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Hydrologic and Hydraulic Analyses of Selected Streams in Erie County, Ohio

By K. Scott Jackson, Chad J. Ostheimer, and
Matthew T. Whitehead

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In Cooperation with the
Erie County Engineer and Vermilion Township of Erie County, Ohio

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CONTENTS

PLATES

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FIGURES

TABLES

CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

Multiply	By	To obtain
foot (ft)	0.3048	meter
square mile (mi^2)	2.590	square kilometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second

In this report, all elevations are referenced to the North American Vertical Datum of 1988 (NAVD88).

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Abstract

Hydrologic and hydraulic analyses were done for parts of Abel Ditch, Edson Creek, Maurer Ditch, and Sherod Creek[1] in northeastern Vermilion Township, Erie County, Ohio. For each stream, instantaneous peak discharges for floods having recurrence intervals of 2, 5, 10, 25, 50, and 100 years were estimated using regional regression equations. Factors used in the regression equations were drainage area, a basin development factor, and average annual precipitation. Drainage areas at the selected stream locations ranged from 0.41 to 4.61 square miles.

A step-backwater model was used to determine water-surface elevation profiles for the 10-year-recurrence-interval (10-year) flood along a selected reach of each stream. The water-surface profile information was then used to prepare a map of flood-plain boundaries. Hydraulic analyses indicated that the 10-year flood was generally confined within the stream channels. At three locations, however, some of the flood discharge escaped the main channel and flowed overland. In two cases, the overland flow returned to the channel from which it escaped. In the third case, flow drained into an adjacent basin. A separate analysis, in which concurrent flood peaks on the streams studied were assumed, indicated that water would spill over the Sherod Creek and the Maurer Ditch divides and that some of this water would eventually enter the Edson Creek Basin downstream from the study area.

[1]Locally the upper reach of Sherod Creek, south of the Conrail Railroad, is known as Japson Ditch. However, for simplicity it will be referred to as Sherod Creek along its entirety.

Introduction

The upper basins of four streams, Abel Ditch, Edson Creek, Maurer Ditch, and Sherod Creek[1], in the vicinity of the city of Vermilion, Erie County, Ohio, have recently undergone residential and commercial development, and more development is expected in the future. Development in the upper basins may result in increases in peak flood discharges, potentially causing increased flood damages along the downstream reaches of these streams. The Erie County Engineer and Vermilion Township officials are considering various options to mitigate downstream flood damages on the four streams. In order to assess the alternatives for flood protection, Erie County, Vermilion Township of Erie County, and the U.S. Geological Survey (USGS) initiated a cooperative study to investigate aspects of the hydrology and hydraulics of the four streams.

Description of the study area

Erie County is in north-central Ohio along the southern shore of Lake Erie (figure 1). The city of Vermilion lies in the northeastern corner of Erie County and the northwestern corner of Lorain County. The four streams of concern flow northward and drain into Lake Erie. Parts of the stream reaches have been

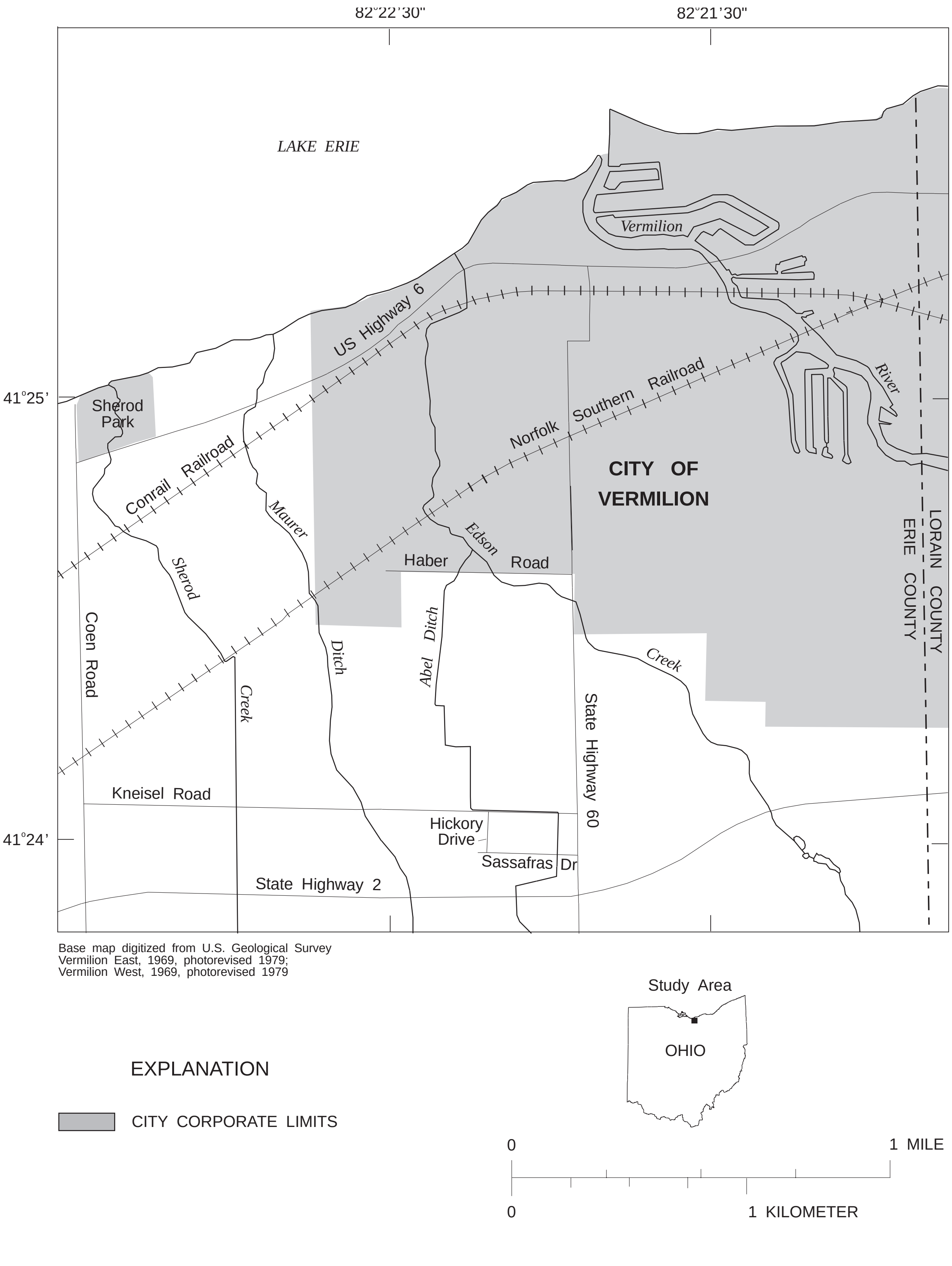


Figure 1. Location of study area near Vermillion, Ohio.

straightened and periodically cleared of brush and debris along the banks. No flood protection measures (levees or dikes) are currently in place along any of the stream reaches.

The areas of the most concentrated residential development in these otherwise rural, lightly populated stream basins are along State highway 60 and between Kneisel Road and State Highway 2. The Erie County Engineer expects more development to occur in future years within the four watersheds.

Purpose and scope

This report describes methods and results of hydrologic and hydraulic analyses of Abel Ditch, Edson Creek, Maurer Ditch, and Sherod Creek. The analyses include (1) estimates of peak flood discharges corresponding to floods with recurrence intervals of 2, 5, 10, 25, 50, and 100 years and (2) determination of water-surface-elevation profiles and flood-plain boundaries corresponding to the 10-year-recurrence-interval (10-year) flood. As part of the analyses, the 10-year flood profiles were developed along the four streams in order that local officials may assess various alternatives to mitigate flood damages.

Hydraulic analyses were done for selected reaches of the four streams studied. The downstream limit of the hydraulic analyses for Abel Ditch and Edson Creek is the Vermilion corporate boundary (along Haber Road) and the upstream limit is State Highway 2. The hydraulic analyses for Maurer Ditch and Sherod Creek were studied from their mouths (at Lake Erie) to State Highway 2.

Acknowledgments

The authors appreciate the support of the Erie County Commissioners and the Vermilion Township Trustees. The authors also appreciate the cooperation of personnel of the Office of the Erie County Engineer in this study. In particular, the authors would like to thank Kenneth Fortney, Erie County Drainage Superintendent, for providing technical assistance and reviews throughout the investigation.

Study methods

Data collection

Field visits were made to Erie County to collect data needed to determine stream channel roughness-coefficients (Manning’s *n*), cross-section elevations, and hydraulic structure geometries. Drainage-basin divides for the streams, initially defined on topographic maps, were field checked for accuracy. Most of the channel and overbank cross-section elevation data for use in the hydraulic models were obtained from field surveys. In some cases, elevation data were estimated by interpolation between surveyed cross sections. For this investigation, 95 cross sections were surveyed and 34 sections were interpolated. Additionally, in a few instances, some overbank elevation data were obtained from 2-ft-contour maps supplied by the Erie County Engineer.

Geometries of 19 culverts also were surveyed. Three culverts currently in place along Kneisel Road are scheduled for replacement by the Erie County Engineer in the near future. The design plans for these new culverts were obtained from the Engineer to ensure that the hydraulic models developed for this investigation would reflect future conditions. All surveys by the USGS met or exceeded third-order vertical accuracy standards (Federal Geodetic Control Committee, 1984) and are referenced to the North American Vertical Datum of 1988 (NAVD88).

Estimation of peak flood discharge

No historical streamflow data are available for the four streams of interest in this study. The most applicable USGS flood-frequency report (Sherwood, 1993) was used to estimate peak flood discharges at selected locations along each of the four streams. This report was selected for use in this study because the basin characteristics of the four streams studied in Erie County (small basin size and varying degrees of urbanization) are similar to those for the streams used to develop multiple-regression equations in the report. Explanatory variables (drainage area, basin development factor, and average annual precipitation) were used to determine peak flood discharges having recurrence intervals of 2, 5, 10, 25, 50, and 100 years.

Drainage areas were determined by digitizing the field checked basin divides on U.S. Geological Survey 7.5-minute topographic quadrangle maps. The drainage areas of the study reaches range from 0.41 to 4.61 mi^2. The basin development factor, a measure of the urban development within the basin, was estimated according to methods described by Sherwood (1993). This factor is used to account for channel improvements, channel linings, storm drains, and curb-and-gutter streets (Sauer and others, 1983). Average annual precipitation was estimated using a map presented by Sherwood (1993).

Development of water-surface profiles

The step-backwater hydraulic analysis model HEC-RAS 2.1 (U.S. Army Corps of Engineers, 1997 a-c) was used to determine steady-state water-surface profiles for each of the four streams based on the 10-year peak discharges determined in the hydrologic analyses. Input data for the models included stream cross-section and hydraulic-structure geometries, 10-year peak discharges, and roughness coefficients. The four streams have narrow channels, generally ranging from about 5 to 15 ft in width. Typically, flows in small streams may encounter rapid transitions in channel geometry, likely leading to abrupt changes in cross-sectional area and conveyance between sections. To help diminish abrupt transitions of area and conveyance, the maximum distance between open-channel cross sections was held to less than 500 ft; however, the distance between sections in the models is typically much less than 500 ft.

HEC-RAS default values for expansion and contraction coefficients were used for most of the cross sections in the model. At select locations, typically upstream and downstream from hydraulic structures, default values for the coefficients were modified on the basis of engineering judgement. At structures with abrupt flow transitions, contraction- and expansion-loss coefficients were typically increased from the HEC-RAS default values to account for the additional losses.

Starting water-surface elevations for all four streams were established using the normal depth[2] (slope conveyance) option in HEC-RAS. A main-channel slope was computed using the average of main-channel streambed elevations from two surveyed cross sections near the downstream limit of each stream reach. These main-channel slopes were assumed to approximate the respective energy slopes for the purposes of normal depth calculations.

[2]Normal depth is the depth of uniform flow. Flow is considered uniform if the energy line, water surface, and channel bottom are all parallel (Chow, 1959).

Hydrologic analyses

Peak flood discharges having recurrence intervals of 2, 5, 10, 25, 50, and 100 years were estimated for selected locations along each stream. These estimates and the respective explanatory variables are listed in table 1. For Able Ditch and Edson Creek, the hydrologic analyses were extended beyond the downstream limit of the hydraulic analyses (Haber Road) to the mouths of the two streams.

Hydraulic analyses

All hydraulic analyses in this investigation were based on computations of one-dimensional, steady, gradually varied flow. The analyses are also based on the assumption that flow is unobstructed in all stream channels and through all hydraulic structures modeled. Flooding on each stream was initially evaluated independently of the other streams.

Values of selected hydraulic parameters used in the hydraulic models are listed in table 2. The results of the final hydraulic analyses done for this study are presented in tabular and graphical formats. Selected results of the HEC-RAS model are presented in tables 3 to 6 at the back of this report.

The locations of cross sections used in the models and the flood-boundary delineations for the stream reaches studied are shown on plate 1 in the back pocket of this report. Flood-boundary delineations were established using the computed edge-of-water stations at each cross section. The edge-of-water stations between adjacent cross sections were then connected by straight lines. In a few instances, at locations where the straight lines would cross the thalweg of the stream (near channel bends), visual interpolation was used to define the flood boundary.

Water-surface profiles corresponding to the 10-year flood are presented in figures 2 to 5 at the back of this report. These profiles show computed water-surface elevations plotted by distance from a reference location. Also depicted on the profiles are the minimum channel elevations at each cross section and the hydraulic structures.

Inspection of the water-surface profiles indicates that backwater[3] occurs on Maurer Ditch and

[3]Water backed up or retarded in its course as compared with its normal or natural condition (Langbein and Iseri, 1960).

Table 1. Hydrologic parameters and discharge estimates for selected locations in Erie County, Ohio

[Abbreviations; mi^2, square miles; in, inches: ft^3/s, cubic feet per second; ft, feet]

Location	Drainage area (mi^2)	Basin development factor[a]	Average annual precipitation[a] (in.)	Peak flood discharge estimates for selected recurrence intervals[a] (ft^3/s)					
				2-year	5-year	10-year[b]	25-year	50-year	100-year
ABEL DITCH									
At mouth[c]	0.67	3	33	65	109	139	184	216	252
2,850 ft upstream from Haber Road	.53	3	33	55	92	117	153	179	209
Kneisel Road	.49	3	33	52	88	111	146	170	198
EDSON CREEK									
At mouth[c]	4.61	1	33	219	396	538	745	912	1090
Norfolk Southern Railroad[c]	4.29	0	33	200	363	494	684	838	1000
Above Abel Ditch	3.48	0	33	174	313	423	583	711	849
3,477 ft upstream from Haber Road	3.26	0	33	166	299	403	555	676	807
MAURER DITCH									
At mouth	0.86	0	33	67	116	151	202	240	282
Norfolk Southern Railroad	.61	0	33	53	91	117	156	184	215
Kneisel Road	.41	0	33	41	69	87	115	134	157
SHEROD CREEK									
At mouth	1.28	3	33	100	173	225	301	358	421
Norfolk Southern Railroad	.87	3	33	77	132	169	225	266	311
Kneisel Road	.71	3	33	67	114	145	192	225	263

[a] For information on methods used to determine this item refer to Sherwood (1993).
[b] Peak flood discharge estimates used to determine the water-surface elevation profiles.
[c] Located downstream from study reach.

Table 2. Selected hydraulic parameters used for the step-backwater models in Erie County, Ohio

[Abbreviations: ft, feet; ft/ft, feet per foot]

Stream	Baseline reference location[a]	Number of cross sections surveyed	Number of cross sections interpolated	Number of hydraulic structures	Slope used for normal depth calculation (ft/ft)	Manning's roughness coefficient (n)			
						Lowest value for main channel	Highest value for main channel	Lowest value for overbanks	Highest value for overbanks
Abel Ditch	Haber Road	30	11	8	0.00905	0.032	0.075	0.025	0.044
Edson Creek	Haber Road	14	4	2	.00499	.032	.044	.042	.070
Maurer Ditch	Mouth	24	10	5	.02963	.032	.046	.028	.065
Sherod Creek	Mouth	27	9	7	.00513	.034	.052	.028	.045

[a] Downstream limit of the study reach.

Sherod Creek, upstream from the Conrail and the Norfolk Southern (NS) railroad embankments.

Because of the amount of backwater upstream from the NS railroad, two farm-field culverts (one on Maurer Ditch and one on Sherod Creek) were completely inundated, making culvert hydraulics inapplicable at these locations. Therefore, these two culverts were treated as open-channel cross sections in the models.

When road overflow occurs at a culvert, the HEC-RAS user's manual states that the model always uses a weir-flow computation to determine the amount of flow passing over the road (U.S. Army Corps of Engineers, 1997 c). The validity of the use of this type of computation must be checked. In order for a weir-flow computation to be considered valid, the road embankment must be high enough to cause the flow to pass through critical depth[4]. If the road-embankment heights are small enough, the road does not act like a weir, and a weir-flow computation is not valid. Instead, the road effectively acts as a contraction of open-channel flow. For situations in which road grades do not act like weirs, Shearman and others (1986) recommend abandoning culvert and weir hydraulics in favor of composite sections (the combination of the road and culvert cross-section geometries) to reflect pseudo-open-channel conditions.

Preliminary analyses indicated that road overflow may occur at one location on Sherod Creek and three locations on Abel Ditch. Analysis of the Sherod Creek profile indicated that flow would overtop a farm-field culvert (at river station 5187) and that the HEC-RAS weir-flow computation was appropriate at this structure. At the three locations along Abel Ditch, (river stations 0, 3044, and 5148) the road embankments were not high enough to cause weir flow to occur. Therefore, composite sections were used at these three locations to compute the water-surface profile.

Computation of overland flow

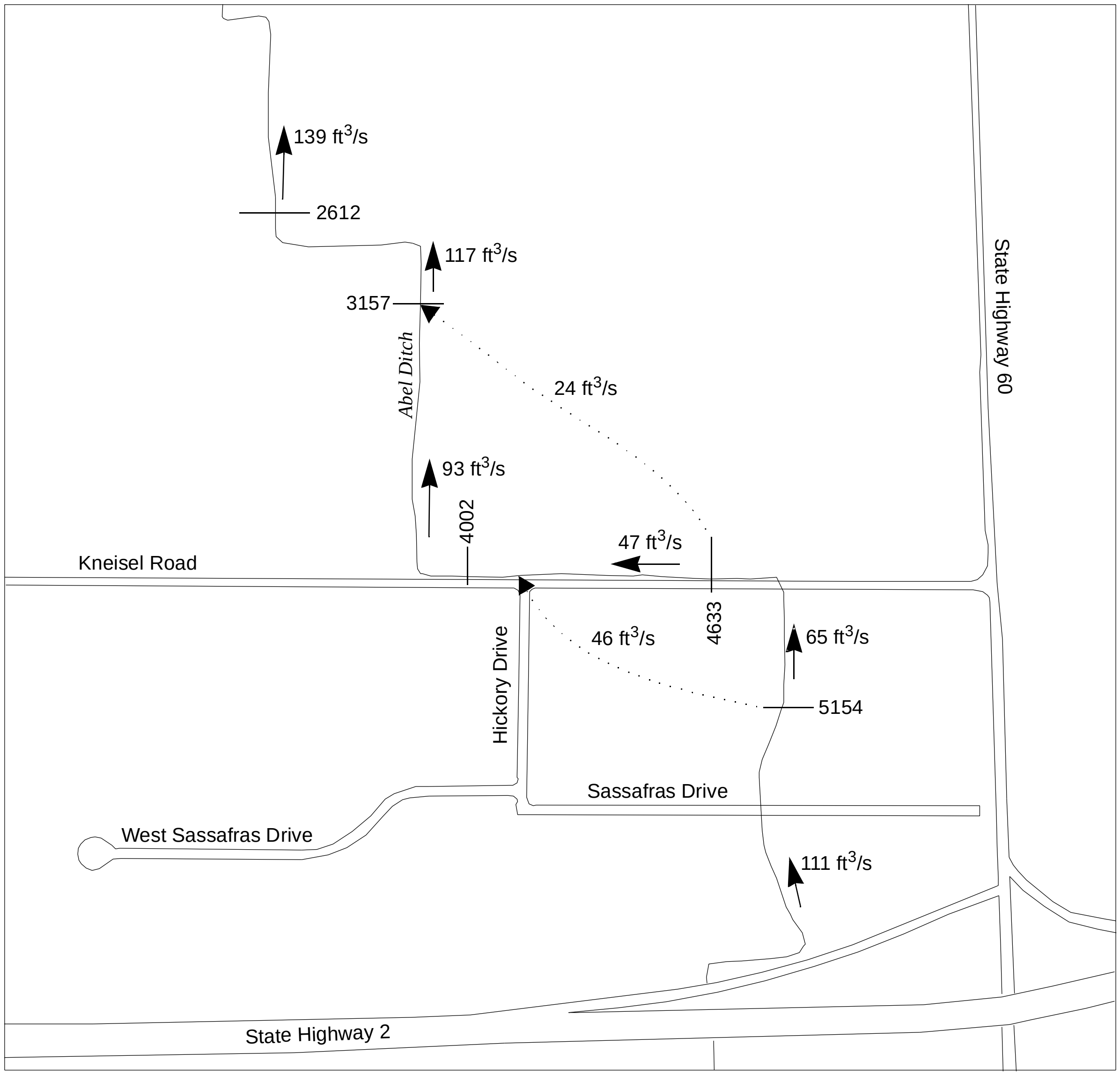
The hydraulic models developed for the 10-year floods on Abel Ditch and Sherod Creek indicate that some of the 10-year peak flood discharge escapes the main channel and adjacent flood plain and flows overland. The terrain from the NS railroad southward to State Highway 2 is relatively flat. It is within this area, on these two streams, that water was found to leave the main channel and assumed to move overland (plate 1). Preliminary analyses indicated that certain culverts on the two streams could not pass the entire peak flood discharge. An iterative process was used to determine the amount of discharge that a culvert approach cross section could convey before the computed water surface (backwater) exceeded a confining streambank elevation. The remaining portion of the total peak discharge not conveyed by the approach section is the amount of overland flow.

Analyses of the flooding along Abel Ditch indicate that some of the peak flood discharge leaves the main channel at two locations, one downstream and one upstream from Kneisel Road. In both instances, the flow is expected to move overland for some distance and then return to Abel Ditch at separate downstream locations.

Downstream from Kneisel Road, a culvert for a private driveway (river station 4624) causes enough backwater that some of the peak flood discharge leaves the main channel on the north side and flows northwest. It was determined the main channel could convey 47 ft^3/s at the culvert's approach section (river station 4633) and that 24 ft^3/s would leave the main channel (fig. 6). The 24 ft^3/s is expected to move overland and return to the main channel near river station 3157. The 24 ft^3/s that leaves the main channel was subtracted from the original discharge estimates (listed in table 1) for all cross sections in the model upstream from section 3157 to section 4633.

Upstream from Kneisel Road, at station 5148, another culvert causes sufficient backwater for some of the peak flood discharge to leave the main channel of Abel Ditch. The escaping discharge flows in a northwesterly direction toward Hickory Drive. Model results indicate that the main channel would convey 65 ft^3/s and that 46 ft^3/s would leave the channel at river station 5154 (fig. 6). According to the Erie County Engineer, a planned storm drain, to be constructed in the vicinity of the Kneisel Road and Hickory Drive intersection, will be capable of returning any overflow discharge into the Abel Ditch main channel just upstream from the cross section at river station 4002. It is assumed that this storm drain will route the overland flow of 46 ft^3/s under Kneisel Road and back into the main channel of Abel Ditch. The 46 ft^3/s that left the main channel of Abel Ditch was subtracted from the original discharge estimates (listed in table 1) for

[4] The depth of flow at which the specific energy is a minimum for a given discharge (Chow, 1959).



EXPLANATION

24 ft^3/s APPROXIMATE DIRECTION AND AMOUNT OF DISCHARGE (CUBIC FEET PER SECOND) OF THE OVERLAND FLOW

65 ft^3/s DIRECTION AND AMOUNT OF MAIN-CHANNEL DISCHARGE (CUBIC FEET PER SECOND)

5154 CROSS SECTION LOCATION AND RIVER STATION (NOT ALL SECTIONS ARE SHOWN ON THIS FIGURE)

Figure 6. Overland flow and main channel discharges for the 10-year-recurrence-interval flood on Abel Ditc Erie County, Ohio.

cross sections upstream from river station 4002 to river station 5154.

On Sherod Creek, because of the backwater upstream from the NS railroad embankment, some flow escapes the main channel at the approach section to the NS railroad culvert (river station 5304). This flow is expected to move to the northeast, parallel to the railroad embankment, into the Maurer Ditch Basin (plate 1). The amount of discharge that leaves Sherod Creek and flows into Maurer Ditch was determined to be 106 ft^3/s. Subsequently, all original estimates of peak flood discharge of Sherod Creek downstream from the railroad were reduced by 106 ft^3/s.

Concurrent flooding analysis

Flooding was initially considered to occur independently at each of the streams studied. This approach was taken because of uncertainty about the timing of peak flows on each stream. Results of the independent flooding analyses, however, indicated that flooding would be worsened if peak discharges on all streams occurred concurrently. As a consequence, a separate analysis was done with the assumption that flood peaks would occur concurrently. The concurrent-flooding analysis was done by means of the same steady-state step-backwater methods used for the independent analyses, with two exceptions: (1) water that spilled over the topographic divide of one stream was manually routed into the stream of the receiving drainage, and (2) adjacent streams that share a common unbroken water surface (due to backwater, for example) were rated together to approximately apportion the flow between the streams.

The concurrent-flooding analysis indicated that water would spill over the Sherod Creek and the Maurer Ditch divides and that some of that water eventually would enter the Edson Creek Basin downstream from the study area. The concurrent-flooding analysis indicated that the water-surface elevations at the Sherod Creek and Maurer Ditch approach sections to the NS railroad would increase by 0.40 ft and 1.18 ft, respectively, over that determined in the independent flooding analyses. Because of the increased water depths at the approach sections, peak flows through the NS railroad culverts on Sherod Creek and Maurer Ditch are estimated to increase by 4 ft^3/s and 11 ft^3/s, respectively. The concurrent-flooding analysis further indicated that water entering Edson Creek over the topographic divide it shares with Maurer Ditch would not alter peak flows or water-surface elevations on Edson Creek within the study area. Water-surface profiles from the concurrent-flooding analysis are shown on figures 4 and 5 in addition to the water-surface profiles determined from the independent flooding analyses.

Summary

Hydrologic and hydraulic analyses were done for select reaches of Abel Ditch, Edson Creek, Maurer Ditch, and Sherod Creek in northeastern Vermilion Township, Erie County, Ohio. Hydrologic analyses were conducted to estimate peak flood discharges for the four streams. Hydraulic models were developed to determine water-surface profiles along the stream reaches for the 10-year-recurrence-interval (10-year) peak flood discharges.

Estimates of peak flood discharge corresponding to floods with recurrence intervals of 2, 5, 10, 25, 50, and 100 years were developed for selected locations along the four streams studied. No historical streamflow data are available for the studied streams; thus, regional regression equations were used to estimate peak flood discharges because of the main criteria involved: small drainage area and the degree of urbanization occurring within the watersheds. The explanatory variables used in the regression equations were drainage area, basin development factor, and average annual precipitation.

Hydraulic models were developed for each of the four streams based on the 10-year peak discharges established in the hydrologic analyses using the step-backwater hydraulic analysis model HEC-RAS. Cross-sectional elevation data, hydraulic-structure geometries, and roughness coefficients were collected in the field and used as input for the models. Data for 95 open-channel cross sections and 22 hydraulic structures were collected by the USGS.

Preliminary analyses indicated that weir flow over road embankments might occur at four culverts. From further analysis, only one of the weir-flow computations was assessed to be valid. The other three culverts did not have high enough road embankments for valid weir-flow computations and were modeled using composite sections.

The analyses of the 10-year flooding for Abel Ditch and Sherod Creek indicate that some of the total peak flood discharge leaves the main channel and is assumed to move overland. Along Abel Ditch, some of the total flood flow leaves the main channel at two locations, one upstream and one downstream from

Kneisel Road. After leaving the main channel, flow moves overland and then returns to the channel. On Sherod Creek upstream from the Norfolk Southern railroad, some of the total flood flow is expected to leave the main channel to the northeast. The escaping flow parallels the railroad embankment and drains into Maurer Ditch.

Results of the independent flooding analyses indicated that flooding would be worsened if all streams experienced peak flows concurrently. Due to the uncertainty about the timing of peak flows on the streams studied, a separate analysis was done with the assumption that flood peaks would occur concurrently on each of the streams studied. This concurrent-flooding analysis indicated that water would spill over the Sherod Creek and the Maurer Ditch divides with some of that water would eventually enter the Edson Creek drainage downstream of the study area. The analysis further indicated that water entering Edson Creek over the topographic divide that it shares with Maurer Ditch would not alter peak flows or water-surface elevations on Edson Creek within the study area.

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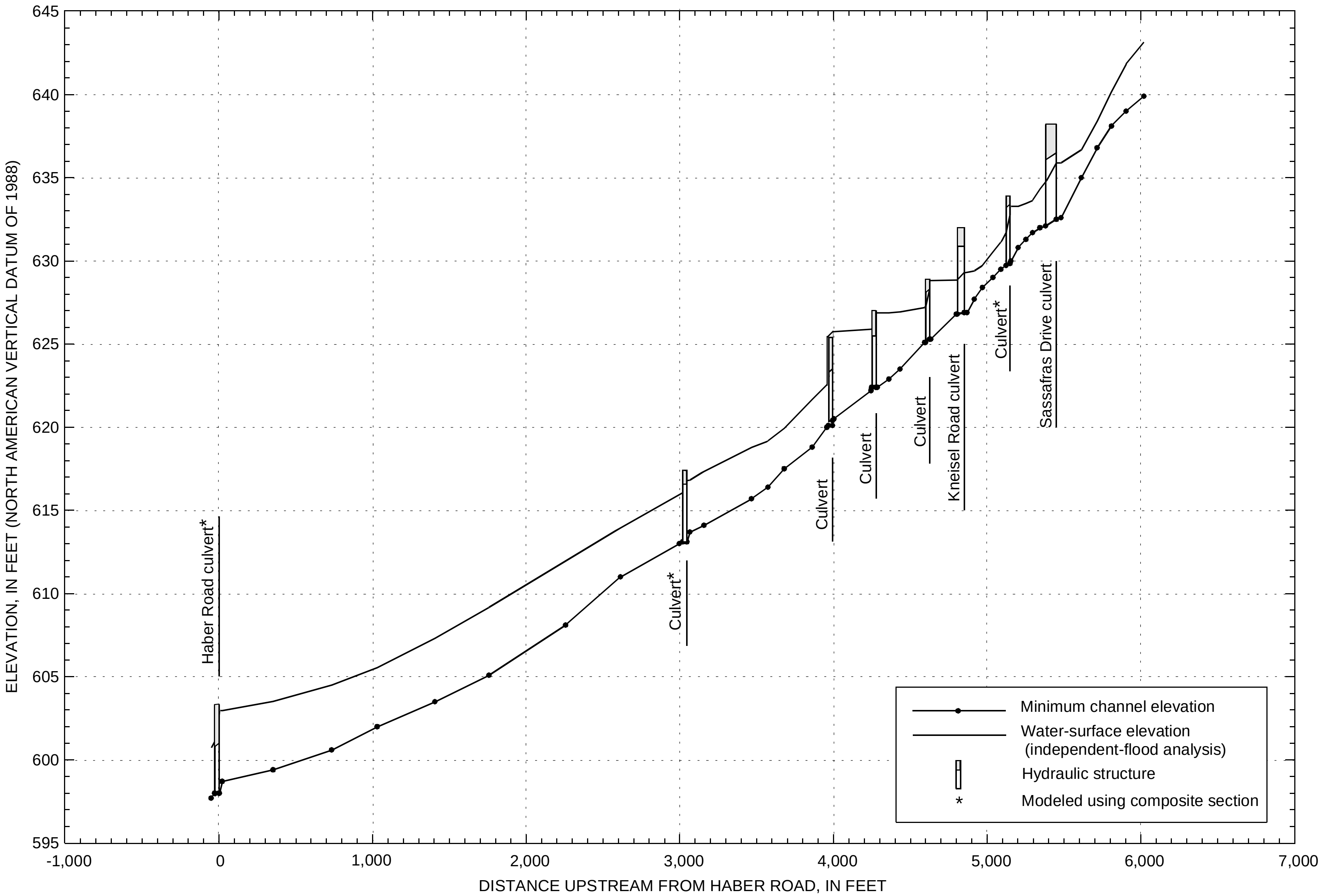

Figure 2. Computed water-surface profile for 10-year-recurrence-interval peak flood discharge, Abel Ditch, Erie County, Ohio.

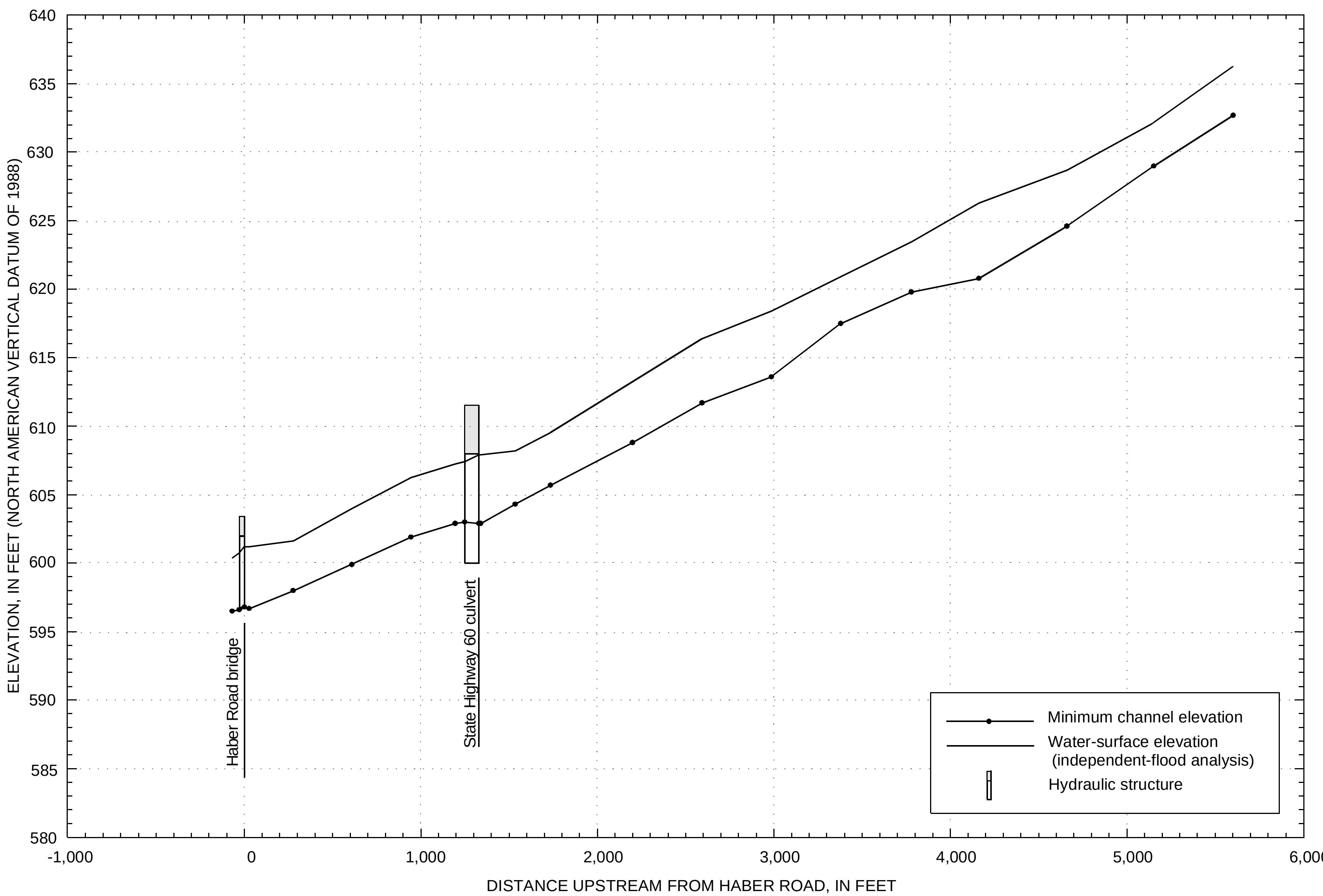

Figure 3. Computed water-surface profile for 10-year-recurrence-interval peak flood discharge, Edson Creek, Ohio.

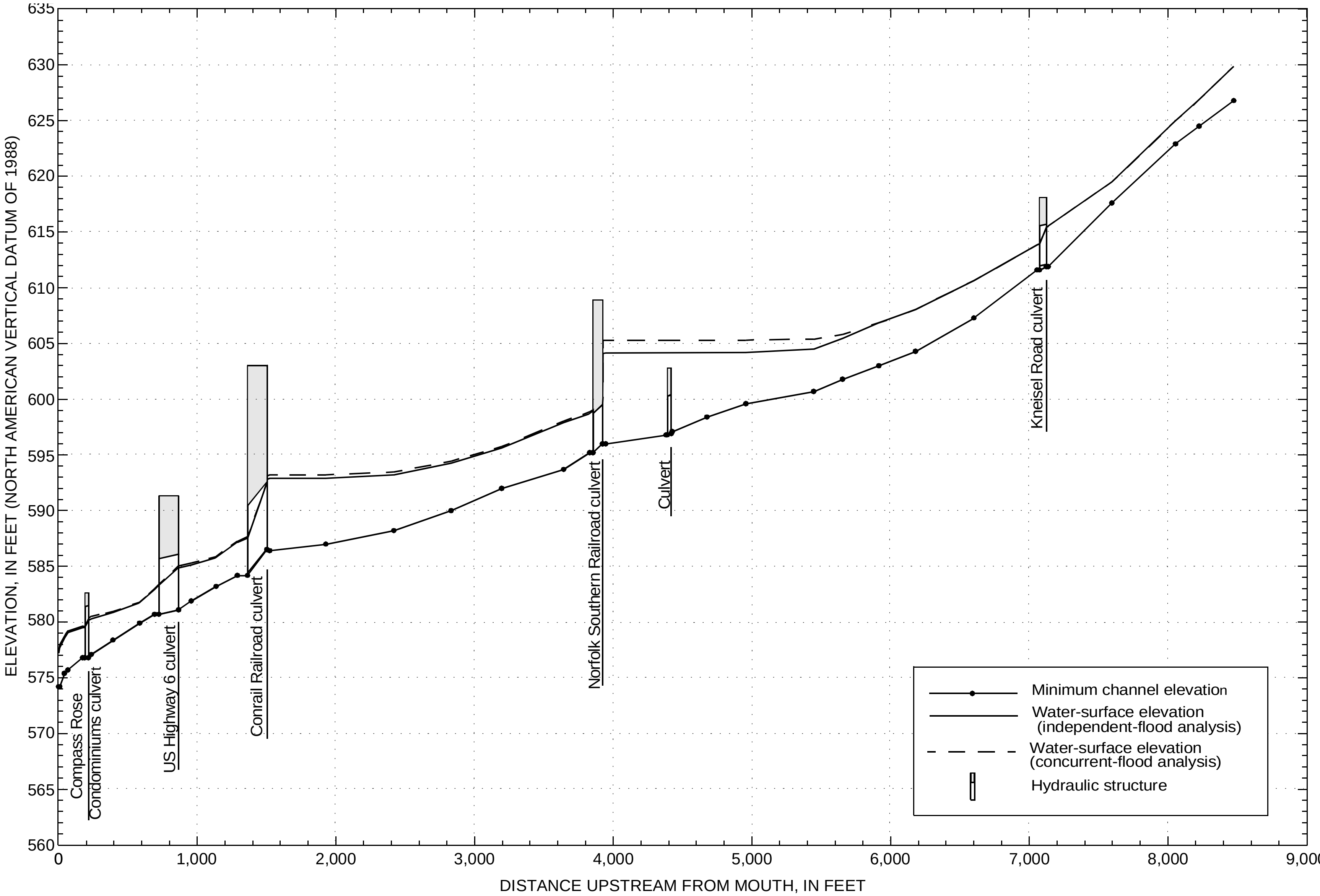

Figure 4. Computed water-surface profile for 10-year-recurrence-interval peak flood discharge, Maurer Ditch, Erie County, Ohio.

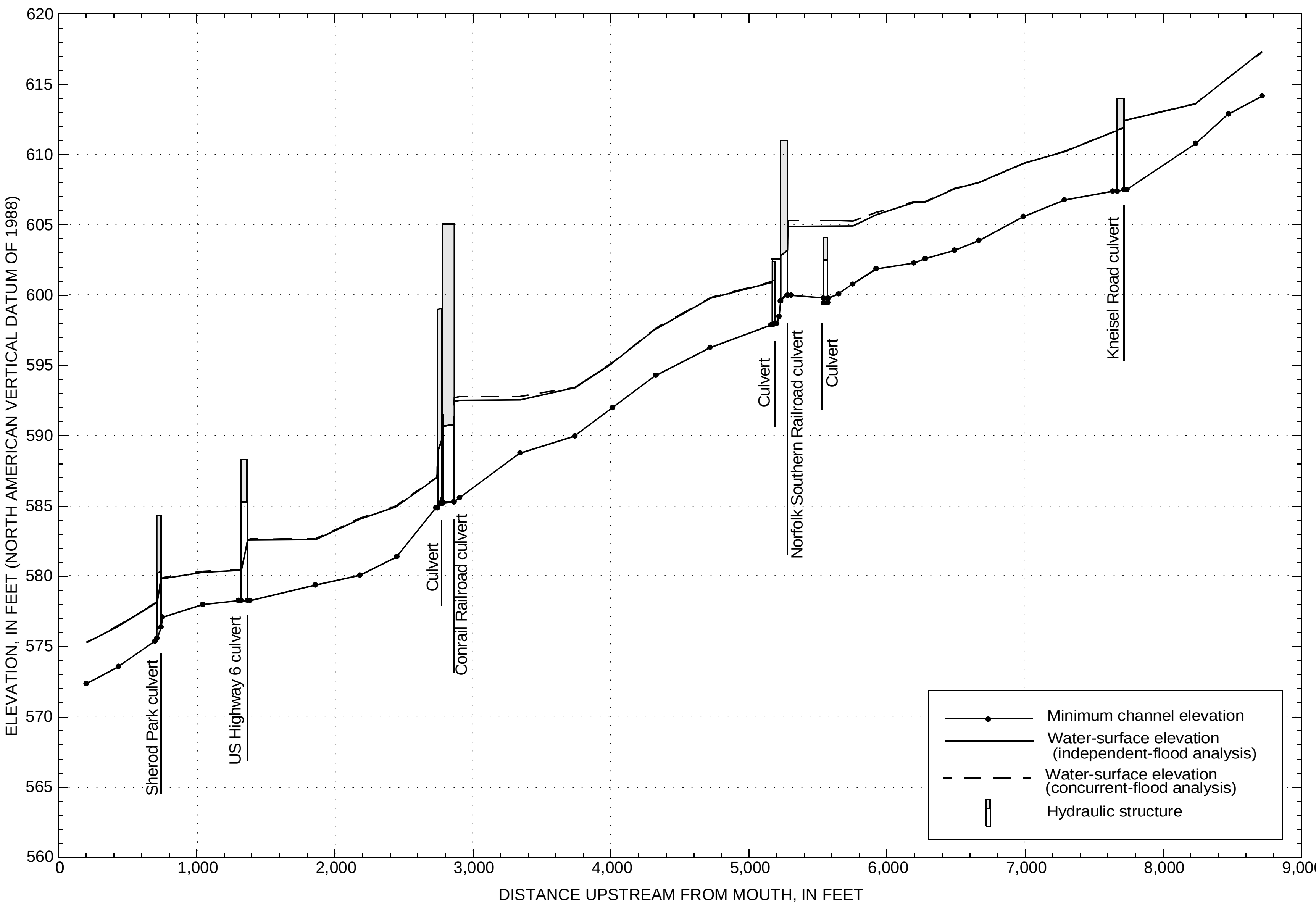

Figure 5. Computed water-surface profile for 10-year-recurrence-interval peak flood discharge, Sherod Creek, Erie County, Ohio.

Table 3. Selected hydraulic parameters from HEC-RAS output for Abel Ditch, Erie County, Ohio

[Abbreviations: ft, feet; ft^3/s, cubic feet per second; ft/ft, foot per foot; ft/s, feet per second; ft^2, square feet]

Distance from Haber Road[a] (ft)	Discharge (ft^3/s)	Minimum channel elevation (ft)	Water-surface elevation (ft)	Energy-grade-line elevation (ft)	Energy-grade-line slope (ft/ft)	Mean channel velocity (ft/s)	Section flow area (ft^2)	Section top width (ft)	Channel Froude number
-51[b]	139	597.7	600.73	601.23	0.0091	5.70	24.37	13.60	0.75
-29[b]	139	598.0	601.13	601.55	.0239	5.16	26.93	13.36	.64
-28[b]	139	598.0	601.18	602.12	.0868	7.82	17.78	6.20	.81
0	139	598.0	602.63	603.03	.0154	5.11	27.18	6.75	.45
0					**Haber Road culvert**[c]				
1	139	598.0	602.97	603.07	0.0009	2.56	62.47	42.04	0.26
20	139	598.7	602.97	603.10	.0015	2.98	54.43	41.99	.33
352	139	599.4	603.53	603.75	.0024	3.73	37.31	14.28	.41
733	139	600.6	604.52	604.77	.0030	4.06	34.27	13.87	.45
1030	139	602.0	605.55	605.87	.0044	4.56	30.49	14.79	.56
1406	139	603.5	607.31	607.67	.0051	4.87	28.54	13.43	.59
1758	139	605.1	609.17	609.57	.0056	5.03	27.62	12.92	.61
2256	139	608.1	611.94	612.35	.0055	5.15	26.98	12.54	.62
2612	139	611.0	613.96	614.36	.0057	5.04	27.58	14.77	.64
2996	117	613.0	615.95	616.24	.0041	4.26	27.49	14.74	.55
3018	117	613.1	616.07	616.49	.0067	5.18	22.57	12.61	.68
3019	117	613.1	616.09	616.49	.0272	5.14	22.77	12.66	.67
3044	117	613.1	616.79	617.08	.0196	4.34	27.01	11.95	.49
3044					**Culvert**[c]				
3045	117	613.1	616.79	617.09	0.0035	4.33	27.09	12.00	0.48

Table 3. Selected hydraulic parameters from HEC-RAS output for Abel Ditch, Erie County, Ohio —Continued

[Abbreviations: ft, feet; ft^3/s, cubic feet per second; ft/ft, foot per foot; ft/s, feet per second; ft^2, square feet]

Distance from Haber Road[a] (ft)	Discharge (ft^3/s)	Minimum channel elevation (ft)	Water-surface elevation (ft)	Energy-grade-line elevation (ft)	Energy-grade-line slope (ft/ft)	Mean channel velocity (ft/s)	Section flow area (ft^2)	Section top width (ft)	Channel Froude number
3064	117	613.7	616.82	617.18	.0049	4.82	24.42	12.22	.57
3157	117	614.1	617.36	617.68	.0057	4.53	26.45	24.24	.52
3465	93	615.7	618.81	618.97	.0030	3.25	33.98	46.61	.40
3573	93	616.4	619.18	619.44	.0059	4.09	23.21	18.97	.55
3679	93	617.5	619.92	620.33	.0113	5.13	18.14	11.98	.73
3860	93	618.8	621.68	622.02	.0078	4.65	19.98	10.86	.60
3957	93	620.0	622.54	623.09	.0145	5.92	15.70	9.35	.81
3967	93	620.1	622.68	623.24	.0147	5.99	15.51	9.03	.81
3993					**Culvert**				
3994	93	620.4	625.75	625.80	0.0004	1.89	58.20	44.16	0.18
4002	93	620.5	625.75	625.81	.0005	2.00	46.43	44.05	.19
4243	47	622.2	625.89	625.95	.0009	1.88	25.03	12.74	.24
4249	47	622.4	625.90	625.95	.0009	1.88	24.99	12.76	.24
4275					**Culvert**				
4276	47	622.4	626.89	626.91	0.0001	1.13	45.82	28.55	0.11
4284	47	622.4	626.89	626.91	.0002	1.20	42.39	28.01	.12
4360	47	622.9	626.90	626.94	.0005	1.62	29.25	16.06	.19
4432	47	623.5	626.94	627.01	.0012	2.13	22.04	11.75	.27
4592	47	625.1	627.19	627.45	.0070	4.10	11.46	9.38	.65
4598	47	625.1	627.26	627.49	.0060	3.88	12.12	9.66	.61

Table 3. Selected hydraulic parameters from HEC-RAS output for Abel Ditch, Erie County, Ohio —Continued

[Abbreviations: ft, feet; ft^3/s, cubic feet per second; ft/ft, foot per foot; ft/s, feet per second; ft^2, square feet]

Distance from Haber Road[a] (ft)	Discharge (ft^3/s)	Minimum channel elevation (ft)	Water-surface elevation (ft)	Energy-grade-line elevation (ft)	Energy-grade-line slope (ft/ft)	Mean channel velocity (ft/s)	Section flow area (ft^2)	Section top width (ft)	Channel Froude number
4624					**Culvert**				
4625	47	625.3	628.82	628.85	0.0004	1.42	38.83	126.44	0.16
4633	47	625.3	628.83	628.85	.0002	1.17	46.75	126.47	.13
4799	65	626.8	628.85	629.00	.0028	3.14	20.73	12.72	.43
4806	65	626.8	628.87	629.02	.0027	3.09	21.01	12.79	.43
4850					**Kneisel Road culvert**				
4851	65	626.9	629.28	629.39	0.0022	2.66	24.48	13.57	0.35
4869	65	626.9	629.32	629.43	.0020	2.59	25.07	13.69	.34
4915	65	627.7	629.42	629.59	.0052	3.36	19.34	15.38	.53
4969	65	628.4	629.72	630.07	0138	4.75	13.68	13.52	.83
5037	65	629.0	630.54	630.89	.0107	4.79	13.56	11.64	.78
5089	65	629.5	631.12	631.45	.0107	4.64	14.00	11.14	.73
5122	65	629.7	631.72	631.98	.0261	4.10	15.86	10.92	.60
5123	65	629.7	631.75	632.11	.0408	4.81	13.52	10.36	.74
5148	65	629.8	632.80	633.28	.0500	5.56	11.68	4.93	.64
5148					**Culvert**[c]				
5149	65	629.8	633.27	633.32	0.0008	1.90	48.62	94.59	0.22
5154	65	630.0	633.28	633.33	.0007	1.73	52.74	97.69	.20
5201	111	630.8	633.28	633.45	.0039	3.30	33.66	18.64	.43
5252	111	631.3	633.46	633.72	.0059	4.09	27.14	17.55	.58

Table 3. Selected hydraulic parameters from HEC-RAS output for Abel Ditch, Erie County, Ohio —Continued

[Abbreviations: ft, feet; ft^3/s, cubic feet per second; ft/ft, foot per foot; ft/s, feet per second; ft^2, square feet]

Distance from Haber Road[a] (ft)	Discharge (ft^3/s)	Minimum channel elevation (ft)	Water-surface elevation (ft)	Energy-grade-line elevation (ft)	Energy-grade-line slope (ft/ft)	Mean channel velocity (ft/s)	Section flow area (ft^2)	Section top width (ft)	Channel Froude number
5296	111	631.7	633.63	634.21	.0154	6.14	18.07	12.75	.91
5344	111	632.0	634.34	634.83	.0107	5.65	19.66	11.29	.75
5379	111	632.1	634.74	635.14	.0068	5.08	21.86	10.66	.61
5449					**Sassafras Drive culvert**				
5450	111	632.5	635.89	636.11	0.0023	3.71	29.93	13.20	0.38
5480	111	632.6	635.90	636.23	.0036	4.62	24.01	11.48	.47
5612	111	635.0	636.70	637.12	.0157	5.16	21.51	16.37	.79
5714	111	636.8	638.42	638.89	.0190	5.52	20.12	16.03	.87
5808	111	638.1	640.16	640.82	.0210	6.52	17.04	10.01	.88
5904	111	639.0	641.85	642.70	.0172	7.46	15.84	9.71	.85
6019	111	639.9	643.14	643.30	.0021	3.24	35.34	17.38	.37

[a] Positive values measured upstream from the upstream face of Haber Road. Negative values measured downstream from the upstream face of Haber Road.
[b] Located downstream from study reach.
[c] Modeled using composite section.

Table 4. Selected hydraulic parameters from HEC-RAS output for Edson Creek, Erie County, Ohio

[Abbreviations: ft, feet; ft^3/s, cubic feet per second; ft/ft, foot per foot; ft/s, feet per second; ft^2, square feet]

Distance from Haber Road[a] (ft)	Discharge (ft^3/s)	Minimum channel elevation (ft)	Water-surface elevation (ft)	Energy-grade-line elevation (ft)	Energy-grade-line slope (ft/ft)	Mean channel velocity (ft/s)	Section flow area (ft^2)	Section top width (ft)	Channel Froude number
-69[b]	423	596.5	600.37	600.85	0.0050	5.59	75.70	26.56	0.58
-29[b]	423	596.6	600.75	601.00	.0020	4.00	105.84	29.02	.37
0					**Haber Road bridge**				
1	423	596.8	601.20	601.42	0.0013	3.71	113.91	29.74	0.33
27	423	596.7	601.21	601.47	.0016	4.09	103.37	29.23	.38
276	423	598.0	601.64	602.32	.0066	6.62	63.90	26.13	.75
609	423	599.9	604.00	604.69	.0076	6.75	73.82	86.90	.77
944	423	601.9	606.25	606.75	.0050	5.83	99.17	114.58	.64
1195	423	602.9	607.26	607.51	.0020	4.08	113.02	201.70	.42
1248	423	603.0	607.44	607.59	.0009	3.10	136.32	162.88	.29
1327					**State Highway 60 culvert**				
1328	423	602.9	607.91	608.08	0.0006	3.28	128.86	51.91	0.26
1340	423	602.9	607.91	608.09	.0010	3.35	126.16	48.81	.32
1535	423	604.3	608.20	608.55	.0066	4.79	88.35	40.25	.57
1735	423	605.7	609.55	609.92	.0070	4.89	86.53	39.84	.58
2199	423	608.8	613.23	613.99	.0105	7.11	67.94	49.25	.76
2592	423	611.7	616.40	616.73	.0048	4.69	98.97	61.16	.51
2987	423	613.6	618.43	618.93	.0062	6.32	103.70	77.83	.59
3379	423	617.5	620.94	621.06	.0047	3.53	193.73	184.98	.45
3778	403	619.8	623.45	623.90	.0114	5.43	77.55	65.96	.69

Table 4. Selected hydraulic parameters from HEC-RAS output for Edson Creek, Erie County, Ohio —Continued

[Abbreviations: ft, feet; ft^3/s, cubic feet per second; ft/ft, foot per foot; ft/s, feet per second; ft^2, square feet]

Distance from Haber Road[a] (ft)	Discharge (ft^3/s)	Minimum channel elevation (ft)	Water-surface elevation (ft)	Energy-grade-line elevation (ft)	Energy-grade-line slope (ft/ft)	Mean channel velocity (ft/s)	Section flow area (ft^2)	Section top width (ft)	Channel Froude number
4160	403	620.8	626.22	626.43	.0043	3.73	127.13	116.98	.43
4659	403	624.6	628.63	628.83	.0055	3.60	111.90	64.11	.48
5152	403	629.0	632.10	632.69	.0112	6.19	65.08	26.98	.70
5602	403	632.7	636.21	636.58	.0068	4.86	82.92	33.95	.54

[a] Positive values measured upstream from the upstream face of Haber Road. Negative values measured downstream from the upstream face of Haber Road.

[b] Located downstream from study reach.

Table 5. Selected hydraulic parameters from HEC-RAS output for Maurer Ditch, Erie County, Ohio

[Abbreviations: ft, feet; ft^3/s, cubic feet per second; ft/ft, foot per foot; ft/s, feet per second; ft^2, square feet]

Distance upstream from mouth (ft)	Discharge (ft^3/s)	Minimum channel elevation (ft)	Water-surface elevation (ft)	Energy-grade-line elevation (ft)	Energy-grade-line slope (ft/ft)	Mean channel velocity (ft/s)	Section flow area (ft^2)	Section top width (ft)	Channel Froude number
0	151	574.2	577.20	578.29	0.0296	8.39	18.01	6.00	0.85
8	151	574.2	577.74	578.52	.0207	7.10	21.44	9.55	.67
41	151	575.4	578.60	579.08	.0122	5.57	27.13	14.34	.71
68	151	575.7	579.10	579.28	.0037	3.43	44.05	20.57	.41
173	151	576.8	579.52	579.90	.0083	4.93	31.61	20.37	.61
188	151	576.8	579.54	580.11	.0135	6.04	25.02	12.60	.69
214					**Compass Rose Condominiums culvert**				
215	151	576.8	580.16	580.52	0.0036	4.79	31.52	35.17	0.49
237	151	577.1	580.33	580.60	.0032	4.38	41.20	42.44	.50
393	151	578.4	580.88	581.11	.0032	3.84	39.36	21.71	.50
585	151	579.9	581.75	582.25	.0113	5.69	26.51	18.74	.84
693	151	580.7	582.90	583.41	.0103	5.77	26.61	17.89	.77
723	151	580.7	583.29	583.62	.0042	4.62	33.79	21.34	.57
865					**U.S. Highway 6 culvert**				
866	151	581.1	584.87	585.09	0.0022	3.80	41.12	36.57	0.36
956	151	581.9	585.14	585.33	.0030	3.99	54.99	39.26	.44
1136	151	583.2	585.85	586.33	.0097	5.60	26.98	15.39	.75
1290	151	584.2	587.17	587.51	.0060	4.69	32.22	16.71	.59
1363	151	584.2	587.57	587.84	.0033	4.15	36.43	18.30	.46
1502					**Conrail Railroad culvert**				
1503	151	586.5	592.82	592.90	0.0004	2.28	66.37	117.47	0.17
1523	151	586.4	592.91	592.91	.0001	.77	229.07	119.61	.07

Table 5. Selected hydraulic parameters from HEC-RAS output for Maurer Ditch, Erie County, Ohio —Continued

[Abbreviations: ft, feet; ft^3/s, cubic feet per second; ft/ft, foot per foot; ft/s, feet per second; ft^2, square feet]

Distance upstream from mouth (ft)	Discharge (ft^3/s)	Minimum channel elevation (ft)	Water-surface elevation (ft)	Energy-grade-line elevation (ft)	Energy-grade-line slope (ft/ft)	Mean channel velocity (ft/s)	Section flow area (ft^2)	Section top width (ft)	Channel Froude number
1927	151	587.0	592.93	592.98	.0004	1.77	99.42	61.90	.16
2418	151	588.2	593.23	593.41	.0024	3.40	44.36	15.30	.35
2831	151	590.0	594.28	594.49	.0027	3.62	42.23	19.32	.37
3196	151	592.0	595.65	596.04	.0069	5.00	30.17	13.63	.59
3642	151	593.7	597.93	598.17	.0034	3.98	37.98	13.25	.41
3831	117	595.2	598.73	599.04	.0067	4.53	25.84	13.42	.58
3853	117	595.2	598.92	599.18	.0052	4.11	28.46	14.08	.51
3923					**Norfolk Southern Railroad culvert**				
3924	117	596.0	604.14	604.15	0.0001	0.79	147.86	423.34	0.06
3946	117	596.0	604.15	604.15	.0000	.58	310.12	435.92	.05
4381	117	596.8	604.16	604.16	.0000	.52	341.58	173.76	.04
4425	117	597.1	604.16	604.16	.0000	.59	301.95	175.21	.05
4675	117	598.4	604.16	604.18	.0002	1.31	127.48	134.03	.12
4956	117	599.6	604.23	604.31	.0009	2.20	53.19	19.66	.24
5445	117	600.7	604.54	604.66	.0016	2.77	42.28	16.94	.31
5653	117	601.8	605.50	605.82	.0059	4.55	25.73	12.64	.56
5916	117	603.0	606.88	607.13	.0043	4.06	28.88	13.93	.48
6178	117	604.3	608.06	608.35	.0050	4.28	27.36	12.81	.52
6600	117	607.3	610.67	611.09	.0085	5.21	22.46	11.75	.66
7056	87	611.6	613.87	614.10	.0048	3.91	22.27	12.07	.51
7072	87	611.6	613.94	614.17	.0038	3.83	22.71	12.20	.47

Table 5. Selected hydraulic parameters from HEC-RAS output for Maurer Ditch, Erie County, Ohio —Continued

[Abbreviations: ft, feet; ft^3/s, cubic feet per second; ft/ft, foot per foot; ft/s, feet per second; ft^2, square feet]

Distance upstream from mouth (ft)	Discharge (ft^3/s)	Minimum channel elevation (ft)	Water-surface elevation (ft)	Energy-grade-line elevation (ft)	Energy-grade-line slope (ft/ft)	Mean channel velocity (ft/s)	Section flow area (ft^2)	Section top width (ft)	Channel Froude number
7121					**Kneisel Road culvert**				
7122	87	611.9	615.45	615.64	0.0055	3.46	25.17	9.93	0.37
7135	87	611.9	615.54	615.71	.0056	3.34	26.09	11.01	.38
7596	87	617.6	619.47	619.71	.0148	4.01	24.18	38.33	.69
8056	87	622.9	624.99	625.11	.0095	2.85	31.93	70.05	.54
8225	87	624.5	626.85	627.26	.0160	5.18	18.51	45.61	.71
8475	87	626.8	629.88	630.04	.0080	3.30	26.39	19.57	.50

Table 6. Selected hydraulic parameters from HEC-RAS output for Sherod Creek, Erie County, Ohio

[Abbreviations: ft, feet; ft^3/s, cubic feet per second; ft/ft, foot per foot; ft/s, feet per second; ft^2, square feet]

Distance upstream from mouth (ft)	Discharge (ft^3/s)	Minimum channel elevation (ft)	Water-surface elevation (ft)	Energy-grade-line elevation (ft)	Energy-grade-line slope (ft/ft)	Mean channel velocity (ft/s)	Section flow area (ft^2)	Section top width (ft)	Channel Froude number
199	119	572.4	575.29	575.40	0.0051	2.66	44.78	36.48	0.42
433	119	573.6	576.50	576.68	.0057	3.42	34.84	18.26	.44
696	119	575.4	578.08	578.29	.0064	3.71	32.08	20.93	.48
711	119	575.6	578.18	578.41	.0083	3.83	31.09	20.33	.53
739					**Sherod Park culvert**				
740	119	576.4	579.84	579.95	0.0019	2.59	46.02	25.36	0.26
750	119	577.1	579.85	579.98	.0055	2.93	40.67	24.11	.40
1042	119	578.0	580.34	580.36	.0004	1.27	125.33	127.52	.15
1302	119	578.3	580.45	580.48	.0005	1.33	89.28	85.00	.18
1320	119	578.3	580.45	580.49	.0010	1.74	68.29	84.99	.24
1366					**U.S. Highway 6 culvert**				
1367	119	578.3	582.57	582.62	0.0003	1.76	67.72	100.84	0.15
1385	119	578.3	582.59	582.63	.0002	1.48	80.32	101.04	.13
1858	119	579.4	582.62	582.97	.0060	4.72	25.23	11.79	.57
2182	119	580.1	584.09	584.28	.0028	3.47	34.30	14.89	.40
2448	119	581.4	585.00	585.28	.0050	4.27	27.90	13.70	.53
2731	119	584.9	586.97	587.58	.0139	6.24	19.06	12.39	.89
2741	119	584.9	587.19	587.70	.0092	5.68	20.94	12.75	.73
2772					Culvert				
2773	119	585.2	591.34	591.43	0.0005	2.46	48.43	46.24	0.18
2777	119	585.2	591.34	591.44	.0005	2.46	48.44	46.27	.18

Table 6. Selected hydraulic parameters from HEC-RAS output for Sherod Creek, Erie County, Ohio

[Abbreviations: ft, feet; ft^3/s, cubic feet per second; ft/ft, foot per foot; ft/s, feet per second; ft^2, square feet]

Distance upstream from mouth (ft)	Discharge (ft^3/s)	Minimum channel elevation (ft)	Water-surface elevation (ft)	Energy-grade-line elevation (ft)	Energy-grade-line slope (ft/ft)	Mean channel velocity (ft/s)	Section flow area (ft^2)	Section top width (ft)	Channel Froude number
2861					**Conrail Railroad culvert**				
2862	119	585.3	592.48	592.54	0.0003	2.10	56.73	65.69	0.14
2902	119	585.6	592.55	592.55	.0000	.68	223.00	84.13	.05
3342	119	588.8	592.57	592.62	.0015	1.95	73.38	59.61	.24
3739	119	590.0	593.46	593.62	.0046	3.46	43.53	54.05	.44
4012	119	592.0	595.15	595.46	.0102	4.63	29.39	36.23	.64
4324	119	594.3	597.64	597.87	.0060	3.87	30.76	16.95	.51
4719	119	596.3	599.79	599.99	.0048	3.57	33.33	17.63	.46
5158	63	597.9	600.91	600.94	.0008	1.50	42.00	21.95	.19
5168	63	597.9	600.91	600.95	.0008	1.49	42.18	21.99	.19
5187					**Culvert**				
5188	63	598.0	602.54	602.56	0.0002	1.09	57.96	22.32	0.11
5198	63	598.0	602.54	602.56	.0002	1.12	56.29	23.62	.12
5217	63	598.5	602.54	602.57	.0003	1.20	52.51	20.97	.13
5227	63	599.6	602.54	602.59	.0010	1.73	36.34	18.73	.22
5278					**Norfolk Southern Railroad culvert**				
5279	63	600.0	604.91	604.92	0.0000	0.57	137.48	1541.26	0.05
5304	63	600.0	604.92	604.92	.0000	.46	187.21	1541.30	.04
5572	169	599.8	604.93	604.94	.0002	1.30	298.12	330.66	.12
5650	169	600.1	604.94	604.96	.0004	1.75	211.24	272.95	.16
5750	169	600.8	604.96	605.26	.0043	4.44	38.06	13.31	.46
5919	169	601.9	605.75	606.10	.0055	4.73	35.76	14.87	.54
6193	169	602.3	606.62	606.77	.0013	3.08	54.92	15.41	.29

Table 6. Selected hydraulic parameters from HEC-RAS output for Sherod Creek, Erie County, Ohio

[Abbreviations: ft, feet; ft^3/s, cubic feet per second; ft/ft, foot per foot; ft/s, feet per second; ft^2, square feet]

Distance upstream from mouth (ft)	Discharge (ft^3/s)	Minimum channel elevation (ft)	Water-surface elevation (ft)	Energy-grade-line elevation (ft)	Energy-grade-line slope (ft/ft)	Mean channel velocity (ft/s)	Section flow area (ft^2)	Section top width (ft)	Channel Froude number
6276	169	602.6	606.64	607.06	.0065	5.18	32.61	14.51	.61
6488	169	603.2	607.59	607.78	.0020	3.52	47.97	16.86	.37
6664	169	603.9	608.02	608.38	.0055	4.84	34.90	13.43	.53
6986	169	605.6	609.39	609.55	.0025	3.45	73.82	153.06	.37
7283	169	606.8	610.25	610.53	.0044	4.24	36.16	42.84	.48
7633	145	607.4	611.61	611.84	.0032	3.87	37.51	11.00	.37
7666	145	607.4	611.73	611.95	.0029	3.74	38.90	12.85	.35
7715					**Kneisel Road culvert**				
7716	145	607.5	612.41	612.57	0.0018	3.20	45.25	149.88	0.29
7737	145	607.5	612.50	612.60	.0013	2.79	68.99	215.56	.25
8233	145	610.8	613.64	613.85	.0059	4.31	80.58	427.38	.54
8471	145	612.9	615.47	616.17	.0159	6.71	21.60	11.80	.87
8717	145	614.2	617.26	617.43	.0023	3.32	45.98	38.45	.38