THE EROSION OF A CHANNELIZED STREAM IN AN URBANIZED BASIN AT WINDING HOLLOW COUNTRY CLUB, COLUMBUS, OHIO

A Senior Thesis

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for the Bachelor of Science Degree

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I would like to thank Christopher Merz for his help in the field to measure stream profiles. I would also like to thank Dr. Garry McKenzie for his suggestions, recommendations, and his guidance and understanding in the preparation of this thesis.

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INTRODUCTION

Erosion refers to all processes by which material at or near the surface is decomposed, disintegrated, removed, and transported from place to place. Research on the stream at Winding Hollow Country Club involved the monitoring of erosion within the channel during the nine months from December, 1976 to August, 1977.

In recent years, erosion has been a noticeable problem at Winding Hollow. Widening and deepening of the channel has accelerated to such an extent that large blocks of bank material and trees have fallen into the stream and new bridges have had to be installed. Several factors may be cited for increased erosion, but most of the erosion is probably occurring because of the great increase of urbanization and the recent channelization of the stream. The purpose of this study is to document the amount of erosion which occurred in the channel over the nine month monitoring period.

I became aware of the channel erosion problem at the country club while employed there for three summers (1974-1976). I observed the stream before and after channelization, which allowed me to note the changes that took place.

The Hydrologic Cycle and Runoff

In a drainage basin, water from rainfall reaches the ground and flows by gravity from higher to lower topography. That part of rainfall that occurs as runoff, subsurface flow, and groundwater flow makes up total runoff. The flow of water overland and into channels occurs rather quickly after rainfall and is known as runoff. Subsurface flow is water which infiltrates the upper layers of soil and percolates through the soil laterally to a channel such as a stream. The water which infiltrates deep into the regolith or bedrock before reaching a stream is known as groundwater flow. Streamflow following a storm is largely in response to runoff; the groundwater and subsurface response is slower and with less volume. The volume of total runoff is proportional to the amount of rainfall, land slope, infiltration, vegetation, soil type, and urbanization in a drainage basin. Besides total runoff, some water from rainfall is retained by vegetation, evaporates at the surface, or is trapped in depression storage areas (ponds and lakes).

The Unit Hydrograph

In a basin, both the peak flow and volume of runoff for an average time of a standard storm may be expressed by the unit hydrograph. The unit hydrograph shows the percentage of the storm runoff occurring in each successive unit. A standard storm can be derived from measuring individual storms at gaging stations.

Figure 1 is a hypothetical unit hydrograph taken from Leopold (1963) representing an undisturbed basin. One significant parameter which relates the storm and runoff is the lag time. Lag time is the interval between the center of mass of rainfall and the center of mass of the resultant hydrograph. Lag time is a function of the mean basin slope and basin length.

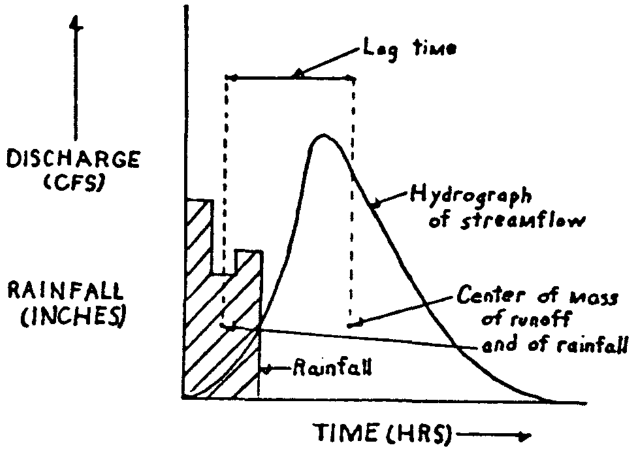


Figure 1. Hypothetical unit hydrograph of an undistrubed basin. (Leopold, 1963.)

THE NATURE OF THE DRAINAGE BASIN

The drainage basin which directs runoff to the stream at Winding Hollow Country Club is located in Franklin County on the northeast side of Columbus, Ohio. The western portion of the basin lies within Clinton Township while the eastern portion lies within Mifflin Township. It has an area of 1.69 square miles and a maximum relief of 120 feet (Figure 2). The bedrock in the area is not exposed because of the thickness of the glacial till cover. The glacial till, and more importantly the soils, play a major role in the amount of total runoff in the basin.

Bedrock Geology

The youngest bedrock in the study area is the Devonian Ohio and/or Olentangy shale (Figure 3). It is carbonaceous to arenaceous and has a gentle southeasterly dip. The shale has a maximum thickness of 480 feet and occurs at a minimum of 150 feet below the surface.

Glacial Geology

The Wisconsinan till in the area occurs mainly as ground moraine and is clay and silt rich; although it does contain

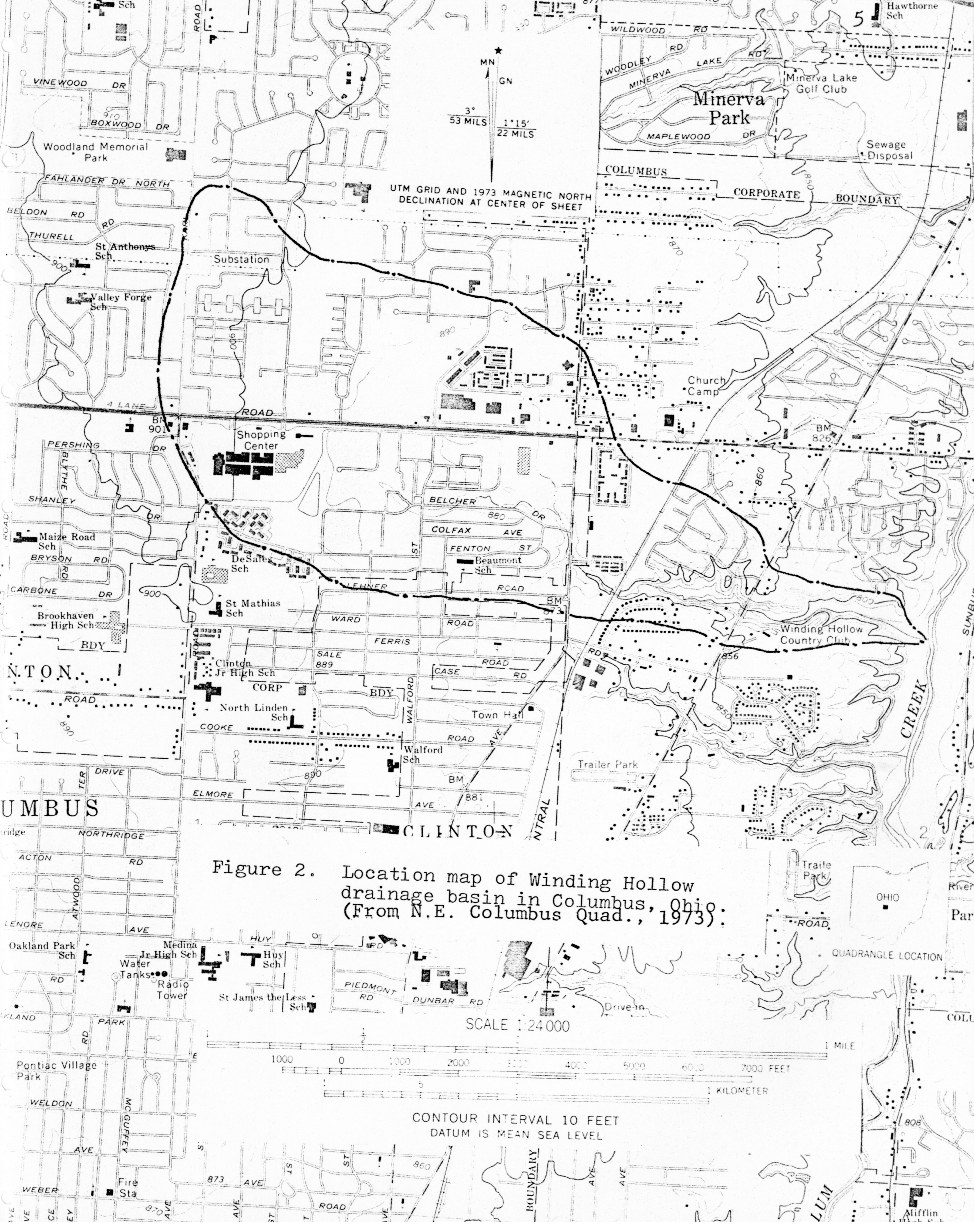
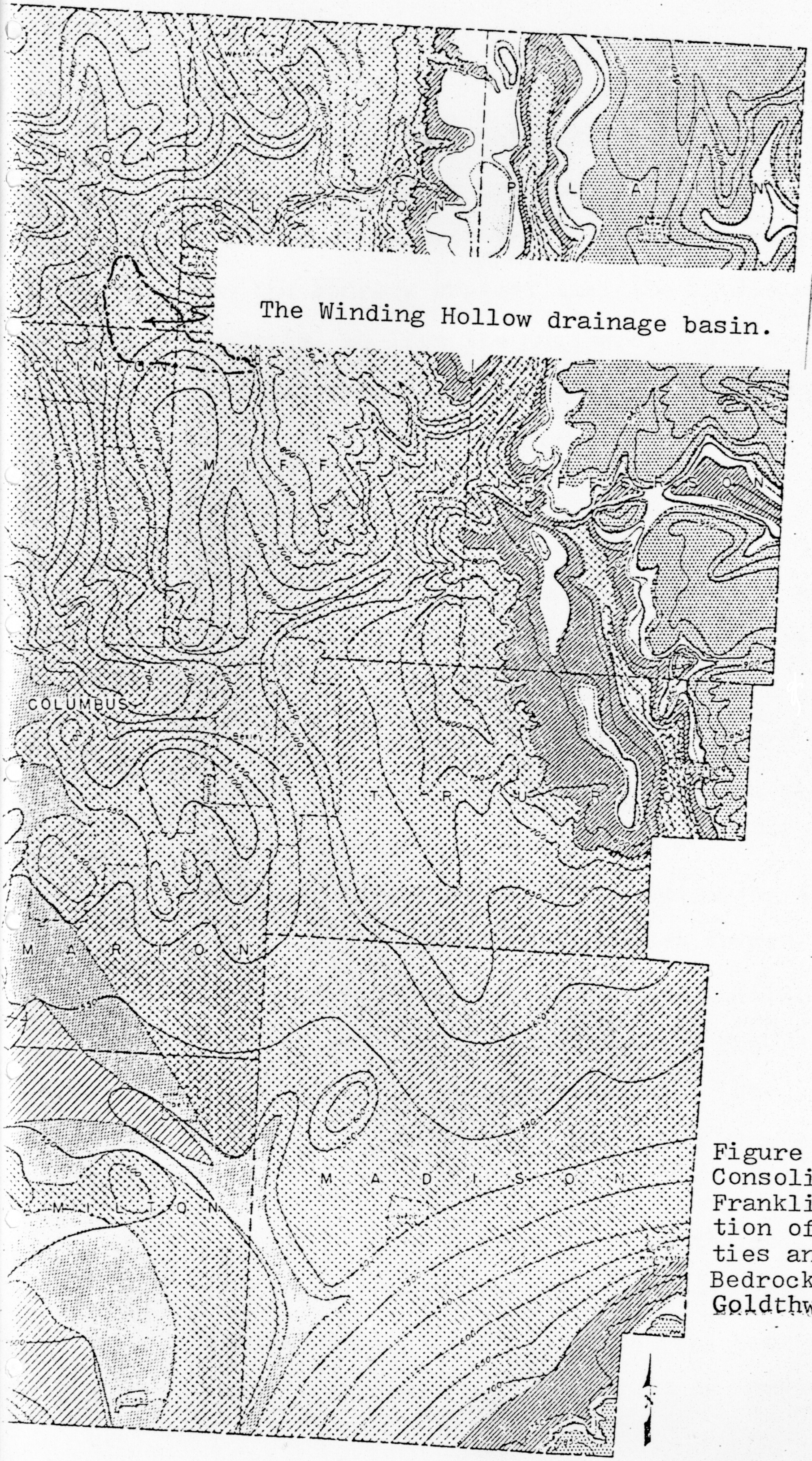


Figure 2. Location map of Winding Hollow drainage basin in Columbus, Ohio. (From N.E. Columbus Quad., 1973).



EXPLANATION

MISSISSIPPIAN

▩ **LOWER CUYAHOGA FORMATION**
Series of alternating layers of sandy shale and sandstone. Ample water supplies are available for farm, domestic, and small industrial use. Potential yields of as much as 30 gpm may be expected from the sandstone layers.

☐ **SUNBURY SHALE**
This argillaceous shale is not considered to be a reliable source of ground water.

☐ **BEREA SANDSTONE**
Thin to massively bedded sandstone ranging from 5 to 55 feet thick. Yields of as much as 25 gpm may be developed in Blendon, Plain, and Jefferson Townships.

▨ **BEDFORD SHALE**
Soft argillaceous shale 50 to 90 feet thick. Very poor source of ground water in Franklin County.

DEVONIAN

▦ **OHIO AND/OR OLENTANGY SHALE**
Carbonaceous shale grading to soft clayey shale. Not a dependable source of ground water in the county. Generally yields less than 2 gpm.

▩ **DELAWARE AND/OR COLUMBUS LIMESTONE**
The Delaware formation is a thin to massively bedded dense limestone, with some thin shaly layers. Yields of less than 3 gpm may be expected. The Columbus limestone is the principal aquifer in the western half of Franklin County. Industrial supplies may be developed, however, relatively high hardness, dissolved solids, and hydrogen sulfide may be characteristic of water from deep wells.

SILURIAN

▨ **BASS ISLANDS DOLOMITE**
The Bass Islands dolomite is exposed in Pleasant Township and crops out beneath thick glacial fill in the buried valleys of western Franklin County. It is the most important bedrock acquifer in the county and has a potential yield of up to 400 gallons a minute. As with other limestone aquifers in the county, the degree of mineralization increases with depth.

Figure 3. Map of a Portion of the Consolidated Rock Units in Eastern Franklin County, Ohio with Description of their Water-Bearing Properties and Showing Contours on the Bedrock Surface. (Schmidt and Goldthwait, 1958).

ALTITUDE IN FEET ABOVE SEA LEVEL
CONTOUR INTERVAL 50 FEET

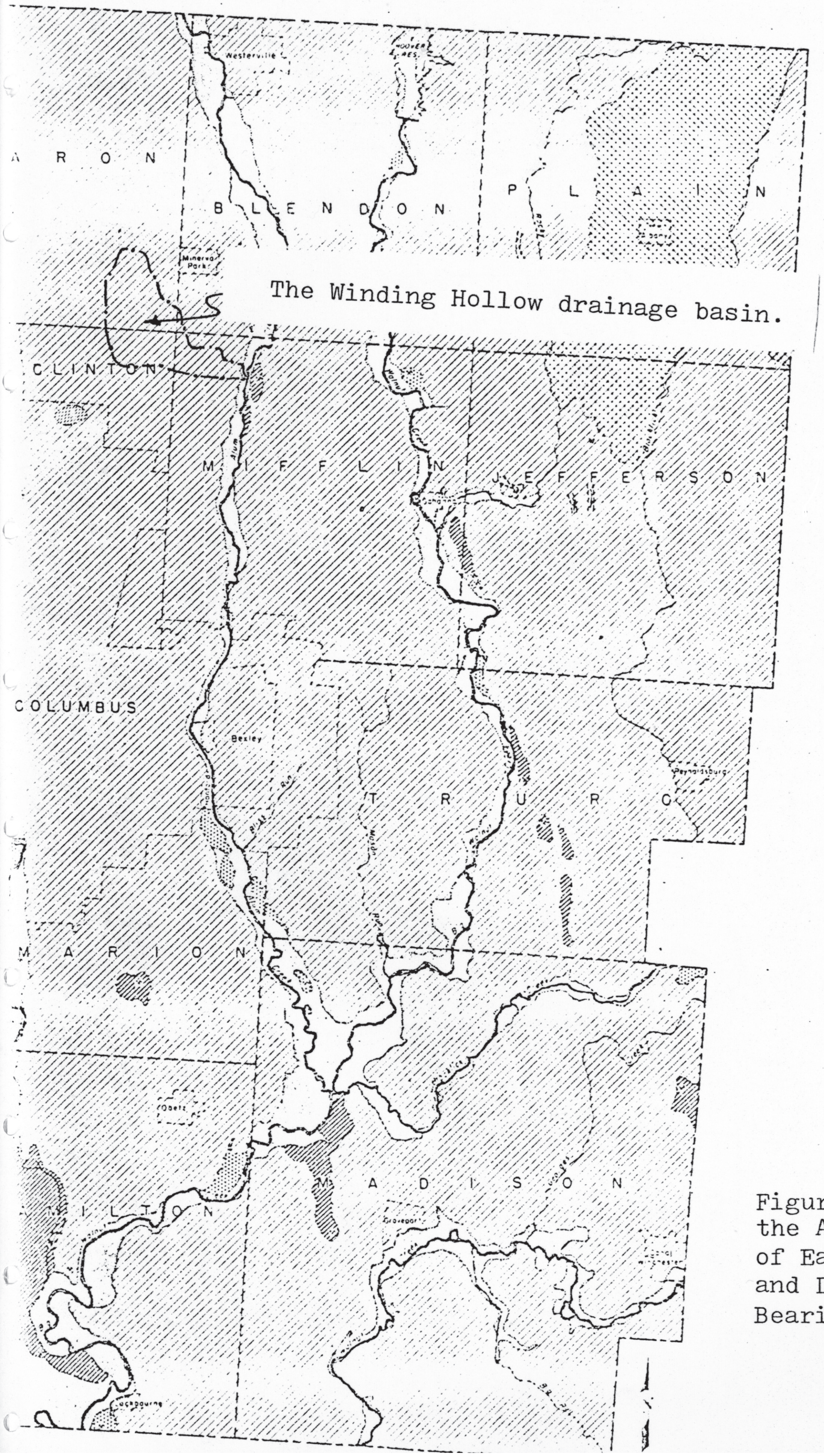
SCALE IN MILES
0 1 2 3 4

many pebbles and boulders (Figure 4). More than 80 percent of these boulders are dolomitic and some are up to five feet in diameter. The axes of the rocks and the striations on the bedrock suggest that the source of this glacial material is from the northwest. The soils are from 34 to 60 inches deep in the till, except near the stream channel where till often outcrops.

Soils

The three major soil groups which are found in the nearly level and gently sloping areas of the basin are the Bennington and Cardington silt loams and the Pewamo silty clay loam. In the upper portion of the stream channel, the Alexandria silt loam is found and occupies gently sloping to steep topography. These soils formed in deposits of silt and clay loam glacial till. Occupying the lower stream flood plain is the Eel silt loam which formed in loamy recent alluvium deposited by flood waters (Figure 5). Some distinctive properties of a soil include drainage conditions, permeability, and water capacity. The soils found in the Winding Hollow drainage basin are discussed under these categories.

The drainage conditions of the soils are classified from very poorly-drained to well-drained. The Pewamo and the Bennington loams both are very poorly drained soils in that the water table remains at or near the surface for the



The Winding Hollow drainage basin.

EXPLANATION

RECENT

☐ **ALLUVIAL DEPOSITS**
Silt and gravel deposited by the present streams on their flood plains. Because these deposits are thin and generally impermeable, they are not a source of ground water. Wells that penetrate these deposits may encounter valley-train deposits, and yield large ground-water supplies.

PLEISTOCENE (WISCONSIN STAGE)

▨ **VALLEY-TRAIN DEPOSITS**
Outwash deposits of sand and gravel deposited in the valleys by flooding meltwater from the glacier. These deposits occur above present drainage as gravel terraces and generally do not receive infiltration from major streams. These deposits are very permeable and increase the recharge potential for the underlying formations, which usually consist of valley-train deposits below drainage.

▨ **KAMES AND ESKERS**
Sand and gravel deposited as hills and ridges. Some of these are covered with thin till or contain till masses. Quantity of water obtainable depends upon the thickness of the material and amount of recharge.

▨ **END MORAINE**
Generally till, in places stony or sandy, with interbedded sand and gravel lenses. Deposited as hills and ridges at the edge of the glacier. Small farm and domestic water supplies are generally developed from wells in the lenses of sand and gravel.

▨ **GROUND MORAINE**
Till generally more than 20 feet thick, although bedrock may be exposed in a few places. Meager water supplies in the till, but adequate supplies for farm and domestic use are sometimes developed in the thin lenses of sand and gravel inerbedded in the till.

▨ **LAKE BEDS**
Clay and silt which settled in small lakes near the melting ice edge. These deposits range from 10 to 20 feet thick and are not a source of ground water.

Drainage Channels

Gravel Pit

Figure 4. Map of a Portion of the Alluvial and Glacial Deposits of Eastern Franklin County, Ohio and Description of their Water-Bearing Properties. (Schmidt and Goldthwait, 1958)

GEOLOGY BY RICHARD P. GOLDTHWAIT

SCALE IN MILES
0 1 2 3 4

Figure 7

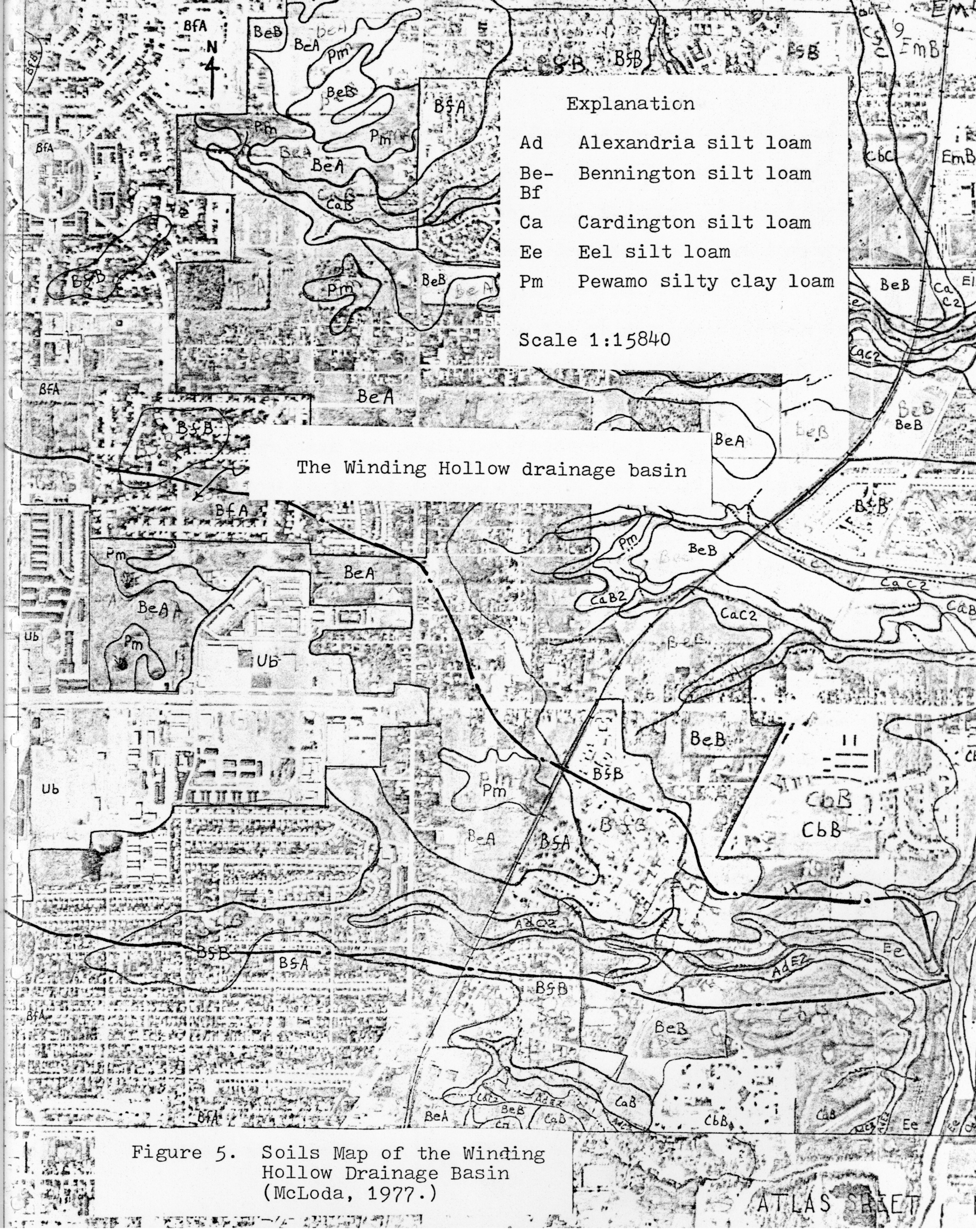


Figure 5. Soils Map of the Winding Hollow Drainage Basin (McLoda, 1977.)

greater part of the year. The Cardington and the Eel loams are moderately well-drained soils; water is removed from the soil slowly and the soil is wet only for part of the time. The Alexandria silt loam is well-drained which means water is readily removed from the soil, but not rapidly.

The permeability refers to the rate at which water moves downward in undisturbed soil material in the absence of a seasonal or temporary water table (McLoda,1977). The soils in the drainage basin all have moderately slow permeability (average 0.06 to 0.6 inches of water per hour) in the subsoil and in the underlying glacial till (Table 1). This can be compared to a gravel soil with rapid permeability (greater than 6.0 inches of water per hour).

The water capacity is a measure of the ability of a soil to hold water. The Bennington, Cardington and Alexandria silt loams have moderate water capacities while the Pewamo and Eel loams have high water capacities. In determining available water capacity, the most important soil characteristics are organic matter content, texture and structure.

In general, most of the soils in the drainage basin have a high water table, moderately slow permeability, and a moderate water capacity. These properties suggest a low infiltration capacity of the soil. One reason for this is the high water table which indicates an already wetted soil with little subsurface flow. Also the slow permeability implies little porosity within the soil, and the moderate water capacity shows that only a small amount of water can be held. Bruce (1966) states that runoff occurs when the precipitation rate exceeds the infiltration capacity of the soil. Thus, for the soils of the Winding Hollow drainage basin, the runoff is expected to be relatively high since the infiltration capacity of the soil is low for any given storm.

Name	Depth to Seasonal High Water Table (feet)	Depth from Surface (inches)	Range in Permeability (in.per hr.) (1)-(2)	Available Water Capacity (in.per in. of soil)
Alexandria silt loam	4	0-8	2.0-6.0	0.14-0.18
		8-42	0.2-2.0	0.10-0.16
		42-60	0.2-2.0	0.08-0.12
Bennington silt loam	½ to 1½	0-9	2.0-6.0	0.16-0.20
		9-35	0.06-0.6	0.10-0.16
		35-60	0.06-0.2	0.08-0.12
Cardington silt loam	1½ to 3	0-6	2.0-6.0	0.16-0.20
		6-34	0.2-0.6	0.10-0.16
		34-60	0.2-0.6	0.08-0.12
Eel silt loam	1½ to 3 (subject to flooding)	0-9	2.0-6.0	0.18-0.22
		9-37	0.6-2.0	0.14-0.18
		37-60	0.6-2.0	0.08-0.12
Pewamo silty clay loam	0 to ½	0-13	2.0-6.0	0.18-0.24
		13-44	0.2-0.6	0.14-0.18
		44-60	0.2-0.6	0.10-0.14

Table 1. Some Estimated Properties of the Soils in the Winding Hollow Drainage Basin (McLoda,1977).

CHANGES IN THE DRAINAGE SYSTEM

Urbanization of the Basin

Urbanization is the construction of residential and/or commercial establishments, roads, streets, parking lots, and other impermeable surfaces, and construction of artificial channels such as storm sewers and culverts. As the basin undergoes urbanization, the amount of impermeable surface and artificial channels increase. This allows less water to infiltrate to the water table and more to contribute to runoff. Figure 6 is a hypothetical graph adapted from Leopold. It compares the amount of runoff for a standard storm before and after a basin was urbanized. As expected urbanization increases volume of runoff for any particular storm. In East Meadow Brook, Long Island, New York, Seaburn (1969) found that urbanization increased runoff from 1.1 to 4.6 times, with an average increase of 2.5 times.

With a great volume of runoff being channeled artificially, the current velocity increases, thus allowing more runoff to the stream in a shorter period of time. As Figure 7 of the unit hydrograph indicates, for any given storm the lag time is less and the peak discharge is greater within an urbanized basin.

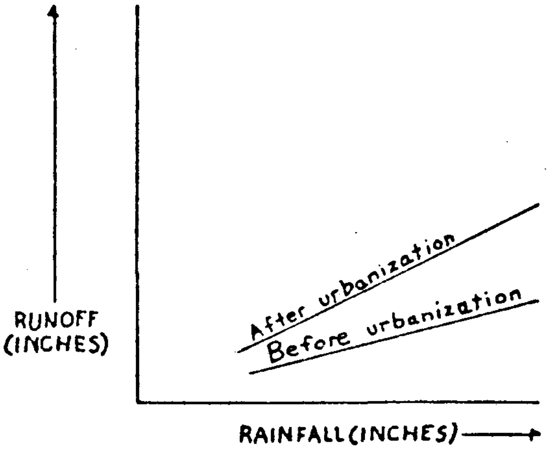


Figure 6. Hypothetical graph of a standard storm before and after urbanization. (Adapted from Leopold, 1963.)

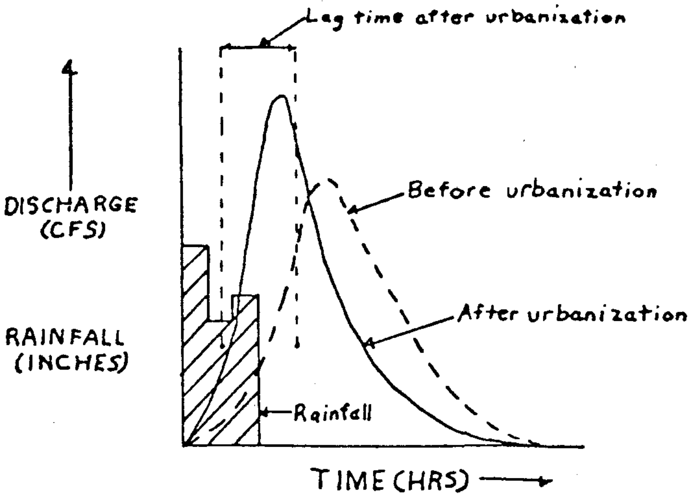


Figure 7. Hypothetical unit hydrograph of a basin before and after urbanization. (Leopold, 1963.)

Since the discharge for any given storm increases with urbanization, the flood peaks occur more often within the basin. Anderson (1970) found in northern Virginia that urbanization increased the amount of flood peaks by a factor of 2 to 3. Johnson and Sayre (1973) indicate in their study conducted in Houston, Texas that urbanization increased the 50 year flood by a factor of nine. As expected, the effects are greater for smaller recurrence intervals than for larger recurrence intervals of flood peaks.

In recent years, there has been a significant increase of urbanization within the Winding Hollow drainage basin. Appendix I discusses the methods of determining percentage of urbanization and impermeable surfaces. For example, in 1955 the study area was estimated to be 10 percent urbanized with 2.16 percent of the surface being impermeable. Today the basin is estimated to be 69 percent urbanized with 14.9 percent impermeable surface. This increase in urbanization contributes to a greater amount of discharge in the basin for any particular storm by means of more runoff and a higher current velocity. Therefore the potential for increased erosion and more flood peaks has been intensified. Figure 8 shows an example of the more common place flooding which has recently occurred in the drainage basin.

8A. Normal flow of stream before rainfall.

8B. Overbank flow of stream after heavy rainfall.

Figure 8. Flooding in the Winding Hollow Drainage Basin.

Channelization of the Stream

The stream at Winding Hollow was channelized in the Autumn of 1974 to prevent its meandering onto the fairways of the country club. Figure 9 is a map of the stream indicating the location of the channel before and after channelization. As shown, part of the stream was moved within the south valley wall. In this area the channel has a low sinuosity and is unstable due to high, steep till banks with little vegetation. These banks are very susceptible to erosion, especially since urbanization has increased the discharge for any given storm.

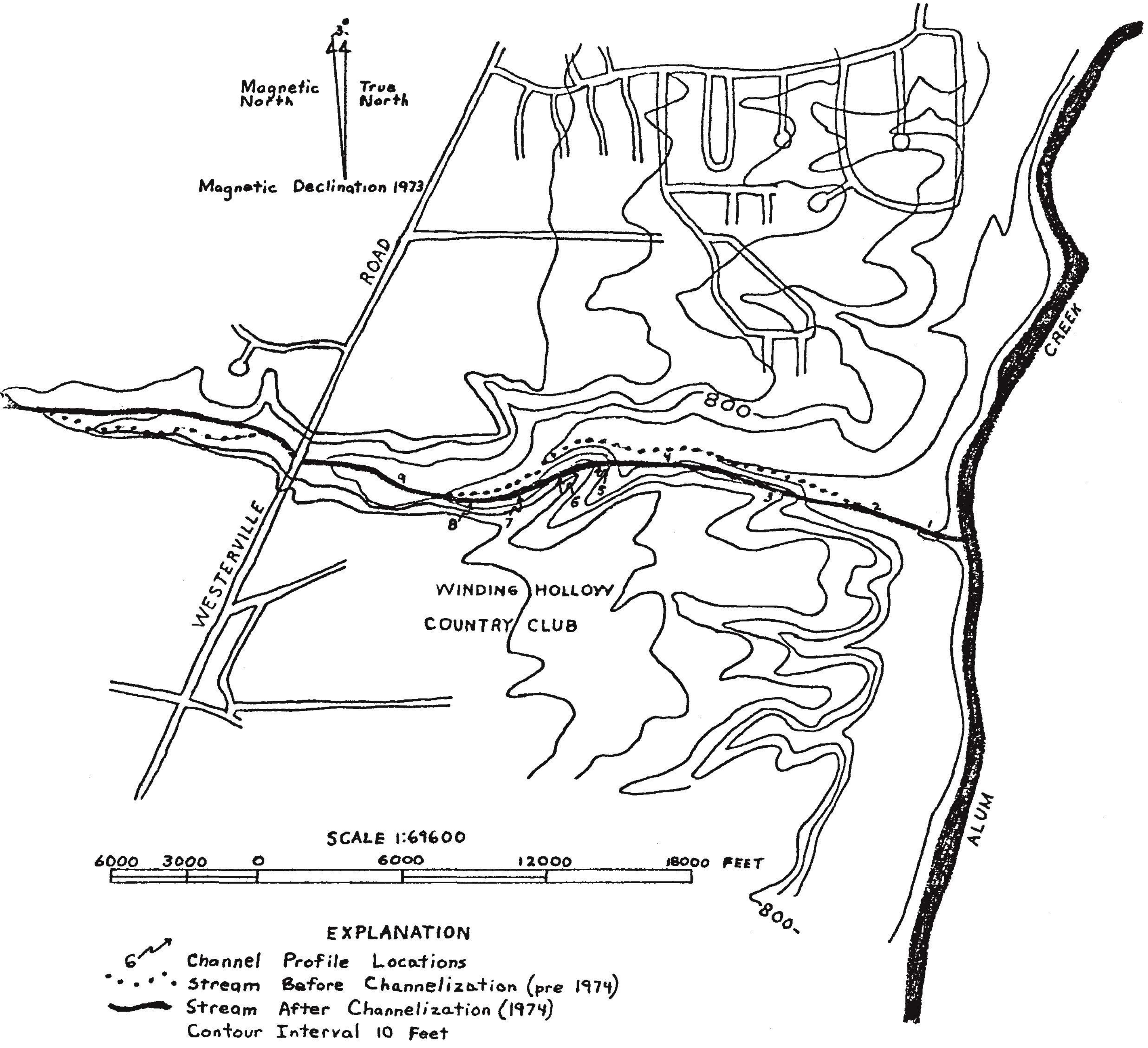


Figure 9. The stream at Winding Hollow before and after channelization. (Adapted from N.E. Columbus Quad., 1973).

DISCHARGE OF THE BASIN

Due to the fact that no stream gage was installed to determine actual discharges during storm events, there is no record of maximum discharge for the nine-month period of study. In an attempt to estimate the minimum discharges that might occur, calculations for the Winding Hollow drainage basin are shown in Table 2 according to the equation used in 1977 publication of Floods in Ohio by Webber.

The equation that relates the discharge for peak flows to basin parameters has been developed for many gaging stations through multiple regression analysis of data. In Ohio, the equation is only useful for drainage basins that lie in the following areas: the Little Scioto River basin, Great Miami River basin, Mississinewa River basin, and the Wabash River basin. This regression equation is only accurate for unregulated streams and unurbanized drainage areas. Therefore the discharge for peak flows are probably at a minimum in the Winding Hollow basin because of the effect of urbanization.

Equation, based on 82 gaging stations: $Q_t=aA^wSl^xE^yP^z$

where:

Q_t= discharge in ft^3/s for a T year recurrence interval

A = drainage area in $miles^2$= 1.69

Sl= main-channel slope in ft/mile= 92.2

E = average basin elevation index in 1000's of feet above mean sea level= 0.805

P = average annual precipitation in inches minus 27.0= 36.0-27.0=9.0

a = regression constant

w,x,y,z = regression exponents

Peak discharge in ft^3/s

Q_2 (2 - year) = 268
Q_5 (5 - year) = 477
Q_{10} (10 year) = 633
Q_{25} (25 year) = 857
Q_{50} (50 year) = 1027
Q_{100} (100 year) = 1213

Table 2. Calculated Discharge for the Winding Hollow Drainage Basin (Unurbanized).

EROSION OF THE STREAM CHANNEL

Technique

The stream channel at Winding Hollow was monitored to document the amount of erosion which occurred from December, 1976 to August, 1977. As shown in Figure 9, the nine areas which were monitored lie between Westerville Road and Alum Creek and most of them occur in the channelized area. The method of monitoring the erosion at each area consisted of installing a marker on both sides of the channel and connecting them with a taut rope perpendicular to the stream. The rope is marked off in one-foot increments and the vertical distance between the rope and channel is measured at each of these increments. During the monitoring period each area was measured three to four times to establish a profile. The profiles show graphically the amount of erosion which occurred in these areas within the nine-month period.

Channel Profiles and Erosion

At Winding Hollow, the channel has been subject to a large amount of erosion. Two processes of erosion which have greatly effected the stream are mass movement and hydraulic action. Mass movement occurs when the soil becomes thoroughly wetted causing the banks to weaken. Therefore slumps and falls occur along the stream bank. Mass movement is also created by the stream undercutting the slope of the banks. The force of water striking against the bottom and the banks of the channel involves hydraulic action which removes and transports material downstream. These erosional processes are responsible for the widening and deepening of the stream channel.

Table 3 reveals the amount of channel erosion from each area as documented by the profiles made during the study period. The locations of the profile areas are shown on Figure 9.

Profiles 5 and 6 (Figure 10) represent the two areas that exhibited the greatest amount of erosion. The volume of material that eroded between these two areas is estimated to be approximately 25,555 feet.^{3} A similar area, as shown in profile 3 (Figure 11) is located further downstream and has also lost a large amount of material. These areas have eroded greatly because of the stream channelization within the unstable south valley wall. At these locations, the till walls occur on a slope and are high and steep with little vegetation. Therefore the walls are very susceptible to hydraulic action and mass movement. Figure 12 reveals a slump structure that occurs in the area of profile 3. The structure was observed during the first Spring after channelization (1974) and was probably caused by saturation of

Profile	Erosion(ft.^{2})	Explanation of Area
1	1	unchannelized; low, vegetated, sloping banks; near mouth of stream.
2	1	unchannelized; low,vegetated, sloping banks; valley location.
3	35	channelized; high, steep, unvegetated banks; south valley wall location; low sinuosity; slumping.
4	3	channelized; high, steep, unvegetated banks; valley location.
5	160	channelized; high, steep, unvegetated banks; south valley wall location; low sinuosity.
6	109	channelized; high, steep, unvegetated banks; south valley wall location; low sinuosity.
7	42	channelized; low, vegetated banks; valley location; less resistant carbonate till and unconsolidated channel sand and gravel.
8	11	channelized; low,vegetated banks; valley location.
9	15	unchannelized; low, terraced, vegetated banks; valley location; removal of culvert caused downcutting of stream to bring gradient to equilibrium.

Table 3. Channel Erosion Documented from Area Profiles.

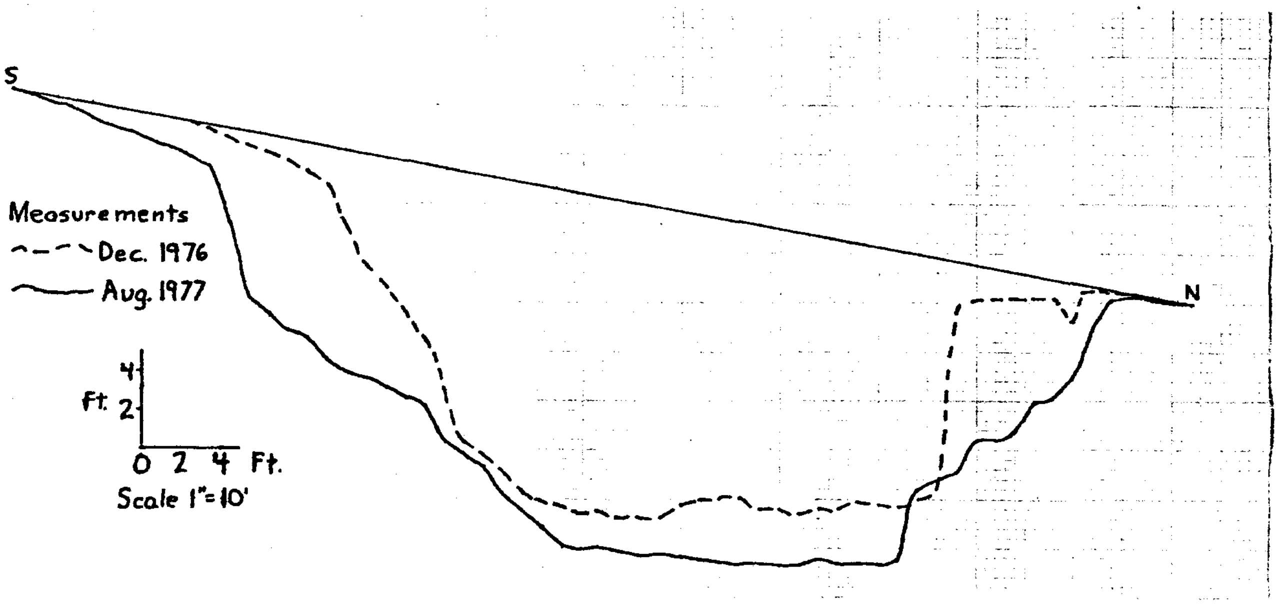


Figure 10A. Profile 5

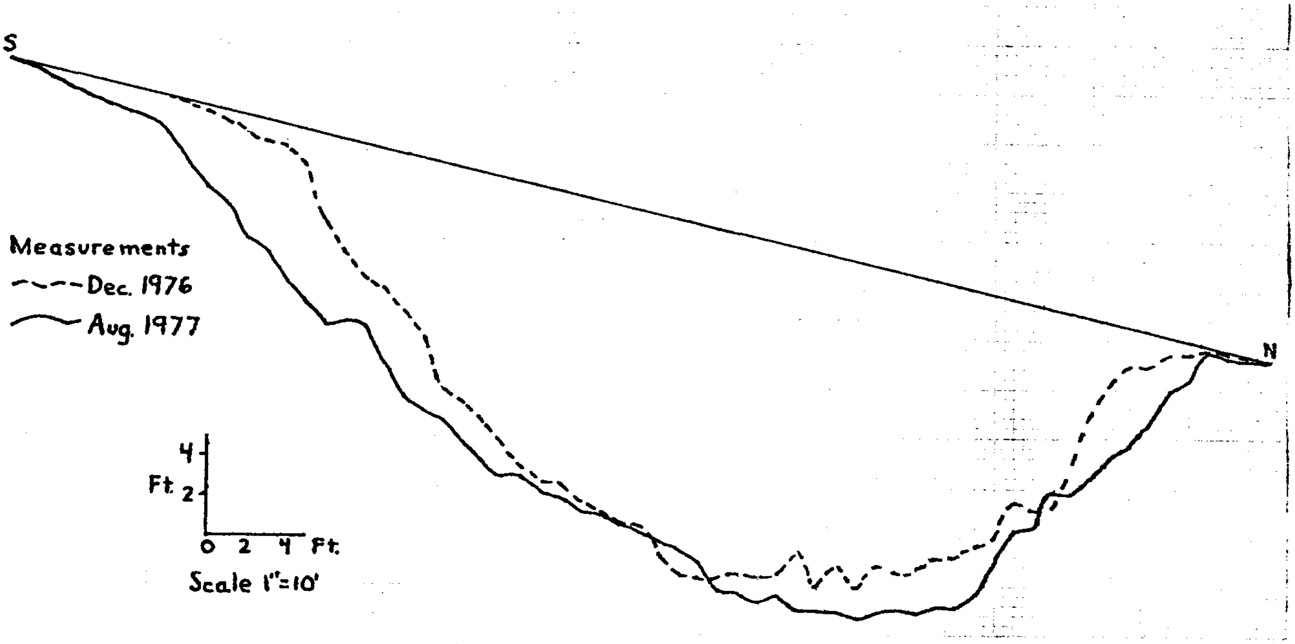


Figure 10B. Profile 6

Figure 10. Changes in the Stream Channel in the Areas of Profiles 5 and 6.

Figure 10C. Upstream view of Profiles 5 and 6 in December, 1976. Banks are steep and large blocks of material have fallen into the stream.

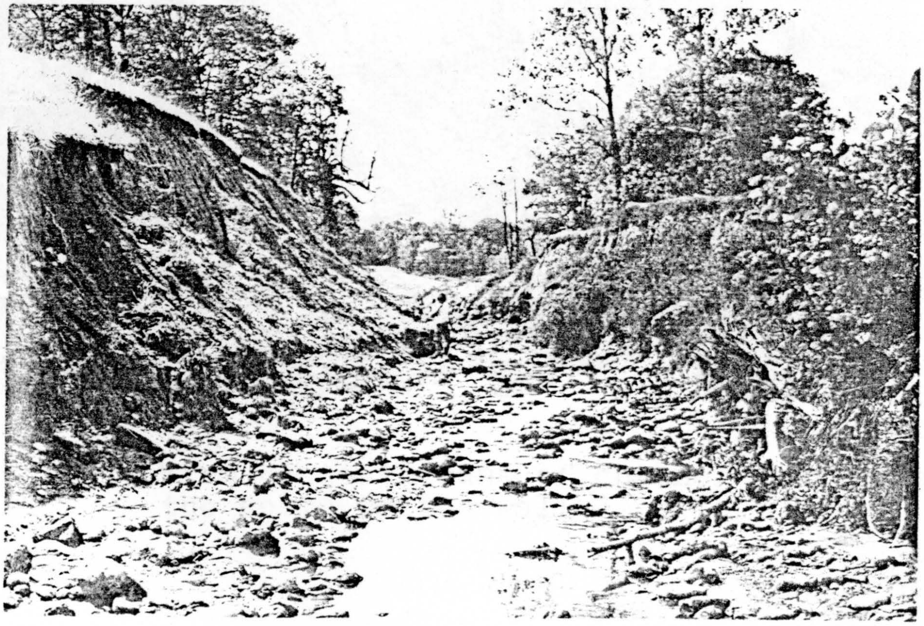


Figure 10D. Upstream view of Profiles 5 and 6 in August, 1977. Banks are less steep and smaller material slides into the stream.

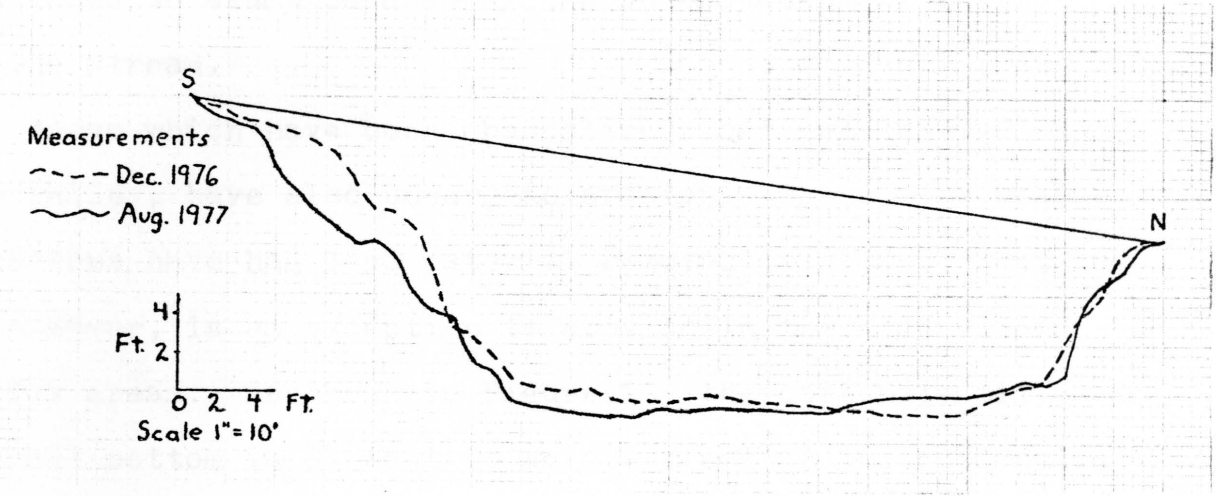


Figure 11A. Profile 3.

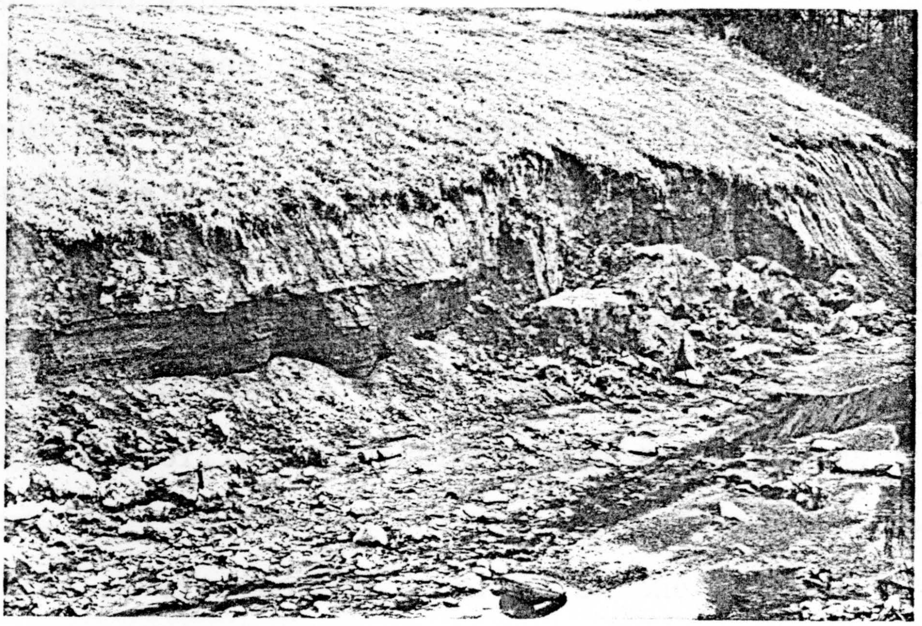


Figure 11B. View of south bank of channel located along the south valley wall.

Figure 11. Changes in the Stream Channel in the Profile 3 Area.

bank material over the previous Winter. The bank still continues to slump because of the undercutting of the toe by the stream.

Areas which have been channelized, but are located in the valley, have also undergone erosion. These more stable locations have had less material removed. (Table 3) Profile 7, however, is an exception to erosion in the channelized valley areas. As shown in Figure 13, the carbonate till channel bottom is downcut to an older bed of unconsolidated sand and gravel. This underlying channel fill is easily eroded when exposed.

Profile 9 has undergone erosion processes even though it does not occur in the channelized area. (Figure 14) The removal of a culvert 40 feet downstream from profile 9 has resulted in downcutting of the channel in an attempt to bring the stream back to an equilibrium gradient. Measurements made before the culvert was removed showed negligible change in profile. However, within three months (June - August, 1977) after the culvert was removed, approximately 15^2 feet of erosion had occurred in the channel bottom.

The two profile areas downstream from channelization underwent little change during the monitoring period. Profiles 1 and 2 (Figure 15) exhibit the least amount of erosion in the study area. These low sloping vegetated banks, characteristic of the unchannelized areas, are more resistant to erosion processes.

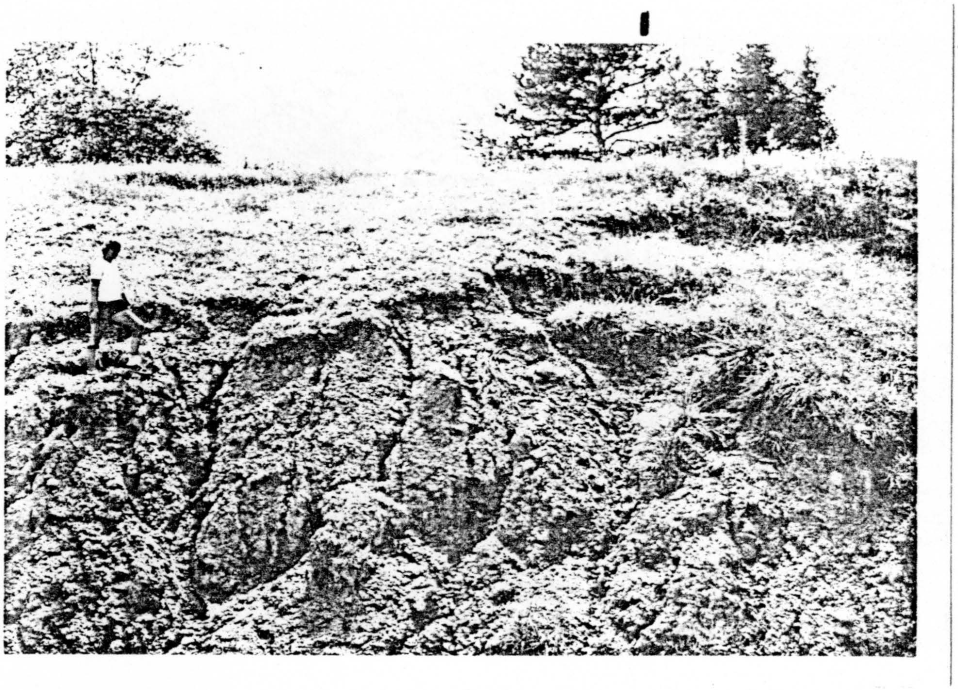


Figure 12. Slump Structure in the Profile 3 Area.

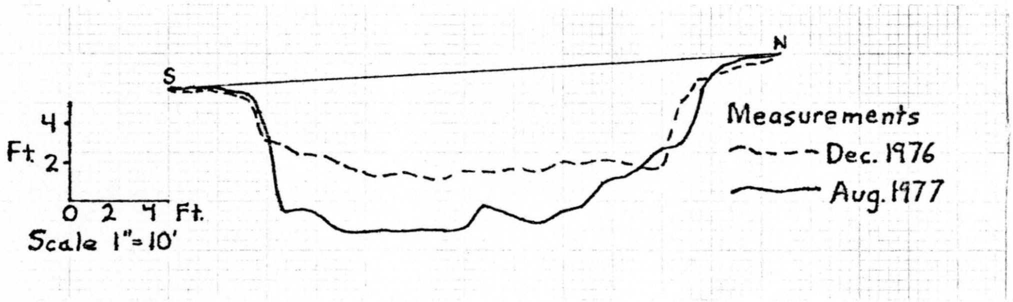


Figure 13A. Profile 7.

Figure 13. Changes in the Stream Channel in the Profile 7 Area.

Figure 13B. View of carbonate layer overlying an older bed of unconsolidated sand and gravel.

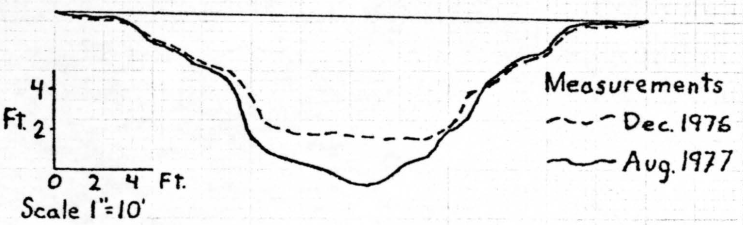


Figure 14. Downcutting of stream channel has caused loss of material at the profile 9 area.

Figure 15A. Downstream view of the Profile 1 area.

Figure 15B. Upstream view of the Profile 2 Area.

Figure 15. Areas Downstream From Channelization.

CONCLUSION

As the intended purpose of this study, measured profiles have documented the amount of erosion which has occurred in the stream channel at Winding Hollow from December, 1976 to August, 1977. The two major causes of erosion are urbanization of the drainage basin and channelization of the stream.

Urbanization has increased the amount of discharge in the basin, thus contributing a greater volume of runoff and a higher current velocity in the stream for any particular storm. Channelization has decreased the sinuosity of the stream and has located the banks in unstable, high, steep, unvegetated areas. Together, urbanization of the drainage basin and channelization of the stream have significantly increased the amount of mass movement and hydraulic action which occurs in the channel at Winding Hollow.

RECOMMENDATIONS AND FURTHER STUDY

The most economical and feasible way to reduce erosion in the channel is to pile limestone riprap along the banks and bottom such as in Figure 16.

Figure 16. Reinforcement of banks and channel with limestone riprap.

However, to completely stabilize the channel, it should be relocated away from the valley walls. Also, the banks and channel bottom should be protected with gabions and armor plating. This recommendation of channel reinforcement is the most extensive means to controlling erosion at the country club.

Some ideas for further study of the Winding Hollow drainage basin include: channel bank soil and till analysis to determine grain size, permeability, strength, etc.; setting up a stream hydrograph so actual discharges and lag times are known; comparing weather conditions to erosion and flooding of the channel. In general, many studies can be made and combined to determine erosion of a channelized stream in an urbanized basin.

APPENDIX I

Method Used to Determine the Percentage of Urbanization and Impermeable Surfaces in the Winding Hollow Drainage Basin

The percentage of urbanization and impermeable surfaces can be determined by the use of a grid placed over a topographic map of the basin. The number of evenly spaced nodes of the grid which fall on an urbanized area are totaled and divided by the number of nodes contained in a square mile to determine the area urbanized. To get the percentage of urbanization, divide the area urbanized by the area of the drainage basin. The percentage of impermeable surfaces is obtained by multiplying the area urbanized times the "sampled percent impermeable surfaces". From various studies of drainage basins, the U. S. Geological Survey has derived the "sampled percent impermeable surfaces" for particular types of urbanization. The formula for percent urbanization and percent impermeable surfaces of Winding Hollow drainage basin is shown in Table 4.

where:

21.6 = sampled percent impermeable surface

A = total number of nodes: urbanized

B = number of nodes/mi.^{2}

C = area of drainage basin

$A \div B$ = area urbanized

$(A \div B) \div C$ = percentage of urbanization

$21.6 x (A \div B)$= percentage of impermeable surfaces.

Table 4. Determining the percentage of urbanization and impermeable surfaces in a medium density residential drainage basin.

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