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Flood Study of the Tittabawassee River from Secord to Sanford Dam

Gladwin and Midland County, Michigan

Submitted to:
Mr. David Kepler
Four Lake Task Force
233 E. Larkin
Midland, Michigan 48640

Submitted by:
GEI Consultants of Michigan, P.C.
10501 West Research Drive, Suite G100
Milwaukee, Wisconsin 53226
414-930-7534

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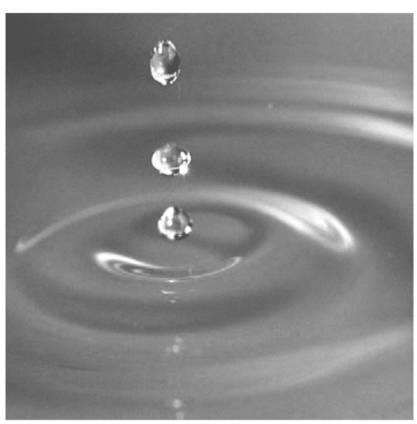

Paul D. Drew P.E., CFM
Project Manager

William H. Walton P.E. (MI), S.E.
Engineer of Record

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Executive Summary

Project Purpose

Following the May 19, 2020, storm event that resulted in minor downstream erosion damage to Secord Dam, severe downstream erosion damage to the Smallwood Dam and a catastrophic failure of the Edenville and Sanford Dams, the Four Lakes Task Force (FLTF) requested GEI Consultants of Michigan, P.C. (GEI) to provide "planning-level" opinions of probable construction costs (OPCC) to reconstruct and/or rehabilitate the four dams formerly owned by Boyce Hydro (Boyce). The OPCC were developed from "high-level" design concepts and anticipated list of reconstruction and rehabilitation activities for the water retaining structures at each dam and preliminary spillway rating curve calculations. The total OPCC for each of the four dams to pass the ½ Probable Maximum Flood (PMF) was approximately $337 million (+50% / - 30% cost variance) and the incremental cost to increase the spillway capacity from the ½ PMF to the full PMF was estimated to be approximately 42% higher, or $142 million, for a total of $479 million (+50% / - 30% cost variance). These OPCC do not include restoration of new power generation at the four dam sites. The FLTF is using these planning-level cost estimates to begin budgetary planning for the reconstruction / rehabilitation of the four projects. The FLTF understands that the cost estimates were developed using preliminary spillway rating curve calculations and that a more comprehensive flood study is needed to better understand the Tittabawassee River system and further refine and optimize the reconstruction and repair designs for each of the four dams. The following are the primary goals related to this flood study:

- Update PMF Inflow Hydrographs (*To be Completed by Ayres Associates, Inc. (Ayres)).*
- Develop a hydraulic computer model to establish flood elevations from the Secord Dam to approximately 2 miles downstream of Sanford Dam for the proposed spillway configurations to pass at a minimum the ½ PMF in accordance with State of Michigan EGLE requirements.
- Evaluate spillway configurations to pass at a minimum the ½ PMF in accordance with State of Michigan EGLE requirements. *Note that the "½ PMF" is not half of the PMF value. Verbal consultation with EGLE personnel clarified that "½ PMF" in the context of State of Michigan EGLE standards refers to the flood calculated to result from one-half of the PMP.*
- Develop floodplain inundation mapping to identify roads, highways, habitable structures, and other critical infrastructure impacted from the proposed spillway configurations for the range of design storms up to and including the 100 year-storm ½ PMF and PMF.

Existing Conditions Spillway Capacity

In April 2020, the FLTF requested that GEI review the available hydraulic information and develop new spillway discharge rating curves for each project (Ref. GEI 2020b). The updated spillway discharge rating curves were submitted to Ayres for their use in the current PMF study update and included in the U.S. Army Corps of Engineers (USACE) Hydrologic Engineer Center Hydrologic Modeling System (HEC-HMS) flood routing model. The following is a summary of the existing spillway capacity for the Secord, Smallwood, Edenville and Sanford Projects.

Table ES-1: Summary of Existing Spillway Discharge Capacity (Prior to May 19, 2020)

Parameter	Secord Project	Smallwood Project	Edenville Project		Sanford Project
			Edenville Dam	Tobacco Dam	
Zero-Freeboard Tainter Gate Spillway Capacity (cfs)	7,695	10,185	10,750	9,920	29,690
Zero-Freeboard Elevation (feet)	757.8	715.7	682.1	683.1	636.8
Abutment Overflow (cfs)	4,440	19,650	-	-	-
Zero-Freeboard Fuse Plug Spillway Capacity (cfs)	-	-	-	-	6,485
Total Spillway Capacity (cfs)	12,135	29,835	20,670		36,175

Notes: Elevations are in NGVD29.

Existing Conditions Flood Routing

GEI has reviewed the May 2020, PMF Report by Ayres Associates, Inc. (Ref. Ayres, 2020) prepared for Secord, Smallwood, Edenville and Sanford dams. This report was prepared before the May 2020 flood and used only data available prior to that event. Following the May 2020 event, modifications were made to the analysis based on post-failure observations and model adjustments with enhanced calibration of the model from high flow measurements. GEI has reviewed the 2020 Ayres Study and the associated HEC-HMS model and generally agree with the methodology and results of the study. Existing conditions modeling results for the ½ PMF and PMF are summarized and compared in **Table ES-2** through **Table ES-5**.

Table ES-2: Secord Dam Flood Routing Results – Existing Conditions

Parameter or Modeling Result	½ PMF	PMF
Peak Inflow (cfs)	18,075	43,020
Peak Outflow Spillway (cfs)	7,700	8,125
Peak Outflow Tea Creek Ridgeline	4,885	25,200
Embankment Overtopping	0	7,750
Total Outflow	12,585	41,075
Maximum Reservoir El. (feet)	757.8	759.7
Freeboard (Dam Crest El. 757.8)	0.0	-1.9

Table ES-3: Smallwood Dam Flood Routing Results – Existing Conditions

Parameter or Modeling Result	½ PMF	PMF
Peak Inflow (cfs)	19,065	58,640
Peak Outflow (cfs)	18,895	58,110
Maximum Reservoir El. (feet)	713.3	718.4
Freeboard (Dam Crest El. 715.7)	2.4	-2.7

Table ES-4: Edenville Dam Flood Routing Results – Existing Conditions

Parameter or Modeling Result	½ PMF	PMF
Peak Inflow (cfs)	41,260	116,525
Peak Outflow (cfs)	37,845	115,885
Maximum Reservoir El. (feet)	684.2	686.8
Freeboard (Dam Crest El. 682.1)	-2.1	-4.7

Table ES-5: Sanford Dam Flood Routing Results – Existing Conditions

Parameter or Modeling Result	½ PMF	PMF
Peak Inflow (cfs)	37,695	116,065
Peak Outflow (cfs)	35,480	112,295
Maximum Reservoir El. (feet)	637.2	644.3
Freeboard (Dam Crest El. 636.8)	-0.4	-7.5

Design Storm Selection

Following the Edenville and Sanford Dam failures, the Michigan Dam Safety Task Force evaluated the statutory structure, budget, and program design of the Water Resources Division Dam Safety Program, the adequacy of Michigan's dam safety standards, and the level of investment needed in Michigan's dam infrastructure. The project team of GEI, Ayres and Applied Weather Associates (AWA) are developing the design storm of these four dams at this time of this reporting. We understand that the current spillway capacity requirement (1/2 PMF) will likely change as a result of the Dam Safety Task Force recommendation and will follow the current Federal Emergency Management Agency (FEMA) Dam Safety Federal Guideline P-94 – *Selecting and Accommodating Inflow Design Floods for Dams* (Ref. FEMA, 2013) based on dam hazard potential.

FEMA acknowledges that no single approach to the selection of an Inflow Design Flood (IDF) is adequate for existing or planned dams. FEMA identifies the following approaches to defining the IDF to accommodate the wide variety of situations, resources, and conditions:

- Prescriptive approach - *This approach is similar to the current state of Michigan EGLE requirement of the ½ PMF.*

- Site Specific PMP - T*he FLTF currently has Applied Weather Associates (AWA) under contract to calculate a site specific PMP and probability assessment of various rainfall depths for the Tittabawassee River basin. AWA will provide the updated rainfall depths and distributions to Ayres to develop site specific ½ PMF and PMF inflow hydrographs.*
- Incremental Consequence Analysis - *An incremental consequence analysis may be the preferred way to select the IDF. However, we recommend not completing an incremental consequence analysis until the site specific Probable Maximum Precipitation (PMP) and PMF analysis is completed later this year by AWA and Ayres.*
- Risk Informed Decision Making (RIDM) - *AWA will derive the Annual Exceedance Probability (AEP) of the rainfall up to and including the PMP. This will provide the recurrence interval of rainfall depths for critical durations and can be used for the RIDM process for dam design and selection of the IDF.*

Considering the schedule of the site specific PMP and PMF study by AWA and Ayres, an interim IDF was selected for the purposes of this flood study and developing 30% design plans and budgetary costs for the FLTF projects. The current state of Michigan EGLE spillway requirement for high hazard dams is the ½ PMF; however, the project team (GEI, Spicer Group, Inc., Essex Partnership and the FLTF) collaboratively selected a more conservative design criteria considering the uncertainty of the state of Michigan EGLE spillway capacity requirements and the upcoming site specific PMP and PMF study.

For the purposes of this study, the selected IDF is the ½ PMF plus a 15% to 30% increase in peak inflow (1/2 PMF +). Once the site specific PMP, PMF, studies are complete; the IDF will be re-evaluated using the techniques prescribed in FEMA P-94. The selected ½ PMF + peak inflows are summarized in **Table ES-6**.

Table ES-6: Summary of Inflow Design Flood (1/2 PMF + Design Storm)

Dam	½ PMF	PMF	½ PMF +[1]
Secord Dam	18,075	43,020	**21,150**
Smallwood Dam	19,065	58,640	**24,550**
Edenville Total	41,260	116,525	**52,275**
Sanford Dam	37,695	116,065	**47,300**

1. The current IDF for the four FLTF Projects is the ½ PMF + design storm contingency.

Hydraulic Analysis

GEI performed hydraulic analysis to evaluate the proposed spillway upgrades at each of the FLTF projects during the ½ PMF + design storm. Based on the existing conditions of the FLTF projects, GEI has developed new conceptual spillway and dam configurations which would allow the FLTF dams to safely pass the ½ PMF + design storm with requisite freeboard to retain wind set-up and wave runup without overtopping. The proposed configurations consist of reconstruction or rehabilitation of earthen embankments, demolition, and replacement of the primary Tainter gate spillways with new active hydraulic crest gates, construction of low-level outlets through the old powerhouse conveyances, and new passive overflow auxiliary spillways. Hydraulic modeling results for the proposed dam configurations for the ½ PMF + design storm flows are summarized and compared in **Table ES-7** through **Table ES-10**.

Table ES-7: Secord Dam Flood Routing Results – Proposed Conditions

Parameter or Modeling Result	½ PMF+
Initial Water Surface El. (feet)	750.8
Peak Inflow (cfs)	21,150
Peak Outflow (cfs)	17,230
Maximum Reservoir El. (feet)	755.2
Freeboard (Tea Creek E. 755.0) (feet)	-0.2
Freeboard (Dam Crest El. 758.0) (feet)	2.8

Table ES-8: Smallwood Dam Flood Routing Results – Proposed Conditions

Parameter or Modeling Result	½ PMF+
Initial Water Surface El. (feet)	704.8
Peak Inflow (cfs)	24,550
Peak Outflow (cfs)	24,100
Maximum Reservoir El. (feet)	713.1
Freeboard (Dam Crest El. 715.0) (feet)	1.9

Table ES-9: Edenville Dam Flood Routing Results – Proposed Conditions

Parameter or Modeling Result	½ PMF+
Initial Water Surface El. (feet)	675.8
Peak Inflow (cfs)	52,275
Peak Outflow (cfs)	47,000
Maximum Reservoir El. (feet)	681.2
Freeboard (Dam Crest El. 685.5) (feet)	4.3

Table ES-10: Sanford Dam Flood Routing Results – Proposed Conditions

Parameter or Modeling Result	½ PMF+
Initial Water Surface El. (feet)	630.8
Peak Inflow (cfs)	47,300
Peak Outflow (cfs)	46,000
Maximum Reservoir El. (feet)	635.0
Freeboard (Dam Crest El. 638.0) (feet)	3.0

Next Steps

- The FLTF currently has AWA under contract to estimate site specific PMP and probability assessment of various design storm rainfall depths for the Tittabawassee River basin. A site-specific study of the PMP and PMF can result in a lower and more appropriate estimate of the ½ PMF and PMF.
- AWA will provide the updated rainfall depths and distributions to Ayres to develop site specific ½ PMF and PMF inflow hydrographs. The ongoing updated PMP and PMF study by AWA and Ayres is expected to be completed in the June 2021.
- Once the site specific PMP, PMF, and AEP studies are complete in June 2021; GEI will perform an incremental consequence analysis and risk assessment to determine the Inflow Design Flood (IDF) using the techniques prescribed in FEMA P-94.

1. Introduction

1.1 Purpose

Following the May 19, 2020, storm event that resulted in moderate downstream erosion damage to Secord Dam, severe downstream erosion damage to the Smallwood Dam and a catastrophic failure of the Edenville and Sanford Dams, the Four Lakes Task Force (FLTF) requested GEI Consultants of Michigan, P.C. (GEI) to provide "planning-level" opinions of probable construction costs (OPCC) to reconstruct and/or rehabilitate the four dam developments formerly owned by Boyce Hydro (Boyce). As documented in the July 2020 Post Failure Reconstruction Cost Analysis prepared by GEI (Ref. GEI, 2020a), the OPCC assumed reconstruction or repair of the dams without hydropower generation and increasing spillway capacity to pass the ½ Probable Maximum Flood (PMF) in accordance with the Michigan Department of Environment, Great Lakes and Energy (EGLE) requirements for high hazard dams. The FLTF also requested that GEI develop an OPCC to pass the full PMF in case the State of Michigan EGLE, at a future date, increases the high hazard dam minimum spillway capacity requirement above the ½ PMF, or if the probable maximum precipitation (PMP) estimates for the region increase. The OPCC were developed from "high-level" design concepts and anticipated list of reconstruction and rehabilitation activities for the water retaining structures at each dam and preliminary spillway rating curve calculations. The total OPCC for each of the four dams to pass the ½ PMF was approximately $337 million (+50% / - 30% cost variance) and the incremental cost to increase the spillway capacity from the ½ PMF to the full PMF was estimated to be approximately 42% higher, or $142 million, for a total of $479 million (+50% / - 30% cost variance).

The FLTF is using these planning-level engineer's opinion of construction cost estimates to begin budgetary planning for the reconstruction / rehabilitation of the four projects. The FLTF understands that the cost estimates were developed using preliminary spillway rating curve calculations and that a more comprehensive flood study is needed to better understand the Tobacco and Tittabawassee River systems and further refine and optimize the reconstruction and repair designs for each of the spillway dams at the four projects. GEI attended a meeting with members from the FLTF, Spicer Group Inc. (SGI) and the Essex Partnership on August 6, 2020, to discuss the following goals related to this flood study:

1. Update Probable Maximum Flood (PMF) Inflow Hydrographs (*To be Completed by Ayres by mid-2021*): In spring of 2020 Ayres Associates (Ayres), under contract to SGI, performed an updated PMF study to re-evaluate the PMF using improved precipitation, streamflow, and watershed data in accordance with current Federal Energy Regulatory Commission (FERC) engineering guidelines. The PMF study was completed prior to the May 19, 2020 storm event. Ayres subsequently calibrated the PMF model using the recorded rainfall from the May 2020 storm and provided GEI updated PMF inflow hydrographs for each of the four projects. Furthermore, Ayres also established peak flow rates for the 100-, 200-, 500-, and 1,000-year recurrence interval storms using the National Oceanic and Atmospheric Administration (NOAA) National Weather Service Atlas 14 Point Precipitation Frequency Estimates.

2. Establish Flood Elevations: The majority of the lands bordering the Tittabawassee and Tobacco Rivers are Federal Emergency Management Agency (FEMA) "Zone A" floodplains, meaning base-flood elevations were not established by a detailed study and the floodplain limits were determined by approximate methods. The only stretch of river with established 100-year flood elevations is from downstream of Edenville Dam to immediately downstream of Sanford Dam. A primary goal of this flood study is to develop a hydraulic computer model to establish flood elevations from Secord Dam reservoir to approximately 2 miles downstream of Sanford Dam for the proposed spillway configurations to pass at a minimum the ½ PMF in accordance with State of Michigan EGLE requirements.
3. Evaluate Proposed Spillway Configurations: As documented in the GEI Post Failure Reconstruction Cost Analysis, another primary goal of this flood study is to evaluate spillway configurations to pass at a minimum the ½ PMF in accordance with State of Michigan EGLE requirements.
4. Establish Floodplain Inundation Mapping: Develop floodplain inundation mapping to identify abutting roads, highways, bridge crossing, schools, habitable structures, and other critical infrastructure impacted from the proposed spillway configurations for the range of design storms. The floodplain inundation mapping results will be used by the FLTF and other project stakeholders to make an informed decision on the proposed spillway capacity design storm.

1.2 Authorization

The work was authorized by the FLTF under Task Order #3 dated August 19, 2020 in accordance with the Master Services Agreement dated May 29, 2020.

1.3 Project Personnel

The following GEI personnel were primarily responsible for performing the hydrology and hydraulics analyses for this report:

Project Manager:	Paul D. Drew, P.E., CFM
Water Resources Engineer:	Nate Jorgensen, P.E.
Water Resources Engineer:	Eric Holmstead, E.I.T.
Water Resources Engineer:	Emma Giese, E.I.T.
Project Reviewer:	Nick Miller, P.E., P.H.
Project Principal:	Richard J. Anderson, P.E.
Engineer of Record	William H. Walton, P.E.(MI), S.E.

This work was coordinated with Mr. Dave Kepler from the FLTF and Mr. Ron Hansen, P.E., P.S. from SGI.

1.4 Elevation Datum

Elevations listed herein are referenced to the National Geodetic Vertical Datum of 1929 (NGVD29). Vertical datum conversions to the site datum and North American Vertical Datum of 1988 (NAVD88) are included in **Table 1**.

Table 1: Vertical Datum Conversions

Project	Summer Lake Level (Site Datum)[1]	Summer Lake Level (NGVD29)	Winter Lake Level (NGVD29)	VertCon[2] Conversion	Summer Lake Level (NAVD88)	Winter Lake Level (NAVD88)
Secord	745.0	**750.8**	**747.8**	-0.5	750.3	747.3
Smallwood	699.0	**704.8**	**701.8**	-0.5	704.3	701.3
Edenville	670.0	**675.8**	**672.8**	-0.6	675.2	672.2
Sanford	625.0	**630.8**	**627.8**	-0.6	630.2	627.2

1: Datum conversion Site Datum to NGVD = +5.8 feet.
2: National Geodetic Survey Height Conversion: https://geodesy.noaa.gov/TOOLS/Vertcon/vertcon.html

1.5 Limitation of Liability

Our professional services for preparing this Flood Study were performed in accordance with generally accepted engineering practices; no other warranty, express or implied, is made.

2. Description of Project Structures

2.1 General Project Descriptions

Secord Dam (FERC Project No. 10809), Smallwood Dam (FERC Project No. 10810), and Edenville Dam are located on the Tittabawassee River system in Gladwin County, Michigan. The Sanford Dam (FERC Project No. 2785) is located approximately 8.5 miles northwest of Midland, Michigan in Midland County. The locations of the dams are illustrated on **Figure 1**.

Sanford Dam and Edenville Dam breached on May 19, 2020 after several days of intense rainfall across the Tobacco and Tittabawassee River watersheds. Smallwood Dam incurred significant downstream erosion damage due to high flows through the gated spillway and over the auxiliary spillway channel and resulting scour erosion of the downstream slope embankments and abutments. The downstream erosion damage to Secord dam was minimal with no overtopping or significant damage reported. The FERC in a letter dated May 20, 2020 ordered Boyce to fully drawdown the impoundments to the sill of the gated spillways behind all four dams. Several of the water retaining structures, including the Tobacco embankments and the Tobacco Spillway at the Edenville Project were still impounding water since no flow allowed through the turbine units and no low-level outlet is present to fully drawdown the impoundments. The Sanford right embankment and fuse plug spillway were completely breached but the spillway and powerhouse structures are still standing with no observable movement. Key project data for the Secord, Smallwood, Edenville and Sanford Projects (Prior to the May 19, 2020 Failure) are provided in **Table 2**.

Table 2: Key Existing Project Data (Prior to the May 19, 2020 Failure)

Structural Parameter	Secord Project	Smallwood Project	Edenville Project		Sanford Project
			Edenville Dam	Tobacco Dam	
Min. Dam Crest El. (feet)	757.8	715.7	682.1	683.1	636.8
Normal Operating Pool El. (feet)	750.8	704.8	675.8		630.8
Spillway Invert El. (feet)	742.8	694.8	667.8	667.8	622.3
Number of Tainter Gates	2	2	3	3	6
Gate Numbering (left to right looking downstream)	1 to 2	2 to 1	6 to 4	3 to 1	1 to 6
Gate 1 Width (feet)	20.5	25.3	20	23.6	25.4
Gate 1 Max Opening (feet)	7.5	10.0	9.5	9.5	10.1
Gate 2 Width (feet)	23.8	25.3	20	20	22.0
Gate 2 Max Opening (feet)	10.5	9.9	8.9	4.5	10.8
Gate 3 Width (feet)	-	-	23.5	23.6	22.0
Gate 3 Max Opening (feet)	-	-	9.6	8.9	10.8
Gate 4 Width (feet)	-	-	-	-	22.0
Gate 4 Max Opening (feet)	-	-	-	-	10.9

Structural Parameter	Secord Project	Smallwood Project	Edenville Project		Sanford Project
			Edenville Dam	Tobacco Dam	
Gate 5 Width (feet)	-	-	-	-	22.0
Gate 5 Max Opening (feet)	-	-	-	-	11.0
Gate 6 Width (ft)	-	-	-	-	25.4
Gate 6 Max Opening (ft)	-	-	-	-	10.9
Auxiliary Spillway Type	-	Overflow	-	-	Fuse Plug
Auxiliary Spillway El. (ft)	-	709.5	-	-	631.8
Auxiliary Spillway Length (feet)	-	680	-	-	190

2.2 Secord Dam

The Secord Dam is located on the Tittabawassee River, a tributary of the Saginaw River, and is approximately 41 river miles upstream of the City of Midland in Midland County, Michigan (see **Figure 2**). The facility is owned and operated by the FLTF and the FERC License is currently maintained by Boyce. Construction of the dam was completed in 1925 to provide storage and headwater level control for the purpose of hydroelectric power generation. The FERC issued an original license for the Project in 1998. From left to right[1], the project consists of a 650-foot-long left earth fill embankment with toe finger drains with a minimum dam crest elevation of El. 757.8[2] feet; a 25-foot-wide powerhouse containing one Francis type turbine generating unit with a rated capacity of 1.2 MW, a 46.3-foot-wide gated spillway with two Tainter gates, and an approximately 350-foot-long right earthfill embankment with toe finger drains. The Exhibit F Drawings from the FERC license, illustrating the typical plan and sections for each of the existing project structures are included in **Appendix A.1**. The Secord Hydroelectric Project is classified as having a high hazard potential based on estimated downstream impacts in the event of failure.

The reinforced concrete spillway structure is a hollow reinforced concrete barrel arch and ogee shaped rollway slab structure with two Tainter gate bays. The left Tainter gate is 20.5-feet-wide by 10-feet-high and the right Tainter gate is 23.8-feet-wide by 10-feet-high. The spillway ogee crest is at El. 742.8 feet. The gates are operated by hydraulic hoist chains and cables with the operators located directly adjacent to the hoist above each gate on an elevated platform. The hydraulic gate hoist was installed in 2019, replacing the original electric hoist and trolley system. Secondary gate hoist hardware was added to both gates in 2021 to supplement the primary gate hoists. Both gates are currently fully open and flows through the spillway are run-of-river.

2.3 Smallwood Dam

The Smallwood Dam is located on the Tittabawassee River, a tributary to the Saginaw River, and is approximately 35 river miles upstream of the City of Midland in Midland County, Michigan (See

[1] All references to left and right herein are with respect to looking in a downstream direction.
[2] All references to elevation herein are with respect to National Geodetic Vertical Datum of 1929 (NGVD29) unless otherwise noted.

Figure 3). The facility is owned and operated by the FLTF and the FERC License is currently maintained by Boyce. Construction of the dam was completed in 1925 to provide storage and headwater level control for the purpose of hydroelectric power generation. From left to right, the project consists of a 1,000-foot-long left earth fill embankment, an approximately 52-foot-wide gated spillway with two Tainter gates, a 25-foot-wide powerhouse containing one Francis type turbine generating unit with a rated capacity of 1.2 MW, and a 125-foot-wide right earthfill embankment.

The Exhibit F Drawings from the FERC license illustrating the typical plan and sections for each of the existing project structures are included in **Appendix A.2**. The Smallwood Hydroelectric Project is classified as having a high hazard potential based on estimated downstream impacts in the event of a failure.

The reinforced concrete spillway is a hollow reinforced concrete barrel arch and ogee shaped rollway slab structure with two Tainter gate bays. The left and right Tainter gate is 25.4-feet-wide by 10-feet-high. The spillway ogee crest is at El. 694.8 feet. The gates are operated by hydraulic hoist with the operators located directly adjacent to the hoist above each gate on an elevated platform. The hydraulic gate hoist was installed in 2019, replacing the original electric hoist, chains, cables and trolley system. Secondary gate hoist hardware was added to both gates in 2021 to supplement the primary gate hoists. Both gates are currently fully open the flows past the dam are run-of-river.

The leftmost 680 feet of the left embankment is constructed approximately 3 feet lower at El. 709.5 than the embankment crest and acts as a passive auxiliary spillway with a gravel roadway crest and vegetated upstream and downstream slopes with a steel sheet pile (SSP) training wall to contain flows in a channel and protect the main left embankment from auxiliary spillway erosion and scour. The left embankment section to the right of the auxiliary spillway is approximately 320 feet long and protected with SSP installed on the upstream face of the dam at El. 715.7 that extends to the Tainter gate spillway.

2.4 Edenville Dam

The Edenville Dam is located on the Tittabawassee and Tobacco Rivers in the town of Edenville, Michigan approximately 22 river miles upstream of the City of Midland, Michigan (See **Figure 4**). The facility is owned and operated by the FLTF. Construction of the dam was completed in 1925 to provide storage and headwater control for the purpose of hydroelectric power generation. From left to right, the Tittabawassee River portion of the project consist of a 680-foot-long left earthfill embankment with a minimum crest at El. 682.1, a 68.6-foot-wide gated spillway with three Tainter gates, a 50.6-foot-wide powerhouse containing two Francis type turbine generating units with a combined rated capacity of 6 MW, and a 2,800-foot-long right earthfill embankment that extends to the Michigan M-30 Highway embankment to the west. The Edenville Dam structures impound Wixom Lake. The Exhibit F Drawings from the FERC license illustrating the typical plan and sections for each of the existing project structures are included in **Appendix A.3**. The Tittabawassee River section of the Edenville Project is classified as having a high hazard potential based on estimated downstream impacts in the event of a failure.

The Edenville (Tittabawassee side) reinforced concrete spillway is a hollow reinforced concrete barrel arch and ogee shaped rollway slab structure with three Tainter gate bays. The left gate (Bay 6) is 23.6-feet-wide by 9.5-feet-high and the center and right Tainter gates (Bay 5 and Bay 4) are 20.0-feet-wide by 9.5-feet-high. The gates are operated by hydraulic hoist with the operators located directly adjacent to the hoist above each gate on an elevated platform. The three gates are currently fully open.

The M-30 Highway Bridge separates the east side (Tittabawassee River) from the west (Tobacco River) side of Wixom Lake. The hydraulic capacity of the M-30 bridge is insignificant compared to the hydraulic capacity of the Tittabawassee and Tobacco Tainter gate spillways and acts as a water surface equalization causeway between the two sides of the impoundment (Wixom Lake).

From left to right, the Tobacco River portion of the project consist of a 520-foot-long left embankment with a minimum dam crest at El 683.1, a 72.2-foot-wide gated spillway with three Tainter gates, and a 2,050-foot-long right embankment that extends to Hunter Road. The Exhibit F Drawings from the FERC license illustrating the typical plan and sections for each of the existing project structures are included in **Appendix A.3**. The Tobacco section of the Edenville Project is classified as having a high hazard potential based on estimated downstream impacts in the event of a failure.

The reinforced concrete spillway on the Tobacco River side of the dam is a hollow reinforced concrete barrel arch and ogee shaped rollway slab structure with three Tainter gate bays. The left gate (Bay 3) and right gate (Bay 1) are 23.6-foot-wide by 9.5-feet-high and the center Tainter gate (Bay 2) is 20.0-feet-wide by 9.5-feet-high. The gates are operated by hydraulic hoist with the operators located directly adjacent to the hoist above each gate on an elevated platform. The gates and major portions of the rollways and barrel arches have recently been removed in February 2021 to install a stepped concrete broad crested weir for run-of-river flow at a sill El. 647.6 ft or 20.2 ft below the former ogee spillway sill.

2.4.1 Edenville Dam Failure

Over a two-day period from May 16 to May 18, 2020, the Tittabawassee and Tobacco River watersheds incurred heavy rainfall totals ranging from 6 to 8 inches concentrated in Gladwin and Midland Counties. Saturated ground conditions combined with additional rainfall starting in the evening of May 18th through the early afternoon of May 19th resulted in Tittabawassee and Tobacco Rivers surpassing flood stages in many areas. During the flood event Boyce opened all six (6) Tainter Gates (Tobacco Bay No. 1 through No. 3, and Tittabawassee Bay No. 4 through No. 6) were opened (8 feet to 9 feet) to keep up with the flows of the Tittabawassee River. At approximately 5:30 p.m. Eastern Standard Time (EST), the Wixom Lake water surface elevation rose to El. 680.6 within 1.5 feet of the embankment crest (El. 682.1) and a portion of the left embankment failed due to excessive seepage and sloughing of the downstream slope causing an uncontrolled release of the reservoir.

The internal erosion failure of the left embankment resulted in a breach channel that extended approximately 500 feet from the left abutment to immediately adjacent to the Tittabawassee River side Tainter gate spillway. The flood wave was conveyed south through an approximately 1,300-feet-long, 400-foot-wide and 40-feet-deep (from the former embankment crest) breach channel formed by the failure. During the failure, the Tittabawassee River side of the impoundment drained, rapidly forcing increased flow and velocities through the M-30 bridge channel resulting in scour and erosion that eventually lead to the failure of the M-30 bridge. The headwaters of the Tobacco River bypassed the limited capacity of the Tobacco River side Tainter gate spillway and head cut a breach channel that extended from the M-30 bridge to the Tittabawassee River breach channel.

2.4.2 Edenville Dam Stabilization

The ongoing Edenville Dam interim stabilization consists of two construction phases as part of the State of Michigan EGLE, Water Resources Division Conditional Permit (Emergency Permit). The permit was issued on November 19, 2020 and includes permit conditions for Wixom Lake (Edenville Dam impoundment), the Tobacco and Tittabawassee Rivers.

Phase 1 construction of the Edenville Dam stabilization is currently underway on the Tobacco Spillway and includes lowering the existing Tainter gate spillway and restoring the natural flow path of the Tobacco River. Phase 2 Stabilization encompasses the Tittabawassee reach of Edenville Dam. In general, all remaining water retaining structures of the Tittabawassee section of the Edenville Dam are deficient for safely maintaining an impoundment. The schedule for the Phase 1 and 2 stabilization is construction completion from 2021 to 2022. Phase 2 is being designed under the FLTF in close coordination with EGLE. Following implementation of the Phase 2 stabilization, we understand the FLTF desires to undertake further engineering to fully rehabilitate the Edenville Dam to allow safe impoundment of water to its pre-breach level at the normal operating pool.

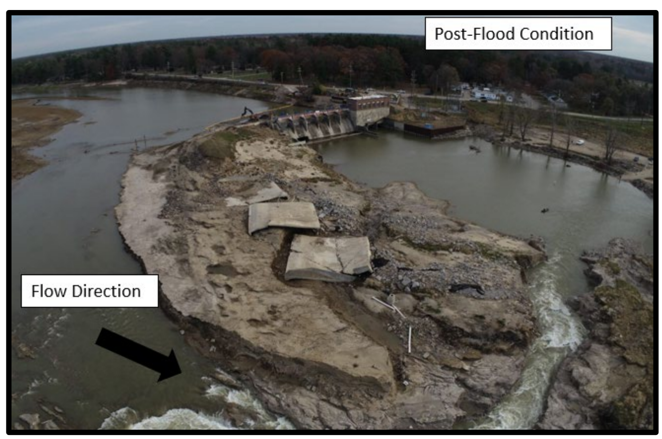
2.5 Sanford Dam

The Sanford Dam is located on the Tittabawassee River, a tributary to the Saginaw River, and is approximately 11 river miles upstream of the City of Midland in Midland County, Michigan (See **Figure 5**). The facility is owned and operated by the FLTF and the FERC license is currently maintained by Boyce. Construction of the dam was completed in 1925 to provide storage and headwater level control for the purpose of hydroelectric power generation. From left to right, the project consists of a 175-foot-long left earthfill embankment with toe finger drains, a 71-foot-long powerhouse containing three Francis turbine generating units, a 148.2-foot-wide gated spillway with six Tainter gates, a 320-foot-long saddle earthfill dike, a 190-foot-wide fuse plug spillway with a concrete overflow section and a 680 foot-long-right earthfill embankment with a minimum dam crest at El 636.8. The Exhibit F Drawings from the FERC license illustrating the typical plan and sections for each of the existing project structures are included in **Appendix A.4**. The Sanford Hydroelectric Project is classified as having a high hazard potential based on estimated downstream impacts in the event of a failure.

The reinforced concrete spillway is a hollow reinforced concrete barrel arch and ogee shaped rollway slab structure with six Tainter gate bays. The left gate (Bay 1) is 25.4-feet-wide by 10-feet-high, the center gates (Bay 2 through Bay 5) are 22-feet-wide by 10-feet-high, and the right gate (Bay 6) is 25.4-feet wide by 10-feet-high. The gates are operated by hydraulic hoist with the operators located directly adjacent to the hoist above each gate on an elevated platform. The hydraulic gate hoists were installed in 2019, replacing the original electric hoist and trolley system.

The fuse-plug auxiliary spillway was constructed in the early 2000s on the right embankment. The auxiliary spillway consisted of a sloping reinforced concrete base slab and vertical side walls within which "erodible" sandy fill and a sloping clay core wall was placed to create a continuous water retaining structure. The auxiliary spillway was 190-feet long with a concrete sill at El. 631.8 feet. The top of the fuse-plug was designed to initiate under flood pool conditions when the headwater level rose above starter notch El. 634.8 feet. The downstream toe of the fuse plug was armored with riprap for a downstream distance of 40 feet to protect against erosion and undermining during either high tailwater events or during operation.

2.5.1 Sanford Dam Failure



During the May 19, 2020 flood event all six (6) Tainter gates were fully opened (10 feet to 11 feet above the ogee sill) in attempt to safely discharge the flood flows of the Tittabawassee River. At approximately 5:30 pm EST the upstream Edenville Dam breached resulting in the Sanford Dam headwater rising to 12.5-inches above the powerhouse floor to approximate El. 638.8. With headwater rising rapidly, the fuseplug embankment did not breach as designed. The right embankment adjacent to the left fuse plug training wall was overtopped by approximately 2 feet and eventually breached at approximately 7:30 pm EST resulting in the catastrophic failure of the Sanford Dam and nearly full loss of reservoir.

The left embankment was overtopped by approximately 2 feet during the flood event causing head cutting erosion of the embankment crest and access road. The switchyard, which is located just downstream of the left embankment toe, was saturated (muddy) and covered in silt and sandy sediment deposits from the embankment overtopping and high tailwater during the May 2020 storm event.

The fuse plug spillway failed to initiate prior to the right embankment overtopping. The overtopping of the right embankment and undermining of the foundation soils led to the catastrophic failure of the fuse plug spillway resulting in the concrete chute detaching from the training walls and migrating approximately 50 feet downstream. The remaining fuse plug spillway is damaged beyond repair and will be demolished and hauled offsite as part of the Sanford Dam interim stabilization construction planned for 2021.

2.5.2 Sanford Dam Stabilization

The Natural Resource Conservation Service (NRCS) has identified that the Sanford Dam interim stabilization and sediment removal may be eligible for NRCS Emergency Watershed Protection (EWP) Program funding. The EWP Program will contribute up to 75 percent of the construction costs for eligible emergency projects. During the GEI October 2020 inspection, we shared and discussed a conceptual level design to achieve the following goals of the Sanford Dam interim stabilization project with Mr. Dan Vasher (NRCS):

1. Stabilize the existing breach channel,
2. Provide an armored channel adjacent to the existing breach channel to convey base river flows and flood flows up to the 200-year event to prevent further headcutting, erosion and transport of riverbed materials and sediments downstream. Steel sheet piling will be driven to glacial till at three transverse sections across the flow channel to allow the channel to be stepped in profile to minimize gradients and protect against headcutting.
3. Drive SSP into till along the alignment of the proposed right embankment cutoff wall from the existing spillway structure up to the right abutment and backfill with rockfill to stabilize to protect the remnant embankments from overtopping and erosion.

Following the inspection, GEI developed conceptual design drawings and cost estimates for the interim stabilization of the Sanford Dam embankment and breach channel to initiate the NRCS EWP funding request. The general construction sequence includes the following:

1. Construct temporary access road causeway in the tailrace upstream of the breach channel,
2. Drive steel sheet piling and place rock to stabilize the existing breach channel,
3. Drive sheeting and buttress on right embankment to the left of the existing breach channel,
4. Drive sheeting and buttress on the right embankment to the right of the existing breach channel,
5. Construct the new 200-year flow discharge channel, and
6. Cut down steel sheet pile in front of the 200-year flow channel and divert baseflow from the existing breach channel to the new 200-year flow channel.

The Sanford Dam temporary breach stabilization is currently planned for 2021 to 2022.

3. Existing Spillway Capacity

3.1 Summary of Existing Discharge Rating Curves

In April 2020, the FLTF requested that GEI review the available hydraulic information and develop new spillway discharge rating curves for each project (Ref. GEI 2020b). The updated spillway discharge rating curves were submitted to Ayres for their use in the current PMF study update and included in the U.S. Army Corps of Engineers (USACE) Hydrologic Engineer Center Hydrologic Modeling System (HEC-HMS) flood routing model. The following is a summary of available data, methodology, and assumptions used to estimate the spillway discharge capacity of the Secord, Smallwood, Edenville and Sanford Projects for flows up to the PMF.

3.1.1 Secord Dam

The GEI computed Secord Tainter gate spillway discharge capacity is provided in **Appendix B.1**. The zero-freeboard discharge capacity at El. 757.8 is estimated to be approximately 7,695 cubic feet per second (cfs). GEI developed a two-dimensional (2D) USACE Hydrologic Engineering Center – River Analysis System (HEC-RAS) computer model to evaluate the percentage of the PMF that discharges into Tea Creek through the Secord Lake ridgeline with many residences along the east side of Secord Lake. The results of the analysis suggest that approximately 860 cfs overflows the left abutment and 3,580 cfs discharges over the Secord Lake ridgeline into Tea Creak, which discharges around the dam and into the Tittabawassee River downstream of the dam for a total zero-freeboard discharge capacity of approximately 12,135 cfs (see **Appendix B.1**).

GEI compared the two Tainter gate discharge rating curve with the rating curve presented in the Mead & Hunt 1994 report titled *Secord Dam Flood Routing* (M&H 1994). As shown in **Appendix B.1**, the overall shape of the GEI rating curve compares well with the rating curve provided in Section 6.0 of the current Supporting Technical Information Document (STID); however, the GEI rating curves indicates a lower discharge capacity at higher heads. A likely reason for this discrepancy is the limited maximum gate opening height opening of 7.5 feet (recorded during the December 2019 gate tests) of gate No. 1 compared to 10.5 feet of gate No. 2. If Gate No. 1 could be opened to 10.5 feet, the Tainter gate discharge capacity would be increased to 8,540 cfs.

3.1.2 Smallwood Dam

The GEI computed Smallwood Tainter gate spillway discharge capacity curve is provided in **Appendix B.2**. The zero-freeboard discharge capacity is estimated to be approximately 10,185 cfs at El. 715.7. In 1999 a steel sheet pile cutoff wall was installed along the upstream face of the left embankment for a length of 320 feet from the spillway. The remaining 680 feet of the embankment would be overtopped during the PMF. The left embankment overtopping discharge capacity is 19,650 cfs at the top of the sheet pile wall at El. 715.7 for a total Smallwood Project zero-discharge capacity of 29,835 cfs (see **Appendix B.2**).

GEI compared the total Smallwood Project rating curve with the spillway rating included in the current STID. As shown in **Appendix B.2**, the rating curves do not compare well. The current STID does not appear to account for the 2016 crest raise of the left embankment to El. 712.5 for 260 feet north of the sheet pile wall.

3.1.3 Edenville Dam

GEI computed Edenville Tainter gate spillway discharge capacity for the Edenville gates and the Tobacco gates. The zero-freeboard discharge capacity of the three Edenville gates is approximately 10,750 cfs and the zero-freeboard discharge capacity of the three Tobacco gates is 9,920 cfs, resulting in a total zero-freeboard discharge capacity of 20,670 cfs at El. 682.1 (see **Appendix B.3**).

GEI compared the Tainter gate discharge rating curve with the spillway rating curve developed by the Michigan Department of Environment, Great Lakes and Energy (EGLE) in 2019. As shown in **Appendix B.3**, the rating curves compare well with some minor variations but with a nearly identical zero-freeboard discharge capacity estimate.

3.1.4 Sanford Dam

GEI computed Sanford Tainter gate spillway and fuse plug spillway discharge capacity. The zero-freeboard (El. 636.8) six Tainter gate discharge capacity is approximately 29,690 cfs and the fuse gate discharge capacity is approximately 6,485 cfs, resulting in a total zero-freeboard discharge capacity of 36,175 cfs (see **Appendix B.4**). GEI compared the total spillway rating curve with the rating curve presented in the current STID. As shown in **Appendix B.4**, the rating curve compares very well.

Table 3 below summarizes the total existing spillway discharge capacity of each of the FLTF Projects.

Table 3: Summary of Spillway Discharge Capacity

Parameter	Secord Project	Smallwood Project	Edenville Project		Sanford Project
			Edenville Dam	Tobacco Dam	
Zero-Freeboard Tainter Gate Spillway Capacity (cfs)	7,695	10,185	10,750	9,920	29,690
Zero-Freeboard Elevation (feet)	757.8	715.7	682.1	683.1	636.8
Abutment Overflow (cfs)	4,440	19,650	-	-	-
Zero-Freeboard Fuse Plug Spillway Capacity (cfs)	-	-	-	-	6,485
Total Spillway Capacity (cfs)	12,135	29,835	20,670		36,175

4. Hydrology

4.1 Overview

GEI has reviewed the May 2020, PMF Report by Ayres Associates, Inc. (Ref. Ayres, 2020) prepared for Secord, Smallwood, Edenville and Sanford dams. This report was prepared before the May 2020 flood and used only data available prior to that event. Following the May 2020 event, modifications were made to the analysis. These modifications are discussed below but are still under technical and regulatory review. As of this writing, no formal report on the post-May-2020 PMF updates exists.

A PMF is produced by extreme rainfall events occurring in conjunction with a conservatively selected set of hydrologic and watershed conditions to produce the largest flood that is reasonably possible and often governs spillway design for high hazard dams.

Key components of a PMF determination include the following:

1. Basin Delineation – modeling boundaries,
2. Design Rainfall – Probable Maximum Precipitation (PMP) – amount of rainfall before losses,
3. Rainfall Loss Rates – amount of rainfall not available for direct runoff,
4. Baseflow – amount of inflow prior to rainfall event, and streamflow continuing after direct runoff has ceased,
5. Unit Hydrograph – temporal pattern of runoff from 1 inch of excess rainfall during a unit duration,
6. Channel Routing – storage and discharge through stream channels, and
7. Reservoir Routing – storage in reservoirs and discharge from dams.

Each of these components used to develop the PMF is described in more detail below. All were utilized as input parameters in the USACE HEC-HMS model, Versions 4.3 and 4.6.1(Ref. USACE 2017 and 2020). The HEC-HMS model generates estimated flood hydrographs based on input parameters representing the above-listed hydrologic components.

4.2 Basin Delineation

The Tittabawassee (including the tributary Tobacco) River watershed above Sanford Dam was delineated using digital USGS 7.5-minute, 1:24,000 scale topographic maps and contours derived from the USGS 1/3-arc-second National Elevation Dataset (NED) and county Light Detection and Ranging (LiDAR) data. The total watershed area tributary to Sanford Dam (downstream most dam) is approximately 945 square miles. The entire watershed was modeled as thirteen (13) sub-basins. See the 2020 Ayres PMF Study report for more information (Ref. Ayres, 2020).

4.3 Design Rainfall – Probable Maximum Precipitation (PMP)

The Probable Maximum Precipitation (PMP) depths for the watershed were estimated using the Electric Power Research Institute (EPRI) Probable Maximum Precipitation Study for Wisconsin and Michigan dated July 1993 (Ref. EPRI 1993). The warm season and Mesoscale Convective Storm (MCS) storms were computed using ArcGIS by distributing the precipitation among the modeled sub-basins according to the EPRI guidance. Ayres used ArcGIS to construct storm isohyets and compute sub-basin precipitation sequences following the general guidelines (storm orientation, axis rotation, and temporal rainfall distribution) presented in the EPRI application guidelines.

The critical storms for Secord and Smallwood were the 24-hour MCS type storms. For Secord, the critical storm was a 300-square-mile MCS, oriented 305 degrees from north and centered on sub-basins 2 and 8 which drain to Secord Lake. For Smallwood, a 450-square-mile MCS storm centered on the four sub-basins draining to its reservoir (1, 2, 4 and 8) and oriented 230 degrees from north was modeled. **Table 4** and **Table 5** lists the 24-hour peak hourly precipitation depths by sub-basin for the critical Secord and Smallwood storms, respectively.

Table 4: Probable Maximum Storm Depths – Secord

Sub-Basin	24-hour Depth (inches)	Maximum 1-hour Depth (inches)
1 – Secord	16.44	5.72
8 – West Branch Tittabawassee	15.75	5.45

Table 5: Probable Maximum Storm Depths – Smallwood

Sub-Basin	24-hour Depth (inches)	Maximum 1-hour Depth (inches)
1 – Secord	15.92	5.13
2 – Sugar Spring	14.52	4.63
4 – Smallwood	14.48	4.61
8 – West Branch Tittabawassee	15.10	4.83

The critical storm for both Edenville and Sanford was an 850-square-mile storm positioned over the watershed upstream of Edenville. **Table 6** summarizes the total 72-hour precipitation and maximum 1-hour precipitation for this event by sub-basin.

Table 6: Probable Maximum Storm Depths – Edenville and Sanford

Sub-Basin	72-hour Depth (inches)	Maximum 1-hour Depth (inches)
1 – Secord	16.66	2.93
2 – Sugar Springs	15.94	2.77
3a – Chappel / Upper Cedar	16.05	2.82
3b – Lower Cedar, North and Middle Tobacco	17.45	3.16
3C – South Br Tobacco	16.10	2.78
4 – Smallwood	19.35	3.66
5a – Molasses	13.48	2.21
6 – Edenville – Tobacco	15.40	2.63
7 – Sanford	7.88	1.15
8 – West Branch Tittabawassee	15.65	2.70

See the 2020 Ayres PMF Study report for more information (Ref. Ayres, 2020).

4.4 Rainfall Loss Rates

Runoff volume is the rainfall volume minus initial losses (surface depression storage, interception by vegetation, and initial soil infiltration capacity of the ground prior to reaching saturation) and ongoing losses due to soil infiltration. The 2020 Ayres PMF study estimated the watershed loss rates using a spatial analysis by SGI consisting of overlaying the USDA SSURGO database for Gladwin, Midland Roscommon, Clare, Bay, Ogemaw, Arenac, and Isabella Counties on the sub-basin boundaries. Hydrologic losses were modeled in quasi-distributed manner by modeling each sub-basin as three parallel sub-basins, one representing high permeability soils, one representing moderately permeable soils and one representing low permeability surficial soils.

Based on the spatial analysis by SGI, the surface soil units in each basin were tabulated according to area covered and the minimum of K_{sat} (saturated hydraulic conductivity) range for the least permeable layer in the top 60-inches of the soil column. This approach gave 10 to 15 sub-basin K_{sat} classes based on the minimum published data in each surface soil unit. They were grouped into the following four general categories:

Zero Losses: Soils with a minimum-of-range K_{sat} of 0.0 inch per hour to 0.016 inches per hour in the top 60 inches of the soil column. These were initially assigned a HEC-HMS constant loss rate of zero and input to the model as an impervious percentage of the other loss-class or frozen soil sub-basins. The assigned impervious percentage did not change as the result of calibration, either before or after the 2020 flood.

Low Permeability: Soils with a minimum-of-range K_{sat} values from 0.06 inch per hour to 0.2 inches per hour. These were initially assigned a constant loss rate of 0.1 inches per hour. In model calibration prior to May 2020, this value was adjusted upward to 0.35 inches per hour. In the model recalibration following the 2020 event, the low-permeability soil loss rates were reduced to values ranging from 0.1 inches per hour to 0.25 inches per hour, depending on the subbasin based on calibrated conditions during the May 2020 flood event.

Moderate Permeability: Soils with a minimum-of-range K_{sat} values ranging from 0.6 inches per hour to 2.0 inch per hour. These soils generally had a minimum-of-range K_{sat} of either 1.5 or 2.0 inches per hour. These selected loss rates exceeded the maximum hourly precipitation rates used in model calibration but do generate runoff during the PMF, consistent with the concept that watersheds have a "variable contributing area" which expands as precipitation becomes more intense.

High Permeability: Soils with minimum-of-range K_{sat} values of 6 inches per hour. These were assigned a loss rate of 6 inches per hour and showed no computed runoff during either the calibration events or the PMF.

No initial losses were modeled in either the calibration runs or the PMF modeling. See the 2020 Ayres PMF Study report for more information (Ref. Ayres, 2020).

4.5 Unit Hydrographs

The 2020 Ayres PMF study used the Clark (Ref. Clark, 1945) unit hydrograph method to simulate the timing of the runoff response from each model subbasin. The Clark time of concentration (T_c) and storage coefficient (R) parameters were derived from a 1994 analysis conducted by Mead & Hunt for Wolverine Power, then-owner of the dams. The Clark parameters were revised based on calibration to events in 2014 and 2017 prior to preparation of the May 2020 report and revised again after the May 2020 flood. See the 2020 Ayres PMF Study report for more information (Ref. Ayres, 2020).

4.6 Baseflow

For the PMF calculation, baseflows were set to reproduce a starting baseflow of approximately 2 cfs per square mile.

4.7 Channel and Reservoir Routing

The 2020 Ayres PMF Study used the Muskingum-Cunge routing method using a trapezoidal channel section with slopes measured from the National Elevation Dataset. Manning's n-values of 0.08 were used to represent combined channel and floodplain flow during extreme flood events. The Secord, Smallwood, Edenville, Sanford, Lake Lancer Dam, Wiggins Lake, and Ross Lake impoundments and dams were included as storage elements in the HEC-HMS model. Spillway rating curves were provided by GEI and developed in the Discharge Rating Curve study developed in April 2020 (Ref. GEI, 2020b). Dams not owned by the FLTF were obtained from a request from the State of Michigan EGLE. Elevation-area curves were developed from the NED and County provided 2020 LiDAR. All reservoirs were assumed to be at their normal maximum operation pool at the beginning of the flood routing. Spillway gates were opened and were assumed to deploy immediately to minimize pool surcharging and providing no intentional flood storage. See the 2020 Ayres PMF Study report for more information (Ref. Ayres, 2020).

4.8 HEC-HMS Model Calibration and Selected Model Parameters

The original 1994 PMF study did not include model calibration to observed storm events. At the time, there were few large events covered in the available stream gages, flood records were unreliable and the only rainfall gages were in the upper reaches of the Tobacco watershed. For the 2020 Ayres PMF study, additional data sources included the new stream gage on the Tobacco River at Beaverton and hourly records of pool levels and gate openings at the Secord, Smallwood, and Edenville Dams. In addition, NEXRAD precipitation data, "ground-truthed" against the hourly gage at Gladwin provided new and more detailed precipitation time series for the April 13-16, 2014 and June 22-25, 2017 calibration storm events. Based on the model calibration, the HEC-HMS model was adopted for estimating the PMF as developed for the May 2020 report. **Table 7** summarizes the sub-basin parameters applied to the PMF analysis as of May 15, 2020. See the 2020 Ayres PMF Study report for more information (Ref. Ayres, 2020).

Table 7: Summary of Final Sub-Basin Model Parameters as of May, 2020 PMF Report

Sub-Basin	Area (sq. miles)	Unit Hydrograph		Loss Class Percentage			
		T_c (hours)	R (hours)	Zero	Low (0.35 in/hr)	Moderate (1.5-2 in/hr)	High (>6 in/hr)
1	129.1	13	19	3.9	49.6	26.5	20.1
2	34.4	15	10	5.8	61.6	27.0	5.2
3a	117.2	22	15	9.0	48.5	30.9	11.6
3b	136.9	29	20	16.9	51.6	27.6	3.9
3C	153.3	36	24	23.1	45.5	29.1	2.3
4	77.4	18	25	8.3	63.6	15.5	12.7
5a	77.9	18	25	2.3	29.8	3.3	64.6
5b	76.4	7	10	8.1	43.1	7.3	41.5
6	50.5	14	8	39.0	17.2	28.1	15.6
7	40.8	13	20	22.1	42.6	15.9	19.4
8	46.3	20	14	3.2	40.0	42.1	14.7
Secord Lake	1.5	1	1	100	0	0	0
Wixom Lake	3.1	1	1	100	0	0	0

Following the May 19th, 2020 floods and failures of Edenville Dam and Sanford Dam, the HEC-HMS model was reviewed, new NEXRAD precipitation data were analyzed in consultation with the National Weather Service, and revisions were made to the HEC-HMS model to better fit the 2020 flood observations as well as the 2014 and 2017 flood data. The revised model is considered provisional at this time pending further refinement of the 2020 precipitation data and additional hydrology review. **Table 8** summarizes the provisional basin parameters after May 16, 2020.

Table 8: Summary of Sub-Basin Model Parameters after Review of May 16-19, 2020 Flood Data (PROVISIONAL)

Sub-Basin	Area (sq. miles)	Unit Hydrograph		Loss Class Percentage			
		T_c (hours)	R (hours)	Zero	Low (0.1 – 0.25 in/hr)	Moderate (1.5-2 in/hr)	High (>6 in/hr)
1	129.1	11	17	3.9	49.6	26.5	20.1
2	34.4	13	9	5.8	61.6	27.0	5.2
3a	117.2	15	13	9.0	48.5	30.9	11.6
3b	136.9	20	16	16.9	51.6	27.6	3.9
3C	153.3	29	23	23.1	45.5	29.1	2.3
4	77.4	13	18	8.3	63.6	15.5	12.7
5a	77.9	14	20	2.3	29.8	3.3	64.6
5b	76.4	6	8	8.1	43.1	7.3	41.5
6	50.5	13	7	39.0	17.2	28.1	15.6
7	40.8	10	16	22.1	42.6	15.9	19.4
8	46.3	15	11	3.2	40.0	42.1	14.7
Secord Lake	1.5	1	1	100	0	0	0
Wixom Lake	3.1	1	1	100	0	0	0

4.9 Study Results

GEI has reviewed the 2020 Ayres Study and the associated HEC-HMS model and generally agree with the methodology and results of the study.

Modeling results for the ½ PMF and PMF are summarized and compared in **Table 9** through **Table 12**. The estimates presented in Tables 9 to 12 represent the results of the most recent provisional model, as revised to account for observations during the May 2020 flood. During the ½ PMF, the reservoir surcharges above the Secord Lake Ridgeline at El. 755.0 and significantly floods the eastern shoreline residential properties, yards, and streets. Note also that the "½ PMF" is not half of the PMF value. Verbal consultation with EGLE personnel clarified that "½ PMF" in the context of State of Michigan EGLE standards refers to the flood calculated to result from one-half of the PMP.

Table 9: Secord Dam Flood Routing Results – Existing Conditions (PROVISIONAL)

Parameter or Modeling Result	½ PMF	PMF
Peak Inflow (cfs)	18,075	43,020
Peak Outflow Spillway (cfs)	7,700	8,125
Peak Outflow Tea Creek Ridgeline	4,885	25,200
Embankment Overtopping	0	7,750
Total Outflow	12,585	41,075
Maximum Reservoir El. (feet)	757.8	759.7
Freeboard (Dam Crest El. 757.8)	0.0	-1.9

As indicated in **Table 9**, the Secord Dam ½ PMF results in a peak inflow of 18,075 cfs, a maximum reservoir elevation of 757.8, and a peak discharge of 12,585 cfs, with zero freeboard. The PMF results in a peak inflow of 43,020 cfs, a maximum reservoir elevation of 759.7, a peak discharge of 41,075 cfs and an existing dam overtopping depth of 1.9 feet. The PMF overtopping duration is estimated to be 26 hours. The PMF inflow, outflow and stage hydrographs as presented in the 2020 Ayres PMF study are shown in **Appendix C.1**.

Table 10: Smallwood Dam Flood Routing Results – Existing Conditions (PROVISIONAL)

Parameter or Modeling Result	½ PMF	PMF
Peak Inflow (cfs)	19,065	58,640
Peak Outflow (cfs)	18,895	58,110
Maximum Reservoir El. (feet)	713.3	718.4
Freeboard (Dam Crest El. 715.7)	2.4	-2.7

As indicated in **Table 10**, the Smallwood Dam ½ PMF results in a peak inflow of 19,065 cfs, a maximum reservoir elevation of 713.3, a peak discharge of 18,895 cfs. The PMF results in a peak inflow of 58,640 cfs, a maximum reservoir elevation of 718.4, a peak discharge of 58,110 cfs and a dam crest overtopping depth of 2.7 feet. The PMF overtopping duration is estimated to be 20 hours. The PMF inflow, outflow and stage hydrographs as presented in the 2020 Ayres PMF study are shown in **Appendix C.2**.

Table 11: Edenville Dam Flood Routing Results – Existing Conditions (PROVISIONAL)

Parameter or Modeling Result	½ PMF	PMF
Peak Inflow (cfs)	41,260	116,525
Peak Outflow (cfs)	37,845	115,885
Maximum Reservoir El. (feet)	684.2	686.8
Freeboard (Dam Crest El. 682.1)	-2.1	-4.7

As indicated in **Table 11**, the Edenville Dam ½ PMF results in a peak inflow of 41,260 cfs, a maximum reservoir elevation of 684.2, a peak discharge of 37,845 cfs and a dam crest overtopping depth of 2.1 feet. The ½ PMF overtopping duration is estimated to be 31 hours. The PMF results in a peak inflow of 116,525 cfs, a maximum reservoir elevation of 686.8, a peak discharge of 115,885 cfs and a dam crest overtopping depth of 4.7 feet. The PMF overtopping duration is estimated to be 56 hours. The PMF inflow, outflow and stage hydrographs as presented by Ayres in their 2020 Study is shown in **Appendix C.3**.

Table 12: Sanford Dam Flood Routing Results – Existing Conditions (PROVISIONAL)

Parameter or Modeling Result	½ PMF	PMF
Peak Inflow (cfs)	37,695	116,065
Peak Outflow (cfs)	35,480	112,295
Maximum Reservoir El. (feet)	637.2	644.3
Freeboard (Dam Crest El. 636.8)	-0.4	-7.5

As indicated in **Table 12**, the Sanford Dam ½ PMF results in a peak inflow of 37,695 cfs, a maximum reservoir elevation of 637.2, a peak discharge of 35,480 cfs, and 0.4 feet of dam crest overtopping. The ½ PMF overtopping duration is estimated to be 14 hours. The PMF results in a peak inflow of 116,065 cfs, a maximum reservoir elevation of 644.3, a peak discharge of 112,295 cfs and an overtopping depth of 7.5 feet. The PMF overtopping duration is estimated to be 48 hours. The PMF inflow, outflow and stage hydrographs are provided in **Appendix C.4**.

4.10 Previous PMF Studies

Previous studies have been performed to assess the flood hydrology and spillway hydraulics for the Secord, Smallwood, Edenville and Sanford dams. The PMF was originally computed by Mead and Hunt, Inc. using the 1993 EPRI Wisconsin-Michigan PMP Study. The 1994 PMF Study (Ref. Mead & Hunt, 1994) was performed as part of an evaluation of the PMF throughout the Tittabawassee River basin. In 2011, Mill Road Engineering concluded that the 1994 model misrepresented the offset in timing between the Tittabawassee River and Tobacco River contributions to Lake Wixom. The two branches of the reservoir were re-analyzed using a HEC-RAS model resulting in lower peak inflow at Edenville Dam. **Table 13** summarizes the results of the available PMF studies for the Secord, Smallwood, Edenville and Sanford Projects.

Table 13: Summary of Previous PMF Studies

Date	Author	Secord	Smallwood	Edenville	Sanford
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 Associates (Model calibrated in 2014, 2017 floods only)	29,400	41,200	80,900	80,600
2020	Ayres Associates (Model recalibrated after May 2020 flood (provisional))	43,020	58,640	116,525	116,065
% PMF Increase since 1994 using provisional Ayers 2020 recalibrated model		*58%*	*43%*	*88%*	*54%*

As show in **Table 13**, the 2020 PMF study, after incorporating the May 2020 flood data, significantly increased the PMF estimates at each of the FLTF projects. The 2020 studies were the first to include calibration to observations of actual flood events and associated precipitation. The May 2020 Ayres report attributes the increase primarily to the use of more conservative hydrologic loss rates derived from the calibration efforts.

Considering the significant increase in the PMF, the FLTF currently has Applied Weather Associates (AWA) under contract to estimate site specific PMP and probability assessment of various rainfall depths for the Tittabawassee and Tobacco River basins. The FLTF recognizes that PMP and PMF studies that use the most common sources of the PMP information (such as the regional HMRs or EPRI 1993), include generalized rainfall values that are not site specific and tend to represent the largest PMP values across a broad region of Michigan. A site-specific study of the PMP and PMF can result in a lower and more appropriate estimate of the ½ PMF and PMF. AWA will provide the updated rainfall depths and distributions to Ayres to develop site specific ½ PMF and PMF inflow hydrographs. The updated PMP and PMF study by AWA and Ayres is expected to be completed in the second quarter of 2021.

4.11 Flood Frequency Estimates

Ayres performed a flood frequency analysis as part of the 2020 PMF study to estimate the peak inflow for a range of frequency storms at the FLTF projects. The peak discharges were calculated using the recalibrated provisional HEC-HMS model and National Oceanic and Atmospheric Administration (NOAA) National Weather Service Atlas 14 Point Precipitation Frequency Estimates. The Atlas 14 rainfall depths were included in the HEC-HMS model and routed to determine the peak inflow for each of the FLTF projects. The flood frequency analysis results for the FLTF projects are shown in **Figure 6** through **Figure 9** and are summarized in **Table 14**.

Table 14: Ayres Flood Frequency Estimates Based on Post-May-2020 Model Calibration

Dam	100-year inflow (cfs)	200-year inflow (cfs)	500-year inflow (cfs)	1,000-year inflow (cfs)
Secord Dam	8,370	10,315	13,360	16,110
Smallwood Dam	9,890	11,935	15,190	18,680
Tittabawassee	*10,945*	*13,735*	*17,605*	*21,595*
Tobacco	*16,395*	*19,070*	*27,920*	*34,785*
Edenville Total[1]	26,740	32,800	45,180	55,535
Sanford Dam	24,630	30,570	43,640	54,925

1. The peak discharge of the Tittabawassee and Tobacco River occur at different time steps; therefore, the Edenville total is not additive.

Ayres also conducted a statistical flood frequency analysis at Edenville Dam using reconstructed project inflows derived from operation records between 1929 and the present. The HEC-SSP software, version 2.2, was used to conduct a Bulletin 17C Log Pearson analysis of the maximum estimated annual inflows for the period of record (Ref. USACE, 2019b). **Table 15** list the flood frequency values derived for Edenville Dam using this methodology.

Table 15: Ayres Statistical Flood Frequency Estimates at Edenville Dam Using Historic Operation Records

Dam	10-year inflow (cfs)	50-year inflow (cfs)	100-year inflow (cfs)	200-year inflow (cfs)	500-year inflow (cfs)
Edenville Dam	12,900	18,700	21,300	24,000	27,800

Comparing Table 14 and 15 at Edenville shows a significant increase in flow from historic flood frequency discharge rates compared with the 2020 Ayres study based on the Post May 2020 calibration and flow and model refinement. Flood frequency estimates were also derived from the State of Michigan Department of Environmental Quality (DEQ) Flood discharge database. The DEQ flood frequency analysis results for the FLTF projects are summarized in **Table 16**.

Table 16: DEQ Flood Frequency Estimates

Dam	10-year inflow (cfs)	50-year inflow (cfs)	100-year inflow (cfs)	200-year inflow (cfs)	500-year inflow (cfs)
Secord Dam	2,800	3,900	4,300	4,800	5,400
Smallwood Dam	4,200	6,000	6,700	7,300	8,200
Tittabawassee	*6,500*	*9,500*	*9,900*	*12,000*	*14,000*
Tobacco	*6,800*	*9,300*	*10,000*	*11,000*	*13,000*
Edenville Total[1]	13,000	18,800	19,900	23,000	27,000
Sanford Dam	13,000	19,000	20,000	23,000	28,000

A comparison between the three flood frequency curves show that the peak discharges computed with Ayres' recalibrated HEC-HMS model are significantly higher than the DEQ peak discharges or similar discharge values calculated by Ayres using Edenville project records. The increase in the 100-year flow using the recalibrated HEC-HMS model was 96% higher at Secord Dam, 64% higher at Smallwood Dam, 34% higher at Edenville and 23% higher at Sanford than the DEQ statistical estimates. The increase in the 200-year flow was 114% higher at Secord Dam, 63% higher at Smallwood Dam, 43% higher at Edenville Dam and 33% higher at Sanford Dam.

As shown on **Figure 6** and **Figure 7**, when using the flood frequency values derived from NOAA Atlas 14 and the recalibrated HEC-HMS model, the Secord Dam ½ PMF is estimated to have an annual exceedance probability (AEP) of 1 in 2,000, and the Smallwood Dam ½ PMF is estimated to have an annual exceedance probability of 1 in 1,200. As shown in **Figure 8** and **Figure 9**, the Edenville and Sanford flood frequency curves are much flatter resulting in a ½ PMF estimated to be the 400-year event at Edenville Dam and the 350-year event at Sanford Dam. Considering the large variation in the flood frequency estimates, the flood frequency curves developed using NOAA Atlas 14 Rainfall data and the recalibrated HEC-HMS model were overly conservative and an unrealistic representation of the flood frequency at the FLTF dams. One issue that may be affecting the estimates of flood frequency for a larger drainage area (e.g., Edenville and Sanford), is that the NOAA Atlas 14 does not provide a reduction factor for rainfall over larger areas. One product of the AWA study will be issuing an AEP of the rainfall up to and including the PMP, with a site-specific watershed areal adjustment factor applied. This will provide the recurrence interval of rainfall depths for critical durations with adjustments for larger drainage areas. Like the site specific PMP and PMF studies, the AEP study is expected to be completed in the second quarter of 2021.

4.12 Dams Removed Scenarios

Recently Ayres (2020) performed separate HEC-HMS modeling simulations to estimate the inflow hydrographs for the various design storms assuming the dams have been removed and the flood storage associated with the impoundments is eliminated. The dam removed peak flows are summarized in **Table 17** and were used in the hydraulic model to gain a better understanding of the affects the dams have on the Tittabawassee and Tobacco River floodplains. The peak flow rates at the dams increased starting at Smallwood Dam through Sanford Dam due to the loss of impoundment storage and attenuation benefits of the upstream dams and impoundments. See Section 6 below for more information.

Table 17: Dam Removed Scenarios

Dam	100-year Inflow[1] (cfs)	½ PMF Inflow (cfs)	PMF Inflow (cfs)
Secord Dam	4,300	18,075	43,020
Smallwood Dam	6,700	24,400	60,215
Tittabawassee	*9,900*	*22,050*	*51,955*
Tobacco	*10,000*	*24,555*	*67,740*
Edenville Total[2]	19,900	43,940	120,770
Sanford Dam	20,000	43,795	121,285

1. 100-year flow rates from the State of Michigan DEQ Flood discharge database
2. The peak discharge of the Tittabawassee and Tobacco River occur at different time steps; therefore, the Edenville total is not additive.

4.13 Design Storm Selection

In June 2020, Gladwin and Midland Counties signed a resolution to have the four projects (Secord, Smallwood, Edenville and Sanford) condemned in accordance with Part 307 of the Michigan Natural Resources and Environmental Protection Act (NREPA). The FLTF approached the bankruptcy court and recently worked through an agreement to have the ownership of all project transferred to the FLTF, while Boyce will temporarily maintain the FERC licenses. GEI understands that the FERC licenses at each of the FLTF projects will likely be abandoned and the dams will be ultimately regulated by the State of Michigan EGLE. In accordance with Part 315 of Public Act 451 of 1994 Dam Safety of the Michigan State Statues, we understand that the FLTF projects will be classified as high hazard dams and shall be capable of passing the ½ PMF.

Following the Edenville and Sanford Dam failures, the Michigan Dam Safety Task Force evaluated the statutory structure, budget, and program design of the Water Resources Division Dam Safety Program, the adequacy of Michigan's dam safety standards, and the level of investment needed in Michigan's dam infrastructure. Their work culminated in a report to Governor Whitmer and the state legislature dated February 25, 2021, summarizing its findings and recommending regulatory, financial, and programmatic improvements to help ensure Michigan's dams are appropriately maintained, operated, and overseen to protect Michigan residents and aquatic resources.

We understand that the current spillway capacity requirement (1/2 PMF) will likely change as a result of the Dam Safety Task Force recommendation to follow the current Federal Emergency Management Agency (FEMA) Model Dam Safety Program (MDSP) for recommendations for design floods including FEMA P-94 – *Selecting and Accommodating Inflow Design Floods for Dams* (Ref. FEMA, P-94). According to the FEMA P-24 document, the goal of selecting the Inflow Design Flood (IDF) should be to balance the risks of a hydrologic failure of a dam with the potential downstream consequences and the benefits derived from the dam. Selection of the IDF can involve tradeoffs in trying to satisfy multiple objectives including the following:

1. Providing acceptable safety to the public,
2. Effectively applying the resources of the dam owner,
3. Maintaining the credibility of the regulator in representing the interest of the public, and
4. Assessing the desire of the public for the benefits of a dam impoundment in exchange for the inherent risks that come from living downstream of a dam.

FEMA acknowledges that no single approach to the selection of an Inflow Design Flood (IDF) is adequate for all existing or planned dams. FEMA identifies the following approaches to defining the IDF to accommodate the wide variety of situations, resources, and conditions.

- Prescriptive approach – Evaluate the dam based on hazard potential classification of the dam. This approach is intended to be conservative to allow for efficient resource allocation while providing reasonable assurance of the public safety.

  This approach is like the current state of Michigan EGLE requirement of the ½ PMF.

- Site Specific PMP – This approach requires a site specific PMP study.

  As discussed above, the FLTF currently has AWA under contract to calculate a site specific PMP and probability assessment of various rainfall depths for the Tittabawassee River basin. AWA will provide the updated rainfall depths and distributions to Ayres to develop site specific ½ PMF and PMF inflow hydrographs.

- Incremental Consequence Analysis – IDF established by identifying the flood for which the downstream consequences with and without failure are not significantly different. This process is already accepted by the State of Michigan EGLE as the ½ PMF criteria may be reduced to not less than the 200-year flood, with proper documentation evidencing a failure of a dam under ½ PMF conditions will not cause additional flood damage or loss of life.

  An incremental consequence analysis may be the preferred way to select the IDF. However, we recommend not completing an incremental consequence analysis until the site specific PMP and PMF analysis is completed later this year by AWA and Ayres.

- Risk Informed Decision Making (RIDM) – In this method, the IDF is selected as the design flood which assures that a given level of "tolerable risk" is not exceed. The benefit of RIDM is providing dam owner and regulators the ability to cooperatively assess the marginal value of increasing levels of flood protection, balancing capital investment in risk reduction across multiple potential failure modes (PFM), and prioritizing risk reduction across a portfolio of dams. RIDM requires a site-specific evaluation of probability of hydrologic events and performance of the dam during those events and evaluates in detail the social, economic, and environmental consequences of failure.

As discussed above, AWA will derive the AEP of the rainfall up to and including the PMP. This will provide the recurrence interval of rainfall depths for critical durations and can be used for the RIDM process for dam design and selection of the IDF.

Considering the schedule of the site specific PMP and PMF study by AWA and Ayres, an interim IDF was selected for the purposes of this flood study and developing 30% design plans and budgetary costs for the FLTF projects. The current state of Michigan EGLE spillway requirement for high hazard dams is the ½ PMF. However, the project team (GEI, SGI, Essex and the FLTF) collaboratively selected a more conservative design criteria considering the uncertainty of the state of Michigan EGLE spillway capacity requirements and the upcoming site specific PMP and PMF study.

As discussed in Section 4.11 above, the Secord ½ PMF is estimated to be the 2,000-year storm and the Smallwood Dam ½ PMF is estimated to be the 1,200-year storm event. The design team acknowledges the limitations of these flood frequency curves and elected to increase the design flood at both Secord and Smallwood to the 5,000-year flood event (calculated by Ayres) or 1/5000 (0.0002 Annual Exceedance Probability). This resulted in a peak inflow increase of approximately 17% at Secord and 29% at Smallwood Dam. The flood frequency curves at Edenville and Sanford were overly conservative and an unrealistic representation of the flood frequency at the FLTF projects. Therefore, for the purposes of this analysis, a 15% increase in the HEC-HMS discharge ratio was applied for the Edenville and Sanford projects. This 15% discharge ratio increase resulted in a ½ PMF peak inflow increase of 26% at Edenville Dam and Sanford Dam. For the purposes of this study, the selected IDF is the ½ PMF plus a 15% to 30% increase in peak inflow (1/2 PMF +), depending on the dam site. Once the site specific PMP, PMF, and AEP studies are complete; the IDF will be re-evaluated using the techniques prescribed in FEMA P-94. The selected ½ PMF + peak inflows are summarized in **Table 18**.

Table 18: Summary of Inflow Design Flood (1/2 PMF + Design Storm)

Dam	½ PMF	PMF	½ PMF +[1]	Notes	Annual Exceedance Probability (AEP)
Secord Dam	18,075	43,020	**21,150**	½ PMF + 17% Peak Inflow	1/5000 or 0.0002
Smallwood Dam	19,065	58,640	**24,550**	½ PMF + 28% Peak Inflow	1/5000 or 0.0002
Edenville Total	41,260	116,525	**52,275**	½ PMF + 26% Peak Inflow	TBD
Sanford Dam	37,695	116,065	**47,300**	½ PMF + 26% Peak Inflow	TBD

1. The current IDF for the FLTF Projects is the ½ PMF +

5. Hydraulic Analysis

5.1 Hydraulic Design

GEI performed hydraulic analysis to evaluate the proposed spillway upgrades at each of the FLTF projects during the ½ PMF + design storm. Based on the existing conditions of the FLTF projects, GEI has developed new conceptual spillway and dam configurations which would allow the FLTF dams to safely pass the ½ PMF + design storm with residual freeboard below the dam crest. The proposed configurations consist of reconstruction or rehabilitation of earthfill embankments, demolition, and replacement of the primary Tainter gate spillways with crest control gates on new concrete weirs within the spillway and powerhouse walls, construction of low-level outlets, and new passive overflow auxiliary spillways. The following sections summarize the general proposed dam configurations of the FLTF projects.

5.2 Hydraulic Design Criteria

GEI performed hydraulic analysis and modeling to appropriately size the proposed primary and auxiliary spillways for each of the FLTF projects. The proposed spillways were designed to achieve the following design goals:

- The reconstruction / rehabilitation of the FLTF projects will provide 75+ year design service life.
- The reconstruction / rehabilitation of the FLTF projects will be designed to meet the current industry standards of engineering practice and design standards for high hazard dams in accordance with State of Michigan EGLE.
- The proposed primary spillways when combined with the auxiliary spillways should have sufficient capacity to pass the ½ PMF + design storm without overtopping the earthfill embankments and provide sufficient freeboard below the dam crest.
- The target routed ½ PMF + and freeboard for the FLTF projects include the following:

Table 19: Summary of 1/2 PMF + Design Storm Target Stage and Freeboard

Dam	½ PMF + Stage (feet)	Min. Dam Crest El. (feet)	Freeboard (feet)	Notes
Secord Dam	755.0	758.0	**3.0**	Secord Lake Ridgeline at El. 755.0
Smallwood Dam	713.0	715.0	**2.0**	Raise Dam Crest 2.5 feet to El. 715.0
Edenville Total	681.5	685.5	**4.0**	Raise Dam Crest 3.5 feet to El. 685.5
Sanford Dam	635.5	638.0	**2.5**	Raise Dam Crest 1.2 feet to El. 638.0

- The structural integrity of the earthfill dam and foundation should not be jeopardized by auxiliary spillway operations.
- Operation of the gates will be the primary means for regulated releases to the Tittabawassee River under both normal and flood conditions.

- Auxiliary spillways will have passive steel (pipe) pin-flashboard or un-gated fixed weir overflow crest to assist in safely passing the ½ PMF + Design Storm without human intervention.
- The proposed auxiliary spillways and stilling basin should fit within the footprint of the existing embankments to minimize the impact to downstream wetlands, streams, and floodplains.
- The impoundments will be drawn down in winter in accordance with the current lake levels (see **Table 1** in Section 1.4) to prevent static ice loading on the auxiliary flash pin and board or ungated fixed weir spillways.

5.2.1 Secord Dam – Spillway Upgrades

The existing Tainter gate spillway will be partially demolished and the two (2) Tainter gates will be replaced with hydraulic crest gates at El. 734.8 to increase the spillway capacity. The left crest gate (Bay No. 1) will be 18-feet-wide by 16-feet-high and the right crest gate (Bay No. 2) will be 21-feet-wide by 16-feet-high. The automated hydraulically operated crest gates will be designed to open and close with minimal human intervention during normal operation or during flood events. In the event of loss of power or control the gates can be depressurized and they will automatically lower to full discharge condition. The powerhouse will be decommissioned, and the scroll case/ Francis wheel/ draft tube bay converted to a low-level outlet, with trash racks and a steel head gate and the remaining water passages partially filled with mass concrete. The low-level outlet with head gates will be designed to pass 100 to 300 cfs to pass baseflows during the winter months to prevent icing on the gates or flow over the gates for prolonged periods during the winter.

As documented in the Preliminary Design Basis Report by GEI in April 2020 (Ref. GEI, 2020b), a significant portion of the inflow into Secord Lake discharges over the east side populated Secord Lake Ridgeline and left abutment rim at El. 755.0 before reaching the dam. The goal of this proposed configuration is to pass the ½ PMF + design storm without surcharging the reservoir above the Secord Lake Ridgeline and reduce flood impacts to the eastern shoreline residential properties, yards, and streets.

A new 130-foot-wide steel pipe pin flashboard overflow spillway within a concrete chute will be constructed at El. 748.5 with timber flashboards that extend up to El. 752.0 to maintain the normal summer pool at El. 750.8. The pin-flashboards will be designed to fail with greater than one and a half foot of head over at El. 753.5 to provide additional spillway capacity during the ½ PMF + design storm. The overflow spillway will discharge into a concrete chute and 130-foot wide United States Bureau of Reclamation (USBR) Type III stilling basin to dissipate and transfer flow into the downstream discharge channel. Downstream of the stilling basin, the ½ PMF + Design Storm is routed approximately 600 feet downstream to the confluence with the Tittabawassee River in a rock lined spillway discharge channel. A concrete lined drop structure will be constructed within the discharge channel at the downstream confluence with the Tittabawassee River where subcritical flow in the discharge channel would rapidly transition to supercritical flow in the drop structure where a hydraulic jump would likely form in the channel. A rock-lined discharge channel will be cheaper than concrete for initial construction costs but will require a scheduled monitoring and maintenance of the downstream channel, and adjacent areas, following a flood event that requires use of the channel.

The earthfill embankment dam crest will be widened and raised at the left abutment and both upstream and downstream slopes will be flattened to provide adequate stability in accordance with EGLE requirements under normal, flood and drawdown pool loading criteria. A new permanent hot-rolled steel sheet pile with interlock sealants cutoff wall will be constructed upstream of the earthfill dam crest and extend through sand fill dam into the glacial clay till to provide a seepage cutoff on both sides of the spillway. General site plans and cross section for the Secord Dam rehabilitation project are provided in **Appendix D.1**.

5.2.2 Smallwood Dam – Spillway Upgrades

The existing Tainter gate spillway will be partially demolished and the two (2) Tainter gates will be replaced with hydraulic crest gates at sill El. 688.8 to increase the spillway capacity. The left crest gate (Bay No. 2) and the right gate (Bay No. 1) will be 22.6-feet-wide by 16-feet-high. The automated crest gates would be designed to open and close with minimal human intervention during normal operation or during flood events. The hydraulic gate operators will be supported on a new, reinforced concrete center pier. The upstream portions of the barrel arches below El. 688.8 will remain and the crest gates and their anchorage embedment will be founded on new mass concrete. A reinforced concrete stepped chute will convey water that discharges over the crest gates down to a new reinforced concrete stilling basin. Both the left and right spillway walls will be extended downstream and raised to provide adequate flow clearance and accommodate flattening of the flanking embankments.

The powerhouse will be decommissioned, and the scroll case/ Francis wheel/ draft tube bay converted to a low-level outlet, with trash racks and a steel head gate and the remaining water passages partially filled with mass concrete. The low-level outlet with head gates will be designed to pass 100 to 300 cfs to pass baseflows during the winter months to prevent icing on the gates or flow over the gates for prolonged periods during the winter.

A new 150-foot-wide ungated steel pipe pin flashboard overflow spillway within and concrete chute will be constructed immediately adjacent to the steel sheet pile section of the left embankment at El. 706.0 with timber flashboards that extend up to El. 710.0. The pin-flashboards will be designed to fail with greater than one and a half foot of head over the top of the flashboards at El. 711.5 to provide additional spillway capacity during the ½ PMF + design storm. The overflow spillway will discharge into a 150-foot wide USBR Type III stilling basin to dissipate energy and to reduce scour and erosion in the discharge channel. Downstream of the stilling basin, the ½ PMF + design storm will be routed approximately 350 feet downstream to the confluence with the Tittabawassee River in a rock-lined spillway discharge channel. The discharge channel includes a trapezoidal cross section with a berm to protect from overtopping.

The earth fill embankment crest will be widened and raised, upstream and downstream slopes will be flattened to provide adequate stability in accordance with EGLE stability requirements under normal flood pool loading criteria. A new permanent hot-rolled steel sheet pile cutoff with interlock sealants will be constructed upstream of the dam crest (to the left of the proposed auxiliary spillway) and extend through sand fill dam into the clay till to provide a seepage cutoff. General site plans and cross section for the Smallwood Dam rehabilitation are provided in **Appendix D.2**.

5.2.3 Edenville Dam – Spillway Upgrades

The Edenville Tainter gate spillway and left-side powerhouse units will be demolished and the three (3) Tainter gate spillway bays will be replaced with hydraulic crest gates at El. 659.8 to increase the spillway capacity. Each gate will be 24-feet-wide by 16-feet-high. The automated hydraulically operated crest gates would be designed to open and close with minimal human intervention during normal operation or during flood events. In the event of loss of power or control the gates can be depressurized and they will automatically lower to full discharge condition.

The powerhouse will be decommissioned, and the right powerhouse unit will be decommissioned, and the scroll case/ Francis wheel/ draft tube bay converted to a low-level outlet, with trash racks and a steel head gate and the remaining water passages partially filled with mass concrete. The low-level outlet with a head gate will be designed to pass 100 to 300 cfs to pass baseflows during the winter months to prevent icing on the gates or flow over the gates for prolonged periods during the winter.

The Tobacco Dam Tainter gate spillway will be partially demolished and the three (3) Tainter gates will be replaced with automated hydraulic crest gates at El. 659.8 to increase spillway capacity. The left and right crest gates (Bay No. 3 and Bay No. 1) will be 18.3-feet-wide by 16-feet-high and the center crest gate (Bay No. 2) will be 15.5-feet-wide by 16-feet-high. A new low-level outlet structure such a siphon or low-level gate will be constructed under one the crest gates to pass base river flow.

A new 250-foot-wide, 12-cycle labyrinth auxiliary concrete chute spillway will be constructed at El. 678.0 within the former left embankment of the Edenville Dam to provide additional spillway capacity during the ½ PMF + design storm. The proposed spillway structure will discharge through a 250-foot-wide concrete spillway chute. The new chute slope would be constructed at 2.5H:1V. To meet current freeboard requirements, the new chute walls would vary from about 30-feet-high downstream of the labyrinth spillway to about 20-feet-high in the steep portion of the chute. The new chute slab would be a minimum of 2-foot-thick and will include an appropriate drainage system. A concrete cutoff wall would also be constructed at the downstream end of the auxiliary spillway chute for scour protection. The overflow spillway will discharge into a 250-foot wide USBR Type III stilling basin to dissipate energy and to reduce scour and erosion in the discharge channel. Further downstream of the stilling basin, the ½ PMF + design storm is routed approximately 1,200 feet downstream to the confluence with the Tittabawassee River through the Edenville Dam breach channel. The reinforced concrete labyrinth weir walls will be designed for 5 kips/ft ice loading with an assumed 3-foot winter drawdown.

The original earthfill embankment upstream and downstream slopes will be flattened and widened to provide adequate stability in accordance with EGLE stability requirements under normal flood pool loading criteria. The new left embankment dam will be a zone earthfill dam with upstream riprap, steel sheet pile core wall into glacial till and downstream filter/drain system and slope meeting EGLE standards. A new permanent steel sheet pile cutoff will be constructed upstream of the dam crest and extend through dams into the clay till to provide a seepage cutoff. General site plans and cross section for the Edenville Dam rehabilitation are provided in **Appendix D.3**.

5.2.4 Sanford Dam – Spillway Upgrades

The Tainter gate spillway and powerhouse will be partially demolished and the six (6) Tainter gates will be replaced with eight (8) hydraulic crest gates at sill El. 614.8 to increase the spillway capacity. The crest gates would range from 16.5-feet-wide to 23-feet-wide by 16-feet-high. The hydraulic gate operators will be supported on a new, reinforced concrete piers. The upstream portions of the barrel arches below El. 614.8 will remain and the crest gates and their anchorage embedment will be founded on new mass concrete. The gates will discharge on to a short section of concrete rollway and into a new reinforced concrete stilling basin. The rightmost two powerhouse bays will be converted into an additional crest gate bay and the leftmost draft tube bay converted to a low-level outlet. Remaining sections of hollow bays and water passages filled with mass concrete.

A new 250-foot-wide 12-cycle labyrinth auxiliary spillway will be constructed at El. 632.5 within the former right embankment of the Sanford Dam to provide additional spillway capacity during the ½ PMF + design storm. The proposed spillway structure will discharge through a 250-foot-wide concrete spillway chute. The new chute slope would be constructed at 2.5H:1V. To meet current freeboard requirements, the new chute walls would vary from about 18-feet-high downstream of the labyrinth spillway to about 15-feet-high in the steep portion of the chute. The new chute slab would be a minimum of 2-foot-thick and would include an appropriate drainage system. A concrete cutoff wall would also be constructed at the downstream end of the auxiliary spillway chute for scour protection. The overflow spillway will discharge into a 250-foot wide USBR Type III stilling basin to dissipate energy and to reduce scour and erosion in the discharge channel. Further downstream of the stilling basin, the ½ PMF + design storm is routed approximately 350 feet downstream to the confluence with the Tittabawassee River through the former Sanford Dam breach channel. The reinforced concrete labyrinth weir walls will be designed for 5 kips/ft ice loading with an assumed 3-foot winter drawdown.

The existing embankment crest will be widened and slopes will be flattened to provide adequate stability in accordance with EGLE stability requirements under normal and flood pool loading criteria.

The new right and left embankment dam will be a zoned earthfill dam with upstream riprap, steel sheet pile core wall into glacial till and downstream filter/drain system and slope meeting EGLE standards. A new permanent steel sheet pile cutoff will be constructed to the left and right of the proposed auxiliary spillway on the upstream side of the dam crest and extend through the dam into the clay till to provide a seepage cutoff. General site plans and cross section for the Sanford Dam rehabilitation are provided in **Appendix D.4**. Key project data for the Secord, Smallwood, Edenville and Sanford Projects rehabilitation / reconstruction projects are provided in **Table 20**.

Table 20: Key Proposed Project Data (1/2 PMF + Design Storm Configuration)

Parameter	Secord Project	Smallwood Project	Edenville Project		Sanford Project
			Edenville Dam	Tobacco Dam	
Spillway Invert El. (feet)	734.8	688.8	659.8	659.8	614.8
No. of New Crest Gates	2	2	3	3	8
Gate 1 Width (feet)	18.0	22.6	24.0	18.3	16.5
Gate 2 Width (feet)	21.0	22.6	24.0	15.5	16.5
Gate 3 Width (feet)	-	-	24.0	18.3	21.5
Gate 4 Width (feet)	-	-	-	-	18.0
Gate 5 Width (feet)	-	-	-	-	18.0
Gate 6 Width (feet)	-	-	-	-	18.0
Gate 7 Width (feet)	-	-	-	-	18.0
Gate 8 Width (feet)	-	-	-	-	23.0
Min. Dam Crest El. (feet)	758.0	715.0	685.5		638.0
Normal Pool El. (feet)	750.8	704.8	675.8		630.8
Aux. Spillway Type	Flashboard	Flashboard	Labyrinth	-	Labyrinth
Aux. Spillway El. (feet)	748.5	706.0	678.0	-	632.5
Pin Flashboard El. (feet)	752.0	710.0	-	-	-
Aux. Spillway Length (feet)	130.0	150.0	250.0	-	250.0

5.3 Empirical Equations Analysis

Prior to developing the hydraulic computer models, GEI evaluated proposed crest gates and auxiliary spillways using traditional empirically based equations. This provides an initial evaluation of the hydraulic performance of the proposed spillways structures for each of the FLTF projects up to the ½ PMF + design storm. Conceptual-level proposed spillway rating curves were developed using the methods prescribed in the United States Bureau of Reclamation Design of Small Dams (Ref. USBR, 1987) and Hydraulic Design of Labyrinth Weirs – Henry T, Falvey (Ref., Falvey 2003). The following sections summarize the computations used to develop preliminary proposed spillway discharge rating curves. The supporting rating curve calculations are provided in **Appendix E**.

5.3.1 Crest Gate Spillways

In accordance with the *Design of Small Dams* (Ref. USBR, 1987), the crest gate spillway calculations were computed using the weir equation: $\mathbf{Q = CLH_e^{3/2}}$, where:

Q = discharge, cfs
C = discharge coefficient
L = effective crest length, feet
H_e = energy head on crest, feet

We adopted a standard Steel-Fab, Inc. (Steel-Fab) crest gate profile closely approximates that of the lower nappe of sharp crested weir discharging at the design head of the crest gate. This ideal shape has been modified to provide positive pressure at all heads up to the design head. According to Steel-Fab (crest gate manufacturer in Fitchburg, MA), the discharge coefficient of the standard Steel-Fab crest gate at design head is estimated to be a minimum of 3.5 when the crest gates is fully down, and the water level is at the design head equal to height of the gate. At water levels less than the design head, the discharge coefficient decreases. At water levels greater than the design head, the discharge coefficient increases.

The effective length **L** of a spillway crest used in spillway discharge computations is expressed by the equation: $\mathbf{L = L' - 2(NK_p + K_a)\,H_e}$, where:

L = effective length, ft
L' = net length of crest, ft
N= number of piers
K_p = pier contraction coefficient
K_a = abutment contraction coefficient
H_e = energy head on crest, ft

5.3.2 Auxiliary Overflow Spillways

In accordance with the *Design of Small Dams* (Ref. USBR, 1987), the pin flashboard spillway calculations were computed using the weir equation: $\mathbf{Q = CLH_e^{3/2}}$, where:

Q = discharge, cfs
C = discharge coefficient
L = effective crest length, ft
H_e = energy head on crest, ft

The discharge coefficient was computed using the nomographs provided in Chapter A5 of the USGS *Measurement of Peak Discharge at Dams by Indirect Method (*USGS 1968) assuming an upstream slope of 2.5H:1V and downstream slope equal to 2.5H:1V.

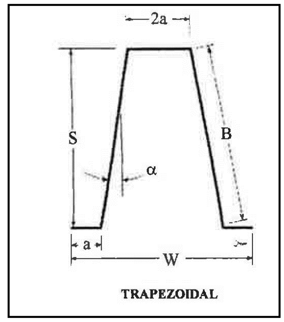
The effective length **L** of a spillway crest used in spillway discharge computations is expressed by the equation: $\mathbf{L = L' - 2(NK_p + K_a)\,H_e}$, where:

L = effective length, ft
L' = net length of crest, ft
N= number of piers
K_p = pier contraction coefficient
K_a = abutment contraction coefficient
H_e = energy head on crest, ft

5.3.3 Labyrinth Spillways

Conceptual-level proposed labyrinth spillway rating curves were developed using the methods prescribed in *The Hydraulic Design of Labyrinth Weirs* (Ref. Falvey, 2003). The discharge characteristics of labyrinth weirs are primarily a function of the following:

- P – Weir Height
- S – Cycle Depth
- B – Cycle Length
- h – depth of flow over the weir
- W – Width of the weir
- L – Developed Length of the Labyrinth
- α – Wall Angle
- Crest Length, L = 2B+4a *f*
- Magnification, M = L/W



The discharge can be expressed as Q = *f* (h/P, L/W, α Shape).

5.4 Proposed Conditions HEC-RAS Model

Once the initial evaluation of the hydraulic performance of the proposed spillways structures for each of the FLTF projects were completed, GEI developed a more detailed hydraulic model using the USACE HEC-RAS, Version 5.0.7. computer model to further evaluate the proposed spillway capacity of the FLTF crest gates and auxiliary spillways. The HEC-RAS model was separated into multiple models to reduce modeling computation time and increase modeling stability. The HEC-RAS model and flood inundation mapping extended from Secord Lake to approximately 2-miles downstream of Sanford Dam. The location of the river reaches is illustrated in **Figure 10** and summarized in **Table 21**.

Table 21: Summary of HEC-RAS Models

Model Reach	FLTF Dam	Reach Description	River	Reach Length (River Mile)
1	Secord	Secord Dam to Confluence with Tea Creek	Tittabawassee	6.1
2	Smallwood	Confluence with Tea Creek to Highwood Road	Tittabawassee	9.2
3	Tobacco / Edenville	Dale Road / Highwood Road to Curtis Road	Tobacco / Tittabawassee	12.1
4	Sanford	Curtis Road to M-30 (Meridian Road)	Tittabawassee	13.6

The HEC-RAS computer model can perform one-dimensional (1D) and two-dimensional (2D) unsteady flow modeling. The 2D unsteady flow modeling capabilities are useful for estimating the considerable amount of lateral flow that occurs in the Tea Creek floodplain, developed areas adjacent to Secord Lake and the relatively flat downstream topographic features. The following sections summarize the development of the HEC-RAS 2D hydraulic model, results, and conclusions. HEC-RAS input and output data sheets are included in **Appendix F**.

5.4.1 HEC-RAS Reaches

The flood study begins upstream of Secord Dam and continues through four (4) distinct river reaches to the M-30 Highway Bridge downstream of Sanford Dam on the Tittabawassee River. Each of these reaches are described in more detail below.

5.4.1.1 Model Reach 1 – Secord Dam to Confluence with Tea Creek (Secord Dam)

This reach consists of the Secord Lake impoundment and the first 2.6 miles downstream of Secord Dam, which includes the area immediately downstream of the dam to the confluence with Tea Creek, including Secord Dam Road bridge crossings immediately downstream of the dam. The river reach immediately downstream of the dam is meandering with relatively flat (0.0006 feet per foot) channel slopes resulting in tranquil flow regimes under normal conditions. In general, the overbanks are surrounded by heavy forests and dense underbrush. Residential development along the riverbanks starts near the town of Secord, MI approximately 2.5 miles downstream of Secord Dam and extend into the Smallwood Lake impoundment approximately 7.5 miles downstream.

The left (eastern) shoreline of Secord Lake is approximately 3 feet lower than the Secord Dam crest elevation. The former hydro operators relied on “flowage rights” of the eastern shoreline to discharge a significant portion of the inflow into Secord Lake as discharge capacity over the populated ridgeline before reaching the dam. This overflow presents a significant risk to the eastern shoreline residential properties including streets, utilities, homes, and occupied residential property. The overflow continues east to the Tea Creek tributary and eventually to the confluence of the Tittabawassee river approximately 2.5 miles downstream.

One major roadway crossing with possible constrictions over the Tittabawassee River include:

- Secord Dam Road crosses over the Tittabawassee River immediately downstream of Secord Dam. Secord Dam road carries the 2-lane paved road and spans 266 feet with a maximum opening height of about 40 feet.

5.4.1.2 Reach 2 – Confluence with Tea Creek to Highwood Road (Smallwood Dam)

This reach consists of approximately 5.2 miles between the confluence with Tea Creek and approximately 4.0 miles downstream of Smallwood Dam. The Tittabawassee River is hydraulically controlled by the Smallwood Dam Tainter gates for a distance approximately 3.0 miles upstream of the dam. Downstream of Smallwood dam, the first 2.3 miles are similar in nature to the Secord Dam reach as described above. The river is contained between steep overbank areas with heavy forests and the channel is generally flat (0.0001 feet per foot) resulting in tranquil flows under normal conditions. As river flow exit the narrower river section, the floodplain widens, and the channel slope flattens near Highwood Road approximately 3.8 miles downstream of Smallwood Dam.

Two major roadways crossings with possible constrictions over the Tittabawassee River include:

- M-61 crosses over the Tittabawassee River approximately 1.9 miles upstream of Smallwood Dam near Gladwin, MI. M-61 carries the 2-lane paved road and spans 250 feet with an opening height of about 32 feet.
- Highwood Road crosses over the Tittabawassee River approximately 3.8 miles downstream of Smallwood Dam. Highwood Road carries the 2-lane paved road and spans 144 feet with an opening height of about 15 feet.

5.4.1.3 Reach 3 – Highwood Road to Curtis Road (Edenville Dam – Tittabawassee River)

This reach consists of approximately 12.1 miles between Highwood Road and Curtis Road on the Tittabawassee River. Heavy residential development begins approximately 4.8 miles downstream of Highwood road near the Estey Road bridge and the upstream limit of Wixom Lake. Downstream of Estey Road, the riverbanks are heavily developed with dwellings and docks along the former riverbanks and shoreline of Wixom Lake and was formerly hydraulically controlled by the Tainter gate operations of Edenville Dam. Following the May 2020 storm event, the water level has dropped nearly 30 feet exposing the original Tittabawassee River floodplain. The Tittabawassee River is currently bypassing the Edenville Dam Tainter gate spillway and flowing through the left embankment breach channel. As discussed above, the Phase 2 construction of the Edenville Dam stabilization is being designed under the FLTF in close coordination with EGLE. Following implementation of the Phase 2 stabilization, we understand the FLTF desires to fully rehabilitate the Edenville Dam and restore Wixom Lake to its pre-breach level.

Three major roadways with possible constrictions cross over the Tittabawassee River including:

- Estey Road crosses over the Tittabawassee River approximately 7.8 miles downstream of Smallwood Dam near Billings, MI. Estey Road carries the 2-lane paved road and spans 204 feet with a maximum opening height of about 31 feet.
- State Highway M-30 (downstream of Edenville Dam) crosses over the Tittabawassee River approximately 1.0 miles downstream of Edenville Dam near Edenville, MI. M-30 carries the 2-lane paved road and spans 360 feet with a maximum opening height of about 29 feet.
- Curtis Road crosses over the Tittabawassee River approximately 1.5 miles downstream of Edenville Dam. Curtis Road carries the 2-lane paved road and spans 315 feet with an opening height of about 26 feet.

5.4.1.4 Reach 3a – Tobacco River (Edenville Dam – Tobacco River)

The Tobacco River reach consists of approximately 5.7 miles between Dale Road and the Tobacco River side of Edenville Dam to the confluence of the Tittabawassee River immediately upstream of Curtis Road. The Tobacco reach is similar in nature to the Tittabawassee River Reach 3 as described above. The riverbanks are heavily developed with dwellings and docks along the former shoreline of Wixom Lake and hydraulically controlled by the Tainter gate operations of the Tobacco spillway. Following the catastrophic failure of the Edenville Dam left embankment and M-30 causeway, the river has dropped approximately 15 feet below the normal operating pool and the Tobacco River is currently diverted to the Tittabawassee River through the M-30 breach channel. As discussed above, the Phase 1 construction of the Edenville Dam stabilization is underway on the Tobacco Spillway and includes lowering the existing Tobacco Dam Tainter gate spillway and restoring the natural flow path of the Tobacco River. Downstream of the Tobacco spillway, the Tobacco River flows approximately 1.4 miles to confluence with the Tittabawassee River in between the M-30 and Curtis Road Bridges. The overbank downstream of the Tobacco spillway is heavily forested with limited residential development.

Two major roadways with possible constrictions cross over the Tittabawassee River include:

- Dale Road crosses over the Tittabawassee River approximately 4.3 miles upstream of Edenville Dam near Beaverton, MI. Dale Road carries the 2-lane paved road and bridge and spans 200 feet with a maximum opening height of about 17 feet.
- Temporary State Highway M-30 Causeway bridge divides the Tobacco and Tittabawassee River side of Wixom Lake. The M-30 causeway failed during the May 2020 Flood event and a temporary bridge is being reconstructed. The M-30 bridge geometry was input into the HEC-RAS model based on the MDOT bridge plans dated October 18, 2020.

5.4.1.5 Reach 4 – Curtis Road to M-30 (Sanford Dam)

This reach consists of approximately 13.6 miles between Curtis Road to approximately 2 miles downstream of Sanford Dam. The reach is similar in nature to the Tittabawassee River Reach 3 and 3a as described above. The riverbanks are heavily developed dwellings and parks along the former riverbanks and shoreline of Sanford Lake and was formerly hydraulically controlled by the Tainter gate operations of Sanford Dam. Following the catastrophic failure of the Sanford Dam right embankment the river has dropped nearly 20 feet below the normal operating level exposing the original Tittabawassee River floodplain. The Tittabawassee river is currently diverted around the Tainter gate spillway through the right embankment breach channel. As discussed above the Sanford Dam stabilization and downstream debris removal may be eligible for NRCS EWP Program funding. Following implementation of the Sanford Dam stabilization, we understand the FLTF desires to fully rehabilitate the Sanford Dam and restore Sanford Lake to its pre-breach level.

Four major roadway crossings over the Tittabawassee River include:

- US-10 crosses over the Tittabawassee River approximately 0.7 miles upstream of Sanford Dam near Sanford, MI. Highway 10 carries the 4-lane paved road on two separate 2-lane bridges and spans 300 feet with an opening height of about 40 feet.
- Saginaw Road crosses over the Tittabawassee River approximately 0.4 miles downstream of Sanford Dam near Sanford, MI. Saginaw Road carries the 2-lane paved road and spans 200 feet with an opening height of about 25 feet.
- Pere-Marquette Rail – Trail of Mid-Michigan crosses over the Tittabawassee River approximately 0.45 miles downstream of Sanford Dam near Sanford, MI. The Trail bridge carries pedestrian and bicycle traffic and spans 200 feet with an opening height of about 21 feet.

- M-30 (Meridian Road) crosses over the Tittabawassee River approximately 1.8 miles downstream of Sanford Dam near Sanford, MI. Highway M-30 carries the 2-lane paved road and spans 900 feet with an opening height of about 30 feet.

5.4.2 Data Sources

Below is a list of existing documents and data provided by SGI and Ayres for the purposes of the hydraulic analysis:

- Post May 2020 Flood Aerials: High Resolution images for Wixom and Sanford Lakes.
- FEMA, Flood Insurance Studies, Flood Insurance Rate Maps (FIRMs), Geographical Information Systems (GIS) shapefiles and the Effective HEC-RAS model, extending from downstream of the Sanford Dam to just downstream of the Edenville Dam.
- Available bridge plans for all road crossings from Secord Dam Road immediately downstream of Secord Dam to M-30 located approximately 2 miles downstream of Sanford Dam.

5.4.3 Model Terrain

The terrain data was developed using GIS and RAS Mapper (within HEC-RAS) from multiple Digital Elevation Model (DEM) data sources, including the following:

- Midland and Gladwin County terrain data, digital elevation models (DEMs) LiDAR data:
  - Pre-May 2020 Flood: 2017 LiDAR data for Gladwin and Midland Counties.
  - Post-May 2020 Flood: August 2020 LiDAR data from Gladwin and Midland Counties. Limits from Sanford to approximately 1.3 miles north of Secord.
- Bathymetry Source:
  - Estimated from SonarChart underwater contours (https://webapp.navionics.com).
  - Available lake and river sounding and bathymetric contour data.
  - MDOT and SGI measurements.
- Available lake and river sounding and bathymetric contours.

The downstream terrain was developed from Secord Lake to approximately 2.0 miles downstream of Sanford Dam immediately downstream of the M-30 Highway bridge. To route flows from Secord Dam to Sanford lake, estimated bathymetry was added to the terrain for Secord Lake, Smallwood Lake, Wixom Lake, Sanford Lake, Tobacco and Tittabawassee Rivers. This was necessary because the DEMs obtained from Gladwin and Midland Counties included flat terrain within the reservoirs and rivers at the water surface elevations. To add estimated bathymetric data, the terrain was modified using available bathymetric maps, hydraulic computer models, and bridge crossing plans data. All elevation data in the HEC-RAS model was referenced to the NAVD88 datum. For information regarding conversions to the NGVD29 datum, refer to Section 2.6. Details of the terrain development are provided in **Appendix F**.

5.4.4 2D Model Development

The HEC-RAS 2D model uses an unstructured computational mesh, which allows computation cells to have up to eight sides and can be a mixture of cell shapes and sizes. Each computation cell and cell face are based on the details of the underlying terrain to develop the geometric and hydraulic property tables for the flow simulations. This allows the use of larger computational cells without losing the details of the underlying terrain that determines the movement of flow. Using the HEC-RAS 2D flow area editor, one computation mesh was generated that covered the domain of the study area. The 2D model domain is shown in **Appendix F**. A nominal mesh cell size of 100 feet was initially selected for the mesh with break lines and refinement regions used to reduce the size of mesh cells and to align the cells with the pertinent project features such as the project spillways, embankments, Secord Lake Ridgeline, Edenville and Sanford breach channels, roadway bridges and the primary direction of flow. This served to enhance the model resolution, stability and accuracy at the spillway, embankment, and bridges. **Table 22** summarizes the resulting mesh geometry for each of the FLTF projects.

Table 22: Summary of HEC-RAS River Reaches

River Reach	Reach Description	Nominal Mesh Cell Size (feet)	No. of Mesh Cells	Maximum Cell Area (sq. feet)	Minimum Cell Area (sq. feet)	Average Cell Area (sq. feet)
1	Secord Dam to Confluence with Tea Creek	100	61,966	23,449	10.5	7,498
2	Confluence with Tea Creek to Highwood Road	100	67,090	10,000	2.6	3,103
3	Dale Road / Highwood Road to Curtis Road	100	98,994	83,830	36.5	6,106
4	Curtis Road to M-30 (Meridian Road)	100	80,079	10,000	3.8	5,985

5.4.5 Spillways

A HEC-RAS 2D flow area connection was added to include the dam embankment crest elevation, crest width, upstream and downstream slopes, crest gate and auxiliary spillway geometry.

5.4.6 Surface Roughness

HEC-RAS uses the Manning's n-value roughness coefficient to account for the effects of surface roughness, vegetation, channel irregularities, channel alignment, scour and deposition, obstructions, and channel / floodplain flow. The selected Manning's n-values are based on the following data sources and summarized in **Table 23**:

- Land Cover Layer: National Land Cover Database (NLCD) – Gladwin County (https://datagateway.nrcs.usda.gov/GDGOrder.aspx).

- Manning's n-values: Selected based on site conditions using engineering judgement and reference materials including "Open Channel Hydraulics" by Chow 1959.

Table 23: HEC-RAS Model Land Use Types and Associated Manning's n-values

Land Use Classification Description	Manning's n-value	Land Use Classification Description	Manning's n-value
Alfalfa	0.06	Millet	0.06
Apples	0.10	Mixed Forest	0.12
Barley	0.06	Oats	0.06
Barren	0.04	Open Water	0.04
Canola	0.06	Other Crops	0.06
Corn	0.06	Other Hay/Non-alfalfa	0.06
Deciduous Forest	0.15	Peas	0.06
Developed/High	0.15	Potatoes	0.06
Developed/Low	0.06	Safflower	0.06
Developed/Med	0.10	Shrubland	0.06
Developed/Open	0.05	Sorghum	0.06
Evergreen Forest	0.15	Spring Wheat	0.06
Fallow/Idle Cropland	0.06	Triticale	0.06
Grassland/Pasture	0.04	Winter Wheat	0.06
Herbaceous Wetlands	0.04	Woody Wetlands	0.10

5.4.7 Bridges

A total of eleven (11) bridge crossing are located on the Tittabawassee and Tobacco rivers from Secord Dam Road immediately downstream to M-30 (Meridian Road) located approximately 2 miles downstream of Sanford Dam. In the current version of HEC-RAS, the bridge modeling capabilities are limited and there is no direct way to input a clear span bridge into a 2D flow area. One commonly accepted way to model bridge openings is using a "Storage Area / 2D Connection" (SA/2D) connection with a series of culvert openings equal to the flow area of the clear span bridge. The bridge geometry was based on geometry provided the Michigan Department of Transportation (MDOT) and the Gladwin and Midland County Road Commissions. **Table 24** summarizes the bridge geometry included in the 2D HEC-RAS model.

Table 24: Summary of HEC-RAS Bridge Crossings

River Reach	Bridge	High Chord El. (feet)	Low Chord El. (feet)	Channel Invert (feet)	Bridge Span (feet)	Deck Width (feet)	No. Piers	Pier Width (feet)
1	Secord Dam Road	743.8	740.9	701.1	266	32	2	3.2
2	M-61	716.3	714.0	682.0	250	32	3	2.0
2	Highwood Road	685.0	683.6	669.3	144	37.3	2	2.0
3	Estey Road	685.5	678.6	647.9	204	36.0	2	2.0
3	M-30 DS Edenville	657.6	653.6	624.7	360	35.7	5	3.0
3	Curtis Road	652.5	649.5	623.3	315	40.0	2	3.0

River Reach	Bridge	High Chord El. (feet)	Low Chord El. (feet)	Channel Invert (feet)	Bridge Span (feet)	Deck Width (feet)	No. Piers	Pier Width (feet)
3a	Dale Road	688.6	681.6	663.8	200	36.0	2	2.0
3a	M-30 Causeway	684.4	678.0	657.9	204	34.5	0	N/A
4	US- 10	641.5	639.5	600.4	300	125.0	2	3.0
4	Saginaw Road	626.3	623.6	598.4	200	50.0	2	2.0
4	Recreation Trail	624.8	619.3	598.4	200	15.0	0	N/A
4	M-30 DS Sanford	629.3	627.9	594.9	900	45.0	6	2.0

5.4.8 Flood Routing

The upstream control for the hydraulic model was set as the ½ PMF + design storm flow hydrograph at the upstream end of the reservoir. This resulted in a total hydrograph duration of 144 hours with 60-minute time step for each hydrograph increment. This duration was selected to minimize errors and allow for more accurate flood routing and rating curve calculations for each of the FLTF proposed spillways.

The downstream boundary condition was set to the normal depth slope equal to the channel slope throughout the simulation, which ranged from 0.0005 feet/foot (ft/ft) to 0.0006 ft/ft. The 2D hydraulic calculations were performed in the HEC-RAS model using unsteady flow simulations with a variable time step based on the courant number calculated for cells within the computation mesh. This allows for longer time steps during intervals of lower velocities and shorter time steps during intervals with higher velocities. This is ideal for spillway flood studies as it allows for the time step to decrease as flow rates and velocities through the spillway increase. HEC-RAS 2D can solve full momentum equations or a simplified version of the equations (known as the diffusion wave equations). The full momentum equations were used in the 2D model calculations.

5.5 Sensitivity Analysis

During development of the HEC-RAS hydraulic model, various model domain configurations were tested to reduce calculation errors. Due to improvements made to methods for model mesh development in HEC-RAS Version 5.0.7, sensitivity analyses for standard mesh sizes were deemed unnecessary since the model mesh can be refined at specific areas of concern using refinement regions. Mesh refinements and details were added using numerous break lines and refinements regions to model domain as required.

The sensitivity of the model to other calculation options and tolerances were evaluated including varying the simulation time step and calculation option theta (implicit weighting factor). The Manning's n-values were adjusted by 20 percent for the ½ PMF + design storm. The results of the selected sensitivity analyses are described in Section 6.6 and documented in **Appendix F**.

6. Flood Routing Results

GEI performed hydraulic modeling to evaluate the proposed spillway capacity upgrades at each of the FLTF projects during the ½ PMF + design storm. A summary of HEC-RAS input and output are provided in **Appendix F**. The GIS-based inundation maps are described in Section 7.0 are provided in **Appendix G**.

6.1 Design Storms

The HEC-RAS model was used to delineate the floodplain inundation limits and flood profiles for the following scenarios:

- <u>½ PMF + Design Storm Spillway Upgrades:</u> The ½ PMF + design storm proposed spillway configurations described in Section 5.2 were routed through the HEC-RAS model to estimate the peak water surface elevations and floodplain limits.
- <u>½ PMF + Design Storm Secord and Smallwood Dams in Place Existing Conditions:</u> The Edenville and Sanford dams catastrophically failed during the May 2020 flood event; however, the Secord and Smallwood dams remain in place and recently underwent interim repair measures to reduce dam safety concerns for the 2020 / 2021 winter and spring runoff. Secord and Smallwood Dams will be rehabilitated first before the downstream Edenville and Sanford Dams are fully reconstructed. The FLTF requested additional inundation mapping and flood profiles to establish "existing conditions" and to demonstrate the flood reduction to the upstream homeowners by providing spillway capacity upgrades and increased freeboard protection. GEI developed HEC-RAS spillway geometry using recent spillway surveys and maximum gate opening tests performed prior to the May 2020 flood event as documented in the April 2020 Discharge Rating Curve Study performed by GEI (Ref. GEI, 2020b).
- <u>100-year, ½ PMF and PMF - No Dams in Place:</u> Assuming the dams have been removed and the natural stream cross-section is restored. A simplified stream channel was developed to fully remove the powerhouse and spillway structures and remove a substantial trapezoidal section of the flanking embankments for this scenario. This scenario was used to gain a better understanding of the affects the dams have on the Tittabawassee and Tobacco River floodplains. Specifically, to demonstrate the flood reduction by inflow attenuation (if any) offered by the dams as compared to the dams in place scenario. *Note: the dam removed runs were completed using steady state discharges provided by the DEQ and Ayers. The results presented in this report for No Dams in Place are preliminary and should not be used as a final direct comparison to the ½ PMF+ Design storms which use full hydrograph flood routing for each of the FLTF dams. Following completion of the AWA and Ayres PMP and PMF studies, the No Dams in Place flood routing will be updated for a more direct comparison of water surface elevation results.*

6.2 Secord Dam

6.2.1 Secord Dam Flood Routing Results

The proposed spillway rating curves developed using the 2D HEC-RAS model was input into the HEC-HMS model as the primary spillway to determine the final flood routing results. Based on the proposed spillway configuration for Secord Dam, the ½ PMF + design storm results in a peak inflow of 21,150 cfs, a maximum reservoir water surface at El. 755.2, a peak discharge of 17,230 cfs, and a minimum of 2.8-feet of dam crest freeboard and minor overtopping 0.2 feet of the east Secord Lake ridgeline at El. 755.0. The Secord Dam ½ PMF + design storm inflow, outflow, and stage hydrographs are shown on **Figure 11**. During the peak of the ½ PMF + design storm, flow through the spillway gates would be 20.4 feet deep at a velocity of about 16 feet per second (fps). Based on the configuration described above, the proposed Secord Dam spillway configuration would have sufficient discharge capacity to safely pass the ½ PMF + design storm with over 2.5 feet of freeboard at the dam.

The proposed Secord Dam spillway discharge rating curves calculated by the 2D HEC-RAS model are compared to the empirical equation-based rating curves in **Figure 12**. In general, the empirical rating curves align well with the rating curves calculated by the 2D model up to the ½ PMF + design storm that shows water level of El. 755.2, meaning that downstream submergence has little impact on the discharge capacity of the spillway. During the ½ PMF + design storm the downstream tailwater rise to El. 726.6 which is approximately 8.2 feet lower than the spillway crest El. 734.8; therefore, the tailwater submergence ratio is not high enough to cause an increase in the upstream headwater elevation during the ½ PMF + design storm. Output data from the HEC-HMS model are summarized in **Table 25**.

Table 25: Secord Dam Flood Routing Results – Proposed Conditions

Parameter or Modeling Result	½ PMF + Design Storm
Initial Water Surface El. (feet)	750.8
Peak Inflow (cfs)	21,150
Peak Outflow (cfs)	17,230
Maximum Reservoir El. (feet)	755.2
Freeboard (Tea Creek E. 755.0) (feet)	-0.2
Freeboard (Dam Crest El. 758.0) (feet)	2.8

6.2.2 Reach 1 – Secord Dam to Confluence with Tea Creek (Secord Dam) Flood Routing Results

The Reach 1 flood routing results at select cross sections upstream and downstream of the Secord Dam are presented in **Table 26**. The tabulated results include the peak water surface elevation and inundation limits for the existing, proposed and dam removed scenarios for each of the selected design storms. The Model Reach 1 flood profiles and inundation mapping are provided in **Appendix G.1**. Note, the reported elevations in the 2D HEC-RAS model in Secord Lake were approximately 0.7 feet higher than HEC-HMS largely due to the increased storage volume used in the HEC-HMS model compared to HEC-RAS. The limits of the 2D HEC-RAS model do not include the entire Secord Lake to reduce computational flood routing times and increase model stability.

Table 26: Reach 1 Flood Routing Results

River Station	Structure Description	Secord Dam In-Place			Secord Dam Removed		
		FEMA Zone A Floodplain (feet)	½ PMF Design Storm Existing Conditions (feet)	½ PMF + Design Storm Proposed Conditions (feet)	100-Year Dam Removed (feet)	½ PMF Dam Removed (feet)	PMF Dam Removed (feet)
1978+50	Secord Dam Headwater	753.8	757.9	755.2	717.2	728.9	740.6
	Secord Dam Tailwater	N/A	724.1	726.6	N/A	N/A	N/A
1975+70	Secord Dam Road	N/A	723.8	726.5	713.2	724.9	738.8
1854+90	Confluence with Sugar River	N/A	708.0	709.0	703.8	711.7	716.4
1850+85	Confluence with Tea Creek	N/A	706.9	707.2	703.0	709.4	713.4

Reach 1 is in a FEMA Zone A floodplain, meaning that base flood elevations (100-year) were not established from a detailed study and floodplain limits were estimated by approximate methods. A FEMA Letter of Map Amendment (LOMA) was completed by Mill Road Engineering in 2015 resulting in a 100-year flood elevation of 753.8 in Secord Lake. A design criterion of the proposed spillway modifications is to provide equivalent or greater flood discharge capacity for the 100-year storm and not increase the current 100-year floodplain elevation of 753.8. The current FEMA inundation limits are included in the inundation mapping provided in **Appendix G.1**.

The existing conditions model results indicate that during the ½ PMF + design storm Secord lake surcharges above the east Secord Lake Ridgeline and left abutment at El. 755.0 (2.9 feet of overtopping) before reaching the dam resulting in severe flooding to the eastern reservoir shoreline dwellings, residential properties, yards, and roads. The overflow is routed east into Tea Creek and then eventually into the Tittabawassee River approximately 2.4 miles downstream of Secord Dam. The proposed spillway upgrades result in nearly 3 feet of flood reduction in Secord Lake and limits the overtopping of the Secord Lake Ridgeline to 0.2 feet. The total number of homes in the ½ PMF existing configuration floodplain is 557 while the total number of homes in the ½ PMF + design storm proposed configuration is 225 resulting in a proposed reduction of 332 homes out of the ½ PMF + design storm floodplain. However, the ½ PMF and full PMF with the dam removed still result in an estimated 18 homes impacted during the ½ PMF and an estimated 225 homes impacted during the PMF. The model results show that the Secord Dam is the primary contributor the extensive flooding upstream of the Secord Lake Dam, specifically the eastern shoreline and does not provide significant flood control benefits downstream. The total number if impacted structures in the Secord Dam floodplain are summarized in **Table 27**.

Table 27: Impacted Structures in the Secord Dam Floodplain

Dam Condition	Scenario	Estimated No, of Structures Impacted
Dam In	FEMA 100-Year Flood	62
	Half PMF Existing	557
	Half PMF+ Design Storm Proposed	225
Dam Removed	100-Year	0
	Half PMF	18
	PMF	225

The flood routing results indicate that during the ½ PMF + design storm, the Secord Dam tailwater is increased from El. 724.1 to El. 726.6 when compared to existing conditions as a result of increased flow routed through the spillway and reduction of flow overtopping the Secord Lake Ridgeline during routing of flows through the proposed condition.

At the Secord Dam Road Bridge about 0.06 miles downstream of Secord Dam, the ½ PMF existing and ½ PMF + design storm proposed water surface elevations are 723.8 and 726.5 respectively, while the dam removed ½ PMF and PMF water surface elevations are 724.9 (due to upstream Secord Lake attenuation) and 738.8, respectively. Each of these water surface profiles are below the low chord of the Secord Dam Road bridge deck at El. 740.9.

At the confluence with Sugar Creek, approximately 2.3 miles downstream of Secord Dam, the ½ PMF existing and ½ PMF + design storm proposed conditions water surface elevations nearly converge within about 0.5 feet of El. 708.5. The ½ PMF dam removed water surface elevation is about 3.2 feet higher at El. 711.7 (due to upstream Secord Lake attenuation). The PMF dam removed flood profile is nearly 8.0 feet higher at El. 716.4.

At the confluence with Tea Creek, approximately 2.4 miles downstream of Secord Dam, the ½ PMF existing and ½ PMF + design storm proposed conditions water surface elevations converge within about 0.2 feet of El. 707.0. The ½ PMF dam removed water surface is approximately 2.5 feet higher (due to upstream Secord Lake attenuation) at El. 709.4 and the PMF dam removed water surface elevation is about 6.5 feet higher at El. 713.4.

As shown in Appendix G, the preliminary results do not suggest an increase of habitable structures flooded downstream of Secord Dam during the ½ PMF+ design storm. Furthermore, the number of homes east of the Secord Lake Ridgeline is significantly decreased during the ½ PMF + design storm. These results are preliminary and will be updated following completion of the AWA and Ayres site specific PMP and PMF study.

6.3 Smallwood Dam

6.3.1 Smallwood Dam Flood Routing Results

The proposed spillway rating curves developed using the 2D HEC-RAS model was input into the HEC-HMS model as the primary spillway to determine the final routing results. Based on the proposed spillway configuration for the Smallwood Dam, the ½ PMF + design storm results in a peak inflow of 24,505 cfs, a maximum reservoir water surface at El. 713.1, a peak discharge of 24,100 cfs, and a minimum of 1.9-feet of dam crest freeboard. The Smallwood Dam ½ PMF + design storm inflow, outflow, and stage hydrographs are shown on **Figure 13**. During the peak of the ½ PMF + design storm, flow through the spillway gates would be 24.3 feet deep at a velocity of about 19 fps. Based on the configuration described above, the proposed Smallwood Dam spillway configuration would have sufficient discharge capacity to safely pass the ½ PMF + design storm with over 1.9 feet of freeboard.

The proposed Smallwood Dam spillway discharge rating curves calculated by the 2D model are compared to the empirical equation-based rating curves in **Figure 14**. In general, the empirical rating curves align well with the rating curves calculated by the 2D model up to the ½ PMF + design storm that shows a water level of El. 713.1, meaning that downstream submergence has little impact on the discharge capacity of the spillway. During the ½ PMF + design storm the downstream tailwater rise to El. 699.6 which is approximately 10.1 feet higher than the spillway crest El. 688.8. In general, tailwater submergence ratio begins to reduce spillway capacity when the tailwater depth divided by the headwater energy depth above the spillway is greater than 0.67; therefore, the tailwater submergence ratio of 0.44 is not high enough to cause an increase in the upstream headwater elevation during the ½ PMF + design storm. Output data from the HEC-HMS model are summarized in **Table 28**.

Table 28: Smallwood Dam Flood Routing Results – Proposed Conditions

Parameter or Modeling Result	½ PMF+ Design Storm
Initial Water Surface El. (feet)	704.8
Peak Inflow (cfs)	24,550
Peak Outflow (cfs)	24,100
Maximum Reservoir El. (feet)	713.1
Requisite Freeboard (Dam Crest El. 715.0) (feet)	1.9

6.3.2 Reach 2 - Confluence with Tea Creek to Highwood Road (Smallwood Dam) Flood Routing Results

The Reach 2 flood routing results at select cross sections upstream and downstream of Smallwood Dam are presented in **Table 29**. The tabulated results include the peak water surface elevation and inundation limits for the existing, proposed and dam removed scenarios for each of the selected design storms. The Model Reach 2 flood profiles and inundation mapping are provided in **Appendix G.2**.

Table 29: Reach 2 Flood Routing Results

River Station	Structure Description	Smallwood Dam In-Place			Smallwood Dam Removed		
		FEMA Zone A Floodplain (feet)	½ PMF Design Storm Existing Conditions (feet)	½ PMF + Design Storm Proposed Conditions (feet)	100-Year Dam Removed (feet)	½ PMF Dam Removed (feet)	PMF Dam Removed (feet)
1677+00	M-61 Bridge	N/A	715.5	713.8	697.4	707.5	718.2
1570+40	Smallwood Dam Headwater	706.1	714.9	713.1	688.3	700.4	710.5
	Smallwood Dam Tailwater	N/A	699.5	699.6	N/A	N/A	N/A
1368+25	Highwood Road Bridge	N/A	688.1	688.1	682.4	690.0	699.6

Reach 2 is in a FEMA Zone A floodplain. A FEMA LOMA was completed by Mill Road Engineering in 2015 resulting in a 100-year flood elevation of 706.1 in Smallwood Lake. A design criterion of the proposed spillway modifications is to provide equivalent or greater flood discharge capacity for the 100-year storm and not increase the current 100-year floodplain elevation of 706.1. The current FEMA inundation limits are included in the inundation mapping provided in **Appendix G.2**.

The existing conditions model results indicate that during the ½ PMF + design storm, Smallwood Lake surcharges above the left embankment at El. 709.5 resulting in embankment overtopping and severe flooding to the undeveloped property immediately downstream of the left embankment. The proposed spillway upgrades result in nearly 2 feet of flood reduction during the ½ PMF + design storm and eliminates the overtopping of the left embankment. The total estimate number of inundated homes in the ½ PMF existing configuration floodplain is estimated at 277, while the total number of inundated homes in the ½ PMF + design storm proposed new dam configuration results in an estimated 215 inundations, resulting in a proposed reduction of 62 homes that are outside of the ½ PMF + design storm floodplain. Sensitivity analyses were completed to expand the proposed footprint of the pin-flashboard overflow spillway to be the full length of the existing left abutment to further reduce the number of upstream homes flooded during the ½ PMF. The results of the sensitivity analysis suggest that expanded the auxiliary spillway from 150 feet wide to 500 feet wide resulted in approximately 0.1 feet of flood depth reduction. The scenario is severely limited by the downstream existing grade at elevation 706.0. Constructing a new discharge channel to convey flows from El. 706 to the Tittabawassee river would require significant excavation and would be cost prohibitive for an insignificant increase in flood protection.

The dam removed scenario results in a significant decrease of headwater elevations in Smallwood Lake and eliminates discharge to over the left abutment during the ½ PMF. The ½ PMF flood is generally contained within the existing impoundment with an estimated 69 number of homes inundated. However, the PMF results in severe flooding with 382 homes impacted upstream of the dam. The model results show that the Smallwood Dam is the primary contributor the extensive flooding upstream of the Dam, during the ½ PMF + design storm and does not provide significant flood control benefits downstream. The total number if impacted structures in the Smallwood Dam Floodplain are summarized in **Table 30**.

Table 30: Impacted Structures in the Smallwood Dam Floodplain

Dam Condition	Scenario	Estimate No. of Structures Impacted
Dam In	FEMA 100-Year	0
	Half PMF Existing	277
	Half PMF + Design Storm Proposed	215
Dam Removed	100-Year	0
	Half PMF	69
	PMF	382

At the M-61 Road Bridge approximately 1.9 miles upstream of Smallwood dam, the bridge deck is nearly overtopped at El. 715.5 during the ½ PMF existing conditions configuration, while the proposed spillway upgrades result in 1.7 feet of flood reduction at El. 713.8. The dam removed ½ PMF flood profiles is nearly 8 feet lower at El. 707.5 while the dam removed PMF is nearly 3 feet higher at El. 718.2.

Downstream of Smallwood dam, the tailwater is nearly identical for the ½ PMF + existing and proposed spillway configurations at El. 699.6.

At the Highwood Road Bridge approximately 3.8 miles downstream of Smallwood dam, the ½ PMF existing, ½ PMF + design storm proposed dam improvements and ½ PMF dam removed water surface elevations converge within a foot of El. 689.0 (due to upstream Smallwood Dam attenuation) resulting in 3 to 4 feet of bridge overtopping. The PMF dam removed flood profile is nearly 10 feet higher at El. 699.6 resulting in over 14 feet of overtopping likely resulting in catastrophic failure of Highwood Road bridge.

As shown in Appendix G, the preliminary results do not suggest an increase of habitable structures flooded downstream of Smallwood Dam during the ½ PMF+ design storm. These results are preliminary and will be updated following completion of the AWA and Ayres site specific PMP and PMF study.

6.4 Edenville Dam

6.4.1 Edenville Dam Flood Routing Results

The proposed spillway rating curves developed using the 2D HEC-RAS model were input into the HEC-HMS model as the primary spillway to determine the final routing results. Based on the new spillway configuration for Edenville Dam, the ½ PMF + design storm proposed results in a peak inflow of 52,280 cfs, a maximum reservoir water surface at El. 681.2, a peak discharge of 47,000 cfs, and a minimum of 4.0-feet of dam crest freeboard at El. 685.5. The Edenville Dam ½ PMF + design storm inflow, outflow, and stage hydrographs are shown on **Figure 15**. During the peak of the ½ PMF + design storm, flow through the spillway gates on the Tittabawassee River would be about 21.4 feet deep with a velocity of about 16 fps and flow through the spillway gates on the Tobacco River would be about 22.4 feet deep with velocities varying from about 12 fps for the 18-ft wide gates to about 14 fps for the narrower 15-ft wide center gate. Based on the configuration described above, the proposed Edenville Dam spillway configuration would have sufficient discharge capacity to safely pass the ½ PMF + design storm with over 4.0 feet of freeboard.

The proposed Edenville Dam crest gate spillway discharge rating curves calculated by the 2D model are compared to the empirical equation-based rating curves in **Figure 16**. In general, the empirical rating curves align well with the rating curves calculated by the 2D model up to the ½ PMF + design storm that shows a water level at El. 681.2, meaning that downstream submergence has little impact on the discharge capacity of the spillway. During the ½ PMF + design storm, the downstream tailwater rise to El. 653.6 which is approximately 6.2 feet lower than the spillway crest El. 659.8. Therefore, the tailwater submergence ratio is not high enough to cause an increase in the upstream headwater elevation during the ½ PMF + design storm. Output data from the HEC-HMS model are summarized in **Table 31**.

Table 31: Edenville Dam Flood Routing Results – Proposed Conditions

Parameter or Modeling Result	½ PMF + Design Storm
Initial Water Surface El. (feet)	675.8
Peak Inflow (cfs)	52,275
Peak Outflow (cfs)	47,000
Maximum Reservoir El. (feet)	681.2
Requisite Freeboard (Dam Crest El. 685.5) (feet)	4.3

The Highway 30 (M-30) causeway that separates the Tobacco and Tittabawassee sides of the Wixom Lake was modeled based on the Temporary M-30 bridge alignment included in the MDOT bridge plans dated October 28, 2020. The overall bridge span is approximately 234 feet with a clear span of 204 between the temporary steel sheet piling on the north and south abutments. The HEC-RAS model results suggest that the headwater during the ½ PMF + design storm is El. 682.0 on the Tobacco side and El. 681.7 on the Tittabawassee side resulting in a headwater differential of 0.3 feet. Approximately 7,900 cfs is bypassed through the M-30 bridge during the peak conditions of the ½ PMF + design storm to route the excess flows from the Tobacco side to the labyrinth auxiliary spillway on the Tittabawassee side (see **Figure 17**). These results suggest that the construction of the temporary M-30 bridge does not significantly impact or hydraulically limit the spillway capacity of the proposed labyrinth auxiliary spillway on the Tittabawassee River portion of the project. However, during the ½ PMF + design storm the M-30 causeway bridge is likely overtopped and would potentially cutoff dam operator and emergency vehicle access during extreme flood events. We understand that the M-30 causeway will be temporary, and a new permanent M-30 causeway bridge will be constructed in the future and should be raised to prevent overtopping or washout. The FLTF have engaged initial discussions with MDOT regarding flood levels during the design storm and will provide hydraulic flood routing results prior to the planning and design of the permanent bridge crossing.

6.4.2 Reach 3 – Highwood Road to Curtis Road (Edenville Dam) Flood Routing Results

The Reach 3 flood routing results at select cross sections upstream and downstream of Edenville Dam are separated between the Tittabawassee River presented in **Table 32** and the Tobacco River presented in **Table 33**. Note, the reported elevations in the 2D HEC-RAS model in Wixom Lake were approximately 0.5 feet higher than HEC-HMS largely due to the one (1) combined storage area of both the Tittabawassee and Tobacco portions of the reservoir modeled in HMS. The tabulated results include the peak water surface elevation and inundation limits for the existing, proposed and dam removed scenarios for each of the selected design storms. The Model Reach 3 flood profiles and inundation mapping are provided in **Appendix G.3**.

Table 32: Reach 3 Flood Routing Results (Tittabawassee River)

River Station	Structure Description	Edenville Dam In-Place		Edenville Dam Removed		
		FEMA Zone A Floodplain (feet)	½ PMF + Proposed Conditions (feet)	100-Year Dam Removed (feet)	½ PMF Dam Removed (feet)	PMF Dam Removed (feet)
1097+60	Estey Road Bridge	N/A	683.1	666.1	672.9	683.3
804+90	Edenville Dam Headwater	677.5	681.7	643.8	651.4	661.2
	Edenville Dam Tailwater	638.9	653.6	N/A	N/A	N/A
752+00	M-30 Highway Bridge	638.2	651.5	641.8	649.9	659.4
725+45	Curtis Road Bridge	637.9	649.3	640.4	648.4	657.6

Table 33: Reach 3 Flood Routing Results (Tobacco River)

River Station	Structure Description	Edenville Dam In-Place		Edenville Dam Removed		
		FEMA Zone A Floodplain (feet)	½ PMF + Proposed Conditions (feet)	100-Year Dam Removed (feet)	½ PMF Dam Removed (feet)	PMF Dam Removed (feet)
804+90	Dale Road Bridge	N/A	688.4	677.3	685.1	694.9
1002+15	Tobacco Spillway Headwater	677.5	682.0	645.6	651.5	662.5
	Tobacco Spillway Tailwater	640.6	650.8	N/A	N/A	N/A

Upstream of Edenville Dam, Model Reach 3 is in a FEMA Zone A floodplain. A FEMA LOMA was completed by Mill Road Engineering in 2015 resulting in a 100-year flood elevation of 677.5 in Wixom Lake. Downstream of Edenville Dam, Model Reach 3 is in a FEMA Zone AE floodplain, meaning that base flood elevations were established by a detailed study. The FEMA 100-year tailwater on the Tittabawassee River portion of Edenville Dam is El. 638.9 while the tailwater on the Tobacco River portion of Edenville Dam is El. 640.6. A design criterion of the proposed spillway modifications is to provide equivalent or greater flood discharge capacity for the 100-year storm and not increase the current 100-year floodplain elevation of 677.5. The current FEMA inundation limits are included in the inundation mapping provided in **Appendix G.3**.

During the May 2020 flood event, the Wixom lake water surface elevation rose to within 1.5 feet of the left embankment crest El. (682.1 – 1.5 = 680.6 feet) immediately before the Edenville Dam failure. During the ½ PMF + design storm, Wixom Lake surcharges approximately 6 feet to El. 681.5 which is approximately 0.9 feet higher than the estimated May 2020 lake level of El. 680.6. For the ½ PMF + design storm, the embankments will be raised to El. 685.5 to provide additional freeboard for wind setup and wave runup.

The total estimated number of inundated homes in the proposed ½ PMF + design storm floodplain is 1,079, which is a decrease of 428 homes from the estimated inundation area of the pre-Edenville Dam failure half PMF estimated inundation area, which resulted in 1,507 homes in the floodplain. The dam removed scenarios results in a significant decrease of headwater elevations in Wixom Lake. The ½ PMF flood is generally contained within the existing impoundment with an estimated 31 homes inundated. However, the PMF results in severe flooding with 246 homes potentially impacted. The model results show that the Edenville Dam is the primary contributor to the flooding upstream of the Dam, during the ½ PMF + design storm and does not provide significant flood control benefits downstream. The total number if impacted structures in the Edenville Dam Floodplain are summarized in **Table 34**.

Table 34: Impacted Structures in the Edenville Dam Floodplain

Dam Condition	Scenario	Estimate No. of Structures Impacted
Dam In	FEMA 100-Year*	64
	Half PMF (Pre-failure)	1,507
	Half PMF+ Design Storm Proposed	1,079
Dam Removed	100-Year	10
	Half PMF	31
	PMF	246

*The FEMA 100-Year Floodplain was not mapped for portions of the southeast side of Wixom Lake, which could result in an under-representation of the impacted structures in the floodplain.

The effects of the surcharged impoundment extend approximately 5.5 miles upstream on the Tittabawassee River near the Estey Road bridge. The Estey Road bridge is not overtopped with the river rising to El. 683.1. The dam removed ½ PMF flood profiles is slightly lower at El. 672.9 while the dam removed PMF is nearly 10.5 feet higher at El. 683.3.

On the Tobacco River, the surcharged impoundment extends approximately 5.8 river miles upstream of the Tobacco spillway. During the ½ PMF + design storm the Tobacco River rises to El. 688.4 at the Dale Road bridge located approximately 4.3 miles upstream of the Tobacco spillway resulting in approximately 0.2 feet of bridge overtopping. The dam removed ½ PMF flood profiles is almost 3.5 feet lower at El. 685.1 while the dam removed PMF is nearly 6.5 feet higher at El. 694.9.

Downstream of Edenville spillway on the Tittabawassee River, the tailwater for the ½ PMF + design storm proposed spillway configurations are at El. 653.6. Downstream of Tobacco spillway on the

Tobacco River, the tailwater for the ½ PMF + design storm for proposed spillway configurations is at El. 650.8.

At the M-30 Highway Bridge located about 1.0 miles downstream of Edenville Dam, the ½ PMF + design storm proposed spillway improvement water surface elevation is at El. 651.5 while the dam removed ½ PMF and PMF water surface elevations are at El. 649.9 and El. 659.4, respectively.

At the Curtis Road Bridge located about 1.5 miles downstream of Edenville Dam, the ½ PMF + design storm proposed water surface elevation is at El. 649.3 while the dam removed ½ PMF and PMF water surface elevations are at El. 648.4 and El. 657.6, respectively. Each of these water surface profiles are below the low chord of the bridge deck at El. 649.5, except for the PMF, which overtops the bridge by approximately 8.1 feet.

6.4.3 Sanford Dam Flood Routing Results

The proposed spillway rating curves developed using the 2D HEC-RAS model was then input into the HEC-HMS model as the primary spillway to determine the final routing results. Based on the new spillway configuration for the Sanford Dam, the ½ PMF + design storm results in a peak inflow of 47,300 cfs, a maximum reservoir water surface at El. 635.0, a peak discharge of 46,000 cfs, and a minimum of 3.0-feet of dam crest freeboard. The Sanford Dam ½ PMF + design storm inflow, outflow, and stage hydrographs are shown on **Figure 18**. During the peak of the ½ PMF + design storm, flow through the spillway gates would be 20.2 feet deep at a velocity of about 13 fps. Based on the configuration described above, the proposed Sanford Dam spillway configuration would have sufficient discharge capacity to safely pass the ½ PMF storm with 3.0 feet of freeboard.

Prior to the May 2020 breach of the right embankment, the tailwater increased and completely submerged the switchyard immediately downstream of the right embankment (see **Figure 19**). The elevation of the switchyard ranges from El. 618.0 to El. 620.0 and the flood levels completely submerged the chain link fence surrounding the switchyard. Exact tailwater elevations are not available from Boyce records; however, this anecdotal evidence suggests that the tailwater increased approximately 8 to 10 feet prior to the failure resulting in a tailwater elevation ranging from El. 626.0 to El. 628.0. The downstream tailwater is impacted by several factors. Approximately 2,200 feet downstream, the Sanford Road Bridge and Pere-Marquette Trail bridge constrict the cross-sectional area of the Tittabawassee River. Approximately 650 feet further downstream the confluence with the Salt River contributes additional flood flow from the Salt River watershed. Furthermore, the left floodplain located immediately downstream consists of a public park and ball fields that are low (El. 613.0+/-) relative to the ½ PMF + design storm tailwater of El. 632.1 and a significant amount of flood flow is conveyed around the bridges in the low-lying floodplain. The Salt River is not included in the Tittabawassee River watershed at Sanford Dam, so we added the DEQ estimated 100-year flood flow rate of 16,000 cfs concurrent with the ½ PMF + design storm flow. During the ½ PMF + design storm the downstream tailwater rise to El. 632.1 which is approximately 17.3 feet higher than the spillway crest El. 614.8. In general, tailwater submergence begins to reduce spillway capacity when the tailwater depth dived by the headwater energy depth above the spillway is greater than 0.67; therefore, the tailwater submergence ratio of 0.82 is high enough to cause 0.5 feet of increase in the upstream headwater elevation during the ½ PMF + design storm. When the Salt River contributing flow is removed, the tailwater reduces to El. 630.6, illustrating that the variability in the Salt River has an appreciable impact on the tailwater elevation downstream of Sanford Dam.

The proposed Sanford Dam crest gate spillway discharge rating curves calculated by the 2D model are compared to the empirical equation-based rating curves in **Figure 20**. In general, the empirical rating is slightly offset with the rating curves calculated by the 2D model up to the ½ PMF + design storm compares to a water level of El. 635.1, meaning that downstream submergence has a relatively minor impact on the discharge capacity of the spillway. Output data from the HEC-HMS model are summarized in **Table 35**.

Table 35: Sanford Dam Flood Routing Results – Proposed Conditions

Parameter or Modeling Result	½ PMF+ Design Storm
Initial Water Surface El. (feet)	630.8
Peak Inflow (cfs)	47,300
Peak Outflow (cfs)	46,000
Maximum Reservoir El. (feet)	635.0
Requisite Freeboard (Dam Crest El. 638.0) (feet)	3.0

6.4.4 Reach 4 – Curtis Road to M-30 (Sanford Dam) Flood Routing Results

The Reach 4 flood routing results at select cross sections upstream and downstream of the Sanford Dam are presented in **Table 36**. The tabulated results include the peak water surface elevation and inundation limits for the existing, proposed and dam removed scenarios for each of the selected design storms. The Model Reach 4 flood profiles and inundation mapping are provided in **Appendix G.4**.

Table 36: Reach 4 Flood Routing Results

River Station	Structure Description	Sanford Dam In-Place		Sanford Dam Removed		
		FEMA Zone AE Floodplain (feet)	½ PMF + Design Storm Proposed Conditions (feet)	100-Year Dam Removed (feet)	½ PMF Dam Removed (feet)	PMF Dam Removed (feet)
585+80	Upstream Limit of Impoundment (West Baker Road)	634.6	640.7	633.3	639.0	651.6
314+00	Burns Road	632.2	637.5	630.0	634.1	647.2
153+00	US-10 Bridge	631.9	636.6	627.9	633.6	646.4
114+50	Sanford Dam Headwater	631.6	635.0	627.8	631.6	639.8
	Sanford Dam Tailwater	N/A	632.1	N/A	N/A	N/A
92+50	Saginaw Road Bridge	N/A	631.5	627.8	631.4	639.8
18+00	Highway M-30/Meridian Road Bridge	N/A	629.0	627.8	629.1	635.6

Upstream of Sanford Dam, Reach 4 is in a FEMA Zone AE floodplain with a Sanford Lake 100-year elevation of 631.6. Downstream of Sanford Dam, Reach 4 is in FEMA Zone A floodplain meaning that 100-year tailwater elevations are not available downstream of the Sanford dam; however, the Zone A floodplain inundation limits indicate significant flooding and high tailwater as discussed above. A design criterion of the proposed spillway modifications is to provide equivalent or greater flood discharge capacity for the 100-year storm and not increase the current 100-year floodplain elevation of 631.6. The current FEMA inundation limits are included in the inundation mapping provided in **Appendix G.3**.

During the May 2020 flood event, the crest of the right embankment at El. 636.8 was overtopped by approximately 2 feet at El. 638.8 feet which lead to catastrophic failure of the embankment. During the ½ PMF + design storm, Sanford Lake surcharges approximately 4.2 feet to El. 635.0 which is approximately 3.7 feet lower than the estimated May 2020 lake level of El. 638.8. The embankments will be raised to El. 638.0 to provide additional freeboard for wind setup and wave runup.

The estimated total number of homes in the proposed ½ PMF + design storm floodplain is 193, which is a decrease of 70 homes from the computed inundation area of the pre-Sanford Dam failure half PMF estimated inundation area, which resulted in an estimated 263 homes in the floodplain. The dam removed scenarios results in a slight decrease of headwater elevations in Sanford Lake. The ½ PMF flood is generally contained within the existing impoundment with an estimated 13 homes inundated. However, the PMF results in severe flooding with an estimated 948 homes impacted. The total number if impacted structures in the Edenville Dam Floodplain are summarized in **Table 37**.

Table 37: Impacted Structures in the Sanford Dam Floodplain

Dam Condition	Scenario	Estimate No. of Structures Impacted
Dam In	FEMA 100-Year Flood	86
	Half PMF+ (Pre-failure)	263
	Half PMF+ Design Storm Proposed	193
Dam Removed	100-Year	75
	Half PMF	213
	PMF	948

During the ½ PMF + design storm, the Tittabawassee River rises to El. 640.7 near Baker Road located approximately 8.9 miles upstream of the Sanford spillway. The dam removed ½ PMF flood profiles is slightly lower at El. 639.0 while the dam removed PMF is nearly 11 feet higher at El. 651.6.

Near Burns Road approximately 3.8 miles upstream of the Sanford spillway, the Tittabawassee River rises to El. 637.5 during the proposed ½ PMF + design storm. The dam removed ½ PMF flood profiles is slightly lower at El. 634.1 while the dam removed PMF is nearly 10 feet higher at El. 647.2.

At the US-10 Bridge located about 0.7 miles upstream of Sanford Dam, the ½ PMF proposed water surface elevation is 636.6 while the dam removed ½ PMF and PMF water surface elevations are 633.6 and 646.4, respectively. The ½ PMF + design storm proposed and ½ PMF water surface profiles are below the low chord at El. 639.5 while the PMF dam removed water surface profile overtops the bridge by nearly 5 feet.

At the Saginaw Road Bridge located about 0.4 miles downstream of Sanford Dam, the ½ PMF proposed water surface elevation is 631.5 while the dam removed ½ PMF and PMF water surface elevations are 631.4 and 639.8, respectively. Each of these water surface profiles are above the high chord of the bridge deck at El. 629.3.

6.5 Sensitivity Analysis Results

6.5.1 Hydraulic Model

For the Manning's n-value sensitivity analysis, the Manning's n-values were varied by ±20 percent to determine the effects of the selected values. To reduce computation time, sensitivity analysis was only performed on Reach 2, the Tea Creek Confluence to Highwood Road. To evaluate the sensitivity to the Manning n-values, the results of the sensitivity analysis were compared to the base model. The results compared the peak water surface elevation and maximum velocity at selected locations. The results of the HEC-RAS hydraulic model Manning's n-value sensitivity analyses area summarized in **Table 38**.

Table 38: Hydraulic Model Manning's N-value Sensitivity Analysis Summary

Parameter	Location	Base Case	Higher n-values (+20%)	Lower n-values (-20%)	Differences (feet)	
Peak Water Surface Elevation	M-61 Bridge	713.8	714.1	713.7	0.3	-0.1
	Smallwood Dam	713.1	713.4	713.1	0.3	0.0
	Highwood Road	688.1	688.8	687.6	0.7	-0.5
Maximum Velocity	M-61 Bridge	5.5	5.5	5.7	0.0	0.2
	Smallwood Dam	18.8	18.8	18.8	0.0	0.0
	Highwood Road	6.0	5.7	6.8	-0.3	0.8

As indicated in **Table 38**, the hydraulic model is moderately sensitive to changes in Manning's n-values. In general, the hydraulic model responded as expected to the changes in Manning's n-values. The higher n-values resulted in generally higher water surface elevations and lower velocities and the lower n-values resulted in lower water surface elevations, and higher velocities. Overall, the hydraulic model responded as expected to the changes in Manning's n-values and the selected Manning's n-values are considered appropriate for the flood study analysis and inundation mapping.

In addition to the Manning's n-values, several calculation options were evaluated including calculation time step, the calculation option theta (implicit weighting factor) and the maximum number of calculation iterations. Different time-step intervals, implicit weighting factors, and number of iterations were evaluated and resulted in water surface elevation varying by less than 0.1 feet. Time-step intervals between 5 and 0.25 seconds were evaluated. An implicit weighting factor of 0.6 was selected as the HEC-RAS User's Manual indicates this produces more accurate results (per USACE, 2016). Based on the sensitivity analysis results, the model results proved to be the most sensitive to the Manning's n-values. The model did not prove to be highly sensitive to the selection of the other parameters.

7. Inundation Mapping and Flood Profiles

7.1 Introduction

GEI developed inundation maps and flood profiles downstream of each of the FLTF projects to illustrate the floodplain inundation limits at critical locations upstream and downstream of the FLTF dams. The inundation mapping also identifies roads, highways, bridges, and other critical infrastructure impacted by the flood, including major roads expected to be overtopped. The FLTF Dam inundation maps are provided in **Appendix G.** The inundation maps meet FERC requirements for Dam breach analysis and inundation mapping, were developed from GIS from RAS Mapper output shapefiles and rasters. The inundation maps were developed with ESRI's ArcMap software version 10.6. The raster clip tool within the ArcMap software was instrumental in compiling the RAS Mapper output shapefiles for map display. Developing the map layouts required the use of the Data Driven Pages tool within the ArcMap software.

7.2 Coordinate System

The GIS based inundation maps were developed using the Universal Transverse Mercator (UTM) 1983, Zone 13 coordinate system horizontal datum in feet.

7.3 Map Development

The inundation maps were developed in GIS from RAS Mapper output shapefiles and raster files. The RAS Mapper output shapefiles consist of a raster layer with the specified output parameters for each mesh cell that conveys flow. For example, the maximum inundation depth is output in one layer with a depth value for each inundated mesh cell. In addition to displaying the RAS Mapper raster output results, the cross sections and required attributes were also developed. The cross-section attributes were extracted from the RAS Mapper raster results. To extract the attributes for the cross sections from the RAS Mapper results several profiles were added into RAS Mapper to obtain the maximum inundation depths and average flow velocities. The peak flow and water surface elevations were extracted from the storage area connection results.

The inundation boundary was developed from the raw RAS Mapper output line shapefile. The shapefiles were imported into GIS and were reviewed and modified to minimize the rendering errors associated with the terrain and RAS Mapper water surface raster files.

7.4 Inundation Maps and Shapefiles

The inundation maps were developed to meet FLTF Project Emergency Action Plans, EGLE and FERC requirements, needs of potential Michigan emergency management end users, and to display the model results. The approximate inundation limits are shown to provide a visual benchmark for areas inside and outside the inundation area.

The critical infrastructure of schools, fire stations, police stations, and hospitals were extracted from available GIS data bases and aerial imagery. Highways, bridges and roads are shown for geographic reference and as potential evacuation routes and are drawn from TIGER/Line shapefiles as of 2018. The aerial photography is from the National Agricultural Imagery Program, USDA, as of 2017.

8. Conclusions and Next Steps

This report presents the hydrology and hydraulic analyses for the proposed modifications to the Secord, Smallwood, Edenville and Sanford Dams. The conclusions and results provided above are summarized here:

- GEI has reviewed the May 2020, PMF Report by Ayres Associates, Inc. (Ref. Ayres, 2020) prepared for Secord, Smallwood, Edenville and Sanford Dams. This report was prepared before the May 2020 flood and used only data available prior to that event. Following the May 2020 event, modifications were made to the analysis. For the purposes of this study, the selected IDF is the ½ PMF plus a 15% to 30% increase in peak inflow (1/2 PMF + design storm). The selected ½ PMF + design storm peak inflows are summarized below.

Summary of Inflow Design Flood (1/2 PMF + Design Storm)

Dam	½ PMF	PMF	½ PMF +[1]	Notes	Annual Exceedance Probability (AEP)
Secord Dam	18,075	43,020	**21,150**	½ PMF + 17% Peak Inflow	1/5000 or 0.0002
Smallwood Dam	19,065	58,640	**24,550**	½ PMF + 28% Peak Inflow	1/5000 or 0.0002
Edenville Total	41,260	116,525	**52,275**	½ PMF + 26% Peak Inflow	TBD
Sanford Dam	37,695	116,065	**47,300**	½ PMF + 26% Peak Inflow	TBD

1. The current IDF for the FLTF Projects is the ½ PMF +

- GEI performed hydraulic analysis to evaluate the proposed spillway upgrades at each of the four FLTF projects during the ½ PMF + design storm. Based on the existing conditions of the FLTF projects, GEI has developed new conceptual spillway and dam configurations which would allow the FLTF dams to safely pass the ½ PMF + design storm with residual freeboard. The proposed configurations consist of reconstruction or rehabilitation of earthen embankments, demolition, and replacement of the primary Tainter gate with hydraulically operated crest gates in the primary spillways, construction of low-level outlets, and new passive overflow auxiliary spillways.

<u>Secord Dam Summary and Design Storm Flood Routing Results</u>:

- The existing Secord Dam has a total zero-discharge capacity of 12,135 cfs at embankment El. 757.8. The existing conditions Secord Dam ½ PMF results in a peak inflow of 18,075 cfs, a maximum reservoir elevation of 757.8, and a peak discharge of 12,585 cfs. The PMF results in a peak inflow of 43,020 cfs, a maximum reservoir elevation of 759.7, a peak discharge of 41,075 cfs and an overtopping depth of 1.9 feet.
- In the proposed Secord Dam configuration, the existing Tainter gate spillway will be partially demolished and the Tainter gates will be replaced with hydraulic crest gates at El. 734.8 to increase the spillway capacity. We selected left crest gate (Bay No. 1) will be 18-feet-wide by 16-feet-high and the right crest gate (Bay No. 2) will be 21-feet-wide by 16-feet-high. A new 130-foot-wide pin flashboard overflow spillway will be constructed at El. 748.5 with timber flashboards that extend up to El. 752.0 to provide additional spillway capacity during the ½ PMF + design storm.

- The ½ PMF + design storm proposed conditions flood routing results indicate that the proposed modifications to the Secord Dam spillway can pass the ½ PMF + design storm inflow of 21,150 cfs with a peak outflow of 17,230 cfs at a peak reservoir water surface El. of 755.2 feet. These results indicate that the project has adequate spillway capacity to pass the ½ PMF + design storm while providing more than 2.8 feet of residual freeboard below the dam crest.

<u>Smallwood Dam Summary and Flood Routing Results</u>:

- The existing Smallwood Dam has a total zero-freeboard capacity of 29,835 cfs at the top of the sheet pile wall at El. 715.7. The existing conditions Smallwood Dam ½ PMF results in a peak inflow of 19,065 cfs, a maximum reservoir elevation of 713.3, a peak discharge of 18,895 cfs. The PMF results in a peak inflow of 58,640 cfs, a maximum reservoir elevation of 718.4, a peak discharge of 58,110 cfs and an overtopping depth of 2.7 feet.
- In the proposed Smallwood Dam configuration, the existing Tainter gate spillway will be partially demolished and the two (2) Tainter gates will be replaced with hydraulic crest gates at El. 688.8 to increase the spillway capacity. The left crest gate (Bay No. 2) and the right gate (Bay No. 1) will be 22.6-feet-wide by 16-feet-high. A new 150-foot-wide ungated steel pin and timber flashboard overflow spillway will be constructed immediately adjacent to the steel sheet pile section of the left embankment at El. 706.0 to provide additional spillway capacity during the ½ PMF + design storm.
- The ½ PMF + design storm proposed conditions flood routing results indicate that the proposed modifications to the Smallwood Dam spillway can pass the ½ PMF + design storm inflow of 24,505 cfs with a peak outflow of 24,100 cfs at a peak reservoir water surface El. of 713.1 feet. These results indicate that the project has adequate spillway capacity to pass the ½ PMF + design storm while providing more than 1.9 feet of residual freeboard below the proposed dam crest.

<u>Edenville Dam Summary and Flood Routing Results</u>:

- The existing Edenville Dam has a total zero-freeboard discharge capacity of 20,670 cfs at embankment El. 682.1. The existing conditions Edenville Dam ½ PMF results in a peak inflow of 41,260 cfs, a maximum reservoir elevation of 684.2, a peak discharge of 37,845 cfs and an overtopping depth of 2.1 feet. The existing conditions PMF results in a peak inflow of 116,525 cfs, a maximum reservoir elevation of 686.8, a peak discharge of 115,885 cfs and an overtopping depth of 4.7 feet.
- In the proposed Edenville configuration, the Edenville Tainter gate spillway and powerhouse will be demolished and the three (3) Tainter gate spillway bays will be replaced with hydraulic crest gates at El. 659.8 to increase the spillway capacity. Each crest gate will be 24-feet-wide by 16-feet-high. The Tobacco Dam Tainter gate spillway will be partially demolished and the three (3) Tainter gates will be replaced with automated hydraulic crest gates at El. 659.8 to increase spillway capacity. The left and right crest gates (Bay No. 3 and Bay No. 1) will be 18-feet-wide by 16-feet-high and the center crest gate (Bay No. 2) will be 15.5-feet-wide by 16-feet-high. A new 250-foot-wide 12-cycle auxiliary spillway will be constructed at El. 678.0 within the former left embankment of the Edenville Dam to provide additional spillway capacity during the ½ PMF + design storm.
- The ½ PMF + design storm proposed conditions flood routing results indicate that the proposed modifications to the Edenville Dam spillway can pass the ½ PMF + design storm inflow of 52,280 cfs with a peak outflow of 47,000 cfs at a peak reservoir water surface El. of

681.2 feet. These results indicate that the project has adequate spillway capacity to pass the ½ PMF + design storm while providing more than 4.3 feet of residual freeboard below the proposed dam crest.

Sanford Dam Summary and Flood Routing Results:

- The existing Sanford Dam has a total zero-freeboard discharge capacity of 36,175 cfs at the top of the embankment at El. 636.8. The existing conditions Sanford Dam ½ PMF results in a peak inflow of 37,695 cfs, a maximum reservoir elevation of 637.2, a peak discharge of 35,480 cfs, and 0.4 feet of dam crest overtopping. The overtopping duration is estimated to be 14 hours. The PMF results in a peak inflow of 116,065 cfs, a maximum reservoir elevation of 644.3, a peak discharge of 112,295 cfs and an overtopping depth of 7.5 feet.
- In the proposed Sanford Dam configuration, the existing Tainter gate spillway and powerhouse will be partially demolished and the six (6) Tainter gates will be replaced with eight (8) hydraulic crest gates at El. 614.8 to increase the spillway capacity. The crest gates would range from 16.5-feet-wide to 23-feet-wide by 16-feet-high. A new 250-foot-wide 12-cycle auxiliary spillway will be constructed at El. 632.5 within the former right embankment of the Sanford Dam to provide additional spillway capacity during the ½ PMF + design storm.
- The ½ PMF + design storm proposed conditions flood routing results indicate that the proposed modifications to the Sanford Dam spillway can pass the ½ PMF + design storm inflow of 47,300 cfs with a peak outflow of 46,000 cfs at a peak reservoir water surface El. of 635.0 feet. These results indicate that the project has adequate spillway capacity to pass the ½ PMF + design storm while providing more than 3.0 feet of residual freeboard below the proposed dam crest.

Summary of Ongoing Flood Studies and Next Steps:

- The FLTF currently has AWA under contract to estimate site specific PMP and probability assessment of various rainfall depths for the Tittabawassee River basin. A site-specific study of the PMP and PMF can result in a lower and more appropriate estimate of the ½ PMF and PMF. The updated PMP and PMF study by AWA and Ayres is expected to be completed in May 2021.
- AWA will provide the updated rainfall depths and distributions to Ayres to develop site specific ½ PMF and PMF inflow hydrographs. The updated PMP and PMF study by AWA and Ayres is expected to be completed in the June 2021.
- Once the site specific PMP, PMF, and AEP studies are complete; GEI will perform and incremental consequence analysis to determine the IDF using the techniques prescribed in FEMA P-94.

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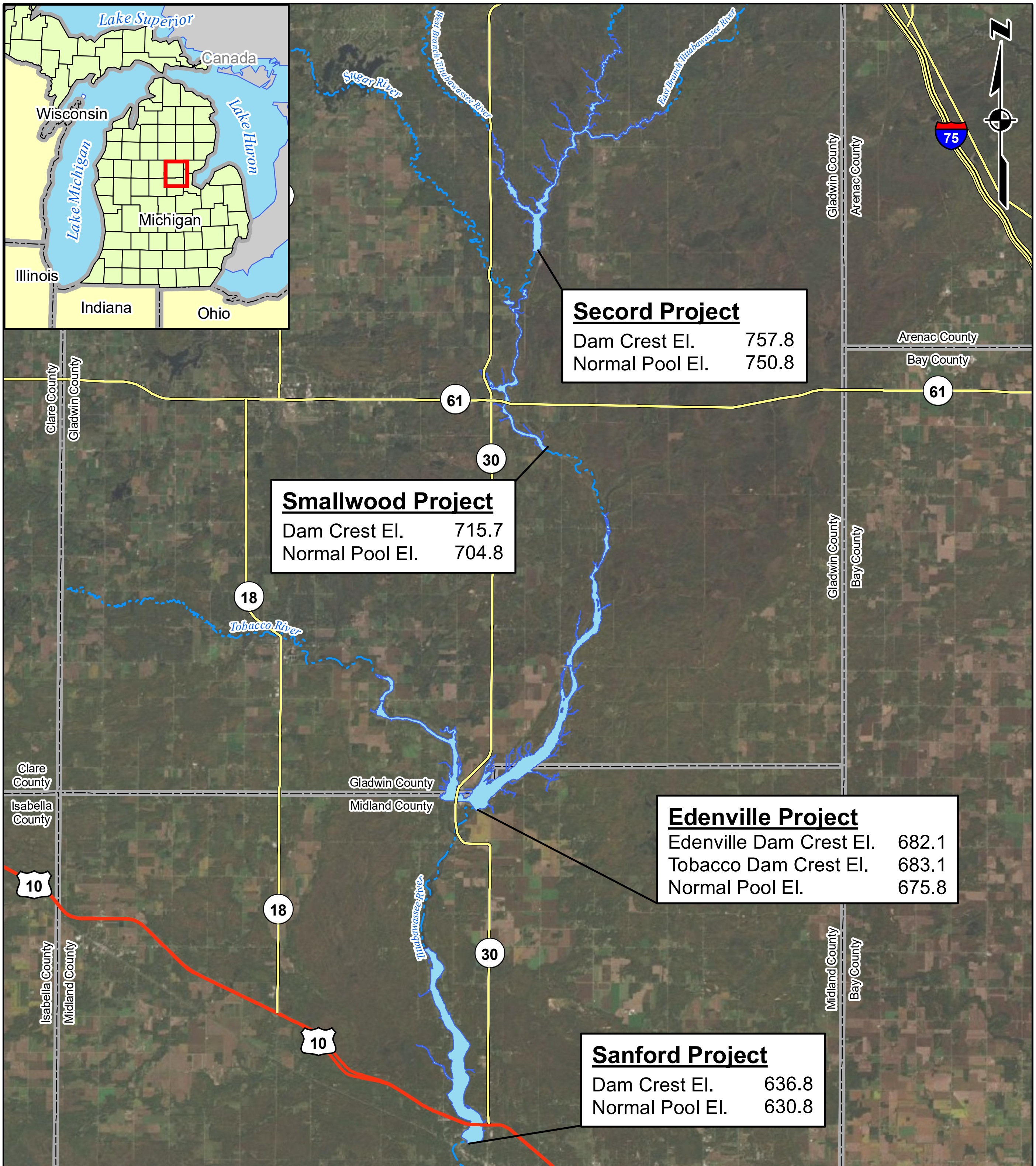
Figures

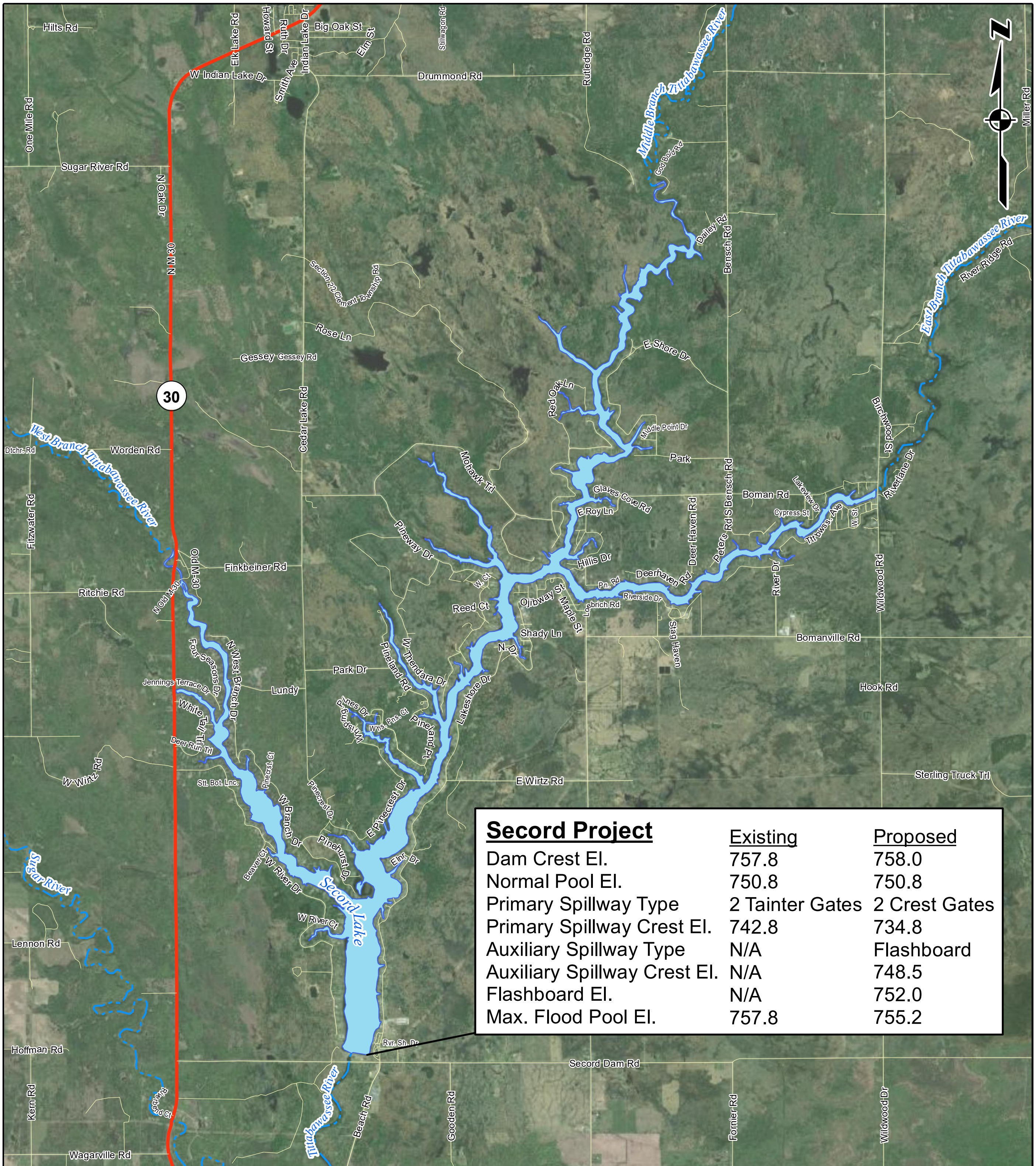


0 4 8

Scale, Miles

Note: All elevations referenced to the National Geodetic Vertical Datum of 1929 (NGVD29). The acronym "El." represents Elevation.

Flood Study of the Tittabawassee River from Secord to Sanford Dam	GEI Consultants	FLTF DAMS LOCATION MAP
Four Lakes Task Force Gladwin and Midland County, Michigan	Project 2002879	March 2021 Figure 1



Secord Project

	Existing	Proposed
Dam Crest El.	757.8	758.0
Normal Pool El.	750.8	750.8
Primary Spillway Type	2 Tainter Gates	2 Crest Gates
Primary Spillway Crest El.	742.8	734.8
Auxiliary Spillway Type	N/A	Flashboard
Auxiliary Spillway Crest El.	N/A	748.5
Flashboard El.	N/A	752.0
Max. Flood Pool El.	757.8	755.2

0 1 2
Scale, Miles

Note: All elevations referenced to the National Geodetic Vertical Datum of 1929 (NGVD29). The acronym "El." represents Elevation.

Flood Study of the Tittabawassee River from Secord to Sanford Dam

Four Lakes Task Force
Gladwin and Midland County, Michigan

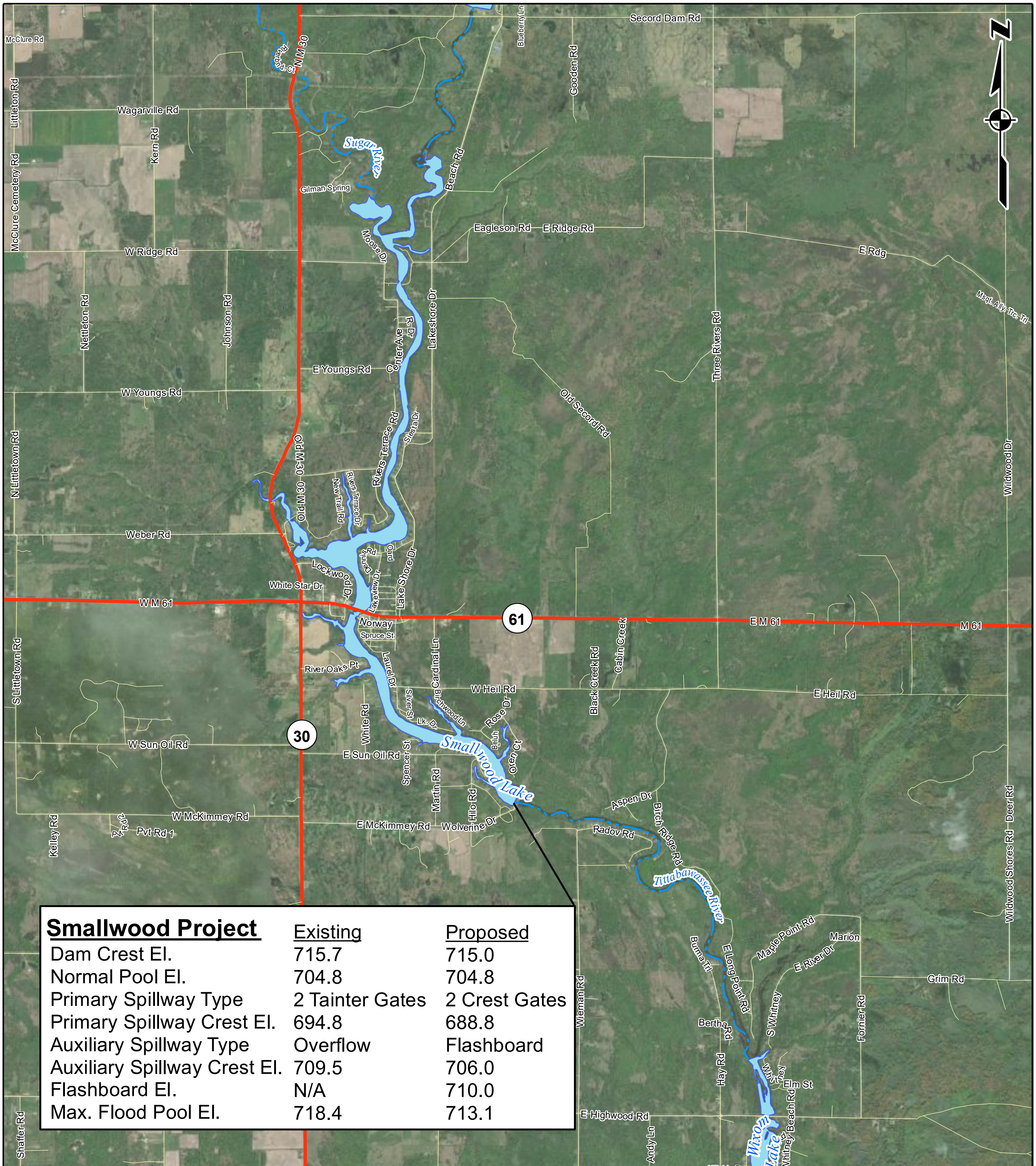
GEI Consultants

Project 2002879

SECORD DAM
SITE LOCATION MAP

March 2021

Figure 2



Smallwood Project	Existing	Proposed
Dam Crest El.	715.7	715.0
Normal Pool El.	704.8	704.8
Primary Spillway Type	2 Tainter Gates	2 Crest Gates
Primary Spillway Crest El.	694.8	688.8
Auxiliary Spillway Type	Overflow	Flashboard
Auxiliary Spillway Crest El.	709.5	706.0
Flashboard El.	N/A	710.0
Max. Flood Pool El.	718.4	713.1

0 1 2
Scale, Miles

Note: All elevations referenced to the National Geodetic Vertical Datum of 1929 (NGVD29). The acronym "El." represents Elevation.

Flood Study of the Tittabawassee River from Secord to Sanford Dam

Four Lakes Task Force
Gladwin and Midland County, Michigan

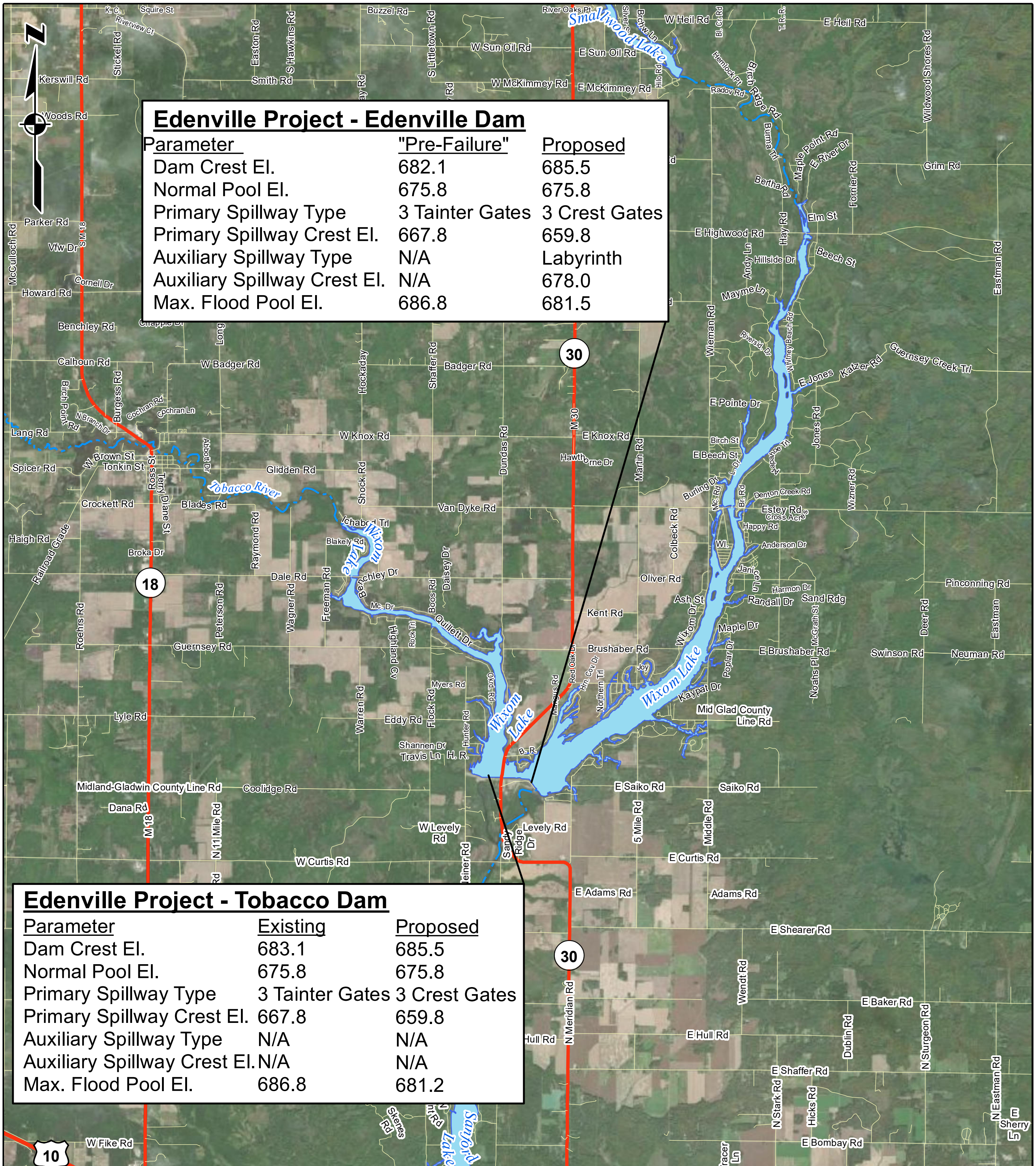
GEI Consultants

Project 2002879

SMALLWOOD DAM
SITE LOCATION MAP

March 2021

Figure 3



Edenville Project - Edenville Dam

Parameter	"Pre-Failure"	Proposed
Dam Crest El.	682.1	685.5
Normal Pool El.	675.8	675.8
Primary Spillway Type	3 Tainter Gates	3 Crest Gates
Primary Spillway Crest El.	667.8	659.8
Auxiliary Spillway Type	N/A	Labyrinth
Auxiliary Spillway Crest El.	N/A	678.0
Max. Flood Pool El.	686.8	681.5

Edenville Project - Tobacco Dam

Parameter	Existing	Proposed
Dam Crest El.	683.1	685.5
Normal Pool El.	675.8	675.8
Primary Spillway Type	3 Tainter Gates	3 Crest Gates
Primary Spillway Crest El.	667.8	659.8
Auxiliary Spillway Type	N/A	N/A
Auxiliary Spillway Crest El.	N/A	N/A
Max. Flood Pool El.	686.8	681.2

0 2 4

Scale, Miles

Note: All elevations referenced to the National Geodetic Vertical Datum of 1929 (NGVD29). The acronym "El." represents Elevation.

Flood Study of the Tittabawassee River from Secord to Sanford Dam

Four Lakes Task Force
Gladwin and Midland County, Michigan

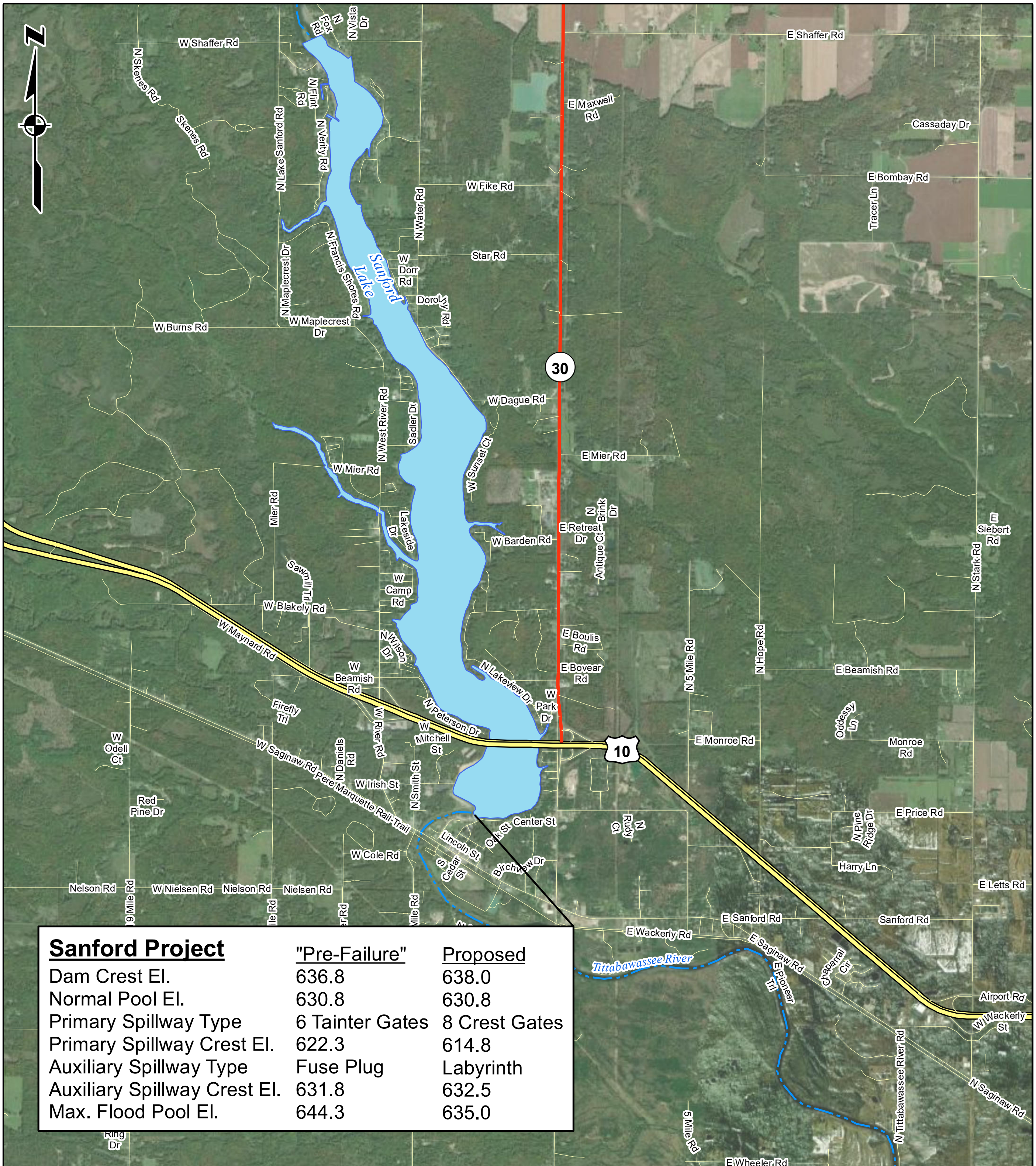
GEI Consultants

Project 2002879

EDENVILLE DAM
SITE LOCATION MAP

March 2021

Figure 4



Sanford Project

	"Pre-Failure"	Proposed
Dam Crest El.	636.8	638.0
Normal Pool El.	630.8	630.8
Primary Spillway Type	6 Tainter Gates	8 Crest Gates
Primary Spillway Crest El.	622.3	614.8
Auxiliary Spillway Type	Fuse Plug	Labyrinth
Auxiliary Spillway Crest El.	631.8	632.5
Max. Flood Pool El.	644.3	635.0

0 1 2
Scale, Miles

Note: All elevations referenced to the National Geodetic Vertical Datum of 1929 (NGVD29). The acronym "El." represents Elevation.

Flood Study of the Tittabawassee River from Secord to Sanford Dam

Four Lakes Task Force
Gladwin and Midland County, Michigan

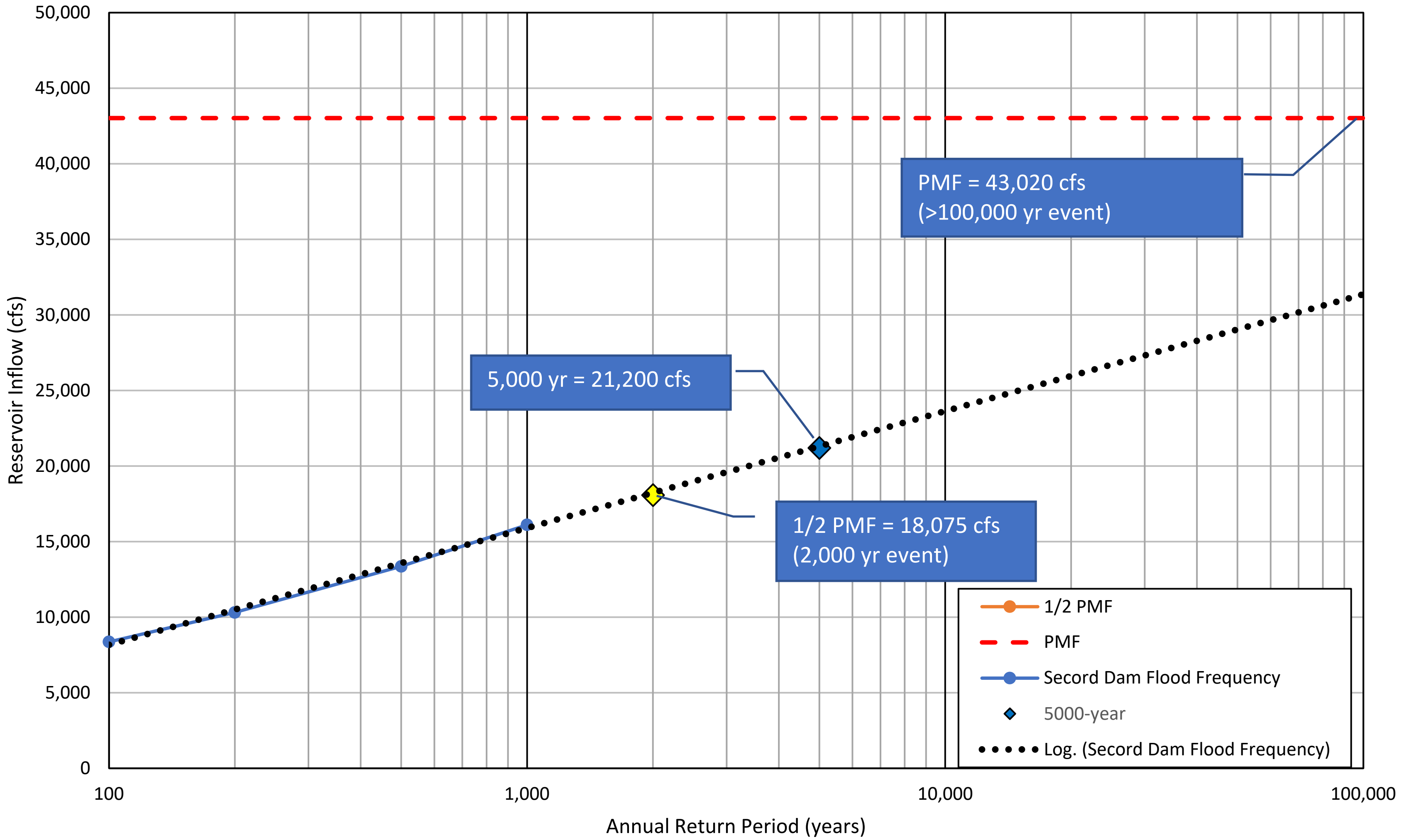
GEI Consultants

Project 2002879

SANFORD DAM
SITE LOCATION MAP

March 2021

Figure 5

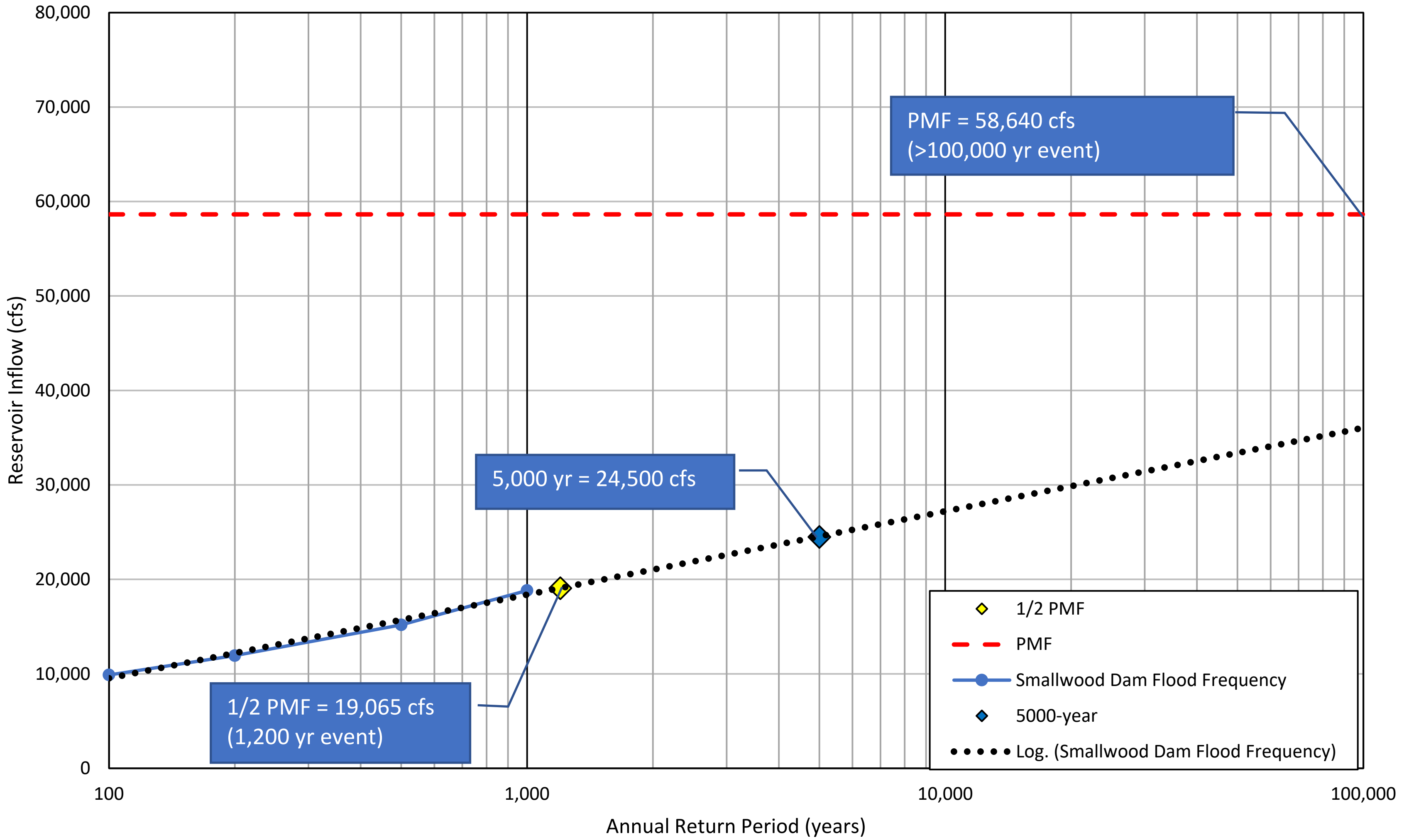


Flood Frequency and Hydraulic Analysis - Secord Dam
Client: Four Lakes Task Force (FLTF)
Location: Gladwin County, MI

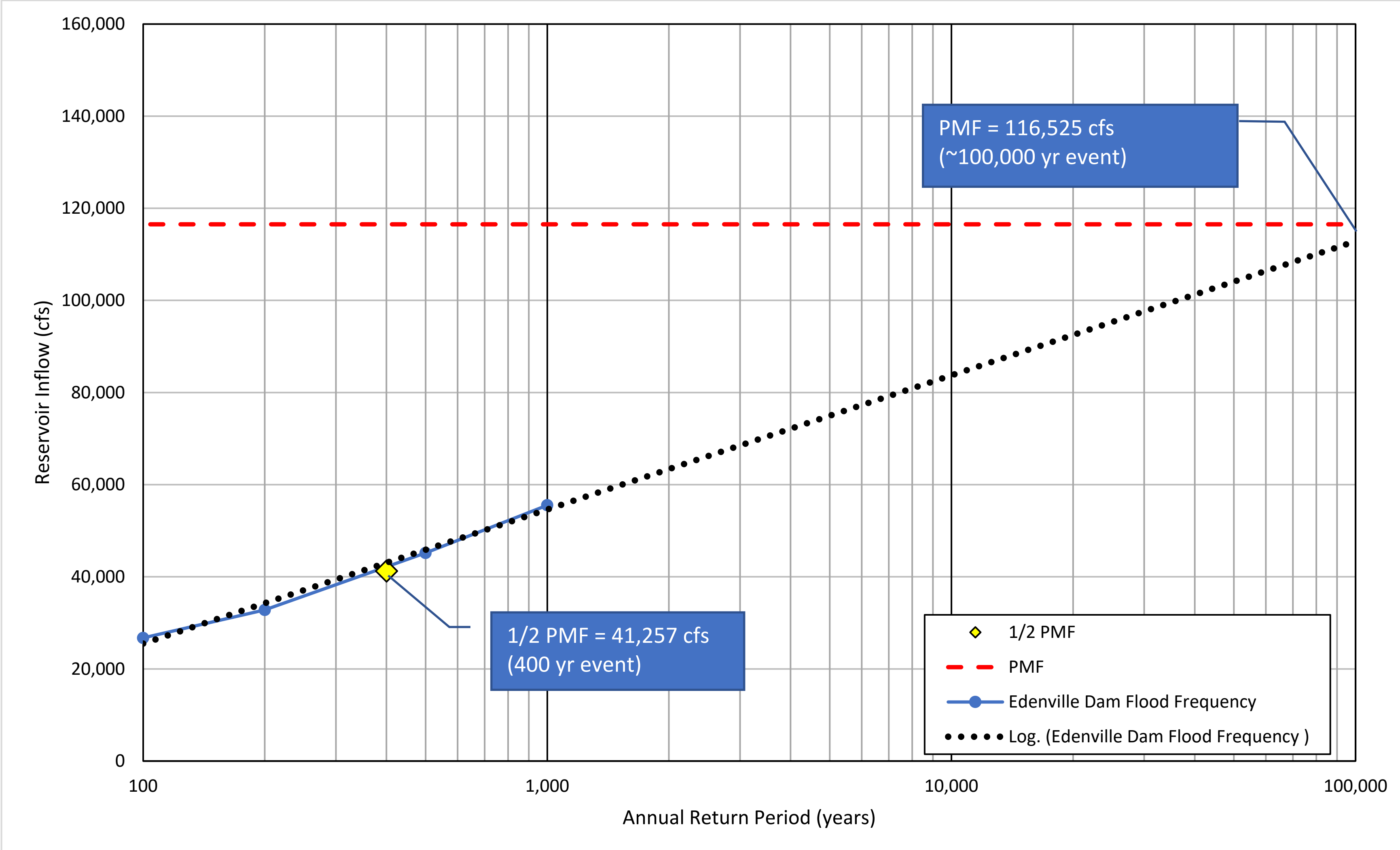
GEI Consultants

Flood Frequency
Secord Dam

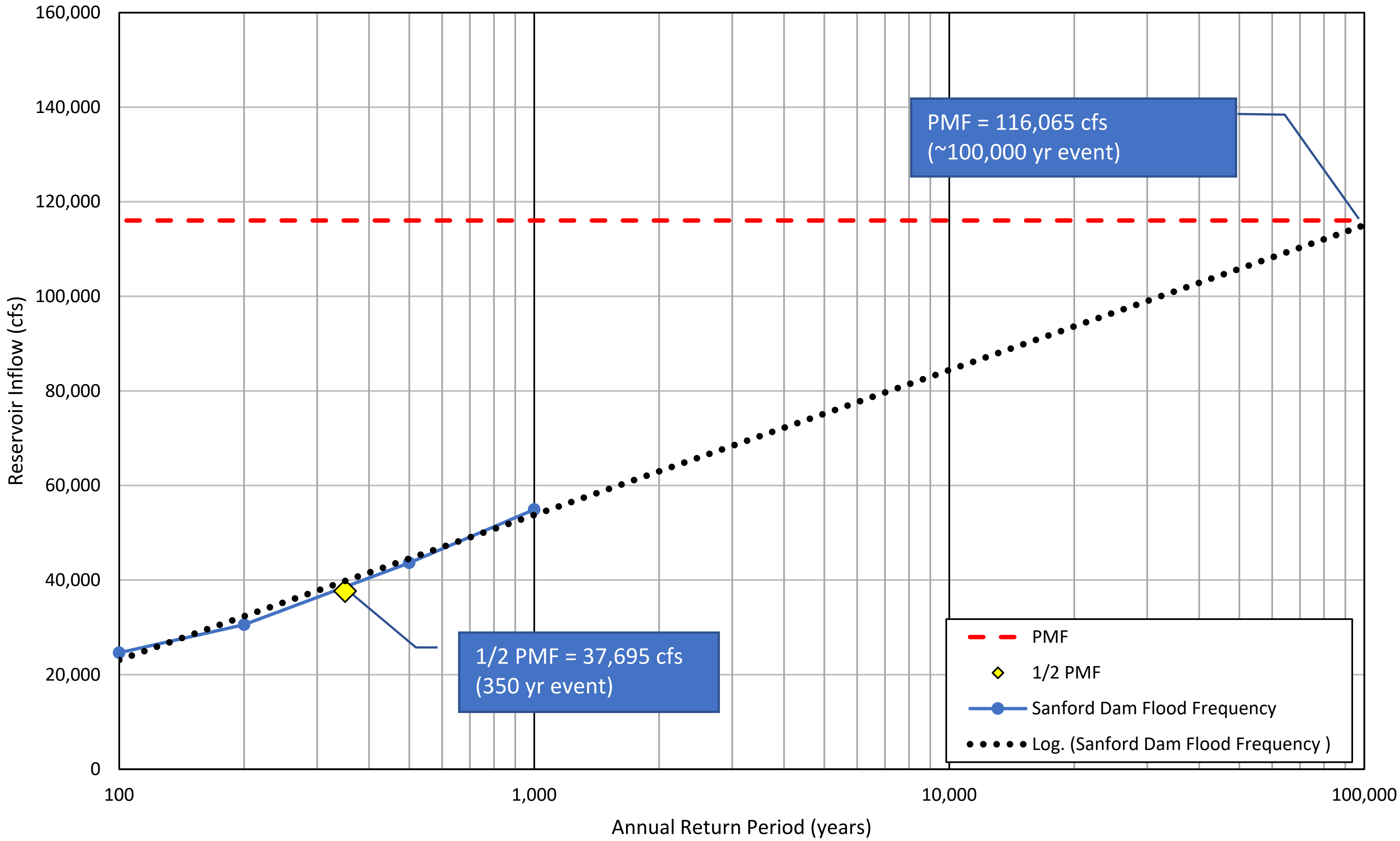
Project 2002879	**March 2021**	**Figure 6**



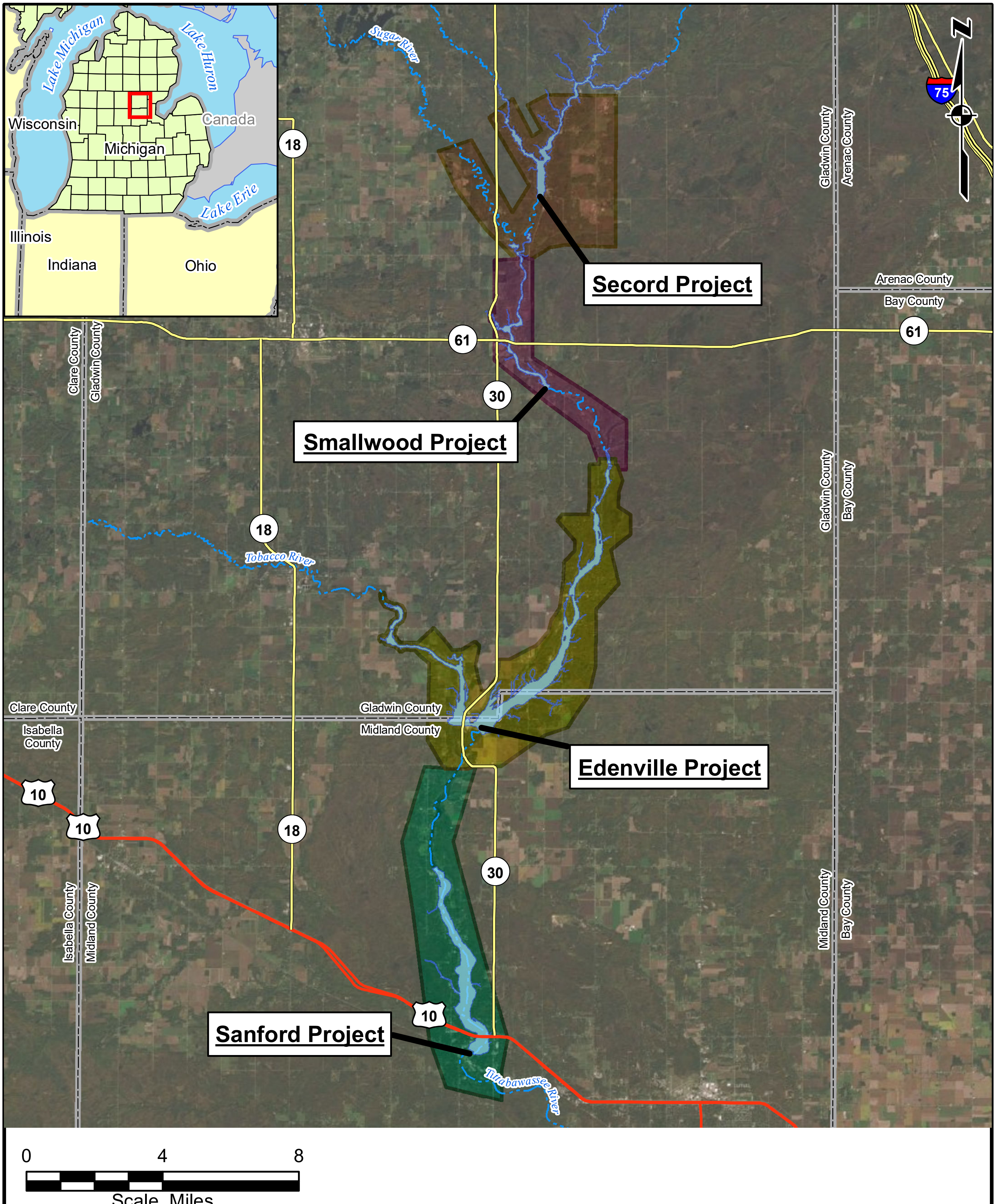
Flood Frequency and Hydraulic Analysis - Smallwood Dam **Client: Four Lakes Task Force (FLTF)** **Location: Gladwin County, MI**	GEI Consultants	**Flood Frequency** **Smallwood Dam**
	Project 2002879	**March 2021** / **Figure 7**



Flood Frequency and Hydraulic Analysis - Edenville Dam **Client: Four Lakes Task Force (FLTF)** **Location: Gladwin County, MI**	GEI Consultants	**Flood Frequency** **Edenville Dam**	
	Project 2002879	**March 2021**	**Figure 8**



Flood Frequency and Hydraulic Analysis - Sanford Dam **Client: Four Lakes Task Force (FLTF)** **Location: Midland County, MI**	GEI Consultants	**Flood Frequency** **Sanford Dam**	
	Project 2002879	**March 2021**	**Figure 9**



Flood Study of the Tittabawassee River
from Secord to Sanford Dam

Four Lakes Task Force
Gladwin and Midland County, Michigan

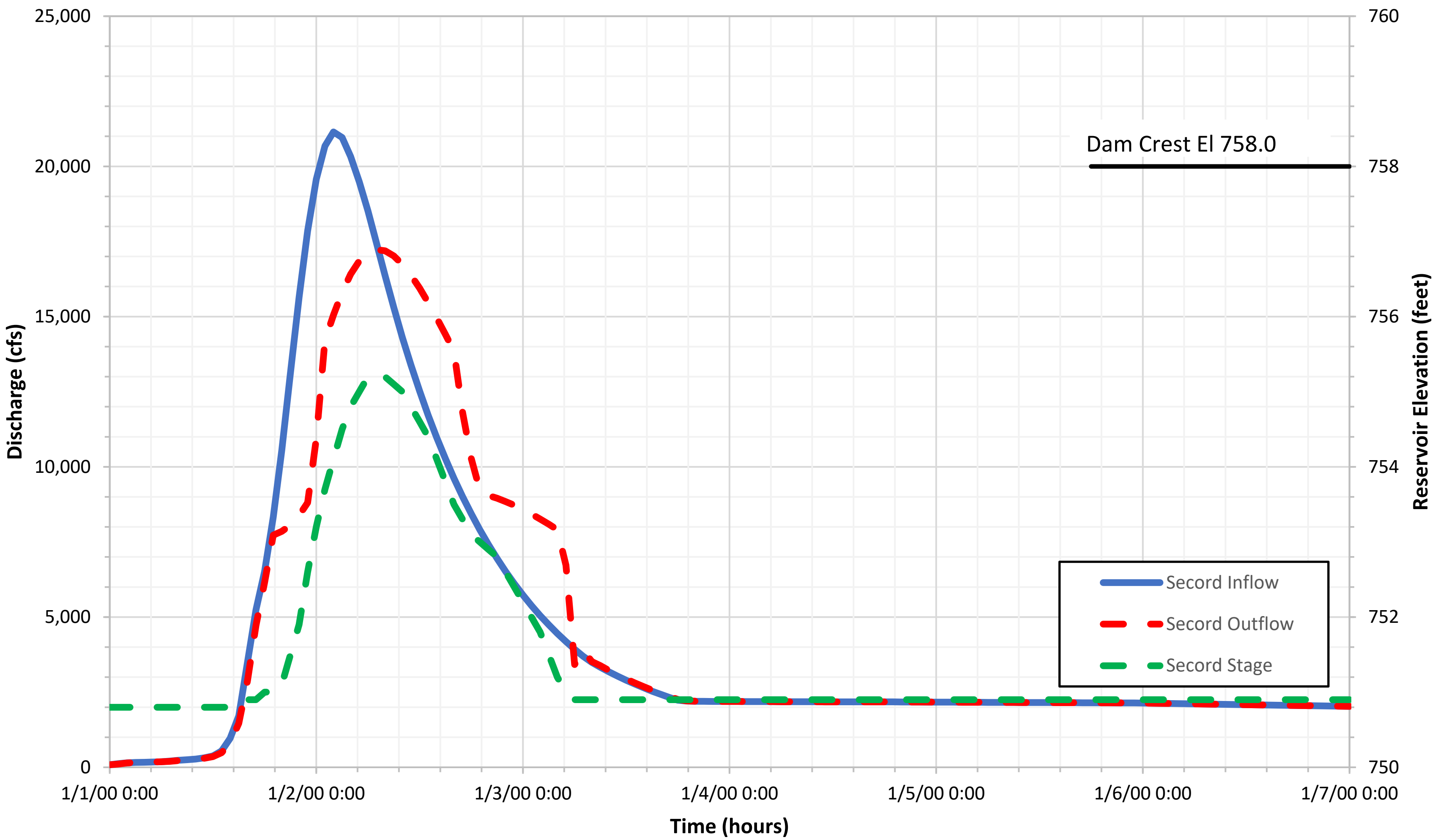
GEI Consultants

Project 2002879

FLTF
HEC-RAS MODELS
RIVER REACH MAP

March 2021

Figure 10



Secord Dam
Client: Four Lakes Task Force
Location: Gladwin County, Michigan

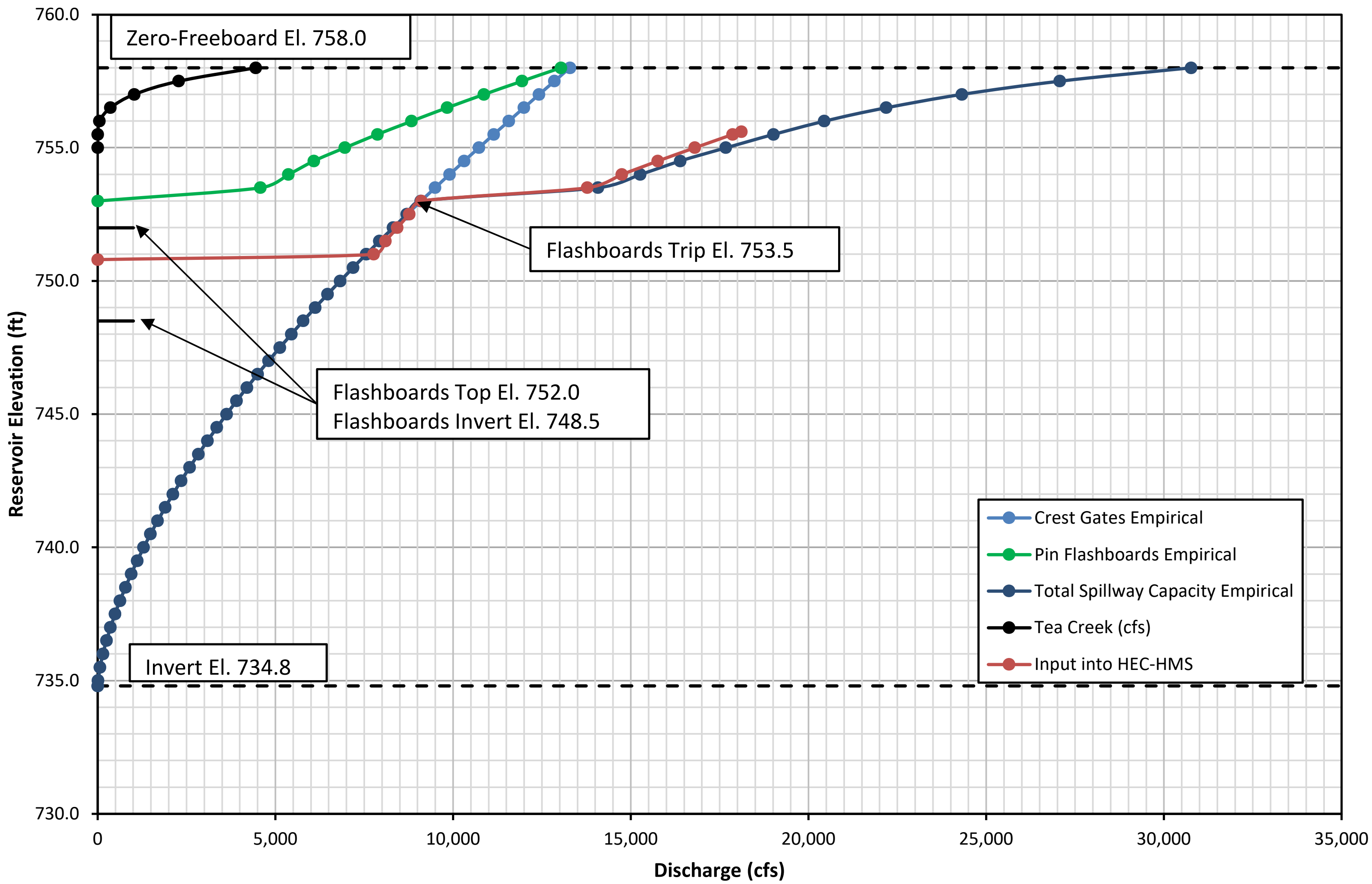
GEI Consultants

Proposed Conditions 1/2 PiMF + Flood Routing Results

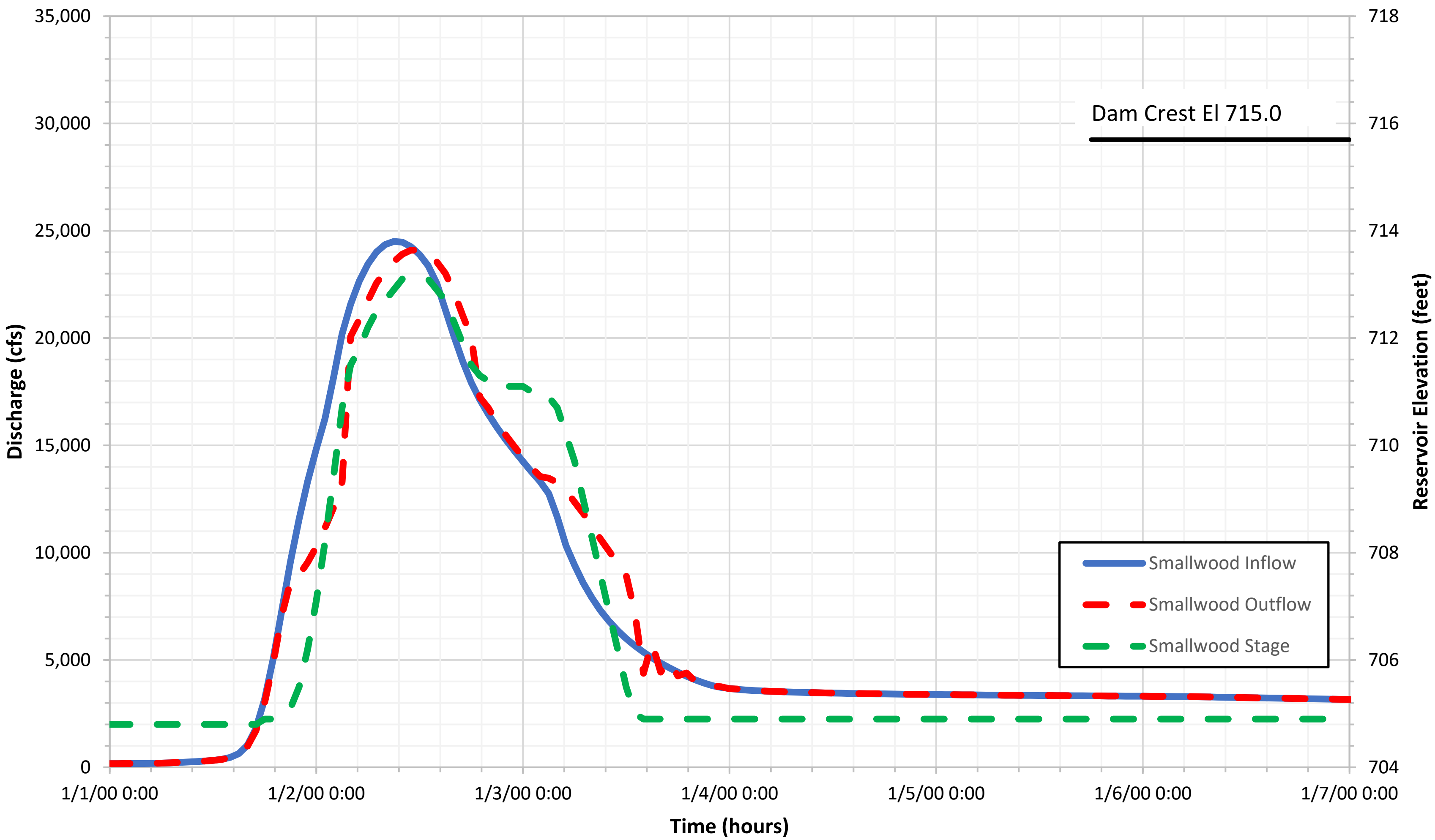
Project 2002879

March 2021

Figure 11



Secord Dam **Client: Four Lakes Task Force** **Location: Gladwin County, Michigan**	GEI Consultants	**Secord Dam 1/2 PMF + Spillway Rating Curves**
	Project 2002879	**January 2021** **Figure 12**

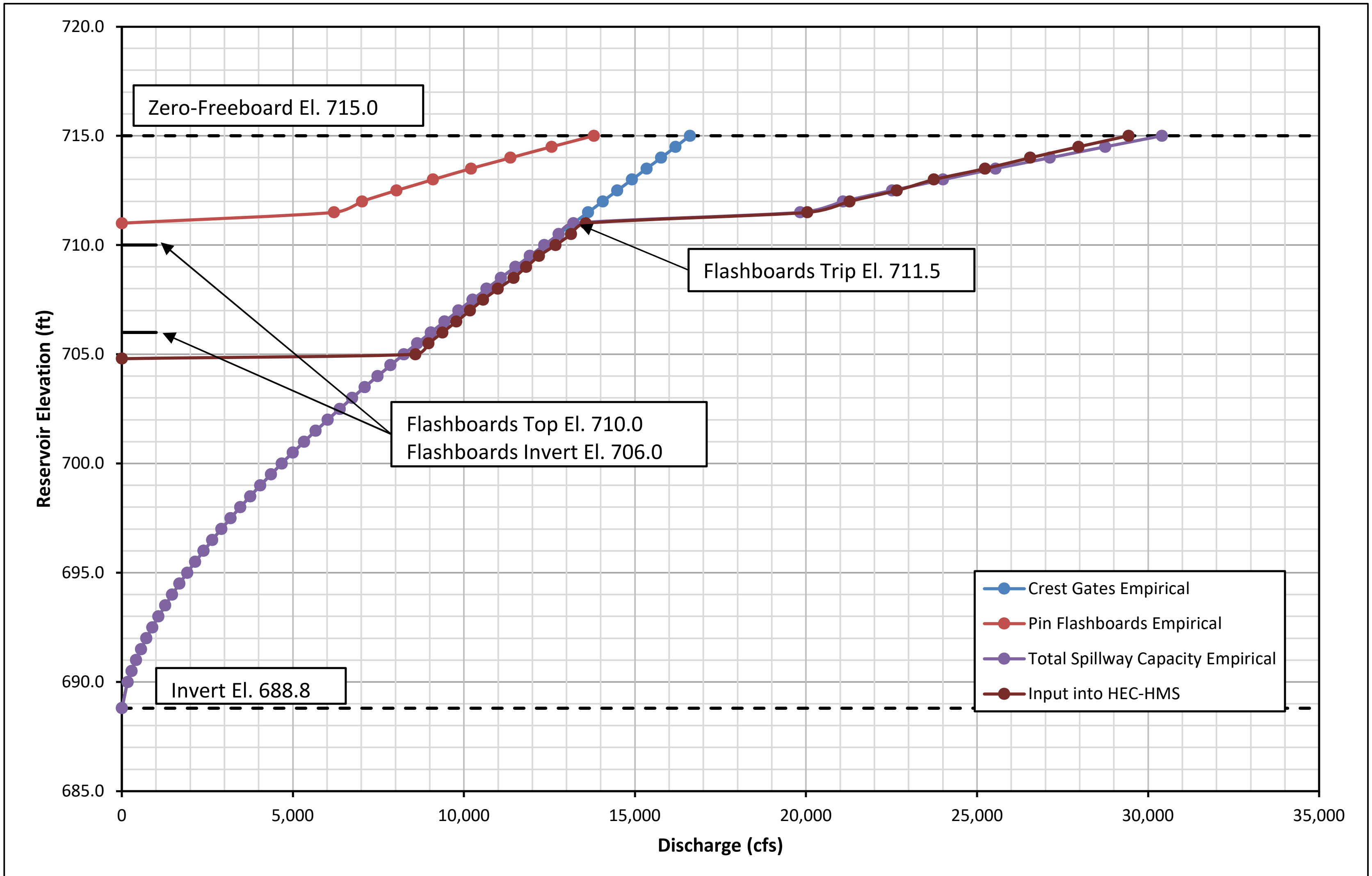


Smallwood Dam
Client: Four Lakes Task Force
Location: Gladwin County, Michigan

GEI Consultants

Proposed Conditions 1/2 PMF + Flood Routing Results

Project 2002879 | **March 2021** | **Figure 13**

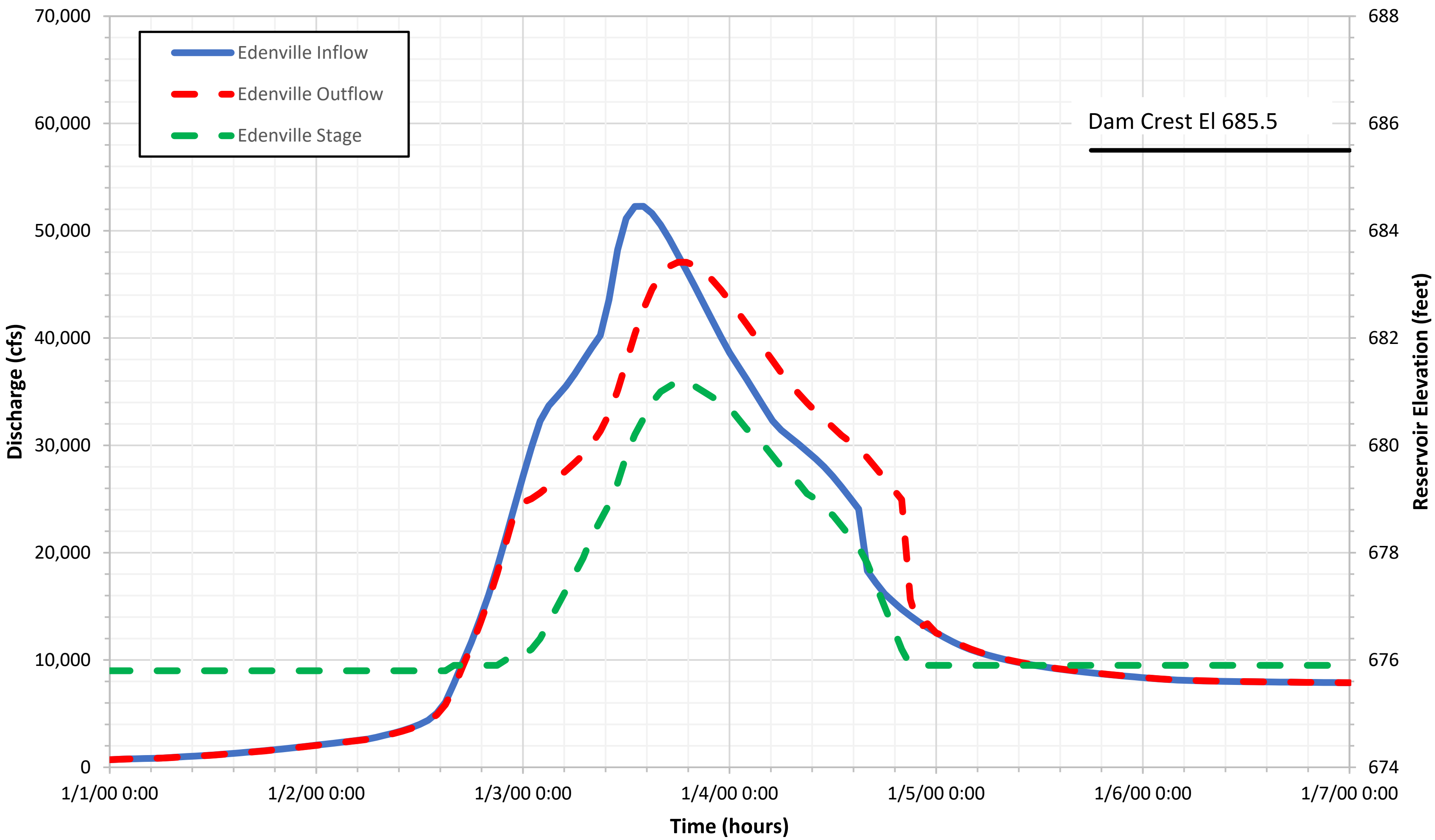


Smallwood Dam
Client: Four Lakes Task Force
Location: Gladwin County, Michigan

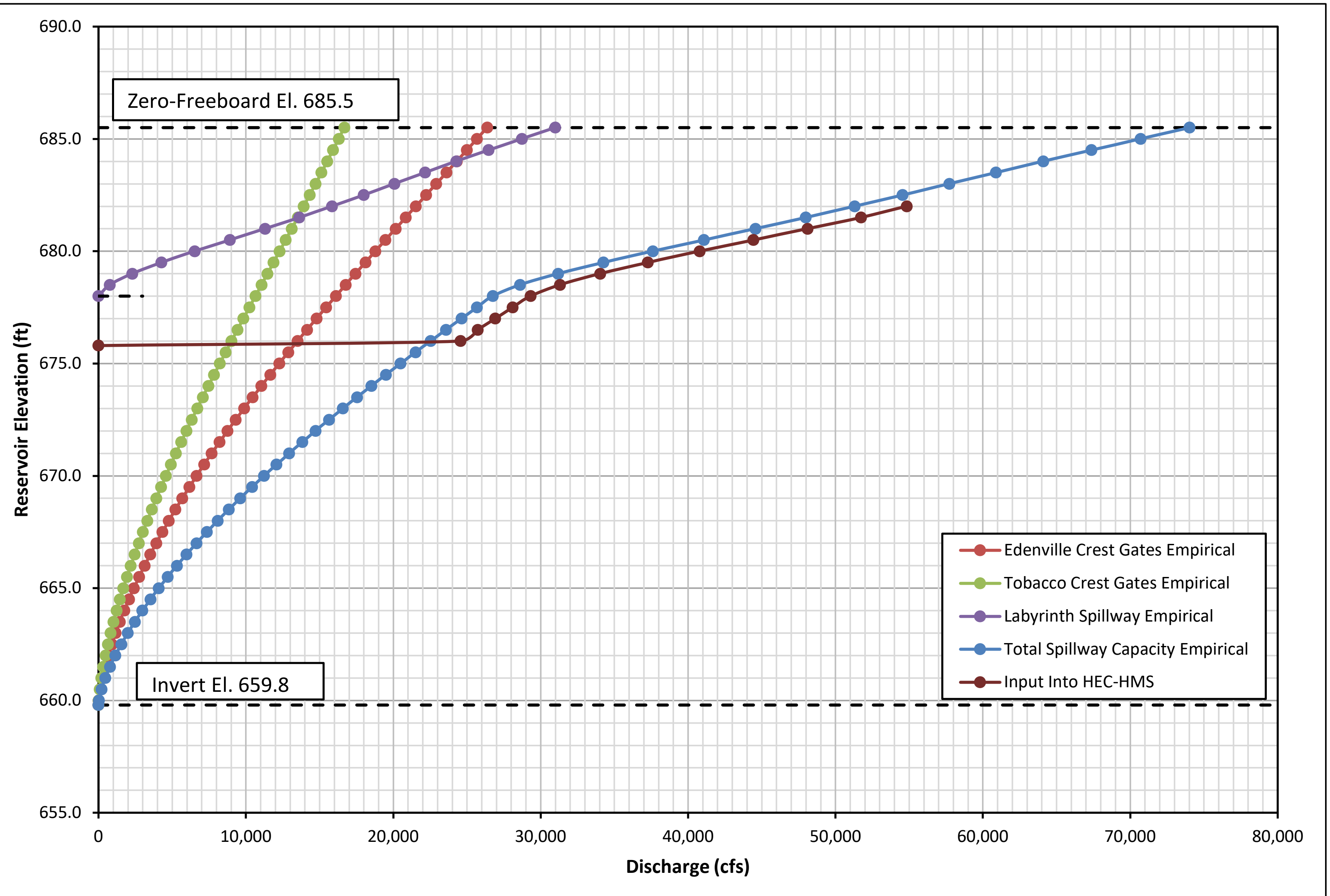
GEI Consultants

Smallwood Dam 1/2 PMF + Spillway Rating Curves

Project 2002879 | **March 2021** | **Figure 14**



Edenville Dam **Client: Four Lakes Task Force** **Location: Gladwin County, Michigan**	GEI Consultants	**Proposed Conditions 1/2 PiMF + Flood Routing Results**
	Project 2002879	**March 2021** **Figure 15**

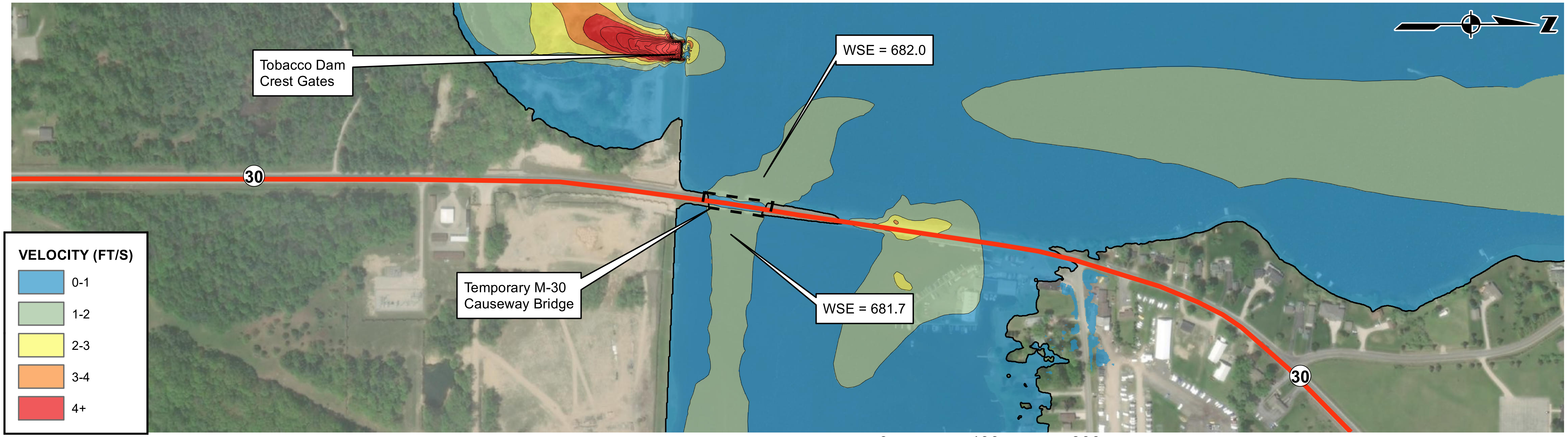


Edenville Dam
Client: Four Lakes Task Force
Location: Gladwin County, Michigan

GEI Consultants

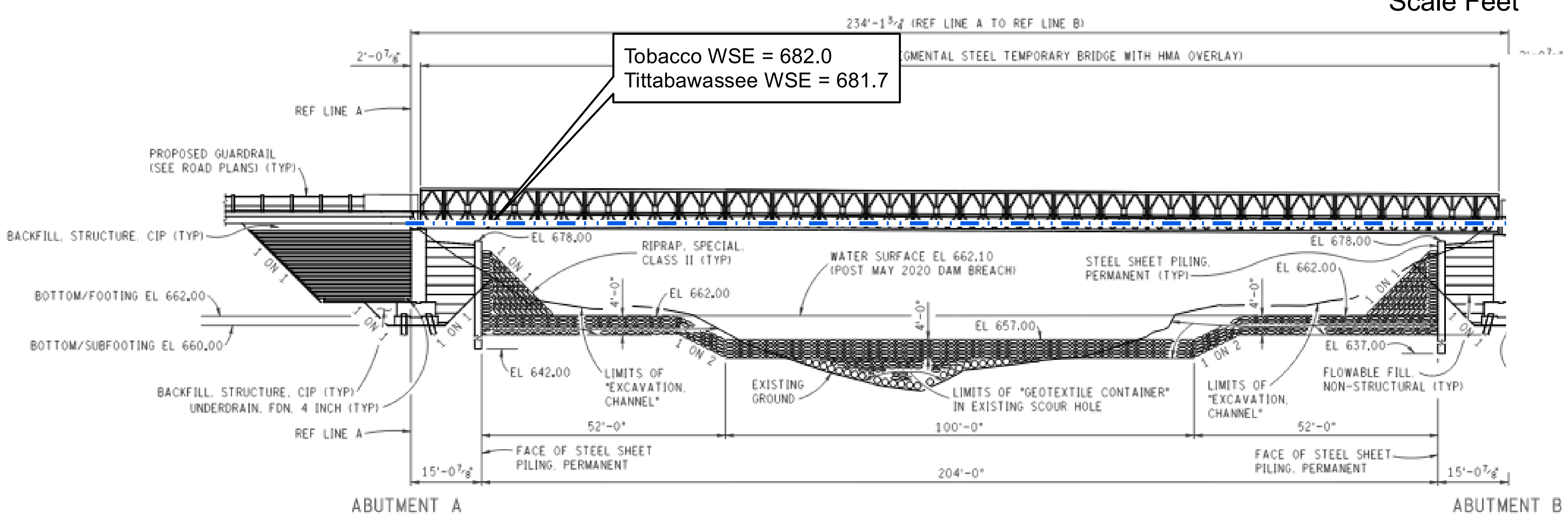
Edenville Dam 1/2 PMF + Spillway Rating Curves

Project 2002879 | **March 2021** | **Figure 16**

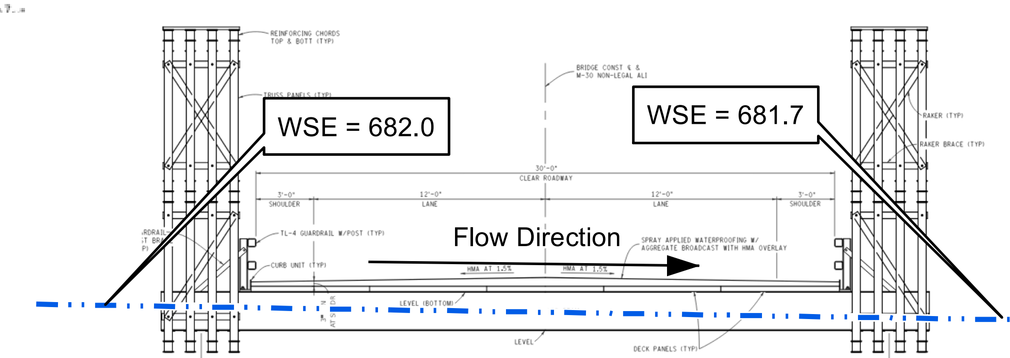


PLAN
M-30 CAUSEWAY VELOCITY

0 400 800
Scale Feet



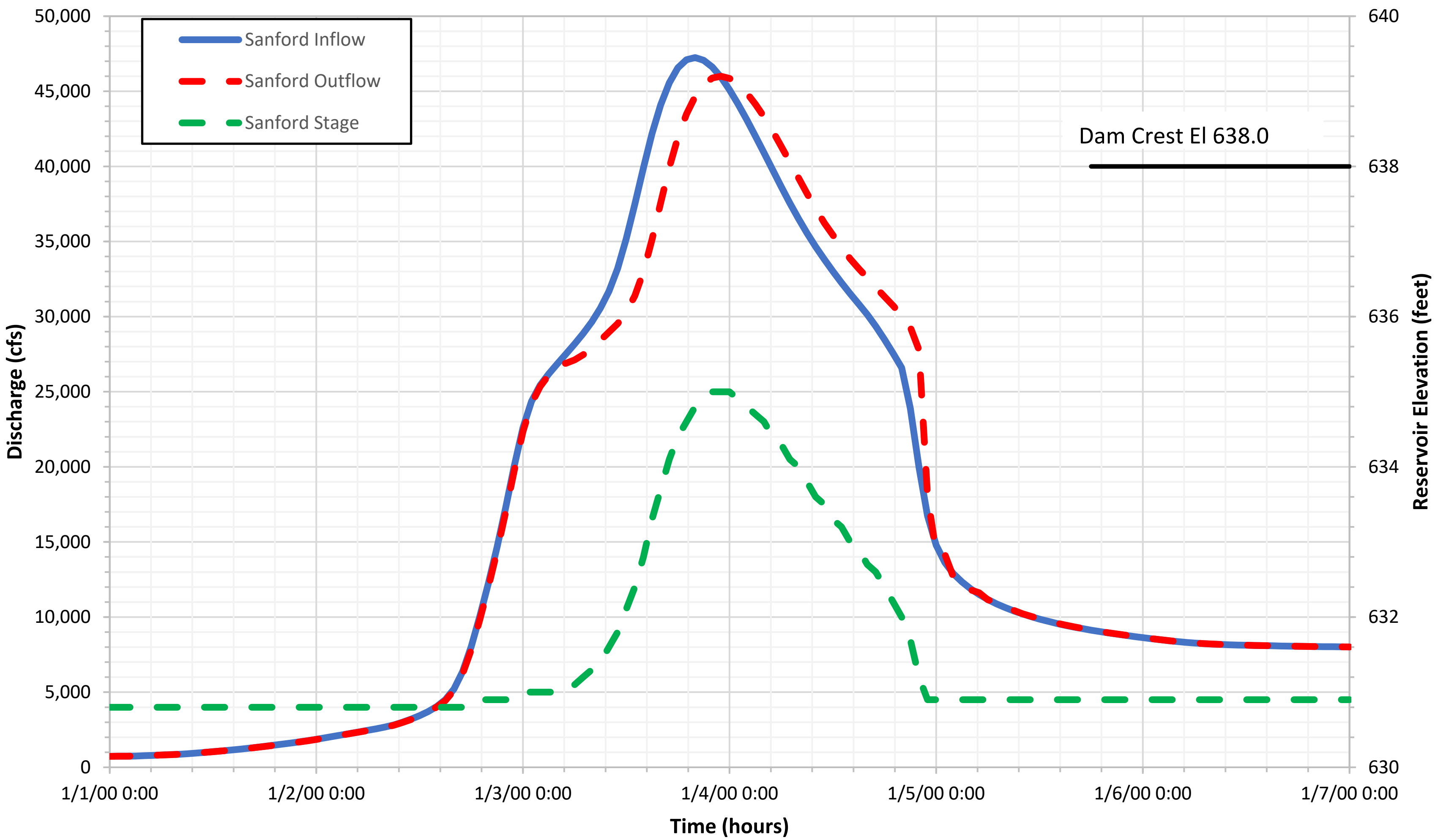
ELEVATION
M-30 CAUSEWAY WATER SURFACE
NOT TO SCALE



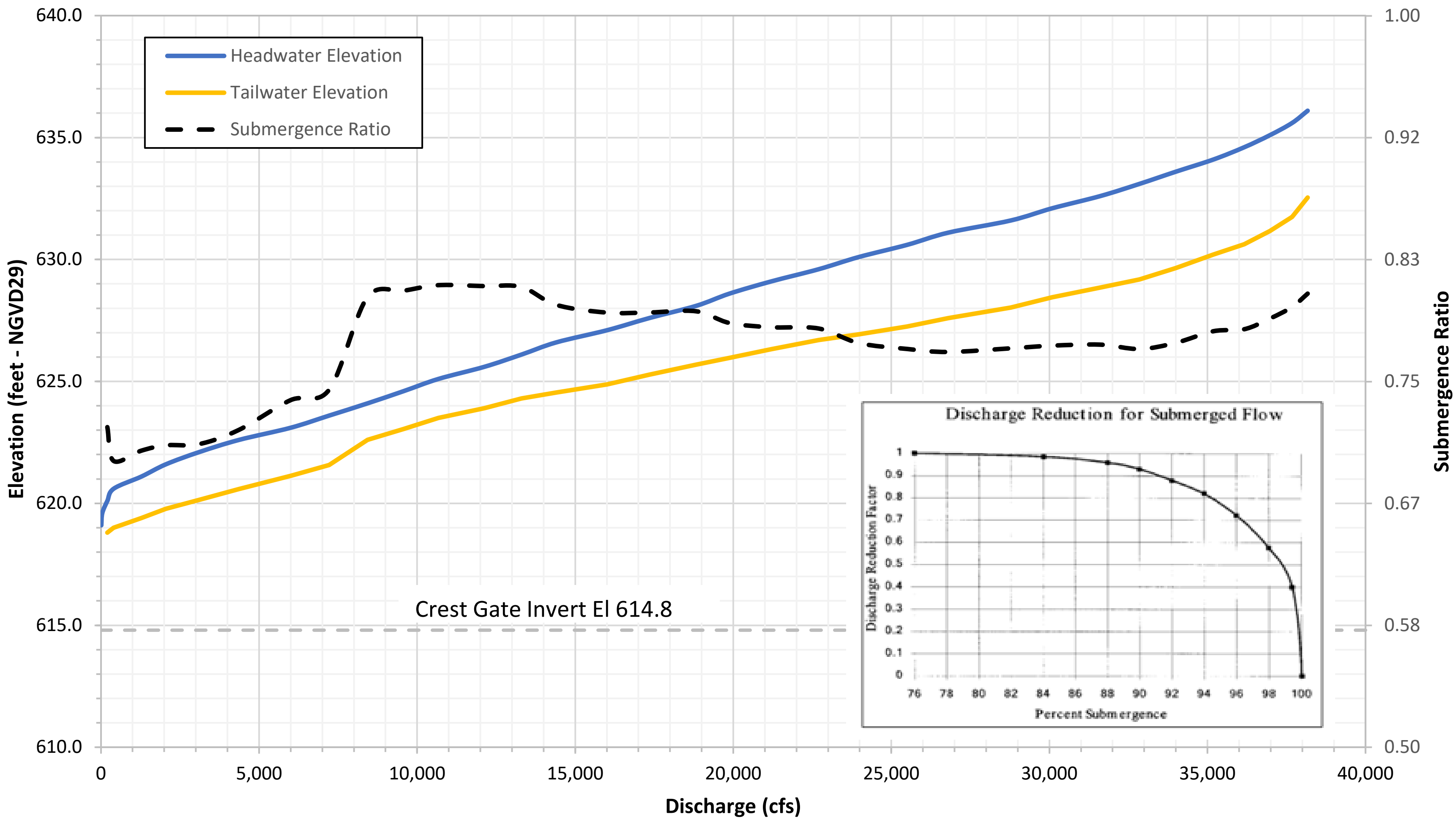
SECTION
M-30 CAUSEWAY WATER SURFACE
NOT TO SCALE

Notes:
1. All elevations referenced to the National Geodetic Vertical Datum of 1929 (NGVD29). The acronym "El." represents Elevation.

Flood Study of the Tittabawassee River from Secord to Sanford Dam	GEI Consultants	EDENVILLE DAM M-30 CAUSEWAY BRIDGE FLOOD ROUTING
Four Lakes Task Force Gladwin and Midland County, Michigan	Project 2002879	March 2021 Figure 17

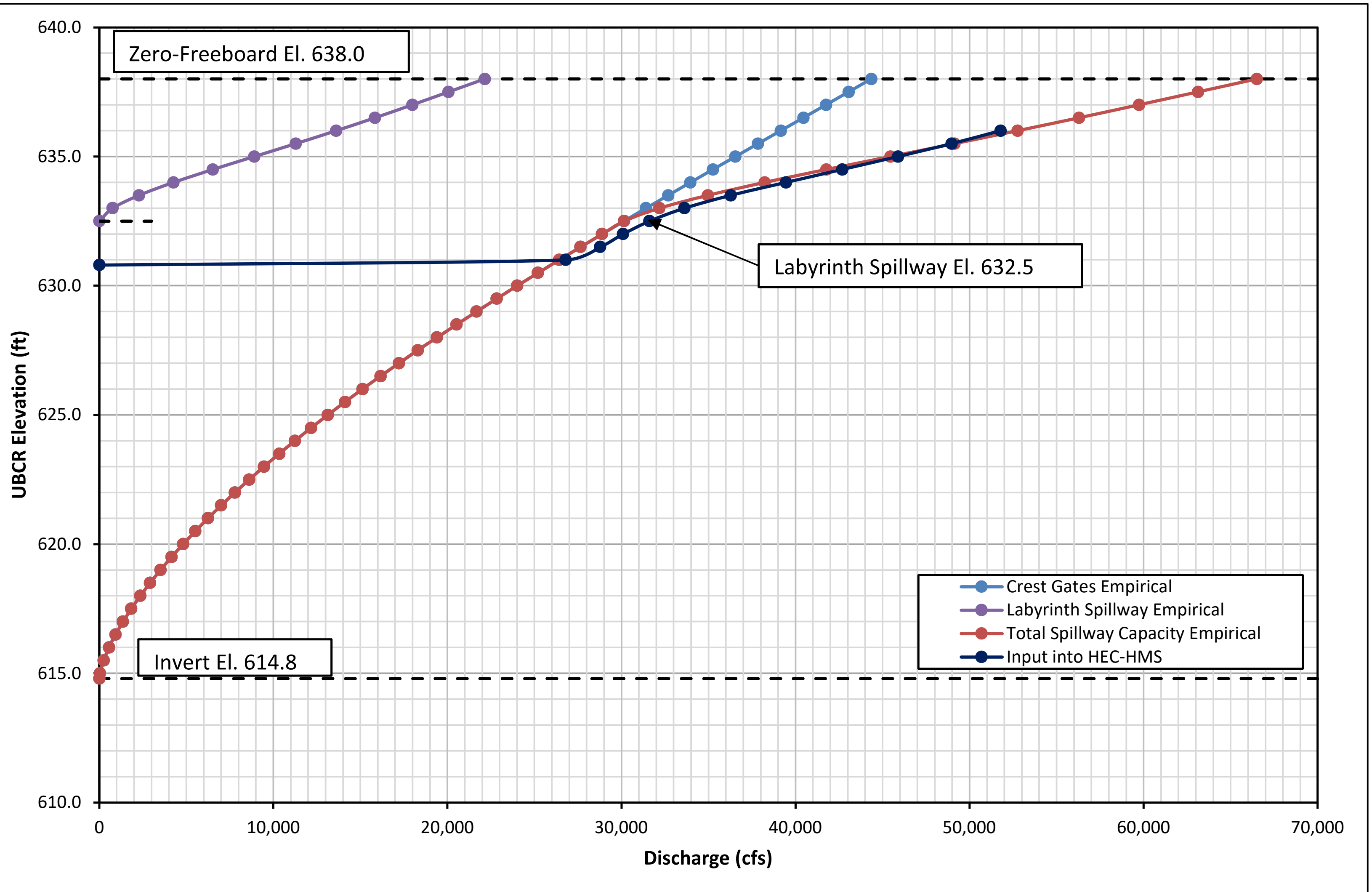


Sanford Dam **Client: Four Lakes Task Force** **Location: Midland County, Michigan**	GEI Consultants	**Proposed Conditions 1/2 PMF + Flood Routing Results**
	Project 2002879	**March 2021** **Figure 18**



Note: Submergence Ratio = (Tailwater Elevation - Gate Invert) / (Headwater Elevation - Gate Invert)

Sanford Dam **Client: Four Lakes Task Force** **Location: Gladwin County, Michigan**	GEI Consultants	**Sanford Dam Tailwater Submergence with 100-year Salt River Flow**
	Project 2002879	**March 2021** **Figure 19**



Sanford Dam **Client: Four Lakes Task Force** **Location: Midland County, Michigan**	GEI Consultants	**Sanford Dam Spillway Rating Curves**
	Project 2002879	**March 2021** **Figure 20**

Appendix A

Exhibit F Drawings

Appendix A.1 – Secord Dam

Appendix A.2 – Smallwood Dam

Appendix A.3 – Edenville Dam

Appendix A.4 – Sanford Dam

Appendix A

Exhibit F Drawings

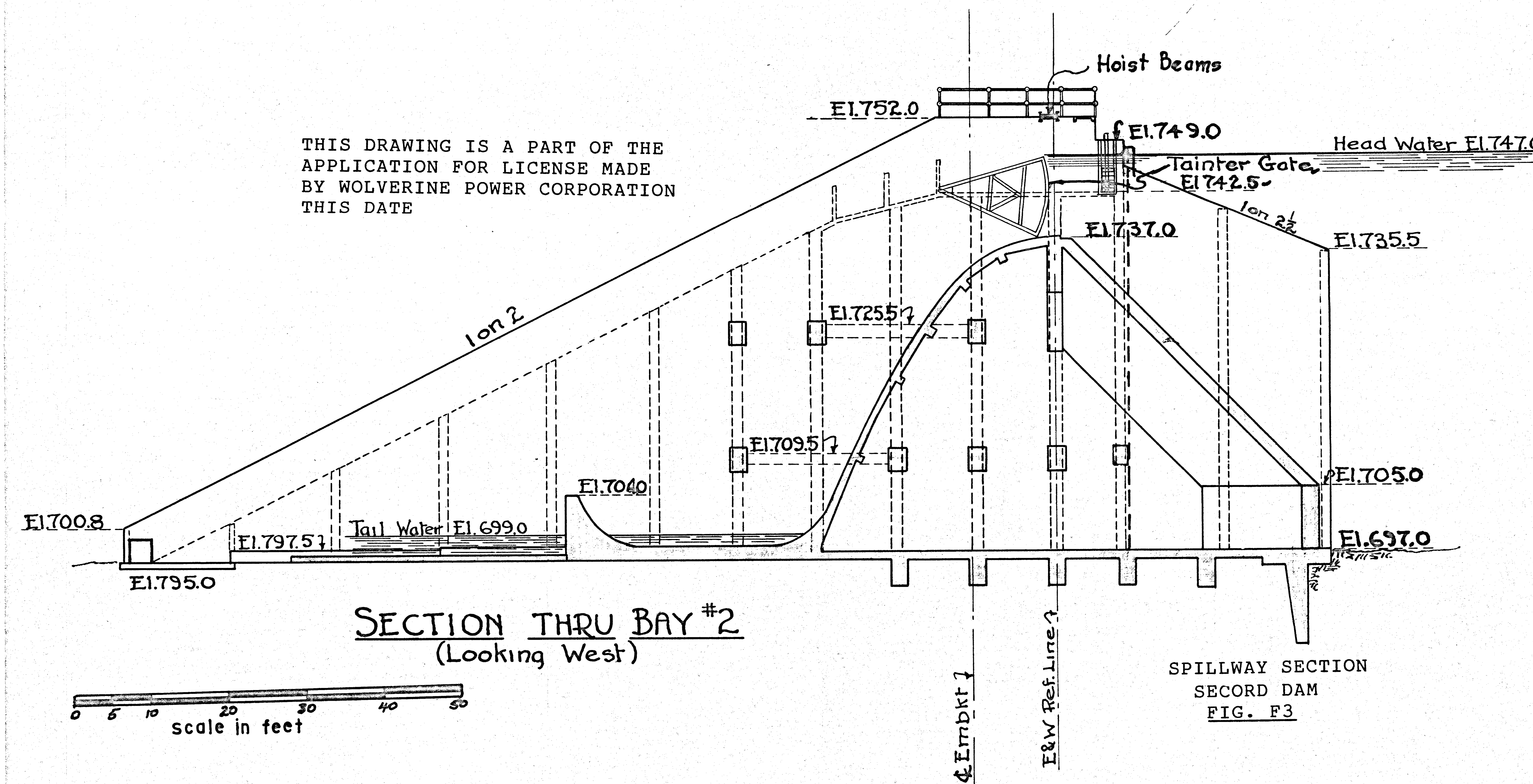
Appendix A.1 – Secord Dam


drawn using HAH 1923 survey
N
UP Stream
Secord Lake
Powerhouse
Fig. 4. Section
Spillway
Fig 3 Section
Embankment
Fig. 5. Section
Down Stream
Smallwood Lake
n/s 1/4 line
section 15
section 22
750
740
730
720
710
700
700
710
720
730
740
750
THIS DRAWING IS A PART OF THE
APPLICATION FOR LICENSE MADE
BY WOLVERINE POWER CORPORATION
THIS DATE
0 50 100 200 300
scale in feet
PC 11/86
WOLVERINE POWER CORP
SECORD DAM
SURVEY PLAN
FIG. F1

THIS DRAWING IS A PART OF THE APPLICATION FOR LICENSE MADE BY WOLVERINE POWER CORPORATION THIS DATE

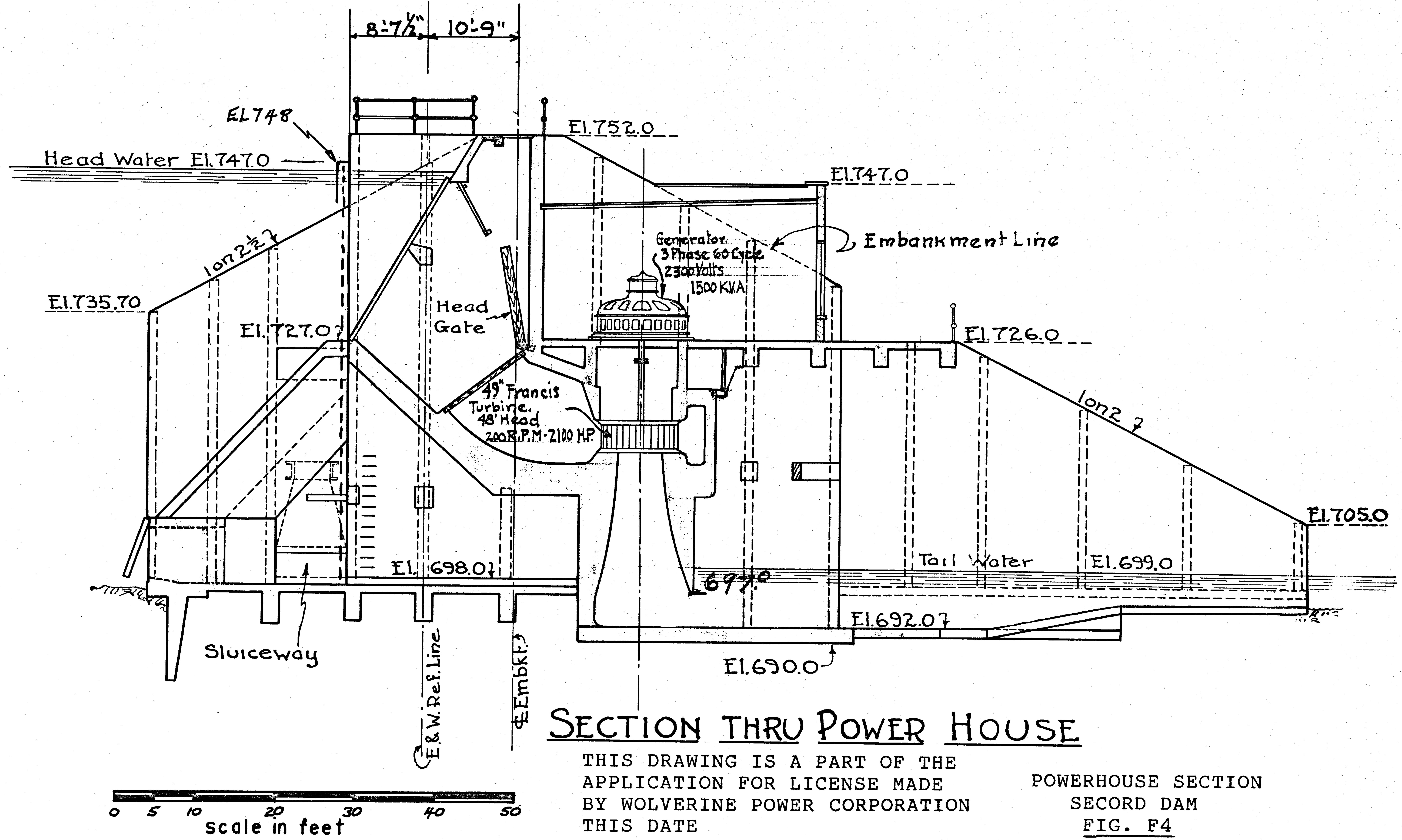
PLAN VIEW
SECORD DAM
FIG. F2

THIS DRAWING IS A PART OF THE
APPLICATION FOR LICENSE MADE
BY WOLVERINE POWER CORPORATION
THIS DATE



SECTION THRU BAY #2
(Looking West)

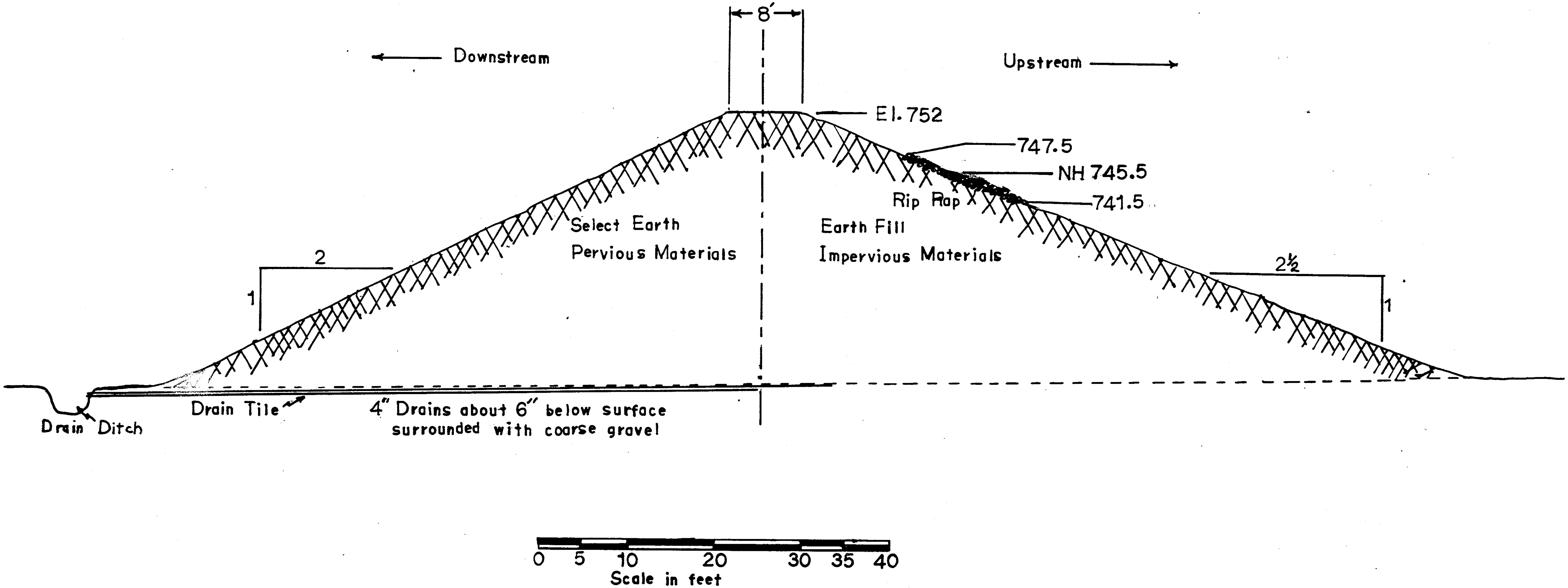
SPILLWAY SECTION
SECORD DAM
FIG. F3



SECTION THRU POWER HOUSE

THIS DRAWING IS A PART OF THE APPLICATION FOR LICENSE MADE BY WOLVERINE POWER CORPORATION THIS DATE

POWERHOUSE SECTION
SECORD DAM
FIG. F4



Embankment Section
Secord Dam
Fig. F5

Appendix A

Exhibit F Drawings

Appendix A.2 – Smallwood Dam

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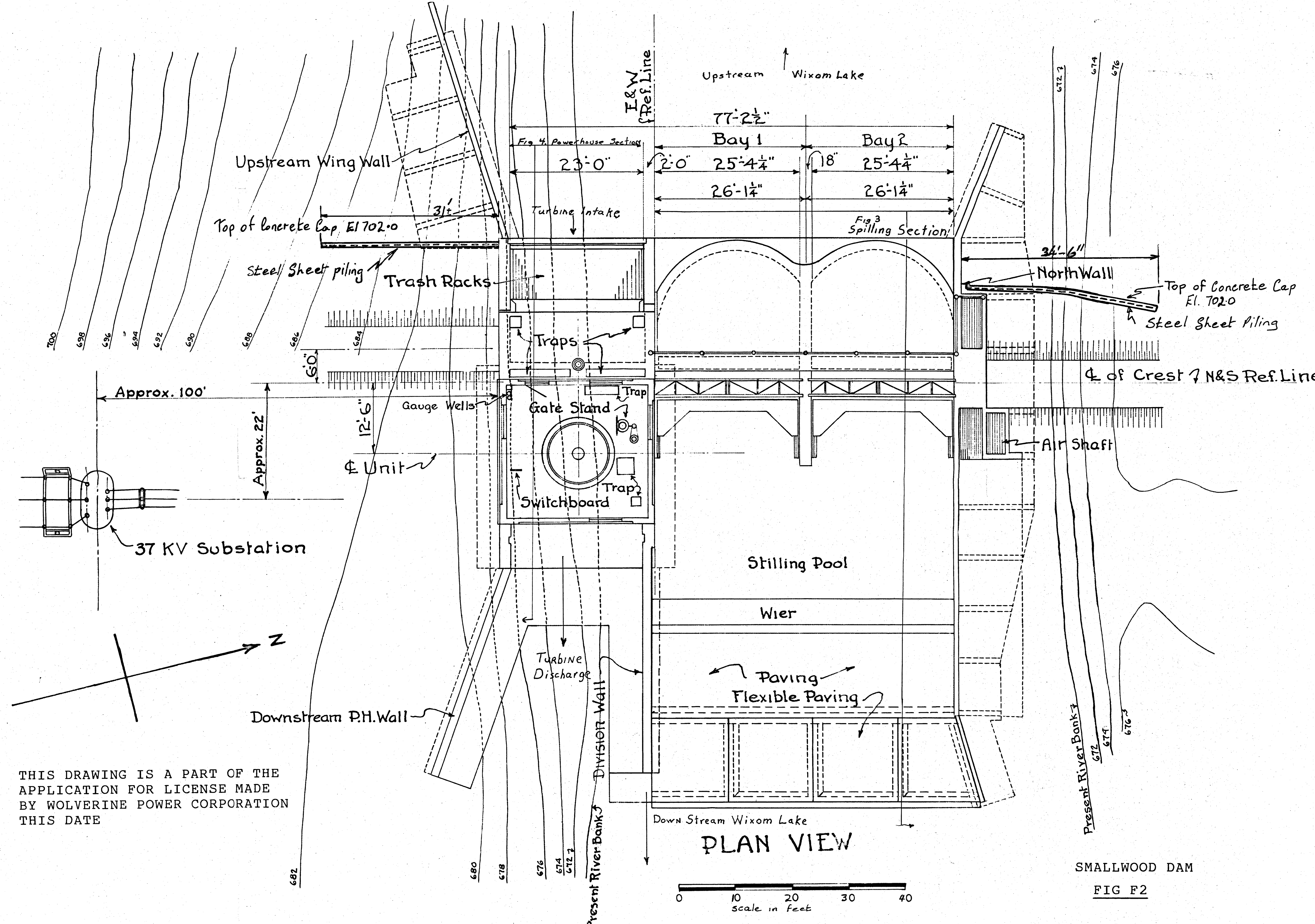
THIS DATE



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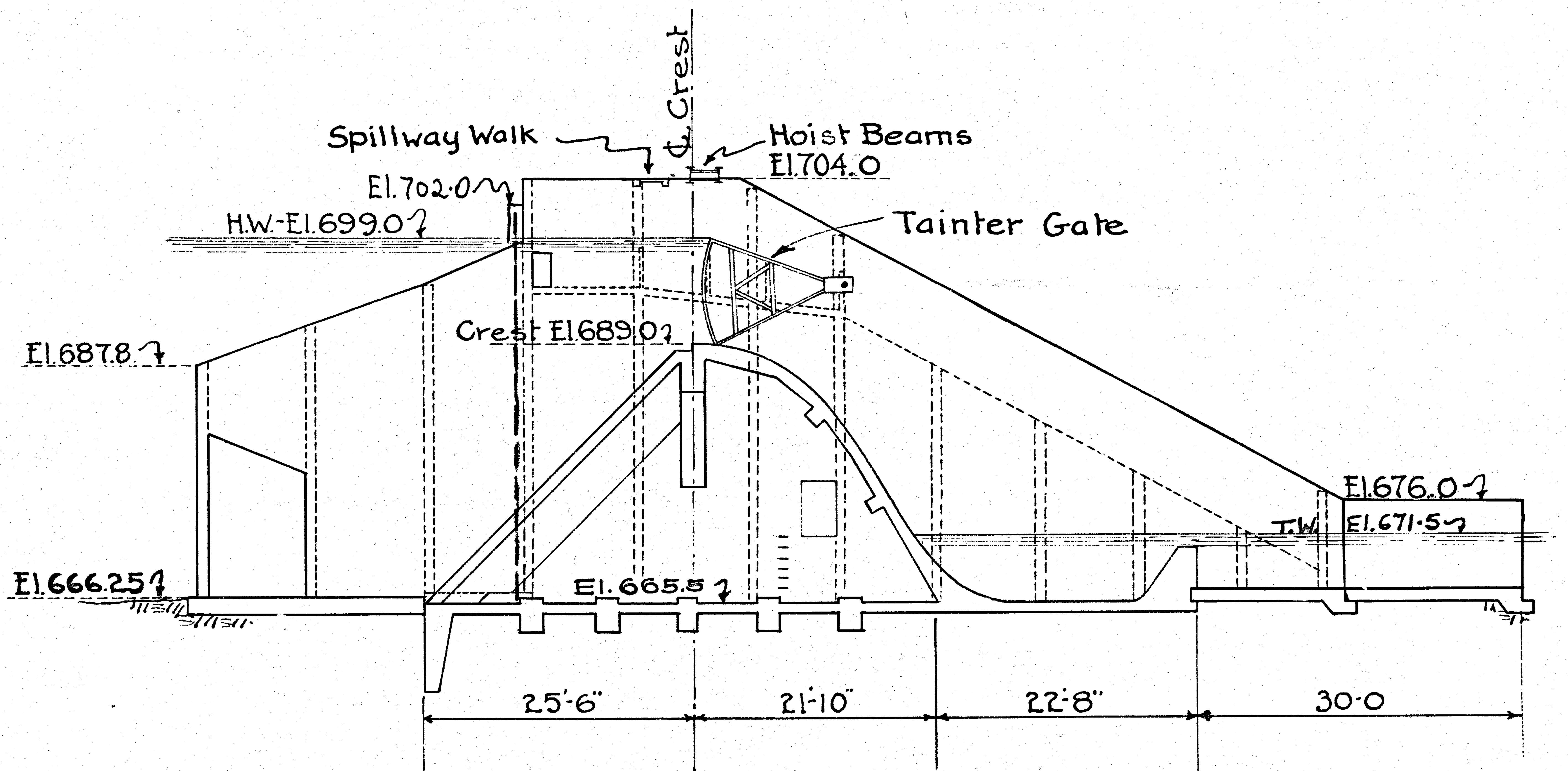
APPLICATION FOR LICENSE MADE
BY WOLVERINE POWER CORPORATION
THIS DATE

PLAN VIEW

SMALLWOOD DAM

FIG F2



SECTION THRU BAY 2
(Looking North)

0 10 20 30 40
Scale in Feet

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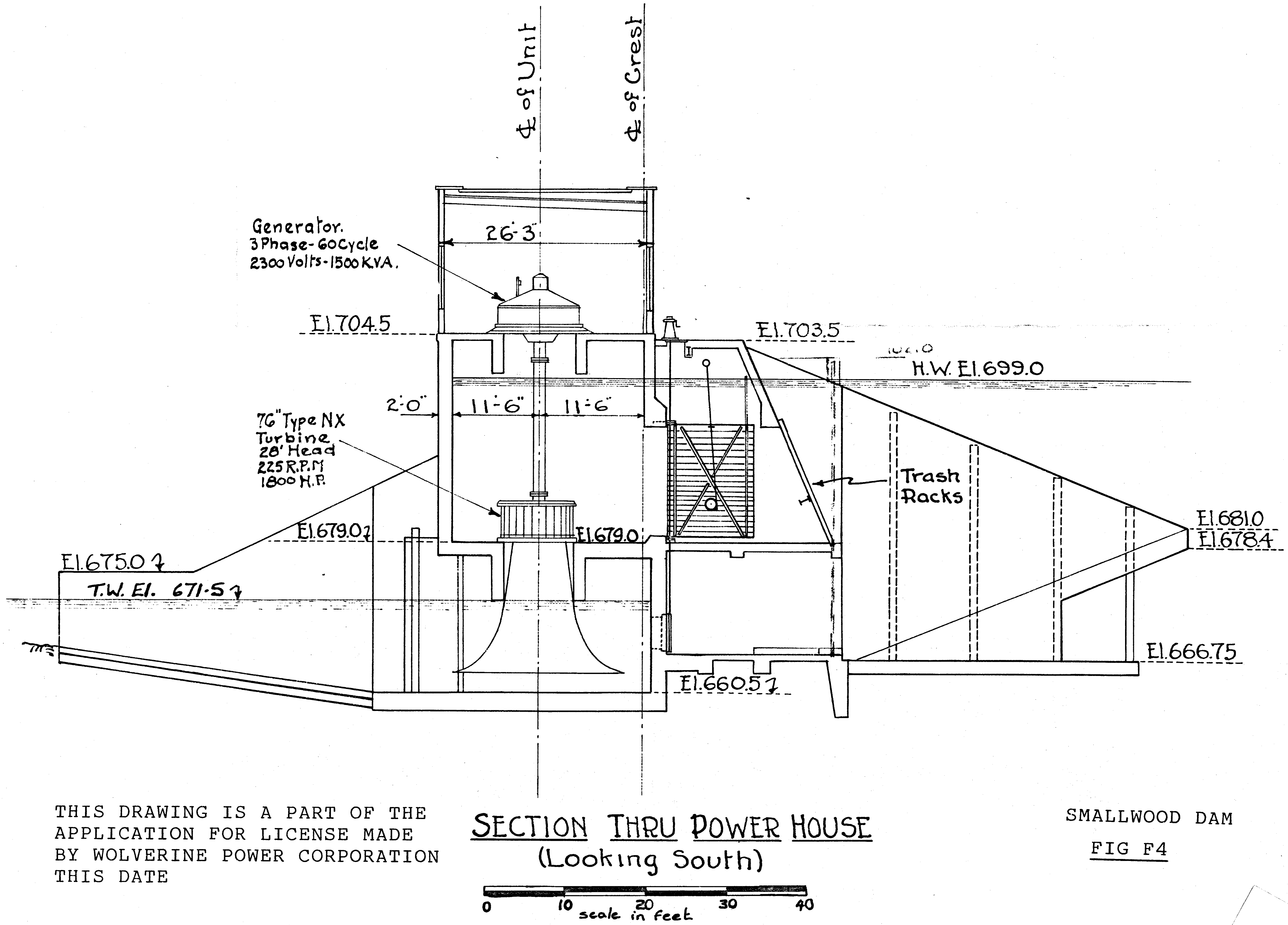
APPLICATION FOR LICENSE MADE
BY WOLVERINE POWER CORPORATION
THIS DATE

SMALLWOOD DAM

FIG F3

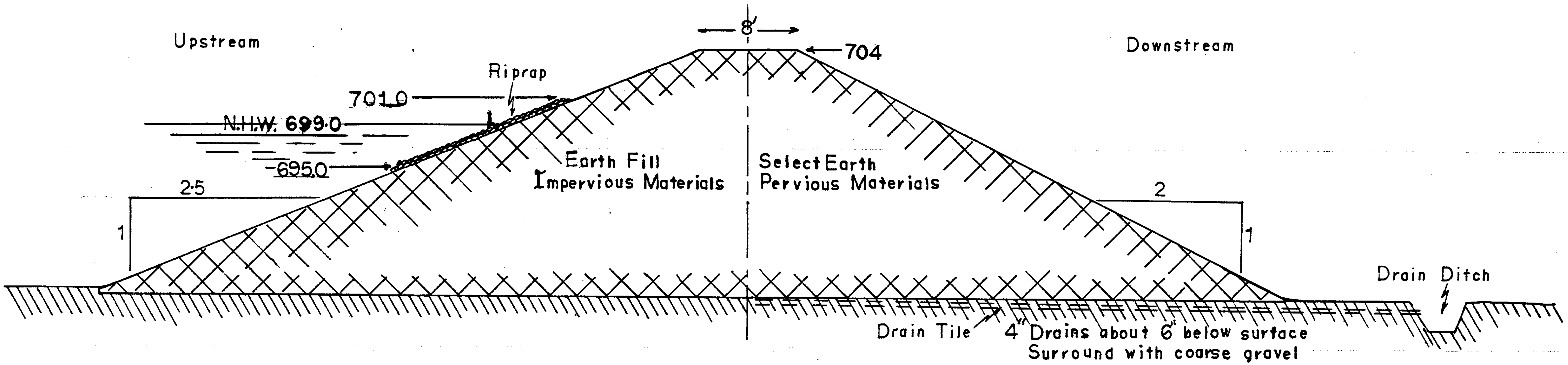


THIS DRAWING IS A PART OF THE APPLICATION FOR LICENSE MADE BY WOLVERINE POWER CORPORATION THIS DATE

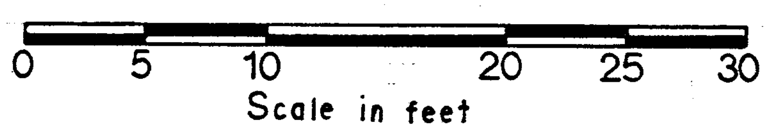
SECTION THRU POWER HOUSE
(Looking South)

SMALLWOOD DAM

FIG F4



P.C. 10/86



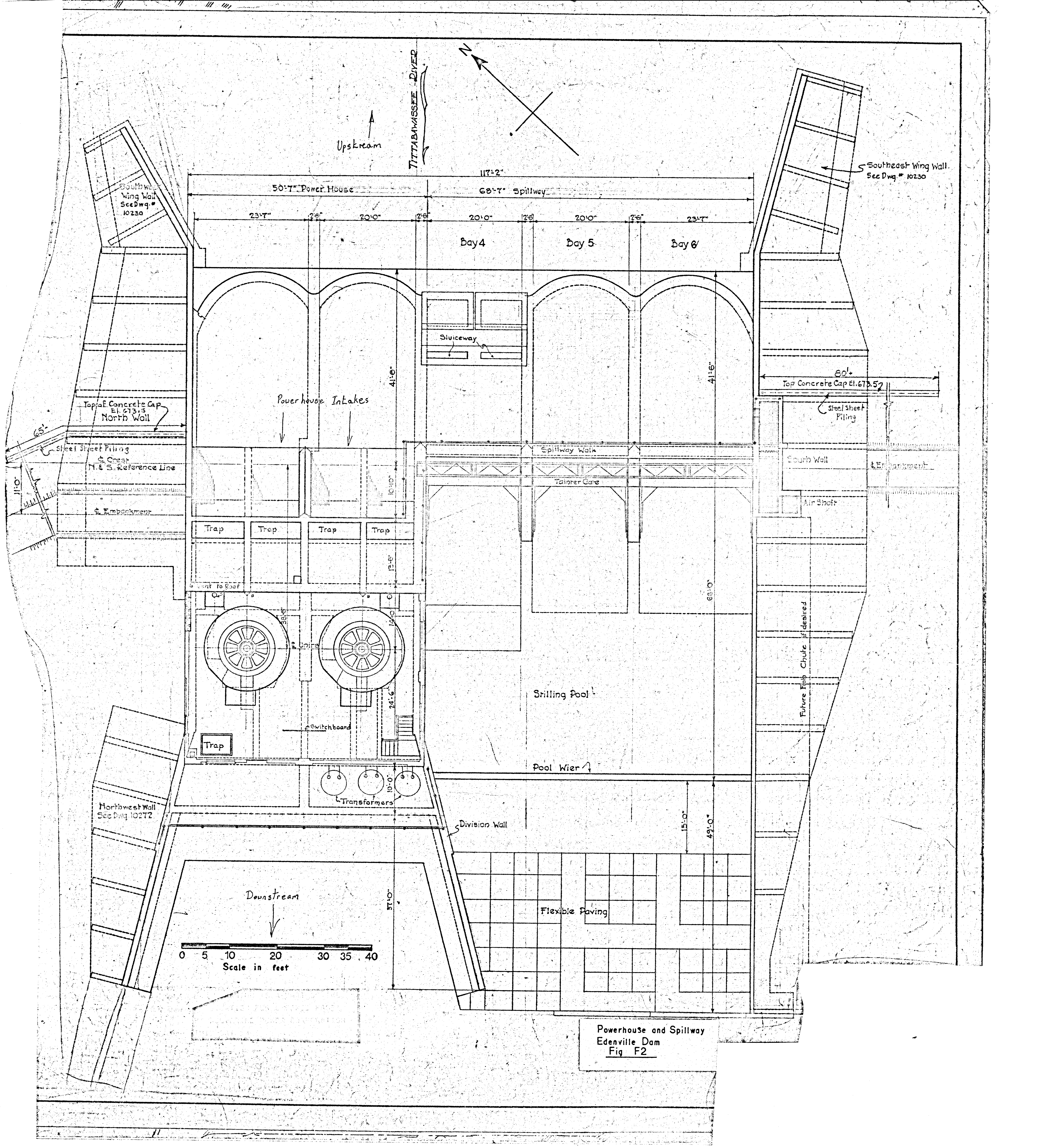
Embankment Section
Smallwood Dam
Fig E5

Appendix A

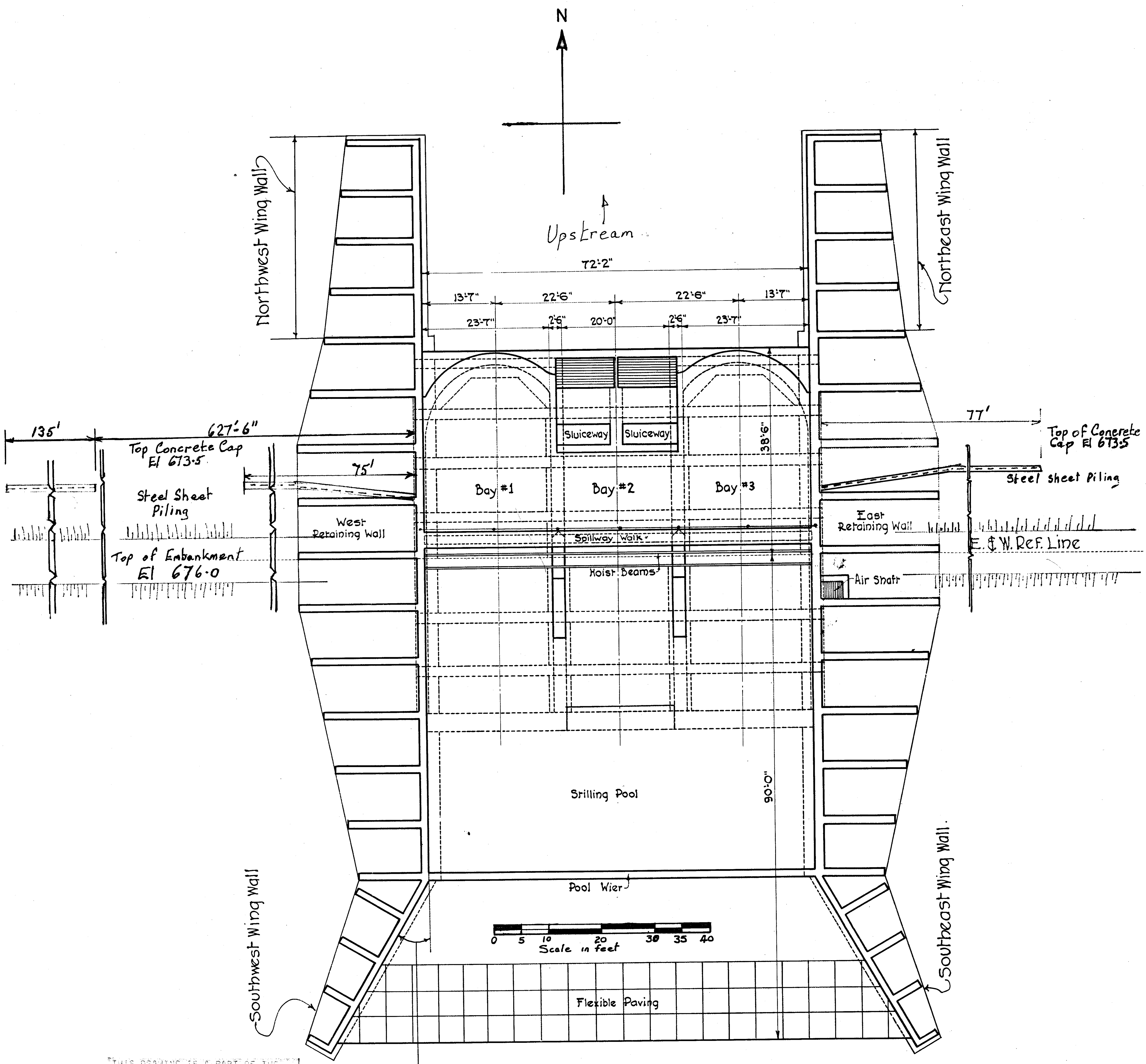
Exhibit F Drawings

Appendix A.3 – Edenville Dam


N.
W.
E.
S.
TOBACCO RIVER
Tobacco Spillway
Canal
Bottom at El. 660±
RIVER
TITTABAWASSEE
GLADWIN CO. 35
36
TOBACCO TWP.
MIDLAND CO. 2
1
EDENVILLE TWP.
2 - Generators 3750 K.V.A. each
2 - Turbines 3900 H.P. each @ 45' Hd.
SECTION THRU POWER HOUSE
SECTION THRU SPILLWAYS
PLAN OF POWER HOUSE
SECTION THRU CANAL
SECTION THRU EMBANKMENT
Pond El. 671.5
Scale in feet (1" = 200')
Power House Section Fig. F4
Spillway Section Fig. F5
Embankment Section Fig. F6
EXHIBIT B2
WOLVERINE POWER CORPORATION
EDENVILLE PLANT
PLAN AND SECTIONS
HOLLAND, ACKERMAN & HOLLAND
Consulting Engineers
Ann Arbor
Chicago
7606



Powerhouse and Spillway
Edenville Dam
Fig F2



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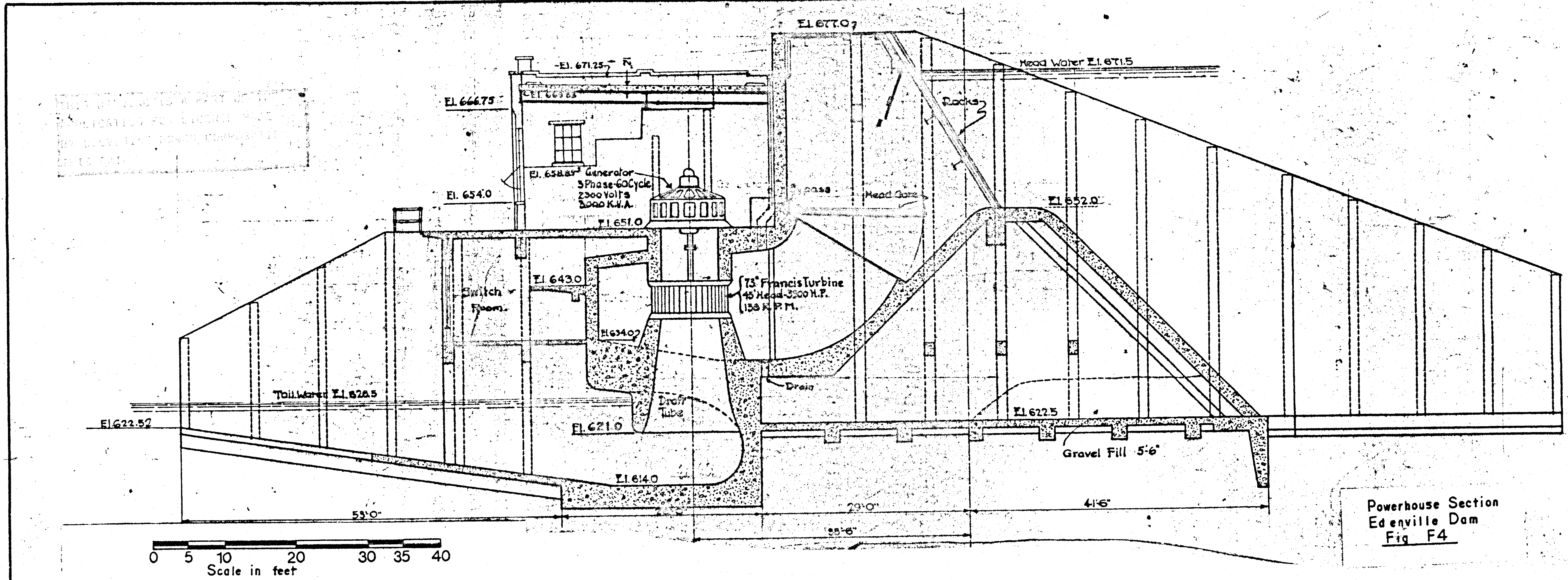
THIS DATE

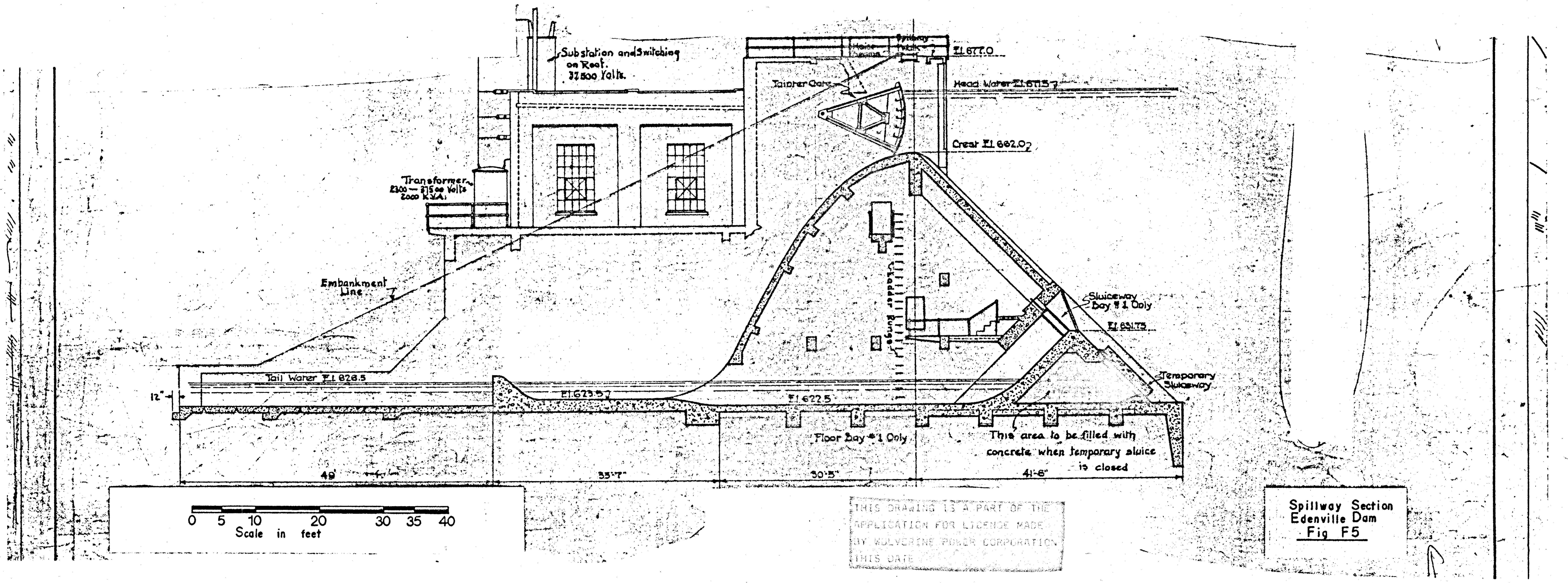
Tobacco Spillway
Edenville Dam
Fig F3

NOTE:-Angles of all wing walls to be determined in Field.

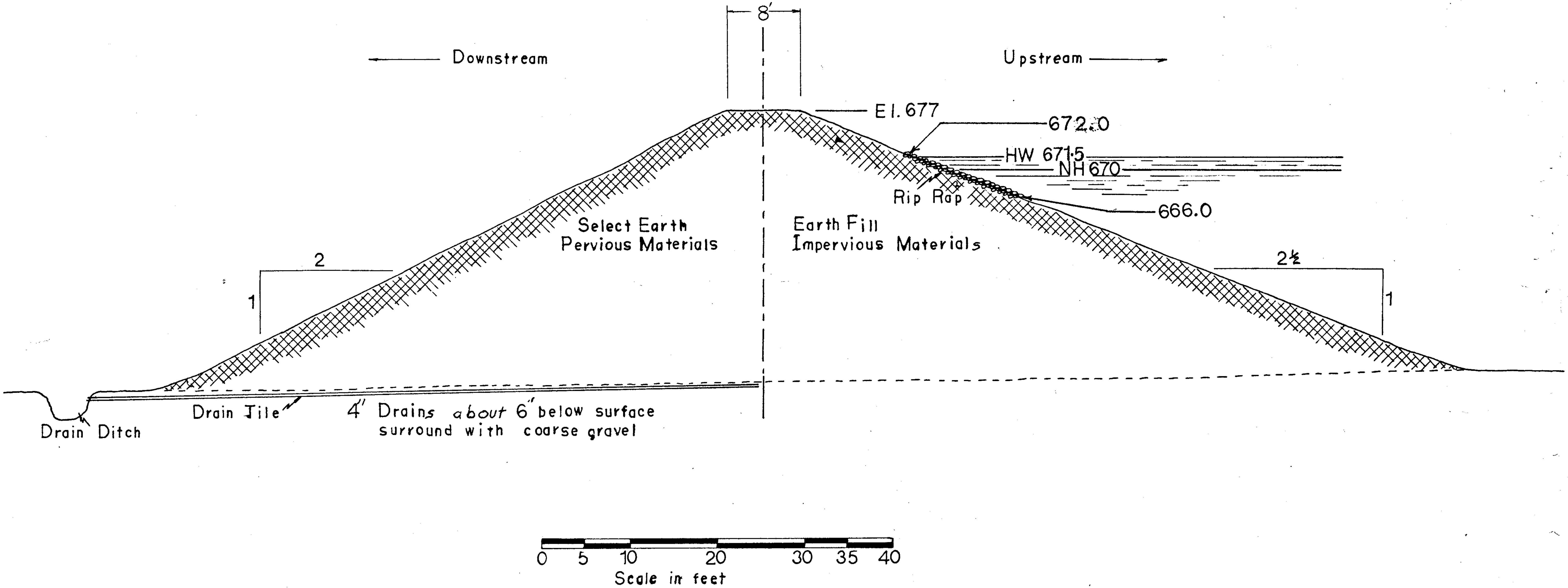
10210-2



Powerhouse Section
Edenville Dam
Fig F4



Spillway Section
Edenville Dam
Fig F5



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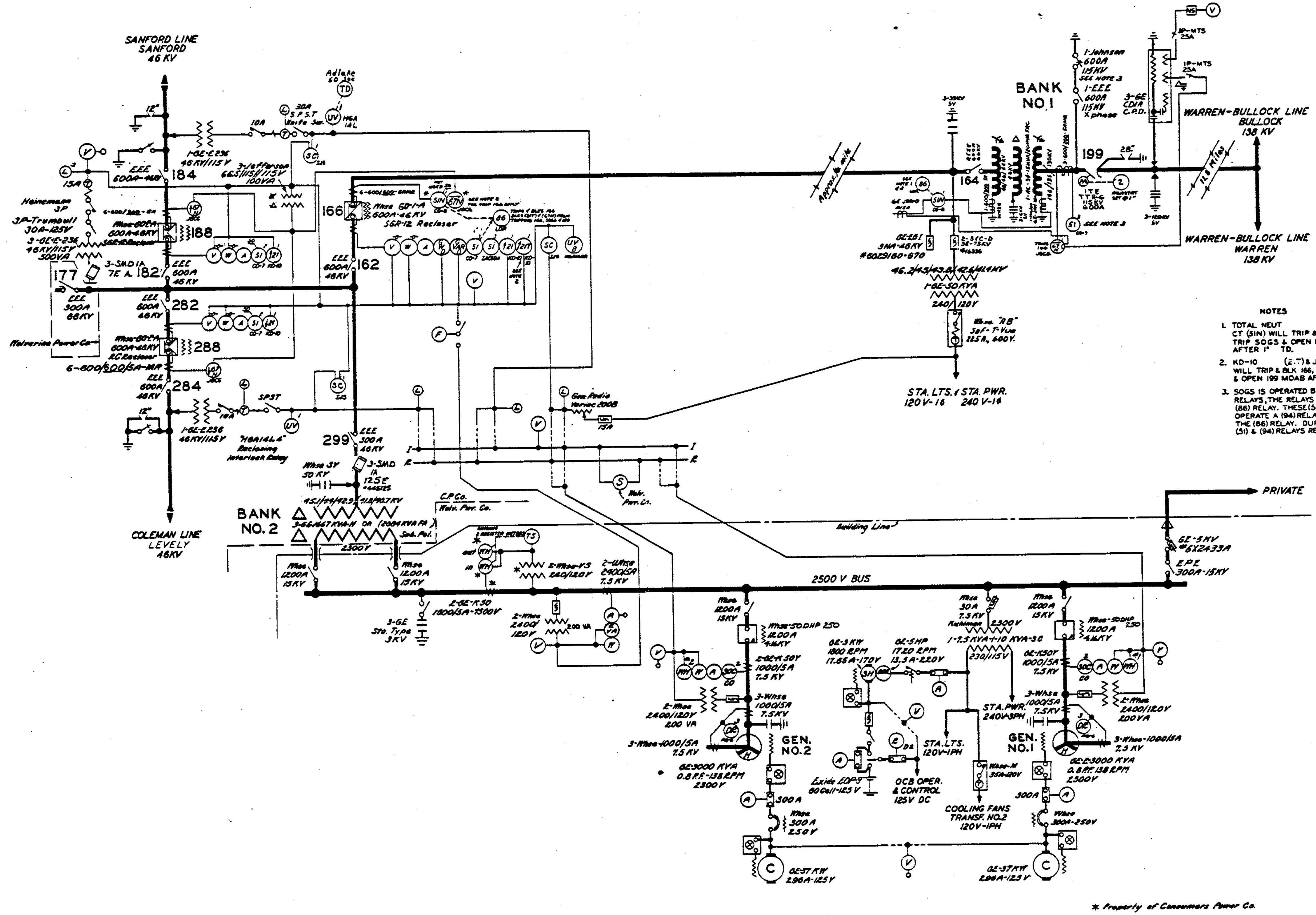
APPLICATION FOR LICENSE MADE
BY WOLVERINE POWER CORPORATION
THIS DATE

Embankment Section
Edenville Dam
Fig F6



NOTES

1. TOTAL NEUT
   CT (51N) WILL TRIP & BLK 166, TRIP SOGS & OPEN 199 MOAB AFTER 1" TD.
2. KD-10 (2.T) & JBCC IOC (67N) WILL TRIP & BLK 166, TRIP SOGS & OPEN 199 MOAB AFTER 1" TD
3. SOGS IS OPERATED BY THE TB1 (51) RELAYS, THE RELAYS IN NOTE 2 & THE TB1 (86) RELAY. THESE (51) RELAYS ALSO OPERATE A (94) RELAY WHICH OPERATES THE (86) RELAY. DURING TEST THE (51) & (94) RELAYS REMAIN IN SERVICE.

IN CCH
BATTERY – MCGRAW-EDISON, 3MEA-75, 24CELL, 75AH, 48V DC
BATTERY CHARGER – MCGRAW-EDISON, EBC48-10, 10A, 48V DC
IN SUB AT PLANT
BATTERY – EXIDE. 60-CA-9, 200AH, 125V DC
BATTERY CHARGER – PCP. SD-130-25, 125VDC, 25A
REMOTE ALARM TO SAGINAW POWER CONTROL

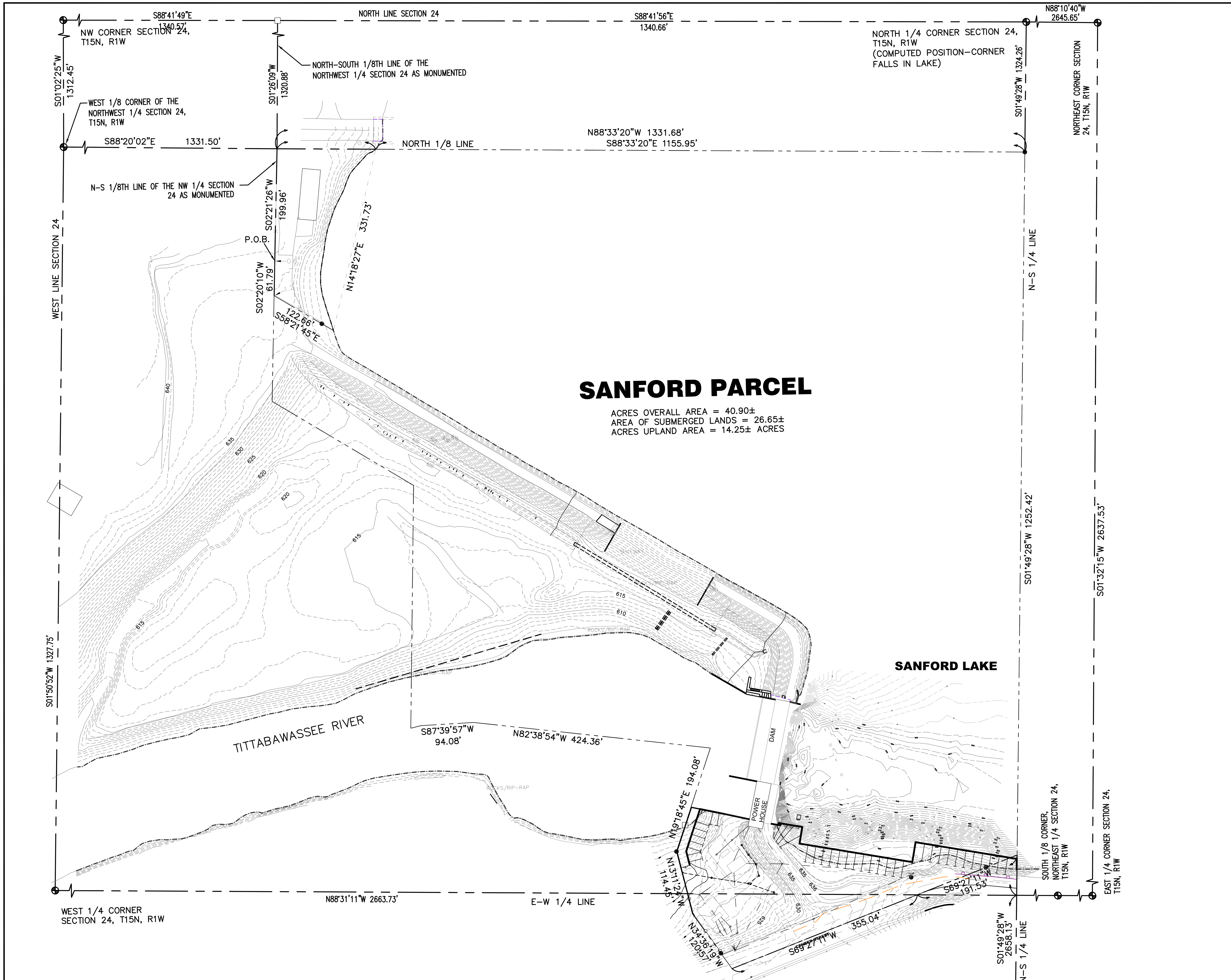
Fig. F7

DR GTWATTERS	3-5-81	CONSUMERS POWER CO.	EDENVILLE DAM	
APP E R Longm...	3-11-81	ELECTRIC ENGINEERING DEPARTMENT		
APP P Lolich	3-11-81	JACKSON, MICHIGAN	C REGION	EDENVILLE IMLNE
APP S Grana-Girard	3-11-8·	CORRECTED TO 7-5-88 AU	NO. WD136	SHEET 1

Appendix A

Exhibit F Drawings

Appendix A.4 – Sanford Dam



-- CONTAINS CRITICAL ENERGY INFRASTRUCTURE INFORMATION; DO NOT RELEASE --

BOYCE HYDRO POWER, LLC

Lee W. Mueller, Architect, Co-Member Manager

PO BOX 15
6000 S-M30
EDENVILLE, MI 48620
(989) 689-3161

LICENSED PROFESSIONAL

REVISIONS

NO.	DATE	BY
DESCRIPTION		
0	9/23/2013	MGM
DRAWING ORIGINATION		
1	05/24/2019	MGM
SHOW SITE AFTER UPGRADE		

THIS DRAWING IS SCALED TO PRINT ON 24" x 36" PAPER

DRAWING TITLE

NEW TURBINE UNIT #1 GENERAL PLAN

FILE	Sanford U1 turbine upgrade Ex F
SCALE	AS NOTED
DRAWN	MGM
CHECKED	LWM
APPROVED	
REV. DATE	05/24/2019

DRAWING NO.

P-2785-17

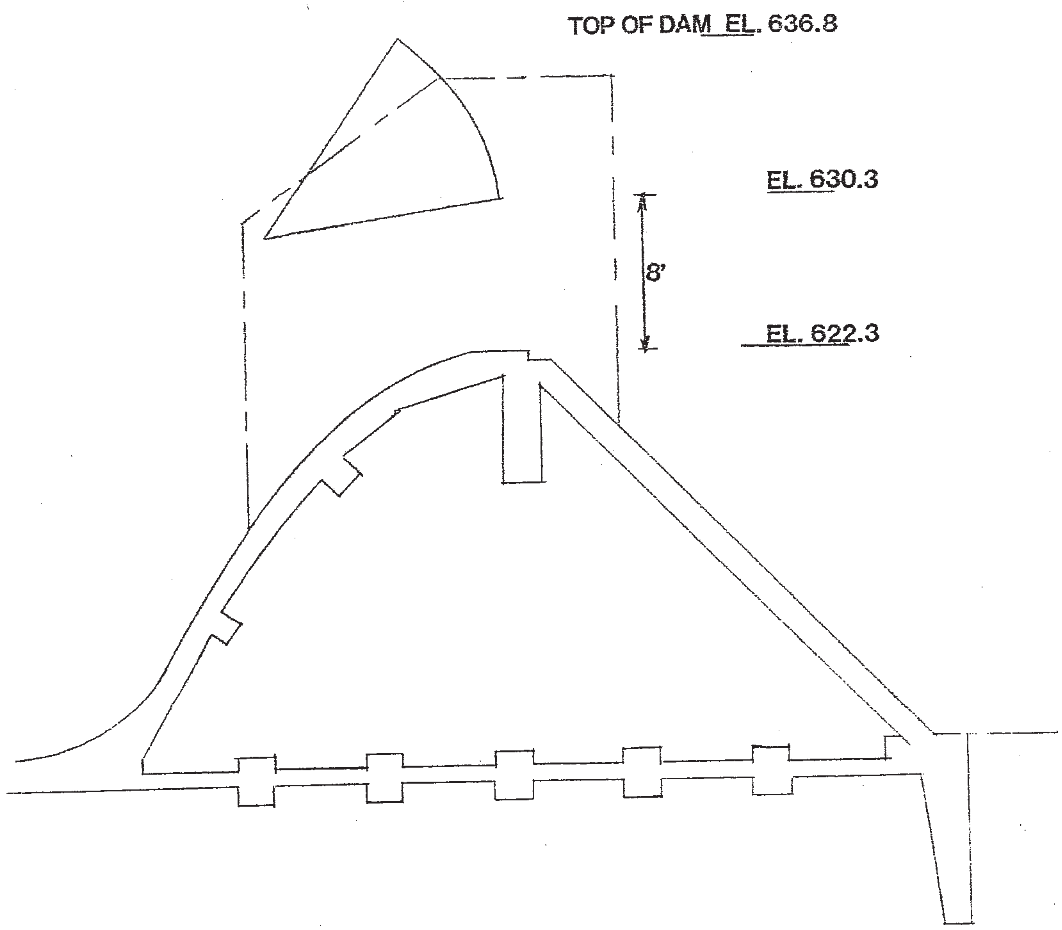
FERC PROJECT NO. 2785

SANFORD DAM EXHIBIT F-1

GENERAL PLAN

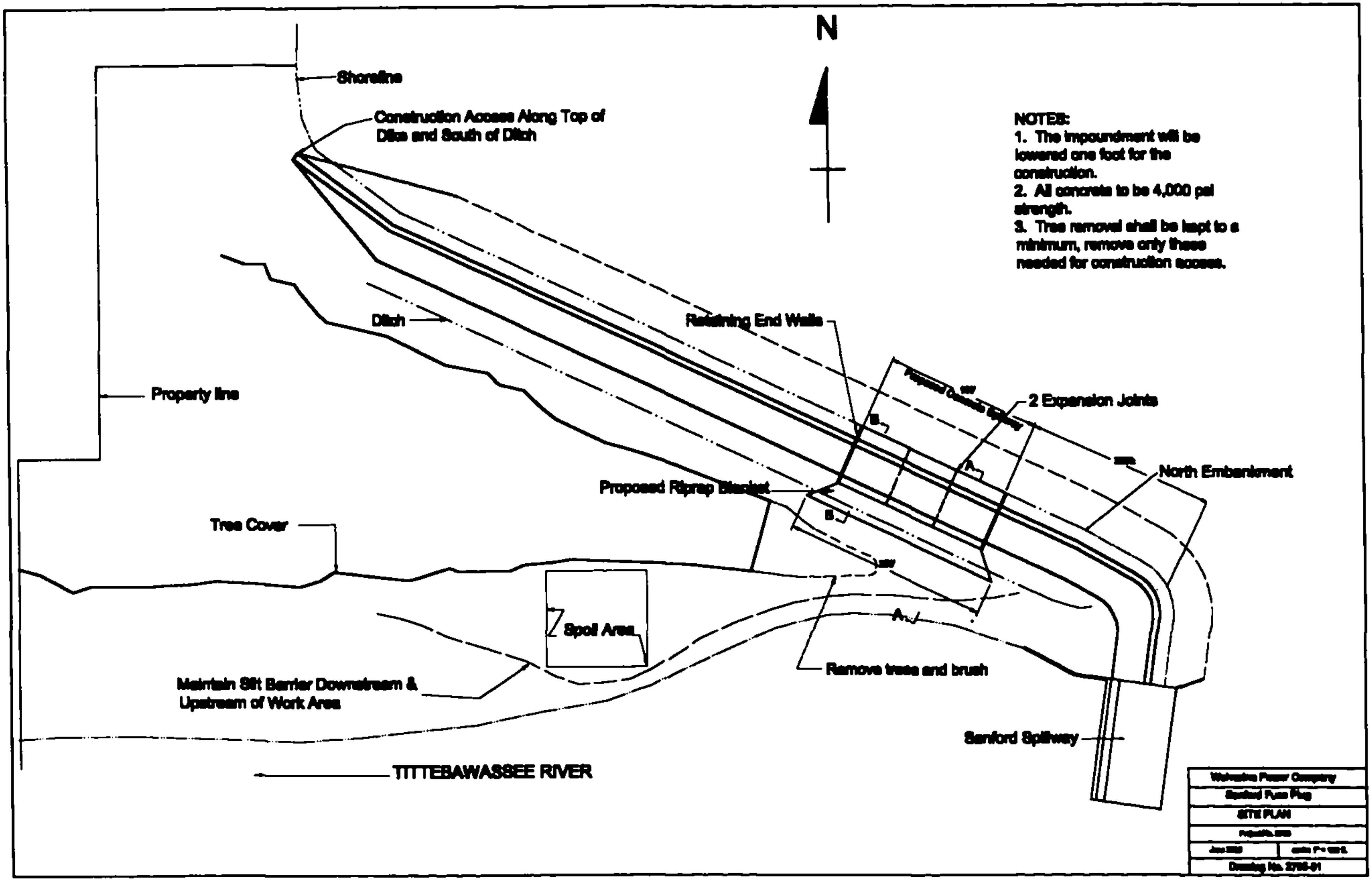
0 80 160 240

SCALE: 1"= 80'

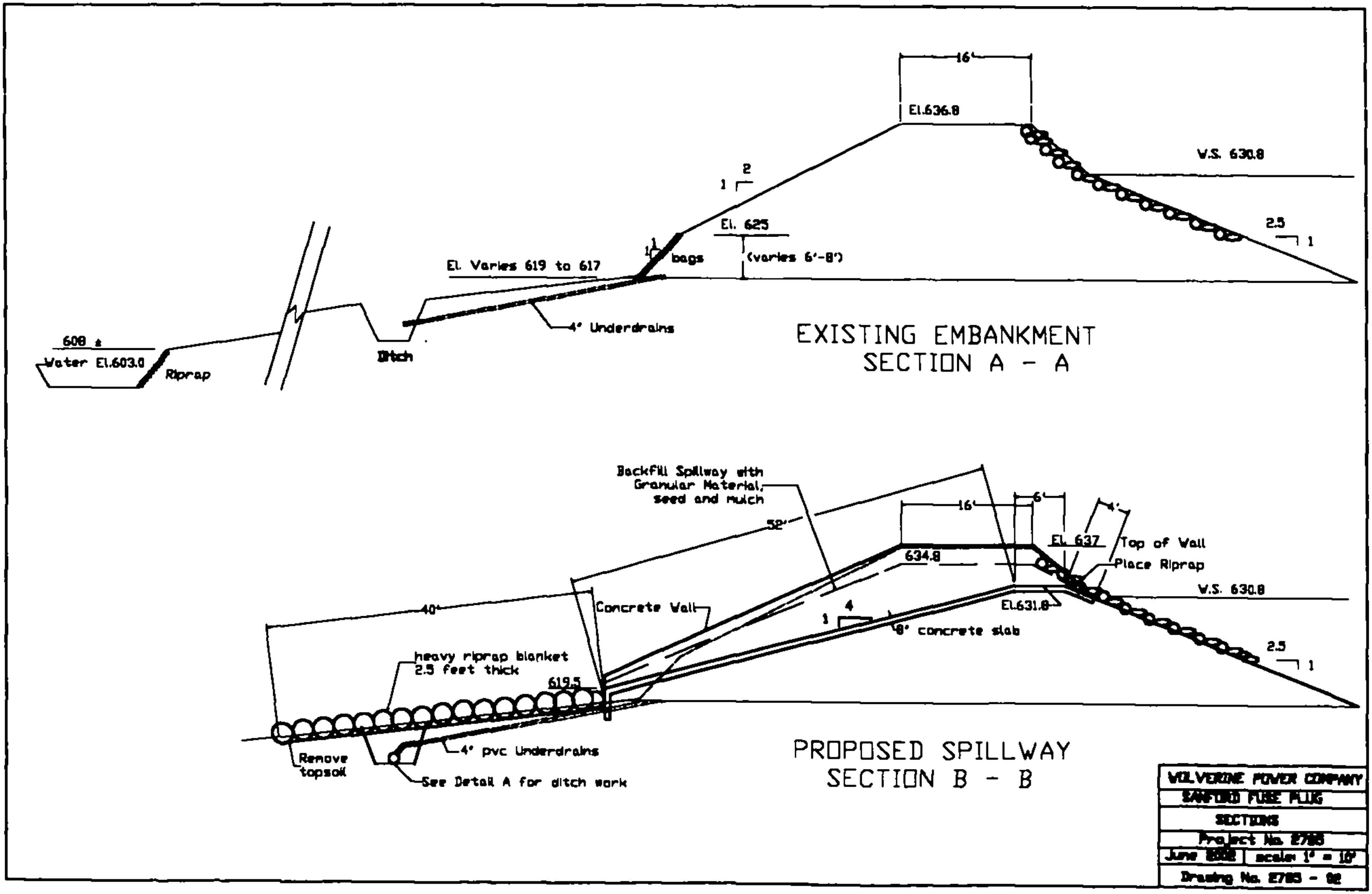


TYPICAL SPILLWAY CROSS SECTION

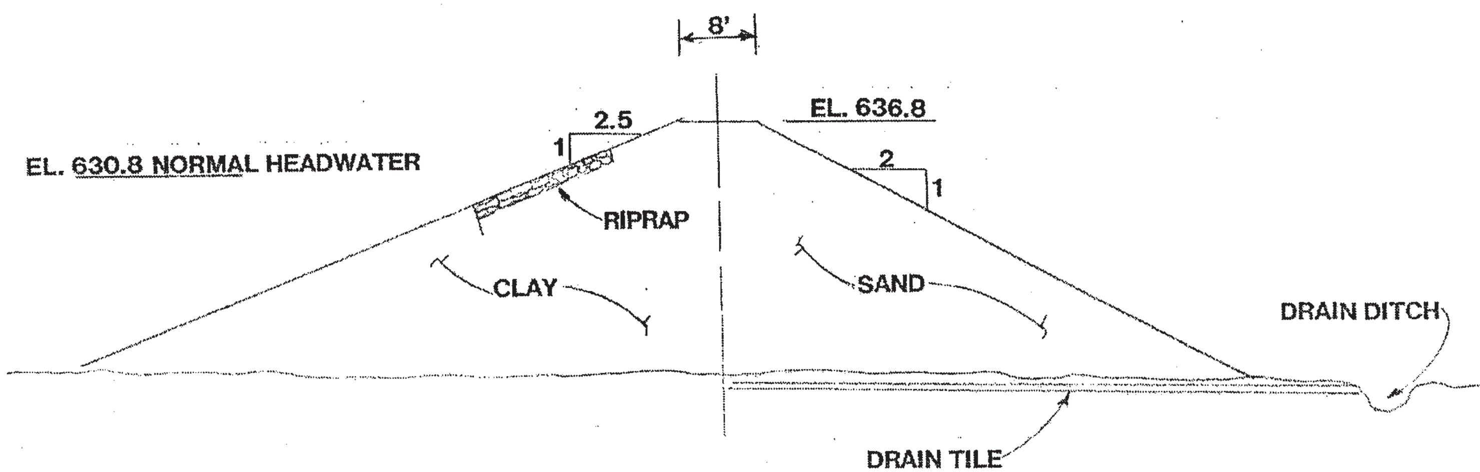
FIGURE 4



Unofficial FERC-Generated PDF of 20030718-0217 Received by FERC OSEC 07/03/2003 in Docket#: P-2785-000

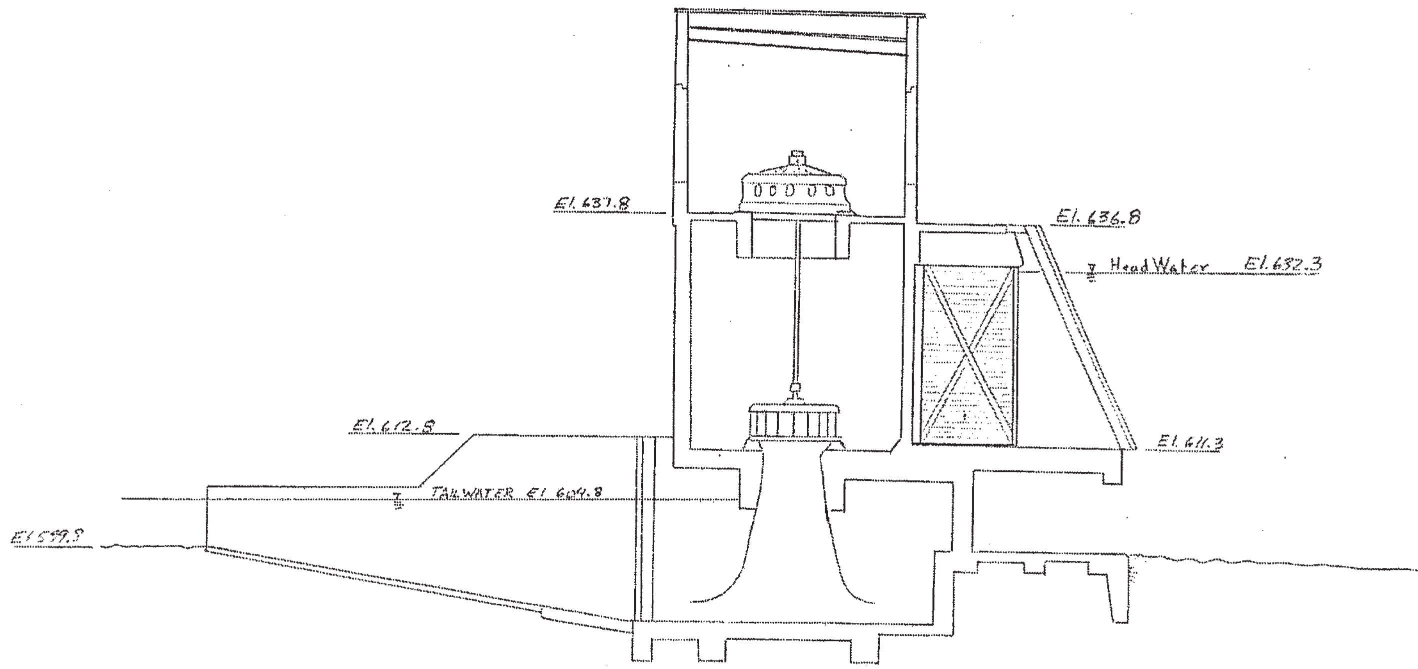


Unofficial FERC-Generated PDF of 20030718-0217 Received by FERC OSEC 07/03/2003 in Docket#: P-2785-000



EMBANKMENT CROSS SECTION

FIGURE 3



TYPICAL SECTION THRU POWERHOUSE

FIGURE 5

Appendix B

Existing Conditions Spillway Rating Curves

Appendix B.1 – Secord Dam

Appendix B.2 – Smallwood Dam

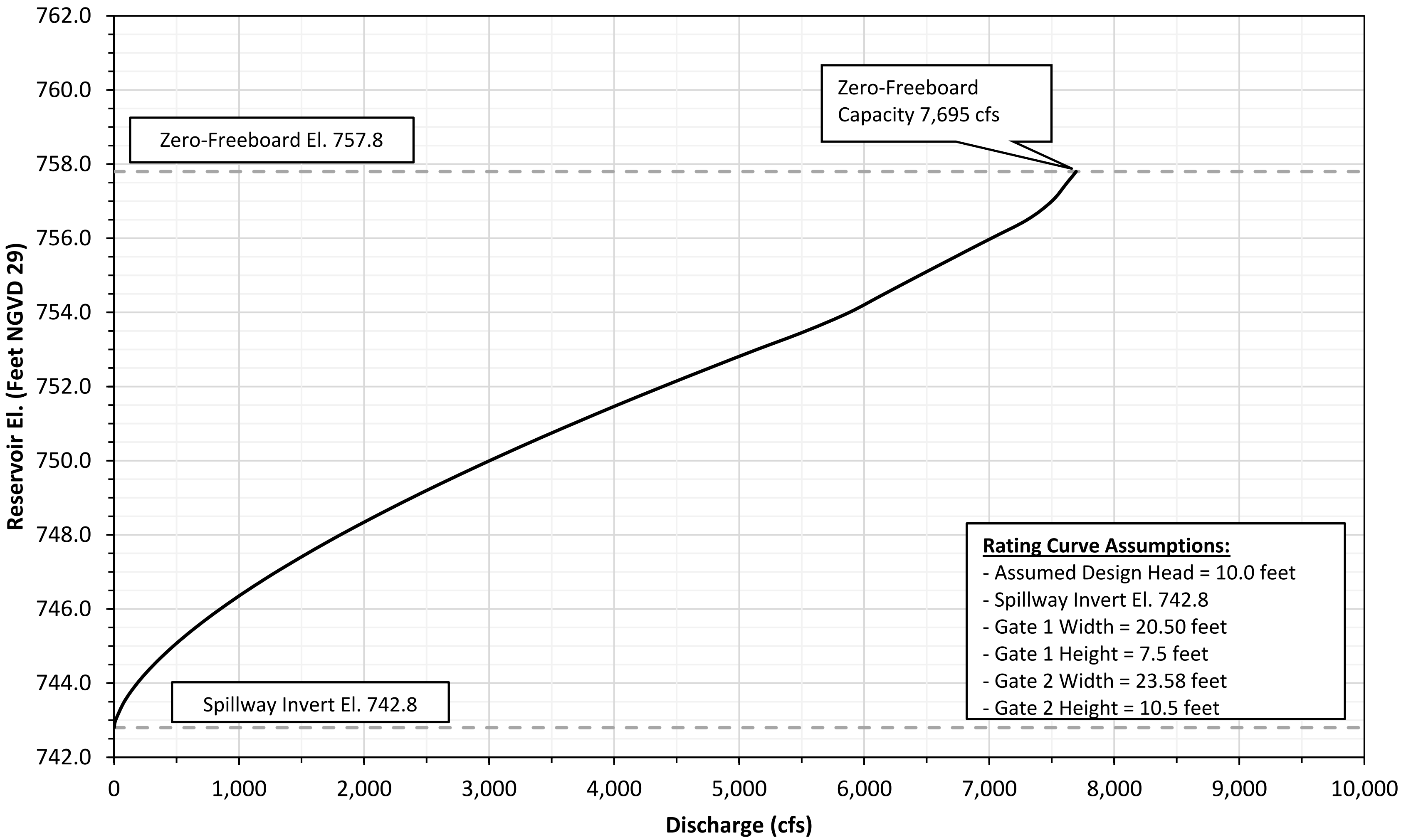
Appendix B.3 – Edenville Dam

Appendix B.4 – Sanford Dam

Appendix B

Existing Conditions Spillway Rating Curves

Appendix B.1 – Secord Dam

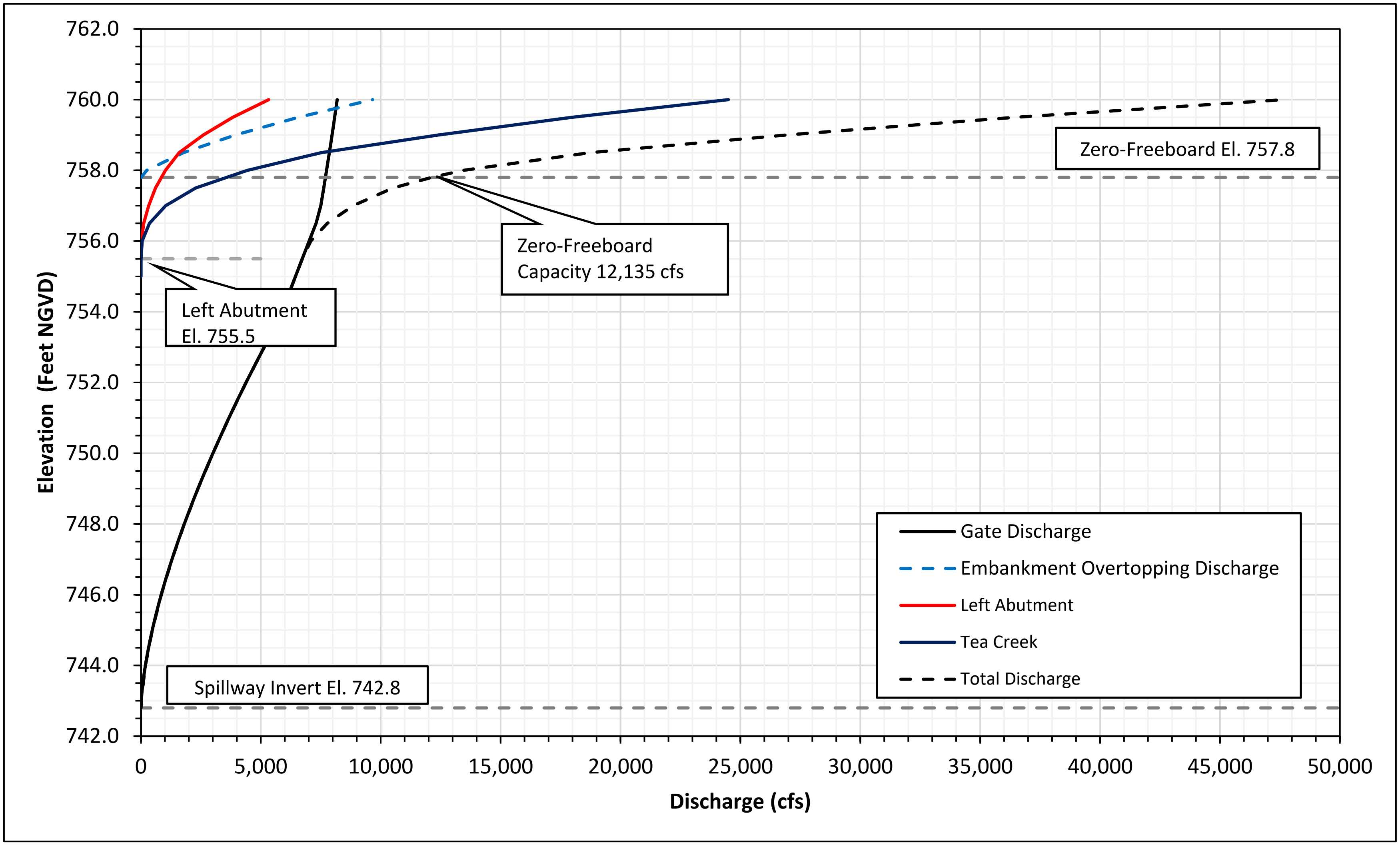


Secord Dam
Four Lakes Task Force
FERC Project No. 10809
Gladwin, Michigan

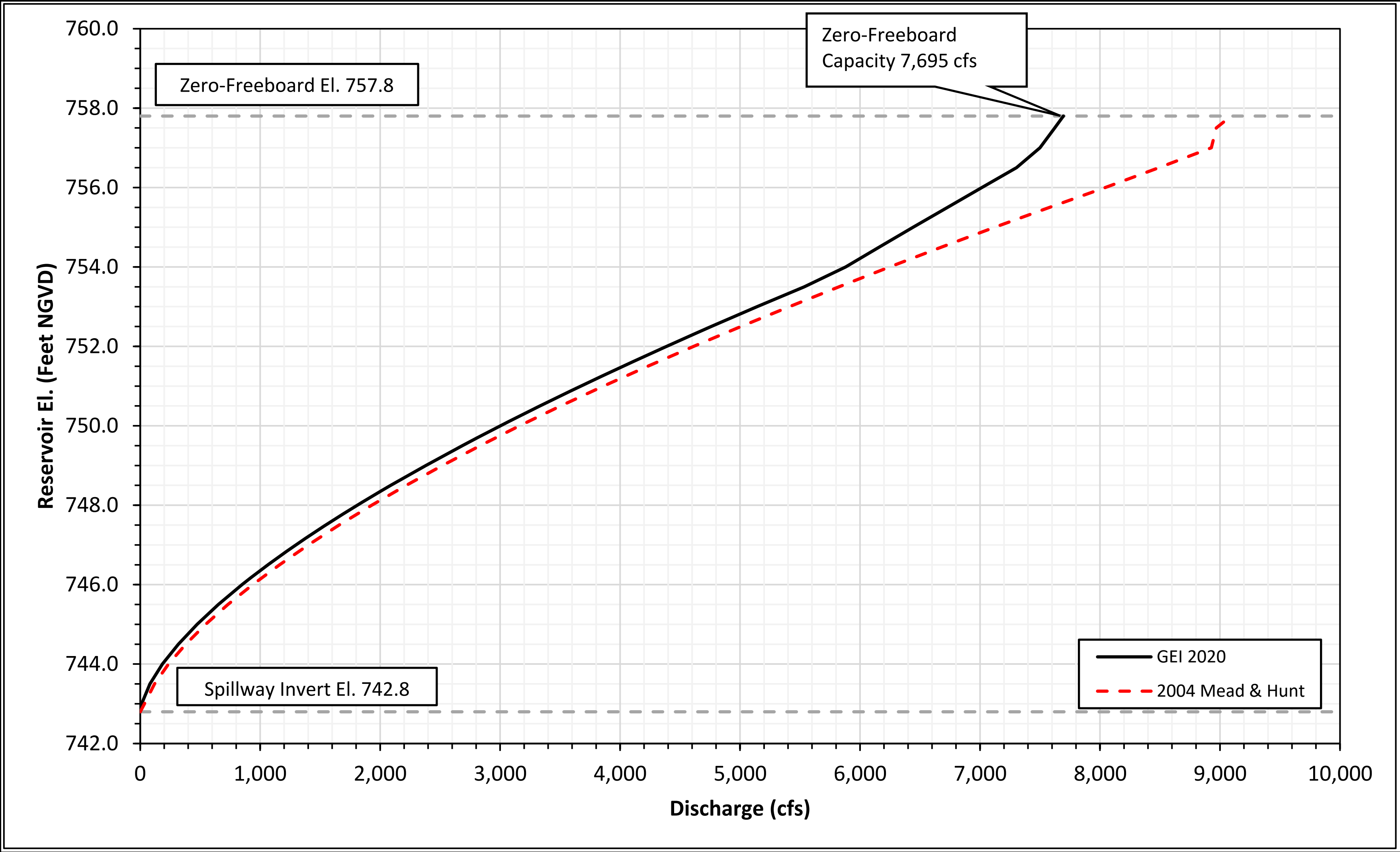
GEI Consultants

Secord Dam
Tainter Gate Spillway
Discharge Rating Curve

Project 2002879	**March 2021**	**Appendix B.1**



Secord Dam **Four Lakes Task Force** **FERC Project No. 10809** **Gladwin, Michigan**	GEI Consultants	**Secord Dam** **Total Spillway** **Discharge Rating Curve**	
	Project 2002879	**March 2021**	**Appendix B.1**

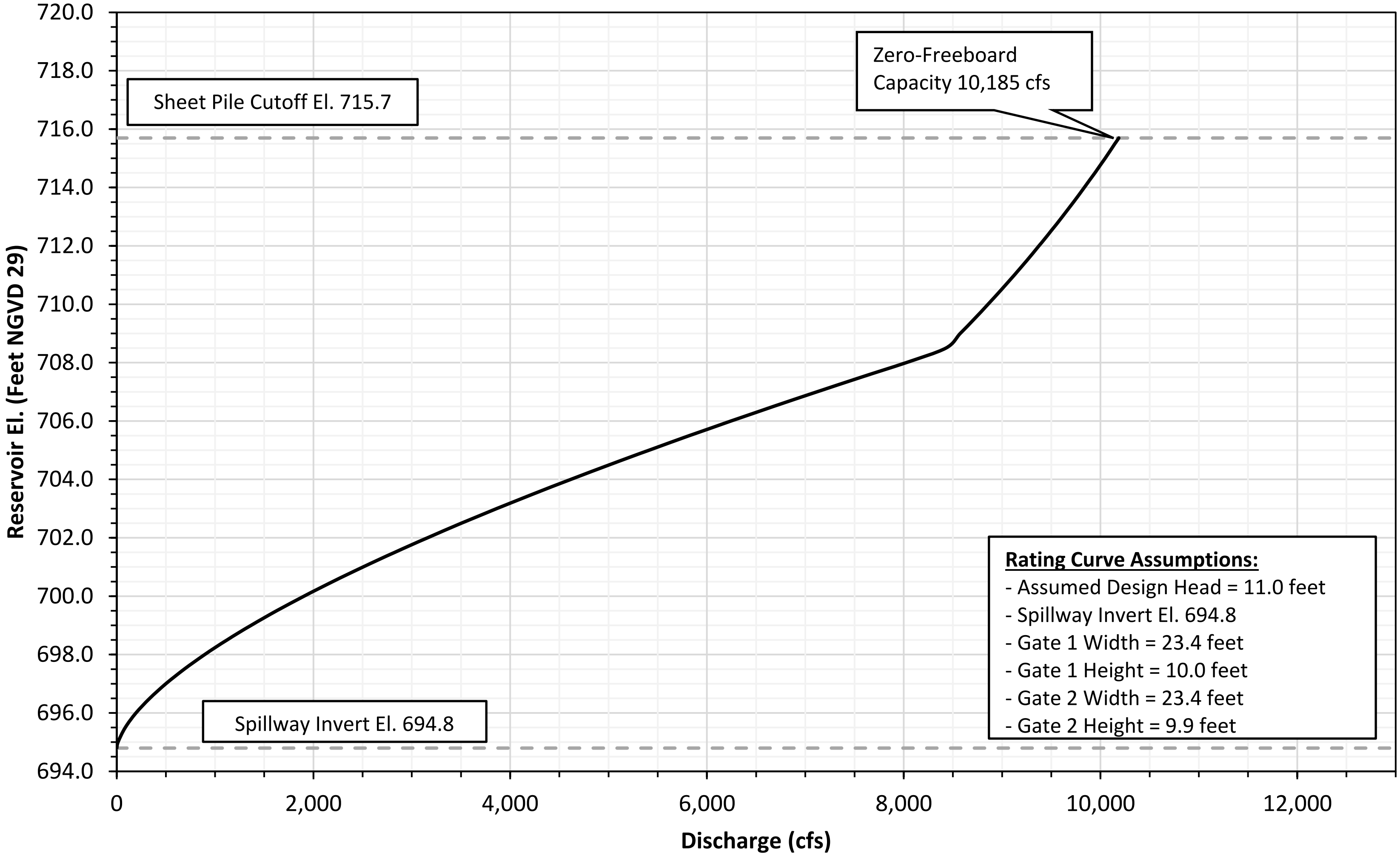


Secord Dam **Four Lakes Task Force** **FERC Project No. 10809** **Gladwin, Michigan**	GEI Consultants	**Secord Dam** **Comaprison of Historic Spillway Discharge Rating Curves**	
	Project 2002879	**March 2021**	**Appendix B.1**

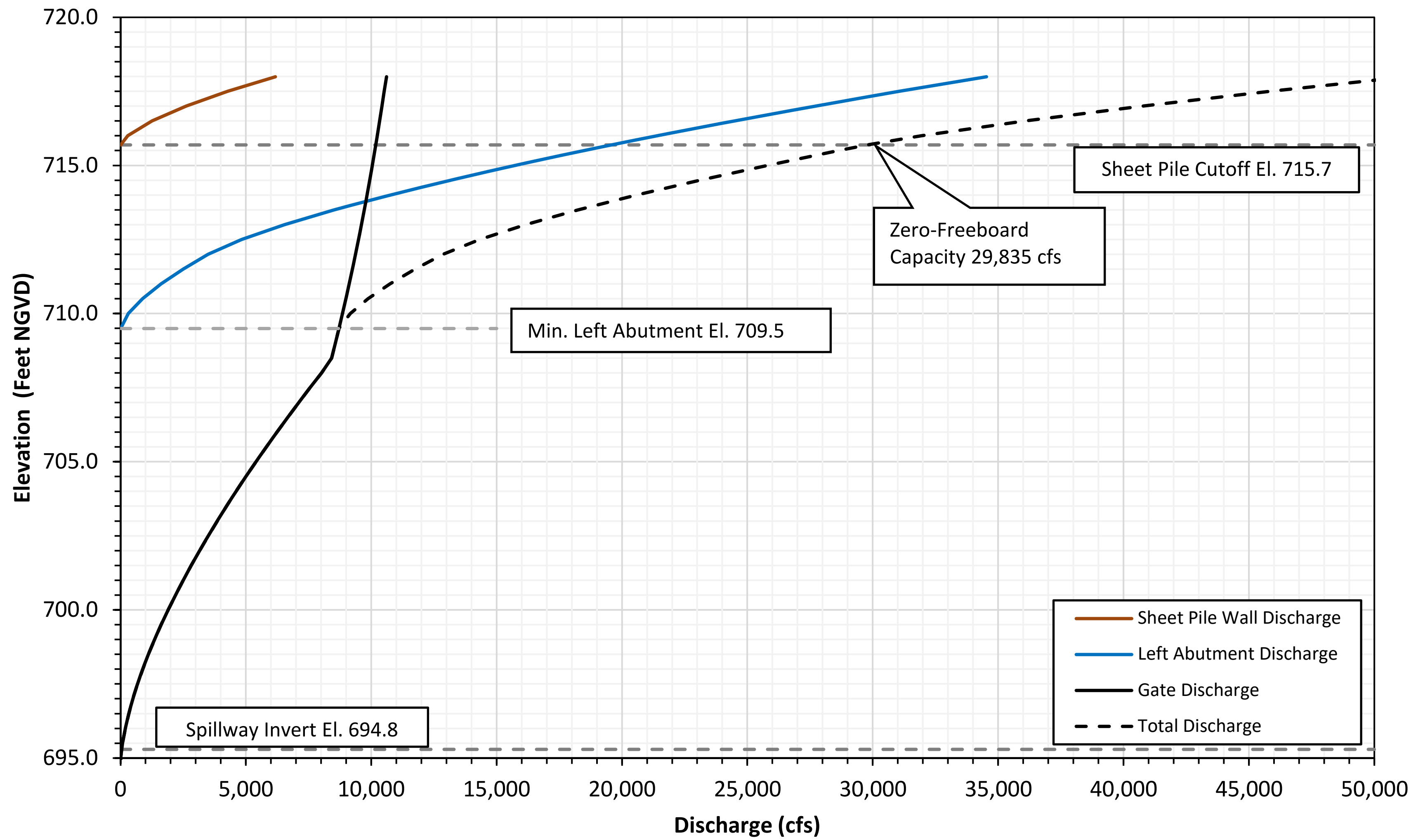
Appendix B

Existing Conditions Spillway Rating Curves

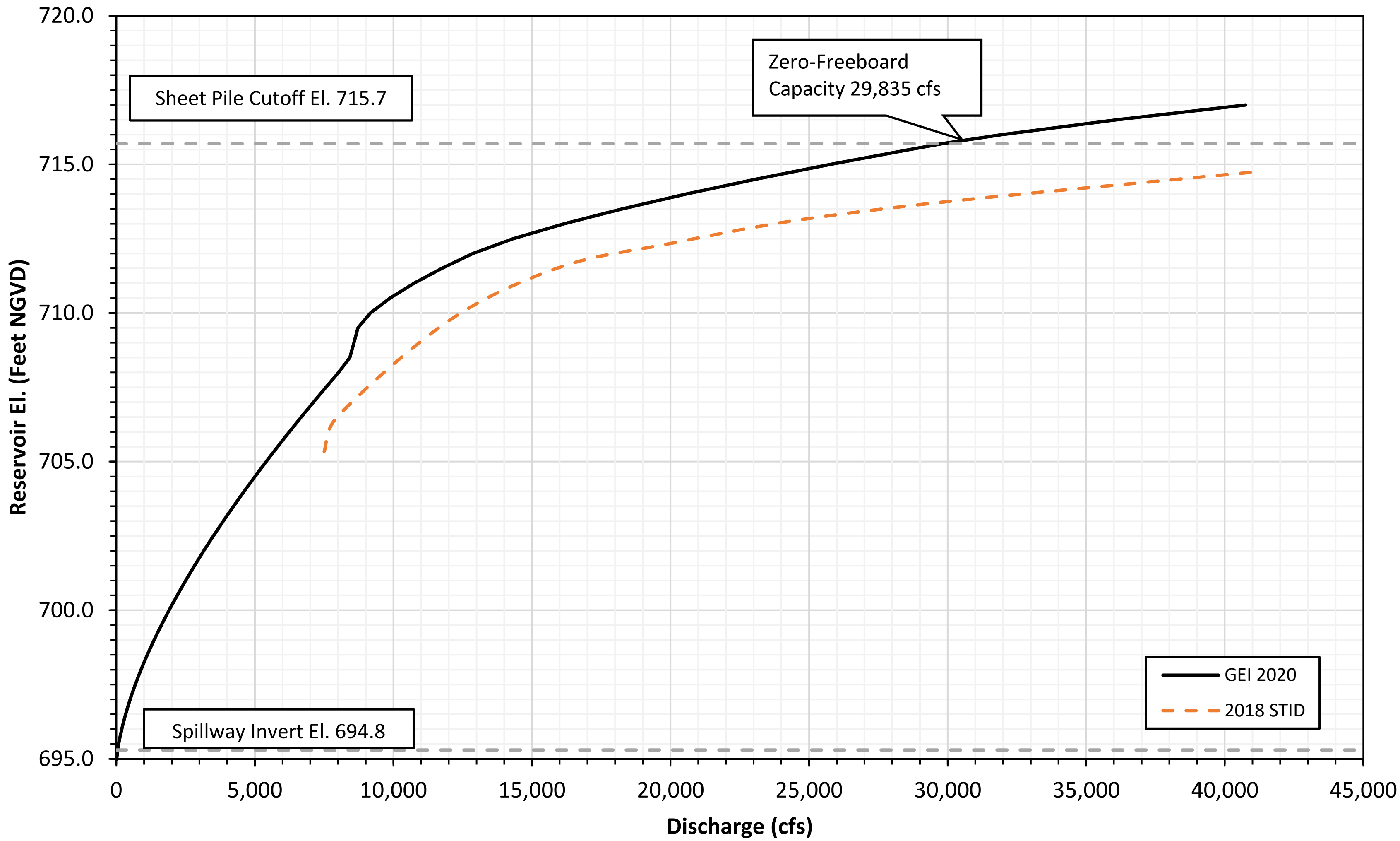
Appendix B.2 – Smallwood Dam



Smallwood Dam **Four Lakes Task Force** **FERC Project No. 10810** **Gladwin, Michigan**	GEI Consultants	**Smallwood Dam** **Tainter Gate Spillway** **Discharge Rating Curve**
	Project 2002879	**March 2021** — **Appendix B.2**



Smallwood Dam **Four Lakes Task Force** **FERC Project No. 10810** **Gladwin, Michigan**	GEI Consultants	**Smallwood Dam** **Total Spillway** **Discharge Rating Curve**
	Project 2002879	**March 2021** / **Appendix B.2**

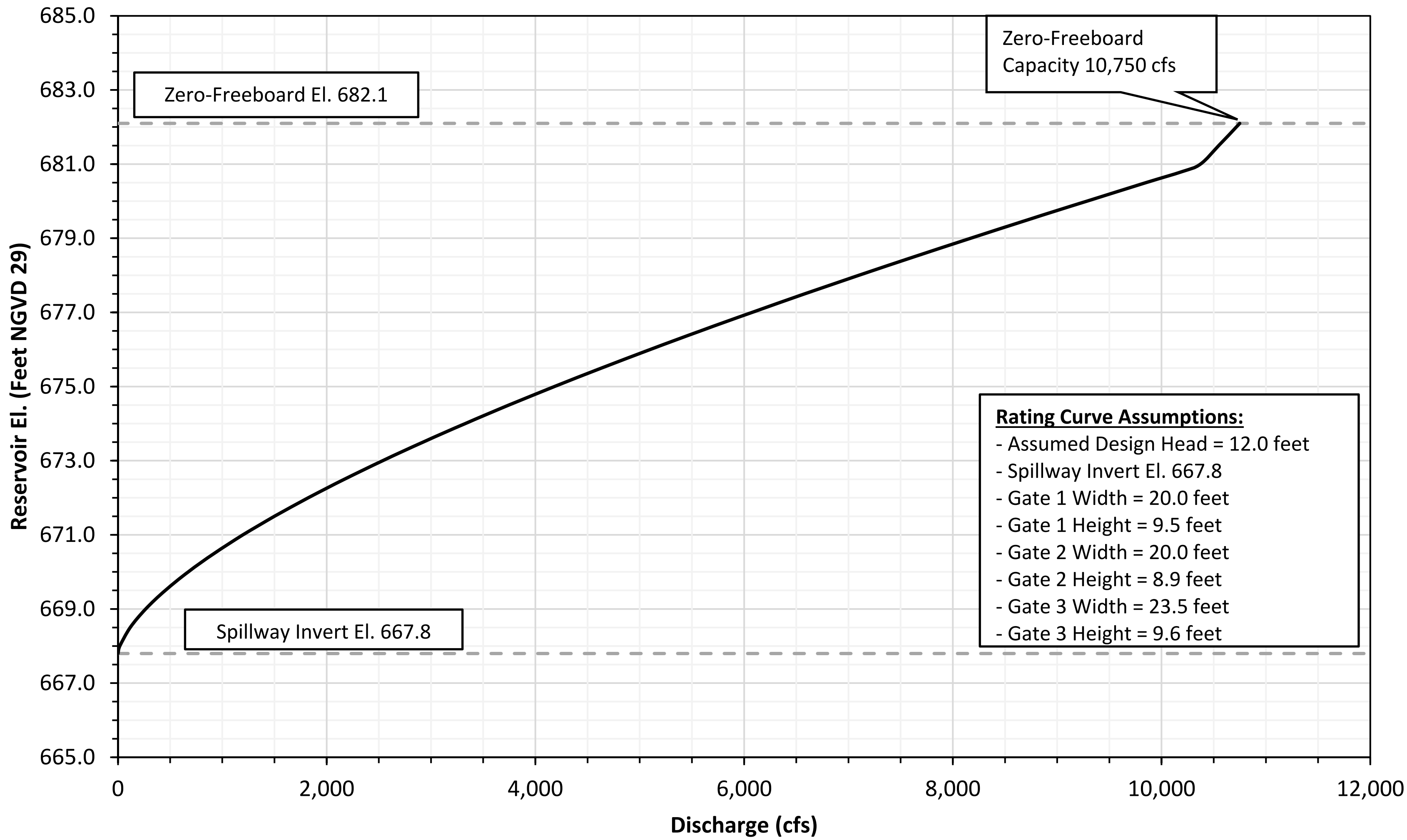


Smallwood Dam **Four Lakes Task Force** **FERC Project No. 10810** **Gladwin, Michigan**	GEI Consultants	**Smallwood Dam** **Comparison to Historic Spillway Discharge Rating Curves**	
	Project 2002879	**March 2021**	**Appendix B.2**

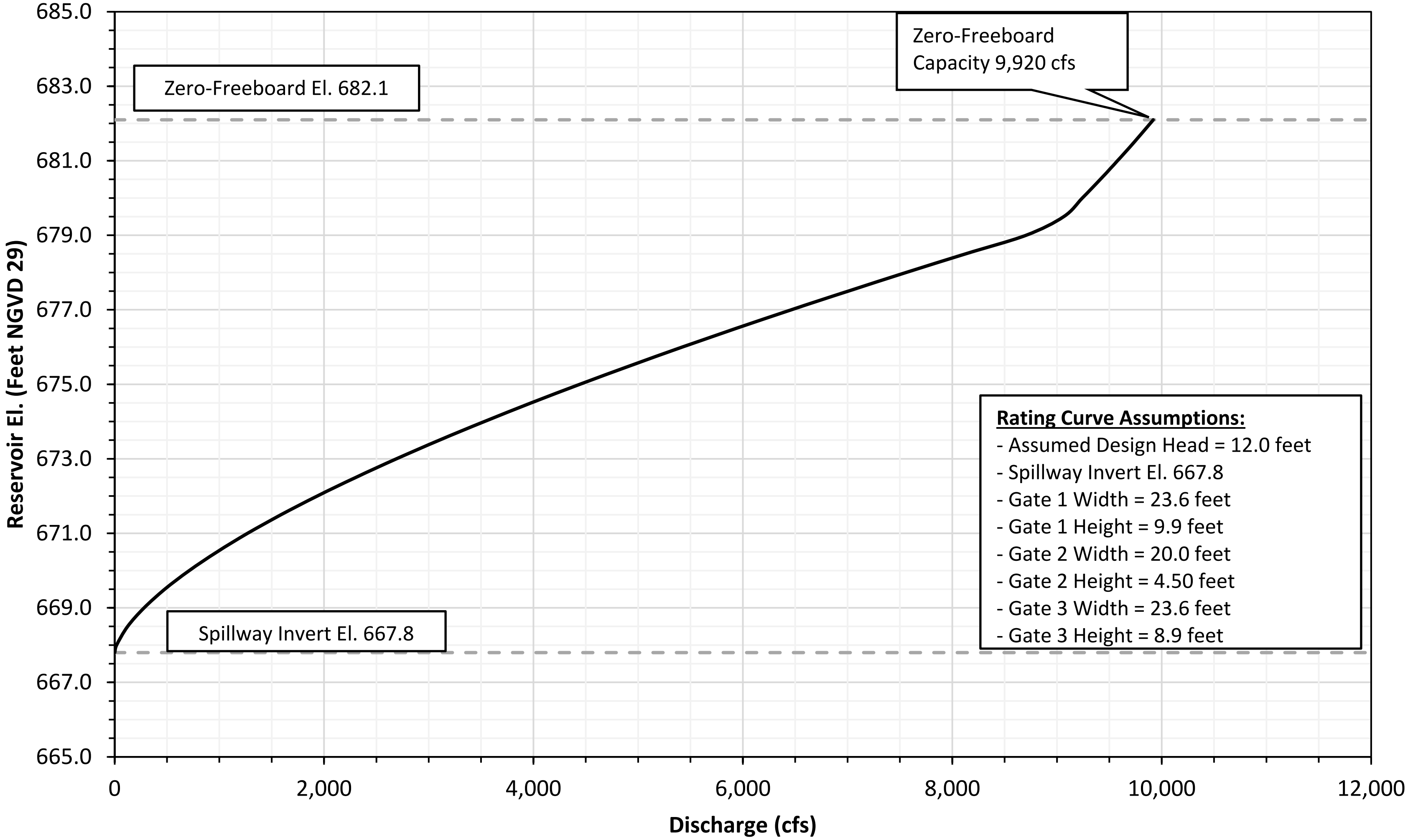
Appendix B

Existing Conditions Spillway Rating Curves

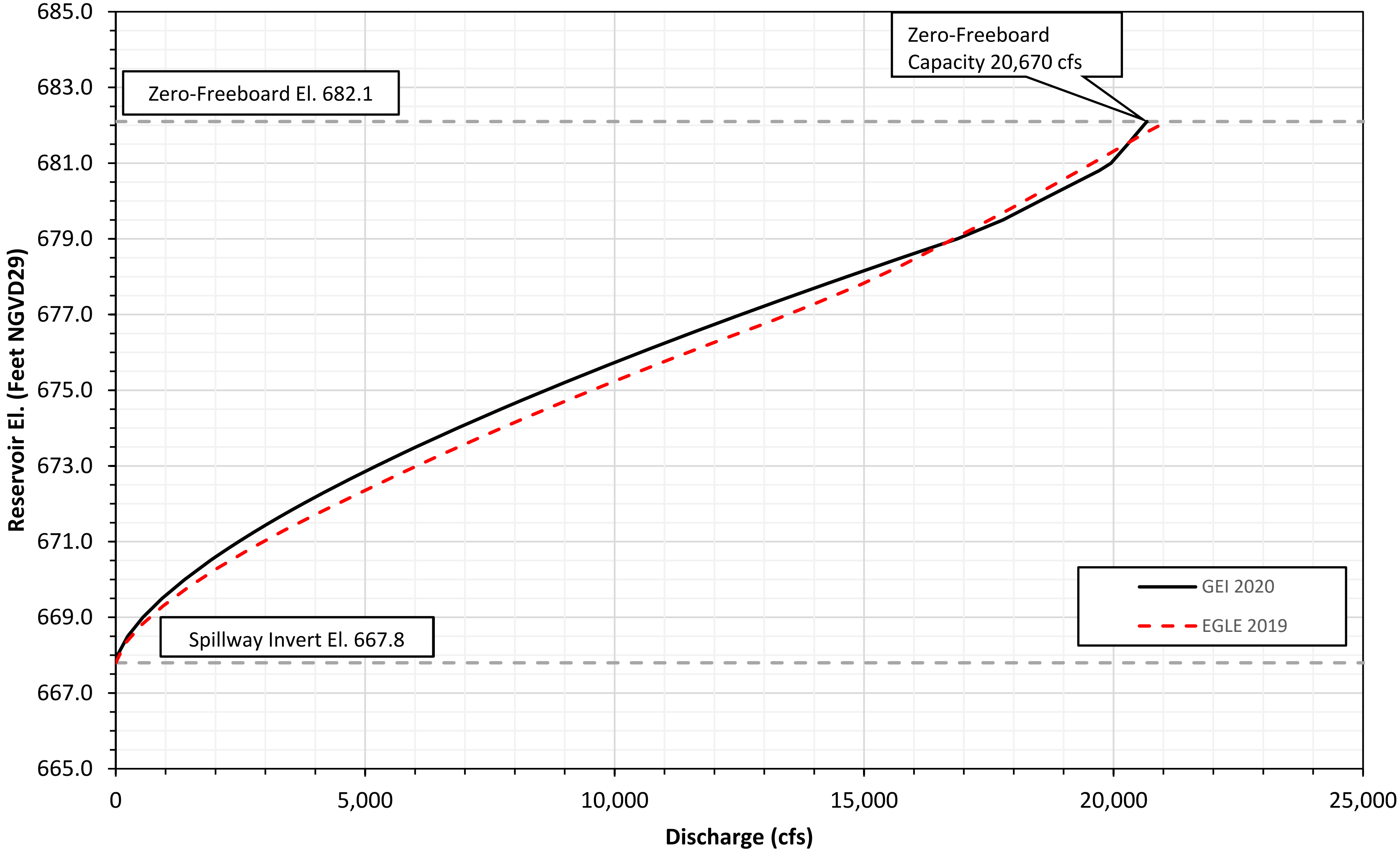
Appendix B.3 – Edenville Dam



Edenville Dam **Four Lakes Task Force** **FERC Project No. 10809** **Gladwin, Michigan**	GEI Consultants	**Edenville Dam** **Tainter Gate Spillway** **Discharge Rating Curve** **(Edenville Gates)**	
	Project 2002879	**March 2021**	**Appendix B.3**



Edenville Dam **Four Lakes Task Force** **FERC Project No. 10809** **Gladwin, Michigan**	GEI Consultants	**Edenville Dam** **Tainter Gate Spillway** **Discharge Rating Curve** **(Tobacco Gates)**
	Project 2002879	**March 2021** / **Appendix B.3**

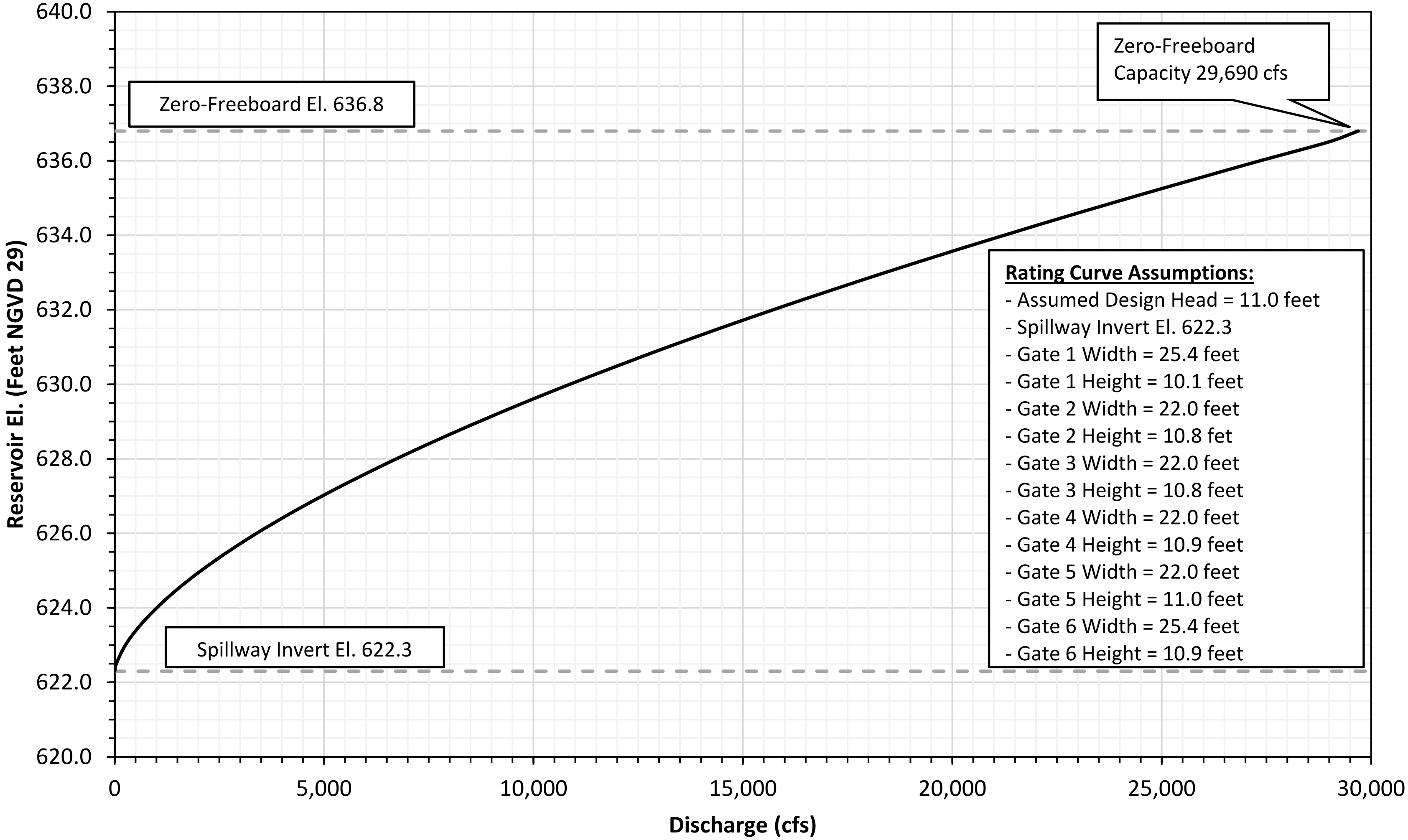


Edenville Dam **Four Lakes Task Force** **FERC Project No. 10809** **Gladwin, Michigan**	GEI Consultants	**Edenville Dam** **Spillway Discharge Rating Curve Comparison**	
	Project 2002879	**March 2021**	**Appendix B.3**

Appendix B

Existing Conditions Spillway Rating Curves

Appendix B.4 – Sanford Dam

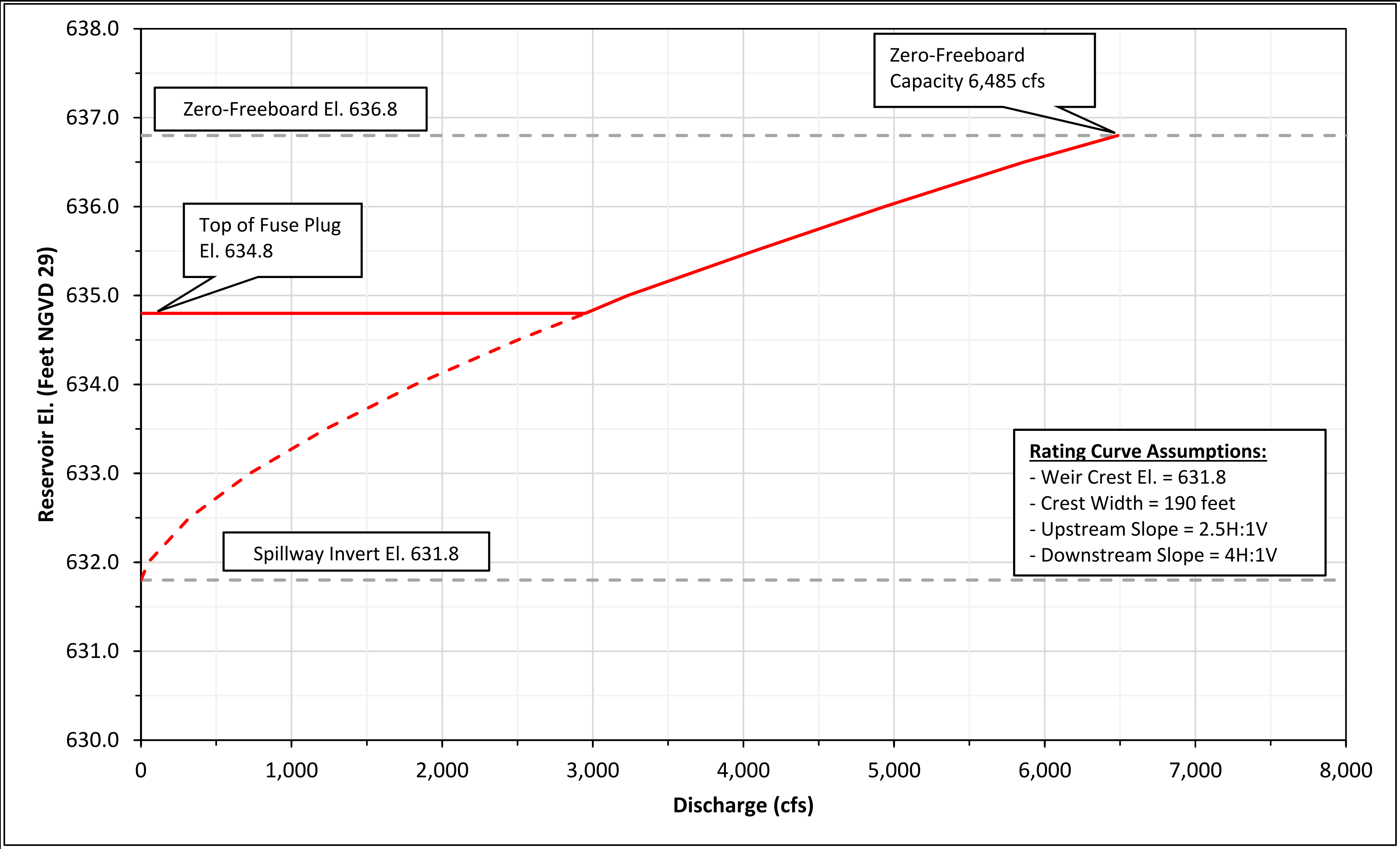


Sanford Dam
Four Lakes Task Force
FERC Project No. 10809
Gladwin, Michigan

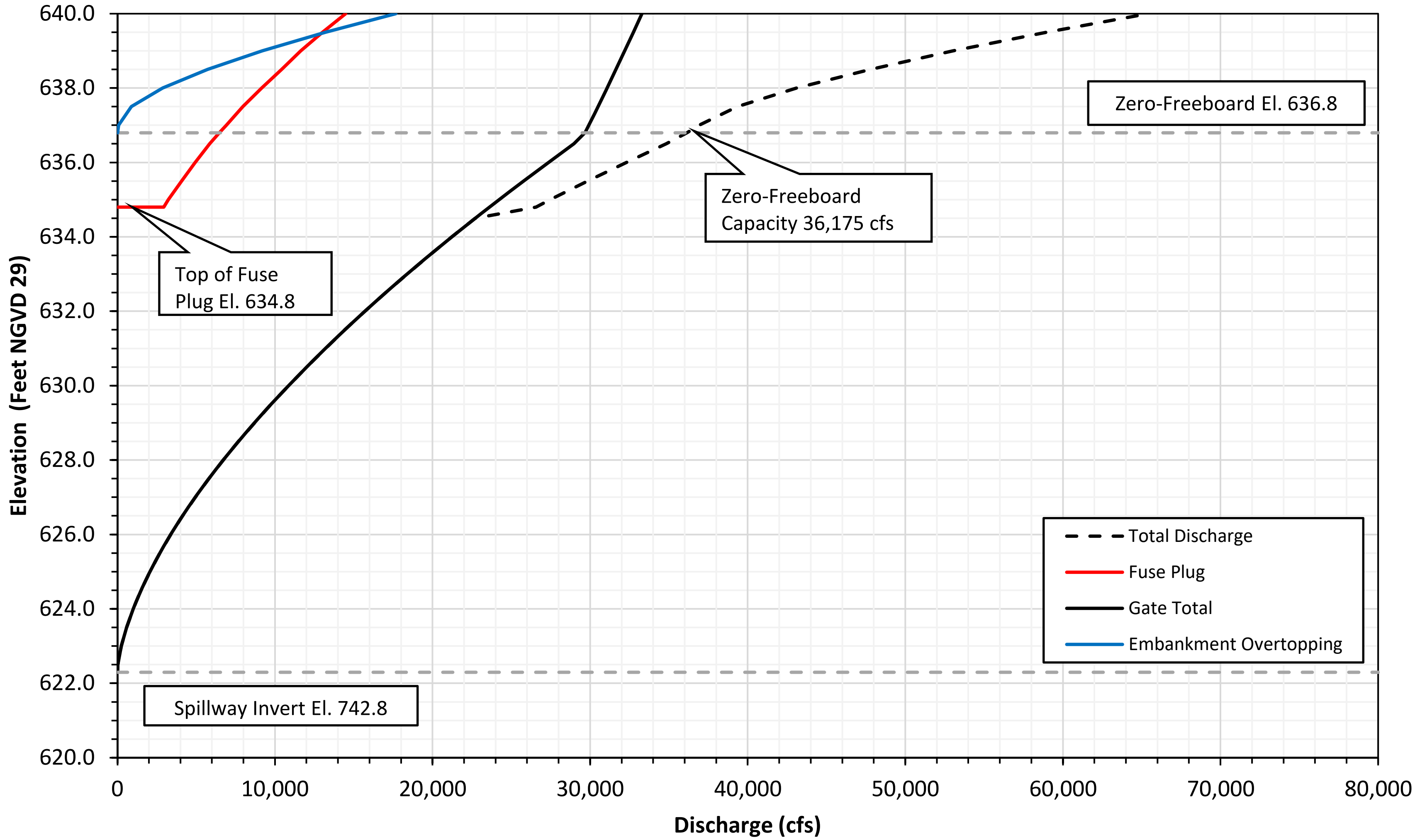
GEI Consultants

Sanford Dam
Tainter Gate Spillway
Discharge Rating Curve

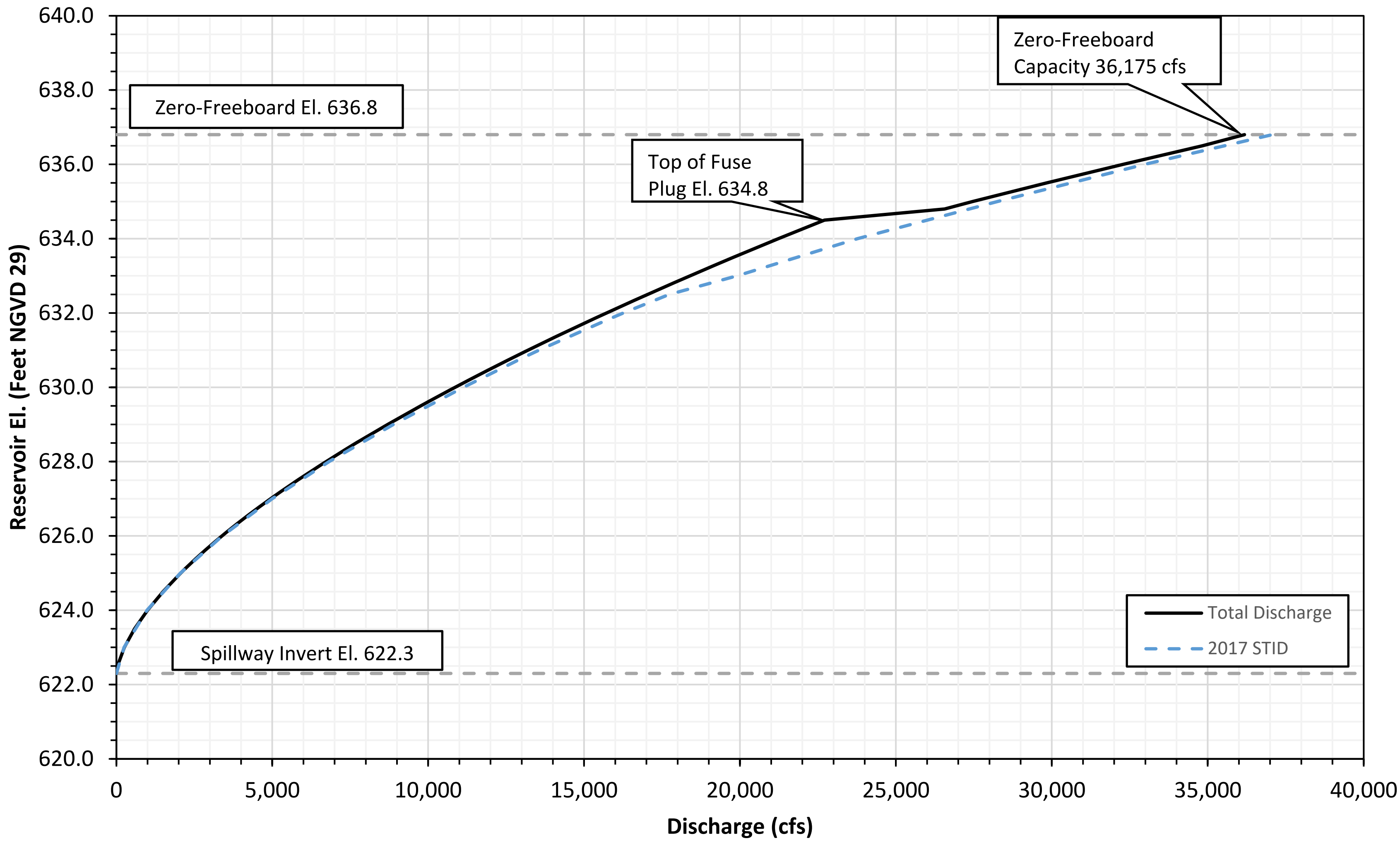
Project 2002879	**March 2021**	**Appendix B.4**



Sanford Dam **Four Lakes Task Force** **FERC Project No. 10809** **Gladwin, Michigan**	GEI Consultants	**Sanford Dam** **Fuse Plug Spillway** **Discharge Rating Curve**
	Project 2002879	**March 2021** — **Appendix B.4**



Sanford Dam **Four Lakes Task Force** **FERC Project No. 10809** **Gladwin, Michigan**	GEI Consultants	**Sanford Dam** **Total Spillway** **Discharge Rating Curve**	
	Project 2002879	**March 2021**	**Appendix B.4**



Sanford Dam **Four Lakes Task Force** **FERC Project No. 10809** **Gladwin, Michigan**	GEI Consultants	**Sanford Dam** **Comparison of Historical Spillway Discharge Rating Curves**	
	Project 2002879	**March 2021**	**Appendix B.4**

Appendix C

Existing Conditions HEC-HMS Flood Routing Results

Appendix C.1 – Secord Dam

Appendix C.2 – Smallwood Dam

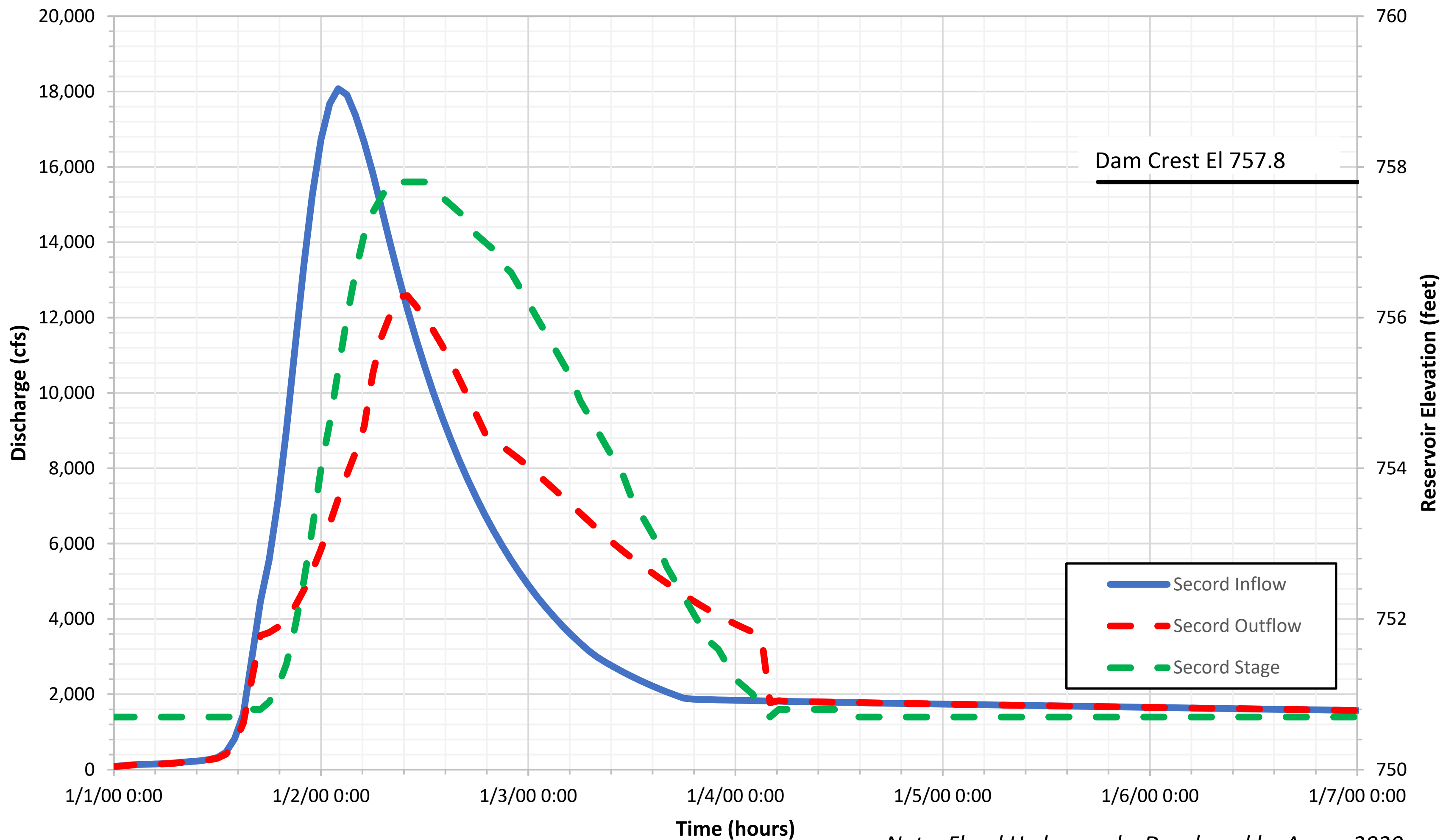
Appendix C.3 – Edenville Dam

Appendix C.4 – Sanford Dam

Appendix C

Existing Conditions HEC-HMS Flood Routing Results

Appendix C.1 – Secord Dam



Note: Flood Hydrographs Developed by Ayres, 2020

Secord Dam
Client: Four Lakes Task Force
Location: Gladwin County, Michigan

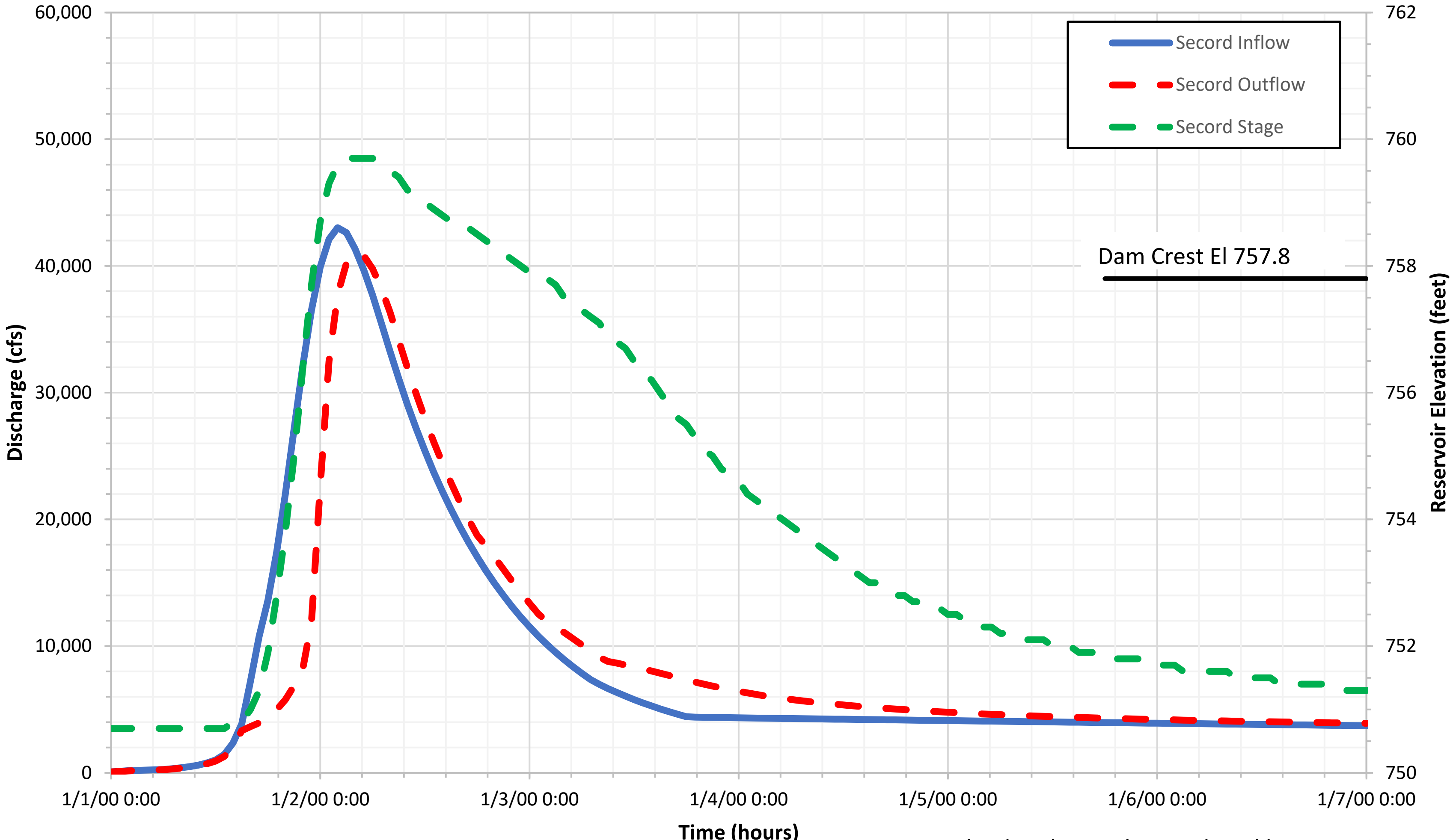
GEI Consultants

Existing Conditions 1/2 PMF Flood Routing Results

Project 2002879

March 2021

Appendix C.1



Note: Flood Hydrographs Developed by Ayres, 2020

Secord Dam
Client: Four Lakes Task Force
Location: Gladwin County, Michigan

GEI Consultants

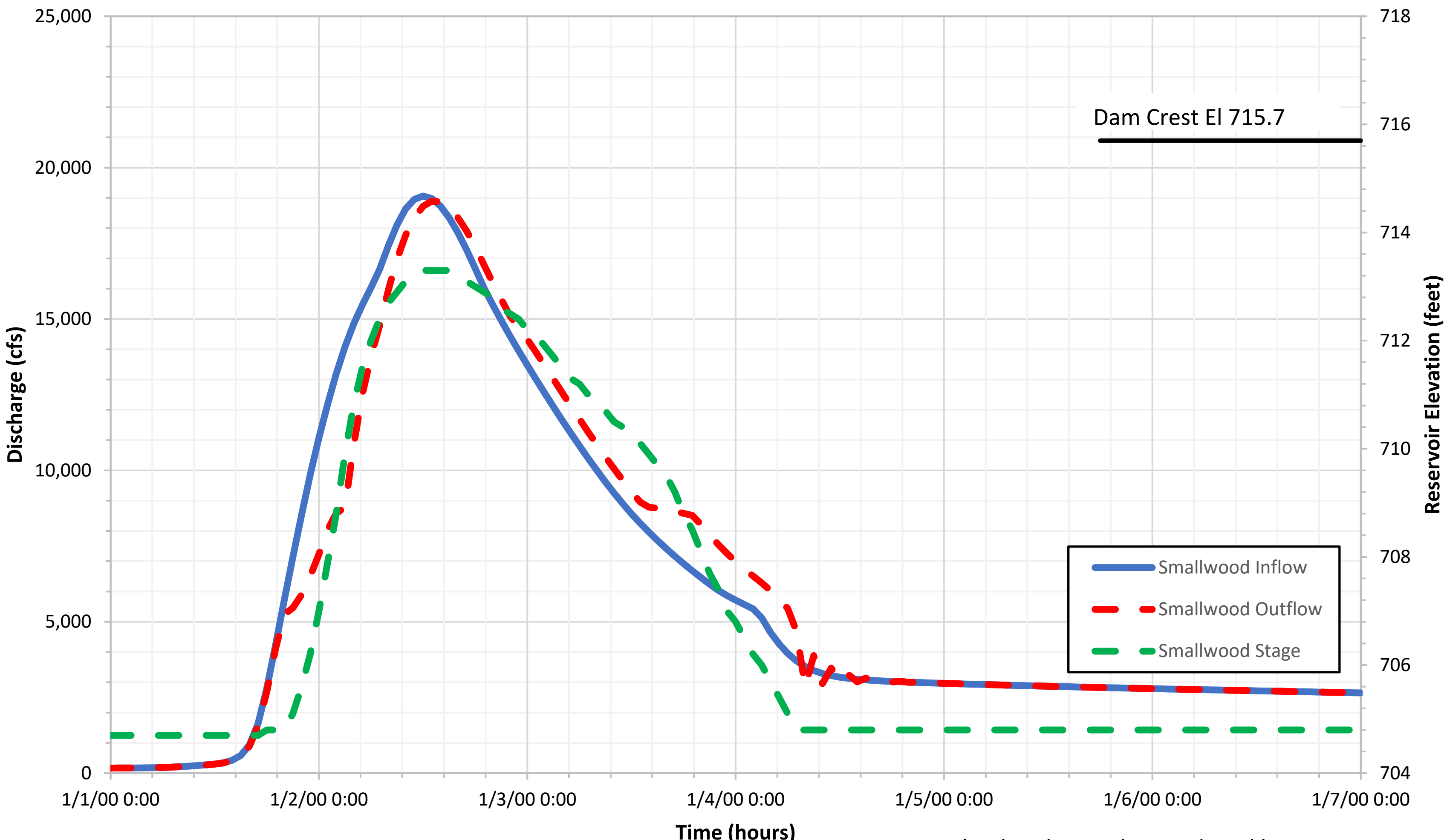
Existing Conditions PMF Flood Routing Results

Project 2002879 | **March 2021** | **Appendix C.1**

Appendix C

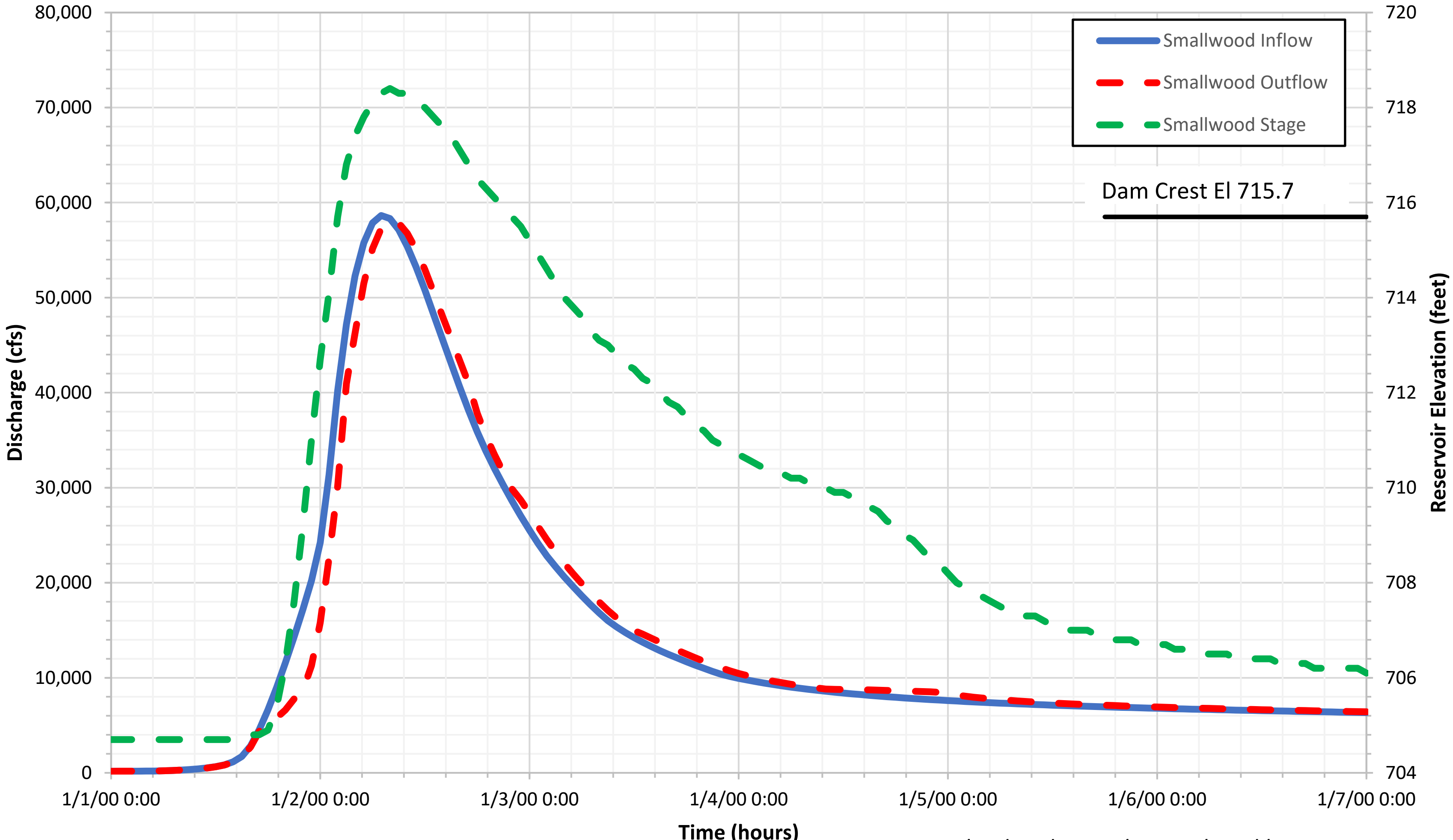
Existing Conditions HEC-HMS Flood Routing Results

Appendix C.2 – Smallwood Dam



Note: Flood Hydrographs Developed by Ayres, 2020

Smallwood Dam **Client: Four Lakes Task Force** **Location: Gladwin County, Michigan**	GEI Consultants	**Existing Conditions 1/2 PMF Flood Routing Results**
	Project 2002879	**March 2021** **Appendix C.2**



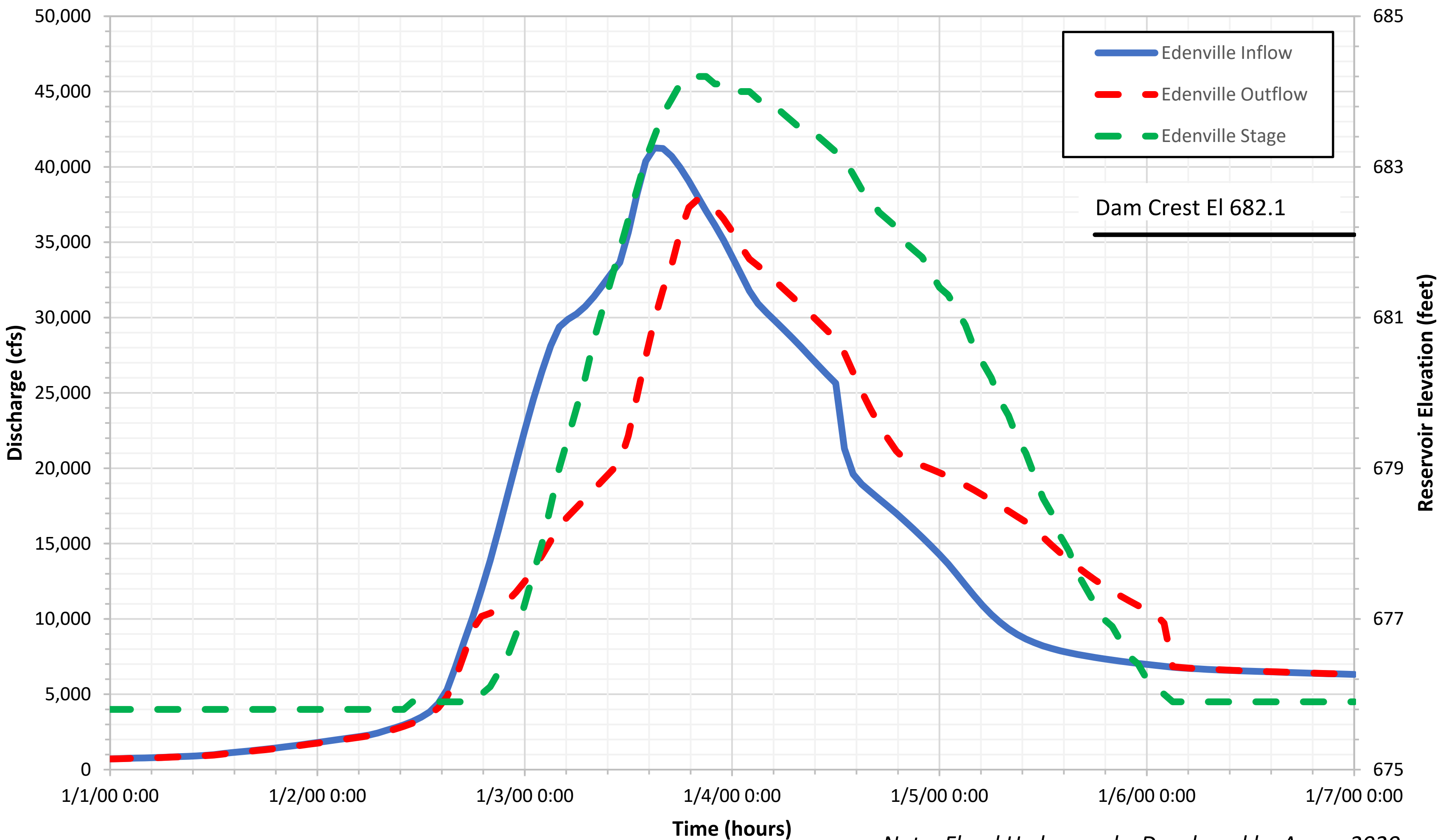
Note: Flood Hydrographs Developed by Ayres, 2020

Smallwood Dam **Client: Four Lakes Task Force** **Location: Gladwin County, Michigan**	GEI Consultants	**Existing Conditions PMF Flood Routing Results**
	Project 2002879	**March 2021** **Appendix C.2**

Appendix C

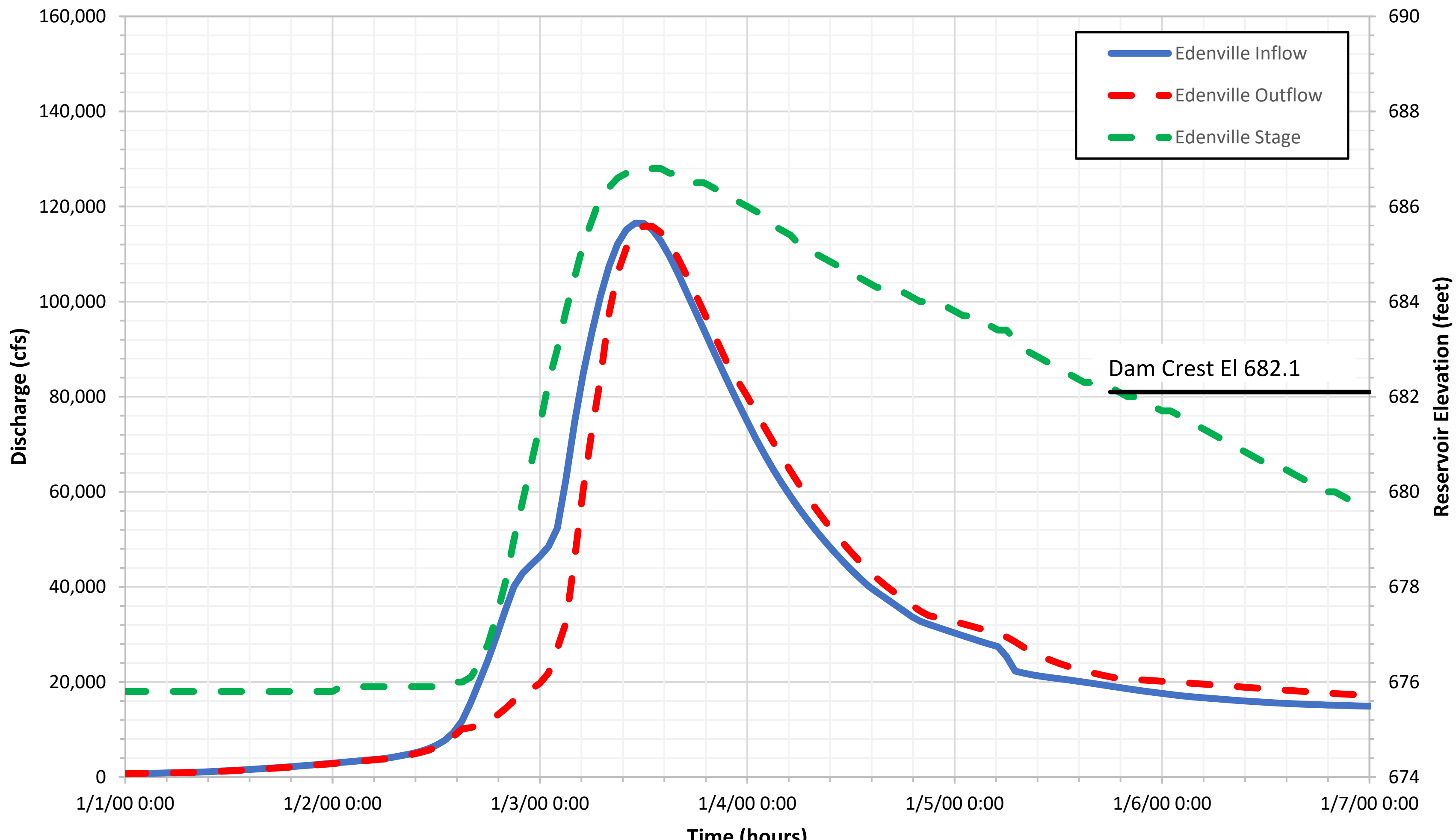
Existing Conditions HEC-HMS Flood Routing Results

Appendix C.3 – Edenville Dam



Note: Flood Hydrographs Developed by Ayres, 2020

Edenville Dam **Client: Four Lakes Task Force** **Location: Gladwin County, Michigan**	GEI Consultants	**Existing Conditions 1/2 PMF Flood Routing Results**
	Project 2002879	**March 2021** **Appendix C.3**



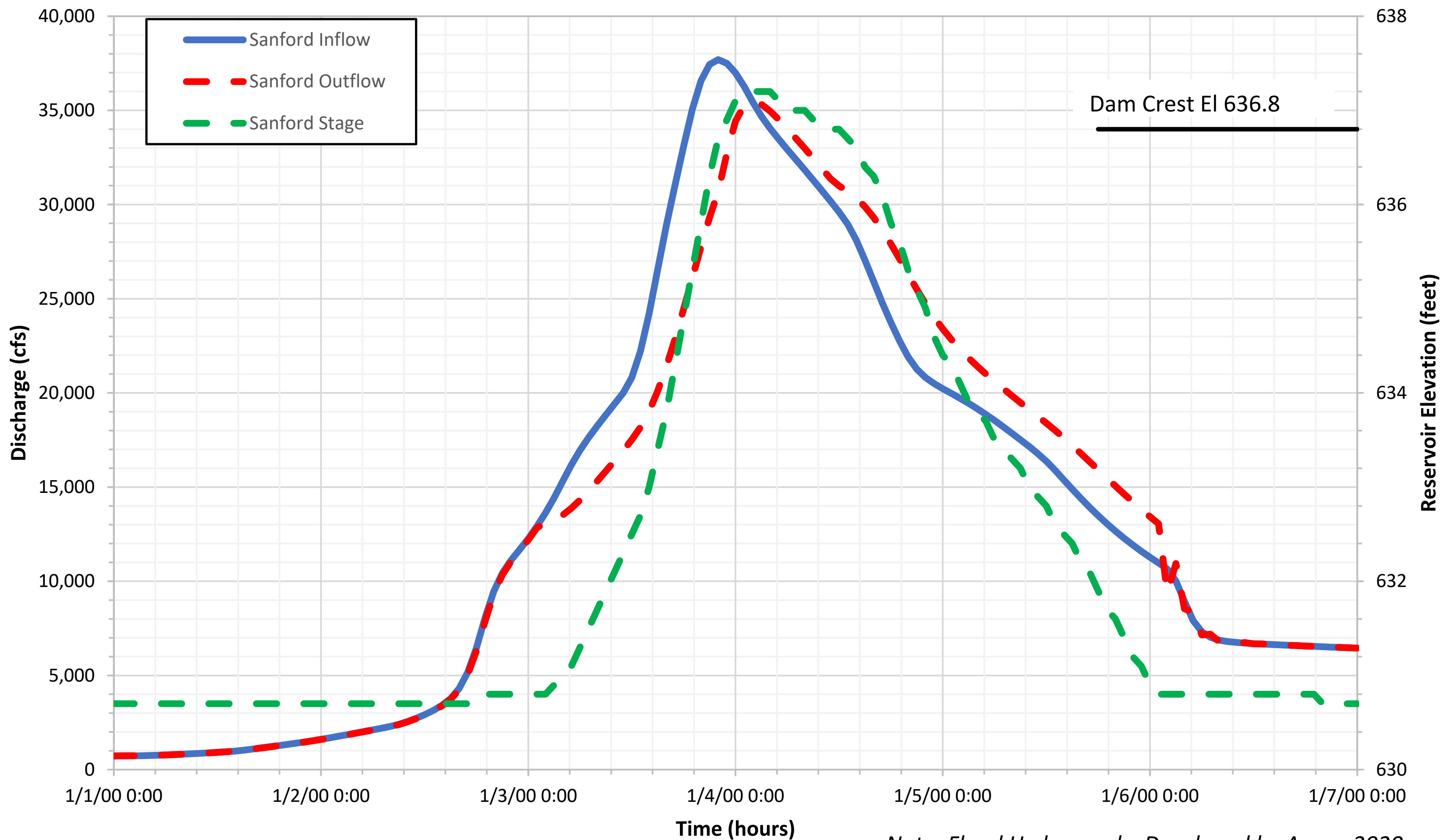
Note: Flood Hydrographs Developed by Ayres, 2020

Edenville Dam **Client: Four Lakes Task Force** **Location: Gladwin County, Michigan**	GEI Consultants	**Existing Conditions PMF Flood Routing Results**	
	Project 2002879	**March 2021**	**Appendix C.3**

Appendix C

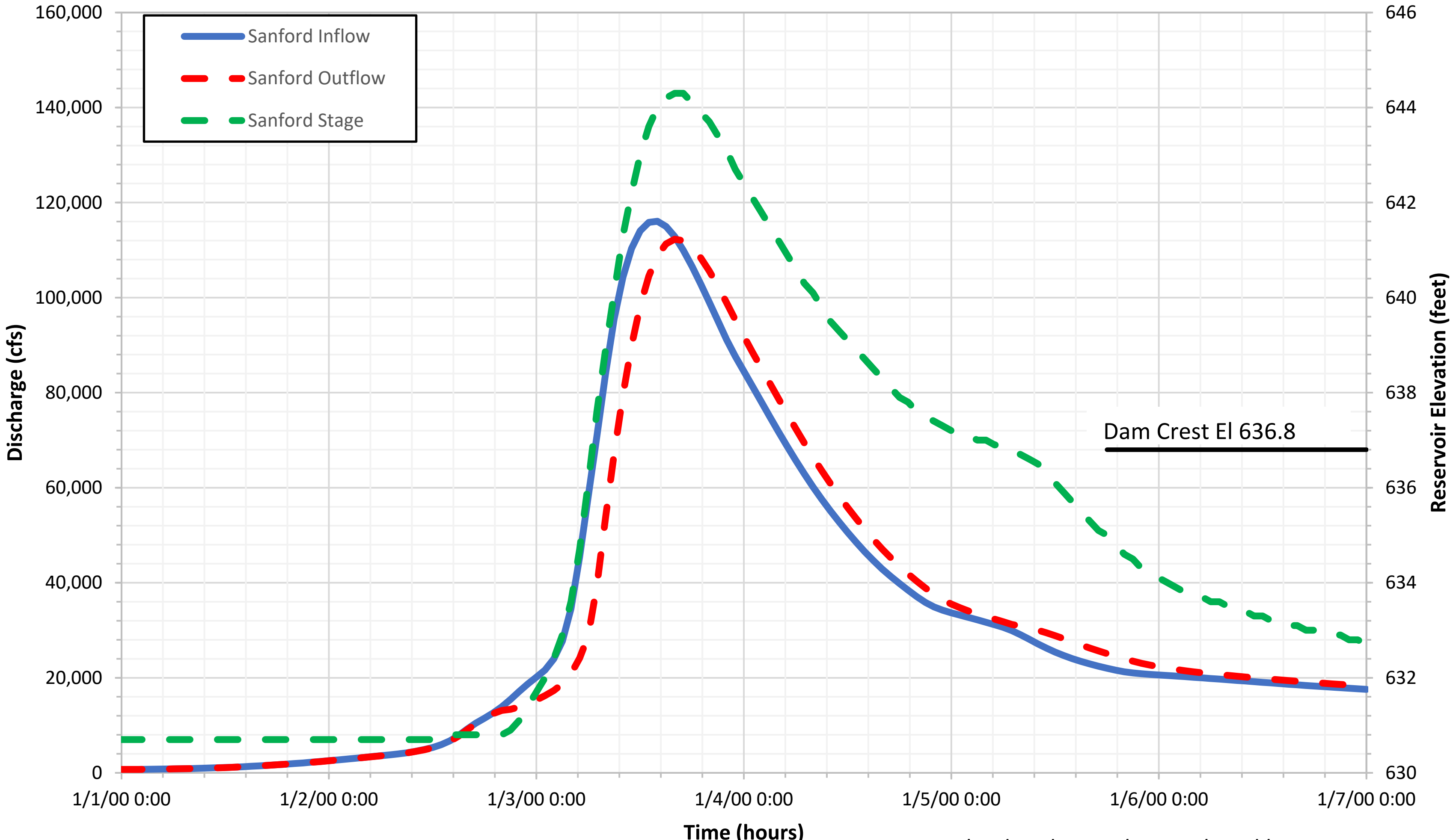
Existing Conditions HEC-HMS Flood Routing Results

Appendix C.4 – Sanford Dam



Note: Flood Hydrographs Developed by Ayres, 2020

Sanford Dam **Client: Four Lakes Task Force** **Location: Midland County, Michigan**	GEI Consultants	**Existing Conditions 1/2 PMF Flood Routing Results**
	Project 2002879	**March 2021** **Appendix C.4**



Note: Flood Hydrographs Developed by Ayres, 2020

Sanford Dam **Client: Four Lakes Task Force** **Location: Midland County, Michigan**	GEI Consultants	**Existing Conditions PMF Flood Routing Results**
	Project 2002879	**March 2021** **Appendix C.4**

Appendix D

Proposed Conditions Spillway Upgrades

Appendix D.1 – Secord Dam

Appendix D.2 – Smallwood Dam

Appendix D.3 – Edenville Dam

Appendix D.4 – Sanford Dam

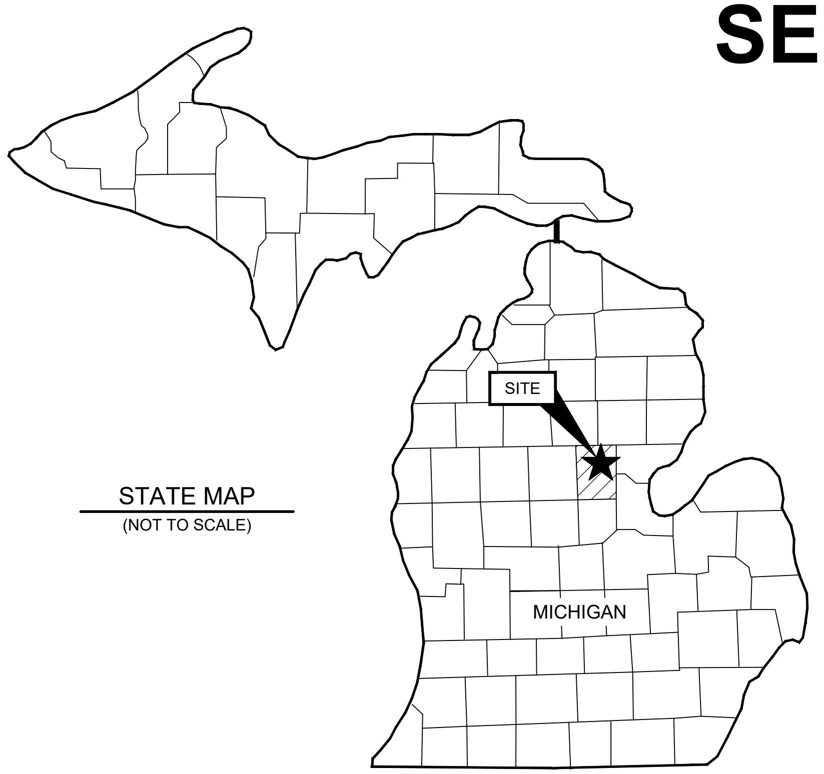
Appendix D

Proposed Conditions Spillway Upgrades

Appendix D.1 – Secord Dam

SECORD DAM CONCEPTUAL DESIGN

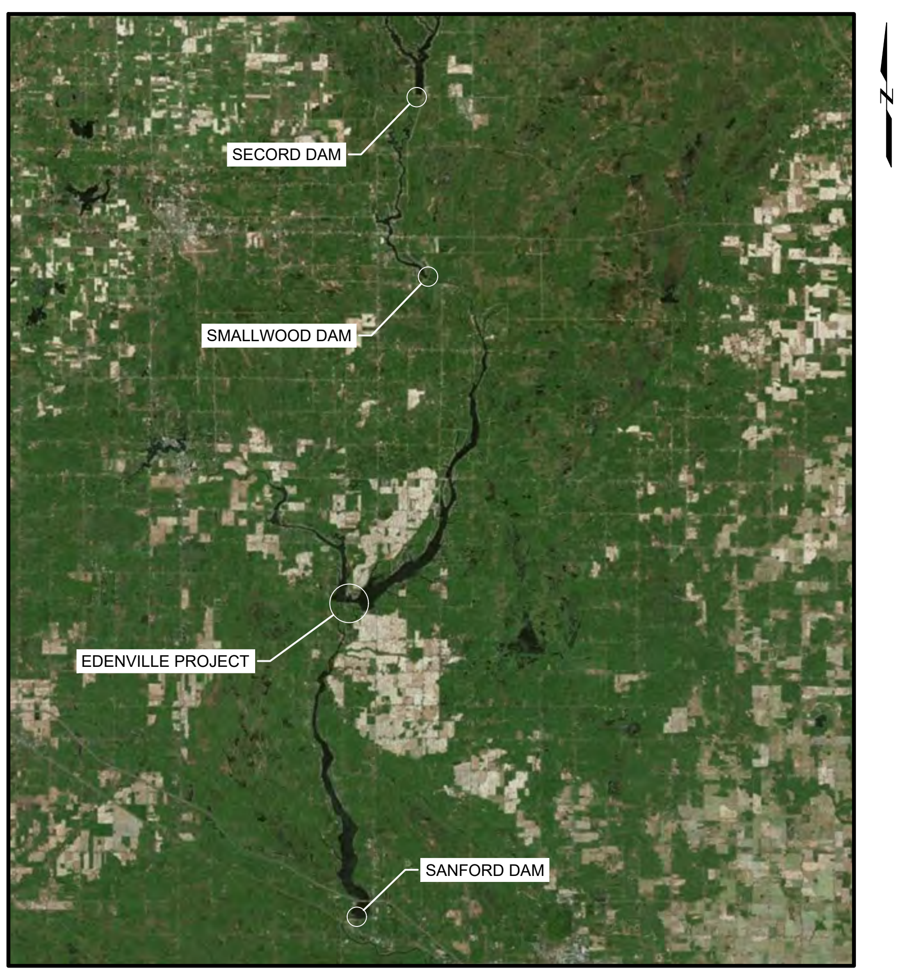
GLADWIN COUNTY, MICHIGAN
FOUR LAKES TASK FORCE
FERC PROJECT NO. 10809



STATE MAP
(NOT TO SCALE)

SITE AERIAL
(NOT TO SCALE)

SHEET INDEX



SOURCE:
AERIAL IMAGE TAKEN FROM GOOGLE EARTH

SITE LOCATION
(NOT TO SCALE)

PREPARED FOR:

FOUR LAKES TASK FORCE
233 E. LARKIN
MIDLAND, MI 48640

PREPARED BY:

GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414) 930-7534

GEI Consultants

SPICER GROUP INC.
230 S. WASHINGTON AVE.
SAGINAW, MI 48607
TEL. (989) 754-4717
FAX. (989) 754-4440

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NO.	DATE	ISSUE/REVISION	APP
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DWG. NO.
G-01

SHEET NO.
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1. GENERAL

SPACIAL DATUM INFORMATION

- VERTICAL: NATIONAL GEODETIC VERTICAL DATUM OF 1929 (NGVD29).
- HORIZONTAL: NORTH AMERICAN DATUM OF 1983 (NAD83), MICHIGAN STATE PLANE, CENTRAL ZONE.
- A CONVERSION OF +5.8' IS REQUIRED WHEN CONVERTING VERTICAL DAM DATUM TO NGVD29 (E.G., HEADWATER ELEVATION AT DAM DATUM IS 745.0' AND AT NGVD29 DATUM IS 750.8').
- A CONVERSION OF -0.512' IS REQUIRED WHEN CONVERTING VERTICAL NGVD29 DATUM TO NAVD88 DATUM.
- CONTROL MONUMENTS ON-SITE SHALL BE REFERRED TO CONFIRM HORIZONTAL AND VERTICAL MEASUREMENTS.

BASEMAP DATA

- SITE TOPOGRAPHY AND AERIAL IMAGE OBTAINED DRONE FLIGHT PERFORMED BY SPICER GROUP IN 2020.
- COVER SHEET AERIAL IMAGES OBTAINED FROM GOOGLE EARTH REPRESENT CONDITIONS IN JUNE, 2018.
- OBTAINED FROM BOYCE HYDRO:
  - ORIGINAL CONSTRUCTION DRAWINGS
  - EXHIBIT F LICENSE DRAWINGS

DESIGN PARAMETERS

- NORMAL RESERVOIR ELEVATION 750.8' (+0.3' / -0.4')
- WINTER RESERVOIR OPERATIONS: MINIMUM 747.8' (+0.7')
- ORDINARY HIGH WATER MARK ELEVATION 704.3 (±0.5')

DESIGN REFERENCE STANDARDS

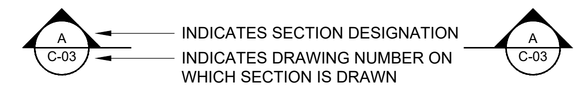
- (USBR, 1987) UNITED STATES DEPARTMENT OF THE INTERIORER, BUREAU OF RECLAMATION, "DESIGN OF SMALL DAMS", 1987.
- (USACE, 1995) UNITED STATES ARMY CORPS OF ENGINEERS, ENGINEERING AND DESIGN, "CONSTRUCTION CONTROL FOR EARTH AND ROCK-FILL DAMS", EM 1110-2-1911, 1995.
- (ACI, 2001) AMERICAN CONCRETE INSTITUTE, "CONTROL OF CRACKING IN CONCRETE STRUCTURES" (ACI 224), 2001.
- (USACE, 2004) UNITED STATES ARMY CORPS OF ENGINEERS, ENGINEERING AND DESIGN, "GENERAL DESIGN AND CONSTRUCTION CONSIDERATIONS FOR EARTH AND ROCK-FILL DAMS", EM 1110-2-2300, 2004.
- (ACI, 2006) AMERICAN CONCRETE INSTITUTE, "CODE REQUIREMENTS FOR ENVIRONMENTAL ENGINEERING CONCRETE STRUCTURES" (ACI 350), 2006.
- (ACI, 2011) AMERICAN CONCRETE INSTITUTE, "BUILDING CODE REQUIREMENTS FOR STRUCTURAL CONCRETE" (ACI 318), 2011.
- (FERC, 2016) FEDERAL ENERGY REGULATORY COMMISSION, ENGINEERING GUIDELINES FOR EVALUATION OF HYDROPOWER PROJECTS (MOST RECENT VERSIONS)

ABBREVIATIONS

BO = BOTTOM OF
C = CENTER LINE
MM = MOVEMENT MONUMENT
CONC = CONCRETE
CONT = CONTINUOUS
CTRD = CENTERED
D/S = DOWNSTREAM
EO = EDGE OF
EX = EXISTING
EF = EACH FACE
EL = ELEVATION (FEET)
HW = HEADWATER
MAX = MAXIMUM
OC = ON CENTER
OCEW = ON CENTER EACH WAY
OHWM = ORDINARY HIGH WATER MARK
PL = PLATE
PMF = PROBABLE MAXIMUM FLOOD
SDF = SPILLWAY DESIGN FLOOD
SSP = STEEL SHEET PILE
STD = STANDARD
STIFF = STIFFENER
TBD = TO BE DETERMINED
TO = TOP OF
TW = TAILWATER
TYP = TYPICAL
UON = UNLESS OTHERWISE NOTED
U/S = UPSTREAM
VIF = VERIFY IN FIELD
WL = WETLAND
W/ = WITH

SECTION AND DETAIL LEGEND

SECTION



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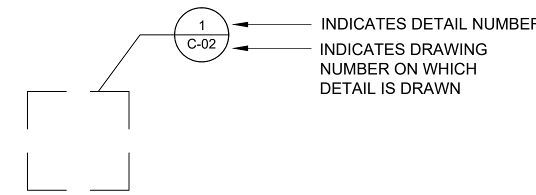


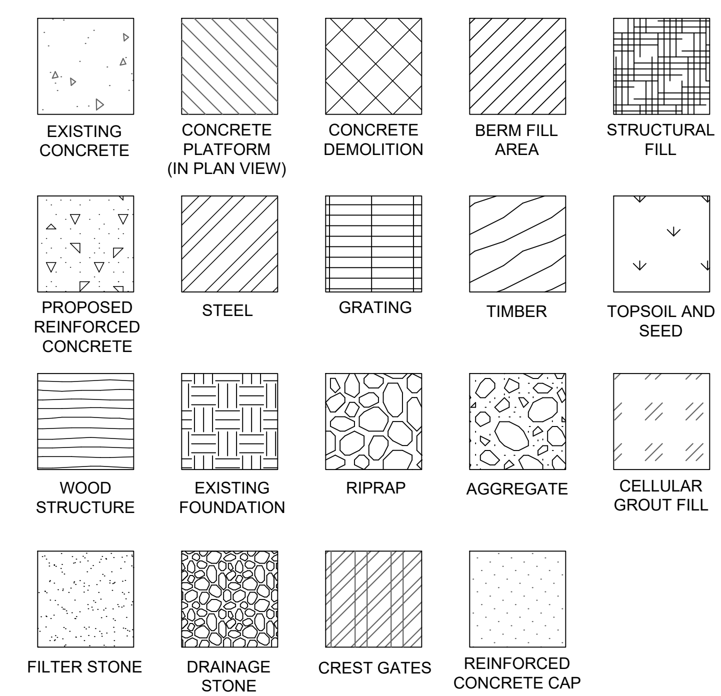
LINETYPE LEGEND

- CENTERLINE
- WATER ELEVATION
- OVERHEAD ELECTRIC LINES (O/E)
- FENCE LINE (STEEL)
- FENCE LINE (WOOD)
- UNDERGROUND CABLE (CATV)
- GAS LINE (GAS)
- EDGE OF ROADWAY (UNPAVED)
- ROADWAY CENTERLINE
- BURIED PIPING
- SILT FENCE
- EXISTING MAJOR CONTOURS (750)
- EXISTING MINOR CONTOURS
- DESIGN MAJOR CONTOURS (750)
- DESIGN MINOR CONTOURS

SYMBOLS LEGEND

- WATER ELEVATION
- FLOW DIRECTION
- 1H:1V CUT SLOPE
- 1H:1V FILL SLOPE
- POWER POLE
- SB-1 SOIL BORING
- MW #1 MONITORING WELL
- BM #1 SURVEY REFERENCE MONUMENT (CONTORL POINT / BENCHMARK)
- SURVEY MOVEMENT MONUMENT
- SB-3 SOIL BORING COMPLETED BY STEARNS DRILLING, 1996
- SB-1 SOIL BORING COMPLETED BY RC ASSOCIATES, INC., 2001
- SB-5 SOIL BORING COMPLETED BY McDOWELL & ASSOCIATES, 2005
- DRAIN TILES

HATCH LEGEND



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GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed:	P. DREW
Checked:	P. DREW
Drawn:	A. SAMPSON
Approved By:	B. WALTON

Four Lakes Task Force
FERC Project No. 10809

GEI Project 2002879

Secord Dam Conceptual Design
Gladwin County, Michigan

GENERAL NOTES AND LEGEND

DWG. NO. G-02

SHEET NO. 2

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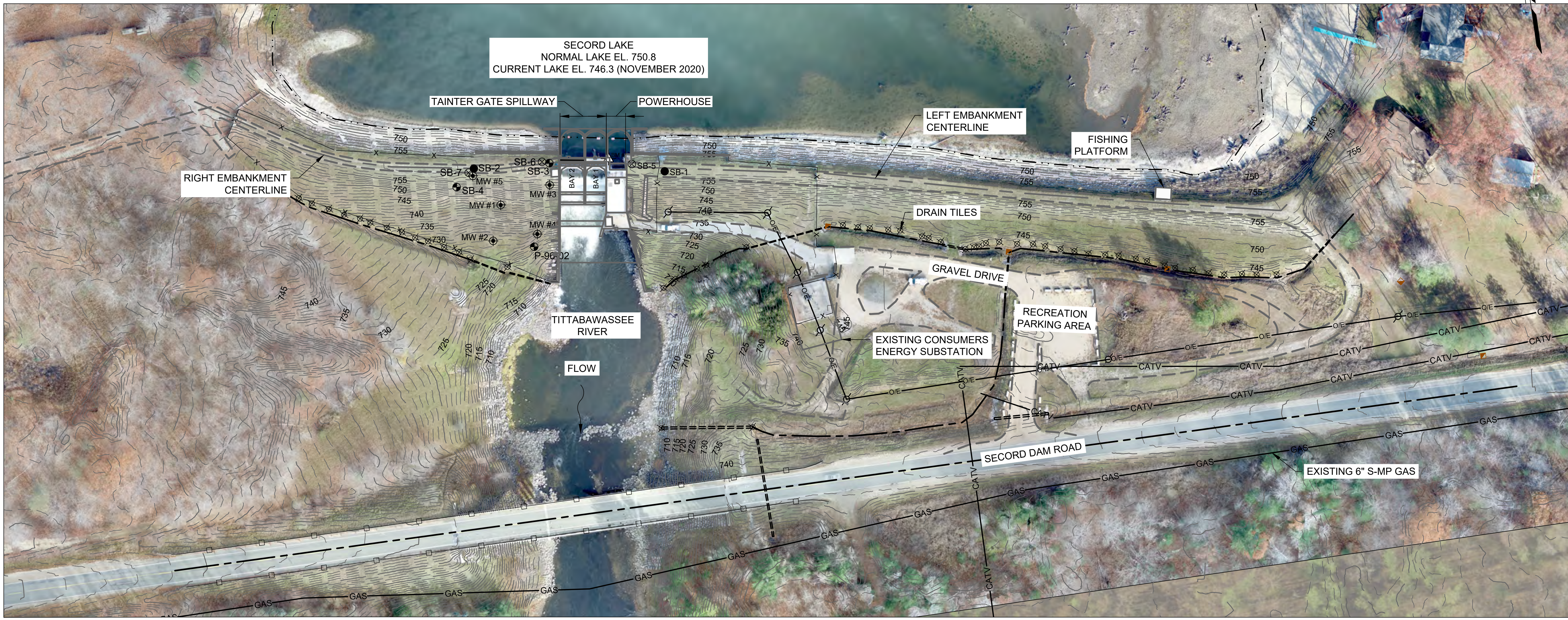

LINETYPE LEGEND

——	CENTERLINE
· · ·	WATER ELEVATION
O/E	OVERHEAD ELECTRIC LINES
X	FENCE LINE (STEEL)
□	FENCE LINE (WOOD)
CATV	UNDERGROUND CABLE
— —	EDGE OF ROADWAY (UNPAVED)
— · —	ROADWAY CENTERLINE
- - -	BURIED PIPING
GAS	GAS LINE
750	EXISTING MAJOR CONTOURS
— —	EXISTING MINOR CONTOURS

SYMBOLS LEGEND

SB-3	SOIL BORING COMPLETED BY STEARNS DRILLING, 1996
SB-1	SOIL BORING COMPLETED BY RC ASSOCIATES, INC., 2001
SB-5	SOIL BORING COMPLETED BY McDOWELL & ASSOCIATES, 2005
	DRAIN TILES
	FLOW DIRECTION
MW #1	MONITORING WELL
BM #1	SURVEY REFERENCE MONUMENT

EXISTING CONDITIONS SITE PLAN

0 50 100
SCALE, FT

SURVEY CONTROL MONUMENT LOCATIONS

ID	ELEVATION	COMMENT
BM #1	758.45	EXISTING BENCHMARK CAP IN NORTHEAST CORNER OF SPILLWAY WALKWAY.

NOTES:

1. Vertical datum: National Geodetic Vertical Datum of 1929 (NGVD29)
2. Spatial datum: North American Datum of 1983 (NAD83), Michigan State Plane, Central Zone

Attention: 0 1" If this scale bar does not measure 1" then drawing is not original scale.

NO.	DATE	ISSUE/REVISION	APP
0	xx/xx/xxxx	CONCEPTUAL DESIGN SUBMITTAL	--

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GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed:	P. DREW
Checked:	P. DREW
Drawn:	A. SAMPSON
Approved By:	B. WALTON

Four Lakes Task Force
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GEI Project 2002879

Secord Dam Conceptual Design
Gladwin County, Michigan

SITE PLAN - EXISTING CONDITIONS

DWG. NO. C-01

SHEET NO. 3

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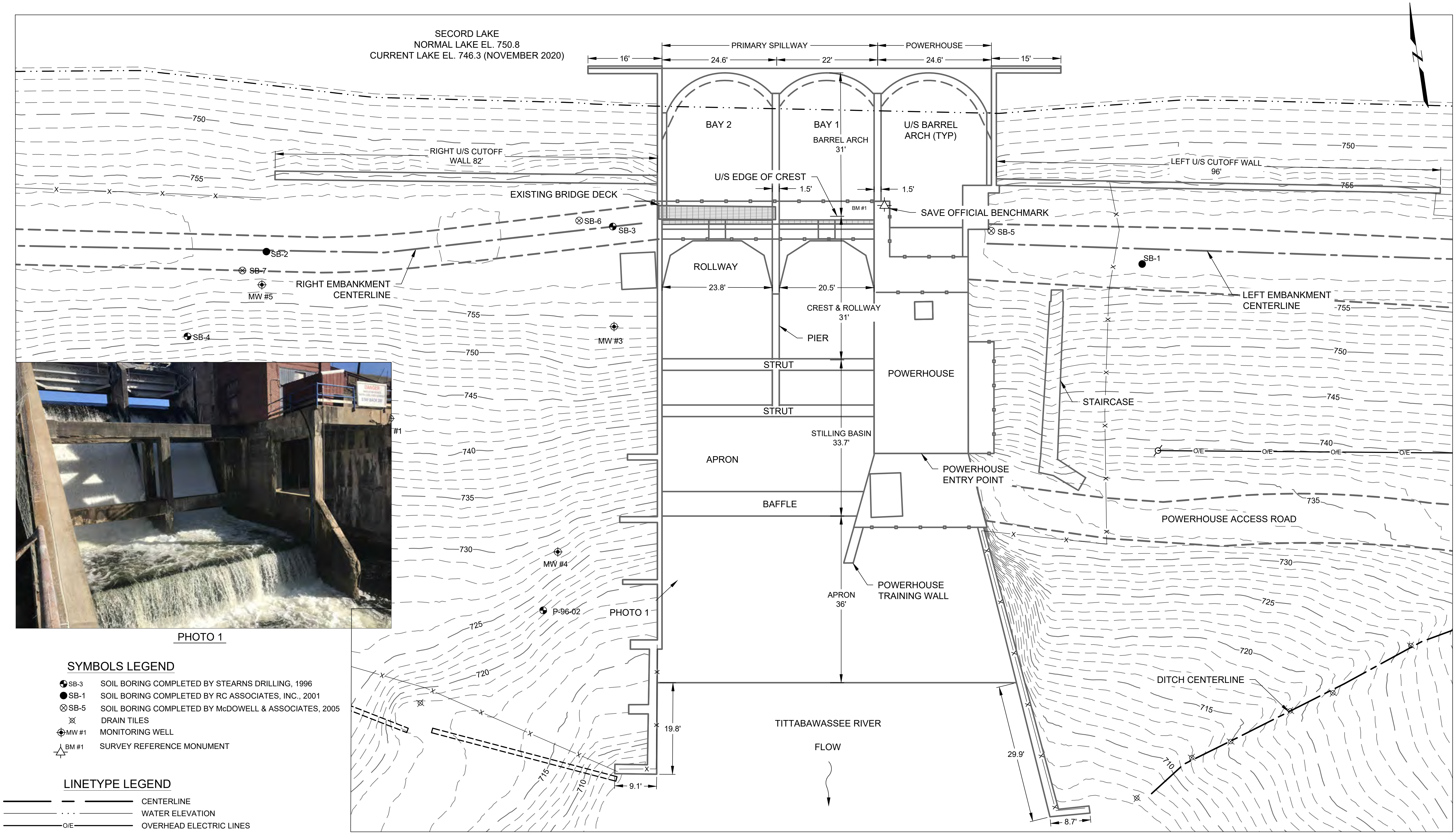

PHOTO 1

SYMBOLS LEGEND

- SB-3 — SOIL BORING COMPLETED BY STEARNS DRILLING, 1996
- SB-1 — SOIL BORING COMPLETED BY RC ASSOCIATES, INC., 2001
- SB-5 — SOIL BORING COMPLETED BY McDOWELL & ASSOCIATES, 2005
- DRAIN TILES
- MW #1 — MONITORING WELL
- BM #1 — SURVEY REFERENCE MONUMENT

LINETYPE LEGEND

- CENTERLINE
- WATER ELEVATION
- O/E — OVERHEAD ELECTRIC LINES
- X — FENCE LINE (STEEL)
- EDGE OF ROADWAY (UNPAVED)
- BURIED PIPING
- 750 — EXISTING MAJOR CONTOURS
- EXISTING MINOR CONTOURS

OUTLET WORKS - EXISTING PLAN VIEW

0 10 20
SCALE, FT

Attention:
0 1"
If this scale bar does not measure 1" then drawing is not original scale.

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10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed:	P. DREW
Checked:	P. DREW
Drawn:	A. SAMPSON
Approved By:	B. WALTON

Four Lakes Task Force
FERC Project No. 10809

GEI Project 2002879

Secord Dam Conceptual Design
Gladwin County, Michigan

OUTLET WORKS - EXISTING CONDITIONS PLAN

DWG. NO. C-02

SHEET NO. 4

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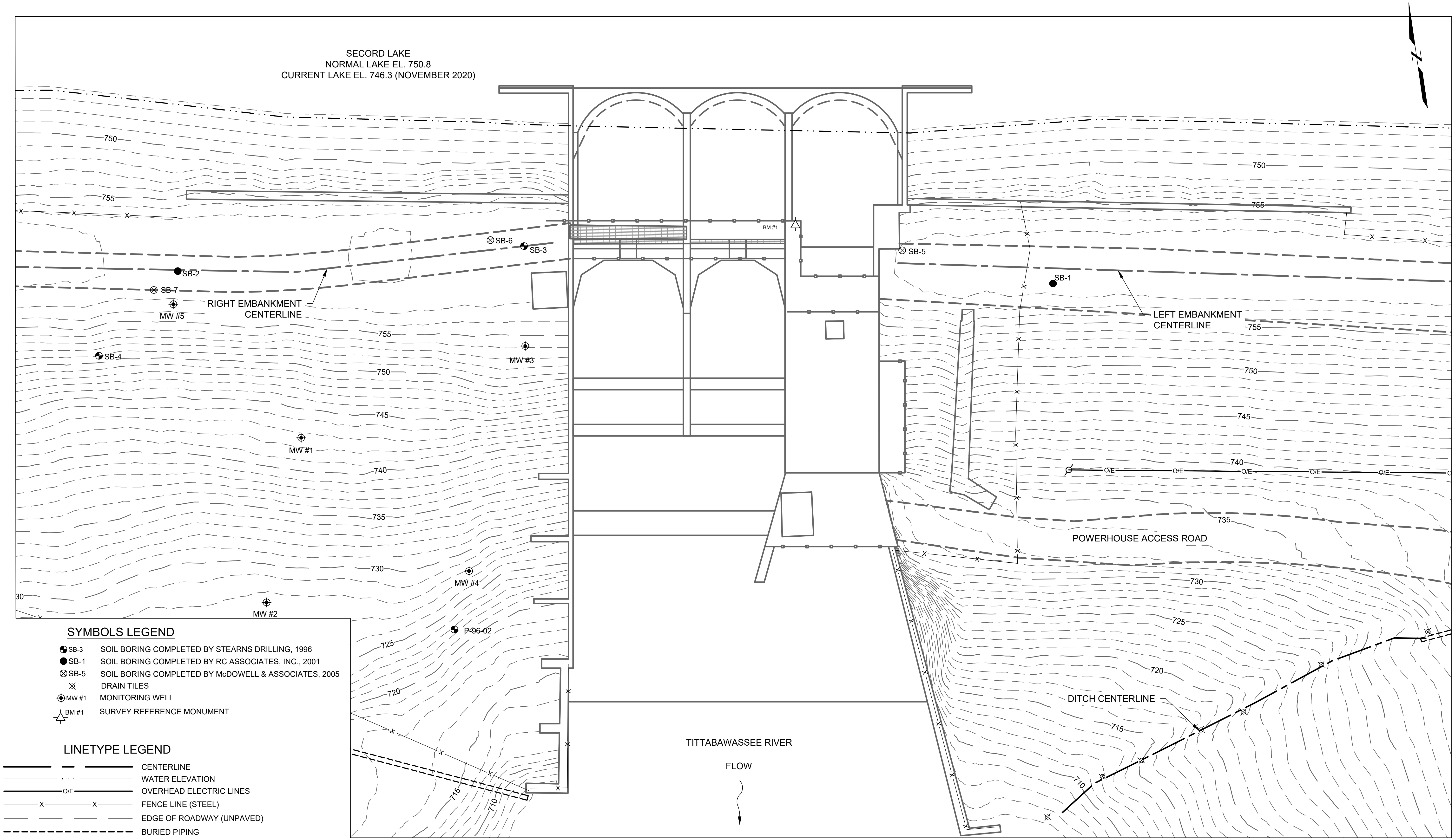

SYMBOLS LEGEND

- SB-3 — SOIL BORING COMPLETED BY STEARNS DRILLING, 1996
- SB-1 — SOIL BORING COMPLETED BY RC ASSOCIATES, INC., 2001
- SB-5 — SOIL BORING COMPLETED BY McDOWELL & ASSOCIATES, 2005
- DRAIN TILES
- MW #1 — MONITORING WELL
- BM #1 — SURVEY REFERENCE MONUMENT

LINETYPE LEGEND

- CENTERLINE
- WATER ELEVATION
- O/E — OVERHEAD ELECTRIC LINES
- X — FENCE LINE (STEEL)
- EDGE OF ROADWAY (UNPAVED)
- BURIED PIPING
- 750 — EXISTING MAJOR CONTOURS
- EXISTING MINOR CONTOURS

OUTLET WORKS - PLAN VIEW

0 10 20
SCALE, FT

Attention:	NO.	DATE	ISSUE/REVISION	APP
0 1" If this scale bar does not measure 1" then drawing is not original scale.	0	xx/xx/xxxx	CONCEPTUAL DESIGN SUBMITTAL	--

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Saginaw, MI 48607 Tel.
989-754-4717 Fax.
989-754-4440
www.SpicerGroup.com

GEI Consultants
GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed:	P. DREW
Checked:	P. DREW
Drawn:	A. SAMPSON
Approved By:	B. WALTON

Four Lakes Task Force
FERC Project No. 10809

GEI Project 2002879

Secord Dam Conceptual Design
Gladwin County, Michigan

OUTLET WORKS - TEMPORARY COFFERDAMS PLAN

DWG. NO. C-03

SHEET NO. 5

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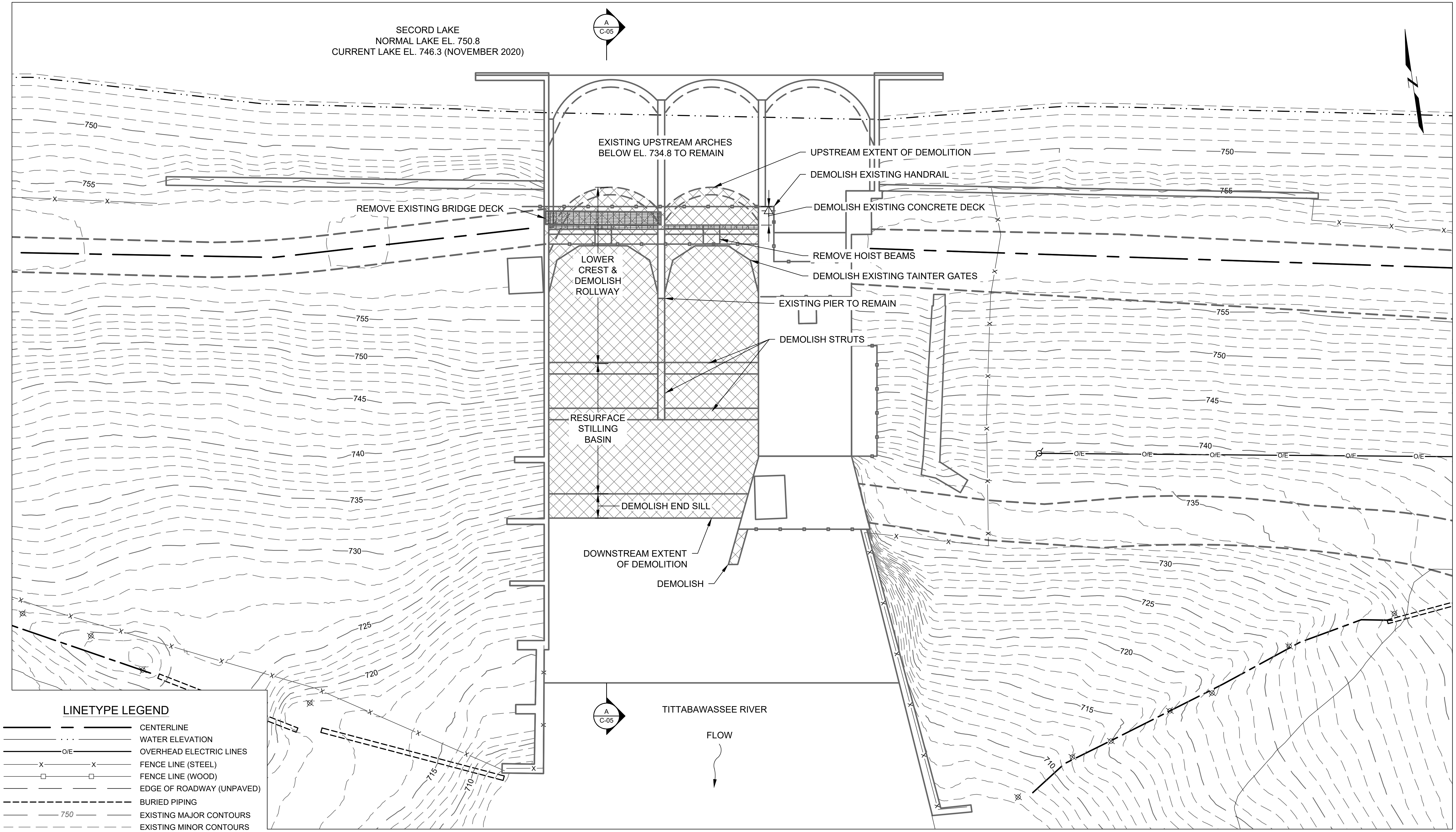

OUTLET WORKS - DEMOLITION PLAN VIEW

0 10 20
SCALE, FT

LINETYPE LEGEND

- CENTERLINE
- WATER ELEVATION
- OVERHEAD ELECTRIC LINES (O/E)
- FENCE LINE (STEEL)
- FENCE LINE (WOOD)
- EDGE OF ROADWAY (UNPAVED)
- BURIED PIPING
- EXISTING MAJOR CONTOURS (750)
- EXISTING MINOR CONTOURS

HATCH LEGEND

- GRATING
- CONCRETE DEMOLITION

SYMBOLS LEGEND

- DRAIN TILES
- FLOW DIRECTION

Attention: 0 1" If this scale bar does not measure 1" then drawing is not original scale.

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GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed:	P. DREW
Checked:	P. DREW
Drawn:	A. SAMPSON
Approved By:	B. WALTON

Four Lakes Task Force
FERC Project No. 10809

GEI Project 2002879

Secord Dam Conceptual Design
Gladwin County, Michigan

OUTLET WORKS - DEMOLITION PLAN

DWG. NO. C-04

SHEET NO. 6

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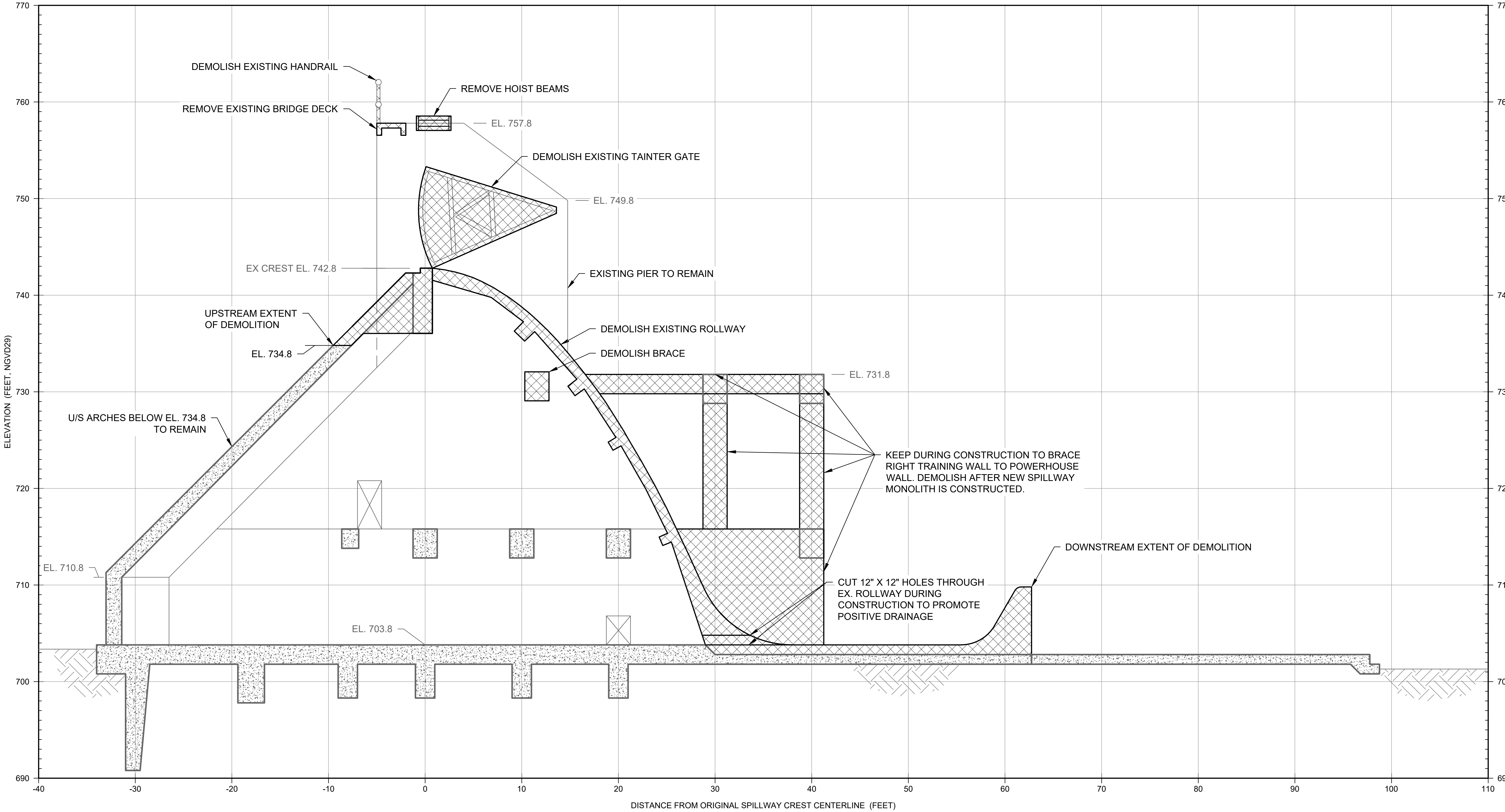

A
C-04

SECTION
SPILLWAY DEMOLITION

0 5 10
SCALE, FT

HATCH LEGEND

CONCRETE DEMOLITION | EXISTING CONCRETE | EXISTING FOUNDATION

Attention:
0 1"
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NO.	DATE	ISSUE/REVISION	APP
0	xx/xx/xxxx	CONCEPTUAL DESIGN SUBMITTAL	--

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GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed: P. DREW
Checked: P. DREW
Drawn: A. SAMPSON
Approved By: B. WALTON

Four Lakes Task Force
FERC Project No. 10809
GEI Project 2002879

Secord Dam Conceptual Design
Gladwin County, Michigan

OUTLET WORKS - DEMOLITION SECTION

DWG. NO.
C-05
SHEET NO.
7

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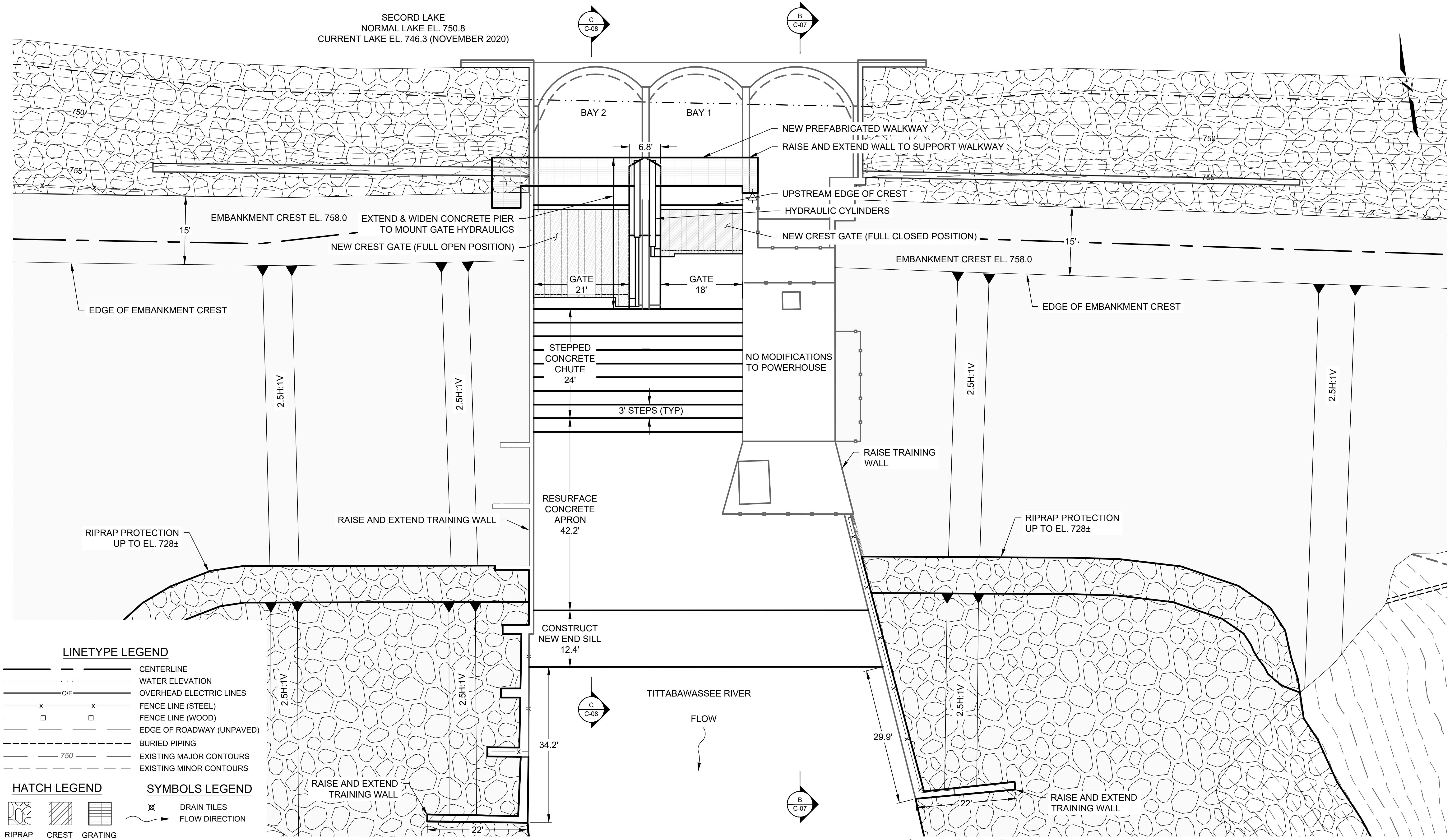

OUTLET WORKS - MODIFICATIONS PLAN VIEW

0 10 20
SCALE, FT

Attention:
0 1"
If this scale bar does not measure 1" then drawing is not original scale.

NO.	DATE	ISSUE/REVISION	APP
0	xx/xx/xxxx	CONCEPTUAL DESIGN SUBMITTAL	--

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989-754-4440
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GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
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Gladwin County, Michigan

OUTLET WORKS - MODIFICATIONS PLAN VIEW

DWG. NO.
C-06

SHEET NO.
8

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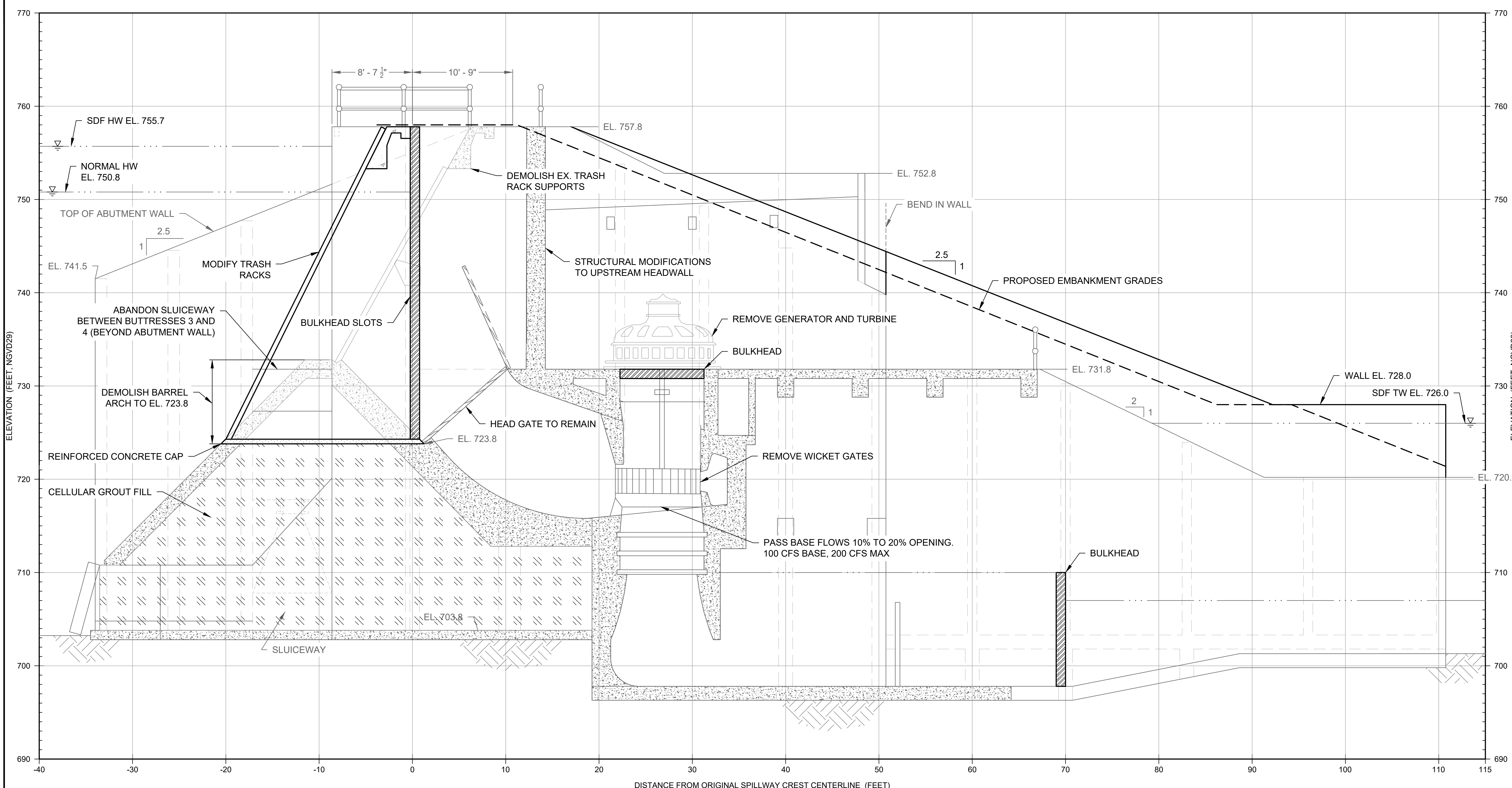

B
C-06

SECTION
POWERHOUSE

0 5 10
SCALE, FT

HATCH LEGEND

EXISTING CONCRETE	EXISTING FOUNDATION	REINFORCED CONCRETE CAP	CELLULAR GROUT FILL	TIMBER

Attention:
0 1"
If this scale bar does not measure 1" then drawing is not original scale.

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Saginaw, MI 48607 Tel.
989-754-4717 Fax.
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GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed: P. DREW
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POWERHOUSE - MODIFICATIONS SECTION

DWG. NO.
C-07

SHEET NO.
9

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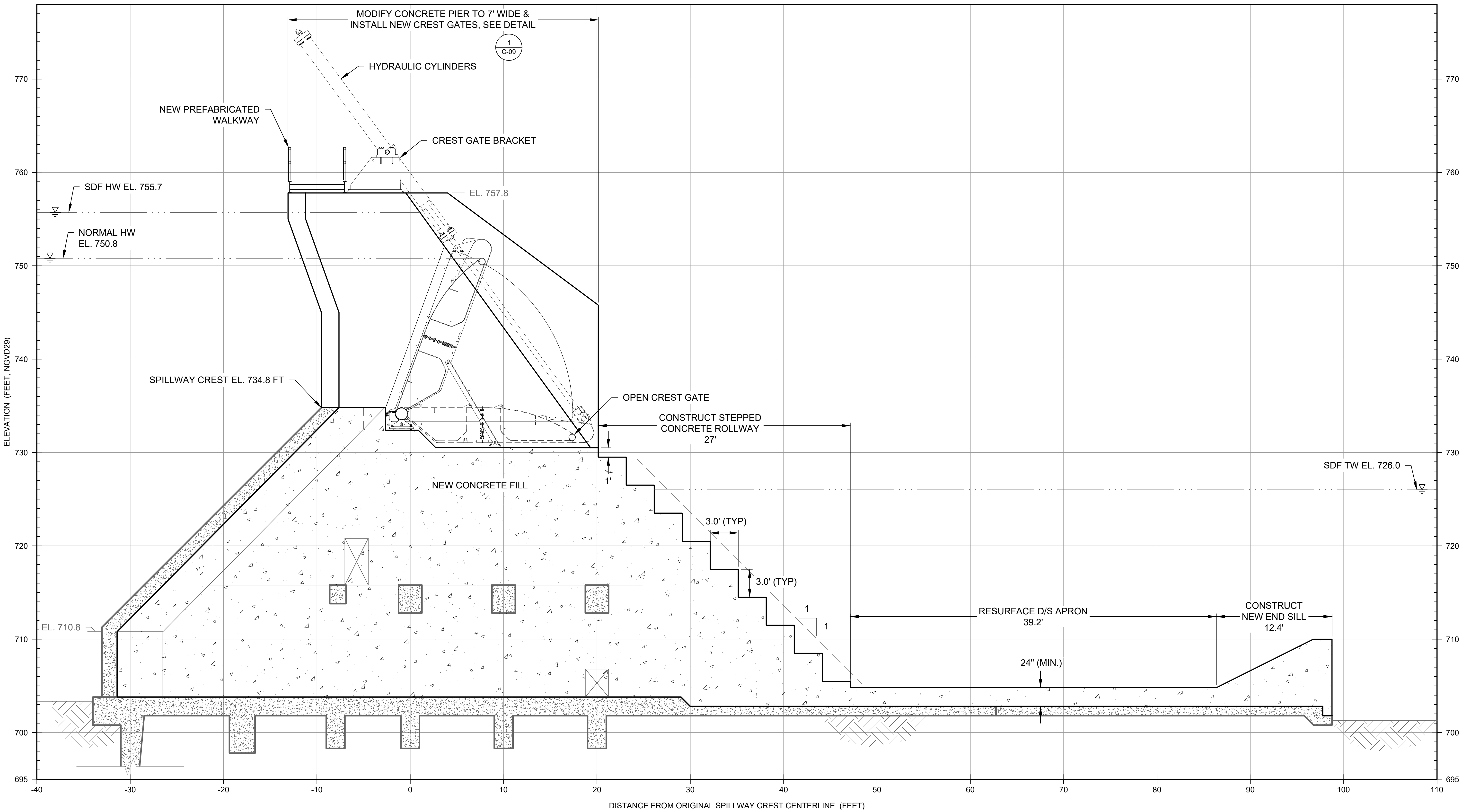

C SECTION
C-06 BAY 2 SPILLWAY

0 5 10
SCALE, FT

HATCH LEGEND

PROPOSED REINFORCED CONCRETE | EXISTING CONCRETE | EXISTING FOUNDATION

Attention:
0 1"
If this scale bar does not measure 1" then drawing is not original scale.

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GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
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PRIMARY SPILLWAY - MODIFICATIONS SECTION

DWG. NO. C-08

SHEET NO. 10

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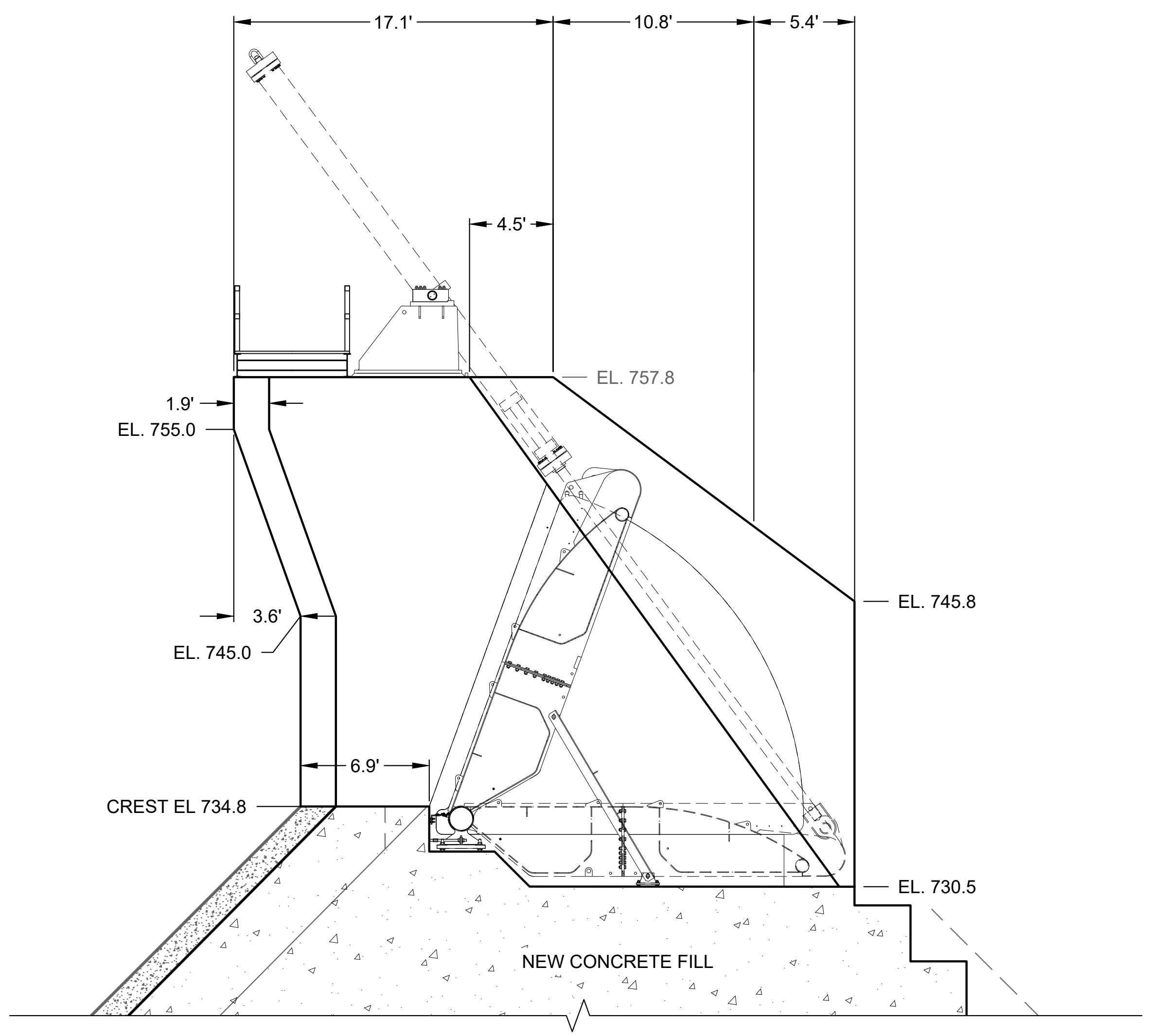
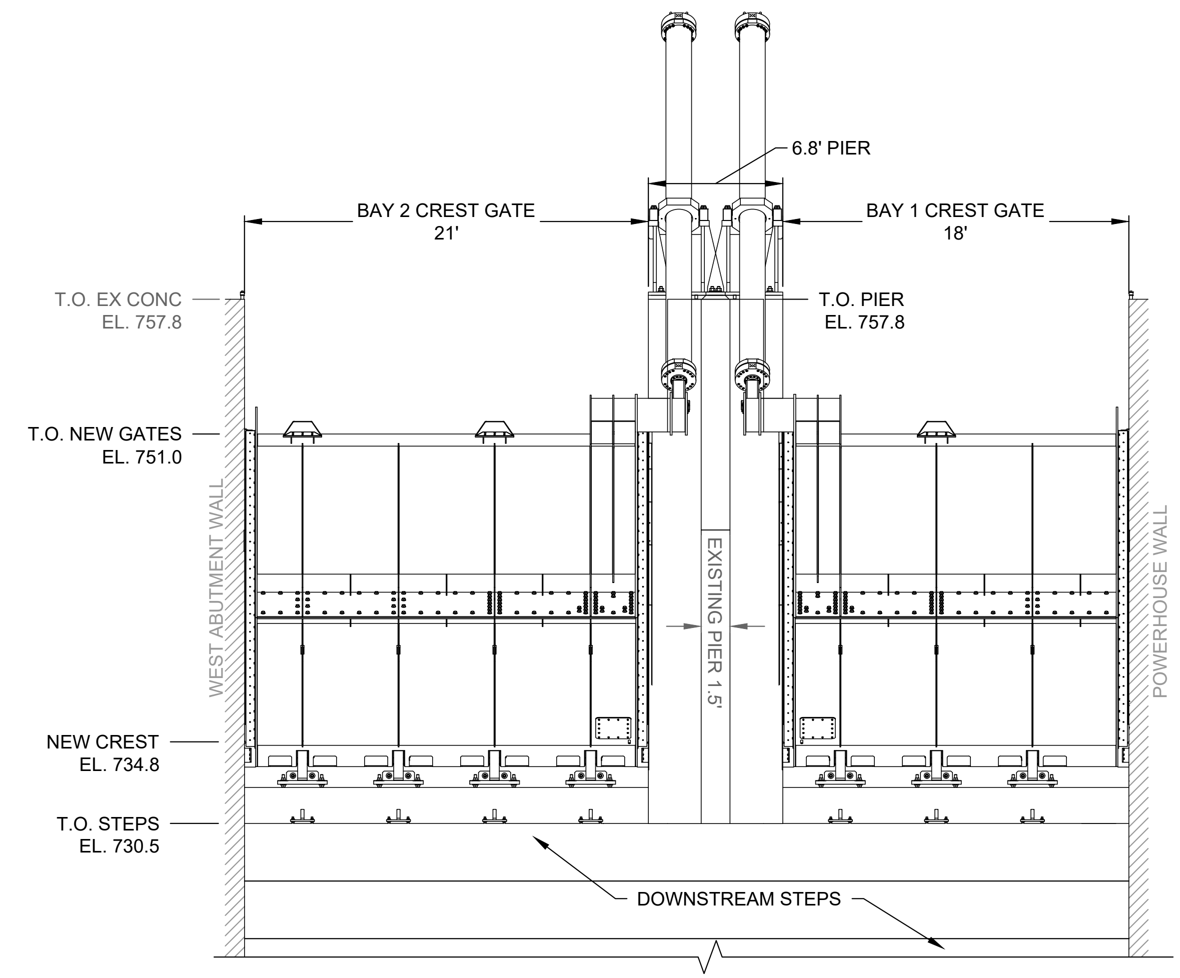


SECTION



DOWNSTREAM ELEVATION

(LOOKING UPSTREAM)

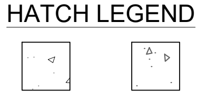
1 / C-08 DETAIL

PIER-MOUNTED CREST GATE

0 5 10

SCALE, FT

HATCH LEGEND



PROPOSED REINFORCED CONCRETE

EXISTING CONCRETE

Attention:

0 1"

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Saginaw, MI 48607 Tel.
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G100
MILWAUKEE, WI 53226
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PRIMARY SPILLWAY - CREST GATE DETAILS

DWG. NO.
C-09

SHEET NO.
11

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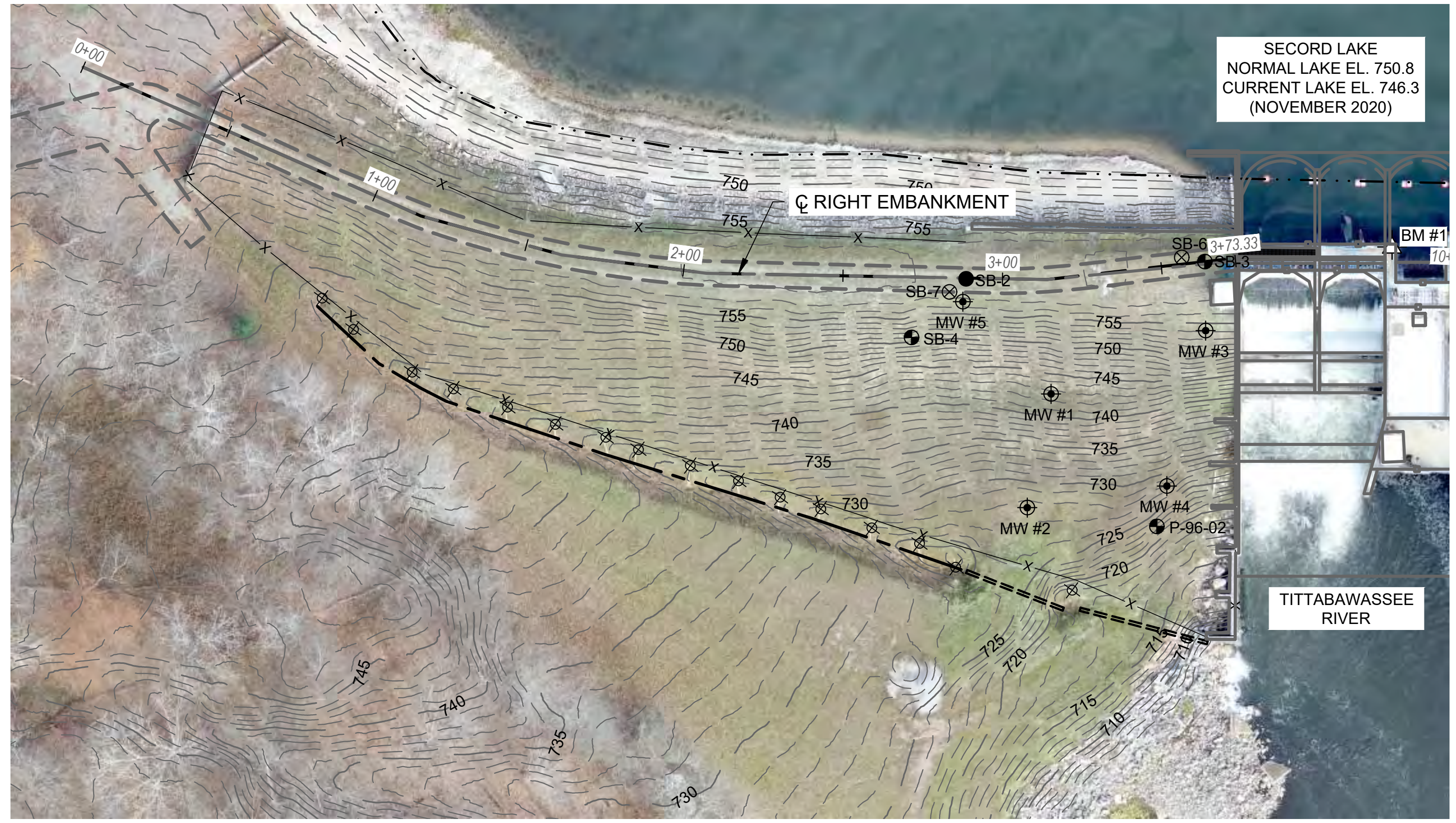
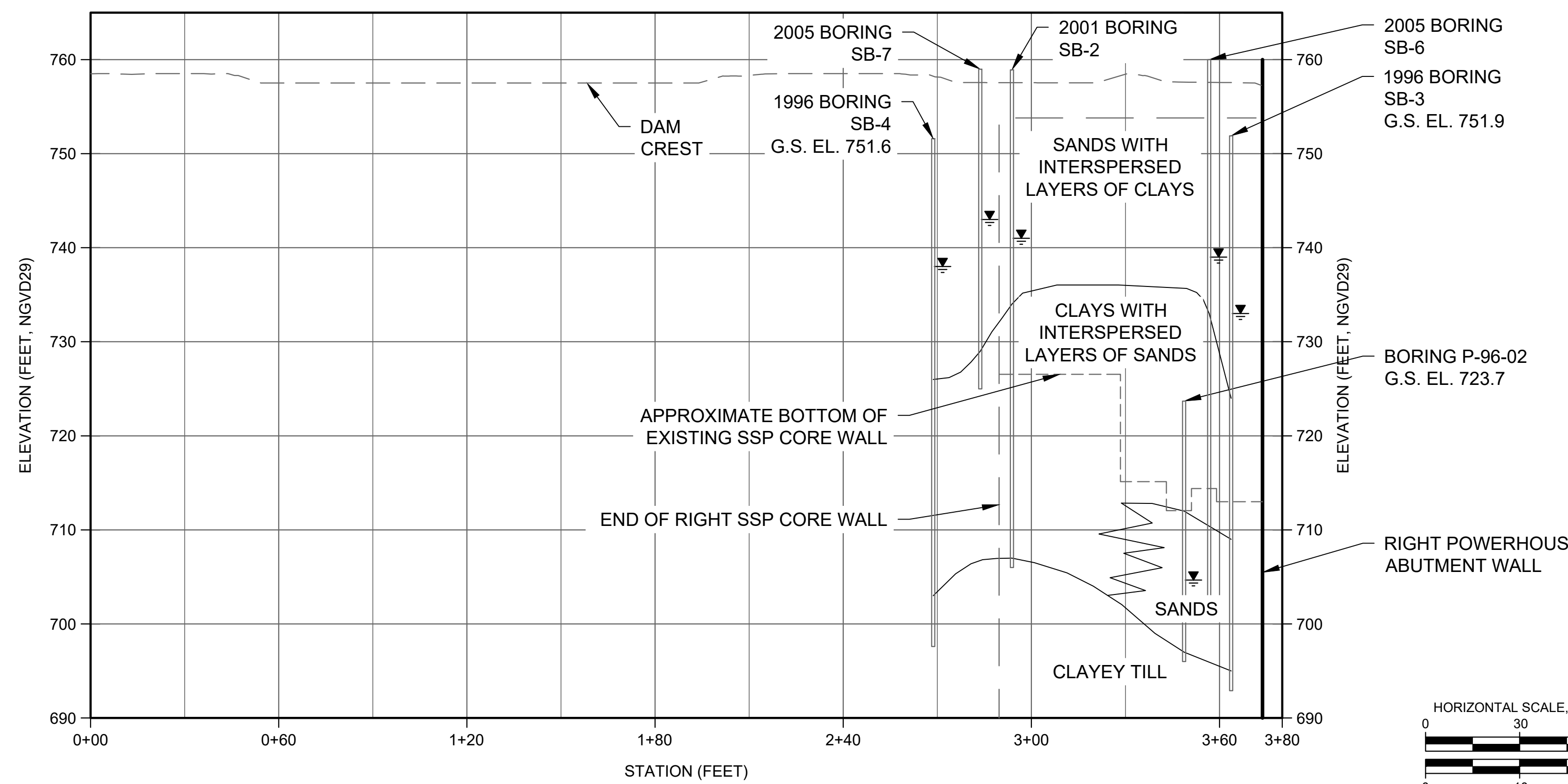


RIGHT EMBANKMENT EXISTING CONDITIONS PLAN



PROFILE

RIGHT EMBANKMENT

HORIZONTAL SCALE, FEET
0 30 60

VERTICAL SCALE, FEET
0 10 20

NOTE: 3x VERTICAL EXAGGERATION

LINETYPE LEGEND

- CENTERLINE
- WATER ELEVATION
- FENCE LINE (STEEL)
- FENCE LINE (WOOD)
- EDGE OF ROADWAY (UNPAVED)
- ROADWAY CENTERLINE
- BURIED PIPING
- 750 EXISTING MAJOR CONTOURS
- EXISTING MINOR CONTOURS
- EXISTING SURFACE ELEVATION
- SSP CORE WALL EXTENTS

SYMBOLS LEGEND

- SB-3 SOIL BORING COMPLETED BY STEARNS DRILLING, 1996
- SB-1 SOIL BORING COMPLETED BY RC ASSOCIATES, INC., 2001
- SB-5 SOIL BORING COMPLETED BY McDOWELL & ASSOCIATES, 2005
- DRAIN TILES
- MW #1 MONITORING WELL
- BM #1 SURVEY REFERENCE MONUMENT

NOTES:

1. RIGHT EMBANKMENT SOIL PROFILE DEVELOPED FROM SECORD SUPPORTING TECHNICAL INFORMATION DOCUMENT, FEBRUARY 2006.

Attention:

0 1"

If this scale bar does not measure 1" then drawing is not original scale.

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230 S. Washington Ave.
Saginaw, MI 48607 Tel.
989-754-4717 Fax.
989-754-4440
www.SpicerGroup.com

GEI Consultants

GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed:	P. DREW
Checked:	P. DREW
Drawn:	A. SAMPSON
Approved By:	B. WALTON

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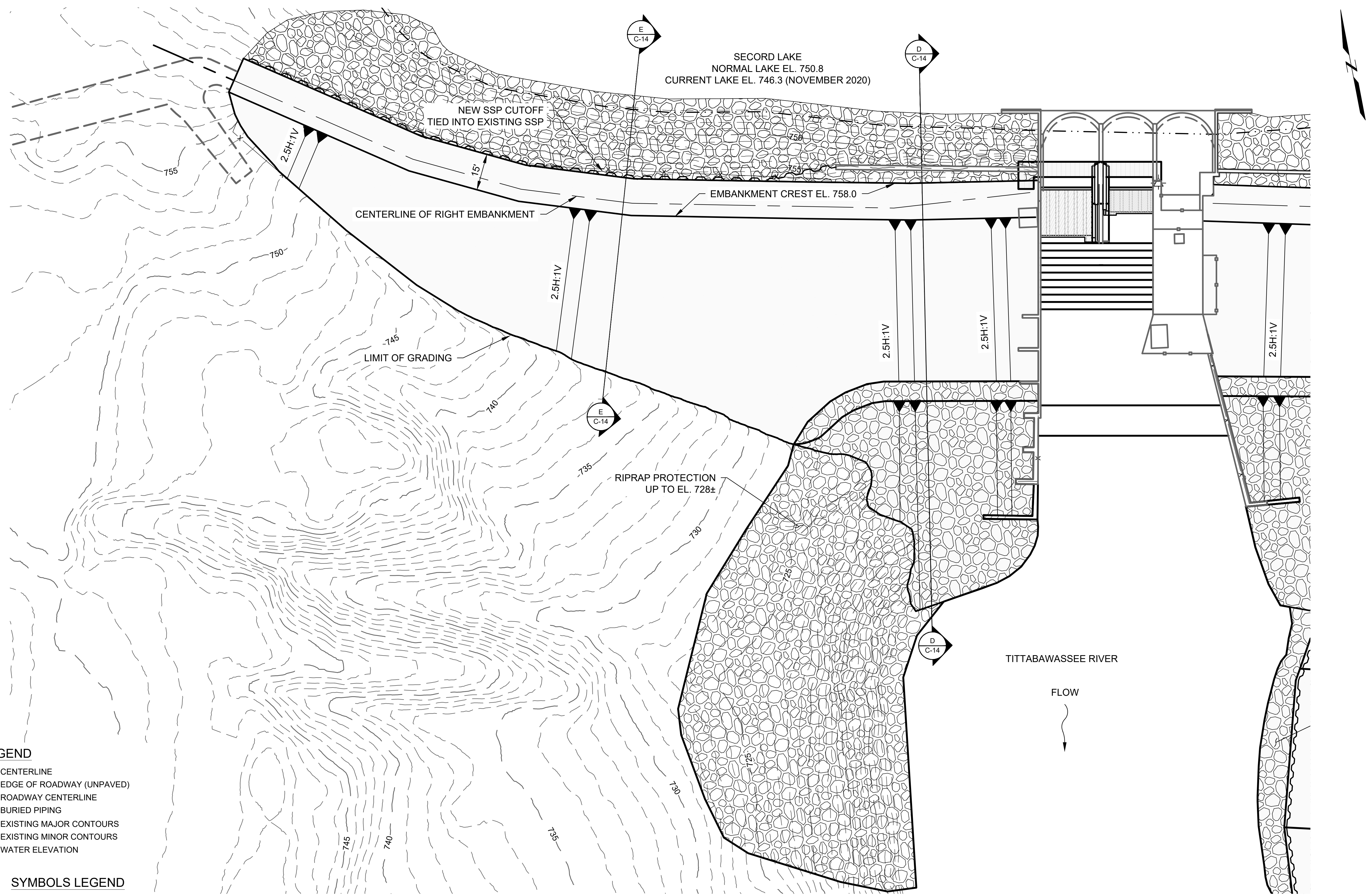
Secord Dam Conceptual Design
Gladwin County, Michigan

RIGHT EMBANKMENT - EXISTING SITE PLAN AND ELEVATION PROFILE

DWG. NO. C-10

SHEET NO. 12



RIGHT EMBANKMENT MODIFICATIONS PLAN

0 20 40
SCALE: 1" = 20'

LINETYPE LEGEND

- CENTERLINE
- EDGE OF ROADWAY (UNPAVED)
- ROADWAY CENTERLINE
- BURIED PIPING
- 750 EXISTING MAJOR CONTOURS
- EXISTING MINOR CONTOURS
- WATER ELEVATION

HATCH LEGEND

- RIPRAP
- BERM FILL AREA

SYMBOLS LEGEND

- 1H:1V CUT SLOPE
- 1H:1V FILL SLOPE

Attention: 0 1" If this scale bar does not measure 1" then drawing is not original scale.

NO.	DATE	ISSUE/REVISION	APP
0	xx/xx/xxxx	CONCEPTUAL DESIGN SUBMITTAL	--

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SAGINAW OFFICE
230 S. Washington Ave.
Saginaw, MI 48607 Tel.
989-754-4717 Fax.
989-754-4440
www.SpicerGroup.com

GEI Consultants
GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed:	P. DREW
Checked:	P. DREW
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Gladwin County, Michigan

RIGHT EMBANKMENT - MODIFICATIONS PLAN

DWG. NO. C-11

SHEET NO. 13

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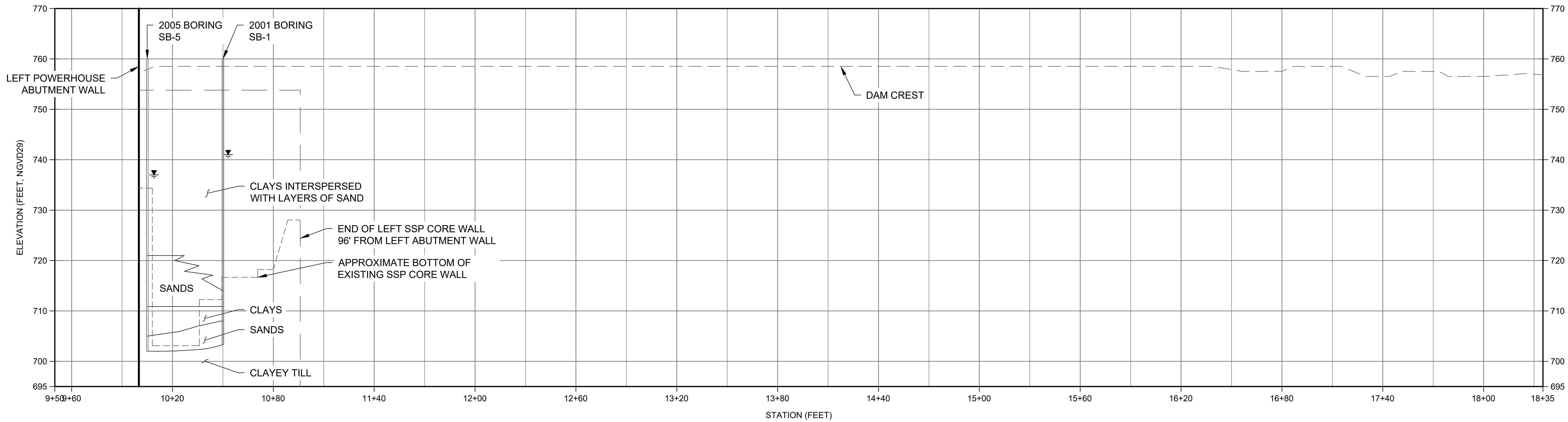
LEFT EMBANKMENT EXISTING CONDITIONS PLAN

SCALE, FT (0, 30', 60')



LINETYPE LEGEND

- CENTERLINE
- WATER ELEVATION
- FENCE LINE (STEEL)
- FENCE LINE (WOOD)
- EDGE OF ROADWAY (UNPAVED)
- ROADWAY CENTERLINE
- BURIED PIPING
- EXISTING MAJOR CONTOURS (750)
- EXISTING MINOR CONTOURS
- EXISTING SURFACE ELEVATION
- SSP CORE WALL EXTENTS

SYMBOLS LEGEND

- SB-3 SOIL BORING COMPLETED BY STEARNS DRILLING, 1996
- SB-1 SOIL BORING COMPLETED BY RC ASSOCIATES, INC., 2001
- SB-5 SOIL BORING COMPLETED BY McDOWELL & ASSOCIATES, 2005
- DRAIN TILES
- MW #1 MONITORING WELL
- BM #1 SURVEY REFERENCE MONUMENT

PROFILE
LEFT EMBANKMENT

HORIZONTAL SCALE, FEET (0, 30, 60)
VERTICAL SCALE, FEET (0, 10, 20)
NOTE: 3x VERTICAL EXAGGERATION

NOTES:
1. LEFT EMBANKMENT SOIL PROFILE DEVELOPED FROM SECORD SUPPORTING TECHNICAL INFORMATION DOCUMENT, FEBRUARY 2006.

Attention: 0 — 1"
If this scale bar does not measure 1" then drawing is not original scale.

NO.	DATE	ISSUE/REVISION	APP
0	xx/xx/xxxx	CONCEPTUAL DESIGN SUBMITTAL	--

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989-754-4440
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GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed:	P. DREW
Checked:	P. DREW
Drawn:	A. SAMPSON
Approved By:	B. WALTON

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Gladwin County, Michigan

LEFT EMBANKMENT - EXISTING SITE PLAN AND ELEVATION PROFILE

DWG. NO. C-12

SHEET NO. 14

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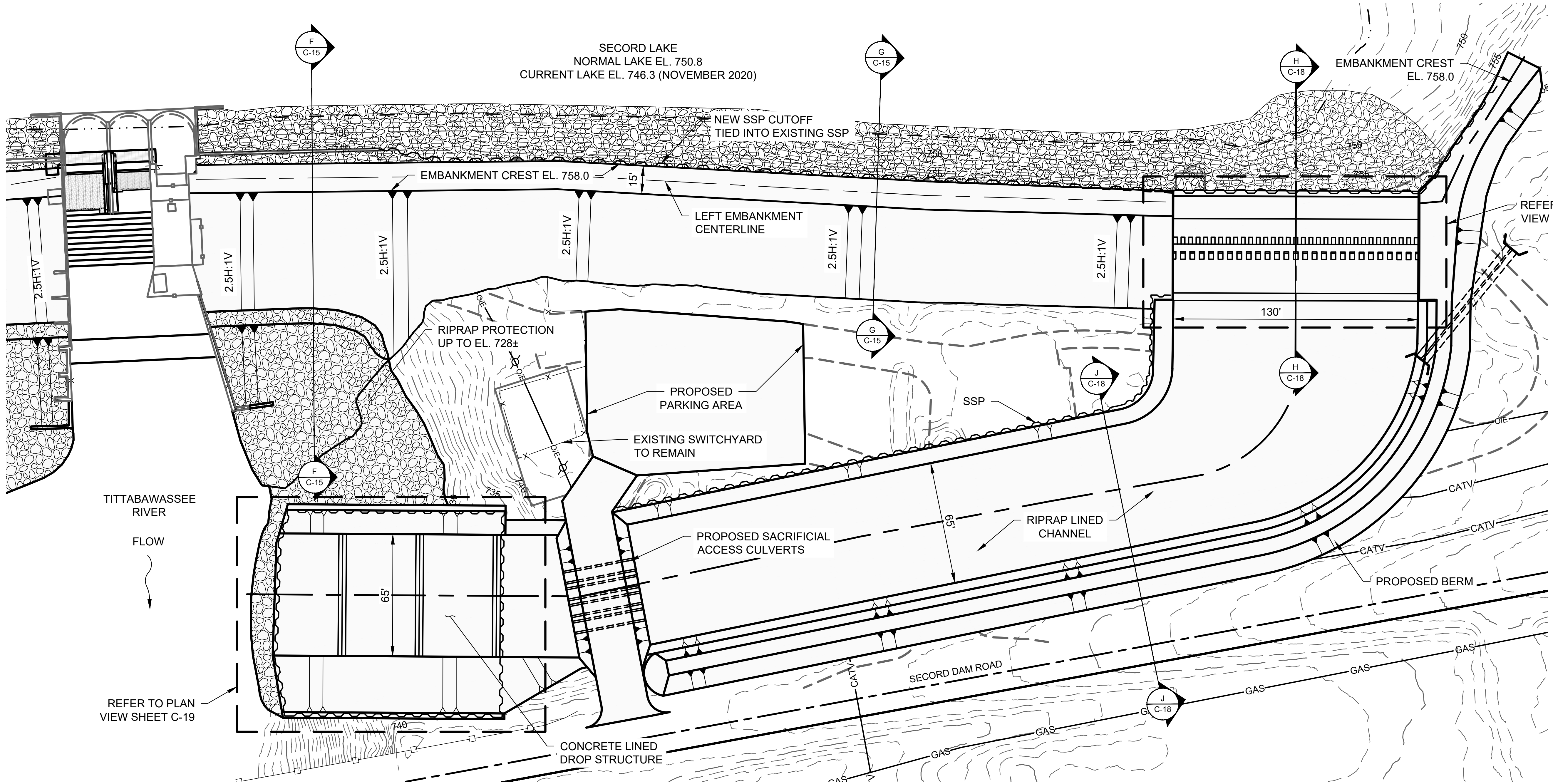

AUXILIARY SPILLWAY PLAN

0 30 60
SCALE, FEET

LINETYPE LEGEND

- CENTERLINE
- EDGE OF ROADWAY (UNPAVED)
- ROADWAY CENTERLINE
- BURIED PIPING
- 750 EXISTING MAJOR CONTOURS
- EXISTING MINOR CONTOURS
- WATER ELEVATION

HATCH LEGEND

RIPRAP

BERM FILL AREA

SYMBOLS LEGEND

1H:1V CUT SLOPE

1H:1V FILL SLOPE

Attention:

0 1"

If this scale bar does not measure 1" then drawing is not original scale.

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0	xx/xx/xxxx	CONCEPTUAL DESIGN SUBMITTAL	--

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Saginaw, MI 48607 Tel.
989-754-4717 Fax.
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GEI Consultants
GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed:	P. DREW
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Secord Dam Conceptual Design
Gladwin County, Michigan

LEFT EMBANKMENT - MODIFICATIONS PLAN

DWG. NO. C-13

SHEET NO. 15

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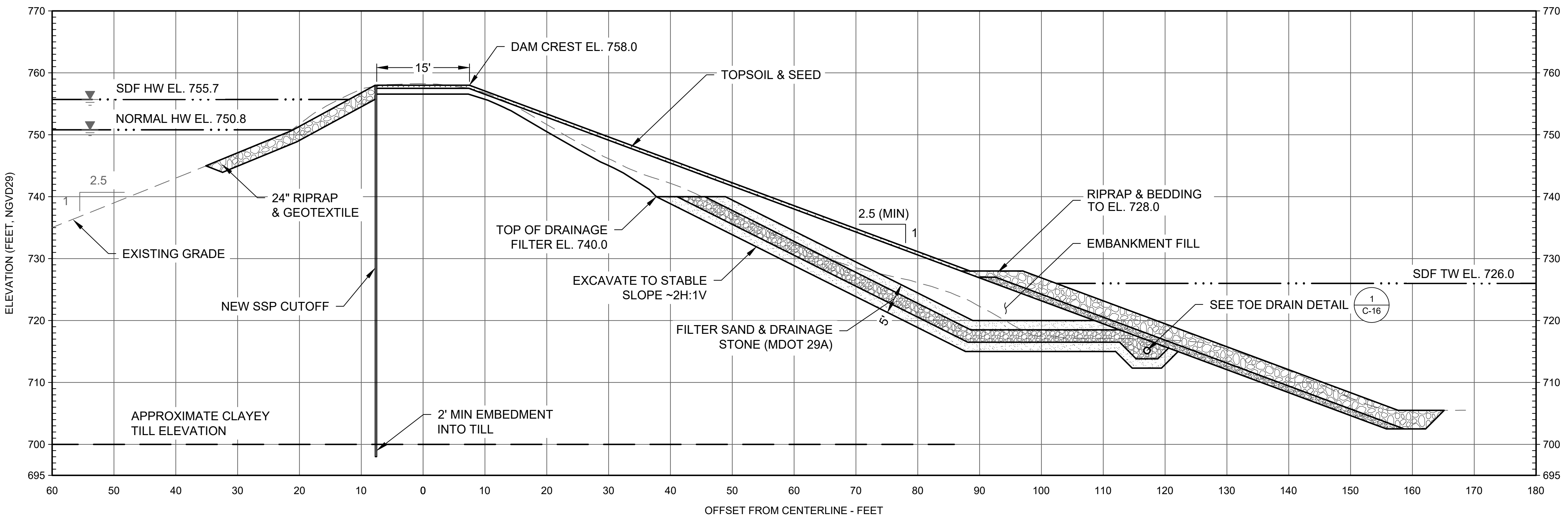
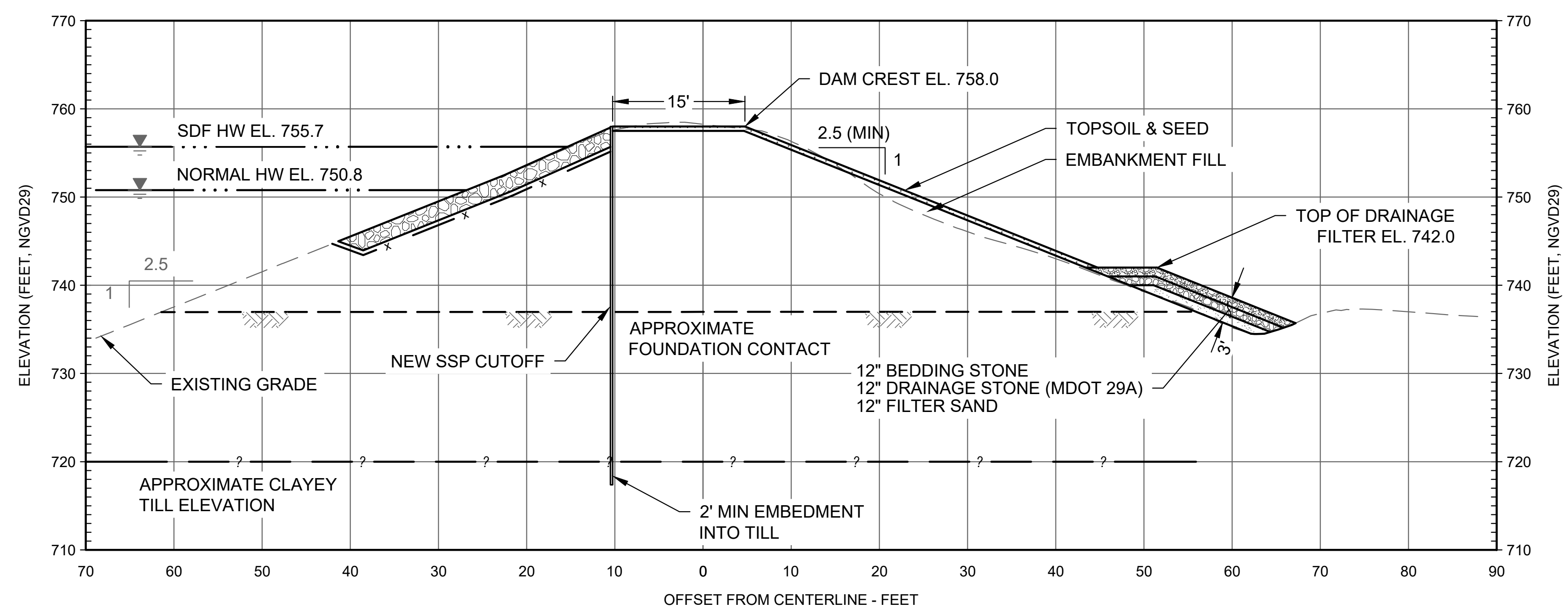


D C-11 SECTION
RIGHT EMBANKMENT

HORIZONTAL SCALE, FEET 0 10 20
VERTICAL SCALE, FEET 0 10 20
NO VERTICAL EXAGGERATION



E C-11 SECTION
RIGHT EMBANKMENT

HORIZONTAL SCALE, FEET 0 10 20
VERTICAL SCALE, FEET 0 10 20
NO VERTICAL EXAGGERATION

Attention: 0 1" If this scale bar does not measure 1" then drawing is not original scale.

NO.	DATE	ISSUE/REVISION	APP
0	xx/xx/xxxx	CONCEPTUAL DESIGN SUBMITTAL	--

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GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed: P. DREW
Checked: P. DREW
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FERC Project No. 10809
GEI Project 2002879

Secord Dam Conceptual Design
Gladwin County, Michigan

RIGHT EMBANKMENT - MODIFIED SECTIONS

DWG. NO. C-14
SHEET NO. 16

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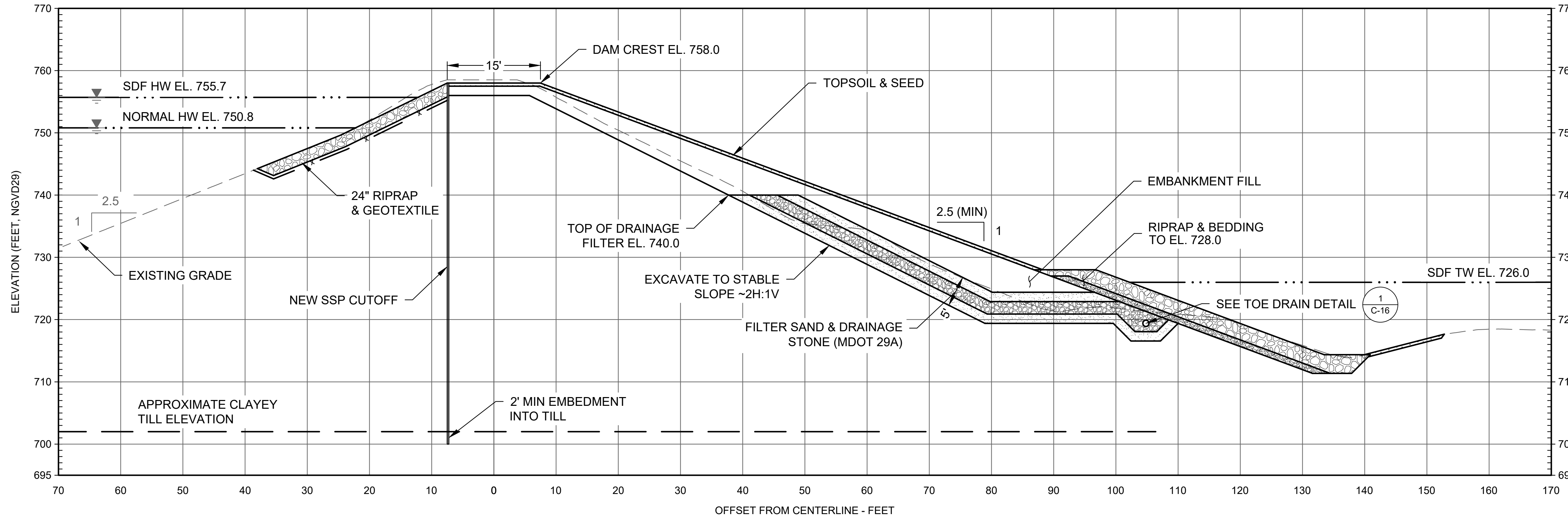
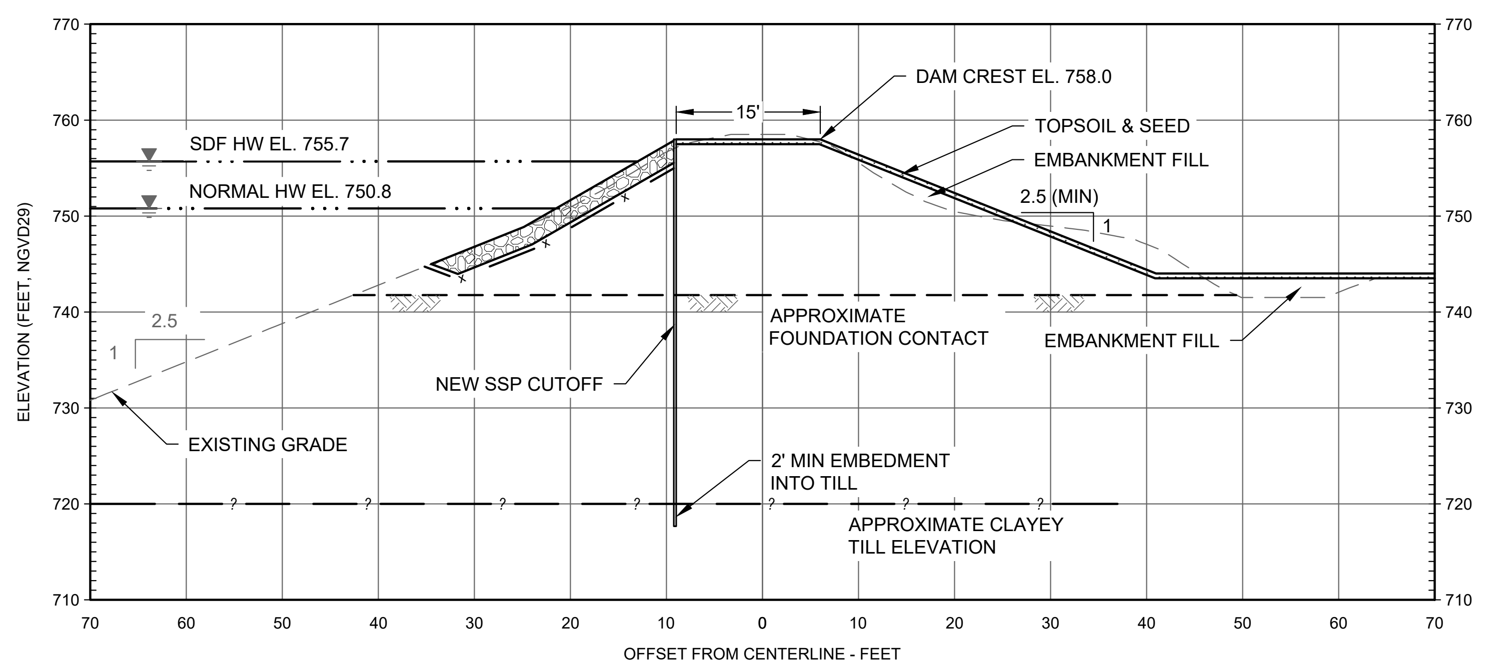


F
C-13
SECTION
LEFT EMBANKMENT

HORIZONTAL SCALE, FEET
0 10 20
VERTICAL SCALE, FEET
NO VERTICAL EXAGGERATION



G
C-13
SECTION
LEFT EMBANKMENT

HORIZONTAL SCALE, FEET
0 10 20
VERTICAL SCALE, FEET
NO VERTICAL EXAGGERATION

Attention:
0 1"
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0	xx/xx/xxxx	CONCEPTUAL DESIGN SUBMITTAL	--

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Gladwin County, Michigan

LEFT EMBANKMENT - MODIFIED SECTIONS

DWG. NO.
C-15

SHEET NO.
17

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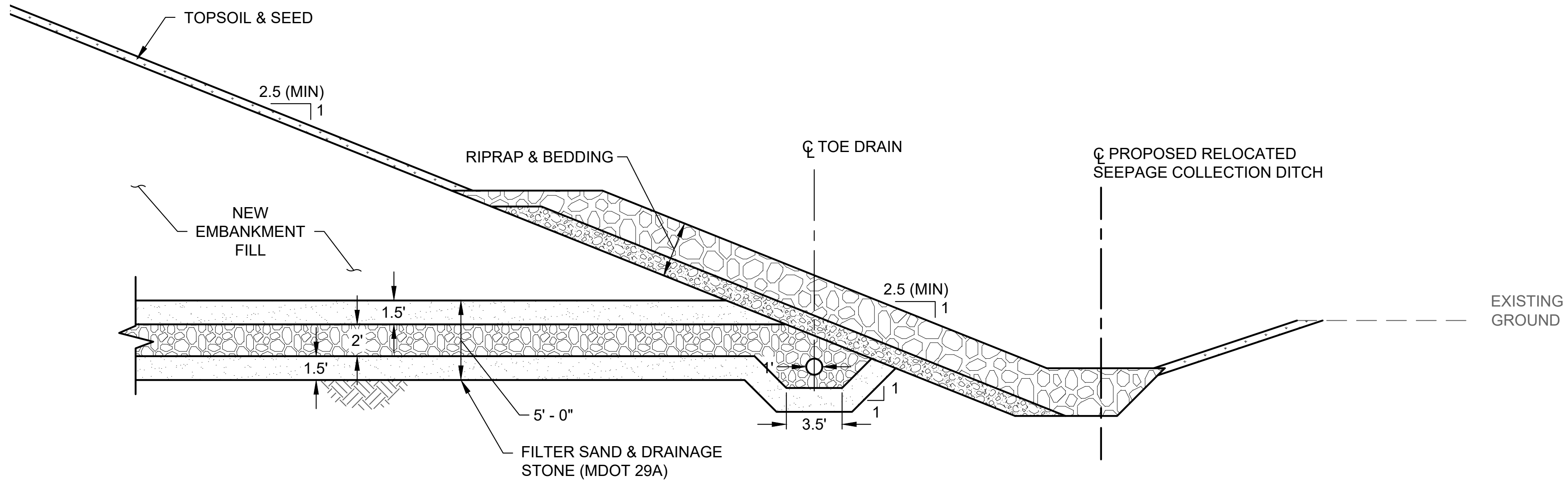
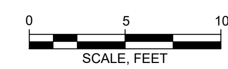


1 DETAIL
C-14 C-15 TOE DRAIN



Attention:				
0 1"				
If this scale bar does not measure 1" then drawing is not original scale.	0	xx/xx/xxxx	CONCEPTUAL DESIGN SUBMITTAL	--
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Gladwin County, Michigan

RIGHT AND LEFT EMBANKMENTS - MODIFICATION DETAILS

DWG. NO. C-16

SHEET NO. 18

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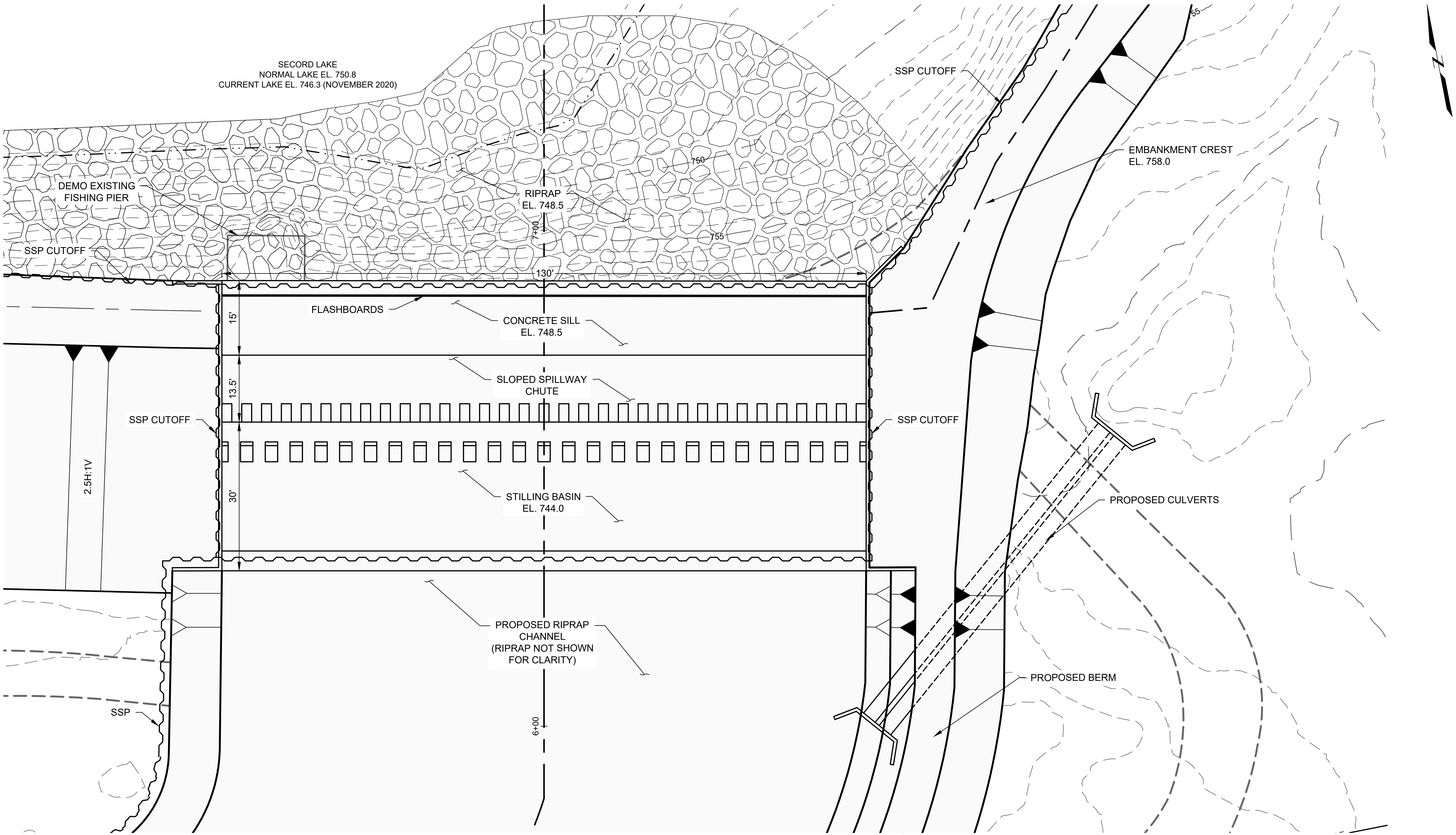

PLAN VIEW

PROPOSED AUXILIARY SPILLWAY

0 10 20
SCALE, FEET

Attention:
0 1"
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NO.	DATE	ISSUE/REVISION	APP
0	xx/xx/xxxx	CONCEPTUAL DESIGN SUBMITTAL	--

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Gladwin County, Michigan

AUXILIARY SPILLWAY -
PROPOSED PLAN VIEW

DWG. NO.
C-17

SHEET NO.
19

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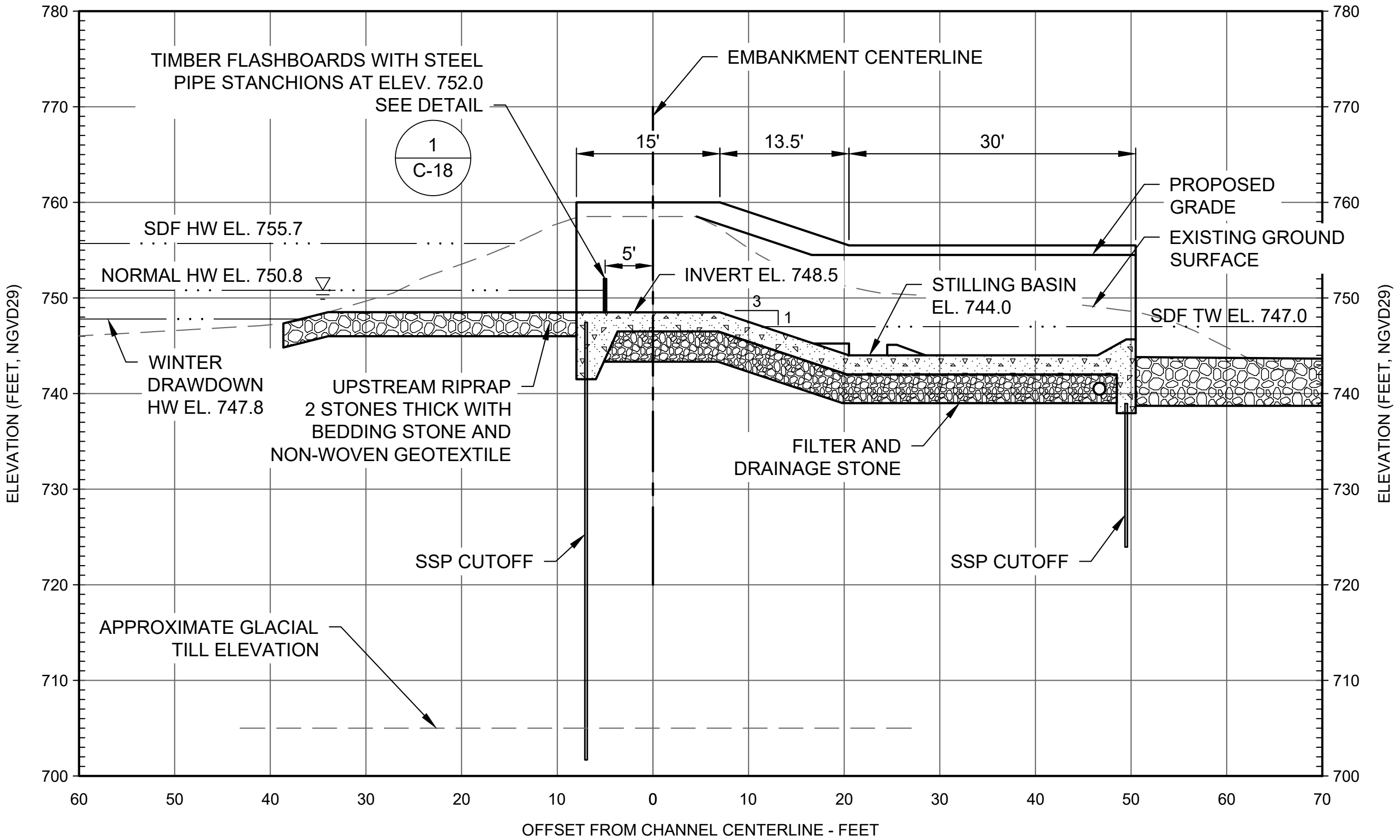
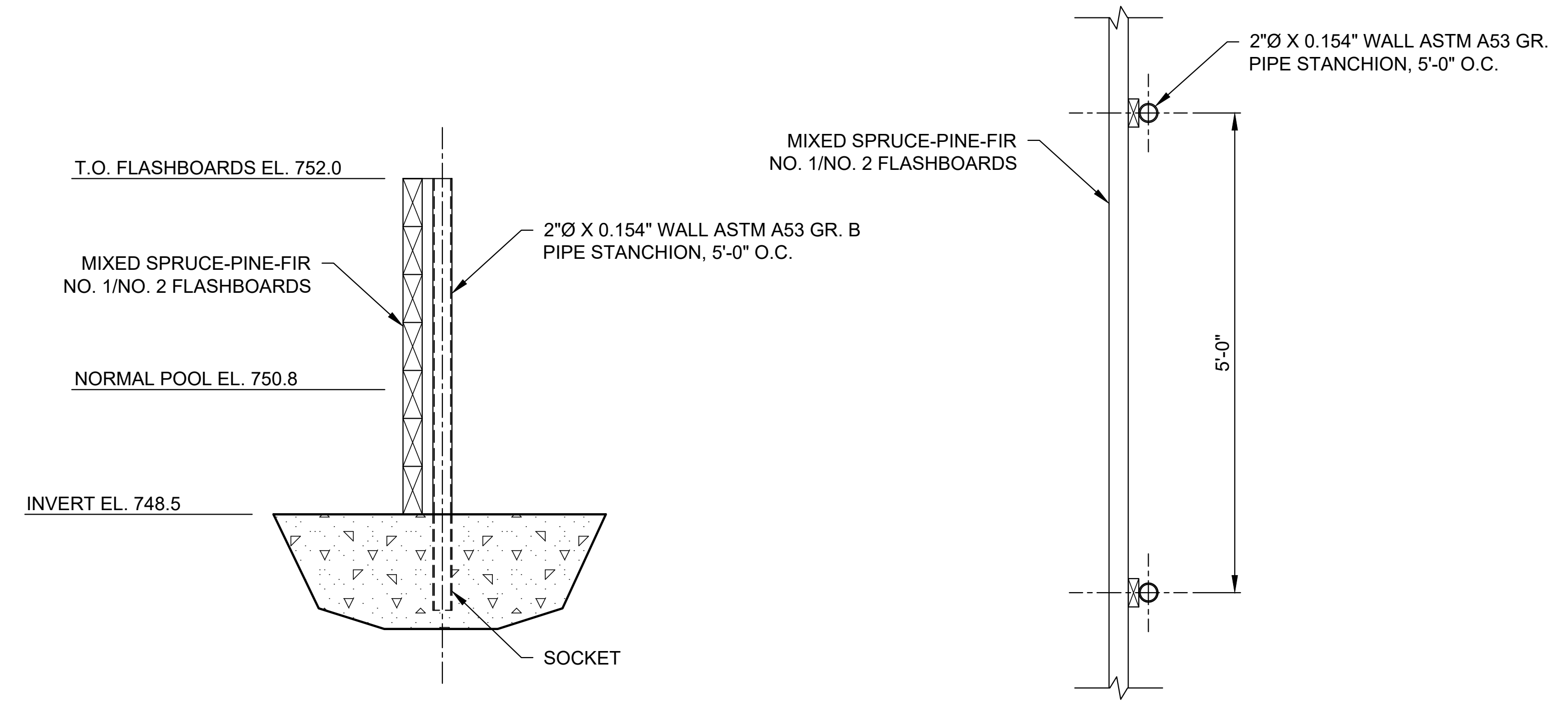


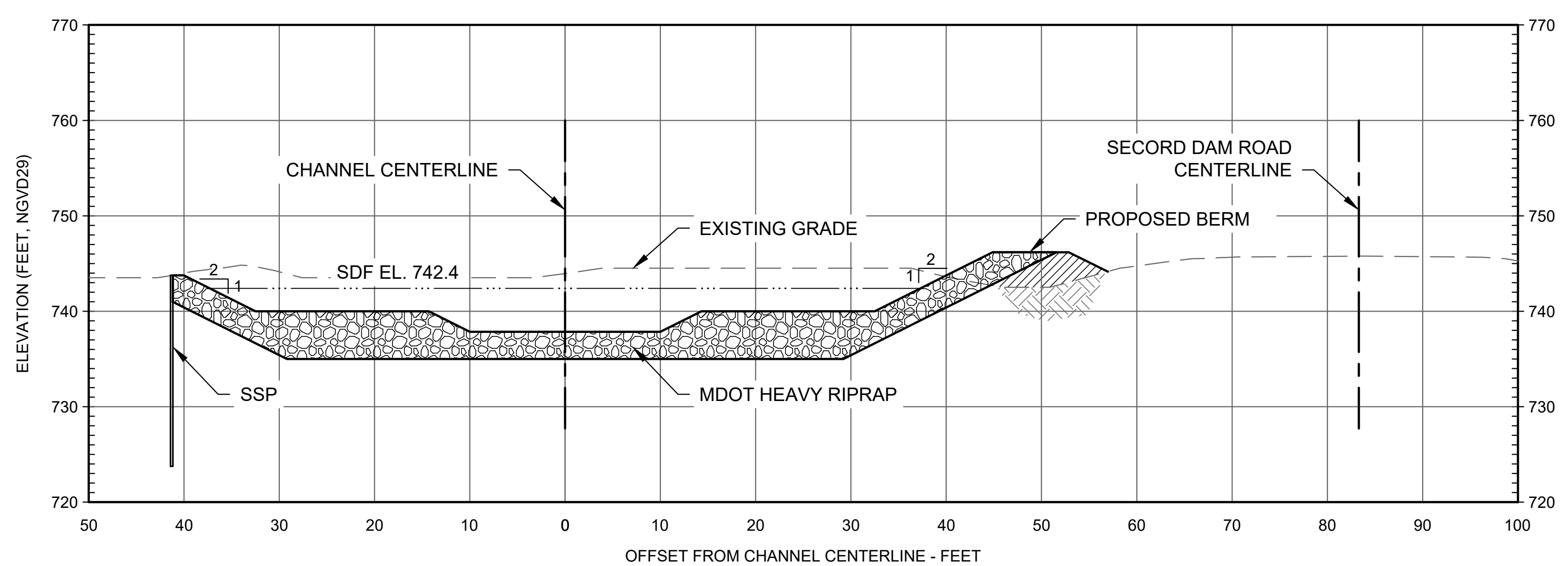
HORIZONTAL SCALE, FEET
0 10 20
0 10 20
VERTICAL SCALE, FEET
NO VERTICAL EXAGGERATION

H
C-13
SECTION
PROPOSED SPILLWAY



1
C-18
DETAIL
FLASHBOARD AND STANCHION

0 1 2
SCALE, FEET



HORIZONTAL SCALE, FEET
0 10 20
0 10 20
VERTICAL SCALE, FEET
NO VERTICAL EXAGGERATION

J
C-13
SECTION
PROPOSED SPILLWAY CHANNEL

Attention:
0 1"
If this scale bar does not measure 1" then drawing is not original scale.

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GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed: P. DREW
Checked: P. DREW
Drawn: A. SAMPSON
Approved By: B. WALTON

Four Lakes Task Force
FERC Project No. 10809

GEI Project 2002879

Secord Dam Conceptual Design
Gladwin County, Michigan

AUXILIARY SPILLWAY - PROPOSED SPILLWAY CROSS SECTION

DWG. NO.
C-18

SHEET NO.
20

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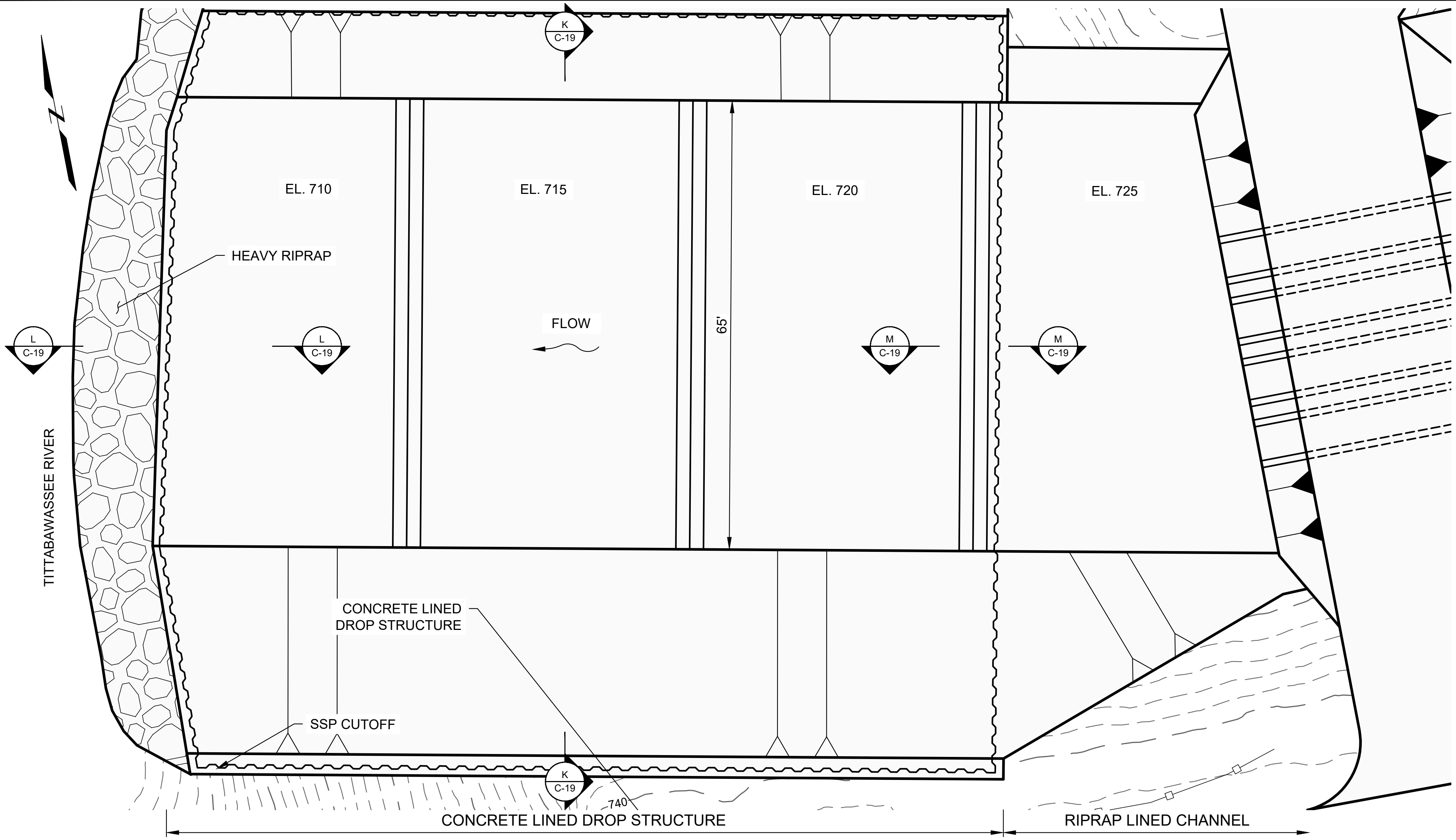
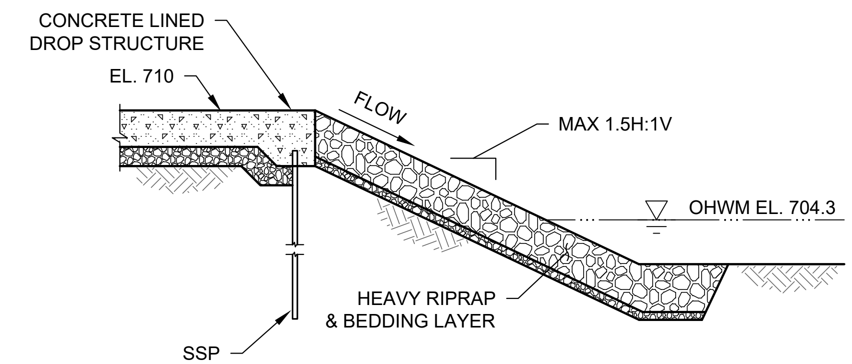
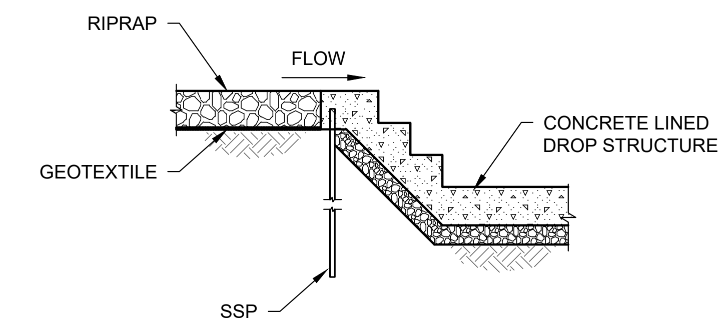


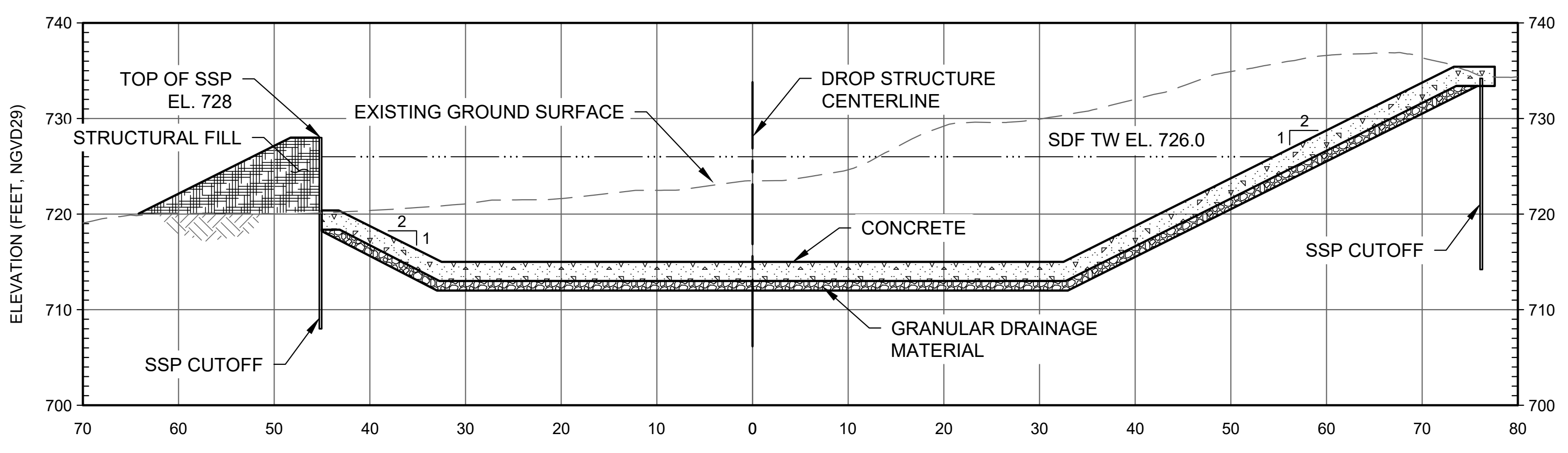
DROP STRUCTURE PLAN



L C-19 SECTION
AUX. SPILLWAY OUTLET



M C-19 SECTION
CHANNEL/DROP STRUCTURE CONNECTION



K C-19 SECTION
CONCRETE LINED DROP STRUCTURE

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GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed: P. DREW
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Approved By: B. WALTON

Four Lakes Task Force
FERC Project No. 10809
GEI Project 2002879

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Gladwin County, Michigan

AUXILIARY SPILLWAY TERMINAL STRUCTURE - PROPOSED PLAN AND SECTION

DWG. NO. C-19
SHEET NO. 21

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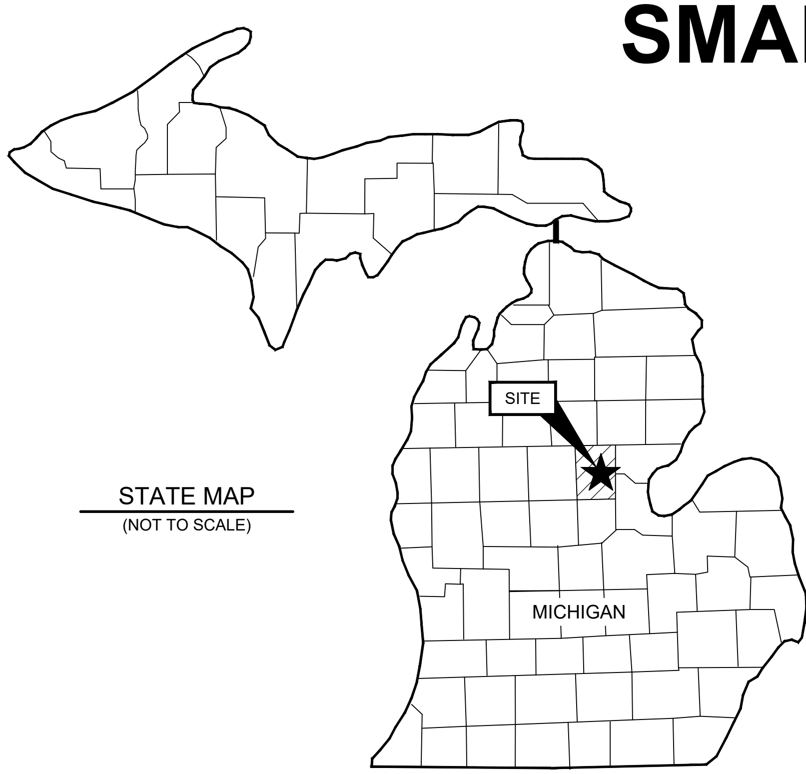
Appendix D

Proposed Conditions Spillway Upgrades

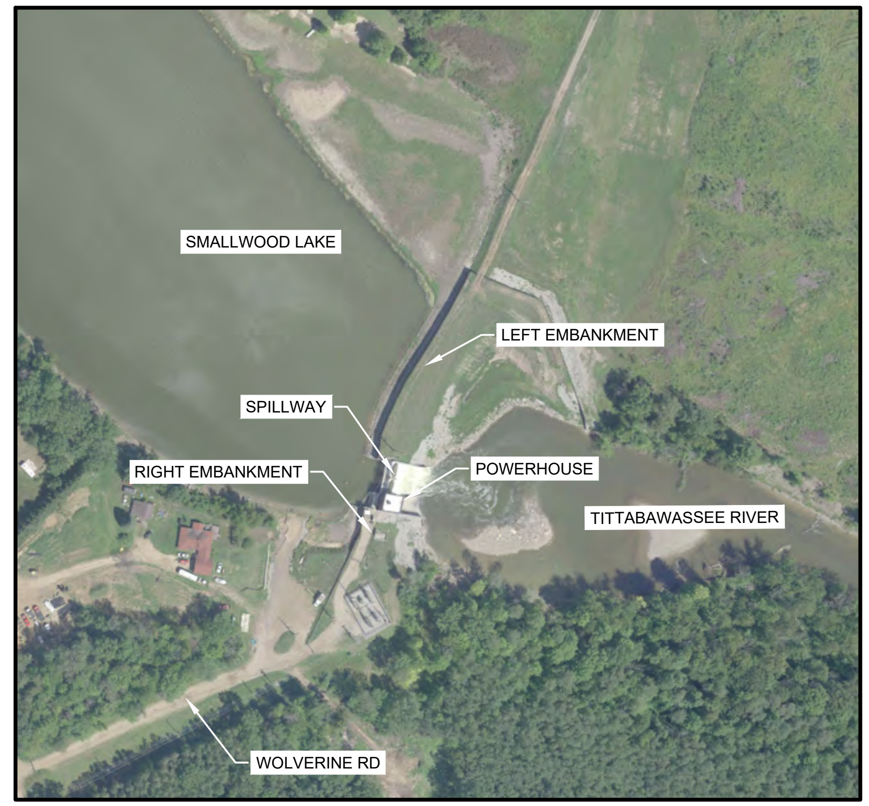
Appendix D.2 – Smallwood Dam

SMALLWOOD DAM CONCEPTUAL DESIGN

GLADWIN COUNTY, MICHIGAN
FOUR LAKES TASK FORCE
FERC PROJECT NO. 10810



STATE MAP
(NOT TO SCALE)



SITE AERIAL
(NOT TO SCALE)

SHEET INDEX

SOURCE:
AERIAL IMAGE TAKEN FROM GOOGLE EARTH

SITE LOCATION
(NOT TO SCALE)

PREPARED FOR:

FOUR LAKES TASK FORCE
233 E. LARKIN
MIDLAND, MI 48640

PREPARED BY:

GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414) 930-7534

SPICER GROUP INC.
230 S. WASHINGTON AVE.
SAGINAW, MI 48607
TEL. (989) 754-4717
FAX. (989) 754-4440

GEI PROJECT NO. 2002879

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DWG. NO.
G-01

SHEET NO.
1

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1. GENERAL

SPACIAL DATUM INFORMATION

- VERTICAL: NATIONAL GEODETIC VERTICAL DATUM OF 1929 (NGVD29).
- HORIZONTAL: NORTH AMERICAN DATUM OF 1983 (NAD83), MICHIGAN STATE PLANE, CENTRAL ZONE.
- A CONVERSION OF +5.8' IS REQUIRED WHEN CONVERTING VERTICAL DAM DATUM TO NGVD29 (E.G., HEADWATER ELEVATION AT DAM DATUM IS 699.0' AND AT NGVD29 DATUM IS 704.8').
- A CONVERSION OF -0.541' IS REQUIRED WHEN CONVERTING VERTICAL NGVD29 DATUM TO NAVD88 DATUM.
- CONTROL MONUMENTS ON-SITE SHALL BE REFERRED TO CONFIRM HORIZONTAL AND VERTICAL MEASUREMENTS.

BASEMAP DATA

- SITE TOPOGRAPHY AND AERIAL IMAGE OBTAINED DRONE FLIGHT PERFORMED BY SPICER GROUP IN 2020.
- COVER SHEET AERIAL IMAGES OBTAINED FROM GOOGLE EARTH REPRESENT CONDITIONS IN JUNE, 2018.
- OBTAINED FROM BOYCE HYDRO:
  - ORIGINAL CONSTRUCTION DRAWINGS
  - EXHIBIT F LICENSE DRAWINGS

DESIGN PARAMETERS

- NORMAL RESERVOIR ELEVATION 704.8' (+0.3' / -0.4')
- WINTER RESERVOIR OPERATIONS: MINIMUM 701.8'
- ORDINARY HIGH WATER MARK ELEVATION 675.2'

DESIGN REFERENCE STANDARDS

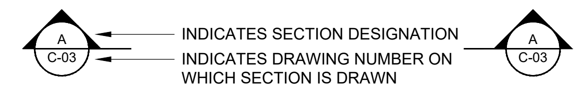
- (USBR, 1987) UNITED STATES DEPARTMENT OF THE INTERIORER, BUREAU OF RECLAMATION, "DESIGN OF SMALL DAMS", 1987.
- (USACE, 1995) UNITED STATES ARMY CORPS OF ENGINEERS, ENGINEERING AND DESIGN, "CONSTRUCTION CONTROL FOR EARTH AND ROCK-FILL DAMS", EM 1110-2-1911, 1995.
- (ACI, 2001) AMERICAN CONCRETE INSTITUTE, “CONTROL OF CRACKING IN CONCRETE STRUCTURES” (ACI 224), 2001.
- (USACE, 2004) UNITED STATES ARMY CORPS OF ENGINEERS, ENGINEERING AND DESIGN, "GENERAL DESIGN AND CONSTRUCTION CONSIDERATIONS FOR EARTH AND ROCK-FILL DAMS", EM 1110-2-2300, 2004.
- (ACI, 2006) AMERICAN CONCRETE INSTITUTE, “CODE REQUIREMENTS FOR ENVIRONMENTAL ENGINEERING CONCRETE STRUCTURES” (ACI 350), 2006.
- (ACI, 2011) AMERICAN CONCRETE INSTITUTE, “BUILDING CODE REQUIREMENTS FOR STRUCTURAL CONCRETE” (ACI 318), 2011.
- (FERC, 2016) FEDERAL ENERGY REGULATORY COMMISSION, ENGINEERING GUIDELINES FOR EVALUATION OF HYDROPOWER PROJECTS (MOST RECENT VERSIONS)

ABBREVIATIONS

BO = BOTTOM OF
C = CENTER LINE
MM = MOVEMENT MONUMENT
CLSM = CONTROLLED LOW-STRENGTH MATERIAL
CONC = CONCRETE
CONT = CONTINUOUS
CTRD = CENTERED
D/S = DOWNSTREAM
EO = EDGE OF
EX = EXISTING
EF = EACH FACE
EL = ELEVATION (FEET)
HW = HEADWATER
MAX = MAXIMUM
OC = ON CENTER
OCEW = ON CENTER EACH WAY
OHWM = ORDINARY HIGH WATER MARK
PL = PLATE
PMF = PROBABLE MAXIMUM FLOOD
SDF = SPILLWAY DESIGN FLOOD
SSP = STEEL SHEET PILE
STD = STANDARD
STIFF = STIFFENER
TBD = TO BE DETERMINED
TO = TOP OF
TW = TAILWATER
TYP = TYPICAL
UON = UNLESS OTHERWISE NOTED
U/S = UPSTREAM
VIF = VERIFY IN FIELD
WL = WETLAND
W/ = WITH

SECTION AND DETAIL LEGEND

SECTION



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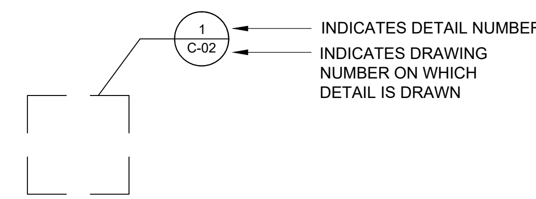

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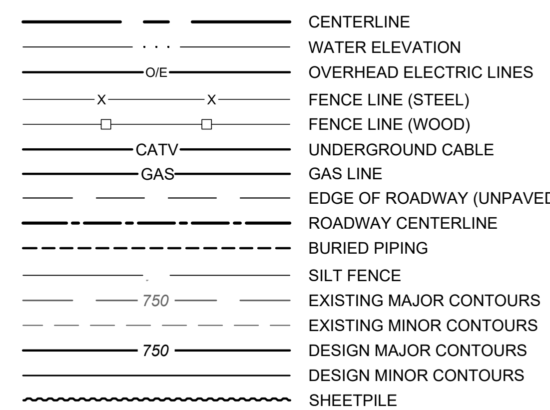
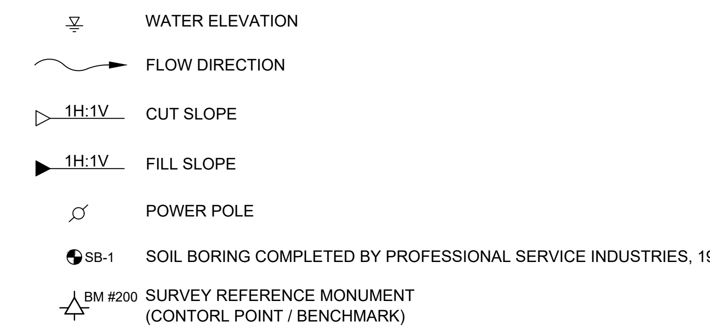


SYMBOLS LEGEND



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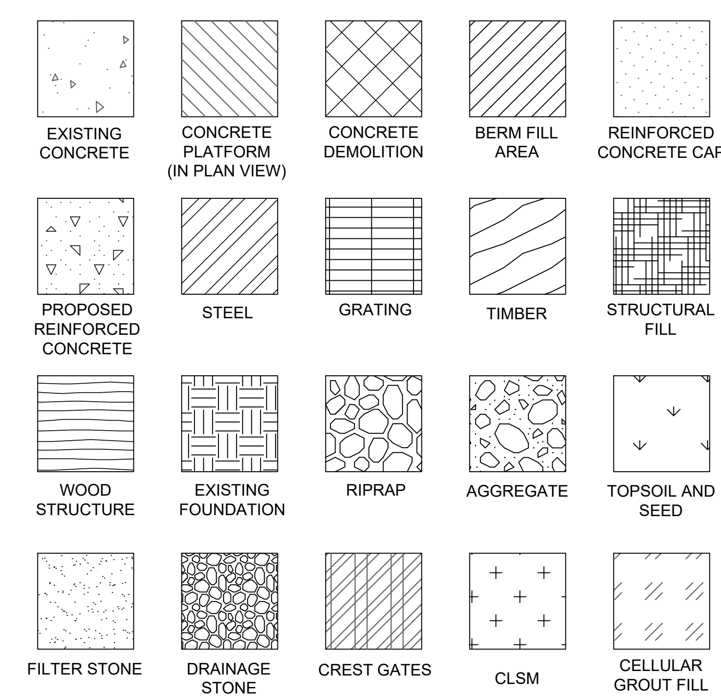

Attention:				
0 1"				
If this scale bar does not measure 1" then drawing is not original scale.				
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	NO.	DATE	ISSUE/REVISION	APP

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GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed:	P. DREW
Checked:	P. DREW
Drawn:	A. SAMPSON
Approved By:	B. WALTON

Four Lakes Task Force
FERC Project No. 10810

GEI Project 2002879

Smallwood Dam
Gladwin County, Michigan

GENERAL NOTES AND LEGEND

DWG. NO. G-02

SHEET NO. 2

LINETYPE LEGEND

CENTERLINE	
WATER ELEVATION	
OVERHEAD ELECTRIC LINES	O/E
FENCE LINE (STEEL)	X
FENCE LINE (WOOD)	
EDGE OF ROADWAY (UNPAVED)	
BURIED PIPING	
EXISTING MAJOR CONTOURS	750
EXISTING MINOR CONTOURS	
SHEETPILE	

SYMBOLS LEGEND

SB-3	SOIL BORING COMPLETED BY PROFESSIONAL SERVICE INDUSTRIES, 1997
	FLOW DIRECTION
BM #200	SURVEY REFERENCE MONUMENT
	POWER POLE

EXISTING CONDITIONS SITE PLAN

0 30' 60'
SCALE, FT

SURVEY CONTROL MONUMENT LOCATIONS

ID	ELEVATION	NORTHING	EASTING
BM #200	710.61	234,396.048	19,693,143.919
CONTROL POINT	702.36	234,431.875	19,693,171.675

NOTES:

1. VERTICAL DATUM: NATIONAL GEODETIC VERTICAL DATUM OF 1929 (NGVD29)
2. SPATIAL DATUM: NORTH AMERICAN DATUM OF 1983 (NAD83), MICHIGAN STATE PLANE, CENTRAL ZONE

Attention:
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GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed:	P. DREW
Checked:	P. DREW
Drawn:	A. SAMPSON
Approved By:	B. WALTON

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GEI Project 2002879

Smallwood Dam
Gladwin County, Michigan

SITE PLAN - EXISTING CONDITIONS

DWG. NO. C-01

SHEET NO. 3

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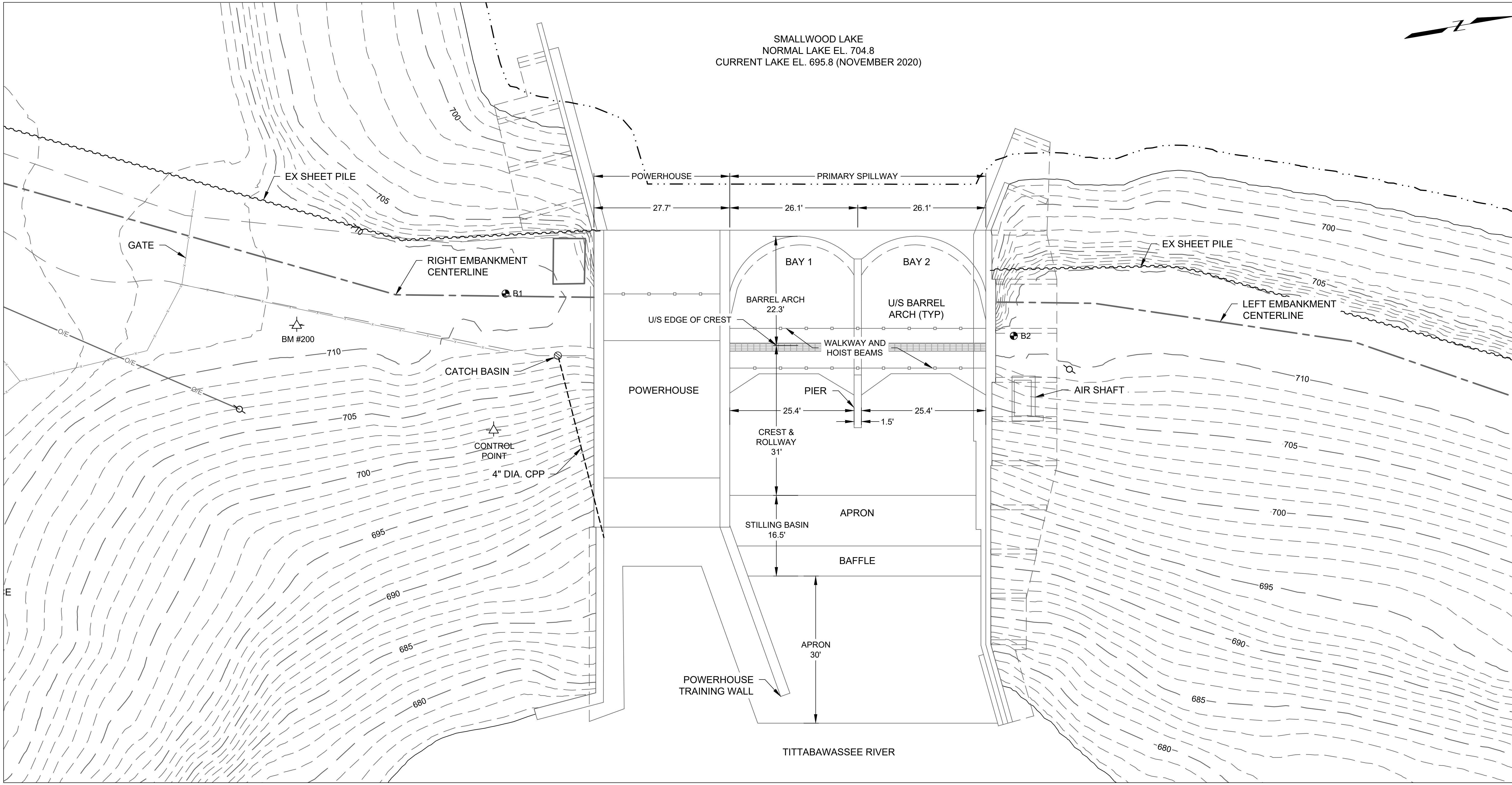

OUTLET WORKS - EXISTING PLAN VIEW

0 10' 20'
SCALE, FT

LINETYPE LEGEND

- CENTERLINE
- WATER ELEVATION
- OVERHEAD ELECTRIC LINES (O/E)
- FENCE LINE (STEEL)
- FENCE LINE (WOOD)
- EDGE OF ROADWAY (UNPAVED)
- BURIED PIPING
- EXISTING MAJOR CONTOURS (750)
- EXISTING MINOR CONTOURS
- SHEETPILE

SYMBOLS LEGEND

- SB-3 SOIL BORING COMPLETED BY PROFESSIONAL SERVICE INDUSTRIES, 1997
- FLOW DIRECTION
- BM #200 SURVEY REFERENCE MONUMENT
- POWER POLE

Attention: 0 1"
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989-754-4717 Fax.
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GEI Consultants
GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed: P. DREW
Checked: P. DREW
Drawn: A. SAMPSON
Approved By: B. WALTON

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Gladwin County, Michigan

OUTLET WORKS - EXISTING CONDITIONS PLAN

DWG. NO. C-02
SHEET NO. 4

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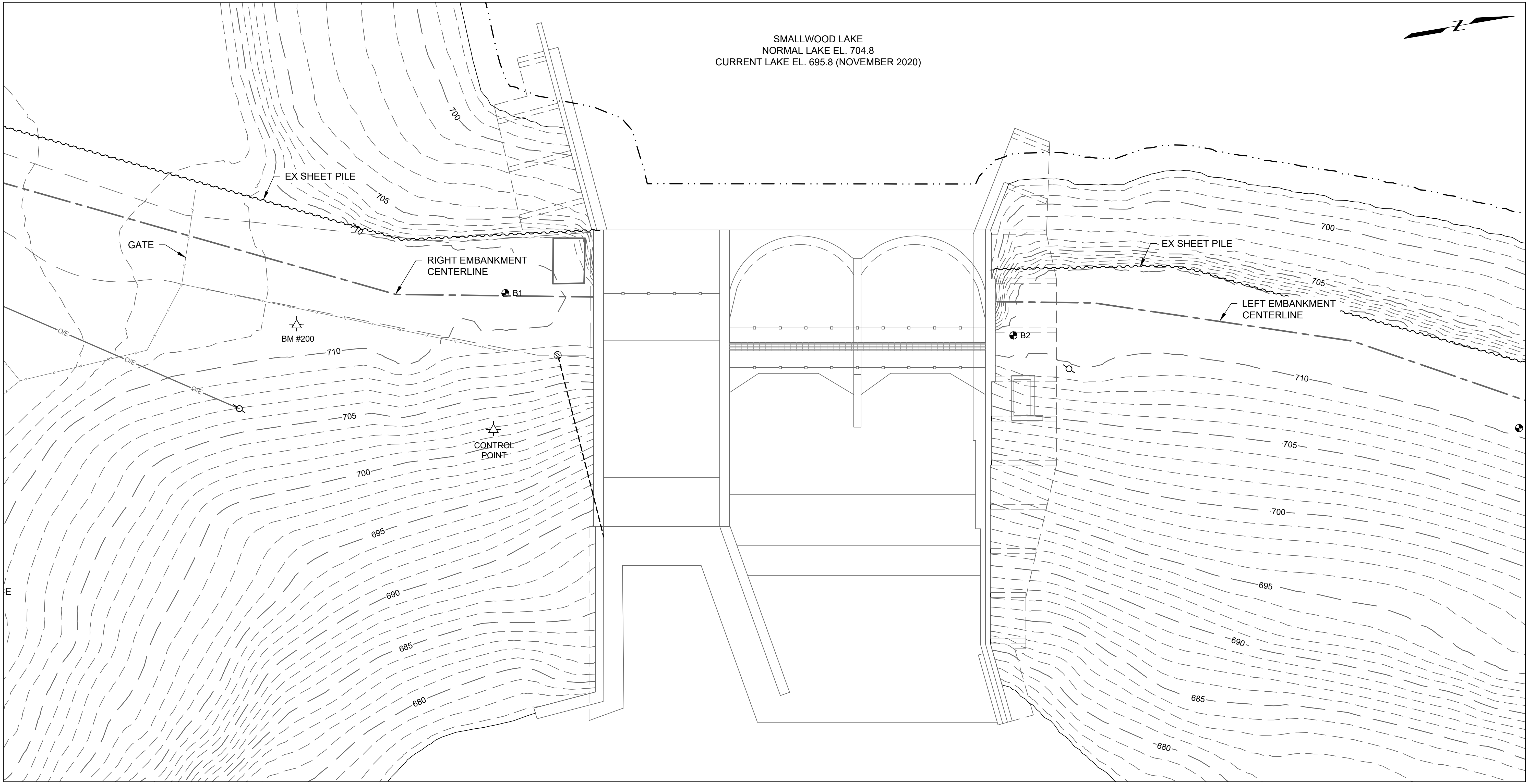

OUTLET WORKS - PLAN VIEW

0 10' 20'
SCALE, FT

LINETYPE LEGEND

- CENTERLINE
- WATER ELEVATION
- OVERHEAD ELECTRIC LINES (O/E)
- FENCE LINE (STEEL)
- FENCE LINE (WOOD)
- EDGE OF ROADWAY (UNPAVED)
- BURIED PIPING
- EXISTING MAJOR CONTOURS (750)
- EXISTING MINOR CONTOURS
- SHEETPILE

SYMBOLS LEGEND

- SB-3 — SOIL BORING COMPLETED BY PROFESSIONAL SERVICE INDUSTRIES, 1997
- FLOW DIRECTION
- BM #200 — SURVEY REFERENCE MONUMENT
- POWER POLE

Attention:
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GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed:	P. DREW
Checked:	P. DREW
Drawn:	A. SAMPSON
Approved By:	B. WALTON

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Smallwood Dam
Gladwin County, Michigan

OUTLET WORKS - TEMPORARY COFFERDAMS PLAN

DWG. NO. C-03

SHEET NO. 5

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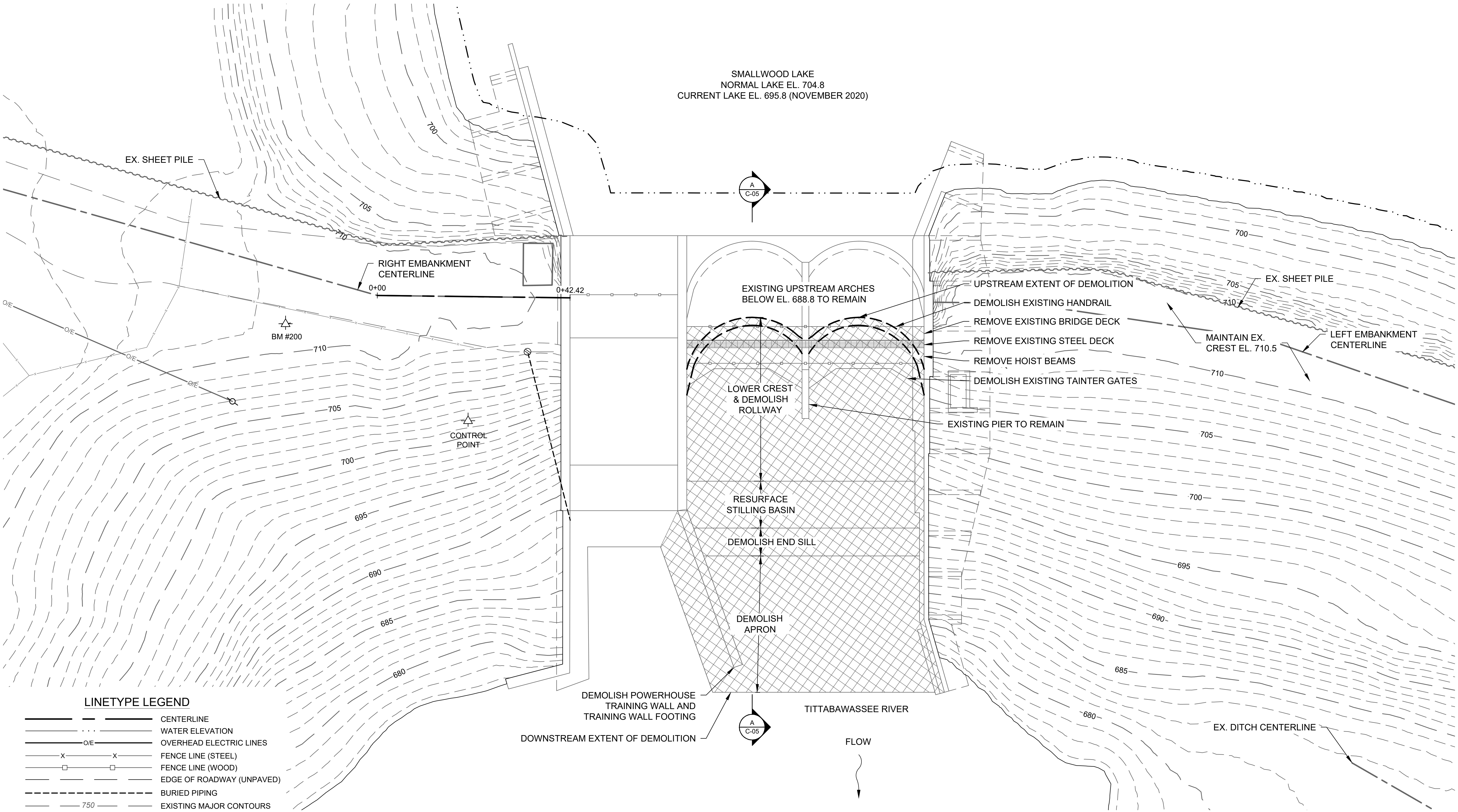

LINETYPE LEGEND

- CENTERLINE
- WATER ELEVATION
- OVERHEAD ELECTRIC LINES (O/E)
- FENCE LINE (STEEL)
- FENCE LINE (WOOD)
- EDGE OF ROADWAY (UNPAVED)
- BURIED PIPING
- EXISTING MAJOR CONTOURS (750)
- EXISTING MINOR CONTOURS

HATCH LEGEND

- CONCRETE DEMOLITION
- GRATING

SYMBOLS LEGEND

- FLOW DIRECTION

OUTLET WORKS - DEMOLITION PLAN VIEW

0 10 20
SCALE, FT

Attention: 0 1"
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GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed:	P. DREW
Checked:	P. DREW
Drawn:	A. SAMPSON
Approved By:	B. WALTON

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Smallwood Dam
Gladwin County, Michigan

OUTLET WORKS - DEMOLITION PLAN

DWG. NO. C-04

SHEET NO. 6

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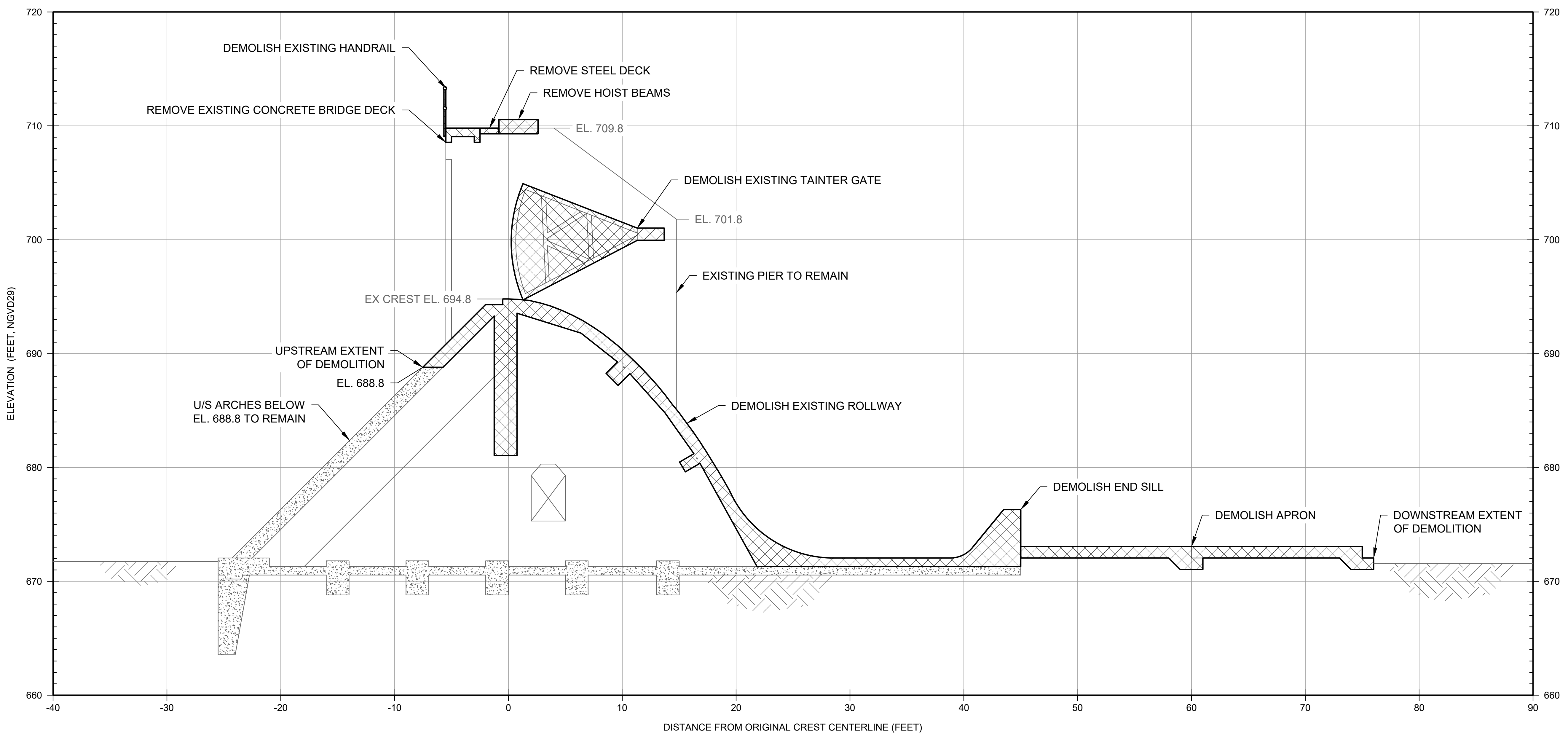

A / C-04 SECTION
SPILLWAY DEMOLITION

0 5 10
SCALE, FT

LINETYPE LEGEND

- WATER ELEVATION
- EXISTING FEATURE
- PROPOSED FEATURE

HATCH LEGEND

CONCRETE DEMOLITION | EXISTING CONCRETE | EXISTING FOUNDATION

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989-754-4717 Fax.
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GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed:	P. DREW
Checked:	P. DREW
Drawn:	A. SAMPSON
Approved By:	B. WALTON

Four Lakes Task Force
FERC Project No. 10810

GEI Project 2002879

Smallwood Dam
Gladwin County, Michigan

OUTLET WORKS - DEMOLITION SECTION

DWG. NO. C-05

SHEET NO. 7

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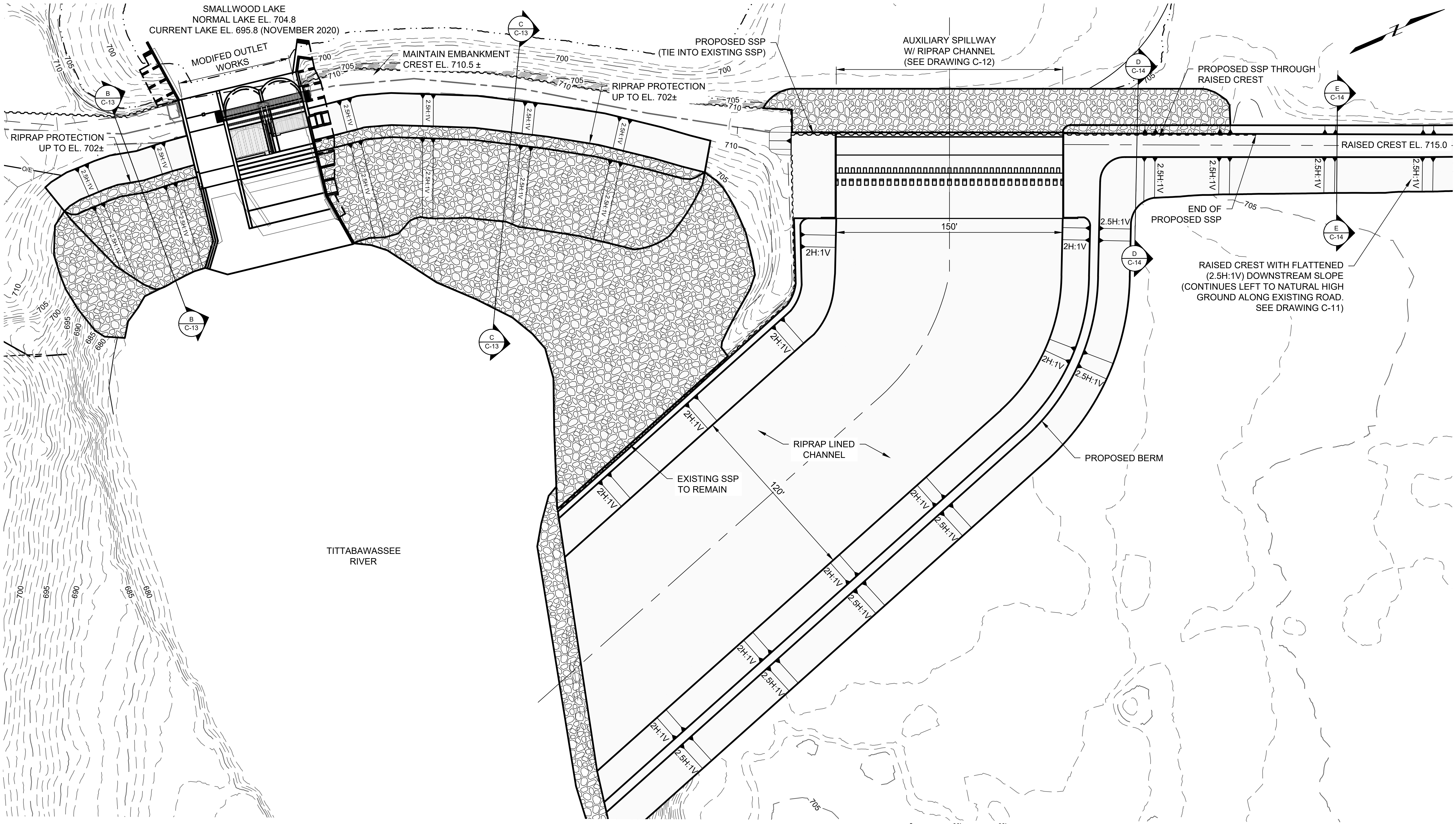

SITE PLAN - PROPOSED MODIFICATIONS

Attention: 0 1" If this scale bar does not measure 1" then drawing is not original scale.			
0	xx/xx/xxxx	CONCEPTUAL DESIGN SUBMITTAL	-
NO.	DATE	ISSUE/REVISION	APP

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989-754-4717 Fax.
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GEI Consultants
GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
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Gladwin County, Michigan

SITE PLAN - PROPOSED MODIFICATIONS

DWG. NO. C-06

SHEET NO. 8

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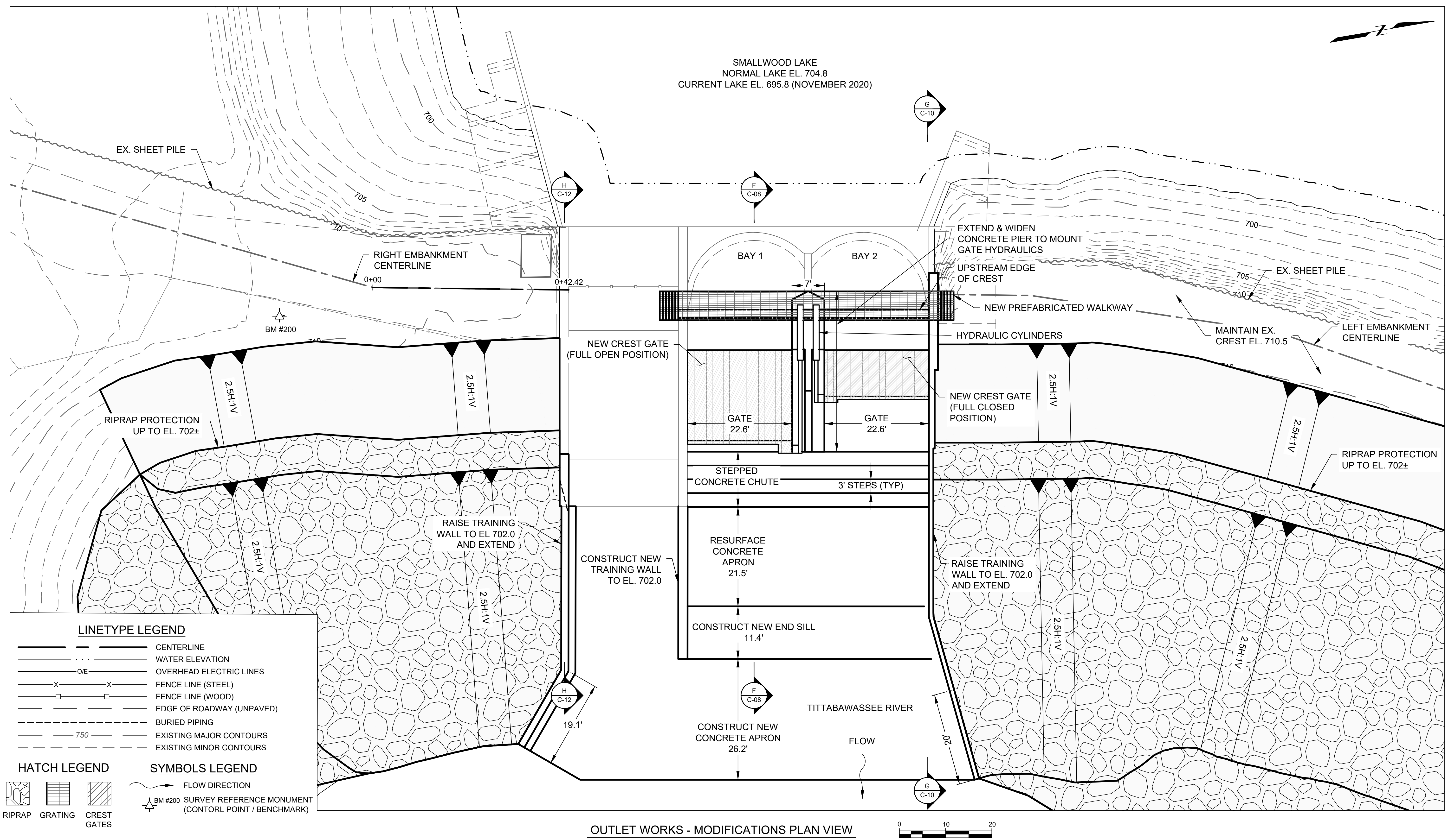

OUTLET WORKS - MODIFICATIONS PLAN VIEW

0 10 20
SCALE, FT

Attention: If this scale bar does not measure 1" then drawing is not original scale.

NO.	DATE	ISSUE/REVISION	APP
0	xx/xx/xxxx	CONCEPTUAL DESIGN SUBMITTAL	-

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989-754-4717 Fax.
989-754-4440
www.SpicerGroup.com

GEI Consultants
GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed: P. DREW
Checked: P. DREW
Drawn: A. SAMPSON
Approved By: B. WALTON

Four Lakes Task Force
FERC Project No. 10810

GEI Project 2002879

Smallwood Dam
Gladwin County, Michigan

OUTLET WORKS - MODIFICATIONS PLAN VIEW

DWG. NO. C-07

SHEET NO. 9

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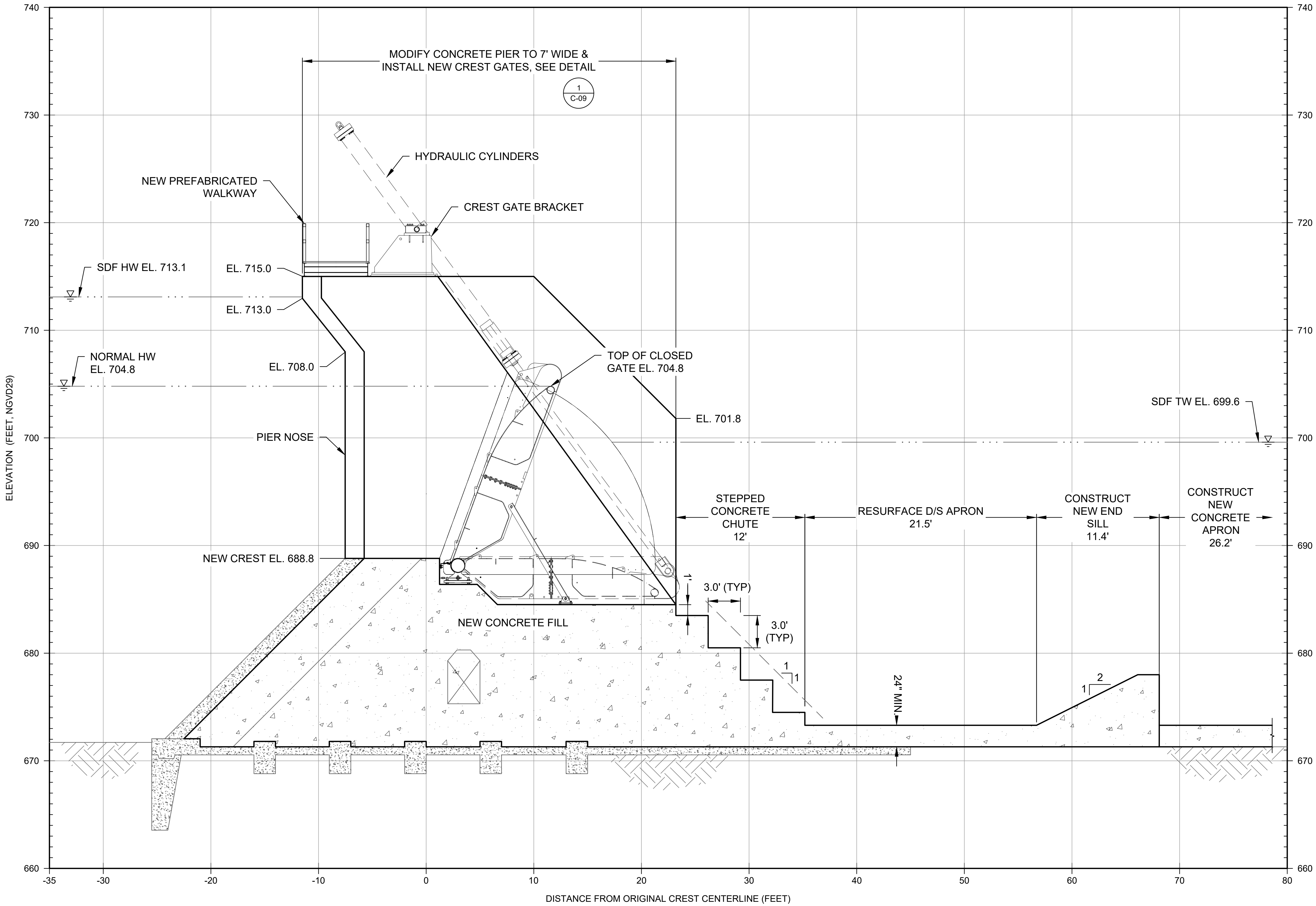

LINETYPE LEGEND

- WATER ELEVATION
- EXISTING FEATURE
- PROPOSED FEATURE

HATCH LEGEND

PROPOSED REINFORCED CONCRETE | EXISTING CONCRETE | EXISTING FOUNDATION

F / C-07 **SECTION**
SPILLWAY BAY 1

0 5 10

Attention:				
0 1"				
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10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

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Gladwin County, Michigan

PRIMARY SPILLWAY -
MODIFICATIONS SECTION

DWG. NO.
C-08

SHEET NO.
10

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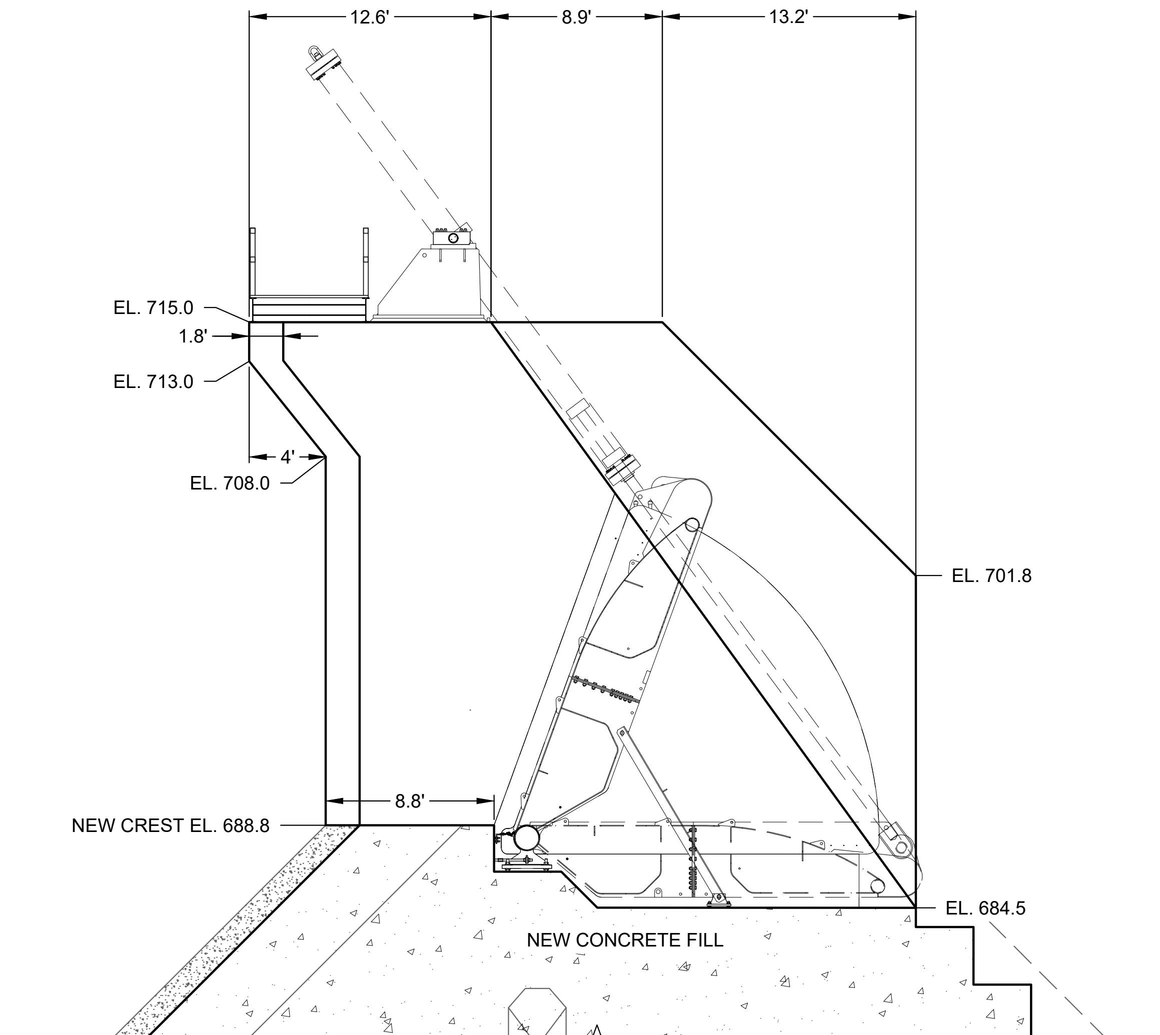
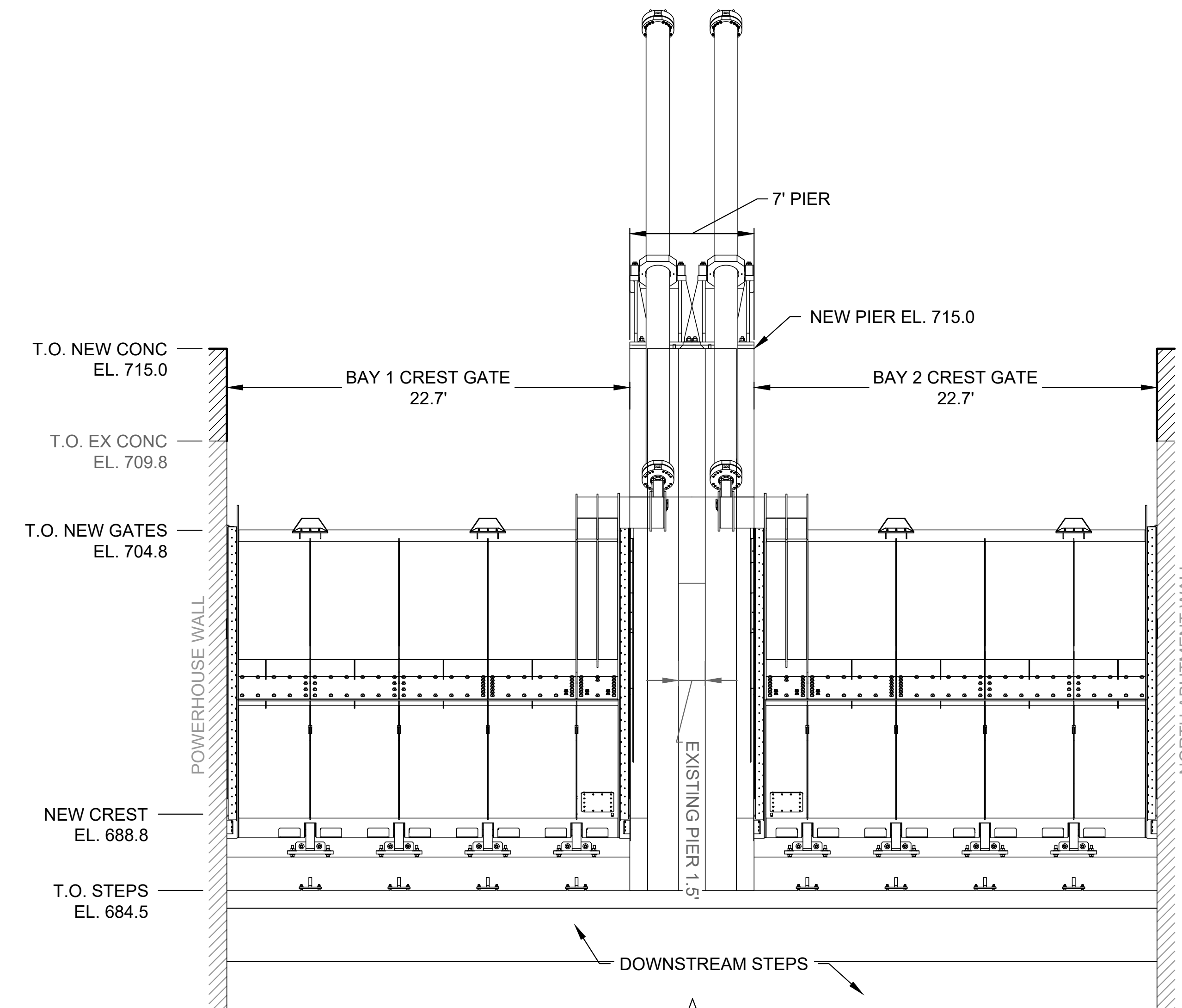


SECTION



DOWNSTREAM ELEVATION
(LOOKING UPSTREAM)

1
C-08

DETAIL
PIER-MOUNTED CREST GATE

0 5 10

0	xx/xx/xxxx	CONCEPTUAL DESIGN SUBMITTAL	-
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10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed:	P. DREW
Checked:	P. DREW
Drawn:	A. SAMPSON
Approved By:	B. WALTON

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PRIMARY SPILLWAY - CREST GATE DETAILS

DWG. NO. C-09

SHEET NO. 11

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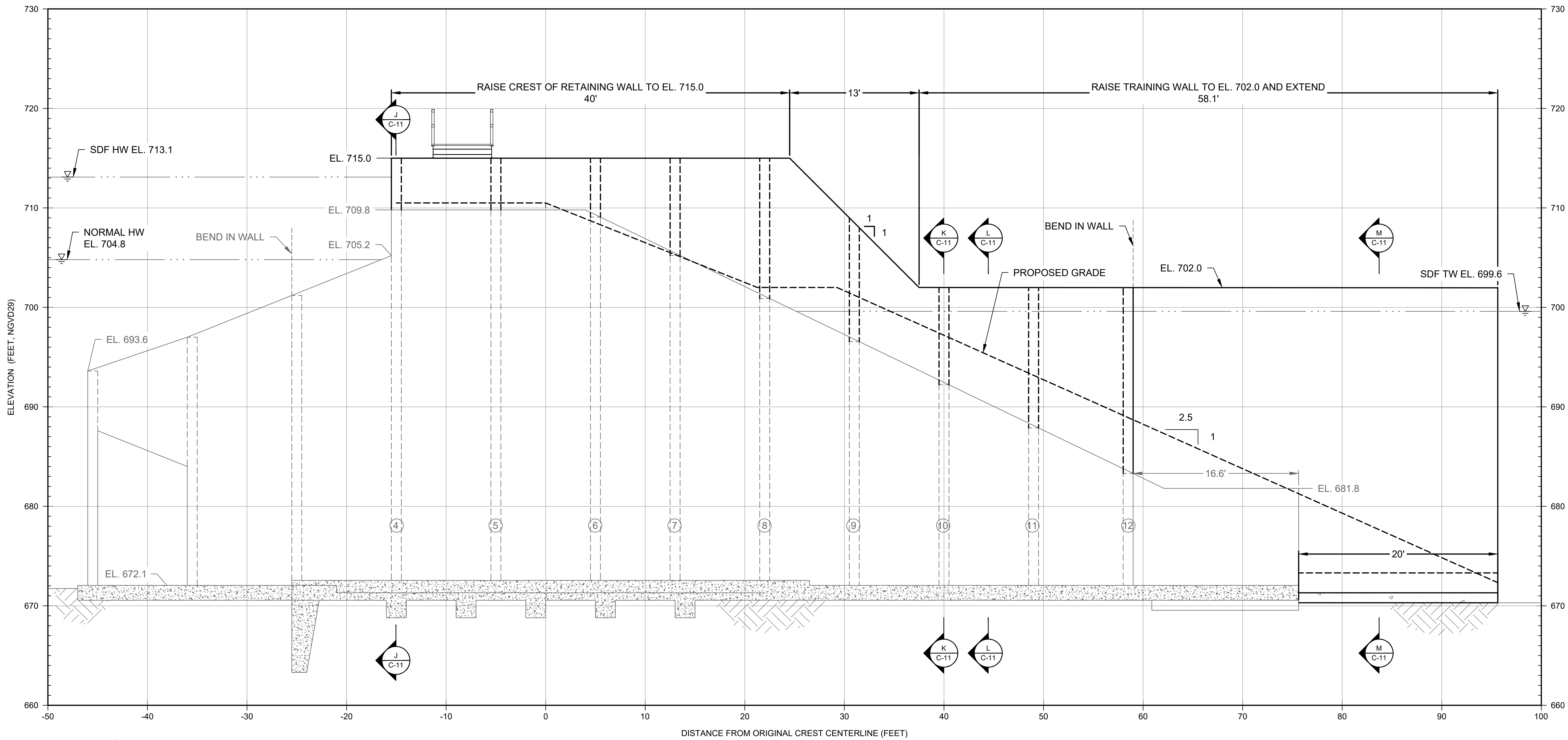

LINETYPE LEGEND

- WATER ELEVATION
- EXISTING FEATURE
- PROPOSED FEATURE

G / C-07 SECTION
NORTH TRAINING WALL

0 5 10

HATCH LEGEND

EXISTING CONCRETE
EXISTING FOUNDATION

SYMBOL LEGEND

(1) BUTTRESS NUMBER

0	xx/xx/xxxx	CONCEPTUAL DESIGN SUBMITTAL	-
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Saginaw, MI 48607 Tel.
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GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed:	P. DREW
Checked:	P. DREW
Drawn:	A. SAMPSON
Approved By:	B. WALTON

Four Lakes Task Force
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Smallwood Dam
Gladwin County, Michigan

NORTH TRAINING WALL - MODIFICATIONS SECTION

DWG. NO. C-10

SHEET NO. 12

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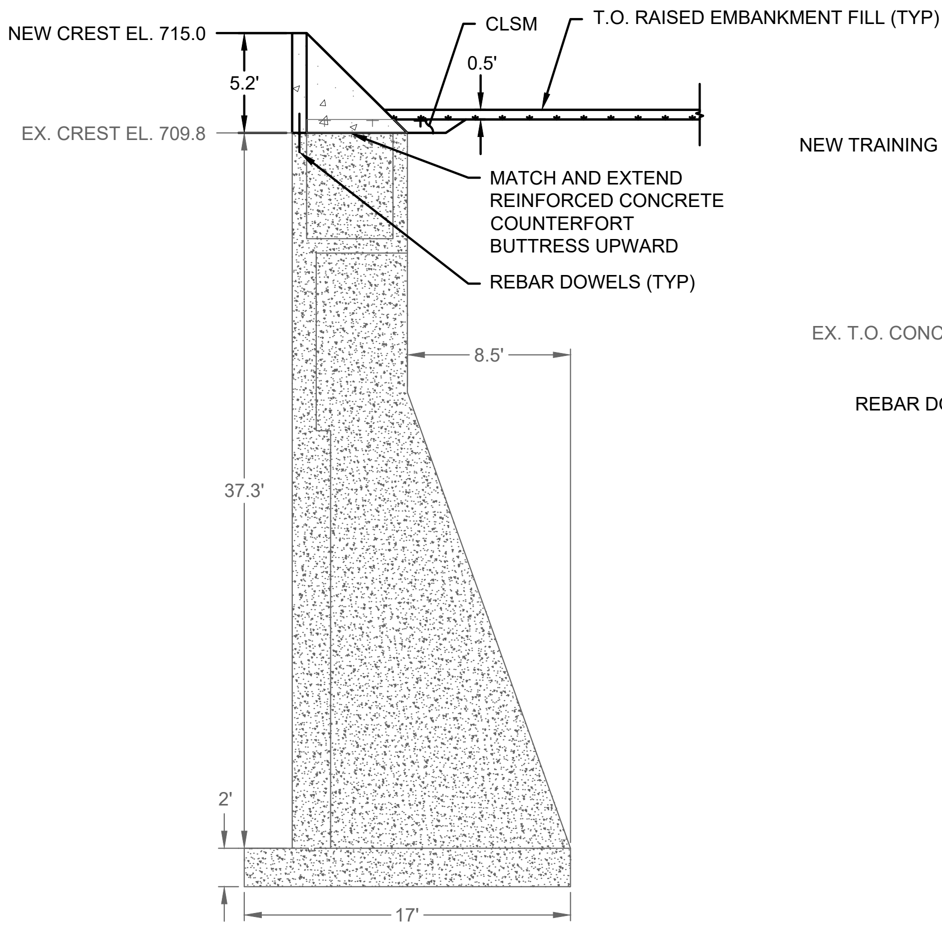
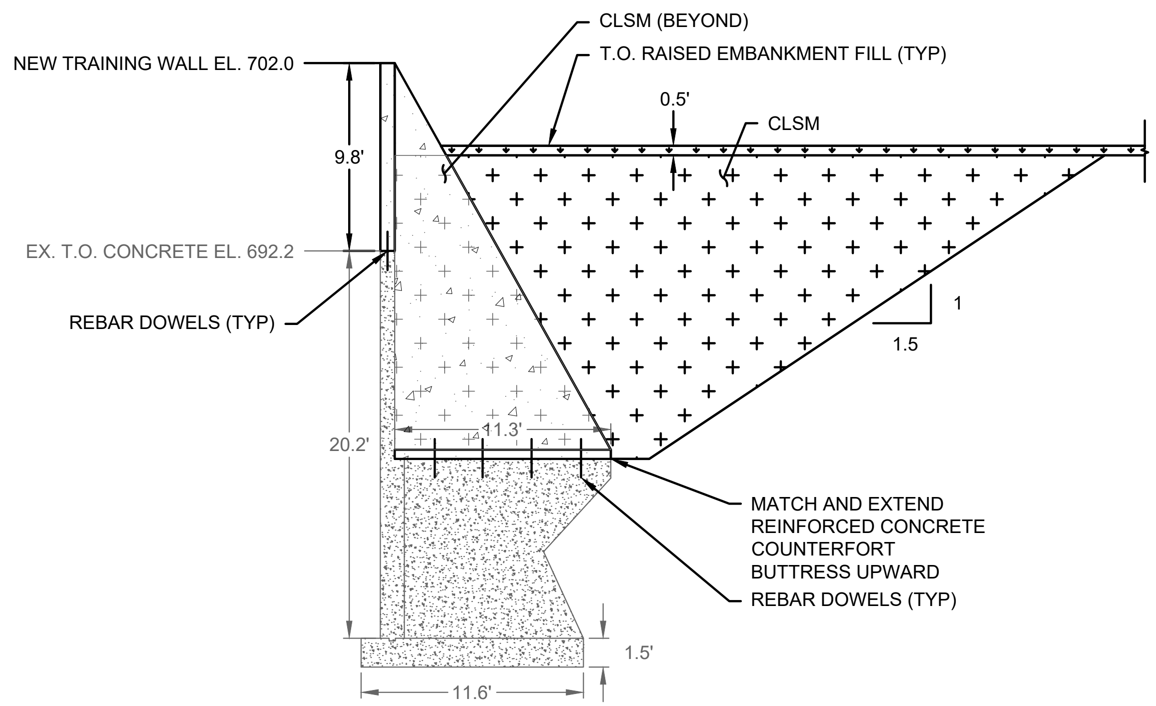


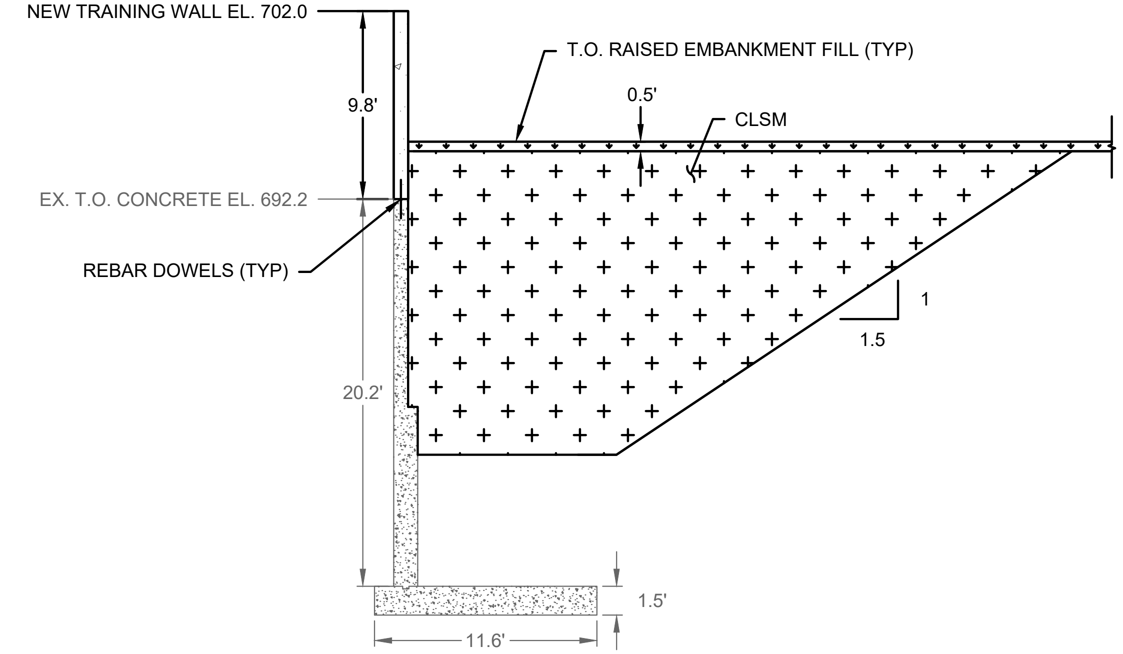
J
C-10
SECTION
BUTTRESS 4

0 5 10



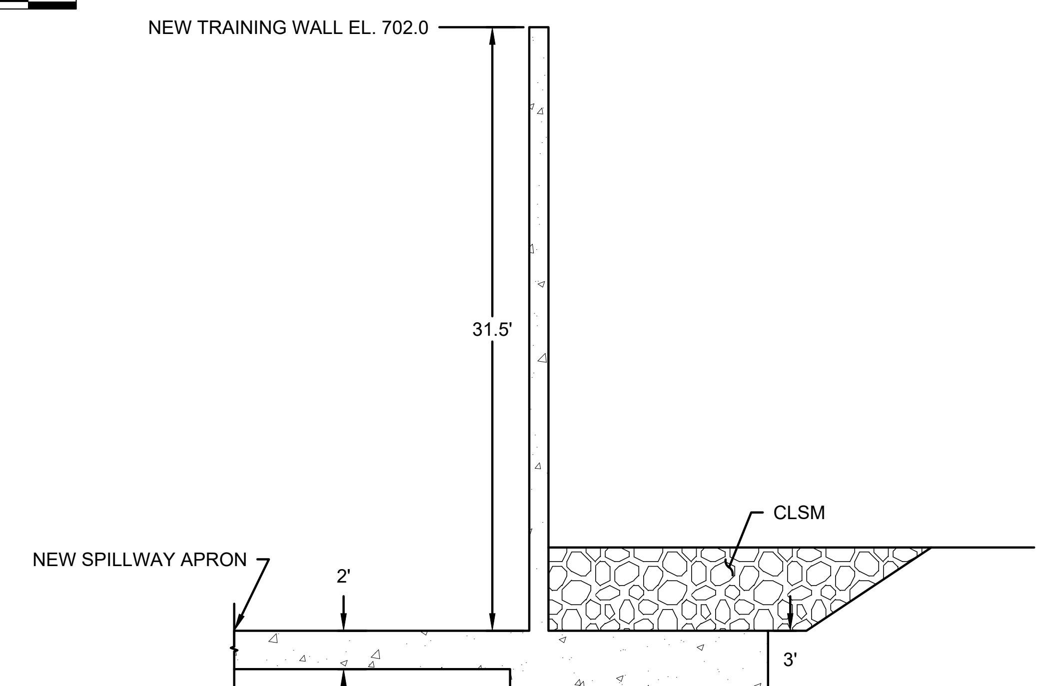
K
C-10
SECTION
BUTTRESS 10

0 5 10



L
C-10
SECTION
BETWEEN BUTTRESSES 10 & 11

0 5 10



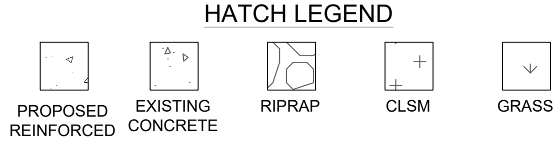
M
C-11
SECTION
NEW WALL EXTENSION

0 5 10

LINETYPE LEGEND

EXISTING FEATURE
PROPOSED FEATURE

HATCH LEGEND



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GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed:	P. DREW
Checked:	P. DREW
Drawn:	A. SAMPSON
Approved By:	B. WALTON

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Smallwood Dam
Gladwin County, Michigan

NORTH TRAINING WALL - MODIFICATIONS DETAILS

DWG. NO.
C-11

SHEET NO.
13

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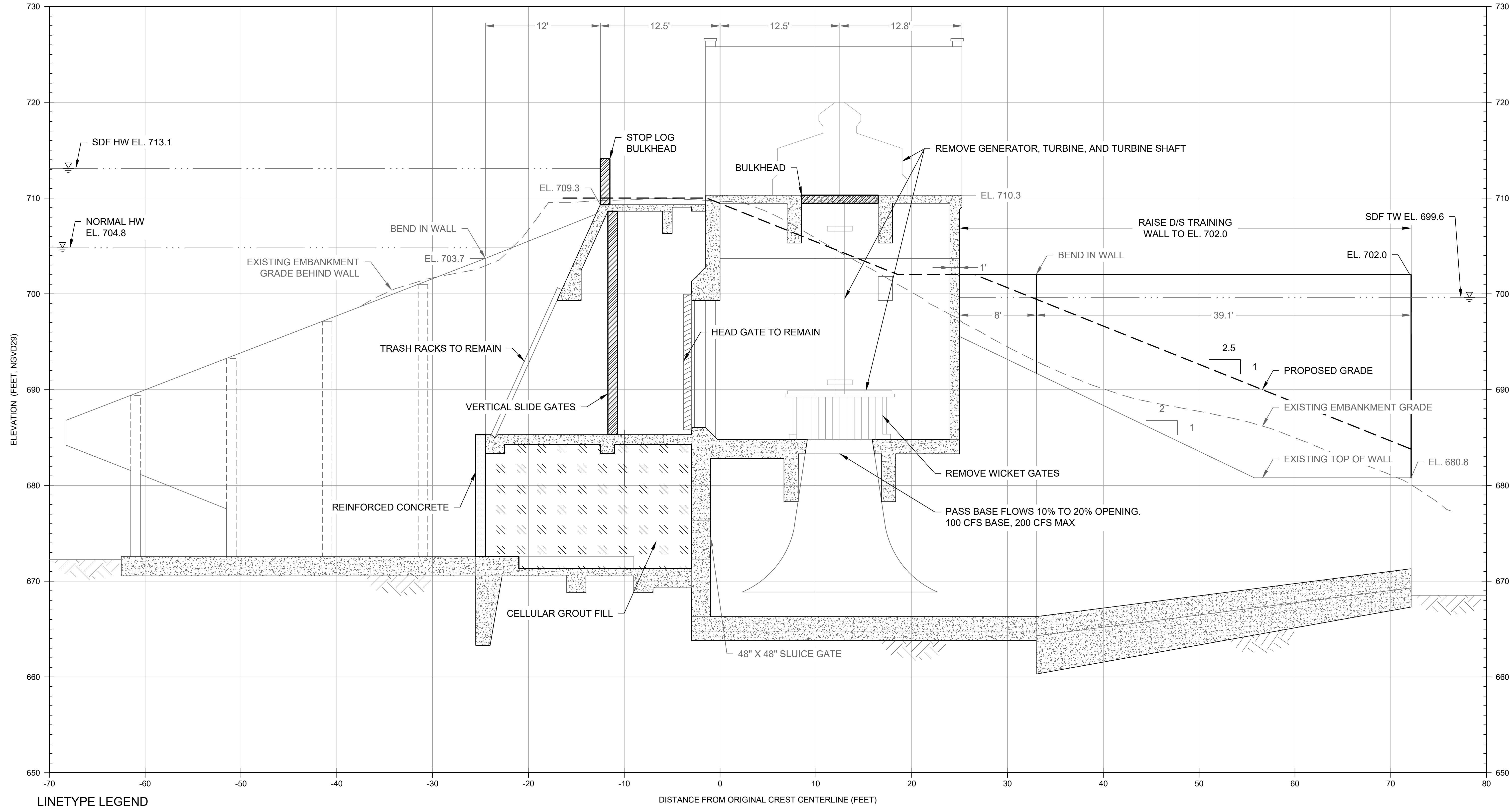

LINETYPE LEGEND

- WATER ELEVATION
- EXISTING FEATURE
- PROPOSED FEATURE

H / C-07 SECTION
POWERHOUSE

0 5 10

HATCH LEGEND

EXISTING CONCRETE | EXISTING FOUNDATION | REINFORCED CONCRETE CAP | CELLULAR GROUT FILL | TIMBER

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G100
MILWAUKEE, WI 53226
(414)930-7540

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Checked: P. DREW
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Smallwood Dam
Gladwin County, Michigan

POWERHOUSE - MODIFICATIONS SECTION

DWG. NO. C-12

SHEET NO. 14

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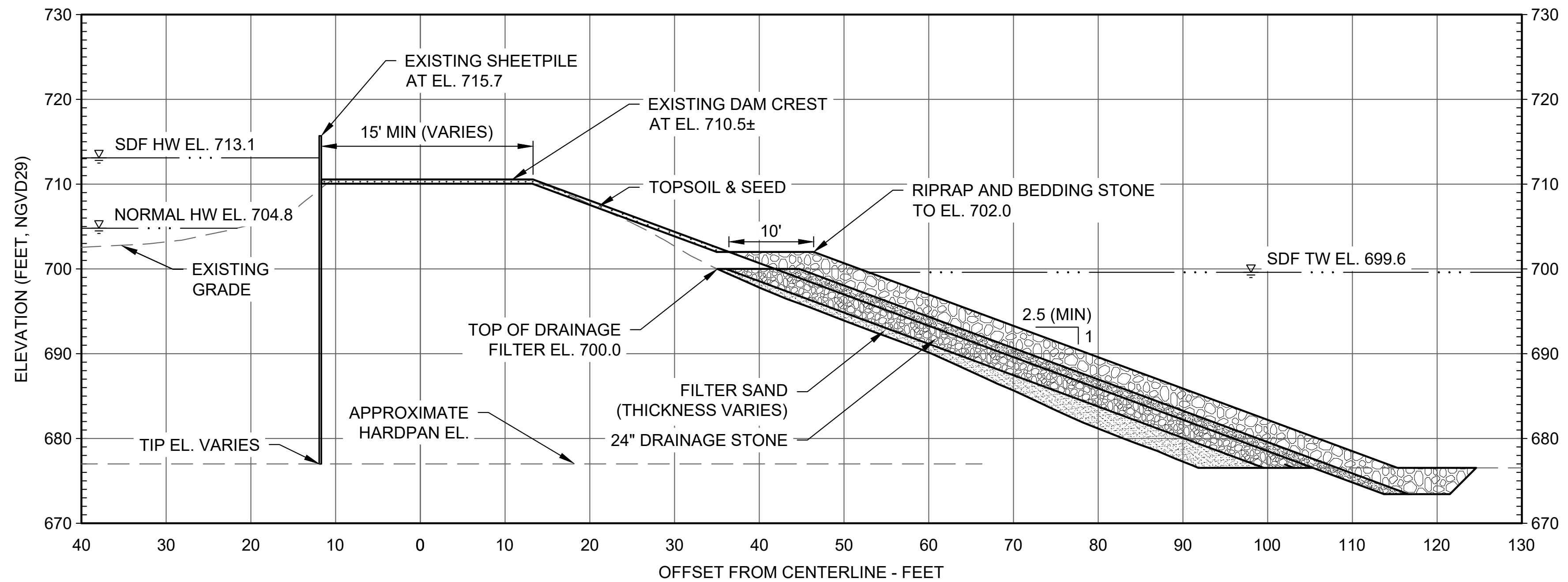
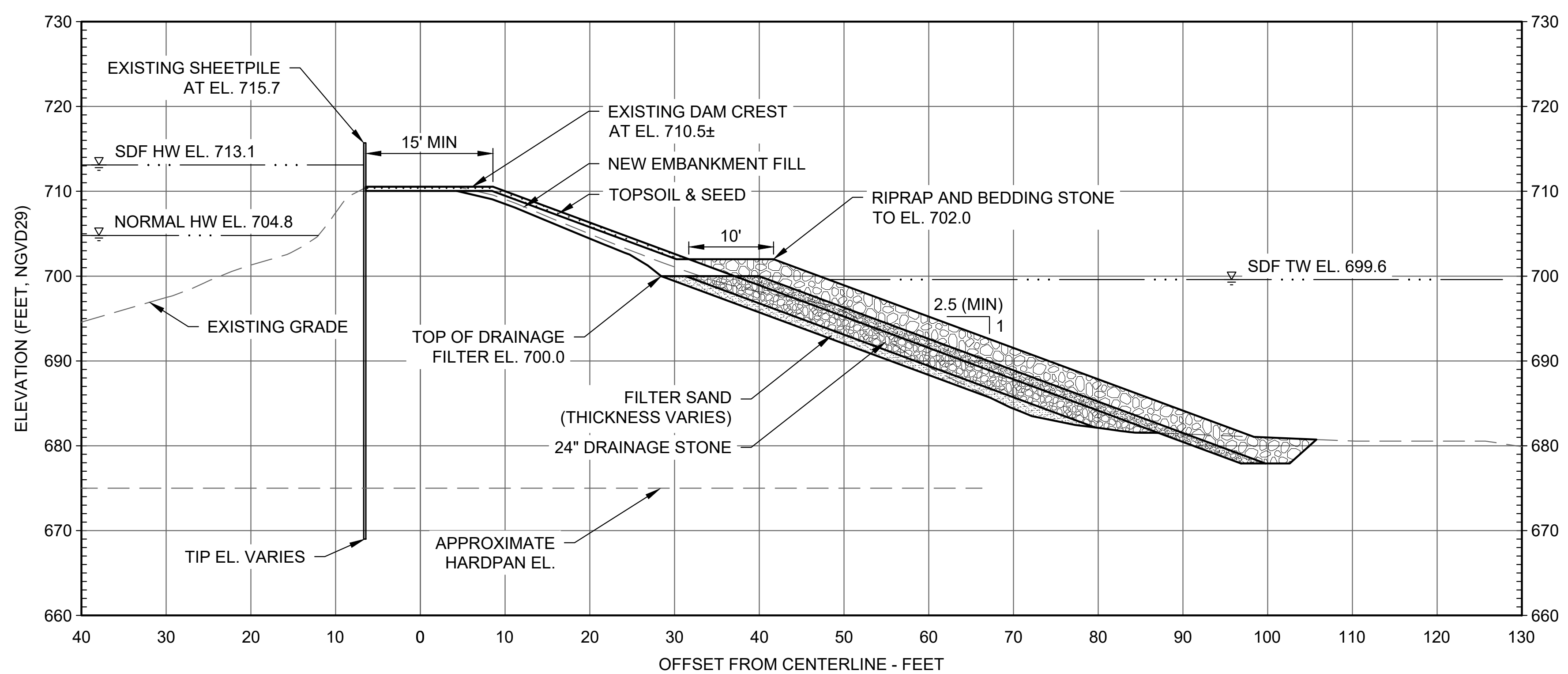


B / C-06 SECTION
RIGHT EMBANKMENT



C / C-06 SECTION
LEFT EMBANKMENT

Attention:
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0	xx/xx/xxxx	CONCEPTUAL DESIGN SUBMITTAL	-

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G100
MILWAUKEE, WI 53226
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Smallwood Dam
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EMBANKMENTS - MODIFICATIONS
SECTIONS (SHEET 1 OF 2)

DWG. NO. C-13
SHEET NO. 15

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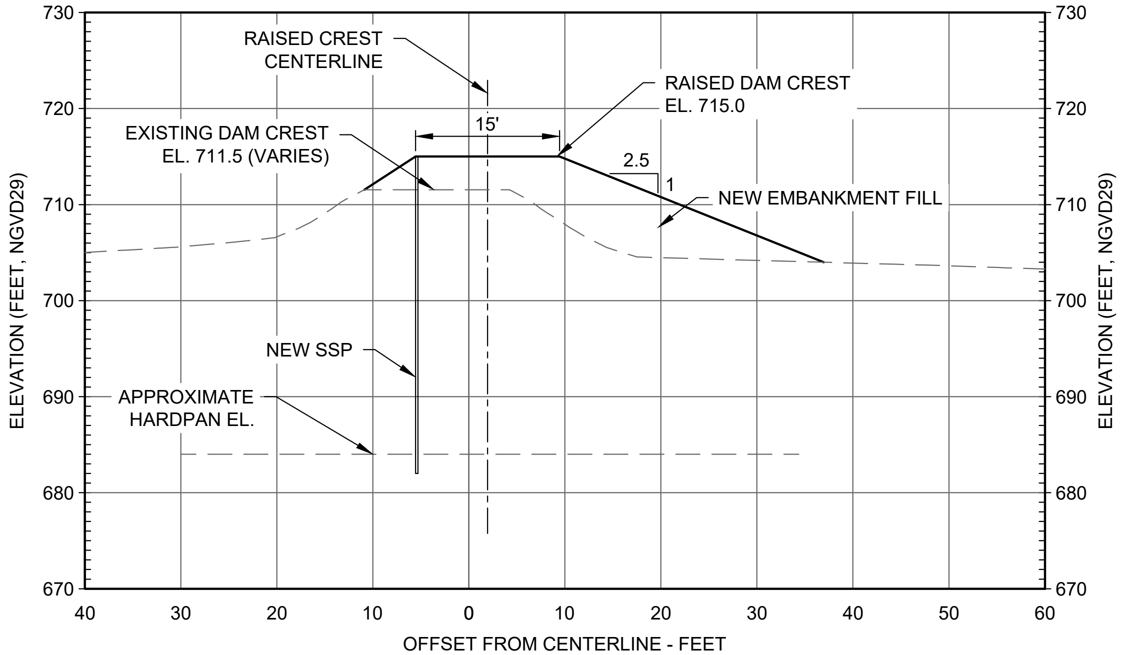
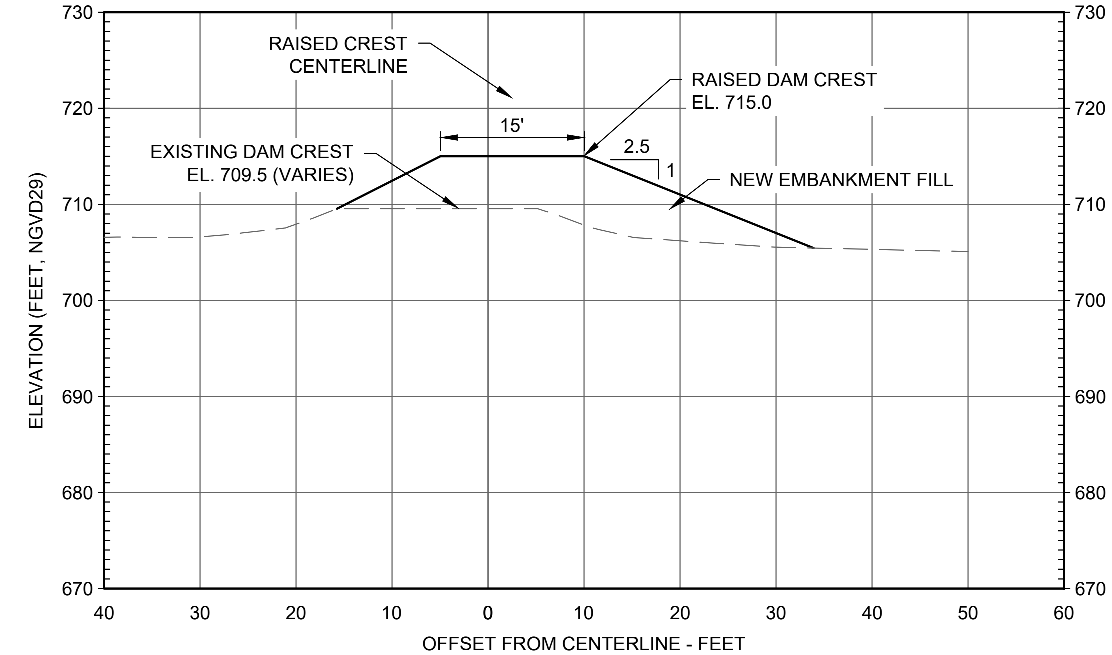


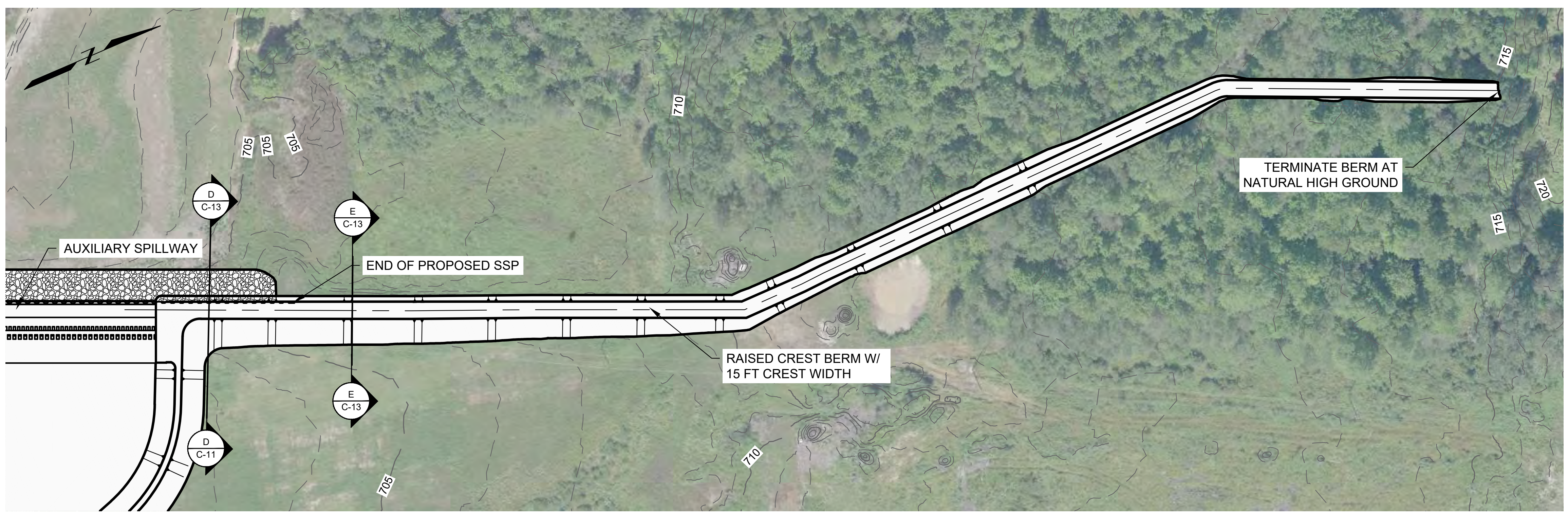
D SECTION
C-06 C-14 LEFT EMBANKMENT W/ SSP CUTOFF

HORIZONTAL SCALE, FEET 0 10 20
VERTICAL SCALE, FEET 0 10 20
NO VERTICAL EXAGGERATION



E SECTION
C-06 C-14 LEFT EMBANKMENT BERM DETAIL

HORIZONTAL SCALE, FEET 0 10 20
VERTICAL SCALE, FEET 0 10 20
NO VERTICAL EXAGGERATION



LEFT EMBANKMENT PLAN

0 60' 120'
SCALE, FEET

Attention:				
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	NO.	DATE	ISSUE/REVISION	APP

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989-754-4717 Fax.
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G100
MILWAUKEE, WI 53226
(414)930-7540

Designed:	P. DREW
Checked:	P. DREW
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FERC Project No. 10810

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Smallwood Dam
Gladwin County, Michigan

EMBANKMENTS - MODIFICATIONS
SECTIONS (SHEET 2 OF 2)

DWG. NO. C-14

SHEET NO. 16

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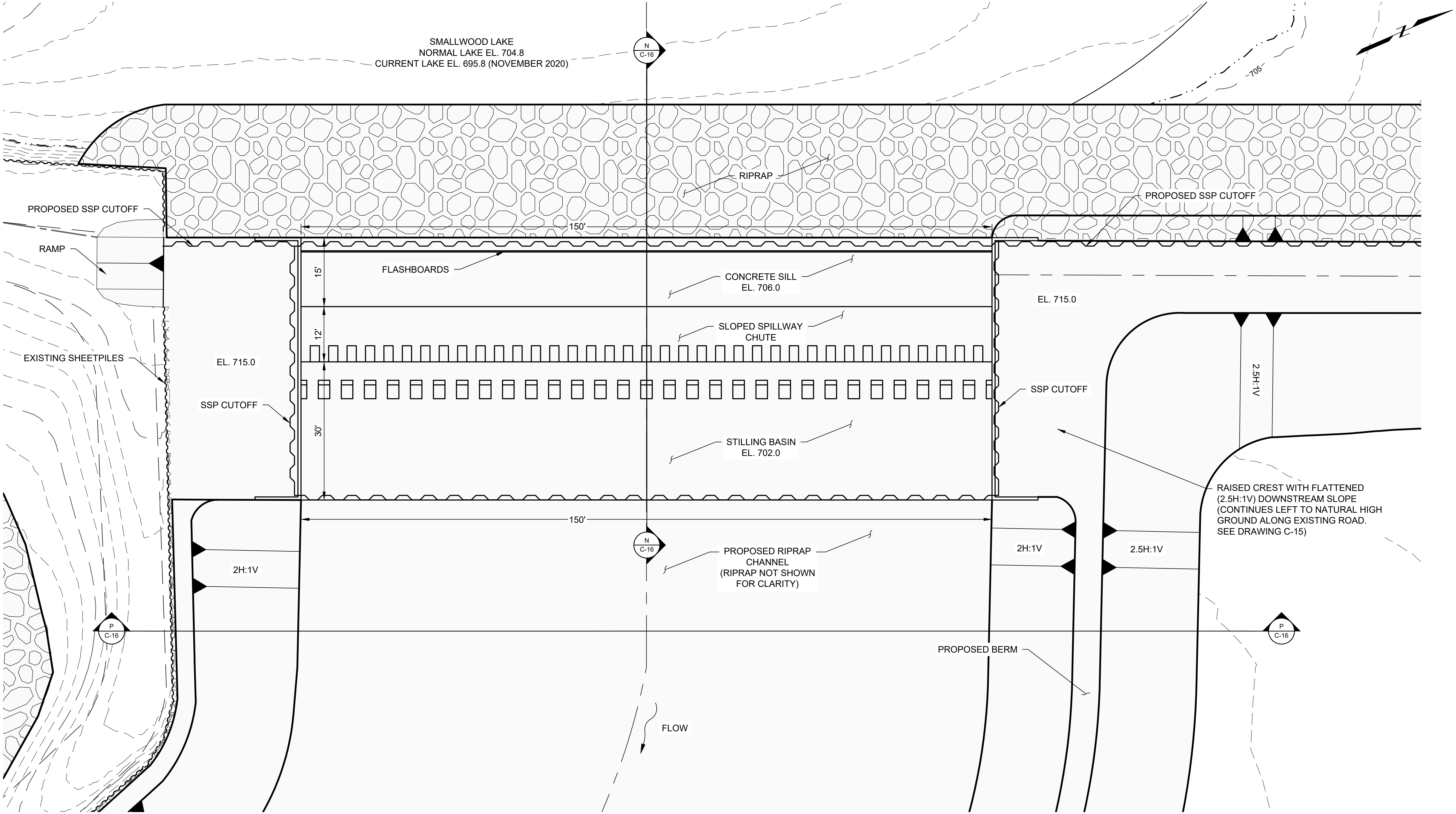

PLAN VIEW

PROPOSED AUXILIARY SPILLWAY

0 10' 20'
SCALE, FEET

Attention:

0 1"

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0	xx/xx/xxxx	CONCEPTUAL DESIGN SUBMITTAL	-

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GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed:	P. DREW
Checked:	P. DREW
Drawn:	A. SAMPSON
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Smallwood Dam
Gladwin County, Michigan

AUXILIARY SPILLWAY - PROPOSED PLAN VIEW

DWG. NO.
C-15

SHEET NO.
17

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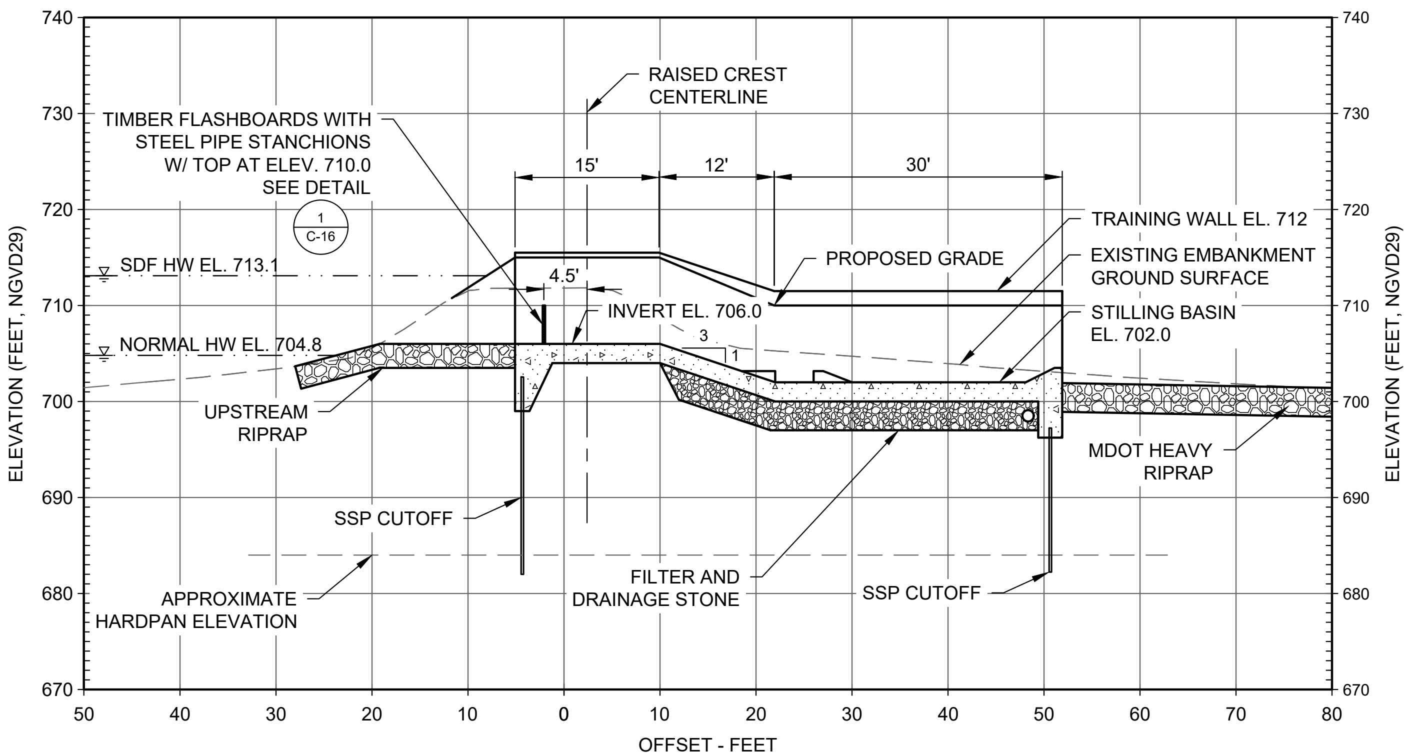
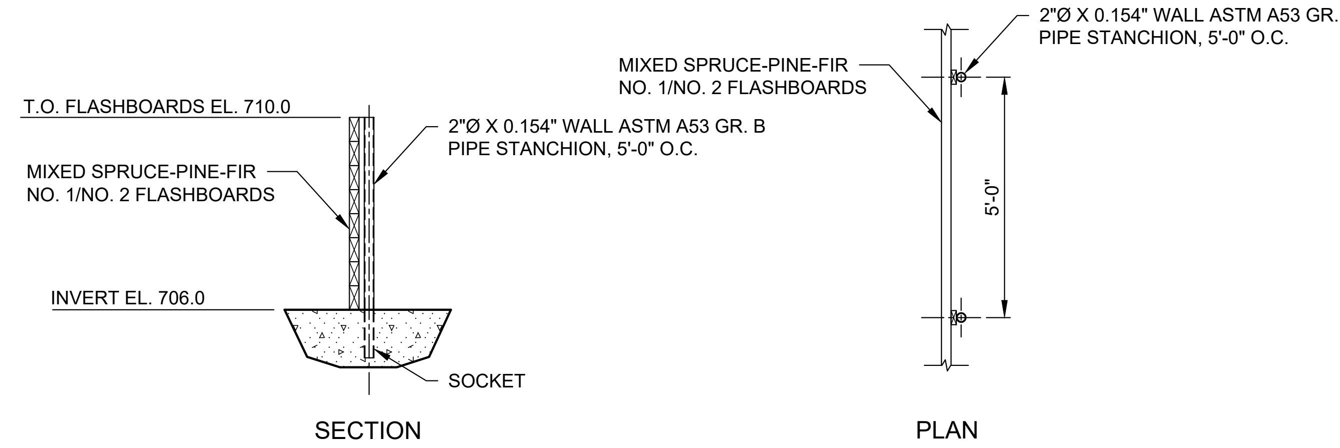


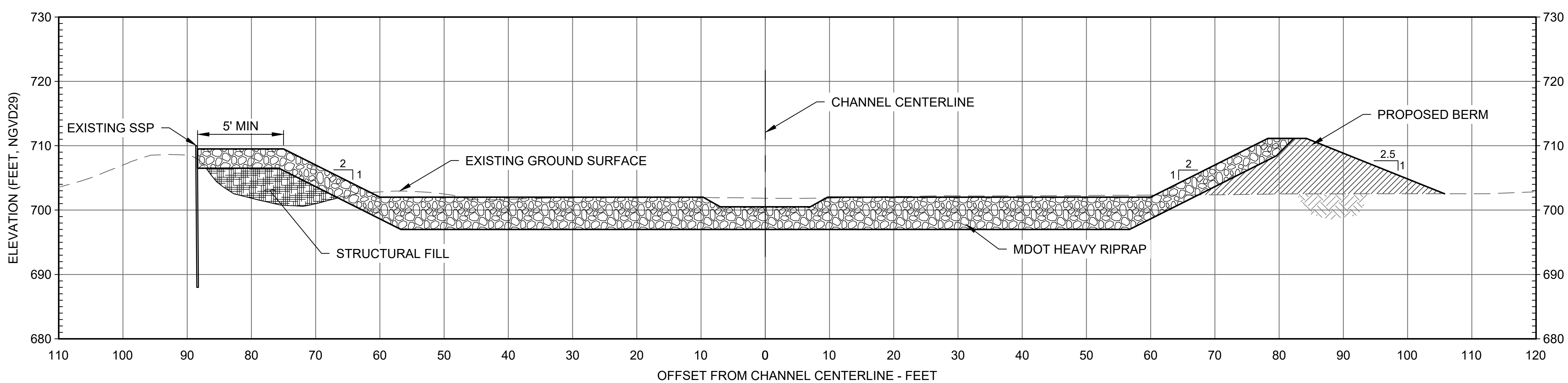
N
C-15
SECTION
PROPOSED SPILLWAY

HORIZONTAL SCALE, FEET
0 10 20
VERTICAL SCALE, FEET
NO VERTICAL EXAGGERATION



1
C-16
DETAIL

0 2' 4'
SCALE, FEET



P
C-15
SECTION
PROPOSED SPILLWAY CHANNEL

HORIZONTAL SCALE, FEET
0 10 20
VERTICAL SCALE, FEET
NO VERTICAL EXAGGERATION

Attention:
0 1"
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GEI CONSULTANTS OF MICHIGAN, P.C.
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MILWAUKEE, WI 53226
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Designed:	P. DREW
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Smallwood Dam
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AUXILIARY SPILLWAY - PROPOSED SPILLWAY & CHANNEL CROSS SECTIONS, SPILLWAY DETAILS

DWG. NO.
C-16
SHEET NO.
18

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Appendix D

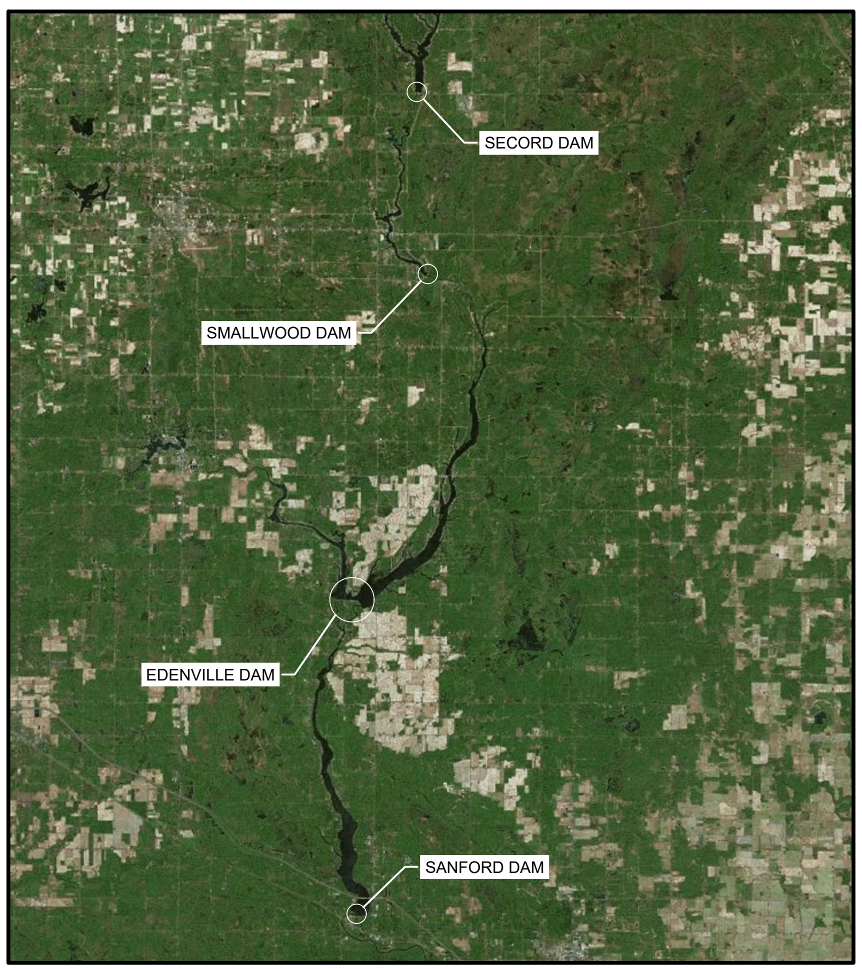
Proposed Conditions Spillway Upgrades

Appendix D.3 – Edenville Dam

EDENVILLE DAM
CONCEPTUAL DESIGN

GLADWIN COUNTY, MICHIGAN
FOUR LAKES TASK FORCE

STATE MAP
(NOT TO SCALE)



SOURCE:
AERIAL IMAGE TAKEN FROM GOOGLE EARTH

SITE LOCATION
(NOT TO SCALE)

SITE AERIAL
(NOT TO SCALE)

SHEET INDEX

SHEET NO.	DRAWING NO.	TITLE
1	G-01	COVER SHEET AND SITE LOCATION
2	G-02	GENERAL NOTES AND LEGEND
3	C-01	TOBACCO SITE PLAN - EXISTING CONDITIONS "POST EDENVILLE DAM FAILURE"
4	C-02	EDENVILLE SITE PLAN - EXISTING CONDITIONS "POST EDENVILLE DAM FAILURE"
5	C-03	TOBACCO - EXISTING CONDITIONS PLAN "POST AECOM STABILIZATION"
6	C-04	TOBACCO OUTLET WORKS - DEMOLITION SECTION
7	C-05	TOBACCO OUTLET WORKS - MODIFICATIONS PLAN
8	C-06	TOBACCO PRIMARY SPILLWAY - MODIFICATIONS SECTION (SHEET 1 OF 2)
9	C-07	TOBACCO PRIMARY SPILLWAY - MODIFICATIONS SECTION (SHEET 2 OF 2)
10	C-08	TOBACCO PRIMARY SPILLWAY - CREST GATE DETAILS
11	C-09	EDENVILLE SITE PLAN - EXISTING CONDITIONS "POST GEI STABILIZATION"
12	C-10	EDENVILLE OUTLET WORKS - DEMOLITION PLAN
13	C-11	EDENVILLE OUTLET WORKS - MODIFICATIONS PLAN
14	C-12	EDENVILLE PRIMARY SPILLWAY - MODIFICATIONS SECTION
15	C-13	EDENVILLE POWERHOUSE - MODIFICATIONS SECTION
16	C-14	TOBACCO RIGHT EMBANKMENT - MODIFICATIONS
17	C-15	TOBACCO LEFT EMBANKMENT - MODIFICATIONS
18	C-16	EDENVILLE RIGHT EMBANKMENT - MODIFICATIONS SECTION
19	C-17	EDENVILLE EMBANKMENTS - MODIFICATIONS
20	C-18	EDENVILLE EMBANKMENTS - MODIFICATIONS SECTIONS & DETAILS
21	C-19	TITTABAWASSEE BREACH CHANNEL - PROPOSED LABYRINTH SPILLWAY PLAN
22	C-20	TITTABAWASSEE BREACH CHANNEL - PROPOSED LABYRINTH SPILLWAY SECTION & DETAILS

PREPARED FOR:

FOUR LAKES TASK FORCE
233 E. LARKIN
MIDLAND, MI 48640

PREPARED BY:

GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414) 930-7534

SPICER GROUP INC.
230 S. WASHINGTON AVE.
SAGINAW, MI 48607
TEL. (989) 754-4717
FAX. (989) 754-4440

GEI PROJECT NO. 2002879

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NO.	DATE	ISSUE/REVISION	APP
0	X/X/2021	CONCEPTUAL DESIGN SUBMITTAL	XXX

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DWG. NO. G-01

SHEET NO. 1

1. GENERAL

SPACIAL DATUM INFORMATION

- VERTICAL: NATIONAL GEODETIC VERTICAL DATUM OF 1929 (NGVD29).
- HORIZONTAL: NORTH AMERICAN DATUM OF 1983 (NAD83), MICHIGAN STATE PLANE, CENTRAL ZONE.
- A CONVERSION OF +5.8' IS REQUIRED WHEN CONVERTING VERTICAL DAM DATUM TO NGVD29 (E.G., HEADWATER ELEVATION AT DAM DATUM IS 670.0' AND AT NGVD29 DATUM IS 675.8').
- A CONVERSION OF -0.558' IS REQUIRED WHEN CONVERTING VERTICAL NGVD29 DATUM TO NAVD88 DATUM.
- CONTROL MONUMENTS ON-SITE SHALL BE REFERRED TO CONFIRM HORIZONTAL AND VERTICAL MEASUREMENTS.

BASEMAP DATA

- SITE TOPOGRAPHY AND AERIAL IMAGE OBTAINED DRONE FLIGHT PERFORMED BY SPICER GROUP IN 2020.
- COVER SHEET AERIAL IMAGES OBTAINED FROM GOOGLE EARTH REPRESENT CONDITIONS IN JUNE, 2018.
- OBTAINED FROM BOYCE HYDRO:
  - ORIGINAL CONSTRUCTION DRAWINGS
  - EXHIBIT F LICENSE DRAWINGS

DESIGN PARAMETERS

- NORMAL RESERVOIR ELEVATION 675.8' (+0.3' / -0.4')
- WINTER RESERVOIR OPERATIONS: MINIMUM 672.8' (+0.7')

DESIGN REFERENCE STANDARDS

- (USBR, 1987) UNITED STATES DEPARTMENT OF THE INTERIORER, BUREAU OF RECLAMATION, "DESIGN OF SMALL DAMS", 1987.
- (USACE, 1995) UNITED STATES ARMY CORPS OF ENGINEERS, ENGINEERING AND DESIGN, "CONSTRUCTION CONTROL FOR EARTH AND ROCK-FILL DAMS", EM 1110-2-1911, 1995.
- (ACI, 2001) AMERICAN CONCRETE INSTITUTE, “CONTROL OF CRACKING IN CONCRETE STRUCTURES” (ACI 224), 2001.
- (USACE, 2004) UNITED STATES ARMY CORPS OF ENGINEERS, ENGINEERING AND DESIGN, "GENERAL DESIGN AND CONSTRUCTION CONSIDERATIONS FOR EARTH AND ROCK-FILL DAMS", EM 1110-2-2300, 2004.
- (ACI, 2006) AMERICAN CONCRETE INSTITUTE, “CODE REQUIREMENTS FOR ENVIRONMENTAL ENGINEERING CONCRETE STRUCTURES” (ACI 350), 2006.
- (ACI, 2011) AMERICAN CONCRETE INSTITUTE, “BUILDING CODE REQUIREMENTS FOR STRUCTURAL CONCRETE” (ACI 318), 2011.
- (FERC, 2016) FEDERAL ENERGY REGULATORY COMMISSION, ENGINEERING GUIDELINES FOR EVALUATION OF HYDROPOWER PROJECTS (MOST RECENT VERSIONS)

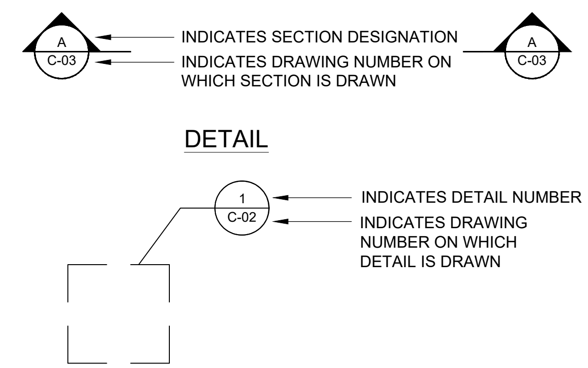
ABBREVIATIONS

BO = BOTTOM OF
C = CENTER LINE
MM = MOVEMENT MONUMENT
CONC = CONCRETE
CONT = CONTINUOUS
CTRD = CENTERED
D/S = DOWNSTREAM
EO = EDGE OF
EX = EXISTING
EF = EACH FACE
EL = ELEVATION (FEET)
HW = HEADWATER
MAX = MAXIMUM
OC = ON CENTER
OCEW = ON CENTER EACH WAY
OHWM = ORDINARY HIGH WATER MARK
PL = PLATE
PMF = PROBABLE MAXIMUM FLOOD
SDF = SPILLWAY DESIGN FLOOD
SSP = STEEL SHEET PILE
STD = STANDARD
STIFF = STIFFENER
TBD = TO BE DETERMINED
TO = TOP OF
TW = TAILWATER
TYP = TYPICAL
UON = UNLESS OTHERWISE NOTED
U/S = UPSTREAM
VIF = VERIFY IN FIELD
WL = WETLAND
W/ = WITH

SECTION AND DETAIL LEGEND

SECTION

DETAIL



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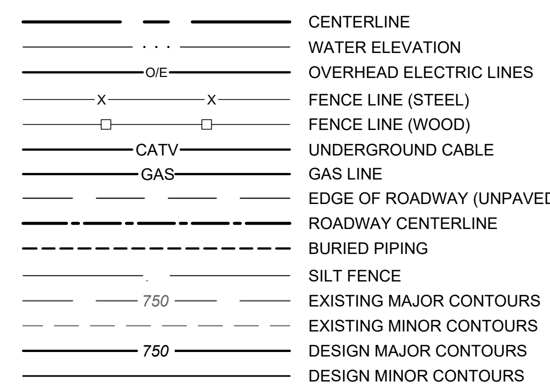
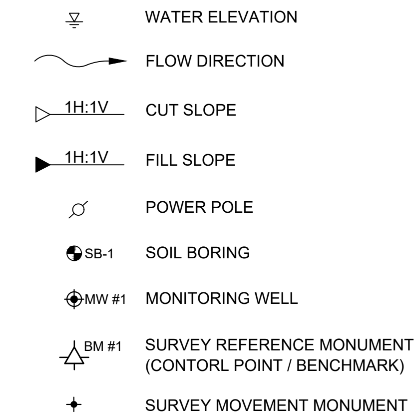
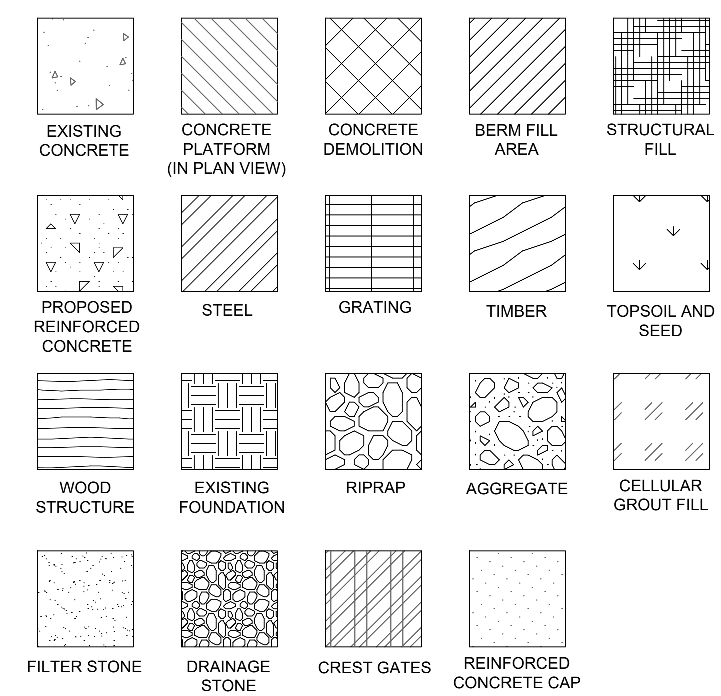


SYMBOLS LEGEND



HATCH LEGEND



Attention:

0 1"

If this scale bar does not measure 1" then drawing is not original scale.

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Saginaw, MI 48607 Tel.
989-754-4717 Fax.
989-754-4440
www.SpicerGroup.com

GEI Consultants
GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed:	P. DREW
Checked:	P. DREW
Drawn:	A. SAMPSON
Approved By:	B. WALTON

Four Lakes Task Force

GEI Project 2002879

Edenville Dam
Conceptual Design
Gladwin County, Michigan

GENERAL NOTES AND LEGEND

DWG. NO.
G-02

SHEET NO.
2

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LINETYPE LEGEND

- CENTERLINE
- WATER ELEVATION
- OVERHEAD ELECTRIC LINES
- FENCE LINE (STEEL)
- FENCE LINE (WOOD)
- EDGE OF ROADWAY (UNPAVED)
- BURIED PIPING
- EXISTING MAJOR CONTOURS
- EXISTING MINOR CONTOURS
- SHEETPILE

SYMBOLS LEGEND

- SB-3 SOIL BORING
- FLOW DIRECTION
- BM #200 SURVEY REFERENCE MONUMENT
- POWER POLE

TOBACCO SITE PLAN - EXISTING CONDITIONS
"POST EDENVILLE DAM FAILURE"

0 100 200
SCALE, FEET

NOTES:
1. VERTICAL DATUM: NATIONAL GEODETIC VERTICAL DATUM OF 1929 (NGVD29)
2. SPATIAL DATUM: NORTH AMERICAN DATUM OF 1983 (NAD83), MICHIGAN STATE PLANE, SOUTH ZONE

Attention: 0 1" If this scale bar does not measure 1" then drawing is not original scale.

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Saginaw, MI 48607 Tel.
989-754-4717 Fax.
989-754-4440
www.SpicerGroup.com

GEI Consultants
GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed:	P. DREW
Checked:	P. DREW
Drawn:	A. SAMPSON
Approved By:	B. WALTON

Four Lakes Task Force

GEI Project 2002879

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Gladwin County, Michigan

TOBACCO SITE PLAN - EXISTING CONDITIONS "POST EDENVILLE DAM FAILURE"

DWG. NO. C-01

SHEET NO. 3

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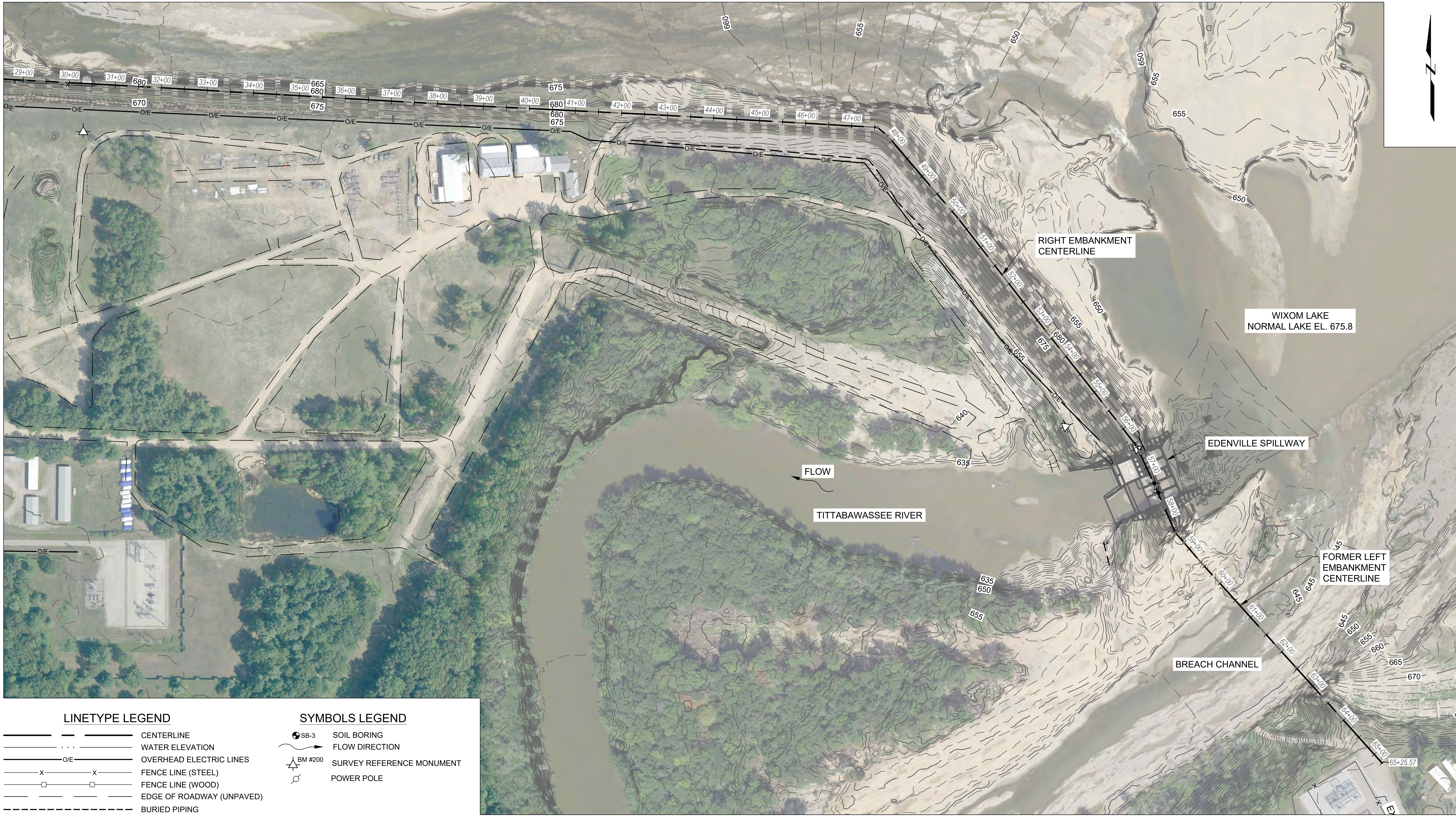

LINETYPE LEGEND

- CENTERLINE
- WATER ELEVATION
- O/E — OVERHEAD ELECTRIC LINES
- X — FENCE LINE (STEEL)
- FENCE LINE (WOOD)
- EDGE OF ROADWAY (UNPAVED)
- BURIED PIPING
- 750 — EXISTING MAJOR CONTOURS
- EXISTING MINOR CONTOURS
- SHEETPILE

SYMBOLS LEGEND

- SB-3 — SOIL BORING
- FLOW DIRECTION
- BM #200 — SURVEY REFERENCE MONUMENT
- POWER POLE

EDENVILLE SITE PLAN - EXISTING CONDITIONS
"POST EDENVILLE DAM FAILURE"

0 100 200
SCALE, FEET

NOTES:
1. VERTICAL DATUM: NATIONAL GEODETIC VERTICAL DATUM OF 1929 (NGVD29)
2. SPATIAL DATUM: NORTH AMERICAN DATUM OF 1983 (NAD83), MICHIGAN STATE PLANE, SOUTH ZONE

Attention:
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Saginaw, MI 48607 Tel.
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GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed:	P. DREW
Checked:	P. DREW
Drawn:	A. SAMPSON
Approved By:	B. WALTON

Four Lakes Task Force

GEI Project 2002879

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EDENVILLE SITE PLAN - EXISTING CONDITIONS "POST EDENVILLE DAM FAILURE"

DWG. NO. C-02

SHEET NO. 4

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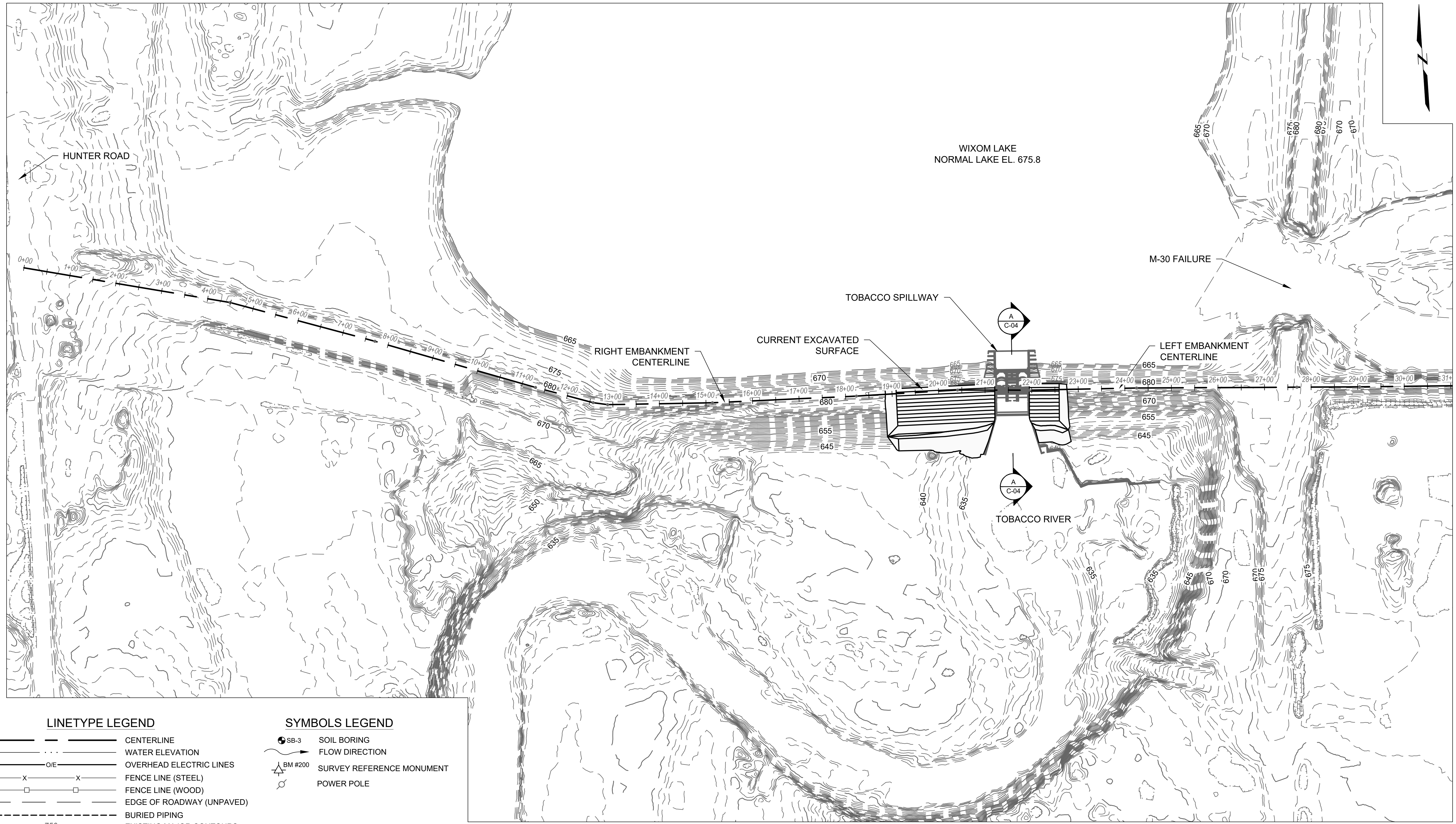

LINETYPE LEGEND

- CENTERLINE
- WATER ELEVATION
- OVERHEAD ELECTRIC LINES (O/E)
- FENCE LINE (STEEL)
- FENCE LINE (WOOD)
- EDGE OF ROADWAY (UNPAVED)
- BURIED PIPING
- EXISTING MAJOR CONTOURS (750)
- EXISTING MINOR CONTOURS
- SHEETPILE

SYMBOLS LEGEND

- SB-3 SOIL BORING
- FLOW DIRECTION
- BM #200 SURVEY REFERENCE MONUMENT
- POWER POLE

TOBACCO - EXISTING CONDITIONS PLAN "POST AECOM STABILIZATION"

0 100 200
SCALE, FEET

NOTES:

1. VERTICAL DATUM: NATIONAL GEODETIC VERTICAL DATUM OF 1929 (NGVD29)
2. SPATIAL DATUM: NORTH AMERICAN DATUM OF 1983 (NAD83), MICHIGAN STATE PLANE, SOUTH ZONE

Attention:
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GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed:	P. DREW
Checked:	P. DREW
Drawn:	A. SAMPSON
Approved By:	B. WALTON

Four Lakes Task Force

GEI Project 2002879

Edenville Dam
Conceptual Design
Gladwin County, Michigan

TOBACCO - EXISTING CONDITIONS PLAN "POST AECOM STABILIZATION"

DWG. NO.
C-03

SHEET NO.
5

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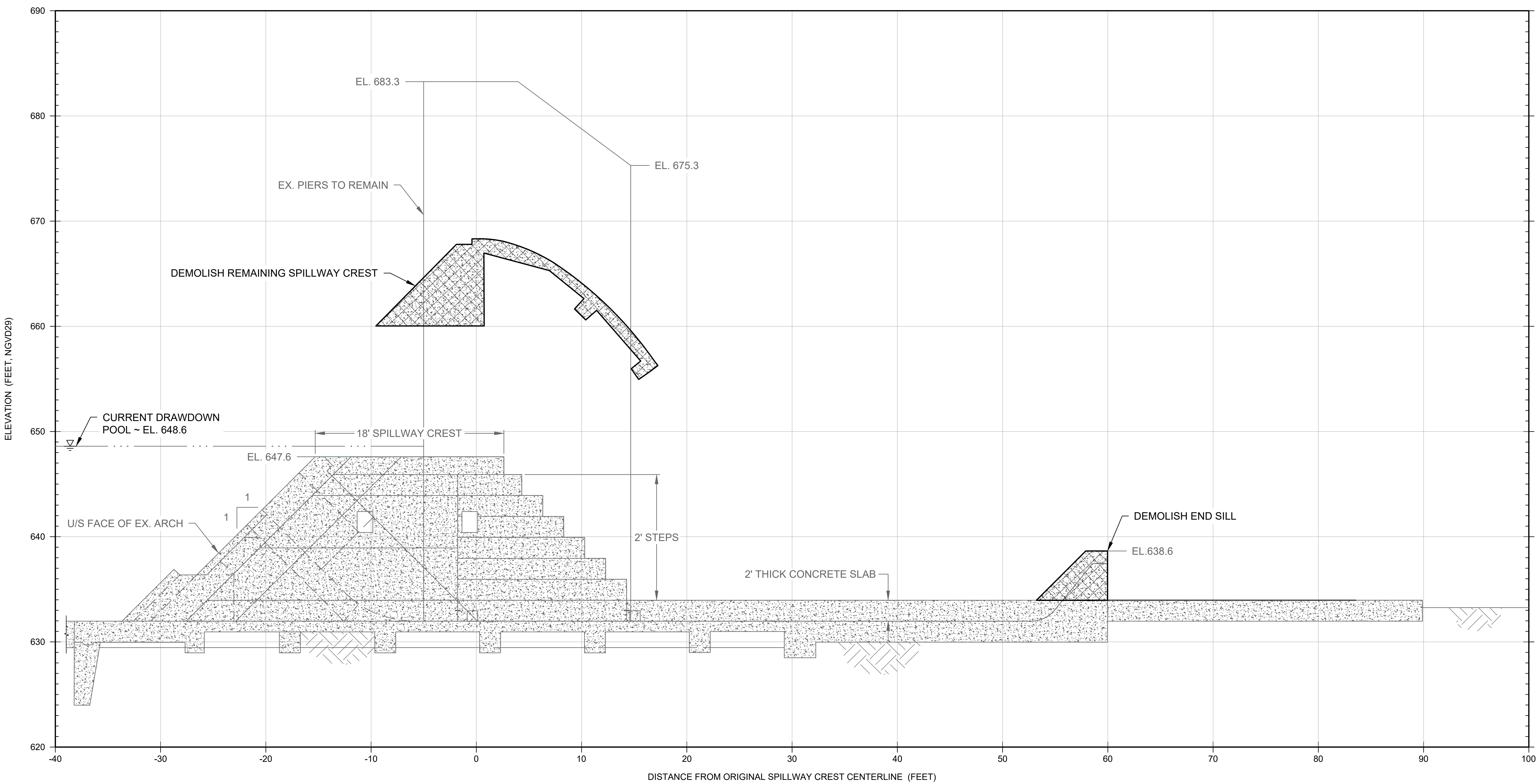

A
C-03
SECTION
SPILLWAY BAY 2

0 5 10
SCALE, FT

HATCH LEGEND

PROPOSED REINFORCED CONCRETE | EXISTING CONCRETE | EXISTING FOUNDATION | DEMOLITION

Attention:	NO.	DATE	ISSUE/REVISION	APP
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GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed:	P. DREW
Checked:	P. DREW
Drawn:	A. SAMPSON
Approved By:	B. WALTON

Four Lakes Task Force

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TOBACCO OUTLET WORKS - DEMOLITION SECTION

DWG. NO. C-04

SHEET NO. 6

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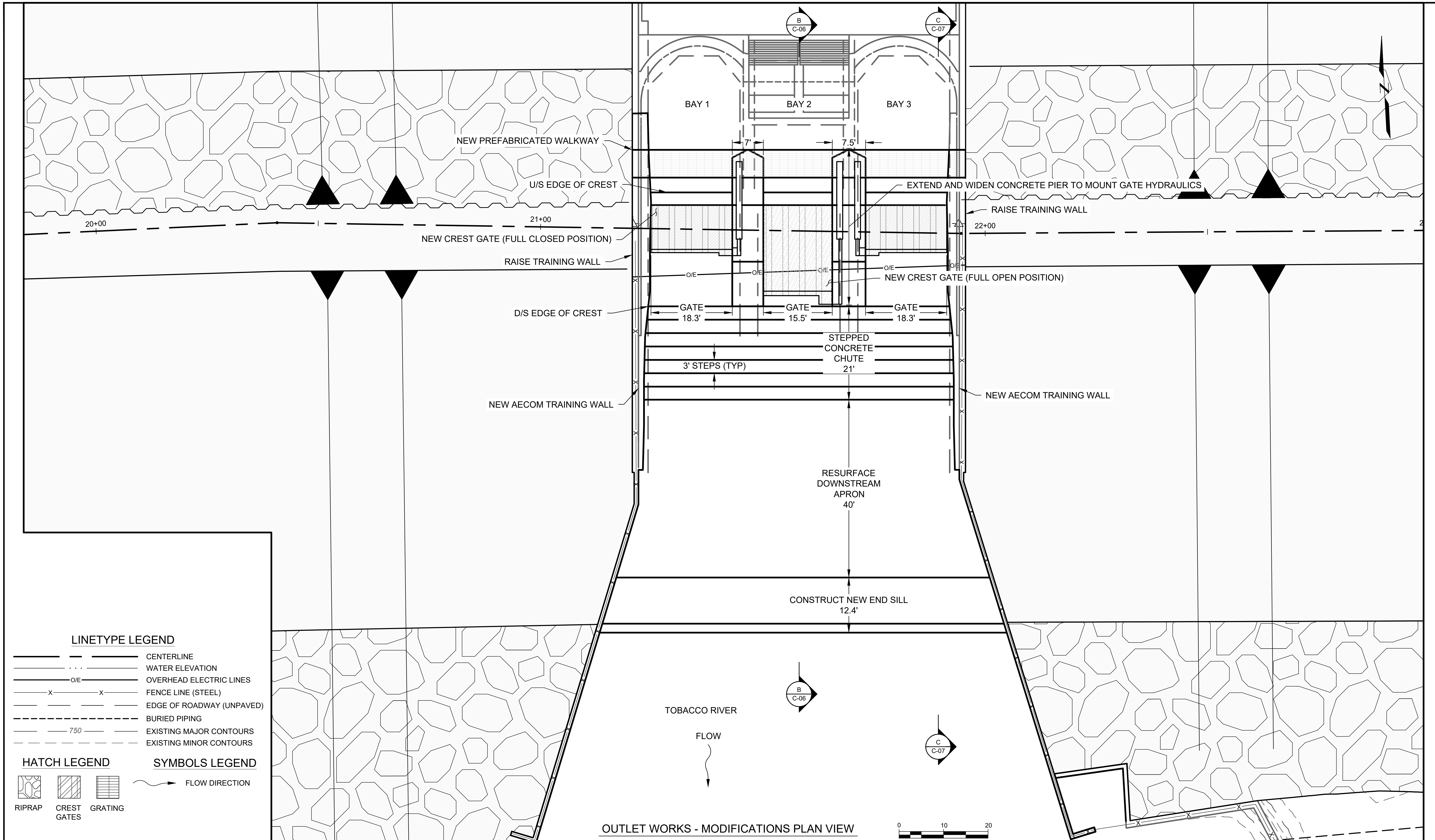

OUTLET WORKS - MODIFICATIONS PLAN VIEW

Attention: 0 1" If this scale bar does not measure 1" then drawing is not original scale.

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www.SpicerGroup.com

GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed: P. DREW
Checked: P. DREW
Drawn: A. SAMPSON
Approved By: B. WALTON

Four Lakes Task Force

GEI Project 2002879

Edenville Dam
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Gladwin County, Michigan

TOBACCO OUTLET WORKS - MODIFICATIONS PLAN

DWG. NO. C-05

SHEET NO. 7

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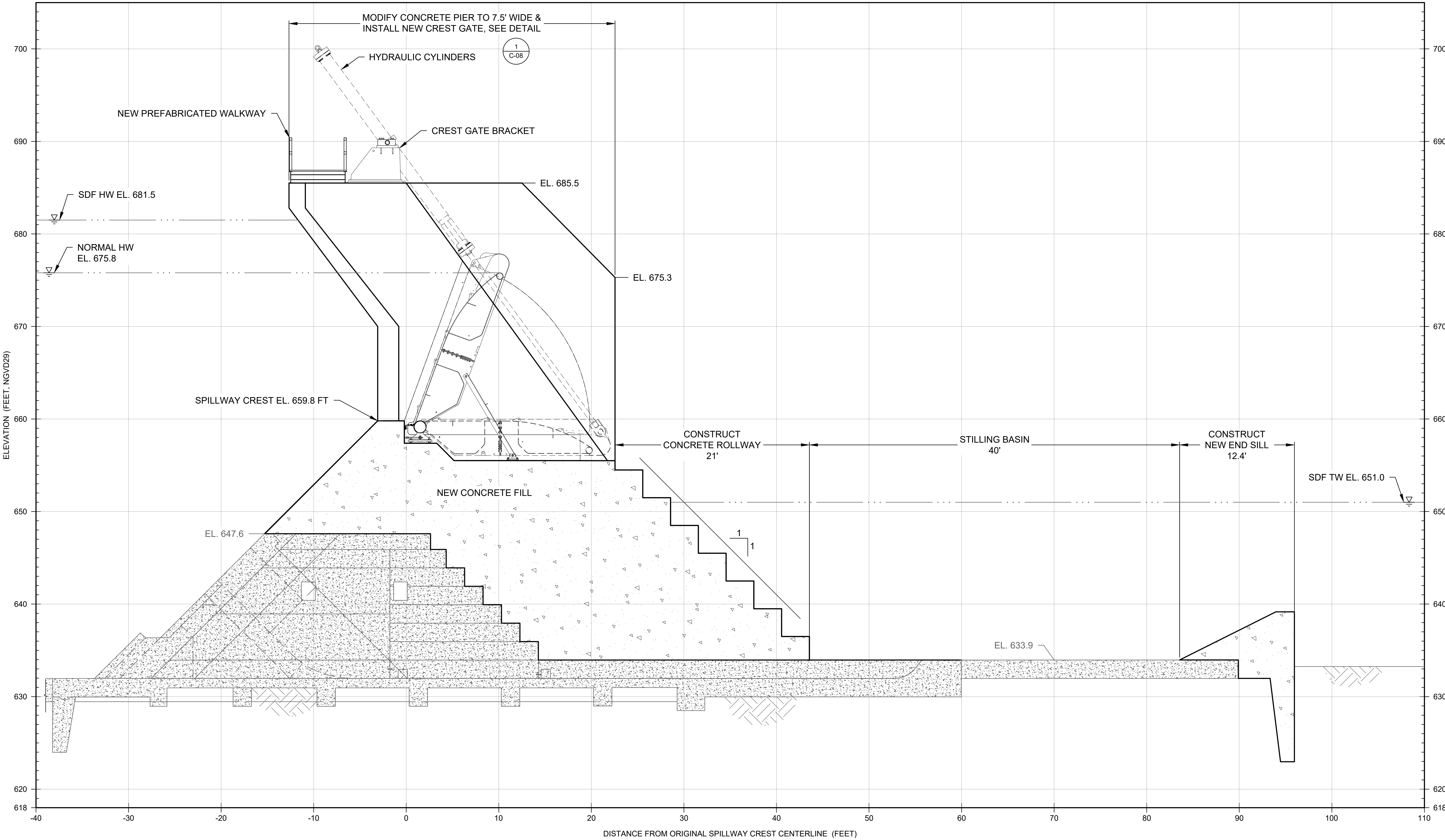

B
C-05
SECTION
SPILLWAY BAY 2

0 5 10
SCALE, FT

HATCH LEGEND

PROPOSED REINFORCED CONCRETE | EXISTING CONCRETE | EXISTING FOUNDATION

Attention:
0 1"
If this scale bar does not measure 1" then drawing is not original scale.

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10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed:	P. DREW
Checked:	P. DREW
Drawn:	A. SAMPSON
Approved By:	B. WALTON

Four Lakes Task Force

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TOBACCO PRIMARY SPILLWAY - MODIFICATIONS SECTION (SHEET 1 OF 2)

DWG. NO.
C-06

SHEET NO.
8

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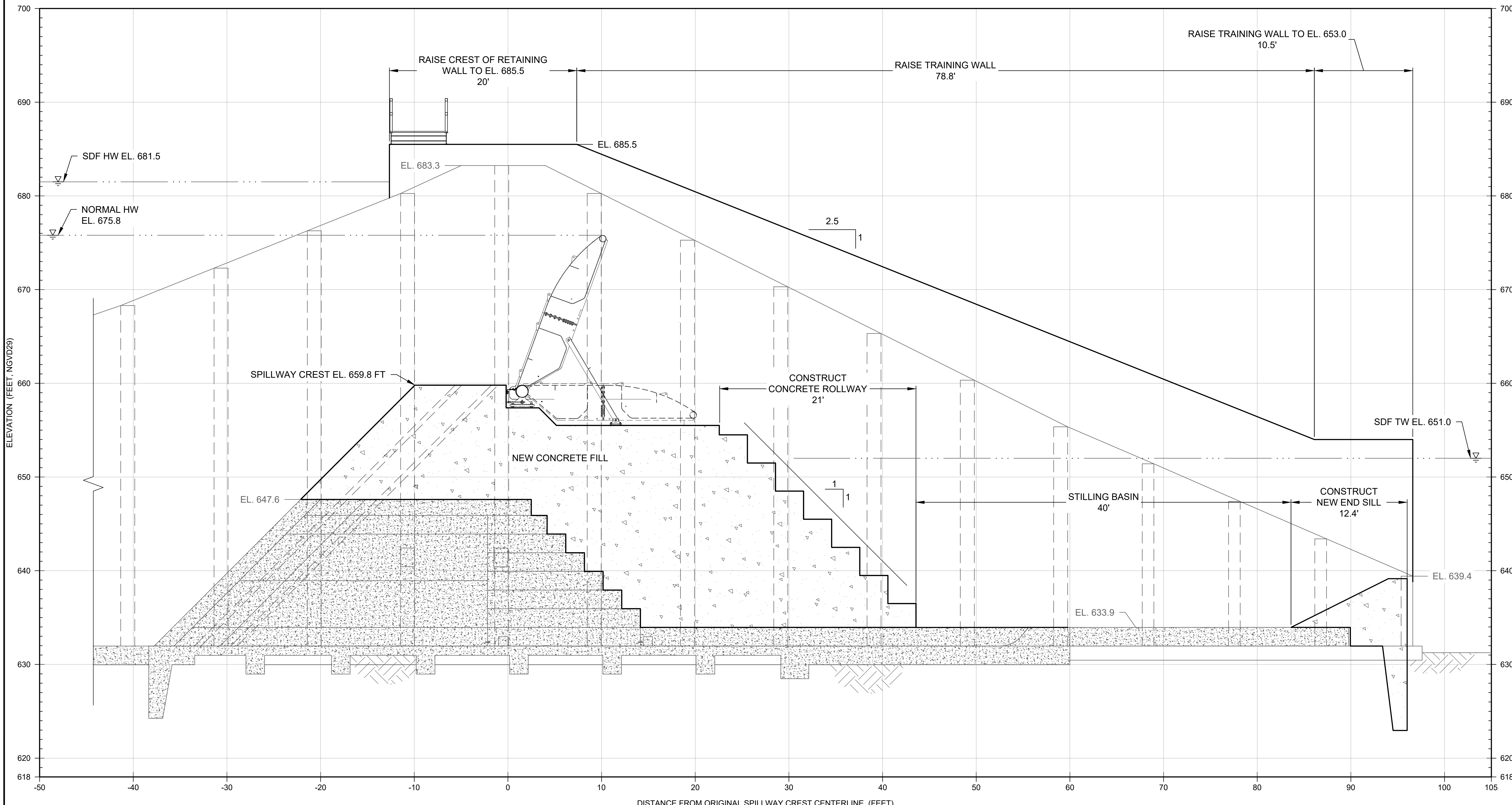

C
C-05

SECTION
SPILLWAY& LEFT TRAINING WALL

0 5 10
SCALE, FT

HATCH LEGEND

PROPOSED REINFORCED CONCRETE | EXISTING CONCRETE | EXISTING FOUNDATION

Attention:

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Saginaw, MI 48607 Tel.
989-754-4717 Fax.
989-754-4440
www.SpicerGroup.com

GEI Consultants
GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed: P. DREW
Checked: P. DREW
Drawn: A. SAMPSON
Approved By: B. WALTON

Four Lakes Task Force

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TOBACCO PRIMARY SPILLWAY - MODIFICATIONS SECTION (SHEET 2 OF 2)

DWG. NO. C-07

SHEET NO. 9

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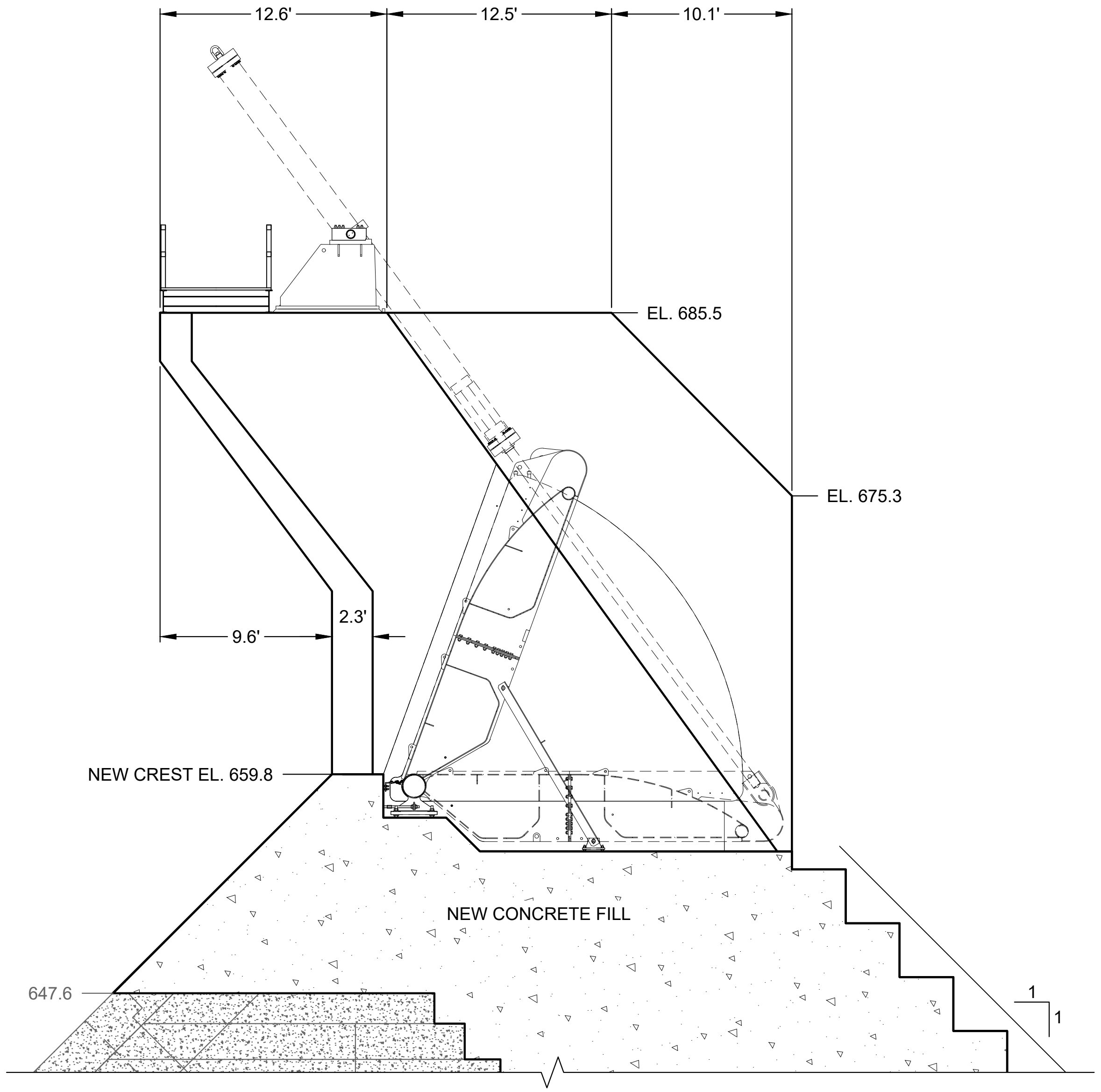

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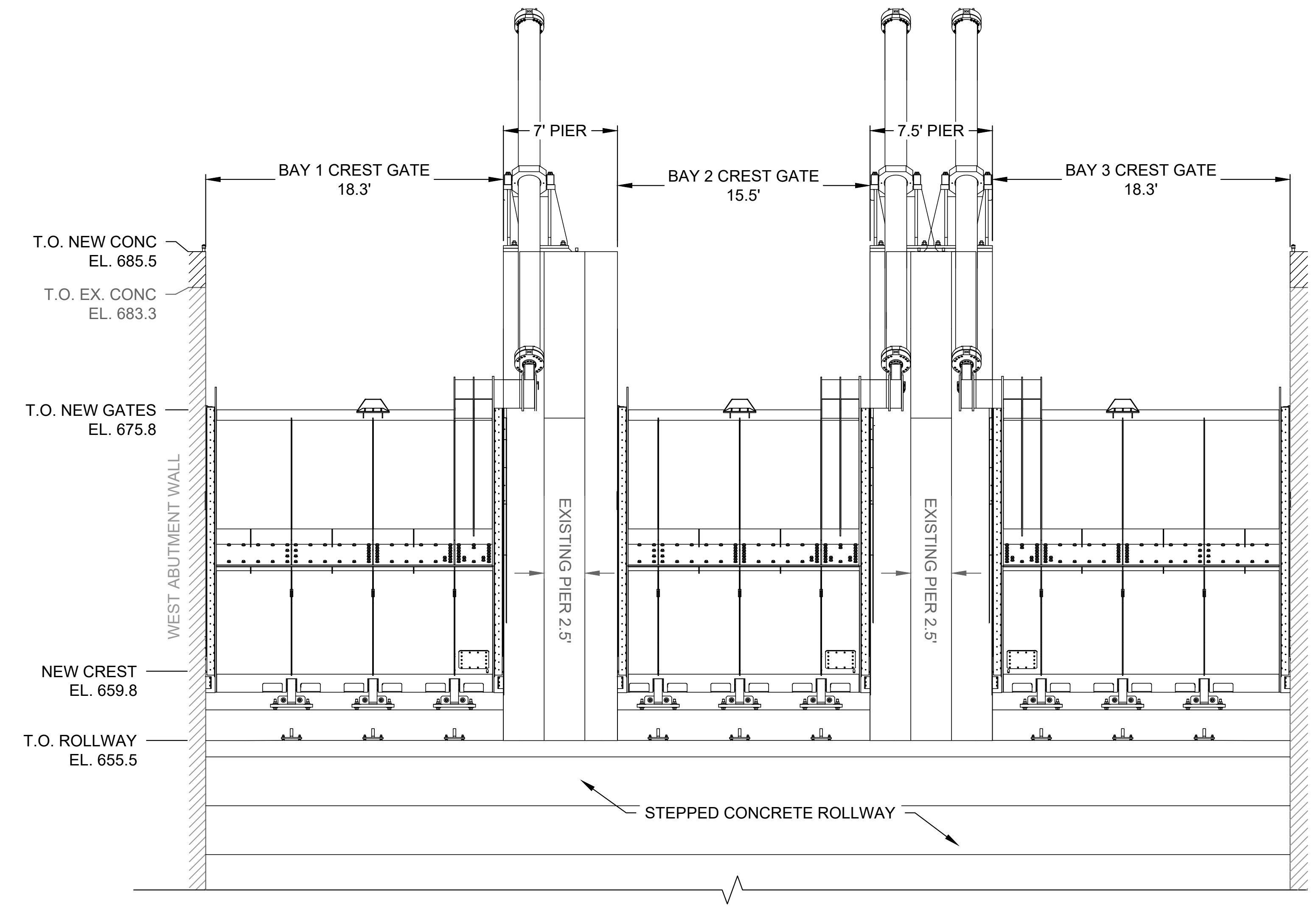

DOWNSTREAM ELEVATION
(LOOKING UPSTREAM)

1 / C-06 DETAIL
PIER-MOUNTED CREST GATE

0 5 10
SCALE, FT

HATCH LEGEND

PROPOSED REINFORCED CONCRETE
EXISTING CONCRETE

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230 S. Washington Ave.
Saginaw, MI 48607 Tel.
989-754-4717 Fax.
989-754-4440
www.SpicerGroup.com

GEI Consultants
GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed:	P. DREW
Checked:	P. DREW
Drawn:	A. SAMPSON
Approved By:	B. WALTON

Four Lakes Task Force

GEI Project 2002879

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TOBACCO PRIMARY SPILLWAY - CREST GATE DETAILS

DWG. NO. C-08

SHEET NO. 10

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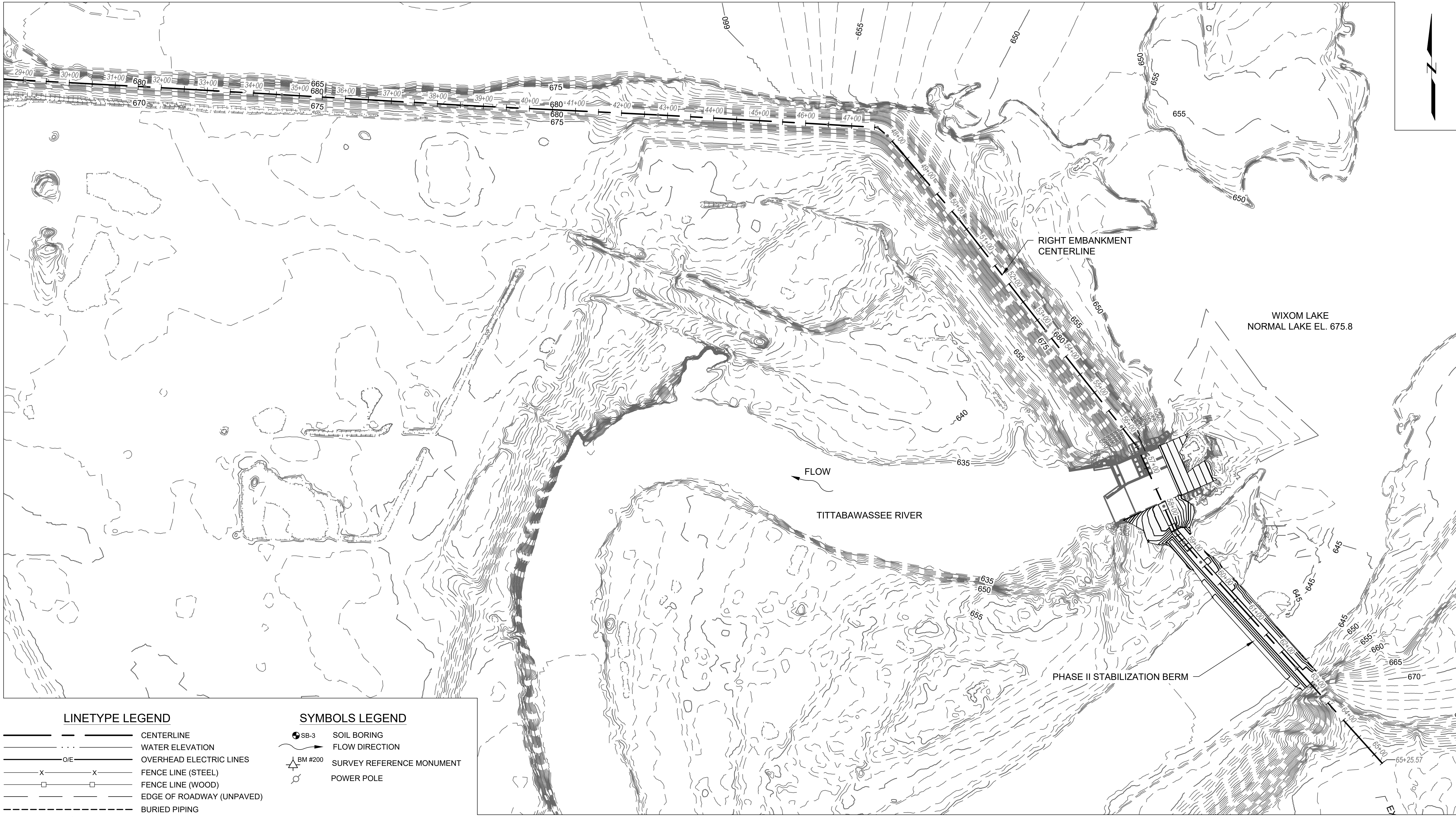

LINETYPE LEGEND

- CENTERLINE
- WATER ELEVATION
- OVERHEAD ELECTRIC LINES (O/E)
- FENCE LINE (STEEL)
- FENCE LINE (WOOD)
- EDGE OF ROADWAY (UNPAVED)
- BURIED PIPING
- EXISTING MAJOR CONTOURS (750)
- EXISTING MINOR CONTOURS
- SHEETPILE

SYMBOLS LEGEND

- SB-3 SOIL BORING
- FLOW DIRECTION
- BM #200 SURVEY REFERENCE MONUMENT
- POWER POLE

EDENVILLE SITE PLAN - EXISTING CONDITIONS "POST GEI STABILIZATION"

0 100 200 SCALE, FEET

NOTES:

1. VERTICAL DATUM: NATIONAL GEODETIC VERTICAL DATUM OF 1929 (NGVD29)
2. SPATIAL DATUM: NORTH AMERICAN DATUM OF 1983 (NAD83), MICHIGAN STATE PLANE, SOUTH ZONE

Attention: 0 1" If this scale bar does not measure 1" then drawing is not original scale.

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Saginaw, MI 48607 Tel.
989-754-4717 Fax.
989-754-4440
www.SpicerGroup.com

GEI Consultants
GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed: P. DREW
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Gladwin County, Michigan

EDENVILLE SITE PLAN - EXISTING CONDITIONS "POST GEI STABILIZATION"

DWG. NO. C-09

SHEET NO. 11

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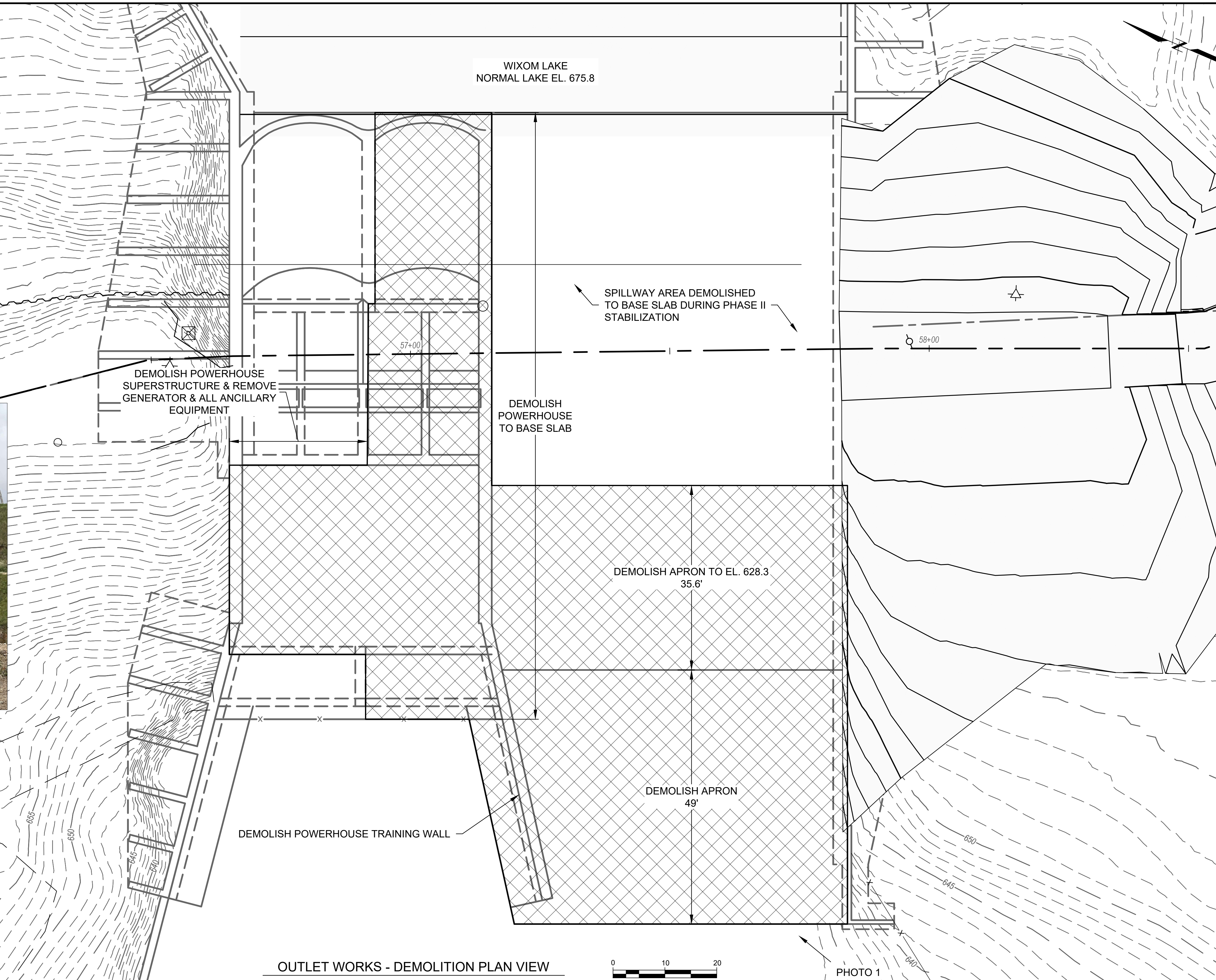

OUTLET WORKS - DEMOLITION PLAN VIEW

PHOTO 1

LINETYPE LEGEND

- CENTERLINE
- WATER ELEVATION
- O/E — OVERHEAD ELECTRIC LINES
- FENCE LINE (STEEL)
- FENCE LINE (WOOD)
- EDGE OF ROADWAY (UNPAVED)
- BURIED PIPING
- 750 — EXISTING MAJOR CONTOURS
- EXISTING MINOR CONTOURS

HATCH LEGEND

DEMOLITION

SYMBOLS LEGEND

FLOW DIRECTION

Attention:

0 1"

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GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed:	P. DREW
Checked:	P. DREW
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Gladwin County, Michigan

EDENVILLE OUTLET WORKS - DEMOLITION PLAN

DWG. NO. C-10

SHEET NO. 12

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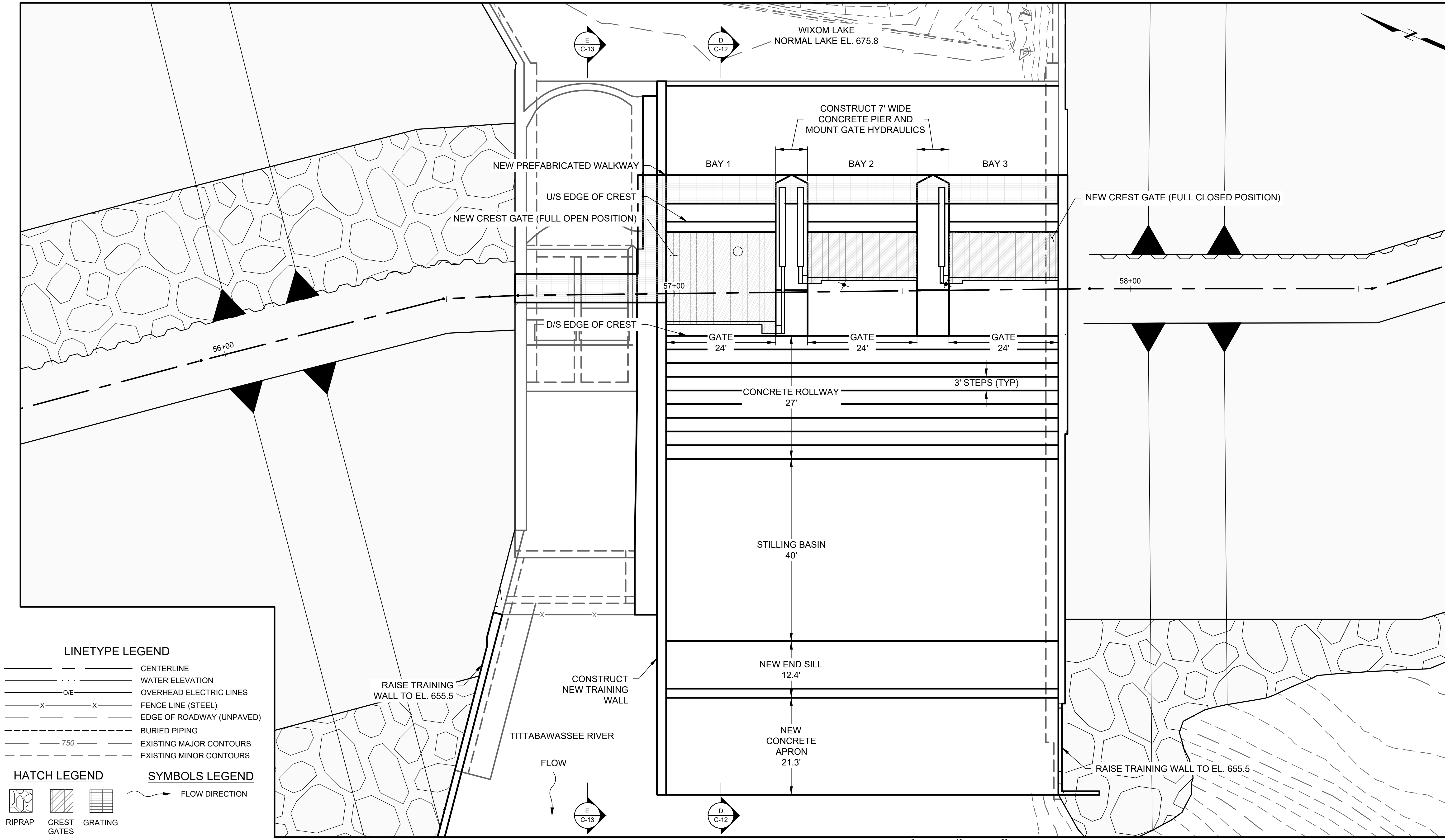

OUTLET WORKS - MODIFICATIONS PLAN VIEW

0 10 20
SCALE, FT

Attention:

0 1"

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GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

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Drawn:	A. SAMPSON
Approved By:	B. WALTON

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GEI Project 2002879

Edenville Dam
Conceptual Design
Gladwin County, Michigan

EDENVILLE OUTLET WORKS - MODIFICATIONS PLAN

DWG. NO.
C-11

SHEET NO.
13

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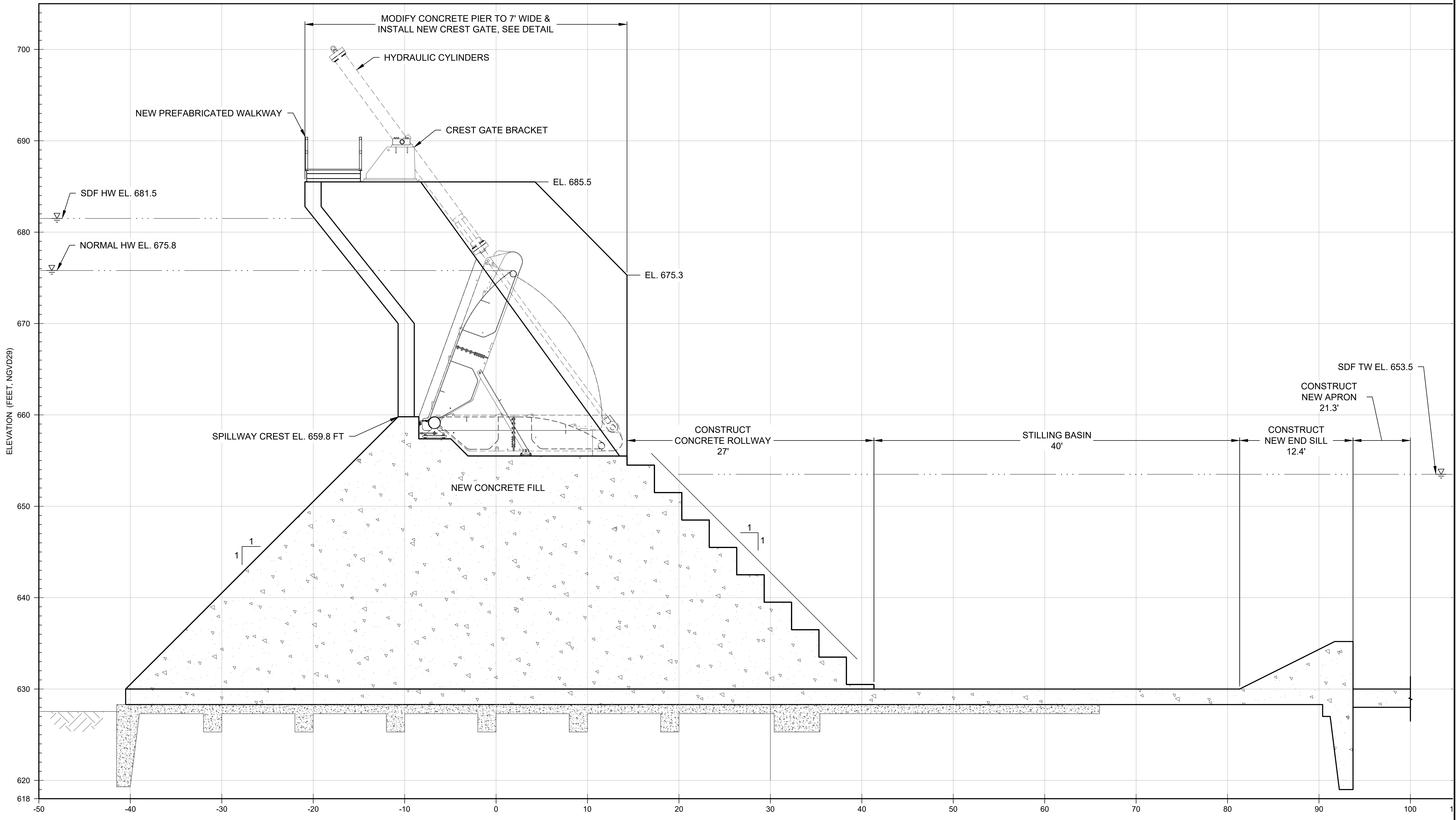

D
C-11
SECTION
SPILLWAY

0 5 10
SCALE, FT

HATCH LEGEND

EXISTING CONCRETE
EXISTING FOUNDATION
PROPOSED REINFORCED CONCRETE

Attention:
0 1"
If this scale bar does not measure 1" then drawing is not original scale.

NO.	DATE	ISSUE/REVISION	APP
0	xx/xx/xxxx	CONCEPTUAL DESIGN SUBMITTAL	--

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Spicer group
SAGINAW OFFICE
230 S. Washington Ave.
Saginaw, MI 48607 Tel.
989-754-4717 Fax.
989-754-4440
www.SpicerGroup.com

GEI Consultants
GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed: P. DREW
Checked: P. DREW
Drawn: A. SAMPSON
Approved By: B. WALTON

Four Lakes Task Force
GEI Project 2002879

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Gladwin County, Michigan

EDENVILLE PRIMARY SPILLWAY - MODIFICATIONS SECTION

DWG. NO. C-12
SHEET NO. 14

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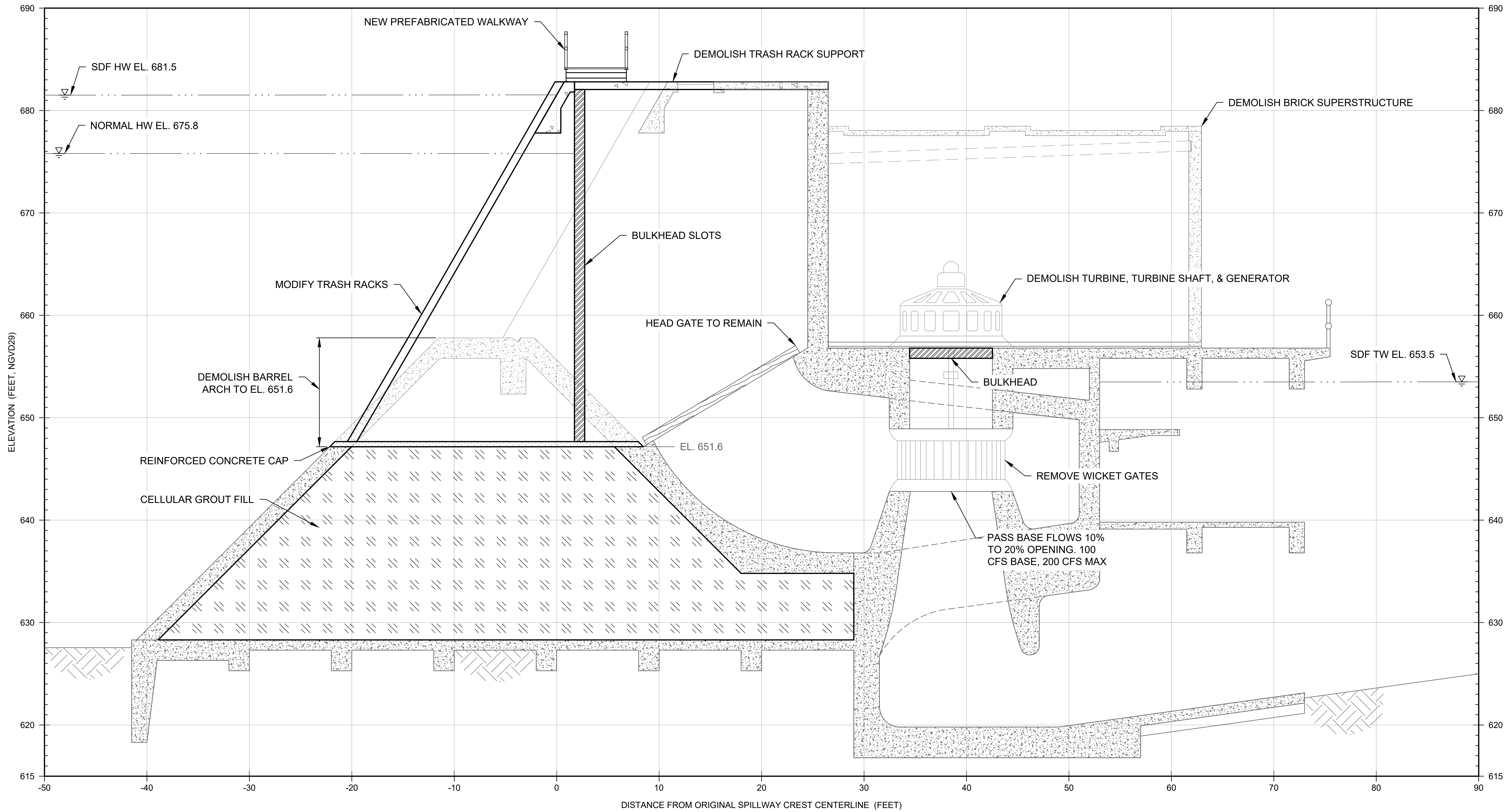

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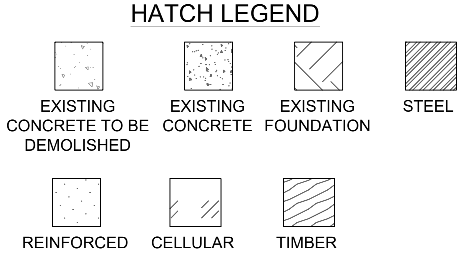

E / C-11 SECTION
POWERHOUSE

0 5 10
SCALE, FT

Attention:				
0 1"				
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	NO.	DATE	ISSUE/REVISION	APP

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Saginaw, MI 48607 Tel.
989-754-4717 Fax.
989-754-4440
www.SpicerGroup.com

GEI Consultants
GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed:	P. DREW
Checked:	P. DREW
Drawn:	A. SAMPSON
Approved By:	B. WALTON

Four Lakes Task Force

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EDENVILLE POWERHOUSE - MODIFICATIONS SECTION

DWG. NO. C-13

SHEET NO. 15

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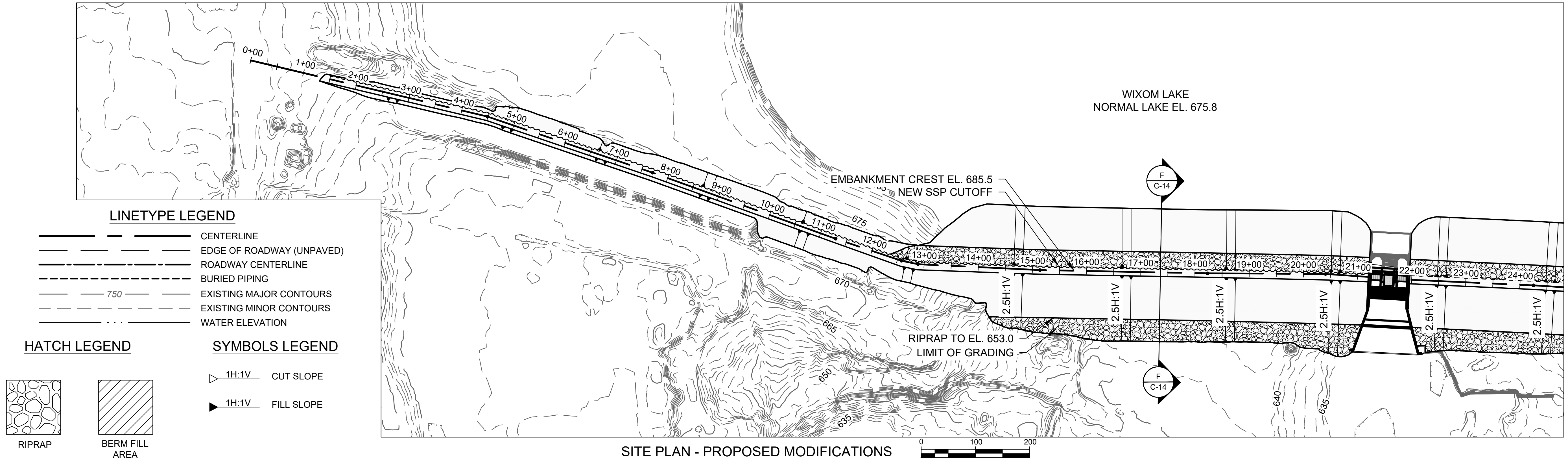
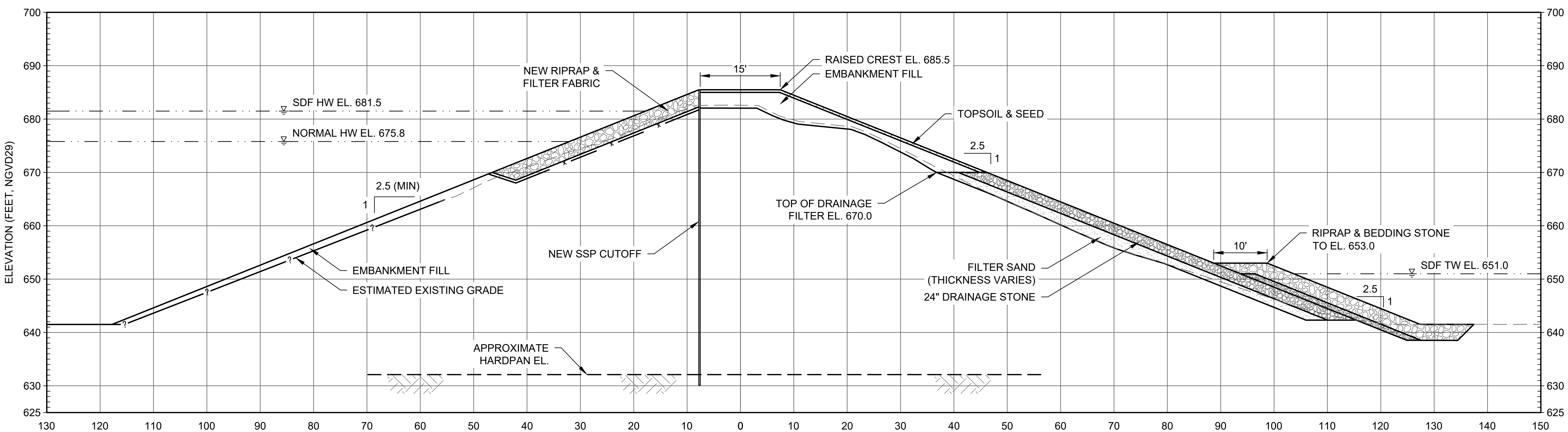


SITE PLAN - PROPOSED MODIFICATIONS
TOBACCO - RIGHT EMBANKMENT

0 100 200
SCALE, FEET



F
C-14
SECTION
TOBACCO - RIGHT EMBANKMENT

HORIZONTAL SCALE, FEET
0 10 20
0 10 20
VERTICAL SCALE, FEET
NO VERTICAL EXAGGERATION

Attention:
0 1"
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SAGINAW OFFICE
230 S. Washington Ave.
Saginaw, MI 48607 Tel.
989-754-4717 Fax.
989-754-4440
www.SpicerGroup.com

GEI Consultants
GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed:	P. DREW
Checked:	P. DREW
Drawn:	A. SAMPSON
Approved By:	B. WALTON

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Edenville Dam
Conceptual Design
Gladwin County, Michigan

TOBACCO RIGHT EMBANKMENT - MODIFICATIONS

DWG. NO.
C-14

SHEET NO.
16

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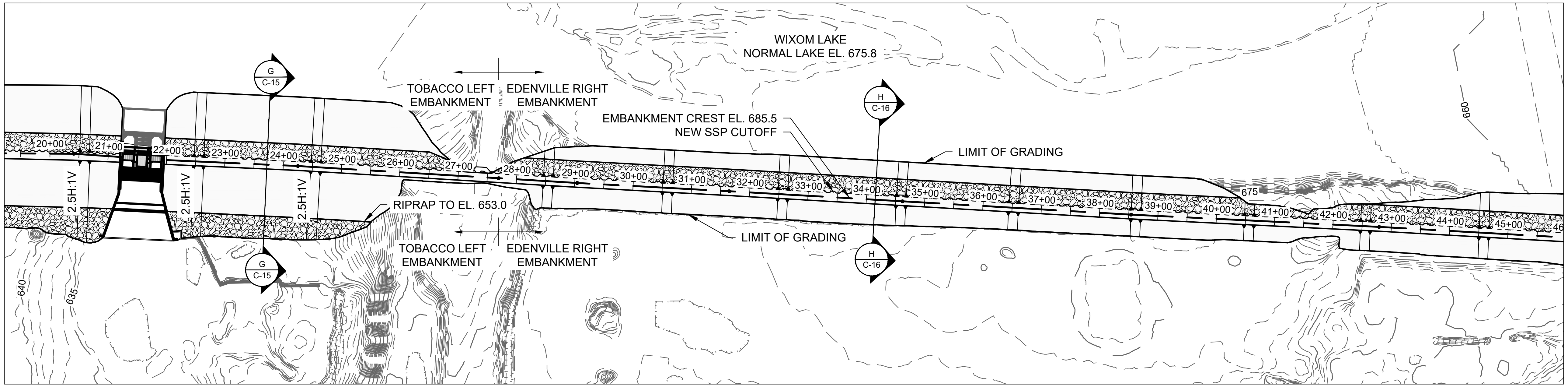
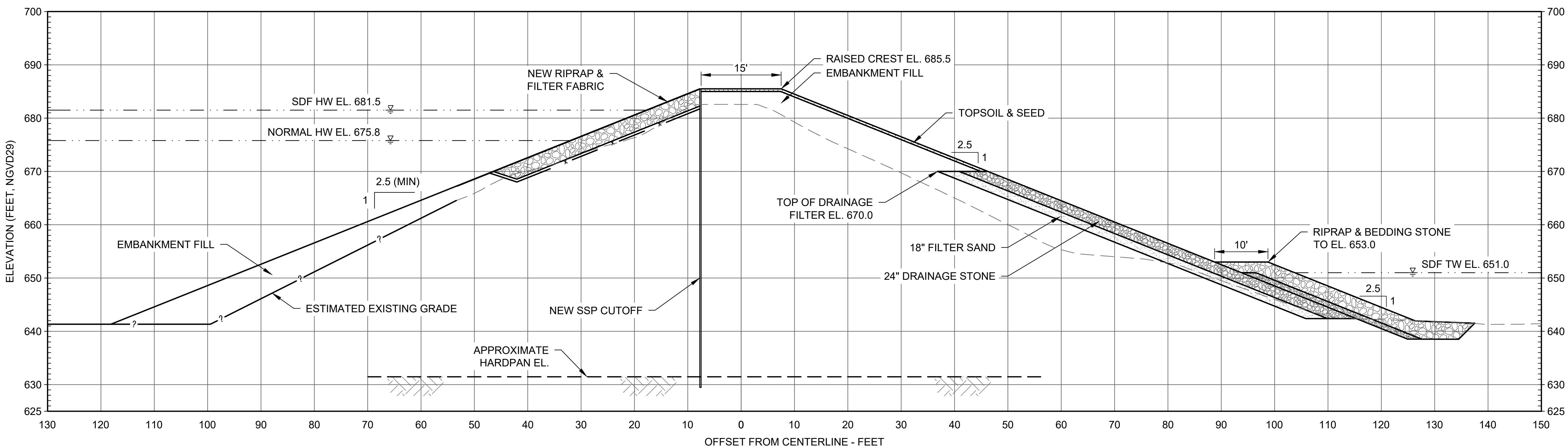


SITE PLAN - PROPOSED MODIFICATIONS

TOBACCO LEFT & TITTABAWASSEE RIGHT EMBANKMENTS

0 100 200 SCALE, FEET



G C-15 SECTION

TOBACCO LEFT EMBANKMENT

HORIZONTAL SCALE, FEET 0 10 20

VERTICAL SCALE, FEET 0 10 20

NO VERTICAL EXAGGERATION

Attention:				
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Saginaw, MI 48607 Tel.
989-754-4717 Fax.
989-754-4440
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GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed:	P. DREW
Checked:	P. DREW
Drawn:	A. SAMPSON
Approved By:	B. WALTON

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Conceptual Design
Gladwin County, Michigan

TOBACCO LEFT EMBANKMENT - MODIFICATIONS

DWG. NO. C-15

SHEET NO. 17

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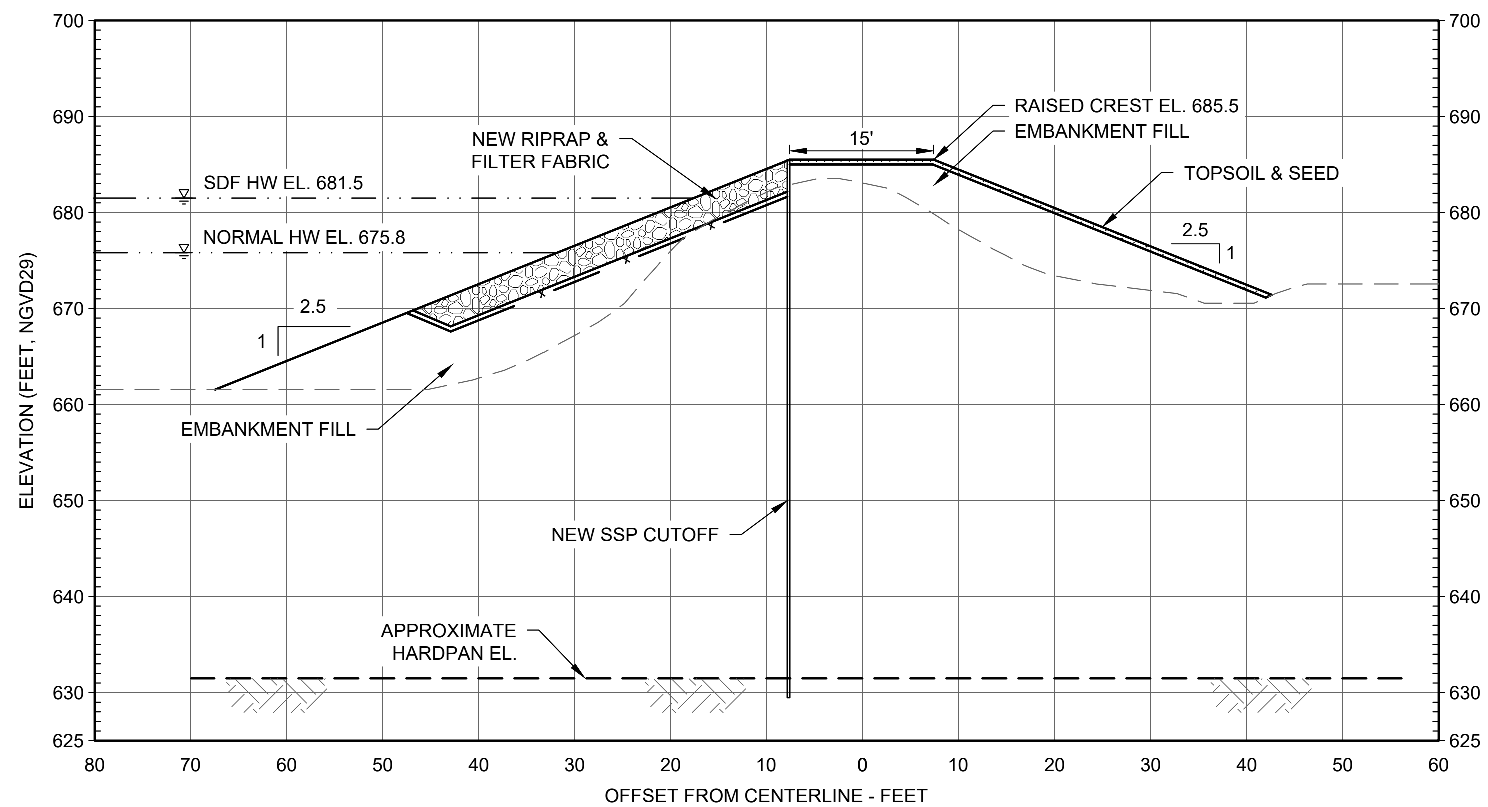
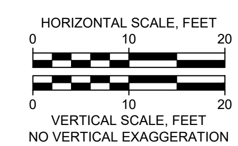


H
C-15
SECTION
EDENVILLE RIGHT EMBANKMENT



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SAGINAW OFFICE
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Saginaw, MI 48607 Tel.
989-754-4717 Fax.
989-754-4440
www.SpicerGroup.com

GEI Consultants
GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed:	P. DREW
Checked:	P. DREW
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Approved By:	B. WALTON

Four Lakes Task Force

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Conceptual Design
Gladwin County, Michigan

EDENVILLE RIGHT EMBANKMENT - MODIFICATIONS SECTION

DWG. NO.
C-16

SHEET NO.
18

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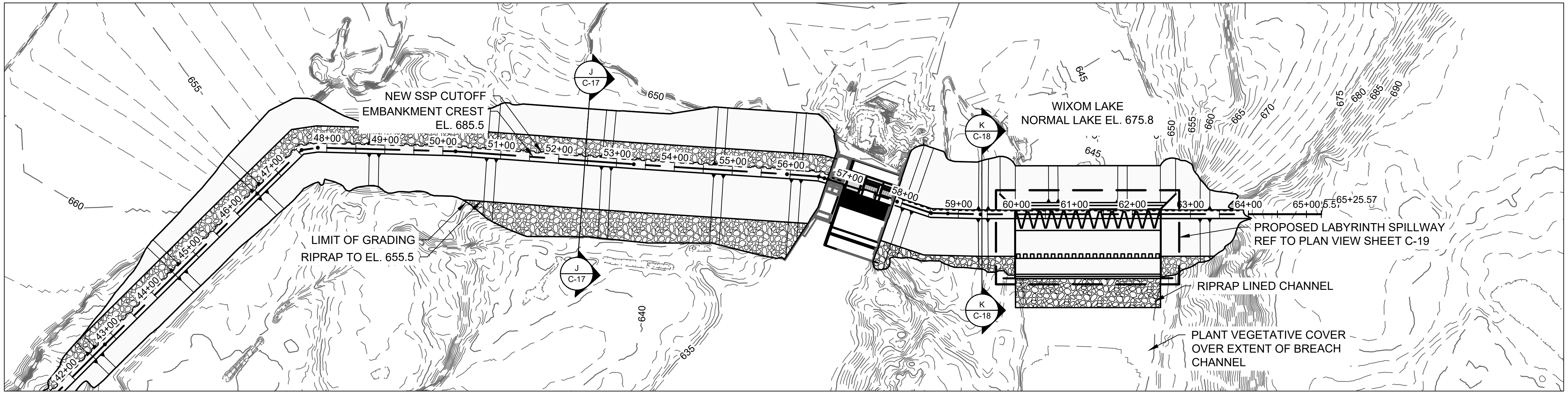
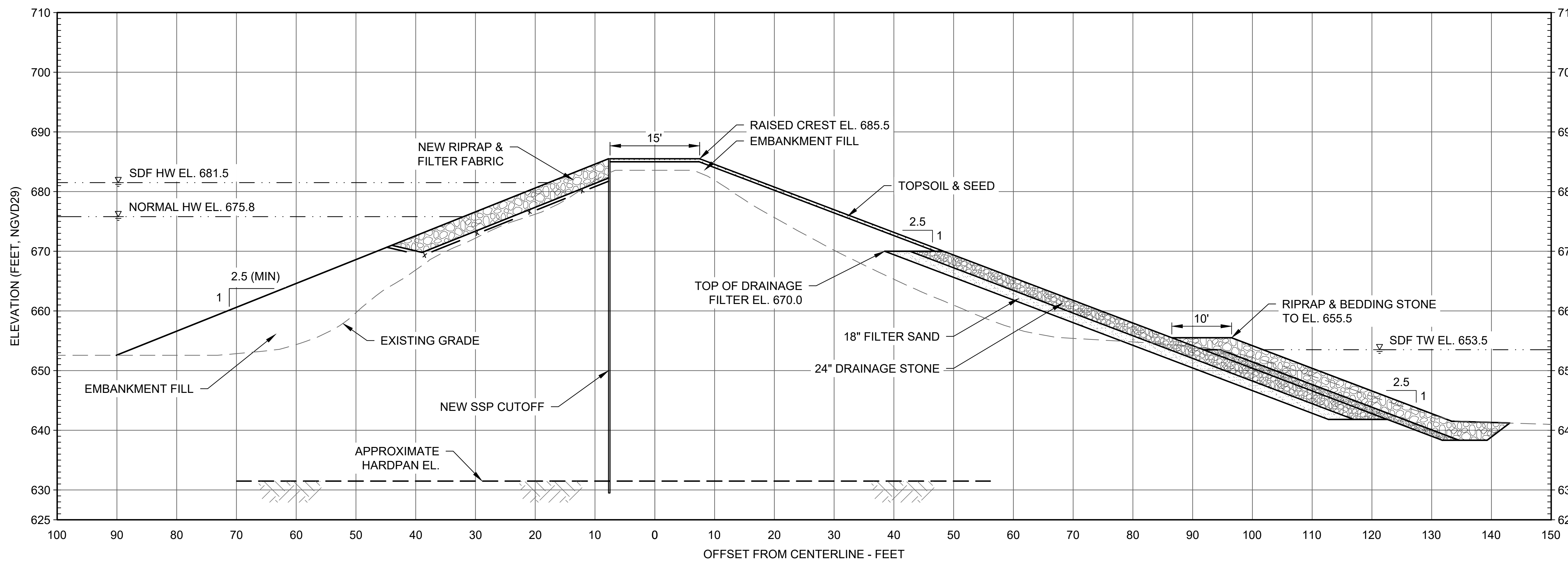


SITE PLAN - PROPOSED MODIFICATIONS

EDENVILLE RIGHT & LEFT EMBANKMENTS

0 100 200
SCALE, FEET



J
C-17
SECTION
EDENVILLE RIGHT EMBANKMENT

HORIZONTAL SCALE, FEET
0 10 20
0 10 20
VERTICAL SCALE, FEET
NO VERTICAL EXAGGERATION

Attention:	NO.	DATE	ISSUE/REVISION	APP
0 1" If this scale bar does not measure 1" then drawing is not original scale.	0	xx/xx/xxxx	CONCEPTUAL DESIGN SUBMITTAL	--

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Spicer group
SAGINAW OFFICE
230 S. Washington Ave.
Saginaw, MI 48607 Tel.
989-754-4717 Fax.
989-754-4440
www.SpicerGroup.com

GEI Consultants
GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed:	P. DREW
Checked:	P. DREW
Drawn:	A. SAMPSON
Approved By:	B. WALTON

Four Lakes Task Force

GEI Project 2002879

Edenville Dam
Conceptual Design
Gladwin County, Michigan

EDENVILLE EMBANKMENTS - MODIFICATIONS

DWG. NO.
C-17

SHEET NO.
19

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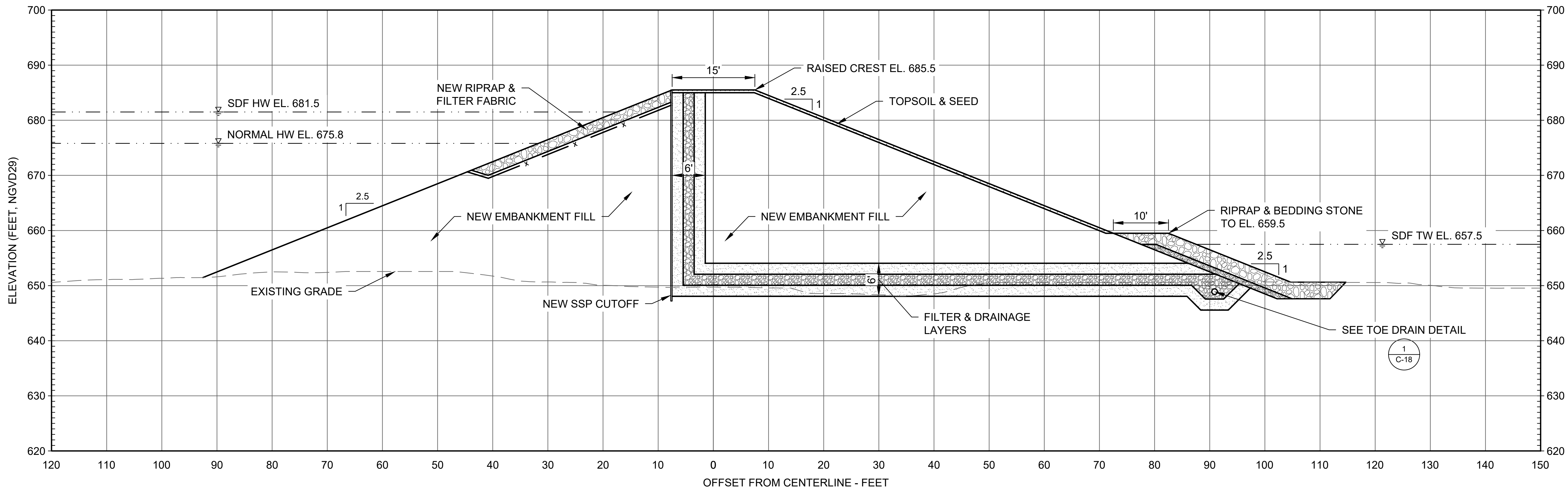
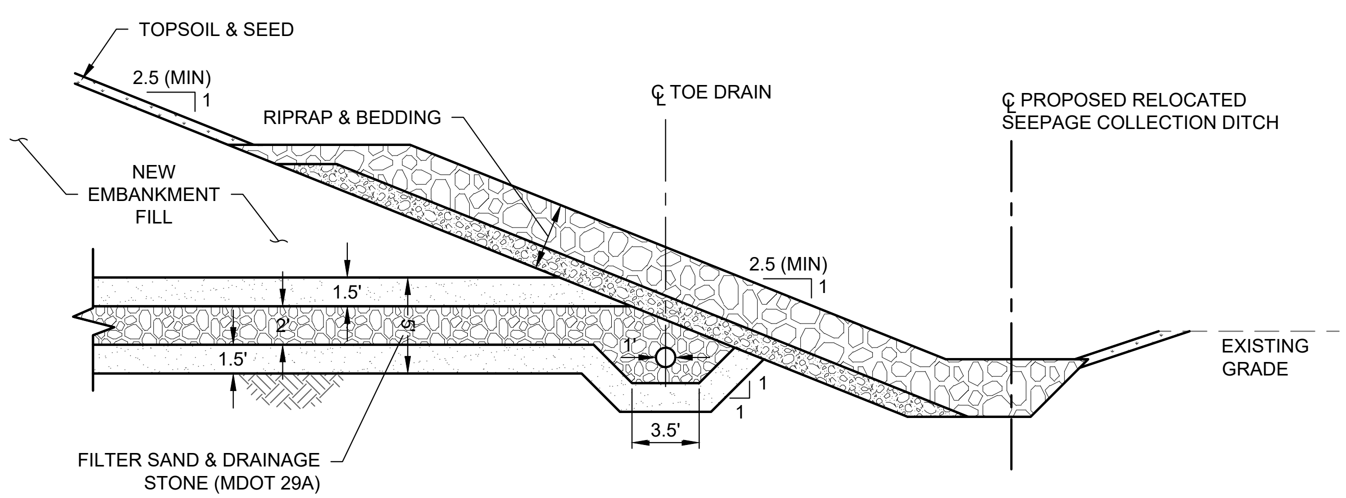


K
C-17
SECTION
EDENVILLE LEFT EMBANKMENT

HORIZONTAL SCALE, FEET
0 10 20
0 10 20
VERTICAL SCALE, FEET
NO VERTICAL EXAGGERATION



1
C-18
DETAIL
TOE DRAIN

0 5 10
SCALE, FEET

Attention:	NO.	DATE	ISSUE/REVISION	APP
0 1" If this scale bar does not measure 1" then drawing is not original scale.	0	xx/xx/xxxx	CONCEPTUAL DESIGN SUBMITTAL	--

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989-754-4717 Fax.
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GEI Consultants
GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed:	P. DREW
Checked:	P. DREW
Drawn:	A. SAMPSON
Approved By:	B. WALTON

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GEI Project 2002879

Edenville Dam
Conceptual Design
Gladwin County, Michigan

EDENVILLE EMBANKMENTS - MODIFICATIONS SECTIONS & DETAILS

DWG. NO.
C-18

SHEET NO.
20

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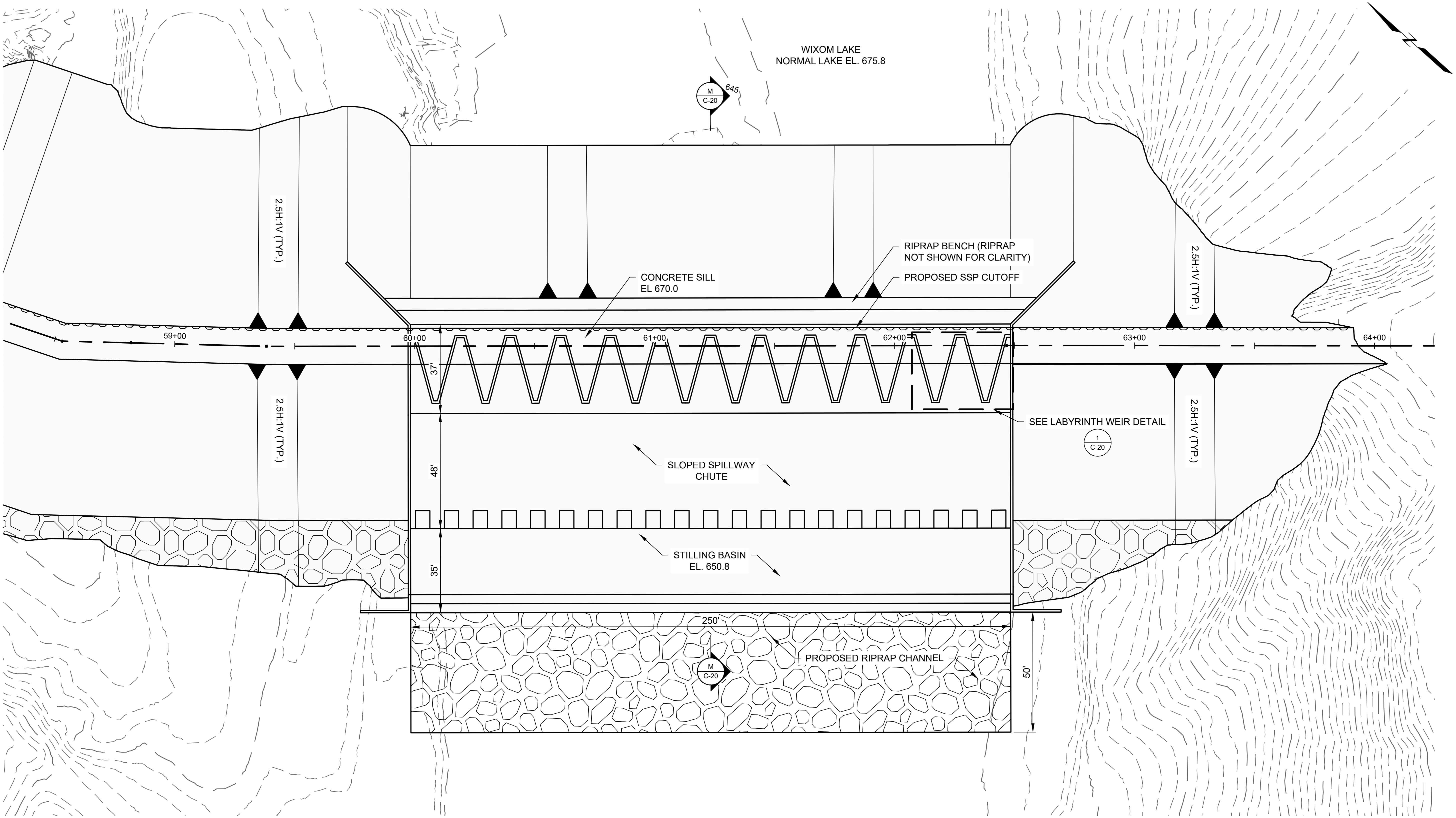

PLAN VIEW

PROPOSED LABYRINTH SPILLWAY

0 20 40

SCALE, FEET

Attention:

0 1"

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989-754-4717 Fax.
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GEI Consultants

GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed:	P. DREW
Checked:	P. DREW
Drawn:	A. SAMPSON
Approved By:	B. WALTON

Four Lakes Task Force

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Edenville Dam
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Gladwin County, Michigan

TITTABAWASSEE BREACH CHANNEL - PROPOSED LABYRINTH SPILLWAY PLAN

DWG. NO.
C-19

SHEET NO.
21

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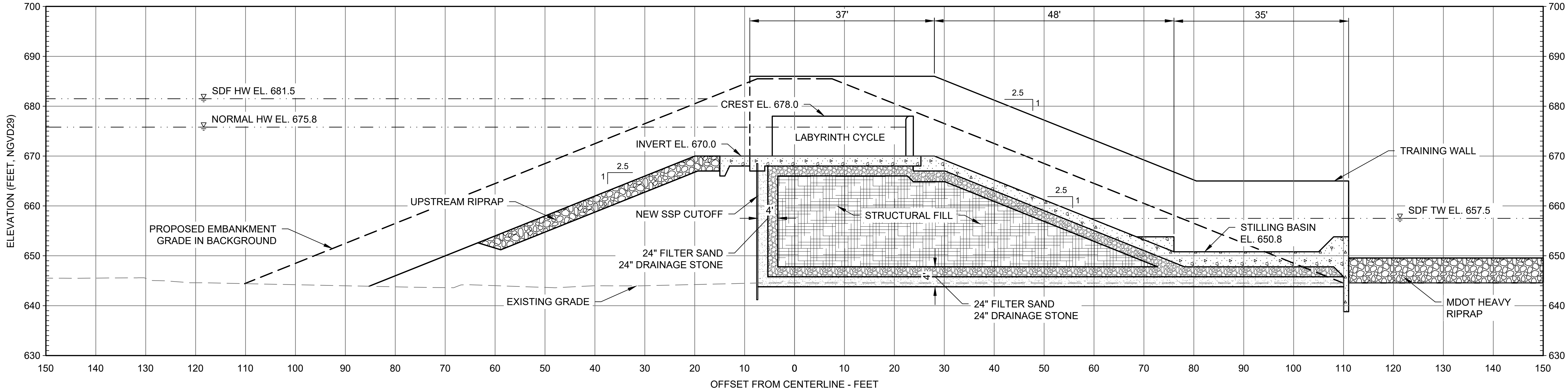
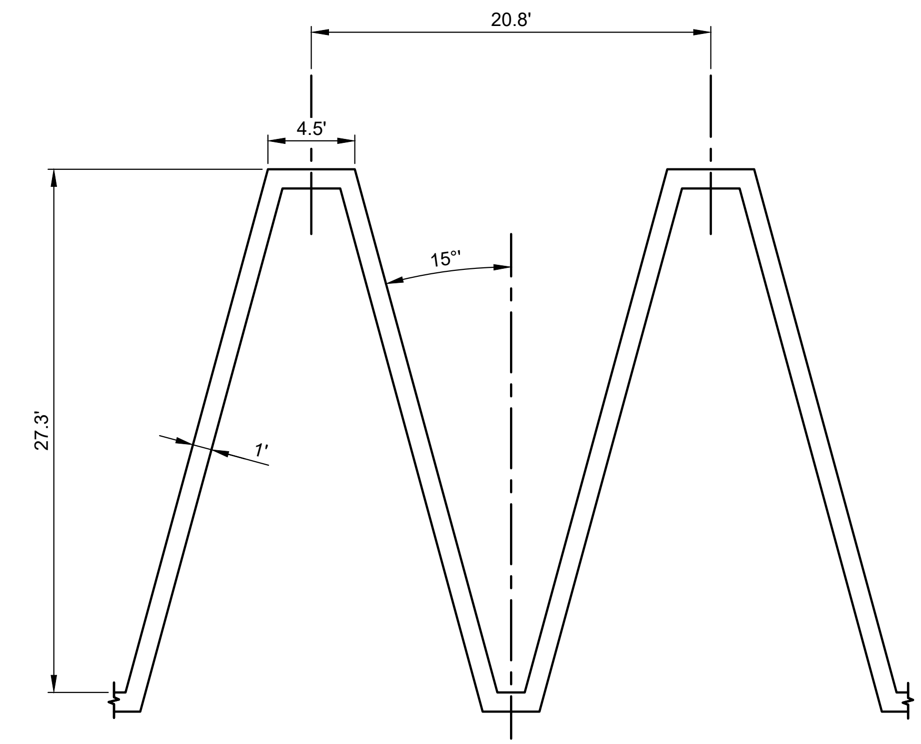


M
C-19
SECTION
PROPOSED SPILLWAY

HORIZONTAL SCALE, FEET
0 10 20
VERTICAL SCALE, FEET
NO VERTICAL EXAGGERATION



1
C-19
DETAIL
LABYRINTH WEIR CYCLE

0 5 10
SCALE, FEET

Attention:

0 1"

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230 S. Washington Ave.
Saginaw, MI 48607 Tel.
989-754-4717 Fax.
989-754-4440
www.SpicerGroup.com

GEI Consultants

GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed:	P. DREW
Checked:	P. DREW
Drawn:	A. SAMPSON
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Four Lakes Task Force

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Conceptual Design
Gladwin County, Michigan

TITTABAWASSEE BREACH CHANNEL - PROPOSED LABYRINTH SPILLWAY SECTION & DETAILS

DWG. NO.
C-20

SHEET NO.
22

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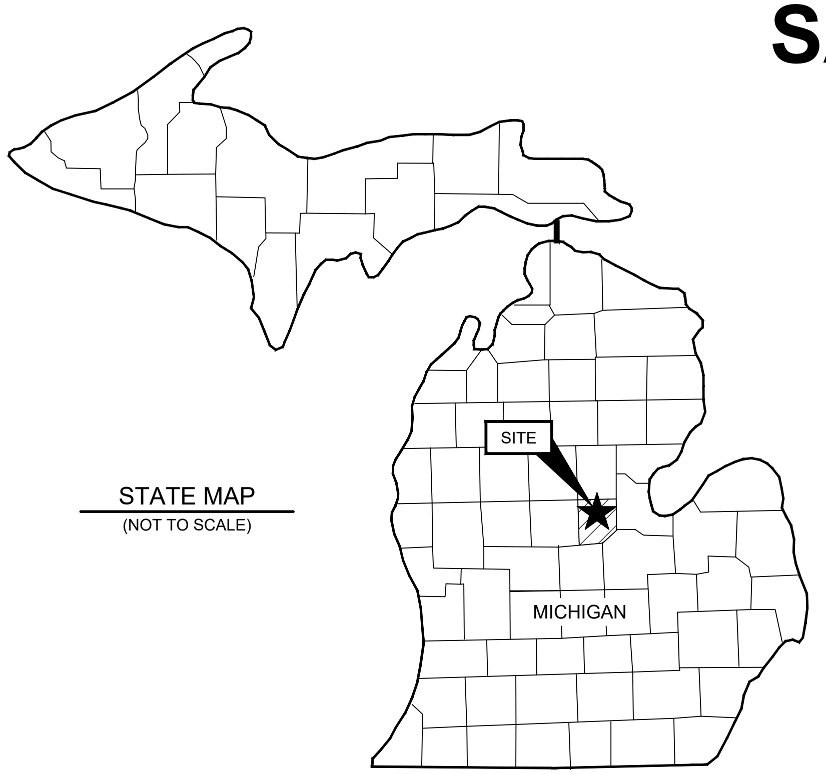
Appendix D

Proposed Conditions Spillway Upgrades

Appendix D.4 – Sanford Dam

SANFORD DAM CONCEPT DESIGN

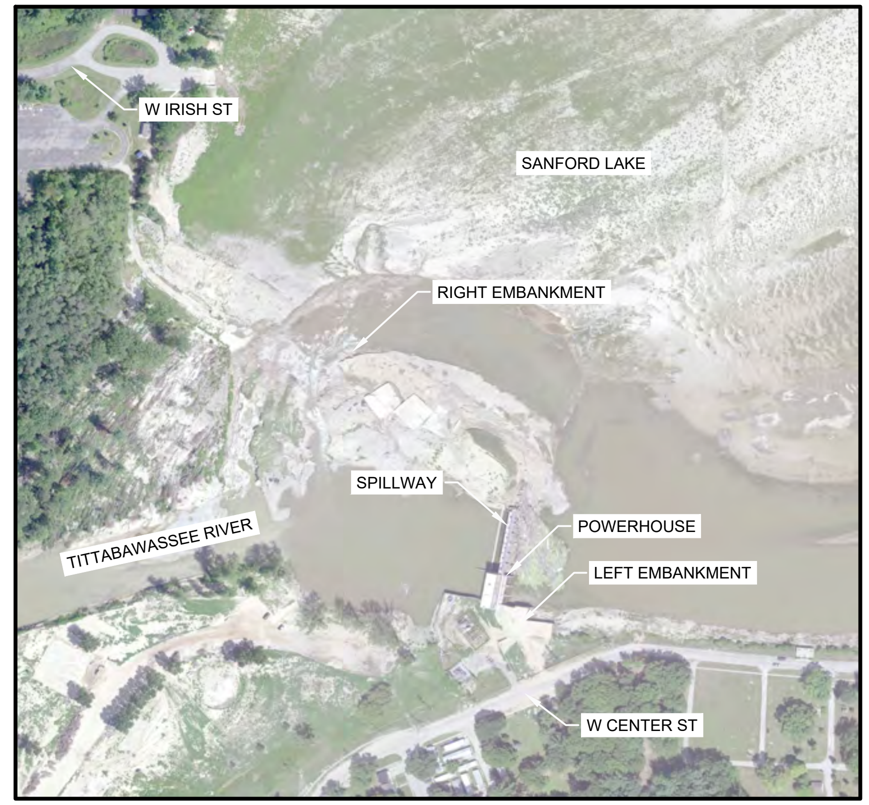
MIDLAND COUNTY, MICHIGAN
FOUR LAKES TASK FORCE
FERC PROJECT NO. 2785



STATE MAP
(NOT TO SCALE)

SOURCE:
AERIAL IMAGE TAKEN FROM GOOGLE EARTH

SITE LOCATION
(NOT TO SCALE)



SITE AERIAL
(NOT TO SCALE)

SHEET INDEX

SHEET NO.	DRAWING NO.	TITLE
1	G-01	COVER SHEET AND SITE LOCATION
2	G-02	GENERAL NOTES AND LEGEND
3	C-01	SITE PLAN - EXISTING CONDITIONS PLAN POST-EMBANKMENT BREACH
4	C-02	SITE PLAN - EXISTING CONDITIONS POST-BREACH CHANNEL TEMPORARY STABILIZATION
5	C-03	OUTLET WORKS - TEMPORARY COFFERDAMS PLAN & SECTIONS
6	C-04	OUTLET WORKS - DEMOLITION PLAN
7	C-05	OUTLET WORKS - DEMOLITION SECTION
8	C-06	POWERHOUSE - DEMOLITION SECTION
9	C-07	OUTLET WORKS - MODIFICATIONS PLAN
10	C-08	PRIMARY SPILLWAY - MODIFICATIONS SECTION
11	C-09	PRIMARY SPILLWAY - CREST GATE DETAILS
12	C-10	POWERHOUSE - MODIFICATIONS SECTION
13	C-11	POWERHOUSE - LOW LEVEL OUTLET - MODIFICATIONS SECTION
14	C-12	SITE PLAN - PROPOSED MODIFICATIONS
15	C-13	EMBANKMENTS - MODIFICATIONS SECTIONS
16	C-14	PHASE 2 LABYRINTH SPILLWAY TEMPORARY COFFERDAM PLAN
17	C-15	LABYRINTH SPILLWAY - PROPOSED PLAN VIEW
18	C-16	LABYRINTH SPILLWAY - PROPOSED SPILLWAY & CHANNEL CROSS SECTIONS

PREPARED FOR:

FOUR LAKES TASK FORCE
233 E. LARKIN
MIDLAND, MI 48640

PREPARED BY:

GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414) 930-7534

GEI Consultants

SPICER GROUP INC.
230 S. WASHINGTON AVE.
SAGINAW, MI 48607
TEL. (989) 754-4717
FAX. (989) 754-4440

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DWG. NO.
G-01

SHEET NO.
1

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1. GENERAL

SPACIAL DATUM INFORMATION

- VERTICAL: NATIONAL GEODETIC VERTICAL DATUM OF 1929 (NGVD29).
- HORIZONTAL: NORTH AMERICAN DATUM OF 1983 (NAD83), MICHIGAN STATE PLANE, CENTRAL ZONE.
- A CONVERSION OF +5.8' IS REQUIRED WHEN CONVERTING VERTICAL DAM DATUM TO NGVD29 (E.G., HEADWATER ELEVATION AT DAM DATUM IS 625.0' AND AT NGVD29 DATUM IS 630.8').
- A CONVERSION OF -0.568' IS REQUIRED WHEN CONVERTING VERTICAL NGVD29 DATUM TO NAVD88 DATUM.
- CONTROL MONUMENTS ON-SITE SHALL BE REFERRED TO CONFIRM HORIZONTAL AND VERTICAL MEASUREMENTS.

BASEMAP DATA

- SITE TOPOGRAPHY AND AERIAL IMAGE OBTAINED DRONE FLIGHT PERFORMED BY SPICER GROUP IN 2020.
- COVER SHEET AERIAL IMAGES OBTAINED FROM GOOGLE EARTH REPRESENT CONDITIONS IN JUNE, 2018.
- OBTAINED FROM BOYCE HYDRO:
  - ORIGINAL CONSTRUCTION DRAWINGS
  - EXHIBIT F LICENSE DRAWINGS

DESIGN PARAMETERS

- NORMAL RESERVOIR ELEVATION 630.8' (+0.3' / -0.4')
- WINTER RESERVOIR OPERATIONS: MINIMUM 627.8' (+0.7')
- SDF RESERVOIR ELEVATION 635.4'

DESIGN REFERENCE STANDARDS

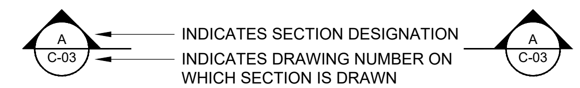
- (USBR, 1987) UNITED STATES DEPARTMENT OF THE INTERIORER, BUREAU OF RECLAMATION, "DESIGN OF SMALL DAMS", 1987.
- (USACE, 1995) UNITED STATES ARMY CORPS OF ENGINEERS, ENGINEERING AND DESIGN, "CONSTRUCTION CONTROL FOR EARTH AND ROCK-FILL DAMS", EM 1110-2-1911, 1995.
- (ACI, 2001) AMERICAN CONCRETE INSTITUTE, “CONTROL OF CRACKING IN CONCRETE STRUCTURES” (ACI 224), 2001.
- (USACE, 2004) UNITED STATES ARMY CORPS OF ENGINEERS, ENGINEERING AND DESIGN, "GENERAL DESIGN AND CONSTRUCTION CONSIDERATIONS FOR EARTH AND ROCK-FILL DAMS", EM 1110-2-2300, 2004.
- (ACI, 2006) AMERICAN CONCRETE INSTITUTE, “CODE REQUIREMENTS FOR ENVIRONMENTAL ENGINEERING CONCRETE STRUCTURES” (ACI 350), 2006.
- (ACI, 2011) AMERICAN CONCRETE INSTITUTE, “BUILDING CODE REQUIREMENTS FOR STRUCTURAL CONCRETE” (ACI 318), 2011.
- (FERC, 2016) FEDERAL ENERGY REGULATORY COMMISSION, ENGINEERING GUIDELINES FOR EVALUATION OF HYDROPOWER PROJECTS (MOST RECENT VERSIONS)

ABBREVIATIONS

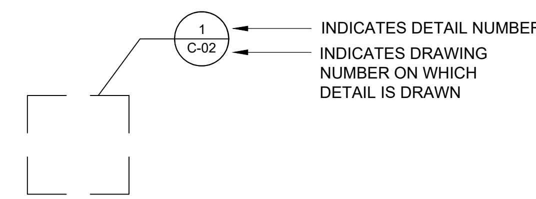
BO = BOTTOM OF
C = CENTER LINE
MM = MOVEMENT MONUMENT
CONC = CONCRETE
CONT = CONTINUOUS
CTRD = CENTERED
D/S = DOWNSTREAM
EO = EDGE OF
EX = EXISTING
EF = EACH FACE
EL = ELEVATION (FEET)
HW = HEADWATER
MAX = MAXIMUM
OC = ON CENTER
OCEW = ON CENTER EACH WAY
OHWM = ORDINARY HIGH WATER MARK
PL = PLATE
PMF = PROBABLE MAXIMUM FLOOD
SDF = SPILLWAY DESIGN FLOOD
SSP = STEEL SHEET PILE
STD = STANDARD
STIFF = STIFFENER
TBD = TO BE DETERMINED
TO = TOP OF
TW = TAILWATER
TYP = TYPICAL
UON = UNLESS OTHERWISE NOTED
U/S = UPSTREAM
VIF = VERIFY IN FIELD
WL = WETLAND
W/ = WITH

SECTION AND DETAIL LEGEND

SECTION



DETAIL



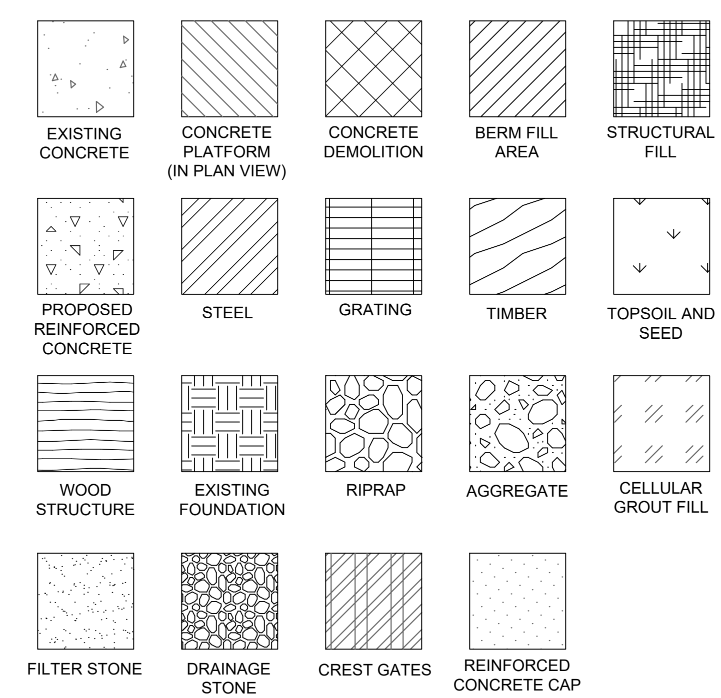
SYMBOLS LEGEND

WATER ELEVATION
FLOW DIRECTION
1H:1V CUT SLOPE
1H:1V FILL SLOPE
POWER POLE
SB-1 SOIL BORING
MW #1 MONITORING WELL
BM #1 SURVEY REFERENCE MONUMENT (CONTORL POINT / BENCHMARK)
SURVEY MOVEMENT MONUMENT

LINETYPE LEGEND

CENTERLINE
WATER ELEVATION
O/E OVERHEAD ELECTRIC LINES
X FENCE LINE (STEEL)
FENCE LINE (WOOD)
CATV UNDERGROUND CABLE
GAS GAS LINE
EDGE OF ROADWAY (UNPAVED)
ROADWAY CENTERLINE
BURIED PIPING
SILT FENCE
750 EXISTING MAJOR CONTOURS
EXISTING MINOR CONTOURS
750 DESIGN MAJOR CONTOURS
DESIGN MINOR CONTOURS

HATCH LEGEND



Attention:				
0 — 1"				
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	NO.	DATE	ISSUE/REVISION	APP

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GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed:	P. DREW
Checked:	P. DREW
Drawn:	A. SAMPSON
Approved By:	B. WALTON

Four Lakes Task Force
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Sanford Dam Conceptual Design
Midland County, Michigan

GENERAL NOTES AND LEGEND

DWG. NO. G-02

SHEET NO. 2

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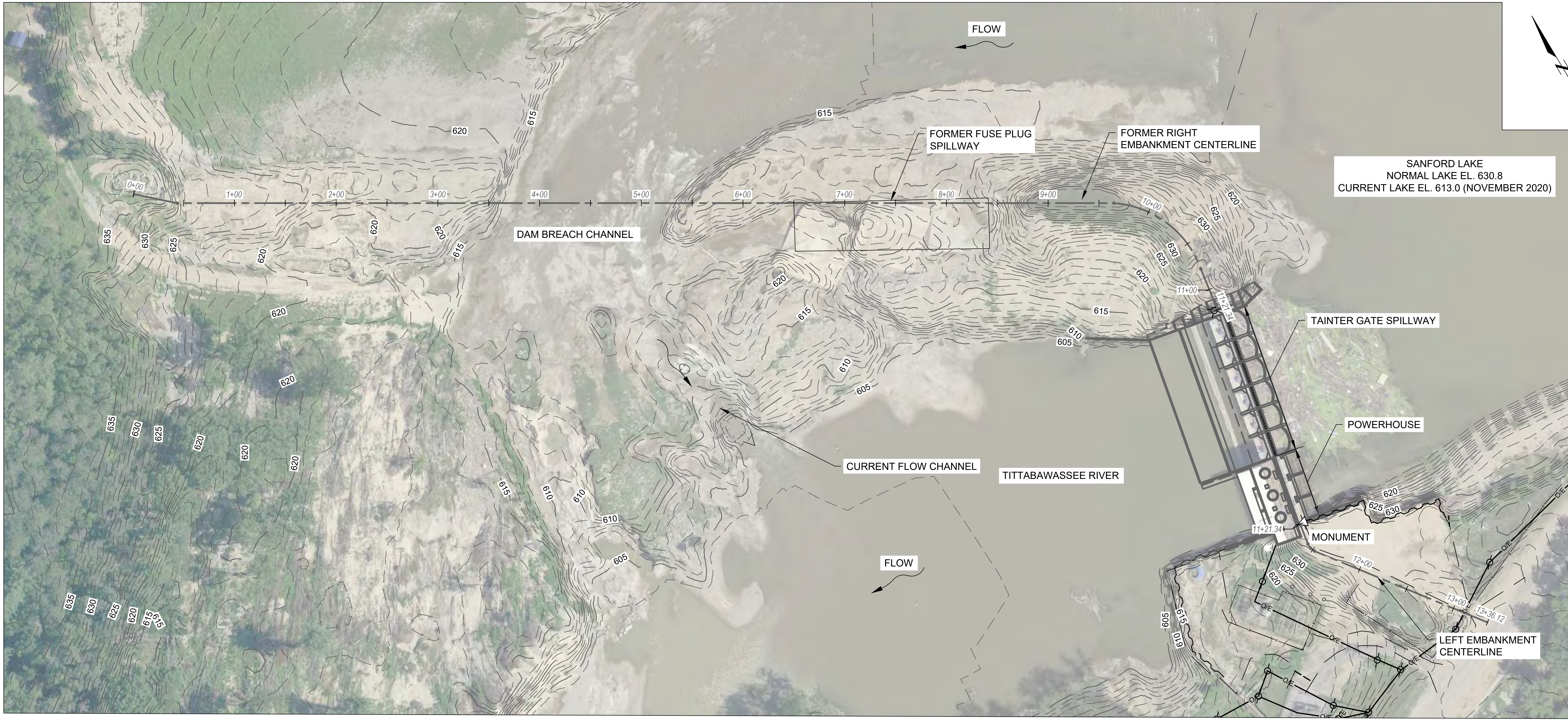

LINETYPE LEGEND

- CENTERLINE
- WATER ELEVATION
- OVERHEAD ELECTRIC LINES (O/E)
- FENCE LINE (STEEL)
- FENCE LINE (WOOD)
- UNDERGROUND CABLE (CATV)
- EDGE OF ROADWAY (UNPAVED)
- ROADWAY CENTERLINE
- BURIED PIPING
- GAS LINE (GAS)
- EXISTING MAJOR CONTOURS (750)
- EXISTING MINOR CONTOURS

SYMBOLS LEGEND

- DRAIN TILES
- FLOW DIRECTION
- SURVEY REFERENCE MONUMENT (BM #1)

EXISTING CONDITIONS SITE PLAN

0 50 100
SCALE, FEET

SURVEY CONTROL MONUMENT LOCATIONS

ID	ELEVATION	NORTHING	EASTING
MONUMENT	637.86	793,278.682	13,119,772.561

NOTES:

1. VERTICAL DATUM: NATIONAL GEODETIC VERTICAL DATUM OF 1929 (NGVD29)
2. SPATIAL DATUM: NORTH AMERICAN DATUM OF 1983 (NAD83), MICHIGAN STATE PLAN, SOUTH ZONE

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Saginaw, MI 48607 Tel.
989-754-4717 Fax.
989-754-4440
www.SpicerGroup.com

GEI Consultants
GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed: P. DREW
Checked: P. DREW
Drawn: A. SAMPSON
Approved By: B. WALTON

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FERC Project No. 2785

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SITE PLAN - EXISTING CONDITIONS
POST-EMBANKMENT BREACH

DWG. NO. C-01

SHEET NO. 3

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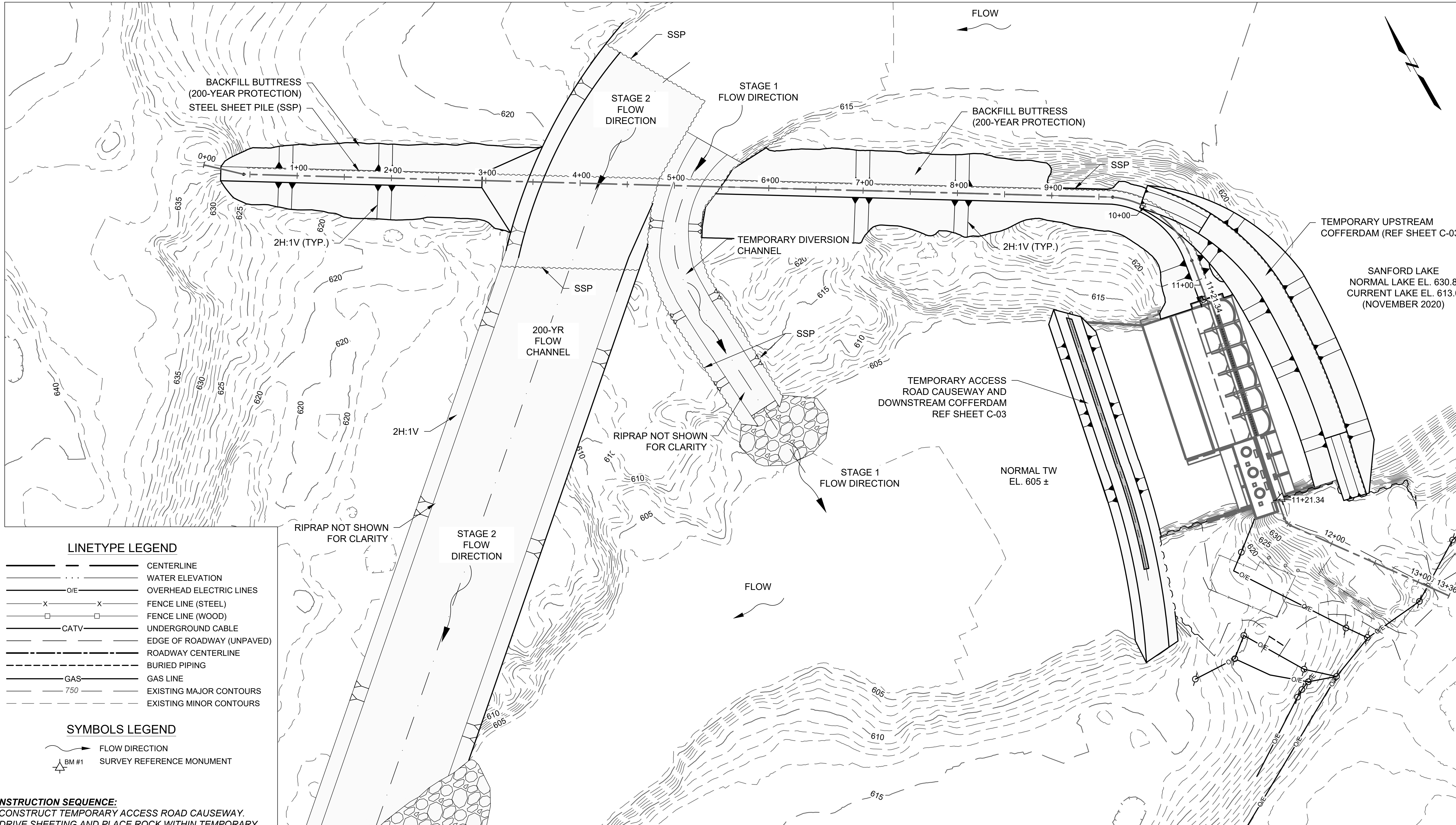

LINETYPE LEGEND

— — —	CENTERLINE
— · · · —	WATER ELEVATION
——O/E——	OVERHEAD ELECTRIC LINES
——X——X——	FENCE LINE (STEEL)
——□——□——	FENCE LINE (WOOD)
——CATV——	UNDERGROUND CABLE
— — — —	EDGE OF ROADWAY (UNPAVED)
—·—·—	ROADWAY CENTERLINE
- - - - -	BURIED PIPING
——GAS——	GAS LINE
—— 750 ——	EXISTING MAJOR CONTOURS
— — — —	EXISTING MINOR CONTOURS

SYMBOLS LEGEND

~→	FLOW DIRECTION
BM #1	SURVEY REFERENCE MONUMENT

CONSTRUCTION SEQUENCE:

1. *CONSTRUCT TEMPORARY ACCESS ROAD CAUSEWAY.*
2. *DRIVE SHEETING AND PLACE ROCK WITHIN TEMPORARY DIVERSION CHANNEL.*
3. *DRIVE SHEETING AND BUTTRESS ON RIGHT EMBANKMENT (TO THE LEFT OF THE DIVERSION CHANNEL).*
4. *DRIVE SHEETING AND BUTTRESS ON THE RIGHT EMBANKMENT (TO THE RIGHT OF THE DIVERSION CHANNEL).*
5. *CONSTRUCT 200-YEAR FLOW CHANNEL.*
6. *CUT DOWN STEEL SHEET PILE IN FRONT OF THE 200-YEAR FLOW CHANNEL AND DIVERT BASE-FLOW FROM THE TEMPORARY DIVERSION CHANNEL (STAGE 1 FLOW DIRECTION) TO 200-YEAR FLOW CHANNEL (STAGE 2 FLOW DIRECTION).*

EXISTING CONDITIONS - SITE PLAN

0 50 100
SCALE, FEET

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0	xx/xx/xxxx	CONCEPTUAL DESIGN SUBMITTAL	--

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Saginaw, MI 48607 Tel.
989-754-4717 Fax.
989-754-4440
www.SpicerGroup.com

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GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed:	P. DREW
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Four Lakes Task Force
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SITE PLAN - EXISTING CONDITIONS
POST-BREACH CHANNEL
TEMPORARY STABILIZATION

DWG. NO. C-02

SHEET NO. 4

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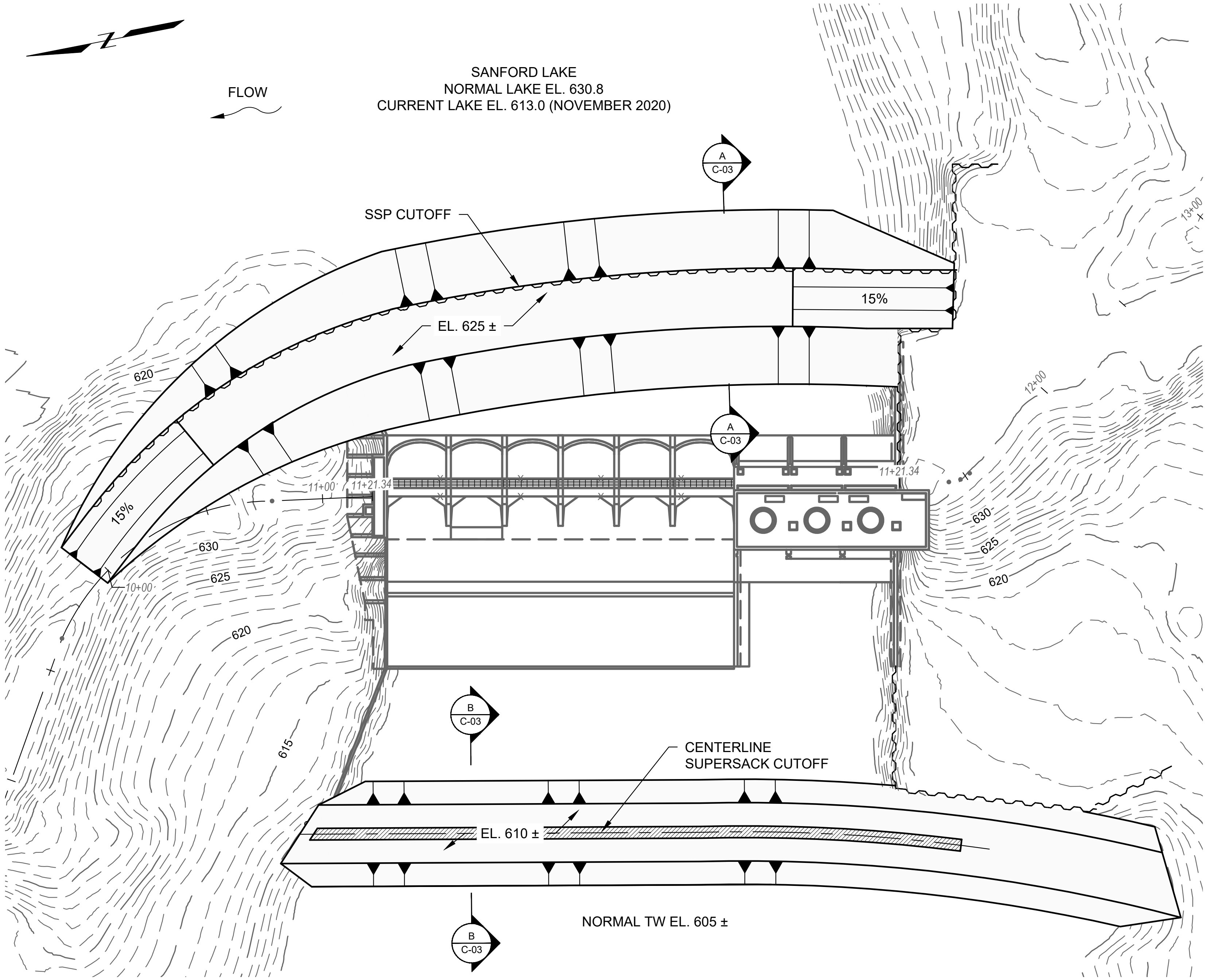
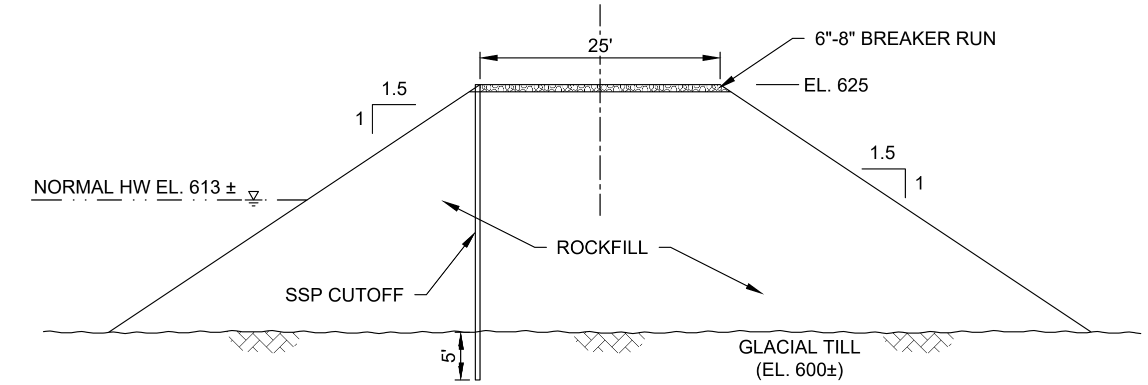


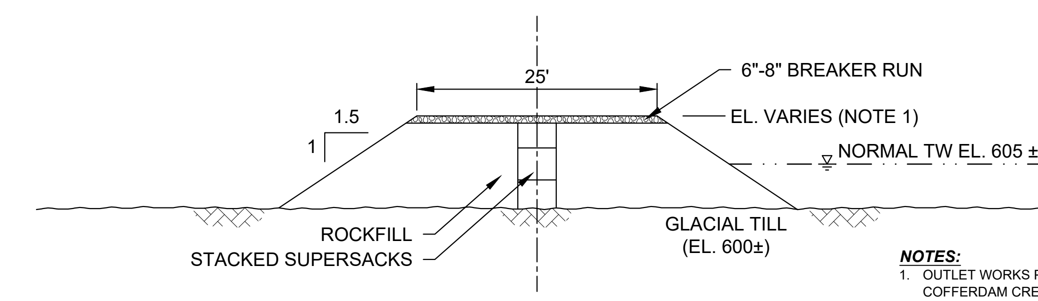
SITE PLAN - PROPOSED MODIFICATIONS

0 30 60 SCALE, FEET



A SECTION
C-03 UPSTREAM COFFERDAM
C-14

0 10 20 SCALE, FEET



B SECTION
C-03 DOWNSTREAM COFFERDAM
C-14

0 10 20 SCALE, FEET

NOTES:

1. OUTLET WORKS PHASE 1 DOWNSTREAM COFFERDAM CREST ELEVATION 610 ±.
2. LABYRINTH SPILLWAY PHASE 2 DOWNSTREAM COFFERDAM CREST ELEVATION 620 ±.

LINETYPE LEGEND

- CENTERLINE
- 750 EXISTING MAJOR CONTOURS
- EXISTING MINOR CONTOURS
- WATER ELEVATION

SYMBOLS LEGEND

- 1H:1V CUT SLOPE
- 1H:1V FILL SLOPE

PROPOSED CONSTRUCTION SEQUENCE:

1. FULLY DRAW DOWN IMPOUNDMENT, STABILIZE EXISTING PROJECT STRUCTURES, REMOVE DEBRIS AND INSPECT SPILLWAY AND POWERHOUSE. (TO BE COMPLETED BY BOYCE)
2. CONTRACTOR MOBILIZATION, LEFT AND RIGHT ABUTMENT RECONSTRUCTION AND DEVELOP LAYDOWN AND CONTRACTOR WORK AREAS.
3. STABILIZE RIGHT EMBANKMENT BREACH CHANNEL AND FULLY DIVERT WATER FROM SPILLWAY AND POWERHOUSE AREA.
4. CONSTRUCT PHASE I UPSTREAM AND DOWNSTREAM COFFERDAMS AT GATED SPILLWAY AND POWERHOUSE.
5. DEMOLISH EXISTING GATED SPILLWAY AND POWERHOUSE.
6. CONSTRUCT NEW GATED SPILLWAY.
7. REMOVE PHASE I COFFERDAMS AND CONSTRUCT PHASE II UPSTREAM AND DOWNSTREAM COFFERDAMS AT NEW AUXILIARY LABYRINTH SPILLWAY LOCATED AT BREACH CHANNEL AREA. DIVERT RIVER FLOWS THROUGH NEW GATED SPILLWAY.
8. CONSTRUCT NEW AUXILIARY LABYRINTH SPILLWAY AND RECONSTRUCT FLANKING EMBANKMENTS.
9. REMOVE PHASE II COFFERDAMS.
10. REFILL SANFORD LAKE AND MONITOR PERFORMANCE.
11. FINAL SITE RESTORATION AND CONTRACTOR DEMOBILIZATIONS.

Attention: 0 1" If this scale bar does not measure 1" then drawing is not original scale.

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Saginaw, MI 48607 Tel.
989-754-4717 Fax.
989-754-4440
www.SpicerGroup.com

GEI Consultants
GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed:	P. DREW
Checked:	P. DREW
Drawn:	A. SAMPSON
Approved By:	B. WALTON

Four Lakes Task Force
FERC Project No. 2785

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OUTLET WORKS - TEMPORARY COFFERDAMS PLAN & SECTIONS

DWG. NO. C-03

SHEET NO. 5

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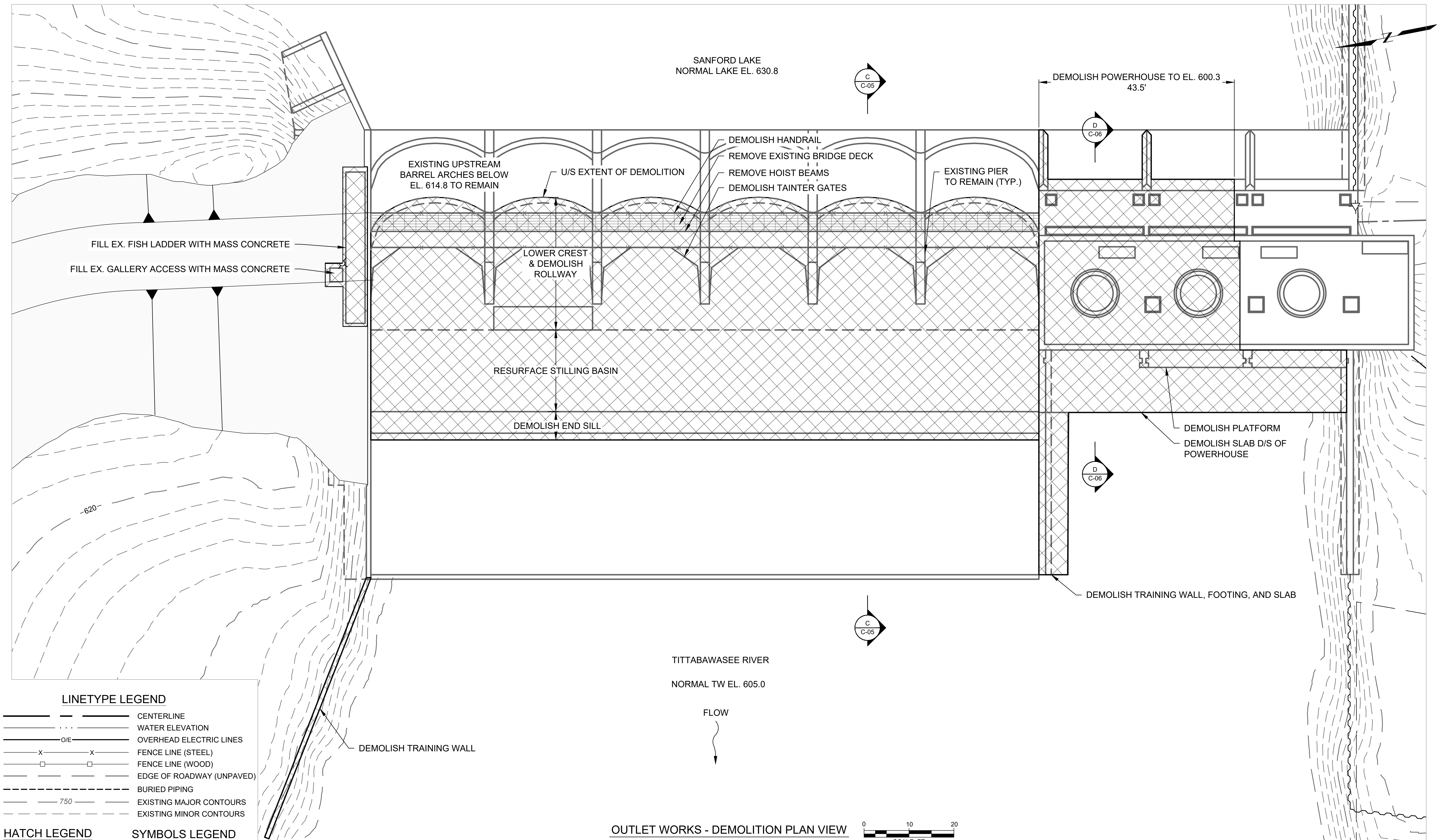

LINETYPE LEGEND

- CENTERLINE
- WATER ELEVATION
- O/E — OVERHEAD ELECTRIC LINES
- X — FENCE LINE (STEEL)
- FENCE LINE (WOOD)
- EDGE OF ROADWAY (UNPAVED)
- BURIED PIPING
- 750 — EXISTING MAJOR CONTOURS
- EXISTING MINOR CONTOURS

HATCH LEGEND

GRATING — DEMOLITION

SYMBOLS LEGEND

- BENCHMARK
- FLOW DIRECTION

OUTLET WORKS - DEMOLITION PLAN VIEW

0 10 20
SCALE, FT

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GEI Consultants — GEI CONSULTANTS OF MICHIGAN, P.C. 10501 WEST RESEARCH DRIVE G100 MILWAUKEE, WI 53226 (414)930-7540

Designed:	P. DREW
Checked:	P. DREW
Drawn:	A. SAMPSON
Approved By:	B. WALTON

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OUTLET WORKS - DEMOLITION PLAN

DWG. NO. C-04

SHEET NO. 6

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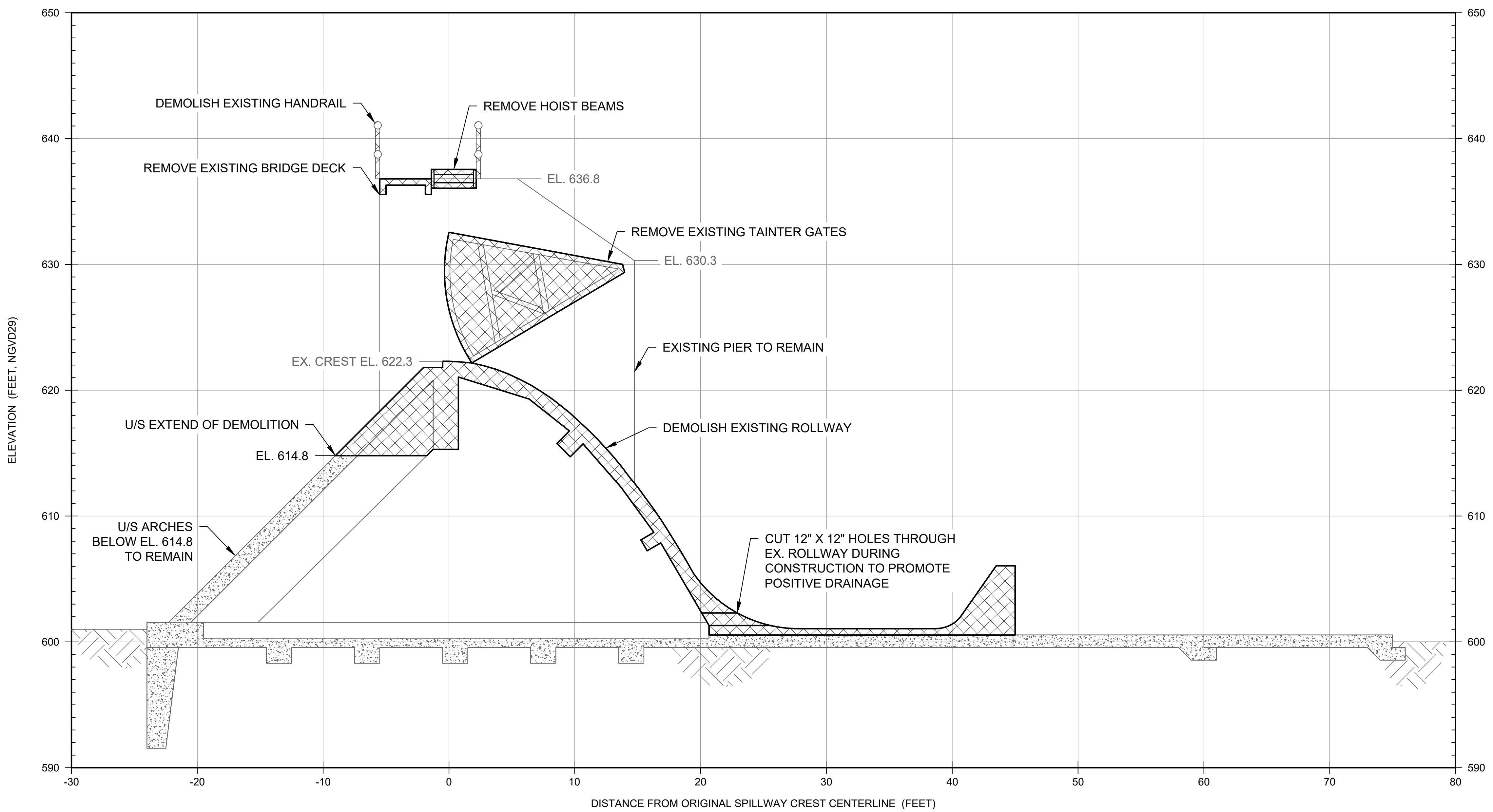


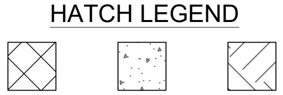
C
C-04

SECTION

SPILLWAY DEMOLITION

0 5 10
SCALE, FT

HATCH LEGEND



CONCRETE DEMOLITION | EXISTING CONCRETE | EXISTING FOUNDATION

Attention:
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Saginaw, MI 48607 Tel.
989-754-4717 Fax.
989-754-4440
www.SpicerGroup.com

GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed:	P. DREW
Checked:	P. DREW
Drawn:	A. SAMPSON
Approved By:	B. WALTON

Four Lakes Task Force
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OUTLET WORKS - DEMOLITION SECTION

DWG. NO. C-05

SHEET NO. 7

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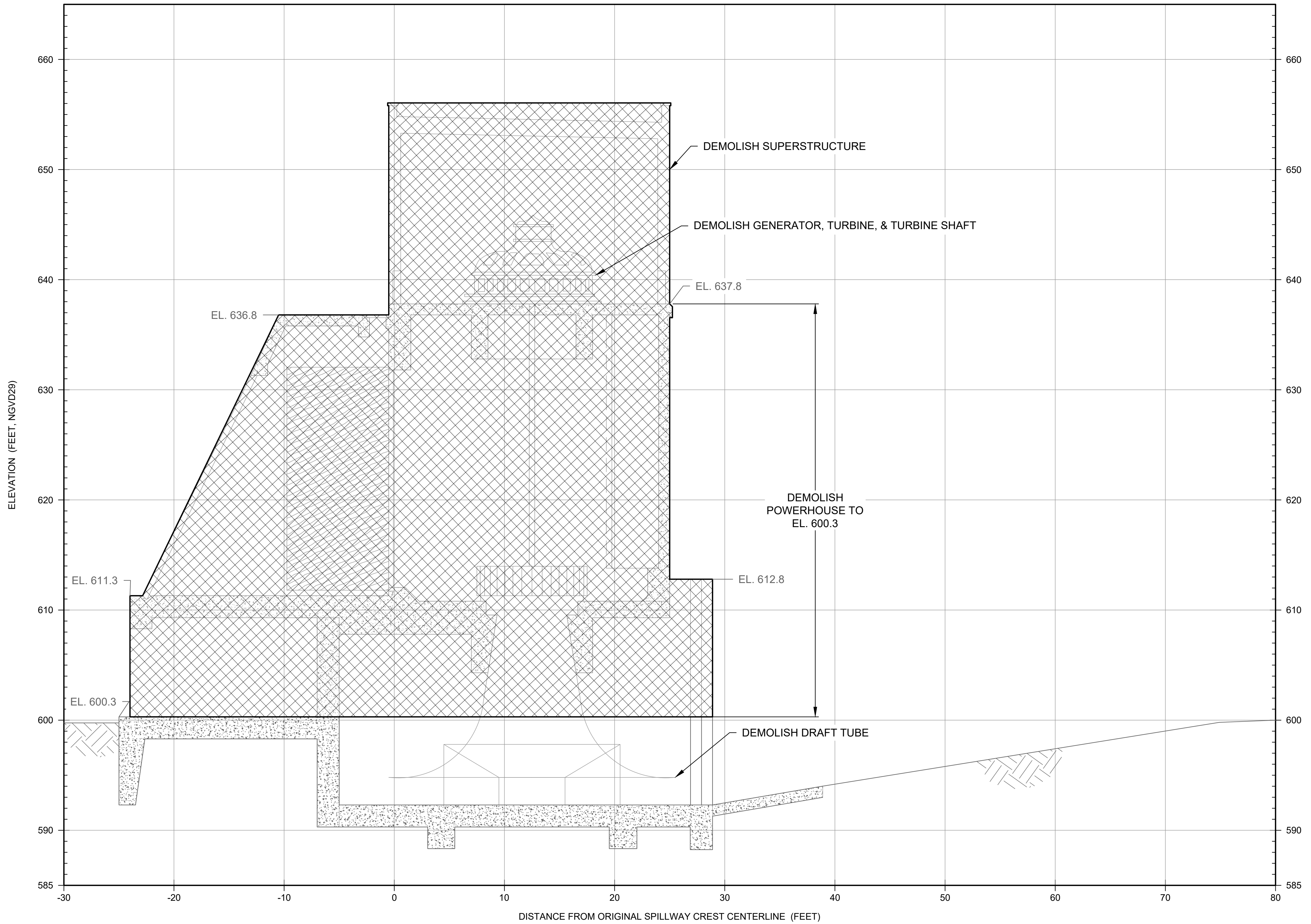

D
C-04
SECTION
POWERHOUSE DEMOLITION

0 5 10
SCALE, FT

HATCH LEGEND

CONCRETE DEMOLITION | EXISTING CONCRETE | EXISTING FOUNDATION

Attention: 0 1"
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230 S. Washington Ave.
Saginaw, MI 48607 Tel.
989-754-4717 Fax.
989-754-4440
www.SpicerGroup.com

GEI Consultants
GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed: P. DREW
Checked: P. DREW
Drawn: A. SAMPSON
Approved By: B. WALTON

Four Lakes Task Force
FERC Project No. 2785

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Midland County, Michigan

POWERHOUSE - DEMOLITION SECTION

DWG. NO.
C-06

SHEET NO.
8

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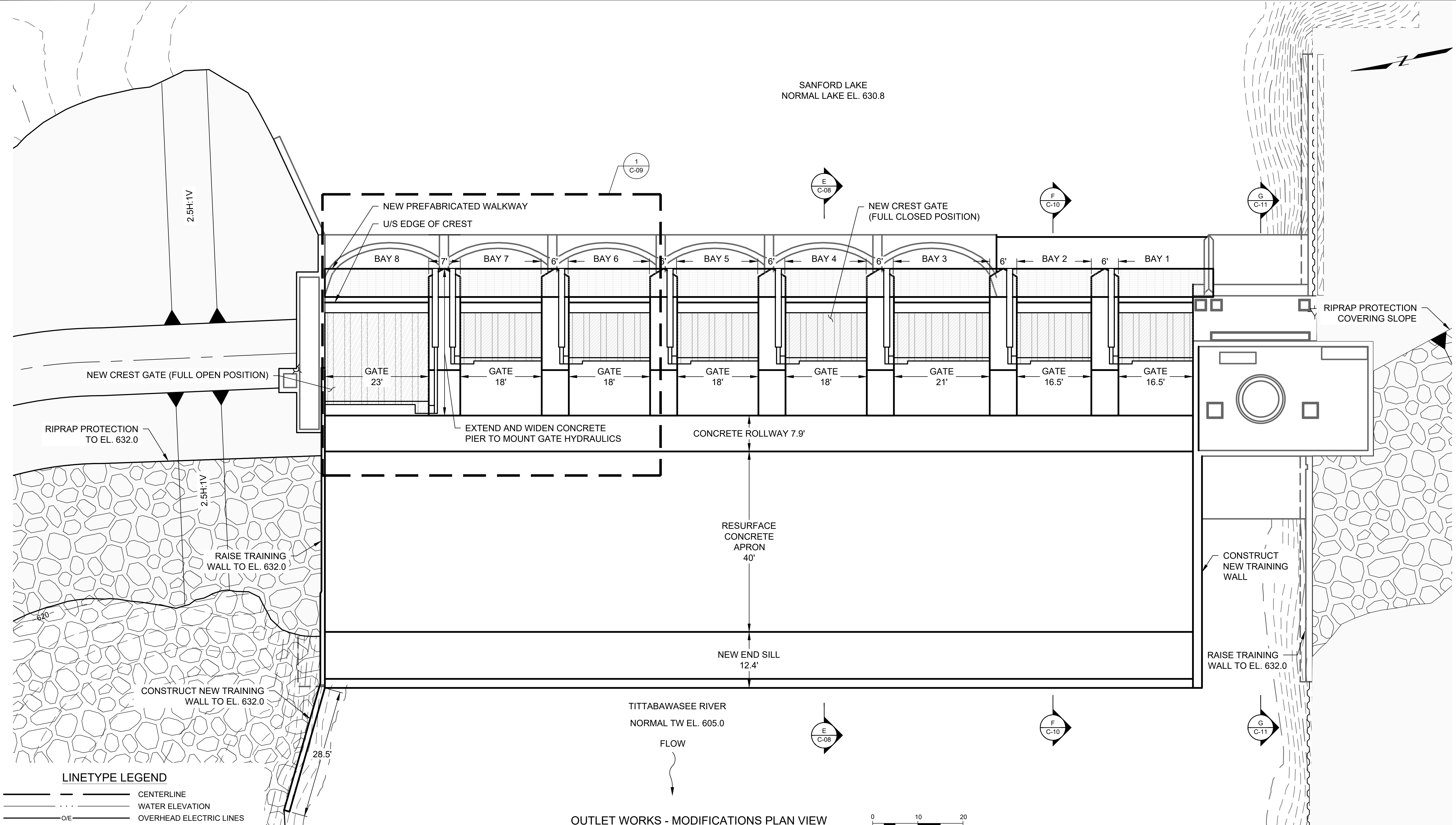

OUTLET WORKS - MODIFICATIONS PLAN VIEW

0 10 20
SCALE, FT

LINETYPE LEGEND

- CENTERLINE
- WATER ELEVATION
- O/E — OVERHEAD ELECTRIC LINES
- EDGE OF ROADWAY (UNPAVED)
- 750 — EXISTING MAJOR CONTOURS
- EXISTING MINOR CONTOURS

HATCH LEGEND

RIPRAP — CREST GATES — GRATING

SYMBOLS LEGEND

- BENCHMARK
- FLOW DIRECTION

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Designed: P. DREW
Checked: P. DREW
Drawn: A. SAMPSON
Approved By: B. WALTON

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OUTLET WORKS - MODIFICATIONS PLAN

DWG. NO. C-07
SHEET NO. 9

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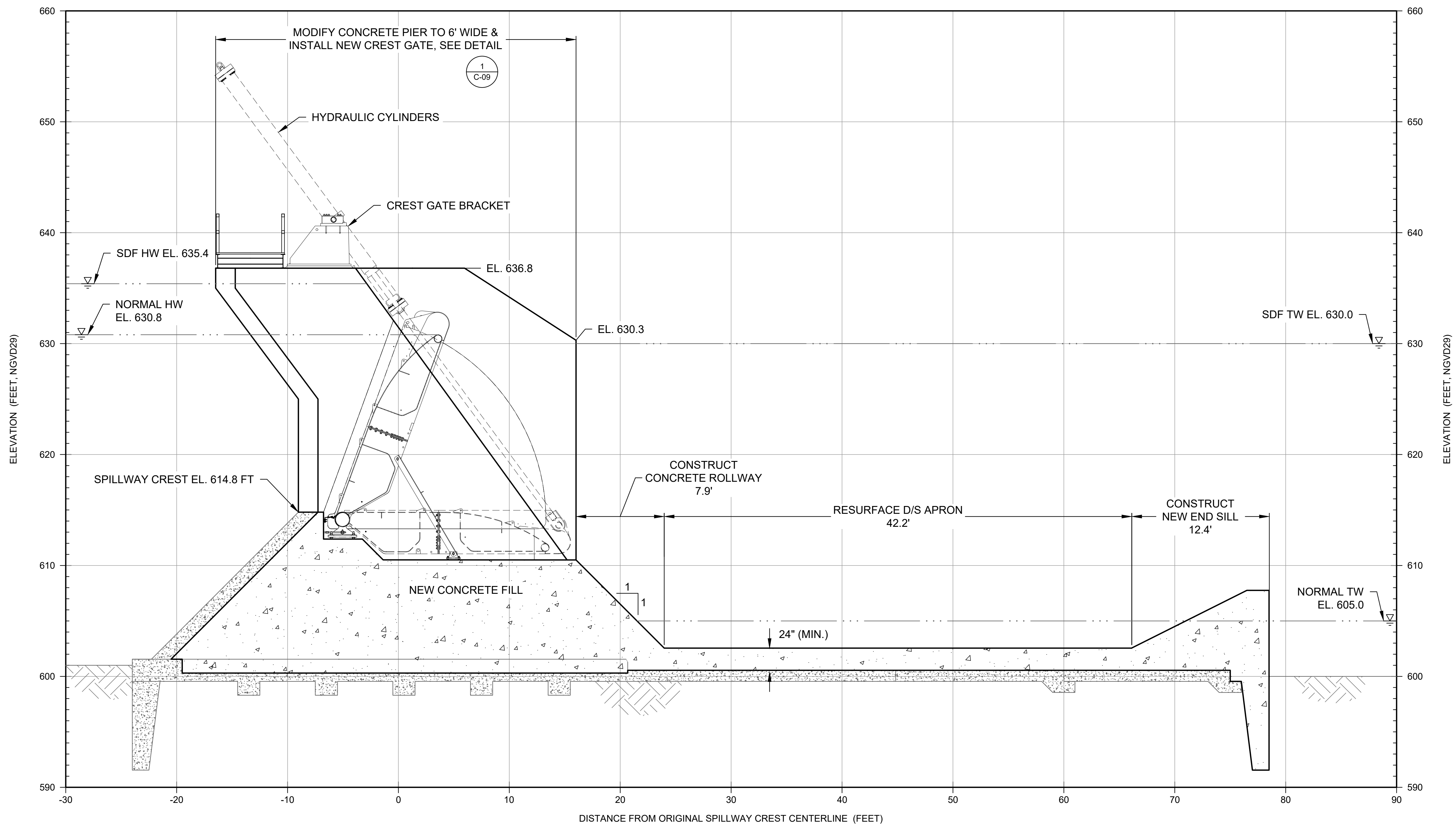

E
C-07
SECTION
BAY 4 SPILLWAY

0 5 10
SCALE, FT

HATCH LEGEND

PROPOSED REINFORCED CONCRETE | EXISTING CONCRETE | EXISTING FOUNDATION

Attention:
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SAGINAW OFFICE
230 S. Washington Ave.
Saginaw, MI 48607 Tel.
989-754-4717 Fax.
989-754-4440
www.SpicerGroup.com

GEI Consultants
GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed: P. DREW
Checked: P. DREW
Drawn: A. SAMPSON
Approved By: B. WALTON

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PRIMARY SPILLWAY - MODIFICATIONS SECTION

DWG. NO. C-08

SHEET NO. 10

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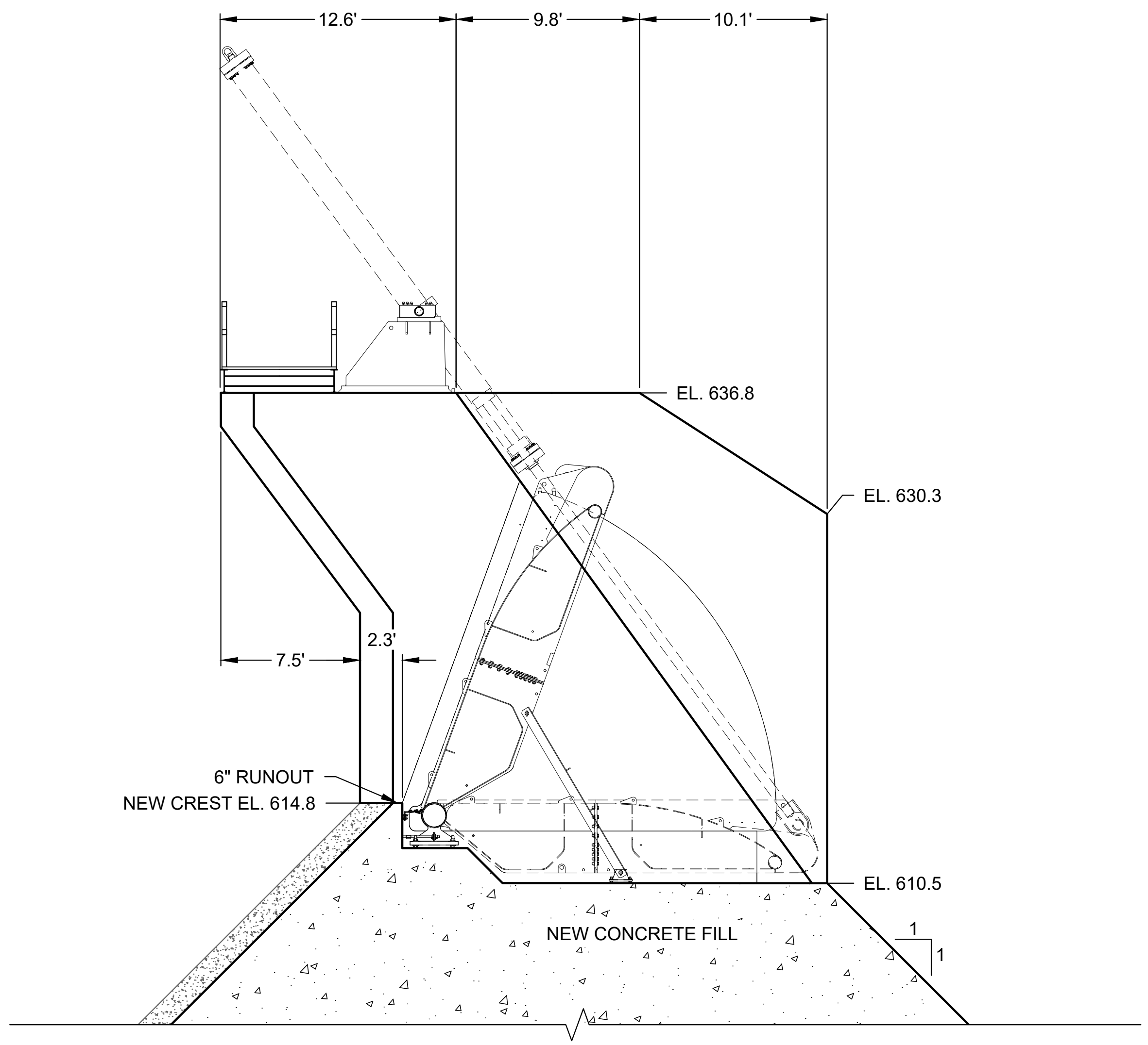

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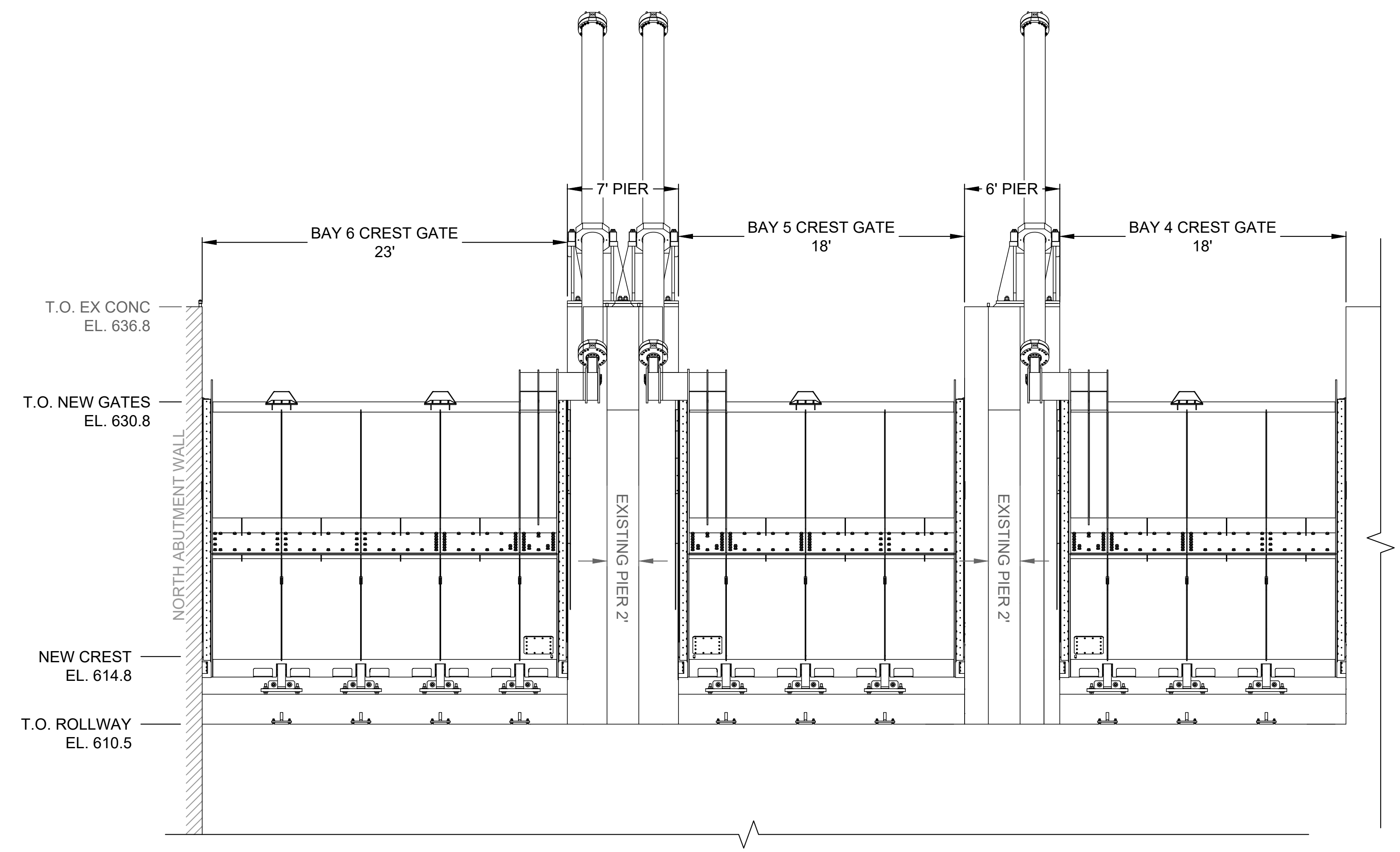
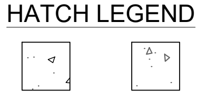


DOWNSTREAM ELEVATION
(LOOKING UPSTREAM)

1 DETAIL
C-08 C-10 PIER-MOUNTED CREST GATE

0 5 10
SCALE, FT

HATCH LEGEND



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989-754-4717 Fax.
989-754-4440
www.SpicerGroup.com

GEI Consultants
GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed:	P. DREW
Checked:	P. DREW
Drawn:	A. SAMPSON
Approved By:	B. WALTON

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PRIMARY SPILLWAY - CREST GATE DETAILS

DWG. NO.
C-09

SHEET NO.
11

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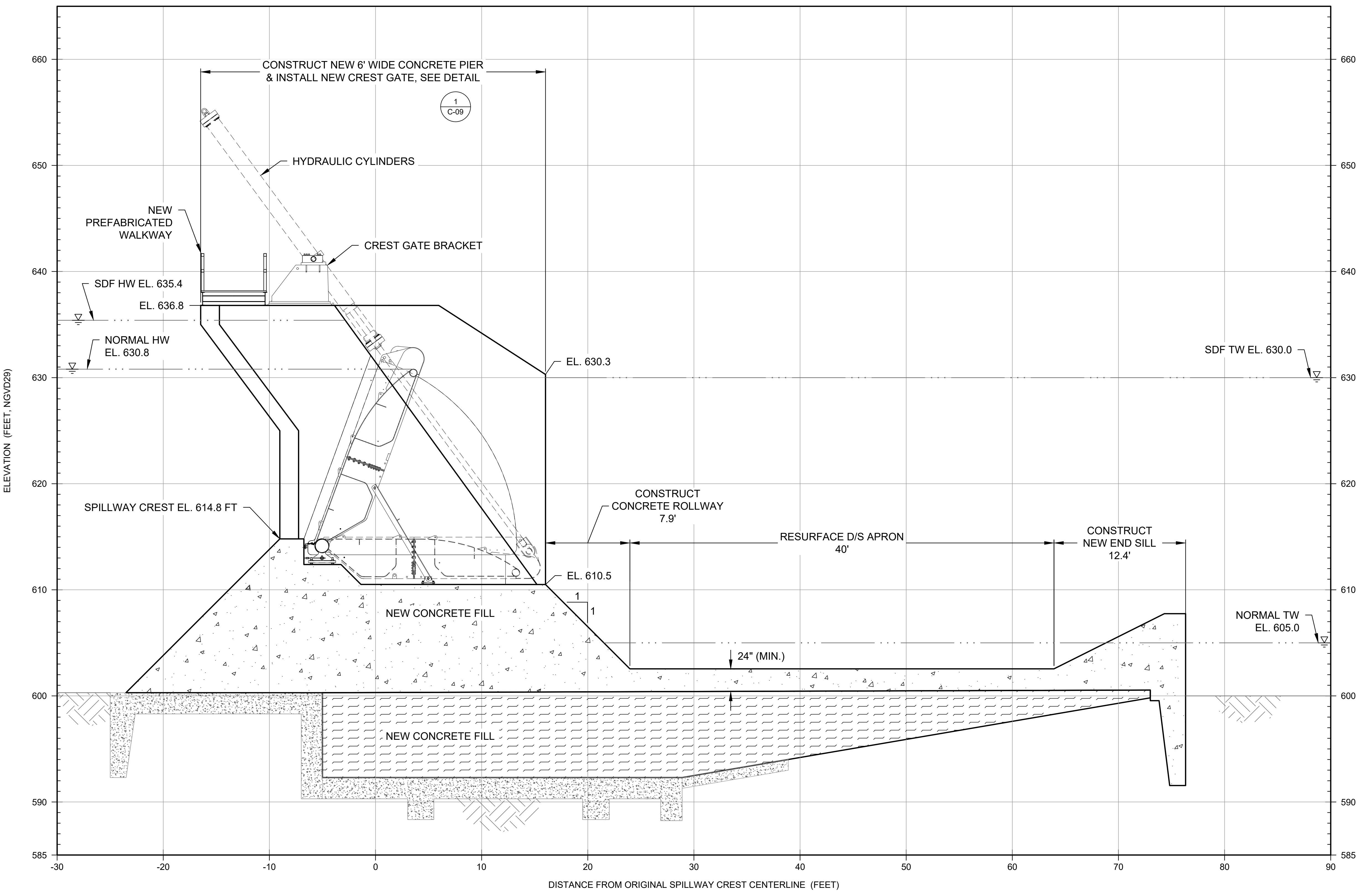

F / C-07 SECTION
POWERHOUSE BAY 2

SCALE, FT

HATCH LEGEND

EXISTING CONCRETE | EXISTING FOUNDATION | PROPOSED REINFORCED CONCRETE | CONCRETE FILL

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230 S. Washington Ave.
Saginaw, MI 48607 Tel.
989-754-4717 Fax.
989-754-4440
www.SpicerGroup.com

GEI Consultants
GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed: P. DREW
Checked: P. DREW
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Approved By: B. WALTON

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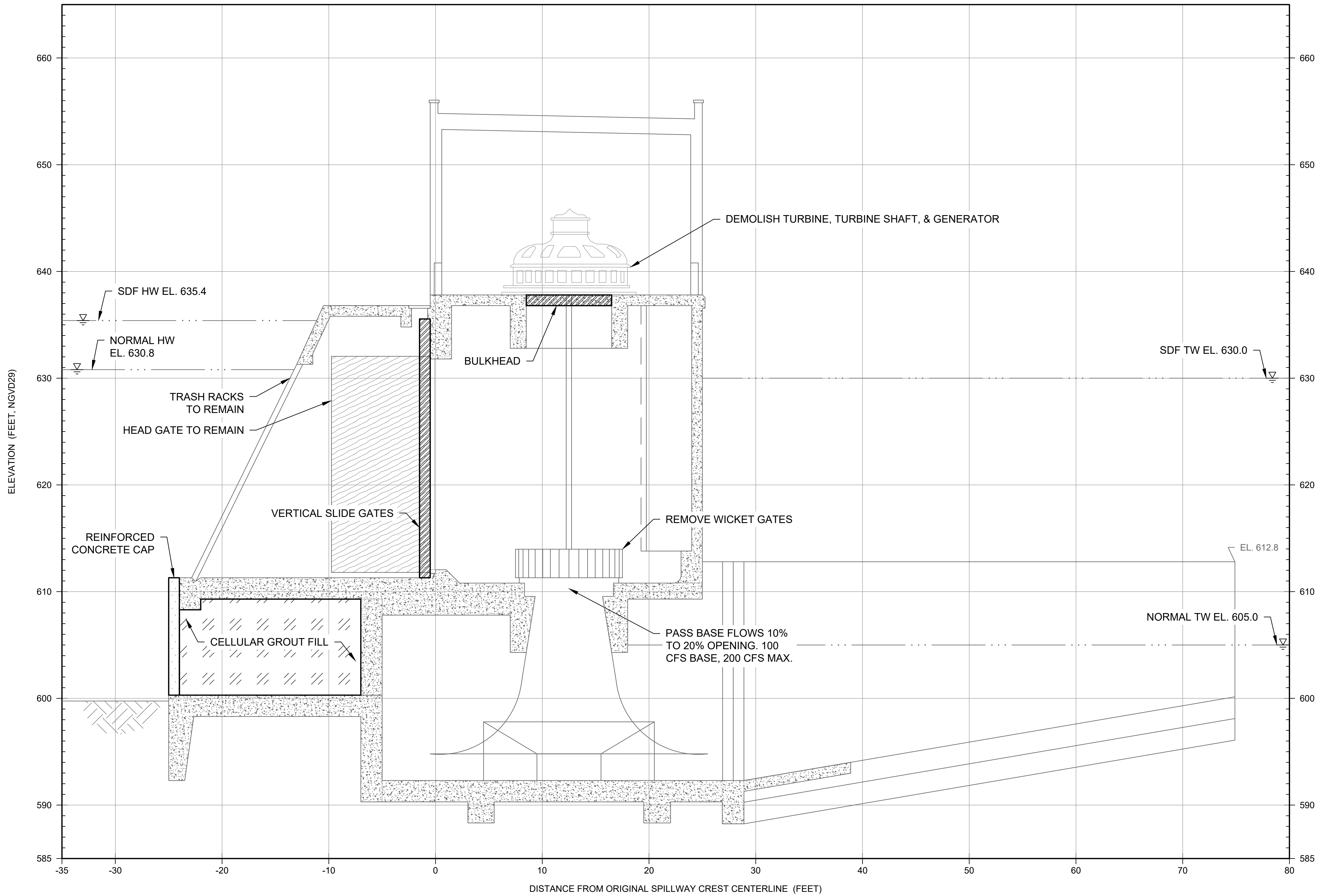
POWERHOUSE - MODIFICATIONS SECTION

DWG. NO. C-10

SHEET NO. 12



G / C-07 SECTION
POWERHOUSE

0 5 10
SCALE, FT

HATCH LEGEND

EXISTING CONCRETE | EXISTING FOUNDATION | PROPOSED REINFORCED CONCRETE | CELLULAR GROUT FILL | REINFORCED CONCRETE CAP

Attention: 0 1" If this scale bar does not measure 1" then drawing is not original scale.

NO.	DATE	ISSUE/REVISION	APP
0	xx/xx/xxxx	CONCEPTUAL DESIGN SUBMITTAL	--

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Saginaw, MI 48607 Tel.
989-754-4717 Fax.
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GEI Consultants
GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed: P. DREW
Checked: P. DREW
Drawn: A. SAMPSON
Approved By: B. WALTON

Four Lakes Task Force
FERC Project No. 2785

GEI Project 2002879

Sanford Dam Conceptual Design
Midland County, Michigan

POWERHOUSE - LOW LEVEL OUTLET - MODIFICATIONS SECTION

DWG. NO. C-11

SHEET NO. 13

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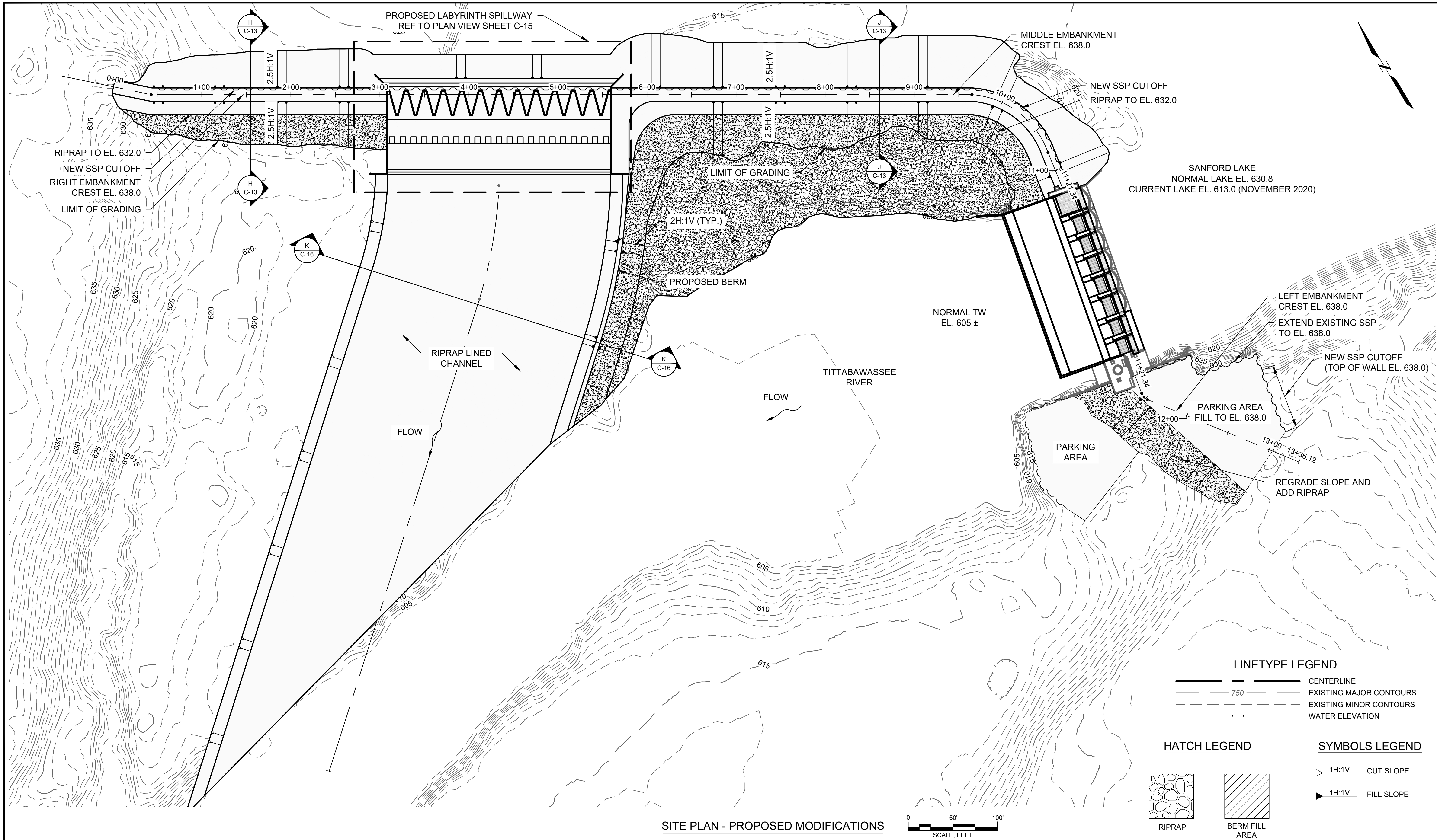

0	xx/xx/xxxx	CONCEPTUAL DESIGN SUBMITTAL	--
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GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
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Four Lakes Task Force
FERC Project No. 2785

GEI Project 2002879

Sanford Dam Conceptual Design
Midland County, Michigan

SITE PLAN -
PROPOSED MODIFICATIONS

DWG. NO. C-12

SHEET NO. 14

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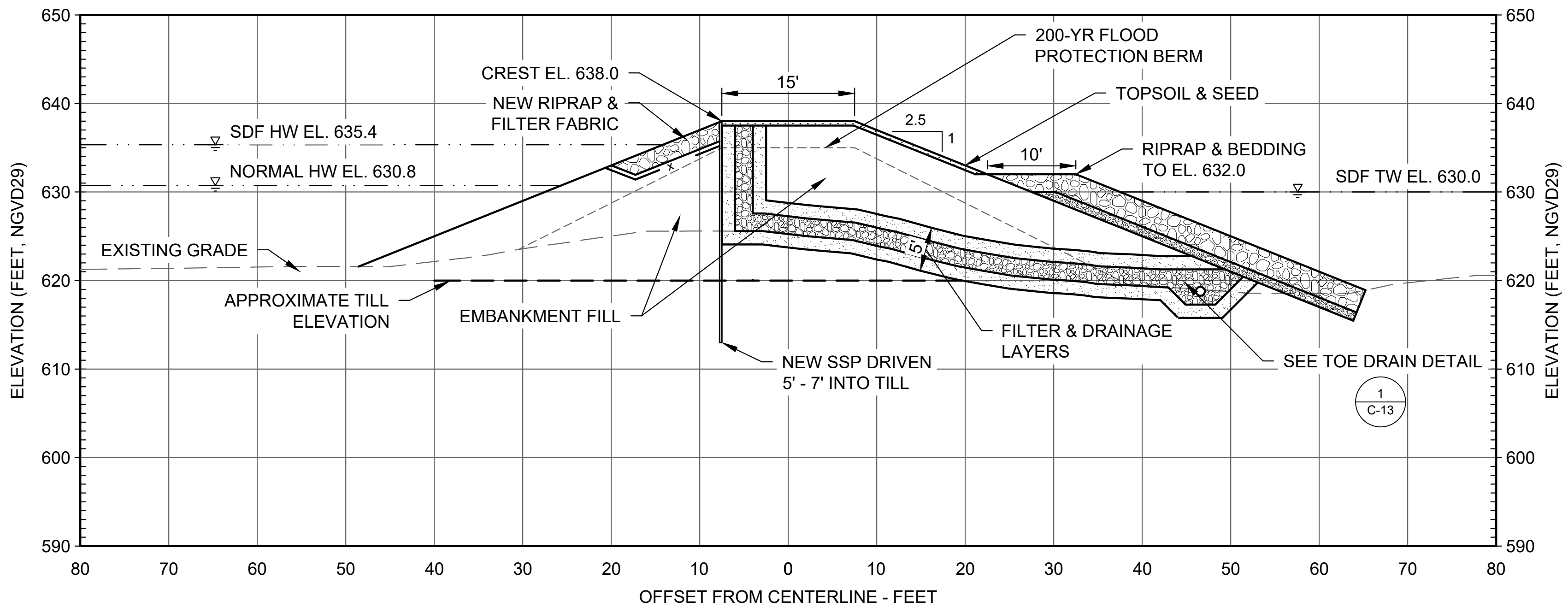
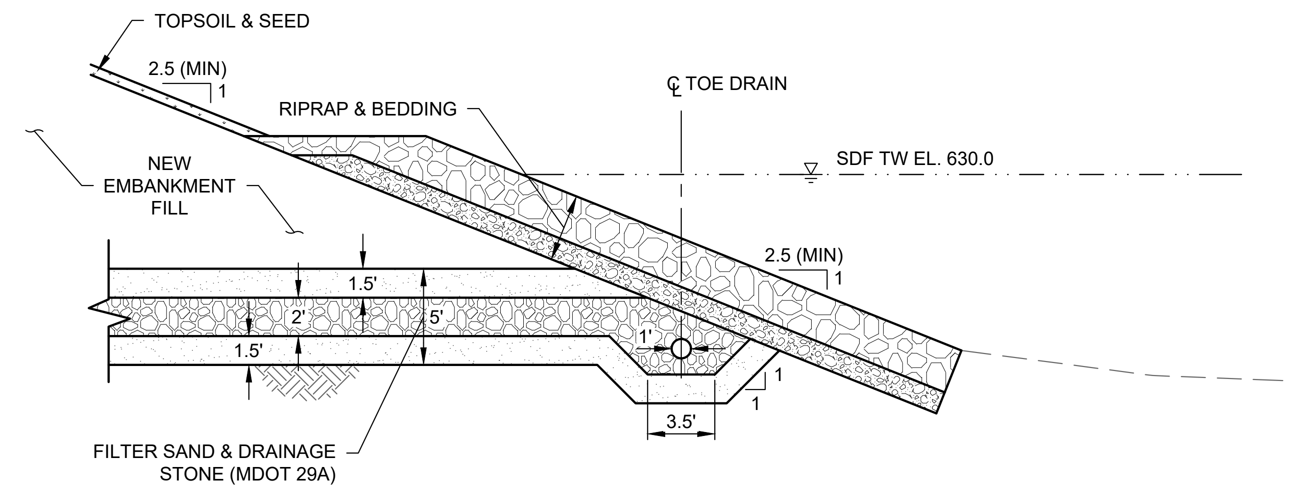


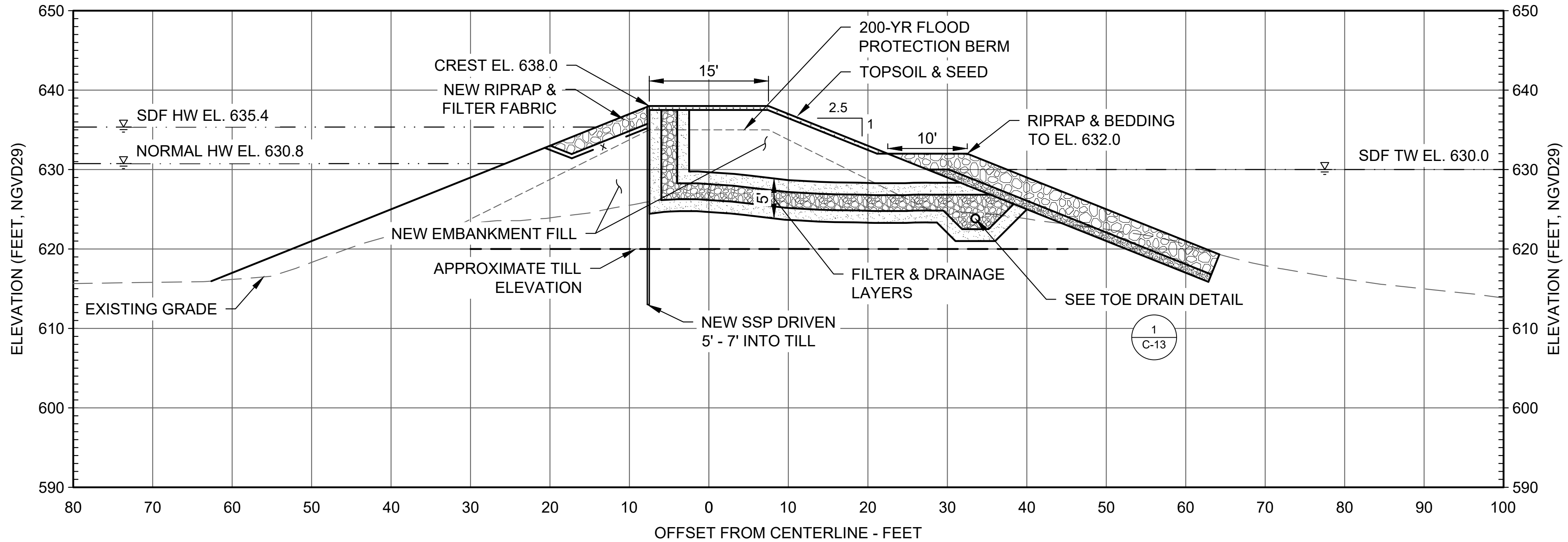
H
C-12
SECTION
RIGHT EMBANKMENT

HORIZONTAL SCALE, FEET
0 10 20
VERTICAL SCALE, FEET
NO VERTICAL EXAGGERATION



1
C-13
DETAIL
TOE DRAIN

0 5 10
SCALE, FEET



J
C-12
SECTION
MIDDLE EMBANKMENT

HORIZONTAL SCALE, FEET
0 10 20
VERTICAL SCALE, FEET
NO VERTICAL EXAGGERATION

Attention:
0 1"
If this scale bar does not measure 1" then drawing is not original scale.

NO.	DATE	ISSUE/REVISION	APP
0	xx/xx/xxxx	CONCEPTUAL DESIGN SUBMITTAL	--

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230 S. Washington Ave.
Saginaw, MI 48607 Tel.
989-754-4717 Fax.
989-754-4440
www.SpicerGroup.com

GEI Consultants
GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed: P. DREW
Checked: P. DREW
Drawn: A. SAMPSON
Approved By: B. WALTON

Four Lakes Task Force
FERC Project No. 2785

GEI Project 2002879

Sanford Dam Conceptual Design
Midland County, Michigan

EMBANKMENTS - MODIFICATIONS SECTIONS

DWG. NO. C-13

SHEET NO. 15

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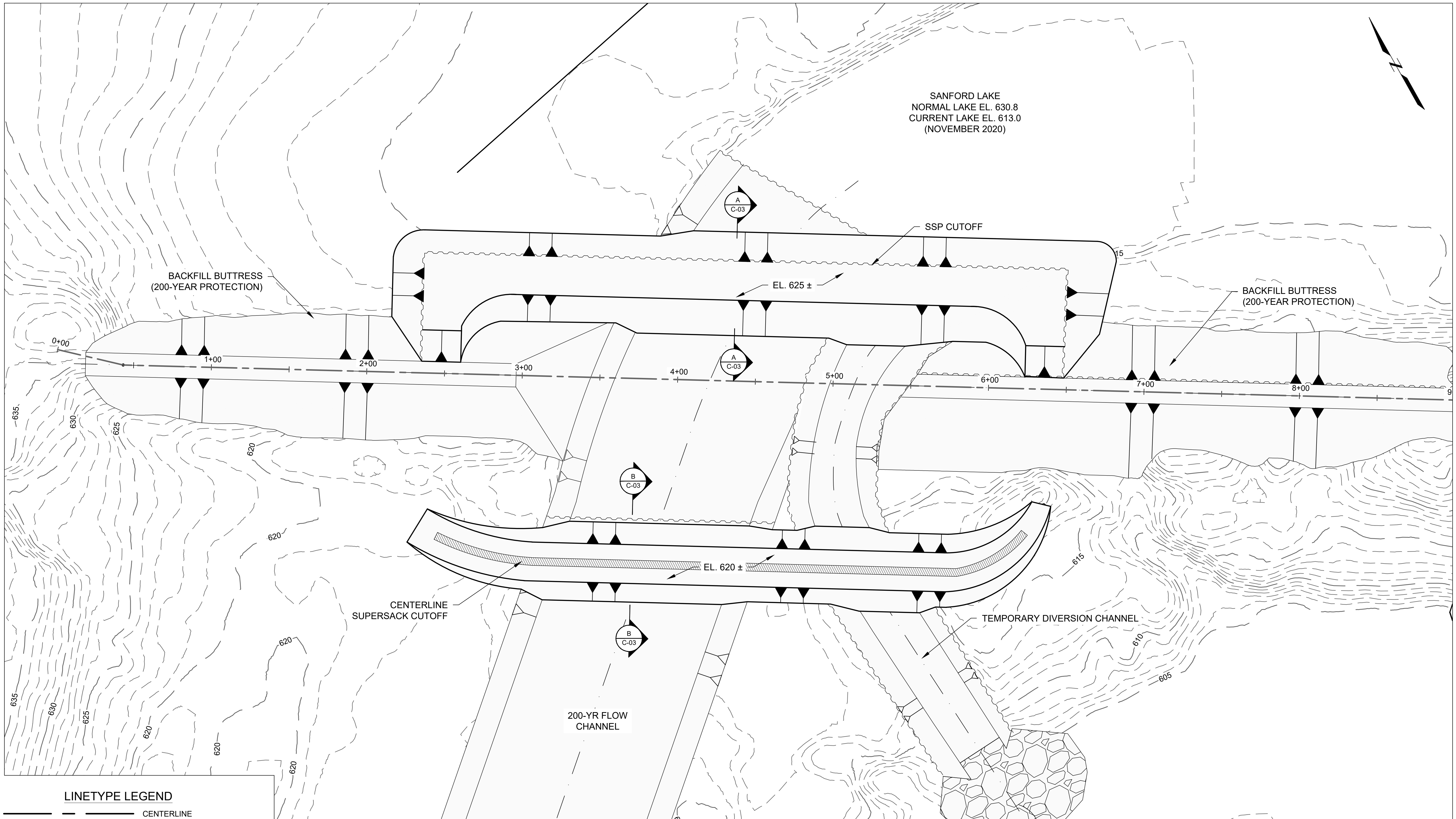

LINETYPE LEGEND

- CENTERLINE
- 750 — EXISTING MAJOR CONTOURS
- EXISTING MINOR CONTOURS

SITE PLAN

0 30 60
SCALE, FEET

SYMBOLS LEGEND

- 1H:1V CUT SLOPE
- 1H:1V FILL SLOPE

Attention:
0 1"
If this scale bar does not measure 1" then drawing is not original scale.

NO.	DATE	ISSUE/REVISION	APP
0	xx/xx/xxxx	CONCEPTUAL DESIGN SUBMITTAL	--

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Saginaw, MI 48607 Tel.
989-754-4717 Fax.
989-754-4440
www.SpicerGroup.com

GEI Consultants
GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed:	P. DREW
Checked:	P. DREW
Drawn:	A. SAMPSON
Approved By:	B. WALTON

Four Lakes Task Force
FERC Project No. 2785

GEI Project 2002879

Sanford Dam Conceptual Design
Midland County, Michigan

PHASE 2 LABYRINTH SPILLWAY
TEMPORARY COFFERDAM PLAN

DWG. NO.
C-14

SHEET NO.
16

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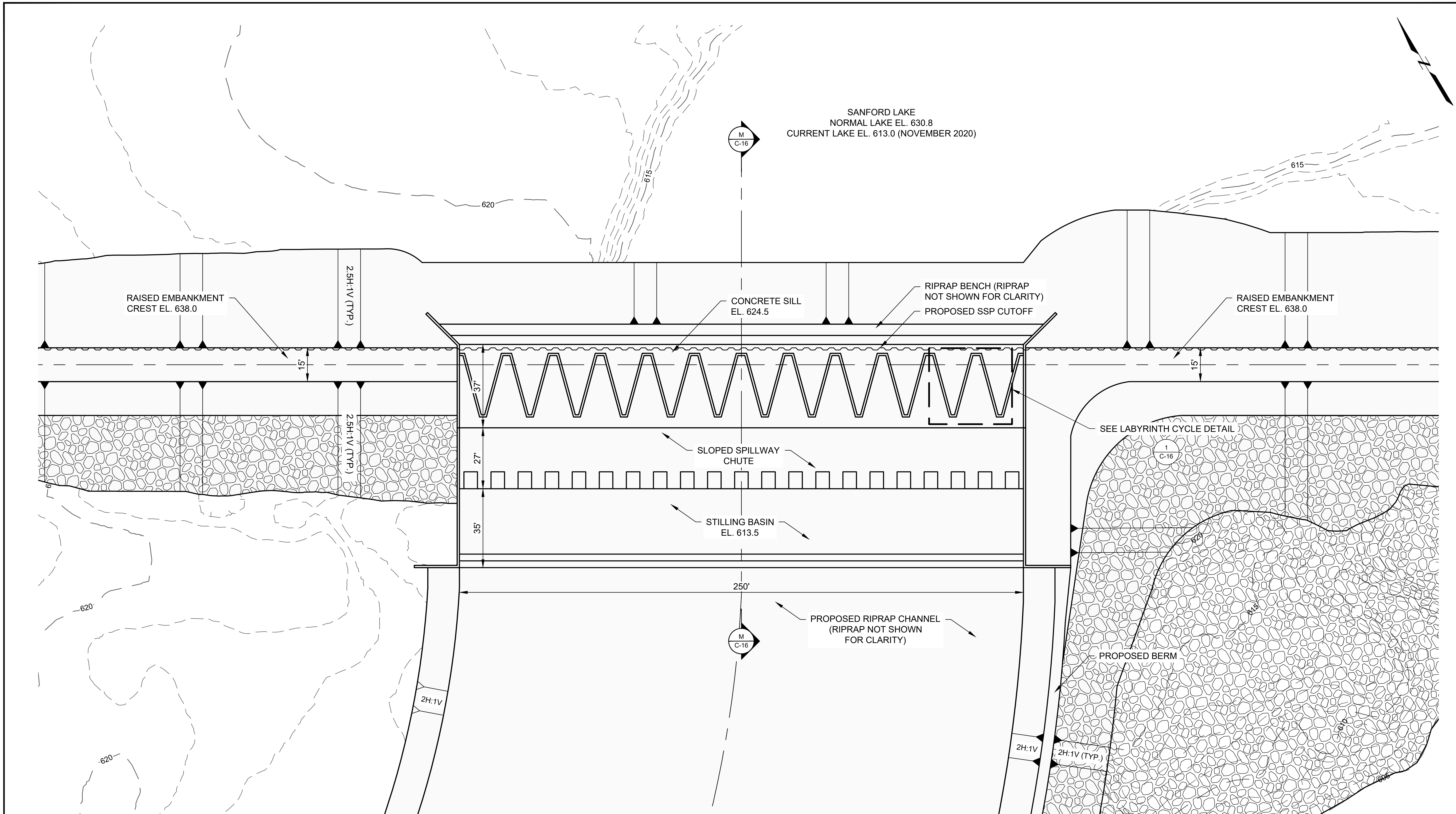

PLAN VIEW

PROPOSED LABYRINTH SPILLWAY

0 20 40
SCALE: 1" = 20'

Attention:
0 1"
If this scale bar does not measure 1" then drawing is not original scale.

NO.	DATE	ISSUE/REVISION	APP
0	xx/xx/xxxx	CONCEPTUAL DESIGN SUBMITTAL	--

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GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed:	P. DREW
Checked:	P. DREW
Drawn:	A. SAMPSON
Approved By:	B. WALTON

Four Lakes Task Force
FERC Project No. 2785

GEI Project 2002879

Sanford Dam Conceptual Design
Midland County, Michigan

LABYRINTH SPILLWAY - PROPOSED PLAN VIEW

DWG. NO.
C-15

SHEET NO.
17

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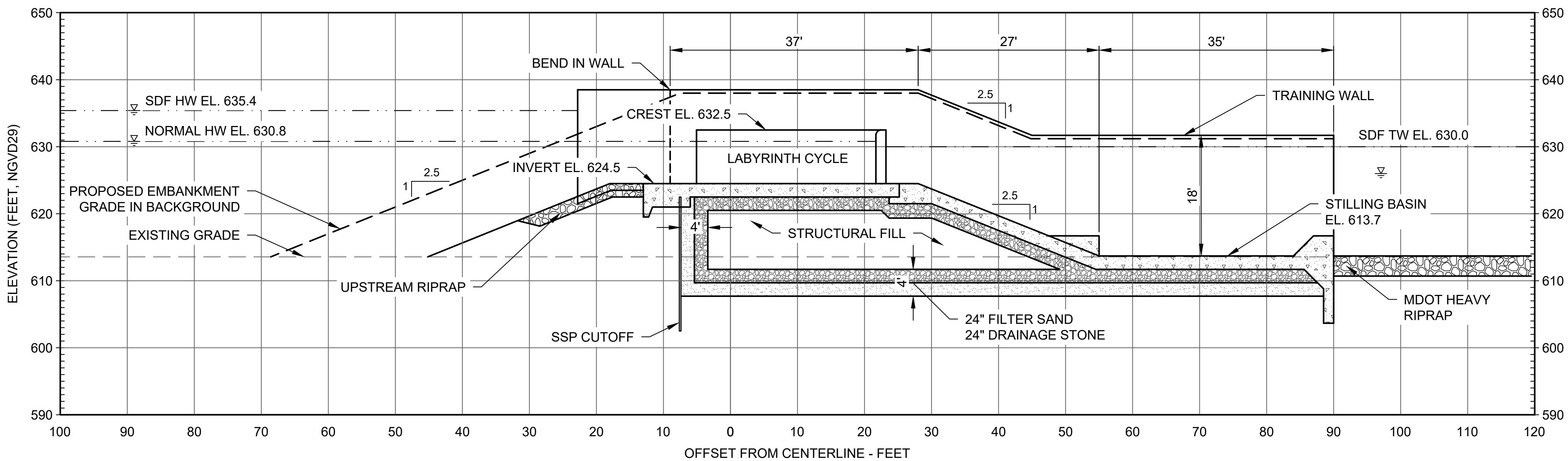
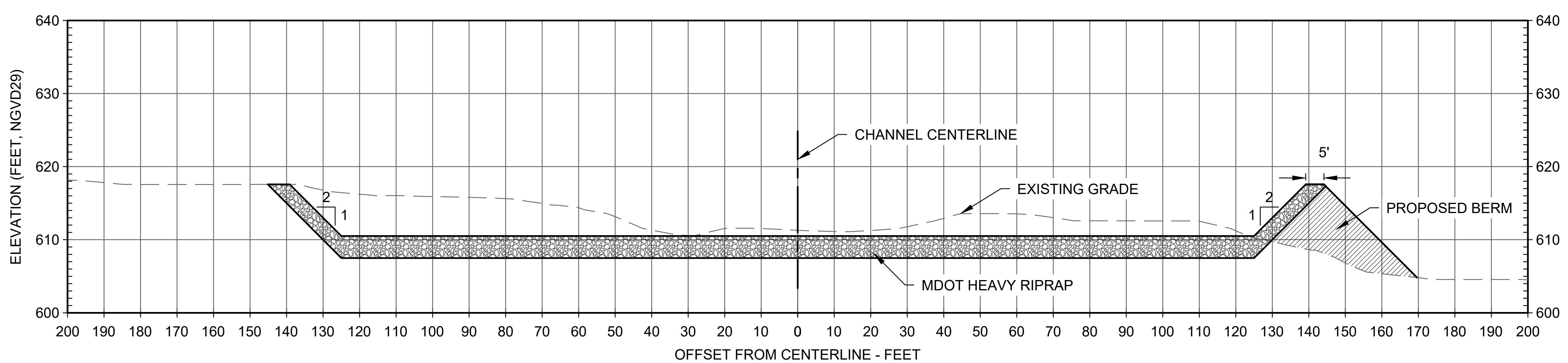


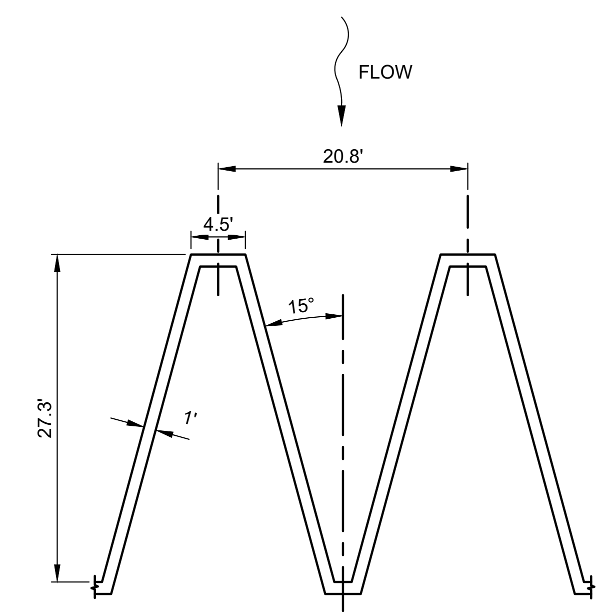
M C-15 SECTION
PROPOSED SPILLWAY

HORIZONTAL SCALE, FEET 0 10 20
VERTICAL SCALE, FEET 0 10 20
NO VERTICAL EXAGGERATION



K C-12 SECTION
PROPOSED SPILLWAY CHANNEL

HORIZONTAL SCALE, FEET 0 20 40
VERTICAL SCALE, FEET 0 10 20
NOTE: 2x VERTICAL EXAGGERATION



1 C-15 DETAIL
LABYRINTH WEIR CYCLE

SCALE, FEET 0 8 16

Attention:	NO.	DATE	ISSUE/REVISION	APP
0 1" If this scale bar does not measure 1" then drawing is not original scale.	0	xx/xx/xxxx	CONCEPTUAL DESIGN SUBMITTAL	--

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GEI CONSULTANTS OF MICHIGAN, P.C.
10501 WEST RESEARCH DRIVE
G100
MILWAUKEE, WI 53226
(414)930-7540

Designed:	P. DREW
Checked:	P. DREW
Drawn:	A. SAMPSON
Approved By:	B. WALTON

Four Lakes Task Force
FERC Project No. 2785

GEI Project 2002879

Sanford Dam Conceptual Design
Midland County, Michigan

LABYRINTH SPILLWAY - PROPOSED SPILLWAY & CHANNEL CROSS SECTIONS

DWG. NO. C-16

SHEET NO. 18

\\MSN1L-AMICH C:\Temp Local C\FLTF\Sanford\CAD\Design\Task4-4_Concept Design\C-03_Plan_Embankment.dwg - 1/25/2021

Appendix E

Proposed Conditions Spillway Capacity Rating Curve Calculations

Appendix E.1 – Secord Dam

Appendix E.2 – Smallwood Dam

Appendix E.3 – Edenville Dam

Appendix E.4 – Sanford Dam

Appendix E

Proposed Conditions Spillway Capacity Rating Curve Calculations

Appendix E.1 – Secord Dam

GEI Consultants

CLIENT:	Four Lakes Task Force		
PROJECT:	Secord Dam	Project: 2002879	Pages:
SUBJECT:	1/2 PMF + Spillway Design (Crest Gates)	Date: 11/12/2020	By: P. Drew
		Checked:	By:
		Approved:	By:

Purpose: Develop a spillway discharge rating curve for the proposed spillway

Procedure: Follow design steps presented in *Discharge Characterisitics of Broad-Crested Weirs*

References:
USBR (1987). Design of Small Dams
USGS (1957). Geological Survey Circular 397 Discharge Characteristics of Broad-Crested Weirs, J.H. Tracy
USGS (1968). Measurement of Peak Discharge at Dams by Indirect Method, Harry Hulsing

Input Variables:

Weir Crest El.	734.8	ft	L, Width Along Dam Axis	16.00	ft
Average Gate Weir Crest Width, b	19.5	ft	Number of Piers, N	1.0	-
Upstream Slope	1H:1V	Hor:Ver	Pier Contraction Coeff., Kp	0.01	-
Upstream Slope factor, Kr	Varies	-	Abutment Shape	45 Degree	-
Downstream Slope	1H:1V	Hor:Ver	Contraction Coeff., Ka	0.1	-
Downstream Slope Factor	Varies	-			
Number of Gates	2				

Step 1: Develop Spillway Discharge Rating Curve

Eq. (1-1) $Q=CbH^{3/2}$ USBR (1987) - Equation 3 pg. 365 (Discharge over uncontrolled crest)

where:

Q = Flow Rate (cfs)

C = Discharge Coefficient (USGS 1957), Figure 11 -- Discharge Coefficieints for broad-crested weirs with upstream face slope of 1:1

b = L' - 2(NKp + Ka)H (width of weir normal to flow)

H= Total Energy Head

Reservoir El. (ft)	Head, H (ft)	H/L	Weir Coeff.,C	D/S Slope Adjust[1].	Adjusted Weir Coeff.,C[2]	Effective Length (1 Gate) (ft), L'	Crest Gate Discharge (1 Gate) (cfs)	Crest Gate Discharge (Total) (cfs)	Comments
734.8	0.0	0.0	2.88	1.00	2.88	19.5	0	0	Spillway Invert
735.0	0.2	0.0	2.88	1.00	2.88	19.5	5	10	
735.5	0.7	0.0	2.87	1.00	2.87	19.5	33	65	
736.0	1.2	0.1	2.86	1.00	2.86	19.4	73	146	
736.5	1.7	0.1	2.86	1.00	2.86	19.3	122	245	
737.0	2.2	0.1	2.85	1.00	2.85	19.3	180	359	
737.5	2.7	0.2	2.85	1.00	2.85	19.2	243	487	
738.0	3.2	0.2	2.86	1.00	2.86	19.2	313	627	
738.5	3.7	0.2	2.86	1.00	2.86	19.1	389	778	
739.0	4.2	0.3	2.87	1.00	2.87	19.0	470	939	
739.5	4.7	0.3	2.87	1.00	2.87	19.0	556	1,111	
740.0	5.2	0.3	2.88	1.00	2.88	18.9	647	1,293	
740.5	5.7	0.4	2.89	1.00	2.89	18.9	742	1,485	
741.0	6.2	0.4	2.91	1.00	2.91	18.8	843	1,686	
741.5	6.7	0.4	2.92	1.00	2.92	18.7	948	1,897	
742.0	7.2	0.5	2.93	1.00	2.93	18.7	1,058	2,116	
742.5	7.7	0.5	2.95	1.00	2.95	18.6	1,173	2,345	
743.0	8.2	0.5	2.96	1.00	2.96	18.6	1,292	2,583	
743.5	8.7	0.5	2.98	1.00	2.98	18.5	1,415	2,830	
744.0	9.2	0.6	3.00	1.00	3.00	18.4	1,543	3,087	
744.5	9.7	0.6	3.02	1.00	3.02	18.4	1,676	3,351	
745.0	10.2	0.6	3.04	1.00	3.04	18.3	1,813	3,625	
745.5	10.7	0.7	3.06	1.00	3.06	18.3	1,954	3,908	
746.0	11.2	0.7	3.08	1.00	3.08	18.2	2,099	4,199	
746.5	11.7	0.7	3.10	1.00	3.10	18.1	2,249	4,498	
747.0	12.2	0.8	3.12	1.00	3.12	18.1	2,403	4,806	
747.5	12.7	0.8	3.14	1.00	3.14	18.0	2,561	5,123	
748.0	13.2	0.8	3.16	1.00	3.16	18.0	2,724	5,447	
748.5	13.7	0.9	3.18	1.00	3.18	17.9	2,890	5,779	
749.0	14.2	0.9	3.21	1.00	3.21	17.8	3,060	6,120	
749.5	14.7	0.9	3.23	1.00	3.23	17.8	3,234	6,467	
750.0	15.2	1.0	3.25	1.00	3.25	17.7	3,411	6,823	
750.5	15.7	1.0	3.27	1.00	3.27	17.7	3,592	7,185	
751.0	16.2	1.0	3.29	1.00	3.29	17.6	3,777	7,554	Normal Pool
751.5	16.7	1.0	3.31	1.00	3.31	17.5	3,965	7,930	
752.0	17.2	1.1	3.33	1.00	3.33	17.5	4,156	8,312	
752.5	17.7	1.1	3.35	1.00	3.35	17.4	4,350	8,700	
753.0	18.2	1.1	3.37	1.00	3.37	17.4	4,547	9,095	
753.5	18.7	1.2	3.39	1.00	3.39	17.3	4,747	9,494	
754.0	19.2	1.2	3.41	1.00	3.41	17.2	4,950	9,899	
754.5	19.7	1.2	3.43	1.00	3.43	17.2	5,154	10,309	
755.0	20.2	1.3	3.45	1.00	3.45	17.1	5,362	10,723	Tea Creek
755.5	20.7	1.3	3.47	1.00	3.47	17.1	5,571	11,142	
756.0	21.2	1.3	3.49	1.00	3.49	17.0	5,782	11,564	
756.5	21.7	1.4	3.50	1.00	3.50	16.9	5,995	11,990	
757.0	22.2	1.4	3.52	1.00	3.52	16.9	6,210	12,420	
757.5	22.7	1.4	3.53	1.00	3.53	16.8	6,426	12,852	
758.0	23.2	1.5	3.55	1.00	3.55	16.8	6,643	13,286	Zero Freeboard

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CLIENT:	Four Lakes Task Force		
PROJECT:	Secord Dam	Project: 2002879	Pages:
SUBJECT:	1/2 PMF + Spillway Design (Auxiliary Flashboards)	Date: 11/12/2020	By: P. Drew
		Checked:	By:
		Approved:	By:

Purpose: Develop a spillway discharge rating curve for the proposed spillway

Procedure: Follow design steps presented in *Discharge Characterisitics of Broad-Crested Weirs*

References:
USBR (1987). Design of Small Dams
USGS (1957). Geological Survey Circular 397 Discharge Characteristics of Broad-Crested Weirs, J.H. Tracy
USGS (1968). Measurement of Peak Discharge at Dams by Indirect Method, Harry Hulsing

Input Variables:

Weir Crest El.	748.5	ft	L, Width Along Dam Axis	6.00	ft
Weir Crest Width, b	130.0	ft	Number of Piers, N	1.0	-
Upstream Slope	2H:1V	Hor:Ver	Pier Contraction Coeff., Kp	0.0	-
Upstream Slope factor, Kr	Varies	-	Abutment Shape	45 Degree	-
Downstream Slope	2H:1V	Hor:Ver	Contraction Coeff., Ka	0.1	-
Downstream Slope Factor	Varies	-			

Step 1: Develop Spillway Discharge Rating Curve

Eq. (1-1) $Q=CbH^{3/2}$ USBR (1987) - Equation 3 pg. 365 (Discharge over uncontrolled crest)

where:
Q = Flow Rate (cfs)
C = Discharge Coefficient (USGS 1957), Figure 11 -- Discharge Coefficieints for broad-crested weirs with upstream face slope of 2:1
b = L' - 2(NKp + Ka)H (width of weir normal to flow)
H= Total Energy Head

Reservoir El. (ft)	Head, H (ft)	H/L	Weir Coeff.,C	D/S Slope Adjust[1].	Adjusted Weir Coeff.,C[2]	Effective Length (Gate 1) (ft), L'	Discharge (cfs)	Comments
748.5	0.0	0.0	2.89	1.00	2.89	130.0	0	Spillway Invert
749.0	0.5	0.1	2.89	1.00	2.89	129.9	0	
749.5	1.0	0.2	2.90	1.00	2.90	129.8	0	
750.0	1.5	0.3	2.92	1.00	2.92	129.7	0	
750.5	2.0	0.3	2.95	1.00	2.95	129.6	0	
751.0	2.5	0.4	2.99	1.00	2.99	129.5	0	Normal Pool
751.5	3.0	0.5	3.04	0.98	2.97	129.4	0	
752.0	3.5	0.6	3.08	0.98	3.02	129.3	0	
752.5	4.0	0.7	3.13	0.98	3.07	129.2	0	
753.0	4.5	0.8	3.19	0.98	3.12	129.1	0	
753.5	5.0	0.8	3.24	0.98	3.18	129.0	4,580	
754.0	5.5	0.9	3.29	0.98	3.23	128.9	5,366	
754.5	6.0	1.0	3.34	0.96	3.21	128.8	6,079	
755.0	6.5	1.1	3.39	0.96	3.26	128.7	6,950	Tea Creek
755.5	7.0	1.2	3.44	0.96	3.30	128.6	7,869	
756.0	7.5	1.3	3.48	0.96	3.35	128.5	8,830	
756.5	8.0	1.3	3.52	0.96	3.38	128.4	9,831	
757.0	8.5	1.4	3.56	0.96	3.42	128.3	10,868	
757.5	9.0	1.5	3.59	0.96	3.45	128.2	11,936	
758.0	9.5	1.6	3.62	0.96	3.47	128.1	13,032	Zero Freeboard

GEI Consultants

CLIENT:	Four Lakes Task Force
PROJECT:	Secord Dam — Project: 2002879 — Pages:
SUBJECT:	1/2 PMF + Spillway Design (Total) — Date: 11/12/2020 — By: P. Drew
	Checked: — By:
	Approved: — By:

Reservoir El. (ft)	Gated Spillway (cfs)	Auxiliary Spillway (cfs)	Tea Creek (cfs)	Total Spillway Capacity (cfs)	Comments
734.8	0	0	0	0	Primary Gated Spillway
735.0	10	0	0	10	
735.5	65	0	0	65	
736.0	146	0	0	146	
736.5	245	0	0	245	
737.0	359	0	0	359	
737.5	487	0	0	487	
738.0	627	0	0	627	
738.5	778	0	0	778	
739.0	939	0	0	939	
739.5	1,111	0	0	1,111	
740.0	1,293	0	0	1,293	
740.5	1,485	0	0	1,485	
741.0	1,686	0	0	1,686	
741.5	1,897	0	0	1,897	
742.0	2,116	0	0	2,116	
742.5	2,345	0	0	2,345	
743.0	2,583	0	0	2,583	
743.5	2,830	0	0	2,830	
744.0	3,087	0	0	3,087	
744.5	3,351	0	0	3,351	
745.0	3,625	0	0	3,625	
745.5	3,908	0	0	3,908	
746.0	4,199	0	0	4,199	
746.5	4,498	0	0	4,498	
747.0	4,806	0	0	4,806	
747.5	5,123	0	0	5,123	
748.0	5,447	0	0	5,447	
748.5	5,779	0	0	5,779	Auxiliary Spillway
749.0	6,120	0	0	6,120	
749.5	6,467	0	0	6,467	
750.0	6,823	0	0	6,823	
750.5	7,185	0	0	7,185	
751.0	7,554	0	0	7,554	Normal Pool
751.5	7,930	0	0	7,930	
752.0	8,312	0	0	8,312	
752.5	8,700	0	0	8,700	
753.0	9,095	0	0	9,095	
753.5	9,494	4,580	0	14,074	
754.0	9,899	5,366	0	15,265	
754.5	10,309	6,079	0	16,387	
755.0	10,723	6,950	0	17,674	
755.5	11,142	7,869	5	19,015	Tea Creek
756.0	11,564	8,830	50	20,444	
756.5	11,990	9,831	360	22,182	
757.0	12,420	10,868	1,030	24,317	
757.5	12,852	11,936	2,280	27,068	
758.0	13,286	13,032	4,445	30,763	Zero-Freeboard

Appendix E

Proposed Conditions Spillway Capacity Rating Curve Calculations

Appendix E.2 – Smallwood Dam

GEI Consultants

CLIENT:	Four Lakes Task Force		
PROJECT:	Smallwood Dam	Project: 2002879	Pages:
SUBJECT:	1/2 PMF + Spillway Design (Crest Gates)	Date: 11/12/2020	By: P. Drew
		Checked:	By:
		Approved:	By:

Purpose: Develop a spillway discharge rating curve for the proposed spillway

Procedure: Follow design steps presented in *Discharge Characterisitics of Broad-Crested Weirs*

References:
USBR (1987). Design of Small Dams
USGS (1957). Geological Survey Circular 397 Discharge Characteristics of Broad-Crested Weirs, J.H. Tracy
USGS (1968). Measurement of Peak Discharge at Dams by Indirect Method, Harry Hulsing

Input Variables:

Weir Crest El.	688.8	ft	L, Width Along Dam Axis	16.00	ft
Gate Weir Crest Width, b	22.6	ft	Number of Piers, N	1.0	-
Upstream Slope	1H:1V	Hor:Ver	Pier Contraction Coeff., Kp	0.01	-
Upstream Slope factor, Kr	Varies	-	Abutment Shape	45 Degree	-
Downstream Slope	1H:1V	Hor:Ver	Contraction Coeff., Ka	0.1	-
Downstream Slope Factor	Varies	-			
Number of Gates	2				

Step 1: Develop Spillway Discharge Rating Curve

Eq. (1-1) $Q=CbH^{3/2}$ USBR (1987) - Equation 3 pg. 365 (Discharge over uncontrolled crest)

where:
Q = Flow Rate (cfs)
C = Discharge Coefficient (USGS 1957), Figure 11 -- Discharge Coefficieints for broad-crested weirs with upstream face slope of 1:1
b = L' - 2(NKp + Ka)H (width of weir normal to flow)
H= Total Energy Head

Reservoir El. (ft)	Head, H (ft)	H/L	Weir Coeff.,C	D/S Slope Adjust[1].	Adjusted Weir Coeff.,C[2]	Effective Length (1 Gate) (ft), L'	Discharge (1 Gate) (cfs)	Discharge (Total) (cfs)	Comments
688.8	0.0	0.0	2.88	1.00	2.88	22.6	0	0	Spillway Invert
690.0	1.2	0.1	2.86	1.00	2.86	22.3	84	168	
690.5	1.7	0.1	2.86	1.00	2.86	22.2	141	282	
691.0	2.2	0.1	2.85	1.00	2.85	22.1	206	412	
691.5	2.7	0.2	2.85	1.00	2.85	22.0	279	558	
692.0	3.2	0.2	2.86	1.00	2.86	21.9	359	717	
692.5	3.7	0.2	2.86	1.00	2.86	21.8	444	889	
693.0	4.2	0.3	2.87	1.00	2.87	21.7	536	1,072	
693.5	4.7	0.3	2.87	1.00	2.87	21.6	633	1,266	
694.0	5.2	0.3	2.88	1.00	2.88	21.5	735	1,471	
694.5	5.7	0.4	2.89	1.00	2.89	21.4	843	1,686	
695.0	6.2	0.4	2.91	1.00	2.91	21.3	955	1,911	
695.5	6.7	0.4	2.92	1.00	2.92	21.2	1,073	2,145	
696.0	7.2	0.5	2.93	1.00	2.93	21.1	1,195	2,390	
696.5	7.7	0.5	2.95	1.00	2.95	21.0	1,322	2,644	
697.0	8.2	0.5	2.96	1.00	2.96	20.9	1,453	2,907	
697.5	8.7	0.5	2.98	1.00	2.98	20.8	1,589	3,179	
698.0	9.2	0.6	3.00	1.00	3.00	20.7	1,730	3,460	
698.5	9.7	0.6	3.02	1.00	3.02	20.6	1,875	3,750	
699.0	10.2	0.6	3.04	1.00	3.04	20.5	2,025	4,049	
699.5	10.7	0.7	3.06	1.00	3.06	20.4	2,178	4,356	
700.0	11.2	0.7	3.08	1.00	3.08	20.2	2,336	4,672	
700.5	11.7	0.7	3.10	1.00	3.10	20.1	2,498	4,996	
701.0	12.2	0.8	3.12	1.00	3.12	20.0	2,664	5,328	
701.5	12.7	0.8	3.14	1.00	3.14	19.9	2,834	5,668	
702.0	13.2	0.8	3.16	1.00	3.16	19.8	3,007	6,015	
702.5	13.7	0.9	3.18	1.00	3.18	19.7	3,185	6,369	
703.0	14.2	0.9	3.21	1.00	3.21	19.6	3,366	6,731	
703.5	14.7	0.9	3.23	1.00	3.23	19.5	3,550	7,099	
704.0	15.2	1.0	3.25	1.00	3.25	19.4	3,737	7,474	
704.5	15.7	1.0	3.27	1.00	3.27	19.3	3,927	7,855	
705.0	16.2	1.0	3.29	1.00	3.29	19.2	4,121	8,242	Normal Pool
705.5	16.7	1.0	3.31	1.00	3.31	19.1	4,317	8,634	
706.0	17.2	1.1	3.33	1.00	3.33	19.0	4,516	9,031	Auxiliary Spillway
706.5	17.7	1.1	3.35	1.00	3.35	18.9	4,717	9,433	
707.0	18.2	1.1	3.37	1.00	3.37	18.8	4,920	9,840	
707.5	18.7	1.2	3.39	1.00	3.39	18.7	5,125	10,250	
708.0	19.2	1.2	3.41	1.00	3.41	18.6	5,332	10,664	
708.5	19.7	1.2	3.43	1.00	3.43	18.5	5,541	11,081	
709.0	20.2	1.3	3.45	1.00	3.45	18.4	5,751	11,501	
709.5	20.7	1.3	3.47	1.00	3.47	18.3	5,962	11,924	
710.0	21.2	1.3	3.49	1.00	3.49	18.1	6,174	12,348	
710.5	21.7	1.4	3.50	1.00	3.50	18.0	6,387	12,774	
711.0	22.2	1.4	3.52	1.00	3.52	17.9	6,601	13,201	
711.5	22.7	1.4	3.53	1.00	3.53	17.8	6,814	13,629	
712.0	23.2	1.5	3.55	1.00	3.55	17.7	7,028	14,057	
712.5	23.7	1.5	3.56	1.00	3.56	17.6	7,242	14,485	
713.0	24.2	1.5	3.58	1.00	3.58	17.5	7,456	14,912	
713.5	24.7	1.5	3.59	1.00	3.59	17.4	7,669	15,338	
714.0	25.2	1.6	3.60	1.00	3.60	17.3	7,882	15,763	
714.5	25.7	1.6	3.61	1.00	3.61	17.2	8,093	16,187	
715.0	26.2	1.6	3.62	1.00	3.62	17.1	8,304	16,608	Zero Freeboard

GEI Consultants

CLIENT:	Four Lakes Task Force		
PROJECT:	Smallwood Dam	Project: 2002879	Pages:
SUBJECT:	1/2 PMF + Spillway Design (Auxiliary Flashboards)	Date: 11/12/2020	By: P. Drew
		Checked:	By:
		Approved:	By:

Purpose: Develop a spillway discharge rating curve for the proposed spillway

Procedure: Follow design steps presented in *Discharge Characterisitics of Broad-Crested Weirs*

References: USBR (1987). Design of Small Dams
USGS (1957). Geological Survey Circular 397 Discharge Characteristics of Broad-Crested Weirs, J.H. Tracy
USGS (1968). Measurement of Peak Discharge at Dams by Indirect Method, Harry Hulsing

Input Variables:

Weir Crest El.	706.0	ft	L, Width Along Dam Axis	6.00	ft
Weir Crest Width, b	150.0	ft	Number of Piers, N	1.0	-
Upstream Slope	2H:1V	Hor:Ver	Pier Contraction Coeff., Kp	0.0	-
Upstream Slope factor, Kr	Varies	-	Abutment Shape	45 Degree	-
Downstream Slope	2H:1V	Hor:Ver	Contraction Coeff., Ka	0.1	-
Downstream Slope Factor	Varies	-			

Step 1: Develop Spillway Discharge Rating Curve

Eq. (1-1) $Q=CbH^{3/2}$ USBR (1987) - Equation 3 pg. 365 (Discharge over uncontrolled crest)

where:
Q = Flow Rate (cfs)
C = Discharge Coefficient (USGS 1957), Figure 11 -- Discharge Coefficieints for broad-crested weirs with upstream face slope of 2:1
b = L' - 2(NKp + Ka)H (width of weir normal to flow)
H= Total Energy Head

Reservoir El. (ft)	Head, H (ft)	H/L	Weir Coeff.,C	D/S Slope Adjust[1].	Adjusted Weir Coeff.,C[2]	Effective Length (Gate 1) (ft), L'	Discharge (cfs)	Comments
706.0	0.0	0.0	2.89	1.00	2.89	150.0	0	Spillway Invert
706.5	0.5	0.1	2.89	1.00	2.89	149.9	0	
707.0	1.0	0.2	2.90	1.00	2.90	149.8	0	
707.5	1.5	0.3	2.92	1.00	2.92	149.7	0	
708.0	2.0	0.3	2.95	1.00	2.95	149.6	0	
708.5	2.5	0.4	2.99	1.00	2.99	149.5	0	
709.0	3.0	0.5	3.04	0.98	2.97	149.4	0	
709.5	3.5	0.6	3.08	0.98	3.02	149.3	0	
710.0	4.0	0.7	3.13	0.98	3.07	149.2	0	
710.5	4.5	0.8	3.19	0.98	3.12	149.1	0	
711.0	5.0	0.8	3.24	0.98	3.18	149.0	0	
711.5	5.5	0.9	3.29	0.98	3.23	148.9	6,198	Flasboards Trip
712.0	6.0	1.0	3.34	0.96	3.21	148.8	7,022	
712.5	6.5	1.1	3.39	0.96	3.26	148.7	8,030	
713.0	7.0	1.2	3.44	0.96	3.30	148.6	9,092	
713.5	7.5	1.3	3.48	0.96	3.35	148.5	10,204	
714.0	8.0	1.3	3.52	0.96	3.38	148.4	11,363	
714.5	8.5	1.4	3.56	0.96	3.42	148.3	12,562	
715.0	9.0	1.5	3.59	0.96	3.45	148.2	13,798	Zero Freeboard

GEI Consultants

CLIENT:	Four Lakes Task Force		
PROJECT:	Smallwood Dam	Project: 2002879	Pages:
SUBJECT:	1/2 PMF + Spillway Design (Total)	Date: 11/12/2020	By: P. Drew
		Checked:	By:
		Approved:	By:

Reservoir El. (ft)	Gated Spillway (cfs)	Auxiliary Spillway (cfs)	Total Spillway Capacity (cfs)	Comments
688.8	0	0	0	Primary Gated Spillway
690.0	168	0	168	
690.5	282	0	282	
691.0	412	0	412	
691.5	558	0	558	
692.0	717	0	717	
692.5	889	0	889	
693.0	1,072	0	1,072	
693.5	1,266	0	1,266	
694.0	1,471	0	1,471	
694.5	1,686	0	1,686	
695.0	1,911	0	1,911	
695.5	2,145	0	2,145	
696.0	2,390	0	2,390	
696.5	2,644	0	2,644	
697.0	2,907	0	2,907	
697.5	3,179	0	3,179	
698.0	3,460	0	3,460	
698.5	3,750	0	3,750	
699.0	4,049	0	4,049	
699.5	4,356	0	4,356	
700.0	4,672	0	4,672	
700.5	4,996	0	4,996	
701.0	5,328	0	5,328	
701.5	5,668	0	5,668	
702.0	6,015	0	6,015	
702.5	6,369	0	6,369	
703.0	6,731	0	6,731	
703.5	7,099	0	7,099	
704.0	7,474	0	7,474	
704.5	7,855	0	7,855	
705.0	8,242	0	8,242	
705.5	8,634	0	8,634	
706.0	9,031	0	9,031	Auxiliary Spillway
706.5	9,433	0	9,433	
707.0	9,840	0	9,840	
707.5	10,250	0	10,250	
708.0	10,664	0	10,664	
708.5	11,081	0	11,081	
709.0	11,501	0	11,501	
709.5	11,924	0	11,924	
710.0	12,348	0	12,348	
710.5	12,774	0	12,774	
711.0	13,201	0	13,201	
711.5	13,629	6,198	19,827	Flasboards Trip
712.0	14,057	7,022	21,079	
712.5	14,485	8,030	22,515	
713.0	14,912	9,092	24,004	
713.5	15,338	10,204	25,543	
714.0	15,763	11,363	27,126	
714.5	16,187	12,562	28,749	
715.0	16,608	13,798	30,406	Zero-Freeboard

Appendix E

Proposed Conditions Spillway Capacity Rating Curve Calculations

Appendix E.3 – Edenville Dam

GEI Consultants

CLIENT:	Four Lakes Task Force		
PROJECT:	Edenville Dam (Tittabawassee)	Project: 2002879	Pages:
SUBJECT:	1/2 PMF + Spillway Design (Crest Gates)	Date: 11/12/2020	By: P. Drew
		Checked:	By:
		Approved:	By:

Purpose: Develop a spillway discharge rating curve for the proposed spillway

Procedure: Follow design steps presented in *Discharge Characterisitics of Broad-Crested Weirs*

References: USBR (1987). Design of Small Dams
USGS (1957). Geological Survey Circular 397 Discharge Characteristics of Broad-Crested Weirs, J.H. Tracy
USGS (1968). Measurement of Peak Discharge at Dams by Indirect Method, Harry Hulsing

Input Variables:

Weir Crest El.	659.8	ft	L, Width Along Dam Axis	16.00	ft
Gate 1 Weir Crest Width, b	24.0	ft	Number of Piers, N (1,3)	1.0	-
Upstream Slope	2H:1V	Hor:Ver	Pier Contraction Coeff., Kp	0.01	-
Upstream Slope factor, Kr	Varies	-	Abutment Shape	45 Degree	-
Downstream Slope	2H:1V	Hor:Ver	Contraction Coeff., Ka (1,3)	0.1	-
Downstream Slope Factor	Varies	-			
Number of Gates	3				

Step 1: Develop Spillway Discharge Rating Curve

Eq. (1-1) $Q=CbH^{3/2}$ USBR (1987) - Equation 3 pg. 365 (Discharge over uncontrolled crest)

where:

Q = Flow Rate (cfs)

C = Discharge Coefficient (USGS 1957), Figure 11 -- Discharge Coefficieints for broad-crested weirs with upstream face slope of 1:1

b = L' - 2(NKp + Ka)H (width of weir normal to flow)

H= Total Energy Head

Reservoir El. (ft)	Head, H (ft)	H/L	Weir Coeff.,C	D/S Slope Adjust[1].	Adjusted Weir Coeff.,C[2]	Effective Length (1 Gate) (ft), L'	Discharge (1 Gate) (cfs)	Discharge (Total) (cfs)	Comments
659.8	0.0	0.0	2.89	1.00	2.89	24.0	0	0	Spillway Invert
660.0	0.2	0.0	2.89	1.00	2.89	24.0	6	19	
660.5	0.7	0.0	2.89	1.00	2.89	23.9	40	121	
661.0	1.2	0.1	2.89	1.00	2.89	23.7	90	271	
661.5	1.7	0.1	2.89	1.00	2.89	23.6	152	455	
662.0	2.2	0.1	2.90	1.00	2.90	23.5	223	668	
662.5	2.7	0.2	2.90	1.00	2.90	23.4	302	905	
663.0	3.2	0.2	2.91	1.00	2.91	23.3	389	1,166	
663.5	3.7	0.2	2.92	1.00	2.92	23.2	482	1,447	
664.0	4.2	0.3	2.93	1.00	2.93	23.1	583	1,748	
664.5	4.7	0.3	2.94	1.00	2.94	23.0	689	2,067	
665.0	5.2	0.3	2.95	1.00	2.95	22.9	802	2,405	
665.5	5.7	0.4	2.96	1.00	2.96	22.8	920	2,759	
666.0	6.2	0.4	2.98	1.00	2.98	22.7	1,043	3,130	
666.5	6.7	0.4	2.99	1.00	2.99	22.6	1,173	3,518	
667.0	7.2	0.5	3.01	1.00	3.01	22.5	1,307	3,921	
667.5	7.7	0.5	3.03	1.00	3.03	22.4	1,447	4,340	
668.0	8.2	0.5	3.04	1.00	3.04	22.3	1,592	4,775	
668.5	8.7	0.5	3.06	1.00	3.06	22.2	1,741	5,224	
669.0	9.2	0.6	3.08	1.00	3.08	22.1	1,896	5,687	
669.5	9.7	0.6	3.10	1.00	3.10	22.0	2,055	6,165	
670.0	10.2	0.6	3.12	1.00	3.12	21.9	2,219	6,657	
670.5	10.7	0.7	3.14	1.00	3.14	21.8	2,387	7,162	
671.0	11.2	0.7	3.16	1.00	3.16	21.6	2,560	7,681	
671.5	11.7	0.7	3.18	1.00	3.18	21.5	2,737	8,212	
672.0	12.2	0.8	3.19	1.00	3.19	21.4	2,919	8,756	
672.5	12.7	0.8	3.21	1.00	3.21	21.3	3,104	9,312	
673.0	13.2	0.8	3.23	1.00	3.23	21.2	3,293	9,880	
673.5	13.7	0.9	3.25	1.00	3.25	21.1	3,486	10,459	
674.0	14.2	0.9	3.27	1.00	3.27	21.0	3,683	11,049	
674.5	14.7	0.9	3.29	1.00	3.29	20.9	3,883	11,650	
675.0	15.2	1.0	3.31	1.00	3.31	20.8	4,087	12,260	
675.5	15.7	1.0	3.33	1.00	3.33	20.7	4,293	12,879	
676.0	16.2	1.0	3.35	1.00	3.35	20.6	4,503	13,508	
676.5	16.7	1.0	3.37	1.00	3.37	20.5	4,715	14,145	
677.0	17.2	1.1	3.39	1.00	3.39	20.4	4,930	14,789	
677.5	17.7	1.1	3.41	1.00	3.41	20.3	5,147	15,441	
678.0	18.2	1.1	3.43	1.00	3.43	20.2	5,366	16,099	
678.5	18.7	1.2	3.44	1.00	3.44	20.1	5,588	16,764	
679.0	19.2	1.2	3.46	1.00	3.46	20.0	5,811	17,434	
679.5	19.7	1.2	3.48	1.00	3.48	19.9	6,036	18,108	
680.0	20.2	1.3	3.49	1.00	3.49	19.8	6,262	18,787	
680.5	20.7	1.3	3.51	1.00	3.51	19.7	6,490	19,470	
681.0	21.2	1.3	3.52	1.00	3.52	19.5	6,719	20,156	
681.5	21.7	1.4	3.54	1.00	3.54	19.4	6,948	20,844	
682.0	22.2	1.4	3.55	1.00	3.55	19.3	7,178	21,533	
682.5	22.7	1.4	3.56	1.00	3.56	19.2	7,408	22,224	
683.0	23.2	1.5	3.57	1.00	3.57	19.1	7,639	22,916	
683.5	23.7	1.5	3.59	1.00	3.59	19.0	7,869	23,608	
684.0	24.2	1.5	3.60	1.00	3.60	18.9	8,100	24,299	
684.5	24.7	1.5	3.61	1.00	3.61	18.8	8,330	24,989	
685.0	25.2	1.6	3.62	1.00	3.62	18.7	8,559	25,677	
685.5	25.7	1.6	3.63	1.00	3.63	18.6	8,788	26,363	Zero-Freeboard

CLIENT:	Four Lakes Task Force		
PROJECT:	Edenville Dam (Tobacco)	Project: 2002879	Pages:
SUBJECT:	1/2 PMF + Spillway Design (Crest Gates)	Date: 11/12/2020	By: P. Drew
		Checked:	By:
		Approved:	By:

Purpose: Develop a spillway discharge rating curve for the proposed spillway

Procedure: Follow design steps presented in *Discharge Characterisitics of Broad-Crested Weirs*

References: USBR (1987). Design of Small Dams
USGS (1957). Geological Survey Circular 397 Discharge Characteristics of Broad-Crested Weirs, J.H. Tracy
USGS (1968). Measurement of Peak Discharge at Dams by Indirect Method, Harry Hulsing

Input Variables:

Weir Crest El.	659.8	ft	L, Width Along Dam Axis	16.00	ft
Avg. Gate 1 Weir Crest Width, b	17.2	ft	Number of Piers, N (1,3)	1.0	-
Upstream Slope	2H:1V	Hor:Ver	Pier Contraction Coeff., Kp	0.01	-
Upstream Slope factor, Kr	Varies	-	Abutment Shape	45 Degree	-
Downstream Slope	2H:1V	Hor:Ver	Contraction Coeff., Ka (1,3)	0.1	-
Downstream Slope Factor	Varies	-			
Number of Gates	3				

Step 1: Develop Spillway Discharge Rating Curve

Eq. (1-1) $Q=CbH^{3/2}$ USBR (1987) - Equation 3 pg. 365 (Discharge over uncontrolled crest)

where:

Q = Flow Rate (cfs)

C = Discharge Coefficient (USGS 1957), Figure 11 -- Discharge Coefficieints for broad-crested weirs with upstream face slope of 1:1

b = L' - 2(NKp + Ka)H (width of weir normal to flow)

H= Total Energy Head

Reservoir El. (ft)	Head, H (ft)	H/L	Weir Coeff.,C	D/S Slope Adjust[1].	Adjusted Weir Coeff.,C[2]	Effective Length (1 Gate) (ft), L'	Discharge (1 Gate) (cfs)	Discharge (Total) (cfs)	Comments
659.8	0.0	0.0	2.89	1.00	2.89	17.2	0	0	Spillway Invert
660.0	0.2	0.0	2.89	1.00	2.89	17.1	4	13	
660.5	0.7	0.0	2.89	1.00	2.89	17.0	29	86	
661.0	1.2	0.1	2.89	1.00	2.89	16.9	64	193	
661.5	1.7	0.1	2.89	1.00	2.89	16.8	108	323	
662.0	2.2	0.1	2.90	1.00	2.90	16.7	158	474	
662.5	2.7	0.2	2.90	1.00	2.90	16.6	214	641	
663.0	3.2	0.2	2.91	1.00	2.91	16.5	275	824	
663.5	3.7	0.2	2.92	1.00	2.92	16.4	340	1,021	
664.0	4.2	0.3	2.93	1.00	2.93	16.3	410	1,231	
664.5	4.7	0.3	2.94	1.00	2.94	16.2	484	1,453	
665.0	5.2	0.3	2.95	1.00	2.95	16.1	562	1,687	
665.5	5.7	0.4	2.96	1.00	2.96	16.0	644	1,932	
666.0	6.2	0.4	2.98	1.00	2.98	15.9	729	2,188	
666.5	6.7	0.4	2.99	1.00	2.99	15.8	818	2,454	
667.0	7.2	0.5	3.01	1.00	3.01	15.7	910	2,730	
667.5	7.7	0.5	3.03	1.00	3.03	15.5	1,005	3,015	
668.0	8.2	0.5	3.04	1.00	3.04	15.4	1,103	3,310	
668.5	8.7	0.5	3.06	1.00	3.06	15.3	1,205	3,614	
669.0	9.2	0.6	3.08	1.00	3.08	15.2	1,309	3,926	
669.5	9.7	0.6	3.10	1.00	3.10	15.1	1,416	4,247	
670.0	10.2	0.6	3.12	1.00	3.12	15.0	1,525	4,576	
670.5	10.7	0.7	3.14	1.00	3.14	14.9	1,637	4,912	
671.0	11.2	0.7	3.16	1.00	3.16	14.8	1,752	5,256	
671.5	11.7	0.7	3.18	1.00	3.18	14.7	1,869	5,607	
672.0	12.2	0.8	3.19	1.00	3.19	14.6	1,988	5,965	
672.5	12.7	0.8	3.21	1.00	3.21	14.5	2,110	6,329	
673.0	13.2	0.8	3.23	1.00	3.23	14.4	2,233	6,700	
673.5	13.7	0.9	3.25	1.00	3.25	14.3	2,359	7,076	
674.0	14.2	0.9	3.27	1.00	3.27	14.2	2,486	7,457	
674.5	14.7	0.9	3.29	1.00	3.29	14.1	2,614	7,843	
675.0	15.2	1.0	3.31	1.00	3.31	14.0	2,745	8,234	
675.5	15.7	1.0	3.33	1.00	3.33	13.9	2,876	8,628	
676.0	16.2	1.0	3.35	1.00	3.35	13.8	3,009	9,027	
676.5	16.7	1.0	3.37	1.00	3.37	13.7	3,143	9,428	
677.0	17.2	1.1	3.39	1.00	3.39	13.6	3,277	9,832	
677.5	17.7	1.1	3.41	1.00	3.41	13.4	3,413	10,239	
678.0	18.2	1.1	3.43	1.00	3.43	13.3	3,549	10,647	
678.5	18.7	1.2	3.44	1.00	3.44	13.2	3,686	11,057	
679.0	19.2	1.2	3.46	1.00	3.46	13.1	3,823	11,468	
679.5	19.7	1.2	3.48	1.00	3.48	13.0	3,960	11,879	
680.0	20.2	1.3	3.49	1.00	3.49	12.9	4,097	12,290	
680.5	20.7	1.3	3.51	1.00	3.51	12.8	4,233	12,700	
681.0	21.2	1.3	3.52	1.00	3.52	12.7	4,370	13,110	
681.5	21.7	1.4	3.54	1.00	3.54	12.6	4,506	13,518	
682.0	22.2	1.4	3.55	1.00	3.55	12.5	4,641	13,924	
682.5	22.7	1.4	3.56	1.00	3.56	12.4	4,776	14,328	
683.0	23.2	1.5	3.57	1.00	3.57	12.3	4,910	14,729	
683.5	23.7	1.5	3.59	1.00	3.59	12.2	5,042	15,127	
684.0	24.2	1.5	3.60	1.00	3.60	12.1	5,174	15,522	
684.5	24.7	1.5	3.61	1.00	3.61	12.0	5,304	15,912	
685.0	25.2	1.6	3.62	1.00	3.62	11.9	5,433	16,298	
685.5	25.7	1.6	3.63	1.00	3.63	11.8	5,560	16,679	Zero-Freeboard

LABYRINTH WEIR DESIGN
No Approach Velocity

PROJECT:	Edenville Labyrinth	TIME:	16:42:20
PROJECT NO.	2002879	DATE:	17-Feb-21
FLOOD CRITERIA:	1/2 PMF +	BY:	PDD

USER INPUT

Max. Res	Zr	681.5	ft	Thickness			
Crest el.	Zc	678.0	ft	Wall	Tw	1.5	ft
Floor el.	Zf	670.0	ft	Slab	Ts	1.5	ft
Spillway width	Ws	250.0	ft	Cutoff Depth			
Apex Width	2a	3	ft	Sheet Pile	Ds	1	ft
No. of cycles	n	12		Conc Wall	Dc	1	ft
Magnification	L/W	3					

CHECK ON RATIOS

L_{de}/B = 0.34 Ld/B RATIO IS OK

H_o/P = 0.44 Ho/P RATIO IS OK

α = 15.22 Angle IS OK

Note: L_{de}/B must be <= 0.35

Ho/P must be <= 0.9

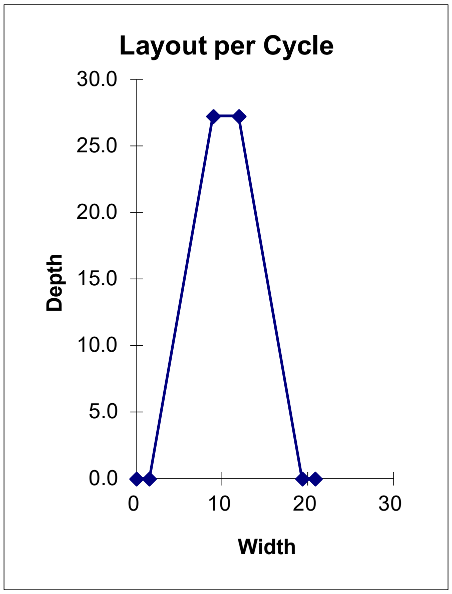
α must be >= 6 deg

LABYRINTH DIMENSIONS (Per Cycle)

Wall Height	P	8	ft
Width	W	20.83	ft
Length	L	62.50	ft
Wall Length	B	28.25	ft
Depth	D	27.26	ft
Head max	H	3.50	ft
Wall Angle	α	15.22	deg
Length of Interference	L_{de}	9.71	ft

CREST LAYOUT
(One Cycle)

X	Y
0	0
1.50	0
8.92	27.26
11.92	27.26
19.33	0
20.83	0



DISCHARGE

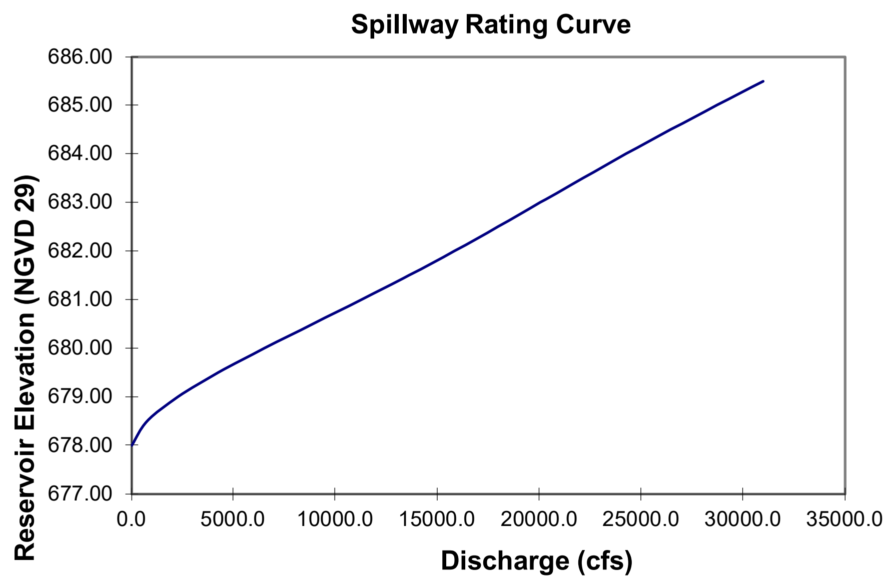
Qmax 13,614 cfs

COEFFICIENTS

Column	4.00
Cd lower	0.51
Cd Upper	0.58
Cd	0.52
Efficacy	2.05

RATING CURVE

HEAD	H_o/P	C_{lower}	C_{upper}	C_d	Q	RES
7.50	0.94	0.37	0.43	0.38	30977	685.50
7.00	0.88	0.38	0.44	0.39	28719	685.00
6.50	0.81	0.39	0.46	0.40	26461	684.50
6.00	0.75	0.41	0.47	0.41	24268	684.00
5.50	0.69	0.42	0.49	0.43	22147	683.50
5.00	0.63	0.44	0.51	0.45	20068	683.00
4.50	0.56	0.46	0.53	0.47	17982	682.50
4.00	0.50	0.49	0.55	0.49	15842	682.00
3.50	0.44	0.51	0.58	0.52	13614	681.50
3.00	0.38	0.54	0.60	0.54	11292	681.00
2.50	0.31	0.56	0.61	0.56	8905	680.50
2.00	0.25	0.57	0.62	0.57	6525	680.00
1.50	0.19	0.58	0.62	0.58	4265	679.50
1.00	0.13	0.57	0.60	0.57	2282	679.00
0.50	0.06	0.54	0.56	0.54	767	678.50
0.00	0.00	0.49	0.49	0.49	0	678.00



Discharge Coefficient Table Tullis et al. (1995)

Angle wall makes with centerline α

	6	8	12	15	18	25	35	90
	-------	-------	-------	-------	-------	-------	-------	-------
A0	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49
A1	-0.24	1.08	1.06	1.00	1.32	1.51	1.69	1.46
A2	-1.20	-5.27	-4.43	-3.57	-4.13	-3.83	-4.05	-2.56
A3	2.17	6.79	5.18	3.82	4.24	3.40	3.62	1.44
A4	-1.03	-2.83	-1.97	-1.38	-1.50	-1.05	-1.10	

GEI Consultants

CLIENT:	Four Lakes Task Force		
PROJECT:	Edenville Dam	Project: 2002879	Pages:
SUBJECT:	1/2 PMF + Spillway Design (Total)	Date: 11/12/2020	By: P. Drew
		Checked:	By:
		Approved:	By:

Reservoir El. (ft)	Tittabawassee Gated Spillway (cfs)	Tobacco Gated Spillway (cfs)	Total Gated Spillway (cfs)	Labyrinth Spillway (cfs)	Total	Comments
659.8	0	0	0		0	Spillway Invert
660.0	19	13	32		32	
660.5	121	86	208		208	
661.0	271	193	464		464	
661.5	455	323	778		778	
662.0	668	474	1,141		1,141	
662.5	905	641	1,547		1,547	
663.0	1,166	824	1,990		1,990	
663.5	1,447	1,021	2,468		2,468	
664.0	1,748	1,231	2,979		2,979	
664.5	2,067	1,453	3,521		3,521	
665.0	2,405	1,687	4,092		4,092	
665.5	2,759	1,932	4,691		4,691	
666.0	3,130	2,188	5,318		5,318	
666.5	3,518	2,454	5,972		5,972	
667.0	3,921	2,730	6,651		6,651	
667.5	4,340	3,015	7,356		7,356	
668.0	4,775	3,310	8,085		8,085	
668.5	5,224	3,614	8,837		8,837	
669.0	5,687	3,926	9,613		9,613	
669.5	6,165	4,247	10,412		10,412	
670.0	6,657	4,576	11,232		11,232	
670.5	7,162	4,912	12,074		12,074	
671.0	7,681	5,256	12,937		12,937	
671.5	8,212	5,607	13,819		13,819	
672.0	8,756	5,965	14,721		14,721	
672.5	9,312	6,329	15,641		15,641	
673.0	9,880	6,700	16,580		16,580	
673.5	10,459	7,076	17,535		17,535	
674.0	11,049	7,457	18,506		18,506	
674.5	11,650	7,843	19,493		19,493	
675.0	12,260	8,234	20,493		20,493	
675.5	12,879	8,628	21,508		21,508	
676.0	13,508	9,027	22,535		22,535	Normal Pool
676.5	14,145	9,428	23,573		23,573	
677.0	14,789	9,832	24,622		24,622	
677.5	15,441	10,239	25,680		25,680	
678.0	16,099	10,647	26,747	0	26,747	Labyrinth Spillway
678.5	16,764	11,057	27,821	767	28,588	
679.0	17,434	11,468	28,901	2,282	31,183	
679.5	18,108	11,879	29,987	4,265	34,252	
680.0	18,787	12,290	31,077	6,525	37,602	
680.5	19,470	12,700	32,170	8,905	41,076	
681.0	20,156	13,110	33,265	11,292	44,558	
681.5	20,844	13,518	34,362	13,614	47,976	
682.0	21,533	13,924	35,458	15,842	51,300	
682.5	22,224	14,328	36,553	17,982	54,535	
683.0	22,916	14,729	37,645	20,068	57,713	
683.5	23,608	15,127	38,735	22,147	60,882	
684.0	24,299	15,522	39,820	24,268	64,088	
684.5	24,989	15,912	40,901	26,461	67,362	
685.0	25,677	16,298	41,975	28,719	70,694	
685.5	26,363	16,679	43,042	30,977	74,019	Zero-Freeboard

Appendix E

Proposed Conditions Spillway Capacity Rating Curve Calculations

Appendix E.4 – Sanford Dam

GEI Consultants

CLIENT:	Four Lakes Task Force		
PROJECT:	Sanford Dam	Project: 2002879	Pages:
SUBJECT:	1/2 PMF + Spillway Design (Crest Gates)	Date: 11/12/2020	By: P. Drew
		Checked:	By:
		Approved:	By:

Purpose: Develop a spillway discharge rating curve for the proposed spillway

Procedure: Follow design steps presented in *Discharge Characterisitics of Broad-Crested Weirs*

References: USBR (1987). Design of Small Dams
USGS (1957). Geological Survey Circular 397 Discharge Characteristics of Broad-Crested Weirs, J.H. Tracy
USGS (1968). Measurement of Peak Discharge at Dams by Indirect Method, Harry Hulsing

Input Variables:

Weir Crest El.	614.8	ft	L, Width Along Dam Axis	16.00	ft
Avg. Gate 1 Weir Crest Width, b	18.6	ft	Number of Piers, N (1,3)	1.0	-
Upstream Slope	2H:1V	Hor:Ver	Pier Contraction Coeff., Kp	0.0	-
Upstream Slope factor, Kr	Varies	-	Abutment Shape	45 Degree	-
Downstream Slope	2H:1V	Hor:Ver	Contraction Coeff., Ka (1,3)	0.1	-
Downstream Slope Factor	Varies	-			
Number of Gates	8				

Step 1: Develop Spillway Discharge Rating Curve

Eq. (1-1) $Q=CbH^{3/2}$ USBR (1987) - Equation 3 pg. 365 (Discharge over uncontrolled crest)

where:

Q = Flow Rate (cfs)

C = Discharge Coefficient (USGS 1957), Figure 11 -- Discharge Coefficieints for broad-crested weirs with upstream face slope of 1:1

b = L' - 2(NKp + Ka)H (width of weir normal to flow)

H= Total Energy Head

Reservoir El. (ft)	Head, H (ft)	H/L	Weir Coeff.,C	D/S Slope Adjust[1].	Adjusted Weir Coeff.,C[2]	Effective Length (1 Gate) (ft), L'	Discharge (1 Gate) (cfs)	Discharge (Total) (cfs)	Comments
614.8	0.0	0.0	2.88	1.00	2.88	18.6	0	0	Spillway Invert
615.0	0.2	0.0	2.88	1.00	2.88	18.6	5	38	
615.5	0.7	0.0	2.87	1.00	2.87	18.5	31	248	
616.0	1.2	0.1	2.86	1.00	2.86	18.4	69	553	
616.5	1.7	0.1	2.86	1.00	2.86	18.3	116	926	
617.0	2.2	0.1	2.85	1.00	2.85	18.2	169	1,355	
617.5	2.7	0.2	2.85	1.00	2.85	18.1	229	1,832	
618.0	3.2	0.2	2.86	1.00	2.86	18.0	294	2,353	
618.5	3.7	0.2	2.86	1.00	2.86	17.9	364	2,913	
619.0	4.2	0.3	2.87	1.00	2.87	17.8	439	3,511	
619.5	4.7	0.3	2.87	1.00	2.87	17.7	518	4,143	
620.0	5.2	0.3	2.88	1.00	2.88	17.6	601	4,809	
620.5	5.7	0.4	2.89	1.00	2.89	17.5	689	5,508	
621.0	6.2	0.4	2.91	1.00	2.91	17.4	780	6,238	
621.5	6.7	0.4	2.92	1.00	2.92	17.3	875	6,999	
622.0	7.2	0.5	2.93	1.00	2.93	17.2	974	7,790	
622.5	7.7	0.5	2.95	1.00	2.95	17.1	1,076	8,610	
623.0	8.2	0.5	2.96	1.00	2.96	17.0	1,182	9,459	
623.5	8.7	0.5	2.98	1.00	2.98	16.9	1,292	10,336	
624.0	9.2	0.6	3.00	1.00	3.00	16.8	1,405	11,240	
624.5	9.7	0.6	3.02	1.00	3.02	16.7	1,522	12,172	
625.0	10.2	0.6	3.04	1.00	3.04	16.6	1,641	13,130	
625.5	10.7	0.7	3.06	1.00	3.06	16.5	1,764	14,114	
626.0	11.2	0.7	3.08	1.00	3.08	16.4	1,890	15,123	
626.5	11.7	0.7	3.10	1.00	3.10	16.3	2,020	16,157	
627.0	12.2	0.8	3.12	1.00	3.12	16.2	2,152	17,214	
627.5	12.7	0.8	3.14	1.00	3.14	16.1	2,287	18,294	
628.0	13.2	0.8	3.16	1.00	3.16	16.0	2,425	19,397	
628.5	13.7	0.9	3.18	1.00	3.18	15.9	2,565	20,520	
629.0	14.2	0.9	3.21	1.00	3.21	15.8	2,708	21,664	
629.5	14.7	0.9	3.23	1.00	3.23	15.7	2,853	22,826	
630.0	15.2	1.0	3.25	1.00	3.25	15.6	3,001	24,007	
630.5	15.7	1.0	3.27	1.00	3.27	15.5	3,151	25,205	
631.0	16.2	1.0	3.29	1.00	3.29	15.4	3,302	26,419	
631.5	16.7	1.0	3.31	1.00	3.31	15.3	3,456	27,648	
632.0	17.2	1.1	3.33	1.00	3.33	15.2	3,611	28,890	
632.5	17.7	1.1	3.35	1.00	3.35	15.1	3,768	30,144	
633.0	18.2	1.1	3.37	1.00	3.37	15.0	3,926	31,409	
633.5	18.7	1.2	3.39	1.00	3.39	14.9	4,085	32,683	
634.0	19.2	1.2	3.41	1.00	3.41	14.8	4,246	33,966	
634.5	19.7	1.2	3.43	1.00	3.43	14.7	4,407	35,256	
635.0	20.2	1.3	3.45	1.00	3.45	14.6	4,569	36,551	
635.5	20.7	1.3	3.47	1.00	3.47	14.5	4,731	37,850	
636.0	21.2	1.3	3.49	1.00	3.49	14.4	4,894	39,151	
636.5	21.7	1.4	3.50	1.00	3.50	14.3	5,057	40,454	
637.0	22.2	1.4	3.52	1.00	3.52	14.2	5,220	41,757	
637.5	22.7	1.4	3.53	1.00	3.53	14.1	5,382	43,058	
638.0	23.2	1.5	3.55	1.00	3.55	14.0	5,544	44,356	Zero-Freeboard

LABYRINTH WEIR DESIGN
No Approach Velocity

PROJECT:	Sanford Labyrinth	**TIME:**	17:04:02
PROJECT NO.	2002879	**DATE:**	17-Feb-21
FLOOD CRITERIA:	1/2 PMF +	**BY:**	PDD

USER INPUT

Max. Res	**Zr**	636.0	**ft**	**Thickness**			
Crest el.	**Zc**	632.5	**ft**	**Wall**	**Tw**	1.25	**ft**
Floor el.	**Zf**	624.5	**ft**	**Slab**	**Ts**	1.25	**ft**
Spillway width	**Ws**	250.0	**ft**	**Cutoff Depth**			
Apex Width	**2a**	3	**ft**	**Sheet Pile**	**Ds**	1	**ft**
No. of cycles	**n**	12		**Conc Wall**	**Dc**	1	**ft**
Magnification	**L/W**	3					

CHECK ON RATIOS

Lde/B =	0.34	**Ld/B RATIO IS OK**
H_o/P =	0.44	**Ho/P RATIO IS OK**
α =	15.22	**Angle IS OK**

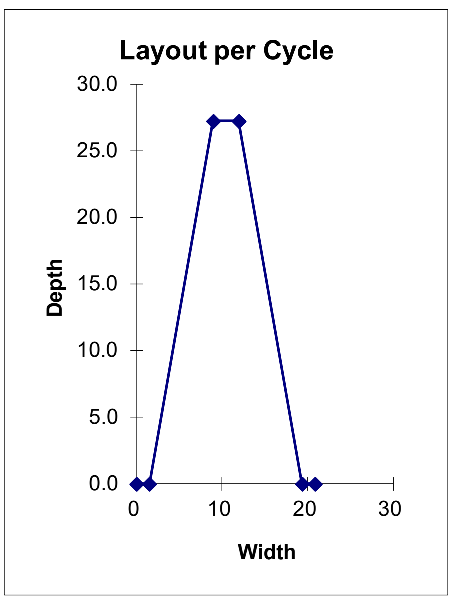
Note: L_{de}/B must be <= 0.35
Ho/P must be <= 0.9
α must be >= 6 deg

LABYRINTH DIMENSIONS (Per Cycle)

Wall Height	**P**	8	**ft**
Width	**W**	20.83	**ft**
Length	**L**	62.50	**ft**
Wall Length	**B**	28.25	**ft**
Depth	**D**	27.26	**ft**
Head max	**H**	3.50	**ft**
Wall Angle	α	15.22	**deg**
Length of Interference	L_{de}	9.71	**ft**

CREST LAYOUT
(One Cycle)

X	Y
0	0
1.50	0
8.92	27.26
11.92	27.26
19.33	0
20.83	0



DISCHARGE

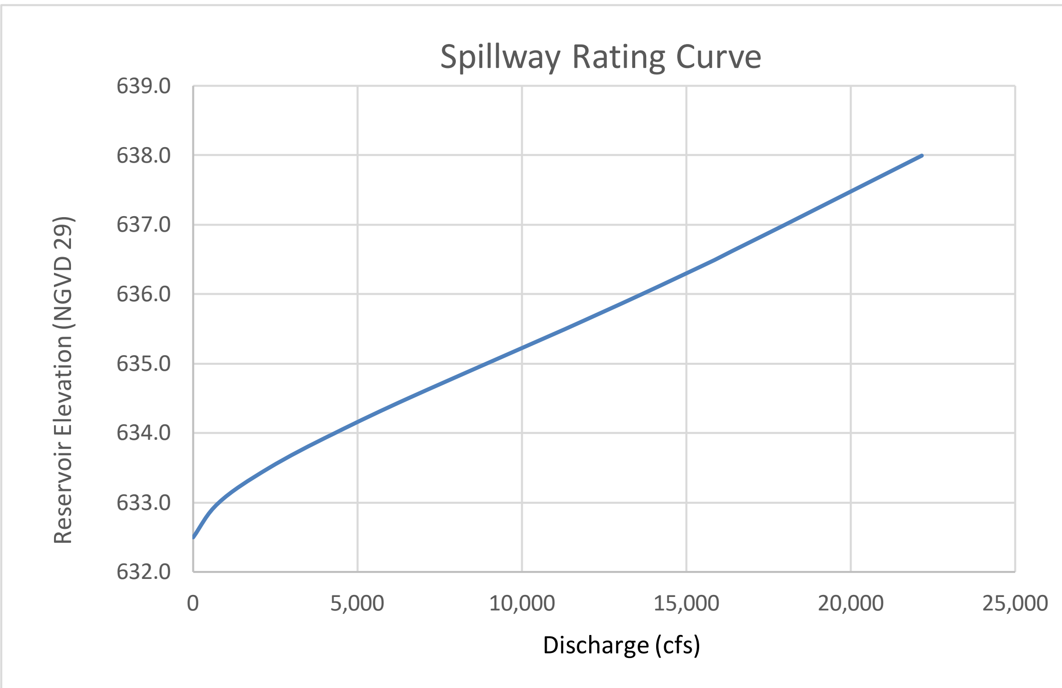
Qmax	13,614	**cfs**

COEFFICIENTS

Column	4.00
Cd lower	0.51
Cd Upper	0.58
Cd	0.52
Efficacy	2.05

RATING CURVE

HEAD	H_o/P	C_{lower}	C_{upper}	C_d	Q	RES
5.50	0.69	0.42	0.49	0.43	22147	638.00
5.00	0.63	0.44	0.51	0.45	20068	637.50
4.50	0.56	0.46	0.53	0.47	17982	637.00
4.00	0.50	0.49	0.55	0.49	15842	636.50
3.50	0.44	0.51	0.58	0.52	13614	636.00
3.00	0.38	0.54	0.60	0.54	11292	635.50
2.50	0.31	0.56	0.61	0.56	8905	635.00
2.00	0.25	0.57	0.62	0.57	6525	634.50
1.50	0.19	0.58	0.62	0.58	4265	634.00
1.00	0.13	0.57	0.60	0.57	2282	633.50
0.50	0.06	0.54	0.56	0.54	767	633.00
0	0	0.49	0.49	0.49	0	632.5



Discharge Coefficient Table Tullis et al. (1995)

	Angle wall makes with centerline α							
	6	**8**	**12**	**15**	**18**	**25**	**35**	**90**
	-------	-------	-------	-------	-------	-------	-------	-------
A0	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49
A1	-0.24	1.08	1.06	1.00	1.32	1.51	1.69	1.46
A2	-1.20	-5.27	-4.43	-3.57	-4.13	-3.83	-4.05	-2.56
A3	2.17	6.79	5.18	3.82	4.24	3.40	3.62	1.44
A4	-1.03	-2.83	-1.97	-1.38	-1.50	-1.05	-1.10	

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CLIENT:	Four Lakes Task Force		
PROJECT:	Sanford Dam	Project: 2002879	Pages:
SUBJECT:	1/2 PMF + Spillway Design (Total)	Date: 11/12/2020	By: P. Drew
		Checked:	By:
		Approved:	By:

Reservoir El. (ft)	Gated Spillway (cfs)	Labyrinth Spillway (cfs)	Total Spilway (cfs)	Comments
614.8	0	0	0	Spillway Invert
615.0	38	0	38	
615.5	248	0	248	
616.0	553	0	553	
616.5	926	0	926	
617.0	1,355	0	1,355	
617.5	1,832	0	1,832	
618.0	2,353	0	2,353	
618.5	2,913	0	2,913	
619.0	3,511	0	3,511	
619.5	4,143	0	4,143	
620.0	4,809	0	4,809	
620.5	5,508	0	5,508	
621.0	6,238	0	6,238	
621.5	6,999	0	6,999	
622.0	7,790	0	7,790	
622.5	8,610	0	8,610	
623.0	9,459	0	9,459	
623.5	10,336	0	10,336	
624.0	11,240	0	11,240	
624.5	12,172	0	12,172	
625.0	13,130	0	13,130	
625.5	14,114	0	14,114	
626.0	15,123	0	15,123	
626.5	16,157	0	16,157	
627.0	17,214	0	17,214	
627.5	18,294	0	18,294	
628.0	19,397	0	19,397	
628.5	20,520	0	20,520	
629.0	21,664	0	21,664	
629.5	22,826	0	22,826	
630.0	24,007	0	24,007	
630.5	25,205	0	25,205	
631.0	26,419	0	26,419	
631.5	27,648	0	27,648	
632.0	28,890	0	28,890	
632.5	30,144	0	30,144	Auxiliary Spillway
633.0	31,409	767	32,176	
633.5	32,683	2,282	34,965	
634.0	33,966	4,265	38,231	
634.5	35,256	6,525	41,780	
635.0	36,551	8,905	45,456	
635.5	37,850	11,292	49,142	
636.0	39,151	13,614	52,766	
636.5	40,454	15,842	56,296	
637.0	41,757	17,982	59,739	
637.5	43,058	20,068	63,125	
638.0	44,356	22,147	66,502	Zero-Freeboard

Appendix F

Proposed Conditions HEC-RAS Model Input and Output Data Sheets

Appendix F.1 – Secord Dam

Appendix F.2 – Smallwood Dam

Appendix F.3 – Edenville Dam

Appendix F.4 – Sanford Dam

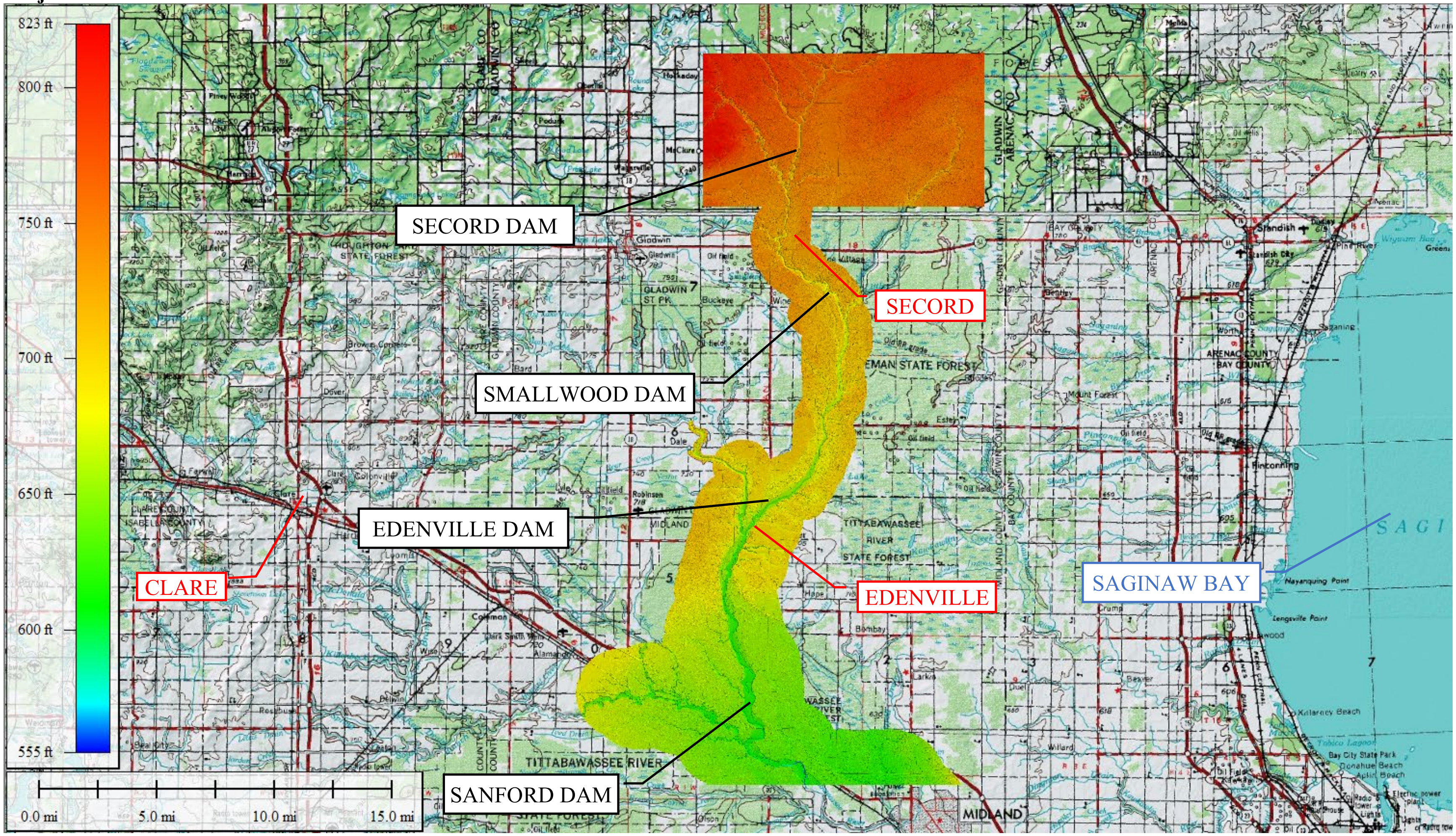
Appendix F

Proposed Conditions HEC-RAS Model Input and Output Data Sheets

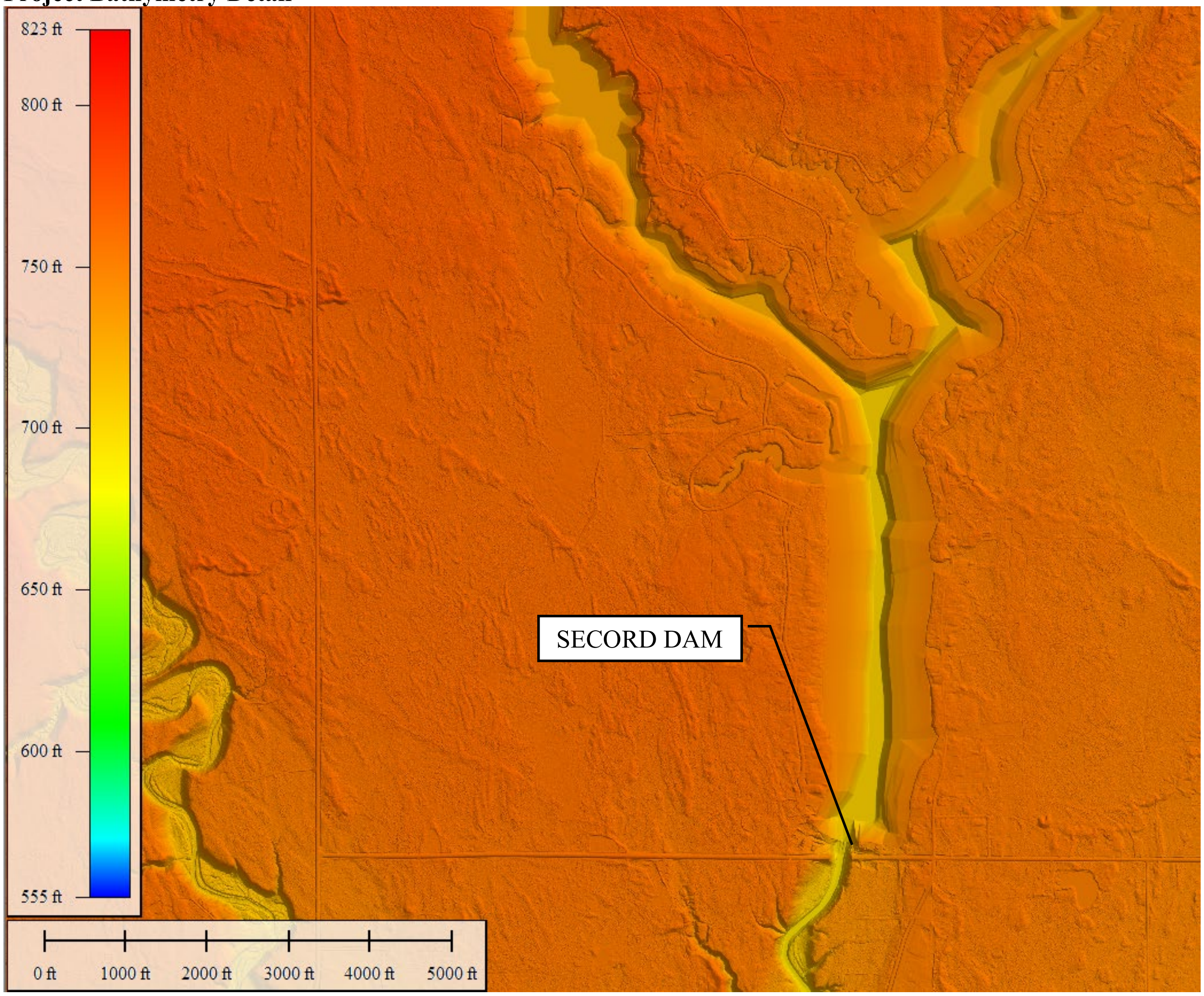
Appendix F.1 – Secord Dam

INPUT

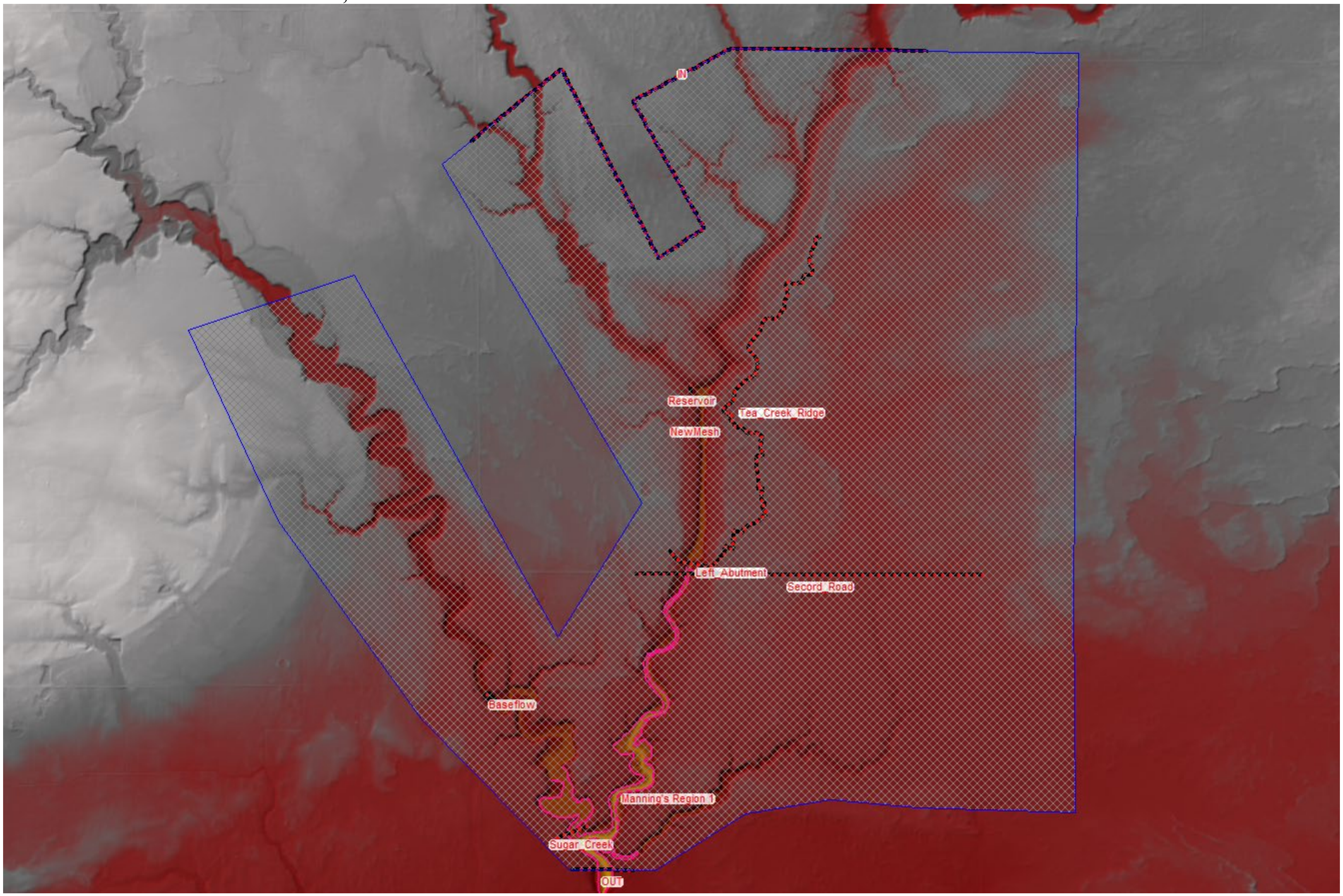
Project LiDAR Data Extents



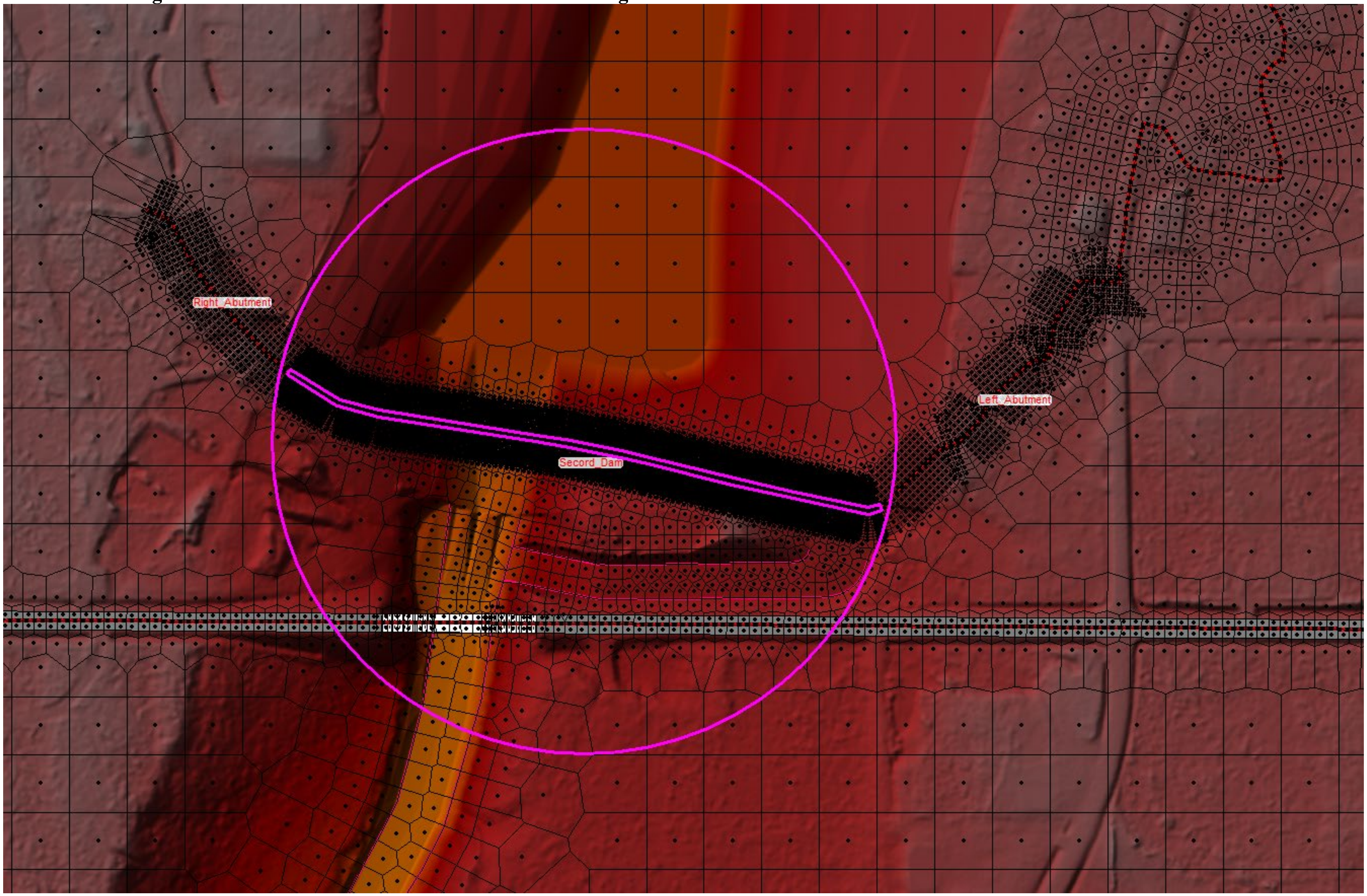
Project Bathymetry Detail

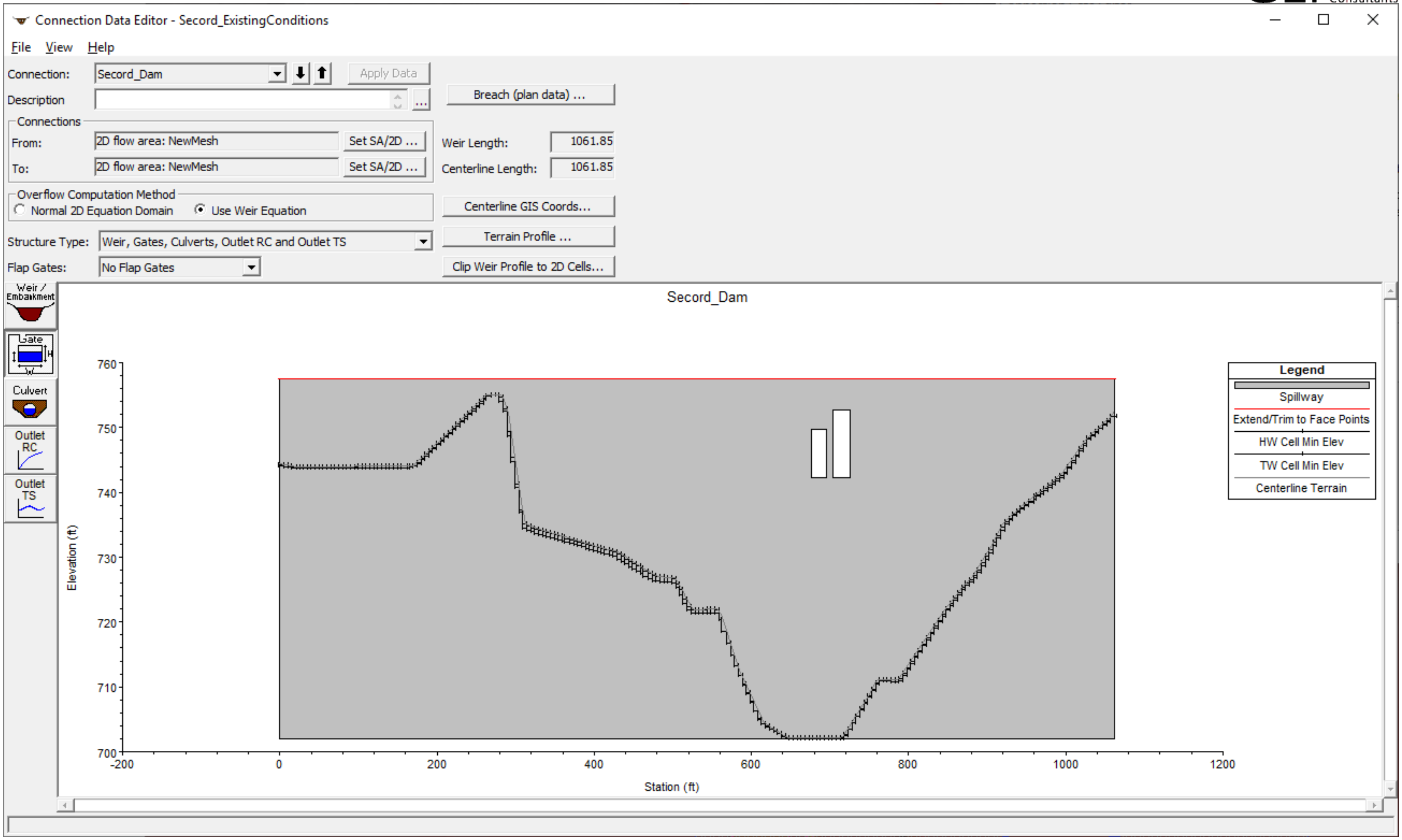


HEC-RAS 2-Dimensional Model Mesh, 100-ft cell size

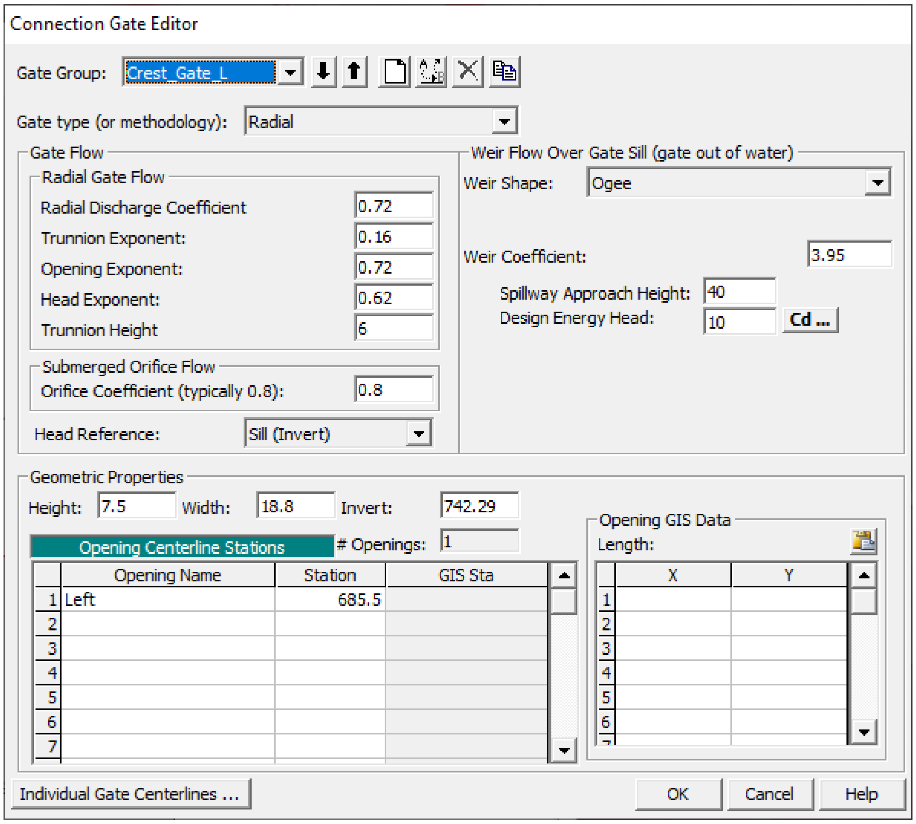


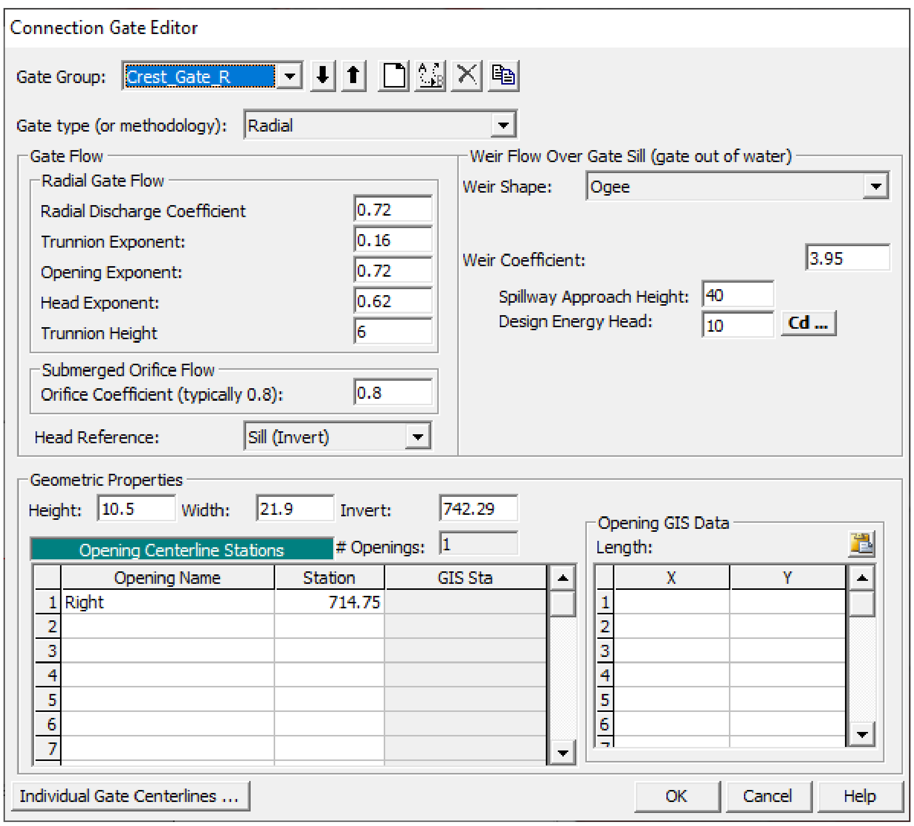
HEC-RAS Storage Area/2D Area Connections – Secord Dam Existing Conditions



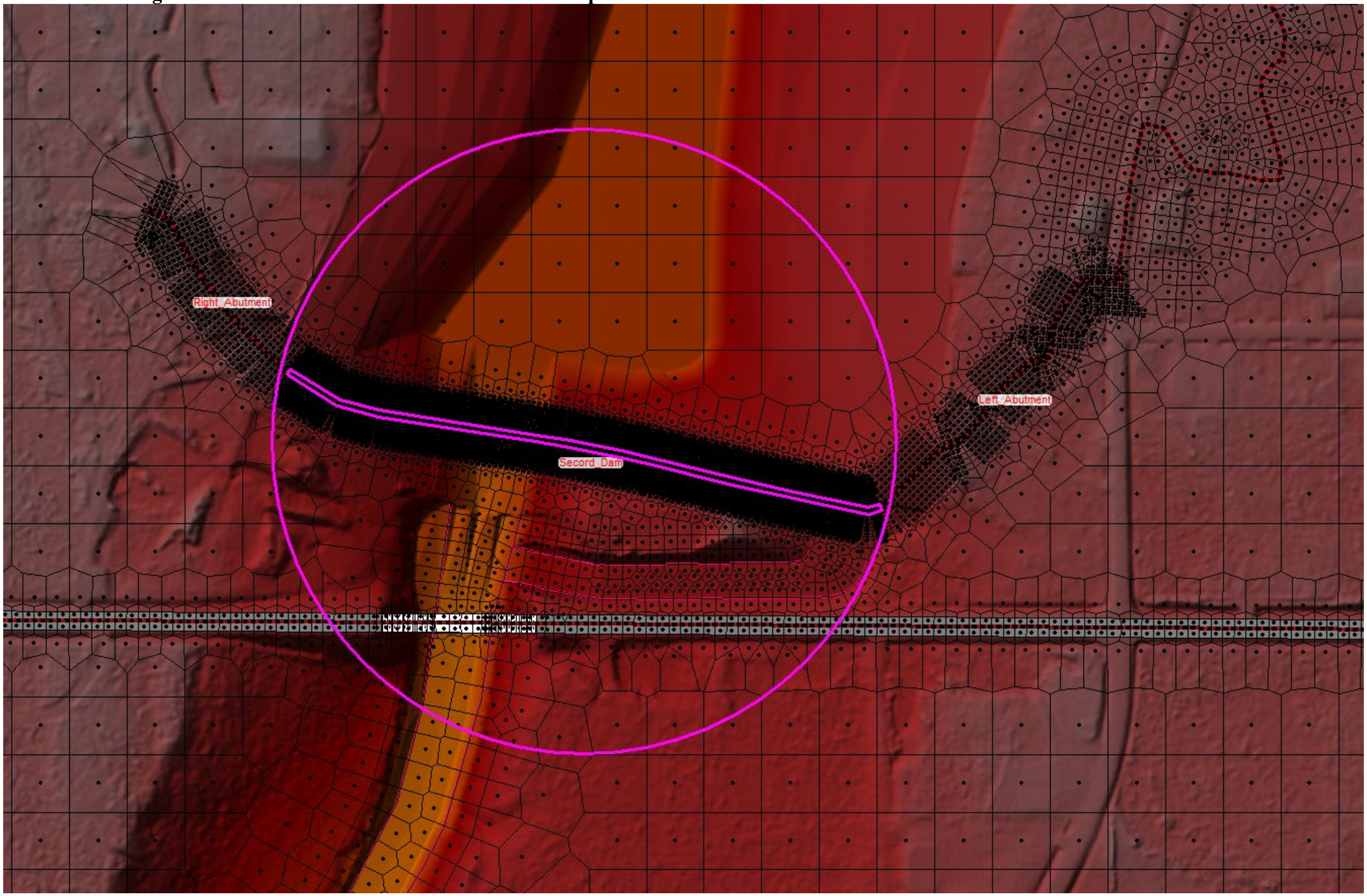

Connection Data Editor - Secord_ExistingConditions
File View Help
Connection: Secord_Dam
Apply Data
Description
Breach (plan data) ...
Connections
From: 2D flow area: NewMesh
Set SA/2D ...
To: 2D flow area: NewMesh
Set SA/2D ...
Weir Length: 1061.85
Centerline Length: 1061.85
Overflow Computation Method
Normal 2D Equation Domain
Use Weir Equation
Centerline GIS Coords...
Structure Type: Weir, Gates, Culverts, Outlet RC and Outlet TS
Terrain Profile ...
Flap Gates: No Flap Gates
Clip Weir Profile to 2D Cells...
Weir / Embankment
Gate
Culvert
Outlet RC
Outlet TS
Secord_Dam
Elevation (ft)
Station (ft)
Legend
Spillway
Extend/Trim to Face Points
HW Cell Min Elev
TW Cell Min Elev
Centerline Terrain

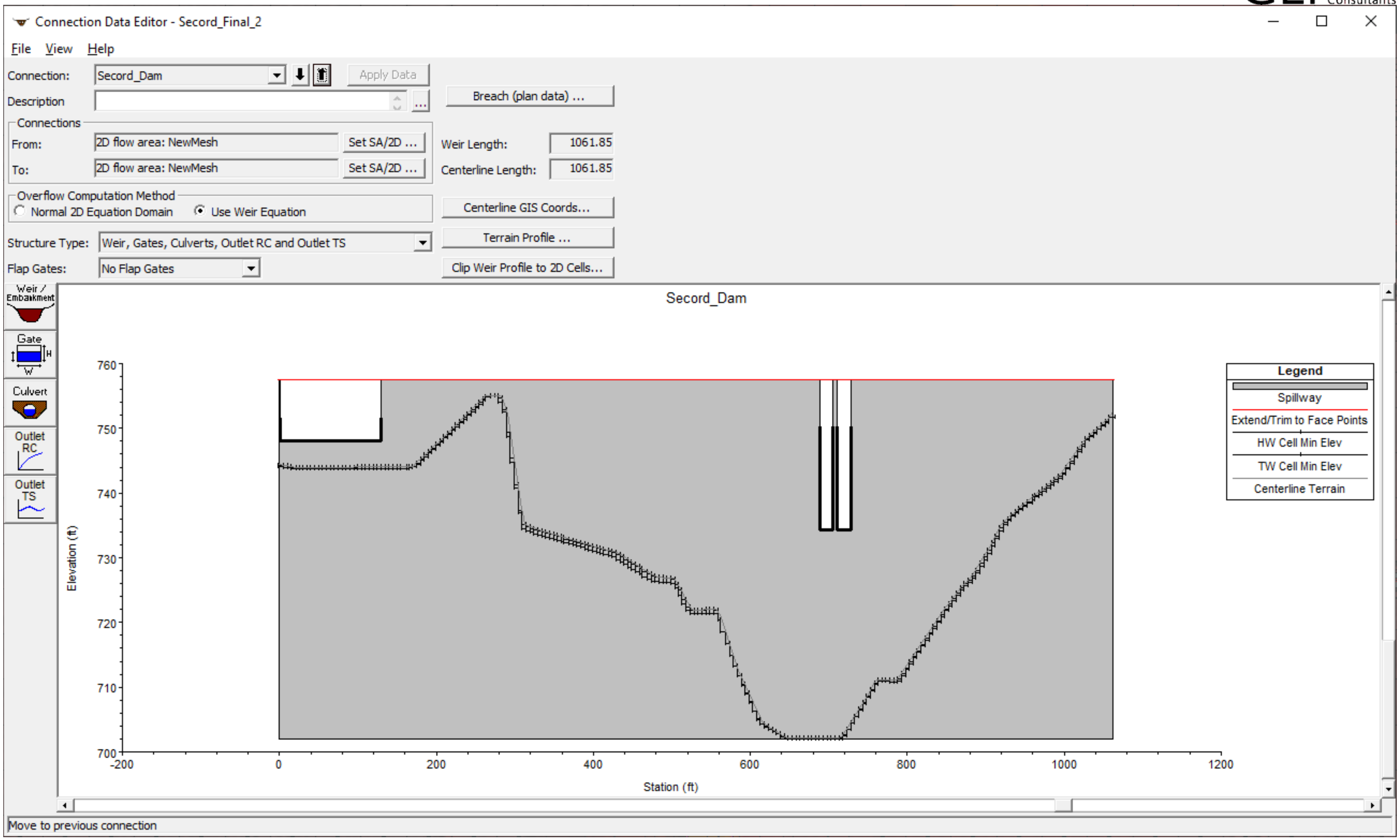
GEI Consultants

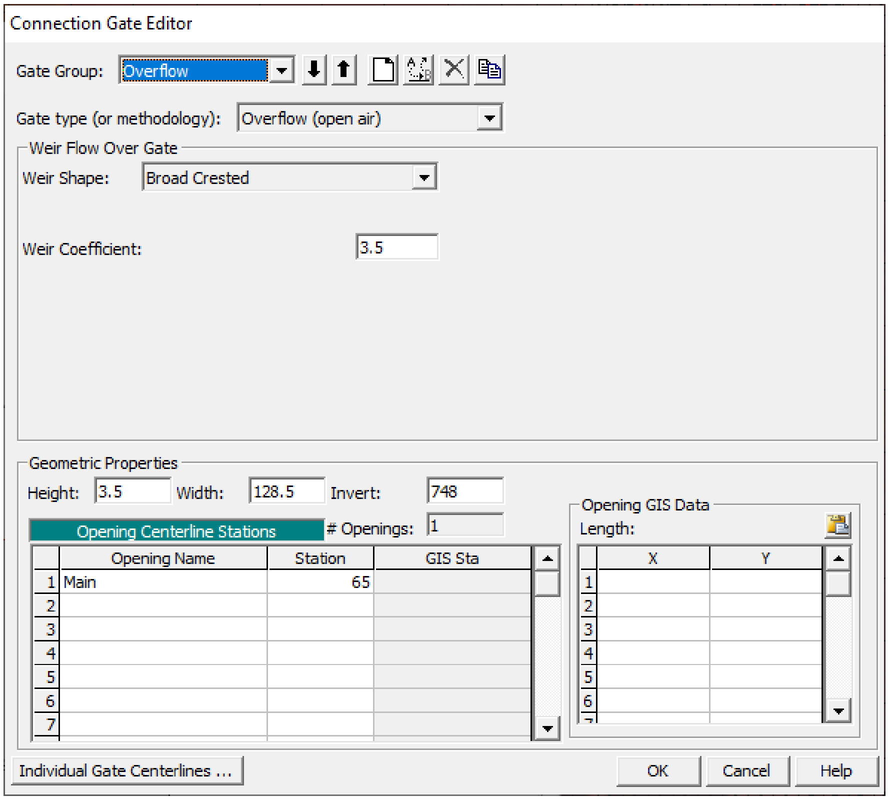


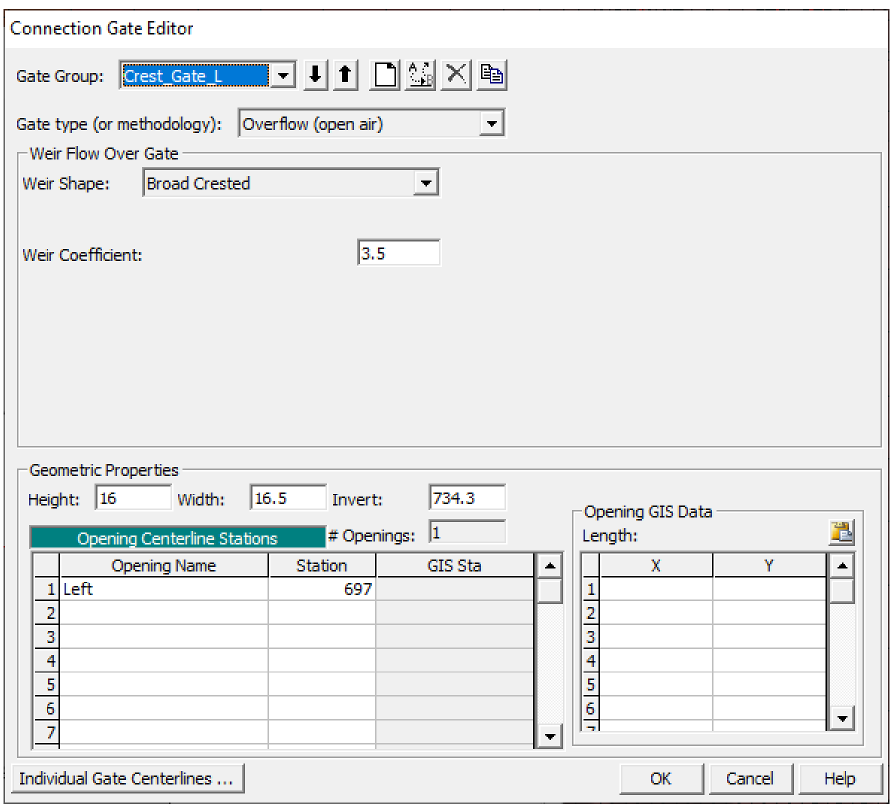


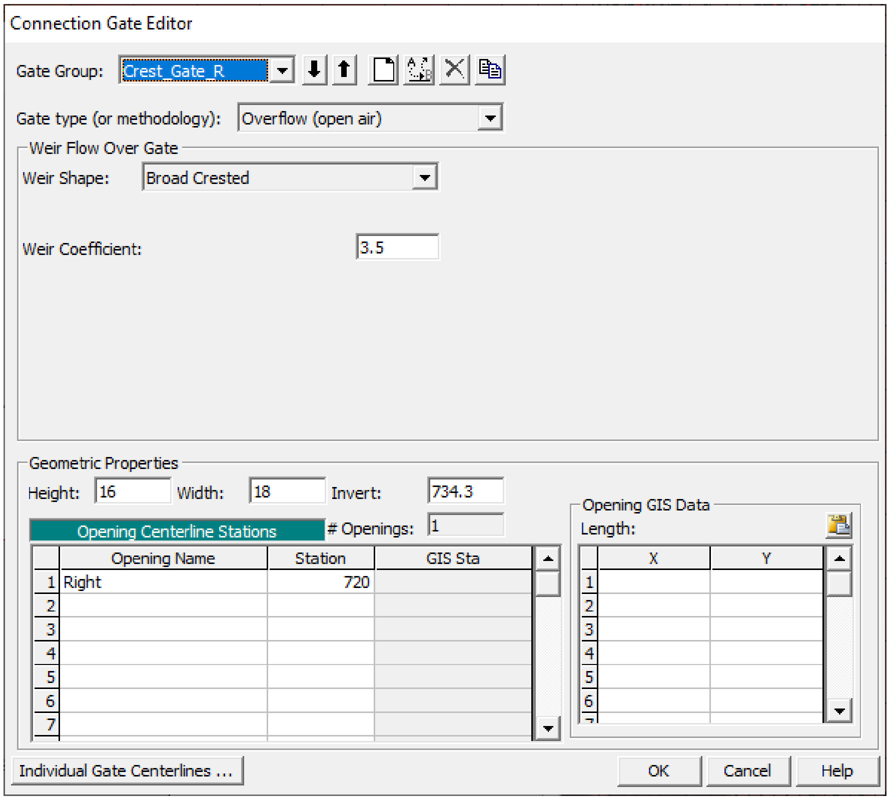
HEC-RAS Storage Area/2D Area Connections – Secord Dam Proposed Conditions



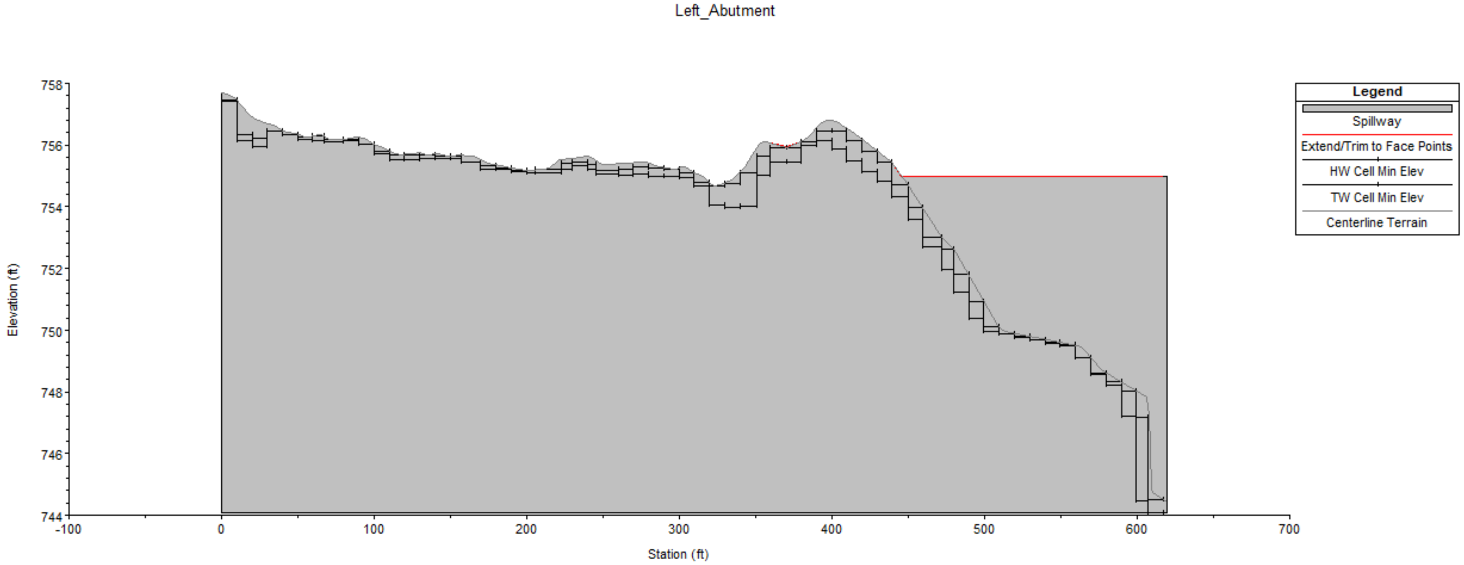

Connection Data Editor - Secord_Final_2
File View Help
Connection: Secord_Dam
Apply Data
Description
Breach (plan data) ...
Connections
From: 2D flow area: NewMesh Set SA/2D ...
To: 2D flow area: NewMesh Set SA/2D ...
Weir Length: 1061.85
Centerline Length: 1061.85
Overflow Computation Method
Normal 2D Equation Domain
Use Weir Equation
Centerline GIS Coords...
Structure Type: Weir, Gates, Culverts, Outlet RC and Outlet TS
Terrain Profile ...
Flap Gates: No Flap Gates
Clip Weir Profile to 2D Cells...
Weir / Embankment
Gate
Culvert
Outlet RC
Outlet TS
Secord_Dam
Elevation (ft)
760
750
740
730
720
710
700
-200
0
200
400
600
800
1000
1200
Station (ft)
Legend
Spillway
Extend/Trim to Face Points
HW Cell Min Elev
TW Cell Min Elev
Centerline Terrain
Move to previous connection

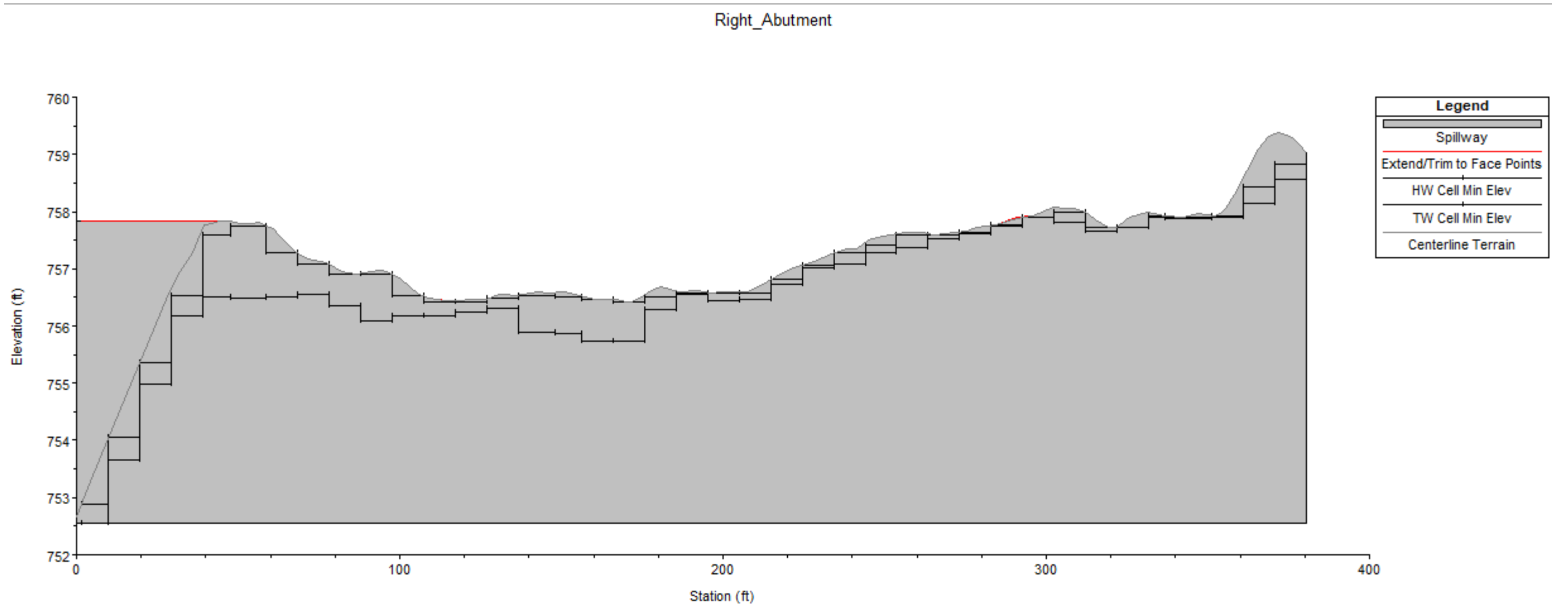

Connection Gate Editor
Gate Group: Overflow
Gate type (or methodology): Overflow (open air)
Weir Flow Over Gate
Weir Shape: Broad Crested
Weir Coefficient: 3.5
Geometric Properties
Height: 3.5 Width: 128.5 Invert: 748
Opening Centerline Stations # Openings: 1
Opening Name Station GIS Sta
1 Main 65
Opening GIS Data
Length:
X Y
Individual Gate Centerlines ...
OK Cancel Help


Connection Gate Editor
Gate Group: Crest_Gate_L
Gate type (or methodology): Overflow (open air)
Weir Flow Over Gate
Weir Shape: Broad Crested
Weir Coefficient: 3.5
Geometric Properties
Height: 16 Width: 16.5 Invert: 734.3
Opening Centerline Stations # Openings: 1
Opening Name Station GIS Sta
1 Left 697
Opening GIS Data
Length:
X Y
Individual Gate Centerlines ...
OK Cancel Help

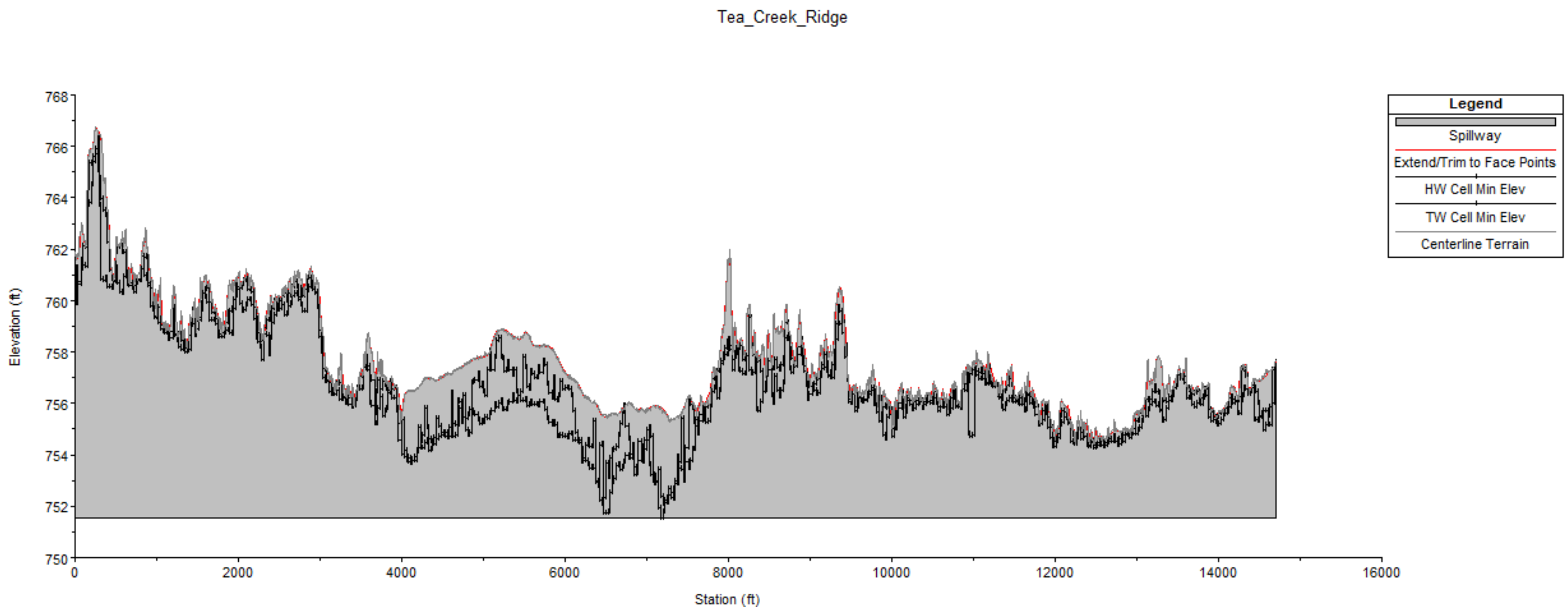

Connection Gate Editor
Gate Group: Crest_Gate_R
Gate type (or methodology): Overflow (open air)
Weir Flow Over Gate
Weir Shape: Broad Crested
Weir Coefficient: 3.5
Geometric Properties
Height: 16
Width: 18
Invert: 734.3
Opening Centerline Stations
Openings: 1
Opening Name
Station
GIS Sta
1 Right 720
2
3
4
5
6
7
Opening GIS Data
Length:
X
Y
1
2
3
4
5
6
Individual Gate Centerlines ...
OK
Cancel
Help

HEC-RAS Storage Area/2D Area Connection – Secord Dam Abutments

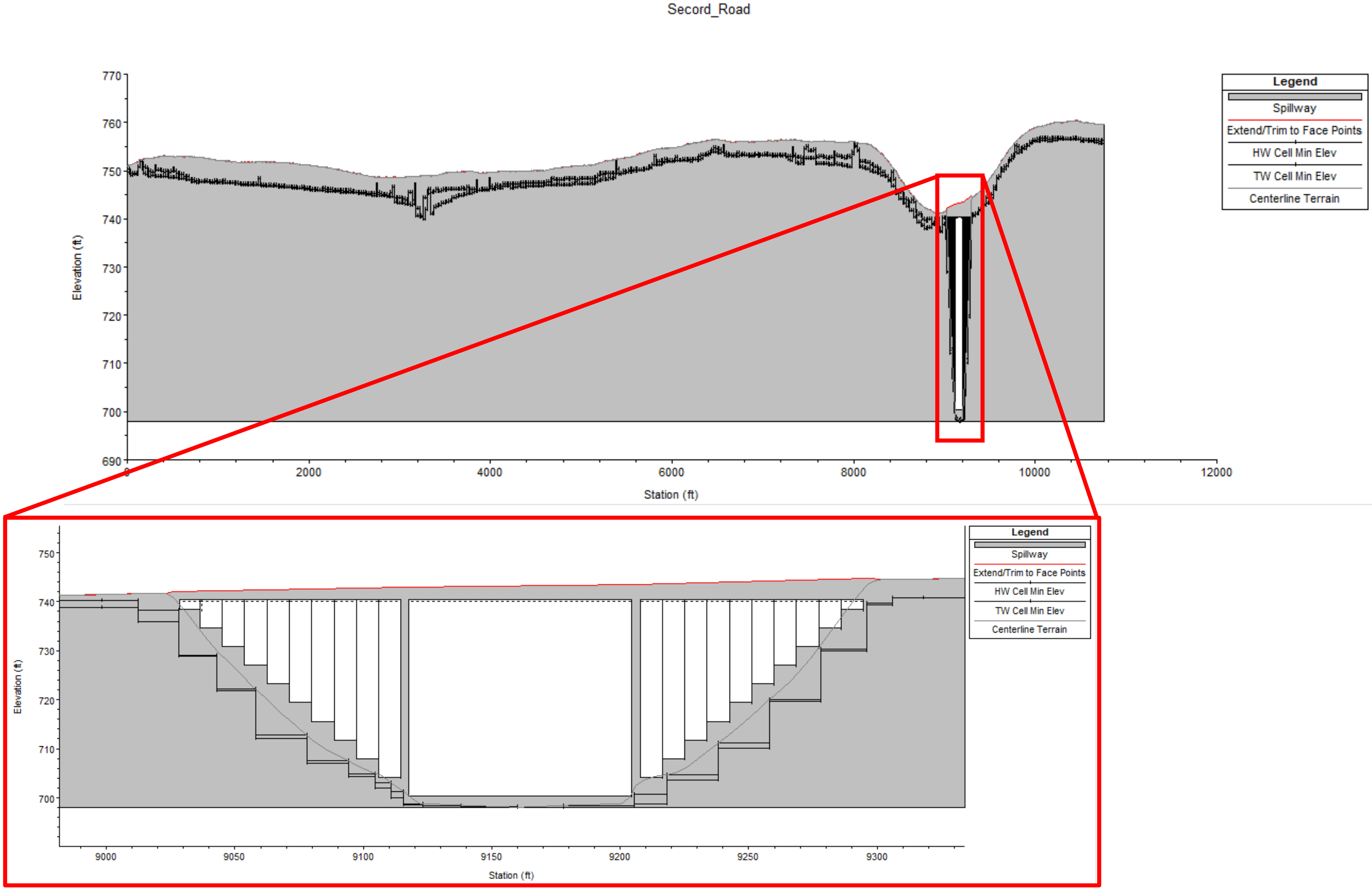


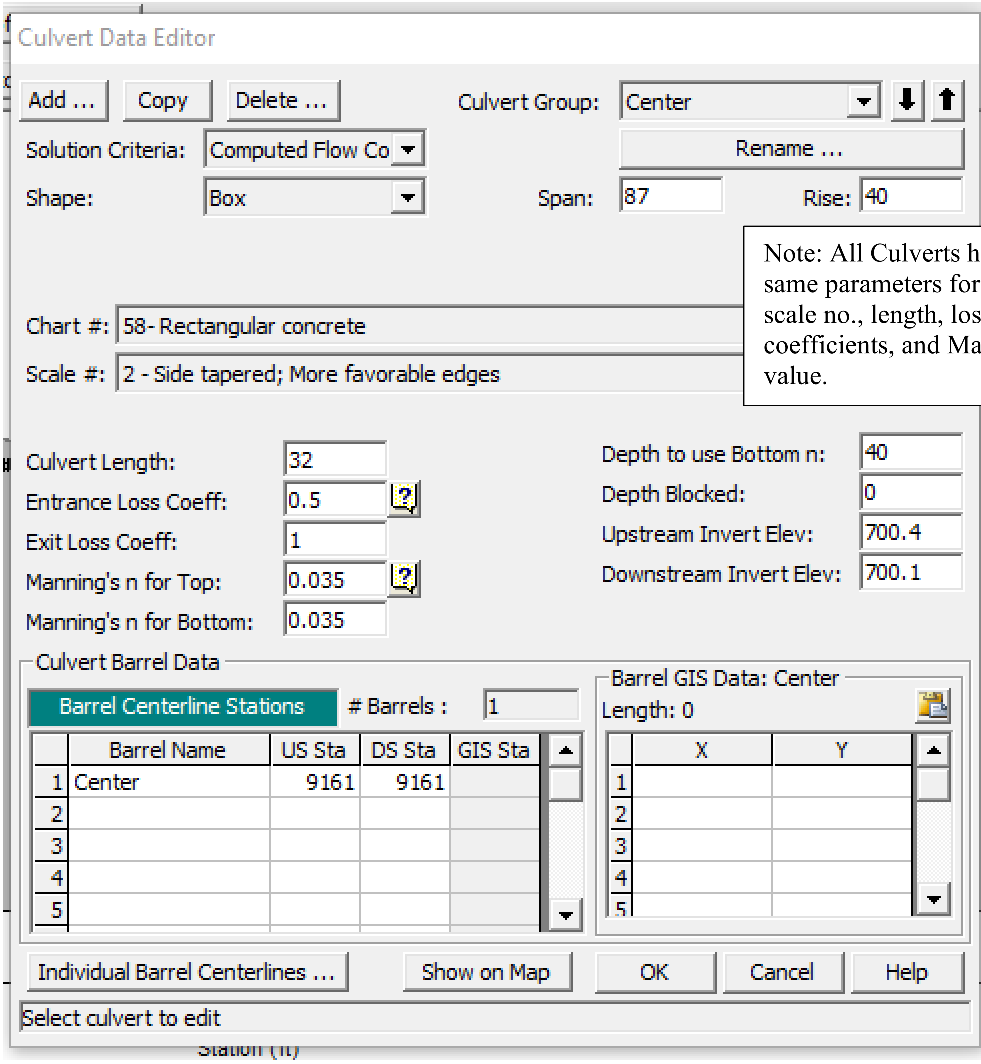


HEC-RAS Storage Area/2D Area Connection – Tea Creek Ridgeline



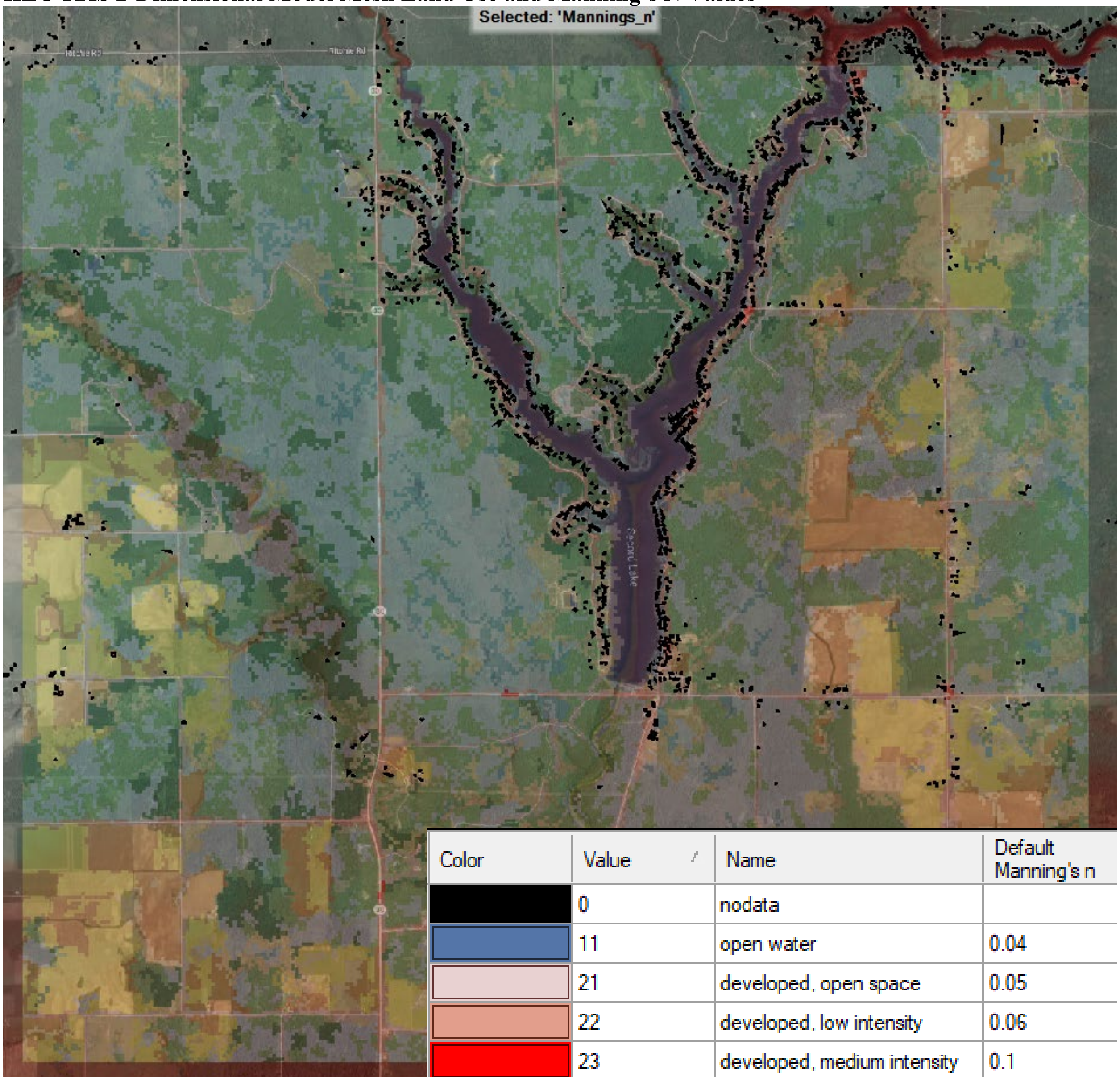
HEC-RAS Storage Area/2D Area Connection – Secord Dam Road





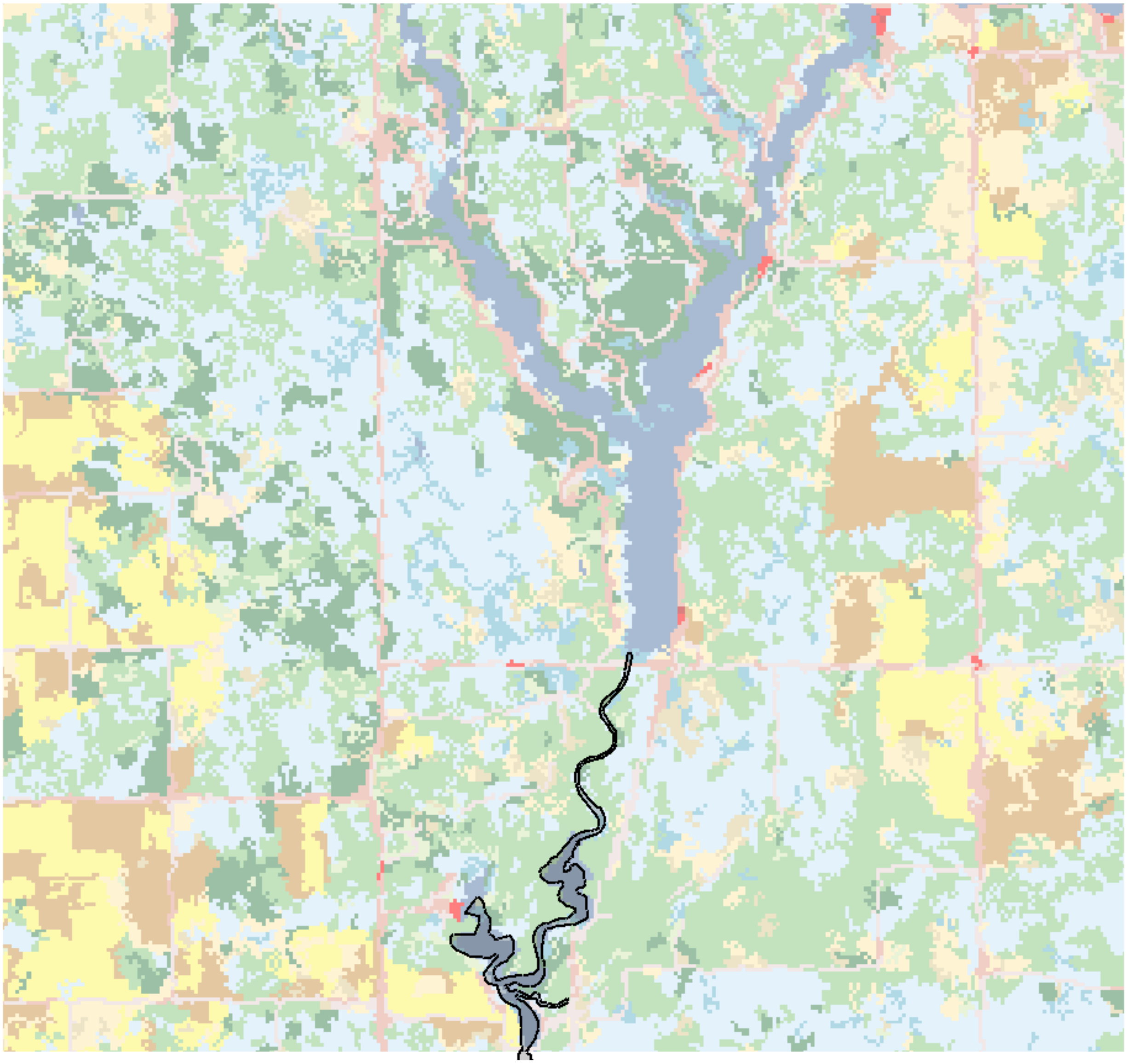
Note: All Culverts have the same parameters for chart no., scale no., length, loss coefficients, and Manning's n-value.

HEC-RAS 2-Dimensional Model Mesh Land Use and Manning's N Values

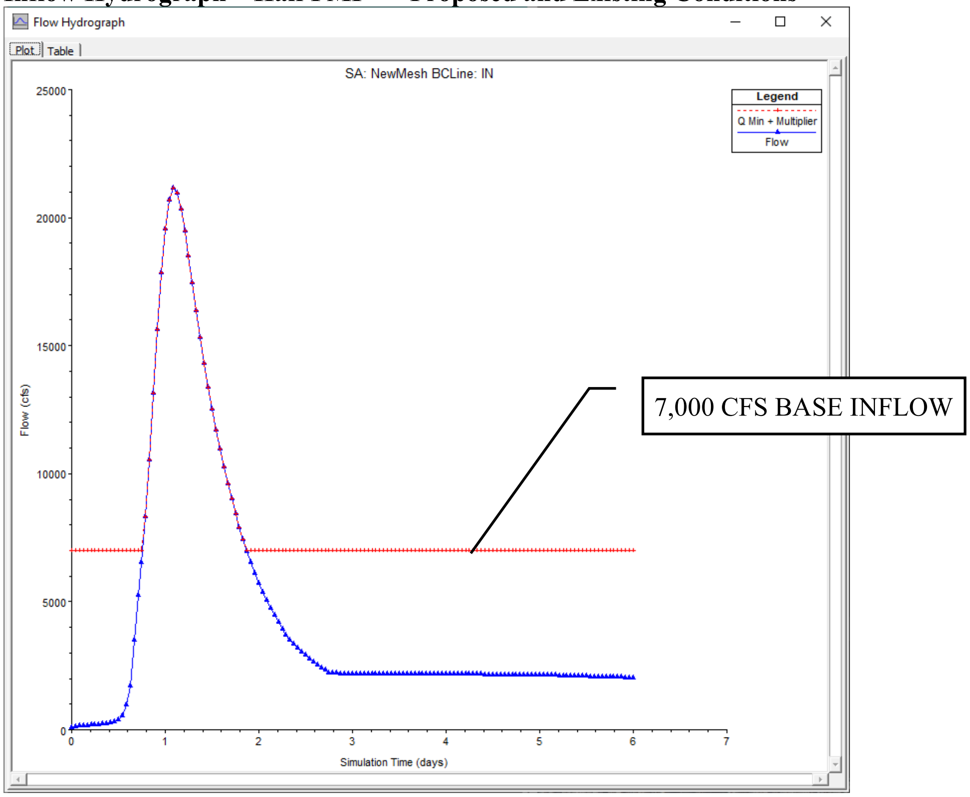


Color	Value	Name	Default Manning's n
(black)	0	nodata	
(blue)	11	open water	0.04
(light pink)	21	developed, open space	0.05
(salmon)	22	developed, low intensity	0.06
(red)	23	developed, medium intensity	0.1
(dark red)	24	developed, high intensity	0.15
(light grey)	31	barren land rock/sand/clay	0.04
(light green)	41	deciduous forest	0.15
(dark green)	42	evergreen forest	0.15
(pale green)	43	mixed forest	0.12
(tan)	52	shrub/scrub	0.06
(pale yellow)	71	grassland/herbaceous	0.04
(yellow)	81	pasture/hay	0.04
(brown)	82	cultivated crops	0.06
(light blue)	90	woody wetlands	0.1
(teal)	95	emergent herbaceous wetla...	0.05

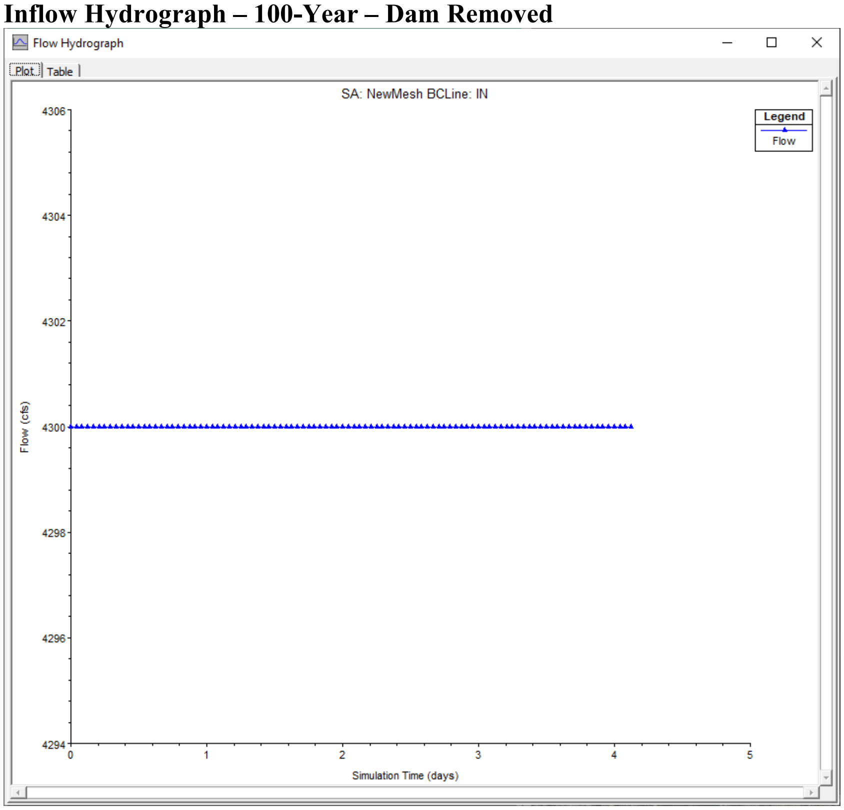
Manning N Overide Region
n = 0.035



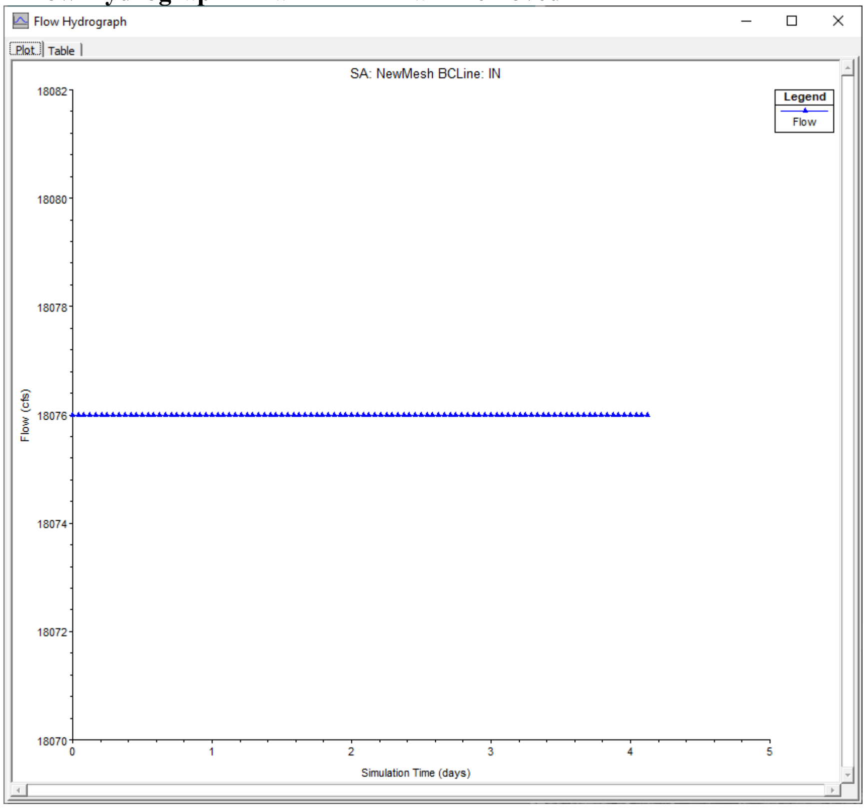
Inflow Hydrograph – Half PMF+ – Proposed and Existing Conditions



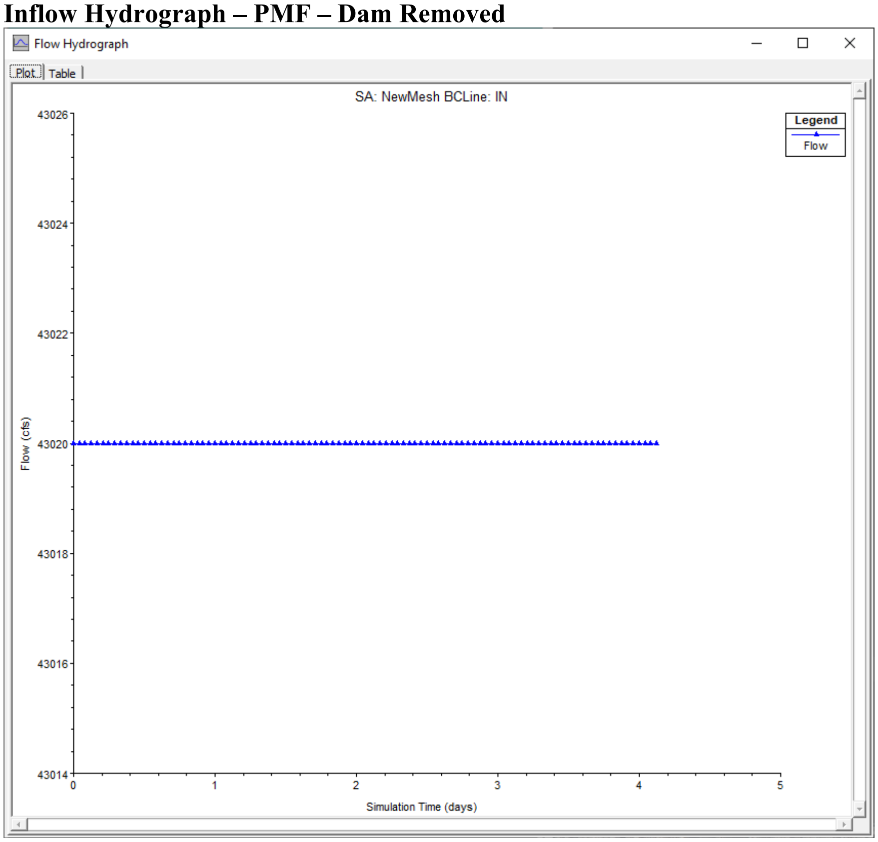
Inflow Hydrograph – 100-Year – Dam Removed



Inflow Hydrograph – Half PMF – Dam Removed

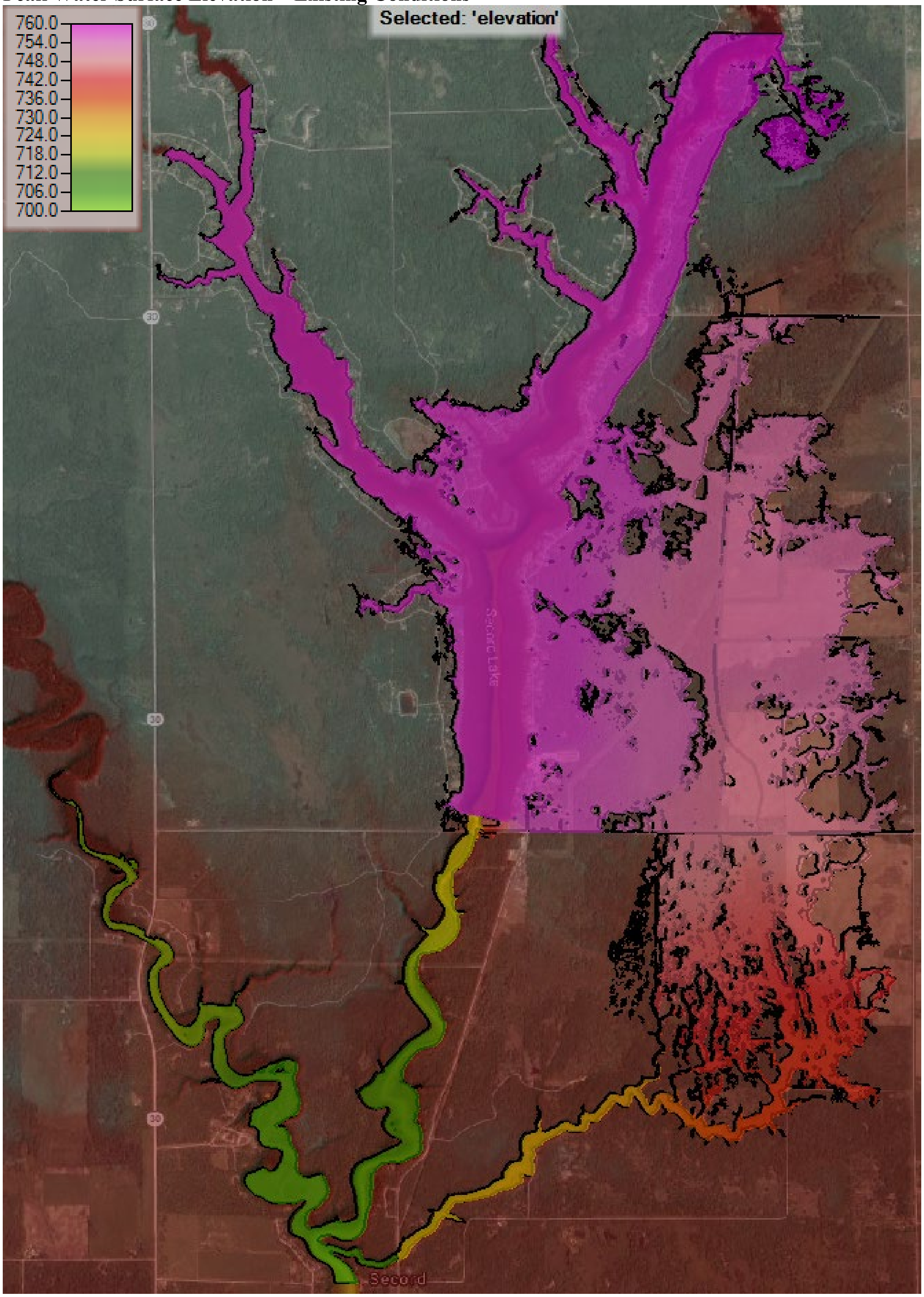


Inflow Hydrograph – PMF – Dam Removed



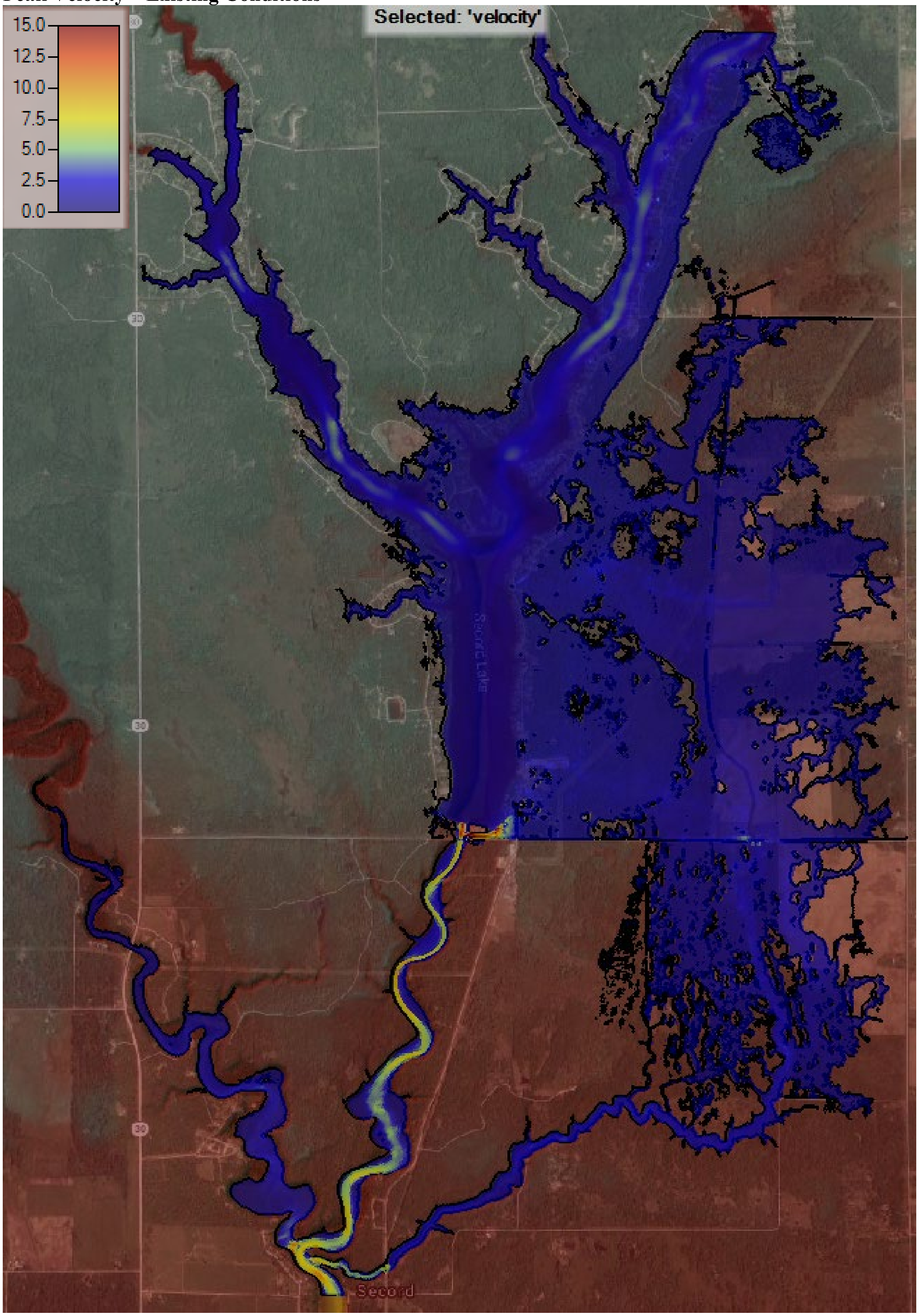
OUTPUT

Peak Water Surface Elevation – Existing Conditions

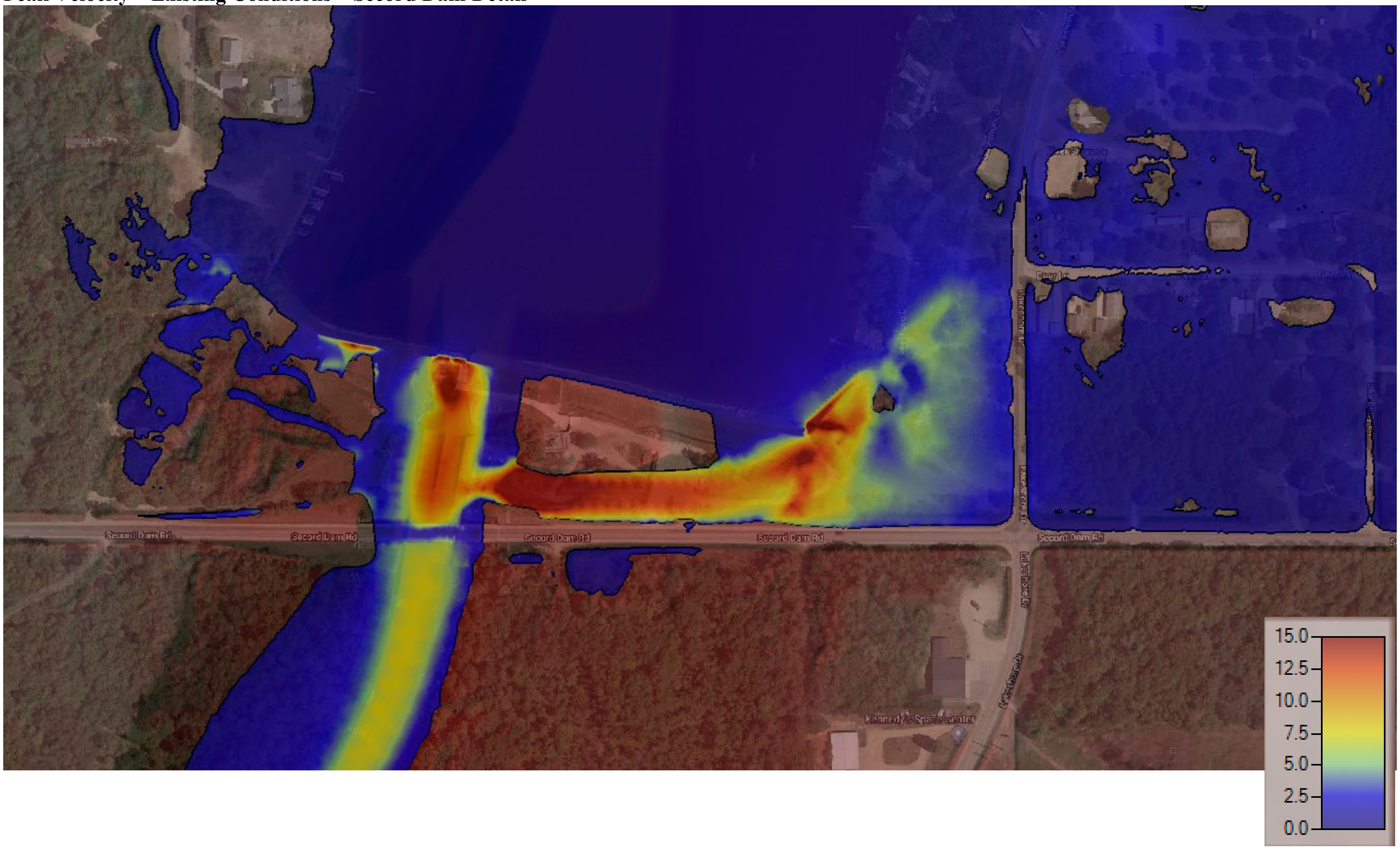


Peak Water Surface Elevation – Existing Conditions – Secord Dam Detail

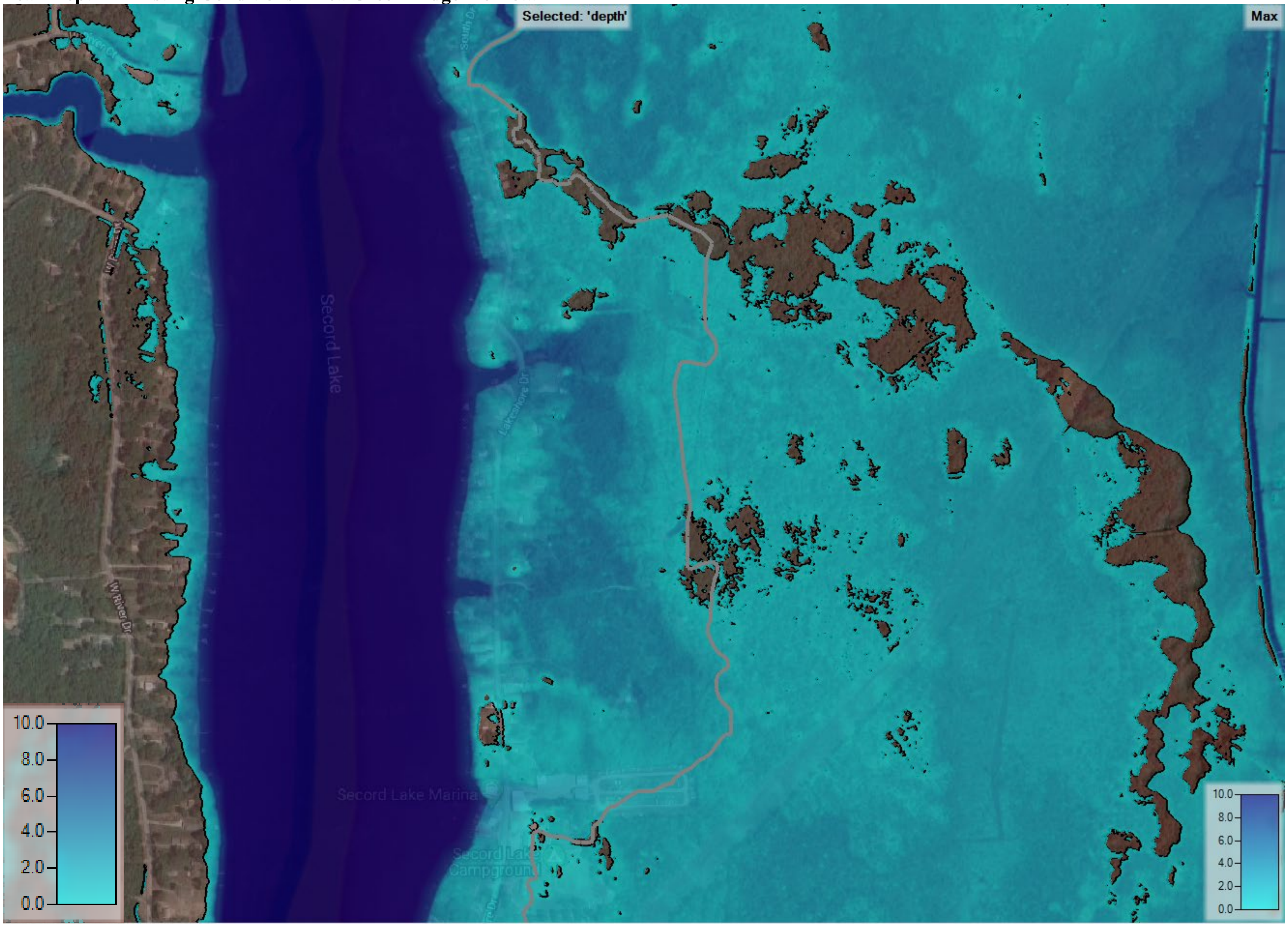
Peak Velocity – Existing Conditions



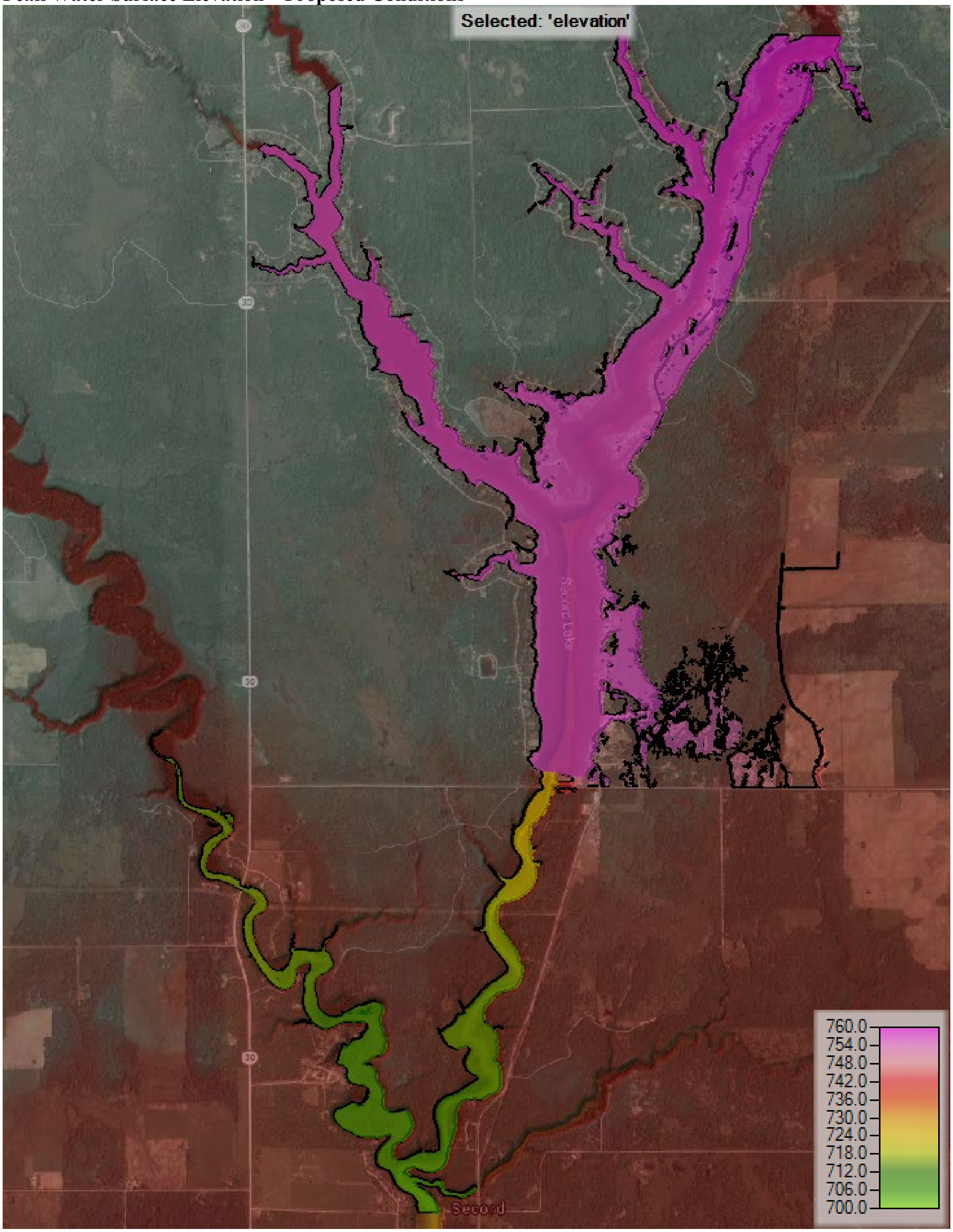
Peak Velocity – Existing Conditions – Secord Dam Detail



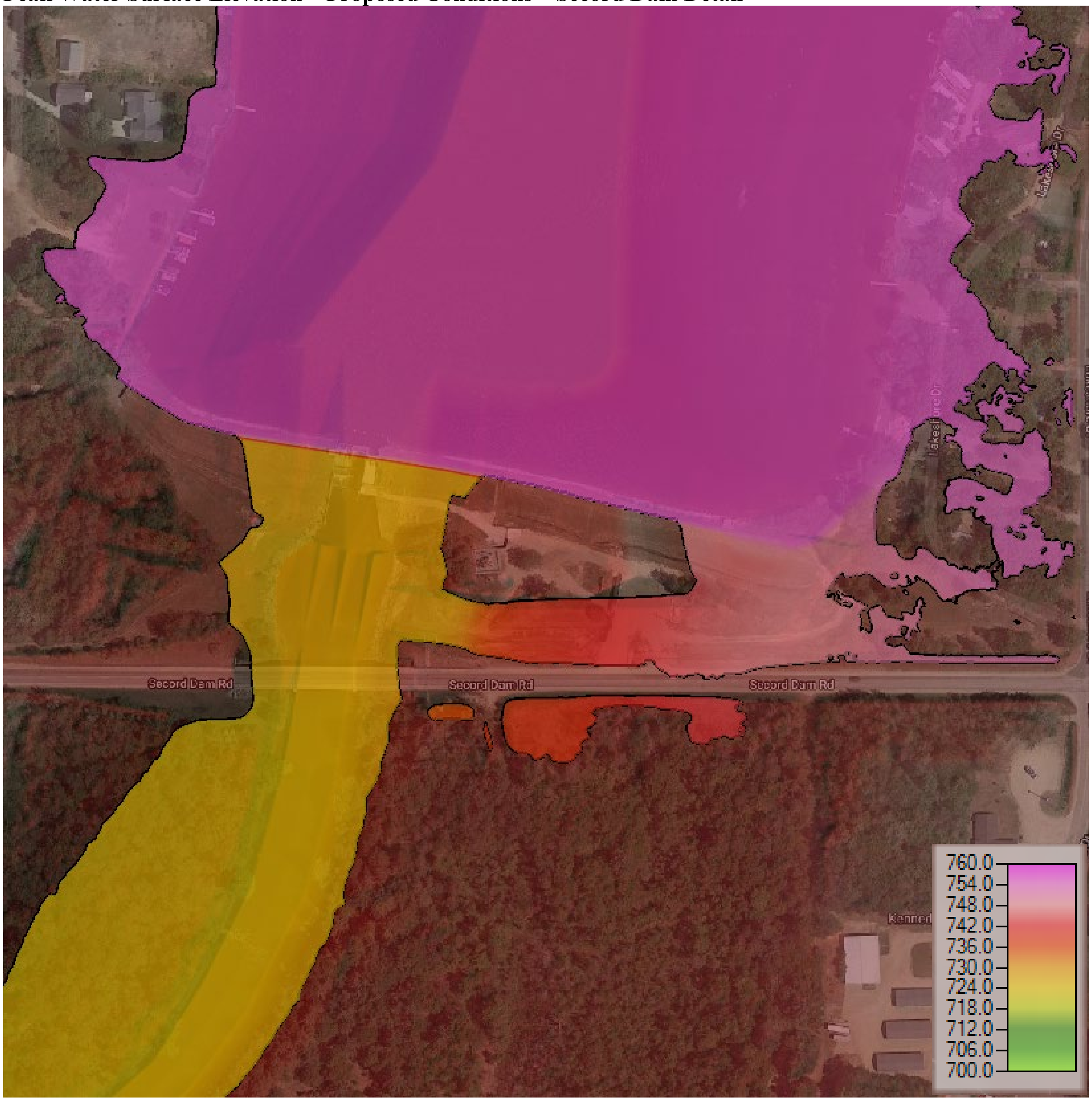
Peak Depth – Existing Conditions – Tea Creek Ridgeline Detail



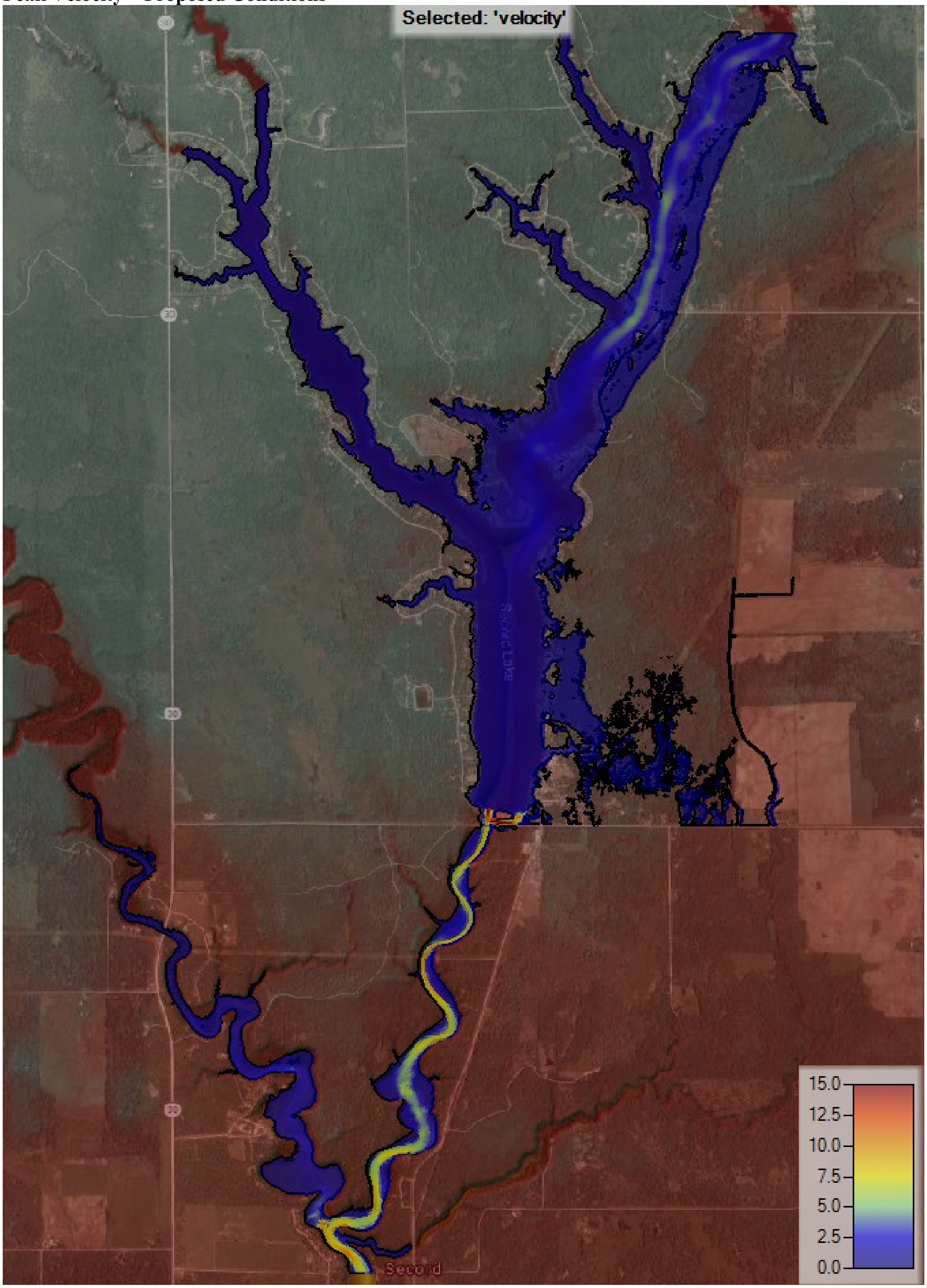
Peak Water Surface Elevation – Proposed Conditions



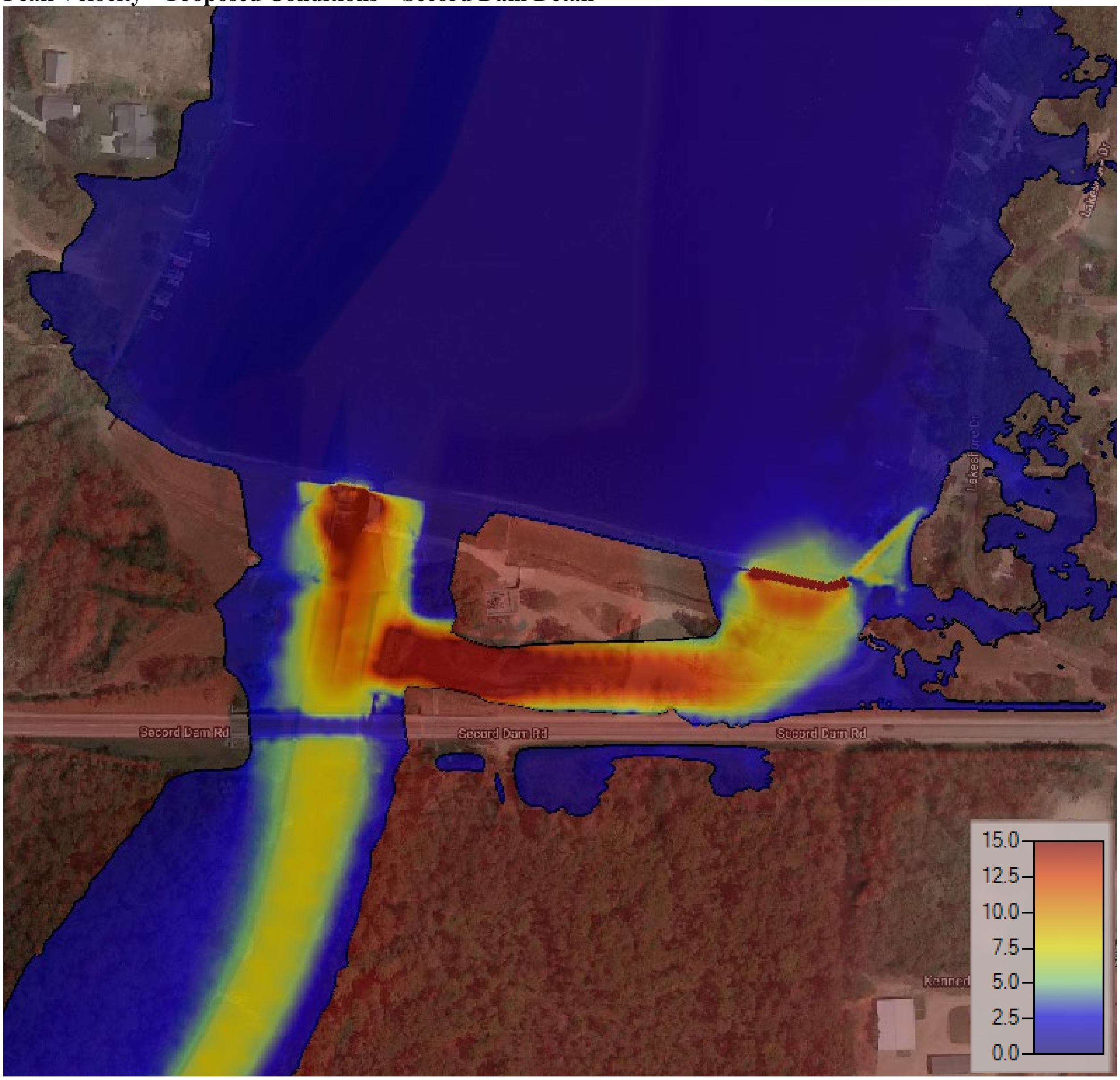
Peak Water Surface Elevation – Proposed Conditions – Secord Dam Detail



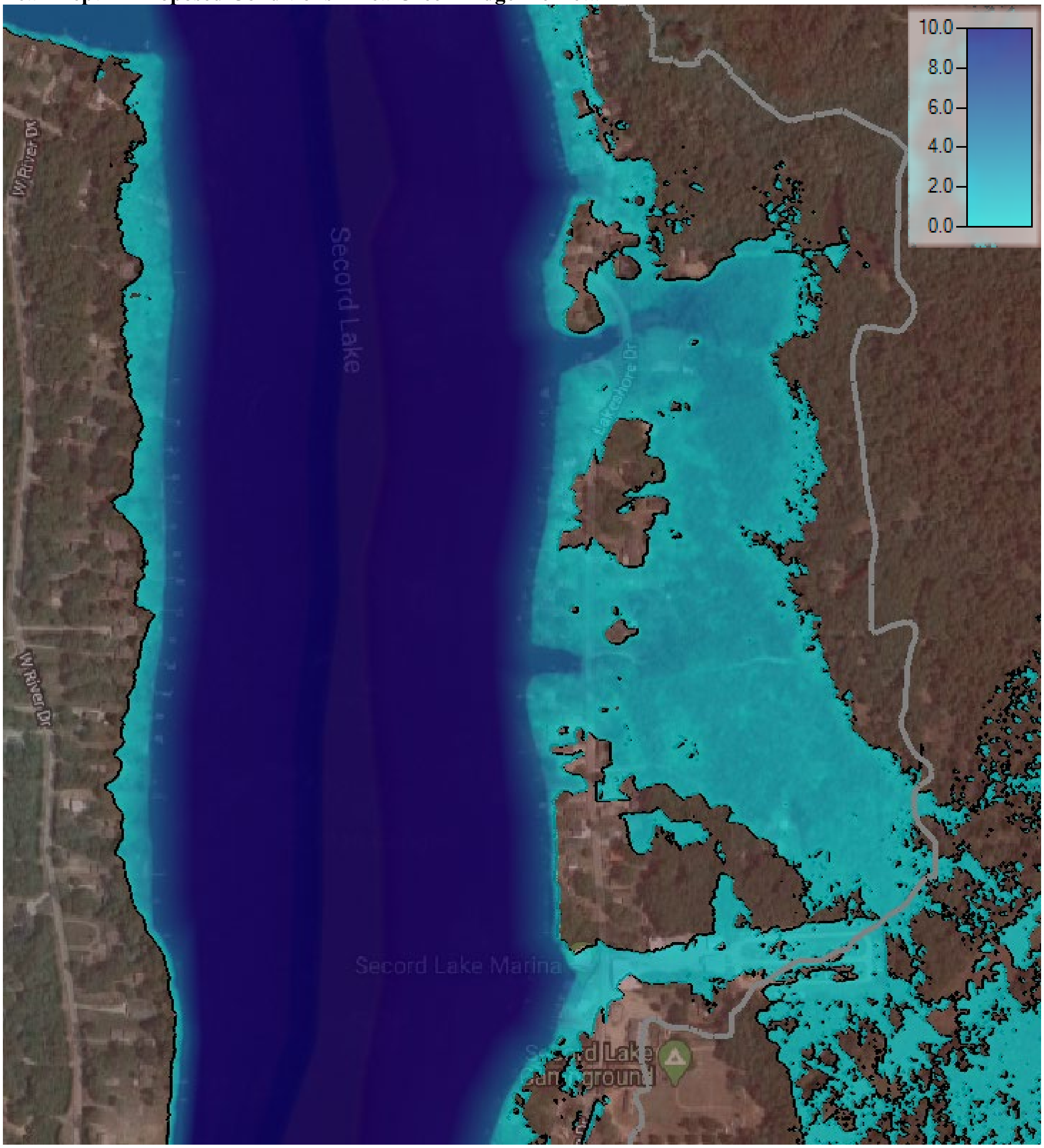
Peak Velocity – Proposed Conditions



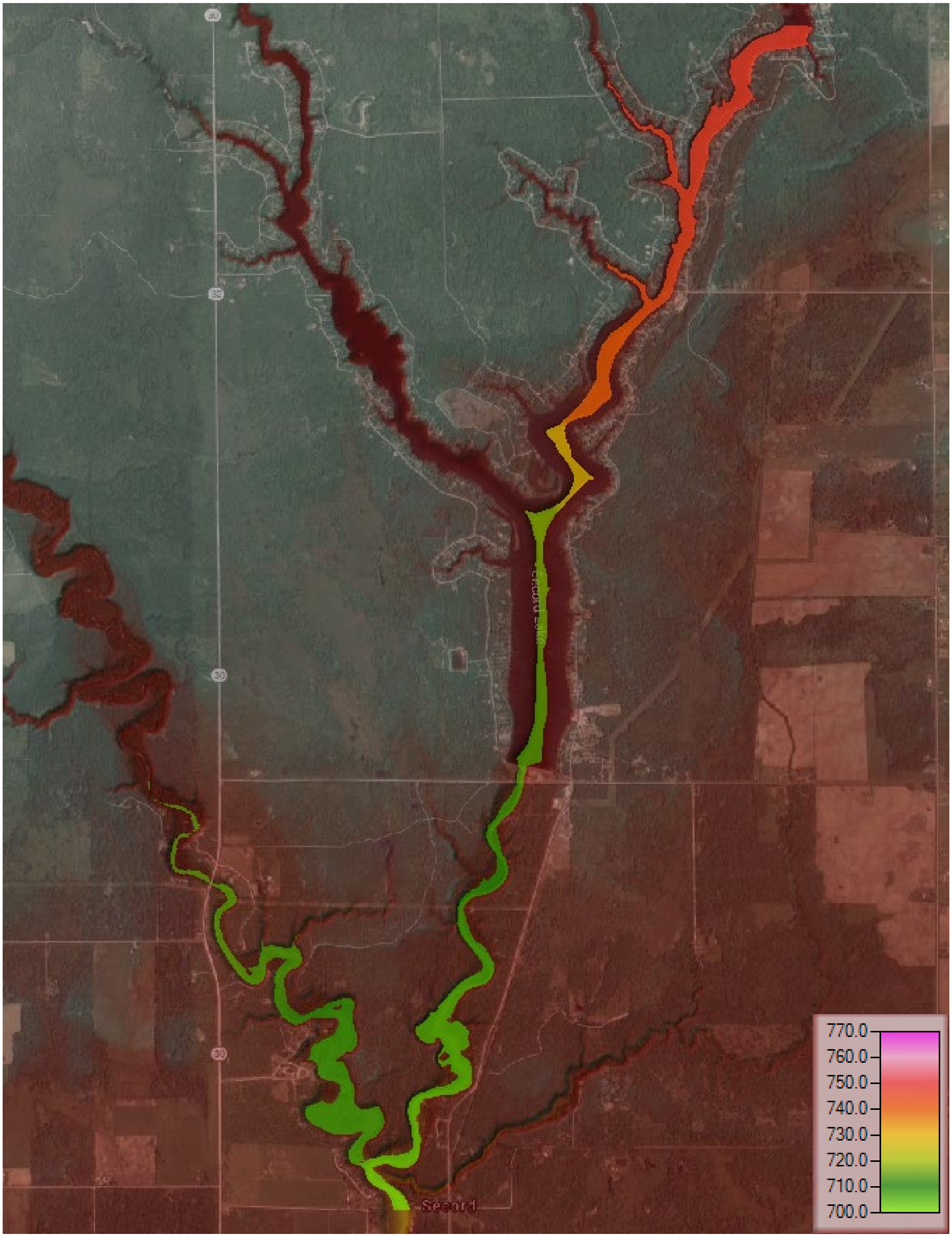
Peak Velocity – Proposed Conditions – Secord Dam Detail



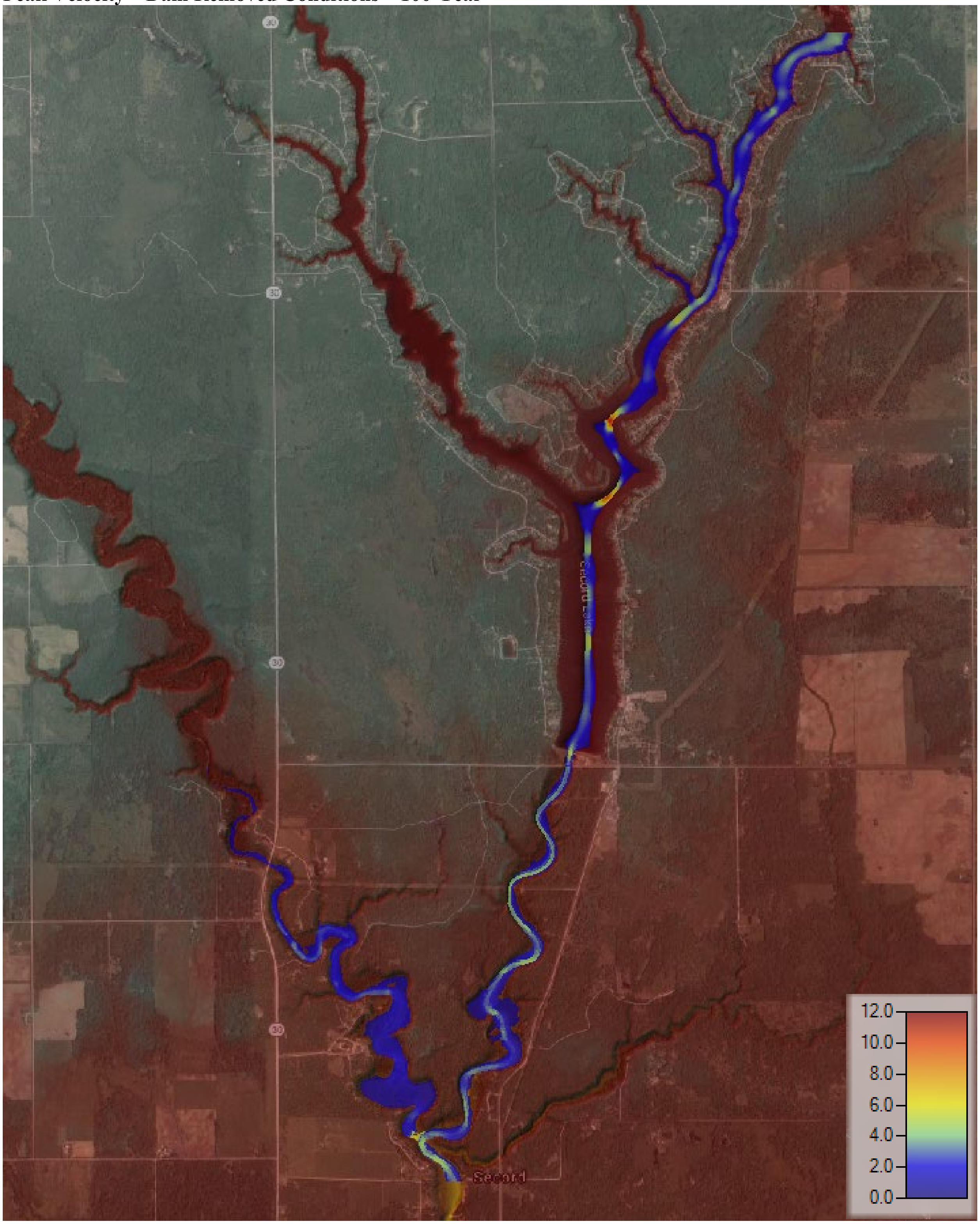
Peak Depth – Proposed Conditions – Tea Creek Ridgeline Detail



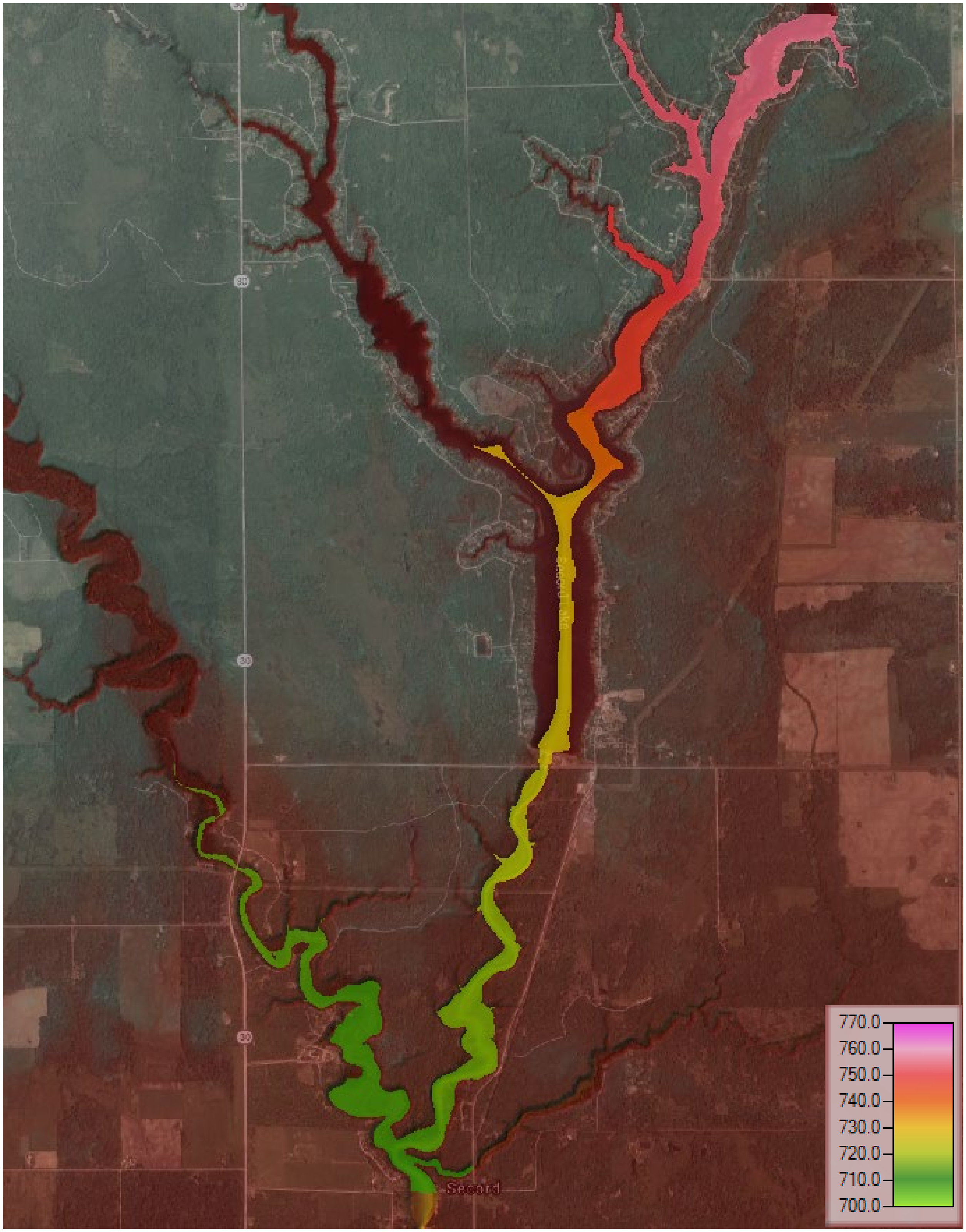
Peak Water Surface Elevation – Dam Removed Conditions – 100-Year



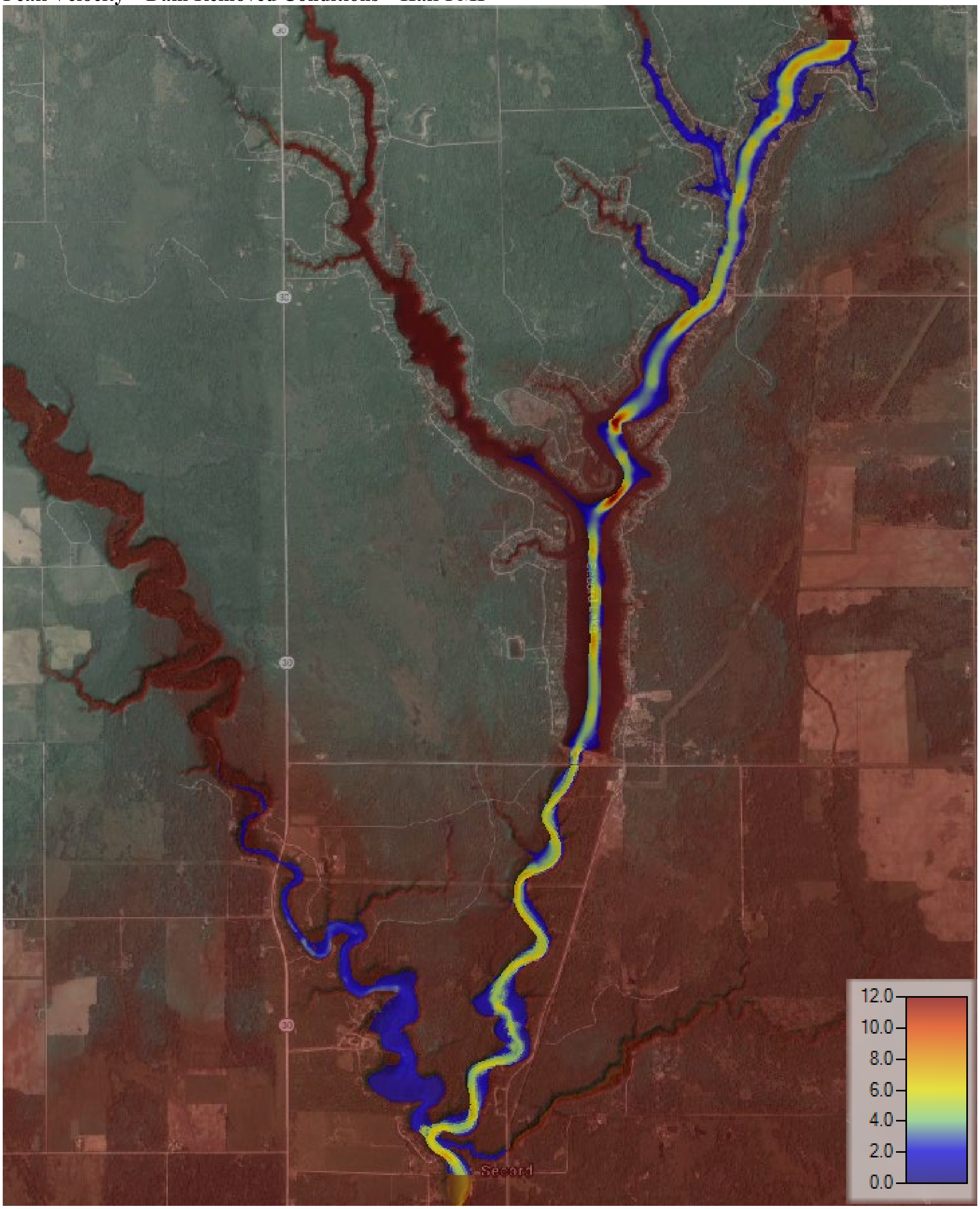
Peak Velocity – Dam Removed Conditions – 100-Year



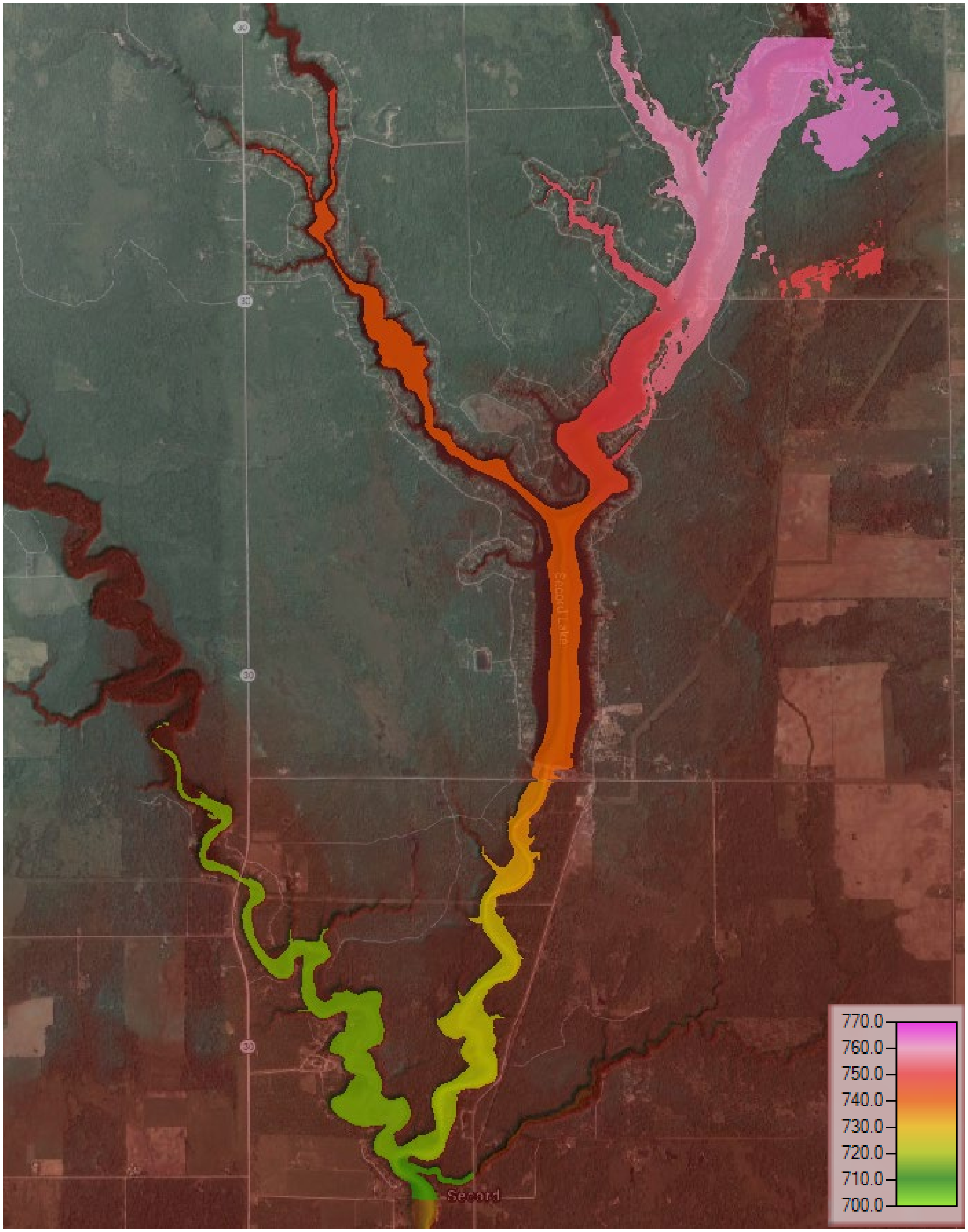
Peak Water Surface Elevation – Dam Removed Conditions – Half PMF



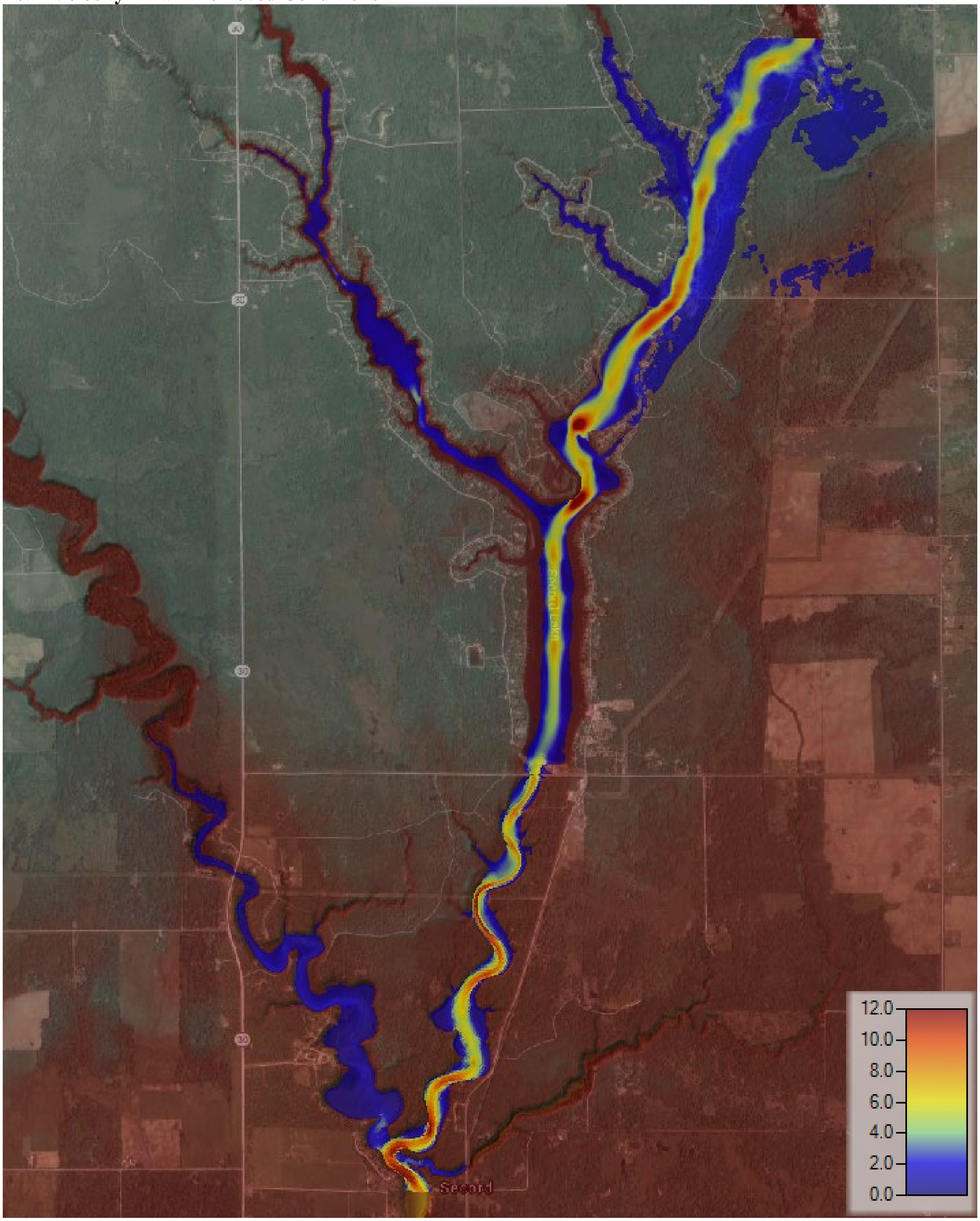
Peak Velocity – Dam Removed Conditions – Half PMF



Peak Water Surface Elevation – Dam Removed Conditions – PMF



Peak Velocity – Dam Removed Conditions – PMF

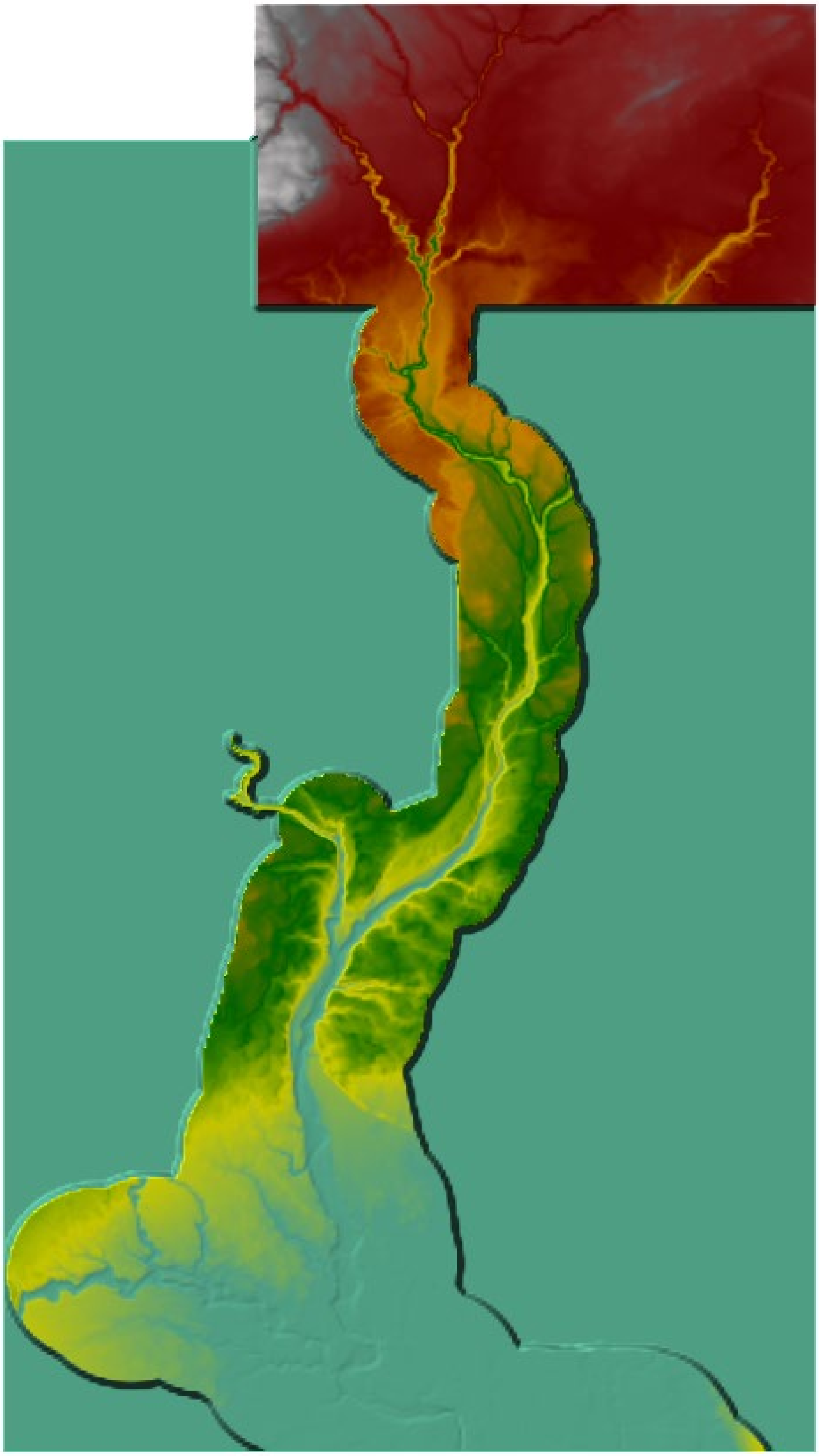


Appendix F

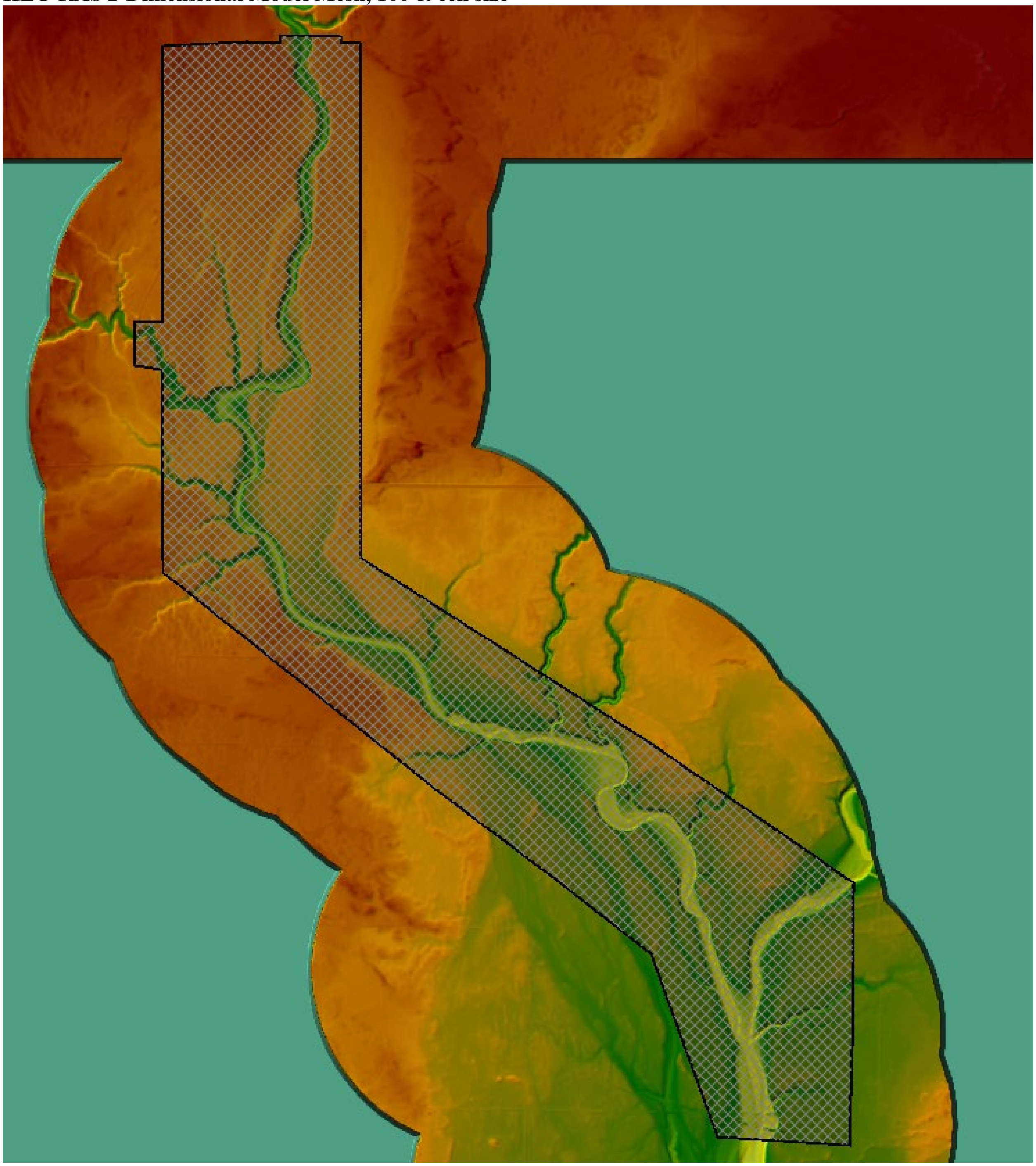
Proposed Conditions HEC-RAS Model Input and Output Data Sheets

Appendix F.2 – Smallwood Dam

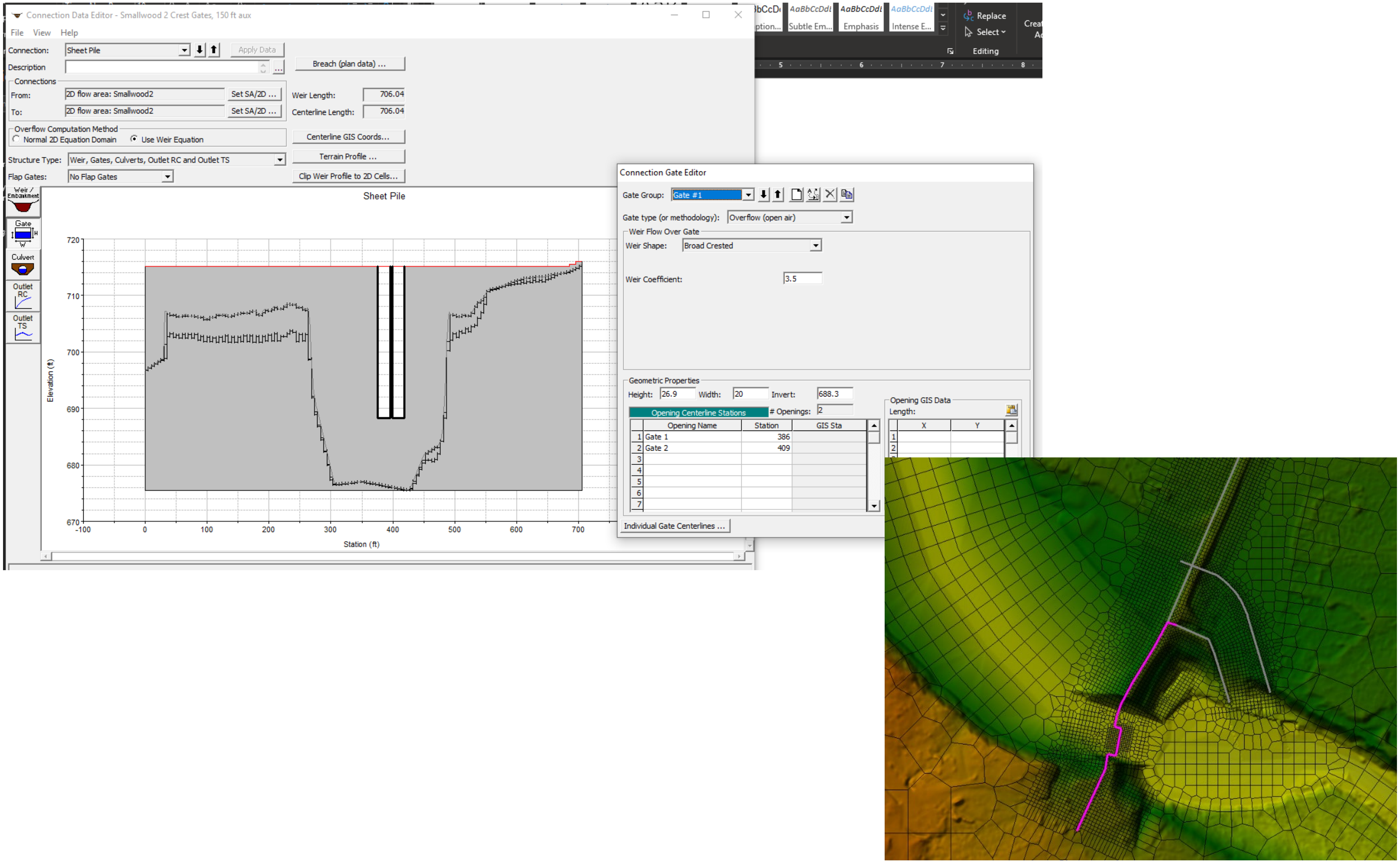
HEC-RAS Input
Project LiDAR Data Extents



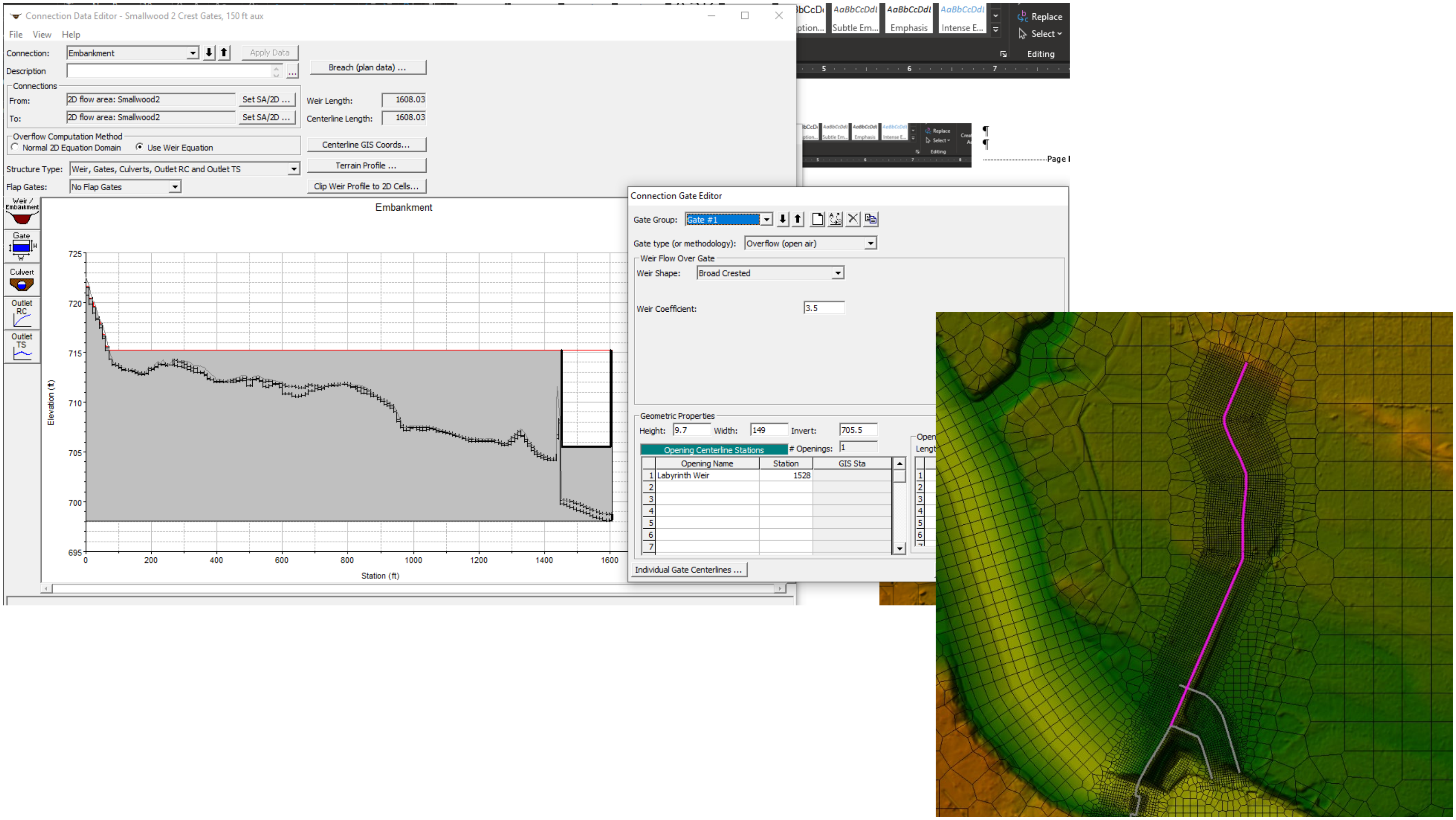
HEC-RAS 2-Dimensional Model Mesh, 100-ft cell size



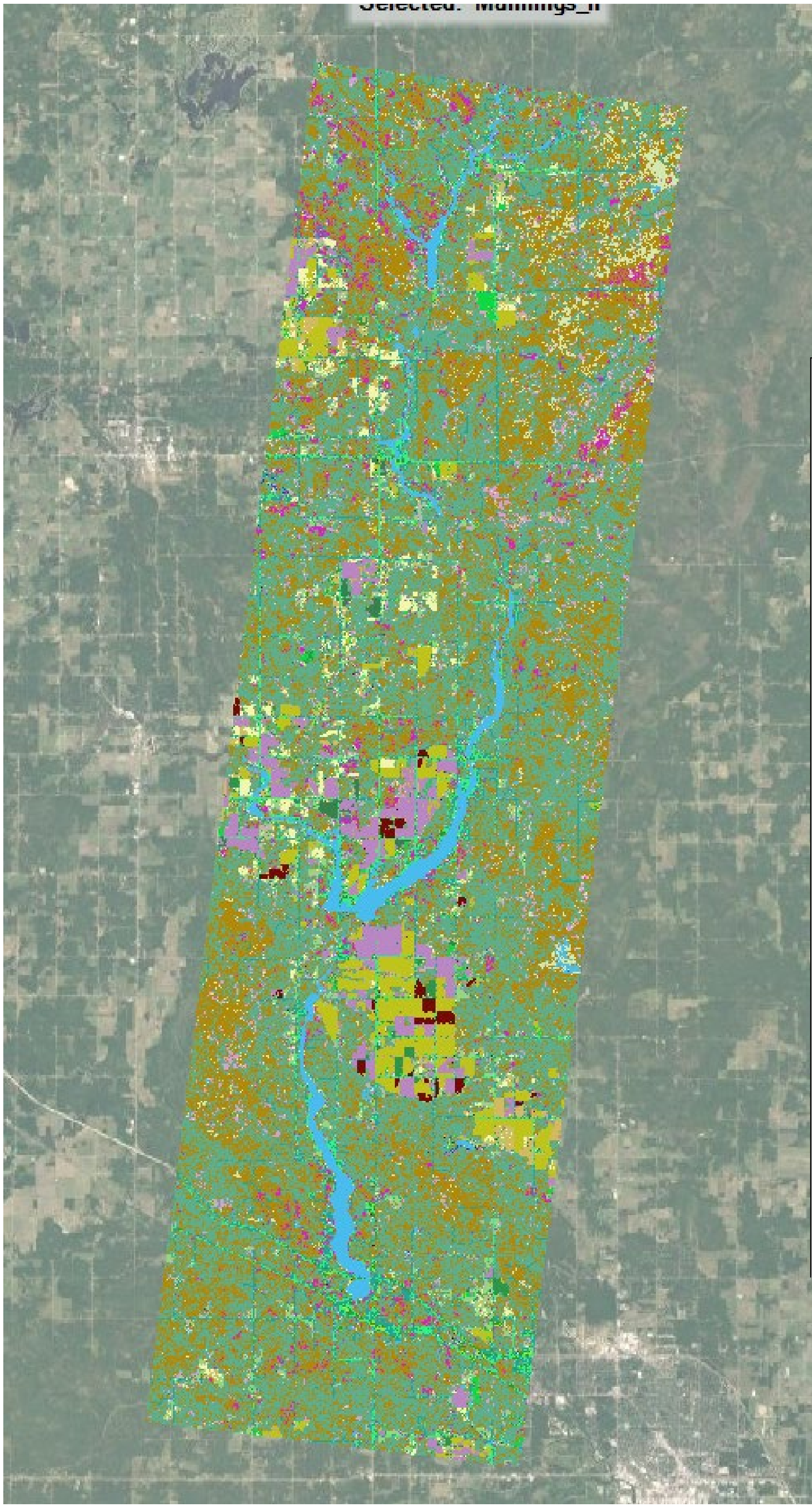
HEC-RAS Storage Area/2D Area Connections



HEC-RAS Storage Area/2D Area Connection



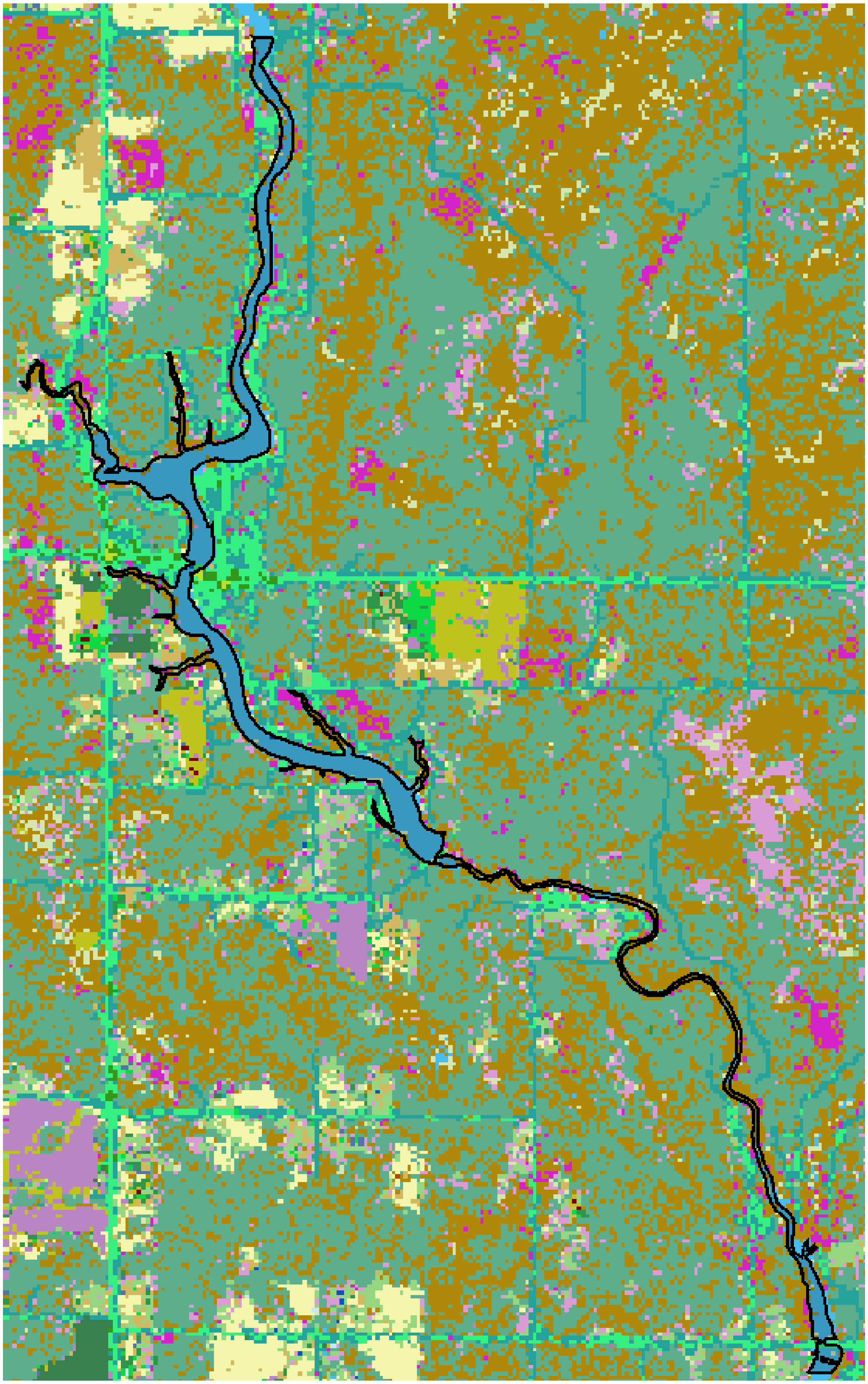
HEC-RAS 2-Dimensional Model Mesh Land Use and Manning's N Values



Color	Value	Name	Default Manning's n
	0	nodata	
	1	alfalfa	0.06
	10	deciduous forest	0.15
	11	developed/high intensity	0.15
	12	developed/low intensity	0.06
	13	developed/med intensity	0.1
	14	developed/open space	0.05
	15	dry beans	0.06
	16	evergreen forest	0.15
	17	fallow/idle cropland	0.06
	18	grassland/pasture	0.04
	19	herbaceous wetlands	0.04
	2	apples	0.1
	20	mixed forest	0.12
	21	oats	0.06
	22	open water	0.04
	23	other crops	0.06
	24	other hay/non alfalfa	0.06
	25	peas	0.06
	26	pop or orn corn	0.06
	27	potatoes	0.06
	28	rye	0.06
	29	shrubland	0.06
	3	barren	0.04
	30	sorghum	0.06
	31	soybeans	0.05
	32	sugarbeets	0.06
	33	sweet corn	0.08
	34	triticale	0.06
	35	winter wheat	0.06
	36	woody wetlands	0.1
	4	blueberries	0.08
	5	christmas trees	0.15
	6	clover/wildflowers	0.06
	7	corn	0.06
	8	cucumbers	0.06
	9	dbl crop winwht/corn	0.06

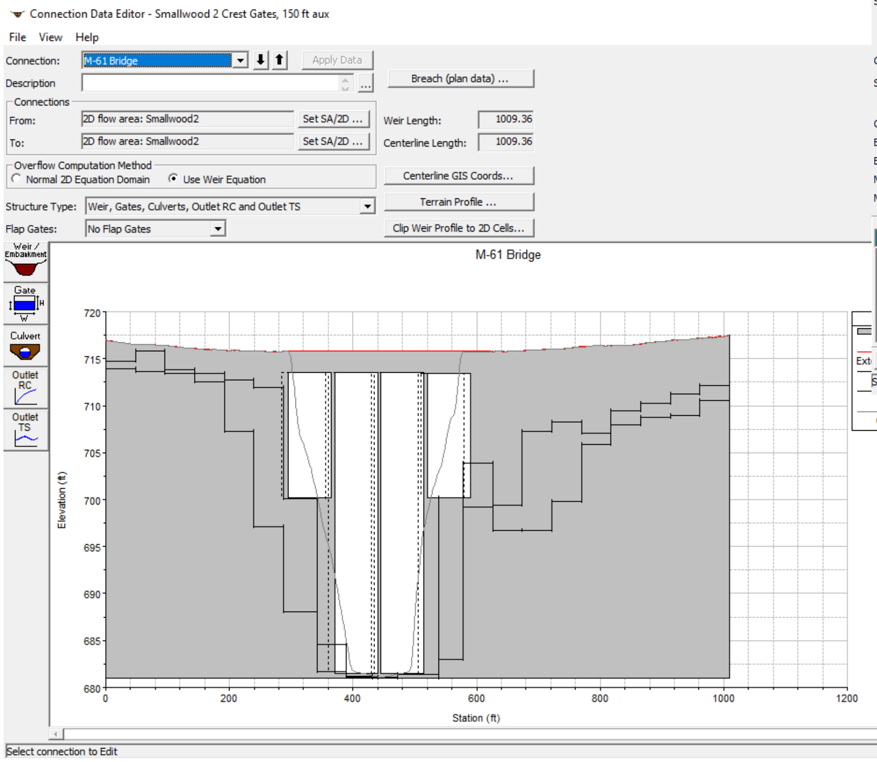
Manning N Overide Region

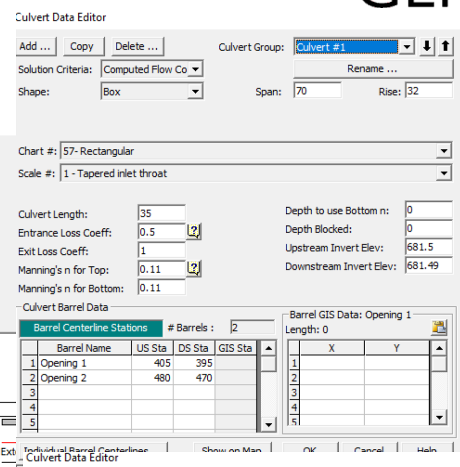
N = 0.035

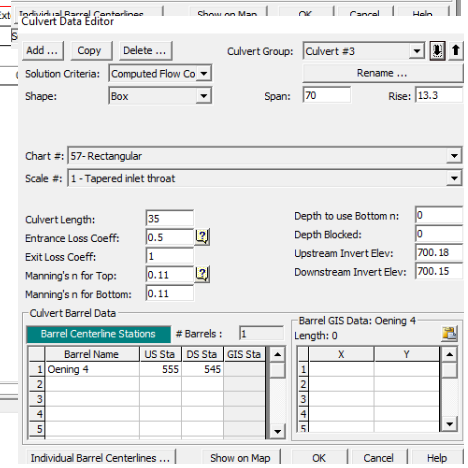


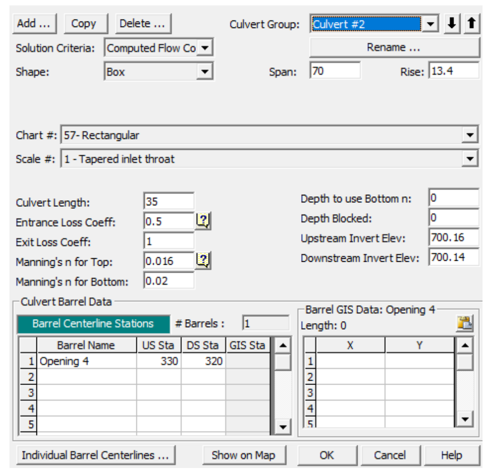
HEC-RAS 2D Bridges

M-61 Bridge

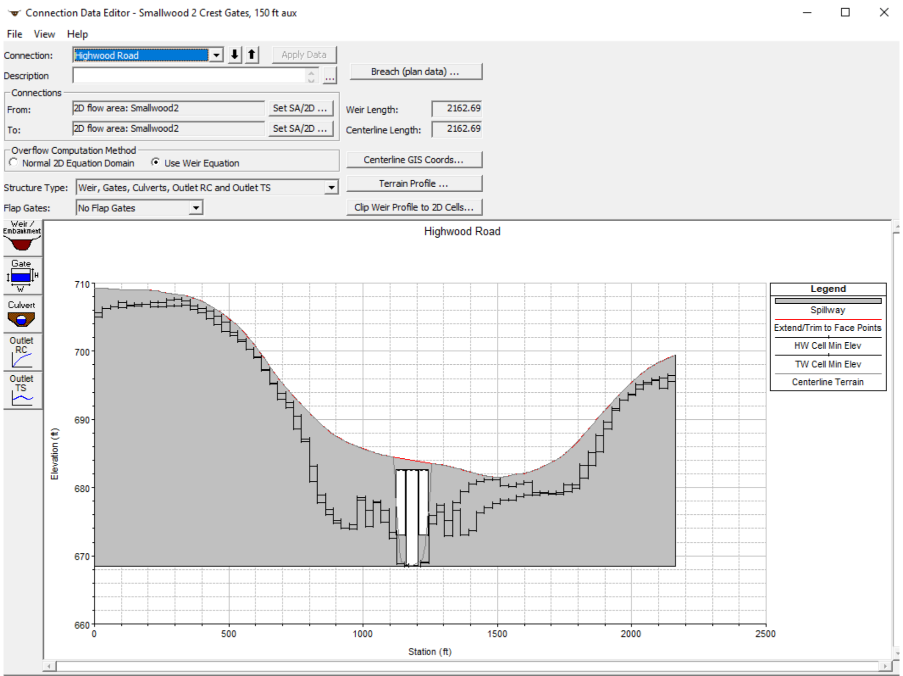


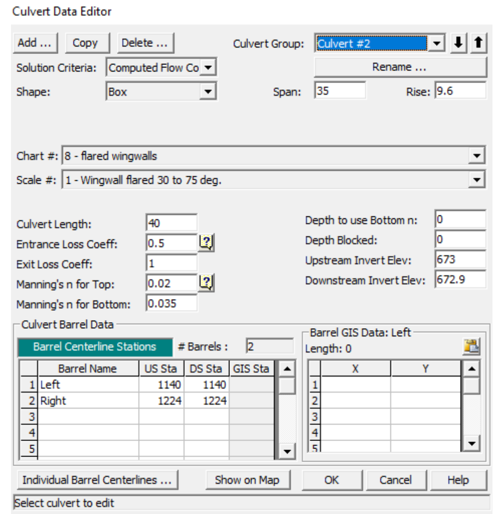


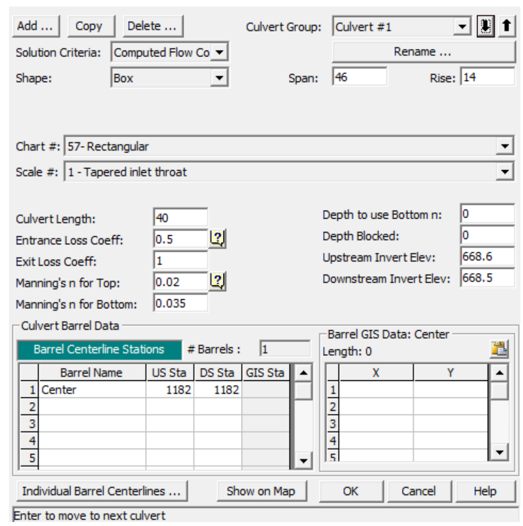


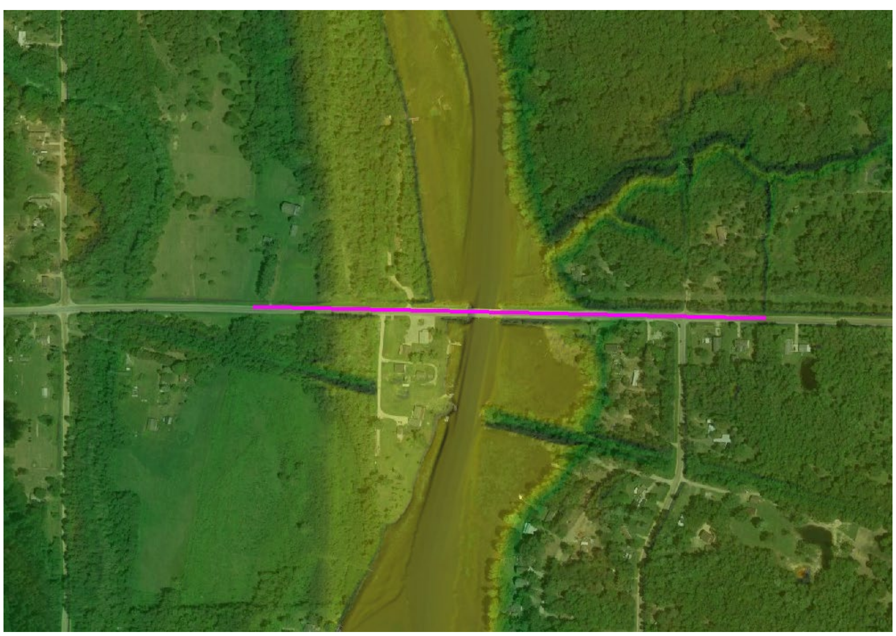


Highwood Road Bridge

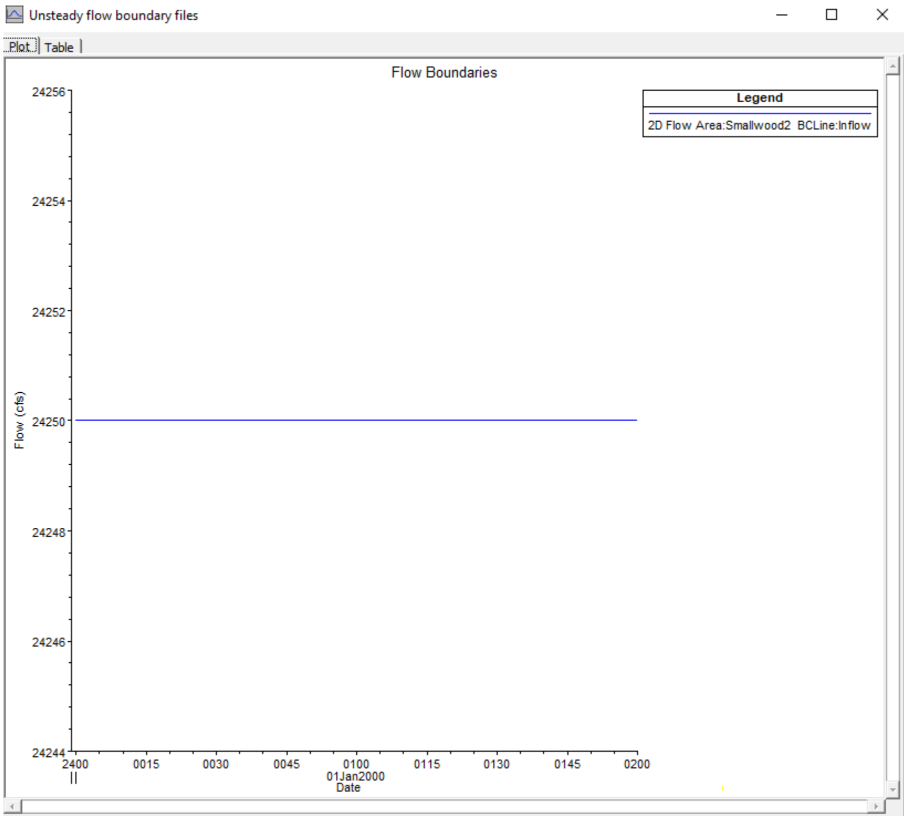




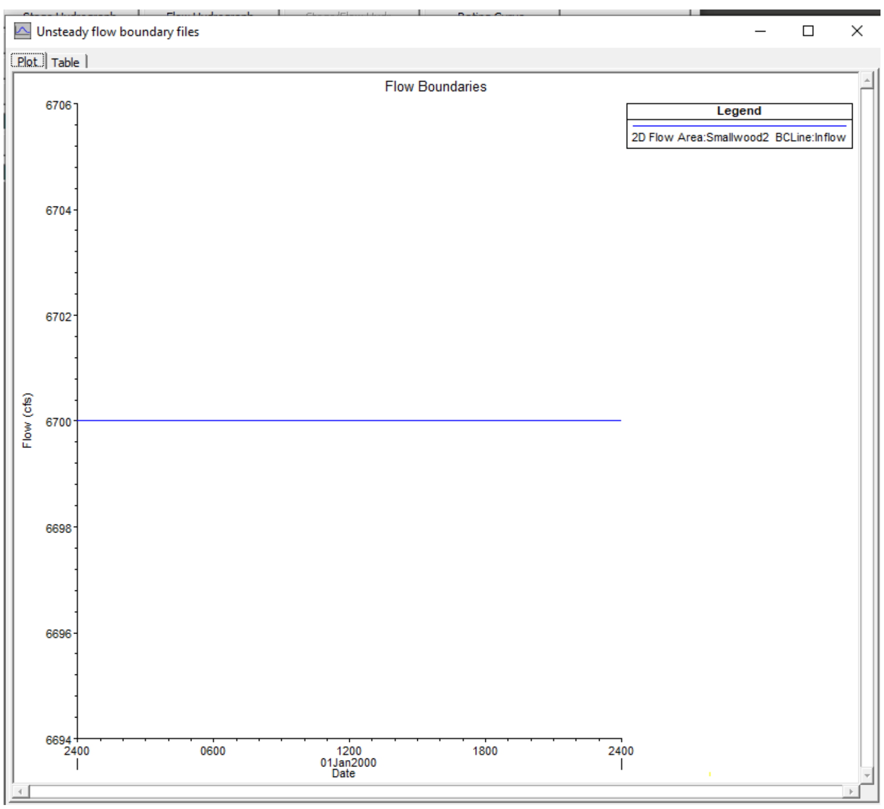




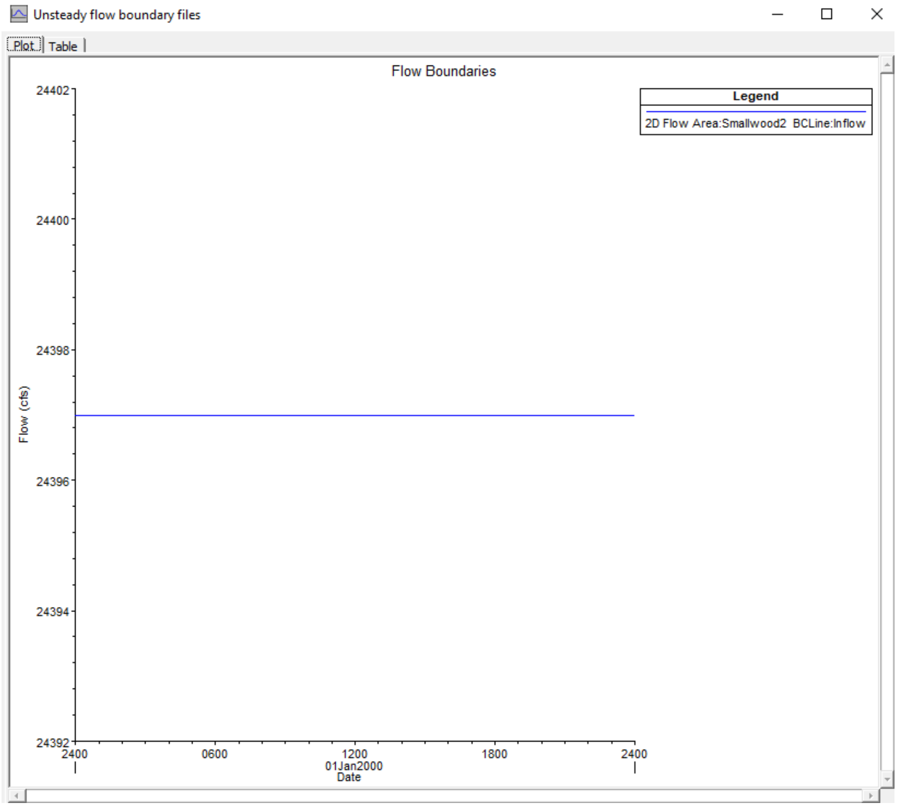
HEC-RAS Flow Inflow Hydrographs
Half PMF+



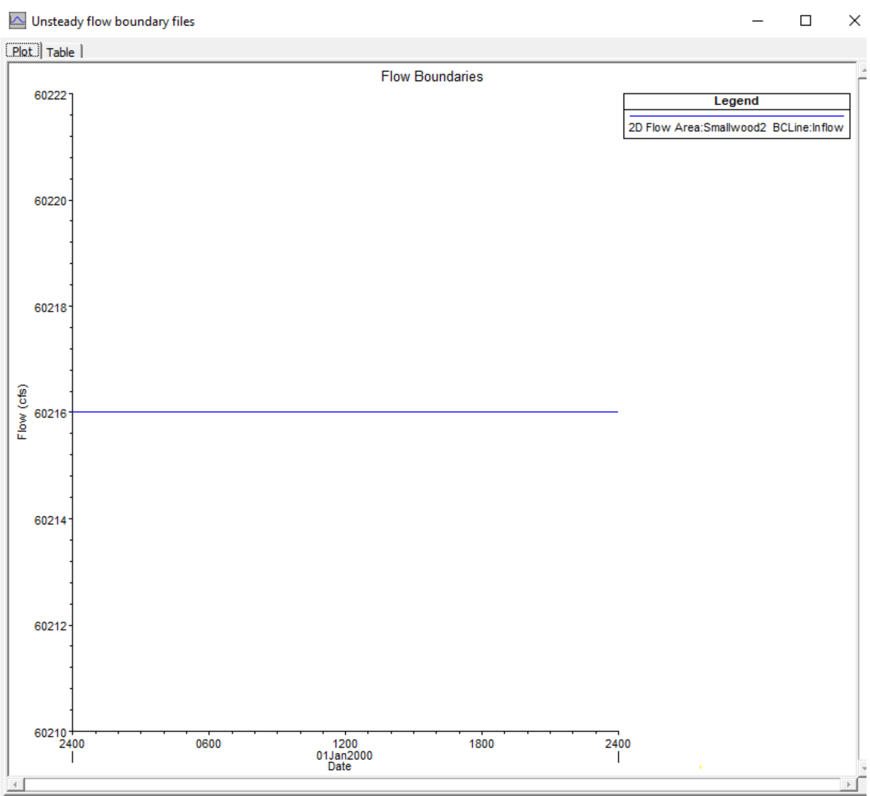
100 Year



Half PMF

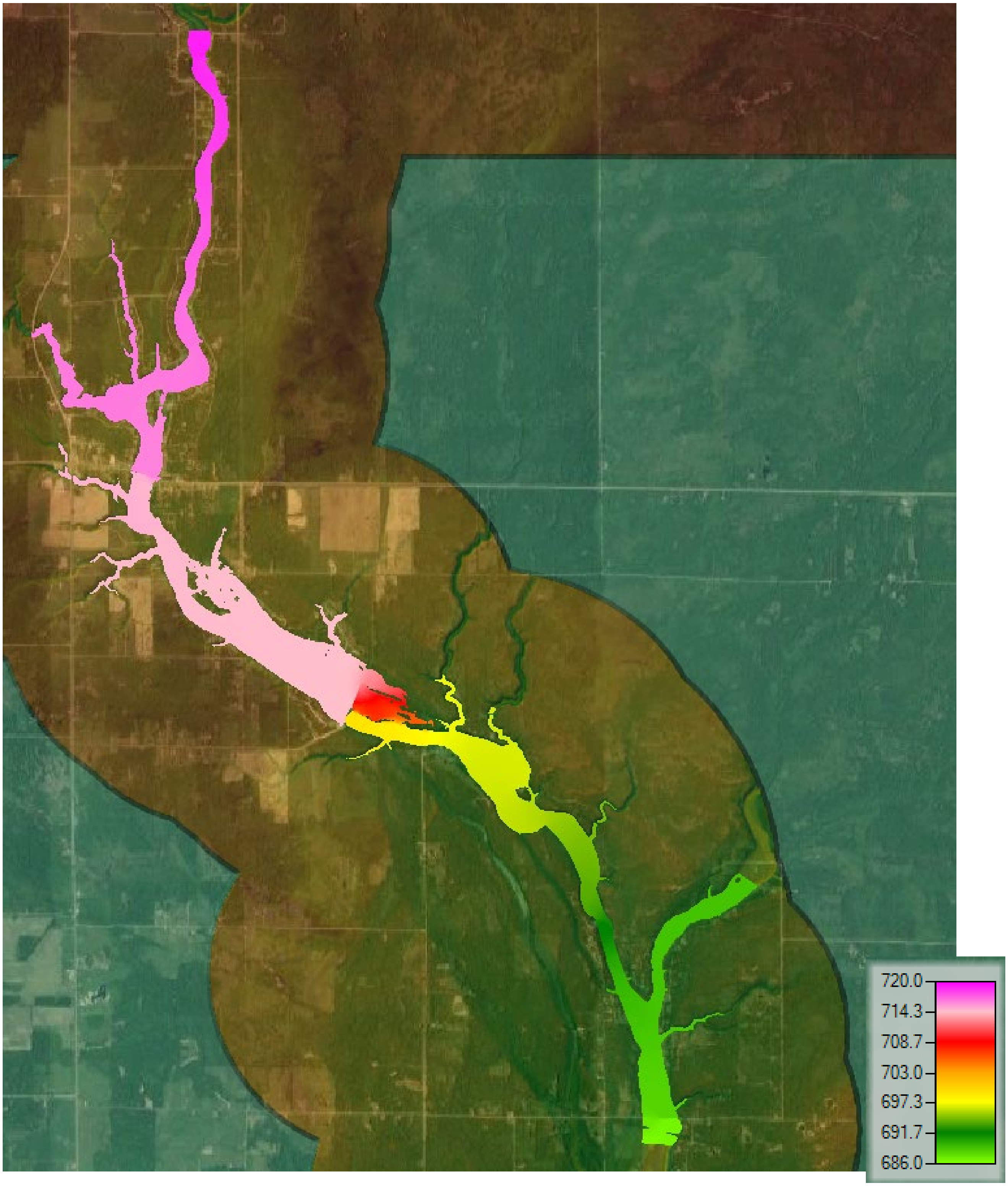


Full PMF

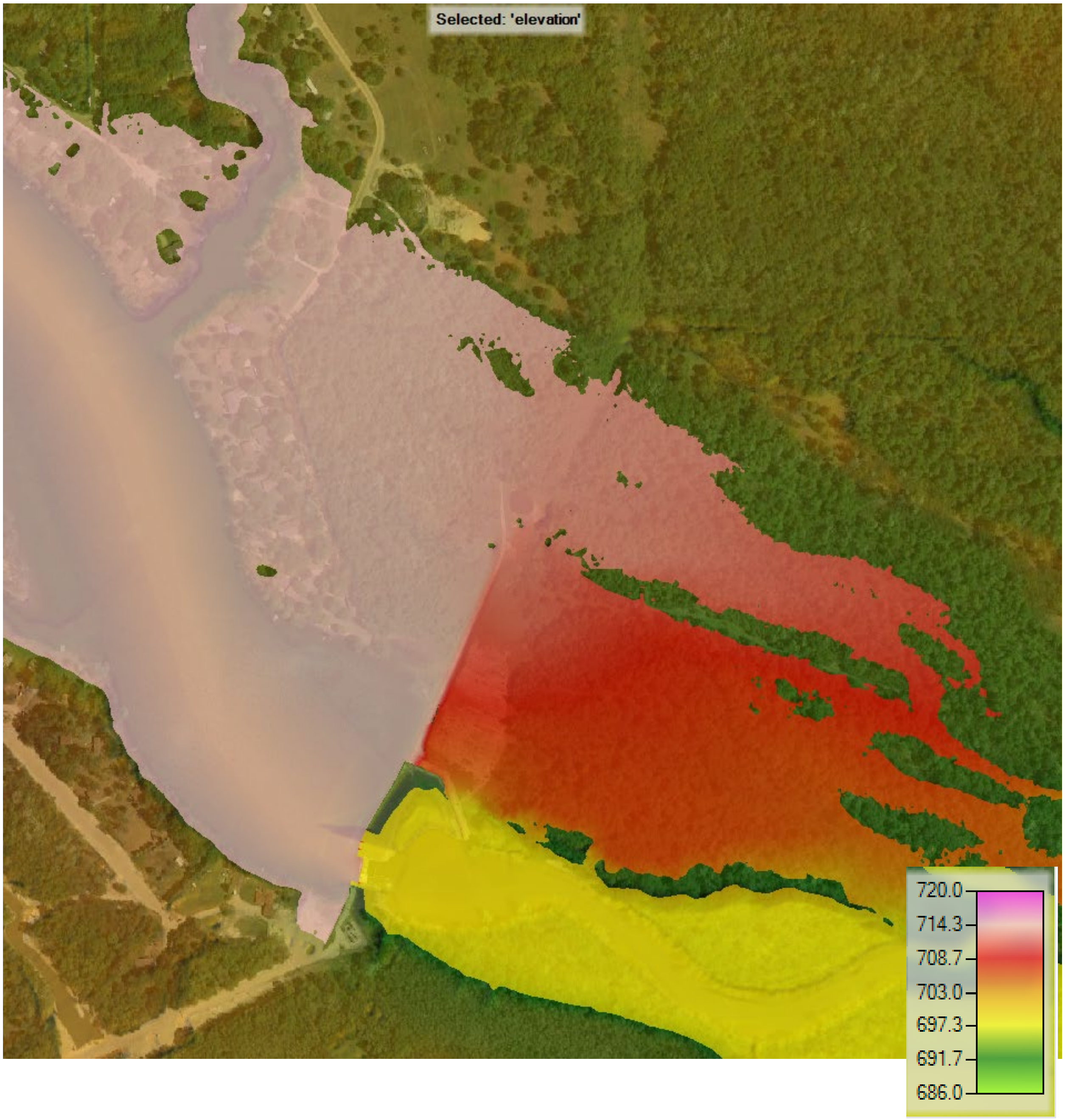


OUTPUT

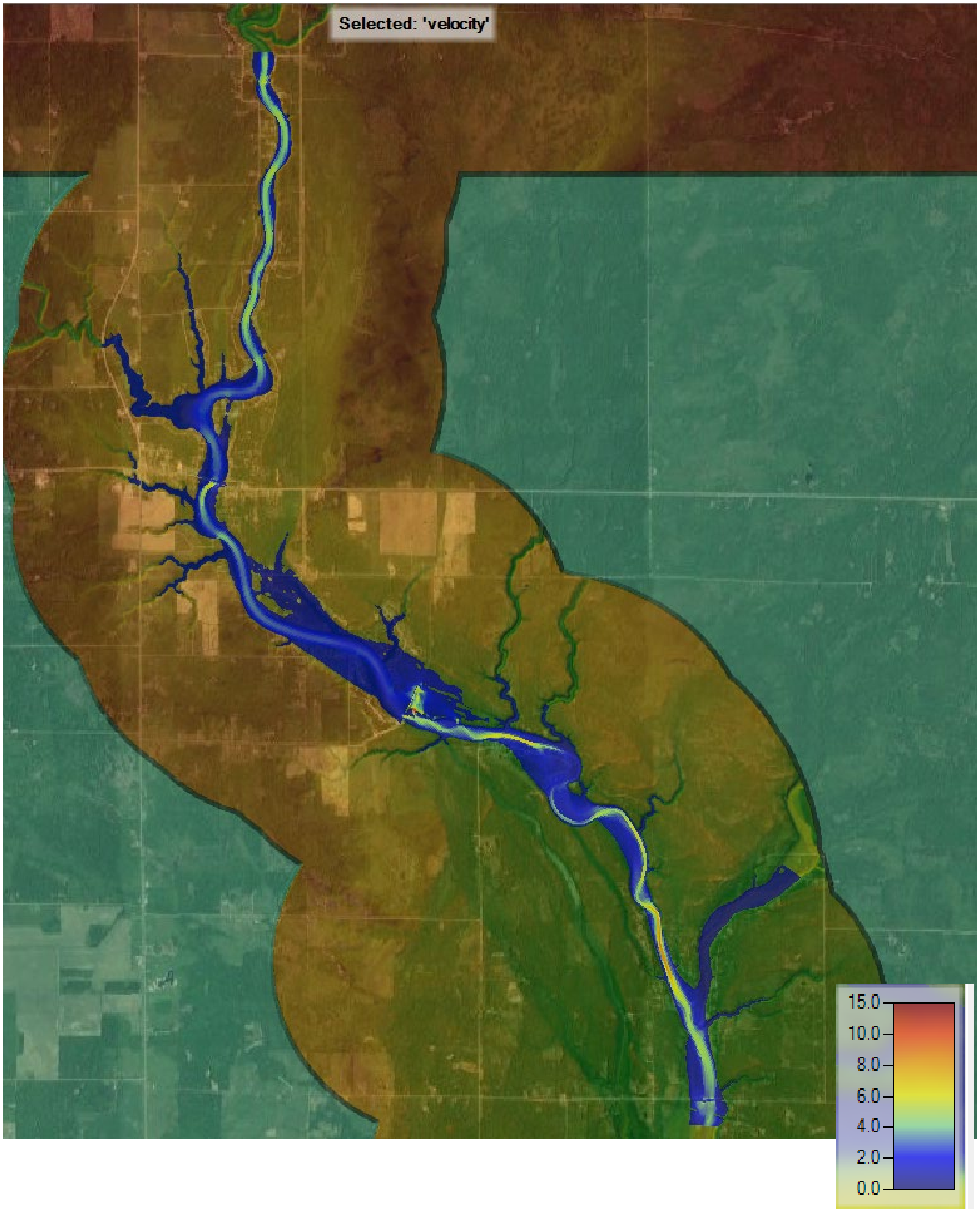
Peak Water Surface Elevation – Existing Conditions



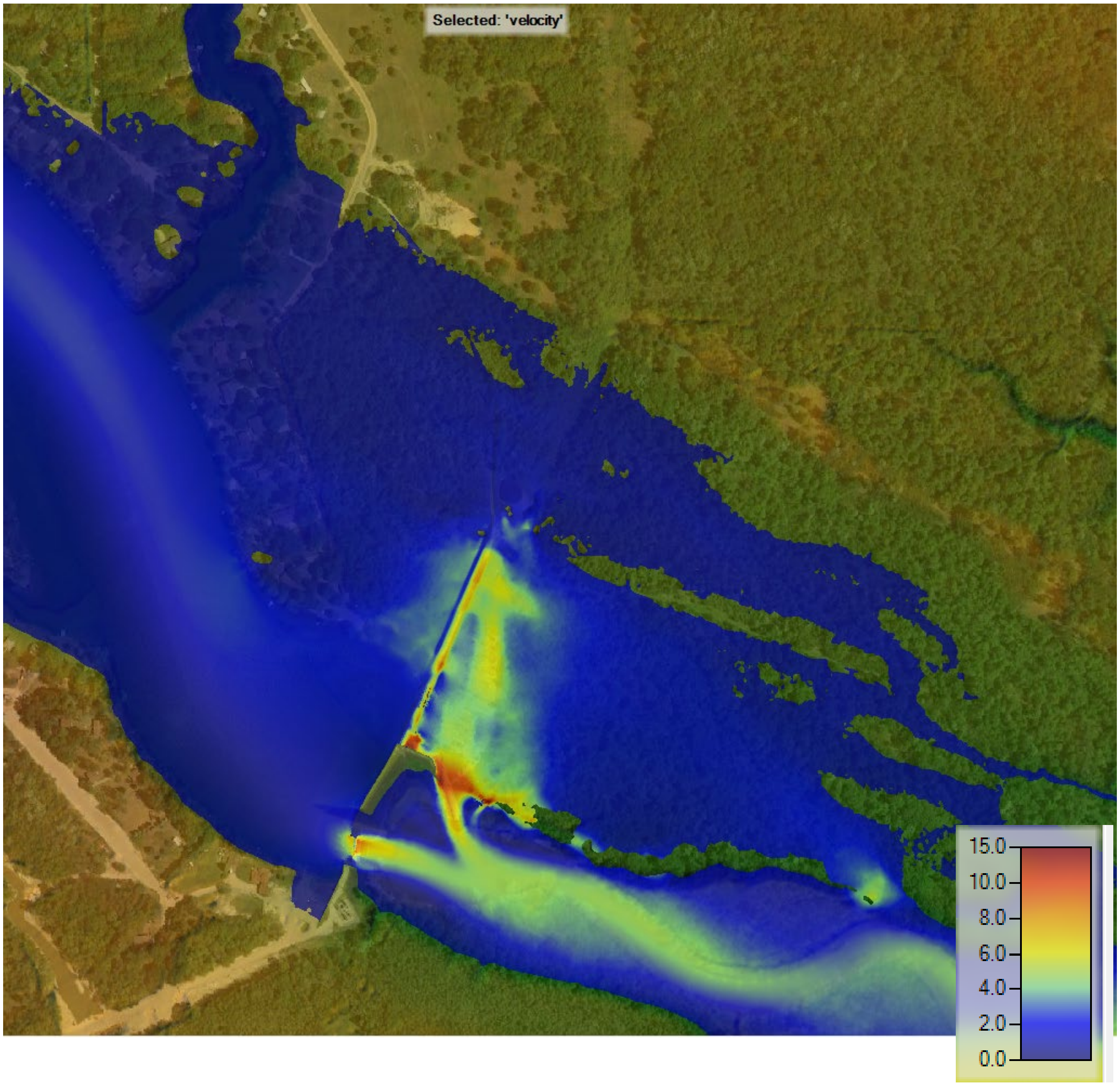
Peak Water Surface Elevation – Existing Conditions Smallwood Dam Detail



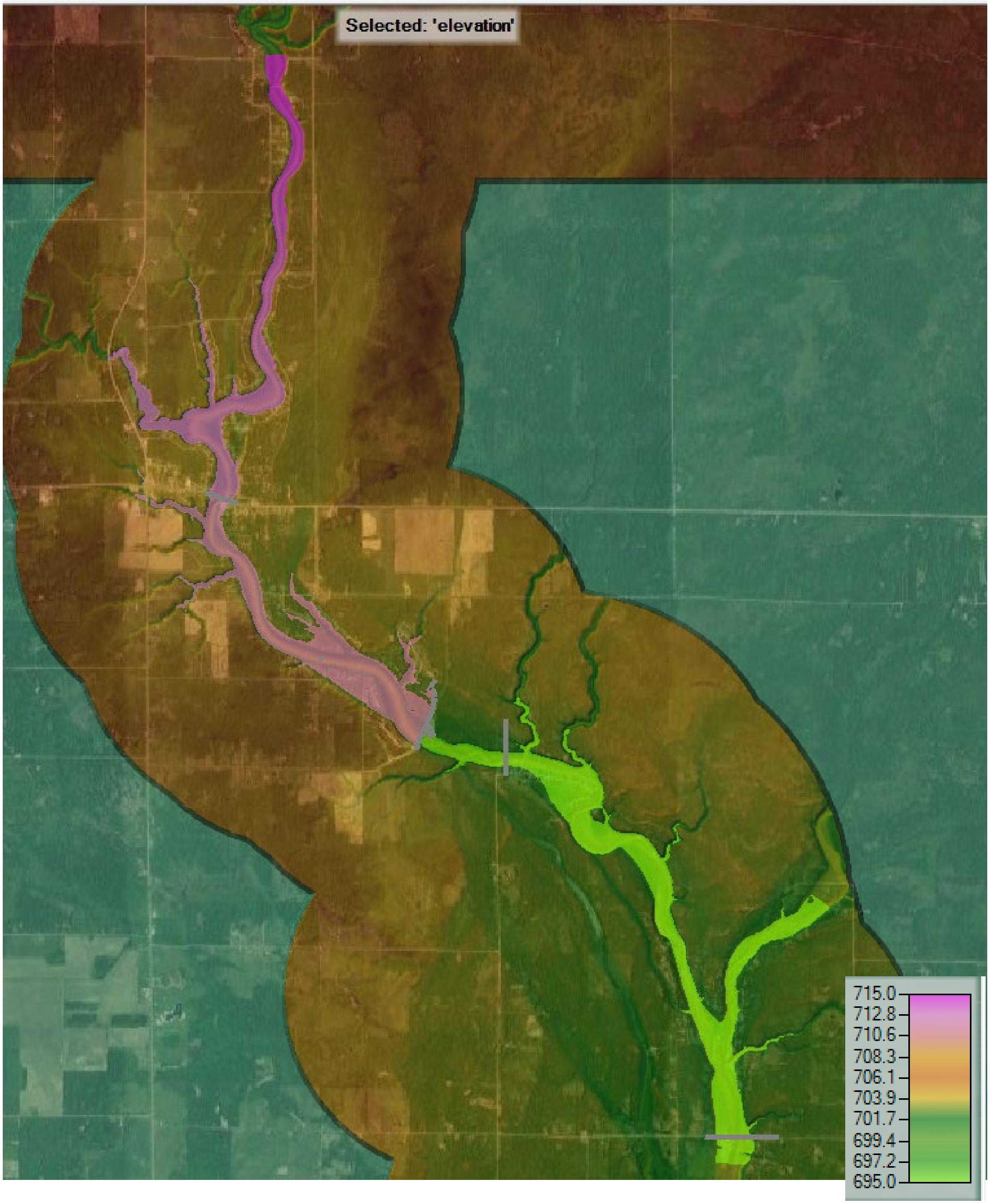
Peak Velocity – Existing Conditions



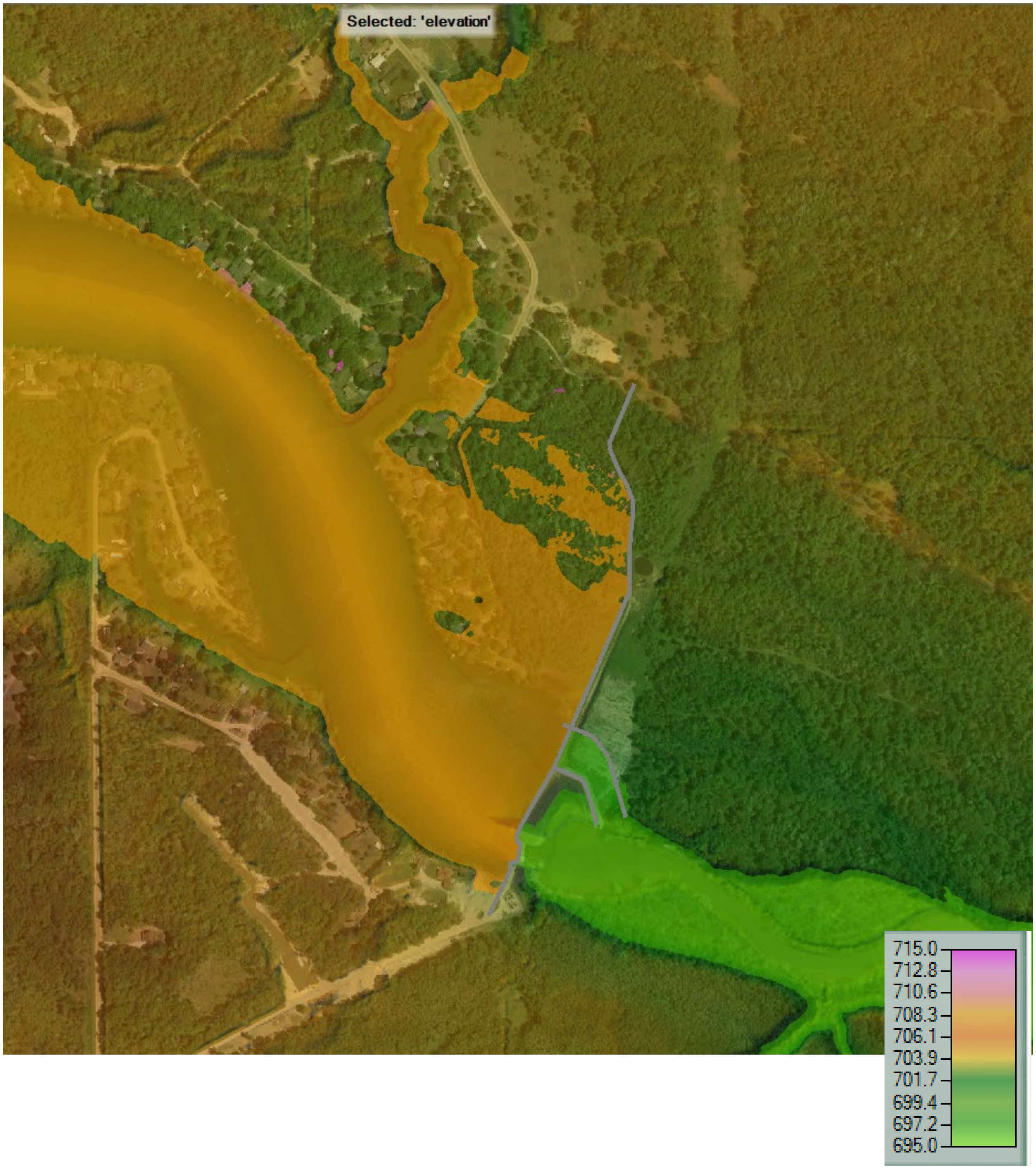
Peak Velocity – Existing Conditions Smallwood Dam Detail



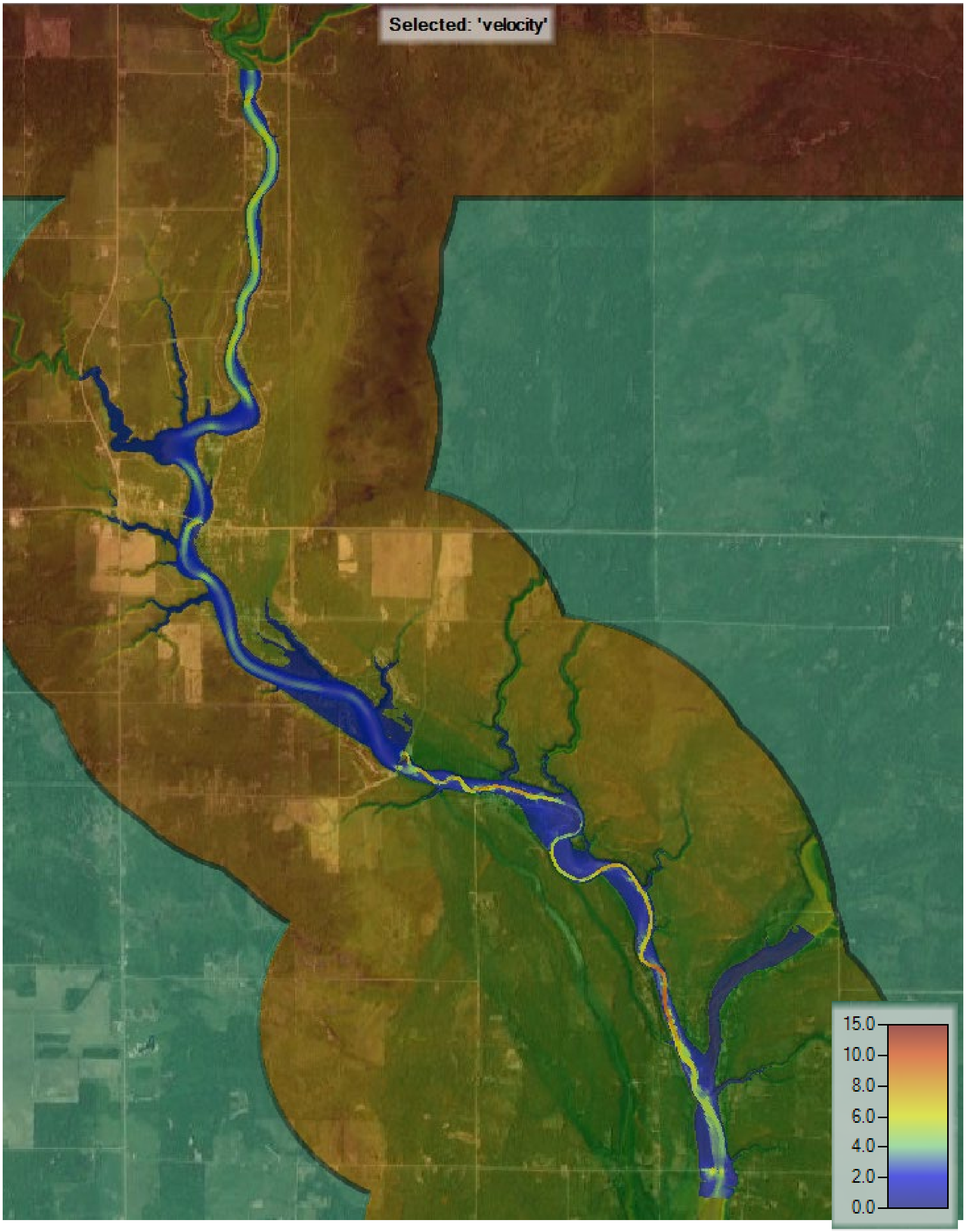
Peak Water Surface Elevation – Proposed Conditions



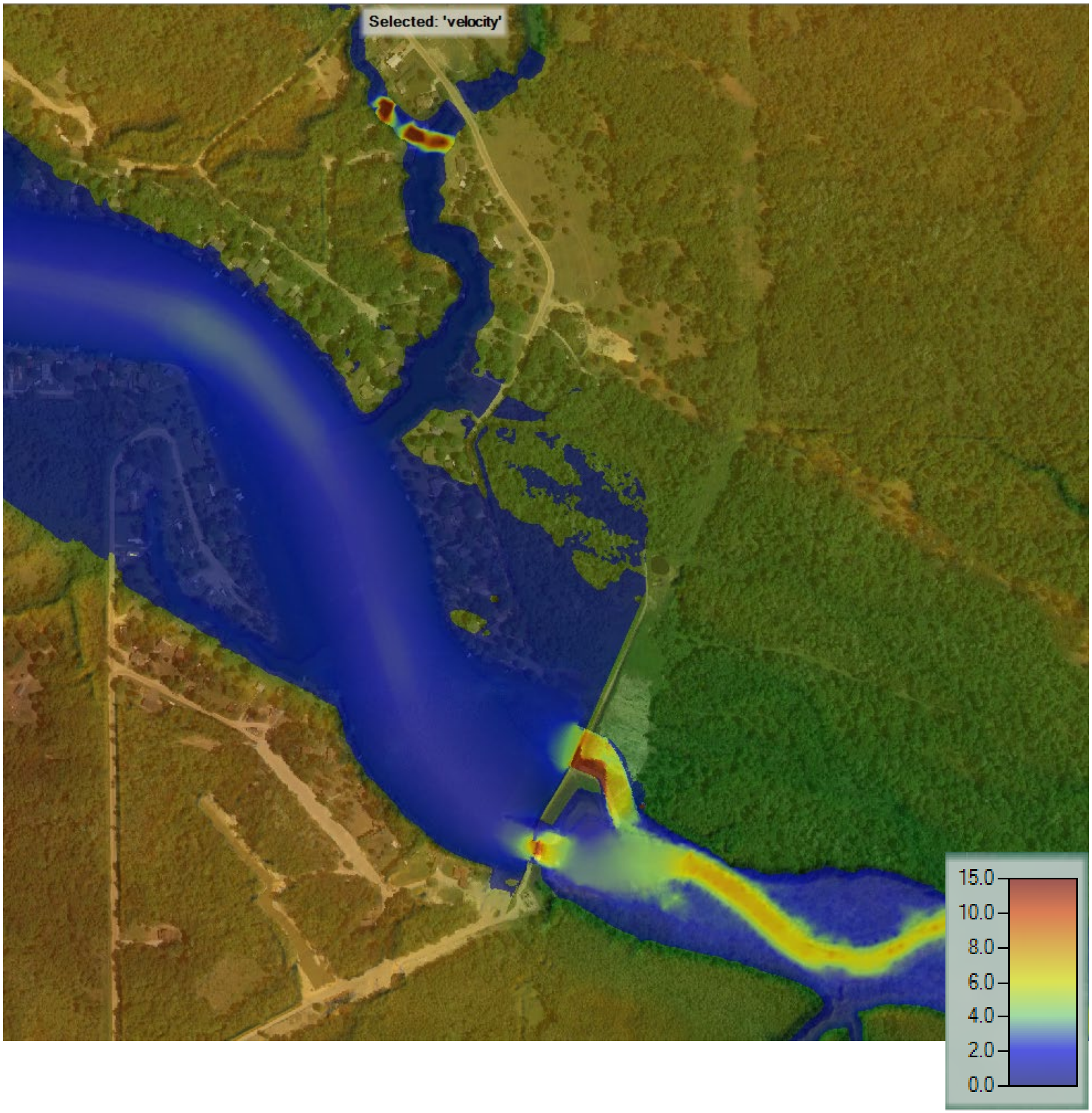
Peak Water Surface Elevation – Proposed Conditions Smallwood Dam Detail



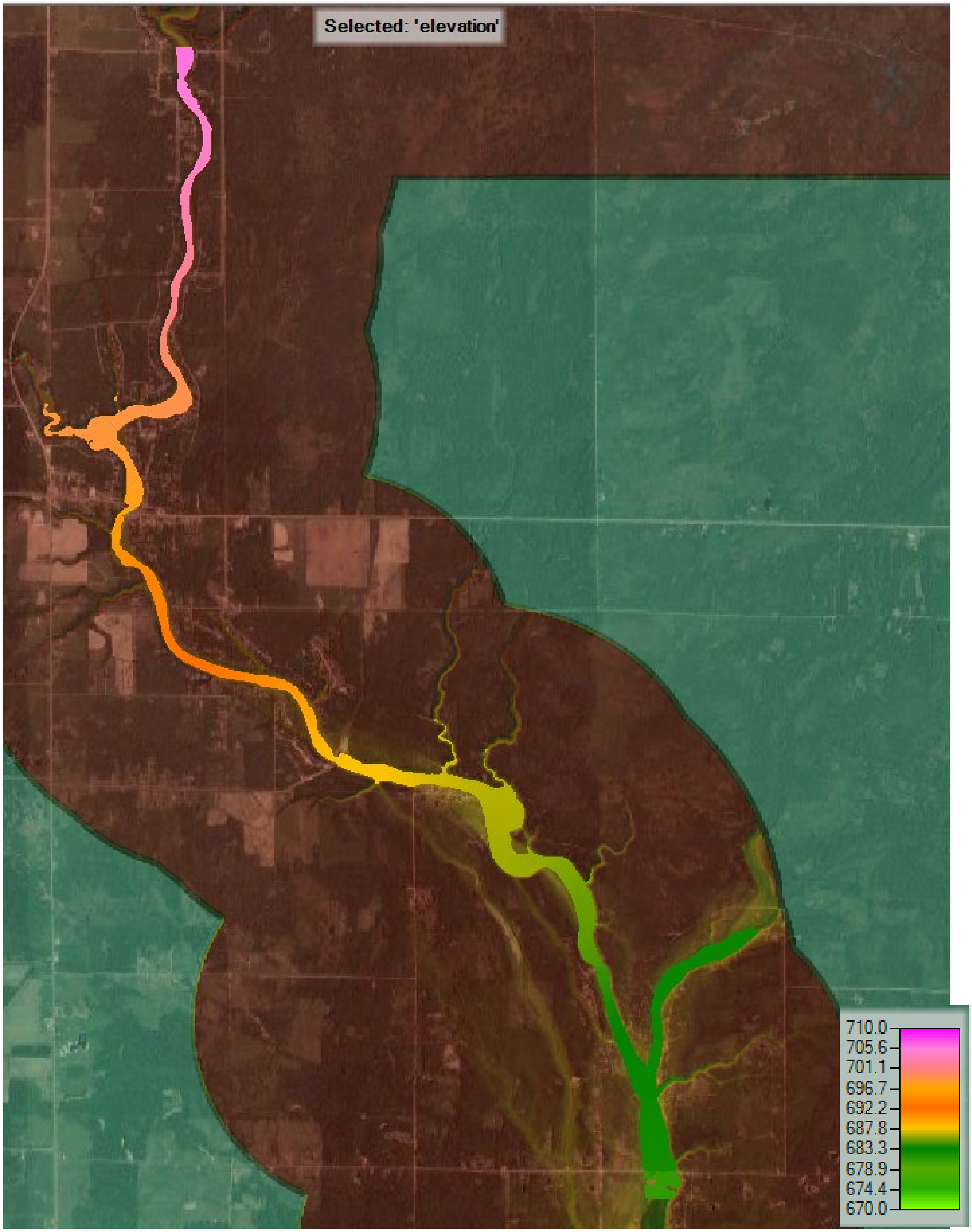
Peak Velocities - Proposed Conditions



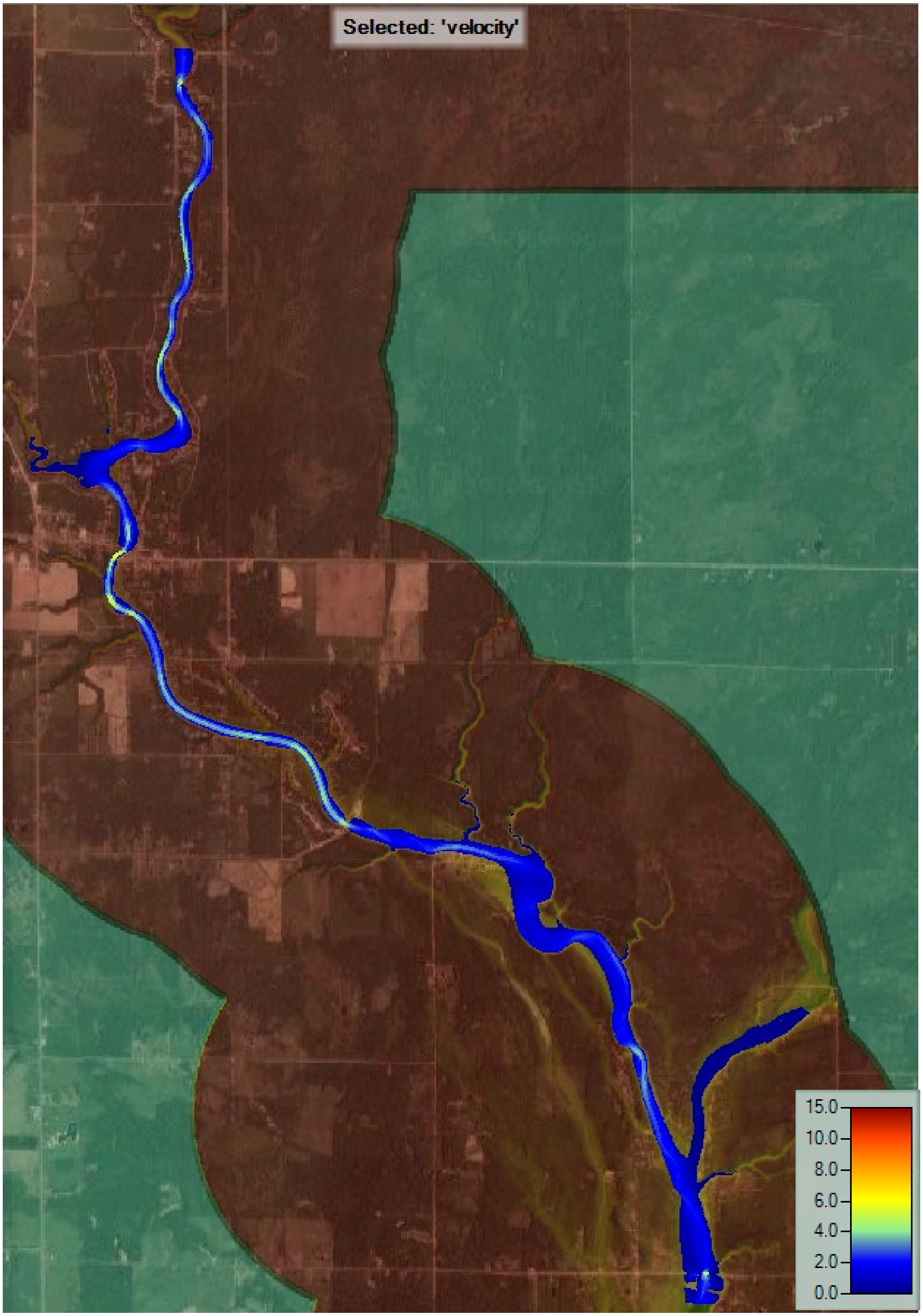
Peak Velocities - Proposed Conditions Smallwood Dam Detail



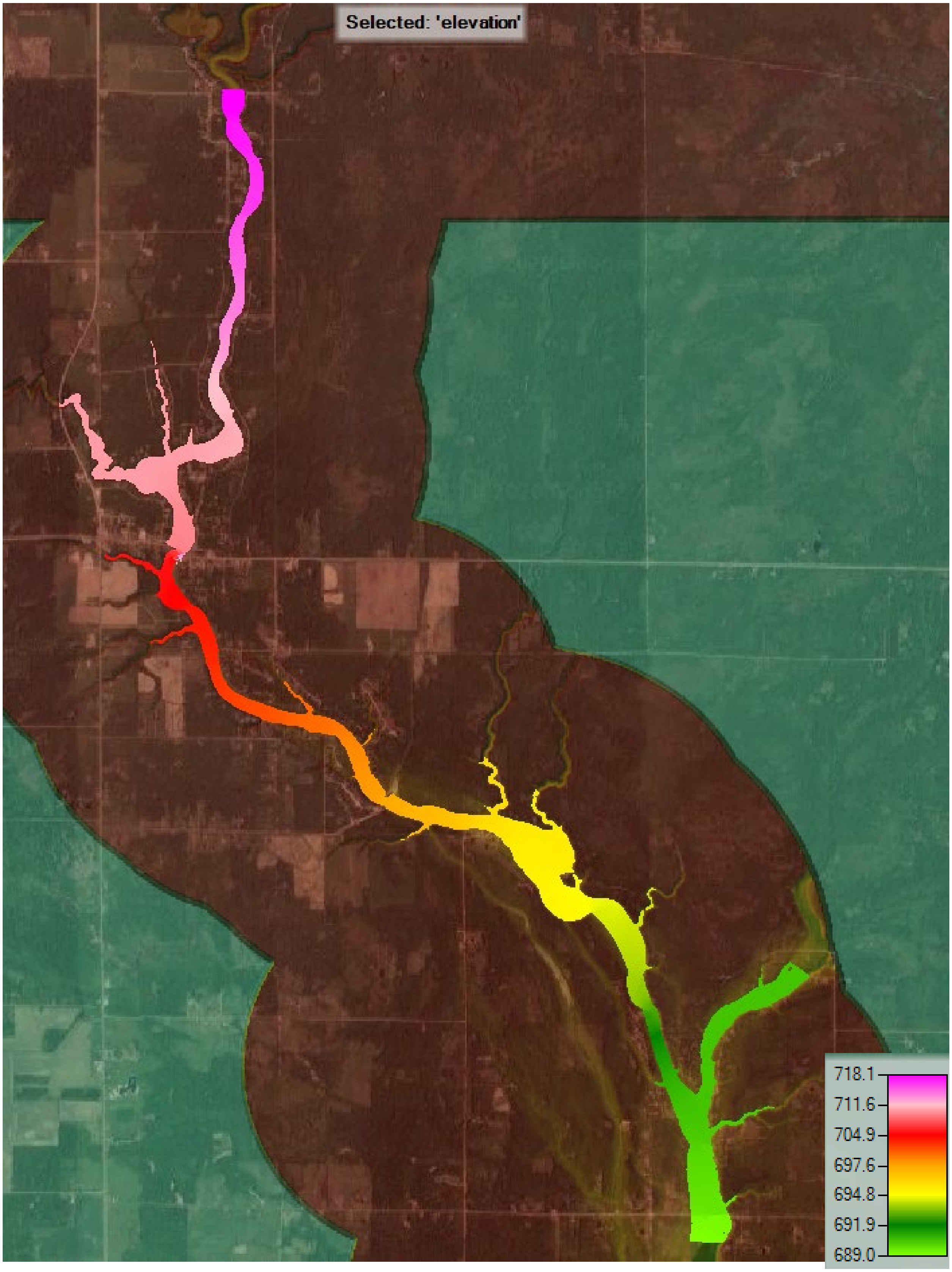
Peak Water Surface Elevation – 100-Year Flow Dam Removed



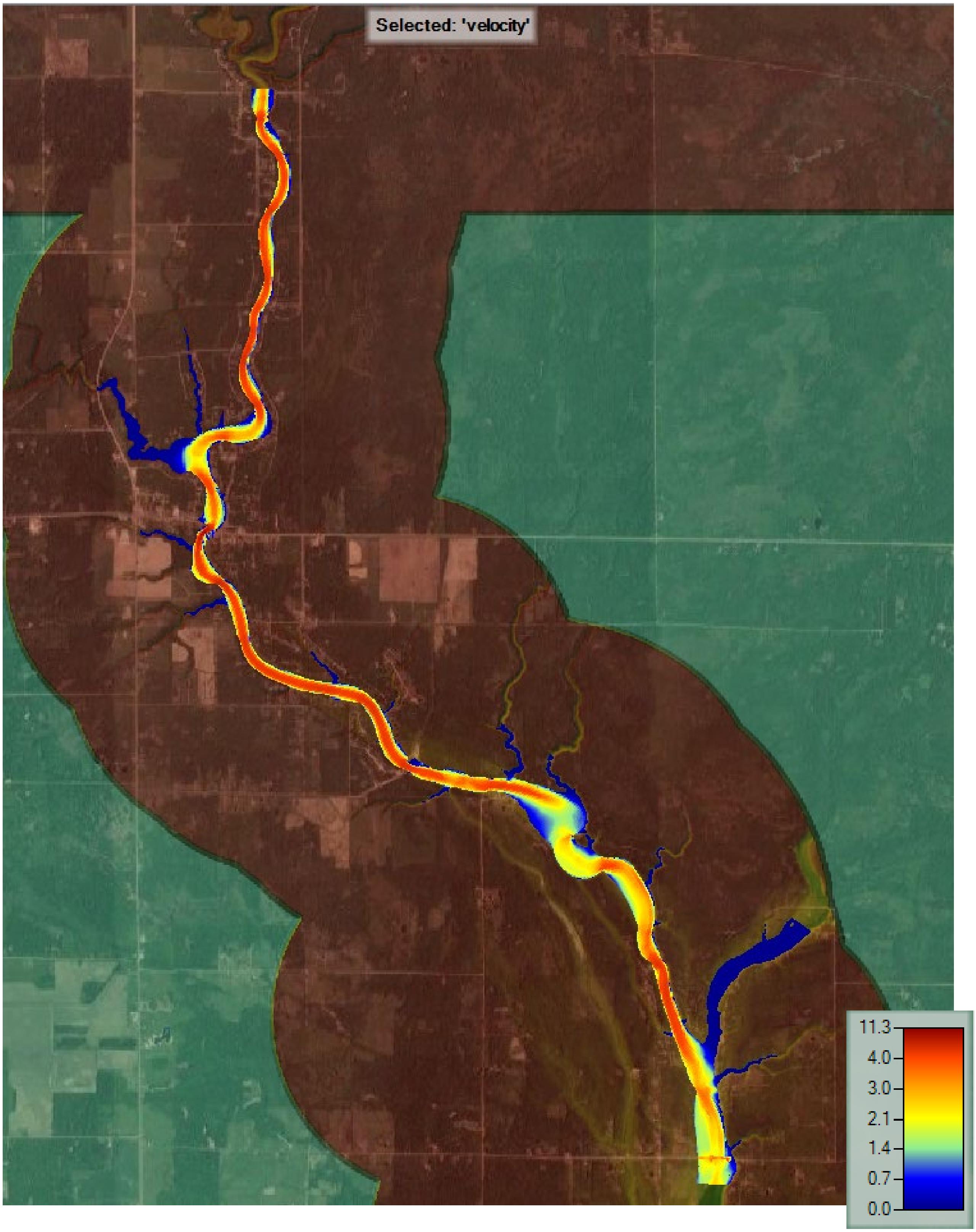
Peak Velocity – 100-Year Flow Dam Removed



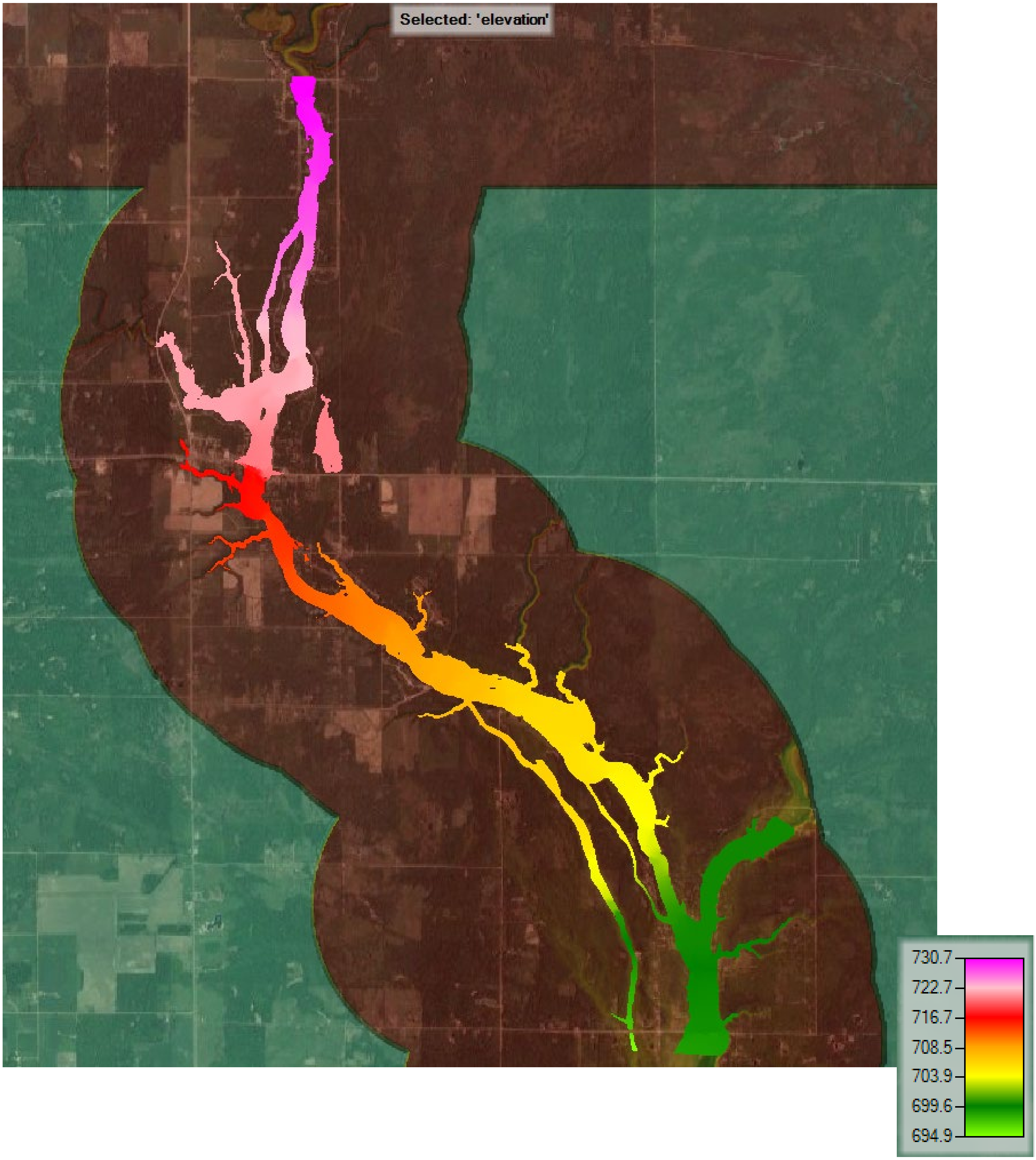
Peak Water Surface Elevation – Half PMF Dam Removed



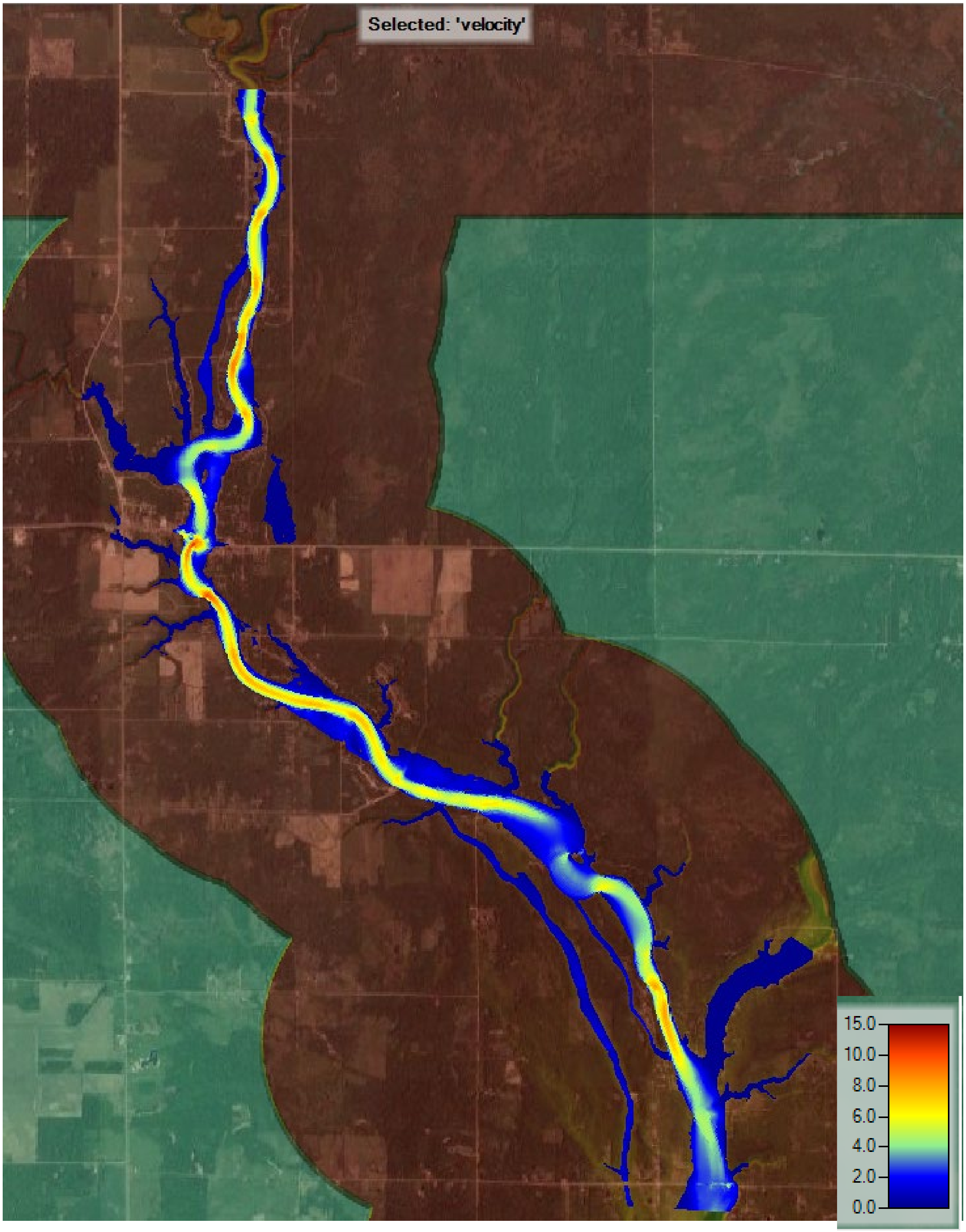
Peak Velocity – Half PMF Dam Removed



Peak Water Surface Elevation – Full PMF Dam Removed



Peak Velocity – Full PMF Dam Removed



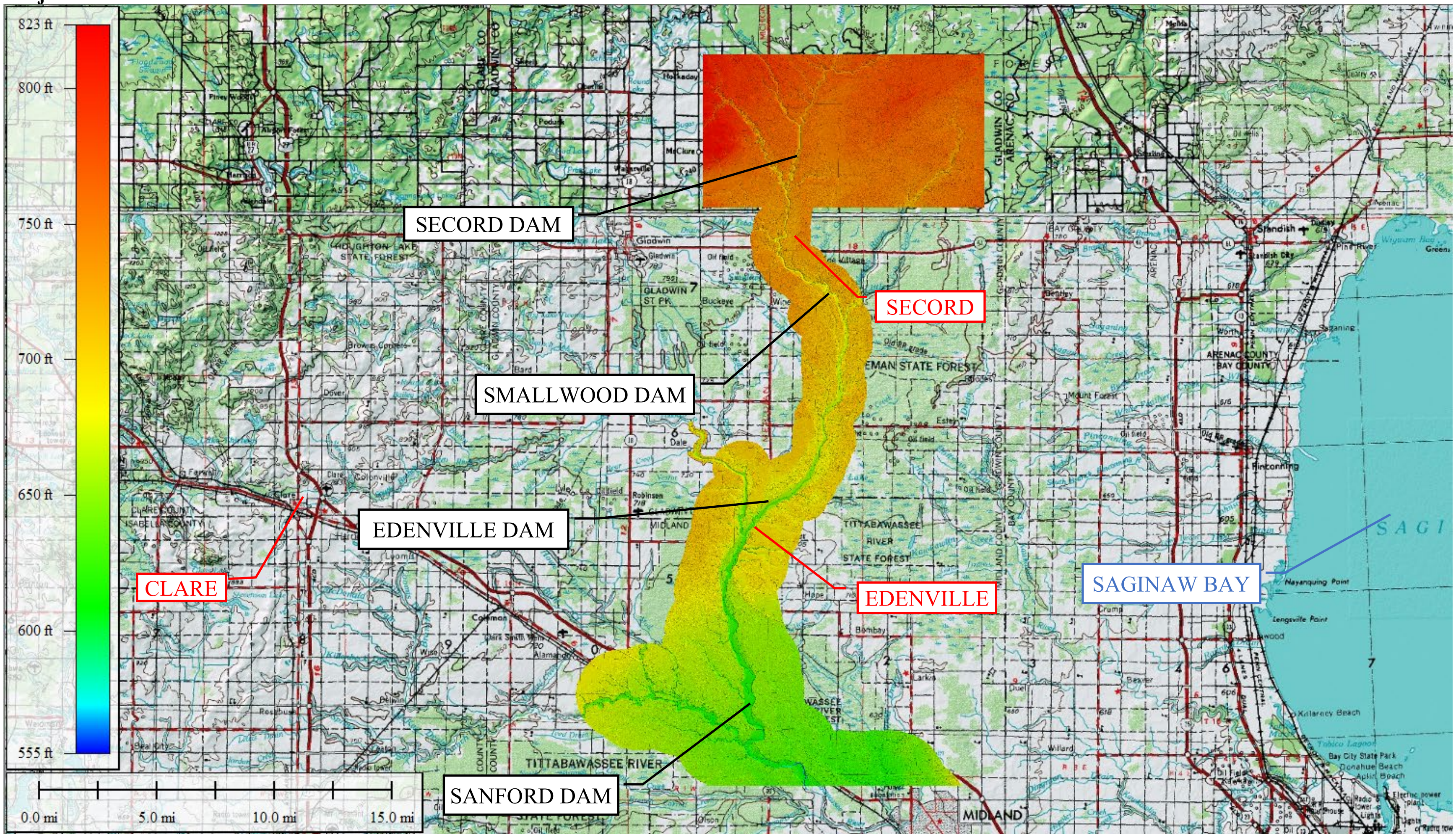
Appendix F

Proposed Conditions HEC-RAS Model Input and Output Data Sheets

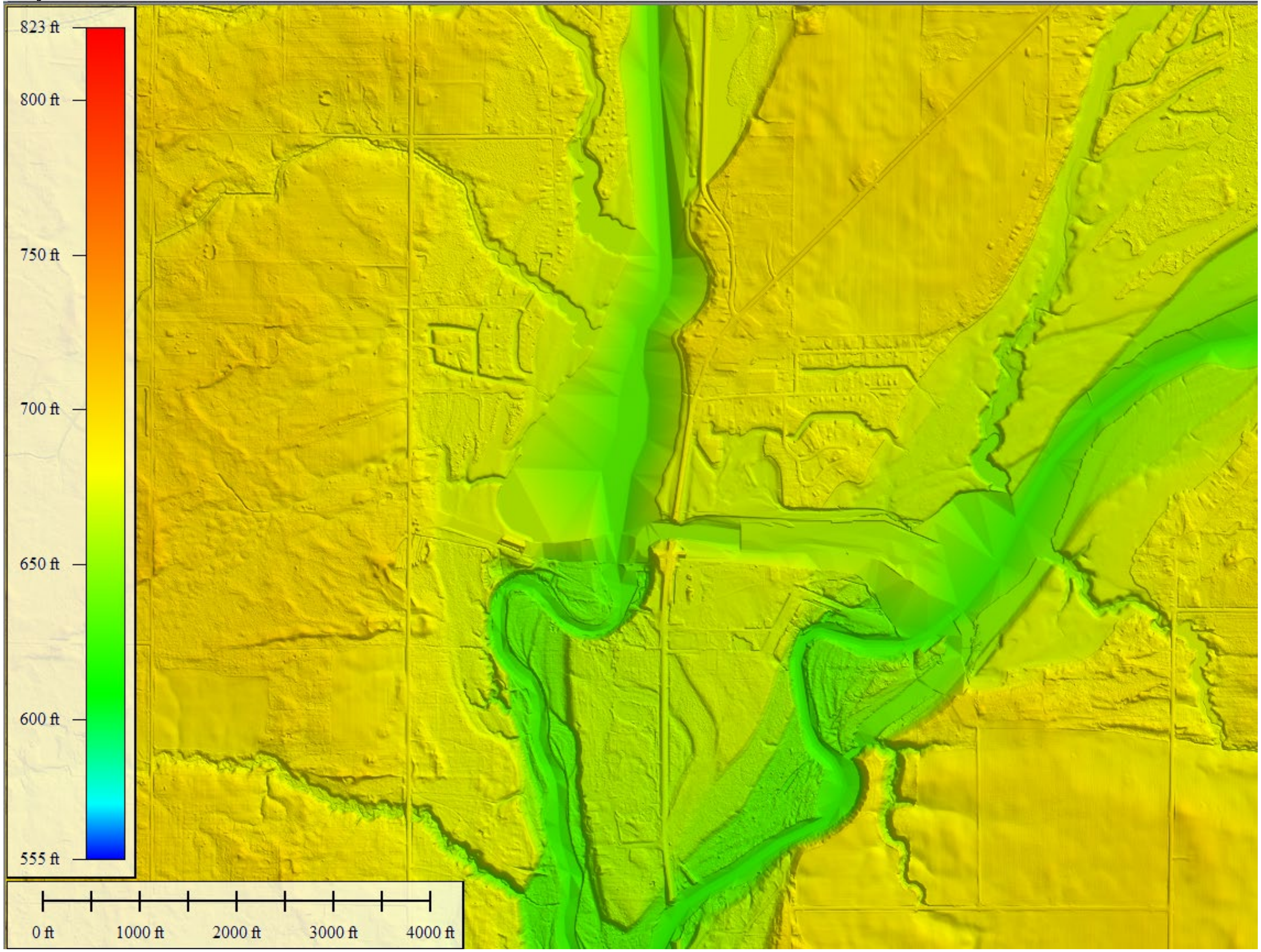
Appendix F.3 – Edenville Dam

INPUT

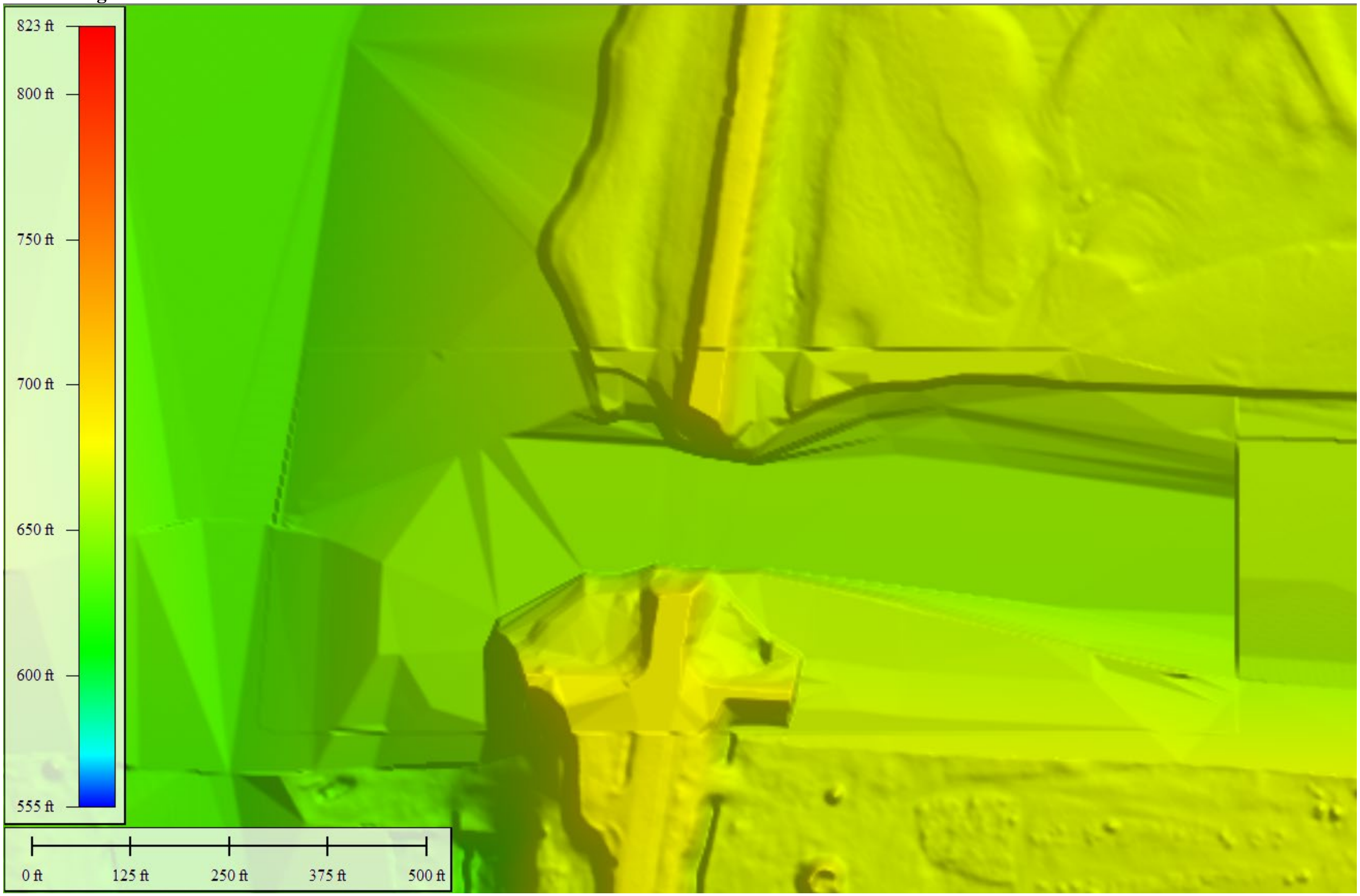
Project LiDAR Data Extents



Project Site Detail



M-30 Bridge Channel Detail



HEC-RAS 2-Dimensional Model Mesh, 100-ft cell size

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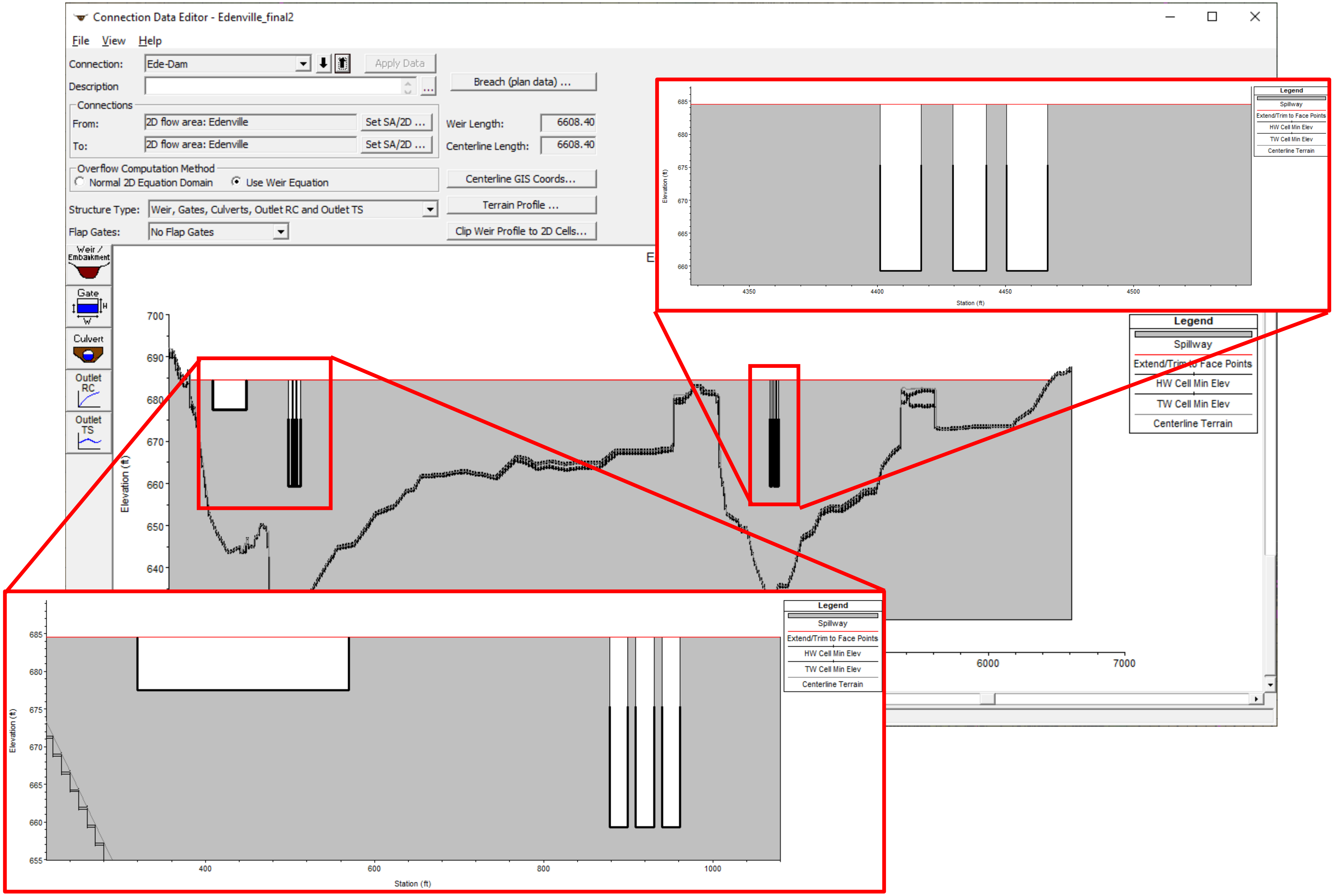
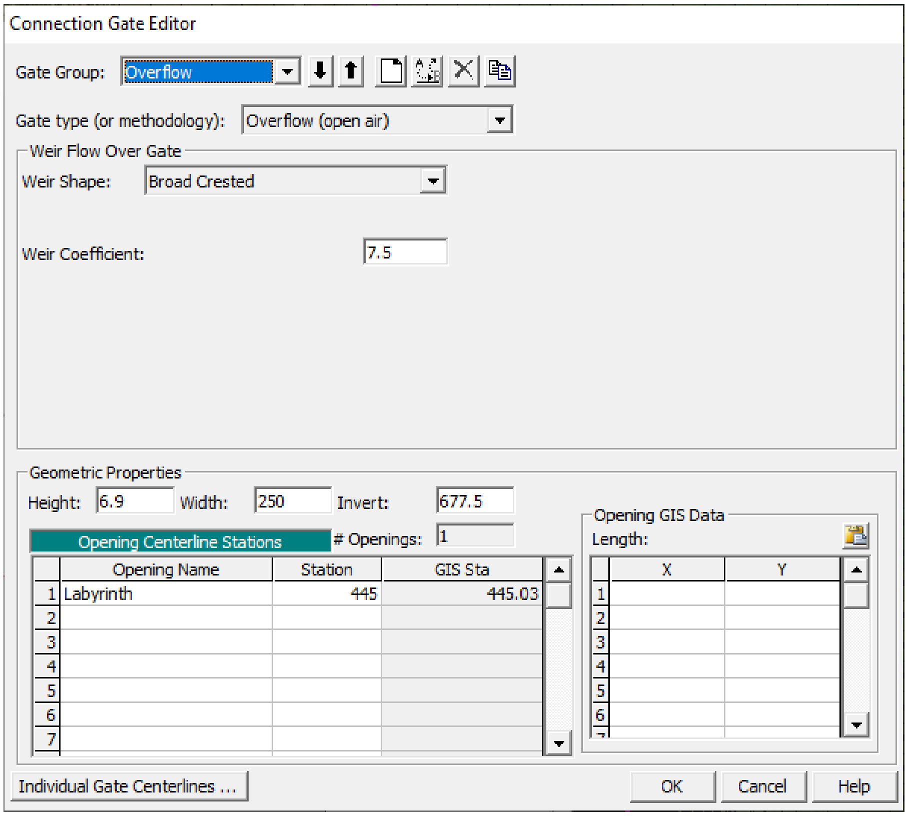
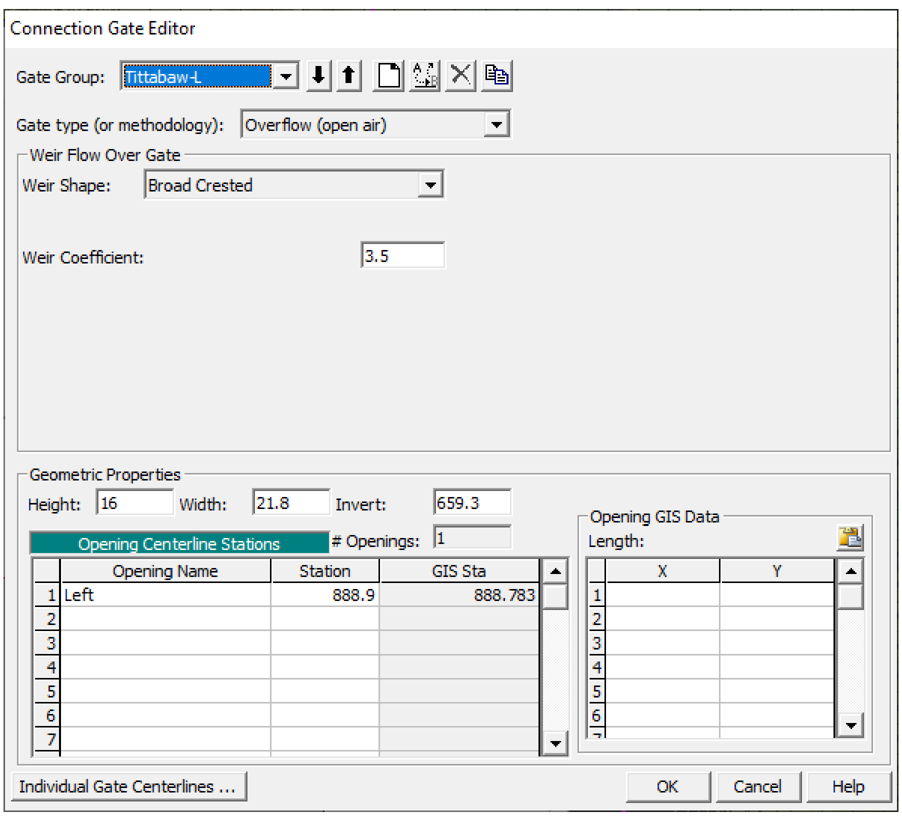
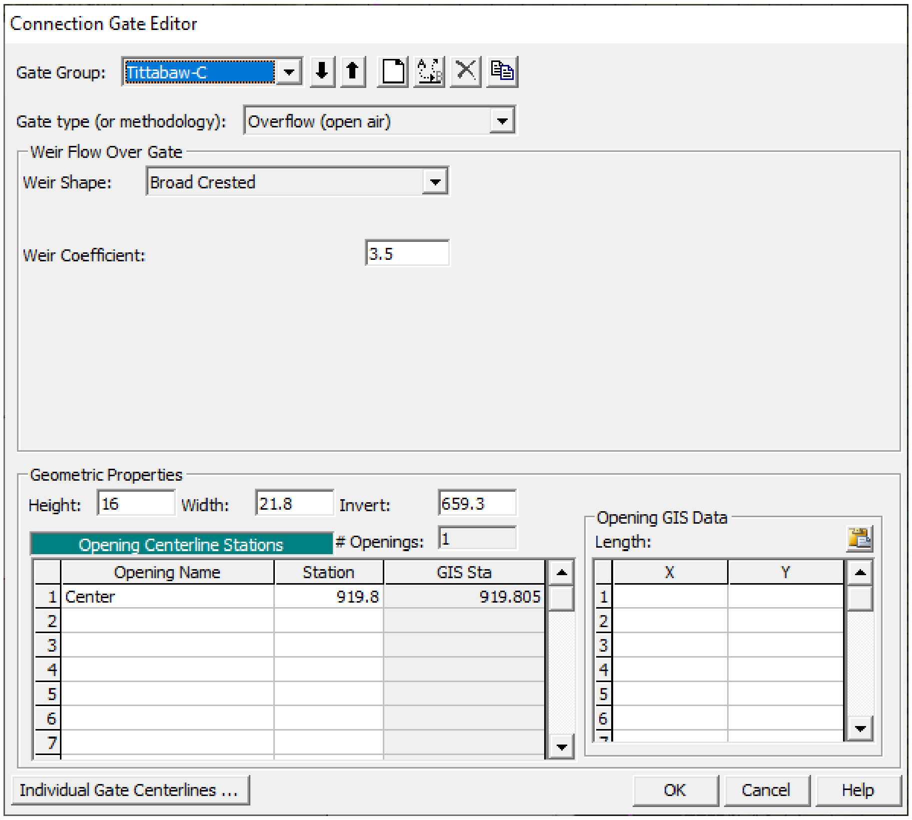
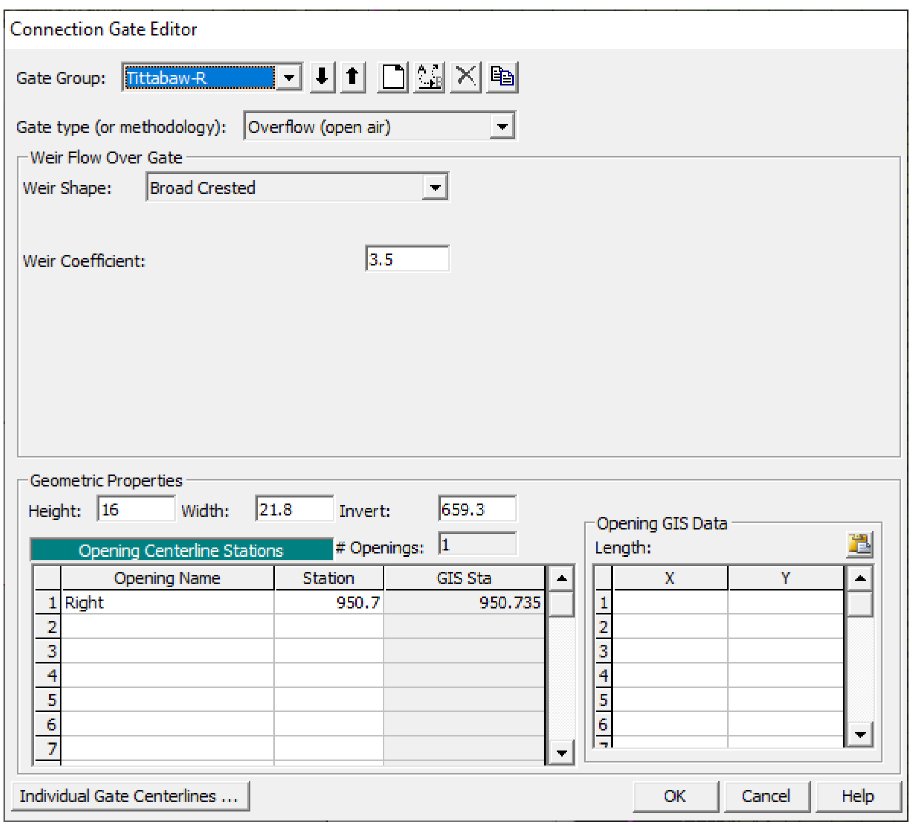
HEC-RAS Storage Area/2D Area Connections – Edenville Dam Proposed Conditions

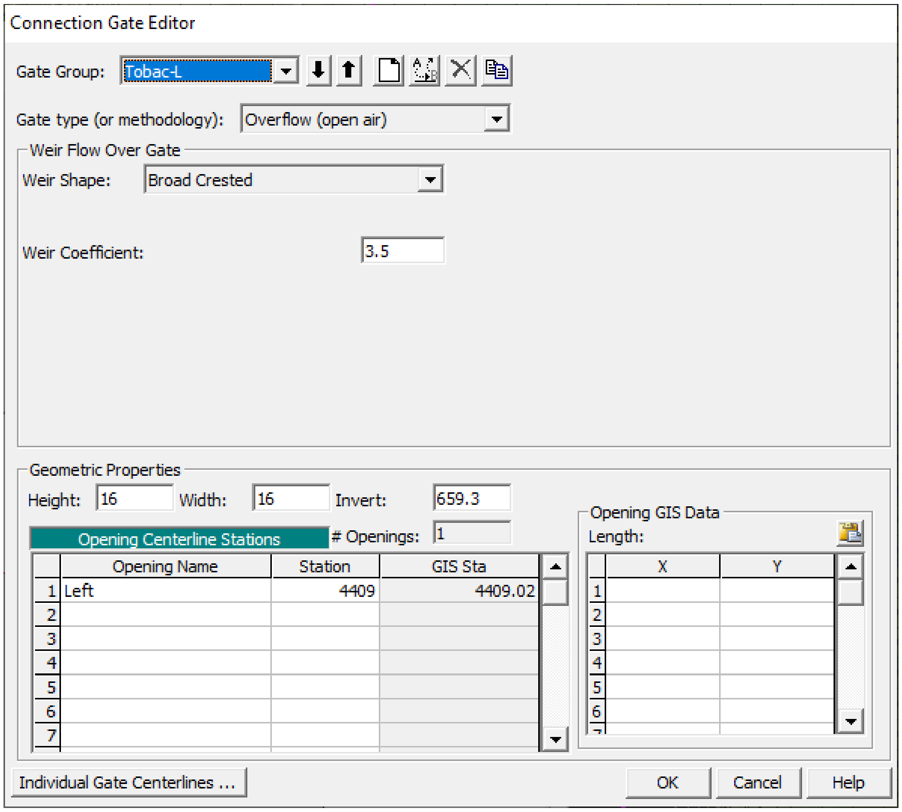

Connection Data Editor - Edenville_final2
File
View
Help
Connection:
Ede-Dam
Apply Data
Description
Breach (plan data) ...
Connections
From:
2D flow area: Edenville
Set SA/2D ...
To:
2D flow area: Edenville
Set SA/2D ...
Weir Length:
6608.40
Centerline Length:
6608.40
Overflow Computation Method
Normal 2D Equation Domain
Use Weir Equation
Centerline GIS Coords...
Structure Type:
Weir, Gates, Culverts, Outlet RC and Outlet TS
Terrain Profile ...
Flap Gates:
No Flap Gates
Clip Weir Profile to 2D Cells...
Weir / Embankment
Gate
Culvert
Outlet RC
Outlet TS
Elevation (ft)
Station (ft)
Legend
Spillway
Extend/Trim to Face Points
HW Cell Min Elev
TW Cell Min Elev
Centerline Terrain

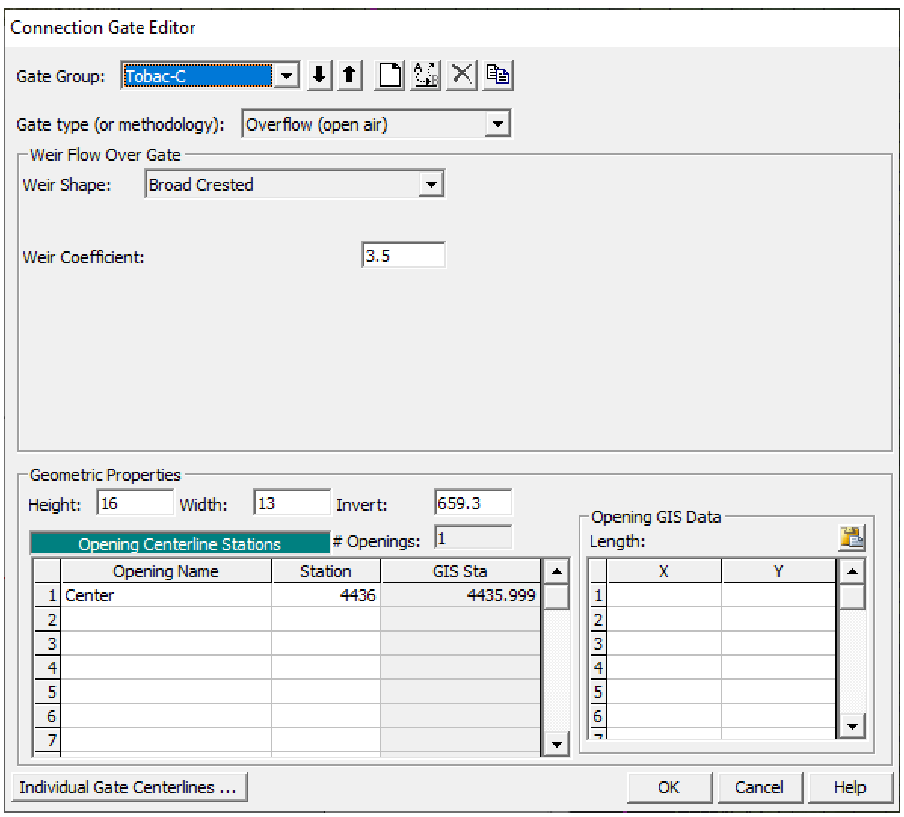

Connection Gate Editor
Gate Group: Overflow
Gate type (or methodology): Overflow (open air)
Weir Flow Over Gate
Weir Shape: Broad Crested
Weir Coefficient: 7.5
Geometric Properties
Height: 6.9 Width: 250 Invert: 677.5
Opening Centerline Stations # Openings: 1
Opening Name Station GIS Sta
1 Labyrinth 445 445.03
Opening GIS Data
Length:
X Y
Individual Gate Centerlines ...
OK Cancel Help

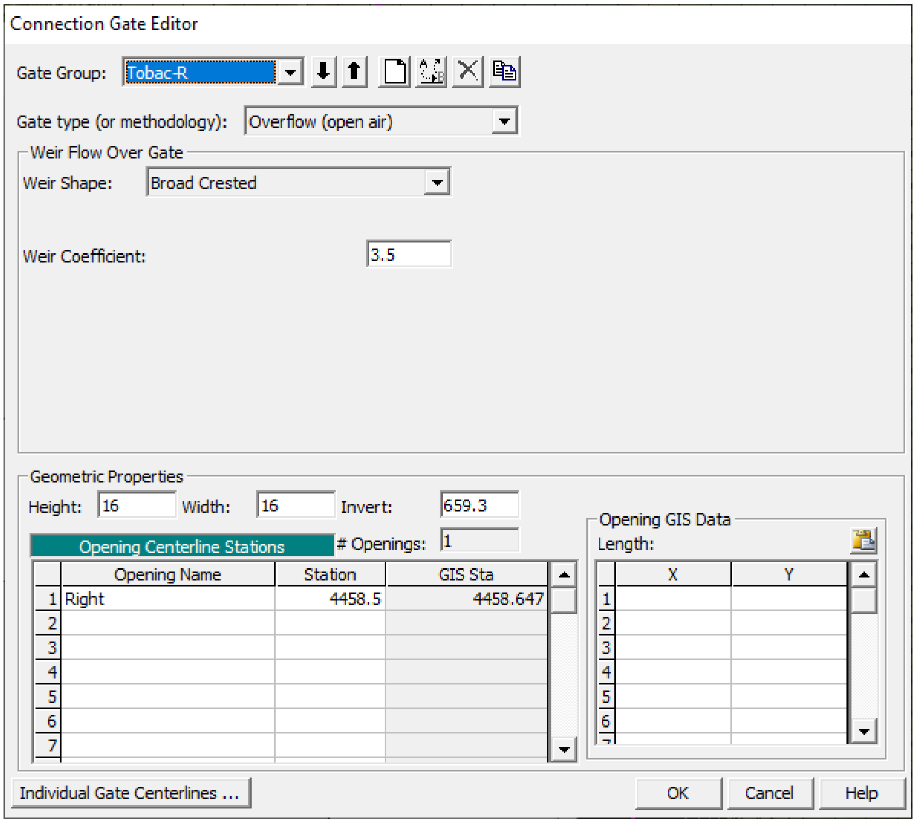

Connection Gate Editor
Gate Group: Tittabaw-L
Gate type (or methodology): Overflow (open air)
Weir Flow Over Gate
Weir Shape: Broad Crested
Weir Coefficient: 3.5
Geometric Properties
Height: 16 Width: 21.8 Invert: 659.3
Opening Centerline Stations # Openings: 1
Opening Name Station GIS Sta
1 Left 888.9 888.783
Opening GIS Data
Length:
X Y
Individual Gate Centerlines ...
OK Cancel Help


Connection Gate Editor
Gate Group: Tittabaw-C
Gate type (or methodology): Overflow (open air)
Weir Flow Over Gate
Weir Shape: Broad Crested
Weir Coefficient: 3.5
Geometric Properties
Height: 16
Width: 21.8
Invert: 659.3
Opening Centerline Stations
Openings: 1
Opening Name
Station
GIS Sta
1 Center 919.8 919.805
2
3
4
5
6
7
Opening GIS Data
Length:
X
Y
1
2
3
4
5
6
Individual Gate Centerlines ...
OK
Cancel
Help

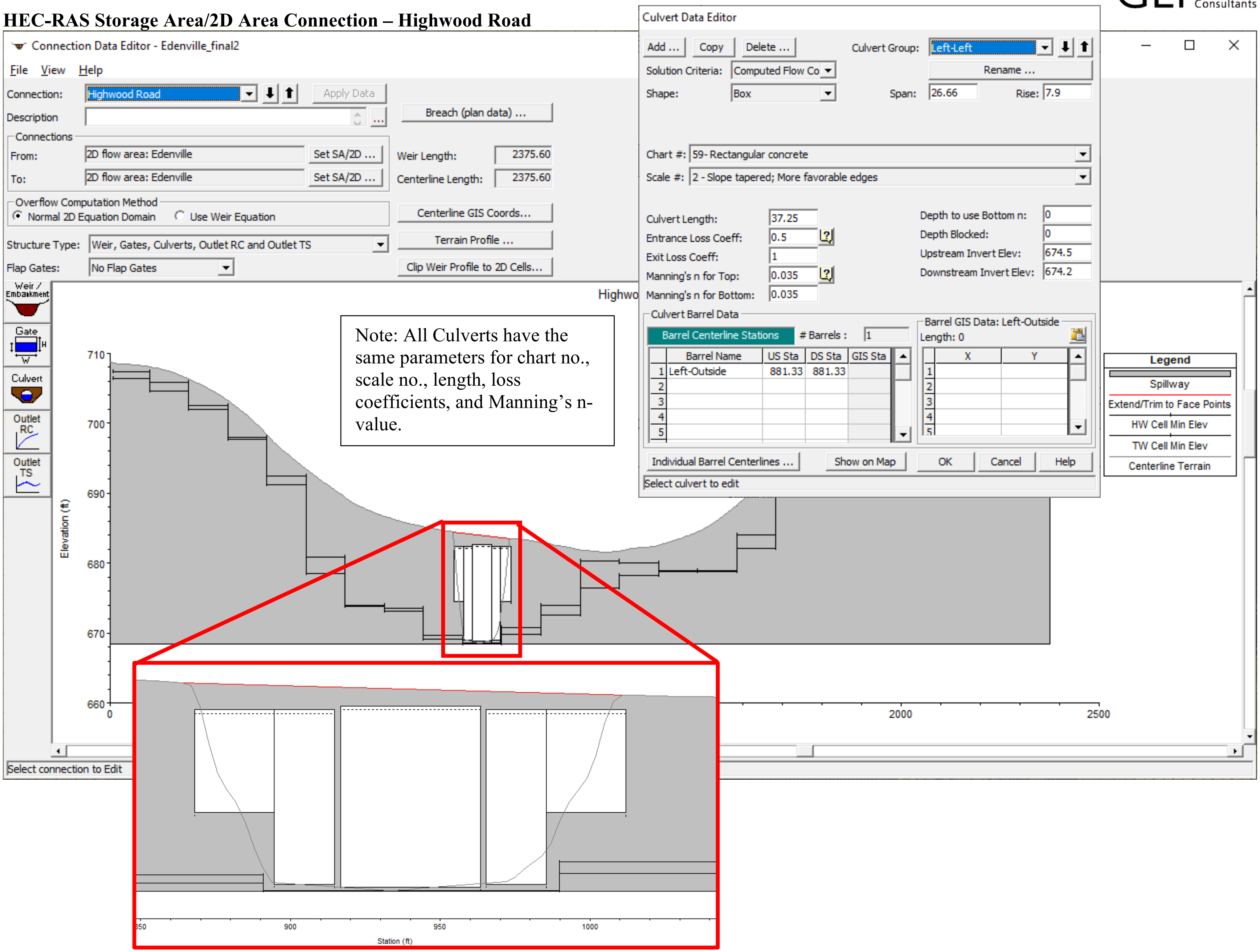

Connection Gate Editor
Gate Group: Tittabaw-R
Gate type (or methodology): Overflow (open air)
Weir Flow Over Gate
Weir Shape: Broad Crested
Weir Coefficient: 3.5
Geometric Properties
Height: 16
Width: 21.8
Invert: 659.3
Opening Centerline Stations
Openings: 1
Opening Name
Station
GIS Sta
1 Right 950.7 950.735
2
3
4
5
6
7
Opening GIS Data
Length:
X
Y
1
2
3
4
5
6
Individual Gate Centerlines ...
OK
Cancel
Help


Connection Gate Editor
Gate Group: Tobac-L
Gate type (or methodology): Overflow (open air)
Weir Flow Over Gate
Weir Shape: Broad Crested
Weir Coefficient: 3.5
Geometric Properties
Height: 16 Width: 16 Invert: 659.3
Opening Centerline Stations
Openings: 1
Opening Name Station GIS Sta
1 Left 4409 4409.02
Opening GIS Data
Length:
X Y
Individual Gate Centerlines ...
OK Cancel Help

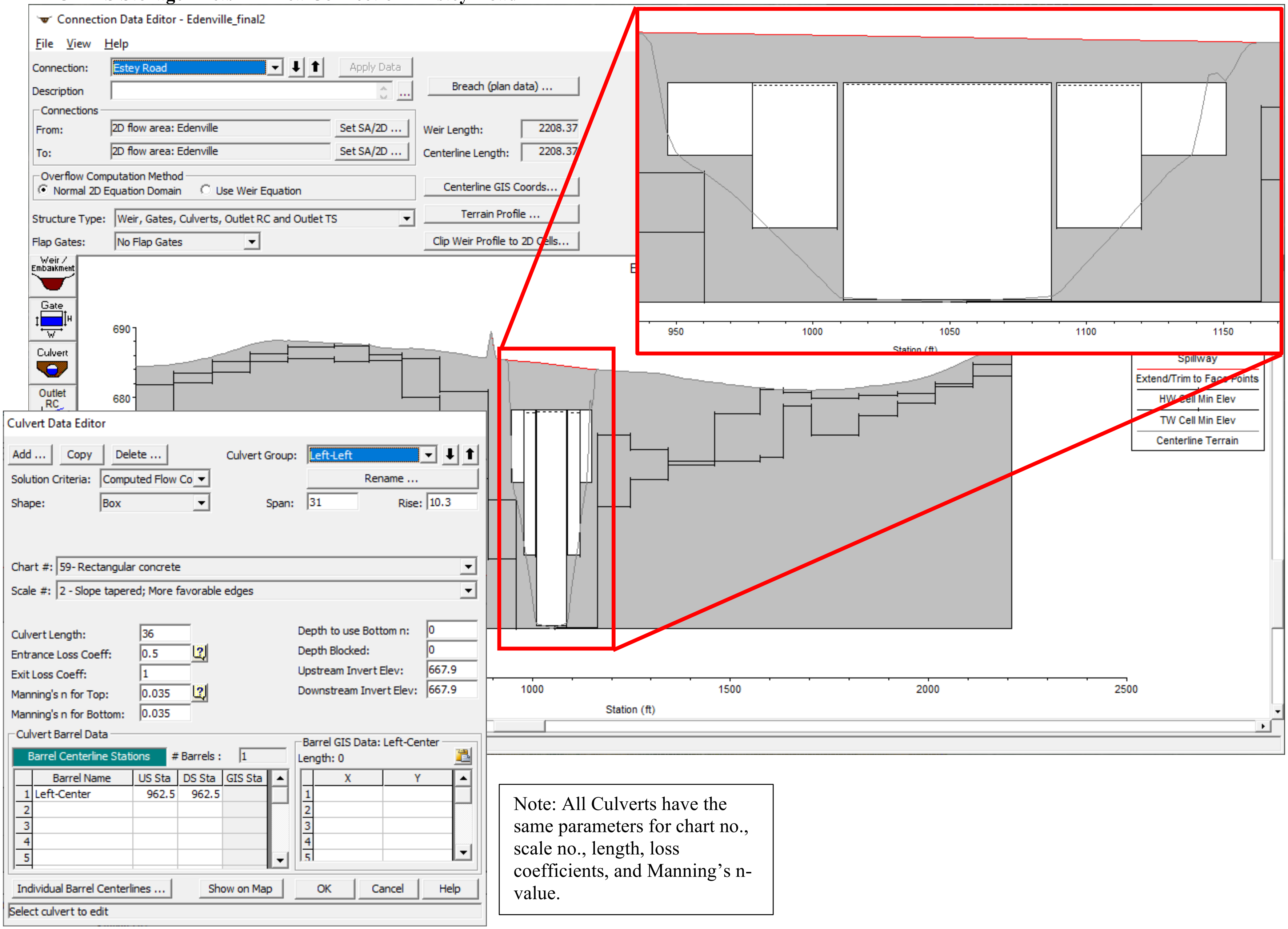

Connection Gate Editor
Gate Group: Tobac-C
Gate type (or methodology): Overflow (open air)
Weir Flow Over Gate
Weir Shape: Broad Crested
Weir Coefficient: 3.5
Geometric Properties
Height: 16 Width: 13 Invert: 659.3
Opening Centerline Stations
Openings: 1
Opening Name Station GIS Sta
1 Center 4436 4435.999
Opening GIS Data
Length:
X Y
Individual Gate Centerlines ...
OK Cancel Help


Connection Gate Editor
Gate Group: Tobac-R
Gate type (or methodology): Overflow (open air)
Weir Flow Over Gate
Weir Shape: Broad Crested
Weir Coefficient: 3.5
Geometric Properties
Height: 16
Width: 16
Invert: 659.3
Opening Centerline Stations
Openings: 1
Opening Name
Station
GIS Sta
1 Right 4458.5 4458.647
Opening GIS Data
Length:
X
Y
Individual Gate Centerlines ...
OK
Cancel
Help

HEC-RAS Storage Area/2D Area Connection – Highwood Road

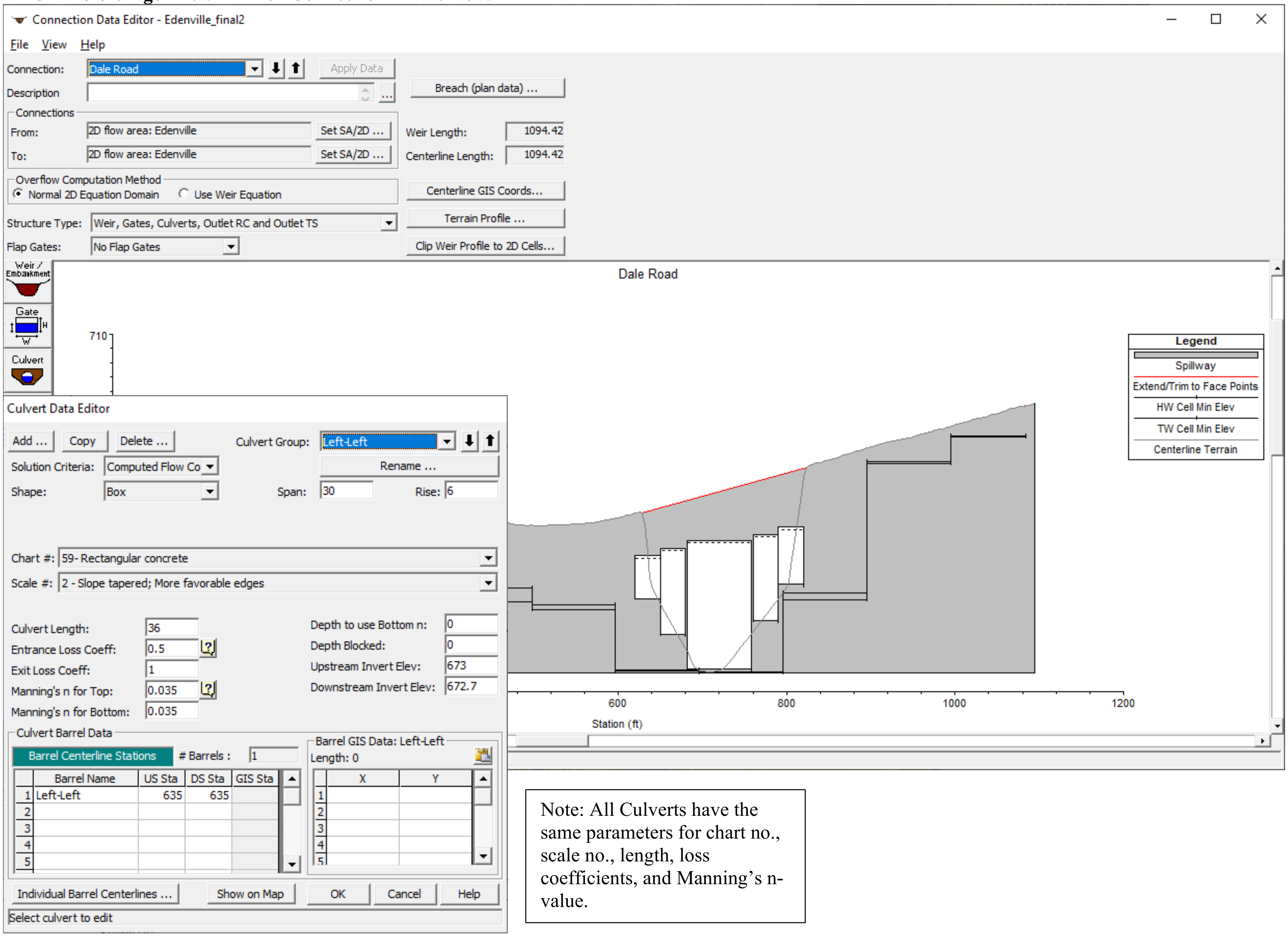


HEC-RAS Storage Area/2D Area Connection – Estey Road



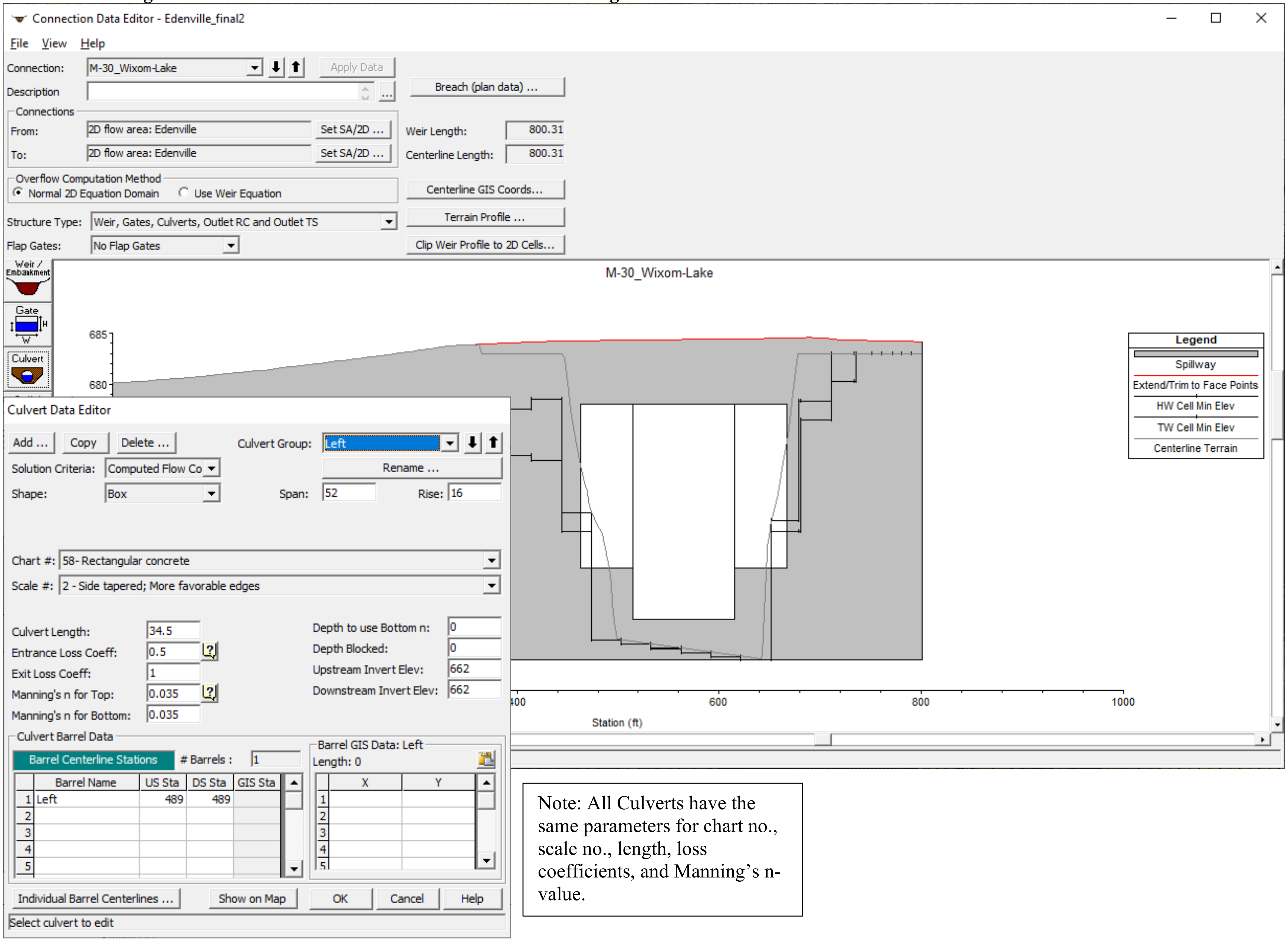
Note: All Culverts have the same parameters for chart no., scale no., length, loss coefficients, and Manning's n-value.

HEC-RAS Storage Area/2D Area Connection – Dale Road



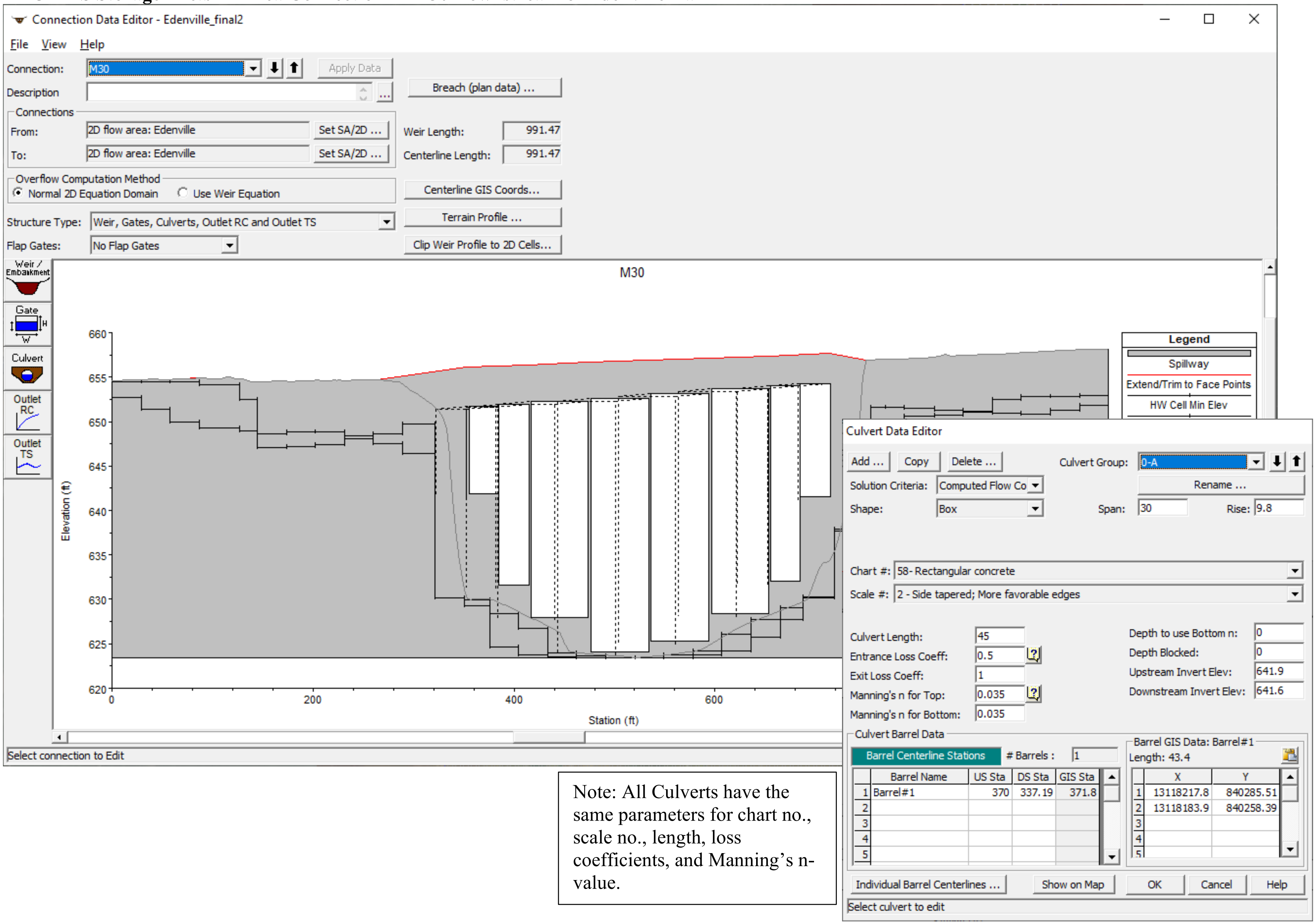
Note: All Culverts have the same parameters for chart no., scale no., length, loss coefficients, and Manning's n-value.

HEC-RAS Storage Area/2D Area Connection – M-30 Wixom Lake Bridge



Note: All Culverts have the same parameters for chart no., scale no., length, loss coefficients, and Manning's n-value.

HEC-RAS Storage Area/2D Area Connection – M-30 Downstream of Edenville Dam



Note: All Culverts have the same parameters for chart no., scale no., length, loss coefficients, and Manning's n-value.

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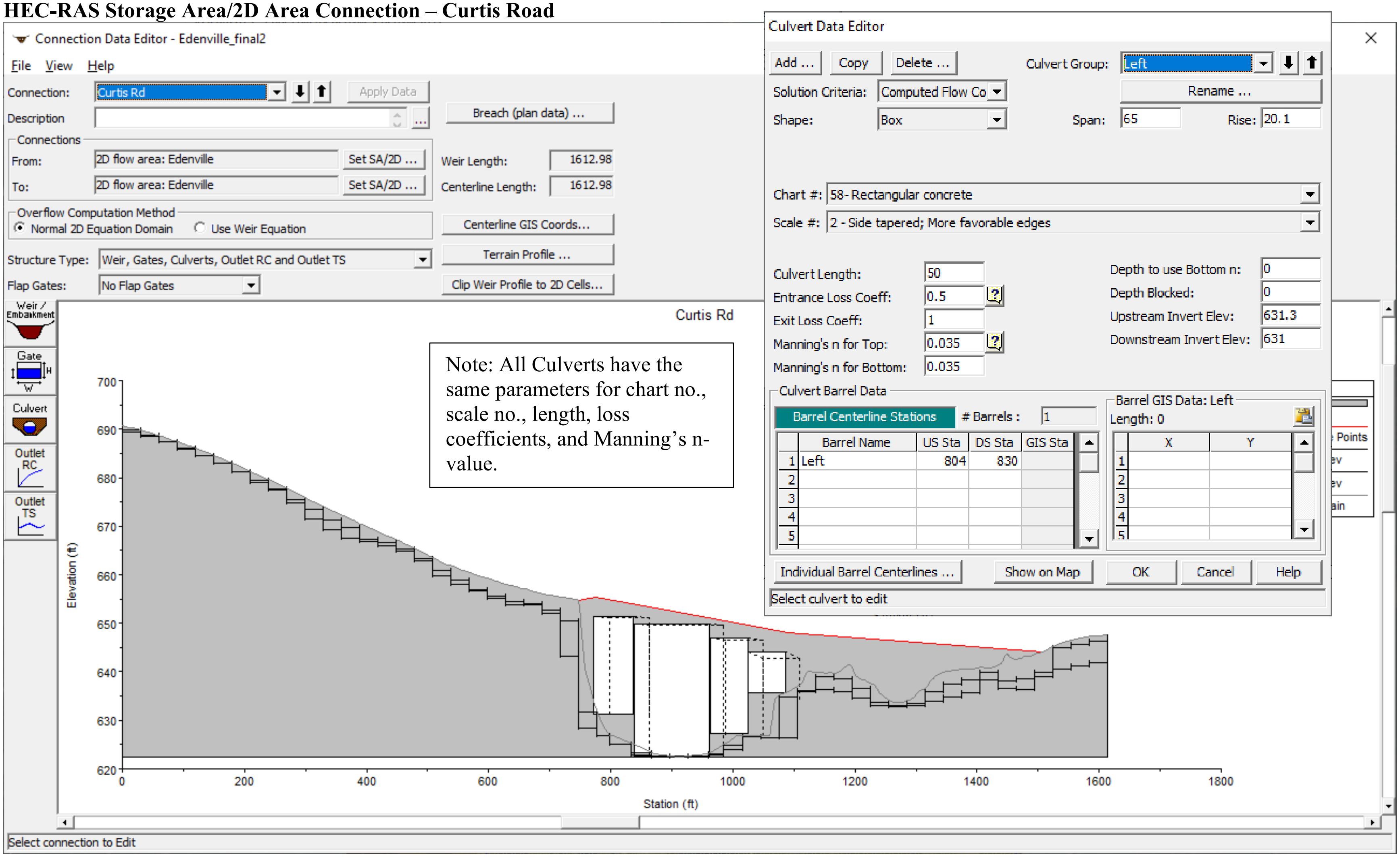
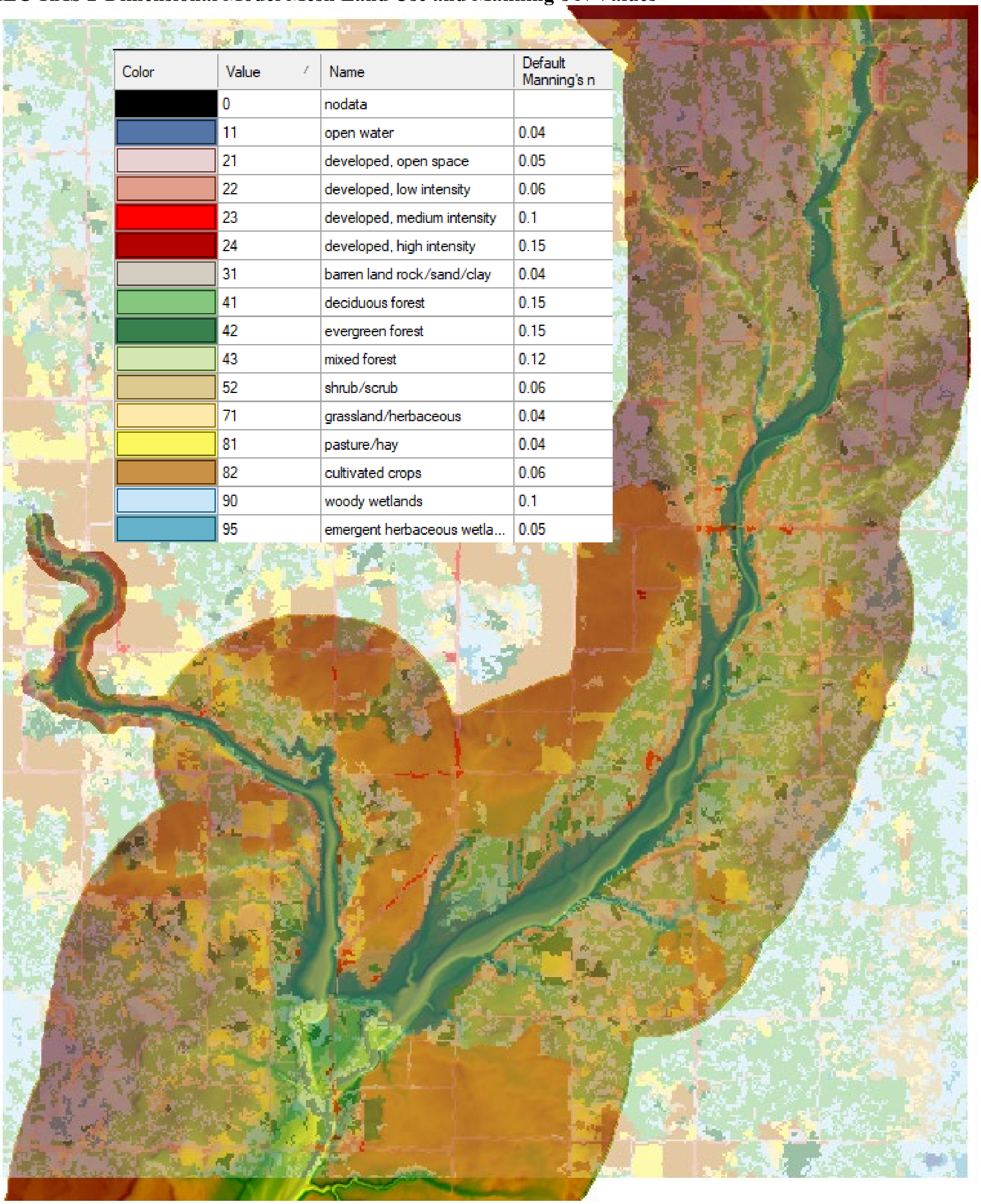
HEC-RAS Storage Area/2D Area Connection – Curtis Road

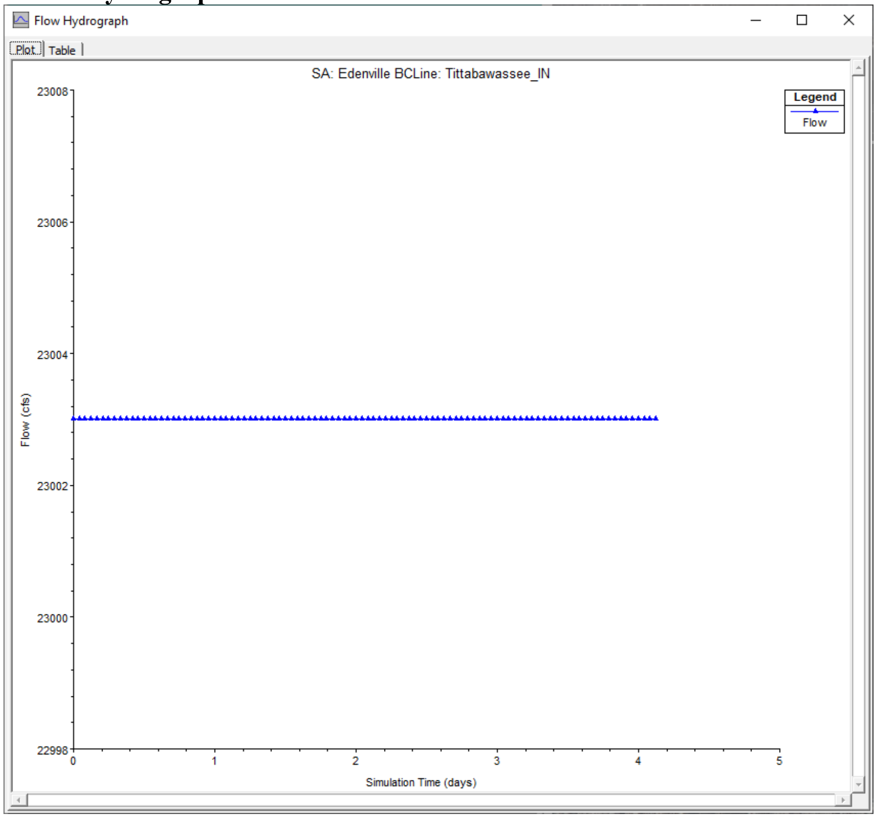


HEC-RAS 2-Dimensional Model Mesh Land Use and Manning's N Values

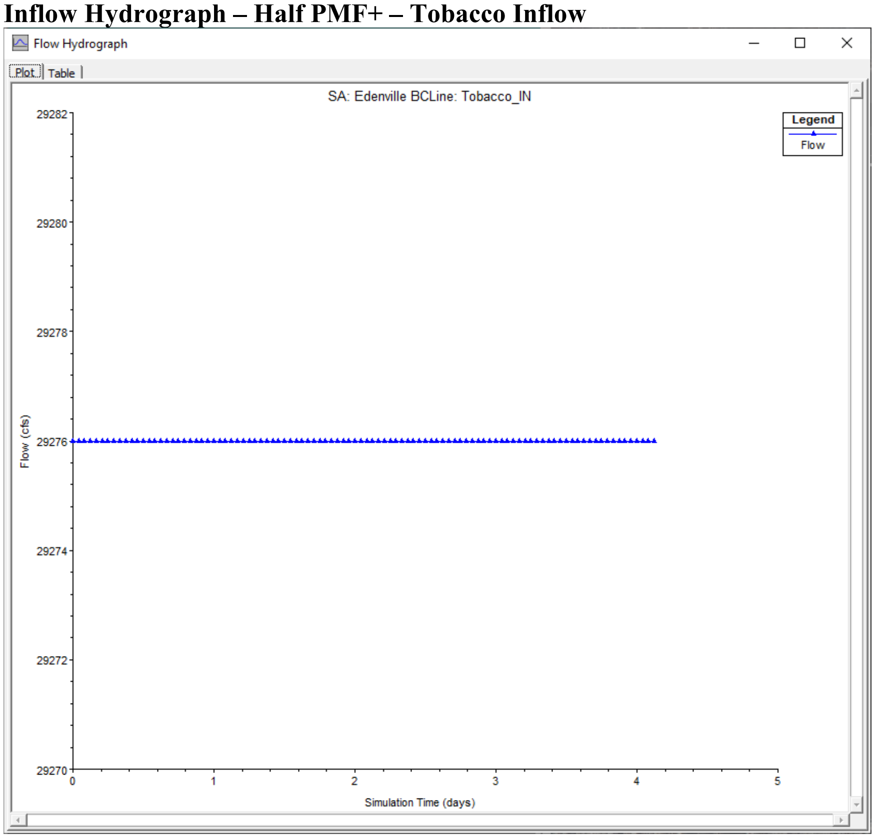


Color	Value	Name	Default Manning's n
	0	nodata	
	11	open water	0.04
	21	developed, open space	0.05
	22	developed, low intensity	0.06
	23	developed, medium intensity	0.1
	24	developed, high intensity	0.15
	31	barren land rock/sand/clay	0.04
	41	deciduous forest	0.15
	42	evergreen forest	0.15
	43	mixed forest	0.12
	52	shrub/scrub	0.06
	71	grassland/herbaceous	0.04
	81	pasture/hay	0.04
	82	cultivated crops	0.06
	90	woody wetlands	0.1
	95	emergent herbaceous wetla...	0.05

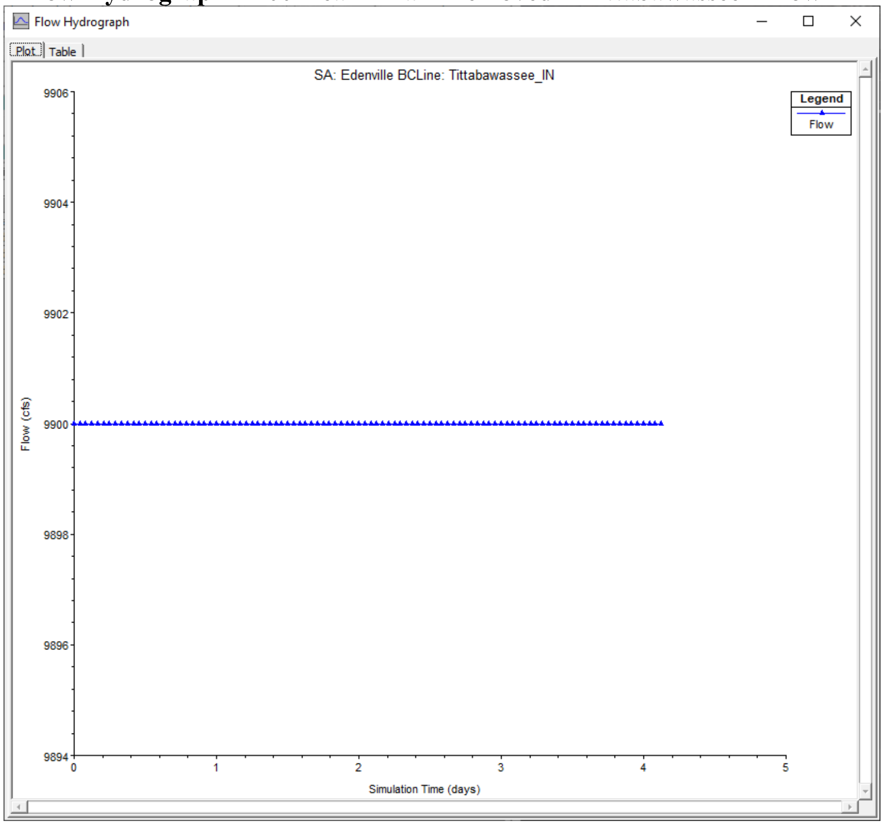
Inflow Hydrograph – Half PMF+ – Tittabawassee Inflow



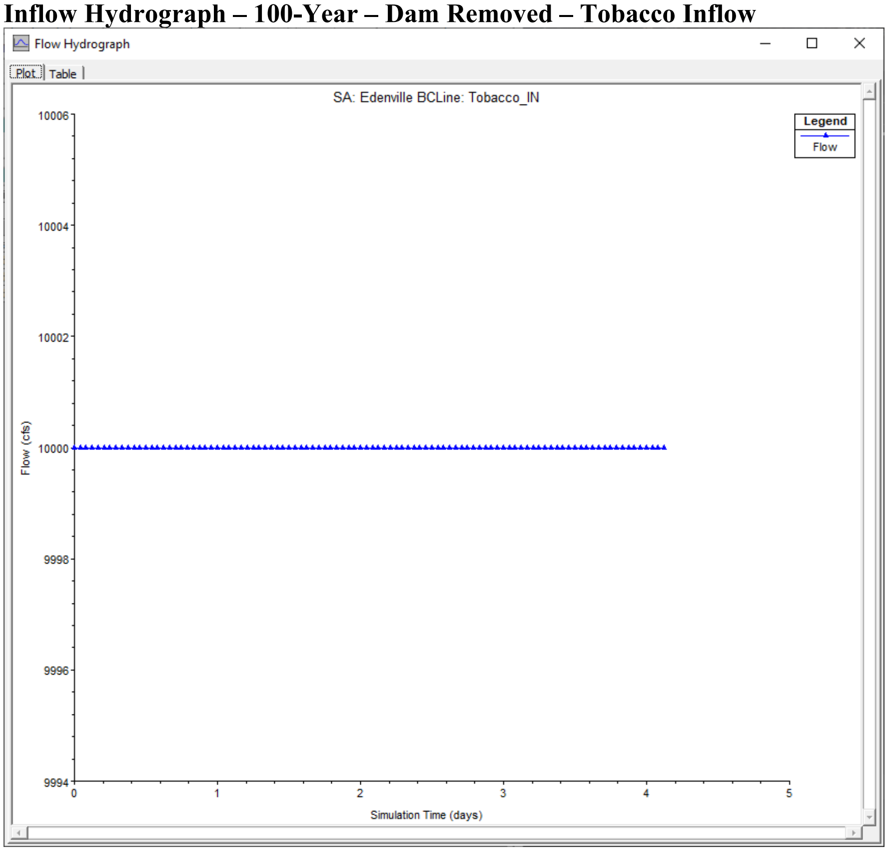
Inflow Hydrograph – Half PMF+ – Tobacco Inflow



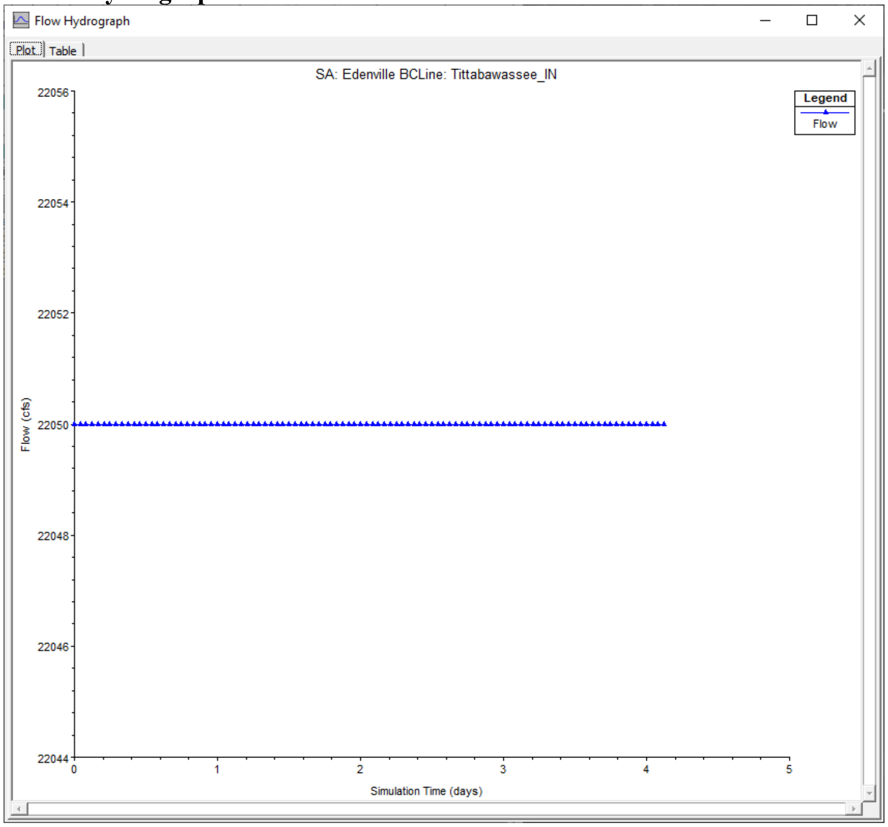
Inflow Hydrograph – 100-Year – Dam Removed – Tittabawassee Inflow



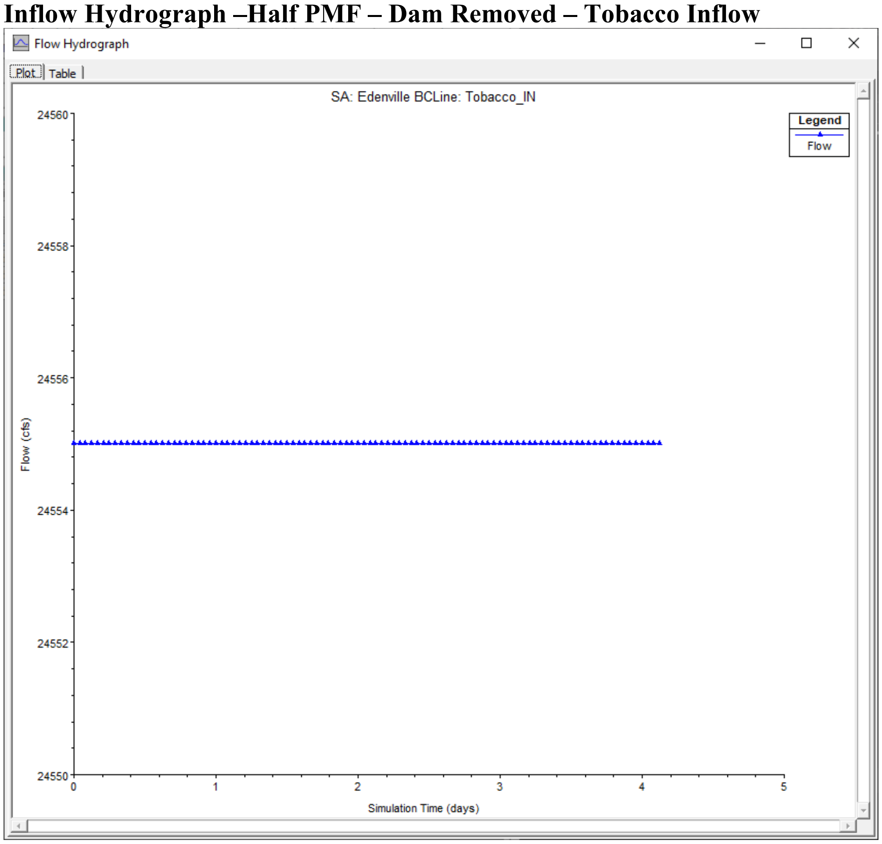
Inflow Hydrograph – 100-Year – Dam Removed – Tobacco Inflow



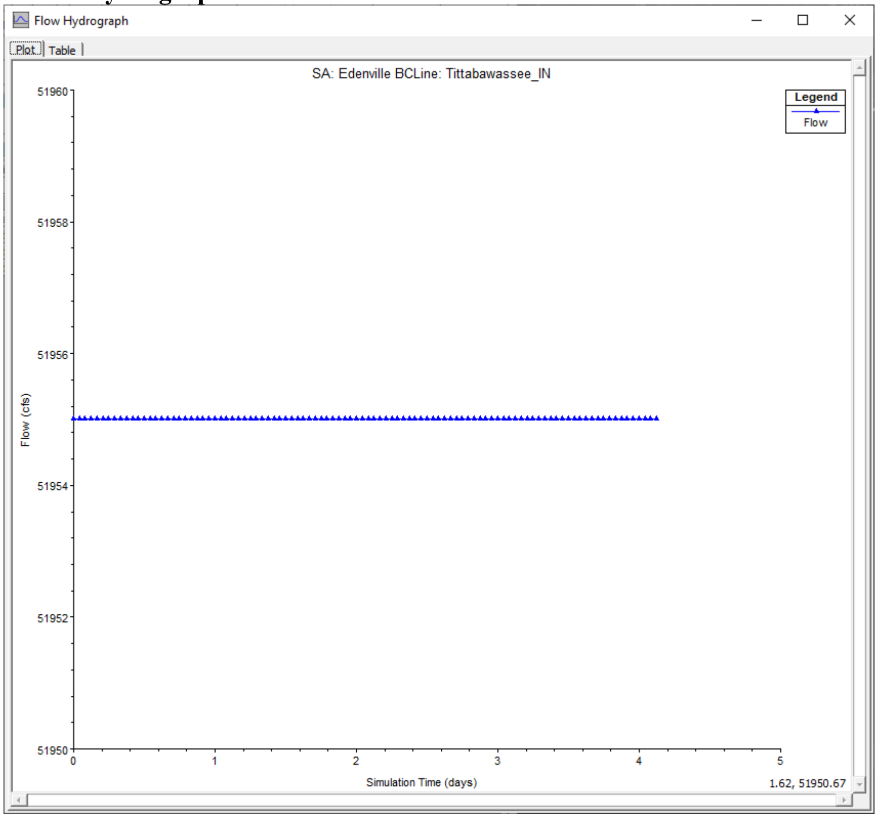
Inflow Hydrograph – Half PMF – Dam Removed – Tittabawassee Inflow



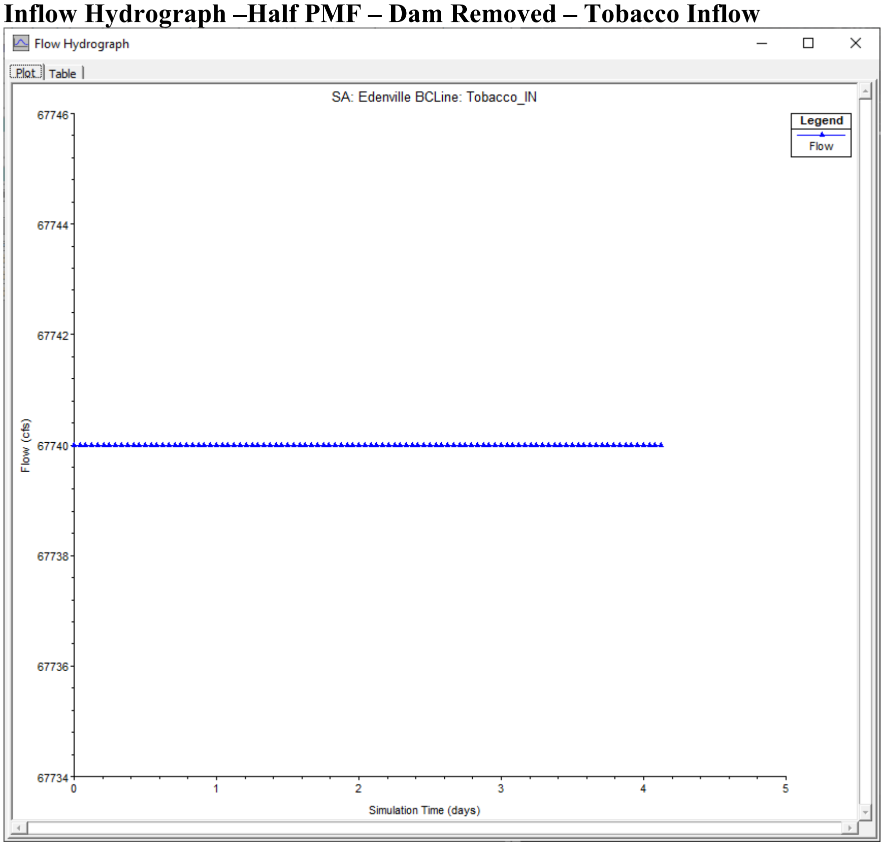
Inflow Hydrograph –Half PMF – Dam Removed – Tobacco Inflow



Inflow Hydrograph – Half PMF – Dam Removed – Tittabawassee Inflow

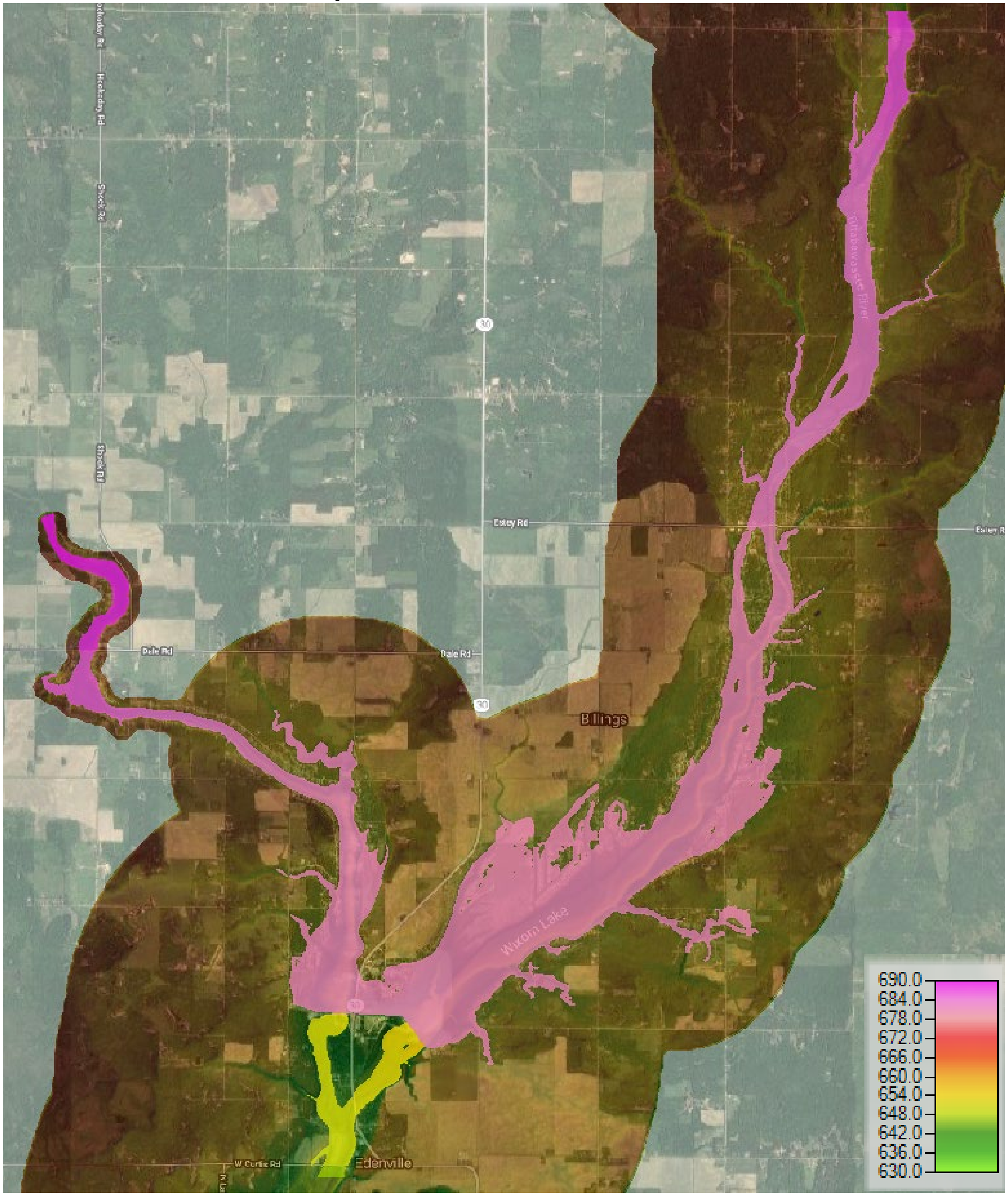


Inflow Hydrograph –Half PMF – Dam Removed – Tobacco Inflow



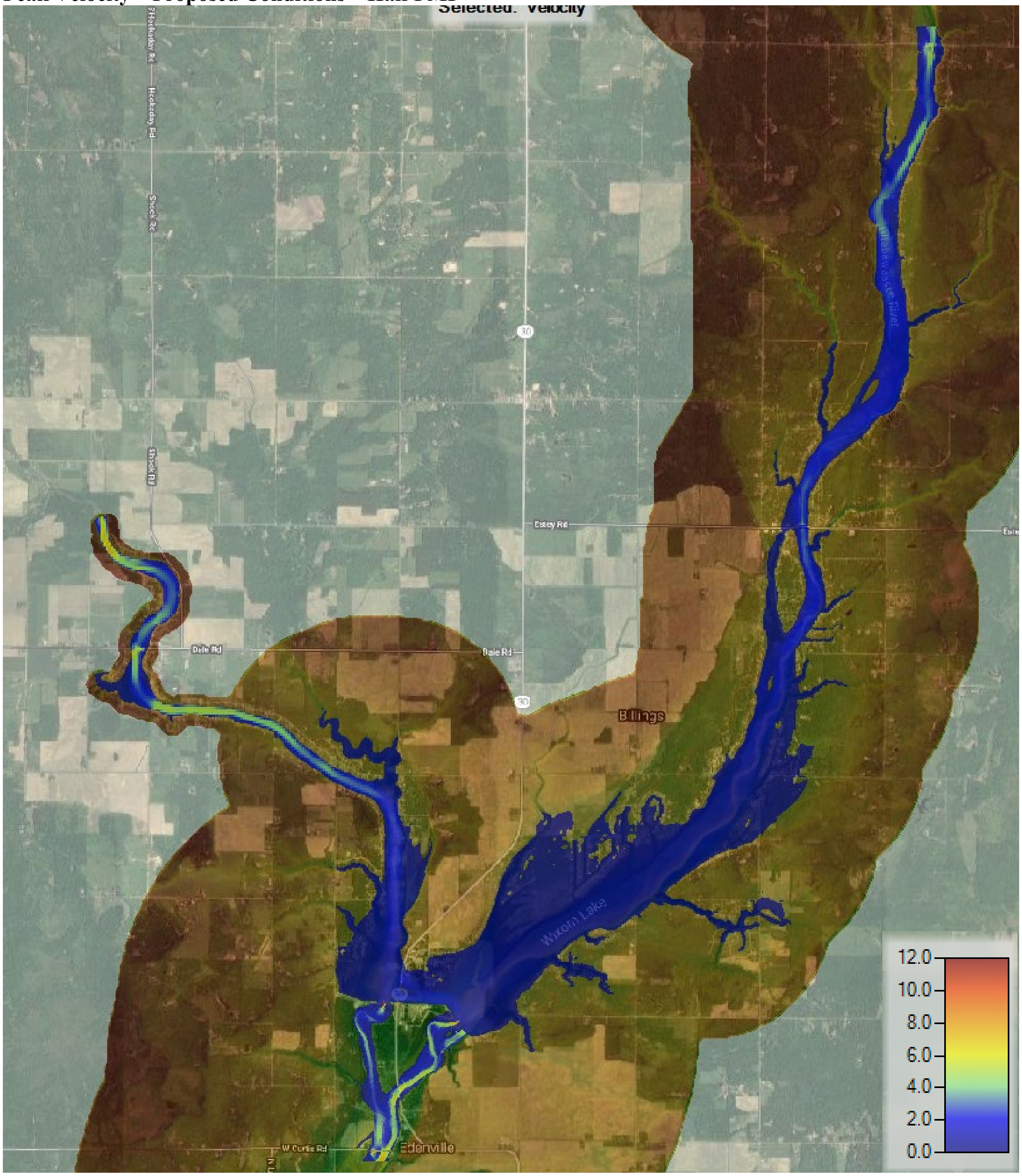
OUTPUT

Peak Water Surface Elevation – Proposed Conditions – Half PMF+

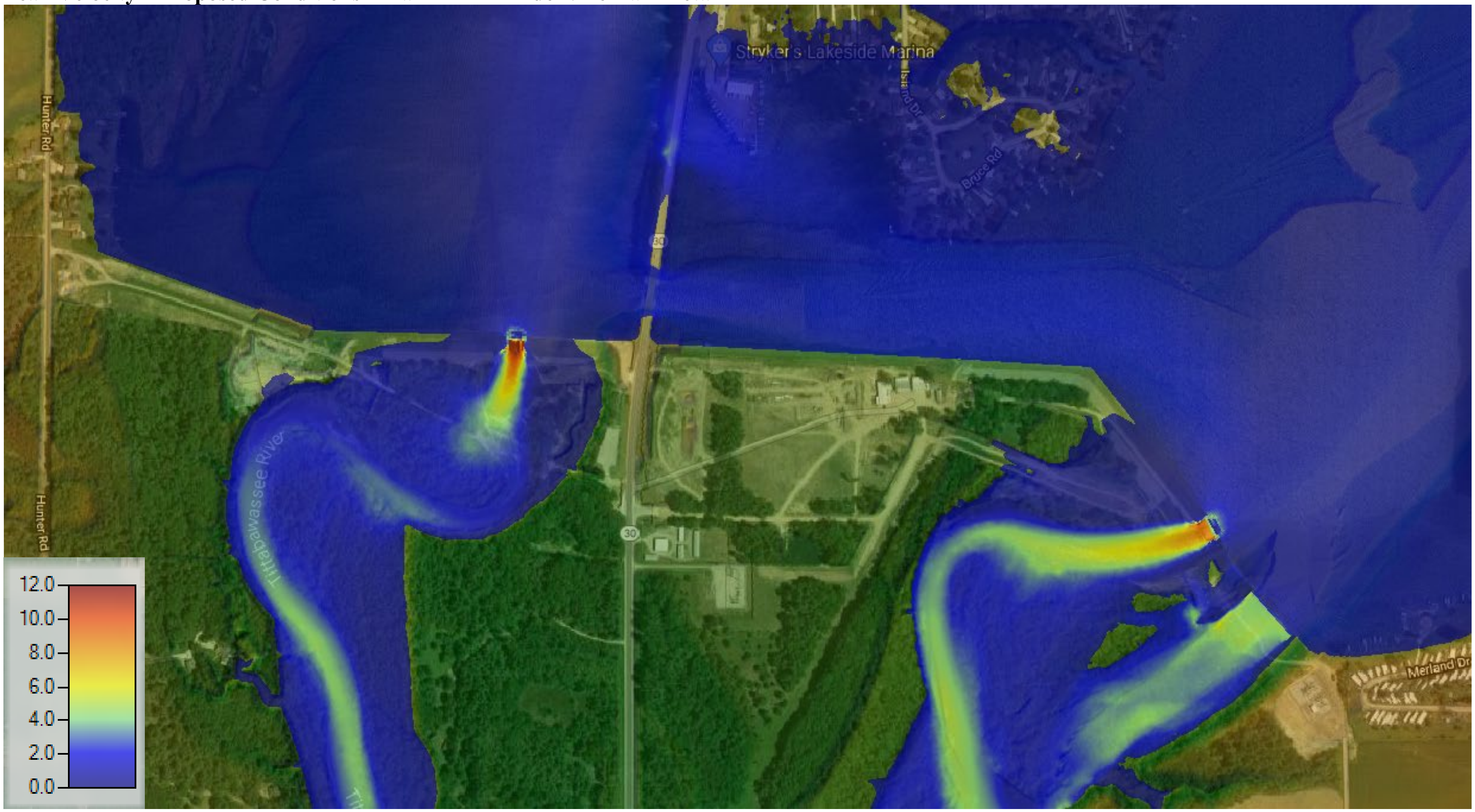


Peak Water Surface Elevation – Proposed Conditions – Half PMF + – Edenville Dam Detail

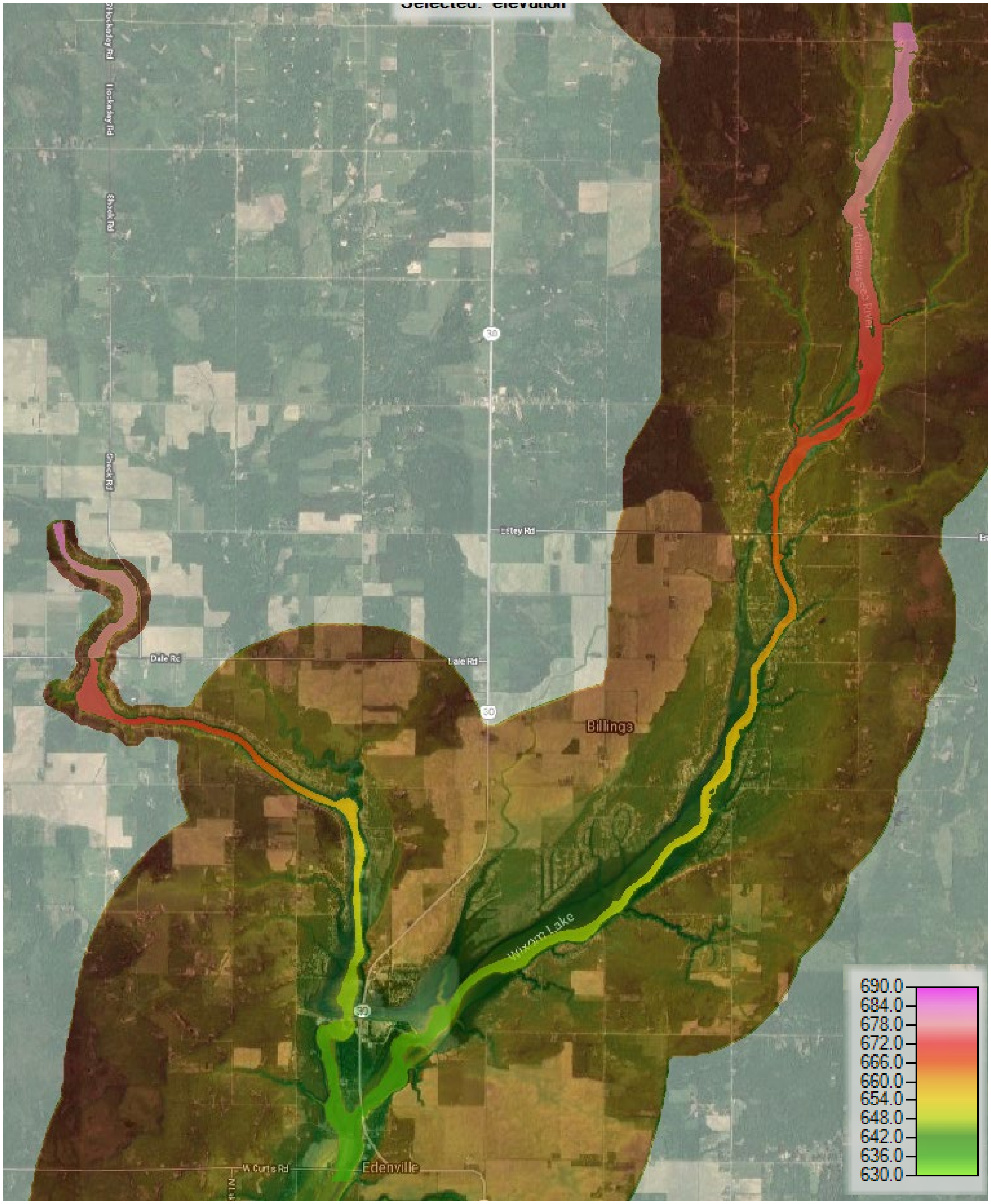
Peak Velocity – Proposed Conditions – Half PMF+



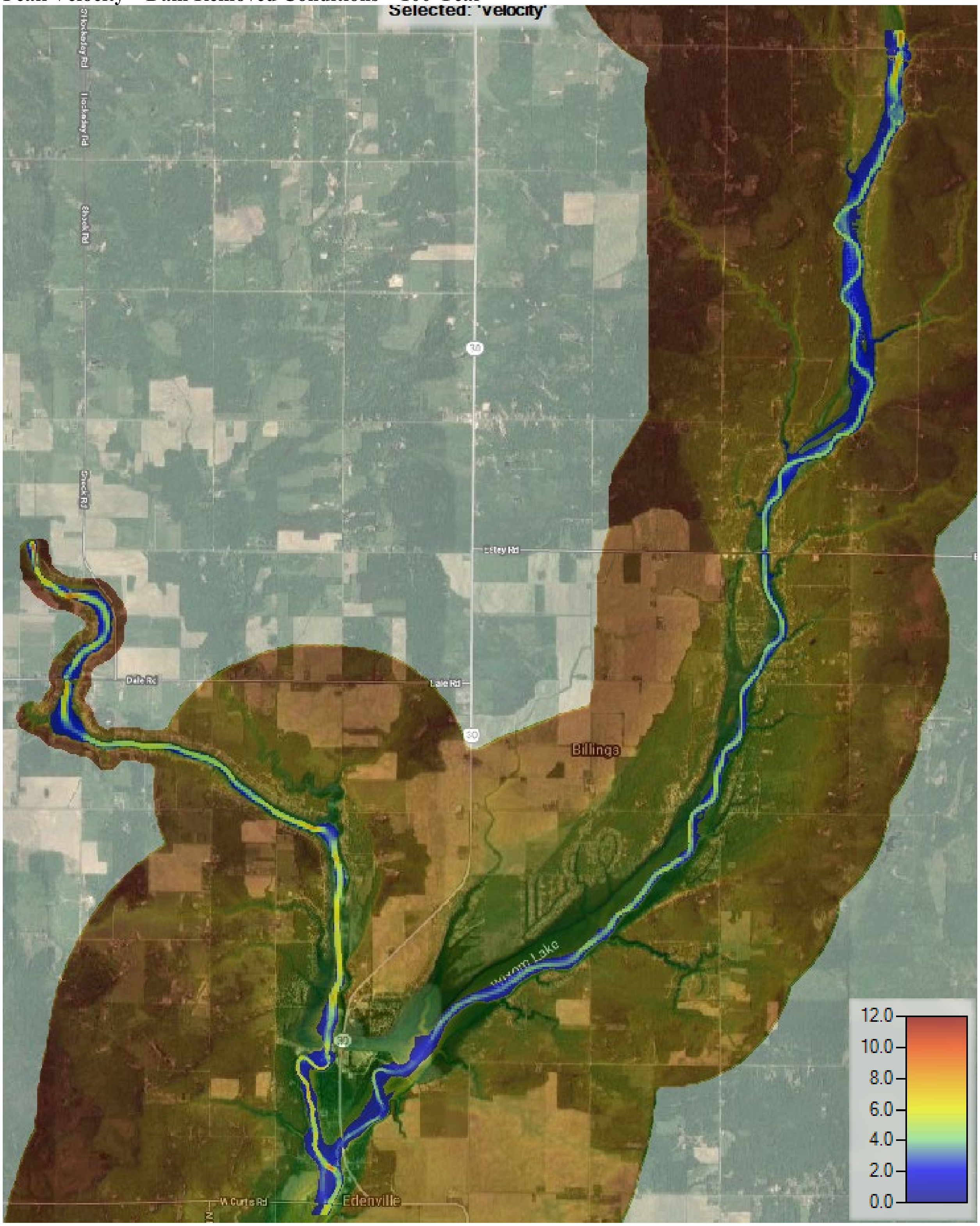
Peak Velocity – Proposed Conditions – Half PMF+ – Edenville Dam Detail



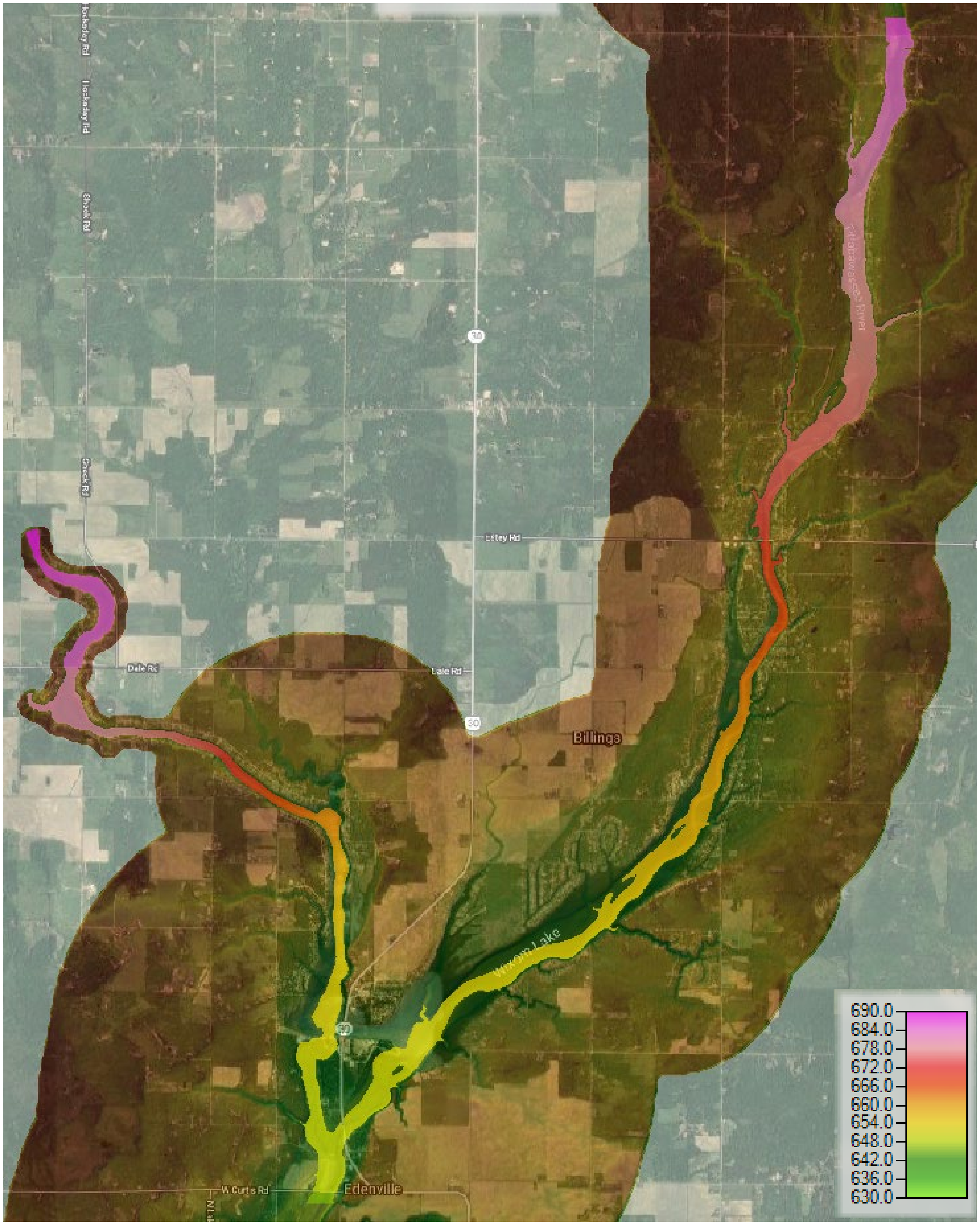
Peak Water Surface Elevation – Dam Removed Conditions – 100-Year



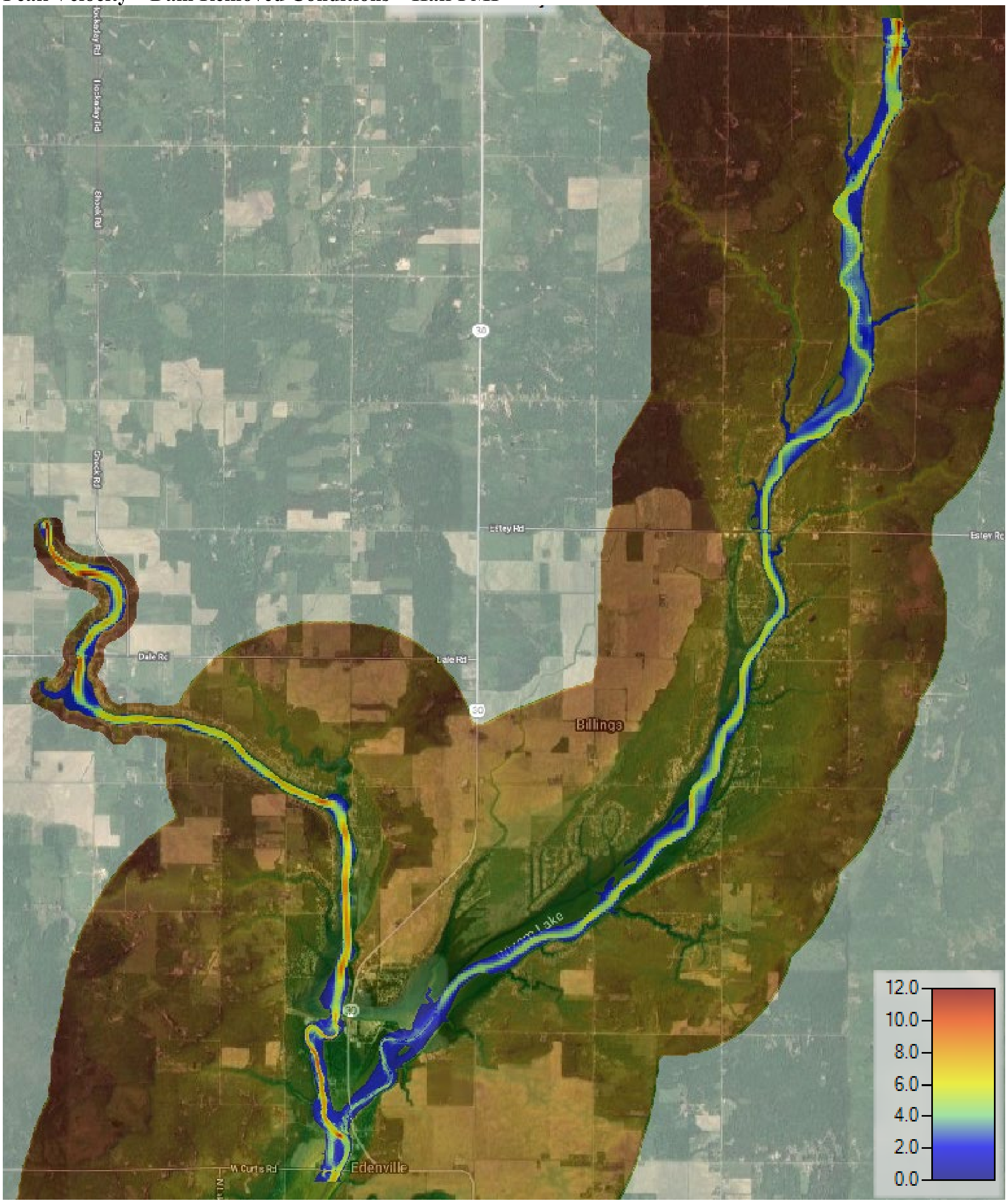
Peak Velocity – Dam Removed Conditions – 100-Year



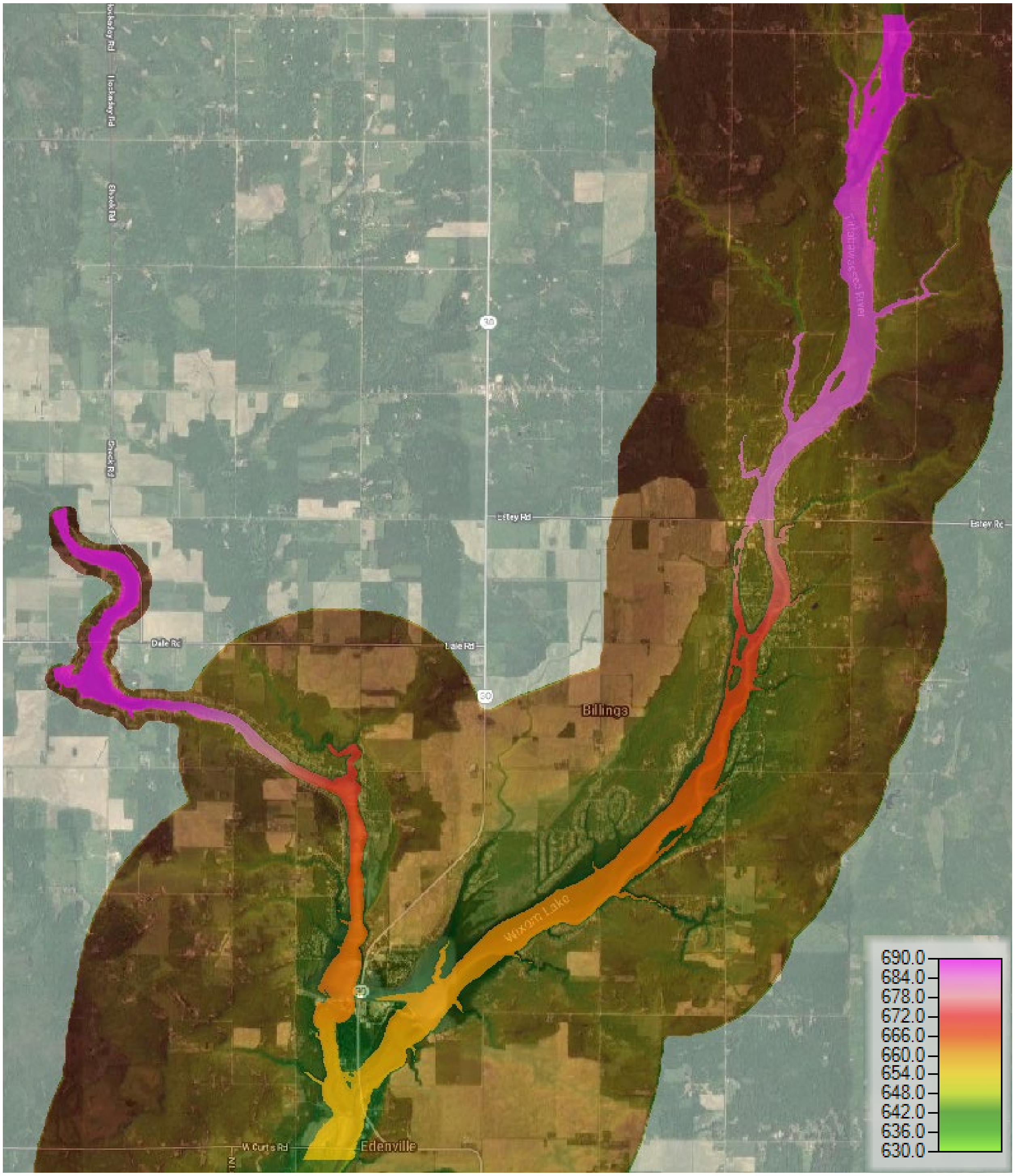
Peak Water Surface Elevation – Dam Removed Conditions – Half PMF



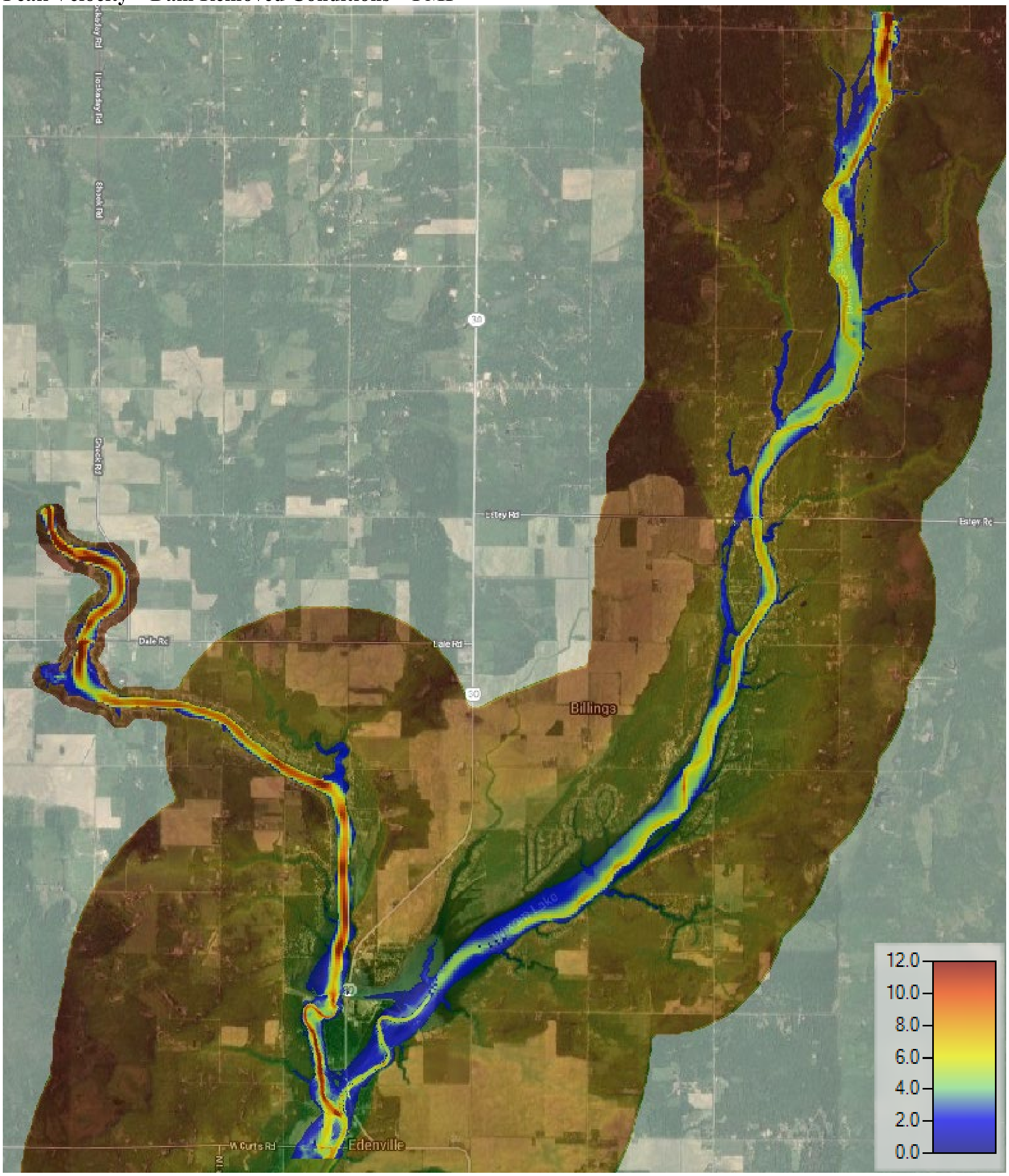
Peak Velocity – Dam Removed Conditions – Half PMF



Peak Water Surface Elevation – Dam Removed Conditions – PMF



Peak Velocity – Dam Removed Conditions – PMF

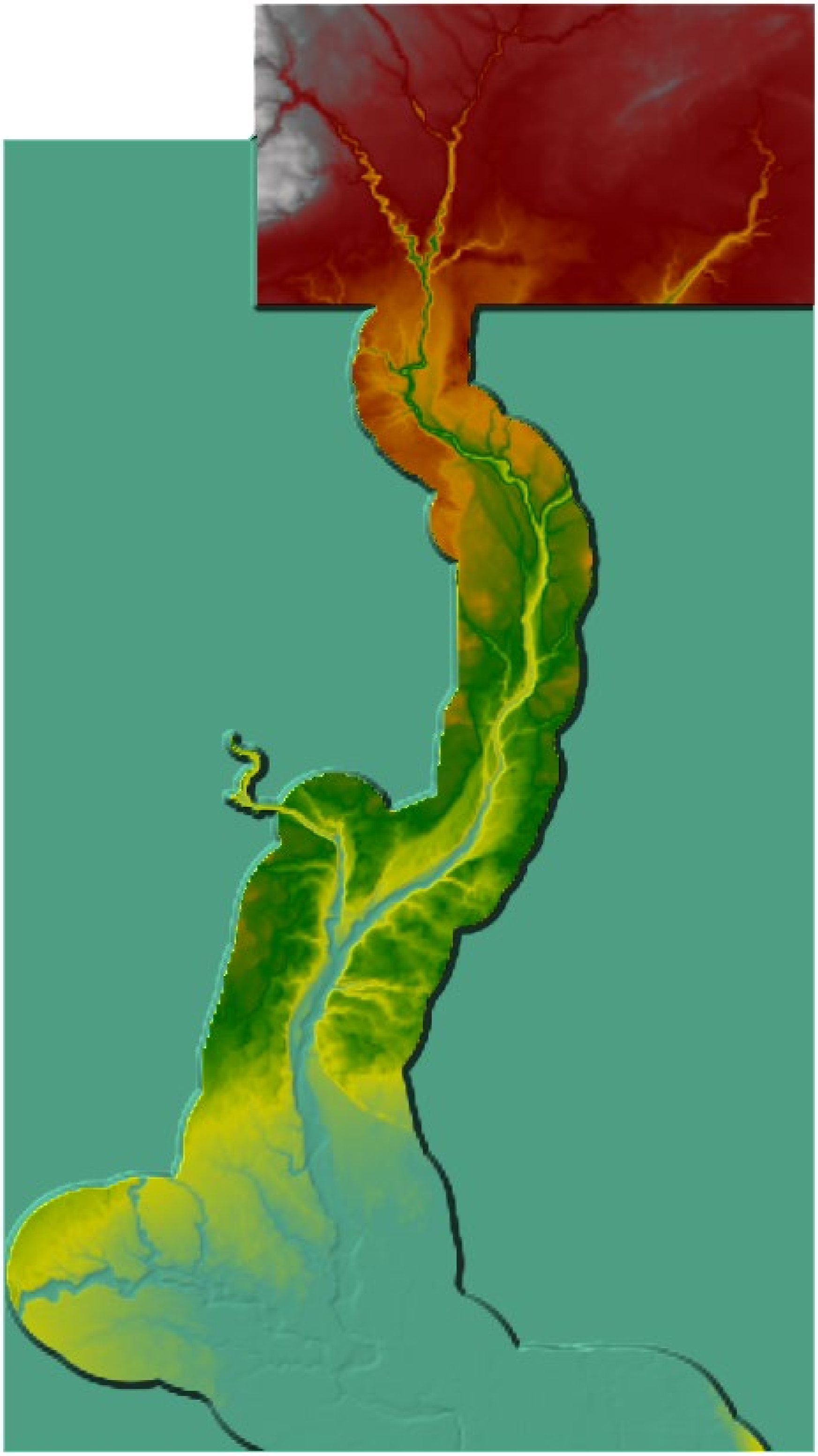


Appendix F

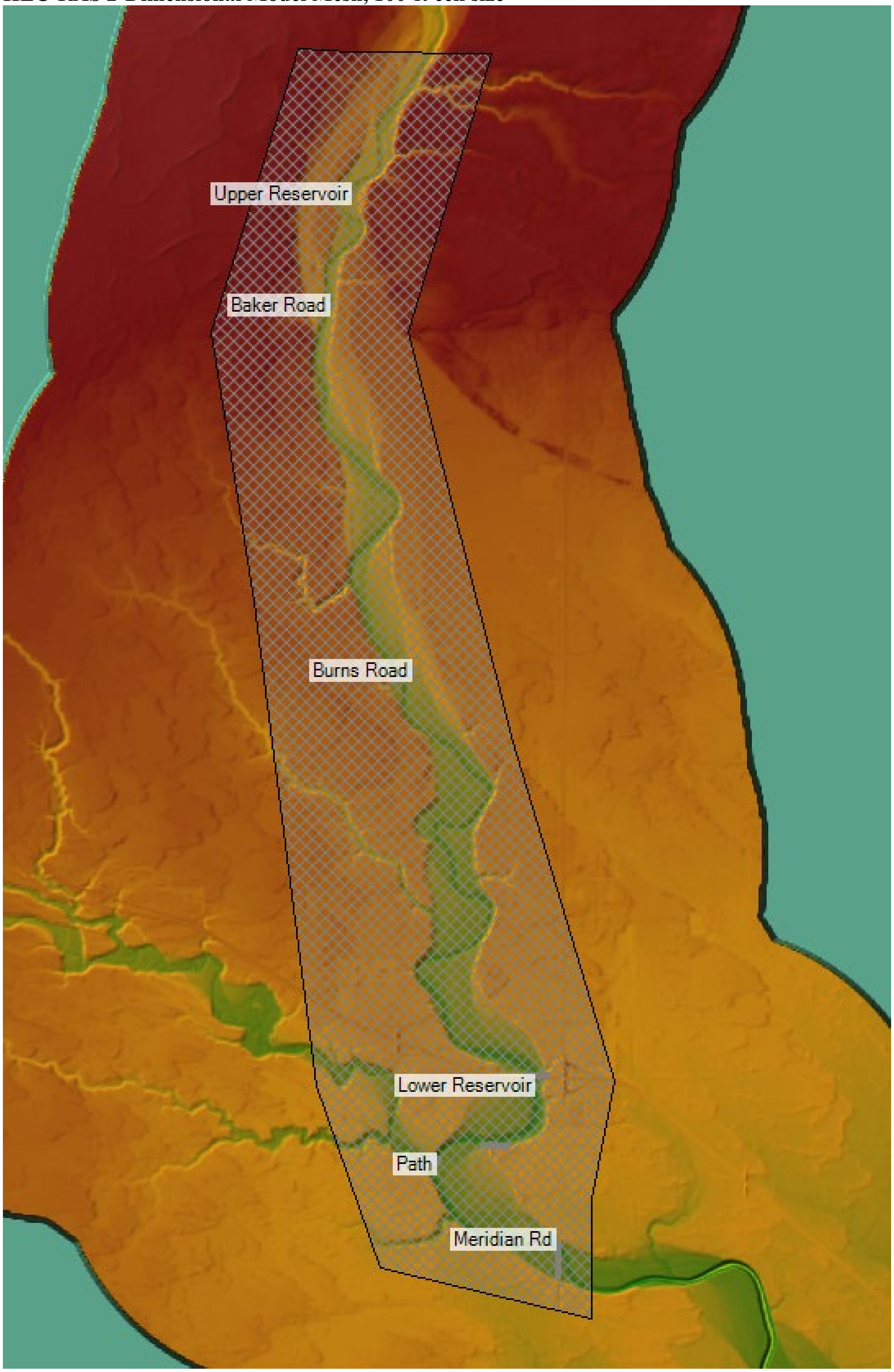
Proposed Conditions HEC-RAS Model Input and Output Data Sheets

Appendix F.4 – Sanford Dam

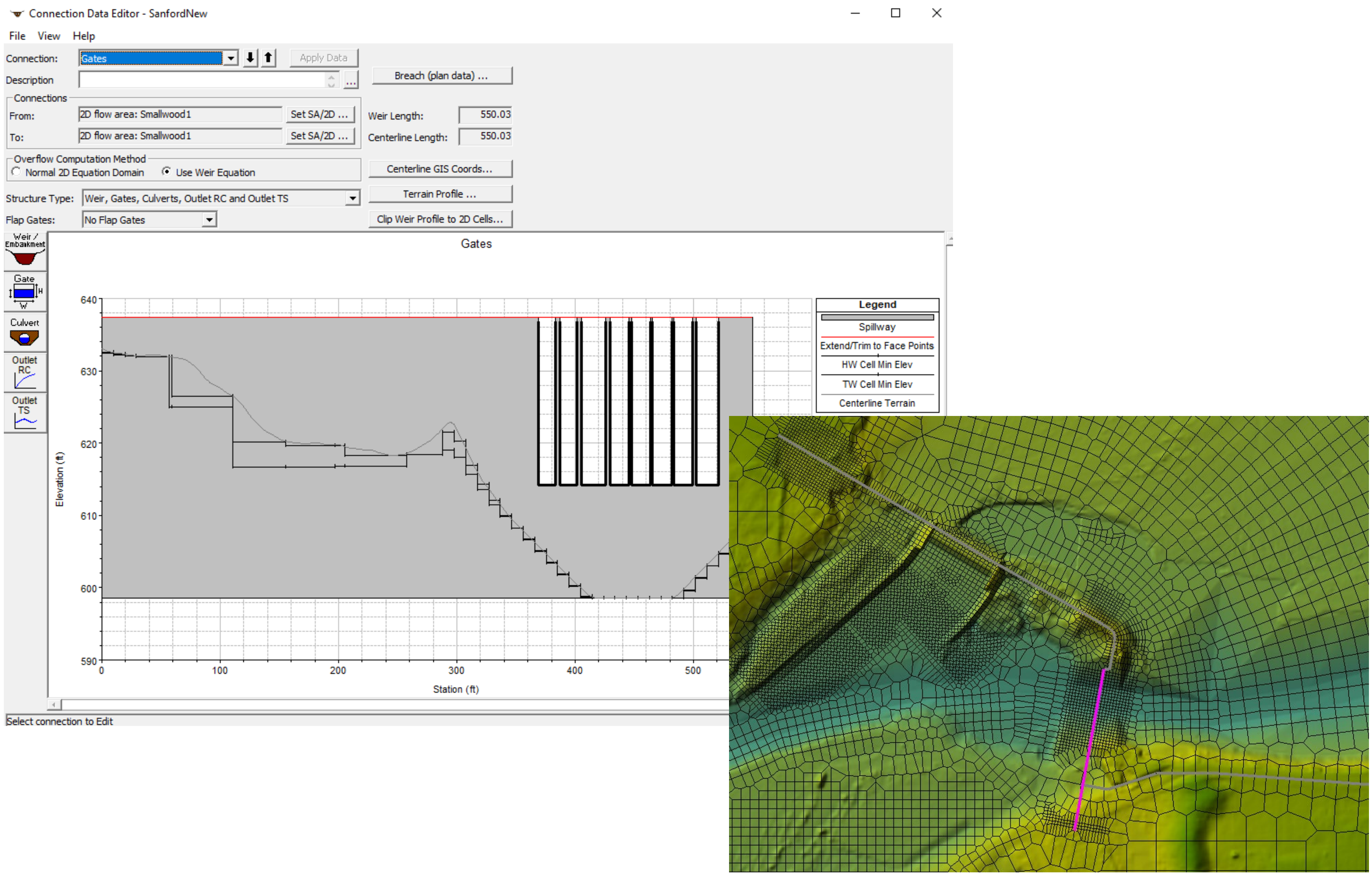
HEC-RAS Input
Project LiDAR Data Extents



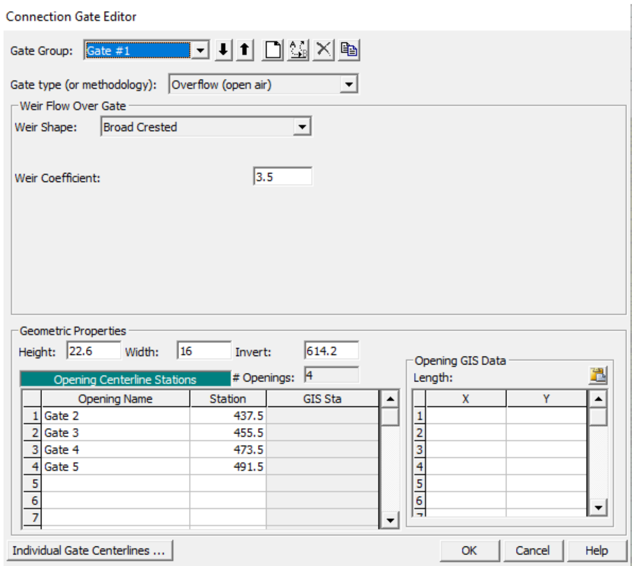
HEC-RAS 2-Dimensional Model Mesh, 100-ft cell size

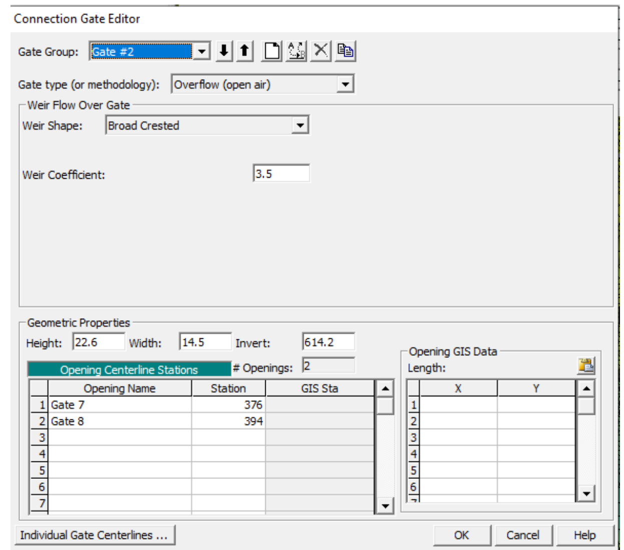


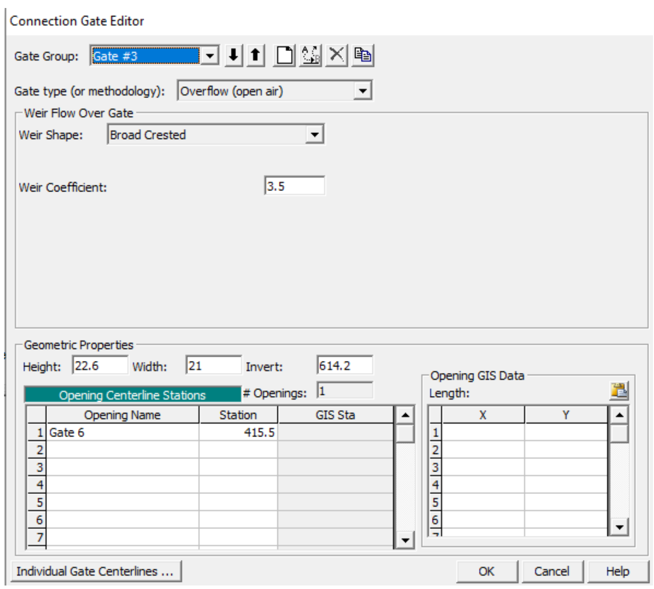
HEC-RAS Storage Area/2D Area Connections - Gates

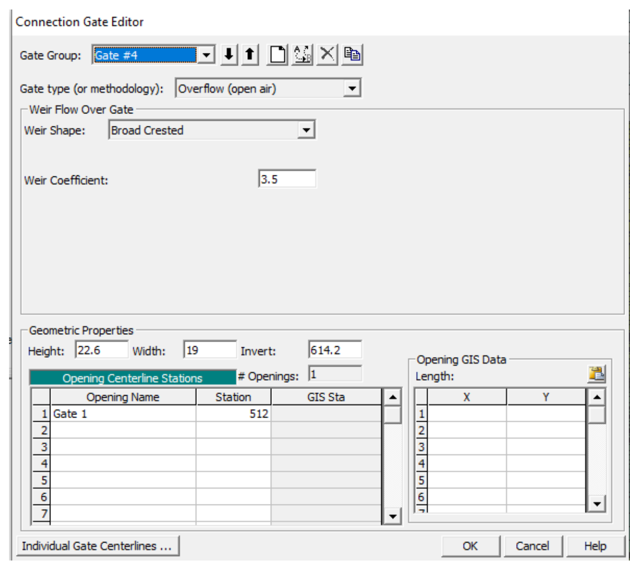


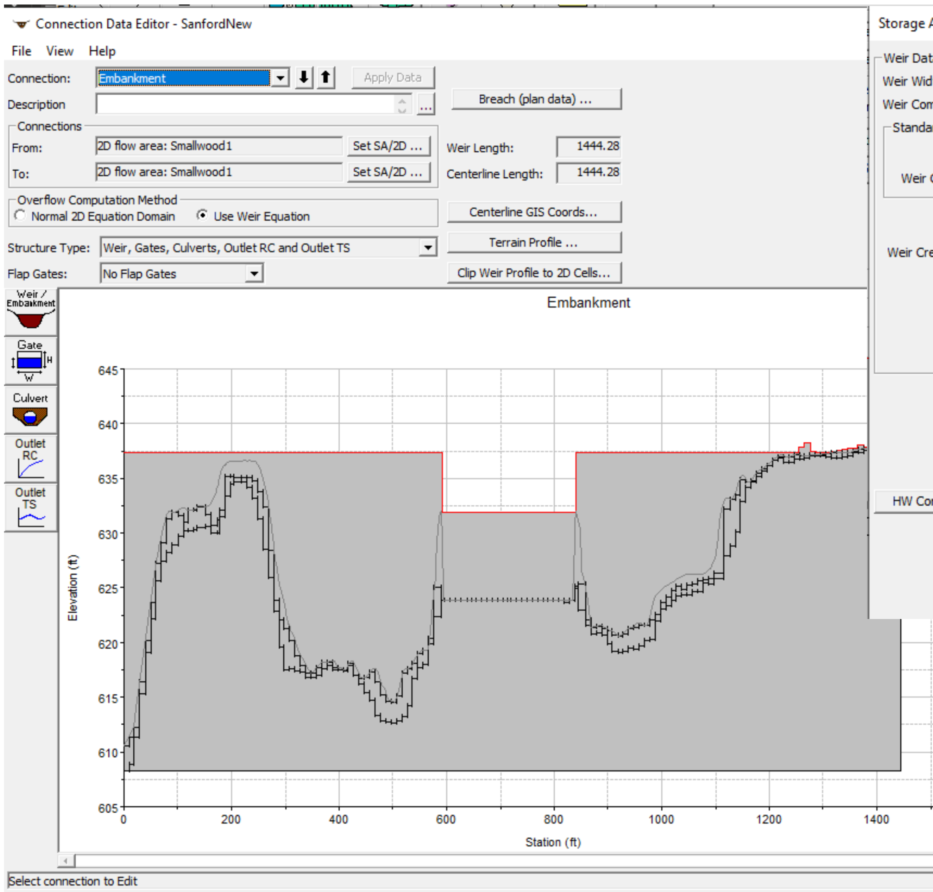
HEC-RAS Storage Area/2D Area Connection – Gates cont.

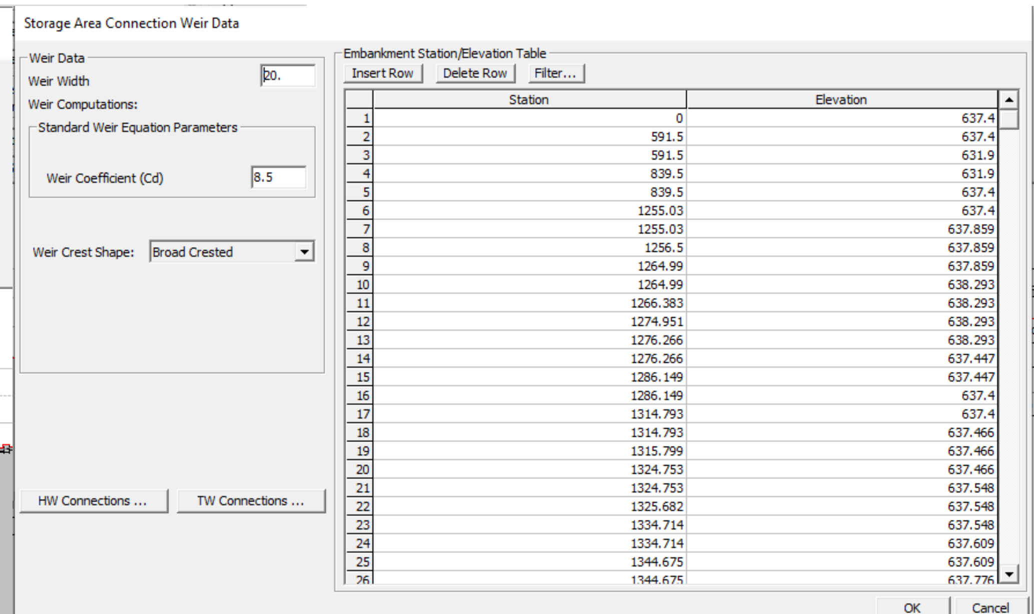


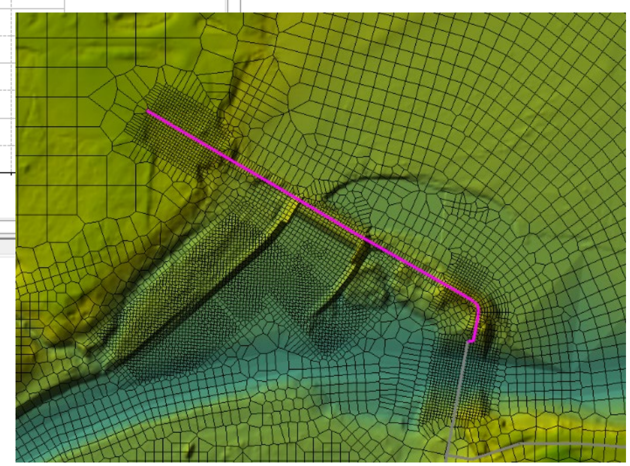






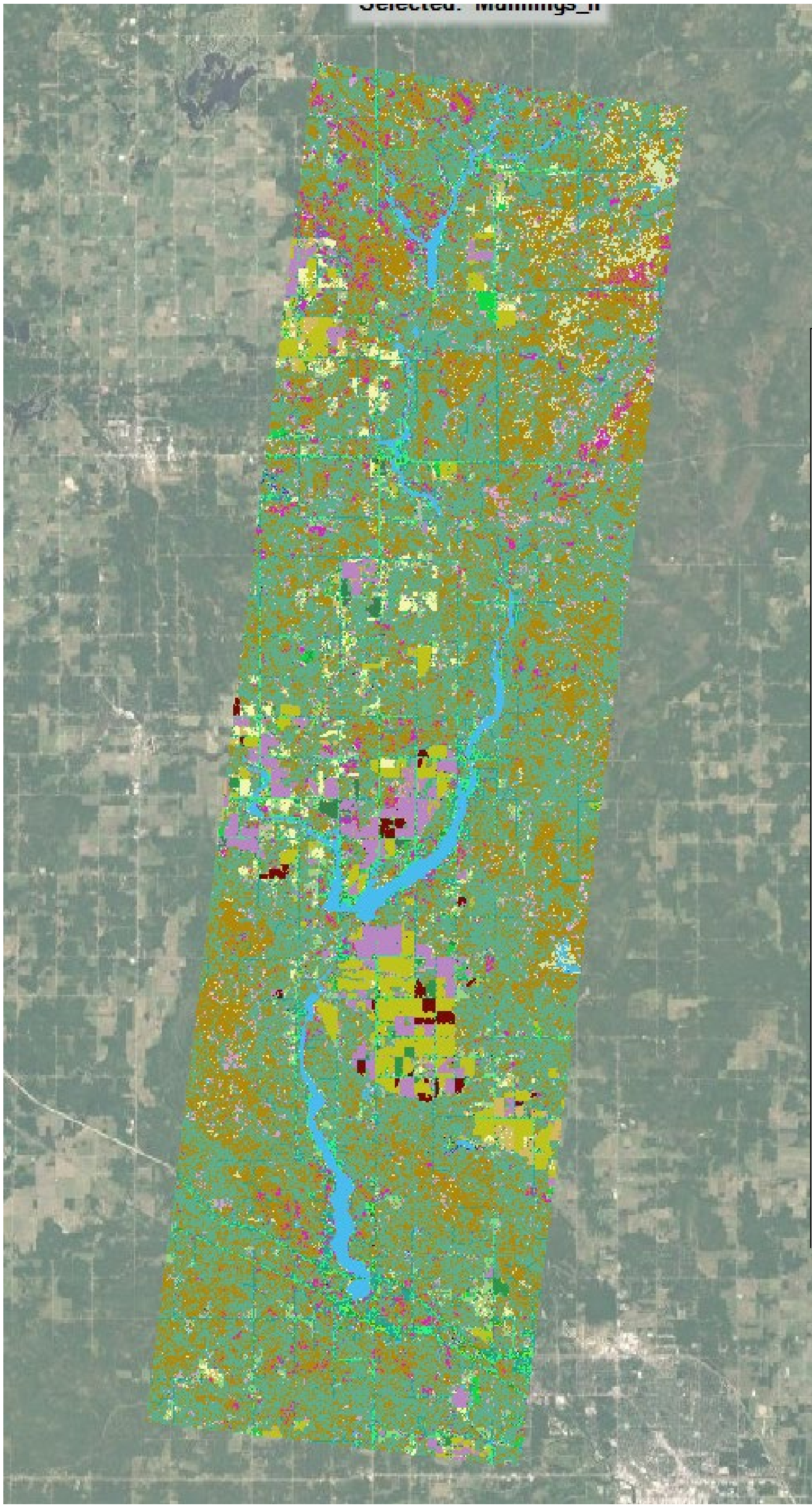






HEC-RAS Storage Area/2D Area Connection – Embankment.

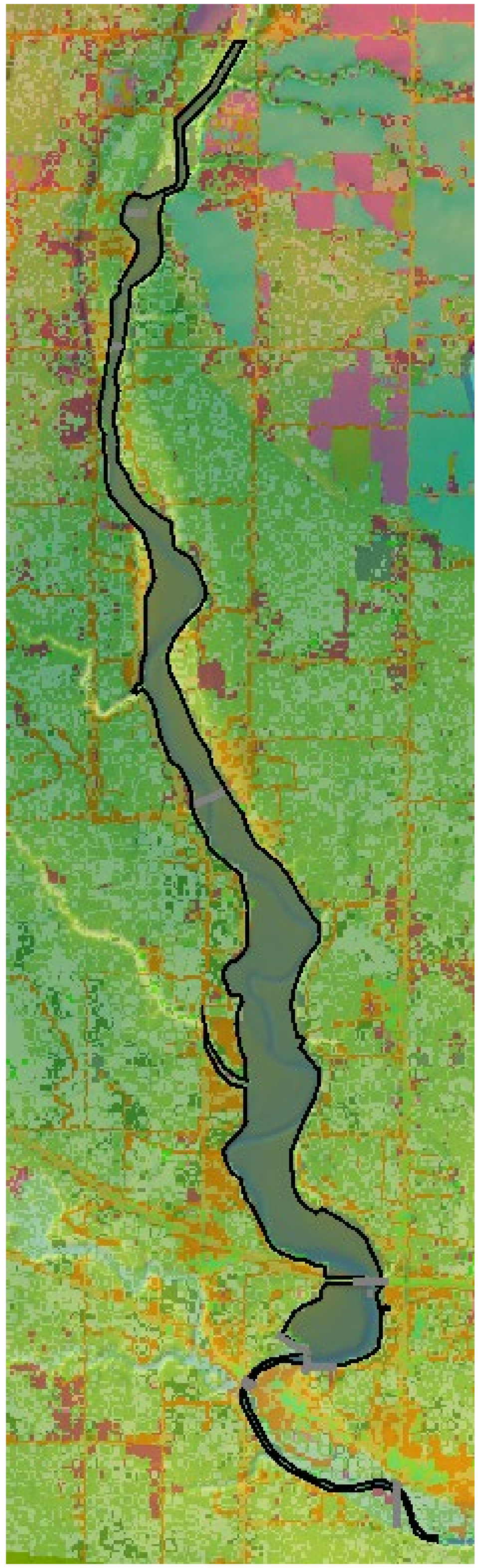
HEC-RAS 2-Dimensional Model Mesh Land Use and Manning's N Values



Color	Value	Name	Default Manning's n
	0	nodata	
	1	alfalfa	0.06
	10	deciduous forest	0.15
	11	developed/high intensity	0.15
	12	developed/low intensity	0.06
	13	developed/med intensity	0.1
	14	developed/open space	0.05
	15	dry beans	0.06
	16	evergreen forest	0.15
	17	fallow/idle cropland	0.06
	18	grassland/pasture	0.04
	19	herbaceous wetlands	0.04
	2	apples	0.1
	20	mixed forest	0.12
	21	oats	0.06
	22	open water	0.04
	23	other crops	0.06
	24	other hay/non alfalfa	0.06
	25	peas	0.06
	26	pop or orn corn	0.06
	27	potatoes	0.06
	28	rye	0.06
	29	shrubland	0.06
	3	barren	0.04
	30	sorghum	0.06
	31	soybeans	0.05
	32	sugarbeets	0.06
	33	sweet corn	0.08
	34	triticale	0.06
	35	winter wheat	0.06
	36	woody wetlands	0.1
	4	blueberries	0.08
	5	christmas trees	0.15
	6	clover/wildflowers	0.06
	7	corn	0.06
	8	cucumbers	0.06
	9	dbl crop winwht/corn	0.06

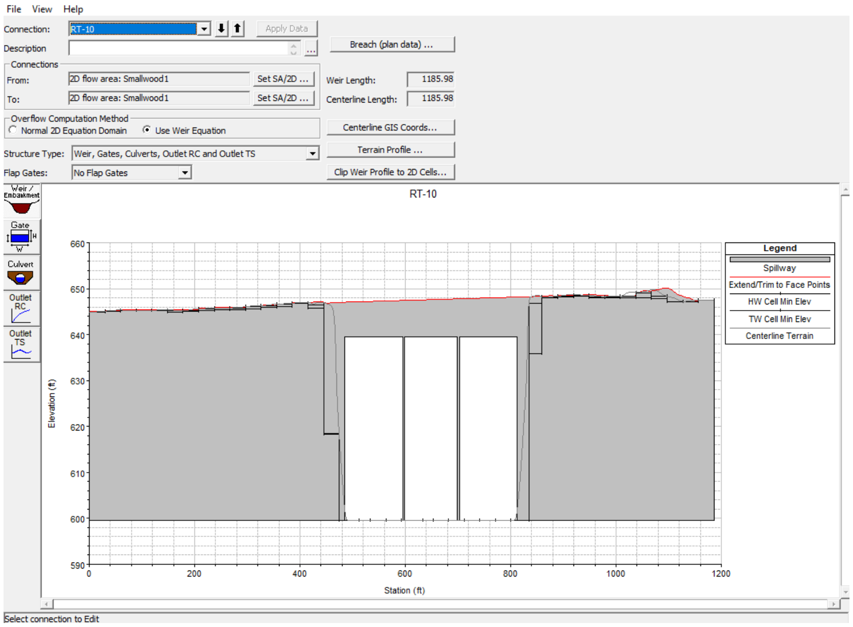
Manning N Overide Region

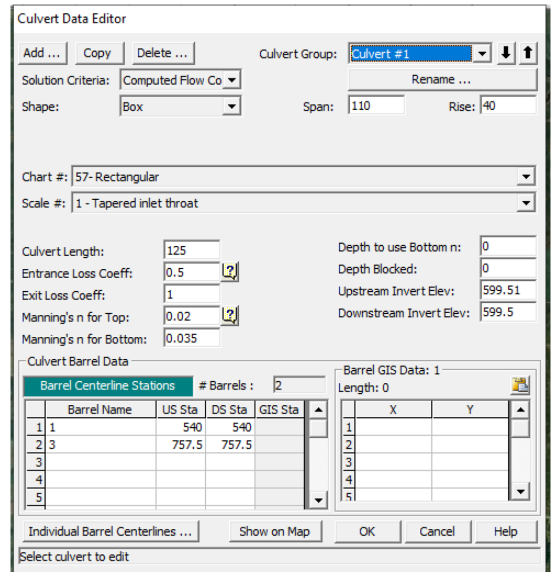
N = 0.035

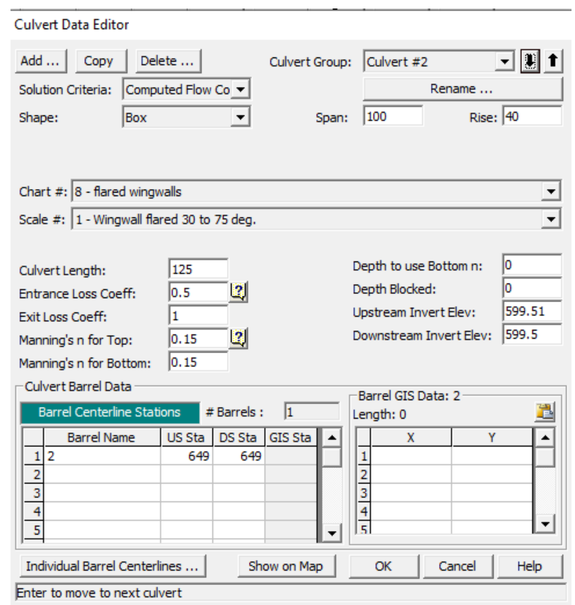


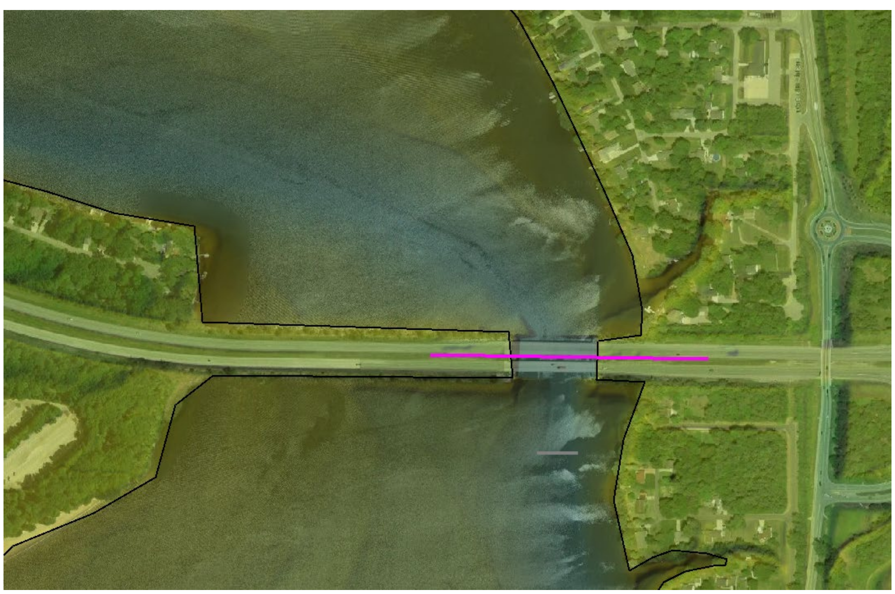
HEC-RAS 2D Bridges

RT-10 Bridge









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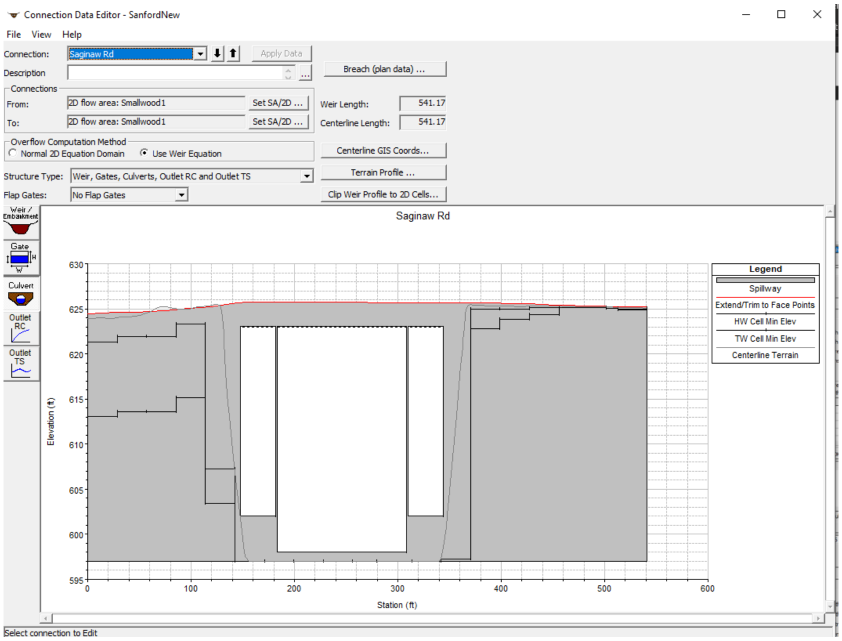
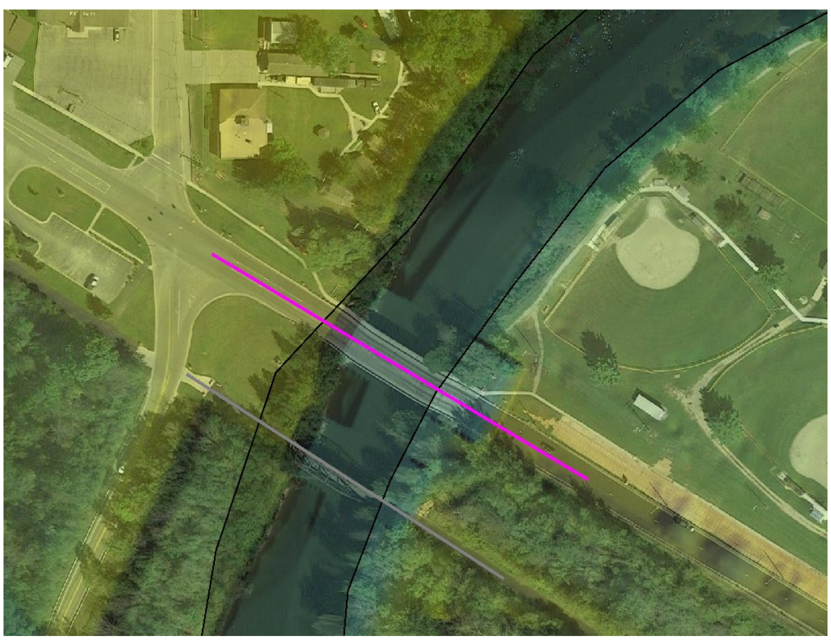
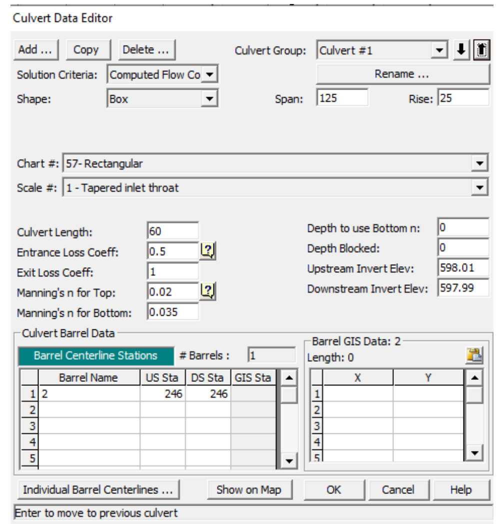
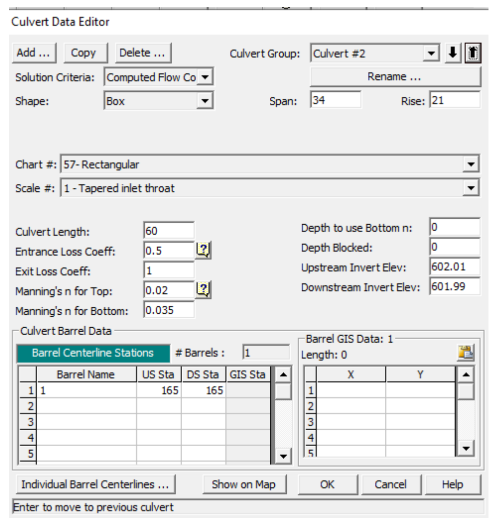
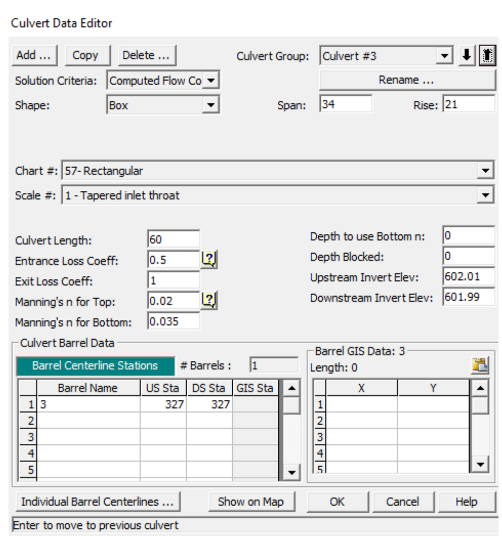
Saginaw Road Bridge



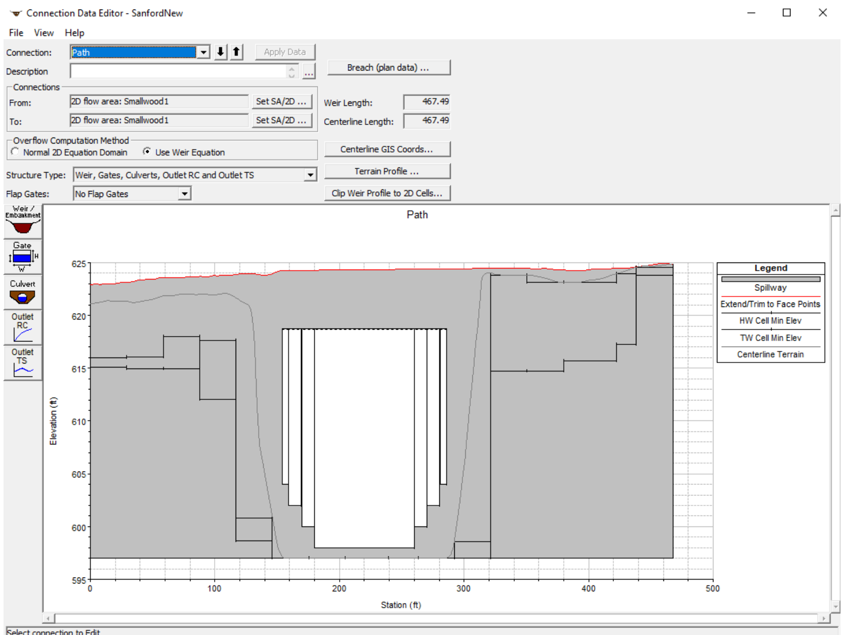


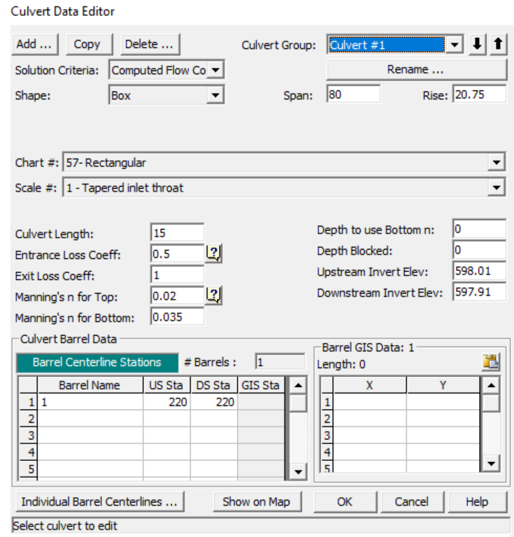


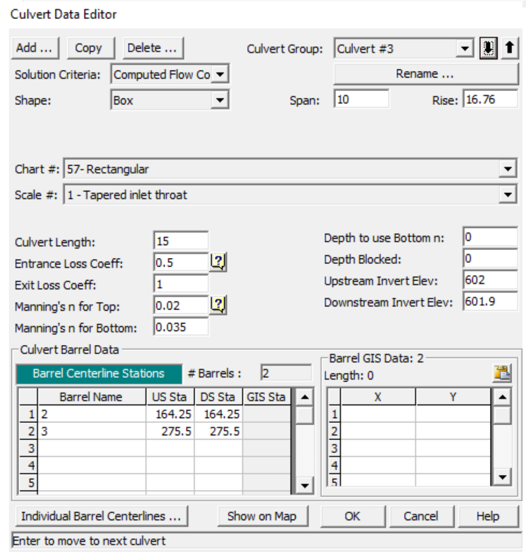


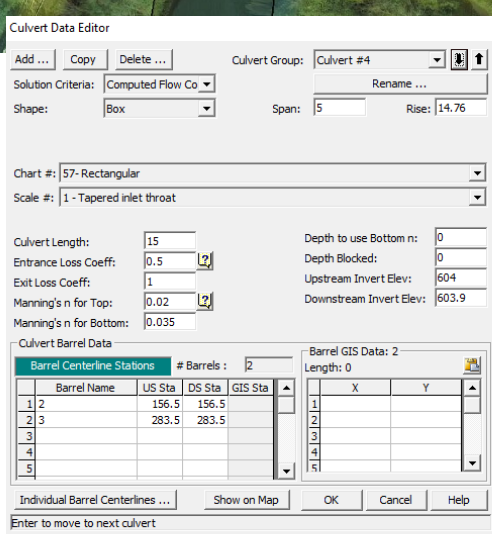


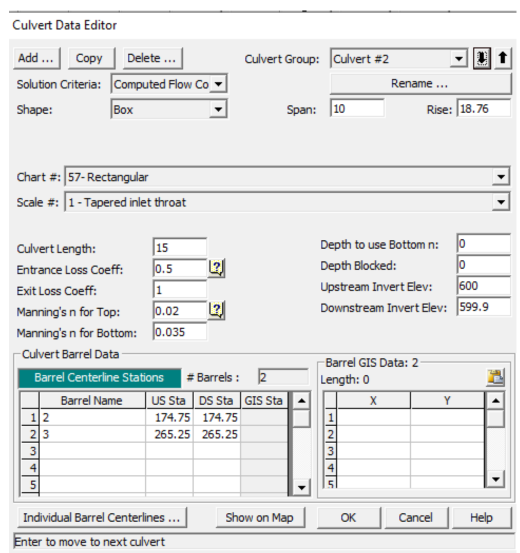
Rail Trail Bridge



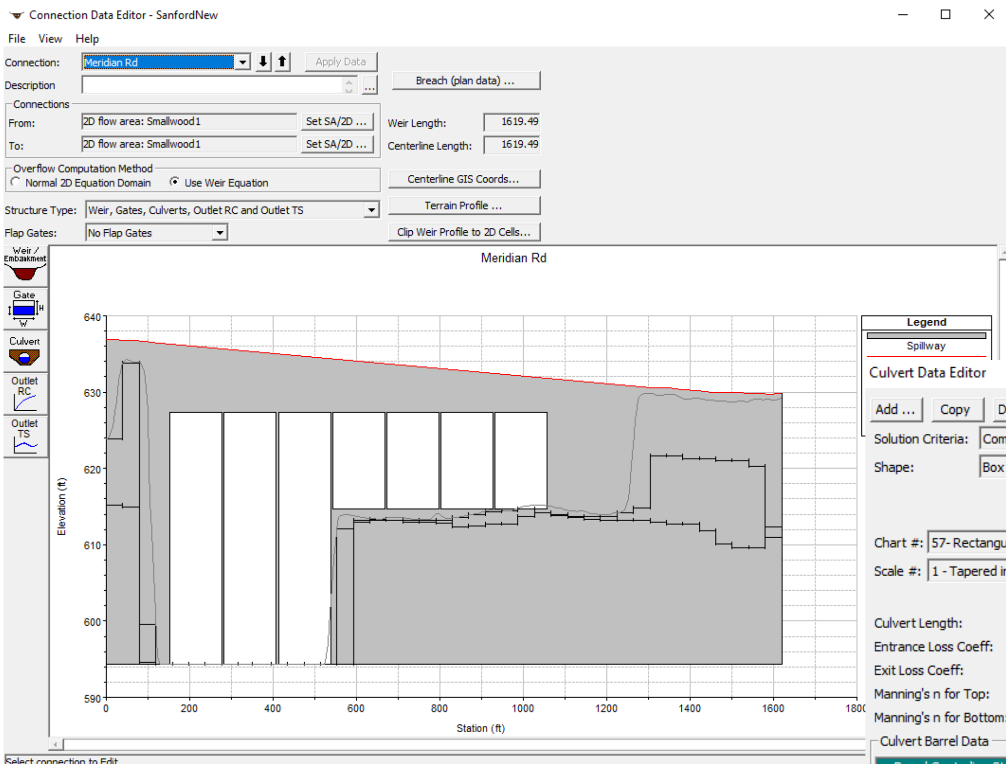


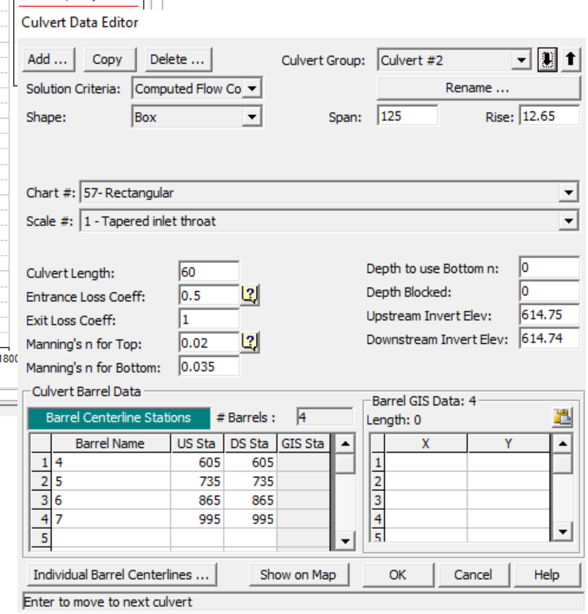


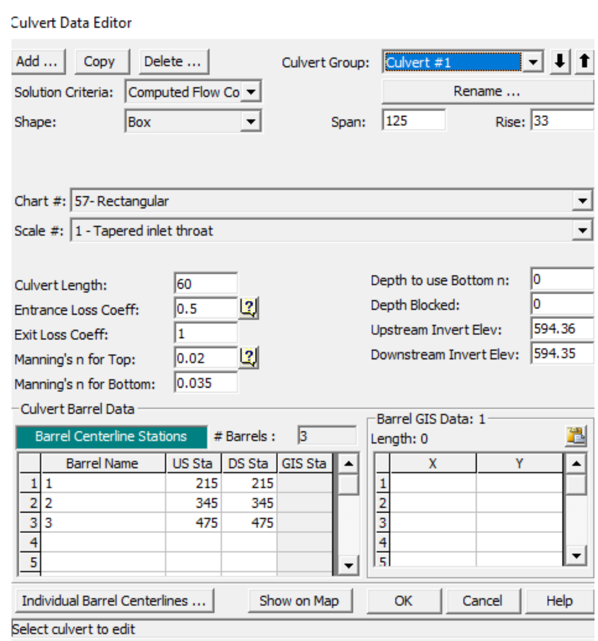




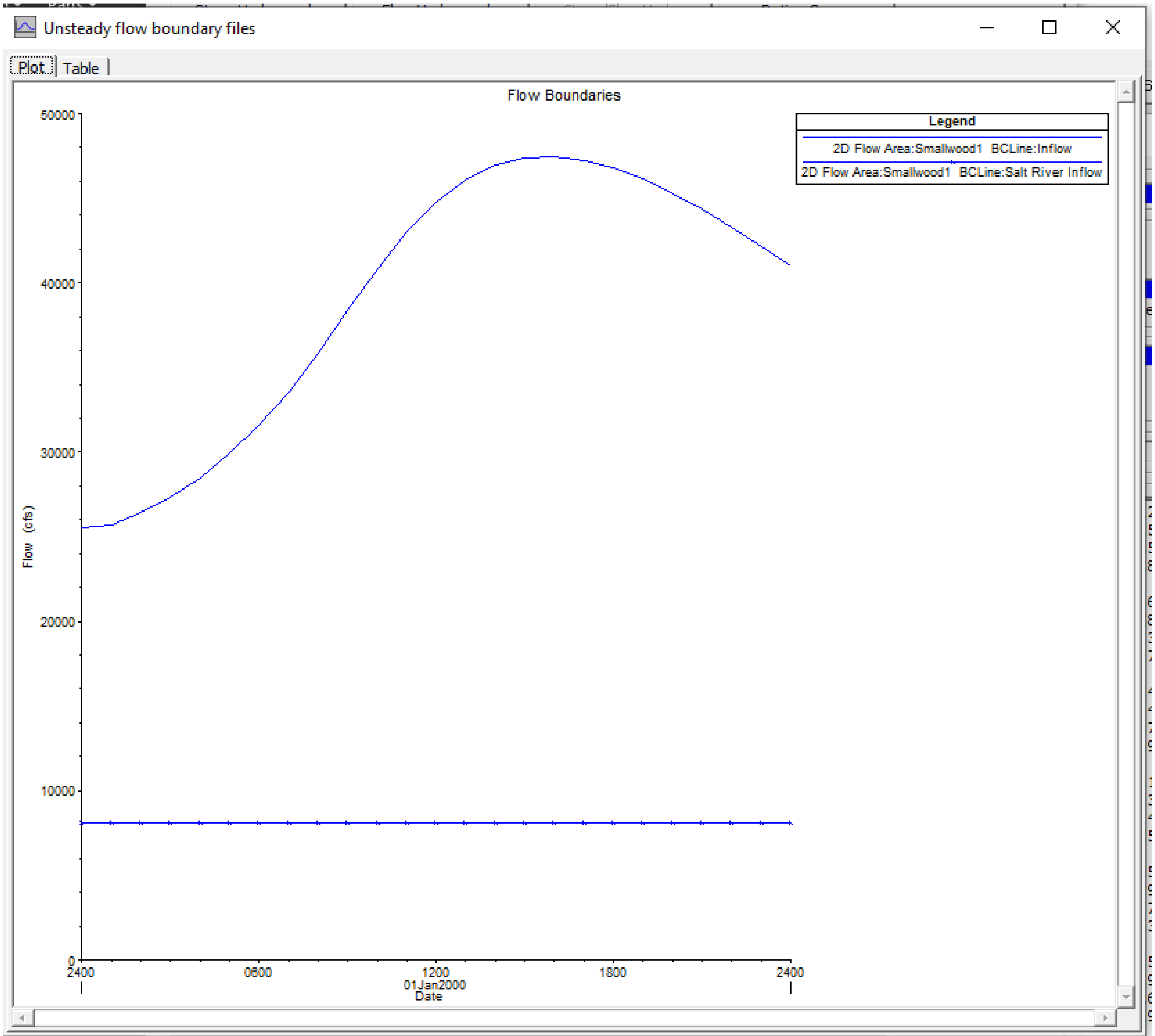
Meridian Road



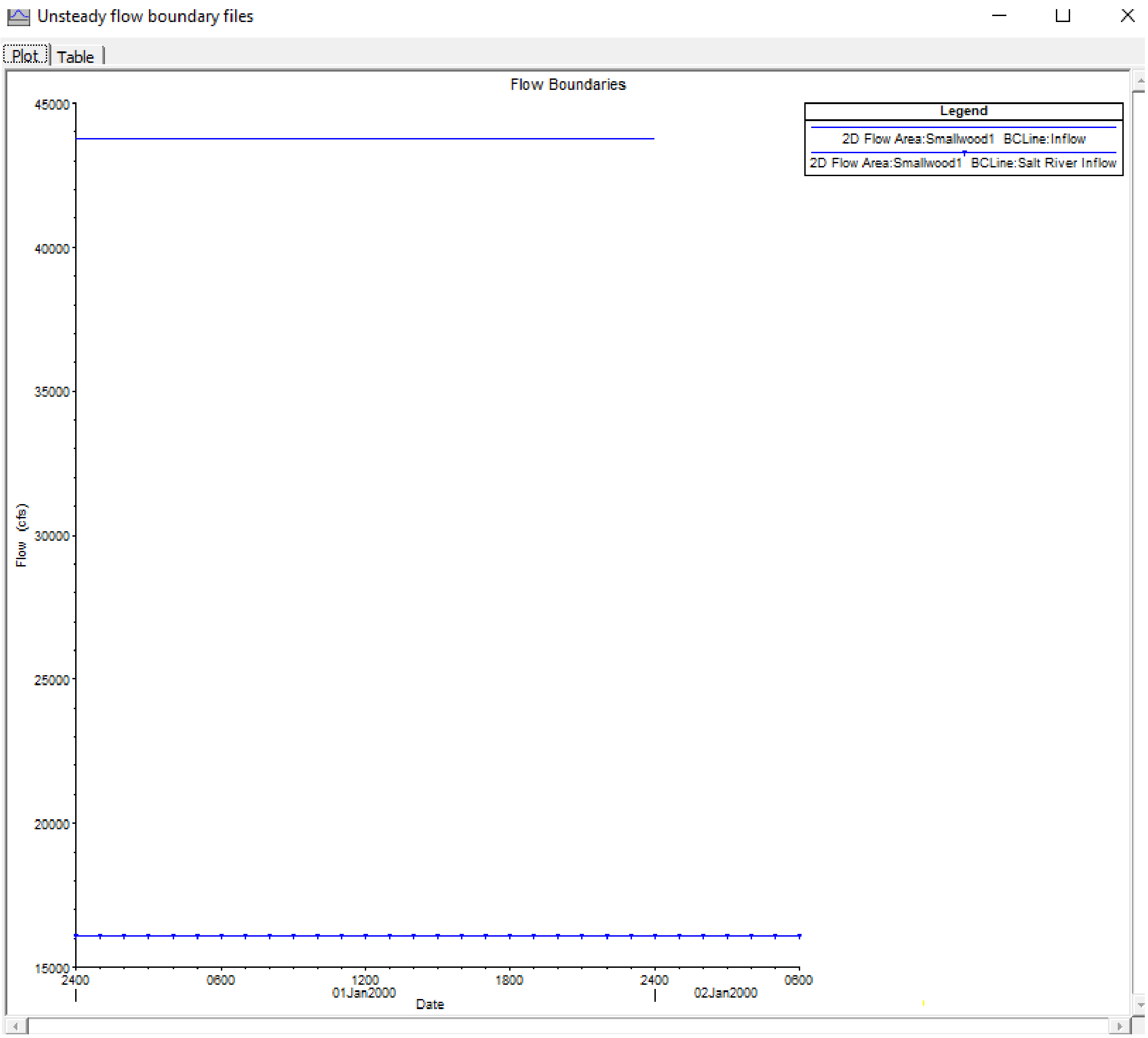




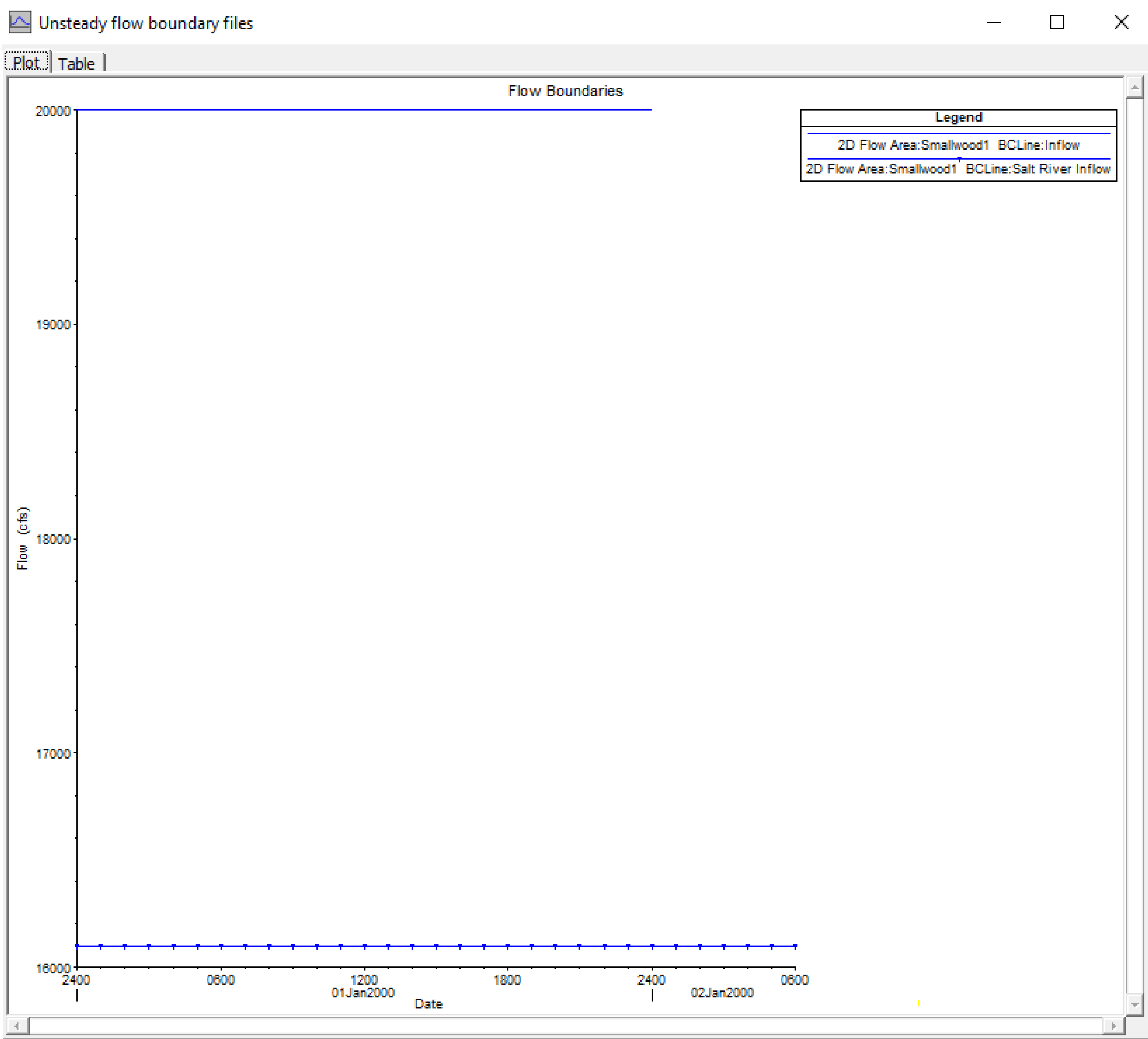
Inflow Hydrograph – Half PMF+ – Proposed and Existing Conditions



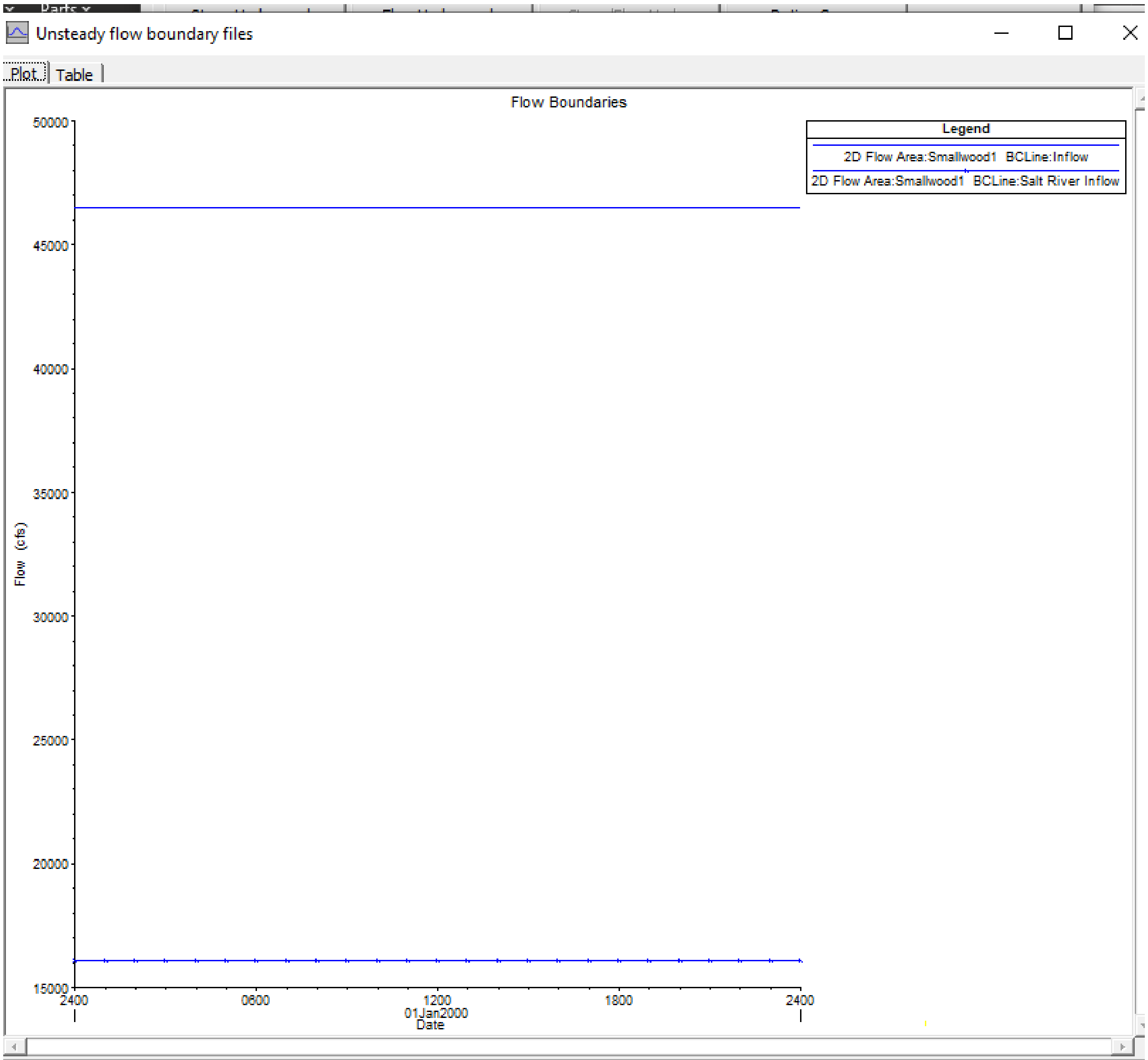
Inflow Hydrograph – Half PMF+ –



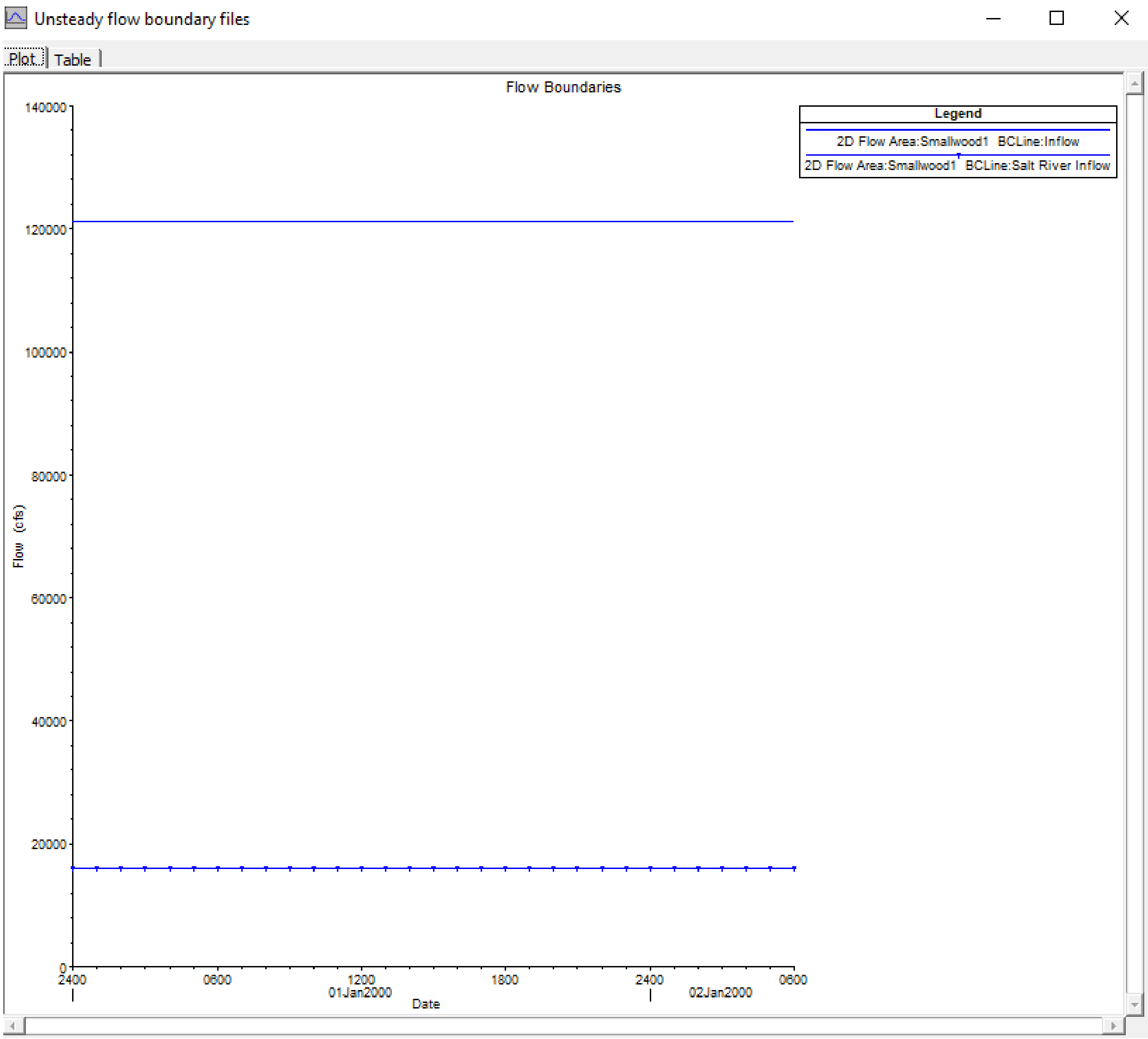
Inflow Hydrograph – 100-Yaer, Dam Removed



Inflow Hydrograph – Half PMF, Dam Removed



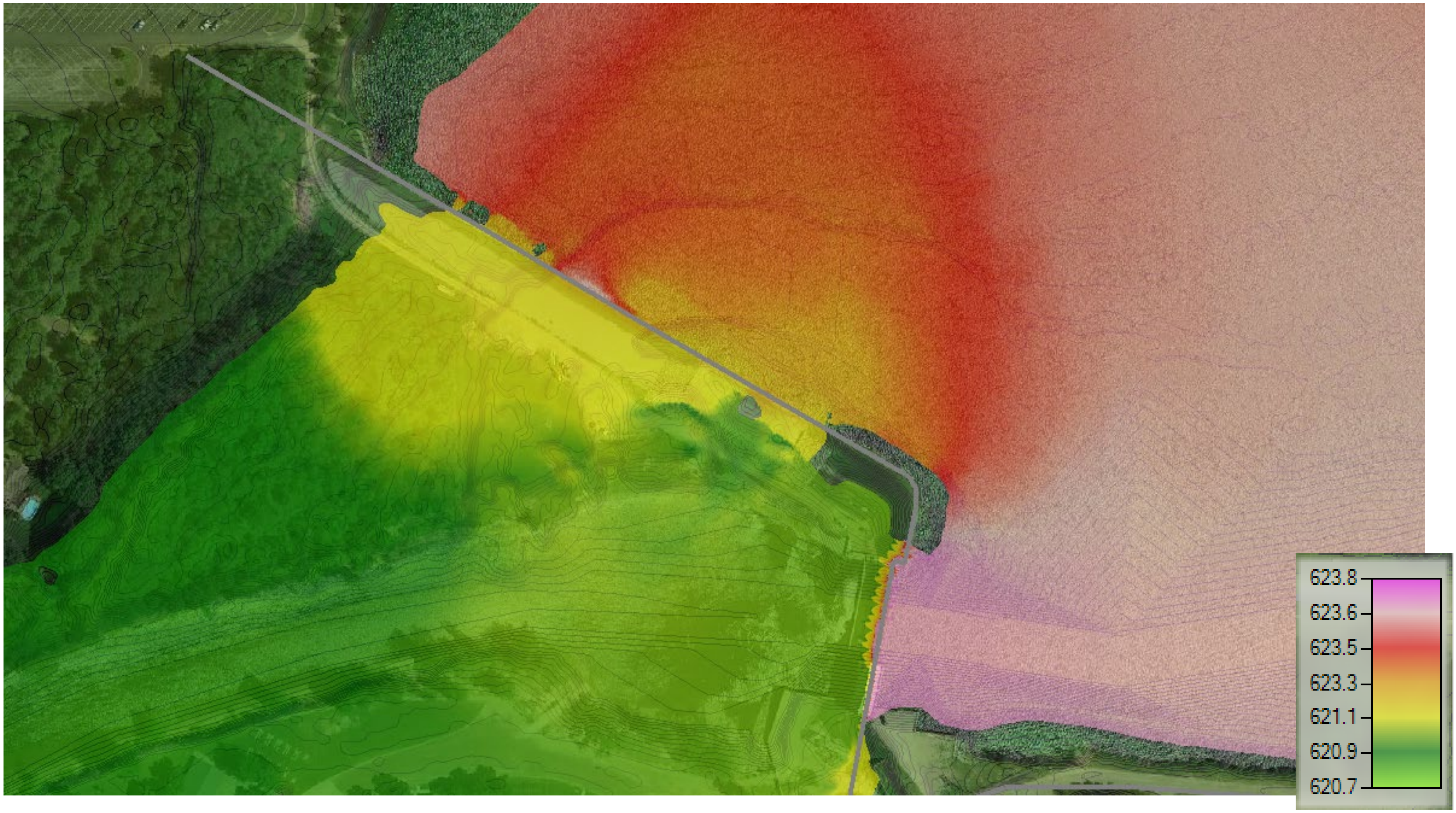
Inflow Hydrograph – Full PMF, Dam Removed



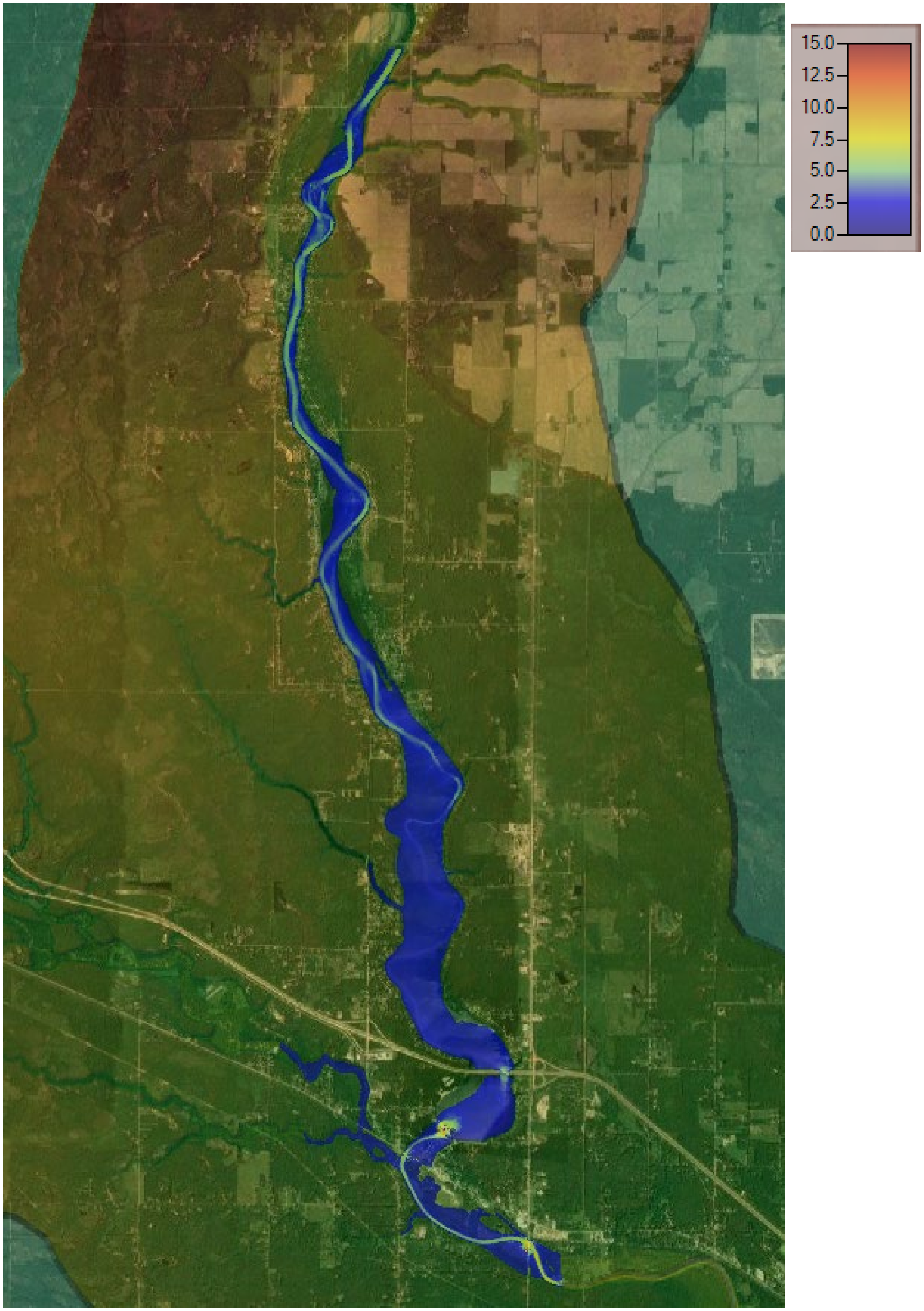
OUTPUT

Peak Water Surface Elevation – Existing Conditions

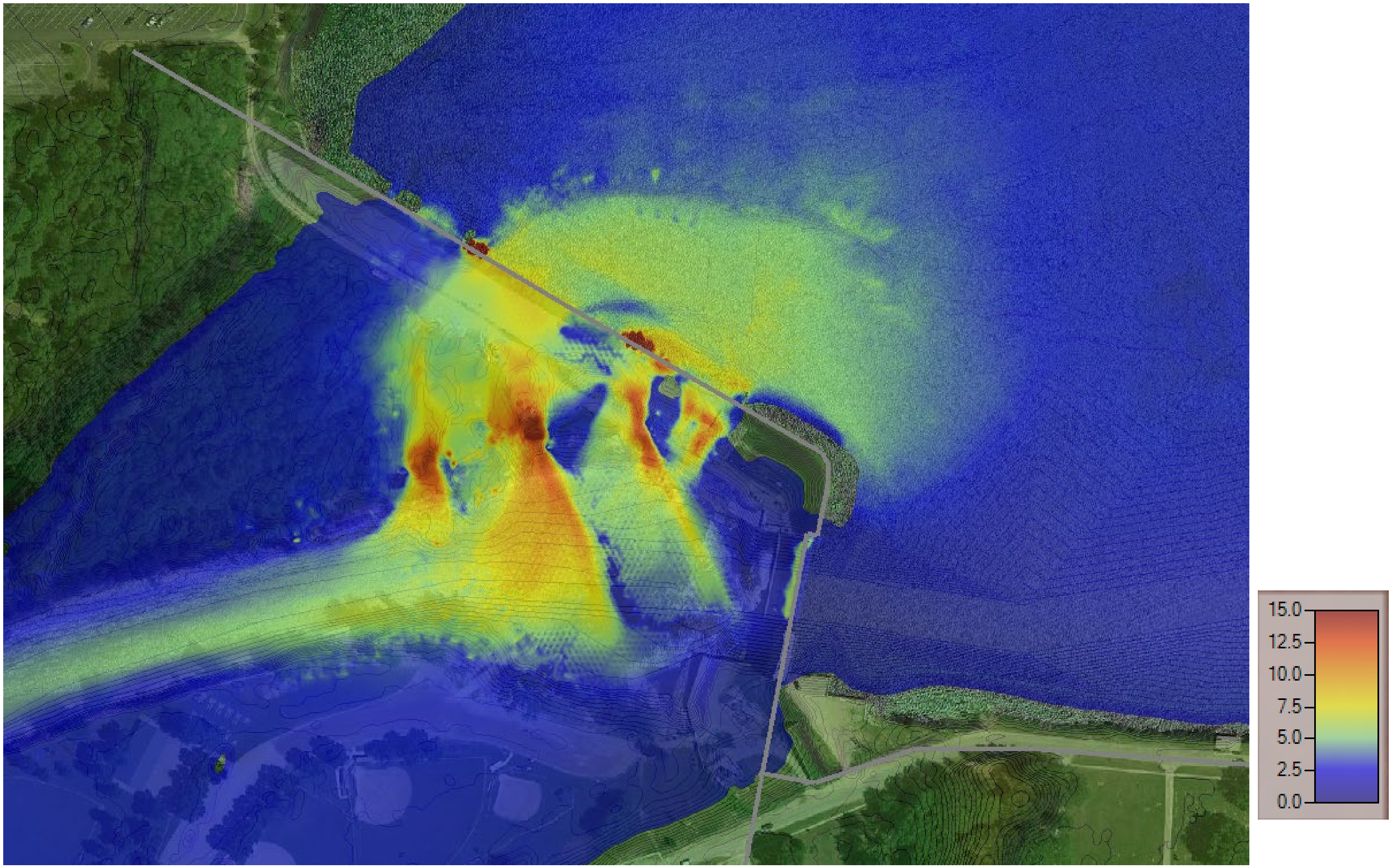
Peak Water Surface Elevation – Existing Conditions – Sanford Dam Detail



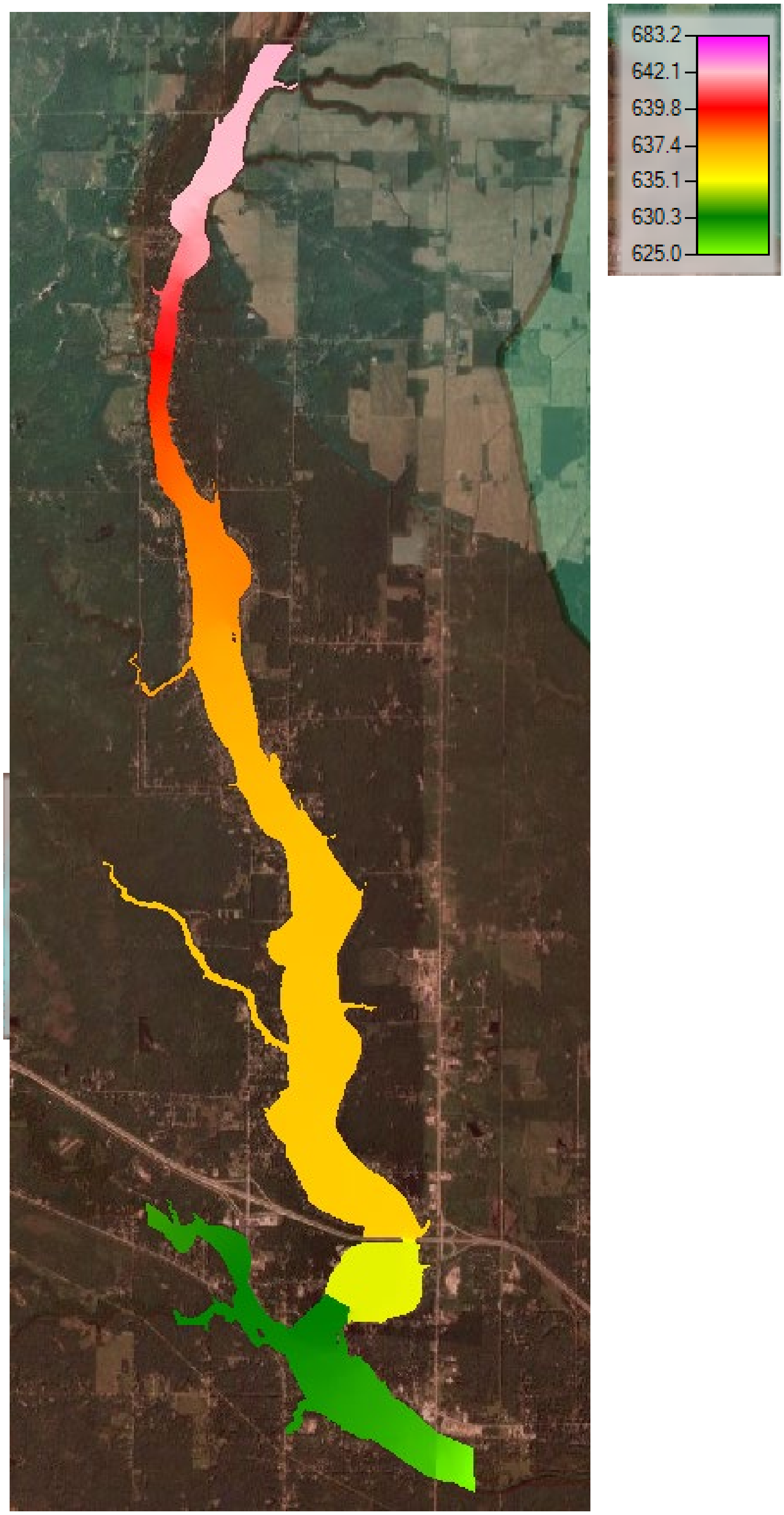
Peak Velocity – Existing Conditions



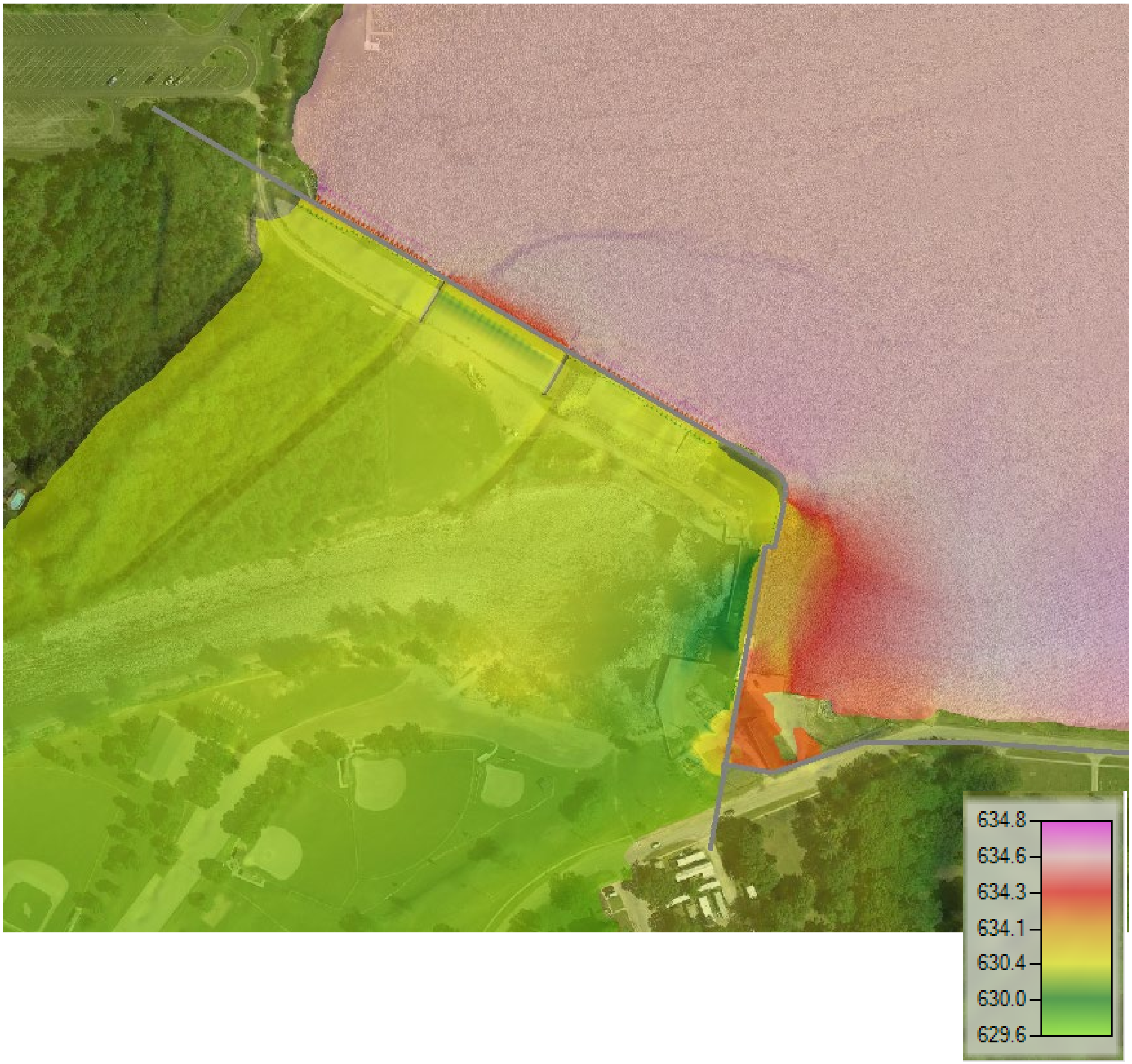
Peak Velocity – Existing Conditions – Sanford Dam Detail



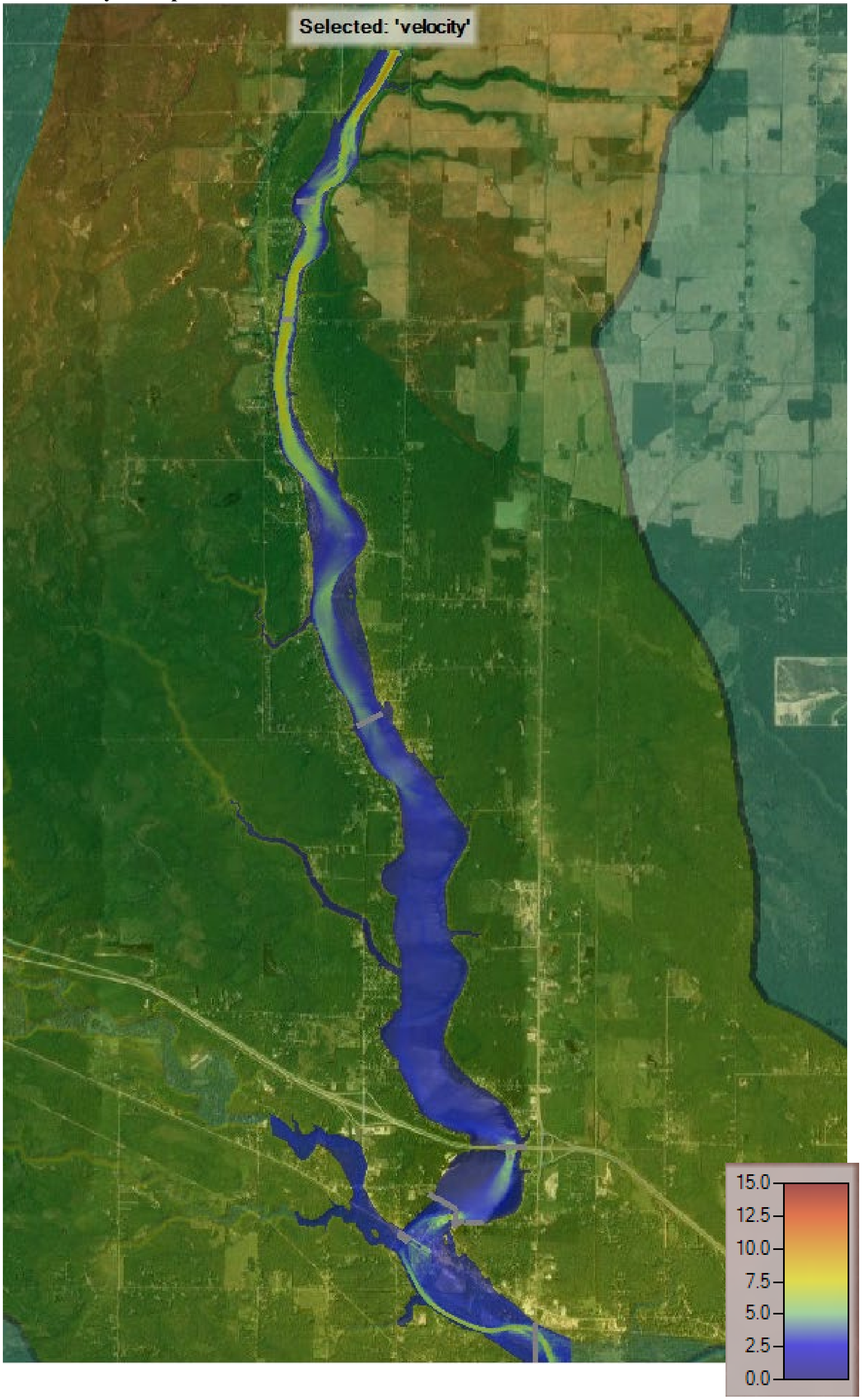
Peak Water Surface Elevation – Proposed Conditions



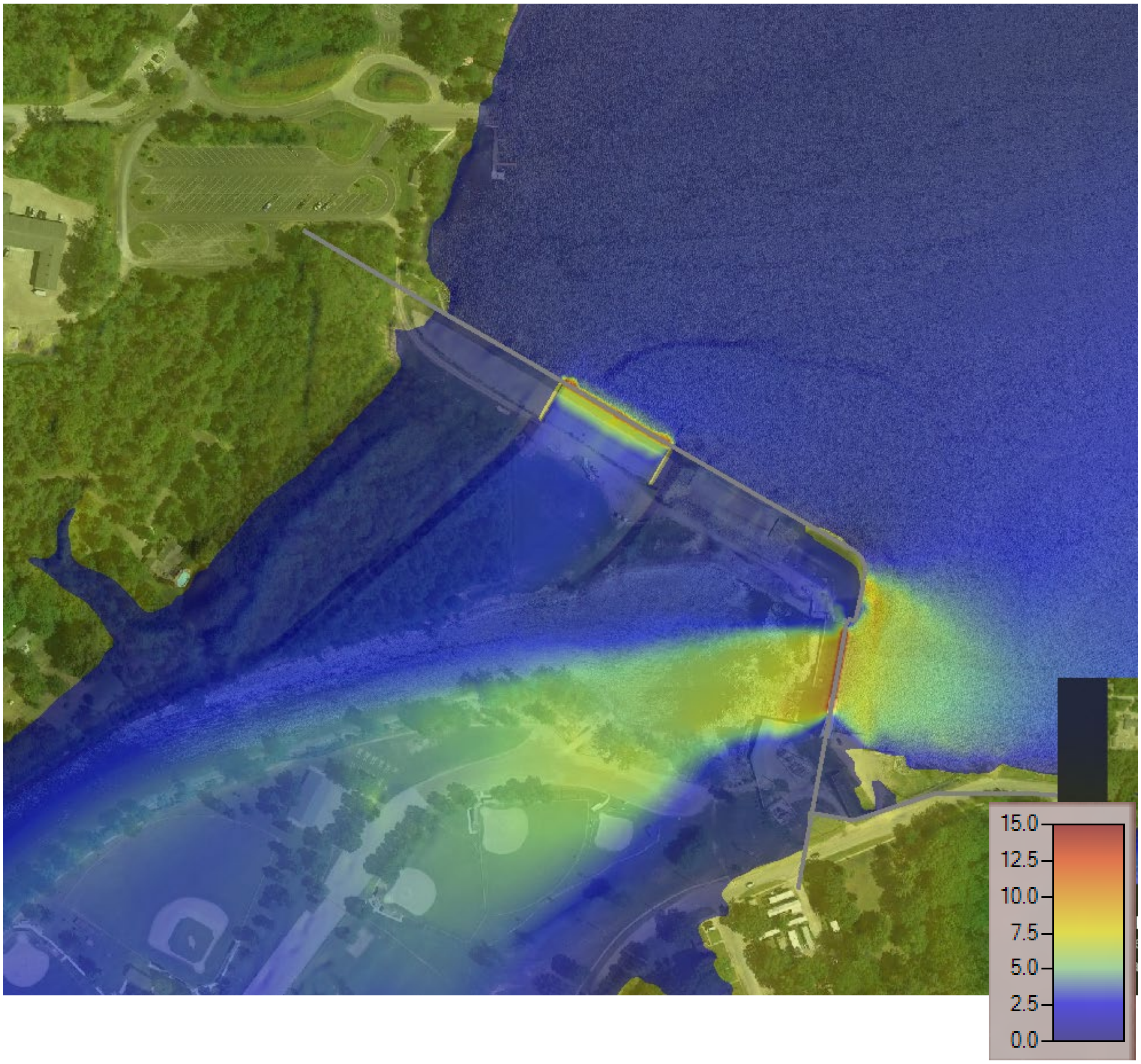
Peak Water Surface Elevation – Proposed Conditions – Sanford Dam Detail



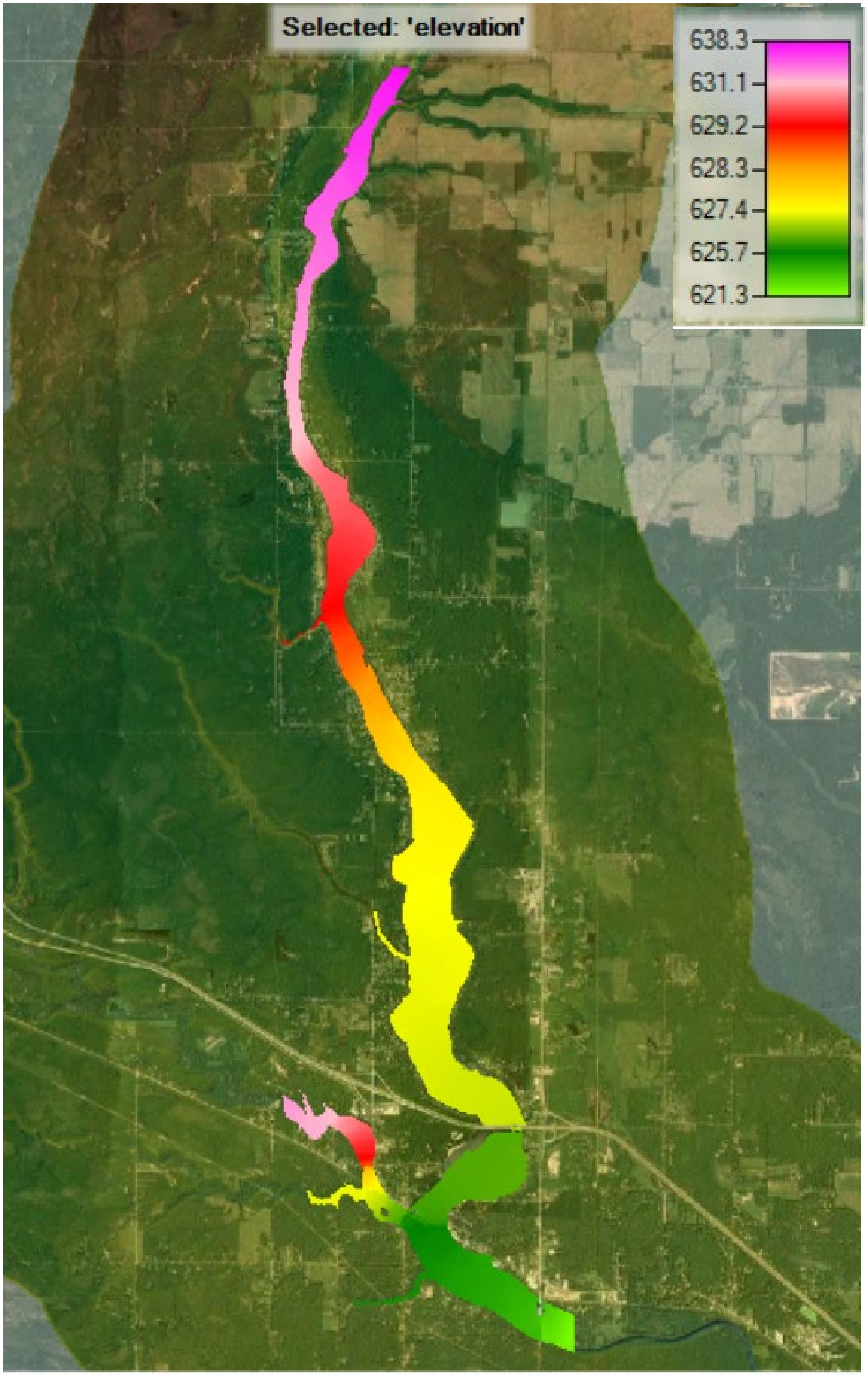
Peak Velocity – Proposed Conditions



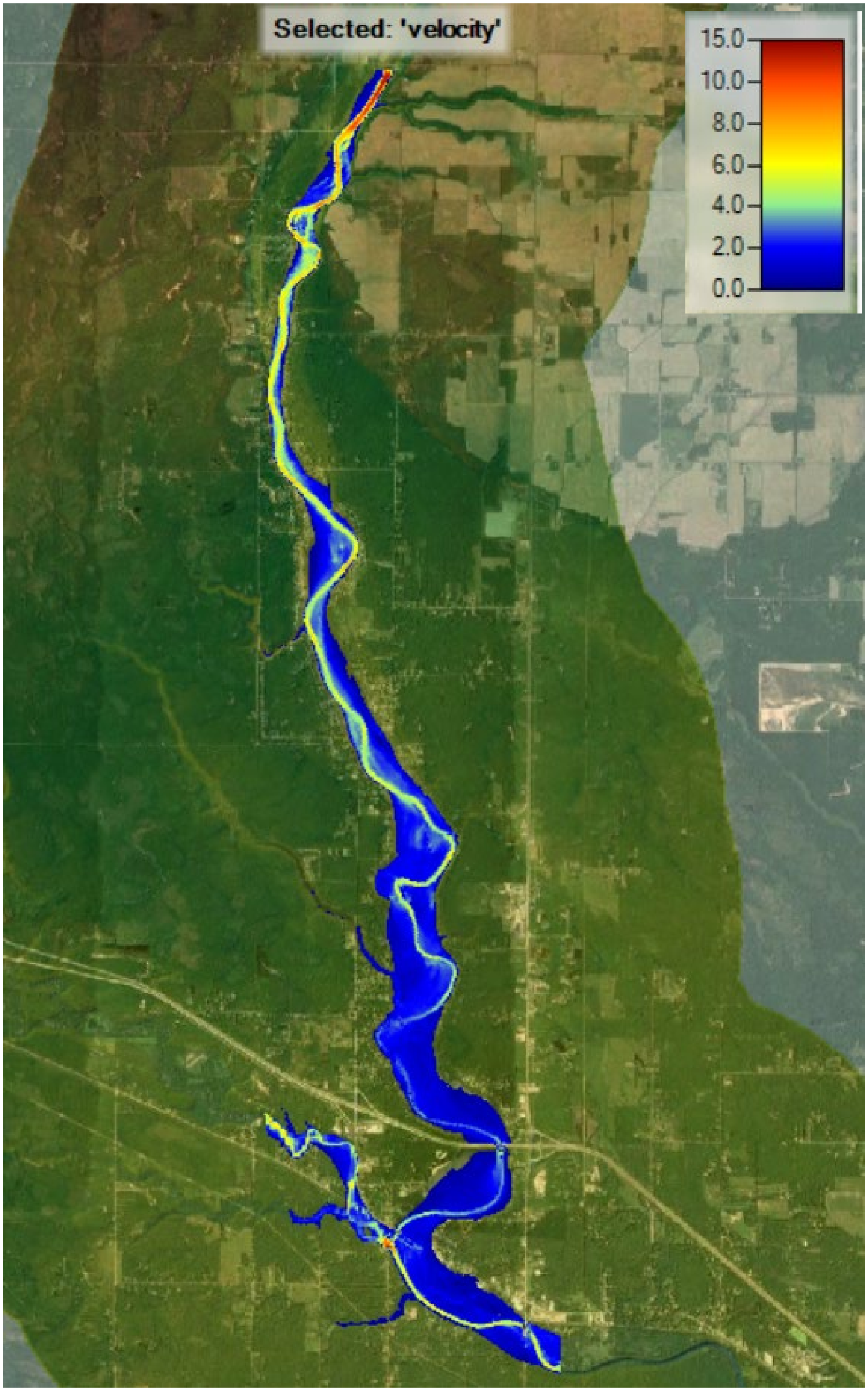
Peak Velocity – Proposed Conditions – Sanford Dam Detail



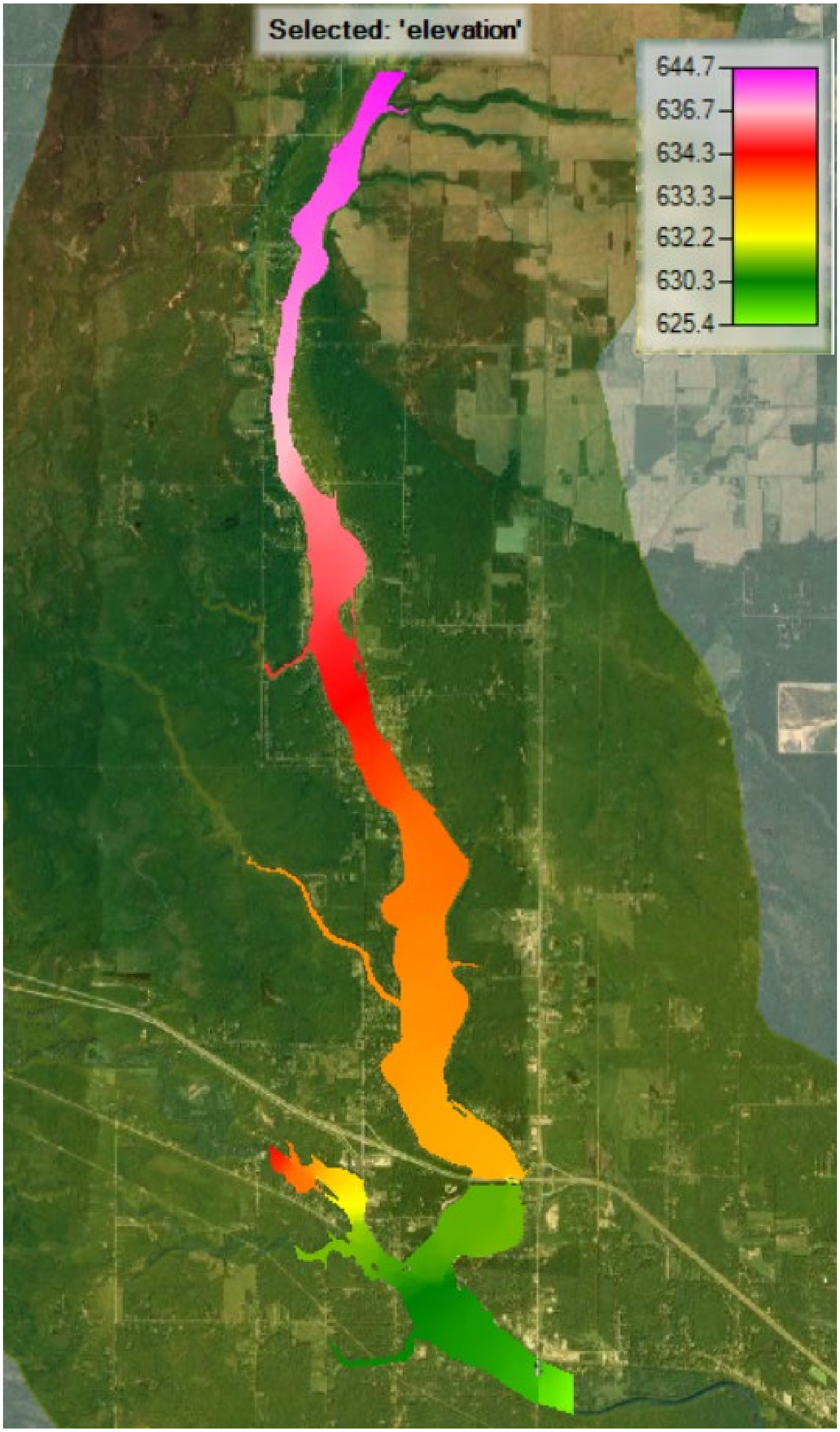
Peak Water Surface Elevation – Dam Removed Conditions – 100-Year



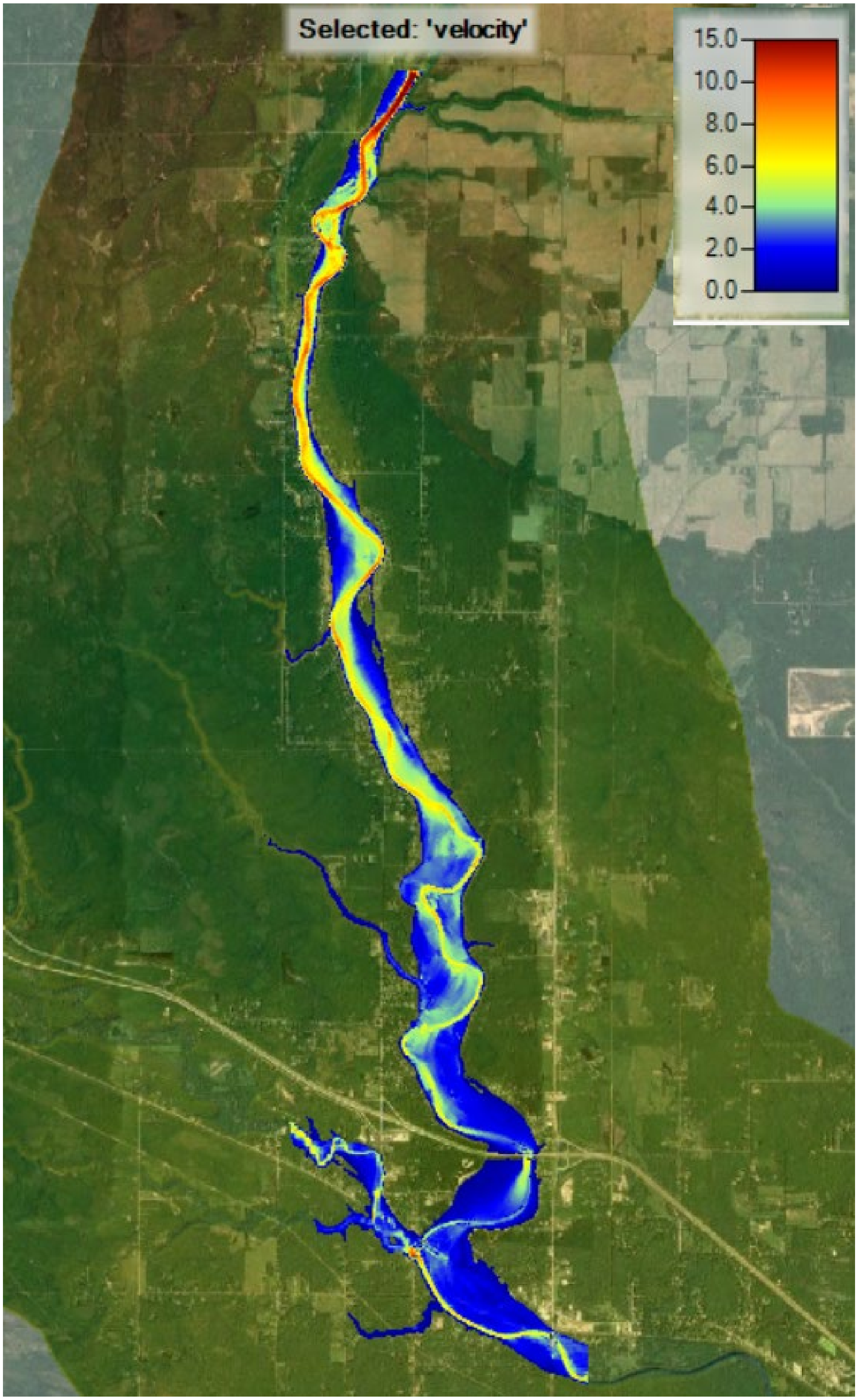
Peak Velocity – Dam Removed Conditions – 100-Year



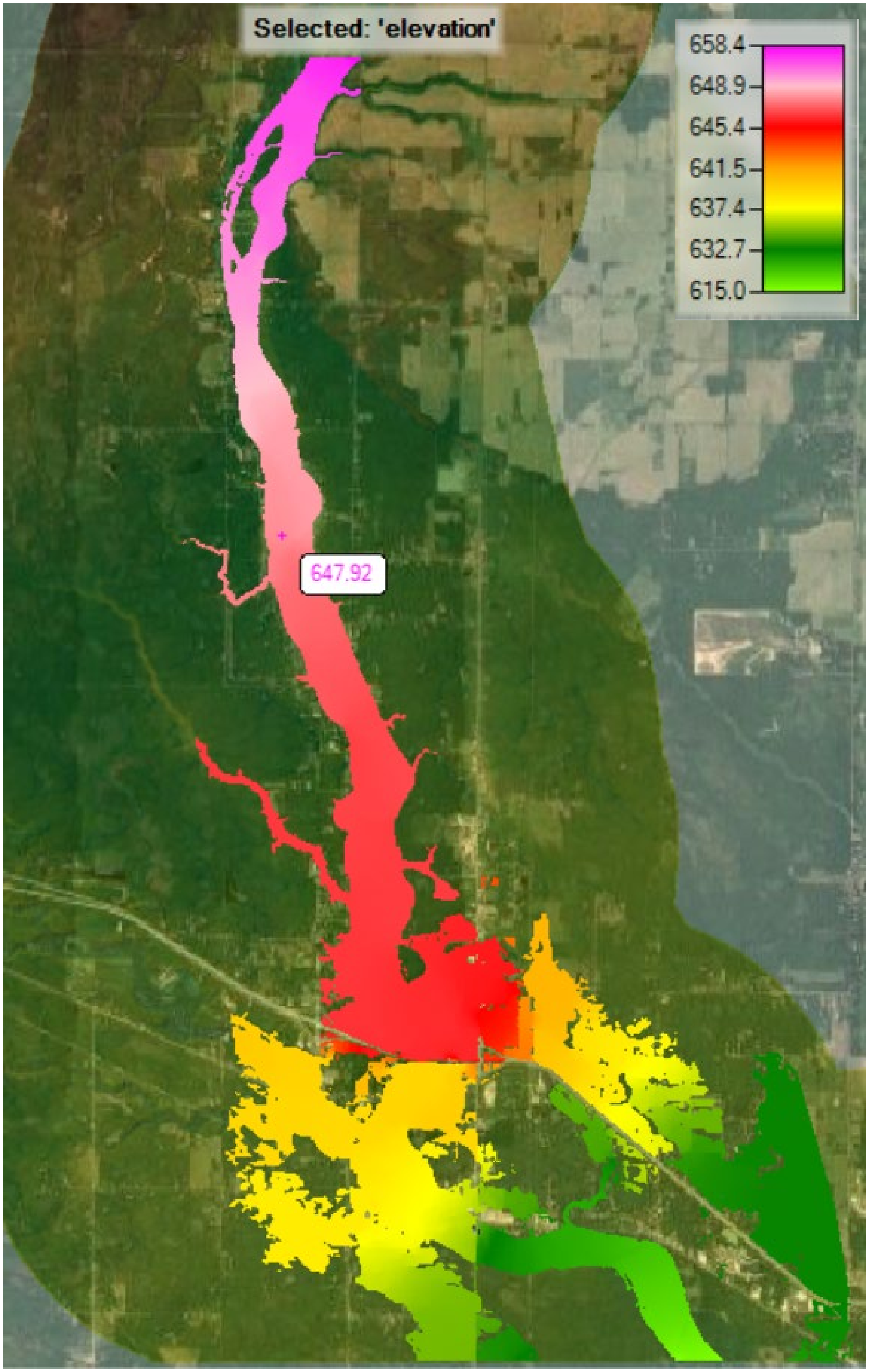
Peak Water Surface Elevation – Dam Removed Conditions – Half PMF



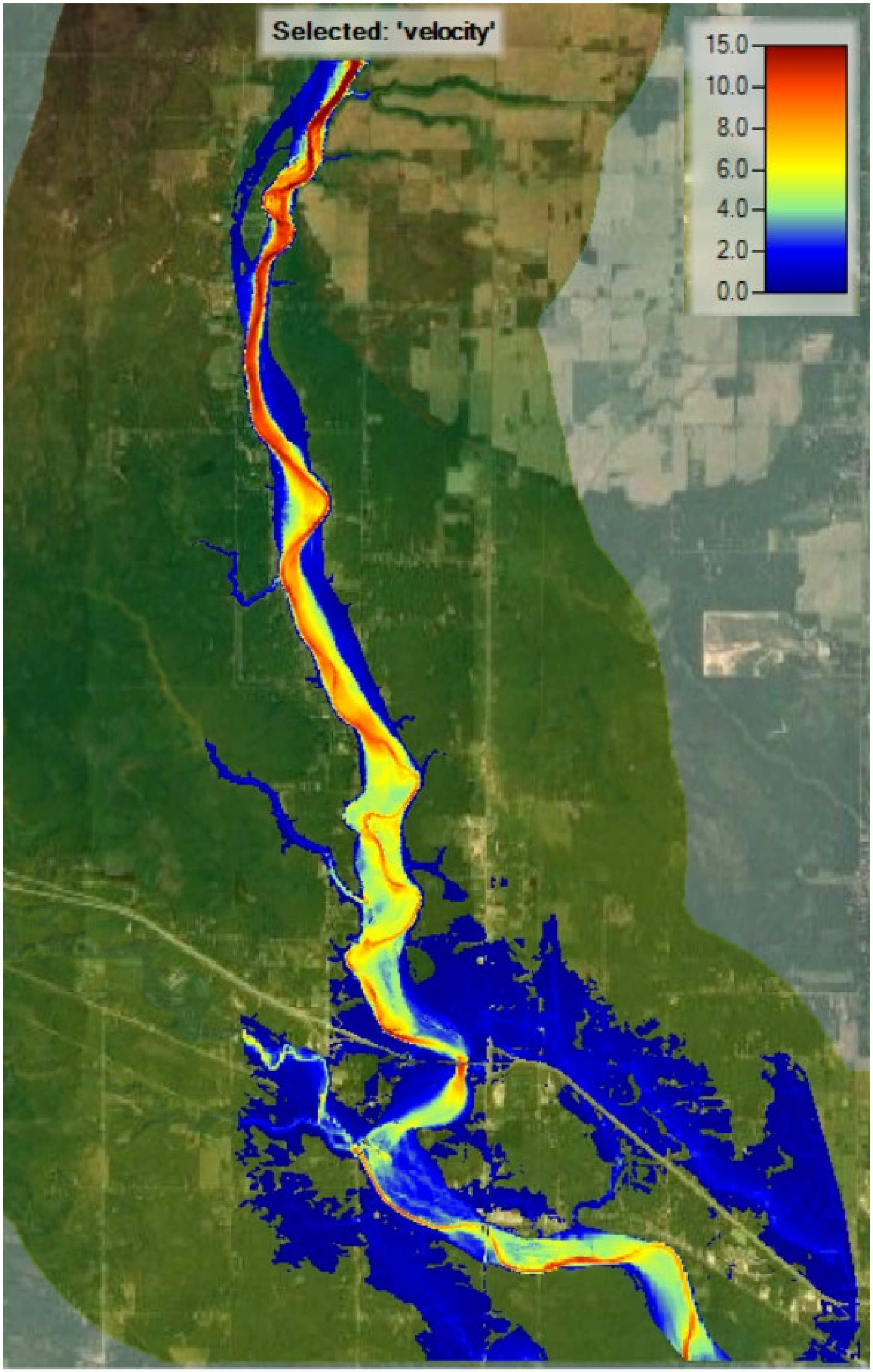
Peak Velocity – Dam Removed Conditions – Half PMF



Peak Water Surface Elevation – Dam Removed Conditions – PMF



Peak Velocity – Dam Removed Conditions – PMF



Appendix G

Inundation Mapping and Flood Profiles

Appendix G.1 – Secord Dam

Appendix G.2 – Smallwood Dam

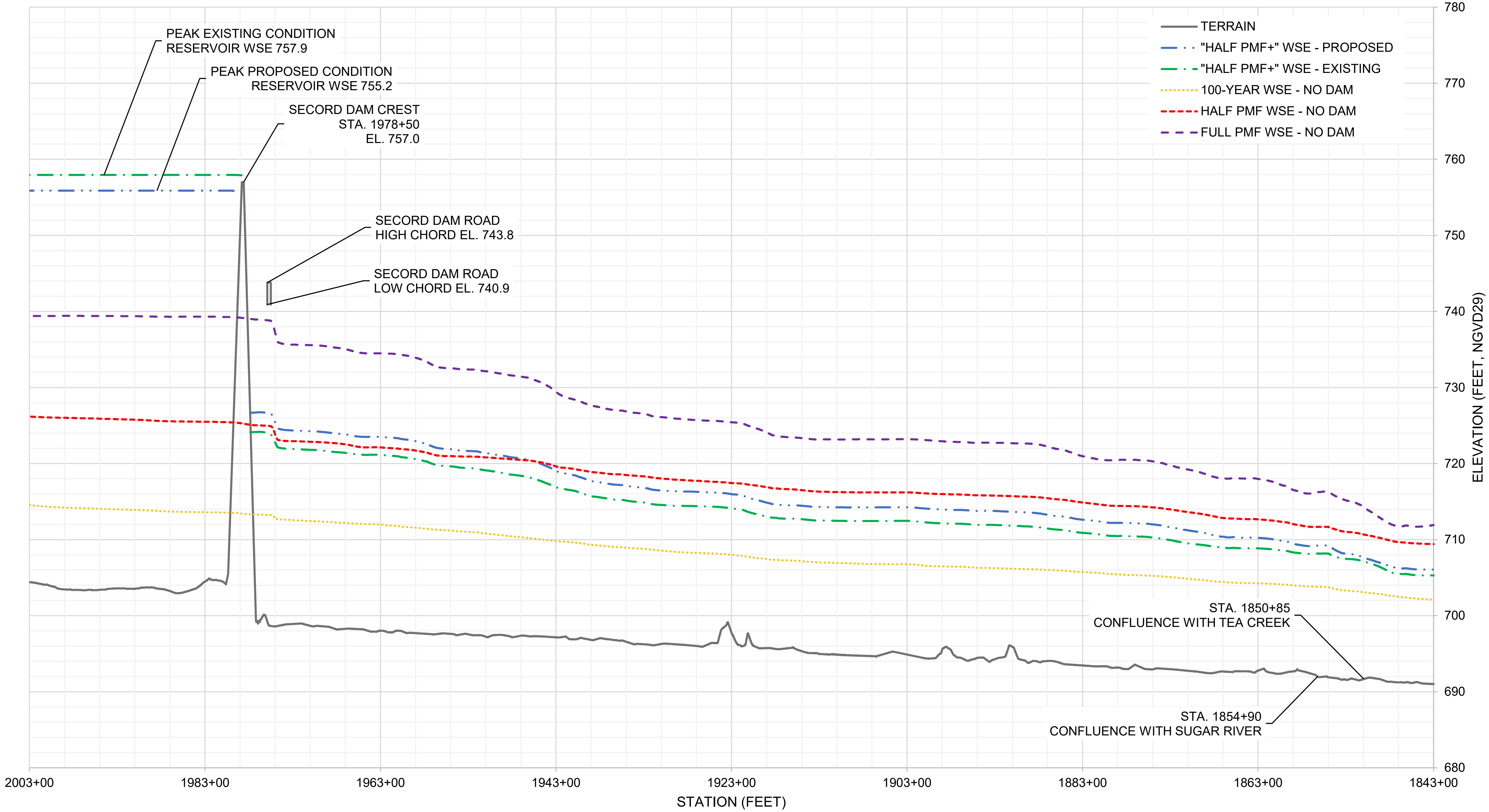
Appendix G.3 – Edenville Dam

Appendix G.4 – Sanford Dam

Appendix G

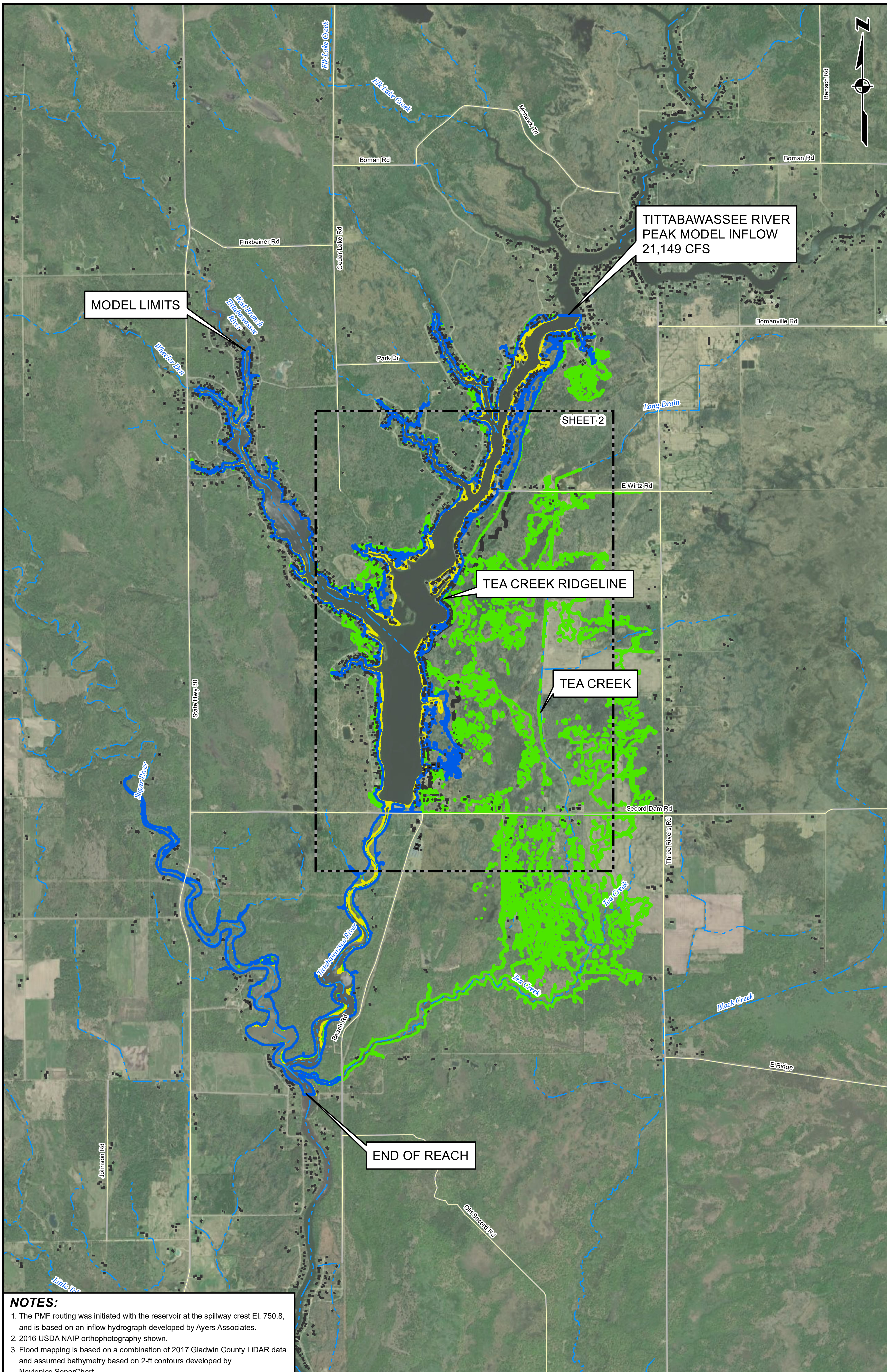
Inundation Mapping and Flood Profiles

Appendix G.1 – Secord Dam



Flood Study of the Tittabassee River from Secord to Sanford Dam	GEI Consultants	SECORD DAM FLOODING PROFILES	
Four Lakes Task Force Gladwin and Midland County, Michigan	Project 2002879	March 2021	Appendix G

https://geiconsultant-my.sharepoint.com/personal/njorgensen_geiconsultants_com/Documents/Documents/00 - Work at Home/FLTF/Results/[Secord Profile.xlsx]Appendix G



NOTES:

1. The PMF routing was initiated with the reservoir at the spillway crest El. 750.8, and is based on an inflow hydrograph developed by Ayers Associates.
2. 2016 USDA NAIP orthophotography shown.
3. Flood mapping is based on a combination of 2017 Gladwin County LiDAR data and assumed bathymetry based on 2-ft contours developed by Navionics SonarChart.

0 1,500 3,000 6,000

Scale, Feet

- Half PMF+ Proposed Floodplain
- Half PMF+ Existing Floodplain
- FEMA 100-Year Floodplain
- Sheet Index
- Structures
- Main_Roads

GEI Consultants

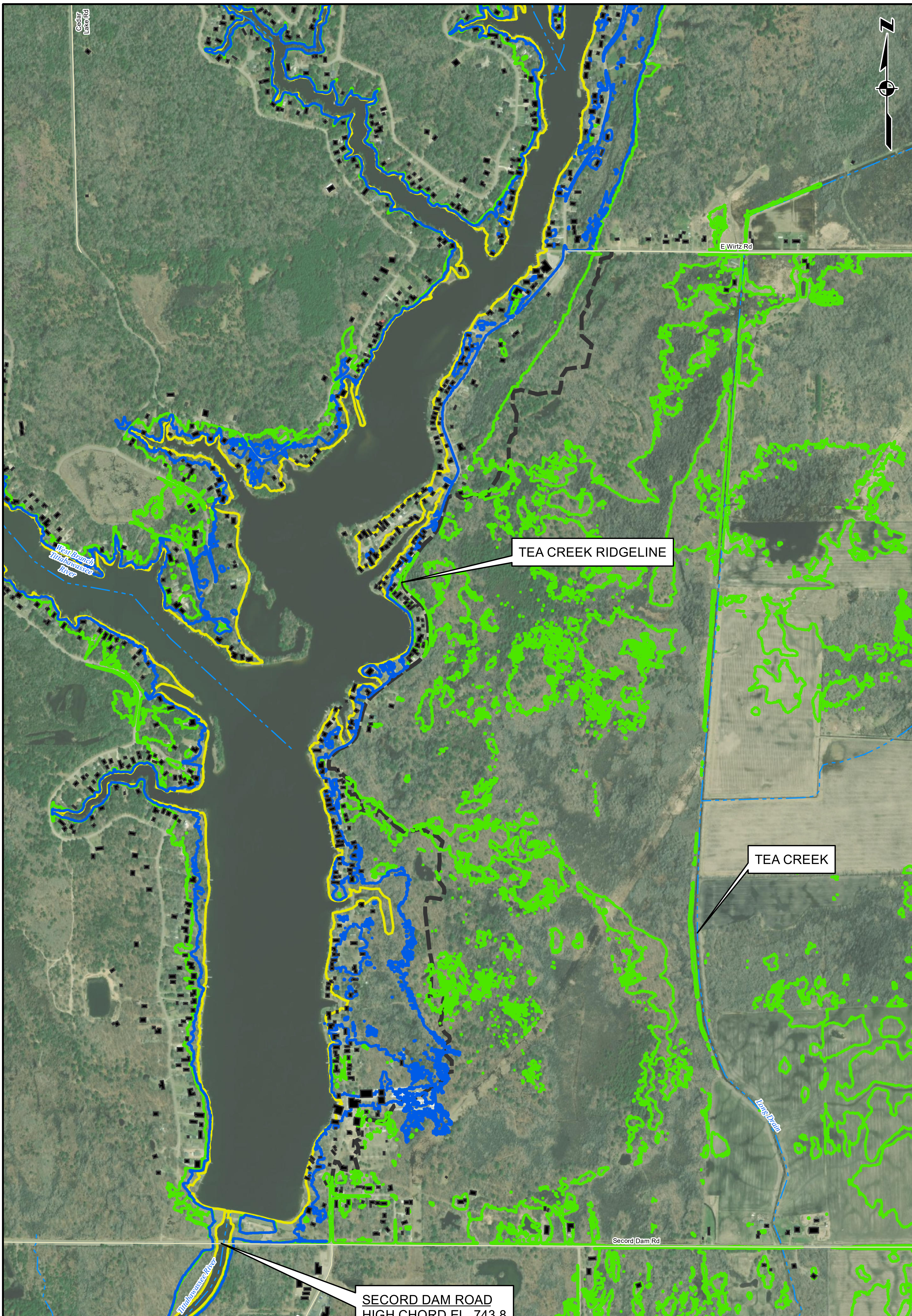
Project 2002879

Flood Study of the Tittabawassee River from Secord to Sanford Dam
Four Lakes Task Force
Gladwin and Midland County, Michigan

SECORD DAM HYPOTHETICAL "HALF PMF+" INUNDATION MAPS (SHEET 1 OF 2)

March 2021

Appendix G



NOTES:

1. The PMF routing was initiated with the reservoir at the spillway crest El. 750.8, and is based on an inflow hydrograph developed by Ayers Associates.
2. 2016 USDA NAIP orthophotography shown.
3. Flood mapping is based on a combination of 2017 Gladwin County LiDAR data and assumed bathymetry based on 2-ft contours developed by Navionics SonarChart.

GEI Consultants

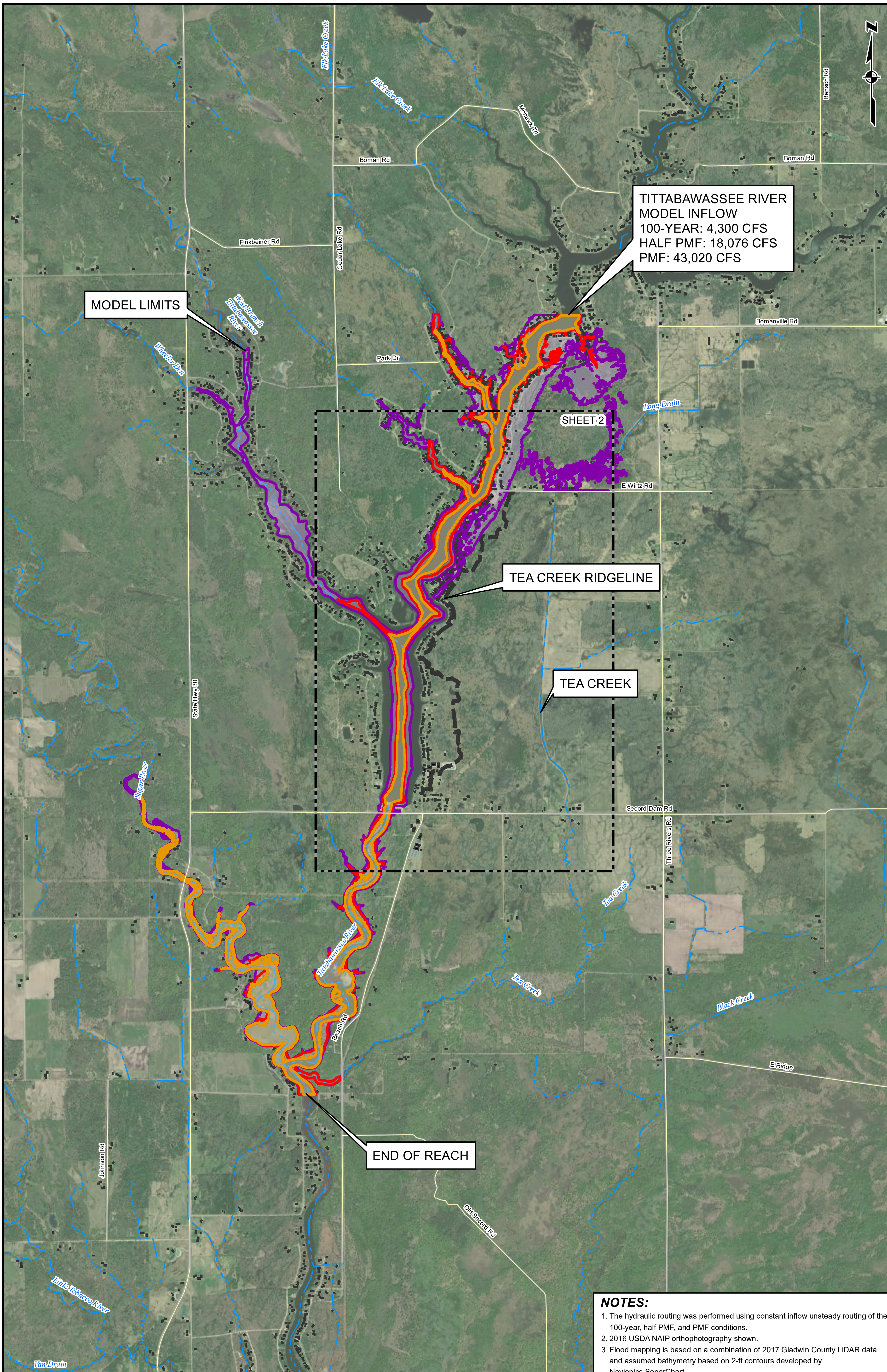
Project 2002879

Flood Study of the Tittabawassee River from Secord to Sanford Dam
Four Lakes Task Force
Gladwin and Midland County, Michigan

SECORD DAM HYPOTHETICAL "HALF PMF+" INUNDATION MAPS (SHEET 2 OF 2)

March 2021

Appendix G



NOTES:

1. The hydraulic routing was performed using constant inflow unsteady routing of the 100-year, half PMF, and PMF conditions.
2. 2016 USDA NAIP orthophotography shown.
3. Flood mapping is based on a combination of 2017 Gladwin County LiDAR data and assumed bathymetry based on 2-ft contours developed by Navionics SonarChart.

0 1,500 3,000 6,000

Scale, Feet

- Full PMF Floodplain
- Half PMF Floodplain
- FEMA 100-Year Floodplain
- Sheet Index
- Structures
- Roads

GEI Consultants

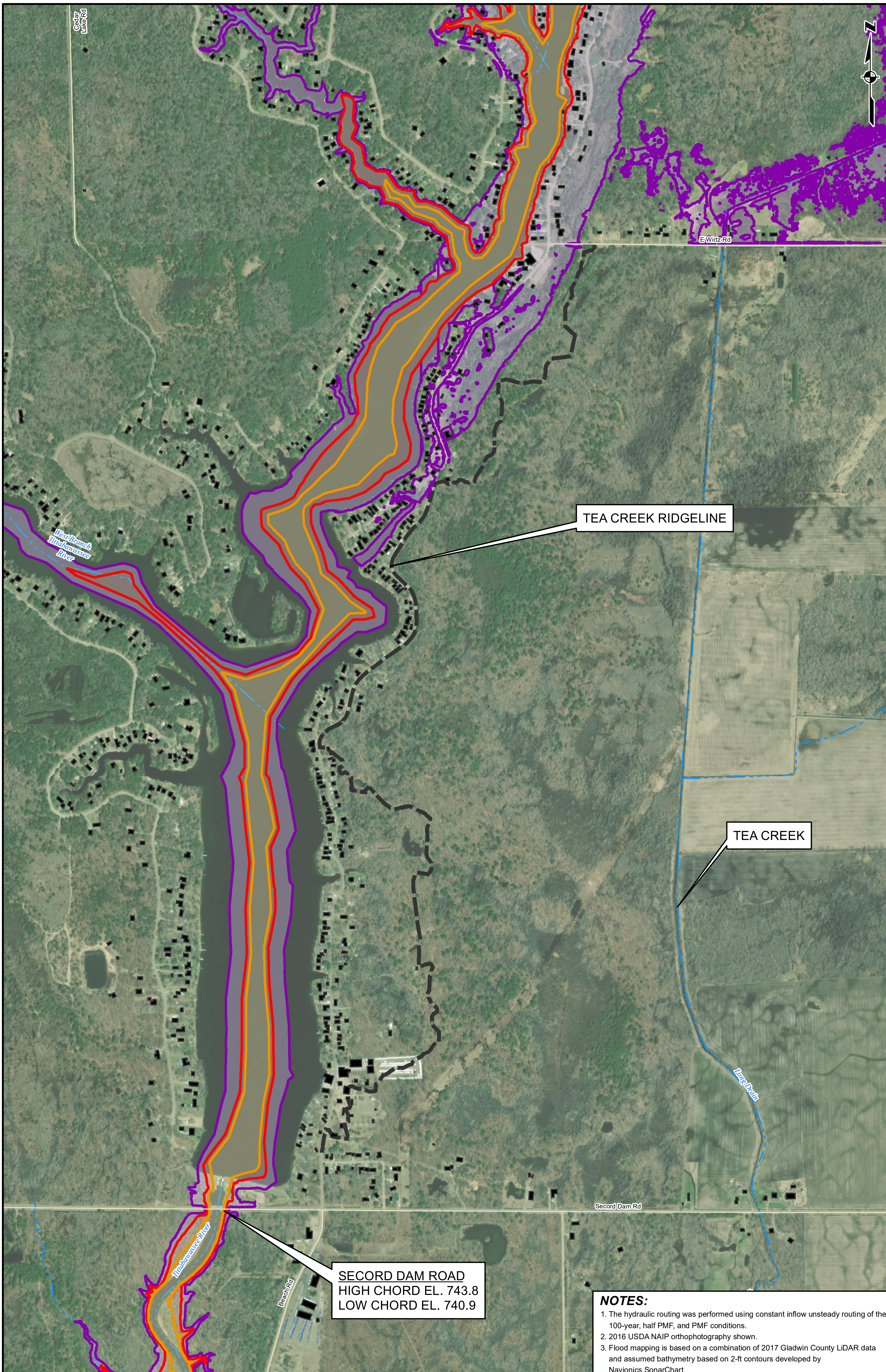
Project 2002879

Flood Study of the Tittabawassee River from Secord to Sanford Dam
Four Lakes Task Force
Gladwin and Midland County, Michigan

SECORD DAM HYPOTHETICAL DAM REMOVED CONDITIONS (SHEET 1 OF 2)

March 2021

Appendix G



NOTES:

1. The hydraulic routing was performed using constant inflow unsteady routing of the 100-year, half PMF, and PMF conditions.
2. 2016 USDA NAIP orthophotography shown.
3. Flood mapping is based on a combination of 2017 Gladwin County LiDAR data and assumed bathymetry based on 2-ft contours developed by Navionics SonarChart.

0 500 1,000 2,000

Scale, Feet

- Full PMF Floodplain
- Half PMF Floodplain
- FEMA 100-Year Floodplain
- Sheet Index
- Structures
- Roads

GEI Consultants

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Flood Study of the Tittabawassee River from Secord to Sanford Dam
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SECORD DAM HYPOTHETICAL DAM REMOVED CONDITIONS (SHEET 2 OF 2)

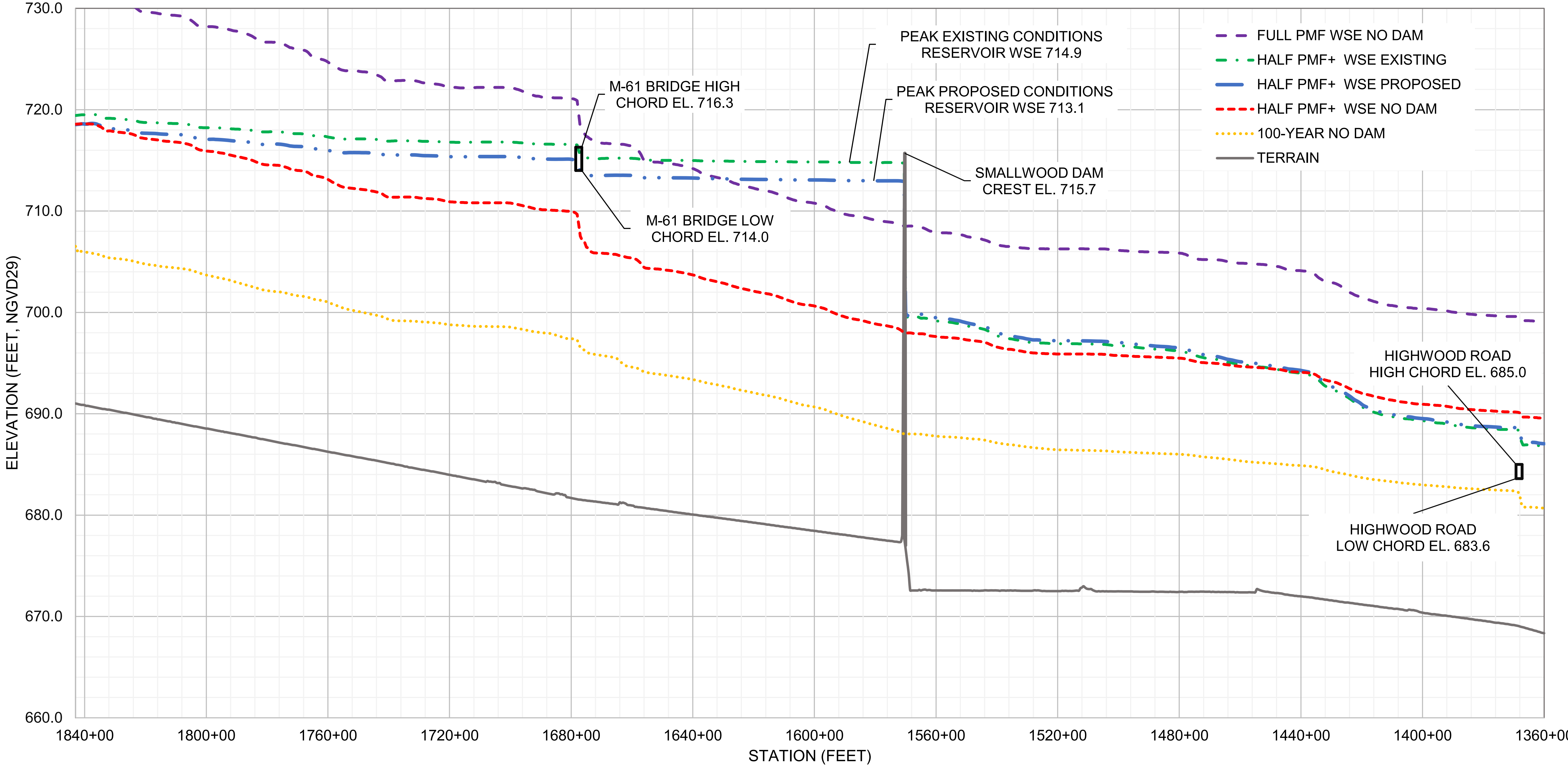
March 2021

Appendix G

Appendix G

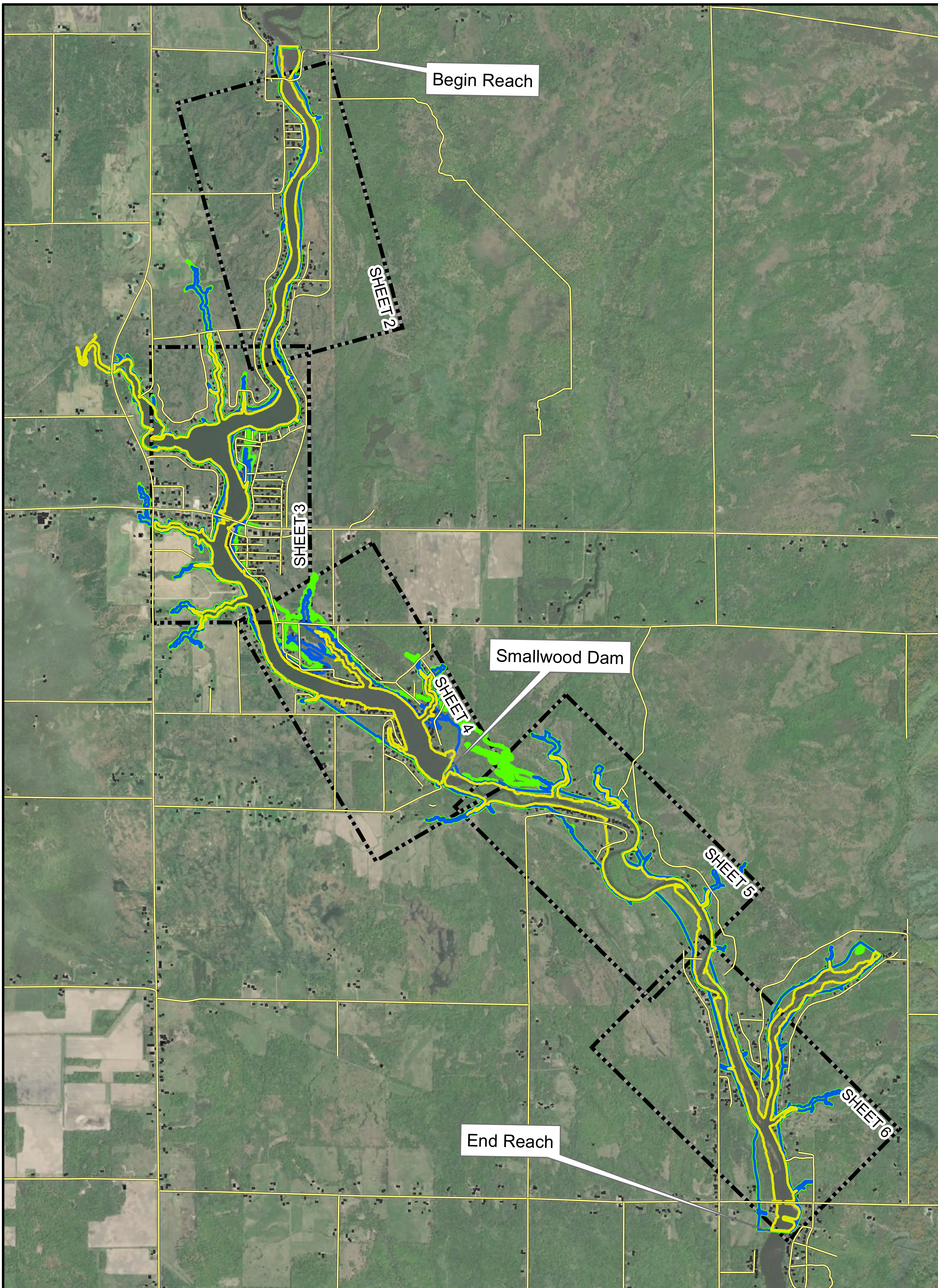
Inundation Mapping and Flood Profiles

Appendix G.2 – Smallwood Dam



https://geiconsultant-my.sharepoint.com/personal/eholmstead_geiconsultants_com/Documents/Documents/Temp/Four Lakes Task Force/[Smallwood FLood Profile.xlsx]Figure 1

Flood Study of the Tittabassee River Smallwood Dam Gladwin County, Michigan	GEI Consultants	SMALLWOOD DAM FLOODING PROFILES
Four Lakes Task Force Midland, Michigan	Project 2002879	March 2021 Appendix G



NOTES AND LEGEND:

1. Inundation limits are based on flows provided by Ayers Associates,
2. 2016 USDA NAIP orthophotography shown.
3. Flood mapping is based on LiDAR collected in August 2020 and assumed bathymetry.

Sheet Index
Roads
Structures
FEMA 100-Year Floodplain
Half PMP+ - Proposed
Half PMF+ - Existing

N W E S

0 1,250 2,500 5,000
Scale, Feet

GEI Consultants

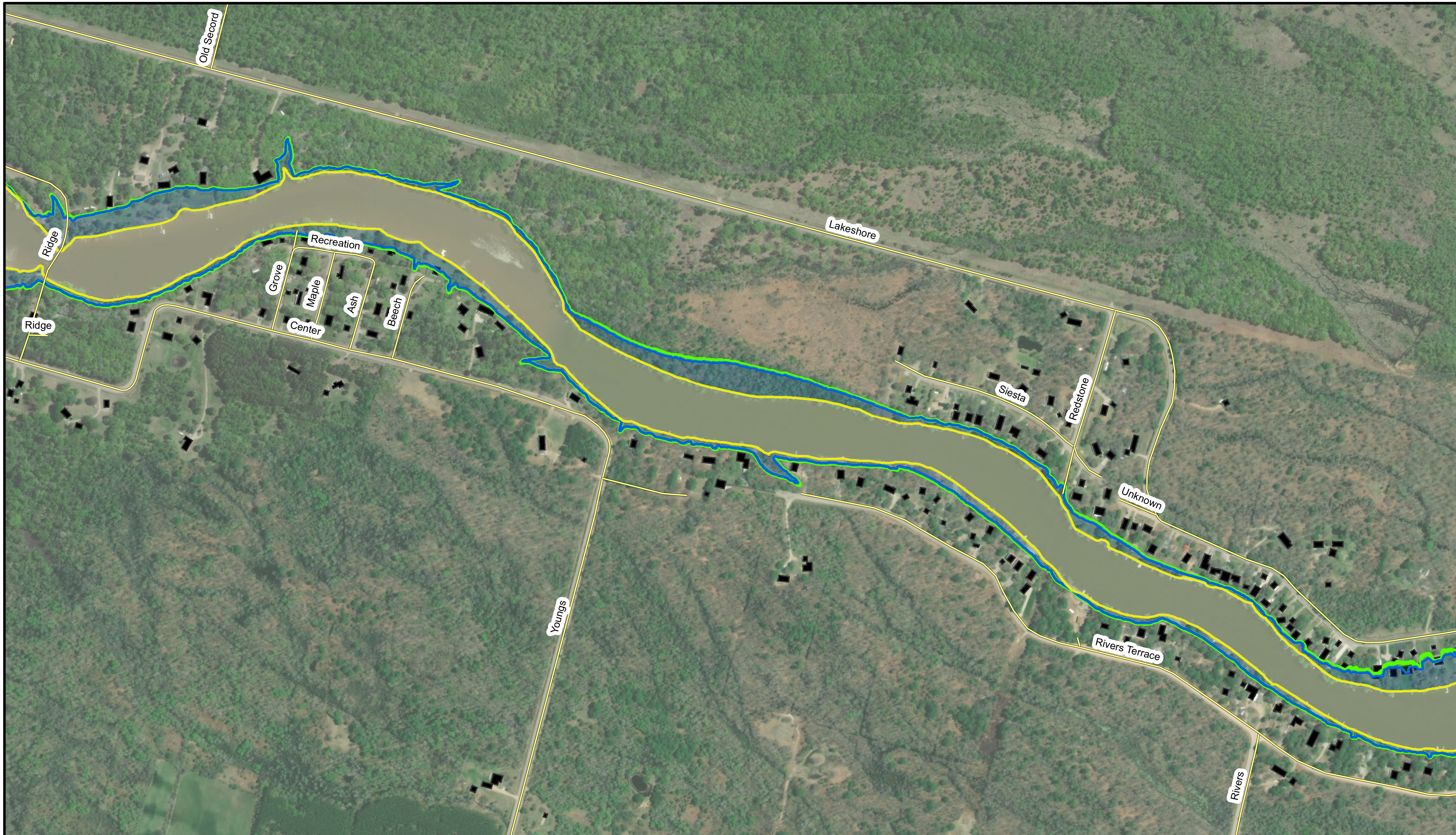
Four Lakes Task Force
Smallwood Dam
Inundation Mapping

Project 2002879

SMALLWOOD DAM
INUNDATION MAPS
(SHEET 1 OF 6)

March 2021

Figure D-1



NOTES AND LEGEND:

1. Inundation limits are based on flows provided by Ayers Associates,
2. 2016 USDA NAIP orthophotography shown.
3. Flood mapping is based on LiDAR collected in August 2020 and assumed bathymetry.

- Sheet Index
- Roads
- Structures
- FEMA 100-year Floodplain
- Half PMF+ - Proposed
- Half PMF+ - Existing

0 250 500 1,000

Scale, Feet

GEI Consultants

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Smallwood Dam
Inundation Mapping

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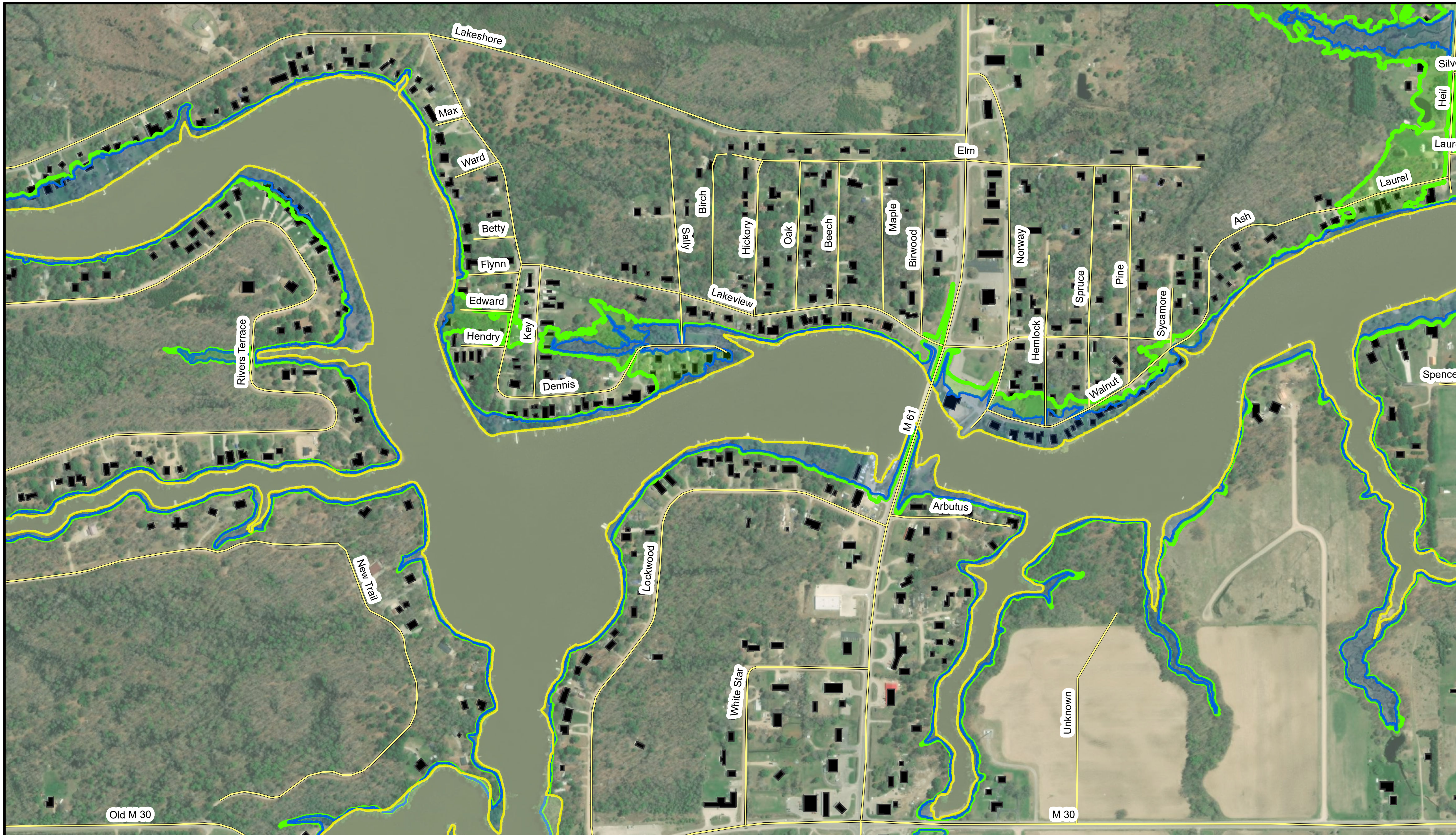
SMALLWOOD DAM
INUNDATION MAPS
(SHEET 2 OF 6)

March 2021

Figure D-2



NOTES AND LEGEND:

1. Inundation limits are based on flows provided by Ayers Associates,
2. 2016 USDA NAIP orthophotography shown.
3. Flood mapping is based on LiDAR collected in August 2020 and assumed bathymetry.

Sheet Index
Roads
Structures
FEMA 100-year Floodplain
Half PMF+ - Proposed
Half PMF+ - Existing

N E S W

0 250 500 1,000
Scale, Feet

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Smallwood Dam
Inundation Mapping

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SMALLWOOD DAM
INUNDATION MAPS
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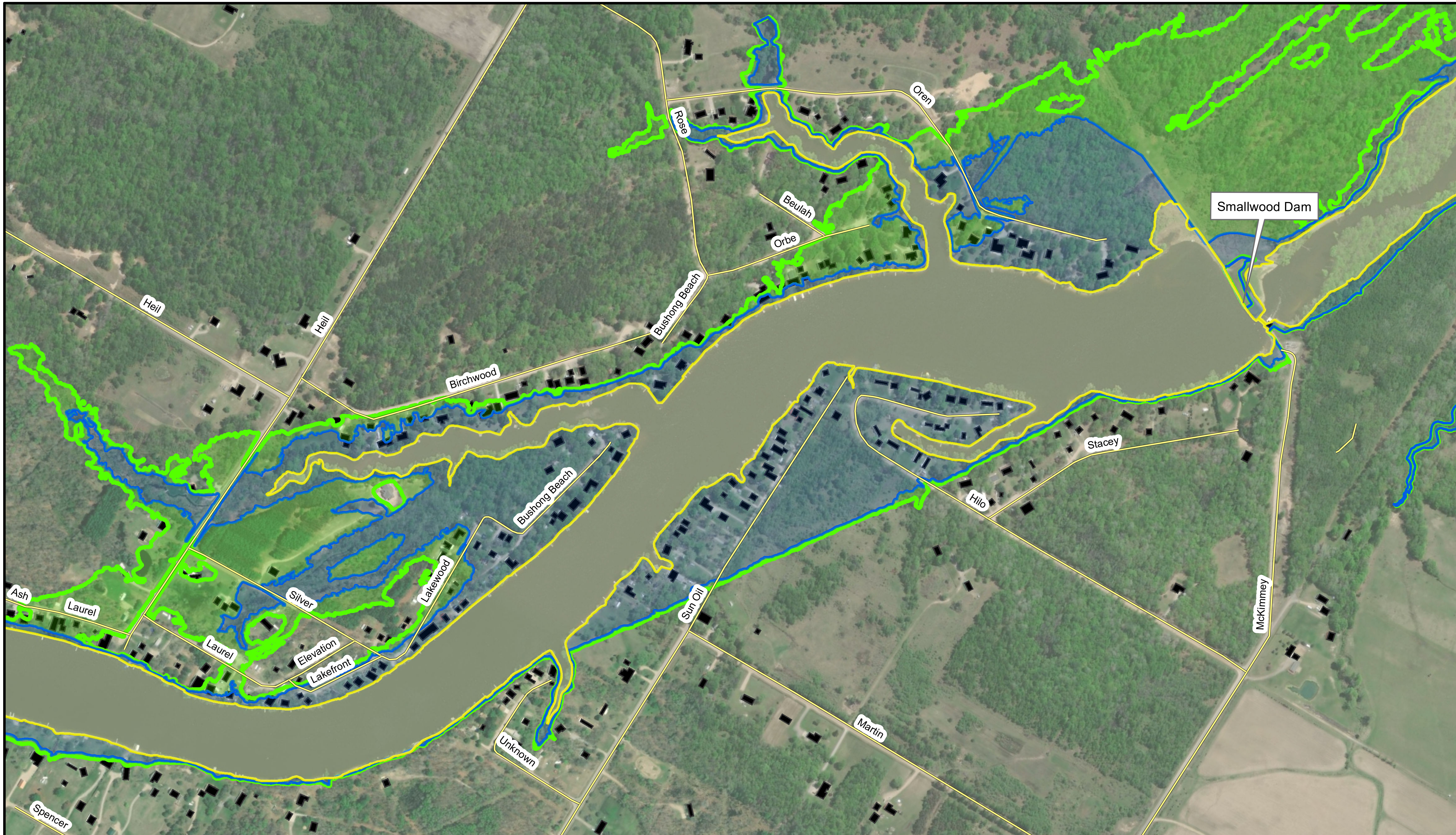
Figure D-3



NOTES AND LEGEND:

1. Inundation limits are based on flows provided by Ayers Associates,
2. 2016 USDA NAIP orthophotography shown.
3. Flood mapping is based on LiDAR collected in August 2020 and assumed bathymetry.

Sheet Index
Roads
Structures
FEMA 100-year Floodplain
Half PMF+ - Proposed
Half PMF+ - Existing

0 250 500 1,000
Scale, Feet

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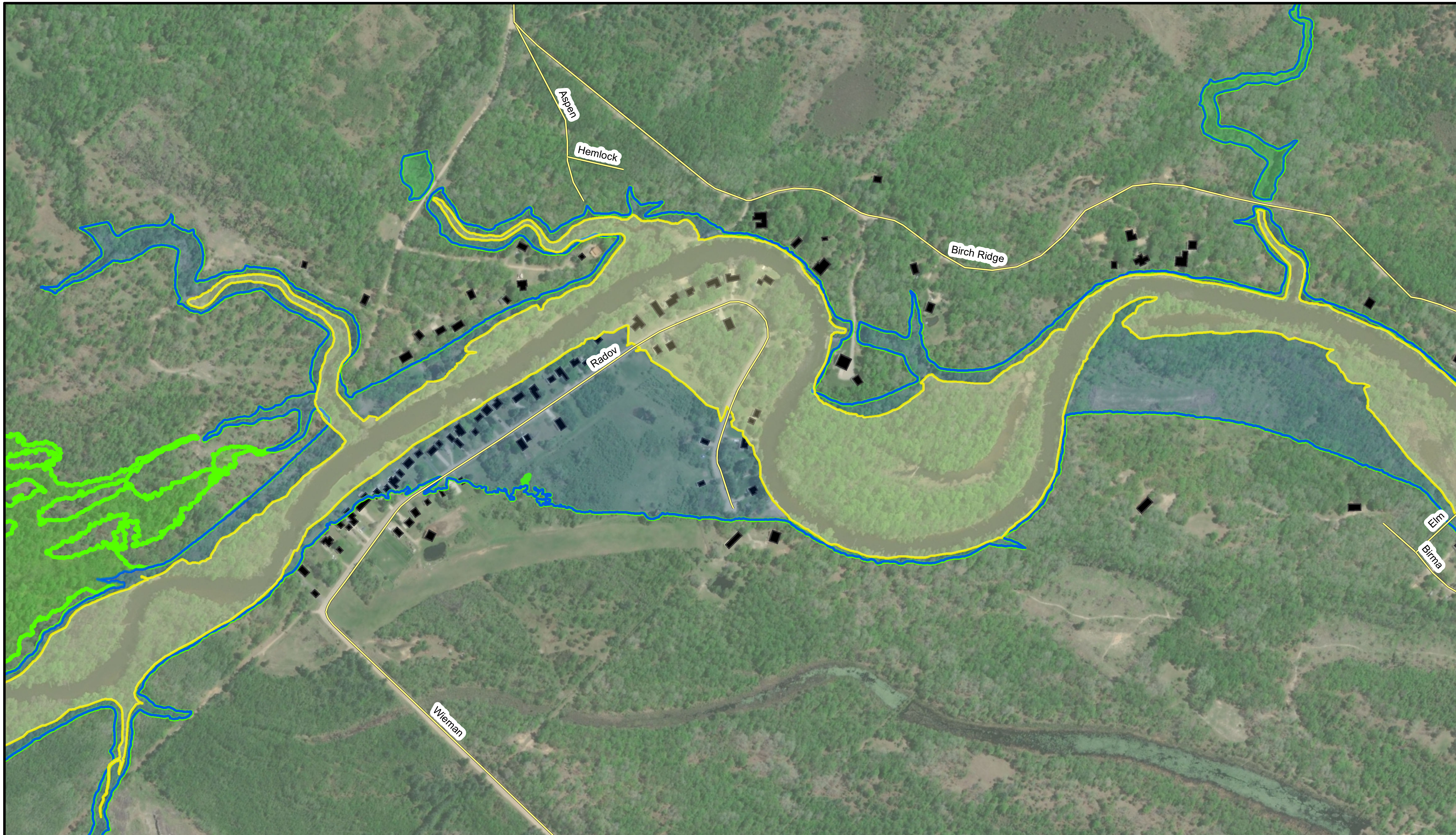
SMALLWOOD DAM
INUNDATION MAPS
(SHEET 4 OF 6)

March 2021 Figure D-4



NOTES AND LEGEND:

1. Inundation limits are based on flows provided by Ayers Associates,
2. 2016 USDA NAIP orthophotography shown.
3. Flood mapping is based on LiDAR collected in August 2020 and assumed bathymetry.

Sheet Index
Roads
Structures
FEMA 100-year Floodplain
Half PMF+ - Proposed
Half PMF+ - Existing

0 250 500 1,000
Scale, Feet

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SMALLWOOD DAM
INUNDATION MAPS
(SHEET 5 OF 6)

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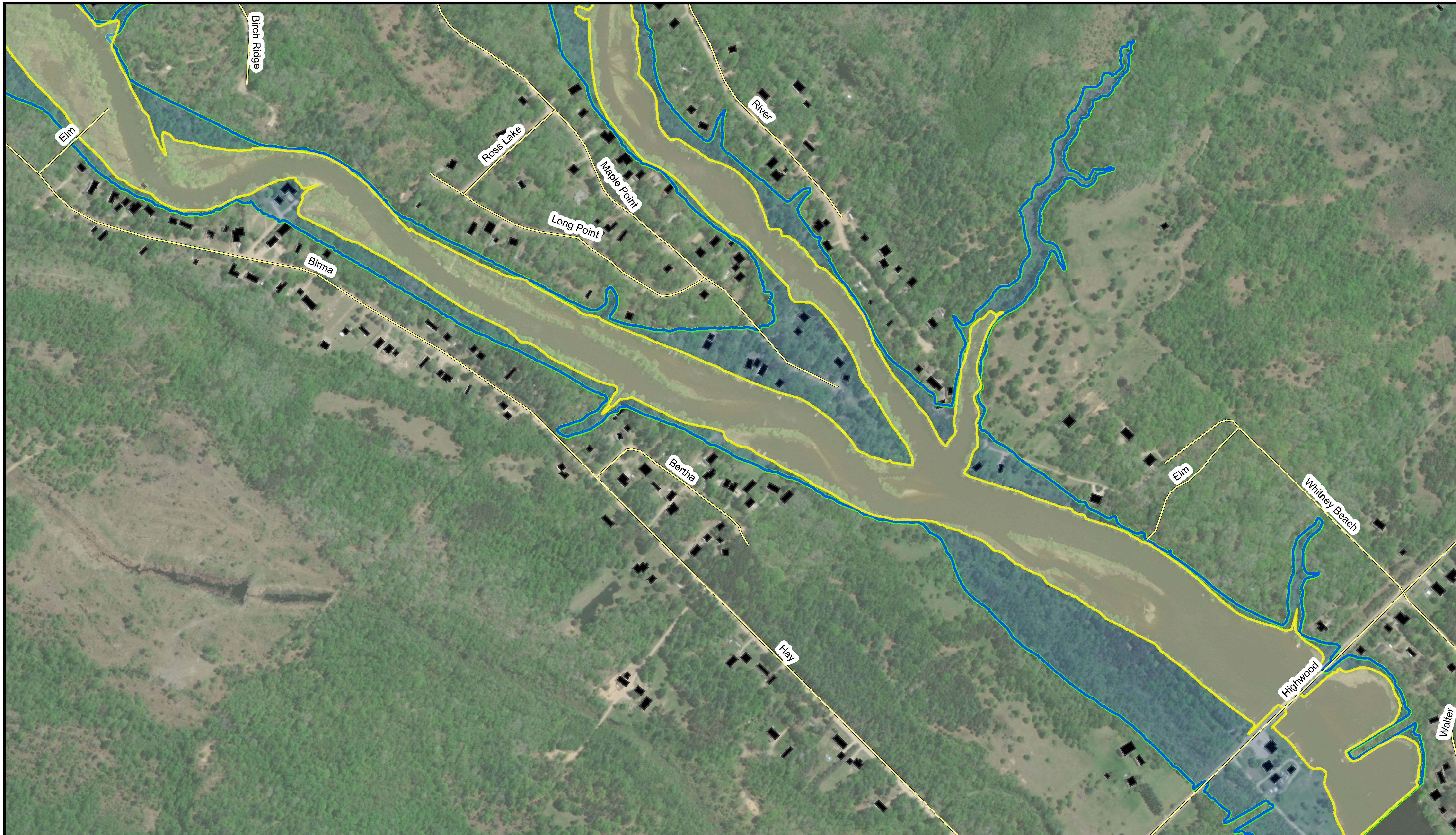
Figure D-5



NOTES AND LEGEND:

1. Inundation limits are based on flows provided by Ayers Associates,
2. 2016 USDA NAIP orthophotography shown.
3. Flood mapping is based on LiDAR collected in August 2020 and assumed bathymetry.

- Sheet Index
- Roads
- Structures
- FEMA 100-year Floodplain
- Half PMF+ - Proposed
- Half PMF+ - Existing

N E S W

0 250 500 1,000

Scale, Feet

GEI Consultants

Four Lakes Task Force
Smallwood Dam
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SMALLWOOD DAM
INUNDATION MAPS
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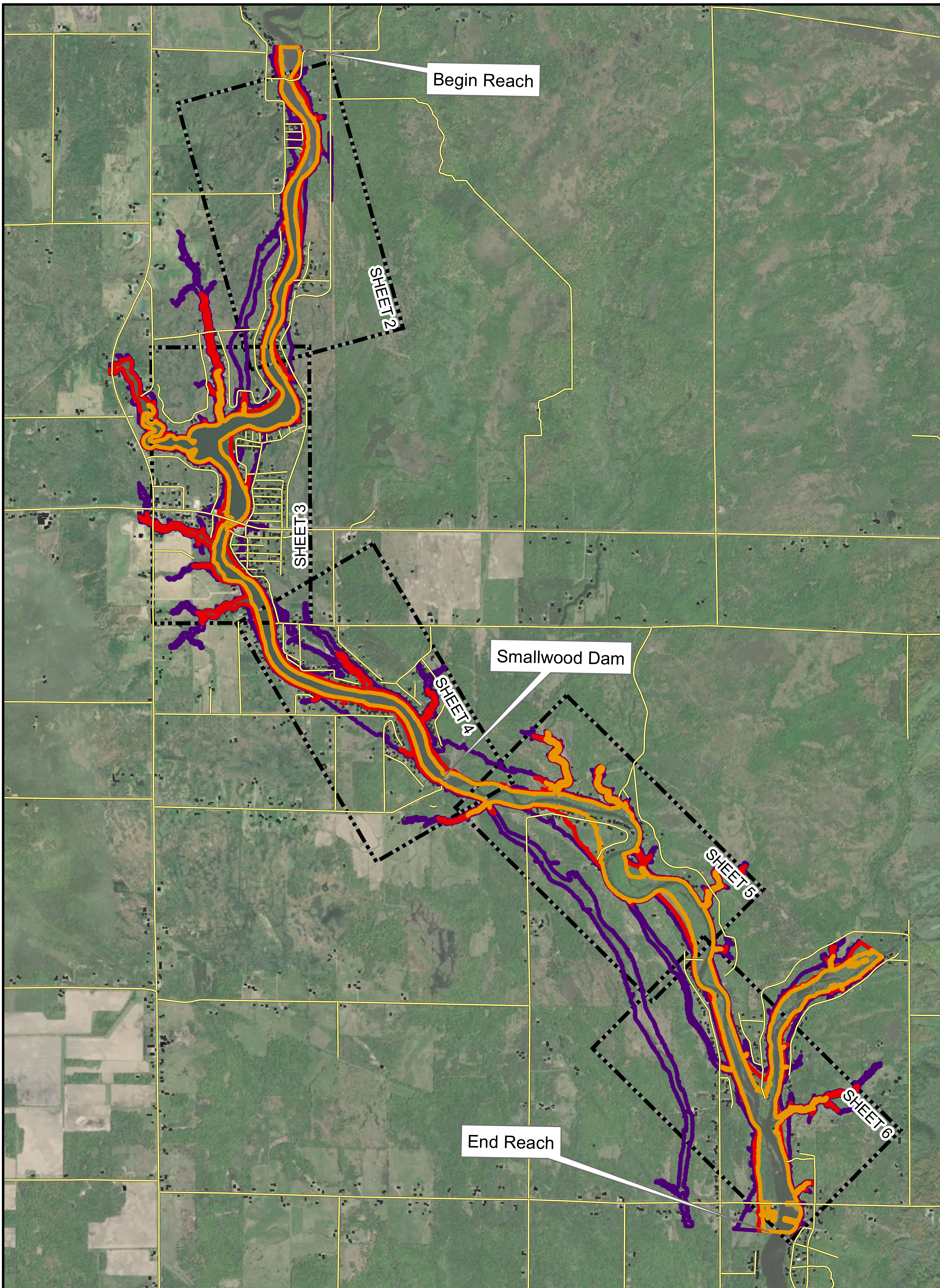
Figure D-6



NOTES AND LEGEND:

1. Inundation limits are based on flows provided by Ayers Associates,
2. 2016 USDA NAIP orthophotography shown.
3. Flood mapping is based on LiDAR collected in August 2020 and assumed bathymetry.

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Roads

Structures

Full PMF - No Dam

Half PMF - No Dam

100-Year - No Dam

N W E S

0 1,250 2,500 5,000

Scale, Feet

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SMALLWOOD DAM
INUNDATION MAPS
(SHEET 1 OF 6)

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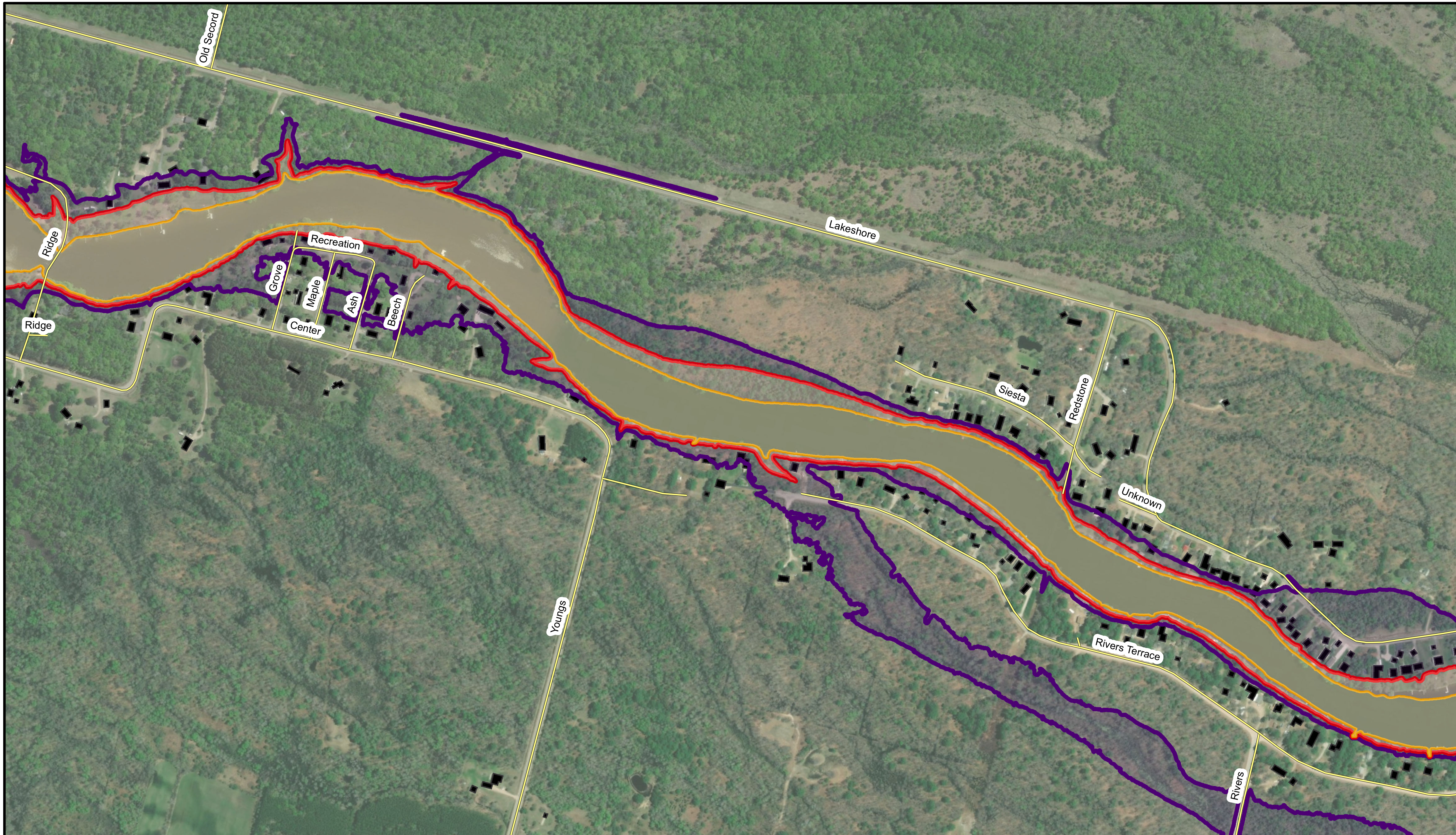
Figure D-1



NOTES AND LEGEND:

1. Inundation limits are based on flows provided by Ayers Associates,
2. 2016 USDA NAIP orthophotography shown.
3. Flood mapping is based on LiDAR collected in August 2020 and assumed bathymetry.

Sheet Index
Roads
Structures
100-Year - No Dam
Half PMF - No Dam
Full PMF - No Dam

0 250 500 1,000
Scale, Feet

GEI Consultants

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Inundation Mapping

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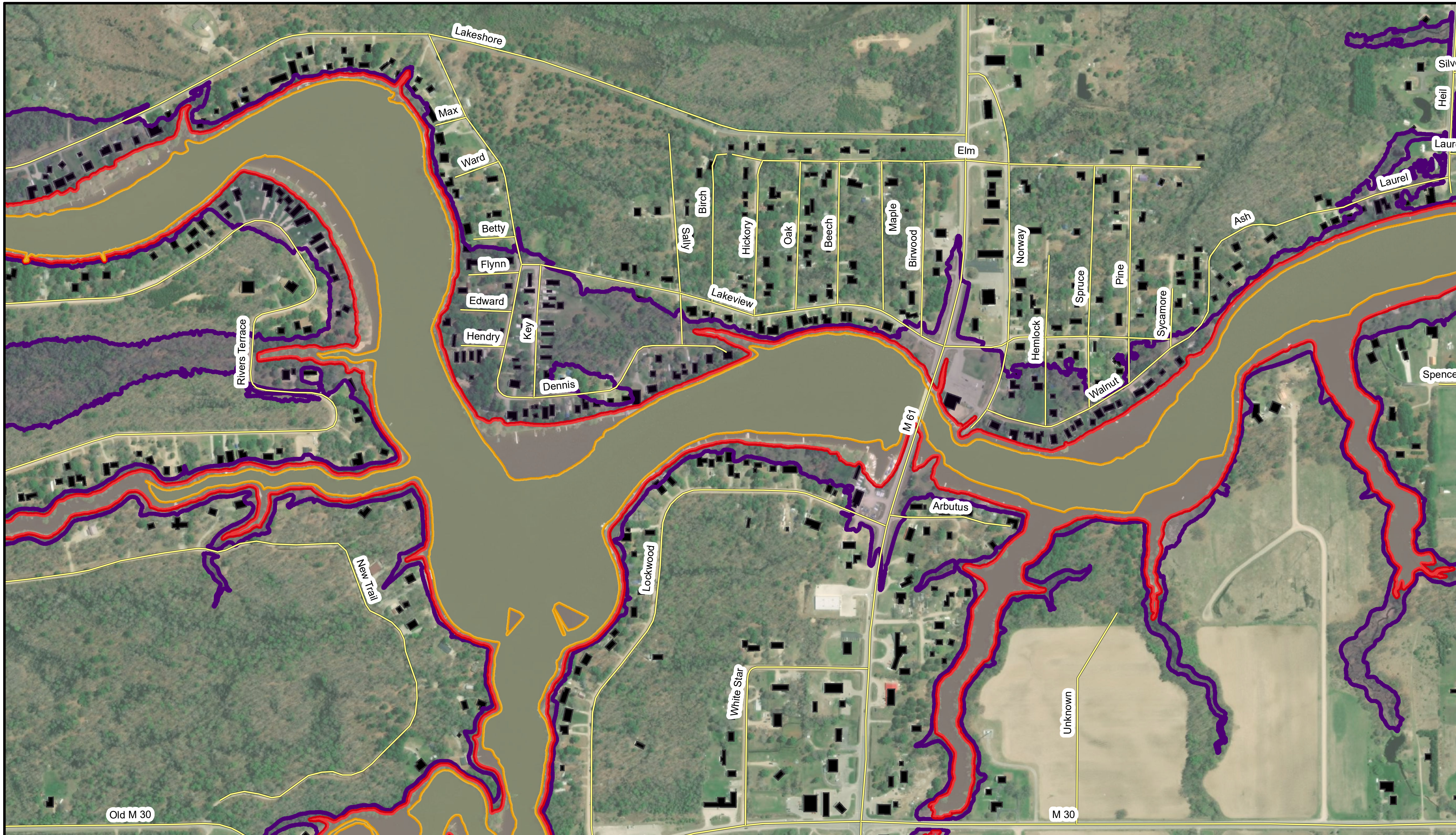
SMALLWOOD DAM
INUNDATION MAPS
DAM REMOVED
(SHEET 2 OF 6)

March 2021

Figure D-2



NOTES AND LEGEND:

1. Inundation limits are based on flows provided by Ayers Associates,
2. 2016 USDA NAIP orthophotography shown.
3. Flood mapping is based on LiDAR collected in August 2020 and assumed bathymetry.

Sheet Index
Roads
Structures
100-Year - No Dam
Half PMF - No Dam
Full PMF - No Dam

N E S W

0 250 500 1,000
Scale, Feet

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Smallwood Dam
Inundation Mapping

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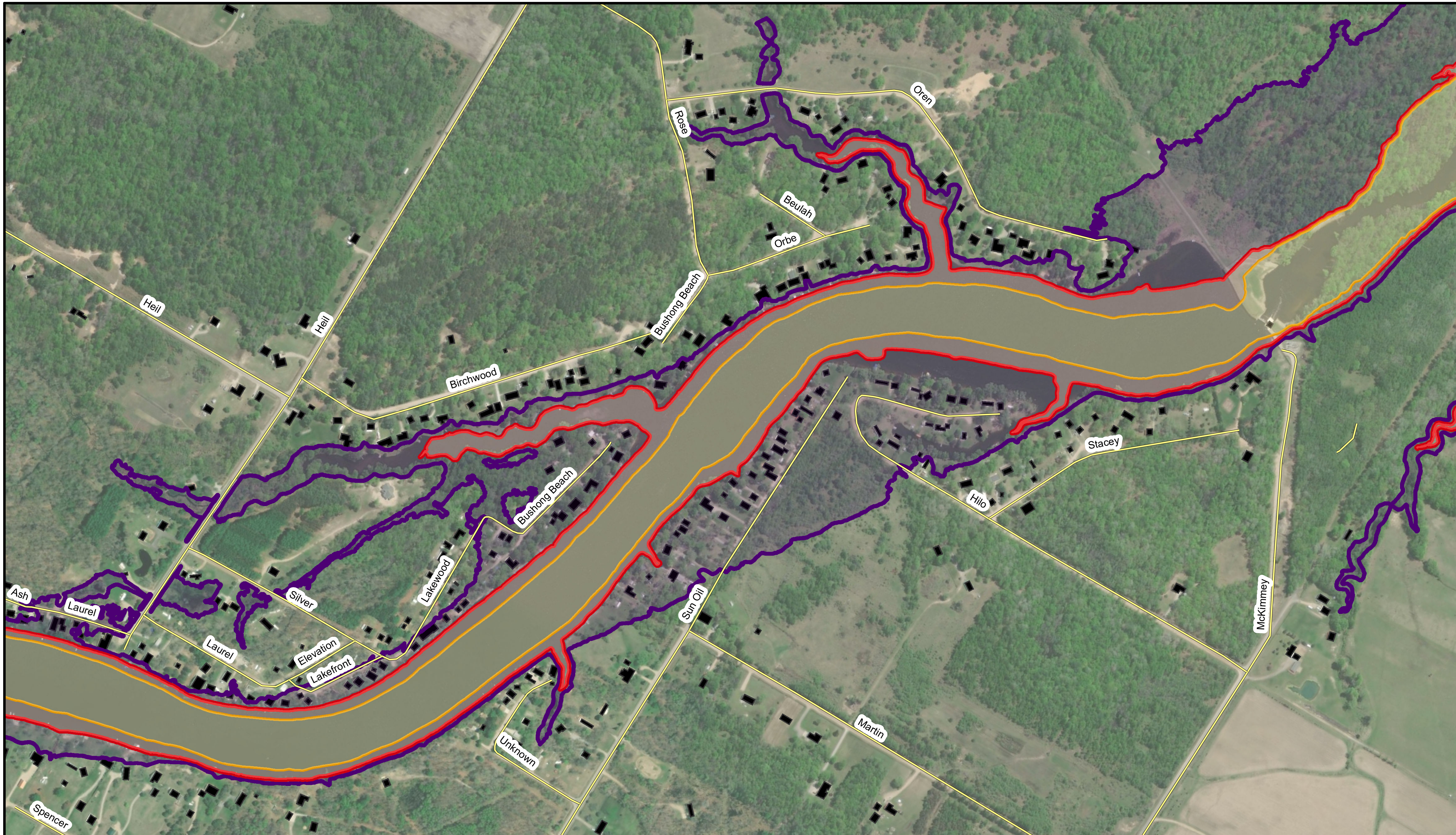
SMALLWOOD DAM
INUNDATION MAPS
DAM REMOVED
(SHEET 3 OF 6)

March 2021

Figure D-3



NOTES AND LEGEND:

1. Inundation limits are based on flows provided by Ayers Associates,
2. 2016 USDA NAIP orthophotography shown.
3. Flood mapping is based on LiDAR collected in August 2020 and assumed bathymetry.

Sheet Index
Roads
Structures
100-Year - No Dam
Half PMF - No Dam
Full PMF - No Dam

N E S W

0 250 500 1,000
Scale, Feet

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SMALLWOOD DAM
INUNDATION MAPS
DAM REMOVED
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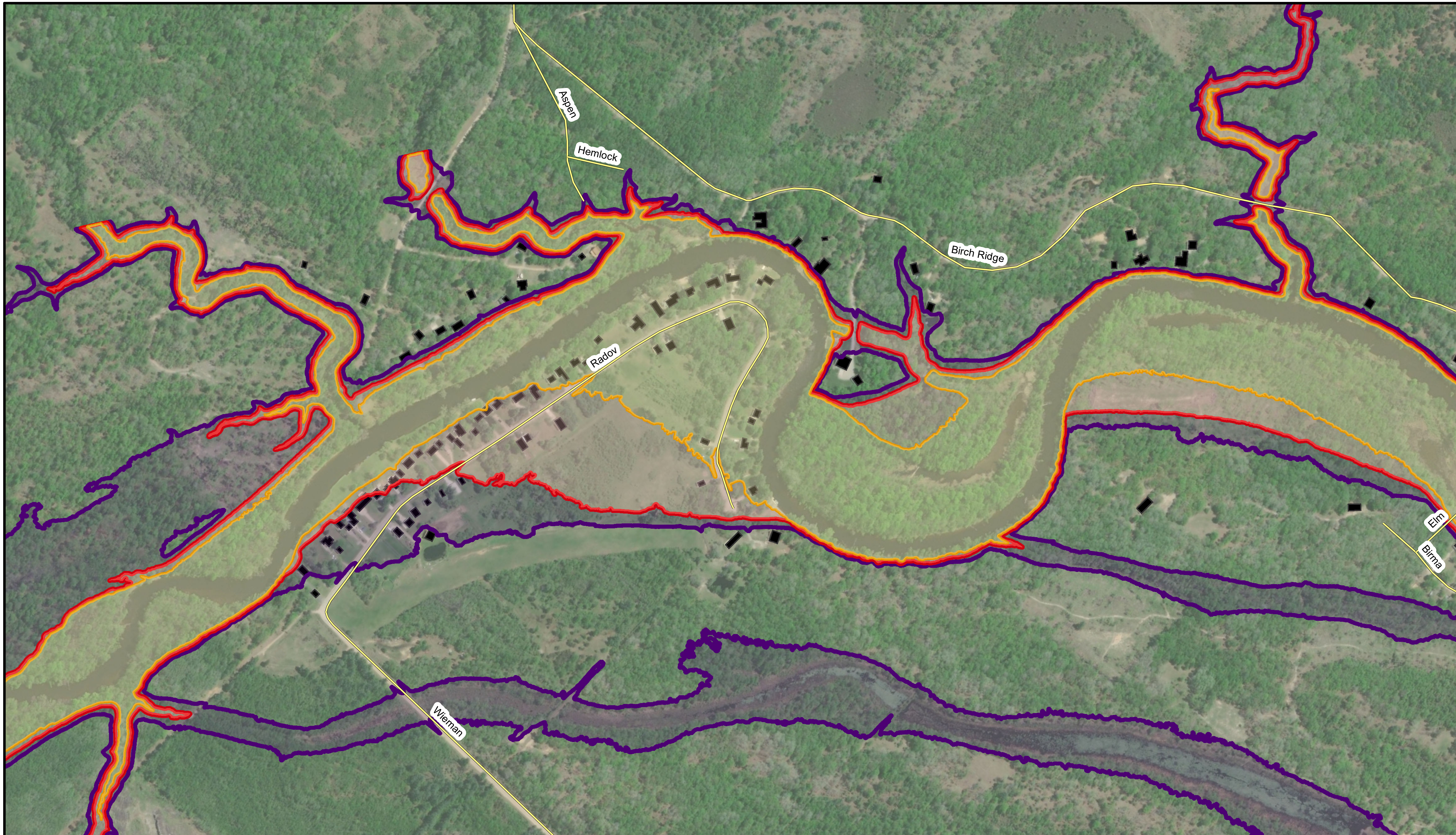

NOTES AND LEGEND:

1. Inundation limits are based on flows provided by Ayers Associates,
2. 2016 USDA NAIP orthophotography shown.
3. Flood mapping is based on LiDAR collected in August 2020 and assumed bathymetry.

Sheet Index
Roads
Structures
100-Year - No Dam
Half PMF - No Dam
Full PMF - No Dam

N E S W

0 250 500 1,000
Scale, Feet

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SMALLWOOD DAM
INUNDATION MAPS
DAM REMOVED
(SHEET 5 OF 6)

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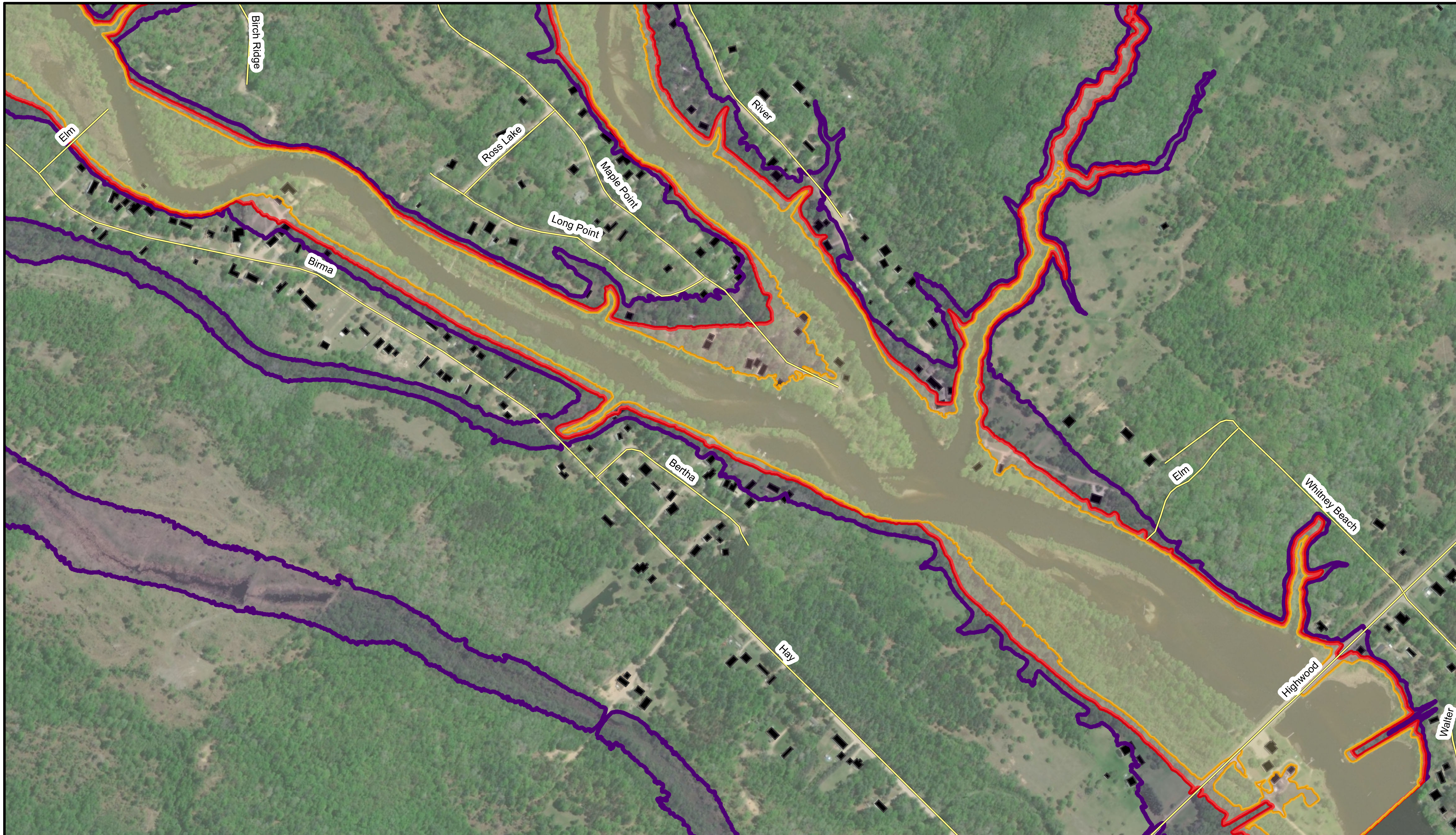

NOTES AND LEGEND:

1. Inundation limits are based on flows provided by Ayers Associates,
2. 2016 USDA NAIP orthophotography shown.
3. Flood mapping is based on LiDAR collected in August 2020 and assumed bathymetry.

Sheet Index
Roads
Structures

100-Year - No Dam
Half PMF - No Dam
Full PMF - No Dam

0 250 500 1,000
Scale, Feet

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SMALLWOOD DAM
INUNDATION MAPS
DAM REMOVED
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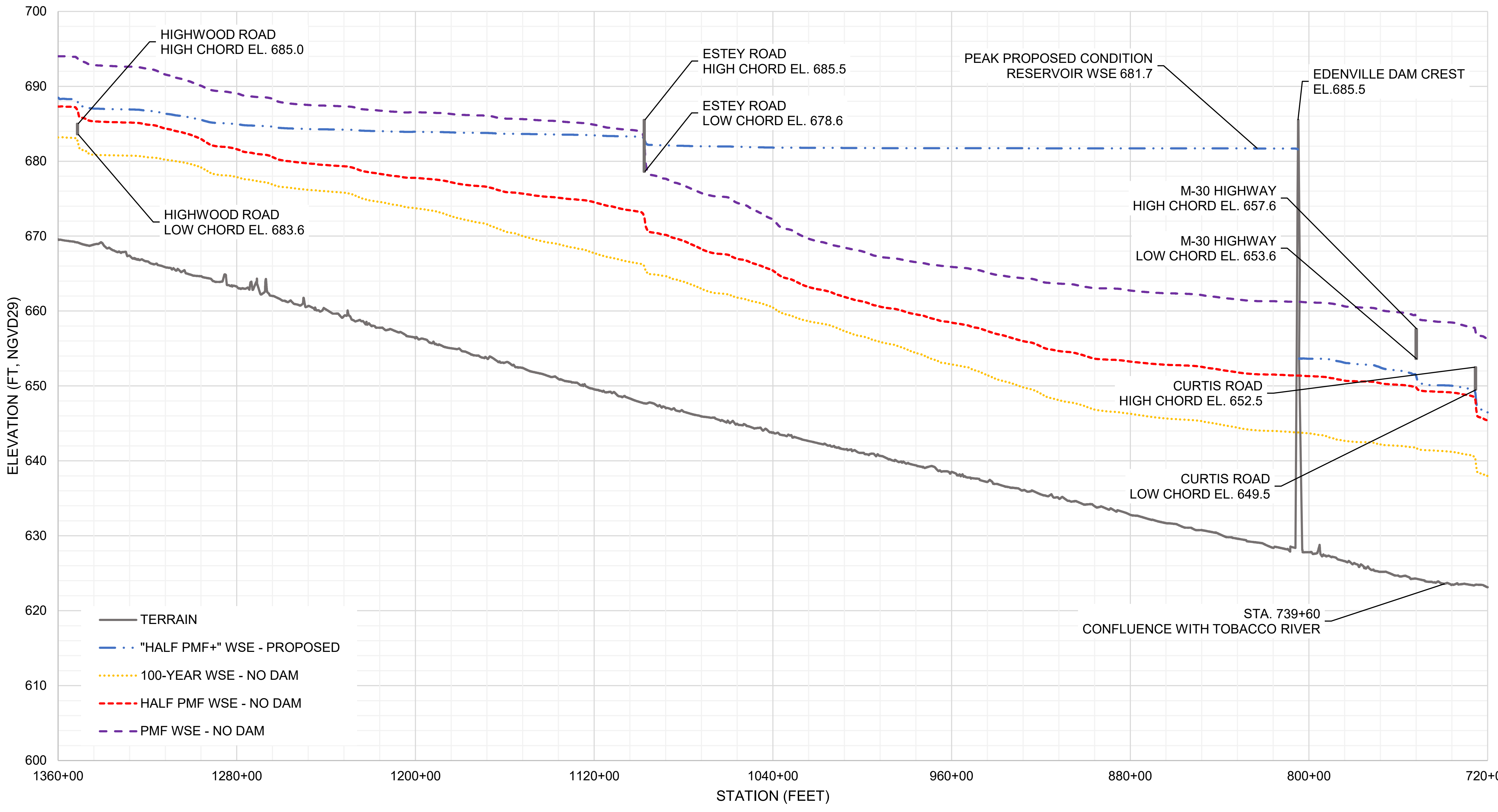
Appendix G

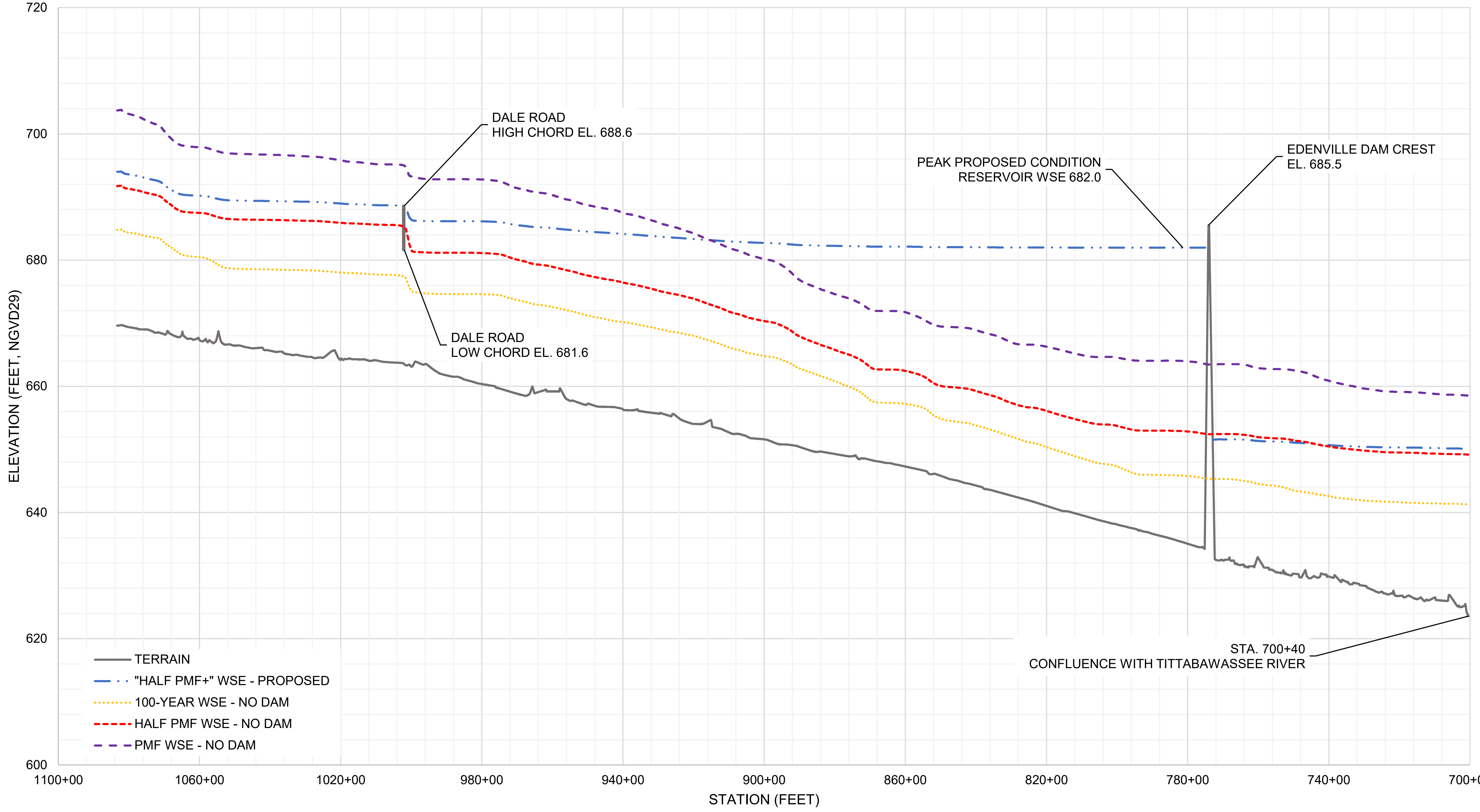
Inundation Mapping and Flood Profiles

Appendix G.3 – Edenville Dam



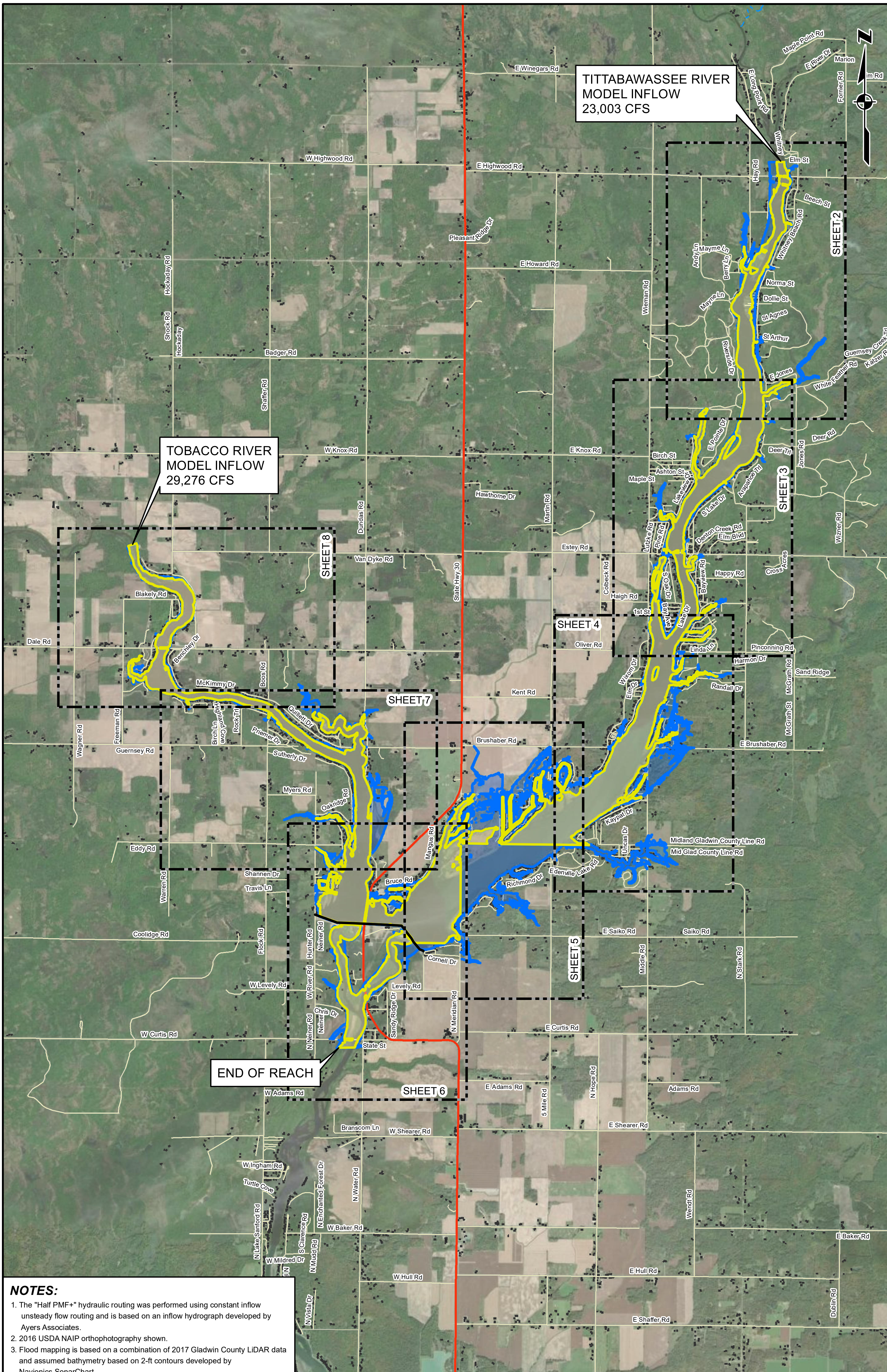
https://geiconsultant-my.sharepoint.com/personal/njorgensen_geiconsultants_com/Documents/Documents/00 - Work at Home/FLTF/Results/[Edenville Profile.xlsx]Figure 1 - Tittabawassee

Flood Study of the Tittabassee River from Secord to Sanford Dam	GEI Consultants	EDENVILLE DAM FLOODING PROFILES TITTABAWASSEE RIVER REACH
Four Lakes Task Force Gladwin and Midland County, Michigan	Project 2002879	March 2021 Appendix G



https://geiconsultant-my.sharepoint.com/personal/njorgensen_geiconsultants_com/Documents/Documents/00 - Work at Home/FLTF/Results/[Edenville Profile.xlsx]Figure 1 - Tobacco

Flood Study of the Tittabassee River from Secord to Sanford Dam Four Lakes Task Force Gladwin and Midland County, Michigan	GEI Consultants Project 2002879	EDENVILLE DAM FLOODING PROFILES TOBACCO RIVER REACH March 2021 Appendix G



NOTES:

1. The "Half PMF+" hydraulic routing was performed using constant inflow unsteady flow routing and is based on an inflow hydrograph developed by Ayers Associates.
2. 2016 USDA NAIP orthophotography shown.
3. Flood mapping is based on a combination of 2017 Gladwin County LiDAR data and assumed bathymetry based on 2-ft contours developed by Navionics SonarChart.

0 2,500 5,000 10,000
Scale, Feet

"Half PMF+" Floodplain
FEMA 100-Year Floodplain
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EDENVILLE DAM HYPOTHETICAL "HALF PMF+" INUNDATION MAPS
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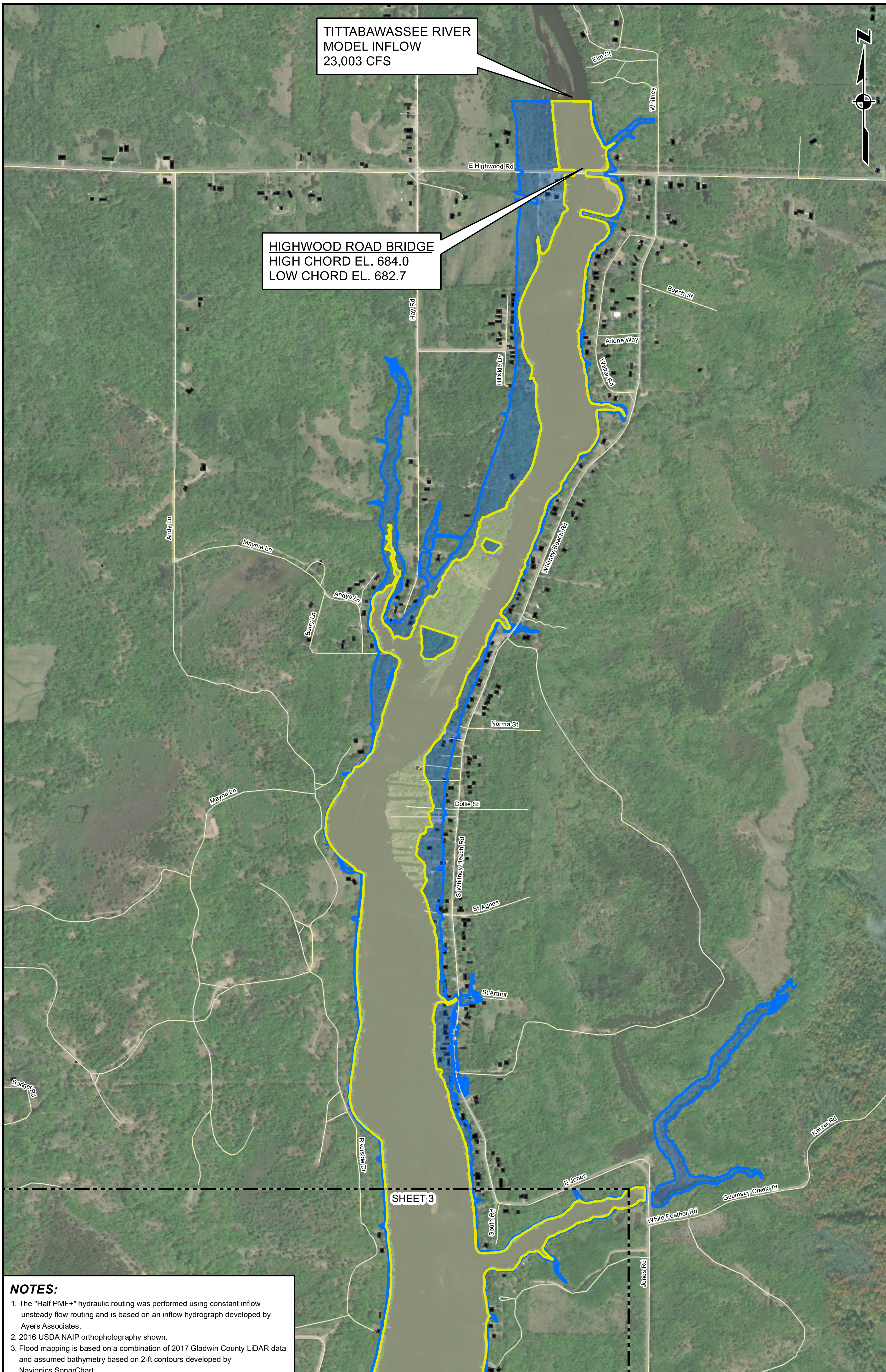

NOTES:

1. The "Half PMF+" hydraulic routing was performed using constant inflow unsteady flow routing and is based on an inflow hydrograph developed by Ayers Associates.
2. 2016 USDA NAIP orthophotography shown.
3. Flood mapping is based on a combination of 2017 Gladwin County LiDAR data and assumed bathymetry based on 2-ft contours developed by Navionics SonarChart.

0 500 1,000 2,000

Scale, Feet

"Half PMF+" Floodplain
FEMA 100-Year Floodplain
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Four Lakes Task Force
Gladwin and Midland County, Michigan

EDENVILLE DAM HYPOTHETICAL "HALF PMF+" INUNDATION MAPS PROPOSED CONDITIONS (SHEET 2 OF 8)

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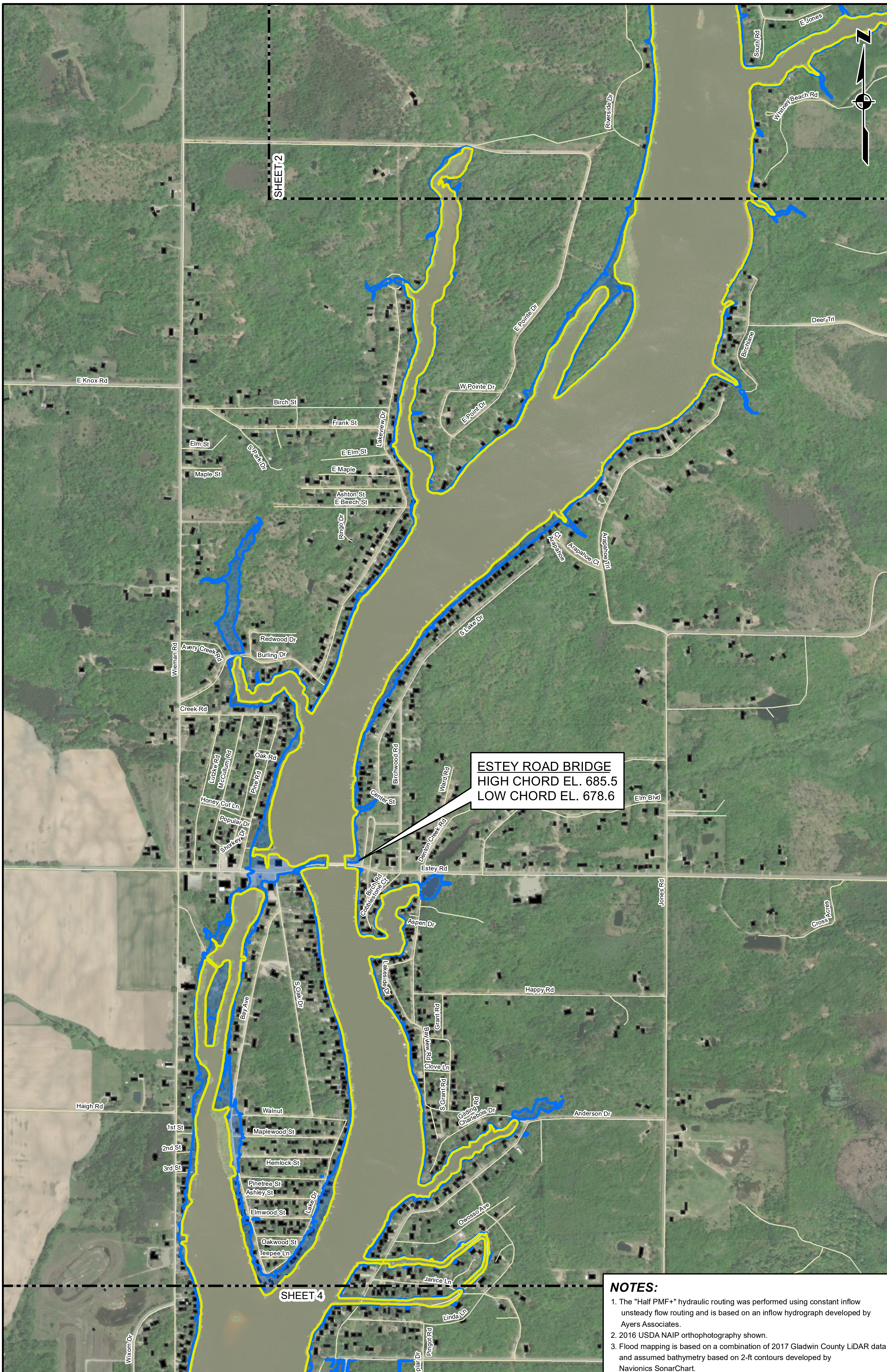

NOTES:

1. The "Half PMF+" hydraulic routing was performed using constant inflow unsteady flow routing and is based on an inflow hydrograph developed by Ayers Associates.
2. 2016 USDA NAIP orthophotography shown.
3. Flood mapping is based on a combination of 2017 Gladwin County LiDAR data and assumed bathymetry based on 2-ft contours developed by Navionics SonarChart.

0 500 1,000 2,000

Scale, Feet

"Half PMF+" Floodplain

FEMA 100-Year Floodplain

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Gladwin and Midland County, Michigan

EDENVILLE DAM HYPOTHETICAL "HALF PMF+" INUNDATION MAPS PROPOSED CONDITIONS (SHEET 3 OF 8)

March 2021

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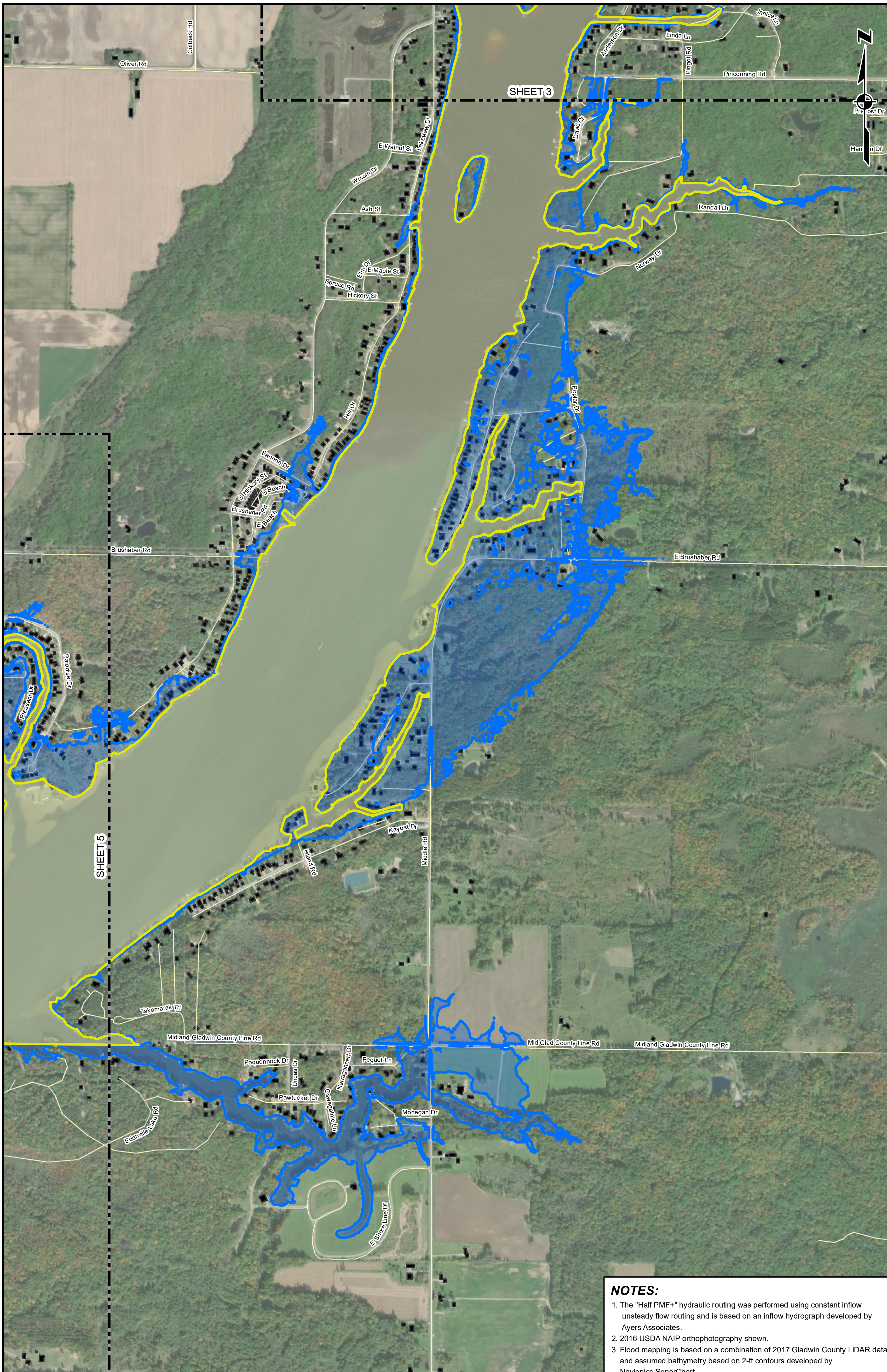

NOTES:

1. The "Half PMF+" hydraulic routing was performed using constant inflow unsteady flow routing and is based on an inflow hydrograph developed by Ayers Associates.
2. 2016 USDA NAIP orthophotography shown.
3. Flood mapping is based on a combination of 2017 Gladwin County LiDAR data and assumed bathymetry based on 2-ft contours developed by Navionics SonarChart.

0 500 1,000 2,000
Scale, Feet

"Half PMF+" Floodplain
FEMA 100-Year Floodplain
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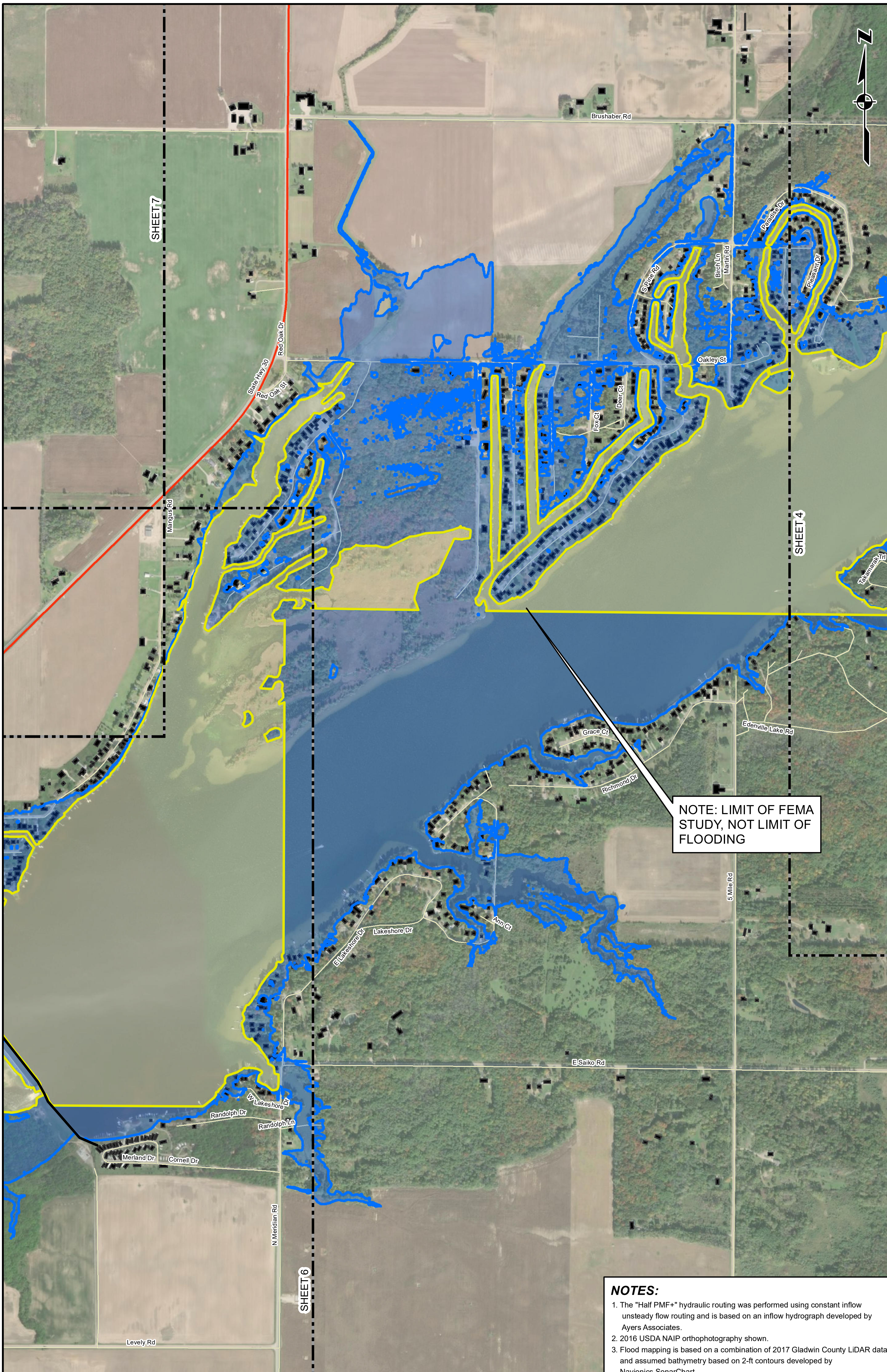
Flood Study of the Tittabawassee River from Secord to Sanford Dam Four Lakes Task Force Gladwin and Midland County, Michigan

EDENVILLE DAM HYPOTHETICAL "HALF PMF+" INUNDATION MAPS PROPOSED CONDITIONS (SHEET 4 OF 8)

March 2021

Appendix G



NOTES:

1. The "Half PMF+" hydraulic routing was performed using constant inflow unsteady flow routing and is based on an inflow hydrograph developed by Ayers Associates.
2. 2016 USDA NAIP orthophotography shown.
3. Flood mapping is based on a combination of 2017 Gladwin County LiDAR data and assumed bathymetry based on 2-ft contours developed by Navionics SonarChart.

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EDENVILLE DAM HYPOTHETICAL "HALF PMF+" INUNDATION MAPS
PROPOSED CONDITIONS
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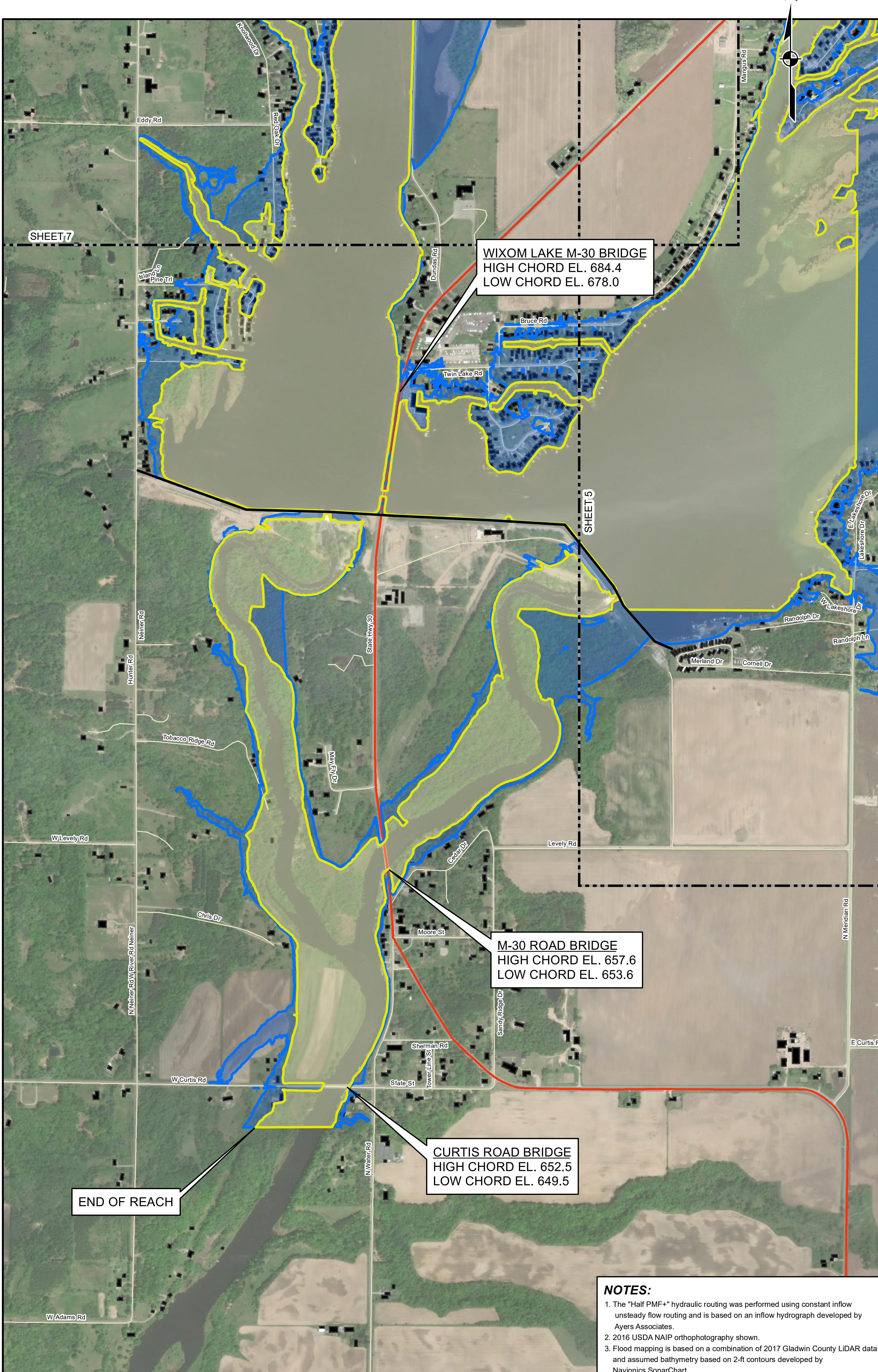

NOTES:

1. The "Half PMF+" hydraulic routing was performed using constant inflow unsteady flow routing and is based on an inflow hydrograph developed by Ayers Associates.
2. 2016 USDA NAIP orthophotography shown.
3. Flood mapping is based on a combination of 2017 Gladwin County LiDAR data and assumed bathymetry based on 2-ft contours developed by Navionics SonarChart.

0 500 1,000 2,000

Scale, Feet

- "Half PMF+" Floodplain
- FEMA 100-Year Floodplain
- Sheet Index
- Structures
- Roads

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Project 2002879

Flood Study of the Tittabawassee River from Secord to Sanford Dam
Four Lakes Task Force
Gladwin and Midland County, Michigan

EDENVILLE DAM HYPOTHETICAL "HALF PMF+" INUNDATION MAPS
PROPOSED CONDITIONS
(SHEET 6 OF 8)

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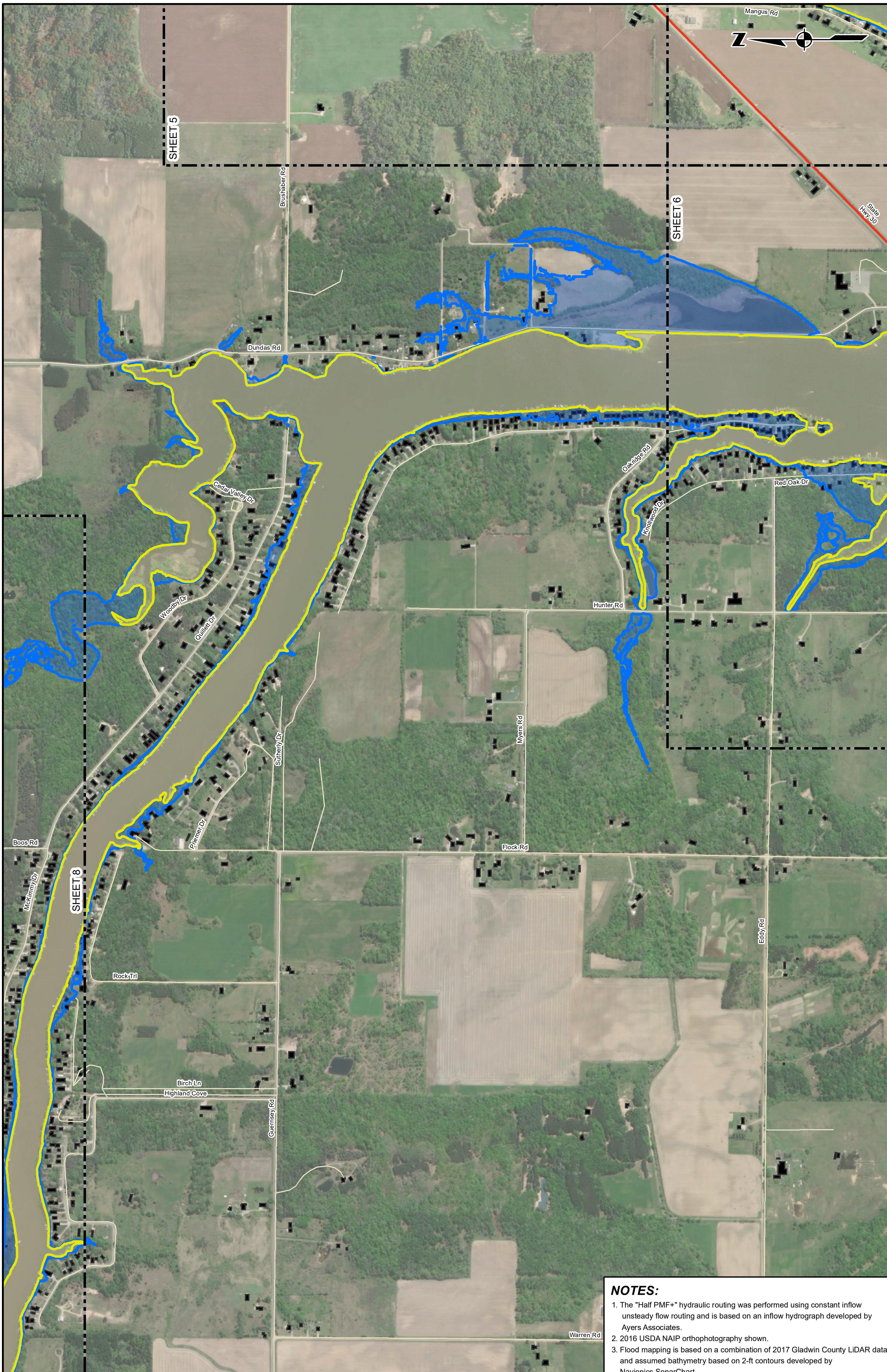

NOTES:

1. The "Half PMF+" hydraulic routing was performed using constant inflow unsteady flow routing and is based on an inflow hydrograph developed by Ayers Associates.
2. 2016 USDA NAIP orthophotography shown.
3. Flood mapping is based on a combination of 2017 Gladwin County LiDAR data and assumed bathymetry based on 2-ft contours developed by Navionics SonarChart.

0 500 1,000 2,000

Scale, Feet

"Half PMF+" Floodplain
FEMA 100-Year Floodplain
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Flood Study of the Tittabawassee River from Secord to Sanford Dam
Four Lakes Task Force
Gladwin and Midland County, Michigan

EDENVILLE DAM HYPOTHETICAL "HALF PMF+" INUNDATION MAPS
PROPOSED CONDITIONS
(SHEET 7 OF 8)

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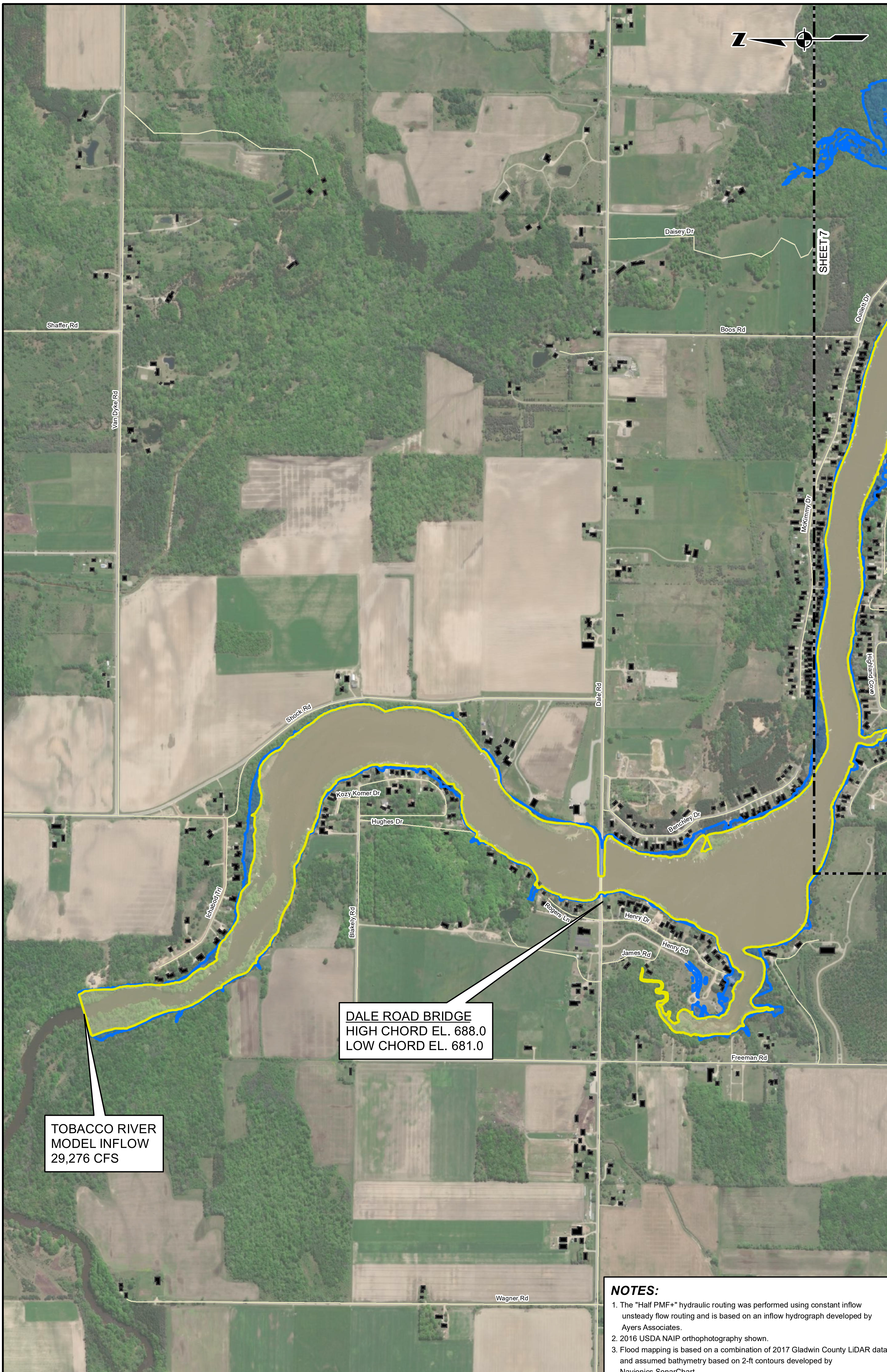

NOTES:

1. The "Half PMF+" hydraulic routing was performed using constant inflow unsteady flow routing and is based on an inflow hydrograph developed by Ayers Associates.
2. 2016 USDA NAIP orthophotography shown.
3. Flood mapping is based on a combination of 2017 Gladwin County LiDAR data and assumed bathymetry based on 2-ft contours developed by Navionics SonarChart.

0 500 1,000 2,000
Scale, Feet

"Half PMF+" Floodplain
FEMA 100-Year Floodplain
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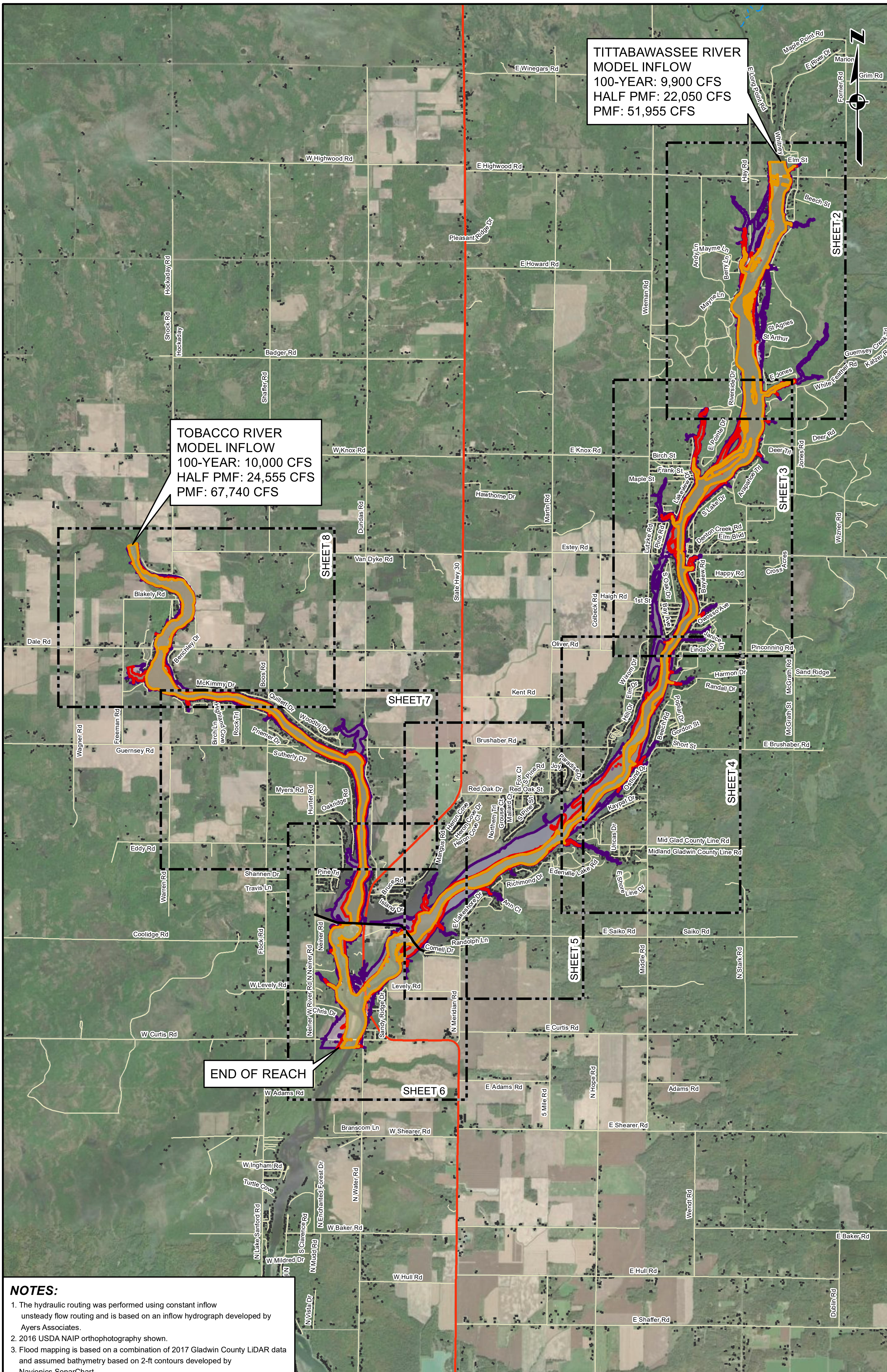
Flood Study of the Tittabawassee River from Secord to Sanford Dam
Four Lakes Task Force
Gladwin and Midland County, Michigan

EDENVILLE DAM HYPOTHETICAL "HALF PMF+" INUNDATION MAPS PROPOSED CONDITIONS (SHEET 8 OF 8)

March 2021 Appendix G



NOTES:

1. The hydraulic routing was performed using constant inflow unsteady flow routing and is based on an inflow hydrograph developed by Ayers Associates.
2. 2016 USDA NAIP orthophotography shown.
3. Flood mapping is based on a combination of 2017 Gladwin County LiDAR data and assumed bathymetry based on 2-ft contours developed by Navionics SonarChart.

0 2,500 5,000 10,000
Scale, Feet

- PMF Floodplain
- Half PMF Floodplain
- FEMA 100-Year Floodplain
- Sheet Index
- Structures
- Roads

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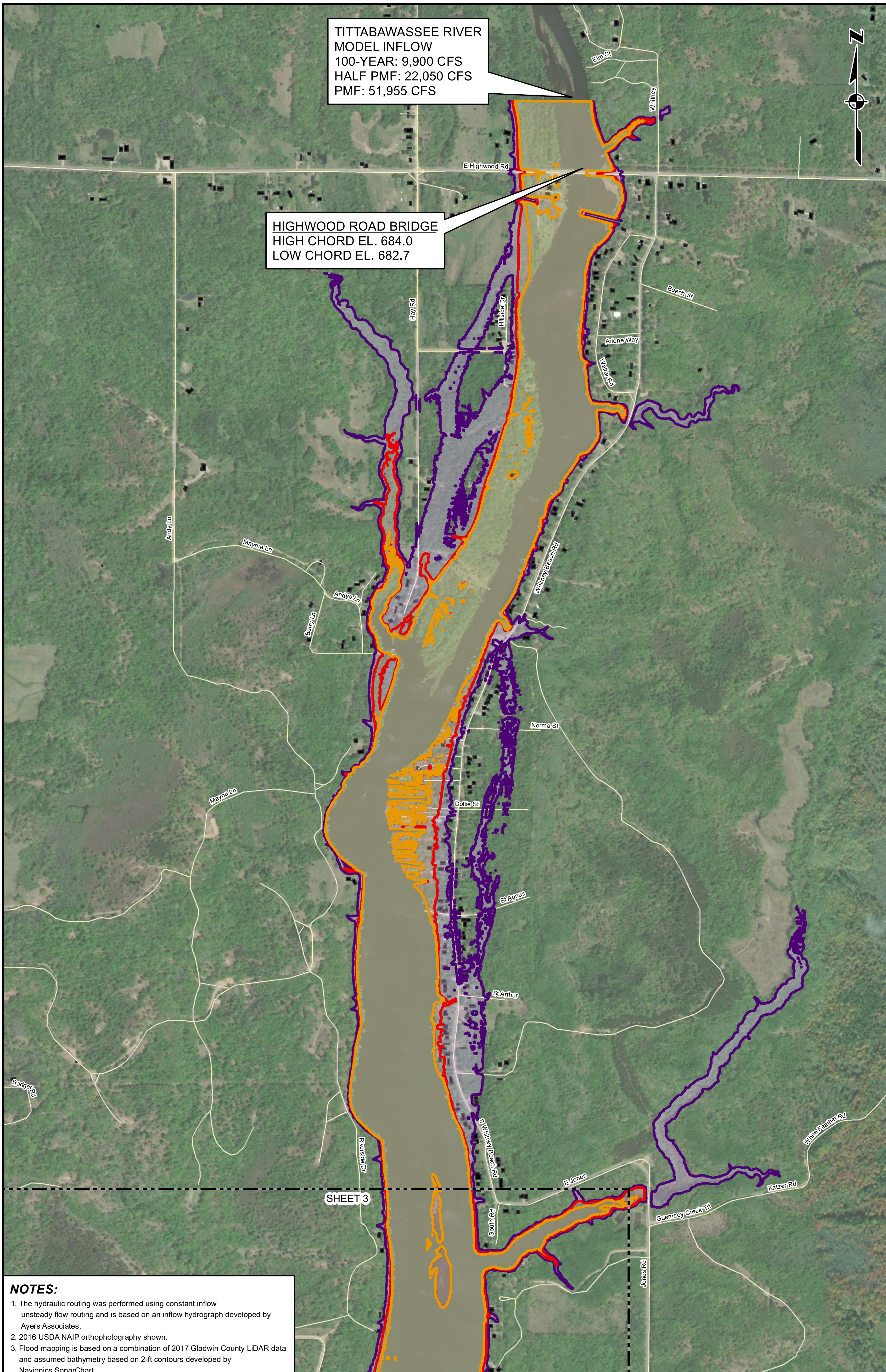
Project 2002879

Flood Study of the Tittabawassee River from Secord to Sanford Dam
Four Lakes Task Force
Gladwin and Midland County, Michigan

EDENVILLE DAM HYPOTHETICAL DAM REMOVED CONDITIONS (SHEET 1 OF 8)

March 2021

Appendix G



NOTES:

1. The hydraulic routing was performed using constant inflow unsteady flow routing and is based on an inflow hydrograph developed by Ayers Associates.
2. 2016 USDA NAIP orthophotography shown.
3. Flood mapping is based on a combination of 2017 Gladwin County LiDAR data and assumed bathymetry based on 2-ft contours developed by Navionics SonarChart.

0 500 1,000 2,000

Scale, Feet

PMF Floodplain
Half PMF Floodplain
FEMA 100-Year Floodplain
Sheet Index
Structures
Roads

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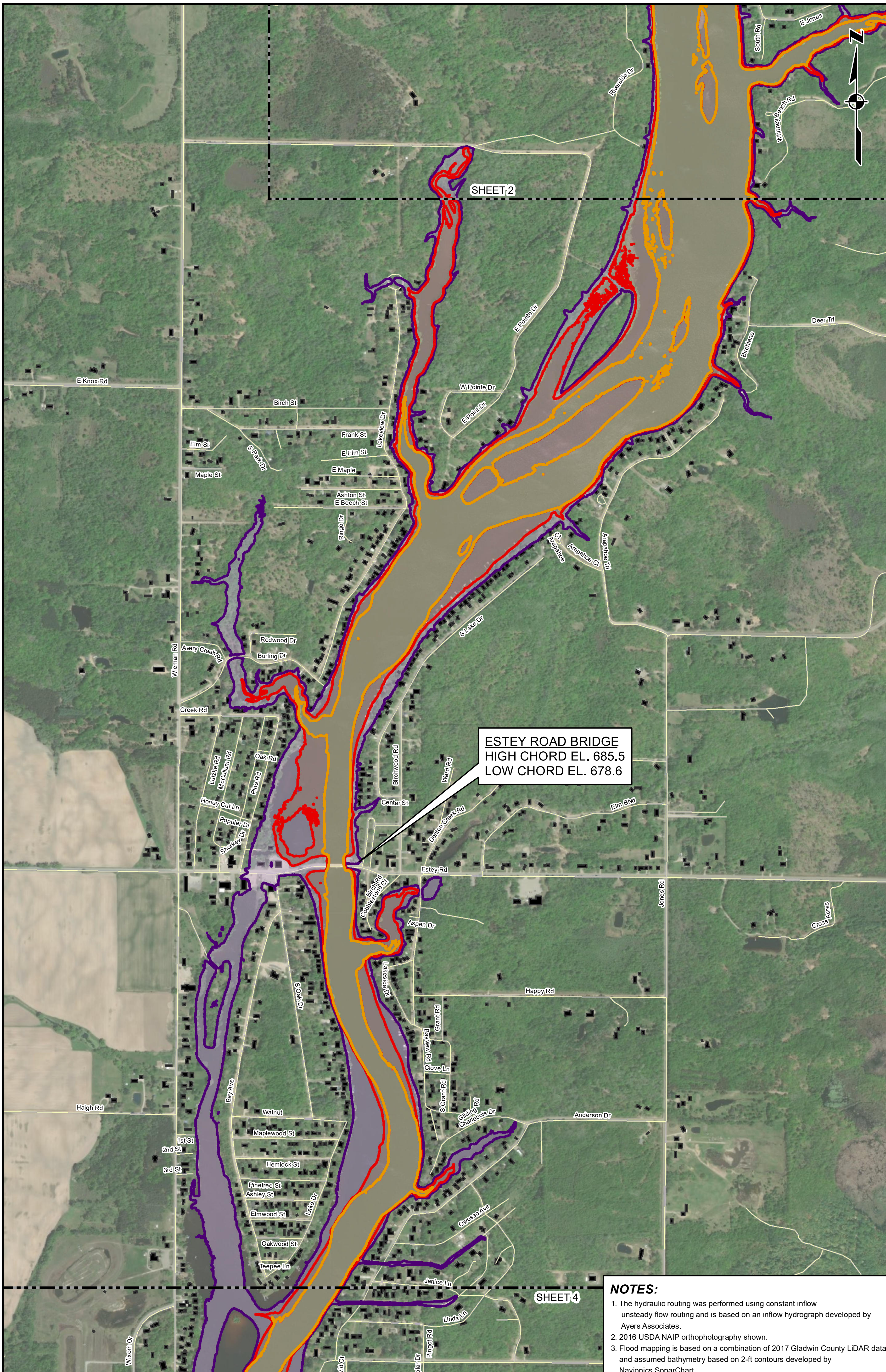
Flood Study of the Tittabawassee River from Secord to Sanford Dam
Four Lakes Task Force
Gladwin and Midland County, Michigan

EDENVILLE DAM HYPOTHETICAL DAM REMOVED CONDITIONS (SHEET 2 OF 8)

March 2021

Appendix G



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3. Flood mapping is based on a combination of 2017 Gladwin County LiDAR data and assumed bathymetry based on 2-ft contours developed by Navionics SonarChart.

0 500 1,000 2,000

Scale, Feet

- PMF Floodplain
- Half PMF Floodplain
- FEMA 100-Year Floodplain
- Sheet Index
- Structures
- Roads

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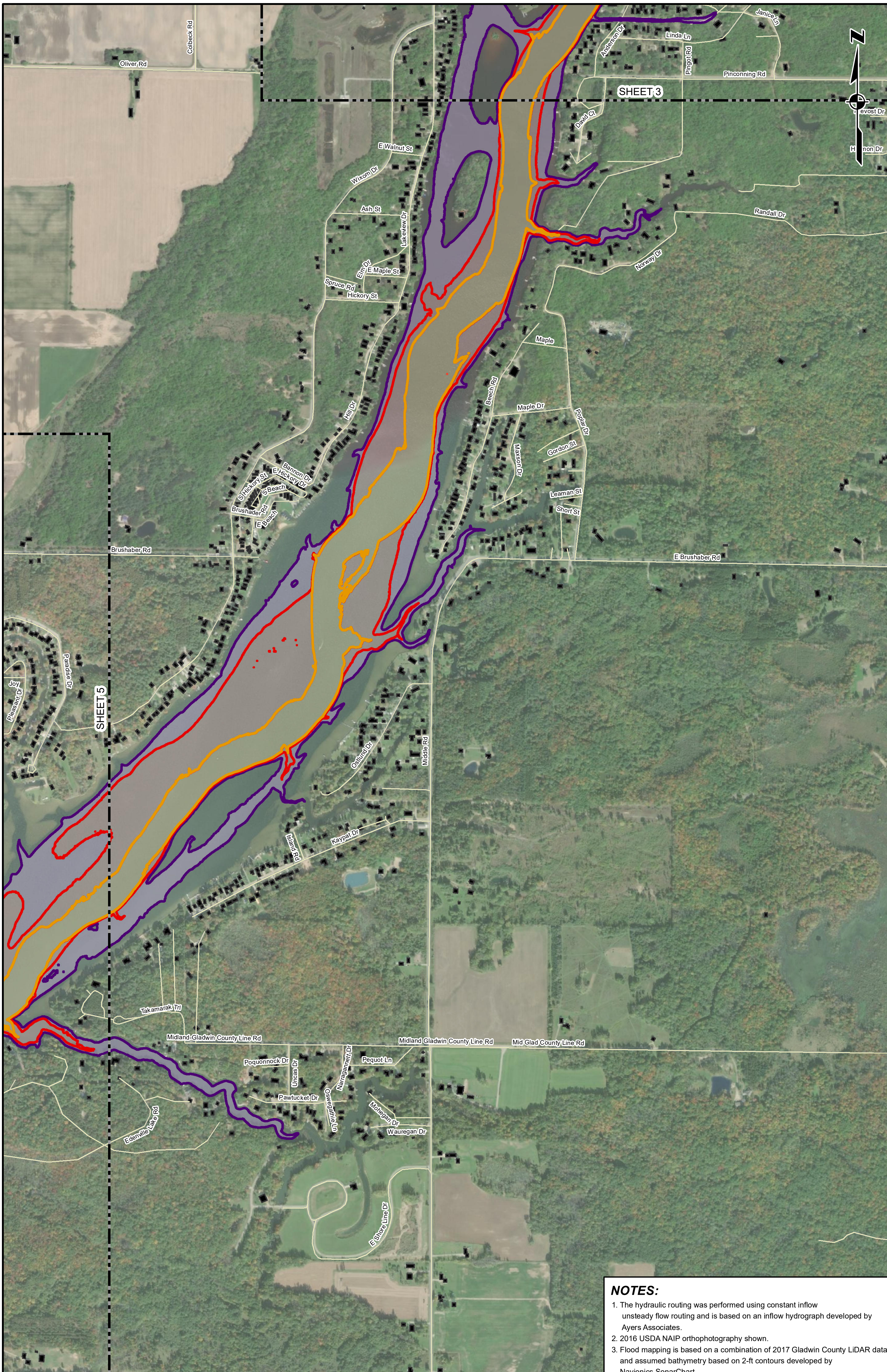
Flood Study of the Tittabawassee River from Secord to Sanford Dam
Four Lakes Task Force
Gladwin and Midland County, Michigan

EDENVILLE DAM HYPOTHETICAL DAM REMOVED CONDITIONS
(SHEET 3 OF 8)

March 2021

Appendix G



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3. Flood mapping is based on a combination of 2017 Gladwin County LiDAR data and assumed bathymetry based on 2-ft contours developed by Navionics SonarChart.

0 500 1,000 2,000

Scale, Feet

PMF Floodplain
Half PMF Floodplain
FEMA 100-Year Floodplain
Sheet Index
Structures
Roads

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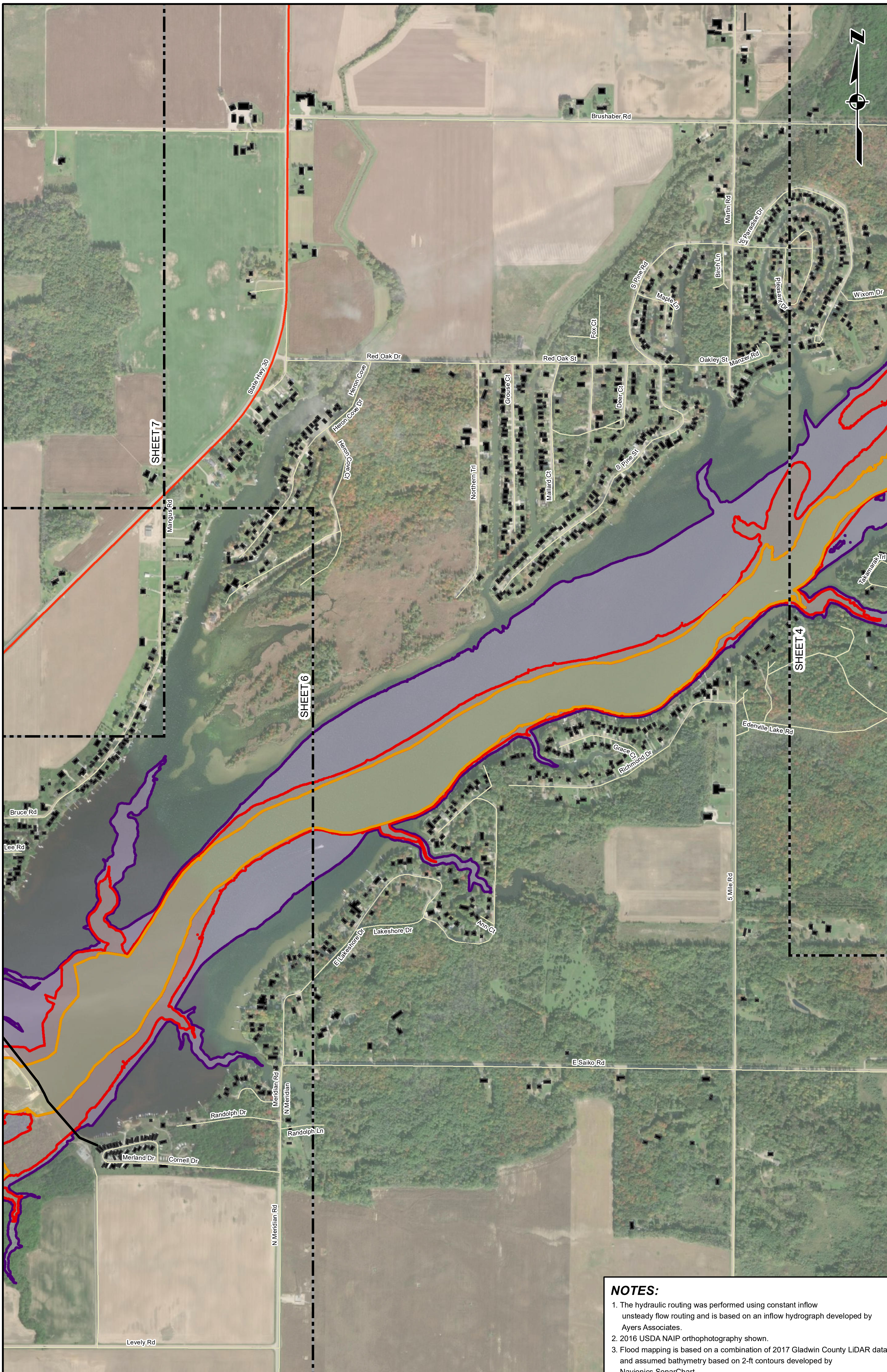
Flood Study of the Tittabawassee River from Secord to Sanford Dam
Four Lakes Task Force
Gladwin and Midland County, Michigan

EDENVILLE DAM HYPOTHETICAL DAM REMOVED CONDITIONS
(SHEET 4 OF 8)

March 2021

Appendix G



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3. Flood mapping is based on a combination of 2017 Gladwin County LiDAR data and assumed bathymetry based on 2-ft contours developed by Navionics SonarChart.

0 500 1,000 2,000

Scale, Feet

- PMF Floodplain
- Half PMF Floodplain
- FEMA 100-Year Floodplain
- Sheet Index
- Structures
- Roads

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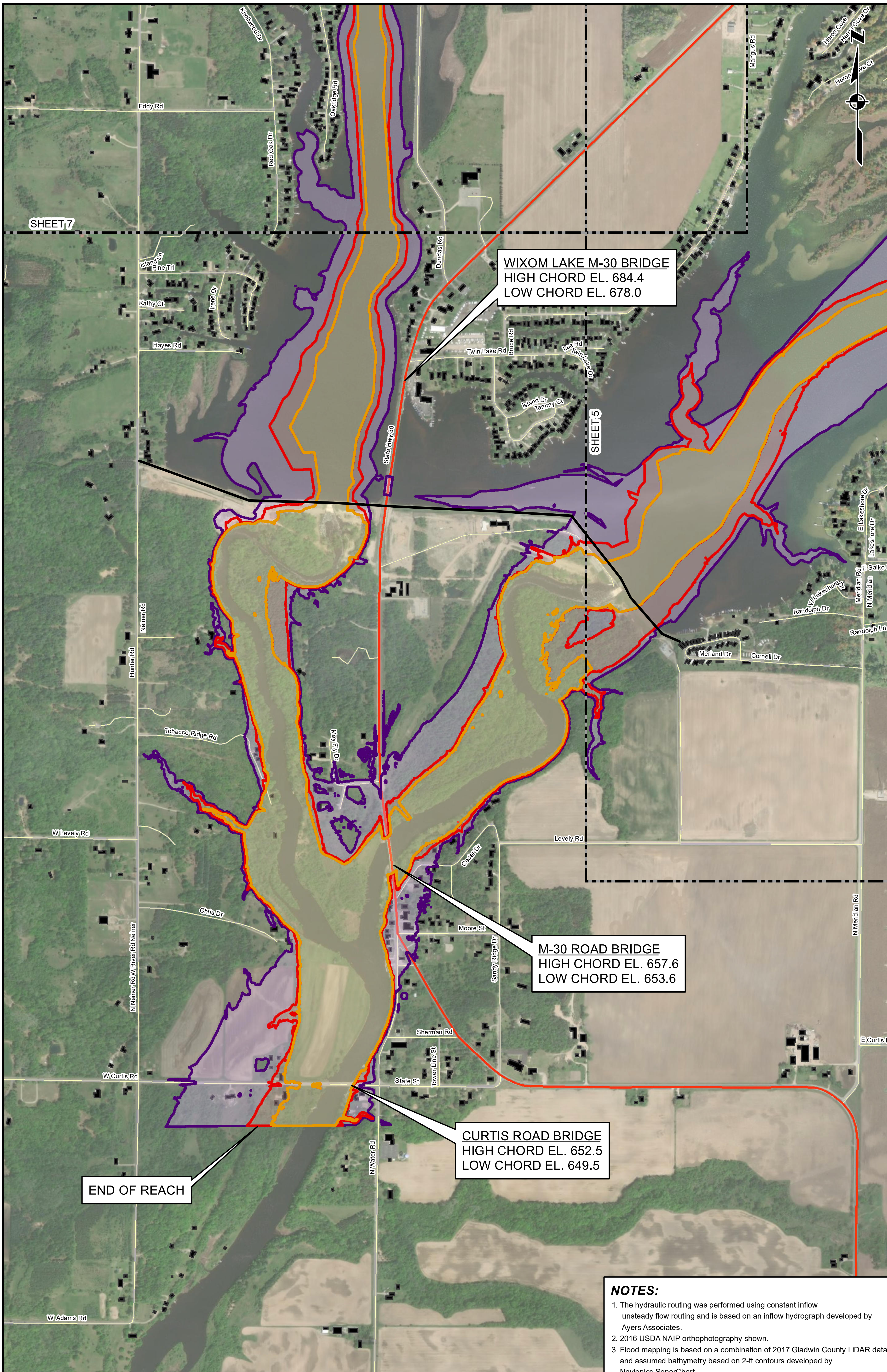
Flood Study of the Tittabawassee River from Secord to Sanford Dam Four Lakes Task Force Gladwin and Midland County, Michigan

EDENVILLE DAM HYPOTHETICAL DAM REMOVED CONDITIONS (SHEET 5 OF 8)

March 2021

Appendix G



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3. Flood mapping is based on a combination of 2017 Gladwin County LiDAR data and assumed bathymetry based on 2-ft contours developed by Navionics SonarChart.

0 500 1,000 2,000
Scale, Feet

- PMF Floodplain
- Half PMF Floodplain
- FEMA 100-Year Floodplain
- Sheet Index
- Structures
- Roads

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Flood Study of the Tittabawassee River from Secord to Sanford Dam
Four Lakes Task Force
Gladwin and Midland County, Michigan

EDENVILLE DAM HYPOTHETICAL DAM REMOVED CONDITIONS (SHEET 6 OF 8)

March 2021

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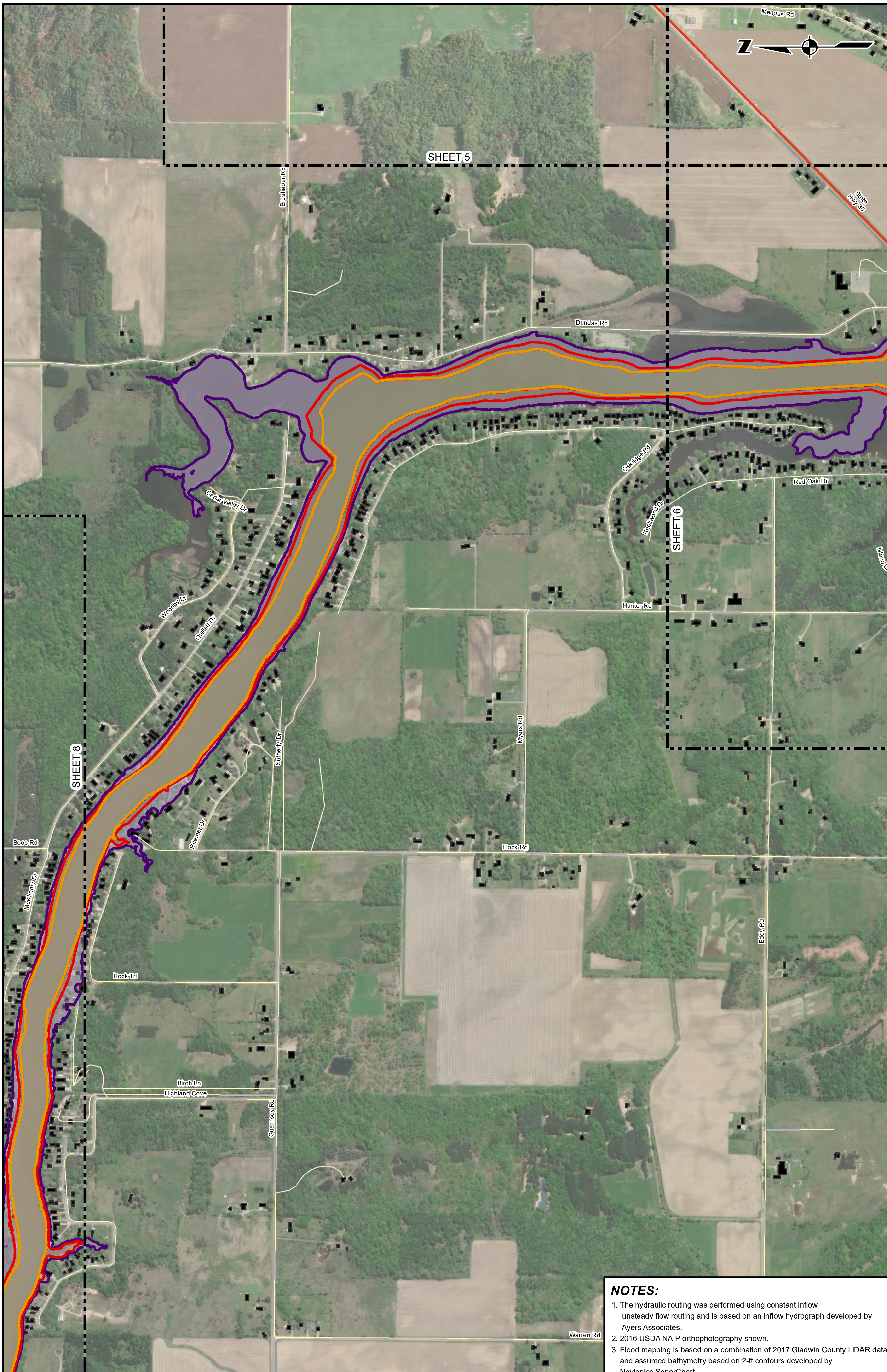

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2. 2016 USDA NAIP orthophotography shown.
3. Flood mapping is based on a combination of 2017 Gladwin County LiDAR data and assumed bathymetry based on 2-ft contours developed by Navionics SonarChart.

0 500 1,000 2,000

Scale, Feet

- PMF Floodplain
- Half PMF Floodplain
- FEMA 100-Year Floodplain
- Sheet Index
- Structures
- Roads

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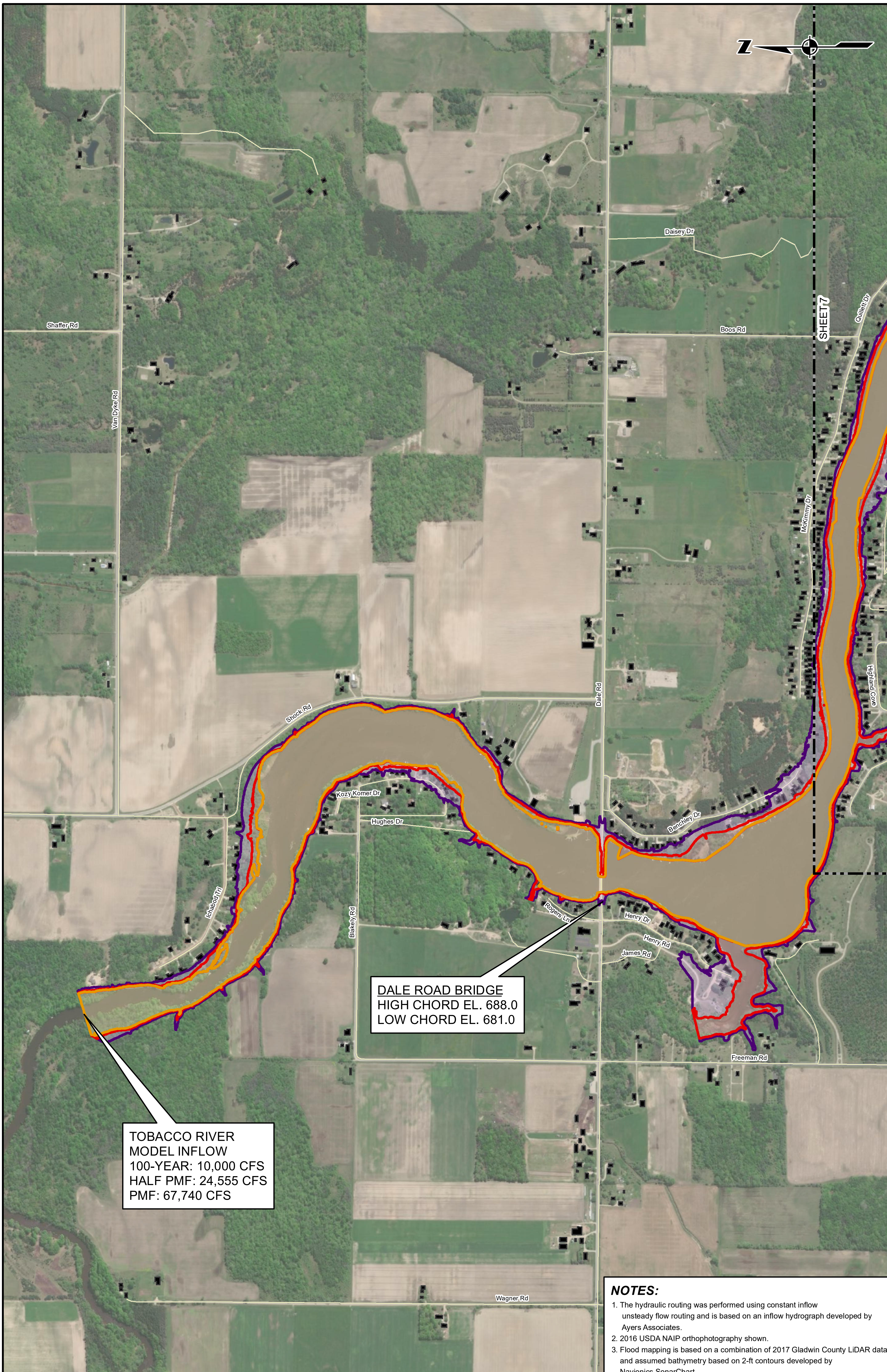
Flood Study of the Tittabawassee River from Secord to Sanford Dam Four Lakes Task Force Gladwin and Midland County, Michigan

EDENVILLE DAM HYPOTHETICAL DAM REMOVED CONDITIONS (SHEET 7 OF 8)

March 2021

Appendix G



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3. Flood mapping is based on a combination of 2017 Gladwin County LiDAR data and assumed bathymetry based on 2-ft contours developed by Navionics SonarChart.

0 500 1,000 2,000

Scale, Feet

- PMF Floodplain
- Half PMF Floodplain
- FEMA 100-Year Floodplain
- Sheet Index
- Structures
- Roads

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Flood Study of the Tittabawassee River from Secord to Sanford Dam
Four Lakes Task Force
Gladwin and Midland County, Michigan

EDENVILLE DAM HYPOTHETICAL DAM REMOVED CONDITIONS (SHEET 8 OF 8)

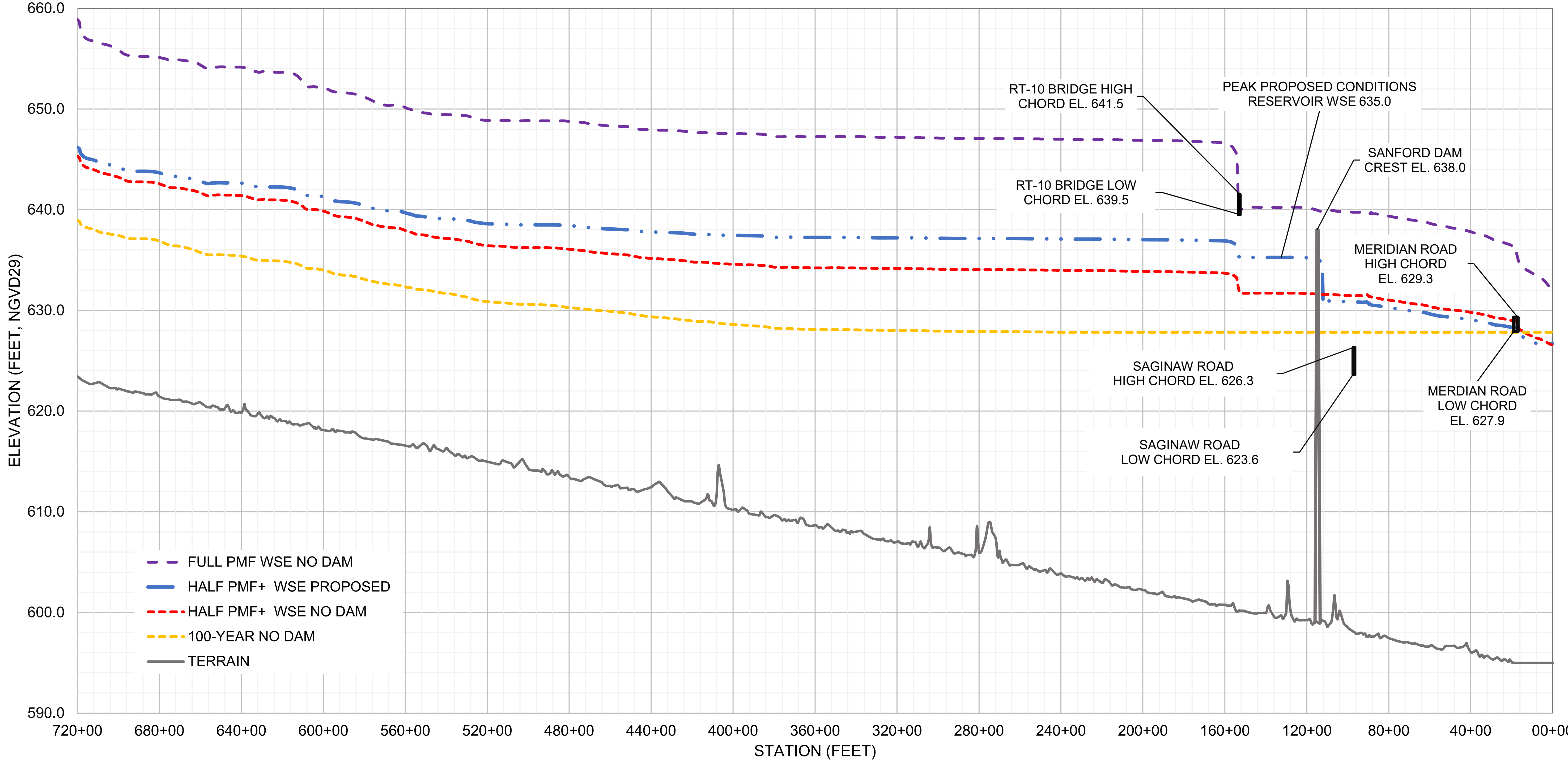
March 2021

Appendix G

Appendix G

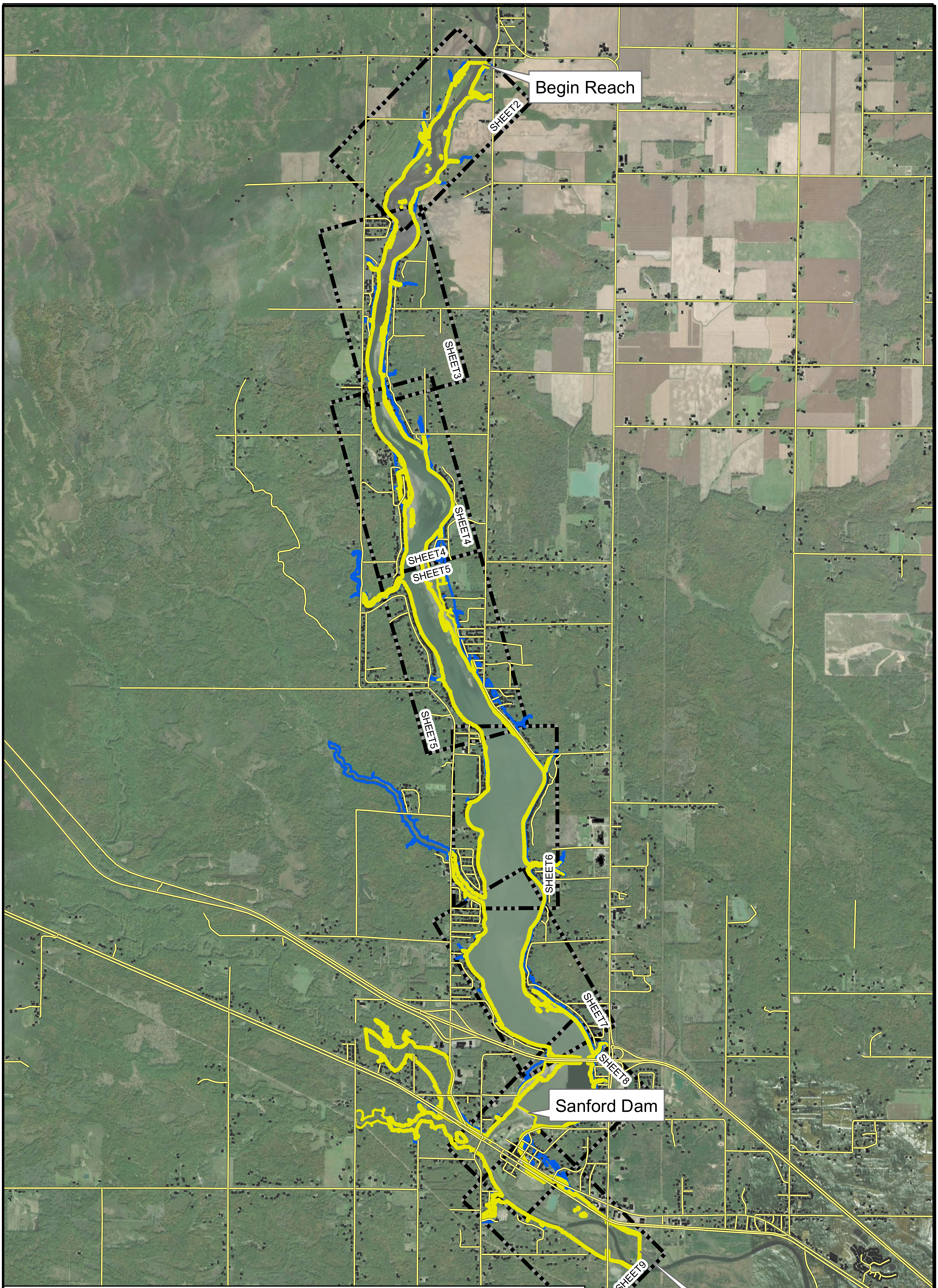
Inundation Mapping and Flood Profiles

Appendix G.4 – Sanford Dam



Flood Study of the Tittabassee River Smallwood Dam Midland County, Michigan	GEI Consultants	SANFORD DAM FLOODING PROFILES
Four Lakes Task Force Midland, Michigan	Project 2002879	March 2021 Appendix G

https://geiconsultant-my.sharepoint.com/personal/eholmstead_geiconsultants_com/Documents/Documents/Temp/Four Lakes Task Force/[Sanford FLood Profile.xlsx]Figure 1



NOTES AND LEGEND:

1. Inundation limits are based on flows provided by Ayers Associates,
2. 2016 USDA NAIP orthophotography shown.
3. Flood mapping is based on LiDAR collected in August 2020 and assumed bathymetry.

Sheet Index	FEMA 100-Year Floodplain
Roads	Half PMF+ - Proposed
Structures	

N W E S

0 1,850 3,700 7,400

Scale, Feet

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Four Lakes Task Force
Sanford Dam
Inundation Mapping

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SANFORD DAM
INUNDATION MAPS
(SHEET 1 OF 9)

March 2021

Figure D-1

NOTES AND LEGEND:

1. Inundation limits are based on flows provided by Ayers Associates.
2. 2016 USDA NAIP orthophotography shown.
3. Flood mapping is based on LiDAR collected in August 2020 and assumed bathymetry.

Sheet Index
Roads
Structures
FEMA 100-Year Floodplain
Half PMF+ - Proposed

0 250 500 1,000
Scale, Feet

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Sanford Dam
Inundation Mapping

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SMALLWOOD DAM
INUNDATION MAPS
(SHEET 2 OF 9)

March 2021 Figure D-2

NOTES AND LEGEND:

1. Inundation limits are based on flows provided by Ayers Associates,
2. 2016 USDA NAIP orthophotography shown.
3. Flood mapping is based on LiDAR collected in August 2020 and assumed bathymetry.

Sheet Index
Roads
Structures
FEMA 100-Year Floodplain
Half PMF+ - Proposed

N E S W

0 250 500 1,000
Scale, Feet

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SMALLWOOD DAM
INUNDATION MAPS
(SHEET 3 OF 9)

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March 2021

Figure D-3

NOTES AND LEGEND:

1. Inundation limits are based on flows provided by Ayers Associates,
2. 2016 USDA NAIP orthophotography shown.
3. Flood mapping is based on LiDAR collected in August 2020 and assumed bathymetry.

Sheet Index
Roads
Structures
FEMA 100-Year Floodplain
Half PMF+ - Proposed

N E S W

0 250 500 1,000
Scale, Feet

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SMALLWOOD DAM
INUNDATION MAPS
(SHEET 4 OF 9)

March 2021 Figure D-4

NOTES AND LEGEND:

1. Inundation limits are based on flows provided by Ayers Associates,
2. 2016 USDA NAIP orthophotography shown.
3. Flood mapping is based on LiDAR collected in August 2020 and assumed bathymetry.

Sheet Index
Roads
Structures
FEMA 100-Year Floodplain
Half PMF+ - Proposed

0 250 500 1,000
Scale, Feet

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SMALLWOOD DAM
INUNDATION MAPS
(SHEET 5 OF 9)

March 2021

Figure D-5

NOTES AND LEGEND:

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2. 2016 USDA NAIP orthophotography shown.
3. Flood mapping is based on LiDAR collected in August 2020 and assumed bathymetry.

Sheet Index
Roads
Structures
FEMA 100-Year Floodplain
Half PMF+ - Proposed

0 250 500 1,000
Scale, Feet

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SMALLWOOD DAM
INUNDATION MAPS
(SHEET 6 OF 9)

March 2021

Figure D-6

NOTES AND LEGEND:

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2. 2016 USDA NAIP orthophotography shown.
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Sheet Index
Roads
Structures
FEMA 100-Year Floodplain
Half PMF+ - Proposed

0 250 500 1,000
Scale, Feet

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SMALLWOOD DAM
INUNDATION MAPS
(SHEET 7 OF 9)

March 2021 Figure D-7

NOTES AND LEGEND:

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Sheet Index
Roads
Structures
FEMA 100-Year Floodplain
Half PMF+ - Proposed

0 250 500 1,000
Scale, Feet

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SMALLWOOD DAM
INUNDATION MAPS
(SHEET 8 OF 9)

March 2021

Figure D-8

NOTES AND LEGEND:

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- Sheet Index
- Roads
- Structures
- FEMA 100-Year Floodplain
- Half PMF+ - Proposed

0 250 500 1,000
Scale, Feet

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Sanford Dam
Inundation Mapping

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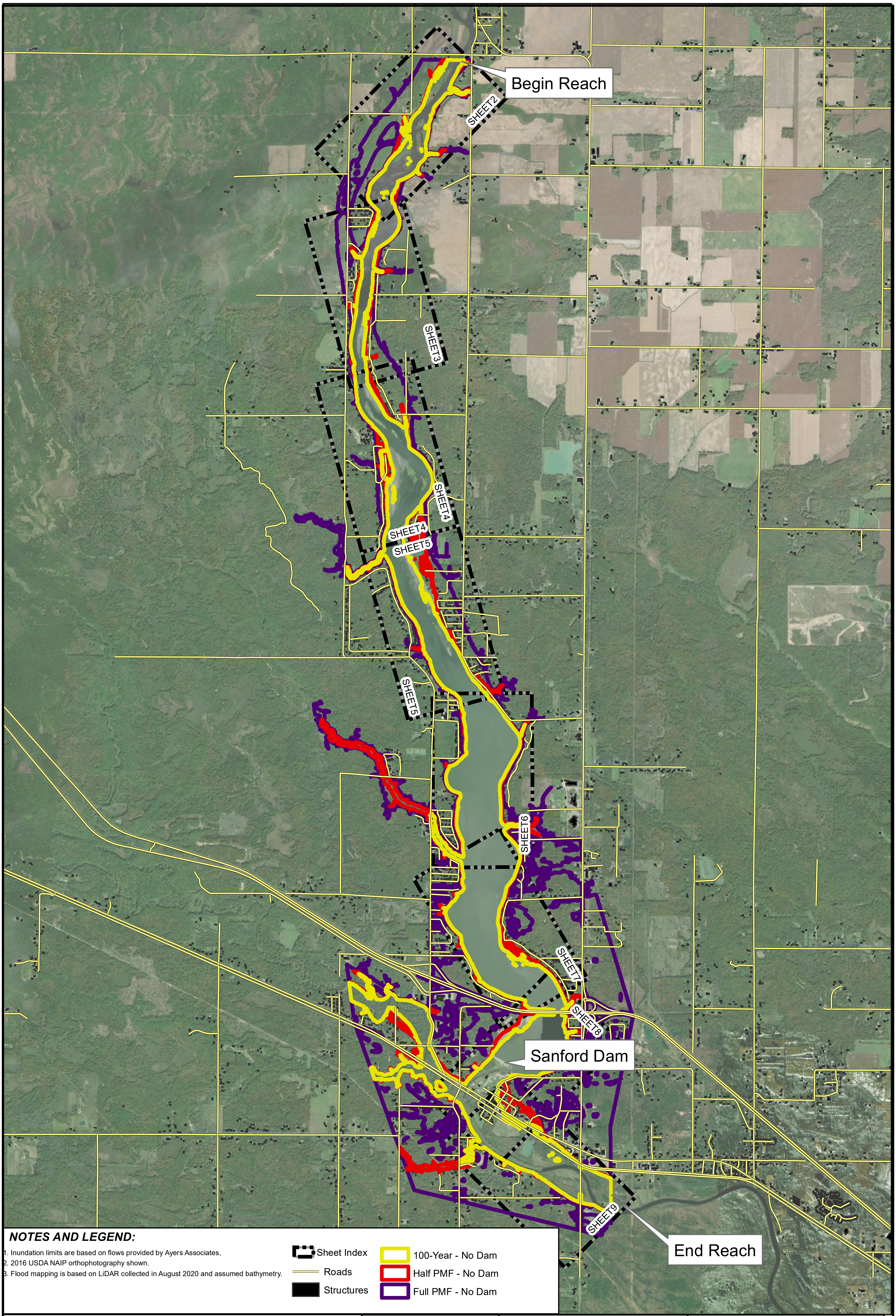
SMALLWOOD DAM
INUNDATION MAPS
(SHEET 9 OF 9)

March 2021

Figure D-9



N W E S

0 1,850 3,700 7,400
Scale, Feet

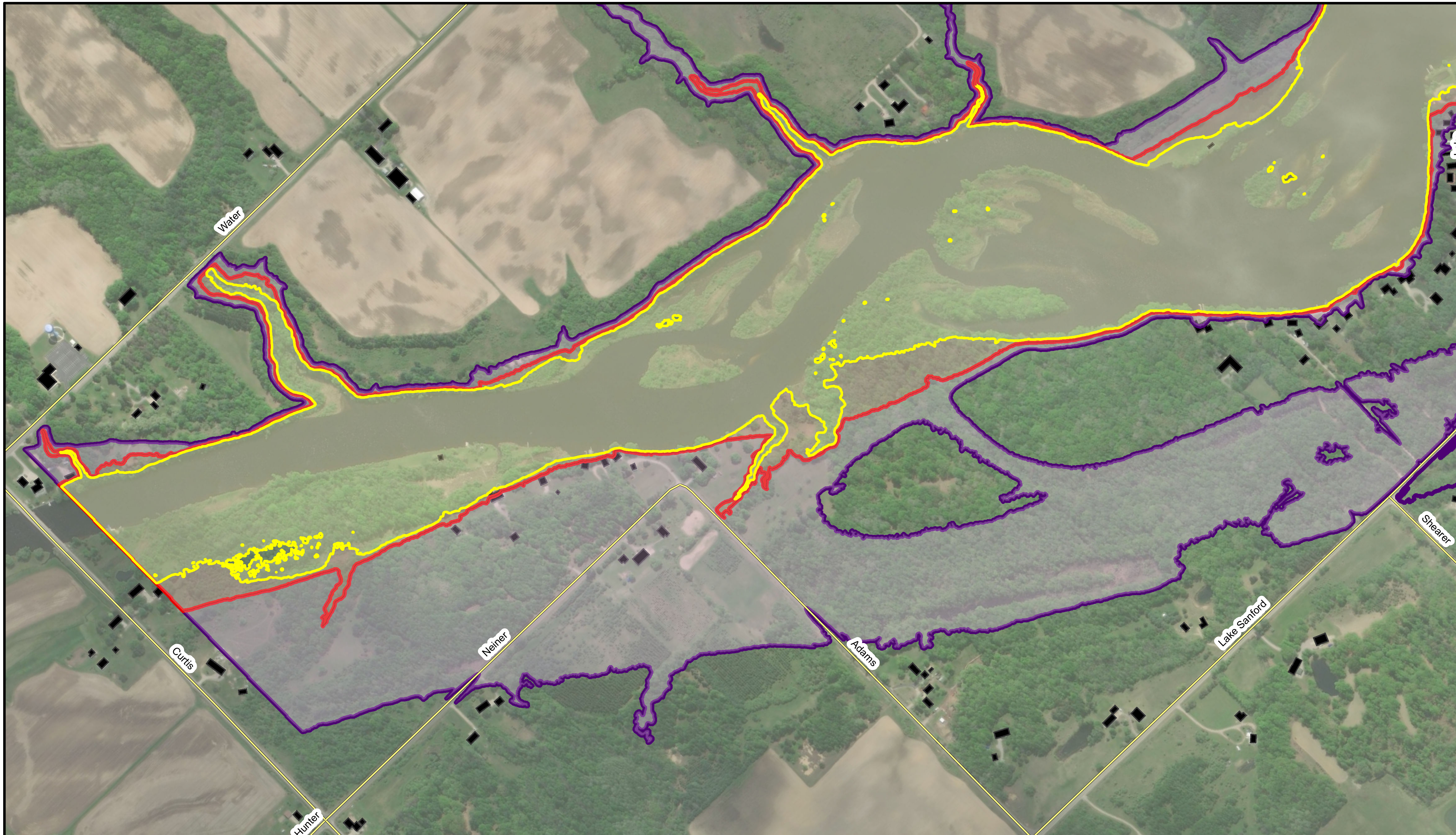
GEI Consultants

Four Lakes Task Force
Sanford Dam
Inundation Mapping

Project 2002879

SANFORD DAM
INUNDATION MAPS
(SHEET 1 OF 9)

March 2021 Figure D-1



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- Sheet Index
- Roads
- Structures
- 100-Year - No Dam
- Half PMF - No Dam
- Full PMF - No Dam

0 250 500 1,000
Scale, Feet

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Inundation Mapping

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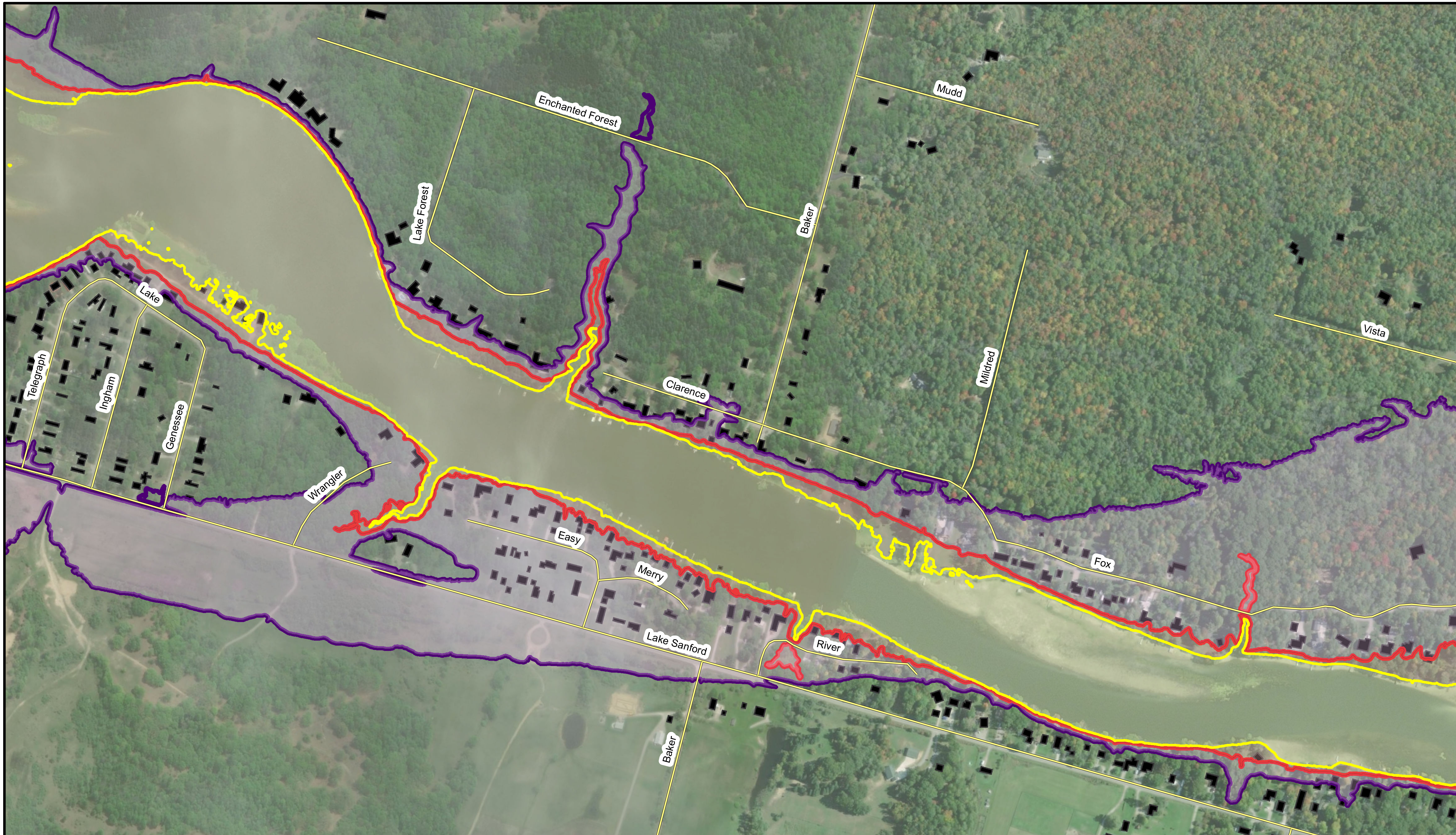
SMALLWOOD DAM
INUNDATION MAPS
DAM REMOVED
(SHEET 2 OF 9)

March 2021

Figure D-2



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- Sheet Index
- Roads
- Structures
- 100-Year - No Dam
- Half PMF - No Dam
- Full PMF - No Dam

N E S W

0 250 500 1,000

Scale, Feet

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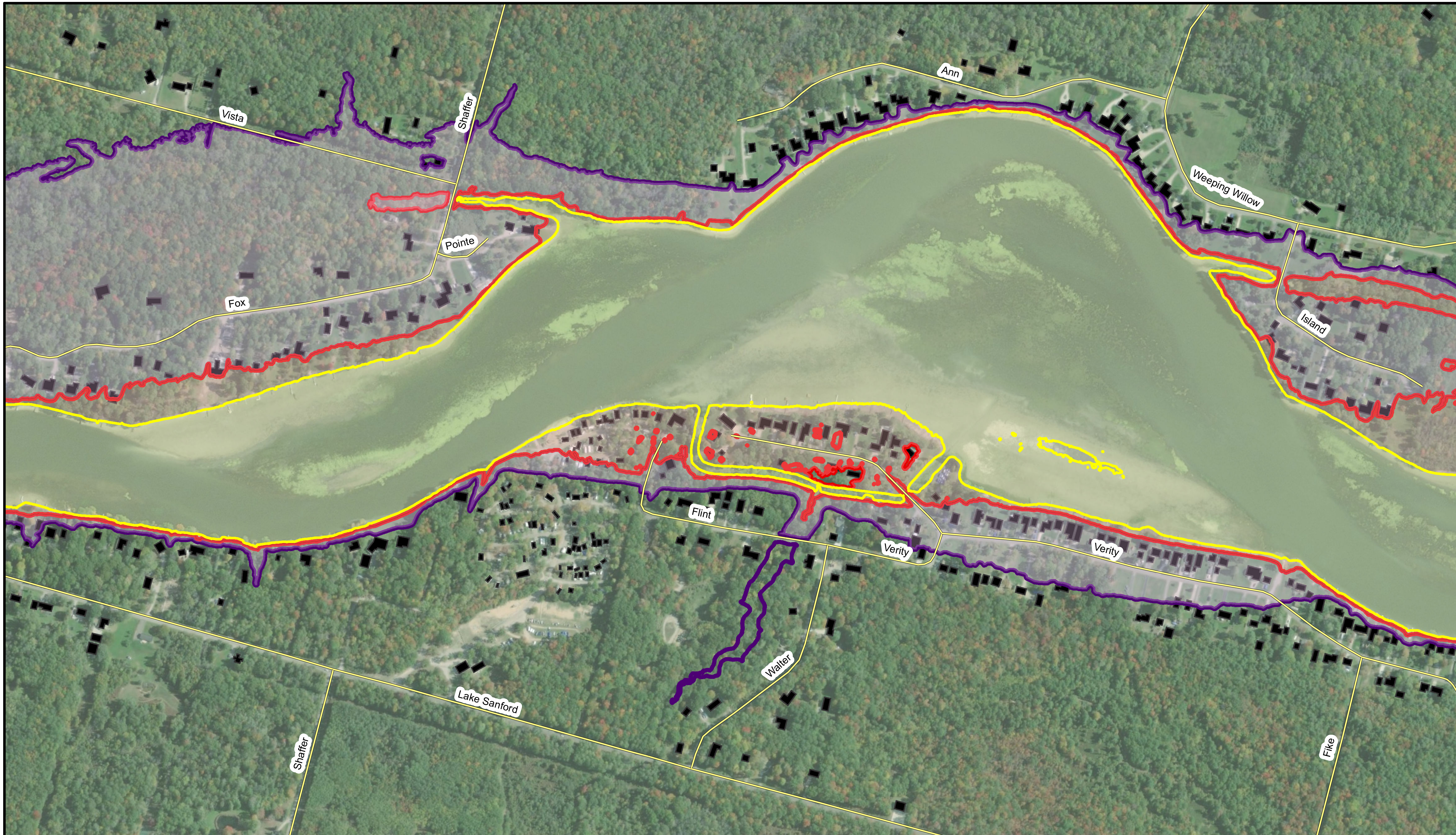
Sanford Dam
Inundation Mapping

Project 2002879

SMALLWOOD DAM
INUNDATION MAPS
DAM REMOVED
(SHEET 3 OF 9)

March 2021

Figure D-3



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Sheet Index
Roads
Structures
100-Year - No Dam
Half PMF - No Dam
Full PMF - No Dam

0 250 500 1,000
Scale, Feet

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Inundation Mapping

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SMALLWOOD DAM
INUNDATION MAPS
DAM REMOVED
(SHEET 4 OF 9)

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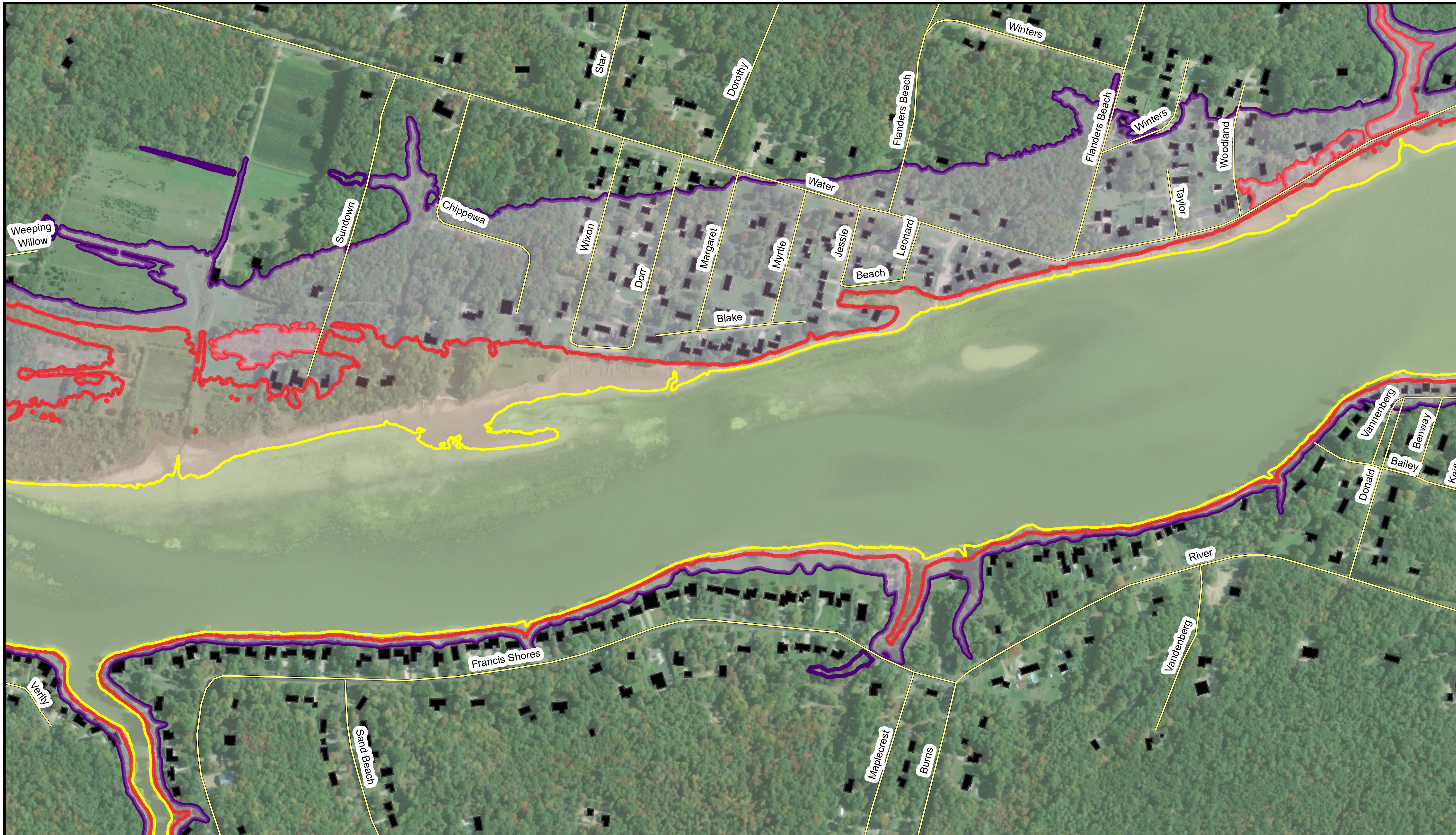

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3. Flood mapping is based on LiDAR collected in August 2020 and assumed bathymetry.

Sheet Index
Roads
Structures
100-Year - No Dam
Half PMF - No Dam
Full PMF - No Dam

0 250 500 1,000
Scale, Feet

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Sanford Dam
Inundation Mapping

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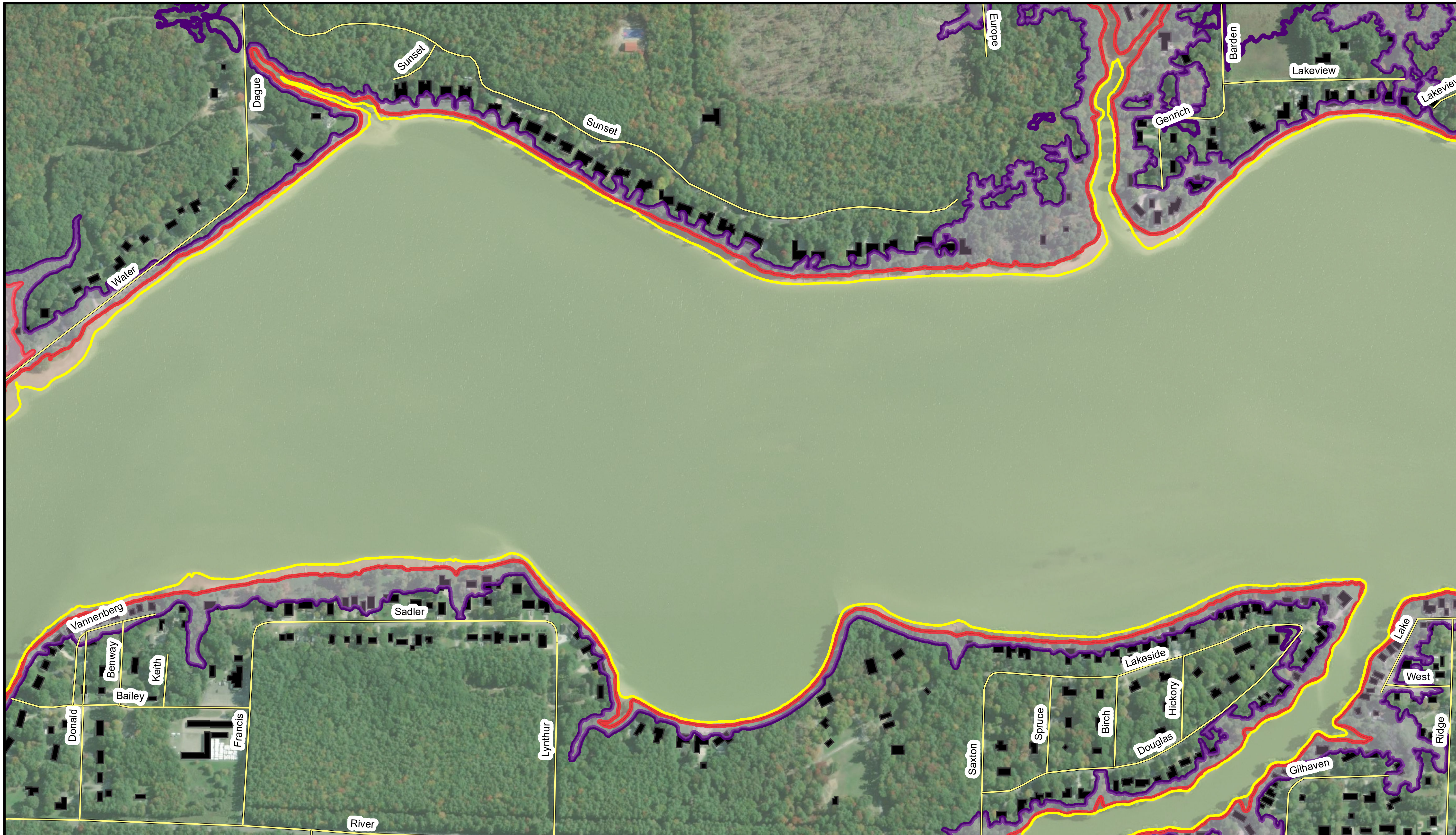
SMALLWOOD DAM
INUNDATION MAPS
DAM REMOVED
(SHEET 5 OF 9)

March 2021 Figure D-5



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Sheet Index
Roads
Structures
100-Year - No Dam
Half PMF - No Dam
Full PMF - No Dam

N E S W

0 250 500 1,000
Scale, Feet

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SMALLWOOD DAM
INUNDATION MAPS
DAM REMOVED
(SHEET 6 OF 9)

March 2021 Figure D-6

NOTES AND LEGEND:

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- Sheet Index
- Roads
- Structures
- 100-Year - No Dam
- Half PMF - No Dam
- Full PMF - No Dam

N E S W

0 250 500 1,000

Scale, Feet

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SMALLWOOD DAM
INUNDATION MAPS
DAM REMOVED
(SHEET 7 OF 9)

March 2021

Figure D-7

NOTES AND LEGEND:

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Sheet Index
Roads
Structures
100-Year - No Dam
Half PMF - No Dam
Full PMF - No Dam

0 250 500 1,000
Scale, Feet

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SMALLWOOD DAM
INUNDATION MAPS
DAM REMOVED
(SHEET 8 OF 9)

March 2021

Figure D-8

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- Sheet Index
- Roads
- Structures
- 100-Year - No Dam
- Half PMF - No Dam
- Full PMF - No Dam

0 250 500 1,000
Scale, Feet

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SMALLWOOD DAM
INUNDATION MAPS
DAM REMOVED
(SHEET 9 OF 9)

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