SUSCEPTIBILILITY OF COASTAL PLAIN AQUIFERS TO CONTAMINATION, FAIRFAX COUNTY, VIRGINIA

A COMPUTER COMPOSITE MAP

By
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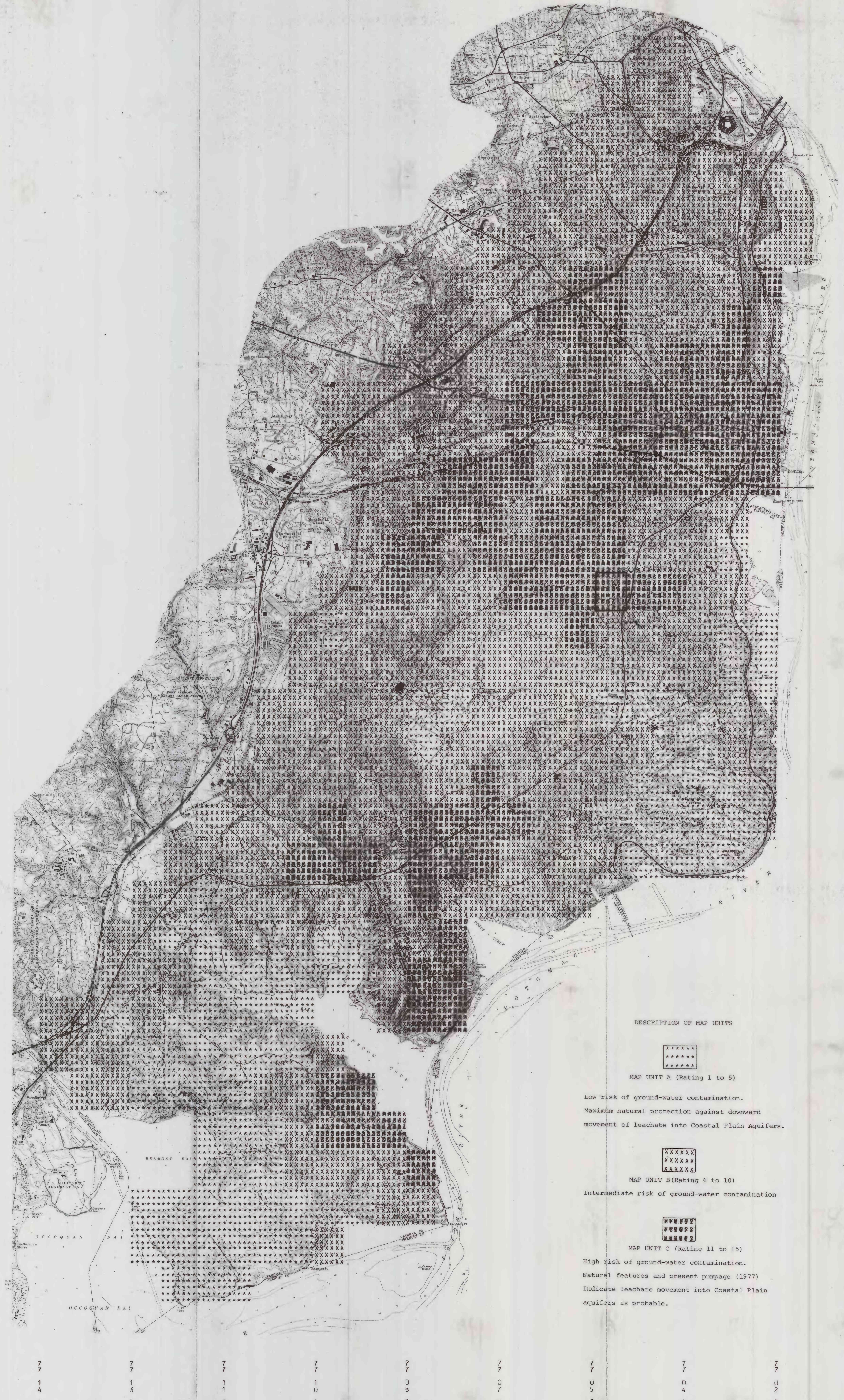
1978



SCALE 1:48 000

CONTOUR INTERVAL 20 FEET

DESCRIPTION OF MAP UNITS

MAP UNIT A (Rating 1 to 5)

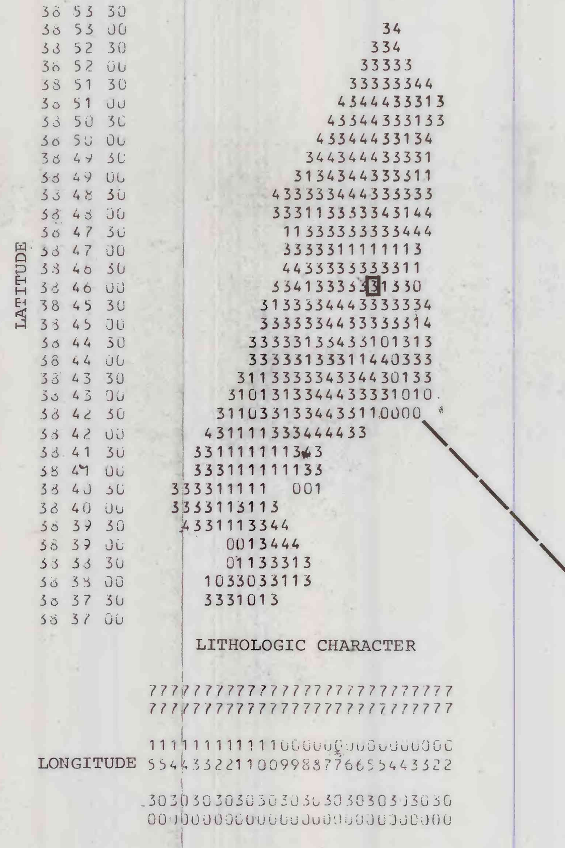
Low risk of ground-water contamination. Maximum natural protection against downward movement of leachate into Coastal Plain Aquifers.

MAP UNIT B(Rating 6 to 10)

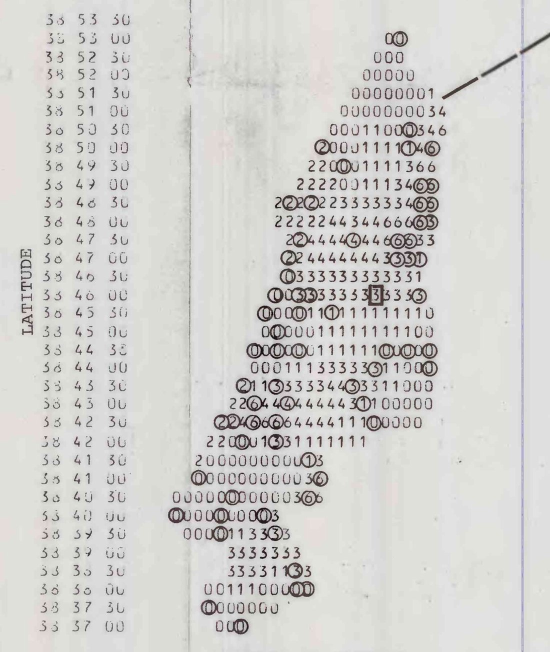
Intermediate risk of ground-water contamination

MAP UNIT C (Rating 11 to 15)

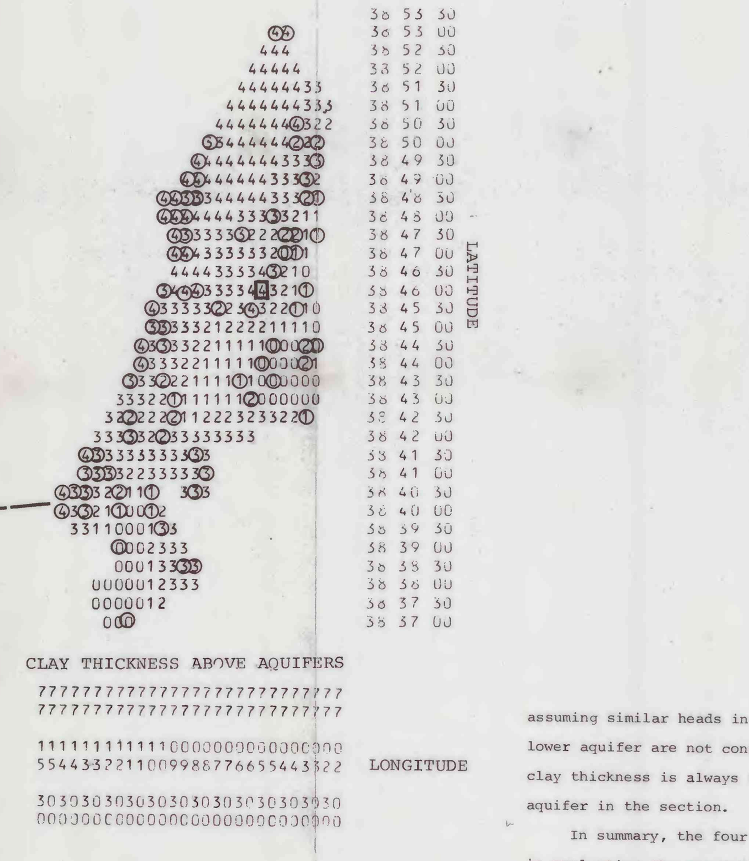
High risk of ground-water contamination. Natural features and present pumpage (1977) Indicate leachate movement into Coastal Plain aquifers is probable.



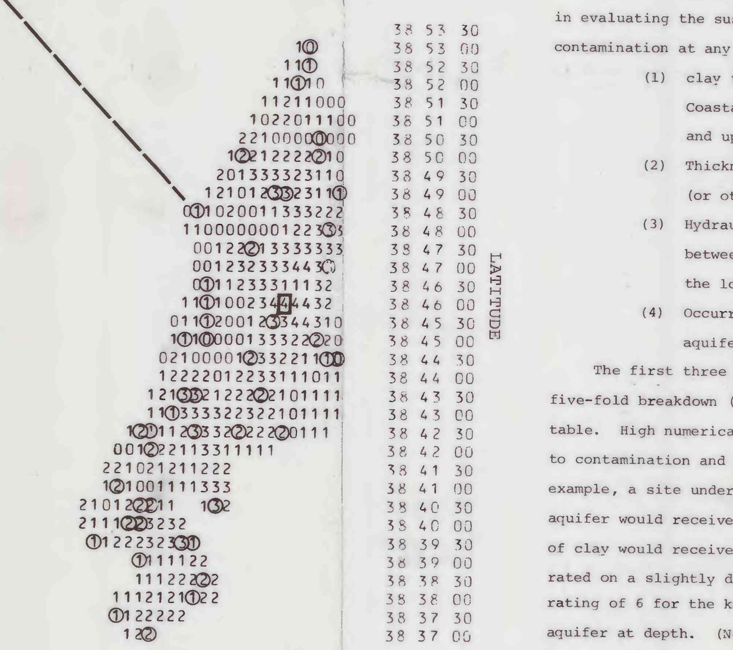
LITHOLOGIC CHARACTER



AQUIFER OCCURRENCE



CLAY THICKNESS ABOVE AQUIFERS



HYDRAULIC GRADIENT

HYDROGEOLOGIC FACTORS	DATA SOURCES*	MAP CLASSIFICATION	CONTAMINATION SUSCEPTIBILITY RATING
Thickness of clay in confining bed overlying the lower aquifer or other sand aquifers in Potomac Group.	Unpublished map of clay thickness and logs of test borings and wells	Less than 50 feet of clay	4
		50-100 feet of clay	3
		100-150 feet of clay	2
		150-200 feet of clay	1
		more than 200 feet of clay	0
Lithologic character of upper 25 feet of Coastal Plain sediments.	Preliminary geologic map of the Coastal Plain in Fairfax County, Virginia (Force, 1975) and logs of test borings and water wells	Mostly sand; 0-5 feet of clay	4
		5-10 feet of clay	3
		10-15 feet of clay	2
		15-20 feet of clay	1
		20-25 feet of clay	0
Hydraulic gradient direction and head difference between lower Potomac aquifer and surficial deposits (water table).	Potentiometric surface map for the lower aquifer of the Cretaceous Potomac Group in Fairfax Co., Va. (Johnston and Larson, 1977). Water table estimated from test borings and 1:24,000 topographic quadrangle maps	Downward hydraulic gradient: Head difference:	
		more than 200 feet	4
		100-200 feet	3
		50-100 feet	2
		0-50 feet	1
		Upward hydraulic gradient	0
Aquifer occurrence.	Map showing lithofacies and inferred subsurface distribution of channel-fill sands in the Potomac Group in Fairfax Co., Va. (Johnston and Froelich, 1977; and unpublished transmissivity map)	Known high transmissivity aquifer at depth	6
		Inferred high transmissivity aquifer at depth	4
		Known moderate transmissivity aquifer at depth	3
		Inferred outcrop area of high transmissivity aquifer	2
		Possible occurrence of moderate transmissivity aquifer	1
		No known aquifer of moderate or high transmissivity	0
		Range of possible ratings on map	0-18

* Unpublished maps available at U. S. Geol. Survey WRD Field Office, Fairfax, Va.

SOURCES AND CRITERIA FOR MAP UNITS USED TO DEPICT SUSCEPTIBILITY OF COASTAL PLAIN AQUIFERS TO CONTAMINATION

EXPLANATION

Scale = 1:288,000

Each symbol represents one 2400 x 3000 foot cell

○ Well control point (not shown for lithologic character source map)

□ Example cell shown in diagrams and discussed in "how this map was made".

INTRODUCTION

The appearance of contaminated water in a well means that the owner has a serious problem and must seek an alternate water supply. The source of contamination may be nearby (such as septic tank failure or fuel tank leakage) and relatively easy to correct. On the other hand it may indicate that an underground water-bearing formation (termed an aquifer) is contaminated over a wide area and an important resource is being gradually destroyed. Rates of ground-water movement are slow (generally a few tenths to one foot per day). Thus the discovery of contaminated water in a well far distant from the source of contaminant probably indicates that water is degraded throughout a large area. Unlike rivers and lakes, ground water cannot be quickly flushed free of pollutants. Rehabilitation of a polluted aquifer is complicated, takes a long time, is costly, and is sometimes impossible. The use of retrieval wells to pump out the contaminated water, or the excavation of the pollutant source (dump or other waste disposal site) are corrective measures that have been used with mixed results. Sometimes the aquifer simply must be "written off" as a water resource.

Certain land uses, especially surface waste disposal in dumps, landfills, seepage pits, and so forth, have a high potential for causing contamination of the underlying ground water. Other land uses, such as parks or low-density developments, have minimal potential for contamination. Some areas have natural resistance against the movement of contaminants into aquifers, whereas other areas have a high risk of such movement. The difference in the degree of protection depends upon certain natural geologic and hydrologic features plus the locations and pumping rates of water wells. This map is intended to classify the Coastal Plain of Fairfax County according to the degree of natural protection afforded against contamination of the principal source of ground water.

Water wells in the Coastal Plain of Fairfax County draw water from aquifers composed of sand layers. In parts of Fairfax County, particularly near Alexandria and in the Fort Belvoir area, the sands are thick and permeable. High-capacity wells yielding several hundred gallons per minute can be constructed here.

The sand aquifers are naturally recharged by rainfall that infiltrates to the water table and slowly migrates downward and laterally into the sand aquifers. Rainfall passing through a waste disposal site may emerge at the surface or enter underlying material as a noxious, foul-smelling contaminated liquid termed "leachate". The movement of leachate into the sand aquifers depends upon factors such as the direction of ground water movement (both natural and as influenced by pumping from wells), the presence of barriers (clay beds) or relatively easy passageways (sand beds) and others. The movement of contaminants is controlled by a number of factors that are listed in the accompanying table and described in more detail in the technical discussion.

HOW TO USE THIS MAP

This map contains much generalized information and therefore should be used with caution. The three map units are labeled A, B, and C in order of increasing risk of ground-water contamination. Area A offers the greatest natural protection against movement of contaminants into sand aquifers. The favorable rating may result from the occurrence of thick clay beds above a sand aquifer, upward movement of ground water in the area, or the lack of a good sand aquifer at depth (or some combination of these factors). The upper diagram in the sketch at right illustrates these features. Area C offers the least protection against leachate movement into the aquifers. The occurrence of thick sands above the aquifer coupled with downward movement of ground water locally (either natural or induced by pumping from wells) are characteristics of Area C. These features are illustrated in the lower diagram in the sketch. Area B is characterized by intermediate and uncertain protection for the ground water resource. Area B locally may be underlain by a good aquifer with thick overlying clay beds and low rates of downward movement, or an aquifer where ground water movement is upward, or some combination of

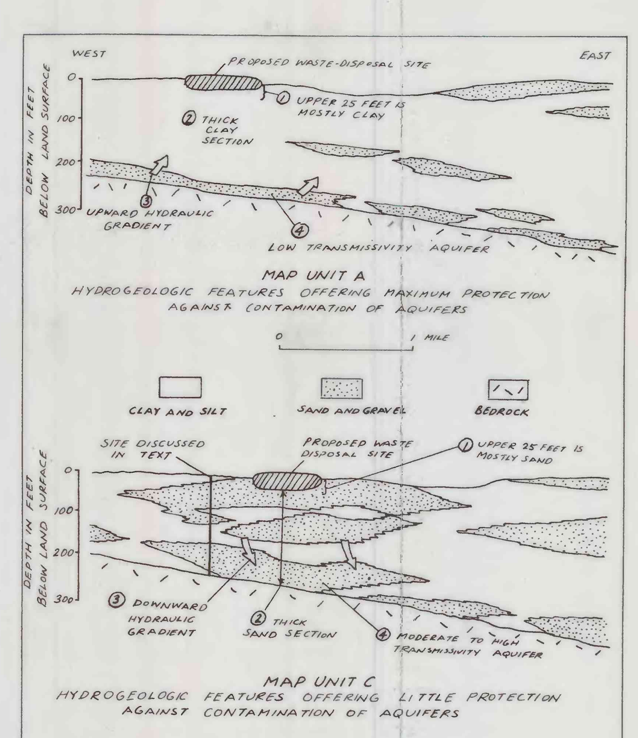
HOW THIS MAP WAS MADE

The computer-generated composite map was made by combining four source maps of the Coastal Plain of Fairfax County, Virginia. Source maps were stored in the computer by a process called digitizing. This was accomplished by superimposing a grid on each map and recording a latitude-longitude location and numeric identification code for the map unit that occurs in each cell. A cell is one sampling unit, which measures 2400 feet by 3000 feet, and covers 165 acres. Each cell is about 1/4 square mile in area and there are 396 cells on the map. Numbers were assigned to the units on each digitized map in order of increasing susceptibility to pollution. Then the computer added these numbers to produce an overall contamination susceptibility rating for each cell. Hydrogeologic conditions within a cell are not uniform, nevertheless a representative number is recorded for each cell. The degree of representing actual conditions is therefore dependent on the cell size.

In order to make the map easier to read and use, the susceptibility ratings, which range from 1 to 15, were divided into three groups which are shown on the large map at the left. Areas with low susceptibility to contamination (1 to 5) are depicted with a light symbol, and areas with high susceptibility (11 to 15) are shown with a dark symbol. To find the particular characteristics that make up the final susceptibility rating for an individual cell, first determine the latitude and longitude of the cell, and refer to the four source maps and the accompanying table. For example, the high susceptibility cell located at 38°46'00" north latitude and 77°05'30" west longitude has a susceptibility rating of 14, with the following characteristics:

(1) Between 5 and 10 feet of clay in the upper 25 feet of Coastal Plain sediments,
(2) downward hydraulic gradient with more than 200 feet of head difference,
(3) less than 50 feet of clay overlying the uppermost sand aquifer, and
(4) known moderate transmissivity aquifer at depth.

The characteristics of this cell that combine to produce the high susceptibility rating of 14 are illustrated in the lower diagrammatic cross section. Because the same rating may be the result of different sets of characteristics from the source maps, it is necessary to examine all four maps to determine the conditions for a particular cell.



DIAGRAMMATIC SECTIONS SHOWING FEATURES AFFECTING SUSCEPTIBILITY OF COASTAL AQUIFERS TO CONTAMINATION

TECHNICAL DISCUSSION

The aquifer system in the Coastal Plain of Eastern Fairfax County consists of shallow unconfined sand aquifers (suitable primarily for low-yield domestic wells), at least one confined aquifer that is a major water-bearing zone, and a thick confining bed of low to extremely low permeability. The principal confined aquifer consists of channel-fill sand deposits that are generally thickest and most abundant in the lower 100 feet of the Coastal Plain sediments (see Johnston and Froelich, 1977, for further discussion). This unit termed the lower aquifer has a transmissivity ranging from less than 100 ft^2/d to about 2500 ft^2/d. Well yields can be as much as 700 gal/min; however, in many areas, yields are less than 100 gal/min. The confining bed consists of clayey sands of low permeability and high-montmorillonite clays of extremely low permeability.

The initial constraint on contamination of the lower aquifer is the permeability of the earth materials immediately underlying a waste disposal site. Permeable sands facilitate migration of potential contaminants to the water table. Thick clay beds in the unsaturated zone greatly impede movement and may attenuate certain undesirable constituents. A thick clay layer may so restrict downward leachate movement that the leachate overflows and pollutes streams.
Recent studies by Cartwright and others (1977) conclude that small concentrations of montmorillonite will sorb heavy metals such as lead, cadmium, and zinc but not chlorides and certain organics. Thus a clayey sand that permits slow penetration might be the best underlying material for disposal sites with certain leachates. Only a detailed investigation involving actual earth materials and leachate from a given site can make a valid appraisal of the optimum composition of earth materials. For the purpose of this map, the viewpoint is taken that the best protection of the lower aquifer or other sand aquifers is achieved with thick clay beds in the unsaturated zone.

Upon reaching the water table, downward movement to the lower aquifer primarily involves leakage across the clay confining bed and associated sand lenses. Movement across the confining bed can be expressed by the Darcy equation as follows:

$$Q = KA\frac{dh}{db}$$

where Q = flow rate (in gallons per minute for example).
K = hydraulic conductivity of the confining bed (feet per day for example).
A = area of downward movement (square feet).
dh = difference in hydraulic head between water table and artesian head in lower aquifer (feet).
and db = thickness of confining bed (feet).

Because the clay has such low hydraulic conductivity, the critical factors in movement into the lower aquifer are probably clay thickness and hydraulic head difference. Where the confining clays are missing or lenticular (as in the outcrop area), the difference in hydraulic head becomes all important. Where there are upward hydraulic gradients, downward movement of contaminants is impossible. However, relatively small downward gradients in the sandy outcrop areas may induce substantial downward movement of contaminants.

Hydraulic gradient is a transient condition that depends upon the location and withdrawal rates of pumping wells at any given time. Head differences used in this map are based on 1976 conditions and can be expected to change in the future. However, a comparison of the 1960 and 1976 potentiometric surfaces for the lower aquifer (Johnston and Larson, 1977) show a similar configuration although considerable changes in artesian head occur locally.

The vertical distribution of heads in the Coastal Plain deposits is not known in detail. Head difference has been arbitrarily taken as the difference between the water table and the artesian head in the lower aquifer. Locally (for example near Mount Vernon, Virginia) confined sand aquifers occur 100 to 200 feet above the lower aquifer. Heads in these intermediate sands are somewhat different than in the lower

assuming similar heads in these intermediate sands and the lower aquifer are not considered serious. Note that the clay thickness is always taken above the uppermost sand aquifer in the section.

In summary, the four hydrogeologic factors considered in evaluating the susceptibility of the Potomac aquifer to contamination at any given site are as follows:

(1) clay thickness in the top 25 feet of the Coastal Plain sediments (unsaturated zone and upper part of the zone of saturation)
(2) Thickness of clay overlying the lower aquifer (or other intermediate sand aquifer locally)
(3) Hydraulic gradient direction--head difference between the water table and artesian head in the lower Potomac aquifer.
(4) Occurrence of moderate to high transmissivity aquifer at depth or in outcrop.

The first three factors are classified according to a five-fold breakdown (0 to 4) as shown on the accompanying table. High numerical ratings indicate greater susceptibility to contamination and low ratings less susceptibility. For example, a site underlain by 20 feet of clay above the lower aquifer would receive a rating of 4 whereas one with 250 feet of clay would receive a zero rating. Aquifer occurrence is rated on a slightly different scale (0 to 6) with a maximum rating of 6 for the known occurrence of a high transmissivity aquifer at depth. (Note: this is a conservative viewpoint because dilution of leachate will be greater in a high-transmissivity aquifer).

As shown, the summary rating for the four factors can theoretically range from zero to 18. Actual ratings, however, range from 1 to 15. High ratings (16 to 18) do not occur because, for example, large differences of hydraulic head (4) do not occur where thick sand sections (4) overlie known high transmissivity aquifers (6). It should be emphasized that these ratings have no quantitative significance and are only intended to indicate relative susceptibility (or lack of it) to contamination.

The accompanying sketch compares features of an area with low map rating (and thus little risk of contamination) with features of an area with high map rating (and high risk of contamination).

A system for evaluating the likelihood of contaminating ground water at specific sites has been described by LeGrand (1964). This system utilizes a point-count method to rate some of the hydrogeologic factors considered here. LeGrand's method requires that the distance between wells and disposal site be known and thus is more applicable for specific site evaluations than a regional classification of susceptibility to contamination as presented here.

The preparation of a map that evaluates risk of ground-water contamination in a format useful for planners and government officials requires certain assumptions and generalizations as discussed. In the past, many planners have inclined toward the simplistic approach of designating outcrop areas of aquifers as "aquifer protection areas." This approach can be misleading in the Atlantic Coastal Plain where many outcrop areas are aquifer discharge areas. Also in many areas of heavily pumped Coastal Plain aquifers, it has been shown that vertical leakage across confining beds is more important than outcrop recharge (see for example Cosner (1975), Mack (1974), and Johnston and Leahy (1977)).

A report that discusses all facets of the geology, ground-water hydraulics, and chemistry involved in aquifer protection cannot be applied by planners without assistance--and in practice rarely is. The map presented here is a compromise between a rigorous presentation (involving at least 6 maps) and the "save the outcrop" approach.

In particular the map is a preliminary appraisal intended to classify the Coastal Plain of Fairfax County as follows:

(1) Areas where leachate can readily enter the lower aquifer and thus are unsuitable for surface waste-disposal sites,
(2) areas offering great natural protection against leachate migration into the lower aquifer and thus most favorable for waste disposal sites, and
(3) areas where the contamination risk is uncertain and onsite investigations involving test drilling are needed to ascertain the subsurface geology and hydraulic head distribution.

Note that even the "most favorable" sites will require some onsite investigation to confirm the preliminary appraisal given here.

SELECTED REFERENCES

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