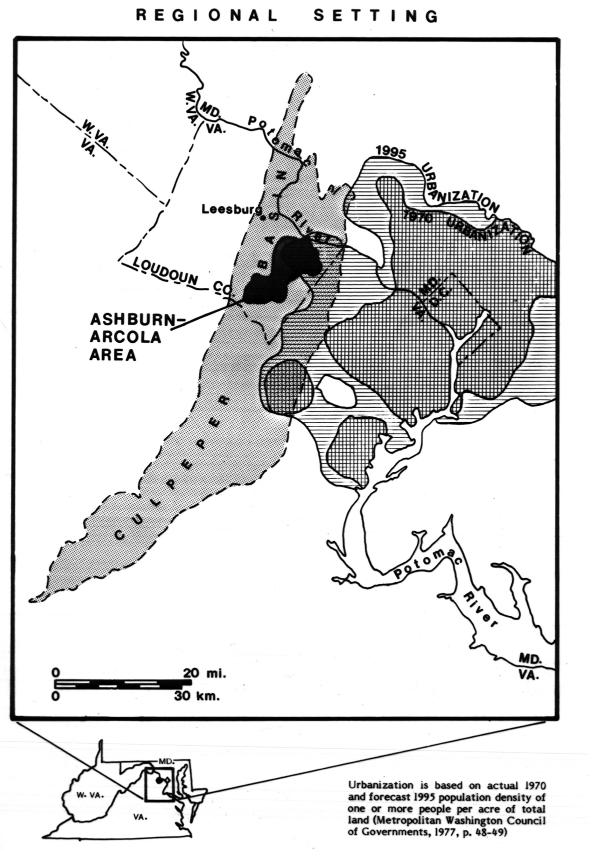
FIGURE 1.-- REGIONAL SETTING



Urbanization is based on actual 1970 and forecast 1995 population density of one or more people per acre of total land (Metropolitan Washington Council of Governments, 1977, p. 48-49)

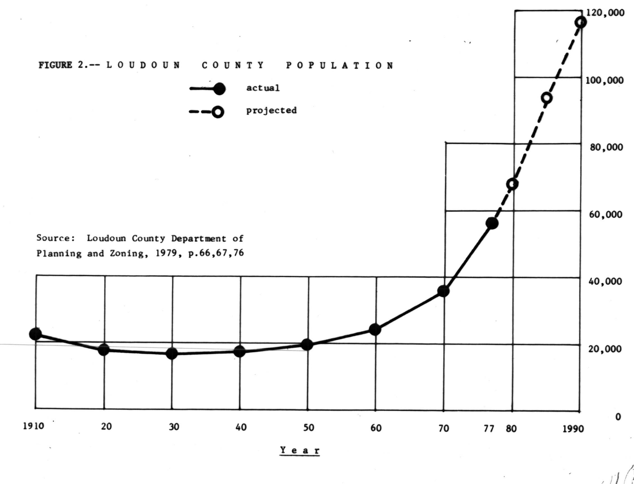
INTRODUCTION

Changing the nature and intensity of land use in an area can profoundly affect and be affected by the land's geologic and hydrologic characteristics. Understanding and wisely applying appropriate geologic and hydrologic information to guide land-use changes can provide both economic and environmental benefits.

The Ashburn-Arcola area is located in Loudoun County, Virginia, which is on the western fringe of intensive development pressure from the Washington metropolitan area (see figure 1). Most of the county is currently in farms, woodland, and small rural communities, but new subdivisions and commercial facilities are growing at its eastern border. The county population remained close to 20,000 through the 1800's and up to 1960. From 1960 to 1977, however, it more than doubled from 24,459 to 58,500. Most of the growth occurred in the extreme eastern portion of the county, including part of this study area (Loudoun County Department of Planning and Zoning, 1979, p. 66-67). The county population is projected to double again to 116,000 by 1990 (see figure 2). In 1978, nearly 11,000 new housing units were approved or pending approval for construction in eastern Loudoun County (Loudoun County Department of Planning and Zoning, 1979, p. 76, 83). The eastern half of Loudoun County lies in the Triassic Culpeper basin, whose geology and hydrology are the subject of recent extensive study by the U.S. Geological Survey. Studies relating directly to this map include geologic mapping by Lee (1979) and Froelich (1982, in preparation) and an index to flood-prone area studies (Morsches and Zenone, 1981).

This map is one of several which provide interpretations of selected geologic and hydrologic data applicable to land-use planning for the Ashburn and Arcola area in Loudoun County. The study area comprises the Broad Run watershed with the exclusion of the southeastern third, which is drained by the Horsepen Run tributary. The southeastern third of the watershed is excluded because most of it lies outside Loudoun County or is occupied by Dulles International Airport. The land-use planning issues in the remaining study area are representative of many of those found throughout the Culpeper basin.

FIGURE 2.-- LOUDOUN COUNTY POPULATION



EXPLANATION

STUDY AREA BOUNDARY

SUBBASIN DRAINAGE DIVIDES

The study area can be subdivided into discrete areas drained by major tributaries. These boundaries indicate clearly which sections of the surface drainage system are most immediately affected by runoff from any given site.

100-YEAR FLOOD PLAIN

A 100-year flood plain is an area that has about one chance in one hundred of being flooded in any year. This description is commonly misinterpreted as meaning that when a "100-year flood" occurs in one year, a flood of such magnitude will not recur within the next 100 years. A flood in one year, however, has little relationship to what will occur in later years. "One-hundred year floods" can and sometimes do recur, for example, after 10 years, or 3, or even in the same year. The frequency of a 100-year flood is only a statistical probability, based on past observations. The actual 100-year flood plain may be more extensive than shown if development upstream has increased, if water is diverted into the basin (such as by storm sewers), or if manmade or natural obstructions occur in the flood plain. Conversely, the 100-year flood plain may be less extensive than shown if flood-control dams or other flow-regulating structures are installed, or if water is diverted out of the basin.

The areas shown on the map represent the widest extent of the approximate 100-year flood plain delinated by either the Soil Conservation Service (SCS) (U.S. Department of Agriculture, 1974) or the U.S. Geological Survey (USGS) (1973, 1974a, 1974b), or both. Both sources agree closely in most places.

The USGS 100-year "flood prone area" boundaries were derived from data on regional flood levels, supplemented in the Sterling quadrangle (USGS, 1973) by stream profiles based on high-water marks. Current land use patterns were assumed to persist indefinitely into the future. Flood plains generally were not mapped in headwater areas of streams where the flood plain is less than 500 feet wide.

The SCS 100-year "flood hazard area" boundaries were estimated from computer-calculated peak flows based on regional gaged-stream data, which were then fitted to surveyed cross-sections of the stream valley. Flood plains were not mapped in headwater areas upstream from proposed SCS flood-control structures or other limits determined by Loudoun County. Land-use patterns assumed in the calculations were based on development projected for the next 10-15 years (until 1984-89), according to existing zoning regulations.

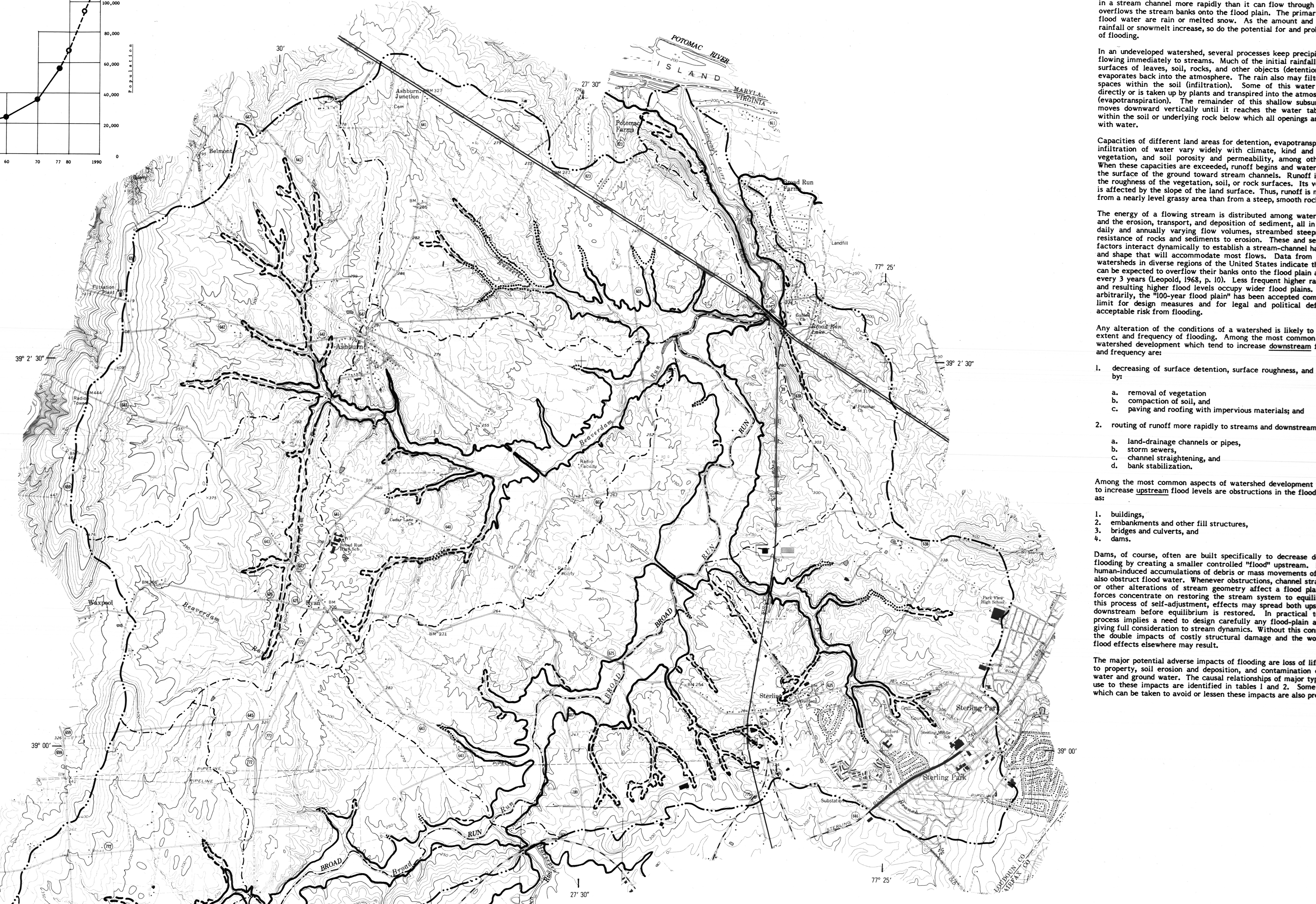
FLOOD-PRONE SOILS

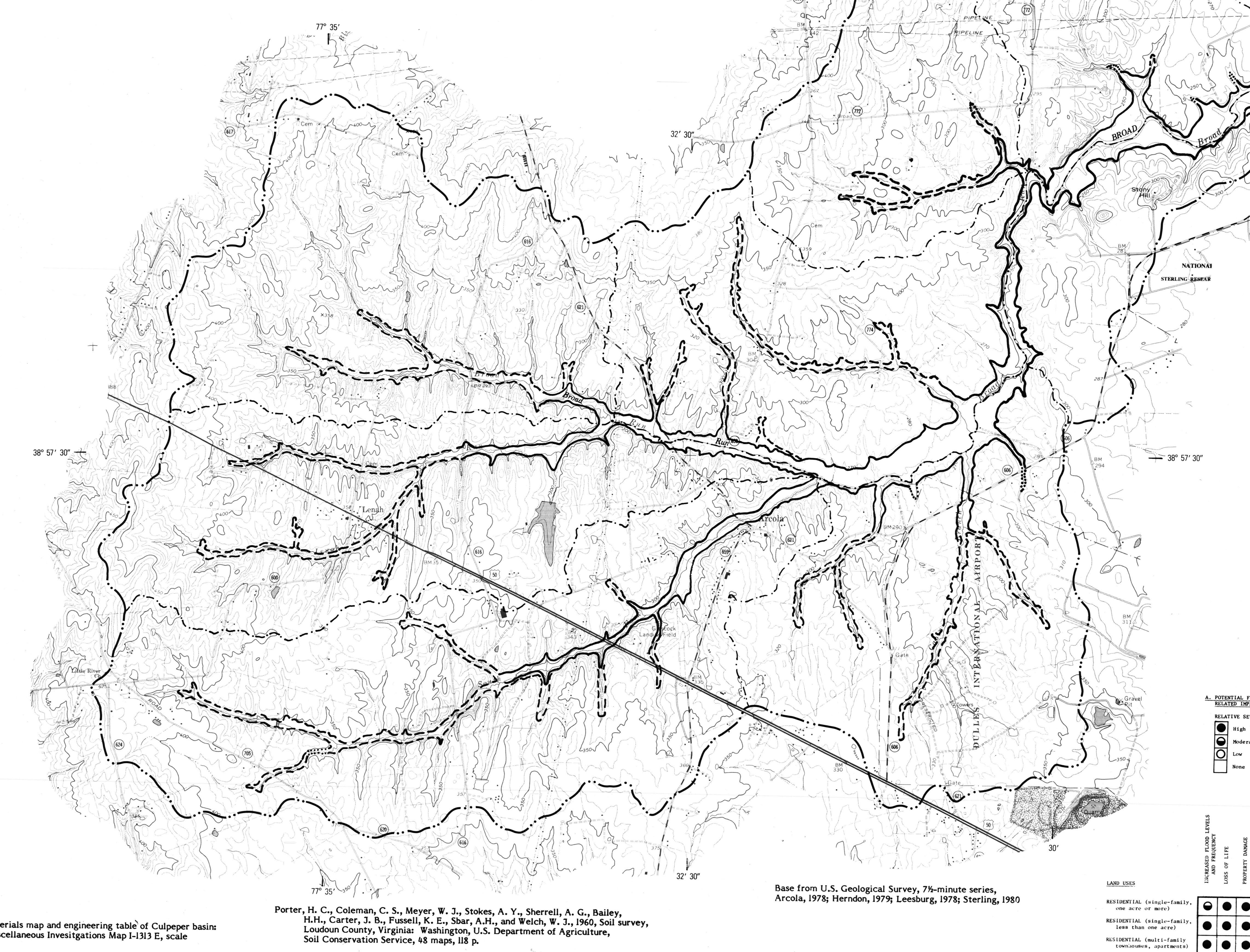
Alluvium consists of nonconsolidated layers of clay, silt, sand, gravel, and boulders deposited in valley bottoms by past floods. The SCS designates some soils developed on alluvium as "subject to flooding and overflow" on the basis of valley bottom positions and the morphological development of the soil (Richard Weber, Loudoun County soil scientist, oral communication, 1981). The areas shown on the map represent all SCS-designated flood-prone soils which are not included in the "100-year flood plain" areas (Porter and others, 1960; Weber 1981, p. 67). Most are in the smaller headwater stream valleys. These areas are flooded more frequently than the 100-year flood plain, sometimes one or more times yearly.

The remaining areas of alluvial deposits also may be flooded, but less frequently. They occur in the narrow valley bottoms of most headwater streams. Although not mapped here, their locations can be found in Lee (1979). The engineering properties of these deposits have been summarized by S.F. Obermeier and W.H. Langer of the U.S. Geological Survey (written communication, 1982) and by Froelich (1982).

OTHER FLOOD-PRONE AREAS

These areas are designated "flood-prone" to complete a pattern topographically consistent with the other categories. That is, if flood waters cover a 100-year flood plain or flood-prone soils, the valley shape indicates that these areas also would be flooded.





DYNAMICS OF FLOODING: AN OVERVIEW

Flooding is a natural phenomenon which occurs when water accumulates in a stream channel more rapidly than it can flow through it, and thus overflows the stream banks onto the flood plain. The primary sources of flood water are rain or melted snow. As the amount and intensity of rainfall or snowmelt increase, so do the potential for and probable height of flooding.

In an undeveloped watershed, several processes keep precipitation from flowing immediately to streams. Much of the initial rainfall collects on surfaces of leaves, soil, rocks, and other objects (detention) and later evaporates back into the atmosphere. The rain also may filter into pore spaces within the soil (infiltration). Some of this water evaporates directly or is taken up by plants and transpired into the atmosphere (evapotranspiration). The remainder of this shallow subsurface water moves downward vertically until it reaches the water table, a level within the soil or underlying rock below which all openings are saturated with water.

Capacities of different land areas for detention, evapotranspiration, and infiltration of water vary widely with climate, kind and amount of vegetation, and soil porosity and permeability, among other factors. When these capacities are exceeded, runoff begins and water flows over the surface of the ground toward stream channels. Runoff is slowed by the roughness of the vegetation, soil, or rock surfaces. Its velocity also is affected by the slope of the land surface. Thus, runoff is much slower from a nearly level grassy area than from a steep, smooth rock surface.

The energy of a flowing stream is distributed among water movement and the erosion, transport, and deposition of sediment, all in relation to daily and annually varying flow volumes, streambed steepnesses, and resistance of rocks and sediments to erosion. These and several other factors interact dynamically to establish a stream-channel having a size and shape that will accommodate most flows. Data from small rural watersheds in diverse regions of the United States indicate that streams can be expected to overflow their banks onto the flood plain about twice every 3 years (Leopold, 1968, p. 10). Less frequent higher rates of flow and resulting higher flood levels occupy wider flood plains. Somewhat arbitrarily, the "100-year flood plain" has been accepted commonly as a limit for design measures and for legal and political definitions of acceptable risk from flooding.

Any alteration of the conditions of a watershed is likely to change the extent and frequency of flooding. Among the most common aspects of watershed development which tend to increase downstream flood levels and frequency are:

1. decreasing of surface detention, surface roughness, and infiltration by:
   a. removal of vegetation
   b. compaction of soil, and
   c. paving and roofing with impervious materials; and
2. routing of runoff more rapidly to streams and downstream by:
   a. land-drainage channels or pipes,
   b. storm sewers,
   c. channel straightening, and
   d. bank stabilization.

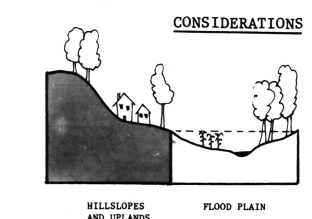
Among the most common aspects of watershed development which tend to increase upstream flood levels are obstructions in the flood plain such as:

1. buildings,
2. embankments and other fill structures,
3. bridges and culverts, and
4. dams.

Dams, of course, often are built specifically to decrease downstream flooding by creating a smaller controlled "flood" upstream. Natural or human-induced accumulations of debris or mass movements of earth can also obstruct flood water. Whenever obstructions, channel straightening, or other alterations of stream geometry affect a flood plain, stream forces concentrate on restoring the stream system to equilibrium. In this process of self-adjustment, effects may spread both upstream and downstream before equilibrium is restored. In practical terms, this process implies a need to design carefully any flood-plain alterations, giving full consideration to stream dynamics. Without this consideration, the double impacts of costly structural damage and the worsening of flood effects elsewhere may result.

The major potential adverse impacts of flooding are loss of life, damage to property, soil erosion and deposition, and contamination of surface water and ground water. The causal relationships of major types of land use to these impacts are identified in tables 1 and 2. Some measures which can be taken to avoid or lessen these impacts are also presented.

TABLE 1.-- HILLSLOPES AND UPLANDS: FLOOD-RELATED LAND-USE CONSIDERATIONS



A. POTENTIAL FLOOD-RELATED IMPACTS — RELATIVE SEVERITY: ● High; ◒ Moderate; ○ Low; (blank) None

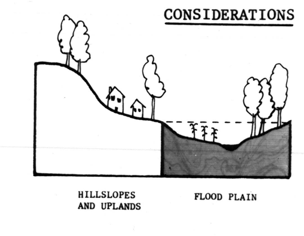
B. DEVELOPMENT CHARACTERISTICS — PROBABLE INTENSITY: ● High; ◒ Moderate; ○ Low; (blank) None

LAND USES	INCREASED FLOOD LEVELS AND FREQUENCY	LOSS OF LIFE	PROPERTY DAMAGE	EROSION AND DEPOSITION	SURFACE AND GROUND WATER POLLUTION (from runoff)	VEGETATION REMOVAL	SOIL COMPACTION	IMPERVIOUS SURFACE (paving, roofs) and percent impervious (adapted from U.S.D.A., 1975, p.2-5; and Klein, 1979, p. 960)	STORM SEWER OR LAND DRAINAGE	ONSITE SEPTIC SYSTEM	SANITARY SEWER SYSTEM	TOXIC MATERIALS ON OR IN GROUND
RESIDENTIAL (single-family, one acre or more)	○	○	○	○	◒	○	○	○ 0-20		◒		
RESIDENTIAL (single-family, less than one acre)	◒	◒	◒	◒	◒	◒	◒	◒ 25-65	○	●	◒	
RESIDENTIAL (multi-family townhouses, apartments)	◒	◒	◒	◒	◒	◒	●	◒ 44-56	◒		●	
COMMERCIAL (business area, shopping mall)	●	●	●	●	●	●	●	● 85-95	●		◒	
INDUSTRIAL (variable--light and heavy)	●	●	●	●	●	●	●	● 72	●		●	●
HIGHWAYS, ROADS	●	●	●	●	●	●	●	● 56-100	●			
LANDFILL	◒	◒	◒	●	●	●	●	◒ 25-75				●
AGRICULTURE (crops, pasture)	◒	◒	◒	●	◒	●		○ 0-56	◒			◒
OUTDOOR RECREATION AND OPEN SPACE	○	○	○	○	○	○	○	○ 0-17		○		

C. ACTIONS TO REDUCE IMPACTS

LAND USES							
RESIDENTIAL (single-family, one acre or more)	Minimize vegetation removal, soil compaction, and other runoff increases	Reestablish vegetation after construction, especially on slopes	Minimize impervious area	(shaded)	Prevent septic drain field overflow	(shaded)	Minimize natural drainage disruption
RESIDENTIAL (single-family, less than one acre)				Develop least permeable soils to minimize runoff increase	Prevent septic drain field or sewer line leakage	Consider detention ponds	
RESIDENTIAL (multi-family townhouses, apartments)					Prevent sewer line leakage	Consider detention ponds, roof storage, or porous pavement	
COMMERCIAL (business area, shopping mall)						Use detention ponds, roof storage, porous pavement, or other runoff retarding measures	
INDUSTRIAL (variable--light and heavy)					Neutralize, contain, or otherwise dispose of wastes securely		
HIGHWAYS, ROADS					(shaded)	Use detention ponds, if runoff warrants	
LANDFILL			Cover wastes daily to minimize infiltration	Locate site to minimize leachate seepage	Monitor, collect, and treat leachate	Detain off-site any runoff increases	(shaded)
AGRICULTURE (crops, pasture)		Use conservation measures to limit erosion, rapid runoff, and dispersion of pesticides, fertilizers, and animal wastes--contouring, strip cropping, detention ponds, etc.					
OUTDOOR RECREATION AND OPEN SPACE		Reestablish vegetation, especially on slopes	(shaded)	(shaded)	Prevent septic drain field overflow	(shaded)	Minimize natural drainage disruption

TABLE 2.-- FLOOD PLAINS: FLOOD-RELATED LAND-USE CONSIDERATIONS



A. POTENTIAL FLOOD-RELATED IMPACTS — RELATIVE SEVERITY: ● High; ◒ Moderate; ○ Low; (blank) None

B. DEVELOPMENT CHARACTERISTICS — PROBABLE INTENSITY: ● High; ◒ Moderate; ○ Low; (blank) None

LAND USES	INCREASED FLOOD LEVELS AND FREQUENCY	LOSS OF LIFE	PROPERTY DAMAGE	EROSION AND DEPOSITION	SURFACE AND GROUND WATER POLLUTION (from runoff)	VEGETATION REMOVAL	SOIL COMPACTION	IMPERVIOUS SURFACE (paving, roofs) and percent impervious (adapted from U.S.D.A., 1975, p.2-5; and Klein, 1979, p. 960)	STREAM CHANNELIZATION	FILL OR EMBANKMENT	BRIDGE OR CULVERT	BUILDING(S)	ONSITE SEPTIC SYSTEM	SANITARY SEWER SYSTEM	TOXIC MATERIALS IN OR ON GROUND	POPULATION CONCENTRATION
RESIDENTIAL (single-family, one acre or more)	◒	●	●	◒	◒	○	○	○ 0-20		○		◒	●			◒
RESIDENTIAL (single-family, less than one acre)	●	●	●	●	●	◒	◒	◒ 25-65	○	◒		●	●	◒		◒
RESIDENTIAL (multi-family townhouses, apartments)	●	●	●	●	●	◒	●	◒ 44-56	◒	◒	○	●		●		●
COMMERCIAL (business area, shopping mall)	●	●	●	●	●	●	●	● 85-95	●	●	◒	●		◒		●
INDUSTRIAL (variable--light and heavy)	●	●	●	●	●	●	●	● 72	●	●	◒	●		●	●	◒
HIGHWAYS, ROADS	●	●	●	●	●	●	●	● 56-100	●	●	●					○
LANDFILL	●	●	●	●	●	●	●	◒ 25-75		●					●	
AGRICULTURE (crops, pasture)	○	○	◒	●	◒	◒		○ 0-56							◒	
OUTDOOR RECREATION AND OPEN SPACE	○	○	○	○	◒	○	○	○ 0-17				○	○			◒

C. ACTIONS TO REDUCE IMPACTS

LAND USES					
RESIDENTIAL (single-family, one acre or more)	INAPPROPRIATE USE				
RESIDENTIAL (single-family, less than one acre)	INAPPROPRIATE USE				
RESIDENTIAL (multi-family townhouses, apartments)	INAPPROPRIATE USE				
COMMERCIAL (business area, shopping mall)	INAPPROPRIATE USE				
INDUSTRIAL (variable--light and heavy)	INAPPROPRIATE USE				
HIGHWAYS, ROADS	Avoid fill, bridges, or other obstructive structures which substantially decrease flood-plain cross-sectional area	Avoid vulnerable, unprotected structures subject to flood damage	(shaded)	Minimize vegetation removal, soil compaction, and other runoff increases	Avoid channelization, or if needed, design to approximate normal stream geometry
LANDFILL	INAPPROPRIATE USE				
AGRICULTURE (crops, pasture)	Avoid obstructive structures which substantially decrease flood-plain cross-sectional area	Avoid vulnerable, unprotected structures subject to flood damage	Avoid permanent habitation	Use conservation measures to limit erosion, rapid runoff, and dispersion of pesticides, fertilizers, and animal wastes--contouring, strip-cropping, detention ponds, etc.	
OUTDOOR RECREATION AND OPEN SPACE			(shaded)	Minimize vegetation removal, soil compaction, and other runoff increases	Avoid septic systems

D. INAPPROPRIATE USES BECAUSE THEY REQUIRE:

LAND USES				
RESIDENTIAL (single-family, one acre or more)	Obstructive buildings, bridges, fill, or other structures which substantially decrease flood-plain cross-sectional area	Vulnerable buildings or other unprotected structures subject to flood damage	Permanent habitation	Septic system
RESIDENTIAL (single-family, less than one acre)				(shaded)
RESIDENTIAL (multi-family townhouses, apartments)				(shaded)
COMMERCIAL (business area, shopping mall)			(shaded)	(shaded)
INDUSTRIAL (variable--light and heavy)			(shaded)	(shaded)
LANDFILL	Waste disposal	(shaded)		

LAND USE AND POTENTIAL FLOOD-RELATED IMPACTS

Land and water cannot be used without affecting and being affected by the physical properties of the land and water itself. Each type and intensity of land and water use (more commonly referred to jointly as "land use") has its own set of impacts at any given site. A primary goal of environmental planning is to minimize the adverse environmental impacts and to maximize the beneficial effects of existing and proposed land-use patterns. Two major questions which usually are raised during the planning process are:

1) where is the environmentally most appropriate location for a given land use or uses?; and

2) what are the environmentally most appropriate site development and management methods once a site has been selected?

The information in tables 1 and 2 addresses these questions as they relate to flood plains and flooding. Table 1 considers development in hillslope or upland locations which drain onto flood plains; table 2 considers development on flood plains themselves. In each table, nine common categories of land use are presented. Potential flood-related impacts of each use, development characteristics which contribute to these impacts, and actions which can reduce impacts are presented. The flood-plain development table (table 2) also identifies uses which are inappropriate because avoidance of resultant flood hazards is very difficult or costly.

The tables can be used in three ways. First, as an aid to site selection, the tables can be used to determine quickly the potential impacts of a particular land use and the relative severity of those impacts. This determination can be made by simply following the given land-use row to Box A, "Potential Flood-Related Impacts." The "relative severity" should be understood as only that. It is not an absolute rating. Severity of impact can, in fact, vary widely among separate occurrences within the same land use category. "Relative severity" points out the degree of concern appropriately given to preventing a potential impact.

The last four types of impacts shown in the tables (loss of life, property damage, erosion and deposition, and water pollution) may result from two different chains of events. On one hand, these impacts may result directly from a given use. For example, clearing ground for residential development in hillslope or upland areas can increase erosion on the site. On the other hand, when a land use contributes to flooding (first impact listed in each table), the other four impacts will be increased in the path of the flood. Thus, the impervious roofs and driveways of residential developments can contribute to flooding by increasing runoff. More flooding, in turn, causes more erosion and deposition in the flood plain. Where both direct and indirect impacts may occur, only the more severe is shown on the table.

A second use of the tables is provided by box C, "Actions to Reduce Impacts." When a site is already committed to a specific land use, some of the actions which can be taken to lessen or eliminate the adverse impacts during construction, use, or maintenance are listed in this box. For instance, in hillslope and upland single-family residential use on 1-acre or larger lots (first row), flood risks can be reduced by preserving or adding vegetative cover, by minimizing impervious area, by installing septic systems which are not subject to overflow, and by preserving or restoring the natural drainage system. In general, the more severe the potential impact (box A), the more critical is remedial action (box C). On flood plains, several land uses may have severe impacts for which site modifications will provide insufficient relief. Avoiding these uses is the most effective solution. Box D indicates these "inappropriate uses" and the reasons why they are inappropriate.

The third use of the tables can be to gain a more detailed understanding of the causes of land-use impacts. "Development Characteristics" are specific actions or properties commonly associated with one or more types of land use. Development characteristics of each land use and the likely relative intensity of each characteristic are indicated in box B. "Relative intensity" implies the degree of change that can be expected in comparison with the pre-existing conditions of the site. For instance, typical hillslope and upland residential use (single-family, on 1 acre or more) can be expected to involve low intensity of vegetation removal and soil compaction, a low percentage of impervious surfaces, and moderate intensity of septic drainage. Identifying the specific development characteristics which contribute to flood-related impacts can further clarify how to lessen or avoid these impacts. The user should realize that characteristics noted on the tables may vary in intensity or may not even occur in any specific situation. The tables simply show characteristics which typically do occur and whose effects therefore merit consideration.

Finally, it should be emphasized that these tables are concerned only with the flood-related aspects of land use. Those who make comprehensive decisions about land-use changes weigh and integrate this information with information on the land use implications of other environmental factors such as water supply and quality, soil stability, mineral resources, vegetation, and wildlife, and with many other social, economic, legal, and political factors.

REFERENCES

Froelich, A. J., 1982, Surface materials map and engineering table of Culpeper basin: U.S. Geological Survey Miscellaneous Invesitgations Map I-1313 E, scale 1:125,000 (in preparation).

Klein, R. D., 1979, Urbanization and stream quality impairment: Water Resources Bulletin, v. 15, no. 4, p. 948-963.

Lee, K. Y., 1979, Triassic-Jurassic geology of the northern part of the Culpeper basin, Virginia and Maryland: U.S. Geological Survey Open-File Report 79-1557, 16 maps, 10 p.

Leopold, L. B., 1968, Hydrology for urban land-use planning--a guidebook on the hydrologic effects of urban land use: U.S. Geological Survey Circular 554, 18 p.

Loudoun County Department of Planning and Zoning, 1979, Loudoun County resource management plan: Leesburg, Virginia, 262 p.

Metropolitan Washington Council of Governments, 1977, Impact assessment: 1980, 1985, 1995, land use and growth pattern implications of forecasts: Washington, D.C., 86 p.

Morsches, S. A., and Zenone, Chester, 1981, Index to flood-prone area studies in the Culpeper basin, Virginia and Maryland: U.S. Geological Survey Miscellaneous Investigations Map I-1313A, scale 1:125,000.

Porter, H. C., Coleman, C. S., Meyer, W. J., Stokes, A. Y., Sherrell, A. G., Bailey, H.H., Carter, J. B., Fussell, K. E., Sbar, A.H., and Welch, W. J., 1960, Soil survey, Loudoun County, Virginia: Washington, U.S. Department of Agriculture, Soil Conservation Service, 48 maps, 118 p.

U.S. Department of Agriculture, Soil Conservation Service, 1974, Flood hazard analyses, Broad Run-Sugarland Run, Loudoun County, Virginia: Richmond, 15 maps (scale 1:6,000), 14 plates, 14 p.

________ 1975, Urban hydrology for small watersheds: Engineering Division, Technical Release no. 55, 107 p.

U.S. Geological Survey, 1973, Map of flood-prone areas, Sterling quadrangle, Virginia-Maryland: scale 1:24,000.

________ 1974a, Map of flood-prone areas, Arcola quadrangle, Virginia: scale 1:24,000.

________ 1974b, Map of flood-prone areas, Herndon quadrangle, Virginia: scale 1:24,000.

________ 1980, Land use and land cover, 1972-77, Culpeper basin, Virginia-Maryland: Miscellaneous Field Studies Map MF-1208, scale 1:125,000.

Weber, Richard, 1981, Interpretive guide to soils and geology for planning in Loudoun County, Virginia: Draft report on file in Loudoun County soil scientist's office, Leesburg, Virginia.

Base from U.S. Geological Survey, 7½-minute series, Arcola, 1978; Herndon, 1979; Leesburg, 1978; Sterling, 1980

SCALE 1:24 000
1 ½ 0 1 MILE
1 .5 0 1 KILOMETERS
CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL

LAND-USE IMPLICATIONS OF FLOODING:
ASHBURN-ARCOLA AREA OF NORTHERN VIRGINIA

By
David B. Harper
1982

U.S. Geological Survey
Open-File Report 82-23