:

- The differences in performance due to varying inlet gate sizes for a fixed levee alignment are much smaller (typically 0.1 - 0.2 ft) than the differences due to varying levee alignment (and consequent flood storage volumes) which are in the 1.3 - 1.5 foot range for downstream locations.
- The small inlet gate variant is the most effective measure, both in terms of maximizing downstream water level reduction and minimizing water level increases in the Nookachamps area.

Table 4: Change in 100-yr WSEL for the Nookachamps Storage measures relative to the Base Condition (ft)

	Low Storage						**High Storage**					
	without Bridge Modifications			**with Bridge Modifications**			**without Bridge Modifications**			**with Bridge Modifications**		
Location	Small Gates	Medium Gates	Large Gates	Small Gates	Medium Gates	Large Gates	Small Gates	Medium Gates	Large Gates	Small Gates	Medium Gates	Large Gates
RM 17.04 (USGS Gage)	-0.45	-0.36	-0.31	-0.61	-0.48	-0.44	-1.89	-1.72	-1.63	-2.00	-1.85	-1.76
RM 17.56 (u/s BNSF Bridge)	-0.43	-0.35	-0.3	-0.67	-0.52	-0.48	-1.76	-1.61	-1.53	-2.17	-2.00	-1.91
RM 22 (Harts Slough)	-0.19	-0.11	-0.03	-0.30	-0.16	-0.12	0.04	0.20	0.29	0.07	0.22	0.32
Nookachamps Basin	0.28	0.51	0.74	0.62	0.70	0.69	0.40	0.82	0.92	0.43	0.86	0.97

Based on this finding, the results presented in the performance matrices and in the following discussion refer to the small inlet gate variant only.

50-yr Results without Bridge Modifications

Under the low storage variant, flood levels in the Nookachamps basin are reduced by about 0.9 feet relative to the Base Condition. Downstream peak flows are reduced by about 5,000 cfs, resulting in a reduction in downstream peak water levels of about 0.5 ft.

With the high storage variant, Nookachamps basin flood levels are reduced by about 0.5 feet relative to the Base Condition. Downstream peak flows are reduced by approximately 19,000 cfs, resulting in flood level reductions of between 1.4 and 2.0 feet depending on location.

50-yr Results with Bridge Modifications

Under the low storage variant, flood levels in the Nookachamps basin are increased by 1.3 feet relative to the Base Condition. Downstream peak flows and water levels are essentially unchanged.

With the high storage variant, Nookachamps basin flood levels are reduced by about 1.0 foot relative to the Base Condition. Downstream peak flows are reduced by approximately 15,500 cfs, resulting in flood level reductions between 1.1 and 1.8 feet depending on location.

100-yr Results without Bridge Modifications

Under the low storage variant, flood levels in the Nookachamps basin are increased by 0.3 feet relative to the Base Condition. Downstream peak flows are reduced by about 5,700 cfs, resulting in a reduction in downstream peak water levels of about 0.5 feet or less.

With the high storage variant, Nookachamps basin flood levels are increased by 0.4 feet relative to the Base Condition. Downstream peak flows are reduced by approximately 19,000 cfs, resulting in flood level reductions of between 1.3 and 1.9 feet depending on location.

100-yr Results with Bridge Modifications

Under the low storage variant, flood levels in the Nookachamps basin are increased by 0.6 feet relative to the Base Condition. Downstream peak flows are reduced by about 6,500 cfs, resulting in a reduction in flood levels of between 0.3 and 0.7 feet.

With the high storage variant, Nookachamps basin flood levels are increased by 0.4 feet relative to the Base Condition, and downstream peak flows are reduced by approximately 20,000 cfs, resulting in flood level reductions of between 1.2 and 2.2 feet depending on location.

Other Results

The Nookachamps Storage measure as currently configured is effective in reducing downstream water levels in all cases, however water levels in the Nookachamps basin are increased under the 100-year flood. In addition, in-channel water surface elevations at the upper end of the Nookachamps reach (just downstream of the SR-9 bridge) are increased above Base Conditions in all cases. The measure steepens the water surface profile between Sedro-Woolley and the BNSF bridge in Burlington, resulting in an increase in water level at the upstream end and a decrease at the downstream end of the Nookachamps reach.

Flood levels in the area of greatest spill at Sterling are generally reduced, resulting in a reduction in peak spill rates. However, the duration of spill at Sterling is increased because the measure prevents early usage of the Nookachamps basin for flood storage and keeps flows higher longer on the receding limb of the flood hydrograph. Under the high storage variant, this results in greater volumes of spill at Sterling than under the Base Condition for both the 50-year and 100-year events. Spill hydrographs at Sterling for the Base Condition and the low storage and high storage Nookachamps measures are provided for 50-year events in Figures 11 and 12 and for 100-year events in Figures 13 and 14.

Note that the community of Clear Lake lies on the eastern edge of the Nookachamps basin. A separate community levee measure for protection of Clear Lake is discussed in Section 4.16.

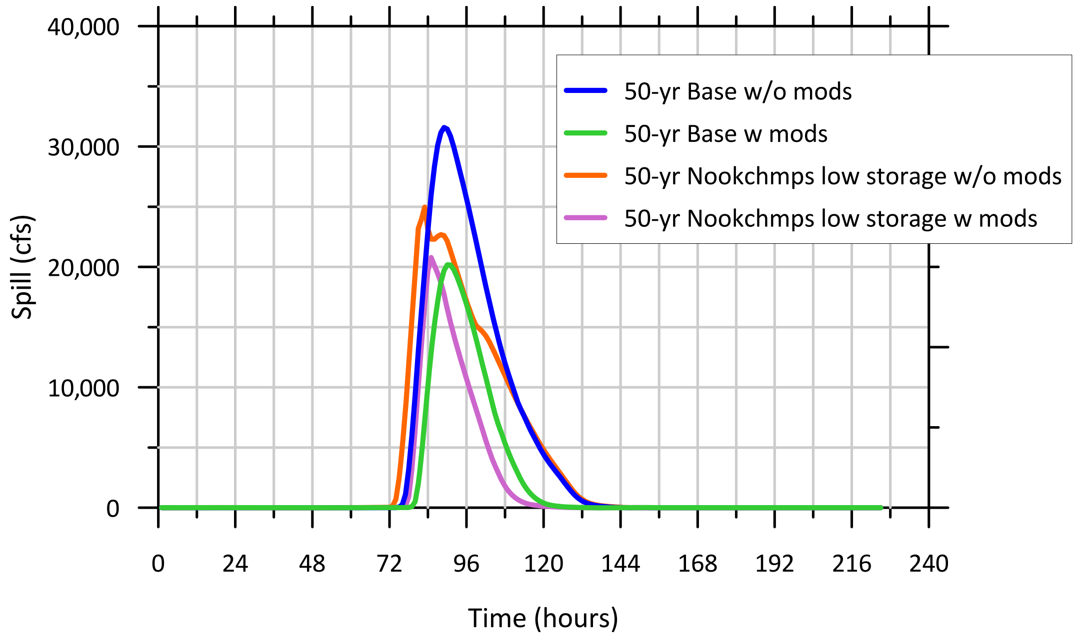

Figure 11: 50-Year Spill Hydrographs at Sterling for Base Condition and Nookachamps low storage measures

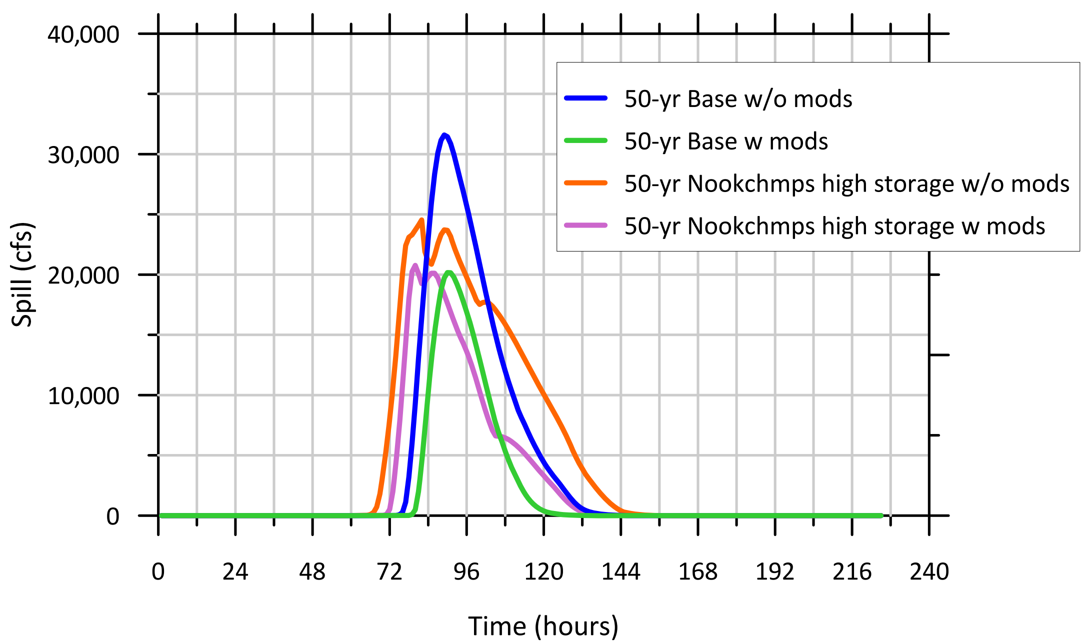

Figure 12: 50-Year Spill Hydrographs at Sterling for Base Condition and Nookachamps high storage measures

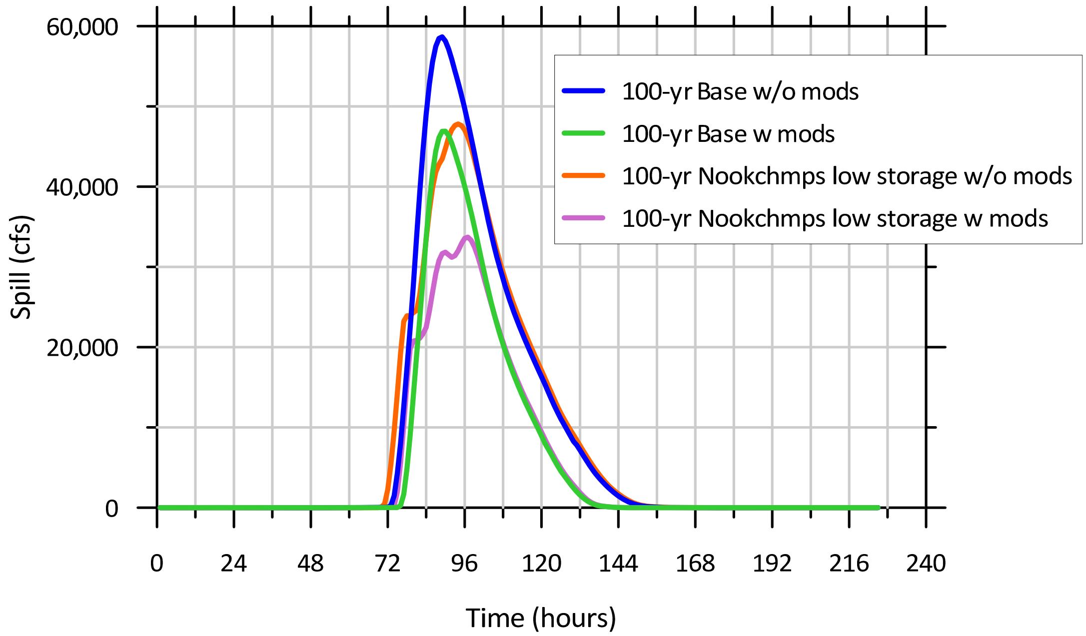

Figure 13: 100-Year Spill Hydrographs at Sterling for Base Condition and Nookachamps low storage measures

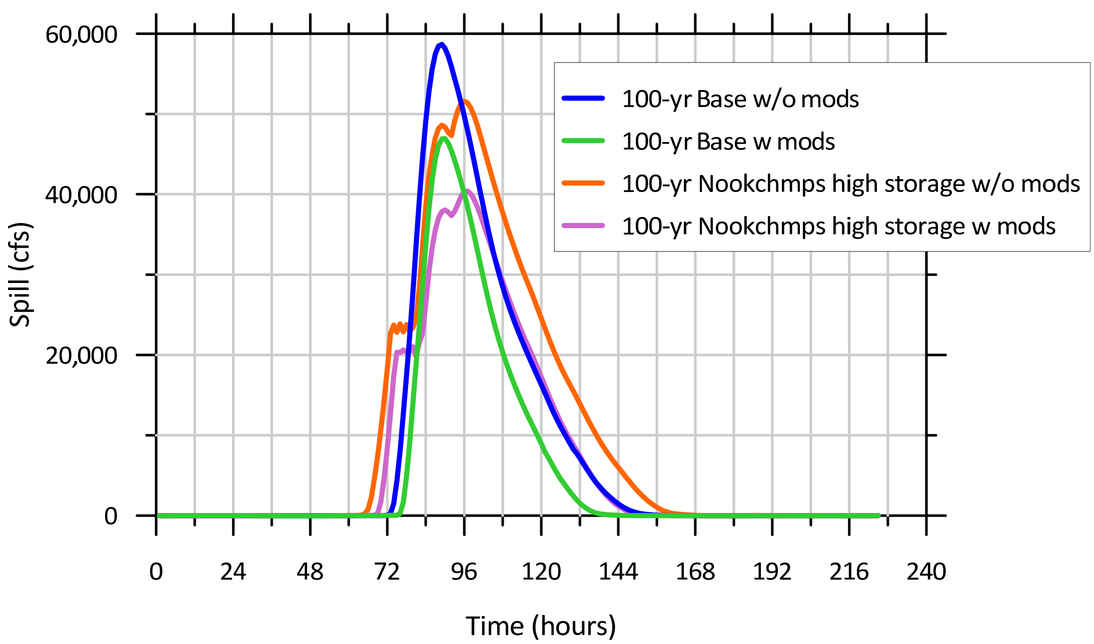

Figure 14: 100-Year Spill Hydrographs at Sterling for Base Condition and Nookachamps high storage measures

4.8 North Mount Vernon (Riverbend) Levee (RIVERBND)

The purpose of the North Mount Vernon Levee is to prevent spill from the Riverbend area into Mount Vernon. The measure comprises a levee (or flood wall) along a proposed north-south alignment through the Riverbend immediately west of Wal-Mart and approximately following the Mount Vernon urban growth area boundary (Figure 15). The levee would tie into existing or future structures at the upstream and downstream ends. From preliminary modeling results, the levee would have a minimum crest elevation of approximately 40.5 feet plus freeboard, with higher elevations at its north end where it transitions into the existing levee or future Three Bridge Corridor setback levee.

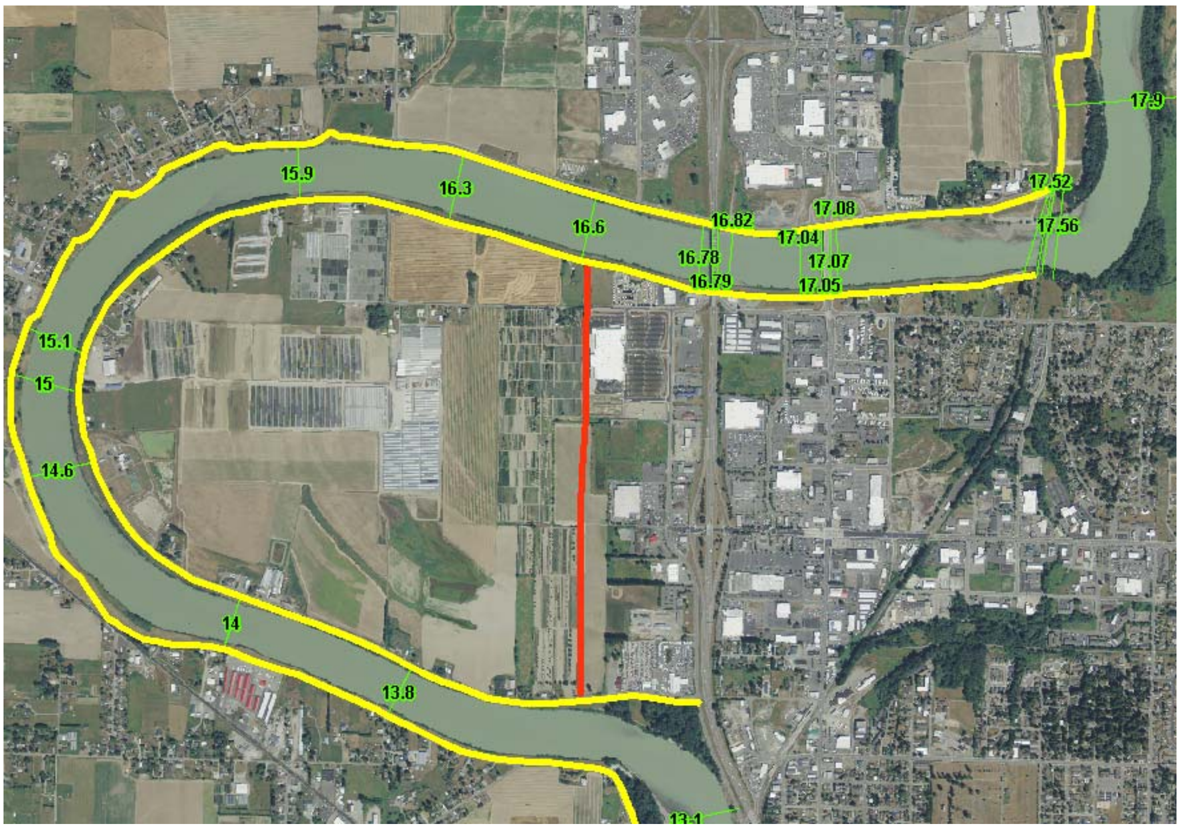

Figure 15: North Mount Vernon Levee.

(Orange line shows proposed alignment, yellow line shows existing levees.)

Because the existing Riverbend levees are not overtopped during the 50- or 100-year events considered for this analysis, the effect of this measure was analyzed by first assuming an “existing condition” with a 300 ft wide levee breach on the left bank downstream of the Three Bridge Corridor, causing flow into the Riverbend area. A portion of this water then flows east across Interstate-5 into North Mount Vernon and the remainder spills back into the Skagit River over the levees at the downstream end of the Riverbend. The measure is intended to protect Mount Vernon under this scenario.

For modeling purposes, the performance of the North Mount Vernon Levee was analyzed with the Base Condition measures in place, with and without bridge modifications in the Three Bridge Corridor.

50-year Results:

Under the existing condition for a 50-year event and with the assumed levee breach, a maximum of about 13,500 cfs would flow into the Riverbend storage area, of which 9,400 cfs would cross I-5 into North Mount Vernon. Water surface elevations in both the Riverbend and North Mount Vernon storage areas reach 39.6 feet. With the measure in place, all flow into North Mount Vernon is cut off, resulting in a maximum water surface elevation in the Riverbend storage area of 40.1 feet without Three Bridge Corridor bridge modifications, and 40.2 feet with bridge modifications.

100-year Results:

Under the existing condition for a 100-year event and with the assumed levee breach, a maximum of about 15,800 cfs would flow into the Riverbend storage area, of which 8,200 cfs would cross I-5 into North Mount Vernon. Water surface elevations in both the Riverbend and North Mount Vernon storage areas reach 39.9 feet. With the measure in place, all flow into North Mount Vernon is cut off, resulting in a maximum water surface elevation in the Riverbend storage area of 40.3 feet without Three Bridge Corridor bridge modifications, and 40.5 feet with bridge modifications.

4.9 Sterling Levee (STERL)

The Sterling Levee is intended to reduce spill from the right bank of the Skagit in the Sterling area. Spill at Sterling flows north across SR-20 and then spreads both west, following the general course of Gages Slough to flood Burlington, and north. An alignment for the Sterling Levee has not been agreed upon and is immaterial from the point of view of the hydraulic effectiveness of the measure. The alignment shown in Figure 16 following SR-20 is one of several possible alignments and is included for illustrative purposes only.

The amount of spill at Sterling is very sensitive to the assumed debris load on the BNSF bridge. As with all analyses presented in this report, the average debris load is assumed. For modeling purposes, the Sterling Levee was set to existing spill elevations (under existing conditions, spill is controlled partly by SR-20 and partly by high ground to the north of SR-20), but with a minimum elevation of 48.5 ft NAVD88. This elevation, determined from the hydraulic model results, prevents spill during the 50-year **existing** condition peak flow with no freeboard and is consistent with the stated objective of providing less than 100-year flood protection to rural areas.

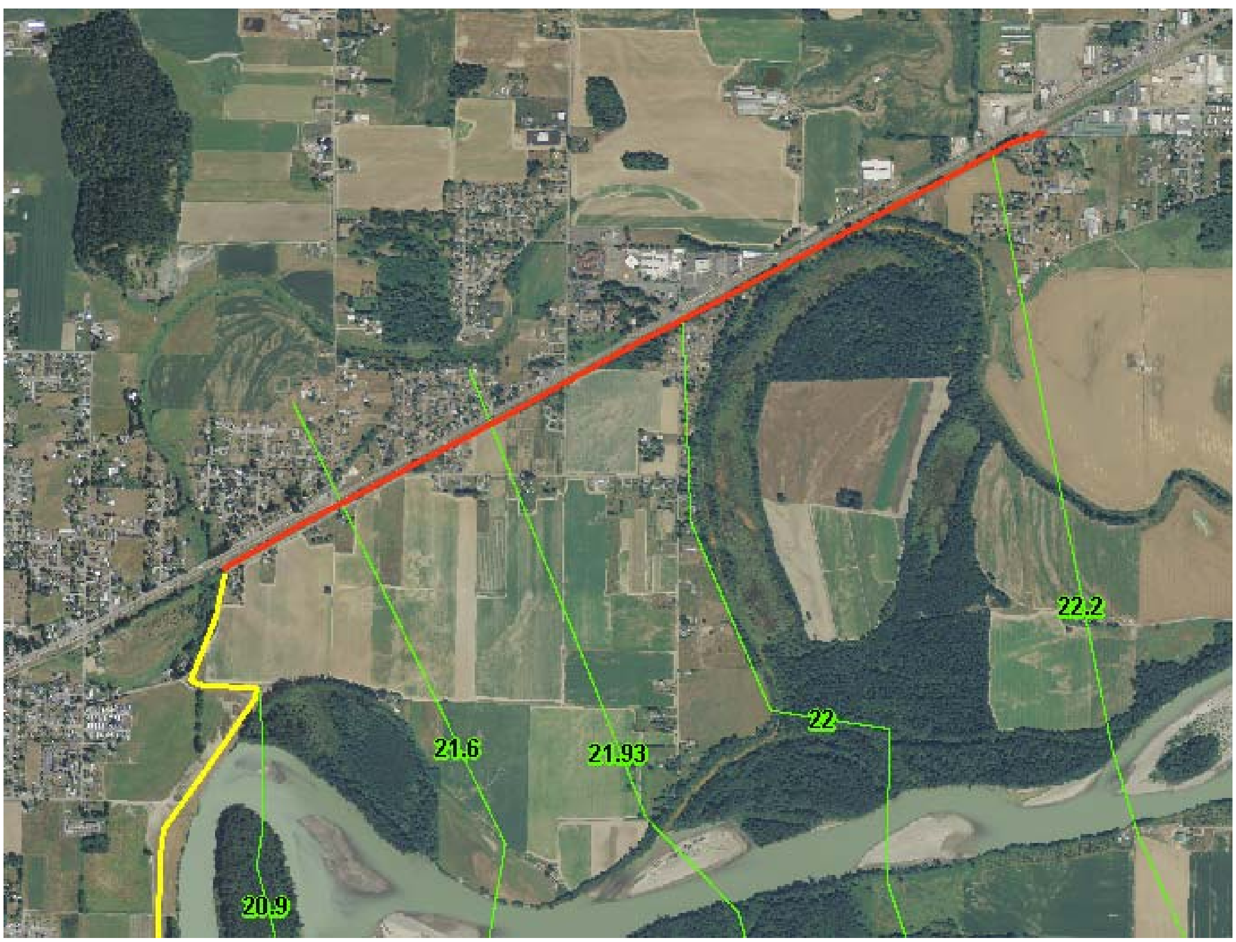

Figure 16: Assumed Sterling Levee alignment.

(Orange line shows assumed Sterling Levee alignment, yellow line shows existing DD12 levee alignment.)

Details of the performance of the Sterling Levee measure are provided in the summary matrices. Comparison should be made against the "Base Condition" modeling results.

50-year Results without Bridge Modifications:

Relative to the Base Condition without bridge modifications, the Sterling measure reduces the peak spill rate at Sterling by about 26,500 cfs from 31,600 cfs to 5,100 cfs. The levee height for the Sterling measure was set to the **existing** condition 50-year elevation. This is slightly lower than the 50-year elevation for the Base Condition without bridge modifications, hence spill is not completely eliminated during the 50-year event.

Water levels in the Sterling area are increased by about 1.5 ft. Peak flows on the mainstem Skagit downstream from the Three Bridge Corridor are increased by about 16,500 cfs. Maximum water levels are increased by 1.7 ft in the Three Bridge Corridor with somewhat smaller increases as one moves downstream. The increased peak flow and water levels result in overtopping of levees downstream from the Three Bridge Corridor at a number of locations, with a combined peak spill into the floodplain below the Three Bridge Corridor of about 8,500 cfs compared with 3,900 cfs under the Base Condition without Bridge Modifications.

50-year Results with Bridge Modifications:

The Sterling measure eliminates spill during the 50-year event for this condition. Spill at Sterling for this condition without the Sterling measure is 20,200 cfs.

Water levels in the Sterling area are increased by about 1.2 ft. Peak flows on the mainstem Skagit downstream from the Three Bridge Corridor are increased by about 10,300 cfs. Maximum water levels are increased by 1.0 ft in the Three Bridge Corridor with somewhat smaller increases as one moves downstream. The increased peak flow and water levels result in overtopping of levees downstream from the Three Bridge Corridor at a number of locations with a combined peak spill into the floodplain below the Three Bridge Corridor of about 9,200 cfs, compared with 5,300 cfs under the Base Condition with Bridge Modifications.

100-year Results without Bridge Modifications:

Spill at Sterling is reduced by about 28,700 cfs during the 100-year event for this condition from about 58,700 cfs to 29,900 cfs.

Water levels in the Sterling area are increased by about 1.4 ft. Peak flows on the mainstem Skagit in the Three Bridge Corridor are increased by about 30,300 cfs. Maximum water levels are increased by 2.2 ft in the Three Bridge Corridor with progressively smaller increases further downstream as water is lost from the channel due to spill. With the increased peak flows, levees are overtopped at a number of locations downstream from the Three Bridge Corridor, with a combined peak spill into the floodplain below the Three Bridge Corridor of about 27,700 cfs, compared with 6,400 cfs under the Base Condition without Bridge Modifications.

100-year Results with Bridge Modifications:

Spill at Sterling is reduced by about 26,100 cfs during the 100-year event for this condition from about 46,900 cfs to 20,800 cfs.

Water levels in the Sterling area are increased by about 1.5 ft. Peak flows on the mainstem Skagit in the Three Bridge Corridor are increased by about 23,500 cfs. Maximum water levels are increased by 1.5 ft in the Three Bridge Corridor with progressively smaller increases further downstream as water is lost from the channel due to spill. With the increased peak flows, levees are overtopped at a number of locations downstream from the Three Bridge Corridor, with a combined peak spill into the floodplain below the Three Bridge Corridor of about 30,000 cfs, compared with 10,600 cfs under the Base Condition with Bridge Modifications.

Spill hydrographs at Sterling for the 100-year event for the Base Condition and Sterling Levee measures are shown in Figure 17.

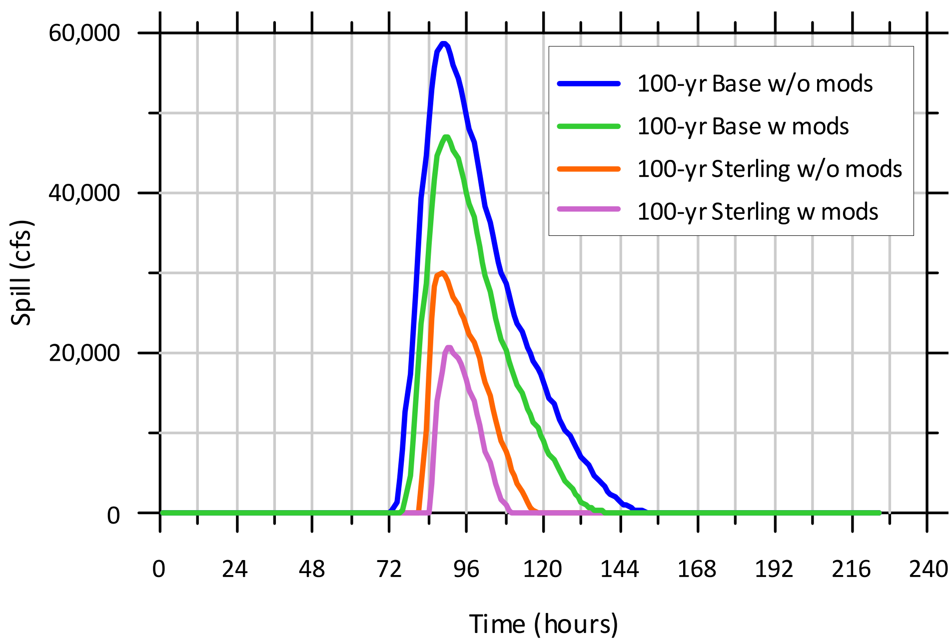

Figure 17: Spill Hydrographs at Sterling for Base Condition and Sterling Levee Measures

4.10 East Mount Vernon Levee

The East Mount Vernon Levee is intended to prevent floodwater from backing up into Mount Vernon from the left bank Skagit floodplain immediately downstream from Mount Vernon. Except in the Nookachamps and Riverbend areas, floodplain flows and floodplain inundation for the study are modeled using FLO-2D. Since work in this report is restricted to analyses using HEC-RAS, focusing on discharges and water levels in the mainstem Skagit and the North and South Forks, analysis of the impacts of the East Mount Vernon Levee has been deferred to a future study phase.

4.11 Improve Existing Levees

This measure considers levee improvements downstream from the Three Bridge Corridor.

It is envisaged that levees in urban areas will be improved to provide 90% assurance of containing the 100-year flood. That is, given uncertainties in discharge estimates, channel roughness, and debris impacts, there would be a remaining 10% chance of levees being overtopped in a 100-year event. Levees in rural area will be improved to provide a lesser level of protection which would not allow FEMA certification.

No geotechnical aspects of levee design and performance are considered in this report, thus the focus of analysis here is solely on the levee profile required to prevent overtopping at required design flows.

The design flow for a given level of protection however depends on assumptions regarding implementation of upstream measures and assumptions regarding upstream spill (notably at Sterling) and bridge debris loads (at the BNSF bridge), neither of which are known with certainty.

For the measures considered in this report, the 100-year peak discharge in the Three Bridge Corridor (at the USGS gage site) is estimated to range from 142,100 cfs for the Base Condition without bridge modifications with the high volume Nookachamps Storage measure, to 194,400 cfs for the Base Condition with bridge modifications with the Sterling Levee measure.

Accordingly, water surface profiles were determined for mainstem peak flows of 143,000 cfs, 167,000 cfs, and 206,000 cfs, covering the range of flows of potential interest. Water surface profiles and existing top of levee profiles, showing locations where the levee crest elevation would need to be raised, are shown in Figures 18 through 23, and the results are summarized in Table 5. Note that no freeboard has been applied to the water surface profile as would be required to determine levee crest elevations for the purpose of FEMA levee system accreditation.

Table 5: Locations where levee crest elevations would need to be raised under Improve Existing Levees measure

Reach	Locations (by River Mile) where levee crest elevations would need to be raised to contain flow of:					
	143,000 cfs		167,000 cfs		206,000 cfs	
	left bank	right bank	left bank	right bank	left bank	right bank
Mainstem	RM 12.5 to 13	RM 18 to 18.5 and RM 21 to 22 (DD12 and Sterling)	RM 12 to 13	RM 17.5 to 22 (DD12 and Sterling)	entire levee from confluence to BNSF bridge	entire levee from confluence to Sedro-Woolley bridge
North Fork	none	none	RM 8 to 9	none	from RM 4.5 to confluence	entire levee to confluence
South Fork	RM 4 to 4.5 (near Fisher Slough)	none	RM 3.5 to 4.5 (near Fisher Slough); and RM 6 to 8	minor raises (less than 1') throughout	entire levee to confluence	entire levee to confluence

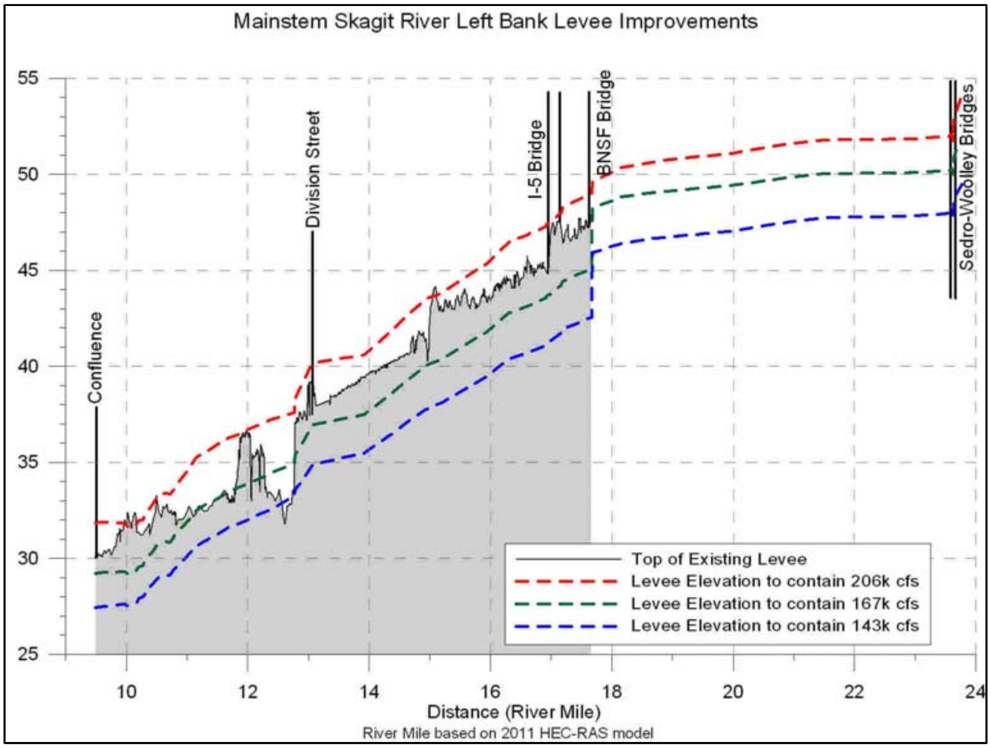

Figure 18: Levee improvement elevations for mainstem left bank.

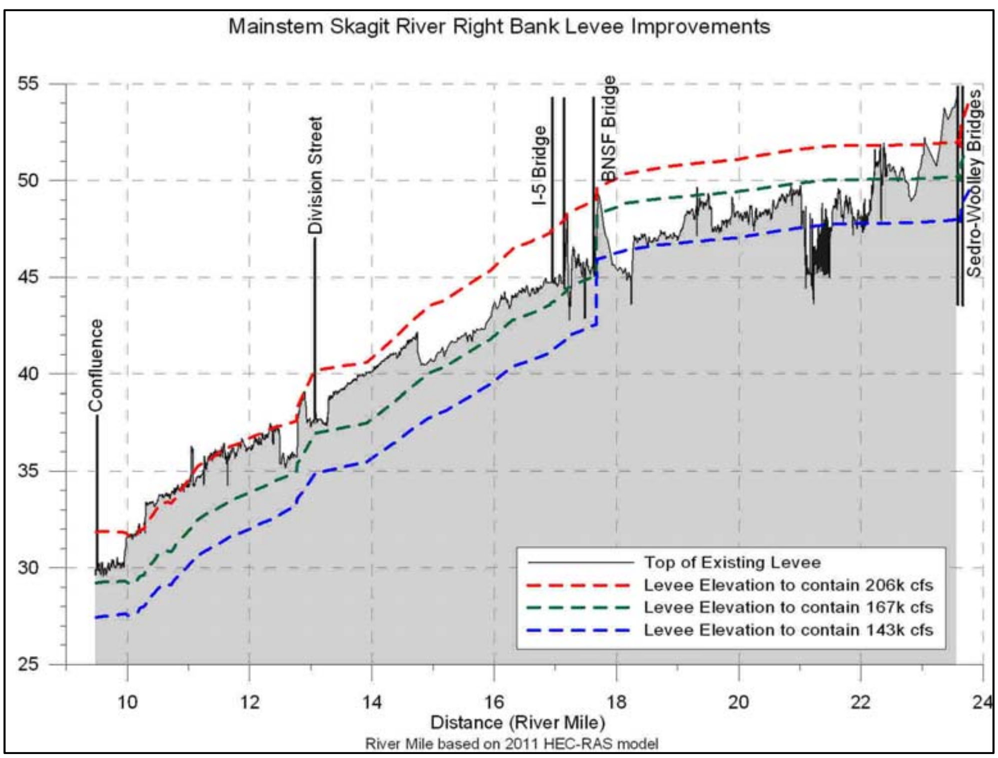

Figure 19: Levee improvement elevations for mainstem right bank.

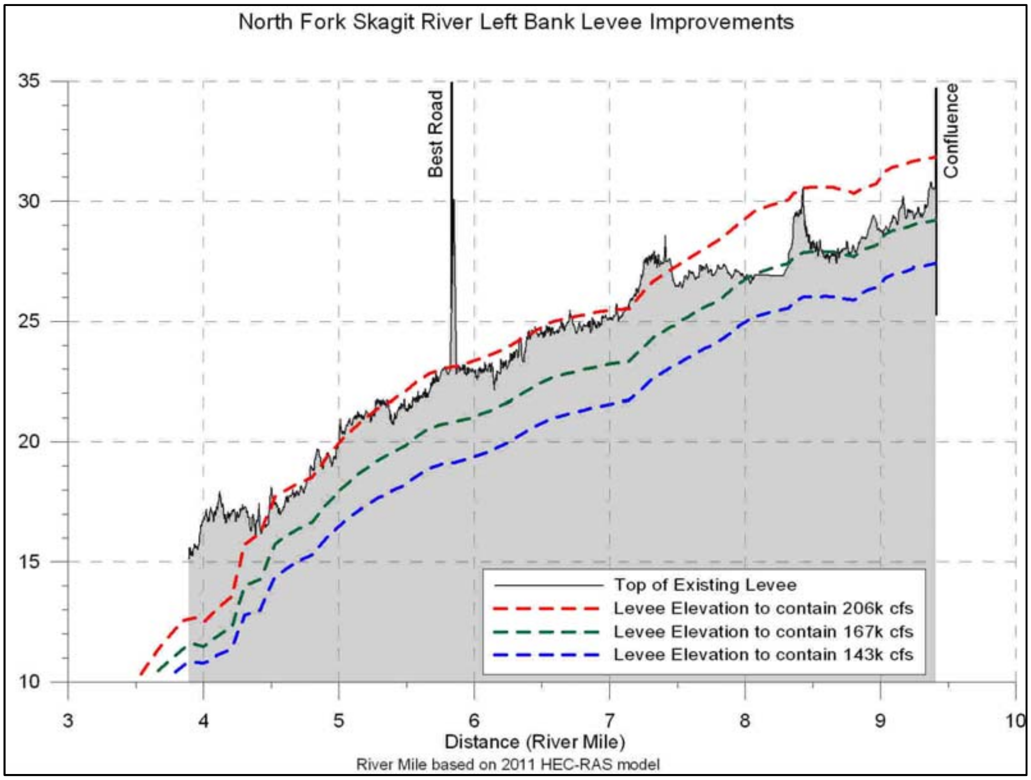

Figure 20: Levee improvement elevations for North Fork left bank.

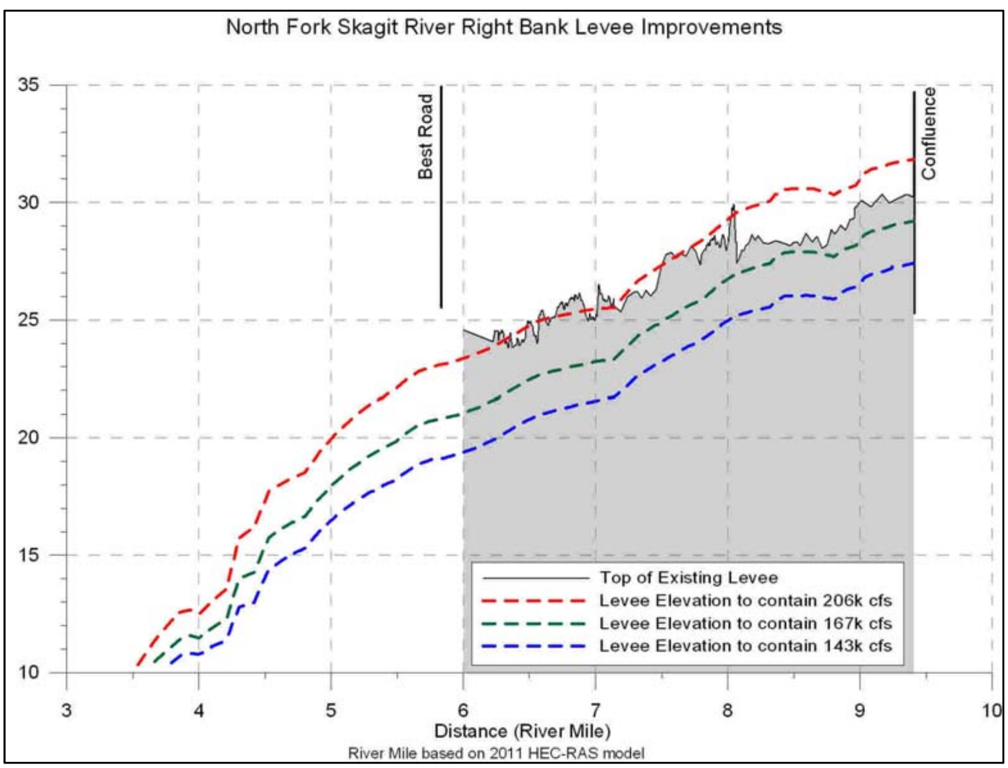

Figure 21: Levee improvement elevations for North Fork right bank.

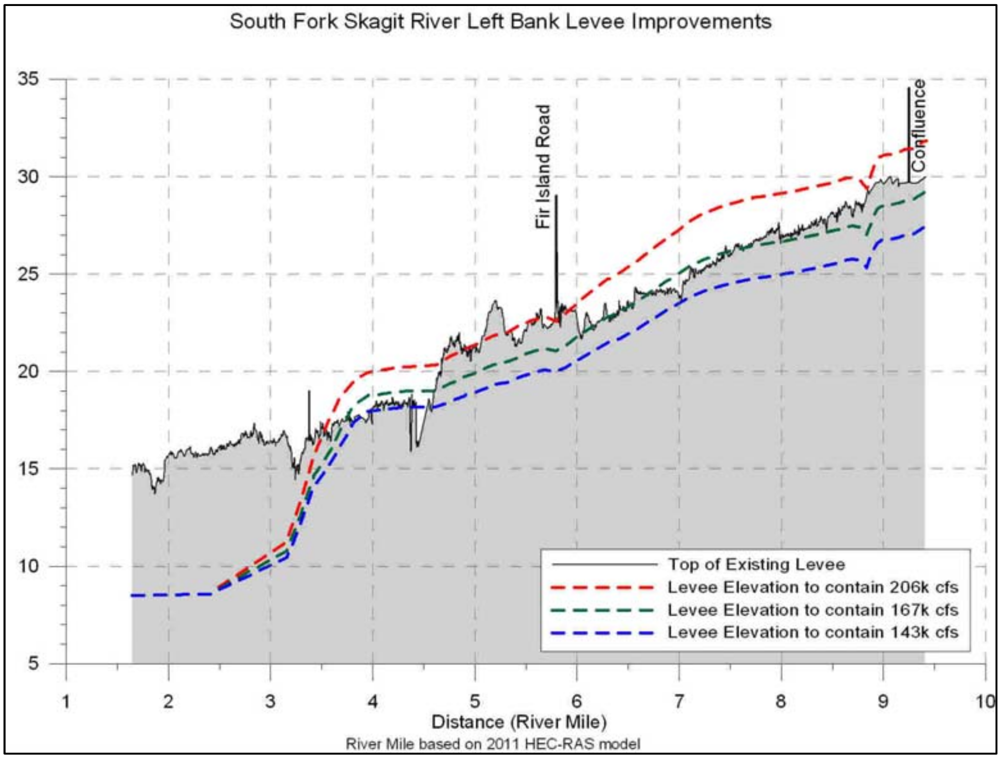

Figure 22: Levee improvement elevations for South Fork left bank.

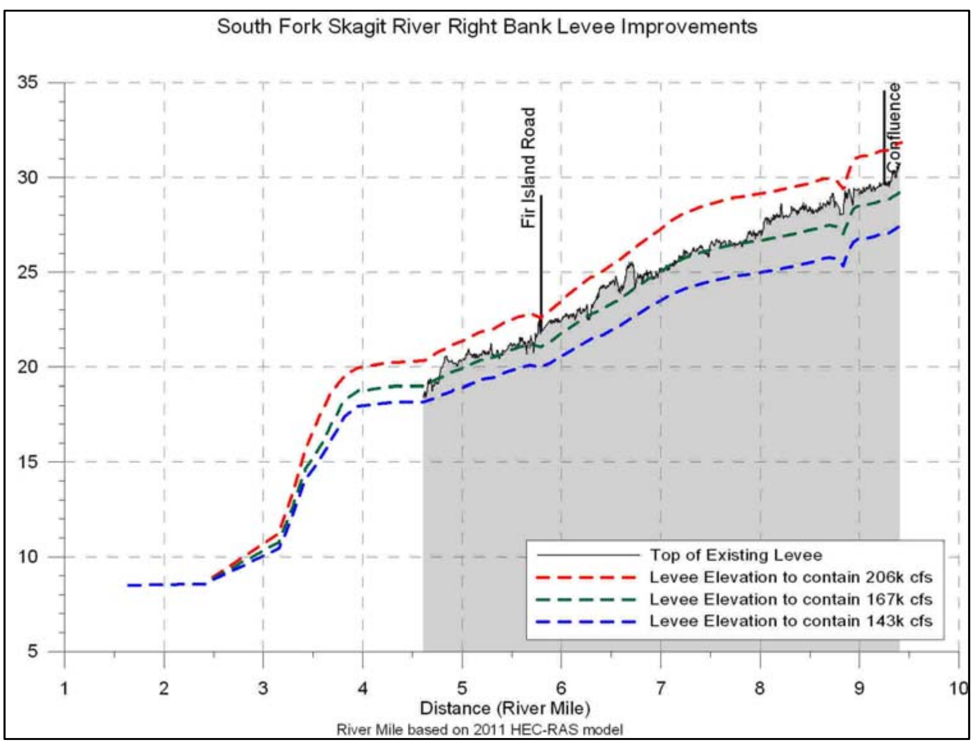

Figure 23: Levee improvement elevations for South Fork right bank.

4.12 Levee Setbacks (LEVSETBK)

The Levee Setback measure aims to improve flood conveyance throughout the Skagit River downstream of the Three Bridge Corridor. By setting levees back where required, this measure would provide a minimum corridor width between levees of approximately 1,500 feet from the Three Bridge Corridor down to the forks, and of approximately 1,000 feet down each fork. This is similar to the minimum corridor width targeted in previous analyses of levee setback measures considered by the USACE but in the present analysis, setbacks are only proposed where required to provide the minimum corridor width, as opposed to providing a fixed setback for the entire mainstem below the Three Bridge Corridor and along the North Fork, as was done in previous analysis.

Beginning at the Three Bridge Corridor, the current levee alignments were examined to identify areas where the distance between levees was significantly narrower than 1,500 feet on the mainstem or 1,000 feet on either fork. The appropriate cross-sections in the HEC-RAS model were then modified by setting levees back as needed to provide the target corridor width. Levees were setback on one bank only based on qualitative consideration of cost. Mainstem levees affected are on the right bank through Riverbend, past Division Street to just downstream of Edgewater Park; and on the right bank near the east terminus of Jungquist Road. On the North Fork, levees affected are on the left bank just downstream of the confluence and from Dry Slough Road downstream to the confluence with Skagit Bay. The only levee affected on the South Fork is on the right bank between Moore and Polson Roads. Figure 24 shows the areas where levees would be setback relative to existing alignments.

As with other measures, the levee setbacks were examined in comparison to a base condition with bridge modification and without bridge modifications and for both the 50-year and 100-year events.

50-year Results without Bridge Modifications:

Relative to the Base Condition without bridge modifications, the levee setback measure results in an increase in the mainstem 50-year peak flow of about 3,800 cfs from the Three Bridge Corridor downstream to the forks, and a change in peak water level varying from a 0.3 ft increase upstream from Division Street to a 0.5 ft decrease in the Three Bridge Corridor. The local increase in water level near Division Street is caused by a local constriction formed by the closed landfill on the right bank which we assume would not be removed under this measure. The impact of the measure extends upstream past Sterling where the peak water level is reduced by about 0.2 ft and spill is reduced by about 3,600 cfs. Downstream from the forks, the measure results in an increase in the peak flow on the North Fork of about 5,200 cfs along with an increase in peak water level of about 0.1 ft. On the South Fork, the peak flow is reduced by about 1,500 cfs and the peak water level is reduced by up to 0.2 ft, resulting in a reduction in spill from the South Fork of about 1,200 cfs.

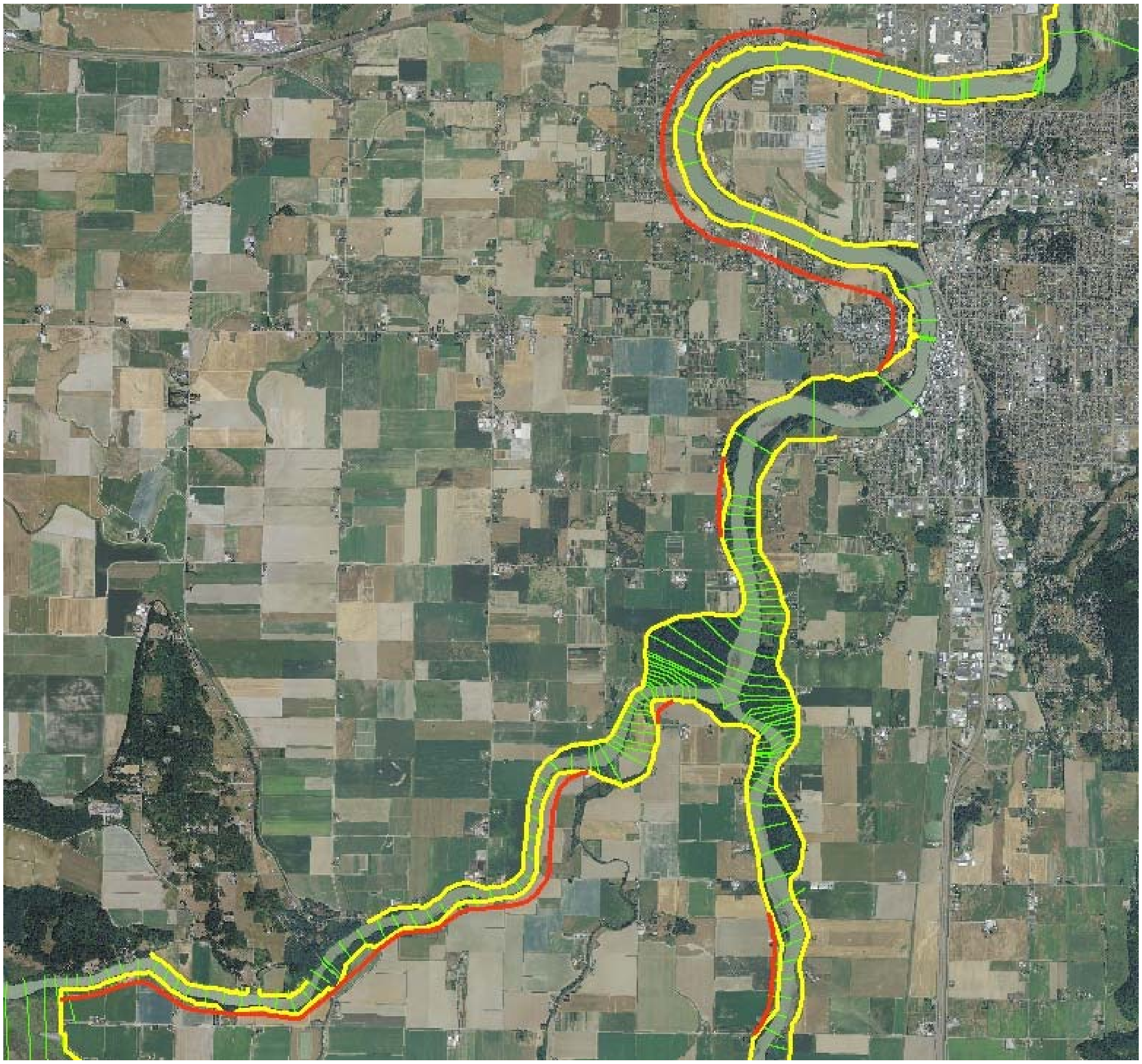

Figure 24: Levee Setbacks
(Orange lines show levee setbacks, yellow line shows current levee alignment)

50-year Results with Bridge Modifications:

Relative to the Base Condition with bridge modifications, the levee setback measure results in an increase in the mainstem 50-year peak flow of about 4,100 cfs from the Three Bridge Corridor downstream to the forks, and a change in peak water level varying from a 0.3 ft increase upstream from Division Street to a 0.6 ft decrease in the Three Bridge Corridor. The local increase in water level near Division Street is caused by a local constriction formed by the closed landfill on the right bank which we assume would not be removed under this measure. The impact of the measure extends upstream past Sterling where the peak water level is reduced by about 0.2 ft and spill is reduced by about 3,600 cfs. Downstream from the forks, the measure results in an increase in the peak flow on the North Fork of about 5,700 cfs along with an increase in peak water level of 0.1 to 0.2 ft. On the South Fork, the peak flow is reduced by up to 1,500 cfs and the peak water level is reduced by up to 0.2 ft, resulting in a reduction in spill from the South Fork of about 600 cfs.

100-year Results without Bridge Modifications:

Relative to the Base Condition without bridge modifications, the levee setback measure results in an increase in the mainstem 100-year peak flow of about 5,400 cfs from the Three Bridge Corridor downstream to the forks, and a change in peak water level varying from a 0.4 ft increase upstream from Division Street to a 0.5 ft decrease in the Three Bridge Corridor. The local increase in water level near Division Street is caused by a local constriction formed by the closed landfill on the right bank which we assume would not be removed under this measure. The impact of the measure extends upstream past Sterling where the peak water level is reduced by about 0.2 ft and spill is reduced by about 5,400 cfs. Downstream from the forks, the measure results in an increase in the peak flow on the North Fork of about 6,900 cfs along with an increase in peak water level of from 0.1 to 0.2 ft. On the South Fork, the peak flow is reduced by about 1,500 cfs and the peak water level is reduced by up to 0.2 ft, resulting in a reduction in spill from the South Fork of about 500 cfs.

100-year Results with Bridge Modifications:

Relative to the Base Condition with bridge modifications, the levee setback measure results in an increase in the mainstem 100-year peak flow of about 6,300 cfs from the Three Bridge Corridor downstream to the forks, and a change in peak water level varying from a 0.4 ft increase upstream from Division Street to a 0.6 ft decrease in the Three Bridge Corridor. The local increase in water level near Division Street is caused by a local constriction formed by the closed landfill on the right bank which we assume would not be removed under this measure. The impact of the measure extends upstream past Sterling where the peak water level is reduced by about 0.2 ft and spill is reduced by about 6,200 cfs. Downstream from the forks, the measure results in an increase in the peak flow on the North Fork of about 7,000 cfs along with an increase in peak water level of from 0.1 to 0.2 ft. On the South Fork, the peak flow is reduced by about 1,500 cfs and the peak water level is reduced by about 0.1ft, resulting in a modest reduction in spill from the South Fork.

4.13 Fir Island and Mount Vernon Bypasses (FIR BPS, FIR + MTV BPS)

The Fir Island Bypass would increase flood conveyance capacity at the downstream end of the system, with the objective of lowering water levels at the head of the North and South Forks, and increasing water surface slope and hence discharge through the mainstem Skagit downstream from the Three Bridge Corridor. To produce larger reductions in water levels upstream from Mount Vernon, the Fir Island Bypass measure was also analyzed in conjunction with the Mount Vernon Bypass measure. The Fir Island and Fir Island + Mount Vernon Bypass measures were both examined with the Base Condition measures in place, with and without bridge modifications in the Three Bridge Corridor. The following variants on the measures were considered:

- Fir Island Bypass:

  The Fir Island Bypass would divert flow from the left bank of the North Fork near RM 7.0. Diversions into the bypass would be controlled by a 1,000-ft long weir with a crest elevation of 15.0 ft (the approximate 2-year water surface elevation). The bypass itself would be a 2.9-mile long, 500-ft wide channel with an invert at existing ground elevations, which vary from around 10 ft at the upstream end to around 5 ft at the downstream end where the bypass would discharge into Skagit Bay. Levees on each side of the bypass would tie in to existing levees on the North Fork at the upstream end and to sea dikes at the downstream end.

- Fir Island Bypass + Mount Vernon Bypass:

  This variant combines the Fir Island Bypass with the Mount Vernon Bypass, which consists of a 500-ft wide, 0.8-mile long channel that begins near RM 13.7 (about 0.8 miles upstream from the Division Street bridge), flows south through West Mount Vernon, and rejoins the Skagit River near RM 11.7. Diversions in to the Mount Vernon Bypass would be controlled by a 1,000-ft long weir with crest elevation of 29.0 ft, a little higher than the existing 2-year water surface elevation. As with the other bypasses, the bypass invert would be at the existing ground elevation and the flow would be constrained by levees on each side of the bypass which tie in to existing levees at the upstream and downstream ends.

The bypass alignments considered are shown in Figures 25 and 26. Each variant was modeled with and without bridge modifications at the Three Bridge Corridor. It is envisaged that the design of the Fir Island Bypass measure would be integrated with the state Department of Fish and Wildlife Fir Island Farms restoration project[5]. The area of this proposed restoration project is shown on Figure 25.

[5] http://wdfw.wa.gov/lands/wildlife_areas/skagit/restoration_study.php

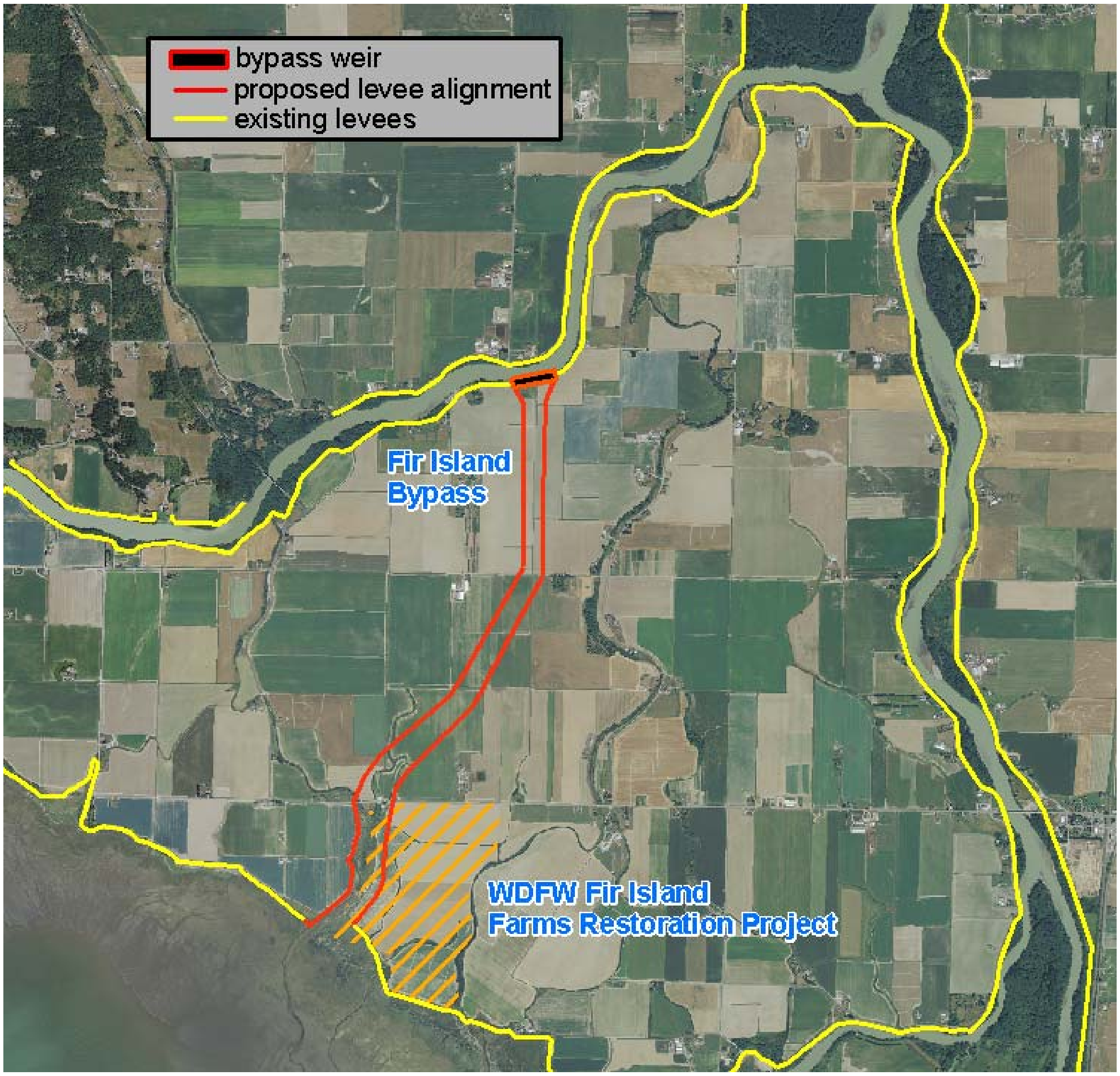

Figure 25: Fir Island Bypass alignment

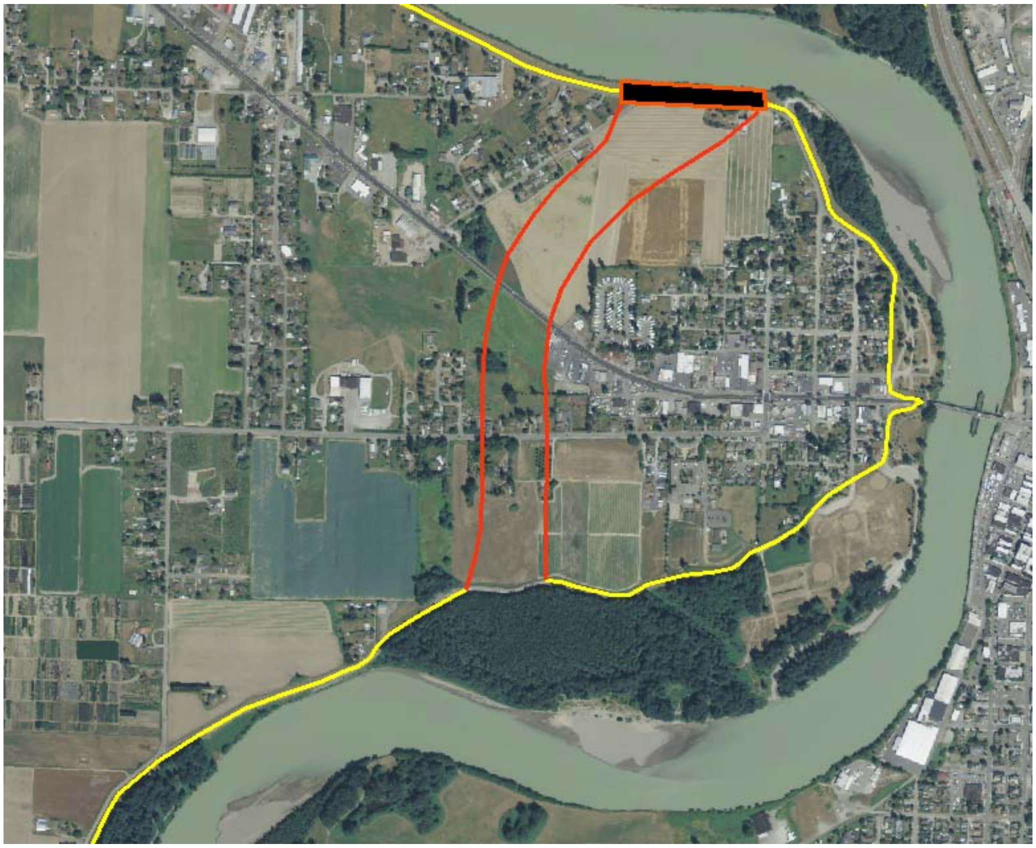

Figure 26: Mount Vernon Bypass alignment

Details of the performance of these measures are provided in the performance matrices. Comparison should be made against the "Base Condition" modeling results.

Results

The Fir Island Bypass (with a diversion structure at RM 7.0 on the North Fork) is generally ineffective, with or without bridge modifications. Without bridge modifications, the bypass diverts a maximum flow of approximately 10,500 cfs out of the North Fork during the 50-year event and approximately 11,700 cfs during the 100-year event. With bridge modifications, the bypass diverts a maximum flow of 11,200 cfs and 12,400 cfs for the 50- and 100-year events respectively. Water level reductions at the head of the forks are about 0.2 ft for both the 50-year and 100-year events, with or without bridge modifications, with lesser reductions as one moves upstream. Water level reductions at the Anacortes WTP are less than 0.1 ft for both the 50-year and 100-year events, with or without bridge modifications.

Greater conveyance improvements and water level reductions in and upstream from Mount Vernon are achieved for the Fir Island Bypass measure in conjunction with the Mount Vernon Bypass. Water level reductions with the Mount Vernon Bypass extend as far upstream as Sedro-Woolley, resulting in a modest reduction in spill at Sterling, and a modest increase in peak flows throughout the downstream system. Keys results for the Fir Island Bypass with the Mount Vernon Bypass are summarized in Table 6.

Table 6: Performance of Fir Island Bypass Measure with Mount Vernon Bypass

Performance Metric	Fir Island Bypass plus Mount Vernon Bypass			
	without Bridge Modifications		with Bridge Modifications	
	50-yr	100-yr	50-yr	100-yr
Change in peak spill at Sterling (cfs)	-2,500	-4,000	-2,300	-4,300
Change in peak WL at Sterling (ft)	-0.1	-0.1	-0.1	-0.2
Change in peak discharge at Anacortes WTP (cfs)	3,300	4,000	3,400	4,300
Change in peak WL at Anacortes WTP (ft)	-0.9	-0.9	-0.9	-1.0
Peak discharge Mount Vernon Bypass (cfs)	25,500	29,100	27,100	31,800
Change in peak WL mainstem Skagit at the forks (ft)	0.0	0.1	0.0	0.1
Peak discharge Fir Island Bypass (cfs)	10,900	12,100	11,600	12,800

Note: All changes are relative to Base Conditions

4.14 Swinomish Bypass (SWIN BPS)

The Swinomish Bypass would divert water out of the mainstem Skagit immediately downstream from Burlington and discharge to Padilla Bay. By reducing water levels downstream from Burlington, water surface slope and discharge capacity are increased through the Three Bridge Corridor. Diverting water out of the system just below Burlington reduces discharges and water levels in the Skagit through and downstream from Mount Vernon. The measure comprises a diversion structure at RM 15.9 consisting of three, 200-ft long fuse plug levees, designed to give way individually at elevations of 38.3 ft, 38.5 ft, and 38.7 ft. Once the fuse plugs are activated, a breach would develop down to a sill elevation of 28 ft, the approximate natural ground level. Flow would travel west down a 7.3-mile long, 1,000-ft wide bypass channel with levees on each side, running roughly parallel to SR-20 and discharging into Swinomish Slough. A channel with a 40-ft bottom width and 1V:3H side slopes would be excavated for the length of the bypass to provide drainage. The downstream end of the bypass would be protected from tidal inundation by means of elevation-controlled tide gates.

The approximate alignment of the bypass is shown in Figure 27. It is envisaged that design of the bypass would be integrated with proposed restoration efforts for Telegraph Slough, e.g. under the Puget Sound Nearshore Ecosystem Restoration Project (PSNERP, 2011). The general area targeted for restoration south of SR-20 is shown in Figure 27. The bypass outfall location shown in Figure 27, discharging directly to Swinomish Slough, is the most downstream possible location. The final outfall location, when integrated with restoration measures, would most likely be east (upstream) of that shown in Figure 27.

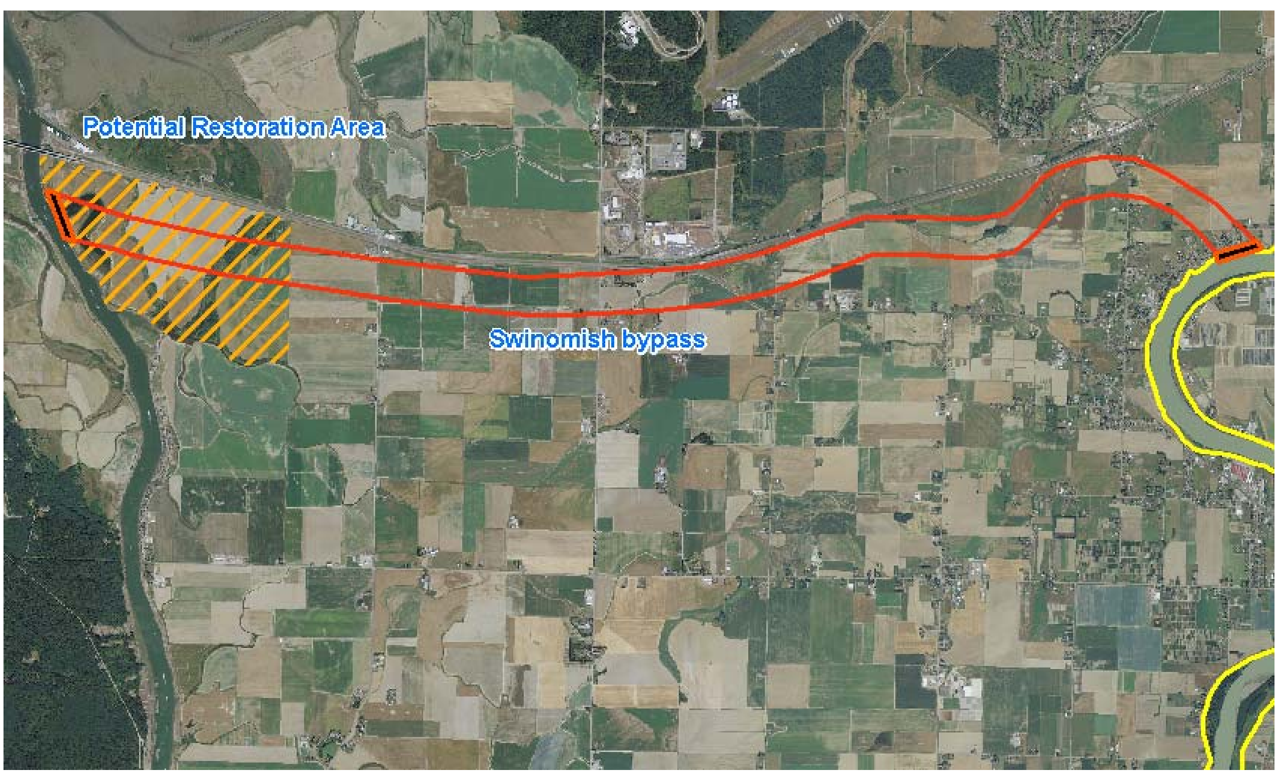

Figure 27: Swinomish Bypass alignment.

The Swinomish Bypass measure was modeled with the two Base Condition scenarios, with and without bridge modifications. Details of the performance of the measure are provided in the summary matrices. Comparison should be made against the "Base Condition" modeling results.

The Swinomish Bypass measure results in substantial reductions in spill from the system at Sterling as well as appreciable reductions in discharge and water levels throughout the system downstream from the bypass. Results at key locations for the Swinomish Bypass measure are summarized in Table 7, spill hydrographs at Sterling for 50- and 100-year events are shown in Figures 28 and 29, and ground and water surface profiles for the bypass itself are shown in Figure 30.

Table 7: Performance of Swinomish Bypass measure

Performance Metric	Swinomish Bypass			
	without Bridge Modifications		with Bridge Modifications	
	50-yr	100-yr	50-yr	100-yr
Change in peak spill at Sterling (cfs)	-9,000	-19,200	-10,500	-20,000
Change in peak WL at Sterling (ft)	-0.5	-0.7	-0.7	-0.8
Change in peak discharge in Three Bridge Corridor (USGS gage site) (cfs)	14,000	20,800	17,700	22,000
Change in peak WL in Three Bridge Corridor (USGS gage site) (ft)	-1.4	-2.3	-2.0	-2.6
Peak discharge Swinomish Bypass (cfs)	32,400	48,000	46,600	51,600
Change in peak discharge Division Street (cfs)	-13,600	-23,800	-19,700	-29,600
Change in peak WL Division Street (ft)	-1.2	-2.1	-1.7	-2.3

Note: All changes are relative to the Base Condition

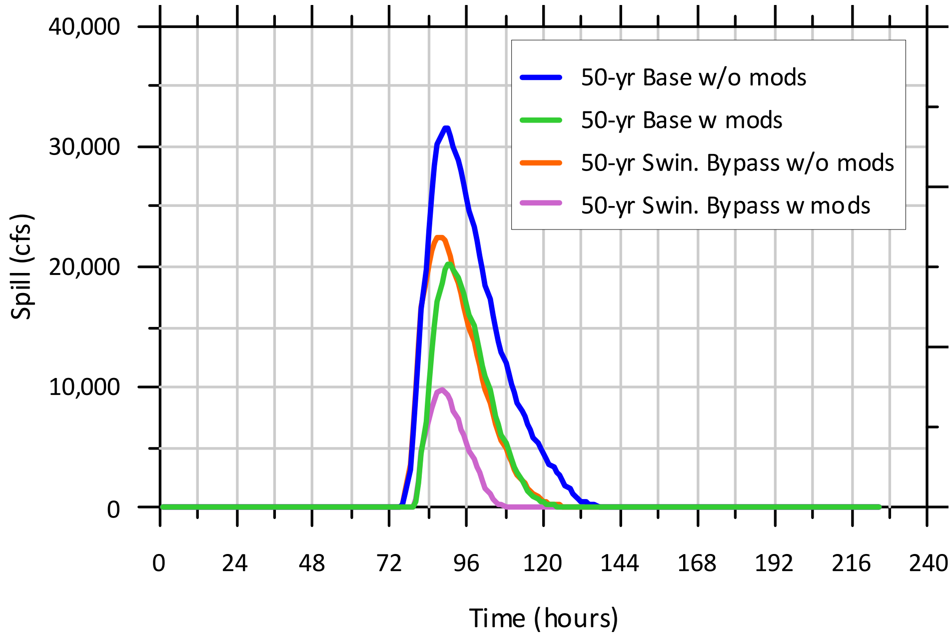

Figure 28: 50-Year Spill Hydrographs at Sterling for Base Condition and Swinomish Bypass Measures

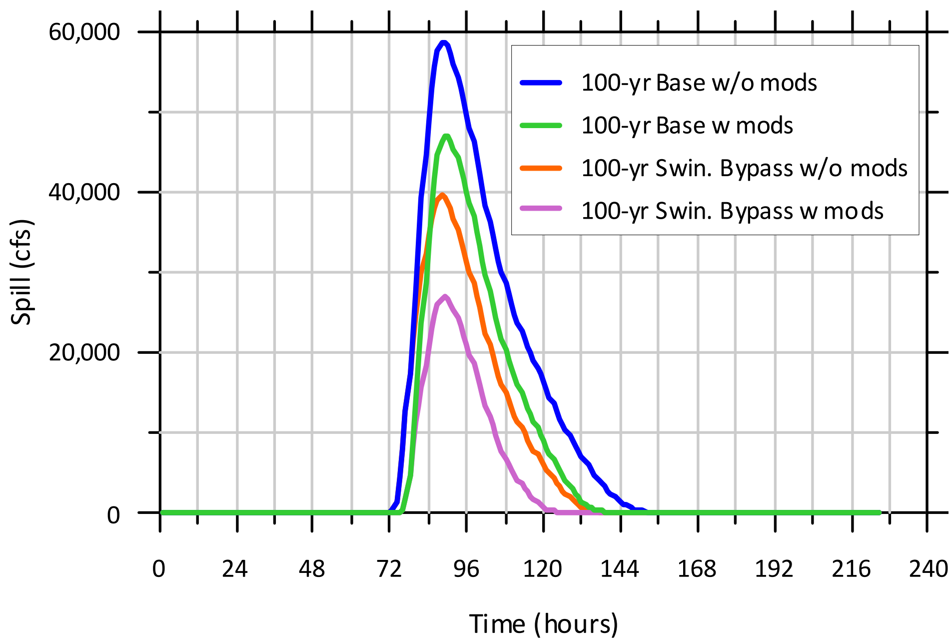

Figure 29: 100-Year Spill Hydrographs at Sterling for Base Condition and Swinomish Bypass Measures

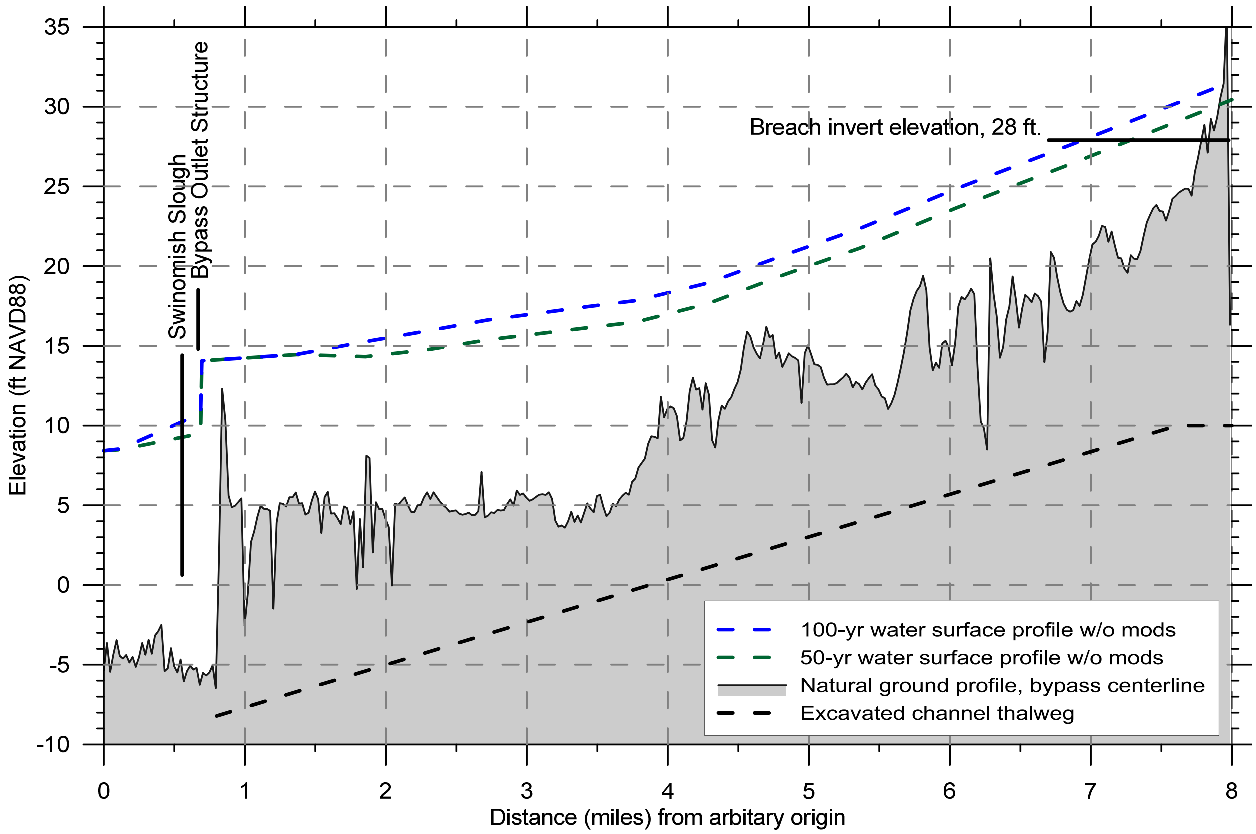

Figure 30: Swinomish Bypass Ground and Water Surface Profiles

4.15 Improve Outlet Structures

Under this measure, outlet structures in the sea dikes would be improved to facilitate drainage of floodplain flows into Padilla Bay or Skagit Bay. The structures would be designed to reduce the duration of flooding in areas behind the sea dikes. Analysis in this report focused on outlet structure improvements at the mouth of Joe Leary Slough only. Similar improvements would be made at several other locations, for example at the outlets of Indian Slough and Sullivan Slough.

Previous FLO-2D modeling shows that floodwaters escaping the right bank of the Skagit River upstream from Burlington flow northwest and west, with a significant portion of that flow ultimately draining into Padilla Bay via Joe Leary Slough. Tidal flooding of land in the lower reaches of Joe Leary Slough is currently controlled by an existing outlet structure comprising twelve 48-inch diameter culverts with flap gates to prevent flow reversal. The design basis for the existing structure is not known but we assume that it is intended to handle local runoff only. For current purposes, we have assumed that the existing culverts would be replaced by twelve 72-inch diameter culverts (or equivalent) with flap gates, more than doubling the effective opening of the existing outlet structure. It is envisaged that replacement of the existing outlet structure would be integrated with estuarine restoration at the mouth of Joe Leary Slough as outlined in the USACE Evaluation Area Studies (USACE , 2002). The portion of the Evaluation Area Studies report pertaining to Joe Leary Slough is provided in Appendix B. The location of the existing Joe Leary Slough outlet structure and the maximum limits of the potential restoration area are shown in Figure 31.

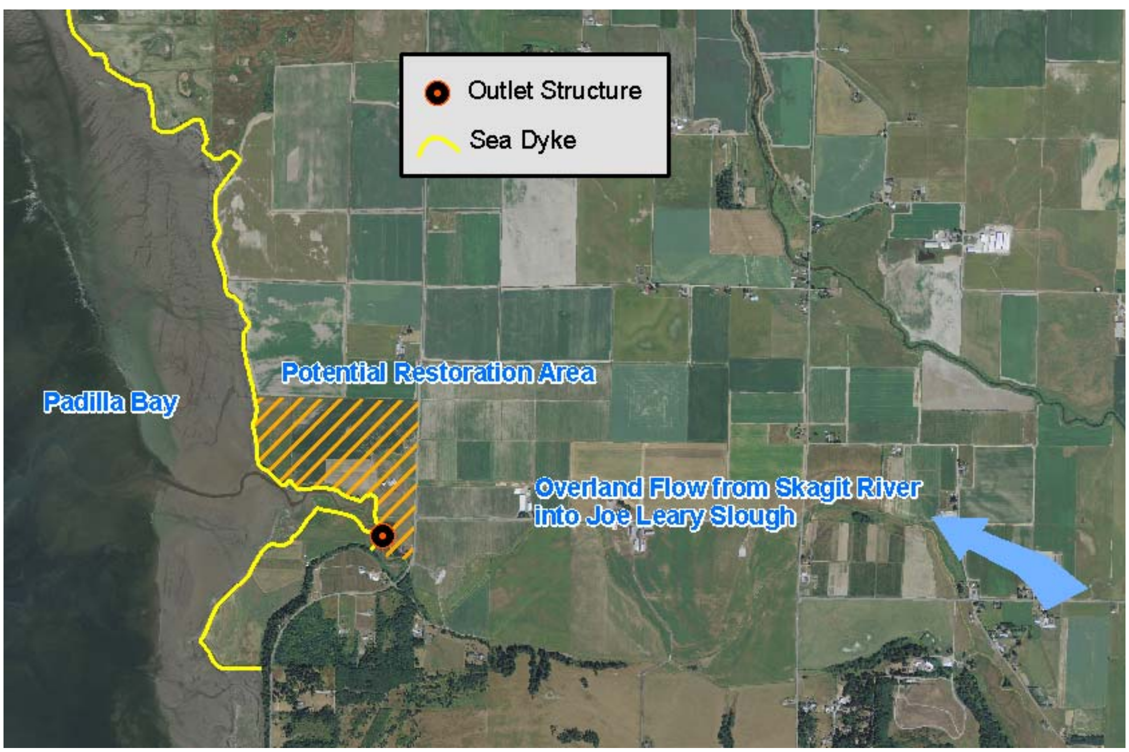

Figure 31: Joe Leary Slough Outlet Structure and Restoration Area

No modeling of floodplain flows was conducted for this measure. Rather it was assumed that for both 50- and 100-year floods on the Skagit, spill from the Skagit would be sufficient to completely fill storage behind the sea dikes at the outlet from Joe Leary slough. Given anticipated spill rates and volumes at Sterling, we would in fact expect the sea dikes to be overtopped from the landward side. The total storage to the top of the sea dikes (approximately elevation 11.5 ft NAVD88) is estimated at approximately 21,000 acre-ft. Under existing conditions without flood fighting, it is estimated that approximately 136,000 acre-ft would spill from the Skagit at Sterling in a 100-year event.

A simple stand-alone HEC-RAS model was used to determine the time required to evacuate this storage for both the existing and improved outlet structures. The assumed tidal boundary condition was the same as that used in the 2011 existing condition hydraulic analyses (USACE, 2011b) for the mouths of the North and South Forks of the Skagit, with a primary peak at Mean Higher High Water (8.39 ft NAVD88), a secondary peak at Mean High Water (7.49 ft NAVD88), and a low at Mean Low Water. The outlet structure discharge hydrograph and water level hydrograph upstream (landward) from the structure for the existing (4-ft culverts) and improved structure (6-ft culverts) are shown in Figure 32. The stage hydrograph for the tidal boundary condition is also shown in Figure 32.

The simulation results in Figure 32 show draw down of water stored behind the sea dike assuming no additional or continuing inflow via Joe Leary Slough and thus represent somewhat faster draw down rates than might be expected in practice. Figure 32 (bottom panel) shows, for example, draw down from elevation 11.5 ft (top of sea dike) to elevation 6 ft in 7 days with the existing outlet structure and in 4 days with the improved structure. Similarly, draw down to elevation 4 ft is achieved in about 11 days with the existing structure and 8 days with the improved structure. Acceptable target draw down times should be determined in consultation with the local community.

Note that the performance of outlet structures is dependent on the ability of the sea dikes to withstand overtopping flows from the landward side associated with large spills from the Skagit. Further assessment is needed of sea dike performance under overtopping conditions.

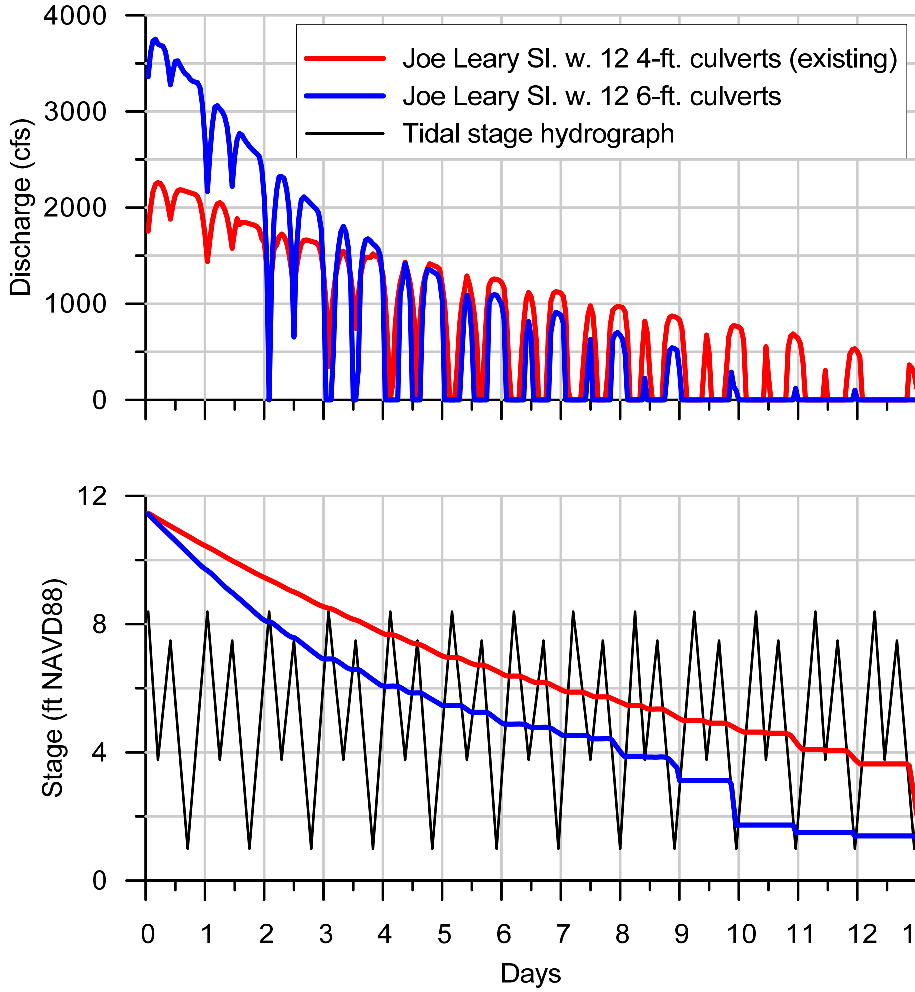

Figure 32: Joe Leary Slough Outlet Structure Stage and Discharge Hydrographs

4.16 Other Facility and Community Levees

The scope of work for the study included analysis of several facility and community levees at: United General Hospital (Figure 33), Clear Lake (Figure 34), West Mount Vernon (Figure 35), La Conner (Figure 36), and Sedro-Woolley Waste Water Treatment Plant (Figure 37). These are outside the model domain of the HEC-RAS model and/or are small enough to have no off-site hydraulic effects.

United General Hospital

The alignment of the proposed facility levee for United General Hospital is shown in Figure 33. One of the principal flood management issues affecting the hospital is egress. Hydraulic model results show that raising the elevation of SR-20 from the hospital east to Sedro-Woolley to ensure egress during 100-year conditions would have minimal hydraulic impact due to only minor overtopping between the hospital and town. The peak 100-year water surface elevation at the hospital under existing conditions is 49.0 ft NAVD88. The lowest point on SR-20 between the hospital and Sedro-Woolley is at elevation 48.6 ft NAVD88. Approximately 800 ft of roadway would have to be raised to bring the minimum top of road to elevation 49 ft NAVD88. Approximately 4,000 ft would have to be raised to bring the elevation to 50 ft NAVD88. If SR-20 20 is used for egress, the top of road elevation will be dictated by the hydraulic performance of other measures.

Figure 33: United General Hospital facility levee

Possible egress from the hospital to the north via Collins Road was also examined. The lowest elevation on Collins Road between the hospital and Cook Road, as estimated from LIDAR data, is approximately 38 ft NAVD88 where Collins Road crosses Gages Slough about 600 ft north of the hospital. During 100-year conditions, Collins Road would be overtopped either by water backing up Gages Slough or as a result of water overtopping SR-20 east of the hospital and then flowing west to Collins Road following the general alignment of Gages Slough. To prevent overtopping as a result of water backing up Gages Slough, several hundred feet of Collins Road would have to be raised by as much as 11 feet. To prevent overtopping of Collins Road as a result of spill over SR-20 east of the hospital would require that SR-20 be raised or that spill be passed under Collins Road by means of culverts or bridge crossings. We conclude that egress via SR-20 is the better of the two options.

Clear Lake

A significant portion of the Clear Lake community experiences flooding under existing 100-year conditions. The Clear Lake measure comprises levees to protect the community from flooding and local raising of SR-9 south of Clear Lake to provide assured access during 100-year flooding (Figure 34).

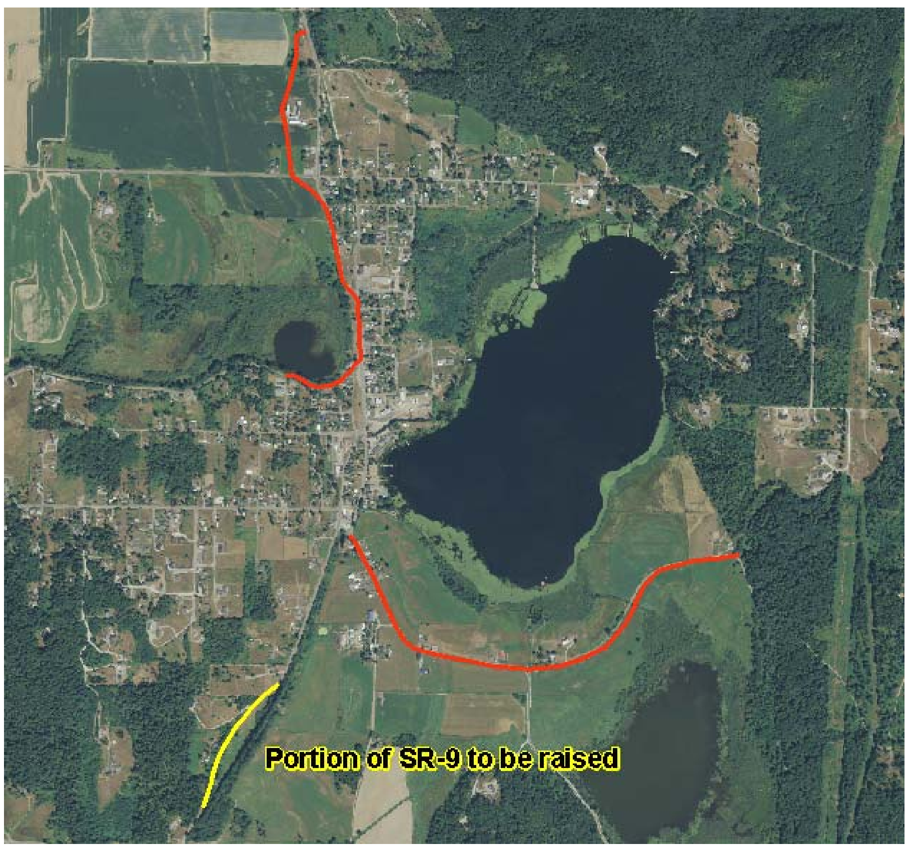

Figure 34: Clear Lake community levees

The impacts of the Clear Lake community levees were modeled in HEC-RAS. It was confirmed that there are no hydraulic impacts to the adjacent Nookachamps flood storage areas. The elevation of the Clear Lake levees will be dictated by the hydraulic performance of other measures. The levee round the south end of Clear Lake would include a gated outlet structure to provide for discharge from the lake. To provide assured access from the south during 100-year flood conditions, approximately 1,700 ft of SR-9 would need to be raised. The low elevation in SR-9 south of Clear Lake, as estimated from LIDAR data, is approximately 40 ft NAVD88 compared with a 100-year water surface elevation of approximately 49.0 ft under existing conditions.

West Mount Vernon

The alignment of the West Mount Vernon community levee (Figure 35) is intended to protect the majority of developed property in West Mount Vernon but to not include rural areas. The approximate alignment shown in Figure 35 should be refined based on community input. The design of the West Mount Vernon community levee will also depend on other measures included within flood management alternatives under consideration. For example, a flood management alternative incorporating the Mount Vernon Bypass measure would significantly influence the design of the West Mount Vernon community levee.

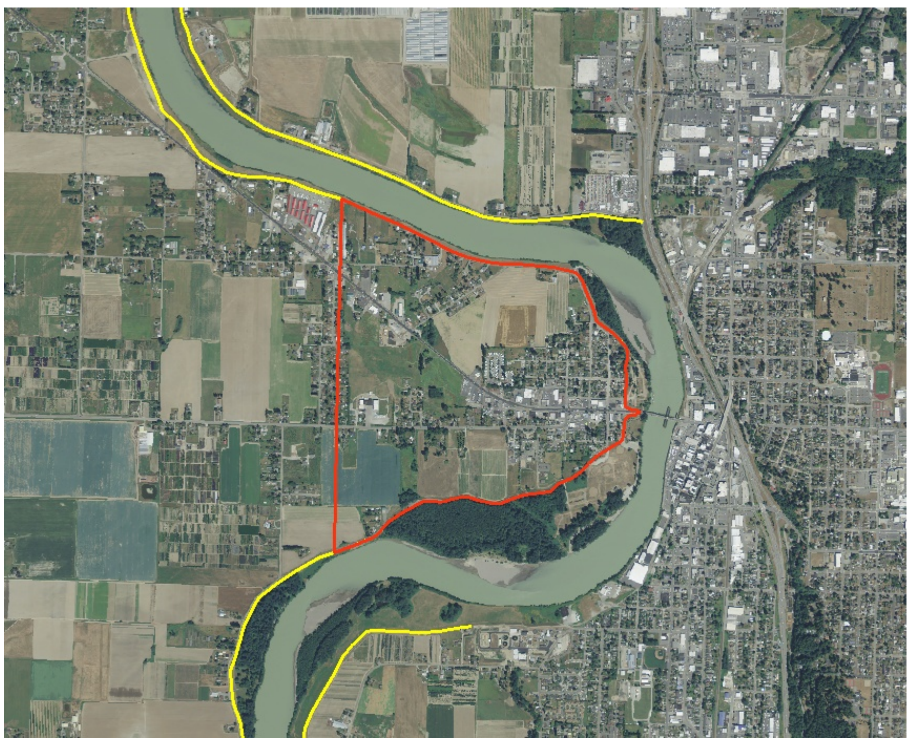

Figure 35: West Mount Vernon community levee

La Conner

The alignment of the La Conner community levee (Figure 36) is based on existing flood management plans. No information is available on the condition of existing levees; improvements to existing levees may be required to provide adequate protection.

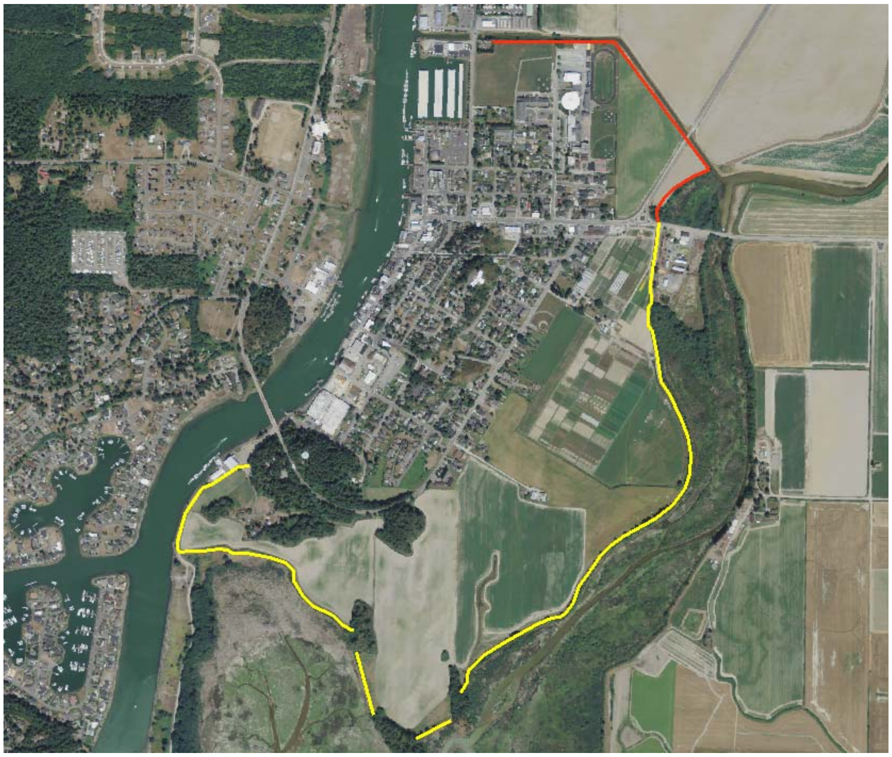

Figure 36: La Conner community levee

(Orange line shows proposed alignment; yellow line shows existing levee)

Sedro-Woolley

The Sedro-Woolley Waste Water Treatment Plant (SWWWTP) facility levee will be required to provide protection for the 200-year event – to approximately elevation 57 ft NAVD88 for existing conditions with assumed average debris load on the abandoned Great Northern Railroad bridge. Conceptual design of protection for low lying parts of the city near the SWWWTP will require further consultation with the community.

Figure 37: Sedro-Woolley Waste Water Treatment Plant facility levee

It is expected that community levees will form part of one or more flood management alternatives which include larger measures having more significant hydraulic impacts. Selection of those flood management alternatives will be required to define flood levels before meaningful analysis and design of the community levees can be undertaken.

5.0 References

Northwest Hydraulic Consultants, Inc., 2011. Update to Bridge Debris Loading Assumptions. Memorandum to Skagit County, 14 October 2011.

Puget Sound Nearshore Ecosystem Restoration Project, 2011. Strategic Restoration Conceptual Engineering – Final Report, March 2011.

US Army Corps of Engineers, 2002. Skagit River Flood Control Project – Environmental Restoration and Mitigation Planning. Evaluation Area Studies. Draft Report, USACE Seattle District, January 2002.

US Army Corps of Engineers, 2011a. Skagit River Flood Risk Management Feasibility Study. Hydrology Technical Documentation, Draft Report, USACE Seattle District, March 2011.

US Army Corps of Engineers, 2011b. Skagit River Flood Risk Management Feasibility Study. Hydraulic Technical Documentation, Draft Report, USACE Seattle District, April 2011.

Appendix A

Skagit River GI Study

Seasonality Assessment of Flood Storage

Memorandum

Northwest Hydraulic Consultants
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Seattle, WA 98188
206.241.6000
206.439.2420 (fax)

DATE: 15 June 2010 PROJECT: 21739
TO: Lorna Ellestad
COMPANY/AGENCY: Skagit County
FROM: Pat Flanagan and Malcolm Leytham
SUBJECT: Skagit River GI Study – Seasonality Assessment of Flood Storage

We have completed a preliminary assessment of the impact of seasonal variation in flood storage on regulated flood hydrographs as defined in Task Order #4 (Amendment 1). This memorandum describes our analysis and the impact to regulated flows in the Skagit River at Concrete.

1.0 Introduction

According to the current Water Control Manuals (WCMs), the flood control storage required at Upper Baker and Ross reservoirs varies seasonally as shown in Table 1:

Table 1: Flood control storage requirements at Upper Baker and Ross

Upper Baker	
Date	(ac-ft)
October 1	0
November 1	16,000
November 15	74,000
March 1	74,000
April 1	0

Ross	
Date	(ac-ft)
October 1	0
October 15	20,000
November 1	43,000
November 15	60,000
December 1	120,000
March 15	120,000

As noted in Section 2.0, the flood storage requirements for Upper Baker, as described in the WCM, is slightly different from the requirement under the current FERC project license. All analyses described in this memo have assumed the flood control storage requirements per the WCM.

Hydrologic analyses of existing condition regulated flows conducted to date have ignored the seasonal variation of flood control storage and have assumed that the required maximum amount of storage (74,000 ac-ft at Upper Baker and 120,000 ac-ft at Ross) is available for all floods, regardless of the date of occurrence. The full amount of flood storage is not required at Upper Baker until November 15 and at Ross until December 1. The purpose of the work described in this memo was to assess the impact of lower flood control storage requirements prior to December 1 on regulated peak flows on the Skagit River near Concrete (i.e. downstream from the Baker River confluence).

2.0 Reservoir Record Analysis

Daily time series of reservoir elevations for Upper Baker and Ross were obtained from PSE (via Skagit County), the USGS, and the Corps. For Upper Baker, gaps in the USGS daily data were filled with the PSE data to create a continuous record for water years 1977 through 2009. For Ross, the USGS daily data were filled with data from the Corps to create a continuous record for water years 1962 through 2009. The reservoir elevation time series were converted to time series of reservoir storage using elevation/storage data provided in the WCMs.

It is recognized that the period of historic reservoir elevation or storage data obtained for this work (1977 through 2009 at Upper Baker, and 1962 through 2009 at Ross) may not be representative of future project operations. Accordingly, discussions were held with representatives from both Puget Sound Energy (PSE) and Seattle City Light (SCL) to determine what period of historic reservoir elevation or storage data is expected to be most representative of future conditions, especially in the early part of the flood control season.

Upper Baker

According to representatives from PSE, prior to 1984, flood control operations at Upper Baker provided 16,000 acre-ft of storage on 1 November and 74,000 acre-ft on 15 November, with more of a “stair-step” change in flood control storage between those two dates than at present. Since 1984, project operations have assumed a linear transition in the storage required between those two dates, hence providing more assured flood control early in the flood control season.

Operations at Upper Baker have also deviated from expected future operations since 2004. In accordance with the requirements of a relicensing agreement, an Interim Protection Plan (IPP) was introduced in 2004 to improve fish habitat in the Baker River by reducing rapid fluctuations in flow. Under IPP-related project operations, more storage than required would be available in the Baker River project early in the flood control season. IPP operations are expected to continue until approximately 2012 when new turbine units will be installed at the project.

Under the terms of Article 107c of the new FERC license, PSE is required to “develop means and operational changes to operate the Project reservoirs in a manner addressing imminent flood events”. These changes may include “additional reservoir drawdown below the maximum established flood pool”. It is anticipated that any operational changes to address “imminent floods” would take place after about 2012; the nature and impact of any such changes is not yet known.

A further change affecting flood control performance has been the implementation by PSE since about 2006 of flood control pool buffers at both Upper Baker and Lower Baker. The buffers provide additional storage above that required for flood control operations per the operating license. At Upper Baker, this additional storage is 26,000 acre-ft, so that the bottom of the buffer is approximately 7 ft below the maximum permissible pool elevation in the flood control season. At Lower Baker, the bottom of the buffer is approximately 5 ft below the spillway crest elevation, representing approximately 9,850 acre-ft of storage below the spillway crest. The purpose of the buffers is to provide PSE with operational flexibility while avoiding, to the extent possible, incursion into the formal flood control storage space at Upper Baker. PSE operates the reservoirs to try to maintain water levels toward the low end of these buffers (water levels are generally maintained 2 to 3 feet above the bottom of the buffer), however there is no formal operating policy for the buffers. It should also be noted that the Corps only manages flood control space at the Upper Baker project.

It was noted in the course of discussion with PSE staff that the flood control storage requirements at Upper Baker as described in the WCM differ slightly from the storage required per the project's FERC license. Under the FERC license, which PSE views as the controlling document, 16,000 acre-feet of storage is required at Upper Baker between 15 October and 1 November. Under the current WCM, flood control storage would be increased from 0 acre-feet on 1 October to 16,000 acre-feet on 1 November. Comment from the Corps (e-mail from Dan Johnson dated 7 June 2010) confirms that PSE will be required to provide 16,000 acre-feet of storage in Upper Baker by 15 October per the current license.

While future operations at Upper Baker are expected to differ from past operations in a number of respects, for current purpose it is assumed that future operations will be most similar to operations in the 20-year period 1984-2003.

Ross

The situation at Ross is less clear than at Upper Baker. As discussed later in this section, Ross Reservoir often provides significantly greater storage early in the flood control season than is required under the terms of its operating license. According to a representative from SCL, Ross reservoir elevations in the early fall are driven by a combination of factors including summer/fall weather conditions, energy demand, fisheries compliance requirements, and conditions in the energy market in general. SCL stressed that while no significant changes in operational practices were anticipated in the foreseeable future, there was also no guarantee that early flood control season storage at Ross would be greater than required in the future. Considering trends in energy demand, SCL suggested that reservoir data from the period 1990 through present would be more indicative of future operations than data from earlier periods.

Data for the periods 1984-2003 at Upper Baker and 1990-2009 at Ross were analyzed to produce summary "hydrographs" and duration curves of reservoir elevation and available storage. Summary hydrographs are provided in Figures 1 through 4, while duration curves are provided in Figures 5 through 8.

The summary hydrographs (Figures 1 through 4) show percentiles of stage or available volume on a given day of the year, as well as the required flood storage. The Upper Baker plots show that from October 1 to November 15 the median available flood storage is much less than the full

74,000 ac-ft required after November 15. While this is consistent with the requirements of the 2000 Baker WCM, it demonstrates that it is inappropriate to assume that full flood control storage is available for all floods regardless of their date of occurrence. The plots for Ross show that for most of October, the median available flood storage is close to or exceeds the full 120,000 ac-ft required after December 1. The plots for Ross also show that in many years, the storage available greatly exceeds the flood control requirements.

Duration curves (Figures 5 through 8) were developed for two-week periods in October and November, as well as for the balance of the flood control season from December through February. The duration curves show that in early October, the full flood storage has historically only been provided about 10% of the time at Upper Baker and 45% of the time at Ross. After December 1, the full flood storage has historically been available over 90% of the time at both projects. While these data show that project operations are consistent with the respective WCMs, the duration curves again serve to demonstrate that it is inappropriate to assume that the full amount of flood control storage is available early in the flood control season.

3.0 Impact of Reduced Flood Storage on Regulated Peak Flows

10- and 100-year flood hydrographs were routed through Upper Baker and Ross to the Skagit River USGS gage near Concrete using the Corps reservoir routing spreadsheet "model"[1]. To represent the seasonally varying flood control storage requirements, simulations were conducted for two week periods from October 1 to November 30, and for the remainder of the flood control season after December 1, when the full amount of flood control storage is required at both projects. The initial conditions in the two reservoirs were set to the required flood storage on the middle date of each two week period.

The "average" regulating scheme previously used by the Corps was assumed. This assumes that outflow at both projects would be restricted before the **unregulated** flow at Concrete reaches the flood damage threshold of 90,000 cfs. Upper Baker releases were set to the minimum of 5000 cfs[2] three hours before the 90,000 cfs threshold flow was reached at Concrete, while Ross releases were set to 0 cfs eight hours before the threshold flow was reached at Concrete[3]. These releases are maintained until reservoir levels rise to a point which triggers greater releases as specified under the respective Spillway Gate Regulation Schedules. Simulation results are provided in Table 2 on the following page.

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[1] Flood hydrographs for this purpose were those included in the Corps spreadsheet model and were based on unregulated 10-year and 100-year winter peak flows on the Skagit River near Concrete of 154,000 cfs and 299,000 cfs respectively. The May 2008 Draft Revised Flood Insurance Study reports 10-year and 100-year unregulated peak discharges of 159,000 cfs and 278,000 cfs respectively.

[2] There is a perception in some quarters that a release of 5,000 cfs from the Baker project is required to generate power to operate the project for flood control. The actual minimum release required to generate power for station operation for a single turbine is about 1,600 cfs. There is no operational reason why the release from Upper Baker cannot be reduced below the current 5000 cfs minimum if desirable.

[3] Note that some Corps routing simulations for Ross assume a release of 0 cfs, while other simulations assume 5,000 cfs. It is not clear how this restricted release rate was determined for any particular simulation.

Table 2: Reservoir routing by two-week period

Two-Week Period	10-year Event: Contribution to Regulated Peak Discharge at Concrete (cfs)		10-year Event: Regulated Peak Discharge, Skagit River near Concrete (cfs)[a]	100-year Event: Contribution to Regulated Peak Discharge at Concrete (cfs)		100-year Event: Regulated Peak Discharge, Skagit River near Concrete (cfs)[a]	Starting Flood Storage: Upper Baker		Starting Flood Storage: Ross	
	From Upper Baker	From Ross		From Upper Baker	From Ross		ft, NAVD88	ac-ft	ft, NAVD88	ac-ft
10/1 to 10/15	17,000	13,000	142,000	34,000	34,000	281,000	727.04	3,700	1603.63	10,100
10/16 to 10/31	15,000	10,000	137,000	34,000	28,000	276,000	725.42	11,700	1601.80	31,600
11/1 to 11/15	5,000	7,000	125,000	29,000	28,000	269,000	718.12	46,100	1600.09	51,500
11/16 to 11/30	5,000	0	118,000	11,000	21,000	244,000	711.70	74,000	1596.72	90,100
Full Storage (Routed by NHC)	5,000	0	118,000	11,000	12,000	239,000	711.70	74,000	1594.09[b]	119,900
Full Storage (Routed by COE)	n/a	n/a	118,000	n/a	n/a	232,000	711.70	74,000	1594.13[b]	119,500

a. Unregulated 10-yr and 100-yr winter peak flows for this analysis would be 154,000 and 299,000 cfs respectively.

b. There are minor inconsistencies in the Skagit WCM with regard to both the stage/storage relationship at Ross and the pool elevation corresponding to the December 1 flood control storage requirement.

Modifications to the Corps spreadsheets' representation of the Spillway Gate Regulation Schedules (SGRSs) were made for both Upper Baker and Ross[4]. The SGRSs from the 2001 Skagit WCM and the 2000 Baker WCM were implemented in the spreadsheet model to determine required releases from the projects at high pool levels. The SGRSs control the release from both projects during large events based on the reservoir pool elevation and the rate of rise (or reservoir inflow if known). The differences in SGRS representation between the Corps spreadsheets and NHC's analysis result in slightly different regulated peak discharge at Concrete for the 100-year event (see last two rows in Table 2[5]).

The simulation results in Table 2 show a 20% increase in both 10-year and 100-year regulated peak flow at Concrete for an event occurring in early October instead of December when full flood storage is required to be available. The SGRS curves control the outflow at both projects in both the 10- and 100-year events when less than the full amount of flood storage is available at the start of the simulation. The SGRS are not activated during the 10-year event when full flood storage is available.

4.0 Impact of Reduced Flood Storage on Flood Risk

The analysis described in Section 3 indicates that a nominal 10-year or 100-year winter flood event occurring in the first two weeks of October would result in a regulated peak at Concrete some 20% higher than for similar events occurring after December 1, when the full amount of flood control storage is available at both Ross and Upper Baker. However, to gain insight into the effect of reduced flood storage on flood risk, one obviously also has to consider the probability of damaging floods occurring early in the flood season.

Ideally for this type of analysis one would determine 10-year and 100-year unregulated flood hydrographs for each two-week window within the flood season and then route those flows to produced 10-year and 100-year regulated flows for each two-week period. However, the unregulated flood hydrographs available are based on analysis of annual maximum winter (i.e. October through March) flows[6] only; more detailed analyses of unregulated flows by month or by two-week window are not available.

In the absence of more detailed information, our assessment of risk is based on a simple analysis of the temporal distribution of annual maximum winter flows within the flood control season. Examination of the reconstructed record of unregulated 1-day winter peak flows for the Skagit River near Concrete shows that 42% of winter floods occur prior to 1 December. The seasonal distribution of unregulated 1-day peak flows is illustrated in Figure 9 and tabulated in Table 3.

---

[4] Modifications were made to: 1) simplify the computational procedure used in the spreadsheet for the Upper Baker SGRSs, and 2) add relevant portions of the Ross SGRSs (the spreadsheet originally provided by the Corps did not include the Ross SGRSs).

[5] Note that analyses from the Corps are only available for the "Full Storage" scenario.

[6] More specifically the analysis is based on annual maximum winter (defined as October through March) flows for those years in which the annual maximum flow occurred in the winter. There are four years in the period of record (water years 1931, 1937, 1992, and 1993) in which the annual maximum flow did not occur in the period October through March and which are consequently excluded from analysis. This results in some slight underrepresentation of dry years in the flood frequency analyses.

The one-day maximum winter discharges for the period of record are also plotted against time of occurrence in Figure 10. The record used for this analysis comprises the four historic events (water years 1898, 1910, 1918 and 1922) and the systematic record from water years 1925 through 2007, for a total of 83 events, as obtained from Corps HEC-FFA input files dated February 2008.

Table 3: Distribution of 1-Day Winter Peak Flows

Period	No. of Events in Period	Cumulative Percentage to End of Period
Oct 1-15	3	4
Oct 16-31	14	20
Nov 1-15	9	31
Nov 16-30	9	42
Dec 1-15	14	59
Dec 16-31	7	67
Jan 1-15	8	77
Jan 16-31	9	88
Feb 1-15	4	93
Feb 16-28	3	96
Mar 1-15	2	99
Mar 16-31	1	100
Total	83	

One approach to estimate the impact of the seasonal variation of flood storage on 100-year regulated flow is to simply weight the regulated flows from Table 2 on the basis of the historic frequency of occurrence of annual maximum winter flows within each of the two-week windows used for analysis, as shown in Table 4 below.

Table 4: Weighted Estimates of Regulated Discharges, Skagit River near Concrete

Period	Percentage of Winter Floods Occurring in Period	Regulated Peak Flow from 10-yr Event (cfs)	Weighted 10-yr Discharge (cfs)	Regulated Peak Flow from 100-yr Event (cfs)	Weighted 100-yr Discharge (cfs)
Oct 1-15	4	142,000	5,680	281,000	11,240
Oct 16-31	16	137,000	21,920	276,000	44,160
Nov 1-15	11	125,000	13,750	269,000	29,590
Nov 16-30	11	118,000	12,980	244,000	26,840
After Dec 1	58	118,000	68,440	239,000	138,620
		Sum	**122,770**		**250,450**
		Ratio to Discharge w Full Storage	**1.040**		**1.048**

5.0 Conclusion and Recommendations

Table 4 indicates that consideration of the seasonal variation of flood control storage would increase estimates of the 10-year and 100-year peak flow quantiles for the Skagit River near Concrete by about 4% and 5% respectively.

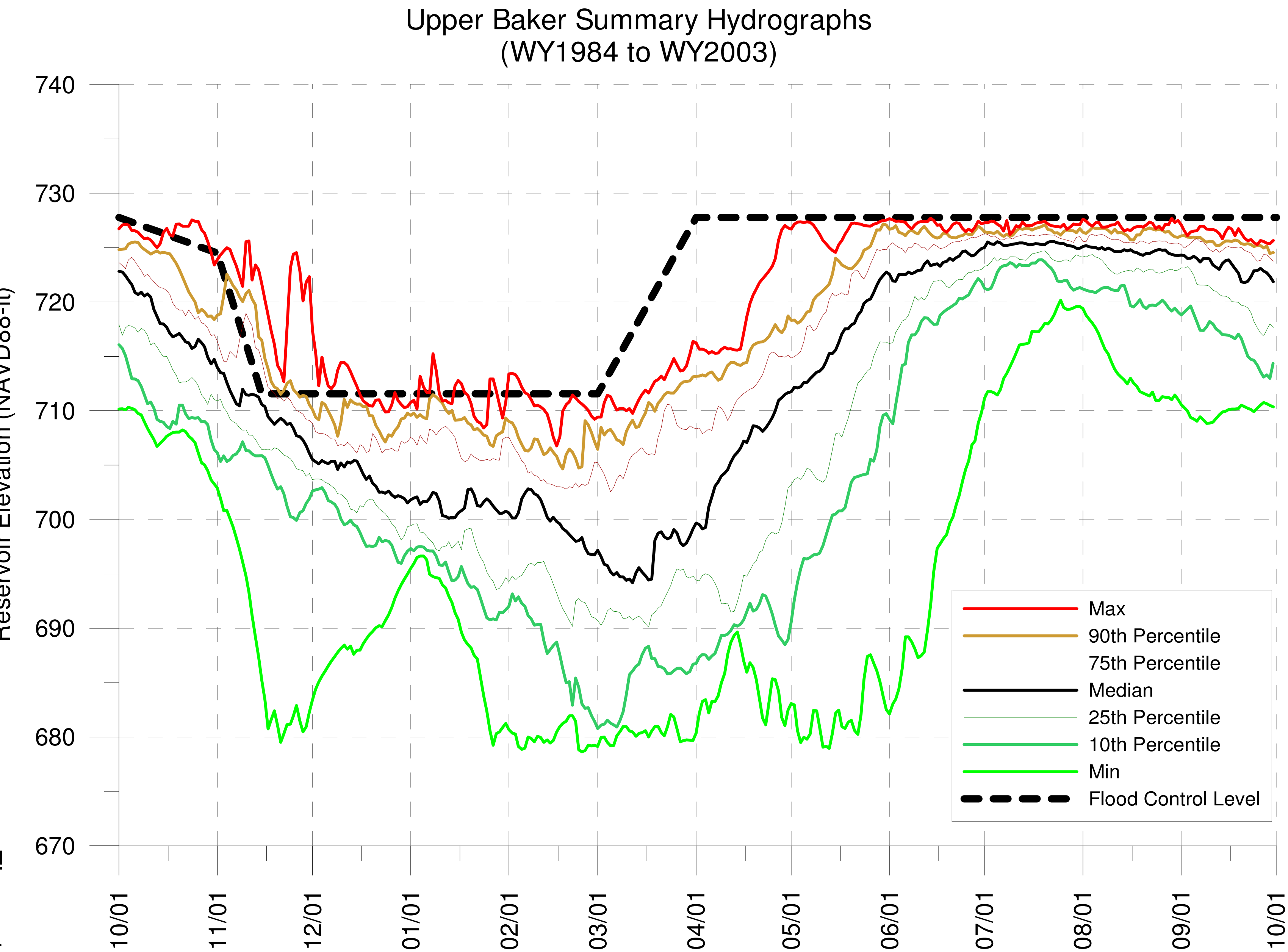
These estimates are probably slightly high for several reasons:

1) The required flood control storage amounts at Upper Baker are assumed to follow the WCM. This is inconsistent with the FERC license under which PSE operates. The FERC license provides somewhat more storage (up to 8,000 acre ft) in the 1 October – 1 November period than indicated in the WCM manual.
2) The weighting approach used here assumes that the probability of an extreme flood occurring in a particular 2-week window can be determined from the percentage of annual winter peak flows occurring in that window. This approach probably overstates the risk of extreme floods at the start of the flood control season (especially in the 1-15 October period) where dry antecedent moisture conditions have a significant influence on storm runoff. On the other hand, the record of flows on the Skagit only shows 1 event greater than 150,000 cfs occurring after 1 January. Inclusion of smaller post 1 January events in the analysis may have the effect of diluting the percentage of large floods that occur prior to the availability of full flood control storage.
3) The above analysis strictly follows the WCM flood control storage curves. As indicated in Figure 4, the storage available at Ross is often significantly greater than required throughout the flood control season.

The impact of the seasonal variation of flood control storage on flood damage estimates has not been determined.

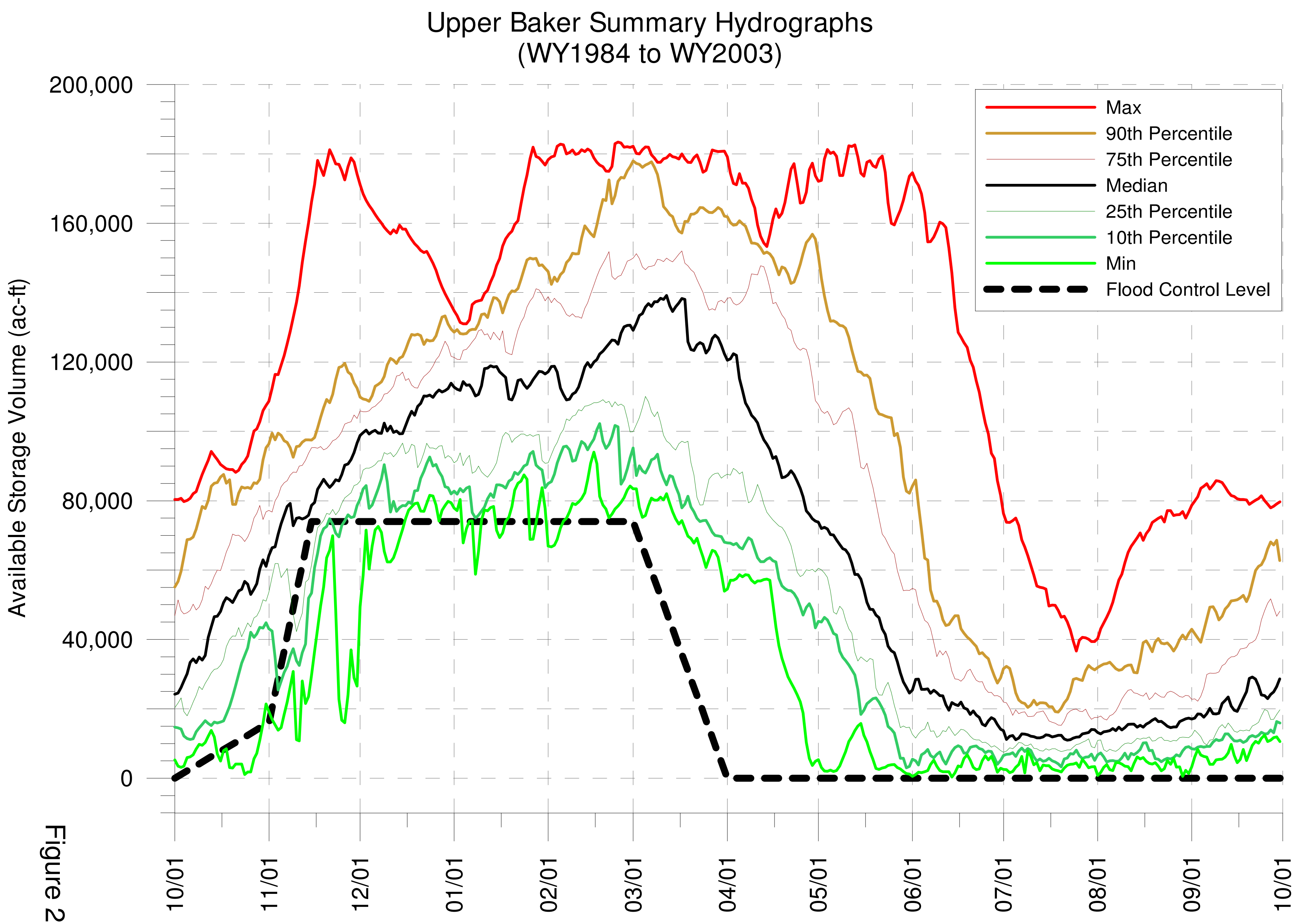
Our recommendations are as follows:

1) The Baker Project WCM should be updated to show flood control storage requirements per the current FERC license. Future updates to the WCM should be anticipated and coordinated with PSE to reflect operational changes adopted as a result of future implementation of new FERC license conditions.
2) In view of the apparently modest impact that the seasonal variation of flood control storage has on flood quantiles, we recommend that this effect NOT be incorporated directly into the analysis and characterization of existing condition Skagit River hydrology.
3) The hydrology technical documentation should clearly document assumptions regarding the seasonal variation of flood control storage and the approximate impact of those assumptions on flood quantile estimates.
4) Any analyses undertaken of the value of additional storage at the Baker or Skagit Projects should recognize and account for the limitations in the analysis of existing condition hydrology. The analysis presented in this memo indicates that modification of operations to require full flood storage earlier in the flood control season, could reduce weighted average flood quantiles by about 5%.
5) Consideration should be given to including the effects of seasonal variation of flood control storage when describing uncertainty in project performance for flood damage analyses using HEC-FDA.
6) This analysis should be revisited if Climate Change impacts are to be considered for future with or without project conditions.



Upper Baker Summary Hydrographs
(WY1984 to WY2003)
Reservoir Elevation (NAVD88-ft)
740
730
720
710
700
690
680
670
10/01
11/01
12/01
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
Max
90th Percentile
75th Percentile
Median
25th Percentile
10th Percentile
Min
Flood Control Level

Figure 1



Upper Baker Summary Hydrographs
(WY1984 to WY2003)
Available Storage Volume (ac-ft)
200,000
160,000
120,000
80,000
40,000
0
10/01
11/01
12/01
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
Max
90th Percentile
75th Percentile
Median
25th Percentile
10th Percentile
Min
Flood Control Level

Figure 2

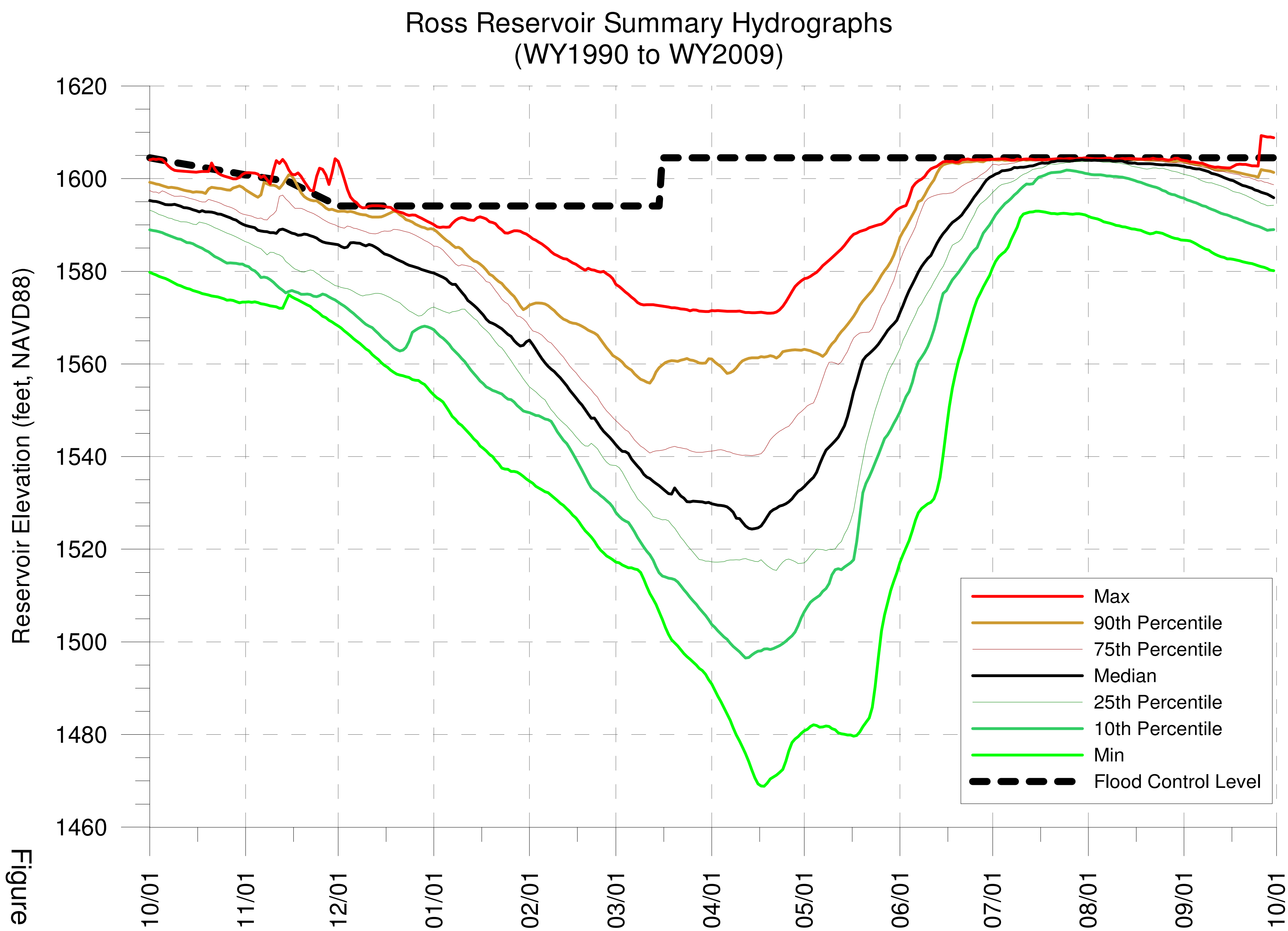
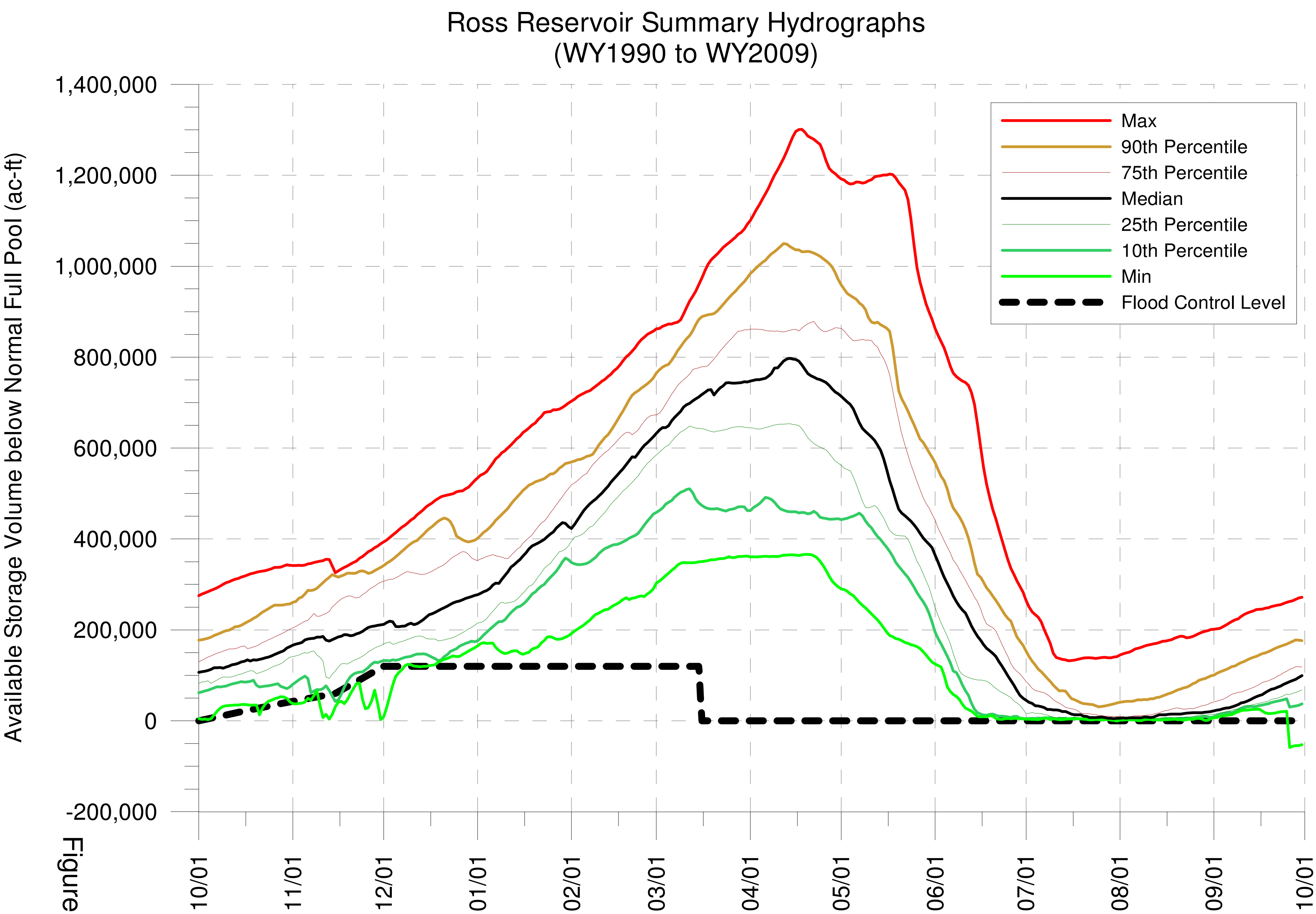

Ross Reservoir Summary Hydrographs
(WY1990 to WY2009)
Reservoir Elevation (feet, NAVD88)
1620
1600
1580
1560
1540
1520
1500
1480
1460
10/01
11/01
12/01
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
Max
90th Percentile
75th Percentile
Median
25th Percentile
10th Percentile
Min
Flood Control Level

Figure 3



Ross Reservoir Summary Hydrographs
(WY1990 to WY2009)
Available Storage Volume below Normal Full Pool (ac-ft)
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
-200,000
10/01
11/01
12/01
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
Max
90th Percentile
75th Percentile
Median
25th Percentile
10th Percentile
Min
Flood Control Level

Figure 4

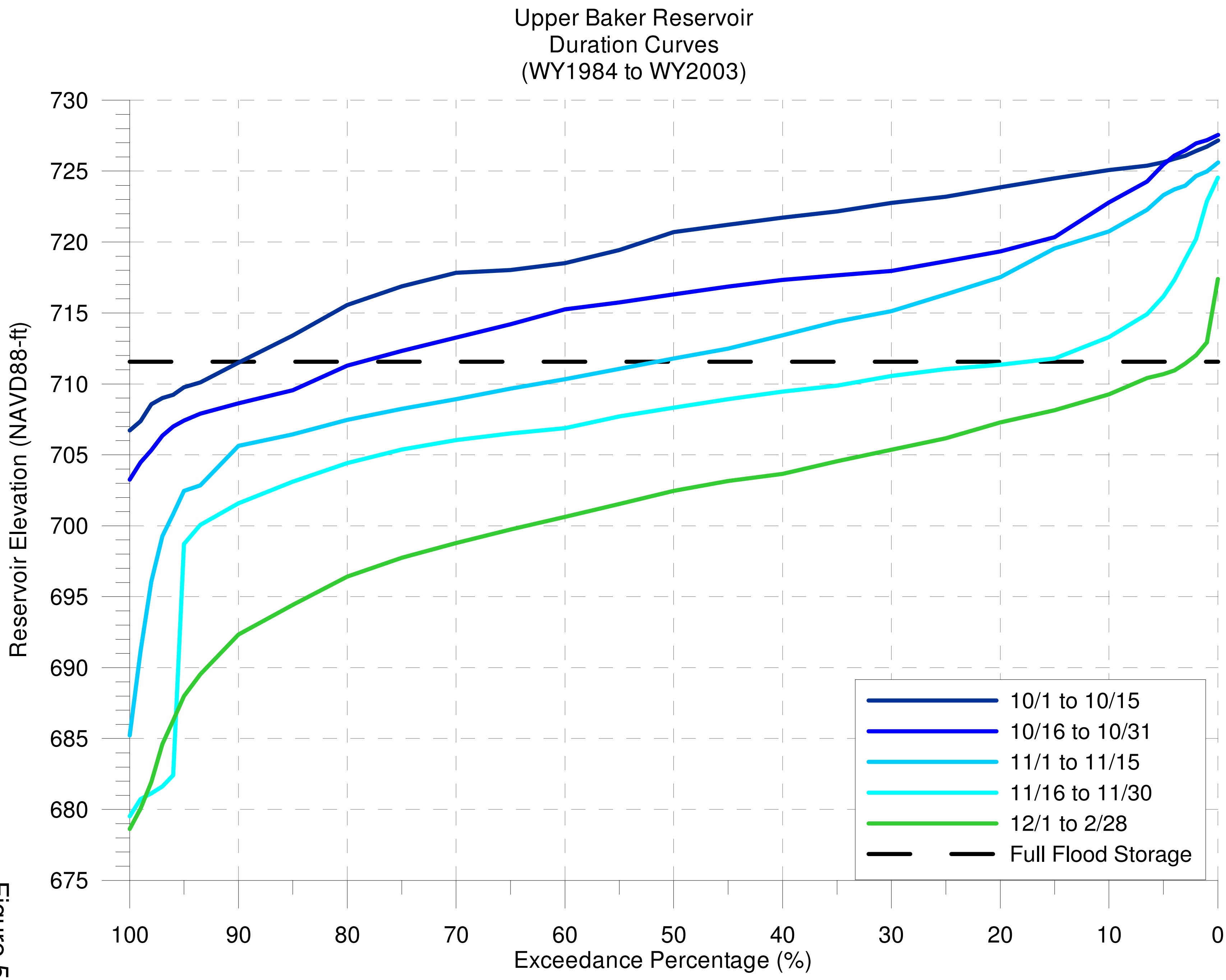

Upper Baker Reservoir
Duration Curves
(WY1984 to WY2003)
Reservoir Elevation (NAVD88-ft)
730
725
720
715
710
705
700
695
690
685
680
675
100
90
80
70
60
50
40
30
20
10
0
Exceedance Percentage (%)
10/1 to 10/15
10/16 to 10/31
11/1 to 11/15
11/16 to 11/30
12/1 to 2/28
Full Flood Storage

Figure 5

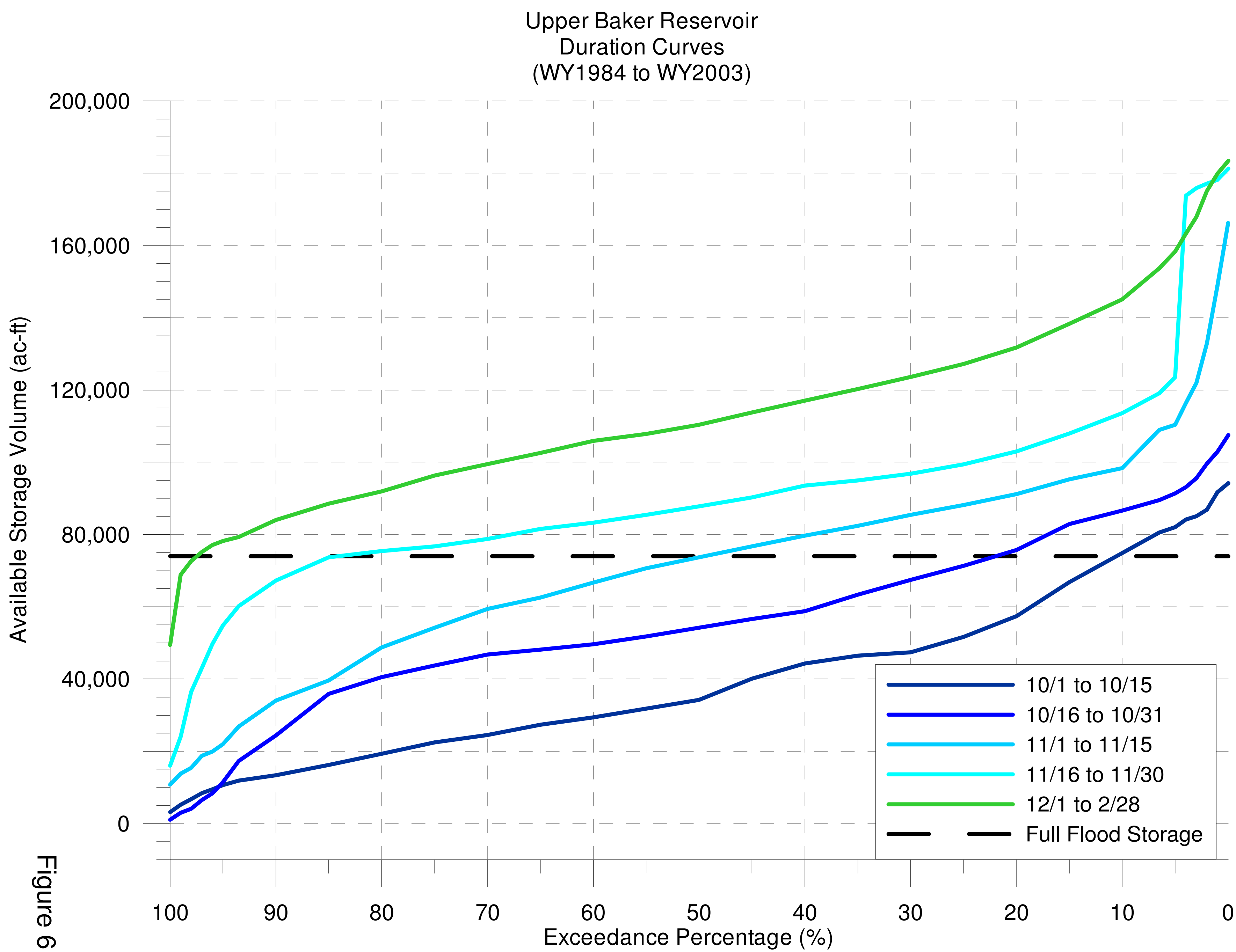

Upper Baker Reservoir
Duration Curves
(WY1984 to WY2003)
Available Storage Volume (ac-ft)
200,000
160,000
120,000
80,000
40,000
0
100
90
80
70
60
50
40
30
20
10
0
Exceedance Percentage (%)
10/1 to 10/15
10/16 to 10/31
11/1 to 11/15
11/16 to 11/30
12/1 to 2/28
Full Flood Storage

Figure 6

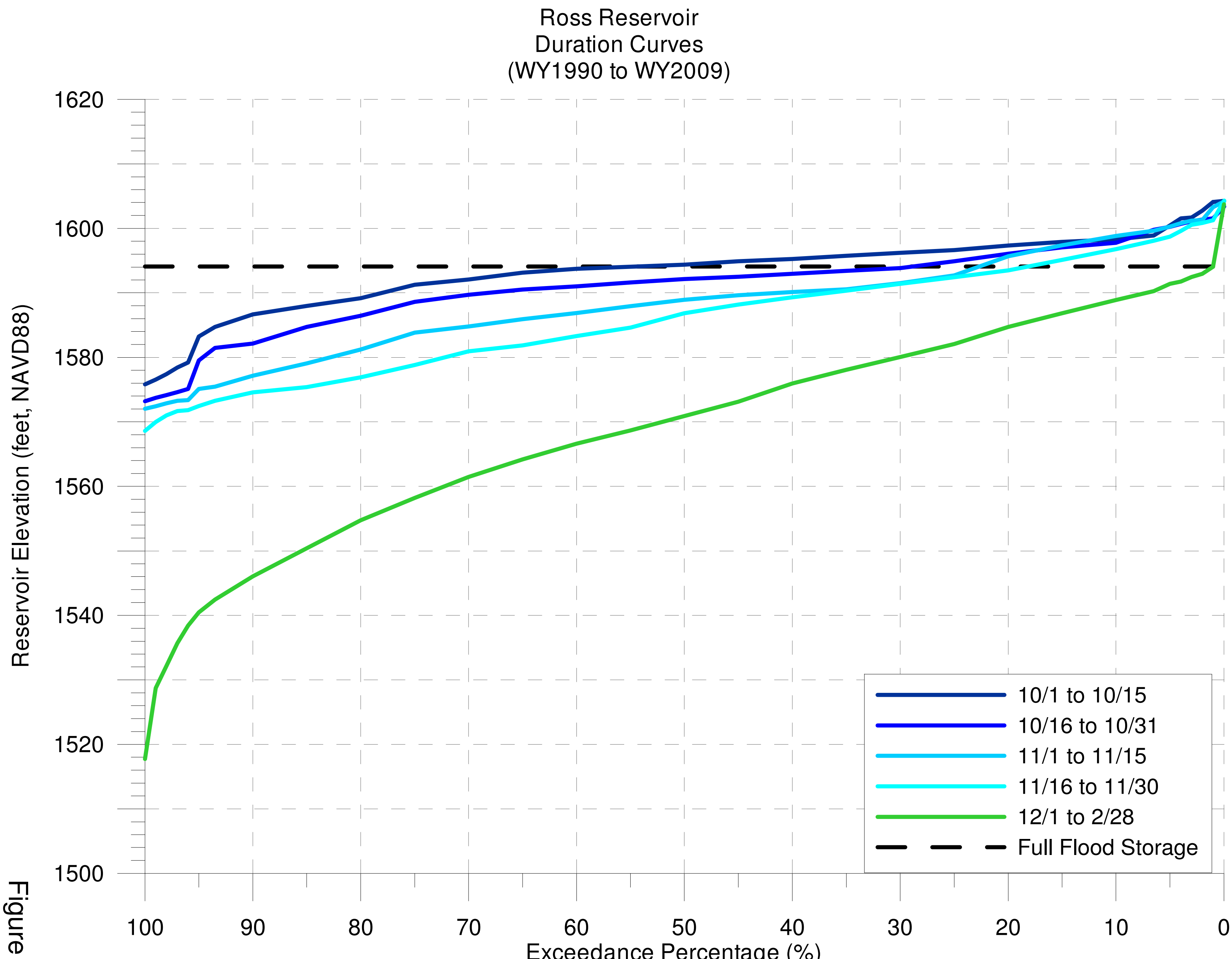
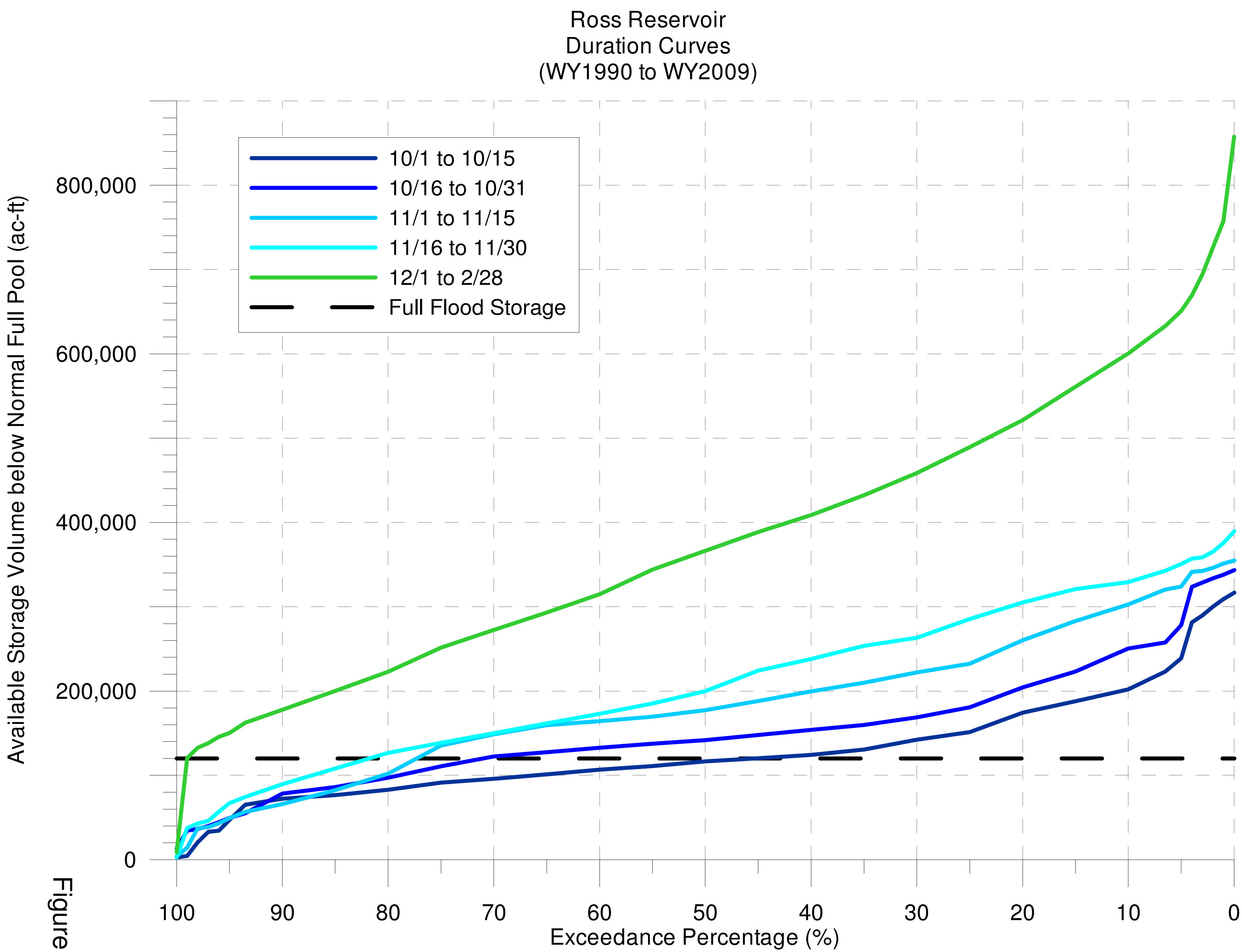

Ross Reservoir
Duration Curves
(WY1990 to WY2009)
Reservoir Elevation (feet, NAVD88)
1620
1600
1580
1560
1540
1520
1500
100
90
80
70
60
50
40
30
20
10
0
Exceedance Percentage (%)
10/1 to 10/15
10/16 to 10/31
11/1 to 11/15
11/16 to 11/30
12/1 to 2/28
Full Flood Storage

Figure 7



Ross Reservoir
Duration Curves
(WY1990 to WY2009)
10/1 to 10/15
10/16 to 10/31
11/1 to 11/15
11/16 to 11/30
12/1 to 2/28
Full Flood Storage
Available Storage Volume below Normal Full Pool (ac-ft)
800,000
600,000
400,000
200,000
0
100
90
80
70
60
50
40
30
20
10
0
Exceedance Percentage (%)

Figure 8

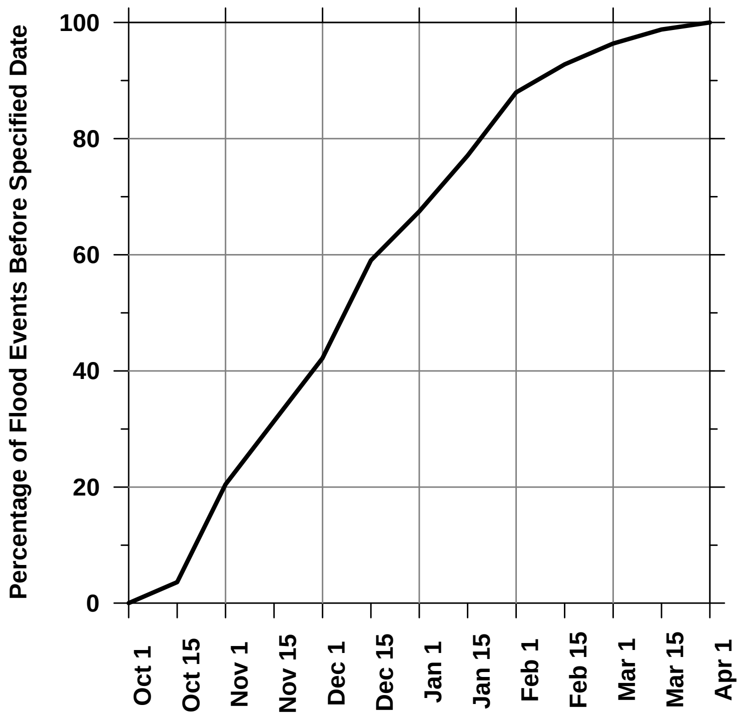


Figure 9: Cumulative seasonal distribution of winter floods.

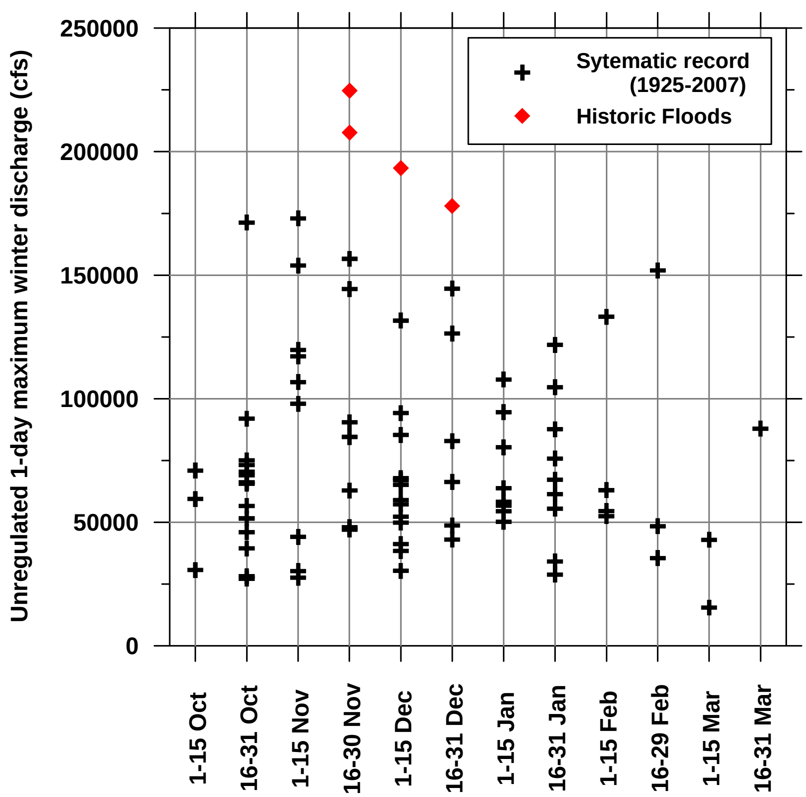


Figure 10: Magnitude and seasonal distribution of winter floods.

Appendix B

Evaluation Area Studies Report
Joe Leary Slough
(from USACE, 2002)

4.2.9 Joe Leary Slough

The minimum alternative at this slough includes the setback of the north levee downstream of the existing tide gate (approximately 200 feet), revegetation of the levees, natural marsh recovery, and placement of LWD.

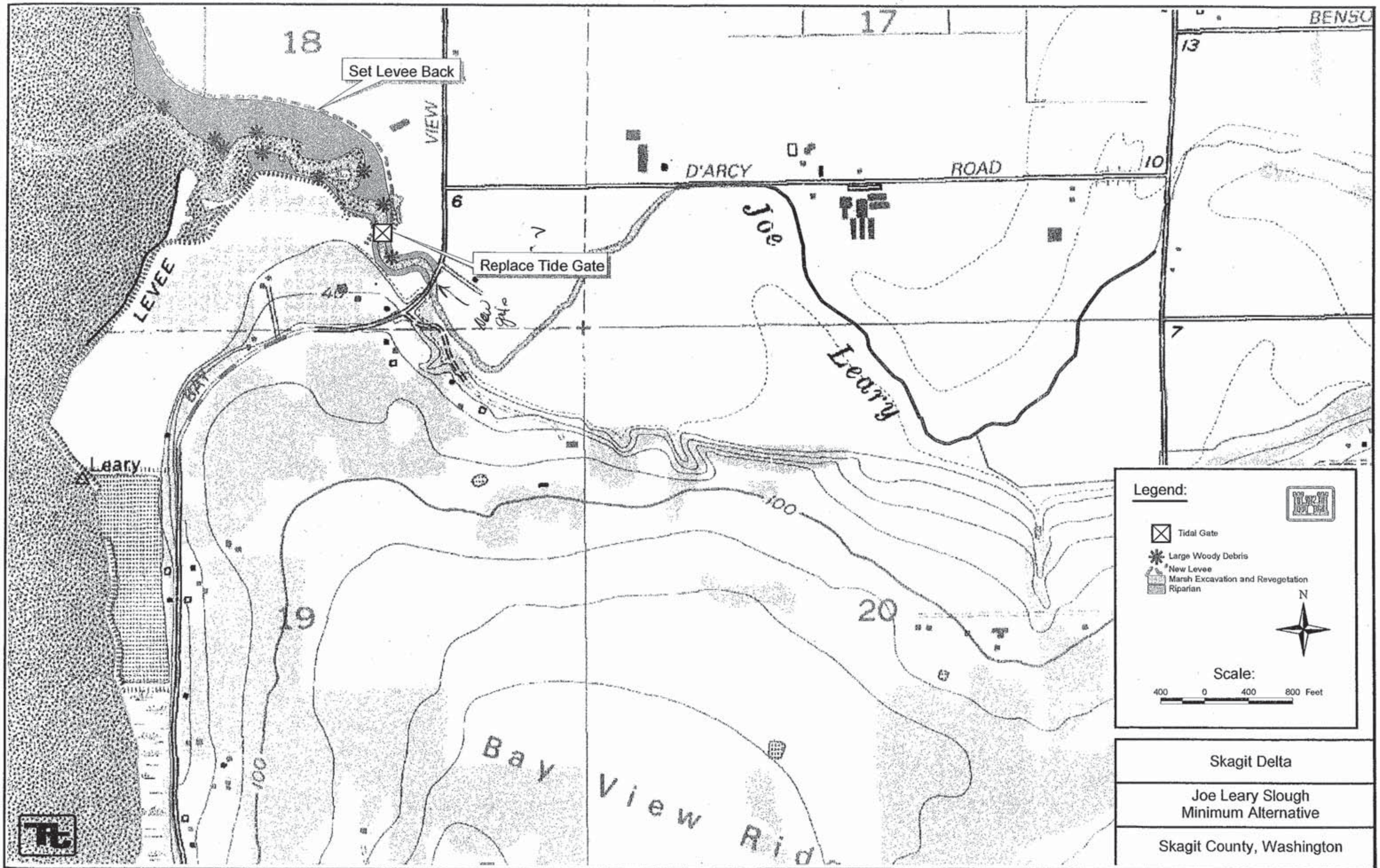
The moderate alternative includes all of the measures in the minimum alternative. However, the north bank levee setback is greater (approximately 500 feet), the tide gate will be replaced with a self-regulating tide gate, and a riparian buffer is included on both banks (approximately 100 feet wide) from Bayview Edison Road crossing up to D'arcy Road.

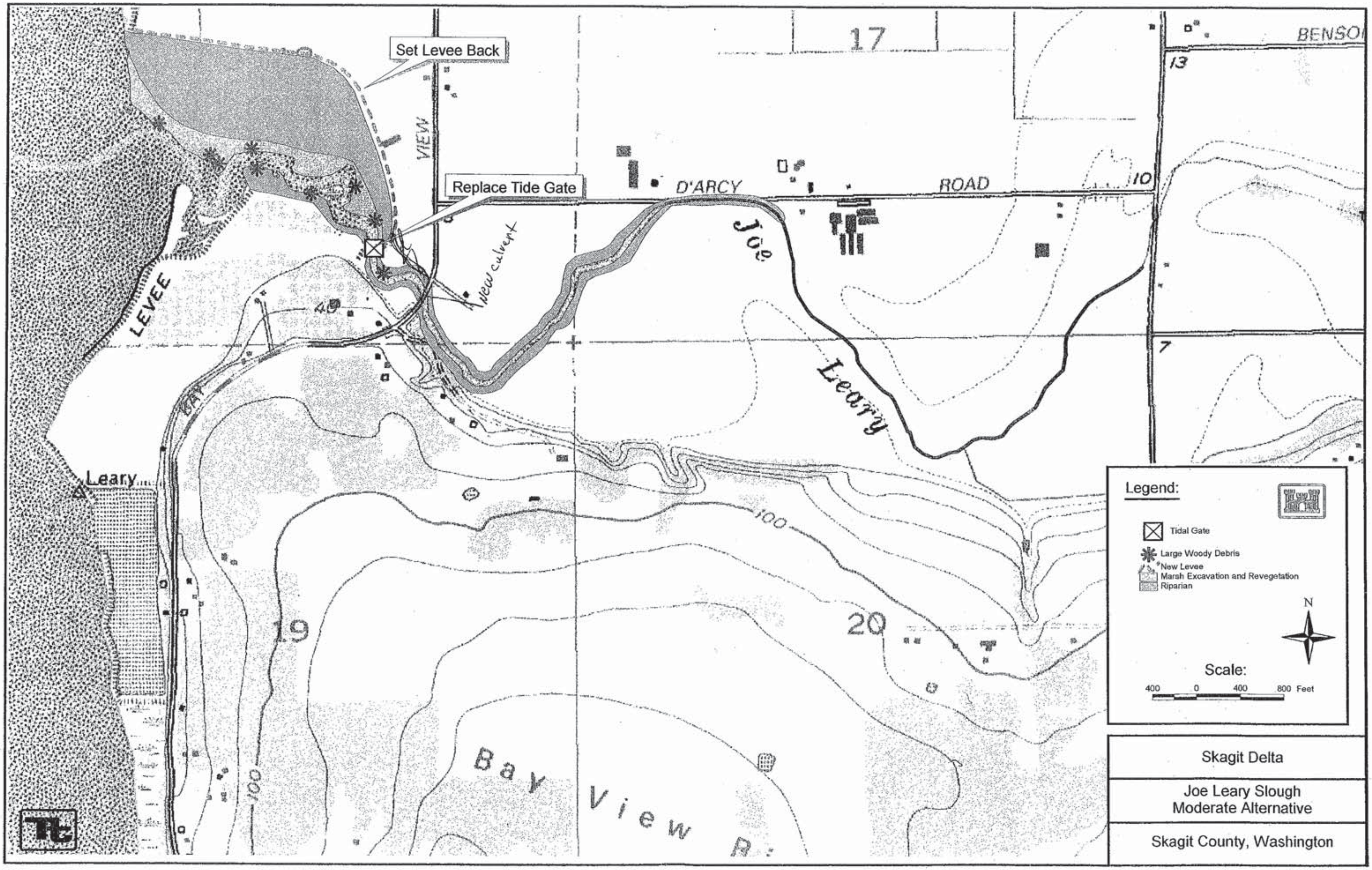
The maximum alternative includes all of the measures from the moderate alternative. However, the north bank levee will be setback by approximately 1000 feet, the channel upstream of the road crossing will be realigned to a more natural meandering pattern, and the riparian buffer along the channel will extend to approximately 200 feet.

Summary of Joe Leary Slough Alternatives

Restoration Elements	**Minimum**	**Moderate**	**Maximum**
North Bank Levee	Setback 200' west of tide gate	Setback 500' west of tide gate	Setback 1000' west of tide gate
Tide Gates		Replace existing with SRT	Replace existing with SRT
Channel Realignment			Re-meander channel away from D'arcy Road by 200'
Riparian Revegetation	Levees	100' east of tide gate to D'arcy Road	200' east of tide gate

All Alternatives Include:	• Placement of LWD • Riparian revegetation along levees downstream of tide gate • Marsh recovery • Removal of non-native plants


18
17
13
10
7
6
19
20
Set Levee Back
Replace Tide Gate
VIEW
D'ARCY
ROAD
BENSO
Joe
Leary
LEVEE
Leary
BAY
100
40
Bay View Rid
Legend:
Tidal Gate
Large Woody Debris
New Levee
Marsh Excavation and Revegetation
Riparian
N
Scale:
400
0
400
800 Feet
Skagit Delta
Joe Leary Slough
Minimum Alternative
Skagit County, Washington



Set Levee Back
Replace Tide Gate
New culvert
VIEW
D'ARCY
ROAD
17
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10
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Joe
Leary
LEVEE
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BAY
40
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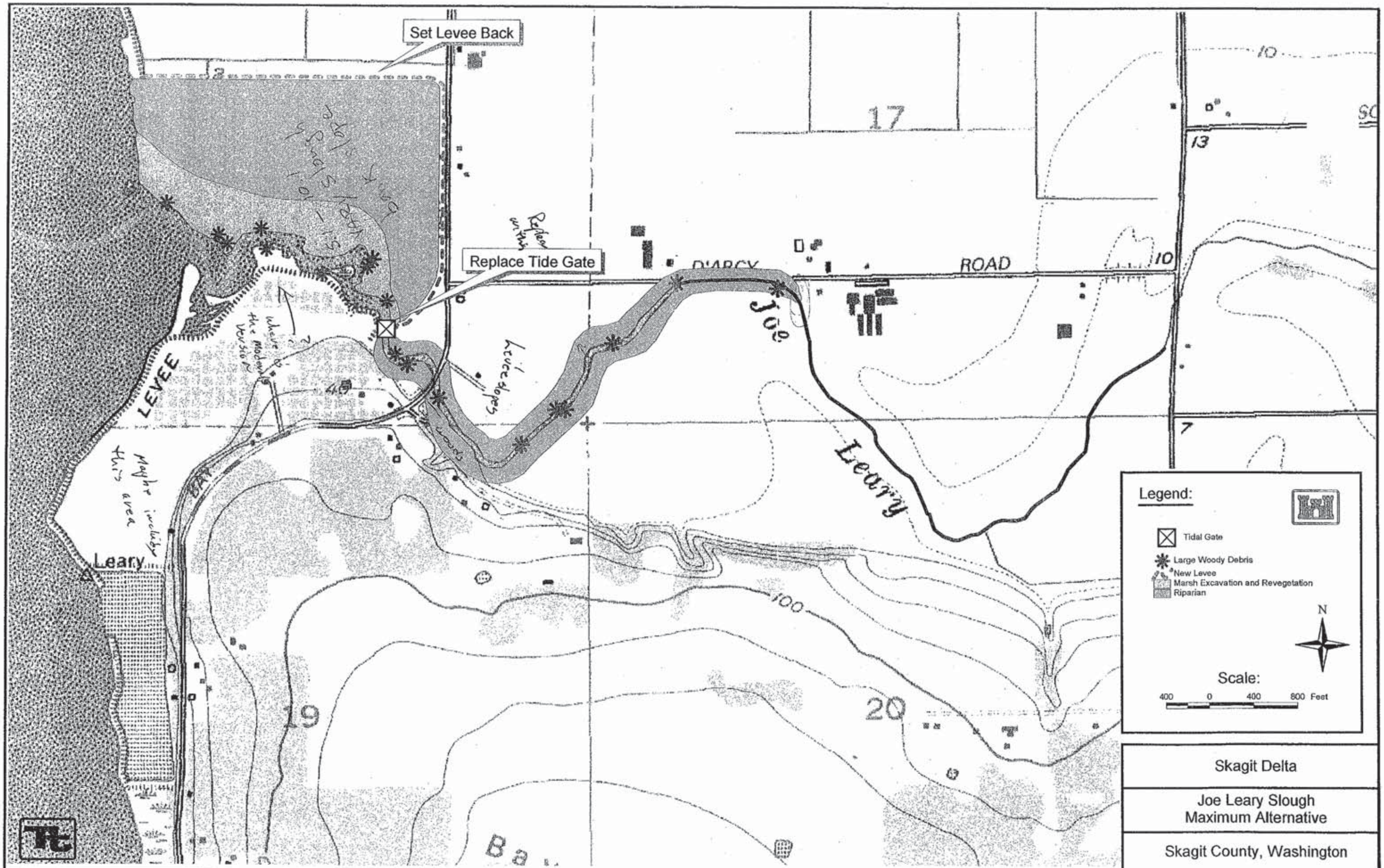
Bay View R
Legend:
Tidal Gate
Large Woody Debris
New Levee
Marsh Excavation and Revegetation
Riparian
N
Scale:
400 0 400 800 Feet
Skagit Delta
Joe Leary Slough
Moderate Alternative
Skagit County, Washington



Set Levee Back
Replace Tide Gate
D'ARCY ROAD
Joe Leary
LEVEE
Leary
17
13
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100
Legend:
Tidal Gate
Large Woody Debris
New Levee
Marsh Excavation and Revegetation
Riparian
N
Scale:
400 0 400 800 Feet
Skagit Delta
Joe Leary Slough
Maximum Alternative
Skagit County, Washington