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Channel Erosion and Sediment Transport in Pheasant Branch Basin Near Middleton, Wisconsin-- A Preliminary Report

PREPARED BY
UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
IN COOPERATION WITH
CITY OF MIDDLETON AND
WISCONSIN GEOLOGICAL AND NATURAL HISTORY SURVEY

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R. S. Grant and Gerald Goddard

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CONVERSION TABLE

For readers who prefer metric units, data in this report may be converted by the following factors:

Multiply	By	To obtain
inch (in.)	25.40	millimeter (mm)
foot (ft)	304.8	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square foot (ft^2)	0.0929	square meter (m^2)
acre	0.4047	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot (ft^3)	0.0283	cubic meter (m^3)
acre-feet	1,233	cubic meter (m^3)
foot per second (ft/s)	0.3048	meter per second (m/s)
cubic foot per second (ft^3/s)	0.0283	cubic meter per second (m^3/s)
part per million (ppm)	1.000	milligram per liter (mg/L)
pound (lb)	453.5	gram (g)
ton, short	0.9072	megagram (Mg)

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ABSTRACT

The purpose of this 5-year study is to (1) evaluate the sediment transport, streamflow characteristics, and stream-channel morphology in the Pheasant Branch basin near Middleton, Wisconsin; (2) relate the above to land-use practices; and (3) provide a method of evaluating the effect that changes in land-use practices will have on Pheasant Branch. The study is being conducted by the U.S. Geological Survey in cooperation with the city of Middleton and the Wisconsin Geological and Natural History Survey.

The purpose of the first year of study was to evaluate sediment transport, streamflow characteristics, and stream-channel morphology and to document historical erosion in the study area. Findings are presented from the first year of study in this report. Pheasant Branch, a tributary to Lake Mendota, drains 23.1 square miles of glacial drift. Channel erosion is severe within the city of Middleton, requiring extensive use of erosion-control structures in some locations. Channel dredging near the mouth and into Lake Mendota is required occasionally for boating.

Streamflow gages, rain gages, automatic sediment samplers, and monumented cross-section sites were established in 1977. A cross-section survey of Pheasant Branch in 1971 provided data for quantification of stream-channel changes since that time.

Comparing the cross-section surveys of 1971 and 1977 shows the channel thalweg (low point in stream channel) lowered 3 to 4 feet at some sites in the urban reach from U.S. Highway 12 downstream to Century Avenue. In the reach downstream from Century Avenue, average channel width increased from about 35 to 48 feet, and the average channel cross-section area increased 86 percent. Six erosion-control structures previously installed by the city in the urban reach appear to have had some benefit in controlling head cutting in the channel.

INTRODUCTION

Pheasant Branch, a tributary to Lake Mendota at Middleton in Dane County, Wis., drains an area of 23.1 mi^2 consisting of rolling hills in the upland to flat heavily cultivated fields in the flood plain. Urbanization in the basin has been increasing at a rapid rate and is projected to accelerate.

With the increase in urbanization, associated problems of stream-channel erosion and suspended sediment in Pheasant Branch have developed. Stream-channel erosion downstream from U.S. Highway 12 has become so severe that numerous erosion-control structures have been installed. Increasing amounts of sediment are being carried into Lake Mendota, requiring occasional dredging near the mouth of the stream to maintain recreational boating. Pheasant Branch Marsh downstream from Century Avenue traps some of the sediment and thus reduces sedimentation in Lake Mendota.

The purpose of this 5-year study is to (1) measure the sediment transport, streamflow characteristics, and stream-channel morphology in the Pheasant Branch basin; (2) relate the above to land use and increased urbanization; and (3) use a computer simulation model to project the effect that changes in land use will have on the hydrology of the study area. This report evaluates channel erosion and sedimentation from data collected during the first year of the study and documents historical erosion problems.

To evaluate channel erosion and sedimentation in the basin, streamflow, suspended-sediment concentrations, channel geometry, and precipitation data were collected during 1977 and 1978. Locations of sampling sites are shown in figure 1. Continuous streamflow records were obtained at five gaging stations; suspended-sediment samples were taken by automatic samplers at three sites and manually at two sites; surveys of stream channel cross sections were made for another study in 1971 and repeated for this study in 1977. Precipitation was recorded at four sites. Of the five streamflow-sediment gaging stations in the Pheasant Branch basin, three monitor rural areas, two urban drainage, and two the effects of Pheasant Branch Marsh on sediment trapping and peak-flow attenuation. One of these stations also monitors suspended-sediment discharge into Lake Mendota. These data were compiled to determine whether the channel geometry has changed since 1971 and to account for the effect of land-use practices on channel erosion and sedimentation.

This study is being made by the U.S. Geological Survey in cooperation with the city of Middleton and the Wisconsin Geological and Natural History Survey. The U.S. Army Corps of Engineers has assisted by funding the operation of four gaging stations as part of another project. In addition, the Dane County Regional Planning Commission also has funded the operation of gaging stations and rain gages.

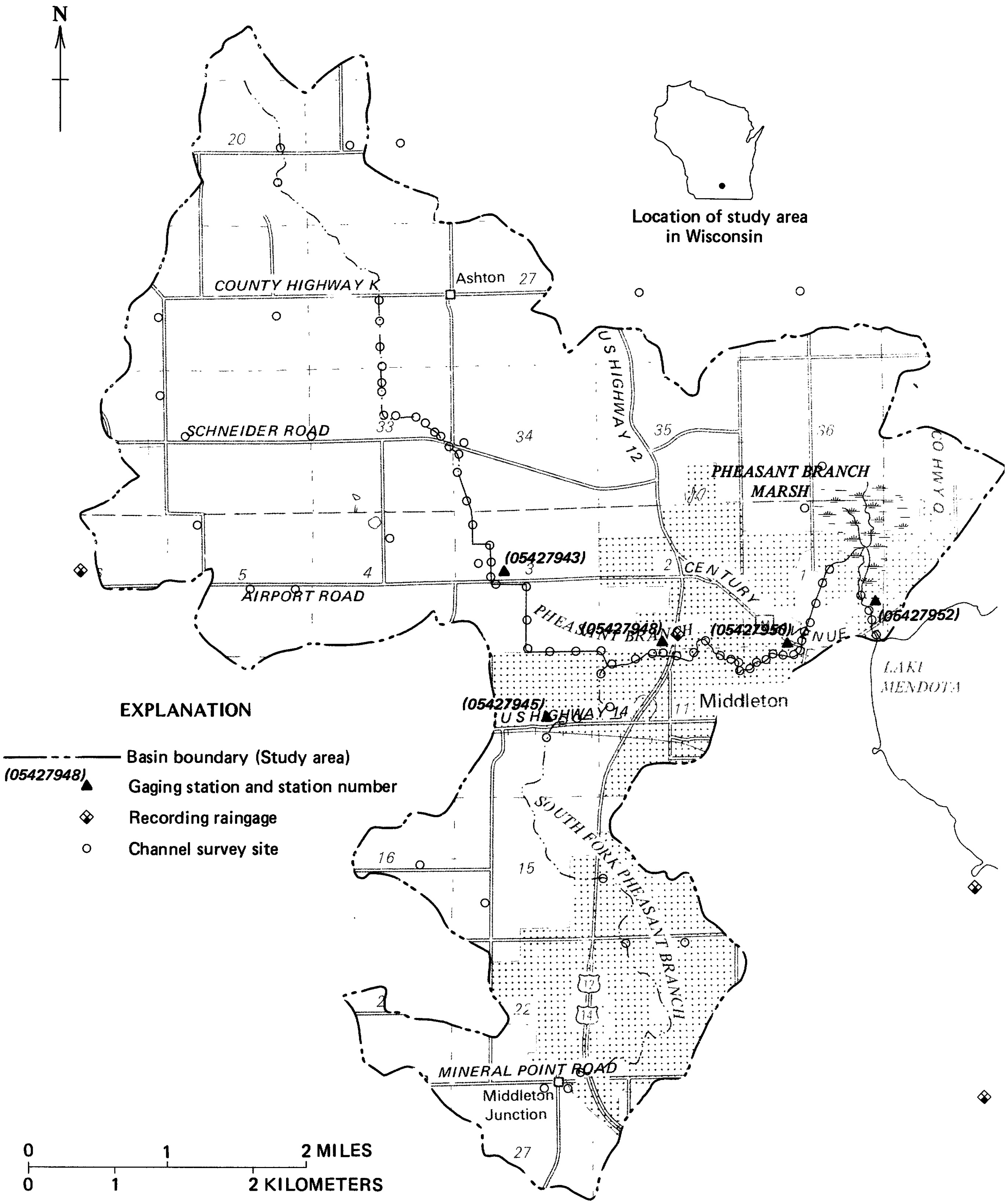

Figure 1. Location of study area, gaging stations, rain gages, and channel-survey sites.

HISTORICAL EROSION

During the 1950's, land use in the Middleton area (fig. 1) changed from agricultural to increasingly more urban with greater population density. Along with land-use changes, erosional problems developed in the Pheasant Branch basin.

Before 1950, Pheasant Branch flowed from the west along the north edge of Middleton, northward through Pheasant Branch Marsh, and into Lake Mendota. During the 1950's, the creek changed course, bypassing the marsh and flowing easterly and northeasterly along Century Avenue. Trash dumping at the entrance to the marsh may have caused the rerouting of the creek (D'Onofrio, oral commun., 1975). The gradient of the creek increased from about 18 to 24 ft/mi. During the late 1950's, urban development continued in the Middleton area, including construction of a sanitary sewer along the creek valley from Century Avenue to U.S. Highway 12, cutting off several stream meanders near Park Street.

Due to evidence of erosion accompanying increased urban development in the Middleton area, five concrete drop structures were constructed across the creek in 1968 between Century Avenue and U.S. Highway 12 to reduce stream gradient (Middleton Department of Public Works, oral commun., 1978). Additional stream straightening also was done, and portions of the banks were riprapped to reduce erosion. Between 1960 and 1967, in response to increasing population, nine storm sewers emptying into Pheasant Branch were built in Middleton. These storm sewers decreased the lag time for storm water to reach the stream.

In 1967, the Middleton Lakeshore Problems Commission published recommendations on how to solve Middleton's channel-erosion problems and suggested relocation of the creek so that it would again flow through the Pheasant Branch Marsh before entering Lake Mendota (D'Onofrio, 1967). Sediment and associated chemical pollutants could thus be filtered out by the marsh. By 1971 this was accomplished, and the gradient was again reduced to about 18 ft/mi.

The population of Middleton has increased from 8,246 in 1970 to an estimated 11,564 in 1978--a 40 percent increase (Wisconsin Department of Administration, 1978). Projections for 1990 indicate a potential urban population of approximately 20,000 (Plan Commission, City of Middleton, 1973). With projected population increase for the Middleton area, channel erosion may again increase in the basin.

CHANNEL EROSION

Channel changes are largely caused by changes in stream discharge and the sediment load being carried. If peak streamflows tend to increase through the years, the stream channel adapts by increasing its size. The channel also can decrease in size if peak flows diminish. A stream burdened with a sediment load may not have the erosive capacity that it would have

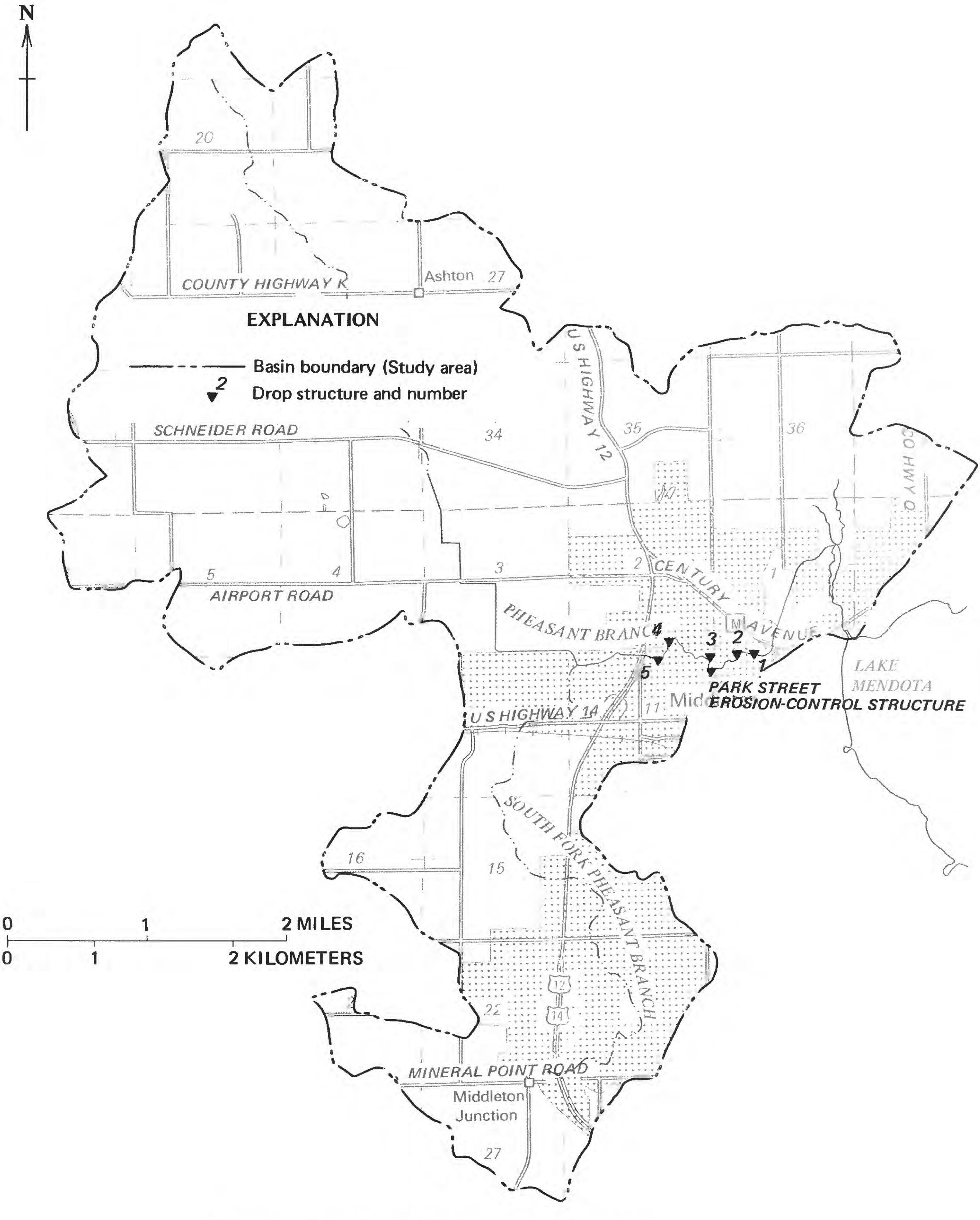

Figure 2. Location of drop structures between Century Avenue and U. S. Highway 12.

if the water carried only a small amount of sediment. Thus, channel size in a stream reach also is affected somewhat by the type and concentration of sediment in the water entering the reach from upstream or from tributaries entering the reach.

Erosion-Control Structures

Because of severe channel-erosion problems between U.S. Highway 12 and Century Avenue, five drop structures were installed by the city of Middleton to decrease stream gradient (fig. 2). The structures also were designed as fords for a nature trail crossing the stream at these locations. An erosion-control structure also is located at the upstream end of the Park Street culvert. Photographs of typical structures are shown in figures 3 and 4.

Figure 3. View upstream of drop structure 4.

Figure 4. View downstream at Park Street erosion-control structure.

The reach between U.S. Highway 12 and Century Avenue is so steep that six structures are not enough to decrease the overall effective stream gradient. Thus, high flow stream-velocity reductions probably occur only in a short reach upstream from each structure where velocities may drop below erosive levels. The structures, however, do inhibit downward cutting of the channel upstream from each structure.

The concrete structure housing sewer and water pipes at the upstream side of the Century Avenue bridge (figs. 5 and 6) inhibits downcutting also. Headward erosion from downstream uncovered the structure sometime before 1971. Severe headward erosion would have continued upstream if the structure had not been present.

Major changes in thalweg elevation (low point in stream channel) have occurred between U.S. Highway 12 and the upstream end of Pheasant Branch Marsh 1 mi upstream from Lake Mendota.

Stream-Channel Changes

The stream channel and flood-plain elevations of Pheasant Branch were determined in 1971 by the U.S. Geological Survey as part of a flood investigation for the Dane County Regional Planning Commission (Lawrence and Holmstrom, 1973). The stream was surveyed from the mouth at Lake Mendota upstream to County Highway K (fig. 1). To assess changes in the stream channel since 1971, the reach was surveyed again in 1977.

Figure 5. View upstream under Century Avenue bridge in 1972 (Note concrete structure across stream at upstream side of bridge).

A plot of thalweg elevation versus stream length (fig. 7) for 1971 and 1977 shows considerable change in some locations during the 6-year period. A second plot of change in thalweg elevation versus stream length (fig. 8) illustrates the magnitude of the changes. The streambed was lower in 1977 by more than 4 ft in some locations whereas in other locations it was 1.5 ft higher. The net overall change in thalweg elevation, as can be seen from the line of zero change, is downward from 1971 to 1977. Average changes in thalweg elevation are presented in table 1.

Photographs of the channel at Century Avenue in 1972 and 1978 illustrate the magnitude of the channel-erosion problem (figs. 5 and 6). The concrete structure in the streambed containing sewer and water pipes was buried beneath the streambed during construction in 1959. About 4 vertical feet of the structure were exposed by 1978. The Century Avenue bridge was widened in about 1973 and the streambanks were riprapped, but this probably did not contribute much to the erosion problems downstream from the bridge.

Some locations of zero or near zero elevation change are at road crossings where culverts are located (Park Street, U.S. Highway 12, Airport Road, Schneider Road). The drop structures also inhibit thalweg degradation upstream. However, there appears to be increased thalweg degradation downstream from most of the drop structures, as can be seen in figure 8.

Some reaches of channel upstream from U.S. Highway 12 were dredged between the 1971 and 1977 surveys. Location and extent of dredging have not been determined at this time.

To evaluate changes in channel size between 1971 and 1977, cross-section properties were computed at each survey site using a common water-surface elevation. The common water-surface elevation was chosen as the elevation caused by the mean annual flood (occurs on the average of once in every 2.33 years). This flood was assumed to represent the channel-forming discharge.

Step-backwater computations were made to determine the elevation of the mean annual flood at each cross section in 1971. Channel width, cross-section area, and mean depth were computed at each cross section for the mean annual flood elevation. The same elevations were applied to the 1977 survey cross sections. Channel width, cross-section area, and mean depth were computed and then compared with the 1971 channel data.

The change in stream-channel width between 1971 and 1977 is shown in figure 9. The mean width of the stream between Pheasant Branch Marsh and County Highway K was 29.5 ft in 1971 and 30.1 ft in 1977, an average increase of about 2 percent. A very large increase in mean width occurred between Pheasant Branch Marsh and Century Avenue, from 34.7 to 47.8 ft between 1971 and 1977. This channel was constructed in 1971 to reroute the

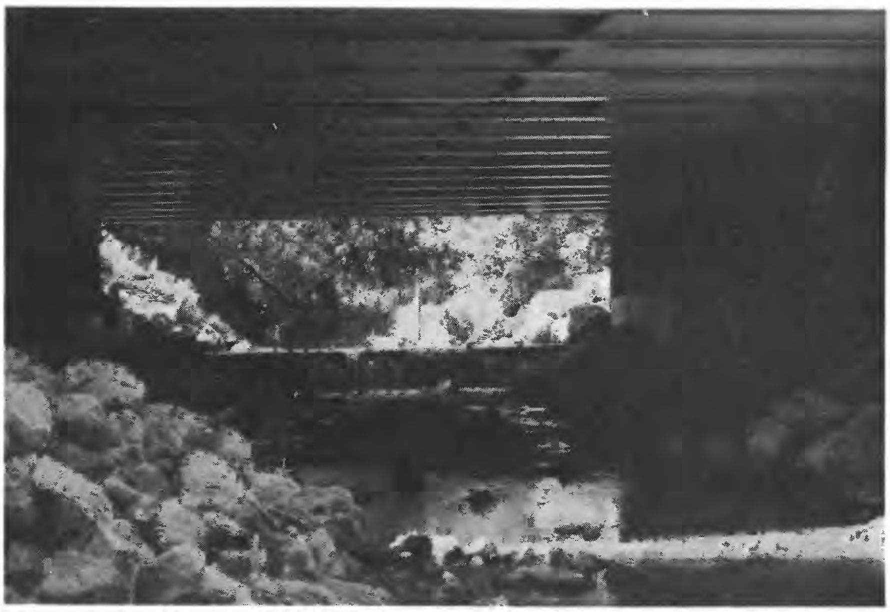

Figure 6. View upstream under Century Avenue bridge in 1978 (Note concrete structure exposed 4 feet vertically).

Table 1.--Change in stream-channel properties between 1971 and 1977

Reach	Location	Average change in thalweg elevation (ft)	Mean channel width (ft)			Mean channel cross-section area (ft^2)		
			1971	1977	Percent change	1971	1977	Percent change
1	Pheasant Branch Marsh to Century Avenue	-2.1	35.3	47.8	35.4	79.7	148	85.7
2	Century Avenue to Park Street	-1.3	28.1	28.9	2.8	93.5	112	19.8
3	Park Street to U.S. Highway 12	-0.1	30.7	30.1	-2.0	110	121	10.0
4	U.S. Highway 12 to South Fork Pheasant Branch	-0.3	31.6	35.8	13.3	124	155	25.0
5	South Fork Pheasant Branch to Airport Road	-0.9	29.6	32.2	8.8	79.0	106	34.2
6	Airport Road to Schneider Road	-1.4	34.3	30.8	-10.2	79.8	91.3	14.4
7	Schneider Road to County Highway K	+0.1	22.6	18.9	-16.4	49.7	43.1	-13.3

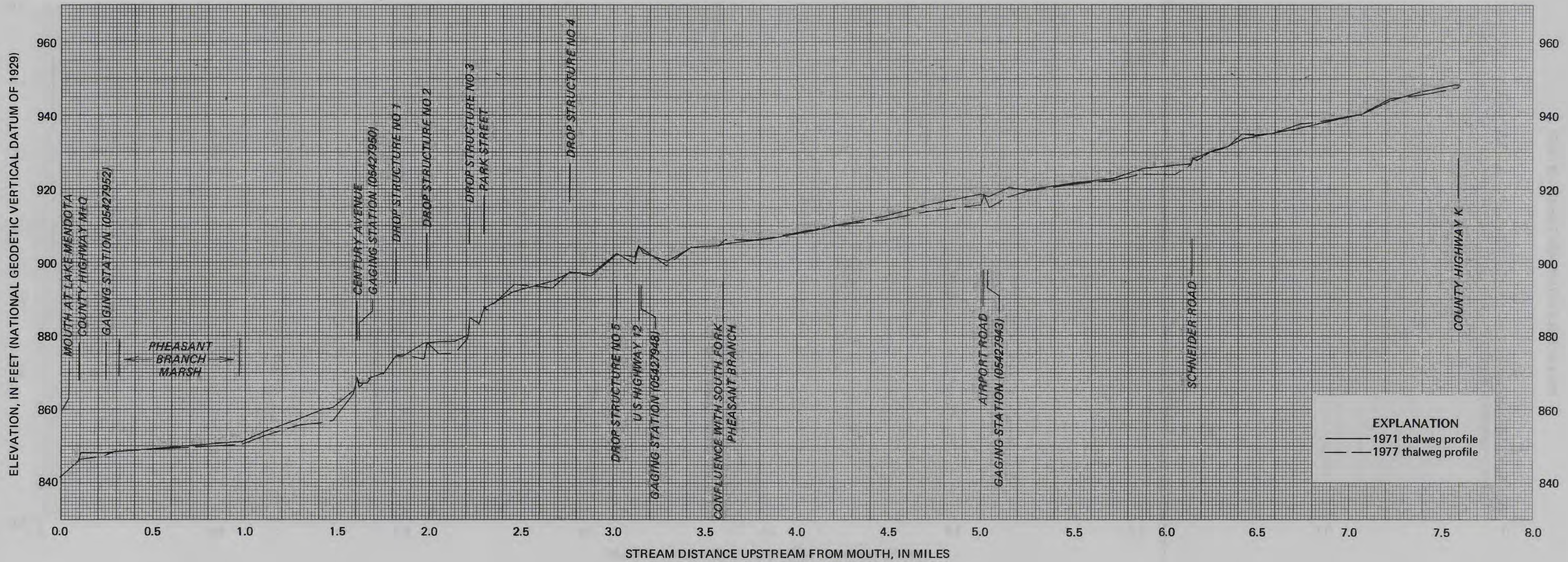

Figure 7. Relationship of thalweg elevation to stream distance.

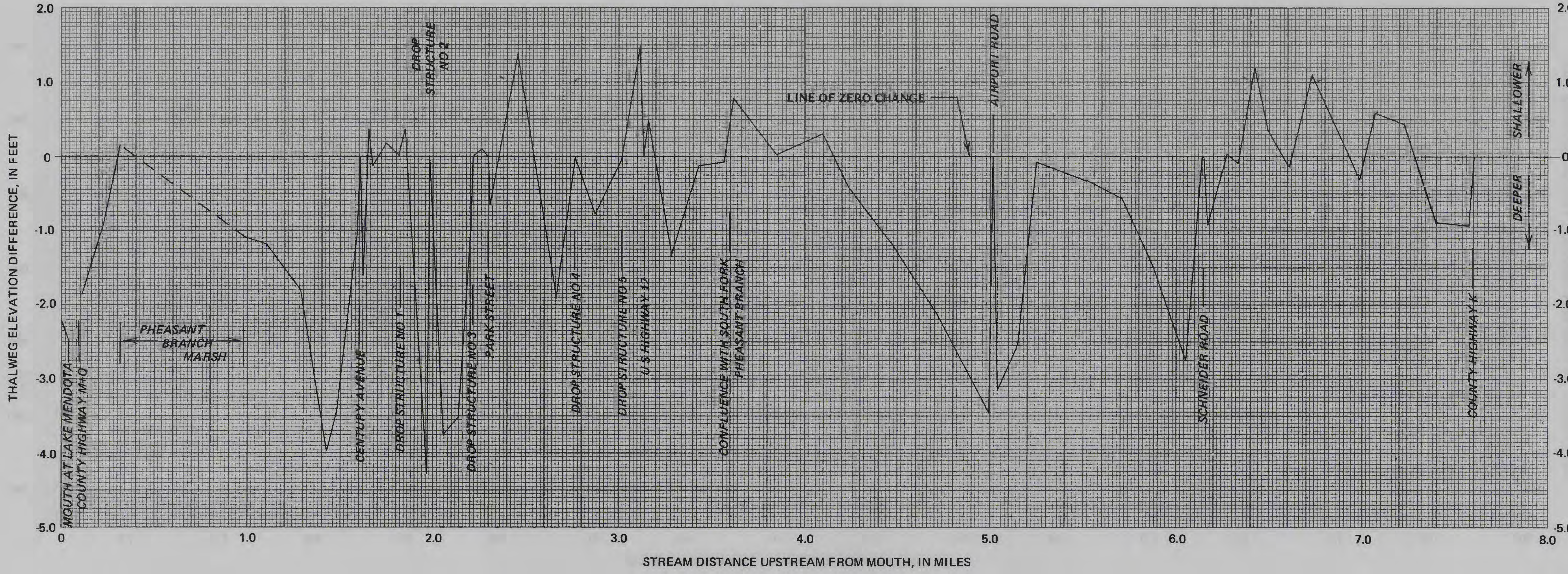

Figure 8. Change in thalweg elevation between 1971 and 1977.

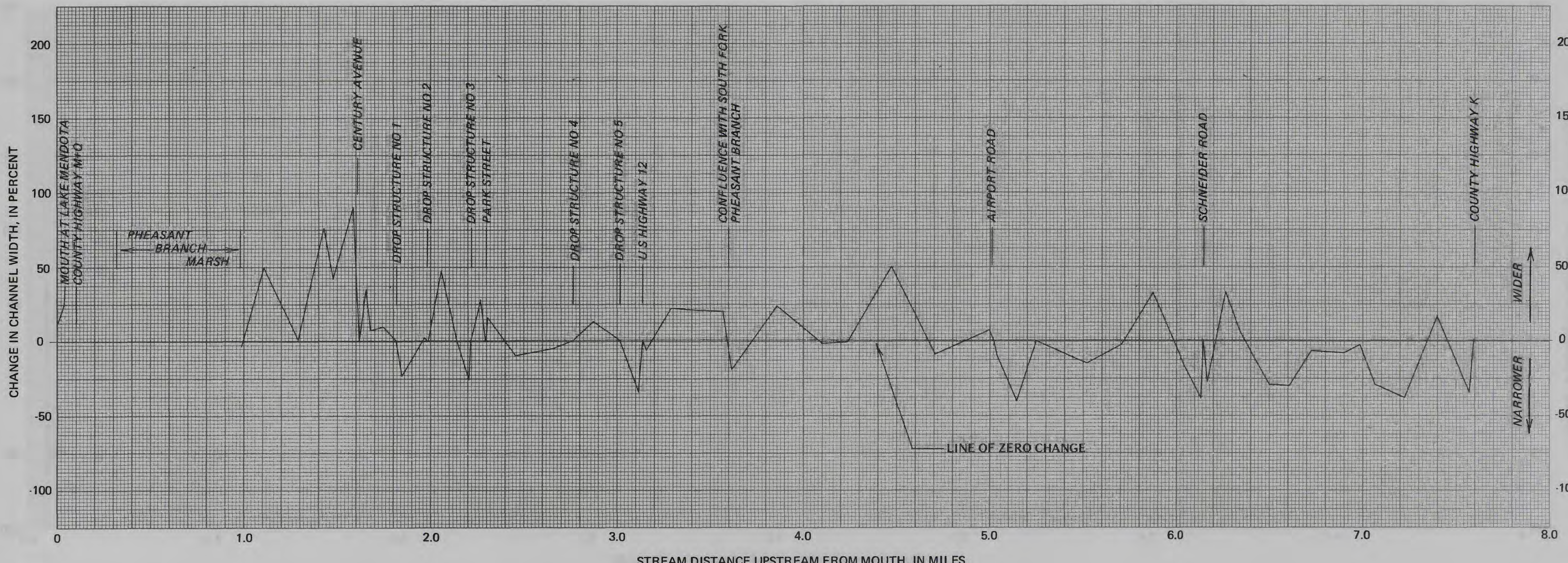

Figure 9. Change in channel width between 1971 and 1977.

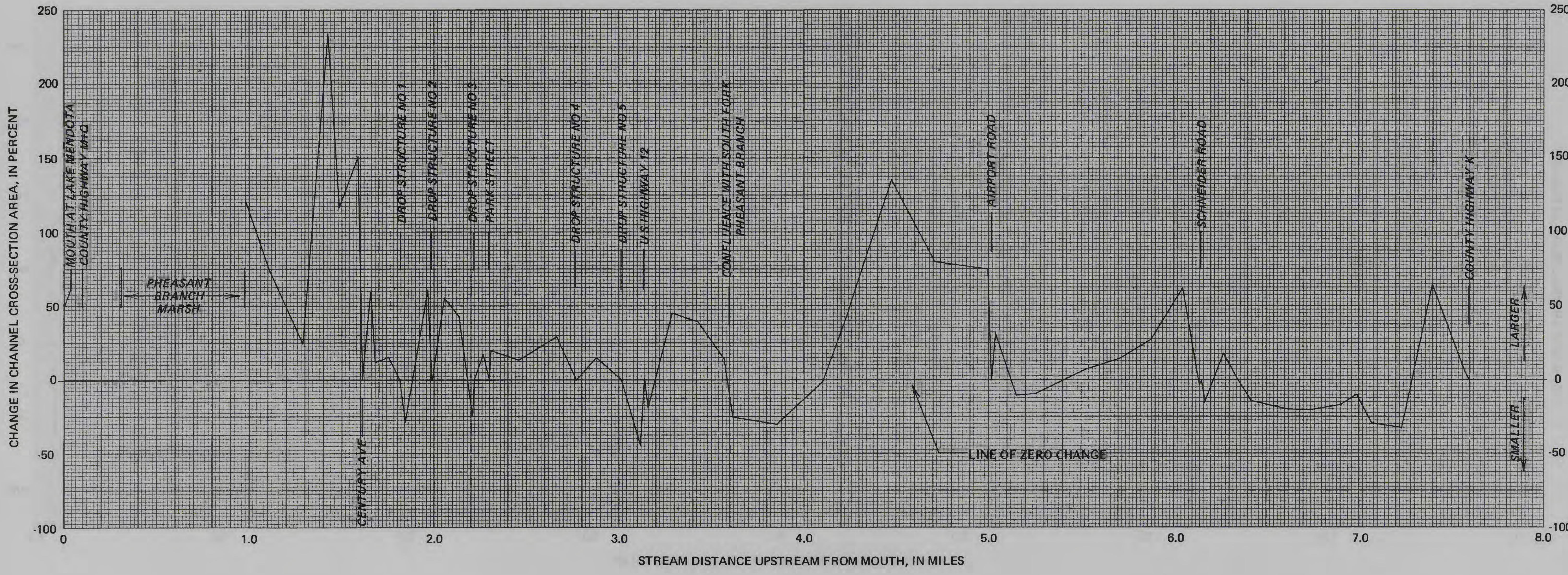

Figure 10. Change in channel cross-section area between 1971 and 1977.

stream through the Pheasant Branch Marsh before it reached Lake Mendota. The large channel changes in this reach may have been caused by the channel adjusting to the flow and also by increased flows caused by urbanization. Table 1 presents channel cross-section data for seven reaches of Pheasant Branch for 1971 and 1977.

The change in channel cross-section area is shown in figure 10. The average channel cross-section area was 81.4 ft^2 in 1971, increasing to 99.4 ft^2 in 1977, a 22.1 percent increase.

Change in channel volume was computed assuming channel length had not changed. Large-scale maps (1 in. = 100 ft) from 1971 aerial photography were used to measure channel length from Lake Mendota to Airport Road. U.S. Geological Survey topographic maps of the area upstream from Airport Road were used. Total channel volume between Pheasant Branch Marsh and County Highway K increased 22.1 percent between 1971 and 1977. The maximum increase was 85.8 percent between the marsh and Century Avenue.

Figure 11. View of bank erosion downsteam from drop structure 5.

Table 2.--Mean stream-channel changes between Pheasant Branch Marsh and County Highway K, from 1971 to 1977

Year	Mean depth (ft)	Mean width (ft)	Mean cross-sectional area (ft^2)	Total volume (ft^3)
1971	2.76	29.5	81.4	2,829,000
1977	3.30	30.1	99.4	3,455,000
Percent change	19.6	2.03	22.1	22.1

A summary of channel changes between the marsh and County Highway K is presented in table 2. These data show that more than 90 percent of the channel erosion was associated with vertical cutting. The bank erosion that occurs generally is above the mean annual flood level. Bank erosion is caused by the erosion of the banks near the channel bed and the consequent slumping of the upper part of the banks into the channel. Soils along Pheasant Branch through the city consist mainly of Rodman sandy loam. This soil is excessively drained and is extremely susceptible to erosion. Also, a good level of plant cover to help prevent erosion (Glocker and Patzer, 1978) is difficult to maintain on this soil. Bank erosion at one site is shown in figure 11.

Sediment Transport

Suspended-sediment load and peak-flow data for stations at U.S. Highway 12 and Century Avenue are presented in table 3 for the major storms in 1978. Suspended-sediment loads for the 1978 water year, October 1, 1977, to September 30, 1978, were nearly the same at both locations. The eight storms accounted for almost 99 percent of the suspended-sediment load for the year.

The decreases in suspended-sediment load for some storms may be caused by sediment trapping and deposition upstream from the drop structures and the erosion-control structure at Park Street. The channel upstream from this structure has been dredged several times, indicating that the structure does trap sediment. The small percentage of differences in suspended-sediment loads also may be subject to measurement accuracy. Further calibration of the automatic samplers may be needed.

Continued monitoring of streamflow and suspended sediment at the gaging stations in the basin will help identify the sources of sediment. The gaging stations at Century Avenue and the mouth of Pheasant Branch will define the effectiveness of Pheasant Branch Marsh in trapping sediment and also provide estimates of suspended-sediment yields to Lake Mendota.

Table 3.--Suspended-sediment load and peak flow at U.S. Highway 12 (05427948) and Century Avenue (05427950) for storms in 1978

Date	Suspended-sediment load (tons)			Peak flow (ft^3/s)		
	U.S. Highway 12	Century Avenue	Percent change	U.S. Highway 12	Century Avenue	Percent change
April 6	13	16	23	31	30	- 3.2
May 12-15	323	318	- 1.5	159	162	1.9
June 16-19	2,254	2,330	3.4	382	383	.3
June 25-27	1,345	1,090	-19	380	378	- .5
June 30-July 3	1,561	1,802	15	479	483	.8
July 20-22	313	314	.3	85	72	-15
September 17-18	435	354	-19	267	236	-12
September 20	85	66	-22	111	93	-16
Totals for 8 storms	6,329	6,290	- .6			
Yearly total (October 1977-September 1978)	6,413	6,363	- .8			

Stream-Channel Changes in the Future

To determine further stream-channel changes and to identify the causes of these changes, detailed channel-morphology studies will continue. To estimate the effect of increased urbanization on sedimentation and stream-channel changes, relations between channel size and streamflow will be studied to determine if increased runoff through the years is the principal cause of the severe channel erosion. Historical streamflow will be simulated with a rainfall-runoff model calibrated by Spooner (1978) in a storm-water-management study for the city of Middleton. Predevelopment streamflow will be compared to postdevelopment flows to determine if runoff has increased substantially. Using stream-channel changes, land-use changes noted over the study period, and projected land-use changes, future stream-channel size can then be estimated by using a model which simulates alluvial channel changes in response to upstream streamflow and sediment discharge (U.S. Army, Corps of Engineers, 1977).

If increasing runoff is the principal cause of channel erosion, a determination might then be made of the streamflow regime necessary to halt or reverse the channel-erosion process in the urban reach. Such runoff reductions may be achieved by land-management techniques that increase infiltration in critical areas that are at present subject to excess runoff. Thus, structural alternatives may not be useful in the basin upstream from the city. Within the city itself, however, structures may be necessary.

SUMMARY AND CONCLUSION

To study channel erosion and sediment transport in the Pheasant Branch basin an extensive data-collection network of streamflow gages, automatic sediment samplers, and rain gages was established during 1977. A stream-channel geometry network of monumented channel-survey sites on Pheasant Branch and its tributaries also was developed.

Comparing a cross-section survey made in 1977 with a 1971 survey made for a flood-plain study shows the channel thalweg lowered 3 to 4 ft at some sites in the urban reach. In the reach downstream from Century Avenue, channel width increased from about 35 to 48 ft, and channel cross-section area increased 86 percent. Effects of six erosion-control structures previously installed by the city in the urban reach have not been thoroughly evaluated, but appear to have had some benefit in controlling head cutting in the channel upstream from each structure.

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