FLUVIAL MORPHOLOGY OF WOLF CREEK AND BERGER DITCH AND ESTIMATES OF SEDIMENT DELIVERY TO MAUMEE BAY

UNIVERSITY OF TOLEDO

FOR THE:
WOLF CREEK AND BERGER DITCH
LUCAS COUNTY, OHIO

PREPARED FOR:
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1.0 INTRODUCTION

The purposes of this work were: to produce stream cross-section data for the model under development by LimnoTech for sediment entering Maumee Bay and to develop empirical estimates of the total annual sediment loading to Maumee Bay from Berger Ditch.

The watershed of Berger Ditch includes the watershed of Wolf Creek, which once had a natural confluence with Lake Erie at a point approximately 2 miles east of Maumee Bay State Park. At a point located at the southeastern corner of the Oregon, OH Water Treatment Plant (WTP), Wolf Creek was diverted into Berger Ditch, and its channel to the east was filled and is now planted in row crops (Figure 1). In generally accepted parlance and for the purposes of this report, upstream of the Oregon WTP is known as Wolf Creek and adjacent to and downstream of the WTP is known as Berger Ditch.

1.1 Methods

Three field sites were chosen in order to accurately characterize Wolf Creek and Berger Ditch. Field Site 1 encompasses Wolf Creek north of Seaman Road and south of Corduroy Road. Berger Ditch was surveyed at Field Site 2, near the City of Oregon Water Treatment Plant along the west side of North Curtice Road and at Field Site 3 in Maumee Bay State Park (MBSP), just north of the junction of Cedar Point Road and North Curtice Road.

The character of Wolf Creek and Berger Ditch was described by measuring channel dimensions and flow at each Field Site. This was accomplished by surveying the longitudinal profile and several cross sections at each selected reach. In addition, water velocity was measured at each cross section surveyed, and sediment was characterized using by completing sediment counts at each cross section. The water velocity data, along with the cross-sectional area of each creek calculated from the surveyed cross sections was used to calculate the amount of flow at each Field Site.

1.1.1 Survey of Wolf Creek; Field Site 1, Downstream Seaman Rd.

A 1200-foot longitudinal profile reach was established along the left bank of Wolf Creek beginning at a concrete farm equipment crossing located about 300 feet downstream of Seaman Rd (Figure 1). A self-leveling laser level with top mount rod and sensor were used to survey the longitudinal profile. Due to dense vegetation and lack of definable stream features, stations were chosen based on visibility, noted gradient changes, and changes in flow. Thirty-nine stations were surveyed along the 1200-foot longitudinal profile, with the turning points established whenever the laser could no longer be sighted. A total of six turning points were required. The culvert where Wolf Creek flows under Seaman Road was used as a benchmark for this Site.

Five cross sections were surveyed along Wolf Creek, one each at 69, 264, 514.75, 887, and 1131 feet on the longitudinal profile (Figure 1). A Cam-line, a steel cable marked at one-foot intervals with numbered brass grommets (www.forestry-suppliers.com), was stretched across the creek from the top of the left bank to the top of the right bank, and changes in gradient or topography were surveyed. Once the survey was completed, average measures of water velocity were taken using a flow meter and moving from left bank to right bank at the same station where each cross section was surveyed.

1.1.2 Survey of Berger Ditch; Field Site 2, Adjacent to Oregon WTP

A 600-foot longitudinal profile reach was established along the left bank of Berger Ditch (Figure 1) beginning approximately 100 feet from the 90 degree bend to the south that occurs at the corner of the WTP property. A self-leveling laser level with top mount rod and sensor were used to survey the longitudinal profile. Due to lack of definable stream features, stations were chosen based on noted gradient changes and changes in flow. Twelve stations were surveyed along the 600-foot longitudinal profile. No turning points were required for this Field Site. A curved concrete headwall located south of the area of the longitudinal profile on the west side of North Curtice Road was used as a benchmark for this Site.

Two cross sections were surveyed at Field Site 2; one at 191.6 feet and one at 496.2 feet on the longitudinal profile (Figure 1). The cross section locations were chosen as representative areas of flow. A Cam-line was stretched across the creek from the top of the left bank to the top of the right bank, and changes in gradient or topography were surveyed. Once the survey was completed, average measures of water velocity were taken using a flow meter and moving from left bank to right bank at the same station where each cross section was surveyed.

1.1.3 Survey of Berger Ditch; Field Site 3, Maumee Bay State Park

A 1000-foot longitudinal profile was established along the left bank of Berger Ditch (Figure 1) beginning at the Cedar Point Road bridge. A self-leveling laser level with top mount rod and sensor were used to survey the longitudinal profile. Due to lack of definable stream features, stations were chosen to represent apparent changes in cross-section. Nineteen stations were surveyed along the 817-foot longitudinal profile.

Three cross sections were surveyed at Field Site 3, at 100 feet, 535 feet and 750 feet on the longitudinal profile (Figure 1). A Cam-line was stretched across the creek from the top of the left bank to the top of the right bank, and any change in gradient or topography was surveyed. The United States Geological Survey (USGS) has a gauging station (USGS 04194085) within this reach of Berger Ditch. Data from this station were used to assess the water velocity at Field Site 3.

All survey data was entered into an Excel spreadsheet and converted into actual elevations using the benchmarks indicated for each Field Site. The data was then pasted into RiverMorph v 4.1 software for fluvial geomorphological data analysis.

The RiverMorph analysis was conducted by first subjecting cross-section data sets and longitudinal profiles to QA/QC, and attempting to identify any natural stream features that might be useable in the stream classification or modeling efforts. The stream cross sections were then exported back to Excel and sent on to LimnoTech for use in their sediment modeling of the mouth of Berger Ditch and Maumee Bay.

The stream cross sections and longitudinal profiles for the Field Sites appear in Appendix A. Note that for Field Site 1 (watershed area = 10.5 square miles) and Field Site 2 (watershed area 15 square miles), bankfull elevation was approximated as predicted by the USGS regional curve for Region A (Sherwood and Huitger 2005). No reliable field indicators of bankfull flow elevation could be located in the field at any of the field sites.

1.1.4 Sediment Characterization

Sediment particle sizes were sampled at each cross section at Field Sites 1 and 2 using a Wolman pebble count as described by Bunte and Abt (2001). One hundred sediment counts were taken at each cross section by establishing ten transects approximately one foot apart and sampling at ten regular intervals along each transect. The particles sampled were those first encountered by blind placement of an index finger pushed down to the streambed; size was determined by comparison to a portable sand gauge, for larger particles, the *b*-axis was measured in inches using a folding carpenters rule.

All particle sizes were entered into an Excel spreadsheet, converted to millimeters, and placed into size categories that correspond to the size of the holes in standard sieve sets. The data was then pasted into RiverMorph v 4.1 software for analysis of particle size distribution.

Field Site 1 was examined in vain for point bars within which to gather sediment core data to calibrate a sediment discharge model. Field Site 1 held the most promise for having developed point bars, but the ditch has been dipped out and straightened repeatedly, most recently in 2006. Field Sites 2 and 3 were also confirmed to lack point bars.

Because of water depths at Field Site 3, sediment sampling was conducted by Ponar dredge at four locations.

The results of the sediment characterizations for each Field Site appear in Appendix B.

1.2 Stability Assessment

Hull performed the bank erosion hazard index (BEHI), estimate of near-bank stress, and Pfankuch channel stability rating for the stream banks at Field Site 1. These ratings were performed to determine the relative stability of the stream banks, and thus help determine the proportion of sediment in Wolf Creek that is contributed by the stream banks.

The BEHI (Rosgen 2006) is designed to determine the relative erosivity of a stream bank based on easily gathered field measurements. The BEHI method gathers information on the height of the stream banks relative to the bankfull depth, root depth as a proportion of bank height, root density, bank angle and amount of protection of bare soil surfaces. The results of BEHI assessment of a 400-foot subsection of Field Site 1 appear in Appendix D.

The near-bank stress (NBS) analysis is designed to determine the degree of risk of bank erosion associated with in-stream conditions that lead to stress on the stream banks. The method was used at the general prediction level (Level II, Rosgen 2006) using Method 3 (ratio of pool slope to average water surface slope). The results of the NBS assessment of a 400-foot subsection of Field Site 1 appear in Appendix D.

The BEHI and NBS results were then used to predict a total contribution of sediment from the Field Site 1 stream banks for this reach based on an empirical relationship developed by Rosgen (2006) to predict streambank erosion from BEHI and NBS.

Hull considered performing the Pfankuch channel stability rating for Field Site 1, but did not perform it. The Pfankuch rating is used to select which empirical sediment rating curve to use in running the Flowsed/Powersed models. Since these models could not be run due to lack of other data (see below), the Pfankuch score was not needed.

1.3 Sediment Modeling

Hull considered collecting data on bedload sediment discharge at the bankfull stage with the intent of using existing sediment rating curves (Rosgen, 2006) to run Flowsed/Powersed sediment modeling. Flowsed/Powersed allows calculation of statistically reliable annual sediment discharge from a stream using empirically-derived sediment rating curves and USGS gauging data. USGS staff (Greg Koltun, pers. comm.) suggests that sediment bedload is an insignificant proportion of the total sediment load of Ohio's shallow-slope streams in glacial till. Because stream power in these streams is low relative to the high-gradient gravel-bed streams where these empirical sediment rating curves were developed, and sediments are relatively fine, the majority of sediment is represented as total suspended solids at all velocities. In addition, flood frequency tables (i.e., Weibull tables) are not available for the MBSP gauging station due to the short time it has been in operation, further precluding the use of the Flowsed/Powersed software.

Given these limitations, Hull used the most robust correlations available between discharge and suspended solid material to calculate total annual sediment discharge to Maumee Bay from Berger Ditch in 2007.

2.0 RESULTS

The longitudinal profile, cross sections and sediment data for Field Sites 2 and 3 appears in Appendix A. These two field sites were extensively hydrologically modified and both were subject to backwater effect from Lake Erie. Measured flow in Field Sites 2 and 3 averaged 8.1 cfs (from field velocity probe data) and 10.7 cfs (from USGS gauging station data), respectively, on the day of survey. The longitudinal profiles for these two stream reaches had essentially no bed slope. These stream reaches were considered poor candidates for Rosgen classification.

Field Site 1 was subjected to Rosgen classification. This reach of Wolf Creek is heavily hydrologically modified by deepening and straightening, but it is probably not regularly influenced by backwater effects from Lake Erie. In addition, this reach corresponds to the location of a new USGS gauging station at Seaman Rd. (USGS Station 04194082) installed in 2008. Reliable field indicators of bankfull discharge elevation could not be discerned (see longitudinal profiles and cross sections, Appendix A), so empirical estimates of bankfull discharge could not be calculated. Hull substituted regional curves developed for Ohio by USGS (Sherwood and Huitger 2005) to estimate the bankfull discharge elevation in this reach.

The Field Site 1 reach of Wolf Creek is classified as a Rosgen type C5 stream with an abnormally low width/depth ratio (Appendix C). Measured discharge within the cross sections at Field Site 1 at the time of survey ranged from 10.0 to 15.1 cfs and averaged 12.3 cfs. Bankfull velocity and discharge for Field Site 1 were estimated by several methods (Appendix C). The estimation method selected as most applicable for Field Site 1 used Manning's n value selected by Rosgen stream type. This estimation method yielded a bankfull velocity of 3 feet per second and bankfull discharge of 344 cubic feet per second (cfs). Note that this is somewhat lower than the discharge of 417 cfs predicted by the USGS regional curve (Sherwood and Huitger 2005).

The natural sediments in Wolf Creek and Berger Ditch range from silt and clay (<0.062 mm) to course gravel (16-22.6 mm). The D84 particle size for Field Site 1 ranged from 0.46 to 1.48 mm, for Field Site 2 ranged from 0.14 to 0.25 mm. Note that the sediment size distribution for Field Sites 1 and 2 are based on data collected using a Wolman particle count, and thus reflect the size distribution of particles lying on the stream bed surface. At Field Site 3 (within MBSP), data were collected using a Ponar dredge and thus reflect the size distribution of sediments in approximately the top 3 to 4 inches of stream bed sediments. D85 values at Field Site 3 ranged from 1.77 to 16.40 mm. The sediment size distributions for Field Site 3 compared with the other two sites suggest that accumulating fine particles tend to be deposited over coarser materials in the stream bed.

Hull determined that the stream banks at Field Site 1 had a bank-erosion hazard index (BEHI) of between 10 and 28, corresponding to narrative ratings of low to moderate. Hull estimates that of the 400 feet of channel assessed, approximately 80% (320 feet) had a moderate BEHI, and 20% (80 feet) had a low BEHI. Hull also determined based on the longitudinal profile data that the dominant near-bank stress (NBS) rating for this 400-foot reach was 'Low'.

Hull then used the Yellowstone curve (Rosgen 2006) to predict annual streambank erosion rates for this reach. For the streambanks with low BEHI/low NBS, the predicted bank erosion rate is about 0.032 feet/year. For the streambanks with moderate BEHI/low NBS, the predicted bank erosion rate is about 0.18 feet/year. The table below shows the calculation of an estimate of total annual streambank erosion rate per unit length.

BEHI Rating	**NBS Rating**	**Bank erosion rate[1] (feet/yr)**	**Length of bank (feet)**	**Study bank height (feet)**	**Erosion subtotal ($feet^3$/yr)**	
Low	Low	0.032	80	5	12.8	
Moderate	Low	0.18	320	5	288	
		Totals	**400**		**300.8**	
				Rate	**0.752**	**ft^3/ft/yr**

[1] From Rosgen, 2006, Figure 7-44: Prediction of Annual Streambank Erosion Rates

Extrapolated from this single reach to the entire length of the Wolf Creek/Berger Ditch system (2.8 miles or 14,800 feet), this analysis predicts a total streambank sediment contribution of approximately 11,100 ft^3/yr per bank, or 22,200 ft^3/yr. This figure amounts to 822 cubic yards per year, or 1,068 tons of sediment/year (1,050 metric tons/year) contributed from Wolf Creek/Berger Ditch stream banks.

Hull used data gathered from the USGS gauging station in MBSP to estimate the total sediment contribution of Berger Ditch to Maumee Bay in 2007. The data set includes water discharge data for a seven month period between May 2007 and December 2007.

Hull used two different data sets to establish a correlation between water discharge and sediment discharge at the Berger Ditch USGS gauging station. The first data set was published by USGS in 2006 (Brady 2007). This data set was collected from July to August 2006. It involved capturing a one-liter water sample and measuring the mass of all sediment within the sample (suspended sediment concentration or SSC). The following correlation was developed by Hull from USGS data:

$$y = 3.7378x + 44.518$$

$r^2 = 0.39$

n = 64

Where:

y = suspended sediment concentration (SSC) in mg/L

x = discharge in cubic feet per second.

n = number of data points

NOTES: Hull removed one observation of negative flow from the USGS data set; the range of discharge in the correlation was 15.2 to 118.4 cfs

In 2008, the University of Toledo installed a multiport sampler designed to sample water at five locations in the water column at approximately the same time. This method was used because of the concern that water samples from a single point within the water column might poorly represent total sediment load in the water column due to separation of various particle size fractions by vertical position. Hull developed a correlation for five observations made using the multiport sampler on 6/10/08, 7/3/08, 7/9/08, 7/24/08 and 7/28/08:

$$y = 0.2633x + 30.629$$

$r^2 = 0.92$

n = 5

Where:

y = total suspended solids (TSS) concentration in mg/L

x = discharge in cubic feet per second.

n = number of data points

NOTE: The range of discharge in the correlation was 0 to 470 cfs

Hull then applied these two correlations (Appendix E) in an Excel spreadsheet to estimate total sediment discharge from Berger Ditch in 2007. The results were extrapolated for the whole year from the 7 months of flow data available. The year 2007 included a peak storm of 256 cfs on August 20, 2007.

The correlation from USGS data yielded a 2007 estimate of 1845 metric tons discharged from Berger Ditch to Maumee Bay. The correlation from UT data yielded a 2007 estimate of 311 metric tons discharged from Berger Ditch to Maumee Bay.

3.0 DISCUSSION

Historically, the areas of Wolf Creek and Berger Ditch subject to Lake Erie influence were part of a large coastal estuary system characterized by extensive wetlands (e.g., Gottgens et al. 1998). In an estuary system, sediment loads from the watershed are deposited as stream velocities decrease within the area of lake influence, building shallow lacustrine emergent wetland habitat. Removal of these coastal wetland areas, extensive land creation via filling, and hydrologic modification of the inflowing streams to improve drainage allows these sediments from the watershed to directly enter the lake, resulting in the sedimentation and sediment-borne pollutant problems observed today in Maumee Bay.

The simple sediment model developed in this study was unable to reconcile the total 2007 sediment delivery results developed from the two independent correlations of water and sediment discharge. The 2006 USGS correlation predicts about 1845 metric tons of sediment delivered to Maumee Bay in 2007, while the 2008 UT correlation predicts about 311 tons total sediment delivery.

Hull is aware of differences in sampling and analytical methods between UT and USGS that could account for some proportion of this discrepancy. Gray et al. (2000) describes a systematic comparison of results for laboratory TSS and SSC analyses on paired samples by USGS. Among the findings of this study, USGS observed that as the proportion of sand size material exceeded about 25% of the sediment dry weight, SSC tended to exceed the corresponding paired TSS value. Hull found that the percentage of sand ranged from 24.8% to 52% at Field Site 1, 22.2% to 27.7% at Field Site 2, and 18.1% to 30.9% at Field Site 3, suggesting that water column samples of suspended sediment could have readily exceeded 25% sand. USGS (2000) concludes that TSS is fundamentally unreliable for analysis of natural water samples. Based on this study, Hull concludes that the estimate of 2007 total sediment load based on the USGS correlation of discharge to SSC is the more reliable of the two estimates.

An unknown amount of estimation error may result from extrapolation of the USGS correlation beyond the data limits used to derive the correlation. Hull notes that the range of water discharge observed in 2007 fell within the range of discharge measurements (0 to 470 cfs) used to derive the UT correlation, while both the low and high ends of the 2007 range of flows fell outside the range of discharge measurements used to derive the USGS correlation (15.2 to

118.4 cfs). Simple extrapolation of the linear USGS correlation into the range of very high flows could have resulted in significant overestimation of sediment transport.

This study estimates the total contribution of erosion from stream banks to sediment in Wolf Creek at about 1,000 metric tons/year. Assuming that Hull's estimate of 1845 metric tons is an accurate estimate of the sediment delivered to Maumee Bay in 2007, streambank erosion would appear on first analysis to be the source of the majority of the sediment delivered to Maumee Bay. However, the stream evidently is aggrading and does not move its entire sediment load, as it is necessary to dig out accumulated sediments on a regular basis. This loss of sediment from Wolf Creek and Berger Ditch through ditch maintenance cannot be estimated accurately but it is probably significant. Because of this large, unknown sediment sink in the watershed, the proportional contribution of the various sediment sources (e.g., soil erosion, streambank erosion, runoff from impervious surfaces) to total sediment load cannot be estimated with any confidence.

4.0 REFERENCES

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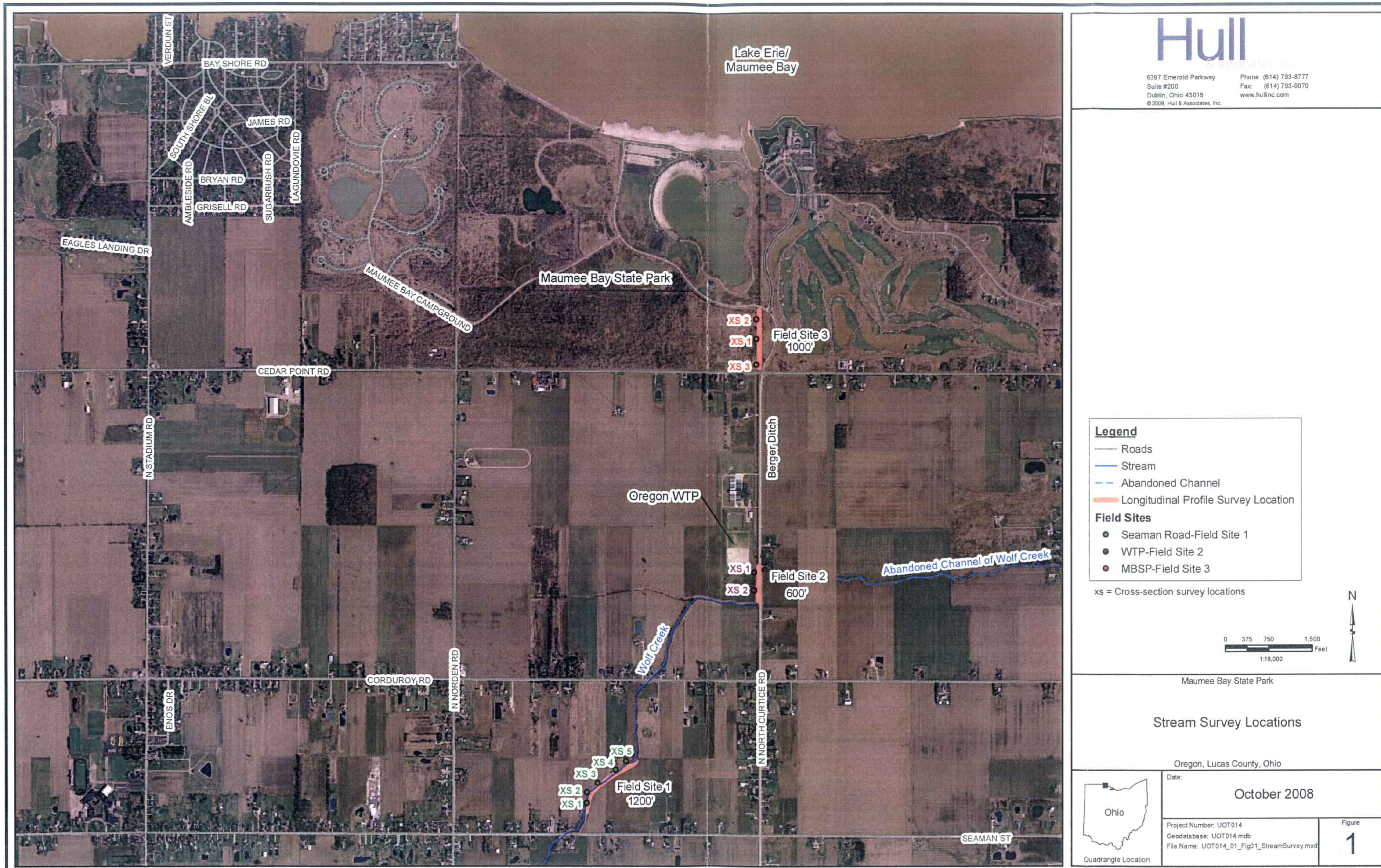
FIGURES


Lake Erie/
Maumee Bay
VERDUN ST
BAY SHORE RD
SOUTH SHORE BL
JAMES RD
AMBLESIDE RD
BRYAN RD
GRISELL RD
SUGARBUSH RD
LAGUNDOVIE RD
EAGLES LANDING DR
MAUMEE BAY CAMPGROUND
Maumee Bay State Park
XS 2
XS 1
XS 3
Field Site 3
1000'
CEDAR POINT RD
N STADIUM RD
Berger Ditch
Oregon WTP
XS 1
XS 2
Field Site 2
600'
Abandoned Channel of Wolf Creek
Wolf Creek
CORDUROY RD
N NORDEN RD
ENOS DR
N NORTH CURTICE RD
XS 5
XS 4
XS 3
XS 2
XS 1
Field Site 1
1200'
SEAMAN ST
Produced using ArcGIS 9.2
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Suite #200
Dublin, Ohio 43016
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Legend
Roads
Stream
Abandoned Channel
Longitudinal Profile Survey Location
Field Sites
Seaman Road-Field Site 1
WTP-Field Site 2
MBSP-Field Site 3
xs = Cross-section survey locations
N
0 375 750 1,500 Feet
1:18,000
Maumee Bay State Park
Stream Survey Locations
Oregon, Lucas County, Ohio
Ohio
Quadrangle Location
Date:
October 2008
Project Number: UOT014
Geodatabase: UOT014.mdb
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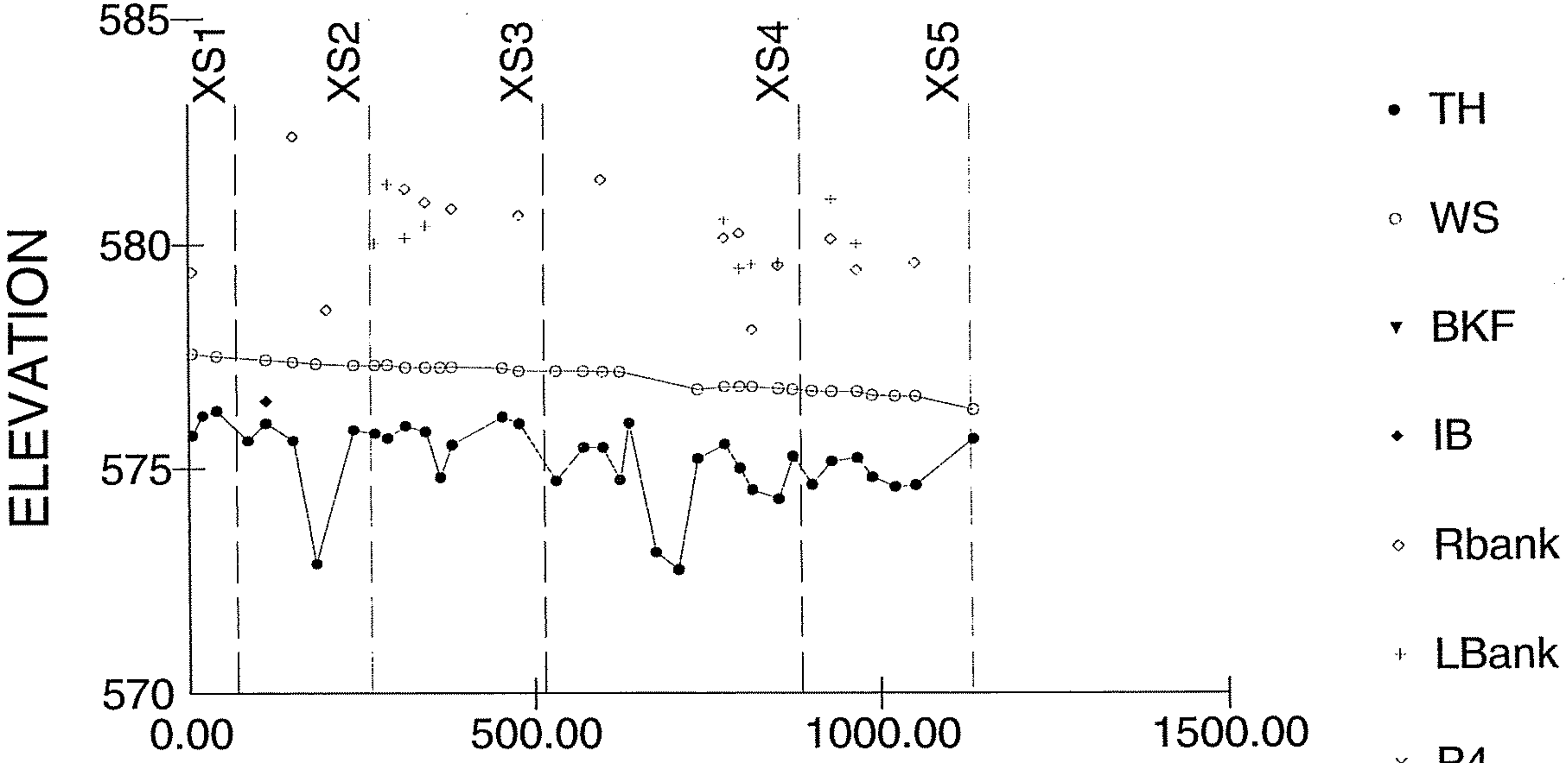
Figure
1

APPENDIX A

RiverMorph v. 4.1 Output

Wolf Creek at Seaman Road



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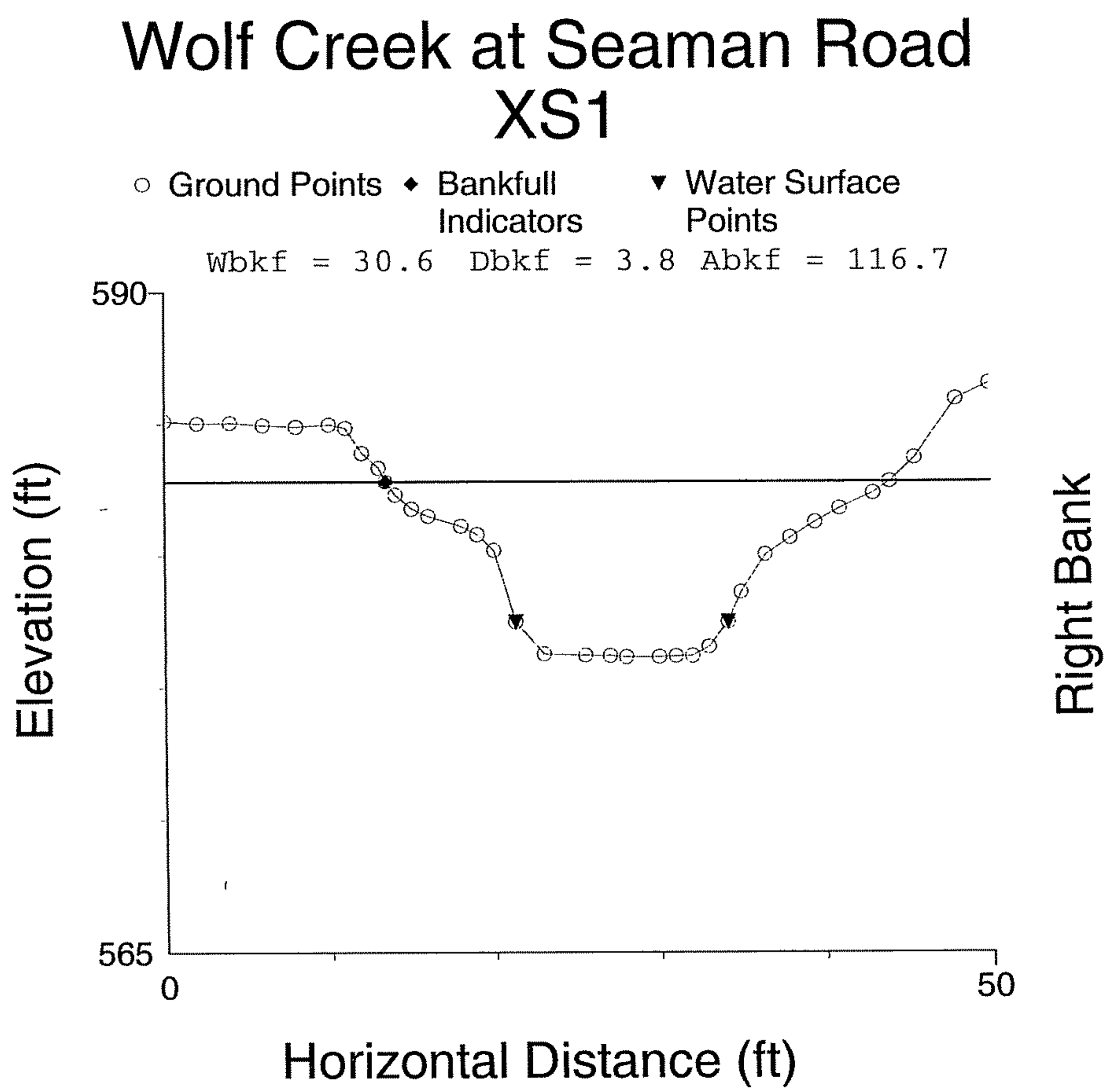
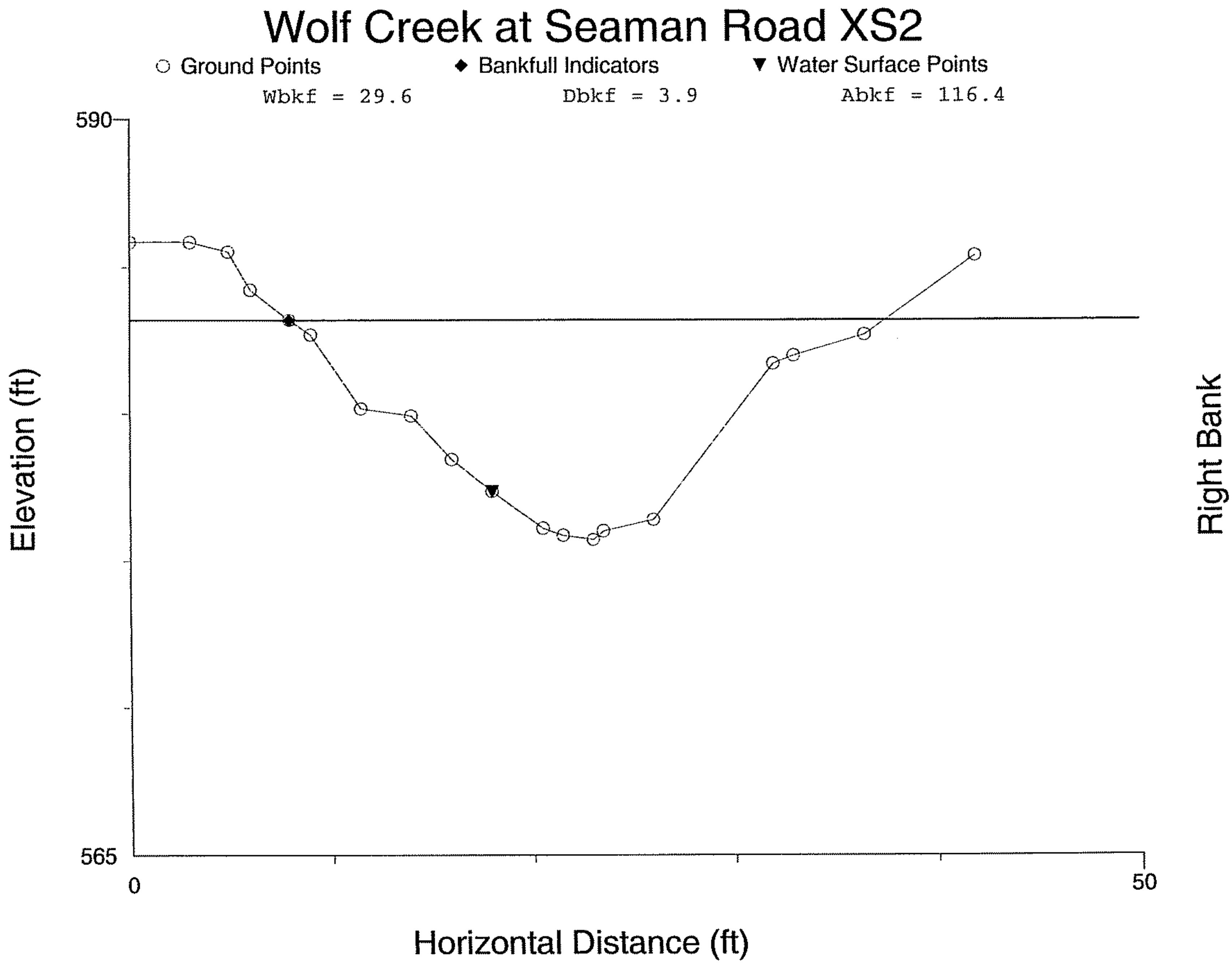

Wolf Creek at Seaman Road
XS1
Ground Points
Bankfull Indicators
Water Surface Points
Wbkf = 30.6 Dbkf = 3.8 Abkf = 116.7
590
565
0
50
Elevation (ft)
Right Bank
Horizontal Distance (ft)



Wolf Creek at Seaman Road XS2
Ground Points
Bankfull Indicators
Water Surface Points
Wbkf = 29.6
Dbkf = 3.9
Abkf = 116.4
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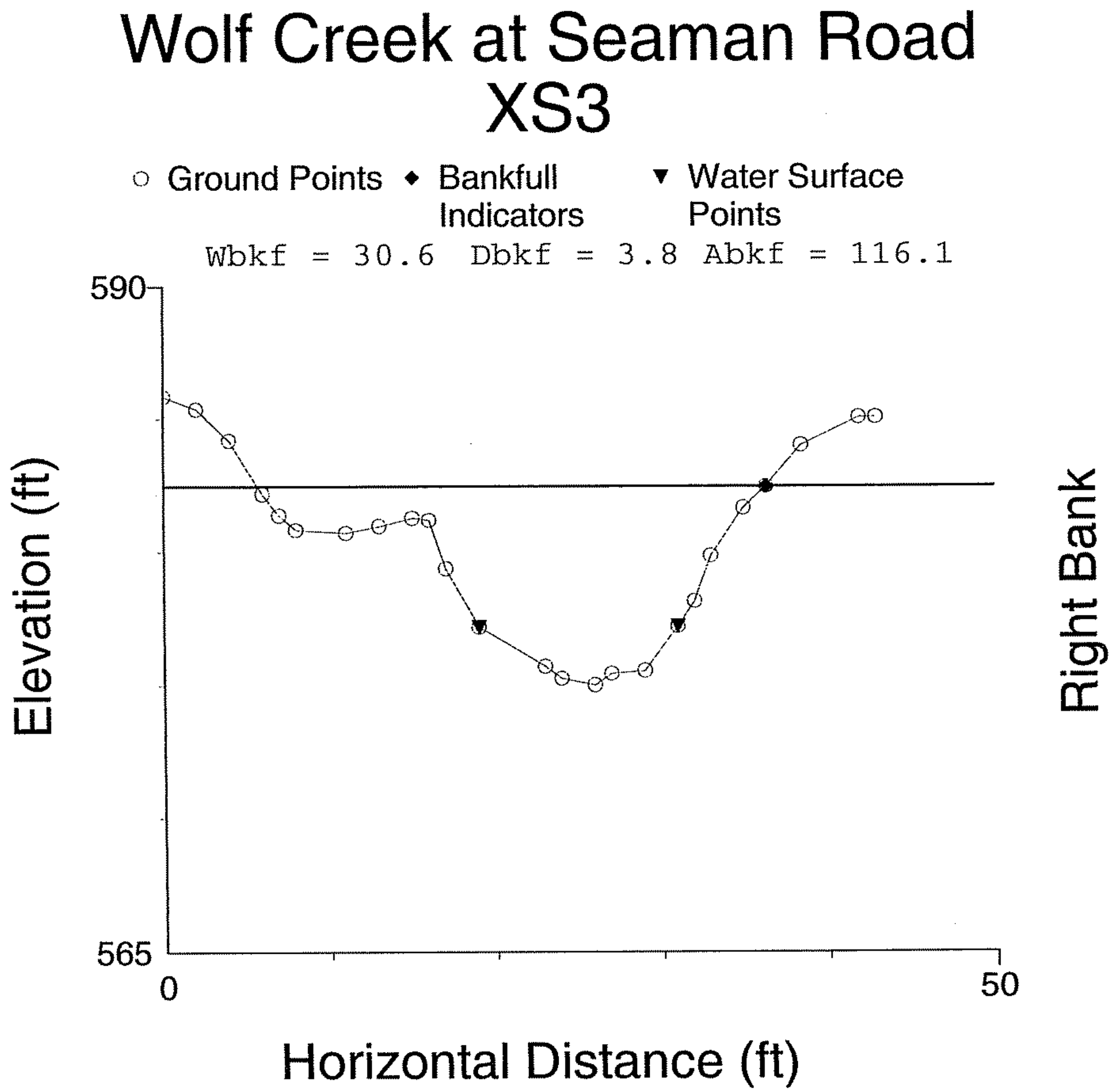
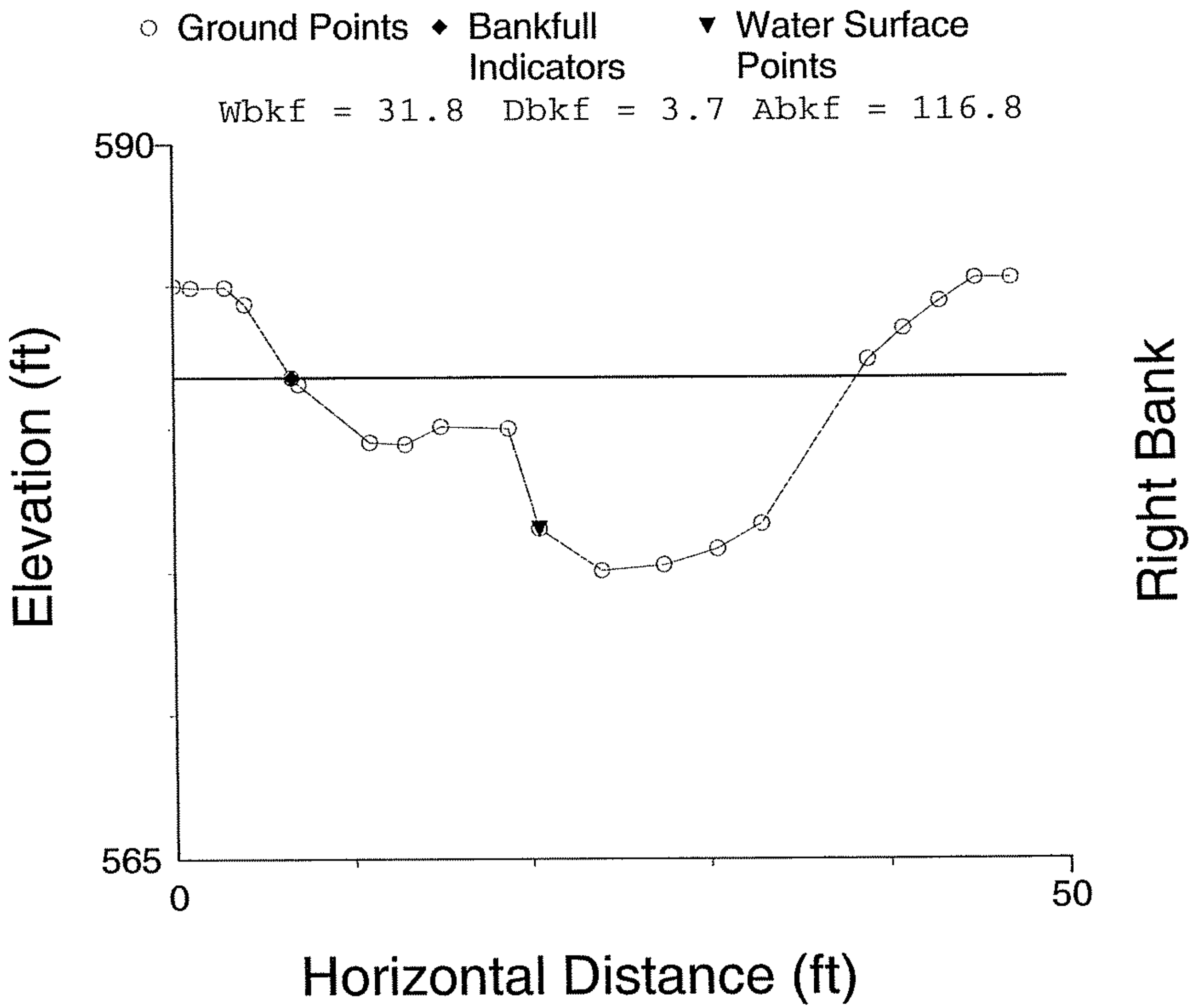
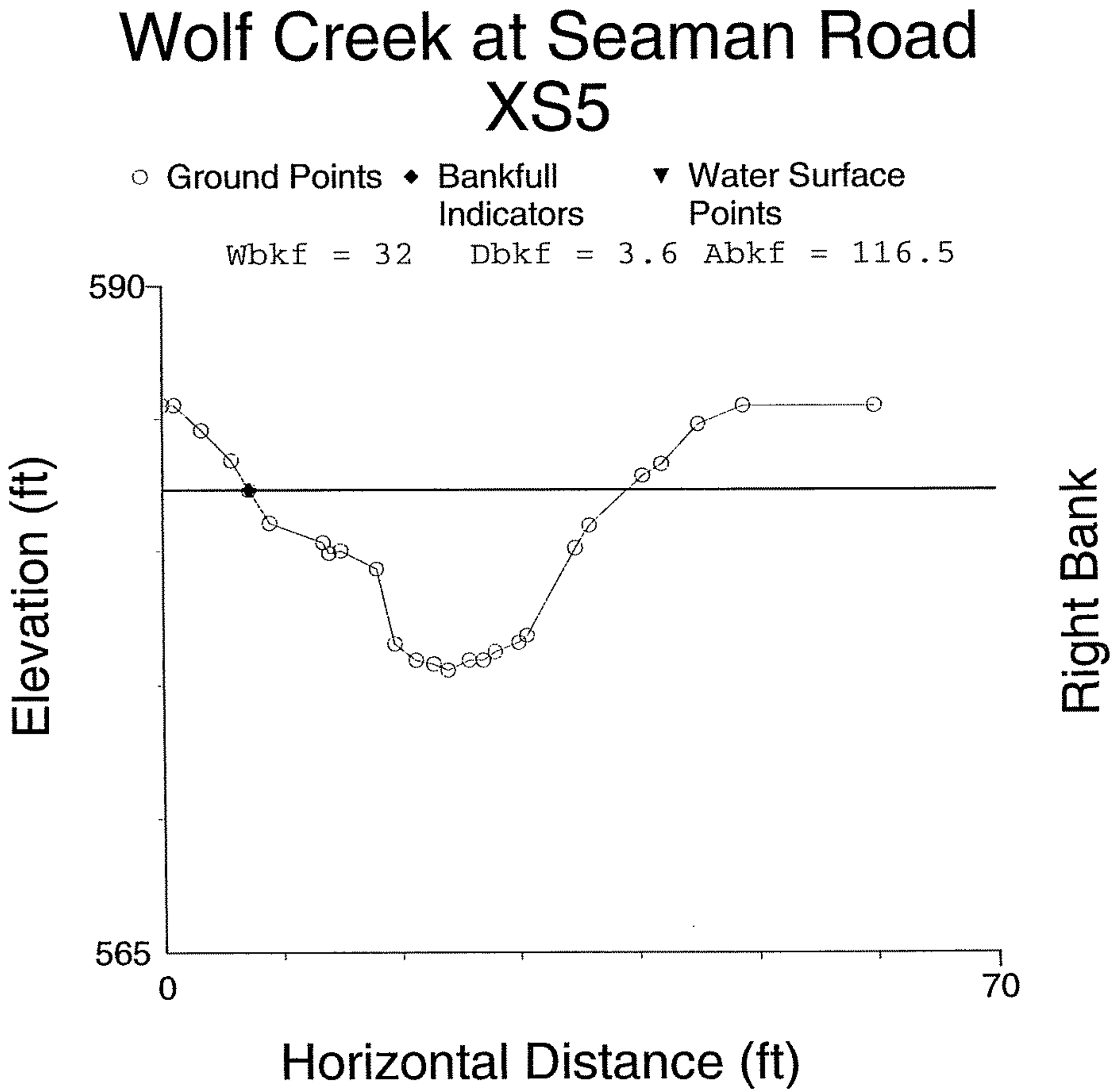
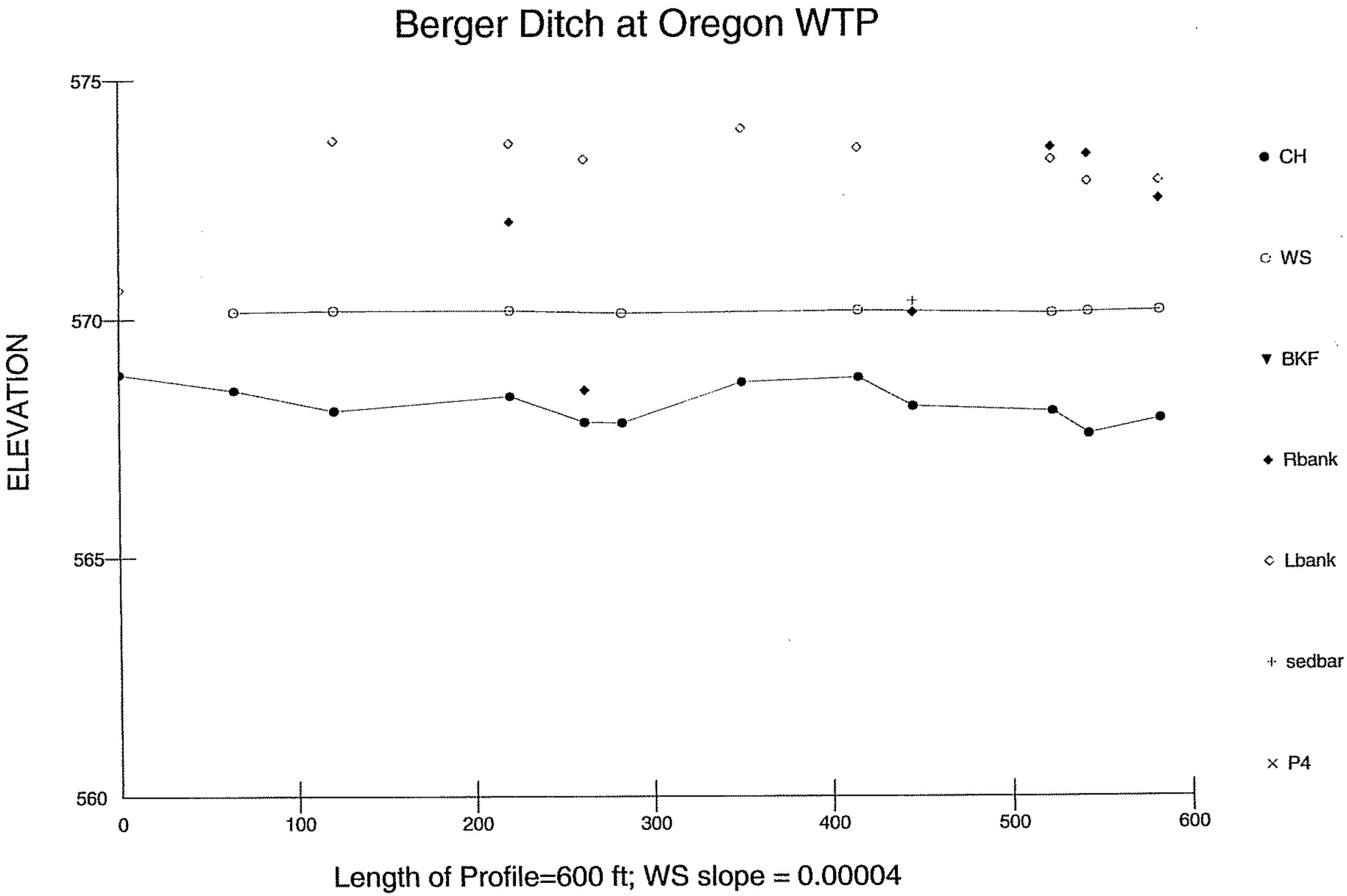
565
Elevation (ft)
0
50
Horizontal Distance (ft)
Right Bank


Wolf Creek at Seaman Road
XS3
Ground Points
Bankfull Indicators
Water Surface Points
Wbkf = 30.6 Dbkf = 3.8 Abkf = 116.1
590
565
0
50
Elevation (ft)
Horizontal Distance (ft)
Right Bank

Wolf Creek at Seaman Road
XS4

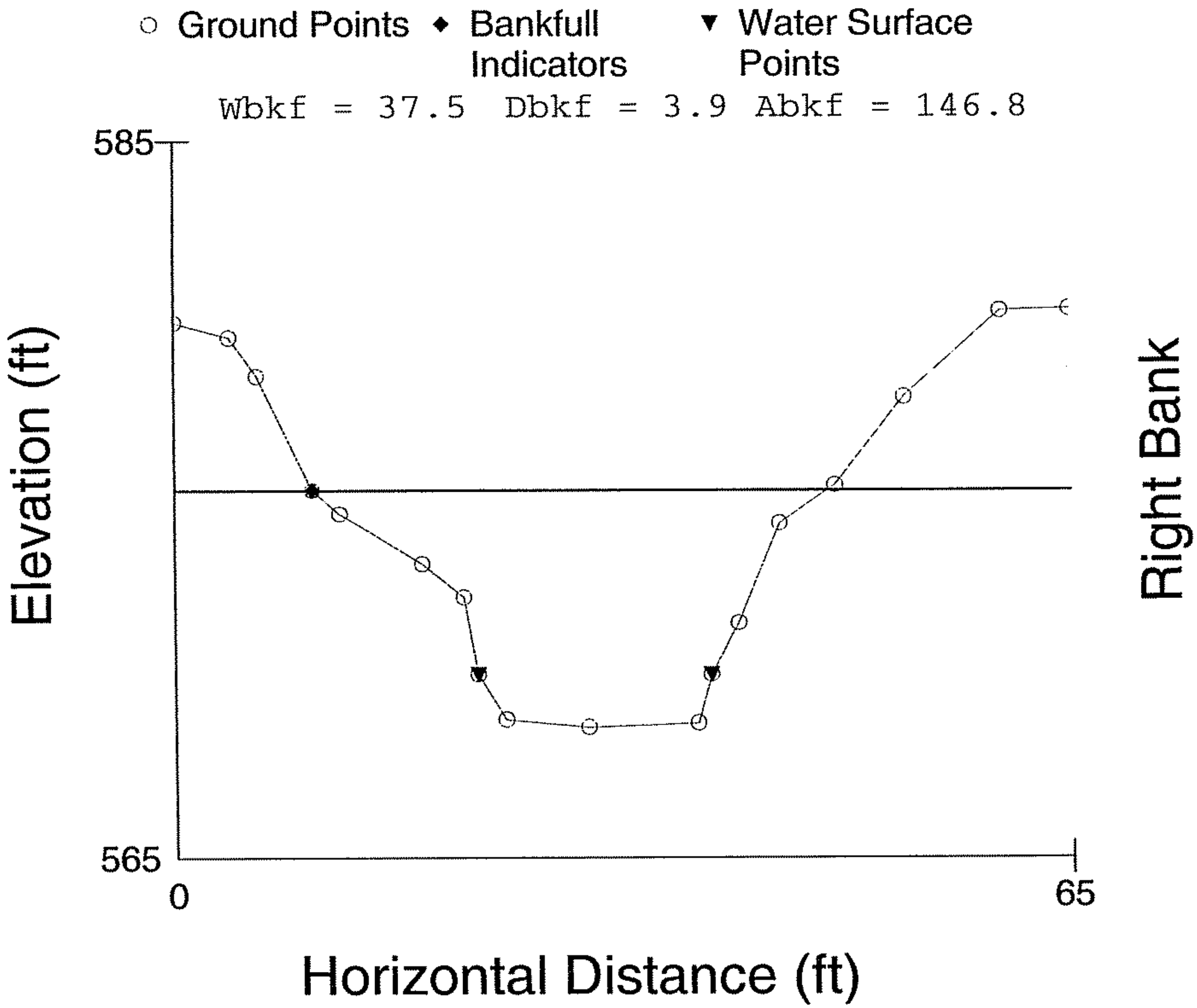


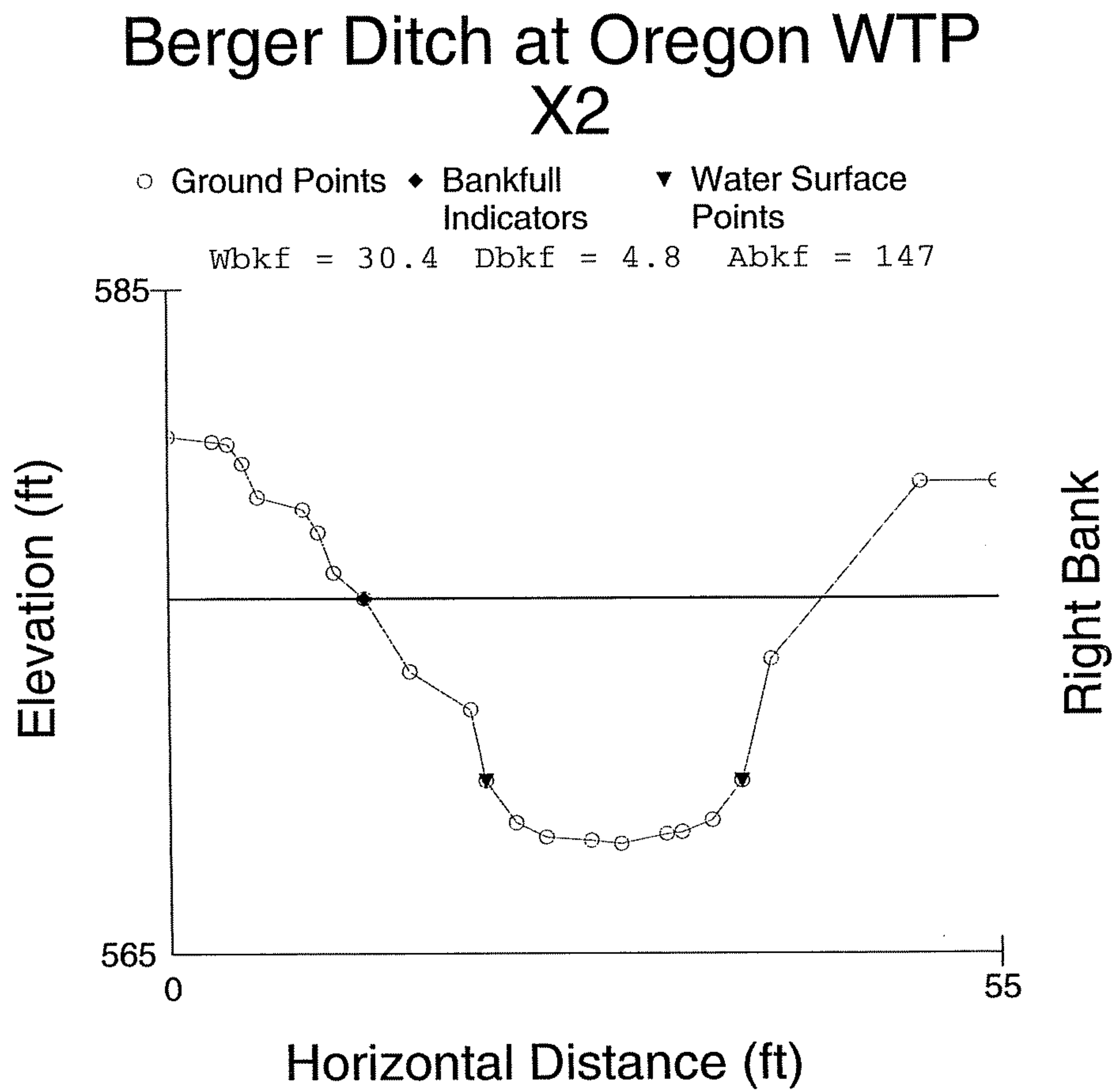

Wolf Creek at Seaman Road
XS5
Ground Points
Bankfull Indicators
Water Surface Points
Wbkf = 32 Dbkf = 3.6 Abkf = 116.5
590
565
0
70
Elevation (ft)
Right Bank
Horizontal Distance (ft)



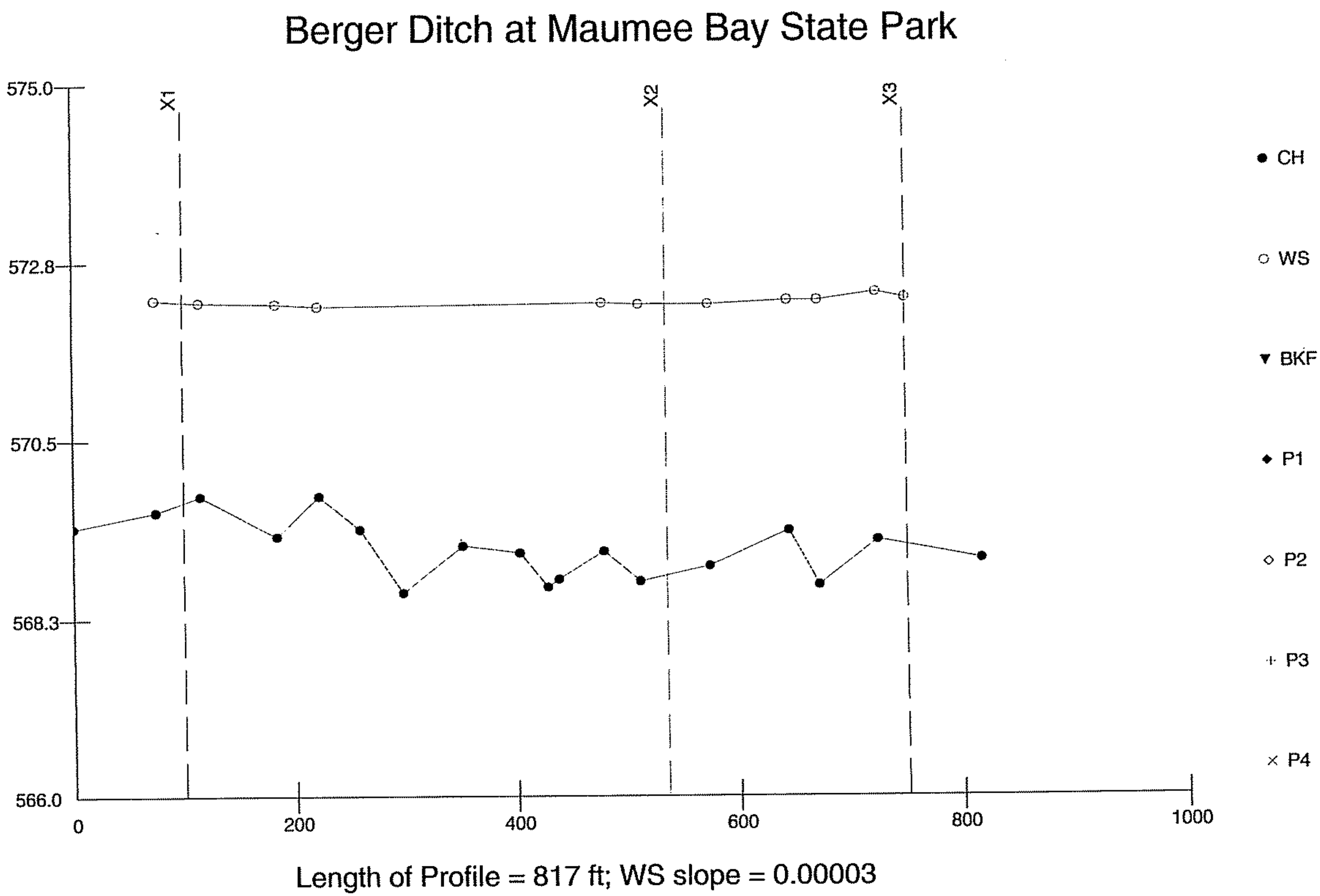
Berger Ditch at Oregon WTP
ELEVATION
575
570
565
560
0
100
200
300
400
500
600
CH
WS
BKF
Rbank
Lbank
sedbar
P4
Length of Profile=600 ft; WS slope = 0.00004

Berger Ditch at Oregon WTP
X1

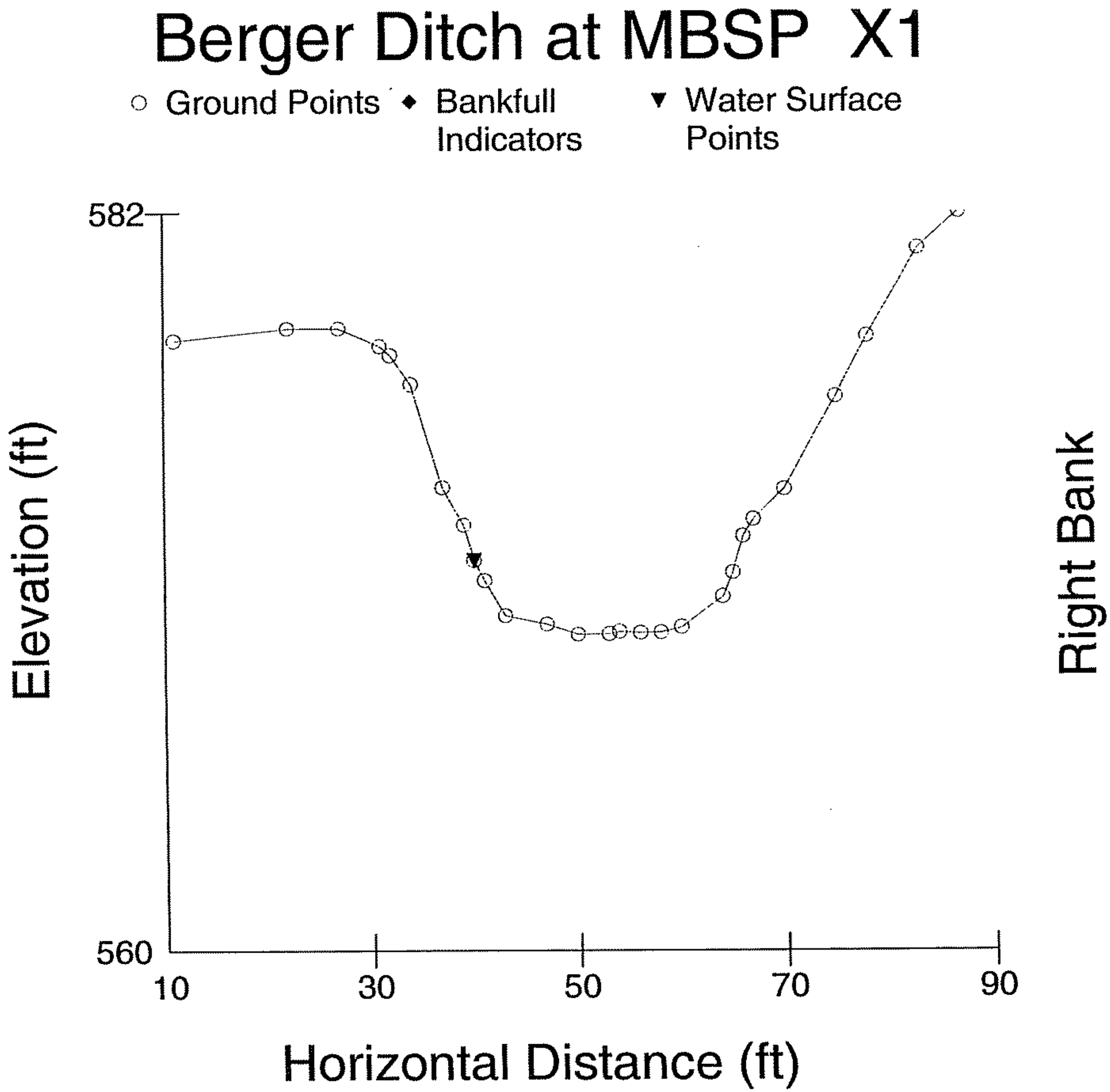




Berger Ditch at Oregon WTP
X2
Ground Points
Bankfull Indicators
Water Surface Points
Wbkf = 30.4 Dbkf = 4.8 Abkf = 147
585
565
0
55
Elevation (ft)
Right Bank
Horizontal Distance (ft)

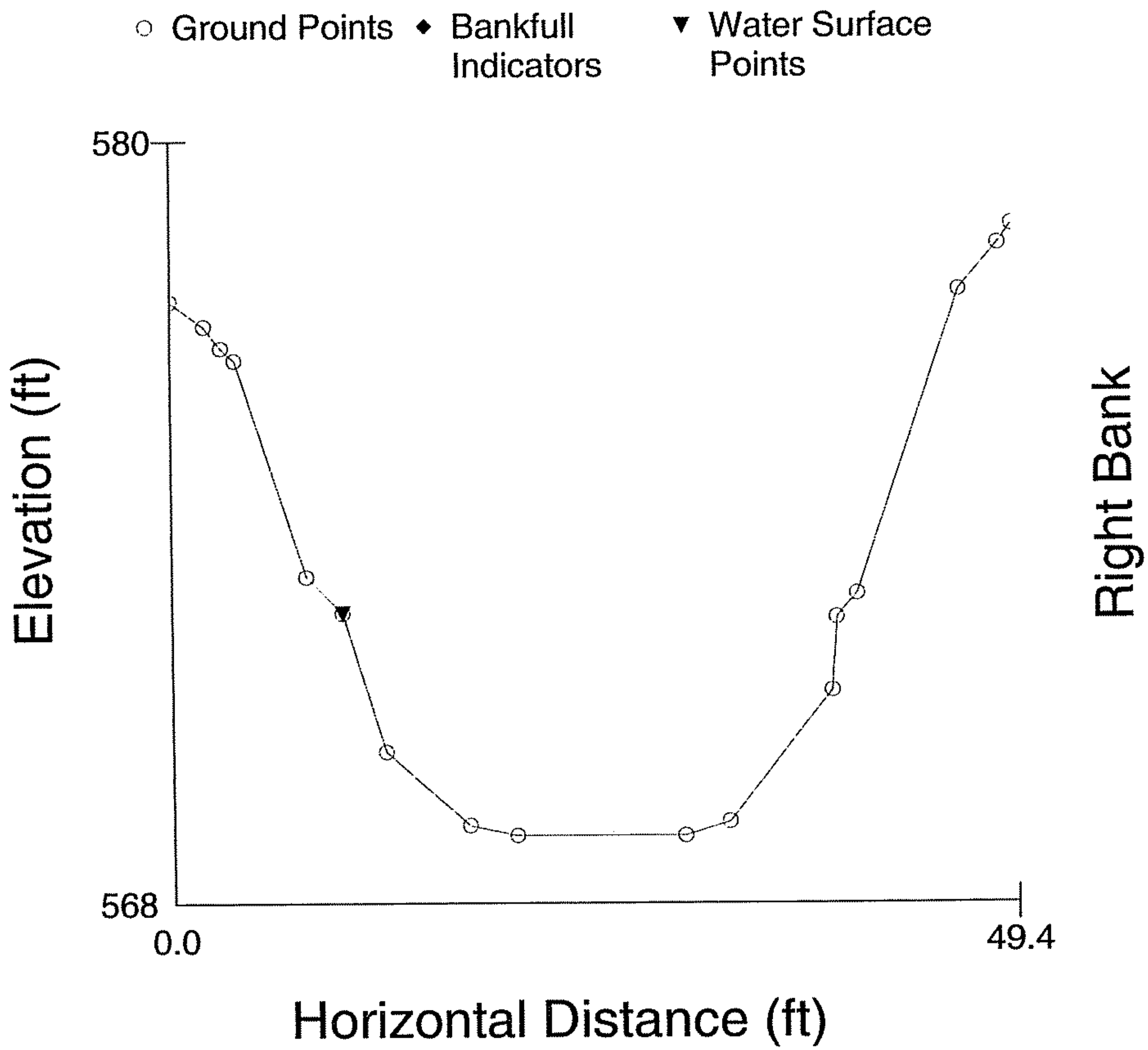


Berger Ditch at Maumee Bay State Park
575.0
572.8
570.5
568.3
566.0
X1
X2
X3
0
200
400
600
800
1000
CH
WS
BKF
P1
P2
P3
P4
Length of Profile = 817 ft; WS slope = 0.00003

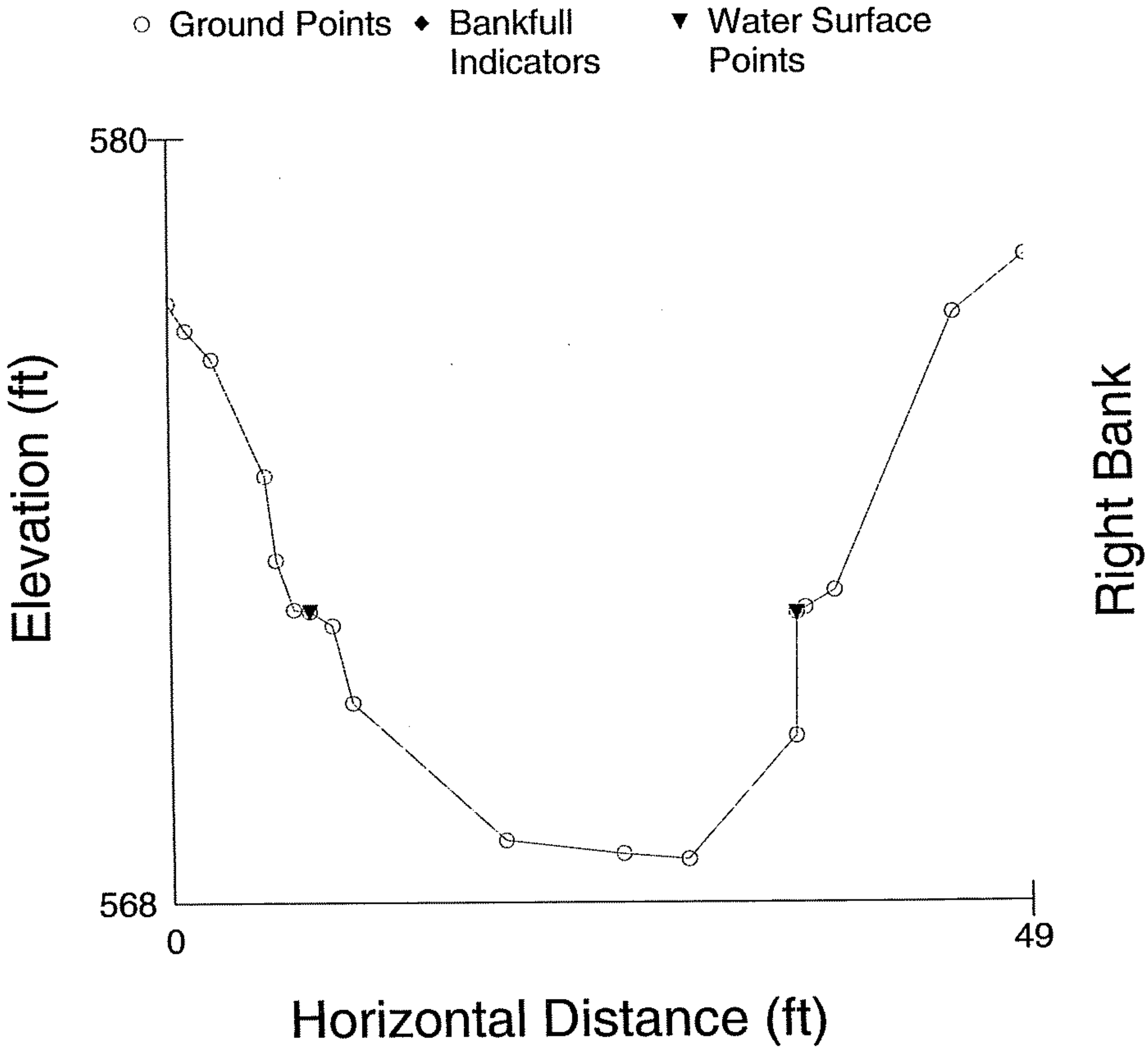


Berger Ditch at MBSP X1
Ground Points
Bankfull Indicators
Water Surface Points
582
560
Elevation (ft)
10
30
50
70
90
Horizontal Distance (ft)
Right Bank

Berger Ditch at MBSP X2



Berger Ditch at MBSP X3



APPENDIX B

Sediment Data

RIVERMORPH PARTICLE SUMMARY

River Name: Wolf Creek
Reach Name: Reach 1 - Seaman Road
Sample Name: X1
Survey Date: 04/29/2008

Size (mm)	TOT #	ITEM %	CUM %
0 - 0.062	37	36.63	36.63
0.062 - 0.125	17	16.83	53.47
0.125 - 0.25	5	4.95	58.42
0.25 - 0.50	8	7.92	66.34
0.50 - 1.0	14	13.86	80.20
1.0 - 2.0	8	7.92	88.12
2.0 - 4.0	2	1.98	90.10
4.0 - 5.7	0	0.00	90.10
5.7 - 8.0	6	5.94	96.04
8.0 - 11.3	1	0.99	97.03
11.3 - 16.0	1	0.99	98.02
16.0 - 22.6	2	1.98	100.00
22.6 - 32.0	0	0.00	100.00
32 - 45	0	0.00	100.00
45 - 64	0	0.00	100.00
64 - 90	0	0.00	100.00
90 - 128	0	0.00	100.00
128 - 180	0	0.00	100.00
180 - 256	0	0.00	100.00
256 - 362	0	0.00	100.00
362 - 512	0	0.00	100.00
512 - 1024	0	0.00	100.00
1024 - 2048	0	0.00	100.00
Bedrock	0	0.00	100.00

D16 (mm)	0.03
D35 (mm)	0.06
D50 (mm)	0.11
D84 (mm)	1.48
D95 (mm)	7.6
D100 (mm)	22.6
Silt/Clay (%)	36.63
Sand (%)	51.49
Gravel (%)	11.88
Cobble (%)	0
Boulder (%)	0
Bedrock (%)	0

Total Particles = 101.

RIVERMORPH PARTICLE SUMMARY

River Name: Wolf Creek
Reach Name: Reach 1 - Seaman Road
Sample Name: X2
Survey Date: 04/29/2008

Size (mm)	TOT #	ITEM %	CUM %
0 - 0.062	63	62.38	62.38
0.062 - 0.125	4	3.96	66.34
0.125 - 0.25	4	3.96	70.30
0.25 - 0.50	8	7.92	78.22
0.50 - 1.0	5	4.95	83.17
1.0 - 2.0	4	3.96	87.13
2.0 - 4.0	1	0.99	88.12
4.0 - 5.7	2	1.98	90.10
5.7 - 8.0	3	2.97	93.07
8.0 - 11.3	1	0.99	94.06
11.3 - 16.0	2	1.98	96.04
16.0 - 22.6	0	0.00	96.04
22.6 - 32.0	0	0.00	96.04
32 - 45	1	0.99	97.03
45 - 64	3	2.97	100.00
64 - 90	0	0.00	100.00
90 - 128	0	0.00	100.00
128 - 180	0	0.00	100.00
180 - 256	0	0.00	100.00
256 - 362	0	0.00	100.00
362 - 512	0	0.00	100.00
512 - 1024	0	0.00	100.00
1024 - 2048	0	0.00	100.00
Bedrock	0	0.00	100.00

D16 (mm)	0.02
D35 (mm)	0.04
D50 (mm)	0.05
D84 (mm)	1.21
D95 (mm)	13.53
D100 (mm)	64
Silt/Clay (%)	62.38
Sand (%)	24.75
Gravel (%)	12.87
Cobble (%)	0
Boulder (%)	0
Bedrock (%)	0

Total Particles = 101.

RIVERMORPH PARTICLE SUMMARY

River Name: Wolf Creek
Reach Name: Reach 1 - Seaman Road
Sample Name: X3
Survey Date: 04/29/2008

Size (mm)	TOT #	ITEM %	CUM %
0 - 0.062	51	51.00	51.00
0.062 - 0.125	21	21.00	72.00
0.125 - 0.25	9	9.00	81.00
0.25 - 0.50	9	9.00	90.00
0.50 - 1.0	4	4.00	94.00
1.0 - 2.0	1	1.00	95.00
2.0 - 4.0	3	3.00	98.00
4.0 - 5.7	0	0.00	98.00
5.7 - 8.0	0	0.00	98.00
8.0 - 11.3	1	1.00	99.00
11.3 - 16.0	1	1.00	100.00
16.0 - 22.6	0	0.00	100.00
22.6 - 32.0	0	0.00	100.00
32 - 45	0	0.00	100.00
45 - 64	0	0.00	100.00
64 - 90	0	0.00	100.00
90 - 128	0	0.00	100.00
128 - 180	0	0.00	100.00
180 - 256	0	0.00	100.00
256 - 362	0	0.00	100.00
362 - 512	0	0.00	100.00
512 - 1024	0	0.00	100.00
1024 - 2048	0	0.00	100.00
Bedrock	0	0.00	100.00

D16 (mm)	0.02
D35 (mm)	0.04
D50 (mm)	0.06
D84 (mm)	0.33
D95 (mm)	2
D100 (mm)	16
Silt/Clay (%)	51
Sand (%)	44
Gravel (%)	5
Cobble (%)	0
Boulder (%)	0
Bedrock (%)	0

Total Particles = 100.

RIVERMORPH PARTICLE SUMMARY

River Name:	Wolf Creek
Reach Name:	Reach 1 - Seaman Road
Sample Name:	X4
Survey Date:	04/29/2008

Size (mm)	TOT #	ITEM %	CUM %
0 - 0.062	42	43.75	43.75
0.062 - 0.125	24	25.00	68.75
0.125 - 0.25	8	8.33	77.08
0.25 - 0.50	8	8.33	85.42
0.50 - 1.0	5	5.21	90.62
1.0 - 2.0	5	5.21	95.83
2.0 - 4.0	1	1.04	96.87
4.0 - 5.7	1	1.04	97.92
5.7 - 8.0	2	2.08	100.00
8.0 - 11.3	0	0.00	100.00
11.3 - 16.0	0	0.00	100.00
16.0 - 22.6	0	0.00	100.00
22.6 - 32.0	0	0.00	100.00
32 - 45	0	0.00	100.00
45 - 64	0	0.00	100.00
64 - 90	0	0.00	100.00
90 - 128	0	0.00	100.00
128 - 180	0	0.00	100.00
180 - 256	0	0.00	100.00
256 - 362	0	0.00	100.00
362 - 512	0	0.00	100.00
512 - 1024	0	0.00	100.00
1024 - 2048	0	0.00	100.00
Bedrock	0	0.00	100.00

D16 (mm)	0.02
D35 (mm)	0.05
D50 (mm)	0.08
D84 (mm)	0.46
D95 (mm)	1.84
D100 (mm)	8
Silt/Clay (%)	43.75
Sand (%)	52.08
Gravel (%)	4.17
Cobble (%)	0
Boulder (%)	0
Bedrock (%)	0

Total Particles = 96.

RIVERMORPH PARTICLE SUMMARY

River Name: Wolf Creek
Reach Name: Reach 1 - Seaman Road
Sample Name: X5
Survey Date: 04/29/2008

Size (mm)	TOT #	ITEM %	CUM %
0 - 0.062	28	27.45	27.45
0.062 - 0.125	1	0.98	28.43
0.125 - 0.25	3	2.94	31.37
0.25 - 0.50	3	2.94	34.31
0.50 - 1.0	2	1.96	36.27
1.0 - 2.0	2	1.96	38.24
2.0 - 4.0	3	2.94	41.18
4.0 - 5.7	0	0.00	41.18
5.7 - 8.0	0	0.00	41.18
8.0 - 11.3	0	0.00	41.18
11.3 - 16.0	2	1.96	43.14
16.0 - 22.6	3	2.94	46.08
22.6 - 32.0	6	5.88	51.96
32 - 45	22	21.57	73.53
45 - 64	12	11.76	85.29
64 - 90	2	1.96	87.25
90 - 128	9	8.82	96.08
128 - 180	4	3.92	100.00
180 - 256	0	0.00	100.00
256 - 362	0	0.00	100.00
362 - 512	0	0.00	100.00
512 - 1024	0	0.00	100.00
1024 - 2048	0	0.00	100.00
Bedrock	0	0.00	100.00

D16 (mm)	0.04
D35 (mm)	0.68
D50 (mm)	28.87
D84 (mm)	61.92
D95 (mm)	123.35
D100 (mm)	180
Silt/Clay (%)	27.45
Sand (%)	10.79
Gravel (%)	47.05
Cobble (%)	14.71
Boulder (%)	0
Bedrock (%)	0

Total Particles = 102.

Note: This was a riffle that was constructed as grade control from artifical substrates - this does <u>not</u> represent sediment particle size distribution in Wolf Creek.

-Hugh Crowell

RIVERMORPH PARTICLE SUMMARY

River Name: Wolf Creek
Reach Name: Reach 2 - WTP
Sample Name: X1
Survey Date: 04/29/2008

Size (mm)	TOT #	ITEM %	CUM %
0 - 0.062	68	67.33	67.33
0.062 - 0.125	16	15.84	83.17
0.125 - 0.25	9	8.91	92.08
0.25 - 0.50	1	0.99	93.07
0.50 - 1.0	1	0.99	94.06
1.0 - 2.0	1	0.99	95.05
2.0 - 4.0	0	0.00	95.05
4.0 - 5.7	1	0.99	96.04
5.7 - 8.0	3	2.97	99.01
8.0 - 11.3	1	0.99	100.00
11.3 - 16.0	0	0.00	100.00
16.0 - 22.6	0	0.00	100.00
22.6 - 32.0	0	0.00	100.00
32 - 45	0	0.00	100.00
45 - 64	0	0.00	100.00
64 - 90	0	0.00	100.00
90 - 128	0	0.00	100.00
128 - 180	0	0.00	100.00
180 - 256	0	0.00	100.00
256 - 362	0	0.00	100.00
362 - 512	0	0.00	100.00
512 - 1024	0	0.00	100.00
1024 - 2048	0	0.00	100.00
Bedrock	0	0.00	100.00

D16 (mm)	0.02
D35 (mm)	0.03
D50 (mm)	0.05
D84 (mm)	0.14
D95 (mm)	1.95
D100 (mm)	11.3
Silt/Clay (%)	67.33
Sand (%)	27.72
Gravel (%)	4.95
Cobble (%)	0
Boulder (%)	0
Bedrock (%)	0

Total Particles = 101.

RIVERMORPH PARTICLE SUMMARY

River Name: Wolf Creek
Reach Name: Reach 2 - WTP
Sample Name: X2
Survey Date: 04/29/2008

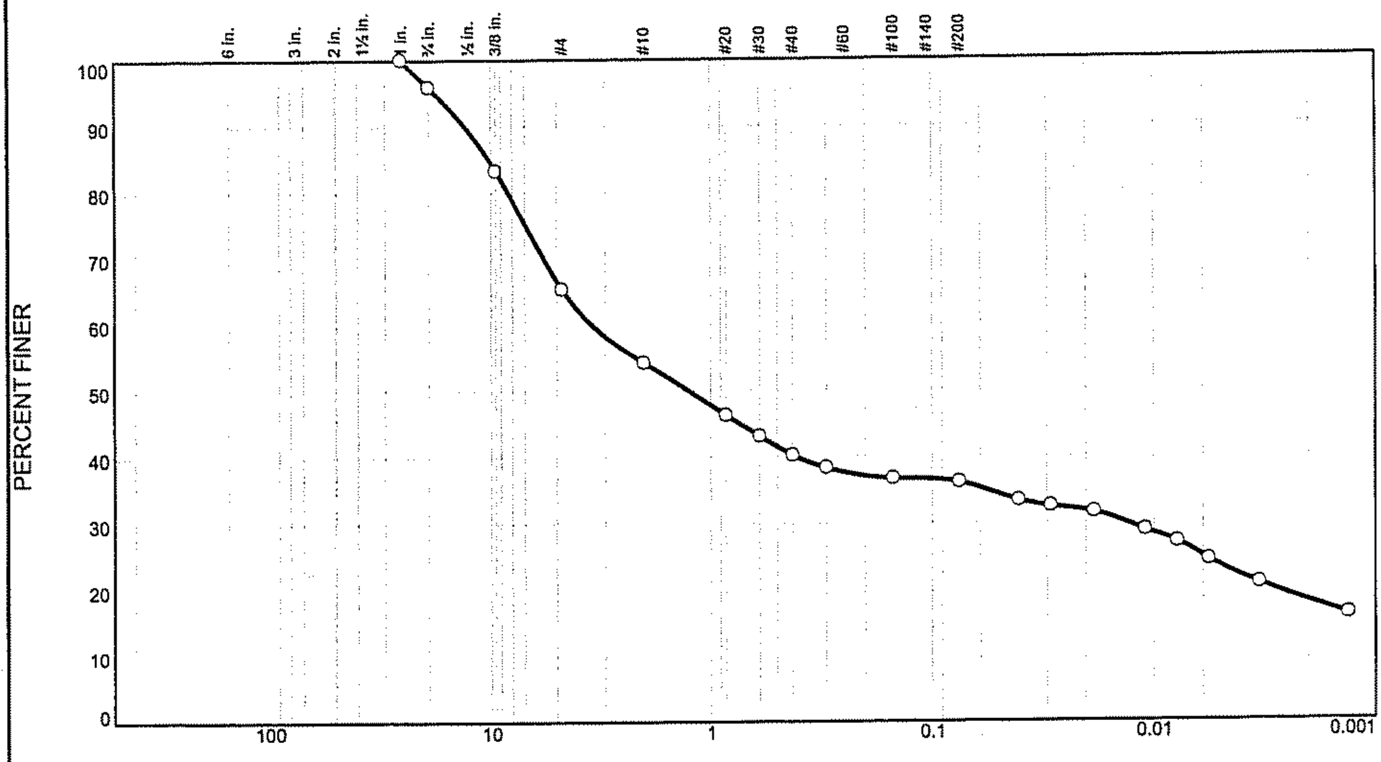
Size (mm)	TOT #	ITEM %	CUM %
0 - 0.062	63	70.00	70.00
0.062 - 0.125	1	1.11	71.11
0.125 - 0.25	12	13.33	84.44
0.25 - 0.50	2	2.22	86.67
0.50 - 1.0	2	2.22	88.89
1.0 - 2.0	3	3.33	92.22
2.0 - 4.0	5	5.56	97.78
4.0 - 5.7	1	1.11	98.89
5.7 - 8.0	1	1.11	100.00
8.0 - 11.3	0	0.00	100.00
11.3 - 16.0	0	0.00	100.00
16.0 - 22.6	0	0.00	100.00
22.6 - 32.0	0	0.00	100.00
32 - 45	0	0.00	100.00
45 - 64	0	0.00	100.00
64 - 90	0	0.00	100.00
90 - 128	0	0.00	100.00
128 - 180	0	0.00	100.00
180 - 256	0	0.00	100.00
256 - 362	0	0.00	100.00
362 - 512	0	0.00	100.00
512 - 1024	0	0.00	100.00
1024 - 2048	0	0.00	100.00
Bedrock	0	0.00	100.00

D16 (mm)	0.01
D35 (mm)	0.03
D50 (mm)	0.04
D84 (mm)	0.25
D95 (mm)	3
D100 (mm)	8
Silt/Clay (%)	70
Sand (%)	22.22
Gravel (%)	7.78
Cobble (%)	0
Boulder (%)	0
Bedrock (%)	0

Total Particles = 90.

2008 from MBSP park reach of Berger

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	4.1	30.6	11.1	14.0	4.1	12.8	23.3

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
1	100.0		
.75	95.9		
.375	83.3		
#4	65.3		
#10	54.2		
#20	46.2		
#30	43.0		
#40	40.2		
#50	38.3		
#100	36.7		
#200	36.1		

* (no specification provided)

Material Description

Atterberg Limits (ASTM D 4318)

PL= LL= PI=

Classification

USCS= AASHTO=

Coefficients

D_{85}= 10.2445 D_{60}= 3.4903 D_{50}= 1.2700

D_{30}= 0.0136 D_{15}= D_{10}=

C_u= C_c=

Date Tested: 5-15-08 **Tested By:** MIKE GERDEMAN

Remarks

Sample No.: E08-434 **Source of Sample:** **Date Sampled:** 5-9-08

Location: MARINA S-1 **Elev./Depth:**

Checked By: CLIFF GORDON **Title:** TECHNICIAN I

HULL & ASSOCIATES, INC.

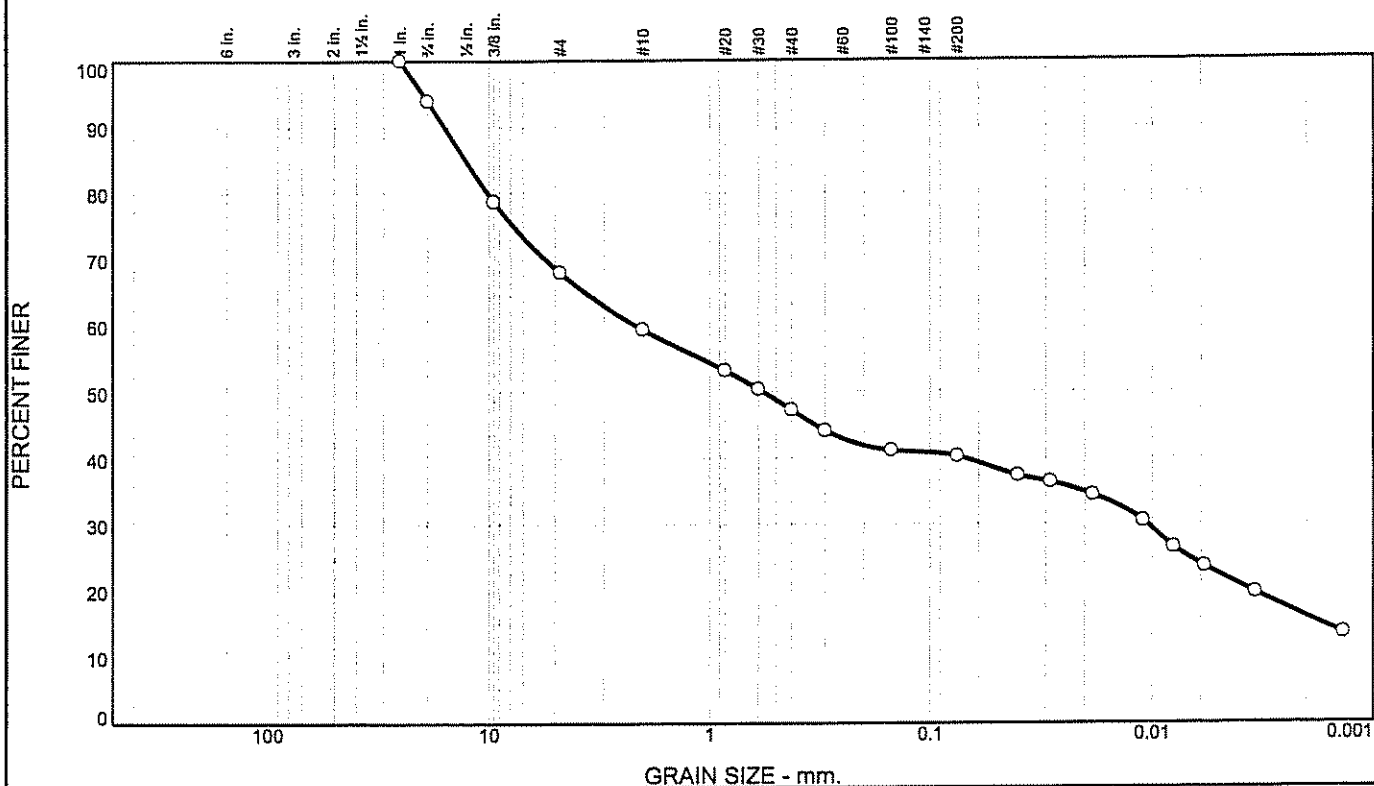
Erie, MI

Client: UNIVERSITY OF TOLEDO

Project: MAUMEE BAY SEDIMENT STUDY

Project No: UOT-014 **Figure**

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	6.1	26.0	8.6	12.1	7.0	17.9	22.3

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
1	100.0		
.75	93.9		
.375	78.7		
#4	67.9		
#10	59.3		
#20	53.1		
#30	50.3		
#40	47.2		
#50	44.1		
#100	41.1		
#200	40.2		

* (no specification provided)

Material Description

X-SEC 1 @ 890'

Atterberg Limits (ASTM D 4318)

PL= LL= PI=

Classification

USCS= AASHTO=

Coefficients

D_{85}= 12.8442 D_{60}= 2.1748 D_{50}= 0.5788

D_{30}= 0.0107 D_{15}= 0.0017 D_{10}=

C_u= C_c=

Date Tested: 5-15-08 **Tested By:** MIKE GERDEMAN

Remarks

Sample No.: E08-435 **Source of Sample:** **Date Sampled:** 5-9-08

Location: SOUTH OF MARINA S-2 **Elev./Depth:**

Checked By: CLIFF GORDON **Title:** TECHNICIAN I

HULL & ASSOCIATES, INC.

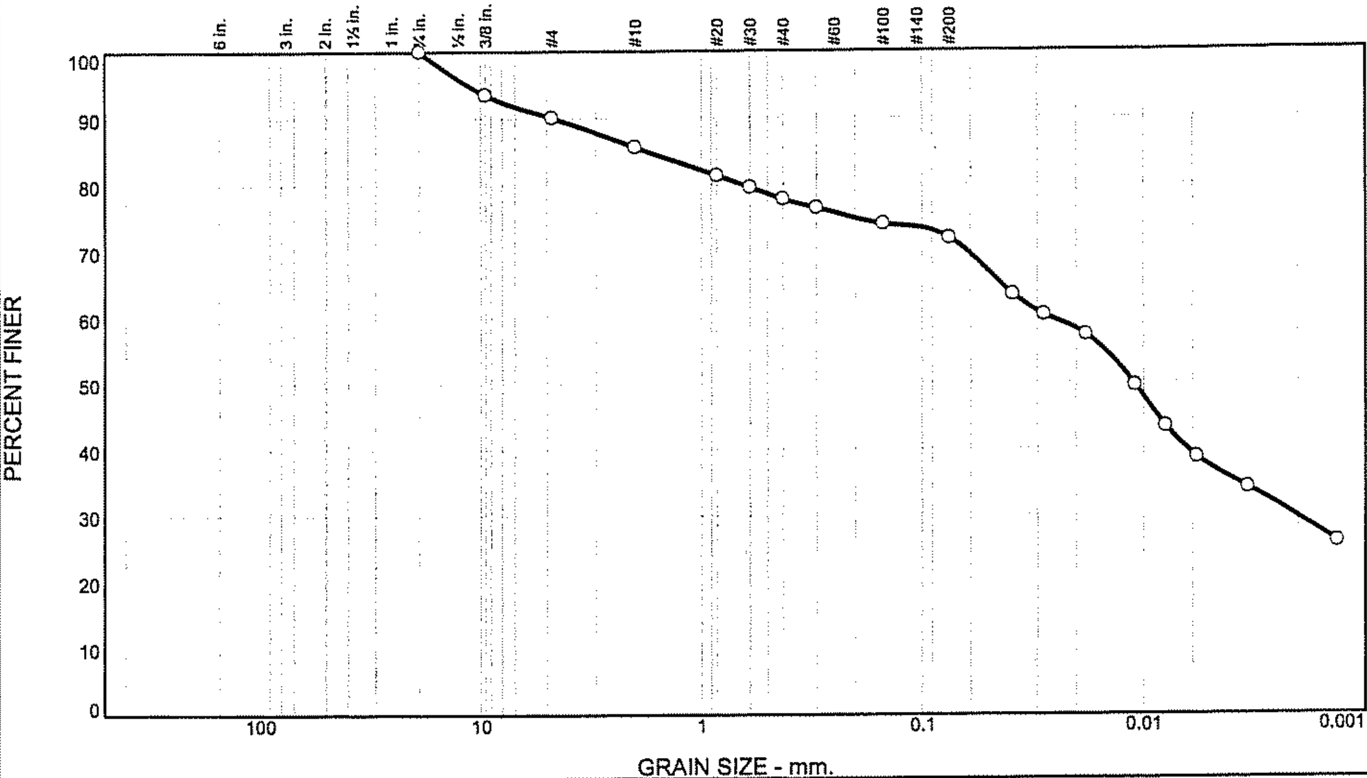
Erie, MI

Client: UNIVERSITY OF TOLEDO

Project: MAUMEE BAY SEDIMENT STUDY

Project No: UOT-014 **Figure**

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	10.0	4.4	7.8	5.9	34.7	37.2

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.75	100.0		
.375	93.5		
#4	90.0		
#10	85.6		
#20	81.4		
#30	79.5		
#40	77.8		
#50	76.5		
#100	74.1		
#200	71.9		

* (no specification provided)

Material Description

Atterberg Limits (ASTM D 4318)

PL= LL= PI=

Classification

USCS= AASHTO=

Coefficients

D_{85}= 1.7708 D_{60}= 0.0268 D_{50}= 0.0112
D_{30}= 0.0021 D_{15}= D_{10}=
C_u= C_c=

Date Tested: 5-15-08 **Tested By:** MIKE GERDEMAN

Remarks

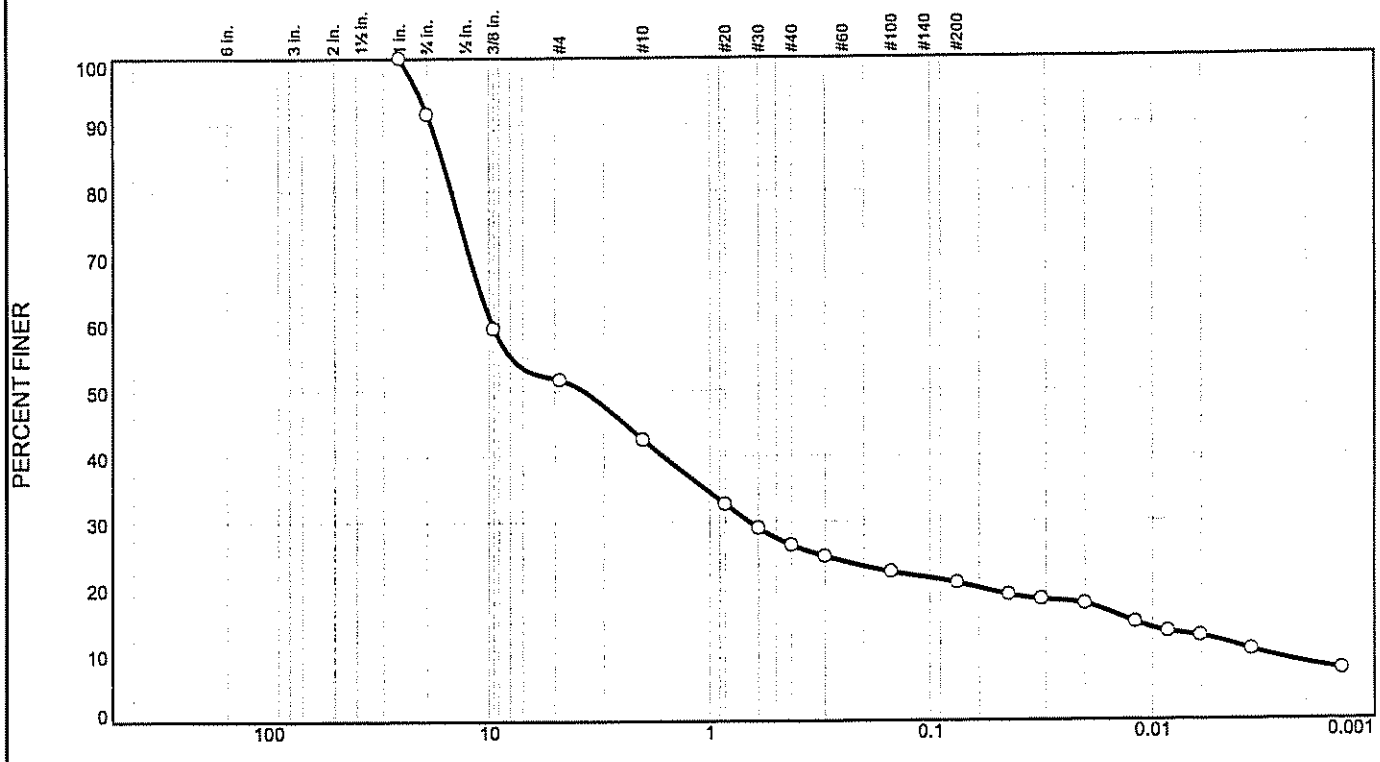
Sample No.: E08-436 **Source of Sample:** **Date Sampled:** 5-9-08
Location: X-SEC 2 @ 535' S-3 **Elev./Depth:**
Checked By: CLIFF GORDON **Title:** TECHNICIAN I

HULL & ASSOCIATES, INC.

Erie, MI

Client: UNIVERSITY OF TOLEDO
Project: MAUMEE BAY SEDIMENT STUDY
Project No: UOT-014 **Figure**

Particle Size Distribution Report



% +3"	% Gravel Coarse	% Gravel Fine	% Sand Coarse	% Sand Medium	% Sand Fine	% Fines Silt	% Fines Clay
0.0	8.5	39.9	9.1	16.1	5.7	8.8	11.9

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
1	100.0		
.75	91.5		
.375	59.3		
#4	51.6		
#10	42.5		
#20	32.7		
#30	29.0		
#40	26.4		
#50	24.8		
#100	22.4		
#200	20.7		

* (no specification provided)

Material Description

DOWNSTREAM OF CEDAR POINT BRIDGE

Atterberg Limits (ASTM D 4318)

PL= LL= PI=

Classification

USCS= AASHTO=

Coefficients

D_{85}= 16.3980 D_{60}= 9.7122 D_{50}= 3.7640
D_{30}= 0.6641 D_{15}= 0.0127 D_{10}= 0.0032
C_u= 3050.33 C_c= 14.26

Date Tested: 5-15-08 **Tested By:** MIKE GERDEMAN

Remarks

Sample No.: E08-437 **Source of Sample:** **Date Sampled:** 5-9-08
Location: MAUMEE BAY S-4 **Elev./Depth:**
Checked By: CLIFF GORDON **Title:** TECHNICIAN I

HULL & ASSOCIATES, INC. Erie, MI	**Client:** UNIVERSITY OF TOLEDO **Project:** MAUMEE BAY SEDIMENT STUDY **Project No:** UOT-014 **Figure**

APPENDIX C

Stream Classification Data

Worksheet 5-3. Field form for Level II stream classification (Rosgen, 1996; Rosgen and Silvey, 2005).

Stream: **Wolf Creek, Reach - Reach 1 - Seaman Road**	
Basin:	Drainage Area: **6720** acres **10.5** mi^2
Location:	
Twp.&Rge: **;**	Sec.&Qtr.: **;**
Cross-Section Monuments (Lat./Long.): **41.65667 Lat / 83.37861 Long**	Date: **4/28/2008**
Observers:	Valley Type: VIII

Bankfull WIDTH (W_{bkf}) WIDTH of the stream channel at bankfull stage elevation, in a riffle section.	**31.92**	ft
Bankfull DEPTH (d_{bkf}) Mean DEPTH of the stream channel cross-section, at bankfull stage elevation, in a riffle section ($d_{bkf} = A / W_{bkf}$).	**3.64**	ft
Bankfull X-Section AREA (A_{bkf}) AREA of the stream channel cross-section, at bankfull stage elevation, in a riffle section.	**116.16**	ft^2
Width/Depth Ratio (W_{bkf} / d_{bkf}) Bankfull WIDTH divided by bankfull mean DEPTH, in a riffle section.	**8.77**	ft/ft
Maximum DEPTH (d_{mbkf}) Maximum depth of the bankfull channel cross-section, or distance between the bankfull stage and Thalweg elevations, in a riffle section.	**6.75**	ft
WIDTH of Flood-Prone Area (W_{fpa}) Twice maximum DEPTH, or ($2 \times d_{mbkf}$) = the stage/elevation at which flood-prone area WIDTH is determined in a riffle section.	**60**	ft
Entrenchment Ratio (ER) The ratio of flood-prone area WIDTH divided by bankfull channel WIDTH (W_{fpa} / W_{bkf}) (riffle section).	**1.88**	ft/ft
Channel Materials (Particle Size Index) D_{50} The D_{50} particle size index represents the mean diameter of channel materials, as sampled from the channel surface, between the bankfull stage and Thalweg elevations.	**0.11**	mm
Water Surface SLOPE (S) Channel slope = "rise over run" for a reach approximately 20–30 bankfull channel widths in length, with the "riffle-to-riffle" water surface slope representing the gradient at bankfull stage.	**0.0011**	ft/ft
Channel SINUOSITY (k) Sinuosity is an index of channel pattern, determined from a ratio of stream length divided by valley length (SL / VL); or estimated from a ratio of valley slope divided by channel slope (VS / S).	**1.1**	

Stream Type **C5** (See **Figure 2-14**)

Bankfull Velocity / Discharge Estimate Form

Stream Name	Wolf Creek at Seaman Road
Reach ID	XS 3 - Watershed at reach = 10.5 sq.mi.
Observers	
Date	4/28/2008
Gage	None

INPUT VARIABLES			
Bankfull Area	116.0	A_{bkf}	ft^2
Bankfull Width	30.6	W_{bkf}	W
D84 @ Riffle (in mm)	1.5	Dia.	mm
Bankfull Slope	0.0011	S	ft/ft
Gravitational Accelleration	32.2	g	ft/s^2
Drainage Area	10.5	DA	mi^2

OUPUT VARIABLES			
Mean Bankfull Depth	3.79	d_{bkf}	ft
Wetted Perimeter	38.18	WP	ft
D84 @ Riffle (in feet) (or use protrusion ht.)	0.00	Dia.	ft
Hydraulic Radius	3.04	R	ft
R/D84	617.34	R/D84	ft/ft
Shear Velocity	0.33	U*	ft/s
Friction Factor	18.62	U/U*	ft/s

Method		Velocity		Discharge	
Friction Factor/Relative Roughness u = [2.83 + 5.66 Log (R/D84)]U*		6.11	ft/s	708.7	CFS
Roughness Coefficient: Mannings n from R/D84 (Limerino's curve)	Manning's n = 0.017; $u = (1.4895*R^{.667}*S^{.5})/n$	6.11	ft/s	708.7	CFS
Roughness Coefficient: Mannings n from R/D84 (Rosgen West curve)	Manning's n = 0.038; $u = (1.4895*R^{.667}*S^{.5})/n$	2.73	ft/s	316.5	CFS
Roughness Coefficient: Mannings n from Jarrett $n = 0.39*S^{.38}*R^{-.16}$	Manning's n = 0.025; $u = (1.4895*R^{.667}*S^{.5})/n$	4.23	ft/s	490.4	CFS
Roughness Coefficient: Mannings n from Stream Type	Manning's n = 0.035; $u = (1.4895*R^{.667}*S^{.5})/n$	2.96	ft/s	343.6	CFS ←
Roughness Coefficient: Mannings n known	Manning's n = 0.035; $u = (1.4895*R^{.667}*S^{.5})/n$	2.96	ft/s	343.6	CFS
Darcy-Weisbach Factor f from R/D84	f = 0.023; $u = \sqrt{(8gRS/f)}$	6.17	ft/s	715.9	CFS
Other:			ft/s		CFS
Continuity Equations: Regional Curve u = Q / A	Curve Used: USGS Ohio Region A curve (2005)		ft/s	417.0	CFS
Continuity Equations USGS Gage; R.I. for bankfull Q	Gage Used:		ft/s		CFS

Chosen estimation method	Manning's N from Stream Type C5
Reason	In range of discharge measurements for Berger Ditch gauging station, and corresponds to USGS regional curve

APPENDIX D

Bank Erosion Hazard Index and
Near-Bank Stress Data Forms

Worksheet C-1. Form to calculate Bank Erosion Hazard Index (BEHI) variables and an overall BEHI rating. Use **Figure C-2** variables to determine BEHI Score.

Stream:	Wolf Creek	Location:	N Seaman Rd.
Station:	6+00 Left Bank	Observers:	Hugh Crowell
Date: 4/16/08	Stream Type: C5	Valley Type:	VIII

Variable						BEHI Score (Fig. C-2)
Study Bank Height / Bankfull Height (C)	Study Bank Height (ft) = 5 (A)	Bankfull Height (ft) = 3.5 (B)	(A) / (B) =	1.4 (C)		4
Root Depth / Study Bank Height (E)	Root Depth (ft) = – (D)	Study Bank Height (ft) = – (A)	(D) / (A) =	.90 (E)		2
Weighted Root Density (G)		Root Density as % = 60 (F)	(F) x (E) =	54 (G)		4
Bank Angle (H)			Bank Angle as *Degrees* =	70 (H)		5
Surface Protection (I)			Surface Protection as % =	20 (I)		7

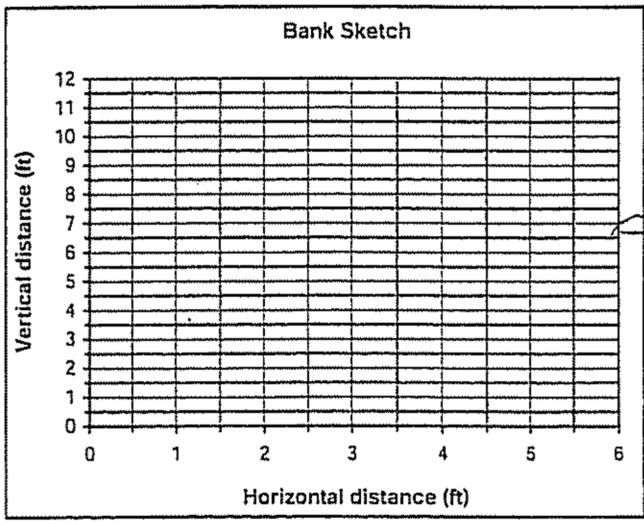
Bank Material Adjustment:
- **Bedrock** (Overall Very Low BEHI)
- **Boulders** (Overall Low BEHI)
- **Cobble** (Subtract 10 points if uniform medium to large cobble)
- **Gravel or Composite Matrix** (Add 5–10 points depending on percentage of bank material that is composed of sand)
- **Sand** (Add 10 points)
- **Silt/Clay** (no adjustment)

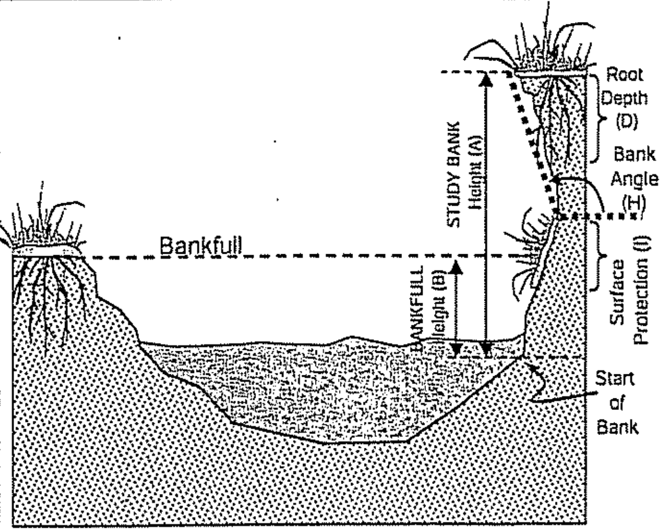
Bank Material Adjustment: –

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage: –

Very Low	Low	Moderate	High	Very High	Extreme
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50

Adjective Rating and Total Score: Mod 22





Worksheet C-1. Form to calculate Bank Erosion Hazard Index (BEHI) variables and an overall BEHI rating. Use **Figure C-2** variables to determine BEHI Score.

Stream:	Wolf Creek	Location:	N Seaman Rd.
Station:	6+00 R bank	Observers:	Hugh Crowell
Date:	4/16/08	Stream Type: C5	Valley Type: VIII

Variable	Input 1	Input 2	Result	BEHI Score (Fig. C-2)
Study Bank Height / Bankfull Height (C)	Study Bank Height (ft) = 5 (A)	Bankfull Height (ft) = 3.5 (B)	(A) / (B) = 1.4 (C)	4
Root Depth / Study Bank Height (E)	Root Depth (ft) = – (D)	Study Bank Height (ft) = – (A)	(D) / (A) = 1.0 (E)	0
Weighted Root Density (G)	Root Density as % = 80 (F)		(F) x (E) = 80 (G)	2
Bank Angle (H)			Bank Angle as Degrees = 60 (H)	4
Surface Protection (I)			Surface Protection as % = 100 (I)	0

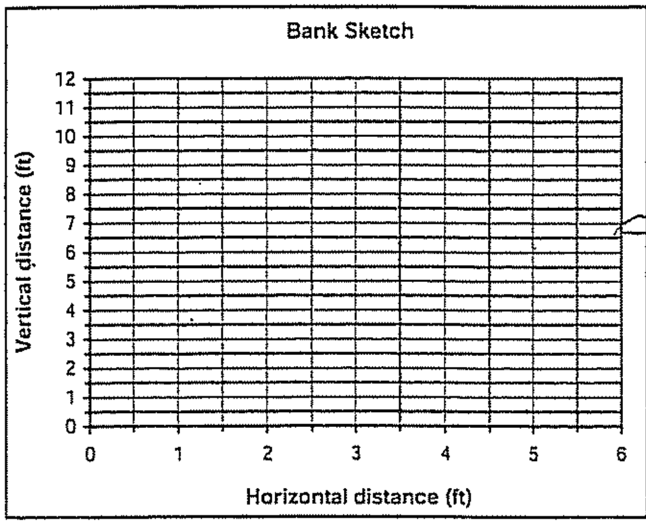
Bank Material Adjustment:

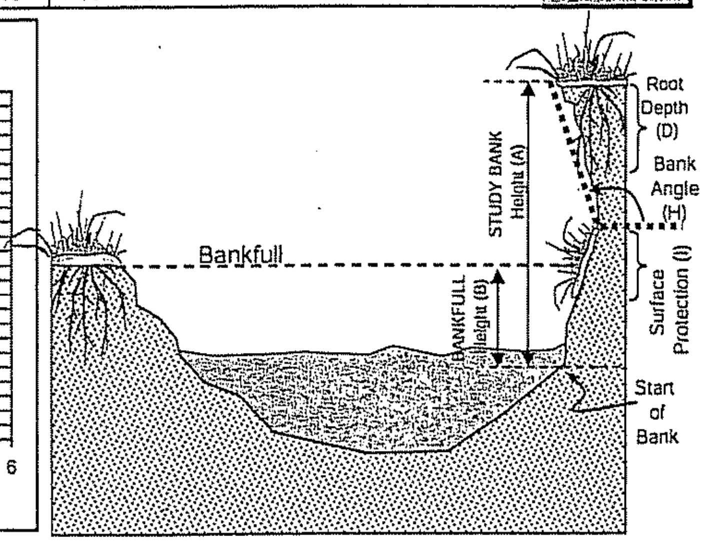
- **Bedrock** (Overall Very Low BEHI)
- **Boulders** (Overall Low BEHI)
- **Cobble** (Subtract 10 points if uniform medium to large cobble)
- **Gravel or Composite Matrix** (Add 5–10 points depending on percentage of bank material that is composed of sand)
- **Sand** (Add 10 points)
- **Silt/Clay** (no adjustment)

Bank Material Adjustment: –

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage: –

Very Low	Low	Moderate	High	Very High	Extreme	Adjective Rating and Total Score
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50	Low / 10





Worksheet C-1. Form to calculate Bank Erosion Hazard Index (BEHI) variables and an overall BEHI rating. Use **Figure C-2** variables to determine BEHI Score.

Stream:	Wolf Creek	Location:	N. Seaman Rd
Station:	5+10 R. bank	Observers:	M. Crowell
Date:	4/16/08	Stream Type: C5	Valley Type: VIII

Study Bank Height / Bankfull Height (C) — BEHI Score (Fig. C-2)

Study Bank Height (ft) =	5 (A)	Bankfull Height (ft) =	3.5 (B)	(A) / (B) =	1.4 (C)	4

Root Depth / Study Bank Height (E)

Root Depth (ft) =	(D)	Study Bank Height (ft) =	(A)	(D) / (A) =	1.0 (E)	0

Weighted Root Density (G)

Root Density as % =	50 (F)	(F) x (E) =	50 (G)	4

Bank Angle (H)

Bank Angle as *Degrees* =	45 (H)	3

Surface Protection (I)

Surface Protection as % =	20 (I)	7

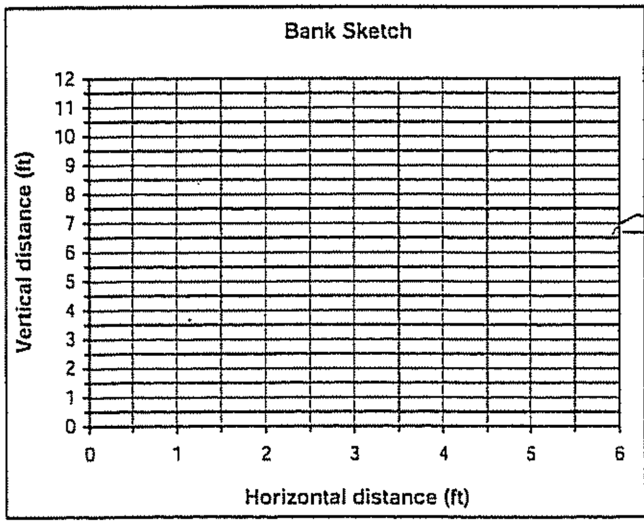
Bank Material Adjustment:
- **Bedrock** (Overall Very Low BEHI)
- **Boulders** (Overall Low BEHI)
- **Cobble** (Subtract 10 points if uniform medium to large cobble)
- **Gravel or Composite Matrix** (Add 5–10 points depending on percentage of bank material that is composed of sand)
- **Sand** (Add 10 points)
- **Silt/Clay** (no adjustment)

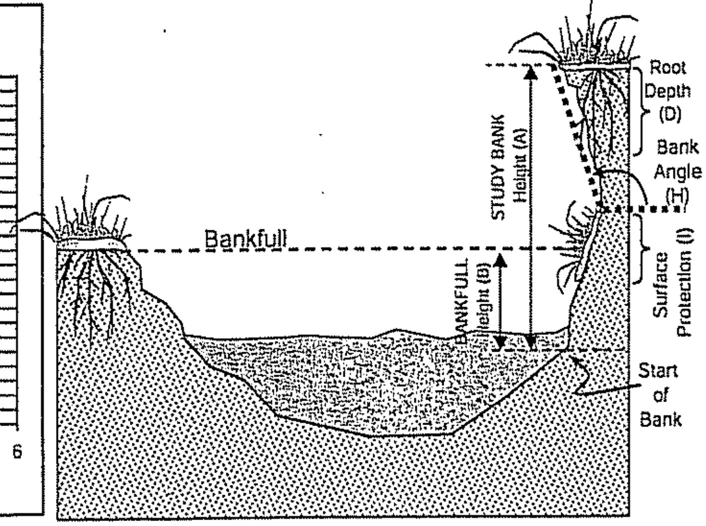
Bank Material Adjustment: —

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage: —

Very Low	Low	Moderate	High	Very High	Extreme
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50

Adjective Rating and Total Score: Low 18





Worksheet C-1. Form to calculate Bank Erosion Hazard Index (BEHI) variables and an overall BEHI rating. Use **Figure C-2** variables to determine BEHI Score.

Stream:	Wolf Creek	Location:	N. Seaman Rd.
Station:	5+10 L bank	Observers:	H. Crowell
Date:	7/16/08 Stream Type: C5	Valley Type:	VIII

Variable	Input 1	Input 2	Result	BEHI Score (Fig. C-2)
Study Bank Height / Bankfull Height (C)	Study Bank Height (ft) = 5 (A)	Bankfull Height (ft) = 3.5 (B)	(A) / (B) = 1.4 (C)	4
Root Depth / Study Bank Height (E)	Root Depth (ft) = – (D)	Study Bank Height (ft) = – (A)	(D) / (A) = 0.9 (E)	2
Weighted Root Density (G)		Root Density as % = 20 (F)	(F) x (E) = 18 (G)	7
Bank Angle (H)			Bank Angle as *Degrees* = 70 (H)	5
Surface Protection (I)			Surface Protection as % = 10 (I)	8

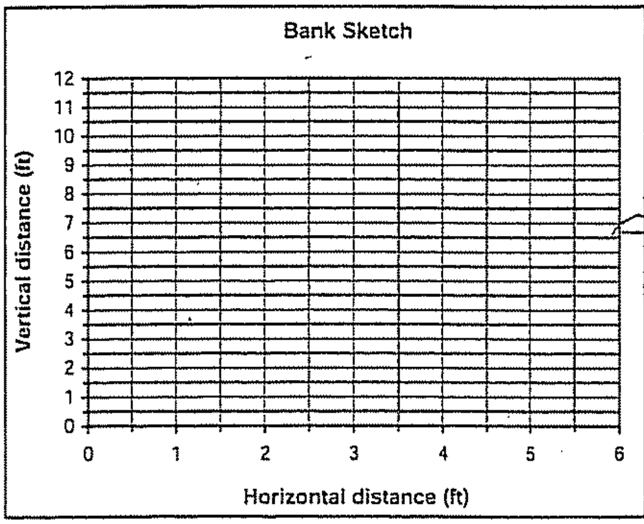
Bank Material Adjustment:
- **Bedrock** (Overall Very Low BEHI)
- **Boulders** (Overall Low BEHI)
- **Cobble** (Subtract 10 points if uniform medium to large cobble)
- **Gravel or Composite Matrix** (Add 5–10 points depending on percentage of bank material that is composed of sand)
- **Sand** (Add 10 points)
- **Silt/Clay** (no adjustment)

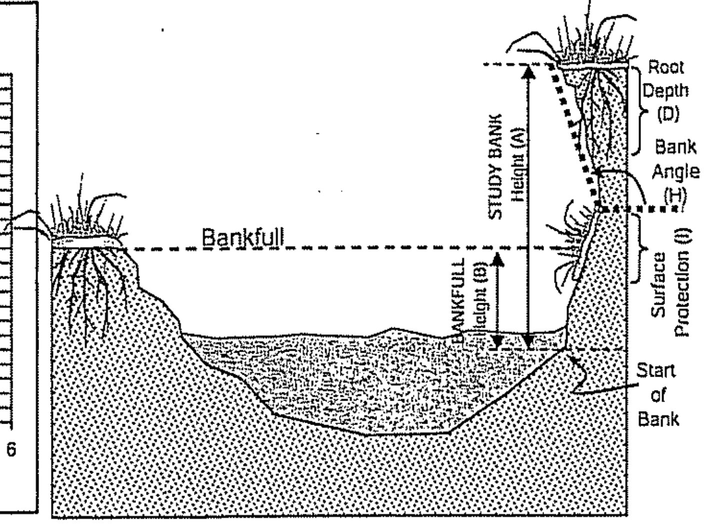
Bank Material Adjustment: –

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage: –

Very Low	Low	Moderate	High	Very High	Extreme
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50

Adjective Rating and Total Score: MOD 26





Worksheet C-1. Form to calculate Bank Erosion Hazard Index (BEHI) variables and an overall BEHI rating. Use **Figure C-2** variables to determine BEHI Score.

Stream:	Wolf Creek	Location:	N. Seaman Rd
Station:	4+80 R bank	Observers:	M. Crowell
Date:	4/16/08	Stream Type: C5	Valley Type: VIII

Variable	Inputs	Calculation	BEHI Score (Fig. C-2)
Study Bank Height / Bankfull Height (C)	Study Bank Height (ft) = 5 (A); Bankfull Height (ft) = 3.5 (B)	(A)/(B) = 1.4 (C)	4
Root Depth / Study Bank Height (E)	Root Depth (ft) = (D); Study Bank Height (ft) = (A)	(D)/(A) = 0.9 (E)	2
Weighted Root Density (G)	Root Density as % = 25 (F)	(F) x (E) = 22.5 (G)	7
Bank Angle (H)	Bank Angle as Degrees = 62 (H)		4
Surface Protection (I)	Surface Protection as % = 75 (I)		3

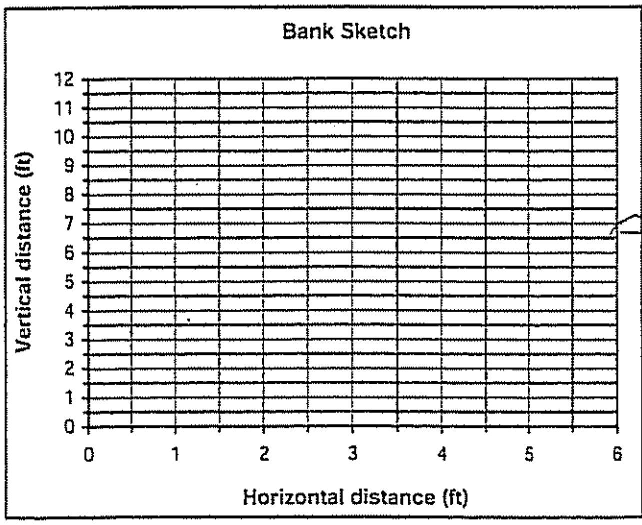
Bank Material Adjustment:
- **Bedrock** (Overall Very Low BEHI)
- **Boulders** (Overall Low BEHI)
- **Cobble** (Subtract 10 points if uniform medium to large cobble)
- **Gravel or Composite Matrix** (Add 5–10 points depending on percentage of bank material that is composed of sand)
- **Sand** (Add 10 points)
- **Silt/Clay** (no adjustment)

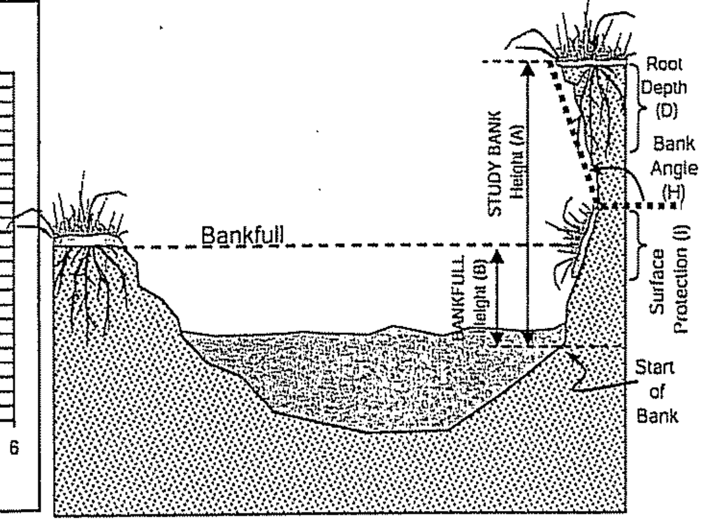
Bank Material Adjustment: —

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage: —

Very Low	Low	Moderate	High	Very High	Extreme
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50

Adjective Rating and Total Score: Mod 20





Worksheet C-1. Form to calculate Bank Erosion Hazard Index (BEHI) variables and an overall BEHI rating. Use **Figure C-2** variables to determine BEHI Score.

Stream:	Wolf Creek	Location:	N. Seaman Rd.
Station:	4+50 L bank	Observers:	H. Crowell
Date: 4/16/08	Stream Type: C5	Valley Type:	VIII

BEHI Score (Fig. C-2)

Study Bank Height / Bankfull Height (C)

Study Bank Height (ft) =	5 (A)	Bankfull Height (ft) =	3.5 (B)	(A) / (B) =	1.4 (C)	4

Root Depth / Study Bank Height (E)

Root Depth (ft) =	(D)	Study Bank Height (ft) =	(A)	(D) / (A) =	0.9 (E)	2

Weighted Root Density (G)

Root Density as % =	30 (F)	(F) x (E) =	27 (G)	6

Bank Angle (H)

Bank Angle as *Degrees* =	58 (H)	4

Surface Protection (I)

Surface Protection as % =	10 (I)	9

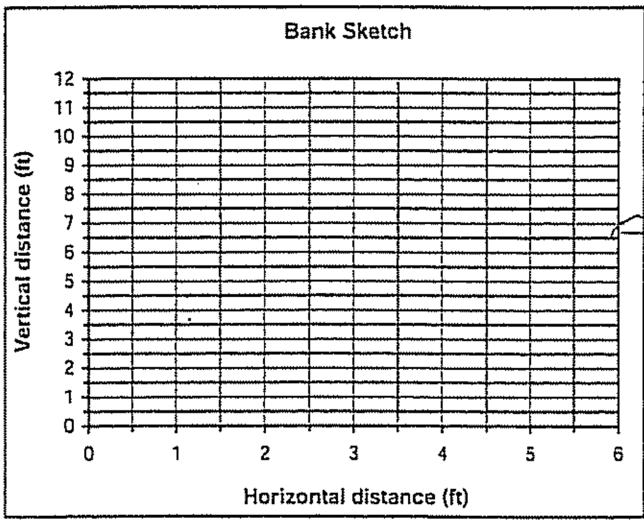
Bank Material Adjustment:
- **Bedrock** (Overall Very Low BEHI)
- **Boulders** (Overall Low BEHI)
- **Cobble** (Subtract 10 points if uniform medium to large cobble)
- **Gravel or Composite Matrix** (Add 5–10 points depending on percentage of bank material that is composed of sand)
- **Sand** (Add 10 points)
- **Silt/Clay** (no adjustment)

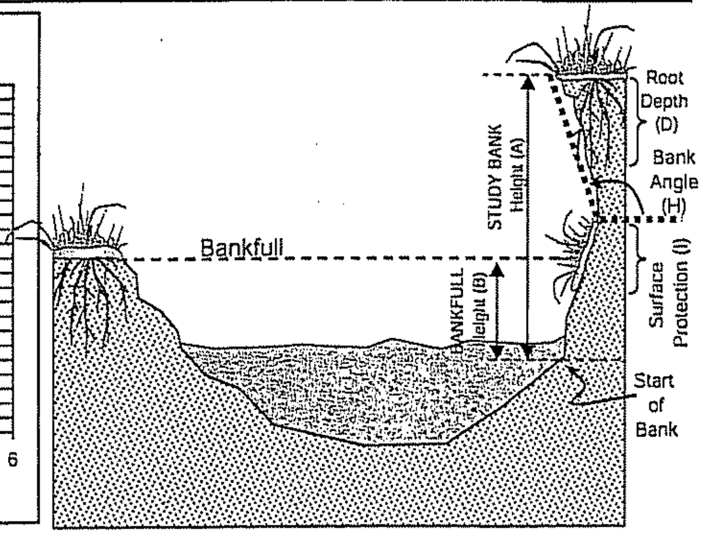
Bank Material Adjustment: –

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage: –

Very Low	Low	Moderate	High	Very High	Extreme
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50

Adjective Rating and Total Score: MOD 25





Worksheet C-1. Form to calculate Bank Erosion Hazard Index (BEHI) variables and an overall BEHI rating. Use **Figure C-2** variables to determine BEHI Score.

Stream:	Wolf Creek	Location:	M. Seaman Rd.
Station:	3+75 R	Observers:	M. Crowell
Date: 4/16/08	Stream Type: C5	Valley Type:	VIII

Study Bank Height / Bankfull Height (C) — BEHI Score (Fig. C-2)

Study Bank Height (ft) =	Bankfull Height (ft) =	(A) / (B) =	BEHI Score
5 (A)	3.5 (B)	1.4 (C)	4

Root Depth / Study Bank Height (E)

Root Depth (ft) =	Study Bank Height (ft) =	(D) / (A) =	BEHI Score
(D)	(A)	1.0 (E)	0

Weighted Root Density (G)

Root Density as % =	(F) x (E) =	BEHI Score
50 (F)	50 (G)	4

Bank Angle (H)

Bank Angle as *Degrees* =	BEHI Score
73 (H)	5

Surface Protection (I)

Surface Protection as % =	BEHI Score
90 (I)	1

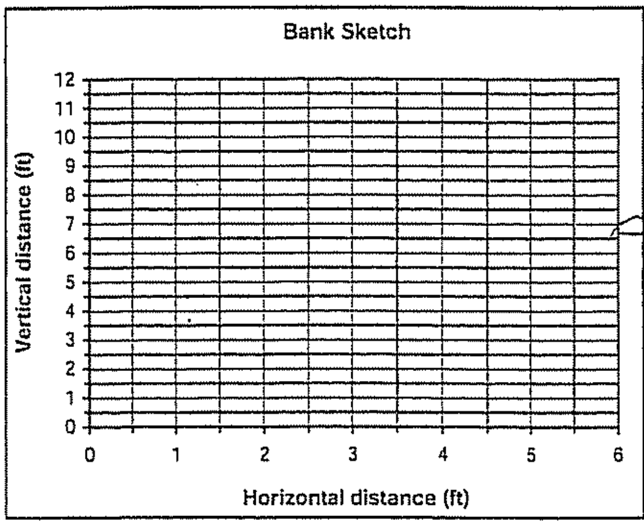
Bank Material Adjustment:
- **Bedrock** (Overall Very Low BEHI)
- **Boulders** (Overall Low BEHI)
- **Cobble** (Subtract 10 points if uniform medium to large cobble)
- **Gravel or Composite Matrix** (Add 5–10 points depending on percentage of bank material that is composed of sand)
- **Sand** (Add 10 points)
- **Silt/Clay** (no adjustment)

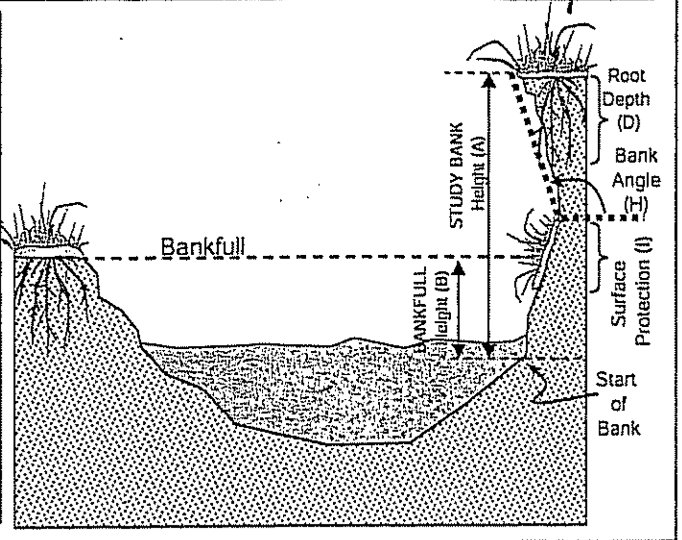
Bank Material Adjustment: —

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage: —

Very Low	Low	Moderate	High	Very High	Extreme
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50

Adjective Rating and Total Score: Low 14





Worksheet C-1. Form to calculate Bank Erosion Hazard Index (BEHI) variables and an overall BEHI rating. Use **Figure C-2** variables to determine BEHI Score.

Stream:	Wolf Creek	Location:	N. Seaman Rd.
Station:	3+20 → 2+00 R+L	Observers:	H. Crowell
Date: 7/16/08	Stream Type: C5	Valley Type:	VIII

Study Bank Height / Bankfull Height (C) — BEHI Score (Fig. C-2)

Study Bank Height (ft) =	5 (A)	Bankfull Height (ft) =	3.5 (B)	(A) / (B) =	1.4 (C)	4

Root Depth / Study Bank Height (E)

Root Depth (ft) =	(D)	Study Bank Height (ft) =	(A)	(D) / (A) =	0.7 (E)	3

Weighted Root Density (G)

Root Density as % =	10 (F)	(F) x (E) =	7 (G)	9

Bank Angle (H)

Bank Angle as *Degrees* =	36 (H)	3

Surface Protection (I)

Surface Protection as % =	10 (I)	9

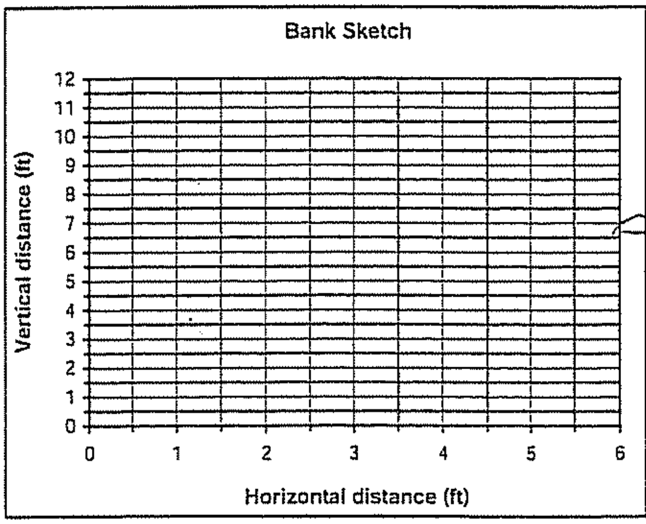
Bank Material Adjustment:
- **Bedrock** (Overall Very Low BEHI)
- **Boulders** (Overall Low BEHI)
- **Cobble** (Subtract 10 points if uniform medium to large cobble)
- **Gravel or Composite Matrix** (Add 5–10 points depending on percentage of bank material that is composed of sand)
- **Sand** (Add 10 points)
- **Silt/Clay** (no adjustment)

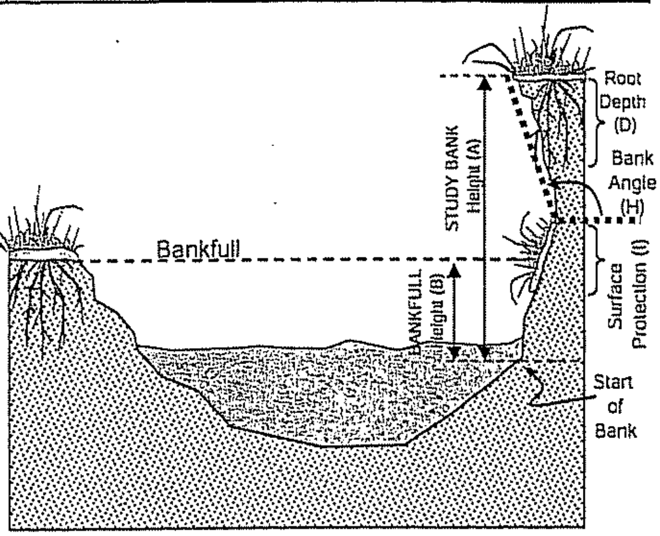
Bank Material Adjustment

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage

Very Low	Low	Moderate	High	Very High	Extreme
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50

Adjective Rating and Total Score: Mod 28





ii. Near-Bank Stress

Worksheet C-2. Various field methods of estimating Near-Bank Stress (NBS) risk ratings to calculate erosion rate.

Estimating Near-Bank Stress (NBS)

Stream: Wolf Creek		Location: N. Seaman Road	
Station: 2+00 → 6+00	Stream Type: C5		Valley Type: VIII
Observers: H. Criswell			Date: 4/14/08

Methods for estimating Near-Bank Stress (NBS)

(1) Channel pattern, transverse bar or split channel/central bar creating NBS..........	Level I	Reconaissance
(2) Ratio of radius of curvature to bankfull width (R_c / W_{bkf})........	Level II	General prediction
(3) Ratio of pool slope to average water surface slope (S_p / S)........	Level II	General prediction
(4) Ratio of pool slope to riffle slope (S_p / S_{rif})........	Level II	General prediction
(5) Ratio of near-bank maximum depth to bankfull mean depth (d_{nb} / d_{bkf})........	Level III	Detailed prediction
(6) Ratio of near-bank shear stress to bankfull shear stress (τ_{nb} / τ_{bkf})........	Level III	Detailed prediction
(7) Velocity profiles / Isovels / Velocity gradient........	Level IV	Validation

Level I

(1)
Transverse and/or central bars-short and/or discontinuous........ NBS = High / Very High
Extensive deposition (continuous, cross-channel)........ NBS = Extreme
Chute cutoffs, down-valley meander migration, converging flow........ NBS = Extreme

Level II

(2)

Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	Ratio R_c / W_{bkf}	Near-Bank Stress (NBS)

(3)

Pool Slope S_p	Average Slope S	Ratio S_p / S	Near-Bank Stress (NBS)
.00028	0.0011	0.25	Low

(4)

Pool Slope S_p	Riffle Slope S_{rif}	Ratio S_p / S_{rif}	Near-Bank Stress (NBS)

Dominant Near-Bank Stress
Low

Level III

(5)

Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	Ratio d_{nb} / d_{bkf}	Near-Bank Stress (NBS)

(6)

Near-Bank Max Depth d_{nb} (ft)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d_{bkf} (ft)	Average Slope S	Bankfull Shear Stress τ_{bkf} (lb/ft^2)	Ratio τ_{nb} / τ_{bkf}	Near-Bank Stress (NBS)

Level IV

(7)

Velocity Gradient (ft / sec / ft)	Near-Bank Stress (NBS)

Converting values to a Near-Bank Stress (NBS) rating

Near-Bank Stress (NBS) ratings	Method number (1)	(2)	(3)	(4)	(5)	(6)	(7)
Very Low	N/A	> 3.00	< 0.20	< 0.40	< 1.00	< 0.80	< 0.50
Low	N/A	2.21 – 3.00	**0.20 – 0.40**	0.41 – 0.60	1.00 – 1.50	0.80 – 1.05	0.50 – 1.00
Moderate	N/A	2.01 – 2.20	0.41 – 0.60	0.61 – 0.80	1.51 – 1.80	1.06 – 1.14	1.01 – 1.60
High	See	1.81 – 2.00	0.61 – 0.80	0.81 – 1.00	1.81 – 2.50	1.15 – 1.19	1.61 – 2.00
Very High	(1)	1.50 – 1.80	0.81 – 1.00	1.01 – 1.20	2.51 – 3.00	1.20 – 1.60	2.01 – 2.40
Extreme	Above	< 1.50	> 1.00	> 1.20	> 3.00	> 1.60	> 2.40

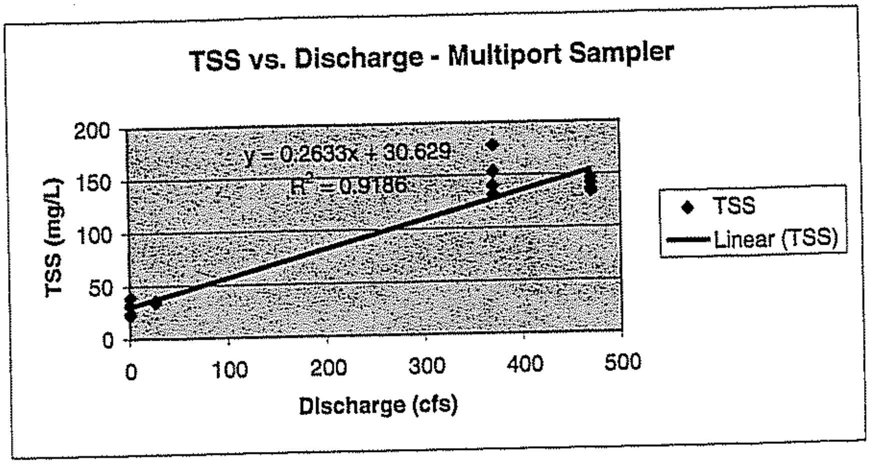
Overall Near-Bank Stress (NBS) rating	

APPENDIX E

Correlations of Discharge vs. Sediment Concentration

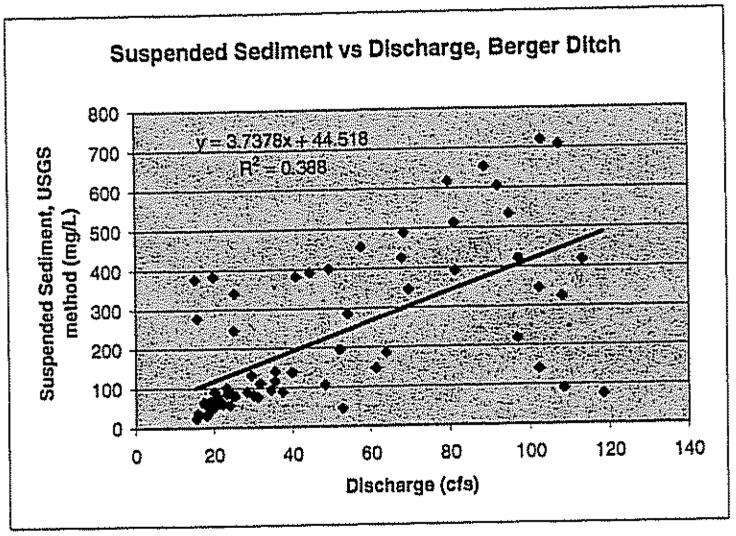
Correlation of Total Suspended Solids vs. Discharge at USGS Gauging Station 04194085, Berger Ditch, Maumee Bay State Park
Data from University of Toledo

Date	Discharge	TSS
6/10/2008	26	34
	26	35
	26	36
7/3/2008	470	142
	470	134
	470	142
	470	147
	470	136
7/9/2008	370	153
	370	132
	370	178
	370	140
7/24/2008	0.18	39
	0.18	23
	0.18	24
7/28/2008	0	23
	0	32



Suspended Sediment Concentration vs. Discharge at USGS Gauging Station 04194085, Berger Ditch, Maumee Bay State Park
Data collected by USGS between 6/29/2006 and 7/30/2006

Suspended sediment (mg/L)	Discharge (cfs)
76	118.4
417.6	113.1
90.8	108.4
325	108
709	107.4
719.5	102.8
345.9	102.3
140.5	102.1
421.9	97
219.3	96.7
534.9	94.7
605.5	91.9
653.8	88.6
392.8	81.2
512.3	81.1
617.7	79.6
346.5	69.47
490	68.4
426.2	67.84
186.2	63.81
146.4	61.15
454.3	57.39
286.8	53.93
45.4	52.7
195.5	51.98
400	49.18
105.6	48.15
392.6	44.45
382.7	40.94
139	39.69
89.5	37.31
141.4	35.46
117.3	35.31
94	34.34
112	31.63
76.6	31.05
81.5	30.21
131.9	29.44
89.7	28.44
80.6	25.21
340.6	25.13
246	25.03
81.5	24.68
55.8	23.95
97	23.47
85.4	23.28
100.8	23.17
59	22.1
65.2	21.68
61	20.8
79.9	20.62
90.9	19.96
51.5	19.84
383.7	19.81
65.9	18.92
40.4	18.7
30.2	18.01
33.2	17.92
60.8	17.45
64.8	17.43
37.2	15.84
278.4	15.64
23.6	15.54
377.2	15.15



Data collected 6/29/06 through 7/30/06
note: single negative discharge value removed

APPENDIX F

Photographs

PHOTO 1: Wolf Creek at Field Site 1: View of Creek at 265' on the longitudinal profile.

PHOTO 2: Berger Ditch at Field Site 2: surveyed reach adjacent to Oregon WTP.

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Stream Morphology Study

Site Photographs

Wolf Creek and Berger Ditch
Lucas County, Ohio

Date: OCTOBER 2008

Project Number: UOT014

File Name: UOT014.300.0006.xls

PHOTO 3: Berger Ditch at Field Site 3: surveyed reach within Maumee Bay State Park

PHOTO 4: Wolf Creek, Field Site 1: view of severe erosion of R bank.

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Photo 5: Wolf Creek, Field Site 1: Location of BEHI, R bank at 375' on long pro showing bank angle of 73 degrees, very high surface protection, high rooting density and depth.

PHOTO 6: University of Toledo students surveying cross section at Field Site 2.

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PHOTO 7: University of Toledo students measuring water velocity at Field Site 2.

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