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Skagit River Flood Damage Reduction Study

Hydraulic Measure Evaluation

US Army Corps of Engineers
Linda Smith, Project Manager and Ted Perkins, Hydraulic Engineer
Skagit County

US Army Corps of Engineers

Skagit River Flood Damage Reduction Study

Evaluation Process

1)Measures – Identify and Screen

2)Combine into Alternatives

3)Screen Alternatives (Econ, Environmental, Socio/cultural, Engineering)

4)Select for Detailed Design and Evaluation

5)Recommended Plan for Federal Implementation

6)Workshops, Scoping Meetings

7)Variety of floods evaluated – 5-500. Do not just focus on 100 year

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Status

- Identified measures
- Modeled measure ability to reduce flood stages (today's discussion)
- Complete preliminary costs for measures (Jan)
- Model damages prevented by each measure (Jan-early Feb)
- Compare measure costs to damages reduced – without real estate(Feb)

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Purpose of a Flood Damage Reduction Study

Looking to Reduce Flood Damage in a way that:

- Yields Maximum Net Economic Benefit
- Performs Efficiently and Effectively, Even Under Extreme Events
- Protects the Environment

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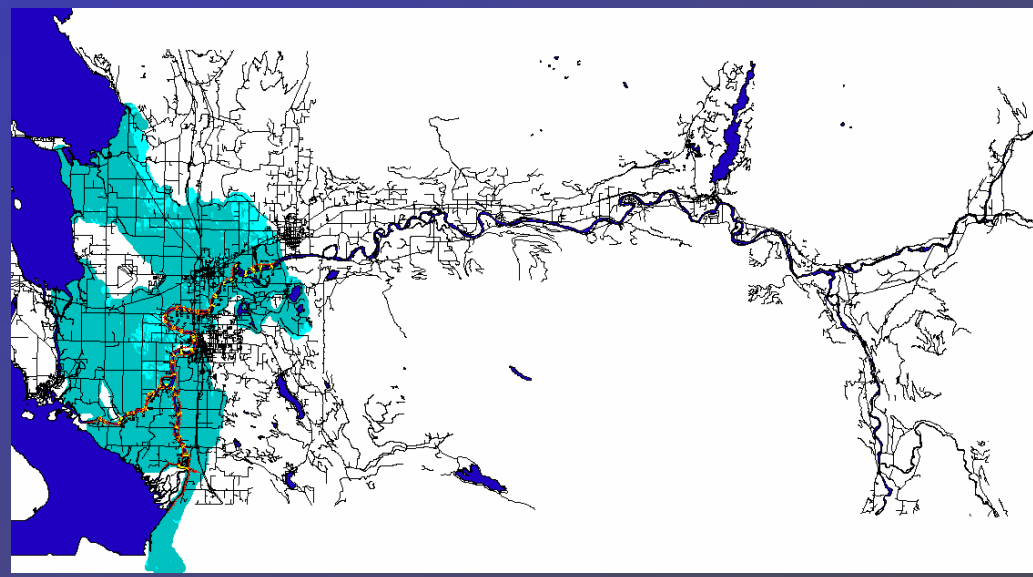
How Hydrology and Hydraulics are Used in a Flood Damage Reduction Study

- Determine Areas Vulnerable to Flooding
- Determine Extent of Existing Condition Damages
- Evaluate How Well Proposed Measures Work and Change the River



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Defining Flood Events

Flood Event	Recurrence	Chance of Occurrence
10-year	10%	1 in 10
25-year	4%	1 in 25
50-year	2%	1 in 50
100-year	1%	1 in 100
500-year	0.2%	1 in 500

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Skagit River Regulated Instantaneous Peak Flows

Recurrence	at Concrete Gage (cfs)	at Sedro-Woolley (cfs)	at Mount Vernon Gage (cfs)	MV Gage Stage (ft)
10-year	120,400	125,100	117,400	34.90
25-year	158,000	163,400	146,000	38.04
50-year	192,100	198,500	190,900	42.35
100-year	235,400	242,000	230,100	45.90
500-year	386,900	380,800	346,400	55.03

Flows at Mount Vernon are only if flows do not break through levee system.
Current Levees have roughly a 160,000 cfs capacity

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Different Ways to View the Problem and Potential Solutions

- Too Much Water
- Not Enough Space for Water to flow
- Flood Protection along river needs to be improved
- Reduced Development in flood prone areas

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Flood Damage Reduction Study Measures

- Dams
- Off-Channel Storage
- Diversions and Sloughs
- Ring Dikes
- Improved Levees
- Levee Setbacks
- Dredging
- Non-Structural
- Debris Management

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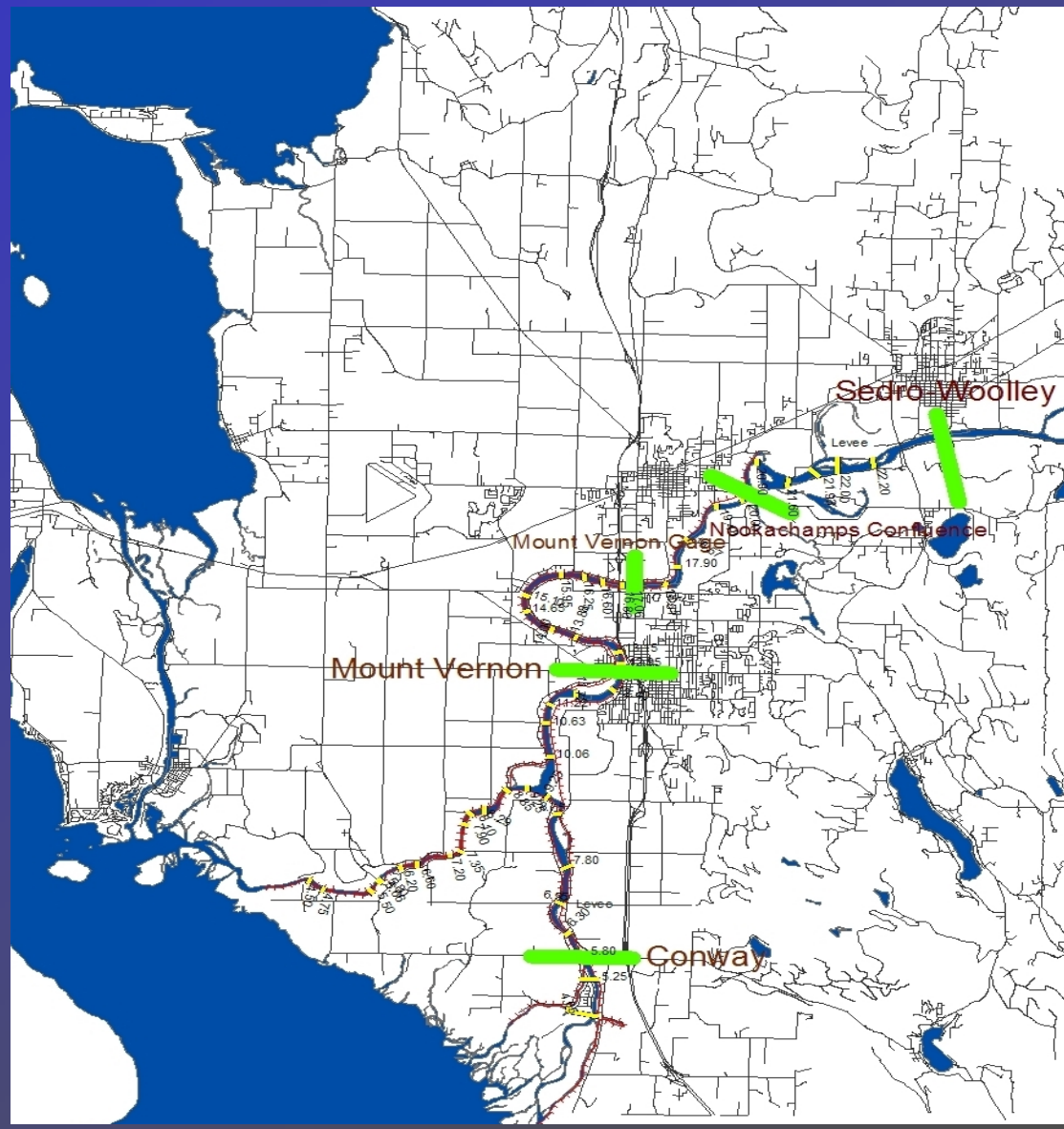
Locations of Interest

- Sedro-Woolley
- Nookachamps Confluence
- Mount Vernon Gage
- Mount Vernon at Division Street Bridge
- Conway



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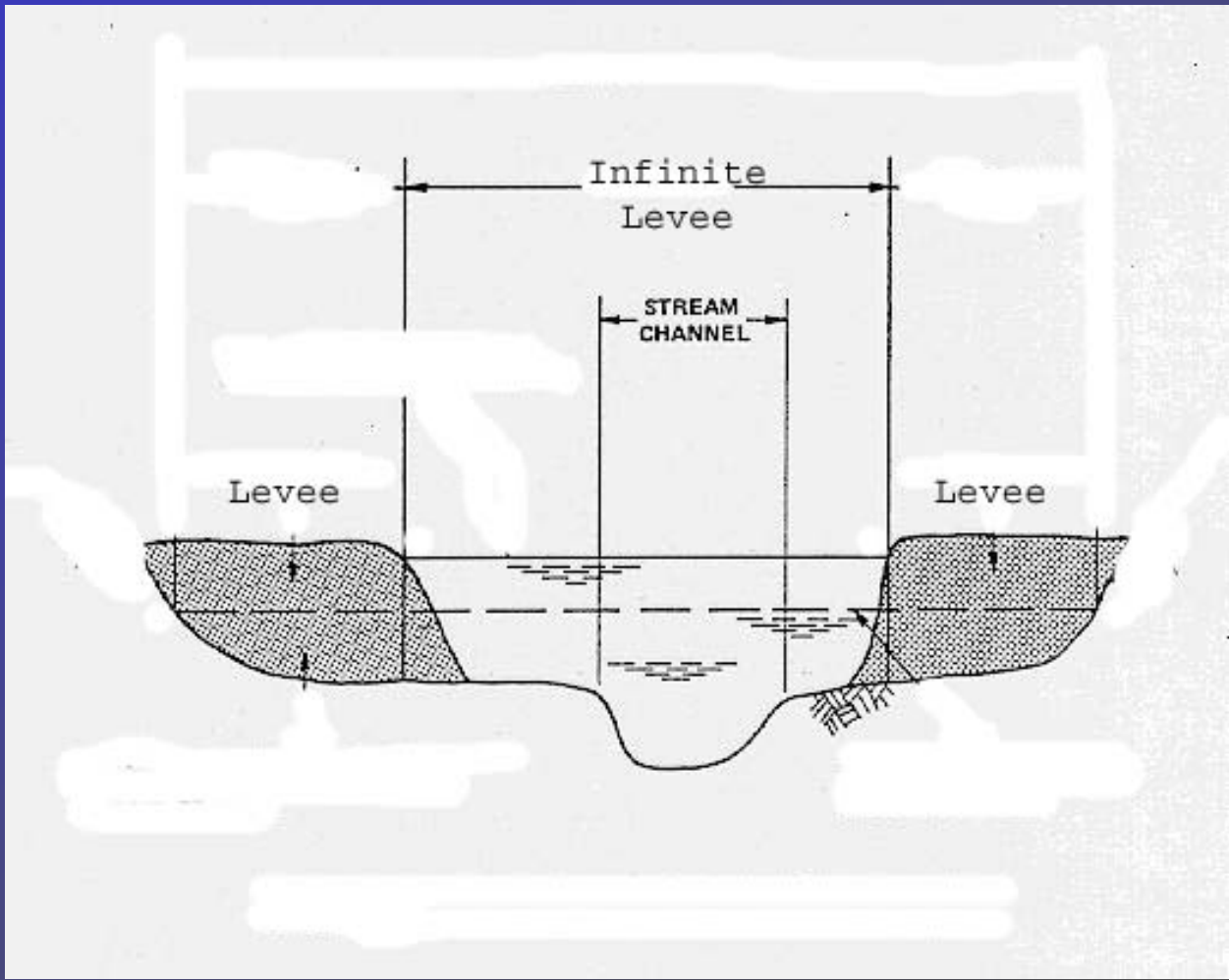
Infinite Levee Comparison

- Used to evaluate how close protection is to keeping water within the levees



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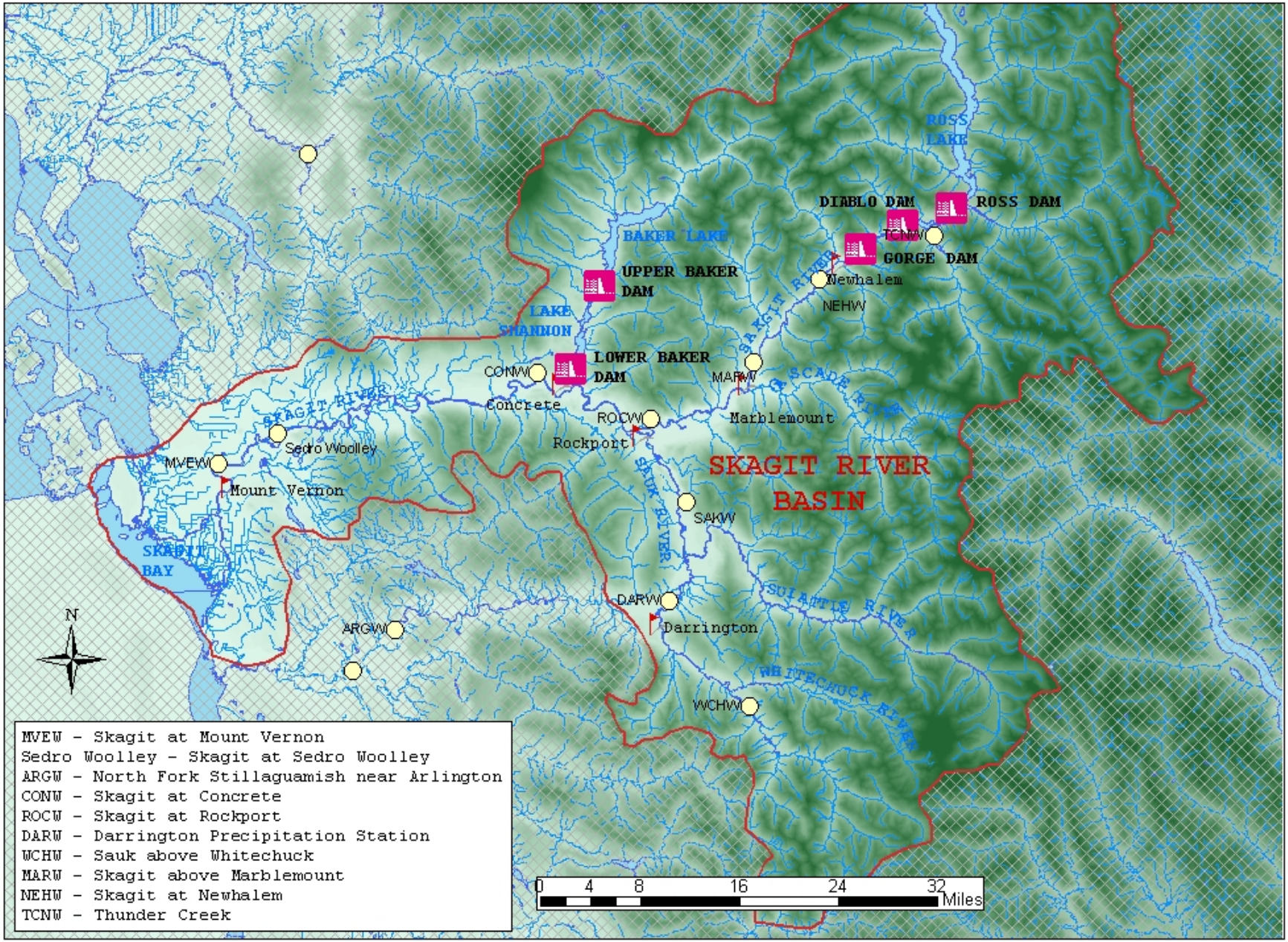
Dams

- Upper Baker Dam
- Lower Baker Dam
- Ross Dam
- Diablo Dam
- Gorge Dam

- New Dams


ROSS LAKE
DIABLO DAM
ROSS DAM
TCNW
GORGE DAM
BAKER LAKE
UPPER BAKER DAM
Newhalem
NEHW
SKAGIT RIVER
LAKE SHANNON
LOWER BAKER DAM
CONW
Concrete
MARW
SCADE RIVER
ROCW
Rockport
Marblemount
SKAGIT RIVER BASIN
Sedro Woolley
MVEW
Mount Vernon
SAKW
SAUK RIVER
SKAGIT BAY
DARW
Darrington
SUIATTLE RIVER
ARGW
WHITECHUCK RIVER
WCHW
N
0 4 8 16 24 32 Miles
MVEW - Skagit at Mount Vernon
Sedro Woolley - Skagit at Sedro Woolley
ARGW - North Fork Stillaguamish near Arlington
CONW - Skagit at Concrete
ROCW - Skagit at Rockport
DARW - Darrington Precipitation Station
WCHW - Sauk above Whitechuck
MARW - Skagit above Marblemount
NEHW - Skagit at Newhalem
TCNW - Thunder Creek

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Upper Baker Dam

Measures to Improve Existing Flood Damage Reduction:

- Reduced Minimum Outflow (5,000 cfs to 0 cfs)
- Additional Storage
- Flood Storage Timing
- Pre-Flood Event Drawdown
- Dam Modifications (Added Outflow Capacity)

Upper Baker Dam Average Existing Condition Outflow

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Recur-rence	Upper Baker Peak Inflow (cfs)	Upper Baker Inflow Contributing to Peak (cfs)	Upper Baker Outflow Contributing to Peak (cfs)	If Outflow is cut to zero
10-year	27,900	16,400	5,000	0
25-year	35,900	23,700	5,000	0
50-year	42,900	28,400	5,000	6,500
100-year	50,800	33,700	9,000	17,500
500-year	73,400	49,000	49,000	49,000

Upper Baker Dam Average Existing Condition Outflow

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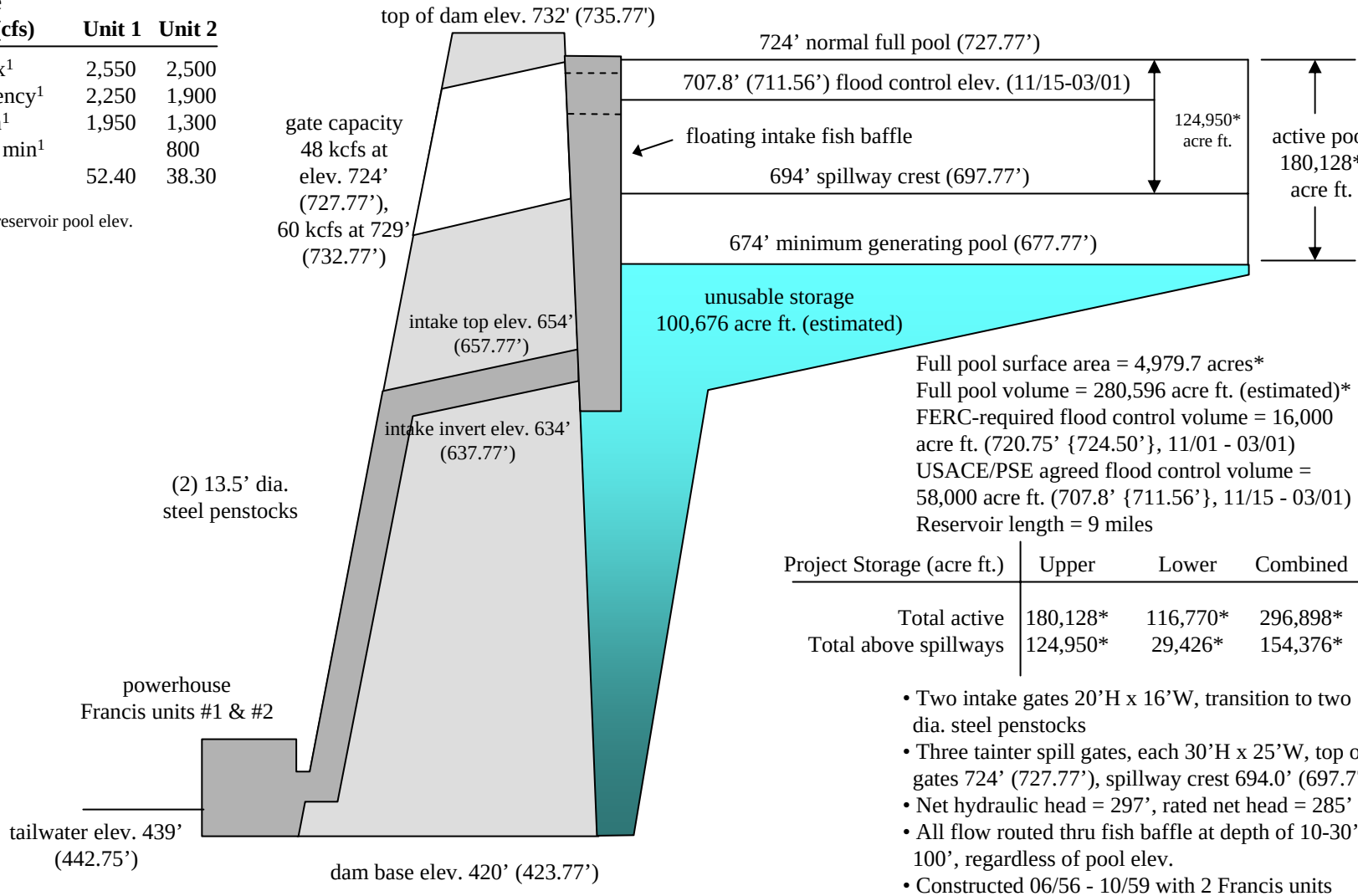
Recur-rence	Existing Condition Outflow (cfs)	Minimum Outflow to zero (cfs)	Storage Added to 85K	Storage Added to 100K
10-year	5,000	0	0	0
25-year	5,000	0	0	0
50-year	5,000	6,500	0	0
100-year	9,000	17,500	10,500	7,500
500-year	49,000	49,000	49,000	49,000

Upper Baker Dam

Section View - Not to Scale

Turbine Operation (cfs)	Unit 1	Unit 2
normal max[1]	2,550	2,500
peak efficiency[1]	2,250	1,900
normal min[1]	1,950	1,300
emergency min[1]		800
MW	52.40	38.30

1 varies with reservoir pool elev.



NGVD 29 Elevations (NAVD 88 Elevations)

Full pool surface area = 4,979.7 acres*
Full pool volume = 280,596 acre ft. (estimated)*
FERC-required flood control volume = 16,000 acre ft. (720.75' {724.50'}, 11/01 - 03/01)
USACE/PSE agreed flood control volume = 58,000 acre ft. (707.8' {711.56'}, 11/15 - 03/01)
Reservoir length = 9 miles

Project Storage (acre ft.)	Upper	Lower	Combined
Total active	180,128*	116,770*	296,898*
Total above spillways	124,950*	29,426*	154,376*

- Two intake gates 20'H x 16'W, transition to two 13.5' dia. steel penstocks
- Three tainter spill gates, each 30'H x 25'W, top of gates 724' (727.77'), spillway crest 694.0' (697.77')
- Net hydraulic head = 297', rated net head = 285'
- All flow routed thru fish baffle at depth of 10-30' & 100', regardless of pool elev.
- Constructed 06/56 - 10/59 with 2 Francis units
- Concrete gravity dam 1200' long, 312' high
- 12' roadway at elev. 732' (735.77')

**** Reservoir pool volumes and full pool surface areas have been adjusted using reservoir storage-elevation relationships updated as of May 2003 based on 2001 survey data.***

Filename: dams schematics 060903

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Outflow Capacity Limitation

Upper Baker Pool Elevation (ft NAVD 88)	711.56	708.83	704.92
Upper Baker Storage Space (acre-feet)	74,000	85,000	100,000
Maximum Outflow (cfs)	17,269	12,958	8,402

Flood Flows (>90K) on Skagit River versus Flood Storage Availability

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Peak Flows Occurring Before	October 15th	October 31st	November 15th	December 1st
Percentage	2.4%	17.6%	24.7%	35.3%
Upper Baker Storage	0	16,000	74,000	74,000
Ross Storage	20,000	43,000	60,000	120,000

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Lower Baker Dam

Flood Damage Reduction Measures:

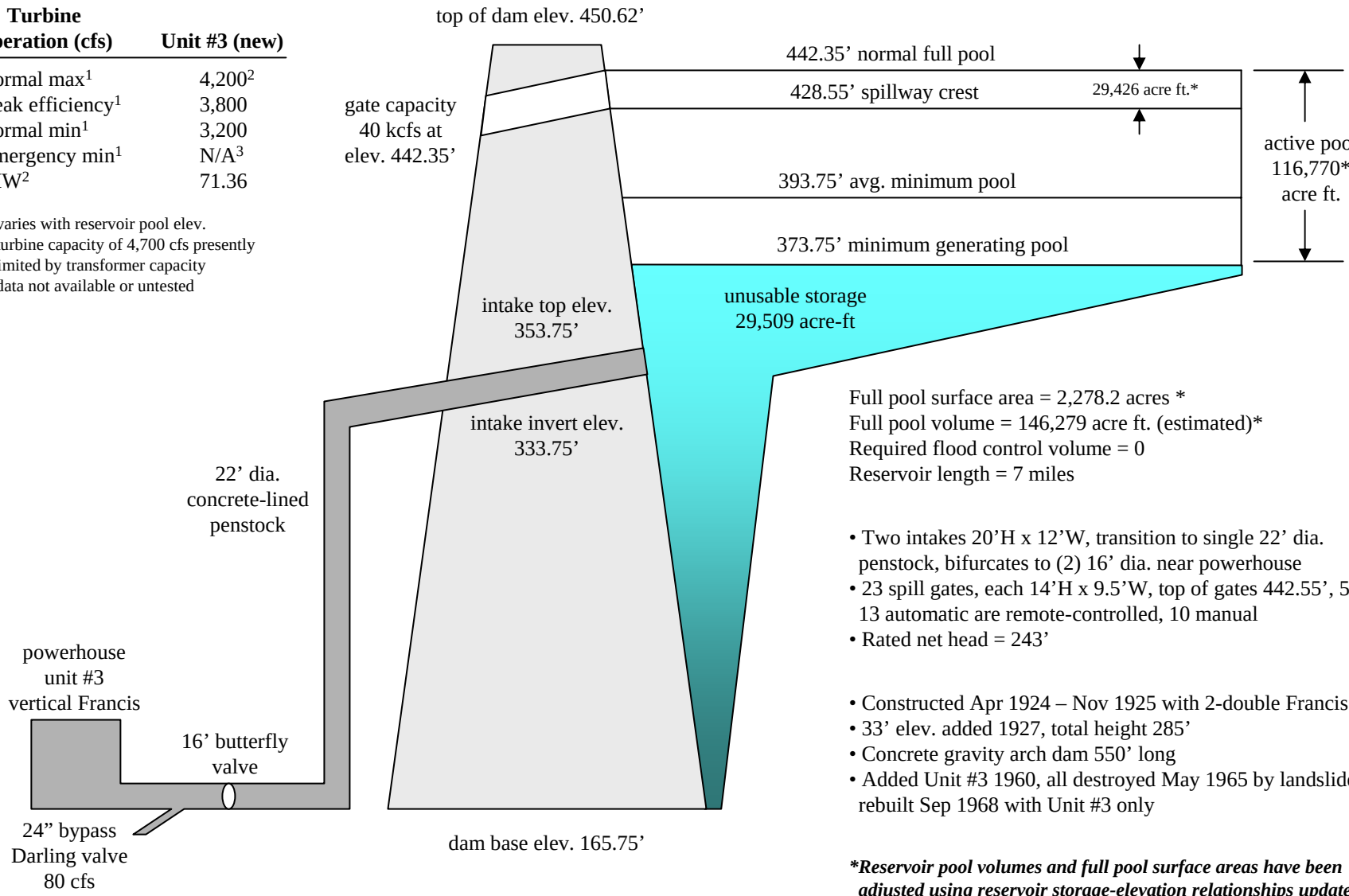
- Adding Flood Storage
- Pre-Flood Event Drawdown
- Dam Modifications (Added Outflow Capacity)

Lower Baker Dam

Section View - Not to Scale

Turbine Operation (cfs)	Unit #3 (new)
normal max[1]	4,200[2]
peak efficiency[1]	3,800
normal min[1]	3,200
emergency min[1]	N/A[3]
MW[2]	71.36

1 varies with reservoir pool elev.
2 turbine capacity of 4,700 cfs presently limited by transformer capacity
3 data not available or untested



NAVD 88 Elevations

Full pool surface area = 2,278.2 acres *
Full pool volume = 146,279 acre ft. (estimated)*
Required flood control volume = 0
Reservoir length = 7 miles

- Two intakes 20'H x 12'W, transition to single 22' dia. penstock, bifurcates to (2) 16' dia. near powerhouse
- 23 spill gates, each 14'H x 9.5'W, top of gates 442.55', 5 of 13 automatic are remote-controlled, 10 manual
- Rated net head = 243'

- Constructed Apr 1924 – Nov 1925 with 2-double Francis units
- 33' elev. added 1927, total height 285'
- Concrete gravity arch dam 550' long
- Added Unit #3 1960, all destroyed May 1965 by landslide, rebuilt Sep 1968 with Unit #3 only

Reservoir pool volumes and full pool surface areas have been adjusted using reservoir storage-elevation relationships updated as of May 2003 based on 2001 survey data.

Filename: dams schematics_new elevations_ 092603

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Outflow Capacity Limitation

Lower Baker Pool Elevation (ft NAVD 88)	435.54	428.55	420.52
Lower Baker Storage Space (acre-feet)	14,500	29,400	45,000
Maximum Outflow (cfs)	17,450	4,000	4,000

Lower Baker 25-year Regulation

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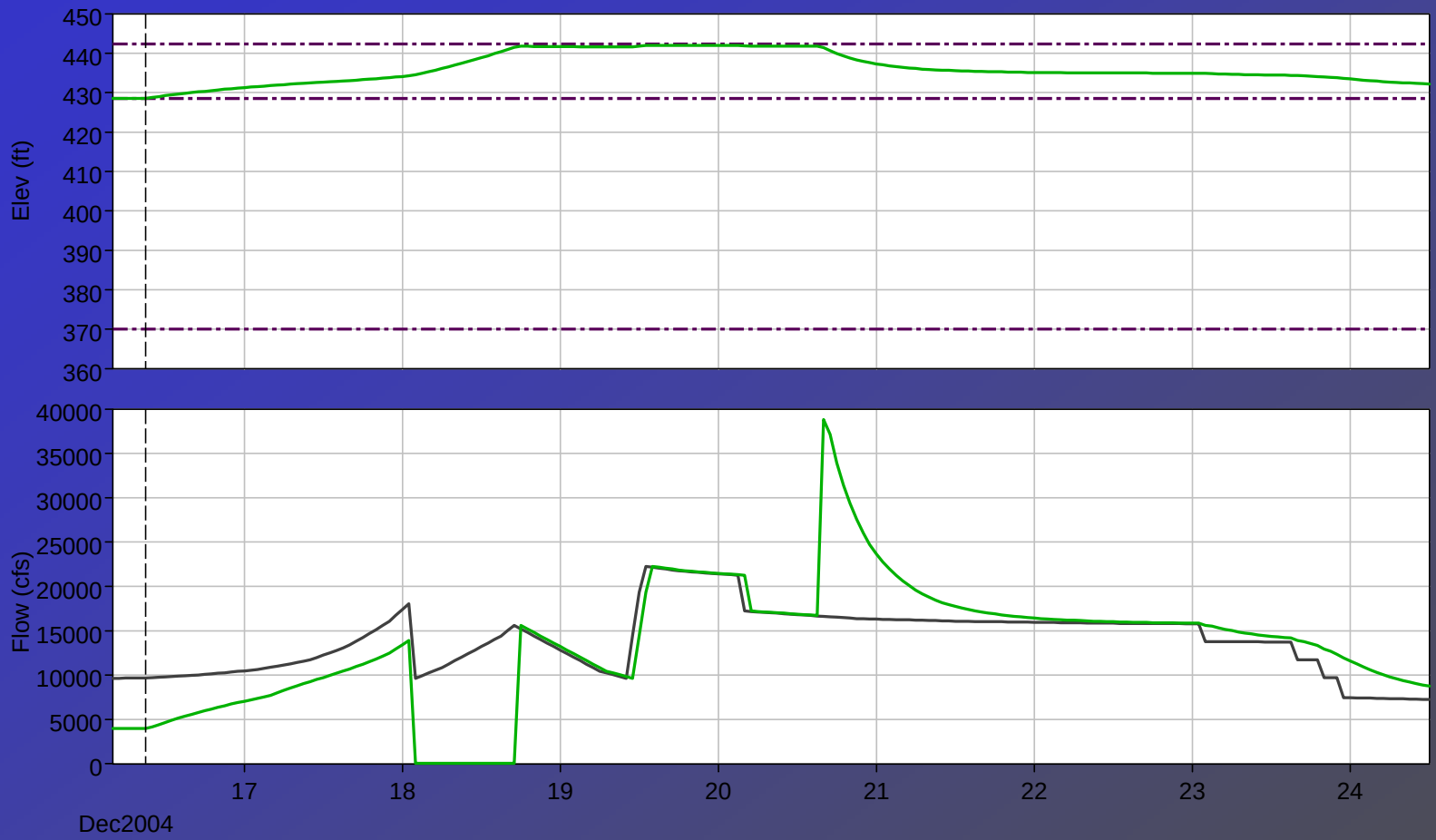

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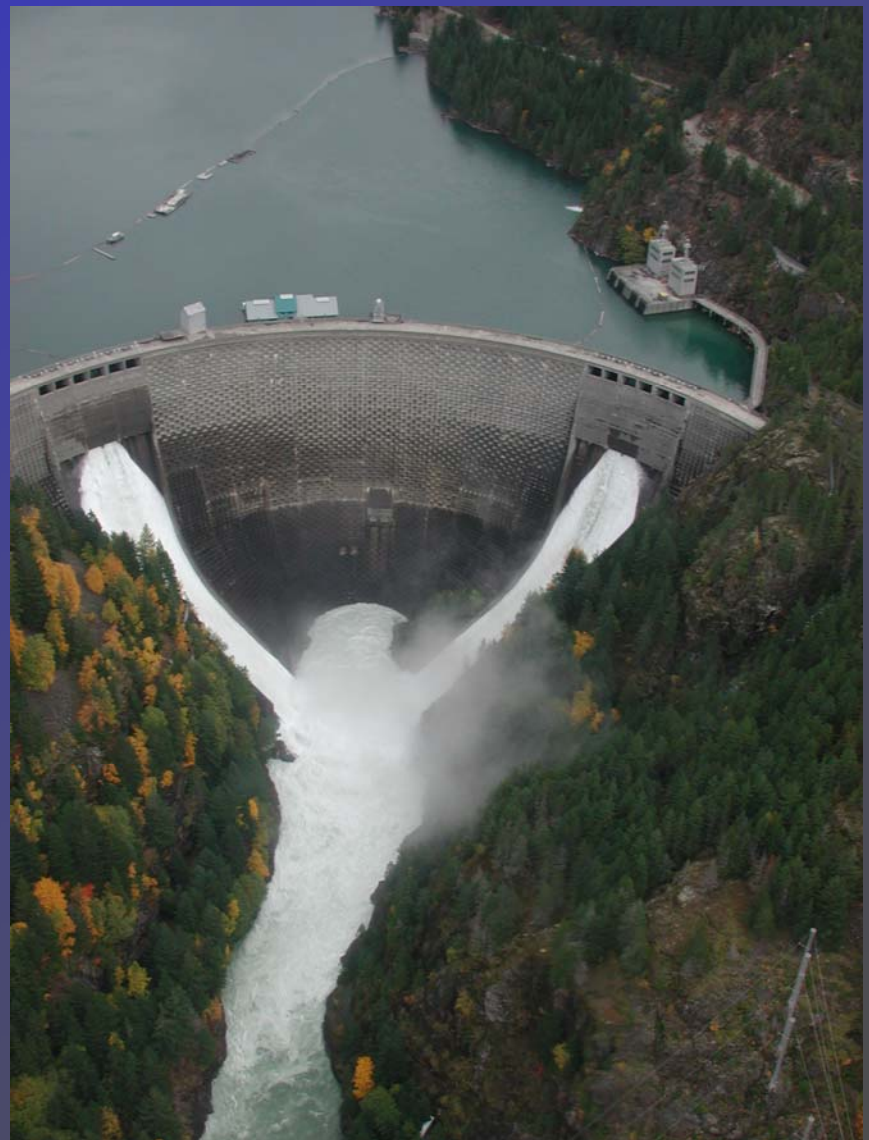
Ross Dam

Measures to Improve Existing Flood Damage Reduction:

- Additional Storage
- Flood Storage Timing
- Pre-Flood Event Drawdown



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Ross Dam Average Existing Condition Outflow

Recur-rence	Ross Peak Inflow (cfs)	Ross Inflow Contributing to Peak (cfs)	Ross Outflow Contributing to Peak (cfs)
10-year	32,400	28,300	0
25-year	45,040	38,460	0
50-year	56,100	47,990	0
100-year	68,540	58,400	13,500
500-year	104,200	88,670	36,500

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Diablo Dam

- Storage available between Normal Full Pool and Minimum Power Pool = 6,988 acre-feet

(Elev. 1197 to 1205)

- Volume per hour released from Ross before the storm ~2000 acre-feet

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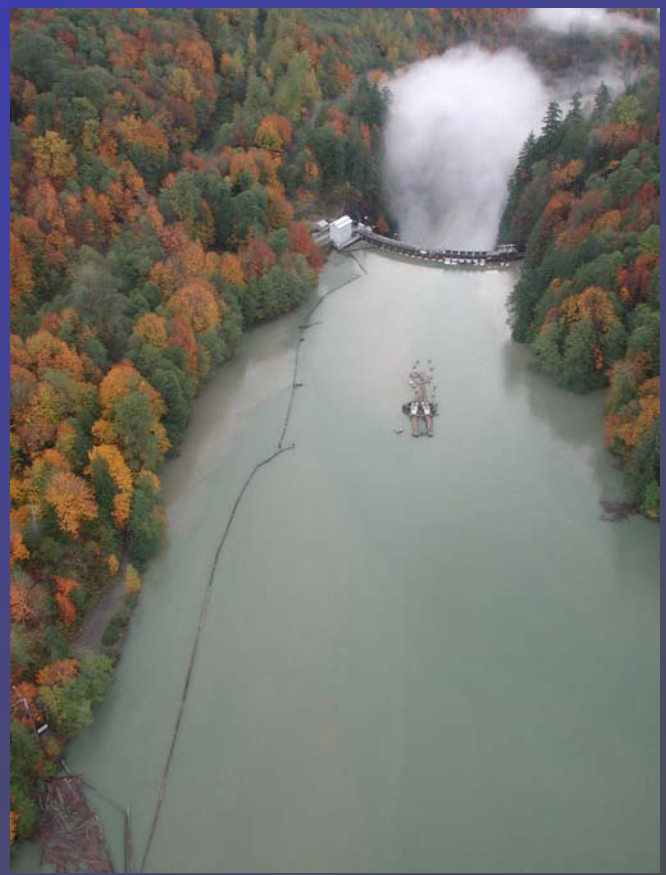
Gorge Dam

- Storage available between Normal Full Pool and Minimum Power Pool = 1,347 acre-feet

(Elev. 869 to 875)



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New Dams

- Sauk River Dam
- Cascade River Dam

Both are Wild and Scenic Rivers which do not allow dams

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Off-Channel Storage

- Cockreham Island (RM 35 to RM 39) – 5,400 acre-feet
- River Bend – (RM 13 to 17) – 4,000 acre-feet

Fills up in less than an hour at peak of 100-year

- Nookachamps
- Hart's Slough

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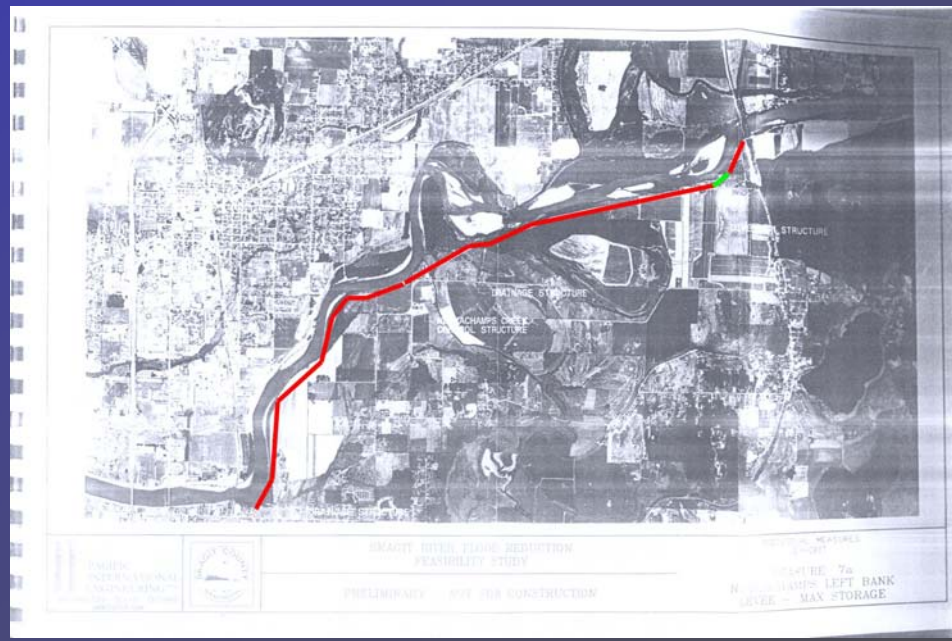
Nookachamps

- Contained up to 48 feet NGVD 29
- Gate closed until flows reach 140,000 cfs and then completely opens
- Gate is 300 feet wide and 15 feet high
- Storage = 98,000 acre-feet at an elevation of 48 feet NGVD 29



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Hart's Slough

- Contained up to 48 feet NGVD 29
- Gate closed until flows reach 140,000 cfs and then completely opens
- Gate is 170 feet wide and 15 feet high
- Storage = 17,000 acre-feet at an elevation of 48 feet NGVD 29

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Off-Channel Storage

Location	Existing Condition 100-year Elevation (ft)	Nooka-champs 100-year Storage Elevation (ft)	Hart's Slough 100-year Storage Elevation (ft)	Existing Condition 10-year Elevation (ft)	Nooka-champs Storage 10-year Elevation (ft)	Hart's Slough 10-year Storage Elevation (ft)
Sedro-Woolley	52.0	54.0 2.0	52.0 0.0	43.7	47.0 3.3	43.8 0.1
Nooka-champs	49.7	49.8 0.1	49.5 0.2	40.2	43.1 2.9	40.4 0.2
Mount Vernon Gage	45.9	43.6 2.3	45.8 0.1	34.9	35.7 0.8	35.1 0.2
Division Street Bridge	36.2	34.3 1.9	36.2 0.0	27.8	28.4 0.6	27.9 0.1
Conway	21.3	20.2 1.1	21.2 0.1	15.7	16.1 0.4	15.8 0.1

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Diversions and Sloughs

- Samish Bypass
- Swinomish Bypass (Avon)
- Mount Vernon Bypass
- Fir Island Slough

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Samish Bypass

- More Excavation than Avon Bypass
- Different Fish Species issues
- Not Currently Being Evaluated

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Avon Bypass

- 2000 feet wide
- 11.4 miles long
- Flows into Swinomish Slough
- Fuse Plug – Design to Fail Levee
- Starts failing at a stage of 34.5 feet
- 3-Bridge Corridor 500 foot Setback is part of measure

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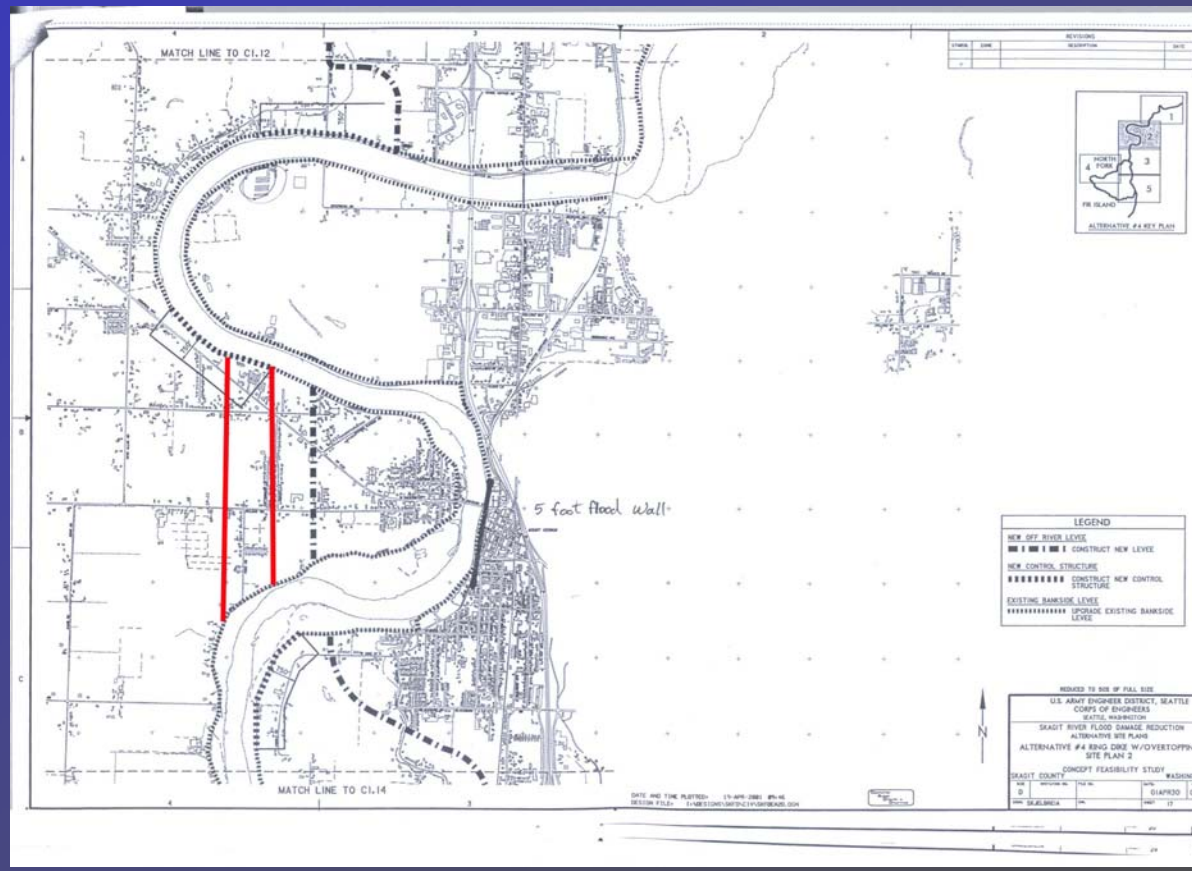
Mount Vernon Bypass

- Overcomes Constriction at Division Street Bridge
- 500 feet wide
- 1 mile long



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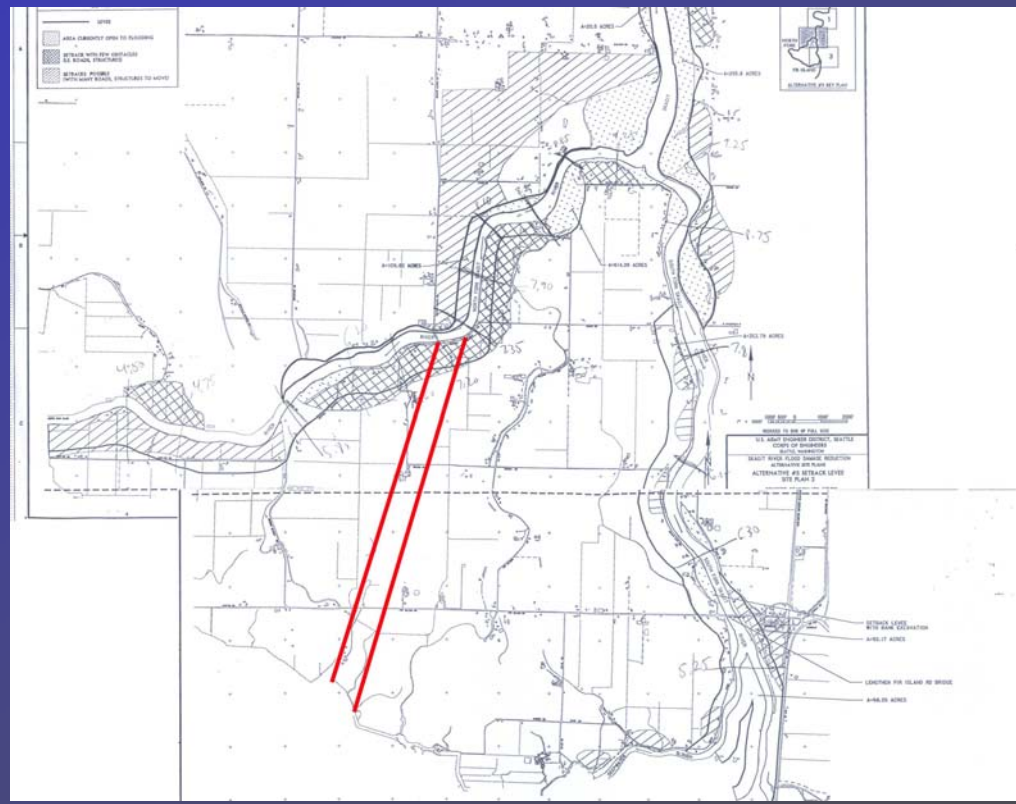
Fir Island Slough

- Overcomes constriction of Lower North Fork
- 500 feet wide
- 14,000 feet long



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Diversions and Sloughs

Location	Existing Condition 100-year Elevation (ft)	Swinomish Diversion Elevation (ft)	Mount Vernon 500 foot Bypass Elevation (ft)	Mount Vernon 1500 foot Bypass Elevation (ft)	Fir Island 500 foot Slough Elevation (ft)
Sedro-Woolley	52.0	49.2 2.8	50.9 1.1	50.8 1.2	51.9 0.1
Nooka-champs	49.7	44.4 5.3	48.0 1.7	47.7 2.0	49.5 0.2
Mount Vernon Gage	45.9	41.6 4.3	44.0 1.9	43.6 2.3	45.7 0.2
Division Street Bridge	36.2	32.9 3.3	34.9 1.3	34.6 1.6	35.7 0.5
Conway	21.3	19.1 2.2	21.4 0.1	21.5 0.2	20.4 0.9

Diversions and Sloughs

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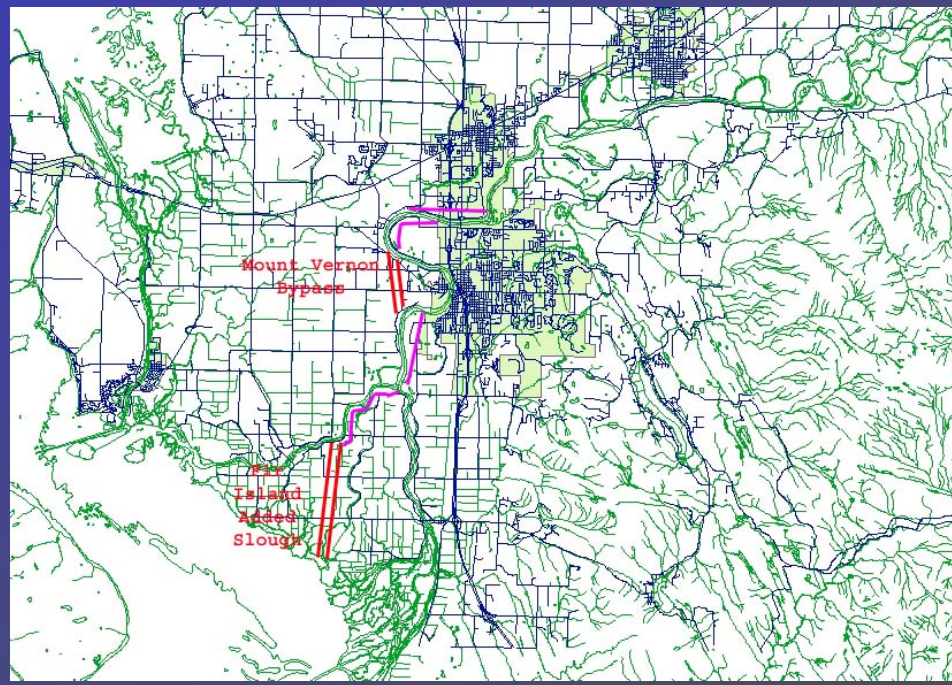
Location	Existing Condition 100-year Elevation (ft)	MV and Fir Island Slough 500 feet Elevation (ft)	MV and Fir Island Slough 1500 feet w/Setback Elevation (ft)
Sedro-Woolley	52.0	50.9 1.1	49.0 3.0
Nooka-champs	49.7	48.0 1.7	43.4 6.3
Mount Vernon Gage	45.9	43.9 2.0	40.6 5.3
Division Street Bridge	36.2	34.4 1.8	32.0 4.2
Conway	21.3	18.5 2.8	18.5 2.8



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Ring Dikes

- Burlington
- North Mount Vernon
- West Mount Vernon
- East Mount Vernon
- LaConner
- Sedro-Woolley
- Sedro-Woolley WWTP
- Anacortes Water Treatment Plant

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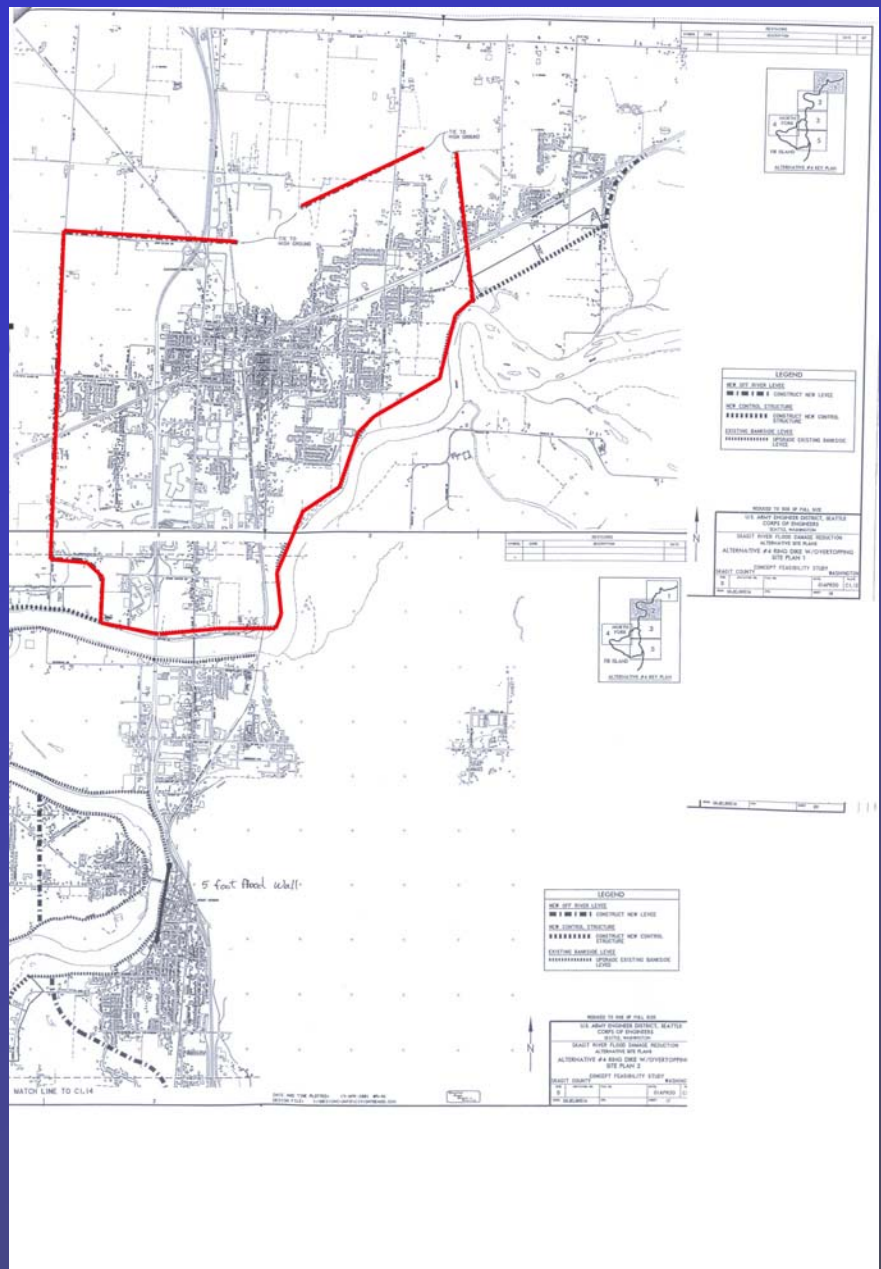
Burlington Ring Dike



North Mount Vernon Ring Dike

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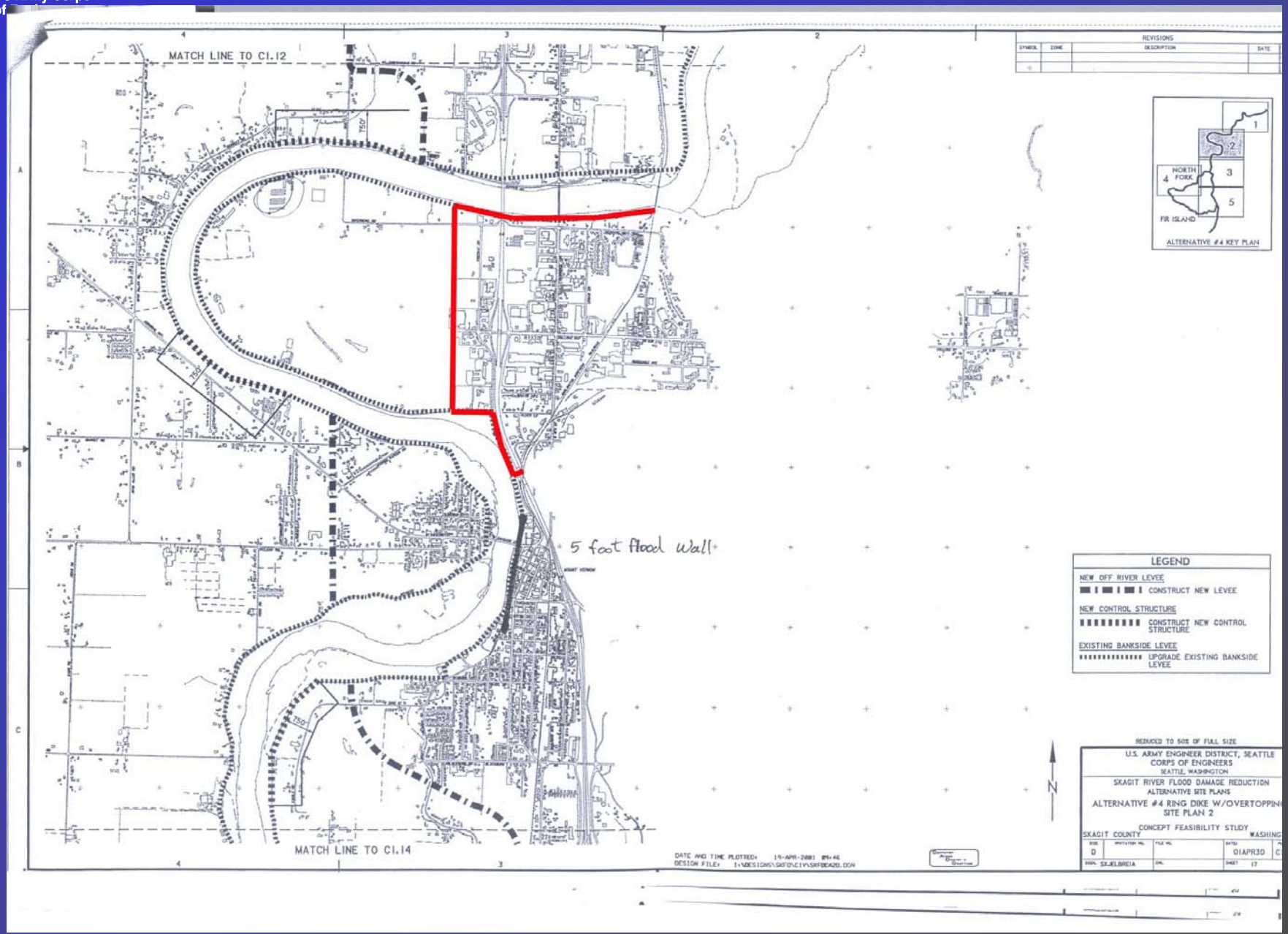

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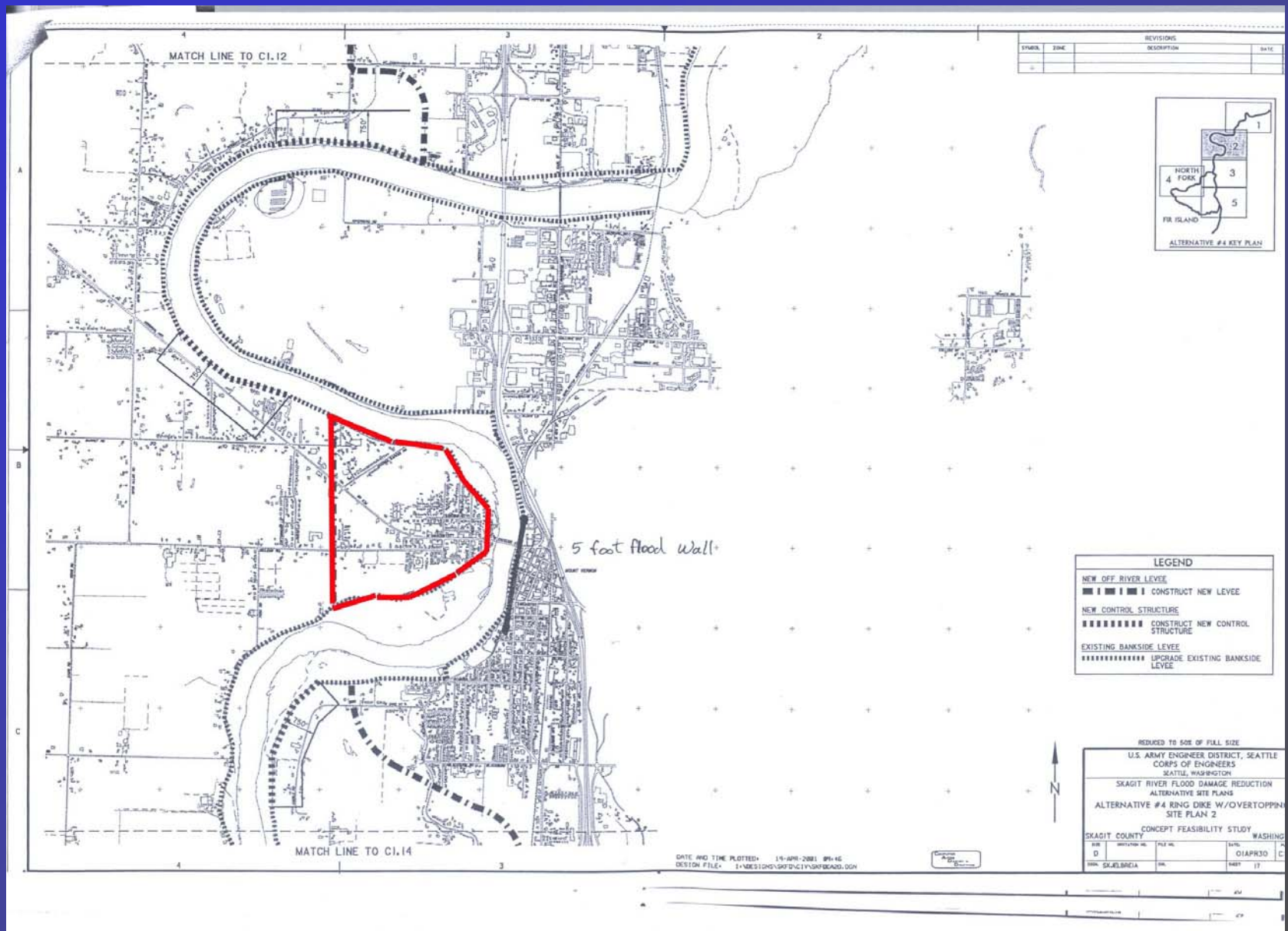
West Mount Vernon Ring Dike



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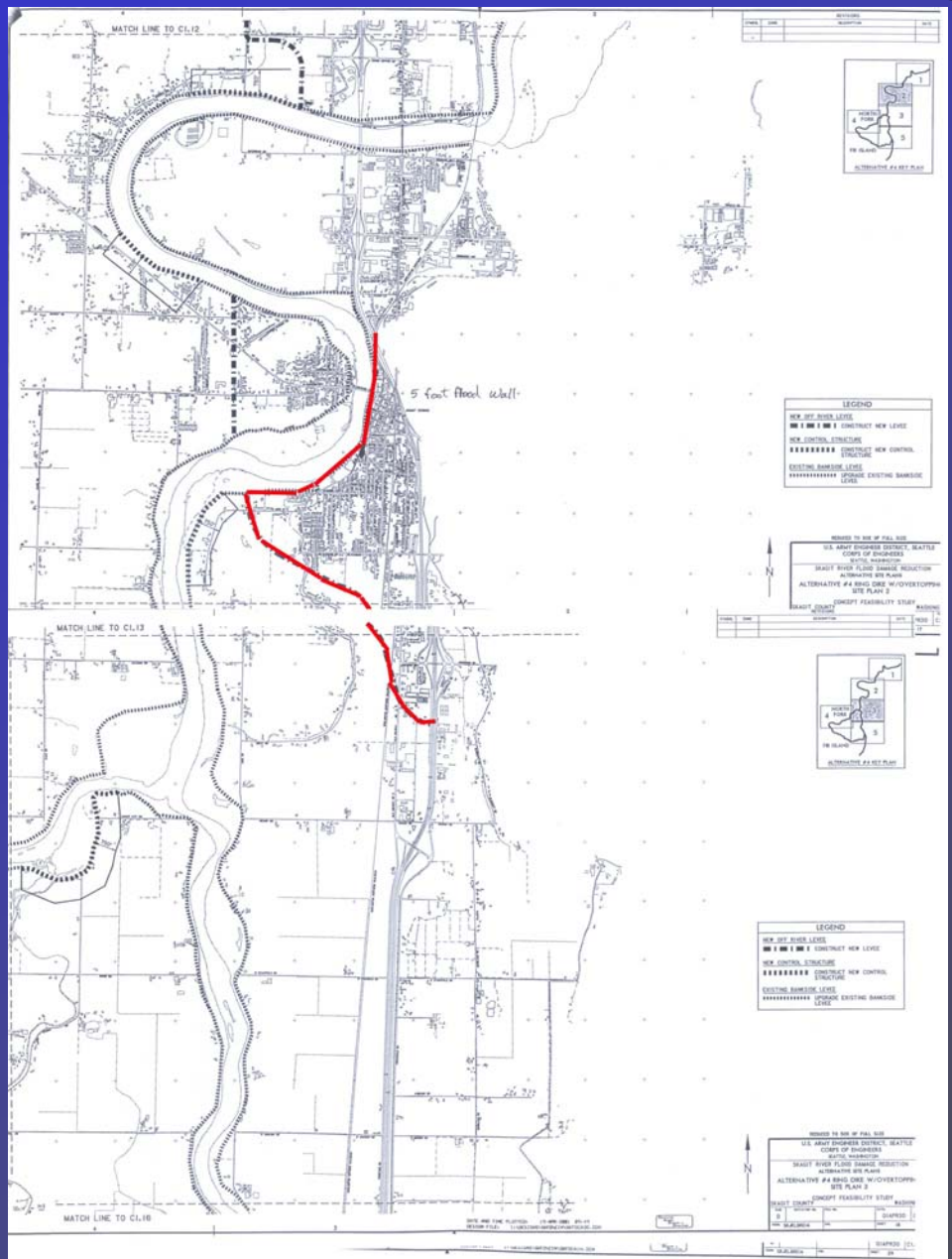
East Mount Vernon Ring Dike



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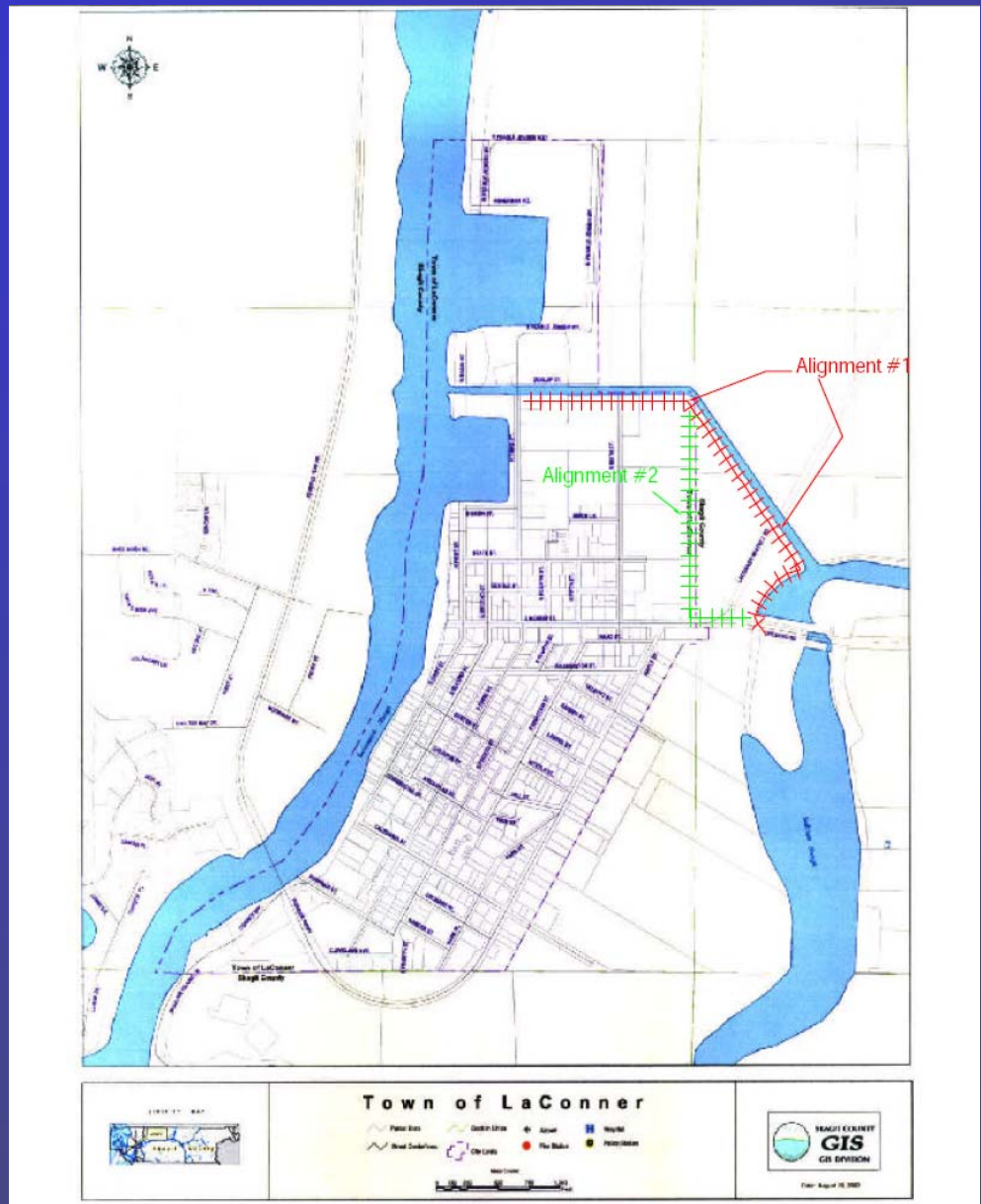
LaConner Ring Dike



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Sedro-Woolley Ring Dike

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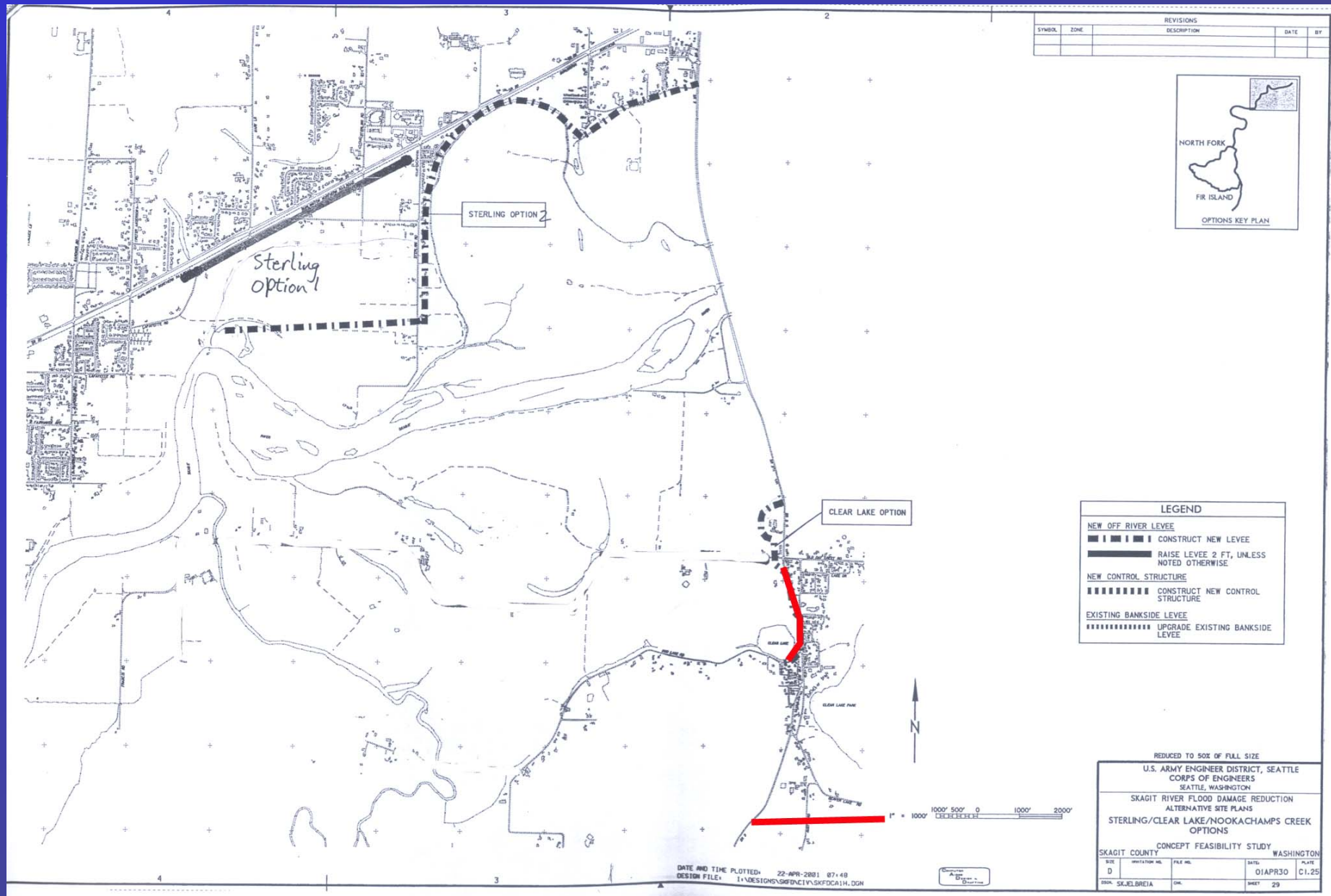
Clear Lake Ring Dike



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Improved Levees

- Left Bank to Mount Vernon
- Left Bank from Mount Vernon to SF Mouth
- Right Bank

Improved Levees Not Including Freeboard

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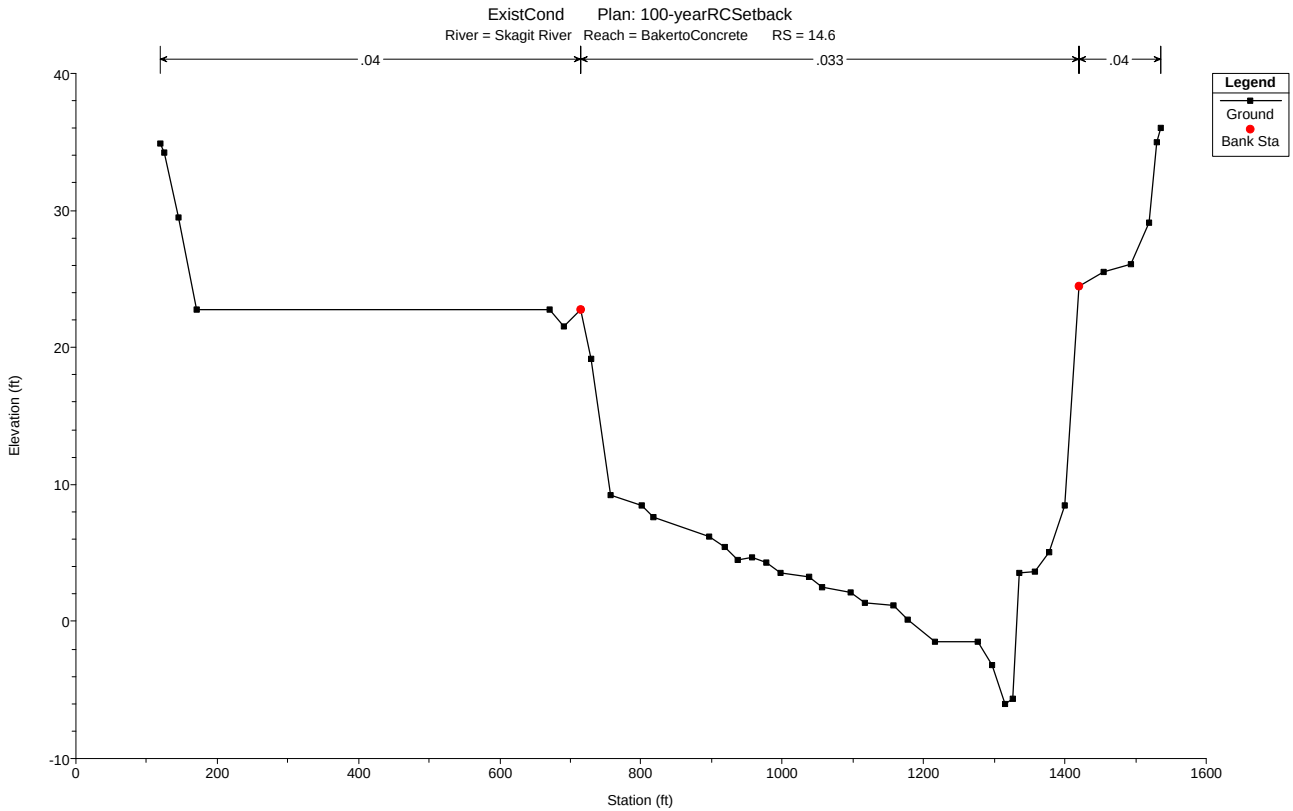
Recurrence	Nooka-champs	Mount Vernon Gage	Division Street Bridge	Conway
10-year	40.2	34.9	27.8	15.7
25-year	43.2	38.0	30.2	17.3
50-year	45.6	42.4	33.4	19.5
100-year	49.7	45.9	36.2	21.3
500-year	61.9	55.0	43.1	25.8

Levee Setbacks

- 3-Bridge Corridor to Skagit Bay
- With and Without Excavation
- Overbank excavated 20 feet (5 million cubic yards)



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Levee Setback

Location	Existing Condition 100-year Stage (ft)	500-foot Setback Stage (ft)	500-foot Setback with Excavation Stage (ft)
Sedro-Woolley	52.0	49.6 2.4	48.7 3.3
Nookachamps	49.7	45.7 4.0	37.7 12.0
Mount Vernon Gage	45.9	43.2 2.7	35.1 10.8
Division Street Bridge	36.2	34.2 2.0	25.5 11.1
Conway	21.3	20.2 1.1	9.3 12.0

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Dredging

- 60 million cubic yards from Sedro-Woolley to mouth for 100-year conveyance
- Short-term fix and high O&M cost

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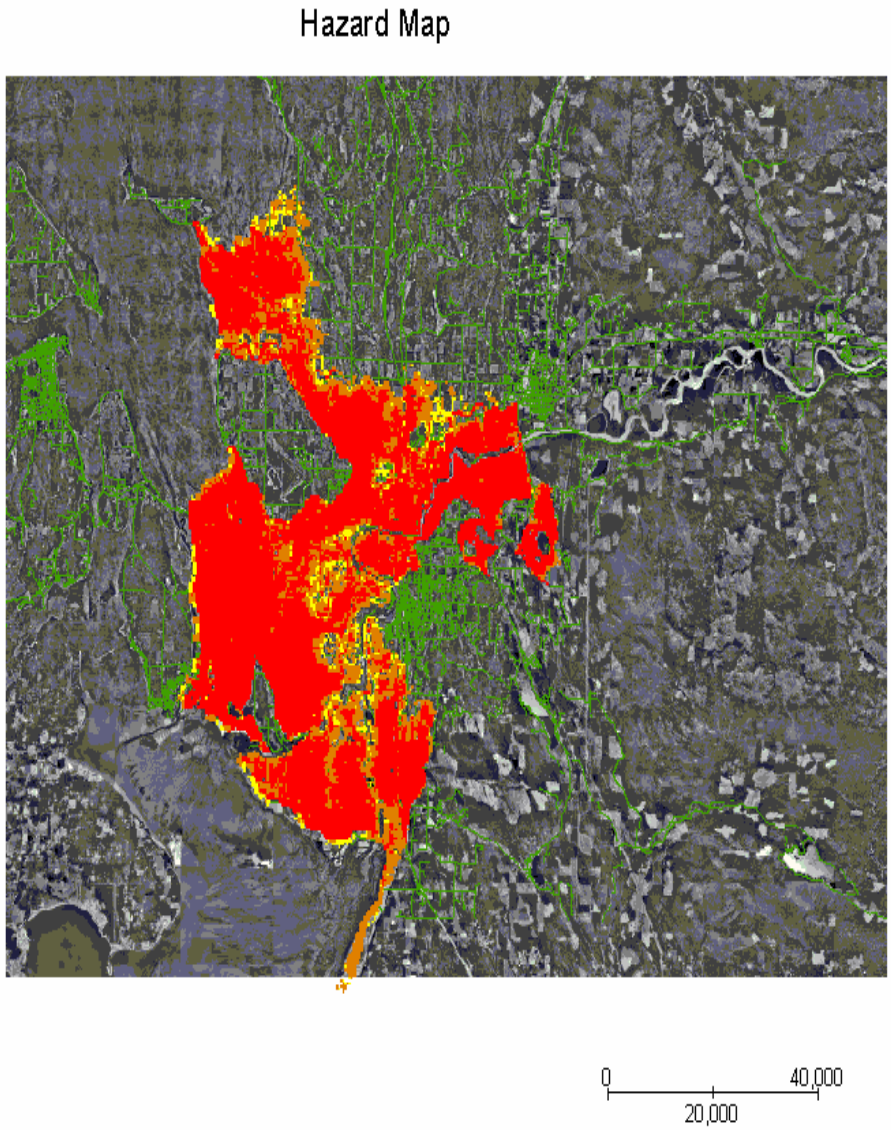
Non-structural

- Buying out flood prone houses
- Raising houses



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Debris Management

Flood at Nooka-champs Confluence	Without Debris	With Debris
25-year	40.9 2.3	43.2
50-year	43.6 2.0	45.6
100-year	48.5 1.2	49.7
500-year	60.2 1.7	61.9

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Skagit River Flood Damage Reduction Study Hydraulic Measure Evaluation

Linda Smith, Project Manager and Ted Perkins, Hydraulic Engineer