Four Lakes Task Force Engineering and Technical Symposium

Session 2 - Hydrology and Hydraulics

Paul Drew and Eric Holmstead
October 20, 2022

GEI Consultants

Four Lakes Task Force

Spicer group

Paul Drew and Eric Holmstead - Introductions

Paul Drew – GEI Program Manager

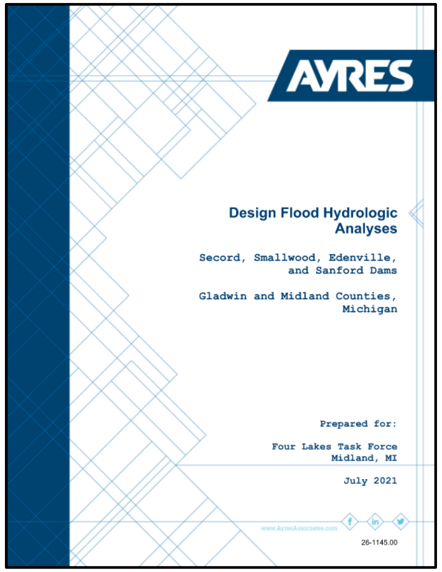
- GEI FLTF Program Manager Since February 2020
- Born and Raised in Milwaukee, Wisconsin (Bucks in Six)
- Frequents Midland's Golf Courses (Above Average Golfer)

Eric Holmstead – GEI Water Resources Engineer

- Wife Expecting First Child in November
- Born and Raised in Maryland, works in Denver
- Would be extremely competitive in the 5'-6" and shorter category in ultramarathons (if it existed)

Acknowledgements

- Applied Weather Associates
  - Site Specific Probable Maximum Precipitation Study, (June 2021)
- Ayres Associates Inc.
  - Site Specific Probable Maximum Flood Study, (May 2020 to June 2022)
- Spicer Group Inc.
  - Teaming Partner Since 2020


AYRES

Design Flood Hydrologic Analyses

Secord, Smallwood, Edenville, and Sanford Dams

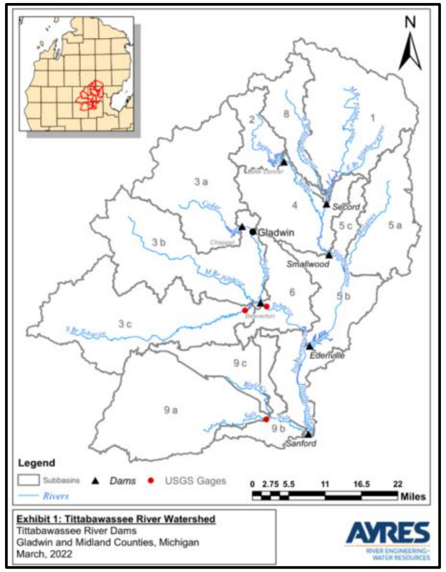
Gladwin and Midland Counties, Michigan

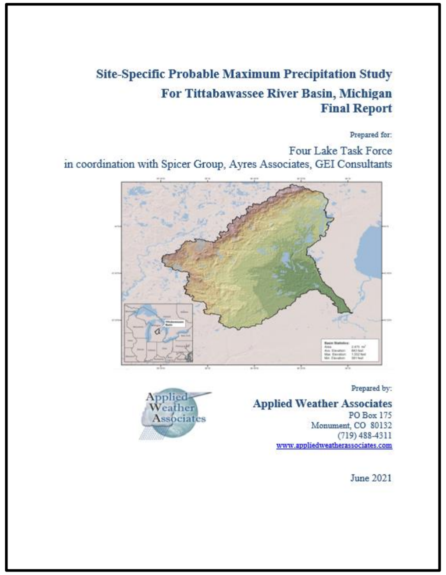
Prepared for:

Four Lakes Task Force
Midland, MI

July 2021

26-1145.00




Site-Specific Probable Maximum Precipitation Study
For Tittabawassee River Basin, Michigan
Final Report

Prepared for:
Four Lake Task Force
in coordination with Spicer Group, Ayres Associates, GEI Consultants

Prepared by:
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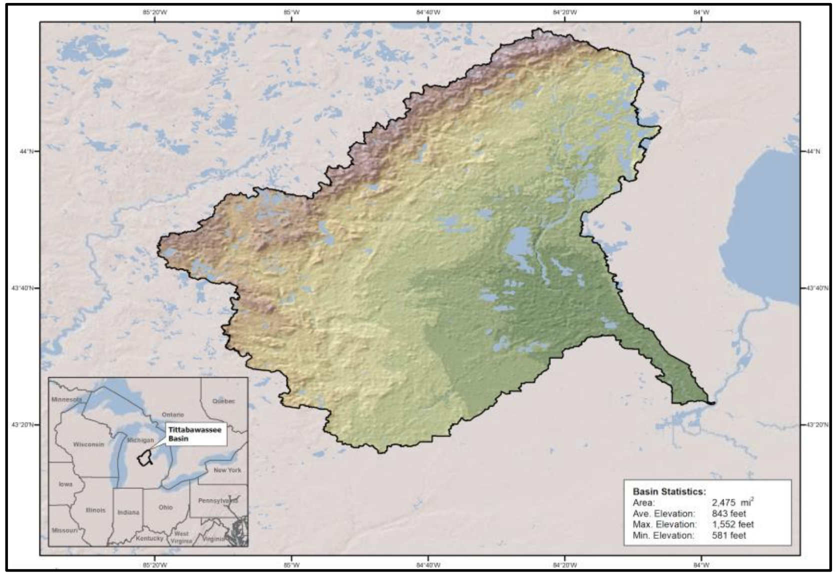
June 2021



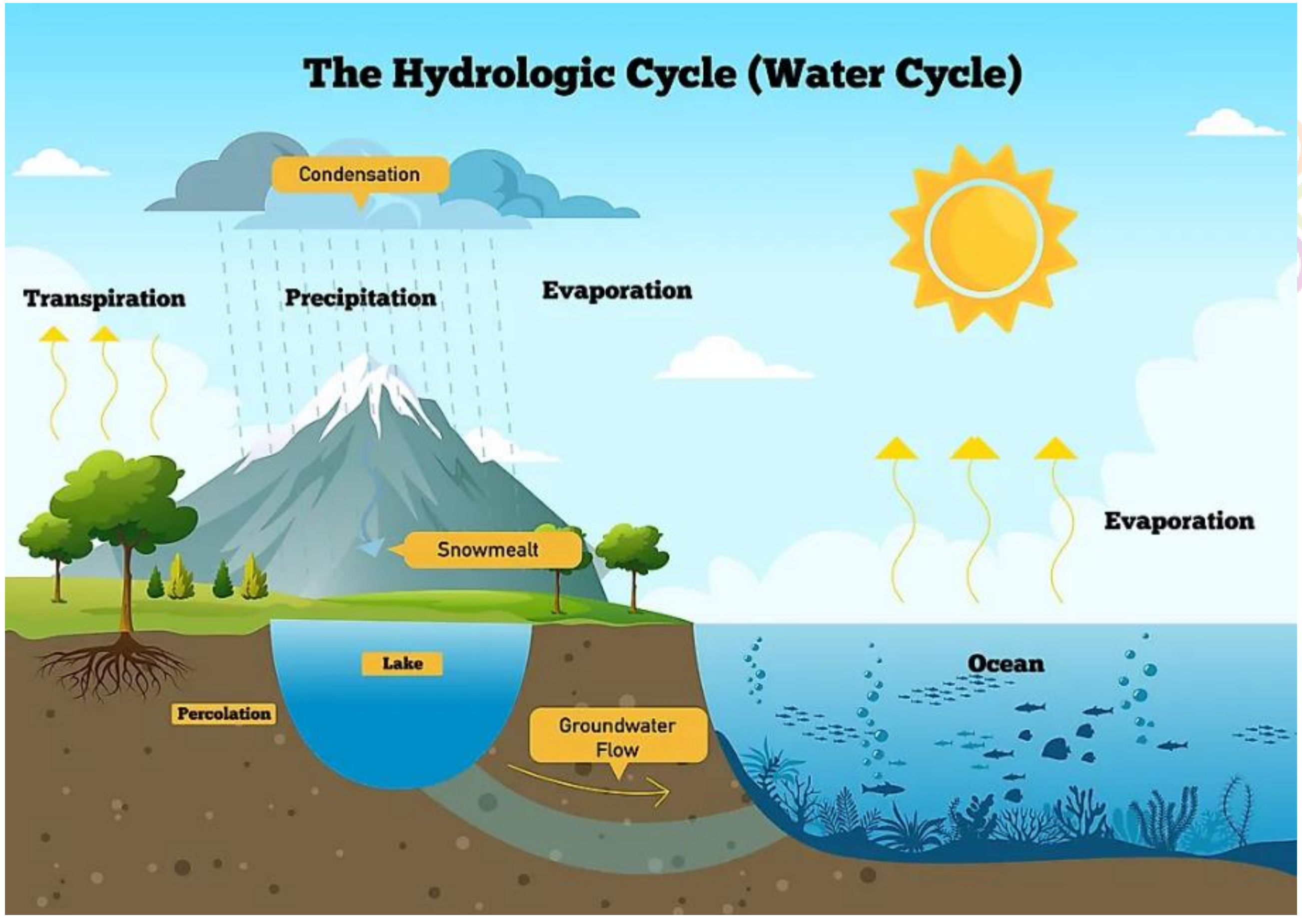
Session 2 – Hydrology and Hydraulics - Topics

- Introduction to Hydrology and Hydraulics
- Selection of Design Storms
- Risk Informed Decision Making
- Summary of Proposed Spillway Improvements

Introduction to Hydrology and Hydraulics

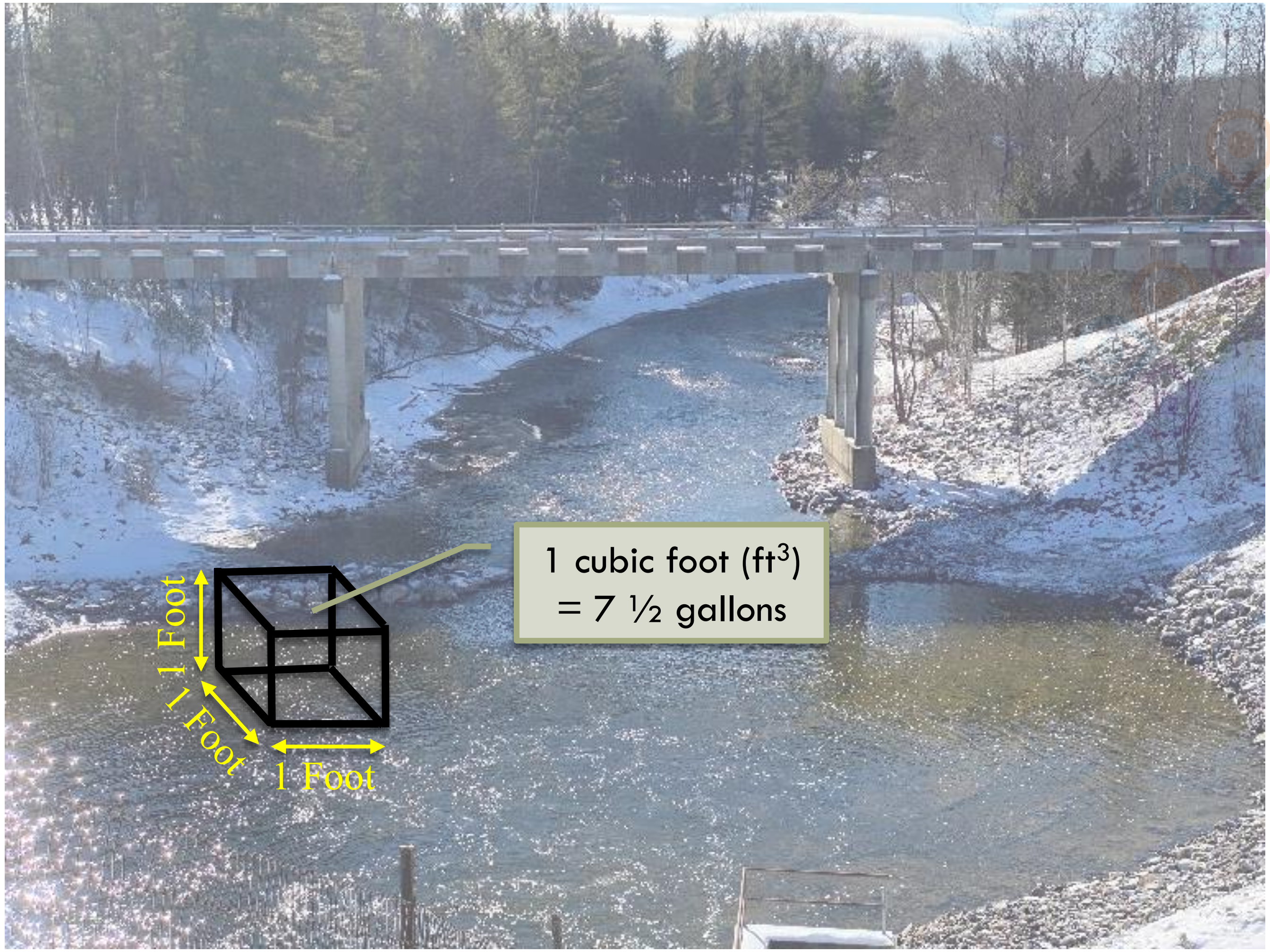
Hydrology and Hydraulics - Introduction

- What is Hydrology?
  - Study of the distribution and movement of water on both on and below earths surface.
  - Water Cycle
    - Evaporation
    - Condensation
    - Precipitation
    - Infiltration
    - Run-Off
  - **Dam Design**
    - Base River Flows (Seasonal)
    - Probability of Rainfall Events (inches / hour)
    - Volume of water in river system (pass through the dam)
- How do we measure this?



Hydrology and Hydraulics – Unit of Measure

- Unit of Measure = CFS
- What is a CFS?
- Definition: Cubic Feet Per Second
- 100 cfs = One hundred boxes of these are moving by a point in the river every second
- **<u>Let's convert this to beer (feel free to check my math)</u>**
- 80 bottles of beer ~ 1 cubic foot
  - 100 cfs = 8,000 Bottles of Two-Hearted Floating Downstream every second
- Peak Outflow at EDN During May 2020 = 20,000 cfs
  - 1.6M beers
- 20,000 cfs = Enough water to fill an Olympic swimming pool every 4 seconds



Hydrology and Hydraulics - Spillways

- Hydraulic Structures
  - Dam Structure provides controlled release of water downstream
    - Powerhouses
    - Outlet Works
    - Spillways
  - Three main components
    - Crest (hydraulic control)
      - Fixed Crest
      - Gates
    - Chute
    - Energy Dissipation

Hydrology and Hydraulics – Tittabawassee River Flood Study

- Performed a flood study from Secord to Sanford Dams
  - AWA, Ayres, SGI and GEI (2020 to 2022)
- Primary goals of the flood study:
  - *Probability of Floods in any given year*
  - *Quantify how much water we are playing with*
  - *Select flood(s) for design (peak flow rates)*
  - *How do you safely pass flood flows through the dam hydraulic structures?*
  - Establish flood inundation limits on TBW and TBO Rivers

Selection of Design Storms

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Selection of Design Storms

Probabilistic Storms

(100-, 200-, 500-, 1,000-, 5,000-year)

- Probabilistic Storms
  - Rare Events
  - 100-year
  - 1/100 chance of happening in any given year
  - 7-inches of rain in 24-hours
- Deterministic Storms
  - Extreme Events
  - PMF
  - 24 inches of rain in 24-hours
- What are designing to now?

Deterministic Storms

Probable Maximum Flood (PMF) and Fractional PMFs

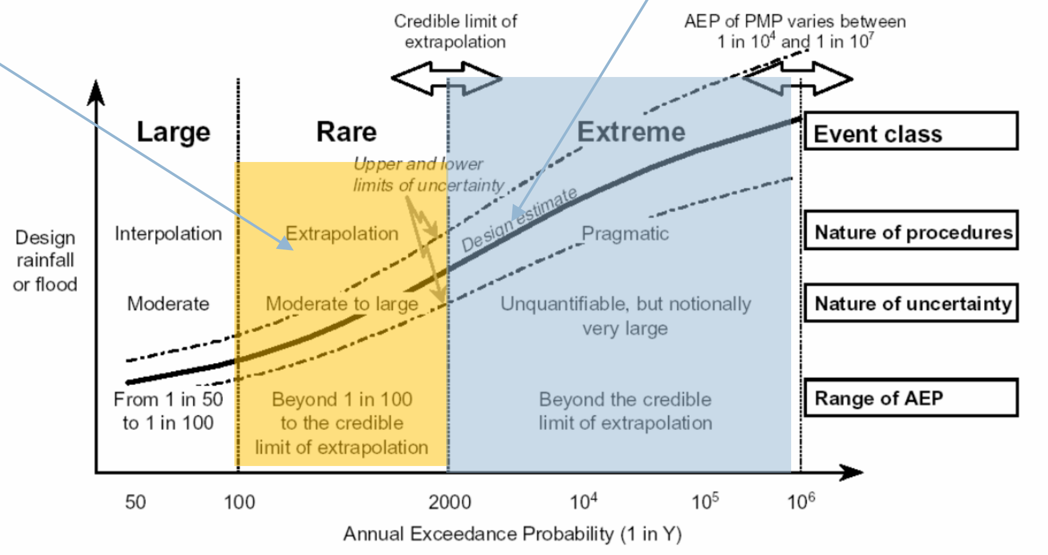


Figure 3-1.—Characteristics of notional floods (Nathan and Weinmann, 2001).

PMF is produced by extreme rainfall within a watershed to produce the largest flood that is reasonable possible and often governs spillway design for high hazard dams

Selection of Design Storms

Site-Specific Hydrology

- Applied Weather Associates
  - Rainfall Study (100-yr to PMF)
- Ayres Associates, Inc.
  - Estimate Flow Rates (100-yr to PMF)
  - May 2020 Flood Storm Calibration
- Lots of options what do we design to?
  - ½ PMP, 5,000-year, 10,000-year PMF?

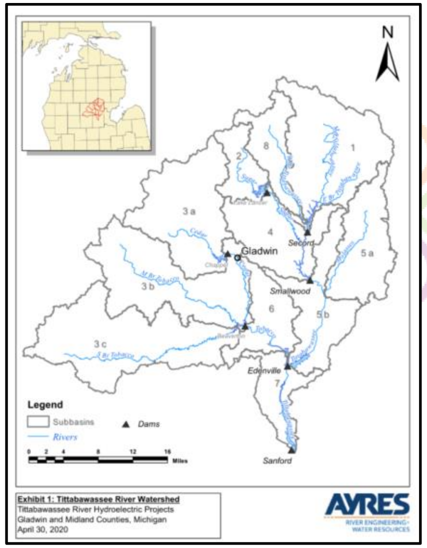
EGLE Requirement →

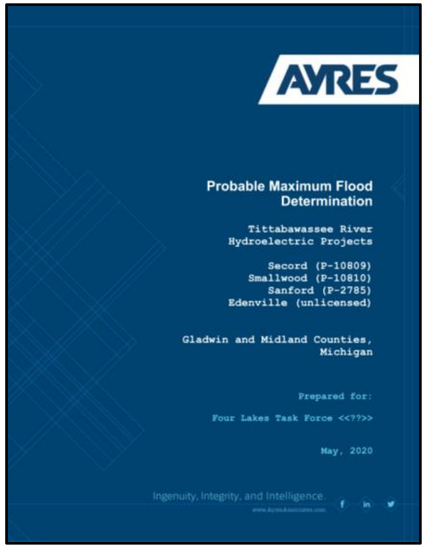
Summary of Peak Inflows at the FLTF Projects				
Storm Event	Secord	Smallwood	Edenville	Sanford
2-year	2,025	3,225	5,430	5,750
5-year	2,970	4,750	8,650	9,100
10-year	3,655	5,900	11,200	11,800
25-year	4,755	7,120	15,200	16,000
50-year	5,685	7,990	18,700	19,700
100-year	6,730	11,090	22,400	23,600
200-year	7,900	13,145	27,300	26,000
500-year	9,710	15,035	34,600	33,300
1,000-year	11,300	17,050	39,300	38,900
½ PMP	**12,700**	**18,440**	**44,600**	**44,900**
5,000-year	15,900	24,335	55,400	54,600
10,000-year	18,200	28,300	64,300	61,800
PMF	29,200	48,000	113,400	117,200

Selection of Design Storms

Flood	Author	Secord Project	Smallwood Project	Edenville Project	Sanford Project
100-year	EGLE (2020)	4,300	6,700	19,000	20,000
100-year	**Ayres (2021)**	**6,730**	**11,090**	**22,400**	**23,600**
	% 100-year Increase	**56%**	**65%**	**18%**	**18%**

Date	Author	Secord Project	Smallwood Project	Edenville Project	Sanford Project
1994	Mead & Hunt, Inc.	27,200	41,000	74,400	75,500
2011	Mill Road Engineering	N/A	N/A	62,000	N/A
2020	Ayres (2014, 2017 Floods)	29,400	41,200	80,900	80,600
2021	**Ayres (2014, 2017, 2020 Floods)**	**29,200**	**48,200**	**113,400**	**117,200**
	% PMF Increase	**7%**	**17%**	**40%**	**45%**





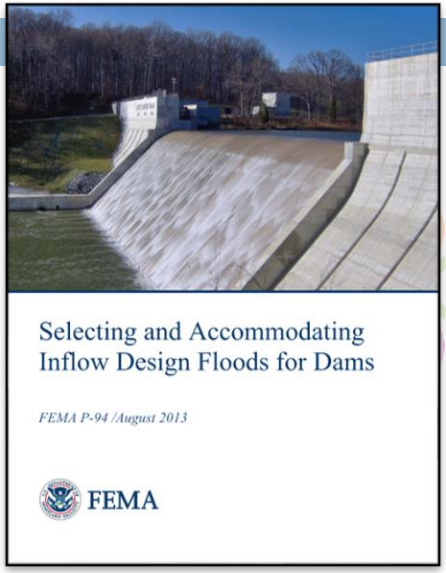
- **Key Point(s)**
  - Peak Discharge(s) values increased at all four FLTF Projects (price of poker is going up)
  - Need to use updated hydrology to select design storm for FLTF Restoration Projects
  - Use Risk-Based Approach to meet or exceed EGLE Discharge Capacity for High-Hazard Dams

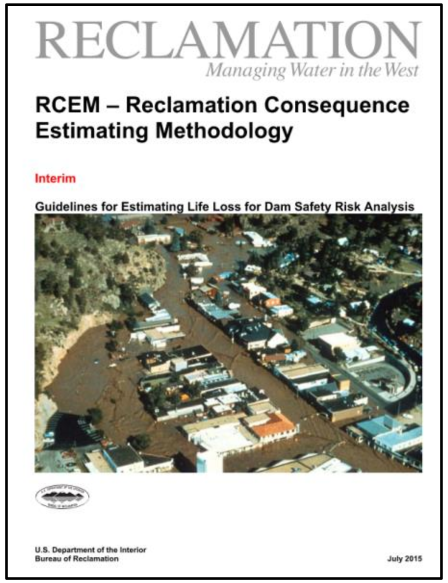
Risk Informed Decision Making (RIDM)

FEMA P-94 Inflow Design Flood Selection

- <u>The current spillway EGLE capacity (1/2 PMP)</u>
- Follow FEMA Model P-94 Guidelines for Selecting the IDF
- Satisfy Multiple Objectives
  - Provide acceptable public safety
  - Effectively utilize owner's resources
  - Maintain credibility of dam regulator
  - Balance risk of dam with benefits of the dam

  "No single approach to selection of an IDF is adequate…"

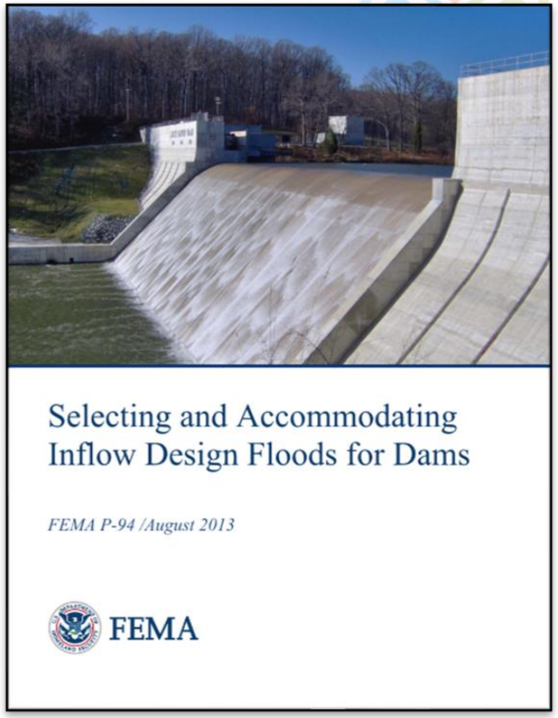




FEMA P-94 Inflow Design Flood Selection

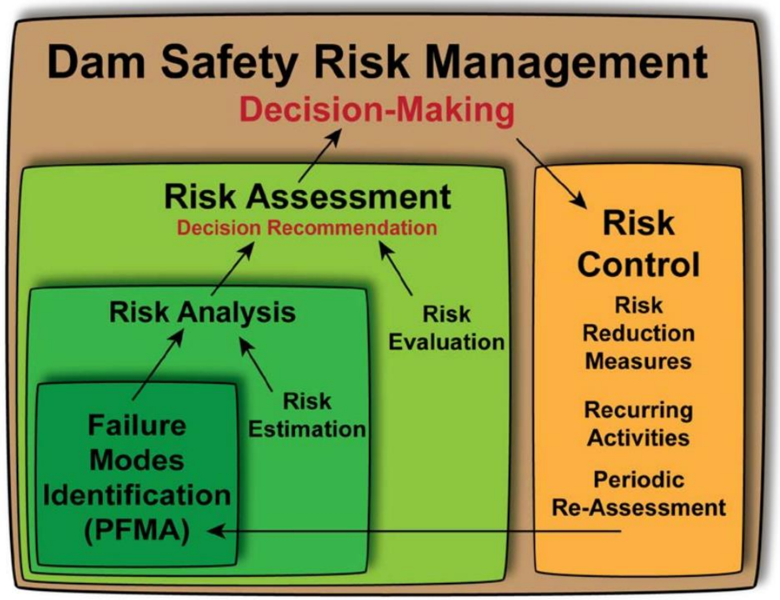
FEMA's Recommended IDF Approach Alternatives

1. Prescriptive – IDF based on dam size or downstream hazard
    - Current EGLE Requirement (1/2 PMP)☑
2. Site-specific PMP / PMF Study☑
    - AWA and Ayres Flood Study
3. Risk-informed Decision Making (RIDM)
4. Incremental Consequence Analysis



FEMA P-94 Inflow Design Flood Selection

3. Risk Informed Decision Making (**All Dams Have Risk**)
   - Dam Safety Risk Evaluation
     - Likelihood of Loading (100-yr to PMF)
     - Dam Response (how the spillway perform during the flood)
     - Estimate Consequence to quantify Risk (life loss, economic)
     - Assessing the risk to inform dam safety decisions
   - Used to inform decisions related to infrastructure investments
     - Bigger Spillways
     - Monitoring
     - Inspection
     - Improvements



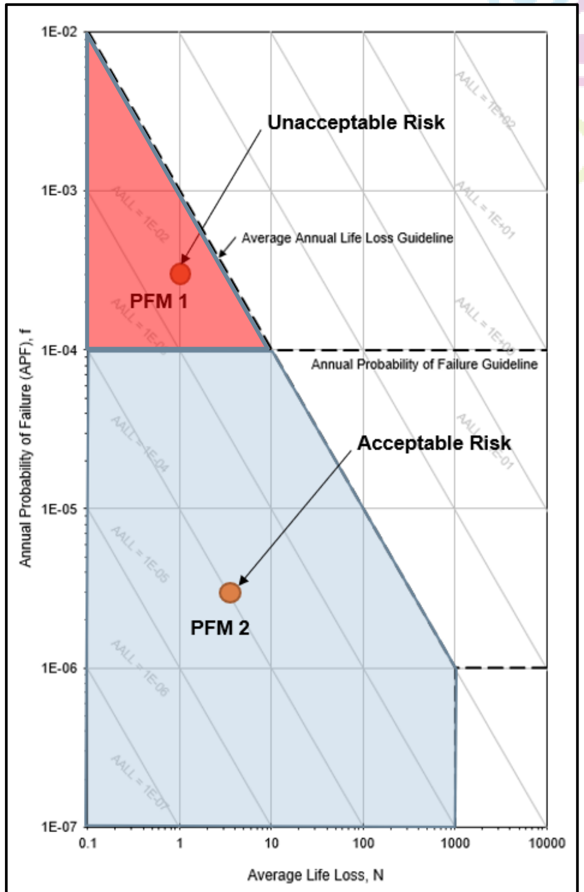
FEMA P-94 Inflow Design Flood Selection

3. ## Risk Informed Hydrologic Analysis

Incremental Risk = *Loading Probability* x *Probability of Failure Under Loading* x *Consequences of Failure*

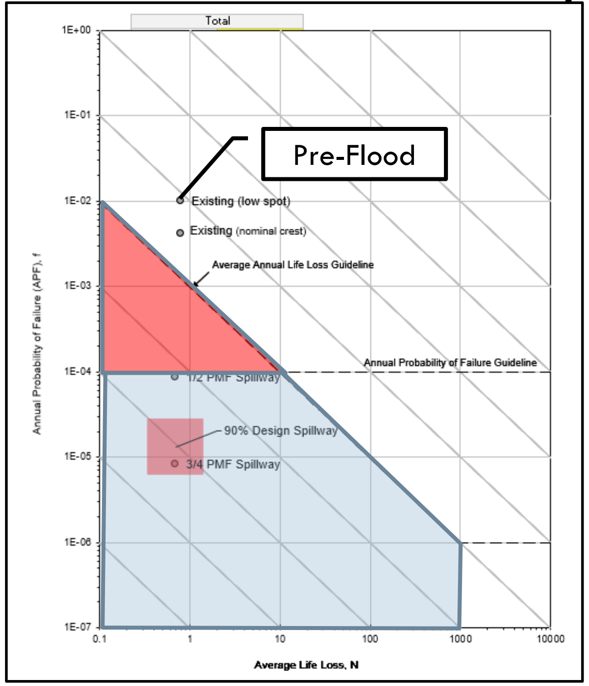
(Loading Probability x Probability of Failure Under Loading = Likelihood of Failure; Consequences of Failure = Incremental Consequences)

- Develop Hydrologic Loads (Normal, Flood)
- Evaluate Alternative Spillway Configurations
- Access Hydrologic Potential Failure Mode Probabilities
- Quantify Consequences of Dam Failure
- Quantify Dam Safety Risks
- Select the IDF based on Public Tolerance and Risk Guidelines
  - Individual incremental life safety risk
  - F-N Chart
    - Y- Axis = Annual Probability of Failure (APF)
    - X – Axis Average Life Loss
  - Sloping societal risk line; as consequences increase, APF should decrease
  - Live in the Blue Region (Acceptable) vs Red Region (Unacceptable)

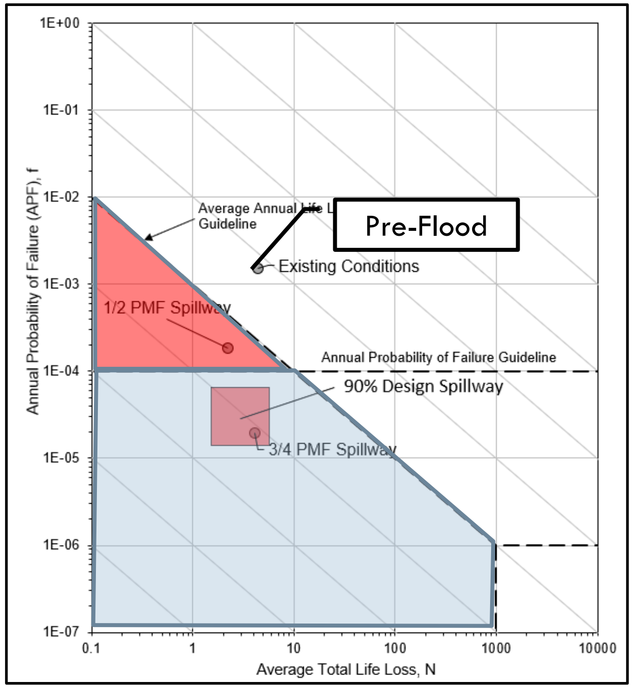


KEY TAKE AWAY

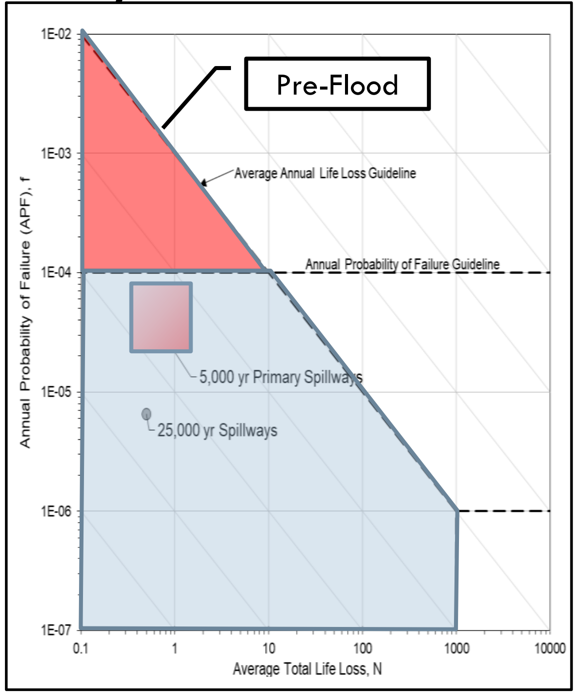
- ❑ Proposed design spillway configurations provides acceptable level of risk to projects
- ❑ **Similar Risk Profile across all FLTF Projects**
- ❑ **SFD Dam Developed Using Incremental Consequence Analysis**



❑ SCD Dam (100%)

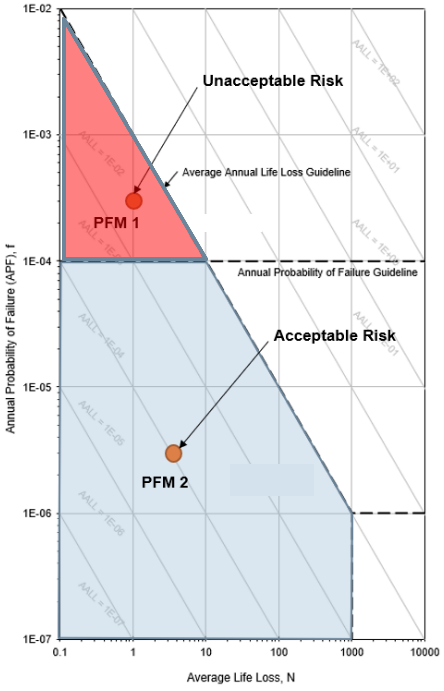


❑ SWD Dam (100%)



❑ EDN Dam

(60% heading to 90%)



❑ Example

❑ SFD Dam (Next Slide)

FEMA P-94 Inflow Design Flood Selection

4. Incremental Consequence Analysis

- Compare Downstream Impact of Flood with Dam Breached vs No Dam Breach
- Is there a flood which creates no additional consequences?
- X Axis = 100-yr to PMF
- Y Axis = Consequences
- ***No Additional Consequence = < 2 feet of incremental rise***

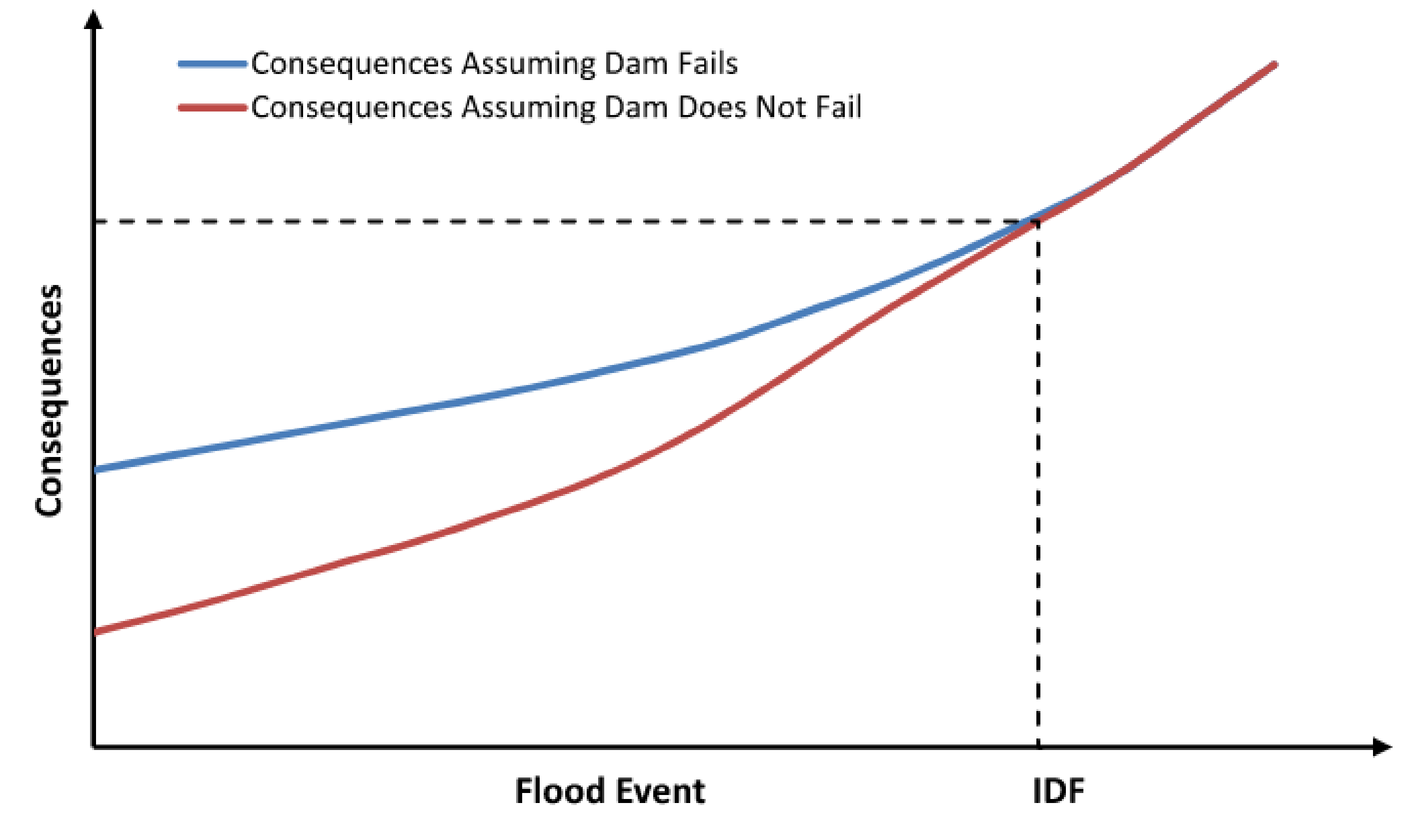
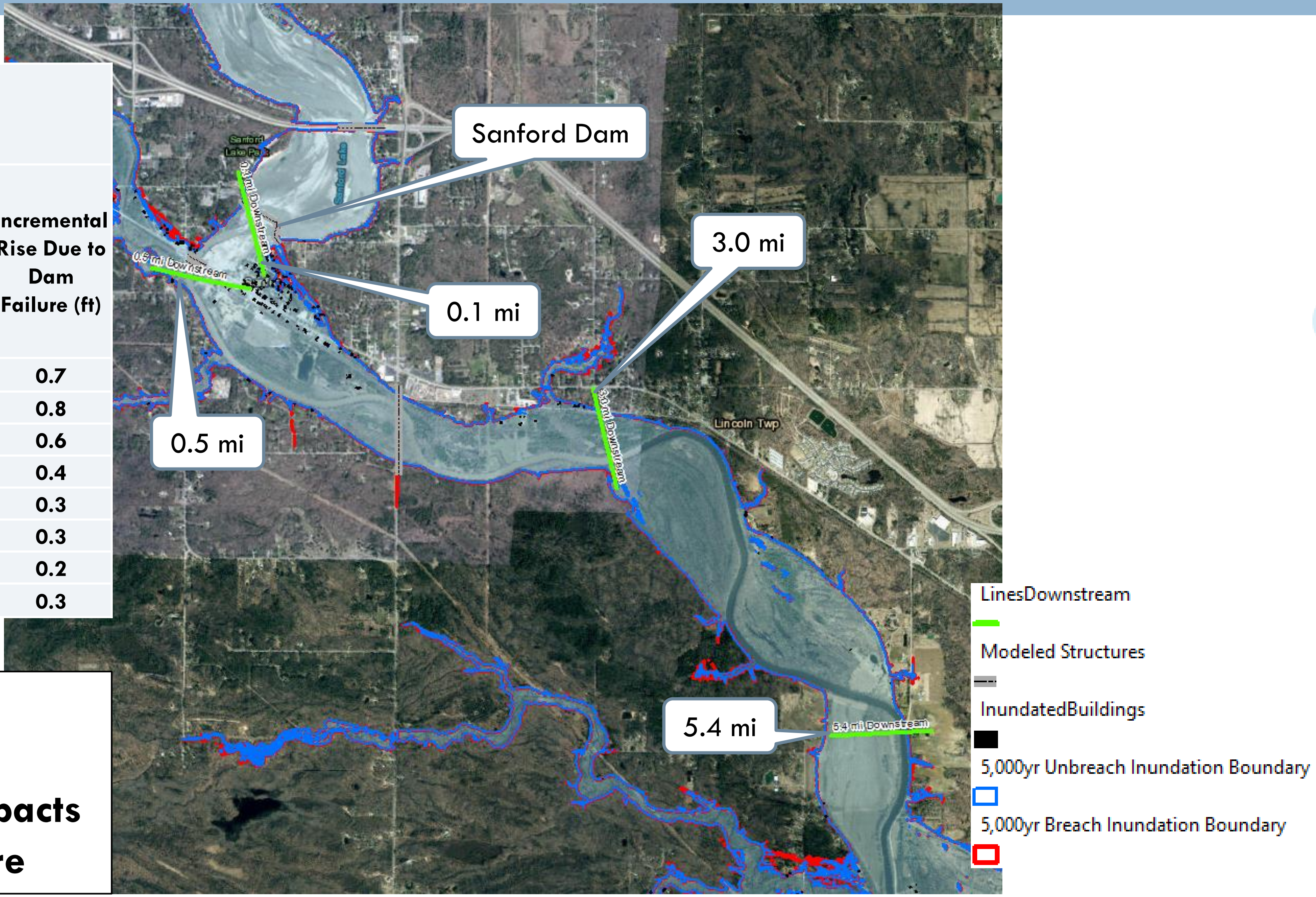


Figure 1 Conceptual Comparison of Incremental Consequences

IDF Incremental Rise Results

Sanford Dam Failure (Updated) Tittabawassee River Flow: 54,600 cfs Salt River Flow: 8,400 cfs			
Miles Downstream of Sanford Dam	Peak Water Elevation Due to Dam Failure (ft)	Peak Water Elevation Prior to Dam Failure (ft)	**Incremental Rise Due to Dam Failure (ft)**
0.1	632.2	631.5	**0.7**
0.5	632.0	631.2	**0.8**
3.0	627.3	626.7	**0.6**
5.4	623.1	622.7	**0.4**
7.0	620.8	620.5	**0.3**
8.8	619.3	619.0	**0.3**
10.5	618.9	618.7	**0.2**
13.0	613.3	613.0	**0.3**



- IDF Flow = 54,600 cfs
  - Outflow From EDN
- **No new incremental impacts compared to Dam Failure**

IDF Incremental Rise Results

Sanford Dam Failure (Updated) Tittabawassee River Flow: 56,300 cfs Salt River Flow: 8,400 cfs			
Miles Downstream of Sanford Dam	Peak Water Elevation Due to Dam Failure (ft)	Peak Water Elevation Prior to Dam Failure (ft)	**Incremental Rise Due to Dam Failure (ft)**
0.1	632.2	631.5	**0.7**
0.5	632.0	631.2	**0.8**
3.0	627.3	626.7	**0.6**
5.4	623.1	622.7	**0.4**
7.0	620.8	620.5	**0.3**
8.8	619.3	619.0	**0.3**
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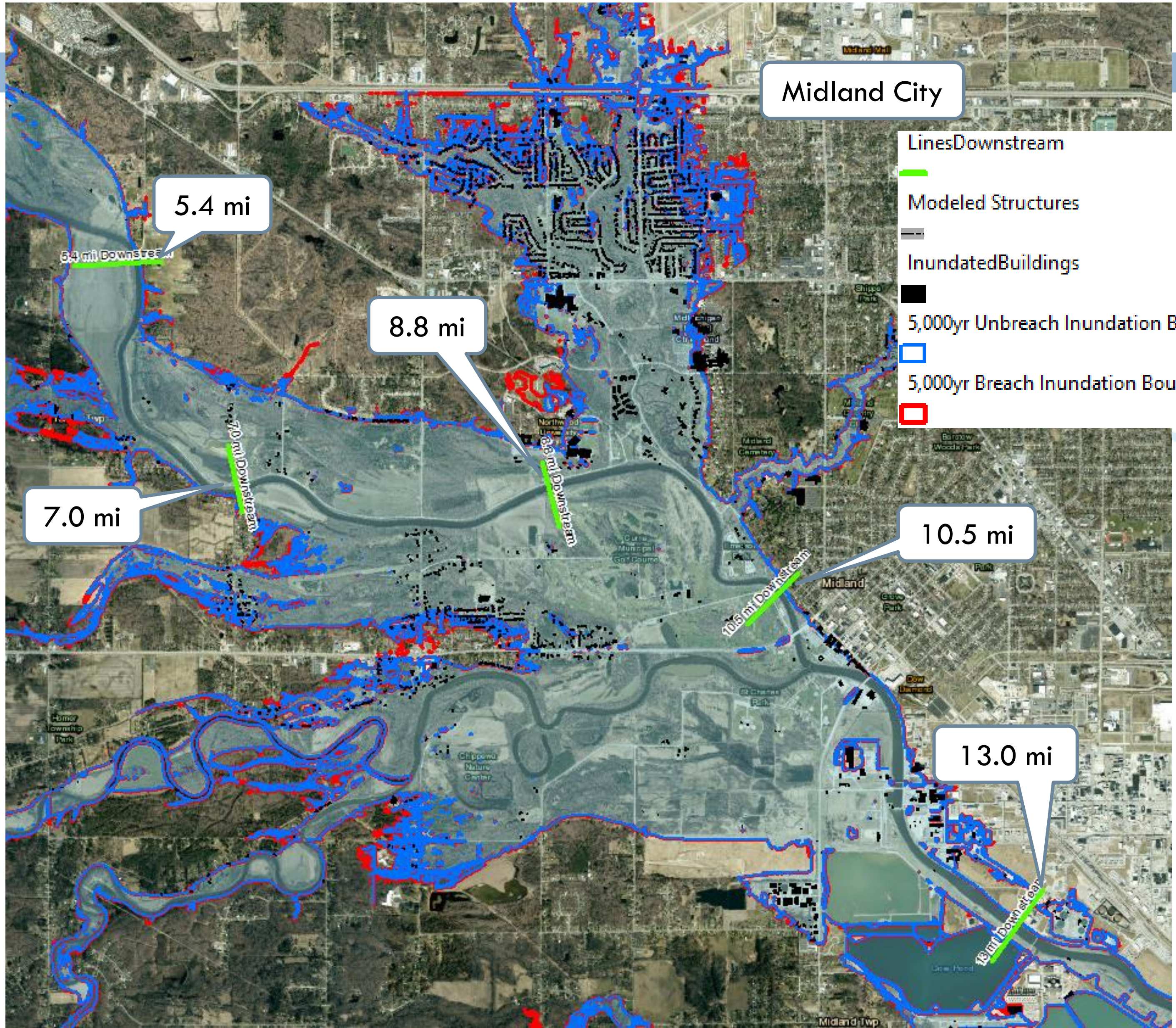
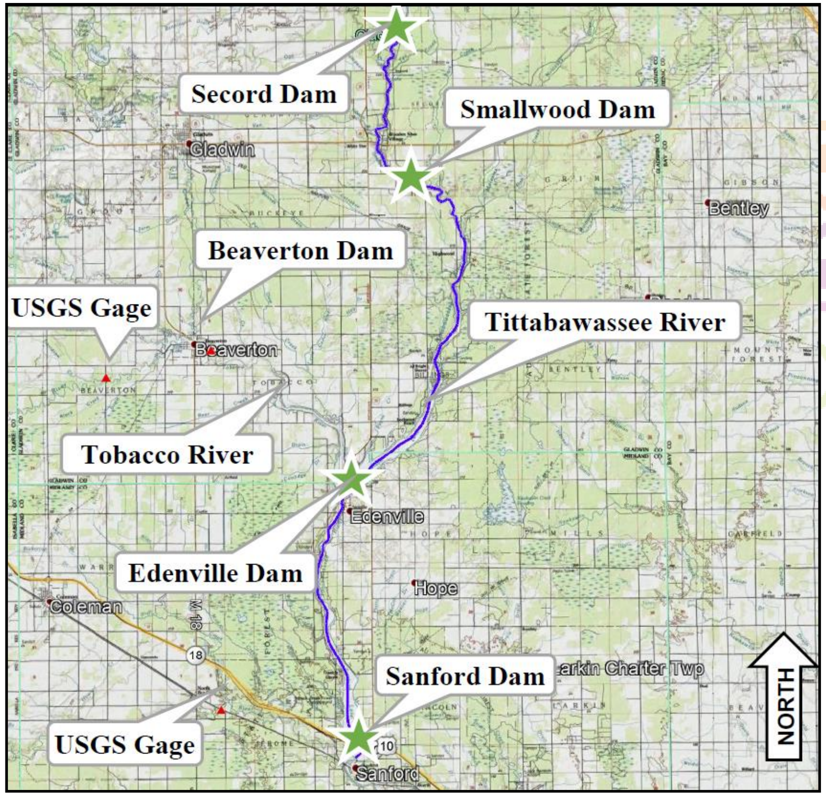
- ❑ IDF Flow = 54,600 cfs
  - ❑ Outflow From EDN
- ❑ **No new incremental impacts compared to Dam Failure**



Selected Inflow Design Flood

- Key Take Aways
  - Site-Specific Flood Studies of Probabilistic and Deterministic Storms ✓
  - Used Risked-Based Approach to Design Storm Selection in Accordance with FEMA, USACE, USBR Guidelines ✓
  - Similar Risk-Profile Across All Projects ✓
  - Selected IDF Meets and Exceeds EGLE Requirements ✓



Description	Secord Project	Smallwood Project	Edenville Project	Sanford Project
½ PMF EGLE Requirement	12,700	15,600	46,000	44,900
GEI (IDF)	**18,200**	**28,300**	**55,400**	**54,600**
% IDF Increase above ½ PMF EGLE Requirement	**43%**	**81%**	**20%**	**21%**

Secord Dam

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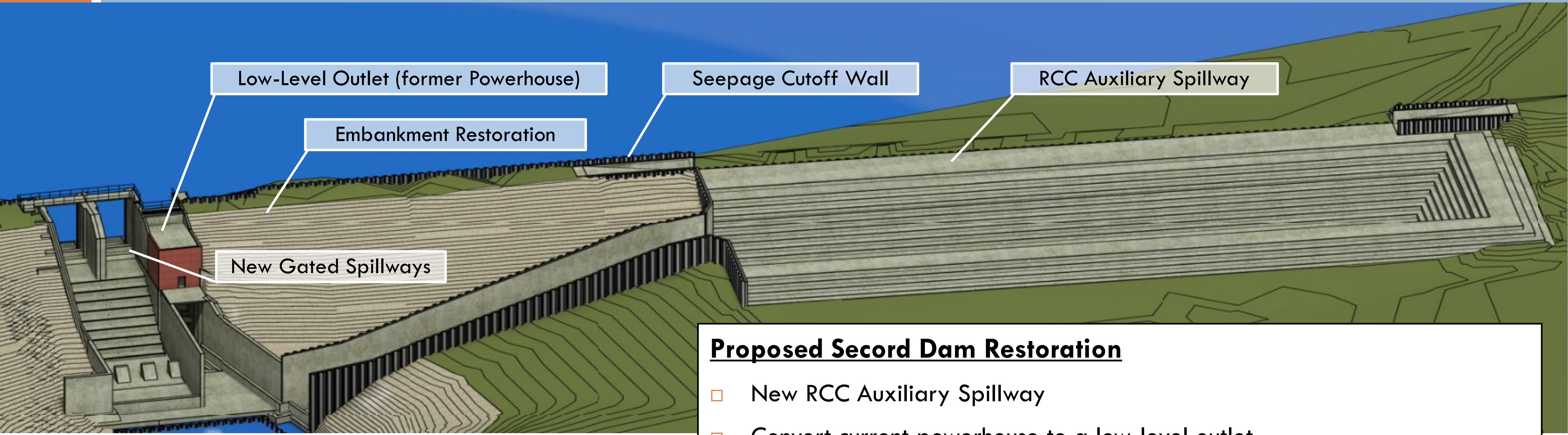
Secord Dam – Stabilization (Post-May 2020 Flood)

- No auxiliary spillway
- Limited discharge capacity through Tainter gates

Secord Dam – Restoration (2022 to 2024)



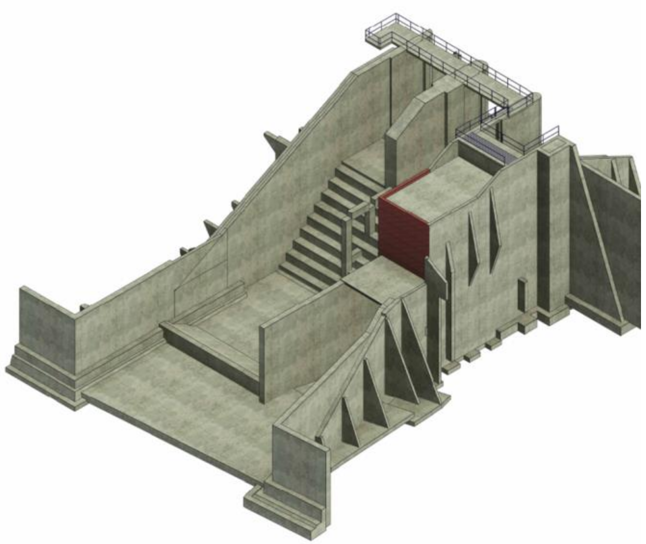
Proposed Secord Dam Restoration

- New RCC Auxiliary Spillway
- Convert current powerhouse to a low-level outlet
- Update primary spillways (new concrete weir, new crest gates)
- Improved Stilling Basin, heavy rock in river channel
- Embankment flattening/extension
  - Sheet Pile Cutoff
  - Aggregate filter

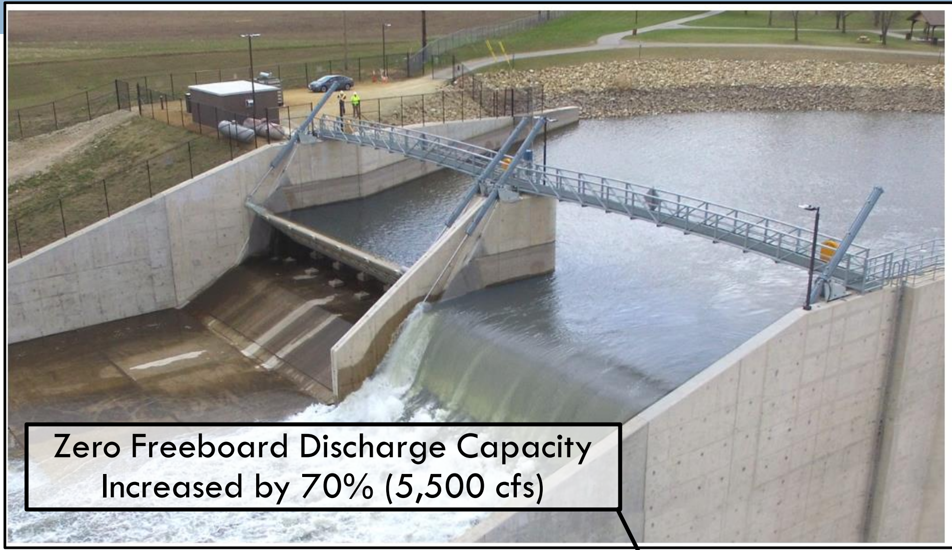
Secord Dam – Restoration (2022 to 2024)

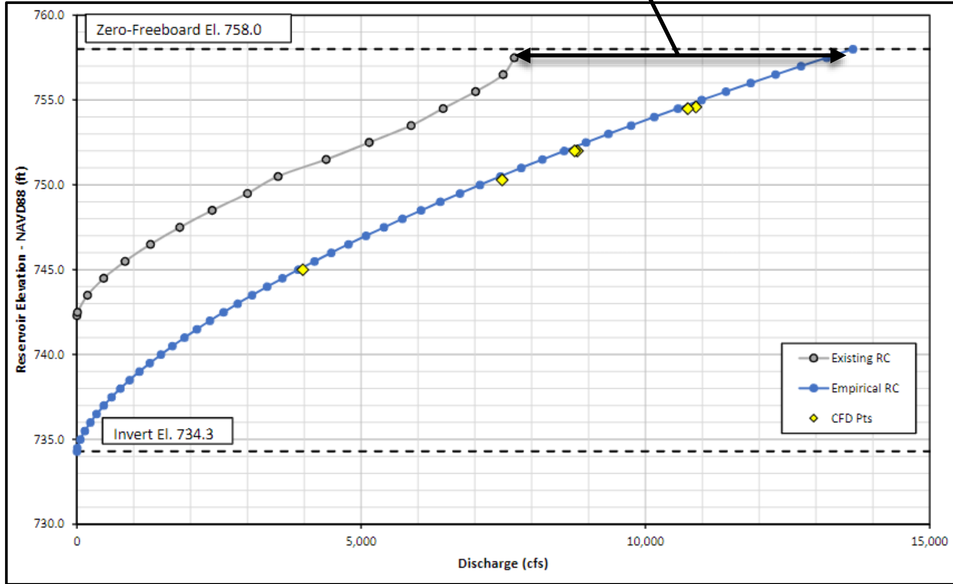
Primary Spillway Gates

Existing Primary Spillway
- Discharge Capacity = 8,000 cfs

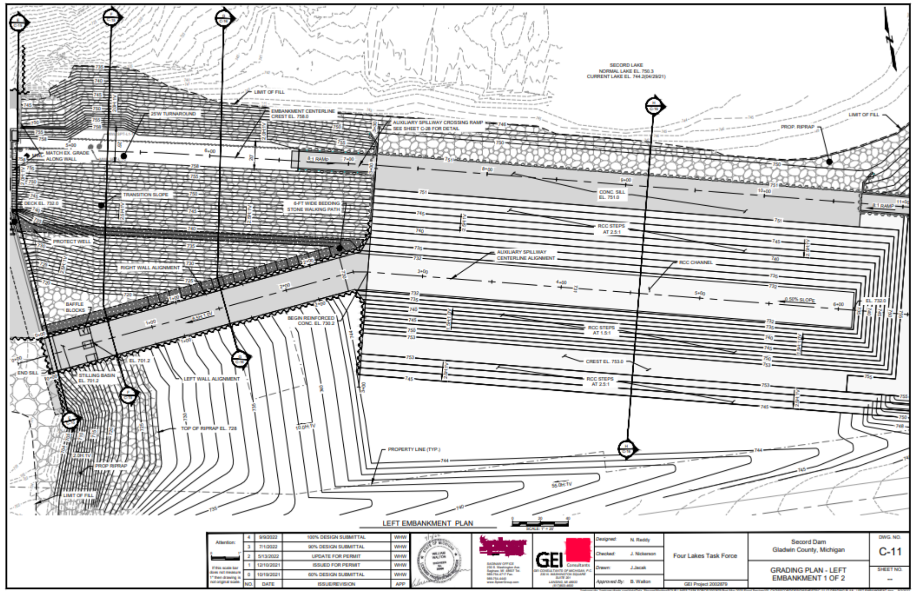


Proposed Primary Spillway
- Discharge Capacity = 13,500 cfs



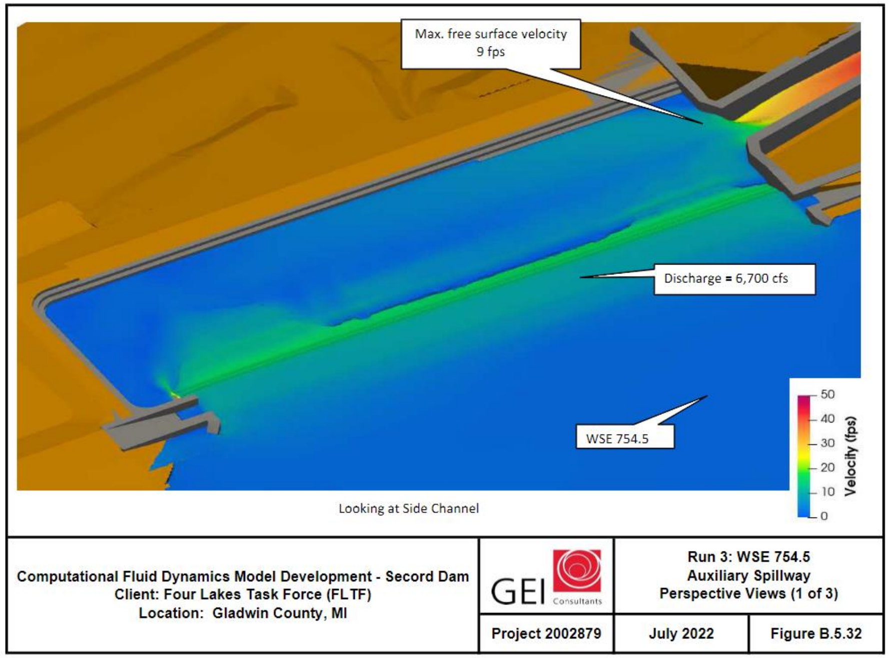


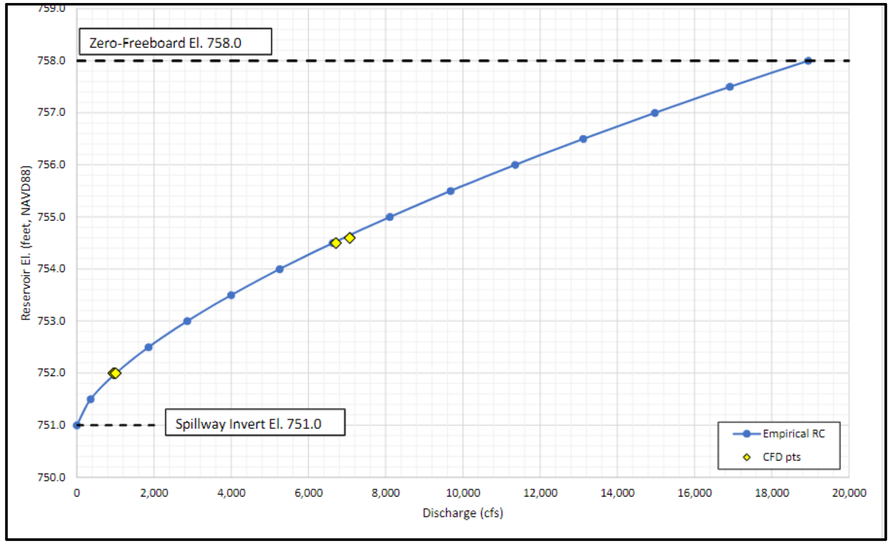
Secord Dam – Restoration (2022 to 2024)



Auxiliary Spillway

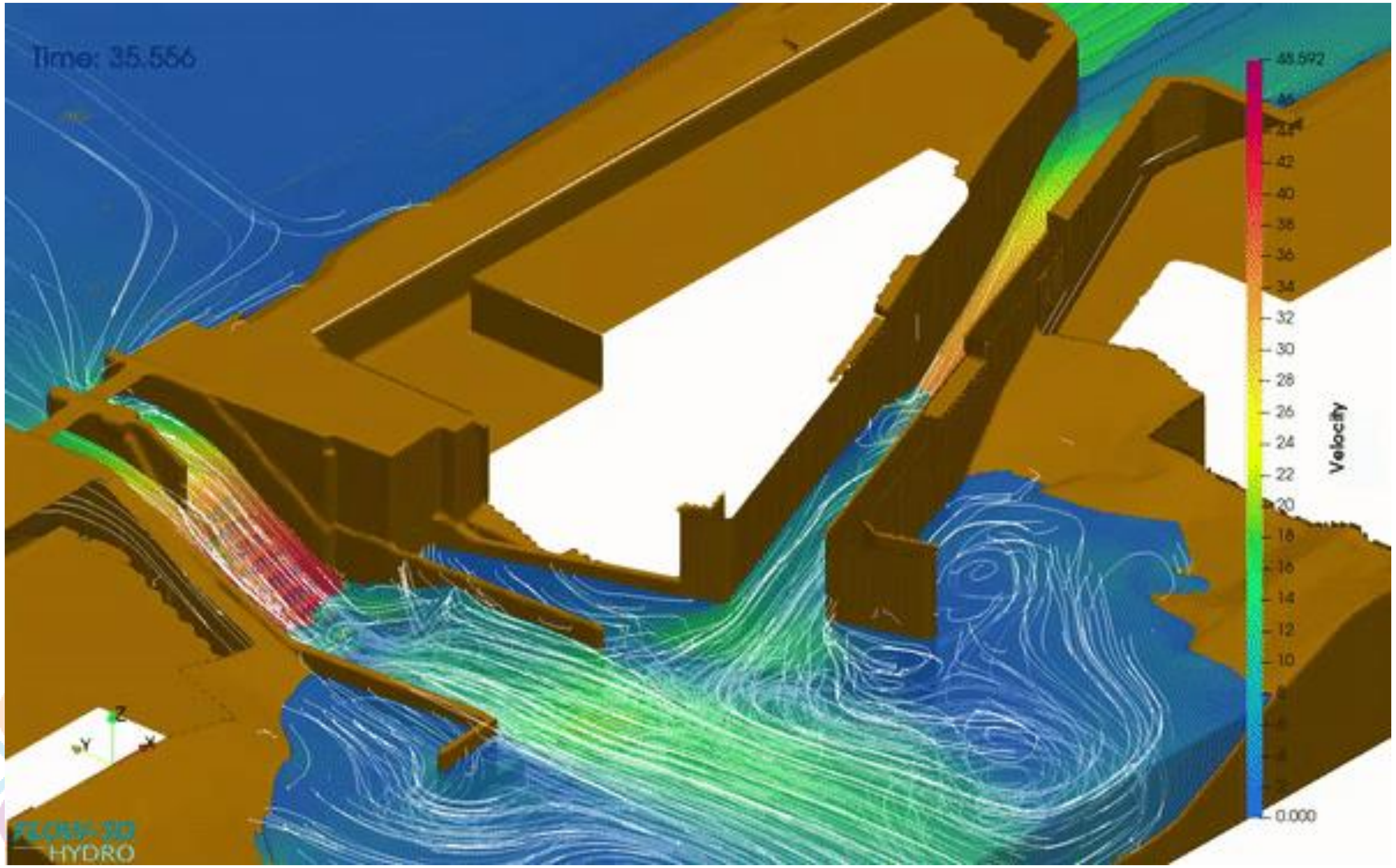
- Existing – 0 cfs
- Proposed Existing Auxiliary Spillway = 19,000 cfs



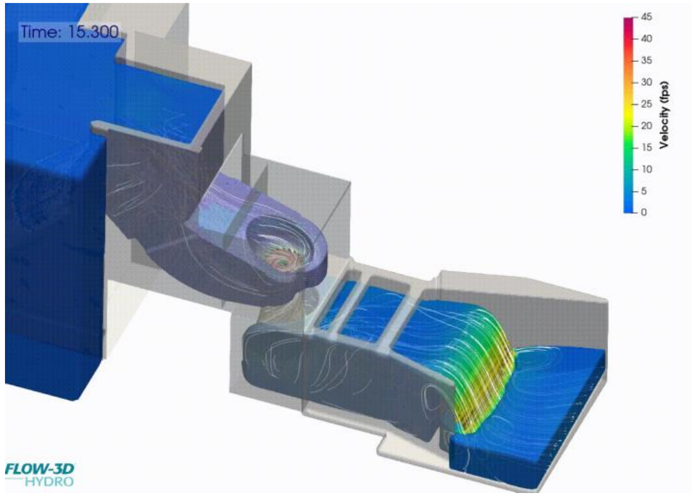


Secord Dam – Restoration (2022 to 2024)

Parameter	Pre-Flood Spillway Configuration	Restoration Spillway Configuration
IDF Inflow (cfs)	18,200	
Zero-Freeboard Tainter Gate Spillway Capacity (cfs)	8,000	13,500
Auxiliary Spillway Zero-Freeboard Capacity (cfs)	0	19,000
Total Spillway Capacity (cfs)	8,000	32,500
Spillway Capacity Increase	**24,500 cfs**	



Primary and auxiliary spillways at max flows



Powerhouse converted to low level outlet

Smallwood Dam

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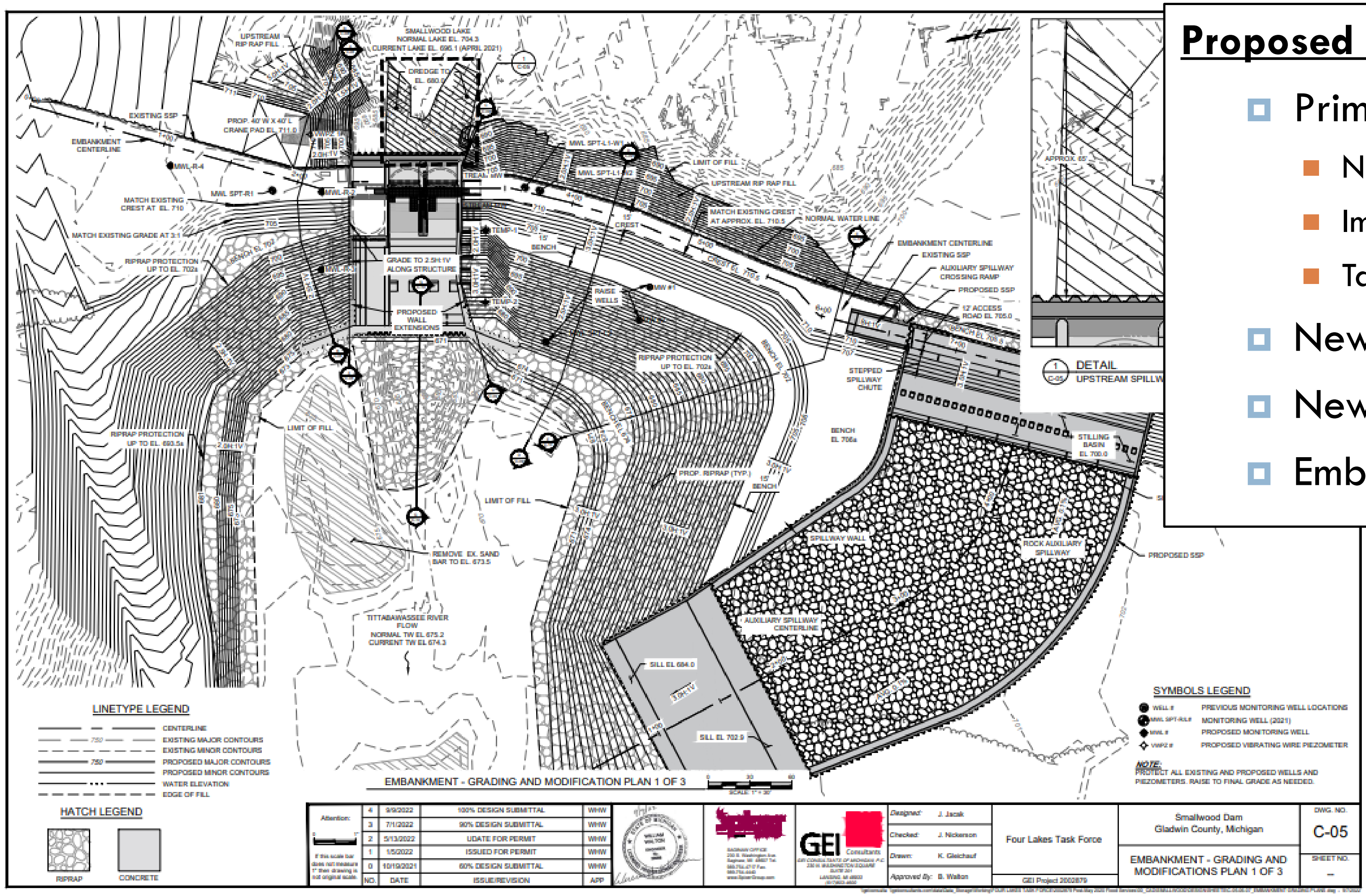
Smallwood Dam – Stabilization (Post-May 2020 Flood)

Smallwood Dam – Restoration (2022 to 2024)



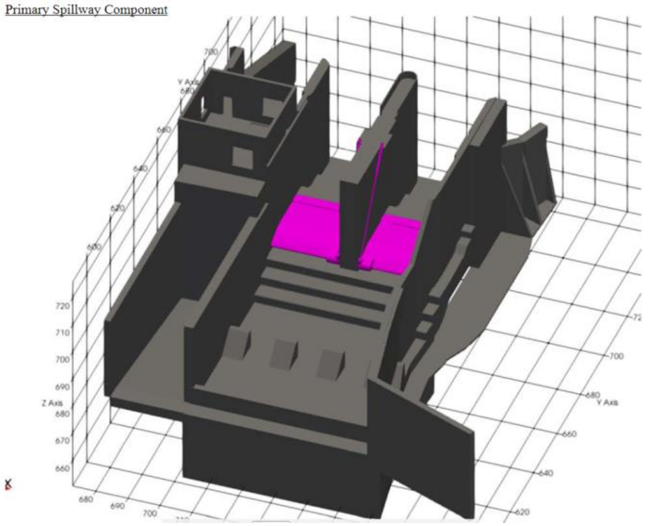
Proposed Smallwood Dam Restoration

- Primary Spillway Modifications
  - New Crest Gates
  - Improved Stilling Basin
  - Taller and longer training walls
- New Auxiliary Spillway
- New Low-Level-Outlet
- Embankment Improvements

Smallwood Dam – Restoration (2022 to 2024)

Primary Spillway Gates

Photo 7.6: Overtopping of spillway left training wall during May 2020 event.

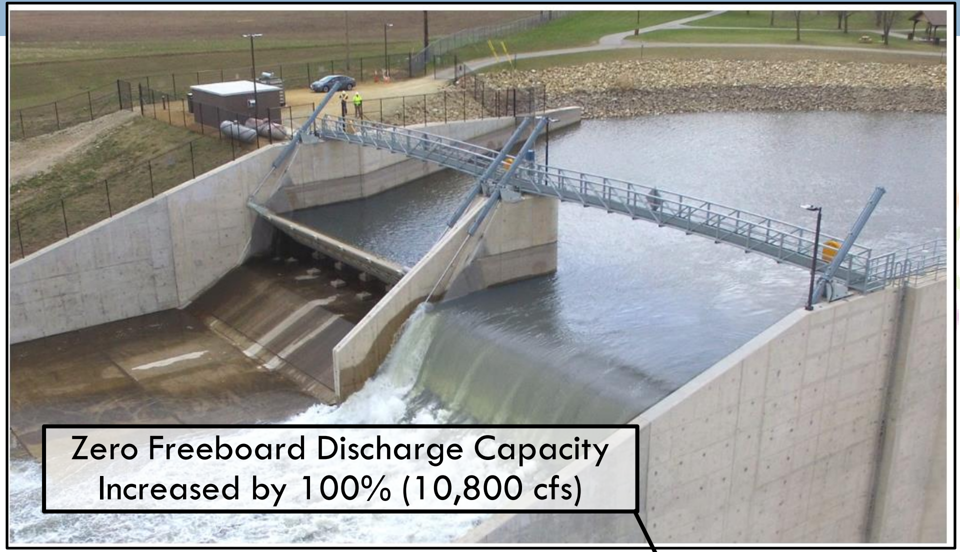


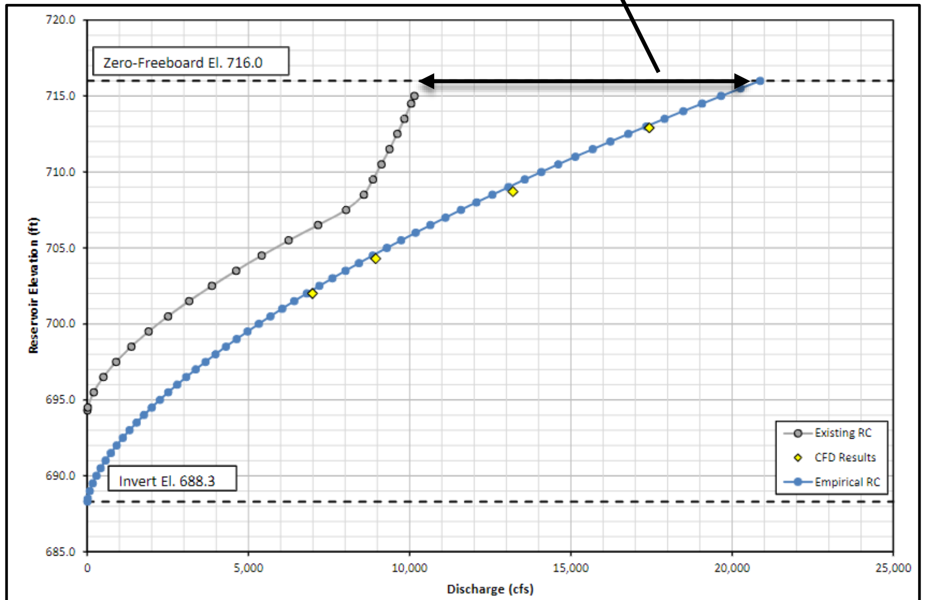
Existing Primary Spillway

- Discharge Capacity = 10,000 cfs

Proposed Primary Spillway

- Discharge Capacity = 20,800 cfs

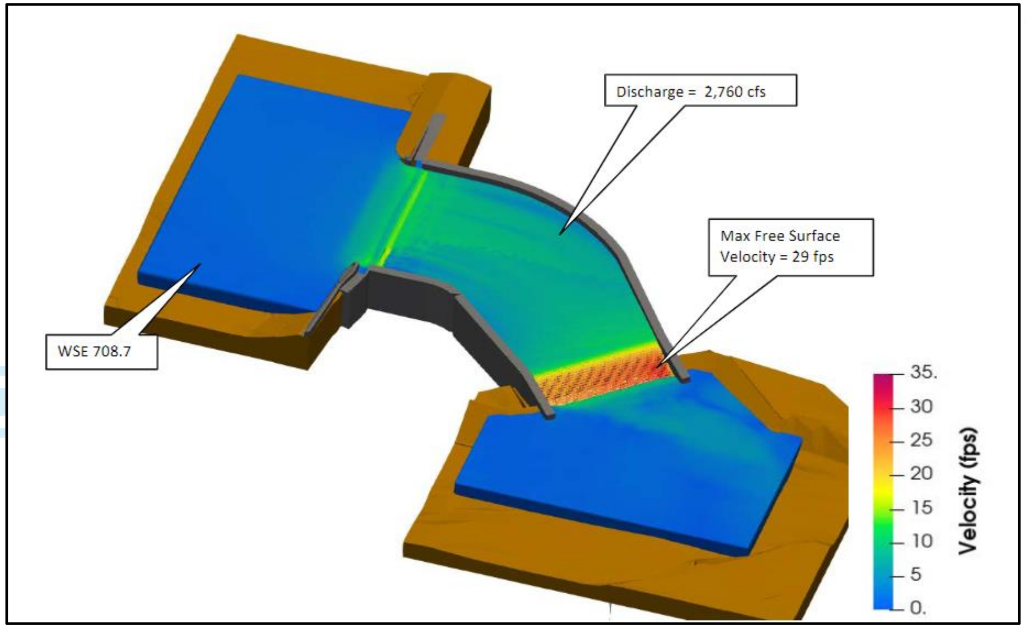




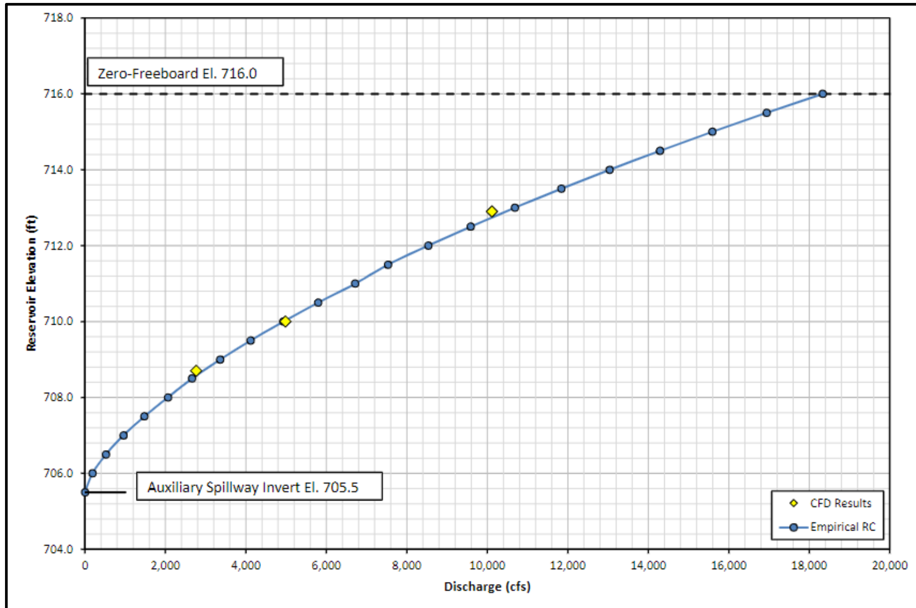
Smallwood Dam – Restoration (2022 to 2024)

Existing Auxiliary Spillway
- Discharge Capacity = 18,000 cfs
- Uncontrolled Release over left embankment (low spot)
- Not acceptable dam safety risk

Key Points
- Proposed spillway designed for IDF
- Reduces risk of left embankment overtopping
- IDF (28,300 cfs) exceeds EGLE Required Spillway Capacity of ½ PMP (18,440 cfs)

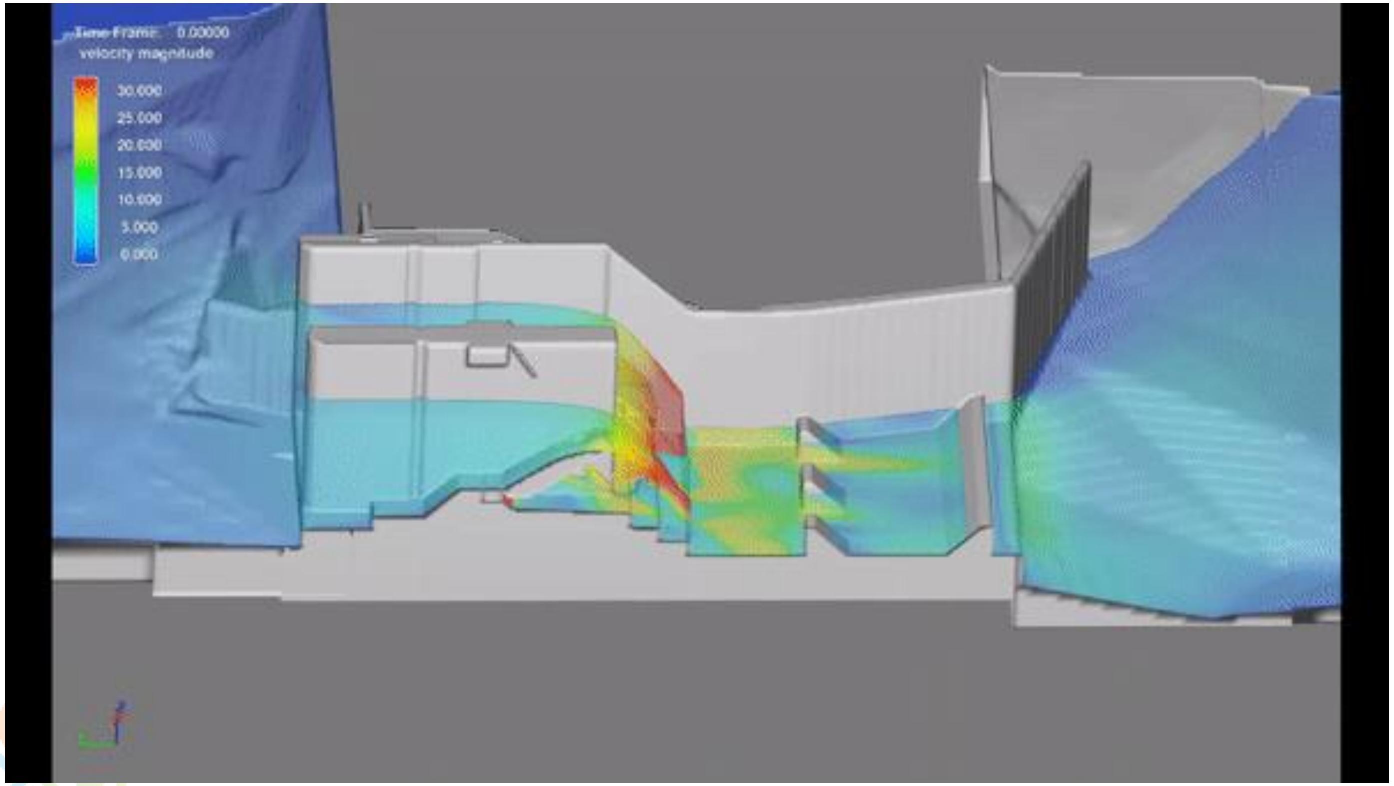


Proposed Auxiliary Spillway
- Discharge Capacity = 18,300 cfs
- Controlled Auxiliary spillway

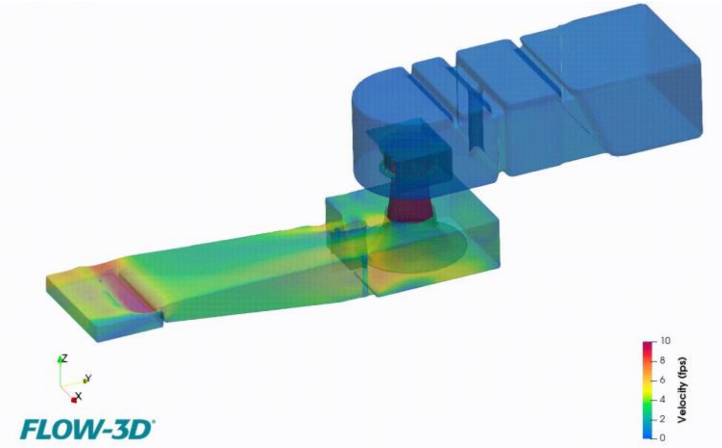


Smallwood Dam – Restoration (2022 to 2024)

Parameter	Pre-Flood Spillway Configuration	Restoration Spillway Configuration
IDF Inflow (cfs)	28,300	
Zero-Freeboard Tainter Gate Spillway Capacity (cfs)	10,000	20,800
Auxiliary Spillway Zero-Freeboard Capacity (cfs)	18,000	18,300
Total Spillway Capacity (cfs)	28,000	39,100
Spillway Capacity Increase	**11,100 cfs**	



Normal pool, gates half open

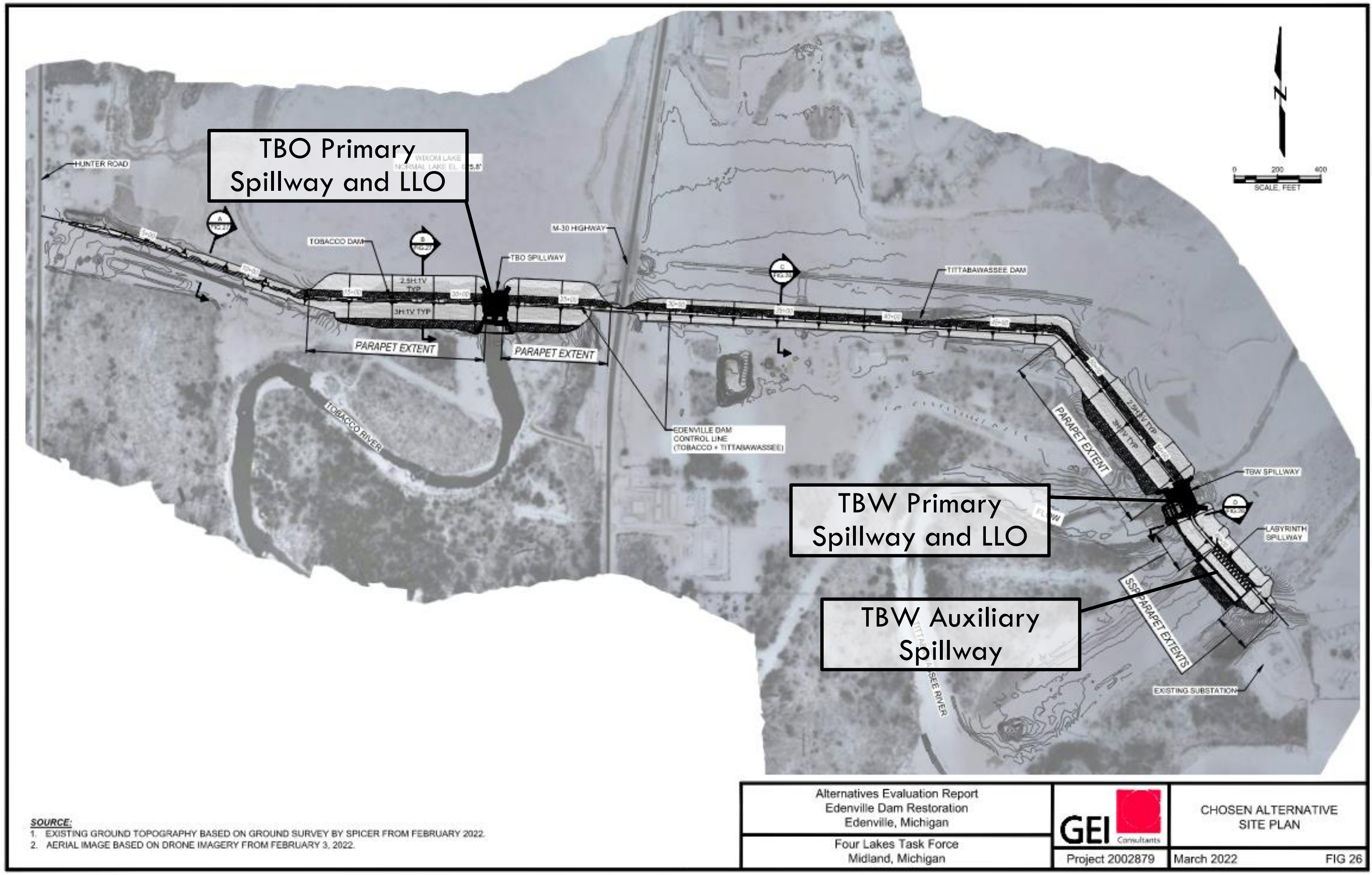


Powerhouse converted to low level outlet

Edenville Dam

3.0 Edenville SQRA 5,000-year Spillway Configuration

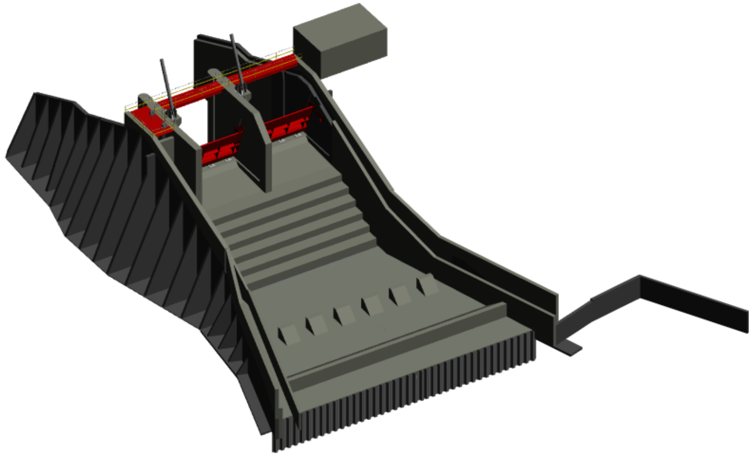
- Proposed Spillway Configuration
  - 2-16.5-foot-high crest gates (TBO)
    - Spillway Crest El. 659.2
  - 3-16.5-foot-high crest gates (TBW)
    - Spillway Crest El. 659.2
  - 275-foot-wide auxiliary spillway (TBW)
    - Crest El. 676.4
  - Dam Crest El. 684.9



Edenville Dam – Restoration (2023 – 2026)

TBO Primary Spillway Gates

Pre-Flood Primary Spillway
- Discharge Capacity = 9,900 cfs

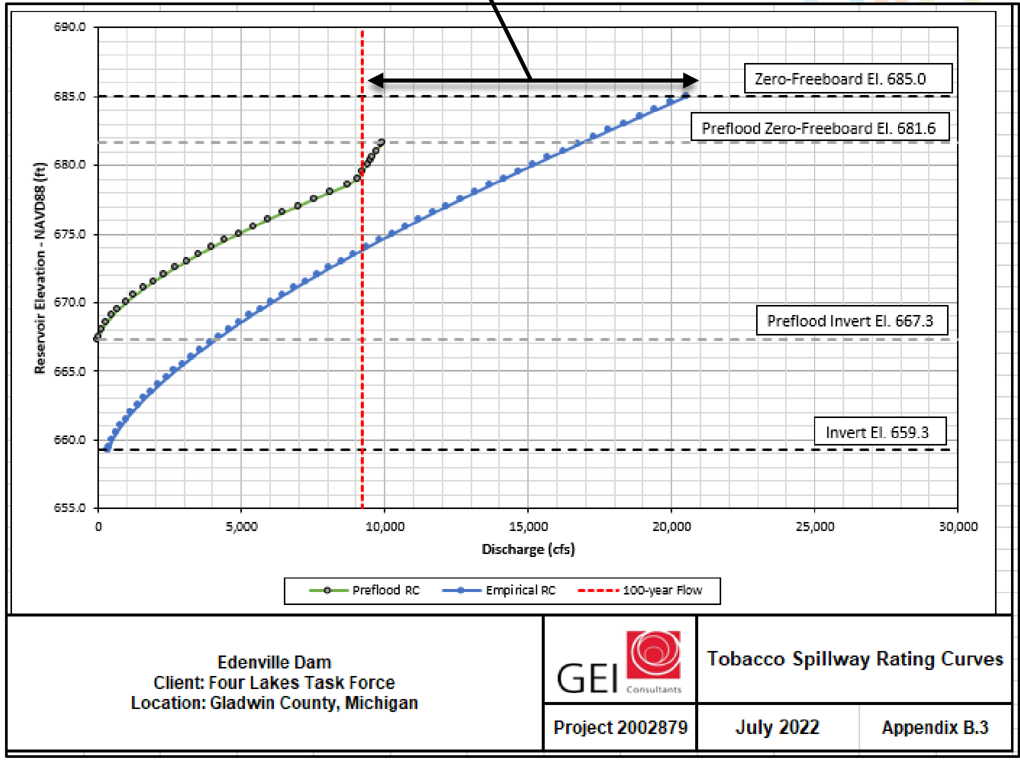


Proposed Primary Spillway
- Discharge Capacity = 19,700 cfs

LLO Capacity
- Discharge Capacity = 800 cfs

- Tobacco (TBO) Primary Spillway Modifications
  - Construct two new 27-foot-wide, 16.5-foot-tall crest gates
  - Construct vertical 5x7-foot LLO gate

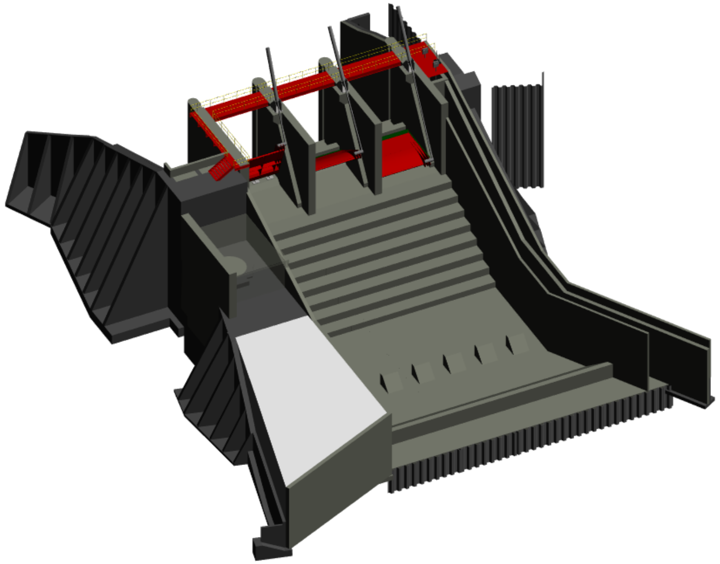
Zero Freeboard Discharge Capacity Increased by 100% (9,800 cfs)



Edenville Dam – Restoration (2023 – 2026)

TBW Primary Spillway Gates

Pre-Flood Primary Spillway
- Discharge Capacity = 10,750 cfs

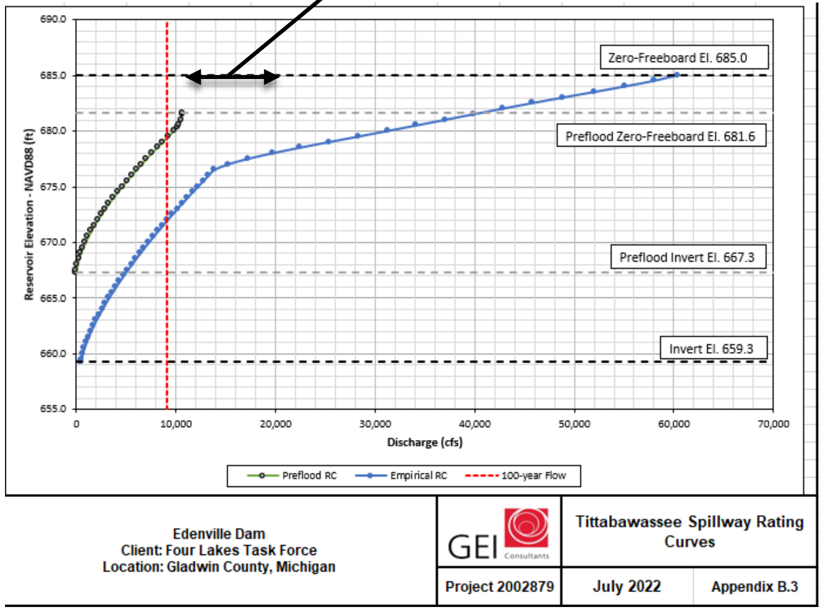


Proposed Primary Spillway
- Discharge Capacity = 22,600 cfs

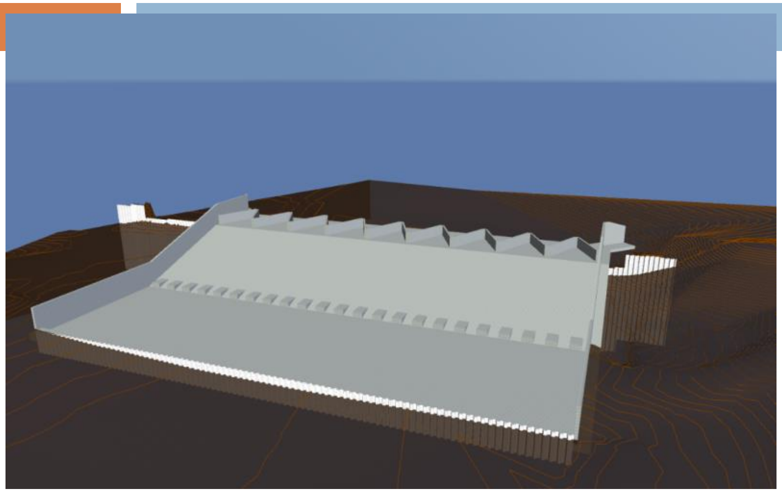
LLO Capacity
- Discharge Capacity = 1,100 cfs

- Tittabawassee (TBW) Primary Spillway Modifications
  - Demolish the left bay of the TBW powerhouse
  - Construct three new 21.75-foot-wide, 16.5-foot-tall crest gates
  - Construct vertical 7x7-foot LLO gate

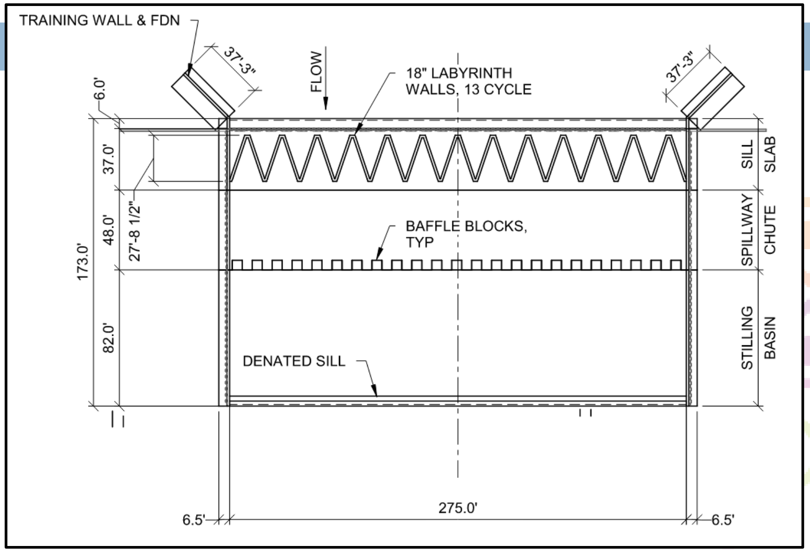
Zero Freeboard Discharge Capacity Increased by 100% (11,850 cfs)

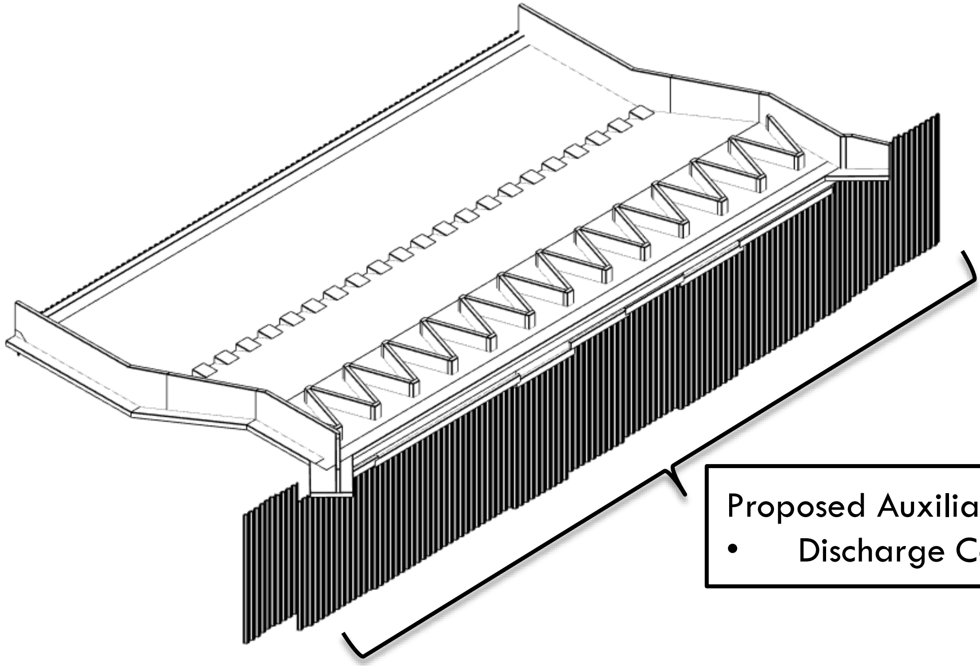


Review Structural Drawings – Auxiliary Spillway (AS)



- New Auxiliary Spillway
  - 275-foot-wide Labyrinth Spillway
  - Located in TBW Left Embankment
  - Discharges for floods greater than 200-year





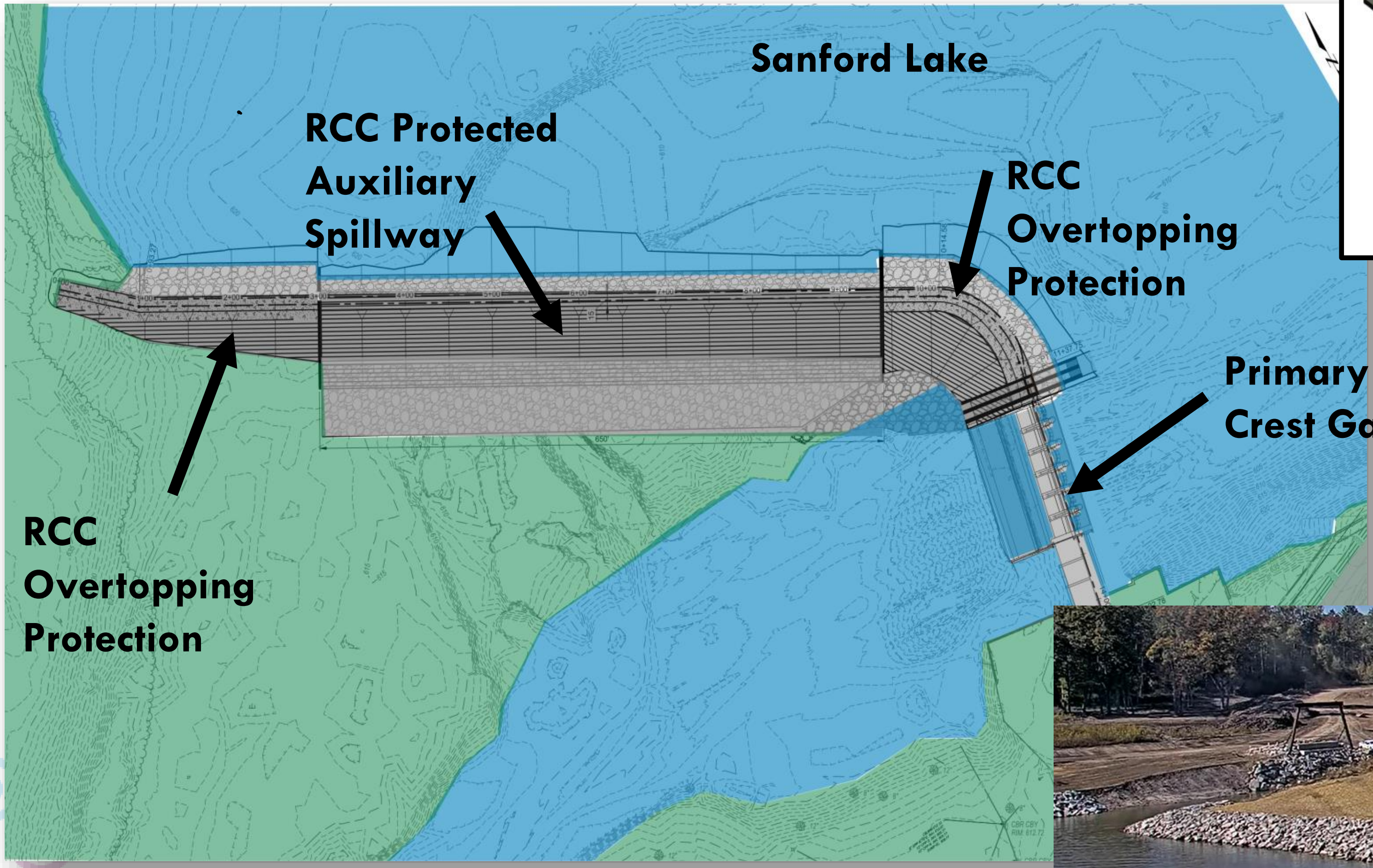
Proposed Auxiliary Spillway
- Discharge Capacity = 36,500 cfs

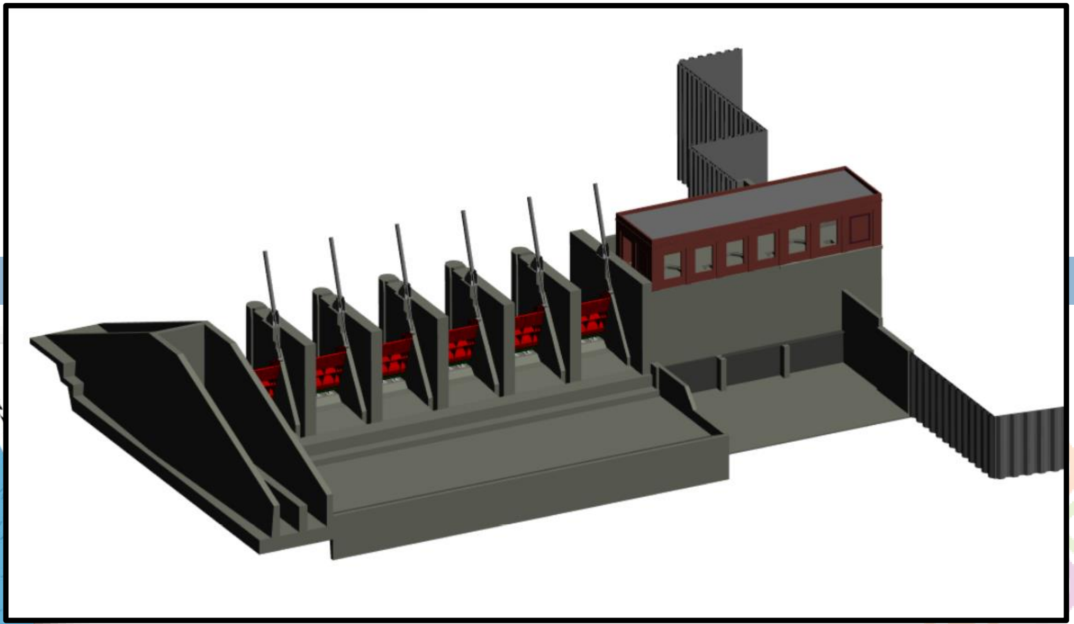
Parameter	Pre-Flood Spillway Configuration	Restoration Spillway Configuration
IDF Inflow (cfs)	55,400	
Zero-Freeboard Tainter Gate Spillway Capacity (cfs)	20,650	44,200
Auxiliary Spillway Zero-Freeboard Capacity (cfs)	0	36,500
Total Spillway Capacity (cfs)	20,650	80,700
Spillway Capacity Increase	**60,050 cfs**	

Sanford Dam

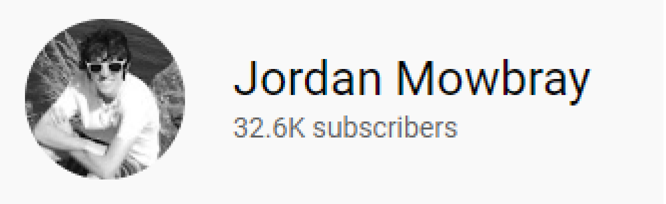
Four Lakes Task Force

SANFORD DAM RESTORATION

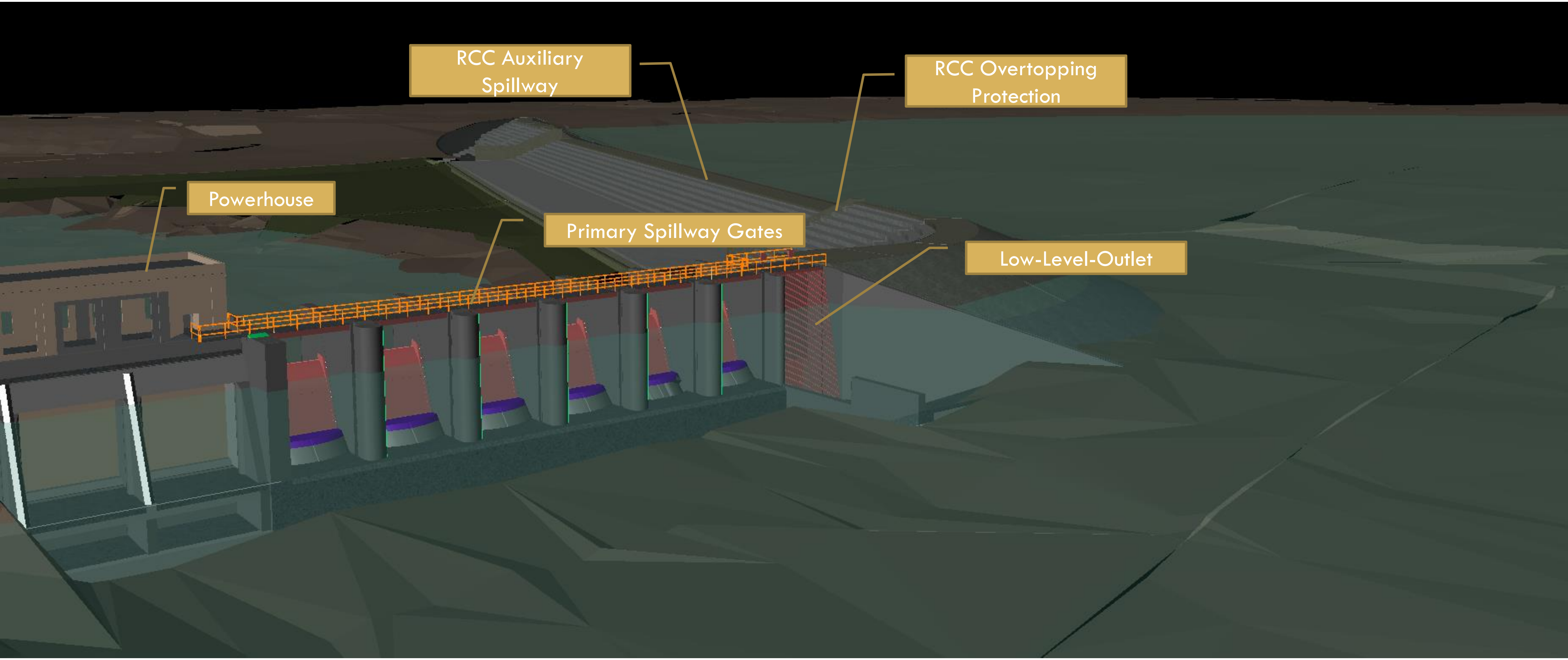




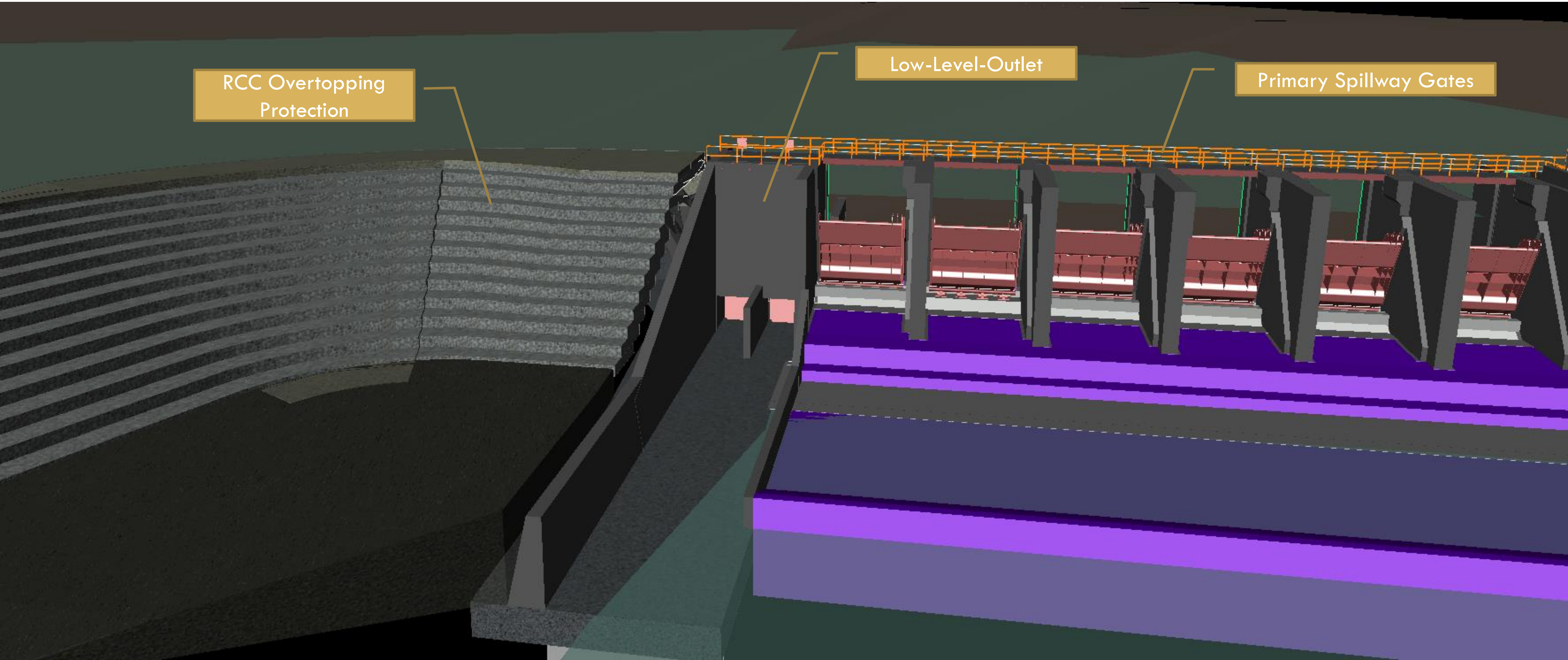
Smash That Like Button!



Sanford Dam Restoration (2023 – 2025)



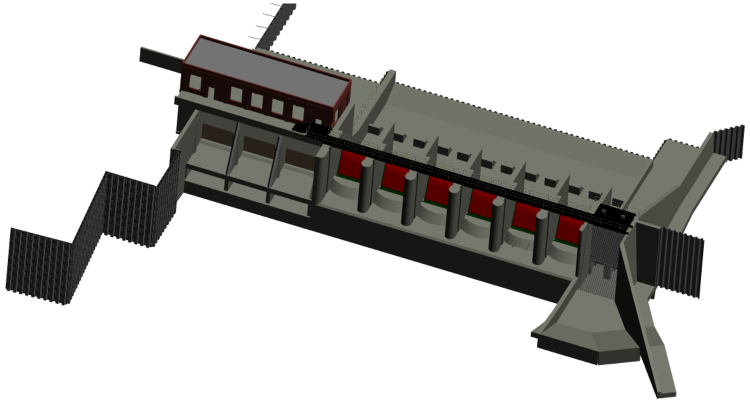
Sanford Dam Restoration (2023 – 2025)



Sanford Dam Restoration (2023 – 2025)

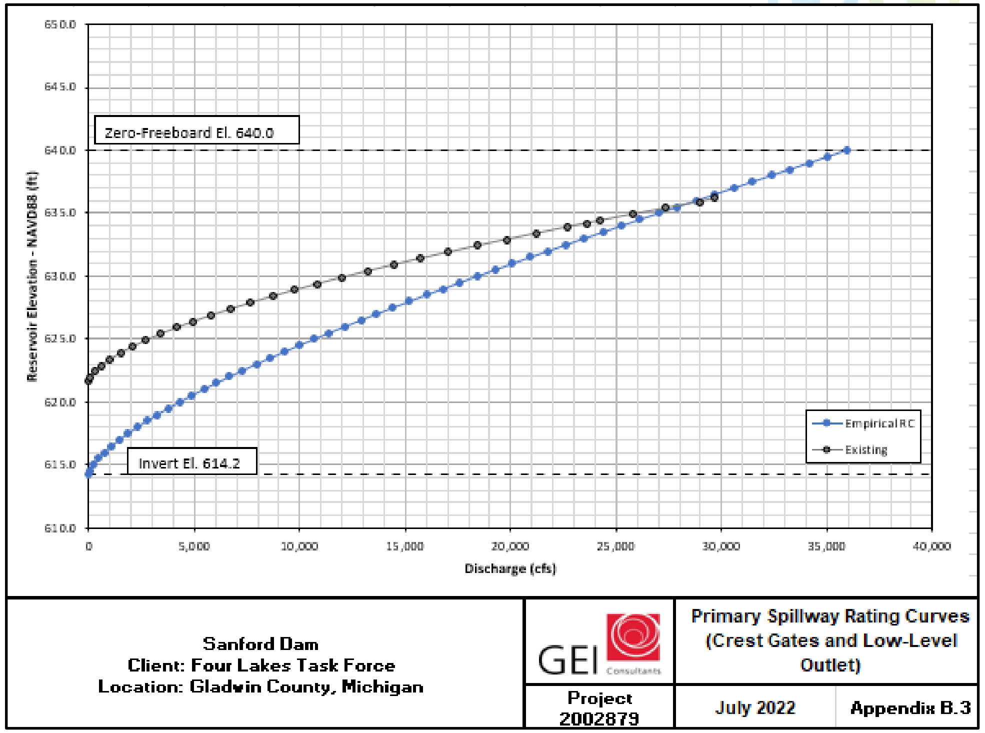
- Sanford (SFD) Primary Spillway Modifications
  - Construct six new 18-foot-wide, 16.5-foot-tall crest gates
  - Construct vertical 7x8 foot LLO gate(s)

Pre-Flood Primary Spillway
- Discharge Capacity = 29,700 cfs



Proposed Primary Spillway
- Discharge Capacity = 35,900 cfs

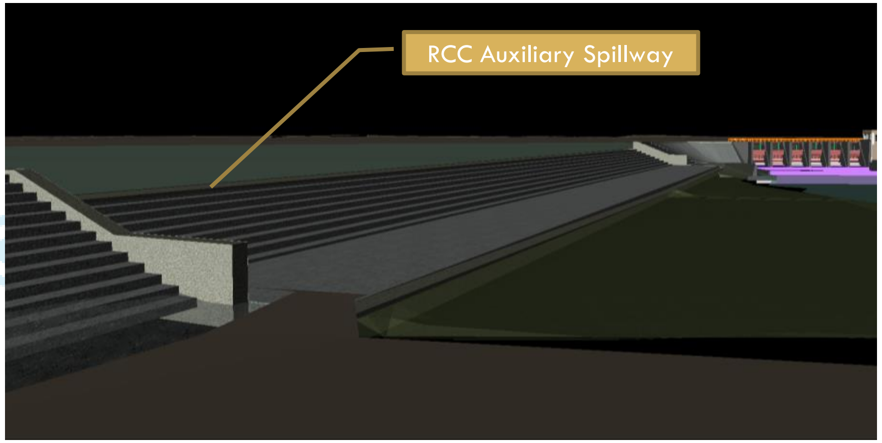
LLO Capacity
- Discharge Capacity = 1,900 cfs



Sanford Dam Restoration (2023 – 2025)

- New Auxiliary Spillway
  - Located in SFD Right Embankment
  - 650-foot-wide RCC Spillway

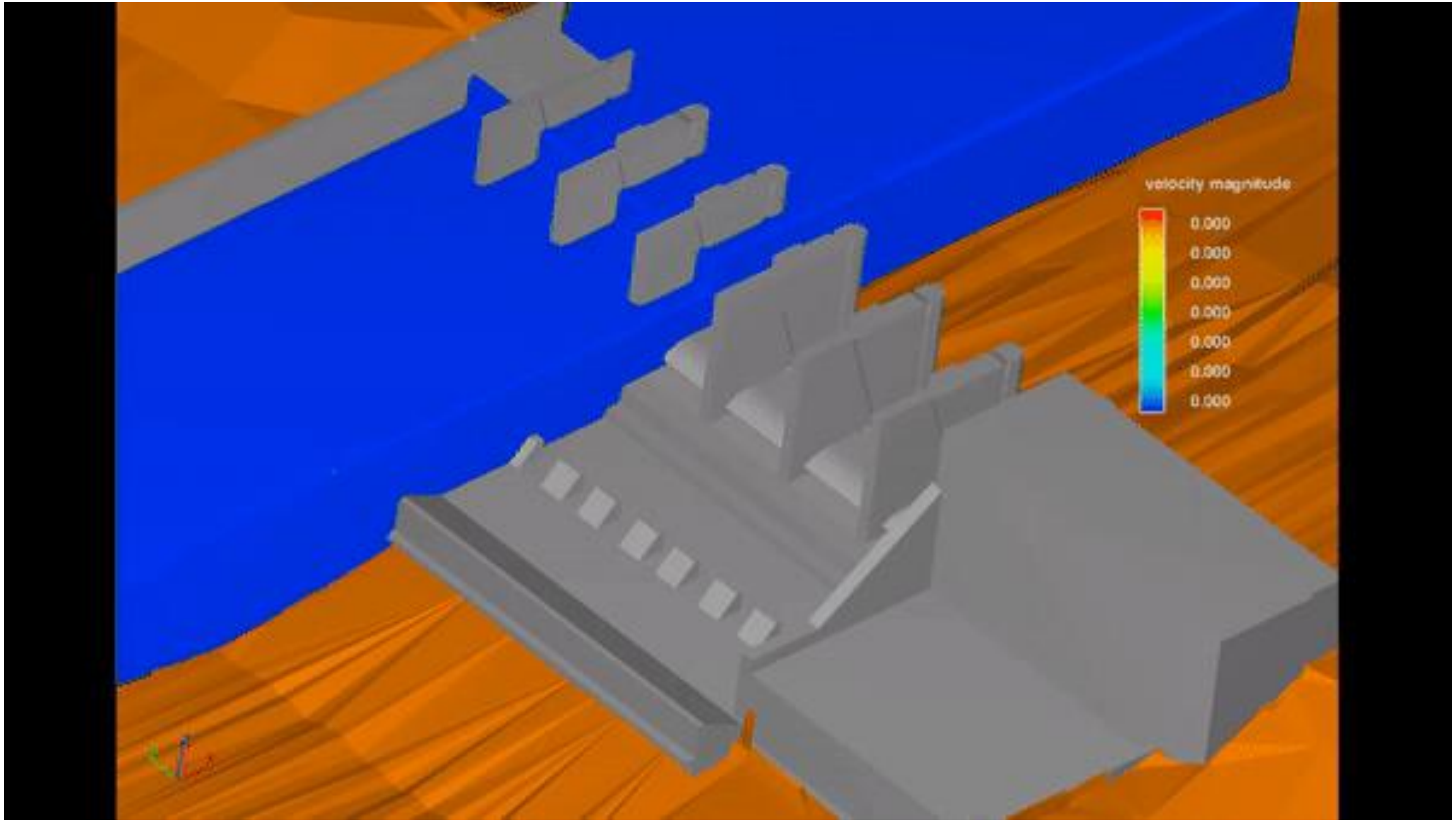
Pre-Flood Auxiliary Spillway
- Discharge Capacity = 6,500 cfs



Proposed Primary Spillway
- Discharge Capacity 39,700

Parameter	Pre-Flood Spillway Configuration	Restoration Spillway Configuration
IDF Inflow (cfs)	54,600	
Zero-Freeboard Tainter Gate Spillway Capacity (cfs)	29,700	37,800
Auxiliary Spillway Zero-Freeboard Capacity (cfs)	6,500	39,700
Total Spillway Capacity (cfs)	36,200	77,500
Spillway Capacity Increase	**41,300**	

Sanford Dam Restoration (2023 – 2025)



200-year flood,
gates full open

Thank You

- FLTF
- GEI Consultants
- Spicer Group Inc.
- Ayres Associates Inc.
- Applied Weather Associates