Engineers, Surveyors, Planners, Scientists

MEMO

Date: December 22, 2023

To: CJ Onyak, PE – Northeast Ohio Regional Sewer District

From: Shawn Arden, PE; Sam Austen, EI

Subject: Project 1641: Vaughn Road Flooding Mitigation
Cuyahoga River HEC-RAS Analysis with USGS Provisional Model

Copies: File

1.0 Introduction

EMH&T is providing this memorandum to summarize a hydraulic analysis performed in support of Northeast Ohio Regional Sewer District (NEORSD) Project 1641: Vaughn Road Flood Mitigation. NEORSD requested EMH&T to evaluate the flood hazard impacts associated with Project 1641 and the adjacent Bend 6 Channel Lengthening Project proposed by the United States Army Corps of Engineers (USACE). For this analysis, EMH&T was provided a provisional existing condition hydraulic model of the Cuyahoga River in the vicinity of Vaughn Road prepared by the United States Geological Survey (USGS). EMH&T reviewed the model to evaluate its correlation to a rating curve for an existing USGS stream gaging station at Jaite (located immediately downstream of Vaughn Road) and to evaluate the flood hazard impacts of the proposed projects. The model was reviewed to determine the resulting level of service for Vaughn Road and the flood hazard impacts upstream near Boston Mills upon implementation of both projects.

2.0 Technical Analysis

EMH&T performed the hydrologic and hydraulic calculations in this evaluation following standard FEMA guidelines for similar riverine flood hazard investigations. Peak streamflow rates were determined through a statistical analysis following techniques published by the USGS. Riverine hydraulic calculations were performed using the USACE HEC-RAS computer program.

2.1 Floodplain Hydrology

EMH&T estimated peak discharge rates for the Cuyahoga River at various recurrence intervals using statistical methods published in Bulletin 17C using data recorded at USGS gaging stations. Three stations are present on this segment of the Cuyahoga River: USGS gaging station 04208000 located downstream of Old Rockside Road in Independence, USGS gaging station 04206000 upstream of Portage Path in Akron, and USGS gaging station 04206425 directly downstream of

Vaughn Road in Brecksville (Jaite), Ohio. The gage period of record and drainage areas are provided in Table 1.

TABLE 1
USGS Gaging Station Information

Gaging Station	Location	Drainage Area (Square Miles)	Period of Record (Years)
04208000	Independence	707	94
04206425	Jaite	555	11
04206000	Akron	404	100

Bulletin 17C statistical methods develop a flood flow-frequency curve at a given location by fitting annual peak streamflow rates to a log-Pearson Type III distribution. Separate flood flow-frequency curves can be developed for each gaging station. It is important to note that the USGS developed new rating curves for Jaite (Gaging Station 04206425) and Independence (Gaging Station 04208000) in 2023 in conjunction with a flood inundation mapping study being conducted at NEORSD's request. The pre-September 2023 and revised September 2023 rating curves are shown in Figure 4, in addition to the field measurements for flow and stage that were collected by USGS personnel. The rating curve revision has resulted in USGS publishing revised annual peak streamflow rates for the Jaite gaging station; the USGS has not published revised annual peak streamflow rates for the Independence gaging station.

Gaging Station 04206425 at Jaite does not have a long enough period of record to produce reliable peak streamflow estimates using Bulletin 17C statistical methods. Therefore, EMH&T utilized methods for gage adjusted peak discharge values published in USGS WRIR 03-4164 "Techniques for Estimating Flood-Peak Discharges of Rural, Unregulated Streams in Ohio" to estimate peak flows at this location using the Bulletin 17C results from the gage at Independence. The resulting peak discharge rates for the Cuyahoga River at Jaite are provided in Table 2. These discharge rates were utilized for the Project 1641 hydraulic design calculations and to calibrate Manning's n values.

Separate from EMH&T's analyses for Project 1641, USACE performed a detailed hydrologic study for the Cuyahoga River watershed. Hydrologic calculations were performed using the USACE HEC-HMS computer program with calibration to the USGS gaging station at Independence. This study produced a 100-year flood hydrograph for the Cuyahoga River with a peak discharge rate of 18,710 cfs. EMH&T utilized this hydrograph for floodplain management purposes, specifically to determine if there are any upstream impacts to existing structures in the Boston Mills area. Peak discharge rates at Vaughn Road reported by USACE for other recurrence intervals are also shown in Table 2.

TABLE 2
Estimated Cuyahoga River Peak Discharge Rates at Vaughn Road

Recurrence Interval (Years)	USACE Flow (cfs)	EMH&T Flow (cfs)
2	8,263	8,600
5	11,067	11,800
10	12,912	14,100
25	15,257	16,900
50	16,934	19,600
100	18,710	22,200

Both EMH&T and USACE based their hydrologic calculations, in part, on annual peak streamflow rates recorded at the USGS gaging station in Independence. The USGS did not update published annual peak streamflow values at the Independence station associated with the 2023 rating curve update. Therefore, the flood flow-frequency values presented in Table 2 were not affected by the 2023 USGS rating curve update.

2.2 Hydraulics

2.2.1 USGS Provisional Existing Condition Model: The USGS provided NEORSD with a provisional existing condition HEC-RAS model for the Cuyahoga River for use in this evaluation. The model was developed in HEC-RAS v6.1 as a 1-dimensional steady-state model and includes an approximately 32,000 foot reach of the Cuyahoga River from just downstream of I-271 to just upstream of the confluence with Chippewa Creek. The USGS model applied a channel Manning's n value of 0.046 and an overbank Manning's n value of 0.08. EMH&T executed the model as it was provided by the USGS. A discharge rating curve at the Jaite gaging station location was extracted from the model and overlaid with the published USGS rating curve for the gaging station. This plot is shown in Figure 4. The rating curve from the USGS 1-dimensional steady-state model compares similarly to the USGS field observations at the gaging station.

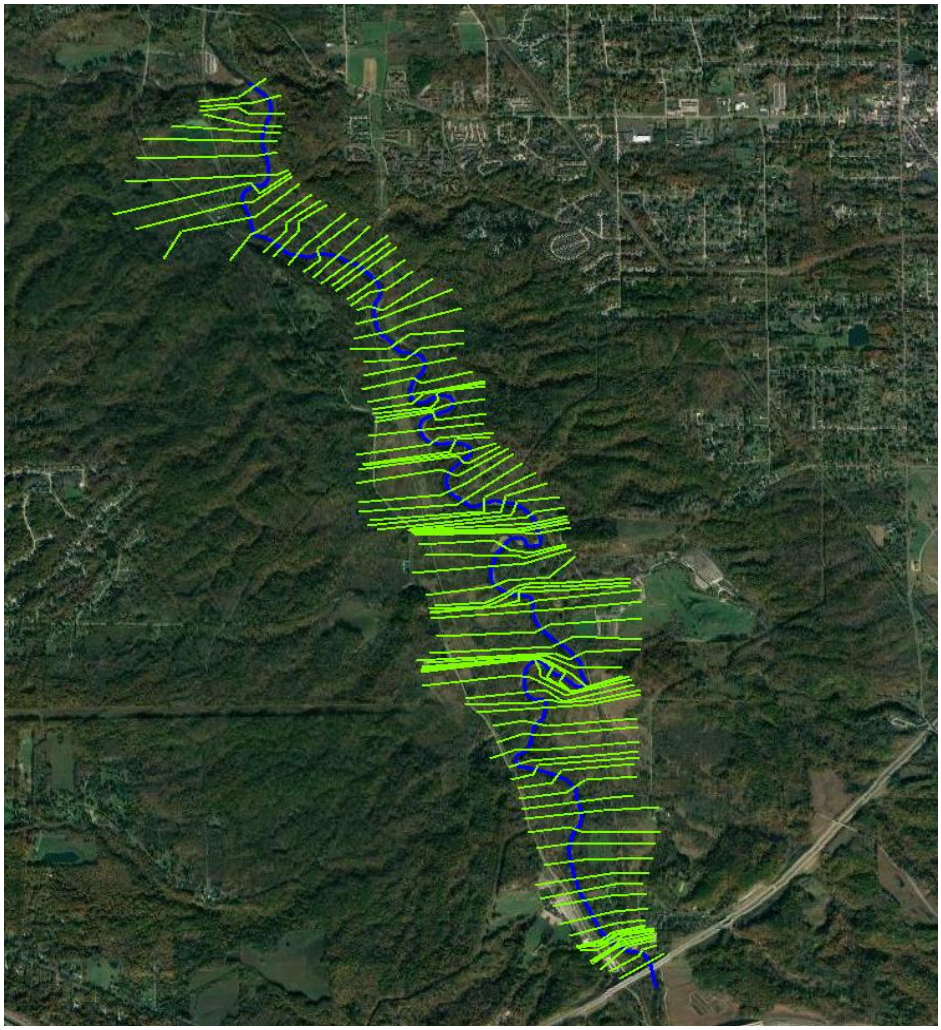


Figure 1. Limits of USGS Provisional Model from I-271 to confluence with Chippewa Creek

2.2.2 Modified Existing Condition Model (ECM): Based on our previous hydraulic evaluations of the proposed NEORSD and USACE projects at Vaughn Road, EMH&T believes a 2-dimensional analysis is required to accurately represent the hydraulic conditions at Vaughn Road for these projects. EMH&T replaced the existing condition 1-dimensional cross sections in the USGS model with a 2-dimensional mesh from River Stations 24530 to 9970 (refer to Figure 2) using the terrain provided by the USGS. The 2-dimensional mesh bounding locations were selected to coincide with locations where channel and overbank flow direction are in alignment and far enough away from Vaughn Road as to not influence the hydraulic calculations at this point of interest. EMH&T applied the same Manning's n values to the 2-dimensional mesh as were applied to the USGS provisional 1D cross sections (channel = 0.046, overbanks = 0.08).

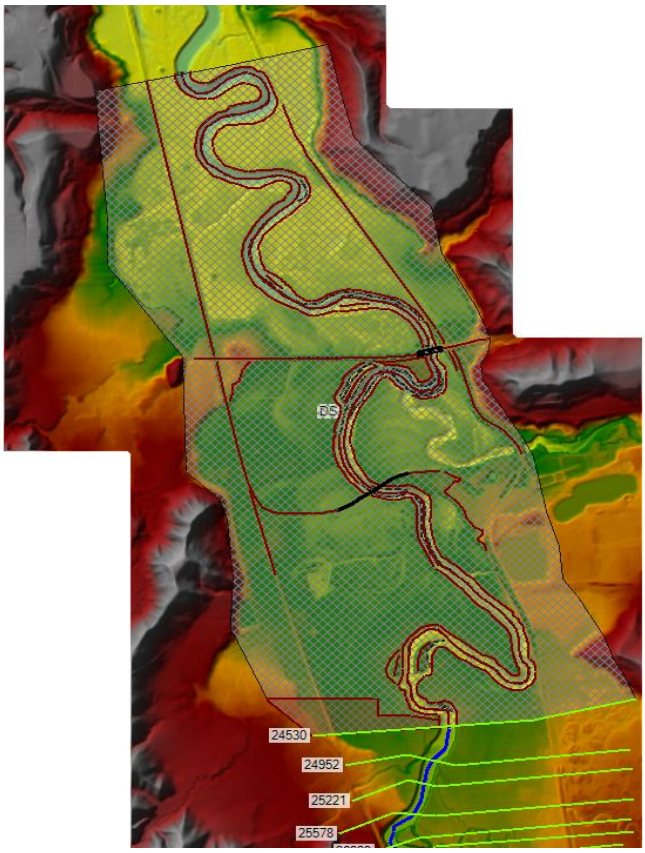


Figure 2. Existing Conditions Model 2-dimensional Mesh Location

1-dimensional inline connections with a 2-dimensional mesh require the edge of the mesh to be directly in-line with the upstream cross section. EMH&T found that adjusting the ineffective areas at River Station 24530 and the upstream cross sections was advantageous in creating a smooth transition from the 1-dimensional reach. Analyses of the reach downstream of River Station 9970 identified significant model instabilities when interfacing with the 2-dimensional mesh, thus the additional model geometry downstream of River Station 9970 was truncated from the model. A new external downstream boundary condition was inserted at this location with a normal depth slope of 0.0004 ft/ft, which is similar to the energy grade line slope at this location in the provisional model. Channel geometry detail was added to the 2-dimensional mesh using data from the provisional model cross sections via the terrain modification toolset.

A discharge rating curve at the Jaite stream gauge location was extracted from the model and overlaid with similar rating curves from other models evaluated by EMH&T. This plot is shown in Figure 5. The rating curve for the Modified ECM shows less discharge than the USGS published rating curve for the gaging station, the USGS field measurements, and the USGS provisional existing condition model. This result may be an indicator that the 2-dimensional mesh has incorporated additional losses into the model that were not present in the 1-dimensional provisional model.

EMH&T also executed the Modified ECM for the USACE 100-year flood hydrograph to evaluate flood hazard impacts at Boston Mills. The Modified ECM resulted in similar 100-year peak flood elevations at Boston Mills as the USGS Provisional Existing Condition Model. These elevations were 657.24 and 657.33 for the Modified ECM and USGS Provisional Existing Condition Model, respectively.

2.2.3 Calibrated Modified Existing Condition Model (ECM): Noting the discharge rating curve for the Modified ECM was underestimating discharge as compared to the various USGS calculations discussed in the prior section, EMH&T developed a calibrated version of the Modified ECM to better replicate the USGS results at the Jaite gaging station. This effort required the Manning's n value for the channel section in the 2-dimensional mesh to be lowered from 0.046 to 0.040. The resulting discharge rating curve at Jaite is shown in Figure 5, and exhibits improved correlation to the USGS calculations when streamflow is contained within the channel. For the USACE 100-year flood hydrograph, the 100-year peak flood elevation at Boston Mills was again 657.24, consistent with the Modified ECM. The inundation mapping for the Calibrated Modified Existing Condition Model with the 100-year USACE hydrograph is provided in Exhibit 1.

EMH&T further evaluated the Calibrated Modified ECM to determine if detailed 2-dimensional overbank Manning's n values would result in significant changes to the overbank water surface elevations. Sections were added to the Manning's n grid in the RAS Mapper tool for short grass (n = 0.035), gravel (n = 0.025), light brush and trees in summer (n = 0.06), and medium to dense brush in summer (n = 0.100). The added detail did not result in significant changes in peak water surface elevations in the 2-dimensional mesh area. The results of the models with and without the detailed Manning's n overbank values can be seen in Table 3. Based on these results the detailed Manning's n values were not carried forward in the analyses.

Table 3
Model Results With Simplified and Detailed Manning's n Overbank Values

Measurement Location	Simplified n Model Water Surface Elevation (ft)	Detailed n Model Water Surface Elevation (ft)
At upstream of Vaughn Rd Bridge	645.77	645.77
At Jaite, OH gage	645.30	645.27
Maximum WSE at Roadway	645.98	645.97

2.2.4 Proposed Condition Model: EMH&T developed a proposed condition model building from the Calibrated Modified ECM. The proposed roadway grading for NEORSD Project 1641 (overtopping elevation = 646.0) as well as proposed geometry for the USACE Channel Lengthening Project were carried over from previous EMH&T models to this model terrain via the terrain modification toolset. These project locations are shown in Figure 3. EMH&T analyzed additional scenarios for the Vaughn Road improvement, with the proposed roadway elevation raised to 647.0'

and 648.2'. The Calibrated Modified ECM 100-year flood profile and the 100-year flood profiles of each proposed condition alternative can be found in Figure 6.

EMH&T executed the proposed condition model using the USACE 100-year flood hydrograph to evaluate flood hazard impacts to existing structures in the Boston Mills area. Peak flood elevations computed for the various model scenarios (comparison of Calibrated Modified ECM to Proposed Condition Model) are shown in Table 4. The analyses indicate that the proposed NEORSD and USACE projects will result in an increase in 100-year peak water surface elevations upstream of the improvements, but these increases will dissipate and return to the existing condition flood profile prior to reaching Boston Mills. Further, the analyses also indicate the alternative scenarios to raise the Vaughn Road profile to 647.0' and 648.2' will also not result in an increase in 100-year flood elevations affecting structures at Boston Mills. Higher roadway elevations for Vaughn Road will extend the location where the proposed condition flood profile returns to match the existing condition flood profile, as shown in Table 5. The 100-year flood inundation mapping for each proposed condition scenario is included on Exhibit 1.

TABLE 4
100-Year Peak Water Surface Elevations at Boston Mills

Upstream Boston Cross Section	Vaughn Rd Elev.			
	Calibrated MECM	646.00'	647.00'	648.20'
XS 29806	657.24	657.24	657.24	657.24
XS 29981	657.54	657.54	657.54	657.54
XS 30386	658.07	658.07	658.07	658.07

Table 5
Location Where 100-Year Flood Profile Ties Back to Existing Condition for Each Proposed Roadway Raising Scenario

Vaughn Road Proposed Elevation (ft)	First Unimpacted River Station Upstream of Vaughn Road
646.00'	27648
647.00'	28298
648.20'	29495[1]

1. First cross section downstream from Boston Mills

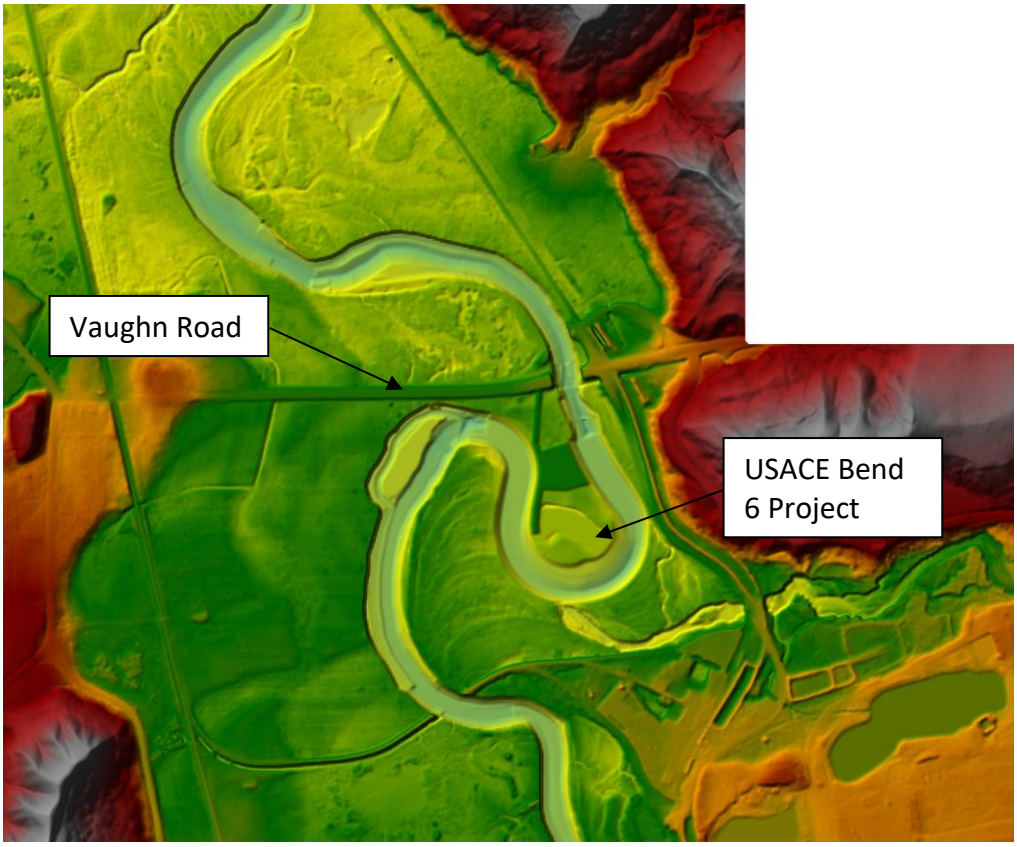


Figure 3. Proposed Conditions Location with Roadway raised to 646' and Bend 6 Constructed

EMH&T also executed the proposed condition model using the EMH&T developed design storm flood hydrographs to evaluate the resultant overtopping frequency for Vaughn Road following implementation of the NEORSD and USACE projects. Peak flood elevations computed for the various model scenarios at the Vaughn Road overtopping location are shown in Table 6. Peak flood elevations computed for the various model scenarios at the Jaite gaging station downstream of Vaughn Road are shown in Table 7. Peak velocities through the existing Vaughn Road bridge are shown in Table 8.

The analyses indicate that Vaughn Road will overtop at a discharge rate of approximately 12,000 cfs. This represents a 5-year level of service using the design peak discharge rates, and approximately a 7.5-year level of service using the USACE peak discharge rates. Based on the revised USGS peak annual streamflow measurements at the Jaite gage, recorded streamflow exceeded 12,000 cfs in one year (2014) over the eleven year period of record for the gaging station. Refer to Section 3.0 – Discussion for additional information.

3.0 Discussion

The goals of this analysis were to evaluate the potential flood hazard impacts of the proposed projects at an upstream location near Boston Mills, as well as the resultant level of service for Vaughn Road with respect to overtopping during a flood event. The hydraulic models indicate that the proposed projects will not result in an increase in 100-year flood elevations at Boston Mills. The Calibrated Modified ECM and the Proposed Condition Model each indicate a peak 100-year water surface elevation of 657.24 near Boston Mills.

The Proposed Condition Model indicates that Vaughn Road (elevated to 646.0') will overtop at a discharge rate of approximately 12,000 cfs. Based on the modeling performed, this correlates to a 5-year level of service using the design discharge rates and approximately a 7.5-year level of service using the USACE discharge rates. It should be noted that the discharge rating curve for the Calibrated Modified ECM reasonably matches the USGS field measurements, which were collected during non-flood conditions (streamflow rates generally less than 6,000 cfs). Although constant Manning's n values are commonly used in hydraulic analyses, it is widely accepted that n values tend to decrease relative to increases in flow depth. This is an indicator that the channel Manning's n value used in the model (0.040) may be conservative for analysis of higher streamflow rates. Finally, EMH&T has observed through prior modeling for Project 1641 that the discharge rate associated with initial Vaughn Road overtopping is highly dependent on channel conveyance and the selected channel Manning's n value. Based on these statements, EMH&T anticipates the Proposed Condition Model is conservative and the actual recurrence interval associated with Vaughn Road overtopping is closer to (but not necessarily achieving) the desired 10-year event than is reflected in the model results.

The additional modeling scenarios indicate that if Vaughn Road were to be raised to elevation 647.0' with the USACE project complete, the flow required to initiate roadway overtopping would increase to approximately 14,100 cfs, which is the approximately the 10-year design flow. Similarly, if Vaughn Road was raised to 648.2' with the USACE project complete, the discharge rate at initial overtopping is approximately 16,300 cfs, which is equivalent to between a 10-year and 25-year event. Further increases in the proposed roadway elevation will result in additional incremental increases in the overtopping level of service. However, these scenarios also include the following risks:

- Additional increases in peak velocity and scour potential at the Vaughn Road bridge (as shown in Table 8)
- Additional increases in peak velocity potentially affecting the USACE Bend 6 improvement.
- Additional lateral encroachment outside of the existing Vaughn Road right-of-way into park lands (Cuyahoga Valley National Park and Cleveland Metroparks).
- Additional risks to roadway embankment erosion during flood events.
- Additional construction cost associated with increased embankment and stabilization quantities.

Given the above information, the proposed roadway design at elevation 646.0' is expected to provide a level of service between a 5-year and 10-year event. Considerations to achieve additional level of service benefits may be better served by focusing on future replacement (widening) of the Vaughn Road bridge instead of further raising of the roadway profile.

TABLE 6
Peak Water Surface Elevations for Various Design Discharge Rates at Vaughn Road

Flood Frequency	EMH&T Estimated Cuyahoga River Qpeak at Vaughn Road	WSE at Roadway Overtopping Point (ft)			
		Existing (640.8')	Vaughn Road Elevation 646.0'	Vaughn Road Elevation 647.0'	Vaughn Road Elevation 648.2'
-	1,000 cfs	634.41	635.78	635.78	635.78
-	2,500 cfs	637.36	638.43	638.43	638.43
-	4,000 cfs	639.61	640.55	640.55	640.55
-	5,510 cfs	641.52	642.35	642.35	642.35
-	6,010 cfs	641.90	642.80	642.80	642.80
2yr	8,600 cfs	643.53	644.51	644.50	644.51
5yr	11,800 cfs	644.53	645.88	645.88	645.88
10yr	14,100 cfs	645.10	646.70	647.03	647.09
25yr	16,900 cfs	645.66	647.19	647.80	648.36
50yr	19,600 cfs	646.16	647.53	648.26	649.16
100yr	22,200 cfs	646.70	647.86	648.57	649.53

1. Overtopping range highlighted.

Table 7
Peak Water Surface Elevations for Various Design Discharge Rates at Jaite, OH Stream Gage

Flood Frequency	EMH&T Estimated Cuyahoga River Qpeak at Vaughn Road	WSE at Gauge (ft)			
		Existing	Vaughn Road Elevation 646.0'	Vaughn Road Elevation 647.0'	Vaughn Road Elevation 648.2'
-	1,000 cfs	634.15	634.15	634.15	634.15
-	2,500 cfs	637.02	637.02	637.02	637.02
-	4,000 cfs	639.22	639.21	639.21	639.21
-	5,510 cfs	641.07	641.06	641.06	641.06
-	6,010 cfs	641.51	641.50	641.50	641.50
2yr	8,600 cfs	642.94	642.99	642.99	642.99
5yr	11,800 cfs	643.84	644.06	644.06	644.06
10yr	14,100 cfs	644.38	644.68	644.75	644.75
25yr	16,900 cfs	644.97	645.24	645.40	645.48
50yr	19,600 cfs	645.51	645.71	645.84	645.97
100yr	22,200 cfs	645.98	646.10	646.22	646.35

Table 8
Peak Velocity Through the Bridge

Flood Frequency	EMH&T Estimated Cuyahoga River Qpeak at Vaughn Road	Peak Velocity Through Bridge (ft/s)			
		Existing	Vaughn Road Elevation 646.0'	Vaughn Road Elevation 647.0'	Vaughn Road Elevation 648.2'
-	1,000 cfs	3.3	3.3	3.3	3.3
-	2,500 cfs	5.0	4.8	4.8	4.8
-	4,000 cfs	6.2	5.9	5.9	5.9
-	5,510 cfs	6.9	6.7	6.7	6.7
-	6,010 cfs	7.2	7.0	7.0	7.0
2yr	8,600 cfs	8.4	8.6	8.6	8.6
5yr	11,800 cfs	9.3	10.1	10.1	10.1
10yr	14,100 cfs	9.7	11.0	11.3	11.3
25yr	16,900 cfs	10.0	11.2	12.3	12.7
50yr	19,600 cfs	10.2	11.6	12.5	13.0
100yr	22,200 cfs	10.3	12.0	12.7	13.2

Figure 4
USGS Pre September 2023 Rating Curve vs Revised September 2023 Rating Curve at Jaite, OH Gaging Station with Field Measurements

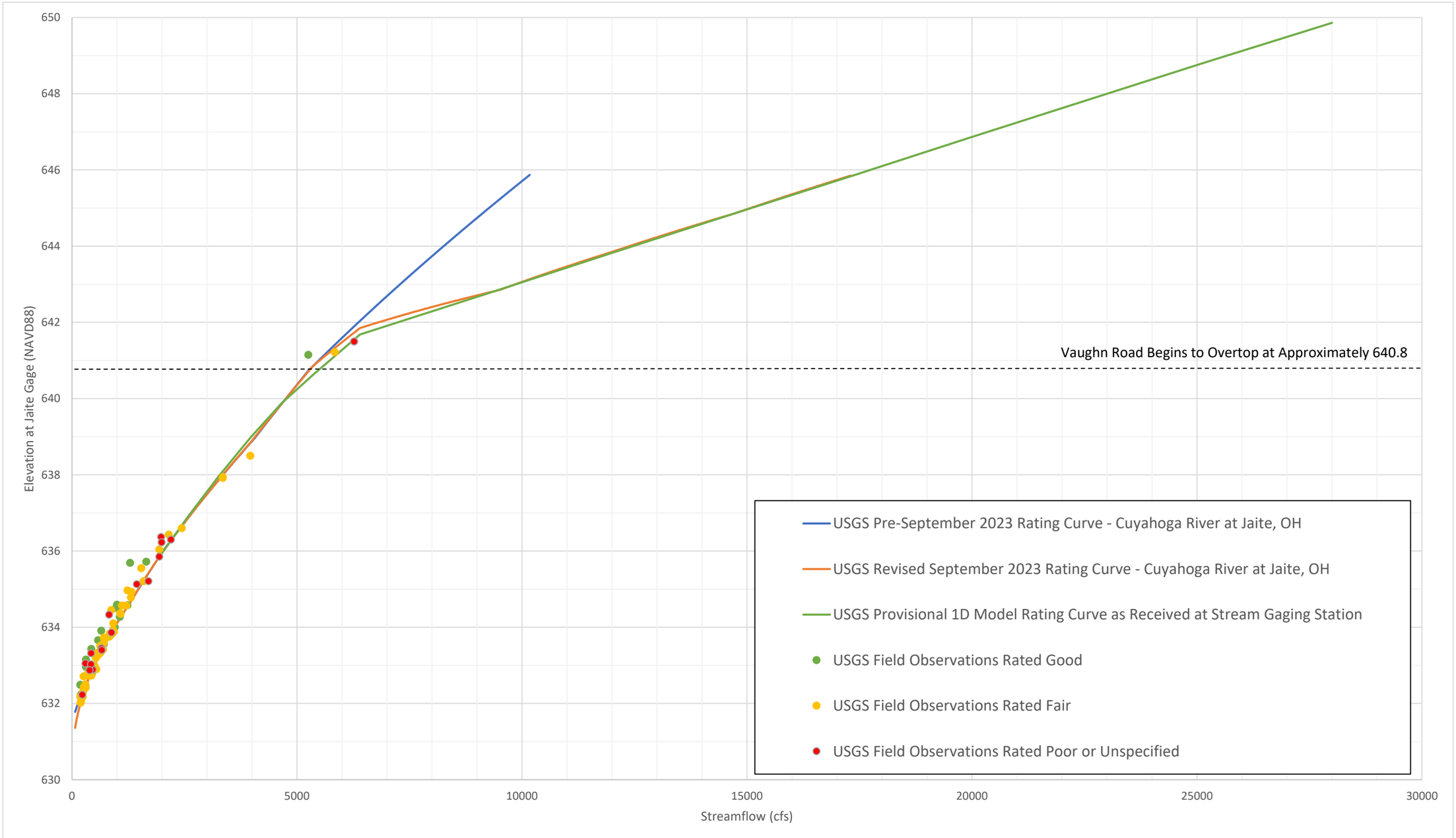


Figure 5
USACE and EMH&T Existing Condition Model Rating Curves with USGS Revised September 2023 Rating Curve at Jaite, OH Gaging Station

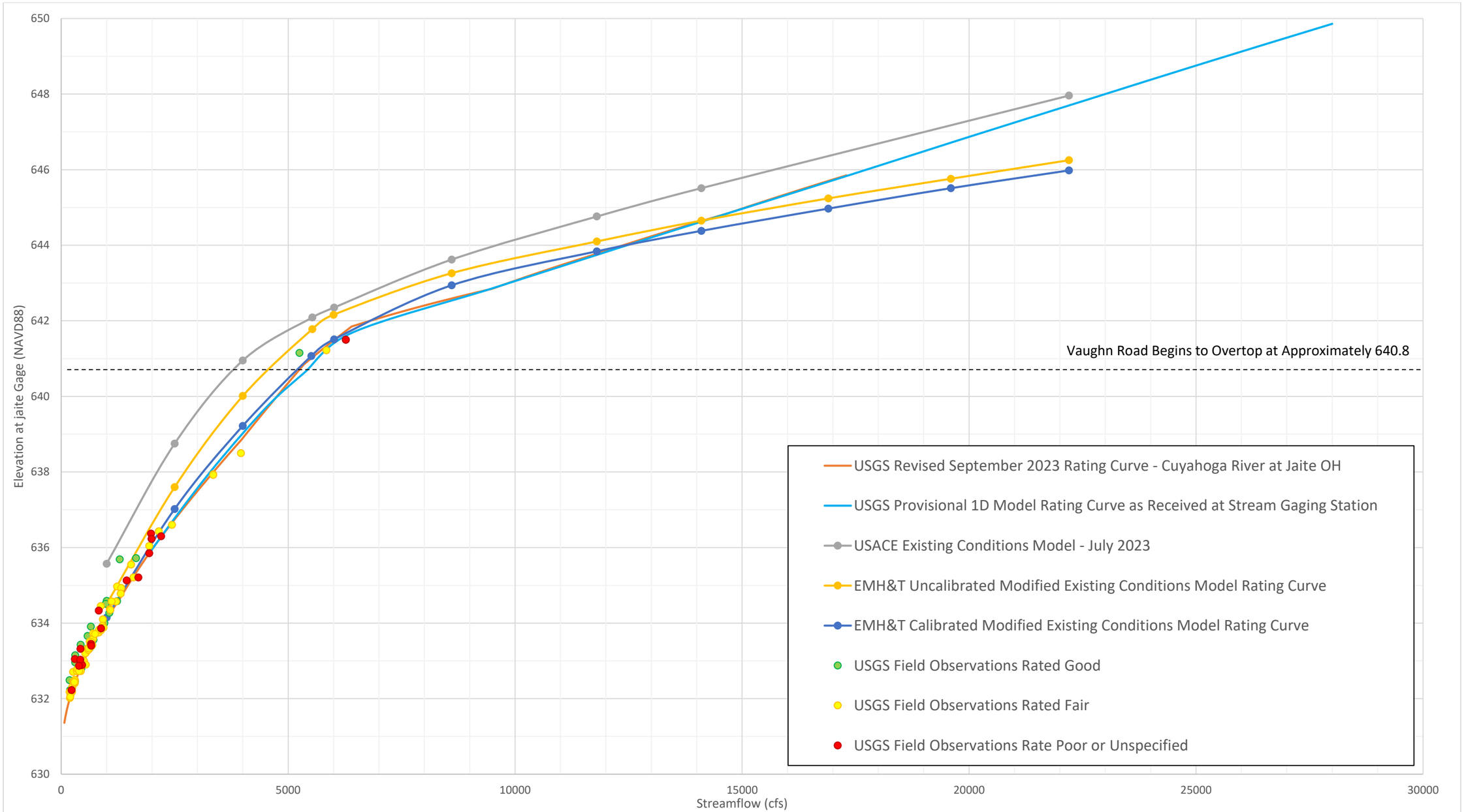
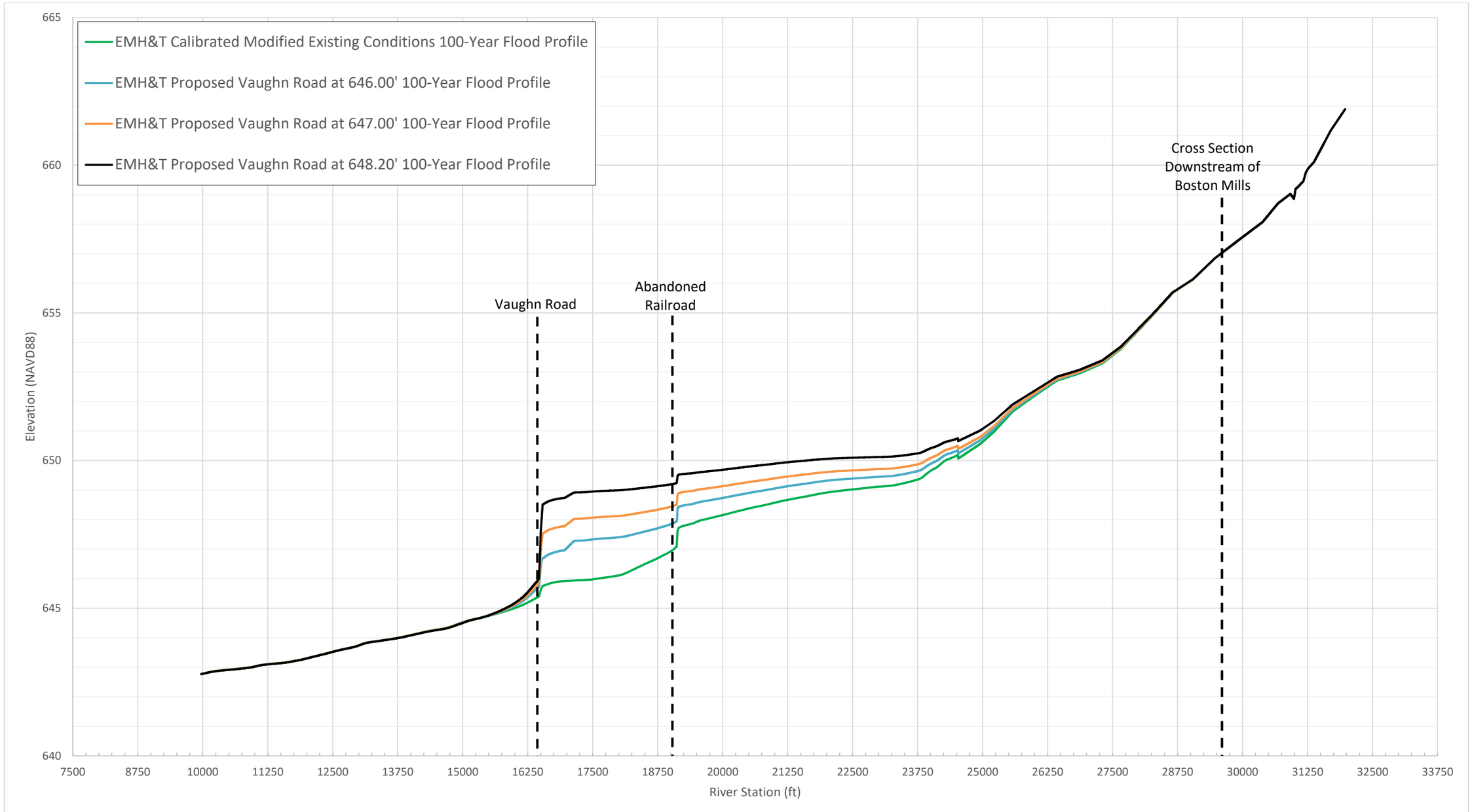


Figure 6
Proposed Condition 100-Year Flood Profiles – Vaughn Road at Elevation 646.00', 647.00', and 648.20' Alternatives



LEGEND

- Calibrated Modified Ex. Condition 100–Year Floodplain
- Prop. Vaughn Rd at 646.00' 100–Year Floodplain
- Prop. Vaughn Rd at 647.00' 100–Year Floodplain
- Prop. Vaughn Rd at 648.20' 100–Year Floodplain
- Ex. Model Cross Section
- 2–Dimensional Mesh Perimeter
- County Boundary

SOURCE

Elevation
- USGS Terrain
- CVE Field Survey (2021)

Imagery
- Cuyahoga County (2017)
- Summit County (2017)

Floodplain Elevation
- EMH&T Hydraulic Analysis (2023)

Horizontal Datum: NAD 1983 State Plane Ohio North
Vertical Datum: North American Vertical Datum of 1988

CUYAHOGA COUNTY

SUMMIT COUNTY

RIVERVIEW RD

VAUGHN RD

W HIGHLAND RD

SNOWVILLE RD

CUYAHOGA RIVER

Vaughn Road - Roadway Project Limits

MATCH LINE – SEE SHEET 02

GRAPHIC SCALE
0 150 300 600
1 inch = 300 feet

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Northeast Ohio Regional Sewer District

CITY OF BRECKSVILLE, CUYAHOGA COUNTY, OHIO
EXHIBIT
FOR
VAUGHN ROAD FLOOD MITIGATION PROJECT 1641
EXHIBIT 1: INUNDATION MAPPING

NORTHEAST OHIO REGIONAL SEWER DISTRICT

DATE	JOB NO.
DECEMBER 22, 2023	2021-0275
SCALE	SHEET
1" = 300'	01/02

MATCH LINE – SEE SHEET 01

CUYAHOGA COUNTY
SUMMIT COUNTY

COLUMBIA RD

RIVERVIEW RD

CUYAHOGA RIVER

BOSTON MILLS RD

W HINES HILL RD

I-271

24530
24952
25221
25578
26029
26431
26857
27301
27648
27896
28298
28652
29047
29495
29806
29981
30386
30678
30919
30988
31017
31082
31169
31217
31266
31373
31697
31973

GRAPHIC SCALE
0 150 300 600
1 inch = 300 feet

LEGEND

- Calibrated Modified Ex. Condition 100–Year Floodplain
- Prop. Vaughn Rd at 646.00' 100–Year Floodplain
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- Ex. Model Cross Section
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SOURCE

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- Summit County (2017)

Floodplain Elevation
- EMH&T Hydraulic Analysis (2023)

Horizontal Datum: NAD 1983 State Plane Ohio North
Vertical Datum: North American Vertical Datum of 1988

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Northeast Ohio Regional Sewer District

CITY OF BRECKSVILLE, CUYAHOGA COUNTY, OHIO
EXHIBIT
FOR
VAUGHN ROAD FLOOD MITIGATION PROJECT 1641
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NORTHEAST OHIO REGIONAL SEWER DISTRICT

DATE	JOB NO.
DECEMBER 22, 2023	2021-0275
SCALE	SHEET
1" = 300'	02/02

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