Present and Potential Impacts on Ground Water in the Potomac River Basin in Maryland

Prepared by

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I. Introduction

This report assesses the status of ground water in the Potomac River Basin in Maryland and the potential impact of existing point and nonpoint pollution sources on ground water in the region. It is based on information currently available from state and federal agencies. This information, organized in a database created in Dbase IV, includes properties of water-bearing formations, ground water quality, ground water use, and pollution sources to ground water. The text of this report, the data analyzed and cited, and the findings and conclusions are derived from the Ground Water Database for the Potomac River Basin in Maryland.

Methods

Description of aquifers and their properties was obtained primarily from Md DNR (1987) and from other references cited. General aquifer transmissivities obtained by Otton and Hilleary (1985) and those mapped by the Maryland Department of Natural Resources for the Coastal Plain, were used to identify aquifers that are susceptible to contamination by pollution sources at the land surface.

The EPA STORET database yielded ground water quality data for wells within the Potomac River Basin in Maryland. For many of the chemical parameters, there were an insufficient number of observations to draw any conclusions about the status of ground water quality. Summary statistics were calculated for the more commonly measured parameters: alkalinity, chloride, conductivity, iron, sodium, pH, and total dissolved solids. Metals and organic compounds were rarely analyzed.

Ground water use data was obtained primarily from Md DNR (1987b), and the number of people depending upon ground water for drinking water, from Maryland Census Data (1980).

Various agencies in the state of Maryland and the United States Environmental Protection Agency supplied information on potential pollution sources in the Potomac River Basin:

Maryland Department of Environment
- Hazardous and Solid Waste Management Administration
  - Landfills
  - Permitted ground water discharges
- Water Management Administration
  - Septic system data

Maryland Department of Agriculture:
- Pesticide use, types and quantities applied
- Dairy cattle populations

Maryland Bureau of Mines
- Permitted, active surface and deep coal mines

Environmental Protection Agency
EPA Chesapeake Bay Program
Landuse statistics
Manure production

Region III Office
Listing of CERCLIS sites

Data were usually provided as county averages or totals, and more rarely, by hydrologic sub-basin. For those counties whose boundaries extend beyond the Potomac drainage area, county totals or acreages were adjusted by proportional surface area or population within the Potomac Basin.

Organization of the database and programs for analyzing the data are described in Appendix A.

Findings

1) Pollution of ground water from both point and non-point sources has been confirmed throughout the state.

2) The number and the distribution of monitoring sites for ground water within the Potomac River Basin in Maryland is inadequate to determine the overall status of ground water quality in relation to Safe Drinking Water Act standards.

3) Areas underlain by carbonaceous rocks in the Valley and Ridge Province and the Hagerstown Valley are vulnerable to ground water contamination. Coastal Plain aquifers in sedimentary formations are also moderately susceptible to degradation.

4) The largest sources of non-point pollution (i.e., septic systems and intense farming) threaten the quality of heavily used, vulnerable ground water resources in limestone regions.

5) In Western Maryland, the most serious threat to ground water quality is acidification by abandoned deep coal mines.

6) Highest use of ground water occurs in Charles, Frederick, and Washington counties, while more people in Charles, Frederick, and Prince George's counties depend upon ground water for drinking water supplies.

7) The concentration of point pollution sources is correlated with population density.

Recommendations call for improvements in gathering and management of data pertaining to ground water. The report also suggests the need for detailed mapping of vulnerable areas and more extensive monitoring of ground water quality (See Section IV). By reducing non-point pollution sources with better farming practices and through strategic location of potential point sources, the state can prevent ground water contamination.

II. Ground Water Resources in the Potomac River Basin

Physiography and Hydrology

The Potomac River Basin, the source of flow for the second largest tributary to the Chesapeake Bay, drains 3,818 square miles in the state of Maryland. Extending across the five physiographic provinces of Maryland, the Potomac basin represents the varied geologic histories of each region. The five physiographic provinces, depicted in Figure I-1, are: the Coastal Plain Province, Piedmont Province, Blue Ridge Province, Valley and Ridge Province, and Appalachian Plateau Province.

The basin is divided into five hydrologic sub-basins, as shown in Figure I-2. Sub-basin boundaries do not necessarily correspond with the limits of physiographic provinces. The basin also contains nine counties in Maryland, shown in Figure I-3.

Much of the Potomac River flow is derived from water beneath the land surface that moves vertically and laterally, leaving the ground as seeps or springs that ultimately become small tributaries. Water supply to the basin begins with precipitation. Average annual precipitation within the Maryland portion of the basin varies from 35 to 55 inches. Precipitation is lowest (35 inches) at the foothills of the Allegheny Mountains but increases rapidly to 50 inches on the western divide in the headwaters region of the North Branch Potomac River. To the east, along the crest of the Blue Ridge, precipitation increases to 45 inches; throughout the Piedmont, the annual precipitation ranges from 38 to 40 inches; in the Coastal Plain, average annual precipitation is 40 to 44 inches (ICPRB, 1979). Precipitation is somewhat greater in summer than in winter; much of the winter precipitation is snow, although periods of continuous snow cover are rare.

Rain and melting snow that falls within the drainage basin travel to stream channels by overland flow, infiltrate into the ground, or return to the atmosphere by evaporation from soil and water bodies or transpiration from plants (evapotranspiration). Trainer and Watkins (1975) calculated that an average 33 per cent of the annual precipitation leaves the upper Potomac River basin as stream flow; therefore, the majority of the water supplied to the basin as precipitation is removed by evapotranspiration.

The quantity of water lost through evapotranspiration varies with the available energy that drives evaporation; thus, it is seasonally dependent. In the cool season (November through May), more water is available than can be used for evapotranspiration, and a large portion of this water recharges

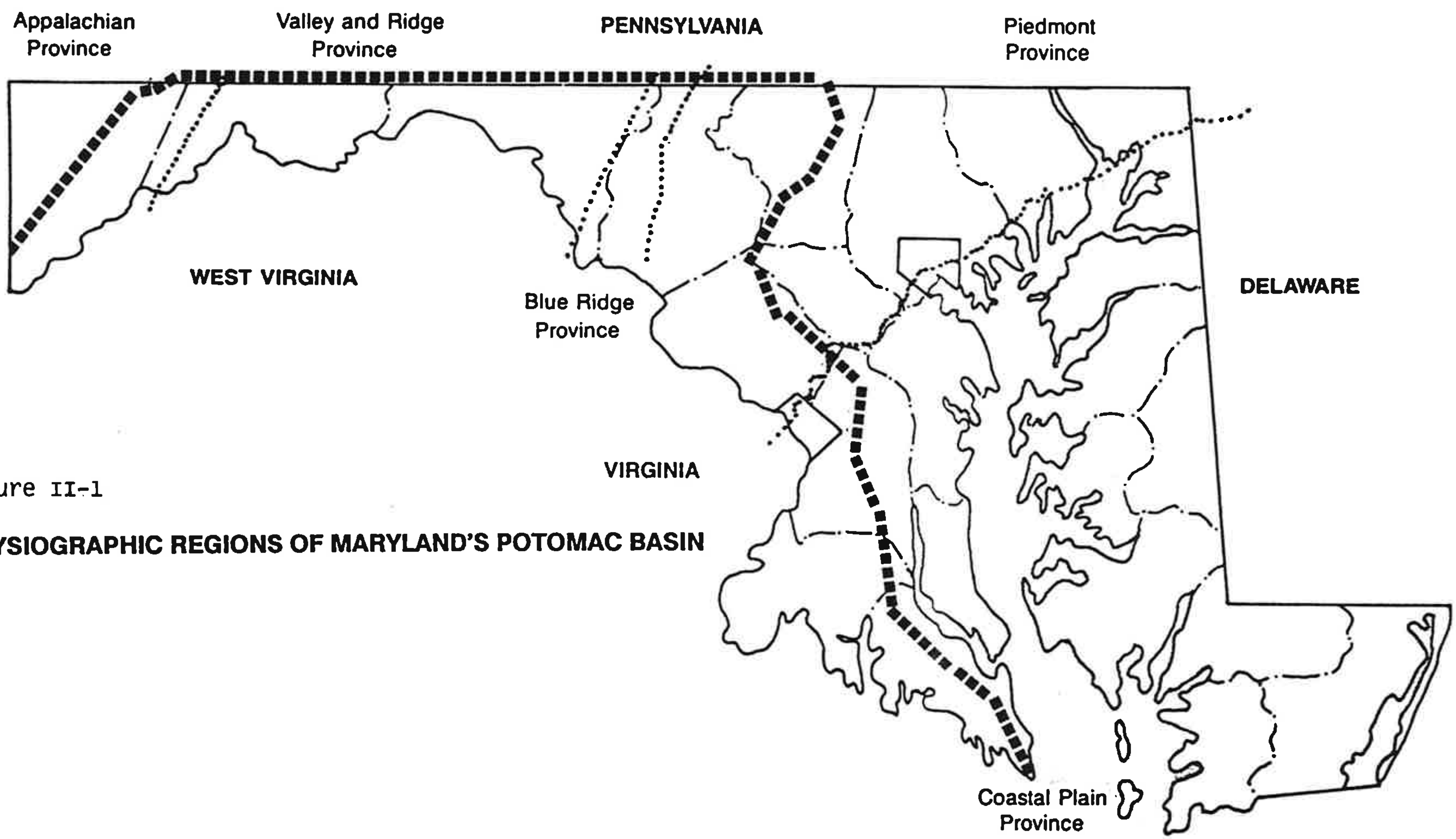

Figure II-1

PHYSIOGRAPHIC REGIONS OF MARYLAND'S POTOMAC BASIN

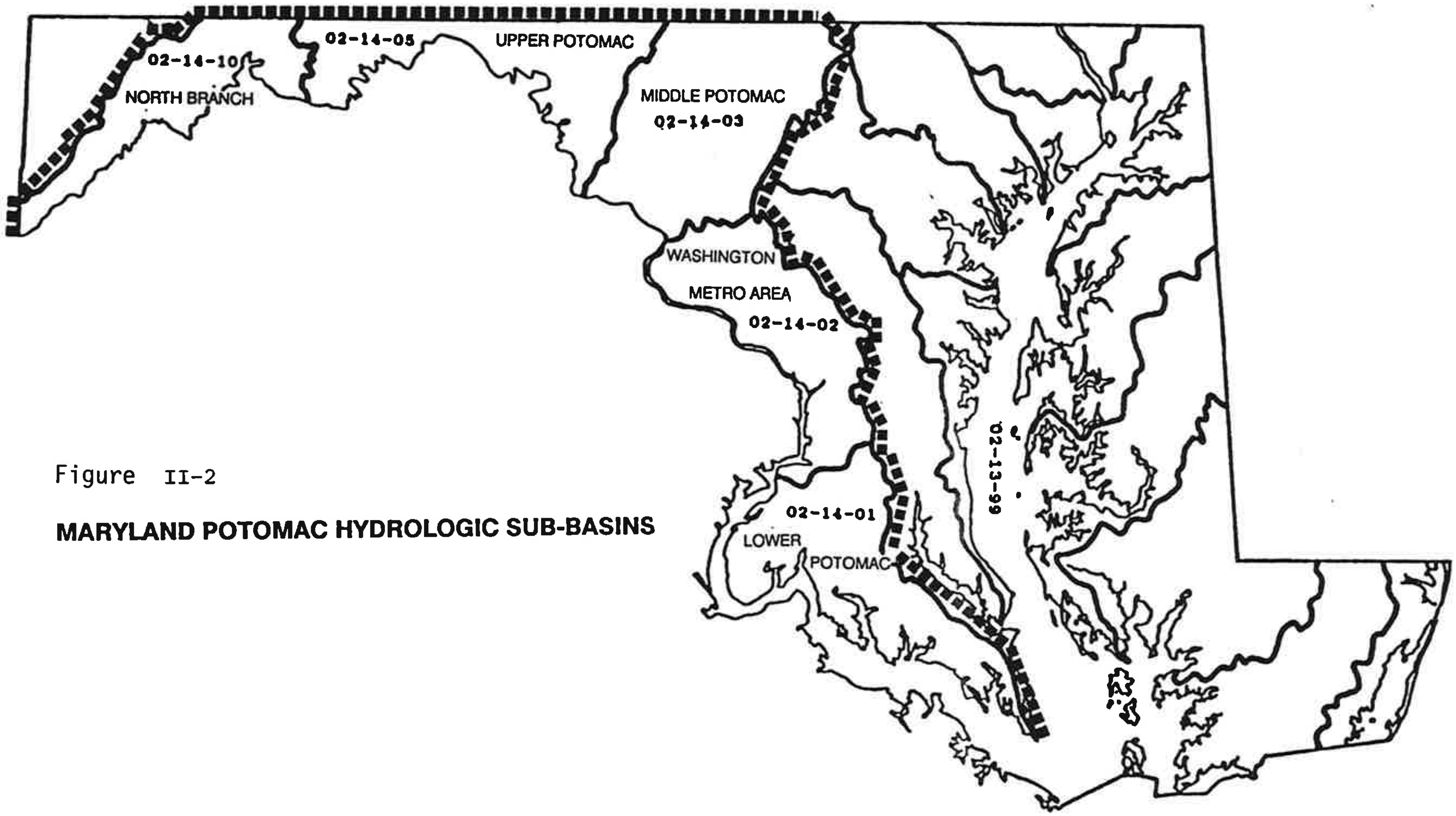

Figure II-2

MARYLAND POTOMAC HYDROLOGIC SUB-BASINS

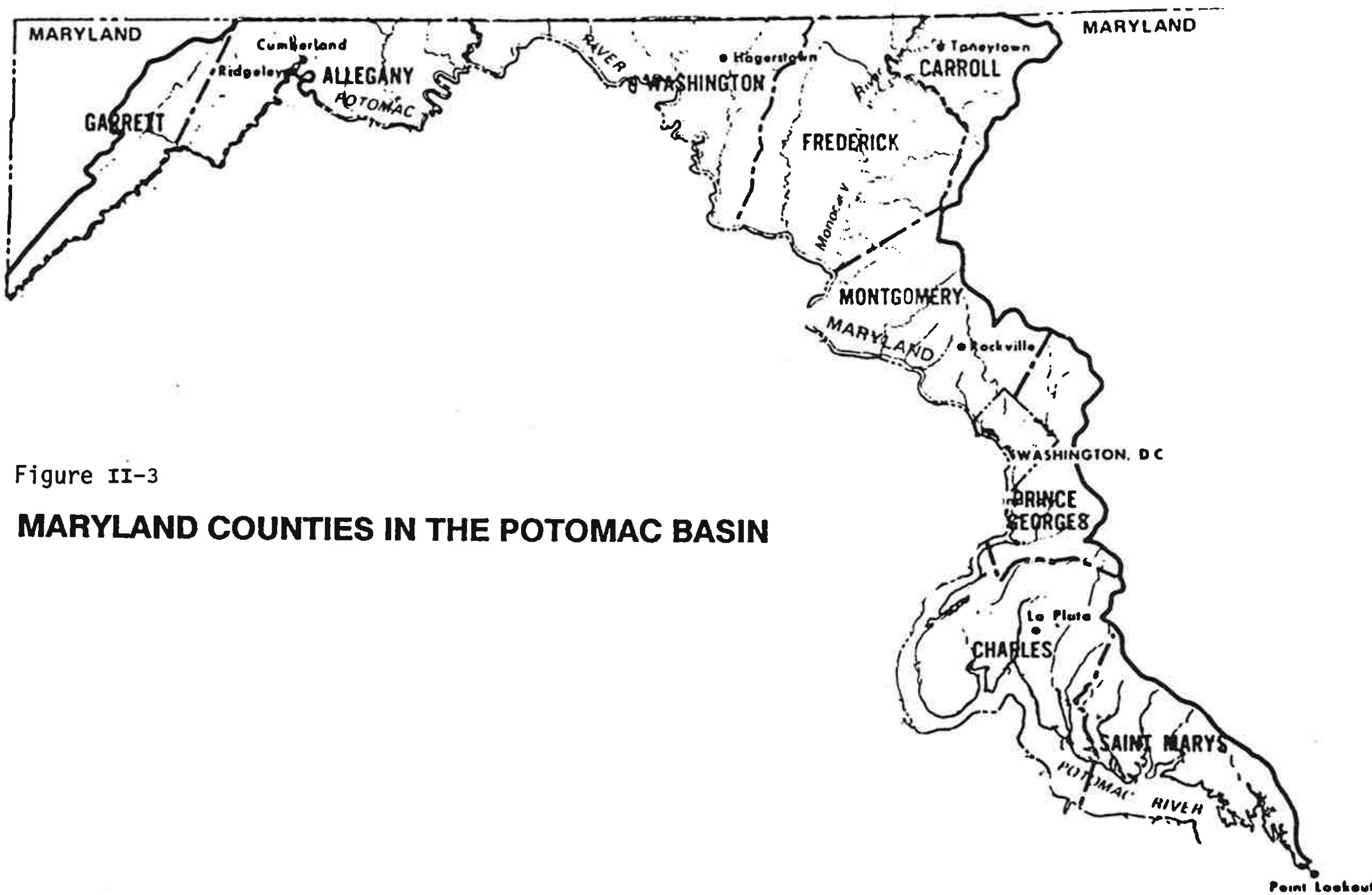

Figure II-3

MARYLAND COUNTIES IN THE POTOMAC BASIN

ground water. In the warm season (June to October), when growing plants are using soil water and evaporation is at a maximum, less water is available to recharge ground water reservoirs.

Studies based on separation of streamflow hydrographs into base flow and surface runoff show that the recharge of ground water resources in the Maryland Piedmont is equivalent to 16 to 27 per cent of precipitation (Richardson, 1982, as quoted by Otton and Hilleary, 1985). Average recharge in this area is equivalent to about 430,000 gallons per square mile per day.

Geology and Hydrology of Ground Water Resources in the Potomac River Basin

The following description of the geology and ground water hydrology of the physiographic provinces is derived from Maryland Department of Natural Resources (1987a).

Coastal Plain

The Coastal Plain is geologically the youngest province in Maryland, composed of numerous formations of unconsolidated sediments that range in age from the Cretaceous period (144 million years old) to the present. Each formation containing sands, silts, and clays tilts away from the Piedmont Province and becomes thicker toward the Atlantic Ocean. The formations outcrop in parallel belts that become successively younger away from the Fall Line, as illustrated in Figure II-4. The Coastal Plain sediments, particularly the sand and gravel portions of formations, store large amounts of ground water. Composition and grain size vary laterally and vertically within each formation; thus, the productivity of an aquifer may vary depending upon the location of a production well. Ground water in the Coastal Plain occurs under unconfined (at the water table) and artesian (confined) conditions.

Important Coastal Plain aquifers within the Potomac River Basin include the Patuxent, Patapsco, Magothy, and Piney Point aquifers. The Potomac Group is a geologic unit of Cretaceous age (66 to 144 million years old) that outcrops in a wide, irregular band just to the southeast of the Fall line. The Potomac Group sediments were deposited in an environment of lakes, swamps and river flood plains. Within the Potomac Group are three distinct formations, from bottom to top and oldest to youngest: the Patuxent Formation, Arundel Formation, and the Patapsco-Raritan Formations. The Patuxent and Patapsco Formations, the most heavily used aquifers in Maryland, are water-bearing sand layers, channel deposits and sand lens deposits. In contrast, the Arundel Formation, which overlays the Patuxent Aquifer, is primarily a clay layer that serves as an aquiclude.

Within the Potomac Basin, the Patuxent formation is used for water supply in its updip portions in Prince George's and Charles counties. In these updip locations, the water quality is generally good. The water is soft, low in total dissolved solids, and low in chlorides.

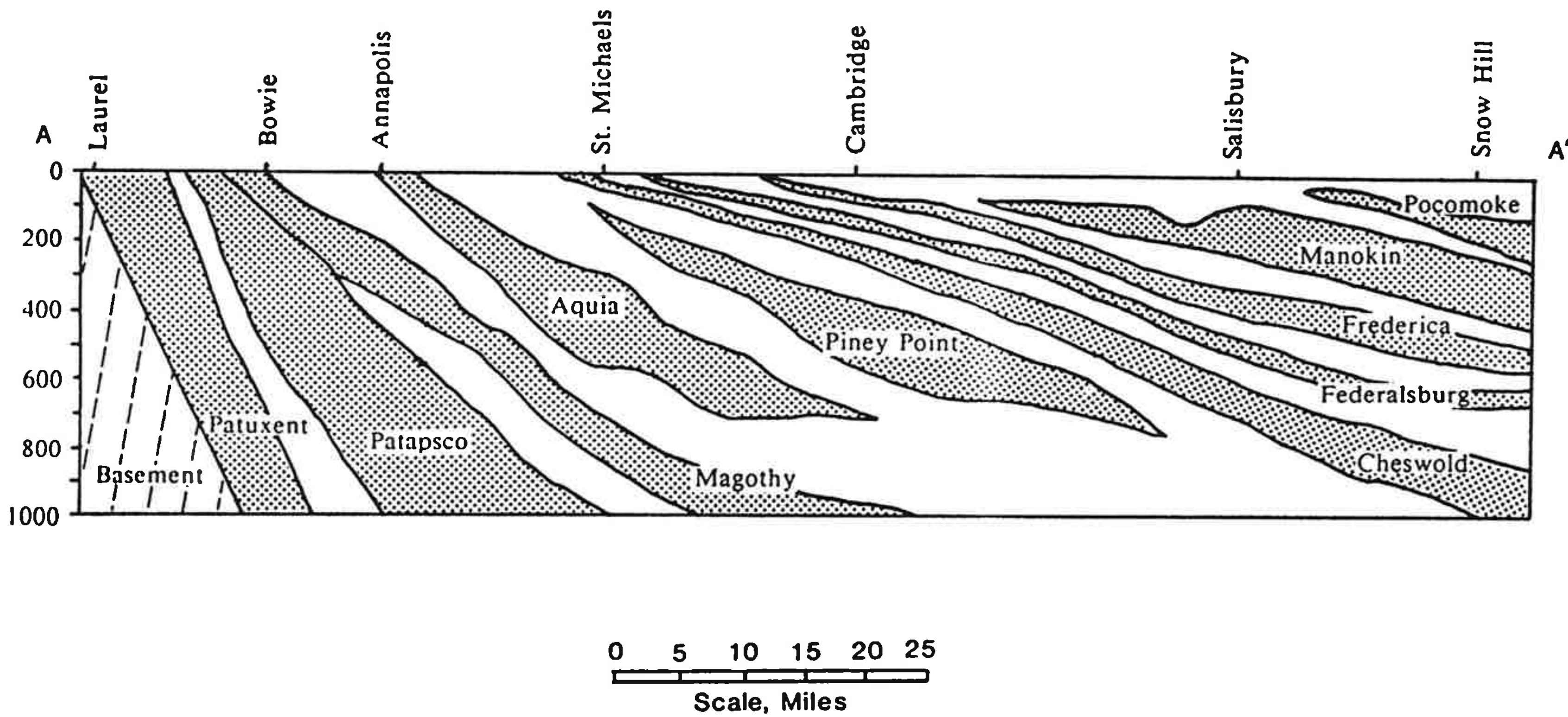

Figure II-4. **Cross Section Showing Major Aquifers of the Maryland Coastal Plain**

Source: Maryland DNR, 1987a

The Patapsco-Raritan Formation contains multiple aquifers composed of irregularly stratified interbedded, silt, clay, and sand with minor amounts of gravel. The composition of the Patapsco Formation is between 25 and 50 percent sand, which is generally finer textured than in the Patuxent Formation (Hansen, 1972b). The outcrop zone occurs in a broad belt about 5 miles wide from Delaware southwestward to Washington D.C. and to the west of the Potomac River in Virginia beneath tributaries of the Potomac River in Virginia (Slaughter and Otton, 1968). Within the Potomac Basin, the Patuxent Formation is used for water supply in updip areas in Charles County and Prince Georges County (Md DNR 1987b). The water quality is generally good. Papatsco-Raritan water usually contains less than 10 ppm of chlorides west of the Chesapeake Bay (Hansen 1972b). Water from the updip portions of the formation tends to be soft and acidic, with low total dissolved solids. High iron concentrations are a problem in some portions of this formation.

Intrusion of brackish water in the Indian Head area of Charles County is becoming a ground water quality problem. The Town of Indian Head has experienced a decline in the quality of ground water used for drinking water. The Patapsco Formation provides most of the the potable water for the area, including the Town of Indian Head. The nearby Naval Ordnance Station, which has pumped large quantities of ground water since the 1890's, withdrew 1.4 mgd in 1985 (Md DNR, 1984; Md DNR, 1987b). Prior to the beginning of pumpage of water by the Naval facility, most wells had water levels above sea level, but the potentiometric surface in the area has been below sea level for several decades (Md DNR, 1984). Mapping of the potentiometric surface shows a cone of depression, centered at the Naval Ordnance Station, that extends into the channel of the Potomac River estuary (Slaughter and Otton, 1968), indicating that the estuary may be providing recharge to the Patapsco aquifer. Examination of water quality in wells in the area indicates that salt water intrusion is occurring in the upper/middle sands of the Patapsco Formation, but that the Patuxent Formation is not affected.

The Magothy Formation has one of the most extensive water-bearing units in the Coastal Plain. It receives most of its recharge near its updip limits, which occur in Prince Georges, Anne Arundel, Kent and Cecil counties. The Magothy Formation consists of medium to coarse-grained sand and fine gravel interbedded with silts and clays. The coarser sands and gravels generally occur at the base of the formation, while clays increase toward the top. The Magothy Formation was deposited in a near-shore marine environment at a time during the Cretaceous period when rising sea levels were encroaching on land. In the

Potomac River Basin, the Magothy lies beneath the southwestern portion of Prince Georges County and the northeastern part of Charles County. Both counties withdraw considerable quantities of water (1.5 and 3.1 mgd, respectively) from the Magothy Formation. Water quality in the Magothy aquifer is acceptable for most uses. The lowering of the potentiometric surface caused by increasingly large water withdrawals in some areas overlying the Magothy Formation indicate that brackish water intrusion may present a problem. In fact, from 1970 to 1980, pumpage from wells near Waldorf more than doubled because of growth in the area (Md DNR, 1984), and potentiometric levels in the southwestern portion of the Magothy aquifer near Waldorf and Chalk Point are below sea level. At present, the rate of withdrawal in this area has increased to a level that is equal to the recharge rate; thus, further exploitation of this ground water resource may promote brackish water intrusion and endanger the quality of the ground water. Alternative water sources include deep well development in the Potomac Group formations, as well as several surface water options.

The Aquia Formation was deposited in a shallow marine environment during the Paleocene period (58 to 66 million years ago). It is often referred to as the Aquia Greensand because of the greenish-brown minerals glauconite and goethite which compose 20 to 70 per cent of the formation. Grain size is coarser toward the top of the formation and decreases downdip as silt and clay contents increase. Permeability also decreases downdip, following the gradient in grain size. The Aquia Formation is separated from the Magothy Formation beneath by silt and clay formations that serve as an aquitard. On the western shore of the Bay, aquifer recharge occurs in the outcrop area that extends from the Potomac River Bluffs in western Charles County to Sandy Point in Anne Arundel County (Hansen, 1972b). Natural water quality in the Aquia aquifer is generally good and in many cases, suitable for domestic use without treatment.

In the Potomac Basin, St. Mary's County withdraws substantial amounts of water from the Aquia Aquifer; withdrawals by users in Prince Georges and Charles counties are much lower (Md DNR, 1987b). In addition, there are many shallow water-table wells in the aquifer outcrop areas of Prince Georges and Charles counties. Historical studies of the Aquia Formation show a lowering of the entire potentiometic surface and the existence of an expanding cone of depression around the Patuxent Naval Air Station at Lexington Park. The Aquia aquifer subcrops under the Chesapeake Bay and some of its estuarine tributaries. Thus, the updip portion of the aquifer located near these subcrop areas is vulnerable to saltwater intrusion.

The Nanjemoy Formation, composed of clayey sand in its updip area and silty clay in downdip areas, functions as an aquitard in Charles County, but it serves as a poor aquifer in St. Mary's County, where permitted users withdraw 10,000 gpd (Md DNR, 1984; Md DNR, 1987b). The Nanjemoy outcrops in stream valleys in western Charles County and dips to the east-southeast (Md DNR, 1984).

The Piney Point Formation, underlying St. Mary's and Calvert counties and much of the Eastern Shore, was deposited in a shallow marine environment during the Eocene epoch (37 to 58 million years ago). Erosion truncated the top of the formation, and with the deposition of the Calvert Formation above it, no outcrop was left exposed. Piney Point Aquifer extends southward from its subsurface line of truncation, which runs from north of Leonardtown in St. Mary's County to Caroline County on the Eastern Shore. The Piney Point Formation is composed of medium to coarse sand with some layers of shell debris, fine sand and clay. In St. Mary's County, there is a hydraulic connection between sands of the Piney Point and Nanjemoy aquifers. Since the Piney Point Aquifer has no outcrop zone, it is recharged by leakage from surrounding aquifers (including the Nanjemoy aquifer) through semi-permeable confining beds and from water table aquifers. Withdrawals from this aquifer for water supply in St. Mary's County are 0.5 mgd (Md DNR, 1987b).

Within the Potomac River Basin, the outcrop area of the Calvert Formation occurs in a 20 to 30 mile wide belt that extends through Charles, St. Mary's and southern Prince George's counties. Within the outcrop area, the Calvert Formation may yield small amounts of water to shallow wells. Wells tapped in lenses and thin beds of sand within the formation may be locally productive; however, in 1985, there were no users withdrawing over 10,000 gpd from the Calvert Formation on the western shore of the Chesapeake Bay.

Piedmont Province

A sharp transition between the unconsolidated sediments of the Coastal Plain and the crystalline rocks of the Piedmont occurs at the Fall Line. The rolling topography of the Piedmont, with an elevation of 400 to 800 feet, extends westward from the Fall Line to Catoctin Mountain. Three types of geology predominate in the Piedmont. The Piedmont Upland (in Montgomery County) is composed of highly metamorphosed rocks such as schist, gneiss, quartzite, phyllite and marble. To the west, the Frederick Valley is underlain by limestones and has an average elevation of 300 feet, while in the Triassic Upland, underlain by sandstones, siltstones, and shales, the average elevation is approximately 500 feet.

The crystalline rocks of the Eastern Division and the sedimentary rocks of the Western Division have very low primary porosities. Unless there is weathering or fracturing, which create secondary porosity, water movement within the impermeable rocks is restricted by the lack of pore space and an integrated network of openings. As a result, transmissivities are very low. However, significant quantities of ground water occur in some areas of the Piedmont. The quantity of ground water available depends upon the following factors:

1. Fracturing of the rock creates spaces for entry of water where subsequent chemical weathering by ground water may enlarge openings, thus increasing storage capacity. In this region, weathering occurs most rapidly in fractured limestone because the rock is dissolved by ground water. In the Piedmont, most wells are less than 200 feet deep because the number of fractures generally decreases at depths greater than 300 feet.

2. Saprolite is formed when ground water, circulating through the fractured upper layer of bedrock, removes the most soluble constituents and leaves disintegrated rock that still maintains the original texture and structure of the parent rock. Thickness, porosity, and permeabiity of the saprolite are major factors governing the occurrence of ground water because saprolite contains most of the ground water stored in the crystalline rock aquifers. Permeability of saprolite can vary widely, depending on the parent rock. For example, gneiss and quartzose schist, which contain significant proportions of quartz, weather to a sandy, permeable saprolite, whereas rocks with little quartz, such as gabbro and metabasalt, tend to weather to less permeable saprolite with higher clay content (Nutter and Otton, 1969). The Piedmont bedrock is covered in soil and saprolite, which varies in thickness from 0 to greater than 100 feet, with an average thickness of 45 feet.

3. Topography influences the lateral flow of ground water, as well as the yield. Wells in valleys generally produce three to four times as much water as wells on hilltops (Nutter and Otton, 1969).

4. Rock type and its fracturing and weathering characteristics determine the quantity and quality of ground water. Using data from over 1000 wells from different crystalline rock types of the Piedmont in Baltimore County, Nutter and Otton (1969) found no significant differences in yields from different Piedmont rock types. Mean yields of wells in various rock types varied from 7.8 to 11.9 gpm; the overall mean yield for all formations was 9.4 gpm. However, in the Potomac River Basin, the Wakefield Marble and Silver Run Limestone Formations are more productive.

Their well yields, which vary from 1 to 575 gpm and average 90 gpm, are among the highest yields in any limestone aquifer in Maryland (Otton and Richardson, 1958). Significant ground water withdrawals by permitted appropriators in the Piedmont portion of the Potomac River Basin are taken from the Wakefield Marble (Md DNR, 1987b)

5. Recharge of unconfined aquifers in the Piedmont is derived from precipitation. Nutter and Otton (1969) estimated that the effective ground water recharge from precipitation is approximately 11 inches per year, or about 500,000 gpd (Md DNR, 1987b).

Mapping well yields of the Piedmont, Nutter and Otton (1969) found great areal variability in ground water availability, which is influenced by geologic structure, lithology, joint spacing, thickness of saprolite, and topographic position. Transmissivities vary from less than 100 gpd to 35,000 gpd/foot, but are more commonly in the range of 2000 to 7000 gpd per foot.

To the west of the Piedmont, the mountains of the Blue Ridge, Valley and Ridge, and Appalachian Plateau Provinces, are part of an an ancient mountain system that was eroded to a flat plain over a period of 200 to 300 million years. This plain was uplifted, the less resistant rocks were eroded by streams, and more resistant rocks remained as mountain ridges.

Blue Ridge Province

The Blue Ridge Province lies mostly within Frederick County and consists of the Middletown Valley and three ridges (Catoctin Mountain, South Mountain, and Elk Ridge). In the mountains, metabasalt is the predominant rock type, with quartzite forming erosion-resistant ridges. The maximum elevation is 2000 feet near the Maryland-Pennsylvania border. The Middletown Valley, which lies between the mountain ridges in southwestern Frederick County, is underlain by grandiorite and granite gneiss. In the valley, ground water occurs in fractures and in the overlying saprolite in sufficient quantities to supply adequate amounts of water for domestic use (approximately 1 per cent of the total ground water used in the state). Wells in the limestones of the Frederick Valley (Tomstown dolomite, Frederick limestone, and Grove limestone) produce 2 to 275 gallons of ground water per minute, with an average of 27 gpm (Otton and Richardson, 1958). However, the productivity of Blue Ridge aquifers is not sufficient to supply industrial uses. Ground water from the limestones of the Frederick Valley is very hard (high in calcium bicarbonate)

Valley and Ridge Province

The Valley and Ridge Province, a series of ridges and valleys that extends westward from the Blue Ridge for 65 miles, is separated into two distinct zones: the Great Valley and Allegheny Ridge area. The Great Valley, underlain by a thick series of limestones and shales, yields the highest quantities of ground water because of interconnecting solution channels in the limestone and dolomite. Seven limestone formations outcrop in the Great valley in west-central Maryland. These include the Tomstown, Waynesboro, Elbrook, and Conococheague formations of Cambrian age, and the Beekmantown, Stones River, and Chambersburg limestones of Ordovician age. The total thickness of limestones in the valley is estimated to be 8,500 to 10,400 feet (Otton and Richardson, 1958). Most of the water in the upper few tens of feet of limestone probably occurs under water-table conditions. Recharge occurs from local precipitation, but ground water is continually moving from the interstream recharge areas to the surface streams where it is carried away from the valley.

Little ground water storage is thought to occur at depths of 300 to 400 feet. The average yield of domestic wells has been estimated at 8 to 10 gpm, but industrial wells in and near Hagerstown produce as much as 200 gpm (Otton and Richardson, 1958). The mean specific capacity, 3.7 gpm per foot, is similar to that obtained for the Frederick valley. Many large springs, with yields that range from 10 to 100 gpm, occur in the Hagerstown valley. Water quality is generally good, although the water is very hard calcium bicarbonate water, and high dissolved iron concentrations may be found locally.

The Allegheny Ridge area, composed of folded sedimentary rocks of Cambrian to Permian age (245 to 570 million years old), extends westward from the Great Valley to the Allegheny Front near Frostburg. Parallel ridges of sandstone lie in a northeast-southwest direction between valleys composed of shale and limestone beds. These rocks were originally unconsolidated sediments of fluvial and marine origin. Pore spaces were filled by minerals precipitated from circulating ground water, and the weight of overlying sediments compacted the sediments into hard sedimentary rocks (sandstone, siltstone, shale, limestone, and dolomite) and folded them. Because of the compaction, these rocks have very low primary porosity and permeability. Fractures and solution of the rocks have produced some secondary porosity, with the degree of porosity depending upon the rock type and degree of folding. In general, sandstone and limestone formations are the most productive aquifers. Most wells produce only enough water for domestic, light commercial, and some agricultural uses, with yields from 1 to 400 gpm. Water quality varies; ground water from shales often has high total dissolved solids, and high dissolved iron concentrations occur.

Appalachian Plateau

Although topographically similar to the Valley and Ridge Province, the Appalachian Plateau results from a unique geological history. The raised mountainous plateau is composed of strata of sandstones, siltstones, limestones and shales of Devonian to Permian age (245 to 408 million years old) lying in broad folds, with ridges standing 500 to 800 feet above the surrounding land surface. Maryland's highest point, Backbone Mountain, with an elevation of 3,360 feet, is located within this province. Differential weathering and erosion have caused the upland to be deeply incised by streams flowing between long, weather-resistant sandstone ridges lying in a northeast direction.

As in the Valley and Ridge Province, porosity and permeability depend on the frequency, density, and interconnection of fractures, which vary with rock type. Generally, the most productive aquifers are sandstone. Coal beds may also be productive aquifers because of fracturing, but water quality tends to be very poor. Although siltstone and shale are relatively poor aquifers, they are used for small farm, light commercial and domestic supplies, since they underlie much of the province. Ground water occurs under water-table and artesian conditions, but flowing wells are rare. Average yields are 25 gpm.

Influence of Ground Water on Potomac River Hydrology

The elevation and slope of geologic formations in the Potomac River Basin and their storage and subsurface transport characteristics influence stream flow, especially between precipitation events. In fact, during extended dry periods, ground water provides most of the flow to streams. Trainer and Watkins (1975) analyzed base runoff and low flow from representative small basins of the Potomac underlain by different rock types: fractured rock having thin regolith, fractured rock having thick regolith, and carbonate rock.* The average base flow for basins with thick regolith is appreciably greater than that from basins with thin regolith (0.44 vs 0.21 cfs/sq mi), and basins underlain largely by carbonate rock yield markedly higher mean annual base runoff (0.56 cfs/sq mi) than the other rock types.

The major tributaries in the upper Potomac River basin yield similar amounts of total runoff per unit area; however, they display a wide range of mean low flows, reflecting the limited distribution of more productive aquifers (Trainer and Watkins, 1975). The data presented in Table II-1 show that average low flows in stream basins in the Great Valley are greater than in other tributary basins of the upper Potomac River basin. Highest low flows occur in basins that are underlain by carbonate rock.

It is interesting to look at mean annual discharge and low flow in tributary watersheds and compare them with the total discharge for the entire Potomac River Basin. The North Branch of the Potomac (flow measured near Cumberland, Md), which represents 8 per cent of the drainage area of the Potomac basin, contributes 11 per cent of the mean annual flow, including releases from the Savage Reservoir, but only 3 per cent of

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*Through separation of hydrographs for four years, Trainer and Watkins estimated the mean daily base runoff from 17 tributary basins; these mean base runoff flows correspond to the discharge values occurring on the flow-duration curve from 39 to 61 percent of the time with an average frequency of 52 per cent. Therefore, they used the 52 percentile discharge value as an estimate of the mean daily base runoff of streams in the upper Potomac River basin. For low flow, they used the minimum 7-day mean low flow at a recurrence interval of 2 years.

UPPER POTOMAC RIVER BASIN

Table II-1. Low flow from representative tributary basins of the Potomac River basin in bedrock geohydrologic terranes.

Station[1]	Tributary Basin	[2]$M_{7,2}$ (cfs/sq.mi)	[3]$M_{7,10}$ (cfs/sq.mi)
Basins underlain by fractured rock having thin regolith			
5950	North Branch Potomac River at Steyer, MD	0.10	0.05
5965	Savage River near Barton, MD	0.03	0.01
5970	Crabtree Creek near Swanton, MD	0.08	0.05
6410	Hunting Creek at Jimtown, MD	0.10	0.06
6415	Fishing Creek near Lewistown, MD	0.18	0.10
Basins underlain by fractured rock having thick regolith			
6375	Catoctin Creek near Middletown, MD	0.04	0.01
6390	Monocacy River at Bridgeport, MD	0.02	0.01
6395	Big Pipe Creek at Bruceville, MD	0.18	0.07
6425	Linganore Creek near Frederick, MD	0.17	0.08
6450	Seneca Creek at Dawsonville, MD	0.21	0.05
Basins underlain by carbonate rock			
6145	Conococheague Creek at Fairview, MD	0.17	0.09
6195	Antietam Creek near Sharpsburg, MD	0.27	0.20

1 Stream-gaging station, U. S. Geological Survey.
2 Minimum mean 7-day low flow at 2-year recurrence interval.
3 Minimum mean 7-day low flow at 10-year recurrence interval.

the low flow. In contrast, Antietam Creek, which drains areas underlain by Grove, Tomstown, and Elbrook limestones, contributes 2 per cent of the mean annual discharge and 5 per cent of the low flow from 2 per cent of the drainage basin area. Similar observations have been made for the Conococheague Creek and Shenandoah River basins, which are partially underlain by carbonate rock.

The Chemical Quality of Ground Water

The chemical composition of rain and snow is the basis for ground water chemistry and for chemical reactions that occur in the substrata. Generally, precipitation contains total dissolved solids in concentrations of several milligrams per liter to several tens of milligrams per liter and is slightly to moderately acidic, depending upon the geographic location (Freeze and Cherry, 1979). In general, rain and snowmelt are extremely dilute, somewhat acidic, oxidizing solutions that can quickly cause chemical reactions in geologic materials into which they infiltrate (Freeze and Cherry, 1979).

The mineral composition of an aquifer in part determines the chemical quality of natural ground water. As water moves through the saturated zone, chemical reactions take place between the water and minerals that compose the aquifer. The reaction of water and carbon dioxide, which is generated by the decay of organic matter and by respiration of plant roots, produces carbonic acid. The carbon dioxide-containing water percolating through the soil dissolves certain minerals, and carbonic acid is consumed in the process. For example, limestone readily goes into solution as calcium bicarbonate in the presence of carbonic acid.

As ground water moves along its flow path in the saturated zone, the concentration of total dissolved solids and major ions increases. In fact, studies have shown that ground water undergoes a chemical evolution toward the composition of seawater with time, gradually changing from a carbonic acid to a sulfate and finally to a chloride composition. Shallow ground water in recharge areas is normally lower in dissolved solids than water residing deeper in the same system (Freeze and Cherry, 1979). For example, in the updip areas of the Aquia Formation, the water is characterized by low TDS, low pH, and moderately high iron levels. Toward the downdip portions of the aquifer, TDS and pH increase, while iron levels decrease (MD DNR, 1987a). The change in iron concentrations is probably related to differences in sulfate compositions of the shallow and deeper ground water. Large sedimentary basins can be characterized by three zones: the upper zone, which has active ground water flushing through relatively well-leached rocks; the intermediate zone, with less active ground water circulation and higher total dissolved solids; and the lower zone, with very sluggish ground water flow, high chloride and total dissolved solids concentrations (Freeze and Cherry, 1979).

Indicators of Ground Water Quality

The following chemical characteristics are used to describe the suitability of ground water for various types of use:

1) Total Dissolved Solids (TDS)- a measure of the concentration of all mineral salts, excluding suspended sediments, colloidal particles, or dissolved gases. Water that contains more than 500 ppm TDS may be unsuitable for domestic use and many industrial uses.

2) pH- measures how acidic or alkaline a solution is in terms of hydrogen ion concentration.

3) Hardness- measured as calcium or magnesium carbonate. Water with hardness over 150 ppm must be treated or softened to be used for water supply.

4) Dissolved inorganic constituents- Among the many inorganic constituents that occur in ground water, the major ions (Na^+, Mg^{2+}, Ca^{2+}, Cl^-, HCO^-_3, and SO_4^{2-}) comprise more than 90% of the total dissolved solids. The quantity of the major, minor, and trace inorganic constituents in ground water are determined by: the elemental composition of the geologic layers through which the water moves, properties of chemicals being transported, rates of the chemical reactions, the rate of ground water movement, and the sequence in which the water has come into contact with various minerals in the flow path (Freeze and Cherry, 1979).

5) Dissolved organic constituents - Dissolved organic matter (DOM) occurs naturally in ground water in concentrations of 0.1 to 10 milligrams per liter (Freeze and Cherry, 1979). Although little is known about the source or the composition of dissolved organic matter, research suggests that humic acid and fulvic acid are the major compounds in DOM.

Ground Water Quality and Drinking Water Standards

The state of Maryland has established maximum contaminant level (MCL) standards for inorganic and organic contaminants in drinking water, based on adverse health effects resulting from long term exposure (COMAR 26.04.01--See Apendix C). The MCL for nitrate, 10 mg/l, is applicable to both community and non-community ground water supply systems. All other MCL's, for compounds including metals, pesticides, and coliforms, (listed in Appendix C) apply only to community water supply systems. However, community water systems are required to monitor for MCL compliance only once every three years. In contrast, the level of nitrate, which may indicate the transport of other pollutants, must be measured every year. If a contaminant level in a public ground water supply system should exceed the established MCL, the source of the contaminant is identified, and the water quality problem is corrected. EPA recently eported that the safety of drinking water from non-public supplies used by 3 million people in Maryland is not being ensured. Non-public supplies include drinking water at schools, restaurants, campgrounds and other public facilities. These facilities are not connected to public supplies, which are tested regularly. There have been no reported outbreaks of disease associated with these non-public supplies in the past 12 years, but these supplies could represent a threat to public health since they are not tested (Baltimore Sun, December 13, 1988).

When MCL violations in community supply systems occur, the states report them to the EPA, which maintains a Federal Reporting Data System. According to the database, between 0 and 5% of Maryland's population depending on ground water as its primary source of drinking water was served by ground water supply systems containing MCL violations in 1987. This percentage increased from 1986 to 1987 (USEPA, 1989b).

Although a regulation and monitoring scheme exists for public ground water supply systems, the protection of private ground water wells from contamination is less clearly established. Private drinking water supply wells are inspected and monitored only when first installed, or when sampling is requested.

Ground Water Quality Status in the Potomac River Basin

According to a search of the EPA Storet database for ground water quality information in the Potomac River Basin in Maryland, approximately 37,000 observations or analyses were made from 4701 ground water samples during the period from 1975 to 1989. Chemical parameters were selected for inclusion in the Potomac River basin database on the basis of two criteria: they are chemicals regulated by the Safe Drinking Water Act, and the results of over 800 analyses for each of the parameters during the 1975-1989 period are available on Storet. Appendix D contains a list of parameters selected for a STORET database search and indicates those for which data was actually retrieved.

The US Geologic Survey has monitored ground water quality at 212 sites within the Potomac River basin in Maryland in the period between 1975 and 1989. The distribution of USGS sampling wells is uneven. One well is sampled in Prince George's County, while 70 ground water sampling sites exist in Frederick County. In addition, Montgomery County has sampled and analyzed ground water from 100 sites, which are probably near landfills. There are 14 aquifers for which ground water quality was sampled from more than four wells; however, none of these lie in the Piedmont province.

Data for inorganic chemical quality comprises the majority of the data set obtained from STORET. Regular monitoring of ground water for pesticide residues in Maryland has only recently begun, and the quantity of monitoring data available is inadequate to detect pesticide contamination of important ground water resources. Monitoring data for 25 pesticides in ground water within the Potomac River Basin exists in the STORET database in Maryland. However, for most of pesticides monitored, there were less than 20 ground water samples taken in the entire Potomac River Basin, and most of the observations were at the analytical detection level, which varied widely (from 0.01 ug/l to 10 ug/l for the same pesticide).

When the level of a substance analyzed is below the analytical detection limit, the detection limit value is reported in STORET with a remark code adjacent to it. Remark codes signifying that the actual concentration was below the detection limit appeared less than a dozen times for some of the metals analyzed by USGS. The Montgomery County water quality data contained a greater number of similar remark codes, and a variety of detection limits for each parameter were indicated, suggesting that perhaps the analyses were performed by different laboratories. Since no further information was available, the remark codes were stripped from the data, and the detection limit was used as the parameter concentration in the data analysis. This procedure may result in a slight overestimation of minimum or median concentrations.

Before grouping the data geographically, median parameter concentrations were calculated for each sampling well. Then, the median values for sampling wells were combined to obtain minimum, maximum, and median parameter concentrations for each county, and for each aquifer, where the relationship between sampling wells and aquifer source was known. Within the USGS data set, sufficient data for six parameters were available to represent reliable summary statistics; unfortunately, these did not include nitrate. For other chemical constituents, such as metals, there were 1 to 3 analyses per county. A check of metals concentrations against drinking water standards showed no levels exceeding standards, except for one measurement of mercury at 2.5 ug/l in ground water from the Magothy aquifer in Charles County. Many samples exceeded the Safe Drinking Water Act MCL of 300 ug/l for iron. The Montgomery County data, in contrast, contains many metals concentrations that exceed standards.

Following is a discussion of ground water quality in the physiographic regions, based on the ground water quality monitoring data, and identification of local ground water quality problems. ground water quality summarized by county and by aquifer from available STORET data is presented on Tables II-2 and II-3.

Coastal Plain

Median values of major ground water constituents used to judge the suitability of water for use are listed for Coastal Plain aquifers in Table II-4 These values represent average chemical quality for entire water-bearing formations, in contrast to the data in Tables II-2 and II-3, which are restricted to the Potomac River Basin.

Most water in the Coastal Plain aquifers is soft to moderately hard (60 to 120 mg/l as $CaCO_3$) (USGS, 1986). Concentrations of total dissolved solids and iron vary greatly. In Charles County, the median TDS concentration is greater than 200 mg/l; however, the aquifer(s) containing the high TDS concentrations cannot be identified because few sampling wells in this location were associated with aquifer names in the STORET data set.

High iron concentrations are often a problem in the updip portions of the Magothy, Patuxent and Patapsco-Raritan formations (MdDNR, 1987a). The median iron concentration (415 ug/l) in the ground water of Charles county exceeds the drinking water standard (300 ug/l), and locally high iron concentrations

Table II-2. Summary of Ground Water Quality Data for Maryland Counties in the Potomac River Basin

Alkalinity

county	n	min	max	median
GA	1	82.00	82.00	82.00
WA	8	3.60	295.00	89.00
CL	28	3.00	176.00	14.50
FR	40	13.00	508.50	130.50
MO	43	1.00	2579.00	17.00
PG	1	6.15	6.15	6.15
CH	38	49.20	367.00	153.50
SM	10	4.60	250.00	130.00

Chloride

county	n	min	max	median
AL	2	2.30	2.30	2.30
GA	18	0.60	150.00	1.63
WA	27	0.50	200.00	5.60
CL	28	1.00	140.00	4.05
FR	70	1.20	105.00	9.25
MO	103	1.30	192.00	6.00
PG	1	130.00	130.00	130.00
CH	38	0.90	210.00	6.95
SM	11	0.70	2.50	1.80

Conductivity

county	n	min	max	median
AL	2	385.00	385.00	385.00
GA	17	65.00	3480.00	271.50
WA	32	0.03	2600.00	430.00
CL	6	28.50	561.00	71.50
FR	70	30.00	1056.00	198.75
MO	102	0.00	4560.00	101.00
PG	1	550.00	550.00	550.00
CH	39	150.00	1270.50	322.50
SM	10	258.00	510.00	284.00

Table II-2. Summary of Ground Water Quality Data for Maryland Counties in the Potomac River Basin

Depth

county	n	min	max	median
GA	3	79.20	154.60	95.50
WA	1	15.60	15.60	15.60
FR	42	5.00	100.00	28.50
MO	47	0.00	57.53	17.88
PG	1	23.45	23.45	23.45
CH	16	4.92	238.00	119.65
SM	7	17.46	340.00	29.60

Iron

county	n	min	max	median
AL	2	630.00	630.00	630.00
GA	15	80.00	191000.00	1550.00
WA	2	180.00	230.00	205.00
CL	12	10.00	2300.00	77.50
FR	4	140.00	400.00	175.00
MO	70	15.00	76000.00	71.25
PG	1	15.00	15.00	15.00
CH	33	30.00	14000.00	415.00
SM	11	90.00	1100.00	180.00

Hardness

county	n	min	max	median
AL	2	200.00	200.00	200.00
GA	7	31.00	1650.00	110.00
WA	11	0.00	360.00	170.00
CL	27	7.00	280.00	47.00
FR	47	1.00	490.00	130.00
MO	55	7.00	3081.00	36.00
CH	4	1.00	160.00	130.00
SM	9	10.00	120.00	13.00

Table II-2. Summary of Ground Water Quality Data for Maryland Counties in the Potomac River Basin

Sodium

county	n	min	max	median
AL	2	0.90	0.90	0.90
GA	18	0.40	96.00	3.95
WA	27	0.90	90.00	7.60
CL	12	1.25	40.00	2.50
FR	70	1.70	61.00	5.85
MO	16	1.70	7.50	4.95
PG	1	62.00	62.00	62.00
CH	35	2.10	270.00	67.00
SM	11	4.40	120.00	54.00

pH

county	n	min	max	median
AL	2	8.10	8.10	8.10
GA	17	3.00	8.20	7.00
WA	27	5.60	8.60	7.30
CL	1	6.00	6.00	6.00
FR	70	5.80	8.00	6.70
MO	66	4.40	12.30	6.05
PG	1	5.60	5.60	5.60
CH	37	6.30	8.80	7.90
SM	2	7.70	7.80	7.75

TDS

county	n	min	max	median
AL	2	225.00	225.00	225.00
GA	17	40.00	3360.00	179.50
WA	10	28.00	441.00	247.50
CL	1	34.00	34.00	34.00
FR	61	32.00	627.00	166.00
MO	51	28.00	3006.50	84.00
MO	46	26.00	1634.00	83.50
PG	1	306.00	306.00	306.00
CH	36	56.00	771.50	206.50
SM	7	91.00	171.00	163.00

Table II-3. Summary of Water Quality Data for Aquifers Within the Potomac River Basin

-------------------Appalachian Province-----------------

Alkalinity

aquifer	n	min	max	median
Catoctin	9	15.00	120.00	37.00
Conemaugh	4	55.00	170.00	96.00
Conococheague	5	5.00	243.00	95.00
Frederick	7	127.00	508.50	272.00
Gettysburg_S	5	54.00	247.50	153.00
Metarhyolite	4	13.00	117.00	34.00
New_Oxford	11	8.00	350.00	124.00
Precambrian	7	21.00	290.00	44.00

Chloride

aquifer	n	min	max	median
Allegheny	9	0.85	150.00	4.40
Catoctin	16	1.20	84.00	3.00
Conemaugh	20	0.60	150.00	2.10
Conococheague	5	3.75	84.00	5.50
Frederick	8	4.95	44.50	27.00
Gettysburg_S	5	2.10	37.00	8.85
Metarhyolite	22	1.70	110.00	7.06
Monongahela	4	1.00	42.00	11.85
New_Oxford	11	2.60	21.00	10.60
Precambrian	12	1.00	200.00	28.00

Conductivity

aquifer	n	min	max	median
Allegheny	6	249.00	1600.00	675.00
Catoctin	15	30.00	524.00	87.00
Conemaugh	18	65.00	2905.00	260.25
Conococheague	5	53.00	750.00	232.00
Frederick	8	282.50	1056.00	569.25
Gettysburg_S	5	85.00	400.00	301.00
Metarhyolite	21	53.00	270.00	85.00
New_Oxford	11	15.00	501.50	343.50
Precambrian	12	82.00	1395.00	318.25

Table II-3. Summary of Water Quality Data for Aquifers Within the Potomac River Basin

Depth

aquifer	n	min	max	median
Catoctin	10	5.00	49.52	15.00
Conemaugh	5	70.00	154.60	95.50
Frederick	6	15.00	40.00	22.50
Gettysburg_S	5	20.00	30.00	29.00
New_Oxford	10	16.23	48.00	27.00
Precambrian	6	20.00	50.00	30.00

Iron

aquifer	n	min	max	median
Allegheny	6	450.00	105000.00	1410.00
Conemaugh	12	130.00	191000.00	1550.00

Hardness

aquifer	n	min	max	median
Catoctin	11	17.00	200.00	44.00
Conemaugh	13	34.00	1650.00	110.00
Conococheague	4	19.00	200.00	82.00
Frederick	8	130.00	490.00	255.00
Gettysburg_S	5	40.00	220.00	130.00
Metarhyolite	7	21.00	200.00	28.00
Monongahela	4	17.00	200.00	124.50
New_Oxford	11	11.00	260.00	150.00
Precambrian	8	36.00	380.00	115.00

Sodium

aquifer	n	min	max	median
Allegheny	8	1.45	95.00	18.05
Catoctin	15	1.71	17.00	2.70
Conemaugh	19	0.40	95.00	5.70
Conococheague	4	2.60	17.00	6.35
Frederick	8	4.00	12.00	9.10
Gettysburg_S	5	3.80	8.75	6.60
Metarhyolite	22	2.19	40.00	4.78
New_Oxford	11	1.40	12.50	9.45
Precambrian	12	1.45	90.00	9.95

Table II-3. Summary of Water Quality Data for Aquifers Within the Potomac River Basin

-------------------Coastal Plain------------------------

Alkalinity

aquifer	n	min	max	median
Cretaceous	15	100.00	310.00	146.00
Magothy	5	129.00	184.00	152.00
Patapsco	7	150.00	367.00	252.00
Patuxent	7	6.15	342.50	158.00

Chloride

aquifer	n	min	max	median
Cretaceous	15	1.90	60.00	18.00
Magothy	5	1.15	2.20	1.20
Patapsco	8	0.90	210.00	35.25
Patuxent	6	1.30	130.00	16.40

Conductivity

aquifer	n	min	max	median
Cretaceous	15	245.00	730.00	370.00
Magothy	4	290.00	357.00	306.25
Patapsco	8	270.00	1270.50	520.25
Patuxent	7	242.00	647.00	473.00

Table II-3. Summary of Water Quality Data for Aquifers Within the Potomac River Basin

Depth

aquifer	n	min	max	median
Cretaceous	8	50.58	238.00	105.06

Iron

aquifer	n	min	max	median
Cretaceous	15	30.00	13000.00	220.00
Magothy	5	140.00	600.00	385.00
Patapsco	6	80.00	4600.00	565.00

Hardness

Sodium

aquifer	n	min	max	median
Cretaceous	15	56.00	180.00	76.00
Magothy	5	8.50	16.50	15.00
Patapsco	7	20.00	270.00	110.00

Table II-4. Water Quality Data for Major Coastal Plain Aquifers, (Median concentration in mg/l)

Parameter	Piney Point	Aquia	Magothy	Potomac
TDS	<250	194	151	61
Hardness	23-140	73	70	14
Chloride	2.7	2.5	2.0	10-250
Sodium	17	40	3.6	4.1
Iron			>300 updip	>300 updip
Nitrate	<10	<10	<10	<10

Source: USGS (1988)

occur in the Magothy and Patapsco formations. By comparison, the median and range of iron levels in St. Mary's County ground water, based upon fewer sampling sites, is much lower.

Chloride levels within the Potomac River Basin agree with values in Table II-4. The maximum chloride level in Charles County, in the Patapsco formation, may indicate salt water intrusion. The Town of Indian Head has experienced an increase in total dissolved solids (from 200 ppm to over 400 ppm) in its drinking water, and in 1983, brominated compounds were detected (Md DNR, 1984).

Sodium concentrations in ground water within the Coastal Plain region of the Potomac River Basin appear to be elevated compared to average values for the Coastal Plain aquifers given by USGS (1986). High values seem to be evenly distributed through counties and aquifers, with the exception of the Magothy aquifer.

Piedmont

Ground water quality in Piedmont aquifers is generally good, water is soft, and total dissolved solids are low, but dissolved iron concentrations are high in some locations (> 0.3 ppm) (Maryland DNR, 1984a). Harder water may be pumped from limestone or marble aquifers. Median chloride and sodium concentrations for the aquifers average about 10 mg/l. Low concentrations of chloride and dissolved solids are confirmed by the work of Otton and Hilleary (1988) on springs draining shistose or quartzose rocks in the Piedmont . Median concentrations of nitrate plus nitrite (as nitrogen) in samples from the principal non-Coastal Plain aquifers are considerably lower than the drinking water standard of 10 mg/l (USGS 1988).

Western Maryland
(The Blue Ridge, Valley and Ridge, and Appalachian Plateau Provinces)

Generally, water is suitable for most uses, although hardness varies widely, and high dissolved iron concentration is a frequent problem. Otton and Hilleary (1985) analyzed water from 24 springs in the Piedmont and Appalachian Provinces in Maryland and found that none of the samples exceeded USEPA maximum contaminant levels for aluminum, cadmium, chromium, copper, lead, lithium, mercury, nickel, silver, and zinc. Ground water quality data obtained for the Potomac River Basin in Maryland also show that chemical parameter levels meet drinking water standards.

The ground water quality data obtained from STORET indicate that moderately hard water occurs in Washington County; in the Metarhyolite, New Oxford, and Gettysburg Shale formations in Frederick County; and in the Conemaugh and Monogahela Formations in Allegany and Garrett counties. Ground water in Frederick and Washington counties has moderate levels of iron (175-205 mg/l), and the ground water of the Appalachian Plateau (Allegany and Garrett counties; Conemaugh and Allegheny formations) shows extremely elevated median iron levels. Trainer and Watkins (1975) also report that shallow ground waters (within a few feet of the surface) in the Appalachian Plateau and the western part of the Valley and Ridge province contain high concentrations of iron, sulfate, and hydrogen sulfide. Median iron concentrations range from 0.6 to 1.5 mg/l, while maximum concentrations occur at hundreds of milligrams per liter. According to the USGS (1988), waters from several springs in western Allegany County contain excessive hardness, acidity, large concentrations of iron, and bacterial contamination. Similar problems have been found in Garrett County, but it is uncertain whether these water quality problems are caused by mining.

Upon exposure to air and water, pyrite (iron sulfide) associated with coal is converted to sulfuric acid. The acidic water holds in solution high concentrations of iron, manganese, and aluminum, and it becomes unsuitable for most uses. Analysis of ground water from mining areas in Southern Garrett County, between Backbone Mountain and the North Branch of the Potomac River, reveals it to be a significant source of acid water, containing large amounts of iron, sulfate, and other dissolved ions, to the river (Duigon and Smigaj, 1985). Present studies of streams draining abandoned mine sites in Garrett County show that stream base flow, which originates as ground water, is only slightly more acidic than high flow, which is dominated by surface runoff. Though metals concentrations vary greatly through time, many samples from streams draining abandoned mines contained iron concentrations as high as 70 mg/l, and sulfate at 500 to 1000 mg/l (John Morgan, personal communication). It is clear from water quality studies in the mining area that deep mines have a far greater impact on ground water and stream quality than do strip mines (Jeff McCombs, personal communication). Since many strip mines are above the water table, the amount of time that water is in contact with pyrite minerals is limited, in contrast to deep mines, where the water percolates around exposed pyrite.

Median total dissolved solids concentrations in Western Maryland counties are 180 to 250 mg/l, in contrast to the much lower TDS concentrations in Piedmont counties. Chloride and sodium concentrations are generally low to moderate, except for a median sodium concentration of 18 mg/l in the Allegheny Formation.

In Adamstown, a rural community underlaid by limestone formations in southeastern Frederick County, individual drinking water wells have been contaminated from existng and past industrial operations. Cearfoss, Washington County, another community located in a limestone region, has had numerous contamination problems from petroleum and agricultural contamination. The state is planning to extend the public water supply system from Hagerstown to remedy the situation.

Influence of Ground Water Quality on Potomac River Water Quality

The chemical quality of ground water greatly influences stream water quality. In the Appalachian Province, the river receives water that has flowed through coal mines to become an acidic sulfate water with high iron, manganese, and aluminum content. However, by the time the water reaches Cumberland, Maryland, the acid has been neutralized by alkaline, most of the metals have been precipitated, and the water acquires a calcium sulfate composition (Trainer and Watkins, 1975). Further additions of bicarbonate from the South Branch, inflow from the Great Valley, Shenandoah River, and Piedmont province combine to maintain the sulfate level in the Potomac River near Washington at low levels.

The hardness of ground water inflows controls, to some extent, the hardness of river water. Generally, the average hardness of Potomac River water decreases markedly after the river leaves the Appalachian Province and flows across the western Valley and Ridge region; it then increases while crossing the Great Valley and decreases again as the river crosses the Piedmont (Trainer and Watkins, 1975).

Ground Water Use in the Potomac River Basin

Under state law, a permit from the Department of Natural Resources is required for the construction of any structure for appropriation or use of ground waters in the state. Only individual domestic users and farms are exempt from the permit requirement. When an average monthly withdrawal amounts exceed 10,000 gallons of water per day, permittees are required to report them to the state. Subdivisions with individual wells are excluded from the reporting requirement.

In 1985, ground water withdrawal within the Potomac basin by reporting appropriators was 19.235 million gallons per day (mgd), or approximately 17 per cent of the total reported ground water withdrawals in the state of Maryland (Md DNR, 1987b). By comparison, total surface water withdrawals for the Potomac basin were approximately 1170 mgd.

Highest ground water withdrawal and use occurs in areas overlying the productive Coastal Plain aquifers and limestone aquifers of the Hagerstown Valley. According to Table II-5, the highest reported withdrawals of ground water occur in the Middle and Lower Potomac River Basins; if ground water withdrawal is considered by physiographic province, highest reported withdrawals occur in the Coastal Plain and in Western Maryland (See Table II-6). Both the Middle Potomac Basin and the Western Maryland contain the limestones of the Hagerstown Valley.

Reporting appropriators withdraw large amounts of ground water from the Aquia, Magothy, and Patapsco formations in the Coastal Plain (Md DNR, 1987b). While permitted withdrawals from the fractured rocks of the Piedmont are low, the productive Grove Limestone and Frederick Limestone aquifers supply a substantial portion of the ground water withdrawn in Western Maryland (Md DNR, 1987b).

Over 390,000 people in the Potomac River Basin in Maryland depend upon ground water for their drinking water, with approximately two thirds drawing water from private wells (See Table II-7). Within the Potomac Basin, the portion of the population using ground water for drinking water varies from 6.4 per cent in Montgomery County to over 98 per cent in St. Mary's and Charles counties.

The number of people who use ground water for drinking water depends upon the productivity of local aquifers, as well as the population density. Charles County stands out as having the largest population (176,000) served by private and public

Table II-5. 1985 Reported ground water Withdrawal in Maryland in the Potomac River Basin (mgd)

North Branch Potomac River	0.823
Upper Potomac River	0.835
Middle Potomac River	6.653
Washington Area Potomac River	1.833
Lower Potomac River	9.091
Total Potomac River	19.235

From: Maryland Water Withdrawal and Use Report for 1985 (Md DNR, 1987b)

Table II-6. Number of People Using Groundwater for Drinking Water in the Potomac River Basin

County	Public Supplies	Private Supplies	Total
AL	1300	20100	21400
CL	5830	38980	44810
CH	70117	106251	176368
FR	3337	68473	71810
GA	1116	2843	3959
MO	3991	42573	46564
PG	27086	41395	68481
SM	12472	36563	49035
WA	5870	36523	42393

Table II-7. 1985 Groundwater Withdrawal in Potomac River Basin in Maryland (mgd)

County	Reported Permitted Withdrawals	Nonreported Permitted Withdrawals	Estimated Domestic Withdrawals	Estimated Farm Irrigation	Estimated Livestock Watering	Power Plants	Total
Allegany	0.283	0.219	1.179	0.000	0.019	0.000	1.700
Carroll	0.866	0.165	2.087	0.013	0.247	0.000	3.378
Charles	6.275	0.420	2.755	0.009	0.022	0.607	10.110
Frederick	4.942	0.380	4.740	0.000	1.565	0.000	11.627
Garrett	0.808	0.109	0.567	0.000	0.096	0.000	1.580
Montgomery	0.743	0.568	2.225	0.018	0.184	0.000	3.738
Prince George's	1.849	0.165	0.585	0.005	0.151	0.000	2.755
St. Mary's	2.478	0.170	1.558	0.000	0.031	0.000	4.237
Washington	1.031	4.839	2.447	0.010	0.650	0.000	8.977
Total	19.275	7.035	18.143	0.055	2.965	0.607	48.273

ground water supply systems. Other counties in which a substantial number of people depend upon ground water for drinking water are: Frederick, Prince George's, St. Mary's, Carroll, Montgomery, and Washington counties.

Although public water supply wells are subject to regular monitoring and compliance requirements, private wells are monitored only when first installed. Thus, private drinking water wells are more vulnerable to undetected contamination. Within the Potomac River Basin, Frederick County has the highest number of people obtaining drinking water from private wells. Carroll, Charles, Montgomery, and Washington counties, also have substantial numbers of private drinking water wells. These data are confirmed by the estimated domestic use presented on Table II-7.

In addition to reported, permitted withdrawals over 10,000 gallons per day, unreported withdrawals of less than 10,000 gpd and domestic, agricultural, and power plant uses in the Potomac River Basin are presented in Table II-7. Total ground water withdrawal for all non-permitted categories is 48 mgd. In general, domestic withdrawals are nearly equal to those by reporting appropriators, and they permitted withdrawals in Allegany, Carroll, Washington, and Montgomery counties. In Frederick County, where the highest quantity of ground water is withdrawn for domestic use, reported withdrawals and domestic use are approximately equal.

III. Identification of Problem Areas for Ground Water in the Potomac River Basin

Areas Vulnerable to Ground Water Contamination

On the land, human economic activities intrude in the hydrologic cycle, which recharges underground water resources and drives ground water movement. Manufacturing, minerals extraction, waste disposal, and agriculture can interfere with the natural cycle of precipitation, infiltration, aquifer recharge and discharge. Although some activities have little or no impact on ground water, the harmful effects of others have been documented. The severity of ground water pollution depends upon the characteristics of the contamination source and the hydrology and geology of the substrata. Of course, contamination of any aquifer type can occur, but water-bearing formations that contain permeable materials or that outcrop in proximity to pollution sources are vulnerable to contamination.

The National Well Water Association has developed DRASTIC, a systematic approach to evaluating the potential for ground water pollution. This scheme is based upon the seven following factors considered to significantly affect ground water pollution potential:

D-Depth to water
R-Recharge (net)
A-Aquifer media
S-Soil media
T-Topography
I-Impact of vadose zone; and
C-Conductivity (hydraulic) of the aquifer.

The NWWA devised a numerical scoring system, or DRASTIC index based on the weights, ranges, and ratings of the seven DRASTIC factors.

Detailed DRASTIC Indices have not been computed for the ground water resources of Maryland. However, the Environmental Protection Agency has conducted the National Pesticide Study and calculated an average DRASTIC index, with special concern for pesticide application, for every county in the United States (USEPA, 1989a). The DRASTIC index as designed for pesticides differs from the general DRASTIC Index only in the assignment of different weights for the seven factors. The agricultural DRASTIC (for pesticides) places higher weighting on topography and soil media to more accurately reflect the effects of pesticide loss on runoff and biodegradation. Thus, for highly soluble pollutants such as nitrate, the higher weighting of these factors might not be desirable.

Alexander et al (1988) established categories of ground water vulnerability based upon a 10/60/30 per cent distribution of the national agricultural DRASTIC Indices. EPA classified as highly vulnerable those counties with scores greater than 143; counties in the moderately vulnerable category had scores greater than 102.

Average DRASTIC Indices for Maryland counties are amoung the criteria used to identify areas of vulnerability to ground water contamination within the Potomac River Basin (See Table III-1). On the basis of DRASTIC scores, all counties in the Coastal Plain (Prince George's, St. Mary's, and Charles) are classified in the highly vulnerable category, while all other counties in the Potomac River Basin fall within the moderately vulnerable category.

Particular areas of vulnerability within counties can be identified on the basis of properties of geologic formations within county boundaries. Aquifer transmissivity and depth to the top of aquifer are two factors that influence the degree of contaminant penetration. Transmissivity is the rate of water movement through a vertical section of an aquifer that is one foot wide, measured in units of feet squared per day or gallons per day per foot. Generally, transmissivities greater than 10,000 ft^2/day represent good aquifers for water well exploitation (Freeze and Cherry, 1979), and therefore, aquifers with a significant rate of ground water movement. Table II-2 lists the mean and range of transmissivities of different rock types in the Maryland Piedmont and Appalachian Provinces. In addition, Maryland DNR (1987a) has mapped transmissivity for the Coastal Plain aquifers of Maryland. For this assessment, aquifers with median transmissivities greater than 1000 ft^2/day, or with maximum transmissivities equal to or greater than 2000 ft^2/day are considered to be vulnerable to contamination. Near outcrop areas, where the top of the aquifer lies less than 100 feet below the land surface, Coastal Plain aquifers have a higher probability for contamination should pollution sources exist.

Vulnerable aquifers, selected using the transmissivity and depth criteria described, are illustrated in Figure II-1 and listed in Table II-3. Highly permeable carbonate formations, which are composed of limestone, dolostone, and marble, are among the aquifers most likely to be contaminated from pollution sources at the land surface. These carbonate formations exist primarily in Washington, Frederick, and Carroll counties. The Oriskany and Greenbrier formations, which contain sandstone and limestone, in Alleghany, Garrett, and Washington counties are also susceptible to contamination. Coastal Plain aquifers that have high transmissivities include the Magothy, Patapsco, and

Patuxent formations. However, as the strata dip downward toward the southeast, with less permeable layers above affording protection from pollutant infiltration, the aquifers become confined aquifers. In the region where each of the Coastal Plain aquifers is unconfined or outcrops, danger of contamination increases, regardless of relative permeability. With the exception of the Piney Point formation, each of the Coastal Plain aquifers described outcrops within the Lower Potomac watershed, resulting in potential danger of aquifer contamination in all the Coastal Plain counties of the Potomac.

Table III-1. Counties, Average DRASTIC Scores, Geologic Formations, and Rock Types in the Potomac River Basin

Appalachian Province

Co.	DRASTIC	System	Aquifer	Rock type		
AL	126	Pennsylvanian	Conemaugh Formation	Sandstone	Shale	Siltstone
AL	126	Mississippian	Greenbrier Formation	Sandstone	Shale	Limestone
AL	126	Mississippian	Pocono Formation	Sandstone	Shale	
AL	126	Devonian	Hampshire Formation	Sandstone	Shale	
AL	126	Devonian	Oriskany Group	Sandstone	Limestone	
AL	126	Devonian	Helderberg Limestone	Limestone		
CL	130	Triassic	New Oxford Formation	Sandstone		
FR	118	Triassic	Gettysburg Shale	Shale		
FR	118	Triassic	New Oxford Formation	Sandstone		
FR	118	Ordovician	Grove Limestone	Limestone		
FR	118	Cambrian	Frederick Limestone	Limestone		
FR	118	Cambrian	Tomstown Formation	Dolostone		
FR	118	Cambrian	Antietam Formation	Quartzite		
FR	118	Cambrian	Harpers Formation	Shale	Phyllite	
FR	118	Cambrian	Weaverton Formation	Quartzite		
FR	118	Cambrian	Catoctin Metabasalt	Metabasalt		
GA	136	Pennsylvanian	Conemaugh Formation	Sandstone	Shale	Siltstone
GA	136	Pennsylvanian	Alleghany-Pottsville	Sandstone	Siltstone	Claystone
GA	136	Mississippian	Greenbrier Formation	Sandstone	Shale	Limestone
GA	136	Mississippian	Pocono Formation	Sandstone	Shale	
GA	136	Devonian	Hampshire Formation	Sandstone	Shale	
MO	129	Triassic	New Oxford Formation	Sandstone		
WA	137	Devonian	Oriskany Group	Sandstone	Limestone	
WA	137	Ordovician	Chambersburg Limestone	Limestone		
WA	137	Cambrian	Conococheague Limestone	Limestone		
WA	137	Cambrian	Tomstown Formation	Dolostone		
WA	137	Cambrian	Harpers Formation	Shale	Phyllite	
WA	137	Cambrian	Weaverton Formation	Quartzite		
WA	137		Beekmantown Group			
WA	137	Ordovician	Martinsburg Shale	Shale		
WA	137	Silurian	Tonoloway Limestone	Limestone		

Table III-1. Counties, Average DRASTIC Scores, Geologic Formations, and Rock Types in the Potomac River Basin

Piedmont Province

Co.	DRASTIC	System	Aquifer	Rock type
CL	130	Paleozoic	Marburg Schist	Schist
CL	130	Paleozoic	Sams Creek Metabasalt	Metabasalt
CL	130	Paleozoic	Wakefield Marble	Marble
FR	118	Paleozoic	Urbana Phyllite	Phyllite
FR	118	Precambrian	Libertytown	Metarhyolite
FR	118	Paleozoic	Marburg Schist	Schist
FR	118	Paleozoic	Sams Creek Metabasalt	Metabasalt
MO	129	Paleozoic	Wissahickon	Schist
MO	129	Paleozoic	Georgetown Mafic	Quartz Gabbro
MO	129	Paleozoic	Ultramafic	Serpentinite

Coastal Plain

Co.	DRASTIC	System	Aquifer	Rock type
CH	157	Tertiary	Aquia Formation	Sand-Silt-Clay
CH	157	Cretaceous	Magothy Formation	Sand-Clay
CH	157	Cretaceous	Patapsco Formation	Silt-Clay-Sand
CH	157	Cretaceous	Patuxent Formation	Sand-Silt-Clay
CH	157	Cretaceous	Potomac Formation	Sand-Silt-Clay
PG	159	Tertiary	Aquia Formation	Sand-Silt-Clay
PG	159	Cretaceous	Magothy Formation	Sand-Clay
PG	159	Cretaceous	Patapsco Formation	Silt-Clay-Sand
PG	159	Cretaceous	Patuxent Formation	Sand-Silt-Clay
SM	165	Tertiary	Piney Point Formation	Sand-Clay
SM	165	Tertiary	Nanjemoy Formation	Clay-Sand-Silt
SM	165	Tertiary	Aquia Formation	Sand-Silt-Clay
SM	165	Cretaceous	Magothy Formation	Sand-Clay
SM	165	Cretaceous	Potomac Formation	Sand-Silt-Clay

Table III-2. Range and median values of transmissivity for rock aquifers in the Maryland Appalachian and Piedmont provinces[1]

Type of Rock	Transmissivity (range in ft^2/d)	Number of values	Median value (ft^2d)
Conglomerate (limestone)	2,000 to 2,500*	3	2,300
Gabbro	5 to 160	3	130
Gneiss	700 to 1,870	2	1,200
Limestone and marble	5 to 26,700	18	1,400
Metabasalt and metarhyolite	70 to 300	5	250
Phyllite	10 to 800	4	70
Quartzite	---	1	450
Sandstone	130 to 1,900	6	500
Schist	270 to 870	7	400
Shale and siltstone	5 to 2,000	17	80

[1] Values weighted in favor of more productive segments of the aquifers.
* Values reported by Trainer and Watkins (1975, p. 19); data from files of U. S. Geological Survey in Reston, VA.

Source: Otton and Hilleary, 1985

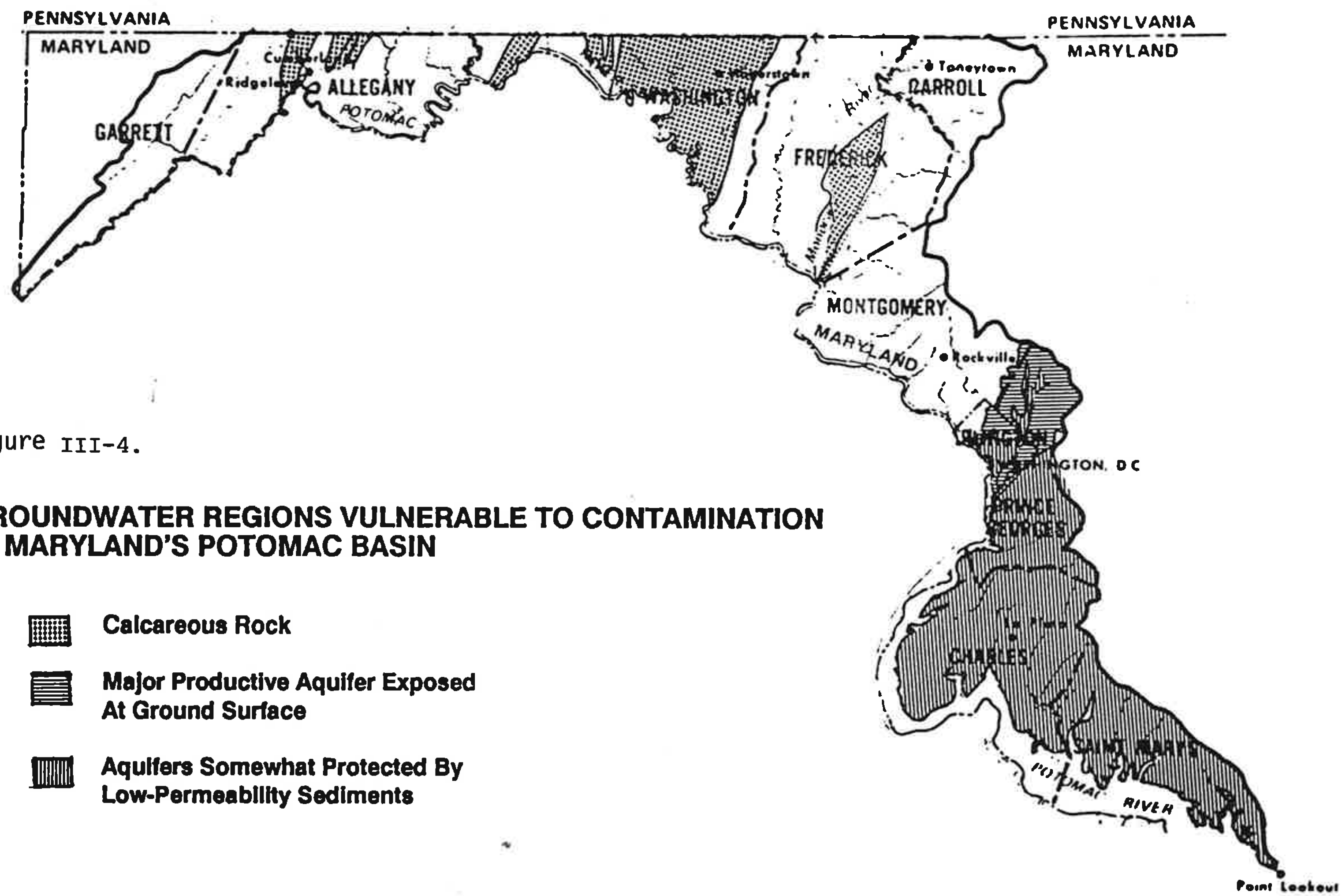

Figure III-4.

GROUNDWATER REGIONS VULNERABLE TO CONTAMINATION IN MARYLAND'S POTOMAC BASIN

- Calcareous Rock
- Major Productive Aquifer Exposed At Ground Surface
- Aquifers Somewhat Protected By Low-Permeability Sediments

Table III-3. Aquifers Vulnerable to Contamination

Vulnerable Aquifers--Based on Transmissivity

Aquifer	County	Rock Types		
Chambersburg Limestone	WA	Limestone		
Conococheague Limestone	WA	Limestone		
Frederick Limestone	FR	Limestone		
Greenbrier Formation	GA	Sandstone	Shale	Limestone
Greenbrier Formation	AL	Sandstone	Shale	Limestone
Grove Limestone	FR	Limestone		
Oriskany Group	WA	Sandstone	Limestone	
Oriskany Group	AL	Sandstone	Limestone	
Magothy Formation	SM	Sand-Clay		
Magothy Formation	CH	Sand-Clay		
Magothy Formation	PG	Sand-Clay		
Patapsco Formation	CH	Silt-Clay-Sand		
Patapsco Formation	PG	Silt-Clay-Sand		
Patuxent Formation	CH	Sand-Silt-Clay		
Patuxent Formation	PG	Sand-Silt-Clay		

Vulnerable Aquifers--Based on Depth to Top of Aquifer

Aquifer	County	Rock Types
Aquia Formation	CH	Sand-Silt-Clay
Aquia Formation	PG	Sand-Silt-Clay
Magothy Formation	PG	Sand-Clay
Patapsco Formation	CH	Silt-Clay-Sand
Patapsco Formation	PG	Silt-Clay-Sand
Patuxent Formation	PG	Sand-Silt-Clay

Known Pollution Sources to Ground Water

Point Source Pollution

Information on known point pollution sources to ground water is available from various state and federal agencies, including the Maryland Department of Environment Hazardous and Solid Waste Management Administration, Bureau of Mines, and the Environmental Protection Agency. The following section describes two types of known point pollution sources: coal mines and hazardous waste sites.

Coal Mines

Abandoned coal mines are a major source of ground water contamination in Western Maryland (USGS, 1988). (See discussion of ground water quality in Western Maryland, Section II). As water moves through the mining layers, it becomes acidic and picks up metals and other ions, eventually affecting the chemical quality of streams. The shallow part of the coal mining area underlying the hills discharges to local streams or it leaks down to deeper portions of the flow system, which discharges into higher order streams at lower elevations.

Coal mining has been a commercially important industry in Allegany and Garrett counties since the early 1800's. With the development of earth moving equipment after World War II, deep mining declined and surface coal mining increased.

The natural hydrologic system of the coal basin has been severely altered by many years of mining. Surface mines intercept surface runoff and alter infiltration patterns. In fact, infiltrating ground water in the northern half of the Georges Creek Basin is intercepted by underground mine workings and channeled to the Hoffman Drainage Tunnel, across the basin divide in Wills Creek (US Army Corps of Engineers, 1977).

The most severe degradation of ground water occurs in abandoned deep mines. Deep mines allow contact between ground water and pyrite above and below the mining cavity, resulting in an accumulated quantity of ground water with degraded quality. Underground mines also act as large sinks, altering ground water flow direction and providing conduits for discharge to the surface (Duigon and Smigaj, 1985). For example, the pumping of water from the Mettiki mines has lowered the water table locally, which may result in a reversal of ground water flow and a decrease in streamflow, unless treated mine and process water is discharged to compensate for this loss (Duigon and Smigaj, 1985). In addition, when coal pillars are removed from worked-out mines, extensive fracturing results as voids collapse, causing permanent modifications to the ground water flow system.

All coal mining activity in the Potomac River Basin in Maryland is located within the North Branch Potomac-Georges Creek Coal Basin, which runs northeast from the beginning of the North Branch, at the West Virginia-Maryland state line, to Frostburg. This coal basin consists primarily of sandstones and shales with occasional coal-bearing Pennsylvanian strata, which are exposed along the slopes of the basin. Fifteen coal seams bedded within the Monongahela, Conemaugh, and Allegheny formations have been mined at some time (US Army Corps of Engineers, 1977).

In the Potomac River Basin in Garrett and Allegany counties, there are 70 active mining facilities that are permitted by the Bureau of Mines; 61 are strip mines. The strip mines are highly concentrated within a valley running in a north-south direction between Westernport and Frostburg. Within this valley, 35 strip mines lie within the George's Creek watershed, and 13 are within Wills Creek drainage. While all currently operating mines in Allegany County are strip mines, intense mining activity in the past has left a legacy of numerous abandoned deep mines (Jeff McCombs, personal communication).

The Potomac drainage portion of Garrett County contains 12 strip mines, five deep mines, and four coal transfer or processing stations. The Kempton Mine, formerly operated by the Davis Coal and Coke Company, located on Laurel Run, is the single worst source of acid mine drainage in the North Branch Potomac River. It is the source of 2.5 to 4 million gallons of acid mine drainage per day (Jeff McCombs, personal communication).

Active mines are now required to treat their waste water and to obtain NPDES permits, and Maryland has developed a program to reclaim abandoned mines under the Abandoned Mine Drainage Abatement Act. However, the large number of abandoned mines (both surface and deep mines) and the extent of the underground workings make remediation of acid mine drainage difficult.

Hazardous Waste Sites

The Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA) established a national inventory of hazardous waste sites and a program to protect public health and the environment from chemical hazards at the sites. By 1986, EPA had inventoried more than 24,000 hazardous waste sites and identified those that required emergency cleanup action or long term remedial action. Those targeted for long term remedial action are placed on Superfund's National Priorities List (NPL). The NPL contains approximately 800 sites in the United States, and an additional 378 are proposed for listing.

A chain of events is initiated under CERCLA when the state and the EPA discover possible hazardous sites through concerned citizens, the news media, and local officials. The status of a hazardous site follows a progression of investigative and remedial actions:

DS-Initial discovery
PA-Preliminary investigation
SI-Site investigation- performed if wastes at the site appear to pose a human health hazard and the owner is reluctant to take action.
HRS-Monitoring data is used to determine the site score on the Hazard Ranking System, a complex scoring system designed to evaluate the risks posed to humans and the environment.
NPL-The site is placed on the National Priorities List by the EPA, based on the Hazard Ranking score.

Once a site is placed on the National Priorities List, an evaluation procedure determines the cleanup method. First, a Remedial Investigation/Feasibility Study (RI/FS) is performed as a basis for selecting several cleanup options, which are subjected to criteria for effectiveness and cost

Under CERCLA, 55 hazardous waste sites that could affect ground water in the Potomac River Basin in Maryland are being investigated. There are no CERCLA sites in Garrett County. Three sites have been placed on the National Priorities list for cleanup under Superfund:

Limestone Road Site in Allegany County
Keystone Landfill in Adams County, Pennsylvania
Southern Maryland Wood Treating Co. in St. Mary's County.

At the Keystone Landfill, located near the Pennsylvania-Maryland state line, ground water is contaminated with organic and inorganic pollutants, including trichloroethylene, tetrachloroethylene, chromium, and lead.

Furthermore, the contamination is migrating south toward Westminister, Maryland, affecting drinking water wells in Carroll County. The owner of the Keystone Sanitary Landfill is pumping ground water to the surface and removing the volatile organic compounds by treating the water through an aeration process (USEPA, 1987).

Non-community and private drinking water wells have been contaminated with creosote near the Southern Maryland Wood Treating Company in St. Mary's County.

Remedial investigation/feasibility studies have been performed for the three sites on the NPL list, and a remedial design is complete for Southern Maryland Wood Treating Company.

The US Naval Ordnance Station in Charles County and the USAF Andrews Air Force Base in Prince George's County have received a final Hazard Ranking (HR). In 1987, contaminated material was removed at Trans Tech/Adamstown in Frederick County and at United Rigging and Hauling in Prince Georges County.

Sources of hazardous substances, such as abandoned industrial sites, are being discovered through requests for ground water testing by citizens with private wells, or through soil testing. These sites may not yet be on the list of CERCLA sites being investigated. One such site is Central Chemical Company's old fertilizer and insecticide plant in Hagerstown. Soil testing showed deposits of DDT, several toxic DDT byproducts, chlordane, and lead and arsenic (Herald Mail, October 7, 1989). Prompted by the Maryland Department of the Environment, Central Chemical has hired a ground water consultant to determne the extent of the contamination. The state has provided funds to monitor the cleanup, once the study is complete.

In some cases, the source of contamination is difficult to determine. For example, in an area west of Hagerstown, toxic organic chemicals, including perchloroethylene, 1,2-dichloroethylene, and trichloroethylene have contaminated the ground water for 30 homes (Herald Mail, October 7, 1989). The state has not determined the source of the contamination, but it has provided funds to monitor the cleanup and test soil samples. In Frederick County, individual wells near the rural community of Adamstown, underlain by limestone formations, have been contaminated from existing and past industrial operations.

Underground Oil and Gasoline Storage Tanks

Petroleum products can enter ground water from underground leaking storage tanks. Because of the high number of ageing storage tanks, several hundred incidents were reported in

Maryland in 1986. Most counties report one or more contamination cases each year (USGS, 1988). The impact of the leakage is usually severe. For example, a water supply well for the town of Thurmont, Frederick County, became contaminated from an old underground fuel tank. The fuel company has drilled a new water production well, but low levels of contamination persist.

When a leaking underground storage tank is reported, remedial action takes place promptly. The old tank is usually removed, along with contaminated soil. Because remedial action takes place quickly, there is no central database for leaking underground storage tank incidents. However, in spite of the local extent and short duration of this type of ground water contamination, it remains a serious problem for those who use ground water supplies.

Known Non-Point Source Pollution

Reports of ground water contamination with nitrates, bacteria, and pesticides are common. However, determining the exact source of non-point pollution of ground water is difficult because it is so disperse. The two major sources of non-point pollution to ground water are agricultural chemicals and malfunctioning septic systems. Malfunctioning septic systems in areas with porous media or high water table can cause ground water contamination with nutrients, bacteria, and viruses. Chemical fertilizers, pesticides, and manure applied to croplands also leach below the root zone, often reaching the saturated zone.

High nitrate levels were found in three drinking water wells at the Todd Village Trailer Park in Carroll County, and contaminated ground water was reported at the Scenic View Mobile Home Park in Washington County. The source of the contamination at both sites is unknown, but there is a high concentration of septic tanks at the Scenic View site, which is also surrounded by cropland where manure is heavily applied (B. O'Brien, personal communication). The town of Cearfoss in the Hagerstown Valley has had numerous problems with pollution of its water supply with petroleum and agricultural chemicals. The state may extend the public water supply system from Hagerstown to correct the situation.

In 1987, an herbicide study was conducted by the state of Maryland. Of eight sampling sites in the Potomac River Basin (in Carroll, Frederick, and Washington counties), 3 tested positive for the presence of herbicides (MDOEP, 1987). While these results testify to the fact that the herbicides atrazine and simazine enter the ground water after being applied at several sites, they do not indicate the spatial and temporal extent and variability of ground water contamination with agricultural chemicals.

Potential Pollution Sources to Ground Water

Although cases of ground water contamination have been documented within the Potomac River basin, the potential for other contamination incidents is substantial. Aquifer pollution may have gone undetected, or previously immobile contaminants can migrate from their source when geohydrologic conditions permit. In the following section, point and nonpoint pollution sources that pose a potential threat to ground water quality are described.

Potential Point Source Pollution

Hazardous Waste Sites

Under CERCLA, numerous hazardous waste sites in the Potomac River basin are being investigated for hazardous conditions posing a threat to the environment or to public health. The number of sites being investigated within the basin are as follows:

14	Discovery (DS)
26	Preliminary Assessment (PA)
11	Site Investigation (SI)

The presence of contaminants in soils has been detected at sites that have not yet received hazard rankings under CERCLA. At three former coal gasification plants, Frederick Town Gas in Frederick County, and Westminster Plant and Cranberry Run Sub Station in Carroll County, the soil is contaminated with coal tar constituents, posing a threat to ground water quality (Baltimore Sun, May 4, 1989). St. Mary's Salvage site, a former salvage yard, was contaminated with PCB's during the shredding of transformers (Baltimore Sun, May 4, 1989). The Hughesville Tire site in Charles County, located near Zekiah Swamp, constitutes a fire hazard with the potential release of oils and other hazardous substances. The investigations currently underway will determine whether these potential sources are harmful to ground water supplies.

Discharges to Ground Water

Any discharge to ground water, regardless of quantity, requires a permit from the Maryland Department of Environment Hazardous and Solid Waste Management Administration. Although the permit application describes the quantity and chemical quality of the discharge, this information has not been compiled, except for a listing of applicants. In the Potomac River Basin, of 83 applications for permits, 25 permits have been issued, and 10 applications are being processed. For the remainder of the applicants a permit is not required, which means that either the water is discharged to surface water, or the discharge is classified as storm water. Permitted dischargers include wastewater treatment plants, car and truck washes, furniture and lumber companies, agricultural research institutions, concrete companies, a coal mine, and other private businesses. Whether or not the discharges pose a threat to ground water quality depends upon the chemical composition of the effluent, the porosity of the surficial material, the nature of the geologic strata, and whether the discharge area constitutes a recharge zone for a productive aquifer.

The state of Maryland has designated three aquifer classes for controlling pollution of ground waters of the state:

1) Type 1 aquifer- transmissivity > 1,000 gal/day/foot
permeability > 100 gal/d/ft^2
TDS < 500 mg/l

2) Type 2 aquifer- transmissivity = 1,000-10,000 gal/day/foot
permeability > 100 gal/d/ft^2
TDS = 500 - 6000 mg/l

or

transmissivity = 1,000-10,000 gal/day/foot
permeability > 100 gal/d/ft^2
TDS = 500-1500 mg/l

3) Type 3 aquifer- All aquifers that do not meet Type 1 and Type 2 criteria

Ground water discharge quality criteria are applied to the three aquifer types. Discharges to type 1 aquifers may not exceed primary or secondary drinking water standards; discharges to type 2 aquifers may not exceed primary or secondary drinking water standards <u>except</u> for dissolved solids.

Landfills

The Hazardous and Solid Waste Management Division also issues permits for solid waste disposal facilities. At present, there are 18 active, permitted landfill sites within the Potomac River Basin; 14 permit applications have been submitted for proposed sites. 24 sites are sanitary landfills or transfer stations for municipal solid waste and are thus potential sources of contamination for ground water. The remaining sites, which are rubble fill facilities, pose no threat to ground water quality.

Newer landfills are located well above maximum water table levels and are required to have a liner and underdrain system to collect leachate for treatment (MDE, 1988). Older landfills, however, are not subject to these requirements except when renewal of landfill permits are sought. As of 1986, more than 100 closed or abandoned landfills represented potential sources of contamination to ground water. The extent and magnitude of the contamination is unknown (USGS, 1988). No central list of abandoned landfill locations exists in the Hazardous and Solid Waste Administration of the Maryland Department of the Environment. Some abandoned landfills are being monitored under the Comprehensive Environmental Response and Recovery Act.

Summary--Point Source Pollution

Known and potential point pollution sources are summarized by type and by county in Table III-4. The data presented do not include the following significant pollution sources for ground water, which have been mentioned in the text: abandoned coal mines, closed or abandoned landfills, and various reported incidences of contamination, which have not been incorporated into a permit or investigation system.

Allegany and Garrett counties have the highest total number of point sources because of intense mining activity, but the two counties have few other types of point sources. The potential effect of point source pollution in these counties is acidification of the ground water and elevated metals concentrations in drinking water wells and in water that ultimately enters streams.

The density of point sources and population size appear to be correlated, as the total number of point sources for Montgomery, Prince Georges, and Washington counties show. Montgomery and Prince George's counties contain the highest number of CERCLA sites, and Montgomery County, the highest number of landfills. Leaching of toxic inorganic and organic chemicals into ground water can occur if no impermeable layer isolates the aquifer from the pollution source.

Table III-4. Potential Point Pollution Sources for Groundwater

County	Landfills	CERCLA	Dischargers	Coalmines	Total
AL	3	5	0	48	56
CL	3	3	4	0	10
CH	2	6	3	0	11
FR	3	2	5	0	10
GA	0	0	0	22	22
MO	7	11	4	0	22
PG	1	14	3	0	18
SM	3	3	3	0	9
WA	3	5	9	0	17

Non-point Source Pollution

Non-point source pollution may have a greater impact on ground water quality than point source pollution. Non-point source pollution results from chemicals applied to croplands, livestock wastes, malfunctioning septic systems, deicing salts applied to roads, and lawn care in urban areas. Because of the extensive areal coverage of non-point pollution sources and the large total contaminant input, contamination of vulnerable subsurface formations is more likely to occur.

Land Use

Land use statistics are a useful indicator of potential non-point source pollution. While forested land represents the most "natural" condition (i.e., controlled by natural geochemical cycles and receiving no chemical inputs from extraneous sources), agricultural and urban land uses indicate a disturbance of natural hydrologic and chemical cycles, and additional chemical inputs.

To assess potential non-point pollution sources to ground water in the Potomac River basin in Maryland, land use data was obtained from the EPA Chesapeake Bay Liason Office (USEPA, 1989c). The data, taken from the 1982 Census of Agriculture and updated by the state office of the US Department of Agriculture, Soil Conservation Service, reflects 1985 land use conditions. Total acreage of four land use types is available for each county: cropland, pasture, woodland, and urban. This data set represents the most accurate available estimate of cropland area, which has the greatest impact on ground water.

The 1985 land use data, obtained by county, was adjusted to the Potomac River basin area. Accurate ratios of basin area to county area were obtained from digitized boundary data on ARCINFO (USGS, 1986).

Table III-5 presents land use for counties in the Potomac River basin by acreage and by percentage. Frederick and Washington counties are highly agricultural, having the largest areas of cropland and pastureland in the basin. Allegany, Carroll and Montgomery counties also have large crop and/or pasture areas. Not surprisingly, the largest proportion of urban land occurs in Montgomery and Prince George's counties. Large forested areas exist in Allegany, Garrett, Frederick and Charles counties.

Table III-5. Land Use in the Potomac River Basin

County	Cropland	Pasture	Forest	Urban
		Acres		
AL	20000	45000	181186	23100
CL	63967	20304	39934	11750
CH	36100	4750	181460	52250
FR	161370	53460	133789	71280
GA	16687	11467	113138	14245
MO	61600	21120	86311	110000
PG	16077	1960	56779	77910
SM	33120	5400	95130	38016
WA	105200	48100	96680	41200
		Percent of County Area		
AL	7	17	67	9
CL	47	15	29	9
CH	13	2	66	19
FR	38	13	32	17
GA	11	7	73	9
MO	22	8	31	39
PG	11	1	37	51
SM	19	3	55	22
WA	36	17	33	14

Nutrient Loading

Nutrients from agricultural fertilizers, lawn fertilizers, manure applied to crops, and malfunctioning septic systems may leach through subsurface layers into the ground water. The primary nutrient of concern is nitrate, which is soluble and, at sufficiently high concentrations, causes methemoglobinemia in infants. Many factors, including precipitation, slope, soil type, tillage practices, form of nitrogen applied, method and timing of application, and quantity of fertilizer or manure applied, influence the amount of nitrate that leaches below the surface to reach ground water. However, modeling and field studies have shown that the overriding factor is the quantity of nutrient applied (Shirmohammadi and Shoemaker, 1988). National studies have found that in the United States, the use of inorganic nitrogen fertilizers increased fourfold between 1960 and 1980, with application rates doubling within that time period (Nielsen and Lee, 1987). Present fertilizer application rates recommended by agricultural extension services are adjusted according to many factors, such as crop type, expected yield, soil type, soil chemistry, and tillage practice (University of Maryland). An attempt to estimate potential nitrogen loading to ground water was not made, but cropland acreage and manure production were used as gross indicators of non-point source nitrogen from agriculture.

Manure production and dairy cow populations in each county (USEPA, 1989c; Md Dept Agriculture, 1987, respectively) indicate the size of the non-point nitrogen source that is applied to crops, left on pastures, or concentrated in feedlots. Within the Potomac River Basin in Maryland the largest source of nutrients from livestock manure is found in Carroll, Frederick, Montgomery, and Washington counties, but the production in Frederick County stands far above that in all other counties.

Tillage practice significantly affects the quantity of nitrogen leached below the root zone (Shirmohammadi and Shoemaker, 1988). Conservation tillage, which includes contour plowing, leaving crop residues, strip cropping, and terracing, retards erosion and surface runoff but tends to increase infiltration of precipitation into crop soils. Percentages of croplands cultivated under conventional and conservation tillage practices in 1985 in the Potomac River basin counties in Maryland are available from the Conservation Tillage Information Center. The most intensively farmed counties in the Piedmont also have the highest portion of cropland in conservation tillage.

In 1984, critical areas for high watershed nutrient loading were identified by the State Soil Conservation Committee. Criteria for selecting critical areas were designed for release of nutrients to streams and included intensity of agricultural land use and cropping, animal waste application, and topography. Although some of the criteria are not applicable for ground water loading, the study identifies watersheds with the highest nutrient inputs. The critical area for potential release of nitrogen in the Potomac River Basin is a contiguous area that includes all of the Monocacy River watershed, Conococheague Creek, Antietam Creek, Catoctin Creek, and Middle Potomac River direct drainage. The results of this analysis support the estimation that highest nutrient inputs are concentrated in Washington, Frederick and Carroll counties within the Potomac River Basin.

According to the National Water Summary (USGS, 1988), approximately 20 percent of Maryland's population is dependent on individual septic systems for waste disposal. If properly installed and operated, a septic system does not adversely affect ground water quality. However, if installed in impermeable soils or high water table, the septic system may pollute ground water with nitrate, chloride, and bacteria. In the Hagerstown Valley (Washington County), ground water has deteriorated in some locations where septic systems were built on sites where soil thickness was insufficient to attenuate the effluent before it reached the carbonate aquifer. Although the number and distribution of failing septic system in the state has not been compiled, the density of septic systems in each county (1980 Maryland Census Data) may be used as a rough guide to the concentration of septic contamination sources. This use of the data involves the assumption that a small percentage of the existing septic systems will be installed improperly or will fail over time. The highest number of septic systems are found in Washington, Frederick, and Montgomery counties.

Pesticides

Another type of potential pollutant to ground water from non-point, agricultural sources is pesticides. According to Nielsen and Lee (1987), agricultural use of pesticides in the United States has risen sharply, nearly tripling since 1964; herbicides, which constitute the major portion of pesticide use on major field and forage crops, accounted for most of the increase.

In 1986, the Maryland Department of Agriculture conducted a survey of pesticide use by farmers, private certified pesticide applicators, commercially licensed businesses, and public agencies. Each chemical was reported in the county where it was actually applied. From the survey responses, the state estimated the quantity of pesticides (active ingredient) applied in each county during 1985. Estimates were made only for those products for which there were enough responses or pounds reported to be reliable. Table III-6 shows the estimated total pounds of pesticide active ingredient applied in each county. As expected, pesticide usage is highest in counties with more agricultural land: Frederick, Carroll and Washington counties.

Forty chemicals used for pest control, including herbicides, insecticides, nematicides, fungicides, and fumigants, are applied to crops in the Potomac River basin in Maryland. Table III-7 presents the type and total quantity of each pesticide used in the Potomac River basin.

The movement of pesticides to ground water from the land surface depends upon the same climatic, hydrologic, and geologic factors that govern nitrate mobility. However, the chemical properties of pesticides, such as solubility, adsorption, and persistence, also strongly influence their fate. There is a national trend in using less persistent, but also more soluble pesticides, with the result that more of the pesticide applied is likely to leach below the root zone into ground water (Nielsen and Lee, 1987).

Under FIFRA (Fungicide, Insecticide, and Rodenticide Act), data concerning pesticide properties and results of environmental fate studies must be submitted to EPA for the pesticide registration process. EPA classifies a pesticide as having a potential to reach ground water if, based on a review of the environmental studies, the pesticide meets at least one of the following criteria:

1) Water solubility > 30 ppm
2) Hydrolysis half-life > 25 weeks
3) Soil half-life > 2 to 3 weeks
4) Soil adsorption coefficient (K_d) < 5

Table III-8 lists the pesticides used in the basin, their chemical class, and the chemical properties influencing subsurface mobility. The last column, indicating whether EPA has issued a health advisory for that chemical, signifies toxicity to human health. If a T (true) appears in one or more of the first three columns, the chemical is likely to move below the land surface to ground water under appropriate geohydrologic conditions. Note that empirical data on the environmental behavior of many pesticides are not available (ND).

Table III-6. Estimated Pesticide Use by County in the Potomac River Basin

County	Pesticide Active Ingredients Pounds
AL	11840
CL	249265
CH	58340
FR	666716
GA	15481
MO	209466
PG	53753
SM	60516
WA	442700

Table III-7. Pesticides, Total Pounds (Active Ingredients) Applied in Maryland Counties of Potomac Basin

Pesticide	Total Pounds
2,4-D	63700
Alachlor	197800
Aldrin	1080
Atrazine	485700
Azinphos-methyl	18800
Bacillus thurigiensis	140
Bensulide	32710
Boric Acid	1260
Carbaryl	15050
Carbofuran	57500
Chlordane	125280
Chlorpyrifos	68500
Cyanazine	200800
Diazinon	24850
Dicamba	30400
Dikar	11000
Dimethoate	13900
Diphenamid	9000
Glyphosate	25050
Heptachlor	9420
Isofenphos	1200
Linuron	5000
MCPP	6770
Malathion	13320
Maleic Hydrazide	41000
Mancozeb	6000
Metam-sodium	2600
Methomyl	3500
Methyl Bromide	12200
Methyl Parathion	1300
Metolachlor	419000
Paraquat	64600
Pichloram	2000
Pyrethrum	1600
Simazine	116600
Sulfur	14100
Sulfuryl Fluoride	13530
Toxaphene	69680
Trichlopyr	2930
Zineb	4500

Few of the pesticides on the list of concern are immobilized on soil or rapidly degraded. The majority of pesticides used in the Potomac basin in Maryland are considered toxic to human health and are likely to be transported in ground water, depending upon soil properties and hydrologic conditions. The organophosphate pesticides are rapidly hydrolyzed in water, however (Pionke and Chesters, 1973). The four most commonly used pesticides, the herbicides atrazine, cyanazine, metolachlor, and simazine, are soluble chemicals that, under appropriate hydrologic conditions, are likely to be transported in ground water.

Table III-8. Properties of Pesticides Applied within the Potomac River Basin in Maryland

Pesticide	Chemical Class	Leacher	Soluble	Persis- tent	Health Advisory
2,4-D	PO	T	T	T	T
Alachlor	AM	T	T	T	T
Aldrin	HH		F	ND	
Atrazine	TZ	T	T	T	T
Azinphos-Methyl	OP		F	ND	
Bensulide	OP		ND	T	
Boric Acid			ND	ND	
Carbaryl	CB		T	F	T
Carbofuran	CB	T	T	T	T
Chlordane	HH		F	ND	T
Chlorpyrifos	OP		F	ND	
Cyanazine	TZ	T	T	T	T
Diazinon	OP		T	T	T
Dicamba	AR	T	T	T	T
Dikar	CB		ND	ND	
Dimethoate	OP		T	ND	
Diphenamid	AM	T	ND	T	T
Glyphosate	AL	T	T	T	T
Heptachlor	HH		F	F	T
Isofenphos	AR		F	ND	
Linuron	UR		T	T	
MCPP	AR		ND	ND	
Malathion	OP		T	ND	
Maleic Hydrazine		T	T	ND	T
Mancozeb	CB		F	ND	
Metam-sodium	CB		T	ND	
Methomyl	CB	T	T	ND	T
Methyl Bromide	HH		T	ND	
Methyl Parathion	OP		T	ND	T
Metolachlor	AM	T	T	T	T
Paraquat	CT		ND	T	T
Pichloram	AR	T	T	T	T
Pyrethrum	AR		F	ND	
Simazine	TZ	T	T	T	T
Sulfur			F	ND	
Sulfuryl Fluoride			ND	ND	
Toxaphene	HH		F	T	T
Trichlopyr	AR		ND	ND	
Zineb	CB		F	ND	

T, True; ND, No Data; F, False

Chemical classes: AL, aliphatic acids; AM, amides and anilides; AR, aromatic acids and esters; CB, carbamates; CT, cationics; HH, halogenated hydrocarbons; OP, organophosphates; PO, phenoxy compounds; TZ, triazines and triazoles; UR, ureas

Sources: Nielsen and Lee, 1987; USDA, 1975; Pionke et al, 1986 Kenaga and Goring, 1980; Callahan, et al., 1979; Farm Chemicals Handbook, 1987

IV. Identification of Potential Impacts to Ground Water

The probability that an activity taking place on the land, whether it is farming, mining, or waste disposal, will impact ground water, and the extent of that impact, is difficult to estimate. Subsurface contamination depends upon multiple factors, including porosity and structure of the geologic strata, the quantity and type of pollutant, frequency and duration of precipitation events, and climate. In this assessment, information on known and potential pollution sources has been related to the location of vulnerable and heavily used aquifers to identify those areas in which impacts to ground water might be expected.

On Table V-1, each county is ranked for selected factors influencing potential contamination of ground water. The entire numerical range for all the counties in each category was divided into four ranges, and the counties were ranked accordingly. A ranking of 1 indicates that the county falls within the top range for that category, and a ranking of 4 shows that the county is in the lowest range. The actual values for each county in each category are given in Table V-2. The summary tables are discussed by physiographic provinces.

Coastal Plain

The Coastal Plain counties are ranked as moderately vulnerable to potential ground water contamination. Prince George's, St. Mary's, and Charles counties are underlain by sedimentary formations that outcrop near the surface or lie beneath permeable sediments. Charles County is heavily dependent upon ground water for many uses, including drinking water, and septic systems are commonly used for wastewater disposal. None of the counties in the Coastal Plain is highly agricultural. While each county has at least one CERCLA site with a Hazard Ranking, Prince George's County has more potential point sources of pollution than the other counties.

Piedmont

Aquifers in the fractured bedrock of the Piedmont are moderately productive, and they are not highly vulnerable to ground water pollution. The largest probable threats to ground water in the Piedmont region of the Potomac River Basin are landfills and hazardous waste sites, especially in Montgomery County. Both Montgomery and Carroll counties have substantial levels of non-point nutrient sources from cropland, livestock wastes and septic systems. However, landfill leachate migrating from the Keystone site just north of the Pennsylvania state line is polluting ground water in Carroll County.

Table IV-1. Counties and Rankings for Groundwater Use, Point and Non-point Contamination Sources

County	Vuln. Aquifer	Use		Point Sources		Non-point Sources				
		Vol	Pop	Pot.	Act.	C	C-T	M	S	P
AL	1	4	4	1	1	4	4	4	3	4
GA	1	4	4	1	1	4	4	4	4	4
WA	1	2	3	2	1	2	2	1	1	2
FR	1	1	2	3	1	1	1	1	1	1
CL	1	3	3	3	4	3	2	2	2	3
MO	4	3	3	1	4	3	1	3	2	3
PG	1	4	2	2	1	4	4	4	3	4
CH	1	1	1	3	1	4	4	4	2	4
SM	1	3	3	3	4	4	3	4	3	4

C = Acres in Cropland
C-T = Acres on Conservation Till
T = Tons of Manure
S = Septic Units
P = Tons of Pesticides Applied

Table IV-2. Groundwater Use, Vulnerable Aquifers, and Pollution Sources for Maryland Counties in the Potomac Basin

County	Vulnerable Aquifers		GW Use		Point Sources		Nonpoint Sources				
	T	D	Vol	Pop	Potent.	Actual	Crops Acres	Cons. Till Acres	Manure Tons	Septic Systems	Pesticides Tons
AL	3	0	1.70	21400	56	1	20000	5780	68555	5819	11840
GA	1	0	1.58	3959	22	0	16687	5023	95678	638	41840
WA	5	0	8.98	42393	17	0	105200	77532	483184	17199	442700
FR	3	0	11.63	71810	10	1	161370	138617	927932	18900	673450
CL	1	0	3.38	44810	10	1	63967	40491	226681	10402	530350
MO	0	0	3.74	46564	22	0	61600	56487	181633	14962	238030
PG	3	4	2.76	68481	18	2	16077	1061	29140	7728	109700
CH	3	3	10.09	176368	11	1	36100	6173	53618	10912	61410
SM	1	3	4.24	49035	9	1	33120	15401	58594	7288	84050

T- Based on Transmissivity
D- Based on Depth

Western Maryland-Blue Ridge, Valley and Ridge, and Appalachian Plateau Provinces

Areas most susceptible to ground water contamination in the Potomac River Basin in Maryland are the Valley and Ridge Province and the Hagerstown Valley, where concentrated pollution sources are underlain by vulnerable subsurface formations. Frederick and Washington counties, which rank highest in every non-point source category, are underlain by major limestone formations. Nutrients and bacteria can easily leach past the root zone through macropores in the carbonaceous rocks to ground water. Unfortunately, large numbers of people in both counties rely on ground water for drinking water. The locations of dischargers, landfills, and waste sites in these counties need to be carefully chosen to avoid seepage of contaminants into the conduits of limestone rocks and transport to ground water.

Allegany and Garrett counties are less densely populated than other counties in the basin. Because of the small population, low ground water yield of bedrock aquifers, and plentiful fresh surface water, ground water use is quite low. The largest single threat to ground water quality in these two counties is acid mine drainage from the large number of abandoned subsurface coal mines. Non-point pollution sources seem to be minimal when compared to that in other areas of the state.

Conclusions and Recommendations

The focus of this assessment is on ground water as a natural resource and on pollution sources that may threaten its quality. Examining potential pollution has value in that it aids in planning and regulating the environmental impact of economic activities in the state. However, it falls short of defining the actual status of ground water resources. The number and the distribution of monitoring sites for ground water within the Potomac River Basin in Maryland is inadequate to determine whether drinking water standards are met for the majority of individual wells. In fact, no nitrate data, and very little microorganism data are found in available water quality databases.

The following recommendations are proposed to protect ground water resources in the future:

1) Develop detailed geologic/hydrologic maps of the counties with aquifers most vulnerable to contamination. The DRASTIC system could be used.

2) Superimpose past, present and proposed pollution sources on the detailed DRASTIC maps.

3) Carefully plan location of landfills, lagoons, and waste sites to avoid contamination of vulnerable formations

4) Encourage the use of agricultural best management practices to prevent contamination to ground water, specifically, reducing the quantity of nutrients and pesticides applied to crops without significantly reducing crop yields, especially in regions having vulnerable ground water supplies.

5) Develop a more extensive ground water monitoring program, with highest priority given to limestone areas

6) Provide a uniform computerized data system to hold data on pollution sources that already reside at various state agencies. Additional information gathering and compilation are needed in the following areas:

County Health Departments. A central repository for county data for drinking water wells.

Bureau of Mines. Listing, including locations, of abandoned mines.

Hazardous and Solid Waste Management Administration. Listing of locations of abandoned landfills and industrial sites.

If more data on ground water resources and pollution sources are made available and accessible, state agencies can make informed decisions to protect the quality of ground water in the state of Maryland.

REFERENCES

Alexander WJ, SK Liddle, RE Mason, WB Yeager. 1988. Ground-water Vulnerability Assessment in Support of the First Stage of the National Pesticide Survey. EPA Contract No. 68-01-6646. Office of Pesticide Programs, US Environmental Protection Agency.

Baltimore Sun, December 13, 1988. "Report says EPA, Md. Fail to Test Non-public Water".

Baltimore Sun, May 4, 1989. "State approves Spending $2.4 Million for Cleanup of Hazardous Waste Sites".

Bureau of the Census. Census of Agriculture for 1982, Vol. 1. Geographic Area Series DE, MD, NY, PA, VA, WV. U.S. Department of Commerce. 1984.

Callahan MA, et al. 1979. Water-Related Environmental Fate of 129 Priority Pollutants. EPA-440/4-79-029a.

Conservation Tillage Information Center. 1985. National Survey. Consrvation Tillage Practices. Maryland County Summary.

Cook, Michael B. Memorandum on Availability of Final Draft Health Advisories for 50 Pesticides. January 18, 1989.

Duigon MT, Smigaj MJ. 1985. First Report on the Hydrologic Effets of Underground Coal Mining in Southern Garrett County, Maryland. Report of Investigations No. 41. Maryland Geological Survey.

Farm Chemicals Handbook. 1989. Meister Publishing Co, Ohio.

Freeze RA, Cherry JA. 1979. Groundwater. Prentice-Hall International, Inc.: London.

Hansen HJ. 1972. A User's Guide for the Artesian Aquifers of the Maryland Coastal Plain. Part Two: Aquifer Characteristics. Maryland Geological Survey.

Hearn JL. January 24, 1989. Memorandum to Maryland Department of the Environment Secretary Martin W. Walsh, Jr. Individual Wells vs. Municipal Water Supply System and Septics vs Municipal Sewage System.

Herald Mail. October 7, 1989. "DDT Cleanup, Tainted Water to be Watched" (Hagerstown, Maryland).

ICPRB. 1979. Potomac River Basin Basics. Interstate Commission on the Potomac River Basin.

Kenaga E, Goring CAI, 1980. Relationship between Water Solubility, Soil Sorption, Octanol-Water Partitioning, and Concentration of Chemcials in Biota. Aquatic Roxicoloty, ASTM STP 707. J.G. Eaton, P.R. Parrish, and AC Hendriks, eds., Am. Soc. for Testing and Materials, pp. 78-115.

McCombs, Jeff. Maryland Bureau of Mines. Personal communication.

Maryland Department of Agriculture. 1986. Maryland Pesticide Use for 1985. MDA 227-87.

Maryland Department of Agriculture. 1987. Maryland Agricultural Statistics. Summary for 1986. MDA113-87.

MDE. 1984. Groundwater Contamination Incidents in Maryland. November 7, 1984.

MDE. 1988. 1985-1987. Water Quality Inventory. Volume 1. 1988 Report to USEPA According to Section 304(b) of the Clean Water Act.

MDE. 1989a. Active Water Quality Permits by Sub-basin. Municipal Discharges--Ground waters. Maryland Department of the Environment, Hazardous and Solid Waste Administration.

MDE. 1989b. Permitted Solid Waste Disposal Facilities. Maryland Department of the Environment, Hazardous and Solid Waste Administration.

MDE. 1989c. Proposed Solid Waste Disposal Facilities. Maryland Department of the Environment, Hazardous and Solid Waste Administration.

Maryland Department of Mines. January 1989. Permitted Maryland Coal Mine Operators.

Md DNR. 1984. Charles County. Water Supply Resources Development and Management Plan. Charles County Department of Public Works.

Md DNR. 1987a. The Quantity and Natural Quality of Ground Water in Maryland. 2nd Edition. Maryland Department of Natural Resources, Water Resources Administration.

Md DNR. 1987b. Maryland Water Withdrawal and Use Report for 1985. Maryland Department of Natural Resources, Water Resources Administration.

Maryland Department of State Planning. 1987. Maryland's Land: A Portrait of Changing Uses, 1973 to 1985. Publication No. 87-7.

Maryland Department of State Planning. 1989. Summary of land use and land use change in the Potomac River Basin in Maryland. 1973-1985.

MDOEP. 1984. Maryland Air and Water Quality Atlas. Department of Health and Mental Hygiene.

MDOEP. 1987. Results of a Maryland Groundwater Herbicide Reconnaissance Survey. Maryland Office of Environmental Programs, Technical Report # 61.

Morgan, John S.L. Howard Needles Tammen and Bergendoff Architects, Engineers, and Planners. Personal Communication.

Nielsen E, Lee, L. 1987. The Magnitude and Costs of Groundwater Contamination from Agricultural Chemicals. A National Perspective. United States Department of Agriculture. Economic Research Services. Economic Report # 576.

Nutter LJ, Otton EG. 1969. Ground-water Occurrence in the Maryland Piedmont. Report of Investigations No. 10. Maryland Geological Survey. Baltimore, Maryland.

O'Brien, B. Personal Communication. Maryland Department of the Environment, Water Management Administration, Water Supply Program.

Otton EG, Hilleary JT. 1985. Maryland Springs- Their Physical, Thermal, and Chemical Characteristics. Maryland Geological Survey. Department of Natural Resources. Report of Investigations No. 42.

Otton EG, Richardson CA. 1958. Limestone Aquifers of Maryland. Economic Geology 53: 722-736.

Pionke H, Glotfelty D, Urban J. 1986. Pesticide Contamination of Ground Water in a Rural Pennsylvania Watershed. Proceedings of the Agricultural Impacts on Ground Water Conference. August 11-13, 1986. Omaha, Nebraska. National Water Well Journal Publishing Co.

Shirmohammadi A, Shoemaker L. 1987. Impact of Best Management Practices on Water Quality in Pennsylvania. Interstate Commission on the Potomac River Basin Report #88-7.

Slaughter TH, Otton EG. 1968. Availability of Ground Water in Charles County, Maryland. Maryland Geological Survey. Bulletin 30.

State Soil and Conservation Committee. 1984. Priority Watersheds for the Potential Release of Agricultural Non-Point Phosphorus and Nitrogen. MDA 213-84.

Trainer FW, Watkins FA. 1975. Geohydrologic Reconnaissance of the Upper Potomac River Basin. United States Geological Survey. Geological Survey Water-Supply Paper 2035.

University of Maryland Agricultural Extension Service. 1989. Plant Nutrient Recommendations Based on Soil Tests.

USDA. 1975a. Control of Water Pollution from Cropland. Vol. I. A Manual for Guideline Development.

USDA. 1975b. Control of Water Pollution from Cropland. Vol. II. An Overview.

USEPA. Storet. Water Quality Data Base System.

USEPA. 1988. Pesticide Use in the Chesapeake Bay Basin. CBP/TRS 23/88.

USEPA. 1989a. National Pesticide Survey.

USEPA. 1989b. Indicators for Measuring Progress in Ground-Water Protection. Office of Water. EPA 440/6-88-006.

USEPA. 1989c. Chesapeake Bay Land Use Data. Chesapeake Bay Liason OFfice. Annapolis, Maryland. April 18, 1989.

USGS. 1986. Land Use and Land Cover Digital Data from 1:250,000- and 1:100,000-Scale Maps.

USGS. 1988. National Water Summary. Maryland and the District of Columbia. Ground-Water Quality.

Appendix A

Description of Groundwater Database

for the Potomac River Basin in Maryland

Dbase IV

Database Files

The following database files contain data on groundwater properties and use, and potential point and non-point sources of pollution in the Potomac River Basin in Maryland:

Database file	Contents
aqprop.dbf	Geologic and hydrologic characteristics of major aquifers
drastic.dbf	Average DRASTIC Indices for counties
aqcowd.dbf	Permitted groundwater withdrawals partitioned by county and aquifer
aqtotals.dbf	Total permitted groundwater withdrawals for aquifers
cototals.dbf	Total permitted groundwater withdrawals for counties
aqqual.dbf	Groundwater quality by aquifers
coqual.dbf	Groundwater quality by counties
landfill.dbf	Information on landfills in each county
cercla.dbf	CERCLA sites in each county
discharg.dbf	Permitted groundwater dischargers
coalmine.dbf	Permitted, active deep and strip coal mines
landuse.dbf	Landuse by counties, adjusted to Potomac Basin
septic.dbf	Number and percentage of population using septic systems in each county
manure.dbf	Manure production and dairy cattle population in each county
pesticide.dbf	Types and estimated applications of pesticides in each county
chemprop.dbf	Chemical properties and toxicities of pesticides used
corank.dbf	Database of rankings for counties

Structure for database: D:\DBASE\MDGW\AQPROP.DBF
Number of data records: 37
Date of last update : 09/26/89

Field	Field Name	Type	Width	Dec	Index
1	SYSTEM	Character	15		N
2	SERIES	Character	3		N
3	AQUIFER	Character	25		N
4	PHYSIOGRAF	Character	2		N
5	ROCK_TYPE1	Character	15		N
6	ROCK_TYPE2	Character	12		N
7	ROCK_TYPE3	Character	12		N
8	TRANS_MIN1	Numeric	5		N
9	TRANS_MAX1	Numeric	5		N
10	TRANS_MD1	Numeric	5		N
11	TRANS_MD2	Numeric	5		N
12	TRANS_MD3	Numeric	5		N
13	STORAGEMIN	Numeric	6	4	N
14	STORAGEMAX	Numeric	6	4	N
** Total **			122		

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Structure for database: D:\DBASE\MDGW\DRASTIC.DBF
Number of data records: 9
Date of last update : 08/16/89

Field	Field Name	Type	Width	Dec	Index
1	CO_NAME	Character	2		N
2	DRASTIC_IN	Numeric	3		N
** Total **			6		

Page # 1

Structure for database: D:\DBASE\MDGW\AQCOWD.DBF
Number of data records: 55
Date of last update : 09/26/89

Field	Field Name	Type	Width	Dec	Index
1	PHYSIOPROV	Character	2		N
2	AQUIFER	Character	25		N
3	CO_NAME	Character	2		N
4	WITHDRAW	Numeric	9	3	N
5	DEPTH_MIN	Numeric	3		N
6	DEPTH_MAX	Numeric	5		N
** Total **			47		

Structure for database: D:\DBASE\MDGW\AQTOTALS.DBF
Number of data records: 30
Date of last update : 09/26/89

Field	Field Name	Type	Width	Dec	Index
1	PROV	Character	2		N
2	AQNAME	Character	15		N
3	TOT_WITHDR	Numeric	6	3	N
** Total **			24		

Page # 1

Structure for database: D:\DBASE\MDGW\COTOTALS.DBF
Number of data records: 9
Date of last update : 07/18/89

Field	Field Name	Type	Width	Dec	Index
1	CO_NAME	Character	2		N
2	REP_WD	Numeric	6	2	N
3	NONREP_WD	Numeric	6	2	N
4	EST_DOM_WD	Numeric	6	2	N
5	EST_IRRIG	Numeric	6	2	N
6	EST_LIVEST	Numeric	6	2	N
7	POWERPLANT	Numeric	6	2	N
8	TOT_WITHDR	Numeric	6	2	N
9	PUB_DW_NO	Numeric	6		N
10	PRIV_DW_NO	Numeric	6		N
11	TOT_DW	Numeric	8		N
** Total **			65		

Page # 1

Structure for database: D:\DBASE\MDGW\AQQUAL.DBF
Number of data records: 173
Date of last update : 07/02/89

Field	Field Name	Type	Width	Dec	Index
1	PHYSIOGRAF	Character	2		N
2	AQUIFER	Character	14		N
3	PARAM	Character	9		N
4	N	Numeric	3		N
5	MIN	Numeric	8	2	N
6	MAX	Numeric	10	2	N
7	MEDIAN	Numeric	10	2	N
** Total **			57		

Structure for database: D:\DBASE\MDGW\COQUAL.DBF
Number of data records: 154
Date of last update : 10/01/89

Field	Field Name	Type	Width	Dec	Index
1	COUNTY	Character	2		Y
2	PARAM	Character	15		N
3	N	Numeric	3		N
4	MIN	Numeric	8	2	N
5	MAX	Numeric	10	2	N
6	MEDIAN	Numeric	10	2	N
** Total **			49		

Structure for database: D:\DBASE\MDGW\LANDFILL.DBF
Number of data records: 33
Date of last update   : 10/01/89

Field	Field Name	Type	Width	Dec	Index
1	CO_NAME	Character	2		N
2	ACTIVE	Logical	1		N
3	PROPOSED	Logical	1		N
4	ABANDONED	Logical	1		N
5	SITE_NAME	Character	40		N
6	PERMIT_NO	Character	12		N
7	EXPIR_DATE	Date	8		N
8	TYPE	Character	3		N
9	MD_GRID_E	Numeric	3		N
10	MD_GRID_N	Numeric	3		N
11	LOC_DESC	Character	30		N
12	FAC_SIZE	Numeric	5		N
13	WASTE_QTY	Numeric	6		N
14	UNITS	Character	3		N
15	NOTES	Character	10		N
16	KNOWN_CONT	Logical	1		N
17	POTENTIAL	Logical	1		N
** Total **			131		

Structure for database: D:\DBASE\MDGW\CERCLA.DBF
Number of data records: 56
Date of last update : 10/01/89

Field	Field Name	Type	Width	Dec	Index
1	CO_NAME	Character	2		N
2	EPA_ID	Character	12		N
3	SITE_NAME	Character	35		N
4	ADDRESS	Character	25		N
5	TOWN	Character	17		N
6	ZIP	Numeric	5		N
7	EVAL_STAT	Character	3		N
8	EV_DATE	Date	8		N
9	REMED_STAT	Character	3		N
10	RE_DATE	Date	8		N
11	POTENTIAL	Logical	1		N
12	KNOWN	Logical	1		N
13	NOTES	Memo	10		N
** Total **			131		

Page # 1

Structure for database: D:\DBASE\MDGW\DISCHARG.DBF
Number of data records: 83
Date of last update : 08/08/89

Field	Field Name	Type	Width	Dec	Index
1	CO_NAME	Character	2		N
2	SITE_NAME	Character	35		N
3	COMMUNITY	Character	15		N
4	BASIN_CODE	Character	8		N
5	TRIB_CODE	Character	2		N
6	TRIB	Character	40		N
7	PERMIT	Logical	1		N
8	P_PROCESS	Logical	1		N
** Total **			105		

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Structure for database: D:\DBASE\MDGW\COALMINE.DBF
Number of data records: 70
Date of last update : 09/29/89

Field	Field Name	Type	Width	Dec	Index
1	CO_NAME	Character	2		N
2	COMPANY	Character	30		N
3	PERMIT_NO	Character	9		N
4	LOCATION	Character	30		N
5	TYPE	Character	7		N
6	BASIN_CODE	Character	8		N
7	TRIB_CODE	Character	2		N
** Total **			89		

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Structure for database: D:\DBASE\MDGW\LANDUSE.DBF
Number of data records: 9
Date of last update : 09/25/89

Field	Field Name	Type	Width	Dec	Index
1	CO_NAME	Character	2		N
2	PCNT_BASIN	Numeric	4	2	N
3	TOT_ACR	Numeric	6		N
4	CROP_ACR	Numeric	6		N
5	CROP_BASIN	Numeric	6		N
6	CROP_PCT	Numeric	4	2	N
7	PAST_ACR	Numeric	6		N
8	PAST_BASIN	Numeric	6		N
9	PAST_PCT	Numeric	4	2	N
10	WOOD_ACR	Numeric	6		N
11	WOOD_BASIN	Numeric	6		N
12	WOOD_PCT	Numeric	4	2	N
13	URBAN_ACR	Numeric	6		N
14	URBN_BASIN	Numeric	6		N
15	URBAN_PCT	Numeric	4	2	N
16	CONS_PCT	Numeric	5	3	N
17	CONV_PCT	Numeric	5	3	N
** Total **			87		

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Structure for database: D:\DBASE\MDGW\SEPTIC.DBF
Number of data records: 9
Date of last update : 09/19/89

Field	Field Name	Type	Width	Dec	Index
1	CO_NAME	Character	2		N
2	SEPT_UNITS	Numeric	6		N
3	PCT_SEPTIC	Numeric	6	3	N
4	POP_PCT	Numeric	6	3	N
** Total **			21		

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Structure for database: D:\DBASE\MDGW\MANURE.DBF
Number of data records: 9
Date of last update : 08/31/89

Field	Field Name	Type	Width	Dec	Index
1	CO_NAME	Character	2		N
2	MANURE_TON	Numeric	8		N
3	DAIR_COWS	Numeric	6		N
** Total **			17		

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Structure for database: D:\DBASE\MDGW\PESTICID.DBF
Number of data records: 108
Date of last update : 09/15/89

Field	Field Name	Type	Width	Dec	Index
1	CO_NAME	Character	2		N
2	PEST_NAME	Character	27		N
3	POUNDS	Numeric	7		N
4	TYPE	Character	9		N
** Total **			46		

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Structure for database: D:\DBASE\MDGW\CHEMPROP.DBF
Number of data records: 40
Date of last update : 09/06/89

Field	Field Name	Type	Width	Dec	Index
1	PEST_NAME	Character	27		N
2	TYPE	Character	7		N
3	CHEM_TYPE	Character	2		N
4	T_HALF	Numeric	4		N
5	PERSIS_MIN	Numeric	5		N
6	PERSIS_MAX	Numeric	5		N
7	SOLUBILITY	Numeric	12	4	N
8	KOC	Numeric	7		N
9	LEACHER	Logical	1		N
10	HEALTH_AD	Logical	1		N
11	RESTRICTED	Logical	1		N
** Total **			73		

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Structure for database: D:\DBASE\MDGW\CORANK.DBF
Number of data records: 9
Date of last update : 09/29/89

Field	Field Name	Type	Width	Dec	Index
1	CO_NAME	Character	2		N
2	USE_VOL	Numeric	1		N
3	USE_POP	Numeric	1		N
4	VUL_AQ	Numeric	1		N
5	PT_POTENT	Numeric	1		N
6	PT_KNOWN	Numeric	1		N
7	CROP_ACRES	Numeric	1		N
8	CONS_TILL	Numeric	1		N
9	MANURE_TON	Numeric	1		N
10	SEPTIC_PCT	Numeric	1		N
11	PEST_TOT	Numeric	1		N
12	LCH_HERB	Numeric	1		N
** Total **			14		

Key fields in each database are indexed, and the index files are used to sort and find data.

Database File	Field Indexed	Index File
aqprop.dbf	aquifer	aqchar.ndx
drastic.dbf	co_name	codras.ndx
aqcowd.dbf	physioprov aquifer co_name	phys.ndx aq.ndx cowd.ndx
cototals.dbf	co_name	cotot.ndx
coqual.dbf	county param	pco.ndx para.ndx
aqchem	physiograf param	physaq.ndx paq.ndx
landfill.dbf	co_name	coland.ndx
cercla.dbf	co_name	cosite.ndx
discharg.dbf	co_name	codis.ndx
coalmine.dbf	co_name	comine.ndx
landuse.dbf	co_name	colu.ndx
septic.dbf	co_name	cosept.ndx
manure.dbf	co-name	coman.ndx
pesticide.dbf	co_name pest_name	copest.ndx pest.ndx

Dbase Programs

Program	Uses Databases:	Generates:
qualprin.prg	coqual.dbf	Table II-2
qprin2.prg	aqqual.dbf	Table II-4
dw.prg	cototals.dbf	Table II-6
aquifers.prg	aqprop.dbf aqcowd.dbf drastic.dbf	Table III-1
sens.prg	aqprop.dbf aqcowd.dbf	Table III-3
countpt.prg	landfill.dbf cercla.dbf discharg.dbf coalmine.dbf	Table III-4
landuse.prg	landuse.dbf	Table III-5
pestsum.prg	pesticide.dbf landuse.dbf	Table III-6 Table III-7
pestleach.prg	chemprop.dbf	Table III-8
ranktable.prg useproc.prg pointproc.prg	corank.dbf cototals.dbf landfill.dbf cercla.dbf discharg.dbf coalmine.dbf	Table IV-1
nonpt.prg	landuse.dbf manure.dbf septic.dbf	
pestproc.prg	pesticide.dbf landuse.dbf	
sumtable.prg	aqcowd.dbf aqprop.dbf cototals.dbf landfill.dbf cercla.dbf discharg.dbf coalmine.dbf landuse.dbf manure.dbf septic.dbf pesticide.dbf	Table IV-2

```
*aquifers.prg
*This program relates three databases and lists county, drastic index, and
* aquifer properties
set talk off
close all
select 1
use drastic
set index to codras
select 2
use aqprop
set index to aqchar, sys
select 3
use aqcowd
set index to cowd, aq, phys
set relation to co_name into drastic, aquifer into aqprop
go top
set heading off
set printer on
set printer to file prop
?
?
?
?"                TableIII-1. Counties, Average DRASTIC Scores, Geologic Formations, and Rock Types in the"
?"                            Potomac River Basin"
?
?"                Appalachian Province"
?
?"                Co. DRASTIC  System        Aquifer                  Rock type"
?
do while .not. eof()
if physioprov = "AP"
? co_name at 15, (drastic->drastic_in) at 22, (aqprop->system) at 28, aquifer at 45 ;
, aqprop->rock_type1 at 70, aqprop->rock_type2 at 83, aqprop->rock_type3 at 93
 endif
 skip
 enddo
 eject
?
?
?"                TableIII-1. Counties, Average DRASTIC Scores, Geologic Formations, and Rock Types in the"
?"                            Potomac River Basin"
?
 ?"                Piedmont Province"
?
?"                Co. DRASTIC  System        Aquifer                  Rock type"
?
go top
do while .not. eof()
if physioprov = "PD"
? co_name at 15, (drastic->drastic_in) at 22, (aqprop->system) at 28, aquifer at 45 ,;
 (aqprop->rock_type1) at 70, aqprop->rock_type2 at 83, aqprop->rock_type3 at 93
```

```
 endif
 skip
 enddo
 ?
 ?
 ?
 ?"              Coastal Plain"
 ?
?"               Co. DRASTIC System          Aquifer                    Rock type"
?
go top
do while .not. eof()
if physioprov = "CP"
? co_name at 15, (drastic->drastic_in) at 22, (aqprop->system) at 28, aquifer at 45 ,;
 (aqprop->rock_type1) at 70, aqprop->rock_type2 at 83, aqprop->rock_type3 at 93
 endif
 skip
 enddo
```

```
*sens.prg
*This program relates two databases and identifies counties and aquifers
*vulnerable to contamination on the basis of transmissivity and depth

select 1
use aqcowd
set index to aq, cowd
select 2
use aqprop
set index to aqchar
set relation to  aquifer into aqcowd
set skip to aqcowd, aqprop
go top
set talk off
set heading off
set printer on
set margin to 8
?
?
?
?"TableIII-3. Aquifers Vulnerable to Contamination"
?
?"Vulnerable Aquifers--Based on Transmissivity"
?
?"Aquifer                      County   Rock Types"
?
list off aquifer + aqcowd->co_name + space(5) + trim(rock_type1) + space (2) +trim(rock_type2) + space(2)+;
 trim(rock_type3) for trans_md1 > 1000 .or. trans_md2 > 1000 .or. trans_md3 > 1000
list off aquifer + aqcowd->co_name + space(5) + rock_type1 + rock_type2 + rock_type3 for trans_max1 > 1999
?
?"Vulnerable Aquifers--Based on Depth to Top of Aquifer"
?
?"Aquifer                      County   Rock Types"
?
list off aquifer + aqcowd->co_name + space (5) + rock_type1 + rock_type2 + rock_type3 ;
for aqcowd->depth_min >= 1 .and. aqcowd->depth_min < 100
* .and. system = "Cretaceous"
*list off aquifer + aqcowd->co_name + space (5) + rock_type1 + rock_type2 + rock_type3;
 *for aqcowd->depth_min > 1 .and. system = "Tertiary"
set printer off
```

```
*qualprin.prg
*This program lists median, minimum, and maximum values for groundwater quality
*parameters (obtained from median values at each well), allowing comparison
* of values among counties

set talk off
     set printer on
     set margin to 15
     set exact off
     ?
     ?
     ?"Table II-2. Summary of Ground Water Quality Data for"
     ?"            Maryland Counties in the Potomac River Basin"
     ?
     ?
     use coqual.dbf
     set index to para.ndx, pco.ndx
     store  "Alk   , Cl    , Conduc, Depth , Fe    , Hard  , Na    , pH    , Diss_R," to paralist
     store 1 to cnt
     do while cnt < 67
store  substr(paralist,cnt,at(",",paralist)-1) to pname
goto top
do case
case pname = "Alk"
?"                   Alkalinity"
?
case pname = "Cl"
?"                   Chloride"
?
case pname = "Conduc"
?"                   Conductivity"
?
case pname = "Depth"
eject
?
?
     ?"Table II-2. Summary of Ground Water Quality Data for"
     ?"            Maryland Counties in the Potomac River Basin"
?
?
?"                   Depth"
?
case pname = "Fe"
?"                   Iron"
?
case pname = "Hard"
?"                   Hardness"
?
case pname = "Na"
     eject
     ?
```

```
     ?
     ?"Table II-2. Summary of Ground Water Quality Data for"
     ?"           Maryland Counties in the Potomac River Basin"
?
?
?"                      Sodium"
?
case pname = "pH"
?"                      pH"
?
 case pname = "Diss_R"
 ?"                     TDS"
 ?
endcase
 list off county, n, min, max, median for param = pname

?
?
?
cnt = cnt + 8
enddo
set printer off
```

```
*qprin2.prg
*This program lists median, minimum, maximum values for groundwater quality
*parameters by Physiographic Province and by aquifer, providing that
*there were more than 3 sampling sites per aquifer.

set talk off
set printer on
set margin to 25
     ?
     ?
     ?"Table II-4. Summary of Water Quality Data for"
     ?"             Aquifers Within the Potomac River Basin"
     ?
     ?
     use aqchem.dbf
     set index to paq.ndx, aq.ndx
     store "Alk   , Cl    , Conduc, Depth , Fe    , Hard  , Na    , pH    " to paralist
     store 1 to cnt
     phys = "AP"
?"-------------------Appalachian Province-----------------"
     ?

     do while cnt < 50
store  substr(paralist,cnt,at(",",paralist)-1) to pname
goto top
do printout
cnt = cnt + 8
enddo

store 1 to cnt
phys = "CP"
eject
     ?
     ?
     ?"Table II-4. Summary of Water Quality Data for"
     ?"             Aquifers Within the Potomac River Basin"
     ?
?
?"-------------------Coastal Plain-----------------------"
?
     do while cnt < 50
store  substr(paralist,cnt,at(",",paralist)-1) to pname
goto top
do printout
cnt = cnt + 8
enddo
set printer off

procedure printout
do case
case pname = "Alk"
```

```
?"                        Alkalinity"
?
case pname = "Cl"
?"                        Chloride"
?
case pname = "Conduc"
?"                        Conductivity"
?
case pname = "Depth"
eject
     ?
     ?
     ?"Table II-4. Summary of Water Quality Data for"
     ?"           Aquifers Within the Potomac River Basin"
     ?
?
?"                        Depth"
?
case pname = "Fe"
?"                        Iron"
?
case pname = "Hard"
?"                        Hardness"
?
case pname = "Na"
?"                        Sodium"
?
case pname = "pH"
?"                        pH"
?

endcase
 list off aquifer, n, min, max, median for param = pname .and. n > 3 .and. physiograf = phys to printer
 ?
?
return
```

```
*dw.prg
*This  program lists number of people using groundwater--public
* and individual supplies--and computes the total

set talk off
set printer on
@ 4,10 say "Table II -6. Number of People Using Groundwater for Drinking
@ 5,24 say "Water in the Potomac River Basin"
@ 7,10 say "County"
@ 7,22 say "Public"
@ 7,37 say "Private"
@ 7,51 say "Total"
@ 8,22 say "Supplies"
@ 8,37 say "Supplies"

use cototals
set index to cotot
store 1 to cnt
store "AL,CL,CH,FR,GA,MO,PG,SM,WA" to gwlist
do while cnt < 26
store substr(gwlist,cnt,at(",",gwlist)-1) to gwname
seek gwname
totpop = pub_dw_no + priv_dw_no
?
? co_name at 14, str(pub_dw_no,6) at 21, str(priv_dw_no,6) at 36,;
 totpop at 47
cnt = cnt + 3
enddo
set printer off
```

```
*countpt.prg
*This program counts the number of point pollution sources of each type
*in each county

set talk off
set print on
set margin to 12
?
?
?
?"Table III-4. Potential Point Pollution Sources for Groundwater"
?
?"County    Landfills  CERCLA     Dischargers  Coalmines   Total"
     ?
     store  "AL,CL,CH,FR,GA,MO,PG,SM,WA" to gwlist
     store 1 to cnt
     do while cnt < 26
*? substr(gwlist,cnt,at(",",gwlist)-1)
store  substr(gwlist,cnt,at(",",gwlist)-1) to gwname
use landfill.dbf
set index to coland
count for co_name = gwname .AND. potential = .T. to lfno
use cercla
set index to cosite
count for co_name = gwname .AND. potential = .T. to cercno
use discharg
set index to codis
count for co_name = gwname  .AND. permit = .T. to dischno1
count for co_name = gwname  .AND. p_process = .T. to dischno2
*dischno = dischno1 = dischno2
use coalmine
set index to comine
count for co_name = gwname  to coalno
totno = lfno + cercno + dischno1 + dischno2 + coalno
?gwname+"  "+str(lfno)+" "+str(cercno)+"  ";
+str(dischno1+dischno2)+"  "+str(coalno)+" "+str(totno)
cnt = cnt + 3
enddo

set print off
```

```
Page #     1

*landuse.prg
*This program lists the acreage and percentage of land in each
* landuse category

set printer on
set device to printer
set talk off
use landuse
set index to colu
set heading off
@ 3,10 say "Table III-5.  Land Use in the Potomac River Basin"
?
?
@ 5,1 say "County"
@ 5,16 say "Cropland"
@ 5, 26 say "Pasture"
@ 5,36 say "Forest"
@ 5,46 say "Urban"
@ 7,30 say "Acres"

store "AL,CL,CH,FR,GA,MO,PG,SM,WA" to gwlist
store 1 to cnt
do while cnt < 26
store substr(gwlist,cnt,at(",",gwlist)-1) to gwname
seek gwname
? co_name at 5, str(crop_basin) at 12, str(past_basin) at 22,;
 str(wood_basin) at 32, urbn_basin at 45
cnt =cnt + 3
enddo

@18,22 say "Percent of County Area"
store 1 to cnt
go top
do while cnt < 26
store substr(gwlist,cnt,at(",",gwlist)-1) to gwname
seek gwname
? co_name at 5, str(crop_pct*100,3) at 17, str(past_pct*100,3) at 27,;
 str(wood_pct*100,3) at 37, str(urban_pct*100,3) at 46
cnt = cnt + 3
enddo
```

Page #   1

```
*pestsum.prg
*calculates total quantity of pesticides applied in 1985 in counties
*calculates total quantity of each pesticide applied in Potomac Basin
* in 1985

set talk off
set printer on
set device to printer
@2,10 say "Table III-6.  Estimated Pesticide Use by County"
@3,10 say "              in the Potomac River Basin"
@5,10 say "County"
@5,20 say "Pesticide Active Ingredients"
@6,30 say "Pounds"
rec_no = 1
     store  "AL,CL,CH,FR,GA,MO,PG,SM,WA" to gwlist
     store 1 to cnt
     do while cnt < 26
*? substr(gwlist,cnt,at(",",gwlist)-1)
store  substr(gwlist,cnt,at(",",gwlist)-1) to gwname
select 1
use landuse
set index to colu
seek gwname
select 2
use pesticide
set index to copest
calculate sum(pounds) for co_name = gwname to totco
totlb = totco * landuse->pcnt_basin
?
?gwname at 14,  str(totlb) at 30
cnt = cnt + 3
enddo
eject

use pesticide
set index to pest
go top
mcount = 1
mname = pest_name
skip
scan
mcount = mcount + IIF(pest_name = mname, 0, 1)
 mname = pest_name
 *?mname + str(mcount)
 endscan
*?mcount

declare pesttot[mcount,2]
go top
mcount = 1
do while .not. eof()
mname = pest_name
```

```
pesttot[mcount,1] = mname
calculate sum(pounds) to pesttot[mcount,2] while pest_name = mname
mcount = mcount + 1
enddo

@2,6 say "Table III-7.  Pesticides, Total Pounds (Active Ingredients)"
@3,6 say "              Applied in Maryland Counties of Potomac Basin"
@6,6 say "Pesticide"
@6,40 say "Total Pounds"
?
all = mcount
mcount = 1
do while mcount < all

?pesttot[mcount,1] at 10,  pesttot[mcount,2] at 40
mcount = mcount + 1
enddo
eject
set printer off
```

```
*pest.leach
* This program generates a table of pesticide properties that influenc
* leaching and fate in the soil environment and an indication whether
* health advisory has been issued.

set talk off
set printer on
set device to printer
use chemprop
set index to pestch

@2,5 say "Table III-8. Properties of Pesticides Applied within the
Potomac"
@3,17 say "River Basin in Maryland"
@5,5 say "Pesticide"
@5,26 say "Chemical"
@5,36 say "Leacher"
@5,45 say "Soluble"
@5,54 say "Persis-"
@5,63 say "Health"
@6,28 say "Class"
@6,55 say "tent"
@6,63 say "Advisory"

declare pestlist[40,6]
go top
mcount =1
do while .not. eof()
pestlist[mcount,1] = pest_name
pestlist[mcount,2] = chem_type
if leacher = .T.
pestlist[mcount,3] = "T"
else
pestlist[mcount,3] = " "
endif
if solubility >= 30
pestlist[mcount,4] = "T"
else
if solubility = 0.0
pestlist[mcount,4] = "ND"
else
pestlist[mcount,4] = "F"
endif
endif
if t_half >= 15 .or. persis_max >= 30
pestlist[mcount,5] = "T"
```

```
else
if t_half = 0 .and. persis_max = 0
pestlist[mcount,5] = "ND"
else
pestlist[mcount,5] = "F"
endif
endif
if health_ad = .T.
pestlist[mcount,6] = "T"
else
pestlist[mcount,6] = " "
endif
mcount = mcount + 1
skip
enddo

mtot = mcount
mcount = 1
do while mcount < mtot
? pestlist[mcount,1] at 5, pestlist[mcount,2] at 30,;
   pestlist[mcount,3] at 39, pestlist[mcount,4] at 47,;
   pestlist[mcount,5] at 56, pestlist[mcount,6] at 65
 mcount = mcount + 1
enddo

?
?"      T, True; ND, No Data; F, False"
?

?"      Chemical classes: AL, aliphatic acids; AM, amides and anilides;
?"      AR, aromatic acids and esters; CB, carbamates; CT, cationics;"
?"      HH, halogenated hydrocarbons; OP, organophosphates; PO, phenoxy
?"      compounds; TZ, triazines and triazoles; UR, ureas"
?
?"      Sources: Nielsen and Lee, 1987; USDA, 1975; Pionke et al, 1986"
?"               Kenaga and Goring, 1980; Callahan, et al., 1979; Farm"
?"               Chemicals Handbook, 1987"
eject
set printer off
```

```
*useproc.prg
*ranks groundwater use based on total estimated use (tot_withrdr)
*and total people served for drinking water (tot_dw)

     store  "AL,GA,WA,FR,CL,MO,PG,CH,SM" to gwlist
     store 1 to cnt
     do while cnt < 26
store  substr(gwlist,cnt,at(",",gwlist)-1) to gwname
select 1
use corank
set index to county
select 2
use cototals
set index to cotot
select 1
seek gwname
select 2
seek gwname
if  tot_withdr < 3
replace corank->use_vol with 4
endif
if  tot_withdr >= 3 .and tot_withdr < 6
replace corank->use_vol with 3
endif
if  tot_withdr >= 6 .and tot_withdr < 9
replace corank->use_vol with 2
endif
if  tot_withdr >= 9 .and tot_withdr < 12
replace corank->use_vol with 1
endif

if tot_dw < 25000
replace corank->use_pop with 4
endif
if  tot_dw >= 25000 .and. tot_dw < 50000
replace corank->use_pop with 3
endif
if  tot_dw >= 50000 .and. tot_dw < 75000
replace corank->use_pop with 2
endif
if  tot_dw >= 75000
replace corank->use_pop with 1
endif

cnt = cnt + 3
enddo
close all
```

```
*pointproc.prg
*counts the number of point pollution sources of each type
*in each county

     store  "AL,GA,WA,FR,CL,MO,PG,CH,SM" to gwlist
     store 1 to cnt
     do while cnt < 26
store  substr(gwlist,cnt,at(",",gwlist)-1) to gwname
use landfill.dbf
set index to coland
count for co_name = gwname .AND. potential = .T. to lfno
use cercla
set index to cosite
count for co_name = gwname .AND. potential = .T. to cercno
*count for co_name = gwname .AND. known = .T. to npl
use discharg
set index to codis
count for co_name = gwname  .AND. permit = .T. to dischno1
count for co_name = gwname  .AND. p_process = .T. to dischno2
use coalmine
set index to comine
count for co_name = gwname  to coalno
totno = lfno + cercno + dischno1 + dischno2 + coalno
use corank
set index to county
seek gwname
if totno <= 6
replace pt_potent with 4
endif
if totno >6 .and. totno <= 12
replace pt_potent with 3
endif
if totno > 12 .and. totno <= 18
replace pt_potent with 2
endif
if totno >18
replace pt_potent with 1
endif
cnt = cnt + 3
enddo
close all
```

```
*nonpt.prg
*ranks counties for nonpoint pollutions sources: croplands, acres
*in conservation till, manure production, and septic system densities

set talk off
     store  "AL,GA,WA,FR,CL,MO,PG,CH,SM," to gwlist
     store 1 to cnt
     do while cnt < 26
store  substr(gwlist,cnt,at(",",gwlist)-1) to gwname
select 1
use corank
set index to county
select 2
use landuse
set index to colu
set relation to co_name into corank
select 1
seek gwname
select 2
seek gwname
if crop_basin < 50000
replace corank->crop_acres with 4
endif
if crop_basin >= 50000 .and. crop_basin < 100000
replace corank->crop_acres with 3
endif
if crop_basin >= 100000 .and. crop_basin  < 150000
replace corank->crop_acres with 2
endif
if crop_basin >= 150000
replace corank->crop_acres with 1
endif

till = crop_basin * cons_pct
if till < 15000
replace corank->cons_till with 4
endif
if till  >= 15000 .and. till  < 30000
replace corank->cons_till with 3
endif
if till >= 30000 .and. till < 45000
replace corank->cons_till with 2
endif
if cons_pct >= 45000
replace corank->cons_till with 1
endif

select 3
use manure
set index to coman
set relation to co_name into landuse
set relation to co_name  into corank
```

```
select 1
seek gwname
select 2
seek gwname
select 3
seek gwname
calcman = manure_ton * landuse->pcnt_basin
if calcman < 100000
replace corank->manure_ton with 4
endif
if calcman >= 100000 .and. calcman < 200000
replace corank->manure_ton with 3
endif
if calcman >= 200000 .and. calcman < 300000
replace corank->manure_ton with 2
endif
if calcman >= 300000
replace corank->manure_ton with 1
endif

select 4
use septic
set index to cosept
set relation to co_name into corank
select 1
seek gwname
select 4
seek gwname
sept_basin = sept_units * pop_pct
if sept_basin < 5000
replace corank->septic_pct with 4
endif
if sept_basin >= 5000 .and. sept_basin < 10000
replace corank->septic_pct with 3
endif
if sept_basin >= 10000 .and. sept_basin < 15000
replace corank->septic_pct with 2
endif
if sept_basin >= 15000
replace corank->septic_pct with 1
endif

cnt = cnt + 3
enddo
close all
```

```
      *pestproc.prg
      *Adjusts pesticide usage figures to Potomac basin area in each
      *county and ranks counties by pesticide usage.

      store  "AL,GA,WA,FR,CL,MO,PG,CH,SM" to gwlist
      store 1 to cnt
      do while cnt < 26
store  substr(gwlist,cnt,at(",",gwlist)-1) to gwname
select 1
use landuse
 set index to colu
seek gwname
select 2
use pesticide
set index to copest
calculate sum(pounds) for co_name = gwname to totco
totlb = totco * landuse->pcnt_basin
use corank
set index to county
seek gwname
if totlb < 200000
replace pest_tot with 4
endif
if totlb >= 200000 .and. totlb < 400000
replace pest_tot with 3
endif
if totlb >= 400000 .and. totlb < 600000
replace pest_tot with 2
endif
if totlb >= 600000
replace pest_tot with 1
endif

cnt = cnt + 3
enddo
close all
```

```
*sumtable.prg
*compiles county totals for vulnerable aquifers, groundwater use, point and nonpoint pollution sources

close all
set printer on
set device to printer
set printer to file sum
@2,0 say "TableIV-2. Groundwater Use, Vulnerable Aquifers, and Pollution Sources for Maryland Counties in the Potomac River Ba
@5,0 say "County"
@5,11 say "Vulnerable"
@5,27 say "GW Use"
@5,40 say "Point Sources"
@5,60 say "Nonpoint Sources"
@5,82 say "Manure"
@5,94 say "Septic"
@5,107 say "Pesticides"
@6,11 say "Aquifers"
@6,24 say "Vol     Pop"
@6,40 say "Potent."
@6,49 say "Actual"
@6,60 say "Crops"
@6,70 say "Cons. Till"
@6,83 say "Tons"
@6,94 say "Systems"
@6,107 say "Tons"
@7,13 say "T   D"
@7,61 say "Acres"
@7,71 say "Acres"
declare sumtab[9,12]
store "AL,GA,WA,FR,CL,MO,PG,CH,SM" to gwlist
store 1 to mcount
store 1 to cnt

do while cnt < 26
store substr(gwlist,cnt,at(",",gwlist)-1) to sumtab[mcount,1]
*counts the number of vulnerable aquifers based on transmissivity
*counts the number of vulnerable Coastal Plain aquifers based on depth
select 1
use aqcowd
set index to aq, cowd
select 2
use aqprop
set index to aqchar
set relation to  aquifer into aqcowd
set skip to aqcowd, aqprop
go top
set heading off
count for  aqcowd->co_name = sumtab[mcount,1] .and. (trans_md1 > 1000;
 .or. trans_md2 > 1000 .or. trans_md3 > 1000 .or. trans_max1 > 1999) to vt
sumtab[mcount,2] = str(vt,1,0)
select 1
```

```
go top
count for physioprov ="CP".and. co_name = sumtab[mcount,1] .and. depth_min < 100  to  dt
sumtab[mcount,3]= str(dt,1,0)

* finds total gw withdrawal by volume and number of people served for each county
use cototals
set index to cotot
seek sumtab[mcount,1]
sumtab[mcount,4] = str(tot_withdr,5,2)
sumtab[mcount,5] = str(tot_dw,6,0)

* counts potential and known point sources of contamination
use landfill
set index to coland
count for co_name = sumtab[mcount,1] .and. potential = .T. to lfno
use cercla
set index to cosite
count for co_name = sumtab[mcount,1] .and. potential = .T. to cercno
count for co_name = sumtab[mcount,1] .and. known = .T. to  kcerc
sumtab[mcount,7] = str(kcerc,1,0)
use discharg
set index to codis
count for co_name = sumtab[mcount,1];
 .and. (permit = .T. .or. p_process = .T.) to dischno
use coalmine
count for co_name = sumtab[mcount,1] to coalno
sumtab[mcount,6] = str(lfno + cercno + dischno + coalno,2,0)

*Obtains totals for landuse, septic systems, manure, and pesticides
select 3
use landuse
set index to colu
seek sumtab[mcount,1]
sumtab[mcount,8] = str(crop_basin,6,0)
ct = crop_basin * cons_pct
sumtab[mcount,9] = str(ct,6,0)

select 4
use manure
set index to coman
set relation to co_name into landuse
seek sumtab[mcount,1]
calcman = manure_ton * landuse->pcnt_basin
sumtab[mcount,10] = str(calcman,6,0)

use septic
set index to cosept
seek sumtab[mcount,1]
basin_sept = sept_units * pop_pct
sumtab[mcount,11]= str(basin_sept,6,0)
```

```
use pesticide
set index to copest
calculate sum(pounds) for co_name = sumtab[mcount,1] to pesttot
sumtab[mcount,12]= str(pesttot,6,0)

?sumtab[mcount,1] at 2, sumtab[mcount,2] at 13, sumtab[mcount,3] at 17,;
 sumtab[mcount,4] at 23, sumtab[mcount,5] at 31, sumtab[mcount,6] at 43,;
 sumtab[mcount,7] at 50, sumtab[mcount,8] at 60, sumtab[mcount,9] at 70,;
 sumtab[mcount,10] at 82, sumtab[mcount,11] at 94, sumtab[mcount,12] at 106

mcount = mcount + 1
cnt = cnt + 3
enddo
*set printer off
*set device to screen
```

Page #   1

```
*ranktable.prg
*master program ranking counties on groundwater use, vulnerable aquifers
*point and non-point sources.  Calls four sub-programs.

close all
set device to printer
set printer on
set talk off

do useproc

do pointproc

do nonpt

do pestproc

@ 5,10 say "Table IV-1. Counties and Rankings for Groundwater Use, Point
@ 6,22 say "Non-point Contamination Sources"
@ 8,10 say "County"
@ 8,20 say "Vuln."
@ 8,28 say "Use"
@ 8,40 say "Point"
@ 8,52 say "Non-point Sources"
@ 9,19 say "Aquifer"
@ 9,40 say "Sources"
@ 10,28 say "Vol"
@ 10,32 say "Pop"
@ 10,39 say "Pot."
@ 10,44 say "Act."
@ 10,52 say "C   C-T   M    S    P"
?
use corank
go top
do while .not. eof()
? co_name at 10, vul_aq at 22, use_vol at 29,;
 use_pop at 33, pt_potent at 40,pt_known at 44,;
 crop_acres at 52, cons_till at 57, manure_ton at 62,;
 septic_pct at 67, pest_tot at 72
skip
enddo
@25,10 say "C = Acres in Cropland"
@26,10 say "C-T = Acres on Conservation Till"
@27,10 say "T = Tons of Manure"
@ 28,10 say "S = Septic Units"
@ 29, 10 say "P = Tons of Pesticides Applied"

set printer off
```

APPENDIX B

Glossary of Groundwater Terms

APPENDIX B

GLOSSARY

Alluvium - Sediments, such as gravel, sand, silt or clay, that have been deposited by running water.

Aquiclude - Impermeable material, such as clay or unfractured rock, that does not transmit significant quantities of ground water to wells.

Aquifer - A geologic formation, group of formations or part of a formation that contains permeable sediment sufficiently saturated to yield significant quantities of water to wells and springs.

Aquitard - Semi-permeable material, such as silt or slightly fractured rock, that transmits some ground water but is not capable of producing significant well yields. Aquitards are often called leaky confining beds.

Base flow - That part of stream discharge that is derived from ground water seeping into a stream.

Confined aquifer - An aquifer that is overlain by a confining bed. The confining bed is significantly less permeable than the aquifer. Artesian aquifer is a synonym.

Confining bed - A layer of low permeability that is stratigraphically adjacent to one of more aquifers. It may lie above or below an aquifer.

Dolomite - A mineral composed of calcium and magnesium carbonate, $CaMg(CO_3)_2$. It is also used as a rock name for formations composed of the mineral dolomite. There are several dolomite formations in the Great Valley (or Hagerstown Valley).

Formation - A body of rock or sediment of similar composition and age.

Hardness - A property of water caused by the combination of calcium and magnesium ions with bicarbonate. Excessive hardness may produce residue on pipes and heaters and promote increased use of laundry detergent and soap.

Impermeable - Little or no ability to transmit fluids.

Limestone - A sedimentary rock, primarily composed of the mineral calcite, formed by either organic or inorganic processes.

Outcrop - The part of a geologic formation or structure that appears at the surface of the earth.

Permeability - A measure of the capacity of a rock or sediment to transmit water.

pH - A measure of the acidity or alkalinity of a solution. The scale ranges from 1 to 14, with pH=1 as most acidic, pH-14 as most alkaline and pH=7 as a neutral value.

Physiographic province - A region of similar geologic structure, climate and erosional history; and whose topography or landforms differ significantly from those of adjacent regions.

Porosity - The percentage of open space or interstices in a rock or sediment. See primary porosity and secondary porosity.

Recharge - The process of absorption and addition of water to the zone of saturation. Ground water replenishment is a synonym.

Saprolite - Saprolite is formed when ground water moves through the fractured upper layer of bedrock and removes the most soluble constituents leaving behind disintegrated rock which remains the original texture and structure of the parent rock.

Sedimentary rock - A rock formed when an accumulation of sediments is consolidated by pressure and/or cementation.

Specific capacity - A measure of the productivity of a well that is obtained by dividing the rate of water discharge from the well by the drawdown of the water level in the well. Specific capacity is usually expressed in gallons per minute per foot of drawdown (gpm/ft).

Storage coefficient - A dimensionless term describing the volume of water that a permeable material will absorb or expel per unit area, per unit change in pressure. Storativity is a synonym.

Subcrop - The outcrop of a formation that is covered by a thin veneer of rock or sediment from a different formation.

Total dissolved solids (TDS) - A measure of all mineral salts contained in a water sample, excluding suspended sediments, colloidal particles and dissolved gases.

Transmissivity - The rate of water movement through a vertical section of an aquifer that is one foot wide. Transmissivity is measured in units such as feet squared per day (ft^2/day) or gallons per day per foot (gpd/ft).

Unconfined aquifer - An acquifer which has no confining beds between the zone of saturation and the surface. There will be a water table in an unconfined aquifer. Water table aquifer is a synonym.

Updip - A direction that is upwards and parallel to the dip of a formation.

Water table - The upper surface of the zone of saturation for ground water. It is an irregular surface with a slope or shape determined by the quantity of ground water and the permeability of earth materials. The water table surface often mimics local topography.

Well yield - The maximum pumping rate that can be supplied by a well without the water level dropping below the pump intake, usually expressed in gallons per minute (gpm) or gallons per day (gpd).

APPENDIX C

Maximum Contaminant Levels for

Drinking Water

Established by the State of Maryland

Drinking Water Standards Established by the State of Maryland

(from COMAR 26.04.01)

These standards apply for each public water system in the state:

<u>Maximum Contaminant Levels for Inorganic Contaminants</u>

	mg/l
As	0.05
Ba	1
Cd	0.01
Cr	0.05
Pb	0.05
Hg	0.002
NO^3 as N	10
Se	0.01
Ag	0.05

(The MCL for NO^3 is applicable to both community and non-community water systems)

Maximum Contaminant Levels for Organic Contaminants

Endrin	0.0002
Lindane	0.004
Methoxychlor	0.1
Toxaphene	0.005
2,4-D	0.1
1,4,5-TP Silvex	0.01
Total Trihalomethanes	0.10

MCL's for Radioactive Substances--applicable to community water systems

1. Alpha particle radioactivity

Ra-226 + Ra-228	5
Gross alpha particle activity	15

2. Beta particle and photon radioactivity from man-made radionuclides

Drinking Water Standards Established by the State of Maryland

(from COMAR 26.04.01)

Maximum Contaminant Levels for Coliform Bacteria

1. Membrane filter technique

1 coliform/100 ml--arithmetic mean of all samples per month

4 coliform/100 ml in more than 5% of the samples when 20 or more are examined per month

2. Fermentation tube method and 10 ml std portions--coliforms may not be present in any of the following:

> 10% of portions in one month

3 or more portions in more than one sample when less than 20 samples examines per month

3 or more portions in more than 5% of the samples if 20 or more samples examined per month.

3. Fermentation tube method and 100 ml std-- coliforms may not be present in any of the following:

> 60% of portions in a month

5 portions in more than one sample when < 5 samples examined per month

5 portions in more than 20% of samples when 5 or more samples examined per month.

4. Systems required to sample at rate of less than 4 per month, compliance with above regulations determined on a 3-month period

APPENDIX D

Parameters Selected for Retrieval in STORET and Those for Which Data Was Obtained

Parameters Selected for Retrieval in Storet

The following parameters were selected for inclusion in the Potomac River Basin Ground Water Database using two criteria: they are regulated by the Safe Drinking Water Act, and the results of over 800 analyses for each of the parameters are available on Storet during the 1975-1989 period.

Storet Code	Parameter	
01002	Arsenic	ug/l
01007	Barium	ug/l
01027	Cadmium	ug/l
00940	Chloride	mg/l
01034	Chromium	ug/l
01042	Copper	ug/l
00951	Flouride	mg/l
01045	Iron, Total	ug/l
01051	Lead	ug/l
71890	Mercury	ug/l
01067	Nickel	ug/l
01147	Selenium	ug/l
01077	Silver	ug/l
00930	Sodium	mg/l
01092	Zinc	ug/l
00620	Nitrate-N	mg/l
00615	Nitrite-N	mg/l
31505	Total Coliform	MPN/100 ml

Not regulated by the SDA, but plentiful data and essential information:

84001	Aquifer Name	
84000	Geologic Age	
00027	Collect Agency	
72000	Land Surface Datum	feet
72019	Depth	feet below surface
00403	pH	
00680	Tot Org Carbon	mg/l
00515	Residue Diss-105 C	mg/l
70300	Residue Diss-180 C	mg/l
00095	Conductivity	microhm
00410	Tot Alk., $CaCo_3$	mg/l
00608	Ammonia + Ammonium	mg/l
00900	T Hardness, $CaCO_3$	mg/l

Appendix E

Largest Ground Water Withdrawals in the Potomac River Basin in Maryland-1985

Garrett		
City of Frostburg, Allegany County	0.162	Pocono
Montgomery		
Commissioners of Poolesville	0.283	New Oxford Formation
NIH (Poolesville)	0.062	
Leisure World of Md. (Silver Spring)	0.052	
Burning Tree Club, Inc. (Bethesda)	0.026	
Prince George's		
USDA Beltsville Agricülrual Research	0.526	Patuxent Formation
St. Mary's		
Waring Assoc., Inc (Lord Calvert and Hills Trailer Parks)	0.133	Piney Point Aquifer
Commissioners of Leonardtown	0.364	Aquia Aquifer
St. Mary's Co. Metropolitan Commission-Lexington Park	0.771	Aquia Aquifer
St. Mary's College of Maryland	0.037	
Washington		
U.S. Army-Ft. Ritchie	0.265	Weaverton
Town of Brunswick, Frederick Co.	0.195	Harpers
Boonsboro Utilities Commission-Keedysville	0.175	Tomstown Dolomite
Boonsboro Utilities Commission-Boonsboro	0.115	Tomstown Dolomite
Town of Clear Springs	0.156	Oriskany Sandstone

*Quarry dewatering

Largest Groundwater Withdrawals in the Potomac River Basin in Maryland 1985

County/Facility	Average Withdrawal (mgd)	Formation
Allegany		
La Vale Sanitary Commission	0.256	
Mt. Savage Water Company	0.020	
Carroll		
Genstar Stone Products-Medford Quarry*	0.931	Wakefield Marble
City of Tanneytown	0.294	New Oxford Formation
Town of Manchester	0.204	Wissahickon Formation
City of Westminister	0.109	
Charles		
Charles Co. Commissioners- Waldorf	2.904	Magothy Aquifer
Potomac Utilities Corp./Charles Co. Dept of Public Words	0.104	Patapsco Formation
Town of Indian Head	0.114	Patapsco Formation
Naval Facilities Engineering Command- Indian Head Ordnance Sta.	1.401	Patapsco Formation
Town of La Plata	0.324	Patapsco Formation
	0.288	
PEPCO-Morgantown	0.607	Patapsco Formation
Charles Co. Commissioners-St. Paul's Smallwood West, White Oak	0.306	Patapsco Formation
Charles Utilities, Inc.- Bryans' Road Community Supply	0.130	Patuxent Formation
Potomac Hgts Mutual Home Owners Assoc	0.192	Patuxent Formation
Frederick		
Hunting Creek Fisheries	0.347	Gettysburg Shale
Frederick County-Ballenger Cr. System	0.148	Grove Limestone
Frederick County-Ballenger Cr. System	0.263	Frederick Limestone
CoPlay Cement Company (Buckeystown)*	0.438	Grove Limestone
Town of Walkersville	0.445	Grove Limestone
Town of Middletown	0.125	Catoctin Metabasalt
Foundtaindale Subdivision	0.133	Catoctin Metabasalt
Braddock Water Company	0.152	Harpers, Antietam, Catoctin
Lehigh Portland Cement Company	0.364	Antietam
Town of Mt. Airy	0.253	Marburg Formation
Lehigh Portland Cement Company (Woodsboro)*	0.364	
Genstar Stone Products Company- Frederick Quarry*	1.617	