USGS
science for a changing world

Prepared in cooperation with the
U.S. Environmental Protection Agency

EPA

Watershed Characteristics and Pre-Restoration Surface-Water Hydrology of Minebank Run, Baltimore County, Maryland, Water Years 2002–04

Scientific Investigations Report 2006–5179

U.S. Department of the Interior
U.S. Geological Survey

Cover. Photograph taken in June 2001 by Robert J. Shedlock of the U.S. Geological Survey at station 01583980, Minebank Run at Loch Raven, Maryland as part of the reconnaissance for the cooperative project described in this report. View is looking downstream at stream channel from the station location.

Watershed Characteristics and Pre-Restoration Surface-Water Hydrology of Minebank Run, Baltimore County, Maryland, Water Years 2002–04

By Edward J. Doheny[1], Roger J. Starsoneck[2], Elise A. Striz[3], and Paul M. Mayer[3]

[1] U.S. Geological Survey, Baltimore, Maryland

[2] Formerly of U.S. Geological Survey, Baltimore, Maryland

[3] U.S. Environmental Protection Agency, Office of Research and Development, Ada, Oklahoma

Prepared in cooperation with the U.S. Environmental Protection Agency

Scientific Investigations Report 2006–5179

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
DIRK KEMPTHORNE, Secretary

U.S. Geological Survey
Mark D. Myers, Director

U.S. Geological Survey, Reston, Virginia: 2006

For product and ordering information:
World Wide Web: http://www.usgs.gov/pubprod
Telephone: 1-888-ASK-USGS

For more information on the USGS--the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment:
World Wide Web: http://www.usgs.gov
Telephone: 1-888-ASK-USGS

The U.S. Environmental Protection Agency (USEPA), through its Office of Research and Development, partially funded and collaborated in the research described here under an interagency agreement (DW-14-93944801-0) with the Water Science Center of the U.S. Geological Survey (USGS) in Baltimore, Md. The research described here has not been subjected to USEPA review and therefore does not necessarily reflect the views of USEPA, and no official endorsement should be inferred.

Suggested citation:
Doheny, E.J., Starsoneck, R.J., Striz, E.A., and Mayer, P.M., 2006, Watershed characteristics and pre-restoration surface-water hydrology of Minebank Run, Baltimore County, Maryland, water years 2002–04: U.S. Geological Survey Scientific Investigations Report 2006–5179, 42 p.

Contents

Figures

Tables

Conversion Factors, Vertical Datum, and Abbreviations

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	0.004047	square kilometer (km^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic foot (ft^3)	0.000023	acre-feet
cubic foot (ft^3)	7.48	gallon
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram (kg)
ton, short (2,000 lb)	907.2	kilogram (kg)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8\times°C)+32$$

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Water year: The 12-month period beginning October 1 and ending September 30. The water year is defined by the calendar year in which it ends. For example, the year beginning October 1, 2002 and ending September 30, 2003, is called "water year 2003." All references to years of operation for monitoring stations in this report are water years.

ABBREVIATIONS AND ACRONYMS

DEPRM	Baltimore County Department of Environmental Protection and Resource Management
EST	Eastern Standard Time
IES	Institute of Ecosystem Studies
MSL	Mean sea level
R^2	Coefficient of determination
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey

Watershed Characteristics and Pre-Restoration Surface-Water Hydrology of Minebank Run, Baltimore County, Maryland, Water Years 2002–04

By Edward J. Doheny, Roger J. Starsoneck, Elise A. Striz, and Paul M. Mayer

Abstract

Stream restoration efforts have been ongoing in Maryland since the early 1990s. Physical stream restoration often involves replacement of lost sediments to elevate degraded streambeds, re-establishment of riffle-pool sequences along the channel profile, planting vegetation in riparian zones, and re-constructing channel banks, point bars, flood plains, and stream-meanders. The primary goal of many restoration efforts is to re-establish geomorphic stability of the stream channel and reduce erosive energy from urban runoff. Monitoring streams prior to and after restoration could help quantify other possible benefits of stream restoration, such as improved water quality and biota.

This report presents general watershed characteristics associated with the Minebank Run watershed; a small, urban watershed in the south-central section of Baltimore County, Maryland that was physically restored in phases during 1999, 2004, and 2005. The physiography, geology, hydrology, land use, soils, and pre-restoration geomorphic setting of the unrestored stream channel are discussed.

The report describes a reach of Minebank Run that was selected for the purpose of collecting several types of environmental data prior to restoration, including continuous-record and partial-record stage and streamflow data, precipitation, and ground-water levels. Examples of surface-water data that were collected in and near the study reach during water years 2002 through 2004, including continuous-record streamflow, partial-record stage and discharge, and precipitation, are described. These data were used in analyses of several characteristics of surface-water hydrology in the watershed, including (1) rainfall totals, storm duration, and intensity, (2) instantaneous peak discharge and daily mean discharge, (3) stage-discharge ratings, (4) hydraulic-geometry relations, (5) water-surface slope, (6) time of concentration, (7) flood frequency, (8) flood volume, and (9) rainfall-runoff relations.

Several hydrologic characteristics that are typical of urban environments were quantified by these analyses. These include (1) large ratios of peak discharge to daily mean discharge as an indicator of flashiness, (2) consistent shifting of the stage-discharge rating over short periods of time that indicates instability of the stream channel, (3) analyses of hydraulic-geometry relations that indicate mean velocities of 11 feet per second or more while the flow is contained in the stream channel, (4) discharges that are 4 to 5 times larger in Minebank Run for corresponding flood frequency recurrence intervals than in Slade Run, which is a Piedmont watershed of similar size with smaller percentages of urban development, and (5) flood waves that can travel through the stream channel at a velocity of 412 feet per minute, or 6.9 feet per second.

Introduction

Since the early 1990s, many stream reaches in Maryland have been physically restored. Restoration has involved replacement of lost sediments to elevate degraded streambeds, re-establishment of riffle-pool sequences along the channel profile, planting vegetation in **riparian zones**[1], and re-constructing channel banks, point bars, flood plains, and stream-meanders. Whereas these stream restoration efforts have been aimed primarily at re-establishing geomorphic stability of the stream channel and reducing the erosive energy of urban runoff, the possible benefits of improved water quality in the surface water and ground water have not been quantified.

The Baltimore County Department of Environmental Protection and Resource Management (DEPRM) has restored numerous streams in the Baltimore metropolitan area (Duerkson and Snyder, 2005). DEPRM selected the Minebank Run watershed as a priority for stream restoration for several reasons. The lower section of the watershed became part of the Baltimore County Park system in 1994. Cromwell Valley Park is considered prime open space in an otherwise urban and suburban section of the Baltimore metropolitan area. The stream channel is incised and over-widened. The instability of the stream channel has caused problems with increased sediment supply, and lateral erosion of the stream channel has exposed and undermined sanitary sewage interceptors

[1] Words in **bold** type are defined in the “Glossary” section of the report.

that were once buried in the channel banks and flood-plain sediments, causing risk of damage (Greenman-Pedersen, Inc. and Coastal Resources, Inc., 2001). Minebank Run is a tributary of the lower Gunpowder Falls, which in turn is a major tributary of the Chesapeake Bay. Ecological recovery of the Bay depends on the reduction of nutrients (phosphorus and nitrogen) and sediment throughout the Bay watershed (U.S. Environmental Protection Agency, 2004).

The stream restoration in the Minebank Run watershed was completed in two phases. The headwater areas of the watershed were restored in 1999, while the rest of the watershed was restored during 2004 and 2005.

In April 2001, the U.S. Environmental Protection Agency (USEPA) began efforts to study streams in the Baltimore metropolitan area to assess the effects of stream channel restoration on ecosystem function and biogeochemical cycling, especially of nitrogen and carbon. Minebank Run was selected for the study because of the opportunity to collect and interpret surface-water, ground-water, and geomorphic data before and after re-planting vegetation in riparian zones, reconfiguring of meanders and point bars, reconstruction of flood plains, and relocation of sections of the channel within the valley. The restoration of Minebank Run has also provided an opportunity to study potential water-quality benefits from implementation of these restoration features. In October 2001, the U.S. Geological Survey (USGS), USEPA, and the Institute of Ecosystem Studies (IES) initiated studies at Minebank Run to investigate the effects of stream restoration on stream hydrology, denitrification, and overall water quality.

This report describes general watershed characteristics associated with the Minebank Run watershed, including the physiography, geology, hydrology, land use, soils, and pre-restoration geomorphic setting. The overall design of the Minebank Run study reach is discussed. Descriptions and examples of streamflow and precipitation data collected in the study reach during water years 2002 through 2004, and selected analyses that describe the pre-restoration surface-water hydrology of Minebank Run, are also presented.

Description of Study Area

Minebank Run is a 3.27-mi^2 (square mile) sub-watershed of the Gunpowder Falls in the south-central section of Baltimore County, Maryland (fig. 1). The stream flows approximately in a northeasterly direction, and the headwaters are on the eastern side of Towson, Maryland. The stream confluences with Gunpowder Falls, approximately 0.30 mi (miles) downstream from the low-head dam below Loch Raven Reservoir.

Stream-channel slopes are about 1 percent or slightly less in most locations. **Relief** ranges from 100 to 300 ft (feet) in most areas of the watershed. The headwaters of Minebank Run have large areas of urban development and **impervious surfaces**. The combination of fairly steep stream slopes, up to 300 ft of relief, and large areas of impervious surfaces cause the stream stage and corresponding discharge to fluctuate quickly during storm events, contributing to **flashy** surface-water hydrology that is characteristic of urban streams (Paul and Meyer, 2001).

Physiographic Setting

The Minebank Run watershed lies in the eastern section of the Piedmont Physiographic Province in Maryland. According to Fenneman (1938), the Piedmont consists of gently rolling hills and ridges with elevations generally less than 800 ft above sea level. The eastern boundary of the Piedmont in Maryland is the Fall Line, which divides the Piedmont from the Western Coastal Plain. The western boundary of the Piedmont in Maryland is Catoctin Mountain. The Piedmont in Maryland covers approximately 2,500 mi^2, which is approximately 26 percent of Maryland's total land area. Piedmont streams have fairly steep gradients with relatively deep and narrow valleys. Streams in the eastern Piedmont drain directly into the Chesapeake Bay, while streams in the western section of the Piedmont drain into the Potomac River (Dillow, 1996).

The Minebank Run watershed boundary lies approximately 4.7 mi northwest of the Fall Line (fig. 2). The watershed consists mainly of two ridges that run approximately from southwest to northeast with a broad, lightly sloping valley in between. The watershed ranges in elevation from about 400 to 500 ft above sea level at the drainage boundaries, to about 150 to 400 ft above sea level in the stream valley. The valley width ranges from approximately 0.6 mi near the headwater and outlet areas, to about 1.5 mi near the mid-point of the watershed.

Geologic Setting

Minebank Run is incised into a narrow stream valley surrounded by uplands that are in the eastern section of the Piedmont Physiographic Province of Baltimore County, Maryland. Underlying the study area is a complex series of Cambro-Ordovician age crystalline rocks belonging to the Glenarm Supergroup, consisting of the Setters Formation, the Cockeysville Marble, and the Loch Raven Schist (fig. 3, table 1). Underlying this supergroup is the Precambrian Baltimore Gneiss, the oldest group of highly metamorphosed rocks in Maryland, which is a group of metamorphosed sediment that is the basement complex for the entire region. The geologic structure of the crystalline rocks in the eastern Piedmont of Maryland and the study area is dominated by a series of gneiss domes, which trend approximately northeast to southwest. The Baltimore Gneiss, which is the core of the domes, was folded, metamorphosed, and eroded when the Glenarm Supergroup was deposited overtop (Vokes, 1957; Crowley and Cleaves, 1974; Crowley and others, 1976).

The crystalline rocks in the study area are overlain by deposits of Quaternary **alluvium** that consist of material from

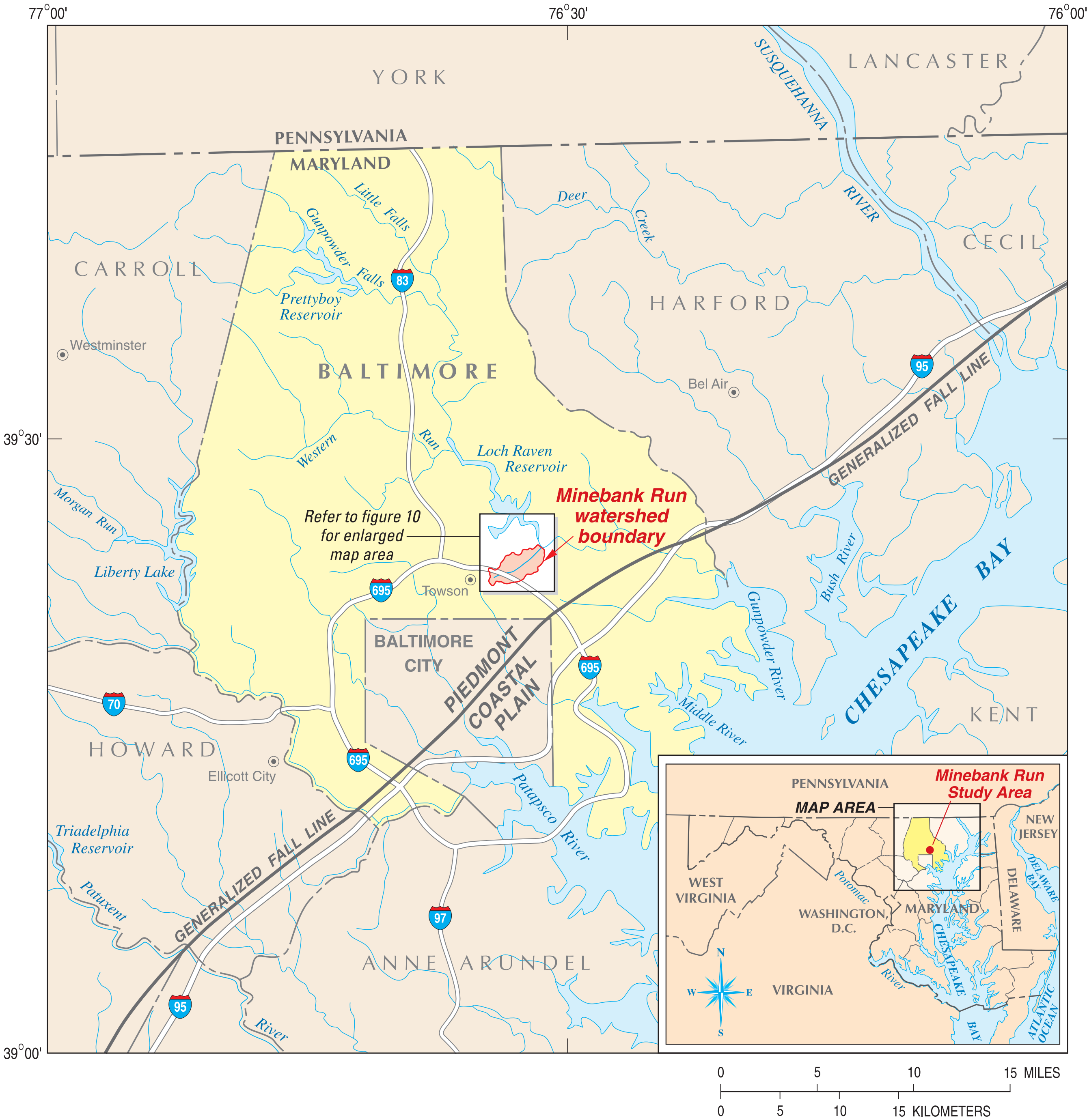


Figure 1. Location of Minebank Run study area, Baltimore County, Maryland.

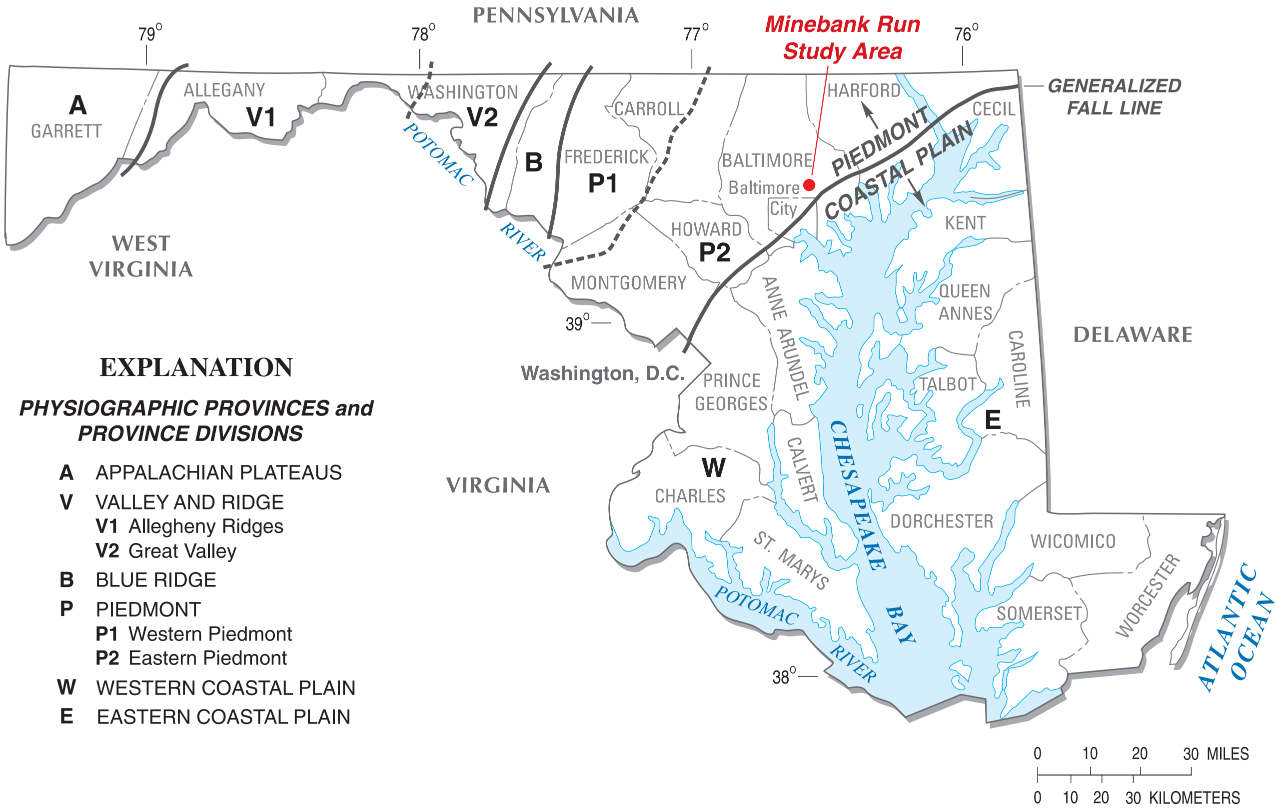


Figure 2. Physiographic provinces and province divisions in Maryland.

the uplands that were deposited in the north flood plain and in the channel bed of Minebank Run. These deposits consist of interbedded unconsolidated gravel, sand, silt, and clay, ranging in thickness from approximately 1.5 ft to 15 ft. Adjacent to the alluvial sediments on the south flood plain is a layer of interbedded, unconsolidated deposits of **colluvium** (Crowley and Cleaves, 1974). A lithologic cross section of the unconsolidated deposits of alluvium and colluvium was developed for the stream channel and flood plain area of Minebank Run in Cromwell Valley Park, approximately 0.97 mi downstream from Interstate 695 and 0.85 mi upstream from the mouth. This cross section was based on a 2001 field survey of the stream channel and flood plain, and lithologic cores that were collected in 2001 and 2004 (fig. 4).

The crystalline rocks in the study area of Minebank Run consist of two mineralogical groups: silicic and carbonate rocks. Throughout the study area, the Cockeysville Marble, a member of the Loch Raven Schist, is composed of calcite and dolomite minerals but also contains large amounts of magnesium. The addition of magnesium was a secondary feature that may have occurred before or during the metamorphism of the limestone. The surrounding uplands are similar to the areas near the stream, and are composed of metamorphosed silicic rocks containing quartz and feldspar minerals. The headwaters of Minebank Run and its smaller tributaries flow on the silicic rocks, and on alluvium deposits in some locations. In the lower reaches of Minebank Run and at the confluence with Gunpowder Falls, the stream flows on unconsolidated deposits of alluvium and colluvium, as well as on outcrops of carbonate rock in some locations (Crowley and Cleaves, 1974). The geology of the eastern Piedmont of Maryland and associated nomenclature are further described in Crowley and others (1976).

Hydrology

Average annual precipitation is about 42 in. for the Baltimore metropolitan area. Average monthly precipitation in the region ranges from about 3 to 4 in. throughout the year. During the spring and summer, however, thunderstorms can cause significant variations in precipitation depending on location (James, 1986).

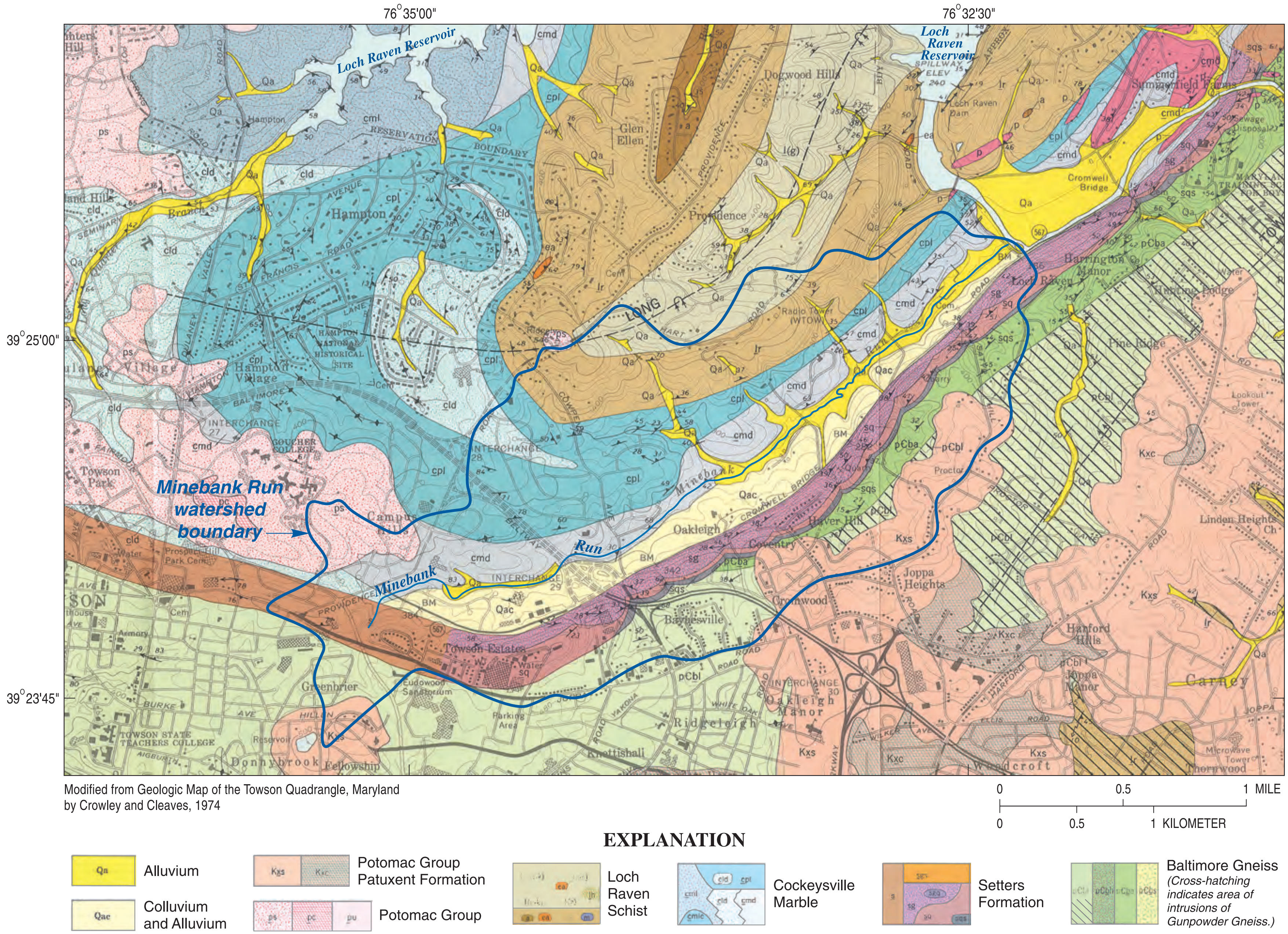


Figure 3. Geology of the Minebank Run watershed, Baltimore County, Maryland.

Table 1. Generalized description of geologic units in the Minebank Run watershed near Towson, Maryland.

[Modified from Crowley and Cleaves, 1974; Crowley and others, 1976]

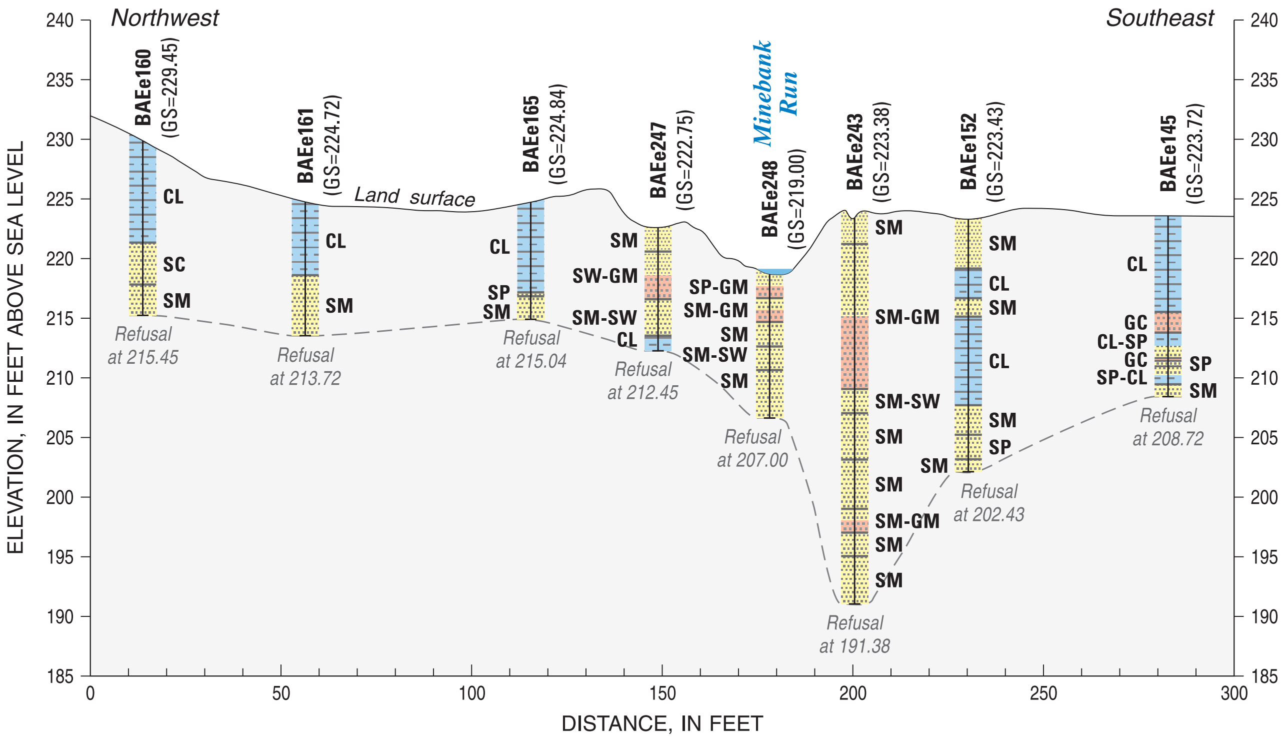
Age	Name	Description
		Unconsolidated to semi-consolidated
Quaternary	**Alluvium**	Interbedded gravel, sand, silt, and clay of variable composition and sorting.
	Colluvium and Alluvium	Unsorted massive clays to gravels interbedded and interfingering with poorly sorted alluvial sands and gravels.
Lower Cretaceous	*Potomac Group* **Patuxent Formation**	Clay and sandy clay, iron cemented layers and lenses of sand and gravel.
Lower Cretaceous(?)	*Potomac Group(?)*	Similar in color, lithology, and sedimentological features to the Patuxent Formation, but of uncertain age, because of their separation from the Patuxent Formation and lack of datable paleontological material.
		Crystalline rocks
Cambro-Ordovician(?)	Glenarm Supergroup *Wissahickon Group* **Oella Formation**	Biotite-plagioclase-muscovite-quartz schist interlayed with biotite-plagioclase-quartz gneiss or feldspar.
	Glenarm Supergroup *Wissahickon Group* **Loch Raven Schist**	Biotite-plagioclase-muscovite-quartz schist with lenses and pods of vein quartz. Hydes Marble Member: Calcite marble, locally philogopitic. Rush Brook Member: Quartz rich schist and gneiss with quartzite.
	Glenarm Supergroup **Cockeysville Marble**	Marble, meta-limestone, meta-dolostone.
	Glenarm Supergroup **Setters Formation**	Gneiss, garnet, schist, and quartzite.
Precambrian	**Baltimore Gneiss**	Biotite microcline quartz-plagioclase gneiss.

Streamflow statistics were developed for two USGS **continuous-record streamflow-gaging stations** that are currently in operation in the Minebank Run watershed (table 2). Station 0158397967, Minebank Run near Glen Arm, Maryland, was activated for the current study during **water year** 2002 and includes data that were collected during the drought in 2002 and subsequent recovery during 2003 and 2004 (James and others, 2003). Station 01583980, Minebank Run at Loch Raven, Maryland, has been in operation for 8 years and provides more long-term data on streamflow characteristics in the watershed.

On the basis of streamflow data for 1997–2004 that were collected at station 01583980, Minebank Run at Loch Raven, Maryland, annual **runoff** averaged approximately 16.5 in. (Saffer and others, 2005). On average, about 60 percent of the annual precipitation at Minebank Run either infiltrates into the ground or is lost to evapotranspiration.

Runoff from heavy rains and severe thunderstorms occasionally causes flooding in the Minebank Run watershed. On the basis of streamflow data for 1997–2004 that were collected at station 01583980, Minebank Run at Loch Raven, Maryland, flood discharges exceeding 1,500 ft^3/s (cubic feet per second) occurred during 4 of these 8 water years. The last major flood occurred on June 12, 2003, with a peak discharge of 1,770 ft^3/s (James and others, 2004). The largest flood during the period of record occurred on September 2, 1997 during a major thunderstorm, when the peak discharge reached 1,960 ft^3/s, with an associated rise in stream stage of more than 6 ft (James and others, 1999).

Except for occasional storm events with sustained heavy rainfall, or those that produce runoff from snowmelt, streamflow in the Minebank Run watershed tends to be very flashy, producing stages that rise and fall very quickly during most storm events. Thus, **daily mean discharges** for Minebank Run are commonly lower than the instantaneous peak discharge. The storm of September 2, 1997, for example, produced a peak discharge of 1,960 ft^3/s at station 01583980, Minebank Run at Loch Raven, Maryland. However, the daily mean discharge for September 2, 1997 at this station was 76 ft^3/s. The flashy nature of Minebank Run can be attributed to the relatively small size of the watershed, significant relief, and urban development in its headwater areas.



UNIFIED SOIL CLASSIFICATION SYSTEM		
SYMBOL AND MAJOR DIVISION	***LETTER***	***DESCRIPTION***
GRAVEL	**GP** **GW** **GM** **GC**	Poorly graded gravel Well graded gravel Silty gravel Clayey gravel
SAND	**SP** **SW** **SM** **SC**	Poorly graded sand Well graded sand Silty sand Clayey sand
SILT	**ML** **OL**	Inorganic silt, very fine sand, and clayey silt Organic silt and organic clayey silt
CLAY	**CL** **OH**	Inorganic clay, silty clay, and sandy clay Organic clay

EXPLANATION

BAEe160 (GS=229.45) — MONITORING WELL OR GEOPROBE BORING SITE, IDENTIFICATION NUMBER, AND GROUND SURFACE (GS) ELEVATION, IN FEET ABOVE MEAN SEA LEVEL

Refusal at 215.45 (Refusal represents possible elevation of the top of weathered bedrock.)

STRATIGRAPHIC CONTACT

Figure 4. Lithologic cross section looking downstream along Minebank Run, Baltimore County, Maryland.

Table 2. Summary of streamflow statistics for Minebank Run streamflow-gaging stations, water years 1997 through 2004.

[mi^2, square miles; ft^3/s, cubic feet per second; [$(ft^3/s)mi^2$], cubic feet per second per square mile; in., inches]

	0158397967 Minebank Run near Glen Arm, Maryland (2002–04)	01583980 Minebank Run at Loch Raven, Maryland (1997–2004)
Drainage area (mi^2)	2.06	2.90
Annual mean discharge (ft^3/s)	3.25	3.51
Highest annual mean discharge (ft^3/s)	4.34 (2004)	5.51 (2003)
Lowest annual mean discharge (ft^3/s)	1.15 (2002)	1.30 (2002)
Highest daily mean discharge (ft^3/s)	61 (Oct. 27, 2003)	150 (Sep. 16, 1999)
Lowest daily mean discharge (ft^3/s)	0.04 (Aug. 17, 2002)	0.13 (Aug. 23, 2002)
Maximum instantaneous peak flow discharge (ft^3/s)	1,390 (June 12, 2003)	1,960 (Sep. 2, 1997)
Minimum instantaneous low flow discharge (ft^3/s)	0.04 (Aug. 17, 2002)	0.08 (July 20, 1999)
Annual runoff (in.)	21.46	16.46
Annual runoff [$(ft^3/s)mi^2$]	1.58	1.21

Land Use

The land-use characteristics of the Minebank Run watershed have changed significantly over the past 65 years. Aerial photographs of the watershed from 1938 and 1953 indicate predominantly agricultural land use, with some forest cover and smaller amounts of urban and suburban development (Agricultural Stabilization Conservation Service, 1938; Agricultural Stabilization Conservation Service, 1953). A comparison of these photographs shows that urban and suburban development increased dramatically between 1938 and 1953 (figs. 5a and 5b). Currently, the Minebank Run watershed can be characterized as a predominantly urban watershed that includes forest cover and open space, and small percentages of agriculture and farmland (Baltimore County Department of Environmental Protection and Resource Management, 2000) (fig. 6).

Land-use data for the Minebank Run watershed were compiled using information from the Baltimore County DEPRM (2000). Data were compiled for the watersheds upstream from the two continuous-record streamflow-gaging stations, and for USGS station 0158398050, which is a **partial-record station** that drains the entire Minebank Run watershed. The approximate percentages of the major land-use types by selected streamflow-gaging station in the Minebank Run watershed in 2000 are shown in table 3.

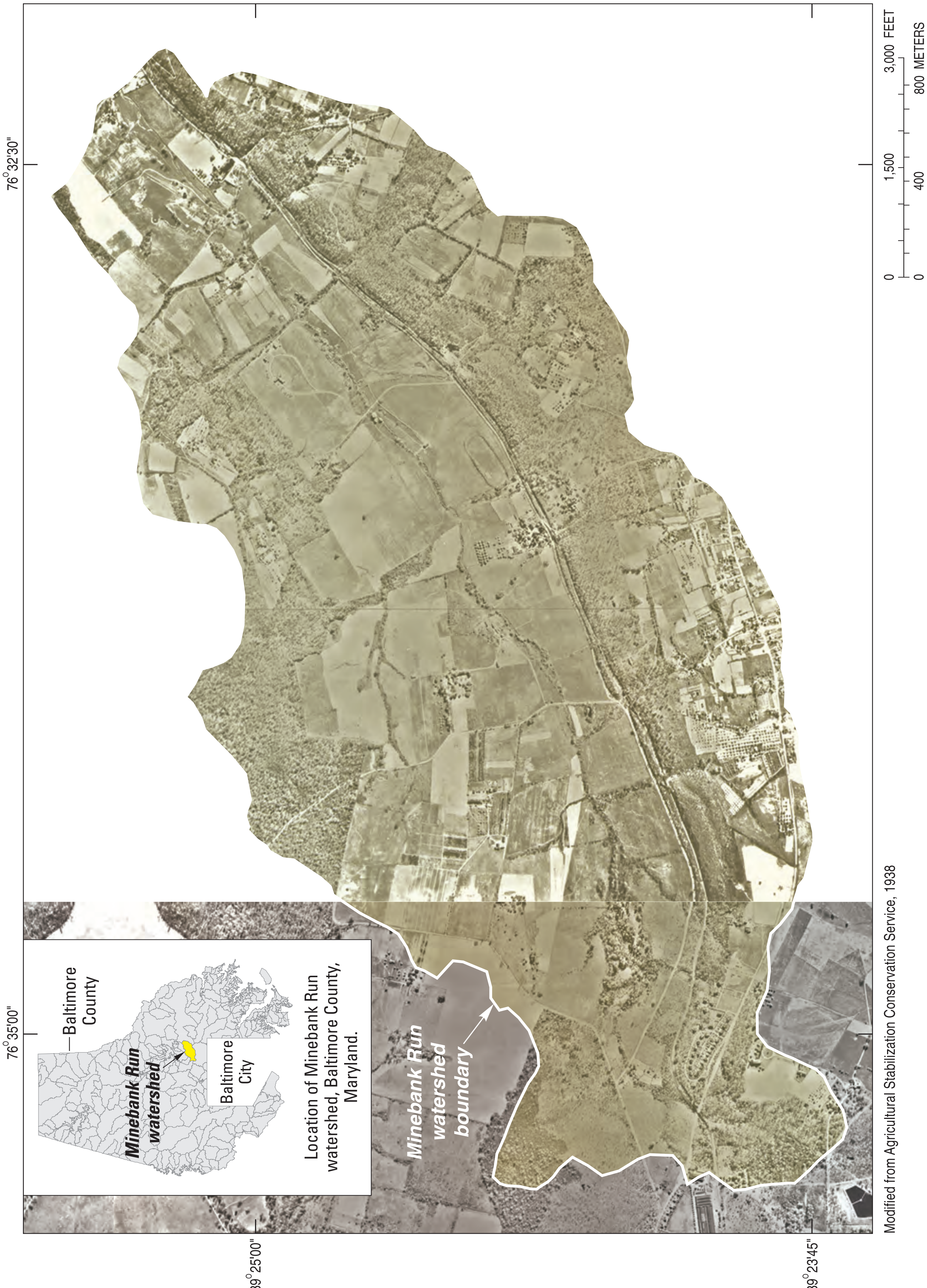
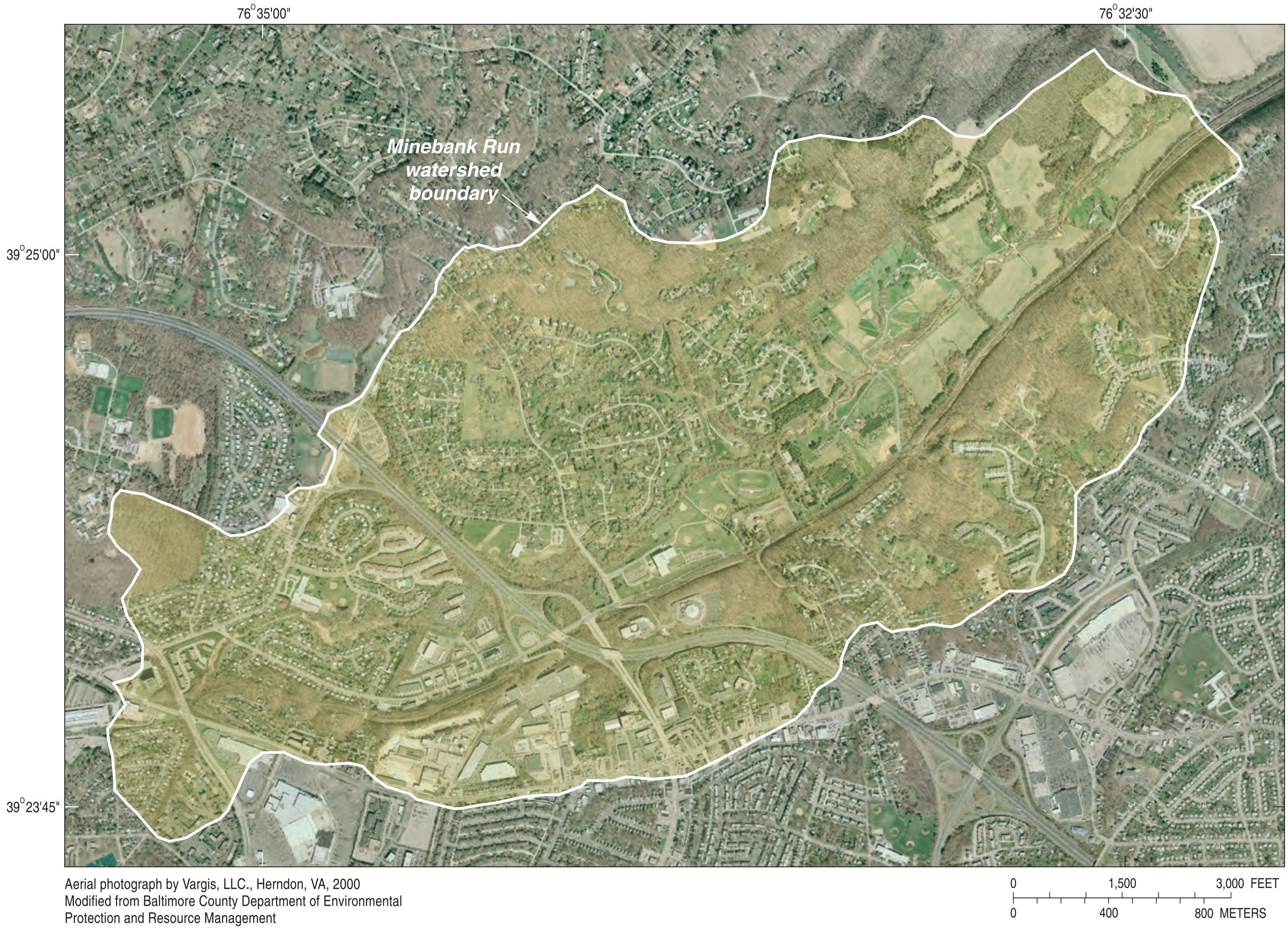


Figure 5a. Aerial photograph of the Minebank Run watershed, 1938.

Figure 5b. Aerial photograph of the Minebank Run watershed, 1953.



Aerial photograph by Vargis, LLC., Herndon, VA, 2000
Modified from Baltimore County Department of Environmental Protection and Resource Management

Figure 6. Aerial photograph of the Minebank Run watershed, 2000.

Table 3. Major land-use types within sub-basins of the Minebank Run watershed drained by selected streamflow-gaging stations, 2000.

Land-use type (in percent)	Station 0158397967 Minebank Run near Glen Arm, Maryland[1]	Station 01583980 Minebank Run at Loch Raven, Maryland[2]	Station 0158398050 Minebank Run at outlet near Carney, Maryland[3]
Urban/suburban	80.6	61.6	56.8
Agriculture/farmland	1.5	1.8	2.1
Forest/open space	16.9	35.3	39.9
Extractive	1.0	1.3	1.2
Total	100.0	100.0	100.0

[1] Drainage area = 2.06 square miles.

[2] Drainage area = 2.90 square miles.

[3] Drainage area = 3.27 square miles.

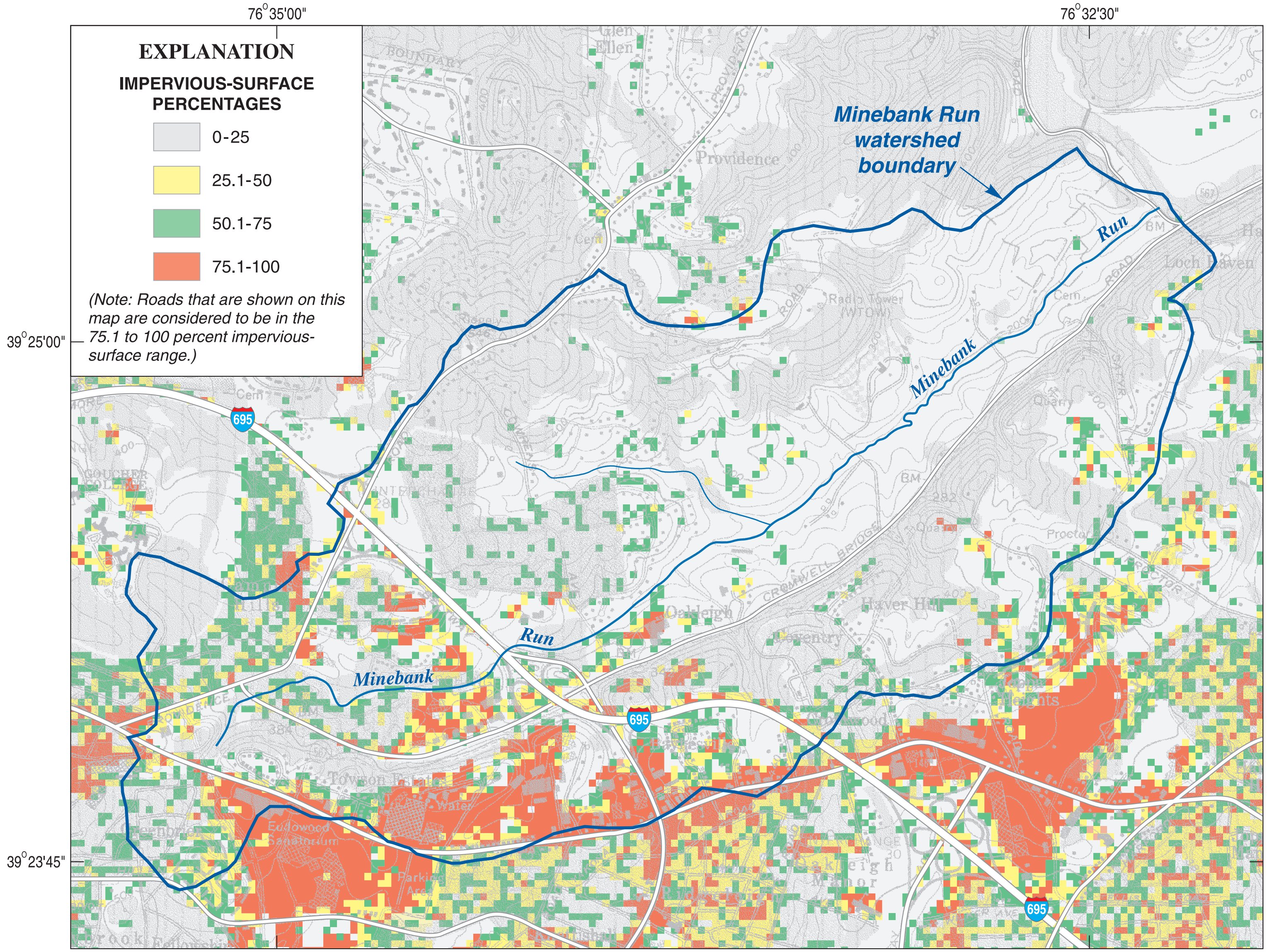
Increases in areas of urban and suburban land use can lead to increased percentages of impervious surfaces. The distribution of impervious surfaces in the Minebank Run watershed is shown in figure 7 (Goetz and others, 2004). In the Minebank Run watershed, the largest percentages of impervious surfaces are in the headwaters of the watershed upstream from the Baltimore Beltway (I-695). Most of these highly impervious areas are at the higher elevations near the southern section of the drainage boundary. These areas, in combination with some direct runoff from I-695, are the likely source of increased storm runoff that causes the stream to be extremely flashy.

Soils

The Baltimore-Conestoga-Hagerstown Soil **Association** has been mapped in the Minebank Run watershed and four principal soil **series** cover the study area (Reybold and Matthews, 1976). The Lindside Series, consisting of deep, moderately well-drained soils in limestone valleys, formed from silty alluvium that was developed from limestone marble and calciferous schist. Lindside Series soils generally are silt loam of varying color near the ground surface that become stratified with silty clay and gravel as depth increases (Reybold and Matthews, 1976). The Hollinger Series consists of deep, well-drained soils on uplands that are formed from weathering of micaceous limestone and calciferous schist. Hollinger Series soils generally are loams or silt loams of varying color near the ground surface. This material commonly overlies a layer of sandy loam and sand that is derived from weathered and disintegrated rock (Reybold and Matthews, 1976). The Baltimore Series consists of deep, well-drained soils that were formed in deposits of weathered, micaceous, colluvium over material that was weathered in place from marble or dolomite (Reybold and Matthews, 1976). The Conestoga Series consists of deep, well-drained soils that are generally found in upland areas of the Piedmont Physiographic Province within Baltimore County. These soils formed in material that was weathered in place from calciferous mica schist and associated marble and limestone (Reybold and Matthews, 1976).

In most of the study area, five soil inclusions have been mapped within the four principal soil series. These include the Baltimore silt loam of the Baltimore Series, the Conestoga loam of the Conestoga Series, the Lindside silt loam of the Lindside Series, and the Hollinger loam and the Hollinger and Conestoga loam of the Hollinger Series. These soils and associated nomenclature are further described in Reybold and Matthews (1976).

In the upper reaches of the watershed, most of the soil in the flood plain of Minebank Run has been mapped as Alluvial Land, which is soil that has been washed from upland areas and deposited on the flood plains. The Alluvial Land soil is mostly sand and lacks finer-grained material that has been carried downstream by runoff and out of bank storm events. In the lower reach of the watershed, which includes the study area, the Lindside soil has been deposited over most of the alluvial sediments.



Topo map from Towson, MD Quadrangle, 1957, photorevised 1966 and 1974, by Crowley, W.P. and Cleaves, E.T.
Impervious-surface data from Goetz, S.J., Jantz, C.A., Prince, S.D., Smith, A.J., Wright, R., and Varlyguin, D., 2004

Figure 7. Distribution of impervious-surface percentages in the Minebank Run watershed.

Geomorphic Setting

From 1999 through 2004, the Minebank Run watershed consisted of a restored section and an unrestored section. The upper 0.80 mi^2 of the watershed was restored in 1999. Restoration was initiated on the lower 2.47 mi^2 of the watershed in 2004 and completed in 2005.

In the restored section of the watershed, the dimension, pattern, and profile of the stream channel were reconstructed to improve bank **stability**. Riffle and pool sequences were re-created by selective placement of rock weirs that were also intended to manage sediment supply. Flood plains were re-established where possible to allow flood flows to spread out in the valley and reduce the energy directed at the channel bed. Channel-bank slopes were reduced in many locations and riparian vegetation was planted on the banks (fig. 8). Low to moderate channel sinuosity was maintained throughout the restored reach to reduce the potential for significant bank erosion and failure.

In the unrestored section of the watershed, similar techniques were employed to reconstruct the stream channel and flood plain during the restoration. The unrestored section of Minebank Run was degraded and overwidened. Much of the stream energy was directed at the channel bed and banks, with little or no opportunity for the stream to overtop the channel banks and spread out over the flood plain. The channel banks were steeply sloped with noticeable bank failures and lateral migration (fig. 9). Overall channel sinuosity was fairly low, but the stream channel also had several locations with considerable meandering that coincided with very unstable channel banks and channel bed. The differences between the restored and unrestored sections of the stream channel at Minebank Run can be seen in figures 8 and 9. A follow-up to this report is planned that will describe data collection and analyses related to the geomorphic condition of the unrestored section of Minebank Run during the study period.

Study Design

This study was designed to investigate the effects of physical restoration of the stream channel on stream hydrology, denitrification, and overall water quality in a selected reach of Minebank Run. Reconnaissance was conducted to select a study reach where different types of restoration features were to be implemented, such as channel-bank and riparian-zone rehabilitation, re-configuration of channel meanders, re-establishment of riffle-pool sequences, and physical movement of the channel within the valley.

Figure 8. Section of restored Minebank Run stream channel upstream from Interstate 695 near Towson, Maryland. (Photograph by Paul M. Mayer, U.S. Environmental Protection Agency)

Figure 9. Section of unrestored Minebank Run stream channel in Cromwell Valley Park downstream from Interstate 695 near Towson, Maryland. (Photograph by Robert J. Shedlock, U.S. Geological Survey)

Initial efforts for selection of a study reach focused on the area near USGS streamflow-gaging station 01583980, Minebank Run at Loch Raven, Maryland. Data collected at this station, which had been operated continuously since water year 1997, possibly could have been included in the study design, eliminating the need for construction and operation of a new continuous-record station. An investigation of the early literature on design and construction of the Baltimore water-supply system, however, indicated the presence of a supply tunnel from Loch Raven Reservoir that tracks through the lower section of the Minebank Run watershed toward Lake Montebello in Baltimore City. The Loch Raven-Montebello supply tunnel goes under the streambed of Minebank Run a short distance upstream of the Minebank Run at Loch Raven, Maryland station (Freeman and Stearns, 1910; Gregory and others, 1934; Greenman-Pederson, Inc., 1996).

During periods of low flow, the stream channel goes dry along variable lengths of Minebank Run upstream of the approximate location of the tunnel. One possible explanation is that leakage into the tunnel could exceed the total flow in the channel during periods of low flow. As the tunnel produces a direct and potentially significant manmade effect on the base flow of the stream, this reach was deemed unsuitable for the study. To avoid tunnel effects, a study reach that begins approximately 0.78 mi upstream of USGS station 01583980 and extends downstream approximately 0.25 mi to the upstream side of the Sherwood Bridge over Minebank Run was selected (fig. 10).

Due to the potential influence of low flows caused by the Loch Raven-Montebello supply tunnel, the study design included installation and operation of a continuous-record streamflow-gaging station at the upstream end of the study reach. A recording precipitation gage was installed in a nearby farm field. A series of **crest-stage partial-record stations** with **staff gages** were installed in the study reach so that peak gage heights could be recorded during storm events, and gage heights could be determined in different locations in the channel while measuring streamflow, water levels in the wells and **piezometers**, and during water-quality sampling.

The study design also included three transects of wells and piezometers that were installed to coincide with the placement of different restoration features. Transects were placed in locations where (1) few or no changes were made to the channel banks, riparian zone, or channel alignment, (2) the meander pattern of the channel was significantly changed, and (3) the stream channel was physically moved within the valley.

Nests of three piezometers were inserted into the channel bed and channel banks of each well transect. Piezometers were made of 1-in. stainless steel pipe screened at the lower 6 in. with 0.01-in. stainless steel mesh. The piezometers were

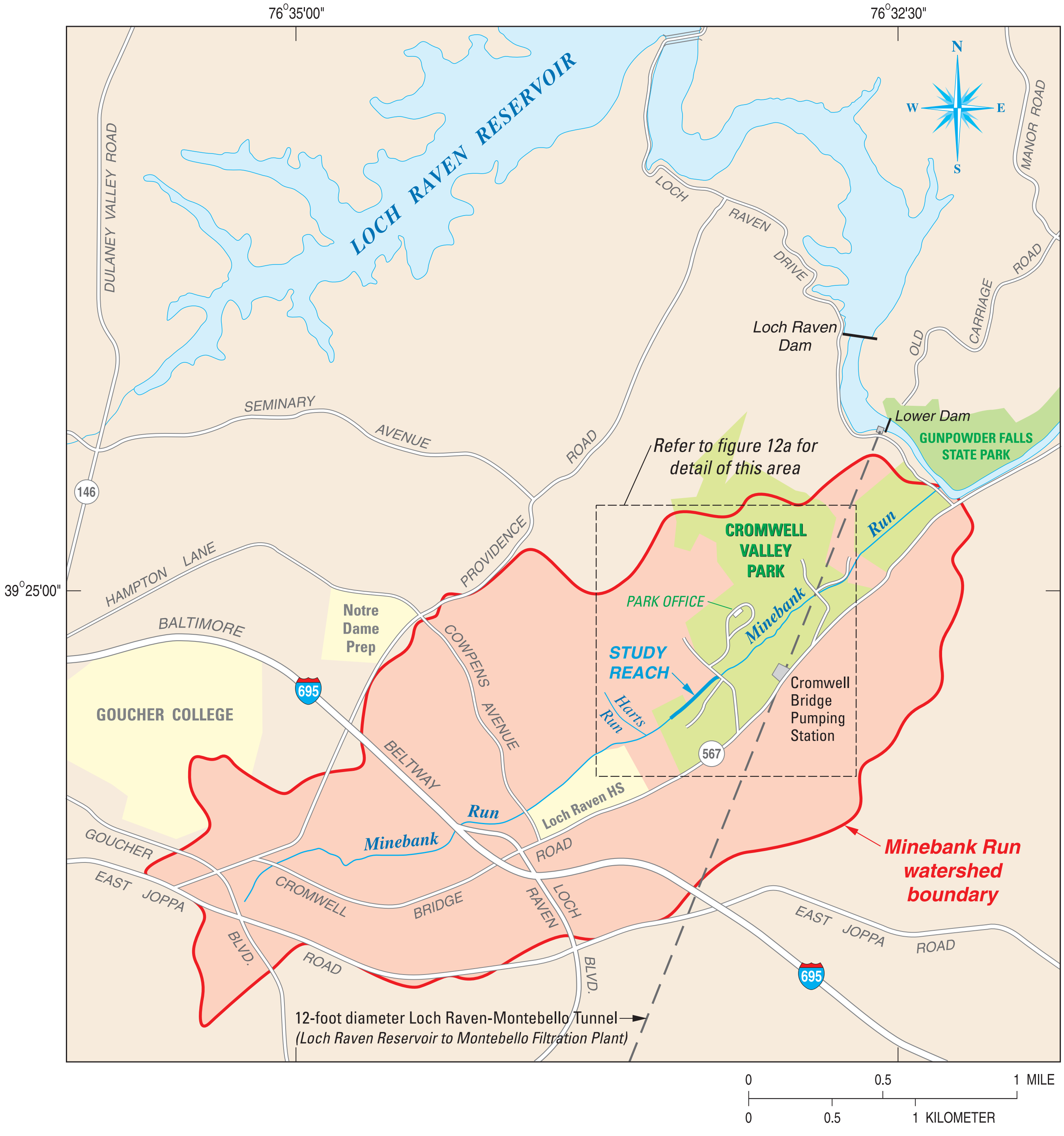


Figure 10. Detailed view of Minebank Run study area, Baltimore County, Maryland.

driven 2 ft, 4 ft, and 6 ft below the elevation of the **thalweg** that existed at the time of installation in November 2001. Monitoring wells were drilled into the flood plains in each well transect and were cased with 2-in.-diameter polyvinyl chloride (PVC). These monitoring wells consisted of (1) a pair of shallow and deep wells located approximately 50 ft landward from each channel bank, and (2) a single deep well located approximately 100 ft landward from each channel bank (fig. 11). The deeper monitoring wells were driven to the depth of refusal whereas the shallow monitoring wells were driven to about half the depth of refusal. The monitoring wells were screened at the lower 5 ft of each well with 0.01-in. screens. The general layout of the study reach for hydrologic data collection, including the locations of the streamflow-gaging station, the precipitation gage, the crest-stage partial-record stations, and the well transects, is shown in figures 12a and 12b.

Data Collection

To document the hydrologic conditions of the Minebank Run study reach prior to restoration of the channel, several different types of data were collected during water years 2002 through 2004. Surface-water data that were collected in and near the study reach include continuous-record gage height and streamflow data, partial-record gage height and streamflow data using staff gages and crest-stage gages, and precipitation data.

Streamflow

Streamflow data were collected in the Minebank Run study reach with two types of stations. These included the continuous-record streamflow-gaging station at the upstream end of the study reach (0158397967), and the crest-stage partial-record stations with staff gages that were located at selected locations along the study reach (Carter and Davidian, 1968; Buchanan and Somers, 1968).

Continuous-Record Streamflow-Gaging Station

A continuous-record streamflow-gaging station was activated just upstream of the three well transects to obtain continuous streamflow data at the upstream end of the study reach. Five-minute unit-value stage data were collected at the upstream end of the Minebank Run study reach beginning in October 2001. Periodic streamflow measurements were made at a range of stages to develop a **stage-discharge rating** for the stream. Rating 1.0, which was in effect at USGS station 0158397967, Minebank Run near Glen Arm, Maryland between October 15, 2001 and August 3, 2002, is shown in figure 13.

Stage-discharge ratings were used in conjunction with the continuous record of gage height to determine the discharge of the stream at 5-minute intervals. The unit-value discharge data were used to compute daily mean discharges for each day of the water year. The daily mean discharges for USGS station 0158397967, Minebank Run near Glen Arm, Maryland, for water year 2002, are shown in figure 14.

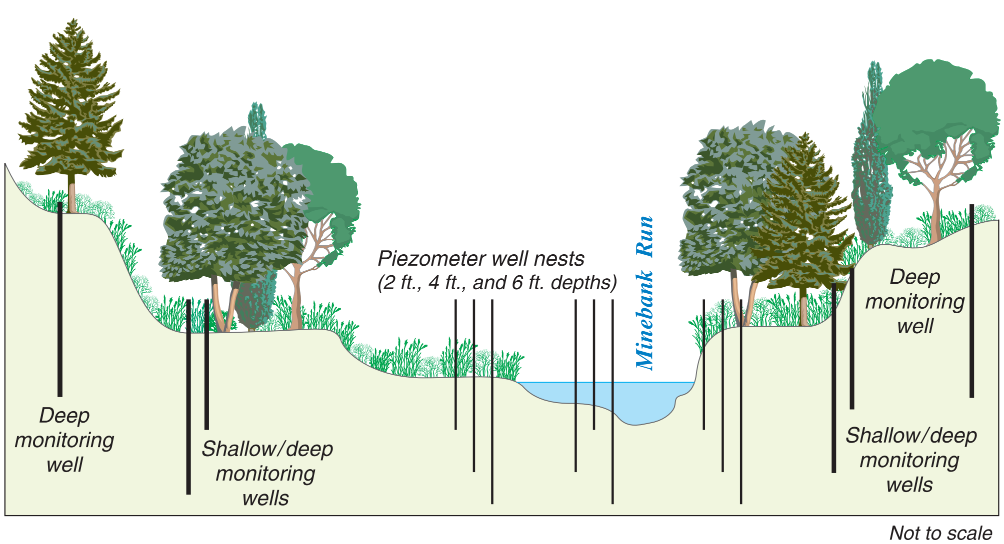


Figure 11. General design of the Minebank Run well and piezometer transects in Cromwell Valley Park, Baltimore County, Maryland. (modified from Federal Interagency Stream Corridor Restoration Working Group, 1998)

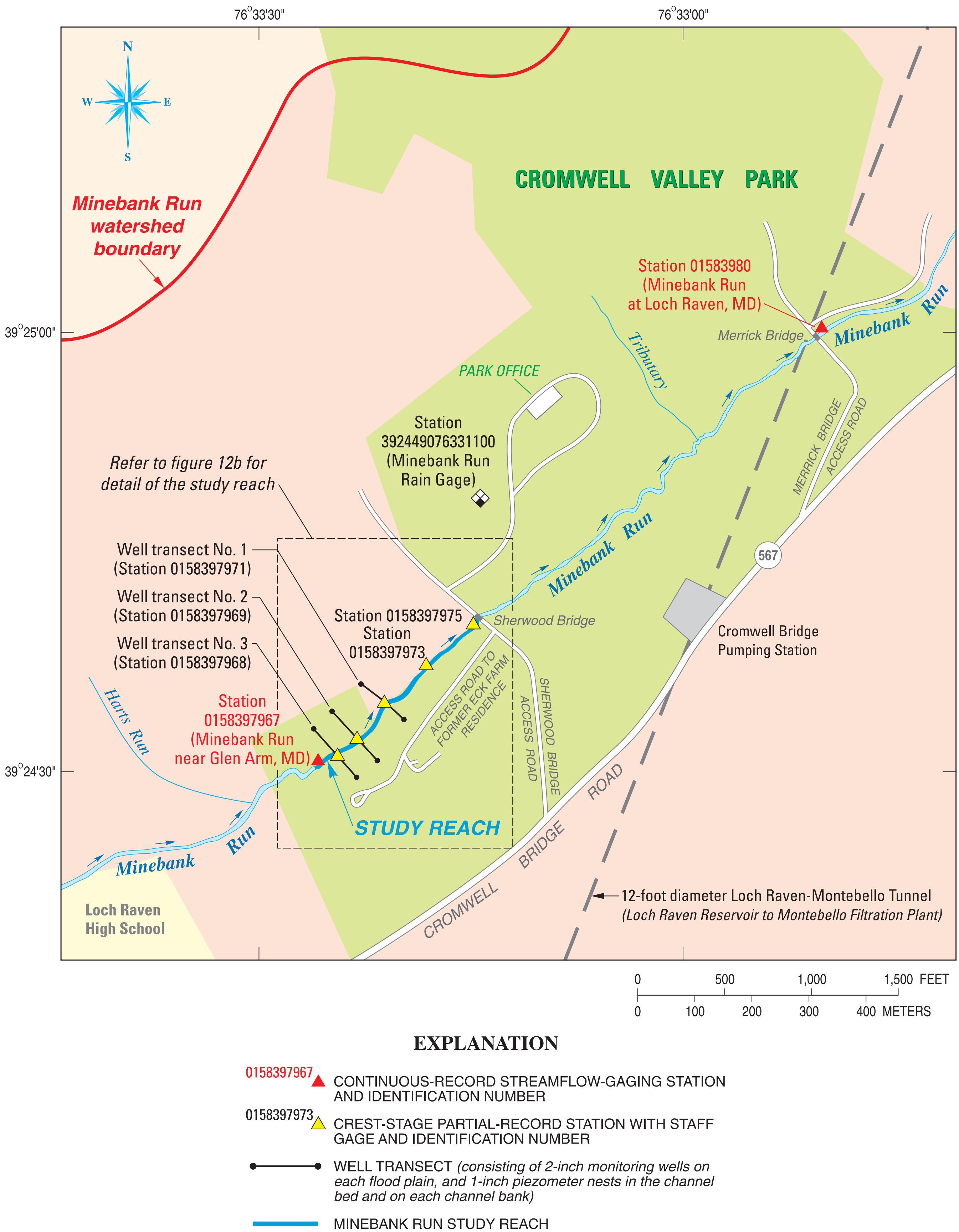


Figure 12a. General layout of the Minebank Run study reach for hydrologic data collection.

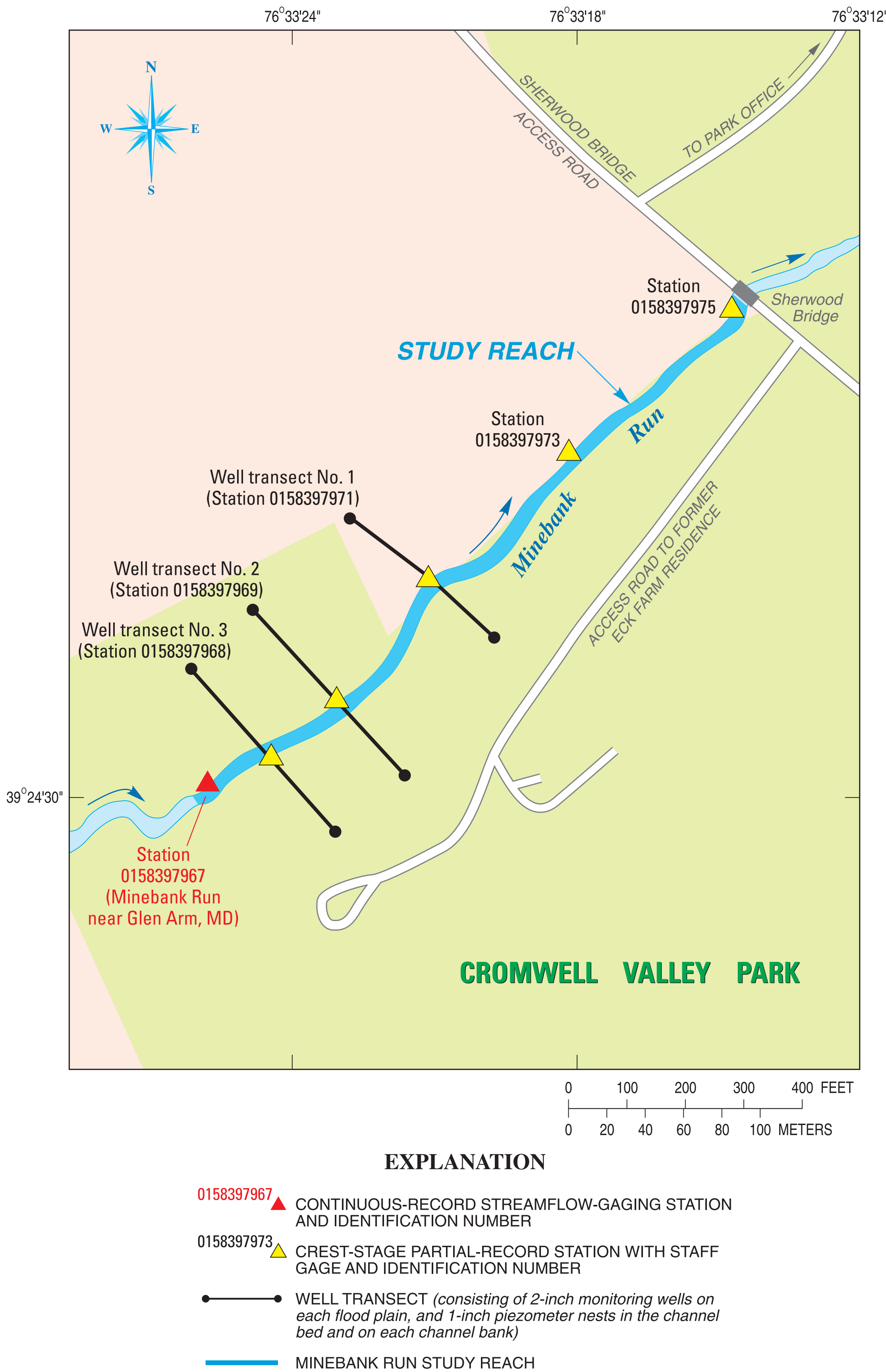


Figure 12b. General layout of the Minebank Run study reach for hydrologic data collection.

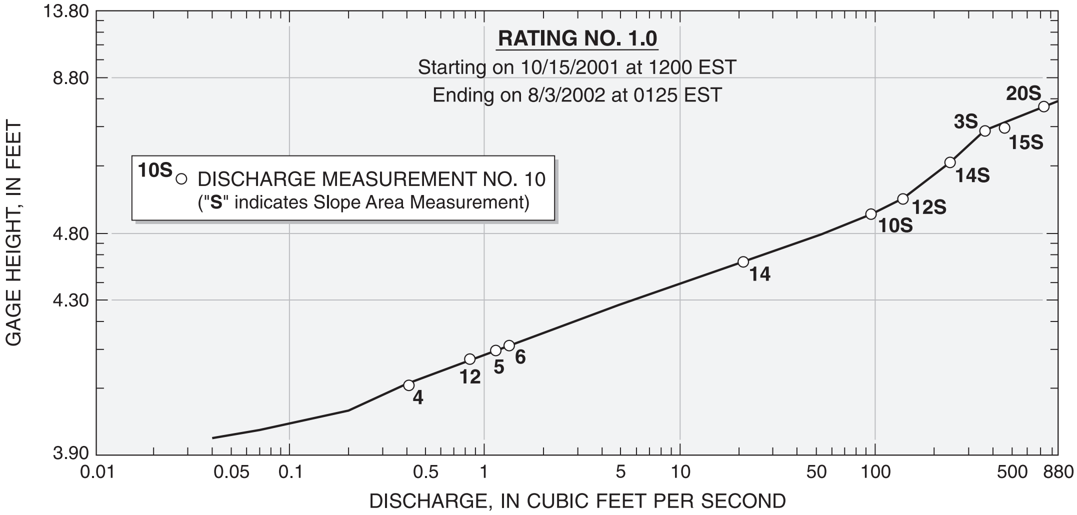


Figure 13. Stage-discharge rating 1.0 for U.S. Geological Survey station 0158397967, Minebank Run near Glen Arm, Maryland.

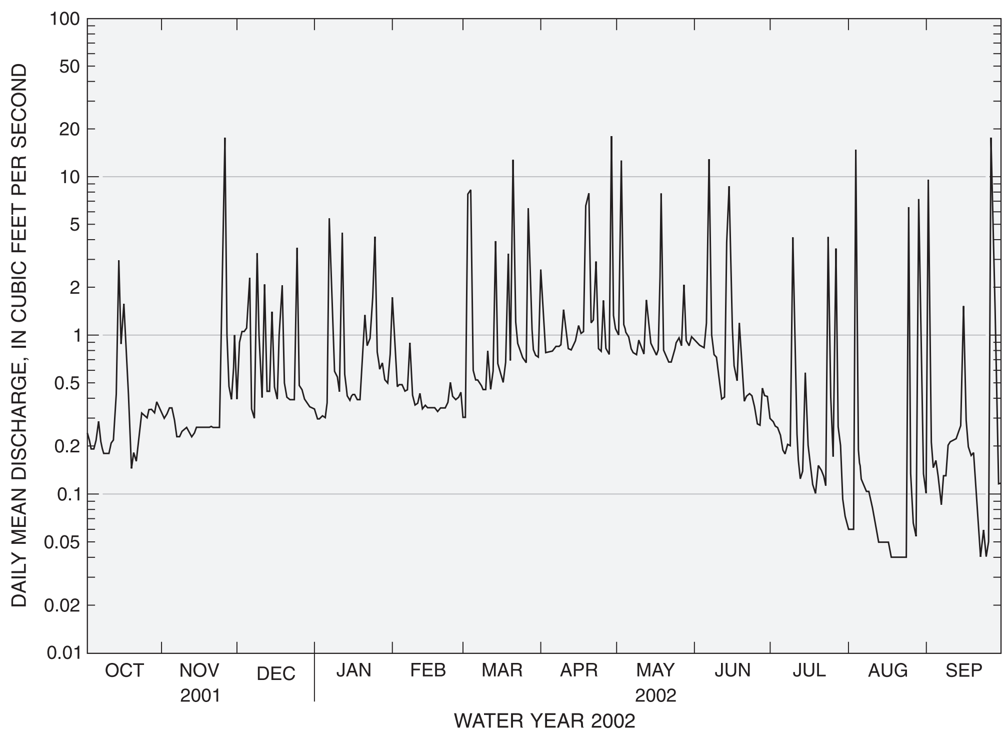


Figure 14. Daily mean discharge for U.S. Geological Survey station 0158397967, Minebank Run near Glen Arm, Maryland, water year 2002.

Discharge measurements require measurements of channel width, depth, and velocity; therefore, these measurements also provide a record of basic channel-geometry variables at a range of gage heights. During water years 2002 through 2004, approximately 110 discharge measurements were made at USGS station 0158397967, Minebank Run near Glen Arm, Maryland. These measurements show the differences in channel-geometry variables that can occur at different gage heights and discharges. The range of data variables for discharge measurements made at USGS station 0158397967, Minebank Run near Glen Arm, Maryland, during water years 2002 through 2004 is shown in table 4.

The mean velocity of streamflow in Minebank Run can exceed 9 ft/s (feet per second) during extreme storm events, as indicated in table 4. The channel width data indicate that the channel remains relatively narrow, with large increases in velocity and discharge. The stream channel confines the streamflow in most locations and does not allow any stream energy to be dissipated in the overbank areas. As a result, most of the stream's energy is directed at the channel bed and banks during higher flows. This causes frequent changes in dimension, pattern, and profile of the stream channel due to bed erosion and aggradation, re-configuring of point bars, and migration of channel banks.

Crest-Stage Partial-Record Stations

Crest-stage partial-record stations were installed at five locations along the Minebank Run study reach. Each crest-stage partial-record station included a staff gage that was used to determine the gage height of the stream at that location (fig. 15). These stations were associated with each of the three

Table 4. Range of data variables for discharge measurements made at U.S. Geological Survey station 0158397967, Minebank Run near Glen Arm, Maryland, water years 2002 through 2004.

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

	Cross-sectional area (ft^2)	Channel width (ft)	Mean channel depth (ft)	Mean velocity (ft/s)	Stream discharge (ft^3/s)
Minimum measured value	0.07	0.50	0.14	0.15	0.04
Maximum measured value	149.7	51.0	2.94	9.29	1,390

Figure 15. Combined crest-stage gage and staff gage at station 0158397968, Minebank Run at Transect 3 near Glen Arm, Maryland. (Photograph by Edward J. Doheny, U.S. Geological Survey)

well transects so that comparative gage height readings could be obtained with water-level measurements in the transect wells. Two other stations were located just downstream of the well transects for use during high-flow events or water-quality sampling. General station information for the crest-stage partial-record stations in the Minebank Run study reach is presented in table 5.

High-water marks from the crest-stage gages at these stations also were documented during water years 2002 through 2004. These marks were used along with data from the continuous-record streamflow-gaging station to determine peak water-surface elevations in the study reach that occurred between site visits. Longitudinal stations along the stream channel were determined for each crest stage gage. Station 0158397975 was assigned a longitudinal station of 5,000 ft and all other locations were measured in reference to this station. The longitudinal-stationing distance and distribution of peak water-surface elevations in the Minebank Run study reach for four selected storm events that occurred during water years 2002 and 2003 are shown in table 6.

There was a range of 8–8.9 ft of fall in the water surface over a distance of 917 ft within the study reach for these four selected storm events (table 6). The gage height at station 0158397967 ranged from 6.88 ft (223.76 ft above mean sea level) to 6.00 ft (222.88 ft above mean sea level), and the peak discharge ranged from 253 ft^3/s to 466 ft^3/s. A profile of the peak water-surface elevations in the Minebank Run study reach for the selected storm events is shown in figure 16.

Table 5. General station information for crest-stage partial-record stations in the Minebank Run study reach.

[º, degrees; ', minutes; ", seconds; mi^2, square miles; MSL, mean sea level]

Station number	Station name	Latitude (º ' ")	Longitude (º ' ")	Drainage area (mi^2)	Gage datum (feet above MSL)	Crest-stage gage base elevation (feet above MSL)
0158397968	Minebank Run at Transect 3 near Glen Arm, Maryland	39 24 37	76 33 22	2.07	212.03	221.09
0158397969	Minebank Run at Transect 2 near Glen Arm, Maryland	39 24 38	76 33 21	2.08	213.73	219.13
0158397971	Minebank Run at Transect 1 near Glen Arm, Maryland	39 24 39	76 33 19	2.09	211.87	216.47
0158397973	Minebank Run below Transect 1 near Parkville, Maryland	39 24 41	76 33 16	2.11	204.95	213.92
0158397975	Minebank Run near Parkville, Maryland	39 24 43	76 33 13	2.20	202.69	208.10

Table 6. Longitudinal stationing and peak water-surface elevations in the Minebank Run study reach for four selected storm events, water years 2002 and 2003.

[ft, feet]

Station number	Station name	Longitudinal stationing (ft)	Water-surface elevation, in feet April 18, 2002	Water-surface elevation, in feet June 6, 2002	Water-surface elevation, in feet February 22, 2003	Water-surface elevation, in feet August 16, 2003
0158397967	Minebank Run near Glen Arm, Maryland	3,650	223.67	223.76	222.88	223.01
0158397968	Minebank Run at Transect 3 near Glen Arm, Maryland	3,830	221.99	222.30	221.75	221.86
0158397969	Minebank Run at Transect 2 near Glen Arm, Maryland	3,978	220.41	220.67	220.17	220.47
0158397971	Minebank Run at Transect 1 near Glen Arm, Maryland	4,215	218.68	218.95	218.10	218.48
0158397973	Minebank Run below Transect 1 near Parkville, Maryland	4,567	214.77	215.01	214.88	214.90

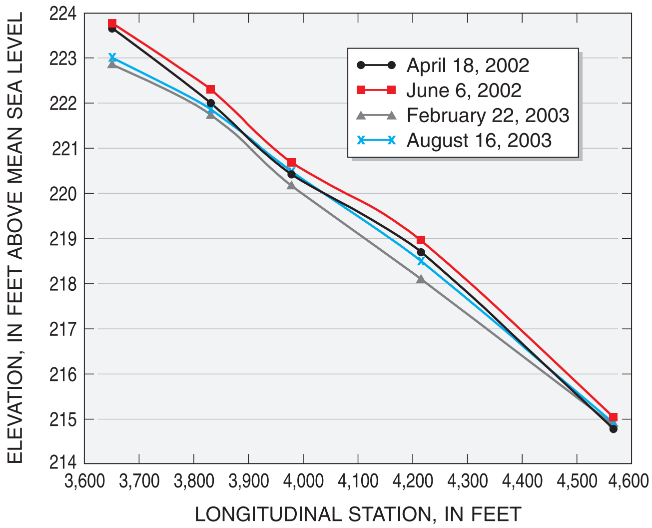


Figure 16. Profile of peak water-surface elevations in the Minebank Run study reach for four selected storm events, water years 2002 and 2003.

Table 7. General station information for rain gage located in the Minebank Run watershed.

[º, degrees; ', minutes; ", seconds]

Station number	392449076331100
Station name	Minebank Run rain gage.
Station location	In farm field, adjacent to Sherwood House in Cromwell Valley Park, near Towson, Maryland.
Latitude	39º 24' 49"
Longitude	76º 33' 11"
Type of gage	Tipping bucket.
Recording interval	5 minutes.

Table 8. Monthly and total precipitation recorded by the Minebank Run rain gage during water years 2002 through 2004.

[precipitation, in inches]

Month	Water year 2002	Water year 2003	Water year 2004
October	0.63	7.45	6.52
November	2.17	4.43	5.39
December	1.87	3.26	5.22
January	2.46	2.58	1.85
February	0.30	6.82	2.71
March	5.02	5.07	2.50
April	4.13	2.69	5.45
May	2.72	7.07	4.61
June	3.30	9.61	4.20
July	2.78	3.90	5.82
August	3.70	4.25	2.15
September	3.87	7.06	5.28
Total	32.95	64.19	51.70

Precipitation

A rain gage was installed near the Minebank Run study reach to obtain precipitation data that correspond to the Minebank Run streamflow-gaging stations located nearby. Neither streamflow-gaging station location was suitable for monitoring precipitation due to the abundance of large trees in the vicinity of the stations. For this reason, the rain gage was installed in a row crop field between the two streamflow-gaging stations (fig. 12a). Five-minute unit-value precipitation data were collected at this location beginning in October 2001. General station information for the rain gage in the Minebank Run watershed is summarized in table 7, and the monthly and total variability of precipitation recorded by the Minebank Run rain gage during water years 2002 through 2004 are shown in table 8.

The variability in precipitation between drought conditions in water year 2002 and the subsequent recovery in water years 2003 and 2004 was extreme (table 8). The total precipitation in water year 2003 was nearly twice that in water year 2002. Although the total precipitation in water year 2004 was significantly less than that in water year 2003, the annual total of 51.7 in. was still about 23 percent higher than the long-term average of 42 in. for the Baltimore region (James, 1986).

Pre-Restoration Surface-Water Hydrology

Discharge-measurement data, streamflow data, and precipitation data collected in the Minebank Run study reach during water years 2002 through 2004 were used in analyses of several characteristics of surface-water hydrology in the watershed. These included (1) rainfall totals, storm duration, and intensity, (2) instantaneous peak discharge and daily mean discharge, (3) stage-discharge ratings, (4) hydraulic-geometry relations, (5) water-surface slope, (6) time of concentration, (7) flood frequency, (8) flood volume, and (9) rainfall-runoff relations.

Rainfall Totals, Storm Duration, and Intensity

Rainfall totals and the duration and intensity of storms were documented for water years 2002 through 2004. A thunderstorm on August 3, 2002 produced 1.18 in. of rainfall in a 1-hour period, for example. The maximum rainfall intensity during this storm was 3.24 in/h (inches per hour), which occurred when 0.27 in. of rain fell during a 5-minute period (fig. 17). Data on storm duration, rainfall totals, and storm intensity for 18 selected storm events in the Minebank Run watershed from water years 2002 through 2004 are shown in table 9.

Several different types of storms struck the Minebank Run watershed during the study period, including thunderstorms, longer-duration regional storms, and a combined rainfall and snowmelt event on February 22, 2003 (table 9). Some storm events produced as much as 2 to 3 in. of rainfall with significant variations in storm duration. Although the thunderstorm on April 19, 2002 produced only 0.80 in. of total rainfall, 0.39 in. fell in one 5-minute period during this storm. The resulting maximum storm intensity of 4.68 in/h was the largest maximum storm intensity recorded in the Minebank Run watershed since October 2001.

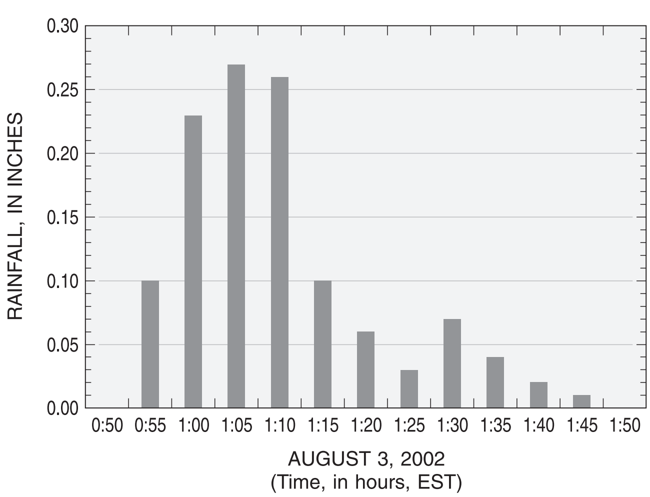


Figure 17. Rainfall intensity and storm duration for the Minebank Run watershed, storm of August 3, 2002.

Comparison of Instantaneous Peak Discharge to Daily Mean Discharge

Comparisons of instantaneous peak discharges and daily mean discharges can provide insights on how quickly streamflow increases and decreases during storm events. Stage and discharge data, collected at the streamflow-gaging station in the Minebank Run study reach, were used to document instantaneous peak discharge and determine daily mean discharges. Stage and discharge hydrographs for the storm of August 3, 2002 at USGS station 0158397967, Minebank Run near Glen Arm, Maryland are shown in figures 18 and 19. A comparison of instantaneous peak discharge and daily mean discharge for the largest storms recorded at USGS station 0158397967, Minebank Run near Glen Arm, Maryland, during water years 2002 through 2004 is shown in table 10.

Stage and discharge in Minebank Run can rise and fall very rapidly (figs. 18–19). During the storm of August 3, 2002, the gage height increased from 3.89 ft to 7.58 ft in less than 30 minutes, representing an increase in discharge from 0.05 ft^3/s to 725 ft^3/s during the same time period. The narrow, pointed-shaped hydrographs for the storm of August 3, 2002 are fairly typical of thunderstorm runoff in small, urban watersheds.

During water years 2002 through 2004, instantaneous peak discharges ranged from 247 to 1,390 ft^3/s and daily mean discharges ranged from 8.0 to 50 ft^3/s at USGS station 0158397967, Minebank Run near Glen Arm, Maryland (table 10). Storms with large instantaneous peak discharges and relatively small daily mean discharges are indicative of heavy rainfall or thunderstorm activity, and generally shorter duration runoff events. Storms with larger daily mean discharges are generally more indicative of longer duration storm events. The storm on February 22, 2003 produced a relatively small instantaneous peak discharge while producing one of the largest daily mean discharges to date at the station due to the combined effects of heavy rainfall and significant snowmelt.

To compare the relative flashiness of specific storm events, the instantaneous peak discharges and daily mean discharges for each storm were divided to develop a ratio. The larger the ratio, the greater the difference between instantaneous peak discharge and daily mean discharge for each storm, and the greater the flashiness. These ratios indicated that the storms of May 17, 2004; April 19, 2002; and August 3, 2002 produced the flashiest conditions in Minebank Run during the pre-restoration study period (table 10).

Table 9. Storm duration, rainfall, and storm-intensity data for 18 selected storm events in the Minebank Run watershed, water years 2002 through 2004.

[EST, Eastern Standard Time; hrs, hours; in., inches; in/h, inches per hour]

Date(s) of storm	Time (EST)	Storm duration (hrs)	Storm rainfall total (in.)	Average storm intensity (in/h)	Maximum storm intensity (in/h)
November 25, 2001	1610–1935	3.42	1.80	0.53	2.88
April 18, 2002	1350–1655	3.08	0.93	0.30	2.76
April 19, 2002	1515–1550	0.58	0.80	1.38	4.68
April 27–28, 2002	2155–1055	13.00	1.57	0.12	0.48
May 2, 2002	0200–0725	5.42	0.98	0.18	1.92
June 6, 2002	1655–1720 1735–1800	0.83	1.06	1.28	3.12
August 3, 2002	0050–0150	1.00	1.18	1.18	3.24
October 10–11, 2002	0535–1255	31.33	3.06	0.10	1.32
February 22, 2003	0610–1440	8.50	2.13	0.25	1.68
June 12, 2003	1620–1820 1910–2025	3.25	2.27	0.70	3.48
June 13, 2003	1835–1945	1.17	0.81	0.69	3.12
August 4, 2003	0155–0945	7.83	0.64	0.08	0.60
September 18–19, 2003	1310–0115	12.08	0.64	0.05	0.48
September 22–23, 2003	1905–0715	12.17	3.15	0.26	2.04
October 14–15, 2003	1840–0020	5.67	2.07	0.37	3.00
November 19, 2003	1315–2130	8.25	2.09	0.25	3.60
June 25, 2004	1520–1645	1.42	0.75	0.53	2.28
July 7, 2004	1405–1655	2.83	1.92	0.68	2.52

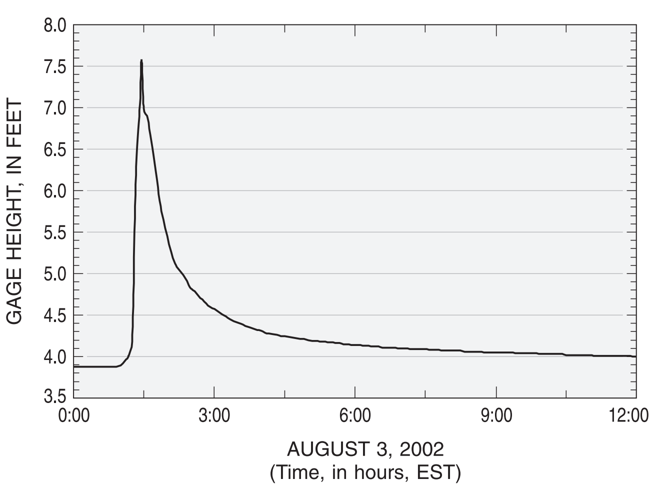


Figure 18. Stage hydrograph for U.S. Geological Survey station 0158397967, Minebank Run near Glen Arm, Maryland, for the storm of August 3, 2002.

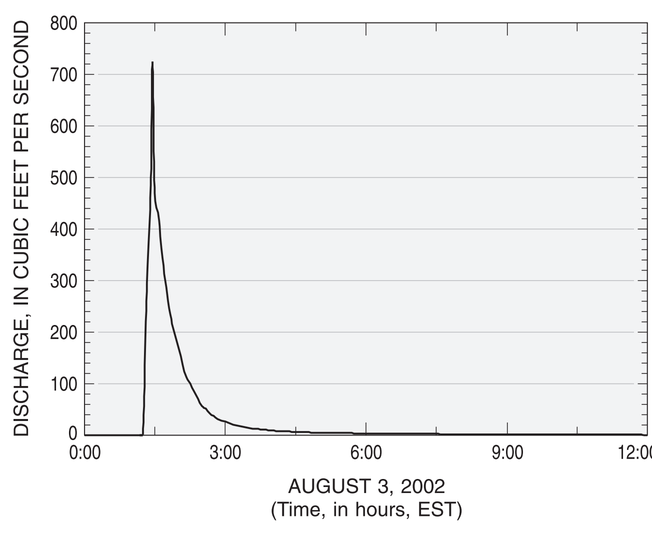


Figure 19. Discharge hydrograph for U.S. Geological Survey station 0158397967, Minebank Run near Glen Arm, Maryland, for the storm of August 3, 2002.

Table 10. Comparison of instantaneous peak discharge and daily mean discharge for the largest storms recorded at U.S. Geological Survey station 0158397967, Minebank Run near Glen Arm, Maryland, water years 2002 through 2004.

[ft, feet; ft^3/s, cubic feet per second]

Date	Peak gage height (ft)	Instantaneous peak discharge (ft^3/s)	Daily mean discharge (ft^3/s)	Ratio of instantaneous to daily mean discharge
June 12, 2003	8.61	1,390	42	33.1
July 7, 2004	7.97	945	27	35.0
July 27, 2004	7.93	919	31	29.6
September 23, 2003	7.78	834	44	19.0
June 13, 2003	7.58	730	29	25.2
August 3, 2002	7.58	725	15	48.3
May 17, 2004	7.55	720	14	51.4
November 19, 2003	7.50	700	35	20.0
June 6, 2002	6.88	466	13	35.8
October 14, 2003	6.84	411	23	17.9
April 19, 2002	6.79	401	8.0	50.1
November 25, 2001	6.73	367	18	20.4
June 25, 2004	6.29	295	14	21.1
August 16, 2003	6.13	272	8.3	32.8
May 25, 2004	6.09	266	10	26.6
September 19, 2003	6.02	256	11	23.3
February 22, 2003	6.00	253	50	5.1
August 4, 2003	5.97	248	8.4	29.5
May 2, 2002	5.96	247	13	19.0

Stage-Discharge Rating Analysis

Large storms and resulting heavy runoff caused stage-discharge ratings at USGS station 0158397967, Minebank Run near Glen Arm, Maryland to change frequently as a consequence of the transport and relocation of bed material in the stream, which changed the **control** conditions downstream from the station. As a result, several revisions to the stage-discharge ratings for the station were necessary to accurately reflect the discharge in the Minebank Run study reach during water years 2002 through 2004. Stage-discharge ratings 1.0 through 4.0 for USGS station 0158397967, Minebank Run near Glen Arm, Maryland were compared to assess differences over time (fig. 20). This analysis was limited to the first four ratings that were in effect at the station, because an artificial control was constructed in October 2003 to prevent frequent changes to the rating. The tendency of the lower end of the stage-discharge rating to shift to the right over time is shown in figure 20. A shift of the stage-discharge rating to the right indicates more discharge for an equivalent gage height. This condition typically occurs when (1) large storms transport sediment downstream and cause filling of the control pool, (2) when a large storm transports gravel, cobbles, and larger rocks from the control riffles and causes less water to back up behind the riffles, or (3) the channel undergoes gradual enlargement, downcutting, or widening due to natural geomorphic processes. These shifts were more pronounced for smaller discharges and were most indicative of measurable changes to the channel bed and control riffles resulting from large storms.

The significant net changes to the stage-discharge rating at station 0158397967 over a relatively short period indicate instability of the stream channel. The tendency of the rating to shift in one direction over time is also indicative of instability and commonly is associated with an urban environment. The timing of the changes in the stage-discharge ratings also can be related directly to particular storm events in the watershed. The changes from rating 1.0 to rating 2.0 were caused by the storm of August 3, 2002. The changes from rating 2.0 to rating 3.0 were caused by the storms of June 12–13, 2003. The changes from rating 3.0 to rating 4.0 were caused by the storm of September 22–23, 2003.

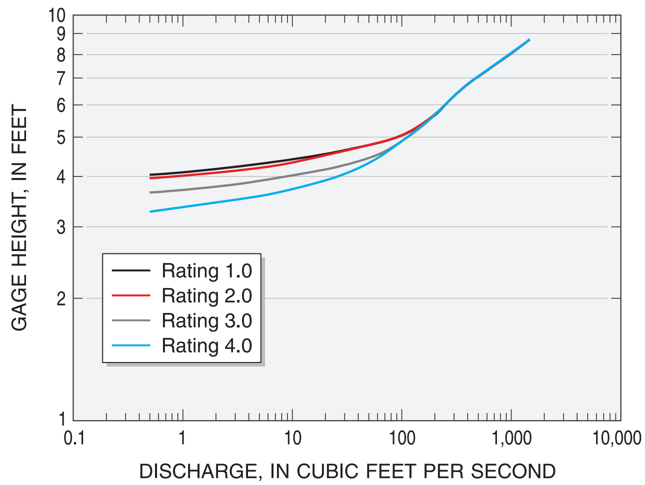


Figure 20. Stage-discharge ratings 1.0 through 4.0 for U.S. Geological Survey station 0158397967, Minebank Run near Glen Arm, Maryland.

Hydraulic-Geometry Relations

Hydraulic-geometry relations were originally described by Leopold and Maddock (1953) as a means of quantifying changes in stream-channel variables with changes in discharge. Hydraulic variables such as cross-sectional area, mean channel depth, channel width, and mean velocity can be related to discharge as a power function by use of simple linear regression. Datasets for determining these relations come from discharge measurements that are made at streamflow-gaging stations (Leopold, 1994).

Discharge measurements made at USGS station 0158397967, Minebank Run near Glen Arm, Maryland during water years 2002 through 2004 were used to relate cross-sectional area, mean channel depth, channel width, and mean velocity to the measured discharge. One hundred ten measurements were used for the analysis, with discharges ranging from 0.04 ft^3/s to 1,390 ft^3/s. Relations were initially developed by using all 110 measurements in the dataset. When the channel variables were plotted against discharge for the complete dataset, however, the data appeared to represent separate populations for low-flow and high-flow conditions. The break between the two data populations occurs at a discharge of about 10 ft^3/s (fig. 21). Due to the possible differences in the hydraulic geometry of the stream channel between low flows and high flows, separate relations were developed for 96 measurements representing discharges less than 10 ft^3/s, and for 14 measurements representing discharges greater than or equal to 10 ft^3/s (figs. 22 and 23). The hydraulic geometry relations that were developed for all three datasets are shown in table 11.

The strongest hydraulic geometry relations are between cross-sectional area and discharge, and all relations are generally stronger for high flows than for low flows on the basis of larger values for the **coefficient of determination** (R^2) (table 11). This can be attributed to (1) significantly fewer high-flow measurements in the dataset, (2) all the high-flow measurements were made in approximately the same location in the channel, and (3) the low-flow measurements were made in slightly different locations in the study reach, depending on the location of the best measuring conditions.

The relation between mean velocity and discharge is very strong for discharges greater than or equal to 10 ft^3/s based on the larger value of R^2, and much less significant for discharges less than 10 ft^3/s based on the lower value of R^2. The slopes of the regression lines, as indicated by the exponent, indicate that for high flows, mean velocity is more responsive to changes in discharge than are channel width or mean channel depth. For low flows, the slopes of the regression lines indicate that channel width is more responsive to changes in discharge than are mean channel depth or mean velocity. Cross-sectional area, which combines the effects of channel width and mean channel depth, is much more responsive to increases in discharge than mean velocity at low flows. For high flows, the slopes of the regression lines for cross-sectional area against discharge and for mean velocity against discharge are nearly equal. This indicates that cross-sectional area is still the most responsive variable to changes in discharge for high flows, but mean velocity is nearly equivalent at high flows based on the slopes of the regression lines.

These hydraulic-geometry-relation equations were used to calculate the variation of cross-sectional area, mean channel depth, channel width, and mean velocity as discharge changes at the streamflow-gaging station. The equations developed for low flows (measured discharges of less than 10 ft^3/s) were used to calculate hydraulic variables for discharges less than 10 ft^3/s. The equations developed for high flows (measured discharges of greater than or equal to 10 ft^3/s) were used to calculate hydraulic variables for discharges of 10 ft^3/s and greater. The results are shown in table 12.

The data in table 12 were compared to cross-sectional variables that were computed from a cross section surveyed in the Minebank Run study reach in December 2002. The cross section was 28 ft downstream from station 0158397967. A plot of the cross section is shown in figure 24. Cross-sectional variables were calculated for this cross section at the point of incipient flooding (elevation 225.78 ft). At this stage, the cross-sectional area was computed as 203 ft^2 (square feet), the mean channel depth was 3.78 ft, and the top width was 53.8 ft. Comparison of these data with the data from table 12 indicates that for a stream discharge of 2,000 ft^3/s and a calculated mean velocity of 11.3 ft/s, the flow is still contained within the stream channel. These data also quantify field observations that indicate the Minebank Run watershed can generate large flow velocities that, in most cases, are directed predominantly within the stream channel.

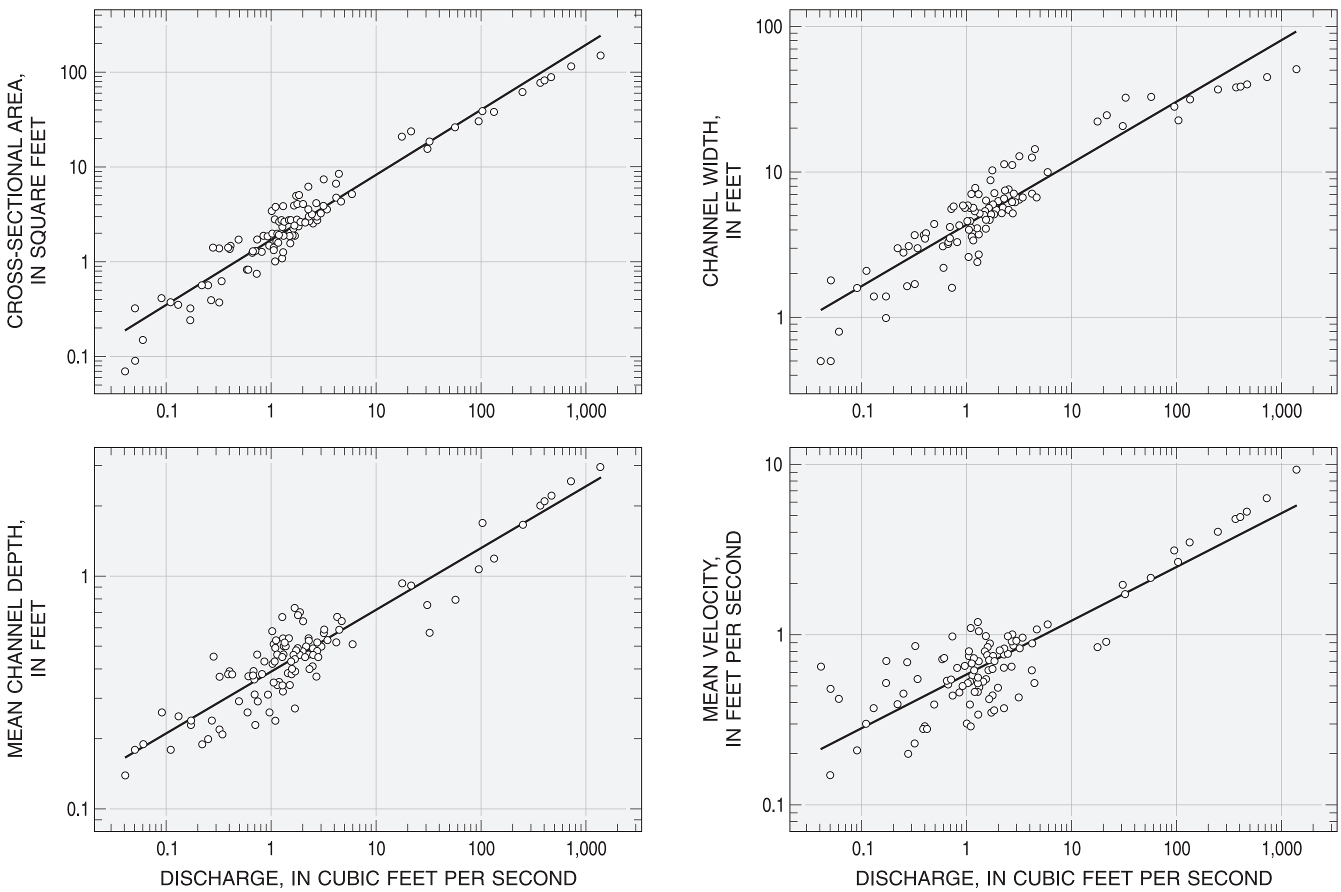


Figure 21. Hydraulic-geometry relations of cross-sectional area, channel width, mean channel depth, and mean velocity against discharge for all discharge measurements made during water years 2002 through 2004 at U.S. Geological Survey station 0158397967, Minebank Run near Glen Arm, Maryland.

Water-Surface Slope

Average water-surface slopes were computed in the study reach for low flows, and for high flows when possible. Ranges of slope were determined for both low flows and high flows during the study period. Low-flow water-surface slopes were determined on the basis of water-surface elevations at the various staff gages in the study reach. High-flow water-surface slopes were determined, where possible, on the basis of water-surface elevations obtained from the continuous-record stream gage and from high-water marks at several crest-stage gages in the study reach.

Average water-surface slopes at low-flow conditions in the study reach were determined on the basis of water-surface elevations that were obtained on 33 separate days between January 2002 and August 2004. The days selected for analysis were those that included the reading of multiple staff gages during low-flow conditions. Slopes were determined by applying simple linear regression to the water-surface elevations and the longitudinal stations of each staff gage on each day. The reach-averaged slope for the 33 days ranged from about 0.009 to 0.010 ft/ft (feet per foot). This represents a relatively small range of low-flow slopes considering the noticeable changes that occurred in the stage-discharge rating during this period of time, indicating that, on average, the low-flow slope in the study reach is maintained over time despite changes to the channel bed and banks within the reach.

Average water-surface slopes at high-flow conditions in the study reach were determined on the basis of water-surface elevations during 28 storm events that occurred between November 2001 and July 2004. The events selected for analysis were based on peak gage heights from the continuous-record stream gage, and from high-water marks at selected crest-stage gages. For certain events, high-water marks could not be obtained in some locations due to submergence of the crest-stage gages or, in some cases, due to damage resulting from high flows and the unstable stream channel. Slopes were determined by applying simple linear regression to the water-surface elevations and the longitudinal stations of each crest-stage gage for each particular event or by determining

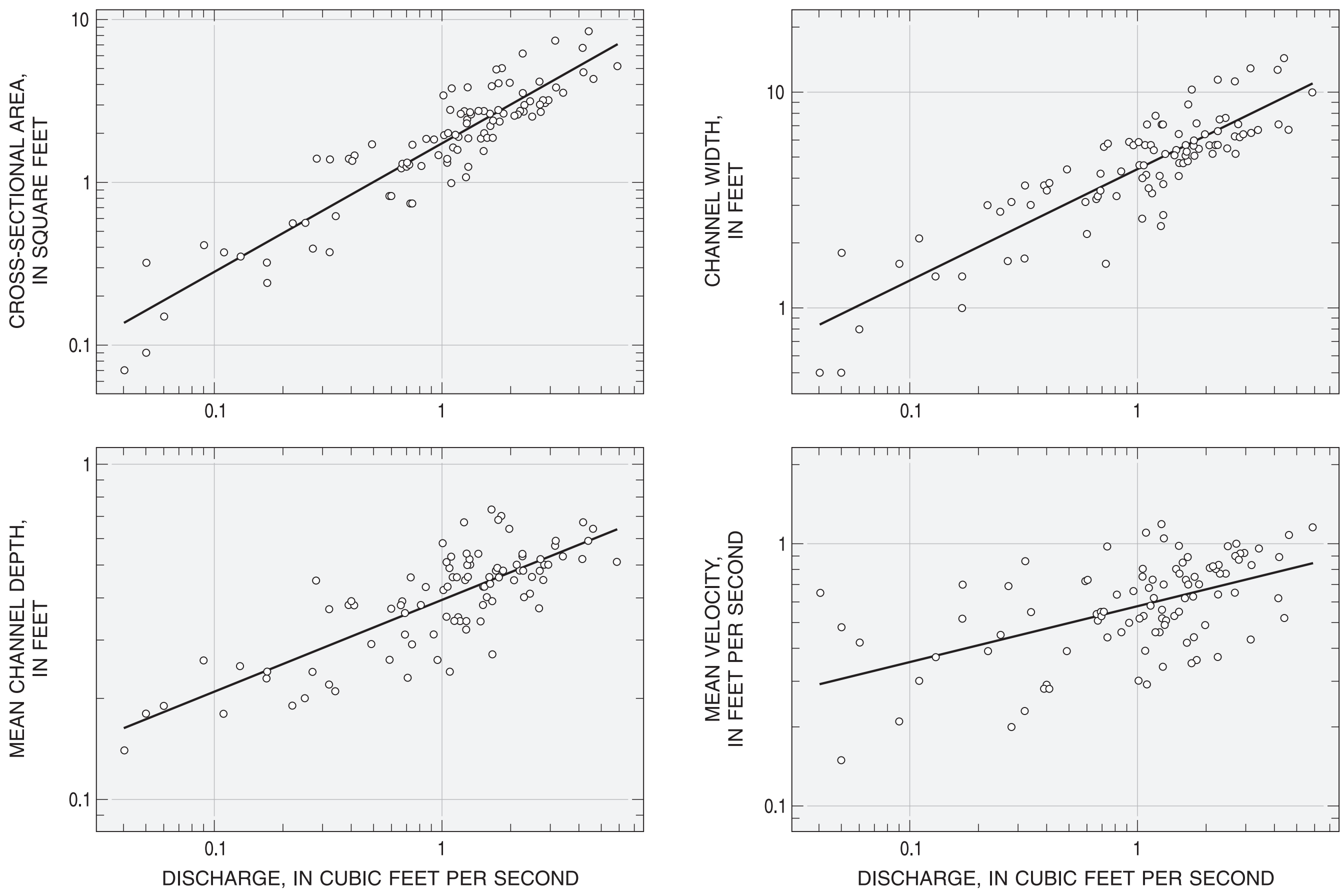


Figure 22. Hydraulic-geometry relations of cross-sectional area, channel width, mean channel depth, and mean velocity against discharge using discharge measurements of less than 10 cubic feet per second made during water years 2002 through 2004 at U.S. Geological Survey station 0158397967, Minebank Run near Glen Arm, Maryland.

the change in elevation of the water surface between crest-stage gages where high-water marks were available. The high-flow slopes for the 28 storm events ranged from 0.008 to 0.012 ft/ft, a slightly larger range than for the low-flow slopes. The data from this analysis indicate that the water-surface slope changes only slightly between low-flow and high-flow conditions. Regardless of flow conditions, the stream channel maintains a water-surface slope of about 1 percent, or 1 ft/ft.

Time of Concentration

Analysis of the time of concentration can provide insight into the hydrologic response of a watershed to precipitation. The time of concentration was defined as the difference in time between the start of rainfall and when discharge begins to increase at the streamflow-gaging station in the study reach (fig. 25). Rainfall data from the precipitation gage and discharge data from USGS station 0158397967, Minebank Run near Glen Arm, Maryland were used to approximate the time of concentration for 18 selected storm events that occurred between November 2001 and July 2004. The times of concentration for each of the 18 selected storm events are shown in table 13.

Times of concentration ranged from 5 to 90 minutes (table 13). Storms with times of concentration of 25 minutes or less are generally indicative of thunderstorms with intense, short-duration rainfall, or longer-duration storms in which rainfall was moderate to heavy as it began. Storms with times of concentration greater than 25 minutes are generally indicative of longer-duration storms with less-intense rainfall, or storms in which rainfall was light to moderate as it began.

Flood Frequency

Flood-frequency analysis can be used to determine estimates of discharge that occur at different **flood recurrence intervals**. Peak-flow data from USGS station 01583980, Minebank Run at Loch Raven, Maryland and USGS station 0158397967, Minebank Run near Glen Arm, Maryland were used to estimate flood frequency for the Minebank Run study

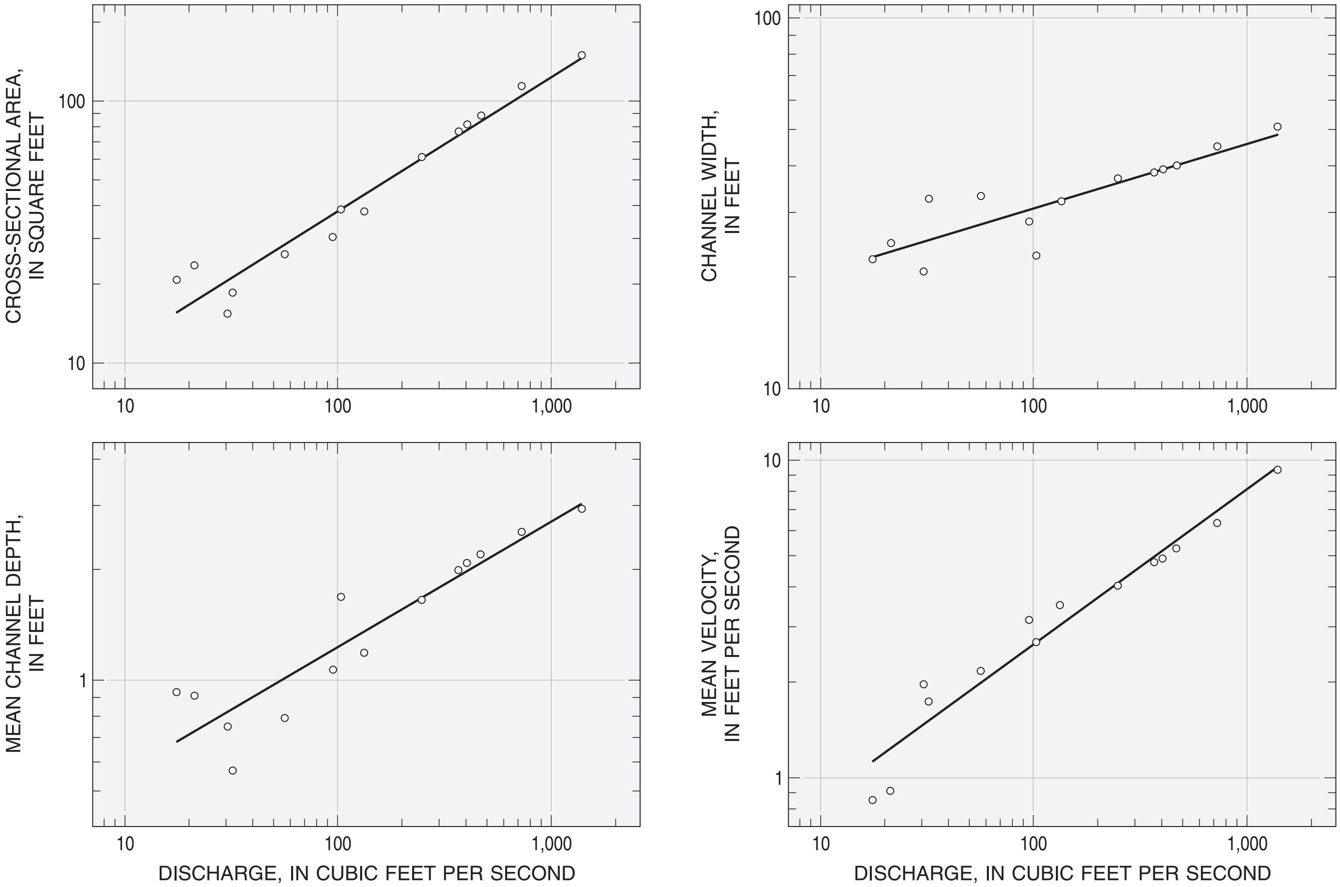


Figure 23. Hydraulic-geometry relations of cross-sectional area, channel width, mean channel depth, and mean velocity against discharge using discharge measurements of greater than or equal to 10 cubic feet per second made during water years 2002 through 2004 at U.S. Geological Survey station 0158397967, Minebank Run near Glen Arm, Maryland.

Table 11. Hydraulic-geometry relations for U.S. Geological Survey station 0158397967, Minebank Run near Glen Arm, Maryland.

[A, cross-sectional area; V, mean velocity; W, channel width; D, mean channel depth; Q, discharge; R^2, coefficient of determination; ≥, greater than or equal to; <, less than; ft, feet; ft^2, square feet; ft/s, feet per second]

Hydraulic variable	All measurements	Q < 10 ft^3/s	Q ≥ 10 ft^3/s
Cross-sectional area (ft^2)	$A = 1.71Q^{0.685}$ $R^2 = 0.94$	$A = 1.74Q^{0.787}$ $R^2 = 0.84$	$A = 3.61Q^{0.511}$ $R^2 = 0.95$
Mean channel depth (ft)	$D = 0.390Q^{0.264}$ $R^2 = 0.89$	$D = 0.393Q^{0.273}$ $R^2 = 0.65$	$D = 0.256Q^{0.341}$ $R^2 = 0.85$
Channel width (ft)	$W = 4.37Q^{0.421}$ $R^2 = 0.88$	$W = 4.41Q^{0.515}$ $R^2 = 0.75$	$W = 13.79Q^{0.174}$ $R^2 = 0.76$
Mean velocity (ft/s)	$V = 0.59Q^{0.315}$ $R^2 = 0.76$	$V = 0.577Q^{0.213}$ $R^2 = 0.29$	$V = 0.278Q^{0.488}$ $R^2 = 0.94$

Table 12. Calculated hydraulic variables for the stream channel with increasing discharge, U.S. Geological Survey station 0158397967, Minebank Run near Glen Arm, Maryland.

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

Stream discharge (ft^3/s)	Cross-sectional area (ft^2)	Mean channel depth (ft)	Channel width (ft)	Mean velocity (ft/s)
0.1	0.28	0.21	1.3	0.35
1.0	1.74	0.39	4.4	0.58
10	11.7	0.56	20.6	0.86
100	38.0	1.23	30.7	2.6
500	86.4	2.13	40.7	5.8
1,000	123	2.70	45.9	8.1
1,500	152	3.10	49.2	9.9
2,000	176	3.42	51.8	11.3

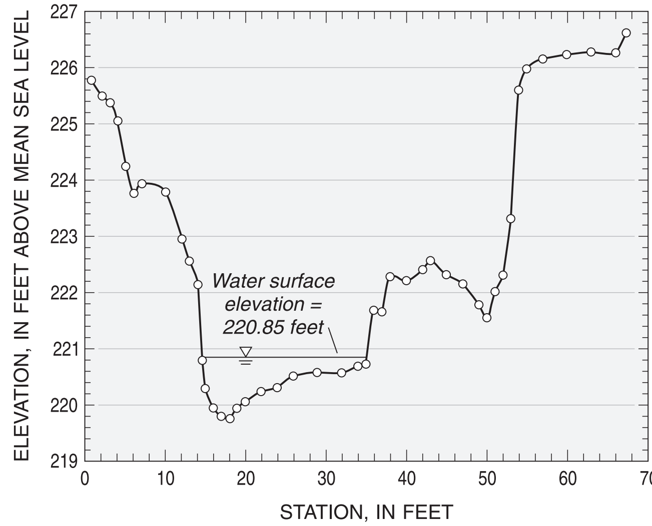


Figure 24. Cross section of Minebank Run stream channel, 28 feet downstream of U.S. Geological Survey station 0158397967, Minebank Run near Glen Arm, Maryland, December 2002.

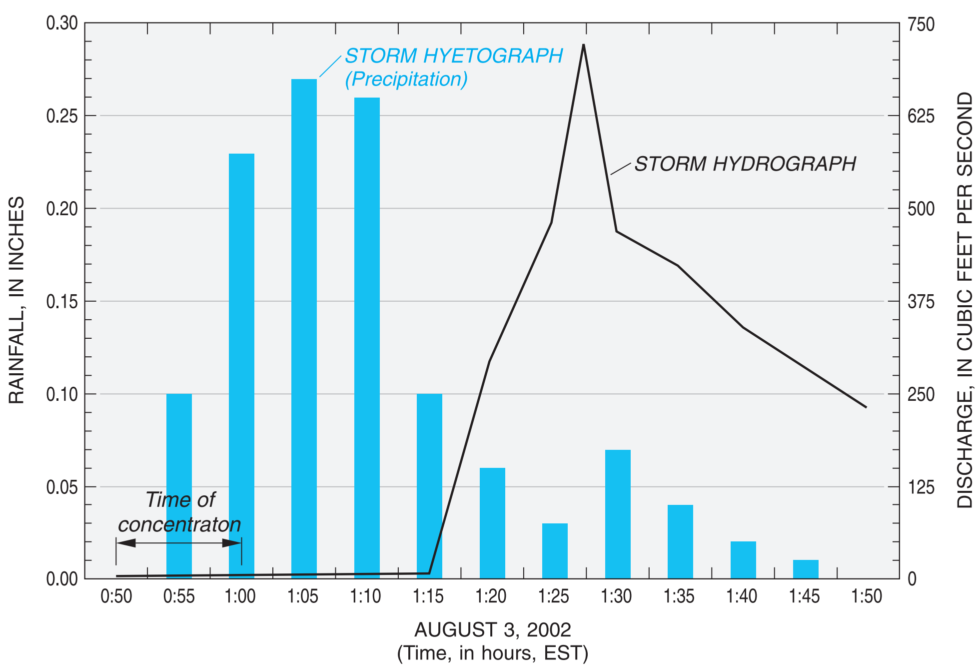


Figure 25. Storm hyetograph, hydrograph, and time of concentration for U.S. Geological Survey station 0158397967, Minebank Run near Glen Arm, Maryland, for the storm of August 3, 2002.

Table 13. Time of concentration for 18 selected storms in the Minebank Run watershed, water years 2002 through 2004.

[EST, Eastern Standard Time; hrs, hours; in., inches; in/h, inches per hour; min, minutes]

Date(s) of storm	Time (EST)	Storm duration (hrs)	Storm rainfall total (in.)	Average storm Intensity (in/h)	Maximum storm intensity (in/h)	Time of concentration (min)
November 25, 2001	1610–1935	3.42	1.80	0.53	2.88	10
April 18, 2002	1350–1655	3.08	0.93	0.30	2.76	25
April 19, 2002	1515–1550	0.58	0.80	1.38	4.68	5
April 27–28, 2002	2155–1055	13.00	1.57	0.12	0.48	90
May 2, 2002	0200–0725	5.42	0.98	0.18	1.92	65
June 6, 2002	1655–1720 1735–1800	0.83	1.06	1.28	3.12	20
August 3, 2002	0050–0150	1.00	1.18	1.18	3.24	10
October 10–11, 2002	0535–1255	31.33	3.06	0.10	1.32	45
February 22, 2003	0610–1440	8.50	2.13	0.25	1.68	50
June 12, 2003	1620–1820 1910–2025	3.25	2.27	0.70	3.48	10
June 13, 2003	1835–1945	1.17	0.81	0.69	3.12	5
August 4, 2003	0155–0945	7.83	0.64	0.08	0.60	15
September 18–19, 2003	1310–0115	12.08	0.64	0.05	0.48	72
September 22–23, 2003	1905–0715	12.17	3.15	0.26	2.04	80
October 14–15, 2003	1840–0020	5.67	2.07	0.37	3.00	35
November 19, 2003	1315–2130	8.25	2.09	0.25	3.60	5
June 25, 2004	1520–1645	1.42	0.75	0.53	2.28	40
July 7, 2004	1405–1655	2.83	1.92	0.68	2.52	40

reach. The analysis was performed using standard techniques specified in “Guidelines for Determining Flood Flow Frequency,” Bulletin 17B (Interagency Advisory Committee on Water Data, 1982).

Station 01583980 has an 8-year peak-flow record whereas station 0158397967 has only a 3-year record. Drainage-area ratios were used to estimate peak discharges at station 0158397967, Minebank Run near Glen Arm, Maryland for water years 1997 through 2001. Measured peak discharges for water years 2002 through 2004 were used with these estimates to estimate an 8-year peak-flow record for station 0158397967.

Flood-frequency estimates for station 0158397967, Minebank Run near Glen Arm, Maryland were compared to estimates for another watershed in the Piedmont Physiographic Province with a similar drainage area. USGS station 01583000, Slade Run near Glyndon, Maryland is in a 2.09-mi^2 watershed and was in operation from 1947 to 1981. The Slade Run station is in a predominantly agricultural (44.7 percent) and forested (42.1 percent) watershed that includes a smaller amount of residential (5.7 percent) and commercial (7.5 percent) land use (McCandless and Everett, 2002). Thus, the Slade Run watershed has 13.2 percent urban and suburban land use at station 01583000. In contrast, the Minebank Run watershed is dominated by 80.6 percent urban and suburban land use at station 0158397967. The results of the flood-frequency analysis for the Minebank Run and the Slade Run stations are shown in table 14.

The flood discharges for Slade Run were significantly lower over the range of flood probabilities than for Minebank Run (table 14). The storm of June 12, 2003, which produced a peak discharge of 1,390 ft^3/s at USGS station 0158397967, Minebank Run near Glen Arm, Maryland, was approximately a 5-year flood event according to the flood frequency analysis. Analysis of the 34-year peak-flow record for USGS station 0158300, Slade Run near Glyndon, Maryland, indicates a peak discharge of 515 ft^3/s during Hurricane Agnes in June 1972. At Slade Run, the recurrence interval for this type of storm is approximately 40 years according to the flood-frequency analysis, whereas a discharge of 515 ft^3/s is only a 1.2-year flood event at Minebank Run. The peak-flow record for station 0158397967 also indicates that Minebank Run exceeded a

Table 14. Comparison of flood-frequency analyses for Minebank Run and Slade Run streamflow-gaging stations.

[yrs, years; ft^3/s, cubic feet per second]

Annual exceedance probability	Recurrence interval (yrs)	Discharge for U.S. Geological Survey station number 0158397967, Minebank Run near Glen Arm, Maryland[1] (1997–2004) (ft^3/s)	Discharge for U.S. Geological Survey station number 01583000, Slade Run near Glyndon, Maryland (1947–1981) (ft^3/s)
0.995	1.005	252.2	46.3
0.990	1.01	283.7	51.1
0.950	1.05	394.4	68.3
0.900	1.11	472.1	80.5
0.800	1.25	589.4	99.5
0.500	2	912.7	154.4
0.200	5	1,437.0	251.0
0.100	10	1,835.0	329.9
0.040	25	2,393.0	448.1
0.020	50	2,849.0	550.8
0.010	100	3,339.0	666.8
0.005	200	3,867.0	798.0
0.002	500	4,631.0	998.2

[1] Peak-discharge record for flood-frequency analysis estimated using drainage area ratios from U.S. Geological Survey station 01583980, Minebank Run at Loch Raven, Maryland, for water years 1997 through 2001.

discharge of 515 ft^3/s four times between June and November 2003, and three times between May and July 2004. These differences in flood-frequency discharges are most likely due to the differences in land use in each watershed, which can directly affect the timing, duration, and amount of runoff that reaches the stream channel during storm events.

The **flow duration** of various **exceedance probabilities** was determined for station 0158397967 during water years 2002 and 2004. For Minebank Run, the annual exceedance probability of 0.995 (1.005-year recurrence interval) was exceeded about 0.024 percent of the time. The annual exceedance probability of 0.500 (2-year recurrence interval) was exceeded about 0.001 percent of the time. Annual exceedance probabilities of 0.100 (10-year recurrence interval) to 0.002 (500-year recurrence interval) were not exceeded during the period of continuous record. These results indicate that in spite of larger flows that occur more frequently in urban watersheds, the percentage of time that the flow remains at these recurrence intervals is relatively small.

Flood Volume

Flood-volume analysis was used to determine the amount of urban runoff typically generated by storm events in the study reach. Peak-flow hydrographs for station 0158397967, Minebank Run near Glen Arm, Maryland were used to estimate flood volumes for 18 selected storm events occurring between November 2001 and July 2004. Flood volume, in ft^3 (cubic feet), was determined by measuring the area under the discharge hydrograph from each storm event for USGS station 0158397967, Minebank Run near Glen Arm, Maryland. Storm events were selected for analysis on the basis of variations in peak discharge, storm duration, and storm intensity. Several types of storm events were analyzed, including short-duration thunderstorms, longer-duration regional storms, and a combined rainfall and snowmelt event. The results are shown in table 15.

Flood volumes ranged from 540,000 to 5,067,700 ft^3 (12.4 to 116.6 acre-feet) for the 18 storm events, representing a range of 4.04 million to 37.91 million gallons of water in runoff generated by these storm events (table 15). A volume of 37.91 million gallons of water is enough to fill a regulation-size football field to a depth of nearly 88 ft.

The three largest flood volumes were relatively similar in magnitude despite differences in storm type, storm duration, rainfall intensity, rainfall amount, and peak discharge (table 15). The storms of February 22, 2003; June 12, 2003; and September 22–23, 2003 produced flood volumes in the range of 4,871,900 to 5,067,700 ft^3 (112 to 116.6 acre-feet).

Table 15. Storm characteristics, peak discharge, and flood volume for 18 selected storm events at U.S. Geological Survey station 0158397967, Minebank Run near Glen Arm, Maryland, water years 2002 through 2004.

[hrs, hours; in., inches; in/h, inches per hour; ft^3/s, cubic feet per second; ft^3, cubic feet]

Date(s) of storm	Storm duration (hrs)	Storm rainfall total (in.)	Average storm intensity (in/h)	Maximum storm intensity (in/h)	Peak discharge (ft^3/s)	Flood volume (ft^3)
November 25, 2001	3.42	1.80	0.53	2.88	367	1,451,000
April 18, 2002	3.08	0.93	0.30	2.76	180	540,000
April 19, 2002	0.58	0.80	1.38	4.68	401	834,900
April 27–28, 2002	13.00	1.57	0.12	0.48	78	1,265,600
May 2, 2002	5.42	0.98	0.18	1.92	247	1,038,100
June 6, 2002	0.83	1.06	1.28	3.12	466	1,133,600
August 3, 2002	1.00	1.18	1.18	3.24	725	1,641,100
October 10–11, 2002	31.33	3.06	0.10	1.32	197	3,021,300
February 22, 2003	8.50	2.13	0.25	1.68	253	4,871,900
June 12, 2003	3.25	2.27	0.70	3.48	1,390	4,933,400
June 13, 2003	1.17	0.81	0.69	3.12	730	1,529,400
August 4, 2003	7.83	0.64	0.08	0.60	248	611,500
September 18–19, 2003	12.08	0.64	0.05	0.48	256	1,838,900
September 22–23, 2003	12.17	3.15	0.26	2.04	834	5,067,700
October 14–15, 2003	5.67	2.07	0.37	3.00	411	2,555,300
November 19, 2003	8.25	2.09	0.25	3.60	700	3,464,800
June 25, 2004	1.58	0.75	0.47	2.28	295	1,251,720
July 7, 2004	2.83	1.92	0.68	2.52	945	3,052,250

The September 22–23, 2003 storm was a longer-duration storm with periods of intense rainfall that produced a peak discharge of 834 ft^3/s. The June 12, 2003 storm was a short duration thunderstorm with mostly intense rainfall that produced a peak discharge of 1,390 ft^3/s. The February 22, 2003 storm was a combined rainfall and snowmelt event with periods of intense rainfall that produced a peak discharge of only 253 ft^3/s. These results indicate that small urban watersheds such as Minebank Run can have vastly different runoff characteristics that result in nearly the same flood volume depending on the type of storm that hits the watershed.

Rainfall-Runoff Relations

Rainfall-runoff relations provide another measure of the hydrologic response of a watershed to storm events. Flood-volume estimates and precipitation data were used to estimate runoff amounts and runoff percentages for the 18 selected storm events occurring at USGS station 0158397967, Minebank Run near Glen Arm, Maryland between November 2001 and July 2004. Runoff amounts were determined by dividing the measured flood volume from each flood hydrograph by the drainage area at the streamflow-gaging station as follows:

$$R_a = \left[V_f / \left(DA * 5280 * 5280 \right) \right] * 12,$$

where

R_a = runoff amount, in inches;

V_f = measured flood volume, in ft^3;

and

DA = drainage area, in mi^2.

The runoff amount was divided by the total amount of rainfall from the given storm to obtain the percentage of total rainfall that becomes runoff for each storm event. The runoff amounts and percentages for the 18 selected storm events are shown in table 16.

There was a significant range of runoff percentages for the Minebank Run watershed upstream of USGS station 0158397967 between November 2001 and July 2004 (table 16). Storms that occurred during extreme drought conditions in water year 2002 generally had a lesser

Table 16. Runoff amounts and percentages for 18 selected storm events at U.S. Geological Survey station 0158397967, Minebank Run near Glen Arm, Maryland, water years 2002 through 2004.

[hrs, hours; in., inches; ft^3/s, cubic feet per second; ft^3, cubic feet]

Date(s) of storm	Storm duration (hrs)	Storm rainfall total (in.)	Peak discharge (ft^3/s)	Flood volume (ft^3)	Runoff amount (in.)	Percentage of total rainfall as runoff
November 25, 2001	3.42	1.80	367	1,451,000	0.30	16.7
April 18, 2002	3.08	0.93	180	540,000	0.11	11.8
April 19, 2002	0.58	0.80	401	834,900	0.17	21.3
April 27–28, 2002	13.00	1.57	78	1,265,600	0.26	16.8
May 2, 2002	5.42	0.98	247	1,038,100	0.22	22.1
June 6, 2002	0.83	1.06	466	1,133,600	0.24	22.3
August 3, 2002	1.00	1.18	725	1,641,100	0.34	29.1
October 10–11, 2002	31.33	3.06	197	3,021,300	0.63	20.6
February 22, 2003	8.50	2.13	253	4,871,900	1.02	47.8
June 12, 2003	3.25	2.27	1,390	4,933,400	1.03	45.4
June 13, 2003	1.17	0.81	730	1,529,400	0.32	39.5
August 4, 2003	7.83	0.64	248	611,500	0.13	20.0
September 18–19, 2003	12.08	0.64	256	1,838,900	0.38	60.0
September 22–23, 2003	12.17	3.15	834	5,067,700	1.06	33.6
October 14–15, 2003	5.67	2.07	411	2,555,300	0.53	25.6
November 19, 2003	8.25	2.09	700	3,464,800	0.72	34.6
June 25, 2004	1.33	0.75	295	1,251,720	0.26	34.9
July 7, 2004	2.67	1.92	945	3,052,250	0.64	33.2

percentage of total rainfall as runoff than storms that occurred after the drought recovery began in fall 2002. On average, the eight storms occurring between November 2001 and October 2002 had 20.1 percent of the total rainfall as runoff. The 10 storms occurring between February 2003 and July 2004 averaged 37.5 percent of the total rainfall as runoff. According to Leopold (1994), the average percentage of runoff from total precipitation for creeks and rivers in the United States is about 30 percent. The average percentage of total precipitation as runoff for the 18 selected storm events in table 16, which represent several different types of storm events during different extreme hydrologic conditions over the study period, was 29.7 percent. Most of the rainfall that does not run off into the stream most likely infiltrates into the ground or is lost to **evapotranspiration**. Some water also may be lost as storage, but this percentage is likely to be very low in the Minebank Run watershed due to considerable basin relief and the large percentage of urban development in the watershed.

Flood hydrographs for USGS stations 0158397967 and 01583980, Minebank Run at Loch Raven, Maryland were used to determine typical runoff characteristics for Minebank Run. On the basis of hydrograph analysis, typical storm events in Minebank Run initially result in a slight increase in discharge from direct runoff, followed by a flood wave that significantly increases the stage and discharge of the stream very quickly. Because the two streamflow-gaging stations on Minebank Run are 4,120 feet (0.78 mi) apart, the hydrographs for both stations can be evaluated to determine the velocity of the flood wave as it moves between them. The arrival times of the flood wave at each station and velocity of the flood wave for 18 selected storm events occurring between water years 2002 and 2004 are shown in table 17.

Flood-wave velocity can vary considerably in Minebank Run (table 17). For most storms, the time between arrival of the flood wave between stations ranges from about 10 to 35 minutes. The two exceptions to this are the October 10–11, 2002 storm and the February 22, 2003 storm. The October 10–11, 2002 storm was a longer duration event (31.33 hours) with fairly low average rainfall intensity (0.10 in/h) that occurred just as the recovery from the drought was beginning. The low flood-wave velocity for this storm might be explained by the combination of low rainfall intensity and dry stream

Table 17. Arrival times and velocity of flood wave for selected storm events at the Minebank Run streamflow-gaging stations, water years 2002 through 2004.

[EST, Eastern Standard Time; min, minute; ft/min, feet per minute]

Date(s) of storm	Station 0158397967 flood wave arrival time (EST)	Station 01583980 flood wave arrival time (EST)	Time between stations (min)	Velocity of flood wave (ft/min)
November 25, 2001	1635	1650	15	274.7
April 18, 2002	1415	1450	35	117.7
April 19, 2002	1535	1545	10	412.1
April 27–28, 2002	0030	0055	25	164.8
May 2, 2002	0550	0610	20	206.1
June 6, 2002	1720	1735	15	274.7
August 3, 2002	0115	0130	15	274.7
October 10–11, 2002	0750	0945	115	35.8
February 22, 2003	0705	0840	95	43.4
June 12, 2003	1645	1700	15	274.7
June 13, 2003	1855	1910	15	274.7
August 4, 2003	0220	0230	10	412.1
September 18–19, 2003	2340	0000	20	206.1
September 22–23, 2003	2100	2130	30	137.3
October 14–15, 2003	1930	1955	25	164.8
November 19, 2003	1405	1430	25	164.8
June 25, 2004	1620	1635	15	274.7
July 7, 2004	1510	1530	20	206.1

channel between the stations that was being replenished during the storm. The low flood wave velocity for the February 22, 2003 storm might be explained by the combination of light to heavy rain and approximately 24 to 30 in. of snow that was on the ground at the time of the storm. Even with periods of fairly heavy rainfall during this storm, the snow on the ground reduced the speed at which runoff reached the channel. As a result, the flood wave also moved through the channel at a lower velocity.

Potential for Future Study

The value of the pre-restoration data collected at Minebank Run during water years 2002 through 2004 would be fully realized by an equivalent period of data collection after the stream channel is physically restored. These latter data would allow for comparison of stream hydrology in the study reach during the pre- and post-restoration periods and the subsequent effects of stream-channel restoration on the surface-water hydrology.

Although this report focuses mainly on the streamflow and precipitation data that were collected during the pre-restoration period, the study also included collection of (1) water levels in the wells and piezometers in the study reach, (2) samples of both streamflow and ground water that were analyzed for chemical constituents, and (3) geomorphic data that physically describe the stream channel cross section and profile, as well as the channel bed and bank composition within the study reach. Ground-water levels and basic water-quality data from this study can be found in the USGS Maryland-Delaware-D.C. annual water-data reports for water years 2002 through 2004 (Curtin and others, 2005; James and others, 2003, 2004; Saffer and others, 2005; Smigaj and others, 2003; U.S. Geological Survey, 2004). Future analyses of these data and synthesis with the streamflow and precipitation data could provide a more complete understanding of the hydrologic system of Minebank Run in the pre-restoration condition.

Post-restoration collection of hydrologic and geomorphic data could also provide some general indications of the long-term response of a stream channel in a small, urban watershed to physical restoration. Long-term data collection could provide some clues as to whether urban stream channels evolve toward dynamic equilibrium and enhanced stability after being physically restored.

Summary

The U.S. Geological Survey, the U.S. Environmental Protection Agency, and the Institute of Ecosystem Studies are conducting an investigation to determine the effects of stream restoration on stream hydrology, denitrification, and overall water quality in a selected reach of Minebank Run. This report describes general watershed characteristics in the Minebank Run watershed, a small urban watershed in the south-central section of Baltimore County, Maryland that was physically restored during 2004 and 2005.

Minebank Run is a 3.27-square-mile sub-watershed of the Gunpowder Falls in the eastern Piedmont Physiographic Province. The watershed includes both silicic and carbonate rocks that are overlain by alluvial and colluvial deposits in the stream valley. Stream-channel slopes are about 1 percent or slightly less in most locations. Relief ranges from 100 to 300 feet in most areas of the watershed. The watershed is predominantly urban and suburban with some forest cover and open space and small percentages of agriculture and farmland. The largest percentages of impervious surfaces are in the predominantly urban areas in the headwaters of the watershed. The stream channel in the study reach is noticeably degraded and overwidened, with steep banks, noticeable bank failures, and lateral migration. The combination of fairly steep stream slopes, nearly 300 feet of relief, and large areas of impervious surfaces cause the stream stage and corresponding discharge to increase and decrease very quickly during storm events.

A study reach along the unrestored section of Minebank Run was selected for collection of several types of environmental data, including continuous-record and partial-record stage and streamflow data, precipitation, and ground-water levels. This report describes and presents examples of the surface-water data that were collected in and near the study reach during water years 2002 through 2004.

The discharge-measurement data, streamflow data, and precipitation data collected in the Minebank Run study reach during water years 2002 through 2004 were used in analyses of several characteristics of surface-water hydrology in the watershed. These included (1) rainfall totals, storm duration, and intensity, (2) instantaneous peak discharge and daily mean discharge, (3) stage-discharge ratings, (4) hydraulic-geometry relations, (5) water-surface slope, (6) time of concentration, (7) flood frequency, (8) flood volume, and (9) rainfall-runoff relations.

These analyses quantified several hydrologic characteristics that are typical of urban environments. These include (1) large ratios of peak discharge to daily mean discharge as an indicator of flashiness in the stream; (2) consistent shifting of the stage-discharge rating over short periods, which indicates instability of the stream channel; (3) analyses of hydraulic-geometry relations that indicate mean velocities of 11 feet per second or greater while the flow is still contained in the stream channel; (4) discharges that are 4 to 5 times larger in Minebank Run for corresponding flood frequency recurrence intervals than in Slade Run, a Piedmont watershed of similar size with smaller percentages of urban development; and (5) flood waves that can travel through the stream channel at velocities of 412 feet per minute, or 6.9 feet per second.

Acknowledgments

The authors would like to thank Kenneth Jewell and Russell Neill of the U.S. Environmental Protection Agency, National Risk Management Laboratory, in Ada, Oklahoma, and Brad Scoggins of the Shaw Corporation for providing critical field assistance in implementation of the study-reach design, and for collection of soil cores in the study reach.

Special thanks are extended to Donald Outen, Karen Ogle, Robert Ryan, Steven Stewart, Candice Croswell, and Nancy Pentz of the Baltimore County Department of Environmental Protection and Resource Management for planning assistance and technical input regarding the stream-restoration project at Minebank Run. Special thanks also are extended to Leo Rebetsky of the Baltimore County Department of Recreation and Parks. As Park Manager of Cromwell Valley Park, Mr. Rebetsky's support, cooperation, and assistance have been critical to successful completion of the work to date.

Thanks also are extended to William Banks, Jeffrey Barbaro, Jonathan Evans, Jeffrey Kvech, Mastin Mount, Robert Pentz, and Richard Saffer of the USGS, and Joseph Fisher, Michael Hansen, and Michael Smigaj, formerly of the USGS, for their assistance with field-construction and data-collection efforts.

Thanks also are extended to John Brakebill, James Dine, Gary Fisher, Earl Greene, Cherie Miller, and Robert Shedlock of the USGS, and Robert James Jr., formerly of the USGS, for their assistance and support with technical issues and data interpretation.

References Cited

Agricultural Stabilization Conservation Service, 1938, Aerial photograph of Minebank Run watershed, Baltimore County, Maryland, 2 sheets, scale 1:15,000.

Agricultural Stabilization Conservation Service, 1953, Aerial photograph of Minebank Run watershed, Baltimore County, Maryland, 2 sheets, scale 1:20,000.

Baltimore County Department of Environmental Protection and Resource Management, 2000, Aerial photograph of Minebank Run watershed, Baltimore County, Maryland, 1 sheet, scale 1:4,800.

Buchanan, T.J., and Somers, W.P., 1968, Stage measurement at gaging stations: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. A7, 28 p.

Carter, R.W., and Davidian, J., 1968, General procedure for gaging streams: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. A6, 13 p.

Crowley, W.P., and Cleaves, E.T., 1974, Geologic map of the Towson quadrangle, Maryland: Maryland Geological Survey, 1 sheet, scale 1:24,000.

Crowley, W.P., Reinhardt, J., and Cleaves, E.T., 1976, Geologic map of Baltimore County and City: Maryland Geological Survey, 1 sheet, scale 1:62,500.

Curtin, S.E., Anderson, A.L., and Saffer, R.W., 2005, Water resources data, Maryland, Delaware, and Washington, D.C., water year 2004, volume 2. Ground-water data: U.S. Geological Survey Water-Data Report MD-DE-DC-04-2, 688 p.

Dillow, J.J.A., 1996, Technique for estimating magnitude and frequency of peak flows in Maryland: U.S. Geological Survey Water-Resources Investigations Report 95–4154, 55 p.

Duerkson, C., and Snyder, C., 2005, Nature-friendly communities: habitat protection and land use planning: Washington, D.C., Island Press, 352 p.

Federal Interagency Stream Corridor Restoration Working Group, 1998, Stream corridor restoration: principles, processes, and practices: Washington D.C., Government Printing Office, Item No. 0120-A (Files available on the World Wide Web at *http://www.nrcs.usda.gov/technical/stream_restoration*).

Fenneman, N.M., 1938, Physiography of the Eastern United States: New York, McGraw-Hill, 714 p.

Freeman, J.R., and Stearns, F.P., 1910, Report on the enlargement and improvement of the Baltimore water supply: Baltimore, Md., King Brothers Printers, 75 p.

Goetz, S.J., Jantz, C.A., Prince, S.D., Smith, A.J., Wright, R., and Varlyguin, D., 2004, Integrated analysis of ecosystem interactions with land use change: The Chesapeake Bay watershed, *in* DeFries, R.S., Asner, G.P., and Houghton, R.A., eds., Ecosystems and land use change: Washington, D.C., American Geophysical Union, p. 263–275.

Greenman-Pederson, Inc., 1996, Preliminary master plan, Cromwell Valley Park, Baltimore County, Maryland: Laurel, Md., 13 p.

Greenman-Pederson, Inc., and Coastal Resources, Inc., 2001, Minebank Run phase II stream restoration, conceptual design and recommendations: Laurel, Md., 58 p.

Gregory, J.H., Requardt, G.J., and Wolman, A., 1934, Report to the Public Improvement Commission of the City of Baltimore on future sources of water supply and appurtenant problems: Baltimore, Md., 226 p.

Interagency Advisory Committee on Water Data, 1982, Guidelines for determining flood flow frequency: Reston, Va., Water Resources Council Bulletin 17B, 28 p.

James, R.W., 1986, Maryland and the District of Columbia surface-water resources, *in* U.S. Geological Survey, National water summary 1985—Hydrologic events and surface-water resources: U.S. Geological Survey Water-Supply Paper 2300, p. 265–270.

James, R.W., Jr., Saffer, R.W., Pentz, R.H., and Tallman, A.J., 2003, Water resources data, Maryland, Delaware, and Washington, D.C., water year 2002, volume 1. Surface-water data: U.S. Geological Survey Water-Data Report MD-DE-DC-02-1, 486 p.

James, R.W., Jr., Saffer, R.W., Pentz, R.H., and Tallman, A.J., 2004, Water resources data, Maryland, Delaware and Washington, D.C., water year 2003, volume 1. Surface-water data: U.S. Geological Survey Water-Data Report MD-DE-DC-03-1, 524 p.

James, R.W., Saffer, R.W., and Tallman, A.J., 1999, Water resources data, Maryland and Delaware, water year 1998, volume 1. Surface-water data: U.S. Geological Survey Water-Data Report MD-DE-98-1, 362 p.

Leopold, L.B., 1994, A view of the river: Cambridge, Mass., Harvard University Press, 298 p.

Leopold, L.B., and Maddock, T., Jr., 1953, The hydraulic geometry of stream channels and some physiographic implications: U.S. Geological Survey Professional Paper 252, 57 p.

McCandless, T.L., and Everett, R.A., 2002, Maryland stream survey: Bankfull discharge and channel characteristics of streams in the Piedmont hydrologic region: Annapolis, Md., U.S. Fish and Wildlife Service, CBFO-S02-02, 41 p.

Paul, M.J., and Meyer, J.L., 2001, Streams in the urban landscape: Annual Review of Ecology and Systematics, v. 32, p. 333–365.

Reybold III, W.U., and Matthews, E.D., 1976, Soil survey, Baltimore County, Maryland: Washington, D.C., U.S. Department of Agriculture, Soil Conservation Service, 149 p.

Saffer, R.W., Pentz, R.H., and Tallman, A.J., 2005, Water resources data, Maryland, Delaware, and Washington, D.C., water year 2004, volume 1. Surface-water data: U.S. Geological Survey Water-Data Report MD-DE-DC-04-1, 540 p.

Smigaj, M.J., Saffer, R.W., and Pentz, R.H., 2003, Water resources data, Maryland Delaware, and Washington, D.C., water year 2002, volume 2. Ground-water data: U.S. Geological Survey Water-Data Report MD-DE-DC-02-2, 573 p.

U.S. Environmental Protection Agency, 2004, The state of the Chesapeake Bay and its watershed: Annapolis, Md., Chesapeake Bay Program, EPA-903-R-04-009, 23 p.

U.S. Geological Survey, Maryland-Delaware-Washington, D.C. District, 2004, Water resources data, Maryland, Delaware, and Washington, D.C., water year 2003, volume 2. Ground-water data: U.S. Geological Survey Water-Data Report MD-DE-DC-03-2, 604 p.

Vokes, H.E., 1957, Geography and geology of Maryland: Maryland Geological Survey Bulletin 19, p. 56–64.

Glossary

A

alluvium Sedimentary material that was deposited by flowing water. Examples of alluvial deposits include deltas, point bars, and sand in the flood-plain areas of rivers or streams.

association Landscape that has distinct proportional patterns of soils.

C

coefficient of determination The fraction of the variation in the dependent variable that is explained by the explanatory variable. The coefficient of determination ranges between 0 and 1. In general, the closer the coefficient of determination is to 1, the more the variation in the dependent variable that is explained by the explanatory variable.

colluvium Loose deposits of collapsed rock debris that accumulate at the base of a cliff or sloping valley.

continuous-record streamflow-gaging station Location where a water-stage recorder is used to collect continuous time-series stage data that are related to systematic discharge measurements at the station. Continuous-record streamflow-gaging stations are commonly operated for the purpose of long-term monitoring or as part of hydrologic investigations.

control The closest natural or constructed section of channel downstream of a streamflow-gaging station that eliminates the effect of all other downstream conditions on the stage and velocity of flow at the station. Control features are usually riffle sections, natural constrictions, or artificial weirs that cause the channel to be shallower, narrower, rougher, or steeper in slope than it is elsewhere.

crest-stage partial-record station A site at which peak stages are determined by use of a crest-stage gage instead of a water-stage recorder. A crest-stage gage will register the peak stage occurring between inspections of the gage. A crest-stage gage can be used to obtain a high-water mark during a flood, or to determine water-surface slopes at different stream stages if placed in multiple locations along a reach of stream. A stage-discharge relation for a crest-stage partial-record station can be developed using discharge data obtained by indirect measurement of peak flow, or direct measurement of a range of discharges by use of a current meter.

D

daily mean discharge Discharge that is computed as the arithmetic mean of the instantaneous discharge values for a given day of the water year.

E

evapotranspiration The total loss of water by evaporation from a particular area, which is equal to the sum of the water lost to the atmosphere by evaporation from water surfaces; from the wetted surfaces of leaves, trees, stems, soil, and rocks; and that lost by transpiration from plants.

exceedance probability The probability that a specific flood event will occur in any one year. The reciprocal of the exceedance probability is the flood recurrence interval. For example, a 50-year flood has a 0.02 probability, or 2-percent chance, of occurring in any given year.

F

flashy A stream or watershed that tends to produce narrow, steeply peaked storm hydrographs that rise and fall very quickly.

flood recurrence interval(s) The average number of years between floods equal to or greater than a specific magnitude.

flow duration The percentage of time that a particular discharge is exceeded during a particular period of station record. Flow duration can be applied to a streamflow volume, or to exceedance of a particular channel feature such as a point bar or the channel banks.

I

impervious surfaces Surfaces such as roads, sidewalks, parking lots, and rooftops that are virtually impermeable and prevent precipitation from infiltrating into the ground, thus increasing surface runoff into streams and rivers.

P

partial-record station A site at which discrete measurements of one or more hydrologic parameters are obtained over a period of time without continuous data being recorded or computed.

piezometer An open-ended vertical pipe that is used for measurement of pressure and changes in pressure at a selected depth within an aquifer.

R

relief The difference between the highest and lowest elevations at any location in a watershed, using a common datum.

riparian zone The vegetated region bordering a stream channel, generally from the low-water channel bed up to and including the tops of the channel banks.

runoff The quantity of water that is discharged, or runs off, from a watershed in a given time period. Runoff data may be expressed as a volume in cubic feet, acre-feet, mean discharge per unit of drainage area in cubic feet per second per square mile, or as a depth of water on the watershed in inches.

S

(soil) series Soils that have similar profiles.

stability The ability of a stream or river to transport its flow and sediment while maintaining its dimension, pattern, and profile with no net change in aggradation or degradation.

staff gage A porcelain, enameled measurement plate that is set vertically along the water's edge to provide a reference for recorded gage heights at a continuous-record streamflow-gaging station, or to provide observed gage heights during site visits to non-recording or partial-record stations.

stage-discharge rating A relation of stream stage or gage height to stream discharge that is developed from a series of discharge measurements made in a particular location. A stage-discharge rating can be presented as a table or graph.

T

thalweg The lowest elevation along a cross section in a stream channel.

W

water year The 12-month period beginning October 1 and ending September 30. The water year is defined by the calendar year in which it ends. For example, the year beginning October 1, 2002 and ending September 30, 2003, is called "water year 2003." All references to years of operation for monitoring stations in this report are water years.

Prepared by Publishing Service Centers 3 and 1.
Edited by Valerie M. Gaine.
Graphics by Timothy W. Auer.
Layout by Ann Marie Squillacci.

For additional information, contact:
Director, MD-DE-DC Water Science Center
U.S. Geological Survey
8987 Yellow Brick Road
Baltimore, MD 21237

or visit our Web site at:
http://md.water.usgs.gov

Doheny, E.J., Starsoneck, R.J., Striz, E.A., and Mayer, P.M.—**Watershed Characteristics and Pre-Restoration Surface-Water Hydrology of Minebank Run, Baltimore County, Maryland, Water Years 2002–04**—USGS Scientific Investigations Report 2006–5179