



Geologic and Hydrologic Map Reports for Land-Use Planning in the Baltimore– Washington Urban Area



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Geologic and Hydrologic Map Reports for Land-Use Planning in the Baltimore-Washington Urban Area

By A. J. Froelich, J. T. Hack, and E. G. Otton

G E O L O G I C A L S U R V E Y C I R C U L A R 8 0 6

*Examples of how geologic and hydrologic map reports on
Montgomery and Prince Georges Counties, Md., can be
used to help identify and solve land- and water-use problems*

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Geologic and Hydrologic Map Reports for Land-Use Planning in the Baltimore-Washington Urban Area

By A. J. Froelich, J. T. Hack, and E. G. Otton

INTRODUCTION

Decisionmakers and land-use planners in the rapidly urbanizing counties near the Nation's Capital have been aware of physical limits and hazards to land and water development for many years; however, geologic and hydrologic information in understandable form on which to base decisions has not been available to them until recently. In 1971, the U.S. Geological Survey (U.S.G.S.), in cooperation with the Maryland Geological Survey (M.G.S.), initiated the Baltimore-Washington Urban Area Study, a pilot project to determine the usefulness of geologic and hydrologic data in helping solve problems of land and water use. The objective of this project was to provide relevant and timely information particularly useful for county and regional planning and plan implementation. The project was not designed to supplant detailed site studies that are needed before and during specific development.

Within the overall Baltimore-Washington Urban Area Study, the U.S.G.S. focused its efforts on studies in Montgomery and Prince Georges Counties, Md., and on a more detailed study of adjacent Washington, D.C. (fig. 1). The M.G.S., which has initiated a long-range program of geologic studies for land-use planning, undertook detailed studies in Baltimore County, Md. (fig. 1). A less detailed geologic map of Baltimore County was also completed (Crowley and others, 1976). In all, 36 map reports have been completed as part of the Baltimore-Washington Urban Area Study; these reports are preceded by an asterisk in the list of references cited.

This Circular summarizes some of the land- and water-use problems in two counties typical of this urban study area—Montgomery and

Prince Georges Counties—and describes how the map reports may be used to identify potential problem areas and assist in problem solving. Table 1 lists reports containing information on the geology, the hydrology, the mineral resources, and land-use planning in the Baltimore-Washington urban area.

To be effective, county planning cannot be carried out totally independently of planning in adjacent jurisdictions, and local planning should be integrated with regional planning. A great variety of environmental planning takes place at all levels, as indicated by the list in table 2 of representative institutional users of geologic and hydrologic map reports. One planning proposal for the Washington metropolitan area calls for suburban growth along several major transportation corridors radiating outward from the urban core; low-density "green-belt" wedges would remain between the corridors. Another regional planning solution to minimize suburban sprawl around Washington is to concentrate growth in outlying "New Towns," such as Columbia, Md., and Reston, Va. Solutions to other regional problems, such as meeting future water-supply needs, also depend on multijurisdictional planning. Basic knowledge of the physical environment can contribute to the solution of some of these complex regional planning problems.

Perhaps the most serious environmental problem confronting rapidly urbanizing Montgomery and Prince Georges Counties today is the need to dispose of increasing volumes of solid and liquid wastes while protecting relatively clean surface waters and avoiding pollution of ground-water resources. Nearly as important to orderly and economic growth are the problems related to using sources of construc-

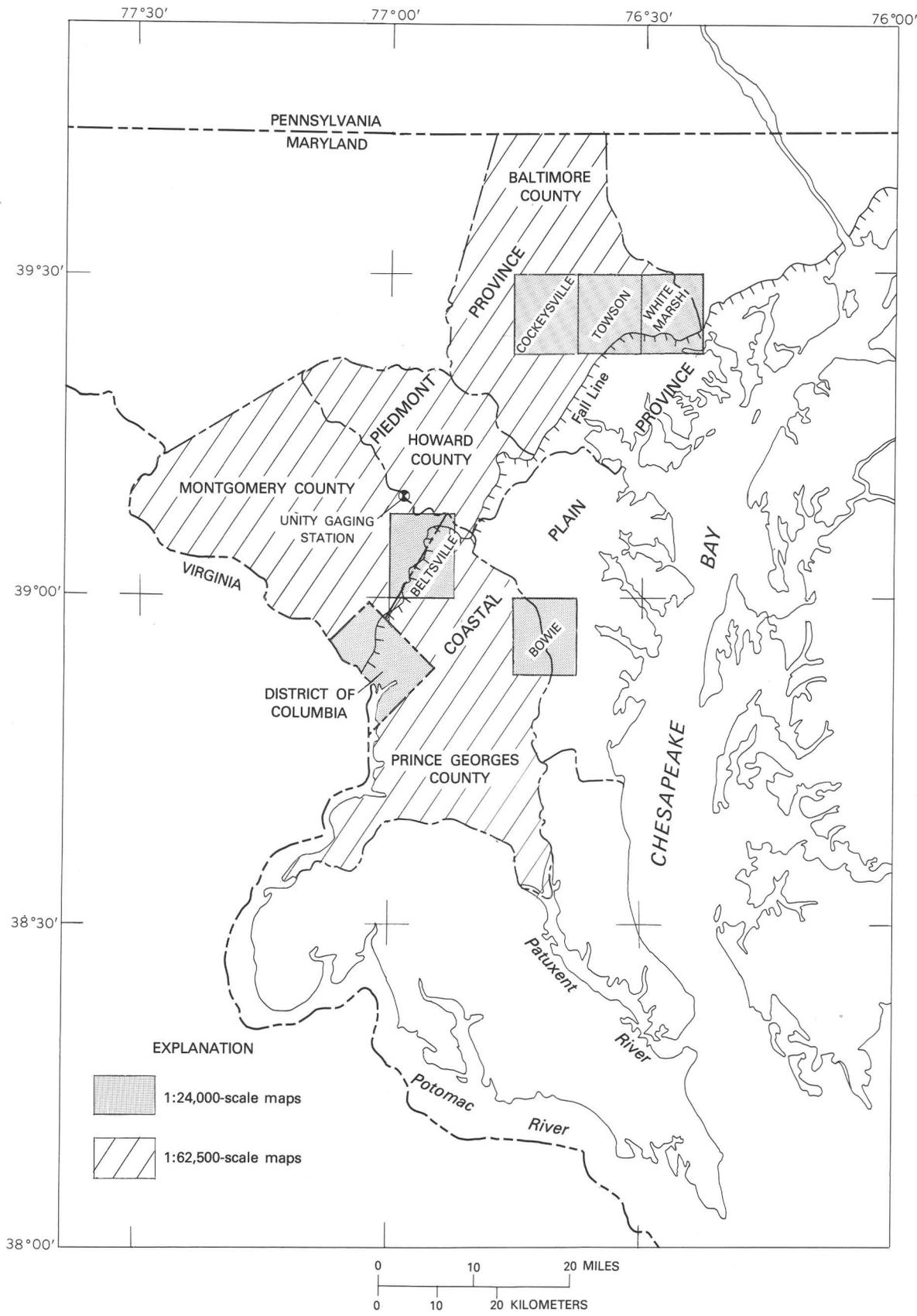


FIGURE 1.—Index map showing areas mapped during the Baltimore-Washington Urban Area Study.

TABLE 1.—Reports containing information on the geology, the hydrology, the mineral resources, and land-use planning in the Baltimore-Washington urban area

[References preceded by an asterisk were prepared during the Baltimore-Washington Urban Area Study; they are interdisciplinary, and each contains a text describing how the geologic, hydrologic, or mineral-resource information can be applied to land-use planning]

Geology ¹	Hydrology ²	Mineral resources ³	Land-use planning
Montgomery County, Md.			
Cloos and Cooke, 1953	Crooks and others, 1967	Cleaves, 1964	Maryland-National Capital Park and Planning Commission, 1968-1972; 1977
Fisher, 1964; 1970	Dingman and Meyer, 1954	Edwards, 1969	
*Froelich, 1974	*Herb, 1976a	Fisher, 1964	
*Froelich, 1975a, b, g, h	Johnston, 1964; 1966	*Froelich, 1975d	*Stewart and Van Driel, 1975
Higgins and Fisher, 1971	*Mayer, 1977	Larrabee, 1969	
Hopson, 1964	Nutter, 1974; 1975	Pearre, 1961	*Van Driel, 1975c, d ⁴
Johnston, 1964	Nutter and Otton, 1969	Reed and Reed, 1969	*Van Driel and Stewart, 1976
Matthews and others, 1961	*Richardson, 1976a, c		
Nutter, 1975			
Reed and Jolly, 1963			
U.S. Geological Survey, 1967a			
*Van Driel, 1975a, b ⁴			
*Withington and Froelich, 1974a, b			
Prince Georges County, Md.			
Cooke and Cloos, 1951	Crooks and others, 1967	Edwards, 1969	*Glaser, 1973
Darton, 1947	*Glaser, 1973	Glaser, 1971	*Hack, 1976a; 1977
Glaser, 1971	Hansen, 1968	*Glaser, 1973	
*Glaser, 1973	*Herb, 1976b	*Hack, 1976b	
Hack, 1955	Johnston, 1964; 1966	Knechtel and others, 1961	
*Hack, 1977	Mack, 1966	Pearre, 1961	
Hansen, 1968	Meyer, 1952		
Jacobeen, 1972	Otton, 1955		
Johnston, 1964	Papadopulos and others, 1974		
Kirby and others, 1967	*Richardson, 1976b, d		
U.S. Geological Survey, 1967b			
*Withington and Froelich, 1974a, b			
Washington, D.C.			
Cloos and Cooke, 1953	Johnston, 1964; 1966		
Cooke and Cloos, 1951	Papadopulos and others, 1974		
Darton, 1947			
Fisher, 1970			
*Froelich, 1975c, e, f			
*Froelich and Hack, 1975			
Johnston, 1964			
Reed and Jolly, 1963			
U.S. Geological Survey, 1967a, b			
Baltimore City and County, Md.			
*Cleaves and others, 1974	Dingman and Ferguson, 1956	*Cleaves and others, 1974	*Cleaves and others, 1974
*Crowley and others, 1976	Nutter, 1974	Edwards, 1969	*Otton and others, 1975; 1978
Higgins and Fisher, 1971	Nutter and Otton, 1969	Knechtel and others, 1961	
*Otton and others, 1975; 1978	*Otton and others, 1975; 1978	*Kuff, 1975	
U.S. Geological Survey, 1967a, b		*Otton and others, 1975; 1978	
		Pearre, 1961	

TABLE 1.—*Reports containing information on the geology, the hydrology, the mineral resources, and land-use planning in the Baltimore-Washington urban area—Continued*

Geology ¹	Hydrology ²	Mineral resources ³	Land-use planning
Other parts of the Baltimore-Washington urban area			
Glaser, 1971	Dingman and Ferguson, 1956	Cleaves, 1964	*Glaser, 1973
*Glaser, 1973		Edwards, 1969	
Hansen, 1968	Dingman and Meyer, 1954	Glaser, 1971	
Higgins and Fisher, 1971		*Glaser, 1973	
Hopson, 1964	*Glaser, 1973	Knechtel and others, 1961	
Jacobeen, 1972	Hansen, 1968		
Nutter, 1974	Nutter, 1974	Pearre, 1961	
*Roen and Froelich, 1976; 1978	Nutter and Otton, 1969		
U.S. Geological Survey, 1976a, b	Otton, 1955		
	Papadopulos and others, 1974		
General references			
	U.S. Soil Conservation Service, Engineering Division, 1975		Geological Society of America, Committee on Environment and Public Policy, 1975
			Imhoff and others, 1978
			Leopold, 1968
			Leopold and others, 1971
			Robinson and Spieker, 1978
			Southeastern Wisconsin Regional Planning Commission, 1968
			Waananen and others, 1977
			William Spangle and Associates and others, 1976

¹ More extensive lists of references pertaining to the geology of Montgomery County were given by Froelich (1975a, b, g, h); for references on Prince Georges County, see Hack (1977).

² More extensive lists of references on the hydrology of Prince Georges County were given by Herb (1976b) and Richardson (1976b, d); for references on Montgomery County, see Herb (1976a) and Richardson (1976a, c).

³ A more extensive list of references on mineral resources of Prince Georges County was given by Hack (1976b); for references on Montgomery County, see Froelich (1975d).

⁴ Computer-generated map.

tion materials—sand, gravel, and crushed stone—that are near the potential markets without degrading the environment; good planning would avoid the loss of these materials because of development over or near the deposits. Finally, the ultimate planning problem is the basis on which plans and plan-implementation decisions are made; we are learning that the expedient, short-term politico-economic choice that results in avoidable environmental damage is usually neither the best nor the only decision possible.

Because both Montgomery and Prince Georges Counties are rapidly growing parts of the expanding Washington metropolitan area, typical urban-area problems common to both include the evaluation and selection of:

1. Sites for waste treatment and disposal facilities.

2. Sites for water-supply storage and treatment facilities.
3. Sources of construction materials.
4. Land and water for parks and open-space preservation.
5. Sites for conventional and nuclear power plants.

Also, both counties need assessments of:

1. Slope stability and landslide-prone areas.
2. Foundation conditions, including areas where heavy construction would have to be limited.
3. Tunneling conditions.
4. Ground-water availability.
5. Valley-bottom land-use problems.
6. Potential pollution hazards, including solid waste, domestic sewage effluent, and siltation.

TABLE 2.—*Representative institutional users of geologic and hydrologic map reports*

Planning Offices
Maryland-National Capital Park and Planning Commission, Planning Department, Silver Spring and Riverdale, Md. Division of Development Review Division of Environmental Planning Division of Research
Montgomery County Government, Rockville, Md. Office of Planning and Capital Programming Office of Environmental Planning Office of Community and Economic Development Department of Architectural Services Department of Public Works Environmental Protection Agency
Prince Georges County Government, Upper Marlboro and Riverdale, Md. Department of Program Planning and Economic Development Department of Public Works and Transportation Health Department Environmental Planning Division
Metropolitan Washington Council of Governments, Washington, D.C. Department of Environmental Services Department of Health and Environmental Protection
Maryland Department of State Planning, Baltimore, Md.
Universities
University of Maryland, College Park, Md. Department of Agronomy Department of Engineering
George Washington University, Washington, D.C. University of the District of Columbia, Van Ness Campus, Department of Earth/Life Sciences, Washington, D.C.
State and Federal Offices
Maryland State Roads Commission, Bureau of Soils and Foundations, Brooklandville, Md. Maryland Geological Survey, The Johns Hopkins University, Baltimore, Md. U.S. Department of Agriculture, Soil Conservation Service, College Park, Md., and Washington, D.C. U.S. National Park Service, Ecological Sciences Laboratory, Washington, D.C. U.S. Geological Survey, Towson, Md., and Reston, Va. U.S. Army Corps of Engineers, Baltimore, Md.
Consulting Engineering and Industrial Firms
Batelle Memorial Institute, Columbus, Ohio Bechtel Associates, Inc., Washington, D.C. CH2M Hill, Inc., Reston, Va., and Corvallis, Oreg. Columbia Gas System Service Corporation, Wilmington, Del. Commonwealth Associates, Inc., Jackson, Mich. Conlin and Gray Associates, Lancaster, Pa. Contee Sand and Gravel, Inc., Laurel, Md. Dames and Moore, Inc., Bethesda, Md. Inland Materials, Inc., Clinton, Md. Kamber Engineering Corp., Rockville, Md. Law Engineering Testing Company, McLean, Va. Pope, Evans and Robbins, Consulting Engineers, New York City, N.Y. Ralph M. Parsons and Associates, Washington, D.C. Schnabel Engineering Associates, Bethesda, Md. Wallace, McHarg, Roberts, and Todd, Philadelphia, Pa. Washington Metropolitan Area Transit Authority, Washington, D.C. Woodward-Clyde Associates, Rockville, Md.

The environmental geologic and hydrologic maps of the two counties published during this study at the scale of 1:62,500 (1 in.=1 mi) can be used in a rational assessment of many urban and regional problems related to land and water use (Froelich, 1974, 1975a, b, d, g, h; Hack, 1976a, b, 1977; Herb, 1976a, b; Mayer, 1977; Richardson, 1976a-d). By using the maps separately and in combination, planners can take into consideration those natural factors that present opportunities for or limitations to many types of development.

Most environmental problems in the bicounty area of Montgomery and Prince Georges Counties relate to the complex relationships between solid earth materials and water in natural processes. Therefore, to clarify these relationships and as a demonstration, the

U.S.G.S. in 1975 began working with the Maryland-National Capital Park and Planning Commission (MNCPPC) in the first cooperative effort of its kind to devise a computerized information system to meet the needs of a local planning program. The U.S.G.S. completed its contribution in late 1976, and the system has been operational since then.

GEOLOGIC SETTING OF THE BALTIMORE-WASHINGTON URBAN AREA

The physical features of Montgomery and Prince Georges Counties, Md., are representative of the entire Baltimore-Washington metropolitan area. The two counties lie across a small part of two distinctly different geologic provinces, the Piedmont to the northwest and the Atlantic Coastal Plain on the southeast. These

provinces are separated by a line or zone known as the Fall Line (fig. 1), which closely approximates the boundary between the two counties. The Fall Line is the imaginary line drawn through the downstream location of falls or rapids that form a natural barrier to navigation on major streams; most of the major cities of the Atlantic Seaboard, including Baltimore and Washington, grew along the Fall Line.

Almost all of Montgomery County is in the Piedmont, which is a terrain formed by the erosion of a thick blanket of weathered material that, in most places, covers hard, crystalline rocks (fig. 2). Sedimentary rocks, chiefly shale, siltstone, and sandstone, are present in western Montgomery County. These rocks are overlain by a veneer of weathered material. Common construction problems in the Piedmont involve either hard rock or poorly drained soils that in places are present at, or just below, the land surface. Topography is gently rolling to hilly and, locally, hills are steep. Water problems involve flooding and waterlogging of valley bottoms, drainage at construction sites, pollution, and difficulties in developing adequate ground-water supplies.

Prince Georges County is almost entirely in the Coastal Plain Province. The subsurface consists of layers of soft sedimentary material—clay, sand, silt, and gravel—that generally can be excavated by power shovels and other equipment. Clay soils and hardpan soils underlain by gravel and sand are present in large areas of the county and may cause severe construction problems. Development of adequate ground-water supplies from major sedimentary aquifers is possible. Firm bedrock is confined to a few small areas along stream valleys near the northern boundary.

HYDROLOGIC CYCLE IN THE BALTIMORE-WASHINGTON URBAN AREA

Among the processes that convert firm bedrock to loose surface materials having characteristic soil profiles are weathering and erosion, both of which function as a result of the hydrologic cycle. The hydrologic cycle is the continuous circulation of water from the land and sea to the atmosphere and back by precipitation, stream runoff, evaporation, and transpiration (fig. 3). The cycle is driven by the sun's energy.

Montgomery and Prince Georges Counties, Md., are in the humid temperate zone where the annual precipitation averages 43 in. (109 cm). The precipitation is rather evenly distributed throughout the year, though August is the wettest month, and February is the driest. The ample precipitation in Maryland provides water to sustain the flow of the streams during most seasons and to replenish the soil moisture and the ground-water reservoirs (or aquifers) after periods of drought. The ground water in all Montgomery County and in all but the very deepest artesian aquifers in southern Prince Georges County is derived from precipitation. A few of these deep aquifers may contain some residual saline water remaining from invasions of ancient seas into the area.

The distribution of precipitation as it reaches the land surface may be expressed quantitatively by the hydrologic equation, which is:

$$P = ET + R \pm S_{GW}$$

where P = precipitation, ET = evapotranspiration, R = stream runoff, and S_{GW} = change in ground-water storage. For the bicounty area, the quantities of water involved may be expressed in inches (centimeters) per year. These quantities are:

$$43 = 28 + 15 + 0 \text{ (inches)}$$

$$109 = 71 + 38 + 0 \text{ (centimeters)}$$

Water is added to and subtracted from the ground-water reservoirs (S_{GW}) throughout seasonal and annual periods. This water may amount to several inches (centimeters) annually; however, during a long period of time, increments and decrements to the ground-water reservoirs must equal zero because the observed water table fluctuates by only 20 feet (6 m), and the reservoirs do not overflow at the surface or become permanently de-watered.

During dry periods, or during periods beginning 3–4 days after heavy precipitation, the flow of streams is sustained largely by ground-water discharge. Some of the flow in regulated streams may result from the release of water stored behind dams. On the average, 60 percent of the total stream runoff is derived from ground water, but this quantity varies in individual basins depending on geology, soil, topography, degree of urbanization, and other less important factors.

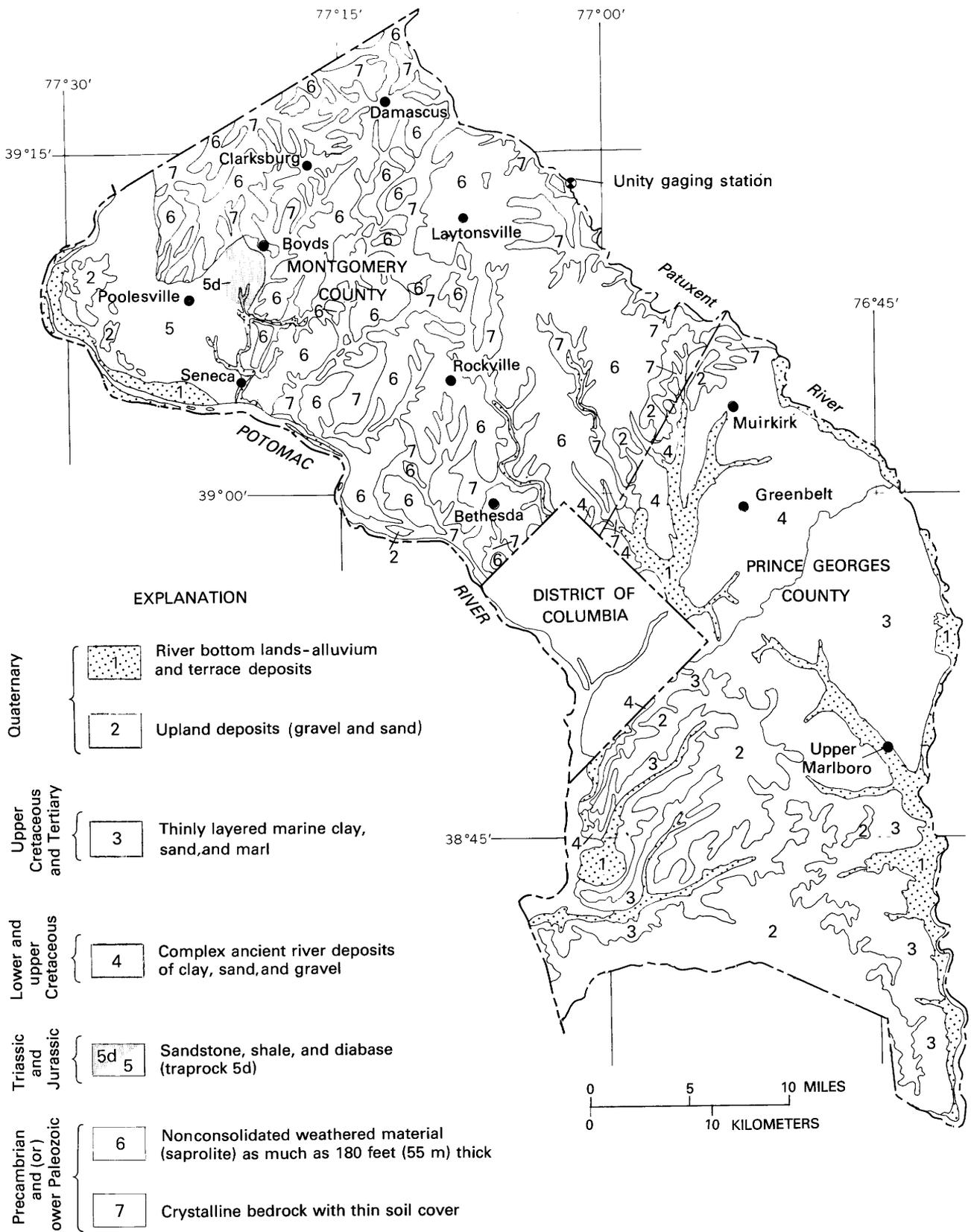


FIGURE 2.—Generalized geologic map of Montgomery and Prince Georges Counties, Maryland. Modified from Froelich (1975a, g) and Hack (1977).

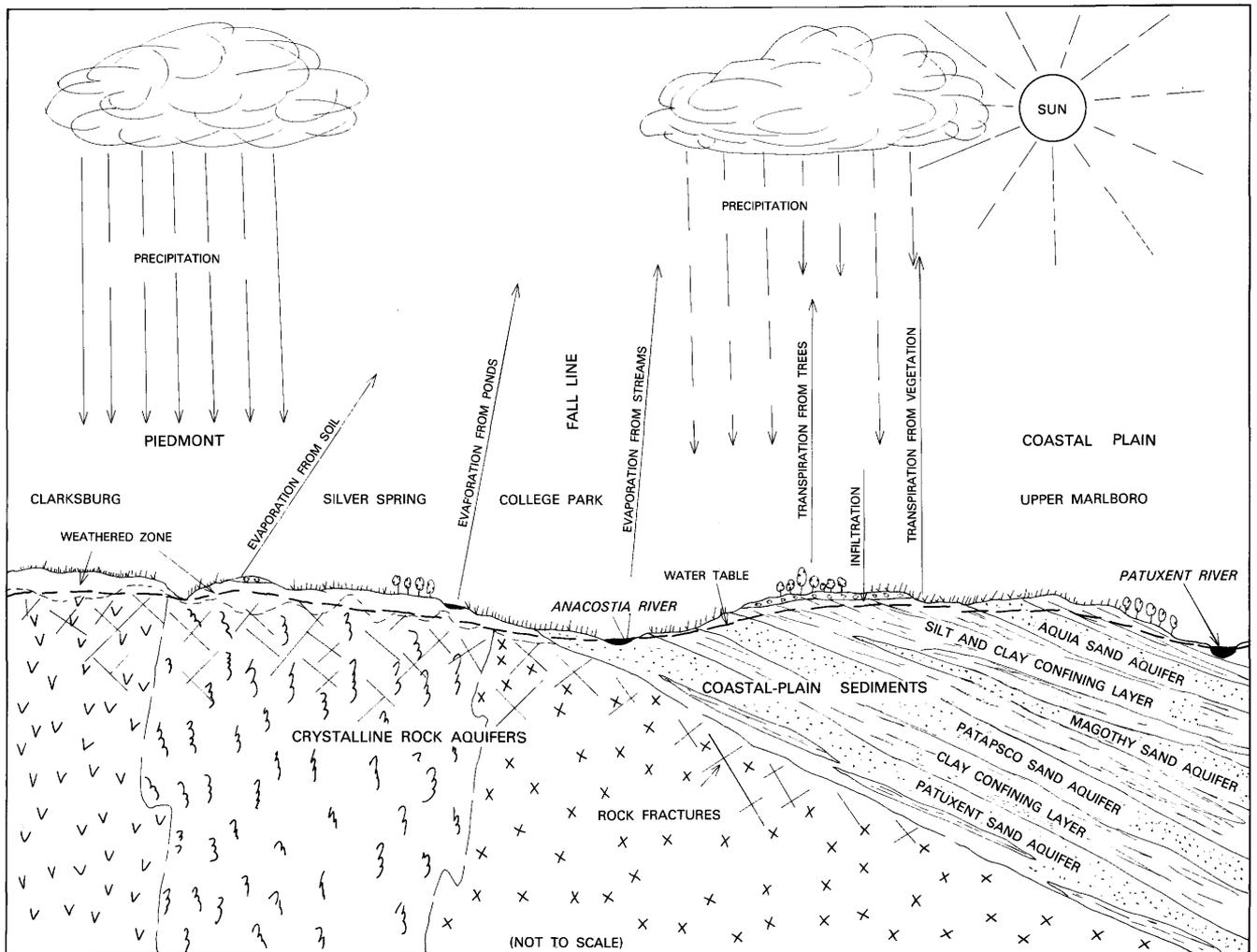


FIGURE 3.—Diagrammatic section from Clarksburg to the Patuxent River in the Baltimore-Washington urban area showing major geologic features and the hydrologic cycle.

Figure 4 shows graphically, by monthly averages, the water budget of the Patuxent River basin above the Unity gaging station (fig. 1). Above the station, the river drains a 35-mi² (90 km²) area underlain by metamorphic and igneous rocks. Figure 4 shows that both precipitation and runoff do not range widely during an average year. It also shows that the ground-water reservoirs are recharged mostly during the period from mid-September through March. The greatest loss of water from the basin by evapotranspiration occurs during the period from early April to mid-September, the

growing season and the period of warm temperatures.

THE USE OF MAP REPORTS FOR THE APPRAISAL OF SOME COMMON LAND-USE PROBLEMS

The map reports at 1:62,500 scale can be used as an aid in making a wide range of planning decisions. Some examples of this applicability are described below.

SLOPE-STABILITY PROBLEMS

As used here, slope stability refers to the susceptibility of natural slopes to failure by

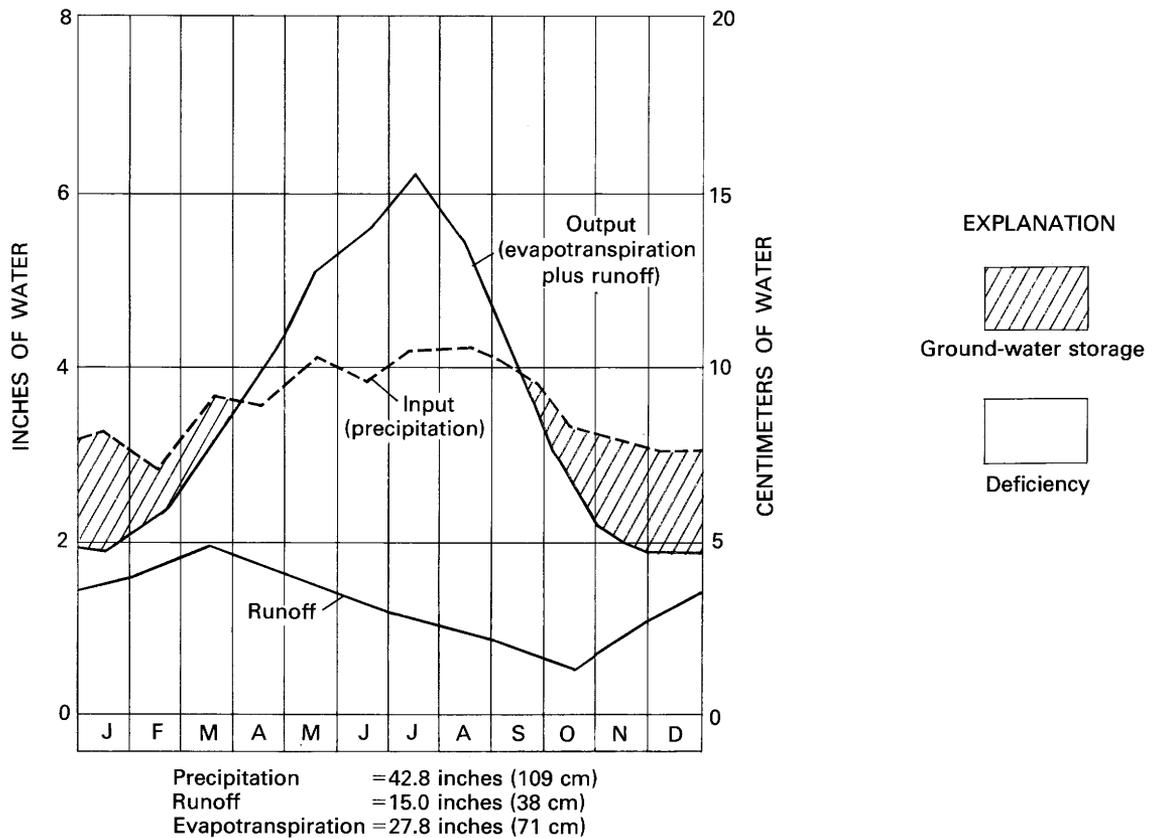


FIGURE 4.—Water budget for the Patuxent River basin above the Unity gaging station.

landslides, creep, or rockfalls as well as the stability of excavations in hillsides and trench walls. A county-wide slope map of Montgomery County was prepared by the MNCPPC in 1977 as an aid to regional planning. The map is the same scale (1:62,500) as the U.S.G.S. maps (Froelich, 1974, 1975a, b, d, g, h; Hack, 1976a, b, 1977; Herb, 1976a, b; Mayer, 1977; Richardson, 1976a-d) and can be overlain on the surface-materials map (I-920-A by Froelich, 1975g) to evaluate slope stability. For example, by overlaying areas of slopes greater than 25 percent on unit 4, which includes Coastal Plain clays (I-920-A), landslide-prone areas are defined. Such areas are particularly likely to fail where natural slopes are disturbed or cut during construction.

A sharp division is present between bedrock and overburden materials in Montgomery

County (fig. 2). The bedrock (fig. 2, unit 7) is mostly hard rock that can be excavated or moved only by blasting. The overburden is loose enough to be excavated with power equipment. In most parts of the country, this material (saprolite, fig. 2, unit 6) is derived from the bedrock by weathering. It averages 45 feet (13.6 m) in thickness and is thicker on the ridge tops than in the valleys. Other kinds of surficial overburden, such as river alluvium and terrace deposits are also present (fig. 5). The depth of this material is shown on the thickness-of-overburden map (I-920-B by Froelich, 1975h), and its characteristics are shown on the surface-materials map (I-920-A). Natural landslides, creep, and rockfalls may take place in Montgomery County on some extraordinarily steep slopes, but only rarely are they solely a consequence of heavy rain.

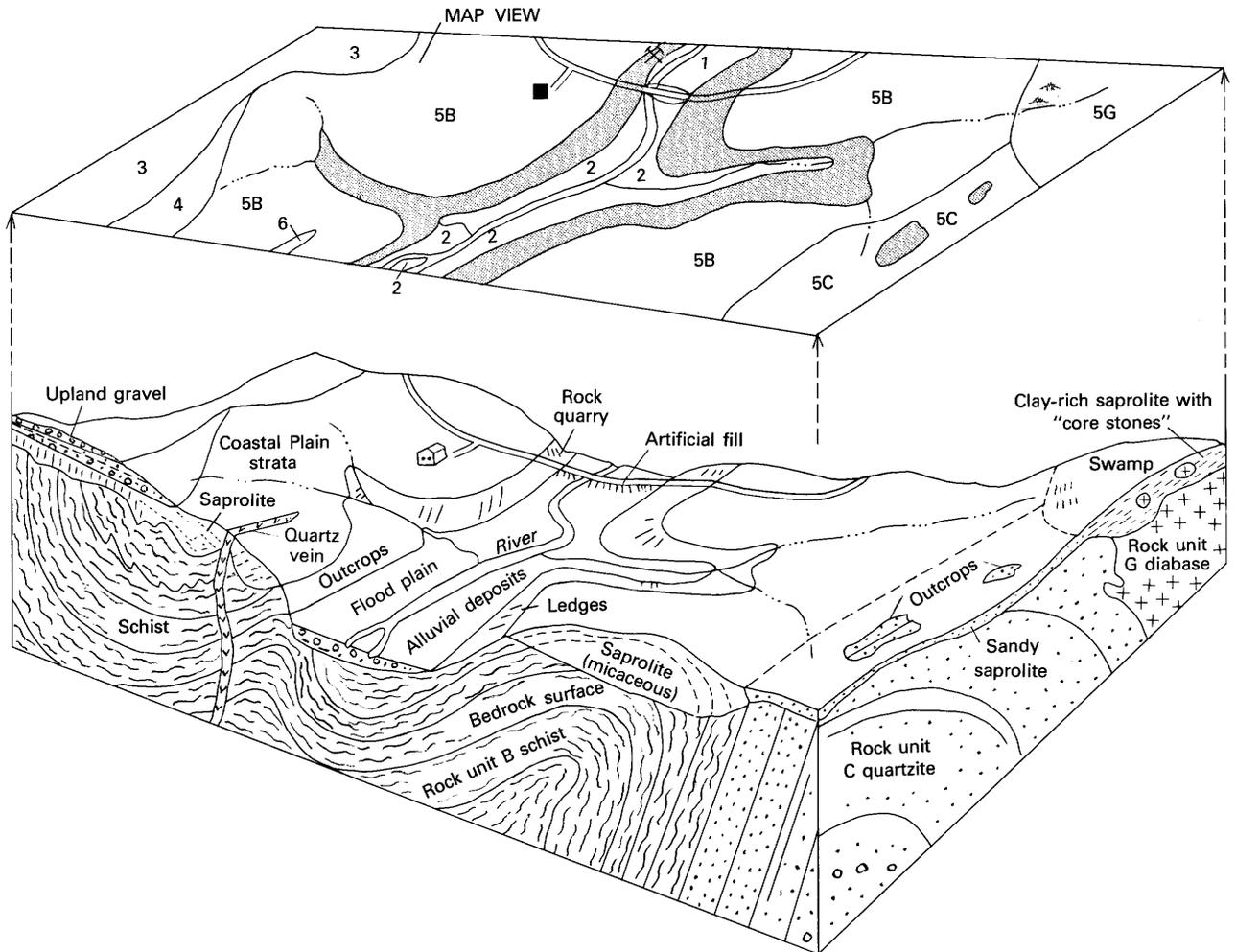


FIGURE 5.—Block diagram of hypothetical area in Montgomery County showing examples of common surface materials that overlie bedrock.

The problem is quite different in Prince Georges County, for hard bedrock is near the surface only in ravines and valleys in the northwestern part of the county near the Montgomery County line (fig. 2). In most of Prince Georges County, the earth materials are usually soft enough to be readily excavated by power shovels. Differences exist, however, in degree of consolidation and strength characteristics of the material. Overconsolidated material (sediments previously compressed by thick overburden, subsequently eroded away) is common. Unfortunately, data are not available to show the depth to overconsolidated material. In general, however, overconsolidated material is present in the older sediments such as the sand, gravel, silt, and clay of unit 4 and the sand and sandy clay of unit 3 (fig. 2). In both units, the overconsolidated material is gen-

erally overlain by a blanket of much weaker material that may range from 5 to 20 feet (1.7–6 m) in thickness. In places, this weaker material is soil derived by weathering from the material below. In places, it is windblown material mostly locally derived from underlying sediments during former periods when the climate was drier than now. Unit 2 (fig. 2) is the upland deposits, which are ancient river gravel, sand, and silt; unit 2 has never been compressed by a thick overburden and thus is not overconsolidated.

Clay, some of it having a long history of instability when disturbed by excavation or loading, is present in Prince Georges County. Clay is particularly common in unit 4 (fig. 2); but in unit 3, thin clay layers are present at various depths. Clay layers in both units have caused stability problems. These problems include



FIGURE 6.—Landslide in Cretaceous clay of unit 4 (fig. 2), southeast Washington, D.C., adjacent to Prince Georges County line.

creep and natural sliding on steep slopes (see fig. 6) as well as difficulty in compacting the clay because of the presence of silty material.

The available data on the location and relative stability of the various kinds of material that may be found in Prince Georges County are shown on map MF-768-B (Hack, 1976a) and map I-1004 (Hack, 1977). These maps are best used for preliminary site evaluation and selection. For example, where the contour lines are close together, steep slopes are indicated. Where steep slopes coincide with a clay bed, slope stability is low. Where contour lines are relatively widely spaced, slopes are gentle, and gently sloping areas underlain by sand or upland gravel are relatively stable.

FOUNDATION CONDITIONS

A wide range in foundation conditions prevails in the bicounty area. These conditions are classified according to (1) the depth of material that can be excavated without blasting, (2) the swelling properties and strength and compressibility of the consolidated material,

and (3) the surface and shallow subsurface drainage conditions.

The thickness-of-overburden map (I-920-B by Froelich, 1975h) can be used to judge the approximate amount of overburden in various regions of Montgomery County. Where the overburden is thick, the character of the foundation material can be judged from the surface-materials map (I-920-A by Froelich, 1975g). Most of Montgomery County is covered by weathered rock overburden (saprolite, fig. 2, unit 6), which, in general, provides good foundation conditions for homes and light structures. The saprolite can be readily excavated without blasting. However, in places, small or isolated bodies of hard rock may be at shallow depth, and such bodies are not indicated on maps I-920-A, B.

In Montgomery County, bedrock crops out or is shallow in more than one-third of the area (fig. 2, unit 7). Where bedrock is shallow or exposed, exploration by means of borings is necessary at construction sites to avoid excessive rock excavation and blasting. The bedrock

map (I-920-D by Froelich, 1975a) furnishes information about the strength and character of near-surface bedrock. One bedrock unit, serpentinite, is especially noteworthy because it has caused many construction problems in the county. It generally is found close to the surface and is unusually difficult to excavate. Furthermore, serpentinite is nearly impervious to water so that drainage through it is poor.

The approximate depth to the water table in Montgomery County is shown in U.S.G.S. open-file report 76-881 (Richardson, 1976a). Information on the depth to the water table and its cyclical fluctuations is of interest to engineers, planners, and others considering land use and foundation conditions. Knowledge of the extent and distribution of areas where the water table is shallow (within 10 feet (3 m) of the land surface) is critical in planning: (1) highway construction, (2) activities involving extensive earthmoving, and (3) large structures having deep foundations. Special engineering treatment may be needed in foundations periodically subject to wetting and drying. Upland, interstream areas where the water table is more than 35 feet (10.6 m) below the land surface, if moderately well drained and underlain by permeable soils, may be suitable for large structures requiring deep foundations. U.S.G.S. open-file report 76-882 (Richardson, 1976c) on the availability of ground water in Montgomery County includes a hydrograph showing that the water level in a 58-foot (17.5-m-) -deep observation well near Damascus fluctuated throughout a range of 20 feet (6 m) during the 5-year period indicated on the graph. Similar fluctuations may be expected in other bedrock wells in Montgomery County and would affect deep foundations.

More than 95 percent of Prince Georges County is underlain by easily excavated material, though earth materials are generally compacted at depths greater than 10-20 feet (3-6 m) below the surface. Locally, hard bedrock is near the surface only in valleys along the Montgomery County line, and, except for small areas of cemented sand that exist in the Aquia Formation (map I-1004 by Hack, 1977), rock excavation is not a problem.

Prince Georges County contains extensive areas underlain by clay, which provides poor foundation conditions (fig. 2, units 3 and 4).

Map MF-768-B delineates areas underlain by a kind of clay (Hack, 1976a, unit 4) that has a particularly bad record for sliding and creep. It does not have swelling properties at all localities; nevertheless, it becomes unstable when wet, especially on sloping ground. In places, it is interbedded with layers of porous sand; saturation of these sand layers increases the landslide hazard. Other clay layers interbedded with sand and gravel are in unit 4 of figure 2 (Hack, 1976a, unit 4+1) and may contain montmorillonite, a clay mineral that swells when wet and shrinks when dry. The clays are commonly covered on the surface by several feet (a meter) of soil material overlying colluvium that contains transported sand or sand and gravel so that the clay may not be readily visible and can be found only by drilling or augering. Caution should be used in planning construction in all areas where clay is present.

In some places in Prince Georges County, fuller's earth (diatomite) is mixed with swelling clay (Hack, 1976a, unit 2). Diatomite, because of its composition and silty texture, is difficult to compact.

The approximate depth to the water table in Prince Georges County is shown in U.S.G.S. open-file report 76-194 (Richardson, 1976b). In Prince Georges County, the water table is commonly within 10 feet (3 m) of the land surface chiefly along stream valleys, and extensive areas along the Patuxent and Potomac Rivers are in this category. Although no hydrographs were given by Richardson (1976b) for Prince Georges County, data from nearby areas indicate that the water table normally fluctuates only a few feet (a meter) during an annual cycle.

Special foundation conditions are present in unit 2 (fig. 2). This unit contains a hardpan layer in the soil 2-3 feet (0.7-1 m) below the surface. This layer is several feet (a meter) thick and is not penetrated by tree roots. It is nearly impervious to water so that in winter and in periods of heavy rain, surface drainage is poor, and some areas of flat ground are flooded. Where large structures that require deep excavations are built, the hardpan layer should not create foundation problems, for it is underlain by loamy sand and sand and gravel. Surface drainage around structures, however, is necessary.

TUNNELING CONDITIONS

During the period of the Baltimore-Washington Urban Area Study, the Washington Metropolitan Area Transit Authority began construction of a municipal subway (METRO). Radiating out from the Nation's Capital like spokes of a wheel, the underground tunnel system traverses Piedmont terrain to the north and west and the Coastal Plain to the south and east. Much of the experience gained during tunneling in Washington may be applicable to other major cities along the Fall Line zone, such as Baltimore, Md., and Richmond, Va. Only generalized aspects of the engineering geology of this tunnel are mentioned briefly here.

The most important aspect of tunneling in the Piedmont is the character and position of the contact between soft, clay-rich weathered material (saprolite) and the underlying hard, fresh bedrock. Physical properties of the weathered material differ radically from those of unweathered rocks; the weathered material is much weaker, more compressible, and more porous and permeable. Tunnels driven through either soft weathered material or hard bedrock seldom have difficult excavation or support problems. Tunnel-boring machines (moles) are routinely used for excavating bedrock and achieve rapid economical rates in sound bedrock. Local problems with fractured, jointed, or faulted bedrock of low strength at contacts between contrasting rock types, possibly accompanied by an influx of water, may require special shoring, lining, and grouting techniques. However, severe excavation problems with attendant high costs are invariably encountered in mixed-face tunnels, where the upper part of the bore is in soft weathered material and the lower part is in hard bedrock. As this crucial contact is commonly irregular, the accurate location of this boundary by means of geologic mapping and a detailed core-drilling program in advance of tunneling is critically important. Maps showing thickness of overburden [I-920-B (Froelich, 1975h); U.S.G.S. open-file reports 75-418 (Van Driel, 1975a) and 75-538 (Froelich, 1975f)] and contours on the base of saprolite [I-920-C (Froelich, 1975b), U.S.G.S. open-file report 75-539 (Froelich, 1975c)] are useful in preliminary design stages to delineate potential problem areas for various tunnel depths.

Tunneling or cut-and-cover excavation in the nonconsolidated sediments of the Coastal Plain presents different engineering problems. The oldest sediments are mainly interbedded sands and clays of the Potomac Group. They are generally almost ideal tunneling materials that are readily excavated and stand well in steep cuts. Minor problems relate to swelling and shrinking of stiff clay (montmorillonite), shear zones containing plastic clay, spalling and heaving of overconsolidated clay, and dewatering of porous sand layers. However, the Potomac sediments are overlain by a sequence of much younger gravel, sand, silt, clay, and peat beds that are generally weak, are commonly water-saturated, and are extremely variable in vertical and lateral distribution. Some of the porous and permeable gravel in contact with underlying clay is a source of concentrated ground-water flow that has caused severe instability during excavation. Because of the erratic distribution of porous gravel deposits, it is very difficult to predict the location and magnitude of potential excavation problems or the necessity for dewatering of aquifers. Careful geologic mapping and a comprehensive drilling and coring program in advance of excavation is usually successful in anticipating these subsurface problems.

The Fall Line zone contains most of the problems discussed above that are found in mixed-face tunneling operations in the Piedmont and Coastal Plain. These problems include irregular surfaces of hard rock beneath soft, water-saturated, porous, gravelly sand deposits of the Coastal Plain; erratically distributed lenses of plastic clay; and highly variable weak and water-saturated sediments near the surface. The Fall Line zone obviously requires the most careful and intense geologic and engineering fieldwork in advance of tunneling.

GROUND-WATER AVAILABILITY

MONTGOMERY COUNTY

The availability of ground water in Montgomery County ranges from poor to fair because most of the county is underlain by dense metamorphic and igneous rocks that are relatively low-yielding aquifers. Ground water is present in these rocks chiefly in a thin zone at the base of the weathered material (saprolite) and in crevices and fractures in the underlying bedrock. Most of the crystalline rocks yield

domestic supplies of at least a few gallons per minute (gpm), sufficient for single-family residences. Only where the rocks are intensely fractured or deeply weathered can ground water be found in larger quantities. Because of fluctuations of the water table, some shallow wells completed in wet years may go dry during droughts.

A veneer of Coastal Plain sediments is present over the dense rocks mainly in a belt a few miles wide near the Prince Georges County line (fig. 2). Throughout most of Maryland, Coastal Plain deposits contain major aquifers, but along the eastern edge of Montgomery County, these sediments either lie above the zone of saturation or are too thin to be significant aquifers. Hence, most wells in this belt are drilled into the underlying crystalline rocks in order to obtain adequate domestic supplies.

U.S.G.S. open-file report 76-882 (Richardson, 1976c) provides information on the relative availability of ground water in Montgomery County. On this map, the county has been divided into six major hydrogeologic units, chiefly on the basis of the variability of well yields from various rock types. The yields of 474 wells were grouped into small (0-5 gpm (0-0.315 L/s), moderate (6-25 gpm (0.38-1.6 L/s)), or large (more than 25 gpm (1.6 L/s)) yields according to aquifer rock type. The various groupings are identified on Richardson's (1976c) map as hydrogeologic units 1 through 6. Unit 1, underlain by gneiss and granite, has the greatest percentage (about 30 percent) of wells having reported yields in excess of 25 gpm (1.6 L/s).

Hydrogeologic unit 2, underlain by schist, has the second greatest percentage of wells having large yields (about 25 percent). The town of Laytonsville is in the center of a large area designated as hydrogeologic unit 2. Thus, for example, a small industry or commercial establishment attempting to develop a ground-water supply of 50 gpm (3.15 L/s) near Laytonsville would find U.S.G.S. open-file report 76-882 useful in evaluating its chances for obtaining the required supply.

Consolidated sedimentary rocks in the western part of the county compose hydrogeologic unit 3, which occupies a large area centered around Poolesville. Unit 3, underlain mainly by Triassic sedimentary rocks, offers the best opportunity to develop moderate to large sus-

tained yields of ground water in Montgomery County. Nutter stated (1975, p. 1) "Ground-water supplies sufficient for most commercial and light industrial use can be developed under favorable hydrogeologic conditions." He pointed out that water is stored in and transmitted through joints, faults, and bedding-plane partings in the sedimentary rocks and that rock type, well depth, and topographic position are other important factors bearing on yield. Although yields of only 17 wells (15 percent) of the 110 wells in unit 3 exceed 25 gpm (1.6 L/s), most of the wells used in the compilation (Richardson, 1976c) are domestic wells probably not pumped at their maximum capacity. As shown in I-920-D (Froelich, 1975a), the sandstone and siltstone bedrock may be greater than 3,300 feet (1,000 m) thick along the western border of the county. Future deep wells may tap water-yielding fractured sandstones not heretofore penetrated by the relatively shallow domestic wells in the area.

PRINCE GEORGES COUNTY

The availability of ground water in Prince Georges County ranges from moderate (25 gpm (1.6 L/s)) to excellent (more than 200 gpm (12.6 L/s)). Except for a few small areas of crystalline rocks along the north and west boundaries, the county is underlain by Coastal Plain sediments (fig. 2). The extensive sediments in the county contain four major aquifers—in ascending order, the Patuxent, Patapsco, Magothy, and Aquia. These aquifers are chiefly sheetlike layers of sand which slope to the southeast where they are found at progressively greater depths (see fig. 3).

The oldest and northernmost aquifer, the Patuxent, has been tapped as a source of ground water throughout a large part of northern and western Prince Georges County. Map A in U.S.G.S. open-file report 76-197 (Richardson, 1976d) provides information on the yields of wells in the Patuxent aquifer and on the iron concentration and hardness of the water. The map shows, by means of contours, the altitude above or below sea level to which wells must be drilled to obtain water from this aquifer.

Map A of U.S.G.S. open-file report 76-197 should be useful in situations such as a government agency wishing to obtain 100 gpm (6.3 L/s) for a proposed research facility near Greenbelt (fig. 2). The minus-100-foot contour

on map A passes through Greenbelt, thus showing the altitude below sea level of the top of the Patuxent aquifer. A nearby well, Cd23, at the Goddard Space Center (see map A, Richardson, 1976d), yielded 162 gpm (10.22 L/s) from this aquifer. Well Cd23 was 6 in. (15 cm) in diameter, 444 feet (135 m) deep, and had 17 feet (5 m) of well screen in it. Map A also shows that the iron content of the water may be expected to be greater than 1.0 mg/L and that the hardness of the water is in the range of 0–60 mg/L. Iron concentrations in excess of 0.3 mg/L may cause staining of fabrics and plumbing fixtures. Hence, the potential user of this water should be prepared to install iron-removal equipment in the water system.

Information similar to that given in map A and the above example for the Patuxent is given in maps B, C, and D of U.S.G.S. open-file report 76-197 (Richardson, 1976d) for the other three aquifers—the Patapsco, Magothy, and Aquia. As the yields of individual wells are related to regional declines in artesian head and to well spacing, ground-water availability in the Coastal Plain is better evaluated in terms of aquifers than in terms of individual well yields. The best technique to appraise a Coastal Plain aquifer is to design a digital-computer model that incorporates all known geologic and hydrologic data. A preliminary model study of Coastal Plain aquifers in the Washington, D.C., area, including Prince Georges County, was made to estimate the water-supply potential (Papadopulos and others, 1974). The study indicated that an additional 110 million gpd (gallons per day) could be withdrawn within 30 mi (48 km) of Washington on an emergency basis. Such large-scale pumpage from the four Coastal Plain aquifers within or outside the county would appreciably lower the ground-water level and reduce ground-water availability within the county.

CONSTRUCTION MATERIALS AND MINERAL RESOURCES

The chief mineral resources produced in the bicounty area are used primarily as construction materials and highway fill. They include crushed stone and building stone from the crystalline Piedmont rocks of Montgomery County and sand, gravel, and clay from the Coastal

Plain sediments of Prince Georges County (fig. 2).

Critical resources necessary for future construction are crushed stone and sand and gravel that are found at or near the surface (fig. 7). To be most economical, they must also be close to the area of use. Fortunately, large reserves of these necessary construction materials remain in the bicounty area, but new sources may be required to fulfill future requirements as urbanization continues. Many valuable near-surface deposits have already been lost because they have been covered by buildings, and streets, and more will be lost unless such deposits are recognized and preserved by land-use planning and plan implementation. Serious consideration should be given to the extraction of these resources prior to urban development. Their extraction can be considered an interim use. After extraction of construction materials, the land can usually be reclaimed for agriculture, recreation, building sites, and in some places, waste disposal. Careful advance planning for reclamation of a proposed site prior to extraction and adherence to the plan can minimize environmental damage.

CRUSHED STONE.—Several large deposits of rock—serpentinite (fig. 2, unit 7) and diabase (fig. 2, unit 5d)—suitable for crushed stone are present in the Piedmont of west-central Montgomery County (I-920-E by Froelich, 1975d). These rocks make aggregate of excellent quality because of their toughness, uniform texture, and resistance to chemical weathering.

Large quantities of crushed serpentinite were produced in 1976 from the major quarry west of Rockville (fig. 8); the material was used as binder and filler for highways, as road metal, and as aggregate in concrete (Larrabee, 1969, p. 29). Large reserves of this deposit remain, but the serpentinite is rapidly being encroached on and covered by detached homes and public buildings.

A large diabase body exposed at land surface near Boyds (fig. 2) contains rock similar to that extensively quarried nearby in Virginia for crushed stone. It is the last major potential source of crushed stone of that type in the bicounty area. A 1-mi² (2.6-km²) area, if excavated to a depth of 50 feet (15 m), would yield about 130 million tons, sufficient for 30 years supply at the present rate of consumption.

WEST

EAST

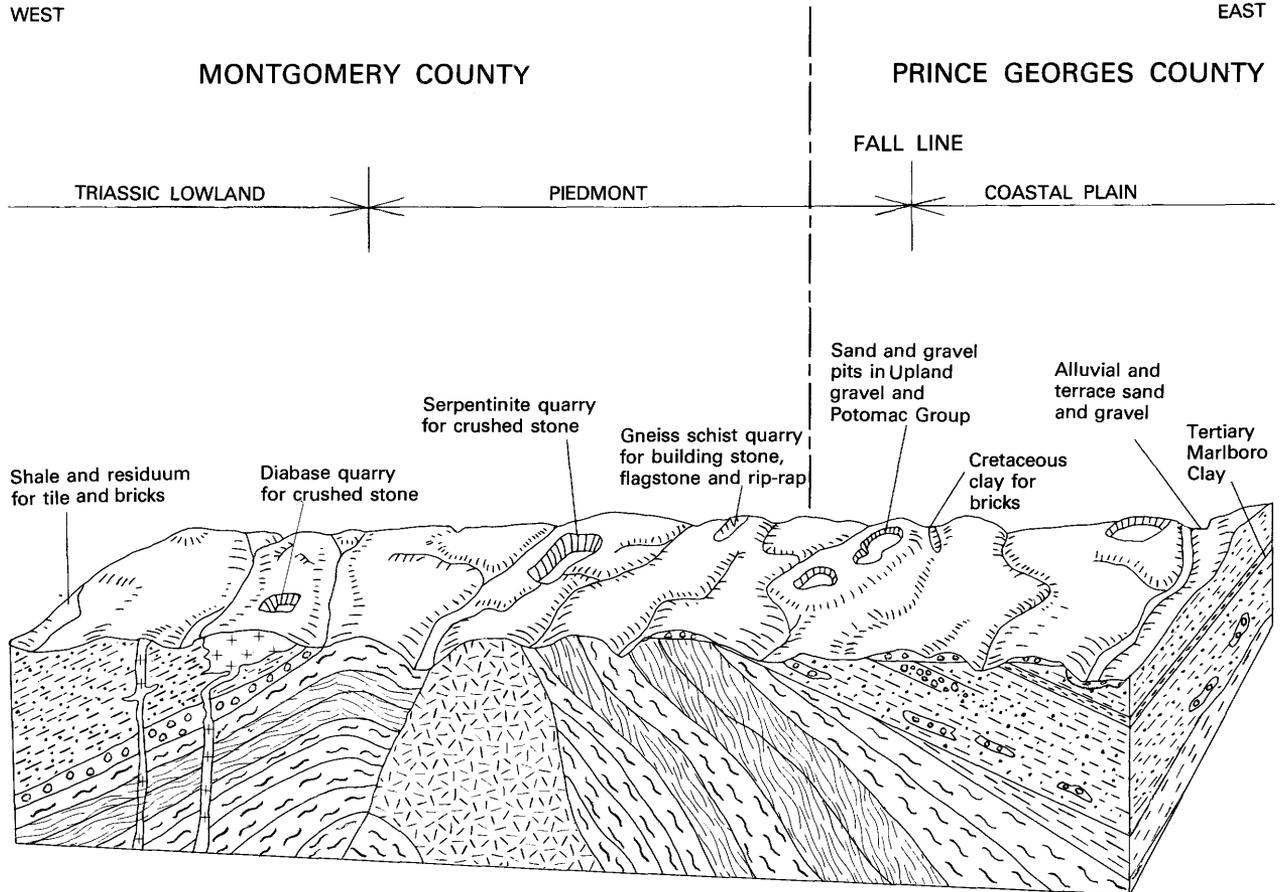


FIGURE 7.—Diagrammatic section across Montgomery and Prince Georges Counties showing occurrence of construction materials and rock and mineral resources.

BUILDING STONE.—Several rock quarries in jointed schist and gneiss (fig. 2, unit 7) west of Bethesda in Montgomery County were producing flagstone, building stone, veneer, slate, fill, and riprap for local use in 1976 (I-920-E by Froelich, 1975d). Extensive reserves of similar rock remain at shallow depth near the Potomac River, but most of the accessible sites are now used as streamside parks or residential areas. Other accessible deposits that have not been commercially evaluated are present in the same outcrop belt along the Patuxent River in the more rural, northern part of the county. In most of the area, however, building-stone needs are met by importation at increased cost. Local building-stone availability can be assessed by using three maps: I-920-E (Froelich, 1975d) shows where building stone was formerly quarried; by overlaying this map on I-920-D (Froelich, 1975a), belts of rock similar to that quarried can be defined; by overlaying the favorable belts on I-920-B (Froelich, 1975h), specific

areas of shallow overburden can be delineated, indicating accessibility of the rock. Once the areas where the building stone is accessible are identified, decisions to open quarries depend on nongeologic factors.

SAND AND GRAVEL.—Sand and gravel constitute the principal mineral resources of Prince Georges County; such resources are mostly depleted or preempted in Montgomery County. Sand and gravel are present in extensive bedded deposits in the Coastal Plain in the northern part of Prince Georges County. Large amounts of gravel and sand have been, and still are being, extracted from many shallow pits (fig. 9). Thick deposits of medium- and coarse-grained quartz sand, as well as lenses and layers of poorly sorted pebble gravel and sand, are common.

Extensive sand and gravel resources are present in the upland deposits in a large triangular area in the southern half of Prince Georges County. The sand and gravel are



FIGURE 8.—Aerial view of quarry in serpentinite west of Rockville, Montgomery County.

present mostly in a shallow sheetlike layer 20 to 40 feet (6–12 m) thick that blankets a plateaulike surface. The texture of these deposits is uneven; the gravel is present in lenticular bars or channels intermixed with sand. In general, the material is finer grained upwards, and 10–15 feet (3–4.5 m) of fine sand and silt is near the surface (fig. 10). The base of the sand and gravel sheet is irregular but forms a sharp boundary with underlying very fine sand.

Large quantities of sand and gravel are present in alluvial flood plains and adjacent terrace deposits of the principal streams, especially the Potomac and Patuxent Rivers. Some of these deposits have been used as sources of construction material, but their extraction presents a potential sediment-pollution hazard; furthermore, the alluvial deposits are subject to flooding. Gravel is also dredged from shoals in the Potomac River that are ancient drowned terrace deposits.

CLAY.—Clay of various kinds is present in many geologic units throughout Prince Georges County but is sparse in Montgomery County,

except in saprolite on crystalline rocks or in residuum on shale. Clay is present in the Coastal Plain of Prince Georges County as lenslike bodies interlayered with sand and gravel. Thick, massive beds of clay (kaolinite and illite) are in a belt passing through Muirkirk (fig. 2) where it was extracted from pits for many years; it is used to make brick, tile, and other ceramics. To the east, the clay is commonly mixed with layers and lenses of sand, and to the south near the Potomac River, the clay commonly contains more than 20 percent montmorillonite, making it unsuitable as brick or ceramic material.

A thin persistent clay layer about 10 to 30 feet (3–9 m) thick, known as the Marlboro Clay, crops out or occurs near the land surface in parts of the southern half of Prince Georges County. In general, the clay contains thin layers of silt and is moderately plastic. According to Glaser (1971, p. 53–55), it has potential use as a ceramic material suitable for face brick and structural tile.

Fresh and weathered shale in southwestern Montgomery County may be suitable for light-



FIGURE 9.—Aerial view of gravel pits, northern Prince Georges County.

weight aggregate or for terra cotta pipe and tile products (Edwards, 1969, p. 24). The shale is common northwest of Seneca, but it is generally silty, locally calcareous, and interbedded with siltstone and sandstone.

DRAINAGE BASINS, LAND-USE PLANNING, AND ZONING

A drainage basin is a landform that includes all the area contributing runoff to a stream; it is bounded by drainage divides that separate the drainage of adjacent basins. A modern approach to comprehensive land-use planning in the bicounty area utilizes the drainage basin as a basic reference unit to which earth science and other data are related. The drainage basin map of Montgomery County (Mayer, 1977) provides a natural framework for the inventory of factors that are critical to urban development in a given basin. For example, urbanization of the headwaters of a stream can

degrade the flood plain and stream channel throughout its length, whereas similar development near the mouth has less effect on the system (U.S. Soil Conserv. Service, 1975). The MNCPPC is exploring the possibility of comprehensive land-use planning and zoning that will encourage development in those parts of the drainage basin that are least sensitive to environmental disruption so that the adverse effects of urbanization on the basin will be minimized.

PROBLEMS OF VALLEY-BOTTOM LANDS

Valley-bottom lands have special problems relating to land use and urbanization. Flooding and high water tables make valley bottoms unfit sites for any type of building that might obstruct the floodway, for underground sewage disposal, and for sanitary landfills. The valley-bottom soils are poorly suitable for use in road subgrades and road fill.



FIGURE 10.—Coarse sand and gravel overlain by fine sand and silt exposed in a pit in southeastern Prince Georges County.

Flooding is a natural characteristic of all streams. A flood takes place when more water comes down the stream than can be carried within the stream channel, and the water spills out over the valley floor or flood plain. Although a stream may flood only a few times a year, a large quantity of water is transported in a short time. Floods can cause economic loss and can be a severe hazard to life and property. They are, however, a significant element in the normal runoff component of the hydrologic cycle.

Flooding is a problem common to the valley-bottom lands in Montgomery and Prince Georges Counties. Severe floods have occurred many times in the area, and local damage has been extensive. U.S.G.S. open-file reports 76-884 and 76-178 (maps by Herb (1976a, b) showing availability of hydrologic data) show the extent of flood-prone areas along the major streams in Montgomery County and Prince

Georges County, respectively. In addition to these maps at a scale of 1:62,500, both counties are completely covered by larger scale U.S.G.S. maps showing flood-prone areas at a scale of 1:24,000; the larger scale maps are available on request from the District Chief, Water Resources Division, U.S.G.S., 8600 La Salle Road, Towson, Md. 21204.

The water table is shallow, 10 feet (3 m) or less, nearly everywhere along the valley-bottom lands in the bicounty area (Richardson, 1976b, c). Swamp conditions persist for most of the year in some localities; elsewhere, drainage ditches have been dug to lower the water table and render the land usable for farming or grazing.

Of course, bottom lands are subject to a fluctuating water table, which rises to the surface during wet periods and falls during droughts. These lands are generally poor sites

for sanitary landfills or for soil-absorption sewage-disposal systems. At many places, discharging ground water may mix with landfill leachate or sewage effluent and contaminate surface waters. Where sanitary landfills are placed in flood plains, the landfill material can physically impede the flow of water during periods of overbank flow and then increase the flood hazards in upstream areas. Where ground water enters an aquifer, leachate or effluent may also enter the aquifer and pollute it. Soil-absorption sewage-disposal systems constructed during dry periods when the water table is below the bottom of the field may function satisfactorily during dry periods. During wet periods, the water table will rise, rendering the system inoperable and resulting in mixing the effluent directly into the surface or ground water.

Obstructions on the flood plain such as undersized bridges, culverts, or approach embankments, or commercial, industrial, or residential buildings may reduce the cross-sectional area and raise the flood stage. Concentrated urban development may impede flow sufficiently to raise the flood stage substantially and to cause increased damage by inundation (Waananen and others, 1977, p. 14).

The valley-bottom lands in both counties are nearly everywhere underlain by alluvial deposits covered by soils of several series. Matthews, Compy, and Johnson (1961, table 6) and Kirby, Matthews, and Bailey (1967, tables 8, 9) indicated that these soils are poorly suitable for road subgrades and for road fill.

SANITARY-LANDFILL SITES

Large quantities of solid waste are being generated by the urbanized counties adjacent to Washington, D.C. To dispose of this material in "garbage dumps" is no longer acceptable, and currently (1976) solid waste is put in engineered and designed "sanitary" landfills (fig. 11). Sanitary landfills differ from garbage dumps in that the solid waste, consisting of trash and garbage, is deposited in unit cells, is compacted by a bulldozer, and is covered at the end of each day by a thin layer (about 6 in. (15 cm)) of soil. This disposal method is a substantial improvement over the older method, but potential hazards of polluting surface and ground-water supplies by leachate persist. The composition of the

leachate is related to the nature of the materials in the fill and is generated by their reacting with infiltrating precipitation. In humid areas such as Maryland, some leachate is generated at all landfills.

Precipitation on the surface infiltrating into the landfill either emerges as flow into a ditch or stream or enters the underlying ground-water reservoir. It is desirable to reduce the quantity of leachate formed and to control or contain leachate that is unavoidably formed. The amount of leachate formed can be reduced somewhat by covering the landfill with material sufficiently impervious to reduce or eliminate water infiltration. The base of the landfill should be above the water table, and if possible, the fill should be placed in a funnel-shaped depression to prevent dispersal of the leachate. In such sites, most leachate in ground-water and surface-water flow can be suitably collected or contained in one or two ponds, and this water can be disposed of or treated as dictated by the chemical composition of the leachate.

To summarize the above discussion, an acceptable landfill site in the Piedmont, (1) should be where the water table is at least 10 feet (3 m) below land surface; (2) should not be adjacent to a stream or a large body of water, especially if the surface water is a source of public supply; (3) should not be where bedrock is within several feet (a few meters) of land surface, especially where the bedrock is highly creviced or fractured porous rock; and (4) should be near an adequate source of suitable cover material (overburden).

Several reports can be used to evaluate landfill sites according to the above-mentioned hydrologic and geologic criteria. U.S.G.S. open-file report 76-881 (Richardson, 1976a) shows depth to water table in Montgomery County and can be used to eliminate areas where the water table is less than 10 feet (3 m) below the land surface. Such areas pose severe hazards for contamination of surface and (or) ground water because downward-percolating leachate may reach the water table without losing many of its undesirable constituents. Proposed sites can be further evaluated by consulting map I-920-B (Froelich, 1975h), which shows thickness of overburden in Montgomery County. Sites proposed in areas where over-



FIGURE 11.—Completed sanitary landfill at Oxon Run, Prince Georges County.

burden thickness is less than 20 feet (6 m) can be ranked lower than sites in areas having more overburden. Moderately well drained sites in interstream areas where the water table is more than 35 feet (10.6 m) below the land surface pose fewer hazards for waste disposal than sites where the water table is shallower than 35 feet (10.6 m).

Map I-920-D (Froelich, 1975a) is also useful as a guide in the selection of sanitary-landfill sites. For example, this map shows that the western part of Montgomery County is underlain by siltstone and sandstone (S1 and S2). Table 1 of map I-920-D indicates that these units have a thin overburden and are highly jointed and fractured. Rocks of this nature may permit rapid movement of landfill leachate into the underlying ground water or into nearby streams. Hence, extreme caution is warranted in selecting sites in units S1 and S2.

The selection of a landfill site in the Coastal Plain generally involves the same criteria discussed for Piedmont sites. However, detailed onsite knowledge of the subsurface geology and the direction and depth of ground-water movement is needed here also. In general, outcrop and shallow subcrop areas of major sand

aquifers should be avoided, especially if the aquifer is being recharged in the area of the landfill. Map MF-768-B (Hack, 1976a) and U.S.G.S. open-file report 76-197 (Richardson, 1976d) can be used as preliminary guides to selecting acceptable landfill areas in Prince Georges County. However, most site evaluations will require detailed drilling to determine the nature of the deposits overlying major aquifers and to ascertain whether or not ground water is moving downward at the site.

Of course, selection of landfill sites involves other considerations beyond those pertaining to geologic and hydrologic factors, but these other criteria are not discussed in this paper. Any final selection of a sanitary landfill site must be based on detailed engineering and geohydrologic studies of any proposed site by specialists qualified in this field. The map reports discussed in this Circular should be used only as preliminary guides and as sources of basic geologic and hydrologic information.

COMPUTER MAPPING AND LAND-USE PLANNING

The various field studies that were done as part of the Baltimore-Washington Urban Area Study resulted in a large amount of planning-

EXPLANATION

MAP UNITS

THIS MAP SHOWS THE OCCURRENCE AND DISTRIBUTION OF NATURAL CONDITIONS CONSIDERED TO BE IMPORTANT IN SELECTING A SITE FOR A BRITARY CAMP. THE DATA WERE OBTAINED FROM A SURVEY OF THE MOUNTAIN AREA IN 1974. THE SURVEY DATA WERE CLASSIFIED INTO 12 CATEGORIES. THE SURVEY DATA WERE CLASSIFIED INTO 12 CATEGORIES. THE SURVEY DATA WERE CLASSIFIED INTO 12 CATEGORIES. THE SURVEY DATA WERE CLASSIFIED INTO 12 CATEGORIES.

COMPOSITE MAPS

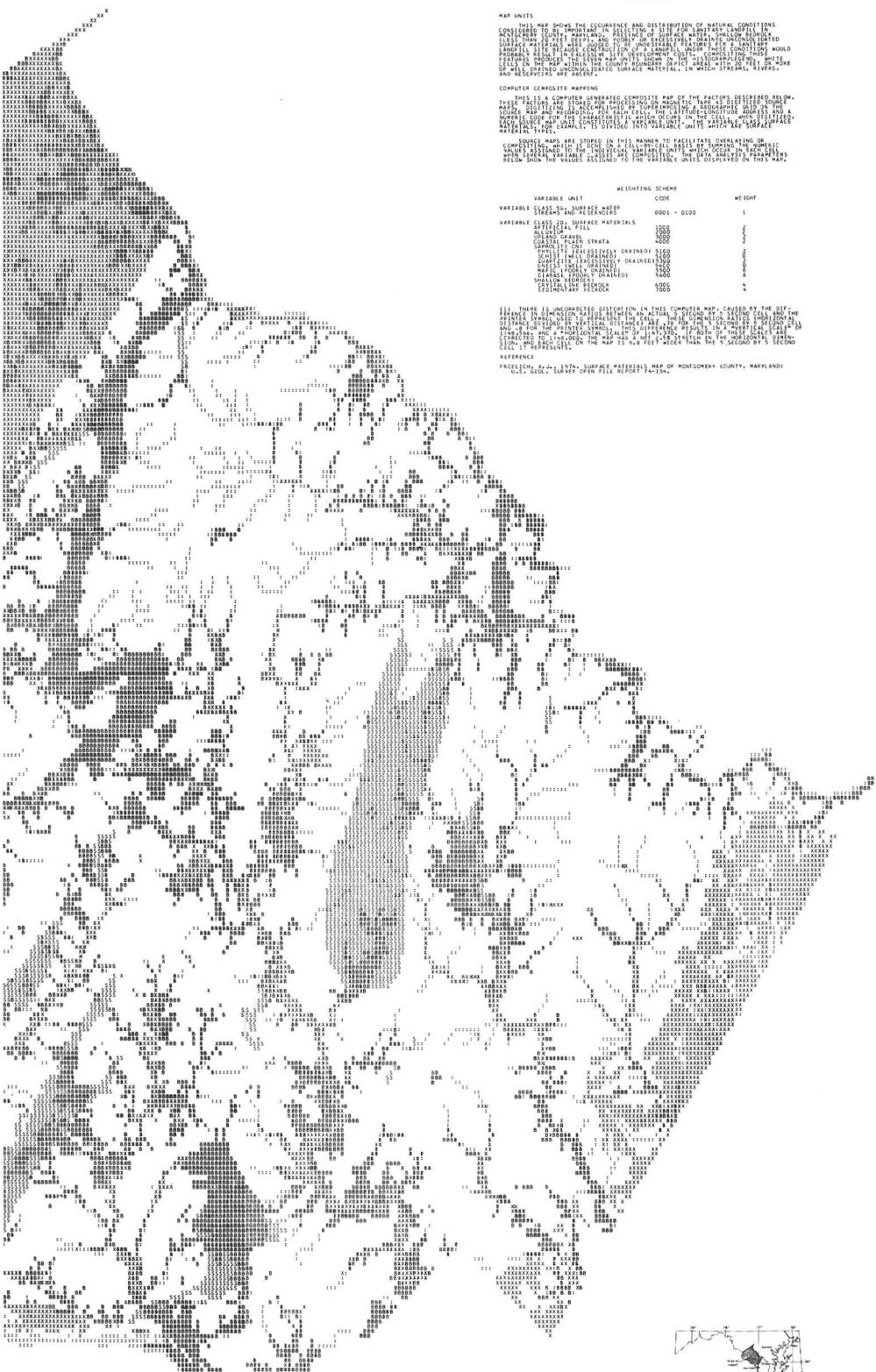
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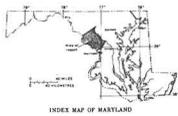
VARIABLE UNIT	WEIGHTING SCHEME		WEIGHT
	CODE		
VARIABLE CLASS OF SURFACE MATERIALS	0001 - 0100		1
VARIABLE CLASS OF SURFACE MATERIALS	1000		2
DIRTY GRASS	1000		

NOTE: THERE IS UNCORRECTED DISTORTION IN THIS COMPUTER MAP, CAUSED BY THE DISTORTION OF THE SOURCE MAPS. THE DISTORTION IS MOST EVIDENT IN THE MOUNTAIN AREA. THE DISTORTION IS MOST EVIDENT IN THE MOUNTAIN AREA. THE DISTORTION IS MOST EVIDENT IN THE MOUNTAIN AREA.

REFERENCE: FIGURE 2-1, 1974 SURFACE MATERIALS MAP OF MONTGOMERY COUNTY, MARYLAND; FIGURE 2-2, 1974 SURVEY OF THE MOUNTAIN AREA, MONTGOMERY COUNTY, MARYLAND.



MONTGOMERY COUNTY,
MARYLAND



oriented earth-science information, most of which is presented in map reports. In order to derive the maximum benefit from these maps, a part of the project was designed to provide a computerized information system that would permit planners to combine already existing planning maps with the new geologic information. These data were combined by use of a cell-based computer-composite-mapping program which stores map information and enables the planners to retrieve information from single maps or combinations of maps at any scale for a particular geographic area. Montgomery County, Md., was divided into 4.5-acre (1.8-hectare) cells by using a latitude-longitude reference system, and county maps showing: (1) contours on base of saprolite, (2) bedrock type, (3) surface materials, (4) topography, (5) drainage network, and (6) land cover and vegetation were digitized.

Information from the surface-materials and drainage-network maps was combined by the computer to produce a composite map showing some of the conditions affecting sanitary-landfill siting in the county (fig. 12). Figure 12 shows all the areas within the county that have the combination of physical characteristics considered optimum for a sanitary-landfill site, as well as those areas having one or more undesirable features. As no ground-water data were then available, this aspect of the siting limitations was not considered.

The digitized earth-science maps and computer system were installed in the MNCPPC computer in June 1976 and are presently being used by urban and environmental planners to create and revise master plans for Montgomery County.

REFERENCES CITED

[Map reports preceded by an asterisk were prepared as part of the Baltimore-Washington Urban Area Study]

- Cleaves, E. T., 1964, Mineral resources of Montgomery and Howard Counties, *in* The geology of Howard and Montgomery Counties: Baltimore, Maryland Geol. Survey, p. 262-269.
- *Cleaves, E. T., Crowley, W. P., and Kuff, K. R., 1974, Towson quadrangle: Maryland Geol. Survey Geol. and Environmental Atlas, scale 1:24,000. (Includes maps showing geology, landforms, estimated thickness of overburden, geologic factors affecting land modification, and mineral-resources and mined-land inventory.)
- Cloos, Ernst, and Cooke, C. W., 1953, Geologic map of Montgomery County [Maryland] and the District of Columbia: Baltimore, Md., Maryland Dept. Geology, Mines and Water Resources, scale 1:62,500.
- Cooke, C. W., and Cloos, Ernst, 1951, Geologic map of Prince Georges County [Maryland] and the District of Columbia: Baltimore, Md., Maryland Dept. Geology, Mines and Water Resources, scale 1:62,500.
- Crooks, J. W., O'Bryan, Deric, and others, 1967, Water resources of the Patuxent River basin, Maryland: U.S. Geol. Survey Hydrol. Inv. Atlas HA-244, scale 1:250,000.
- *Crowley, W. P., Reinhardt, Juergen, and Cleaves E. T., 1976, Geologic map of Baltimore County and City, *map in pocket of* Crowley, W. P., The geology of the crystalline rocks near Baltimore and its bearing on the evolution of the eastern Maryland Piedmont: Maryland Geol. Survey Rept. Inv. 27, 40 p., scale 1:62,500.
- Darton, N. H., 1947, Sedimentary formations of Washington, D.C., and vicinity: Washington, D.C., U.S. Geol. Survey, scale 1:31,680.
- Dingman, R. J., and Ferguson, H. F., 1956, The ground-water resources of the Piedmont part, *in* The water resources of Baltimore and Harford Counties: Maryland Dept. Geology, Mines and Water Resources Bull. 17, p. 1-128.
- Dingman, R. J., and Meyer, Gerald, 1954, The ground-water resources, *in* The water resources of Howard and Montgomery Counties: Maryland Dept. Geology, Mines and Water Resources Bull. 14, p. 1-139.
- Edwards, Jonathan, Jr., 1969, Mineral commodities of Maryland, *in* Ground-water aquifers and mineral commodities of Maryland: Maryland State Planning Dept. Pub. 152, p. 15-36.
- Fisher, G. W., 1964, The Triassic rocks of Montgomery County, *in* The geology of Howard and Montgomery Counties: Baltimore, Maryland Geol. Survey, p. 10-17.
- 1970, The Piedmont; the metamorphosed sedimentary rocks along the Potomac River near Washington, D.C., *in* Fisher, G. W., Pettijohn, F. J., Reed, J. C., Jr., and Weaver, K. N., eds., Studies of Appalachian geology—central and southern: New York, Interscience Publishers, p. 299-315.
- *Froelich, A. J., 1974, Natural soil assemblages map of Montgomery County, Maryland: U.S. Geol. Survey open-file rept. 74-70, 6 p., 1 pl., scale 1:62,500.
- *——— 1975a, Bedrock map of Montgomery County, Maryland: U.S. Geol. Survey Misc. Inv. Map I-920-D, scale 1:62,500.
- *——— 1975b, Contour map of the base of saprolite, Montgomery County, Maryland: U.S. Geol. Survey Misc. Inv. Map I-920-C, scale 1:62,500.
- *——— 1975c, Map showing contours on the base of saprolite, District of Columbia: U.S. Geol. Survey open-file rept. 75-539, 3 p., 1 pl., scale 1:24,000.
- *——— 1975d, Map showing mineral resources of Montgomery County, Maryland: U.S. Geol. Survey Misc. Inv. Map I-920-E, scale 1:62,500.
- *——— 1975e, Map showing surface materials, District of Columbia: U.S. Geol. Survey open-file rept. 75-540, 2 p., 2 pls., scale 1:24,000.

- *—— 1975f, Map showing thickness of overburden, District of Columbia: U.S. Geol. Survey open-file rept. 75-538, 4 p., 1 pl., scale 1:24,000.
- *—— 1975g, Surface materials map of Montgomery County, Maryland: U.S. Geol. Survey Misc. Inv. Map I-920-A, scale 1:62,500.
- *—— 1975h, Thickness of overburden map of Montgomery County, Maryland: U.S. Geol. Survey Misc. Inv. Map I-920-B, scale 1:62,500.
- *Froelich, A. J., and Hack, J. T., 1975, Preliminary geologic map, District of Columbia: U.S. Geol. Survey open-file rept. 75-537, 8 p., 1 pl., scale 1:24,000.
- Geological Society of America, Committee on Environment and Public Policy, 1975, Geologic constraints in the urban environment: Boulder, Colo., 12 p.
- Glaser, J. D., 1971, Geology and mineral resources of southern Maryland: Maryland Geol. Survey Rept. Inv. 15, 84 p., geol. map, scale 1:200,000.
- *—— 1973, Bowie quadrangle: Maryland Geol. Survey Geol. and Environmental Atlas, 3 p., scale 1:24,000. (Includes maps showing geology, mineral resources, general construction conditions, constraints on septic tanks, and ground-water resources.)
- Hack, J. T., 1955, Geology of the Brandywine area and origin of the upland of southern Maryland: U.S. Geol. Survey Prof. Paper 267-A, 43 p.
- *—— 1976a, Map of construction conditions, Prince Georges County, Maryland: U.S. Geol. Survey Misc. Field Studies Map MF-768-B, scale 1:62,500.
- *—— 1976b, Map of mineral resources, Prince Georges County, Maryland: U.S. Geol. Survey Misc. Field Studies Map MF-768-A, scale 1:62,500.
- *—— 1977, Geologic map for land-use planning, Prince Georges County, Maryland: U.S. Geol. Survey Misc. Inv. Map I-1004, scale 1:62,500.
- Hansen, H. J., III, 1968, Geophysical log cross-section network of the Cretaceous sediments of southern Maryland: Maryland Geol. Survey Rept. Inv. 7, 46 p., 8 figs., 17 pls.
- *Herb, W. J., 1976a, Availability of hydrologic data for Montgomery County, Maryland: U.S. Geol. Survey open-file rept. 76-884, 15 p., 1 pl., scale 1:62,500.
- *—— 1976b, Availability of hydrologic data for Prince Georges County, Maryland: U.S. Geol. Survey open-file rept. 76-178, 7 p., 1 fig., scale 1:62,500.
- Higgins, M. W., and Fisher, G. W., 1971, A further revision of the stratigraphic nomenclature of the Wissahickon Formation in Maryland: Geol. Soc. America Bull., v. 82, no. 3, p. 769-774.
- Hopson, C. A., 1964, The crystalline rocks of Howard and Montgomery Counties, in *The geology of Howard and Montgomery Counties*: Baltimore, Maryland Geol. Survey, p. 27-259.
- Imhoff, E. A., Kockelman, W. J., O'Connor, J. T., and LaFevers, J. R., 1978, Methods and criteria for land use and resources planning in surface mined areas, Vol. 2 of *Integrated mined-area reclamation and land-use planning*: Argonne Natl. Lab., ANL/EMR-1, 56 p.
- Jacobeen, F. H., Jr., 1972, Seismic evidence for high angle reverse faulting in the Coastal Plain of Prince Georges and Charles County [sic], Maryland: Maryland Geol. Survey Inf. Circ. 13, 21 p., 10 figs., 2 pls.
- Johnston, P. M., 1964, Geology and ground-water resources of Washington, D.C., and vicinity: U.S. Geol. Survey Water-Supply Paper 1776, 97 p.
- [1966?], Geology and ground-water resources of Washington, D.C., and vicinity [Unpublished appendix of well logs and drill-hole data for U.S. Geol. Survey Water-Supply Paper 1776]: Washington, D.C., n.p. [Available in U.S. Geol. Survey Library, Reston, Va.]
- Kirby, R. M., Matthews, E. D., and Bailey, M. A., 1967, Soil survey of Prince Georges County, Maryland: Washington, D.C., U.S. Soil Conserv. Service, 170 p.
- Knechtel, M. M., Hamlin, H. P., Hosterman, J. W., and Carroll, Dorothy, 1961, Physical properties of nonmarine Cretaceous clays in the Maryland Coastal Plain: Maryland Dept. Geology, Mines and Water Resources Bull. 23, 11 p.
- *Kuff, K. R., 1975, Mined land inventory map of Baltimore County and Baltimore City: Baltimore, Maryland Geol. Survey, scale 1:62,500.
- Larrabee, D. M., 1969, Serpentinite and rodingite in the Hunting Hill quarry, Montgomery County, Maryland: U.S. Geol. Survey Bull. 1283, 34 p.
- Leopold, L. B., 1968, Hydrology for urban land planning—A guidebook on the hydrologic effects of urban land use: U.S. Geol. Survey Circ. 554, 18 p.
- Leopold, L. B., Clarke, F. E., Hanshaw, B. B., and Balsley, J. R., 1971, A procedure for evaluating environmental impact: U.S. Geol. Survey Circ. 645, 13 p., 1 pl.
- Mack, F. K., 1966, Ground water in Prince Georges County: Maryland Geol. Survey Bull. 29, 101 p.
- Maryland-National Capital Park and Planning Commission, 1968-1972, Land-use maps of Montgomery County, Maryland: Silver Spring, Md., scale 1:12,000.
- [1977], Slope map of Montgomery County, Maryland: Silver Spring, Md., scale 1:62,500.
- Matthews, E. D., Compy, E. Z. W., and Johnson, J. C., 1961, Soil survey of Montgomery County, Maryland: U.S. Soil Conserv. Service, Soil Survey Series 1958, no. 7, 107 p.
- *Mayer, Larry, 1977, Drainage basin map of Montgomery County, Maryland: U.S. Geol. Survey open-file rept. 77-512, 3 p., 1 pl., scale 1:62,500.
- Meyer, Gerald, 1952, Ground-water resources of Prince Georges County, in *Geology and water resources of Prince Georges County*: Maryland Dept. Geology, Mines and Water Resources Bull. 10, p. 82-257.
- Nutter, L. J., 1974, Well yields in the bedrock aquifers of Maryland: Maryland Geol. Survey Inf. Circ. 16, 24 p.
- 1975, Hydrogeology of the Triassic rocks of Maryland: Maryland Geol. Survey Rept. Inv. 26, 37 p.
- Nutter, L. J., and Otton, E. G., 1969, Ground-water occurrence in the Maryland Piedmont: Maryland Geol. Survey Rept. Inv. 10, 56 p.

- Otton, E. G., 1955, Ground-water resources of the southern Maryland Coastal Plain: Maryland Dept. Geology, Mines and Water Resources Bull. 15, 347 p., 26 figs., 15 pls.
- *Otton, E. G., Cleaves, E. T., Crowley, W. P., Kuff, K. R., and Reinhardt, Juergen, 1975, Cockeysville quadrangle; Geology, hydrology and mineral resources: Maryland Geol. Survey Quad. Atlas 3, 4 p., scale 1:24,000. (Includes maps showing geology, estimated thickness of overburden, geologic factors affecting land modification, mineral-resources and mined-land inventory, location of wells, springs, and test holes, depth to the water table, availability of ground water, geohydrologic conditions pertaining to domestic underground liquid-waste disposal.)
- *——— 1978, White Marsh quadrangle; Geology, hydrology and mineral resources: Baltimore, Maryland Geol. Survey (Includes maps showing geology, physiography, estimated thickness of overburden, mineral-resources and mined-land inventory, location of wells and springs, depth to the water table, availability of ground water, and geohydrologic conditions pertaining to domestic liquid-waste disposal.)
- Papadopoulos, S. S., Bennett, R. R., Mack, F. K., and Trescott, P. C., 1974, Water from the Coastal Plain aquifers in the Washington, D.C., metropolitan area: U.S. Geol. Survey Circ. 697, 11 p.
- Pearre, N. C., compiler, 1961, Mineral deposits of Maryland, excluding fuels, sand, and gravel: U.S. Geol. Survey Mineral Inv. Resources Map MF-12, scale 1:250,000.
- Reed, J. C., Jr., and Jolly, Janice, 1963, Crystalline rocks of the Potomac River Gorge near Washington, D.C.: U.S. Geol. Survey Prof. Paper 414-H, 16 p.
- Reed, J. C., Jr., and Reed, J. C., 1969, Gold veins near Great Falls, Maryland: U.S. Geol. Survey Bull. 1286, 22 p.
- *Richardson, C. A., 1976a, Approximate depth to the water table, Montgomery County, Maryland: U.S. Geol. Survey open-file rept. 76-881, 4 p., 1 pl., scale 1:62,500.
- *——— 1976b, Areas of shallow water table, Prince Georges County, Maryland: U.S. Geol. Survey open-file rept. 76-194, 3 p., 1 fig., scale 1:62,500.
- *——— 1976c, Availability of ground water in Montgomery County, Maryland: U.S. Geol. Survey open-file rept. 76-882, 13 p., 1 pl., scale 1:62,500.
- *——— 1976d, Availability of ground water in Prince Georges County, Maryland: U.S. Geol. Survey open-file rept. 76-197, 9 p., 4 figs., scale 1:62,500.
- Robinson, G. D., and Spieker, A. M., eds., 1978, Nature to be commanded * * *: U.S. Geol. Survey Prof. Paper 950, 95 p.
- *Roen, J. B., and Froelich, A. J., 1976, Contour map of the base of saprolite, Howard County, Maryland: U.S. Geol. Survey Misc. Field Studies Map MF-772-A, scale 1:62,500.
- *——— 1978, Thickness of overburden map, Howard County, Maryland: U.S. Geol. Survey Misc. Field Studies Map MF-772-B, scale 1:62,500.
- Southeastern Wisconsin Regional Planning Commission, 1968, Floodland and shoreland development guide: Waukesha, Wis., Southeastern Wisconsin Regional Planning Comm. Planning Guide 5, 199 p.
- *Stewart, J. C., and Van Driel, J. N., 1975, The application of a computerized environmental information system to master and sector planning: Maryland-Natl. Capital Park and Planning Comm. Environmental Planning Mon. 8, 34 p.
- U.S. Geological Survey, 1967a, Engineering geology of the Northeast Corridor, Washington, D.C., to Boston, Massachusetts—Bedrock geology: U.S. Geol. Survey Misc. Geol. Inv. Map I-514-A, 9 p., 7 sheets, scale 1:250,000.
- 1967b, Engineering geology of the Northeast Corridor, Washington, D.C., to Boston, Massachusetts—Coastal Plain and surficial deposits: U.S. Geol. Survey Misc. Geol. Inv. Map I-514-B, 9 p., sheets 1-5, scale 1:250,000; sheet 8, scale 1:1,500,000.
- U.S. Soil Conservation Service, Engineering Division, 1975, Urban hydrology for small watersheds: U.S. Soil Conserv. Service Tech. Release 55, variously paged.
- *Van Driel, J. N., 1975a, Digital computer map showing conformation of the bedrock surface, Montgomery County, Maryland: U.S. Geol. Survey open-file rept. 75-418, 1 pl., scale 1:48,000.
- *——— 1975b, Digital computer map showing surface materials, Montgomery County, Maryland: U.S. Geol. Survey open-file rept. 75-419, 1 pl., scale 1:48,000.
- *——— 1975c, Digital topographic map of Montgomery County, Maryland: U.S. Geol. Survey open-file rept. 75-420, 1 pl., scale 1:48,000.
- *——— 1975d, Map showing conditions affecting sanitary landfill siting in Montgomery County, Maryland: U.S. Geol. Survey open-file rept. 75-177, 1 pl., scale 1:48,000. (A computer composite map.)
- *Van Driel, J. N., and Stewart, J. C., 1976, The role of computer mapping in the decision-making process for Montgomery County, Maryland: Review of Public Data Use, v. 4, no. 4, p. 31-40.
- Waananen, A. O., Limerinos, J. T., Kockelman, W. J., Spangle, W. E., and Blair, M. L., 1977, Flood-prone areas and land-use planning—selected examples from the San Francisco Bay region, California: U.S. Geol. Survey Prof. Paper 942, 75 p.
- William Spangle and Associates, F. B. Leighton and Associates, and Baxter, McDonald and Company, 1976, Earth-science information in land-use planning—Guidelines for earth scientists and planners: U.S. Geol. Survey Circ. 721, 28 p.
- *Withington, C. F., and Froelich, A. J., 1974a, Preliminary geologic map of the Beltsville quadrangle, Prince Georges, Montgomery, and Howard Counties, Maryland: U.S. Geol. Survey Misc. Field Studies Map MF-582, 2 sheets, scale 1:24,000.
- *——— 1974b, Selected geologic data for the Beltsville quadrangle, Prince Georges, Montgomery, and Howard Counties, Maryland: U.S. Geol. Survey open-file rept., 10 p., 1 fig., 1 pl., scale 1:24,000.

