NOAA Technical Memorandum
NOS MEMD 12

OLD WOMAN CREEK
NATIONAL ESTUARINE RESEARCH RESERVE

FLUVIAL EROSION, SEDIMENTATION, AND HYDRAULIC GEOMETRY IN THE CONTRIBUTING WATERSHED OF OLD WOMAN CREEK NATIONAL ESTUARINE RESEARCH RESERVE

Washington, D.C.
August 1987

U.S. DEPARTMENT OF COMMERCE / National Oceanic and Atmospheric Administration / Marine and Estuarine Management Division

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UNITED STATES DEPARTMENT OF COMMERCE / National Oceanic and Atmospheric Administration / National Ocean Service

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Marine and Estuarine Management Division

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NOTICE

NOTE TO READERS

On April 7, 1987, the Congress of the United States amended Section 315 of the Coastal Zone Management Act to establish the National Estuarine Reserve Research System (P.L. 99-272). Formerly known as the National Estuarine Sanctuary Program, each national estuarine sanctuary established prior to this date was automatically made part of the new system and designated a national estuarine research reserve. The new System emphasizes the research value of each site since they are areas representative of estuarine ecosystems that are suitable for long-term research and contribute to the biogeographical and typological balance of the System.

REPORT TO
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
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OFFICE OF OCEAN AND COASTAL RESOURCE MANAGEMENT
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ABSTRACT

Natural stream flow and sediment load have affected Old Woman Creek and its estuary for eons. Recently, humans have superimposed their effect on the watershed. The future will bring even greater human modification including increased suburbanization and a new highway bridge across the National Estuarine Sanctuary. The primary objective of this study was to establish baseline sediment and discharge data to permit the monitoring of future change within the fluvial system. Eight cross-sectional profiles were monumented and surveyed for future erosion assessment. Nine other cross-sections were repeatedly surveyed while collecting discharge, sediment concentration, sediment yield, water depth, and stream velocity data. Analysis of these data led to formulation of mathematical relationships between a station's depth and discharge as well as sediment yield and discharge. Further analysis showed that the magnitude and variability of discharge during a particular storm was primarily a function of geomorphologic province, drainage area, estuary level, and human impact. A maximum of 153 cubic feet/second was recorded entering the estuary. The magnitude and variability of sediment concentration during a particular storm was a function primarily of human disturbance of the land and, secondarily, of soil erosion potential and channel composition. Large amounts of sediment were transported

during brief periods of intense precipitation; on 2/25/85, 14.5 ounces/second were contributed to the estuary by the creek.

A permanent stage recorder should be established to continuely monitor water contribution to the estuary from the creek.

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PREFACE

The author would like to acknowledge the substantial support of Shahalam Amin, Sandra Cushing Woods, Jeff Foltz, Carol Toncar, and Department of Geography (all of Kent State University) and both David Klarer and Gene Wright of Old Woman Creek National Estuarine Sanctuary. Jeff Foltz deserves special mention. He regularly measured stream velocities, collected sediment samples, and analyzed them as a part of his M.A. thesis research in geography.

INTRODUCTION

Natural stream flow and sediment load have affected the morphology of Old Woman Creek and its estuary for eons (Fig. 1). Recently, humans have superimposed their effect on the watershed and its drainage network. The future will bring even greater human modification to the area including a new State Route 2 bridge across Old Woman Creek National Estuarine Sanctuary and increased suburbanization. Baseline data is needed now to assess these future effects.

Stream channel processes are essentially a matter of sediment and water transfer and can be investigated using empirical data and analytical procedures. This approach requires the measurement of stream discharge, sediment load, and channel morphology. It has not been done before in the Old Woman Creek system and forms the basis of this investigation.

Objectives

The primary objective was to establish baseline sediment movement, channel morphometry, and stream discharge data for monumented points within the Old Woman Creek system. These data and points are suitable for future comparison and remeasurement studies. These include work on the effects of urban encroachment within the watershed and the effects of relocating State Route 2 to the south across Old Woman Creek. This latter issue has been declared a "priority research" topic by N.O.A.A. and O.D.N.R. (1983, pp. 62-63).

There were six ancillary goals that extended the nature of the research from that of data collection to analysis. Specifically studied were:

1) the effect of land use and soil association on sediment load;
2) drainage area - stream discharge relationships;
3) water depth - stream discharge relationships;
4) stream discharge - suspended sediment yield relationships;
5) relative and absolute sediment contributions made by selected reaches and tributaries;
6) the effect of geomorphological province on stream discharge and sediment load.

In addition, the effects of future urbanization in the Old Woman Creek watershed were predicted by analogy with other studied and urbanized watersheds.

Previous Research

Buchanan (1982, pp. 191-193) has shown that sediment size, accumulation rates, and stream discharge have fluctuated significantly during the Holocene within the site of today's Old Woman Creek estuary. About 8,000 years ago, stream gradients - velocities were higher than now and the channel of Old Woman Creek consisted of coarse to fine sands and silts. Later, as the level of Lake Erie rose, channel gradients - velocities were reduced so that channel deposition became increasingly dominated by finer sediments; within the last 100 years, only silts and clays have accumulated but they have done so at an agriculturally accelerated rate of 0.4 inches/year, possibly ten times faster than the 8,000 year average (Buchanan, 1982, p. 176). The majority of this sediment originates from agricultural land on the Till Plain (Fig. 2) where present erosion is estimated at 2.6 tons per acre per year (Buchanan, 1982, p. 176).

Present "average flow rates along the stream are quite low (less than 0.1 foot (3cm) per second) even during months of greater precipitation; but these rates can accelerate to over ten times this amount (greater than one foot (30 cm) per second) during storm events" (Buchanan, 1982, p. 72). "Flow rates in the upper basin reflect the greatest variability over both long and short-term intervals. Stagnant flow was often encountered at the uppermost sampling point during the summer months. In contrast, out-of-bank flooding and torrential flow were viewed only in the upper basin during significant precipitational events" (Buchanan, 1982, p. 74). "Observed flow rates at downstream sampling points were lower yet more consistent than rates observed in the upper basin ...reflecting the averaging of minor variations in basin precipitation and the larger channel volume in the lower basin. During and after high-flow storm events, increased discharge in the lower basin is manifested more by higher stream levels than by significantly accelerated stream flow rates" (Buchanan, 1982, p. 75).

Humans now have the numbers and technical ability to change one or more parameters in a fluvial system and, thereby, initiate a whole series of natural responses. Engineering structures are one example of human interference and the result of urbanization is another.

Urbanization significantly influences a stream and its watershed by affecting the nature of the storm hydrograph and by altering discharge, channel cutting, and sedimentation rates. For example, if one accepts population/square mile as an indication of urbanization, Hammer (1972) found that average annual floods (one with a 1.78 year recurrence interval) increased by about 18% per square mile of watershed urbanized. In 1964, Harris and Rantz also attempted to compare increase in water yield with increase in urbanization. They stated that yield in the San Francisco Bay area has increased markedly in the years following 1955 when urban development greatly increased. Prior to that time, the ratio of storm outflow and channel seepage on a control watershed was 1.18. After 1955, they reported the ratio to be 1.70 (an increase of 44%) and attributed this increase to the 5% increase in impervious area due to urbanization. Graf (1977) showed that South Branch's drainage area became more efficient in collecting water quickly as it became more suburbanized. The lag time between rainfall and stream response was reduced and the flood peak increased enough to suggest corrective measures be taken in this watershed.

Upstream urbanization also caused downstream channel cutting and sedimentation. Such sedimentation is markedly high during the construction of housing developments (Wolman, 1967). Guy and Ferguson (1963) indicated that approximately 25,000 tons of sediment were deposited for each square mile of residential construction at Lake Barcroft. They also noted that with urbanization a coarser sediment will tend to be deposited in the reservoir than when rural conditions are prevalent. After construction has concluded, impervious areas contribute increased runoff coupled with decreased sediment yield to the channel, thereby, causing erosion and widening to occur (Wolman, 1967; Hammer, 1972). However, the total effect of a given amount of impervious area on its drainage basin is largely dependent on the type and density of storm sewers. Without guttering connected directly to sewers, the effects of impervious areas associated with detached houses is minor (Hammer, 1972). Carter (1961) came to the same conclusion. Hammer (1972) also feels that the effects of urbanization may decrease over time from his study on streets and houses more than thirty years old.

METHODS

This research provided a series of monumented and surveyed cross-sections that will act as baseline data for future studies. Two types of sample stations were established. One type was created primarily for stream discharge and sediment load determination but could also be used for future erosion - sedimentation studies. The second type was solely for future erosion - sedimentation assessment.

Stream Discharge and Sediment Load Determination Stations

Discharge - sediment load stations were established and monumented at critical points within the Old Woman Creek watershed (Fig. 1). In all, nine well distributed stations together gauged each branch of Old Woman Creek, the important tributary junctions, most soil associations, each geomorphic province, and sites immediately upstream of the proposed State Route 2 bridge (Fig. 1; Appendix A). Of these nine stations, seven are presently being used as nutrient sampling sites by the Sanctuary Biologist, D. M. Klarer, and five were used for grab sediment sampling by D. B. Buchanan (1982). Station location, therefore, was based first on geographical and physical criteria and second on a desire to unify this study with those done in the past.

Stations 2 and 3 were on the west branch, stations 4, 5, 6, and 7 were on the middle branch, station 9 was the only station located on the relatively short and narrow east branch, and stations 8 and 10 were on the main creek at or near important creek junctions (Fig. 1; Appendix A). Stations 4 and 5 were on the Till Plain, stations 2, 6, and 7 were in the Berea Escarpment, and stations 3, 8, 9, and 10 were located on the Lake Plain. Each station was photographed (Appendix A) and its cross-section surveyed and monumented by a galvanized pipe topped by an one inch diameter, yellow, plastic plug engraved "O.D.N.R. 433-4601". The channel cross sections were surveyed using a Kern GK1A automatic level, staff, and tape (Plate 1). Instantaneous current velocities were measured for all stations except 6 by cup-type, Pygmy or Gurley, current meters; the former was used to measure velocity in shallow water (Plate 3) while the latter was used in deeper water (Plate 2). At station 6, mean velocity was determined from culvert gradient, radius, and roughness and from daily maximum water depth (Appendix 3). Bridges exist at each station and acted as a sampling platform during periods of high flow.

Discharge was derived from velocities determined by the Manning Equation (station 6, Appendix 3) or the mean section method (other stations, Fig. 5). The latter method overcame the problem of velocity variation at different points in the cross section (Goudie _et al_., 1981). Each segment area was calculated from the following formula:

$$a_i = w_i \frac{(d_{i1} + d_{i2})}{2}$$

and each segment discharge was calculated from:

$$q_1 = a_i\frac{(V_{i1} + V_{i2})}{2}$$

where d_{i1} and d_{i2} are marginal depths, and v_{i1} and v_{i2} are marginal velocities in the verticals measured by the current meter at 0.2 and 0.8 total depth and averaged (Fig. 5). Total area (A) and discharge (Q) were obtained by summing the segment contributions as follows:

$$A = \sum_{i=1}^{n} a_i$$

$$Q = \sum_{i=1}^{n} q_i$$

For maximum accuracy, a large number of subsections were used per cross section. Instantaneous discharges were calculated in this manner at a variety of river stages on 10/1/84, 11/29/84, 12/2/84, 12/15/84, 2/25/85, 2/26/85, 3/1/85, 3/1/85, 4/7/85, and 4/19/85 in order to define the relationship of stage to discharge at a particular station (Fig. 10). Future workers may use these stage-discharge rating curves in conjunction with a continuous trace of creek level (stage) to provide a quick record of discharge.

Ninety to one hundred percent of sediment in most non-mountainous areas of the world have been shown to move as suspended load (Table 7). This is also probably true for the entire Old Woman Creek system but, in the Lake Plain and Till Plain, suspended load accounts for even more of the total load. A depth integrated sampler was used in this study to collect a single, instantaneous, suspended sediment sample from each station for 12 days during the autumn of 1984 and the winter and spring of 1985. However, all such sediment sampling devices are incapable of catching the entire sediment load because they do not measure the sediment moving close to the bed (Leopold et al., 1964, p. 220). The concentration of suspended load (C) that was collected was determined by filtering the samples under vacuum through prewashed, predried, and preweighed filter paper. The filter paper was then redried and weighed and the sediment concentration (C) was expressed as dry weight per volume of mix (ounces/cubic foot). Test - retest analysis was done on 10/1/84 by collecting two different sediment samples from each station and analyzing them separately. The best precision was $\pm 0\%$ (station 9) while the worst was $\pm 25\%$ (station 7). The rest of the stations averaged $\pm 7\%$. Sediment concentration (C) was then converted into approximate sediment yield (G)(ounces/second) by multiplying C x Q; no equal discharge increment or equal transit rate techniques were applied while sampling. The sediment yield data allowed approximate rating curves to be constructed to show the relationship between a particular station's stream discharge and sediment yield (Fig. 11). Such sediment rating curves are often found in the literature and are particularly efficient predictors of sediment yield when a continuous measure of stream discharge is available (Gregory and Walling, 1973, p. 166). Campbell (1962) also used sediment rating curves as measures of soil erosion within a catchment. However, the use of sediment rating curves has also been criticized because the commonly high coefficients of correlation (r^2) between G and Q tend to be reported without mention of G's original derivation from Q (once again) x C.

Erosion Assessment Sites

Eleven erosion assessment sites were established within the drainage area (Fig. 1). Each is composed of a monumented, photographed, and surveyed cross-section and each will be usable as baseline data for future studies. Site location was done carefully so as to position cross-sections in important reaches such as both upstream and downstream of the proposed State Route 2 bridge; cross-sections were also distributed over space with two sites in the Berea Escarpment, five sites on the Lake Plain, and a site on the Till Plain (Fig. 1; Appendix B). Cross-sections were monumented with a galvanized pipe topped with a one inch diameter, yellow, plastic plug engraved "O.D.N.R. 433-4601" and surveyed with a Kern GK1A level, tape, and Philadelphia rod (Plate 1). In cases of deep water, a boat was employed as a platform. Site photographs appear in Appendix B.

RESULTS

Many questions about the sediment movement, water movement, and morphology of Old Woman Creek still remain unsolved or only partially answered. Among those issues falling into this category are the relationship between sediment yield and stream discharge at a site, the interreaction between drainage area and discharge, the relative sediment and discharge contribution of different creek segments on different days, the effect of land use and soil association on sediment load, and the general morphology of the channel. Stream discharge measurement, sediment load sampling, and surveying were used in this study to answer these and other related questions. The average and maximum sediment yield (ounces/second), sediment concentration (ounces/cubic foot), mean velocities, maximum velocities, stream discharge, and maximum stream depth are shown in Table 1. For the purposes of discussion, the data will be divided and analyzed by geomorphic province and station.

Till Plain

The most headward tributaries of the Old Woman Creek system begin on the Till Plain at about 885 feet elevation (Fig. 2). They descend toward the Berea Escarpment at an average stream gradient of 0.34% or 18 feet per mile (Buchanan, 1982, p. 70) and drain an area dominated by row crops-fallow land (Fig.4; Table 4) and the silt loams and loams of the Mahoning-Bogart-Haskins-Jimtown Soil Association (Fig. 3; Table 6). Mahoning soils represent about 40% of the association in terms of area and are among the most easily eroded in Ohio (Fig.3; Table 6) . "The intensive agricultural development of this soil type ... has no doubt reinforced the natural erodability of this material and caused it to be a major source of sediment currently being deposited in Old Woman Creek estuary" (Buchanan, 1982, p.55). Sediment yield from the watershed's Till Plain might exceed 15,000 tons per year; of that approximately 5,000 tons per year is composed of silts and clays (Buchanan, 1982, p.58). The silts and clays are easily"transported into the creek by a single precipitation event" (Buchanan, 1982, p. 58). Although they often settle to the local channel bottom during the considerable periods of no or low discharge on the Till Plain, most fines are eventually moved to the estuary by large flows induced by a major storm or snow melt. However, the coarser fractions that make it to the ditches and creeks of the Till Plain tend to remain there in the source areas (Buchanan, 1982, p.58).

Stations 4 and 5 are located on the Till Plain (Figs. 1,2). Station 4, with only 22% of Station 5's drainage area, always has a higher sediment concentration than station 5

(Table 1). However, station 5 always has more maximum cross-sectional velocity and stream discharge than station 4 (Table 1). On 11/29/84, sediment concentration was higher (0.0430 and 0.0397 ounces/cubic foot) at stations 4 and 5 than at the other stations in the other geomorphologic-soil regions; it is so because of the availability of sediment and the concentrative effects of the no flow condition. This concentrative effect was most pronounced on 12/2/84 at station 4, when its highest recorded sediment concentration of 0.2031 ounces/cubic foot was measured. With the onset of flow on 12/15/84, sediment concentration for both stations decreased to approximately its 11/29/84 level. On 2/25, discharge increased dramatically but sediment concentration did not rise as quickly (Figs. 6c, 6d). Discharges of the following day were reduced by 40-50% but sediment concentration diminished by even more to levels not recorded since before 11/29/84. Possibly the available "plug" of sediment had been pushed through by the comparatively high velocities of 2/25/85 (which exceeded 1 cubic foot/second at station 5). Sediment concentration continued to drop from 2/26/85 through 3/1/85 to 3/23/85 when the lowest level of 0.0128 and 0.0047 ounces/cubic foot were recorded at stations 4 and 5, respectively. By early April, both spring planting and rainfall had occurred and sediment concentration again rose; the third largest flow of the year was recorded on 4/7/85 at stations 4 and 5 (Table 1).

Station 4

It is located upstream of the Berea Escarpment in the Mahoning-Bogart-Haskins-Jimtown Soil Association, 3.5 miles southeast of Berlin Heights where County Line Road crosses over the creek (Figs 1,2,3; Appendix A.4). Station 4's bottom is covered in fine sediment, has a thalweg elevation of 840.9 feet, has approximately 2.3 square miles of drainage area contributing to it, and is about 0.6 miles north from the usual beginning point of flow (Fig. 1). Station 4 is not being used as a nutrient sampling site by David Klarer (Sanctuary Biologist) but was used as a sediment sampling station (number II) by Buchanan (1982). Station 4's data is heavily influenced by agricultural activity; 67% of the sub-basin was in row crops and 77% was fallow (Table 4). Only 18% of the creek's upstream extension had forested banks in 10/84 (Fig. 4). Station 4's data are considered more representative of the Till Plain than those of station 5 which are affected by local channel pooling (J. Foltz, personal communications, 1986).

Raw sediment data and summary sediment data for station 4 are found in Table 1. Analyses of these data and other field evidence show the following:

1. Station 4's sub-basin is highly erodable because of soil type (Fig. 3; Table 6) and the effects of cropping. Of all the stations, station 4 had the largest number of daily first place rankings in sediment concentration (Fig 8a) and sediment concentration per square mile of watershed (Table 2). The first places occur during any season; measured sediment concentration on 11/29/84, 12/2/84, 3/1/85, and 4/7/85 of 0.043, 0.203, 0.022, and 0.102 ounces/cubic foot were the highest recorded for any station on those dates (Fig 8a).

2. During periods of field preparation, high levels of sediment concentration were recorded at station 4(e.g. on 4/7/86) (Table 1).

3. The mean recorded sediment concentration at station 4 (0.0539 oz/ft^3) was the highest of any station (Table 1). Buchanan (1982, Table 8-1) also showed that this station had the highest mean sediment concentration among his 1977 collections.

4. The maximum recorded sediment concentration at station 4 was 0.203 oz/ft^3 on 12/2/84 during a no flow period. In times when stream discharge was occurring, the concentrative effect of pooling was lost, and the maximum recorded sediment concentration became 0.1021 oz/ft^3 on 4/7/85 (Table 1). Buchanan (1982, Table 8-1) reported grab sample

concentrations of up to 2.668 oz/ft^3 during a minor storm event on 7/21/77 but his collection or lab procedure might have been different than our's leading to larger sediment concentration numbers.

5. The minimum recorded sediment concentration at station 4 for both this study and Buchanan's 1982 work was 0.011 oz/ft^3 recorded on 4/19/85 (Table 1). This minimum is higher than the minimum sediment concentration of all stations except station 10.

6. The relationship between stream discharge and suspended sediment concentration is poor with a correlation coefficient of less than 0.40; such scatter is to be expected because suspended load is not a capacity load. Poor relationships between suspended sediment concentration and both maximum and mean cross sectional velocities also were experienced.

7. At station 4, there is an especially predictable relationship between sediment yield (G) and stream discharge (Q): ($G = 0.0282\ Q^{1.2449}$) (Fig. 11).

8. Despite very high sediment concentrations, daily sediment yield through station 4 is not high when compared to

other stations (Fig. 8b). The maximum sediment yield recorded was only 0.76 oz/sec during the late February thaw (Table 1).

Water movement and depth data for station 4 are presented in Table 1. Analysis of these data and other field evidence show the following:

1. Station 4 is located near the headwaters of the Old Woman Creek's middle branch and had relatively low discharges throughout the study period. Both its mean and maximum discharges were the second lowest recorded (Table 1). No flow occurred 33% of the time (flow usually began in the Escarpment during no-flow events at 4) (Fig. 9; Table 1). Even when no discharge was occurring, there was water pooled in the channel up to a gauging station depth of 1.16 feet (Table 1). In order for flow to occur at this station, water depth must exceed a threshold value to overcome local channel morphology. The deepest no flow reading at the gauging station was 1.16 feet while the shallowest reading with discharge was 1.34 feet. Empirically, flow should begin somewhere between those two values; the stage rating curve mathematically predicts a slightly deeper value of 1.57 feet to achieve a discharge of 0.1 cubic feet /second (Fig. 10).

2. At station 4, there was an especially predictable

relationship between gauging station depth (D) and stream discharge (Q). The rating relationship was: $Q = 11.00D_{GS} - 17.20$ ($r^2 = 0.94$) (Fig. 10); power, log, or exponential best-fit equations did not improve this correlation coefficient.

3. It may be possible to roughly predict station 4's instantaneous discharge (Q_{STA4}) by utilizing the observed discharge at station 7 (Q_{STA7}) and the following formula: $Q_{STA4} = 0.0034Q_{STA7}$ ($r^2 = 0.89$). When discharge at station 7 was less than 6.4 cubic feet/second, flow at station 4 was absent; therefore, only Q_{STA7} greater than 6.4 cubic feet/second were used to find this relationship.

4. The maximum measured discharge at station 4 occurred on 2/25/85 and was 16.8 cubic feet/second. Mean discharge was only 2.8 cubic feet/second. Only station 9 reported lower readings (Table 1).

5. Station 4 has the 8th largest watershed and usually (8 out of 9 times) it recorded the 8th largest discharge (Table 1).

6. The maximum recorded velocity was 0.73 feet/second on 2/25/85 at station 4 (Table 1). Buchanan (1982, Table 5-1) recorded a maximum 0.1 feet/second at this station on 7/28/77.

7. The maximum recorded depth at station 4 was 2.9 feet on 2/25/85.

Station 5

It is located just upstream of the Berea Escarpment in the Mahoning-Bogart-Haskins-Jimtown Soil Association, 0.9 miles southeast of Berlin Heights where Bellamy Road crosses the creek (Fig. 1, Appendix A.5). Its bottom is composed of fine sediment with a thalweg elevation of approximately 773.2 feet. Station 5 has approximately 8.0 square miles of watershed contributing to it. It is being used by David Klarer (Sanctuary Biologist) as a nutrient sampling site and was used as a sediment sampling station (number III) by Buchanan (1982). Station 5's data is heavily influenced by agricultural activity: 52% of the sub-basin area was in row crops and 15% was fallow (Table 4). Fifty percent of the 8.4 miles of creek below station 4 and above station 5 had wooded banks in 10/84 (Fig. 4).

Table 1 shows both raw and summary data for station 5. Apparent are numerous parallels between station 5 and the other Till Plain station, 4, which lies upstream (Fig. 1). However, there are also striking differences between them, caused, it is believed, by the large pool at station 5 and/or by the difference in the length of wooded stream margins (18% above station 4 was wooded whereas 59% between station 4 and 5 had tree cover (Fig 4). These differences between the two Till Plain stations are enough and in such a direction as to recommend the emphasis of station 4's data over those of station 5 as descriptors of the "typical" stream characteristics of the Till Plain. Nevertheless, the main points of station 5's sediment data are summarized below:

1. When compared to the smaller watershed of station 4, station 5's subbasin does not contribute as much sediment to the creek in either ounces/cubic foot/square mile or normal concentration terms (Tables 1,3).

2. Station 5 never ranked first in terms of daily sediment concentration. Rather, it had two second and two third highest rankings to put it in fifth position in total first, second, and third placings among the nine stations (Fig 8a).

3. The mean recorded sediment concentration was 0.025 ounces/cubic foot (Table 1). The maximum recorded sediment concentration occurred during spring planting on 4/7/85 and was 0.051/ounces/cubic foot. This was more than that recorded during the late February thaw even though the stream discharge on 2/25/84 was about six times that of 4/7/85. The minimum recorded sediment concentration was 0.0047 on 3/23/85 (Table 1).

4. There was generally a direct relationship between stream discharge and sediment concentration (Fig. 6d).

5. The power relationship $G = 0.0092\ Q^{1.316}$ (where G is sediment yield in ounces/second and Q is stream discharge in cubic feet/second) best describes the relationship between sediment yield and discharge (Fig. 11).

Water movement and depth data for station 5 are presented in Table 1. Analysis of these data and other field evidence show the following:

1. Station 5's watershed was the sixth largest of the nine stations and exhibited relatively moderate amounts of discharge. Its mean discharge was the fifth largest and its maximum discharge was the 4th largest recorded (Table 1). When flows less than 0.1 cubic feet/second were recorded, they were usually a function of the pool directly beneath the Bellamy Road bridge rather than the stream reach itself; riffles lie within view of station 5 and typically displayed visible stream flow. In order for measurable flow to occur at this station, water depth must exceed a threshold value of about 1.9 feet (based on the stage-discharge rating formula and empirical evidence).

2. At station 5, there was an especially predictable relationship between gauging station depth (D_{GS}) and stream discharge (Q). The stage-discharge rating relationship is: $Q = 60.33(D_{GS}-112.26)$ ($r^2 = 0.94$) (Fig 11).

3. It may be possible to estimate station 5's instantaneous discharge (Q_{STA5}) by using the observed discharge at station 7 (Q_{STA7}) and the following formula: $Q_{STA5} = 0.13\ Q_{STA7}^{1.39}$ ($r^2 = 0.86$). When discharge at station 7 was less than 4.2 cubic feet/second, flow at station 5 was absent; therefore, only Q_{STA7} greater than 4.2 cubic feet/second were used to find the relationship between the discharge of stations 5 and 7.

4. Maximum measured discharge on 2/25/85 was 60.2 cubic feet/second. Mean discharge was 12.8 cubic feet/second which, relative to the other stations, is a moderate value (Table 1).

5. Maximum recorded velocity was 1.02 feet/second on 2/25/85 at station 5 (Table 1). Buchanan (1982, Table 5-1) recorded a maximum of 0.1 feet/second at this station on 7/28/77.

6. The maximum recorded depth at station 5 was 3.5 feet on 2/25/85.

Berea Escarpment

Immediately downstream from the relatively flat and predominately row-cropped Till Plain is the Berea Escarpment with its greater relief, steeper slopes and more diverse land uses; in October, 1984, 49% of the Escarpment was row-cropped or fallow. Twenty two percent was woodland, 13% was orchard, and 11% was urban (Figs. 2,4; Table 4). Several soils are found on the Berea Escarpment and support its land use; in order of area covered, the three largest are the Mahoning-Bogart-Haskins-Jimtown (BGHJ), Arkport-Galen (AG), and Allis-Fries (AF) soil associations (Fig. 3, Table 6). Soil texture varies according to association and type from the finer silty clay loam (AF) through silt loams and loams (BGHJ) to coarser loamy fine sand (AG); soil erodability generally increases with decreasing grain size and thus BGHJ and AF soils are potentially more erodable than the coarser AG soils (Table 6). The transportation potential of the creek within the Escarpment is high; the 1.1% (58 feet/mile) average gradient (Buchanan, 1982, p. 71-72) is about three times that of the Till Plain and is enough to keep the 2.3 miles of channel free from siltation. Hence, any fines brought into the Escarpment from the Till Plain or from direct overland flow are flushed through quickly to the Lake Plain, estuary, or Lake Erie.

Station 6 is located in the Berea Escarpment while stations 2 and 7 are in the transitional zone where the Escarpment drains into the Lake Plain. For the purpose of discussion, all three stations have been included in the Berea Escarpment province. Stations 2,6, and 7 all exhibit smaller mean sediment concentration per square mile than did the Till Plain stations (Table 2). Stations 6 and 7 had less sediment concentration than either of the Till Plain stations lying upstream (except on 10/1/84) (Table 1). Apparently, this situation was caused by the Escarpment's greater amount of sediment-free base flow, more exposed bed rock, less agricultural soil disturbance, and fewer acres of highly erodable soil.

Station 2

It is located in the transitional area between two geomorphic provinces (Berea Escarpment and Lake Plain) and two soil associations (Mahoning-Bogart-Haskins-Jimtown and Arkport- Galen), 1.3 miles northwest of Berlinville where Huff Road crosses the west branch of Old Woman Creek (Figs. 1,2,3; Appendix A.5). Station 2's shale and cobble bed has an approximate elevation of 630 feet and has about 4.8 square miles of drainage area. The bed was artificially channalized away from the bridge abutments by the county during the survey period but, with the thaw of late February (Table 5), the bed naturally relocated to about its previous position. Much of station 2's watershed is in the Till Plain although it itself is in the transition between the Escarpment and the Lake Plain. Consequently, 64% of the total watershed was in row crops or fallow and 20% was in woodland in October, 1984. However, within the Escarpment portion of the total watershed, land use was very different; 52% was in row crops or fallow and 30% was in woodland (Table 4). Of a total upstream length of about 6.8 miles, 75% had a forested bank and 32% had a fallow or row cropped stream bank (Fig. 4). Station 2 was not being used as a nutrient sampling site by David Klarer (Sanctuary Biologist) nor as a sediment sampling station by Buchanan (1982).

Raw sediment data and summary data for station 2 are found in Table 1. Analysis of these data and other field evidence show the following.

1. Suspended sediment concentration at station 2 was always comparatively low because the immediate upstream area lacks a readily available sediment supply. In the daily sediment concentration rankings, station 2 recorded no overall first, second, or third places (Fig. 8a) and it usually had the lowest concentration of all the Escarpment stations.

2. The mean recorded sediment concentration at Station 2 (0.0119 Oz/ft^3) was the lowest of any station (Table 1).

The maximum recorded sediment concentration occurred at station 2 on 12/15/84 and was 0.0275 oz./ft.^{3}; this was lower than that recorded at any other station on that day (Table 1). Another large suspended sediment concentration for station 2 occurred on 4/7/85 when plowing and rainfall coincided. Minimum sediment concentration at station 2 was recorded on 3/23/85 and was only 0.0036 oz./ft.^{3}.

3. Generally, there is a good direct relationship between stream discharge and sediment concentration (i.e. as discharge increases so does concentration and vice versa) (Fig. 6A). However, during the high discharges of the late February 1985 thaw, newly available sediment became limited and the graphed sediment peak did not correspond to that of stream discharge (Fig. 6A).

4. At station 2 there is a predictable relationship between sediment yield (G) and stream discharge (Q): $G = 0.0045Q^{1.53}$ (Fig. 11).

5. Daily suspended sediment yield through station 4 was low compared to other stations nearby (Fig. 8b; Table 1) because the banks are often wooded the creek bottom is bedrock-gravel, and some of the soils are of the resistant Arkport-Galen Association (Figs. 3, 4).

Water movement and depth data for station 2 are presented in Table 1. Analyses of these data and other field evidence show the following:

1. Station 2's watershed is the seventh largest of the nine stations and so is its mean discharge and maximum discharge (Table 1). There was always flow at station 2 and its discharge-drainage area relationship for selected days is shown in Figure 9.

2. A stage-discharge rating curve for station 2 could not be established because the channel cross-section was substantially altered by the County Engineer during the study (Appendix A.2).

3. It may be possible to predict station 2's instantaneous discharge (Q_{STA2}) by using the observed discharge at station 8 (Q_{STA8}) and the following formula: $Q_{STA2} = 0.19Q_{STA8}^{0.95}$ ($r^2 = 0.88$).

4. The maximum recorded velocity was 2.91 feet/second at station 2 (Table 1). On 4/19/85 it recorded a maximum velocity that was faster than all other stations and on several other days it ranked in the top three in terms of velocity (Fig. 8c).

5. The maximum recorded depth was 1.0 feet on 12/15/84 (Table 1).

Station 6

It is located in the sandstone Berea Escarpment at a thalweg elevation of 680.2 feet, 0.4 miles west of Berlin Heights on the downstream end of a large, corrugated culvert carrying the middle branch of Old Woman Creek beneath Berlin Road (Figs. 1, 2; Appendix A.6). Station 6's nine square miles of watershed is composed of Mahoning-Bogart-Haskins-Jimtown soils (Fig. 3) and two geomorphic provinces, the Escarpment (where it itself is located) and the larger, agriculturally dominated Till Plain (Fig. 2). Consequently, 77% of the total watershed was in row crops or fallow, 14% forested, 6% in orchards, and 4% urban in October, 1984. However, if only the smaller Escarpment area is considered, a much different picture of land use appears; specifically, in October, 1984, 46% was in row crops or fallow, 17% in forest, 19% in orchard, and 11% urban (however, most of the storm sewer drainage from Berlin Heights is directed by pipe to a point downstream of station 6 and upstream of station 7)(Fig. 4; Table 4). Between station 6 and the more upstream station 5, are 3.6 miles of channel; of this 50% was forested on at least one bank whereas 19% was fallow, 5% was in orchard, 13% was in pasture, and 11% was effected by urbanization in October, 1984 (Fig. 4). Station 6 is being used as a nutrient sampling site by David

Klarer (Sanctuary Biologist) and was used as Site VII by Buchanan (1982) to collect grab sediment samples.

Raw sediment data and summary data for station 6 are listed in Table 1. Analysis of these data and other field evidence show the following:

1. Sediment concentration at station 6 was always low compared to the other eight stations because the immediate upstream area lacked a ready sediment supply and has a significant, sediment-free, base flow. In the daily sediment concentration rankings, station 6 recorded no first, second or third places (Fig. 8a).

2. There are major sediment concentration reducing properties of the reach between stations 5 and 6 and possibly a slower erosion rate than on the Till Plain (Table 3)

3. The mean recorded sediment concentration at station 6 (0.0160 oz./ft.^{3}) is lower than any station except 2 (Table 1). The maximum recorded sediment concentration occurred at station 6 on 12/15/84 and was 0.0366 oz./ft.^{3} (Table 1). Another sediment concentration measurement approximated that of 12/15/84 and occurred during the spring planting on 4/7/85. Although it was a significant concentration for station 6, the 4/7/85 reading was the third lowest for the basin as a whole on that day (Table 1).

Minimum sediment concentration at all Escarpment stations occurred on 3/23/85. At station 6, this reading was 0.0028 oz./ft.^{3} (Table 1).

4. Generally, there is a good direct relationship between stream discharge and sediment concentration (i.e. as discharge increases so does suspended sediment concentration and vice versa)(Fig. 6E). However, during the high discharges of the late February thaw, newly available sediment became limited and the graphed sediment peak did not correspond to that of the stream discharge (Fig. 6E).

5. The relationship between sediment yield (G) and stream discharge (Q) is best described by the following: $G = 0.0045Q^{1.53}$. Its correlation coefficient of 0.78 is not as high as at the other Escarpment stations (Fig. 11).

6. Station 6 with its larger watershed and stream discharge usually had more sediment yield than station 5 with its smaller watershed and greater sediment concentration. However, on 2/25/85 and 2/26/85 this did not happen because of flooding (and loss of sediment-charged water) between stations 5 and 6 (Table 1)(J. Foltz, personal communication, 1986).

Water movement and depth data for station 6 are presented in Table 1. Analyses of these data and other field evidence show the following:

1. Station 6 has the fourth largest watershed of the nine stations and also the fourth largest mean and maximum discharges (Table 1). All recorded discharges were above 0.1 cubic feet/sec. because of the base flow contribution of the Escarpment. However, during the summer and fall, station 6's flow was small compared to its basin area because the Till Plain portion of its basin contributed little to stream flow (Fig. 9).

2. The discharges at station 6 were calculated from depth indirectly using the Manning Formula (Appendix C); no stage-rating curves were, therefore, developed for this station. These calculated discharges appear reasonable because they are always lower than the nearest downstream station (7) and higher than the nearest upstream station (5) (except on 2/26/85 when there was over-bank flooding along the reach).

3. It may be possible to approximately predict station 6's instantaneous discharge (Q_{STA6}) by using the observed discharge at station 7 (Q_{STA7}) and the following formula:
$Q_{STA6} = 0.51Q_{STA7}^{1.08}$ ($r^2 = 0.97$).

4. The maximum calculated discharge at station 6 occurred

on 2/25/85 and was 65 cubic feet/second. Mean discharge was 15.75 cubic feet/second (Table 1).

5. No maximum velocities are available for station 6.

6. The maximum recorded depth at station 6 was 1.4 feet on 2/25/85.

Station 7

It is located in the transitional area between two geomorphic provinces (Berea Escarpment and Lake Plain) and two soil associations (Mahoning-Bogart-Haskins-Jimtown and Allis-Fries), 0.9 miles northwest of Berlin Heights where Mason Road crosses the middle branch of Old Woman Creek (Figs. 1, 2, 3; Table 5; Appendix A.7). Station 7's sand - sandstone bed has an approximate thalweg elevation of 617.1 feet. Its 10.54 square miles of drainage area (Fig. 1) contains mostly Mahoning-Bogart-Haskins-Jimtown soils (Fig. 3) and all three geomorphic provinces (Fig. 2). The Till Plain dominates the watershed in area terms and, consequently, 64% of the total watershed was in row crops or fallow and only 14% was forested, 8% was in orchard, and 5% urban in October, 1984. However, if only the sub-basin of station 7 is considered then a much different picture of land use emerges; specifically, in October, 1984, only 8% was in row crops or fallow, 21% was in forest, 25% was in orchard, and 20% was urbanized or suburbanized (Fig. 4; Table 4).

Between stations 7 and the more upstream station 6 are 0.95 miles of channel; of this, 93% was forested on at least one bank whereas the remainder was residential. However, there are also drinking water storage pools and sewer outfalls along the reach of Old Woman Creek between stations 6 and 7 which significantly effected the water and sediment data. Station 7 is being used as a nutrient sampling site by David Klarer (Sanctuary Biologist) and was used as Site IV by Buchanan (1982) to collect grab sediment samples.

Raw sediment data and summary data for station 7 are found in Table 1. Analysis of these data and other field evidence show the following:

1. Sediment load and stream discharge at station 7 reflects the input and extraction effects of humans as well as local geomorphic, soil, and land use factors. During periods of low water, the Berlin Heights water plant removed water from the middle branch of Old Woman Creek, held it in basins above station 7 and, thereby, usually reduced the reach's erosion potential (except on 11/29/84). Conversely, during higher flows, the input of water from village storm sewers combined with natural flow to increase the erosion of bottom sediment which had accumulated during lower flow; holding basins were not influential during such high flows because by-pass gates precluded further basin infill (J. Foltz, personal communication, 1986).

2. Sediment concentration at station 7 was usually comparatively low because the immediate upstream area lacks a ready sediment supply and has a significant, sediment-free base flow. This is despite the significant impact of humans upstream and the longitudinal gradient which is steeper than in the other geomorphic provinces (Fig. 8a).

3. The pattern of sediment concentration through the year for stations 6 and 7 were broadly similar and there is good association between stream discharge and sediment concentration except on 11/29/84 and 2/25/85; apparently, sediment availability was the limiting factor on 2/25/85 (Figs. 6E, 6F). However, the actual daily suspended sediment concentration was slightly higher at station 7 nine out of 12 times (Table 1).

The mean recorded sediment concentration of station 7 (0.0186 oz./ft.^{3}) is higher than that of the other Escarpment stations but lower than that of the remaining stations (Table 1). The maximum recorded sediment concentration occurred at station 7 during spring planting on 4/7/85 and was 0.0399 oz./ft.^{3}; this was the fourth lowest concentration measured that day (Table 1). Minimum sediment concentration at all Escarpment stations occurred on 3/23/85. At station 7, this reading was 0.0040 oz./ft.^{3}.

5. The relationship between sediment yield (G) and stream discharge (Q) is best described by $G = 0.0044Q^{1.42}$ (Fig. 11). Maximum yield occurred during the biggest flow event on 2/25/85 (3.385 oz./sec.) and was much greater than the yield measured on the same day at station 6 (2.21 oz./sec.) located only 0.95 miles upstream. Stream discharge had increased by about 50% in this short distance largely because of storm sewer input from Berlin Heights.

Water movement and depth data for station 7 are presented in Table 1. Analysis of these data and other field evidence show the following:

1. Station 7 has the third largest drainage area of the nine stations and also the third largest mean and maximum discharges (Table 1). All recorded discharges were above 0.1 cubic feet/second because of the base flow contribution of the Escarpment. Discharge patterns on Figure 6F mirror those of station 6 on Figure 6E but the actual discharges are very different with those of station 7 always higher (Fig. 9; Table 1).

2. At station 7, there was a predictable relationship between gauging station depth (D_{GS}) and stream discharge (Q). The stage-discharge rating relationship is: $Q = 46.70D_{GS} - 27.67$ ($r^2 = 0.86$).

3. It seems possible to approximately predict the instantaneous discharges of stations 4, 5, and 6 from the measured discharge of station 7. The relationships follow:

$$Q_{STA4} = 0.0034Q_{STA7}^{1.96} \qquad (r^2 = 0.89)^{*}$$

$$Q_{STA5} = 0.13Q_{STA7}^{1.39} \qquad (r^2 = 0.86)^{**}$$

$$Q_{STA6} = 0.54Q_{STA7}^{1.08} \qquad (r^2 = 0.97)$$

4. The maximum measured discharge at station 7 occurred on 2/25/85 and was 96.3 cubic feet/second. Mean discharge was 23.5 cubic feet/second (Table 1). Only stations 8 and 10 reported higher readings.

5. Station 7 recorded more first places in the daily maximum velocity rankings than any other station (Fig. 8C). Its maximum recorded velocity was 3.83 feet/second on 2/25/85 (Table 1).

6. The maximum recorded depth at station 7 was 2.7 feet on 2/25/85 (Table 1).

<u>Lake Plain</u>

The Lake Plain lies immediately downstream of the more steeply sloping Berea Escarpment. In October, 1984,

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* Only Q_{STA7} greater than 6.4 cubic feet/second were used

** Only Q_{STA7} greater than 4.2 cubic feet/second were used

48% of the Lake Plain was field cropped or fallow, 27% was wooded, 7% was in orchard, and 4% was urbanized or suburbanized (Fig. 4; Table 4). Several soils are found on the Lake Plain and support its land use; in order of area covered, the largest two are the Kibbie-Tuscola-Colwood (KTC) and Del Ray-Lenawee (DL) Soil Associations (Fig. 3; Table 6). Soil texture varies according to association and type from the finer silt clay-loam (DL) through silt-loam (DL and KTC) to the fine sandy loam of KTC; soil erodability seems to increase with decreasing grain size and, thus, lower erosional rates are probable on the KTC soils (Table 6). "Soils of the KTC association are less prone to erosion because of their coarser texture even though the slopes on which the soils developed are identical to the Del Ray soils" (Buchanan, 1982, p. 56). The average gradient of Old Woman Creek over the easily eroded lacustrine sediments of the Lake Plain is only 0.13% (7 feet/mile) (Buchanan, 1982, p. 72). Because this gradient is about one-third that of the Till Plain and one-ninth that of the Escarpment, the transportation potential of the wide, meandering Old Woman Creek in the Lake Plain is relatively low. Thus, the majority of sediment accumulation in the basin should occur within the Lake Plain channels (Buchanan, 1982, p. 72). In fact, there were many days when the Lake Plain accumulated sediment in its channels but also a few days when its flow was able to scour the bottom and move material into or through the estuary (Table 3). "The clays now being deposited in the estuary probably originate from both the upper till plain and lower lake plain. Because of the proximity of the lake plain to the estuary, the amount of clay reaching the estuary from each source area is probably roughly equal. The coarser silts and fine sands now being deposited in the estuary are probably eroded from fields on the lake plain near the estuary and have short transport distances"(Buchanan, 1982, p. 58).

Stations 3, 8, 9, and 10 are located on the Lake Plain.

Station 3

Its deep, silt and clay cross-section is located on the Lake Plain at a thalweg elevation of about 587.7 feet, 2.8 miles north of Berlinville where Chapin Road crosses the west branch of Old Woman Creek (Figs. 1, 2; Appendix A.3). Station 3's 8.1 square miles of watershed is composed of Kibbie-Tuscola-Colwood, Arkport-Galen, and Mahoning-Bogart-Haskins-Jimtown soils (Fig. 3) and three geomorphological provinces, the agriculturally diverse Lake Plain, the Berea Escarpment, and the field-crop dominated Till Plain (Fig. 2). Of station 3's total watershed, 60% was in field crops or fallow, 22% was forested, 4% was in orchards, and 4% was urbanized or suburbanized in October, 1984 (Fig. 4; Table 4). However, if only the smaller sub-basin between stations 2 and 3 is considered, a slightly different picture of land use appears; specifically, in October, 1984, 67% was in field crops or fallow, 24% was forested, 7% was in orchard, and 4% was urbanized or suburbanized (Fig. 4; Table 4). Station 3 is being used as a nutrient sampling site by David Klarer (Sanctuary Biologist) and was utilized as Site VIII by Buchanan (1982) to collect grab sediment samples.

Raw sediment data and summary data for station 3 are found in Table 1. Analyses of these data and other field evidence show the following:

1. Station 3's sediment concentration was usually relatively high and never affected by periods without stream discharge. Its suspended sediment concentration was always higher than that of station 2, immediately upstream. In the daily sediment concentration ranking, station 3 recorded three firsts, one second, and two third places (Fig. 8a). This puts station 3 into second place behind station 4 in total number of placings. All first places in daily sediment concentration occurred in March and April when stream discharges were low (Fig. 8a; Table 1). Station 2 lies just upstream from station 3 but did not place at all in the same daily sediment concentration rankings (Fig. 8a); this suggests that station 3's sub-basin is an important erosional area.

2. The relatively high suspended sediment concentration at station 3 may have been caused, in part, by a feed lot within its sub-basin.

3. Station 3's sub-basin can be a moderate to high erosion region. On 10/1/84 and 2/25/85, station 3's sub-basin produced large residual suspended sediment concentration/square mile of watershed which is indicative of sub-basin erosion; only station 8 had higher residual suspended sediment concentration/square mile on these dates. More minor erosion occurred on four other days while deposition happened on 12/15/84 and 4/7/85 (Table 3). Low gradients promoted deposition while humans and especially the feed lot activity promoted erosion in this sub-basin.

4. The mean recorded sediment concentration of station 3 (0.0368 oz./$ft.^3$)was lower than that of stations 4 and 8 (Table 1). The maximum recorded sediment concentration of 0.0718 oz./$ft.^3$ occurred during the late February thaw and was greater than that of the Escarpment stations for that date. The minimum suspended sediment concentration of 0.0073 oz./$ft.^3$ occurred on 12/2/84 (Table 1).

5. There was a good direct relationship between station 3's stream discharge and sediment concentration except on 3/23/85 (Fig. 6B). Station 3 was one of the few stations to exhibit an exaggerated suspended concentration peak on 2/25/85 to mirror that of stream discharge; apparently, there was plenty of available sediment in this sub-basin during times of even the highest recorded flow.

6. There is a good relationship between sediment yield (G) and stream discharge (Q). It is best described by $G = 0.0108Q^{1.439}$ (Fig. 11). Maximum yield occurred on 2/25/85 during the biggest recorded flow event (3.303 oz./ft.^{3}) and was the third largest measured that day (Table 1).

Water movement and depth data for station 3 are presented in Table 1. Analysis of these data and other field evidence show the following:

1. Station 3 had the fifth largest drainage area and the sixth largest mean and maximum discharges (Table 1). However, discharge at station 3 was highly variable. On 10/1/84 its sub-basin contributed more flow than expected (from its area) to the discharge of the west branch (Fig. 9A; Table 1). Yet on 11/29/84 and 12/2/84, station 3 recorded two no flow days even though station 2 (upstream) had flow (Table 1).

2. At station 3, there was a predictable relationship between gauging station depth (D_{GS}) and stream discharge (Q). The stage - discharge rating relationship was $Q = 26.74D_{GS} - 74.96$ ($r^2 = 0.87$) (Fig. 10).

3. It may be possible to approximately predict station 3's discharge (Q_{STA3}) by using the observed discharge at station 8 (Q_{STA8}) and the following formula: $Q_{STA3} = 0.11Q_{STA8}^{1.29}$

($r^2 = 0.85$). When discharge at station 8 was less than 7 cubic feet/second, flow at station 3 was absent; therefore, only Q_{STA8} greater than 7 cubic feet/second were used to find this relationship.

4. The maximum recorded discharge at station 3 occurred on 2/25/85 and was 46.0 cubic feet/second. Flooding happened upstream by the gun club and probably reduced this recorded maximum from what it would have been otherwise (J. Foltz, personal communication, 1986). The mean discharge was 11.5 cubic feet/second at station 3 (Table 1).

5. The maximum recorded velocity at station 3 occurred on 2/25/85 and was 0.72 feet/second, substantially lower than that of station 2 (Table 1).

6. The maximum measured water depth at station 3 was 4.6 feet which is exceptionally deep; only station 8 and 10 on the lower Lake Plain recorded depths equal to or greater than it (Table 1).

Station 8

It is located on the Lake Plain at a thalweg elevation of about 586.3 feet, 2 miles northwest of Berlin Heights where the Norfolk and Western Railroad crosses the creek. Its bed is composed of fine sediments. Station 8 is the pivotal site of this study because it is just downstream of the junction between the western and middle branches of Old Woman Creek and above any back-water effect of the estuary (Figs. 1, 2; Appendix A.8). Station 8's 20 square miles of watershed is composed of several soil associations (Fig. 3) and three geomorphic provinces (Fig. 2). Of station 8's total watershed, 61% was in field crops or fallow, 3% was in pasture, 18% was wooded, 6% was in orchard, and 4% was urban in October, 1984 (Fig. 4; Table 4). However, if only the smaller watershed between station 8 and both stations 3 and 7 is considered, a different picture emerges; 41% was in field crops or fallow, 11% was in pasture, 25% was wooded, 5% was in orchard, and 4% was urbanized or suburbanized in October, 1984 (Fig. 4; Table 4). Station 8 is being used as a nutrient sampling site by David Klarer (Sanctuary Biologist).

Raw sediment data and summary data for station 8 are found in Table 1. Analysis of these data and other field evidence show the following:

1. Average suspended sediment concentration at station 8 was higher than that of the other Lake Plain stations and second only to that of station 4 on the Till Plain (Table 1). Station 6 placed first twice and second three times in the daily sediment concentration rankings (Fig. 8a) but recorded no first places during its five largest recorded discharges

(Table 1). The highest sediment concentrations were recorded on 10/1/84, 12/15/84, and 3/24/85 and happened after a significant rainfall event, not during a melt period (Table 5). This may suggest that rain drop impact is important to local sediment production.

2. Station 8's sub-basin can be a sporadically important erosive area. Channel deposits accreted by low flows and other sub-basin material can be readily mobilized by even moderate precipitation (Tables 1, 5). In residual suspended sediment concentration/square mile terms, station 8's sub-basin produced more than any other sub-basin on 10/1/84 and 3/24/85 (Table 3). Net erosion also occurred on 12/15/84.

3. The low gradient channel within station 8's sub-basin can also be sporadically important as a depositional area; seven out of 11 times it was a net accretor suggesting lots of bed and floodplain (?) deposition (Table 3).

4. The mean recorded sediment concentration at station 8 (0.040 oz./$ft.^3$) is higher than any station except station 4 on the Till Plain. The maximum recorded sediment concentration of 0.083 oz./$ft.^3$ occurred on 12/15/84 after a significant rainstorm and was the second largest recorded on that date (Fig. 8a; Tables 1, 5). The minimum sediment concentration of

0.0085 oz./$ft.^3$ occurred on 3/2/85. There is a very good relationship between stream discharge and sediment concentration except on 2/25/85 when available sediment could not satisfy the sediment capacity of the flow (Fig. 6G).

6. The relationship between sediment yield (G) and stream discharge (Q) is best described by: $G = 0.0062Q^{1.463}$ (Fig. 11). Maximum yield occurred on 2/25/85 during the biggest recorded flow event and was the second largest recorded that day (Table 1). On this date, there was overbank flooding downstream of station 7 and at the confluence of the middle and west branches of Old Woman Creek. This reduced stream discharge at station 8 enough so that its recorded flow did not even equal the combined discharge of the upstream stations 3 and 7. In turn, this flooding produced a lower than expected sediment yield at station 8 on 2/25/85 (Figure 11; Table 1).

Water movement and depth data for station 8 are presented in Table 1. Analysis of these data and other field evidence show the following:

1. Station 8 has the second largest drainage area of the nine stations and also had the highest mean discharge and the second highest maximum discharge (Table 1). Solely, station 10 surpassed station 8 in discharge and then only when the

estuary bar was open; when it was closed, station 10 became, functionally, a part of the estuary. Thus, station 8 is pivotal to understanding the totality of stream input into the estuary.

2. At station 8, there was an extremely predictable relationship between gauging station depth (D_{GS}) and stream discharge (Q). The stage-discharge rating relationship was $Q_{STA8} = 57.49D - 161.34D$ ($r^2 = 0.99$) (Fig. 10). These results are very encouraging especially since the station is strategic to the estuary; they suggest that a permanent stage recorder be established here.

3. It may be possible to roughly predict the discharge of stations 2, 3, 7, and 10 by using the observed discharge at station 8 (Q_{STA8}) and the following formulae:

$$Q_{STA2} = 0.19Q_{STA8}^{0.95} \qquad (r^2 = 0.88)$$

$$Q_{STA3} = 0.11Q_{STA8}^{1.20} \qquad (r^2 = 0.85) \quad *$$

$$Q_{STA7} = 0.83Q_{STA8}^{0.91} \qquad (r^2 = 0.82)$$

$$Q_{STA10} = 1.45Q_{STA8}^{0.97} \qquad (r^2 = 0.91) \quad **$$

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* When discharge at station 8 was less than 7.0 cubic feet/second, flow at station 3 was absent; therefore, only Q_{STA7} greater than 7.0 cubic feet/second were used to find Q_{STA3}.

** Q data for 4/7/85 at station 10 was effected by a transitional bar situation and, therefore, excluded.

4. The maximum recorded discharge was 105.2 cubic feet/second on 2/25/85 (Table 1). This was 37 cubic feet/second less than the combined discharges of stations 3 and 7 which lie upstream on different branches of Old Woman Creek. This lessening of discharge with increasing drainage area was unexpected but might be accounted for by over-bank flooding just downstream of station 7 and at the junction of the west and middle branches on 2/25/85. By the next day, discharge at station 8 had dropped markedly to 67.5 cubic feet/second (Table 1). Mean discharge was 33.5 cubic feet/second.

5. When the estuary mouth bar was open (12/15/84, 2/25-26/85, 3/1-1/85), there was a simple relationship between the relative discharges and the relative drainage areas of stations 7, 8, and 10.

6. The maximum recorded velocity was 2.7 feet/second on 2/25/85 (Table 1).

7. The maximum recorded water depth at station 8 was 4.6 feet on 2/25/85 (Table 1).

Station 9

It is located on the Lake Plain at a thalweg elevation of about 597.0 feet, 1.6 miles northwest of Berlin Heights where Deehr Road crosses the east branch of Old Woman Creek (Figs. 1, 2; Appendix A.9). Station 9's 1.1 square miles of watershed is composed of two geomorphic provinces, the Lake Plain and the Escarpment (Fig. 2) and the Del Ray-Lenawee (DL), Mahoning-Bogart-Haskins-Jimtown (MBHJ), and Allis-Fries soil associations (Fig. 3). The soils range in texture from silty clay loam through silt loam to loam and most have high erosion potentials (Table 6). DL and MBHJ soils have already suffered significant erosion from their gentle slopes. However, the natural erodability of Allis-Fries soils might be unrealized because its woodland cover is still largely undisturbed by agriculture (Buchanan, 1982, p. 56). Of station 9's total watershed, 35% is in field crops or fallow, 39% was wooded, and 17% was in orchard in October, 1984 (Fig. 4; Table 4). Station 9 is being used as a nutrient sampling site by David Klarer (Sanctuary Biologist).

Raw sediment data and summary data for stations 9 are found in Table 1. Analysis of these data and other field evidence show the following:

1. Station 9's daily sediment concentrations were usually the lowest recorded on the Lake Plain (Table 1). However, on 2/25/85, the sediment concentration (.211 oz./ft.^{3}) at station 9 was the largest recorded at any of the nine stations (Fig. 8a). The timing of this high sediment load

at station 9 corresponded with that of its largest recorded flow suggesting that abundant sediment within the watershed was available to the first large flow.

2. Station 9's basin displayed an inconsistent erosion pattern in residual suspended sediment concentrations/square mile terms; some days it recorded low to moderate erosion, on others it had moderate erosion, and on 2/25/85 the basin produced 0.19 oz./ft.^{3}/mi.^{2} which was the highest recorded for that date or any other (Table 2).

3. The mean recorded sediment concentration at station 9 was 0.037 oz/ft.^{3}. The maximum recorded was 0.211 oz./ft.^{3} on 2/25/85 which was higher than that of any station for that date. The minimum recorded sediment concentration was 0.0053 oz./ft.^{3} on 3/1/85 which was the lowest of any station that day.

4. At station 9, there is a poor relationship between sediment concentration and stream discharge (Fig. 6H). One big flow created a correspondingly large rise in sediment concentration but, afterwards, variations in discharge were not reflected by corresponding variations in sediment concentration. Rather, sediment concentration continued to fall from 2/25/85 to 3/24/85.

5. The relationship between sediment yield (G) and stream discharge (Q) is best described by the following formula: $G = 0.0098Q^{1.69}$ but the correlation coefficient was only 0.68.

Water movement and depth data for station 9 are presented in Table 1. Analysis of these data and other field evidence show the following:

1. Station 9, located on the minor eastern branch of Old Woman Creek, has the smallest drainage area of all nine stations and also had the smallest mean discharge (2.45 cubic feet/second) (Table 1). Maximum discharge was 8.1 cubic feet/second but all other measured discharges were less than 4.0 cubic feet/second.

2. At station 9, the relationship between gauging station depth (D_{GS}) and stream discharge (Q) was poor probably because of the small sample size and the difficulty in measuring velocity. Depths never exceed 0.6 feet and during lowest water, it was difficult to take undisturbed sediment samples and to make accurate velocity measurements. As a result, velocity and sediment readings were not collected on 11/29/84, 12/2/84, and 4/19/85 when the creek was very shallow.

2. The maximum recorded velocity at station 9 was 3.29

cubic feet/second on 2/25/85 (Table 1). No velocities were recorded at station 9 on 11/29/84, 12/2/84 and 4/19/85 because of measurement difficulties in the very shallow water. However, on five other dates, station 9 recorded the highest maximum velocities of any station (Fig. 8C).

4. The maximum recorded depth at station 9 was 0.6 feet (Table 1).

Station 10

It is located 2.8 miles north-northwest of Berlin Heights where Darrow Road crosses Old Woman Creek and just downstream of the junction of the east branch with the main portion of the creek (Fig. 1; Appendix A.9). It is 0.1 miles upstream of the proposed State Route 2 bridge. Station 10 is on the Lake Plain at a thalweg elevation of about 570.1 feet (Fig. 2; Appendix A.9) and at such a level it felt the backwater effect of the estuary when it was high (Fig. 7). When the estuary was high(e.g. 10/1/84, 11/29/84, 12/2/84, 3/23-24.85, 4/19/85), station 10, in effect, became a part of the estuary and had no perceptable flow even though water depth exceeded 5.0 feet (Table 1). Station 10's 22 square miles of watershed is composed of three geomorphic provinces (Fig. 2) and five different soil associations (Fig. 3). Significant erosion from the gentle slopes covered by Del Ray soil probably occurs on the lacustrine plain just upstream of station 10. However, because the Del Ray soils comprise only a relatively small area (3% of the entire basin)(Table 6) compared to the highly erodable Mahoning type (27% of the entire basin), Del Ray sediment contribution to the estuary must be limited (Buchanan, 1982, p.56). Of station 10's total watershed, 58% was in field crops or fallow, 20% was wooded, 6% was in orchard, 3% was in pasture, and 4% was urbanized or suburbanized in October, 1984 (Fig. 4; Table 4). However, if only the smaller sub-basin was considered a different picture of land use is created; 64% was in field crops, 28% was wooded, and 5% was in pasture in October, 1984 (Fig. 4; Table 4). Station 10 is being used as a nutrient sampling site by David Klarer (Sanctuary Biologist) and was used as Site V by Buchanan (1982) collect grab sediment samples.

Raw sediment data and summary data for station 10 are found in Table 1. Analysis of these data and other field evidence show the following:

1. Suspended sediment concentration at station 10 was always relatively high. The station had the highest sediment concentration twice, on 12/15/84 and 2/25/85, and almost always ranked within the top three stations in daily sediment concentration (Fig. 8a; Table 1). When there was flow at station 10, upstream channel scour produced significant amounts of

suspended sediment. However, station 10's sediment concentration was usually less than the sum of concentrations from stations 8 and 9 suggesting some sediment deposition in the lower Lake Plain before the remainder entered the estuary. Estimation of how much sediment settled out along the lower reaches of Old Woman Creek (where gradient is low and estuary induced slack flow occurs) is beyond the scope of this study but resurvey showed periodic sediment accumulations of more than one foot at station 10 (J. Foltz, personal communication, 1986). Such channel bottom sediment accumulations occurred on the declining limbs of storm hydrographs and were the primary contributors to the future sediment loads of future high flows.

2. Station 10's sub-basin is a low net erosive contributor in suspended sediment concentration/square mile terms (Tables 2, 3). Only on 4/7/85 was there any increase in residual suspended sediment concentration/square mile over that of stations 8 and 9 combined (Table 3).

3. The mean recorded sediment concentration at station 10 was 0.0358 oz./ft.^{3}. The maximum recorded suspended sediment concentration was 0.0945 oz./ft.^{3} on 2/25/85 when a discharge of 153.1 cubic feet/second was occurring. The minimum recorded sediment concentration was a rather large 0.012

ounces/cubic foot on 3/1/85 (Table 1).

4. The relation between suspended sediment concentration and stream discharge was uniquely poor, probably due to the effect of the estuary (Fig. 6I).

5. At station 10, the relationship between stream discharges greater than 0.1 cubic feet/second and sediment yield (G) was poor. Maximum recorded sediment yield for the entire basin occurred at station 10 on 2/25/85 and was 0.1445 ounces/second.

Water movement and depth data for station 10 are presented in Table 1. Analysis of these data and other field evidence show the following:

1. Station 10 had the largest drainage area of the nine stations and, thus, relatively large discharges could be expected and did occur there. However, no flow events happened on half of the field days and these reduced station 10's mean discharge to 31.9 cubic feet/second, the second highest calculated (Table 1). Station 10 is in close proximity to the estuary (in terms of both horizontal and vertical distance) when the estuary mouth bar is open and the level of Lake Erie is low (Fig. 7). Such conditions occurred on 12/15/84,

2/25-26/85, and 3/1-2/85. When Lake Erie rises or the bar closes, station 10 tends to become a functional part of the estuary and both discharge and sediment data change substantially.

2. At station 10, there was no predictable relationship between gauging station depth and stream discharge due to the effect of high estuary levels.

3. It may be possible to predict station 10's instantaneous discharge (Q_{STA10}) by using the observed discharge at station 8 (Q_{STA8}) and the following formula: $Q_{STA10} = 1.45Q_{STA10}^{0.97}$ ($r^2 = 0.91$). However, knowledge of the bar condition and estuary level is imperative to the correct use of this relationship; it cannot be used when the estuary level is high enough to preclude flow at station 10. Thus, the relationship could not be developed using 10/1, 11/29, 12/2/84, 3/23-24/85, 4/7/85, and 4/19/85 data.

4. The maximum measured discharge at station 10 occurred on 2/25/85 and was 153.1 cubic feet/second. This was the largest discharge recorded during the study at any station (Fig. 8d; Table 1). The mean discharge of 31.9 cubic feet/second was heavily effected by the many no flow days.

5. The maximum recorded velocity at station 10 was 0.99 feet/second on 2/25/85. Buchanan (1982, Table 5-1) reported velocities up to 0.16 feet/second at this station on 8/11/77.

6. The maximum measured water depth at station 10 was 5.85 feet in a no flow situation on 11/29/84. Maximum depth with flow was on 4/7/85 at 5.1 feet but this was an anamalous transitional bar situation. True maximum depth with flow was probably less than 5.0 feet.

DISCUSSION

Stream Discharge

The magnitude and variability of stream discharge during a particular storm is primarily explained by four factors: geomorphic province, drainage area, estuary level, and human impact.

Geomorphic Province

Of the three geomorphic provinces, the Berea Escarpment had the greatest effect on stream flow. The structure and lithology of the Escarpment contributed significant amounts of base flow to the creek and, thus, stations 2, 6, and 7 recorded discharge even during the most dry periods. On 10/1/84, 11/29/84, and 12/2/84, station 6 had flow even though its upstream stations did not (Table 1).

Drainage Area

Drainage area (A_d) and discharge (Q) were directly related in most cases. In a relative sense, both mean and maximum discharge tended to increase with increasing drainage area (Tables 1, 4); only stations 5 and 3 were out of expected order. No consistent absolute relationship between Q and A_d for the various stations could be determined even during the large flow of 2/25/85. At bank-full-flow, most research papers from various regions of the world show that the exponent in the relationship $Q = A_d^j$ varies from 0.65 to 0.81 (Leopold *et al.*, 1964, p. 251) but exponent values from Old Woman Creek for the nine station on 2/25/85 showed a wide range, from 1.55 to 3.5.

Estuary Level

Estuary level was determined by the presence or absence of its mouth bar and the level of Lake Erie. When the bar was closed, the estuary level tended to increase; when Lake Erie was high and the bar open, the estuary level was also high. During the estuary's high level periods, measurable stream discharge at station 10 ceased because its water surface level was not different enough from that of the estuary *per se* (Fig. 7). At these times, station 10 became functionally, a part of the estuary. Discharge at no other station was effected in this manner.

Human Impact

Although urbanization, suburbanization, and roads cover only about 8% of the Old Woman Creek watershed, their local effect on the magnitude of flow is already large. Between stations 6 and 7, 28% of the land is urbanized, suburbanized, or under roads and a storm sewer brings the resultantly large amounts of runoff water quickly to the creek (J. Foltz, personal communication, 1986) (Fig. 4). As a result, measured discharge at station 7 was as much as 100% larger than that at station 6 even though station 7's drainage area was just 8% larger. Conversely, during periods of low water, the Berlin Heights water plant removed water from the creek above station 7 and held it in basins before distribution. Thus, even now, there is substantial local impact of humans on the discharge of Old Woman Creek. Future urbanization, suburbanization, and road building will increase the impervious area and require more storm sewers. This, in turn, will increase the size of the average annual flood by reducing the lag time between rainfall and runoff. For example, Hammer (1972) found that the average annual flood (recurrence interval of 1.78 years) increased by 18%/square mile of watershed urbanized. However, the total effect of a given amount of impervious area on its drainage basin is largely dependent on the type and density of its storm sewers.

Sediment Concentration

The magnitude and variability of sediment concentration during a particular storm was primarily explained by soil type, channel composition, discharge, and land use.

Soil Type

K-factors relatively express the potential erodability of a soil type and range, in Ohio, from 0.17 to 0.49 for highly erodable soils. Within the Old Woman Creek watershed, Mahoning, Allis, and Del Ray soils have K-factors exceeding 0.40 and, thus, have significant potential for erosion (Table 6). The natural erodability of Allis soils might be unrealized in the watershed because its woodland cover was still largely undisturbed by agriculture (Buchanan, 1982, p. 56). However, in any case, both Allis and Del Ray soils cannot be important contributors of sediment to the estuary because their areal coverage is so small (less than 4%). Mahoning soils have a higher K-factor than either Allis or Del Ray soils and cover almost seven times as much area as the other two soils combined. "The intensive agricultural development of this soil type...has no doubt reinforced the natural erodability of this material and caused it to be a major source of sediment currently being deposited in Old Woman Creek estuary" (Buchanan, 1982, p. 55). Sediment yield from the watershed's Till Plain might exceed 15,000 tons per year; of that approximately 5,000 tons per year is composed of silts and clays (Buchanan, 1982, p. 58). Although they often settle to the local channel bottom during the considerable periods of no or low discharge on the Till Plain, most fines are eventually moved to the estuary by large flows induced by a major storm or snow melt. Station 4's sub-basin is covered by the Mahoning-Bogart-Haskins-Jimtown Soil Association (Fig. 3). It is extensively used for agriculture and is highly erodable; of all stations, station 4 had the largest number of daily first place rankings in sediment concentration (Fig. 8a).

Channel Composition

The channel is composed of fine sediments at all stations except 2, 6, and 7. Mean sediment concentration at each of these three stations was lower than the other six stations even though their mean velocities were, in general, higher (Table 1). This suggests that local channel composition is related to sediment availability and, in turn, to suspended sediment concentration.

Discharge - Velocity

High discharges and velocities were not, necessarily, associated with high sediment concentrations Rather, cropping, raindrop impact, and sediment availability were more important determiners of sediment concentration than either discharge or velocity at some stations. For example, on 2/25/85, all stations had their largest discharge and velocity but only three recorded their largest sediment concentration (Table 1).

Land Use

Field preparation in the spring and harvesting in the autumn heavily effected the recorded sediment concentrations. Raindrop impact on the disturbed fields was an especially erosive agent on the Till Plain; measured sediment concentration on 4/7/85 at stations 4 and 5 during cropping were higher than their other days with measurable flow.

Feed lot activity above station 3 was also an important local contributor to sediment load. Station 3 recorded three firsts, one second, and two thirds in the daily sediment concentration rankings as a result (Fig. 8a).

Urbanization and suburbanization and roads cover only about 8% of the Old Woman Creek basin but their local effect on the magnitude of the sediment load can be large. Between stations 6 and 7, 28% of the land is urbanized, suburbanized, or under roads and a storm sewer brings the resultantly large amounts of low sediment water quickly to the creek. Both Wolman (1967) and Hammer (1972) cite other cases of where impervious areas contribute increased runoff coupled with decreased sediment yield to the channel and mention that the combination caused erosion and widening to occur downstream. Guy and Ferguson (1963) noted that urbanization tends to contribute coarser sediment to the streams than when agriculture was prevalent.

Woodlots and especially channel banks lined with trees tended to provide less sediment to the creeks than did agriculture.

CONCLUSIONS AND RECOMMENDATIONS

Stream Flow

Several conclusions about the stream flow of Old Woman Creek can be made:

1. Stream depth at the gauging station (D_{GS}) and discharge (Q) are related at most stations. The following formulae allow a station's instantaneous discharge to be estimated from its gauging station depth on a particular day:

$$Q_{STA3} = 26.74D_{GS} - 74.96 \qquad (r^2 = 0.87)$$

$$Q_{STA4} = 11.00D_{GS} - 17.20 \qquad (r^2 = 0.94)$$

$$Q_{STA5} = 60.33D_{GS} - 112.36 \qquad (r^2 = 0.94)$$

Q_{STA6} Use Manning Formula and D_{GS} (see Appendix C)

$$Q_{STA7} = 46.70D_{GS} - 27.67 \qquad (r^2 = 0.86)$$

$$Q_{STA8} = 57.40D_{GS} - 161.34 \qquad (r^2 = 0.99)$$

Power, log, or exponential best-fit equations did not improve these correlation coefficients. Figure 10 presents the stage-rating curves for five different stations. These allow discharge to be quickly and easily estimated by graphical means from a single depth measurement at a station's gauging point.

2. It may be possible to estimate the instantaneous discharge of most stations from measurement at only two stations (7 and 8) and the following formulae:

$Q_{STA2} = 0.19Q_{STA8}^{0.95}$ ($r^2 = 0.88$)

$Q_{STA3} = 0.11Q_{STA8}^{1.20}$ ($r^2 = 0.85$)

$Q_{STA4} = 0.0034Q_{STA7}^{1.96}$ ($r^2 = 0.89$) restrictions apply see p. 36

$Q_{STA5} = 0.13Q_{STA7}^{1.39}$ ($r^2 = 0.86$) restrictions apply see p. 36

$Q_{STA6} = 0.54Q_{STA7}^{1.08}$ ($r^2 = 0.97$)

$Q_{STA10} = 1.45Q_{STA8}^{0.97}$ ($r^2 = 0.91$) restrictions apply see p. 46

3. The magnitude and variability of stream discharge during a particular storm was primarily a function of geomorphic province, drainage area, estuary level, and human impact.

The Berea Escarpment had the greatest effect on stream flow of the three geomorphic provinces. Its structure and lithology contributed significant base flow to the creek and its stations, therefore, always had measurable discharge. This was true even when stations upstream or downstream of the Escarpment were without flow.

Drainage area and discharge were directly related in most cases. In a relative sense, both mean and maximum discharge tended to increase with increasing drainage area (Table 1); only stations 5 and 3 were out of expected order. No consistent absolute relationship between discharge and drainage area could be determined for any day or station.

Estuary level was determined by the estuary's mouth bar and the level of Lake Erie primarily. When the estuary level was higher than the water surface elevation at station 10, no flow was measured at the station. At these times, station 10 became, functionally, a part of the estuary. Discharge at no other station was affected in this manner.

The local effect of urbanization, suburbanization, and roads on discharge is already high. Between stations 6 and 7, 28% of the land was urbanized, suburbanized, or had roads on it and a storm sewer brings the resultantly large amounts of runoff quickly to the creek (Fig. 4). As a result, measured discharge at station 7 was as much as 100% larger than that at station 6 even though station 7's drainage area was just 8% larger (Tables 1, 4). Conversely, during periods of low water, Berlin Heights water plant lowered creek levels further by removing water for basin storage. As urbanization and suburbanization proceed through time, the average annual flood size will be increased by reducing the lag time between rainfall and runoff.

4. The maximum recorded discharge at each station generally reflected the station's relative drainage area. The maximum recorded discharges for all stations occurred on 2/25/85 and were:

$Q_{MAXSTA2}$ = 22.0 cubic feet/second

$Q_{MAXSTA3}$ = 46.0 " "

$Q_{MAXSTA4}$ = 16.8 " "

$Q_{MAXSTA5}$ = 60.2 " "

$Q_{MAXSTA6}$ = 65 " "

$Q_{MAXSTA7}$ = 96.3 " "

$Q_{MAXSTA8}$ =105.2 " "

$Q_{MAXSTA9}$ = 8.1 " "

$Q_{MAXSTA10}$=153.1 " "

Flooding on 2/25/85 occurred between stations 5 and 6, and 7 and 8 as well as at the junction between the middle and west branches of Old Woman Creek. This flooding no doubt reduced recorded discharge readings downstream of station 5 but, in any case, the estuary was receiving 153.1 cubic feet/second of disharge on 2/25/85.

5. Incidences of no discharge were highest at station 10 (influenced by the estuary's backwater effect) and on the Till Plain.

Sediment Load

Several conclusions about the sediment load of Old Woman Creek can be made:

1. Buchanan (1982, p. 57) stated that "the highest erosion rates in the basin are likely to occur in the upper Till Plain of the basin where soil texture, higher slopes, and agricultural activity have served to maximize all the erosional factors involved. The wooded midsection of the basin probably contributes less eroded material because of land cover, even though the slopes here are the steepest in the basin. The lower lake plain soils probably contribute slightly less eroded material per acre than the Till Plain soils, in part as a result of soil texture but also because of lower slopes." This present study generally concurs with the above statement from Buchanan (1982) and found that the highest mean sediment concentration (0.054 oz./ft.^{3}) did, indeed, occur on the Till Plain at station 4. Slightly lower mean concentrations occurred at stations on the Lake Plain whereas much lower ones were recorded at the Escarpment stations (Table 1). However, it is also true that many stations could sporadically record high sediment concentrations. Stations 3, 8, 9, and 10 on the Lake Plain all recorded the highest sediment concentration for a particular day (ranging up to 0.212 oz./ft.^{3}) (Fig. 8a; Table 1). The sub-basins of stations 3, 4, 7, 8, and 9 also recorded net erosion events (Table 3).

2. There were no clear, consistent relationships between the daily sediment concentrations of any two stations and it was obvious that sampling technique, land use, sediment

availability, local rainfall, local soil types, local relief and slope, and time lag between rainfall and runoff were some of the many variables that complicated the picture.

3. The biggest sediment yield for all stations occurred on 2/25/85 when channels were scoured by a big discharge; 14.45 oz./sec. moved past station 10 towards the estuary on that day. Following the big discharge, there was a tendency for sediment supply to become limited along most reaches and for recorded sediment yield and concentration to drop-off rapidly.

4. The power relationship $G = pQ^j$ (where G is sediment yield in oz./sec. and Q is stream discharge) well represented the association between sediment yield and discharge at most stations. They follow:

$$G_{STA2} = 0.0045Q^{1.53} \qquad G_{STA5} = 0.0092Q^{1.316}$$

$$G_{STA3} = 0.0108Q^{1.44} \qquad G_{STA6} = 0.0049Q^{1.467}$$

$$G_{STA4} = 0.0282Q^{1.245} \qquad G_{STA7} = 0.0044Q^{1.42}$$

$$G_{STA8} = 0.0062Q^{1.462}$$

The two lowest exponents come from the Till Plain reiterating the fact that high sediment yields per unit discharge occurred there. Other research has found similar values for the exponent including Walling (1971) whose values were generally between one and two.

5. The magnitude and variability of sediment load during a particular storm event was primarily a function of soil type, channel composition, discharge, and land use.

A soil type's K-factor relatively expresses its potential erodability. In Ohio, K-factors range from 0.17 for sandy soils to 0.49 for highly erodable material. Within the Old Woman Creek basin, Mahoning, Allis, and Del Ray soils have K-factors which exceed 0.40. However, only the Mahoning soil covers a significant area within the basin. It has been intensively used by agriculture and is a major source of sediment currently being deposited in the estuary (Buchanan, 1982, p. 55). Sediment yield from the Mahoning-Bogart-Haskins-Jimtown soils of the Till Plain might exceed 15,000 tons/year; of that, approximately 5,000 tons/year is composed of silts and clays (Buchanan, 1982, p. 58). Most fines are eventually flushed into the estuary or lake by sporadic large flow events but, in between, they commonly settle on the channel bottoms. Station 4 on the Till Plain had the largest number of daily first place rankings in sediment concentration (Fig. 8a).

The channel is composed of fine sediments at stations 3, 4, 5, 8, 9, and 10. Mean sediment concentration at each of these stations was higher than the other 3 stations even though the mean velocities of the 6 stations were, usually, smaller. This suggests that local channel composition is related to sediment availability and, in turn, to suspended sediment concentration.

High discharges were not necessarily associated with high sediment concentrations. Rather, cropping, raindrop impact, and sediment availability were often more important determiners of sediment concentration. For example, on 2/25/85, all stations had their largest discharge and velocity but only three recorded their largest sediment concentration (Table 1).

Land use heavily affected the recorded sediment concentrations. Field preparation in the spring and cropping during the autumn affected the system significantly; measured sediment concentration on 4/7/85 at stations 4 and 5 during cropping were higher than that of other days having some flow. Feed lot activity above station 3 also contributed significant sediment to the Old Woman Creek system; station 3 recorded three firsts, one second, and two thirds in the daily sediment concentration rankings as a result (Fig. 8a). Urbanization, suburbanization, and roads cover about 8% of the Old Woman Creek basin. However, locally their concentration is higher and their impact greater. Between stations 6 and 7, 28% of the land is urbanized, suburbanized, or under roads and a storm sewer brings the resultantly large amounts of low-sediment runoff quickly to the creek. Wolman (1967) and Hammer (1972) have investigated areas where such increased, low-sediment runoff has caused downstream erosion and channel widening.

In summary, sediment concentration in the Old Woman Creek system is determined first by the level of human land disturbance and second by its soil erosion potential (the K-factor). Construction of all types including that of the proposed State Route 2 bridge tends to contribute large amounts of relatively coarse sediment to the stream.

6. Large amounts of sediment are transported during brief periods of intense precipitation (Buchanan, 1982, p. 183). Sediment deposited in the channels following the last big flow event are scoured by the next large flow. If this major discharge event persists, however, sediment concentration will drop-off as sediment availability in the channel diminishes.

7. Erosion assessment sites were monumented and surveyed as a part of this study (Appendix B) so that future erosion can be monitored.

Recommendations

1. Make hourly velocity and depth measurements at station 8 during pre-storm, storm, and post-storm periods to establish representative hydrographs for this important stations.

2. Establish several permanent recording rain guages at well distributed sites within the Old Woman Creek basin. Data from them could be used in a variety of ways including calculating the lag time between rainfall and runoff at

station 8.

3. Establish a permanent stage recorder at station 8 after the stage-discharge relationship presented here is verified by more measurements (see 1 above). This stage recorder will measure the amount of water entering the estuary from the creek system and be a useful companion to the water level recorders in the estuary and near the estuary mouth in Lake Erie which are already in operation. Finally, the data collected by the stage recorder will be useful historically in recording the changes that increasing urbanization, suburbanization, and road building cause.

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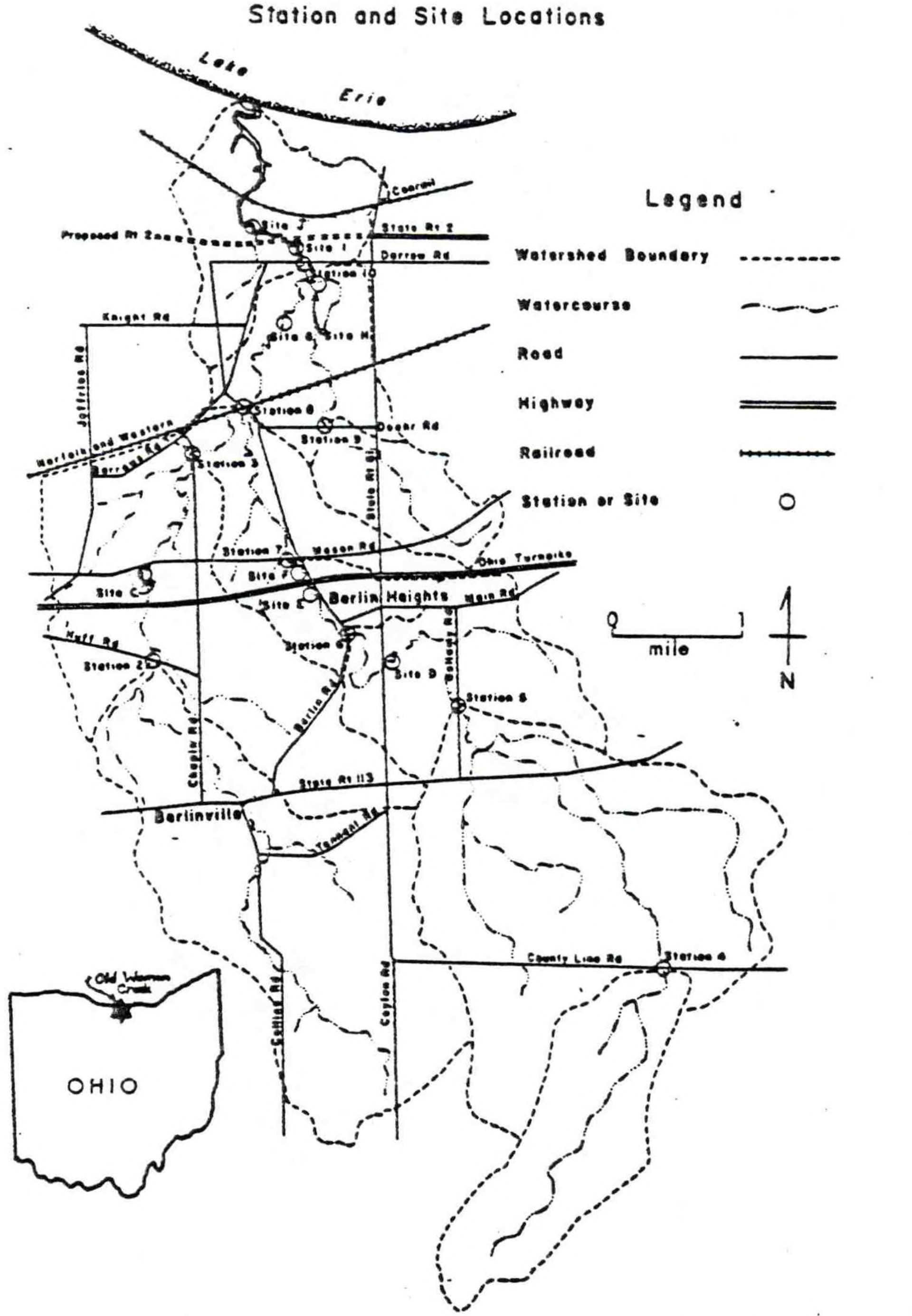
FIGURES

FIGURE 1

Watershed of Old Woman Creek
Station and Site Locations



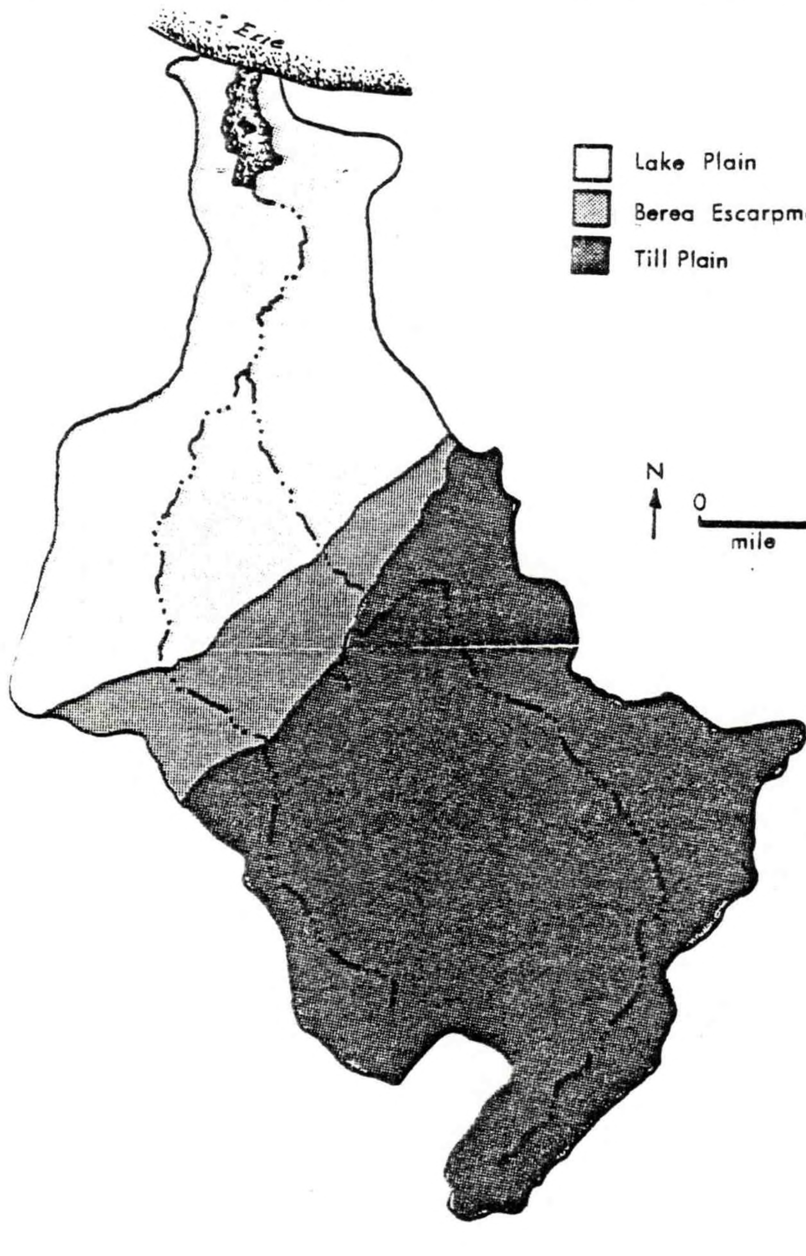


Figure 2. Location of the Three Geomorphic Provinces Within the Old Woman Creek Drainage Basin. Sources: Herendorf, 1966; Carney, 1911; Buchanan, 1982, p. 35.

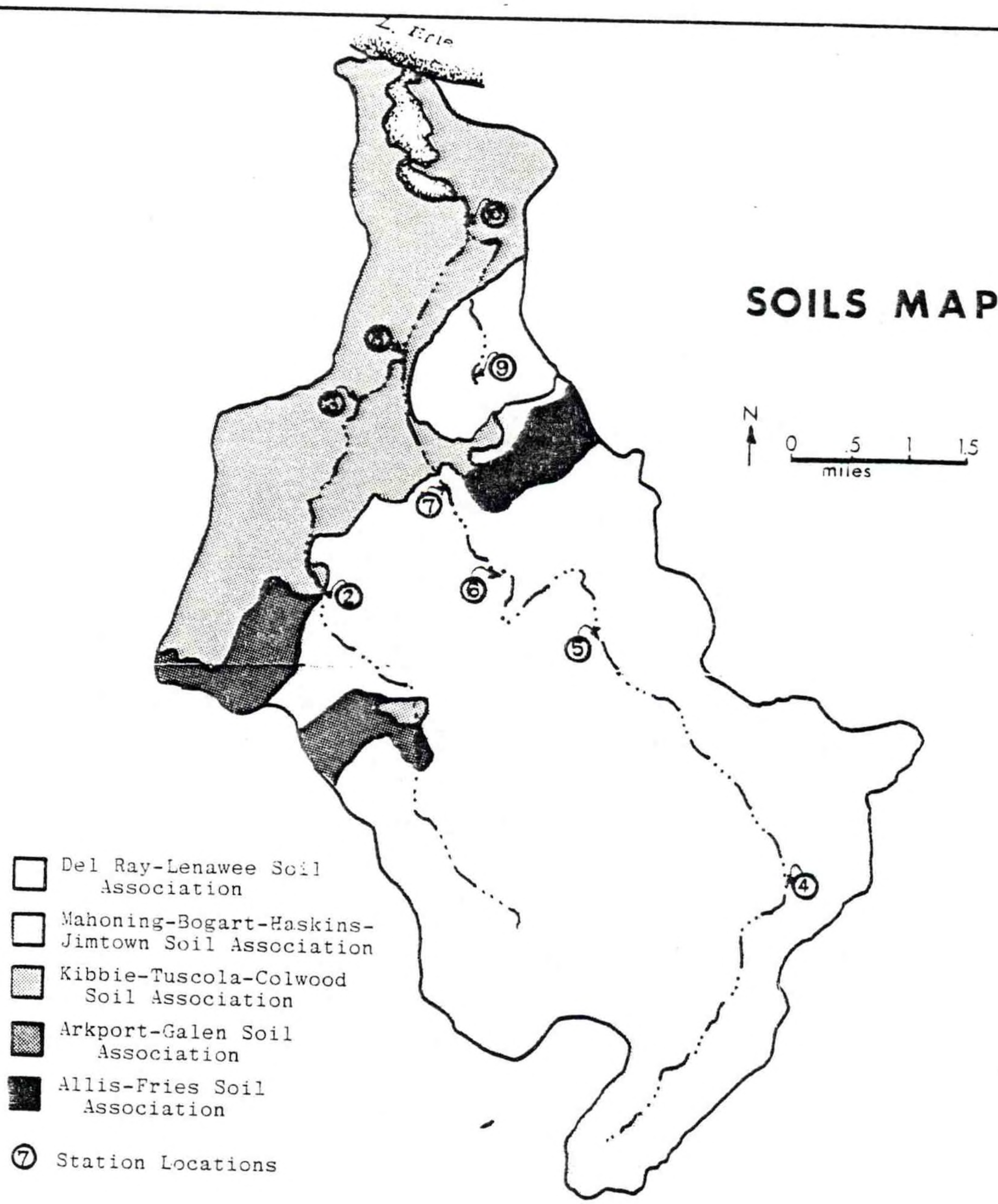


Figure 3. Soil Associations Within the Old Woman Creek Basin.
Sources: Redmond et al, 1971; CES/OSU, 1975; Buchanan, 1982, p. 50

FIGURE 4

LAND USE

OLD WOMAN CREEK WATERSHED

AS OF OCTOBER, 1984

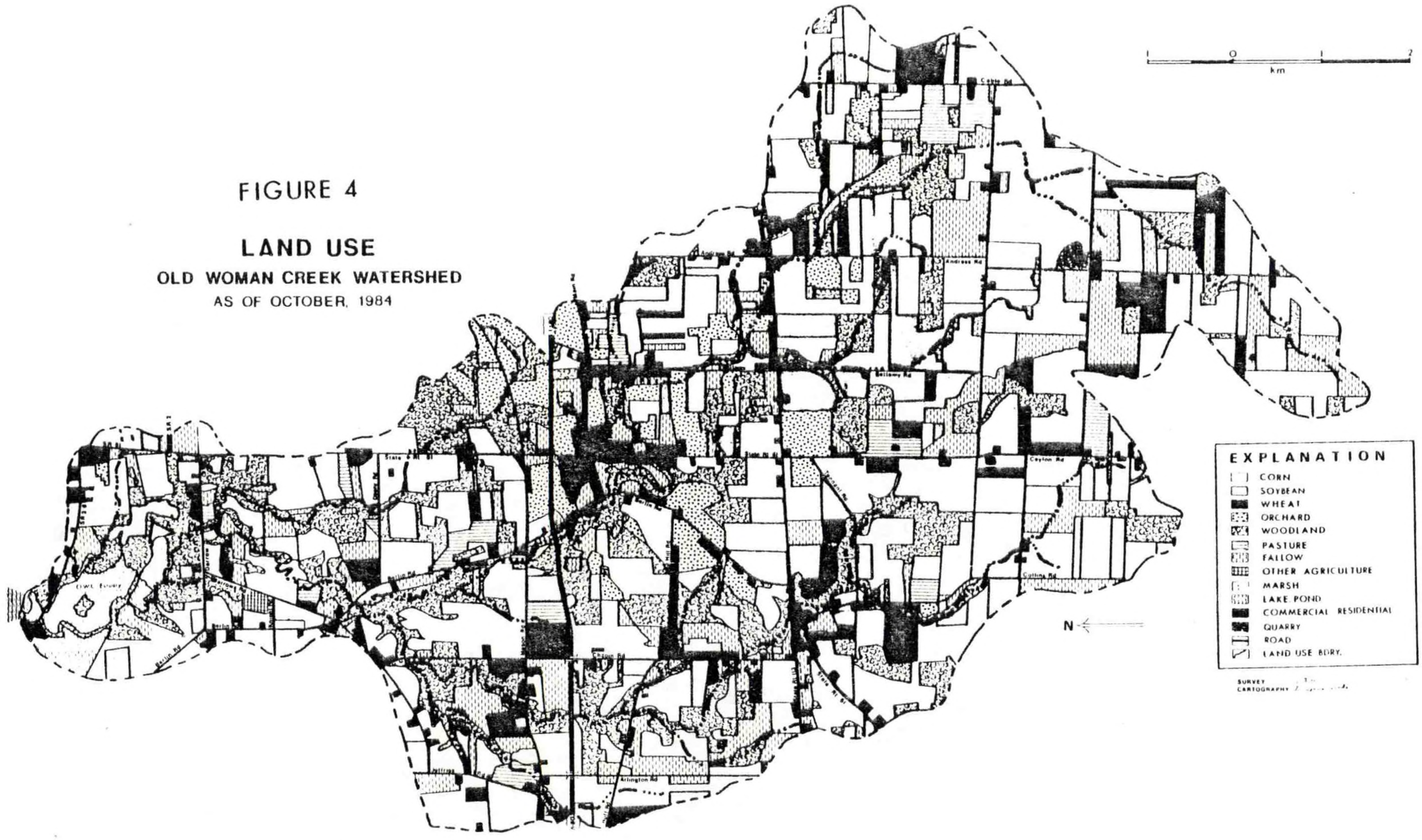
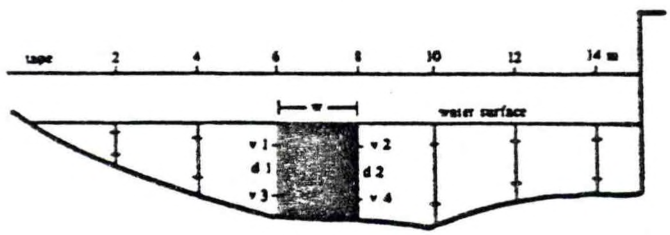


FIGURE 5

An Example of Velocity Area Stream Gauging By Mean Section Method (Goudie *et al.*, 1981)



Horizontal bars indicate current meter measuring depths of 0.2 and 0.8 depth

Explanation:

- d is water depth at a vertical (e.g. 6 or 8 m) where velocity will be measured
- v1 is velocity at 0.2 total depth (d) on a vertical (e.g. 6 or 8 m)
- v2 is velocity at 0.8 total depth (d) on a vertical
- w is the horizontal distance between successive verticals where velocity was measured

Each segment area (a_i) is:

$$a_i = w_i\left(\frac{d_{i1} + d_{i2}}{2}\right)$$

Each segment's discharge (q_i) is:

$$q_i = \left(\frac{\bar{v}_{i1} + \bar{v}_{i2}}{2}\right)a_i$$

where $\bar{v}$ is the mean of a vertical's velocities (e.g. v at 0.2 and 0.8d) or the velocity at 0.6d.

Total discharge (Q) is from:

$$Q = \sum_{i=1}^{n} q_i$$

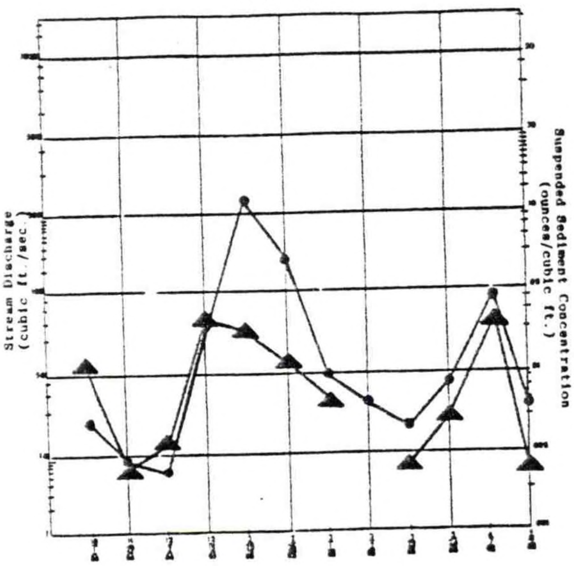
Total cross sectional area (A) is:

$$A = \sum_{i=1}^{n} a_i$$

FIGURE 6

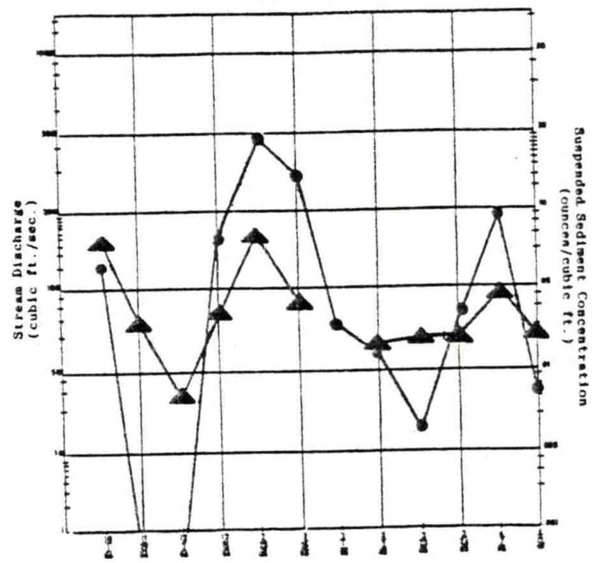
Daily Station Discharges - Suspended Sediment Concentrations

FIGURE 6A



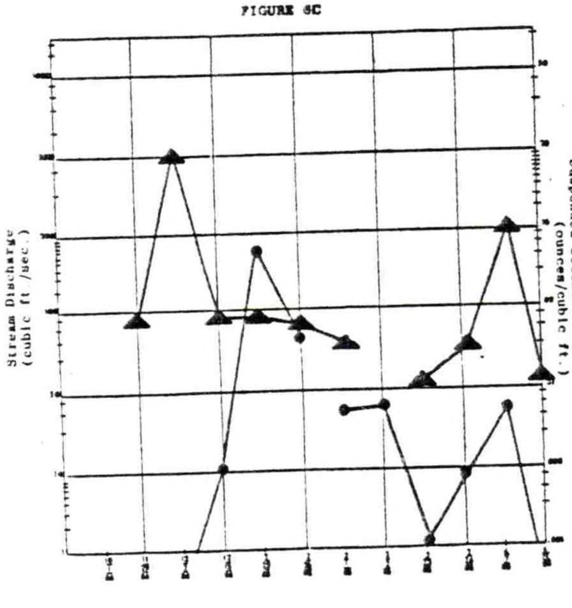
STATION 2 HUFF RD.

FIGURE 6B



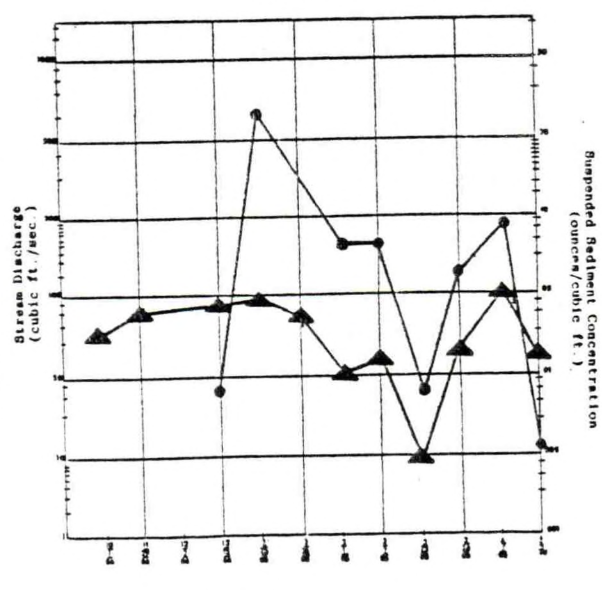
STATION 3 CHAPIN RD.

FIGURE 6C



STATION 4 COUNTY LINE RD.

FIGURE 6D



STATION 5 BELLAMY RD.

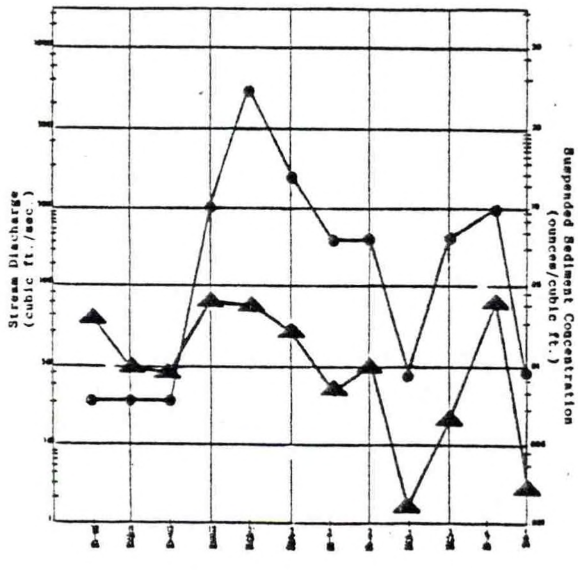
Explanation:

▲ Represents suspended sediment concentration. Refer to the right ordinate for the measured value for a given day. Raw data from Table 1.

● Represents stream discharge. Refer to the left ordinate for the measured discharge for a given day. Raw data from Table 1.

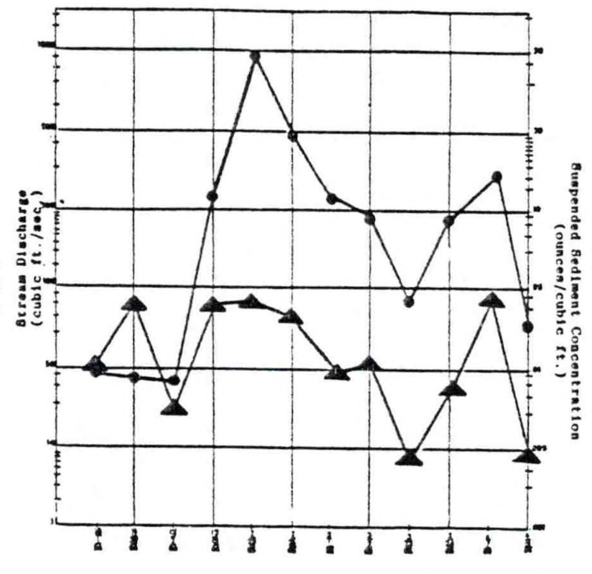
FIGURE 6
{continued}
Daily Station Discharges - Suspended Sediment Concentrations

FIGURE 6E



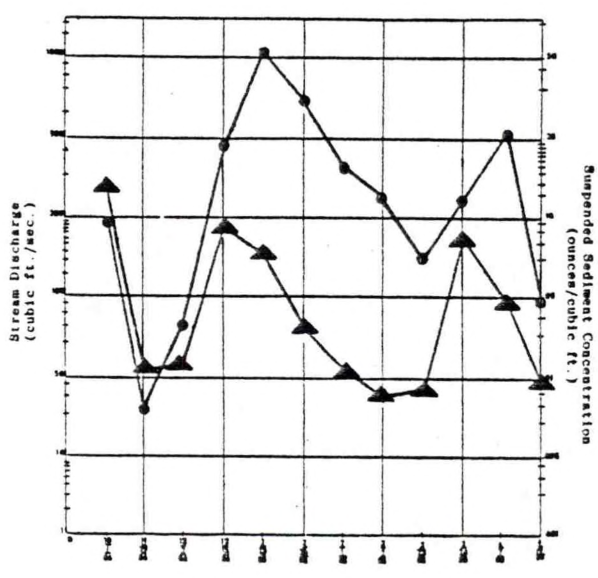
STATION 6 BERLIN RD.

FIGURE 6F



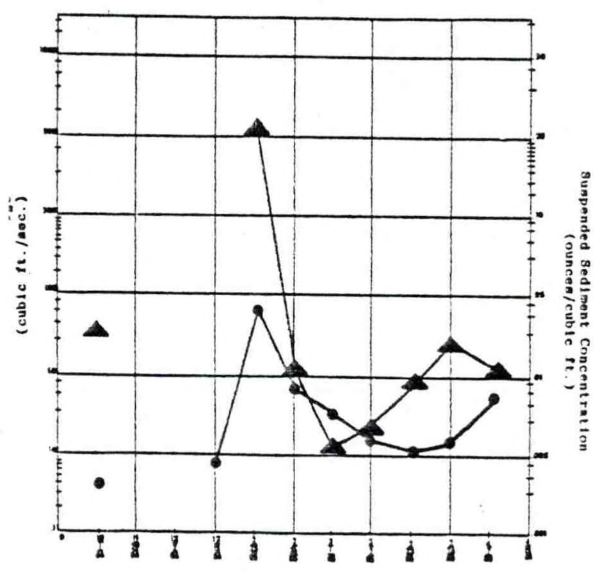
STATION 7 MASON RD.

FIGURE 6G



STATION 8 BERLIN RD.

FIGURE 6H



STATION 9 DEEHR RD.

Explanation:

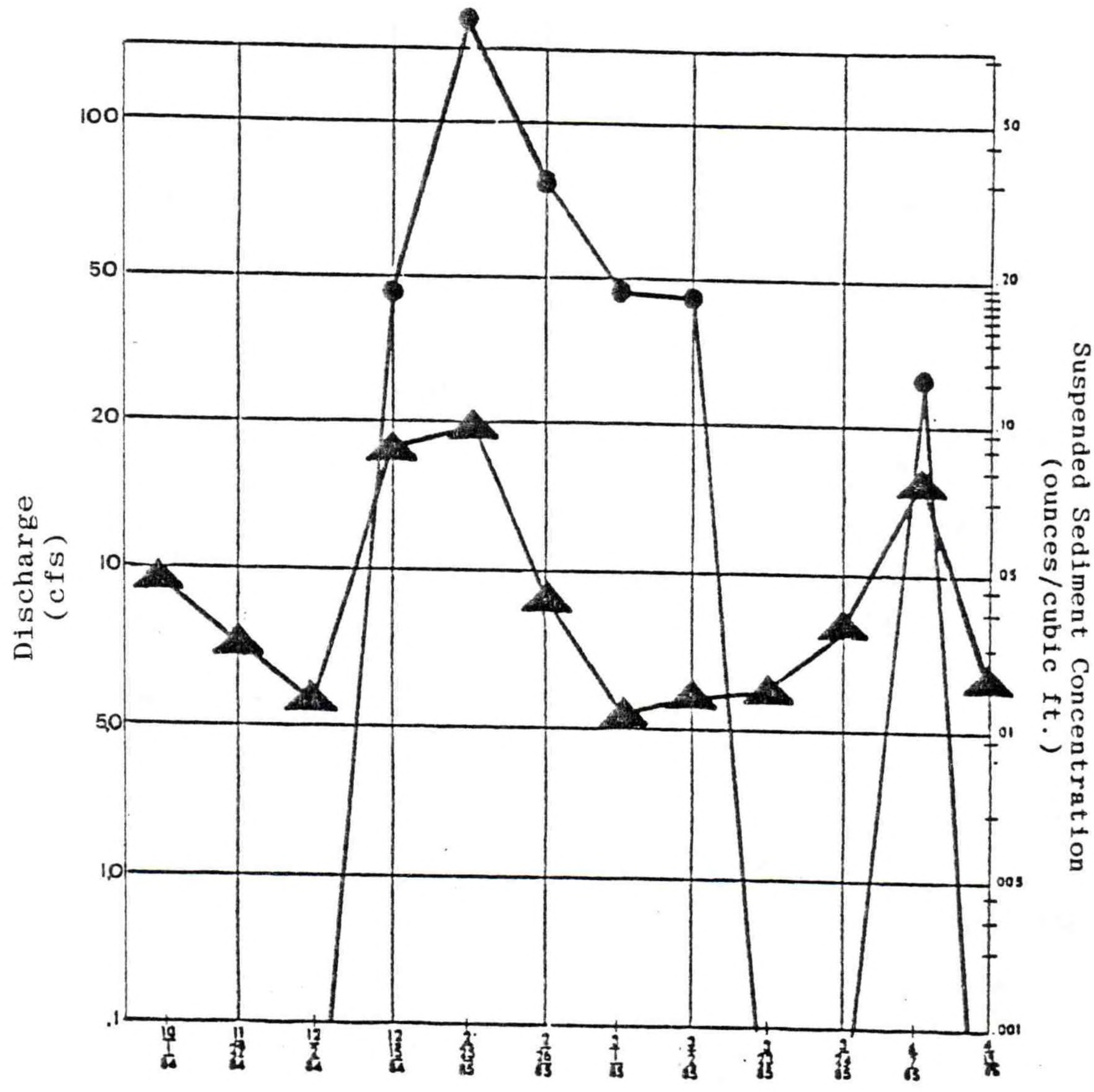
▲ Represents suspended sediment concentration. Refer to the right ordinate for the measured value for a given day. Raw data from Table 1.

● Represents stream discharge. Refer to the left ordinate for the measured discharge for a given day. Raw data from Table 1.

FIGURE 6
{continued}

Daily Station Discharges-Suspended Sediment Concentrations

FIGURE 6I



STATION 10 DARROW RD.

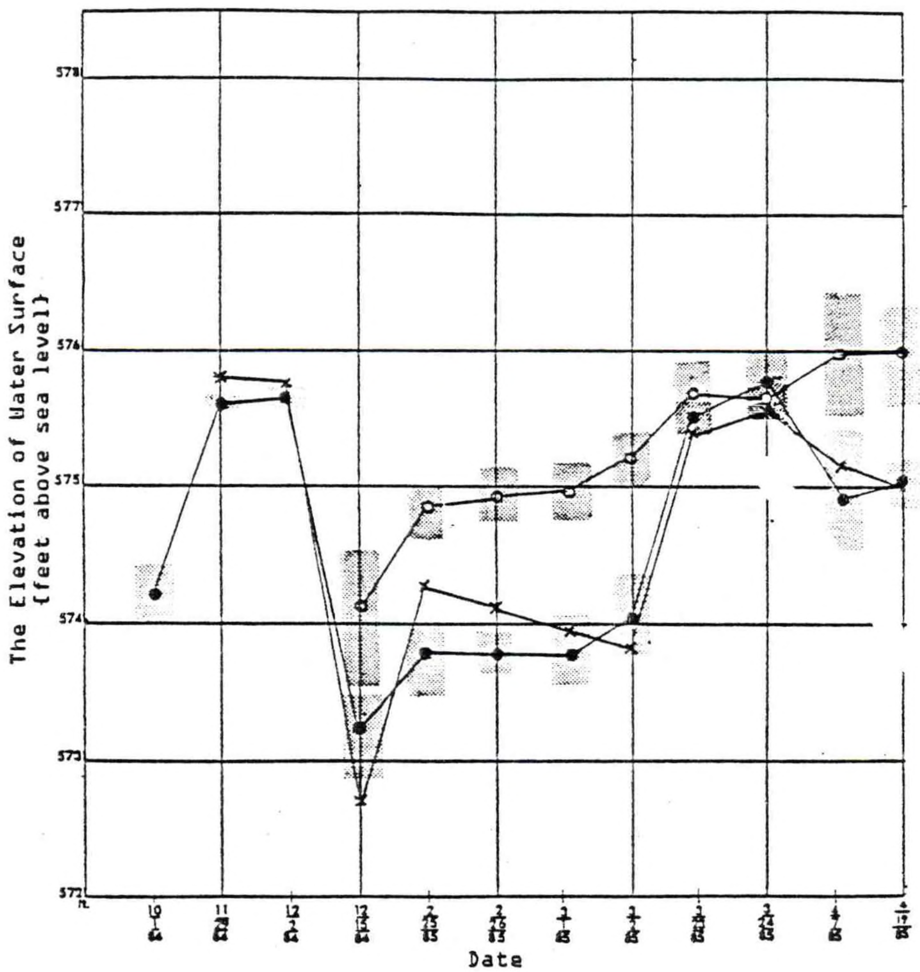
Explanation:

▲ Represents suspended sediment concentration. Refer to the right ordinate for the measured value for a given day. Raw data from Table 1.

● Represents stream discharge. Refer to the left ordinate for the measured discharge for a given day. Raw data from Table 1.

FIGURE 7

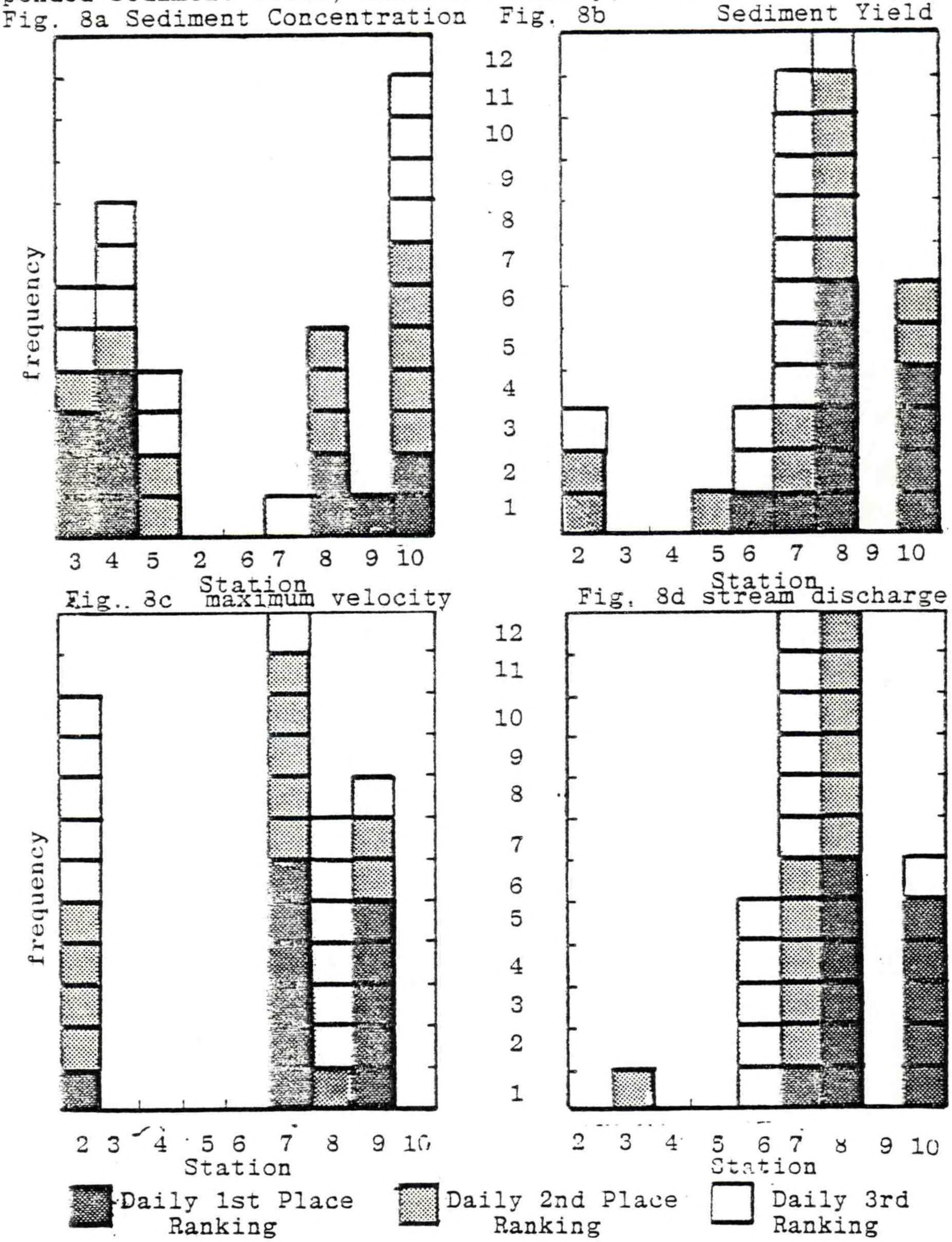
Water Surface Elevation of Lake Erie, the Old Woman Creek Estuary, and Old Woman Creek at Station 10



Explanation:
- O Lake Erie surface elevation, Old Woman Crk.
- ● Old Woman Creek's estuary surface altitude
- × Water surface altitude at Station 10
- ▒ Daily Range

FIGURE 8

Daily Station Rankings For Suspended Sediment Concentration, Suspended Sediment Yield, Maximum Velocity, & Stream Discharge

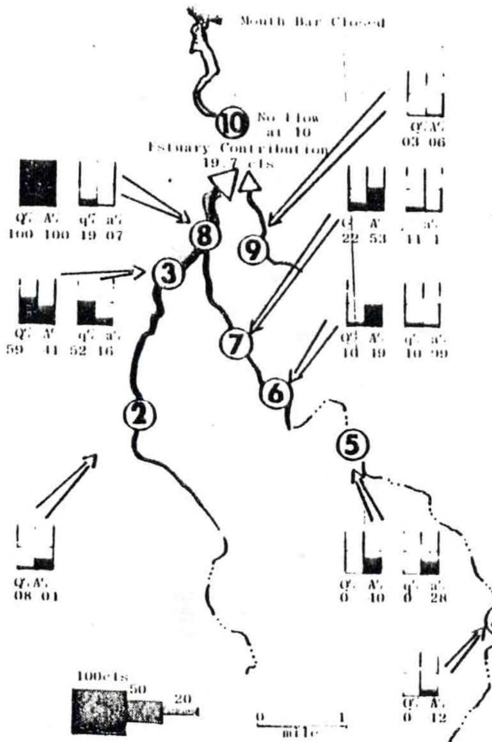


Note: Consult Table 1 for raw data

FIGURE 9

Discharge Variation For Representative Days

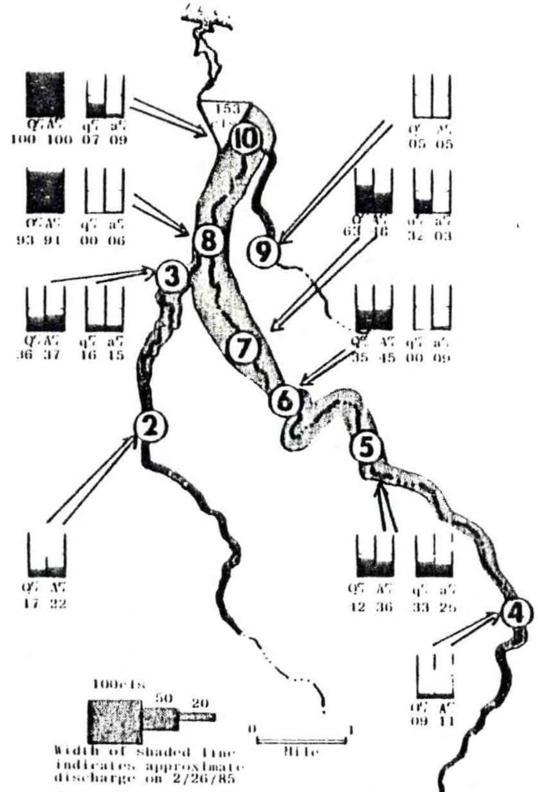
FIGURE 9A
Discharge Variation on 10/1/1986



Width of shaded line indicates approximate discharge on 10/1/84

Q% is the % of station 8's discharge measured at a station
A% is the % of 8's area at a particular station
q% is the % of 8's discharge added by a sub basin
a% is the % of 8's area added by a sub-basin

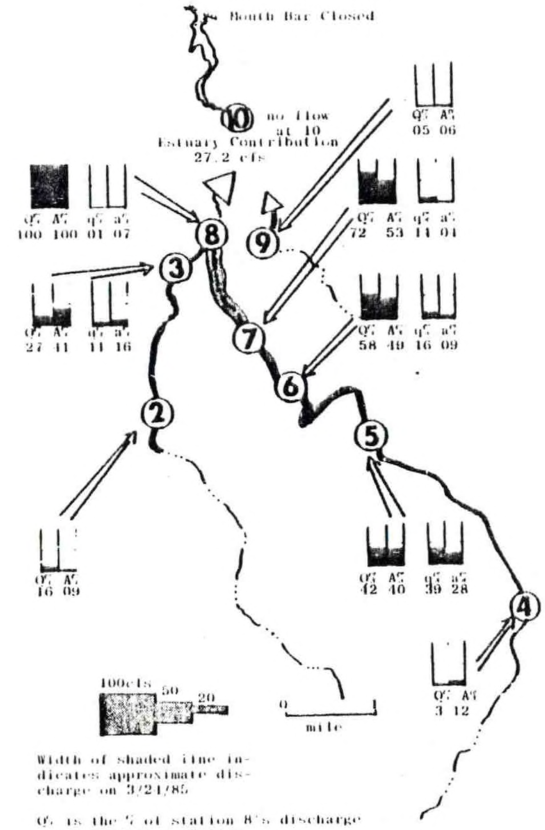
FIGURE 9B
Discharge Variation on 2/26/1985



Width of shaded line indicates approximate discharge on 2/26/85

Q% is the percent of station 10's discharge measured at a station
A% is the % of 10's area at a particular station
q% is the % of 10's discharge added by a sub-basin
a% is the % of 10's area added by a sub-basin

Figure 9C
Discharge Variation on 3/24/85

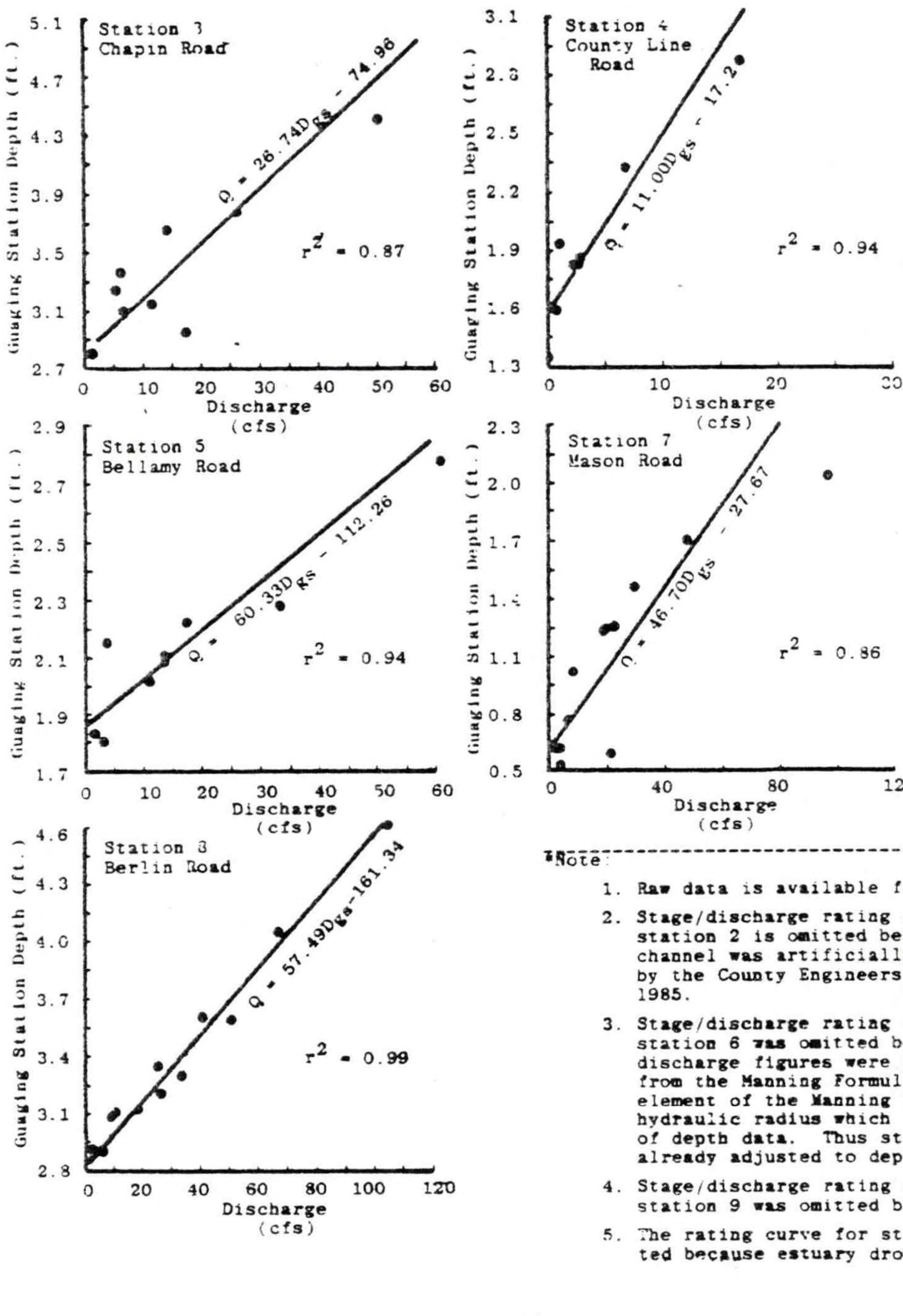


Width of shaded line indicates approximate discharge on 3/24/85

Q% is the % of station 8's discharge measured at a station
A% is the % of 8's area at a particular station
q% is the % of 8's discharge added by a sub-basin
a% is the % of 8's area added by a sub-basin

FIGURE 10

Stage/Discharge Rating Curves*



*Note:

1. Raw data is available from Table 1
2. Stage/discharge rating curve for station 2 is omitted because its channel was artificially modified by the County Engineers during 1984-1985.
3. Stage/discharge rating curve for station 6 was omitted because the discharge figures were produced from the Manning Formula. One element of the Manning Formula is hydraulic radius which involves use of depth data. Thus station 6's Q is already adjusted to depth.
4. Stage/discharge rating curve for station 9 was omitted because of low r^2.
5. The rating curve for station 10 was omitted because estuary drowning effected it.

FIGURE 11

Sediment Yield/Discharge Rating Curves

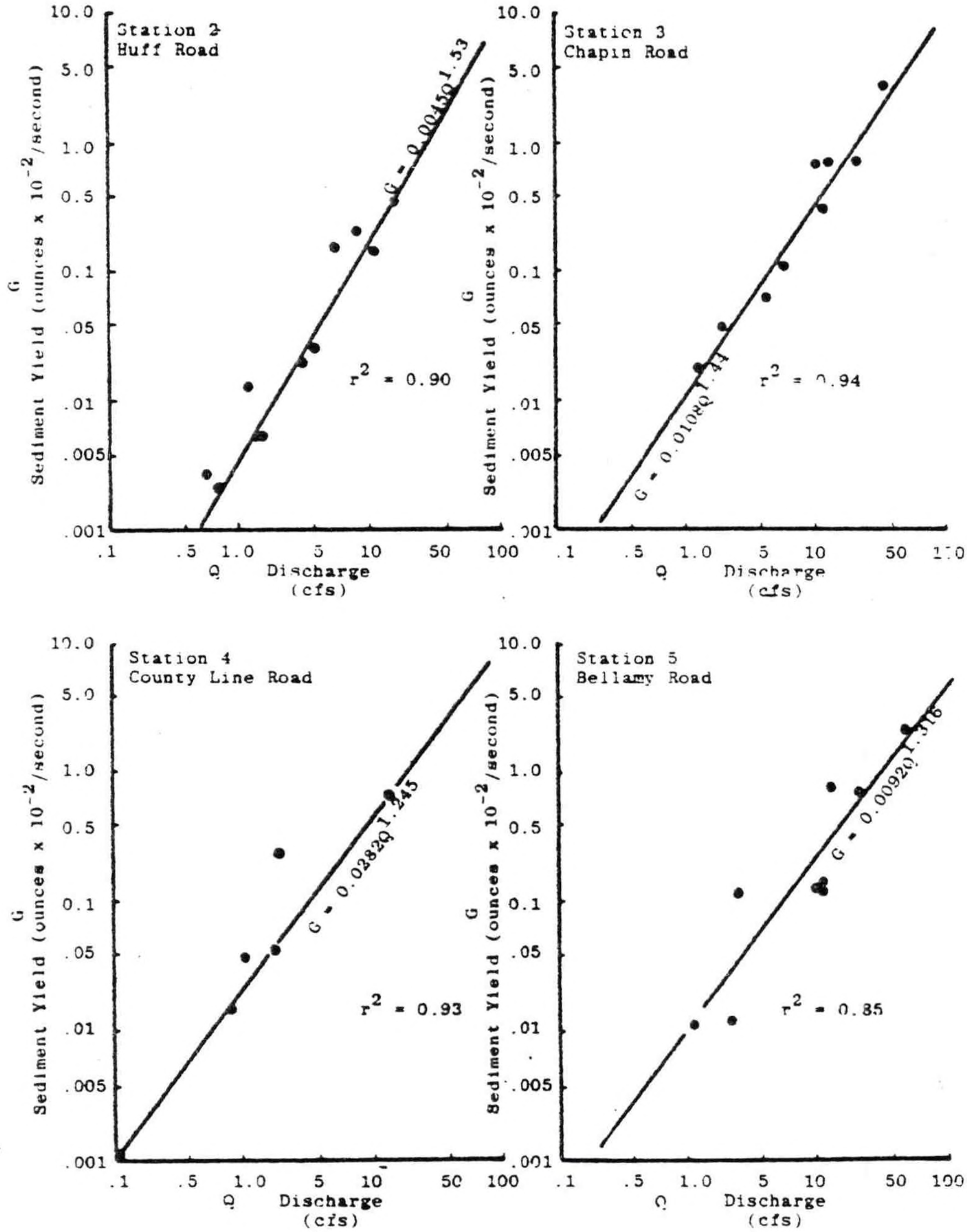
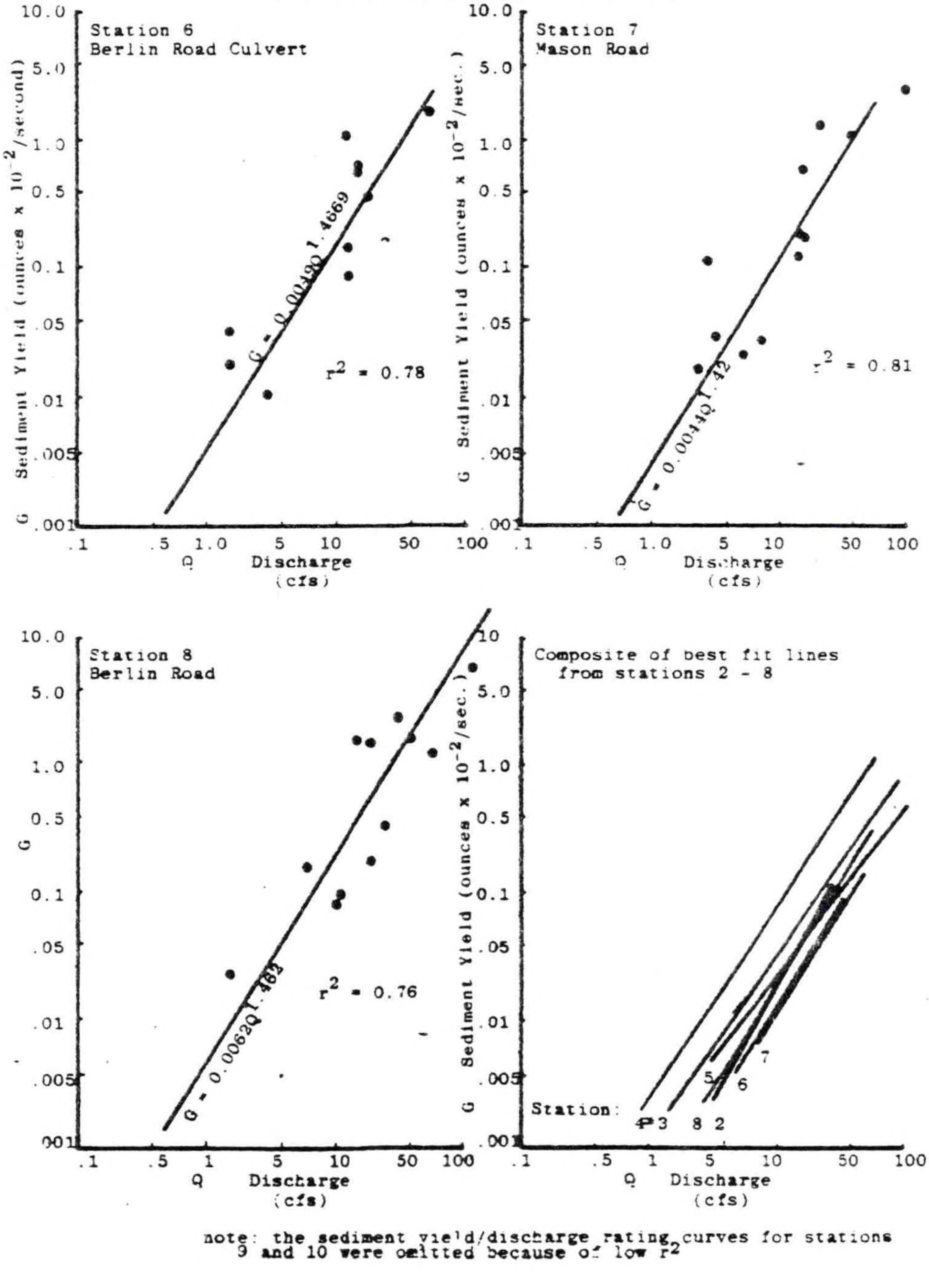


FIGURE 11
(continued)
Sediment Yield/Discharge Rating Curves



note: the sediment yield/discharge rating curves for stations 9 and 10 were omitted because of low r^2

TABLES

TABLE 1

Daily Measured Stream Discharge, Suspended Sediment Concentration, Suspended Sediment Yield, Maximum Water Depth, and Mean-Maximum Velocity for all Stations

	10/1/ 1984	11/29/ 1984	12/2/ 1984	12/15/ 1984	2/25/ 1985	2/26/ 1985	3/1/ 1985	3/2/ 1985	3/23/ 1985	3/24/ 1985	4/7/ 1985	4/19 1985	TOTAL MEAN	TOTAL MAX
STATION 2														
Q^a	01.5	00.8	00.7	006.8	0022.0	12.4	05.0	03.1	01.8	004.2	008.8	02.1	005.8	022.0
C^b	01.17	00.39	00.53	002.75	0002.15	01.33	00.71	—	00.36	000.65	002.70	00.31	001.19	002.75
G^c	01.75	00.31	00.37	018.68	0047.25	16.47	03.55	—	00.65	002.71	023.73	00.65	010.56	047.25
V^d max.	00.52	00.64	00.66	001.96	0002.91	02.47	01.47	01.05	01.05	001.17	002.00	01.09	001.41	002.91
V^e mean	00.27	00.25	00.19	001.05	0001.32	01.44	00.83	00.59	00.40	000.81	001.45	00.62	000.77	001.32
D^f max.	00.8	00.8	00.7	001.0	0000.9	00.7	00.5	00.5	00.5	000.5	000.6	00.3	000.65	001.00
STATION 3														
Q^a	11.4	00.0	00.0	014.2	0046.0	26.2	06.4	05.4	01.5	007.0	017.5	02.7	011.5	046.0
C^b	06.74	02.42	00.73	002.98	0007.18	03.09	—	01.35	01.67	001.68	004.48	01.77	003.68	007.18
G^c	76.75	00.00	00.00	042.27	0330.26	80.87	—	07.28	02.50	011.75	078.40	04.77	070.54	330.28
V^d max.	00.27	00.00	00.00	000.27	0000.73	00.44	00.15	00.12	00.07	000.15	000.37	00.15	000.23	000.73
V^e mean	00.20	00.00	00.00	000.22	0000.57	00.33	00.09	00.08	00.02	000.11	000.27	00.07	000.16	000.57
D^f max.	03.1	02.9	02.9	003.7	0004.6	03.9	03.5	03.4	03.0	003.3	003.3	02.[illegible]	003.31	004.6
STATION 4														
Q^a	00.0	00.0	00.0	001.1	0016.8	06.8	02.5	02.8	00.1	000.9	002.6	00.0	002.8	016.8
C^b	—	04.3	20.31	004.53	0004.53	03.28	02.24	—	01.28	002.14	010.21	01.11	005.39	020.31
G^c	00.00	00.00	00.00	004.98	0076.02	22.28	05.60	—	00.13	001.92	028.56	00.00	019.93	076.02
V^d max.	00.00	00.00	00.00	000.12	0000.73	00.34	00.19	00.21	00.04	000.10	000.19	00.00	000.16	000.73
V^e mean	00.00	00.00	00.00	000.03	0000.43	00.22	00.10	00.11	00.01	000.04	000.11	00.00	000.09	000.43
D^f max.	01.0	01.2	01.1	002.2	0002.9	02.3	01.9	01.9	01.4	001.7	001.9	01.4	001.67	002.9
STATION 5														
Q^a	00.0	00.0	00.0	003.6	0060.2	30.4	13.4	13.4	03.0	010.9	017.3	01.1	012.78	060.2
C^b	02.0	02.97	—	004.19	0004.5	02.71	01.05	01.34	00.47	001.37	05.05	01.30	002.54	005.05
G^c	00.00	00.00	00.00	015.07	0270.58	87.29	14.05	17.94	01.41	014.92	087.26	01.43	067.77	270.58
V^d max.	00.00	00.00	00.00	000.14	0001.02	00.81	00.40	00.42	00.14	000.33	000.47	00.35	000.34	001.02
V^e mean	00.00	00.00	00.00	000.05	0000.66	00.37	00.18	00.19	00.05	000.16	000.25	00.03	000.16	000.66
D^f max.	—	01.9	—	002.8	0003.5	03.0	03.4	03.4	03.1	003.3	002.9	03.0	003.03	003.5
STATION 6														
Q^a	02	02	02	020	0065	25	15	15	04	015	020	04	016	065
C^b	02.21	01.02	00.90	003.66	0003.40	01.81	00.78	01.04	00.18	000.59	003.41	00.19	001.60	003.66
G^c	04	02	02	073	0221	45	12	16	1	009	068	01	038	221
V^d max.	—	—	—	—	—	—	—	—	—	—	—	—	—	—
V^e mean	02.3	02.3	02.3	004.4	0006.3	04.7	04.0	04.0	02.8	004.0	004.4	02.8	003.69	006.3
D^f max.	00.3	00.3	00.3	000.8	0001.4	00.9	00.7	00.7	00.4	000.7	000.8	00.4	000.68	001.4
STATION 7														
Q^a	04.2	03.8	03.3	021.3	0096.3	48.3	22.5	19.4	08.0	018.5	029.5	06.4	023.5	096.3
C^b	01.11	03.34	00.62	003.44	0003.52	02.61	00.95	01.14	00.40	000.75	003.99	00.41	001.86	003.99
G^c	04.66	12.68	02.04	073.18	0338.52	125.92	21.35	22.04	03.16	013.77	117.57	02.62	061.45	338.52
V^d max.	01.81	01.90	01.70	003.52	0003.83	02.89	01.60	01.71	01.06	001.41	002.23	00.80	002.04	003.83
V^e mean	00.46	00.48	00.45	002.45	0001.87	01.10	00.58	00.46	00.26	000.50	000.74	00.19	000.76	002.44
D^f max.	00.6	00.9	00.8	000.6	0002.7	02.3	02.0	01.9	01.8	002.0	002.1	01.7	001.62	002.7
STATION 8														
Q^a	19.2	02.4	07.0	041.6	0105.2	67.2	34.1	26.8	11.7	025.8	051.3	09.9	033.5	105.2
C^b	11.94	01.25	01.47	008.26	0006.63	02.13	01.29	00.85	00.89	007.79	004.79	00.92	004.02	008.26
G^c	228.98	03.00	10.28	343.43	0696.66	143.40	43.93	22.75	10.40	200.75	245.49	09.10	163.18	696.66
V^d max.	00.84	00.12	00.36	001.48	0002.79	02.30	01.64	01.02	00.47	000.95	001.54	00.37	001.16	002.79
V^e mean	00.37	00.05	00.15	000.62	0001.30	00.93	00.33	00.45	00.21	000.42	000.73	00.20	000.48	001.30
D^f max.	03.1	02.9	02.9	003.6	0004.6	03.7	03.5	03.4	03.1	003.6	003.8	03.7	003.49	004.6
STATION 9														
Q^a	00.5	—	—	000.9	0008.1	03.8	02.1	01.4	01.09	001.4	002.8	—	002.45	008.1
C^b	02.23	—	—	—	0021.12	01.26	00.53	00.60	00.99	001.51	001.14	—	003.67	021.12
G^c	01.11	—	—	—	0170.87	04.78	01.11	00.84	01.08	002.11	003.19	—	023.14	170.87
V^d max.	02.56	—	—	01.58	0003.29	02.30	02.72	01.89	02.00	002.19	002.11	—	002.29	003.29
V^e mean	01.32	—	—	00.41	0001.87	01.18	01.57	01.31	00.78	001.32	001.32	—	001.23	001.87
D^f max.	00.2	—	—	00.4	0000.6	00.6	00.4	00.4	00.3	000.3	000.4	00.2	000.37	000.6
STATION 10														
Q^a	00.0	00.0	00.0	045.4	0153.1	72.4	43.0	41.5	00.0	00.0	027.3	00.0	031.9	153.1
C^b	04.06	02.02	01.23	008.46	0009.45	03.31	01.17	01.27	01.36	02.49	006.54	01.50	003.58	009.45
G^c	00.00	00.00	00.00	383.64	1445.13	239.37	50.31	52.71	00.00	00.00	178.34	00.00	391.58	1445.13
V^d max.	00.00	00.00	00.00	000.51	0000.99	00.47	00.27	00.31	00.00	00.00	000.25	00.00	000.23	000.99
V^e mean	00.00	00.00	00.00	000.34	0000.76	00.38	00.21	00.23	00.00	00.00	000.12	00.00	000.17	000.76
D^f max.	—	05.85	05.7	002.8	0004.3	04.1	03.9	03.9	05.4	05.6	005.1	05.0	004.70	005.85

EXPLANATION

a Q is stream discharge in cubic feet per second
b C is suspended sediment concentration in ounces/cubic foot x 10^{-2} (i.e. 0.04oz/ft^3 would be recorded on this table as 04.00) (1 ounce/cubic foot is approximately equivalent to 1 gram/liter)
c G is suspended sediment yield in ounces/second x 10^{-2} and is the product of Q x C
d V max. is the maximum velocity in feet /second measured in any vertical (V1, V2, V3, V4, etc., Fig. 5)
e V mean is the mean velocity in feet/second of all vertical meaurements
f D max. is the maximum water depth in feet at a station

1 Represents the highest reading of a particular parameter on a particular day (only depths with flow are considered)

2 Represents the second highest reading of a particular parameter on a particular day (see depth restriction above)

3 Represents the third highest reading of a particular parameter on a particular day (see depth restriction above)

— Represents no data for that parameter for that particular day

TABLE 2

Daily Suspended Sediment Concentration Per
Square Mile of Watershed

Station	10/1 1984	11/29 1984	12/2 1984	12/15 1984	2/25 1985	2/26 1985	3/1 1985	3/2 1985	3/23 1985	3/24 1985	4/7 1985	4/19 1985	Total Mean	Total Max.
2	0.24	0.08	0.10	0.52	0.37	0.23	0.12	n/d	0.06	0.13	0.46	0.35	0.24[5]	00.52
3	0.83	*	*	0.37	0.88	0.38	n/d	0.17	0.21	0.21	0.55	0.22	0.42[3]	00.88
4	*	*	*	1.95	1.95	1.48	0.97	n/d	0.55	0.93	4.41	*	1.75[2]	04.41
5	*	*	*	0.53	0.57	0.34	0.13	0.17	0.06	0.17	0.64	0.16	0.31[4]	00.64
6	0.22	0.10	0.09	0.37	0.35	0.18	0.08	0.11	0.01	0.06	0.35	0.02	0.16[9]	00.37
7	0.11	0.32	0.06	0.33	0.33	0.25	0.09	0.11	0.04	0.07	0.38	0.04	0.18[8]	00.38
8	0.60	0.06	0.07	0.41	0.33	0.11	0.06	0.04	0.04	0.39	0.24	0.05	0.20[7]	00.60
9	2.01	n/d	n/d	n/d	19.06	1.14	0.48	0.54	0.89	1.36	1.03	n/d	3.31[1]	19.06
10	*	*	*	0.38	0.43	0.15	0.05	0.06	*	*	0.30	*	0.23[6]	00.43

Explanation:

x Represents the ranking of the mean suspended sediment concentration per square mile recorded for a particular station

* Represents a day with no stream discharge; no suspended sediment concentration per square mile were calculated on those days.

n/d Represents no data for a particular day

Note:

All recorded suspended sediment concentrations per $mile^2$ are in ounces per cubic foot x 10^{-2} per square mile

TABLE 3

Station-By-Station Increases In the Daily, Residual Suspended Sediment Concentrations/Square Mile

Station	Sub-basin Area (miles^2)	The Daily Suspended Sediment Concentration/Mile^2 (oz.x10^{-2}/ft.^{3}/mi^2)											
		10/1 1984	11/29 1984	12/2 1984	12/15 1984	2/25 1985	2/26 1985	3/1 1985	3/2 1985	3/23 1985	3/24 1985	4/7 1985	4/19 1985
2	4.85	+0.24	+0.08	+0.11	+0.57	+0.44	+0.27	+0.15	n/da	+0.07	+0.13	+0.56	+0.06
3	3.27	+1.70	no Q	no Q	+0.07	+1.58	+0.54	n/da	n/da	+0.40	+0.31	+0.54	+0.45
4	2.31	no Q	no Q	no Q	+1.96	+1.96	+1.42	+0.98	n/da	+0.55	+0.93	+4.41	no Q
5	5.63	no Q	no Q	no Q	0	0	0	0	0	0	0	0	0
6	1.88	+0.11	0	0	0	0	0	0	0	0	0	0	0
7	0.71	0	+3.27	0	0	+0.17	+1.13	+0.25	+0.14	+0.31	+0.23	+0.82	+0.31
8	1.32	+3.10	0	+0.09	+1.39	0	0	0	0	0	+4.06	0	0
9	1.11	+2.01	n/da	n/da	n/da	+19.03	+1.14	+0.48	+0.54	+0.89	+1.36	+1.03	n/da
10	0.92	no Q	no Q	no Q	0	0	0	0	0	no Q	no Q	+0.46	no Q

Note: "no Q" represents no stream discharge for a particular station and day
"n/da" represents the lack of sufficient data to calculate residual sediment concentration/mile^2

Explanation of Table 3: Residual suspended sediment concentration/square mile is a way of looking at the effect of a particular sub-basin on a stream's sediment load. It is calculated by the following formula:

$$\frac{(\text{C of a particular station i})-(\text{C of the station immediately upstream})}{a_i}$$

Where:
C is suspended sediment concentration in ounces x 10^{-2}/cubic foot (see Table 1)
a is sub-basin area in square miles (Table 3)

Stations recording net increases in residual suspended sediment concentration/mile^2 for a give day are allocated a plus (+) sign followed by the magnitude of that increase.

TABLE 4

Land-Use Within a Station's Watershed
and Within the Morphologic Provinces

Land-Use	Station (square miles in sub-basin above station/square miles in basin above station)*																		Geomorphological Province (stations within province) (watershed area)		
	2		3		4		5		6		7		8		9		10		Till Plain (4, 5) (11.58)	Escarpment (3, 6, 7) (3.84)	Lake Plain (3, 8, 9, 10) (7.33)
	4.85/4.85		3.27/8.12		2.31/2.31		5.63/7.95		1.88/9.82		0.71/10.52		1.32/10.98		1.11/1.11		0.92/22.82				
Field Crops																					
Soybeans	21%	21%	25%	17%	32%	32%	25%	27%	11%	24%	00%	23%	07%	19%	04%	04%	15%	18%	27%	7%	10%
Wheat	08%	06%	4%	05%	07%	07%	05%	06%	02%	05%	00%	05%	02%	05%	08%	.7%	03%	04%	06%	2%	03%
Corn	28%	23%	26%	27%	28%	28%	22%	24%	22%	23%	10%	22%	30%	25%	23%	23%	27%	25%	16%	23%	30%
Woodlands	20%	20%	24%	22%	09%	09%	15%	13%	17%	14%	21%	14%	26%	18%	39%	39%	28%	20%	14%	22%	27%
Orchards	01%	01%	07%	04%	00%	00%	05%	03%	19%	06%	25%	08%	05%	06%	17%	17%	00%	08%	03%	13%	07%
Pastures	03%	03%	01%	02%	00%	00%	03%	02%	02%	02%	00%	02%	11%	03%	00%	00%	05%	03%	03%	.8%	04%
Fallow	10%	10%	12%	11%	17%	17%	15%	15%	11%	15%	06%	14%	04%	12%	07%	07%	09%	11%	13%	12%	09%
Residential	04%	04%	04%	04%	02%	02%	02%	02%	11%	04%	20%	05%	04%	04%	03%	03%	03%	04%	02%	11%	04%
Roads	03%	03%	07%	05%	02%	02%	03%	03%	02%	03%	08%	03%	06%	04%	02%	02%	02%	04%	03%	03%	05%
Creek	03%	03%	03%	03%	01%	01%	04%	03%	03%	03%	04%	03%	05%	03%	04%	04%	05%	04%	03%	04%	04%
Lakes	.2%	.2%	.4%	.3%	.2%	.2%	.3%	.3%	.2%	.3%	03%	.5%	00%	.4%	00%	00%	02%	.4%	.2%	.9%	.2%
Other	.2%	.2%	00%	.1%	02%	02%	00%	.6%	00%	.4%	00%	.4%	00%	.3%	00%	00%	00%	.2%	.4%	.2%	00%

Explanation:

Particular land-uses are expressed as a percentage of the area at the top of the column

* Sub-basin area is that drainage area from the station upstream to the next station; basin area is the total drainage area above the station inclusive of that of the other upstream stations.

TABLE 5

Daily Precipitation and Snow on Ground
at Sandusky, OH.
(inches)

	Day																															
Precipitation	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Month
October		T					.12	.35	.05	T			T	T	.02	.09	T	T	T		.30	.01		.02	T				T			1.06
November		.34			.51	.07			.03	.21	.45	.09			.06													.41	04			2.21
December	.17		.17			.20	T			.08	.01	T	.16	.40					.07	.03	.37				.05		.22	.09		1.01		3.03
January	.58	.09					.01	T			.12				.02		.16	.06				.01	T	.01	.01	.02					T	1.09
February			.08		.04	.21					.38	T	.88									.18	.76	.04	05		.12					2.72
March		01		.48	.49			.10				.52	.01	T						.01			5						2.11	.24	.97	5.44
Snow on Ground																																
December						3	2	2	1																1	1						
January							T	T			3	3	2	2	4	4	7	8	8	8	7	9	8	11	8	11	10	8	7	6	6	
February	5	4	4	4	5	5	5	5	5	5	5	4	6	7	6	5	4	3	2	1												

Explanation:

Represents dates when stream discharge and suspended sediment data were collected

TABLE 6

Soil Types and Association Within the Old Woman Creek Basin

Soil Association Types	Percent of Watershed	Texture	Soil Erodability "K" Factor*
Mahoning-Bogart-Haskins-Jimtown	67%		
Mahoning	27%	Silt Loam	0.49
Bogart	10%	Loam	0.32
Haskins	7%	Loam	0.32
Jimtown	7%	Loam	0.28
Minor Soils	17%		
Kibbie-Tuscola-Colwood	21%		
Kibbie	7%	Fine Sandy Loam	0.37
Tuscola	7%	Fine Sandy Loam	0.37
Colwood	4%	Silt Loam	n/a
Arkport-Galen	4%		
Arkport	2%	Loamy Fine Sand	0.28
Galen	1%	Loamy Fine Sand	0.28
Minor Soils	1%		
Del Ray-Lenawee	4%		
Del Ray	3%	Silt Loam	0.43
Lenawee	1%	Silty Clay Loam	n/a
Minor Soils	<1%		
Allis-Fries	2%		
Allis	1%	Silty Clay Loam	0.43
Fries	<1%	Silty Clay Loam	n/a

---

*"K" factors express the relative erodability of the soil type as indicated by direct loss soil measurements in tons/acre/unit of rainfall. "K" factors in Ohio range from 0.17 for some sandy soils to 0.49 for highly erodable soils.

Source: Buchanan, 1982, p. 52.

TABLE 7

Relative Contribution of Bedload and Suspended Load to Total Sediment Load*

River	Proportion of total sediment load (%) Bedload	Suspened Load
Upper Niger, Baro[1]	6.5	93.5
Lower Niger, Shintaku[1]	5	95
Benue, Yola[1]	6	94
Alpine Mountain rivers[2]	70	30
Central Asian rivers[2]		
a. Mountainous	15-23	77-85
b. Hilly	5-15	85-90
c. Lowland	1-3	97-99
Volga, USSR[2]	0.3-2.0	98-99.7
Mississippi, USA[2]	0.3-10.0	90-99.7
Tyne, Bywell, UK[3]	13	87
East Deveon Catchments[4]		
Catchment 1	11	89
Catchment 2	1.3	98.7
Catchment 3	1.8	98.2
Catchment 4	2.8	97.2
Catchment 5	2.2	97.8

Sources:

*Table 7 has been taken from Gregory and Walling (1973, Table 4.4C)

[1]N.E.D.C.O. (1959) (values of suspended load include both wash load and suspended load totals)

[2]Jarocki (1957)

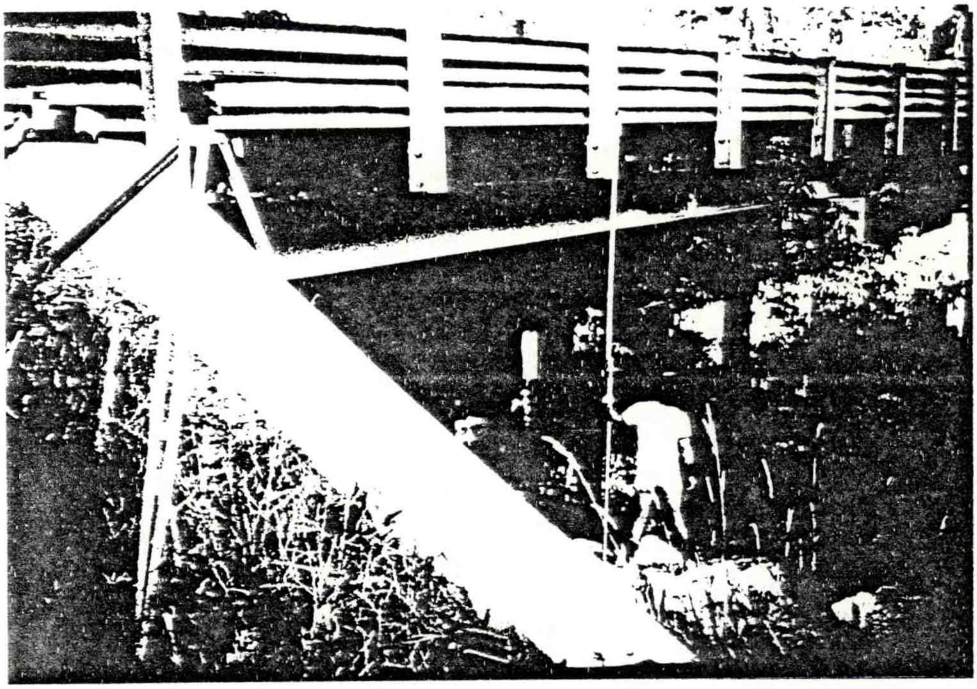
[3]Hall (1967)

[4]Walling (1971)

LIST OF PLATES

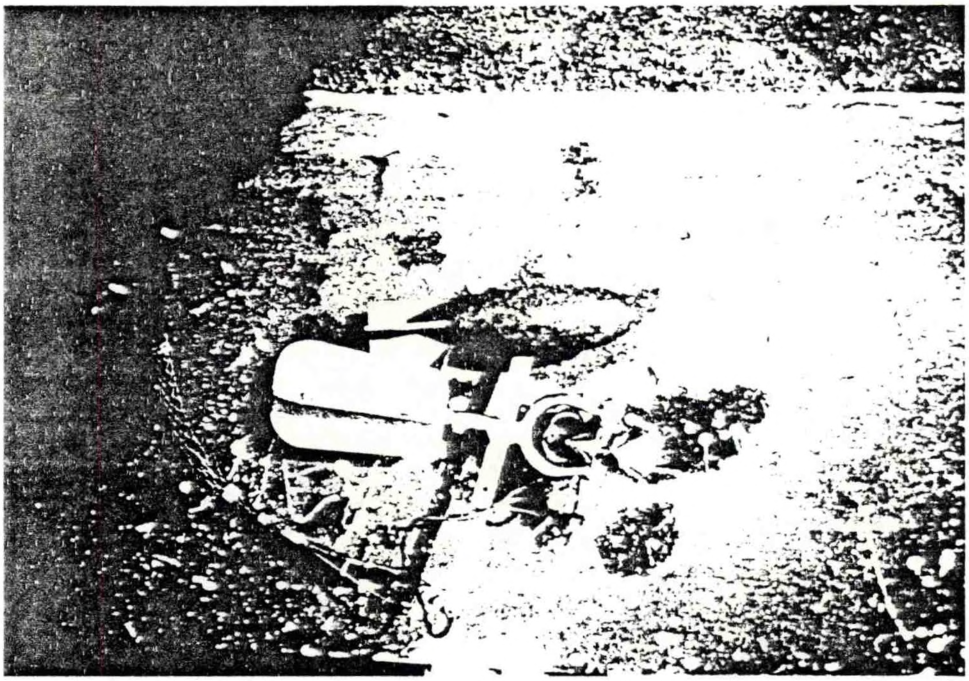
PLATES

PLATE 1



Surveying a Cross-sectional Profile With Level and Staff

PLATE 2



Gurley Current Meter for Measuring Stream Velocity

PLATE 3

Measuring Stream Velocity During Low Flow Using a Pygmy Meter

LIST OF APPENDICES

APPENDIX A.1

Discharge - Sediment Station	Location Description
2	1.3mi NW of Berlinville where Huff Rd. crosses the creek. It is at an elevation of about 630' and has approximately 4.8mi^2 of watershed contributing to it. It is downstream of the Berea escarpment and is not being used as a nutrient sampling site. It is located in the transitional area between the Mahoning-Bogart-Haskins-Jimtown and the Allis-Fries Soil Association.
3	2.8mi N of Berlinville where Chapin Rd. crosses the creek. It is at an elevation of approximately 588' and has approximately 8.1mi^2 of drainage area contributing to it. It is downstream of the Berea escarpment and is being used as a nutrient sampling site. Buchanan (1982) used this same site for grab sampling and called it station VIII. It is located in the Kibbie-Tuscole-Colwood Soils Association.
4	3½mi. SE of Berlin Heights where County Line Rd. crosses the creek. It is at an elevation of about 840.9' and has approximately 2.3 mi^2 of drainage area contributing to it. It is upstream of the Berea escarpment and is not being used as a nutrient sampling site. Buchanan (1982) used this same site for grab sampling and called it station II. It is located in the Mahoning-Bogart-Haskins-Jimtown Soils Association.
5	.9mi SE of Berlin Heights where Bellamy Rd. crosses the creek. It is at an elevation of approximately 773.2' and has approximately 8.0 mi^2 of watershed contributing to it. It is upstream of the Berea escarpment and is being used as a nutrient sampling site. Buchanan (1982) collected grab samples here and called it station III. It is located in the Mahoning-Bogart-Haskins-Jimtown Soils Association.
6	Station 6 is about 0.4mi W of Berlin Heights where Berlin Rd. crosses the well incised creek opposite a cemetary. It is at an elevation of approximately 680.2' and approximately 9.0 mi^2 of drainage area contributing to it. It is upstream of the Berea escarpment and is being used as a nutrient sampling site. It is located in the Mahoning-Bogart-Haskins-Jimtown Soils Association.

APPENDIX A

Station Location Descriptions, Station Photographs, and Station Cross-sectional Profiles

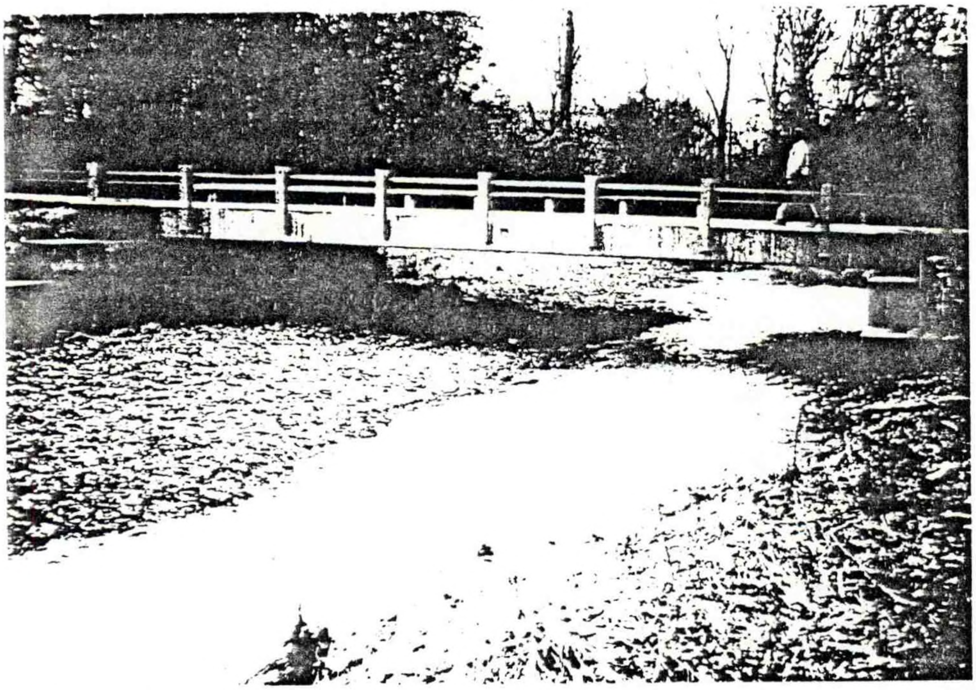
APPENDIX A.1

(Continued)

Discharge - Sediment Station	Location Description
7	.9mi NW of Berlin Heights where Mason Rd. crosses the creek. It is at an elevation of about 617' and has approximately 10.54mi^2 contributing to it. It is downstream of the Berea escarpment and is being used as a nutrient sampling site. Buchanan (1982) collected grab samples here and called it station IV. It is located at the Mahoning-Bogart-Haskins-Jimtown and Alice-Fries Soils Association transition.
8	2 mi NW of Berlin Heights where the Norfolk and Western Railroad crosses the creek and just downstream of of the junction between the western and middle branches of Old Woman Creek. It is at an elevation of about 586' and has about 20.0mi^2 of drainage area contributing to it. It is downsteam of the Berea escarpment, upstream of the proposed location of Route 2, and is being used as a nutrient sampling site. It is located in the transitional zone between the Kibbie-Tuscola-Colwood and Lenawee-Del Rey Soils Associations.
9	1.6mi NW of Berlin Heights where Deehr Rd. crosses the creek. It is at an elevation of about 597' and has about 1.1mi^2 of watershed contributing to it. It is downstream of the Berea escarpment and is being used as a nutrient sampling site. It is in the Lenawee-Del Rey Soils Association.
10	2.8mi NNW of Berlin Heights where Darrow Rd. crosses the creek and just downstream of the junction of the east branch with Old Woman Creek proper. It is at an elevation of approximately 570' and has about 22 mi^2 of watershed contributing to it. It is downstream of the Berea escarpment, 0.1mi upstream from the proposed location of Route 2, and is being used as a nutrient sampling site. Buchanan (1982) collected grab samples here and called it station V. It is in the Kibbie-Tuscola-Colwood Soils Association.

APPENDIX A.2

Station 2



View of station 2's cross section from north

View of station 2 and the channel to the north

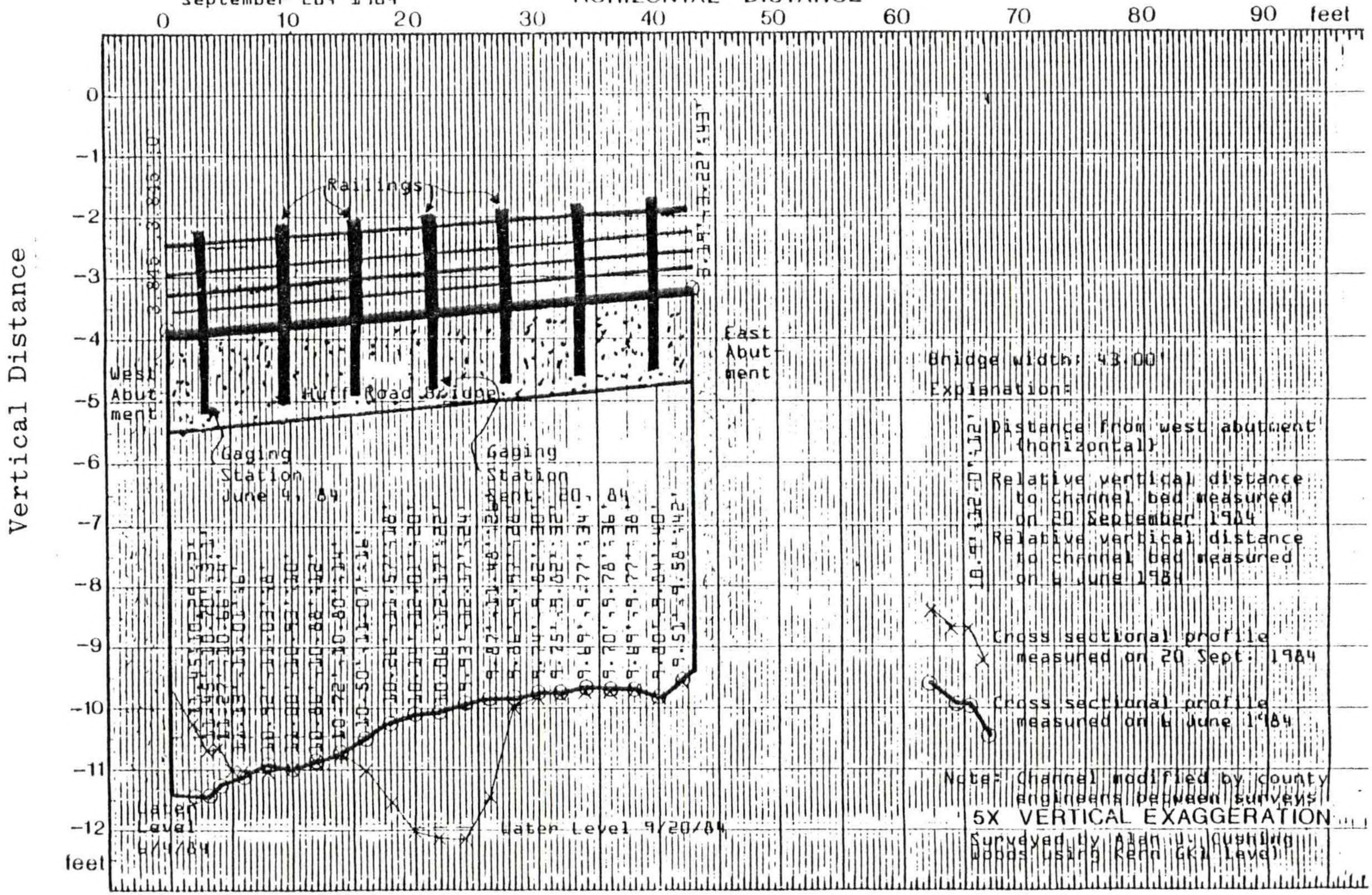
APPENDIX A.2
(continued)

CROSS SECTIONAL PROFILE

LOCATION: STATION 2
Huff Rd. Bridge

DATE: June 6, 1984 and September 20, 1984

DATUM: Relative



APPENDIX A.3

Station 3

View looking north from station 3

APPENDIX A.3

Station 3

CROSS SECTIONAL PROFILE

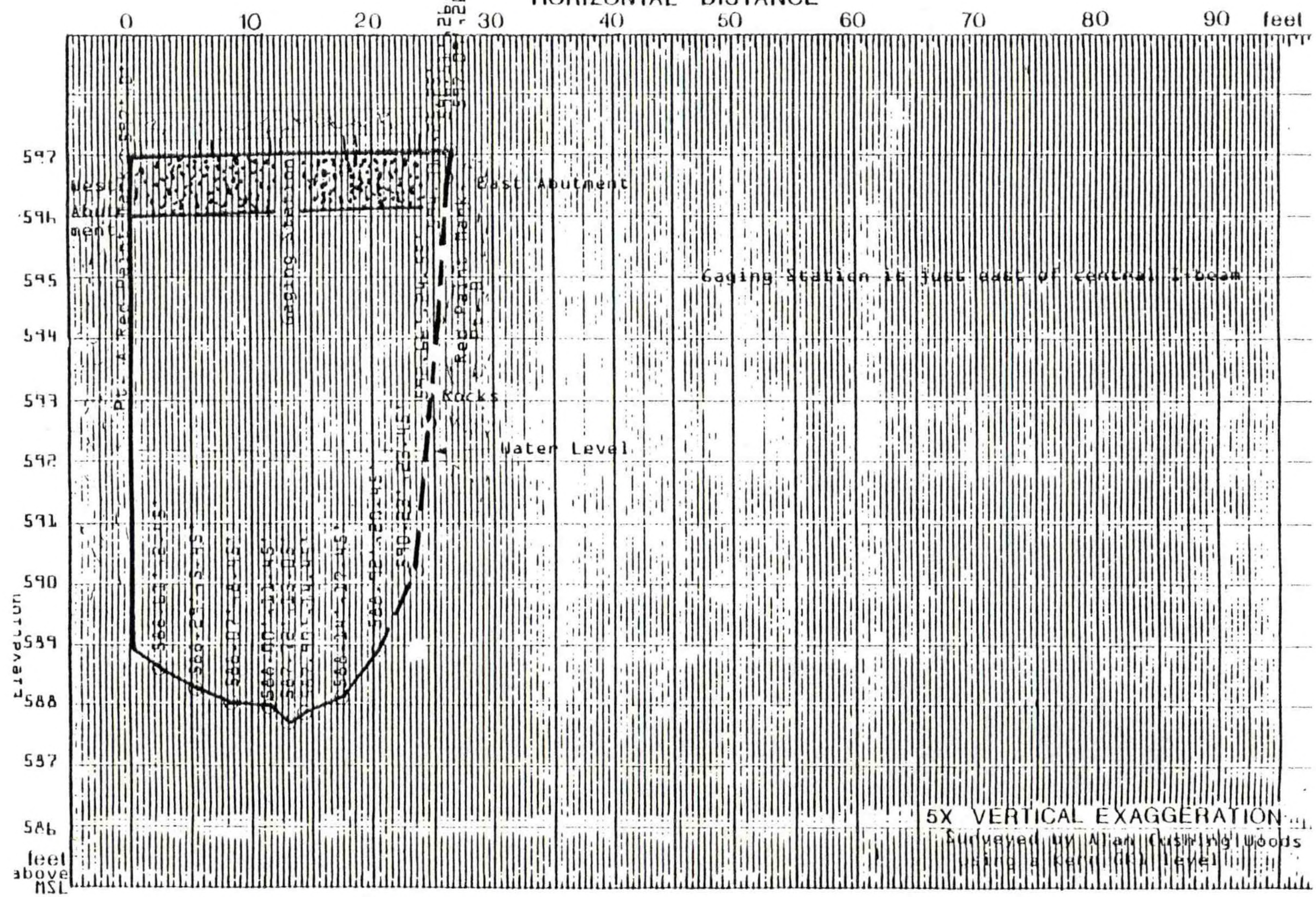
LOCATION: STATION 3

The South Side, Chapin Rd. Bridge

DATE: July 6, 1984

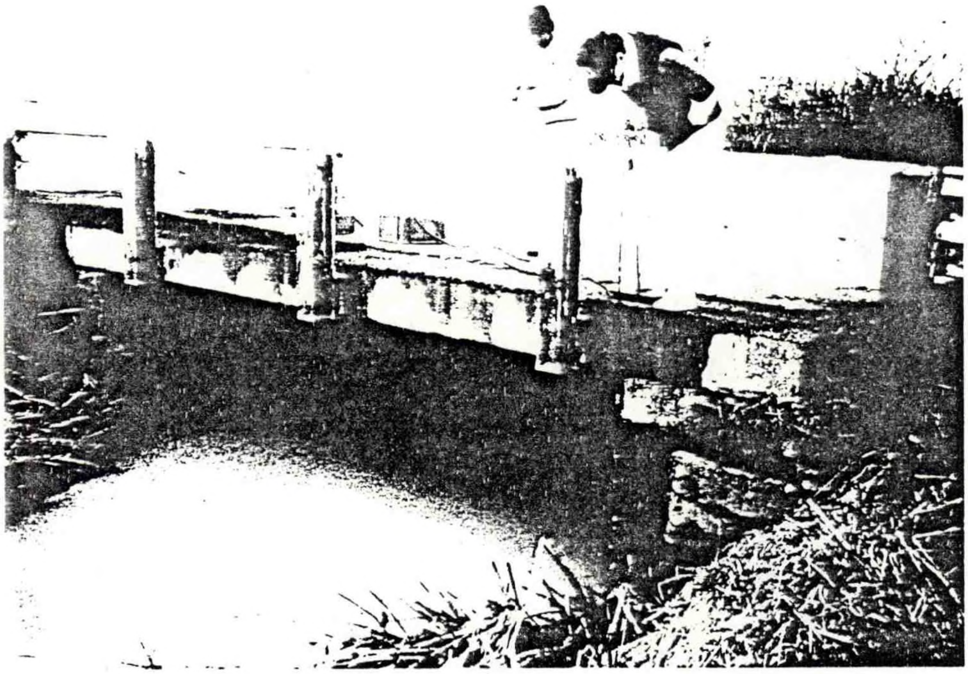
DATUM: Absolute

HORIZONTAL DISTANCE

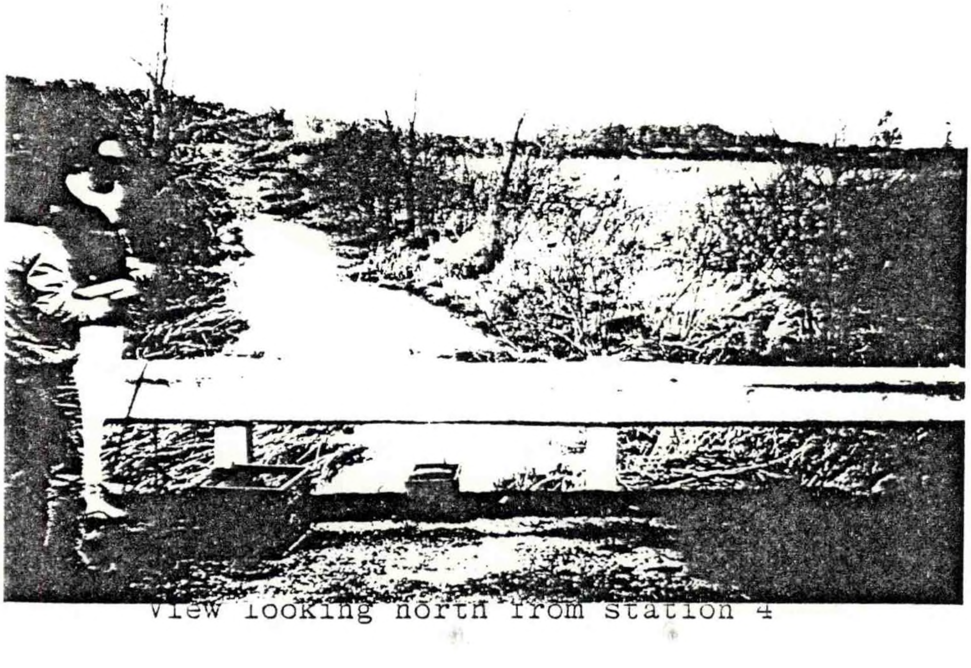


APPENDIX A.4

Station 4

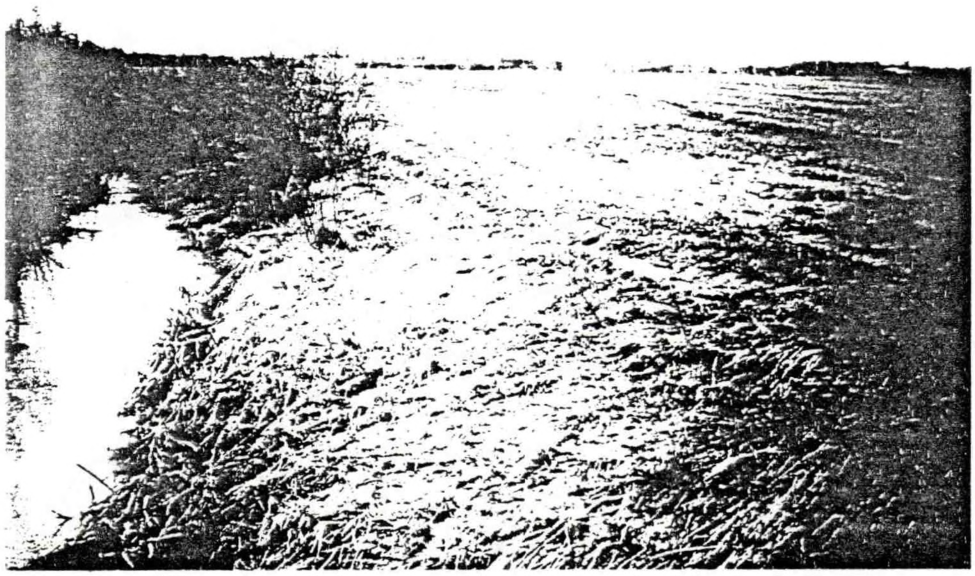


View of station 4's cross section from the north



View looking north from station 4

APPENDIX A.4
(continued)
Station 4



View looking south from station 4

APPENDIX A.4
Station 4

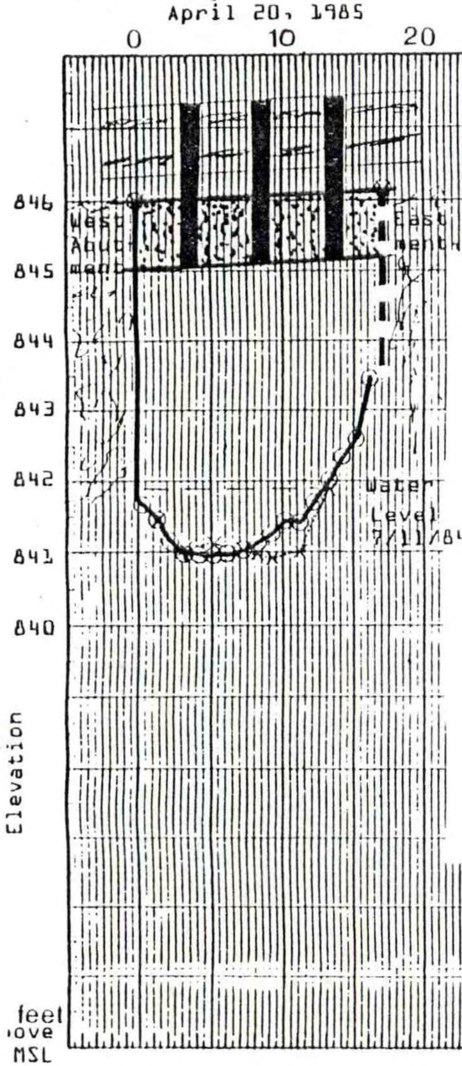
CROSS SECTIONAL PROFILE

LOCATION: STATION 4

DATE: July 11, 1984
April 20, 1985

North Side of Bridge, County Line Road

DATUM: Absolute



July 11, 1984 Survey

	Horizontal Distance from west abutment (feet)	Elevation (feet + MSL)
W BM	0.0	846
	0.3	841.70
	1.3	841.46
	2.3	841.16
	3.3	840.90
	4.3	840.98
	5.3	840.98
	6.3	840.99
	7.3	841.04
GS	8.3	841.18
	9.3	841.29
	10.3	841.41
	11.3	841.36
	12.3	841.72
	13.3	842.04
	14.3	842.37
	15.3	842.62
	16.3	843.49
E BM	17.28	846.16

April 20, 1985 Survey

	Horizontal Distance from west abutment (feet)	Elevation (feet + MSL)
W BM	0.0	846
	1.3	841.41
	3.3	841.07
	5.3	841.12
	7.3	841.02
GS	8.3	840.97
	9.3	840.91
	11.3	841.00
	13.3	841.90
	15.3	842.75
	17.28	846.12

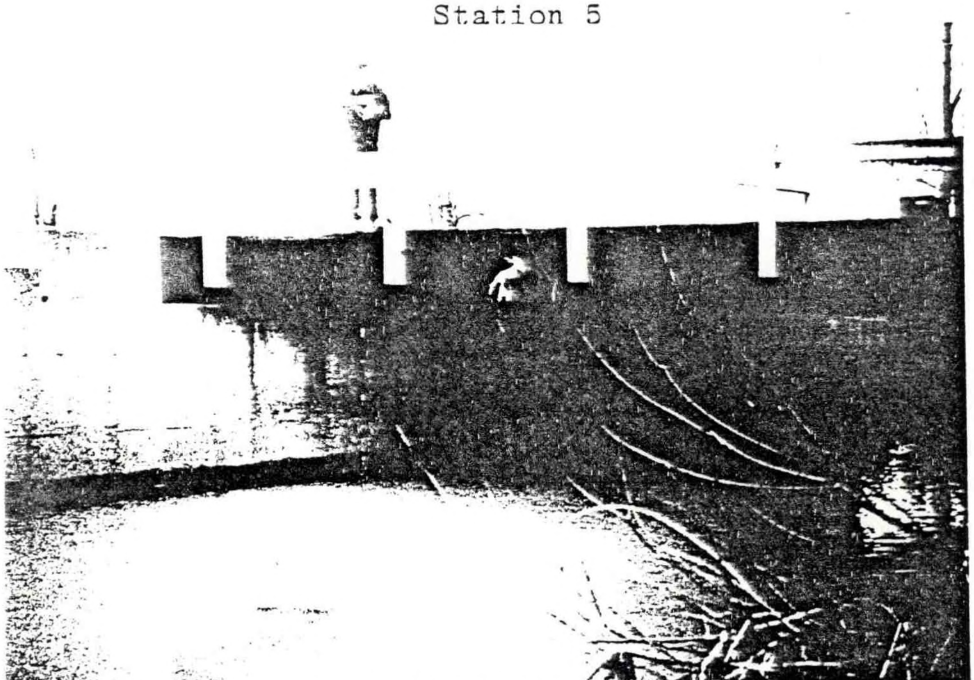
Explanation: July 11, 1984 survey
April 20, 1985 survey
approximate

5X VERTICAL EXAGGERATION

Surveyed by Alan J. Cushing
Woods using Kern GK1 level

APPENDIX A.5

Station 5



Northwestern view of station 5's cross secton

View to the SE of station 5

APPENDIX A.5
(continued)

Station 5

View to the northwest of station 5

APPENDIX A.5
(continued)

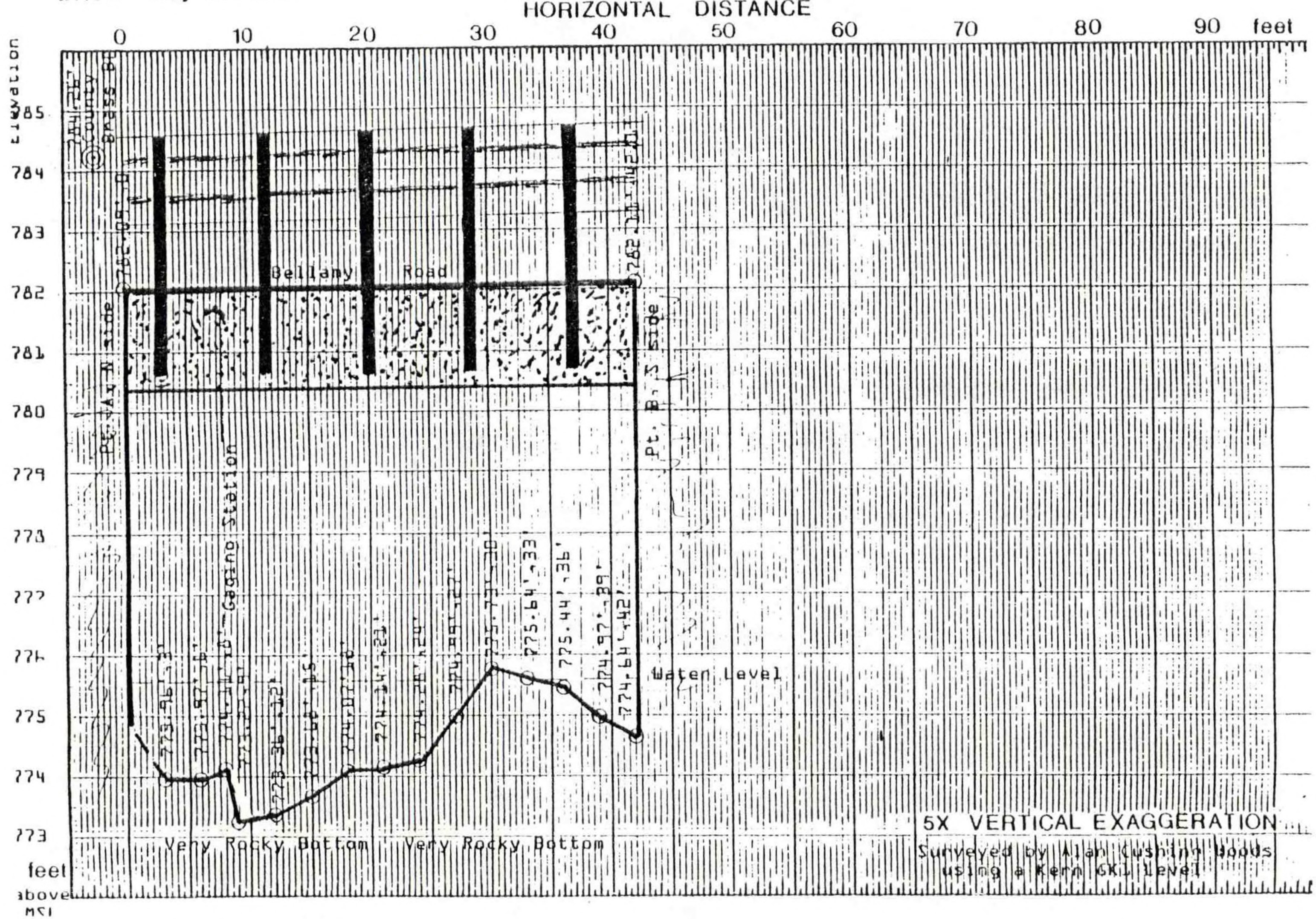
CROSS SECTIONAL PROFILE

LOCATION : STATION 5

The West side, Bellamy Rd. Bridge

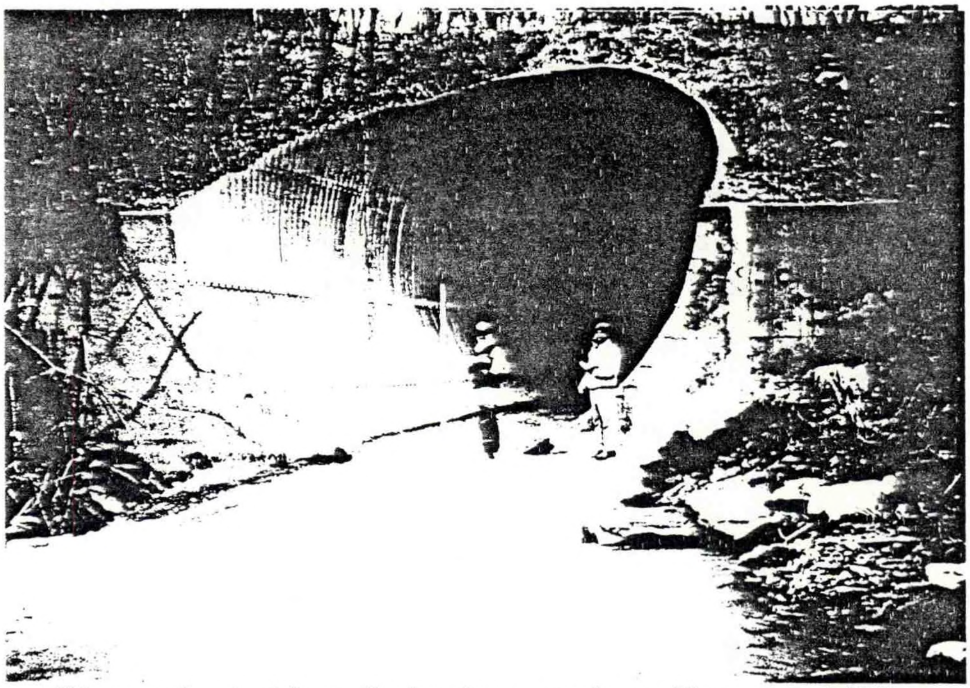
DATE: July 11, 1984

DATUM: Absolute

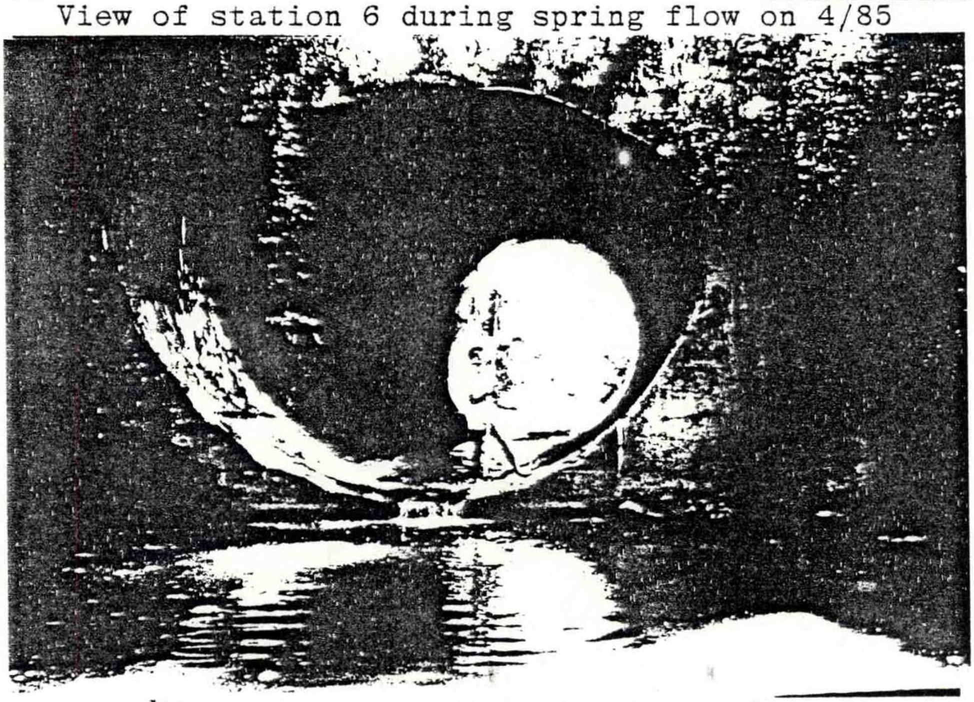


APPENDIX A.6

Station 6



View of station 6 during spring flow on 4/85

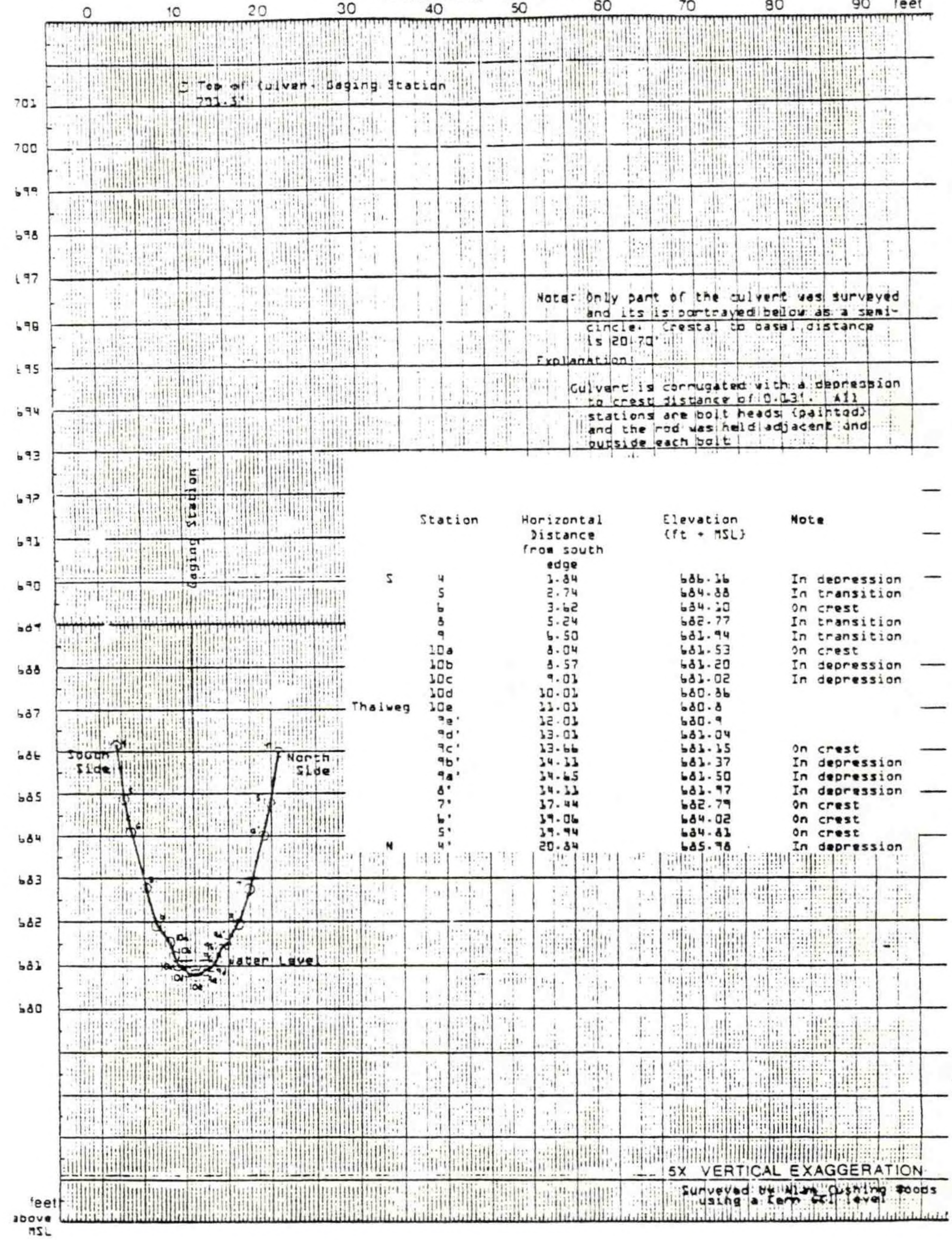


View of station 6 during lower flow

APPENDIX A.6
(continued)
Station 6
Cross sectional Profile

LOCATION : STATION 6
Culvert: W side of Berlin Rd.

DATE: July 12, 1984 DATUM: Absolute



Note: Only part of the culvert was surveyed and its is portrayed below as a semi-circle. Crestal to basal distance is 20.70'

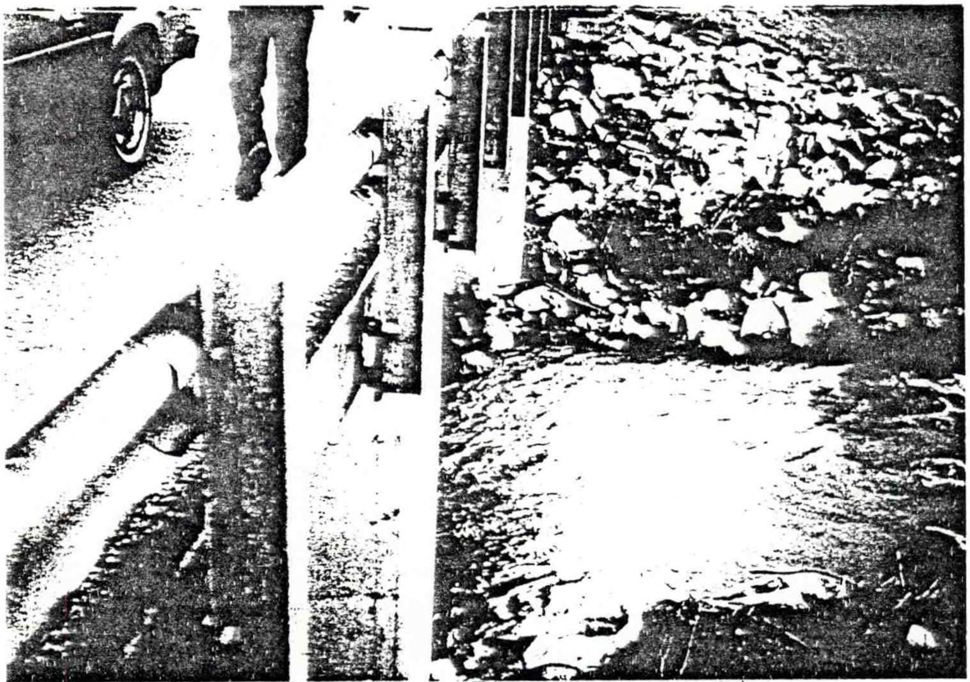
Explanation:

Culvert is corrugated with a depression to crest distance of 0.13'. All stations are bolt heads (painted) and the rod was held adjacent and outside each bolt

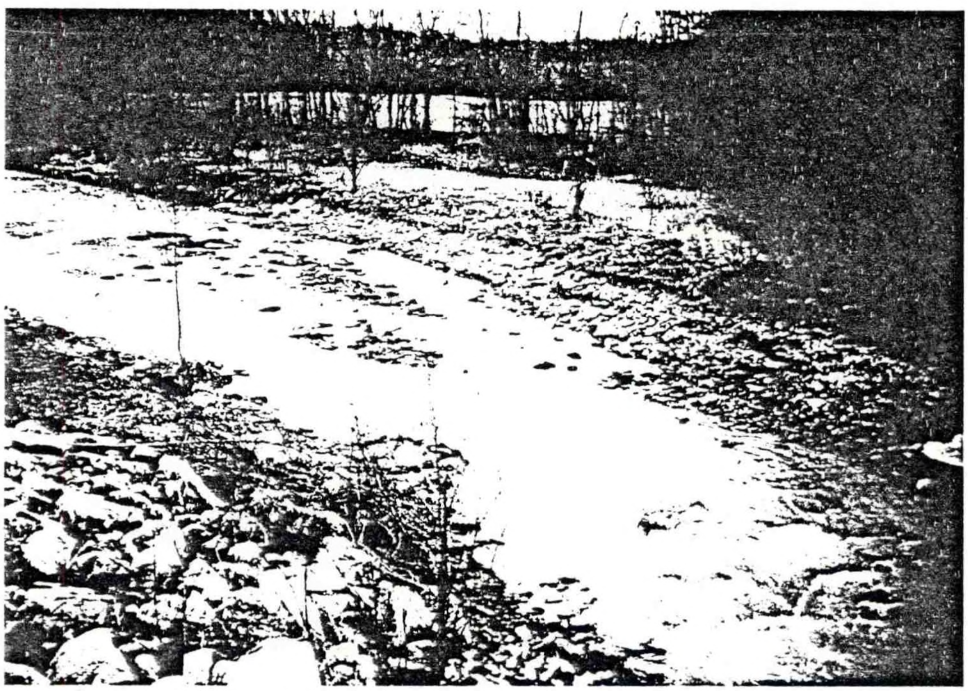
	Station	Horizontal Distance from south edge	Elevation (ft + MSL)	Note
S	4	1.84	686.16	In depression
	5	2.74	684.88	In transition
	6	3.62	684.10	On crest
	8	5.24	682.77	In transition
	9	6.50	681.94	In transition
	10a	8.04	681.53	On crest
	10b	8.57	681.20	In depression
	10c	9.01	681.02	In depression
	10d	10.01	680.86	
Thalweg	10e	11.01	680.8	
	9e'	12.01	680.9	
	9d'	13.01	681.04	
	9c'	13.66	681.15	On crest
	9b'	14.11	681.37	In depression
	9a'	14.65	681.50	In depression
	8'	14.11	681.97	In depression
	7'	17.44	682.79	On crest
	6'	19.06	684.02	On crest
	5'	19.94	684.81	On crest
N	4'	20.84	685.98	In depression

APPENDIX A.7

Station 7



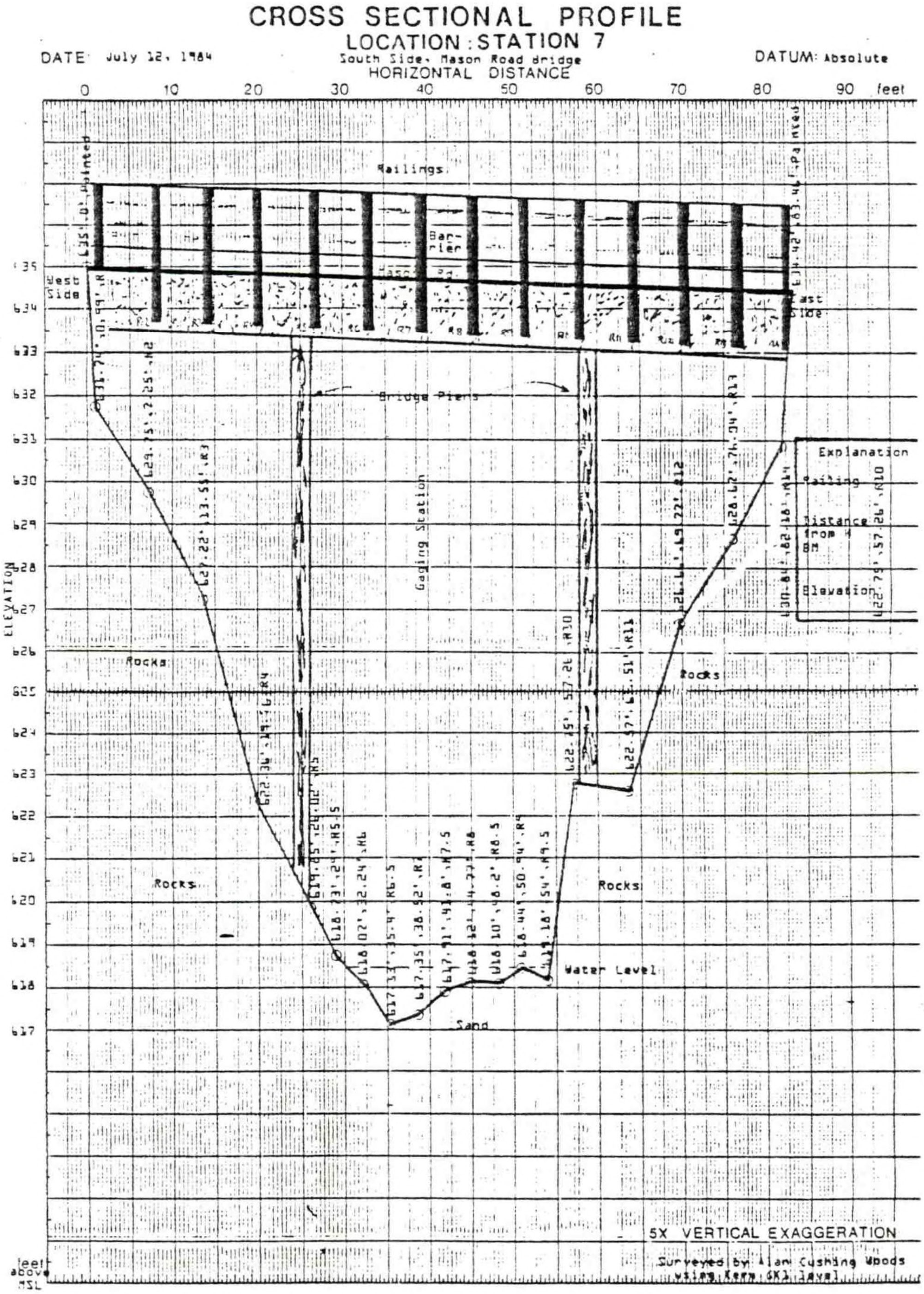
View of station 7's cross-section



View to the south of station 7

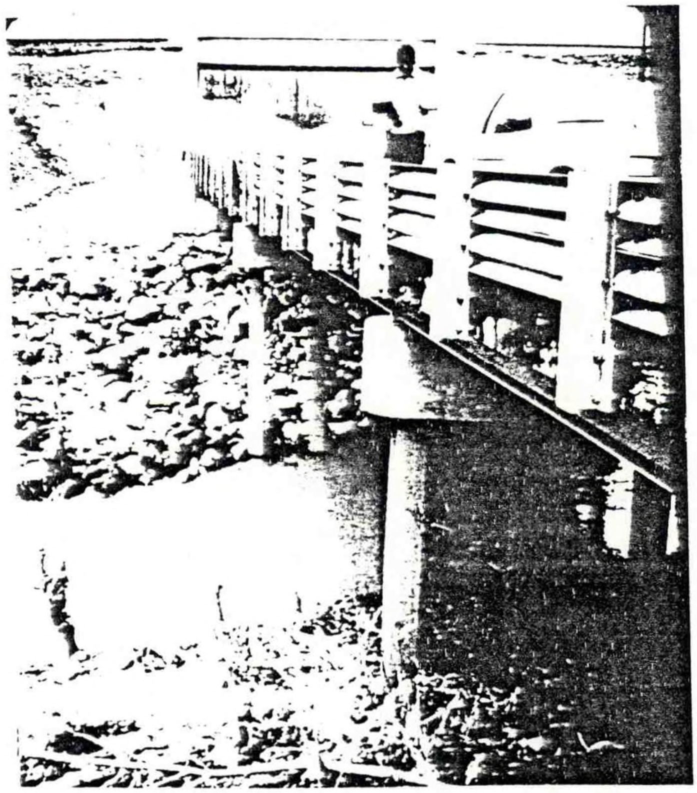
APPENDIX A.7
(continued)

Station 7



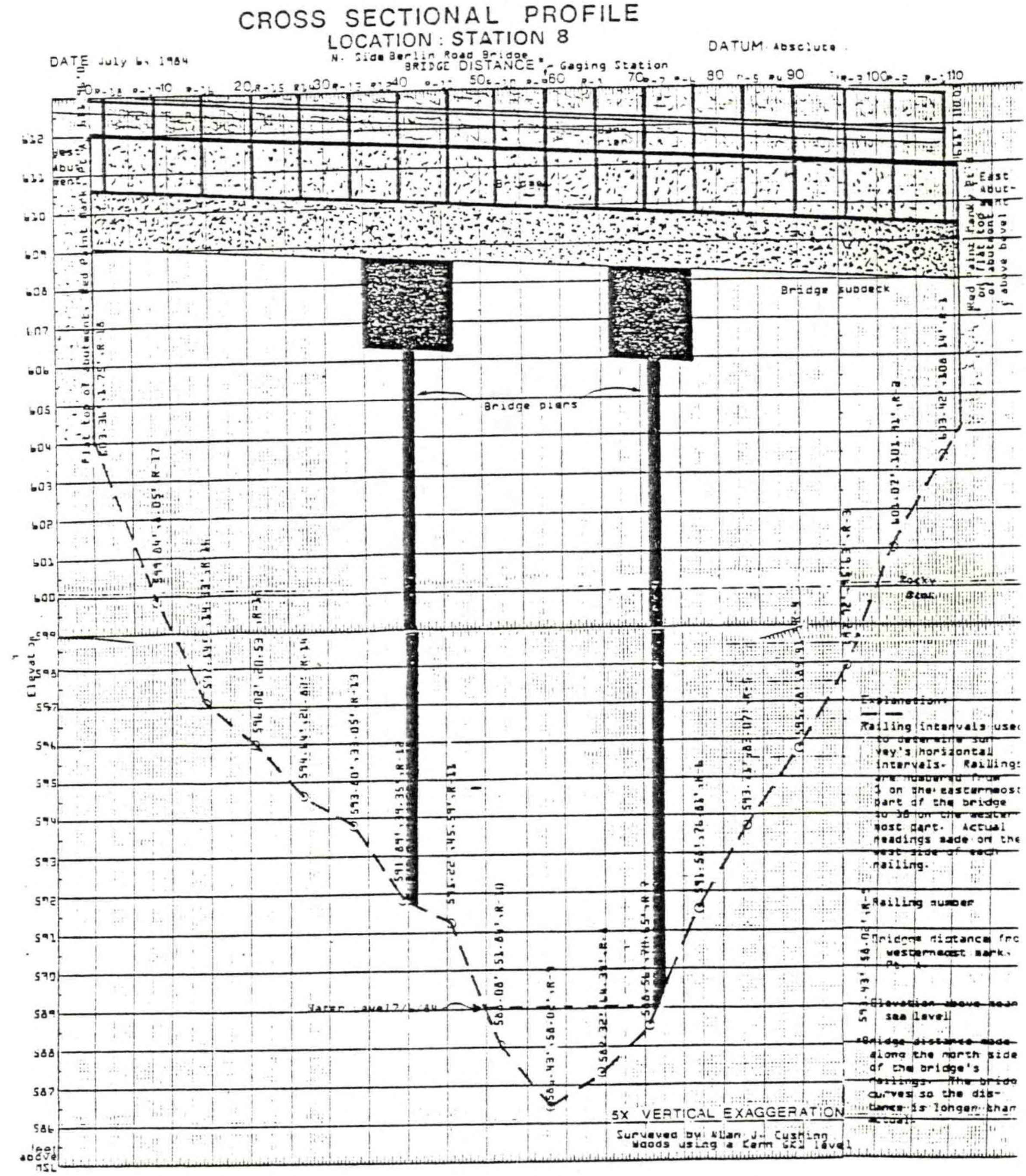
APPENDIX A.8

Station 8



View of station 8's cross section from northwest abutment

APPENDIX A.8
(continued)
Station 8



APPENDIX A.9

Station 9

General view looking northwest from station 9

APPENDIX A.9

(continued)

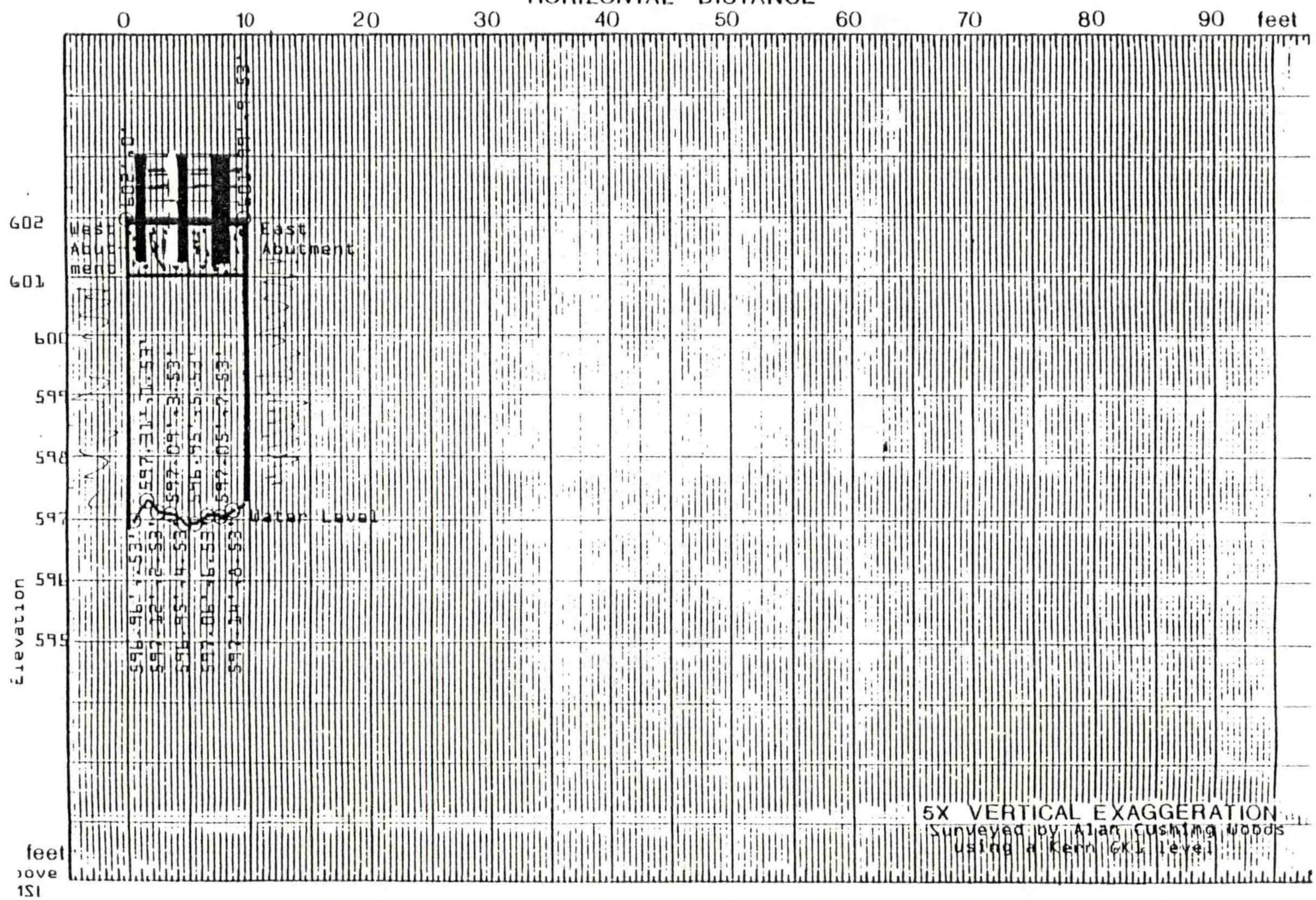
CROSS SECTIONAL PROFILE

LOCATION : STATION 9

DATE: July 11, 1984

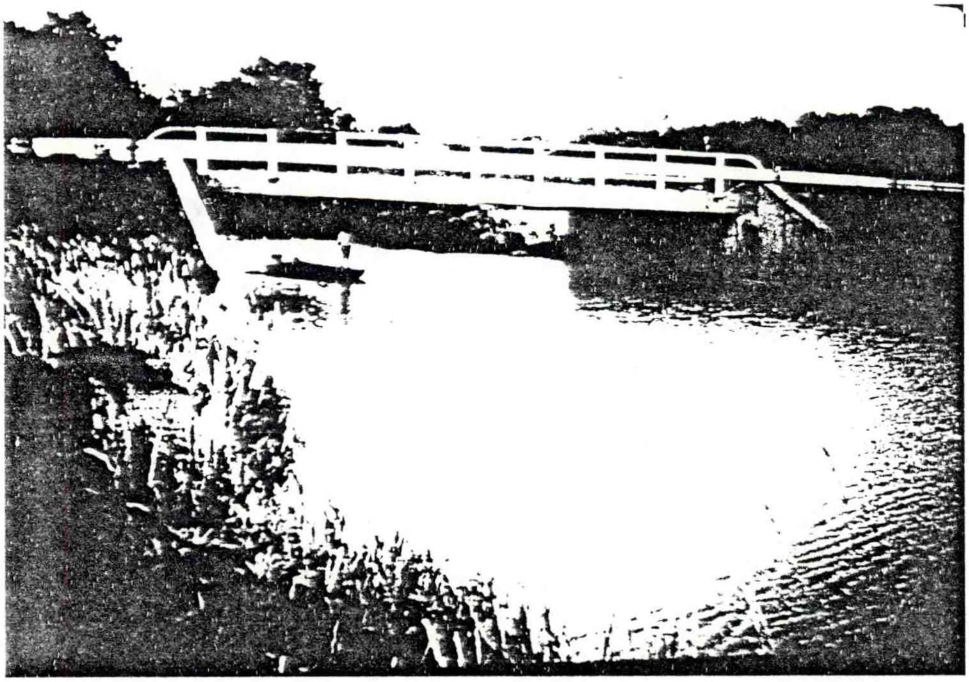
North Side of Deehr Road Bridge

DATUM: Absolute



APPENDIX A.10

Station 10



General view of station 10's cross-section from north

APPENDIX A.10
(continued)

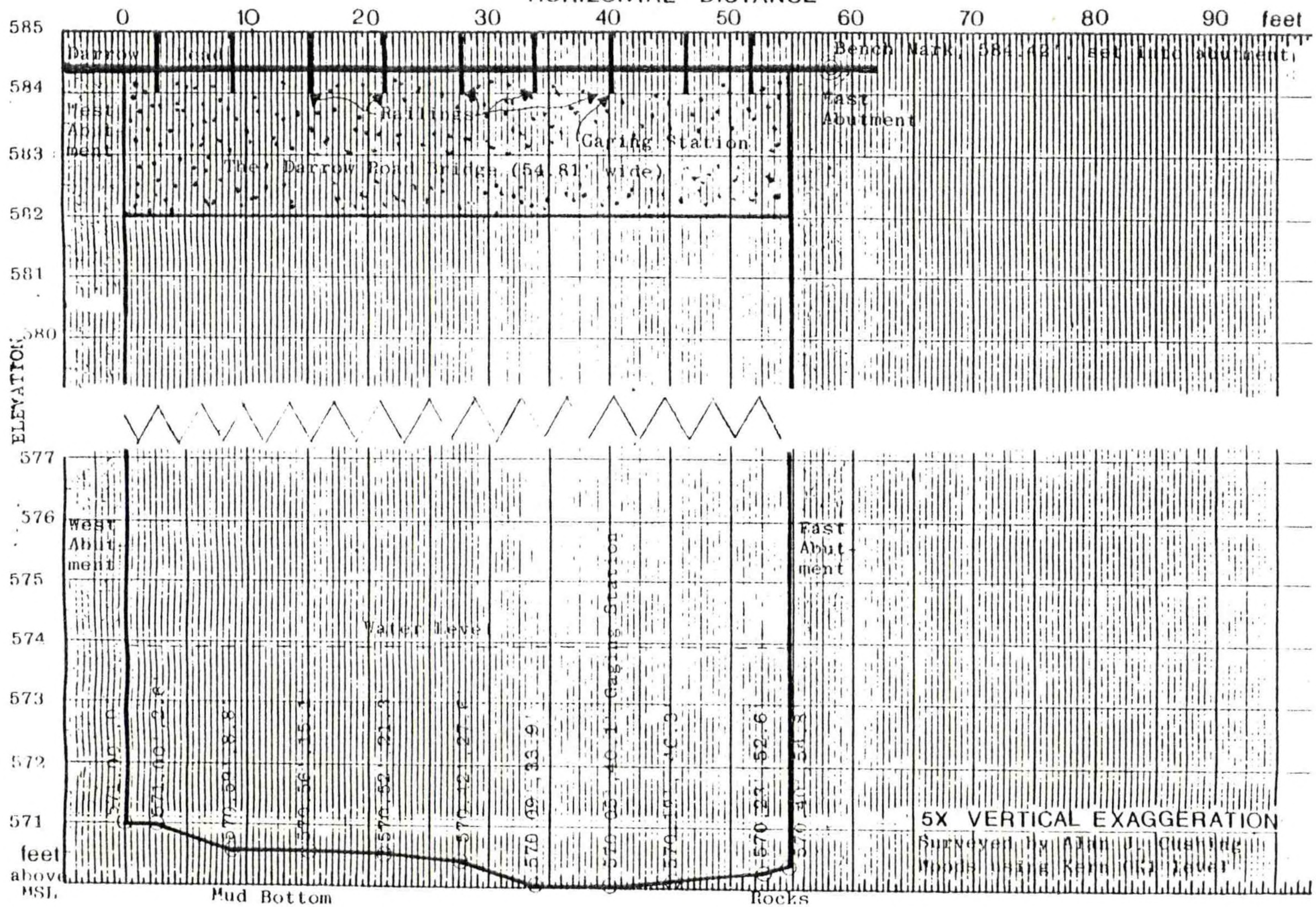
CROSS SECTIONAL PROFILE

LOCATION: STATION 10

DATE: July 11, 1984

Darrow Road Bridge

DATUM: Absolute



APPENDIX B

Erosion Assessment Site Descriptions, Site Photographs, and Site Cross-sectional Profiles

APPENDIX B.1

Locational Descriptions

Erosional Assessment Site		Approximate Elevation
C	It is on the west branch, approximately 0.25 miles downstream of the Ohio Turnpike, 0.75 miles downstream from station 2, and 90' south of the Mason Road bridge. It is within the area of the Kibbie-Tuscola-Colwood Soil Association and the Lake Plain. West pin next to post.	596'
D	It is on the middle branch, approximately 1 mile upstream from station 6, east of State Route 61, at the end of Whipporwill Road, just east of an orange, wooden ranch style house, west of a yellow brick house, and adjacent to a cable telephone support. It is in the Mahoning-Bogart-Haskins-Jimtown Soils Association.	720'
E	It is on the middle branch, 750' upstream of the Ohio Turnpike, 450' upstream of the Berlin Heights Water Works, and 0.4 miles downstream of station 6. It is in the Mahoning-Bogart-Haskins-Jimtown Soils Association and is at the foot of the Berea Escarpment. East pin in adjacent to a sycamore on the floodplain but near the channel while the west pin is adjacent to a fence post.	650'
F	It is on the middle branch, 300 feet upstream from station 7, on the Hask Farm, and directly on the southwest edge of a parking lot. It is in the Mahoning-Bogart-Haskins-Jimtown Soils Association and it is in the Lake Plain-Berea Escarpment transition.	619'
G	It is on the main trunk of the creek, approximately 0.8 miles upstream of station 10, east of Barrows Road, on the property of Wayne Jenkins, and on the outside of a meander just upstream of a steep bank. West pin in adjacent to large trees. On the Lake Plain and in the Kibbie-Tuscola-Colwood Soils Association.	585'

APPENDIX B.1

{continued}

Locational Descriptions

Erosional Assessment Site		Approximate Elevation
H	It is on the east branch, 600' upstream from the main trunk of the creek, 0.2 miles upstream from station 10, and at the foot of a hill. West pin is set next to a willow. It is in the Kibbie-Tuscola- Colwood Soils Association and in the Lake Plain.	575'
I	It is on the main trunk of the creek, 400' north of station 10 and just upstream of the proposed Route 2 bridge. East pin is located at the base of a multi-branched willow. It is in the Lake Plain and is also in the Kibbie-Tuscola-Colwood Soils Association.	565'
J	It is on the main trunk of the creek, south of the railroad bridge, south of the large oaks on the western and southern shores of the creek, and 0.4 miles downstream of site J. Pin is set beneath a low slung willow branch on the northern creek bank. It is in the Lake Plain and is also in the Kibbie-Tuscola-Colwood Soils Association.	562'

APPENDIX B.2

Erosional Assessment Site C

View of the West Pin {Arrow} and Adjacent to Post. Mason Road Bridge is in Background.

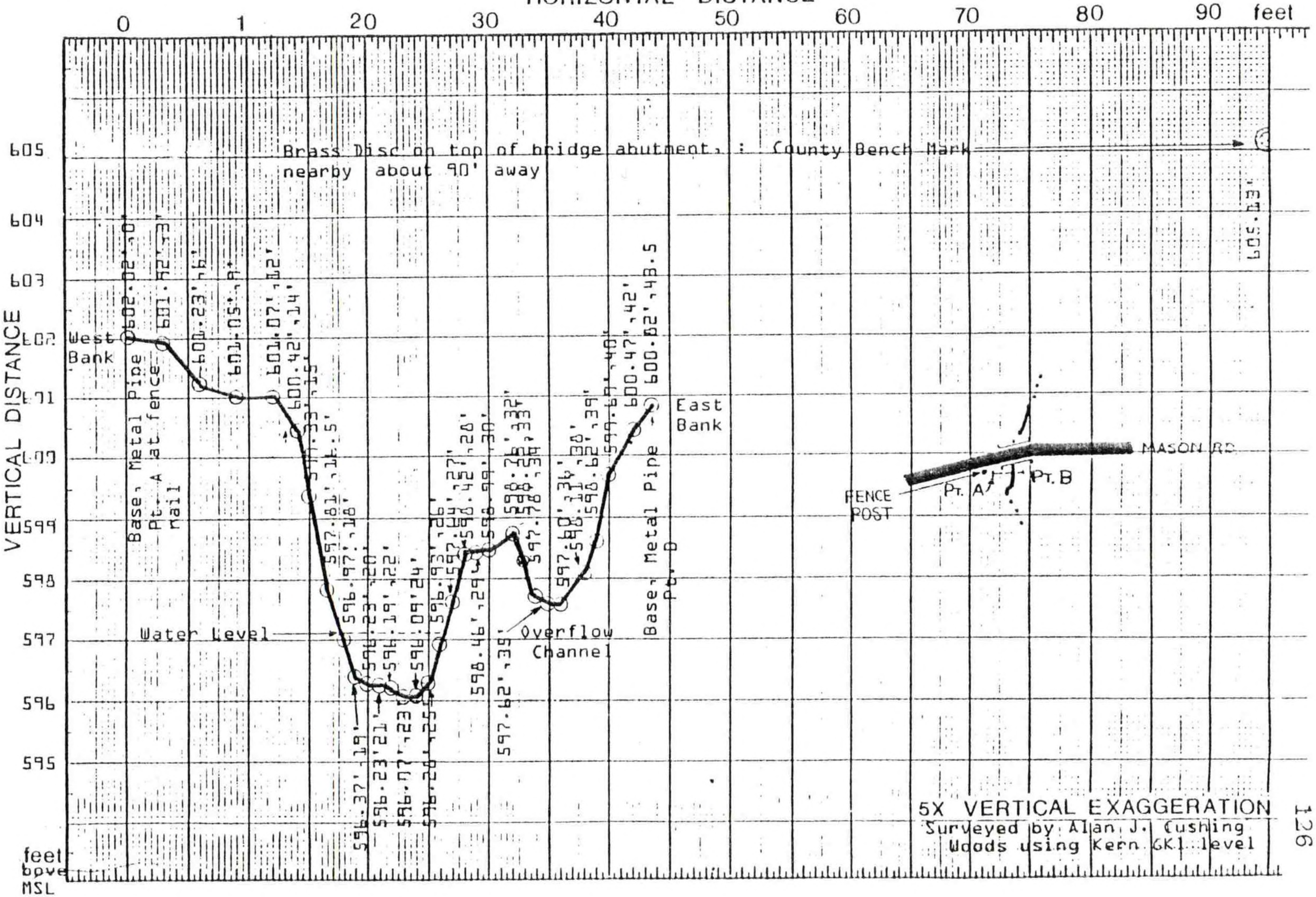
CROSS SECTIONAL PROFILE

LOCATION : SITE C

South of Mason Rd. Bridge

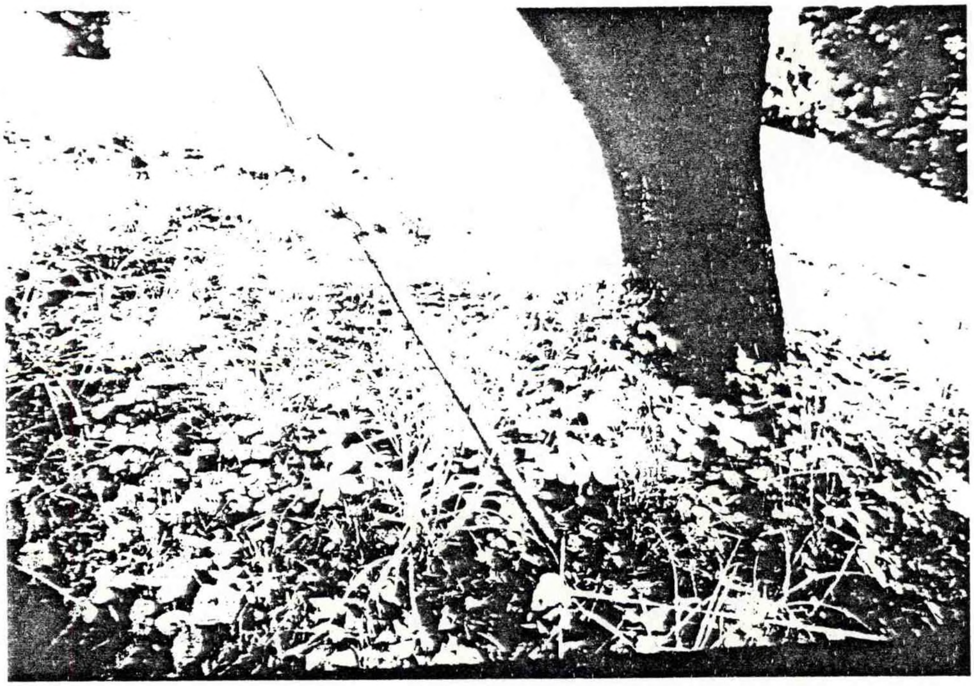
DATE: 6/16/85

DATUM: Absolute

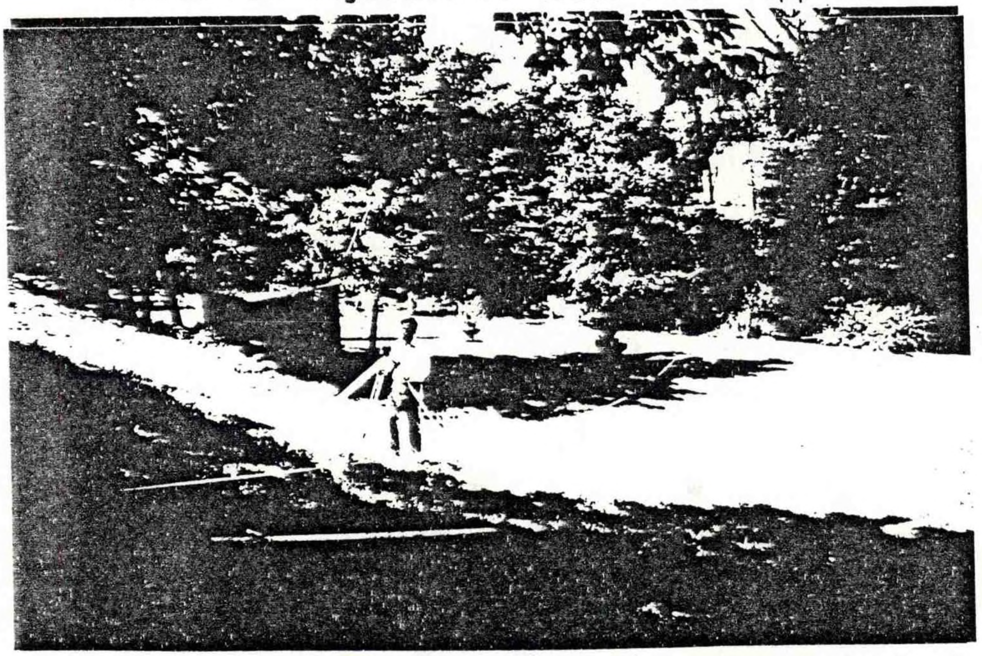


APPENDIX B.3

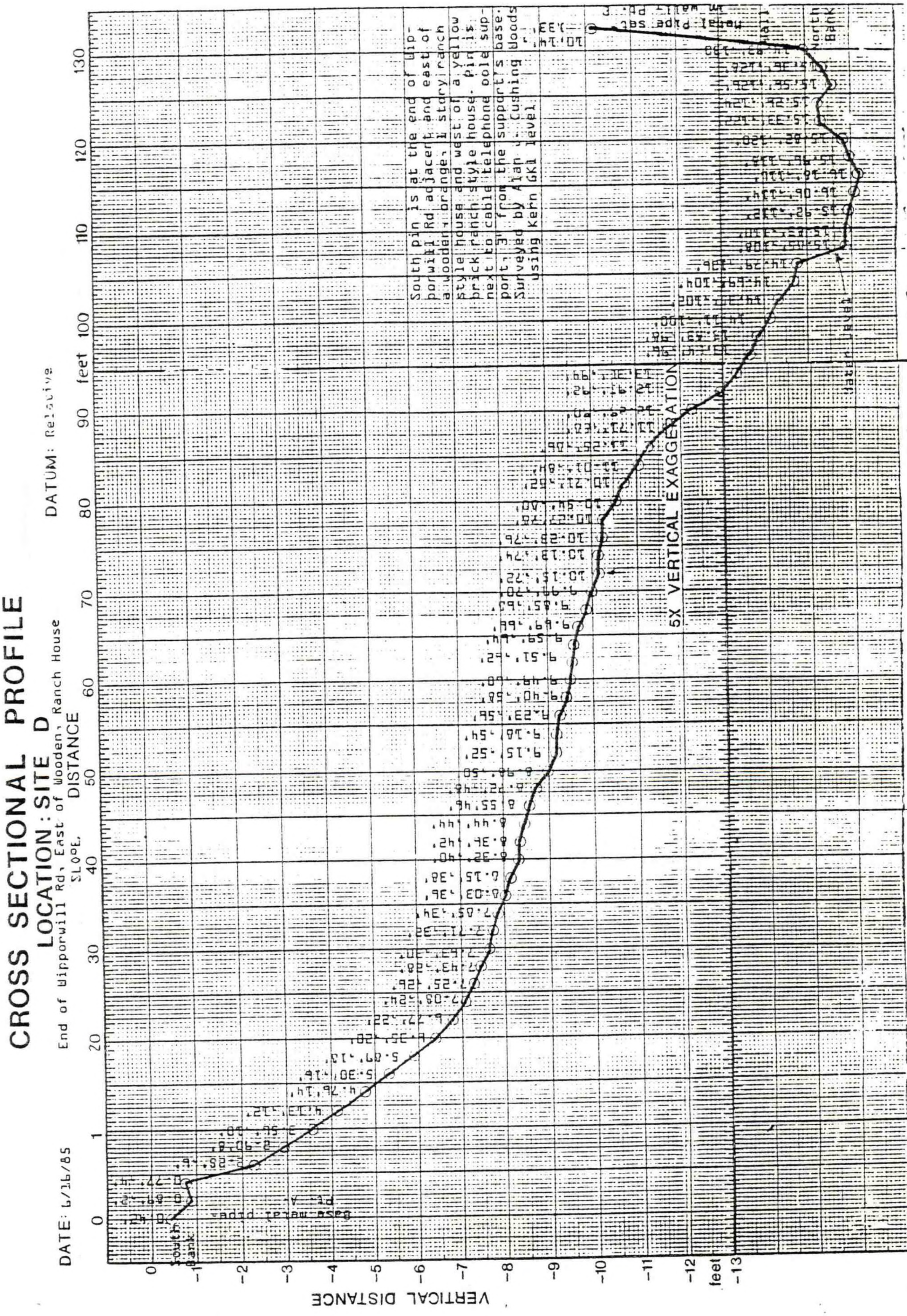
Erosional Assessment Site D

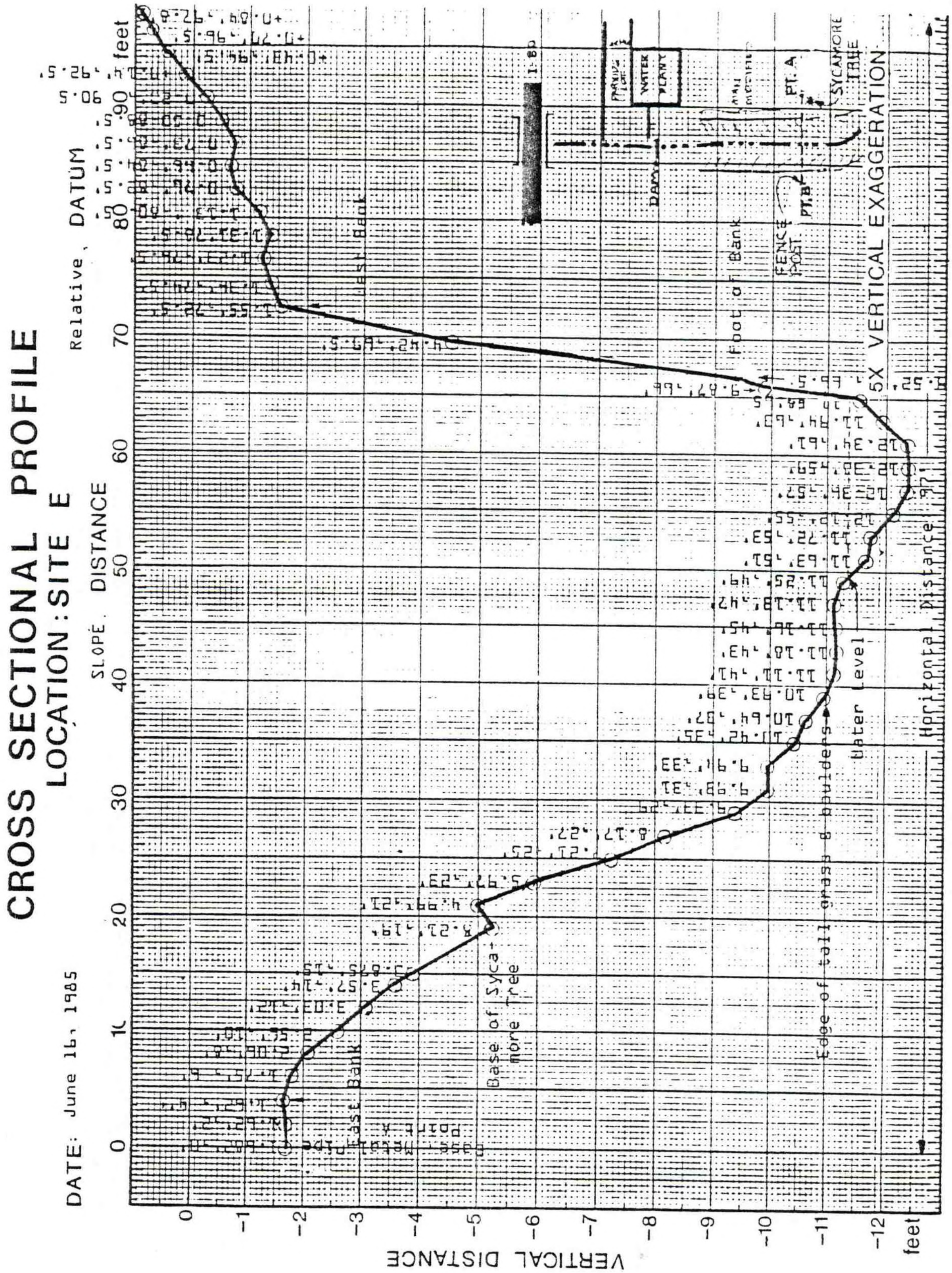


South Pin Adjacent to Cable Pole-Support



Southern Portion of Profile With High, Northern Bank Visible

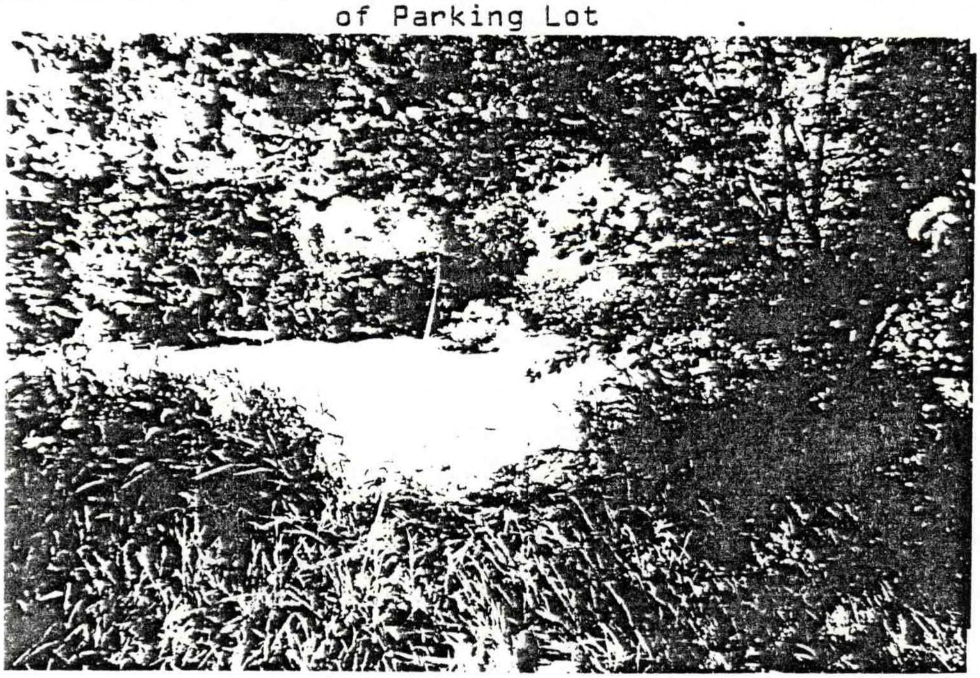

CROSS SECTIONAL PROFILE
LOCATION: SITE D
End of Wipporwill Rd, East of Wooden, Ranch House
SLOPE
DISTANCE
DATE: 6/16/85
DATUM: Relative
feet
5X VERTICAL EXAGGERATION
VERTICAL DISTANCE
South Bank
North Bank
South pin is at the end of Wipporwill Rd adjacent and east of a wooden, orange, 1 story ranch style house and west of a yellow brick ranch style house. Pin is next to cable telephone pole support, 3' from the support's base. Surveyed by Alan J. Cushing Woods using Kern GK1 level.


CROSS SECTIONAL PROFILE
LOCATION: SITE E
DATE: June 16, 1985
SLOPE DISTANCE
Relative DATUM
VERTICAL DISTANCE
feet
5X VERTICAL EXAGGERATION
Horizontal Distance
Water Level
Edge of tall grass & boulders
Base of Sycamore Tree
East Bank
West Bank
Foot of Bank
FENCE POST
PT. A
PT. B
SYCAMORE TREE
WATER PLANT
DAM

APPENDIX B.5

Erosional Assessment Site F

Rod-man is at Northern Witness Pin at the Southwestern Edge of Parking Lot



View of Cross-sectional Profile to South

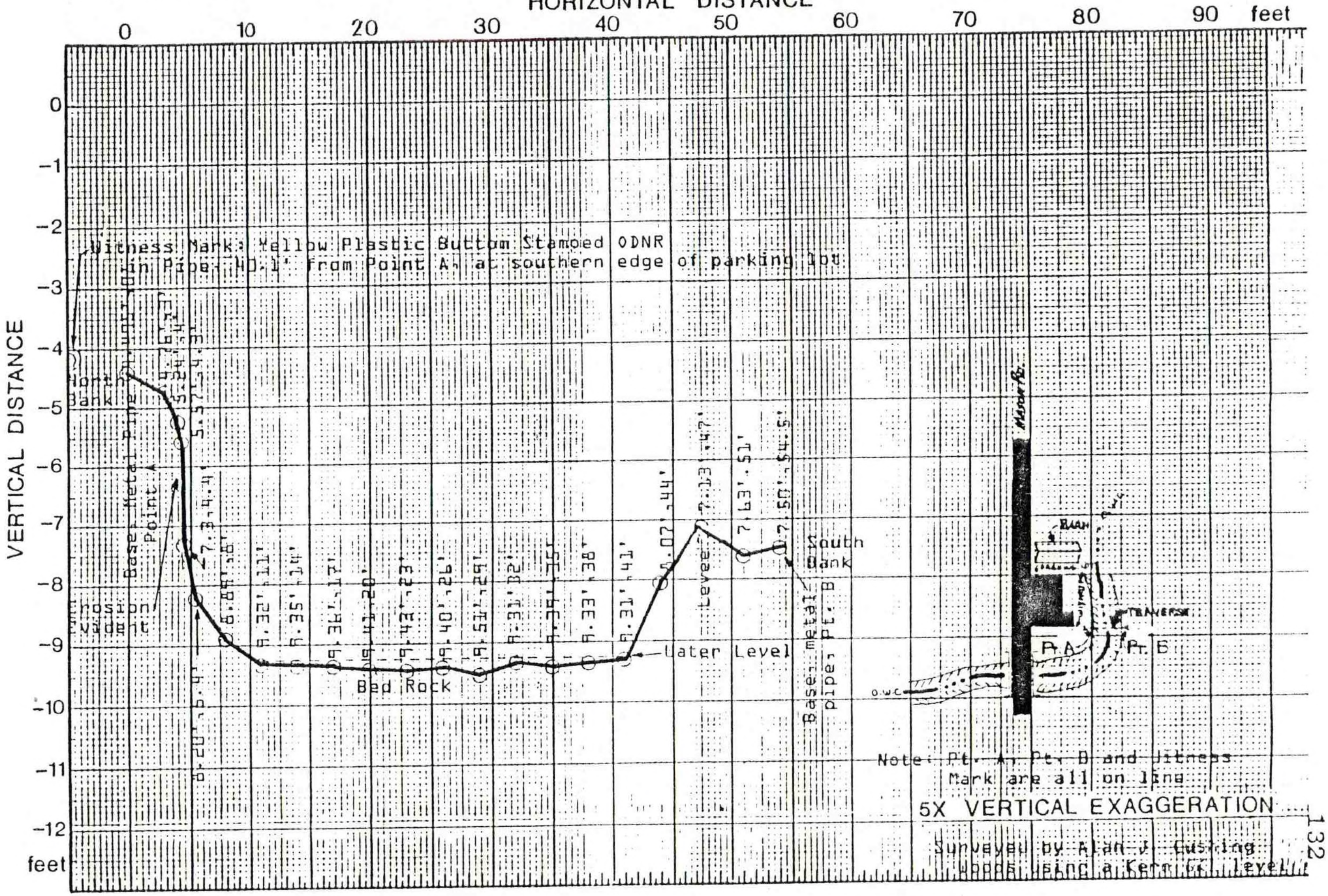
CROSS SECTIONAL PROFILE

LOCATION : SITE F

DATE: 6/16/85

On the Hask Farm, S. of Mason Rd.

DATUM: Relative



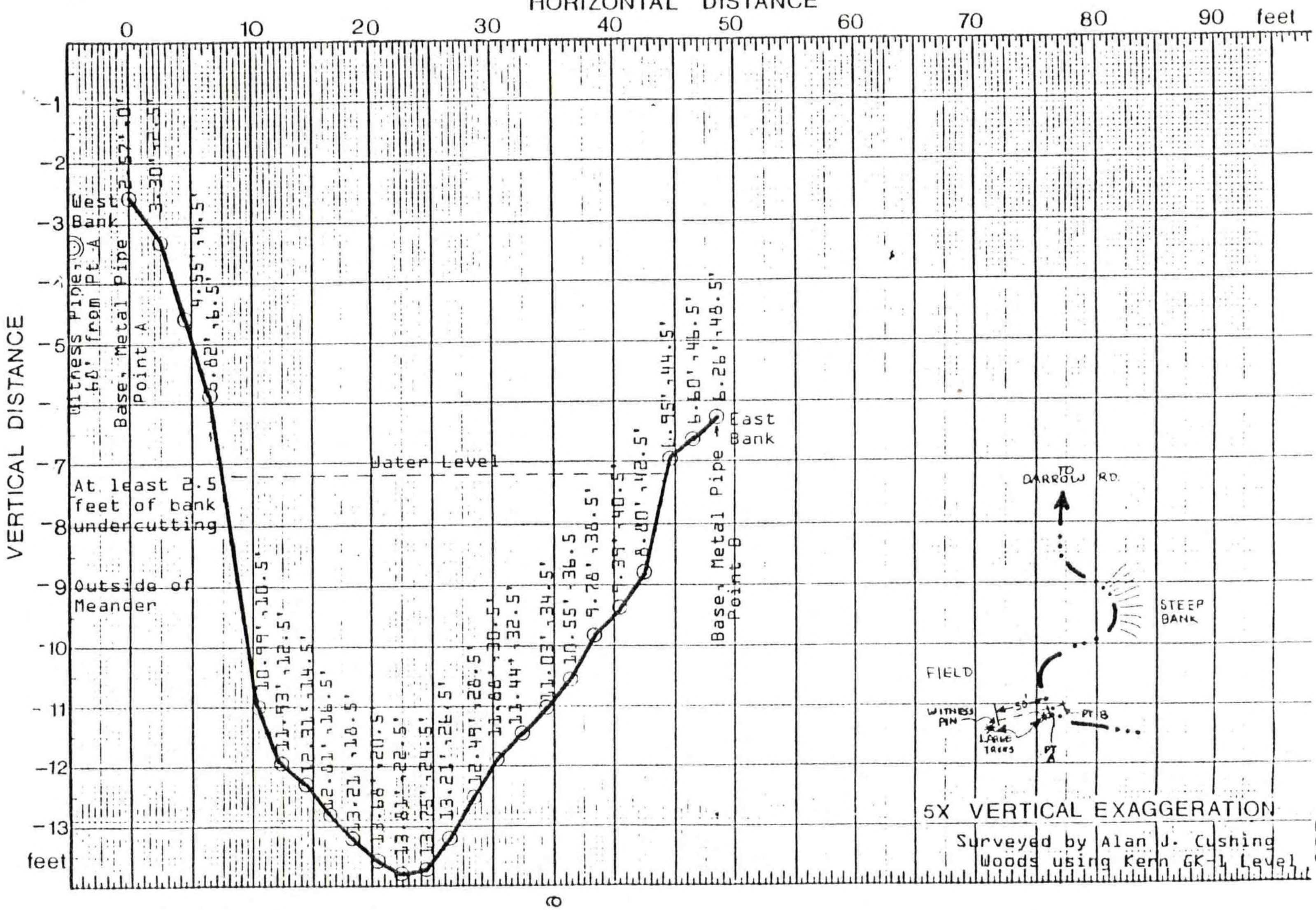
CROSS SECTIONAL PROFILE

LOCATION: SITE G

Wayne Jenkin's Property

DATE: 6/10/85

DATUM: Relative



APPENDIX B.7

Erosional Assessment Site H

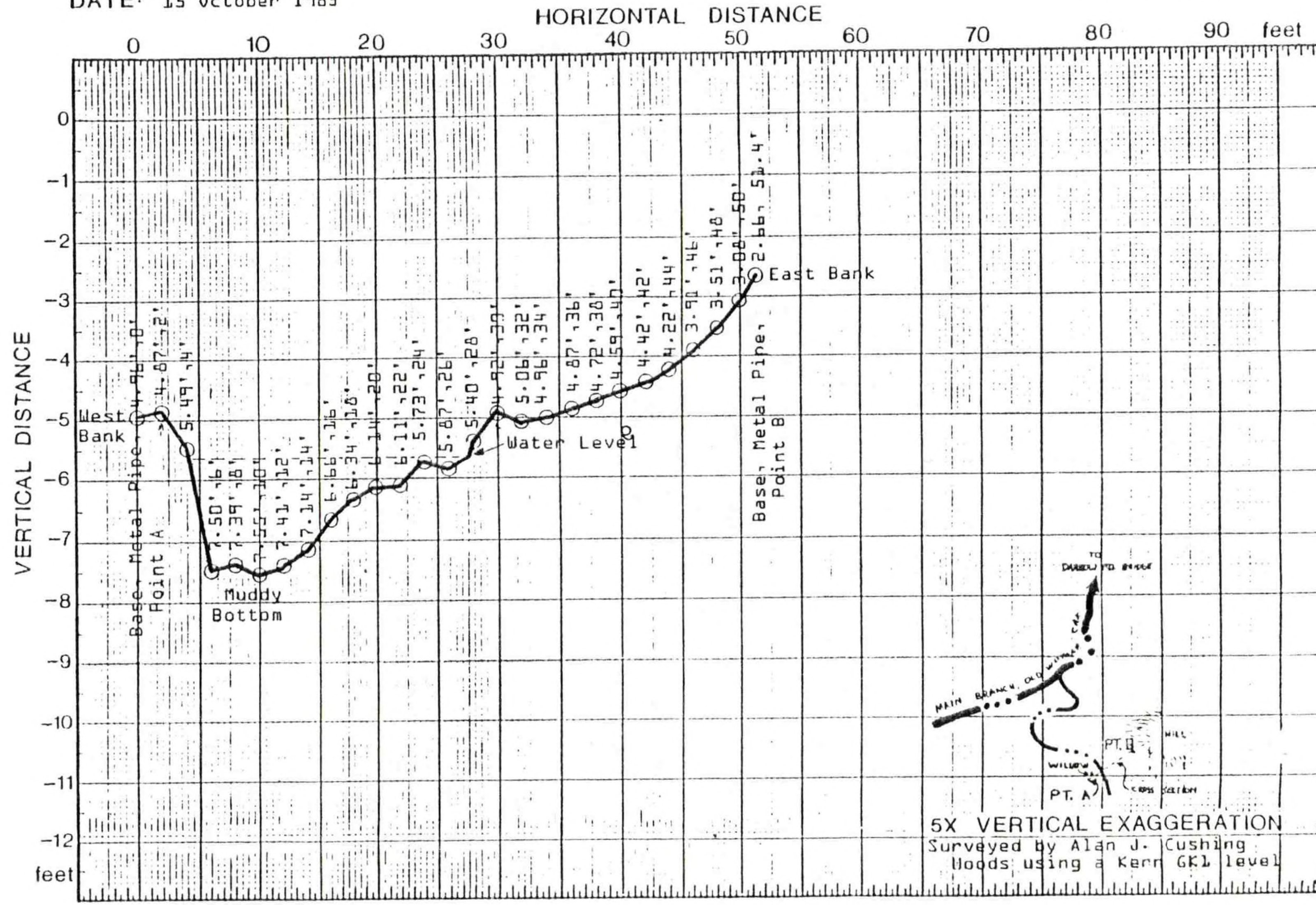
Rod Base is on West Pin With East Brank Behind. Trees Marking Main Creek are Visible to the North

CROSS SECTIONAL PROFILE

LOCATION: SITE H

DATE: 15 October 1985

DATUM: Relative



APPENDIX B.8

Erosional Assessment Site I

Willows on East {Left} Bank Mark Site I. Darrow Road Bridge is Visible Farther South.

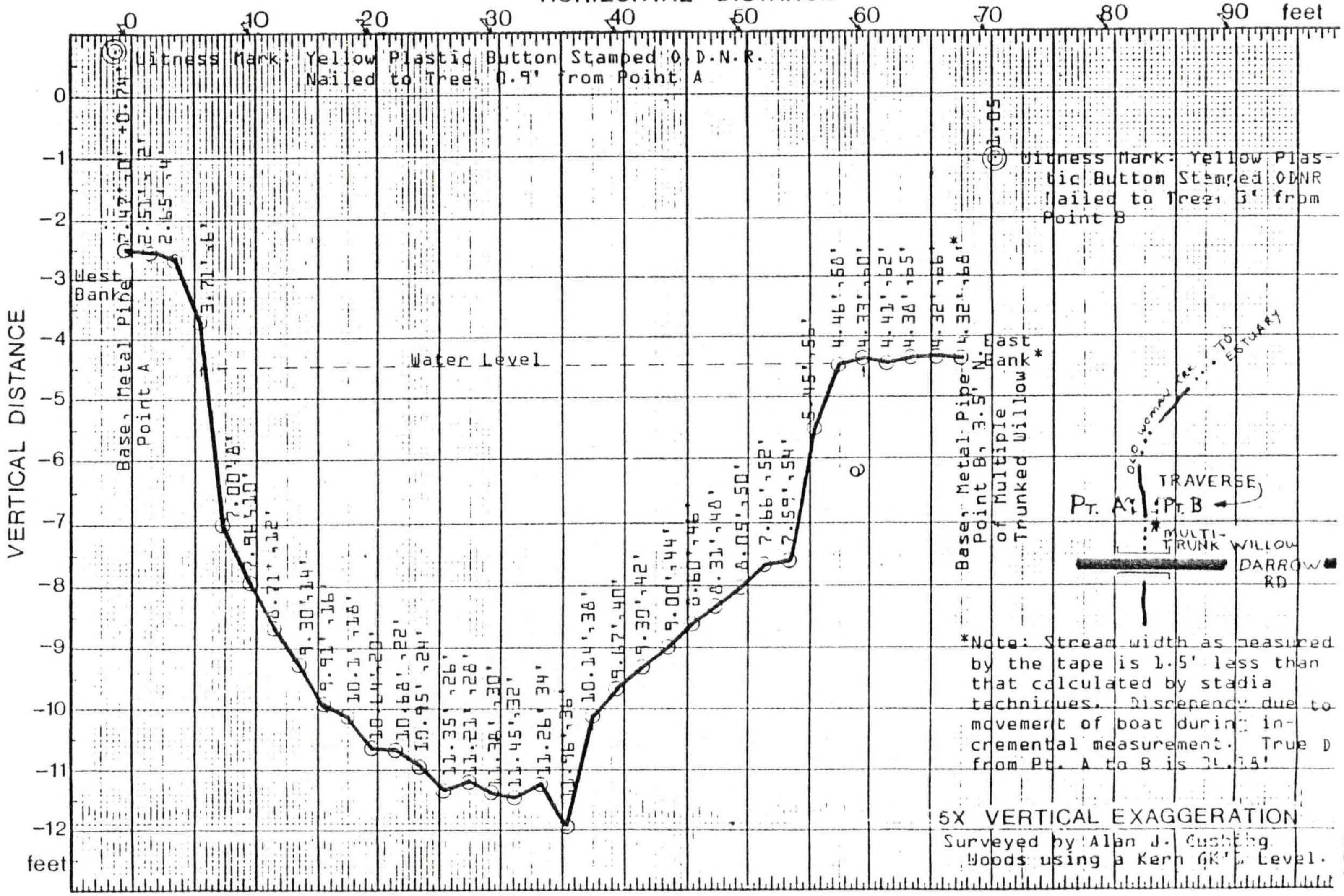
CROSS SECTIONAL PROFILE

LOCATION : SITE I

DATE: 6/10/85

APPROXIMATELY 300' NORTH OF THE DARROW RD. BRIDGE

DATUM: Relative

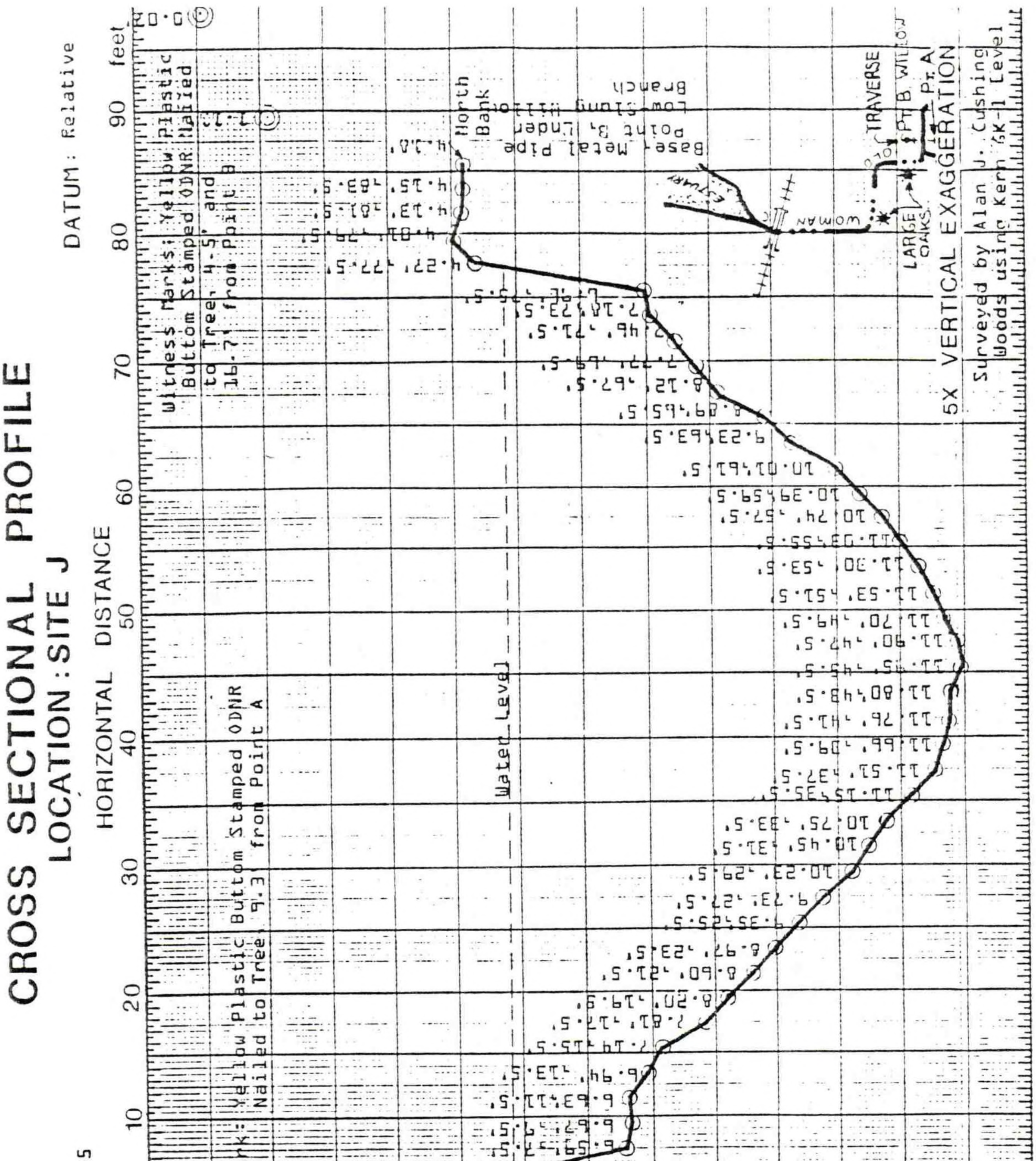


APPENDIX B.9

Erosional Assessment Site J

Rod is on Northern Pin

Looking West From Site J


CROSS SECTIONAL PROFILE
LOCATION: SITE J
DATE: 6/10/85
DATUM: Relative
HORIZONTAL DISTANCE
VERTICAL DISTANCE
feet
Water Level
South Bank
North Bank
Base, Metal Pipe Point A
Base, Metal Pipe Point B, Under Low-Slung Willow Branch
Witness Mark: Yellow Plastic Button Stamped ODNR Nailed to Tree 9.3' from Point A
Witness Marks: Yellow Plastic Button Stamped ODNR Nailed to Tree, 4.5' and 16.7' from Point B
TRAVERSE
PT. B WILLOW
PT. A
LARGE OAKS
WOMAN
5X VERTICAL EXAGGERATION
Surveyed by Alan J. Cushing Woods using Kern GK-1 Level