Simplified Risk Analysis
Overtopping of West Pass Dike
Upper Baker Development, Baker River Project, P-2150

RIDM Level 1 Workshop – Spring 2012

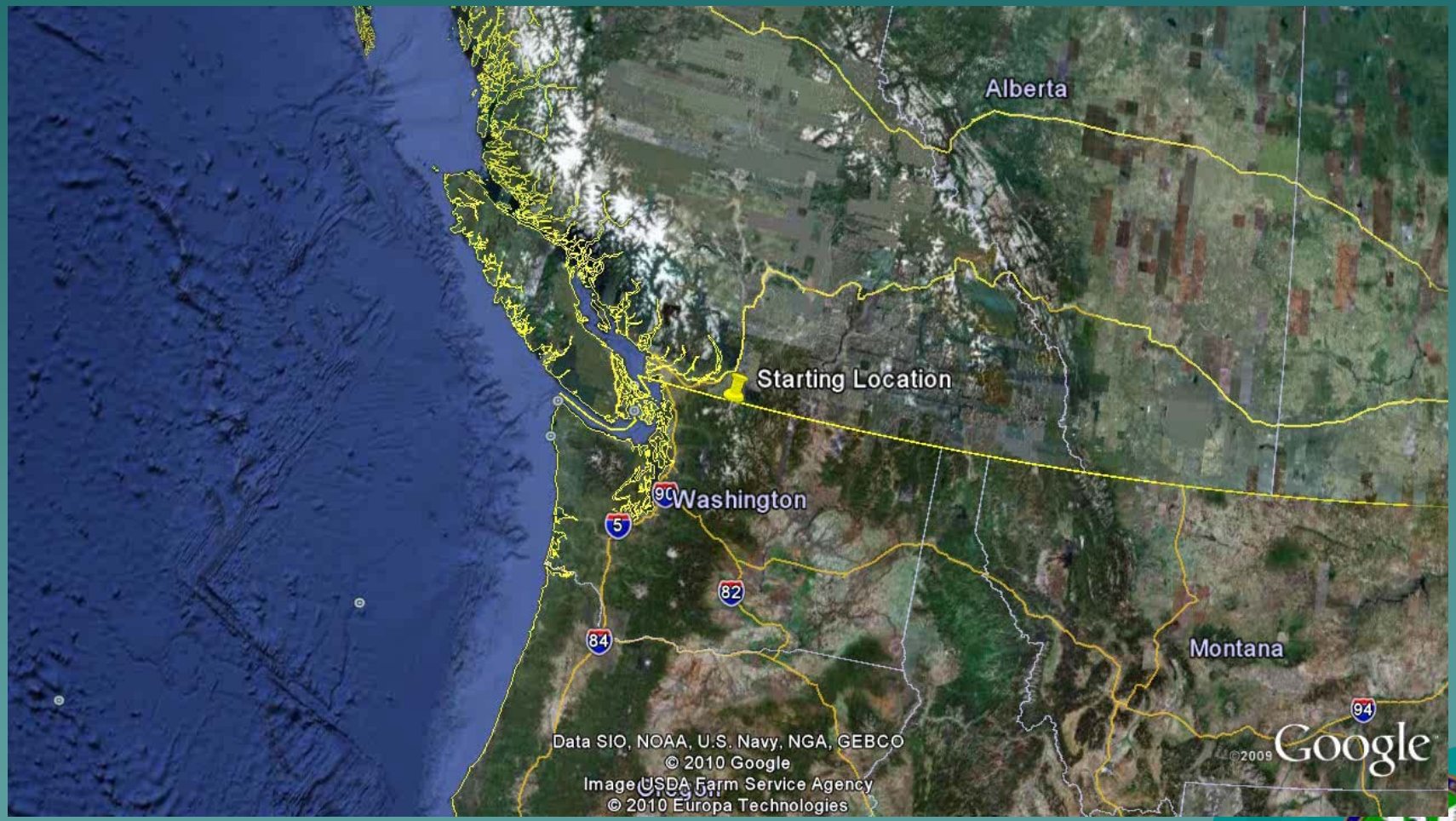
April 10, 2012

Baker River Project

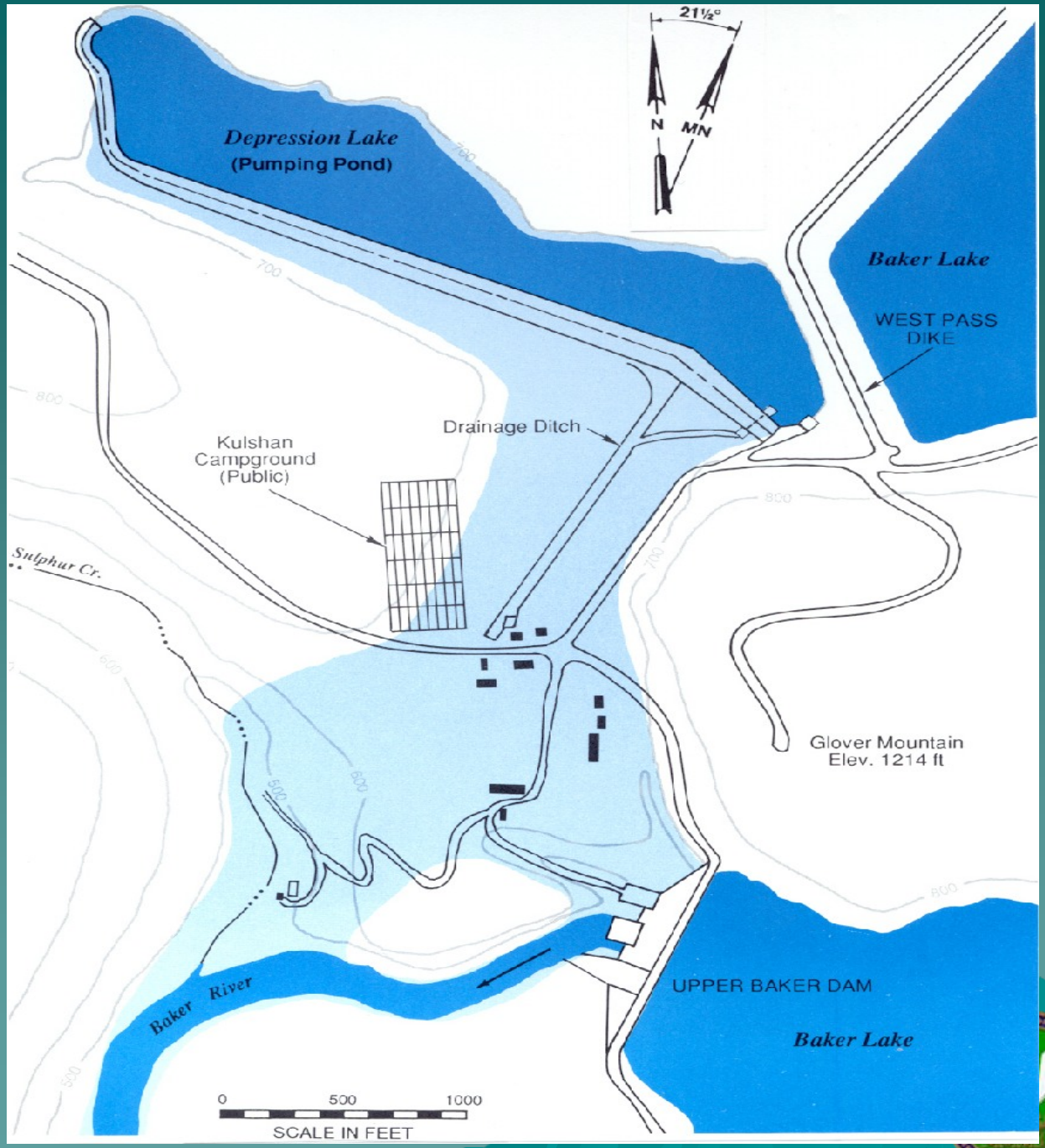
- Upper Baker Dam is a 297-foot-high, “High” hazard concrete gravity dam, with a 285,500 acre-foot reservoir. Located in northwestern WA near Canada.
- West Pass Dike is a 115-foot-high earth and rockfill saddle dam located near the right abutment.
- Owned by Puget Sound Energy (PSE)

Virtual Tour of Baker River Basin

Click to start



Upper Baker Development

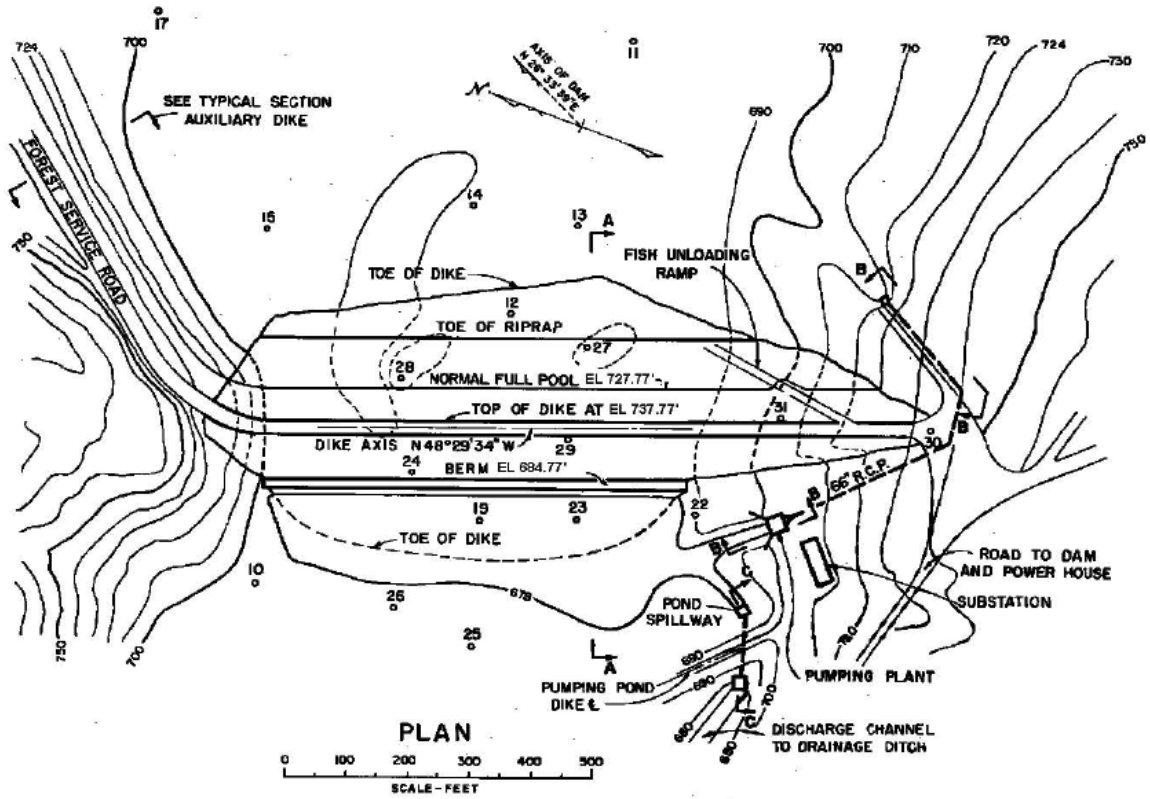


Upper Baker Dam

West Pass Dike

West Pass Dike

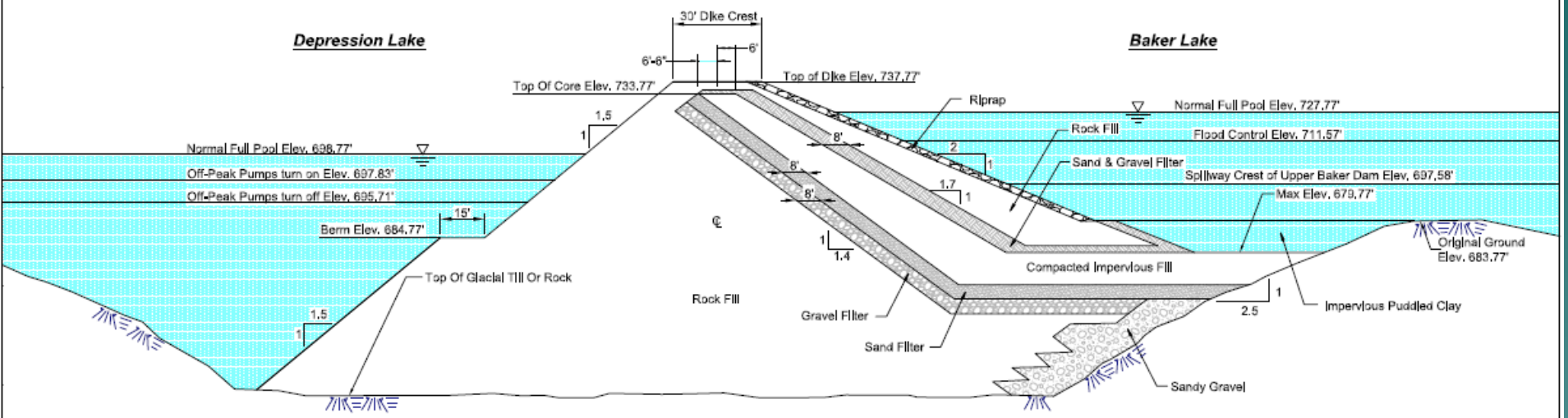
Plan View of WPD



PSE PUGET SOUND ENERGY	MWH	Baker River Dams Project	West Pass Dike Seismic Analysis	West Pass Dike Plan	Exhibit 5.1 June-08

West Pass Dike

Typical Cross Section - Not to Scale
NAVD 88 Datum Elevations



Depression Lake

- Reservoir length = 0.7 miles
- Full pool surface area = 44 acres
- Full pool volume = 234 acre-ft

West Pass Dike

- NATDAM # WA00174
- Earth & Rock filled embankment
- Constructed from May 1957 to October 1959
- Length = 1200'
- Height = 115'
- West Pass Dike overtopping (PMF) = 1.42'
- Underground Koma Kulshan Transmission cable (34.5 kV Power Line) - average 3' below crest, runs along the dike crest on average 11' from NE slope (Baker Lake side)
- Cross-section adapted from original construction drawing, with crest width and side slope inclinations modified according to Leonard, Boudinot & Skodje Dwg. No. 05133TOPO dated 12/27/2007.

Baker Lake

- Reservoir length = 9 miles
- Full pool surface area = 4,980 acres
- Full pool volume = 274,221 acre-ft.
- Storage above spillway gates at Upper Baker Dam = 124,950 acre-ft.
- FERC-required flood control volume = 16,000 acre-ft. (724.57', 10/15 - 03/01)
- USACE flood control volume = an additional 58,000 acre-ft. for a total of 74,000 acre-ft. (711.57', 11/15 - 03/01)
- Peak inflow (PMF)= 157,800 cfs
- Peak outflow (PMF) = 111,500 cfs (Inflow design flood)
- Max pool elevation (PMF)= 739.19'
- Dam overtopping (PMF)= 3.42'

Schematic is shown for illustrative purpose only.

West Pass Dike Soil Properties

Material	Cohesion	Angle of friction	Unit Weight	Density
	c' (psf)	ϕ' (°)	γ (pcf)	slugs/ft^3
Glacial Till	1200	35	145	4.50
Soft Clays and Silts	400	20	110	3.42
Skip-Placed Sandy Gravel	0	35	120	3.73
Puddled Clay	300	15	110	3.42
Impervious Core	800	30	135	4.19
Dumped Rockfill	0	40	130	4.04
Rolled Rockfill	0	45	135	4.19

Table 5.1 - Shear Strength Parameters and Material Properties

Material	Poisson's Ratio	Static			Dynamic		
		Young Modulus	Bulk Modulus	Shear Modulus	Young Modulus	Bulk Modulus	Shear Modulus
	μ	E (psf)	K (psf)	G (psf)	E (psf)	K (psf)	G (psf)
Glacial Till	0.4	1.00E+07	1.67.E+07	3.57.E+06	1.00E+08	1.67E+08	3.57E+07
Soft Clays and Silts	0.4	3.00E+05	5.00.E+05	1.07.E+05	3.00E+06	5.00E+06	1.07E+06
Skip-Placed Sandy Gravel	0.4	6.60E+05	1.10.E+06	2.36.E+05	6.60E+06	1.10E+07	2.36E+06
Puddled Clay	0.4	7.00E+04	1.17.E+05	2.50.E+04	7.00E+05	1.17E+06	2.50E+05
Impervious Core	0.4	1.00E+06	1.67.E+06	3.57.E+05	1.00E+07	1.67E+07	3.57E+06
Dumped Rockfill	0.35	1.50E+06	1.67.E+06	5.56.E+05	1.50E+07	1.67E+07	5.56E+06
Rolled Rockfill	0.35	2.50E+06	2.78.E+06	9.26.E+05	2.50E+07	2.78E+07	9.26E+06

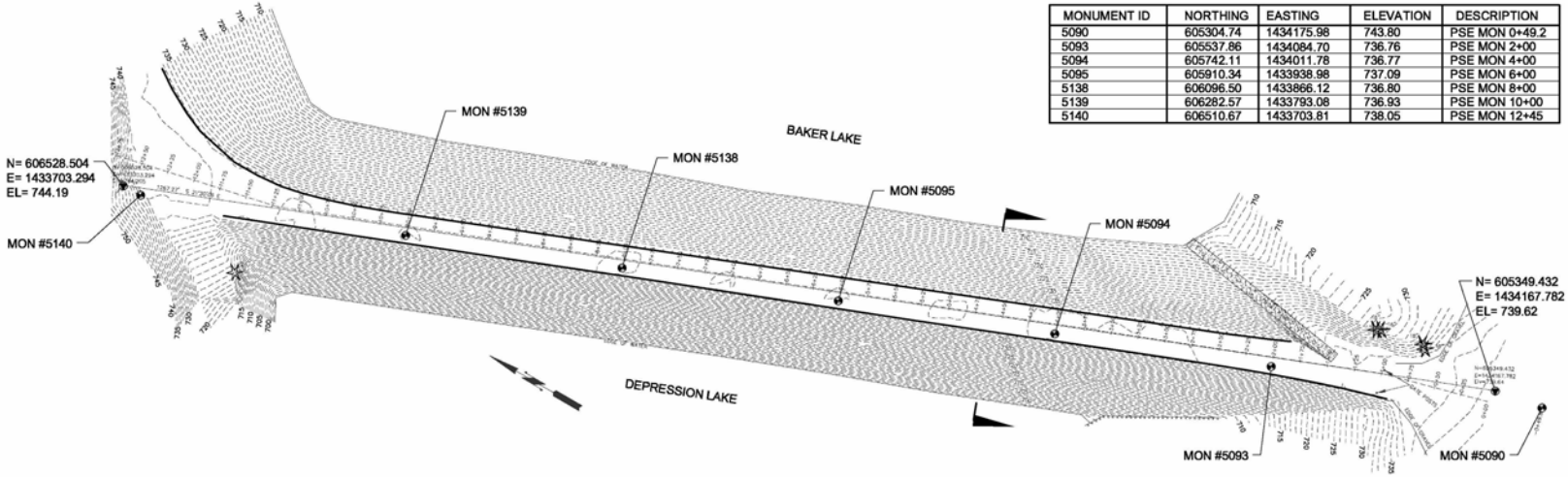
Table 5.2 - Deformation Properties

West Pass Dike - Rolled Rockfill

- There is no clear description or measured soil gradations of the rolled rockfill
- Based on visual observation it consists of sandy gravel with cobbles

PSE MONUMENT TABLE

MONUMENT ID	NORTHING	EASTING	ELEVATION	DESCRIPTION
5090	605304.74	1434175.98	743.80	PSE MON 0+49.2
5093	605537.86	1434084.70	736.76	PSE MON 2+00
5094	605742.11	1434011.78	736.77	PSE MON 4+00
5095	605910.34	1433938.98	737.09	PSE MON 6+00
5138	606096.50	1433866.12	736.80	PSE MON 8+00
5139	606282.57	1433793.08	736.93	PSE MON 10+00
5140	606510.67	1433703.81	738.05	PSE MON 12+45



LEGEND:

- EXISTING GUARD RAIL
- EXISTING FENCE
- EXISTING CONIFER TREE (DIAM)
- EXISTING CONCRETE SURFACE
- EXISTING PSE MONUMNET-METAL DISC IN CASE
- SET CONCRETE MONUMENT MARKED "SKODJE I9645" NOVEMBER 11, 2005

NOTES:

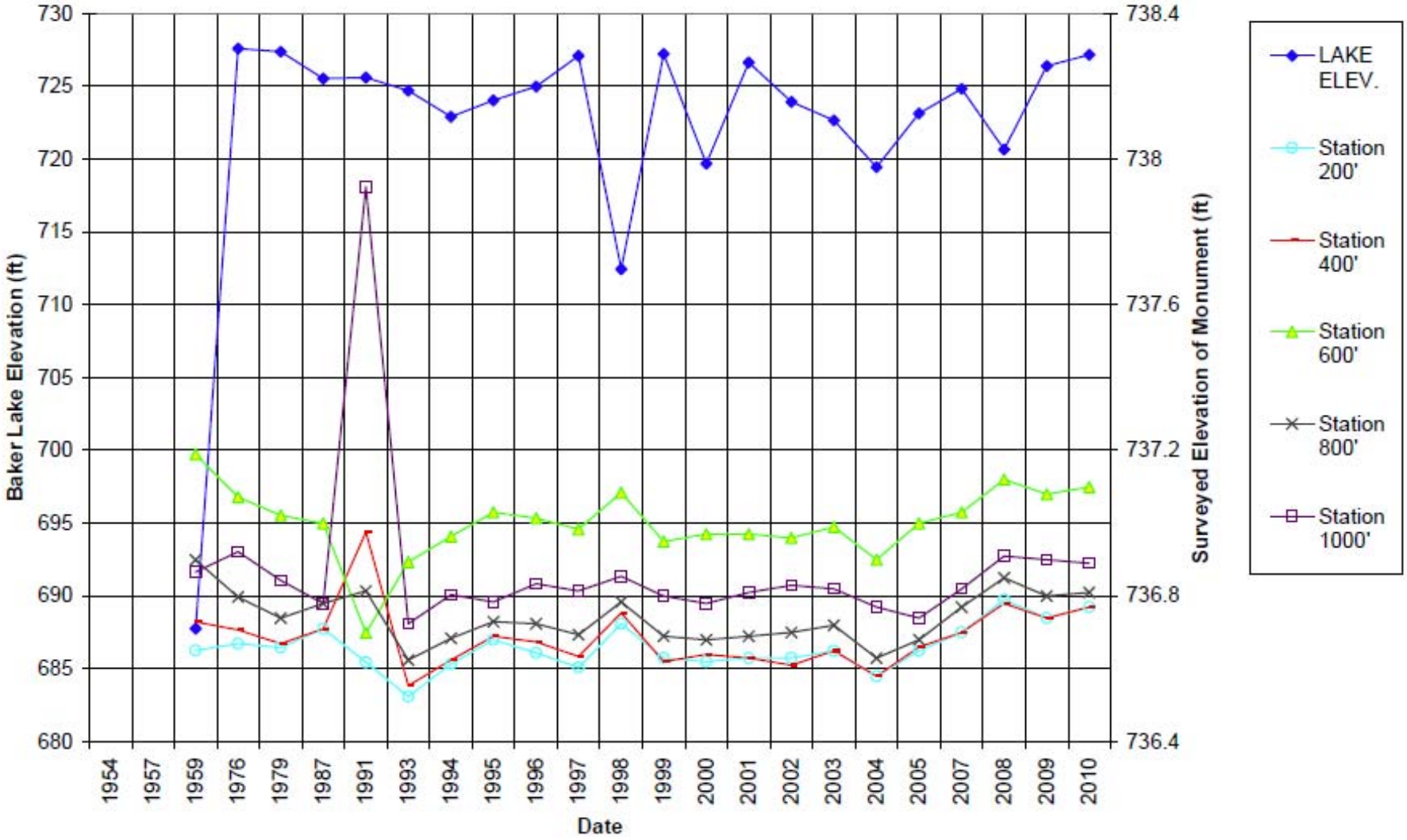
1. THIS FIGURE WAS ADAPTED FROM DWG NO. 05133TOPO.DWG BY LEONARD, BOUDINOT & SKODJE, DATED 12/27/2007. REFER TO THAT DRAWING FOR ADDITIONAL SURVEY NOTES.
2. VERTICAL DATUM: NAVD 88.
3. CONTOUR INTERVAL = 1 FOOT

0 25 50 100

UPPER BAKER DAM

WEST PASS DIKE
MONUMENT LOCATIONS

West Pass Dike Settlement Monuments



corrected June 2010 WPDSLT Datum 88

1/11/2011

2008 Probable Maximum Flood Study Results

Table 8-16. Summary of Final PMF Results

	Peak Magnitude of PMF Inflow Hydrograph (cfs)	Peak Magnitude of Routed PMF Outflow Hydrograph (cfs)	Maximum Reservoir Elevation (feet NAVD88)	Dam Crest Elevation (feet NAVD88)	Dam Overtopping Depth (feet)
Upper Baker Development	157,800	111,500 *a*	739.19	735.77 *b*	**3.42**
Lower Baker Development	136,800	120,300	458.43	444.57 *c*	**13.86**

a. Peak outflow magnitude at the Upper Baker Development includes the overtopping of West Pass Dike

b. This is the elevation of the crest of Upper Baker Dam. The elevation of the crest of West Pass Dike is 737.77 feet NAVD88, which is therefore overtopped by 1.42 feet

c. The elevation used to compute the overtopping depth for Lower Baker Dam is associated with the lowest feature on the crest of the dam which is the top of the parapet wall on the east abutment of the dam.

Overtopping Issues

- Upper Baker Dam overtops by 3.42 feet during the PMF. However, a state-of-the-art stability analysis determined that it would not fail under these overtopping loads.
- PSE completed an extreme flood frequency analysis in 2009 preparing for a possible risk analysis for Upper Baker Dam. This was determined to be unnecessary because of the revised structural analysis.
- West Pass Dike, an embankment dam, nominally overtops by 1.42 feet and is assumed to fail during the PMF.

Where Do We Go Next?

- The 2008 Inflow Design Flood (IDF) Study showed that there are homes in the inundation area from a failure of West Pass Dike during the PMF.
- The December 7, 2009 Dambreak Study of West Pass Dike quantified the inundation zone.
- PSE is scheduled to provide a plan and schedule very soon to respond to the overtopping and potential failure of West Pass Dike issue in accordance with current FERC guidelines.
- The flood frequency analysis shows that the overtopping of West Pass Dike is a 1.5×10^{-7} year event, while the PMF is a 1×10^{-8} year event.

Frequency of Maximum Reservoir Level

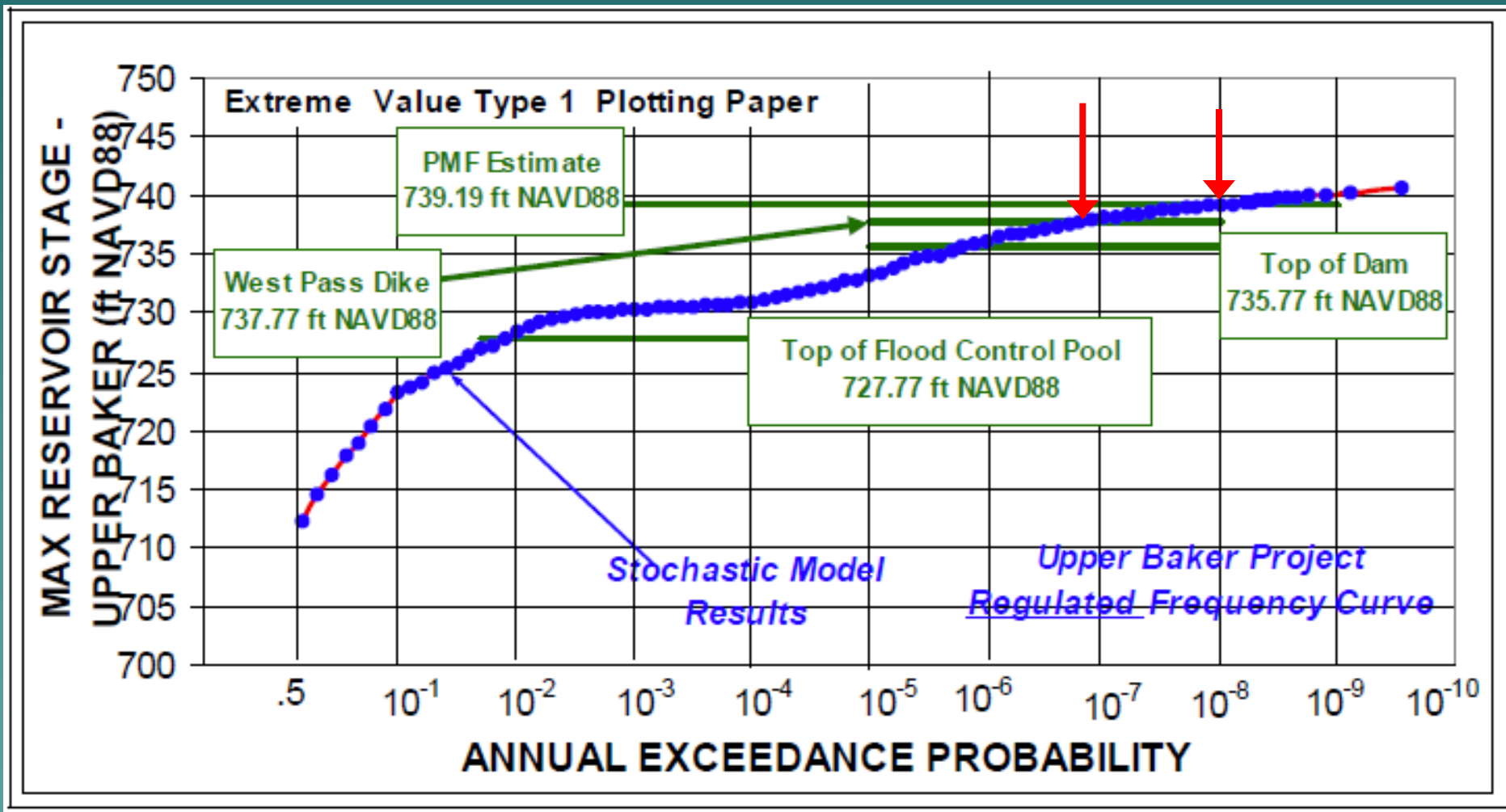


Figure 6-10. Flood-Frequency Curve for Upper Baker Dam – Maximum Reservoir Elevation

Table 6-10. Estimates of Maximum Reservoir Elevations at Upper Baker Dam for Select Annual Exceedance Probabilities		
AEP	**Reservoir Elevation (ft NAVD 88)**	**Reservoir Zone/Project Feature**
1.0×10^{-8}	**739.19**	**Results of Routed PMF**
1×10^{-7}	738.12	
1.5×10^{-7}	737.77	Crest of West Pass Dike
1×10^{-6}	736.14	
1.4×10^{-6}	735.77	Deck Elevation of Upper Baker Dam (at centerline)
1×10^{-5}	733.13	
1×10^{-4}	730.90	
1.7×10^{-4}	730.77	Maximum Surcharge Pool Elevation
1×10^{-3}	730.31	
1×10^{-2}	728.49	
1.3×10^{-2}	727.77	Maximum Flood Control Pool Elevation (normal full pool)

Reason For Risk Analysis

- Should we remediate, i.e., add to the top of the dam, for an event that is very remote, i.e., 6 X 10^{-7} year event?
- However, simply using the extremeness of the loading event neglects the actual Potential Failure Modes (PFMs) and neglects the consequences, i.e., how many people are at risk of dying from that PFM.
- Would conducting a simplified risk analysis provide a different answer than our Engineering Guidelines?

Potential Failure Mode

- PMF occurs and flood begins to overtop West Pass Dike.
  - At some ? overtopping elevation West Pass Dike begins to erode.
    - Erosion continues as flood continues and breach develops.
      - Breach erodes West Pass Dike to the near the foundation.

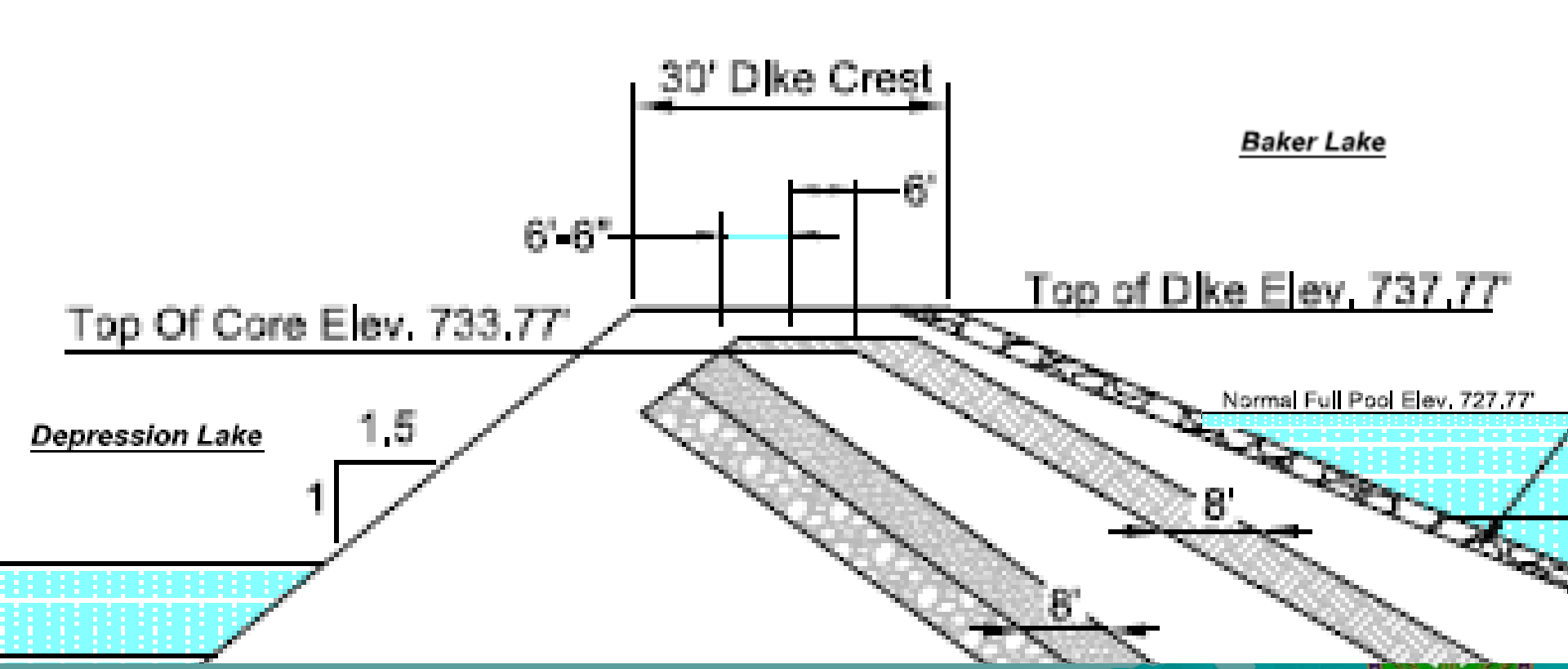
Erodibility of Soil

From BOR Best Practices

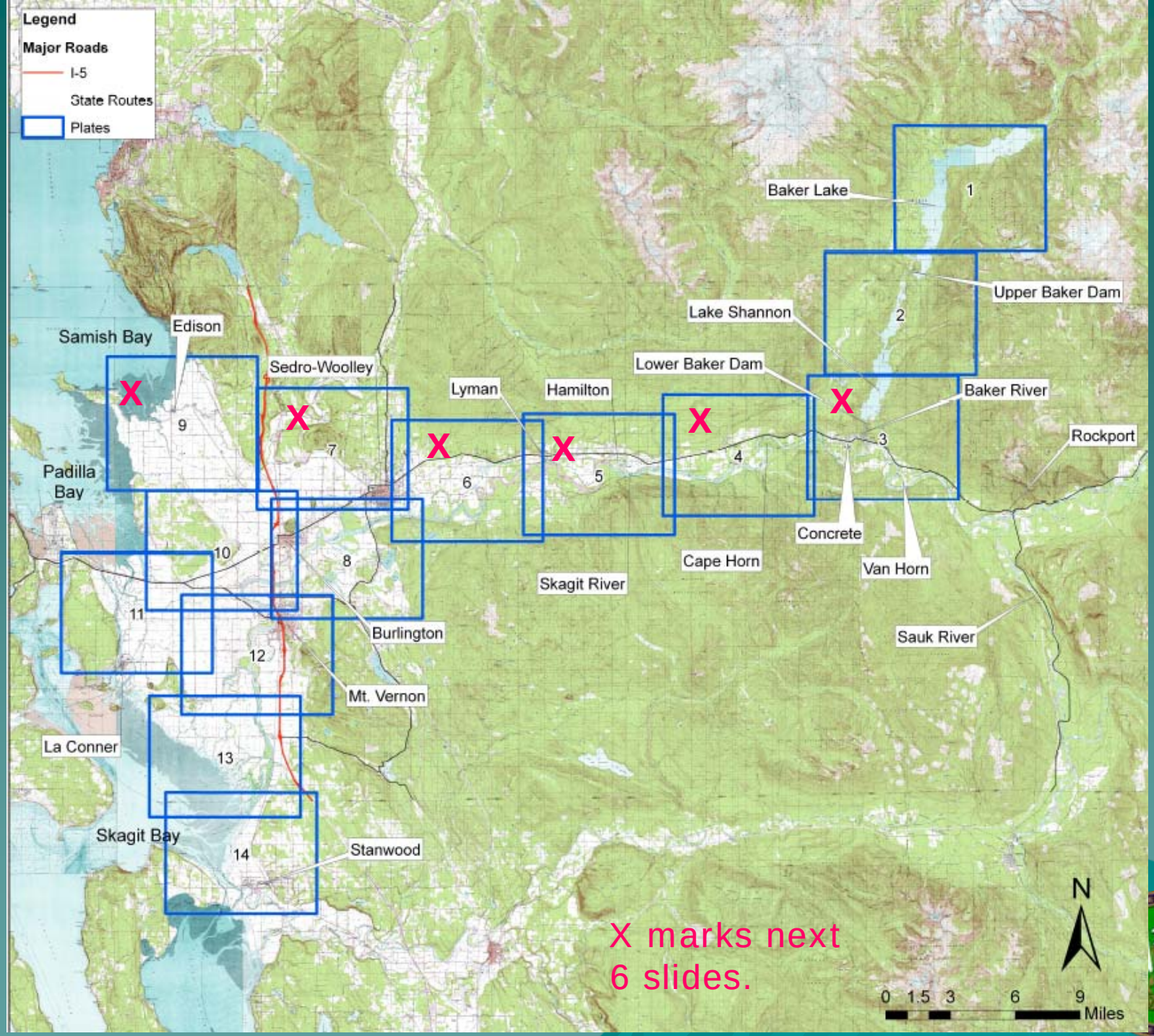
If the equivalent diameter of the surface material (taken as d_{50}) is less than 4 inches, erosion is assumed to initiate at the onset of overtopping. If it is larger than 4 inches, the chart from Frizell et al (1998), Figure 9-1, can be used to estimate the flow at which erosion will initiate. However, it should be noted tha this chart was developed for rip rap. S = the embankment slope (V/H), and C_u is

The SITES method (http://www.nrcs.usda.gov/technical/Eng/sites.html) was developed by the U.S. Department of Agriculture (USDA) from observed behavior of soil and grass lined spillways. Although mostly applicable to soils, it has also been applied to rock. The SITES one-dimensional computer program evaluates the stability and integrity of unlined spillway channels using a three-phase simulation of the headcut erosion processes. Headcut erosion occurs in a

West Pass Dike



Population at Risk



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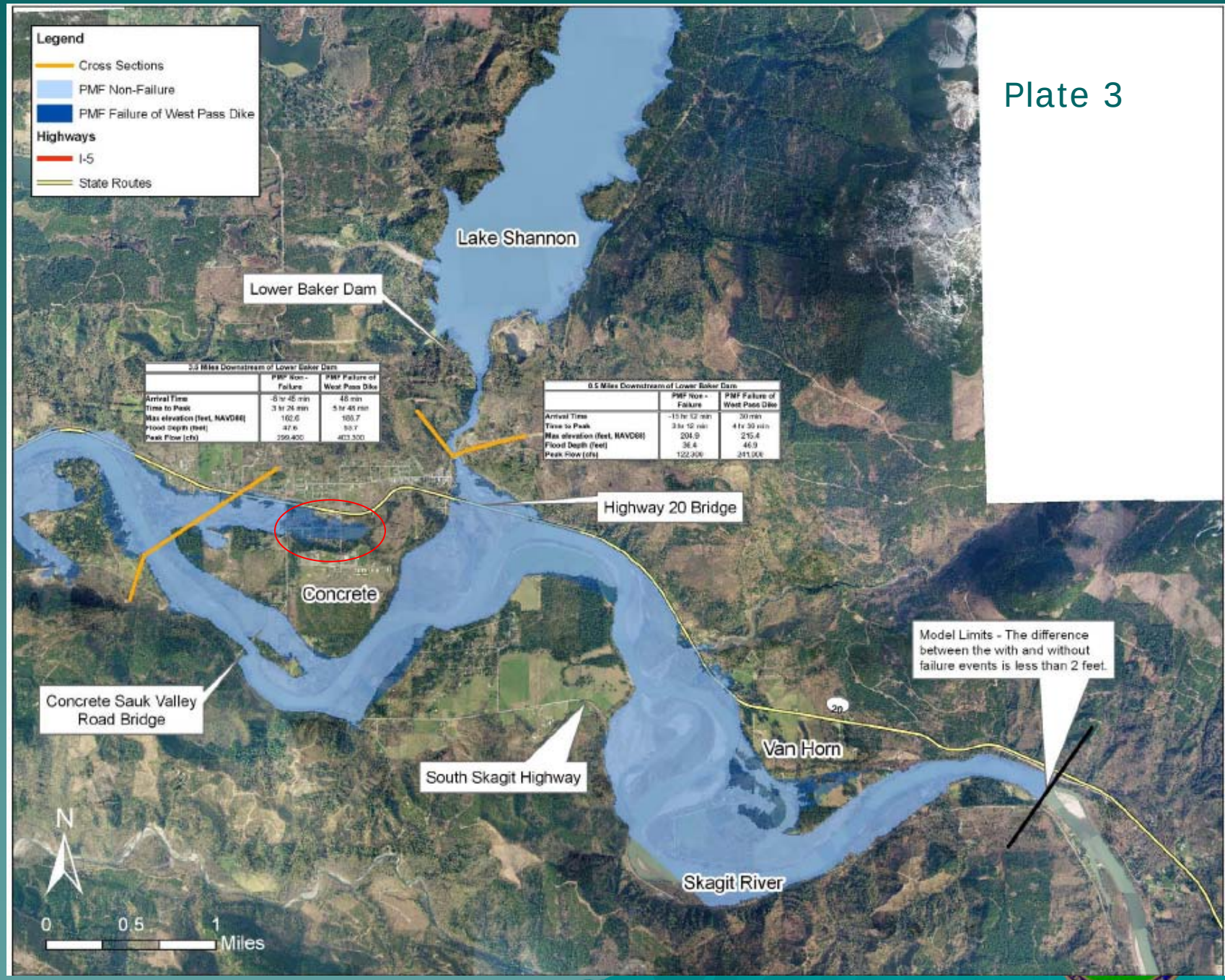

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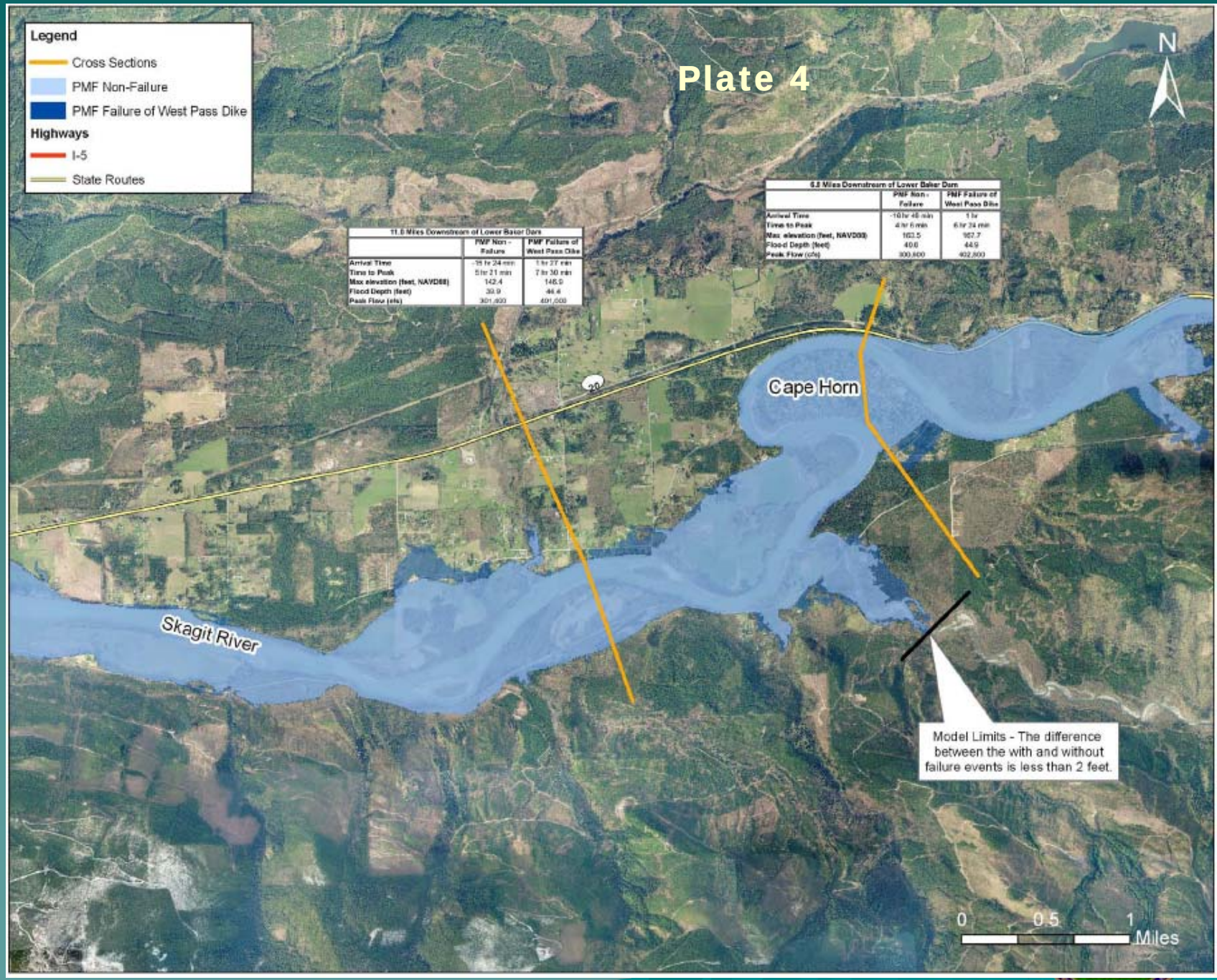

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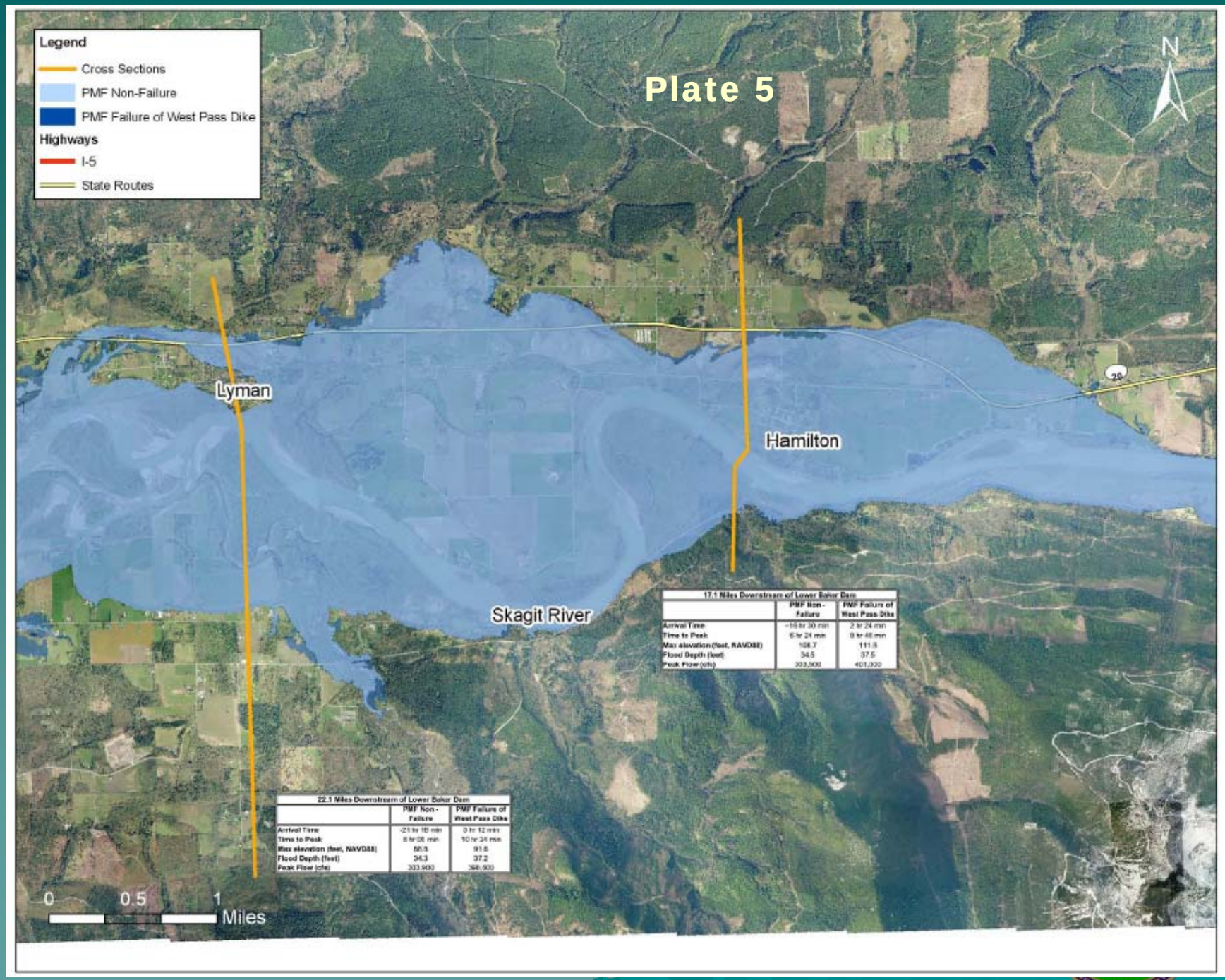

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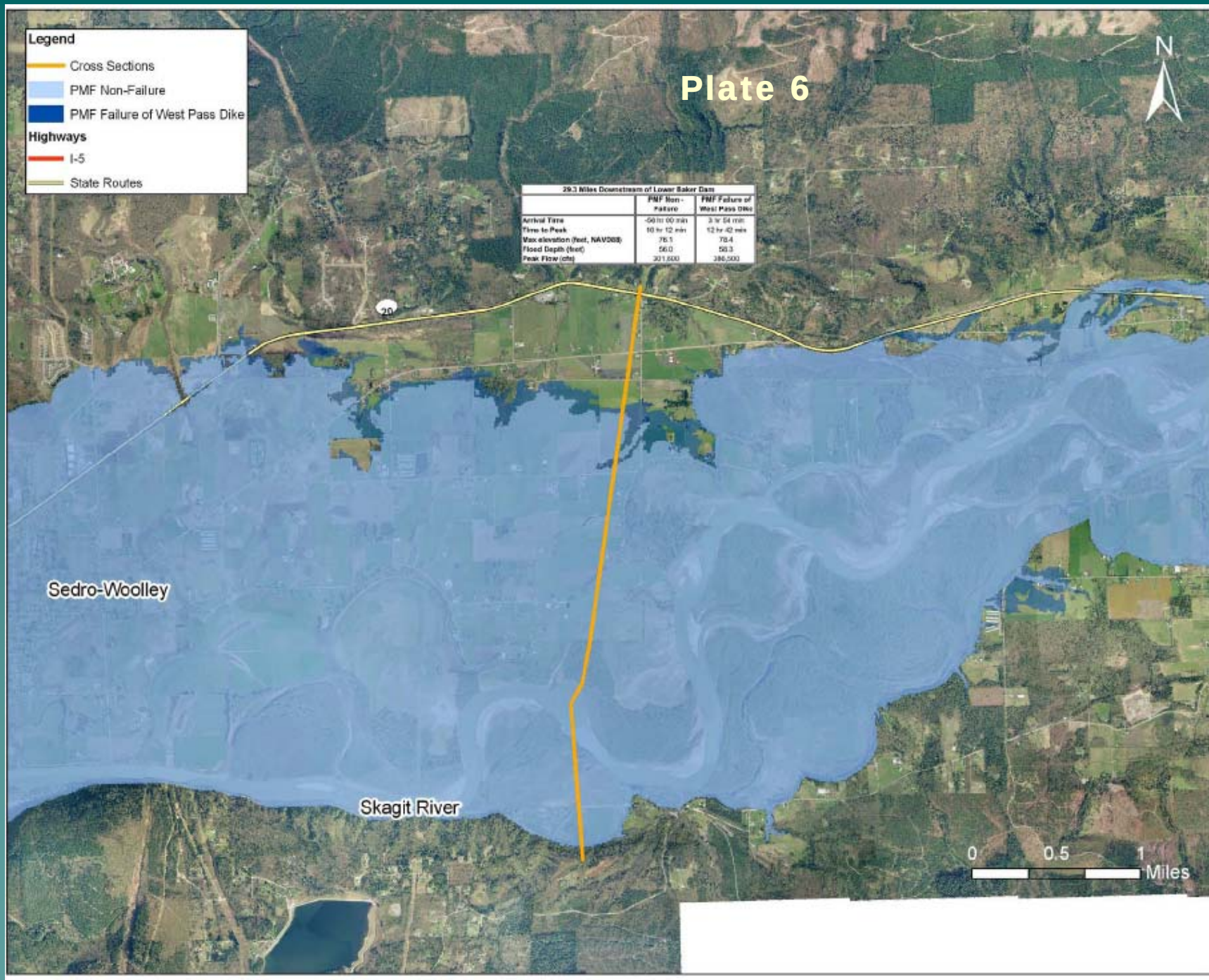

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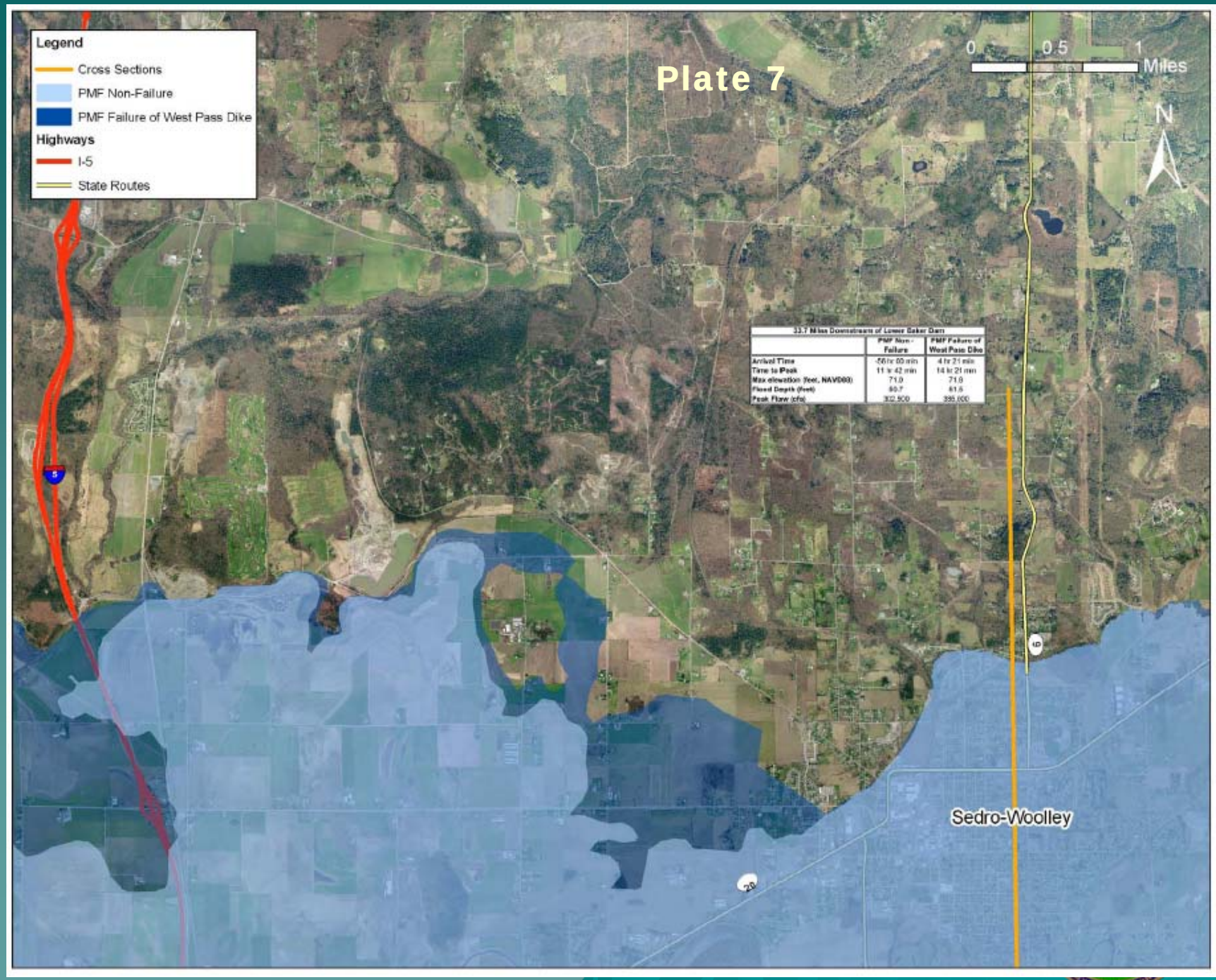

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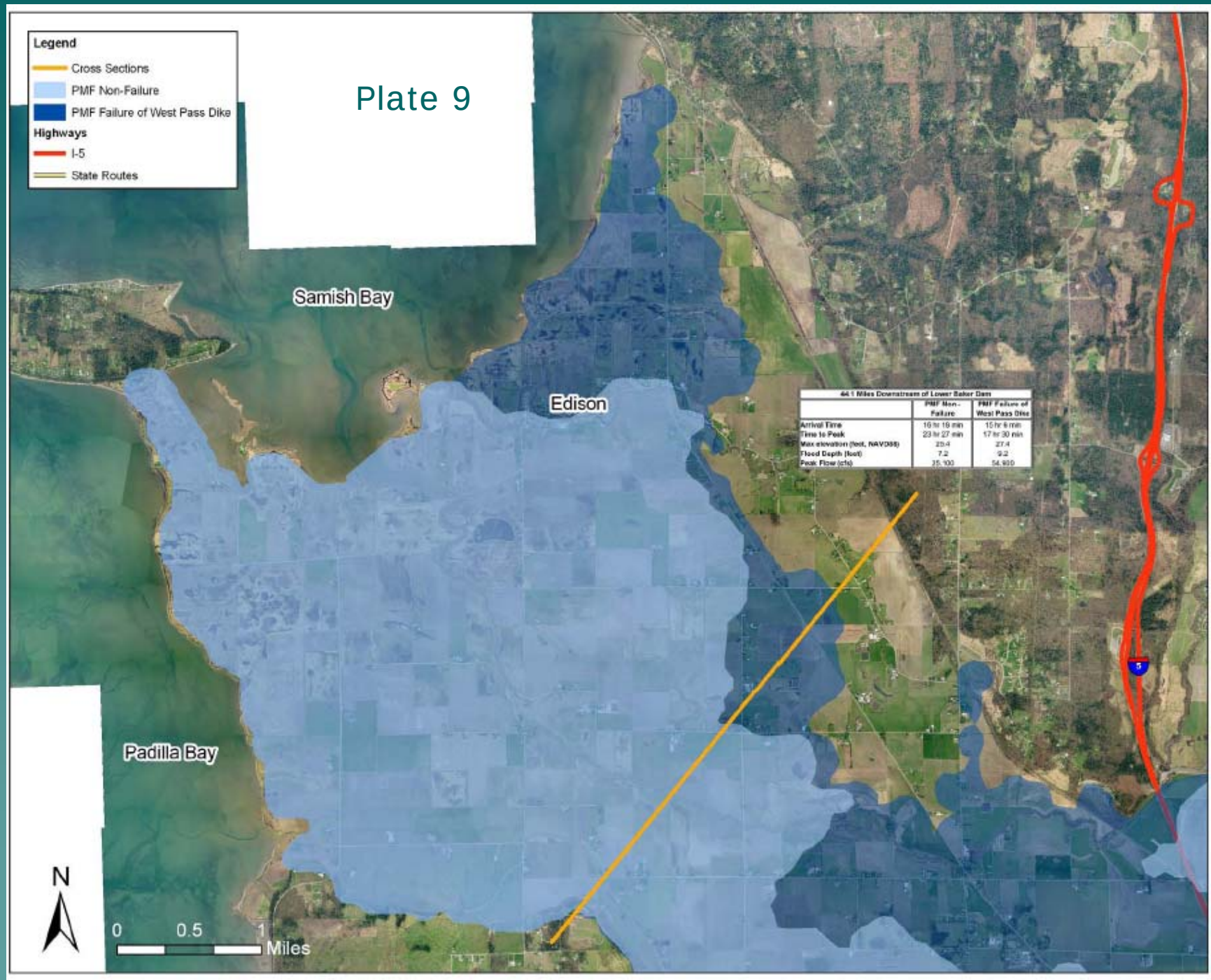


Population At Risk

Population at Risk from a PMF Failure of West Pass Dike		
Rough Cross-Section	**Total Incremental PAR (rounded up to nearest whole number)**	
(all exclude "negative wave")		
8 (river) miles from WPD (0.5 Miles DS of Lower Baker), just above Concrete	1	Plate 2
19 miles from WPD (11 Miles DS of Lower Baker), Includes Cape Horn & Birdsview	180	Plates 3 and 4
25 miles from WPD (17.1 Miles DS of Lower Baker, Includes Hamilton	204	Plates 4 and 5
37 miles from WPD (29.3 Miles DS of Lower Baker)	265	Plate 6
41 miles from WPD (33.7 Miles DS of Lower Baker), Includes Part of Sedro-Wooley	289	Plate 7
Total PAR (all people who incrementally get wet) - Everyone below Plate 7 is inundated by less than 2 feet.	3209	

FERC Screening Level Consequence Tool*

	Low Flood Severity	Medium Flood Severity	High Flood Severity
	(No buildings washed off foundation, less that 10-foot depth of flooding) DV < 50	(Homes destroyed but trees or mangled homes remain, greater than 10-foot depth of flooding) DV > 50	(Instantaneous dam failure, inundation area swept clean of structures, deep flood depth reached very quickly)
No Warning (Excess response time less than 15 minutes)	**0.01**	**0.15**	**0.75**
Some Warning (Excess response time 15 to 60 minutes)	**0.005**	**0.03**	**0.4**
More Warning (Excess response time Greater than 60 minutes)	**0.0003**	**0.02**	**0.2**

* From Wayne Graham's Simplified Procedure for Estimating Loss of Life

FERC Screening Level Consequence Tool*

Distance	Time to impact (min)	Rspnse Time-RT (min)	Excess RT (min)	PAR Description	PAR	Q (cfs)	Topwidth (ft)	DV	Seve-rity	Adjust-ment Factor	PLL
0 to 3	12	-120	132	Campground closed	0	251700	1600	157	HIGH	0.2	0
3 to 9	30		0	No inhabitants	0	241000	500	482	HIGH	0.02	0
9 to 12	40	-120	160	Concrete	55	299400	5280	56	MEDIUM	0.02	1.1
12 to 29	120	-160	280	Hamilton	84	303500	10000	30	LOW	0.0003	0.03
29 to 42	240	-160	400	Sedro Woolley	99	302500	10000	30	LOW	0.0003	0.03

Total = 1.2

* From Wayne Graham's Simplified Procedure for Estimating Loss of Life

PLL Parameters Discussion

PAR

- Based on worst case (i.e. all residents are still in their homes)

DamBreak

- Based on WPD breach flood depths – conservative parameters

Flood Severity

- Based on Depth Velocity (DV) calculation – Flow / topwidth in feet

Warning Time

- A flood of this magnitude will be forecast days in advance
- The only areas flooded are on the margins of the already flooded areas
- Most access roads are already flooded so those inhabitants should have evacuated, but some may not

PLL

PLL as follows

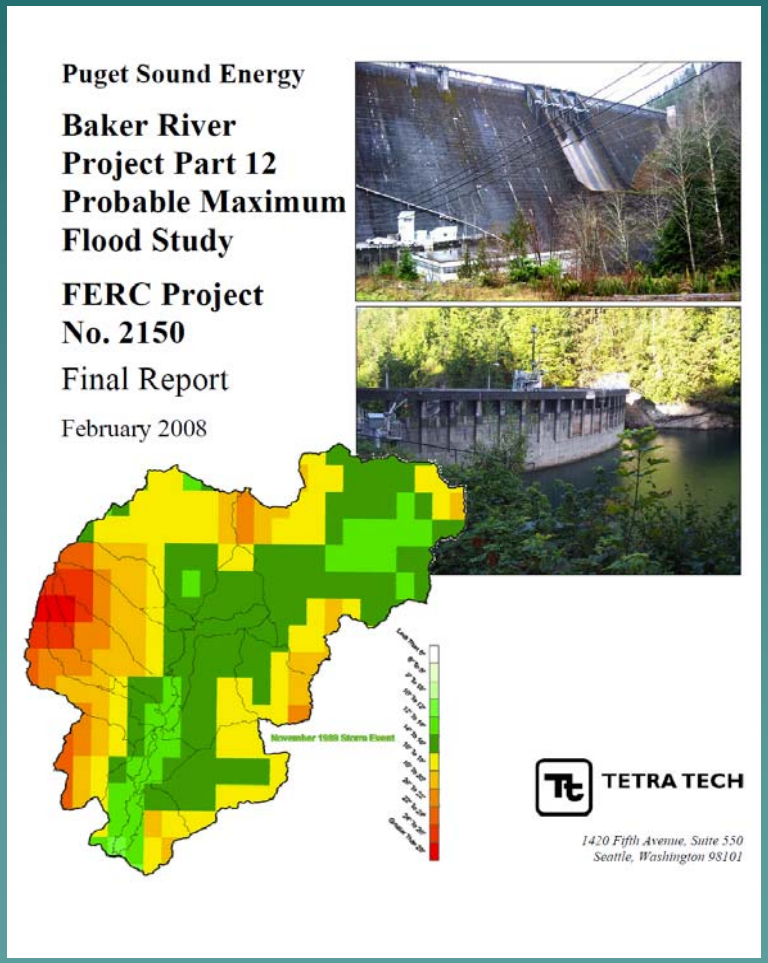
- Kulshan Campground 0
- Concrete 1
- Down through Hamilton
  Mile 12 to 29 – 0
- Down through Sedro Woolley
  Mile 29 to 42 - 0
- Down past Mt Vernon – Mile 42 + - 64 *
- Total 1

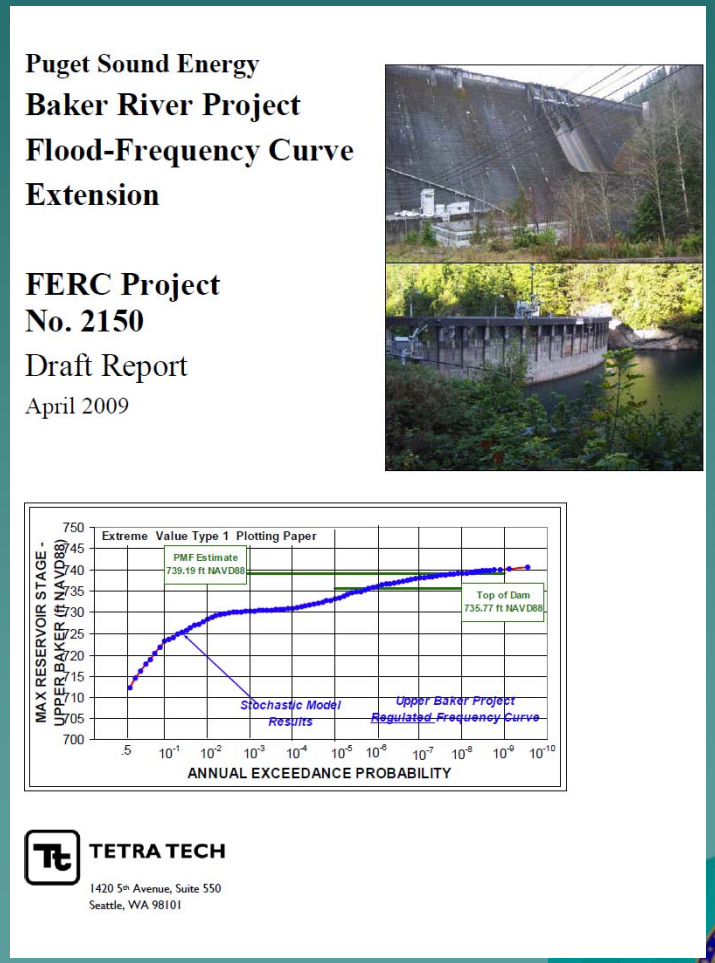
*Flow less than 1 ft/s about 1 ft high

Simplified Risk Analysis

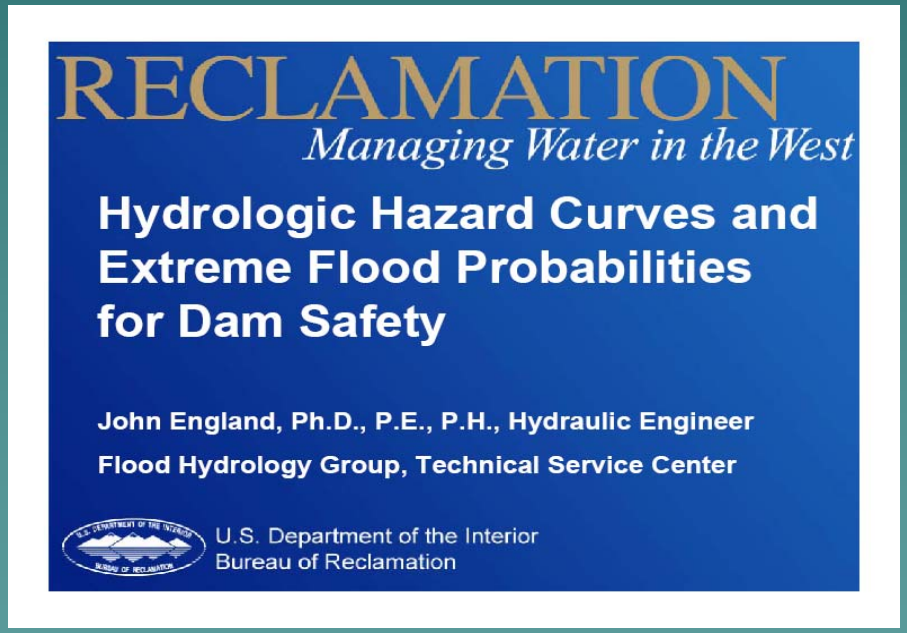
- Simplified version of a risk analysis
- Simplified in every way to demonstrate the process
- Small group to evaluate one PFM
- Overtopping of West Pass Dike during an extreme flood

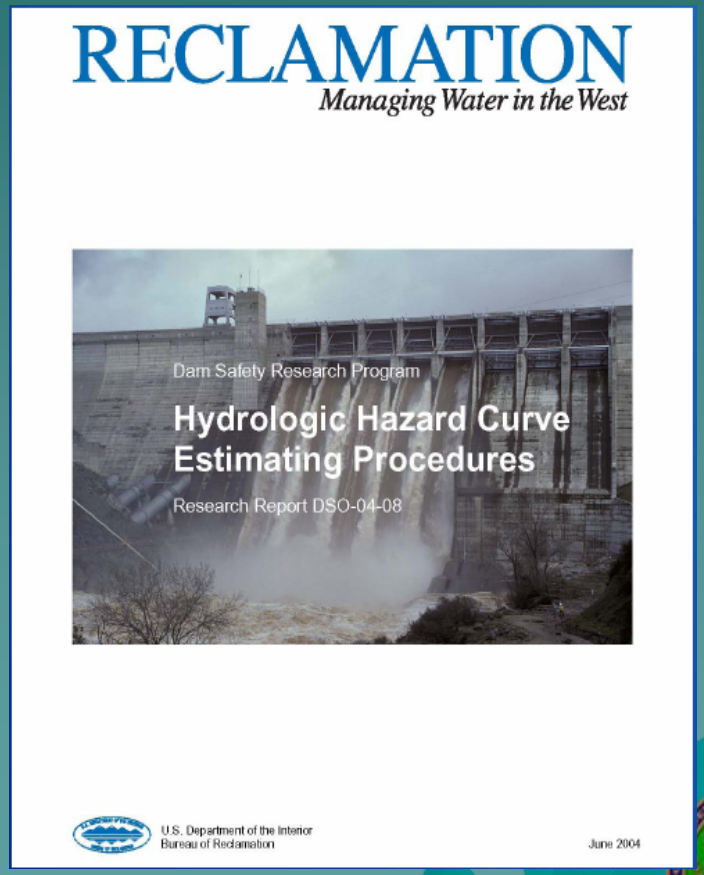
References


Puget Sound Energy
Baker River
Project Part 12
Probable Maximum
Flood Study
FERC Project
No. 2150
Final Report
February 2008
TETRA TECH
1420 Fifth Avenue, Suite 550
Seattle, Washington 98101


Puget Sound Energy
Baker River Project
Flood-Frequency Curve
Extension
FERC Project
No. 2150
Draft Report
April 2009
Extreme Value Type 1 Plotting Paper
PMF Estimate
739.19 ft NAVD88
Top of Dam
735.77 ft NAVD88
Stochastic Model Results
Upper Baker Project Regulated Frequency Curve
MAX RESERVOIR STAGE - UPPER BAKER (ft NAVD88)
ANNUAL EXCEEDANCE PROBABILITY
TETRA TECH
1420 5th Avenue, Suite 550
Seattle, WA 98101

References


RECLAMATION
Managing Water in the West
Hydrologic Hazard Curves and Extreme Flood Probabilities for Dam Safety
John England, Ph.D., P.E., P.H., Hydraulic Engineer
Flood Hydrology Group, Technical Service Center
U.S. Department of the Interior
Bureau of Reclamation


RECLAMATION
Managing Water in the West
Dam Safety Research Program
Hydrologic Hazard Curve Estimating Procedures
Research Report DSO-04-08
U.S. Department of the Interior
Bureau of Reclamation
June 2004

FINE

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    - Erosion continues as flood continues and breach develops.
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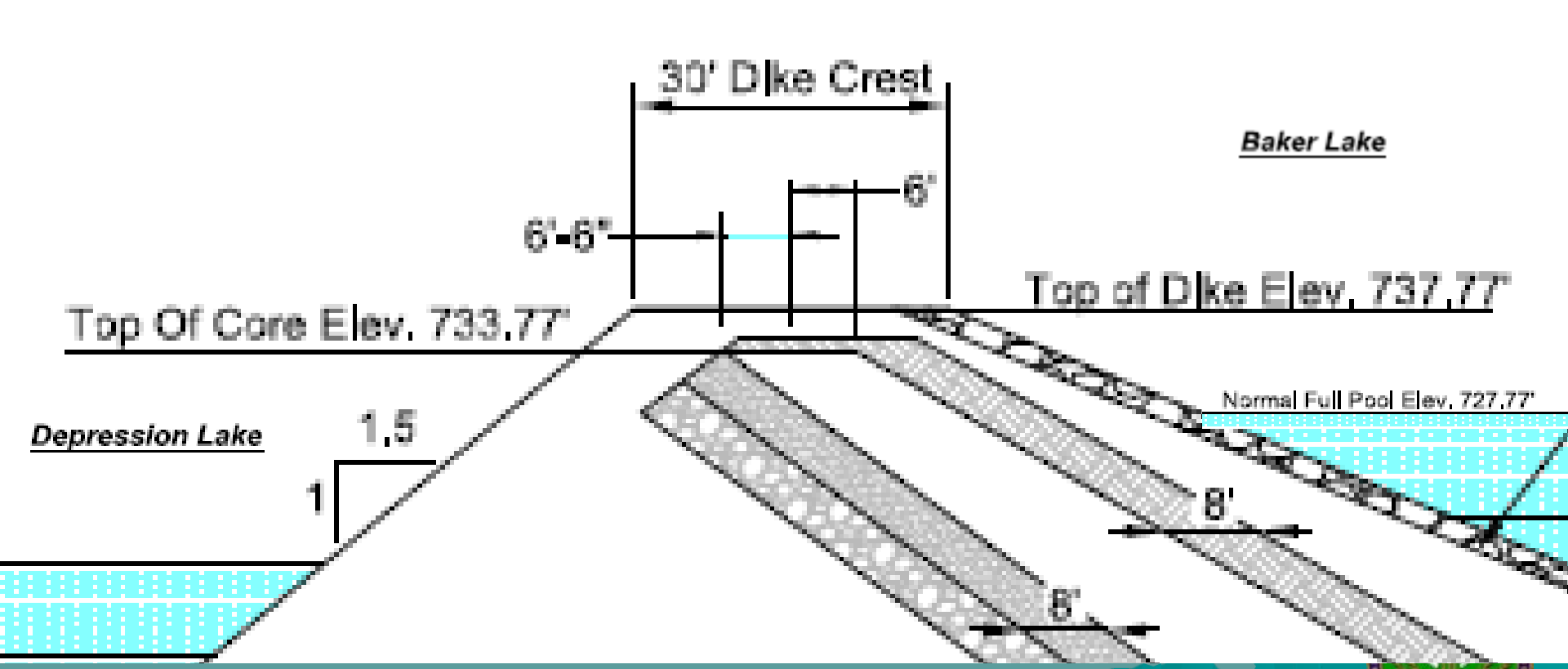
West Pass Dike



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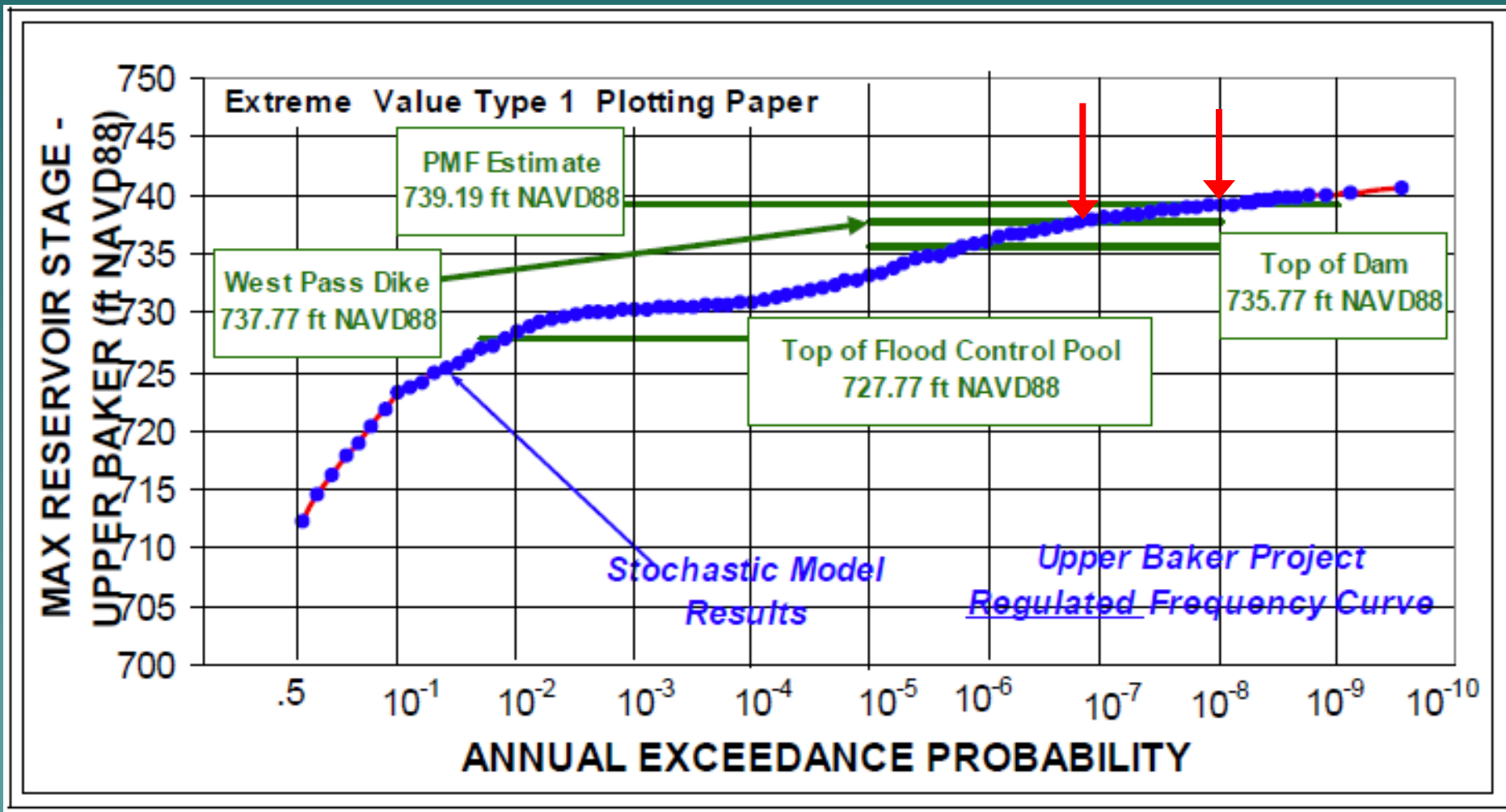

Figure 6-10. Flood-Frequency Curve for Upper Baker Dam – Maximum Reservoir Elevation

Compare to COE Tolerable Risk Chart