IAFSM 2011 Annual Conference

Marriot Bloomington-Normal Hotel & Conference Center

March 9 & 10, 2011

Is it a Levee or a Dam ?

Devils Lake, North Dakota - Update

Stephen L. McCaskie, P.E., G.E., Hanson Professional Services

HANSON

Devils Lake, North Dakota

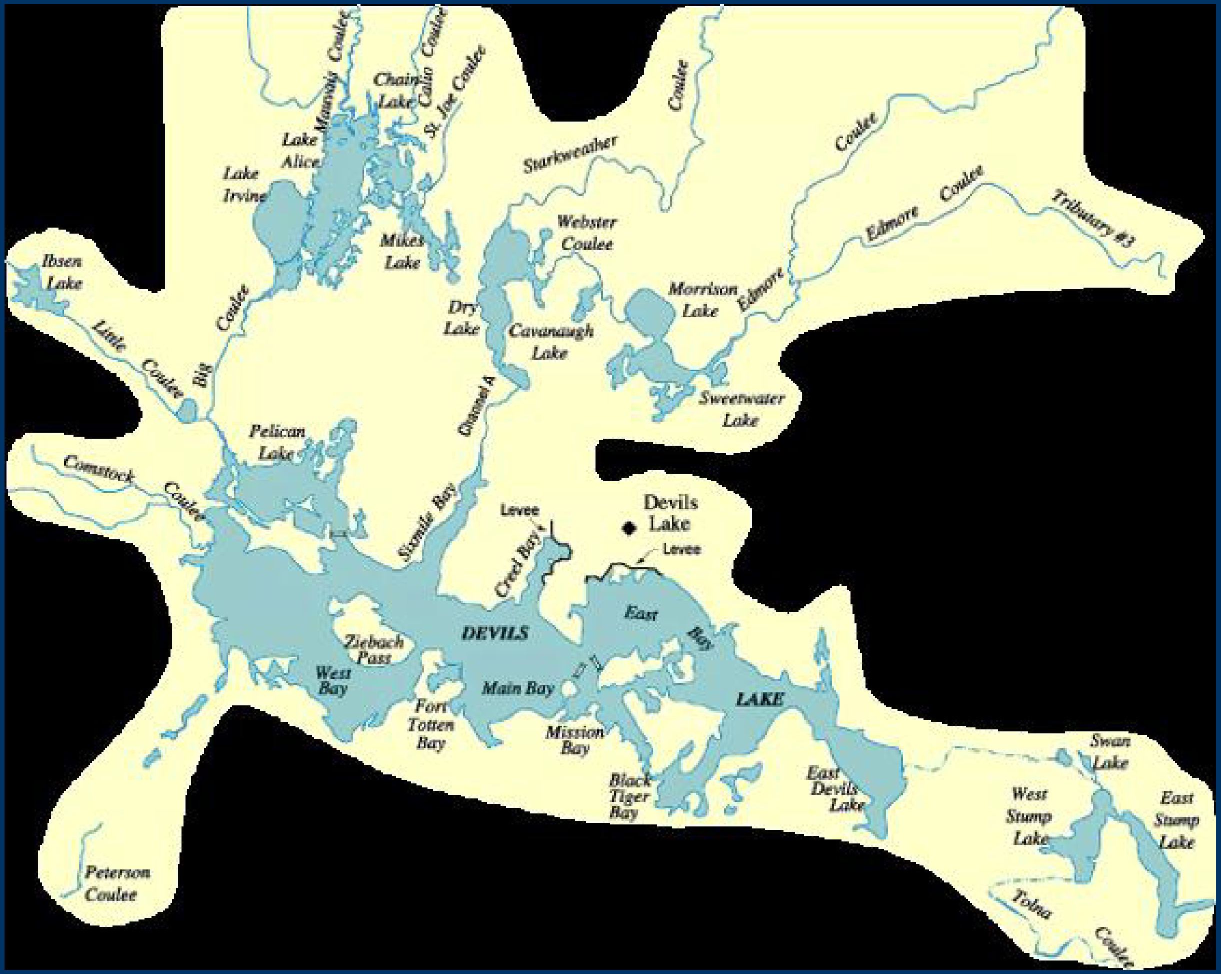
- Problem
- History
- Levee vs. Dam
- RAADS / City Embankments
- Hydraulics & Hydrology
- Geology / Hydrogeology
- Subsurface Conditions
- Dam Analyses
- Project Features and Design
- Instrumentation
- Constructability
- Status
- City Embankments

Problem

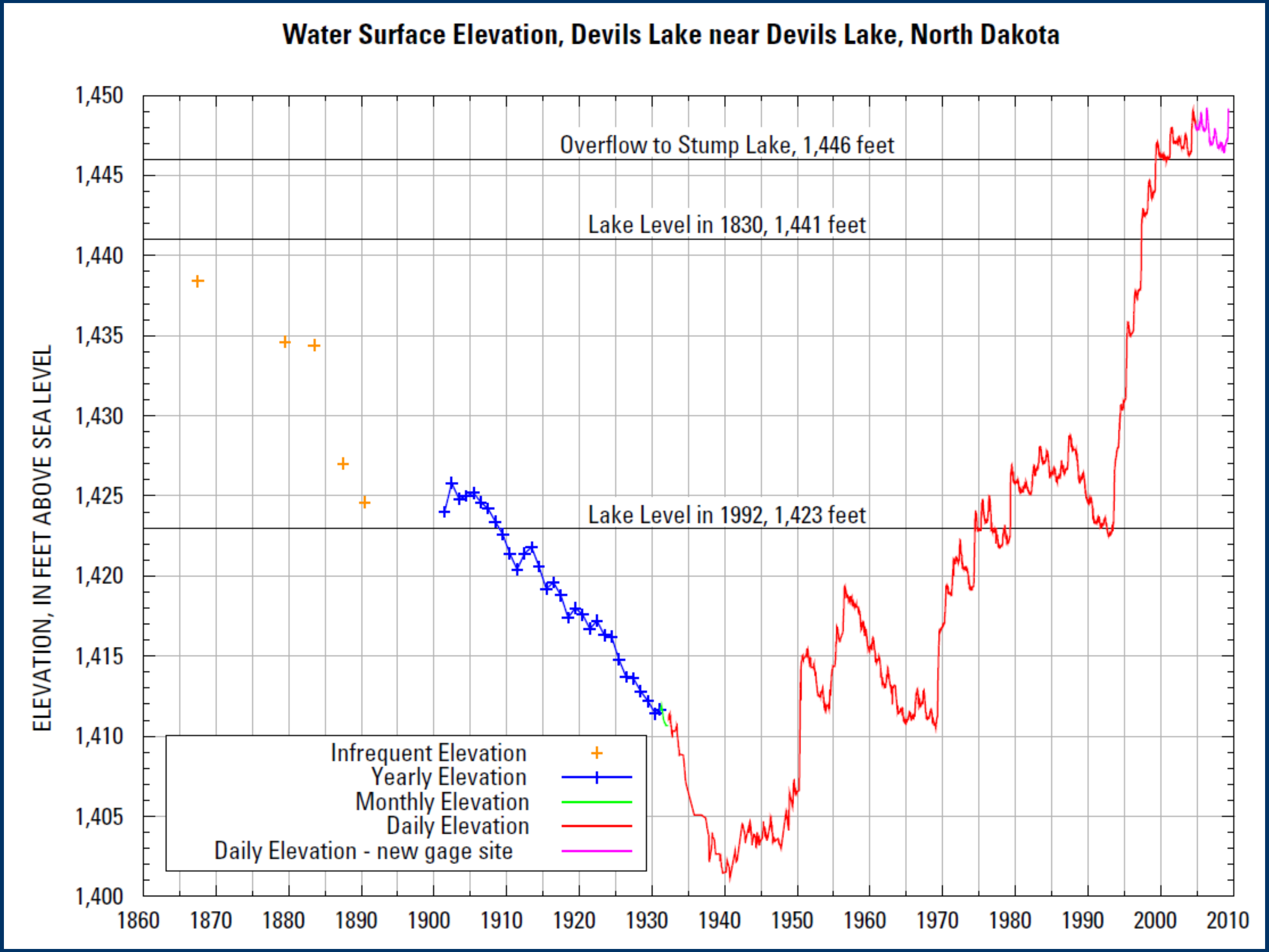
- Since 1990, flooding destroyed hundreds of homes and businesses, inundated thousands of acres of farmland
- North Dakota and the U.S. government have spent more than $450 million in flood mitigation

Devils Lake lies within a 3,810-square-mile closed sub-basin of the Red River of the North

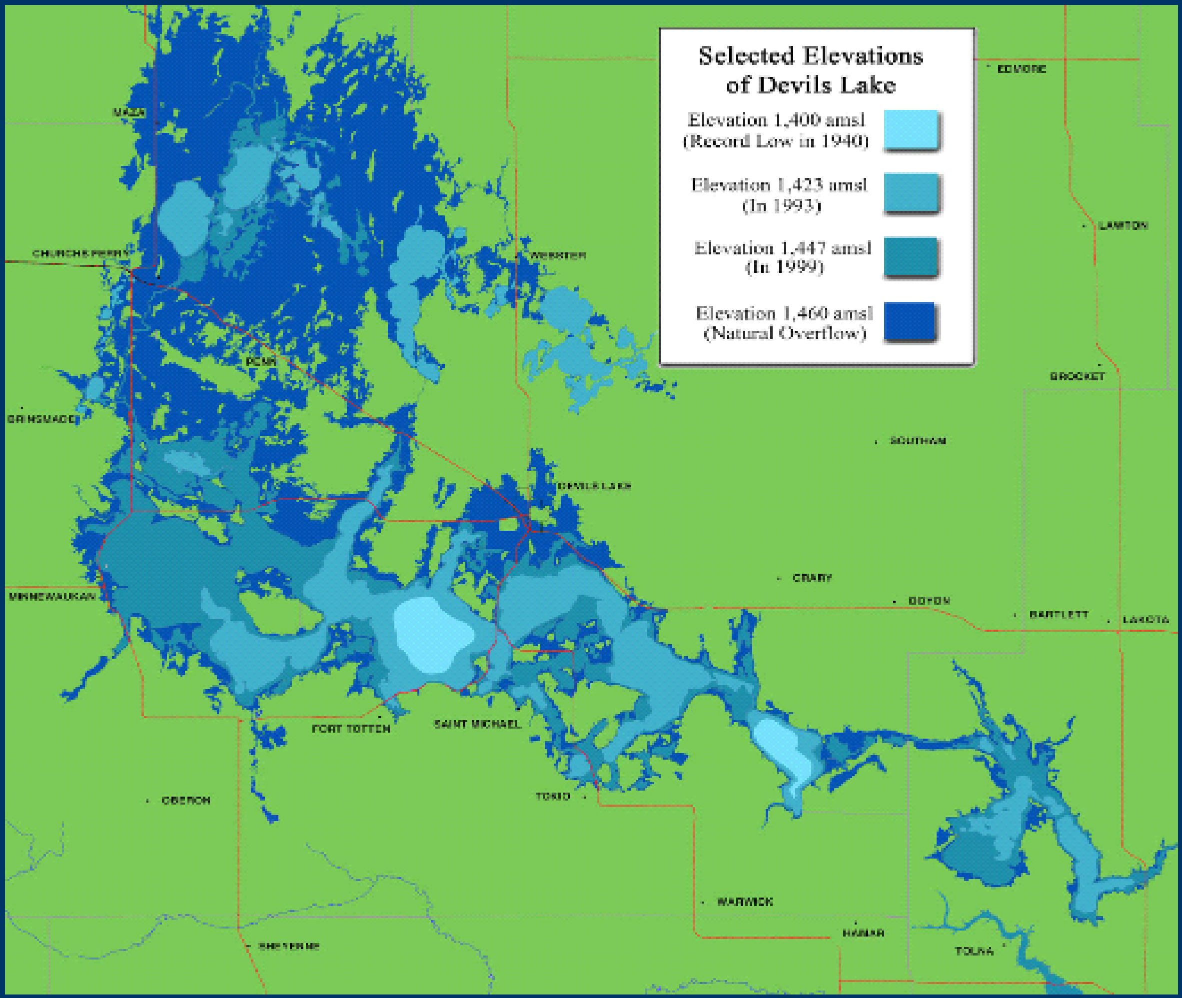
Since glaciation, Devils Lake has naturally fluctuated from dry to overflowing through several coulees



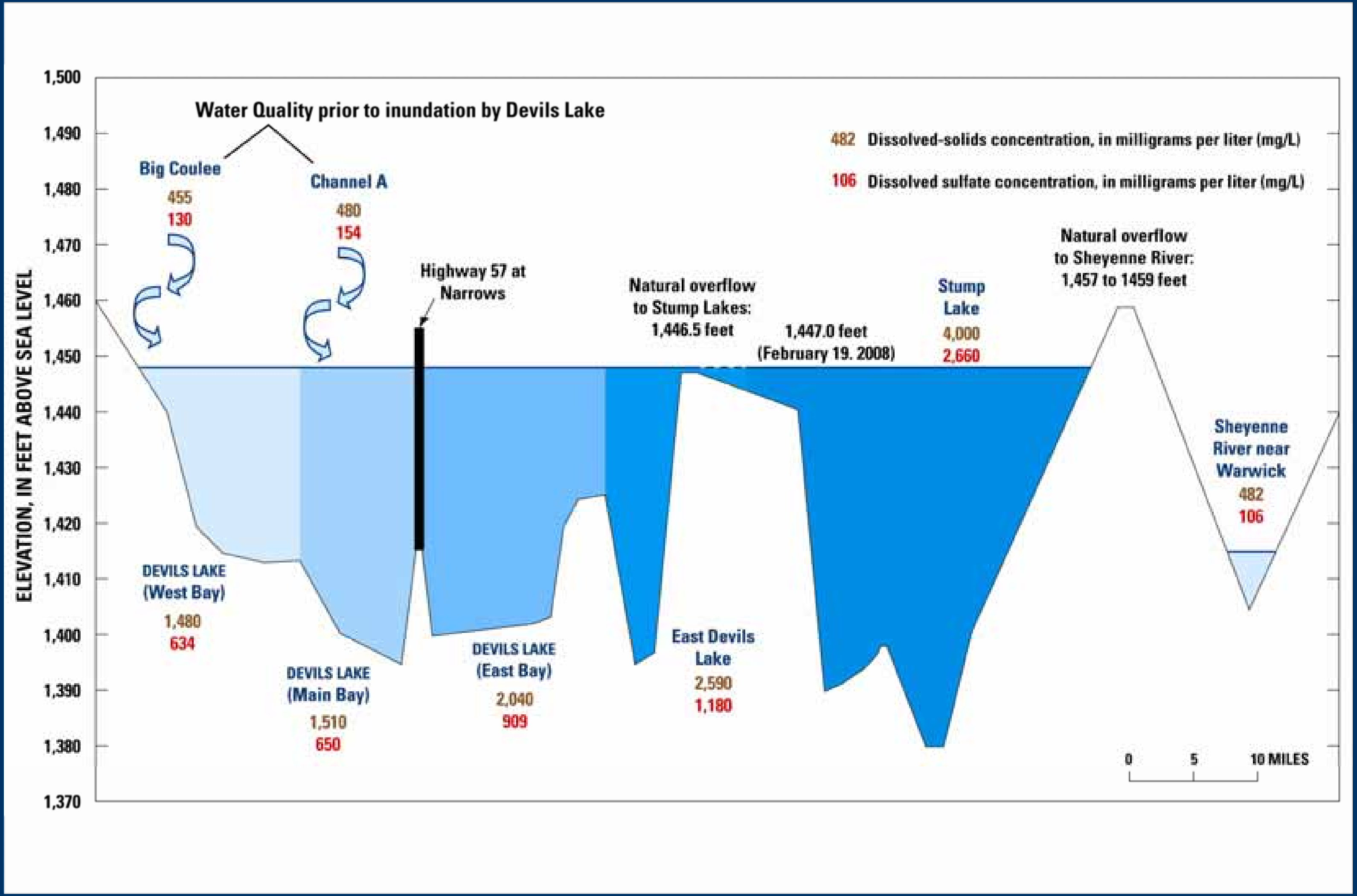
Devils Lake has risen 52 feet since 1940 (1400.9 - 10/24/1940; 1452.05 – 6/27/2010)



Devils Lake spills into Stump Lake at 1446
Current level of 1452 lake covers 258 square miles
At 1459 combined lakes spill into Sheyenne River through Tolna Coulee



Water Quality Issues
Dissolved Solids and Sulfate Concentrations



Water Quality Constraints

Sheyenne River

- **Sulfate 450 mg/l**

Red River of the North

- **Sulfate 250 mg/l**
- **TDS 500 mg/l**

ND State Water Commission

- Designed / constructed Devils Lake West End outlet
- Manitoba lawsuit over 402 Permit denied
- Pumps / pipelines / channels
- Max 250 cfs (permitted) when above 1445.0

History

- RAADS - Roads Acting As Dams
  - Existing roads “elevated” to act as dams
  - Roads not designed / constructed to provide flood protection
  - New embankments designed w/ USACE Dam Safety Criteria
- Devils Lake City Embankments
  - Analyzed for flood damage reduction purposes
  - 1987 Initially authorized / constructed as levees (section 205)
  - Raised 1995, 1997, 2004 under PL84-99 using Flood Control and Coastal Emergency Funds
  - Embankments designed w/ USACE Dam Safety Criteria

Levee vs. Dam

- A levee is defined as an embankment whose primary purpose is to provide flood protection from seasonal high water and therefore subject to water loading for periods of only a few days or weeks a year.
- A dam is “an artificial barrier that has the ability to impound water…for the purpose of storage or control of water”.
- Dam contains water for prolonged periods, longer than normal flood protection requirements, or permanently.

Levee vs. Dam

- Engineering judgment:
  - areas of higher elevations where the embankments are small and tie into high ground – levee criteria;
  - areas where there is a significant amount of water against the structure all the time – dam safety criteria.

RAADS Project

- Portions of ND and BIA roads elevated to "act" as dams
- Many roads within Fort Totten Indian Reservation
- Roads not constructed to function as dams and impound water to protect people and resources from the lake

RAADS Project – Existing Embankments

- Non-engineered
- Multiple raises
- Misc. fill materials
- Pavement / rock
- Non-engineered penetrations
  - Culverts
  - Underground Utilities

FHWA-CFLHD, SLN, BIA, USACE St. Paul District, and ND DOT, proposed safety improvements

- 1999 Task Force – possible solutions
  - Dec 2004 recommended technical solutions
- 2005 SAFETEA-LU authorized FHWA to implement recommendations
- USACE - interagency group to develop a technical design that will accommodate surface transportation and provide a water barrier
- 2008 Environmental Assessment – selected alternatives1A, 2D, 3A and 4B

Section 23 CFR 650.115 (c): Federal Highway Administration (FHWA) design and construction criteria:

Where highway fills are to be used as dams to permanently impound water more than 50 acre-feet (61,710 cubic meters) in volume or 25 feet (7.6 meters) deep, the hydrologic, hydraulic, and structural design of the fill and appurtenant spillways shall have the approval of the State or Federal agency responsible for the safety of dams or like structures within the State, prior to authorization by the Division Administrator to advertise for bids for construction.

Safety of Dams – North Dakota

- North Dakota State Water Commission (NDSWC)

FHWA Project ERFO-1(991)

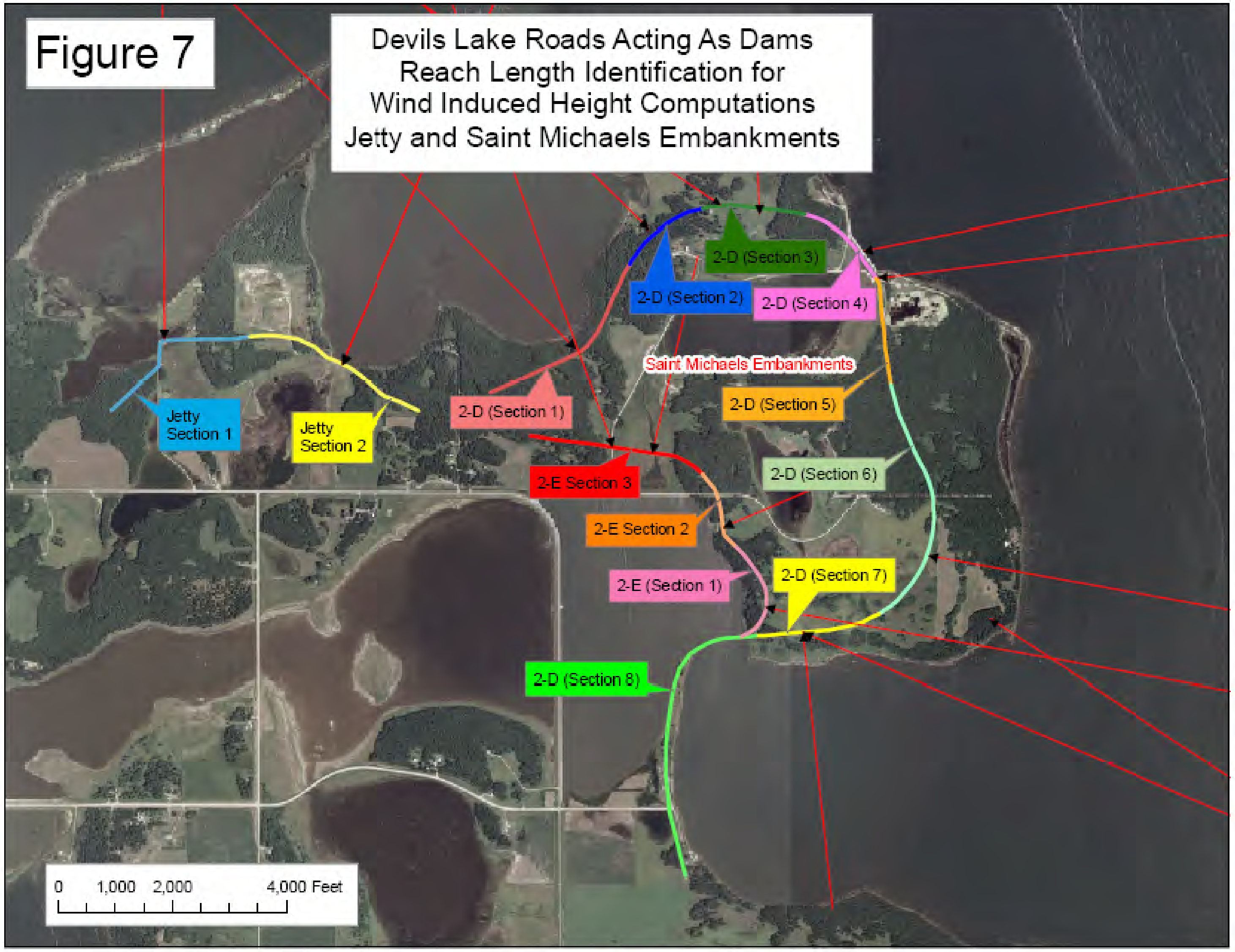
- **Phase 1** - recommendations for / implementation of emergency repairs to BIA roads and/or embankments (short term)
- **Phase 2** - analyses and designs for the preparation of plans and specifications for permanent flooding prevention measures
- USACE retained Bergmann-Hanson JV to assist in completion of the Phase 2 analyses and design, and prepare DDRs

Phase 2 Design Recommendations

- Interim raises of 1455 and 1460, and ultimate of 1468 feet.
- Zoned earth dam with
  - compacted core
  - random fill zone
- Seepage control
  - compacted core
  - sand / toe drain
  - slurry cutoff wall

RAADS Project - Selected Alignments

Hydraulics & Hydrology - RAADS



Hydraulics & Hydrology

- USACE Dam Safety Criteria (DSC)
- Five foot freeboard is adopted:
  - Minimum freeboard – 5 feet
  - Inflow Design Flood (IDF) - ½ PMF (Base Safety Condition) (1,440,000 acre-feet)
  - Maximum wind induced wave runup height - 4.4 feet (4+ mile fetch length)
  - Uncertainty of analytical procedures – PMP combined with probable maximum snow melt
  - Uncertainty for project function - Tolna Coulee, natural outlet at 1459, acts as the spillway for the ultimate lake condition, uncertain performance during a high water event.

Alternative Crest Elevations

- Current elevations (1450-1455)
- Interim raise of 1455 (does not meet DSC)
- Interim raise of 1460 and ultimate raise of 1468 (meets DSC w/ ½ PMF)

Geology / Hydrogeology

- Glaciated Plains Region of the Central Lowlands Province
- Glaciated Plains Region is between the Missouri Escarpment to the west and the Pembina Escarpment to the east
- Terrain is undulating to rolling hills with many “Prairie Potholes” and shallow lakes
- Uncertain connectivity between Devils Lake and underlying Spiritwood Aquifer
- Gneiss basement rock covered by a thick sedimentary rock (Pierre Shale) covered by glacial deposits

Glacial Deposits

- Quaternary Glacial Aqueous (QGA) – overconsolidated silty clays
- Quaternary Old Till (QOT) - overconsolidated unsorted sandy, gravelly, silty clay
- Quaternary Young Till/Drift (QYT) - sandy, gravelly, silty clay or silty clayey sands
- Quaternary/Holocene Lacustrine (QL) - unconsolidated clays, silts, varved clays, and shore deposits of sands and clayey sands (QLA – Marl)
- Quaternary Fill (QF) - gravelly, sandy, silty clay, derived from till / drift deposits

Subsurface Conditions

Geotechnical Explorations 2005, 2006, 2007, 2008, 2009, 2010

- Soil Borings (SPT)
- Cone Penetration Test Soundings (CPT)
- Laboratory Testing
- Potential Borrow Site sampling / testing

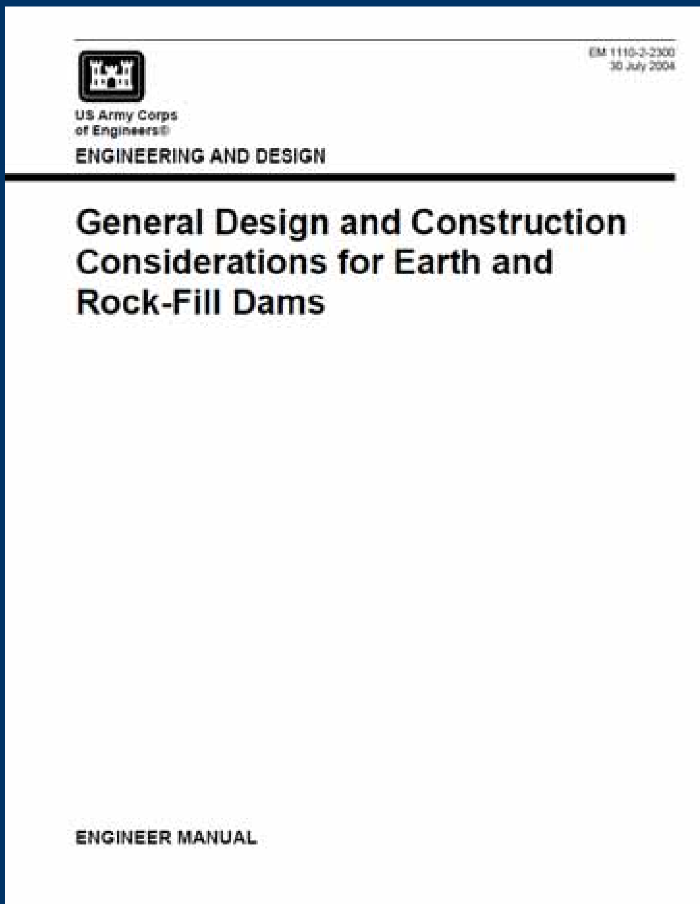
Design Soil Parameters

- Laboratory Test Data
- Lower bound of the 90% Confidence Level
- Literature review / data bases (USACE / USBR)
- Engineering Judgment

Design Soil Parameters

Embankment Unit or Geologic Unit	unit $weight_{sat}$	Drained		Undrained		Permeability	Consolidation			
	(pcf)	phi(Deg.)	c(psf)	phi(Deg.)	c(psf)	k_h(ft/sec)	e_o	C_c	C_r	P_c (psf)
Compacted Core	130	27	230	0	1000	5.15E-09	-	-	-	-
Random Fill	125	34	0	0	600	5.15E-09	-	-	-	-
Sand Drain	133	37	0	37	0	3.00E-04	-	-	-	-
Granular Fill	120	32	0	32	0	1.00E-06	-	-	-	-
Seepage Berm	120	34	0	34	0	1.00E-03	-	-	-	-
Rip Rap	140	32	0	32	0	1.00E-02	-	-	-	-
Slurry Cutoff Wall	85	0	0	0	0	1.60E-09	-	-	-	-
QF (Existing Fill - fine grained)	125	34	0	0 14 (CU)	600 560(CU)	5.15E-09	0.679	0.14	0.02	1,840
QF (Existing Fill - coarse grained)	118	32	0	32	0	1.00E-06	-	-	-	-
QF (Existing Fill - bad)	120	24	0	0	450	1.00E-09	0.744	0.15	0.02	1,400
QL (Lacustrine)	120	13	250	0	700	1.00E-09	0.895	0.21	0.05	2,800
QLA (Recent lacustrine)	112	32	0	0 14.5(CU)	500 600(CU)	6.60E-08	1.078	0.27	0.05	2,800
QLB (Glacio-lacustrine)	110	20	0	0 10.5(CU)	500 520(CU)	2.00E-09	1.067	0.31	0.05	3,500
QLC (Beach deposit)	120	32	0	32	0	1.00E-06	-	-	-	-
QYTA (Young Till)	127	34	0	0 19.5(CU)	1250 1020 (CU)	1.00E-09	0.649	0.13	0.02	2,950
QYTD (Young Till d)	127	34	0	0	1,000	1.00E-08	0.649	0.13	0.02	2,950
QO (Outwash Deposits)	127	34	0	34	0	1.00E-06	-	-	-	-
QGA (Silt)	125	34	0	34	0	1.00E-09	-	-	-	-
QOT (Old Till)	130	34	0	34	0	1.00E-09	-	-	-	-

Dam Analyses



EM 1110-2-2300
30 July 2004

US Army Corps
of Engineers®

ENGINEERING AND DESIGN

General Design and Construction Considerations for Earth and Rock-Fill Dams

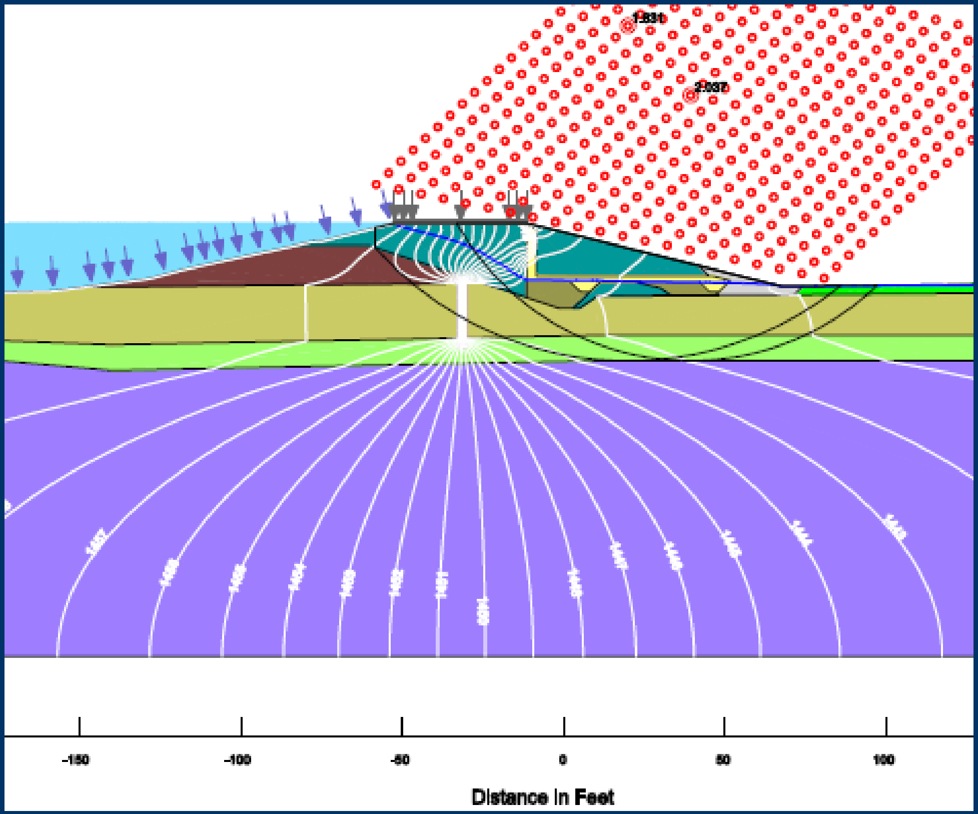
ENGINEER MANUAL

- Seepage Analyses
  - Cracked Section
  - Sand Drain Capacity
  - Sensitivity / Soil Properties
- Slope Stability Analyses
  - End of Construction
  - Short Term Steady State Seepage
  - Long Term Steady State Seepage
  - Staged Construction
- Settlement
  - Overbuild
- Slope Protection
- Filter Criteria
  - (sand drain - single vs two stage filter)

Required Factors of Safety

Analysis Type	Design Condition	Analysis Condition	Embankment Design Elevation	Lake Design Elevation	Minimum FS
Slope Stability	During Construction w/ Unwatering	Undrained, Consolidated / Undrained, and Drained Soil Strengths	1,455 1,460 1,468	1,452.0 (2010) 1,452.0 (2010) 1,452.0 (2010)	1.5 1.5 1.5 1.1 (Drained)
	Short-Term with Steady State Seepage	Undrained Soil Strengths	1,455 1,460 1,468	1,455.0 1,460.0 1,462.9	1.3 1.3 1.3
	Long-Term with Steady State Seepage	Drained Soil Strengths	1,455 1,460 1,468	1,455.0 1,460.0 1,462.9	1.5 1.5 1.5
Seepage	Short-Term & Long-Term with Steady State Seepage	Landside Exit Y-Gradients	1,455 1,460 1,468	1,455.0 1,460.0 1,462.9	2.5[4] 2.5[4] 3.0[5]
		Landside Heave	1,455 1,460 1,468	1,455.0 1,460.0 1,462.9	3.0 3.0 3.0

Dam Analyses - Example



Section **344+00**

Location **BIA 4 South #2**

Design Condition	Embankment Elevation	Lake Water Surface Elevation	Tailwater Elevation	Seepage Results					Slope Stability Results (Min. F.S.)		
				Y Gradient	F.S. Y-Gradient	F.S. Landside Heave	Drain Flow (ft^3/day/ft)	Total Flow (ft^3/day/ft)	Long-Term Drained Strengths	Consol. Undrained Strengths	Short-Term Undrained Strengths
During Construction (13)	1454.5	1452.0	1433.4 (3)	0.14	7.50	N/A		0.2390	1.30 (9)	1.73 (12)	1.73 (12)
Steady Seepage	1455.0	1455.0	1439.2	0.21	3.33	3.31	0.0050	0.0157	1.91		1.69
Steady Seepage	1460.0	1460.0	1440.3	0.31	3.23	3.30	0.0029	0.0164	2.04		1.63
Steady Seepage	1468.0	1462.9	1440.2	0.22	4.55	5.94	0.0137	0.0139	2.04		1.58

Notes: (3) Bottom of inspection trench elevation at section analyzed. (9) Minimum failure surface depth 5 feet w/ 50 psf of cohesion. (12) Minimum failure surface w/ 50 psf of cohesion for QO. (13) Requires PZ 27 Sheet Piling.

Project Features and Design

Embankment dams

- 20 ft top width
- 3.5 to 4H:1V landside slopes
- 4 to 5H:1V lakeside slopes

Roads acting as dams

- minimum 41 ft top width and 4H:1V side slopes

Project Features and Design

Embankment (new / landside improvement to existing)

- Recommend full 1468 base width
- Compacted Core (w/ inspection trench)
- Random Fill
- Granular Fill
- Slurry Cutoff Wall
- Sand Drain (vertical / horizontal)
- Toe Drain (filter stone w/ perforated / slotted collector pipe)

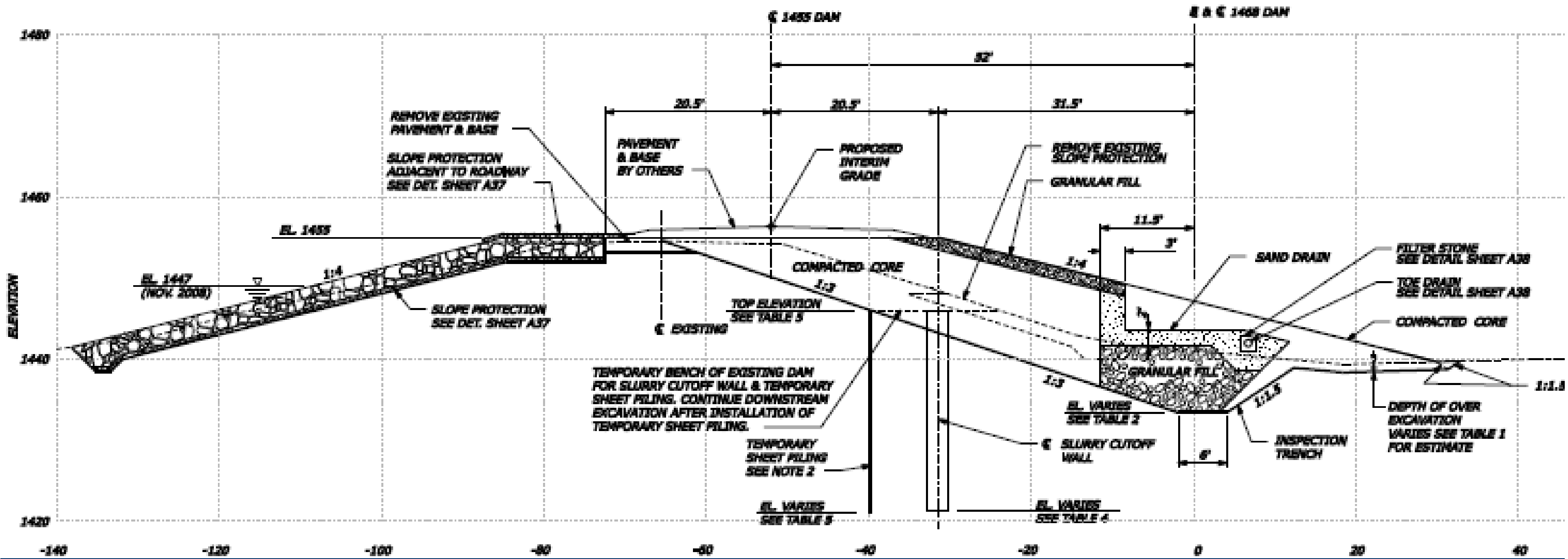
Slope Protection

- Riprap, bedding stone, geotextile fabric

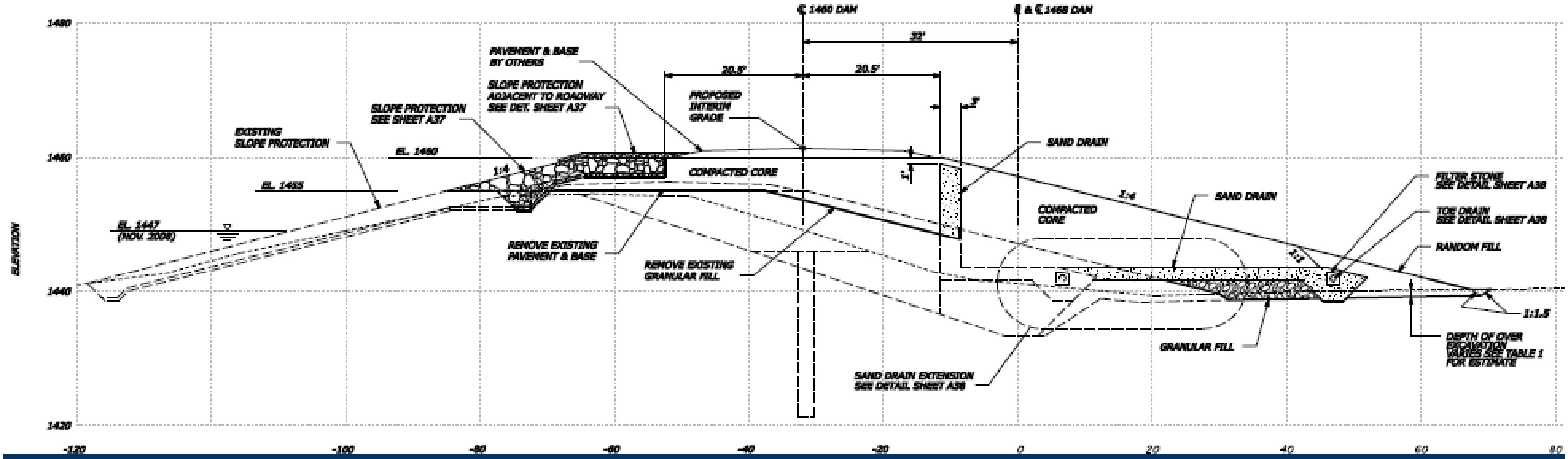
Landside Slope Protection / Filter

- Riprap, bedding stone, filter stone, sand drain

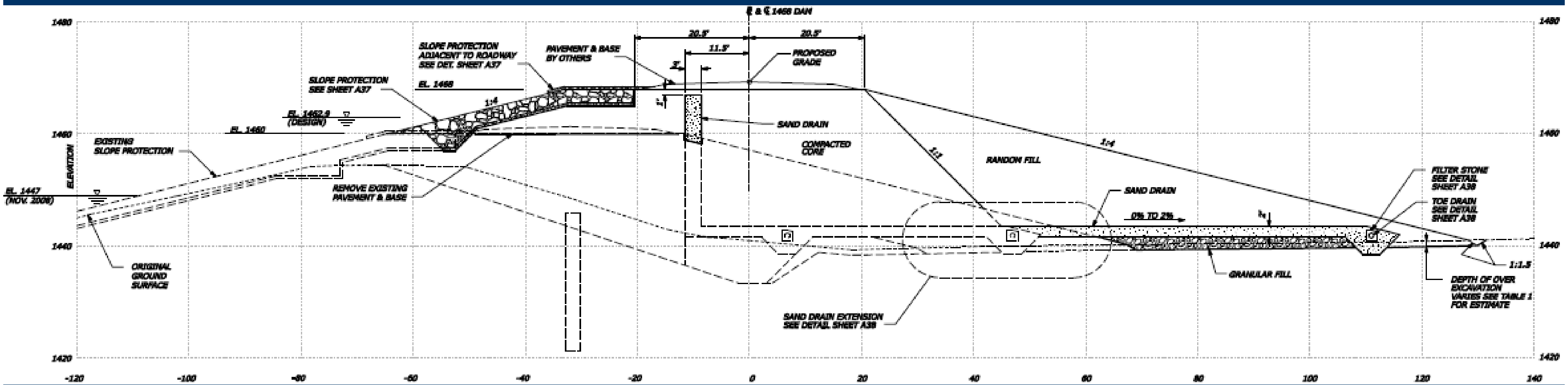
Typical Section (1455)



Typical Section (1460)



Typical Section (1468)



Gradation/Material Requirements for New Embankment Construction

Material	Gradation Requirements	Other Requirements
Collector Pipe	**Maximum Perforations** Slot = 3 mm maximum width Circular = 4 mm maximum dia.	-Meets all requirements for perforated, corrugated, P.E. or plastic pipe (NDDOT, 2008)
Filter Stone	**Sieve Size** **Percent Passing** 1 Inch 100 3/4 Inch 95-100 1/2 Inch 85-100 3/8 Inch 60-90 No. 4 15-25 No. 8 2-10 No. 200 0-3	-Meets all requirements for permeable base aggregate (NDDOT, 2008).
Sand Drain	**Sieve Size** **Percent Passing** 3/8 Inch 100 No. 4 95-100 No. 16 45-80 No. 50 10-30 No. 100 0-10 No. 200 0-3 (delivered) 0-5 (in place)	-Meets all requirements for fine aggregate for concrete (NDDOT, 2008).
Granular Fill	**Sieve Size** **Percent Passing** 1 Inch 100 3/8 Inch 90-100 No. 4 80-100 No. 16 45-100 No. 50 10-60 No. 100 0-25 No. 200 0-12	-Granular SW, SP, SW-SM or SP-SC. -Uniformity Coefficient, $C_u = \geq 4$ -Coefficient of Curvature, $C_z \geq 1$ to ≤ 3
Compacted Core	**Sieve Size** **Percent Passing** 3 Inch 100 No. 200 ≥45	-Cohesive material CL, GC or SC. -Plasticity Index, PI ≥12 to ≤30 -$d_{85} \geq 0.05$ mm
Random Fill	**Sieve Size** **Percent Passing** No. 200 ≥30	-Cohesive material. -Plasticity Index, PI ≥3to ≤35 -$d_{85} \geq 0.05$ mm

Slope Protection

Riprap Gradations

	Gradation 1		Gradation 2		Gradation 3		Gradation 4		Gradation 5	
Thickness (in)	12		18		24		30		36	
Thickness (wet[1]) (in)	18		30		36		42		54	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
W_{100} (lbs)	90	40	200	80	650	260	1500	600	2200	900
W_{50} (lbs)	40	20	80	40	280	130	650	300	930	440
W_{15} (lbs)	20	5	40	10	130	30	330	100	460	130
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
D_{100} (in)	12	9	16	12	24	17	31	23	35	26
D_{50} (in)	9	7	12	9	18	14	24	18	26	21
D_{15} (in)	7	5	9	6	14	8	19	13	21	14

(1) For in-the-wet placement increase thickness by 50 percent.

Bedding Stone Gradations

	Gradation 1		Gradation 2		Gradation 3		Gradation 4		Gradation 5	
Thickness (in)	6		6		12		12		18	
Thickness (wet[1]) (in)	9		9		18		18		30	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
d_{85} (in)	1.5	2.9	1.9	3.7	2.8	5.5	3.8	7.5	4.2	8.4
d_{15} (in)	0.5	1.5	0.6	1.9	0.9	2.8	1.4	4.2	1.5	4.6

(1) For in-the-wet placement increase thickness by 50 percent.

Instrumentation

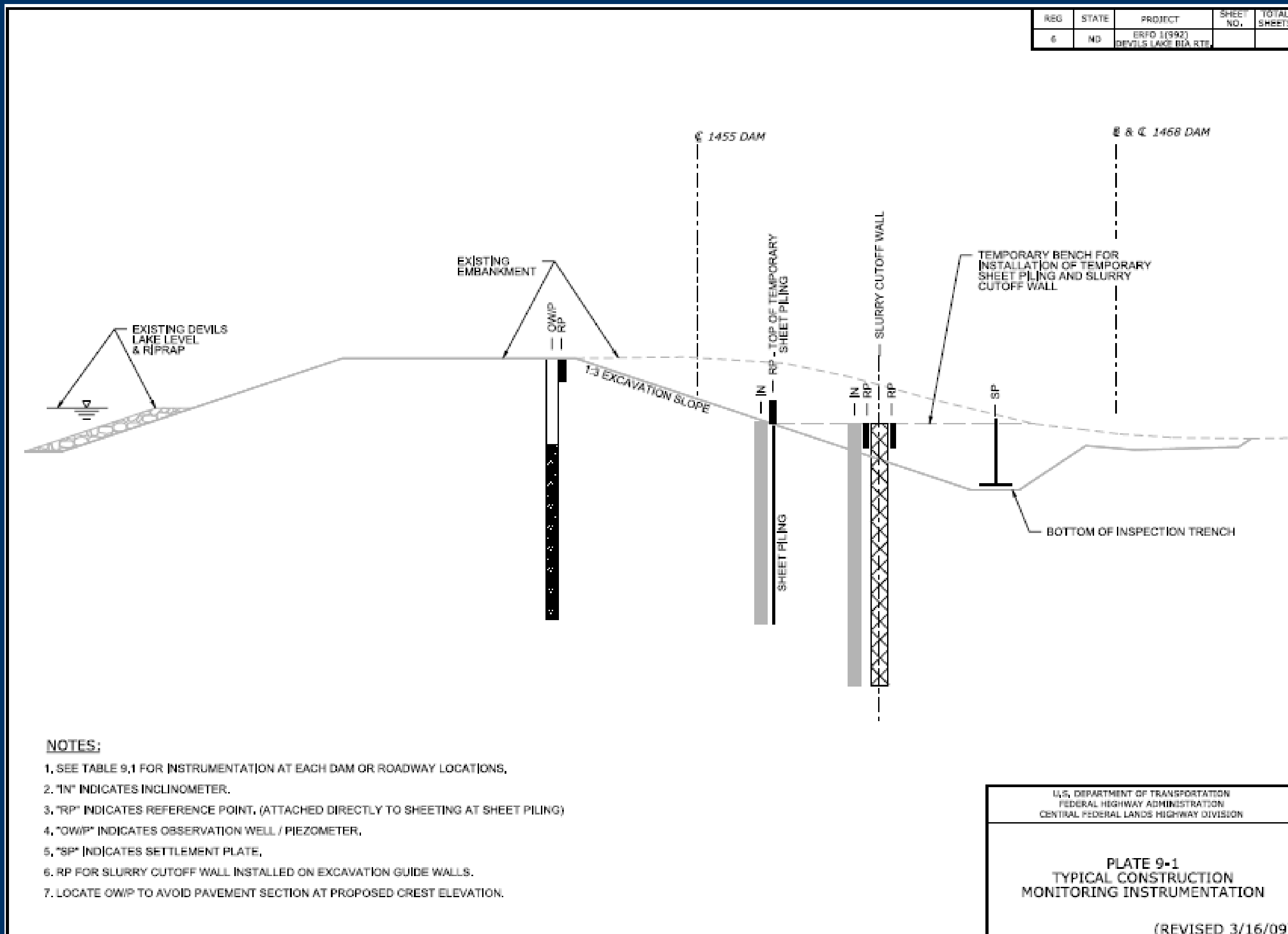
Construction Monitoring

- Settlement Plates
- Inclinometers (slurry cutoff wall, excavation support structures)
- Reference Points (existing embankment)
- Observation wells / piezometers (existing embankment)

Long Term Performance Monitoring

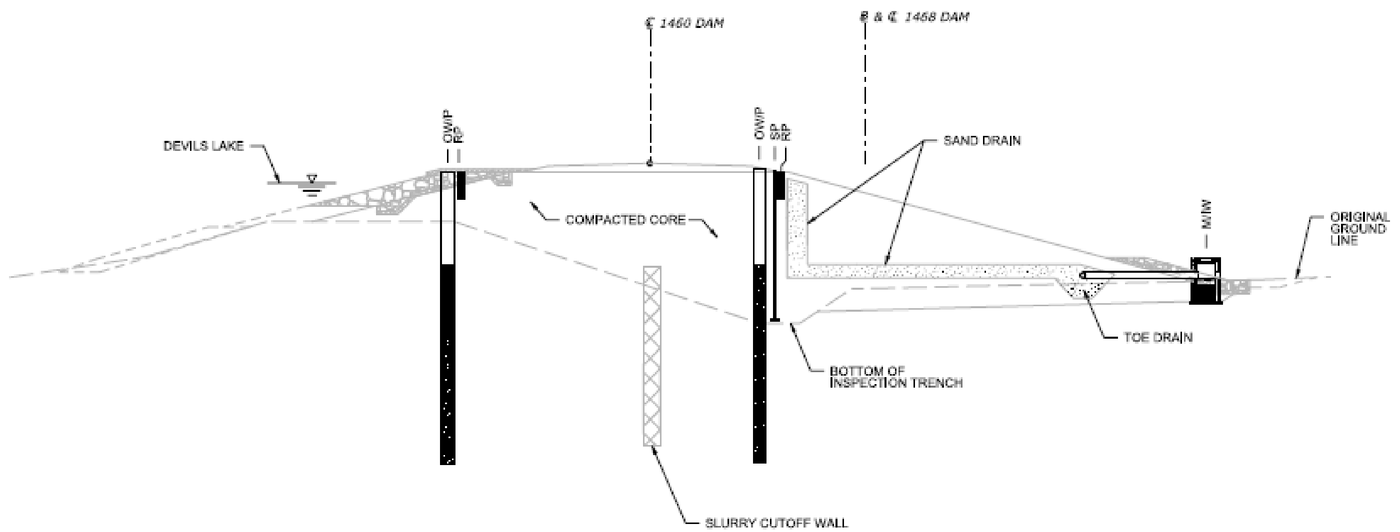
- Settlement Plates
- Reference Points
- Observation wells / piezometers
- Monitoring / Inspection wells with seepage weirs (toe drain collector / discharge pipe)

Construction Monitoring



Long Term Performance Monitoring

REG	STATE	PROJECT	SHEET NO.	TOTAL SHEETS
6	ND	ERFO 1(992) DEVILS LAKE BIA RTE.		



NOTES:

1. SEE TABLE 9.2 FOR INSTRUMENTATION AT EACH DAM OR ROADWAY LOCATIONS.
2. "M/W" INDICATES MONITORING / INSPECTION WELL.
3. "RP" INDICATES REFERENCE POINT.
4. "OW/P" INDICATES OBSERVATION WELL / PIEZOMETER.
5. "SP" INDICATES SETTLEMENT PLATE.

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
CENTRAL FEDERAL LANDS HIGHWAY DIVISION

PLATE 9-2
TYPICAL LONG TERM
PERFORMANCE MONITORING
INSTRUMENTATION

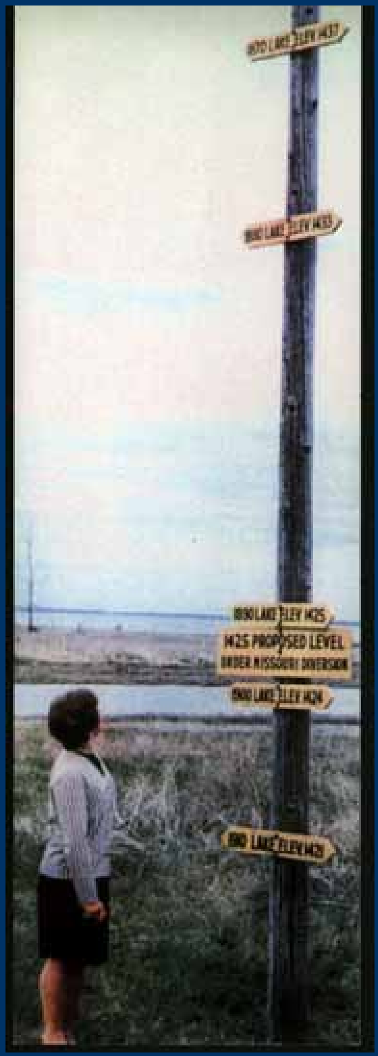
Constructability Issues

- Excavation and removal of landside portion of existing embankments
- Unknown / non-engineered penetrations
- Over excavation of unsuitable foundation soils
- Inspection trench
- Embankment Integrity (seepage control, stability)
- Temporary excavation support / unwatering
- Cofferdam(s)
- Maintenance of traffic

Project Status – Phase 1

- Emergency Repairs to BIA road and embankments (completed 2004)
- Geotechnical Explorations - soil borings and laboratory testing (completed 2008)

Project Status – Phase 2



Trigger level met for Embankment Raise(s)

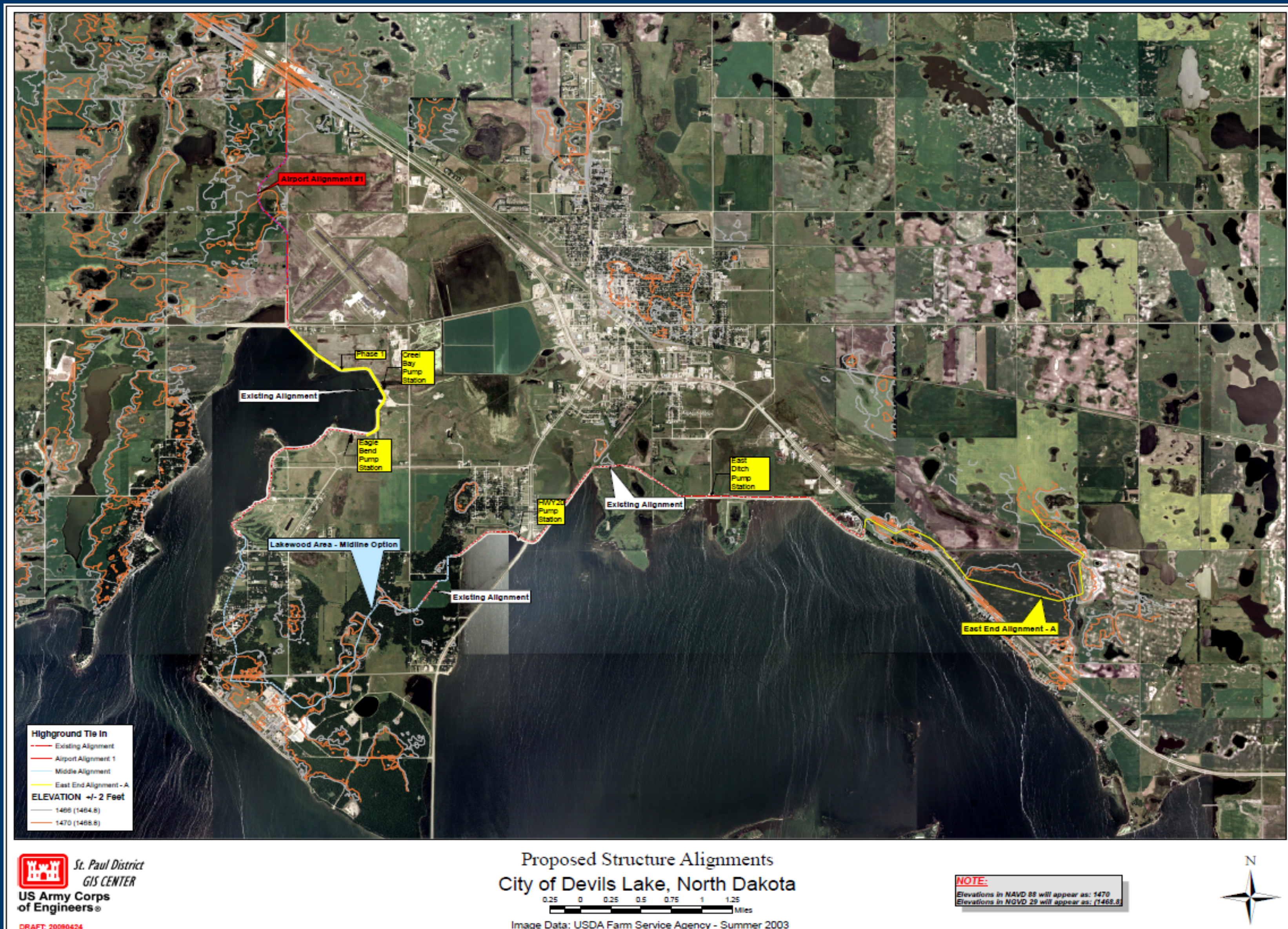
Dam Safety Criteria

- USACE Guidance for Dam certification
- Reasonable Assurance
  - Freeboard
  - Wave Runup
- Unacceptable Risk
  - 50% chance of WSEL 1452 <2015
  - 2% chance of WSEL 1460 <2015

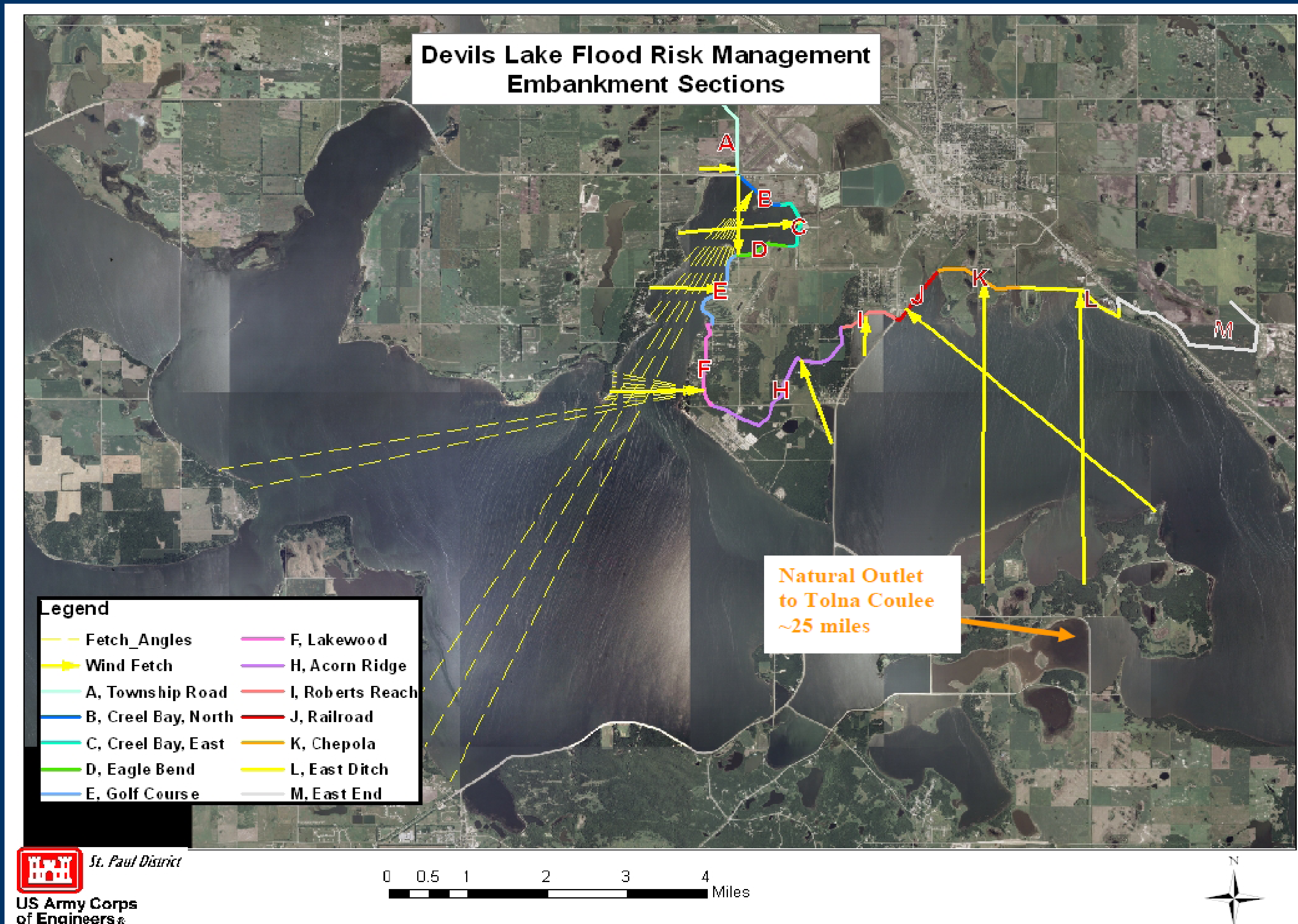
SLN, BIA, FHWA-CFLHD, USBR, KLJ/IB(AE) – construction plans and specifications

Construction of cofferdam(s), embankments (8-12 miles)

Devils Lake City Embankments

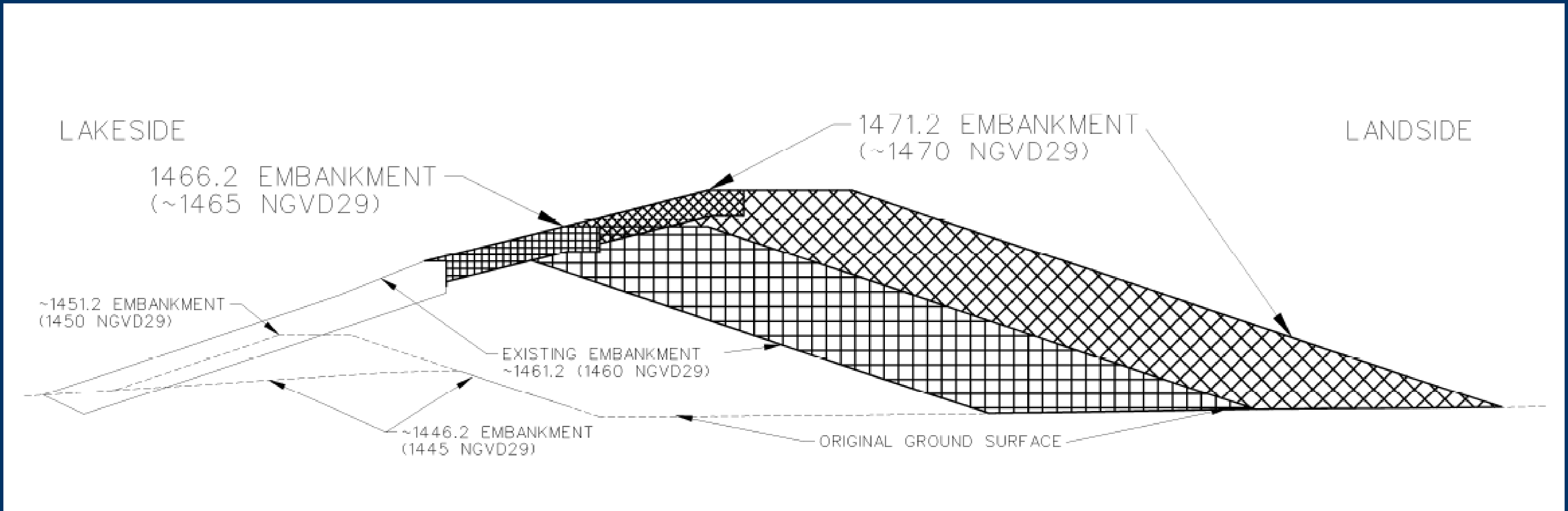


Hydraulics & Hydrology – City Embankments

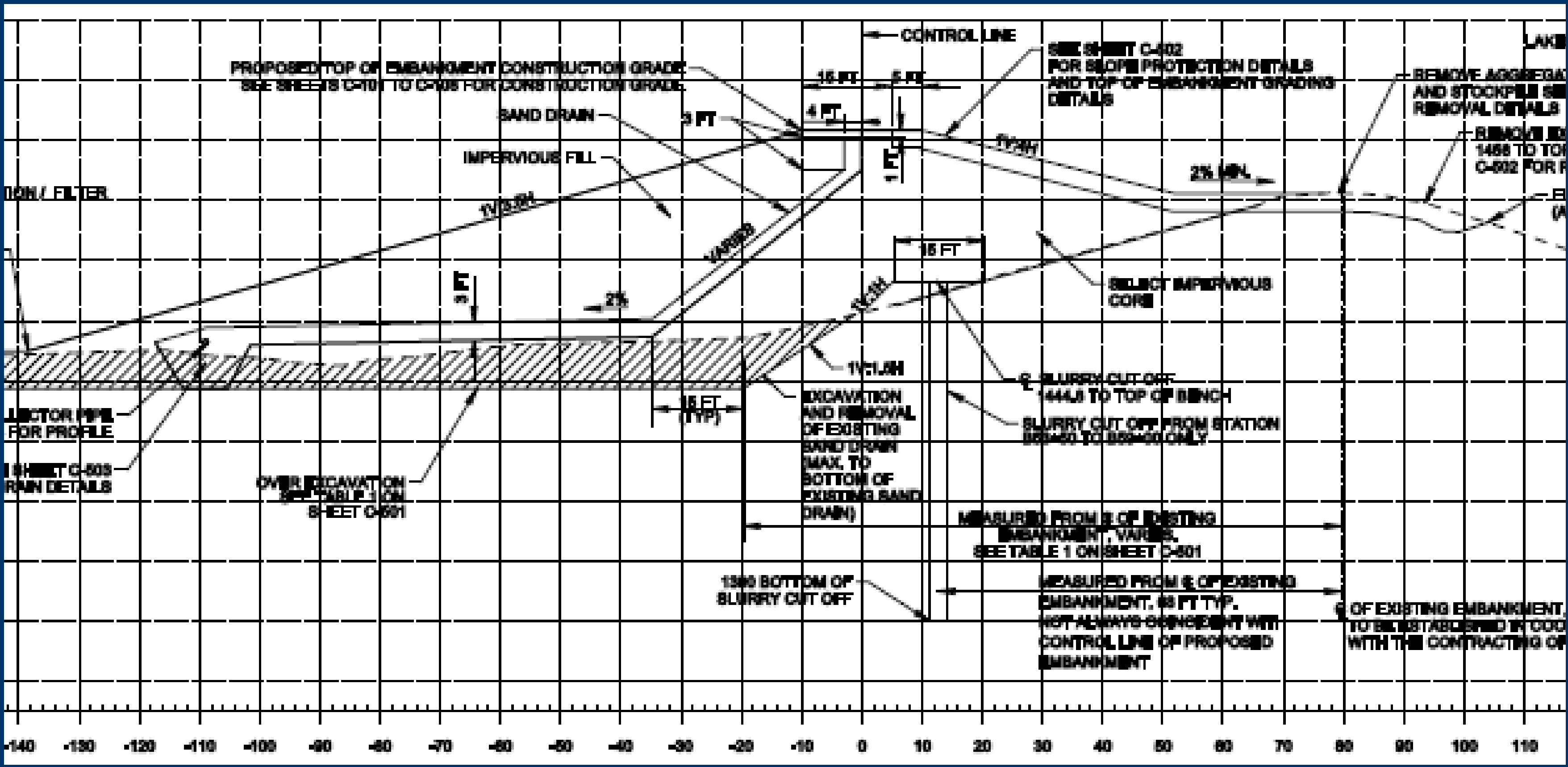


Devils Lake City Embankments

- Landside Improvements
- Slope Protection (riprap/bedding stone)
- Select Impervious Core / Impervious Fill
- Sand Drain



Devils Lake City Embankments



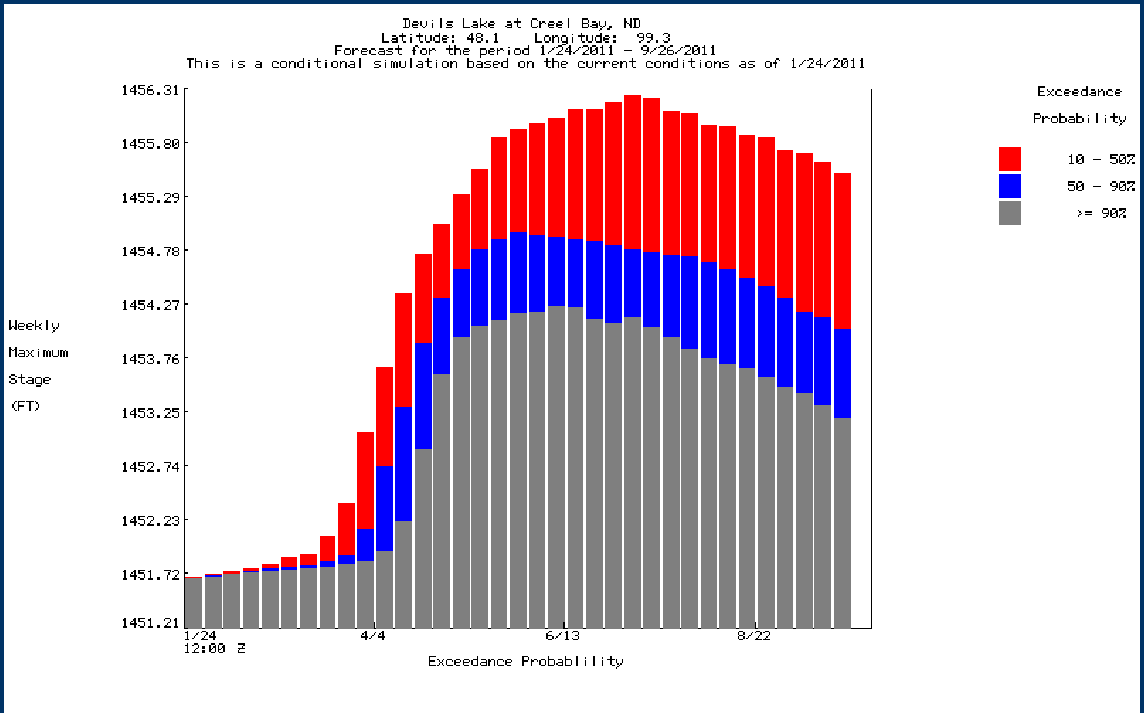
Devils Lake City Embankments

- Under Construction
  - Phase 1 Embankment (1.4 miles) / Creel Bay Pump Station
  - Phase 2A Embankment (0.9 miles)
- In Design / Bidding
  - Phase 2B Embankment (2.5 miles) / East Ditch Pump Station
  - Phase 3 Embankment (X miles) / Lakewood & ND20 Pump Stations

Devils Lake Outlook for Flood Potential…

2011

- 1456.3 (10% chance of exceedance)
- 1455.0 (50% chance of exceedance)
  NWS-FGF 1/27/11
- Current Embankments – 1460.0



Devils Lake Outlook for Flood Potential…

Chance of exceeding 1458.0 –
spill through Tolna Coulee

- 2012 13% (cumulative) 13% (annual)
- 2015 24% (cumulative) 15% (annual)
- 2020 28% (cumulative) 5% (annual)
- 2030 31% (cumulative) 2% (annual)

USGS 1/14/11 based on NWS-FGF 12/22/10

Devils Lake Outlook for Flood Potential…

Spill through Tolna Coulee

- Uncontrolled Release (uncertain outcomes)
- Downstream Impacts
  - Flooding (Sheyenne River / Red River Basin)
  - Erosion / Scour (head cutting to 1446)
  - Damage to Water Crossings (infrastructure)
  - Environmental Damage (wetlands)
  - Water Quality/Aquatic Life

North Dakota State Water Commission

DVLK Flood Protection Efforts

- Expand Existing West End Outlet (250 to 350 cfs)
- Construct East End Outlet - 2nd outlet (250 cfs)
- Construct Tolna Coulee Control Structure (3,000 cfs)
  - "…the most likely site of an uncontrolled release."

Tolna Coulee Control Structure

- Tolna Coulee Control Structure (alternatives)
  - Facilitate “Controlled” release
    - Eliminate a Possible Catastrophic Failure of Tolna Coulee
    - Maintain structural integrity of the coulee
    - Prevent erosion of the outlet
  - Minimize
    - Flooding (Sheyenne River / Red River Basin)
    - Erosion / Scour
    - Downstream Infrastructure Damage
    - Environmental Damage
    - Impact on Water Quality
    - Impact on Cultural Resources

Tolna Coulee Control Structure

- USACE – (PIR) Project Information Report (ongoing)
  - Scour / Schedule / Cost / Economics / Environment
  - Temporary Structure(s) (100% Federal Cost)
  - Permanent Structure(s) (75/25 Cost Share)
  - 1st alternative (Prevent Erosion) Base
  - Grade Control Structure(s)
  - Passive Control
  - Concerns
    - Erosion / Scour (uncontrolled)
    - Schedule (3-years) / Cost
  - Constraints
    - Max. 3,000 cfs
    - Control Elevation 1458 “Pioneer Elevation - 1889”

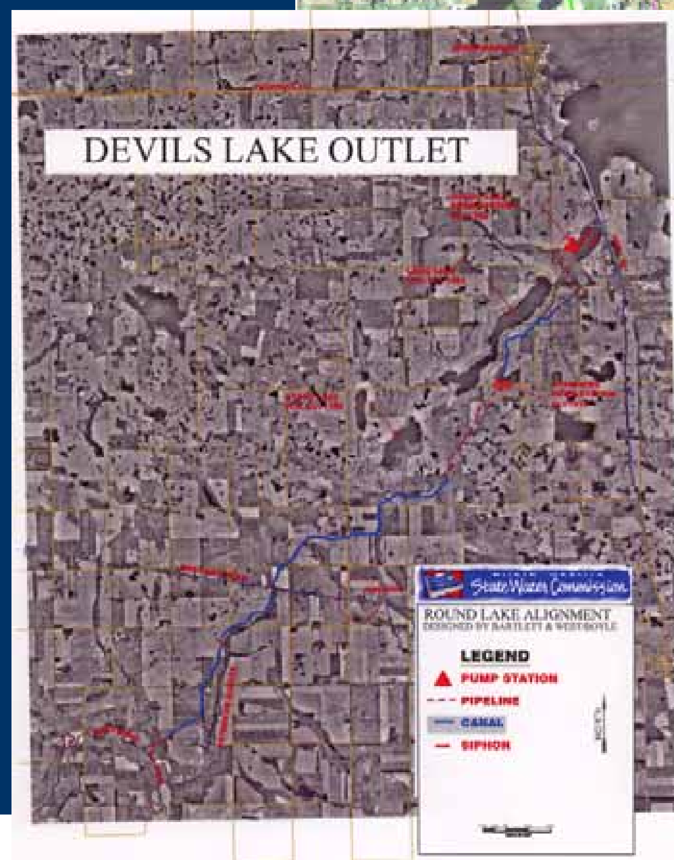
Tolna Coulee Control Structure

- NDSWC – Alternative
  - Permanent Structure(s)
  - Grade Control Structure(s)
  - Passive Control (Weirs)
  - Active Control (Gates / Flashboards)
  - Control Elevation: variable 1458 (Pioneer Elevation) to 1446 (Devils Lake to Stump Lake overflow / Jerusalem Outlet)
  - Concerns
    - Erosion / Scour (uncontrolled)
    - Downstream Mitigation Measures
    - Schedule / Cost

Thank You!

Photo credits: USACE, CFLHD-FHA, USGS, NDSWC, Hanson

HANSON


DEVILS LAKE OUTLET
State Water Commission
ROUND LAKE ALIGNMENT
DESIGNED BY BARTLETT & WEST/BOYLE
LEGEND
PUMP STATION
PIPELINE
CANAL
SIPHON


Devils Lake East End Outlet Alternatives
JERUSALEM CHANNEL
EAST DEVILS LAKE
STUMP LAKE
East End Outlet Alternatives
Black Slough
Black Slough Cutoff
Pipeline/Tunnel Portion
East End Cut Across
Pipeline/Tunnel Portion
County Line Road
Pipeline/Tunnel Portion
Stump Lake Shoreline
Alignment 12A-12C
Alignment 13A
Landsat on May 15, 2010
Bands 7-5-3