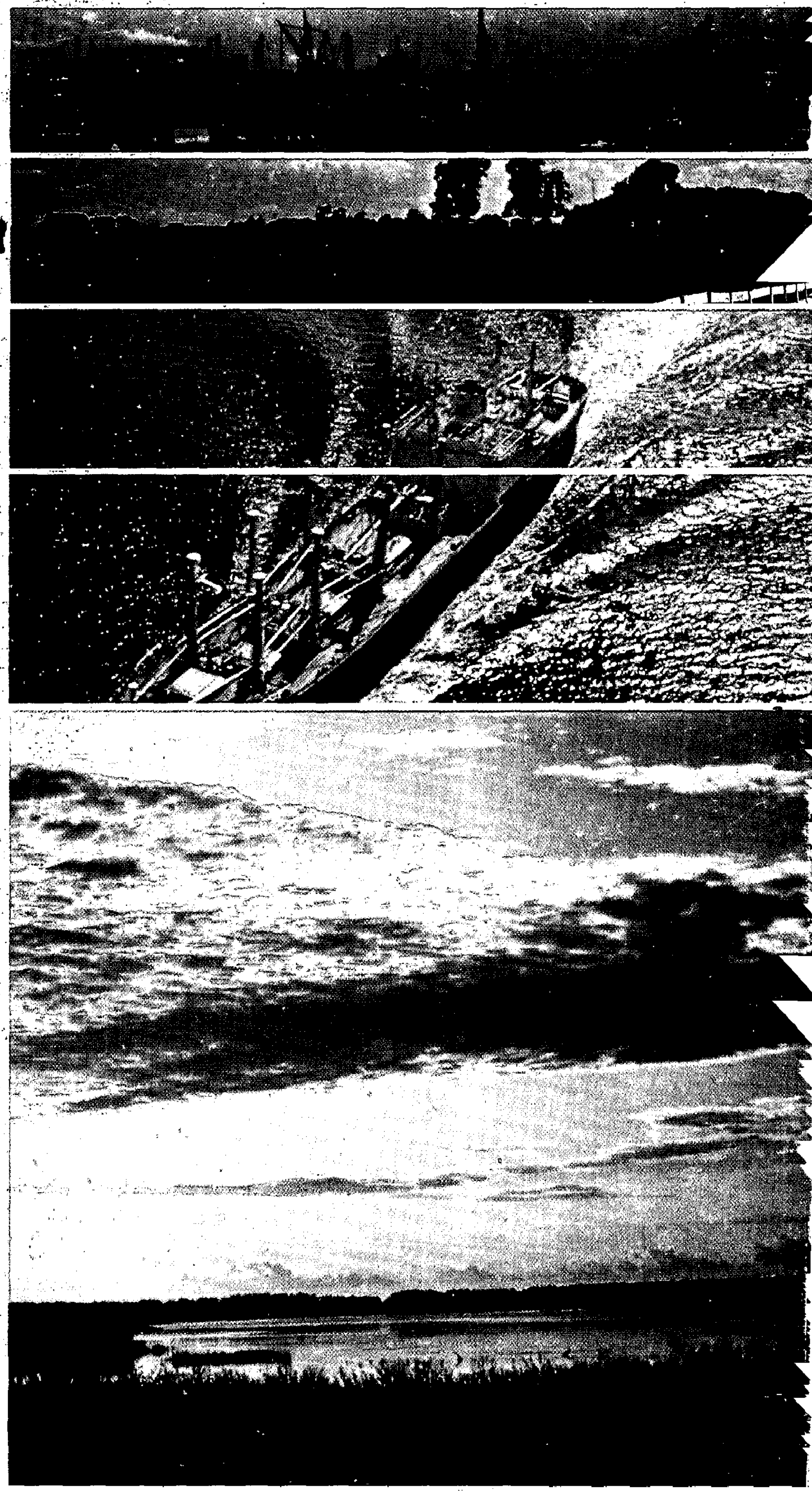
VOLUME 5

Water Supply



U.S. Army Corps of Engineers

Chesapeake Bay

FUTURE CONDITIONS REPORT

PREFACE

The Corps of Engineers' comprehensive study of Chesapeake Bay is being accomplished in three distinct developmental stages or phases. Each of these phases is responsive to one of the following stated objectives of the study program.

1. To assess the existing physical, chemical, biological, economic and environmental conditions of Chesapeake Bay and its related land resources.

2. To project the future water resources needs of Chesapeake Bay to the year 2020.

3. To formulate and recommend solutions to priority problems using the Chesapeake Bay Hydraulic Model.

In response to the first objective of the study, the initial or inventory phase of the program was completed in 1973 and the findings were published in a document titled *Chesapeake Bay Existing Conditions Report*. Included in this seven-volume report is a description of the existing physical, economic, social, biological and environmental conditions of Chesapeake Bay. This was the first published report that presented a comprehensive survey of the entire Bay Region and treated the Chesapeake Bay as a single entity. Most importantly, the report contains the historical records and basic data required to project the future demands on the Bay and to assess the ability of the resource to meet those demands.

In response to the second objective of the study, the findings of the second or future projections phase of the program are provided in this the *Chesapeake Bay Future Conditions Report*. The primary focus of this report is the projection of water resources needs to the year 2020 and the identification of the problems and conflicts which would result from the unrestrained growth and use of the Bay's resources. This report, therefore, provides the basic information necessary to proceed into the next or plan formulation phase of the program. It should be emphasized that, by design, this report addresses only the water resources related needs and problems. No attempt has been made to identify or analyze solutions to specific problems. Solutions to priority problems will be evaluated in the third phase of the program and the findings will be published in subsequent reports.

The *Chesapeake Bay Future Conditions Report* consists of a summary document and 16 supporting appendices. Appendices 1 and 2 are general background documents containing information describing the history and conduct of the study and the manner in which the study was coordinated with the various Federal and State agencies, scientific institutions and the public. Appendices 3 through 15 each contain information on specific water and related land resource uses to include an inventory of the present status and expected future needs and problems. Appendix 16 focuses on the formulation of the initial testing program for the Chesapeake Bay Hydraulic Model. Included in this appendix is a description of the hydraulic model, a list of problems considered for inclusion in the initial testing program and a detailed description of the selected first year model studies program.

The published volumes of the *Chesapeake Bay Future Conditions Report* include:

Volume Number	Appendix Number and Title
1	Summary Report
2	1 – Study Organization, Coordination and History 2 – Public Participation and Information
3	3 – Economic and Social Profile
4	4 – Water-Related Land Resources
5	5 – Municipal and Industrial Water Supply 6 – Agricultural Water Supply
6	7 – Water Quality
7	8 – Recreation
8	9 – Navigation 10 – Flood Control 11 – Shoreline Erosion
9	12 – Fish and Wildlife
10	13 – Power 14 – Noxious Weeds
11	15 – Biota
12	16 – Hydraulic Model Testing

CHESAPEAKE BAY FUTURE CONDITIONS REPORT

APPENDIX 5

MUNICIPAL AND INDUSTRIAL WATER SUPPLY

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CHAPTER I

THE STUDY AND THE REPORT

The Chesapeake Bay Study evolved through the need for a complete and comprehensive investigation of the use and control of the water resources of the Bay Area. Chesapeake Bay is a vast natural resource. Along with its tributaries, the Bay provides a natural transportation network on which the economic development of the Region has been based, a wide variety of water-oriented recreational opportunities, a home for numerous fish and wildlife, a source of water supply for both municipalities and industries, and the site for final disposal of our waste products. All of the natural resources provided by the Bay interact with each other, in conjunction with the activities of man, to form a complex but interrelated system. Unfortunately, problems often arise when man's intended use of one resource conflicts with either the natural environment or man's use of another resource. It was towards a plan for the most efficient use of the Bay's natural resources that the Chesapeake Bay Study was conceived.

In the first phase of the Study, the existing physical, biological, economic, social, and environmental conditions and problem areas were identified and presented in the *Existing Conditions Report*. The *Future Conditions Report,* of which this appendix is a part, presents the findings of the second or projections phase of the Study. Included as part of the second phase are the projections of future water resource needs and problem areas, identification of general means that might best be used to satisfy those needs, and recommendations for future studies and hydraulic model testing. The results of this phase of the Study and this report constitute the next step toward the goal of developing a comprehensive water resource management program for Chesapeake Bay.

The tributaries that flow into the Bay serve as sources of municipal and industrial water supply as do the vast ground water resources that underlie the Bay Region. The demands on both the surface and ground water resources have increased substantially in the past two decades and are expected to increase even more over the next 50 years. As these demands on the Bay's sources of freshwater increase, conflicts will arise between those activities or resources that require freshwater.

The subject of this volume is municipal and industrial water supply, and as such, will focus on the existing and future demands for freshwater in the Bay Region. In addition to identifying the future water supply demands, this volume also provides an assessment of both available freshwater supplies and potential deficits. Also included is a discussion of the measures that can be used to either meet or control future water supply demands. Those studies required to develop comprehensive water supply plans for the Chesapeake Bay Region are also identified.

AUTHORITY

The authority for the Chesapeake Bay Study and the construction of the hydraulic model is contained in Section 312 of the River and Harbor Act of 1965, adopted 27 October 1965, which reads as follows:

> (a) The Secretary of the Army, acting through the Chief of Engineers, is authorized and directed to make a complete investigation and study of water utilization and control of the Chesapeake Bay Basin, including the waters of the Baltimore Harbor and including, but not limited to, the following: navigation, fisheries, flood control, control of noxious weeds, water pollution, water quality control, beach erosion, and recreation. In order to carry out the purposes of this section, the Secretary, acting through the Chief of Engineers, shall construct, operate, and maintain in the State of Maryland a hydraulic model of the Chesapeake Bay Basin and associated technical center. Such model and center may be utilized, subject to such terms and conditions as the Secretary deems necessary, by any department, agency, or instrumentality of the Federal Government or of the States of Maryland, Virginia, and Pennsylvania, in connection with any research, investigation, or study being carried on by them of any aspects of the Chesapeake Bay Basin. The study authorized by this section shall be given priority.
>
> (b) There is authorized to be appropriated not to exceed $6,000,000 to carry out this section.

An additional appropriation for the study was provided in Section 3 of the River Basin Monetary Authorization act of 1970, adopted 19 June 1970, which reads as follows:

> In addition to the previous authorization, the completion of the Chesapeake Bay Basin Comprehensive Study, Maryland, Virginia, and Pennsylvania, authorized by the River and Harbor Act of 1965 is hereby authorized at an estimated cost of $9,000,000.

As a result of Tropical Storm Agnes, which caused extensive damage in Chesapeake Bay, Public Law 92-607, the Supplemental Appropriation Act of 1973, signed by the President on 31 December 1972, included $275,000 for additional studies of the impact of the storm on Chesapeake Bay.

PURPOSE

Historically, measures taken to utilize and control the water and land resources of the Chesapeake Bay Basin have generally been oriented toward solving individual problems. The Chesapeake Bay Study provides a comprehensive study of the entire Bay Area in order that the most beneficial use be made of the water-related resources. The major objectives of the Study are to:

a. Assess the existing physical, chemical, biological, economic, and environmental conditions of Chesapeake Bay and its water resources.

b. Project the future water resources needs of Chesapeake Bay to the year 2020.

c. Formulate and recommend solutions to priority problems using the Chesapeake Bay Hydraulic Model.

The *Chesapeake Bay Existing Conditions Report,* published in 1973, met the first objective of the Study by presenting a detailed inventory of the Chesapeake Bay and its water resources. Divided into a summary and four appendixes, the report presented an overview of the Bay Area and the economy; a survey of the Bay's land resources and its use; and a description of the Bay's life forms and hydrodynamics.

The purpose of the *Future Conditions Report* is to provide a format for presenting the findings of the Chesapeake Bay Study. Satisfying the second objective of the Study, the report describes the present use of the resource, presents the demands to be placed on the resource to the year 2020, assesses the ability of the resources to meet future demands, and identifies additional studies required to develop a management plan for Chesapeake Bay.

This particular appendix was developed as the water supply link in the assessment of the future conditions of the Bay. The findings in this volume, as regards the future needs for water, will provide a basis for comparison with other resource categories. Since it is understood that future growth in water supply demand will vary according to many local conditions, the results presented here are not intended as detailed assessments of the future water needs for the individual water systems. Rather, the demands are intended more as a guide for region-wide resource analysis and problem identification. In the sense that future uses and consumptive losses of water may cause conflicts with other resource categories and uses, the information presented here will also serve to identify these present or emerging conflicts.

SCOPE

The scope of the Chesapeake Bay Study and the *Future Conditions Report* includes the fields of engineering and the social, physical, and biological sciences. The Study is being coordinated with all Federal, State, and local agencies having an interest in Chesapeake Bay. Each resource category or problem area has been treated on an individual basis with demands and potential problem areas projected to the year 2020. The results of the studies conducted for each resource category are presented in a separate appendix to the *Future Conditions Report.* All conclusions are based on historical information supplied by the preparing agencies having expertise in that field. In addition, the basic assumptions and methodologies are quantified for accuracy in the sensitivity section. Only general means to satisfy the projected resource needs are presented, as specific recommendations are beyond the scope of this report.

The geographical area considered in the overall study encompasses those counties or Standard Metropolitan Statistical Areas (SMSA) which adjoin or have a major influence on the Estuary. For purposes of projecting the future demands on the resources of the Bay, economic and demographic projections were made for all subregions and SMSA's within the Study Area. Regarding water supply, the Study Area was divided into 12 subregions as shown on Figure 5-1. The subregions coincide exactly with the standard SMSA and county grouping designations, except Subregions 2 and 4. Subregion 4 is defined for the purpose of this report as Sussex County, Delaware. Subregion 2 is the "non-SMSA," Maryland, portion of the Baltimore Economic Area, expanded to include Cecil County, Maryland. Detailed maps of each of the subregions considered in this appendix are presented as Plates 5-1 through 5-4 at the back of this report.

SUPPORTING STUDIES

This appendix was prepared and coordinated by the Baltimore District, Corps of Engineers; however, much of the information included in this report was derived from other sources. Population projections were prepared for each county in the Bay Area, and each city of over 2,500 persons, by the Bureau of Economic Analysis, U.S. Department of Commerce. Projections of industrial water supply were prepared specifically for the Chesapeake Bay Study by the Bureau of Domestic Commerce of the U.S. Department of Commerce. In addition, all agricultural demands, including rural domestic, livestock and poultry, and irrigation uses, were projected for this Study by the Economic Research Service, U.S. Department of Agriculture. The Economic Research Service work is presented in its entirety in Appendix 6 — Agricultural Water Supply.

The initial data base and resource inventory for all resource categories in the Chesapeake Bay Study, including water supply, were presented in the

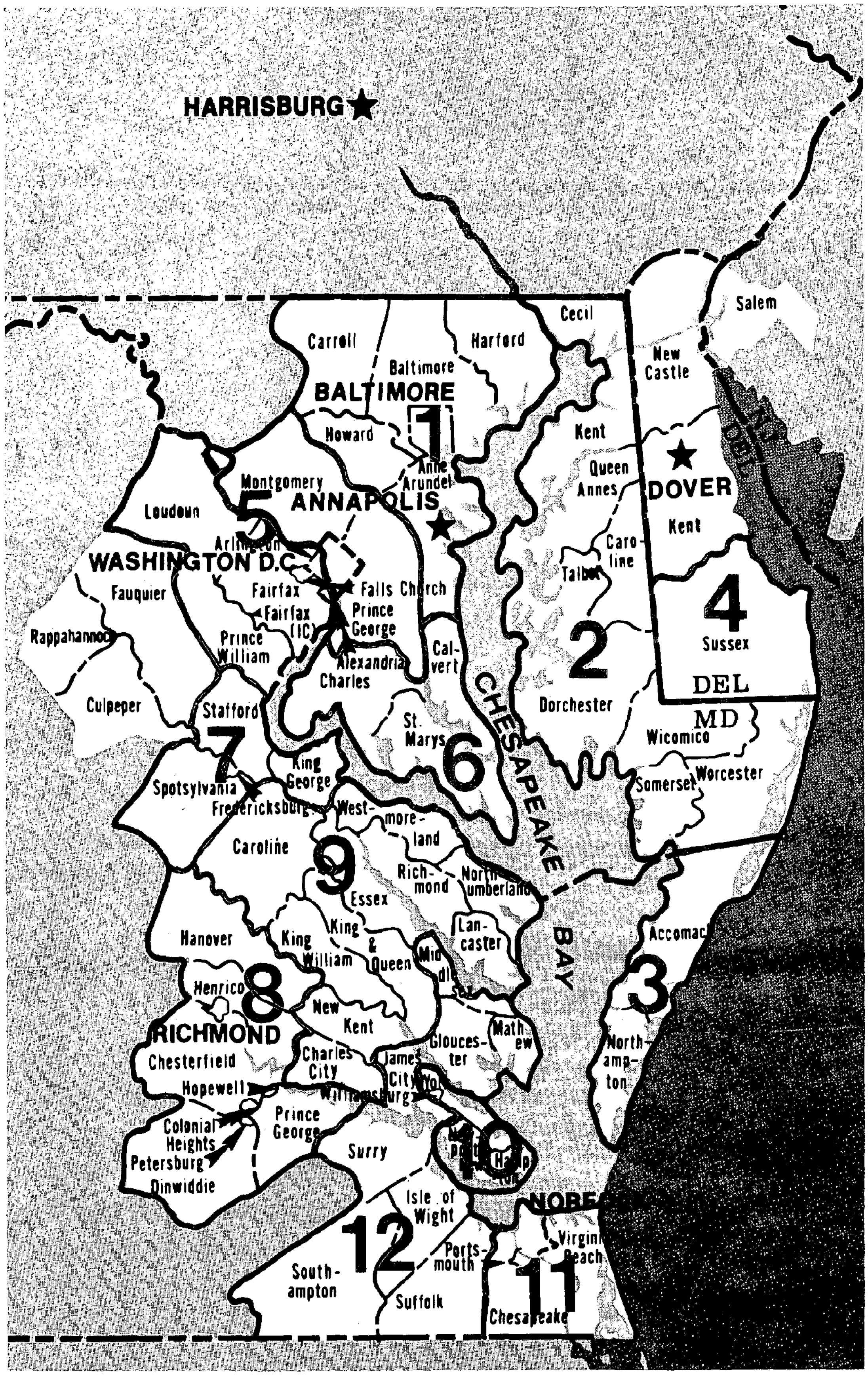


FIGURE 5-1 Subregional Breakdown of the Chesapeake Bay Study Area

Chesapeake Bay Existing Conditions Report. Other studies that provided input to this appendix include the *Northeastern United States Water Supply Report,* and the *North Atlantic Regional Water Resources Study* prepared by the North Atlantic Division, Corps of Engineers. Numerous water supply studies prepared by local planning agencies were also very helpful in the preparation of this appendix. All sources of data used in this appendix are referenced in the bibliography.

STUDY PARTICIPATION AND COORDINATION

Due to the wide scope, large geographical area, and many resources covered by the Chesapeake Bay Study, data input was required from many sources. Various Federal, State, and local agencies throughout the Bay Region have customarily developed expertise in certain areas of water resource development. Although overall coordination of the Study effort was provided by the Corps of Engineers, input from these various sources was required in order to obtain the best Study coordination and problem identification. Therefore, an Advisory Group and a Steering Committee were established. Five Task Groups were also formed to guide preparation of reports on related resource categories. They are:

1. Economic Projection Task Group
2. Water Quality and Supply, Waste Treatment, Noxious Weeds Task Group
3. Flood Control, Navigation, Erosion, Fisheries Task Group
4. Recreation Task Group
5. Fish and Wildlife Coordination Group

Detailed information on the composition of each Task Group as well as the members of the Advisory Group is presented in the Chesapeake Bay Plan of Study and in Appendix 1, "Study Organization, Coordination, and History."

This appendix was prepared by the Baltimore District, Corps of Engineers, under the guidance of the Water Quality and Supply, Waste Treatment, and Noxious Weeds Task Group. The Group is chaired by the Environmental Protection Agency and members include the U.S. Departments of Agriculture, Commerce, Interior, Navy, and Transportation; the Federal Power Commission; the Energy Research and Development Administration; the Corps of Engineers; the Susquehanna River Basin Commission; and representatives of the States of Maryland and Delaware, the Commonwealths of Pennsylvania and Virginia, and the District of Columbia.

CHAPTER II
WATER SUPPLY IN THE CHESAPEAKE BAY AREA

Man uses water to meet a wide variety of needs including domestic (drinking, food preparation, waste transport and fire fighting); agricultural (irrigation and livestock watering) and industrial (processing and cooling) purposes. This appendix focuses on municipal and industrial water needs while agricultural and cooling water needs for power generation are addressed in Appendices 6 and 13, respectively. This chapter includes a summary description of the Bay Region and its resources, an inventory of present municipal and industrial water use and problems, and a description of the water supply management entities within the Region.

DESCRIPTION OF THE REGION

The Chesapeake Bay and the tidal portions of its tributaries combine to form one of the largest estuaries in the United States. The drainage area of the Bay's tributaries totals 64,000 square miles and includes portions of the states of Maryland, West Virginia, Delaware, New York, and the Commonwealths of Virginia and Pennsylvania, and all of the District of Columbia. Many of the more than 150 rivers and creeks which flow to the Bay provide supplies of water needed for municipal, industrial and agricultural purposes. Through these streams, an average of 45,000 million gallons per day of freshwater enter the Bay. The Susquehanna River alone provides approximately 50 percent of the total. Other major rivers in the Bay system include the Potomac, James, York, and Rappahannock, which together provide an additional 40 percent of total inflow.

The length of shoreline of the Bay including tributaries to head of tide, is approximately 6930 miles—about 4010 in Maryland, 2920 in Virginia. The Bay averages 28 feet in depth, making it a comparatively shallow estuary. The maximum depth is 178 feet. The surface area of the Bay is approximately 4,400 square miles, and varies in width from 4 to 30 miles.

Physiographically, the Bay is the drowned river valley of the Susquehanna River. As shown in Figure 5-2, the estuary lies in the Coastal Plain and borders the Piedmont Province. The division between the upland Piedmont Province and the seaward Coastal Plain Province is marked by what is known as the Fall Line. The outcropping or exposure of the crystalline basement, which underlies the Coastal Plain to the east, forms the "line" and also delineates the head of tide. The Piedmont is characterized by metamorphic ridges and folds and steep-sided stream valleys. In general, layers of southeastwardly dipping, sedimentary, unconsolidated materials comprise the eastern and western

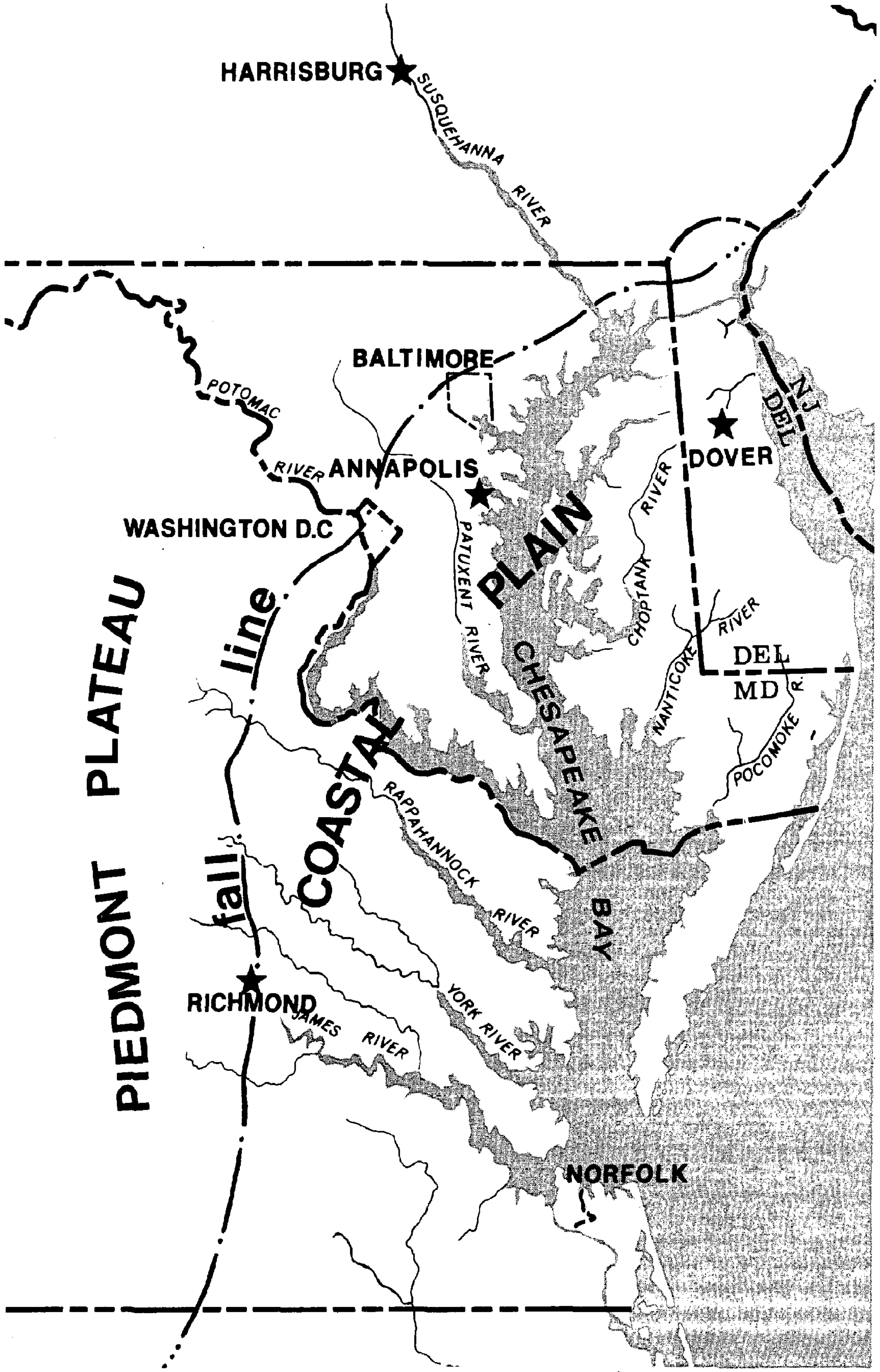


FIGURE 5-2 The Chesapeake Bay Rergion

shore portions of the Coastal Plain. By virtue of its very nature, the Coastal Plain is predominately flat, being somewhat more rolling on the Western Shore than on the Eastern Shore. The underlying sedimentary deposits provide plentiful groundwater supplies to public systems, industries, and individuals throughout the Province.

The Bay Area is characterized by a mild climate, associated with its proximity to the Atlantic Ocean. The annual average temperatures vary between nearly 60° F at the mouth to less than 55° F at the head of the Bay (about 200 miles north). Rainfall averages 44 inches with local variations of from 40 to 46 inches per year. Included in this total rainfall is the water equivalent of an average 13-inch snowfall.

RESOURCES

As a water resource, the Chesapeake Bay provides many benefits for mankind. Typical among these are the fish and wildlife resources—a part of the earth's ecosystem to which man is inexorably linked; recreation opportunities which provide needed respites from everyday pressures; navigation channels which provide for the economic growth and vitality of the region; and water supply to satisfy the many requirements of a "thirsty" society.

In 1970 the navigation arteries of Chesapeake Bay and its tributaries carried nearly 150 million tons of commerce worth billions of dollars. The importance of this activity to the economic structure of the Bay area is thus underscored—especially for the ports of Hampton Roads and Baltimore. These two parts together handle 83 percent of the Bay's commerce. The growing industrial activity associated with port related development has also created large demands for processing and cooling waters.

The fish and wildlife resources of the Chesapeake Bay Area are many and varied. The Bay is one of the most productive estuaries on earth due to its wetland marshes, shallow nature, tidal actions, and wide salinity variations. Including land dwellers, the Bay Area provides habitat for over 2,700 species. Great amounts of seafood are harvested commercially, accumulating to 630 million pounds worth $41 million in 1970. Sport yields of finfish and shellfish were of an estimated like magnitude. Many of the fish and wildlife resources are sensitive to the alterations in salinity patterns that can result from changes in the freshwater inflows to the estuary. In this regard the use of the freshwater tributaries of the Bay for water supply may have a significant impact on fisheries.

The primary mineral resources found in the area are non-precious as well as non-metallic—primarily sand, gravel, stone, clay. These provide building stone and important manufacturing components for brick, pipe, and other building materials. Certain problems are associated with retrieval of these materials. In the area of water supply, for example, sedimentation and turbidity can accompany riverbed dredging for sand and gravel deposits and degrade downstream water supplies. Land mining may result in scarred, erodable, barren areas which allow increased land runoff, decreased groundwater recharge, and other problems such as acid mine drainage. These problems may be troublesome to water supplier.

The Chesapeake Bay also serves as a vast waste assimilator for the activities of the over 8 million Bay Area residents. Municipal, industrial, agricultural, and power heat discharges are increasing along with the population, especially in the urban centers. Presently, most waste discharges and water quality problems in the Bay Area are assimilated and/or confined to the tributary areas. Here, especially in areas of heavy industry, the bottom muds contain massive concentrations of oils, phenols, heavy metals, and other toxic substances. Many acres of shellfish beds are closed for health reasons in areas of heavy waste discharge, as are recreation areas for bacterial pollution. Water quality is a major concern of the supply manager in the design and operation of water treatment facilities in the Bay Region.

Most of the land resource of the Bay Area is considered undeveloped—only 5 percent is devoted to residential, commercial, and industrial activity. Most development is concentrated in the urban centers. Agricultural activities comprise another 30 percent, while woodlands add nearly 50 percent to the land account for the Bay Area. Future patterns that emerge in the use of land will invariably impact dramatically on other resource categories, including water supply.

The Bay also provides for other needs of the people, the value of which are difficult to evaluate. Recreation, for example, aside from the benefits from marinas, boat sales, and hunting licenses and equipment, provides people with relaxation and a peace of mind that is impossible to quantify. There is an undoubtable pleasure to be derived in just being in a natural area undisturbed by the activities of man. Consideration must also be made for these more intrinsic values, so that development or use of a water resource does not impact critically on other uses.

HISTORY

Until the early part of the 19th century, water was generally provided by each individual according to his needs. The country was predominantly rural and supplies of groundwater were readily available. Even in the cities, most homes were supplied by springs or wells—through hand pumps in the kitchen or delivery by cart, sold by the bucket.

The earliest municipal water-works system did not appear until early in the 19th century. Philadelphia was the leader in this regard. Local authorities believed that daily flushing of the streets could alleviate the yellow fever epidemics, and, as a result, water flowed from the Schuylkill River to the City in 1801. As in Philadelphia, other cities were motivated less by a desire for household convenience than by the threats of disease and fire. After cholera outbreaks in London were traced to the water supply in 1849, powerful impetus was placed on the cities to develop safe water supply systems. By 1860, there were 136 city water systems, including one in each of the Nation's sixteen largest cities[1].

Sewage disposal systems, however, numbered only ten. Water systems, proliferated, but no parallel facilities were forthcoming to deal with the increasing waste loads. At the end of the 19th century, thousands of persons living on streets with sewers were still using old privies and cesspools. Many engineering innovations and much in the way of human acceptance were lacking before the indoor flush toilet became a commonplace household item.

Slowly, the evolution towards higher water consumption in the household continued. Human waste contamination of water supplies had increased, and, once the disease risk was clearly demonstrated, it became evident that expanded sewage collection and treatment were needed to protect the public health.

By 1920, the mass production of enamelware and invention of the flush toilet marked the beginning of an era—the "bathroom" became an American middle class necessity. Water closets proliferated along with water-using utensils and before World War II large American cities had use rates four times that of comparable European cities. Today the trend towards higher water consumption continues.

In the Chesapeake Bay Area, there were early advances in water supply development for public use. Baltimore's first system to supply water to the residents of the City began operation in 1807[2]. It was operated by a private company which used the Jones Falls as a source, distributing the water through wooden mains. By 1881, the system had become public and a new supply on the Gunpowder Falls had been developed. Water was transported to the City through a tunnel.

Richmond was the pioneer in the Virginia portion of the Study Area, providing public service in 1830[3]. A water-power system was devised to pump water from the James River. Albert Stein, who also engineered systems for Cincinnati and New Orleans, was the innovator of the project.

In the Nation's Capital, Congress, under threat of disease and fear of fire in the government buildings, approved a plan to bring water from above the Great Falls on the Potomac River [4]. The plan, devised by Captain M.Ç. Meigs of the Army Corps of Engineers, included a 12- mile aqueduct which required ten years and many engineering achievements to complete. The project was completed with water flowing in 1853.

Much of the other water supply development in the Bay Area progressed more slowly, with private wells being abandoned only recently in some metropolitan areas. It has only been in the urbanized metropolitan areas where pollution of sources, health problems, and fire threats have occurred, that major municipal systems have been required. Many rural residents, especially those using dependable groundwater sources of good quality, continue to develop and use individual systems.

EXISTING PUBLIC WATER SUPPLY

Of the Bay Area's 7.9 million residents, approximately 6.5 million, or 82 percent, are served by central water supply systems. These systems range in size from those serving as few as 20 persons in small developments to large municipal systems serving commercial, institutional, and industrial establishments, and millions of individuals. For purposes of this study, each of the water supply systems in the Chesapeake Bay Area that serve a population in excess of 2,500 are termed water service areas (WSA's). Together, the WSA's account for 96 percent of the water supplied and 93 percent of the population served by all the central systems.

Municipal water systems provide for a variety of needs which may be generally classified as domestic, commercial, industrial, institutional, and public. In general, domestic uses include those of the household; i.e., food preparation, washing, lawn watering, and sanitation. Uses within the commercial category include restaurants, hotels, laundries, and car washes; while hospitals, schools, and country clubs are classified as institutional. Public uses include fire protection, street cleaning, and government buildings and institutions.

Industrial water supply uses can be classified as process, boiler feed, cooling, and sanitary water. Depending on the extent and composition of a city's industrial makeup and the tendency for local industry to pay for and use public water, a city's industrial component of water use may vary radically. There are public water supply systems in the Bay Area that supply no water to industry and others that support an extensive industrial component. In Hopewell, Virginia, for example, industrial uses comprise 80 percent of the water publicly supplied.

PRESENT WATER USE

To establish a base for projection of future water needs, an inventory was made of public water supply systems, their present population served, and the average water use. The results of the inventory are presented in Table 5-1 for the 49 identified water service areas in the Chesapeake Bay Area. Plates 5-1 through 5-4, located at the rear of the appendix, show the location of each of these service areas. Water supply data for each system were derived primarily from State Department of Health records, County water and sewer reports, and other local and regional plans. Interviews with individuals at the local level were also helpful in gaining additional data.

Wide variations in per capita use rate are evident among the systems listed in Table 5-1. Lows of 50 to 80 gallons per capita per day (gpcd) are found at King's Height, Joppatowne, and Waldorf, in Maryland, and Manassas Park in Virginia. Communities with low use rates are typically more residential in character, providing smaller amounts of water for industrial, commercial, and/or institutional needs. Use rates exceeding 150 gpcd occur in a number of cities: Cambridge, Crisfield, Salisbury, Leonardtown, Seaford, Baltimore, Washington, Hopewell, and Williamsburg. These high use rates can be attributed to several factors, not always consistent from system to system. For example, Hopewell's astonishing 689 gpcd is due to an estimated 22 mgd supplied to several large industries. Significant industrial uses also contributes to the high rates at Cambridge, Salisbury, and Baltimore, while institutional and military demands and tourism, contribute to the higher than normal use at Williamsburg. In contrast, the extensive government activity and array of public facilities in Washington, D.C., cause use rates in the Washington aqueduct service area to be among the highest in the Bay Area. Another component of water use in most systems is leakage. In Crisfield, Maryland, for example, losses due to leakage constitute an unusually high 25 percent of the overall use. Most of the remaining public systems (listed in Table 5-1) have use rates that would be expected from an average amount of residential use and the concomitant mix of other uses (approximately 80 to 150 gpcd).

TABLE 5-1

MUNICIPAL WATER USE, 1970

Subregion and Water Service Area	Population Served, 1970	Average Use, mgd	Per capita Use, gpcd
SUBREGION 1			
Aberdeen	12,400	1.2	98
Annapolis	40,000	4.3	108
Baltimore	1,542,160	245.0	159
Bel Air	10,200	1.0	98
Crofton	6,280	0.8	127
Edgewood (Perryman)	7,800	1.2	154
Havre de Grace	10,000	1.55	155
Joppatowne	8,060	0.62	77
Maryland City	4,400	0.60	136
King's Heights (Odenton)	7,900	0.53	67
Severna Park (Severndale)	15,580	1.8	115
Sykesville-Freedom	7,500	0.6	80
Westminster	11,000	1.1	100
SUBTOTAL	1,673,820	260.3	156
SUBREGION 2			
Cambridge	12,600	3.85	305
Centreville	2,800	0.28	97
Chestertown	4,000	0.53	132
Crisfield	4,040	1.37	339

TABLE 5-1 (continued)

MUNICIPAL WATER USE, 1970

Subregion and Water Service Area	Population Served, 1970	Average Use, mgd	Per capita Use, gpcd
SUBREGION 2 (Cont'd)			
Delmar	3,000	0.30	100
Denton	2,700	0.39	144
Easton	7,800	1.00	128
Elkton	8,500	1.00	118
Pokomoke City	3,330	0.30	90
Princess Anne	2,500	0.22	88
Salisbury	19,000	4.00	210
Snow Hill	3,000	0.47	157
SUBTOTAL	73,270	13.8	188
SUBREGION 3	no large public systems		
SUBREGION 4			
Seaford	5,540	0.84	153
SUBREGION 5			
Washington Suburban Sanitary Commission	1,130,000	124.0	110
Washington Aqueduct	1,033,000	200.0	193
Alexandria	110,000	13.0	118
Fairfax County Water Authority	370,000	36.5	99

TABLE 5-1 (continued)

MUNICIPAL WATER USE, 1970

Subregion and Water Service Area	Population Served, 1970	Average Use, mgd	Per capita Use, gpcd
SUBREGION 5 (Cont'd)			
Goose Creek (Fairfax City)	65,000	7.1	109
Manassas	11,500	1.25	109
Manassas Park	7,000	0.35	50
SUBTOTAL	2,726,500	382.2	140
SUBREGION 6			
Leonardtown	2,500	0.38	152
Lexington Park	10,000	1.00	100
Waldorf	10,000	0.80	80
SUBTOTAL	22,500	2.18	97
SUBREGION 7			
Fredricksburg	19,530	2.6	133
SUBREGION 8			
Ashland	3,750	0.35	93
Colonial Heights-Petersburg	67,000	7.10	106
Hopewell	37,440	25.80	689
Mechanicsville	2,880	0.28	100
Richmond System	390,620	41.10	105
SUBTOTAL	501,690	74.6	149

TABLE 5-1 (continued)

MUNICIPAL WATER USE, 1970

Subregion and Water Service Area	Population Served, 1970	Average Use, mgd	Per capita Use, gpcd
SUBREGION 9			
West Point	2,600	0.26	100
SUBREGION 10			
Newport News System	263,260	27.3	104
SUBREGION 11			
Norfolk System	509,680	52.5	103
Portsmouth System	123,960	13.7	111
SUBTOTAL	633,640	66.2	104
SUBREGION 12			
Williamsburg	16,500	2.50	151
Smithfield	2,710	0.28	103
Suffolk	18,000	1.80	100
SUBTOTAL	37,210	4.58	123
BAY AREA TOTAL	5,959,560	831.2	139

In addition to the "large" water supply systems, defined as serving a population of 2,500 or greater, a certain number of smaller public systems exist in the Bay Area. The aggregated population served by the "small" systems for each county was derived from records of the various state departments of health. Table 5-2 lists the total for each county. In addition to those persons that receive their water through public water supply systems, many rural residents derive their water from private wells or other local sources. The water needs of the rural domestic population is presented, along with irrigation and livestock requirements, in Appendix 6 — *Agricultural Water Supply.* A summary of rural domestic, livestock, and irrigation water use is presented in Attachment 5-F.

EXISTING PROBLEMS AND CONFLICTS

Provision of water for the people of the Bay Area is not accomplished without the water supplier encountering certain problems. Growing affluence and economic development, and the accompanying increased demands for water have required local water authorities to expand treatment and distribution facilities and to search for new sources. In most urban areas, nearby local sources have been completely developed and cities have been searching further and further afield for new supplies. The City of Norfolk, for example, pipes raw water 25 miles from Lake Prince and also maintains a supplementary source on the Nottoway River, which is 50 miles distant. The Newport News water supply network extends 20 miles from the city proper and Baltimore's aqueduct from the Susquehanna River spans 38 miles, overcoming a difference in head of more than 100 feet. Larger and more elaborate projects are certain to emerge in the future as water needs increase and competition grows for dwindling supplies.

A shortage in supply is perhaps the most critical problem facing a water supply facility. The shortages become critical when periods of low streamflow coincide with dry summer periods when consumer demand is highest. Rainfall and other hydrologic and climatic parameters influence the amount of water available in surface sources. Few of those systems that rely on surface waters can effectively develop a source that is 100 percent safe against all droughts without incurring prohibitive costs. Thus, as a matter of course, most utilities must gamble that rainfall will be adequate to replenish dwindling supplies. It is not uncommon, however, for systems dependent on groundwater to have a supply essentially independent of seasonal climatic variation. Due to the massive storage capacity and dampening effect of the aquifers, these systems can usually supply water at a constant rate through the most severe drought.

TABLE 5-2
SERVICE POPULATION: SMALL WATER SYSTEMS, BY COUNTY, 1970

COUNTY	POP.	COUNTY	POP.
SUBREGION 1		SUBREGION 8	
MARYLAND		VIRGINIA	
Anne Arundel	61,100	Chesterfield	36,400
Baltimore	0	Dinwiddie	2,400
Carroll	21,200	Hanover	6,860
Harford	12,700	Henrico	10,900
Howard	4,430	Prince George	4,800
SUBREGION 2		SUBREGION 9	
MARYLAND		VIRGINIA	
Caroline	4,990	Caroline	1,900
Dorchester	9,050	Charles City	0
Kent	2,370	Essex	3,190
Queen Annes	100	King & Queen	190
Somerset	780	King William	950
Talbot	3,340	Lancaster	5,100
Wicomico	1,740	New Kent	1,700
Worcester	12,600	Northumberland	4,050
Cecil	21,300	Richmond	2,210
		Westermoreland	10,000
SUBREGION 3			
VIRGINIA		SUBREGION 10	
Accomack	5,370	VIRGINIA	
Northampton	4,050	York	5,370
SUBREGION 4		SUBREGION 11	
DELAWARE		VIRGINIA	
Sussex	12,800	City of Chesapeake	5,110
		City of Virginia Beach	3,050
SUBREGION 5			
MARYLAND		SUBREGION 12	
Montgomery	1,550	VIRGINIA	
Prince Georges	650	Gloucester	2,000
VIRGINIA		Isle of Wight	3,830
Fairfax	80,900	James City	5,310
Loudoun	3,390	Mathews	130
Prince William	11,100	Middlesex	1,790
		City of Suffolk	6,580
SUBREGION 6		Southampton	5,520
MARYLAND		Surry	940
Calvert	5,150		
Charles	10,900		
St. Marys	7,410		
SUBREGION 7			
VIRGINIA			
King George	3,130		
Spotsylvania	4,430		
Stafford	5,790		

Despoilation of sources is another major problem facing water suppliers in the Chesapeake Bay Area. Surface waters, both reservoirs and free-flowing streams, are especially susceptible to pollution. Sprawling urban developments have encroached in some watersheds, contributing to overland runoff, sedimentation, and other sources of pollution. Agricultural activity contributes to overenrichment, sedimentation, and pesticide pollution. Water suppliers that utilize run-of-the-river sources, such as Richmond on the James River and Washington, D.C., on the Potomac, must contend with domestic and industrial waste discharge from a myriad of upstream sources.

Water systems that depend on groundwater as a source of supply are also susceptible to contamination. Seepage from septic systems and landfills are notable sources of pollution in groundwater supplies, saltwater intrusion is another problem affecting some near-shore areas around the Bay. Long periods of withdrawal in excess of the natural rate of replenishment of the aquifer can cause lowering of the water table and eventual intrusion of saltwater from the ocean or other nearby saltwater body. This condition will often render the water in the aquifers unusable for years.

In addition to the problems encountered by the water developer, certain conflicts and problems arise with respect to other uses and resources as a result of water supply development. Groundwater pumping, for example, may sometimes lower the water table sufficiently to reduce the quality or quantity of groundwater available in adjacent areas. For example, industrial withdrawals near the City of Franklin, Virginia, have, over many years, caused a 150-foot decline in the water table at the point of withdrawal and created a cone of influence that affects the water table 20 miles distant at the City of Suffolk. Also, groundwater withdrawals can be ecologically damaging if the water table is lowered beneath wet environments such as bogs, causing them to lose their saturated condition.

The impacts associated with development of surface waters are often more pronounced than those of groundwater development. Reservoir construction can result in direct reduction of downstream flows, and possibly impact on other downstream uses, including fish and wildlife, recreation, and waste assimilative capacity. Supersaturated gases, temperature shock, oxygen-depleted releases from the hypolimnion, and sudden releases of large volumes of water are other reservoir-related problems to consider with respect to their impact on downstream aquatic life. On the other hand, fishery resources and recreation can also be enhanced during summer months by the artificially sustained flow made possible by a reservoir.

Diversion of water supplies from one watershed to another is an engineering practice that directly removes the water and reduces streamflow by the amount wthdrawn. Baltimore City's authorized 250 mgd withdrawal from above Conowingo Dam on the Susquehanna River (at present only minimally used) has provoked citizen concern as to potential impacts on the Chesapeake Bay fishery.

Conflicts also arise in relation to water rights. In the Western United States, water rights are governed by the law of appropriation which entitles a user who is first in time and who applies the water to a beneficial use to that amount of water in perpetuity. The riparian doctrine, characteristic of the Eastern States, protects adjacent landowners from uses which unreasonably diminish water quality or quantity. The problem often arises in that social and public values are neglected in favor of the economic interests of the private sector. Legislative actions are then required in order to optimize social and cultural water uses in conjunction with the conventional economic values.

Impacts will naturally occur in any water resource development, but the objective should be to minimize the adverse effects to the overall net public and environmental benefit. Positive action is needed to provide a management structure so that water development, while undeniably needed for our progressing society, will not bear unduly on other uses and resources.

MANAGEMENT RESPONSIBILITIES

Management of water supply systems entails confrontation with the problems discussed in the previous section. In short, the management authority is charged with the responsibility to provide water of the quantity and quality demanded within the service area. A multitude of combinations of institutional and administrative arrangements are utilized in providing water for the citizens of the Bay Area. Management structures, set up to provide the needed supplies, can be privately or publicly administered, usually at the local level. Public systems are usually operated by their particular town or city government—as is the case for most of the water service areas considered in this report. Privately owned public systems are a less common means of water supply in the Bay Area. Notable examples of privately owned systems are those at Lexington Park and Bel Air, Maryland, and Alexandria and Hopewell, Virginia.

Larger areas, including several communities, developments, parts of counties, or even states, may be incorporated under a regional-type authority, or commission, to manage all aspects of the region's water needs. This situation has the potential to enable efficient, safe, and economical service to a developing region—especially those with fragmented and localized source developments and conflicting wastewater control programs. The Appomatox River Water Authority and Fairfax County Water Authority are examples of State chartered regional water systems with authority to acquire, construct, operate, and maintain water systems within particular regions. Sometimes these written authorities are extended to include wastewater collection and disposal.

A unique arrangement for water supply exists in Washington, D.C. Due to its status as the Nation's Capital, water supply is, by law, the unique management responsibility of the Federal Government, specifically the U.S. Army Corps of Engineers. Through its Washington Aqueduct Division, the Corps is responsible for raw water transportation and treatment of water for the many residents, public institutions, and government facilities in Washington, D.C., Falls Church, and Arlington County, Virginia.

In addition to specific management structures, various health related, and financial and planning assistance programs are available at the state and Federal level to aid in the development and/or management of water supply resources. At the state level, for example, the District of Columbia, Maryland, Virginia, and Delaware Departments of Health have the responsibility under law for maintaining the health integrity of all public drinking water supplies. Consultation services to local public service agencies are also generally available through the Health Departments, as are planning and associated environmental services.

Responsibility for the overall water resource management is held at the state level by the following agencies:

- State Water Control Board in Virginia
- Department of Environmental Services in Washington, D.C.
- Department of Natural Resources in Maryland
- Department of Environmental Resources in Pennsylvania
- Department of Natural Resources and Environmental Control in Delaware

Generally the scope of these agencies' authority includes planning, program development, regulation, enforcement, and provision of other public services as regard water resources.

As stated in the Department of the Army's *Digest of Water Resources Policies,* the Federal interest in water supply and quality management seeks to "insure a continuing supply of freshwater, adequate in quantity and quality for urban and rural withdrawal and streamflow needs." In practice, however, the policy of the Federal Government has been toward the long range management of supplies, leaving the financial burden of supply to the user. For example, if all costs allocated to water supply are paid by non-Federal interests, the Corps of Engineers has the authority, pursuant to the Water Supply Act of 1958, to include municipal and industrial water supply in any of its reservoir projects. Costs allocated to water supply cannot ordinarily exceed 30 percent of the total project cost, but, if such storage is economically justified, it may be added to any project at any time. Under certain conditions, storage for irrigation on agricultural lands may also be considered as a purpose in Corps dams, but under present interpretation, this applies only to certain western states.

Federal level financial assistance is available for rural community water supply development and planning from the Farmer's Home Administration (FHA) of the U.S. Department of Agriculture. Services that are water supply related, (such as watershed and wastewater facilities, financing, and planning,) are also available to the rural areas through FHA.

Federal assistance can also be sought in water supply development from the Soil Conservation Service (SCS), U.S. Department of Agriculture, but only as it relates to watershed or flood protection. Under certain cost-sharing and other conditions, water supply storage can be included as a purpose in SCS dam projects.

Lastly, the Environmental Protection Agency has public health oriented assistance programs for use by public water utilities. These programs are designed to promote highly reliable, quality supplies through research grants and technical assistance.

EXISTING INDUSTRIAL WATER SUPPLY

The industrial component of the 1970 water demands in the Chesapeake Bay Area is considered in this section. Only the water supply needs of the manufacturing industries are addressed here, including those industries in Standard Industrial Classifications (SIC's) 20 through 39 (as defined by the Federal Office of Management and Budget). Manufacturing activity in the Chesapeake Bay Area is dominated by Primary Metals (SIC 33), Paper (SIC 26), Chemicals (SIC 28), Petroleum (SIC 29), and Food and Kindred Products (SIC 20). Other industrial sectors, such as Finance, Transportation, Services, and Government, are not included in this analysis, as their water demands generally comprise a portion of the public supply. As noted earlier cooling water needs for power generation, which constitute a major sector of demand, are presented separately in Appendix 13: *Power.*

In general, industrial uses of water can be classified as process, boiler feed, cooling, and sanitary. Quality requirements vary widely depending on these uses, and although generalizations for a particular industry and type of use are difficult to make, some observations can be made. For example, low hardness is desirable for canning peas, and low chlorides are critical in the paper bleaching process [6]. In some industries, such as Paper, Chemicals, and Textiles, even the smallest trace of any element such as manganese can make the process impossible [7]. Within an industry, variables in quality requirements also occur. In the Paper sector, for example, photographic paper and cardboard have radically different requirements.

Cooling water, used in condensing and cooling equipment and for quenching in steel roller mills, can be of almost any quality. For instance, Baltimore City provides about 120 mgd of its treated municipal waste effluent to the Bethlehem Steel Corporation for cooling purposes. Much of the other cooling water withdrawals in the Bay Area are derived from brackish sources, defined for purposes of this report as all waters containing greater than 1,000 ppm dissolved solids. Ideally, cooling water is of low temperature, turbidity, and scale-forming materials, especially if it is to be recycled.

Boiler feedwater requires perhaps the most stringent quality control. Only small amounts are needed to replenish that evaporated, but soft water is needed to avoid scale buildup, especially in high-pressure boilers. Water used to meet sanitary needs of industry (toilet facilities, etc.) must, naturally, meet the same drinking water standards as those for municipal supplies.

An important concept in industrial water supply is water recycling or reuse. Since large amounts of water can be reused in many industrial processes, significant savings could be realized if this practice was more widely used.

The tendency of an industry to recirculate water usually depends ultimately on economics. Water will be reused in a particular situation if the costs of recovery and recirculation are less than costs associated with the development of additional sources, or the costs of treatment of the wastewater. In locations where fresh water is scarce or where quality problems require extensive treatment, recirculation may be heavily utilized. Conversely, in areas with plentiful supplies of high quality water, or where wastewater treatment costs are low, reuse is usually uneconomical[20].

Efforts to comply with discharge regulations or to reclaim byproducts have in some instances prompted development of equipment to make recirculation more economical. For example, in the pulp and paper industry, development of special filters to remove small amounts of waste fibers from large amounts of water has enabled large recirculation rates in many plants[21].

Certain other advances in technology serve to illustrate measures that can result in expanded recirculation practice. In many instances, forced air cooling towers have replaced natural draft systems, speeded evaporation and reduced the overall size and cost of recirculation systems[22].

Sequential use of water for cooling in several processes, at gradually increasing temperatures, has also been used to advantage. In steel mill, for example, the coldest water can first be used in the power plant condensers, reused to cool process equipment (operating at 100 to 300° F), and again reused for cooling burner ports or furnace walls[23]. Also, development of new ceramic and alloy materials to withstand high temperatures in industrial processes has enabled use of air cooling techniques where water was previously needed to minimize equipment damage[24].

PRESENT INDUSTRIAL USE

Industrial water use in 1970 was inventoried by the Bureau of Domestic Commerce (BDC), U.S. Department of Commerce. With the aid of the Bureau of Census, data were accumulated Nationwide for industries utilizing 10 million gallons per year (mgy) or more. Data accumulated include: identification of the type of industry based on 4 digit SIC identification, intake (mgy), gross use (mgy), source, employment, treatment, and discharge.

For those plants that utilize more than 10 mgy and did not respond to the survey, information was obtained from the permit applications submitted for discharge permits under the 1899 Refuse Act, from industry directories, and from discussions with BDC industry experts. For the manufacturing plants with intake requirements of less than 10 mgy, total withdrawal demands were estimated through the use of water use ratios reported in the 1963 Census of Manufacturers and estimates of future subregional shares of Gross Product Originating (GPO).

Results of the inventory of industrial water use in the Chesapeake Bay Area are presented in Table 5-3. Due to agreements between the Department of Commerce and the industries participating in the survey, data is not to be released in detail, but is available only on a subregional basis (SMSA and non-SMSA county grouping), as delineated previously in Figure 5-1. For this reason, all tables of industrial water use in this report (except as specifically noted otherwise) include Kent County, Delaware, as part of Subregion 4, in addition to Sussex County, Delaware. Water use in manufacturing by 2-digit SIC is presented in Table 5-4.

Gross use (G) includes all water used, whether fresh, brackish, or recirculated. Intake (I) represents only the actual withdrawal from stream or bay, or other fresh or brackish water source, plus purchases. The consumption category (C) includes all water lost to evaporation or that becomes incorporated into end products. Discharge (D) is merely the difference between intake and consumption (I - C). The final column lists the percent of the gross use that is recycled water [(G-I)/G][8]

As shown in Tables 5-3 and 5-4, total intake from fresh and brackish sources totaled 1,615 mgd in 1970. Ninety-nine percent of this water was used by only 3 percent of the manufacturing establishments which have demands in excess of

TABLE 5-3
INDUSTRIAL WATER USE IN THE CHESAPEAKE
BAY AREA, 1970, mgd

	Subregion	Gross Use (G)	Intake (I)	Consumption (C)	Discharge (D)	$\frac{G-I}{G}$[1]
1	Baltimore SMSA	1,226.1	990.7	43.7	947.0	19.2
2	Non-SMSA, MD	35.5	34.8	0.9	33.9	1.9
3	Non-SMSA, VA	2.6	2.3	0.2	2.1	11.5
4	Non-SMSA, DE[2]	82.7	65.6	1.9	63.7	20.7
5	Washington SMSA	5.4	4.7	0.2	4.5	13.0
6	Non-SMSA, MD	0.8	0.8	0.1	0.7	0.0
7	Non-SMSA, VA	32.9	27.4	1.8	25.6	16.7
8	Richmond and Petersburg SMSA's	400.5	286.8	14.0	272.8	28.4
9	Non-SMSA, VA	52.4	26.5	5.0	21.5	49.4
10	Newport News-Hampton SMSA	114.9	100.2	0.7	99.5	12.8
11	Norfolk-Portsmouth SMSA	32.3	25.3	1.3	24.0	21.7
12	Non-SMSA, VA	621.8	50.4	4.8	45.6	91.9
	TOTAL BAY AREA	2,607.9	1,615.5	74.6	1,540.9	38.1

[1] $\frac{G-I}{G}$ = Percent recycled.

[2] includes Kent Co., Delaware

TABLE 5-4
WATER USE IN MANUFACTURING, BY SECTOR,
CHESAPEAKE BAY AREA, mgd

	Gross Use	Intake	Consumption	Discharge	$\frac{G-I}{G}$
All Manufacturing	2,607.9	1,615.5	74.6	1,540.9	38.1
Food & Kindred Products	79.7	74.3	5.6	68.7	6.8
Paper & Allied Products	644.8	72.8	7.6	65.2	88.7
Chemicals	402.5	328.1	14.5	313.6	18.5
Petroleum	81.6	76.3	0.7	75.6	6.5
Primary Metals	1,094.6	882.3	35.1	847.2	19.4
Other Manufacturing	304.7	181.7	11.1	170.6	40.0

10 million gallons per year (mgy). These plants, which, for the purposes of this study, are termed the "large water users," represent 190 of the 5,800 individual manufacturing establishments in the Bay Area. Thus, most of the plants for which data are aggregated here are small with respect to the amount of water used. Most are also small in terms of employment and production.

In addition to the concentration of water use among a relatively small number of plants, there is also a concentration of water use within particular types of industries. In the Chesapeake Bay Area, 82 percent of the total water used is accounted for by three groups of industries: SIC 26, Paper and Allied Products; SIC 28, Chemicals and Allied Products; and SIC 33, Primary Metals, as shown in Table 5-4.

Recirculaton of supplies is practiced by some industries to conserve water, meet discharge requirements, or, often, to recover components in the wastewater. A measure of the degree to which recirculation technology is utilized in each subregion is shown in the final column of Table 5-3, and for each major type of industry in Table 5-4.

The best recycling efficiency occurs in the paper industry in which 88.7 percent of the gross water used is recycled. In other words, nearly nine times as much water would be needed from the river, or other source, if recirculation was not practiced—645 vs. 73 mgd, on the average. Of the major industries in the Bay Area, the Petroleum industry recycles least, primarily due to the once-through use of brackish water for cooling. However, National figures for Petroleum indicate recirculation at least 10-fold that in Chesapeake Bay.

Water withdrawals, categorized as to source, are shown in Table 5-5. The total amount withdrawn in 1970, is estimated to have been 565,355 mgy, or an average of 1,615 mgd (assuming a 350 day work-year). Sixty-one percent of this is used in the Baltimore SMSA alone with the Richmond and Newport News SMSA's following with 18 and 6 percent, respectively.

In contrast to the Nation as a whole, in which approximately 75 percent of industrial supplies are obtained from freshwater sources, only about 37 percent of all Bay Area industrial withdrawals are from freshwater sources. Table 5-6 details the National breakdown of industrial water use by source versus that in the Bay Area. Brackish use is shown to constitute a major portion of industrial use in the Bay Area. Because many plants are located on, or in close proximity to the Bay, brackish water is substituted for certain operations. The total quantity amounted to an average of 899 mgd (315 bgy), or 56 percent of all withdrawals in manufacturing in 1970. Nationally, only about 18 percent of industrial withdrawals are brackish.

TABLE 5-5
INDUSTRIAL WATER WITHDRAWALS, BY SOURCE, MGD
CHESAPEAKE BAY AREA, 1970

	Subregion	Public	Self-Supplied				Total	Total Fresh	Percent Fresh
			Ground	Surface	Brackish	Other			
1	Baltimore, SMSA	70.0	14.4	2.9	781.2	122.2	990.7	87.3	7.8
2	Non-SMSA, Maryland	3.0	30.0	1.1	0.7	0.0	34.8	34.1	97.9
3	Non-SMSA, Virginia	0.3	1.9	0.0	0.1	0.0	2.3	2.2	95.7
4	Non-SMSA, Delaware[1]	2.7	14.9	48.0	0.0	0.0	65.6	65.6	100.0
5	Washington SMSA	3.3	0.1	1.3	0.0	0.0	4.7	4.7	100.0
6	Non-SMSA, Maryland	0.1	0.7	0.0	0.0	0.0	0.8	0.8	100.0
7	Non-SMSA, Virginia	0.2	0.1	27.1	0.0	0.0	27.4	27.4	100.0
8	Richmond SMSA (also Petersburg)	22.3	0.3	264.2	0.0	0.0	286.8	286.8	100.0
9	Non-SMSA, Virginia	0.2	16.0	0.1	10.3	0.0	26.6	16.3	61.3
10	Newport News SMSA	4.6	5.0	0.0	90.6	0.0	100.2	9.6	9.6
11	Norfolk SMSA	5.6	3.8	0.0	15.9	0.0	25.3	9.4	37.1
12	Non-SMSA, Virginia	0.6	44.9	4.8	0.0	0.0	50.3	50.3	100.0
	TOTAL BAY AREA	112.7	132.1	349.5	898.8	122.2	1615.5	594.5	36.8

[1] includes Kent Co., Delaware

TABLE 5-6

WATER USE IN MANUFACTURING, NATIONAL COMPARISON, BY USE (Billion gallons per year, percent)

	Total Intake	Public	Ground	Surface Fresh	Surface Brackish
Nationally[1]	15,024	1,649	1,653	9,042	2,671
	100.0%	11.0%	11.0%	60.2%	17.8%
Chesapeake Bay	565[2]	39	46	122	315
Study Area, 1970	100.0%	6.9%	8.1%	21.6%	55.8%

1 From Census of Manufacturers, 1972[10]

2 Includes wastewater reuse (7.6 percent of intake).

Perusal of Table 5-5 reveals water use characteristics which are often peculiar to the individual subregions. Industrial water use in Subregion 1 (Baltimore), for instance, is derived predominantly from brackish sources and is used for cooling purposes. While self-supply is the general rule in most of the Study Area, 80 percent of the freshwater in Subregion 1 is provided through public systems, particularly the Baltimore City System. Also of interest is the reuse of about 120 mgd of treated municipal waste by the Bethlehem Steel Corporation. This comprises an extraordinary 7.6 percent of the Bay Area's total industrial intake.

Water used for manufacturing purposes on the Delmarva Peninsula (Subregions 2, 3, and 4) is dominated by the food processing industry. In Subregion 2, Food accounts for 50 percent of industrial withdrawal, and Chemicals (SIC 28) an additional 24 percent[9]. Industrial water use in Subregion 3 (Eastern Shore, Virginia) is predominantly in Food industries. Subregion 4 (lower Delaware) supports large water using industries in the Food and Chemical sectors. Although marked quantities of surface water are used in Subregion 4 (when compared with other Eastern Shore areas), supplies are generally derived from the plentiful Coastal Plain groundwater resource. Manufacturing water use is small in most of the Washington Economic Area (Subregions 5, 6, and 7). Industrial activity in Subregion 5 (the Washington, D.C. SMSA) is dominated by the governmental and service-oriented sectors, and, as such, there is little water use in manufacturing. For the non-SMSA area in Maryland (Subregion 6), water use is concentrated in Food and Lumber[11]. These three counties rely almost entirely on groundwater, but in Subregion 7 (Virginia), 99 percent of withdrawals are fresh surface water. Ninety-five percent of usage in Subregion 7 is by the FMC Corporation at Fredericksburg (SIC 28)[12], which withdraws water directly from the Rappahannock River.

Moving southward in the Chesapeake Bay Study Area to the vicinity of the James River, marked increases are observed in industrial water uses, as shown in Table 5-5. The Richmond SMSA (Subregion 8) contains a heavy concentration of Chemical industries. Five large plants in Hopewell and Chesterfield Counties account for 72 percent of the subregional industrial use (about 200 mgd). Paper manufacturing ranks second, constituting an additional 9 percent of the overall intake. The primary source of supply in the Subregion is fresh surface water from the James River.

Industrial water use in predominantly rural Subregion 9 is dominated by the Chesapeake Corporation (SIC 26) at West Point, which uses 95 percent of all industrial withdrawals in the area. Of note is the effective recirculation technology used by the plant which cuts withdrawal demand by 50 percent. Industrial water use in the balance of the area is light. The dominant source of supply is from wells.

Industrial withdrawals in the Newport News-Hampton SMSA (Subregion 10) are approximately 90 percent brackish. About 80 percent of this, or 71 mgd, is used by the American Oil Company at its Yorktown refinery[13]. In the Norfolk SMSA (Subregion 11), manufacturing usage is again primarily brackish, constituting 63 percent of withdrawals. Public supplies account for an additional 22 percent. Fertilizers and other chemical manufacturing industries use over 40 percent of the subregional industrial water supply.

Subregion 12 is the final area under consideration. Usage in the Subregion amounted to 50.3 mgd, of which 76 percent was employed in paper manufacturing. Groundwater supplies nearly 90 percent of the industrial demands of the area. The Union Camp Corporation alone accounts for groundwater withdrawals of 38.4 mgd from the Potomac Aquifer near Franklin, Virginia[14].

EXISTING PROBLEMS AND CONFLICTS

Certain problems and conflicts arise when different interests are competing for úse of the same resource. From the point of view of the water supply manager, for instance, there are insufficient controls and institutional arrangements to regulate the effects of upstream users on those downstream. Waste discharges and consumptive losses have traditionally occurred without regard to downstream uses, such as recreation and fish and wildlife, as well as additional public and industrial needs. The downstream users must subsequently contend, at some expense, with the polluted and/or depleted supplies. All told, some of the costs of providing goods and services to the people must be borne by society and the environment at large. Polluters use the free resource and leave the problem—costs are borne by subsequent users or uses.

Water quality standards drawn up at the state level, and Federal goals set forth in the 1972 Amendments to the Water Pollution Control Act, have the potential to somewhat equalize the costs between initial and final users along a watercourse. Higher treatment levels and/or increased recirculation and reuse in the manufacturing sector have already improved stream quality in some areas and to some extent have had the effect of redistributing costs back to dischargers. Continuing advances toward established water quality goals and new institutional arrangements will be needed to enhance our waterways in the interest of all users.

Other problems and conflicts discussed previously in conjunction with public water supply apply equally well here, as regards industrial water supply. For example, excessive groundwater withdrawals which deplete the surrounding aquifer and encourage saltwater intrusion, and depletion of surface water flows by diversion or lack of rainfall are typical problems encountered by water suppliers. In turn, pollution and/or depletion of available water flows, resulting from water supply development and use, will sometimes adversely affect other resources, including fish and wildlife, recreation, and the assimilative capacity of streams.

MANAGEMENT RESPONSIBILITY

Management responsibility for industrial water supply usually rests with each particular manufacturer. Managers are left to their own devices to seek out the sources that most economically satisfy their particular quantity and quality requirements. Often, if only a relatively small quantity of water, or water of a particular quality, is needed, a public water supply may be an industry's most economical water source. In this case, management responsibility falls to the public water utility. Management responsibilities of the many water supply related state and Federal agencies have been previously discussed in the "Public Water Supply" section. These apply equally as regards industrial water use activities.

SUMMARY

A summary breakdown of existing *freshwater* use, by type, is presented in Figure 5-3. Included are average water uses for public systems, self-supplied domestic needs, agriculture (livestock, poultry, and irrigation), and self-supplied industry (including wastewater reuse). The segment that represents agriculture in the diagram includes the irrigation requirement as an annual average during a normal precipitation year. The total amount of water represented in the chart is 1,568 mgd. It should be noted that brackish water use, which in 1970 averaged about 899 mgd, is not accounted for in the diagram. Water requirements for cooling in the generation of electric power are also not included here, but are addressed in full in Appendix 13: *Power.*

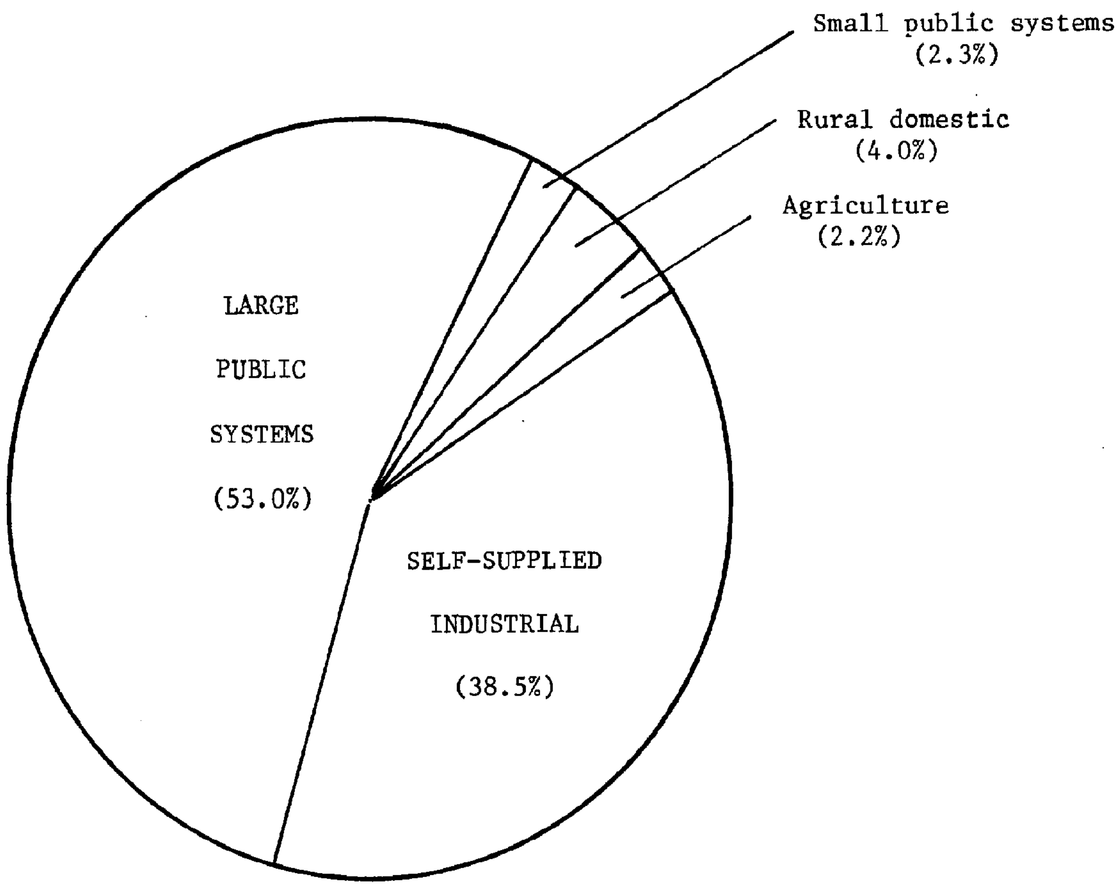


FIGURE 5-3: ANNUAL AVERAGE FRESHWATER USE BY TYPE, 1970

CHAPTER III

FUTURE WATER SUPPLY NEEDS

This chapter is devoted to a projection of future municipal and industrial water supply needs in the Chesapeake Bay Area. For purposes of this analysis projections were made through the year 2020 for:

a. All persons served by central water supply systems
b. All manufacturing industries.

Also contained in this chapter is a presentation of the capacities of the existing water supply systems and sources that provide service to the major centers of population in the Bay Area. Potential future water supply deficits for these central systems were computed by comparing projected future water supply demands with the yield of presently developed sources and the capacity of existing water treatment plants and pumping facilities.

Appendix 6: *Agricultural Water Supply,* contains the complete methodology and projections of agriculture related water demands, including the quantities of water needed to service livestock, irrigate crops, and fulfill the domestic requirements of those persons residing in rural areas that are not served by central water supply systems. Water supply requirements for use in cooling of electric power generating equipment are presented in Appendix 13: *Power.*

The assessment of the water supply situation for communities which are served by central systems is relatively straightforward. The geographic locations of both the supply source and the demand center are specifically defined and comparisons can be readily made of expected water use and the capacity of existing sources and systems. It is considered to be a safe assumption that future population and economic growth will continue to occur predominantly around the existing urban centers.

Except in very isolated instances, however, it is difficult to predict specific future water supply demands for industry and agriculture in terms of specific sources of supply. It was not considered practical, therefore, to be site-specific in projecting the future water supply demands in agriculture as presented in Appendix 6, nor the self-served industrial water supply demands presented herein. Rather, needs of this type have been aggregated and presented as a total for each subregion. The subregional delineations, as shown earlier in Figure 5-1, are the Standard Metropolitan Statistical Areas (SMSA's) and the non-SMSA county groupings as defined by the U.S. Bureau of Census. It is also of importance to note that all economic projections made by the Department of Commerce for this study are based on the same subregions.

In order to assess the capability of the entire freshwater resource of the Chesapeake Bay Area to meet possible future water supply demands, a comparison was made between an estimate of the freshwater available in each subregion and the aggregated water supply demand for each subregion. The total demand was determined by combining the agricultural institutional and self-served industrial water supply demands with the demands generated in areas served by central systems. Possible future deficits were then computed by comparing the total water supply demand with the present yield of all possible water supply sources in the subregion. Types of sources considered include groundwater aquifers, surface streams with significant flows, existing reservoirs, and pipelines importing water from other regions.

Brackish water also comprises an element of supply in the Chesapeake Bay Area. Within some of the manufacturing industries, water of this type (with dissolved solid in excess of 1000 mgl) is acceptable for use in once-through cooling processes. Although the assessment of future needs presented in this Chapter are in terms of freshwater demands, and freshwater supplies, projections are also included for the brackish water demands in manufacturing.

MUNICIPAL WATER SUPPLY DEMANDS

As shown in Chapter II, water supplied through large public systems in the Bay Area amounted to about 831 mgd in 1970. Based on projections of population and economic development in the Bay Area, requirements for water to be served through these public systems will more than double by the year 2000. This section presents the assumptions and methodology used in the projection of the public water supply demand and a detailed presentation of results.

The quantity of water used by a municipality is a function of a variety of factors. Of particular significance are population, population density, per capita income, the quality of the water, the price of the water, whether or not it is metered, and the number and types of industries, commercial establishments, institutions, and office complexes involved. A myriad of these and other factors account for the wide variations in use rate evident in Table 5-1: from lows near 60 gpcd to highs of almost 200 gpcd.

With the passage of time, changes in any one or a number of these factors may occur which will have a direct influence on the quantity of water used within a community. Therefore, in order to forecast expected water demands, it is desirable to analyze each of these parameters in the context of the future. It is well recognized, however, that scientific methods are not available which will yield exact answers as to the future. Rather, forecasting is normally accomplished by applying accepted methodologies to a formulated set of assumptions on future trends.

It is important for those in water resource management positions to be fully aware of the implications of these assumptions when decisions are made in which the magnitude of a future water demand is a significant factor. An analysis of the effects that certain changes in the basic assumptions may have on the future water supply demand is presented in Chapter IV (Sensitivity Analysis). Included is an analysis of alternative population projections in terms of the effect these alternative projections may have on public water use.

In addition, Chapter V (Means to Satisfy the Needs), contains an analysis of certain other variables that affect water use in public systems, such as pricing and metering, to demonstate how they might be used as tools to control demand growth.

ASSUMPTIONS

Certain assumptions are used in this study in the derivation of municipal water supply demands. The most basic assumptions, which concern population growth, increases in per capita water use, and the industrial portion of public supply in each community, are as follows:

a. OBERS projections, Series C, reflect future economic and demographic trends for the Bay Area;

b. The service population in each of the water service areas will remain as a constant proportion of the projected census population;

c. The 1970 per capita use rate for each water service area, for non-industrial uses, is related to per capita income (see Figure 5-4).

d. The per capita use rate (referred to in "c" above) will grow at gradually reducing rates as illustrated in Figure 5-5; (this is based on a 3 percent annual growth rate at 40 gpcd, 1 percent at 80 gpcd, and one-half percent at 150 gpcd);

e. Publicly supplied industrial water use in each community will remain as a constant proportion of the subregional total industrial water publicly supplied (see next section for additional assumptions regarding industrial water demands.)

f. Small centralized water supply systems, which are defined as serving fewer than 2,500 persons, have an initial non-industrial use rate of 85 gpcd.

Other factors which influence a community's demand for water, such as social taste, community character, and public policies, with respect to water use and development, are not directly addressed in the projections presented in this chapter. Forces within society which tend to influence changes in the magnitudes and types of water use within the cities are assumed to remain constant throughout the study period. However, an analysis of the possible influence on water use that may result from institutional changes, such as the use of metering or pricing, is included in Chapter V. As mentioned previously, the changes in water demand occasioned by changes in population projections are presented in Chapter IV.

METHODOLOGY

As discussed previously, municipal demands consist of several elements, including domestic (household), commercial (restaurants, hotels, and service stations), institutional (schools and hospitals), public (street cleaning and fire protection), and industrial. Generally speaking, a given service population with a particular character can be assumed to support commercial, institutional, domestic, and public needs that are indigenous to the area. Thus, the non-industrial components of municipal water use can be expected to grow proportionately with population. Industrial demands, however, are more a function of the manufacturing process involved and are not necessarily directly related to a city's population growth. Thus, the industrial, and the aggregated domestic, commercial, and public demands, were projected separately for each water service area.

Difficulties arose in attempts to determine the industrial component of the usage in each water service area, as data regarding industrial use are not normally compiled as part of the management and operation of most water systems. Thus, a Bay-wide relationship between publicly supplied non-industrial water use and per capita income was derived in order to disaggregate the non-industrial and industrial components of public usage for each water service area. This approach is supported by the fact that as affluence increases, in areas of more highly developed economies, the demand for water for domestic purposes also tends to increase. People in the higher income levels are better able to afford such water-using appliances as washing machines, dishwashers, and air-conditioning. Increased incomes also tend to be accompanied by increased demands for watering of large lawns in suburban areas, and increasing numbers of private swimming pools. Areas of higher per capita income are also associated with a more extensive and diverse commercial activity, as well as increased activity in the public sector.

The relationship between per capita income and per capita non-industrial water use is shown in Figure 5-4. As derived in the Bureau of Domestic Commerce survey of industrial water use, subregional values of all water publicly supplied to industry were used in conjunction with aggregated total public usage in each subregion to determine non-industrial per capita use rate for each subregion. These per capita use rates were plotted against the average per capita income in all areas of greater than 2,500 population in each subregion to obtain the curve in Figure 5-4. Using Figure 5-4 and the appropriate per capita income, an estimate of the 1970 non-industrial usage for each water service area was derived. Adjustments were made in certain cases in which results were unreasonable or in conflict with existing data. Also, the relationship in Figure 5-4 was not used for water systems that were known to supply no industrial needs. In these instances, the 1970 non-industrial use rate is merely that presented in Chapter II, Table 5-1.

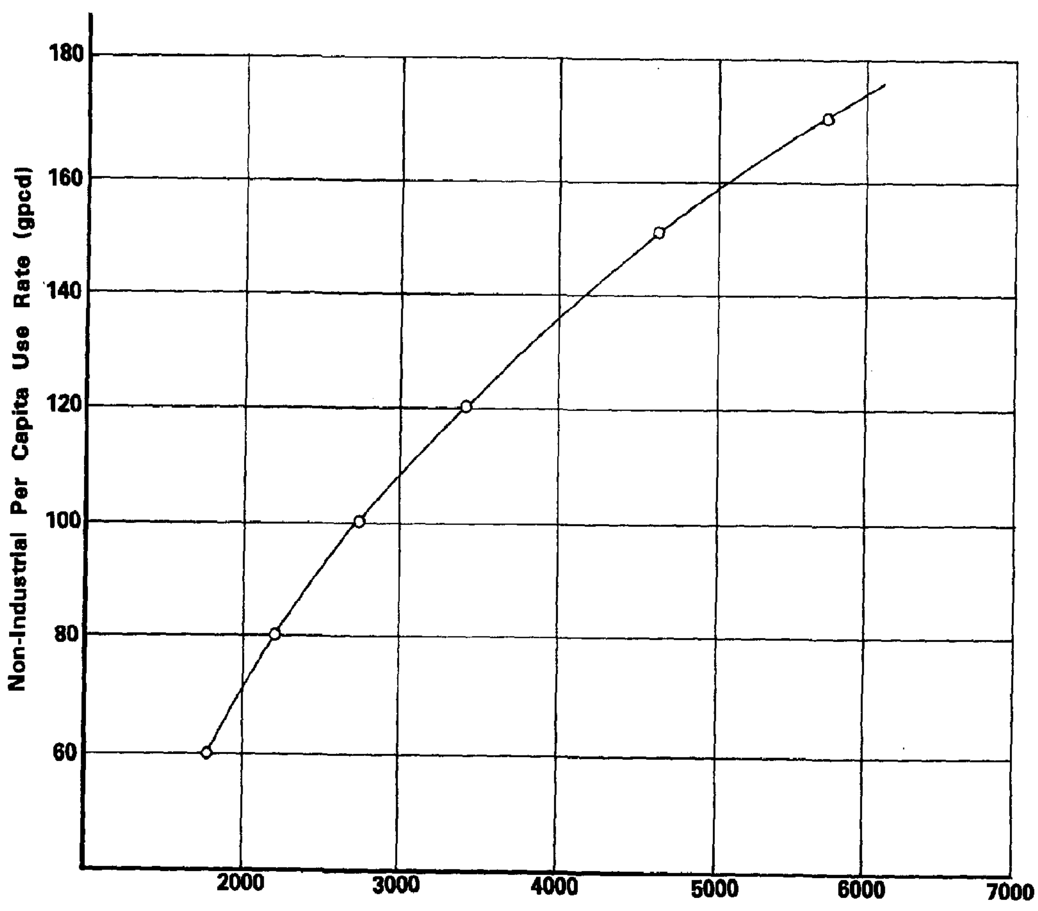


FIGURE 5-4: NON-INDUSTRIAL PER CAPITA USE RATE VERSUS INCOME, 1970

After the 1970 non-industrial per capita use rates were defined for each water service area, projections of the per capita water uses were made using a methodology derived by the Federal Water Pollution Control Administration (now EPA) for the Ohio River basin Comprehensive Survey. A relationship between per capita use rate and annual growth in use rate, as shown in Figure 5-5, was derived through a statistical sampling and analysis of consumption in both small and large cities. The curve was used previously in the North Atlantic Water Resources Study and it is assumed that the future growth in per capita water demand in the Bay Area will occur in a like manner.

Based on this curve, the annual percent rate of increase in per capita water use will be faster in areas with lower use rates, and slower in areas with higher use rates. For example, the usage in service areas with use rates of 150 gpcd will increase more slowly than it would in areas using 40 gpcd. Also, limits in use rates are approached using this methodology, whereas other commonly used projection methodologies allow growth to unrealistically high levels. For example, a standard approach in many projection methodologies is to assume

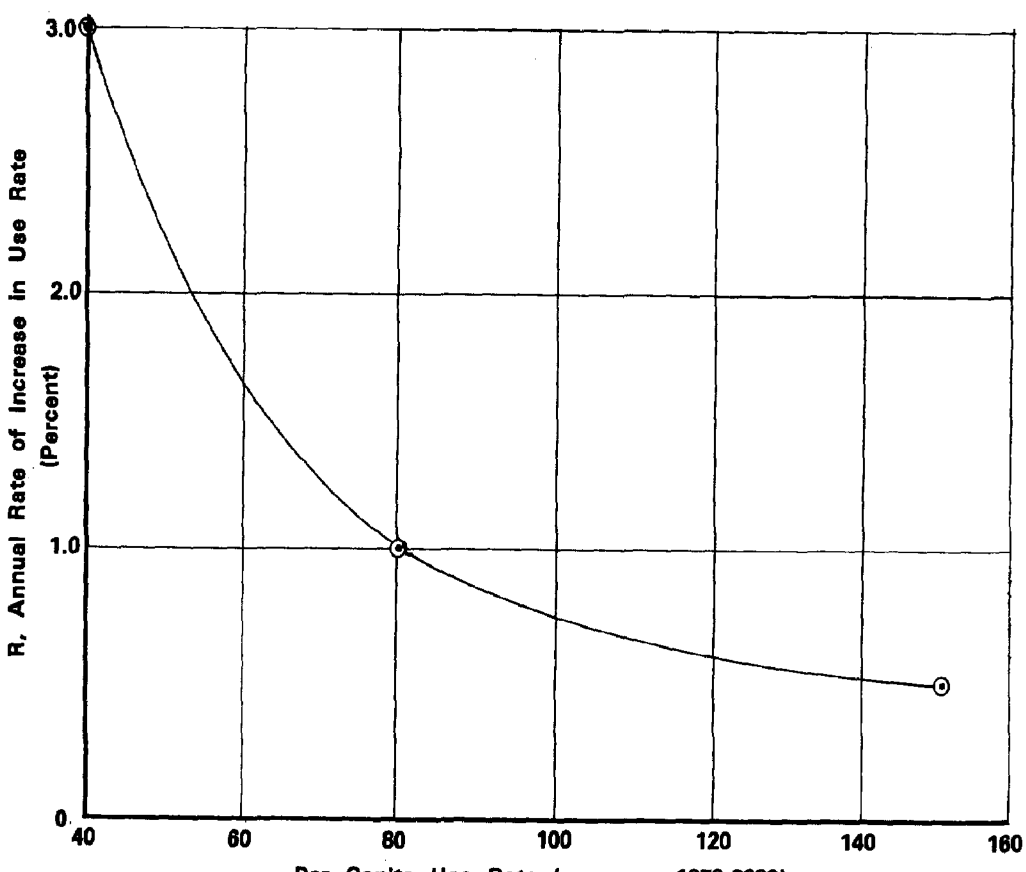


FIGURE 5-5: RATE OF GROWTH IN PER CAPITA USE RATE / RATE (15)

a one percent per year increase in the per capita use rate. The following is a comparison of results using the graduated use rate method and the one percent per year compounded method.

Initial Use Rate	After 50 Years	
	Graduated Method	1% Compounded
(gpcd)		
40	90	66
66	109	108
100	128	164
150	185	247

Per capita use rates, as derived for each community water system using the graduated use rate method, are presented in attachment 5-A.

Following the above determination of projected per capita use rates, the next step in the analysis was to project the population in each of the water service areas. Population projections for the cities and counties of the Chesapeake Bay Area were prepared by the Bureau of Economic Analysis (BEA), U.S. Department of Commerce, from the OBERS Series C economic and demográphic projections. Since the service population in many of the water service areas differed from the known census population in many of the communities (usually due to service outside the defined geographical limits of the community), it was assumed that the proportion between the two population numbers would remain constant from the base year (1970) through the year 2020. The ratio between the service and census population for each community, when applied to the projected census population, as provided by BEA, yields the estimated future service population in each community for each goal year. The projected service populations for each water service area are presented in Attachment 5-A.

Given the projected per capita use rates and the expected populations of the water service areas, the future non-industrial demands on the large systems are the product of the two parameters.

The Industrial water that is publicly supplied in each of the water service areas was disaggregated from the total subregional industrial demands. The projected amount of water publicly supplied to industry for each subregion was disaggregated to the various water service areas based on a shares analysis of future employment growth within each water service area. Implicit in this approach is the assumption that the water utilities will indeed continue to supply expanding industrial needs. It is acknowledged, however, that policy decisions at the local level may influence the future magnitude and distribution of industrial demands in the area.

Small water systems (those serving fewer than 2,500 persons) were projected as an aggregate, by subregion, using the same per capita rate of increase curve as for larger systems (Figure 5-5). Populations were derived by relating projections of total county population to the population of small towns and cities. The historical percentage increase in the growth of small towns and cities in the Chesapeake Bay Area was found to vary according to the regression: $6.0 + 2.33X_i$, where X_i represents the percent increase in county population over the previous decade. Based on previous studies and observations of average water use in the Eastern United States, an initial non-industrial water use rate of 85 gpcd was selected as being representative of the average use in small systems in the Bay Area. It was assumed that there was no industrial component of demand in the small systems.

PROJECTED MUNICIPAL DEMANDS

Based on the methodology discussed in the preceding section the municipal demands were developed. These are presented in Table 5-7, by subregion, for each Water Service Area in the Chesapeake Bay Area. The non-industrial and industrial components, and the total are shown for each goal year, and sums tabulated for each subregion. In some cases, the present demands in some service areas exceed the amount that would normally be expected based on the income or industrial activity of the community. These "unaccounted demands" are carried through as a constant for all the goal years. In such cases, the particular water service area in question is asterisked. These unaccounted for amounts may result from any number of factors, including excess leakage (as is probably the case at Crisfield), unusual military or institutional use (such as at Williamsburg), or public usage in excess of what might be expected (as is the case at Washington). Results for the aggregated water use by small systems in each subregion are detailed in Table 5-8.

INDUSTRIAL WATER SUPPLY DEMANDS

In the previous chapter, industrial water withdrawals were shown to be 1,615 mgd. Of this, however, only 37 percent was from fresh sources, illustrating the importance of brackish water to the industries around the Chesapeake. Other sources include groundwater, surface water, and one instance of wastewater reuse in the Baltimore area. Most of the demands were shown to be concentrated at Baltimore, Richmond, and the Hampton Roads areas. These centers of industrial activity are expected to form the focus of future growth and industrial expansion as well.

TABLE 5-7
PROJECTED MUNICIPAL & INDUSTRIAL DEMANDS

W. S. A.	1970	1980			1990			2000			2020		
	Total	M	I	Total	M	I	Total	M	I	Total	M	I	Total
SUBREGION 1													
Aberdeen	1.2	3.3	0.7	4.0	5.6	0.8	6.4	8.2	0.9	9.1	15.4	1.2	16.6
Annapolis	4.3	5.4	0.8	6.2	6.0	0.7	6.7	6.6	0.5	7.1	7.1	0.4	7.5
Baltimore	245.0	218.8	66.6	285.4	262.6	50.3	312.9	309.9	46.7	356.6	420.6	50.0	470.6
Bel Air	1.0	1.7	0	1.7	2.4	0	2.4	3.0	0	3.0	4.2	0	4.2
Crofton	0.8	1.2	0	1.2	1.6	0	1.6	1.7	0	1.7	1.8	0	1.8
Edgewood (Perryman)	1.2	1.6	0.5	2.1	2.7	0.5	3.2	4.0	0.6	4.6	7.6	1.0	8.6
Havre de Grace	1.55	1.2	0.4	1.6	1.5	0.3	1.8	1.6	0.2	1.8	1.8	0.2	2.0
Joppatowne	0.6	0.9	0	0.9	0.9	0	0.9	1.0	0	1.0	1.2	0	1.2
Maryland City	0.6	1.4	0.1	1.5	2.0	0.1	2.1	2.6	0.1	2.7	4.0	0.1	4.1
King's Heights (Odenton)	0.5	0.8	0	0.8	1.1	0	1.1	1.3	0	1.3	1.8	0	1.8
Severna Park (Severndale)	1.8	3.1	0	3.1	4.4	0	4.4	5.9	0	5.9	9.2	0	9.2
Sykesville - Freedom	0.6	0.9	0	0.9	1.4	0	1.4	1.6	0	1.6	2.3	0	2.3
Westminster	1.1	1.5	0.1	1.6	2.0	0.1	2.1	2.3	0.1	2.4	2.9	0.1	3.0
Subtotal	260.3	242.	69.	311.	294.	53.	347.	350.	49.	399.	480.	53.	533.
SUBREGION 2													
Cambridge*	3.9	1.5	0.9	4.2	1.8	0.7	4.3	2.2	0.9	4.9	3.0	1.2	6.0
Centreville	0.3	0.4	0	0.4	0.5	0	0.5	0.6	0	0.6	0.9	0	0.9
Chestertown	0.5	0.6	0.1	0.7	0.7	0.1	0.8	0.8	0.1	0.9	1.2	0.1	1.3
Crisfield*	1.4	0.3	0.6	1.5	0.4	0.5	1.5	0.5	0.5	1.6	0.6	0.6	1.8
Delmar	0.3	0.4	0	0.4	0.4	0	0.4	0.5	0	0.5	0.6	0	0.6
Denton*	0.4	0.3	0	0.5	0.3	0	0.5	0.4	0	0.6	0.5	0	0.7
Easton	1.0	1.5	0	1.5	1.9	0	1.9	2.4	0	2.4	3.5	0	3.5
Elkton*	1.0	1.1	0	1.2	1.3	0	1.4	1.4	0	1.5	1.8	0	1.9
Pocomoke City	0.3	0.4	0	0.4	0.6	0	0.6	0.7	0	0.7	1.0	0	1.0
Princess Anne	0.2	0.3	0	0.3	0.3	0	0.3	0.4	0	0.4	0.6	0	0.6
Salisbury*	4.0	1.9	1.3	4.5	2.2	1.2	4.7	2.7	1.3	5.3	3.6	1.5	6.4
Snow Hill*	0.5	0.4	0.1	0.7	0.5	0.1	0.8	0.6	0.1	0.9	0.8	0.2	1.2
Subtotal*	13.8	9.1	3.0	16.3	10.9	2.6	17.7	13.2	2.9	20.3	18.1	3.6	25.9
SUBREGION 3													
No Large Systems													
SUBREGION 4													
Seaford	0.8	0.8	0.2	1.0	1.1	0.1	1.2	1.3	0.1	1.4	1.8	0.1	1.9

Note: See Attachment A for tabulation of populations and use rates.

*Totals include unaccounted for balances

TABLE 5-7 (Cont'd)
PROJECTED MUNICIPAL & INDUSTRIAL DEMANDS

W. S. A.	1970	1980			1990			2000			2020		
	Total	M	I	Total	M	I	Total	M	I	Total	M	I	Total
SUBREGION 5													
Washington Suburban Sanitary Commission	124.0	167.0	2.1	169.1	220.4	2.2	222.6	283.3	2.9	286.2	448.4	4.9	453.3
Washington Aqueduct*	200.0	160.8	1.3	219.7	182.5	1.1	241.2	204.9	1.3	263.8	267.9	1.8	327.3
Alexandria	13.0	16.0	0.2	16.2	19.8	0.2	20.0	22.1	0.2	22.3	27.3	0.3	27.6
Fairfax County Water Authority	36.5	68.4	1.0	69.4	103.0	2.4	105.4	146.8	3.5	150.3	275.3	6.7	282.0
Goose Creek - Fairfax City	7.1	15.9	0	15.9	23.3	0.1	23.4	31.5	0.1	31.6	58.2	0.1	58.3
Manassas	1.3	2.1	0	2.1	3.0	0	3.0	3.7	0	3.7	4.8	0	4.8
Manassas Park	0.4	0.8	0	0.8	1.4	0	1.4	2.0	0	2.0	3.9	0	3.9
Subtotal*	382.	431.	5.	494.	553.	6.	617.	694.	8.	760.	1,086.	14.	1,158.
SUBREGION 6													
Leonardtown	0.4	0.3	0	0.3	0.3	0	0.3	0.3	0	0.3	0.4	0.1	0.5
Lexington Park	1.0	1.5	0.1	1.6	2.6	0.1	2.7	4.0	0.1	4.1	8.5	0.2	8.7
Waldorf	0.8	1.4	0.1	1.5	2.5	0.2	2.7	3.9	0.3	4.2	8.4	0.6	9.0
Subtotal	2.2	3.2	0.2	3.4	5.4	0.3	5.7	8.2	0.4	8.6	17.3	0.9	18.2
SUBREGION 7													
Fredricksburg	2.6	2.8	0.3	3.1	3.4	0.2	3.6	4.0	0.2	4.2	5.5	0.3	5.8
SUBREGION 8													
Ashland	0.35	0.5	0	0.5	0.8	0	0.8	1.0	0	1.0	1.3	0	1.3
Colonial Heights - Petersburg	7.1	8.6	0.4	9.0	11.3	0.3	11.6	14.8	0.4	15.2	24.3	0.5	24.8
Hopewell	25.8	5.8	19.8	25.6	7.7	19.5	26.2	10.6	21.1	31.7	18.1	32.0	50.1
Mechanicsville	0.28	1.2	0	1.2	2.3	0	2.3	3.8	0	3.8	8.9	0	8.9
Richmond	41.1	48.6	0.7	49.3	58.5	0.7	59.2	72.2	0.6	72.8	103.3	0.8	104.1
Subtotal	74.6	65.	21.	86.	81.	20.	100.	102.	22.	124.	156.	33.	189.
SUBREGION 9													
West Point	0.26	0.3	0	0.3	0.4	0	0.4	0.4	0	0.4	0.6	0	0.6
SUBREGION 10													
Newport News System	27.3	34.1	2.7	36.8	40.1	2.2	42.3	47.9	2.1	50.0	64.9	2.6	67.5

*Totals include unaccounted for balances.

TABLE 5-7 (Cont'd)
PROJECTED MUNICIPAL & INDUSTRIAL DEMANDS

W. S. A.	1970	1980			1990			2000			2020		
	Total	M	I	Total	M	I	Total	M	I	Total	M	I	Total
SUBREGION 11													
Norfolk System	52.5	60.6	1.1	61.7	70.0	0.8	70.8	82.1	0.9	83.0	107.8	1.1	108.9
Portsmouth System[1]	13.7	15.5	2.5	18.0	19.5	2.1	21.6	23.5	2.1	25.6	32.3	2.9	35.2
Subtotal	66.2	76.1	3.6	79.7	89.5	2.9	92.4	106.	3.0	109.	140.	4.0	144.
SUBREGION 12													
Williamsburg*	2.5	3.5	0	4.2	4.0	0	4.7	4.8	0	5.5	6.5	0	7.2
Smithfield	0.3	0.3	0.1	0.4	0.4	0.2	0.6	0.5	0.3	0.8	0.6	0.6	1.2
Suffolk Area	1.8	2.1	0.7	2.8	2.5	0.9	3.4	3.0	1.4	4.4	4.0	2.9	6.9
Subtotal*	4.6	5.9	0.8	7.4	6.9	1.1	8.7	8.3	1.7	10.7	11.1	3.5	15.3
Chesapeake Bay Area Total	835.	870.	106.	1,039.	1,086.	88.	1,237.	1,335.	89.	1,487.	1,981.	115.	2,159.

[1] Not including Suffolk.

*Totals include unaccounted for balances.

TABLE 5-8
PROJECTED WATER USE BY SMALL SYSTEMS,
CHESAPEAKE BAY AREA, 1970-2020

Subregion	1970 Population (1,000's)	1970 Water Use (mgd)	1980 Pop.	1980 Water Use	1990 Pop.	1990 Water Use	2000 Pop.	2000 Water Use	2010 Pop.	2010 Water Use	2020 Pop.	2020 Water Use
1. Baltimore, SMSA	95.0	8.1	162.7	15.1	205.1	20.7	233.4	25.4	232.2	27.1	224.3	28.0
2. Non-SMSA, MD	56.3	4.8	80.4	7.5	106.5	10.8	136.0	14.8	165.6	19.4	195.0	24.3
3. Non-SMSA, VA	9.4	0.80	10.8	1.0	12.4	1.3	13.7	1.5	15.4	1.8	17.4	2.2
4. Sussex Co., DE	12.8	1.1	19.4	1.8	27.3	2.8	34.0	3.7	42.3	4.9	51.9	6.5
5. Washington, D. C., SMSA	95.4	8.1	38.0	3.5	57.8	5.8	75.0	8.2	103.2	12.1	140.0	17.4
6. Non-SMSA, MD	23.5	2.0	35.8	3.3	58.4	5.9	88.2	9.6	110.2	12.9	124.0	15.5
7. Non-SMSA, VA	13.4	1.1	21.4	2.0	31.5	3.2	45.1	4.9	64.8	7.6	88.0	11.0
8. Richmond, SMSA	61.4	5.2	99.0	9.2	136.6	13.8	175.9	19.2	226.0	26.4	268.6	33.5
9. Non-SMSA, VA	29.3	2.5	39.4	3.7	45.4	4.6	55.7	6.1	67.6	7.9	79.0	9.8
10. Newport News-Hampton SMSA	5.37	0.46	7.89	0.73	11.0	1.1	13.7	1.5	11.1	1.3	8.04	1.0
11. Norfolk-Portsmouth SMSA	8.16	0.69	11.0	1.0	14.8	1.5	19.6	2.1	25.4	3.0	26.4	3.3
12. Non-SMSA, VA	26.1	2.2	35.3	3.3	44.3	4.5	58.9	6.4	78.3	9.2	91.0	11.3
TOTAL	436.1	37.0	561.1	52.1	751.1	76.0	949.2	103.4	1,142.1	133.6	1,313.6	163.8

A major consideration in the projection of industrial water supply demands is the fact that federal water quality goals may impact heavily on industrial water use habits. The 1972 Amendments to the Federal Water Pollution Control Act (PL 92-500), require application of "best practicable" treatment technology by 1978, and of "best available" technology by 1983 (without further defining the quoted terms). In addition, the act advocates that a goal of "zero discharge" of pollutants be sought. As a result, improved recycling technology will probably occur as industries begin to comply with directives, and strive for higher levels of waste treatment.

Significant reductions in intake demand are associated with increased recirculation within an industry. The more that water is recirculated, the less water is needed to replace that discharged. Future water use patterns will thus depend on the degree to which recirculation technology is utilized by the industries in the Chesapeake Bay Area. In consideration of this, three alternative sets of projections were developed to reflect various degrees of recirculation.

The projections vary only in the projected rates of recycling. Such measures of economic growth as production, employment, and earnings are thus the same in all three cases. Following a discussion of the derivation of the alternative projections, the assumptions and methodology used to accomplish the third and final set, which was selected for use in the balance of the report, is presented. The Sensitivity Analysis, to be included as a later chapter in this report, presents, and makes comparisons between, the industrial water supply demands that result from all three of the alternatives.

DISCUSSION

The results of the survey of industrial establishments and water use, as presented in Chapter II, were developed by the Bureau of Domestic Commerce, U.S. Department of Commerce (BDC), under contract with the Baltimore District, U.S. Army Corps of Engineers. The balance of the work performed under this contract involved the projection of future industrial demands. The projections were derived by assuming (in part) that each industry group will achieve, as an average, the maximum theoretically, possible recycling rate (R), by 2020, where $R = {}^{G}/_{I}$ as defined previously in Chapter II. Very marked reductions in industrial withdrawal demands and discharges result from this methodology which is termed Projection Set 1. The gross water use and consumption figures generated in this initial analysis also formed the basis for derivation of the intake demands for all three projection sets.

The values for "recycling rate", obtained through the BDC survey of individual plants, reflect all combinations of in-plant process technology and/or water recycling in the strict sense. The terms "technology" and "recycling" are thus used interchangeably in this report to refer to advances in efficiency in industrial water use, whether it be through improved production processes (which are important factors in certain types of industry) or recycling (which usually occurs in cooling and/or by-product recovery operations).

For comparison purposes, Projection Set 2 was developed which assumed industry would maintain present rates of recycling technology throughout the goal years. Water withdrawal requirements in this case increase proportionally with the projected gross water demand.

A comparison of the plots of the recycling rate associated with Projection Set 1 (assuming implementation of advanced technology) and Set 2 (constant technology) is shown in Figure 5-6. Upon examination, the two projection sets were felt to represent what might best be termed an "envelope" of values that reflect the impact of recycling in future industrial water use. It is felt, for example, that future industrial recycling practice will most probably exceed the conditions of constant recirculation (Set 2). In addition to the influence of the national water quality goals, other factors are known to increase industrial water reuse and subsequently reduce withdrawal requirements. For example, recirculation of supplies is utilized by some industries to recover materials in the process water. Other industries increase their recycling ratios to, very simply, conserve water.

Regarding Projection Set 1, it is likely that a future review and analysis of the National water quality goals may eventually result in a redefinition of certain water quality standards. This would in turn permit industry to fall back from the "maximum theoretically possible" recycling rates, as assumed in Projection Set 1. It has been estimated by the National Water Commission, in their report to the President in 1973, that attainment of the 1983 water quality goals would cost industry $108 billion (in 1972 dollars[51]). It is questionable whether the expenditure of these funds by industry (and ultimately the consumer and taxpayer) will provide equal benefits in terms of environmental quality. It has been estimated by a major chemical manufacturer, for example, that by 1977, 93 percent of their potential BOD will be removed. To remove the next 5 percent will require an additional capital investment of $78 million—a 50 percent investment increase to achieve a mere 5 percent improvement[50].

In view of the above considerations, a third set of industrial demands was derived that reflects a moderate future growth in water use technology. Projection Set 3 was made based on a straight-line continuation of the 1975 to 1980 trend in recycling as projected by BDC for each major industrial sector. The resultant plot of Projection Set 3, shown in Figure 5-7 as "moderate technology," illustrates the trend as compared with Projection Sets 1 and 2, and with historical recycling rates at the national and regional levels. The historical data were compiled from the Special Report Series volume: "Water Use in Manufacturing," from the U.S. Department of Commerce's *Census of Manufacturers.*

INDUSTRIAL WATER USE TECHNOLOGY, PROJECTION SETS 1 AND 2

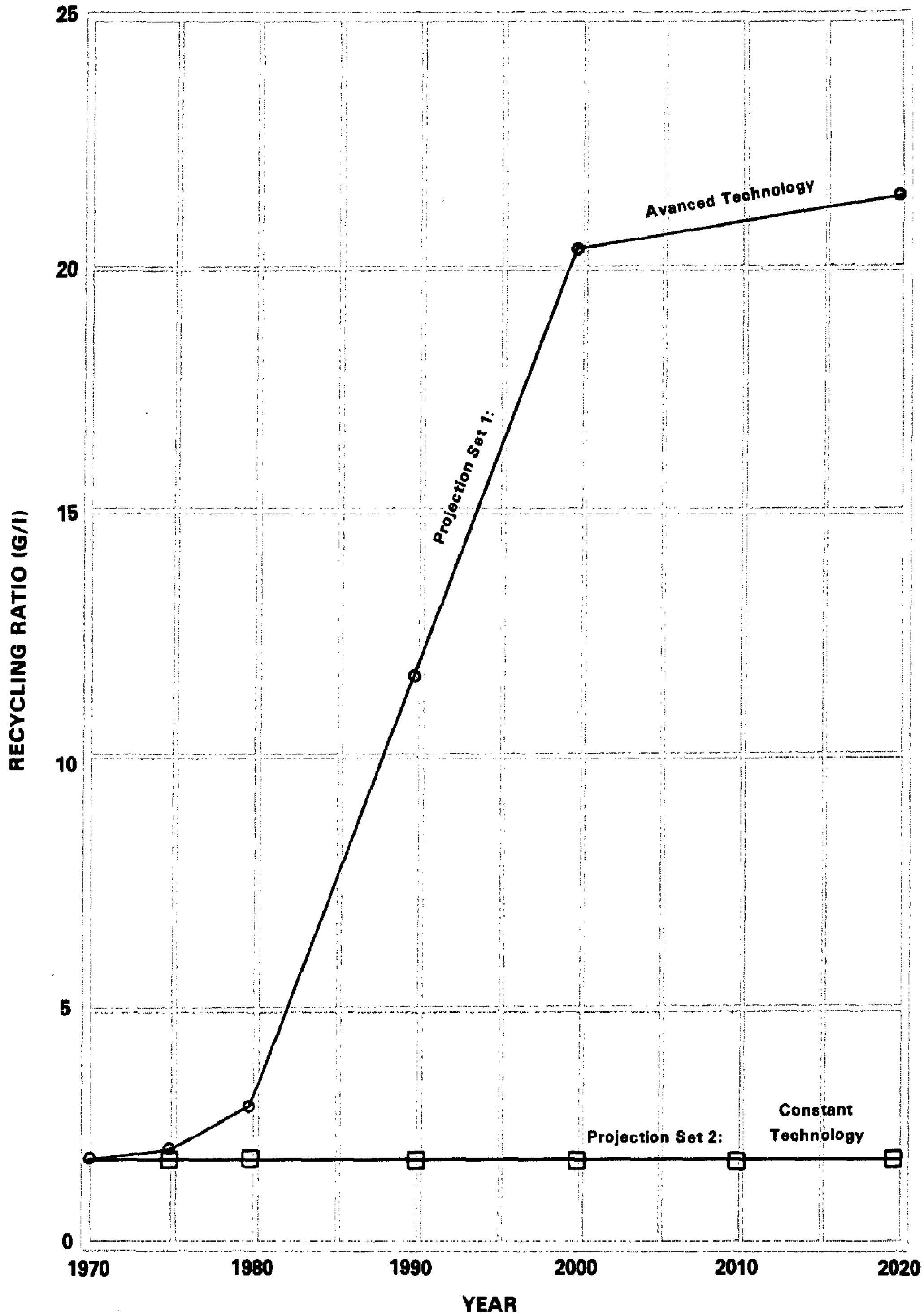


FIGURE 5-6

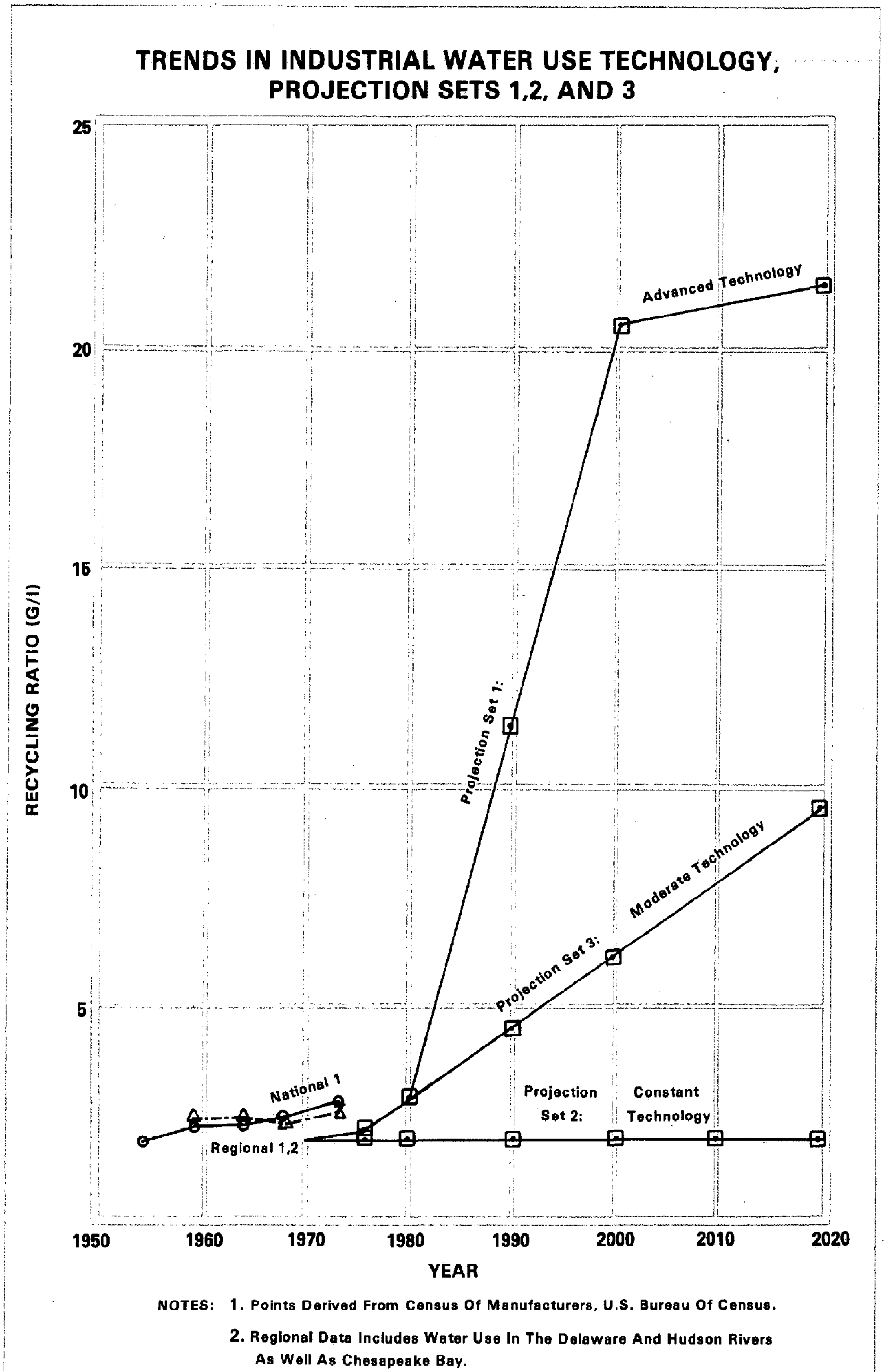

TRENDS IN INDUSTRIAL WATER USE TECHNOLOGY,
PROJECTION SETS 1,2, AND 3
RECYCLING RATIO (G/I)
25
20
15
10
5
1950
1960
1970
1980
1990
2000
2010
2020
YEAR
Advanced Technology
Projection Set 1:
Projection Set 3:
Moderate Technology
National 1
Regional 1,2
Projection
Set 2:
Constant
Technology
NOTES: 1. Points Derived From Census Of Manufacturers, U.S. Bureau Of Census.
2. Regional Data Includes Water Use In The Delaware And Hudson Rivers
As Well As Chesapeake Bay.

FIGURE 5-7

This discussion was presented in order to trace the development of the industrial water demands used in this report. Specific assumptions and details of the methodology are included in the following two sections.

ASSUMPTIONS

Certain basic assumptions were used in the projection of industrial water use for the Chesapeake Bay Area. Uncertainties as to future trends in such things as employment, the Gross National Product, and National water quality goals make certain assumptions necessary. Basic assumptions are also needed concerning the future industrial mix, geographical site locations, and possible improvements in water use technology.

As stated previously, gross water demands remain the same in each of the three projection sets. In the methodology used by the Bureau of Domestic Commerce to derive these gross demands, the following assumptions were made:

a. Gross demands for each industrial sector grow in relation to Gross Product Originating (GPO), as derived from OBERS projections of earnings.

b. Projections of consumptive use are based on a continuation of the 1970 observed relationship of consumption and gross demand.

Projection of water intakes for Projection Set 1 involves a series of assumptions regarding future recycling:

a. "Best available technology" is reflected by the average of the 20 highest recycling ratios reported by any particular 4-digit SIC industry in the 1970 BDC National survey, including the more efficient production technologies.

b. The weighted average of the 4-digit "20-best" reflect the recycling ratios for the entire industry group (2 digit), by 1985.

c. For the year 2000, each industry group will achieve their maximum theoretical recycling rate, towards the National goal of zero discharge of pollutants (the theoretically possible recycling rate is calculated from current gross water uses and projected minimum intakes).

Projection of water intakes in Projection Set 2 assumed a continuation of recycling rates at the 1970 level for each major water-using industrial sector. The water intakes derived in Projection Set 3 assume a straight line continuation of the 1975 to 1980 trend projected in Projection Set 1.

METHODOLOGY

The most important parameter in projecting industrial water needs is the gross water demand, since it is from this that projections of withdrawals and consumptive losses are determined, and upon which the accuracy of all other use components depend.

The gross water demand may be expected to vary directly with manufacturing output—the more products, the greater the demand for water. For the manufacturing sector as a whole, this expectation has been confirmed in the last four censuses of manufactures. In those censuses, the gross water demand per unit output (measured in constant dollars value added in manufacturing) has remained relatively constant, varying by less than 2 percent.

Gross water demands were projected by developing coefficients for each major water-using industry group and the residual industries as a single group by relating the reported 1970 gross water demands to the production proxy (GPO). The latter was derived from the constant dollar earnings and conversion factors provided for the Chesapeake Bay Study in the economic forecasts of OBERS (Office of Business Economics and the Economic Research Service).

The gross water demand can be satisfied by any combination of withdrawal and recycling of water, with the options ranging from once-through use of water, in which case withdrawal equals gross water demand, to a completely closed recycling system in which, after the initial input of water, the withdrawal requirement reduces to zero. It is obvious, then, that if the gross water demand is to be met, the extent to which recycling is practiced determines the amount of water that will be withdrawn. Except for the most simple of manufacturing operations, however, a closed system is impractical, and, manufacturing operations being generally complex combinations of operations, water is consumed or lost from the system by evaporation, leaks, incorporaton into products, etc. In any system in which the gross demand is met in whole or part by recycling, those consumptive losses must be made up by equivalent additions of new intake water. Consumptive losses, then, impose a minimum requirement for withdrawal, and impose a theoretical limit on the ratio of recycled water to gross demand.

Consumption of water as an element in industrial water use is derived by subtracting reported discharges from reported withdrawals. There are inherent errors in this derivation, however, which result from the lesser reliability of the discharge quantities reported (usually estimated) as compared to the reported withdrawals which are usually obtained from meter readings and pumping records. As a result of this, the relationship of consumptive use to gross water demand, or to value added, appears in the Census of Manufacturers to be inconsistent. In this study, because consumptive losses are a critical parameter in the forecasts for future planning, these inconsistencies have been ignored and projections of consumptive use have been based on a continuation of the observed relationship of consumption to gross demand as revealed in the BDC 1970 survey, converging that relationship to the National averages for any particular industry group for which the regional ratios appeared to be unreasonable.

The projected withdrawal requirements (intake) were derived differently for the three alternative projection sets. The methodologies used for derivation of each set are discussed in the following subsections.

Projection Set 1

While it is acknowledged that recycling practices in manufacturing are influenced by many factors, the projected withdrawal requirements for Projection Set 1 were calculated by assuming that improved recycling practices will occur in the future as higher levels of waste treatment are instituted by the manufacturers as required by the 1972 Amendments to the Federal Water Pollution Control Act (PL 92-500). To couple the timetable of improved waste-treatment to projections of industrial water withdrawals, the following assumptions and calculations were made.

It is assumed that the current "best-available" technology is reflected in the average of the 20 highest recycling ratios reported by all individual establishments in any 4-digit SIC industry in the 1970 BDC nationwide survey. The averages are generally referred to as the "20-best" file. Weighing these 20-best averages for the 4-digit SIC industries by the gross water used in each, an equivalent recycling ratio for each 2-digit SIC group was produced. This ratio was then assumed to be achieved by the entire industry group, regionally and nationally, by 1985.

For the year 2000, it was assumed that each industry group will, in the process of achieving the national goal of zero discharge of pollutants, achieve the maximum theoretically possible recycling rate. The theoretical maximum recycling rate is calculated from current gross water uses and projected minimum intakes. The latter is the sum of current consumption and additional consumptive losses that could result from the requirements to abate thermal pollution from all non-contact cooling water used in manufacturing. The losses were estimated on the basis of probable evaporative losses by 2000 from the use of cooling towers and ponds.

From the calculated gross water demands and recycling rates from 1985 and 2000, withdrawal requirements were derived and the degree to which recycled water provided for the gross demand was determined as percent recycled water. For the interim years 1980 and 1990, the percentages of recycled water were computed by compound interest rate formulae based on the differences between values developed for 1970, 1985 and 2000. Beyond the year 2000, recycling rates are kept constant at the theoretically maximum achievable year 2000 rates. The results of this analysis are presented in their entirety in the Sensitivity Analysis section of this report.

Projection Set 2

Industrial water withdrawals were derived in Projection Set 2 by assuming that the recycling rates identified in the BDC survey of industrial water use would remain constant within each industrial sector through the year 2020. Results of this set of calculations are presented in the Sensitivity Analysis section of this report.

Projection Set 3

As discussed previously, Projection Set 3 was developed as a compromise between Projection Sets 1 and 2, being reflective of a more moderate growth in recycling. Future recycling rates for each major industrial sector were determined through a straight-line extension of the 1975 to 1980 trend as projected by the Bureau of Domestic Commerce.

Use of Projection Set 3 acknowledges that, while recycling rates will indeed continue to improve, it is more likely that a lesser degree of implementation of technology in industrial water reuse will occur than that assumed in Projection Set 1. It is in response to this possibility, and towards the desire for a more conservative planning guide, that Projection Set 3 was selected for use in the balance of the analysis.

PROJECTED INDUSTRIAL DEMANDS

Projections of industrial water demands, as derived through the methodology and assumptions implicit in Projection Set 3, are presented in this section. Gross demands, intake, consumption, and discharge are presented for each major water-using industrial sector, and for the manufacturing industries as a whole, in Table 5-9. Industrial water use is also presented on a subregion by subregion basis in Table 5-10. Water intake requirements for each subregion and each goal year are disaggregated as to source, i.e., whether the supply is expected to derive from fresh or brackish sources, and whether the freshwater will come from ground or surface courses. Table 5-10 also shows whether demands are expected to be met by the industries themselves or through public systems. Each of these components has been computed by assuming that each will remain as a constant proportion of total intake through the entire study period.

AVAILABLE WATER SUPPLIES

In order to identify future *freshwater* supply shortages in the major communities of the Chesapeake Bay Area, demands for water supply in each of the defined Water Service Areas are compared with the capacities of the existing systems. Capacities are defined in two ways: as the "safe yield" of presently developed sources, and the capacity of existing pumping systems and treatment plants. The capacities of these systems and sources are presented in this section. The influence of post-treatment storage facilities, as to their effect on the amount of water available during droughts, are neglected for the purposes of this report.

This study has also undertaken an analysis of the overall amount of water that could be developed from all possible sources and made available for use in the area. In this analysis, water supply demands in each subregion for all uses (except cooling in electric power generation) are aggregated and compared with the total of all presently developed freshwater resources and estimates of the resources that could potentially be developed. The total resource includes existing streamflows and diversions, estimates of maximum sustainable groundwater yields, and safe yields of existing reservoirs.

HYDROLOGIC CONSIDERATIONS

The hydrologic cycle in the Bay Area can be viewed as a closed system. In general, conservation occurs in that the amount of water falling as precipitation balances, in the long run, the amount leaving the region through evapotranspiration, stream runoff, or by the discharge of groundwater out of the area. A particular unit of water may, however, undergo many uses and

TABLE 5-9
WATER USE IN MANUFACTURING,
BY SECTOR, CHESAPEAKE BAY AREA, mgd
PROJECTION SET 3

	Gross Water Demand	Intake	Consumption	Discharge	Recycling Rate
ALL MANUFACTURING					
1970	2,607.9	1,615.5	74.2	1,541.3	1.61
1975	3,512.5	1,823.9	112.5	1,711.4	1.93
1980	4,408.2	1,581.4	157.5	1,423.9	2.79
1990	6,001.6	1,344.1	246.4	1,097.7	4.47
2000	8,591.5	1,397.8	341.3	1,056.5	6.15
2020	17,290.2	1,822.9	652.4	1,170.5	9.48
FOOD & KINDRED PRODUCTS (SIC 20)					
1970	79.7	74.3	5.6	68.7	1.07
1975	95.4	81.3	6.1	75.2	1.17
1980	111.1	75.3	6.4	68.9	1.48
1990	146.0	70.2	6.3	63.9	2.08
2000	196.4	73.2	8.4	64.8	2.68
2020	343.9	88.4	14.8	73.6	3.89
PAPER & ALLIED PRODUCTS (SIC 26)					
1970	644.8	72.8	7.6	65.2	8.86
1975	848.2	88.1	17.8	70.3	9.63
1980	1,051.6	100.9	25.2	75.7	10.42
1990	1,546.1	128.7	49.5	79.2	12.01
2000	2,334.9	171.7	74.6	97.1	13.60
2020	5,145.5	306.7	164.4	142.3	16.78
CHEMICALS (SIC 28)					
1970	402.5	328.1	14.5	313.6	1.23
1975	560.1	382.6	19.6	363.0	1.46
1980	719.3	342.3	24.5	317.8	2.10
1990	1,131.5	335.1	33.9	301.2	3.38
2000	1,804.5	388.0	54.2	333.8	4.65
2020	4,319.3	599.9	129.7	470.2	7.20

TABLE 5-9 (Cont'd)
WATER USE IN MANUFACTURING, BY SECTOR, CHESAPEAKE BAY AREA, mgd

	Gross Water Demand	Intake	Consumption	Discharge	Recycling Rate
PETROLEUM (SIC 29)					
1970	81.6	76.3	0.7	75.6	1.07
1975	99.8	79.4	0.9	78.5	1.19
1980	105.3	63.3	1.2	62.1	1.66
1990	136.9	52.6	1.9	50.7	2.60
2000	178.9	50.5	2.5	48.0	3.54
2020	294.8	54.4	4.1	50.3	5.42
PRIMARY METALS (SIC 33)					
1970	1,094.6	882.3	35.1	847.2	1.24
1975	1,423.4	965.5	54.1	911.4	1.47
1980	1,752.1	815.6	78.8	736.8	2.15
1990	2,203.2	630.2	130.0	500.2	3.50
2000	2,823.6	582.9	166.6	416.3	4.84
2020	4,536.8	601.7	267.7	334.0	7.54
OTHER MANUFACTURING					
1970	304.7	181.7	10.7	171.0	1.68
1975	490.6	227.0	14.0	213.0	2.16
1980	668.8	184.0	21.4	162.6	3.63
1990	837.9	127.3	24.8	102.5	6.58
2000	1,253.2	131.5	35.0	96.5	9.53
2020	2,649.9	171.8	71.7	100.1	15.42

TABLE 5-10
PROJECTED WATER USE IN MANUFACTURING, MGD
PROJECTION SET 3
SUBREGION 1

	1970	1980	1990	2000	2020
GROSS USE	1226.1	2179.2	2751.8	3608.4	5997.5
INTAKE	990.7	1034.2	830.2	793.3	856.4
-Public Supply	70.0	69.2	52.6	49.2	52.7
-Brackish	781.2	825.7	638.1	604.5	661.7
-Self-Supplied, fresh	17.3	17.1	13.0	12.0	13.0
Ground	14.4	14.2	10.8	10.0	10.9
Surface	2.9	2.9	2.2	2.0	2.1
-Wastewater	122.2	122.2	126.5	127.6	129.0
CONSUMPTION	43.7	114.2	156.0	201.5	336.4
DISCHARGE	947.0	920.0	674.2	591.8	520.0

SUBREGION 2

	1970	1980	1990	2000	2020
GROSS USE	35.5	44.5	52.2	71.6	124.1
INTAKE	34.8	34.6	30.8	33.8	41.8
-Public Supply	3.0	3.0	2.6	2.9	3.6
-Brackish	0.7	0.7	0.6	0.6	0.8
-Self-Supplied, fresh	31.1	30.9	27.6	30.3	37.4
Ground	30.0	29.8	26.7	29.1	36.0
Surface	1.1	1.1	0.9	1.2	1.4
CONSUMPTION	0.9	1.4	1.9	2.5	4.0
DISCHARGE	33.9	33.2	28.9	31.3	37.8

TABLE 5-10 (cont'd)
PROJECTED WATER USE IN MANUFACTURING, MGD
PROJECTION SET 3
SUBREGION 3

	1970	1980	1990	2000	2020
GROSS USE	2.6	3.3	4.1	5.4	9.2
INTAKE	2.3	2.0	1.7	1.7	1.9
-Public Supply	0.3	0.3	0.2	0.2	0.2
-Brackish	0.1	0.1	0.1	0.1	0.1
-Self-Supplied, fresh	1.9	1.6	1.4	1.4	1.6
Ground	1.9	1.6	1.4	1.4	1.6
Surface	0.0	0.0	0.0	0.0	0.0
CONSUMPTION	0.2	0.2	0.2	0.2	0.4
DISCHARGE	2.1	1.8	1.5	1.5	1.5

SUBREGION 4[1]

	1970	1980	1990	2000	2020
GROSS USE	82.7	86.4	53.1[2]	81.1	175.0
INTAKE	65.6	43.5	18.0	20.6	29.5
-Public Supply	2.7	1.8	0.7	0.8	1.2
-Brackish	0.0	0.0	0.0	0.0	0.0
-Self-Supplied, fresh	62.9	41.7	17.3	19.8	28.3
Ground	14.9	9.9	4.1	4.7	6.7
Surface	48.0	31.8	13.2	15.1	21.6
CONSUMPTION	1.9	2.8	2.3	3.4	7.5
DISCHARGE	63.7	40.7	15.7	17.2	22.0

[1]Includes Kent County, Delaware.
[2]Water use per dollar Gross Product Originating ($GPO) in predominant food industries was deemed high by BDC. Therefore, use rates were trended to equal Baltimore regional averages by 1990, increasing thereafter.

TABLE 5-10 (cont'd)
PROJECTED WATER USE IN MANUFACTURING, MGD
PROJECTION SET 3
SUBREGION 5

	1970	1980	1990	2000	2020
GROSS USE	5.4	8.0	12.0	18.6	41.8
INTAKE	4.7	6.6	8.5	11.3	19.7
-Public Supply	3.3	4.6	6.0	8.0	13.8
-Brackish	0.0	0.0	0.0	0.0	0.0
-Self-Supplied, fresh	1.4	2.0	2.5	3.3	5.9
Ground	0.1	0.2	0.1	0.2	0.4
Surface	1.3	1.8	2.4	3.1	5.5
CONSUMPTION	0.2	0.3	0.5	0.6	1.2
DISCHARGE	4.5	6.3	8.0	10.7	18.5

SUBREGION 6

	1970	1980	1990	2000	2020
GROSS USE	0.8	1.33	2.13	3.47	7.47
INTAKE	0.8	1.33	2.13	3.47	7.47
-Public Supply	0.1	0.17	0.27	0.43	0.93
-Brackish	0.0	0.00	0.00	0.00	0.00
-Self-Supplied, fresh	0.7	1.16	1.86	3.04	6.54
Ground	0.7	1.16	1.86	3.04	6.54
Surface	0.0	0.00	0.00	0.00	0.00
CONSUMPTION	0.1	0.10	0.10	0.10	0.24
DISCHARGE	0.7	1.23	2.03	3.37	7.23

TABLE 5-10 (cont'd)
PROJECTED WATER USE IN MANUFACTURING, MGD
PROJECTION SET 3
SUBREGION 7

	1970	1980	1990	2000	2020
GROSS USE	32.9	57.9	89.3	141.1	331.4
INTAKE	27.4	28.4	28.0	32.3	49.4
-Public Supply	0.2	0.3	0.2	0.2	0.3
-Brackish	0.0	0.0	0.0	0.0	0.0
-Self-Supplied, fresh	27.2	28.1	27.8	32.1	49.1
Ground	0.1	0.1	0.1	0.1	0.2
Surface	27.1	28.0	27.7	32.0	48.9
CONSUMPTION	1.8	2.4	2.7	4.2	9.9
DISCHARGE	25.6	26.0	25.3	28.1	39.5

SUBREGION 8

	1970	1980	1990	2000	2020
GROSS USE	400.5	746.2	1168.9	1862.0	4458.7
INTAKE	286.8	268.9	250.9	283.4	429.9
-Public Supply	22.3	20.9	19.5	22.0	33.4
-Brackish	0.0	0.0	0.0	0.0	0.0
-Self-Supplied, fresh	264.5	248.0	231.4	261.4	396.5
Ground	0.3	0.3	0.3	0.3	0.4
Surface	264.2	247.7	231.1	261.1	396.1
CONSUMPTION	14.0	24.7	35.3	56.3	134.5
DISCHARGE	272.8	244.2	215.6	227.1	295.4

TABLE 5-10 (cont'd)
PROJECTED WATER USE IN MANUFACTURING, MGD
PROJECTION SET 3
SUBREGION 9

	1970	1980	1990	2000	2020
GROSS USE	52.4	80.2	115.4	171.0	366.2
INTAKE	26.5	21.6	19.6	21.0	29.0
-Public Supply	0.2	0.2	0.1	0.2	0.2
-Brackish	10.3	8.3	7.6	8.2	11.2
-Self-Supplied, fresh	16.1	13.1	11.9	12.6	17.6
Ground	16.0	13.0	11.8	12.5	17.5
Surface	0.1	0.1	0.1	0.1	0.1
CONSUMPTION	5.0	5.2	3.7	5.5	11.7
DISCHARGE	21.5	16.4	15.9	15.5	17.3

SUBREGION 10

	1970	1980	1990	2000	2020
GROSS USE	114.9	184.6	255.4	358.6	720.7
INTAKE	100.2	58.8	46.9	46.0	57.9
-Public Supply	4.6	2.7	2.2	2.1	2.6
-Brackish	90.6	53.2	42.4	41.6	52.4
-Self-Supplied, fresh	5.0	2.9	2.3	2.3	2.9
Ground	5.0	2.9	2.3	2.3	2.9
Surface	0.0	0.0	0.0	0.0	0.0
CONSUMPTION	0.7	6.1	8.4	12.0	23.7
DISCHARGE	99.5	52.7	38.5	34.0	34.2

TABLE 5-10 (cont'd)
PROJECTED WATER USE IN MANUFACTURING, MGD
PROJECTION SET 3
SUBREGION 11

	1970	1980	1990	2000	2020
GROSS USE	32.3	53.5	73.3	109.1	236.7
INTAKE	25.3	16.4	13.0	13.6	18.5
-Public Supply	5.6	3.6	2.9	3.0	4.1
-Brackish	15.9	10.3	8.1	8.6	11.6
-Self-Supplied, fresh	3.8	2.5	2.0	2.0	2.8
Ground	3.8	2.5	2.0	2.0	2.8
Surface	0.0	0.0	0.0	0.0	0.0
CONSUMPTION	1.3	1.6	2.4	3.6	7.7
DISCHARGE	24.0	14.8	10.6	10.0	10.8

SUBREGION 12

	1970	1980	1990	2000	2020
GROSS USE	621.8	963.1	1424.0	2161.1	4821.4
INTAKE	50.4	65.1	94.4	137.3	281.4
-Public Supply	0.6	0.8	1.1	1.7	3.5
-Brackish	0.0	0.0	0.0	0.0	0.0
-Self-Supplied, fresh	49.7	64.3	93.3	135.6	277.9
Ground	44.9	58.1	84.3	122.5	251.0
Surface	4.8	6.2	9.0	13.1	26.9
CONSUMPTION	4.8	31.8	47.0	71.3	159.2
DISCHARGE	45.6	33.3	47.4	66.0	122.2

exist in several forms within the cycle. Problems thus arise in an attempt to quantify the supply of water available at a particular time and place, since it varies constantly in quantity and state. It can occur as moisture in the atmosphere, groundwater, reservoir storage, and surface-flowing streams.

Water in free-flowing streams is subject to periods of low rainfall during which streamflows may dramatically decline. The variability of flow in a stream is also a function of topography, the characteristics of the adjacent groundwater aquifers, the type and extent of vegetative ground cover in the basin, and land use. Maintenance of a streamflow record at a particular stream gaging station, over a period of years, enables construction of a "frequency-duration" curve. This curve can be used to determine the average flow of the stream to be expected for a particular duration (typically 1, 7, or 30 days), and particular recurrence interval (usually years).

While the amount of rainfall can have a critical influence on short-term water availability, other factors influence long-term water availability. Urbanization, for example, can directly and indirectly affect the quality and quantity of available supplies. The replacement of forests and other natural vegetative cover with the impervious surfaces of the city, reduces water penetration to the natural groundwater reservoirs, thus reducing groundwater storage. Groundwater storage, which provides flow to the streams during dry periods, becomes reduced and flooding becomes serious due to the rapid runoff during periods of heavy rainfall. The high concentration of population in urbanized areas also affects the water supply availability downstream due to the massive discharges of municipal and industrial wastes. Thus, the very growth that generates the water supply demands may, at the same time, deplete or degrade the existing available resource. Uncertainty concerning future trends in these factors complicates an assessment of water availability.

Areas utilizing groundwater sources, on the other hand, may have additional problems. In coastal or near-shore locations, excessive pumping may cause salt-water intrusion. Fresh groundwater reservoirs normally exert a head on the adjacent salt-water body since they extend above sea level and discharge under the force of gravity to the sea. Under heavy pumping, the water table will drop, and, if not replenished sufficiently by recharge, salt water may pollute the wells. Wells might become useless for years under these conditions. Care must also be taken that septic tank seepage, landfill drainage, or other pollutants are not allowed to penetrate to groundwater supplies.

In certain areas of the country subsidence has occurred due to a drawdown of the water table. The removal of water from the pore spaces in the aquifer allows compaction of the soil and a lowering of the overlying land surface. The decrease in porosity of the aquifer causes a reduction in the potential amount of water recoverable. Aside from this, direct curtailment of pumping may be required due to social and economic impacts resulting from the subsidence.

Although many factors influence a determination of water supply availability, estimates can, and must be made of the available resource. Thorough hydrologic investigation of an area's resources is necessary in order that potential regional shortages can be forecast. Also planning for urban and community development, at the local level, must, of necessity, include provisions for water supply to insure the health and general well-being of both its citizens and business communities. The assumptions employed in assessing the Bay Area's available water supply are discussed in the following section.

ASSUMPTIONS AND CRITERIA

The following assumptions and accompanying criteria were necessary to assess the available water resource:

a. Well yields for each particular system were assumed to be the 12-hour continious pumping yield as provided by the various State Departments of Health, except as noted.

b. Presently developed reservoir capacities are as defined by the particular owner and/or manager of the facility.

c. For run-of-the-river sources, the amount available is defined variably as the 30, 7, and 1-day low flow of the stream, at a 50-year recurrence interval.

d. Assessment of the streamflow available in each subregion, for comparison with demands for *all* uses, is the sum of the 7-day, 10-year low flows of undeveloped streams of greater than 5 cfs discharge.

e. Groundwater availability for each subregion is as estimated by various state and federal studies completed to date.

f. The subregional resource evaluation does not make allowance for potential reservoir development, unless presently slated for construction.

METHODOLOGY AND RESULTS

Water supply availability is defined in two different ways for use in the assessments presented in this report. First, the supply capabilities associated with each water service area are presented, and then the overall resource capability within each of the 12 subregions of the Bay Area is assessed.

Water Service Area Supply

For purposes of this study, the available supply is defined for each water service area by both the source capacity, and the system ("hardware") capacity. The source capacity is the dependable supply that can be expected under drought conditions, measured in million gallons per day (mgd). The criteria vary depending on the type of supply source. The system capacity refers to the capacity of the hardware of the system, encompassing for the purposes of this study the intake pipe and pumps and the treatment plant. Source and system capacities for each water service area are listed in Table 5-11. The smaller of either the source or hardware capacity was used to assess each system's capability to meet future demands.

For water service areas supplied by reservoirs, the available supply is taken as the "safe-yield," as defined by the particular water authority. Most of the systems using reservoirs define their safe-yield by the amount of water available during the drought of record. For example, Baltimore's reservoir system has a defined safe-yield of 243 mgd, based on the 1964-65 drought; while Newport News estimates its safe-yield at 35 mgd, based on the 1954-55 drought.

Only seven WSA's utilize run-of-the-river flows exclusively for their water supply: Havre de Grace and Bel Air, Maryland; Washington, D.C.; and Fredericksburg, Ashland, Richmond, and Hopewell, Virginia. These systems are particularly vulnerable to stream flow variation since drought deficiencies cannot be made up by drawing on reservoir storage. For these, the 1-, 7-, and 30-day low flows that can be expected once in 50 years were the criteria chosen to evaluate the river sources. Data from U.S. Geological Survey papers were used to derive the low-flow frequency curves for each duration.

Systems that use groundwater sources usually have a safe-yield defined by either the 12- or 24-hour pumping capacity of the well system. Long-term, sustained or ultimate yield, however, is generally not defined due to the variabilities inherent in groundwater hydrology. Aquifers used as water sources are often quite extensive, sometimes underlying several counties or entire geographic provinces. Also, since they are by definition contiguous and porous, fluctuations in capacity and yield at a particular point are dependent on the overall pumping pattern. For example, yields of artesian aquifers in much of southeastern Virginia have changed markedly due to the extensive pumping near the City of Franklin (the water table at that location has declined more than 150 feet). It is estimated that at the current rate of pumping, the flow patterns and water table profile in this area will continue to shift and not stabilize until near 2020[16]. For these reasons, it is difficult, if not impossible, to estimate the sustained or ultimate developable yield at a *single*

TABLE 5-11

MUNICIPAL SOURCE AND SYSTEM CAPACITIES, mgd

W.S.A. SUBREGION 1	Source	Source Capacity mgd	Source Capacity how defined	System Capacity mgd	System Capacity how defined
Aberdeen[1]	Wells (6)	1.0	pump	1.5	tr
Annapolis	Wells (7)	6.5	pump	5.1	tr
Baltimore	Patapsco River (1 reservoir)	95.0	60's drought	200.0	tr
	Gunpowder Falls (2 reservoirs)	148.0	60's drought	300.0	tr
	Susquehanna River	250.0	appropriation	250.0	pipe
Bel Air[1] (Md. Water Co.)	Winter's Run	1.1	30-day, 50-yr		
		0.3	7-day, 50-yr	1.5	tr
		—	1-day		
Crofton	Wells (2)	1.0	pump	1.8	tr
Edgewood (Perryman)	Wells (9)	1.9	pump	4.0	"plant"
Havre de Grace	Susquehanna River	1613.0	30-day, 50-yr		
		1355.0	7-day, 50-yr	3.0	tr
		1233.0	low daily natural		

TABLE 5-11 (cont'd)

MUNICIPAL SOURCE AND SYSTEM CAPACITIES, mgd

W.S.A.	Source	Source Capacity		System Capacity	
SUBREGION 1 (cont'd)		mgd	how defined	mgd	how defined
Joppatowne[1]	Wells (2)	1.1	pump	1.5	tr
King's Heights (Odenton)	Wells	1.9	pump	1.3	tr
Maryland City	Wells (3)	0.6	pump	1.2	"plant"
Severna Park (Severndale)	Wells (6)	2.7	pump	3.7	tr
Sykesville-Freedom[2]	Baltimore (Liberty Reservoir)	2.0	Agreement	1.5	tr
Westminster	Cranberry Run & Hull Creek	2.0	"Safe yield"	1.8	tr

[1]Supplemental supplies available via County owned interconnections.

[2]New reservoir at Piney Run to provide 3.5 mgd

SUBREGION 2					
Cambridge	Wells (12)	4.6	pump	5.0	"plant"
Centreville	Wells (3)	1.0	pump	—	—
Chestertown	Wells (7)	0.6	pump	1.0	"plant"
Crisfield	Wells (5)	1.5	pump	1.5	"plant"
Delmar	Wells (3)	0.8	pump	1.5	"plant"

TABLE 5-11 (cont'd)

MUNICIPAL SOURCE AND SYSTEM CAPACITIES, mgd

W.S.A.		Source Capacity		System Capacity	
SUBREGION 2 (cont'd)	Source	mgd	how defined	mgd	how defined
Denton	Wells (2)	0.7	pump	0.7	tr
Easton	Wells (6)	1.7	pump	2.5	"plant"
Elkton	Big Elk Creek	4.0	"Safe yield"	1.5	tr
Pokomoke City	Wells (2)	0.8	pump	—	—
Princess Anne	Wells (2)	0.4	pump	0.7	"plant"
Salisbury	Wells (11)	6.3	pump	6.5	"plant"
Snow Hill	Wells (3)	1.0	pump	2.1	"plant"
SUBREGION 3					
	No large central systems.				
SUBREGION 4					
Seaford	Wells (3)	1.5	pump	1.5	"plant"

TABLE 5-11 (cont'd)

MUNICIPAL SOURCE AND SYSTEM CAPACITIES, mgd

W.S.A. SUBREGION 5	Source	Source Capacity mgd	Source Capacity how defined	System Capacity mgd	System Capacity how defined
Washington Suburban Sanitary Commission	Potomac River[1]	529.0	30-day, 50-yr		
	(avg. flow=6961 mgd)	452.0	7-day, 50-yr	240.0	tr
		440.0	1-day, 50-yr		
	Patuxent River (2 reservoirs)	43.0	'66 drought	65.0	tr
Washington Aqueduct	Potomac River[1]	529.0	30-day, 50-yr		
		452.0	7-day, 50-yr	396.0	tr
		440.0	1-day, 50-yr		
Alexandria	F.C.W.A.	25.0	Agreement	—	—
Fairfax County Water Authority (F.C.W.A.)	Occoquan Cr. (2 reservoirs)	65.0	"Safe yield"	100.0	tr
	Wells (31)	1.8	pump	—	—
Goose Creek (Fairfax City)	Goose Creek (2 reservoirs)	14.4	"Safe yield"	9.5	tr

[1]Dependable flows will increase by 137 mgd by 1990 due to Bloomington Project.

TABLE 5-11 (cont'd)

MUNICIPAL SOURCE AND SYSTEM CAPACITIES, mgd

W.S.A.		Source Capacity		System Capacity	
SUBREGION 5 (cont'd)	Source	mgd	how defined	mgd	how defined
Manassas	Broad Run Res.	8.0	"Safe yield"	4.0	tr
	Wells (13)	2.8	pump		
Manassas Park	Wells (4)	0.8	pump	1.4	tr
SUBREGION 6					
Leonardtown	Wells (2)	0.6	pump	same	
Lexington Park	Wells (4)	1.4	pump	same	
Waldorf	Wells (2)	1.4	pump	same	
SUBREGION 7					
Fredricksburg	Rappahannock River	14.8	30-day, 50-yr	6.0	tr
		9.0	7-day, 50-yr		
		7.7	1-day, 50-yr		

TABLE 5-11 (cont'd)

MUNICIPAL SOURCE AND SYSTEM CAPACITIES, mgd

W.S.A.	Source	Source Capacity		System Capacity	
		mgd	how defined	mgd	how defined
SUBREGION 8					
Ashland	South Anna River	3.4	30-day, 50-yr	1.0	tr
		2.6	7-day, 50-yr		
		0.6	1-day, 50-yr		
Colonial Hts.-Petersburg	Appomattox River (Lake Chesdin)	100.0	"Safe yield"	24.0	tr
Hopewell (Virginia America Water Co.)	Appomattox River	19.6	30-day, 50-yr	31.0	tr
		14.0	7-day, 50-yr		
		13.5	1-day, 50-yr		
Mechanicsville	Wells (6)	0.6	pump	–	–
Richmond	James River	271.0	30-day, 50-yr	66.0	tr
		258.0	7-day, 50-yr		
		236.0	1-day, 50-yr		
SUBREGION 9					
West Point	Wells (2)	0.9	pump	0.9	pump

TABLE 5-11 (cont'd)

MUNICIPAL SOURCE AND SYSTEM CAPACITIES, mgd

W.S.A.	Source	Source Capacity		System Capacity	
		mgd	how defined	mgd	how defined
SUBREGION 10					
Newport News-Hampton	4 Reservoirs: Lee Hall, Harwoods Mill, Skiffes Creek, Diascund	40.0	'54-'55 drought	56.0	tr
	(Note: includes supplemental flow from Chickahominy River)				
SUBREGION 11					
Norfolk	3 Reservoirs: Lake Burnt Mills, Lake Prince, Western Branch; 4 deep wells and Supplemental pumpage from Nottoway & Blackwater Rivers	73.0	"Safe yield"	63.0	tr
Portsmouth	4 Reservoirs: Speight's Run, Lake Kilby, Lake Cohoon, Lake Meade; 2 deep wells	21.0	"Safe yield"	37.5	tr
SUBREGION 12					
Williamsburg	Waller Pond (Supplemented by Newport News)	2.0	"Safe yield"	4.0	tr

TABLE 5-11 (cont'd)

MUNICIPAL SOURCE AND SYSTEM CAPACITIES, mgd

W.S.A.		Source Capacity		System Capacity	
SUBREGION 12 (cont'd)	Source	mgd	how defined	mgd	how defined
Smithfield	Wells (9)	0.7	pump	—	—
Suffolk	Portsmouth (also 2 wells in reserve)	(See "Portsmouth")		—	—

tr., or "plant": treatment plant capacity
pipe: capacity limited by pipe size
pump: pump capacity
appropriation: limit of appropriation by authorizing agency
"safe yield": hydrologic capability of supply source
— : data lacking

geographical point. However, estimates of the ultimate yields of *entire aquifers* have been made, based on recharge and transmissibilty studies. The results of studies of this type were used to derive the developable groundwater yields presented for each subregion in Table 5-12 (See also attachment 5-C).

Subregional Supply

In addition to the treatment of each WSA, as discussed above, the overall available freshwater resource is evaluated on a subregional basis, as summarized in Table 5-12. Groundwater, surface-flowing water, reservoirs, and diversions are addressed, where applicable. Streamflows are listed for all free-flowing surface waters with flows of greater than 5 cfs during the 7-day, 10-year low flow and that are considered developable for municipal or industrial water supply, based on existing reports and estimates. In some instances, data were adjusted from nearby gages if no record was available for a particular stream. In addition, estimated overall groundwater availability is listed for each subregion, based on U.S. Geological Survey and State groundwater survey reports. Safe-yields from *existing* reservoir developments, if any, are also listed. A detailed accounting of surface flows, developable groundwater, and existing storage is presented in Attachments 5-B, C, and D, respectively.

FUTURE NEEDS AND PROBLEM AREAS

Previous sections of this report included inventories of existing water supply facilities, projections of municipal and industrial water demands, and evaluations of the freshwater resources available to meet those demands. This section includes an evaluation of the future needs (deficits) based on a comparison of the developed source and system capacities and projected demands for publicly supplied water. Thus, the magnitude and time-frame of future problem areas are identified for each water service area.

It should be noted that source deficits identified for systems that are reliant on groundwater supplies reflect the limitations of the pumps only and do not wholly indicate the adequacy of the groundwater aquifers themselves. Many systems can increase their available groundwater supply by merely increasing their pumping capacity—development of alternative sources will not be required. In Chestertown, Maryland, for example, where source deficits are identified as early as 1980, it is estimated that the wells that are already in existence could probably provide twice the stated yield by merely increasing the mechanical pumping capability. Additional source development could be effected through the drilling of additional wells.

All demands for the designated WSA's are increased to reflect peaks during maximum 30-, 7-, and 1-day periods using the peaking factors shown in Table 5-13. These factors are consistent with values used in other studies, and with observations by others that demand fluctuations are greater in small systems

TABLE 5-12
SUBREGIONAL FRESHWATER AVAILABILITY, mgd

Subregion	Surface Water[1]	Ground Water	Safe Yield of Existing Storage	Other	Total
1	570[2]	200	254	0	1,024
2	115	750		0	865
3	-	250	-	0	250
4	50	240	-	0	290
5	625[3]	181	130	0	936[3]
6	-	234	-	0	234
7	44	72	3	0	119
8	487	75	116	0	678
9	60	110	-	0	170
10	-	8	64.5[4]	0	72.5[4]
11	-	12	94	0	106
12	-	82	2	0	84

[1]Low flow during 7-day 10-year drought, see Attachment 5-B for inventory.

[2]Includes assumed ultimate allowable from Susquehanna River of 500 mgd.

[3]Dependable flow will increase by 137 mgd by 1990, due to Bloomington project.

[4]Safe yield will increase by 20 mgd with Little Creek Reservoir by 1990.

(17, 18). The diversity of uses in larger systems can act to dampen wide seasonal variation. Variable peaking factors are used for the Washington, D.C., metropolitan area to be consistent with established procedures used in many prior studies of the region (the Northeastern United States Water Supply Study, among others). Peaking factors at Hopewell were reduced due to the heavy use by industry of the public supply (84 percent).

TABLE 5-13

PEAKING FACTORS FOR MUNICIPAL DEMANDS

	Average	30-Day	7-Day	1-Day
Large Systems, > 100,000	1.0	1.2	1.4	1.6
District of Columbia Metro Area	1.0	1.33	1.67	1.77
Small Systems, < 100,000	1.0	1.3	1.6	2.0

The water service areas are discussed in the following pages with respect to the identified needs in each. Also, a comparison is made between the overall subregional resource capability, as tabulated in the previous section, and the summation of all demands—municipal, industrial, institutional, and agricultural—within each subregion. Demands are classified as follows:

a. Large Public Systems—7-day peak demands for all systems serving a population of greater than 2,500, including the industrial component.

b. Small Public Systems—7-day peak demands for systems serving fewer than 2,500 persons.

c. Industrial—fresh water demands for use in manufacturing that are not supplied through public systems.

d. Institutional—average demands from private schools, hospitals, military establishments, etc., that are not served by public systems. (see Attachment 5-E for inventory).

e. Agricultural—fresh water demands for use by the rural domestic population, for livestock and poultry production, and for irrigation during the maximum month during the dryest year in 10 for vegetables and speciality crops, and the dryest year in 5 for field crops and orchards. This component is derived from the Agricultural Water Supply Appendix, and appears as a summary in Attachment 5-F.

Thus, all fresh water withdrawal demands for all uses, which have been derived in a consistent manner for each subregion, are presented and compared with a measure of the available fresh water resource, including discharge of surface-flowing steams, safe-yields of existing reservoirs, and the ultimate sustained groundwater yield. The magnitude and time-frame of a potential regional deficit can thus be identified and a basis formed for area-wide regional planning. Needs will indicate the extent to which a subregion will need reservoir development, importation of supplies from other areas, or other source development, such as reuse or desalination.

Needs are not presented here for cooling water consumed in electric power generation facilities, but, inasmuch as most of these will locate on brackish waters around the Bay, this appears to be a reasonable exclusion. To the extent that future power developments may consume portions of the fresh water supply, the amount should be deducted from the available resource of the particular subregion (see the Power Appendix for water demand in that sector).

SUBREGION 1

Demands are presented for the 13 water service areas of Subregion 1 in Table 5-14, along with the developed source and system capacities of each. Projected deficits are thus identified for the 30-, 7-, and 1-day maximum demands for each WSA. Baltimore is the dominant supplier, providing an average of 245 mgd to over 1.5 million persons—nearly 75 percent of the total subregional population. With the projected growth in demand for the City, and assuming a constant 250 mgd allocation from the Susquehanna River, shortages will not occur in Baltimore during the maximum month until 2020. At existing levels of development and without supplemental supplies, significant deficits appar in Table 5-14 for many cities, most notably Aberdeen and Edgewood-Perryman in Harford County, and Maryland City in Anne Arundel County. Many systems in Harford County, however, are interconnected through a central county-owned system enabling redistribution of supplies to deficit areas. Comparing the sum of source capacities for all WSA's with the aggregated demand, shows 7-day deficits amounting to 49 mgd by 2000, increasing to 241 mgd by 2020.

Aggregated demands for all freshwater uses in Subregion 1 are shown in Table 5-15. Comparison with the total available freshwater resources, including unregulated streamflows, estimated groundwater sustained yields, safe yields of existing reservoir development, and an assumed eventual 500 mgd allocation from the Susquehanna River, indicates that the overall subregional resource is adequate through 2020.

TABLE 5-14
FUTURE MUNICIPAL SOURCE AND SYSTEM DEFICITS, mgd
SUBREGION 1

WATER SERVICE AREA	Capacities (source) (system)		1980 Avg.	1980 30-day	1980 7-day	1980 1-day	1990 Avg.	1990 30-day	1990 7-day	1990 1-day	2000 Avg.	2000 30-day	2000 7-day	2000 1-day	2020 Avg.	2020 30-day	2020 7-day	2020 1-day
Aberdeen		Demand	4.0	5.1	6.3	7.9	6.4	8.3	10.2	12.8	9.1	11.8	14.6	18.2	16.6	21.6	26.6	33.2
	1.0	Source Deficit	3.0	4.1	5.3	6.9	5.4	7.3	9.2	11.8	8.1	10.8	13.6	17.2	15.6	20.6	25.6	32.2
	1.5	System Deficit	2.5	3.6	4.8	6.4	4.9	6.8	8.7	11.3	7.6	10.3	13.1	16.7	15.1	20.1	25.1	31.7
Annapolis		Demand	6.2	8.0	9.9	12.4	6.6	8.6	10.6	13.2	7.1	9.1	11.3	14.1	7.5	9.7	11.9	14.9
	6.5	Source Deficit	0	1.5	3.4	5.9	0.1	2.1	4.1	6.7	0.6	2.6	4.8	7.6	1.0	3.2	5.4	8.4
	5.1	System Deficit	1.1	2.9	4.8	7.3	1.5	3.5	5.5	8.1	2.0	4.0	6.2	9.0	2.4	4.6	6.8	9.8
Baltimore		Demand	285	341	399	456	313	376	438	501	357	428	500	571	471	565	659	754
	493	Source Deficit	0	0	0	0	0	0	0	8	0	0	7	78	0	72	166	261
	500	System Deficit	0	0	0	0	0	0	0	1	0	0	0	71	0	65	159	254
Bel Air		Demand	1.7	2.2	2.7	3.4	2.4	3.1	3.8	4.8	3.0	3.9	4.8	6.0	4.2	5.5	6.7	8.4
	Variable	Source Deficit	0	1.1	2.4	3.4	0	2.0	3.5	4.8	0	2.8	4.5	6.0	0	4.4	6.4	8.4
	1.5	System Deficit	0.2	0.7	1.2	1.9	0.9	1.6	2.3	3.3	1.5	2.4	3.3	4.5	2.7	4.0	5.2	6.9
Crofton		Demand	1.2	1.6	1.9	2.4	1.6	2.1	2.6	3.2	1.7	2.2	2.7	3.4	1.8	2.3	2.9	3.6
	1.0	Source Deficit	0.2	0.4	0.9	1.4	0.6	1.1	1.6	2.2	0.7	1.2	1.7	2.4	0.8	1.3	1.9	2.6
	1.8	System Deficit	0	0	0.1	0.6	0	0.3	0.8	1.4	0	0.5	0.9	1.6	0	0.5	1.1	1.8
Edgewood		Demand	2.1	3.1	3.3	4.1	3.2	4.1	5.1	6.4	4.6	6.0	7.3	9.1	8.6	11.2	13.8	17.2
(Perryman)	1.9	Source Deficit	0.2	1.2	1.4	2.2	1.3	2.2	3.2	4.5	2.7	4.1	5.4	7.2	6.7	9.3	11.9	15.3
	4.0	System Deficit	0	0	0	0.1	0	0.1	1.1	2.4	0.6	2.0	3.3	5.1	4.6	7.2	9.8	13.2
Havre de Grace		Demand	1.6	2.1	2.6	3.2	1.8	2.3	2.9	3.6	1.8	2.3	2.8	3.5	2.0	2.6	3.2	4.0
	3.0	Source Deficit	0	0	0	0.2	0	0	0	0.6	0	0	0	0.5	0	0	0.2	1.0
	3.0	System Deficit	0	0	0	0.2	0	0	0	0.6	0	0	0	0.5	0	0	0.2	1.0
Joppatowne		Demand	0.9	1.2	1.4	1.8	0.9	1.2	1.4	1.8	1.0	1.3	1.6	2.0	1.2	1.6	1.9	2.4
	1.1	Source Deficit	0	0.1	0.3	0.7	0	0.1	0.3	0.7	0	0.2	0.5	0.9	0.1	0.5	0.8	1.3
	1.5	System Deficit	0	0	0	0.3	0	0	0	0.3	0	0	0.1	0.5	0	0.1	0.4	0.7
Maryland City		Demand	1.5	2.0	2.4	3.1	2.1	2.7	3.4	4.3	2.7	3.5	4.4	5.4	4.1	5.4	6.6	8.3
	0.6	Source Deficit	0.9	1.4	1.8	2.5	1.5	2.1	2.8	3.7	2.1	2.9	3.8	4.8	3.5	4.8	6.0	7.9
	1.2	System Deficit	0.3	0.8	1.2	1.9	0.9	1.5	2.2	3.1	1.5	2.3	3.2	4.2	2.9	4.2	5.4	7.1

TABLE 5-14 (Cont'd)
FUTURE MUNICIPAL SOURCE AND SYSTEM DEFICITS, mgd
SUBREGION I

WATER SERVICE AREA	Capacities (source) (system)		1980 Avg.	1980 30-day	1980 7-day	1980 1-day	1990 Avg.	1990 30-day	1990 7-day	1990 1-day	2000 Avg.	2000 30-day	2000 7-day	2000 1-day	2020 Avg.	2020 30-day	2020 7-day	2020 1-day
Kings Heights		Demand	0.8	1.0	1.3	1.6	1.1	1.4	1.8	2.2	1.3	1.7	2.1	2.6	1.8	2.3	2.9	3.6
(Odenton)	1.9	Source Deficit	0	0	0	0	0	0	0	0.3	0	0	0.2	0.7	0	0.4	1.0	1.7
	1.3	System Deficit	0	0	0	0.3	0	0.1	0.5	0.9	0	0.4	0.8	1.3	0.5	1.0	1.6	2.3
Severna Park		Demand	3.1	4.0	5.0	6.2	4.4	5.7	7.0	8.8	5.9	7.7	9.4	11.8	9.2	12.0	14.7	18.4
(Severndale)	2.7	Source Deficit	0.4	1.3	2.3	3.5	1.7	3.0	4.3	6.1	3.2	5.0	6.7	9.1	6.5	9.3	12.0	15.7
	3.7	System Deficit	3.0	0.3	1.3	2.5	0.7	2.0	3.3	5.1	2.2	4.0	5.7	8.1	5.5	8.3	11.0	14.7
Sykesville-		Demand	0.9	1.2	1.4	1.8	1.4	1.8	2.2	2.8	1.6	2.1	2.6	3.2	2.3	3.0	3.7	4.6
Freedom	2.0	Source Deficit	0	0	0	0	0	0	0.2	0.8	0	0.1	0.6	1.2	0.3	1.0	1.7	2.6
	1.5	System Deficit	0	0	0	0.3	0	0.3	0.7	1.3	0.1	0.6	1.1	1.7	0.8	1.5	2.2	3.1
Westminster		Demand	1.6	2.1	2.6	3.3	2.1	2.8	3.3	4.2	2.4	3.0	3.8	4.7	3.0	3.8	4.7	5.9
	2.0	Source Deficit	0	0.1	0.6	1.3	0.1	0.8	1.3	2.2	0.4	1.0	1.8	2.7	1.0	1.8	2.7	3.9
	1.8	System Deficit	0	0.3	0.8	1.5	0.3	1.0	1.5	2.4	0.6	1.2	2.0	2.9	1.2	2.0	2.9	4.1
Total		Demand	311	375	440	507	347	420	492	569	399	483	567	655	533	646	759	879
	518	Source Deficit	0	0	0	0	0	0	0	51	0	0	49	137	15	128	241	361
	528	System Deficit	0	0	0	0	0	0	0	41	0	0	39	127	5	118	231	351

TABLE 5-15
AGGREGATED DEMANDS VERSUS FRESHWATER RESOURCE, mgd
SUBREGION 1

	1970	1980	1990	2000	2020
Large Public Systems	367	440	492	567	759
Small Public Systems	13	24	34	40	45
Industrial	17	17	13	12	13
Institutional	14	14	14	14	14
Agricultural	21	58	60	62	70
TOTAL Demand	432	553	613	695	901
Fresh Water Supply	1,024	1,024	1,024	1,024	1,024
Needs	0	0	0	0	0

SUBREGION 2

The Eastern Shore of Maryland contains 12 water service areas. All the systems use groundwater sources except in the fringes of the Piedmont at Elkton where surface water is used. Table 5-16 details source and system deficits that can be expected with present capacities. Four systems will require source development to meet 30-day maximum demands by 1980: Chestertown, Crisfield, Cambridge, and Easton. Cumulative source capacity for all systems in the subregion will be 9.1 mgd short of the 7-day maximum demand by 2000, increasing to 18.0 mgd in 2020. Comparing the overall availability of freshwater with the demands for all uses in Table 5-17, it can be seen that supplies, if developed, should be adequate through 2020. It should be noted that agriculture accounts for nearly 87 percent of the year 2020 demand, of which about 79 percent is for irrigation needs during a dry year.

SUBREGION 3

The two counties that comprise the Virginia portion of the Eastern Shore are predominantly rural in character and contain only public water systems serving fewer than 2,500 persons. Table 5-18 details the aggregated demands for all uses for Subregion 3. Even with "dry-year" irrigation demands, which are the major demand components, groundwater resources are a more-than-adequate supply source for this area.

TABLE 5-16
FUTURE MUNICIPAL SOURCE AND SYSTEM DEFICITS, mgd
SUBREGION 2

WATER SERVICE AREA	Capacities (source) (system)		1980 Avg.	1980 30-day	1980 7-day	1980 1-day	1990 Avg.	1990 30-day	1990 7-day	1990 1-day	2000 Avg.	2000 30-day	2000 7-day	2000 1-day	2020 Avg.	2020 30-day	2020 7-day	2020 1-day
Cambridge		Demand	4.2	5.5	6.7	8.4	4.3	5.6	6.9	8.6	4.9	6.4	7.8	9.8	6.0	7.8	9.6	12.0
	4.6	Source Deficit	0	0.9	2.1	3.8	0	1.0	2.3	4.0	0.3	1.8	3.2	5.2	1.4	3.2	5.0	7.4
	5.0	System Deficit	0	0.5	1.7	3.4	0	0.6	1.9	3.6	0	1.4	2.8	4.8	1.0	2.8	4.6	7.0
Centreville		Demand	0.4	0.5	0.6	0.8	0.5	0.7	0.8	1.0	0.6	0.8	1.0	1.2	0.9	1.2	1.4	1.8
	1.0	Source Deficit	0	0	0	0	0	0	0	0	0	0	0	0.2	0	0.2	0.4	0.8
	1.0	System Deficit	0	0	0	0	0	0	0	0	0	0	0	0.2	0	0.2	0.4	0.8
Chestertown		Demand	0.7	0.9	1.2	1.4	0.8	1.0	1.2	1.5	0.9	1.2	1.4	1.8	1.3	1.6	2.0	2.5
	0.6	Source Deficit	0.1	0.3	0.6	0.8	0.2	0.4	0.6	0.9	0.3	0.6	0.8	1.2	0.7	1.0	1.4	1.9
	1.0	System Deficit	0	0	0.2	0.4	0	0	0.2	0.5	0	0.2	0.4	0.8	0.3	0.6	1.0	1.5
Crisfield		Demand	1.5	2.0	2.4	3.0	1.5	2.0	2.4	3.0	1.6	2.1	2.6	3.2	1.8	2.3	2.9	3.6
	1.5	Source Deficit	0	0.5	0.9	1.5	0	0.5	0.9	1.5	0.1	0.6	1.1	1.7	0.3	0.8	1.4	2.1
	1.5	System Deficit	0	0.5	0.9	1.5	0	0.5	0.9	1.5	0.1	0.6	1.1	1.7	0.3	0.8	1.4	2.1
Delmar		Demand	0.4	0.5	0.6	0.8	0.4	0.5	0.6	0.8	0.5	0.7	0.8	1.0	0.6	0.8	1.0	1.2
	0.8	Source Deficit	0	0	0	0	0	0	0	0	0	0	0	0.2	0	0	0.2	0.4
	1.5	System Deficit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Denton		Demand	0.5	0.7	0.8	1.0	0.5	0.7	0.8	1.0	0.6	0.8	1.3	1.2	0.7	0.9	1.1	1.4
	0.7	Source Deficit	0	0	0.1	0.3	0	0	0.1	0.3	0	0.1	0.6	0.5	0	0.2	0.4	0.7
	0.7	System Deficit	0	0	0.1	0.3	0	0	0.1	0.3	0	0.1	0.6	0.5	0	0.2	0.4	0.7
Easton		Demand	1.5	2.0	2.5	3.1	1.9	2.4	2.9	3.7	2.4	3.1	3.7	4.7	3.5	4.7	5.7	7.2
	1.7	Source Deficit	0	0.3	0.8	1.4	0.2	0.7	1.2	2.0	0.7	1.4	2.0	3.0	1.8	3.0	4.0	5.5
	2.5	System Deficit	0	0	0	0.6	0	0	0.4	1.2	0	0.6	1.2	2.2	1.0	2.2	3.2	4.7
Elkton		Demand	1.2	1.6	1.9	2.4	1.4	1.8	2.2	2.8	1.5	2.0	2.4	3.0	1.9	2.5	3.0	3.8
	4.0	Source Deficit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1.5	System Deficit	0	0.1	0.4	0.9	0	0.3	0.7	1.3	0	0.5	0.9	1.5	0.4	1.0	1.5	2.3
Pocomoke City		Demand	0.4	0.6	0.7	0.9	0.6	0.8	1.0	1.3	0.7	0.9	1.1	1.3	1.0	1.3	1.6	2.0
	0.8	Source Deficit	0	0	0	0	0	0	0.2	0.5	0	0.1	0.3	0.5	0.2	0.5	0.8	1.2
	1.5	System Deficit	0	0	0	0	0	0	0.2	0.5	0	0	0	0	0	0	0.1	0.5

TABLE 5-16 (Cont'd)
FUTURE MUNICIPAL SOURCE AND SYSTEM DEFICITS, mgd
SUBREGION 2

WATER SERVICE AREA	Capacities (source) (system)		1980				1990				2000				2020			
			Avg.	30-day	7-day	1-day	Avg.	30-day	7-day	1-day	Avg.	30-day	7-day	1-day	Avg.	30-day	7-day	1-day
Princess Anne		Demand	0.3	0.4	0.5	0.6	0.3	0.4	0.5	0.6	0.4	0.5	0.6	0.8	0.6	0.8	1.0	1.2
	0.4	Source Deficit	0	0	0.1	0.2	0	0	0.1	0.2	0	0.1	0.2	0.4	0.2	0.4	0.6	0.8
	0.7	System Deficit	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0.3	0.5
Salisbury		Demand	4.5	5.9	7.2	9.0	4.7	6.1	7.5	9.4	5.3	6.9	8.5	10.6	6.4	8.3	10.2	12.8
	6.3	Source Deficit	0	0	0.9	2.7	0	0	1.2	3.1	0	0.6	2.2	4.3	0.1	2.0	3.9	6.5
	6.5	System Deficit	0	0	0.7	2.5	0	0	1.0	2.9	0	0.4	2.0	4.1	0	1.8	3.7	6.3
Snow Hill		Demand	0.7	0.9	1.1	1.4	0.8	1.0	1.3	1.6	0.9	1.2	1.4	1.8	1.2	1.6	1.9	2.4
	1.0	Source Deficit	0	0	0.1	0.4	0	0	0.3	0.6	0	0.2	0.4	0.8	0.2	0.6	0.9	1.4
	2.1	System Deficit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.3
Total		Demand	16.3	21.2	26.1	32.6	17.7	23.0	28.3	35.4	20.3	26.4	32.5	40.6	25.9	33.7	41.4	51.8
	23.4	Source Deficit	0	0	2.7	9.2	0	0	4.9	12.0	0	3.0	9.1	17.2	2.5	10.3	18.0	28.4
	24.8	System Deficit	0	0	1.3	7.8	0	0	3.5	10.6	0	1.6	7.7	15.8	1.1	8.9	16.6	27.0

TABLE 5-17
AGGREGATED DEMANDS VERSUS FRESHWATER RESOURCE, mgd
SUBREGION 2

	1970	1980	1990	2000	2020
Large Public Systems	22.2	26.1	28.3	32.5	41.4
Small Public Systems	7.7	12.0	17.2	23.7	38.9
Industrial	31.1	30.9	27.6	30.3	37.4
Institutional	2.0	2.0	2.0	2.0	2.0
Agricultural	45.6	108.6	179.6	250.6	744.9
TOTAL Demand	109	180	255	339	865
Fresh Water Supply	865	865	865	865	865
Needs	0	0	0	0	0

TABLE 5-18
AGGREGATED DEMANDS VERSUS FRESHWATER RESOURCE, mgd
SUBREGION 3

	1970	1980	1990	2000	2020
Large Public Systems	0	0	0	0	0
Small Public Systems	1.3	1.6	2.0	2.4	3.5
Industrial	1.9	1.6	1.4	1.4	1.6
Institutional	–	–	–	–	–
Agricultural	17.7	69.7	61.4	53.3	43.3
TOTAL Demand	21	73	65	57	48
Fresh Water Supply	250	250	250	250	250
Needs	0	0	0	0	0

SUBREGION 4

Seaford is the only water servcie area in the Delaware portion of the Chesapeake Bay Study Area, as shown in Table 5-19. With the presently developed groundwater sources, Seaford should be able to meet average demands until 2000, but may need source development by 1990 to meet maximum 30-day demands. Aggregated demands for all uses, including industrial, agricultural, and municipal, are presented in Table 5-20 in

TABLE 5-19
FUTURE MUNICIPAL SOURCE AND SYSTEM DEFICITS, mgd
SUBREGION 4

WATER SERVICE AREA	Capacities (source) (system)		1980				1990				2000				2020			
			Avg.	30-day	7-day	1-day	Avg.	30-day	7-day	1-day	Avg.	30-day	7-day	1-day	Avg.	30-day	7-day	1-day
Seaford		Demand	1.0	1.3	1.5	1.9	1.2	1.6	1.9	2.5	1.4	1.8	2.1	2.7	1.9	2.8	3.4	4.2
	1.5	Source Deficit	0	0	0	0.4	0	0.1	0.4	1.0	0	0.3	0.6	1.2	0.4	1.3	1.9	2.7
	1.5	System Deficit	0	0	0	0.4	0	0.1	0.4	1.0	0	0.3	0.6	1.2	0.4	1.3	1.9	2.7

TABLE 5-20
AGGREGATED DEMANDS VERSUS FRESHWATER RESOURCE, mgd
SUBREGION 4

	1970	1980	1990	2000	2020
Large Public Systems	1.3	1.5	1.9	2.1	3.4
Small Public Systems	1.7	2.9	4.4	5.9	10.4
Industrial	62.9	41.7	17.3	19.8	28.3
Institutional	--	--	--	--	--
Agricultural	17.8	104.4	111.2	120.4	146.8
TOTAL Demand	84	151	135	148	189
Fresh Water Supply	290	290	290	290	290
Needs	0	0	0	0	0

comparison with the estimated overall freshwater availability of 290 mgd. A small amount of freshwater flow in the Nanticoke River is included, but groundwater alone, which constituted 83 percent, or 250 mgd, of the available supply, is sufficient to meet 2020 demands.

SUBREGION 5

This subregion contains the Washington, D.C., metropolitan area where seven water service areas provide water to about 2.8 million persons or about 97 percent of the total subregional population. Major use is made of the Potomac River by the Washington Aqueduct Division of the Corps of Engineers, which services the myriad of needs of the District of Columbia and parts of Northern Virginia. The Washington Suburban Sanitary Commission (WSSC) also uses the Potomac in conjunction with two reservoirs developed on the Patuxent to serve large portions of Prince Georges and Montgomery Counties, Maryland. A third major system is the Fairfax County Water Authority (FCWA) which provides water from Occoquan Creek to large portions of Fairfax County, parts of Prince William County, and the City of Alexandria.

Deficits for each WSA are presented in Table 5-21 based on a comparison of source and system capacities and projected demands. For evaluation of the Potomac River source, demands for Washington Aqueduct and the WSSC are combined. Source capacities for the two systems are then combined: 30-day, 7-day, and 1-day minimum flows of the Potomac and the safe yield of the two reservoirs on the Patuxent River. Source capacity is thus defined as 572, 495,

TABLE 5-21
FUTURE MUNICIPAL SOURCE AND SYSTEM DEFICITS, mgd
SUBREGION 5

WATER SERVICE AREA	Capacities (source) (system)		1980 Avg.	1980 30-day	1980 7-day	1980 1-day	1990 Avg.	1990 30-day	1990 7-day	1990 1-day	2000 Avg.	2000 30-day	2000 7-day	2000 1-day	2020 Avg.	2020 30-day	2020 7-day	2020 1-day
Washington Suburban Sanitary Commission		Demand	169	225	282	299	223	297	372	395	286	381	477	506	453	603	756	802
	305	System Deficit	0	0	0	0	0	0	67	90	0	76	172	201	148	298	451	497
Washington Aqueduct		Demand	220	293	367	389	241	321	402	427	264	351	441	467	327	435	546	579
	396	System Deficit	0	0	0	0	0	0	6	31	0	0	45	71	0	39	150	183
WSSC–Washington Aqueduct (combined)		Demand	(389)	(518)	(649)	(688)	(464)	(618)	(774)	(822)	(550)	(732)	(918)	(973)	(780)	(1038)	(1302)	(1381)
	Variable 1	Source Deficit	0	0	154	205	0	0	142	202	0	23	286	353	0	329	670	761
Alexandria		Demand	16.2	21.5	27.1	28.7	20.0	26.6	33.4	35.4	22.3	29.7	37.2	39.4	27.6	36.9	46.4	49.2
	25.0	Source Deficit	0	0	2.1	3.7	0	1.6	8.4	10.4	0	4.7	12.2	14.4	2.6	11.9	21.4	24.2
	25.0	System Deficit	0	0	2.1	3.7	0	1.6	8.4	10.4	0	4.7	12.2	14.4	2.6	11.9	21.4	24.2
Fairfax County Water Authority		Demand	69.4	92.3	116	123	105	140	175	186	150	199	251	265	282	375	471	499
	66.8	Source Deficit	2.6	25.5	49	56	38	73	108	119	83	132	184	198	215	308	404	432
	100.0	System Deficit	0	0	16	23	5	40	75	86	50	99	151	165	182	275	371	399
Goose Creek (Fairfax City)		Demand	15.9	21.2	26.5	28.1	23.4	31.1	39.1	41.4	31.6	42.0	52.8	55.9	58.3	77.5	97.4	103.6
	14.4	Source Deficit	1.5	6.8	12.1	13.7	9.0	17.7	24.7	27.0	17.2	27.6	38.4	41.5	43.9	63.1	83.0	89.2
	9.5	System Deficit	6.4	11.7	17.0	18.6	13.9	22.6	29.6	31.9	22.1	32.5	43.3	46.4	48.8	68.0	87.9	94.1
Manassas		Demand	2.1	2.7	3.4	4.2	3.0	3.9	4.8	6.0	3.7	4.8	5.9	7.4	4.8	6.2	7.7	9.6
	2.8	Source Deficit	0	0	0.6	1.4	0.2	1.1	2.0	3.7	0.9	2.0	3.1	4.6	2.0	3.4	4.9	6.8
	4.0	System Deficit	0	0	0	0.2	0	0	0.8	2.0	0	0.8	1.9	3.4	0.8	2.2	3.7	5.6
Manassas Park		Demand	0.8	1.0	1.3	1.6	1.4	1.8	2.2	2.8	2.0	2.6	3.2	4.0	3.9	5.1	6.2	7.8
	0.8	Source Deficit	0	0.2	0.5	0.8	0.6	1.0	1.4	2.0	1.2	1.8	2.4	3.2	3.1	4.3	5.4	7.0
	1.4	System Deficit	0	0	0	0.2	0	0.4	0.8	1.4	0.6	1.2	1.8	2.6	2.5	3.7	4.8	6.4
Total		Demand	494	657	823	874	616	821	1029	1094	760	1010	1268	1345	1157	1539	1931	2050
	Variable 2	Source Deficit	0	0	235	298	0	19	304	381	0	208	543	632	0	737	1,206	1,337
	841	System Deficit	0	0	0	33	225	0	188	253	0	169	427	504	316	698	1090	1209

Notes:

	Avg.	30-day	7-day	1-day
1 Variable Source:	7,004	572	495	483
2 Variable Source:	7,071	665	588	576

(Low flows can be expected to increase by 137 mgd by 1990 due to Bloomington Project now under construction).

and 483 mgd for the 30-, 7-, and 1-day low flows, increasing to 709, 632, and 620 mgd, respectively, by 1990, due to the scheduled completion of the Bloomington Lake project. Source deficits amount to 154 mgd during 7-day periods of maximum demand in 1980, increasing to 286 and 670 mgd by 2000 and 2020, respectively. The urgent need for source development is highlighted by the fact that on at least one occasion maximum day demands exceeded the recorded low flow in the Potomac River. Source deficits are also of concern for FCWA and Fairfax City where average day shortages appear by 1980. The sum of demands for all WSA's in the subregion, when compared with the developed source and system capacities, indicates overall 7-day source deficits of 235 mgd by 1980 and 304 mgd by 1990, leaping to 1,206 mgd by 2020.

Aggregated demands for all uses, including public, industrial, and irrigation, are presented in Table 5-22 for Subregion 5. When compared with the available ground and surface supplies and yields of existing reservoirs, significant deficits are identified.

Needs amounting to 36 mgd are calculated for the subregion as a whole by 1990, growing to 1015 mgd by 2020.

TABLE 5-22
AGGREGATED DEMANDS VERSUS FRESHWATER RESOURCE, mgd
SUBREGION 5

	1970	1980	1990	2000	2020
Large Public Systems	638	823	1,029	1,268	1,931
Small Public Systems	13	6	9	13	28
Industrial	1	2	3	3	6
Institutional	5	5	5	5	5
Agricultural	15	33	63	86	118
TOTAL Demand		869	1,109	1,375	2,088
Fresh Water Supply	936	936	1,073[1]	1,073	1,073
Needs	0	0	36	302	1,015

[1] Dependable supply expected to increase by 137 mgd by 1990 due to Bloomington Project.

TABLE 5-23
FUTURE MUNICIPAL SOURCE AND SYSTEM DEFICITS, mgd
SUBREGION 6

WATER SERVICE AREA	Capacities (source) (system)		1980 Avg.	1980 30-day	1980 7-day	1980 1-day	1990 Avg.	1990 30-day	1990 7-day	1990 1-day	2000 Avg.	2000 30-day	2000 7-day	2000 1-day	2020 Avg.	2020 30-day	2020 7-day	2020 1-day
Leonardtown		Demand	0.3	0.4	0.5	0.6	0.3	0.4	0.5	0.7	0.3	0.4	0.5	0.7	0.5	0.7	0.8	1.0
	0.6	Source Deficit	0	0	0	0	0	0	0	0.1	0	0	0	0.1	0	0.1	0.2	0.4
	0.6	System Deficit	0	0	0	0	0	0	0	0.1	0	0	0	0.1	0	0.1	0.2	0.4
Lexington Park		Demand	1.6	2.1	2.7	3.2	2.7	3.5	4.3	5.4	4.1	5.3	6.6	8.2	8.7	11.4	13.9	17.4
	1.4	Source Deficit	0.2	0.7	1.3	1.2	1.3	2.1	2.9	4.0	2.7	3.9	5.2	6.8	7.3	10.0	12.5	16.0
	1.4	System Deficit	0.2	0.7	1.3	1.2	1.3	2.1	2.9	4.0	2.7	3.9	5.2	6.8	7.3	10.0	12.5	16.0
Waldorf		Demand	1.5	2.0	2.4	3.0	2.7	3.5	4.3	5.4	4.2	5.4	6.7	8.4	9.0	11.8	14.4	18.0
	1.4	Source Deficit	0.1	0.6	1.0	1.6	1.3	2.1	2.9	4.0	2.8	4.0	5.3	7.0	7.6	10.4	13.0	16.6
	1.4	System Deficit	0.1	0.6	1.0	1.6	1.3	2.1	2.9	4.0	2.8	4.0	5.3	7.0	7.6	10.4	13.0	16.6
Total		Demand	3.4	4.5	5.6	6.8	5.7	7.4	9.1	11.5	8.6	11.1	13.8	17.3	18.2	23.9	29.1	36.4
	3.4	Source Deficit	0	1.1	2.0	3.4	2.3	4.0	5.7	8.1	5.2	7.7	10.4	13.9	14.8	20.5	25.7	33.0
	3.4	System Deficit	0	1.1	2.0	3.4	2.3	4.0	5.7	8.1	5.2	7.7	10.4	13.9	14.8	20.5	25.7	33.0

SUBREGION 6

The three counties comprising Subregion 6 lie entirely in the Coastal Plain and rely almost entirely on groundwater sources for their water supply. Nineteen percent of the population is served within three water service areas. As shown in Table 5-23, Waldorf and Lexington Park will require source and system development by 1980 to meet 30-day maximum demands. The cumulative 7-day maximum demands for the three WSA's show that incremental source and system developments of 5.7 mgd will be required by 1990, increasing to 10.5 by 2000 and 25.7 by 2020. Table 5-24 compares the aggregated demands for all uses in the subregion with the overall developable freshwater resource. Even with "dry-year" irrigation requirements, the subregion has abundant supplies of groundwater to meet its projected needs.

TABLE 5-24
AGGREGATED DEMANDS VERSUS FRESHWATER RESOURCE, mgd
SUBREGION 6

	1970	1980	1990	2000	2020
Large Public Systems	3.5	5.6	9.1	13.8	29.1
Small Public Systems	3.2	5.3	9.4	15.4	24.8
Industrial	0.7	1.2	1.9	3.0	6.5
Institutional	3.0	3.0	3.0	3.0	3.0
Agricultural	8.2	20.4	53.2	85.9	116.9
TOTAL Demand	19	35	77	121	180
Fresh Water Supply	234	234	234	234	234
Needs	0	0	0	0	0

SUBREGION 7

This small tricounty area in the Virginia portion of the Washington Economic Area, is dominated by the population and industrial concentration at Fredericksburg, which comprises the subregion's only WSA. The source of supply for Fredericksburg is the unregulated Rappahannock River which yields 14.8 mgd during the 30-day duration, 50-year low flow. As shown in Table 5-11, flows decrease to 9.0 and 7.7, for 7-day and 1-day low flows, respectively. In Table 5-25 a comparison between projected demands and the available river flow shows that the Rappahannock is sufficient to meet 30-day maximum demands through 2020.

TABLE 5-25
FUTURE MUNICIPAL SOURCE AND SYSTEM DEFICITS, mgd
SUBREGION 7

WATER SERVICE AREA	Capacities (source) (system)		1980				1990				2000				2020			
			Avg.	30-day	7-day	1-day	Avg.	30-day	7-day	1-day	Avg.	30-day	7-day	1-day	Avg.	30-day	7-day	1-day
Fredricksburg		Demand	3.1	4.0	4.9	6.1	3.6	4.7	5.8	7.2	4.2	5.4	6.7	8.3	5.8	7.6	9.3	11.6
	Variable[1]	Source Deficit	0	0	0	0	0	0	0	0	0	0	0	0.6	0	0	0.3	3.9
	6.0	System Deficit	0	0	0	0.1	0	0	0	1.2	0	0	0.7	2.3	0	1.6	3.3	5.6
[1] Rappahannock River			103.7	14.8	9.0	7.7												

Aggregated demands for all uses in the subregion are compared with the presently available resource in Table 5-26. No deficits are shown to occur through the year 2020. It is of note, however, that of the 81.5 mgd demand projected for 2020, about 60 percent is for the needs of industry.

SUBREGION 8

This five-county area is defined as the Richmond SMSA. Three major public systems—Richmond, Hopewell, and that serving Colonial Heights and Petersburg—provide service to nearly 77 percent of the total subregional population. Table 5-27 lists the WSA's, their projected demands, and the deficits expected based on presently developed source and system capacities. The Appomattox River Water Authority's development at Lake Chesdin on the Appomattox River has a rated safe yield of 100 mgd, which is shown to be adequate for the present water service area far beyond 2020. The James River at Richmond is also sufficient to meet projected needs for the City of Richmond through 2020.

Large deficits appear at Hopewell, however, when demands are compared with the natural flow of the Appomattox River. Service to industry at Hopewell amounted to 21.8 mgd, or about 85 percent of all water supplied by the Virginia American Water Company in 1970, and this grows (assuming Hopewell will provide a similar subregional share in the future) to 32.0 mgd by

TABLE 5-26
AGGREGATED DEMANDS VERSUS FRESHWATER RESOURCE, mgd
SUBREGION 7

	1970	1980	1990	2000	2020
Large Public Systems	4.2	4.9	5.8	6.7	9.3
Small Public Systems	1.8	3.2	5.1	7.8	17.6
Industrial	27.2	28.1	27.8	32.1	49.1
Institutional	0.6	0.6	0.6	0.6	0.6
Agricultural	2.4	4.5	5.2	5.9	4.9
TOTAL Demand	36	41	45	53	82
Fresh Water Supply	119	119	119	119	119
Needs	0	0	0	0	0

TABLE 5-27
FUTURE MUNICIPAL SOURCE AND SYSTEM DEFICITS, mgd
SUBREGION 8

WATER SERVICE AREA	Capacities (source) (system)		1980 Avg.	1980 30-day	1980 7-day	1980 1-day	1990 Avg.	1990 30-day	1990 7-day	1990 1-day	2000 Avg.	2000 30-day	2000 7-day	2000 1-day	2020 Avg.	2020 30-day	2020 7-day	2020 1-day
Ashland		Demand	0.5	0.7	0.8	1.0	0.8	1.0	1.3	1.6	1.0	1.3	1.6	2.0	1.3	1.7	2.1	2.6
	Variable[2]	Source Deficit	0	0	0	0.4	0	0	0	1.0	0	0	0	1.4	0	0	0	2.0
	1.0	System Deficit	0	0	0	0	0	0	0.3	0.6	0	0.3	0.6	1.0	0.3	0.7	1.1	1.6
Colonial Heights—		Demand	9.0	11.8	14.5	18.1	11.6	15.1	18.6	23.2	15.2	19.8	24.3	30.4	24.8	32.2	39.7	49.6
Petersburg	100.0	Source Deficit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	24.0	System Deficit	0	0	0	0	0	0	0	0	0	0	0	0.4	0.8	5.8	10.7	15.7
Hopewell[1]		Demand	25.6	28.2	29.5	30.7	26.2	28.9	30.2	31.5	31.7	34.9	36.3	38.1	50.1	55.2	57.5	60.1
	Variable[3]	Source Deficit	0	8.6	15.5	17.2	0	9.3	16.2	18.0	0	15.3	22.3	24.6	0	35.6	43.5	46.6
	31.0	System Deficit	0	0	0	0	0	0	0	0.5	0.7	3.9	5.3	7.1	19.1	24.2	26.5	29.1
Mechanicsville		Demand	1.2	1.6	1.9	2.4	2.3	3.0	3.7	4.6	3.8	4.9	6.1	7.6	8.9	11.6	14.2	17.8
	0.6	Source Deficit	0.6	1.0	1.3	1.8	1.7	2.4	3.1	4.0	3.2	4.3	5.5	7.0	8.3	11.0	13.6	17.2
	0.6	System Deficit	0.6	1.0	1.3	1.8	1.7	2.4	3.1	4.0	3.2	4.3	5.5	7.0	8.3	11.0	13.6	17.2
Richmond		Demand	49.3	59.2	69.0	78.9	59.2	71.0	82.9	94.7	72.8	87.4	101	116	104	125	146	166
	Variable[4]	Source Deficit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	66.0	System Deficit	0	0	3.0	12.9	0	4.8	16.6	28.4	6.8	21.4	35.0	50.0	38.0	59.0	80.0	100
Total		Demand	85.6	102	116	131	100	119	137	156	125	149	169	194	189	226	260	296
	Variable[5]	Source Deficit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	122.6	System Deficit	0	0	0	0	0	0	14.4	33.4	2.4	26.4	46.4	71.4	66.4	103	139	173

[1] Peaking factors reduced for Hopewell due to large supply to industry.

[2] So. Anna	221	3.4	2.6	0.6
[3] Appomattox	724	19.6	14.0	13.5
[4] James	4,359	271	258	236
others	100.6	100.6	100.6	100.6
[5] Source Capacity Total:	5,405 mgd	395	375	351

2020 (see Table 5-7). It should be noted that the supply in the Appomattox River is supplemented in the vicinity of the intake at Hopewell by the backup of James River water due to tidal influence. Thus, there is an unknown, but perhaps substantial, increment in the quantity of water ultimately available.

Aggregated demands for all uses, including municipal, industrial, and agricultural, are shown in Table 5-28 for Subregion 8. Comparison with the sum of stream discharge, existing safe yield of reservoirs, and of developable groundwater yields, shows overall deficits emerging only after the year 2000. The principal component of demand is that of self-supplied industry, comprising nearly 70 percent of the use in 1970. This decreases to 50 percent, or 397 mgd, by the year 2020.

SUBREGION 9

This predominantly rural, lightly developed area extends from the James River in the south to the shores of the Potomac River in the north. Despite its size, only one public Water Service Area is located in Subregion 9 — West Point in King William County. Table 5-29 shows the projected demands for this system and the deficits to be expected based on the present capacities. Groundwater supplies appear sufficiently developed to meet even maximum day demands through the year 2000.

TABLE 5-28

AGGREGATED DEMANDS VERSUS FRESHWATER RESOURCE, mgd
SUBREGION 8

	1970	1980	1990	2000	2020
Large Public Systems	104	116	137	169	260
Small Public Systems	8	15	22	31	54
Industrial	265	248	231	261	397
Institutional	1	1	1	1	1
Agricultural	7	30	51	72	81
TOTAL Demand	385	410	442	534	793
Fresh Water Suppy	678	678	678	678	678
Needs	0	0	0	0	115

TABLE 5-29
FUTURE MUNICIPAL SOURCE AND SYSTEM DEFICITS, mgd
SUBREGION 9

WATER SERVICE AREA	Capacities (source) (system)		1980				1990				2000				2020			
			Avg.	30-day	7-day	1-day	Avg.	30-day	7-day	1-day	Avg.	30-day	7-day	1-day	Avg.	30-day	7-day	1-day
West Point		Demand	0.3	0.4	0.5	0.6	0.4	0.5	0.6	0.8	0.4	0.5	0.6	0.8	0.6	0.8	1.0	1.2
	0.9	Source Deficit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0.3
	0.9	System Deficit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0.3

Freshwater demands for agriculture-related purposes are expected to increase by more than ten-fold by 2020. Table 5-30 details these and other demands for all uses, the sum of which are then compared with the overall freshwater resource of the subregion. No shortages are identified, indicating the relative wealth of water supplies that are available for use in the area.

TABLE 5-30

AGGREGATED DEMANDS VERSUS FRESHWATER RESOURCE, mgd

SUBREGION 9

	1970	1980	1990	2000	2020
Large Public Systems	0.4	0.5	0.6	0.6	1.0
Small Public Systems	4.0	5.9	7.3	9.7	15.8
Industrial	16.1	13.1	11.9	12.6	17.6
Institutional	0.1	0.1	0.1	0.1	0.1
Agricultural	4.0	18.5	33.2	47.9	51.1
TOTAL Demand	25	38	53	71	86
Fresh Water Supply	170	170	170	170	170
Needs	0	0	0	0	0

SUBREGION 10

Public water supply in this subregion, located near the mouth of the James River at Chesapeake Bay, is dominated by the system managed by Newport News, which is the only Water Service Area in the subregion. Table 5-31 compares projected demands on the Newport News system with the safe-yield of developed sources and its system ("hardware") capacity. Deficits are indicated by 1980 in both categories, but system deficits are reduced for 1990 due to expected completion of the Little Creek pumped storage facility, which will store water from the nearby Chickahominy River, during periods of peak flow. Source depletion will nonetheless occur again for Newport News by 2000. Continuing source and system development is seen as a necessity for this area.

TABLE 5-31
FUTURE MUNICIPAL SOURCE AND SYSTEM DEFICITS, mgd
SUBREGION 10

WATER SERVICE AREA	Capacities (source) (system)		1980				1990				2000				2020			
			Avg.	30-day	7-day	1-day	Avg.	30-day	7-day	1-day	Avg.	30-day	7-day	1-day	Avg.	30-day	7-day	1-day
Newport News-		Demand	36.8	44.2	51.5	58.9	42.3	50.8	59.2	67.7	50.0	60.0	70.0	80.0	67.5	81.0	94.5	108
Hampton	40.0[1]	Source Deficit	0	4.2	11.5	18.9	0	0	0	7.7	0	0	10.0	20.0	7.5	21.0	34.5	48.0
	56.0	System Deficit	0	0	0	2.9	0	0	3.1	11.7	0	4.0	14.0	24.0	11.5	25.0	38.5	52.0

[1] Safe yield will increase to 60 mgd by 1990.

Aggregated demands for all uses, including municipal, self-supplied industrial, and agricultural, are presented in Table 5-32. Assuming complete development of groundwater and completion of the pumped storage facility at Little Creek, supplies should be adequate through 2000 for the subregion as a whole. Additional needs for source development of about 12 mgd will be required by 2020.

TABLE 5-32

AGGREGATED DEMANDS VERSUS FRESHWATER RESOURCE, mgd

SUBREGION 10

	1970	1980	1990	2000	2020
Large Public Systems	38.2	51.5	59.2	70.0	94.5
Small Public Systems	0.7	1.2	1.8	2.4	1.6
Industrial	5.0	2.9	2.3	2.3	2.9
Institutional	4.2	4.2	4.2	4.2	4.2
Agricultural	1.4	1.5	1.3	1.1	1.6
TOTAL Demand	50	61	69	80	105
Fresh Water Supply	73	73	93[1]	93	93
Needs	0	0	0	0	12

1 Reflects increase expected with completion of Little Creek pumped storage facility.

SUBREGION 11

Two major systems supply the water to the urban population of this subregion: Norfolk and Portsmouth. Through these systems Virginia Beach, City of Chesapeake, and Suffolk (Subregion 12) are also served. Projected source and system deficits, based on existing development, are shown in Table 5-33. Immediate needs for source development are indicated for Portsmouth, and the Norfolk system requires increases in both source and system capacities. Together the two systems have maximum 7-day deficits of 21 mgd in 1980, increasing to 63 mgd by 2000, and 117 mgd by 2020. The location of the subregion on coastal saline waters, and the development of nearly all nearby sources, will necessitate large scale development at some distance from the urban center.

TABLE 5-33
FUTURE MUNICIPAL SOURCE AND SYSTEM DEFICITS, mgd
SUBREGION 11

WATER SERVICE AREA	Capacities (source) (system)		1980 Avg.	1980 30-day	1980 7-day	1980 1-day	1990 Avg.	1990 30-day	1990 7-day	1990 1-day	2000 Avg.	2000 30-day	2000 7-day	2000 1-day	2020 Avg.	2020 30-day	2020 7-day	2020 1-day
Norfolk System		Demand	61.7	74.0	86.4	98.7	70.8	85.0	99.1	113.3	83.0	99.4	115.5	132.5	108.9	130	152	174
	73.0	Source Deficit	0	1.0	13.4	25.7	0	12.0	26.1	40.3	10.0	26.4	42.5	59.5	35.9	57.0	79.0	101
	63.0	System Deficit	0	11.0	23.4	35.7	7.8	22.0	36.1	50.3	20.0	36.4	52.5	69.5	45.9	67.0	89.0	111
Portsmouth System		Demand	20.8	25.0	29.1	33.3	25.0	30.0	35.0	40.0	30.0	36.0	42.0	48.0	42.1	50.5	58.9	67.4
(Incl. Suffolk)	21.0	Source Deficit	0	4.0	8.1	12.3	4.0	9.0	14.0	19.0	9.0	15.0	21.0	27.0	20.8	29.2	37.5	45.9
	37.5	System Deficit	0	0	0	0	0	0	0	0	0	0	4.5	10.5	4.6	13.0	21.4	29.9
Total		Demand	82.5	99.0	115.5	132.0	95.8	115.0	134.1	153.3	113.0	135.4	157.5	180.5	151.0	180.5	210.9	241.4
	94.0	Source Deficit	0	5.0	21.5	38.0	1.8	21.0	40.1	59.3	19.0	41.4	63.5	86.5	57.0	86.5	116.9	147.4
	100.5	System Deficit	0	0	15.0	31.5	0	14.5	33.6	52.8	12.5	34.9	57.0	80.0	50.5	80.0	110.4	140.9

Demands for water for all uses are aggregated in Table 5-34 and compared with the estimated overall available freshwater resource from groundwater sources and existing reservoir development. Publicly supplied water remains the largest component of demand through 2020. The overall amount of freshwater internally available within the subregion will run about 22 mgd short of demand by 1980. This deficit will increase to 39 mgd by 1990, and 114 mgd by 2020.

TABLE 5-34
AGGREGATED DEMANDS VERSUS FRESHWATER RESOURCE, mgd
SUBREGION 11

	1970	1980	1990	2000	2020
Large Public Systems[1]	92.7	111.1	128.6	150.5	199.9
Small Public Systems	1.1	1.6	2.4	3.4	5.3
Industrial	3.8	2.5	2.0	2.0	2.8
Institutional[2]	–	–	–	–	–
Agricultural	6.2	12.8	12.2	11.6	11.9
TOTAL Demand	104	128	145	168	220
Fresh Water Supply	106	106	106	106	106
Needs	0	22	39	62	114

[1] Not including Suffolk.
[2] All publicly supplied.

SUBREGION 12

Water service areas at Suffolk, Smithfield, and Williamsburg represents the major cities in this largely rural subregion. Table 5-35 details the projected growth in demand for each WSA and identifies source and system deficits to be expected under current capacities. Immediate shortages are identified for Williamsburg, but it should be noted that supplemental supplies through the Newport News system, unaccounted for here, are provided to Williamsburg on a regular basis. Deficits identified can thus be interpreted as the allocation needed from Newport News in lieu of other source development. Tourism causes large fluctuations in demand at Williamsburg. Smithfield will require only modest source and system development to meet needs in 1990. Since

TABLE 5-35
FUTURE MUNICIPAL SOURCE AND SYSTEM DEFICITS, mgd
SUBREGION 12

WATER SERVICE AREA	Capacities (source) (system)		1980 Avg.	1980 30-day	1980 7-day	1980 1-day	1990 Avg.	1990 30-day	1990 7-day	1990 1-day	2000 Avg.	2000 30-day	2000 7-day	2000 1-day	2020 Avg.	2020 30-day	2020 7-day	2020 1-day
Williamsburg		Demand	4.2	5.5	6.7	8.4	4.7	6.2	7.5	9.4	5.5	7.2	8.8	11.0	7.2	9.5	11.5	14.4
	2.5	Source Deficit	1.7	3.0	4.2	5.9	2.2	3.7	5.0	6.9	3.0	4.7	6.3	8.5	4.7	7.0	9.0	11.9
	4.0	System Deficit	0.2	1.5	2.7	4.4	0.7	2.2	3.5	5.4	1.5	3.2	4.8	7.0	3.2	5.5	7.5	10.4
Smithfield		Demand	0.4	0.5	0.6	0.7	0.6	0.8	1.0	1.3	0.8	1.0	1.2	1.5	1.2	1.6	2.0	2.5
	0.7	Source Deficit	0	0	0	0	0	0.1	0.3	0.6	0.1	0.3	0.5	0.8	0.5	0.9	1.3	1.8
	0.7	System Deficit	0	0	0	0	0	0.1	0.3	0.6	0.1	0.3	0.5	0.8	0.5	0.9	1.3	1.8
Suffolk		Demand	2.8	3.6	4.4	5.5	3.4	4.4	5.5	6.9	4.4	5.7	7.0	8.8	6.9	9.0	11.0	13.8
	–	Source Deficit	–	–	–	–	–	See Subregion 11: "Portsmouth"				–	–	–	–	–	–	–
	–	System Deficit																
Total[1]		Demand	4.6	6.0	7.4	9.2	5.3	6.9	8.5	10.6	6.3	8.2	10.1	12.6	8.4	10.9	13.4	16.8
	3.2	Source Deficit	1.4	2.8	4.2	6.0	2.1	3.7	5.3	7.4	3.1	5.0	6.9	9.4	5.2	7.7	10.2	13.6
	4.7	System Deficit	0	1.3	2.7	4.5	0.6	2.2	3.8	5.9	1.6	3.5	5.4	7.9	3.7	6.2	8.7	12.1

[1] Not including Suffolk.

future needs for public water supply in Suffolk will be met through the Portsmouth system, demands for these two service areas are combined for purposes of this report.

Aggregated demands for all uses within the subregion are listed in Table 5-36 and compared with the overall available freshwater supply. Shortages totaling 90 mgd by 1990, and 315 mgd by 2020, are due mainly to expected industrial growth. Since most of the Chesapeake Bay freshwater drainage has been already developed for use in Subregion 11, the listed freshwater supply is confined mostly to the potential groundwater yield. Drainage of the Nottoway and Blackwater Rivers south into North Carolina presents a substantial additional source for the southern counties of Subregion 12, and indeed, is being actively sought as a source for Norfolk and Portsmouth.

TABLE 5-36
AGGREGATED DEMANDS VERSUS FRESHWATER RESOURCE, mgd
SUBREGION 12

	1970	1980	1990	2000	2020
Large Public Systems[1]	7.4	11.8	14.0	17.1	24.5
Small Public Systems	3.6	5.3	7.3	10.3	18.1
Industrial	49.7	64.3	93.3	135.6	277.9
Institutional	0.1	0.1	0.1	0.1	0.1
Agricultural	7.0	19.0	59.8	100.5	78.7
TOTAL Demand	68	100	174	263	399
Fresh Water Supply	84	84	84	84	84
Needs	0	16	90	179	315

[1] Including Suffolk.

SENSITIVITY ANALYSIS

The demands for future water supply identified in the previous chapter were derived on the basis of certain assumptions. These assumptions were needed in order to transform and simiplify the many uncertainties of the future into a single set of demand projections that reflect the "best estimate" of future conditions.

While many assumptions were used in Chapter III to arrive at an estimate of future water needs, it was felt that two of the more basic determinants of water demand merited additional consideration. These are the topic of this chapter. First, the sensitivity of the projections of municipal water demand presented in Chapter III are analyzed in terms of changing from Series C OBERS projections of economic activity and population to those of Series E. Second, consideration is given to the future improvements in water reuse in manufacturing that may evolve as manufacturers seek to comply with requirements of the 1972 Amendments to the Federal Water Pollution Control Act (P.L. 92-500).

IMPACT OF POPULATION CHANGES ON MUNICIPAL WATER DEMANDS

In making economic and demographic projections for the Chesapeake Bay Study Area, a program of economic measurement, analysis, and projection conducted by the Bureau of Economic Analysis (BEA) — formerly the Office of Business Economics (OBE) — of the U.S. Department of Commerce, and the Economic Research Service (ERS) of the U.S. Department of Agriculture was used. The OBERS program, as it has come to be called, deals with the economic activity of the entire Nation and seeks to provide a regional economic information system covering both the past and the future. The OBERS historical and projected data form a National economic framework within which a region's present and future levels of economic development can be assessed and compared with those of other regions.

In 1967, the Bureau of the Census developed four sets of projections, Series A, B, C, and D, which assumed varying fertility rates. By December 1972, the Census Bureau had abandoned the Series A and B projections and had added Series E and F. At the time the *Existing Conditions Report* was developed the Water Resources Council (WRC) required that all Federal agencies involved in water resources planning use the OBERS Series C projections of population, income, employment, earnings and output. These projections are presented in a multi-volume series of reports entitled the *1972 OBERS Projections — Regional Economic Activity in the U.S.* Starting in 1974 however, WRC directed that agencies involved in water resource planning use the Series E projections (generally, the E Series assumes lower fertility rates as well as less defense spending than the C Series). These Series E projections, published in a seven-volume series in April 1974, were derived from more recent economic and demographic data. Both Series of reports served as basic analytical frameworks for the assessment of the economic implications of proposed water and related land resource development activities in the United States.

Appendix 3—*Economic and Social Profile* includes both the Series C and E projections of population and employment for the Study Area. As noted earlier, the Series C projections are considered to be the baseline or reference projections for this Report since the majority of the resource projections, including water supply demands, were made prior to the adoption of the Series E projections.

As shown on Table 5-37, the Series E projections are based on slightly differing assumptions from Series C. It is expected that water use in public systems would be less than expected under Series C assumptions if conditions implicit in the use of Series E projections are in fact realized. Of the two basic determinants of municipal water use, population is the variable with the greatest influence on water use within the cities. Per capita use is the other variable that, when multiplied by population, yields demand. The per capita use rates that would develop under the Series E assumptions would not be expected to differ significantly from those that would develop under Series C. This is because the factors which influence the character of a community, and which also influence per capita demand (i.e., housing density, per capita income, type and extent of commercial activity, etc.) are felt to be largely insensitive to small changes in population. Also, changes that may occur in the industrial component of municipal demand are felt to be largely reflected in the population differences between Series C and Series E. The population projections by OBERS are derived from National and regional figures on employment and earnings, and as such, are considered to be reflections of future industrial activity.

Population projections, therefore, remain as the single most important and influential of the many determinants of water use in the cities. Table 5-38 provides a comparison of the large system water demands based on the differences between the Series C and Series E population projections. Differences in the demands shown in the table are directly proportional to the differences in population between Series E and Series C.

TABLE 5-37

A COMPARISON OF OBERS SERIES C AND SERIES E PROJECTIONS

Item	Series C	Series E
Growth of Population	Fertility rate of 2,800 children per 1,000 women	Gradual decline of fertility rate from 2,800 to the "replacement fertility rate" of 2,100 children per 1,000 women.
Military Establishment	Projects a decline to 2.07 million people by 1975 and thereafter a constant.	Projects a decline to 1.57 million persons by 1975 and thereafter a constant (due to smaller military establishment and the resultant smaller need for equipment and supplies, a significantly slow rate of growth in the defense-related manufacturing industries is anticipated).
Hours Worked Per Year	Hours worked per employee per year are projected to decline at 0.25 percent per year.	Hours worked per employee per year are projected to decline at 0.35 percent per year.
Product Per Man-Hour	Projected to increase 3.0 percent per year.	Projected to increase 2.9 percent per year.
Earnings Per Worker	Earnings per worker in the individual industries at the national level are projected to converge toward the combined rate for all industries more slowly in the Series E projections than in the Series C projections.	
Employed Population	Projected to increase from 40 to 41 percent of the total population.	Projected to be between 43 and 45 percent of the total population (higher percentages with the E Series reflects expected higher participation rates by women).

As shown on Table 5-38, the majority of the subregions show reduced water demands using the Series E population projections. The most significant reductions occur in the Baltimore Subregion where a 30 percent reduction or 158 mgd is realized by the year 2020. This large decrease is attributed to reductions in population that result from a slower growth in defense-related industries as projected under Series E. Lesser declines in 2020 demand of 17, 15, and 9 percent are noted for the Richmond, Newport News and Norfolk Subregions, respectively.

Only Subregions 5, 6, and 7, which are components of the Washington Economic Area, show larger water demands under Series E than under Series C, however, this only occurs in certain goal years. These larger demands are due primarily to larger than expected population and employment increases in this Economic Area during the two additional years of the observation between the release of the Series C and E projections. By the year 2020, water demands under series E are shown to be less for all subregions.

Periodically, between censuses, the Bureau of Census publishes estimates of population trends in the United States. An analysis of current trends in the Bay Area through 1975 is presented as Attachment 5-G. There is conflicting evidence to indicate the preferability of either Series C or Series E projections. Five of the subregions in the Bay Area (Numbers 3, 4, 9, 11, and 12) show growth in direct disagreement with the Series E trends, while estimated populations in Subregions 5, 6, 7, and 8 indicate trends that are in the same direction as Series E, but that are much more pronounced. Only Subregions 1, 2, and 10 indicate trends that are intermediate to the forecasts of Series C and E.

In summary, it should be noted that the water demands to be met by the municipal systems vary directly with the population served. With specific regard to the differences between water demands under the Series C and E OBERS projections, it is expected that the total municipal demands in the Bay Region would be between 4 and 7 percent lower under the Series E assumptions during the planning period (1980 to 2020).

IMPACT OF WATER REUSE ON INDUSTRIAL DEMANDS

Projections of water demands for use in manufacturing were presented in Chapter III. It was assumed that improvements in water reuse and recycling will occur in the future as industries seek to reduce pollutant discharges and/or reclaim by-products from their wastewaters. Under the baseline industrial projections (Projection Set 3) intake demands were found to decline slightly, from about 1,600 mgd in 1970 to around 1,300 mgd by the year 1990. Projections subsequently increase to about 1,800 mgd by 2020 as industrial water demands increase at a faster rate than the assumed technological advances.

In 1970, large water users (10 mgy or more) used recirculated supplies to provide 38.7 percent of the gross water needed for production. By 1990, this is shown to increase to 77.6 percent, and by 2020 to 89.6 percent. However, even more impressive recycling rates may occur dependent on the manner in which industry responds to the provisions of the 1972 Amendments to the Federal Water Pollution Control Act (P.L. 92-500).

This section is an analysis of the sensitivity of industrial water use projections to changes that may occur in recycling rates in industrial water use. A complete

TABLE 5-38

WATER USE IN MAJOR SYSTEMS UNDER SERIES E POPULATION PROJECTIONS, mgd

	Subregion	Series	1980	1990	2000	2020
1.	Baltimore, SMSA	C	311	347	399	533
		E	281	297	320	375
2.	Non-SMSA, MD	C	16.3	17.7	20.3	25.9
		E	15.1	15.2	16.4	19.5
3.	Non-SMSA, VA	C	0	0	0	0
		E	0	0	0	0
4.	Sussex Co., DE	C	1.0	1.2	1.4	1.9
		E	1.0	1.0	1.1	1.4
5.	Washington, D.C., SMSA	C	494	617	760	1,158
		E	493	639	789	1,146
6.	Non-SMSA, MD	C	3.4	5.7	8.6	18.2
		E	3.6	6.0	9.1	18.1
7.	Non-SMSA, VA	C	3.1	3.6	4.2	5.8
		E	3.2	3.8	4.4	5.7
8.	Richmond, SMSA	C	86	100	124	189
		E	85	99	116	156
9.	Non-SMSA, VA	C	0.3	0.4	0.4	0.6
		E	0.3	0.4	0.3	0.4
10.	Newport News-Hampton SMSA	C	36.8	42.3	50.0	67.5
		E	33.6	38.9	43.9	57.4
11.	Norfolk-Portsmouth SMSA	C	79.7	92.4	109	144
		E	74.7	88.0	101	131
12.	Non-SMSA, VA	C	7.4	8.7	10.7	15.3
		E	6.6	7.8	9.0	12.1
	BAY AREA TOTAL	C	1,039	1,237	1,487	2,159
		E	997	1,196	1,410	1,923

presentation of the assumptions and methodology used in the analysis is included in Chapter III. As explained in Chapter III, the analysis was conducted specifically for the Chesapeake Bay Study by the Bureau of Domestic Commerce (BDC) U. S. Department of Commerce. Projection Sets 1, 2, and 3 were based on the work of BDC using varying assumptions concerning future recycling. All three projection sets are presented here in order to compare the sensitivity of industrial water needs under the full range of assumptions.

ASSUMPTIONS AND METHODOLOGY

In the process of developing a forecast of future industrial water needs for the Chesapeake Bay Area, three separate projection sets were constructed. The projection sets varied only in the assumptions concerning future rates of recycling. Projection Set 1 was based on a series of assumptions related to the National goal of zero discharge of pollutants as set forth in P.L. 92-500. The methodology culminated in the attainment by each industry group of a "maximum theoretically possible" recycling rate by the year 2000. Projection Set 2 was derived assuming that current rates of recycling within each industry group would remain constant through the year 2020. Projection Set 3, which was selected as the baseline projections for future industrial water supply needs in Chapter III, was based on a continuation of the 1975 to 1980 trend in improvement in recycling as derived by BDC in Projection Set 1.

For purposes of discussion, the three projection sets numbered 1, 2, and 3, are termed "advanced", "constant", and "moderate", respectively, in reference to the degree of implementation of technology assumed in each case. A complete discussion of the assumptions and methodology associated with each of the three projection sets is included in Chapter III.

RESULTS

Comparisons of water use in manufacturing for each of the three projection sets is shown in Table 5-39 for the entire Bay Area. Since the measure of production and the amount of water needed per unit production are the same in each projection set, the gross amount of water required and the resulting consumptive losses are also the same in each projection set. By varying the assumptions concerning future rates of recycling, differences are observed in "intake" and "discharge." Intakes are shown to vary by nearly 10 billion gallons per day in the year 2020 between the advanced technology case (Projection Set 1) and the constant technology case (Projection Set 2).

Under assumptions implicit in the moderately advancing technology case (Projection Set 3), water intakes are shown to decline slowly through 1990 and then grow to about 1,800 mgd by the year 2020. This is felt to be the most realistic projection set in terms of planning for Chesapeake Bay. If the water reuse and recycling technology associated with Projection Set 1 is indeed attained, water withdrawals in the Chesapeake Bay Area would be reduced by approximately 1 billion gallons per day in 2020. A plot of projected gross demand, consumption, and intake demands for each projection set are shown in Figure 5-8.

TABLE 5-39

WATER USE IN MANUFACTURING WITH VARIOUS ASSUMPTIONS ON FUTURE TECHNOLOGY

(mgd)

Parameter	Projection Set	1970	1980	1990	2000	2020
Gross Use	All cases	2,608	4,408	6,002	8,592	17,290
Intake	1	1,615	1,581	517	418	804
	2	1,615	2,731	3,718	5,322	10,711
	3	1,615	1,581	1,344	1,398	1,823
Consumption	All cases	74	158	246	341	652
Discharge	1	1,541	1,424	270	76	151
	2	1,541	2,573	3,472	4,981	10,058
	3	1,541	1,424	1,098	1,057	1,171

A breakdown of the intake demands by subregion is presented in Table 5-40 for each projection set. Figures shown for the moderate technology case (Projection Set 3) were taken from Chapter III. These are compared with results assuming attainment of advanced technology and conditions of constant technology (Projection Sets 1 and 2, respectively).

In the projection of industrial water use for the case of advanced technology (Projections Set 1), each major 2-digit industrial sector was investigated. Results of this analysis are presented in Table 5-41 and can be compared with results in Table 5-10 for the moderate technology case. All sectors show impressive recirculation capabilities—the highest being in the Petroleum sector in which 98.6 percent of the gross water use might be recirculated by 2000. This is equivalent to saying that a given unit of intake can be recycled or reused 69 times before being consumed or discharged (recycling rate = G/I). Recycling rates of about 33 for Chemicals and 31 for Paper and Allied Products indicate these industries' ability to recycle water if the best technology is implemented. At present, the Paper industry possesses a recycling rate of 8.9, the best of all Chesapeake Bay major sectors. This means that 88.8 percent of all needs are met by recycled water. Food industries, which incorporate fair amounts of water into products, presently use a unit of water only 1.08 times, but, with estimates of advanced technology, this would grow to 6.99 by 2020.

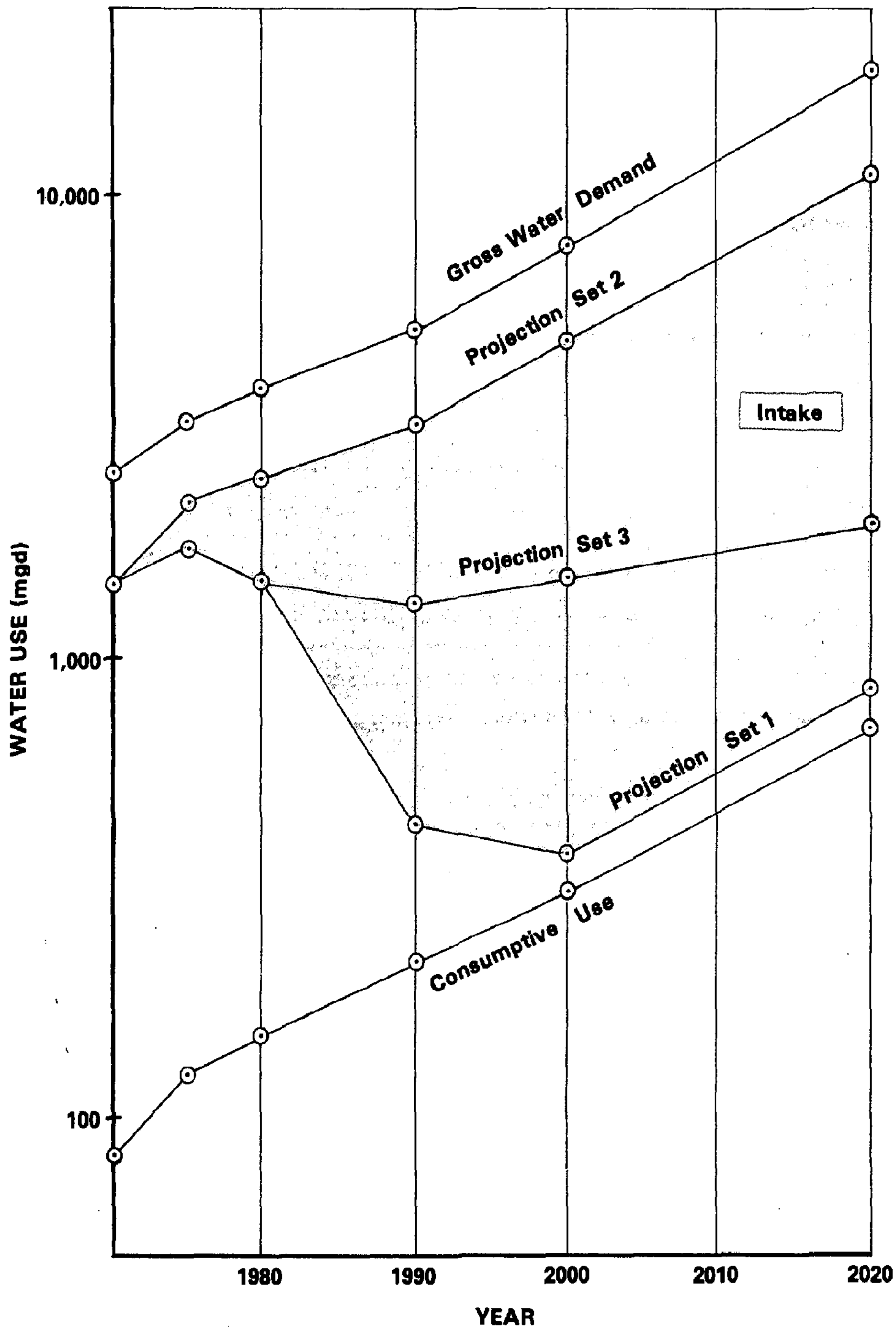


FIGURE 5-8: INDUSTRIAL WATER USE WITH VARIOUS LEVELS OF TECHNOLOGICAL ADVANCE

TABLE 5-40
WATER INTAKES IN MANUFACTURING WITH
VARYING TECHNOLOGY, BY SUBREGION, mgd

Subregion	Year	Gross Demand	Advanced Technology (Proj. Set 1)	Constant Technology (Proj. Set 2)	Moderate Technology (Proj. Set 3)
BAY AREA TOTAL	1970	2,607.9	1,615.5	1,615.5	1,615.5
	1975	3,512.5	1,823.9	2,175.9	1,823.9
	1980	4,408.2	1,581.4	2,730.7	1,581.4
	1990	6,001.6	516.8	3,717.8	1,344.1
	2000	8,591.5	417.6	5,322.1	1,397.8
	2020	17,290.2	803.8	10,710.7	1,822.9
1	1970	1,226.1	990.7	990.7	990.7
	1975	1,703.3	1,174.7	1,376.3	1,174.7
	1980	2,179.2	1,034.2	1,760.8	1,034.2
	1990	2,751.8	282.5	2,223.4	830.2
	2000	3,608.4	217.0	2,915.6	793.3
	2020	5,997.5	358.8	4,846.0	856.4
2	1970	35.5	34.8	34.8	34.8
	1975	39.9	37.8	39.1	37.8
	1980	44.5	34.6	43.6	34.6
	1990	52.5	14.2	51.2	30.8
	2000	71.6	11.7	70.2	33.8
	2020	124.1	19.9	121.7	41.8
3	1970	2.6	2.3	2.3	2.3
	1975	2.9	2.4	2.6	2.4
	1980	3.3	2.0	3.0	2.0
	1990	4.1	1.1	3.7	1.7
	2000	5.4	0.9	4.8	1.7
	2020	9.2	1.6	8.3	1.9
4	1970	82.7	65.6	65.6	65.6
	1975	89.5	61.4	71.0	61.4
	1980	86.4	43.5	68.5	43.5
	1990	53.1	14.0	42.1	18.0
	2000	81.1	12.8	64.3	20.6
	2020	175.0	27.7	138.8	29.5
5	1970	5.4	4.7	4.7	4.7
	1975	6.4	6.0	5.6	6.0
	1980	8.0	6.6	7.0	6.6
	1990	12.0	6.9	10.4	8.5
	2000	18.6	8.2	16.2	11.3
	2020	41.8	18.9	36.3	19.7

TABLE 5-40 (continued)
WATER INTAKES IN MANUFACTURING WITH
VARYING TECHNOLOGY, BY SUBREGION, mgd

Subregion	Year	Gross Demand	Advanced Technology (Proj. Set 1)	Constant Technology (Proj. Set 2)	Moderate Technology (Proj. Set 3)
6	1970	0.8	0.8	0.8	0.8
	1975	1.1	1.1	1.1	1.1
	1980	1.3	1.3	1.3	1.3
	1990	2.1	2.1	2.1	2.1
	2000	3.5	3.5	3.5	3.5
	2020	7.5	7.5	7.5	7.5
7	1970	32.9	27.4	27.4	27.4
	1975	45.4	32.3	37.8	32.3
	1980	57.9	28.4	48.2	28.4
	1990	89.3	3.5	74.3	28.0
	2000	141.1	4.5	117.4	32.3
	2020	331.4	10.6	275.7	49.4
8	1970	400.5	286.8	286.8	286.8
	1975	573.6	326.5	410.7	326.5
	1980	746.2	268.9	534.3	268.9
	1990	1,168.9	55.7	836.9	250.9
	2000	1,862.0	61.0	1,333.2	283.4
	2020	4,458.7	144.4	3,192.4	429.9
9	1970	52.4	26.5	26.5	26.5
	1975	66.6	26.5	33.7	26.5
	1980	80.2	21.6	40.6	21.6
	1990	115.4	10.8	58.4	19.6
	2000	171.0	5.7	86.5	21.0
	2020	366.2	12.3	185.3	29.0
10	1970	114.9	100.2	100.2	100.2
	1975	149.7	79.1	130.5	79.1
	1980	184.6	58.8	161.0	58.8
	1990	255.4	41.2	222.7	46.9
	2000	358.6	14.7	312.7	46.0
	2020	720.7	29.1	628.5	57.9
11	1970	32.3	25.3	25.3	25.3
	1975	41.6	21.0	32.6	21.0
	1980	53.5	16.4	41.9	16.4
	1990	73.3	13.4	57.4	13.0
	2000	109.1	6.7	85.4	13.6
	2020	236.7	14.7	185.3	18.5
12	1970	621.8	50.4	50.4	50.4
	1975	792.5	55.1	64.2	55.1
	1980	963.1	65.1	78.0	65.1
	1990	1,424.0	71.4	115.3	94.4
	2000	2,161.1	70.9	175.0	137.3
	2020	4,821.4	158.3	390.5	281.4

TABLE 5-41
WATER USE IN MANUFACTURING WITH ADVANCED TECHNOLOGY, BY SECTOR, CHESAPEAKE BAY AREA, mgd

	Gross Water Demand	Intake	Consumption	Discharge	Recycling Rate[1]
ALL MANUFACTURING					
1970	2,607.9	1,615.5	74.2	1,541.3	1.63
1975	3,512.5	1,823.9	112.5	1,711.4	1.92
1980	4,408.2	1,581.4	157.5	1,423.9	2.71
1990	6,001.6	516.8	246.4	270.4	12.5
2000	8,591.5	417.6	341.3	76.3	23.8
2020	17,290.2	803.8	652.4	151.4	25.2
FOOD & KINDRED PRODUCTS (SIC 20)					
1970	79.7	74.3	5.6	68.7	1.08
1975	95.4	81.3	6.1	75.2	1.19
1980	111.1	75.3	6.4	68.9	1.53
1990	146.0	38.9	6.3	32.6	4.86
2000	196.4	39.1	8.4	30.7	6.99
2020	343.9	68.6	14.8	53.8	6.99
PAPER & ALLIED PRODUCTS (SIC 26)					
1970	644.8	72.8	7.6	65.2	8.91
1975	848.2	88.1	17.8	70.3	9.69
1980	1,051.6	100.9	25.2	75.7	10.41
1990	1,546.1	112.5	49.5	63.0	13.9
2000	2,334.9	76.5	74.6	1.9	31.3
2020	5,145.5	168.6	164.4	4.2	31.3
CHEMICALS (SIC 28)					
1970	402.5	328.1	14.5	313.6	1.22
1975	560.1	382.6	19.6	363.0	1.46
1980	719.3	342.3	24.5	317.8	2.11
1990	1,131.5	42.3	33.9	8.4	29.5
2000	1,804.5	60.5	54.2	6.3	33.3
2020	4,319.3	144.8	129.7	15.1	33.3

TABLE 5-41 (continued)
WATER USE IN MANUFACTURING WITH ADVANCED TECHNOLOGY,
BY SECTOR, CHESAPEAKE BAY AREA, mgd

	Gross Water Demand	Intake	Consumption	Discharge	Recycling Rate[1]
PETROLEUM (SIC 29)					
1970	81.6	76.3	0.7	75.6	1.07
1975	99.8	79.4	0.9	78.5	1.17
1980	105.3	63.3	1.2	62.1	1.66
1990	136.9	2.8	1.9	0.9	50.6
2000	178.9	2.5	2.5	0.03	69.0
2020	294.8	4.2	4.1	0.05	69.0
PRIMARY METALS (SIC 33)					
1970	1.094.6	882.3	35.1	847.2	1.24
1975	1,423.4	965.5	54.1	911.4	1.47
1980	1,752.1	815.6	78.8	736.8	2.15
1990	2,203.2	191.3	130.0	61.3	11.5
2000	2,823.6	169.0	166.6	2.4	16.9
2020	4,536.8	271.5	267.7	3.8	16.9
OTHER MANUFACTURING					
1970	304.7	181.7	10.7	171.0	1.82
1975	490.6	227.0	14.0	213.0	2.18
1980	668.8	184.0	21.4	162.6	2.85
1990	837.9	129.0	24.8	104.2	9.72
2000	1,253.2	70.0	35.0	35.0	41.3
2020	2,649.9	146.1	71.7	74.4	41.3

[1]Value shown is for large water users only.

It should be reemphasized that this analysis assumes achievement of maximum theoretical technology in the manufacturing industries as the Nation moves towards the goal of zero discharge of pollutants. No connotation as to desirability or undesirability is implied. This information is presented to aid planners as a future decision-making tool, and is intended only as an indicator of the effect that might be expected due to pursual of water quality goals.

Two other considerations are also worthy of note as regards future industrial water use in the Chesapeake Bay Area. First, as was stated in Chapter II, industrial water use is concentrated in a relatively few large plants in particular types of industry. This suggests that the timing and achievement of water resources management goals in the Chesapeake Bay Region are extremely dependent upon the policies and actions of these existing large water-using plants, and upon the growth and expansion of similar industries. Second, while brackish water is presently utilized as a substitute for fresh water, the continuation of its use in similar proportions as the economy of the region grows may not occur. Essentially all brackish water withdrawals at present are for use as cooling water in heat exchange equipment which results in a heated waste water. If thermal pollution control for discharges into the bay and tributaries is required, it is probable that cooling towers and ponds will be utilized and that the cooling water will be recycled rather than discharged. Under those circumstances, the make-up water added to the cooling system to replace water lost through evaporation and blowdown is likely to be fresh rather than brackish to prevent an unacceptable buildup of dissolved solids in the cooling water system. These factors make clear the need for periodic surveys and updates of industrial water use and location especially in the planning stages of future managerial actions that may be influenced by changed water use habits.

In summary, the future amount of water that may be required to meet the needs of industry will depend on the degree of recycling practiced. Within the range of assumption used, water withdrawals could vary from approximately 800 to over 10,000 mgd by 2020. Under the assumptions of "moderate" technological advance, which are considered the most realistic for purposes of this report, withdrawal demands increase to a value of 1800 mgd by the year 2020.

CHAPTER V

MEANS TO SATISFY THE NEEDS

Chapter III included a presentation of the potential water supply deficits that can be expected under the assumed population and economic growth characteristics. This chapter includes a discussion of the alternative measures by which water shortage problems might be alleviated. Both developmental and institutional measures will be considered. Detailed alternatives investigation for specific water service areas, or type of use (industrial, agricultural, public, etc.), are beyond the scope of this study. Future studies and alternatives analysis will be required to arrive at site-specific costs and engineering designs to meet the needs identified in Chapter III.

DEVELOPMENTAL MEASURES

Means to satisfy water supply needs can generally be categorized, as "developmental" or "institutional." Developmental means involve the classical engineering solutions for water supply shortages, such as surface water impoundment, development of ground water, or inter-basin diversion. Transmission and distribution mains, intake structures, and treatment plants are related system engineering developments needed to bring the supply from the source to the consumer. In Chapter III, the deficits identified were based on the maximum demands for durations of 1, 7, and 30 days. This range of demands was developed to highlight the variations in deficit that occur under conditions of average flow and low flow, and to identify areas where water supply problems exist or are emerging. Development of the full range of demands under varying low-flow conditions is also required in order to evaluate the effectiveness of the various alternative means of meeting water supply deficits.

It should also be noted that streamflows shown as the available supply in Chapter III are those low-flows that may be expected only once in 50 years, and, as such, represent relatively rare occurrences. Use of a less severe low-flow, such as 25-year or 10-year, would require tradeoffs between the threat-of-shortage, and the reduced expense.

In the planning stage of an effort to alleviate an identified water supply shortage, the question arises as to what type source to develop—should surface flows, impoundments, wells, or some more unusual source be used, such as desalination or interbasin diversion? Would regionalization of a group of smaller systems under jurisdiction of an area-wide authority provide a more economical and equitable supply for all? Perhaps a small water system would find it more economical to purchase water from a nearby large system rather than develop its own incremental supply. All these factors, plus other problems, and considerations, such as costs, financing, dependabilty, and quality, must be considered when planning a water supply system.

SURFACE SUPPLIES

Surface water presently meets the majority of the municipal and industrial water supply demands in the Chesapeake Bay Area, particularly in areas requiring large supplies. Groundwater, while more evenly distributed around the Bay Area and less susceptible to seasonal fluctuation, is generally more difficult to retrieve in large quantities. River flow is fed by runoff and groundwater discharge from its entire basin, sometimes, as in the case of the Susquehanna and Potomac Rivers, covering thousands of square miles. In addition to the quantity of water available, quality considerations are also very important in the development of surface supplies. Generally speaking, surface sources are much more susceptible to pollutants. Municipal and industrial discharges, pesticides and fertilizers from agricultural lands and even natural properties such as hardness and sediment are just a few of the pollutants that can reduce the utility of the streamflow for downstream users.

Impoundments

A major problem in the use of surface water supplies is the seasonal variation in flow. Peak demands usually coincide with the season of lowest flow in the streams. Dam construction is a means by which reduction of variability can be attained, and the dependable flow or safe yield of a watershed increased. Water is stored in the reservoir during periods of excess flow for use during seasonal periods of low flow and high domestic demands. Over the long term, however, average stream flow must exceed demand by a substantial margin in order to maintain a minimum conservation pool, allow for evapotranspiration, and provide a minimal base-flow below the dam.

For a particular drainage basin, the amount of storage needed to effect a given increase in dependable stream flow is dependent on several variables, including the chronological sequence of flows and the long term variation in stream flow. Hydrographs of the longest and driest period known (or predicted) can be used to construct a mass diagram of aggregated flow with time. This may be used in conjunction with a mass curve of demand to determine the volume of reservoir storage needed to alleviate dry-season deficits[26].

The capacity of a particular reservoir site must also be investigated with respect to the height of dam and resulting water surface area. Curves can be constructed showing the relation between depth and surface area, and between depth and volume storage, known respectively as "area" and "capacity" curves. A typical example is shown in Figure 5-9 for Triadelphia Reservoir on the Patuxent River, Maryland.

Although detailed hydrologic investigations are needed for specific site investigation, generalized relationships can be derived for areas with similar topography, geologic makeup, and climate. For example, using data derived for possible impoundment sites in the Potomac River Basin Study[27], a relationship can be derived between storage volume and increased dependable yield, as shown in Figure 5-10[28]. The sample includes reservoir sites that would provide between 40,000 and 500,000 acre-feet of storage and that would create lakes to be managed as multi-purpose facilities. Thus, assuming the curve is typical of the upland Piedmont Portions of the Chesapeake Bay Area, provision of about 200,000 acre-feet of storage might be expected to increase dependable streamflow by 175 mgd. Management of supplies strictly for water supply purposes, however, could increase the safe-yield substantially.

The cost of a reservoir development is dependent on many variables, often not in the least consistent from project to project. Cost variables to be considered include dam construction, operation, and maintenance; land acquisition; building relocation and demolition; clearing of reservoir site; and highway and railroad relocation.

Local site characteristics peculiar to each project will govern overall costs. The geology of an area, for example, will affect both the type and configuration of the dam. Upstream land use will affect storage needed for sedimentation. In addition, local topography will influence the length and height of dam needed to effect a given storage volume. Presence of valuable residences, farms, railroads, and other developments can increase land acquisition and relocation costs significantly, sometimes to more than 75 percent of total. Typically, the projects are designed to serve as far as 50 years into the future.

Natural Stream Flow

Free-flowing surface waters are another source of supply available to meet expanding needs. The Susquehanna, Potomac, Rappahannock, James, and Appomattox Rivers presently serve as major sources of water supply for the ridges, and fairly steep stream slopes. It is well drained by the many streams and rivers which empty into the Bay[30].

Use of natural stream flows as water supply sources (without impoundment) depends on the minimum predicted flow exceedng the maximum demand during the driest season. Otherwise, off-stream storage facilities or dams will be needed to store water for use during deficit periods, or for release to supplement downstream flows. Based on stream flow records, estimates can be made of the frequency of occurrence of various low-flows. Although low-flow analysis can be estimated for streams without flow records, by synthesizing data from nearby streams, a minimum of 10 years flow record is recommended for analysis of streams with gaging stations. Attachment B details the stream flow of streams in the Chesapeake Bay Area (greater than 5 cfs average discharge) for a 7-day duration low-flow to be expected once in 10, 25, and 50 years.

Tradeoffs are encountered in the development of water supply sources between the threat of shortage and the added expense of developing a more reliable source. The relationship between the low-flow recurrence interval and the probability of its occurrence is shown in Table 5-42. For example, a system designed around a 20-year low-flow has a 5 percent probability of shortage in any given year. The water facilities designer must decide upon the acceptable level of risk to the community. Services for lawn watering and swimming pools, and certain commercial, industrial, and public uses can often be curtailed temporarily without undue hardship or risk to the public health, or community well-being.

TABLE 5-42

PROBABILITY OF LOW-FLOW OCCURRENCE

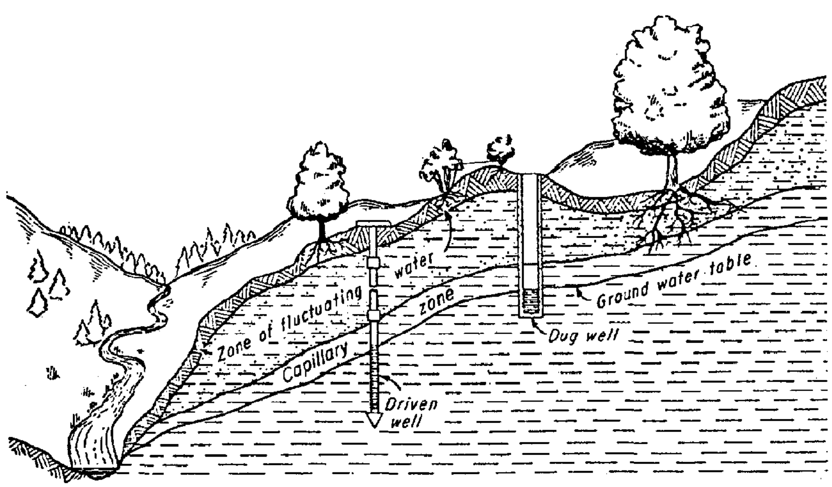
Recurrence Interval, Years	50	25	20	10	5	2
Probability of Occurrence in any particular year, Percent	2	4	5	10	20	50

GROUNDWATER

Groundwater is another water supply source which can be developed to meet needs in deficit areas. Massive amounts of water are stored in the pore spaces of the soils and rock formations of the Bay Area. However, the amount recoverable is governed by economics, and the geo-hyrologic character of the area. Figure 5-11 illustrates the groundwater situation, as it might typically relate to topography in the Piedmont region of the Study Area. Except for "perched" water tables, in which the water is retained, subsurface flow will occur from areas of higher head to eventually discharge into streams, lakes, bay, or oceans. Water withdrawals from wells will cause a lowering of the water table in a three dimensional cone of depression around the well.

Groundwater supplies generally serve their most valuable function in areas with small scale, evenly dispersed demands, such as those for the rural domestic population; agriculture; and small towns, cities, and other facilities. Establishments requiring concentrated large-scale water supply developments have invariably located in Western Shore areas where there is a greater potential for development of surface waters.

Several items must be considered before proceeding with development of a groundwater supply. Short of a complete scientific investigation including test wells, analysis should be made of the bore-hole logs of wells previously drilled in the vicinity, and of other groundwater studies and reports to gain perspective of the geohydrologic profile of the substrata. Estimates are needed of the thickness of the various available aquifers, their depth, porosity, permeability, and quality characteristics, so that alternatives can be evaluated along with costs comparison. Effects of the proposed withdrawals with respect to water table stability and salt water intrusion, should also be considered as should the effects of other pumping patterns in the vicinity. Unfortunately,



Source: Babbitt, Doland, and Cleasby; Water Supply Engineering, McGraw Hill Co., 1962.

FIGURE 5-11: RELATIONSHIP BETWEEN GROUND AND SURFACE WATERS quantitative assessment of these factors is often difficult due to the lack of necessary data, especially for the deeper aquifers. However, complete neglect of these considerations can hasten the inadequacy or pollution of the source, or cause the supply to become uneconomical as the water has to be lifted from greater and greater depths[31].

A detailed assessment of the groundwater system in the Chesapeake Bay Area, including yields, aquifers characterizations, and quality considerations, is presented in Appendix B, Volume 1, of the *Existing Conditions Report of the Chesapeake Bay Study*. Some treatment of considerations in groundwater development will be made here, however, including a short discussion of typical costs.

Types of Wells

Wells can generally be classified by type of construction—whether dug or drilled. Dug wells most commonly occur in rural areas where they are used by the rural domestic population or to meet agricultural needs. They are often excavated by hand with a well lining, casing, or curbing of porous masonry at the aquifer level. Above the aquifer, a watertight masonry liner should be used along with a watertight cover to prevent surface water or other undesirable air- or water-borne debris from entering. Wells excavated in rock are often left unlined.

Drilled wells are generally used to retrieve groundwater supplies from the deeper aquifers. The wells are sunk either by percussion or rotary drilling techniques. They should be cemented above the producing aquifer between the outside of the hole and the inner casing to eliminate the downward flow of surface water contaminants, and to prevent erosion of soil outside the casing[32]. Deep well pumps are generally needed where the suction lift required exceeds 25 feet. Various types of screens and casings are used depending on the geological profile of the aquifer being tapped.

Coastal Plain Groundwater

The Coastal Plain, lying east of the Fall Line (Figure 5-2) is composed of alternating layers of sand, gravel, clay, mud, and silt, dipping southeasterly at an average of about 80 feet per mile in Maryland and 25 feet per mile in southern Virginia. The permeable sand and gravel layers are some of the most productive aquifers in the United States. Yields as high as 4,000 gpm have been achieved from an ancient gravel-filled channel near Salisbury, Maryland[33].

More normally, yields range between 300 and 1,000 gpm, but decrease to near zero at the featheredge of sediments near the Fall Line. Generally, yields of 100 gpm can be developed from the water table aquifier (Quaternary deposits) of Eastern Shore. On the Western Shore portion of the Coastal Plain, a maximum yield of 2,000 gpm has been achieved at Bowie, Maryland[34].

Groundwater in the Piedmont

Typically, only small amounts of water are recoverable from the rock formations of the Piedmont Province portion of the Study Area. Thin layers of weathered material provide for storage and transportation of groundwater and serve as recharge channels to deeper fracture and fault systems. Overlying clays in most areas reduce recharge, however, and yields often respond markedly with varying precipitation. Well yields vary generally between 10 and 50 gpm, but dry well holes are not unknown[35].

Dependable Yield

Although tremendous volumes of water exist in the rocks and sediments of the Chesapeake Bay Area, only a relatively small portion is perennially available for use. The amount recoverable is dependent on several factors including the porosity, permeability, and transmissivity of the aquifer, and, ultimately, on the rate of inflow to the aquifers from stream infiltration, rainfall percolation, and adjacent water-bearing formations. In turn, there are discharges to streams, the Bay, and/or ocean, and losses from the groundwater reservoirs to evapotranspiration. If allowance is made for discharges to the Bay and the Atlantic Ocean and losses to evapotranspiration, estimates can be made of the "base flow" of streams, or the contribution of groundwater to streamflow. This method was used by the United States Geological Survey (USGS) to derive the developable resource of the Eastern Shore of the Study Area (Delmarva Peninsula)[36]. Using these results and the data from other reports and studies, the ultimate developable groundwater resource of the Chesapeake Bay Area was determined, as detailed in Attachment 5-C. These figures should be considered only as gross estimates, however, due to the limited data available and the broad generalizations used.

Sufficient groundwater for local needs can be attained but excessive pumpage can reduce the water table to dangerous levels. Lowering of the pressure in the freshwater zone allows the gradual penetration of saltwater into the aquifer from ocean, bay, tidal river, or canal. Withdrawals of about 3.5 mgd from the Piney Point artesian aquifer at Cambridge, Maryland, have caused water levels to decline by as much as 25 feet at a point 12 miles from the well site[37].

Likewise, heavy use of the Potomac aquifer at Franklin, Virginia, has lowered the water table to 150 feet below sea level since the early 1900's[38]. In contrast, however, withdrawals of 10 mgd at Salisbury, Maryland, have not significantly affected the water table due to the particular conditions there. In general, however, it can be expected that concentrated groundwater withdrawals in excess of 3500 gpm will cause some eventual problems due to excessive drawdown[39].

Groundwater Retrieval Costs

Several considerations must be made before costs of groundwater development can be determined[40]:

a. The probable yield of wells in the various aquifers.

b. Drilling costs and equipment.

c. Spatial distribution of wells.

d. Costs of interconnecting pipelines in multiple well development.

e. Amortization of capital costs and addition of annual maintenance and pumping costs ($/1000 gallons).

As part of the North Atlantic Regional Water Resource Study costs were estimated for development of groundwater in various geologic settings. Although variations will occur depending on local conditions and may other factors, it is noted that costs per 1,000 gallons will vary by only 2 mills for a $2,000 variance in the capital costs of the well[41]. Table 5-43 details estimated costs of groundwater development for a range of well yields in both the Coastal Plain and Piedmont consolidated rocks. Costs shown include capital costs, easements, operation, and maintenance.

TABLE 5-43
REPRESENTATIVE GROUNDWATER RETRIEVAL COSTS, 1970
($/1,000 gallons)

	Yield per Well (Gallons per Minute)			
Coastal Plain	150	350	700	1400
1 well	$0.035	$0.025	$0.021	$0.020
10 wells	$0.045	$0.036	$0.029	$0.024
20 wells	$0.049	$0.041	$0.032	$0.027

It should be noted that cost per 1,000 gallons *at the well head* from a single well, and that for multiple wells, is the same—the higher costs shown in the above table are for the interconnecting pipe. For additional information on well development costs, see the NAR Study, Appendix D, "Geology and Groundwater."

DESALTING AS AN ALTERNATIVE SOURCE

Conversion of brackish water to fresh water is a technique which can be used in areas which have depleted their conventional sources of supply. Given a supply of sea water or other brackish source, freshwater can be derived by various methods of heating with condensation of the resulting steam. Other methods involving membrane processes and freezing processes have also been used.

The choice of a process for application to a particular source of supply is generally based on the least cost to achieve the desired supply. Some of the factors to be considered include:

a. Salt concentration and composition of available feedwater.

b. Quality needed in product water.

c Waste brine disposal difficulties.

d. Type and cost of energy sources available.

e. Size of plant required.

f. Commercial status of the process.

Distillation

Various distillation processes have been used extensively around the world for reclaiming seawater or the more concentrated brines. These are the vertical tube evaporator (VTE), the multistage flash process (MSF), and the vapor compression processs (VC).

The MSF distillation process involves heating the seawater and passing it through progressively lower pressures, causing at each stage some of the water to boil, or "flash," into steam, which then condenses as freshwater.

The VTE process drops the saltwater through long metal tubes being heated by steam in large vertical chambers. Some of the saltwater blows off as steam while some of the steam surrounding the cooler tubes condenses as freshwater. The process is repeated through several stages at progressively lower pressures, to obtain higher efficiency in the use of heat energy.

The VC process involves, in its simplest form, the boiling of brine inside vertical tubes. The steam produced is pressurized and heated with a mechnical compressor and then condensed on the outside of the same tubes. A combined MSF-VC-VTE process has also been proposed to improve efficiency. The VC process has been widely developed for use on vessels on the high seas and at other places with requirements of between 0.02 and 1.0 mgd.

Distillation plants require a source of steam to heat the water and are, for this reason, often most economically operated in conjunction with power generation facilities. Otherwise, steam can be supplied by boilers or vapor compressors. To date, the MSF process has been recognized as the most economical distillation process but development of more efficient heat exchange piping may make VTE more attractive in the future. These processes typically have a waste brine of about 7 to 10 percent salt[42].

Membrane Processes

Membrane processes may have wide application in treating brackish waters of less salinity than seawater — generally 10 ppt is taken as an upper limit. One type of membrane process is electrodialysis. It consists of stacks of membranes that are alternatively permeable to positive and negatively charged ions, but impermeable to ions of the opposite charge. Placed between an anode and cathode, alternate passages between the membranes produce desalinized water. Plants as large as 1.2 mgd have been in operation[43].

Reverse osmosis is another type of membrane process. Membranes are used that are selective of the components in solution that can pass through. The saltwater is first filtered and then raised to a pressure of between 600 and 1,000 psi. The product portion of the water permeates the membranes. Only plants as large as 0.15 mgd have been developed.

Freezing Process

This process involves freezing the saline solution. Freshwater ice crystals are formed, the salts concentrated in the remaining brine solution. Freshwater is then obtained by washing the ice and melting. One of the more successful freeze processes developed to date involves freezing by vacuum evaporation. The resulting water vapor is then compressed and condensed on the ice crystals in a separate compartment. For outputs of 0.5 mgd, 30 KWH electrical energy are needed per 1,000 gallons product, making this one of the more energy consumptive desalting techniques.

Costs

The costs of desalted water will vary considerably depending on plant location, size, type of desalting process, financing, costs of energy, and other variables. Current commercial plants of between 1 and 3 mgd capacity, produce water in the general range of one dollar per 1,000 gallons. This is very expensive considering that surface or groundwater developments rarely exceed $0.10 per thousand-gallons, even for interbasin diversions over long distances. Studies have indicated, however, that large dual purpose desalting plants may produce at a rate of 20 to 40 cents per 1,000 gallons by the 1980's[44]. Collection and water conveyance costs could add another 5 to 10 cents per 1,000 gallons.

INSTITUTIONAL MEASURES

Developmental means will probably continue to be used in most instances to meet expected water demands; however, consideration should also be given in the planning of water supply developments to institutional arrangements (changes in law, custom, or practice) and policy changes which can sometimes increase efficiency of use of existing supplies or otherwise effect a dampening of demand. Examples include pricing and metering to encourage thrift, implementation of plumbing codes to encourage water-saving appliances, and restrictions on use during droughts. Advancing technology and a change in public acceptance could also lead to the reuse of wastewater for municipal purposes in areas depleted of the more traditional sources.

Homeowners, commercial establishments, and industries alike will curtail excess usage, to varying degrees, as water supplies increase in cost. One study has shown that a doubling of price, for a representative 21 metered and public-sewered cities, would result in a 10 percent decrease in household use and a decline of 53 percent in summer sprinkling use, as shown in Figure 5-12[45]. In addition, a survey of many studies has shown that reduction in water use due to installation of meters has varied from 25 to 75 percent[46]. Thus, water use can be expected to diminish if water costs are in some relation to volume consumed, especially for the less essential and more consumptive uses such as lawn sprinkling. It has been found that sprinkling of lawns is one of the uses most responsive to metering and that in areas with flat-rate pricing (constant price rate) the tendency is for over-irrigation of lawns[47].

Water use restrictions are another method of alleviating water supply shortages in a community. As opposed to increasing the volume of supply, this

Source: Hanke, S.H. (45)

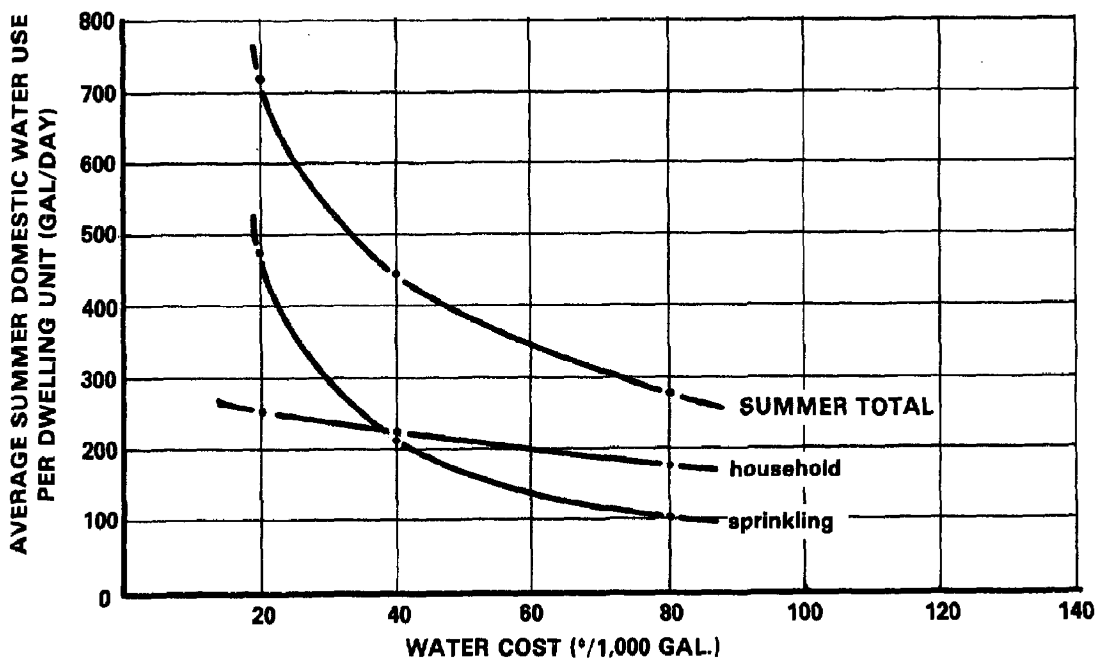


FIGURE 5-12: EFFECT OF PRICE ON DOMESTIC WATER USE

method involves dealing directly with the control of demand so that it can be reduced to more closely approximate the available supply during periods of drought. Use restrictions are most effective when they are applied to uses such as lawn watering, car washing, street cleaning, and non-critical commercial and industrial uses in such a way that major inconvenience and/or economic damage is not suffered by the community. Also, water demands will tend to respond to unit price increases that can be implemented temporarily on those uses that exceed a specified limiting amount.

Another demand-controlling measure is to decline requests for new or additional service from both inside and outside the present system. Similar to sewer moratoria, this type of measure can be used to guide and/or control a community's growth. It should be noted, however, that this type of measure may simply result in the demand and perhaps a problem being shifted to another location within the same region.

Demands for water in industrial processes are another area in which there is potential for water saving. A major portion of this report has addressed the savings that may occur in industrial water use due to the adoption of new process technology and recycling practices. Further advances in technology, above the levels shown, should be encouraged in order to maximize the supply of water available for the many needs of society.

CHAPTER VI

REQUIRED FUTURE STUDIES

The preceding chapters of this appendix include an identification of future water supply requirements and the expected magnitude and time frame of future deficits. In a similar manner, the demands and deficits for other resource categories, such as those for recreation, power, waterborne commerce, and fish and wildlife, are developed and presented in other appendices of this report. Additional studies are required to integrate the needs projected for all resource categories, identify emerging or expected problems and conflicts between Bay users, and develop a comprehensive plan for the overall management of the Bay's resources. This overall plan should be developed and formulated in coordination with Federal, State, and local agencies and the public, with a view toward using the resources of Chesapeake Bay to provide the greatest benefits to the greatest number of people while maintaining the beauty and dignity of the Bay.

With specific regard to water supply, studies and research are required to better define both the expected future water demands and the available supply. These studies are particularly critical in some of the highly urbanized areas such as Washington D.C. where increased growth and large water supply deficits are expected.

Studies of the applicability and cost of various alternative means of providing additional supply should also be undertaken, and be given especially high priority in critical areas such as Southeastern, Virginia, and Washington, D.C. In addition to the more conventional uses of surface and groundwater, consideration should be given to such measures as desalinization, water reuse, and the use of brackish waters. Studies to determine the impacts in the Bay Region of metering and pricing would also be extremely valuable in evaluating these measures as demand controlling alternatives. Similarly, future increases in the price of water would warrant investigation as to the possible effects on regional site locations and water use habits of industrial and commercial establishments.

Additional studies are also required to ascertain the most safe and cost effective means of treating waters for human consumption. Better methods must also be developed for monitoring the quality of treated waters and the impact of the wastes from water treatment facilities on the environment.

Additional investigation is needed to fully assess the groundwater resources of the Region. Except in some areas where deep test wells have been monitored, knowledge of the groundwater resources is limited. An extensive exploration program would enable better mapping of aquifer composition, depth, and thickness and estimates of ultimate developable yields.

As indicated previously, emerging or expected problems and conflicts between Bay users must be identified. One of the most significant Bay conflicts related to water supply is the impact on the fish and wildlife resources of reduced freshwater inflows into the Bay. These reductions in freshwater inflows are the results of increasing consumptive losses and interbasin diversions associated with increased demands for municipal, industrial, and agricultural water. Considerable study is required to better define the expected changes in salinity patterns that will result from varying decreases in freshwater inflows and the impact that these salinity changes will have on the biota of the Bay. The effects of reduced freshwater inflows on wastewater dispersion and the time distribution of nutrients must also be explored.

The Chesapeake Bay Hydraulic Model has the potential to provide some of the physical data that are necessary to make many of the above evaluations. Since varying freshwater inflows can be easily simultated in the model, salinity patterns and flushing characteristics can be developed for any freshwater inflow condition desired. In this manner, the physical impacts of alternative structural or managerial actions can be provided to the appropriate scientists for further evaluation of the environmental impacts.

Two of the initial tests planned for the hydraulic model are related to defining the impacts of changing freshwater inflows to the Bay. The objective of the Chesapeake Bay low freshwater inflow test is to determine the response of the Bay system to depressed freshwater inflows due to both droughts and increased consumptive losses. Emphasis will be placed on developing time histories of salinity concentrations for specific low flow conditions. The time required for the system to return to a state of dynamic normalcy following periods of depressed flow will also be determined.

The second test will be a combined Potomac River Estuary water supply and wastewater disposal test. The objectives of this test are to define the salinity regime and wastewater dispersion patterns in the Upper Potomac Estuary under several freshwater inflow conditions and to determine the impact on both salinities and wastewater dispersion of pumping water out of the estuary at Washington, D.C. A more detailed discussion of the above tests and the capabilities of the hydraulic model may be found in Appendix 16: *Hydraulic Model Testing*.

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GLOSSARY

acre-foot — the volume of water required to cover 1 acre to a depth of 1 foot, equivalent to 43,560 cubic feet.

aquifer — a saturated underground geologic formation of sand, gravel, or other porous material, capable of transmitting water to wells or springs.

consumption — the amount of water lost between point of intake and discharge, by incorporation into products, evaporation, etc.

discharge — the rate of flow of a stream, or of ground water to a well; also rate of wastewater flow from treatment plant or conduit.

ecology — the interrelationship between living things, each other, and their environment.

evapotranspirtation — combined loss of water to the atmosphere by evaporation from water surfaces and plant transpiration.

GPO — Gross product originating — the portion of the Gross National Product originating in each sector of the National economy.

groundwater — water occurring beneath the ground in the saturated pore spaces of the underlying geologic formations.

instream uses — uses for streamflows not requiring withdrawal, such as recreation, fish and wildlife, and navigation.

interbasin diversion — physical transfer of water from one river basin to another.

precipition — any form of rain or snow falling to the earth's surface.

reservoir	—	a pond, lake, aquifer, or basin, either natural or manmade, in which water is stored and/or regulated.
residual population	—	the sum of those persons not served by any central water supply facility; all those persons supplying their own water by well or other means.
riparian doctrine	—	unwritten law historically recognized in the Eastern States guaranteeing streamflows be undiminished in quantity or quality due to unreasonable upstream uses.
runoff	—	the part of precipitation on a drainage basin appearing as streamflow.
S.I.C.	—	Standard Industrial Classification, as defined for each type of economic activity by the Office of Management and Budget.
SMSA	—	Standard Metropolitan Statistical Area — generally, a designation of the U.S. Bureau of Census for cities of 50,000 population, or more, and the socially and economically contiguous counties.
WSA	—	Water Service Area — designation for cities or town in the Chesapeake Bay Study Area of 2,500 population, or more, being served by a central water supply agency or authority.
water table	—	the upper surface of saturation of an underground water body.
withdrawal	—	the removal of water from a natural watercourse or other source for use by industry, the cities, agriculture, or other purpose — also "intake."
yield, dependable or "safe"	—	refers to quantity of water available for use from natural streamflow, or reservoir development, with a shortage occurring only once in "n" years. Dependability is relative to storage provided and drought probability.

yield, ultimate developable	—	for groundwater, refers to sustained perennial amount of water that can be withdrawn—amount cannot exceed recharge of the aquifers.

ATTACHMENT 5-A

PROJECTED NON-INDUSTRIAL WATER DEMANDS
CHESAPEAKE BAY AREA, 1980-2020

WATER SERVICE AREA	1970 USE RATE GPCD	1980 POP. (X1000)	1980 X	1980 D	1990 POP. (X1000)	1990 X	1990 D	2000 POP. (X1000)	2000 X	2000 D	2010 POP. (X1000)	2010 X	2010 D	2020 POP. (X1000)	2020 X	2020 D
01 ELKTON, MD	118.	9.04	126.	1.1	9.51	134.	1.3	10.14	142.	1.4	10.78	149.	1.6	11.41	157.	1.8
02 CAMBRIDGE, MD	96.	14.77	104.	1.5	16.51	111.	1.8	18.25	119.	2.2	20.20	127.	2.6	22.05	135.	3.0
03 CENTREVILLE, MD	97.	3.63	105.	0.4	4.38	113.	0.5	5.15	120.	0.6	6.05	128.	0.8	6.96	136.	0.9
04 CHESTERTOWN, MD	110.	4.71	118.	0.6	5.40	126.	0.7	6.21	134.	0.8	6.90	142.	1.0	7.70	149.	1.2
05 CRISFIELD, MD	64,	4,46	73,	0,3	4,85	82,	0.4	4,98	91,	0.5	5,25	99,	0.5	5,38	107,	0.6
06 DELMAR, MD*	100.	3.28	108.	0.4	3.53	115.	0.4	3.78	123.	0.5	4.03	131.	0.5	4.03	139.	0.6
07 DENTON, MD	87.	2.94	95.	0.3	3.29	103.	0.3	3.46	111.	0.4	3.81	119.	0.5	3.98	127.	0.5
08 EASTON, MD	125.	11.14	133.	1.5	13.70	141.	1.9	16.14	149.	2.4	18.83	156.	2.9	21.64	163.	3.5
09 POKOMOKE CITY, MD	88,	4,50	97,	0,4	5,59	104,	0,6	6,30	112,	0,7	7,20	120,	0,9	8,00	128,	1,0
10 PRINCESS ANNE, MD*	88.	2.82	96.	0.3	3.33	104.	0.3	3.85	112.	0.4	4.10	120.	0.5	4.36	128.	0.6
11 SALISBURY, MD	78.	21.55	86.	1.9	23.55	95.	2.2	25.79	103.	2.7	27.91	111.	3.1	30.03	118.	3.6
12 SNOW HILL, MD	88.	3.68	97.	0.4	4.50	104.	0.5	5.05	112.	0.6	5.59	120.	0.7	6.14	128.	0.8
13 ABERDEEN, MD	98.	31.67	105.	3.3	49.60	113.	5.6	68.03	121.	8.2	89.31	129.	11.5	112.77	137.	15.4
14 ANNAPOLIS, MD*	108.	47.02	116.	5.4	48.91	124.	6.0	49.85	132.	6.6	49.72	139.	6.9	48.50	147.	7.1
15 BALTIMORE SERVICE AREA	119.	1719.36	127.	218.8	1942.67	135.	262.6	2166.82	143.	309.9	2409.95	151.	363.2	2659.05	158.	420.6
16 BEL AIR, MD*	98,	15,98	106,	1,7	20,99	113,	2,4	24,48	121,	3,0	27,96	129,	3,6	30,93	137,	4,2
17 CROFTON, MD*	127.	9.00	135.	1.2	11.00	143.	1.6	11.00	150.	1.7	11.00	158.	1.7	11.00	165.	1.8
18 EDGEWOOD, MD	109,	13,40	117,	1,6	21,40	124,	2,7	29,90	132,	4,0	40,00	140,	5,6	51,20	148,	7,6
19 HAVRE DE GRACE, MD	112.	10.42	120.	1.2	11.64	128.	1.5	11.85	136.	1.6	11.85	143.	1.7	11.64	151.	1.8
20 JOPPATOWNE, MD*	77.	10.00	86.	0.9	10.00	94.	0.9	10.00	102.	1.0	10.00	110.	1.1	10.00	118.	1.2
21 MARYLAND CITY, MD	122.	10.90	130.	1.4	14.30	137.	2.0	18.00	145.	2.6	21.60	153.	3.3	25.10	160.	4.0

ATTACHMENT 5-A (cont'd)
PROJECTED NON-INDUSTRIAL WATER DEMANDS
CHESAPEAKE BAY AREA, 1980-2020

	WATER SERVICE AREA	1970 USE RATE GPCD	1980 POP. [X1000]	1980 X	1980 D	1990 POP. [X1000]	1990 X	1990 D	2000 POP. [X1000]	2000 X	2000 D	2010 POP. [X1000]	2010 X	2010 D	2020 POP. [X1000]	2020 X	2020 D
22	ODENTON (KINGS HTS)*	67.	10.86	76.	0.8	12.74	85.	1.1	14.35	93.	1.3	15.82	101.	1.6	16.90	109.	1.8
23	SEVERNA PARK, MD*	115.	25.30	123.	3.1	33.50	131.	4.4	42.30	139.	5.9	51.30	146.	7.5	59.80	154.	9.2
24	SYKESVILLE-FREEDOM*	80.	10.25	89.	0.9	14.01	97.	1.4	15.72	105.	1.6	17.60	113.	2.0	19.31	120.	2.3
25	WESTMINISTER, MD*	100.	13.97	108.	1.5	17.69	115.	2.0	18.86	123.	2.3	19.90	131.	2.6	20.84	139.	2.9
26	SEAFORD, DE	110.	7.00	118.	0.8	8.50	126.	1.1	9.70	134.	1.3	10.90	142.	1.5	12.10	150.	1.8
27	WASHINGTON SUBRBN S.C.*	110.	1417.60	118.	167.0	1752.60	126.	220.4	2119.80	134.	283.3	2542.30	141.	359.7	3005.50	149.	448.4
28	WASHINGTON AQUEDUCT	140.	1087.76	148.	160.8	1174.23	155.	182.5	1258.96	163.	204.9	1372.78	170.	233.2	1516.73	177.	267.9
29	ALEXANDRIA, VA*	118.	126.80	126.	16.0	148.30	134.	19.8	156.00	142.	22.1	165.10	149.	24.7	174.10	157.	27.3
30	FAIRFAX CO. WTR. AUTH.*	99.	641.53	107.	68.4	900.09	114.	103.0	1199.95	122.	146.8	1564.22	130.	203.8	1992.59	138.	275.3
31	GOOSE CREEK-FRFX. CITY*	109.	136.10	117.	15.9	187.20	125.	23.3	237.70	133.	31.5	306.30	140.	43.0	392.40	148.	58.2
32	MANASSAS, VA*	109.	18.20	117.	2.1	24.22	125.	3.0	27.99	133.	3.7	31.88	140.	4.5	32.13	148.	4.8
33	MANASSAS PARK, VA*	50.	12.99	59.	0.8	19.74	68.	1.4	25.78	77.	2.0	32.84	86.	2.8	41.02	95.	3.9
34	LEONARDTOWN, MD	93.	2.48	101.	0.3	2.66	109.	0.3	2.66	116.	0.3	2.66	124.	0.3	2.66	132.	0.4
35	LEXINGTON PARK, MD	93.	14.99	101.	1.5	23.52	109.	2.6	34.02	116.	4.0	47.59	124.	5.9	64.00	132.	8.5
36	WALDORF, MD*	80.	16.27	89.	1.4	25.49	97.	2.5	36.75	105.	3.9	51.39	113.	5.8	69.97	120.	8.4
37	FREDRICKSBURG, VA	114.	22.95	121.	2.8	26.60	129.	3.4	29.19	137.	4.0	32.25	145.	4.7	35.78	153.	5.5
38	WEST POINT, VA*	100.	3.00	108.	0.3	3.10	115.	0.4	3.50	123.	0.4	3.80	131.	0.5	4.20	139.	0.6
39	ASHLAND, VA*	93.	5.37	101.	0.5	7.03	109.	0.8	8.19	117.	1.0	9.21	124.	1.1	10.10	132.	1.3
40	COLONIAL HTS-PETERSBRG	99.	80.59	107.	8.6	98.88	114.	11.3	121.19	122.	14.8	147.15	130.	19.2	176.17	138.	24.3
41	HOPEWELL, VA	106.	51.20	113.	5.8	63.80	121.	7.7	81.98	129.	10.6	102.56	137.	14.1	125.05	145.	18.1
42	MECHANICSVILLE, VA*	100.	10.90	108.	1.2	19.90	115.	2.3	31.00	123.	3.8	45.60	131.	6.0	63.70	139.	8.9

ATTACHMENT 5-A (cont'd)
PROJECTED NON-INDUSTRIAL WATER DEMANDS
CHESAPEAKE BAY AREA, 1980-2020

WATER SERVICE AREA	1970 USE RATE GPCD	1980			1990			2000			2010			2020		
		POP. (X1000)	X	D	POP. (X1000)	X	D	POP. (X1000)	X	D	POP. (X1000)	X	D	POP. (X1000)	X	D
43 RICHMOND AREA, VA*	105.	431.26	113.	48.6	484.71	121.	58.5	561.41	129.	72.2	639.15	136.	87.2	716.04	144.	103.3
44 NEWPORT NEWS-HAMPTON*	104.	304.92	112.	34.1	335.64	120.	40.1	375.68	127.	47.9	415.72	135.	56.3	453.41	143.	64.9
45 NORFOLK-VA BEACH*	103.	546.90	111.	60.6	590.71	119.	70.0	649.33	126.	82.1	706.03	134.	94.9	758.44	142.	107.8
46 PORTSMOUTH, VA	97.	147.50	105.	15.5	172.75	113.	19.5	194.58	121.	23.5	216.23	129.	27.8	236.37	136.	32.3
47 WILLIAMSBURG, VA	111.	29.49	119.	3.5	31.15	127.	4.0	35.28	135.	4.8	39.42	143.	5.6	43.00	151.	6.5
48 SMITHFIELD, VA	88.	3.20	96.	0.3	3.60	104.	0.4	4.10	112.	0.5	4.50	120.	0.5	4.90	128.	0.6
49 SUFFOLK, VA	97.	20.50	104.	2.1	22.30	112.	2.5	24.90	120.	3.0	27.10	128.	3.5	29.40	136.	4.0
50 FRANKLIN, VA*	123.	12.79	131.	1.7	16.81	139.	2.3	19.60	147.	2.9	22.39	154.	3.5	24.76	162.	4.0

POP.=POPULATION SERVED

X=DEMAND RATE (GPCD)

D=DEMAND (MGD)

*1970 use rate based on estimates of existing use.

ATTACHMENT 5-B
SURFACE WATER FLOWS - SUBREGION 1[3]

Stream	Effective Drainage Area[4] Sq. Mi.	Average Flow MGD	7 Day-10 Yr. Low Flow cfs/Sq. Mi.	7 Day-10 Yr. Low Flow MGD	7 Day-25 Yr. Low Flow cfs/Sq. Mi.	7 Day-25 Yr. Low Flow MGD	7 Day-50 Yr. Low Flow cfs/Sq. Mi.	7 Day-50 Yr. Low Flow MGD
Broad Creek	41	34	0.254	6.8	0.201	5.4	0.148	4.0
Deer Creek	171	140	0.254	28.0	0.201	22.1	0.148	16.3
Bush River	96	77	0.123	7.6	0.087	5.4	0.065	4.0
Little Gunpowder Falls	56	45	0.210	7.6	0.152	5.5	0.119	4.3
South Branch Patapsco River[1]	76	49	0.057	2.8	0.027	1.3	0.017	0.8
Little Patuxent River[2]	161	108	0.121	12.6	0.095	9.9	0.081	8.4
Big Pipe Creek	102	63	0.066	4.3	0.038	2.5	0.025	1.7
			Total	69.7		52.1		39.5

[1]Includes Piney Run

[2]Includes Middle Patuxent

[3]Not including flow of Susquehanna River

[4]Measured at mouth or at interface of brackish water.

ATTACHMENT 5-B (cont'd)
SURFACE WATER FLOWS - SUBREGION 2

Stream	Effective Drainage Area Sq. Mi.	Average Flow MGD	7 Day-10 Yr. Low Flow cfs/Sq. Mi.	7 Day-10 Yr. Low Flow MGD	7 Day-25 Yr. Low Flow cfs/Sq. Mi.	7 Day-25 Yr. Low Flow MGD	7 Day-50 Yr. Low Flow cfs/Sq. Mi.	7 Day-50 Yr. Low Flow MGD
Northeast River	44	37	0.086	2.4	0.061	1.7	0.049	1.4
Elk River	105	86	0.169	11.4	0.133	9.0	0.102	6.9
Chester River	181	112	0.154	18.0	0.112	13.1	0.094	11.0
Choptank River[1]	261	180	0.039	6.6	0.027	4.5	0.022	3.7
Nanticoke River[2]	549	425	0.185	65.5	0.145	51.4	0.132	46.8
Pocomoke River[3]	465	330	0.037	11.1	0.028	8.4	0.023	6.9
			Total	115.0				

[1]Includes Tuckahoe Creek

[2]Includes Marshyhope Creek

[3]Includes Dividing Creek

SURFACE WATER FLOWS - SUBREGION 3

No significant stream flow during low flow periods.

ATTACHMENT 5-B (cont'd)
SURFACE WATER FLOWS - SUBREGION 4

Stream	Effective Drainage Area Sq. Mi.	Average Flow MGD	7 Day-10 Yr. Low Flow cfs/Sq. Mi.	7 Day-10 Yr. Low Flow MGD	7 Day-25 Yr. Low Flow cfs/Sq. Mi.	7 Day-25 Yr. Low Flow MGD	7 Day-50 Yr. Low Flow cfs/Sq. Mi.	7 Day-50 Yr. Low Flow MGD
Nanticoke River	339	262	0.185	40.5	0.145	31.7	0.132	28.9
Marshyhope Creek	83	64	0.185	9.9	0.145	7.7	0.132	7.1
			Total	50.4				

Note: Above includes only drainage to Chesapeake Bay

ATTACHMENT 5-B (cont'd)
SURFACE WATER FLOWS - SUBREGION 5

Stream	Effective Drainage Area Sq. Mi.	Average Flow MGD	7 Day-10 Yr. Low Flow cfs/Sq. Mi.	7 Day-10 Yr. Low Flow MGD	7 Day-25 Yr. Low Flow cfs/Sq. Mi.	7 Day-25 Yr. Low Flow MGD	7 Day-50 Yr. Low Flow cfs/Sq. Mi.	7 Day-50 Yr. Low Flow MGD
Potomac River[1]	11,560	6,961	0.082	611.6	0.067	499.6	0.060	447.5
Seneca Creek	129	74	0.055	4.6	0.034	2.8	0.025	2.1
Anacostia River	169	100	0.052	5.7	0.034	3.7	0.025	2.7
Catoctin Creek, Virginia	90	51	0.055	3.2	0.034	1.9	0.025	1.5
			Total	625.1		508.0		453.8

[1]Flows diverted for water supply included inflows shown.

SURFACE WATER FLOWS - SUBREGION 6

No significant stream flow during low flow periods.

ATTACHMENT 5-B (cont'd)
SURFACE WATER FLOWS - SUBREGION 7

Stream	Effective Drainage Area Sq. Mi.	Average Flow MGD	7 Day-10 Yr. Low Flow cfs/Sq. Mi.	7 Day-10 Yr. Low Flow MGD	7 Day-25 Yr. Low Flow cfs/Sq. Mi.	7 Day-25 Yr. Low Flow MGD	7 Day-50 Yr. Low Flow cfs/Sq. Mi.	7 Day-50 Yr. Low Flow MGD
Rappahannock River	1,599	1,040	0.030	30.9	0.014	14.4	0.009	9.3
Ni, Po, & Matta Rivers	196	120	0.029	3.7	0.018	2.3	0.011	1.4
North Anna River	405	222	0.037	9.7	0.024	6.3	0.017	4.5
			Total	44.3		23.0		15.2

SURFACE WATER FLOWS - SUBREGION 8

Stream	Effective Drainage Area Sq. Mi.	Average Flow MGD	7 Day-10 Yr. Low Flow cfs/Sq. Mi.	7 Day-10 Yr. Low Flow MGD	7 Day-25 Yr. Low Flow cfs/Sq. Mi.	7 Day-25 Yr. Low Flow MGD	7 Day-50 Yr. Low Flow cfs/Sq. Mi.	7 Day-50 Yr. Low Flow MGD
James River	6,797	4,857	0.096	421.0	0.073	320.1	0.059	258.7
Appomattox River	1,335	743	0.037	31.9	0.021	18.1	0.013	11.2
Pamunkey River	1,280	716	0.037	30.6	0.024	19.8	0.017	14.0
Chickahominy River	197	129	0.028	3.6	0.016	2.0	0.010	1.3
			Total	487.1		360.0		285.2

ATTACHMENT 5-B (cont'd)
SURFACE WATER FLOWS - SUBREGION 9

Stream	Effective Drainage Area Sq. Mi.	Average Flow MGD	7 Day-10 Yr. Low Flow cfs/Sq. Mi.	7 Day-10 Yr. Low Flow MGD	7 Day-25 Yr. Low Flow cfs/Sq. Mi.	7 Day-25 Yr. Low Flow MGD	7 Day-50 Yr. Low Flow cfs/Sq. Mi.	7 Day-50 Yr. Low Flow MGD
Mattaponi River	913	559	0.029	17.1	0.018	10.6	0.011	6.5
Pamunkey River	1,448	811	0.037	34.6	0.024	22.4	0.017	15.9
Chickahominy River[1]	444	291	0.028	8.0	0.016	4.6	0.010	2.9
			Total	59.7		37.6		25.3

[1]Flow appropriated for use by Newport News (Subregion 10)

SURFACE WATER FLOWS - SUBREGIONS 10, 11, and 12

No significant stream flow within Chesapeake basin during low flow periods.

ATTACHMENT 5-C

DEVELOPABLE GROUNDWATER RESOURCE

The following discussion presents an overview of data sources and methodologies used to establish potential sustained groundwater yields in the 12 subregions of the Chesapeake Bay Study Area.

SUBREGION 1: The sustained yields in this area were estimated at 200 mgd, based on results computed in the Maryland Water Supply Study, (Part II by the U.S. Geological Survey) 1965. These in turn were based on studies published in various Bulletins of the Maryland Geological Survey.

SUBREGIONS 2, 3, & 4: Results presented in Professional Paper 822 of the USGS: "Water Resources of the Delmarva Peninsula," 1973, were used to establish sustained groundwater yields for these three subregions. Yields from each of seven major aquifers were apportioned based on their areal extent beneath each of the subregions. Results of this analysis appear in the following table.

Aquifer	Total mgd	SUBREGION 2	SUBREGION 3	SUBREGION 4
Non-marine Cretaceous	80	60	0	0
Magothy	10	7	0	0
Aquia-Rancocas	190	132	0	0
Piney Point-Cheswold	80	45	0	10
Federalsburg	50	17	0	15
Fredericka	50	9	0	8
Manokin-Pokomoke-Quaternary	1,040	480	248	209
		749	248	241

Note: Balance of water available accrues to parts of Delaware out of Study Area.

SUBREGION 5: Sustained yields in this area were based on USGS Circular No. 697, 1974 (48), and estimates presented in the Northern Virginia Water Quality Management Plan, 1973. These amount to 170 mgd and 11 mgd for Maryland and Virginia, respectively.

SUBREGION 6: This area is estimated to have a sustained groundwater yield of 234 mgd. The estimated 324 mgd by the Maryland Water Supply Study was reduced by 40 mgd plus 50 mgd to compensate for that allocated to the D.C. area (Subregion 5) from the Magothy and Patapsco aquifer, respectively. This 90 mgd is included in the 170 mgd figure mentioned above.

SUBREGIONS 7 - 12: Using figures derived for purposes of the NAR Study (49), sustained yields for Subregions 7 through 12 were found by apportioning according to area, as shown in the following table. These are rough figures that assume the supplies are everywhere equally available.

	--- NAR AREA ---					
	19: Potomac	20: Rap- York		21: James		
Chesapeake Bay Region	Coastal Plain	Coastal Plain	Piedmont	Coastal Plain	Piedmont	TOTAL
7	28	7	37	-	-	72
8	-	7	21	19	28	75
9	28	72	-	10	-	110
10	-	6	-	2	-	8
11	-	-	-	12	-	12
12	-	15	-	27	-	42(82[1])

[1]includes an additional 40 mgd presently used at Franklin, Virginia. The later figure is used for the overall total in Subregion 12.

ATTACHMENT 5-D
EXISTING STORAGE FACILITIES

Name	Location	Safe Yield (mgd)	Owner
SUBREGION 1			
Loch Raven - Prettyboy System	Baltimore County	148.0	Baltimore
Liberty Lake	Patapsco River	95.0	Baltimore
Atkisson Reservoir	Harford County	11.0	Edgewood Arsenal
		254.0	
SUBREGION 2			
none			
SUBREGIONS 3 and 4 none			
SUBREGION 5			
Triadelphia - Rocky Gorge System	Patuxent River	43.0	Washington Suburban Sanitary Commission
Occoquan Creek Reservoir	Fairfax County	65.0	Fairfax County Water Authority
Goose Creek - Beaverdam Creek System	Loudoun County	14.4	Fairfax City
Broad Run Impoundment	Prince William County	8.0	
		130.4	
SUBREGION 6 none			

ATTACHMENT 5-D (Cont'd)
EXISTING STORAGE FACILITIES

Name	Location	Safe Yield (mgd)	Owner
SUBREGION 7			
Beaverdam Run Reservoir	Aquia Creek	2.5	U. S. Marine Corps
SUBREGION 8			
Lake Chesdin	Appomattox River	100.0	Appomattox River Water Authority
Swift Creek Reservoir	Chesterfield County	12.0	Chesterfield County
Falling Creek	Chesterfield County	3.6	Chesterfield County
		115.6	
SUBREGION 9 none			
SUBREGION 10			
Lee Hall Reservoir	Newport News	40.0	Newport News
Harwoods Mill Reservoir	York County		
Skiffes Creek Reservoir	James City County		
Diascund Reservoir	James City County		
Big Bethel Reservoir	Hampton	4.0	Langley AFB
Jones Pond	York County	0.5	Cheatham Annex.
		64.5	

ATTACHMENT 5-D (Cont'd)
EXISTING STORAGE FACILITIES

Name	Location	Safe Yield (mgd)	Owner
SUBREGION 11			
North Landing Reservoir	Virginia Beach		
Lake Burnt Mills	City of Suffolk	73.0	Norfolk
Lake Prince	City of Suffolk		
Western Branch Reservoir	City of Suffolk		
Speight's Run Reservoir	City of Suffolk		
Lake Kilby	City of Suffolk		
Lake Cohoon	City of Suffolk	21.0	Portsmouth
Lake Meade	City of Suffolk		
		94.0	
SUBREGION 12			
Waller Pond	York County	2.0	Williamsburg

ATTACHMENT 5-E
SIGNIFICANT INSTITUTIONAL WATER USERS,
BY SUBREGION

	Use (mgd)	Source
SUBREGION 1		
Aberdeen Proving Ground	2.5	Deer Creek & Wells
Edgewood Arsenal	2.0	Winter's Run & Wells
U. S. Naval Academy (includes Naval Ship R & D Center)	2.2	Wells
Crownsville State Hospital (Anne Arundel Co.)	1.1	Wells
Curtis Creek Coast Guard	0.6	Surface
Springfield State Hospital (Carroll Co.)	1.3	Piney Run, South Branch Patapsco River
Fort Meade (A. Arundel Co.)	3.5	Little Patuxent River & Wells
Maryland House of Correction (A. Arundel Co.)	0.8	Dorsey Run & Patuxent River
	14.0	
SUBREGION 2		
Bainbridge Naval Training Center (Cecil Co.)	1.5	Susquehanna River
Perry Point Veterans Hospital (Cecil Co.)	0.5	Susquehanna River
	2.0	

ATTACHMENT 5-E (Cont'd)
SIGNIFICANT INSTITUTIONAL WATER USERS,
BY SUBREGION

	Use (mgd)	Source
SUBREGION 3		
no users of greater than 0.1 mgd		
SUBREGION 4		
no users of greater than 0.1 mgd		
SUBREGION 5		
Quantico Marine Base (Prince William Co.)	2.7	Chopawamsic & Aquia Creek & Wells
Agricultural Research Center	0.7	
Lorton Reformatory (Fairfax Co.)	1.6	Occoquan Creek
	5.0	
SUBREGION 6		
Patuxtent Naval Air Station (St. Marys Co.)	1.3	Wells
U. S. Naval Ord nance Station (Charles Co.)	1.7	Wells
	3.0	
SUBREGION 7		
U. S. Naval Ordnance Laboratory (King George Co.)	0.6	Wells
	0.6	

ATTACHMENT 5-E (Cont'd)
SIGNIFICANT INSTITUTIONAL WATER USERS,
BY SUBREGION

	Use (mgd)	Source
SUBREGION 8		
Central State Hospital (Dinwiddie Co.)	0.7	Surface
Richard Bland College (Prince George Co.)	0.1	Wells
	0.8	
SUBREGION 9		
Camp A. P. Hill (Caroline Co.)	0.1	Wells
	0.1	
SUBREGION 10		
Langley Air Force Base, NASA	4.0	Big Bethel Reservoir
Cheatham Annex (York Co.)	0.3	Jones Pond & Wells
	4.3	
SUBREGION 11		
Norfolk Naval Shipyard	57.0	Surface (brackish)
	57.0	
SUBREGION 12		
Frederick College (Suffolk Co.)	0.1	Wells
	0.1	

ATTACHMENT 5-F

AGRICULTURAL WATER USE SUMMARY*, mgd

Subregion	Type Use	1970	1980	1990	2000	2020
1	Irrigation	2.9	38.2	40.5	42.9	47.9
	Livestock	2.5	2.9	3.1	3.2	3.5
	Domestic	15.6	17.2	16.5	15.7	18.4
	Sub-Total	21.0	58.3	60.1	61.8	69.8
2	Irrigation	32.5	94.0	163.1	232.2	722.2
	Livestock	4.2	2.7	2.6	2.6	2.2
	Domestic	8.8	11.9	13.9	15.8	20.5
	Sub-Total	45.6	108.6	179.6	250.6	744.9
3	Irrigation	15.9	66.6	58.1	49.6	39.1
	Livestock	0.2	0.1	0.1	0.1	0.1
	Domestic	1.5	3.0	3.2	3.6	4.1
	Sub-Total	17.6	69.7	61.4	53.3	43.3
4	Irrigation	12.2	96.9	103.0	111.3	136.8
	Livestock	2.0	1.5	1.4	1.3	1.3
	Domestic	3.6	6.0	6.9	7.8	8.7
	Sub-Total	17.8	104.4	111.2	120.4	146.8
5	Irrigation	3.1	21.6	49.9	72.2	103.1
	Livestock	1.7	1.5	1.3	1.1	0.9
	Domestic	10.6	10.1	11.3	12.5	13.8
	Sub-Total	15.4	33.2	62.5	85.8	117.8
6	Irrigation	3.7	14.4	47.5	80.6	112.7
	Livestock	0.3	0.2	0.2	0.2	0.2
	Domestic	4.3	5.8	5.5	5.1	3.9
	Sub-Total	8.2	20.4	53.2	85.9	116.9
7	Irrigation	tr.	0.8	1.2	1.6	2.1
	Livestock	0.3	0.3	0.4	0.4	0.4
	Domestic	2.0	3.4	3.7	4.0	2.4
	Sub-Total	2.4	4.5	5.2	5.9	4.9

*Derived from Appendix 6: Agricultural Water Supply.

ATTACHMENT 5-F (Cont'd)

Subregion	Type Use	1970	1980	1990	2000	2020
8	Irrigation	1.8	21.6	42.1	62.5	70.7
	Livestock	0.7	0.7	0.6	0.5	0.4
	Domestic	4.9	7.9	8.5	9.1	9.9
	Sub-Total	7.3	30.2	51.1	72.1	81.0
9	Irrigation	0.5	13.2	27.4	41.6	44.1
	Livestock	0.6	0.6	0.6	0.6	0.6
	Domestic	2.9	4.6	5.2	5.7	6.4
	Sub-Total	4.0	18.5	33.2	47.9	51.1
10	Irrigation	0.2	0.3	0.4	0.4	0.9
	Livestock	tr.	0.1	0.1	0.1	0.2
	Domestic	1.2	1.1	0.8	0.5	0.6
	Sub-Total	1.4	1.5	1.3	1.1	1.6
11	Irrigation	4.4	9.3	8.8	8.4	9.1
	Livestock	1.2	0.3	0.2	0.2	0.2
	Domestic	0.6	3.3	3.1	2.9	2.5
	Sub-Total	6.2	12.8	12.2	11.6	11.9
12	Irrigation	2.5	10.5	50.6	90.6	68.7
	Livestock	0.6	0.9	1.0	1.0	1.3
	Domestic	3.9	7.7	8.2	8.8	8.7
	Sub-Total	7.0	19.2	59.8	100.5	78.7

tr. = trace

Note: Irrigation use is that during the maximum application month of the dryest year in 10 for vegetables and specialty crops, and the dryest year in 5 for field crops and orchards.

ATTACHMENT 5-G
COMPARISON OF RECENT POPULATION DATA
WITH SERIES C and E POPULATION
PROJECTIONS

SUBREGION[3]	1970	1980 PROJECTION SERIES		1975 (INTERPOLATED)		1975	ESTIMATE[4]	
	CENSUS	C	E	C	E	ESTIMATE	CLOSEST SERIES	DIFFERENCE
1. Balt. SMSA	2,071	2,398	2,170	2,235	2,121	2,137	E	+ 16
2. Non-SMSA MD[1]	205	245	225	225	215	218	E	+ 3
3. Non-SMSA VA	43.4	45.1	41.8	44.3	42.6	46.6	C	+ 2
4. Non-SMSA DE[2]	162	190	174	176	168	180	C	+ 4
5. D.C. SMSA	2,861	3,479	3,474	3,170	3,168	2,944	E	-224
6. Non-SMSA MD	716	138	143	127	130	135	E	+ 5
7. Non-SMSA VA	63.5	77.9	80.6	70.7	72.1	80.0	E	+ 8
8. Richmond-Pts. Col. Hts.	647	776	766	712	707	670	E	- 37
9. Non-SMSA VA	81.8	95.7	90.3	88.8	86.1	90.2	C	+ 1
10. Newport N.-Hamp.	292	331	302	312	297	305	C	- 7
11. Norfolk-Ports.	681	719	674	700	677	715	C	+ 15
12. Non-SMSA VA	149	166	149	158	149	160	C	+ 2
TOTAL BAY AREA	7,373	8,661	8,290	8,019	7,833	7,682	E	-151

[1] Not including Cecil Co., Maryland

[2] Including Kent Co., Delaware

[3] Except as noted, these correspond to the SMSA and NON-SMSA County groupings as defined in the 1970 Census documents.

[4] Current Population Reports, Series P-25 and P-26, U.S. Bureau of the Census, 1976.

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CHAPTER I

THE STUDY AND THE REPORT

AUTHORITY

The authority for the Chesapeake Bay Study and the construction of the hydraulic model is contained in Section 312 of the River and Harbor Act of 1965, adopted 27 October 1965, which reads as follows:

a. The Secretary of the Army, acting through the Chief of Engineers, is authorized and directed to make a complete investigation and study of water utilization and control of the Chesapeake Bay Basin, including the waters of the Baltimore Harbor and including, but not limited to, the following: navigation, fisheries, flood control, control of noxious weeds, water pollution, water quality control, beach erosion, and recreation. In order to carry out the purposes of this section, the Secretary, acting through the Chief of Engineers, shall construct, operate, and maintain in the State of Maryland a hydraulic model of the Chesapeake Bay Basin and associated technical center. Such model and center may be utilized by any department, agency, or instrumentation of the Federal Government or of the States of Maryland, Virginia, and Pennsylvania, in connection with any research, investigation or study being carried on by them of any aspect of the Chesapeake Bay Basin. The study authorized by this section shall be given priority.

b. There is authorized to be appropriated not to exceed $6,000,000 to carry out this section.

An additional appropriation for the study was provided in Section 3 of the River Basin Monetary Authorization Act of 1970, adopted 19 June 1970, which reads as follows:

In addition to the previous authorization, the completion of the Chesapeake Bay Basin Comprehensive Study, Maryland, Virginia, and Pennsylvania, authorized by the River and Harbor Act of 1965 is hereby authorized at an estimated cost of $9,000,000.

As a result of the extensive damage caused by Tropical Storm Agnes in the Chesapeake Bay, Public Law 92-607, the Supplemental Appropriation Act of 1973, signed by the President on 31 October 1972, included $275,000 for additional studies of the impact of the storm on the Chesapeake Bay.

The District Engineer, Baltimore District, was assigned the Chesapeake Bay Study on 3 December 1965. Subsequently, the Chief, Planning Division, Baltimore District, entered into contract with the Economic Research Service to perform a rural water use study in support of the authorized Chesapeake Bay Study.

The Economic Research Service is authorized under Section 601 of the Economy Act (31 U.S.C. 886) to enter into interservice agreements or arrangements to work for reimbursement for other Federal agencies. The products of the agreement between the Corps of Engineers and the Economic Research Service were a section of the Existing Conditions Report and this Appendix.

PURPOSE

The Rural Water Use Appendix is a component of the Chesapeake Bay Study undertaken by the Baltimore Corps of Engineers. The objectives of the Study, as stated in the Chesapeake Bay Plan of Study, are to:

a. Assess the existing physical, chemical, biological, economic and environmental conditions of Chesapeake Bay and its water resources.

b. Project the future water resources needs of Chesapeake Bay to the year 2020.

c. Identify the additional studies to include hydraulic model tests that are needed to formulate a water resources management program for the Bay.

The Chesapeake Bay Existing Conditions Report, which was published in 1973, met the first objective of the study by presenting a detailed inventory and documentation of the existing condition of Chesapeake Bay and its water resources. The report, divided into a summary and four supporting appendices, presents an overview of the people residing in the Bay area and the economy; a survey of the land surrounding the Bay and its use; and a description of the Bay itself, its life forms and hydrodynamics.

The purpose of the Future Conditions Report, as distinct from the study itself, is to provide a format for presenting the findings of the Chesapeake Bay Study. The report, which satisfies the last two objectives of the study, describes the present use of the resource, presents the demands to be placed on the resource to the year 2020, assesses the ability of the resource to meet future demands and identifies the additional studies required to develop a management plan for the Chesapeake Bay.

The purpose of this Appendix on Agricultural Water Supply is to (a) appraise the historical and existing rural water use by subarea; (b) forecast future agricultural activity in the Chesapeake Bay Area; (c) estimate future water use resulting from such activity; (d) determine future water needs of rural nonfarm residents dependent upon wells; and, (e) identify possible problems and conflicts resulting from projected agricultural production and water use, and (f) assess possible means to satisfy future needs.

SCOPE

This Appendix identifies and quantifies current agricultural uses of water in the study area. Agricultural demands are then estimated for the target date period through the year 2020. Finally, the ability of the region to meet those demands is addressed, along with their impacts and the potential problems and conflicts engendered by the demands. An attempt is also made to test the sensitivity of the water use projections by varying several of the basic assumptions made in the analysis.

The conclusions reached are based upon analyses of historical and projected water use in rural areas of fifty-six counties in the Chesapeake Bay area. The counties are located in the States of Delaware, Maryland and Virginia, and are aggregated into fourteen subarea groupings of counties which follow the component state's planning districts. As shown in Table 6-1 and Figure 6-1, five of the subareas are in Maryland and eight are in Virginia. The State of Delaware constitutes a subarea by itself. Because this Appendix addresses rural water supply needs, water use in major cities such as Baltimore and Washington is not included.

Rural domestic water use for farms and for rural residents not served by municipal systems, livestock consumption, and irrigation water use are addressed in the analysis. In the estimation of irrigation and livestock water demand, projections are made separately for different types of agricultural production, including 16 selected crops and 8 types of livestock, poultry and dairy products.

Water use in the study area is projected to target years of 1980, 2000, and 2020, based upon historical data extending from 1949 to 1970. Among the historical data sources are the United States Censuses of Agriculture and Population, projections of aggregated agricultural production by OBERS (see Glossary for definition), and selected demographic projections furnished by the Baltimore District, Corps of Engineers.

SUPPORTING STUDIES

Nearly all of the comprehensive river basin studies have estimated future rural and urban water use as a part of their overall responsibilities. The North Atlantic Regional Water Resources Study, which included the entire Chesapeake Bay area, served as an important source to this Appendix. Future water use rates were derived and updated from work reported in the Water Supply Appendix to the Great Lakes River Basin Study (1973).

Estimates of future agricultural production of crops and livestock, upon which the water use calculations were based, were derived

TABLE 6-1

CHESAPEAKE BAY STUDY

COMPOSITION OF SUBAREAS

Subarea	County
DELAWARE	
	Kent
	New Castle
	Sussex
MARYLAND	
1.	Anne Arundel
	Baltimore
	Carroll
	Harford
	Howard
2.	Caroline
	Cecil
	Kent
	Queen Annes
	Talbot
3.	Dorchester
	Somerset
	Wicomico
	Worcester
4.	Montgomery
	Prince Georges
5.	Calvert
	Charles
	St. Marys

Subarea	County
VIRGINIA	
1.	Accomack
	Northampton
2.	Fairfax
	Loudoun
	Prince William
3.	King George
	Spotsylvania
	Stafford
4.	Chesterfield
	Dinwiddie
	Hanover
	Henrico
	Prince George
5.	Caroline
	Charles City
	Essex
	King & Queen
	King William
	Lancaster
	New Kent
	Northumberland
	Richmond
	Westmoreland
6.	York
7.	Chesapeake City
	Virginia City
8.	Gloucester
	Isle of Wight
	James City
	Mathews
	Middlesex
	Nansemond
	Southampton
	Surry

CHESAPEAKE BAY STUDY AREA

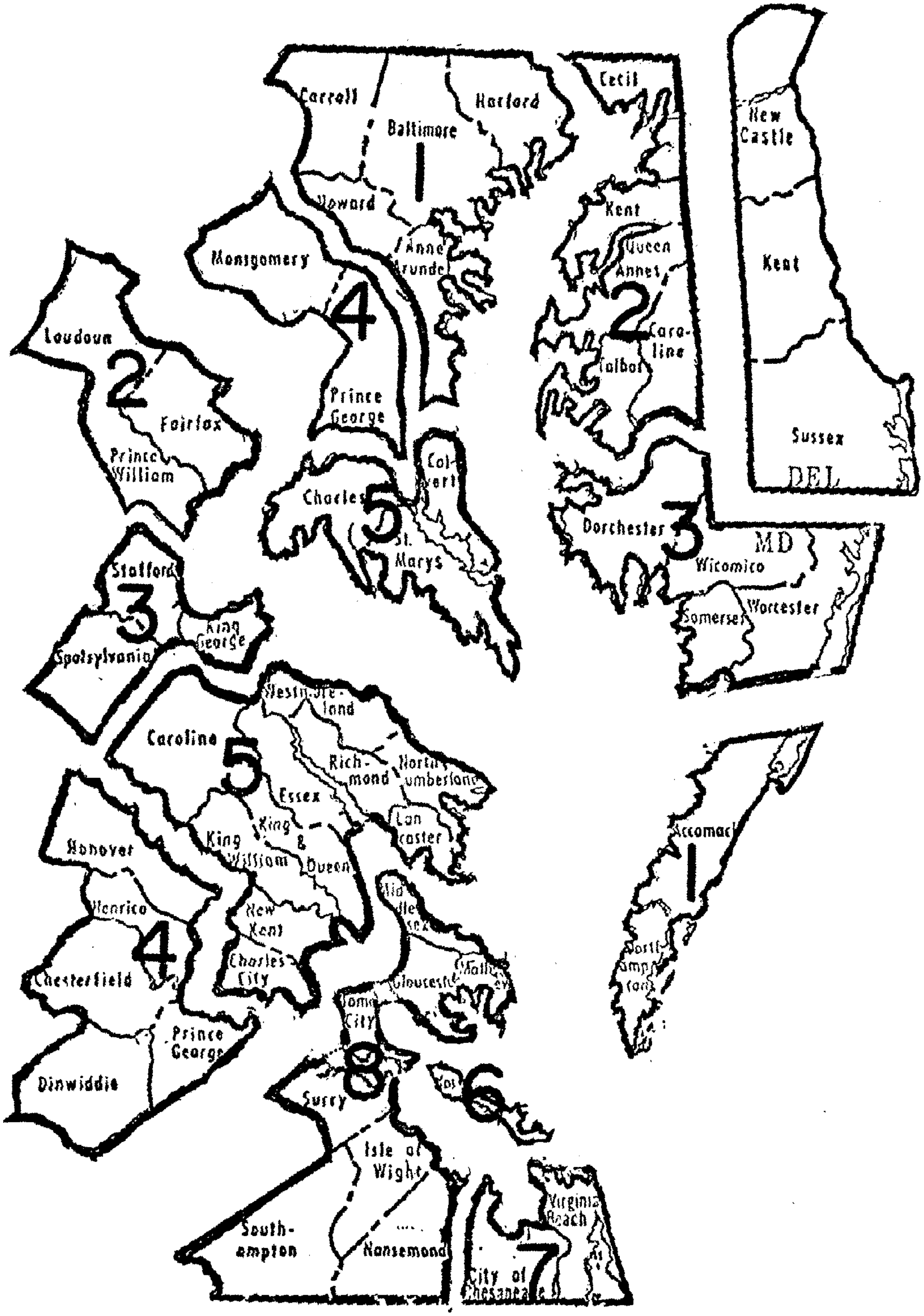


FIGURE 6-1

from State-level OBERS projections of the Water Resources Council.

Finally, an earlier special study of current and historical agricultural water use was completed by ERS in 1972, for the Chesapeake Bay Study. Summarized in the Existing Conditions Report, it formed the basis for the analysis in this Appendix. There has also been coordination with Appendix 5 of the Chesapeake Bay Study in which municipal and industrial water supply are discussed.

STUDY PARTICIPANTS AND COORDINATION

The District Engineer of the Baltimore District, Corps of Engineers has the overall management responsibility for the Chesapeake Bay Study. Because of the magnitude of the study and the complexity of the problems to be analyzed, a study organization composed of representatives from Federal agencies and the involved states was formed early in the study. Each agency represented has been charged with exercising leadership in those disciplines in which it has special competence and is expected to review and comment on work performed by others. To facilitate coordination among the study participants an Advisory Group, a Steering Committee and five working task groups have been formed.

This Appendix was prepared under the general responsibility of the Water Quality and Supply, Waste Treatment, Noxious Weeds Task Group. The Economic Research Service, Agriculture's representative to the Task Group, conducted the required technical studies and prepared the Appendix. Membership and organization of the Task Group is as follows:

WATER QUALITY AND SUPPLY, WASTE TREATMENT,
NOXIOUS WEEDS TASK GROUP

Environmental Protection Agency (Chairman)

Agriculture - Economic Research Service
Commerce - National Marine Fisheries Service
Corps of Engineers
Energy Research and Development Administration
Federal Power Commission
Interior - Bureau of Mines and U.S. Geological Survey

Navy
State of Delaware
State of Maryland
State of Pennsylvania
State of Virginia
District of Columbia
Susquehanna River Basin Commission
Transportation - Coast Guard

Substantial contribution was made to this Appendix by the Soil Conservation Service, USDA, who provided the analysis and projections of irrigation water use. The Office of Business Economics, Department of Commerce, and Corps of Engineers were also important contributors, respectively, of data pertaining to population and to the residual populations unserved by central water systems.

CHAPTER II

AGRICULTURAL WATER SUPPLY IN THE CHESAPEAKE BAY REGION

DESCRIPTION OF REGION

THE CHESAPEAKE BAY REGION, RESOURCES AND HISTORY

The Chesapeake Bay Study Area is located in the southern portion of the northeastern urban complex in the United States, a sprawling chain of urbanized areas extending from Northern Virginia to Massachusetts.

There has been a general postwar movement into urban areas from rural areas in the United States, but along this urban complex the movement has been even more pronounced than for the country as a whole. (1) In the Chesapeake Bay Estuary Area, (2) the population has increased by 60 percent since 1950; from 4,947,215 in 1950 to 7,872,041 by 1970. In the same period, however, the urban population increased by almost 73 percent, while the rural population increased only 16 percent. The urban share of the Estuary Area total population jumped from 75 percent in 1950 to 81 percent by 1970.

During the same period, there has been a sharp shift from agriculture to other areas of employment. As a result of mechanization and other changes, productivity per farm worker has risen at an unprecedented rate. Thus, despite increases in food consumption, the number of agricultural workers has decreased not only as a proportion of all workers, but also absolutely. Again, this movement has been more pronounced in the Chesapeake Bay Study Area than in the country as a whole. (3) In 1950 the farm population in the study area was 345,541, or 29 percent of the rural population, and the farm population constituted 7 percent of the total population. By 1970 it had decreased to 98,588, or 7 percent of the rural population and slightly over 1 percent of the total population.

The effect of these population shifts has been two-fold. First, the shift in the rural population from farm to nonfarm has had a significant effect upon domestic water use. The rural nonfarm population has traditionally enjoyed a higher income than the farm population, and can afford more water consuming conveniences. Its water use rate is thus substantially higher than that of the farm population. When the rural population shifts from farm to nonfarm, therefore, rural domestic water demand is increased over what it would be if the farm-nonfarm relation remained constant.

Second, the increase in the rural nonfarm population directly affects both the quantity and distribution of land in farms, and hence it significantly affects agricultural demand for water. The rural nonfarm population has exerted an ever increasing demand for land and housing, and it places a value on land with which less profitable agricultural uses simply cannot compete. In response to this pressure, the quantity of land in farms in the Chesapeake Bay Study Area fell from 7.5 million acres in 1949 to 5.1 million acres in 1969, a reduction of thirty percent. Remaining agricultural production is concentrated in the areas with the greatest competitive advantage, where agriculture can compete with alternative uses of land such as residential and recreational uses. The increase in demands of the nonfarm population for land thus effects a spatial redistribution and concentration of agricultural production.

Since the conversion of agricultural land to urban and industrial uses has been most pronounced near the expanding centers of Washington, Baltimore, and Norfolk, these demographic and water use trends have been sharpest in those areas.

The Chesapeake Bay Study Area is situated largely in the Atlantic Coastal Plain, with western portions in the Piedmont and Appalachian physiographic provinces. The Atlantic Coastal Plain, separated from the Piedmont by the Fall Line, stretches from Long Island, New York, to the Gulf of Mexico. It is the center of deposition for sediments from the uplifted areas to the west of the Fall Line, and is underlain by a series of unconsolidated, coarse sedimentary deposits. The deposits rest on a basement complex of igneous and metamorphic rock, and they range in thickness from a featheredge at the Fall Line, to 9000 feet at a location north of

Ocean City, Maryland (see Figure 6-3). Their slope varies from 50 feet per mile to 160 feet per mile. The sediments thus dip eastward from successive outcrop areas, and are encountered at increasingly great depths.

The Piedmont is a relatively narrow, moderate relief plateau between the Coastal Plain and the mountains. It is composed of crystalline rock of the igneous and metamorphic classes, rock which to the east forms the basement complex beneath Coastal Plain sediments.

The climate of the study area is best described as temperate. The average annual temperature is 57 degrees Fahrenheit, varying from 37 degrees in January and February to 78 degrees in July. The average temperature during the crop growing season, from April to September, is 70 degrees. (4)

Rainfall in the study area averages 44 inches per year. The average varies, however, with location, from less than 40 inches per year to more than 47 inches. Precipitation varies with the season, as well, and most falls during the spring and summer months (see Table 6-2 and Figure 6-2).

Descriptive Publications

An extensive survey of the water resources of the Delmarva Peninsula, with maps, was completed in 1973 and is available from the U.S. Geological Survey (1973). Also available from the Geological Survey is a study of the water resources in the State of Maryland (1970).

The State of Virginia has conducted an elaborate study of its agricultural water resources, including projections to 2020 (1969).

PRESENT STATUS

Historical rural water use in the Chesapeake Bay Study Area is the summation of three major uses: rural domestic, livestock and poultry, and irrigation. Rural domestic water use is by far the largest component and consists of the water used by rural farm

B-VI-3

TABLE 6-2
CLIMATIC SUMMARY-PRECIPITATION DATA
MONTHLY NORMALS-YEARS 1931 thru 1960

Station	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Annual
Elkton, Md.	3.46	2.99	4.19	3.60	4.25	3.96	4.35	5.02	3.56	3.23	3.55	3.19	45.35
Annapolis, Md.	3.14	2.57	3.62	3.31	3.83	3.51	4.14	4.50	3.46	2.63	2.78	2.85	40.34
Crisfield, Md.	3.56	3.15	4.01	3.66	3.69	3.31	5.05	5.05	3.83	3.37	3.24	2.92	44.89
Salisbury, Md.	3.66	3.21	4.13	3.34	3.62	3.49	4.39	6.01	4.44	3.50	3.21	3.13	46.13
Baltimore, Md.	3.43	2.89	3.82	3.60	3.98	3.29	4.22	5.19	3.33	3.18	3.13	2.99	43.05
Coleman, Md.	3.61	2.93	3.86	3.43	4.17	3.64	4.29	4.97	3.71	3.08	3.41	3.18	44.28
Solomons, Md.	3.55	2.78	3.61	3.50	3.76	3.45	5.57	5.00	3.59	3.11	3.33	2.97	44.22
Washington, D.C.	3.03	2.47	3.21	3.15	4.14	3.21	4.15	4.90	3.83	3.07	2.84	2.78	40.78
Richmond, Va.	3.46	2.90	3.42	3.15	3.72	3.75	5.61	5.54	3.65	3.00	3.04	2.97	44.21
Norfolk, Va. A.P.	3.33	3.21	3.45	3.16	3.36	3.61	5.92	5.97	4.22	2.92	3.05	2.74	44.94

Source: Existing Conditions Report, Vol. II.

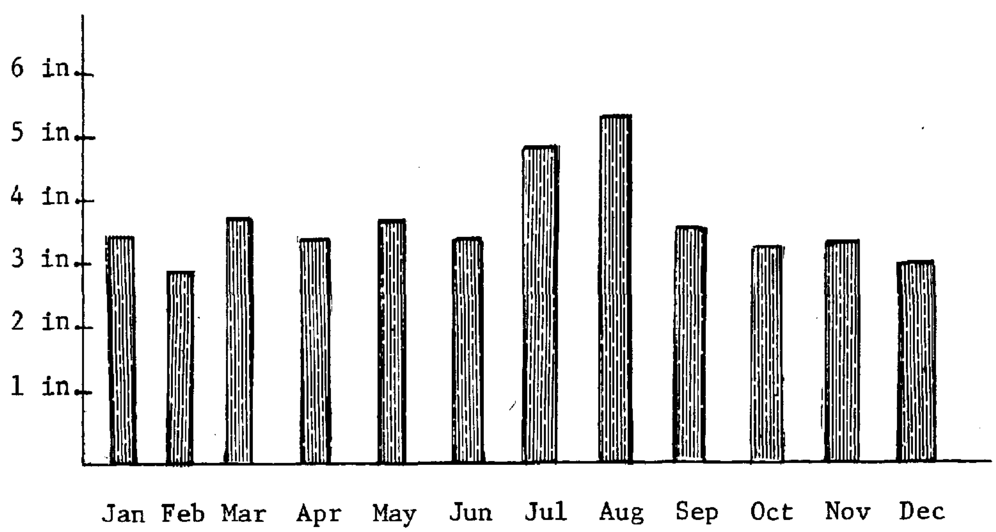


FIGURE 6-2
Monthly mean precipitation. Chesapeake Bay Study Area.

Source: Present Conditions Report, Vol II

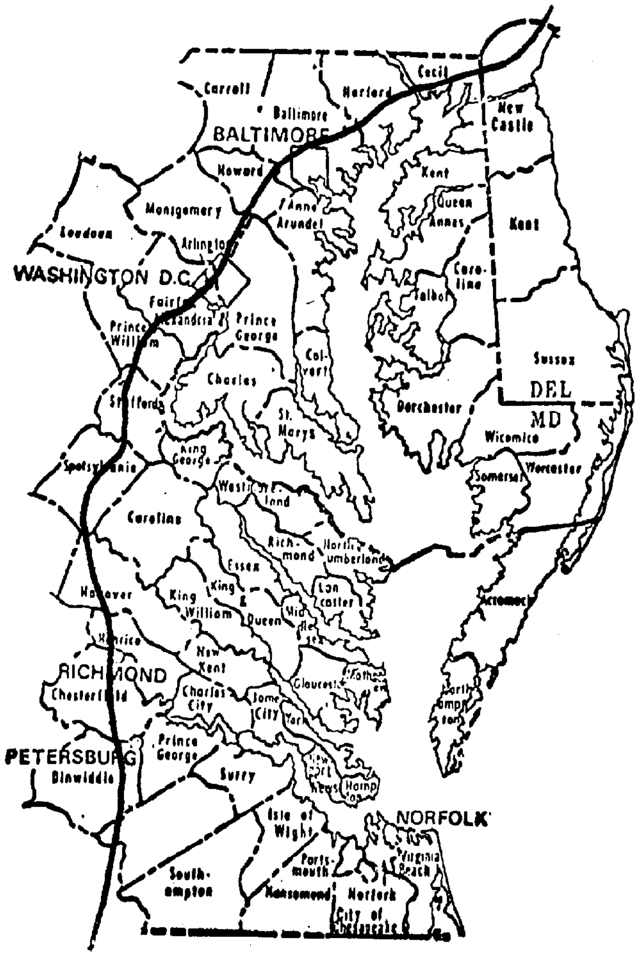
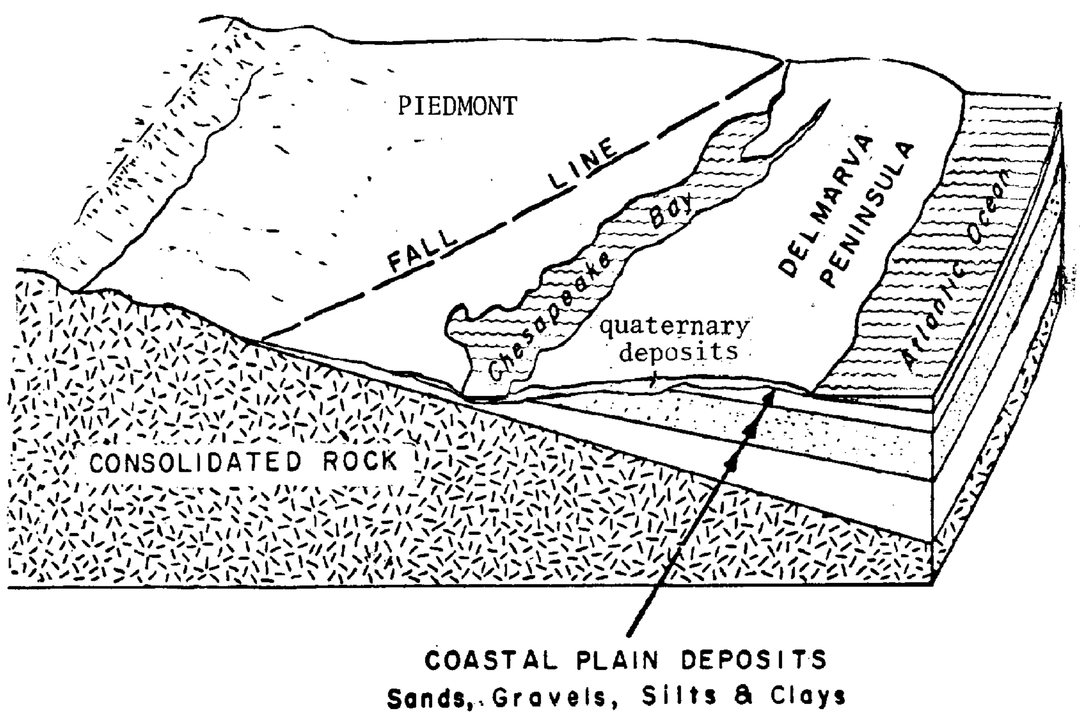


Figure 6-3

Fall Line and Underlying Sediments, Chesapeake Bay Study Area



Source: Modified from Maryland Geological Survey: Water in Maryland. 1970 and rural nonfarm populations. Irrigation water use is the second largest rural water demand; it accounted for 25 percent of rural domestic water use in 1970. The third largest rural water demand is exerted by livestock and poultry, with about 25 percent of the 1970 rural total. Rural industrial water use was not evaluated for this Appendix, but it is included in the Municipal and Industrial Water Supply Appendix.

This section of the report describes historical water use by the nonsystem served domestic, livestock and poultry, and irrigation sectors of the rural economy. Rural domestic water use is estimated for 1950, 1960, and 1970, livestock and poultry water use for 1950, 1959, and 1969, and irrigation water use for 1964 and 1969. The historical years chosen for analysis of each major use depended upon the availability of Census of Population and Census of Agriculture information. The historical uses summarized in this section are described in detail in Rural Water Uses 1950-1960-1970 Chesapeake Bay Study Area by John W. Green and available from Economic Research Service, USDA, Broomall, Pa.

RURAL DOMESTIC WATER USE

The rural population, composed of a rural farm component and a rural nonfarm component, are the major users of water in rural areas. Table 6-4 presents population statistics for the Chesapeake Bay Study Area and its subareas. Rural population increased 16 percent in the study area between 1950 and 1970. Rural population in 1970 was 1,368,364, of which 1,275,568 were classified as rural nonfarm and 92,796 as rural farm. The rural farm population decreased significantly between 1950 and 1970 but the loss was more than matched by the gain in rural nonfarm population.

Water consumption rates differ for persons with and without running water in their homes. The first step in estimating rural domestic water use was therefore to determine what proportion of the rural population had running water and indoor plumbing in their homes. Since the proportion of homes without such facilities was not expected to be the same for nonfarm and farm households, a dwelling unit analysis was carried out for each group and the data aggregated to determine total rural domestic water use.

The dwelling unit analysis consisted of determining the percentage of rural nonfarm and farm dwelling units with running water and multiplying these percentages by the appropriate population number to determine rural nonfarm and farm population served by running water. The population numbers were then multiplied by appropriate water use rates and the results added to obtain total rural domestic water use.

The Census of Housing reports the number of dwelling units with various combinations of modern facilities. Table 6-B-1 of Attachment B shows the total number of nonfarm dwelling units in 1950, 1960, and 1970. It also shows the number of units with running water, toilet, and bath. From this data, the percentage of units with modern facilities was computed. This percentage was then multiplied by the corresponding rural nonfarm population shown in Table 6-4 to determine the rural nonfarm population served by running water, toilet, and bath. It was assumed that the average number of persons per household does not vary with the availability of modern facilities. Table 6-B-2 presents the results of a similar analysis for the rural farm population.

Table 6-B-3 shows the aggregated data from Tables 6-B-1 and 6-B-2. The percentage of the rural population served by running water increased substantially from 1950 to 1970, from less than 41 percent to almost 80 percent. In both 1950 and 1960 the percentage of rural farm dwelling units (and therefore population) served by running water was less than the percentage of rural nonfarm units so served. In 1970, however, the order was reversed in all three state subareas.

Table 6-3 shows annual per capita water use rates for households with and without running water in 1950, 1960, and 1970. The use rates were obtained from information published in the U.S. Geological Survey.

Table 6-3--Annual per capita use of water, households with and without running water, Chesapeake Bay Study Area, 1950, 1960, and 1970

State and water facility available	1950	1960	1970
	---------Gallons per capita---------		
Delaware			
With running water	18,250	18,250	21,900
Without running water	3,650	3,650	3,650
Maryland			
With running water	18,250	18,250	18,250
Without running water	3,650	3,650	3,650
Virginia			
With running water	18,250	18,250	18,250
Without running water	3,650	3,650	3,650

Source: Estimated Use of Water in the U.S. - 1950-1960-1970, USGS Circulars 115, 456, and 676, respectively.

Attachment Table 6-B-4 presents rural population and water use figures for households with and without running water for 1950, 1960, and 1970. Table 6-5 aggregates the with and without numbers to present total rural domestic water use by state and subarea for 1950, 1960, and 1970. Rural domestic water use in the Chesapeake Bay Study Area increased from 11.3 billion gallons in 1950 to 21.3 billion gallons in 1970. This 88 percent increase was due to installation of plumbing facilities in older homes and to new home construction for the increased rural nonfarm population. Delaware accounted for 5 percent of the total rural domestic water use in 1970, Maryland for 55 percent, and Virginia for 40 percent. Delaware increased its rural water consumption by 121 percent between 1950 and 1970, Maryland by 86 percent, and Virginia by 88 percent.

Table 6-4--Population statistics by state and subarea, 1950, 1960 and 1970, Chesapeake Bay Study

State and subarea	Total population			Rural population		
	1950	1960	1970	1950	1960	1970
CHESAPEAKE BAY	1,918,786	3,004,452	4,321,316	1,176,937	1,359,012	1,368,364
DELAWARE	61,336	73,195	80,350	49,620	59,484	68,903
MARYLAND	1,141,305	1,896,927	2,722,364	581,251	693,061	736,555
Study Area						
1----------	507,473	867,721	1,164,911	257,853	313,562	326,233
2----------	99,274	121,498	131,322	86,050	105,570	110,418
3----------	111,349	122,072	127,007	78,978	86,662	93,512
4----------	358,583	698,323	1,183,376	93,744	106,993	107,410
5----------	64,626	87,313	115,748	64,626	80,274	98,982
VIRGINIA	716,145	1,034,330	1,518,602	546,066	606,467	562,906
Study Area						
1----------	51,132	47,601	43,446	48,408	47,601	43,446
2----------	142,316	349,715	603,273	115,355	120,545	111,964
3----------	30,532	37,938	49,050	30,532	37,938	49,050
4----------	158,243	258,539	322,836	113,721	139,288	122,249
5----------	76,549	79,639	81,818	76,549	79,639	79,218
6----------	11,750	21,583	33,203	11,750	15,629	25,437
7----------	142,214	127,736	261,686	55,699	56,884	12,418
8----------	103,409	111,579	123,290	94,052	108,943	119,124

Source: 1950, 1960, and 1970 Census of Population. Population does not include Baltimore, Washington, D.C., or independent Virginia cities. Only Sussex County is included in Delaware totals.

Table 6-4 Population statistics by state and subarea, 1950, 1960 and 1970, Chesapeake Bay Study--Continued

State and subarea	Rural nonfarm population			Rural farm population		
	1950	1960	1970	1950	1960	1970
CHESAPEAKE BAY	848,203	1,176,934	1,275,568	328,734	182,078	92,796
DELAWARE	32,202	47,679	63,335	17,418	11,805	5,568
MARYLAND	434,201	604,748	685,111	147,050	88,313	51,444
Study Area						
1----------	204,796	284,294	307,961	53,057	29,268	18,272
2----------	60,170	88,198	100,248	25,880	17,372	10,170
3----------	54,879	72,275	85,735	24,099	14,387	7,777
4----------	71,852	95,199	101,394	21,892	11,794	6,016
5----------	42,504	64,782	89,773	22,122	15,492	9,209
VIRGINIA	381,800	524,507	527,122	164,266	81,960	35,784
Study Area						
1----------	34,296	40,142	41,342	14,112	7,459	2,104
2----------	91,642	110,693	108,374	23,713	9,852	3,590
3----------	19,309	33,870	47,338	11,223	4,068	1,712
4----------	80,376	123,969	113,224	33,345	15,319	9,025
5----------	43,539	62,471	72,263	33,010	17,168	6,955
6----------	10,535	15,208	25,175	1,215	421	262
7----------	46,146	52,262	11,043	9,553	4,622	1,375
8----------	55,957	85,892	108,363	38,095	23,051	10,761

Source: 1950, 1960 and 1970 Census of Population.

Table 6-5 Rural domestic water use, by state and subarea, 1950, 1960 and 1970, Chesapeake Bay Study

State and subarea	Domestic water use		
	1950	1960	1970
	Million gallons		
CHESAPEAKE BAY	11,280.2	18,739.3	21,278.1
DELAWARE	517.9	828.8	1,146.9
MARYLAND	6,323.8	10,038.4	11,780.4
Study Area			
1----------	3,046.9	4,851.3	5,462.2
2----------	828.2	1,441.6	1,675.8
3----------	665.9	1,061.0	1,325.8
4----------	1,145.8	1,602.7	1,823.0
5----------	637.0	1,081.8	1,493.6
VIRGINIA	4,438.5	7,872.1	8,350.8
Study Area			
1----------	367.4	501.9	528.1
2----------	871.9	1,793.3	1,868.3
3----------	269.2	481.3	753.6
4----------	1,019.8	1,982.8	1,945.9
5----------	572.5	873.8	1,017.2
6----------	121.4	237.8	436.3
7----------	555.2	793.9	184.7
8----------	661.1	1,207.3	1,616.7

LIVESTOCK AND POULTRY WATER USE

Livestock and poultry water consumption is another component of rural water use. Water is required to sustain these animals and to produce farm-marketed livestock and poultry products. Livestock and poultry water use was determined by multiplying inventory numbers or, where appropriate, numbers of animals sold alive listed in Table 6-6 by the animal water use rates listed in Table 6-7.

The numbers of cattle and calves, hogs and pigs, and broilers increased in the study area from 1950 to 1969. Numbers of the other types of livestock and poultry decreased. Broiler numbers increased 160 percent; the number of milk cows, sheep and lambs, and horses and mules decreased 50 percent or more.

The number of cattle and calves in the State of Delaware decreased 33 percent from 1950 to 1969. This decrease was more than offset by a 58 percent increase in the Virginia subarea. The Virginia increase resulted from an increase in pasture farming which allowed farm operators to hold fulltime, off-farm jobs. The number of milk cows decreased substantially in each subarea; there was a 52 percent decline in the study area as a whole.

The number of hogs and pigs doubled in Delaware from 1950 to 1969 and it increased in Maryland and Virginia, for a combined 58 percent increase for the study area. The sheep and lamb population diminished by 46 and 67 percent in Maryland and Virginia, respectively, accounting for most of the 55 percent decline in the study area. The number of horses and mules decreased significantly in all three subareas, resulting in an overall decrease of 70 percent.

Chickens 3 months old and over declined in number in all three states between 1950 and 1969, with the decline somewhat greater in Maryland and Virginia than in Delaware. However, broiler production increased in all three states. The 160 percent increase for the study area was largely the result of increases of 90 and 289 percent in Delaware and Maryland, respectively.

Turkey production in the study area decreased 24 percent between 1950 and 1969. Maryland and Virginia production decreased 59 and 96 percent, respectively. Delaware, however, increased its turkey production 170 percent.

In 1969 most of the production of all types of livestock and poultry, except broilers and turkeys, occurred in Maryland and Virginia. Most of the production of broilers and turkeys in 1969 occurred in Delaware and Maryland.

Table 6-8 shows total livestock and poultry water use for the study area for 1950, 1959, and 1969. Total water used by these categories increased from 3.5 billion gallons in 1950 to 5.3 billion gallons in 1969, a 51 percent increase. Livestock and poultry water use in Delaware increased 88 percent from 1950 to 1969, but only accounted for 18 percent of total livestock and poultry water use in the study area in 1969. Water use in Maryland increased 59 percent between 1950 and 1969, and accounted for 52 percent of total livestock and poultry water use in the study area in 1969. Water use in Virginia increased 24 percent between 1950 and 1969, and accounted for 30 percent of the total livestock and poultry water use in 1969.

Cattle and calves and milk cows are easily the largest livestock users of water in rural areas. In 1969, cattle and calves and milk cows used 55 percent of all water used by livestock and poultry. The 35 percent increase between 1950 and 1969 is a result of both increased numbers and increased consumption per head. For milk cows, the 52 percent decline in numbers from 1950 to 1969 was more than offset by a 133 percent increase in annual consumptive use per animal because of more stringent sanitation codes and greater production per milk cow. Total water use by cattle and calves and milk cows increased in both Maryland and Virginia between 1950 and 1969.

Total water used by hogs and pigs in the study area increased 67 percent between 1950 and 1969, accounting for 9 percent of all livestock and poultry water use in 1969. Water used by hogs and pigs in Delaware, Maryland, and Virginia increased 98, 37, and 102 percent, respectively, between 1950 and 1969. Water use by sheep and lambs and by horses and mules decreased in the study area and in each of the subareas between 1950 and 1969. Dramatic decreases for both types occurred in Virginia. In 1969, sheep and lambs accounted for only 0.3 percent of total livestock and poultry water use in the study area. Horses and mules accounted for 2 percent.

Chickens 3 months old and over increased their water use in each State, and by 94 percent in the study area between 1950 and 1969. The increase in water use resulted solely from increases in per bird consumption probably increased as a result of (1) increased use of confinement between 1950 and 1969, (2) improved breeding, resulting in larger birds and more eggs per bird, (3) increased wastage from more automated watering systems, and (4) increased use of water for sanitation. In 1969, water use by chickens 3 months old and over accounted for 1.5 percent of total water use by livestock and poultry.

Water use by broilers increased a dramatic 429 percent in the study area between 1950 and 1969. Increases of 288, 694, and 179 percent were registered in Delaware, Maryland, and Virginia, respectively, for the same period. Increases resulted from both increased numbers and increased consumptive use per bird. Broilers accounted for only 8 percent of total livestock and poultry water use in 1950, but by 1969 this share increased to 28 percent.

Turkeys accounted for only 0.1 percent of total livestock and poultry water use in 1969. Total water use by turkeys in the State of Delaware increased 420 percent between 1950 and 1969. This large rise resulted from a 170 percent increase in turkey numbers and a 95 percent increase in consumptive use per bird. The increase in consumptive use per bird was probably the result of (1) greater confinement, (2) improved birds through breeding, (3) forced feeding, (4) more wastage from automation, and (5) more water for sanitation.

Table 6-6 Livestock and poultry numbers, by state and subarea, 1950, 1959 and 1969, Chesapeake Bay Study

State and subarea	Cattle and calves			Milk cows		
	1950	1959	1969	1950	1959	1969
	--------Inventory number----------			--------Inventory number----------		
CHESAPEAKE BAY	292,090	383,768	359,880	245,694	195,471	117,732
DELAWARE	28,254	26,396	18,996	31,452	23,500	11,957
MARYLAND	145,378	195,546	154,102	139,701	120,843	73,570
Study Area						
1----------	54,356	89,281	79,353	57,649	55,071	37,843
2----------	41,904	47,155	34,240	47,092	42,683	25,155
3----------	11,362	12,762	8,187	9,565	6,084	2,662
4----------	29,233	31,867	20,893	18,930	13,941	7,172
5----------	8,523	14,481	11,429	6,465	3,064	738
VIRGINIA	118,458	161,826	186,782	74,541	51,128	32,205
Study Area						
1----------	2,044	3,387	2,825	1,651	668	340
2----------	52,254	58,844	57,582	27,018	19,448	10,088
3----------	11,394	14,930	17,689	7,162	4,605	2,630
4----------	18,234	30,550	31,622	12,609	9,835	6,939
5----------	18,296	26,711	25,408	11,461	7,050	4,062
6----------	277	1,119	1,515	332	767	360
7----------	5,005	7,114	5,983	4,919	3,571	2,058
8----------	10,954	19,171	44,158	9,389	5,184	5,728

Table 6-6 Livestock and poultry numbers, by state and subarea, 1950, 1959 and 1969, Chesapeake Bay Study--Continued

State and subarea	Hogs and pigs 1950	Hogs and pigs 1959	Hogs and pigs 1969	Sheep and lambs 1950	Sheep and lambs 1959	Sheep and lambs 1969
	--Number sold alive--			--Inventory number--		
CHESAPEAKE BAY	485,927	548,398	765,451	71,865	57,775	32,379
DELAWARE	40,978	43,328	81,272	2,838	4,349	2,057
MARYLAND	181,559	185,704	248,714	36,003	26,217	19,409
Study Area						
1	70,930	60,642	55,106	10,696	10,206	8,004
2	52,540	58,340	63,844	11,564	7,938	6,508
3	24,314	33,093	83,468	5,622	3,369	1,169
4	22,605	18,616	16,923	5,641	3,406	3,155
5	11,170	15,013	29,373	2,480	1,298	573
VIRGINIA	263,390	319,366	435,465	33,024	27,209	10,913
Study Area						
1	5,973	7,534	13,601	2,832	2,609	790
2	43,465	25,911	20,462	13,271	7,818	4,209
3	7,640	6,574	5,809	2,198	2,909	526
4	37,415	58,389	67,080	3,153	2,612	598
5	31,118	47,081	72,006	5,103	3,941	1,487
6	525	1,115	919	74	205	196
7	20,485	25,769	42,238	2,854	1,095	720
8	116,769	146,943	213,350	3,539	6,020	2,387

Table 6-6-Livestock and poultry numbers, by state and subarea, 1950, 1959 and 1969, Chesapeake Bay Study--Continued

State and subarea	Horses and mules 1950	Horses and mules 1959	Horses and mules 1969	Chickens - 3 months and over 1950	Chickens - 3 months and over 1959	Chickens - 3 months and over 1969
	--Inventory number--			--Inventory number--		
CHESAPEAKE BAY	89,038	28,513	26,576	5,062,745	3,835,506	3,586,849
DELAWARE	8,288	3,093	2,687	757,368	725,705	680,278
MARYLAND	38,364	12,246	14,740	2,378,392	1,625,643	1,810,564
Study Area						
1	12,328	5,175	7,355	1,087,477	753,494	765,892
2	7,849	2,006	2,412	472,662	331,314	206,209
3	6,398	1,631	1,023	427,697	254,525	745,098
4	6,014	2,187	2,891	224,302	105,827	26,538
5	5,775	1,247	1,059	166,254	180,483	66,827
VIRGINIA	42,386	13,174	9,149	1,926,985	1,484,158	1,096,007
Study Area						
1	3,301	792	190	105,741	67,107	203,899
2	6,484	3,251	3,826	206,316	103,249	38,223
3	2,928	1,006	741	150,042	98,385	28,530
4	8,511	3,119	1,646	469,088	408,061	171,300
5	8,784	1,998	895	473,497	313,614	171,650
6	238	96	136	10,161	23,697	15,295
7	1,762	715	722	130,516	135,098	58,465
8	10,378	2,197	993	381,624	334,947	408,645

Table 6-6 Livestock and poultry numbers, by state and subarea, 1950, 1959, and 1969, Chesapeake Bay Study--Continued

State and subarea	Broilers 1950	Broilers 1959	Broilers 1969	Turkeys 1950	Turkeys 1959	Turkeys 1969
	---------Number sold alive----------			---------Number sold alive----------		
CHESAPEAKE BAY	105,619,502	161,235,116	274,344,590	513,635	720,461	390,583
DELAWARE	59,304,111	71,214,647	112,850,951	103,903	412,607	280,185
MARYLAND	38,761,316	80,147,532	150,868,311	254,117	181,113	103,590
Study Area						
1----------	1,151,091	217,200	160,142	103,783	73,120	46,014
2----------	9,330,766	13,760,681	27,783,424	57,192	33,470	4,209
3----------	27,701,341	65,895,051	122,922,845	41,855	59,706	52,120
4----------	457,420	224,300	0	23,607	9,070	112
5----------	120,698	50,300	1,900	27,680	5,747	1,135
VIRGINIA	7,554,075	9,872,937	10,625,328	173,615	126,741	6,808
Study Area						
1----------	4,506,916	4,882,870	8,568,931	39,375	1,624	0
2----------	292,903	66,000	0	33,993	51,697	0
3----------	148,037	160,000	99	11,750	562	0
4----------	1,457,976	3,993,250	2,048,597	15,722	19,248	3,815
5----------	386,273	253,130	2,951	26,183	6,063	993
6----------	13,388	0	0	136	20	0
7----------	336,789	140,287	0	8,336	5,142	1,930
8----------	411,793	377,400	4,750	38,120	42,385	70

Source: Census of Agriculture for 1950, 1959 and 1969.

Table 6-7 --Annual livestock and poultry water use, Chesapeake Bay Study Area, 1950, 1959 and 1969

Type	Subarea	1950	1959	1969
		------Gallons per head------		
Cattle and calves	Delaware	3,650	3,650	4,380
	Maryland	3,650	3,650	4,380
	Virginia	3,650	3,650	3,650 1/
Milk cows	Delaware	5,475	9,125	12,775 2/
	Maryland	5,475	10,950	12,775
	Virginia	5,475	9,125	12,775
Hogs and pigs	Delaware	1,460	1,460	1,460
	Maryland	1,460	1,460	1,460
	Virginia	1,460	1,460	1,460
Sheep and lambs	Delaware	730	730	730
	Maryland	730	730	730
	Virginia	730	730	730
Horses and mules	Delaware	3,650	3,650	4,380
	Maryland	3,650	3,650	4,380
	Virginia	3,650	3,650	3,650 1/
		------Gallons per bird------		
Chickens-3 months and over	Delaware	8.0	15.0	22.0
	Maryland	8.0	15.0	22.0
	Virginia	8.0	15.0	22.0
Broilers	Delaware	2.7	5.0	5.5
	Maryland	2.7	5.0	5.5
	Virginia	2.7	5.0	5.5
Turkeys	Delaware	9.5	11.0	18.5
	Maryland	9.5	11.0	18.5
	Virginia	9.5	11.0	18.5

1/ This water use rate reflects lower water use rates in western Virginia. The state average was used because of lack of specific evidence for higher rates in the Study area. 2/ The rapid increase in the water use of milk cows was due primarily to greater production per milk cow and to more stringent sanitation codes.

Source: Kenneth A. MacKichan, "Estimated Use of Water in the U.S., 1950-1955-1960-1965," U.S. Geological Survey Circulars; and Virginia Polytechnic Institute in-house data.

Table 6-8 Annual livestock and poultry water use, by state and subarea, 1950, 1959 and 1969, Chesapeake Bay Study

State and subarea	Cattle and calves 1950	Cattle and calves 1959	Cattle and calves 1969	Milk cows 1950	Milk cows 1959	Milk cows 1969
	--Million gallons--					
CHESAPEAKE BAY	1065.8	1400.8	1439.6	1345.2	2004.2	1503.8
DELAWARE	103.1	96.3	83.2	172.2	214.4	152.8
MARYLAND	530.6	713.9	674.9	765.0	1323.3	939.6
Study Area						
1----------	198.5	325.9	347.6	315.7	603.0	483.5
2----------	152.9	172.1	149.9	257.9	467.5	321.2
3----------	41.4	46.5	35.8	52.4	66.6	33.9
4----------	106.7	116.4	91.5	103.6	152.6	91.6
5----------	31.1	53.0	50.1	35.4	33.6	9.4
VIRGINIA	432.1	590.6	681.5	408.0	466.5	411.4
Study Area						
1----------	7.4	12.3	10.3	9.0	6.1	4.3
2----------	190.7	214.7	210.2	147.9	177.4	128.9
3----------	41.6	54.4	64.6	39.1	42.0	33.7
4----------	66.5	111.5	115.4	69.0	89.7	88.6
5----------	66.7	97.5	92.5	62.9	64.4	51.8
6----------	1.0	4.1	5.5	1.8	7.0	4.6
7----------	18.2	26.0	21.8	26.9	32.6	26.3
8----------	40.0	70.1	161.2	51.4	47.3	73.2

Table 6-8 Annual livestock and poultry water use, by state and subarea, 1950, 1959 and 1969, Chesapeake Bay Study--Continued

State and subarea	Hogs and pigs 1950	Hogs and pigs 1959	Hogs and pigs 1969	Sheep and lambs 1950	Sheep and lambs 1959	Sheep and lambs 1959
	--Million gallons--					
CHESAPEAKE BAY	298.3	358.7	497.7	33.7	27.9	17.0
DELAWARE	35.9	38.0	71.2	2.1	3.2	1.5
MARYLAND	159.1	162.6	218.0	26.2	19.0	14.2
Study Area						
1----------	62.2	53.1	48.3	7.7	7.4	5.9
2----------	46.0	51.1	56.0	8.5	5.7	4.7
3----------	21.3	29.0	73.1	4.1	2.5	0.9
4----------	19.8	16.3	14.9	4.1	2.5	2.3
5----------	9.8	13.1	25.7	1.8	0.9	0.4
VIRGINIA	103.3	158.1	208.5	5.4	5.7	1.3
Study Area						
1----------	12.2	24.4	47.1	0.4	1/	0.0
2----------	15.4	8.8	3.2	1.2	1.7	0.2
3----------	5.2	4.8	4.2	0.6	1.0	0.3
4----------	4.0	20.0	11.2	0.1	0.1	1/
5----------	6.2	11.5	15.3	0.8	0.2	0.2
6----------	0.5	1.0	0.8	0.1	0.1	0.1
7----------	12.3	16.7	31.8	1.5	0.5	0.1
8----------	47.5	70.9	94.9	0.7	2.1	0.4

Table 6-8 Annual livestock and poultry water use, by state and subarea, 1950, 1959 and 1969, Chesapeake Bay Study--Continued

State and subarea	Horses and mules 1950	Horses and mules 1959	Horses and mules 1969	Chickens - 3 months and over 1950	Chickens - 3 months and over 1959	Chickens - 3 months and over 1969
	Million gallons					
CHESAPEAKE BAY	337.2	106.2	109.7	40.6	58.1	78.8
DELAWARE	30.2	11.3	11.8	6.1	10.9	14.9
MARYLAND	140.0	44.6	64.4	18.8	24.4	39.8
Study Area						
1----------	45.0	18.8	32.2	8.6	11.4	16.9
2----------	28.6	7.3	10.5	3.7	5.0	4.5
3----------	23.4	5.9	4.5	3.4	3.8	16.4
4----------	21.9	8.0	12.6	1.8	1.6	0.6
5----------	21.1	4.6	4.6	1.3	2.6	1.4
VIRGINIA	167.0	50.3	33.5	15.7	22.8	24.1
Study Area						
1----------	12.1	2.9	0.7	0.8	1.0	4.5
2----------	23.7	11.8	14.0	1.6	1.6	0.9
3----------	10.7	3.7	2.6	1.3	1.5	0.7
4----------	31.0	11.4	6.0	3.6	6.2	3.7
5----------	32.0	7.3	3.2	3.9	4.6	3.7
6----------	13.2	2.6	0.8	0.5	0.8	0.2
7----------	6.5	2.6	2.7	1.0	2.0	1.3
8----------	37.8	8.0	3.5	3.0	5.1	9.1

Table 6-8 Annual livestock and poultry water use, by state and subarea, 1950, 1959 and 1969, Chesapeake Bay Study--Continued

State and subarea	Broilers 1950	Broilers 1959	Broilers 1969	Turkeys 1950	Turkeys 1959	Turkeys 1969
	Million gallons					
CHESAPEAKE BAY	285.4	806.1	1,508.7	4.6	7.5	6.9
DELAWARE	160.0	356.1	620.6	1.0	4.5	5.2
MARYLAND	104.5	400.6	829.8	2.3	1.9	1.7
Study Area						
1----------	3.0	1.0	0.9	0.9	0.8	0.8
2----------	25.2	68.8	152.9	0.6	0.3	1/
3----------	74.8	329.5	676.0	0.4	0.7	0.9
4----------	1.2	1.1	0.0	0.2	0.1	1/
5----------	0.3	0.2	1/	0.2	1/	1/
VIRGINIA	20.9	49.4	58.3	1.3	1.1	0.0
Study Area						
1----------	12.2	24.4	47.1	0.4	1/	0.0
2----------	0.8	0.3	0.0	0.3	0.6	0.0
3----------	0.5	0.8	1/	0.1	1/	0.0
4----------	4.0	20.0	11.2	0.1	0.1	1/
5----------	1.2	1.2	1/	0.1	1/	1/
6----------	1/	0.0	0.0	1/	1/	0.0
7----------	1.0	0.7	0.0	1/	1/	1/
8----------	1.2	2.0	1/	0.3	0.4	1/

1/ Less than 0.1.

IRRIGATION WATER USE

Irrigation water is the third component of total rural water use. The amount of water used varies greatly from year to year, depending on climatological conditions and cropping patterns. In the Northeastern United States the amount of moisture occurring naturally as rainfall greatly influences the amount of supplemental irrigation water needed. Cropping patterns, while not usually subject to significant change, also influence the total amount of irrigation water used.

The 1969 Census of Agriculture, for the first time, reported the amount of water used for irrigation on Class 1-5 farms (99.5 percent of all irrigated acres in the study area). From this information the amount of irrigation water applied per acre on Class 1-5 farms was computed. That amount was then multiplied by the total number of irrigated acres to obtain an estimate of the total amount of irrigation water applied (Table 6- 9). The same application methodology was used for 1964. This method implicitly assumes that climatological conditions and cropping patterns were similar in 1964 and 1969, which was not the case: in 1964 there were five to ten inches less rainfall in the Northeast than in 1969.

In spite of these weather conditions, the number of acres irrigated increased 19 percent between 1964 and 1969, from 48,922 acres to 58,314 acres. Maryland showed the greatest change between 1964 and 1969--a 39 percent increase. The total number of irrigated acres was distributed fairly evenly among the three states.

Table 6- 10 shows the distribution of irrigated acres in 1969 by crop. The major irrigated crops in the study area were field corn (6 percent), other field crops (30 percent), vegetables (52 percent), and nursery and other crops (8 percent). Most of the irrigated field corn (54 percent) was in Maryland, while most of the other irrigated field crops (82 percent) were in Delaware and Virginia. Most of the irrigated vegetable production (79 percent) was in Delaware and Maryland, and most of the nursery and other crop irrigation (60 percent) was in Virginia.

The land irrigated in 1969 constituted only a small share (2.7 percent) of the total number of irrigable acres in the study Department of Agriculture. In that estimation, (see Table 6-11) the total shown for each subarea was classified into acres potentially irrigable without additional treatment measures and acres potentially irrigable but requiring additional treatment measures.

SCS developed the data by summing 90 percent of the Class I cropland, 75 percent of the Class 2 cropland, 50 percent of the Class 3 cropland, and 25 percent of the Class 4 cropland from 1967 Conservation Needs Inventory reports. (5)

Over two million acres in the study area are classified as potentially irrigable. Two-thirds of this area (65 percent) would require additional-treatment measures, such as land leveling or drainage. In both Maryland and Virginia, over 300,000 acres could be irrigated without additional treatment measures.

Water use rates in 1969 varied from 4.3 inches in Maryland Subarea 3, to 17.8 inches in Virginia Subarea 6. The latter, however, had an insignificant amount of irrigated land (30 acres). Among the subareas with large amounts of irrigated land, the normal application rate ranged from 3.5 to 5.5 inches, and the average rate for the study area was reputed to be 5.1 inches. The rates for Delaware, Maryland, and Virginia were 4.4, 5.4, and 5.5 inches, respectively. With these rates, total irrigation water used in the study area increased from 6,569.7 million gallons in 1964 to 8,022.3 million gallons in 1969.

Table 6-9--Irrigated farms, acres and water used, by state and subarea, 1964 and 1969, Chesapeake Bay Study

State and subarea	All farms - 1964			All farms - 1969		
	Farms	Acres	Acre-feet water used[1/]	Farms	Acres	Acre-feet water used[2/]
CHESAPEAKE BAY	969	48,922	20,157	917	58,314	24,614
DELAWARE	158	17,542	6,522	164	20,421	7,463
MARYLAND	419	14,307	6,256	491	19,825	8,873
Study Area						
1	108	1,684	1,009	104	1,195	676
2	67	5,018	2,379	86	9,846	4,805
3	124	5,817	2,017	113	6,214	2,210
4	47	702	416	78	939	531
5	73	1,086	435	110	1,631	651
VIRGINIA	392	17,073	7,379	262	18,068	8,278
Study Area						
1	103	11,094	4,573	89	11,964	4,932
2	14	365	198	14	387	201
3	3	103	45	2	4	5
4	196	1,512	670	72	1,285	625
5	10	370	131	11	309	135
6	6	38	56	4	33	49
7	38	3,127	1,379	24	3,099	1,352
8	22	464	327	46	987	979

Table 6-9 Irrigated farms, acres and water used, by state and subarea, 1964 and 1969, Chesapeake Bay Study--Continued

State and subarea	Class 1-5 farms - 1969: Farms	Acres	Acre-feet water used	Water used[3/] 1964	1969	Application rate per acre 1969
				--Million gallons--		---Ac. in.----
CHESAPEAKE BAY	864	57,988	24,419	6,569.7	8,021.8	5.1
DELAWARE	154	20,385	7,452	2,125.6	2,432.3	4.4
MARYLAND	457	19,640	8,778	2,038.8	2,891.6	5.4
Study Area						
1----------	90	1,098	628	328.8	220.4	6.9
2----------	82	9,836	4,800	775.4	1,565.8	5.9
3----------	110	6,198	2,204	657.3	720.2	4.3
4----------	68	880	496	135.5	173.1	6.8
5----------	107	1,628	650	141.8	212.1	4.8
VIRGINIA	253	17,963	8,189	2,405.3	2,697.9	5.5
Study Area						
1----------	88	11,946	4,925	1,490.4	1,607.3	4.9
2----------	14	387	201	64.6	65.6	6.2
3----------	2	4	5	14.7	1.6	15.0
4----------	69	1,261	613	218.3	203.6	5.8
5----------	11	309	135	42.8	44.1	5.2
6----------	4	33	49	18.3	16.0	17.8
7----------	22	3,087	1,347	449.4	440.6	5.2
8----------	43	936	914	106.8	319.1	11.7

1/ Obtained by the following formula:

$$\frac{\text{Acre-feet water used, all farms - 1964}}{\text{Acre-feet water used, all farms - 1969}} = \frac{\text{Acres, all farms - 1964}}{\text{Acres, all farms - 1969}}$$

2/ Obtained by the following formula:

$$\frac{\text{Acre-feet water used , all farms - 1969}}{\text{Acre-feet water used, Class 1-5 farms - 1969}} = \frac{\text{Acres, all farms - 1969}}{\text{Acres, Class 1-5 farms - 1969}}$$

3/ One acre-foot water = 325,900 gallons.

Table 6-10 Irrigated acres by crop, by state and subarea, 1969, Chesapeake Bay Study

State and subarea	Cropland pasture	Field corn	Sorghum	All small grains	Other field crops	Silage	Vegetables	Berries	Orchard	Nursery and other	Total[1/]
	Acres										
CHESAPEAKE BAY	484	3,701	174	761	18,149	299	31,811	487	310	4,899	61,075
DELAWARE	6	807	20	205	7,362	38	12,289	39	182	134	21,082
MARYLAND	361	2,010	20	367	3,319	204	12,814	227	111	1,853	21,286
Study Area											
1----------	59	138	0	6	203	106	400	6	34	132	1,084
2----------	153	1,383	20	281	488	34	7,264	15	42	1,253	10,933
3----------	37	469	0	0	778	5	5,060	184	0	259	6,792
4----------	101	20	0	6	400	49	67	17	6	203	869
5----------	11	0	0	74	1,450	10	23	5	29	6	1,608
VIRGINIA	117	884	134	189	7,468	57	6,708	221	17	2,912	18,707
Study Area											
1----------	2	0	0	0	6,506	0	6,014	187	10	191	12,910
2----------	0	0	0	22	0	46	3	2	7	28	108
3----------	0	1	0	0	0	0	0	0	0	3	4
4----------	48	600	100	10	342	5	173	0	0	27	1,305
5----------	0	50	34	0	0	6	13	10	0	200	313
6----------	0	0	0	0	0	0	0	0	0	32	32
7----------	55	72	0	97	316	0	137	22	0	2,405	3,104
8----------	12	161	0	60	304	0	368	0	0	26	931

Source: 1969 Census of Agriculture

1/ This total differs from the totals in Table 6-13, because of irrigation on acres not classified by the Census as being "in farms."

Table 6-11 Total potentially irrigable land, with and without treatment, by state and subarea, 1969, Chesapeake Bay Study

State and subarea	Potentially irrigable land: Total	With treatment	Without treatment1/
	Acres		
CHESAPEAKE BAY	2,076,616	1,353,886	722,730
DELAWARE	351,003	274,620	76,383
MARYLAND	877,134	575,380	301,754
Study Area			
1	187,137	115,993	71,144
2	363,980	221,351	142,629
3	192,964	145,939	47,025
4	59,682	36,226	23,456
5	73,371	55,871	17,500
VIRGINIA	848,479	503,886	344,593
Study Area			
1	90,224	47,059	43,165
2	70,358	42,849	27,509
3	41,142	24,163	16,979
4	122,148	74,491	47,657
5	212,460	131,426	81,034
6	1,497	867	630
7	69,616	42,516	27,100
8	241,034	140,515	100,519

1/ Does not include acres of land presently irrigated.

Source: Soil Conservation Service, USDA.

TOTAL WATER USE

The rural domestic population is by far the largest rural water user in the study area,as shown in Table 6-12. In 1970, rural domestic water use was five times that of livestock and poultry in 1969, and nearly four times that of irrigation in 1969. Rural domestic use is also the fastest increasing component; its use nearly doubled from 1950 to 1970. This in part resulted from the increasing exodus of suburbanites to the country: as agricultural land is developed for nonagricultural uses, there may be fewer numbers of livestock and poultry, and possibly fewer potentially irrigable acres available for agricultural use.

Livestock and poultry use of water appears to be leveling off. It increased 38 percent from 1950 to 1959, but only 9 percent from 1959 to 1960. Most types of livestock and poultry are declining in number. Water use rates per head or bird are not likely to increase significantly, indicating a leveling off and possibly a decrease in livestock and poultry water use.

Irrigation water use has increased, mostly due to the increase in the number of irrigated acres. It is difficult to draw any further conclusions because of (1) the lack of historical data describing irrigation in the Northeast, and (2) variations in rainfall and its effect on supplemental irrigation.

Total rural water consumption in the Chesapeake Bay Study Area in 1964, using the 1970 domestic consumption data was 36,340.8 million gallons (see Table 6-13). The State of Maryland accounted for 17,454.4 million gallons, or 48 percent of the study area total. Virginia accounted for 12,646.6 million gallons, (35 percent of the total), and Delaware for 6,239.8 million gallons (17 percent of the total).

Table 6- 13 also compares the distribution of rural water use in the Chesapeake Bay with the distribution of rural population and land area. Total water use in Delaware accounted for more of the Chesapeake total than either its rural population or its land area. In Maryland total water use accounted for almost as much of the Chesapeake total as its rural population, and more of the total than its land area. Rural water use in Virginia, on the other hand, accounted for less of the total than either its rural population or its land area.

Table 6-12 Water use by type of use, by state and subarea, reported years, Chesapeake Bay Study

State and subarea	Domestic use 1950	Domestic use 1960	Domestic use 1970	Livestock and poultry use 1950	Livestock and poultry use 1959	Livestock and poultry use 1969	Irrigation use 1964	Irrigation use 1969
	Million gallons							
CHESAPEAKE BAY	12,116.3	20,189.3	22,977.5	3,544.4	4,903.6	5,341.5	6,569.7	8,022.3
DELAWARE	1,353.9	2,278.8	2,846.3	510.6	734.7	961.2	2,125.6	2,432.8
MARYLAND	6,323.8	10,038.4	11,780.4	1,746.5	2,691.3	2,782.4	2,038.8	2,891.6
Study Area								
1----------	3,046.9	4,851.3	5,462.2	641.6	1,021.4	936.1	328.8	220.4
2----------	828.2	1,441.6	1,675.8	523.4	778.8	699.7	775.4	1,565.8
3----------	665.9	1,061.0	1,325.8	221.2	484.5	841.5	657.3	720.2
4----------	1,145.8	1,602.7	1,823.0	259.3	298.6	213.5	135.5	173.1
5----------	637.0	1,081.8	1,493.6	101.0	108.0	91.6	141.8	212.1
VIRGINIA	4,438.6	7,872.1	8,350.8	1,287.3	1,477.6	1,597.9	2,405.3	2,697.9
Study Area								
1----------	367.4	501.9	528.1	49.1	55.2	79.4	1,490.4	1,607.3
2----------	871.9	1,793.3	1,868.3	412.9	434.8	375.0	64.6	65.6
3----------	269.2	481.3	753.6	101.6	110.4	107.1	14.7	1.6
4----------	1,019.9	1,982.8	1,945.9	209.2	291.8	284.0	218.3	203.6
5----------	572.5	873.8	1,017.2	197.9	219.0	215.4	42.8	44.1
6----------	121.4	237.8	436.3	4.4	13.0	11.8	18.3	16.0
7----------	555.2	793.9	184.7	73.6	87.3	89.6	449.4	440.6
8----------	661.1	1,207.3	1,616.7	238.6	266.1	435.6	106.8	319.1

Table 6-13 Percentage of water use, by type and comparison with population and land area, by state and subarea, 1969-1970, Chesapeake Bay Study

State and subarea	Total water use 1969-1970	Distribution of water use: Total 1969-1970	Domestic 1970	Livestock 1969	Irrigation 1969	Distribution of: Rural pop. 1970	Land area 1970
	Mil. gal.	Percent 1/					
CHESAPEAKE BAY	36,340.8	100.00	100.00	100.00	100.00	100.00	100.00
DELAWARE	6,239.8	17.16	12.39	17.99	30.25	10.53	10.00
MARYLAND	17,454.4	48.01	51.27	52.10	35.95	50.71	38.35
Study Area							
1	6,618.7	37.93	46.38	33.65	7.62	44.30	28.69
2	3,941.3	22.58	14.22	25.15	54.14	14.99	21.04
3	2,887.5	16.54	11.25	30.24	24.90	12.69	23.58
4	2,209.6	12.66	15.47	7.67	5.98	14.59	12.89
5	1,797.3	10.29	12.68	3.29	7.34	13.44	13.80
'IRGINIA	12,646.6	34.83	36.34	29.91	33.80	38.76	51.65
Study Area							
1	2,214.8	17.51	6.32	4.97	59.14	7.72	6.80
2	2,308.9	18.27	22.40	23.47	2.41	19.90	12.30
3	862.3	6.82	9.02	6.70	.06	8.72	8.38
4	2,433.5	19.26	23.30	17.77	7.50	21.71	19.00
5	1,276.7	10.09	12.17	12.66	1.38	16.43	23.87
6	464.1	3.67	5.22	0.74	0.59	4.52	1.20
7	714.9	5.64	2.21	5.61	16.21	2.20	5.85
8	2,371.4	18.74	19.36	27.26	11.74	21.16	21.50

1/ Subarea percentages are computed relative to state study area totals, and state study area percentages are computed relative to the Chesapeake Bay Study Area total.

CHAPTER III

FUTURE AGRICULTURAL WATER SUPPLY NEEDS

FUTURE DEMANDS

The demand analysis is broken into subsections, the first of which lists assumptions of a general nature and the methodology applied to all agricultural projections. Each of the following three subsections pertain to a specific aspect of agricultural water demand: domestic, livestock, or irrigation. Methodology and assumptions particular to each are explained, and the demands are analyzed. The demand projections are separated from the text, and given in Attachment C at the end of the Appendix.

GENERAL ASSUMPTIONS AND METHODOLOGY

The location of agricultural production is influenced by a variety of factors, each of which must be taken into account in the projection of future activity. On the demand side, projected national markets have been increasingly important with technological advances in food processing. Transportation, population, and income estimates must also be included. On the supply side, production capacity changes with both availability of resources and technological practices.

To take these factors explicitly into account one would have to employ a relatively elaborate econometric model which specifies each of the causal variables leading to a shift in agricultural production toward one area over the others. The econometric approach to agricultural projections will no doubt be increasingly refined as the period for which appropriate measures are available lengthens and more accurate causal relations are ascertained. At the present time, however, this approach is severely limited by the paucity of relevant data and information on factors which explicitly lead to changes in the distribution of output.

Even after potentially causal factors are specified most econometric forecasting models include as an independent variable the production values from previous time periods, based on the usually high correlation of production values across time. Because of fixed investments, economic activity will rarely show a radical change from one period to the next; and many of the factors which lead to comparative advantage for an area at one time period are likely to be present in another. In agriculture this is especially true where the physical characteristics of soils, climate, and topography seldom change from one period to the next.

Thus at the core of the method of projection used in this report is the relation of a subarea's production in one time period to its production in past periods; and the response of the subarea's agriculture production to change in projected demands. Both of these elements are present in a form of regional analysis called "shift-share" analysis. A modified form of shift-share analysis is employed in the projections in this Appendix.

SHIFT-SHARE ANALYSIS

In shift-share analysis it is assumed that the change in a subarea's production from one time period to the next varies directly with the projected change in the state's production during that period. (This assumption is particularly pertinent in the projection of agricultural production, where the state's market is of great importance in the determination of subarea production levels). The change in production at the state level, in turn, is assumed to be distributed among subareas so that each reflects the change in production over the previous period.

In addition to the state shift is a "distributional shift", or the shift in production whereby a subarea's share of its State's production changes relative to that of other subareas. Again this assumption is pertinent to agriculture in that many of the factors which give one Subarea a comparative advantage over others - soil conditions, climate, and topography - may be expected to continue from one period to the next, and are reflected in a shift in production toward that region.

The change in a Subarea's production is thus accounted for by state changes in production and the shifts in the distribution of State production among its Subareas.

Each of these effects is taken into account when, by the method used in this Appendix, a Subarea's share of State production is projected and applied to target date estimates of state totals. State-level production changes are allocated among the subareas in proportion to their projected shares. Subarea share changes, in turn, take into account the distribution shifts in production among the subareas. (This procedure is hereafter referred to as a "shares analysis." See Attachment A for graphical illustration).

A curvilinear projection of the subarea shares was found to be appropriate in the projection of agricultural activity. If a Subarea's share increased rapidly in the historical period, it was assumed that such increases would not be sustained through the target dates, and they would gradually be toned down. Similarly, if a Subarea's historical shares of State production showed rapid decreases in the historical period, it was assumed the decreases would not be sustained through the target dates.

A projection function which was well suited to these characteristics of agricultural production is the "Spillman" function. For rising subarea shares, the Spillman sets limits by means of a linear regression (6); and it estimated target date shares to approach these limits in a curvilinear fashion, thus registering less rapid increases with time. For a falling trend, the shares were assumed always to remain positive, and zero was set as a limit, with the share approaching it again in a curvilinear fashion to register less rapid decreases with time. The state totals which were allocated among the subareas in this analysis were provided by OBERS. Since they were an important part of the projection procedure, it is desirable to go in some depth into the assumptions which underline the OBERS state-level projections.

OBERS ASSUMPTIONS

The OBERS projections are the output of a program of economic measurement, analysis and projection conducted by the Bureau of Economic Analysis and the Economic Research Service. The program is run under cooperative agreement with the Water Resources Council, and it has been an integral part of the comprehensive water resources planning program and national assessments of water and related land resources.

The objectives of the OBERS program, as listed in its manual, (7) are the development of 1) a regional information system with provisions for rapid data retrieval 2) near term (1980) mid-term (2000) and long term (2020) projections of population, economic activity and land use and 3) analytical systems for use in water resources and other public investment planning.

There are two levels of assumptions in the OBERS projections which are relevant to this report: those of a general nature underlying all OBERS economic projections, and those specific to the projection of agricultural production.

The general assumptions are those pertaining to the economic activity. They include the following, which, being fairly straight-forward, are reproduced in their entirety:

a. Growth of population will be conditioned by a decline of fertility rates from those of the 1962-1965 period. This is true of both Series C and E projections. Series C projections are used in this Appendix.

b. Nationally, reasonably full employment, represented by a 4 percent unemployment rate, will prevail at the points for which projections are made. As in the past, unemployment will be disproportionately distributed regionally, but the extent of the disproportionality will diminish.

c. No foreign conflicts are assumed to occur at the projection dates.

d. Continued technological progress and capital accumulation will support a growth in private output per manhour of 3 percent annually.

e. The new products that will appear will be accommodated within the existing industrial classification system, and, therefore, no new industrial classifications are necessary.

f. Growth in output can be achieved without ecological disaster or serious deterioration, although diversion of resources for pollution control will cause changes in the industrial mix of output.

The following are assumed for the state economic projections:

a. Most factors that have influenced historical shifts in regional "export" industry location will continue into the future with varying degrees of intensity.

b. Trends toward economic area self-sufficiency in local-service industries will continue.

c. Workers will migrate to areas of economic opportunities and away from slow growth or declining areas.

d. Regional earnings per worker and income per capita will continue to converge toward the national average.

e. Regional employment/population ratios will tend to move toward the national ratio. (8)

In addition to this general class of underlying assumptions, there is a set of assumptions which are specific to agricultural projections.

Based on the Series C projections of population and per capita income projections, per capita consumption of agricultural products were estimated as follows:

	1963-65 Av.	1968-70 Av.	1980	2000	2020
	Pounds				
Beef and veal	103	115	130	135	140
Poultry	39	47	59	63	65
Dairy products	627	570	475	450	425
Citrus fruit	66	88	110	118	120
Non-citrus fruit	102	101	99	92	86
Potatoes	110	117	110	110	110
Wheat	158	153	150	141	134
Total	1205	1191	1133	1109	1080

Source: OBERS projections, Vol. 1 (1972).

These figures take into account a rising trend of prices of livestock products relative to those of field crops, but the demands for agricultural products are projected under the assumption that the price of agricultural products relative to all other consumer products "will not be materially altered." There are assumed to be no shortages. (9)

In addition to food demands for agricultural products, there are assumed to exist several nonfood uses of crops, which are incorporated into the OBERS projections. The livestock and poultry populations are assumed to exert a significant demand on feed grains, protein feeds, and roughage, the extent of which depends upon feed utilization per unit of livestock output. Feed utilization in 1980 is assumed to be consistent with current practices and performances. From 1980 to 2020, however, feed utilization is assumed to decline by ten percent, as more efficient use of feed concentrates, expanded use of substitutes for concentrated food sources, and improvements in management and breeding take effect.

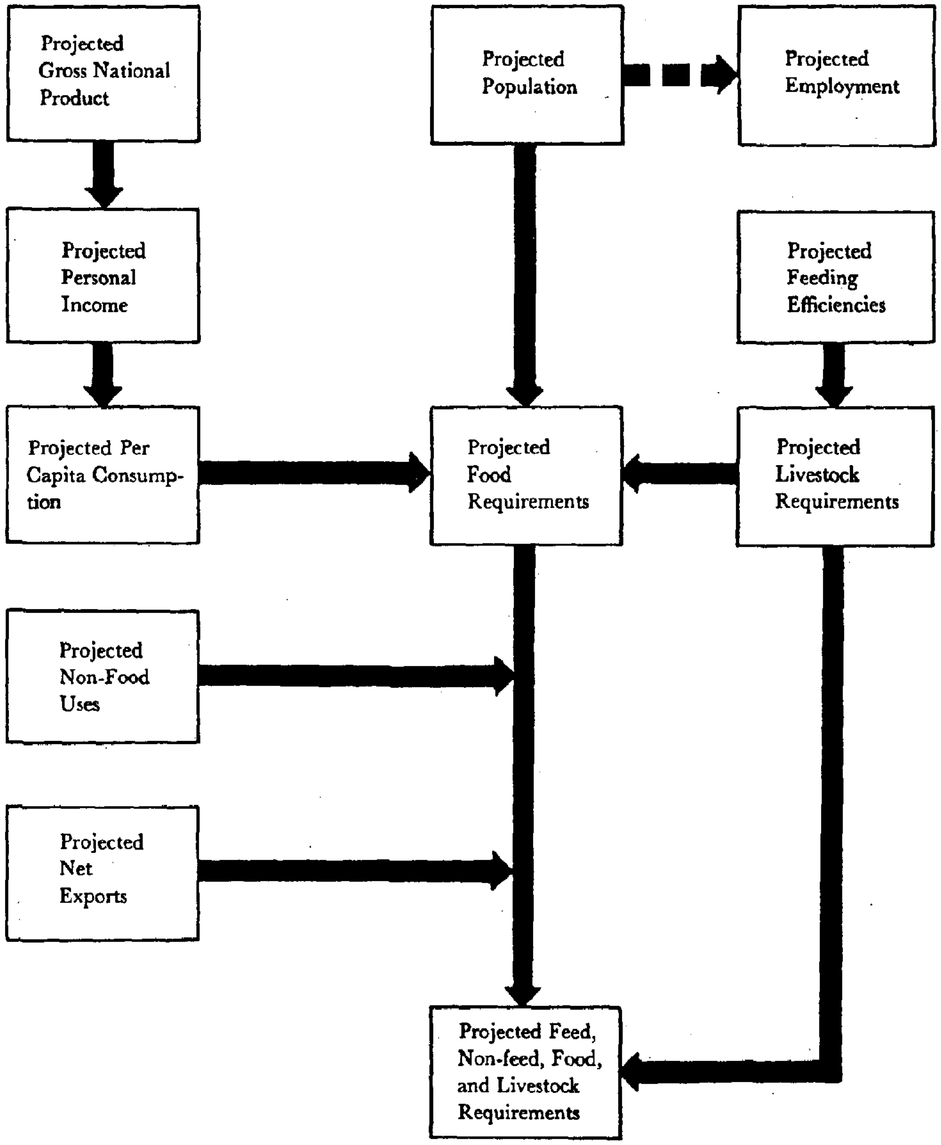
Other domestic nonfood uses of crops are in manufacturing and seed production. The rate of change between the 1959-61 average and the 1980 level was utilized in making the 2000 and 2020 projections of the other nonfood uses of feed grains. Nonfood uses of vegetables, potatoes, and noncitrus fruit were projected to change at the same rate as their respective food uses; and projected changes for other agricultural products were based on extensions of historical data.

A final component of the projected agricultural demands is net exports. Underlying the OBERS projections in this area is the assumption that beyond 1980 U.S. exports will, despite their continued increases, represent a smaller share of total U. S. production. No attempt was made to predict changes in national trade and food aid policies. The export projections are considered an interpretation of the policies as they existed when the projections were made.

In sum, the OBERS agriculture projection incorporates several underlying assumptions pertaining to all economic activity. From projections of gross national product and population use are derived per capita and total domestic food consumption; the livestock requirements, in turn, exert a further demand on crop production, as do the projected nonfood uses and exports.

The procedure is schematically represented in the OBERS documentation, and it is reproduced here in a summary reference (Figure 6-4).

Figure 6-4 -- Projected National Framework of Production Requirements



Source: Water Resources Council 1972, OBERS Projections Volume 1, "Concepts, Methodology and Summary Data."

DOMESTIC WATER DEMANDS

ASSUMPTIONS AND METHODOLOGY

A substantial demand for water in rural area is expected to be exerted by the rural population. Some of it will be satisfied by central water systems, which are addressed in Appendix 5 - Municipal and Industrial Water Supply. In this Appendix, water demands are estimated for the remainder of the rural population, or the "residual" population: the population not served by central water supply systems. The residual, in turn, is divided into its farm and nonfarm components.

a. Farm water demand. The farm population was projected as a function of historical land in farms, number of farms, and average per farm population. These factors were selected as measures which most directly affect the farm population.

First, state-level projections of land in farms were allocated among the subareas by a shares analysis, taking into account the distributional shifts among the subareas. These estimates of land in farms were then combined with projections of a second factor, average farm size, to estimate the number of farms in each subarea at the target dates. Finally, the average per farm population in each subarea was projected (10) and applied to the projected subarea number of farms, yielding estimates of farm population. The estimates obtained by this method--incorporating projections of land in farms, average size farm, and persons per farm-- were commensurate with past trends in farm population.

In the determination of farm water use rates, a major factor is the large scale conversion of farm households to running water systems. There is assumed to be a changing mix of farm households with and without running water, with the former consuming substantially larger quantities of water per capita than the latter. The consumption differential is recognized by the United States Geological Survey in its estimates of use rates for rural households: in Maryland and Virginia, the 1970 use rate was 50 gallons per capita per day (60 gpcd in Delaware), while for farm households without running water the comparable rate was only 10 gpcd. The domestic water demand exerted by farms with running water is thus estimated at five times that exerted by households without running water.

A further difference between farm households with running water and those without is that only for the former do water use rates regularly rise (11). Since per capita income has also tended to rise, the increase in water use may be due to the use of income to purchase water using conveniences. This was assumed to be the case in the projection of use rates for households with running water: that as per capita income rises during the target period (see Appendix 3, Economic and Social Profile), there will also be a rise in per capita water consumption.

The water use rates of households with running water were therefore simulated by a function which grew over time. To take into account the satisfaction of demand for conveniences, though, the rate of growth was assumed to diminish over time, leading to a leveling off of the water use rate as its absolute size increases. (12) (See Table 6-14). The use rate for households without running water was held constant at 1970 levels (10 gpcd).

Table 6-14. Running water use rates, farm population

	1970	1980	2000	2020
	- - - - - gals. per capita per day - - -			
Delaware	60	69	86	103
Md., Va.	50	60	77	94

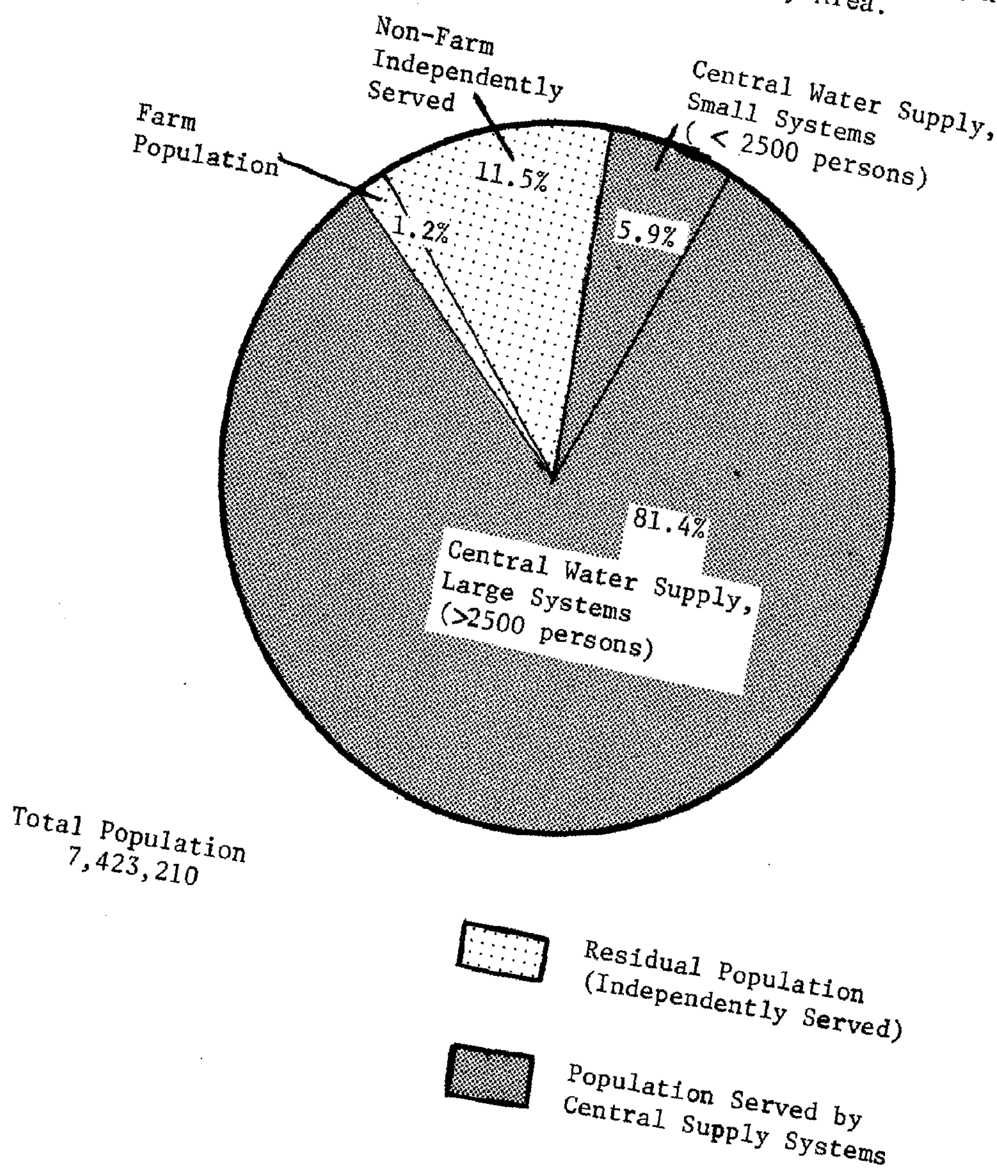
The overall farm water use rate in a subarea was estimated for the target period by projecting from census data the proportion of farm households with and without running water. The farm water use rate varied between the projected rates of farms with and without running water according to this proportion.

b. Domestic nonfarm water demand. The domestic nonfarm water use referred to in this section pertains to the population not served by central supply systems or the "residual" population.

The population served by central supply systems was projected in Appendix 5 by breaking it into two components: the population served by large systems (serving more than 2500 persons) and that served by small systems (serving less than 2500 persons). The former was estimated individually in each subarea and for each large system, the latter as a function of total county population. (13)

The remainder of the population was the residual. The nonfarm residual population was estimated, under the assumption that the farm population is not served by central supply systems, by subtracting the projected farm population from the total residual. (See Figure 6-5).

Figure 6-5 - Water Service in 1970: Population Served by Central Supply Systems, and Residual Population (Independently Served). Chesapeake Bay Study Area.



Nonfarm residual users of water are assumed to consume more per capita than farmers but less than the population served by small water supply systems. In subareas in which farm households dominated the residual, it was assumed that nonfarm residual use rate would approach the farm rate. Conversely, in subareas with relatively few farms, the nonfarm residual population was assumed to have income and demographic characteristics similar to the population served by small central supply systems and its water use rate would accordingly approach the small systems users' rate. (14) (See Table 6-15).

Table 6-15. Small system water use rate (20)

1970	1980	2000	2020
- - - - - - - -	gpcd	- - - - - - - -	
85	93	109	125

The water use rate for the nonfarm residual was therefore estimated to vary between the farm and small system use rates in direct proportion to the percent of the total residual represented by nonfarm component. Where the nonfarm component was largest, its water use rate approximated most closely that attributed to small systems, and where it was smallest, its use rate approximated that attributed to the farm population.

PROJECTED DEMANDS

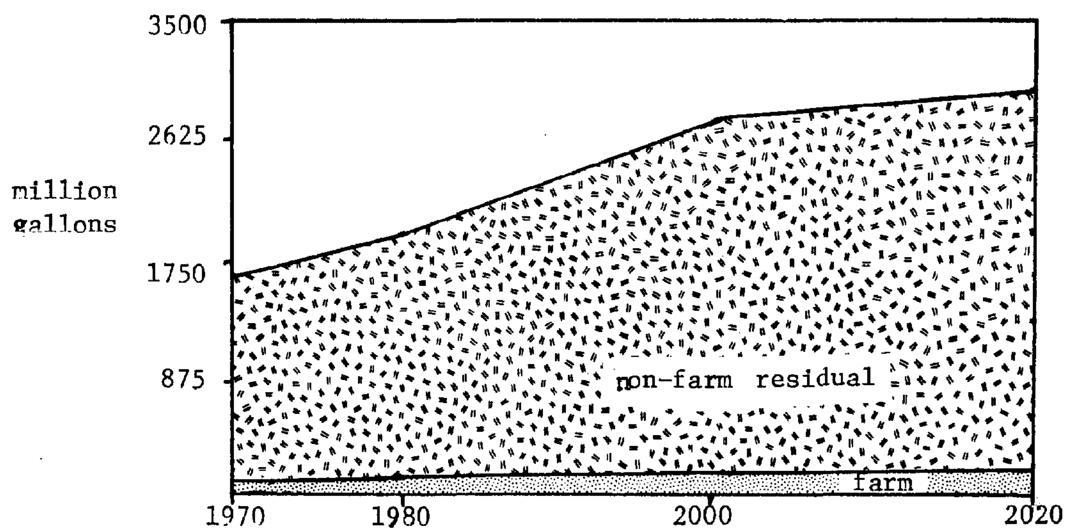
a. Delaware. Only Sussex County was considered in projections of domestic water demand. In 1970, water use of the residual population totaled 1.73 billion gallons. By 1980, the annual rate of consumption is expected to jump to 2.18 billion gallons; by the year 2000, use is expected to total 2.83 billion gallons, and by 2020,the annual consumption rate is expected to rise again to 3.19 billion gallons. Compared with the 1970 total figure, these estimates represent increases of 25 percent for 1980, 63 percent in 2000 and 84 percent by 2020, all substantially greater increases than those projected for the study area as a whole.

As in each of the subareas, the farm population in Sussex County is projected to diminish during the target period: from 5,570 in 1970 to 4,930 in 1980, and to 5,500 by the year 2020. The decreases represent, however, a much less steep rate of change than the average for the Chesapeake Study Area. This reflects the OBERS projection that land in farms in Delaware, in contrast to the rest of the study area, will diminish only slightly, and the expectation that Sussex' share of state land in farms will increase.

As the running water use rate reported for Delaware by the United States Geological Survey for 1970 was somewhat larger than that of the other States in the study area, farm water use rates are somewhat higher in Sussex than in other subareas. Domestic farm water use is projected to rise from 120 million gallons in 1980 to 131 million gallons by 2020.

The nonfarm residual population in Sussex county is projected to rise from the 1970 total of 54,000 to 62,000 in 1980, and to 68,900 in the year 2020. That these increases do not fully reflect the projected rise in population in Sussex during the target period indicates that conversion to central water systems is expected as incomes rise. Following 2000, such conversions outstrip the population increases, and the residual population is projected to fall to 67,800. The water use of the nonfarm residual is expected to rise from 2.06 billion gallons in 1980 to 3.06 billion gallons by 2020. (See Figure 6-6)

Figure 6-6 - Residual water demand in Delaware: projections to 1980, 2000 and 2020.

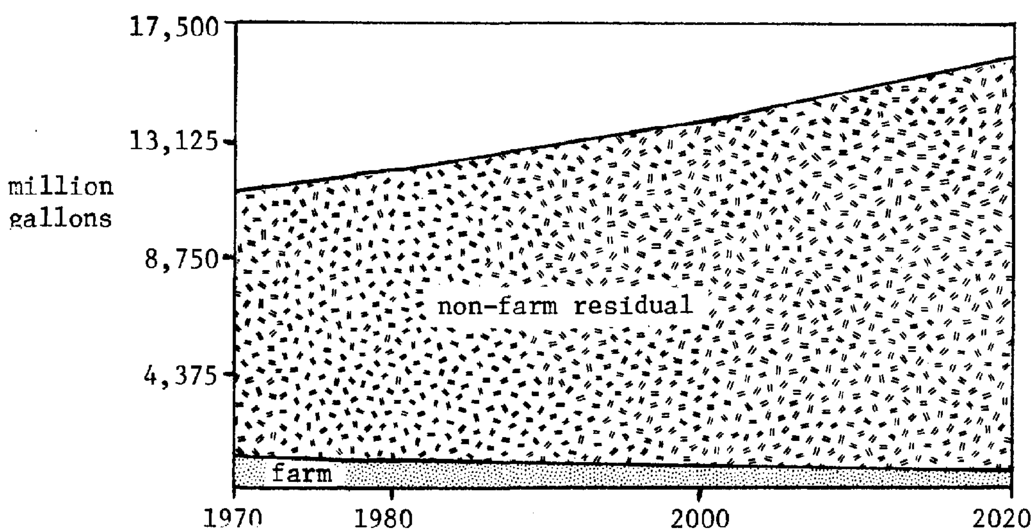


Source: Attachment C, Tables 6-C-2 and 6-C-3.

b. Maryland. The total population in the Maryland portion of the study area is projected to rise from its 1970 total of 2.7 million to 6.8 million in the year 2020, a rise of 150 percent. During the same period the residual population is projected to decline from the 1970 total of 418,000 to 357,000. This drop would indicate that most of the population growth will occur in areas which will be served by central water supply systems. The proportion of the population which is independently served is expected to decline from 15 percent in 1970 to slightly more than 5 percent in the year 2020. Residual water use is expected to rise from the 1970 level of 11.6 billion gallons to 15.8 billion gallons in 2020.

The farm population in the Maryland Study Area is projected to fall from 51,400 in 1970 to only 19,000 by 2020, and its annual water use to drop during the same period from 831 million gallons to 649 million gallons. Because of the decline in land in farms during the target period -- from 2.2 million acres in 1970 to 1.7 million acres in 2020 -- and the expected increase in the average farm size, the number of Maryland farms is expected to fall from 13,700 to only 5,600. This is coupled with a slight drop projected for the average size of farm family, from 3.7 persons to 3.4 persons, in the projection of farm population. The farm water use rate is expected to rise from the 1970 figure of 44 per capita gallons per day (gpcd) to 94 gpcd in 2020, an increase attributed to a rise in both the running water use rate and the proportion of households served with running water.

Figure 6-7. Residual water demand in Maryland: projections to 1980, 2000, and 2020.



Source: Attachment C, Tables 6-C-2 and 6-C-3.

The nonfarm residual population is expected to decline, in the Maryland Study Area, from 367,000 in 1970 to 338,000 by the year 2020. Outweighing the decline, however, is a projected increase in its water use rate, from 80 gpcd in 1970 to 123 gpcd in 2020 as it is expected to more closely approximate that estimated for small systems users. The estimated annual water use of the nonfarm residual therefore rises from 10.8 billion gallons in 1970 to 15.2 billion gallons in 2020, an increase of 41 percent. (See Figure 6-7)

Subarea 1. This subarea, composed of Baltimore and its contiguous counties, had in 1970 the largest residual domestic water use of any of the subareas, 6.20 billion gallons per year. By 1980 the total is expected to increase to 6.27 billion gallons per year, but by the year 2000 the size of the residual is projected to diminish, and its water use is expected to drop to 5.76 billion gallons. By 2020, the general rise in use rates begins once again to outweigh the population decrease, and estimated water use rises to 6.70 billion gallons per year.

The historical data show a decline in land in farms and an increase in the average size of farms which are somewhat sharper than the average for the study area, and this trend is expected to continue into the target period. In 1970, there were 4,360 farms in Subarea 1, a total which is expected to decrease to 3,300 farms in 1980, and 1,550 farms by the year 2020. The farm population is expected to drop from 18,272 in 1970 to 13,170 in 1980, and to only 5,760 in 2020. Its estimated water demand is 274 million gallons in 1980, and 198 million gallons by 2020.

The nonfarm residual population is projected to diminish from 198,000 in 1970 to 181,000 in 1980. The sharpest drop is projected to fall between 1980 and 2000, when there is projected only 141,000 persons. As the Subarea's population is projected to increase during this time, it can be inferred that large scale conversion to central systems will occur between these dates. Following 2000, population increases once again predominate, and by 2020 the nonfarm residual population is expected to number 144,000. Its water use, following the population trends, is projected to fall from 6.00 billion gallons in 1980 to 5.52 billion gallons in 2000, and it rises to 6.50 billion gallons by the year 2020.

Subarea 2. In this subarea domestic water consumption by the residual is expected to climb continuously, from 2.00 billion gallons in 1970 to 2.51 billion gallons of annual use by 1980, 2.82 billion gallons by 2000 and 3.04 billion gallons by the end of the target period, in 2020. Again, these increases are substantially in excess of those projected for the study area as a whole.

Although land in farms in Maryland is projected to fall during the target period, the share of land in farms accounted for by Subarea

2 rises to offset the change. In contrast to the rest of the study area, then, land in farms is projected to decline only slightly during the target period. Thus, though the average farm size in this subarea is largest of any, and it increases to offset the change, the farm population in Subarea 2 is projected to decrease at a slightly more gradual rate than in the study area as a whole.

In addition, a high proportion of farm households in Subarea 2 have historically utilized running water, so that, by 1980, over 95 percent are expected to have this convenience. Reflecting this trend the farm water use rate for Subarea 2 is somewhat higher than the Chesapeake average.

Both the farm population figures and high use rates were considered in the projection of relatively slight declines in farm water use: from the 1970 total of 169.2 million gallons of annual use, it only declines to 165.0 million gallons in 1980 and 148.8 million gallons by the end of the target period.

In Subarea 2 the total population is projected to rise at a rate somewhat less than that of the study area as a whole: from the 1970 total of 131,000, the total is projected to rise to only 153,000 in 1980, 198,000 in 2000 and 247,000 in 2020. The size of the residual population in Subarea 2 is not expected to substantially change during the target period, reflecting the projection that conversion to central supply systems will roughly keep pace with the population increase. The residual population is estimated at roughly 65,000 and, the projected increase in the water use - from 2.25 billion gallons in 1980 to 2.84 billion gallons by 2020 - is largely due to the increase in its water use rate.

Subarea 3. The largest growth in water use of the residual population is expected to occur in this subarea. From the 1970 residual consumption of 1.44 billion gallons, water use is projected to increase to 1.93 billion gallons in 1980. By the year 2000 annual use is expected to reach 3.03 billion gallons and 4.48 billion gallons is the annual use projected by 2020. Compared with the 1970 total, this represents a 100 percent increase by 2000 and more than a 200 percent increase by the end of the target period.

The farm population in Subarea 3 is not expected to diminish as much as other subareas in the Chesapeake Study Area. This is a reflection of relatively slight decreases in land in farms, and the fact that the average number of persons per farm in Subarea 3, only 2.8 in 1970, is not expected to fall much lower in the target period. The farm population, 7,700 in 1970, is thus expected to diminish to 6,200 by 1980, and to start to level off at 4,800 in the year 2000 and 4,100 in 2020. Like others in Maryland a high proportion of farms in Subarea 3 use running water, and the water use rate for farms is and is expected to remain relatively high. Thus despite the estimated reduction in farm population, its water use is expected to rise from 129 million gallons in 1980 to 140 million gallons by 2020.

The bulk of the increase in Subarea 3's domestic water use is due to the expected expansion of water consumption by the nonfarm residual population. As in the rest of the study area, much growth in total population is expected in Subarea 3: from the 1970 total of 127,000, the population is expected to almost double to 247,200 by the year 2020. The nonfarm residual population is expected to grow at an even greater rate than the total population. It is expected to jump from the 1970 total of 45,600 to 96,400 in 2020, and it is projected to represent a rising proportion of the total Subarea 3 population. It can be inferred that a substantial portion of the Subarea's population growth will occur in areas not served by central water supply systems.

The water use of the nonfarm residual is expected to grow from 1.80 billion gallons in 1980 to 4.34 billion gallons by 2020.

Subarea 4. Subarea 4 is composed of the two Maryland counties which are contiguous to Washington, D.C. Perhaps because of the extensive use of central water supply systems, its residual population - approximately 5,900 in 1970 and through the target period - is the smallest of any of the subareas, and its water use reflects this. Only 93.8 million gallons per year were consumed in 1970. The total is expected to jump to 128.0 million gallons in 1980, 194.2 million gallons in 2000, and 244.9 million gallons in 2020.

The sharp declines in the domestic water demand of farms is a reflection of several trends which would tend to diminish the farm population. Both the Maryland total and the Subarea's share of Maryland land in farms are expected to drop during the target period, so that from the 1970 total of 208,000, only 177,000 acres in 1980 and 89,000 acres by the year 2020 are expected to remain in farms. The increase in the average size of farms is greater in Subarea 4 than the Chesapeake average, and the relatively high average number of persons per farm, 4.1 in 1970, is likely to fall rapidly during the target period. Taking these trends into account, the farm population is projected to drop from 6,020 in 1970 to 1,170 by the year 2020.

Since the size of the total residual population is not expected to vary from the 5,900 registered in 1970, and since at that time the residual was entirely composed of farm families, the decline projected for the farm population are matched by the appearance of a nonfarm residual population in the target period. It may be inferred that in Subarea 4 large areas formerly devoted to agriculture will be developed for nonfarm residential use under independent water supply.

The high water use rates of this new nonfarm residual population account for the large increases in domestic water use estimated for Subarea 4. From 1980 to 2020, nonfarm water use is expected to rise from 49 million gallons to 205 million gallons, a fourfold increase.

Subarea 5. This subarea is the only one in Maryland for which a decline in residual water use is projected for the target period. From an estimated level of 2.16 billion gallons of annual demand in 1980, the total is expected to decline to 1.87 billion gallons in 2000 and 1.43 billion gallons in the year 2020.

The farm population is expected to fall from 9,200 in 1980 to 7,980 in 2000 and to 3,600 by 2020. This projection reflects a trend toward a Subarea decline in land in farms which is sharper than that projected for other subareas, although it is mitigated somewhat by the relatively small average size of farms characteristic of the region. Since only 78 percent of farm families had running water in 2000, the farm water use rate lagged behind that of most other subareas. The difference is expected to narrow during the target period, as many farm households convert to running water systems. Farm water use is projected to decline from 147 million gallons in 1980 to 123 million gallons in 2020.

Most of the decline in water use is expected to occur as a result of a shrinking nonfarm residual. Totaling an estimated 60,700 in 1970 and 1980, the nonfarm residual is expected to drop to 45,000 by the year 2000 and to 29,500 by 2020. Since during the same period, the total population is expected to increase, this decline represents a diminishing proportion of population independently served: from 60 percent of the total population in 1970, the residual is expected to represent only 11 percent by the end of the target period. Most of the Subarea's population growth may be expected to occur in areas served by central water supply systems.

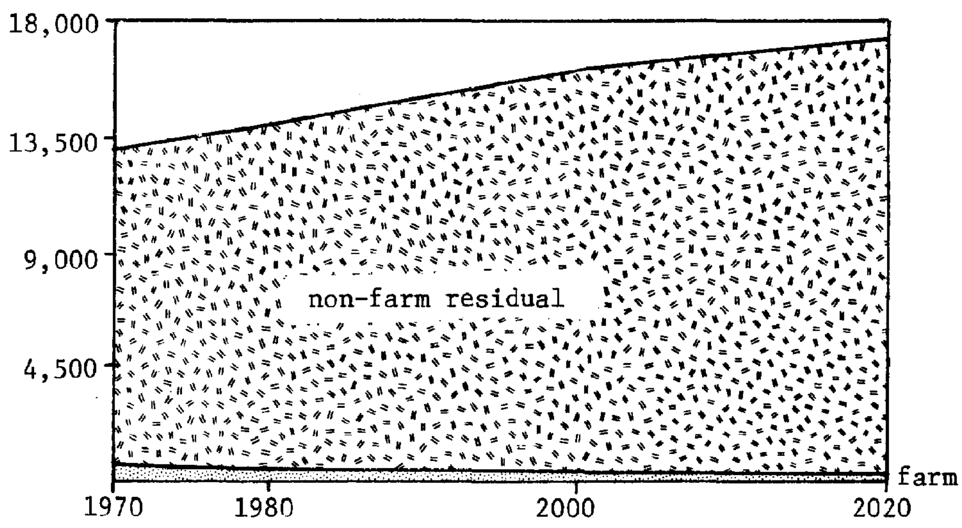
In the period from 1980 to 2020, nonfarm residual water use is projected to fall from 1.75 billion gallons to 1.31 billion gallons.

c. Virginia. The total population in the Virginia portion of the Study Area is estimated to increase even more than that of Maryland: from the 1970 total of 1.5 million it is expected to reach 4.9 million by 2020. As in the other states, however, the residual population is projected to decline during that period, from 468,000 to 389,000. The estimated proportion of the total population which is independently served thus drops sharply from 31 percent in 1970 (the highest of the three States) to only 8 percent by the end of the target period. Estimated residual water use rises from 13.4 billion gallons in 1970 to 17.4 billion gallons in 2020.

The farm population in the Virginia Study Area is expected to diminish, during the target period, by more than 70 percent from 35,800 in 1970 to only 10,300 in 2020. During that period, its annual water demand is also projected to decline, though at a lesser rate, from 530 million gallons to 354 million gallons. Land in farms in the Virginia Study Area is expected to decline during the target period from 2.1 million acres to 1.3 million acres. Coupled with the characteristically large Virginia farms (the 1970 average was 194 acres), this trend leads to an estimated decrease in the number of farms from 10,900 in 1970 to only 3,000 in 2020. The farm water use rate is expected to rise from the 1970 figure of 41 gallons per capita per day (gpcd) to 93 gpcd in 2020, as the proportion of farm households which are served with running water rises from the 1970 figures of only 77 percent to almost 100 percent in 2020.

The projected nonfarm residual population in the Virginia Study Area declines from 432,500 in 1970 to 378,200 by 2020. Despite the decline its annual water use is expected to increase from 12.9 billion gallons in 1970 to 17.1 billion gallons in 2020. This one-third rise is largely a reflection of the expected increase in the per capita use rate from 82 gpcd in 1970 to 124 gpcd in 2020. That increase, in turn, is attributed to a projected rise in the small-system water use rate, which the nonfarm residual rate is expected to approximate as the number of farm households decreases. (See Figure 6-8)

Figure 6-8 - Residual water demand in Virginia: Projections to 1980, 2000 and 2020.



Source: Attachment C, Tables 6-C-2 and 6-C-3.

Subarea 1. This subarea, located on the southern tip of the Delmarva Peninsula, is one of the most rural in the Chesapeake region. The water use of the residual population, 0.98 billion gallons in 1970, is expected to rise at a rate somewhat higher than the Study Area average: annual use is expected to jump to 1.17 billion gallons in 1980, 1.33 billion gallons by 2000, and 1.50 by the year 2020.

Although Subarea 1 is expected to lose some land in farms to other uses during the target period, its loss is the least of any of the subareas. Its 156,000 acres in farms is projected to remain virtually constant through 1980, diminish only slightly to 153,000 acres in 2000, and only to 145,000 acres by the end of the target period. The increasingly large average size of farms in the Subarea, and a fall in the number of persons per farm are reflected in projections of diminishing population, but the decline is expected to level off after the year 2000. The steepest drop in population is expected between the years 1980 and 2000 - from 1,640 to 1,180 - and the farm population is expected to level off to just under 1,000 by the year 2020.

The farm population in this relatively isolated subarea has historically exhibited the lowest proportion in the Chesapeake of households with running water: only 67 percent of all farm households used running water in 1970. Although the total is projected to rise to 80 percent by 1980, and over 92 percent by the year 2000, the paucity of running water facilities is reflected in projections of low farm water use rates in the first part of the target period. Estimated domestic use of water on farms is 30 million gallons in 1980, and it rises slightly to 32 million gallons by 2020.

Subarea 1 is projected to have the smallest increase in total population of any subarea: the total of 43,000 persons in 1970 is expected to rise only 17 percent to 51,000 by the end of the target period. During this time the residual population is expected to remain constant, at roughly 34,000.

Two points of note emerge from these figures: first, Subarea 1 has the highest proportion of independently served population of any of the subareas - close to three-quarters were so served in 1970, and the figure is estimated to drop to only 64 percent by the year 2020. Second, the decline in the farm population is expected to be offset by a rise in the nonfarm residual, signaling the development of farmland for residual use.

The water use of the nonfarm residual is projected to increase from 1.09 billion gallons in 1980 to 1.46 billion gallons by the end of the target period.

Subarea 2. Subarea 2, in contrast to Subarea 1, is a rapidly urbanizing area which touches the District of Columbia to the southwest. It is expected to exhibit one of the largest growth rates in total water use of any of the subareas: from 2.83 billion gallons of annual use in 1970, the residual population is expected to consume 3.56 billion gallons annually by 1980, 4.36 billion gallons by the year 2000, and 4.81 billion gallons by 2020.

A large drop in land in farms is projected for Subarea 2: from 315,000 acres in 1970, the total is expected to drop to only 187,000 acres by the end of the target period. In addition, large increase are projected for the size of farms, and the conjunction of these two trends makes likely a large drop in the Subarea's number of farms. From the 1,350 farms operating in 1970, only 840 are expected to survive to 1980; and by the end of the target period, only 320 are estimated to remain in operation. The loss of these farms is the major factor behind the projected reduction in the farm population from 3,590 in 1970 to only 1,070 in the year 2020. Its estimated water use totals 47 million gallons in 1980, and 37 million gallons in the year 2020.

The total population of the Subarea is expected to increase more than fourfold, from 603,000 in 1970 to over 2,650,000 by the year 2020. Much of this growth is expected in areas served by central supply systems, but enough is expected to occur in areas characterized by independent water supply that the nonfarm residual is projected to grow, as well. Estimated at 90,800 in 1970, the nonfarm residual is estimated to increase to 109,000 in 2000 before it drops to 105,200 in the year 2020. By that time, only four percent of the Subarea's population will be independently served. The water use of the nonfarm residual is projected to rise from 3.51 billion gallons in 1980 to 4.78 billion gallons in 2020.

It is the expected increase in the nonfarm residual population, with its high rate of water consumption, which is the principal factor in Subarea 2's increase in domestic water use.

Subarea 3. Water use by the residual population in Subarea 3 is expected to rise in the early part of the target period, and then fall off sharply. In 1970 an estimated 0.98 billion gallons of water were consumed, a total which is expected to rise to 1.23 billion gallons of annual use by 1980, and 1.44 billion gallons by the year 2000. Before the end of the target period, however the total is expected to fall off to only 0.86 billion gallons annual use.

Trends which affect the farm population in Subarea 3 almost directly parallel those of Subarea 2. The region is marked by a large decline in land in farms (from 148,000 acres in 1970 to an expected 60,000 acres by the end of the target period). At the same time, the average size of farms in the Subarea, already larger than the average for the study area as a whole, is expected to increase rapidly. As a result, the number of farms in Subarea 3 is projected to fall off rapidly from 770 in 1970 to 500 in 1980 and only 150 by the end of the target period.

The domestic water use on farms is further reduced in Subarea 3 by the low average number of persons per farm (only 2.2 as recorded in the 1970 Census). It is expected to drop from 27 million gallons in 1980 to only 16 million gallons in 2020.

The steep increase in population estimated for Subarea 2 does not carry over into Subarea 3. Though the total population is expected to more than double in the target period, from 49,000 in 1970 to 114,000 by 2020, the rate of increase is substantially less than the Study Area average, and is expected to level off toward the end of the target period.

The residual population follows the general population growth early in the target period, but, perhaps reflecting a large scale conversion to central water supply systems, it is expected to fall off rapidly toward the end of the target period, from 36,000 to slightly over 19,000.

It is this expected falloff in the residual population which is reflected in the downward turn in the subarea's residual water use, as it outweighs even the increases in the per capita water use rates of the residual population. Nonfarm residual water use, projected to rise between 1980 and 2000 from 1,202 to 1,420 million gallons, accordingly is expected to fall off to only 845 million gallons by the year 2020.

Subarea 4. Residual water consumption in Subarea 4 of Virginia is expected to increase at a rate above the study area average, although not as great as the rates of increase in Subareas 2 and 3. An estimated 2.41 billion gallons were consumed in 1970, a total which is projected to jump to 3.61 billion gallons by the end of the target period in 2020.

Although the Subarea's acreage in farms is expected to fall at a slightly greater rate than the study area average, it is the rapid increase in the average size of farms which is primarily responsible for the reduction in the subarea's number of farms, and hence its farm population. The farm population, numbering 9,030 in 1970, is expected to fall to only 2,510 by the year 2020. Since only 80 percent of the farms in 1970 utilized running water, farm water use rates are somewhat lower than the average. The domestic demand on farms is thus expected to drop from 138.1 million gallons of annual use in 1970 to 85.4 million gallons in the year 2020.

Projections of total population rise, in Subarea 4, from the 1970 figure of 322,000 to 428,000 in 1980, and to over 1,000,000 in the year 2020. The rate of increase is somewhat above the rate for the Chesapeake Study Area. Despite the population increases, however, the size of the residual population is expected to remain in the range of 80,000 to 90,000, and exhibit only a slight decline during the target period.

The rise in the nonfarm residual water use projected for Subarea 5 is therefore almost entirely due to the expected increases in its per capita use rate. Its estimated water use increases from 2.75 billion gallons in 1980 to 3.53 billion gallons in 2020.

Subarea 5. Despite the size of Subarea 5, its domestic water use in 1970, at 1.35 billion gallons, was relatively small. By 1980, however, annual residual consumption is expected to increase by 25 percent, to 1.70 billion gallons, and by the year 2000, is expected to reach 2.09 billion gallons. By the end of the target period residual water use is expected to total 2.35 billion gallons, an increase of 73 percent over the 1970 figure.

This increase, at a rate twice that of the study area average, is expected to occur despite the diminution of the farm population. Numbering 6,040 in 1970, this component of the residual is projected to drop to 4,920 by 1980, and to only 2,040 by the end of the target period. The projected fall in the Subarea's farm population has historically been due to the rapid increase in the average farm size of the Subarea, a trend which is expected to continue into the future. Domestic farm water use is estimated to diminish from 94 million gallons in 1980 to 69 million gallons in the year 2020.

The expected growth of the domestic water consumption stems from a projected increase in the size of the nonfarm residual population, which is expected to grow from 43,600 in 1970 to 50,600 in 2020. This portion of the population constituted 53 percent of the total Subarea population in 1970, and it is expected to constitute no less than 37 percent by the end of the target period. Its annual demand, estimated to be 2.06 billion gallons in 1980, is projected to rise to 3.06 billion gallons by the year 2020.

Subarea 6. The diminutive size of Subarea 6, on the other hand, is directly reflected in its residual water use - one of the smallest of any subarea - and the total is expected to diminish through the target period. Only an estimated 687 million gallons were consumed in 1970. The total is projected to fall off sharply to 406 million gallons in 1980 and to 198 million gallons by the year 2000. By the year 2020 annual water consumption is expected to rise slightly, to 228 million gallons.

The small farm population, only 260 in 1970, is expected to be further reduced, during the target period, to less than 100. The reduction is largely a reflection of the trend toward larger farms in Subarea 6, and the expected decline in acreage in farms - from 10,600 in 1970 to 6,600 by the end of the target period.

Almost 99 percent of the total residual population is composed of nonfarm households, but this population, too, is expected to fall off sharply, particularly in the early part of the target period. The residual population was estimated at 22,100 in 1970, but it is projected to decrease by almost half - to 11,900 - by the year 1980, and by half again - to less than 5,000 - by the year 2000.

Although the nonfarm residual population is projected to level off at the latter figure, its estimated sharp reduction in the beginning of the target period leads to projection of total water use which also fell off sharply. From 403 million gallons of annual use in 1980, the nonfarm residual is expected to consume only 195 million gallons in 2000, a total which rises but slightly, to 225 million gallons, by the year 2020.

The decrease in the size of the residual would reflect conversion of parts of the Subarea to central supply systems, as the total population is expected to almost double - from 33,000 to 63,000 - between 1970 and the end of the target period. While almost 68 percent of the total population was recorded as independently served in 1970, the comparable figure projected for the year 2020 is a mere 8 percent.

Subarea 7. Like Subarea 6, Subarea 7 is one of the few subareas for which a decline in the total residual water use is expected during the target period. The major decline is projected for the decade between 1970 and the start of the target period in 1980, in which annual consumption is expected to drop from 1.86 billion gallons to 1.19 billion gallons. During the target period the estimated reductions are considerably more gradual, as consumption is projected to fall to only 1.07 billion gallons in the year 2000 and 0.92 billion gallons in 2020.

Subarea 7 is one of the few in which domestic water consumption on farms is expected to rise during the target period. Although the farm population is projected to decline - from 1,380 in 1970 to 750 by 2020 - the decline is not as steep as the average for the study area. Only a slight decrease in land in farms is expected, from 121,000 acres in 1970 to 109,000 acres in 2020. In addition, the relatively high percentage of farm households with running water - 90 percent, in 1970 - is reflected in the farm water use rate, the highest in the Chesapeake Study Area. Domestic farm water consumption is expected to rise from the 23 million gallons consumed in 1970 to 25 million gallons by 1980, and 26 million gallons by the year 2020.

It is the estimated decline in the nonfarm residual population which is reflected in the diminishing total residual water demand, as the nonfarm component consumes 98 percent of the residual water used in Subarea 7. There are two factors prominent in the estimated decline in the residual population between 1970 and 1980: first, a less than average increase projected for the total population and second, a sharply decreased proportion of the population which is expected to be independently served. In that decade, the population of Subarea 7 is projected to increase by only 17 percent, from 261,000 to 306,000 persons. During the same period, the proportion of the population which is independently served is projected to decline from 23.4 percent to only 11.7 percent. As a result of these trends, the residual is expected to decrease sharply, from 59,800 persons in 1970 to only 34,800 in 1980, and its water use from 1,840 million gallons to 1,170 million gallons.

After 1980 the proportion of the population which is independently served is expected to continue to fall rapidly, but the decline is offset by the sharp population growth expected in the Subarea. The fall in the residual population is somewhat moderated, therefore, and its water use is projected to fall only to 894 million gallons by the year 2020.

Subarea 8. The residual domestic water demand in Subarea 8 is estimated at 2.33 billion gallons of annual use in 1970. Consumption is expected to rise fairly rapidly, in the early part of the target period, to 2.80 billion gallons in 1980 and to 3.21 billion gallons by the year 2000. During the latter part of the target period, however, annual consumption is expected to fall off slightly, to 3.17 billion gallons.

The number of farms in Subarea 8 is projected to fall rapidly, from the 3,020 farms in operation in 1970 to 2,070 in 1980, and to only 760 by the year 2020. This is a reflection of the projected decline in the Subarea's share of Virginia land in farms - of 444,000 acres in farmland in 1970, only 245,000 acres is expected to remain in farms by the end of the target period - and increases in the relatively small average size of farms. The farm population is expected to fall accordingly, from a total of 10,760 in 1970 to 7,240 in 1980 and to 2,580 in the year 2020, and its water use is expected to diminish from 149 million gallons in 1970 to 87 million gallons in 2020.

The nonfarm residual population is expected to increase slightly from 75,400 in 1970 to 81,700 in 1980, and fall to 68,500 by the end of the target period. Though it constituted 61 percent of the total in 1970, the projected decline in that proportion to 35 percent in 2020 more than outweighs the relatively slight increase estimated for the Subarea's total population. The estimated nonfarm residual water demand is 2.67 billion gallons in 1980, 3.10 billion gallons in 2000, and 3.08 billion gallons in 2020, an increase due entirely to projected growth in the water use rate.

LIVESTOCK WATER DEMAND

ASSUMPTIONS AND METHODOLOGY

Livestock consumption and sanitary uses represent a second major demand for water in the target years. As in the estimation of irrigation water demand, water use was projected by estimating production in each subarea by shares analysis. Livestock water demands were then estimated using livestock number and water use coefficients.

In this procedure the shares analysis was modified somewhat to take into account the form of the OBERS state livestock projections, which were in terms of live weight demanded at the market in the target date years. Once state level estimates of live weight at market were allocated among the subareas, it was necessary first, to convert market weight into livestock numbers, and second, to take into account the supportive livestock population.

State-level demands for livestock and livestock products were converted to livestock numbers by dividing them by a set of average livestock weights and - in the case of chickens and milk cows - productivity. The set of average livestock weights developed for the conversion of production to livestock numbers is given in Table 6-16. While the weights roughly parallel the 1970 market weights for the Chesapeake region, they nonetheless reflect changes in livestock production now underway. The conversion weights for pork and sheep are slightly higher than current levels, taking into account the development of more efficient feeding practices and improved breeds. Similarly, milk and egg production are assumed to increase over current levels, due to improvements in nutrition and management practices permitting performance tests and selective breeding. The average weight assumed for turkeys, however, is assumed to be slightly below current levels, due to market preferences for slightly smaller birds.

Marketed livestock represent only part of the total livestock population, and only part of livestock water demands. In support of the marketed livestock are breeding flocks and herds, which exert a substantial demand for water. In addition, not all animals are expected to reach marketable age, and those who do not also exert demand for water. Given the numbers of livestock needed to meet demands as projected by OBERS, it was possible to estimate the breeding stock through fertility coefficients and mortality numbers through mortality rates. Livestock numbers were thus expanded to include the supportive livestock population.

Table 6-16-- Average market weights, livestock and livestock products, target projection years 1/

Product	Unit	1980	2000	2020
Hogs - pigs	lb	230	230	230
Sheep - lambs	lb	110	110	110
Broilers	lb	3.5	3.5	3.5
Turkey	lb	15	15	15
Eggs/chicken	eggs	240	265	280
Milk/cow	lb	10818	12097	12218

1/ Weight figures represent weighted averages of young stock and fully grown livestock, derived through examination of historical state data and future projections of average weights. For future average weights, source was Lee A. Christensen, The Economic Base of the Southeast Wisconsin Rivers Basin with Emphasis on the Agricultural Sector; reference Report 13, USDA, ERS, 1970. These figures were used when it was demonstrated that in historical livestock weights the gap between the two study areas was rapidly closing, and that by 1970 most were within 5% of each other.

The water demands of the estimated livestock population were projected on an annual basis, to take into consideration the different time periods during which each of the three components exert demand. Breeding stock or flocks were assumed to exert demand for water during the entire year, while livestock to be marketed only exert demand during the period in which they are raised. Given that mortality had an equal chance of occurrence at any moment during that time, it was assumed that mortality exert demand during roughly half the longevity of marketed animals.

Approximate water use coefficients for each of the components of the livestock population were developed, and applied to project the water demands of each component. In practice, it was found most straightforward to combine these coefficients with the fertility and mortality rates and with the livestock weight and productivity parameters, to derive single number and water use coefficients (see Tables 6-17 and 6-18). The latter, when applied to the subarea demands for livestock and livestock products, yielded estimates of livestock numbers and water use.

Table 6-17-- Livestock water use rates: 1980, 2000, and 2020, Chesapeake Bay Study

Livestock Products Marketed	Water Use Component	1980 Coefficient 1/	1980 Water use coefficient	1980 Period of use	2000 Coefficient	2000 Water use coefficient	2000 Period of use	2020 Coefficient	2020 Water use coefficient	2020 Period of use
			Gallons	Days		Gallons	Days		Gallons	Days
HOGS										
	Marketed animals	1.0	4/day	180	1.0	4/day	180	1.0	4/day	180
	Breeding stock	14.5	4/day	365	16.0	4/day	365	17.0	4/day	365
	Mortality	.10	1/day	82	.07	1/day	78	.05	1/day	75
SHEEP										
	Marketed animals	1.0	1.5/day	180	1.0	2/day	150	1.0	2/day	140
	Breeding stock	1.2	2/day	365	1.25	2/day	365	1.25	2/day	365
	Mortality	.10	.8/day	90	.07	1/day	75	.05	1/day	70
EGGS										
	Laying flock	1.0	26/yr.	*	1.0	26/yr.	*	1.0	26/yr.	*
	Mortality	.08	2.5/day/100 2/	180	.06	3/day/100	180	.05	3/day/100	180
BROILERS										
	Marketed birds	1.0	1.5/yr.	*	1.0	1.5/yr.	*	1.0	1.5/yr.	*
TURKEYS										
	Marketed birds	1.0	18/yr.	*	1.0	18/yr.	*	1.0	18/yr.	*
	Breeding flock	50.0	12/day/100	365	50.0	14/day/100	365	50.0	14/day/100	365
	Mortality	.08	6/day/100	70	.06	6.5/day/100	62	.05	6.5/day/100	62
MILK										
	Milk cows	1.0	14/day 24/day (for milk)	365 300	1.0	14/day 27/day (for milk)	365 300	1.0	14/day 28/day (for milk)	365 300
	Calves 3/	.6	12/day	365	.6	12/day	365	.6	12/day	365
	Mortality	.04	6/day	180	.03	6/day	180	.03	6/day	180

1/ Coefficients relate (1) numbers of marketed animals, or producing animals, to (2) numbers of breeding flocks or herds, and (3) mortality. Numbers of marketed animals or producing animals are estimated by relating projected demands for livestock products to average weights or productivity. Numbers in breeding flocks or herds are estimated by dividing (1) by the coefficients pertaining to (2). Mortality is estimated by multiplying (1) by the rates listed for (3).

2/ Gallons per day per 100 birds.

3/ Dairy calves not sold for beef or veal. Numbers are determined by multiplying number of milk cows by factors listed.

Table 6-18. Livestock number and water use coefficients 1/

		1980	2000	2020
HOGS	number	0.0051	0.0049	0.0048
	water use	3.6039	3.5509	3.5201
SHEEP	number	0.0176	0.0170	0.0168
	water use	8.0503	8.0841	7.8864
CHICKENS	number	0.0045	0.0040	0.0038
	water use	0.1098	0.0993	0.0938
BROILERS	number	0.2857	0.2857	0.2857
	water use	0.4286	0.4286	0.4286
TURKEYS	number	0.0733	0.0720	0.0713
	water use	1.2808	1.2843	1.2816
MILK COWS	number	0.0002	0.0001	0.0001
	water use	1.3977	1.3208	1.3144

1/ Applied to estimated demand for live weight at market or livestock product (milk, eggs).

Source: Tables 6-16 and 6-17.

Two exceptions to this procedure were the estimation of beef cattle and dairy cow water demand. For beef cattle, the dairy cow population is expected to contribute salvage, heifers, and veal calves to beef demand , and the feedlot beef population was estimated only after these dairy components were subtracted from the beef demand allocated to each subarea. In addition, backup inventory was estimated in proportions consistent with each subarea's historical trend. Dairy cow water use was projected to rise proportionally with the increase in milk output per cow.

In the analysis of future livestock water demands, it is evident that per unit livestock water use is almost uniformly lower than the per unit use listed in the U.S. Geological Survey (15), the main source of data for the livestock section of the Existing Conditions Report. The difference in rates is largely attributable to the methodology employed in the projections.

The point of departure in the projection of livestock water use was the estimation of market numbers, the portion of the livestock population which would be required to meet subarea demands. It was assumed that for most livestock (16) the water use rate for this portion of the population would approximate the average rate for a mature animal, the rates given in the U.S. Geological Survey.

From the portion of the livestock population needed to meet demand, however, breeding flocks and mortality numbers were derived, each with explicit reference to the number of days per year they consume water and their consumption rate. The analysis of the livestock population with respect to water consumption was therefore more detailed than a simple measure of inventory or sales, and it was judged that the aggregate nature of the Geological Survey water use rates were no longer appropriate. Yearly per unit use rates were developed as an end product of the analysis of each of the three components of the livestock population required to meet the OBERS estimates of livestock demand.

On a more explicit level, several factors can be listed which would tend to depress the annual per unit water use rates for livestock.

a. Inclusion of backup herd with lower water use rates. This is the case in the analysis of water demands exerted by milk cows. The back-up herd - including heifers and calves - swelled numbers by an average of 64 percent, yet its average water use rate was estimated at only 35 percent that of a milk-producing cow.

b. Inclusion of demand numbers with lower water use rates. Measurement of numbers by inventory in some cases excludes demand numbers from the analysis. An inventory of sheep taken on January 1 (as in the 1969 Census of Agriculture) would not include lamb sales, whose 180-day period of water consumption does not begin until later in the year. Though their use rate approximate those of the backup herd, lambs are assumed to have a shorter life span. Annual water use for this portion of the sheep population is thus cut to a fraction of that of the backup herd, and it depresses the aggregate per unit use rate.

c. Inclusion of mortality numbers. Inclusion of mortality numbers has a dual effect on the per unit water use rate aggregated over all components: not only does this component tend to swell the numbers of livestock counted, but, due to the truncated life span of the animals it represents, its annual use rate is below that of the rest of the herd. The use rate over all components is thus diminished by its inclusion.

d. Combination of factors. The largest differences in per unit use rates are due to a combination of the above three factors. In the case of beef, the water use of one and two year calves is included in the annual use of the backup herd, and their relatively low use rates depress the average. In addition, demand numbers include animals, such as veal, who are marketed before maturity and whose consumption over a shortened life cycle sharply reduces the overall annual use of this portion of the herd. Finally, the overall use rate is reduced by the inclusion of mortality numbers, which were assumed to consume water at an annual rate much reduced from that of mature animals.

In some cases water use rates were projected to increase, due largely to expected increases in per unit output. This effect is seen, for example, in the per unit rate for chickens. The basic rate is projected to jump from 22 gallons per year to 26 gallons per year in the target period, an increase due to an expected increase in annual egg production per bird.

Because of these factors, and the influence of changing average livestock weights, the numbers and per unit water use between 1970 and the target dates are not comparable.

PROJECTED DEMANDS

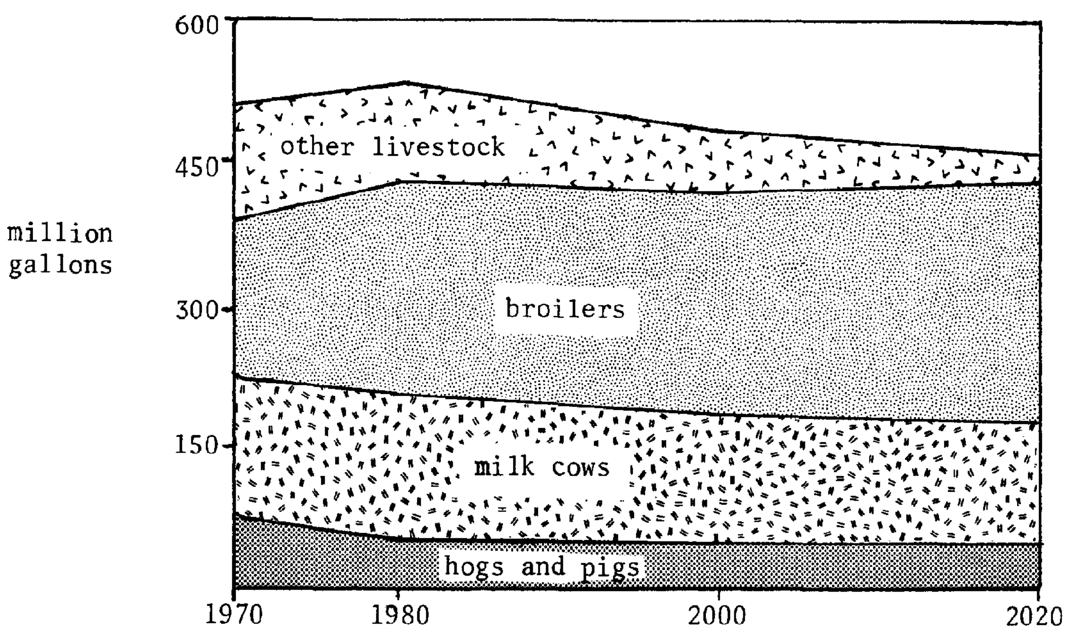
a. Delaware. Though livestock and poultry water demands in Delaware are among the largest in the study area, they are expected to decline from a total of 527 million gallons per year in 1980 to 479 million gallons in 2000 and 460 million gallons in 2020.

The major livestock users of water in Delaware are broilers. The demand for broilers from Delaware is expected to jump from the 1964 total of 415 million pounds (17) to 541 million pounds in 1980 and to 581 million pounds in 2020. Numbers of broilers are expected to rise commensurately. From the 1969 census total of 112 million, the total number of broilers sold is projected to increase to 154 million in 1980 and to 170 million in 2020. Broilers are expected to consume 232 million gallons of water in 1980, or 44 percent of all Delaware livestock and poultry water use, a figure which rises to 249 million gallons (52 percent) in 2000 and 255 million gallons (55 percent) in 2020.

The second major users of water are milk cows. The demand for milk from Delaware is expected to fall from the 164 total of 165 million pounds to 118 million pounds in 1980, and to 100 million pounds in 2020. In 1980, this part of livestock demands is projected to represent 31 percent of the total in Delaware, a proportion which falls slightly during the rest of the target period. Milk cows are expected to consume 164 million gallons of water in 1980, 144 million gallons in 2000, and 131 million gallons in the year 2020.

Hogs and pigs account for the other major use of water among livestock in Delaware. Their estimated consumption is 50 million gallons, or about ten percent of the total. (see Figure 6-9)

Figure 6-9. Livestock water demand in Delaware. Projections to 1980, 2000, and 2020.



Source: Attachment C, Tables 6-C-5 thru 6-C-11.

b. Maryland. The total livestock demand in the Maryland portion of the study area is projected to rise slightly from 2.31 billion gallons in 1980 to 2.43 billion gallons in 2020.

The major livestock users of water in the Maryland Study Area are milk cows, projected to account for 46 percent of the total 1980 water use and 55 percent of the 2020 total. Although the proportion of state production accounted for by the study area is expected to diminish from 50 percent in 1980 to 37 percent in 2020, the decline is outweighed by the projected increase in state-level milk production, from 1.6 billion pounds in 1980 to 2.8 billion pounds in 2020. In addition, per unit consumption is expected to rise due to increased productivity and sanitation needs. Water use by milk cows is therefore projected to increase from 1.07 billion gallons in 1980 to 1.34 billion gallons by 2020.

The second major users of water are cattle and calves, projected to account for 770 million gallons in 1980 and 660 million gallons in 2020, or 33 and 27 percent, respectively, of the Maryland Study Area total for livestock in each of those years. The expected decline is attributed to the projected fall in state beef production during the target period, from 111 million pounds in 1980 to 102 million pounds in 2020. The study area's share of state production is expected to remain roughly constant at 70 percent.

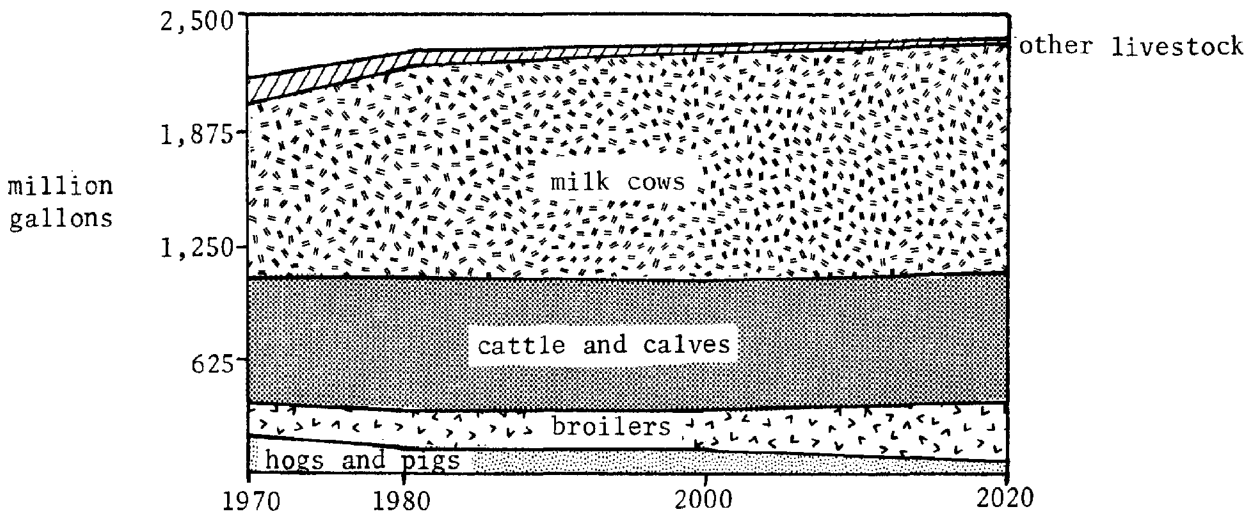
Broilers are the third major users of water in the Maryland Study Area, with a projected demand of 266 million gallons in 1980 and 307 million gallons in 2020. Broiler production in Maryland is expected to be increasingly concentrated in the study area portion of the state, with 88 percent of the state total in 1980 and almost 95 percent by 2020. Broilers are expected to consistently account for 12 percent of the livestock total in the Maryland Study Area.

Hog production in Maryland is also expected to be concentrated in the study area portion of the state, with 95 percent of Maryland hogs in 1980, and almost 100 percent in 2020. Despite this increase, however, state pork production is projected to fall off from 44 million pounds in 1980 to 28 million pounds in 2020, with the result that estimated hog water use falls off from 150 million gallons to 97 million gallons. (See Figure 6-10 below).

Subarea 1. Total livestock and poultry use is projected to increase, in this subarea, from 1.07 billion gallons of annual use in 1980 to 1.18 billion gallons in 2000 and 1.33 billion gallons in 2020. It has by a substantial margin the largest livestock water use of any of the subareas.

Easily the largest users of water among livestock and poultry are milk cows. The demand for milk in Maryland is expected to almost double by the end of the target period, and Subarea 1 is projected

Figure 6-10- Livestock water demand in Maryland. Projections to 1980, 2000, and 2020.



Source: Attachment C, Tables 6-C-5 thru 6-C-11.

to hold a constant twenty-five percent share of the total. Water demands by milk cows are estimated to increase from 599 million gallons in 1980 (56 percent of the Subarea total) to 730 million gallons in 2000 (62 percent) and to 893 million gallons (67 percent) by the end of the target year.

Most of the remaining livestock water in Subarea 1 is used by cattle and calves. Although the Subarea's share of beef sales is expected to increase from 40 percent in 1969 to close to 50 percent by the end of the target period, such increases are offset by projected declines in Maryland beef production. The net result is that water use by beef is expected to remain constant during the target period, at approximately 430 million gallons annually.

Subarea 2. Aggregate water use by livestock and poultry is projected to diminish, during the target period, from 597 million gallons in 1980 to 544 million gallons in 2000 and 513 million gallons in 2020.

Once again the major livestock users of water are milk cows. Although the Subarea share of Maryland milk sales is expected to diminish from 18 percent in 1970 to 17 percent in 1980 and to 10 percent by the end of the target period, the large increase in demand at the state level more than balances the distributional losses. The number of milk cows and backup herds is expected to remain constant during the target period at around 40,000 animals, and their water use is projected to be 380 million gallons, or 65 to 75 percent of the Subarea total.

Cattle and calves represent the next largest users of water, although they are expected to consume diminishing amounts of water during the target period. The decline is due to a falling share of State beef sales - the 16 percent share in 1969 is expected to fall to 11 percent by 2020 - and to the projected decline in beef demand at the state level. Thus the estimated water demand of cattle and calves, 155 million gallons and 26 percent of the Subarea's livestock demands in 1980, is expected to drop to 90 million gallons and 18 percent by the end of the target period.

Hogs and pigs are expected to account for a roughly constant proportion, eight percent, of Subarea livestock demands. Their water demand is projected to fall from 53 million gallons in 1980 to 36 million gallons in 2020, as the increasing Subarea share of State production is offset by the projected decline in Maryland demand for pork.

Subarea 3. In Subarea 3, water use by livestock and poultry is projected to increase slightly during the target period, from 390 million gallons of annual use in 1980 to 412 million gallons in 2000 and 422 million gallons in 2020. The small magnitude of the changes in aggregate demand conceals large shifts in its composition.

The major livestock consumers of water in the Subarea are broilers. Broiler production in Maryland is expected to rise sharply during the target period, from 151 million in 1969 to 201 million in 1980, 211 million in 2000, and 215 million in 2020. Further, this production is expected to be increasingly concentrated in Subarea 3, where the 81 percent share in 1970 is projected to rise to 85 percent in 1980, and to 95 percent by 2020. Water use by broilers is projected to rise from 260 million gallons in 1980 to 306 million gallons by 2020, an increase of eighteen percent and from two-thirds to almost three-quarters of the total.

Another increase in water demand is expected for cattle and calves. This is mainly due to projected increases in the Subarea's share of State beef production, from 2.2 percent of beef sales in 1969 to 4.1 percent in 1980 and to 5.5 percent by the end of the target period. The estimated cattle and calf water demand rises from 50 million gallons in 1980 to 61 million gallons by 2020, and it represents roughly thirteen percent of the Subarea's livestock demand throughout the target period.

These increases are offset, however, by declines in the water use of hogs and pigs and milk cows. The main factor which contributes to the diminishing water use of hogs is the expected decrease in Maryland pork production; and a steadily falling Subarea share of Maryland milk production accounts for the diminishing water demand by milk cows. Together the two account for a decline in estimated Subarea water use of 23 million gallons between 1980 and 2020.

Subarea 4. Livestock water use is projected to decrease sharply in this subarea, from 180 million gallons annually in 1980 to 120 million gallons in 2000 and 83 million gallons in the year 2020. Most of the decline is accounted for by milk cows and cattle and calves, the major livestock water users in the Subarea.

Milk cows represent about half of the Subarea's livestock water use. Although state-level demand for milk is expected to rise in Maryland during the target period, Subarea 4's share of production is expected to decrease from 5.2 percent in 1969 to 4.0 percent in 1980, and to 1.2 percent in 2020. As the distributional decline far outweighs the prodocution increase projected at the state level, water use in milk production is expected to fall sharply, from 89 million gallons annually in 1980 to only 45 million gallons in 2020.

Cattle and calves are expected to account for much of the remaining livestock water use in the Subarea, with approximately 45 percent of the total. As with milk cows, the Subarea's share of the State total beef demand is expected to fall sharply during the target period, from 8.0 percent in 1969 to 6.8 percent in 1980 and to 3.2 percent by 2020. Since the distributional effect is augmented by a projected decline in State demand for beef, cattle and calf water use is expected to fall from 82 million gallons in 1980 to 36 million gallons in 2020, a decline of more than fifty percent.

Subarea 5. While a changing mix of water-consuming livestock is projected for this subarea, the annual livestock water demand is expected to remain constant. In 1980 and 2000, demand is projected to total 77 million gallons, and it is expected to rise only slightly, by the year 2020, to 80 million gallons. Livestock water use in Subarea 5 is among the lowest in the Chesapeake Study Area.

The relatively high water use rates of beef cattle and their backup herds lie behind their projection as the major livestock water consumers in the Subarea. Though only 4 percent of the Maryland beef demand is expected to be filled by Subarea 5, they account for 60 percent of the total estimated livestock water demand. Projected consumption by cattle and calves totals 49 million gallons in 1980, a figure which drops slightly to 47 million gallons by the year 2020.

Also declining is the water demand expected to be exerted by hogs and pigs. The major factor in this projection is the expected reduction in demand for Maryland-produced pork during the target period, as the subarea's proportion of State demand is projected to rise only slightly from the ten percent it accounted for in 1970. Hog water use is expected to fall from 16 million gallons in 1980 to 12 million gallons in 2020.

The effect of the reduction in water use by these two kinds of livestock is counterbalanced, by the end of the target period, by an increase in the water demand of milk cows. Although Subarea 5 has historically accounted for less than 0.4 percent of state milk production, its small share is rising. Since, in addition, milk demand is projected to increase at the state level, the number of milk cows is expected to double during the target period (to slightly more than two thousand cows and their backup). Their estimated water demand rises from 9 million gallons in 1980 (12 percent of the Subarea total) to 20 million gallons by the end of the target period (25 percent).

c. Virginia. Because of a changing mix of livestock water demands in the Virginia portion of the study area, the estimated aggregate fluctuates. From 1.44 billion gallons in 1980, it drops to 1.37 billion gallons in 2000, but it rises again to 1.43 billion gallons in the year 2020.

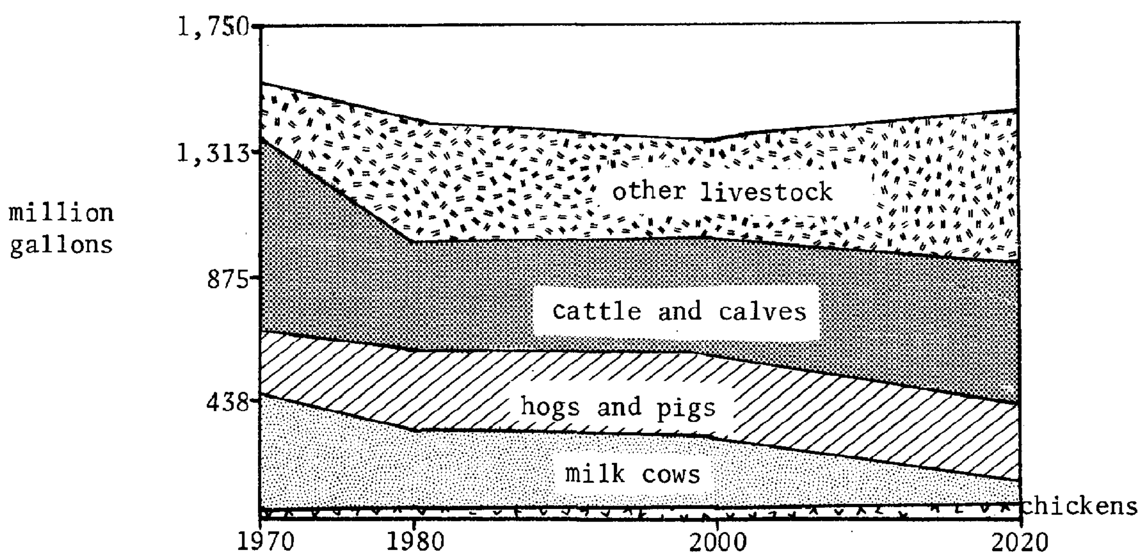
In contrast to both the Delaware and Maryland portions of the study area, the major livestock users of water in Virginia are cattle and calves. They are expected to consume 55.9 million gallons in 1980, a total which rises to 66.2 million gallons in 2020 -- or 56 percent and 66 percent of the State livestock total, respectively, in each of those years. Since the share of the Virginia total accounted for by the study area is expected to drop slightly from the 13 percent registered in 1970, this increase in water use is largely attributed to the sharp increase projected for Virginia beef production in the target period. State beef and veal production is projected to rise from 535 million pounds in 1980 to 931 million pounds by the end of the target period.

The second major users of water in the Virginia Study Area are hogs and pigs. Over half of Virginia's production is concentrated in the study area portion of the State, a proportion which is projected to rise slightly to 60 percent by 2020. This is counterbalanced, however, by a projected decline in State production, from 161 million pounds in 1980 to 123 million pounds in 2020. As a result, the estimated water demand of hogs and pigs dips from 297 million gallons in 1980 to 184 million gallons in 2020, a drop from 20 percent to 13 percent of the Virginia Study Area total.

Milk cows are the third major users of water among Virginia livestock, accounting for 297 million gallons in 1980 (21 percent of the total), and 183 million gallons in 2020 (13 percent of the total). This decline in water use is principally attributed to a shift in Virginia milk production away from the Chesapeake region. From 13 percent of Virginia State production in 1980, the study area's portion is projected to fall to only 7 percent by 2020.

Also expected to exert a significant water demand in Virginia are chickens, with 33 million gallons in 1980 and 40 million gallons in 2020. Slightly over one-fourth of Virginia egg production has been concentrated in the study area, a proportion which is expected to continue into the target period. Thus the increase projected for chicken water use is almost entirely a reflection of the rise projected in Virginia egg production, from 95 million dozen in 1980 to 127 million dozen in 2020. (See Figure 6-11)

Figure 6-11. Livestock water demand in Virginia. Projections to 1980, 2000, and 2020.



Source: Attachment C, Tables 6-C-5 thru 6-C-11.

Subarea 1. In this subarea, as well, a changing mix of livestock is projected, and the water demand aggregated over all livestock uses is expected to fluctuate during the target period. The annual livestock water demand projected for 1980 is 37 million gallons. By 2000 the total falls slightly to 35 million gallons, but by 2020 the projected demand rises to 39 million gallons.

The major users of water among livestock in the subarea are expected to be cattle and calves. The OBERS projections show substantial increases in the Virginia demand for beef: from 352 million pounds in 1964 to 535 million pounds in 1980, and 931 million poounds in 2020. Subarea 1 is expected to account for a roughly constant share of the State total during the target period, and therefore its number of beef cattle are expected to rise accordingly. In 1980 beef cattle are projected to exert 40 percent of the Subarea's livestock water demand at 15 million gallons, figures which rise to 59 percent and 23 million gallons by the end of the target period.

Production and water use of broilers, on the other hand, is expected to drop during the target period. As the Subarea's share of Virginia demands for broilers is projected to rise only slightly during the target period, once again the projected change is a reflection of OBERS state-level estimates of broiler demand. OBERS projects Virginia broiler production to drop, during the target period, from the 1964 level of 146 million pounds to only 12 million pounds by the end of the target period. The projected number of broilers in Subarea 1 thus drops sharply during that period, and their water demand is expected to fall from 8 million gallons in 1980 to only 1 million gallons by 2020.

The final significant users of water in Subarea 1 are hogs and pigs. Increases in the Subarea's share roughly cancel projected decreases at the state level, and water use remains fairly constant at 11 million gallons, or thirty percent of the subarea total.

Subarea 2. The annual livestock and poultry water demand is expected to decline, in this subarea, from 368 million gallons in 1980 to 295 million gallons in 2000 and 256 million gallons in 2020. Almost all of this reduction is accounted for by declines in the water use of cattle and calves and milk cows.

The large increases in Virginia demand for beef are outweighed, in the subarea, by the distributional effect, as the Subarea's share of the State total is expected to decline from 5.5 percent in 1969 to 4.3 percent by 1980 and 2.1 percent by 2020. The number of cattle and calves is expected to drop, during the target period, from 65,000 in 1980 to 55,000 in the year 2020, and projected water use accordingly drops, from 260 million gallons to 227 million gallons.

Similarly, a projected decline in the Subarea's share of milk demand outweighs the estimated increases in milk demand at the state level. From an 8.5 percent share of milk sales in 1969, Subarea 2 is projected to account for 4.4 percent in 1980 and only 0.9 percent by the end of the target period. Thus the water demands by milk cows are projected to drop sharply, from 99 million gallons in 1980 to only 24 million gallons in 2020.

Subarea 3. Livestock and poultry water demands are expected to increase in Subarea 3 from an annual total of 119 million gallons in 1980 to 134 million gallons in 2000 and to 162 million gallons in 2020.

The increase is almost entirely due to expected increases in the cattle and calf water demand which, in turn, is primarily a reflection of the State-level increases projected by OBERS. The Subarea's share of state beef sales is not expected to vary from the 1969 level of 1.5 percent. Due to the state-level increases, the number of cattle and calves is expected to jump from 23,000 in 1980 to 36,000 by 2020. Since water use by beef is high relative to that of other livestock, the water use of this component is expected to rise from 92 million gallons in 1980 to almost 150 million gallons by 2020, or 91 percent of the Subarea total.

The projected increase in water use by beef cattle easily overshadows projected declines in water use by milk cows. The Subarea's share of State milk sales is projected to fall from 1.5 percent in 1969 to 1.0 percent in 1980, and to 0.5 percent by 2020, a decline which again outweighs the projected increase in State milk demand. Water demand by milk cows is thus expected to fall in the target period, from 24 million gallons in 1980 to 13 million gallons in 2020.

Subarea 4. Livestock water use in Subarea 4 is expected to decline sharply during the target period, from an annual rate of 244 million gallons in 1980 to 185 million gallons in 2000 and 154 million gallons in 2020.

Again, major users of water are cattle and calves, although their water consumption is expected to drop from 108 million gallons in 1980 to only 24 million gallons by the end of the target period. The major factor behind this projection is the estimated reduction in the Subarea's share of State beef sales, from 2.5 percent in 1969 to 1.6 percent in 1980 and 0.3 percent in 2020. Thus beef water consumption, projected to represent 44 percent of total Subarea livestock water use in 1980, is expected to drop to only 16 percent of the total by 2020.

A rising proportion of livestock water use in the Subarea is accounted for by milk cows. The number of milk cows is projected to fall slightly, from 8,000 in 1980 to 7,200 after 2000, and water use, accordingly, is expected to drop only slightly from 74 million gallons in 1980 to 71 million gallons in 2020. Neither the Subarea's share (approximately three percent) nor Virginia consumption of milk is expected to dramatically change during the target period.

Finally, hogs and pigs are projected to account for 20 to 33 percent of Subarea livestock demands. Changes in the projected levels of Virginia pork demands, the Subarea's share of those demands, and water use rates tend to cancel each other out, and annual hog water use is expected to remain constant in the target period at approximately 50 million gallons.

Subarea 5. The water demanded by livestock in 1980 is projected to remain fairly stable in the target period, declining only slightly from 223 million gallons of annual use in 1980 to 219 million gallons in 2000 and 210 million gallons by the end of the target period in 2020. For each of the major three livestock water consumers in the Subarea, the projected distributional effect roughly balances the projected changes in demand at the State level, and both numbers of animals and their water use show no appreciable change.

Approximately 55 percent of the Subarea's livestock water use is accounted for by cattle and calves, in which the Subarea's share of State production is projected to drop from 2.00 percent in 1969 to 1.75 percent in 1980 and to 0.95 percent in 2020. The shift is, however, balanced by projected increases in Virginia demand for beef, and water demand is expected to remain constant at roughly 125 million gallons per year.

Almost 30 percent of Subarea 5's livestock water demand is projected for hogs and pigs. Projected declines in Virginia demand for pork are expected to be balanced by the Subarea's share of State sales, which rises from 9 percent in 1969 to an estimated 14 percent in 2020. Hog and pig water consumption is expected to total approximately 60 million gallons throughout the target period.

The third major users of water among the Subarea's livestock are milk cows, where a slightly falling share of milk production (from 1.8 percent in 1969) is expected to balance projected increases in Virginia milk demand. The estimated milk cow demand for water declines slightly from 33 million gallons in 1980 to 26 million gallons in 2020.

Subarea 6. York County is expected to have the lowest livestock water use of any of the subareas, although such water demands are expected to increase sharply during the target period.

Total annual livestock water demands are projected to be 30 million gallons in 1980, a figure which jumps to 42 million gallons by 2000 and 58 million gallons by 2020.

Over half the livestock demand for water in Subarea 6 is exerted by milk cows. The share of Virginia milk production accounted for by the Subarea is expected to rise from 0.5 percent in 1969 to 1.2 percent by the end of the target period, and this increase is matched by state-level expansion in demands for milk. The number of milk cows and their backup is thus projected to rise from 2,000 in 1980 to over 3,300 by 2020. Projected water use rises accordingly, from 19 million gallons in 1980 to 33 million gallons in 2020.

Most of the remaining livestock water use is accounted for by cattle and calves. Although the Subarea's small share of the State total is expected to increase only slightly during the target period, massive projected increases in the demand for beef at the state level would lead to a large jump in both beef cattle numbers and their water use. Water consumption by cattle and calves is expected to rise from 9 million gallons in 1980 to 22 million gallons by the end of the target period.

Subarea 7. Livestock water use is expected to be low in this subarea as well. From only 92 million gallons of annual use in 1980, the total dips to 79 million gallons in 2000 and 72 million gallons in 2020.

The major livestock water demand in the Subarea, representing 40 percent of the total, is exerted by cattle and calves. The number of animals is expected to dip slightly, during the target period, from 8,900 in 1980 to 7,000 in 2020. This is primarily a reflection of a sharp decline in the Subarea's share of Virginia beef production, which is projected to fall from 0.49 percent in 1980 down to 0.22 percent in 2020, and counterbalance the increase in the estimated demand for beef at the state level. Cattle and calf water consumption is expected to decline from 35 million gallons in 1980 to 28 million gallons in 2020.

The principal decline in water use, however, is projected for milk cows. Although state-level demand for milk is expected to rise during the target period, the increase in demand for milk is far outweighed by the declining share of sales projected for the Subarea. From 1.9 percent of State sales in 1969, the portion of State milk demand supplied by Subarea 7 is projected to drop to 1.0 percent in 1980, to 0.5 percent in 2000 and, 0.2 percent by 2020. The estimated water demand of milk cows falls from 22 million gallons in 1980, approximately 24 percent of the Subarea livestock total, to 6 million gallons in 2020, or 8 percent of the Subarea total.

Thus in the projections of water use by cattle and calves and milk cows, the historically declining Subarea share of State production has been the major factor. In the latter case, the decline is so severe that the Subarea's milk production is expected to be almost entirely distributed to other areas within the state.

Hogs and pigs are the other major users of water among livestock, and their water use is projected to remain roughly constant at an annual rate of 30 million gallons. The declining production of pork projected at the State level is balanced by an expected increase in the Subarea's share of State production.

Subarea 8. The already substantial livestock water use in this subarea is expected to increase sharply during the study period. Three hundred twenty-five million gallons of annual livestock water use are expected by 1980; this figure is projected to increase to 381 million gallons by 2000 and to 479 million gallons by the end of the target period.

Most of the gain reflects an expected increase in the water use of cattle and calves. OBERS projects almost a threefold rise in the State demand for beef between 1964 and 2020. At the same time, Subarea 8 is expected to account for an ever-increasing share of the State total: the 1969 share of 2.2 percent with respect to State beef sales is projected to rise to 2.7 percent by 1980 and 3.5 percent by the end of the target period. As a result of these changes the water demands of beef are expected to rise from 160 million gallons in 1980 to 351 million gallons, or almost three-quarters of the total livestock demand in 2020.

Another major water demand in the Subarea is that of hogs and pigs. In the past the Subarea's share of State production has remained roughly constant at one-fifth, and this situation is expected to continue into the target period. The slight decline projected in the water use of hogs, from 126 million gallons in 1980 to 97 million gallons in 2020, is almost entirely a reflection of the projected pork production at the state level.

The volume of water expected to be consumed by cattle and hogs somewhat overshadows the demands of milk cows. Though milk cows have the highest water consumption rates of any of the types of livestock considered, only a small portion (less than one percent) of State demand for milk is expected to be supplied by Subarea 8 during most of the target period. A declining Subarea share of State milk production accounts for the projected fall in water demand by milk cows, from 26 million gallons in 1980 to 11 million gallons in 2020.

IRRIGATION WATER DEMAND

ASSUMPTIONS AND METHODOLOGY

Water demands for irrigation were estimated with reference to crop demand, yield, and total crop acreage.

To begin, crop production in each subarea was projected by a shares analysis, to take into account both distributional shifts among the subareas and the projected changes in state-level demands for each crop.

Yields were then projected. It was assumed, as in the OBERS projections, that the rapid rate of increase in agricultural research and development since the second World War would continue, but at a slower rate, during the period 1970 - 2020. Although more extensive use of fertilizers and pesticides, and improved crop varieties and management practices are expected in the target period, investment in agricultural research and development may be dampened. In addition, a lag is expected in the implementation of new technologies. Both of these factors would tend to diminish the rate of yield growth.

Historical yields were found to vary consistently and significantly: for each crop there appeared differences not only between the Chesapeake Bay Study Area and the rest of the States involved (a discrepancy which was especially large for Virginia), but among the subareas themselves. In the most obvious example, yields of subareas in the Delmarva Peninsula differed for almost all crops from the yields for the Western Shore subareas. It was therefore decided to individually estimate target date yields by crop, for each subarea.

Yields were projected by the function employed in the projection of subarea production shares, with a slight alteration to allow them to vary with time more than the subarea shares of state production were allowed to.(18)

It was possible to estimate acreage for each crop from the estimates of future crop production and expected yield (production per acre).

Irrigation water demand was then projected for each crop and subarea as a function of crop acreage. From past trends and knowledge of present irrigation usage, individuals in each subarea estimated the proportion of subarea acreage to be irrigated in the target period. These proportions were applied to the estimates of total crop acreage to obtain total irrigated acreage.

The net irrigation water requirement in acre-feet per year for the estimated irrigated acreage of each crop was projected by the Soil Conservation Service Computer Center which, using a computer program in its library, followed the procedure outlined in SCS Technical Release Number 21. Data considered were subarea averages of latitude, temperature, and rainfall; and crop transpiration curves for water use during the growing season.

Of major importance in the calculation was potential evapotranspiration (PE), or the amount of water which would be lost to the atmosphere through transpiration from a green crop and evaporation from the soil surface. For each subarea, potential evapotranspiration was calculated using a modified Blancy-Criddle formula, as a function of daylength (itself a function of latitude), temperature, and the transpiration rates of the crops under study at different stages of their growth. The net irrigation requirement was then calculated as the difference between PE and effective rainfall plus carry-over soil moisture.

Factors entering into the calculation of effective rainfall were percolation and runoff losses, assuming storms of average intensity and duration, and the chance of precipitation occurrence. For small vegetables and other specialty crops (19), effective rainfall during the growing season in each subarea was determined assuming a 90 percent chance of occurrence, or assuming the rainfall which is expected to be equalled or exceeded nine years out of ten. For field crops and orchards, effective rainfall was determined assuming an 80 percent chance of occurrence. Irrigation water demand is therefore expected to be less than or equal to the estimated amount in nine years out of ten for field crops and orchards. This demand is indicative of water use during years which are drier than the average because critical water needs were judged most important. Irrigation demand in normal precipitation years is discussed in the Sensitivity section below.

In the calculation of carry-over soil moisture, the soil water holding capacity was assumed to be uniformly that of a loam soil (medium capacity). The amount of water available to a crop under study varied, however, with its rooting depth, with relatively more water available to deeper rooted crops.

Once the net irrigation requirement was determined, gross demands were estimated under the assumption of a 65 percent rate of irrigation efficiency. Only 65 percent of the total water application is assumed to be available for crop use, with the remainder lost through evaporation or conveyance.(20)

The divergence between the historical records of irrigation water use and the projected demand is partly due to the method of projecting demand as a function of the crops' net water requirement. Since this is an ideal amount, it may be in excess of the applications currently recorded, which are often determined by each farmer on the basis of experience. The divergence is further compounded by bias in the Census determinations of irrigation water usage. A comparison of data obtained from irrigation water suppliers with that obtained from farmers suggests that 1) farmers underestimate the amount of water used for irrigation 2) the suppliers overestimate, or 3) both conditions are true. As stated in the 1969 Census of Agriculture

> It was evident, in reviewing the records received from farms in some parts of the country, that some irrigators had no basis for estimating water use in terms of gallons, acre-feet, or depth of application. (21)

Finally, since it has been found relatively easy to correct for errors in responses which overestimate irrigation water by comparing farmers' reports with acceptable maximum application rates, a greater number of underestimation errors in the Census data go undetected than overestimation errors.

The combined effect of ideal demand projections and underestimation bias in historical data - plus the fact that projected demands were given for extremely dry years - leads to larger projected increases in irrigation water demands than for any of the other water uses.

PROJECTED DEMANDS

a. Delaware. This state is expected to exert one of the largest irrigation water demands of any of the subareas. Total irrigated acreage is expected to increase from 20,000 acres in 1970 to 67,000 in 1980 and 91,000 in 2020. Water demands for irrigation are expected to reach over 16 billion gallons in 1980, 19 billion gallons in the year 2000, and over 22 billion gallons in 2020.

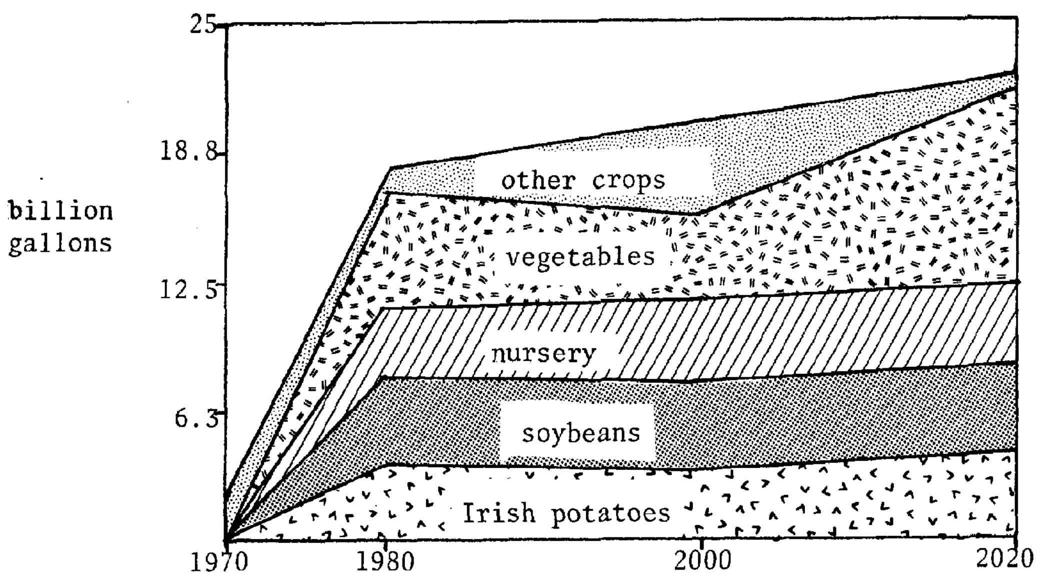
Approximately 40 percent of the estimated Delaware irrigation water demand is accounted for by vegetables. State production is expected so to increase that, even with improved yields, total acreage will rise from 39,000 acres in 1970 to 49,000 acres in 1980, and 55,000 acres in 2020. By 1980, three-quarters of all acreage in vegetables is expected to be irrigated, and the proportion is expected to increase until virtually all vegetable acreage is irrigated by the end of the target period. The projected demand of vegetable crops rises from 6.1 billion gallons in 1980 to 9.0 billion gallons in 2020.

Most of the remaining water demand by irrigation is accounted for by soybeans, nursery crops, and Irish potatoes, with each representing a fifth of the Delaware total irrigation water demand.

Although soybean production is projected to increase in Delaware, these gains are expected to be balanced by increases in yield, so that by the end of the target period total acreage will remain about the same as current levels, at 144,000 acres. It is estimated that only slight increases in the proportion of these acres are to be irrigated, with that proportion hovering around ten percent. Irrigated soybean acreage in Delaware, then, is projected to remain roughly constant in the target period, at 15,000 acres, with a water demand of approximately 4.0 billion gallons annually.

The two other crops which are expected to exert significant water demands are nursery crops and Irish potatoes. The number of irrigated acres in nursery crops is expected to jump from 7,500 in 1980 to 10,000 acres by 2020, and their projected water demand rises from an annual rate of 3.2 billion gallons to 4.3 billion gallons in the same period. The estimated water demand for Irish potato irrigation is expected to rise from 3.4 billion gallons on 6,200 acres in 1980 to 4.0 billion gallons on 7,400 acres in 2020. (see Figure 6-12).

Figure 6-12. Irrigation water demand in Delaware. Projections to 1980, 2000, and 2020.



Source: Attachment C, Table 6-C-12.

b. Maryland. A tenfold increase in total irrigated acreage in the Maryland portion of the study area is expected in the target period, from 19,800 acres in 1970 to 217,800 acres in 2020. The estimated irrigation water demand dwarfs other agricultural water demands, as it rises from 3 billion gallons in 1970 to 11 billion gallons in 1980, 31 billion gallons in 2000, and by 2020, 78 billion gallons.

Much of this demand is expected to be exerted by corn. Total State production is projected to increase from 37 million bushels in 1970 to 80 million bushels in 2020, almost all of which (93 percent in 2020) is expected to be concentrated in the study area portion of the State. Total acreage in corn is projected to rise from 350,600 in 1970 to 496,800 by 2020. Even more rapid than the total acreage expansion, however, is the increase in irrigated acreage, which is projected to rise from a diminutive 0.5 percent of the total in 1970 to 23 percent in 2020, or from 1,900 acres to over 112,000 acres. All these trends, but especially the latter, are reflected in the projections of the irrigation water demand of corn, which rises from 2 billion gallons in 1980 to 45 billion gallons in 2000 and 59 billion gallons by the year 2020.

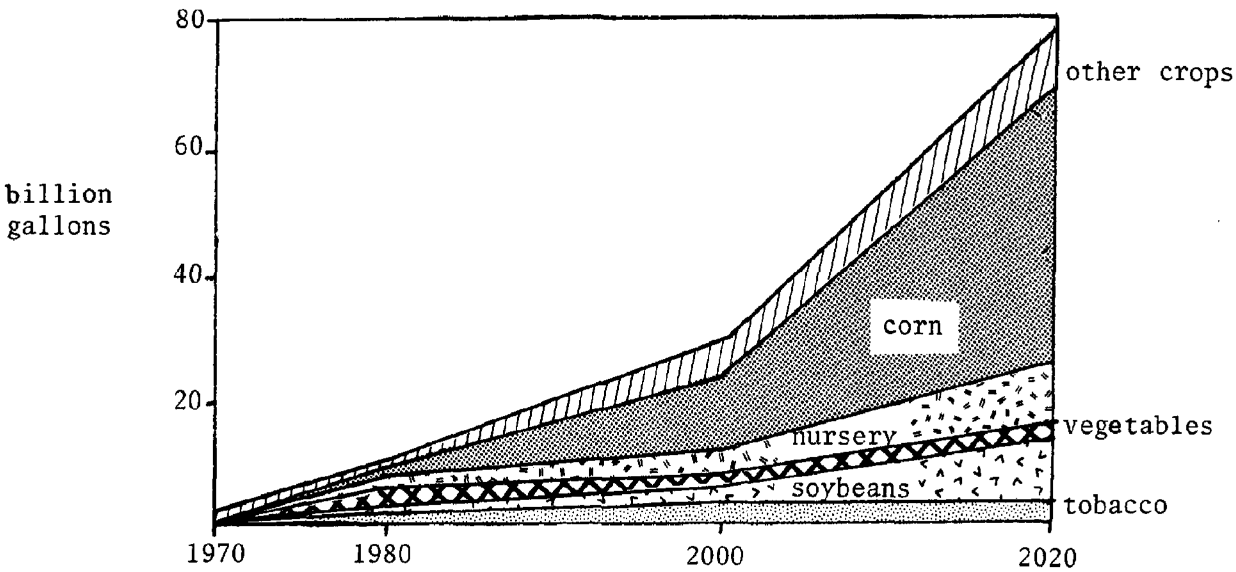
The second major users of irrigation water in the Maryland Study Area are nursery crops, due primarily to the high application rates (almost 1.5 feet per acre) characteristic of nursery irrigation. Though only 340 acres were registered as irrigated in 1970, the total is expected to rise to 5,900 acres by 1980 and to 23,000 acres in 2020. Estimated water demands for nursery crops are 2.6 billion gallons in 1980 and 10.4 billion gallons in 2020.

The irrigation water demand of soybeans in the Maryland Study Area is also projected to rise sharply during the target period, from 0.8 billion gallons in 1980 to 9.7 billion gallons in 2020. Since study area soybean production is projected to diminish slightly in the face of large yield increases, total acres in soybeans is projected to diminish from 161,000 in 1980 to 98,000 by 2020. Counterbalancing this trend, however, is an expected rise in the proportion of acres irrigated, from less than 2 percent is 1980 to 32 percent by the end of the target period,so that from a total of 2,700 in 1980, the estimated irrigated acreage in soybeans rises to 32,000 by 2020.

A fourth major user of irrigation water in Maryland is tobacco, the demand of which is projected to rise from 0.9 billion gallons in 1980 to roughly 3.8 billion gallons in 2000 and 2020. As with soybeans, the increase is almost entirely due to an expansion of tobacco irrigation. From 20 percent in 1980, the proportion of tobacco acreage expected to be irrigated rises to close to 95 percent in 2000 and virtually 100 percent by the end of the target period. The estimated number of tobacco acres under irrigation rises from 4,500 in 1980 to roughly 19,000 after the year 2000.

Finally, vegetables are expected to exert a significant and roughly constant demand for irrigation water in the Maryland Study Area, at 2.6 billion gallons annually throughout the target period. In this projection the estimated decrease in Maryland vegetable acreage - from 62,000 in 1970 to 23,000 in 2020 - is again counterbalanced by an increase in the estimated proportion of acres irrigated from 21 percent in 1970 to almost 65 percent in 2020. (See Figure 6-13)

Figure 6-13. Irrigation water demand in Maryland. Projections to 1980, 2000, and 2020.



Source: Attachment C, Tables 6-C-13 thru 6-C-17.

Subarea 1. In this Subarea, located to the north and west of the Chesapeake Bay, both the number of irrigated acres and the water demands for irrigation are expected to show dramatic increases during the target period. Land in irrigation is expected to increase from 8,800 acres in 1980 to 10,800 acres in 2020, and water demands will jump from 2.9 billion gallons to 3.8 billion gallons annually.

Over 75 percent of these water demands is expected to be generated by nursery crops. The number of acres in irrigation is projected to increase from 5,000 acres in 1980 to 7,000 acres in 2020. Since these increases are expected to be coupled with relatively high application rates of close to sixteen inches per acre per year, the irrigation water demand is projected to total from 2 to 3 billion gallons annually.

One-quarter of all Maryland vegetables are produced in Subarea 1. Although higher yields and a decrease in total acreage in vegetables are projected, the proportion of irrigated acres in vegetable production is expected to rise from 20 to 40 percent during the target period. Thus, a constant 3,000 acres of vegetables are expected to be irrigated, generating annual water demands of 500 million gallons, roughly fifteen percent of the Subarea irrigation total.

The remaining ten percent of the expected irrigation water demand in the Subarea is accounted for by corn, silage, and fruits and nuts.

Subarea 2. Irrigated acreage in this subarea on the Delmarva Peninsula is projected to soar in the target period. From slightly less than 10,000 acres in 1970, the projected irrigated acreage rises to over 15,000 in 1980, to almost 47,000 in 2000, and by 2020 to over 150,000 acres of irrigated crops. In line with the projected acreage, the water demands for irrigation in Subarea 2 are enormous. The Subarea is expected to use 4.3 billion gallons for irrigation in 1980; 16 billion gallons in 2000; and over 55 billion gallons annually by the year 2020. It is the largest single water use in the target period, and accounts for much of the sharp increase projected for the total irrigation water demand of the Chesapeake Bay Study Area.

Most of this projected water demand is accounted for by corn, a crop in which all indicators seem to point to irrigation increases. First, total State production of corn is expected to increase from 37 million bushels in 1970 to 53 million and 65 million in the years 1980 and 2000, respectively. By 2020, State production will have doubled, to close to 80 million bushels. Second, this Subarea, with 40 percent of State production in 1970, is expected to increase its share still further to over 50 percent by the end of the target period. Thus, even though yields are increasing - a factor which would tend to decrease acreage - the net effect is that acreage in corn is expected to jump from 180,000 in 1970 to almost 300,000 by 2020. Finally, the proportion of acres which are irrigated is expected to rise. From a minute 0.75 percent in 1970, the proportion of acres to be irrigated is expected to rise to 1.50 percent by 1980 and to 10.00 percent by the year 2000. By 2020, fully one-third, or 33 percent of the 300,000 acres in corn are projected to be irrigated. Its water demand is expected to rise from 1.6 billion gallons in 1980 to 10.3 billion gallons and 41.2 billion gallons in 2000 and 2020, respectively. The latter figure represents 75 percent of the irrigation water demand of Subarea 2 at that date.

Another substantial irrigation water demand in this Subarea is that projected for soybean production. Subarea 2 produces almost half the State's soybeans at the present time, a figure which is expected to increase slightly during the target period. Although the increase in the Subarea's share of State soybean production is offset by declining total State production and yield increases, which lead to a decrease in the number of acres in soybeans in Subarea 2, the proportion of acres to be irrigated is expected to rise sharply from 1.4 percent in 1980 to 12.0 percent in 2000 and 45.0 percent in 2020. The number of irrigated acres in soybeans is projected to rise accordingly, from 1,000 acres in 1980 to 25,000 acres in the year 2020, in which period the projected annual water demand increases from 0.3 billion gallons to 7.7 billion gallons.

Silage represents the third major demand for irrigation water in Maryland Subarea 2. Total State production is expected to double, and, as the Subarea's share is expected to rise from 17 percent in 1970 to roughly 20 percent in the target period, silage production in this Subarea is expected to more than double. Though slight yield gains will tend to moderate the effect of production increases in determining Subarea acreage in silage, the proportion of silage acres in irrigation is projected to jump from a fraction of one percent (0.2 percent) in 1970 to 1.5 percent in 1980, 12.0 percent in 2000 and close to 40.0 percent by 2020, at which time 12,000 acres are projected to be irrigated. The rise in acreage under irrigation is the major factor behind the sharp increases in silage demand for irrigation water, from 0.1 billion gallons in 1980 to 3.7 billion gallons in 2020.

As the water demand of these three crops increases, those of vegetables and nursery crops are expected to diminish in relative importance in Subarea 2. Although the estimated gross annual water requirement for these two crops increases from 2.3 billion gallons in 1980 to 3.1 billion gallons in 2020, its share of the Subarea total falls from 67 percent to 9 percent during the target period.

Subarea 3. This Subarea, located in the middle section of the Delmarva Peninsula, demonstrates the effects of expected increases in water application rates. Total irrigated acreage is expected to decline, in the target period, from 9,200 acres in 1980 to 8,400 in 2020. At the same time, however, the average gross application rate is estimated to jump from 8.2 acre inches per year to 12.7 acre inches. The combined effect is that the projected total water demand increases from 2.1 billion gallons in 1980 to 2.7 billion gallons in 2000 and 2.9 billion gallons in 2020.

As in Maryland Subarea 2, a major demand for irrigation water is corn, expected to constitute over 70 percent of the Subarea total by the end of the target period. In 1970, Subarea 3 accounted for 30 percent of State corn production, and the share is expected to increase to 40 percent by the end of the target period. The State total for corn production in Maryland is expected to double by 2020, and thus, despite substantial yield increases, total acreage in corn is projected to rise - from 125,000 acres in 1970 to 160,000 in 1980 and close to 190,000 acres by 2020. Its expected annual water demand jumps from 0.8 billion gallons in 1980 to 2.1 billion gallons in 2020. While such acreage in corn might potentially exert a large demand for irrigation water, however, only a small portion of the Subarea's corn acreage is expected to be irrigated: 1.3 percent in 1980, a proportion projected to climb to only 3.0 percent by 2020. Corn acreage under irrigation in the target period is thus not expected to exceed 6,000 acres, and its projected water demand in 2020 does not exceed 2.1 billion gallons.

Of lesser importance in the subarea are vegetables and soybeans. Forty-two hundred acres of vegetables are projected to be irrigated by 1980, a number which drops to 1,200 acres by 2020. Its expected water demand totals 700 million gallons in 1980, or 33 percent of the Subarea irrigation total, and 200 million gallons in 2020, or 7 percent of the total. Irrigated land in soybeans is expected to decline from 1,700 acres in 1980 to 750 acres in 2020, due principally to a diminishing Subarea share of State production. Its irrigation water demand is expected to fall from 500 million gallons in 1980 to 200 million gallons in 2020.

Subarea 4. This Subarea is expected to show one of the largest increases in irrigated acreage in the Chesapeake Bay Study Area. The 1970 total of only 900 acres in irrigation is projected to double to over 1,900 acres by 1980, and to jump to over 14,000 acres by the end of the target period. Annual water demands for irrigation, only 0.2 billion gallons in 1970, are expected to rise to 0.6 billion gallons by 1980 and to 6.1 billion gallons by the year 2020.

Over half the demand for irrigation water in Subarea 4 is accounted for by nursery crops. While only 200 acres of such crops were irrigated in 1970, the total is expected to increase to 600 acres in 1980, and to 8,000 acres in 2020. These acreage increases are coupled with the high application rates characteristic of irrigation for this type of crop, to generate water demands which account for 50 to 60 percent of the subarea's total for irrigation water and close to 4 billion gallons in 2020.

Large increases are also projected in the water demands for corn irrigation in the Subarea. While an insignificant portion of corn acreage, 0.1 percent, was recorded as irrigated in 1970 - a figure which is expected to change little by 1980 - 25 and 50 percent of all acres in corn are projected to be irrigated, respectively, in 2000 and 2020. Although a falling share of State production mitigates these changes, irrigation water demand for corn is expected to increase to 1.1 billion gallons annually by 2020.

Other water demands in the Subarea are those of irrigated tobacco and soybeans. Though for tobacco the proportion of acreage in irrigation is expected to rise from 20 percent in 1980 to 95 percent after the year 2000, Subarea production is projected to fall to less than half the 1970 level, and initial increases in water demands for tobacco are expected to fall off toward the end of the target period, to 500 million gallons. Soybeans are projected to exert demand for irrigation water not in the immediate future, but only by the year 2000, when 850 acres (25 percent of the soybean total) will be irrigated. The water demand for soybean irrigation at that time is expected to total 300 million gallons. The number of irrigated soybean acres, their proportion of the total, and the soybean water demand are all expected to double between 2000 and 2020.

Subarea 5. This Maryland Subarea, located west of the Chesapeake Bay and just north of the Potomac River, is expected to show the largest proportional increases in irrigated acreage and water demands of the subarea in the Chesapeake Study Area. In 1970, only 1,600 acres in the Subarea were irrigated, a use of approximately 0.2 billion gallons. By 1980 over 4,000 acres are projected to be irrigated; by 2000 the figure jumps to 24,000, and it rises over 33,000 acres by the year 2020. Annual water demands are projected to jump to 0.8 billion gallons in 1980, to 5.7 billion gallons in 2000, and to 9.5 billion gallons in 2020.

An increasing proportion of demands for irrigated water in the Subarea stems from nursery crops. The number of irrigated acres in this category is expected to rise from an insignificant quantity in 1970 to 300 acres in 1980, 1,500 acres in 2000, and 8,000 acres in the year 2020. With the high application rates characteristic of nursery irrigation, nursery crop water demands are expected to rise from 12 percent of the Subarea's total in 1980 to nearly 40 percent of the total in 2020, accounting for 0.1 billion gallons at the former date and 3.5 billion gallons at the latter.

As irrigated nursery crops in the Subarea increase in relative importance, tobacco is expected to decline: from seven-eighths of the Subarea irrigation water demands in 1980 to only one-third in 2020. Since tobacco demands substantially less water per acre than nursery crops (0.5 as opposed to 1.5 feet per acre), it is projected to use less irrigation water -- 3.1 billion gallons in 2020 -- than the smaller quantities of irrigated acreage in nursery crops.

Corn and soybean irrigation water demands, though insignificant in the beginning of the target period, are expected to be increasingly important in Subarea 5, and account for one-third of the total irrigation water demand in the Subarea after 2000. By 2000, 25 percent, and by 2020, 50 percent of the Subarea's corn acreage is projected to be irrigated, and- to exert a demand, respectively, of 1.2 billion gallons and 1.5 billion gallons. Three-quarters of the soybean acreage in 2000 and virtually all of that acreage in 2020 is projected to be irrigated, exerting a demand of 1.2 billion gallons and 1.5 billion gallons, respectively, in those target years.

c. Virginia. Irrigated acreage in the Virginia portion of the study area, while not expanding at the Maryland rate, is projected to rise sharply from the 18,100 recorded in 1970 to 68,300 in 2020. Annual water use, 2.9 billion gallons in 1970, is expected to total 14.6 billion gallons in 1980 and 24.0 billion gallons in the years 2000 and 2020.

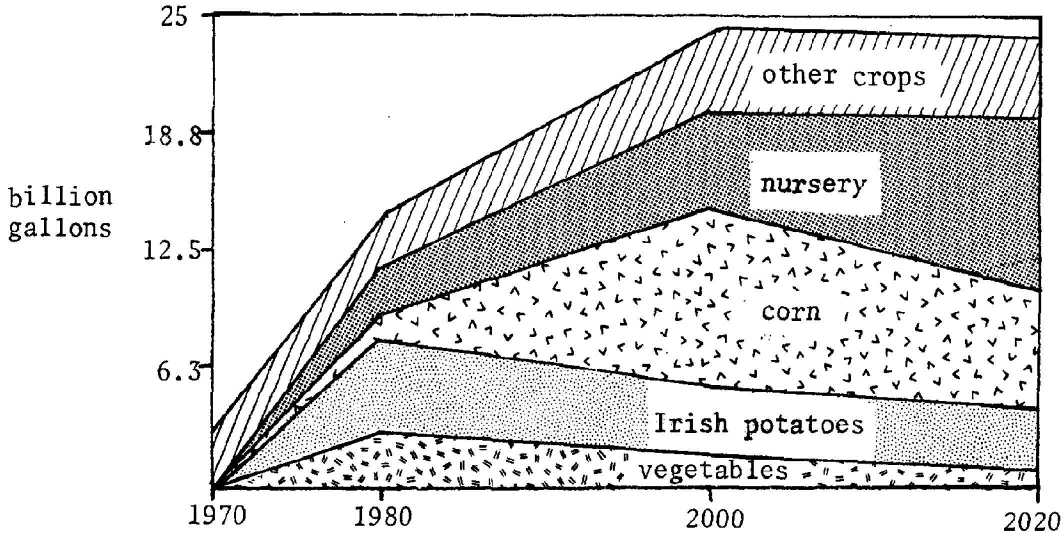
Among the major users of irrigation water in the Virginia Study Area are nursery crops. Irrigated acreage in nursery crops is expected to rise from the total of 2,800 in 1970 to 7,500 in 1980, 16,000 in the year 2000, and 20,500 in 2020. Their estimated annual demand for irrigation water rises proportionately, from 2.8 billion in 1980, to 7.9 billion gallons in the year 2020. The latter figure represents close to one third of the Virginia Study Area total for all crops.

Of similar significance is the water demand expected to be exerted by corn. From a total of 1.1 billion gallons in 1980, its estimated demand rises sharply to 8.0 billion gallons in the year 2000 before dropping once again in 2020 to 6.3 billion gallons. In 1970, only 1 percent of all acreage in corn was recorded as irrigated, a proportion which, however, is expected to rise to 2 percent in 1980, 28 percent in 2000, and 37 percent in 2020. At the same time, total corn acreage in the Virginia Study Area is expected to diminish from 178,600 in 1970 to only 45,000 in 2020, a reflection of a similar decline at the state level. It is the interaction of these two trends which leads to the fluctuating levels of water demand expected of Virginia corn, the estimated increase in the proportion of irrigated acres first outweighing the decrease in total corn acres, then the reverse.

A third major user of irrigation water in the Virginia Study Area is Irish potatoes, accounting for an estimated 5.4 billion gallons in 1980, 4.3 billion gallons in 2000, and 3.4 billion gallons in 2020. This decline is principally a reflection of the drop in potato production projected at the state level, from the 1970 total of 6.2 million bushels to 3.3 million bushels by 2020. It is tempered somewhat by the projected concentration, by 2020, of virtually all of Maryland production in the study area portion of the State.

Vegetables are expected to exert the last major demand for irrigation water in the Virginia Study Area, at 3.0 billion gallons in 1980 and 1.3 billion gallons in 2020. The decline once again reflects a projected drop in state-level production, from 36,500 acres in 1970 to only 13,400 acres by 2020. The estimated share of State production accounted for by the study area rises only slightly, from the 64 percent recorded in 1970 to 72 percent at the end of the target period (see Figure 6-14).

Figure 6-14. Irrigation water demand in Virginia. Projections to 1980, 2000, and 2020.



Source: Attachment C, Tables 6-C-18 thru 6-C-25.

Subarea 1. In contrast to each of the Maryland subareas and Delaware, this group of counties - located at the tip of the Delmarva Peninsula - is expected to show a decline in irrigated acreage and water demands. From 22,000 acres in 1980, cropland with irrigation is projected to drop to 16,000 acres in 2000 and 12,000 acres in 2020. Its water demand of 8.4 billion gallons in 1980, the largest of any subarea but Delaware, is expected to fall to 6.3 billion gallons in 2000 and 4.7 billion gallons in the year 2020.

The largest demand for irrigation water in this subarea is that of Irish potatoes, constituting over two-thirds of the total. In 1970, 90 percent of all potatoes produced in Virginia were raised in Subarea 1; the proportion is expected to rise to 95 percent by 1980 and to 98 percent by the end of the target period. This increase is offset, however, by diminishing State production of potatoes, a decrease of 20 percent by 1980 and close to 50 percent by the end of the target period. Thus, total acreage in potatoes in this subarea is expected to fall from 11,000 in 1980 to 6,800 in 2020, and irrigated acreage, consistently half the total, is projected to fall accordingly. The estimated water demand for potato irrigation drops from 5.4 billion gallons in 1980 to 3.4 billion gallons in 2020.

A second major demand for irrigation water in this subarea is that of vegetables. As in the case of potatoes, Virginia state production is expected to diminish during the target period, total acres in vegetables falling from 21,000 in 1980 to 14,000 in 2000 and 9,600 in 2020 - close to a 60 percent decline from the 23,000 acres in vegetable production in 1970. Again, as a constant half of the total acreage in vegetables is projected to be irrigated, irrigated acreage in vegetables is expected to show a sharp drop, and the irrigation water demand for vegetables is estimated to fall from 3.0 billion gallons in 1980 to 1.3 billion gallons in 2020.

Subarea 2. In this subarea, irrigated acreage is expected to jump from less than 1,000 acres in 1970 to 3,000 acres in 1980, 7,100 acres in the year 2000, and 8,100 acres in 2020. Water use is expected to increase from 0.1 billion gallons in 1970 to 1.1 billion in 1980, 2.7 billion in 2000, and 3.1 billion gallons in 2020.

Over half of the increase in water demands is accounted for by nursery crops. From a negligible number in 1970, irrigated acreage of these crops is expected to rise to 1,500 acres in 1980, 3,400 acres in 2000 and 4,000 acres in 2020. In addition, nursery crops are projected to require high application rates, 15 inches per acre per year. Their projected water use therefore rises from 0.6 billion gallons in 1980 to 1.7 billion gallons in 2020.

Other crops which are expected to exert significant water demands in this subarea are corn, hay, and silage.

Although corn production for the state of Virginia is expected to fall to one-third the current amount in the target period, and the share of state production accounted for by Subarea 2 is projected to fall (from 4 percent to just under 3 percent), the proportion of acres in corn to be irrigated is expected to rise from a negligible amount to over 40 percent. The net effect is an increase in irrigated acres in corn from a negligible amount in 1970, to 240 in 1980, and 1,000 in the years 2000 and 2020. The projected irrigated water demands in the latter years, at 400 million gallons, represent roughly 10 percent of the Subarea total.

Of similar magnitude are the water demands of hay and silage. The state-level increases in hay production are expected to be counterbalanced in the target period both by the Subarea's declining share of that production and by increased yields. The initial increases estimated for hay acreage in the target period are thus not expected to be sustained through the end of the target period. Irrigated acreage is projected to remain a small proportion of the total (only three percent by the end of the target period), and water demands from this source are not expected to exceed 420 million gallons annually. The rise in State production of silage is expected to be counterbalanced by a falling Subarea share and increased yields to produce a drop in total acreage in silage. This drop is counterbalanced, however, by a rapid increase in the proportion of total acres to be irrigated - from less than 1 percent in 1970 to 3 percent in 1980, to 27 percent in 2000 and to almost 60 percent by the year 2020. The number of irrigated acres is therefore expected to level off at approximately 1,100 acres, with an annual water demand of approximately 350 million gallons.

Subarea 3. The irrigation water demands exerted by this subarea on the western edge of the study area are the lowest of any except York County. From a negligible amount of irrigated acreage in 1970, the total is not expected to rise above 600 acres at any time in the target period. There are expected to be only 230 irrigated acres in 1980, exerting a demand of 84 million gallons; 430 acres in the year 2000, with demands of 164 million gallons; and 560 acres in 2020, exerting demands of only 217 million gallons annually.

Roughly two-thirds of the total acreage and water demands are projected to go to nursery crops. Other demands in the Subarea include those exerted by corn and vegetables.

Subarea 4. In this subarea, located also on the western edge of the study area but farther south than Subarea 3, irrigated acreage is expected to increase rapidly. From 1,300 acres and a demand of 0.2 billion gallons in 1970, the number of irrigated acres is expected to increase to 6,000 in 1980; 17,000 in 2000 and close to 20,000 in 2020. Water demands are expected to amount to 2.0 billion gallons in 1980, 5.8 billion in 2000, and 6.7 billion gallons in 2020.

Over half the projected total water demand is accounted for by nursery crops. Although only a negligible amount of irrigation has been employed in this subarea in the past, total irrigated acreage is projected to rise to 2,600 in 1980, 7,800 and then 9,600 in the years 2000 and 2020. Irrigated water demand is projected to rise from 1.0 billion gallons in 1980 to 3.6 billion gallons in the year 2020.

A second major demand in this subarea is that exerted by corn. The expected decline in total corn acreage - from 23,500 in 1970 to 18,000 in 1980, 9,500 in 2000, and 5,470 in 2020 - roughly matches the falloff in the projected Virginia total corn production, since the Subarea's falling share of State production, and its expected increase in yield relative to the rest of the State tend to cancel each other out. The proportion of these acres to be irrigated, however, is expected to rise during the target period from 2 percent in 1970 to 3 percent in 1980, and to 47 percent in 2020. The number of irrigated acres is expected to rise from 600 acres in 1980 to 2,600 in the year 2000, where it is expected to level off with an annual water demand of 1 billion gallons.

Silage and hay are expected to each account for 10 percent of the irrigation water demand during the target period. Although the total number of acres in silage is expected to increase only 10 percent from 1970 to 1980, and only 30 percent from 1970 to the end of the target period, the proportion of acres in irrigation is expected to rise from a negligible amount to 6 percent in 1980 and 25 percent in 2000 and 2020. Six hundred acres are expected to be irrigated in 1980, and 3,000 acres in each of the latter years, with water demands jumping from 200 million gallons in 1980 to 800 million gallons after the year 2000.

In hay production, the Subarea's share of the Virginia total is expected to decline but slightly from the three percent share recorded in 1970, and the 40 percent increases in State production over 1970 levels are accordingly reflected in Subarea production and acreage. Irrigation demands are kept down, however, by the small proportion of hay expected to be irrigated, a total not exceeding 10 percent even by the end of the target period. Annual water demand is expected not to exceed 800 million gallons during the target period.

Subarea 5. One of the largest subareas, Subarea 5 is located on the Western shore of the Chesapeake Bay and encompasses ten counties. Despite its size, however, the irrigation demands of this subarea are relatively moderate. By 1980, only 4,100 acres are expected to be irrigated, a figure which increases to roughly 10,000 acres in the latter part of the target period. Total water demands are expected to increase from 1.2 billion gallons in 1980 to 3.3 billion gallons by the year 2000 and 3.6 billion gallons by 2020.

The largest component of the projected irrigation water demand is the demand of corn, a crop whose share of total Subarea water demands is expected to rise from 33 percent in 1980 to over 50 percent after 2000. As in some of the other subareas, the major factor in the increase is expected to be a sharp rise in the proportion of corn acreage which will be irrigated. In 1970, only 0.1 percent of all corn acreage was reported to be irrigated - by 1980, the proportion is expected to increase to 1.9 percent, by 2000, 14.4 percent, and by the end of the target period in 2020, 24.6 percent. Thus, despite falling State totals and Subarea production of corn, irrigated acreage is expected to rise to 1,100 acres in 1980, and to 5,000 acres after the year 2000. Its estimated water demand jumps from 0.4 billion gallons in 1980 to 1.9 billion gallons in the latter part of the target period.

Other irrigation water demands in Subarea 5 are those of nursery crops and silage. Irrigated acreage in nursery crops is expected to increase from 200 acres in 1970 to 670 acres in 1980, 1,500 acres in the year 2000 and 2,000 acres in 2020. With relatively high application rates of fourteen inches per acre per year, nursery crops are projected to account for roughly 25 percent of the irrigation water demand in the Subarea, at 300 million gallons in 1980 and 800 million gallons in 2020.

The large increase in silage production estimated for the State of Virginia (a doubling of production by 2020) is moderated by a projected increase in yield. Total Subarea acres in silage production, then, are expected to increase from 5,700 in 1970 to only 5,800 by 1980, and 6,800 by the year 2020. Since the proportion of silage acres in irrigation, however, is projected to increase (from 1 percent in 1970 to 18 percent in 1980, and 30 percent after 2000), silage is expected to exert a significant demand for irrigation water in Subarea 5: 300 million gallons in 1980, and 600 million gallons after the year 2000.

Subarea 6. Consisting of only one county, York, this subarea is expected to exert the weakest demand for irrigation water of all the subareas: from 16 million gallons in 1970, the total jumps to 25 million gallons in 1980, 42 million in 2000 and only 83 million gallons in 2020.

The only significant use of irrigation water in Subarea 6 in 1970 occurred in the production of nursery crops, a fact which is not expected to change in the target period. In 1970, 33 acres of nursery crops were irrigated. The total is projected to rise to 60 acres by 1980, and to 200 acres by the year 2020. Application rates though, are expected to decrease from 17.8 inches per acre recorded in 1970 to 15.4 inches per acre per year. Thus, the increase expected in the irrigation water demand in Subarea 6 - from 25 million gallons in 1980 to 83 million gallons in 2020 - is attributable to increased acreage in irrigated nursery crops.

Subarea 7. In this subarea, consisting of Virginia Beach and Chesapeake City, water demands for irrigation are also expected to be relatively slight. Total irrigated acreage is projected to decline slightly from an estimated 3,100 acres in 1980 (the 1970 total) to 2,950 acres in 2000 and 2,850 acres at the end of the target period. An increase in application rates, however, is expected to offset the decline, and, from 670 million gallons in 1970, projected irrigation water use jumps to 970 million gallons in 1980, 920 million gallons in 2000 and 930 million gallons in 2020.

Nursery crops are expected to account for over 80 percent of all irrigation water demands in the Subarea. The irrigated acreage in nursery crops is projected to decline from the 1970 level of 2,400 acres to 2,260 acres in 1980 and 2,100 acres in 2000. The slight increase to 2,300 acres in 2020 still leaves the irrigated acres projected for nursery crops below the 1970 level. Annual irrigation water demand in the target period is expected to fluctuate in the range from 730 to 790 million gallons.

The remaining irrigation water demands in Subarea 7 are expected to be exerted by corn (approximately 100 million gallons annually) and vegetables (70 million gallons in 1980 and 2000, to drop to half that amount in 2020.

Subarea 8. Irrigated acreage in this subarea is expected to jump sharply in the target period from current levels. In 1970, only 1,000 acres of cropland were irrigated; by 1980, this total is projected to reach 2,700 acres, and by 2000, the total is expected to be 18,500 acres. In the latter part of the target period, however, a reduction in the level of crop production in the Subarea is expected to lead to a reduction in irrigated acreage, and the total will fall to 14,900 acres.

Paralleling the trend in acreage irrigated is the demand for irrigation water. In 1970, 0.3 billion gallons of water were the recorded demand in the Subarea. Demand is expected to rise to 0.8 billion gallons in 1980 and to 6.3 billion gallons in 2000; but by 2020, the total is projected to fall off to 5.0 billion gallons.

The most significant crop use of water in the Subarea is that of corn. The Subarea share of Virginia corn production during the target period is expected to remain at roughly 20 percent (up slightly from 16 percent in 1970). Although, following State reductions, subarea production of corn is expected to fall, the proportion of acres in irrigation in the Subarea is expected to rise from 0.3 percent recorded in 1970 to 1.9 percent in 1980, and to close to 50.0 percent after the year 2000. It is largely due to this increase in the production of corn acreage irrigated that estimated annual corn water demand rises from 0.4 billion gallons to 4.7 billion gallons between 1980 and 2000. In the latter part of the target period, however, projected declines in State corn demand lead to an estimated falloff in that demand to 2.9 billion gallons in the year 2020.

A second major user of water in the Subarea is expected to be peanuts. By 1980, Virginia state production is projected to increase by 66 percent, and as the Subarea share is expected to diminish only slightly, Subarea production and acreage are both expected to increase dramatically (a 56 percent increase in production, and 41 percent increase in acreage). One percent of all acreage in peanuts, or 500 acres is expected to be irrigated, exerting an annual demand of 200 million gallons. In the latter part of the target period a declining Subarea share of State production (from 34 percent in 1980 to 12 percent in 2020) is more than offset by increases in irrigation and in production at the state level. Two thousand acres are expected to be irrigated in 2000, and 2,500 acres by 2020, and water demand is projected to jump to 600 million gallons and 800 million gallons respectively in each of those years.

Other major users of irrigation water in the Subarea are expected to be nursery crops and hay. The total number of irrigated acres in nursery crops is expected to increase from 200 in 1980 to 2,000 in 2020, exerting an annual water demand which rises from 100 million to 700 million gallons in the same period. Projected increases in the proportion of hay to be irrigated, from 1 percent in 1980 to roughly 6 percent after 2000, are expected to account for most of the increase in the annual water demand of hay irrigation - from 100 million gallons to 400 million gallons.

TOTAL AGRICULTURAL WATER DEMAND

In 1980 the agricultural water demand in the Chesapeake Bay Study Area is projected to total 76 billion gallons. 42 billion gallons, or 55 percent of the total is accounted for by irrigation; 30 billion gallons (39 percent) is accounted for by domestic water use, and 4 billion gallons (6 percent) is accounted for by livestock.

In the year 2000, the agricultural water demand in the study area is projected to total 114 billion gallons. Seventy-six billion gallons, 67 percent of the total, is attributed to irrigation; 33 billion gallons, or 29 percent of the total is attributed to domestic water consumption and 4 billion gallons, 4 percent of the total, is attributed to livestock.

In the year 2020, agricultural water demand in the study area is projected at 165 billion gallons. Irrigation water demand is projected to account for 76 percent of the total, at 125 billion gallons. Domestic water demand is estimated at 36 billion gallons, or 22 percent of the total, and the water demand exerted by livestock is projected to total 4 billion gallons, or 3 percent of the total. The enormous rise in irrigation water use is due principally to a large increase in the proportion of crop acreage which is expected to be irrigated.

See Table 6-19, Figure 6-15, and Attachment C for tabular and graphical representation of these demands. Attachment C contains a detailed breakdown of water demands by subarea.

Table 6-19 Annual agricultural water use by subarea, projections to 1980, 2000 and 2020, Chesapeake Bay Study

State and subarea	1980				2000				2020			
	Crops 1/	Livestock	Domestic 2/	Total	Crops 1/	Livestock	Domestic 2/	Total	Crops 1/	Livestock	Domestic 2/	Total
						Million gallons						
CHESAPEAKE BAY	42,238.3	4,276.3	29,928.3	76,442.9	75,937.9	4,177.7	33,439.8	113,555.4	124,881.7	4,318.0	35,488.6	164,687.3
DELAWARE	16,903.1	526.7	2,182.9	19,612.7	19,217.2	478.8	2,833.3	22,529.3	22,390.5	459.5	3,188.9	26,038.9
MARYLAND												
Study area	10,674.4	2,312.9	12,862.0	25,849.3	31,182.9	2,328.7	13,599.7	47,111.3	78,018.2	2,429.3	15,843.3	96,290.8
1	2,938.2	1,069.8	6,274.1	10,282.1	3,381.3	1,177.2	5,755.9	10,314.4	3,837.5	1,381.9	6,701.1	11,870.5
2	4,251.1	596.9	2,410.8	7,258.8	16,104.1	544.1	2,748.6	19,396.8	55,671.4	512.7	2,984.5	59,158.6
3	2,050.9	389.8	1,933.7	4,374.4	2,654.9	410.5	3,029.1	6,094.5	2,894.1	422.1	4,483.1	7,799.3
4	588.5	179.6	128.0	896.1	3,338.7	119.9	194.2	3,652.8	6,105.9	82.6	244.9	6,433.4
5	845.7	76.8	2,115.4	3,037.9	5,703.9	77.0	1,871.9	7,652.8	9,509.3	80.0	1,429.7	11,019.0
VIRGINIA												
Study area	14,660.8	1,436.7	14,883.4	30,980.9	25,537.8	1,370.2	17,006.8	3,914.8	24,472.0	1,429.2	16,456.4	42,357.6
1	8,408.5	36.7	1,116.6	9,561.8	6,260.3	35.3	1,329.0	7,624.6	4,737.4	38.6	1,497.0	6,273.0
2	1,106.9	367.6	3,561.0	5,035.5	2,701.1	294.6	4,359.4	7,355.1	3,118.6	255.6	4,813.9	8,188.1
3	84.2	119.2	1,228.9	1,432.3	164.9	133.8	1,440.9	1,739.6	217.1	162.0	860.5	1,239.6
4	2,032.3	244.0	2,875.4	5,151.7	5,813.2	185.4	3,305.0	9,303.6	6,706.0	154.1	3,613.6	10,473.7
5	1,218.2	222.5	1,697.4	3,138.1	3,317.2	219.1	2,094.6	5,630.9	3,581.4	210.3	2,350.9	6,142.6
6	25.1	30.3	406.6	462.0	21.1	42.0	198.5	261.6	83.2	57.7	228.4	369.3
7	972.5	91.5	1,192.7	2,256.7	919.4	79.2	1,068.6	2,067.2	933.9	71.7	919.9	1,925.9
8	813.1	324.9	2,804.8	3,942.8	6,340.6	380.8	3,210.8	9,932.2	5,094.3	479.2	3,172.2	8,745.7

1/ Irrigation demands are for "dry" years. See irrigation "Methodology and Assumptions" for projection methods and "Sensitivity Analysis" for "normal" year irrigation demand.

2/ Residual population, independently served.

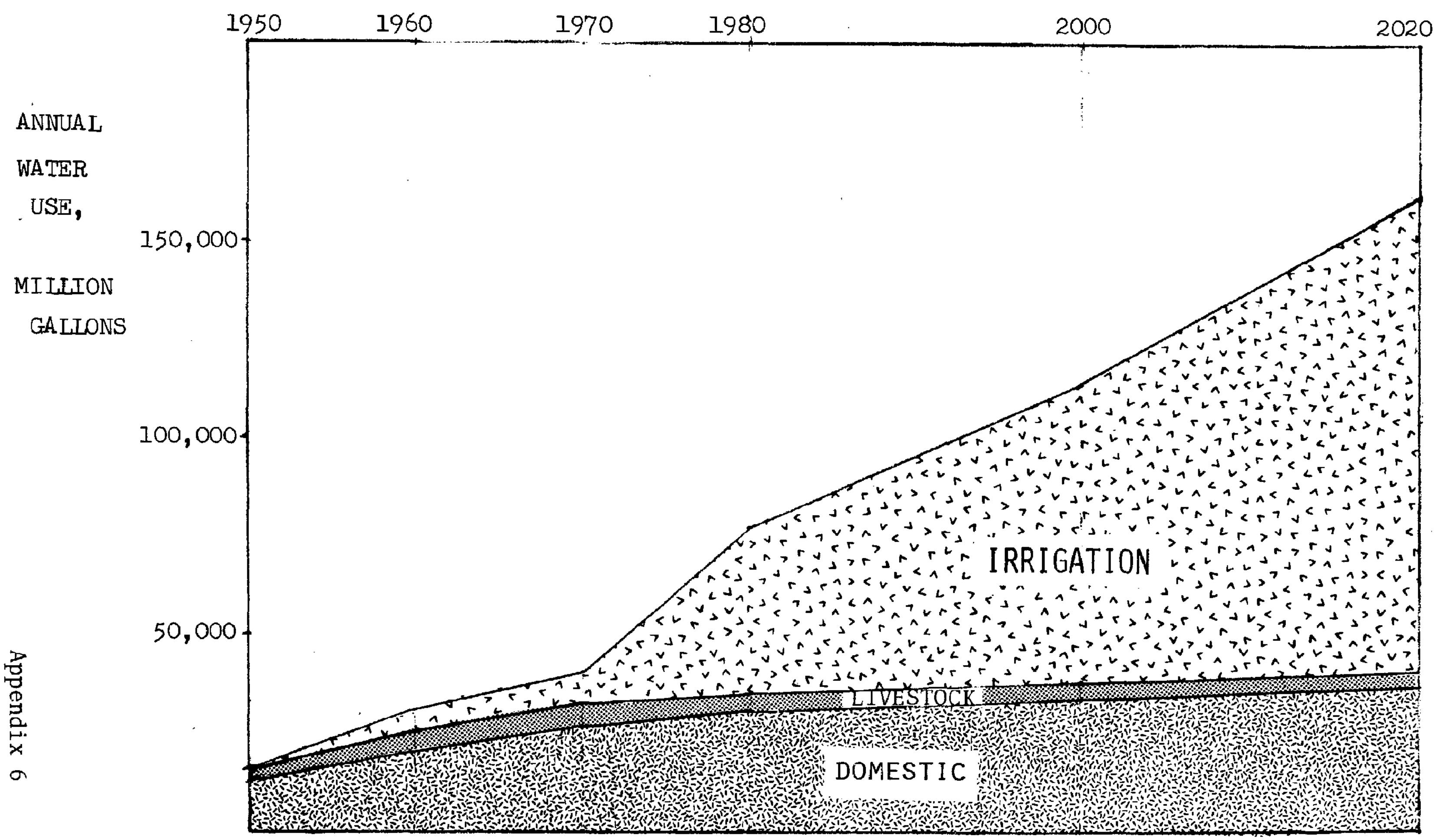


Figure 6-15 - Total Agricultural Water Demands, Chesapeake Bay Study Area 1/

1/ Irrigation demands are for "dry" years. See irrigation "Methodology and Assumptions" for projection methods and "Sensitivity Analysis" for "normal" year irrigation demand.

FUTURE SUPPLY

The agricultural activity projected for the study area is decentralized and in most cases dependent upon ground water for its source of supply. It is fortunate, then, that the Chesapeake Bay is located in one of the most water-rich areas in the United States, the Atlantic Coastal region. The water resources of the Chesapeake have the potential to meet all the demands imposed by agriculture in the foreseeable future.

In this Appendix the agricultural water demands are projected with reference to farming activity in the target years, and especially to factors such as population and food requirements. The factors which influence water supply, however, are somewhat less affected by man's activity. Some of the factors - including climate and the geological underpinnings of a region - will change little if at all during the period under study.

ASSUMPTIONS

Meteorological conditions are assumed to remain constant, essentially unaltered by nature or manmade forces during the period under study. Rainfall is assumed to continue in the area at its present rate, as will temperature, wind, and other factors which affect the rate of evapotranspiration. Soil conditions, which affect the rate of seepage, are also assumed to remain constant. No net withdrawals or additions to the ground water reservoir are assumed in the long run.

This Appendix represents an analysis of supplies and demand of water within the agricultural sector alone. As in all partial analyses, the interrelations with other demand sectors is kept to a minimum, and it is assumed that these competing demands do not severely deplete the ground water reservoir in agricultural areas. Appendix 5 includes additional information on the availability of water supply.

SOURCES OF SUPPLY

Water to fill the agricultural water demand in the study area is supplied by streams or other surface water, wells tapping the ground water reservoir, and by farm ponds of the impoundment and excavation types.

SURFACE WATER

a. Streams. Flowing streams are depended upon by farmers with access to them. Only a small portion of study area water demands are met by streams, though, because of lack of access, variable quality, and poor dependability of flow, especially during periods of drought when spot demands are high. Streamflow is heavily dependent upon precipitation, and where the latter is erratic, supply becomes irregular. (See Chapter IV,"Future Needs and Problem Areas")

b. Impoundment Farm Ponds. One solution to the problem of erratic rainfall has been the "impoundment" type farm pond. Designed to capture surface flow and store it for times of shortages, such ponds are, in effect, earth filled dams protected with spillways and vegetation. They vary in size from small livestock watering ponds to sizeable ponds over forty acres in surface area,which have the capacity to store over two hundred acre-feet of water.

The impoundment farm pond has been especially important as a supply source in the Piedmont, where ground water is not as available as it is in the Coastal Plain and the water table is not so easily tapped. Such ponds have been the chief source of water for irrigation and for livestock in the historical period from 1949 to 1969, and they are expected to continue as such into the future. (22)

With an abundance of impoundment sites of all sizes, the Piedmont is especially fortunate in its large and well distributed impoundment sites (in excess of 640 acres), which have the potential, if developed, to meet rural nonfarm and even industrial needs well into the future. It is anticipated that in areas where farm pond sites and streams are scarce there will be an increasing need for ponds of this type to meet farm and nonfarm demand on a community basis.

GROUND WATER

The aquifers in the Coastal Plain, wherein most of the study area lies, furnish far greater quantities of fresh water than the streams and rivers. Because its unconsolidated sediments contain an abundance of water bearing sands and gravels, the Coastal Plain's ground water from the aquifers is its most widely used source of water.

The sediments of the Atlantic Coastal Plain consist of layers of sand, shelly sands, and gravels separated by clays, each part of a complex system rich in water bearing potential. Much of the Atlantic Coastal Plain, including most of the Delmarva Peninsula, is blanketed by the Quaternary group, a group of geologically recent sediments up to 220 feet in thickness. Characterized by a scarcity of interstitial clay and silt, they possess extremely high water transmissivity. The Quarternary sediments are the most productive water bearing unit in the study area.

The other physiographic province in the study area is the Piedmont, a relatively narrow, moderate relief plateau between the Coastal Plain and the mountains. It is composed of crystalline rock of the igneous and metamorphic classes, rock which to the east forms the basement complex beneath Coastal Plain sediments. Although it is characterized by a wide variety of water yielding properties, the rock of the Piedmont is not generally considered to be good water bearing material. Ground water may contain unacceptably high concentrations of minerals, depending upon the type of rock from which it was obtained.

a. Wells. Springs and wells are an important source of supply for domestic use throughout the study area, for both the farm and the nonfarm residual populations.

In the Coastal Plain the majority of wells are dug or shallow bored. The quality of the water is excellent, and because of the high transmissivity of the aquifers, yields generally run from 300 to 1000 gallons per minute (gpm), with up to 4000 gpm in portions of the study area where the Quaternary aquifer is especially thick. There are several layers of aquifers in the Coastal Plain available to be tapped by wells on the surface. Over most of the Delmarva Peninsula, for example, there are more than five alternative sources of fresh ground water (containing less than 1000 mg/liter dissolved solids). The choice of aquifers is based upon desired water temperature, quality and quantities of the water desired, and the cost of well construction.

Despite its drawbacks, the Piedmont's supply of ground water is available almost everywhere from springs and wells of all depths. The influence of topography is frequently more important to the yield of wells in this region than the composition of the underlying rock: yields of wells in valleys are often significantly greater than the yields of wells located on hillsides. In general, however, Piedmont yields are substantially lower than those of the Coastal Plain, running from five to fifty gallons per minute. Though sufficient to meet domestic needs, wells may not meet irrigation and crop requirements.

b. Dug Farm Ponds. "Dug" or "excavated" ponds are large, shallow pits usually ten to fifteen feet in depth which tap the ground water reservoir.

In the Coastal Plain, the ready accessibility of ground water makes the dug pond the most common source of supply. The high recharge rate of ponds of this type outweighs their generally limited storage capacity to make them a good source of water for irrigation and livestock.

AVAILABLE WATER SUPPLY

Water for the purposes of irrigation, livestock and the rural domestic population is derived from wells, farm ponds and, to the lesser extent, surface flowing streams as discussed in the previous section. The amount of fresh water that will ultimately be available to meet future demand was estimated under the assumption that the ground water reservoir is under equilibrium; that is, in the long term, ground water discharge from an area is equal to the recharge from precipitation and other sources.

In the hydrologic cycle, the first demand for precipitation is the replenishment of soil moisture which is depleted by evaporation and transpiration (evapo-transpiration). After this demand is met, water percolates downward through the soil to the water table, or ground water reservoir. Once in the reservoir, most of this water moves downgradient and discharges into streams, the Bay, or the ocean, though a small amount is transmitted to the deeper artesian aquifers to replenish water withdrawn from artesian sources.

The base flow of streams is that part of total stream flow which is discharged from underlying aquifers; it is therefore a measure of the perennial ground water yield of the study area. This baseflow has been estimated as high as 26 percent of the 44-inch average annual precipitation, and as low as 15 percent. Weighting its measurements by drainage area upstream, the U.S. Geological Survey in the Existing Conditions Report (Appendix B) estimates the stream baseflow to be 20 to 25 percent of the mean annual precipitation, or an annual flow of about 10 inches.

These ten inches represent an annual yield of approximately 275,000 gallons per acre, or 3,521,300 million gallons for the Chesapeake Study Area as a whole (9647.3 mgd). The yield of ground water for farmland, similarly calculated, is presented in Table 6-21.

Table 6-20 - Farm acreage and available ground water: Chesapeake Bay Study Area

	1980	2000	2020
Acreage	4,686,000	4,128,800	3,601,150
Million gallons annually	1,272,500	1,121,200	977,900
Million gallons daily	3,486.2	3,071.7	2,679.1

It should be noted in the interpretation of Table 6-20 that the estimation of agricultural water supply for the study area is heavily weighted toward supplies within the Coastal Plain physiographic province, which are more dependent than Piedmont supplies upon ground water. Due to the relative impermeability of the underlying basement rock in the Piedmont, its water supply is of necessity oriented toward surface water supplies in the form of streams and, primarily, the impoundment type farm pond. It is difficult to estimate the proportion of precipitation which is gathered in impoundments.

A complete inventory of the available water supply from all sources which is available for all uses, is given in Appendix 5 of the Future Conditions Report, "Industrial and Municipal Water Supply."

FUTURE NEEDS AND PROBLEMS

Since in any subarea agricultural demands will be competing with municipal and industrial demands for the available water supply, it is necessary to compare demands of each of these uses with the fresh water supply. Only by such a comparison can the various demands' overall impact on available resources be determined. That analysis is discussed in Appendix 5 of the Chesapeake Bay Future Conditions Report.

Among the problems discussed in this Appendix are agriculture-related problems of erratic supply, salinity, environmental pollutants, and sedimentation.

ERRATIC SUPPLY

PROBLEM

Although the water supply in the Chesapeake Bay Study Area is more than sufficient to meet projected demands when both are considered in aggregate, the analysis would not be complete unless the erratic natures of agricultural demands and of the supply necessary to meet them were considered.

On the demand side, it is important in the efficient production of crops for the soil in which they are raised to have adequate soil moisture in the rooting zone at all times. If the soil moisture in the root zone of a crop is insufficient to ensure its development at the normal rate, its yield is reduced and the crop suffers "moisture stress", a condition of drought.

The quantity of water needed varies not only by crop and by rooting depth, but also by stage of crop growth, by soil type and by temperature and humidity. From Table 6-21 it can be seen that shallow rooted plants are not as drought resistant as those with deeper rooting systems. Virginia data show that shallow rooted plants such as vegetables can be expected to experience 58 days of water shortage 5 out of every 10 years. Another variable is the stage of a crop's growth. Yields can be drastically reduced by water shortages at crucial times. It is generally most important for a crop to receive adequate moisture late in the growing season. Figure 6-16 shows that soybean yield reductions are much greater if moisture stress is experienced in later stages of growth. When soil moisture available to corn during tasselling or pollination is reduced to the wilting level, yields are reduced by as much as 50 percent. If wheat is exposed to moisture stress late in the season, yield is sharply reduced through the shriveling of grain.

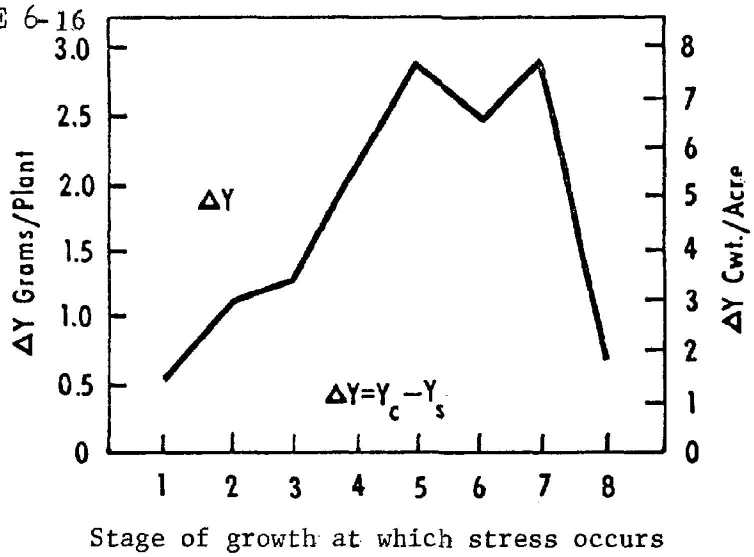
Table 6-21 **Drought Frequency 1/**

Average number days when soil moisture is inadequate for optimum crop yields—April to September:

If plant roots extend to a depth that the soil in its root zone will hold:	One year in ten	Two years in ten	Three years in ten	Five years in ten
	Number of days with a lack of water in:			
1 inch of water	120	97	83	56
2 inches of water	95	70	51	23
3 inches of water	78	49	29	5
4 inches of water	58	32	13	0
5 inches of water	43	19	7	0

1/ Informational source, V.P.I. Technical Bulletin 128, April 1957, "Agricultural Drought in Virginia."

FIGURE 6-16



Change in soybean yields due to moisture stress applied at selected periods of growth

Source: Technical Bulletin, No. 1431. USDA, ERS. 1974

The agricultural water supply can be equally erratic. Although an enormous quantity of ground water is stored in the sediment beneath the study area, only a small portion is recoverable by wells. Further, under the conditions of water table equilibrium assumed in the supply analysis, heavy withdrawals of ground water in one location will both draw down the water table and curtail the base flow of local streams unless sufficient recharge enters the system to cover its losses. The variability which most affects agricultural activity, however, is that associated with precipitation.

Annual precipitation in the Chesapeake region averages 40 to 45 inches, of which 8 to 10 inches is runoff. This supply is more than adequate to meet the total agricultural demands of the study area listed in Table 6-19. (see page 90)

The aggregate supply of water available for agriculture, though - and especially to crops - is highly variable, and this variability is the key to many of the problems of agricultural water supply. Precipitation in the study area varies from one month to the next, (as seen in the monthly precipitation averages given in Figure 6-17), and in summer months it is often in the form of high intensity thundershowers of brief duration.

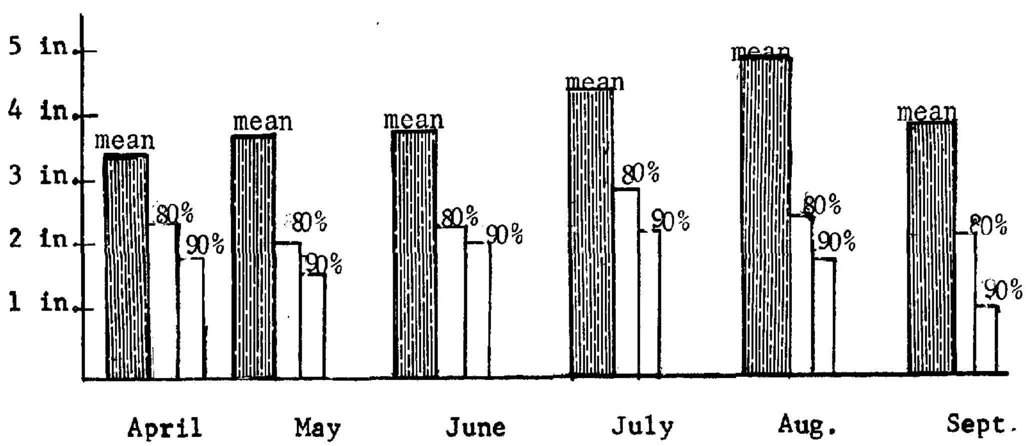


Figure 6-17. Rainfall by month: mean, and 80 percent chance of occurrence, and 90 percent chance of occurrence. Chesapeake Bay Study Area.

Source: Monthy Precipitation Probabilities by Climactic Divisions: 23 Eastern Study. **Miscellaneous Publication No. 1160. Economic Research Service and Environmental Source Services Administrations.** 1969.

Precipitation is also highly variable from one year to the next (see Figure 6-17), and the rain expected to be exceeded eight or nine years in ten is reduced in some parts of the study area to only 40 and 25 percent, respectively, of its monthly mean. This variability has a particularly adverse effect upon crop production, for which the main source of supply might be precipitation. It also affects the water supply of excavated farm ponds, as the water table, the surface of such ponds, varies in response to precipitation.

Thus in any question of water sufficiency for agricultural demand, it is not yearly aggregates but local supplies and demands which are important. If supply problems do arise, they are likely to be location and time specific.

SOLUTIONS

The unpredictability of precipitation in the study area and the poor holding capacity of many of its sandy soils (23) have led to a sharp increase in supplemental irrigation in the region, an increase reflected in the projected demands for irrigation water. Irrigation is expected to be applied not only to highly valued crops, but with increasing frequency to crops with low per-acre value so that the yield reductions attendant upon moisture stress are avoided.

To meet the goal of efficient crop production it is as important in irrigation to achieve the proper distribution of water as it is to achieve the proper volume. It has been shown, for example, that a total application of 21 inches, infrequently distributed over a season, can result in a 58 percent reduction in potato yield over that obtained using 19 inches frequently and evenly applied. (24) If the water needs of a crop cannot be met through irrigation, the damage to crop yield is permanent, and it cannot be rectified by heavy water applications later in the season.

The need for adequate irrigation is particularly important toward the harvest time, for if a crop cannot be brought to maturity because of water shortages, all previous irrigation water will have been wasted.

It is thus not only aggregate volume of water, therefore, but a proper distribution of the supply throughout a season which must be ensured if the supply problem is to be met. The monthly distribution of irrigation water requirements is listed in the Sensitivity Analysis below. Measures to meet this need might be the construction of deep wells for irrigation purposes and the development of large storage ponds for community use. The latter measure might be particularly effective in areas where storage sites are limited. During times of extreme dryness, perhaps a necessary measure is the monitoring of ground water withdrawals by other large users of water, such as food processors, located in agricultural areas.

Another solution to spot shortages is the use of stream water. The problems in stream water use are more numerous, though, than those of ground water use. Streams are more susceptible to pollution than groundwater, for example, and a major problem in their employment up to the present time has been their lack of accessibility. Further, the base flow of streams can be reduced sharply when the gound water table drops in times of drought. This reduces the water available from streams when it is most needed. Nonetheless, the value of streams as a potential source of water cannot be neglected - particularly in areas with skimpy ground water supplies, and where sediment and pollution problems are minimal.

SALINITY

PROBLEM

If streams are to be considered as potential sources of water, the problem of salt water intrusion must be addressed. Crops, livestock, and humans all have a limited tolerance for salt consumption. Irrigation and livestock watering practices must each be altered to take into account the presence of even low concentrations of salts in the water supply.

When salt concentrations reach a conductance of 8 to 10 millimhos per centimeter (8,000 to 10,000 micromhos), all crops show some yield reduction, and for many the reduction is more than fifty percent. In recognition of this data, and the fact that salt accumulates exponentially with evaporation in the top layers of soil, the Report of the National Technical Advisory Committee to the Secretary of the Interior (1968) recommends the following classification for crop salinity hazard:

Table 6-22-Crop Salinity Hazard and Total Dissolved Solids (TDS).

	TDS mg/l	EC mmhos/cm
Water for which no detrimental effects will usually be noticed.................	500	0.75
Water which can have detrimental effects on sensitive crops.................	500-1,000	0.75-1.50
Water that may have adverse effects on many crops and requiring careful management practices...	1,000-2,000	1.50-3.00
Water that can be used for tolerant plants on permeable soils with careful management practices.......	2,000-5,000	3.00-7.50

Source: Report of the National Technical Advisory Committee to the Secretary of the Interior (1968).

Like its demand for fresh water, a crop's tolerance for salt water varies according to its stage of growth. A germinating seedling is most sensitive to salinity, and well established plants tend to be more salt-tolerant than younger plants. Tolerance of salinity also varies from one crop to the next. As seen in Figures 6-18 through 6-20, vegetables are more sensitive to salinity than field or forage crops. (Also shown in the figures is the non-linear crop response to increases in salinity. For many crops, once the threshold concentration is reached in which yields are reduced, additional concentrations tend to further reduce yield rapidly).

Tolerance of salinity varies for each type of consumer. Adult sheep have the highest tolerance, as they can safely consume water containing 12,900 part per million (ppm) dissolved solids. (See Figure 6-21). Pigs and poultry, respectively, can tolerate 4,290 ppm and 2,860 ppm dissolved solids. Most stringent are the standards in water for human consumption. Water containing less than 500 ppm dissolved solids can be safely consumed without awareness of salinity.

Ground water in the study area is generally of good quality, containing less than 250 mg/l dissolved solids. Where it is available, it is generally suitable for all agricultural and domestic uses, except for iron and acidity problems in some locations.

Figure 6-18. Salt tolerance of vegetable crops*

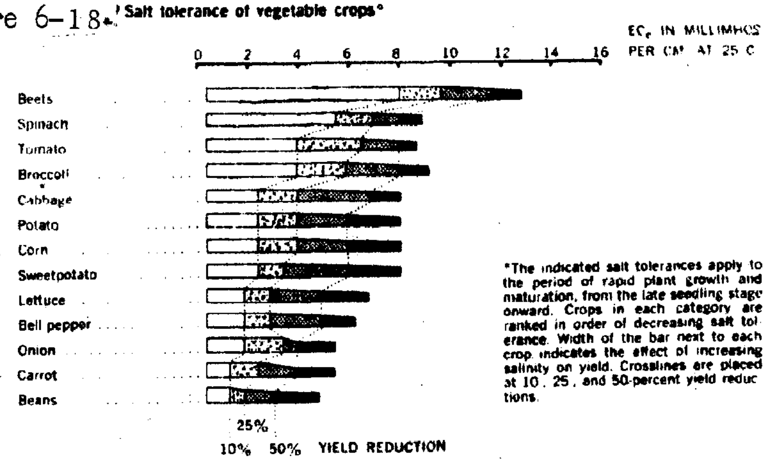
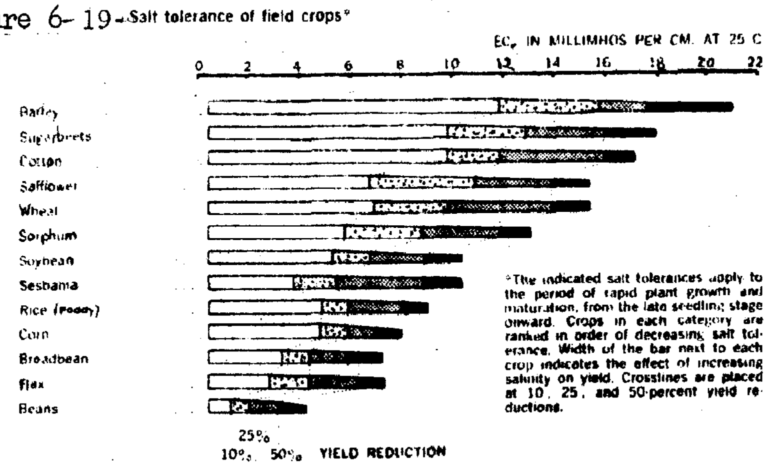


Figure 6-19. Salt tolerance of field crops*



Yield Reduction:

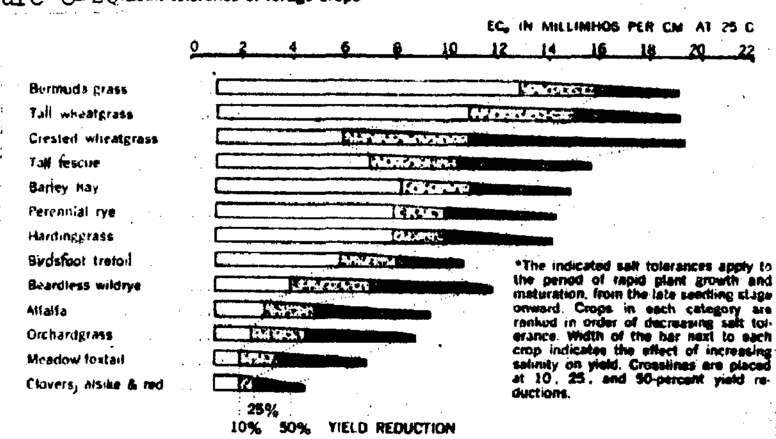
0

10%

25%

50%

Figure 6-20. Salt tolerance of forage crops*



Source: Report of the National Technical Advisory Committee to the Secretary of the Interior (1968).

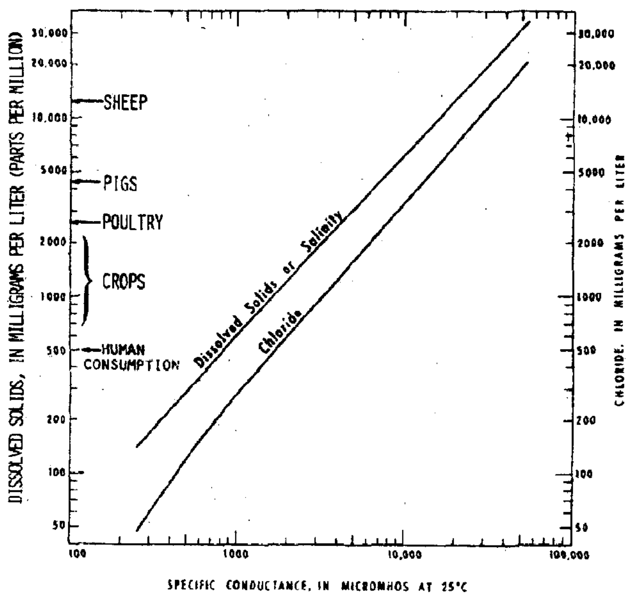


Figure 6-21 - Tolerance to Salinity: Human, Crop, Livestock.

Adapted from Extent of Brackish Water in the Tidal Rivers of Maryland, Maryland Geological Survey, 1970

Streams in the study area, as well, are low in dissolved solids, and are suitable for most agricultural uses, except in the downstream reaches of streams which are subject to tidal intrusions of saline water. Figure 6-22 documents the extent of salt water in Maryland and Delaware. While data on the extent of salinity in Virginia is not available, salt water may be expected to intrude to Fredericksburg along the Rappahannock River, to West Point on the York River, and to Hopewell along the James River. (25)

The actual extent of salinity in stream water depends in part upon quantity of fresh water stream flow, which, in turn is affected by precipitation, overland flow, and base flow water. In a dry year, the fresh water flow can be expected to be considerably reduced, and brackish water may intrude further upstream than it would if more precipitation fell on the region. Base flow can also be reduced by the use of ground water resources to a degree where the water table is drawn down. This practice tends to reduce stream flow at surrounding locations, leading to more intrusion of saline water than would be the case without such withdrawals.

To the extent the withdrawals reverse the normal gradient of ground water, saline water might also intrude into ground water supplies. Although the rate of intrusion into ground water aquifers is minute compared to the surface water rate, (26) the effects can be much more damaging since wells may be unusable for years.

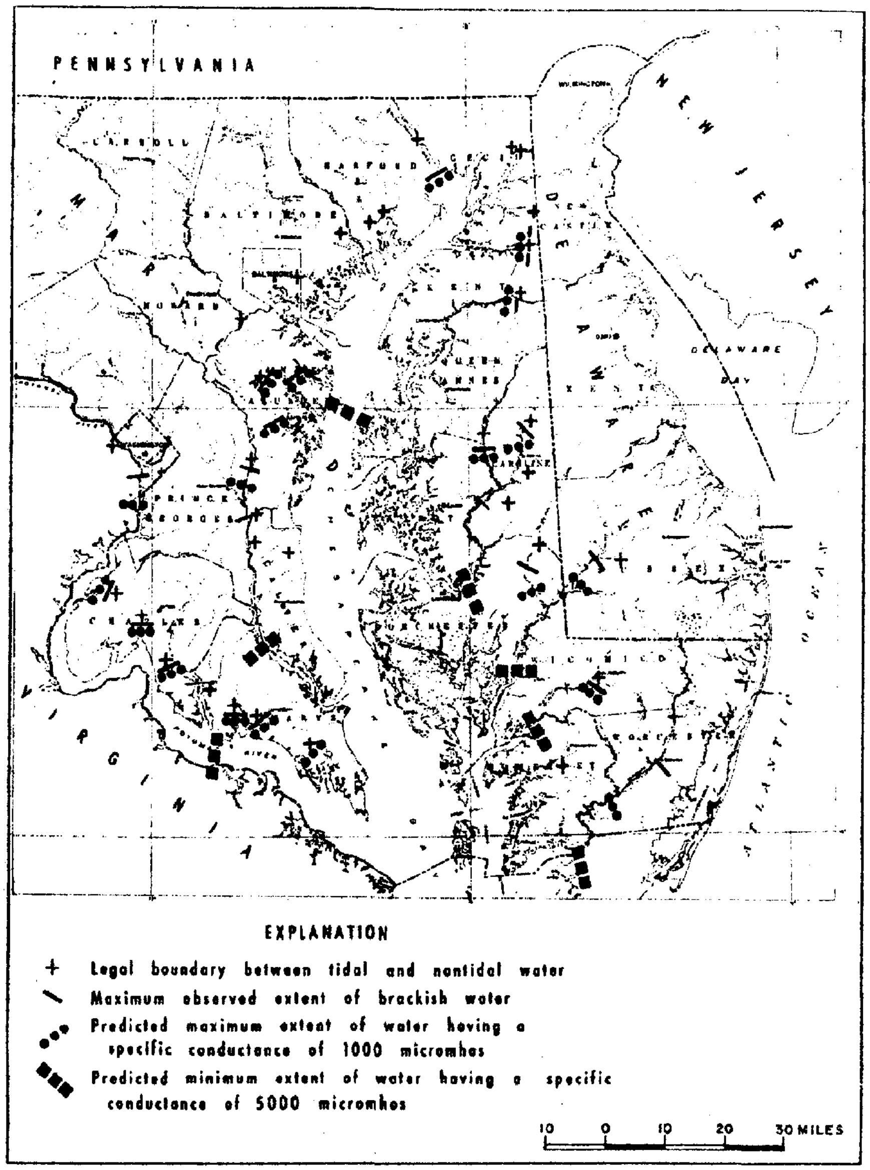


Figure 6-22. Extent of brackish water in Maryland.

Source: <u>Extent of Brackish Water in the Tidal Rivers of Maryland</u>, Maryland Geological Survey, 1970.

Another problem is posed by evaporation. While the above-listed crop salinity tolerances are rough limits within which, under experimental conditions, yields are not affected, in actual practice a considerable part of the gross amount of water applied to crops can be expected to evaporate. Salt concentrations in the soil thus tend to be greater than in application water, and a surplus of water over plant needs must be used to flush them from the soil. In this fashion the use of brackish water entails greater applications of irrigation water than would otherwise be necessary, and it creates a danger of salt contamination in ground water supplies. Evaporation factors must be especially taken into account in times of drought, when salt concentrations of even mildly saline water are much increased after application.

SOLUTION

It is largely a management problem to ensure that withdrawals of water fall within safe consumption limits. Similarly, it is up to the individual manager to safeguard his fields from the effects of concentration buildups due to evaporation.

Large withdrawals from the groundwater reservoir, if saline water intrusion is the result, may on the other hand pose a public problem. The effects of such withdrawals should thus be carefully monitored and, where necessary, accompanied with regulation to protect the reservoir from contamination.

ENVIRONMENTAL POLLUTANTS

As the trend toward larger farms continues, pollutants from agricultural activity can be expected to become a potential source of serious water quality degradation. Large livestock farms require greater quantities of high quality water than the smaller ones, and they accordingly result in larger, more concentrated discharges of pollutants. Livestock wastes are a potential problem since during the target period production is expected to be located more often in large, concentrated feedlots; much of the projected yield increases for crops are predicated upon increased use of chemical fertilizers.

As in the case with other agricultural water problems, these wastes are characterized by variability. Unlike municipal sewage systems in which, as one source states, "a liquid waste stream of reasonably predictable composition and quantity arrives continuously through a well-defined outfall line", agricultural wastes are generated in a series of remote functional units, where distance precludes central disposal. (27) The wastes so generated are often discharged only intermittently into the environment - the result, for example, of the flushing action of storm waters, or the periodic exercise of an agricultural function such as pumping a manure storage pit or applying pesticides.

Agricultural wastes are further characterized as "point" or "nonpoint" sources according to whether or not the wastes are released in a well-defined flow from a clearly identifiable source. While some agricultural pollutants, such as large feedlots or irrigation wastewaters, fall under the definition of agricultural point sources used by the Environmental Protection Agency (EPA), (28) most are released into the environment in nonpoint, or diffuse, flows which are more difficult to control.

The three major types of environmental pollutants discussed in this section are fertilizer, pesticides, and livestock wastes.

FERTILIZER

a. Problem: In recent years the trend toward more widespread use of chemical fertilizer on agricultural land has been largely responsible for their increased productivity. It is an unfortunate side effect of fertilizer use that it may also increase the fertility of streams where agricultural runoff is received. When such streams feed into ponds, the process of "eutrophication" begins, in which nutrients present in the water stimulate the growth of aquatic plants. Algae blooms spread across the surface of the water, and taste and odor problems arise; the aging process is quickened, with a bog or swamp the eventual result.

Nitrates in the runoff from fertilized agricultural areas can also cause health problems. If such runoff contaminates water for consumption, the presence of nitrate causes methoglobinemia, a disease in which the blood is deprived of needed oxygen. In livestock the symptoms are watery eyes, a rough hair coat, and loss of appetite resulting in weight losses or diminished productivity.

The United States Public Health Service defines the standard of nitrate nitrogen consumption at a maximum of 10 parts per million (ppm), an amount considered safe for infant feeding. Alga blooms are generated, however, when the nitrate concentration of pond water reaches only 0.30 ppm and phophorous concentration only 0.01 ppm. The environmental impact of fertilization must be considered, then, even where small amounts are involved. Where large amounts of fertilizer are used, as in the high yield production levels projected in the target period, impacts may be even more significant.

The use of fertilizer in the Chesapeake Bay Study Area is estimated for recommendations for fertilizer applications presented in Attachment D,Table 6-D-1. These rates are not expected to change by 1980, but by the latter part of the target period they may represent application rates which are somewhat lower than the appropriate amounts. Even where yield increases are attributed to improve crop varieties, fertilizer application rates would tend to rise, for it is often the efficient utilization of fertilizer which lies behind the productivity of new varieties.

Table 6-D-2 lists the recommended fertilizer applications for the estimated level of production in the study area. An estimated 63,000 tons of nitrogen was used in 1970, a total which is expected to rise to 73,000 tons by 1980, and to 77,000 tons by the year 2020. Estimated phosphorous applications rise from 68,000 tons in 1970 to 78,000 tons by 2020; and potassium applications in the same period are expected to rise from 73,000 tons to 82,000 tons.

The small increase in fertilizer use, in the face of a general reduction in crop acreage, points to greater concentration of fertilizer.

Given these increased concentrations, the question arises as to the amount of this fertilizer which may be expected to enter the surface and ground waters. Rough estimates of losses range from 0.1 percent to 1 percent of all nutrients applied in a watershed to 6 to 10 percent of nutrients applied on steeply sloping experimental plots. But beyond the simple generalizations that nitrates, the most mobile of nutrients, are likely to enter both gound and surface water, and phosphates are likely to be "fixed" in the soil, little can be said without referring to specific crops, fertilization practices, precipitation, slopes, and soil conditions.

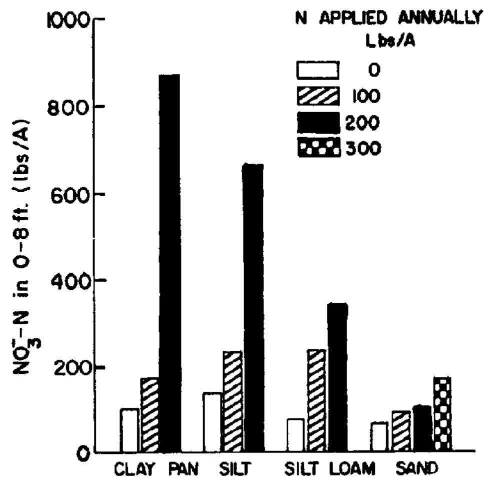
Nutrients are commonly lost through leaching, or percolation down through the soil, and through runoff.

For leaching to occur, it is generally necessary that large quantities of water in excess of the evapo-transpiration requirement of crops be present in the soil; otherwise evaporation near the surface and capillary action tend to hold nutrients near the surface. Leaching losses are thus more likely during the winter and spring than during the crop season.

The influence of the field capacity of a soil on leaching is seen in Figure 6-23. Nitrates accumulate near the surface in clays and silts, which are relatively high in their water holding capacities. Conversely, the low capacity sandy soils contain relatively small nitrate accumulations.

Figure 6-23. Nitrate-N in the upper 8 feet of 4 soil types after the annual application of N fertilizer for 7 years to continuous corn in Missouri.

Source: G.Smith, 1968.



Large amounts of nitrogen, added to the soil as fertilizer, increase the nitrate available for leaching in some cases, but according to one source, no general statement can be made that this is true on a widespread basis. The effect of excess nitrogen fertilizer on the environment is not fully known: in many cases, the nitrate remains within the root zone, and is available for succeeding crops even after irrigation (29). (See Figure 6-24)

The issue of nitrate accumulation is further clouded by the importance of inherent soil fertility. In one experiment (Stewart, 1970), no nitrate accumulated under levels of fertilization (143 kg/ha) which were the average for the test area. Even under very heavy fertilization, there were no accumulations below 30 feet (Table 6-23). The author concludes that the soil fertility level, and not its source, largely determines whether nitrate accumulates.

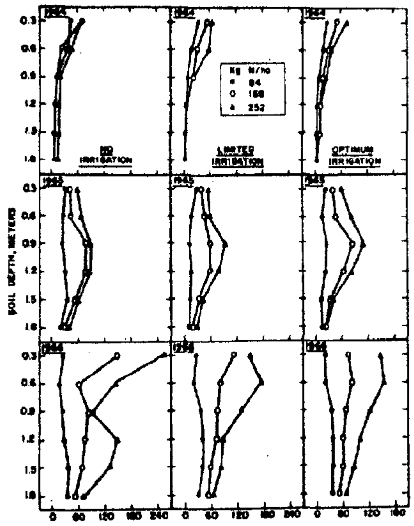


Figure 6-24-Nitrate-nitrogen found in Sharpsburg silty clay loam profiles after corn harvest, as affected by irrigation and amounts of applied nitrogen.

Source: Herron, et al., 1968.

Depth		N applied annually for 5 years, kg/ha			
		0	143	357	892
meters	(feet)	NO_3-N, kg/ha			
0-0.3	(0-1)	0.5	1.2	1.8	202
0.3-0.6	(1-2)	0.0	0.8	6.8	164
0.6-0.9	(2-3)	0.2	0.8	3.9	18
0.9-1.8	(3-6)	0.1	0.7	3.1	13
1.8-2.8	(6-9)	0.2	0.5	6.5	13
2.8-3.7	(9-12)	0.6	0.7	7.8	14
3.7-4.6	(12-15)	0.5	0.2	5.8	14
4.6-5.5	(15-18)	2.0	-	-	20
5.5-6.4	(18-21)	3.4	-	-	15
6.4-7.4	(21-24)	1.4	-	-	10
7.4-8.3	(24-27)	1.0	-	-	3
8.3-9.2	(27-30)	0.7	-	-	2
9.2-10.2	(30-33)	1.3	-	-	1.4
10.2-11.1	(33-36)	1.7	-	-	2.2
11.1-12.0	(36-39)	1.2	-	-	1.4
12.0-12.9	(39-42)	1.3	-	-	1.2
12.9-13.8	(42-45)	1.4	-	-	0.9
13.8-14.8	(45-48)	1.0	-	-	0.5

Table 6-23-Nitrate accumulations under irrigated grain sorghum fields on a slowly permeable soil fertilized with varying rates of ammonium sulfate.

Source: B.H. Stewart, 1970.

The other type of nutrient loss occurs through runoff. Such losses vary by crop, runoff volume, nutrient application level and season.

Figure 6-25 graphically depicts the relation between runoff and nutrients, the impact of increased fertilization on nitrate concentrations and seasonal variations in runoff and nutrient loss. Nitrate losses were substantially higher in the highly fertilized Watershed 2 than in Watershed 1, and in the winter months than in the summer and fall. The effect of the presence of crops in the summer and their absence in winter is seen in both runoff and nitrate concentration patterns. Despite the facts that summer is the season with most precipitation in the watersheds studied and that snowmelt is not an important factor, runoff is highest in the early spring, and it is reduced in summer months when crops are present. Nitrate concentrations, as well, are sharply reduced during the summer months.

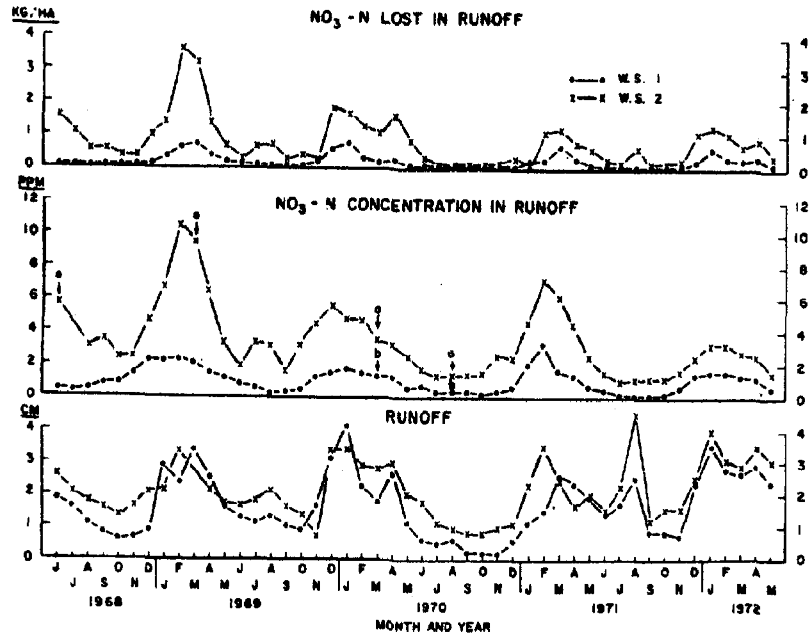


Figure 6-25 - Monthly losses of NO_3-N as related to runoff amounts, NO_3-N concentration in runoff, and fertilization.

a = surface application of 112 kg N/ha;
b = surface application of 56 kg N/ha.

Source: V. J. Kilmer, et. al.

Table 6-24 shows nutrient loss data pertaining to various crops. The concentration of nutrients in runoff is greatest for fallow fields, followed by continuously planted corn and corn, oats, and hay in rotation. In 1967, the concentration of total nitrogen in runoff ranged from a high of 85.71 ppm in a fallow field to a low of 0.39 ppm in a hay field in rotation. Runoff rates clearly vary between crops.

Table 6-24-Annual soil and nutrient losses, by crop

Crop and year	Soil loss	Average annual runoff	Total N		NH_4-N		NO_3-N		P		K	
	lb/ac	inches	lb/ac	ppm[1/]	lb/ac	ppm[1/]	lb/ac	ppm[1/]	lb/ac	ppm[1/]	lb/ac	ppm[1/]
1966												
Fallow	7,600	3.80	25.96	30.16	.29	.34	.80	.93	.04	.04	1.78	2.07
Corn-continuous	720	.91	4.00	19.39	.10	.48	.10	.48	.10	.48	.50	2.42
Corn-rotation	380	2.05	2.00	4.31	.10	.21	.29	.63	.10	.21	.60	1.29
Oats-rotation	20	.20	.10	2.16	0.0	0.0	.10	2.16	0.0	0.0	.10	2.16
Hay-rotation	0	3.41	.30	.39	0.0	0.0	.10	.13	.10	.13	.80	1.04
1967												
Fallow	20,560	4.63	89.93	85.71	.20	.19	.48	.46	2.59	2.47	4.55	4.34
Corn-continuous	6,280	2.98	19.18	28.44	.30	.45	.80	1.19	.04	.05	1.16	1.72
Corn-rotation	1,239	2.35	6.69	12.58	.10	.18	.07	.13	.10	.18	.60	1.12
Oats-rotation	2,040	2.09	9.37	19.81	.10	.21	.16	.34	.10	.21	.60	1.26
Hay-rotation	0	3.83	5.71	6.58	0.0	0.0	.04	.04	.29	.34	5.17	5.97

1/ Average concentration of nutrients in runoff.

Source: Timmons, D. R., Burwell, R. E., and Holt, R. F. 1968. Loss of crop nutrients through runoff. Minnesota Sci. 24 (4): 1.

b. Solutions: It is difficult to state the exact extent of nitrate losses through leaching. Under some conditions nitrates move into groundwater supplies after only one growing season, while under others, it takes ten to fifty years to move through a forty-foot soil profile to enter the groundwater.

It is clear, however, that chances of leached nitrate entering groundwater are considerably reduced if nutrients are not applied in amounts substantially in excess of crop needs, particularly on sandy soils. Growing cover crops in the off season also reduces leaching losses. Such measures are especially important if the water table is close to the surface, as it is on some parts of the Delmarva Peninsula.

Runoff losses of nutrients, while a much greater problem in the study area than leaching losses, can also be controlled through proper applications of fertilizer. If both crop needs and inherent soil fertility are taken into account in fertilizer application, excess nitrate available for runoff is sharply reduced.

Fertilizers can be applied in solution for efficient crop utilization. This technology is likely to be employed to an increasing extent with the spread of irrigation systems, as it cuts both labor costs for the farmer and production costs for manufacturers. The quantity of nitrate available for runoff is also reduced by slow-release fertilizers, applied only once per season.

PESTICIDES

a. Problem: The years following World War II marked a new era in the use of pesticides in the United States with the introduction of DDT and others in the chlorinated hydrocarbon group. These pesticides were noted for their toxicity and persistence, and soon became the most popular pesticides used.

The very properties responsible for their popularity, however, have made pesticides the source of adverse environmental effects such as mortality, loss of production, and changes in estuarine plant life. A concentration of only one part per billion (ppb) DDT has resulted in a twenty percent reduction in oyster growth, and a similar concentration of another chlorinated hydrocarbon, endrin, has caused the death of fish and aquatic life.

The greatest pesticide danger stems from sudden discharges into the environment of relatively high concentrations of the toxic material. A heavy flushing rain over agricultural fields can result in the sudden occurrence in a receiving stream of a pesticide concentration which is overwhelmingly toxic to aquatic life. Seepage from the industrial waste lagoons of pesticide producers, pesticide formulators, and pesticide users has polluted ground and surface waters and rendered them unfit for agricultural use.

More common than a single large discharge is the steady almost continuous discharge from agricultural land of pesticides in small concentrations. Many pesticides, though insoluble, are tightly held by soil particles, and when soil is washed away by agricultural runoff, the pesticide is carried with it in minute quantities. Such losses rarely account for concentrations of more than one part per billion in receiving streams, though up to five percent of all pesticides applied may be lost with sediment.

Table 6-25 is noteworthy, not just for the minute levels of pesticides which are found in the major rivers of the United States, but for the widespread nature of the rivers' contamination. Though the levels of pesticides present amount to only fractions of one part per billion, they are generally found in well over 70 percent of the rivers and lakes surveyed, and some, such as DDT and DDE, are found in 95 percent of the sampled waters.

The danger to the environment of such small, persistent concentrations is considerably greater than their size would seem to indicate. Many pesticides, with DDT a prominent example, leave water preferentially for soil and sediment. Thus, in waters containing only 0.1 ppb of the substance, bottom

Table 6-25-Chlorinated hydrocarbon insecticides and related compounds in major rivers of the United States.[1]

Source: H.P. Nicholson and D.W. Hill, 1970.

Compound	Geographic Distribution (No. States with Positive or presumptively Positive samples)	No. Rivers and Lakes Positive	Sampling Stations Positive No.	Positive and Quantified Range ppb[2]
dieldrin	36	39	56	0.002–0.118
endrin	28	23	30	0.003–0.094
DDT	28	22	23	0.007–0.087
DDE	28	17	18	0.002–0.018
TDE	1	1	1	0.083
aldrin	10	1	1	0.085
heptachlor	16	0	0	–
heptachlor epoxide	0	0	0	–
BHC	2	0	0	trace

[1] Except Alaska and Hawaii. Adapted from data in "Chlorinated Hydrocarbon Pesticides in Major U.S. River Basins" by Weaver, Gunnerson, Breidenbach, & Lichtenberg. Public Health Rpts. 80:481–493. 1965.

[2] Minimum detectable concentrations of dieldrin, endrin, DDT, DDE, aldrin and heptachlor ranged from 0.002 to 0.010 ppb. Comparable values for TDE, heptachlor epoxide and BHC were 0.075, 0.075, and 0.025 ppb, respectively.

sediments have been found to contain from 20 to 500 ppb. Exchange of materials in aquatic life is rapid, and DDT can be found shortly after it appears in the bottom sediments in aquatic plant life. Shortly after it appears in plants it is found in fish. At each step in the food chain, the toxic substance becomes increasingly concentrated, until, by the third or fourth level, the substance reaches a concentration which can cause considerable harm. It is for this reason the minute concentrations of persistent, toxic pesticides are hazardous.

b. Solutions: Since most pesticides from agricultural use enter streams through runoff and soil erosion, the problem of pesticide runoff and hazard can be ameliorated with many of the methods used to control soil erosion. One method, for example, has been to create buffer strips of filiage along the banks of streams to prevent pesticides and herbicides from entering them. In some controlled experiments, concentrations in the receiving stream have been considerably reduced using this method.

Another solution has been the sharp regulation of industrial wastes in which pesticides have been present. In contrast to pesticide concentrations in agricultural runoff, concentrations in industrial wastes have generally been of lethal levels.

The problem of small and widespread pesticide concentrations will not be solved until the very persistent pesticides are no longer used. As in the case of fertilizer, an environmental constraint must be added to the optimization procedure, so that a balance is achieved between effectiveness and cleanliness. Recent technological advances in pesticides appear to be making this possible.

LIVESTOCK WASTE

a. Problem: A major factor in the modern production of livestock has been the concentration of facilities. Broilers are now grown and processed in large enclosures; the production of hogs increasingly takes place in confinement operations; and beef feedlot operations are increasingly concentrated.

Enormous quantities of wastes are generated by such operations: a cattle feedlot with 10,000 head has the same sewage output as a city of 160,000 people. Operations of over one thousand livestock units (30) have been designated point sources of effluent by the Environmental Protection Agency.

Although it represents a considerable reduction from current levels, some 18 to 20 million tons of livestock raw waste can be expected to be generated annually in the Chesapeake Bay Study Area during most of the target period (see Attachment D, Tables 6-D-3 and 6-D-4).

The dangers of runoff from feedlots are well recognized, and it may be expected that during the target period, the combination of environmental controls on small livestock operations and existing controls on increasingly widespread large operations will solve much of the problem. Even if runoff is eliminated, however, two major problems in livestock operations will remain: the seepage of pollutants from livestock wastes into ground water, and the ultimate disposal of such wastes.

Although the soil beneath feedlot operations tends to be compacted and its permeability reduced, enormous concentrations of nitrates nevertheless accumulate beneath such operations. In the experimental results shown in Figure 6-26 and Table 6-26 , an average of 1,436 pounds of nitrate per acre were found in the soil cores taken beneath feedlots, in contrast to the 261 pounds per acre taken from dryland farms. In the groundwater beneath feedlots was found up to 38 parts per million (ppm) of ammonium nitrogen, and an average of 13 ppm nitrate nitrogen.

The second major problem in livestock production is the ultimate disposal of waste matter. At present, the chief means of disposal of captured runoff and the vast quantities of livestock wastes is land spreading. In one ton of manure, there are roughly 10 pounds of nitrate, 5 pounds of phosphate, and 10 pounds of

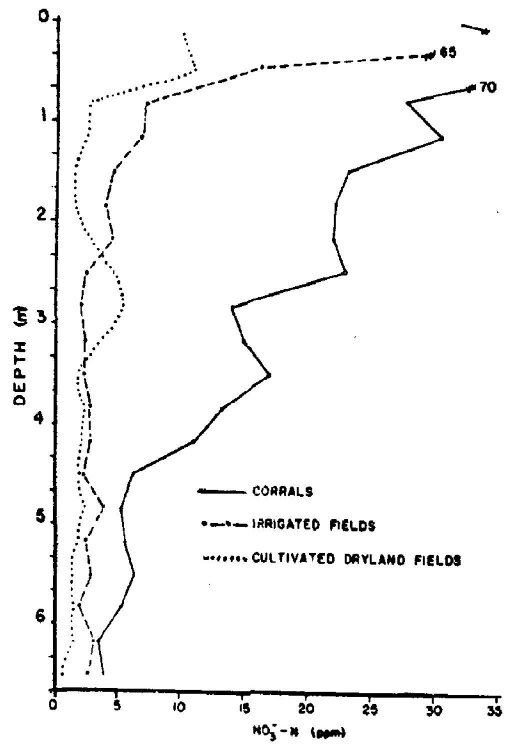


Figure 6-2.6- Average nitrate-nitrogen distribution with depth of profiles as affected by different land uses in eastern Colorado.

Source: B. A. Stewart et al., 1967

Land use	Profiles 0-20 feet: No. sampled	Profiles 0-20 feet: NO_3-N	Water table: No. sampled	Water table: NO_3-N Mean	Water table: NO_3-N Range
		lb./acre		mg/l.	mg/l.
Virgin grassland	17	90	8	11.5	0.1-19
Dryland farming	21	261	4	7.4	5-9.5
Irrigated land (except alfalfa)	28	506	19	11.1	0-36
Irrigated land (alfalfa)	13	79	11	9.5	1-44
Feedlots	47	1,436	33	13.4	0.41

Source: B.A. Stewart, F.G. Viets, Jr., G.L. Hutchinson, and W.D. Kemper. Nitrate and other pollutants under fields and feedlots. Environ. Sci. Technol. 1:736-739. 1967.

Table 6-26-Nitrate content of soil cores and water beneath various land-use patterns in Colorado.

potasium (31). The nutrients can be utilized as fertilizer in crop production, and even under large applications of wastes, crop yields are generally not reduced until the rate exceeds a range of 120 to 240 tons per acre (32).

Long before this limit is reached, however, the nutrient withdrawal requirements of most crops will have been satisfied. The surplus of nutrients in the manure then pose serious problems to water quality through runoff and seepage into groundwater. Since land is at a premium in the Chesapeake Bay Study Area, the owner of a livestock operation may not possess enough land to dispose of his wastes without serious impact on the quality of water.

b. Solutions: Fortunately, the concentrations of nitrates from feedlots fall off rapidly with distance, as their lateral movement through the soil is slow. There is little evidence of nitrates more than two or three hundred feet from the polluting area (33).

Where domestic water supplies are contaminated, therefore, the problem largely reduces to the location and depth of the well. As seen in Figure 6-27, if the source of water is located down the groundwater gradient from the livestock enclosure, pollutants are likely to be picked up, particularly if the well is relatively shallow (Location D). Since feedlots are often located close to the farmhouse, this has frequently been the cause of trouble when nitrate contamination has been found (34). The problem is averted by locating a well up the groundwater gradient from the pollution source and sinking it to a depth sufficient to avoid contaminants (Location A).

One of the solutions to the waste disposal problem has been the sale of wastes from concentrated livestock operations to large cropping operations. This involves high labor and transport costs, however, and the practice is frequently not competitive with the use of chemical fertilizer.

An alternative solution has been the use of aerobic or anaerobic waste ponds for the purpose of degrading the wastes and reducing the acreage of land required for its safe disposal.

The nitrate content of livestock wastes, for example, can be reduced by up to 50 percent in an aerobic waste lagoon, and total solids can be reduced up to 80 percent. (See Tables 6-27 and 6-28. It is expected that the use of waste lagoons will become increasingly important, particularly as public awareness of the problems of nonpoint sources of pollution increases.

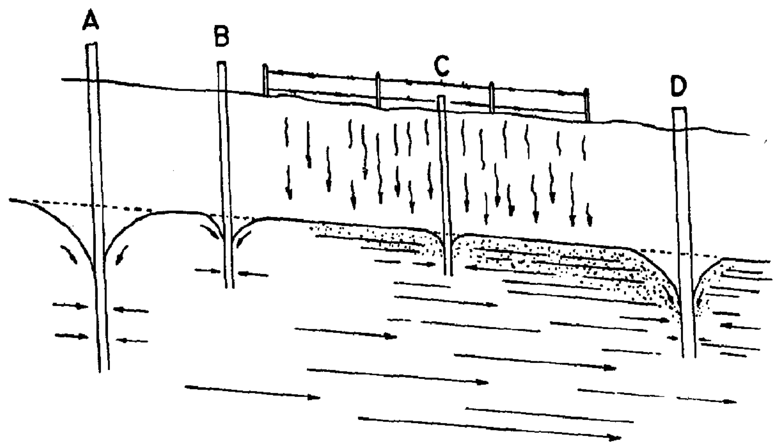


Figure 6-27- Location of wells and nitrate contamination from feedlots.

Source: R. A. Engberg (1967)

Table 6-27-Average reductions of volatile solids, COD, and Kjaldahl nitrogen in 12- to 15-day laboratory aeration studies conducted at two temperatures.

Criteria	Temperature 24 C	4 C
Volatile solids reduction..............	42.3%	20.1%
COD reduction (dichromate)........	53.6%	24.5%
Kjeldahl nitrogen reduction.........	43.5%	15.9%

Source: **Miner, J. R.**, <u>Farm Animal-Waste Managements</u>. (1971)

Table 6-28-Anticipated results of an anaerobic lagoon receiving animal wastes in a moderate climate.

Item	Effluent compared with influent
BOD concentration.........	70 to 90% reduction
Settleable solids............	Nearly complete removal
Total solids.....................	60 to 80% reduction
pH..................................	Little change, remains neutral
Ammonia nitrogen..........	Large increase

Source: Miner, J. R., Farm Animal-Waste Managements. (1971)

Another solution to the problem of waste disposal is the technique of mixing dried wastes with hay and silage for feed. The practice, though still in the experimental stage, is confined to poultry and beef waste processing. Such feed supplements have been found to carry no danger of disease, parasites, or carcass quality degradation, and they are competitive in cost with conventional feed.

SEDIMENTATION

a. Problem: A discussion of the impact of agriculture on the waters of the study area would not be complete unless its contribution to sedimentation were mentioned. In addition to nutrients and pesticides, enormous quantities of sediment enter those waters each year, and agriculture lands and conversion of cropland to other uses are the greatest sources.

Sediment losses involved in the shift of land from rural to urban use stem from activities such as highway construction, land grading without precautionary measures, and the construction of housing developments. (See Figure 6-28). Also a major source of sediment is untreated cropland, as the average sediment loss for this land use is a relatively high 5.5 tons per acre per year. The sediment load interferes with fish production, reduces the capacity of reservoirs, changes the flow of streams, and increases their chances of flooding.

Although it is somewhat less a problem on the Delmarva Peninsula than in the rest of the study area overall sediment loads on the Peninsula have been estimated at 2.5 tons per year. (35).

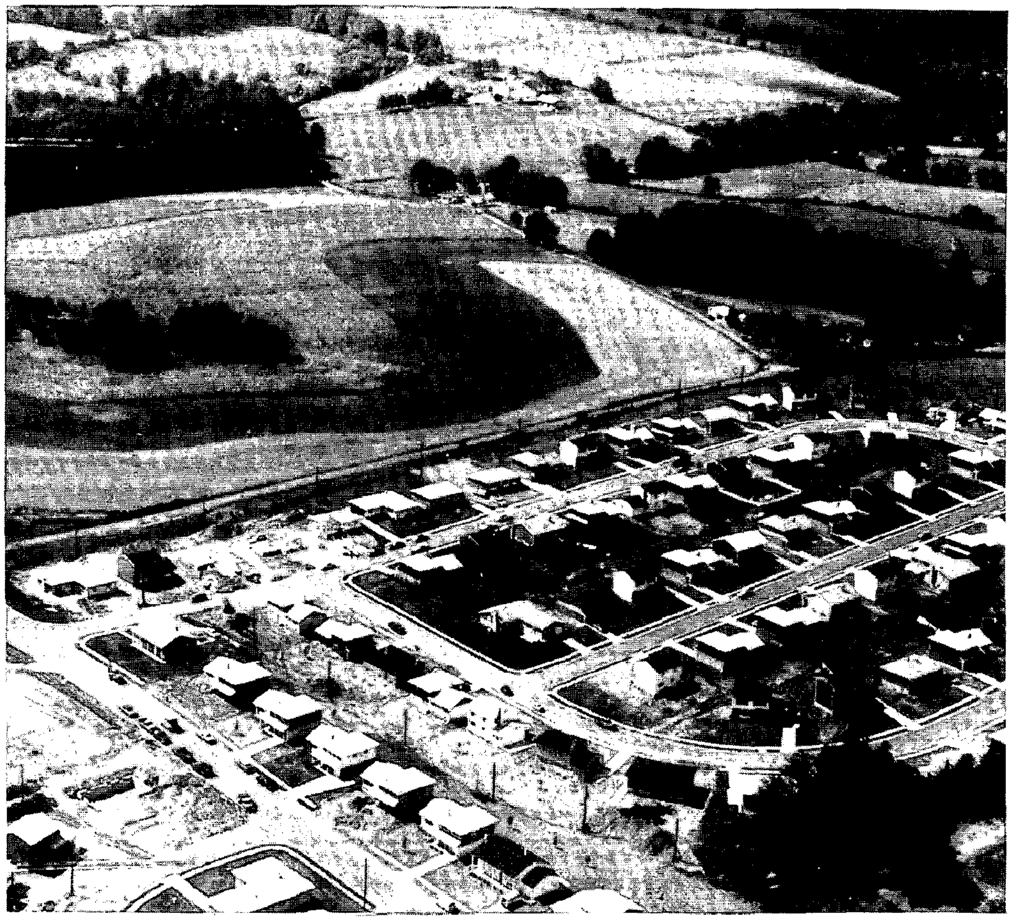


Figure 6-28 - Urban uses displace agricultural lands in the Chesapeake Bay Study Area

b. Solutions: Sediment control laws have recently been passed in all three states in the study area and the losses are expected to be considerably reduced in the target period. Since many of the laws involve conservation measures, agricultural runoff volumes are also expected to be diminished. Hence such measures may reduce the level of nutrient and pesticide pollutants released into the environment through such runoff.

Sediment control measures are expected to be increasingly stringent during the target period, not only for their value in controlling water turbidity, but for their value in reducing the levels of other agricultural pollutants as well.

PROCESSING WASTES

Final mention should be made of pollutants emitted during the processing of agricultural products, an activity which often takes place in the region of agricultural production.

Since processing most commonly involves the removal of organic matter, the biochemical oxygen demand of wastes emitted is considerable. Table 6-29 lists the wastes of various agricultural activities in terms of their five-day biochemical oxygen demand. Of particular significance is the pollution load emitted in the processing of poultry, as it is projected to remain an important and concentrated activity on the Delmarva Peninsula.

The effluents from agricultural product processors should be strictly monitored for their pollutant content.

SENSITIVITY ANALYSIS

This section explores the effects of varying some of the assumptions made in the foregoing demand projections. Some cases are easily quantified, such as variations in the rate of irrigation efficiency or in estimates of irrigated acreage. Others, however, are variations whose effects are impossible to gauge precisely, such as changes in the technology of livestock sanitation. In these cases only the general direction of the variations is discussed.

POPULATION

One of the major shifts in the demographic profile of the United States in recent years has been the sharp decline in the birth rate. This lowered rate would reduce population in the target period from levels estimated with more births, and to take this

Table 6-29 Estimated pollution loadings of selected agricultural processing industries

Processing industry	Annual production, million pounds	5-day BOD: Data in literature	5-day BOD: Pounds BOD per 1000 lb processed	5-day BOD: Potential daily load, 1000 lb	Potential daily population equivalent, millions
Canneries					
Apples	1,218	32 gal 3600 ppm BOD per case of 24 no. 2½ cans	13.3	44	0.26
Peaches	2,970	50 gal 2000 ppm BOD per case of 24 no. 2½ cans	20.8	169	1.02
Corn	2,364	19.5 lb BOD per ton corn processed	9.8	63	0.38
Tomatoes	9,790	8.4 lb BOD per ton tomatoes processed	4.2	113	0.68
Canning, total	...	...	...	1,370	8
Corn wet milling	10,800	1 bu = 1–2 PE	4.5	133	0.80
Cotton, processed through basic dyeing step	4,600	PE (per 1000 lb goods): Sizing 2; Desizing 96; Kiering 108; Bleaching 17; Scouring 12; Mercerizing 83; Basic dyeing 90	68	857	5.14
Dairy		Pounds BOD per 10,000 lb milk equivalent			
Fluid milk	59,000	10	1.0	162	1.0
Evaporated milk	1,880	10.5	2.25	11.6	0.07
Nonfat dry milk	2,176	25.0	20.4	157	0.95
Cheddar cheese	1,157	24.5	23.6	77.6	0.47
Cheddar whey, dried	20% of total	17.0	25.0	9.7	0.06
Cheddar whey	50% of total	350	...	500	3.0
Cottage cheese	1,424	350	16.5	64.5	0.38
Cottage cheese whey	7,500	350	...	1,000	6.0
Hides and leather	1,300	650 gal 1500 ppm per 100 lb hides	81	300	0.18
Meat					
Slaughtering and packing	59,400	14 lb BOD per 1000 lb live weight	14.0	2,300	13.0
Paper and pulp					
Wood pulp	66,000	300 lb BOD per ton of pulp	150.0	27,000	162
Paper and paper board	96,600	68 lb BOD per ton of paper	34.0	9,000	54
Potatoes					
Chips	7.1	29.3 lb BOD per ton raw potatoes	14.6	106	0.64
Dehydrated	2.7	71.1 lb BOD per ton raw potatoes	35.6	93	0.58
Flour and starch	3.2	57.0 lb BOD per ton raw potatoes	28.5	91	0.55
Frozen French fries	5.4	22.0 lb BOD per ton raw potatoes	11.0	57	0.34
Poultry	8,200	33 lb BOD per 1000 birds	10.0	225	1.3
Soybean	300	1.7 lb BOD per 1000 bu	0.19	0.16	0.085
Sugar refining					
Cane	48,000	5.31 lb BOD per ton	Av. 3.0	800	4.8
Beet	47,000	6.64 lb BOD per ton			
Wool scouring	130	8 gal 4000 ppm per lb wool	267	100	0.6

Source: S. R. Hoover (1967)

into account, a new series of OBERS projections were advanced in 1974.

The new projections, entitled Series "E", showed reduced levels of population and of the many economic indices which are related to population. In the Chesapeake Bay Estuary Area, the Series E population projections represent a decline from the Series C projections which amounts to 4.5 percent in 1980, 7.3 percent in the year 2000, and 13.3 percent in 2020, as shown in Table 6-30 .

Table 6-30 - Series "C" and "E" population projections, Chesapeake Bay Estuary Area 1/

	1969	1980	Percent change 2/	2000	Percent change 2/	2020	Percent change 2/
Series C	7,776,041	9,273,603	19.3	10,850,097	39.5	16,320,028	109.9
Series E	7,776,041	8,858,920	13.9	10,343,520	33.0	14,142,280	81.9
Percent change Series C to E		-4.5		-7.3		-13.3	

1/ Series C projections were used in demand projections in this Appendix

2/ Percent change measured from 1969 total.

The effect of a reduced population would normally be expected to reduce agricultural production demands as well. Coupled with the reduction in population however, is another, more recent development: the prospect of large scale exports of American agricultural products. If because of a changing political situation the United States becomes committed to exports of its food products to help alleviate a world shortage, the effect of the reduced domestic population will be mitigated and might well be overcome. If exports increase sufficiently, levels of agricultural production might actually rise over levels projected to support a large domestic population, and the use of water in agriculture will increase over the levels projected in this Appendix. Until the export factor can be taken into account more precisely, as it will be in the newest OBERS projections, the effect of a reduced domestic population on agricultural demand cannot be measured.

The reduction should, however, be reflected in the large portion of the rural population which is not connected with farms or farm services - a population analyzed in this Appendix as the nonfarm residual population. The effect of a population reduction depends to a large degree upon its distribution. If the reduced birth rate is largely an urban phenomenon, the effect upon the residual population will be minimal. If, however, the reduction is evenly distributed or a rural phenomenon, the size of the nonfarm residual can be expected to fall, and its water demand will be reduced accordingly.

LIVESTOCK

In the projection of the livestock water demand, the ratio of the costs of raising livestock to the revenues brought by their sale is of major significance. As the costs of feed increase relative to the revenues farmers receive for the sale of livestock and their products, production is curtailed. Conversely, as the profit margin increases, livestock production increases.

In recent years, cost increases have outpaced revenues received for livestock, a situation which forces many livestock producers to curtail or even halt their operations. If the profit squeeze continues into the target period, the level of livestock production and livestock water demands can be expected to fall below the levels projected in this Appendix. Under these conditions trends of increased per capita consumption of livestock products which are implicit in the OBERS projections will be reversed.

On the other hand, improvements in the technology of livestock sanitation and the movement toward raising livestock in larger lots and enclosures would tend to increase livestock water use. Improvements in sanitation machinery and practices entail a capital outlay which gives the high volume livestock producer an advantage over the low volume producer, insofar as he can spread his investment costs over more animals. The result will tend to accelerate the current movement toward concentration in livestock production. At the same time, the water use rates of livestock raised in concentrated lots would increase with improvements in sanitation technology, since, as with consumer appliances improvements in sanitation generally involve greater water use.

The interaction of cost-related curtailment of production, and sanitation-related increases in livestock water use, will determine the deviation of actual livestock water use from the projections presented in this Appendix.

IRRIGATION

To remain consistent with published state level projections of agricultural production and acreage, the demand projections in this

Appendix were closely tied to the OBERS totals. In contrast to the effects of a population reduction, however, the effects of a change in the estimated number of irrigated acres can be easily quantified.

Alternative projections were made on the basis of opinions of individuals in each of the subareas who were familiar with local agricultural practices. According to some, the OBERS projections overestimate the extent of agricultural activity and irrigated acres in their subarea, while according to others, the OBERS projections underestimate such activity. As seen in Figures 6-29 through 6-34 which chart such divergences, the latter is more often the case.

A second source of variation in the irrigation projections is the amount of assumed precipitation. Irrigation needs were projected for extremely dry conditions: the assumed levels of precipitation would be exceeded 8 years out of 10 for field crops and 9 years out of 10 for vegetables and specialty crops. Under more normal conditions of precipitation, the demand for water can be expected to be considerably reduced. Table 6-32 shows, by subarea, the effect of such reductions upon the projected irrigation water demands, and Figure 6-35 shows their effect upon the aggregate water demand projected for the study area during the target period.

A third assumption whose variation might sharply affect the levels of projected irrigation water is the rate of irrigation efficiency. In the projections in this Appendix, 65 percent of the gross water application is assumed to be utilized by crops, with the rest lost through evaporation or drainage. As the utilization percentage of gross applications drops, more water is necessary to meet crop needs, and, conversely, as it rises, less water is necessary. The rate of irrigation efficiency depends upon a number of factors, including topography, temperature, wind velocity, and soil types. Since it is impossible to exactly predict the figure for large aggregates of irrigated land, the effect of its variation on the amounts of water projected for crop demands is shown in Table 6-31.

Table 6-31 Effect of varying rate of irrigation efficiency on projected irrigation water demand

Rate of Irrigation Efficiency	Percent change in projected irrigation water demand
.50	+30%
.55	+18%
.60	+ 8%
.65	0
.70	- 7%
.75	-13%
.80	-19%

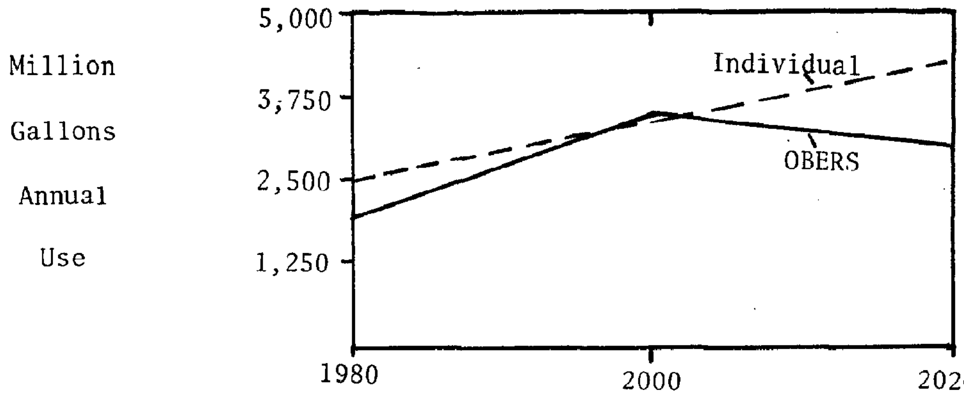


Figure 6-29-Irrigation Water Demand in Maryland Subarea 3: Projections based upon OBERS Acreage Projections and Individual Acreage Estimates.

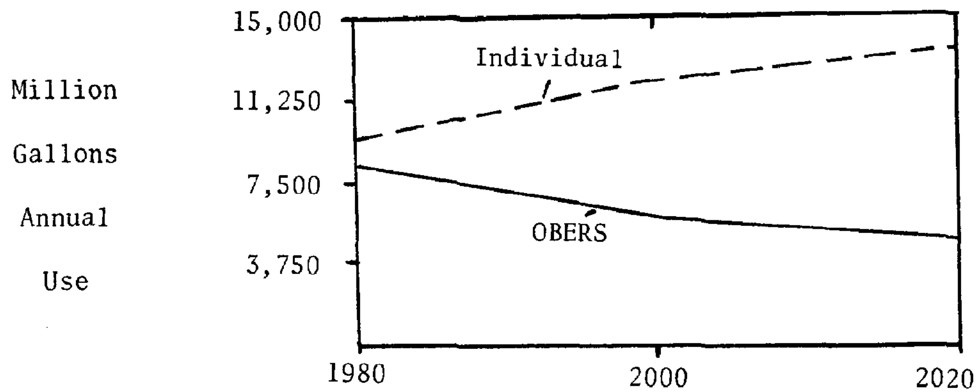


Figure 6-30-Irrigation Water Demand in Maryland Subarea 5: Projections based upon OBERS Acreage Projections and Individual Acreage Estimates.

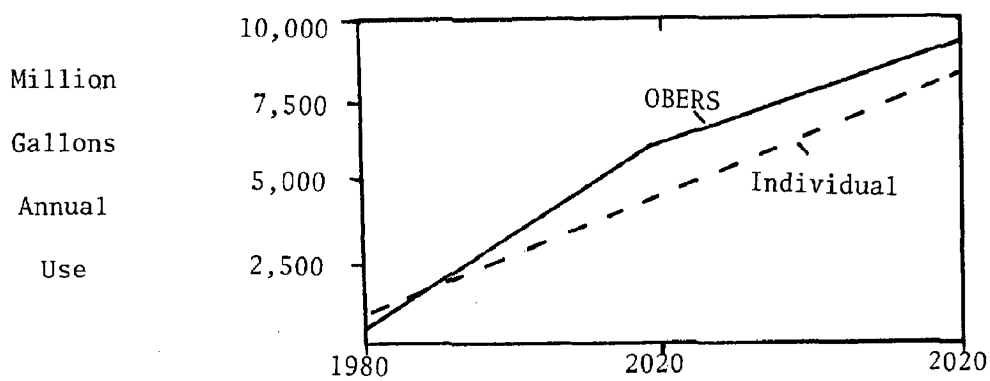


Figure 6-31-Irrigation Water Demand in Virginia Subarea 1: Projections based upon OBERS Acreage Projections and Individual Acreage Estimates.

<u>KEY</u>

----- Irrigation water demand based upon individual acreage estimates.

_____ Irrigation water demand based upon OBERS acreage projections.

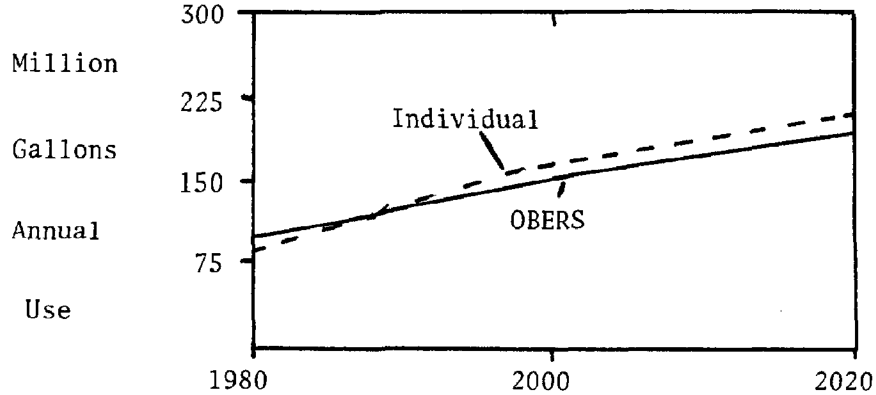


Figure 6-32-Irrigation Water Demand in Virginia Subarea 3: Projections based upon OBERS Acreage Projections and Individual Acreage Estimates.

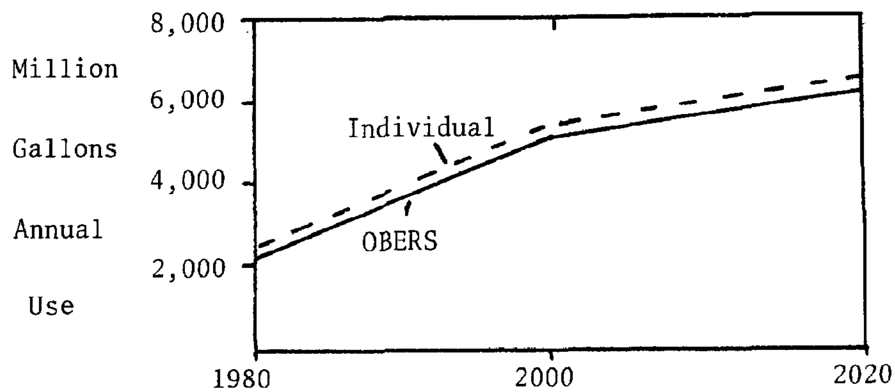


Figure 6-33-Irrigation Water Demand in Virginia Subarea 4: Projections based upon OBERS Acreage Projections and Individual Acreage Estimates.

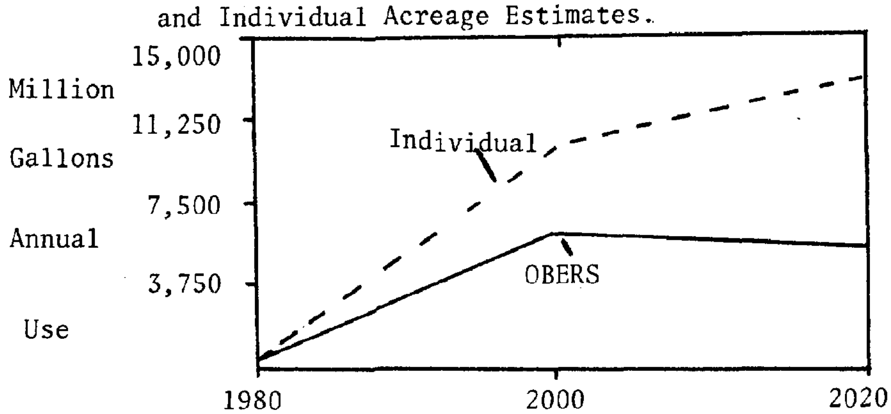


Figure 6-34-Irrigation Water Demand in Virginia Subarea 8: Projections based upon OBERS Acreage Projections and Individual Acreage Estimates.

KEY

----- Irrigation water demand based upon individual acreage estimates.

_____ Irrigation water demand based upon OBERS acreage projections.

Table 6-32-Distribution of irrigation water demands by month, for normal and dry years:[1/] projections to 1980, 2000, and 2020, Chesapeake Bay Study Area

1980 (million gallons)

State and subarea		May	June	July	Aug.	Sept.	Oct.	Seasonal
CHESAPEAKE BAY	Dry	2,633.	9,645.	10,506.	8,689.	6,633.	2,194.	40,299.
	Normal	1,214.	8,085.	9,013.	6,222.	4,864.	1,729.	31,128.
DELAWARE	Dry	1,804.	5,750.	2,196.	2,566.	2,979.	1,233.	16,528.
	Normal	958.	4,801.	1,781.	1,710.	2,368.	963.	12,581.
MARYLAND Study area	Dry	417.	2,204.	4,652.	2,457.	1,017.	207.	10,953.
	Normal	92.	1,928.	4,056.	1,797.	598.	171.	8,642.
1	Dry	299.	769.	1,145.	555.	167.	0.	2,935.
	Normal	36.	796.	1,092.	314.	15.	0.	2,253.
2	Dry	44.	831.	1,900.	883.	464.	74.	4,196.
	Normal	18.	633.	1,626.	726.	325.	61.	3,389.
3	Dry	36.	448.	920.	524.	356.	133.	2,417.
	Normal	22.	359.	766.	373.	255.	110.	1,886.
4	Dry	27.	108.	256.	161.	20.	0.	571.
	Normal	14.	98.	235.	125.	1.	0.	472.
5	Dry	11.	48.	431.	334.	10.	0.	834.
	Normal	2.	42.	337.	259.	2.	0.	642.
VIRGINIA Study Area	Dry	432.	1,691.	3,658.	3,666.	2,637.	754.	12,818.
	Normal	164.	1,336.	3,176.	2,715.	1,898.	595.	9,905.
1	Dry	0.	524.	1,730.	1,881.	1,997.	576.	6,708.
	Normal	0.	278.	1,471.	1,557.	1,520.	452.	5,278.
2	Dry	69.	273.	393.	254.	80.	16.	1,084.
	Normal	11.	252.	382.	136.	26.	11.	817.
3	Dry	6.	17.	24.	24.	10.	1.	83.
	Normal	2.	17.	23.	17.	6.	1.	66.
4	Dry	146.	423.	648.	622.	121.	14.	1,973.
	Normal	63.	398.	582.	413.	49.	11.	1,515.
5	Dry	36.	102.	377.	397.	213.	88.	1,213.
	Normal	13.	74.	382.	300.	161.	73.	923.
6	Dry	3.	8.	7.	5.	1.	0.	24.
	Normal	2.	8.	7.	2.	0.	0.	19.
7	Dry	131.	279.	235.	171.	77.	34.	927.
	Normal	62.	285.	229.	39.	38.	28.	680.
8	Dry	21.	64.	243.	314.	138.	26.	806.
	Normal	11.	44.	180.	251.	99.	21.	606.

2000 (million gallons)

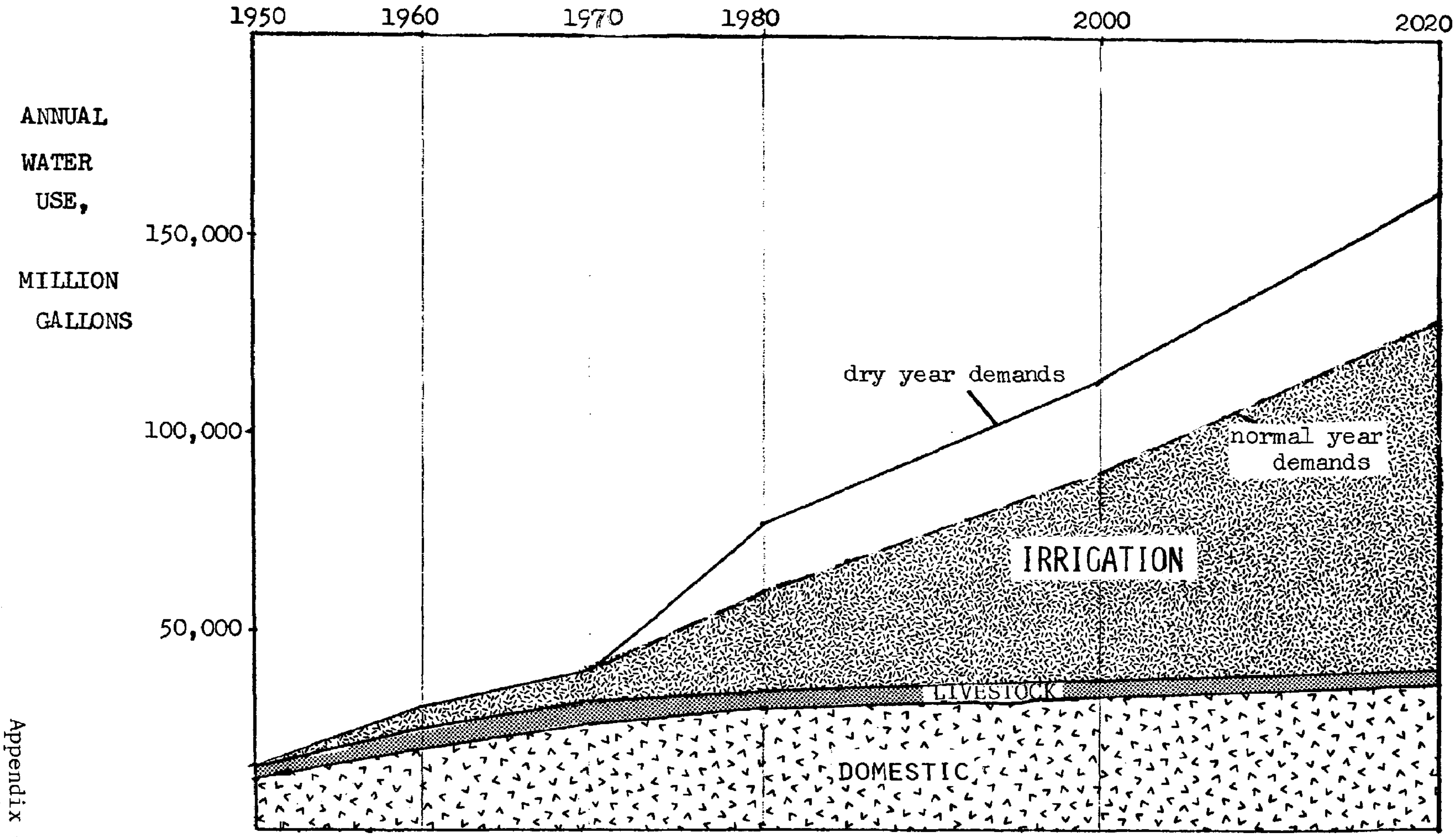
State and subarea		May	June	July	Aug.	Sept.	Oct.	Seasonal
CHESAPEAKE BAY	Dry	3,591.	13,091.	21,976.	20,871.	11,247.	2,779.	73,556.
	Normal	1,644.	10,709.	18,677.	15,790.	8,224.	2,212.	57,256.
DELAWARE	Dry	2,138.	6,765.	2,525.	2,870.	3,195.	1,299.	18,793.
	Normal	1,140.	5,649.	2,060.	1,932.	2,522.	1,015.	14,318.
MARYLAND Study area	Dry	558.	3,187.	11,834.	9,895.	4,306.	880.	30,662.
	Normal	147.	2,469.	10,217.	7,866.	3,150.	720.	24,571.
1	Dry	324.	886.	1,287.	649.	197.	0.	3,343.
	Normal	42.	921.	1,243.	369.	16.	0.	2,591.
2	Dry	58.	1,316.	5,973.	5,274.	2,842.	555.	16,018.
	Normal	23.	767.	5,139.	4,385.	2,259.	454.	13,027.
3	Dry	29.	341.	993.	793.	379.	86.	2,621.
	Normal	18.	257.	845.	614.	257.	71.	2,062.
4	Dry	98.	386.	1,163.	1,007.	332.	53.	3,040.
	Normal	54.	339.	1,076.	821.	197.	40.	2,529.
5	Dry	49.	258.	2,418.	2,172.	556.	186.	5,640.
	Normal	10.	185.	1,914.	1,677.	421.	155.	4,362.
VIRGINIA Study Area	Dry	895.	3,139.	7,617.	8,106.	3,746.	600.	24,101.
	Normal	357.	2,591.	6,400.	5,992.	2,552.	477.	18,367.
1	Dry	0.	413.	1,365.	1,484.	1,487.	382.	5,131.
	Normal	0.	219.	1,160.	1,229.	1,135.	300.	4,043.
2	Dry	145.	584.	1,002.	694.	197.	27.	2,648.
	Normal	23.	540.	983.	354.	41.	18.	1,959.
3	Dry	14.	41.	47.	43.	15.	1.	161.
	Normal	6.	41.	45.	27.	7.	1.	128.
4	Dry	435.	1,220.	1,876.	1,741.	348.	17.	5,636.
	Normal	188.	1,149.	1,676.	1,107.	145.	13.	4,277.
5	Dry	78.	246.	1,096.	1,247.	530.	107.	3,303.
	Normal	29.	162.	863.	983.	398.	90.	2,525.
6	Dry	5.	13.	11.	9.	1.	0.	39.
	Normal	3.	14.	11.	4.	0.	0.	31.
7	Dry	117.	252.	225.	170.	81.	34.	878.
	Normal	55.	255.	216.	48.	42.	28.	644.
8	Dry	102.	371.	1,995.	2,719.	1,085.	32.	6,304.
	Normal	52.	213.	1,444.	2,240.	785.	27.	4,760.

2020 (million gallons)

State and subarea		May	June	July	Aug.	Sept.	Oct.	Seasonal
CHESAPEAKE BAY	Dry	4,795.	18,311.	38,328.	37,373.	19,309.	4,122.	122,238.
	Normal	2,189.	14,392.	33,134.	29,193.	14,397.	3,311.	96,617.
DELAWARE	Dry	2,641.	8,310.	2,992.	3,248.	3,384.	1,316.	21,891.
	Normal	1,416.	6,941.	2,461.	2,226.	2,640.	1,024.	16,709.
MARYLAND Study area	Dry	1,008.	6,357.	27,940.	26,598.	12,789.	2,359.	77,052.
	Normal	214.	4,274.	24,298.	21,648.	9,729.	1,932.	62,195.
1	Dry	348.	1,001.	1,436.	749.	229.	0.	3,764.
	Normal	48.	1,048.	1,400.	428.	18.	0.	2,941.
2	Dry	73.	2,882.	20,091.	20,230.	10,397.	1,849.	55,521.
	Normal	29.	1,081.	17,330.	16,919.	8,386.	1,514.	45,261.
3	Dry	29.	301.	1,081.	983.	405.	59.	2,858.
	Normal	18.	217.	933.	780.	264.	49.	2,260.
4	Dry	308.	1,083.	1,950.	1,641.	646.	100.	5,729.
	Normal	171.	1,027.	1,934.	1,268.	307.	76.	4,783.
5	Dry	250.	1,090.	3,382.	2,995.	1,112.	351.	9,180.
	Normal	48.	901.	2,701.	2,253.	754.	293.	6,950.
VIRGINIA Study Area	Dry	1,146.	3,644.	7,396.	7,527.	3,136.	447.	23,295.
	Normal	559.	3,177.	6,375.	5,319.	2,028.	355.	17,713.
1	Dry	0.	327.	1,079.	1,173.	1,126.	261.	3,966.
	Normal	[illegible]	173.	918.	972.	860.	205.	3,127.
2	Dry	178.	706.	1,142.	782.	217.	27.	3,053.
	Normal	29.	662.	1,134.	397.	41.	18.	2,280.
3	Dry	18.	54.	62.	56.	20.	1.	212.
	Normal	8.	54.	60.	36.	9.	1.	168.
4	Dry	538.	1,482.	2,120.	1,943.	387.	19.	6,488.
	Normal	233.	1,416.	1,912.	1,195.	148.	15.	4,919.
5	Dry	107.	311.	1,179.	1,323.	542.	102.	3,564.
	Normal	40.	221.	939.	1,029.	400.	87.	2,716.
6	Dry	11.	26.	22.	17.	2.	0.	79.
	Normal	5.	27.	22.	7.	0.	0.	62.
7	Dry	128.	274.	236.	174.	61.	17.	889.
	Normal	61.	279.	228.	43.	26.	14.	651.
8	Dry	164.	462.	1,556.	2,060.	780.	19.	5,043.
	Normal	84.	342.	1,163.	1,642.	543.	16.	3,791.

1/ With a sixty-five percent rate of irrigation efficiency, irrigation water demands in a normal year are defined as the gross water requirements for efficient crop production assuming a 30-year mean level of precipitation. Irrigation water demand in a dry year is the gross water requirement for efficient crop production in the dryest year in ten (10%) for vegetables, and specialty crops, and the second dryest year in ten (20%) for field crops and orchards.

Figure 6-35 Total water demands, 1950-1970, and projections to 1980, 2000, and 2020. Irrigation estimated for normal and dry years,[1/] Chesapeake Bay Study



1/ Dry year irrigation demand is projected assuming 80 to 90 percent chance of precipitation occurrence; normal year irrigation demand is projected assuming 30 year mean level of precipitation. The year 1959 was slightly wetter, and the year 1969 considerably wetter, than the 30 year mean levels of precipitation for summer months in the study area. (Climatological Data, Annual Summary for Maryland and Delaware: 1959, 1969. U.S. Department of Commerce, Environmental Data Service).

If the rate of irrigation efficiency varies between 60 and 70 percent, the demand for irrigation water would stay within 8 percent of projected levels. An increase in the efficiency rate to 80 percent, however, would result in a 20 percent reduction in the level of demand, while a fall in the efficiency rate to 50 percent would result in a 30 percent increase in the gross water demand.

Other factors which are less susceptible of quantification are variations in the water holding capacity of soils, and in the technology of irrigation. On sandy soils of low holding capacity, the irrigation water requirement would be slightly greater than that projected assuming a loam soil, and it would be slightly less on clay-loam soils. With respect to technological changes, as irrigation becomes more widespread and the demand for irrigation systems increases, the cost of installing and operating such systems can be expected to fall. The drop in price can be expected to follow not only from economies of large scale manufacture, but from advances in the technology of the systems themselves. Such developments would tend to increase the use of irrigation over levels expected using the current technology.

SUMMARY

Among the major factors which would tend to reduce the total agricultural water demand in the study area are an increase in the rate of irrigation efficiency, and the presence of more precipitation than is assumed in the dry-year projections. Water demand would be further reduced by a decline in the birth rate, affecting both domestic demand and the demand for agricultural products, and by a reduction in livestock production due to profit squeezes.

The agricultural water demand in the study area would tend to be increased by a reduction in the rate of irrigation efficiency, by the presence of irrigation conveyance losses, and in areas where sandy soils prevail. The water demand would also be increased by improvements in the technologies of livestock sanitation and of irrigation by exports of agricultural products to foreign countries, and by a redistribution of population to rural areas.

CHAPTER IV

REQUIRED FUTURE STUDIES

In the projection of the residual population, the population served by small central systems was estimated by relating its rate of growth to the rate of growth of small towns. The population served by large systems was projected individually for each system, and the residual remained after these two components were subtracted from estimates of total population. Since the size of the residual is an important part of the projection of rural domestic water use, the reliability of estimates of such water use in this Appendix would be considerably improved if more exact studies of this population were undertaken.

Also concerning population, it is important to know the distribution of expected changes: whether birth rates are most reduced in urban areas or in rural areas, where major movements to and from rural areas will occur. In this regard, demographic data pertaining to birth rates among different portions of the population, and to migration within the Study Area, might be profitably analyzed. A study of the age structures in different subareas would also be useful.

There is a need for more accurate data concerning water use rates of the residual population. Only crude data is currently available pertaining to per capita water use rates: despite the increased use of water-using appliances from 1950-1970, one source lists the rate as unchanged during that period. The accuracy of domestic water use projections would be considerably improved if data pertaining to use rates and factors affecting their growth became available.

One of the major needs for agricultural water in the Study Area is the elimination of spot shortages of water, a need especially important to the efficient production of crops. As the solutions to this problem will most likely involve a pooling of resources, feasibility and cost benefit studies might well be conducted to bring such projects closer to existence. Such studies would be especially pertinent to the Piedmont region, where availability of ground water is erratic.

If central water supplies are to be used in agriculture, studies will be needed as to:

a. the areas where agricultural activity is likely to persist, considering both comparative advantage of the area's agriculture and pressures for urbanization,

b. the potential sources of water supply in such areas -- water impoundment, ground water, or stream--which can supply the needs of surrounding farms, and

c. the least cost location of the source of supply.

In addition, the costs of community supply from streams or from a location where ground water can be obtained should be estimated, as they affect the individual farmer who utilizes the service. Such central services will be important if the value of fertile farmland is not driven down--because of spot shortages of water--to the point where it cannot compete with other land uses.

A program of studies is needed which directly correlates water quality with agricultural practices in the Chesapeake Bay Study Area. Such studies have been successfully undertaken in other areas of the country such as California, Texas, Missouri, and Alabama. Many of the factors which affect the environmental impacts of agriculture, however--such as topography, soil types, and precipitation--are location specific.

The results of studies which directly apply to conditions in the Chesapeake Bay Study Area would thus be of greater reliability than the results of studies conducted elsewhere in measuring the extent of agricultural impacts on the environment. The accurate measurement of the extent of agricultural impacts on the Chesapeake environment is a necessary step in seeking appropriate and reasonable levels of control consistent with agricultural production goals.

Finally, the hydraulic model constructed in connection with the Chesapeake Bay Study may be of some use in tracing the flow of materials associated with agricultural runoff - notably, sediment, agricultural wastes and nutrients, and pesticides. Problems would be posed in such an endeavor by the dispersion and locational interminacy of agricultural activity. Unlike industrial waste sources, the source of potential agricultural pollutants is difficult to pinpoint, since not only does the location of a type of farming shift, but agricultural pollutant sources within a given area shift as well.

Despite this drawback, the magnitude of agricultural impacts upon the environment are such that such a study would be a useful effort. The drawback may be overcome in several ways. Historical levels of agricultural production at the subarea level may be varied and the effects of the variation upon the impacts traced. Percentages of pollutants which reach the waterways may be also varied, to explore the effects of pollutant regulation. (Since programs which regulate agricultural pollutants are in their incipient stages, a measure of their effectiveness may be thus determined using the hydraulic model). Subareas on the Delmarva peninsula are characterized by high levels of agricultural activity and, in some places, poor drainage: more exacting breakdowns of agricultural activity, and the potential flow of its pollutants from various agricultural activities might be justified for these subareas.

Alternatively, existing data could be used, in connection with the hydraulic model, to identify the source of existing flows of agricultural pollutants. Working backward from effect to cause, the sources of current pollutants may therefore be more effectively monitored. This would be useful not only from the point of view of regulatory agencies, but, since the levels of livestock production and nutrient and pesticide applications can be determined for the source areas, a more exact relationship could be developed linking agricultural activity with its impact upon the Bay. Such a relation would be valuable too in projecting the impact of future agricultural production more exactly than was possible for this Appendix. By continually linking agriculture-related pollutants in the Bay system with the known levels of agricultural activity, the actual effects of regulation, of shifting agricultural activity, and of changing technologies can be estimated as the changes occur. This information would be valuable in assessing the economic and environmental trade-offs associated with alternative water quality standards, various regulations and control methods, and practices that could be used.

AGRICULTURAL WATER SUPPLY

FOOTNOTES

(1) In 1950, for example, 40% of the total population in the United States was rural, and 60% urban. By 1960 the rural population was dropped to 37% and 63% was urban, and in 1970 the population distribution was 26% rural and 74% urban. It should be noted that some of the change in population in 1970 was due to a new urban place definition.

(2) See Chesapeake Bay Study Existing Conditions Report for definition of Chesapeake Bay Estuary Area.

(3) On the national level, evidence of this movement is seen in the decrease of the farm population from 23.0 million, or 15.3 percent of the total population in 1950 to 9.7 million, or 4.8 percent of the total population in 1970. The farm population in 1970.

(4) The Land, Resources and Use. Chesapeake Bay Study Existing Conditions Report, Appendix B, Volume I.

(5) See Conservation Needs Inventory (1967) published by Maryland and Delaware. Total potentially irrigable acres do not include acres presently irrigated.

(6) U. S. Water Resources Council: OBERS Projections, Vol. 1: Concepts, Methodology, and Summary Data. Washington, U.S. Water Resources Council, 1972.

(7) Ibid.

(8) Ibid.

(9) There is cited in support of these assumptions "the known reserves of potential cropland." Since the date of the OBERS projections, however, these reserves have been released and there have been both shortages and increases in the price of food relative to other consumer products.

(10) The projections were accomplished using the Spillman function. The average per farm population was not expected to fall below 2.5 persons.

(11) Estimated Use of Water in the United States: 1960, 1970. United States Geological Survey Circulars 456 and 676.

(12) In this function, when water use is 40 gpcd, the annual rate of increase is 30 percent. When the use rate increases to 80 gpcd, the rate of increase drops to 1.0 percent, and it tapers off to 0.5 percent when the use rate is 150 gpcd is reached. This relation, used by the Corps of Engineers in the projection of use rates of the population served by central systems, was first developed for the Ohio River Basin Framework Study, U.S. Department of the Interior, Federal Water Pollution Control Administration, 1963.
Assuming continuous compounding, use rates may be projected, through an integration procedure, from the equation,

$$U_T = \left[T(3.735966) + U_o^{\,1.279948} \right]^{.781282}$$

where

U_T = use rate at time T

U_o = base rate at time T_o

T = elapsed time, in years from base year T_o.

(13) See Chesapeake Bay Study Future Conditions Report, Appendix 5; Municipal and Industrial Water Supply for details of projection procedure for small systems served population.

(14) To project water demand for small systems, an estimated 1970 use rate of 100 gallons per capita per day (gpcd) was judged appropriate, roughly 85 percent of which would go to non-industrial uses. See Chesapeake Bay Study Future Conditions Report, Appendix 5: Municipal and Industrial Water Supply for details of projection procedure for small systems water use rate.

(15) Geological Survey Circular No. 556. Estimated Use of Water in the United States, 1965.

(16) A notable exception is the case of broilers, whose assumed ninety-day market cycle would not permit maturity. The water use rate per bird, when averaged over the ninety days, is significantly lower than the water use rate reported for mature birds in the U.S. Geological Survey.

(17) In the OBERS projections, 1964 was the most recent historical date in the trend.

(18) The procedure by which the limits are set is well documented in the methodology statement of the OBERS report. OBERS Projections, Vol. 1: Concepts, Methodology, and Summary Data. Washington, U. S. Water Resources Council, 1972.

(19) The estimated irrigation water demand of nursery and specialty crops is based upon individuals' estimates of nursery and specialty acreage in their subareas. Included in this category are nursery stock, golf courses, and other miscellaneous crops not addressed in the OBERS projections.

(20) See Sensitivity section for effects of varying this assumption.

(21) U. S. Census of Agriculture, 1969. Volume II: General Report. Chapter 9: "Irrigation and Drainage on Farms."

(22) In the State of Virginia, where most farm ponds are in the coastal plain and Piedmont Provinces, ponds were constructed at a rate of 1200 per year in the decade from 1960 to 1970. See Water Resources Report: Opportunities for Virginia Agriculture (1969).

(23) Table 6-21 shows the importance of soil texture in drought, since the effect of a sandy soil with poor holding capacity is much the same as the effect of reduced root length.

(24) J. S. Robins and C.E. Domingo, "Potato Yield and Tuber Shape as Affected by Severe Sub-Moisture Activity and Plant Spacing." Agronomy Journal, 48 (1956).

(25) See Appendix 5 of the Future Conditions Report; Municipal and Industrial Water Supply for detail.

(26) In ground water supplies the rate of intrusion is quite slow. It has been estimated that if withdrawals totaled 1½ mgd at Dover, where the aquifer, thickness, at 30 percent porosity, is 200 feet, it would take 7000 years for the nearest saline water to move 12 miles to the pumping center. (See Water Resources of the Delmarva Peninsula, U. S. Geological Survey Professional Paper 822. (1973).

(27) J. R. Miner, "Agricultural Waste Management," (1974).

(28) See Amendments to the Federal Water Quality Act. Public Law 92-500, 92nd Congress S.2770 (1972).

(29) B. A. Stewart, "A Look at Agricultural Practices in Relation to Nitrate Accumulation," (1970).

(30) See Amendments to the Federal Water Quality Act. Public Law 92-500, 92nd Congress S.2770 (1972).

(31) George E. Smith, "Land Spreading as a Disposal Process," (1968).

(32) B. A. Stewart and A.C. Mathers, "Soil Conditions Under Feedlots and on Land Treated with Large Amounts of Animal Wastes," (1971).

(33) George E. Smith, "Nitrate Pollution of Water Supplies," (1969).

(34) Ibid.

(35) North Atlantic Regional Water Resources Study Coordinating Committee. North Atlantic Regional Water Resources Study. Appendix Q: Erosion and Sedimentation, (1972).

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AGRICULTURAL WATER SUPPLY

GLOSSARY

agricultural production — production of 1) assorted crops and vegetables and 2) livestock including poultry and milk cows.

aquifer: a water-bearing stratum of permeable rock, sand, or gravel.

breeder numbers: the stock of animals needed to re-establish the marketed population after sale.

ceiling/base values: limits within which a projected value is expected to fall. For use in a Spillman extrapolation.

control totals: A future estimate for an area which is to be allocated among subareas using the shares technique.

demand derived numbers: livestock numbers projected by dividing estimated livestock weight demands by average weights of livestock.

distributional effect: the shift in regional or subarea production which is due to a shift in distribution relative to others' production.

farm ponds:

a. Impoundment: A natural depression backed by an earth filled dam, designed to capture surface runoff and to store it for times of shortage.

b. Dug: A large shallow pit, usually ten to fifteen feet in depth, which taps the ground water reservoir.

kg/ha.: killograms per hectare, equal to approximately 1.21 pounds per acre.

land-capability classifications: An interpretation of soil information made primarily for agricultural purposes. The first four classes are capable under good management of producing adapted plants, such as forest trees, and the common cultivated field crops and pasture plants.

Class I. Few limitations that restrict their use.

Class II. Some limitations that restrict the choice of plants or require moderate conservation practices.

Class III. Severe limitations that reduce the choice of plants or require special conservation practices, or both.

Class IV. Very severe limitations that restrict the choice of plants, require very careful management, or both.

large water supply system: central water supply systems serving more than 2500 people.

mgd: million gallon per day

mg/1.: milligrams per liter

mho: the meter-kilogram-second unit of electric conductance, equal to the conductance of a conductor in which a potential difference of one volt maintains a current of one ampere.

micromho (μmho): one millionth of a mho.

millimho (mmho): one thousandth of a mho.

mortality numbers: livestock which are not expected to reach marketable age.

state effect: the effect upon subarea production of increases in production at the state level.

OBERS projections: projection of economic activity accomplished by the Bureau of Economic Analysis, the U.S. Department of Commerce, and Economic Research Service, U. S. Department of Agriculture.

residual population: population not served by central water supply and sewage systems.

rural population: "Rural" population is defined by the 1970 Census of Population as "that portion of the population not classified as urban." Urban population is defined as "all persons living in - a) places of 2500 inhabitants or more incorporated as cities, villages, boroughs (except Alaska), and towns (except in the New England States, New York, and Wisconsin), but excluding those persons living in the rural portions of extended cities; b) unincorporated places of 2500 inhabitants or more; and c) other territory, incorporated or unincorporated included in urbanized areas.

shares analysis: technique for estimating futute subarea production whereby a control estimate of an area's production is disaggregated among subarea in accordance with the trends exhibited by the subarea shares in the past.

small water supply system: central water supply systems serving fewer than 2500 people.

Spillman projection function: function used in the projection of economic activity, which permits projected value to vary, within limits, along a curvilinear trend.

subarea: a grouping of counties for projection purposes. Composition of Chesapeake Study subareas is listed in Table 6-1, and illustrated in Figure 6-1.

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WATER QUALITY AND SUPPLY, WASTE TREATMENT, NOXIOUS WEEDS TASK GROUP, CHESAPEAKE BAY STUDY

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Attachment A:

Projection By Shares Analysis--
Graphical Illustration.

Attachment A.

This Attachment gives a graphical illustration of the share projections used in this Appendix.

First a situation is examined in which only the change in production at the state level bears upon the subarea's production. Where R_T, R_F, S_T, and S_F represent production in the subarea and state, respectively, at times T (present) and F (future),

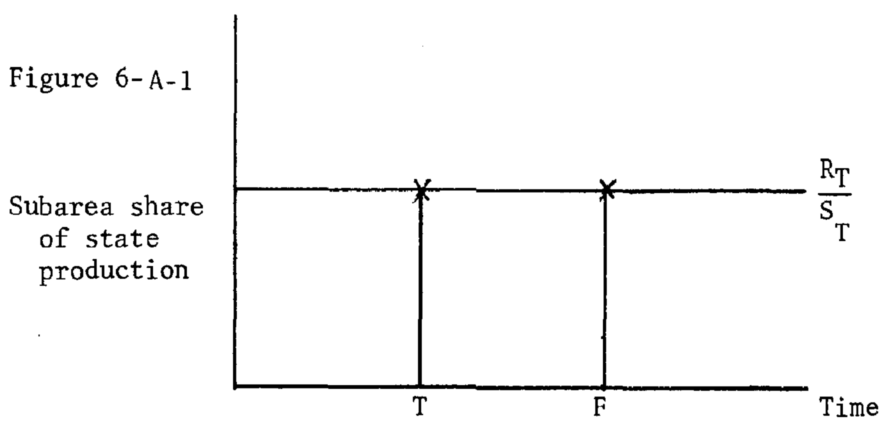
$$R_F = \left(\frac{S_F}{S_T}\right) \cdot R_T$$

$\left(\frac{S_F}{S_T}\right)$, the state's rate of production growth, is applied to production in a subarea at the base time T. This implies that

$$R_F = \left(\frac{R_T}{S_T}\right) \cdot S_F$$

or that the subarea's share of state production remains constant from time T to time F, as seen in Figure 6-A-1

Figure 6-A-1



Now a distributional effect--the shift in production toward one subarea over others--is introduced. Let R_Δ represent the quantity a subarea produces over or under the production attributed to the national effect.

$$R_F = \left(\frac{S_F}{S_T}\right) \cdot R_T + R_\Delta$$

$$R_F = \left(\frac{R_T}{S_T}\right) \quad S_F + \frac{R_\Delta}{S_F} \cdot S_F$$

which may be put in terms of state production in the future at F as

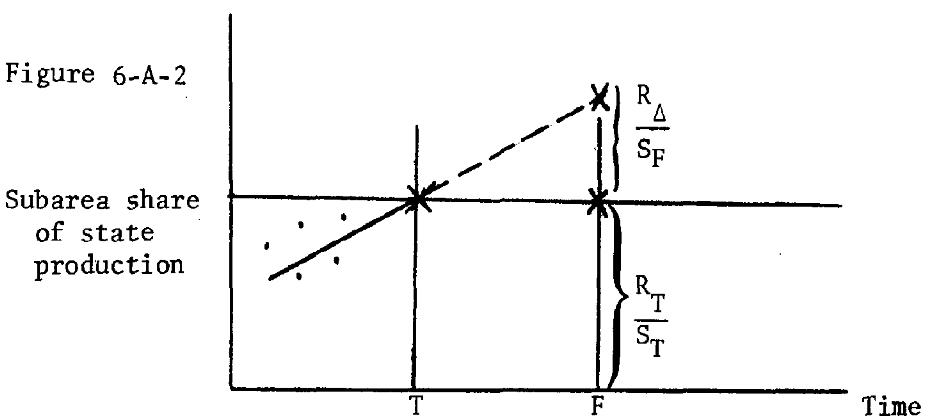
$$R_F = \left[\left(\frac{R_T}{S_T}\right) + \left(\frac{R_\Delta}{S_F}\right)\right] \cdot S_F$$

This equation, which expresses regional production as a share of the projected state production, is fundamental to the method of projection employed in this Appendix.

All subarea production estimates for the target period were derived by projecting the subarea's share--the term in brackets--and applying it to the published OBERS state totals. Its share at time T,

$\left(\frac{R_T}{S_T}\right)$, when multiplied by S_F, yields the regional production at F accounted for by the state effect. The change in the region's share $\left(\frac{R_\Delta}{S_F}\right)$, when similarly multiplied, indicates the distributional effect. (See Figure 6-A-2)

Figure 6-A-2



Attachment B:

Rural Population Dwelling
Unit Analysis--Tables.

Attachment B.

Table 6-B-1--Rural nonfarm dwelling unit analysis, by state and subarea, 1950, 1960 and 1970, Chesapeake Bay Study

State and subarea	1950				1960			
	Total	W/running water, toilet-bath	Per-cent	W/running water, toilet-bath	Total	W/running water, toilet-bath	Per-cent	W/running water, toilet-bath
	---Dwelling units---			--Population--	---Dwelling units---			--Population--
CHESAPEAKE BAY	251,833	110,277	43.79	371,961	359,735	249,626	69.39	828,212
DELAWARE	12,356	6,543	52.95	17,052	20,444	14,382	70.35	33,541
MARYLAND	132,971	69,270	52.09	230,564	187,003	138,324	73.97	452,934
Study Area								
1	59,284	34,401	58.03	118,768	83,472	67,851	81.29	230,956
2	21,240	8,903	41.92	25,376	31,001	20,713	66.81	59,532
3	19,701	7,364	37.38	19,734	26,783	15,388	57.45	41,645
4	18,755	11,721	62.50	44,869	24,898	19,554	78.54	74,719
5	13,991	6,881	49.18	21,817	20,903	14,818	70.89	46,082
VIRGINIA	106,506	34,464	32.36	124,345	152,288	96,920	63.64	341,737
Study Area								
1	11,126	3,296	29.62	10,184	15,753	7,075	44.91	18,025
2	24,131	5,387	22.32	20,301	26,437	20,209	76.44	85,398
3	5,620	2,435	43.33	8,349	10,210	6,407	62.75	21,247
4	20,127	7,990	39.70	31,961	32,405	24,421	75.36	92,616
5	14,733	4,599	31.22	13,104	21,717	11,037	50.82	30,582
6	2,990	1,368	45.75	4,820	4,422	3,505	79.26	12,054
7	10,904	4,802	44.41	20,632	13,780	9,730	72.71	36,923
8	16,875	4,587	27.18	14,994	27,564	14,536	52.74	44,892

Attachment B.

Table 6-B-1--Rural nonfarm dwelling unit analysis, by state and subarea, 1950, 1960 and 1970, Chesapeake Bay Study--Continued

State and subarea	1970			
	Total	W/running water, toilet-bath	Percent	W/running water, toilet-bath
	------Dwelling units-------			--Population--
CHESAPEAKE BAY	412,220	323,682	78.52	1,024,890
DELAWARE	28,123	19,535	69.46	43,994
MARYLAND	216,488	178,256	82.34	576,971
Study Area				
1----------	89,397	80,120	89.62	276,377
2----------	39,386	28,346	71.97	78,199
3----------	35,217	22,880	64.97	58,942
4----------	27,065	24,842	91.79	93,066
5----------	28,423	22,068	77.64	70,387
VIRGINIA	167,609	125,891	75.11	403,925
Study Area				
1----------	16,834	9,727	57.78	23,892
2----------	30,593	27,230	89.01	96,783
3----------	14,728	11,751	79.79	37,877
4----------	32,170	27,134	84.35	95,547
5----------	27,234	17,086	62.74	44,727
6----------	6,916	6,401	92.55	23,299
7----------	3,253	2,447	75.22	8,297
8----------	35,881	24,115	67.21	73,503

Source: Census of Housing and Calculation.

Attachment B.

Table 6-B-2--Rural farm dwelling unit analysis, by state and subarea, 1950, 1960 and 1970, Chesapeake Bay Study

State and subarea	1950				1960			
	Total	W/running water, toilet-bath	Per-cent	W/running water, toilet-bath	Total	W/running water, toilet-bath	Per-cent	W/running water, toilet-bath
	---Dwelling units---			--Population--	---Dwelling units---			--Population--
CHESAPEAKE BAY	88,408	28,737	32.50	106,416	48,077	30,857	64.18	115,555
DELAWARE	5,327	1,839	34.52	6,013	3,488	2,469	70.79	8,356
MARYLAND	39,890	15,430	38.68	57,251	23,067	16,167	70.09	61,361
Study Area								
1----------	14,160	6,803	48.04	25,456	7,867	6,169	78.42	22,931
2----------	7,569	2,867	37.88	9,840	4,795	3,535	73.72	12,818
3----------	7,751	1,968	25.39	6,129	4,187	2,727	65.13	9,364
4----------	5,250	2,471	47.07	10,175	2,787	1,976	70.90	8,301
5----------	5,160	1,321	25.60	5,651	3,431	1,760	51.30	7,947
VIRGINIA	43,191	11,468	26.55	43,152	21,522	12,221	56.78	45,838
Study Area								
1----------	4,505	916	20.33	2,877	2,329	1,418	60.88	4,453
2----------	6,182	2,768	44.78	10,578	2,551	1,898	74.40	7,298
3----------	3,138	687	21.89	2,455	1,153	639	55.42	2,237
4----------	8,302	2,410	29.03	9,458	3,899	2,176	55.81	8,368
5----------	8,635	1,833	21.23	6,979	4,437	2,415	54.43	9,364
6----------	382	175	45.81	557	117	90	76.92	324
7----------	2,527	919	36.37	3,472	1,214	849	69.93	3,233
8----------	9,520	1,760	18.49	6,776	5,822	2,736	46.99	10,561

Attachment B.
Table 6-B-2--Rural farm dwelling unit analysis, by state and subarea, 1950, 1960 and 1970, Chesapeake Bay Study--Continued

State and subarea	1970			
	Total	W/running water, toilet-bath	Percent	W/running water, toilet-bath
	------Dwelling units-------			--Population--
CHESAPEAKE BAY	27,459	22,698	82.66	78,223
DELAWARE	1,794	1,634	91.08	5,071
MARYLAND	14,706	12,684	86.25	45,828
Study Area				
1----------	5,398	4,786	88.66	16,186
2----------	3,070	2,730	88.93	9,056
3----------	2,468	2,145	86.91	8,477
4----------	1,531	1,281	83.67	4,943
5----------	2,239	1,742	77.80	7,166
VIRGINIA	10,959	8,380	76.47	27,324
Study Area				
1----------	693	465	67.10	1,409
2----------	1,146	996	86.91	3,194
3----------	503	435	86.48	1,479
4----------	2,636	2,104	79.82	7,177
5----------	2,245	1,669	74.34	5,140
6----------	74	64	86.49	227
7----------	442	401	90.72	1,248
8----------	3,220	2,246	69.75	7,450

Source: Census of Housing and Calculation.

Attachment B.

Table 6-B-3--Number and percent of rural population served by running water, by state and subarea, 1950, 1960 and 1970, Chesapeake Bay Study

State and subarea	Rural population served by running water			Percent served by running water		
	1950	1960	1970	1950 1/	1960 1/	1970 1/
CHESAPEAKE BAY	478,372	943,766	1,103,113	40.65	69.45	79.81
DELAWARE	23,065	41,897	49,065	46.48	70.44	71.21
MARYLAND	287,813	514,296	622,799	49.52	74.21	84.55
Study Area						
1----------	144,224	253,887	292,563	55.93	80.97	89.68
2----------	35,214	72,350	87,255	40.92	68.53	79.02
3----------	25,863	51,009	67,419	32.75	58.86	72.10
4----------	55,044	83,021	98,009	58.72	77.59	91.25
5----------	27,468	54,029	77,553	42.50	67.31	78.35
VIRGINIA	167,494	387,573	431,249	30.67	63.91	74.66
Study Area						
1----------	13,061	22,477	25,301	41.99	73.37	87.23
2----------	30,879	92,697	99,977	26.77	76.90	89.29
3----------	10,804	23,485	39,356	35.39	61.90	80.24
4----------	41,421	100,984	102,724	36.42	72.50	84.03
5----------	20,083	39,946	49,867	26.24	50.16	62.95
6----------	5,377	12,378	23,526	45.76	79.20	92.49
7----------	24,104	40,155	9,545	43.28	70.59	76.86
8----------	21,765	55,451	80,953	23.14	50.90	67.96

1/ Weighted aggregate percentage obtained by adding number of rural farm and nonfarm households served by running water.

Attachment B.

Table 6-B-4--Rural population and annual water use, with and without running water, by state and subarea, 1950, 1960 and 1970, Chesapeake Bay Study

State and subarea	1950				1960			
	With running water		Without running water		With running water		Without running water	
	Population	Water use	Population	Water use	Population	Water use	Population	Water use
	Number	Mil. gals.	Number	Mil. gals.	Number	Mil. gals.	Number	Mil. gals
CHESAPEAKE BAY	478,379	8,730.3	698,558	2,549.8	943,766	17,223.6	415,245	1,515.5
DELAWARE	23,065	420.9	26,555	96.9	41,897	764.1	17,586	64.2
MARYLAND	287,814	5,252.7	293,437	1,071.0	514,296	9,386.2	178,765	652.6
Study Area								
1----------	144,224	2,632.1	113,629	414.7	253,887	4,633.4	59,675	217.7
2----------	35,215	642.7	50,835	185.5	72,350	1,320.5	33,220	121.4
3----------	25,863	472.0	53,115	193.9	51,009	931.0	35,653	130.2
4----------	55,044	1,004.6	38,700	141.2	83,021	1,515.2	23,972	87.5
5----------	27,468	501.3	37,158	135.7	54,029	986.1	26,245	95.8
VIRGINIA	167,500	3,056.7	378,566	1,381.9	387,573	7,073.3	218,894	798.7
Study Area								
1----------	13,061	238.3	35,347	129.0	22,477	410.2	25,124	91.7
2----------	30,879	563.6	84,476	308.4	92,697	1,691.7	27,848	101.6
3----------	10,804	197.2	19,728	71.9	23,485	428.7	14,453	52.8
4----------	41,421	755.9	72,300	263.9	100,984	1,843.0	38,304	139.8
5----------	20,083	366.5	56,466	206.2	39,946	729.0	39,693	144.8
6----------	5,377	98.1	6,373	23.3	12,378	225.9	3,251	11.9
7----------	24,104	439.8	31,595	115.4	40,155	732.8	16,729	61.0
8----------	21,771	397.3	72,281	263.8	55,451	1,012.0	53,492	195.1

Attachment B.

Table 6-B-4--Rural population and annual water use, with and without running water, by state and subarea, 1950, 1960 and 1970, Chesapeake Bay Study--Continued

State and subarea	1970			
	With running water		Without running water	
	Population	Water use	Population	Water use
	Number	Mil. gals.	Number	Mil. gals.
CHESAPEAKE BAY	1,103,113	20,310.9	265,251	968.2
DELAWARE	49,065	1,074.5	19,838	72.4
MARYLAND	622,799	11,366.2	113,756	415.2
Study Area				
1----------	292,563	5,339.3	33,670	122.9
2----------	87,255	1,592.4	23,163	84.4
3----------	67,419	1,230.5	26,093	95.3
4----------	98,009	1,788.6	9,401	34.4
5----------	77,553	1,415.4	21,429	78.2
VIRGINIA	431,249	7,870.2	131,657	480.6
Study Area				
1----------	25,301	461.8	18,145	66.3
2----------	99,977	1,824.6	11,987	43.7
3----------	39,356	718.2	9,694	35.4
4----------	102,724	1,874.7	19,525	71.2
5----------	49,867	910.0	29,351	107.2
6----------	23,526	429.3	1,911	7.0
7----------	9,545	174.2	2,873	10.5
8----------	80,953	1,477.4	38,171	139.3

Attachment C:

Water Demands Projected to 1980, 2000, and 2020--Maps and Tables.

Attachment C.

Table 6-C-1--Farm and non-farm components of residual** population, by subarea, projections for 1980, 2000, and 2020, Chesapeake Bay Study

State and	1980			2000			2020		
Subarea	Farm	Non-farm	Total	Farm	Non-farm	Total	Farm	Non-farm	Total
	Thousand persons								
CHESAPEAKE BAY	68.7	864.1	932.8	45.0	821.4	866.4	32.8	784.2	817.2
DELAWARE	4.9	62.0	66.9	4.0	68.9	72.9	3.5	67.8	71.3
MARYLAND									
Study Area	38.8	368.2	407.0	25.7	330.8	356.5	19.0	338.1	357.1
1 - - - -	13.2	181.3	194.5	8.3	141.2	149.5	5.8	144.2	150.0
2 - - - -	7.9	68.8	76.7	5.5	66.7	72.2	4.3	63.3	67.6
3 - - - -	6.2	55.3	61.5	4.9	74.0	78.9	4.1	96.4	100.5
4 - - - -	3.9	2.0	5.9	2.0	3.9	5.9	1.2	4.7	5.9
5 - - - -	7.6	60.8	68.4	5.0	45.0	50.0	3.6	29.5	33.1
VIRGINIA									
Study Area	24.9	433.9	458.8	15.2	421.7	436.9	10.3	378.2	388.5
1 - - - -	1.6	32.7	34.3	1.2	33.0	34.2	1.0	32.4	33.4
2 - - - -	2.3	104.2	106.5	1.5	109.0	110.5	1.1	105.2	106.3
3 - - - -	1.3	35.9	37.2	.8	35.9	36.7	.4	18.7	19.1
4 - - - -	6.2	83.5	89.7	3.7	81.6	85.3	2.5	78.1	80.6
5 - - - -	4.9	49.2	54.1	2.9	51.5	54.4	2.0	50.6	52.6
6 - - - -	.2	11.9	12.1	.1	4.9	5.0	*	5.0	5.0
7 - - - -	1.2	34.8	36.0	.9	26.5	27.4	.7	19.8	20.5
8 - - - -	7.2	81.7	88.9	4.1	79.3	83.4	2.6	68.4	71.0

*Less than 100

**Not served by central water supply systems

Attachment C.

Table 6-C-2--Daily domestic water use, farm population, by subarea, projections for 1980, 2000 and 2020, Chesapeake Bay Study

State and Subarea	1980			2000			2020		
	Population	Water use		Population	Water use		Population	Water use	
		Per capita	Total		Per capita	Total		Per capita	Total
	Thousands	Gallons	Thousand gallons	Thousands	Gallons	Thousand gallons	Thousands	Gallons	Thousand gallons
CHESAPEAKE	68.7	55.7	3,823.8	45.0	76.6	3,447.9	32.8	94.8	3,107.8
DELAWARE**	4.9	66.6	328.3	4.0	85.8	345.9	3.5	102.6	358.6
MARYLAND									
Study Area	38.8	56.1	2,175.0	25.8	76.4	1,971.3	18.9	94.1	1,778.4
1 - - - - -	13.2	57.0	750.6	8.3	76.7	637.4	5.8	94.0	541.6
2 - - - - -	7.9	57.3	452.2	5.6	76.9	428.4	4.3	94.1	407.7
3 - - - - -	6.2	56.7	353.3	4.9	76.7	374.9	4.1	94.1	383.6
4 - - - - -	3.9	55.0	215.9	2.0	75.5	152.5	1.2	93.5	109.7
5 - - - - -	7.6	53.1	403.0	5.1	74.8	378.1	3.6	93.2	335.8
VIRGINIA									
Study Area	25.0	52.8	1,320.5	15.2	74.4	1,130.7	10.4	93.3	970.8
1 - - - - -	1.6	49.9	81.7	1.2	72.0	84.9	1.0	91.4	88.5
2 - - - - -	2.3	56.4	129.5	1.5	76.4	114.0	1.1	93.9	100.5
3 - - - - -	1.3	56.4	74.8	0.8	76.7	57.9	0.5	94.0	43.4
4 - - - - -	6.2	53.9	335.2	3.7	75.2	281.6	2.5	93.4	234.0
5 - - - - -	4.9	52.2	256.8	2.9	74.2	217.4	2.0	92.9	189.3
6 - - - - -	0.2	56.4	10.4	0.1	76.3	9.2	0.1	93.9	8.0
7 - - - - -	1.2	57.6	68.6	0.9	77.0	69.5	0.7	94.1	70.1
8 - - - - -	7.2	50.2	363.5	4.1	72.7	296.2	2.6	92.0	237.0

**Sussex County only, at request of Corps of Engineers

Attachment C.

Table 6-C-3--Daily domestic water use, non-farm residual* population, by subarea, projections for 1980, 2000 and 2020, Chesapeake Bay Study

State and Subarea	1980			2000			2020		
	Population	Water use: Per capita	Water use: Total	Population	Water use: Per capita	Water use: Total	Population	Water use: Per capita	Water use: Total
	Thousands	Gallons	Thousand gallons	Thousands	Gallons	Thousand gallons	Thousands	Gallons	Thousand gallons
CHESAPEAKE	864.1	90.5	78,171.5	821.4	107.3	88,167.9	784.2	123.5	96,861.4
DELAWARE**	62.0	91.1	5,652.3	68.9	107.7	7,416.5	67.8	123.6	8,378.1
MARYLAND									
Study Area	368.2	89.8	33,063.4	330.9	106.7	35,288.2	338.1	123.1	41,627.8
1 - - - - -	181.3	90.7	16,438.7	141.2	107.2	15,132.1	144.2	123.5	17,817.6
2 - - - - -	68.8	89.4	6,152.9	66.7	106.5	7,102.1	63.3	122.7	7,769.0
3 - - - - -	55.3	89.4	4,944.5	74.1	107.0	7,924.0	96.4	123.5	11,898.9
4 - - - - -	2.0	67.8	134.8	3.9	97.6	379.6	4.7	118.5	561.2
5 - - - - -	60.8	88.7	5,392.5	45.0	105.5	4,750.4	29.5	121.3	3,581.1
VIRGINIA									
Study Area	433.9	90.9	39,455.8	421.7	107.8	45,463.2	378.3	123.9	46,855.5
1 - - - - -	32.7	91.0	2,977.5	33.0	107.7	3,556.3	32.4	123.7	4,013.0
2 - - - - -	104.3	92.3	9,626.6	109.0	108.6	11,829.5	105.2	124.4	13,088.3
3 - - - - -	35.9	91.8	3,292.2	35.9	108.3	3,889.7	18.7	124.0	2,314.4
4 - - - - -	83.5	90.4	7,542.6	81.6	107.5	8,773.2	78.1	123.7	9,666.3
5 - - - - -	49.2	89.4	4,393.5	51.5	107.1	5,521.3	50.6	123.5	6,251.5
6 - - - - -	11.9	92.5	1,103.5	4.9	108.2	534.6	5.0	124.2	617.8
7 - - - - -	34.8	91.9	3,199.1	26.5	107.9	2,858.2	19.8	123.6	2,450.2
8 - - - - -	81.7	89.6	7,320.8	79.3	107.2	8,500.4	68.4	123.5	8,454.0

*Not served by central water supply systems

**Sussex County only, at request of Corps of Engineers

Attachment C.

Table 6-C-4--Daily domestic water use, total residual* population, by subarea, projections for 1980, 2000 and 2020, Chesapeake Bay Study

State and Subarea	1980			2000			2020		
	Population	Water use		Population	Water use		Population	Water use	
		Per capita	Total		Per capita	Total		Per capita	Total
	Thousands	Gallons	Thousand gallons	Thousands	Gallons	Thousand gallons	Thousands	Gallons	Thousand gallons
CHESAPEAKE	932.8	87.9	81,995.1	866.4	105.7	91,615.9	817.2	122.3	99,969.3
DELAWARE**	66.9	89.3	5,980.6	72.9	106.5	7,762.4	71.3	122.6	8,736.7
MARYLAND									
Study Area	407.0	86.6	35,238.4	356.6	104.5	37,259.6	357.1	121.6	43,406.5
1 - - - -	194.5	88.4	17,189.3	149.5	105.5	15,769.5	150.0	122.4	18,359.2
2 - - - -	76.7	86.1	6,605.0	72.2	104.2	7,530.5	67.6	120.9	8,176.8
3 - - - -	61.5	86.1	5,297.8	78.9	105.1	8,299.0	100.5	122.3	12,282.5
4 - - - -	5.9	59.3	350.7	5.9	90.0	532.1	5.9	113.5	671.0
5 - - - -	68.4	84.7	5,795.6	50.1	102.4	5,128.5	33.1	118.2	3,917.0
VIRGINIA									
Study Area	458.9	88.9	40,776.1	436.9	106.6	46,593.9	388.8	123.0	47,826.1
1 - - - -	34.3	89.1	3,059.2	34.2	106.5	3,641.1	33.4	122.8	4,101.5
2 - - - -	106.6	91.5	9,756.0	110.5	108.1	11,943.5	106.3	124.1	13,188.8
3 - - - -	37.2	90.5	3,366.9	36.7	107.7	3,947.6	19.1	123.2	2,357.6
4 - - - -	89.7	87.9	7,877.8	85.3	106.1	9,054.9	80.6	122.8	9,900.3
5 - - - -	54.1	86.0	4,650.3	54.5	105.4	5,738.7	52.7	122.3	6,440.8
6 - - - -	12.1	92.0	1,113.9	5.1	107.5	543.8	5.1	123.7	625.8
7 - - - -	36.0	90.8	3,267.7	27.4	106.9	2,927.7	20.6	122.5	2,520.4
8 - - - -	88.9	86.4	7,684.3	83.4	105.5	8,796.6	71.0	122.4	8,690.9

*Not served by central water supply systems

**Sussex County only, at request of Corps of Engineers

Attachment C.

Table 6-C-5--Beef cattle and calves, numbers and annual water use by state and by subarea, projections for 1980, 2000, and 2020, Chesapeake Bay Study

State and Subarea	1980 Numbers	1980 Water Use	2000 Numbers	2000 Water Use	2020 Numbers	2020 Water Use
		Thousand gallons		Thousand gallons		Thousand gallons
CHESAPEAKE BAY	430,351	1,631,715	407,346	1,555,006	424,813	1,625,125
DELAWARE	18,097	59,063	7,891	19,391	5,132	12,233
MARYLAND	311,004	1,076,317	283,841	922,611	270,481	792,041
Study Area	210,948	769,562	194,439	701,839	187,918	661,795
1 - - - - -	118,157	433,513	118,686	429,988	121,687	428,312
2 - - - - -	45,965	154,668	36,326	116,712	30,006	89,852
3 - - - - -	12,721	49,985	13,607	54,853	14,944	60,980
4 - - - - -	21,970	82,284	14,209	53,334	9,647	36,061
5 - - - - -	12,135	49,112	11,611	46,952	11,634	46,590
VIRGINIA	1,504,982	6,014,817	1,927,947	7,821,083	2,591,931	10,583,983
Study Area	201,306	803,090	205,016	833,776	231,763	951,097
1 - - - - -	3,555	14,743	4,208	17,747	5,395	22,850
2 - - - - -	64,973	259,519	58,687	240,238	54,855	226,768
3 - - - - -	22,828	91,722	28,036	114,616	35,891	147,789
4 - - - - -	27,883	107,671	14,369	52,882	7,480	24,366
5 - - - - -	31,295	125,552	30,903	125,132	29,871	121,473
6 - - - - -	2,646	9,322	3,923	14,365	5,857	21,962
7 - - - - -	8,926	34,557	7,761	31,057	7,011	28,483
8 - - - - -	39,200	160,004	57,129	237,739	83,990	351,807

Attachment C.

Table 6-C-6--Hogs and pigs, numbers and annual water use by state and by subarea, projections for 1980, 2000, and 2020, Chesapeake Bay Study

State and Subarea	1980 Numbers	1980 Water Use	2000 Numbers	2000 Water Use	2020 Numbers	2020 Water Use
		Thousand gallons		Thousand gallons		Thousand gallons
CHESAPEAKE BAY	699,482	495,989	624,840	450,607	552,446	403,379
DELAWARE	76,131	53,983	72,039	51,951	68,499	50,016
MARYLAND	221,940	157,373	171,909	123,973	134,922	98,516
Study Area	210,842	149,503	166,750	120,254	132,223	96,545
1 - - - -	36,487	25,872	18,461	13,313	9,748	7,117
2 - - - -	74,757	53,009	61,430	44,301	49,754	36,329
3 - - - -	67,271	47,700	62,449	45,036	53,781	39,270
4 - - - -	9,627	6,826	4,301	3,102	2,002	1,462
5 - - - -	22,700	16,096	20,109	14,502	16,938	12,367
VIRGINIA	818,079	580,084	694,187	500,617	591,580	431,955
Study Area	412,509	292,503	386,051	278,402	351,724	256,818
1 - - - -	15,248	10,812	16,363	11,801	16,024	11,700
2 - - - -	11,506	8,159	8,552	6,167	6,576	4,801
3 - - - -	4,727	3,352	2,655	1,914	1,497	1,093
4 - - - -	75,643	53,637	73,812	53,230	68,898	50,307
5 - - - -	85,063	60,317	88,331	63,700	85,220	62,225
6 - - - -	1,308	928	1,119	807	960	701
7 - - - -	41,288	29,276	41,801	30,145	39,548	28,877
8 - - - -	177,726	126,022	153,418	110,638	133,001	97,114

Attachment C.

Table 6-C-7--Sheep and lambs, numbers and annual water use by state and by subarea, projections for 1980, 2000, and 2020, Chesapeake Bay Study

State and Subarea	1980		2000		2020	
	Numbers	Water Use	Numbers	Water Use	Numbers	Water Use
		Thousand gallons		Thousand gallons		Thousand gallons
CHESAPEAKE BAY	19,415	8,851	14,127	6,717	11,202	5,076
DELAWARE	2,129	975	1,403	667	710	333
MARYLAND	13,899	6,366	9,616	4,573	7,104	3,331
Study Area	9,868	4,480	7,032	3,344	5,345	2,506
1 - - - - -	4,241	1,903	3,205	1,524	2,520	1,182
2 - - - - -	3,911	1,791	2,936	1,396	2,287	1,072
3 - - - - -	445	204	138	66	46	22
4 - - - - -	1,067	489	683	325	468	219
5 - - - - -	204	93	70	33	24	11
VIRGINIA	204,276	93,565	214,928	102,206	236,796	111,038
Study Area	7,418	3,396	5,692	2,706	5,147	2,237
1 - - - - -	470	215	257	122	146	69
2 - - - - -	2,204	1,010	1,176	559	657	130
3 - - - - -	487	223	292	139	183	86
4 - - - - -	399	182	170	81	76	36
5 - - - - -	946	433	576	274	368	173
6 - - - - -	0	0	0	0	0	0
7 - - - - -	281	128	152	72	87	41
8 - - - - -	2,631	1,205	3,069	1,459	3,630	1,702

Attachment C.
Table 6-C-8--Chickens, numbers and annual water use by state and by subarea, projections for 1980, 2000, and 2020, Chesapeake Bay Study

State and Subarea	1980		2000		2020	
	Numbers	Water Use	Numbers	Water Use	Numbers	Water Use
		Thousand gallons		Thousand gallons		Thousand gallons
CHESAPEAKE BAY	2,726,672	66,550	2,393,270	59,427	2,340,806	58,566
DELAWARE	535,048	13,059	465,998	11,573	424,125	10,611
MARYLAND	1,043,102	25,459	620,797	15,417	391,878	9,804
Study Area	851,275	20,778	502,296	12,474	312,082	7,808
1	363,132	8,863	180,240	4,476	94,890	2,374
2	132,079	3,224	69,040	1,715	38,278	958
3	245,644	5,996	181,577	4,509	130,432	3,263
4	27,383	668	9,240	229	3,306	83
5	83,037	2,027	62,199	1,545	45,176	1,130
VIRGINIA	5,141,702	125,496	5,302,397	131,680	5,750,626	143,875
Study Area	1,340,349	32,713	1,424,976	35,380	1,604,599	40,147
1	85,725	2,092	98,452	2,445	112,975	2,827
2	5,991	146	619	15	*	2
3	10,832	264	1,901	47	351	9
4	351,962	8,590	333,784	8,289	332,901	8,329
5	132,407	3,232	58,131	1,437	26,592	665
6	47,215	1,152	61,905	1,537	77,934	1,950
7	217,304	5,304	274,881	6,826	338,303	8,464
8	488,913	11,933	595,303	14,784	715,476	17,901

*Less than 100

Attachment C.

Table 6-C-9-- Broilers, numbers and annual water use by state and by subarea, projections for 1980, 2000, and 2020, Chesapeake Bay Study

State and Subarea	1980		2000		2020	
	Numbers	Water Use	Numbers	Water Use	Numbers	Water Use
	Thousands					
CHESAPEAKE BAY	338,282	506,790	361,248	541,873	374,986	562,479
DELAWARE	154,591	231,887	166,089	249,134	169,788	254,682
MARYLAND	201,172	301,759	211,067	316,600	215,834	323,450
Study Area	177,882	266,823	193,012	289,517	204,408	306,612
1	35	53	2	2	*	*
2	4,849	7,273	823	1,234	136	204
3	172,998	259,497	192,187	288,280	204,272	306,408
4	0	0	0	0	0	0
5	*	*	0	0	0	0
VIRGINIA	29,779	44,668	9,897	14,846	3,320	4,980
Study Area	5,809	8,080	2,147	3,222	790	1,185
1	5,386	8,079	2,117	3,176	788	1,182
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	423	1	30	46	2	3
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	0	0	0	0	0	0
8	0	0	0	0	0	0

*Less than 100

Attachment C.

Table 6-C-10 Turkeys, numbers and annual water use by state and by subarea, projections for 1980, 2000, and 2020, Chesapeake Bay Study

State and Subarea	1980		2000		2020	
	Numbers	Water Use	Numbers	Water Use	Numbers	Water Use
CHESAPEAKE BAY	223,236	3,898,475	91,938	1,639,894	38,549	693,730
DELAWARE	204,190	3,566,260	89,654	1,599,153	38,549	692,558
MARYLAND	62,641	1,094,047	9,605	171,313	0	0
Study Area	16,011	279,650	1,858	33,152	0	0
1 - - - -	13,431	234,579	1,780	31,746	0	0
2 - - - -	363	6,340	*	*	0	0
3 - - - -	1,888	32,987	*	1,156	0	0
4 - - - -	*	249	0	0	0	0
5 - - - -	315	5,495	*	154	0	0
VIRGINIA	7,037,830	122,918,895	7,469,907	133,239,614	8,168,223	146,749,373
Study Area	3,035	52,565	426	7,589	*	1,172
1 - - - -	0	0	0	0	0	0
2 - - - -	*	*	0	0	0	0
3 - - - -	0	0	0	0	0	0
4 - - - -	2,655	46,378	408	7,262	*	1,153
5 - - - -	*	288	0	0	0	0
6 - - - -	0	0	0	0	0	0
7 - - - -	331	5,783	*	327	*	*
8 - - - -	*	*	0	0	0	0

*Less than 100

Attachment C. Table

6-C-11--Milk cows and heifers, numbers and annual water use by state and by subarea, projections for 1980, 2000, and 2020, Chesapeake Bay Study

State and Subarea	1980 Numbers	1980 Water Use	2000 Numbers	2000 Water Use	2020 Numbers	2020 Water Use
		Million gallons		Million gallons		Million gallons
CHESAPEAKE BAY	169,477	1,562	159,439	1,563	169,352	1,669
DELAWARE	17,813	164	14,738	144	13,288	131
MARYLAND	240,375	2,216	288,855	2,831	370,864	3,654
Study Area	119,460	1,100	122,554	1,202	137,431	1,354
1 - - - -	65,013	599	74,263	728	90,630	893
2 - - - -	40,877	377	38,631	379	39,006	384
3 - - - -	2,860	26	1,815	18	1,233	12
4 - - - -	9,684	89	6,416	63	4,542	45
5 - - - -	1,025	9	1,428	14	2,023	20
VIRGINIA	245,136	2,260	251,564	2,466	285,289	2,811
Study Area	32,204	298	22,147	217	18,633	184
1 - - - -	87	1	21	2	5	*
2 - - - -	10,719	99	4,855	48	2,432	24
3 - - - -	2,560	24	1,747	17	1,317	13
4 - - - -	8,017	74	7,235	71	7,219	71
5 - - - -	3,583	33	2,916	29	2,622	26
6 - - - -	2,044	19	2,584	25	3,363	33
7 - - - -	2,411	22	1,136	11	592	6
8 - - - -	2,785	26	1,651	16	1,082	11

*Less than 200,000 gallons

Attachment C. Table 6-C-12
Future Irrigation Water Requirements
State Delaware Subarea No. 1

Crop	Seasonal Net Irrig. Requirements (in/ac.)	1980		2000		2020	
		Projected Acres	Seasonal NIR (ac-ft)	Projected Acres	Seasonal NIR (ac-ft)	Projected Acres	Seasonal NIR (ac-ft)
Wheat							
Rye							
Oats							
Barley							
Corn (grain)	8.82	880	647	1,780	1,308	2,650	1,948
Silage							
Sorghum(grain)							
Fruits & Nuts							
Vegetables	3.93	36,970	12,108	44,080	14,436	54,820	17,954
Hay							
Soybeans	6.22	15,040	7,796	15,860	8,220	15,780	8,179
Peanuts							
Cotton							
Tobacco							
Irish Potatoes	12.92	6,250	6,729	6,570	7,074	7,430	8,000
Sweet Potatoes							
Nursery &Other	10.30	7,500	6,438	8,500	7,296	10,000	8,583
Total 1/		66,640	33,718	76,790	38,334	90,680	44,664

1/ Assuming a 65 percent rate of irrigation efficiency, gross water demand, in billion gallons per year:	1980	2000	2020
	16,903	19,217	22,391

Attachment C. Table 6-C-13
Future Irrigation Water Requirements
State Maryland Subarea No. 1

Crop	Seasonal Net Irrig. Requirements (in/ac)	1980		2000		2020	
		Projected Acres	Seasonal NIR (ac-ft)	Projected Acres	Seasonal NIR (ac-ft)	Projected Acres	Seasonal NIR (ac-ft)
Wheat							
Rye							
Oats							
Barley							
Corn (grain)	9.47	380	300	400	316	450	355
Silage	7.21	300	180	300	180	320	192
Sorghum (gr)							
Fruits & Nuts	10.31	90	77	100	86	100	86
Vegetables	4.03	3,000	1,008	3,000	1,008	3,000	1,008
Hay							
Soybeans							
Peanuts							
Cotton							
Tobacco							
IrishPotatoes							
SweetPotatoes							
Nursery&Other	10.31	5,000	4,296	6,000	5,155	7,000	6,014
Total 1/		8,770	5,861	9,800	6,745	10,870	7,655

1/ Assuming a 65 percent rate of irrigation efficiency, gross water demand, in billion gallons per year:	1980	2000	2020
	2,938	3,381	3,838

Attachment C. Table 6-C-14
Future Irrigation Water Requirements
State Maryland Subarea No. 2

Crop	Seasonal Net Irrig. Requirements (in/ac)	1980		2000		2020	
		Projected Acres	Seasonal NIR (ac-ft)	Projected Acres	Seasonal NIR (ac-ft)	Projected Acres	Seasonal NIR (ac-ft)
Wheat							
Rye							
Oats							
Barley							
Corn (grain)	9.87	3,800	3,125	25,000	20,562	100,000	82,250
Silage	7.34	320	195	3,000	1,835	12,000	7,340
Sorghum (gr)							
Fruits & Nuts							
Vegetables	4.23	9,000	3,173	9,380	3,306	11,000	3,878
Hay							
Soybeans	7.34	1,000	612	7,500	4,588	25,000	15,292
Peanuts							
Cotton							
Tobacco							
Irish Potatoes							
Sweet Potatoes							
Nursery&Other	11.00	1,500	1,375	2,000	1,833	2,500	2,292
Total 1/		15,620	8,480	46,880	32,124	150,500	111,052

	1980	2000	2020
1/ Assuming a 65 percent rate of irrigation efficiency, gross water demand, in billion gallons per year:	4,251	16,104	55,671

Attachment C. Table 6-C-15
Future Irrigation Water Requirements
State Maryland Subarea No. 3

Crop	Seasonal Net Irrig. Requirements (in/ac)	1980		2000		2020	
		Projected Acres	Seasonal NIR (ac-ft)	Projected Acres	Seasonal NIR (ac-ft)	Projected Acres	Seasonal NIR (ac-ft)
Wheat	9.02	120	90	70	53	50	38
Rye							
Oats							
Barley							
Corn (grain)	9.02	2,130	1,601	4,230	3,180	5,600	4,209
Silage							
Sorghum (grain)							
Fruits & Nuts	10.46	40	34	20	17	10	9
Vegetables	4.07	4,240	1,438	2,260	767	1,190	404
Hay	10.46	450	392	200	174	100	87
Soybeans	6.48	1,670	902	1,080	583	740	400
Peanuts							
Cotton							
Tobacco							
Irish Potatoes							
Sweet Potatoes	8.83	70	52	70	52	80	59
Nursery & Other	10.46	450	392	540	470	650	567
Total 1/		9,170	4,091	8,470	5,296	8,420	5,773

1/ Assuming a 65 percent rate of irrigation efficiency, gross water demand, in billion gallons per year:	1980	2000	2020
	2,051	2,655	2,894

Attachment C. Table 6-C-16
Future Irrigation Water Requirements
State Maryland Subarea No. 4

Crop	Seasonal Net Irrig. Requirements (in/ac)	1980		2000		2020	
		Projected Acres	Seasonal NIR (ac-ft)	Projected Acres	Seasonal NIR (ac-ft)	Projected Acres	Seasonal NIR (ac-ft)
Wheat							
Rye							
Oats							
Barley							
Corn (grain)	10.37	0	0	2,200	1,901	2,630	2,273
Silage							
Sorghum (grain)							
Fruits & Nuts	11.52	80	77	40	38	20	19
Vegetables	4.33	330	119	480	173	390	140
Hay							
Soybeans	7.43	0	0	850	526	1,600	991
Peanuts							
Cotton							
Tobacco	5.36	900	402	2,620	1,622	1,740	1,077
Irish Potatoes							
Sweet Potatoes							
Nursery & Other	11.52	600	576	2,500	2,400	8,000	7,680
Total 1/		1,910	1,174	8,690	6,660	14,380	12,180

	1980	2000	2020
1/ Assuming a 65 percent rate of irrigation efficiency, gross water demand, in billion gallons per year:	588,487	3,339	6,106

Attachment C. Table 6-C-17
Future Irrigation Water Requirements
State Maryland Subarea No. 5

Crop	Seasonal Net Irrig. Requirements (in/ac)	1980		2000		2020	
		Projected Acres	Seasonal NIR (ac-ft)	Projected Acres	Seasonal NIR (ac-ft)	Projected Acres	Seasonal NIR (ac-ft)
Wheat							
Rye							
Oats							
Barley							
Corn (grain)	9.11	0	0	3,200	2,429	4,070	3,090
Silage							
Sorghum (grain)							
Fruits & Nuts	10.38	50	43	60	52	80	69
Vegetables	4.01	50	17	100	33	90	30
Hay							
Soybeans	6.78	0	0	2,400	1,356	4,520	2,553
Peanuts							
Cotton							
Tobacco	4.50	3,650	1,368	16,560	6,210	16,820	6,307
Irish Potatoes							
Sweet Potatoes							
Nursery & Other	10.38	300	259	1,500	1,298	8,000	6,920
Total 1/		4,050	1,687	23,820	11,378	33,580	18,969

	1980	2000	2020
1/ Assuming a 65 percent rate of irrigation efficiency, gross water demand, in billion gallons per year:	845,583	5,704	9,509

Attachment C. Table 6-C-18
Future Irrigation Water Requirements
State Virginia Subarea No. 1

Crop	Seasonal Net Irrig. Requirements (in/ac)	1980		2000		2020	
		Projected Acres	Seasonal NIR (ac-ft)	Projected Acres	Seasonal NIR (ac-ft)	Projected Acres	Seasonal NIR (ac-ft)
Wheat							
Rye							
Oats							
Barley							
Corn (grain)							
Silage							
Sorghum (grain)							
Fruits & Nuts							
Vegetables	6.71	10,600	5,927	7,030	3,931	4,800	2,684
Hay							
Soybeans							
Peanuts							
Cotton							
Tobacco							
Irish Potatoes	11.94	10,900	10,846	8,600	8,557	6,800	6,766
Sweet Potatoes							
Nursery & Other							
Total 1/		21,500	16,773	15,630	12,488	11,600	9,450

	1980	2000	2020
1/ Assuming a 65 percent rate of irrigation efficiency, gross water demand, in billion gallons per year:	8,409	6,260	4,737

Attachment C. Table 6-C-19
Future Irrigation Water Requirements
State Virginia Subarea No. 2

Crop	Seasonal Net Irrig. Requirements (in/ac)	1980		2000		2020	
		Projected Acres	Seasonal NIR (ac-ft)	Projected Acres	Seasonal NIR (ac-ft)	Projected Acres	Seasonal NIR (ac-ft)
Wheat							
Rye							
Oats							
Barley							
Corn (grain)	10.45	240	209	1,000	871	1,000	871
Silage	7.66	250	160	1,100	702	1,100	702
Sorghum (grain)							
Fruits & Nuts	10.00	400	333	400	333	400	333
Vegetables	2.98	360	89	600	149	600	149
Hay	10.00	200	167	600	500	1,000	833
Soybeans							
Peanuts							
Cotton							
Tobacco							
Irish Potatoes							
Sweet Potatoes							
Nursery & Other	10.00	1,500	1,250	3,400	2,833	4,000	3,333
Total 1/		2,950	2,208	7,100	5,388	8,100	6,221

1/ Assuming a 65 percent rate of irrigation efficiency, gross water demand, in billion gallons per year:	1980	2000	2020
	1,107	2,701	3,119

Attachment C. Table 6-C-20
Future Irrigation Water Requirements
State Virginia Subarea No. 3

Crop	Seasonal Net Irrig. Requirements (in/ac)	1980		2000		2020	
		Projected Acres	Seasonal NIR (ac-ft)	Projected Acres	Seasonal NIR (ac-ft)	Projected Acres	Seasonal NIR (ac-ft)
Wheat							
Rye							
Oats							
Barley							
Corn (grain)	9.60	80	64	100	80	130	104
Silage							
Sorghum (grain)							
Fruits & Nuts							
Vegetables	3.03	30	8	30	8	30	8
Hay							
Soybeans							
Peanuts							
Cotton							
Tobacco							
Irish Potatoes							
Sweet Potatoes							
Nursery &Other	9.64	120	96	300	241	400	321
Total 1/		230	168	430	329	560	433

1/ Assuming a 65 percent rate of irrigation efficiency, gross water demand, in billion gallons per year:

	1980	2000	2020
	84,070	164,881	217,017

Attachment C. Table 6-C-21
Future Irrigation Water Requirements
State Virginia Subarea No. 4

Crop	Seasonal Net Irrig. Requirements (in/ac)	1980		2000		2020	
		Projected Acres	Seasonal NIR (ac-ft)	Projected Acres	Seasonal NIR (ac-ft)	Projected Acres	Seasonal NIR (ac-ft)
Wheat							
Rye							
Oats							
Barley							
Corn (grain)	8.93	600	446	2,600	1,935	2,600	1,935
Silage	6.45	600	322	3,000	1,612	3,100	1,666
Sorghum(grain)							
Fruits & Nuts	8.99						
Vegetables	3.18	250	66	300	80	350	93
Hay	8.99	510	382	1,610	1,206	2,000	1,498
Soybeans							
Peanuts	1.48	0	0	500	62	600	74
Cotton							
Tobacco	7.88	1,310	860	1,350	887	1,400	919
Irish Potatoes							
Sweet Potatoes							
Nursery & Other	8.99	2,640	1,978	7,760	5,814	9,600	7,192
Total 1/		5,910	4,054	17,120	10,390	19,650	13,377

1/ Assuming a 65 percent rate of irrigation efficiency, gross water demand, in billion gallons per year:	1980	2000	2020
	2,032	5,209	6,706

Attachment C. Table 6-C-22
Future Irrigation Water Requirements
State Virginia Subarea No. 5

Crop	Seasonal Net Irrig. Requirements (in/ac)	1980		2000		2020	
		Projected Acres	Seasonal NIR (ac-ft)	Projected Acres	Seasonal NIR (ac-ft)	Projected Acres	Seasonal NIR (ac-ft)
Wheat							
Rye							
Oâts							
Barley							
Corn (grain)	9.22	1,100	845	4,900	3,765	5,000	3,842
Silage	6.64	1,090	603	2,000	1,107	2,100	1,162
Sorghum (grain)							
Fruits & Nuts							
Vegetables	3.43	900	257	600	172	500	143
Hay							
Soybeans	7.59	340	215	730	462	750	475
Peanuts							
Cotton							
Tobacco							
Irish Potatoes							
Sweet Potatoes							
Nursery & Other	9.13	670	510	1,460	1,111	2,000	1,522
Total 1/		4,100	2,430	9,690	6,617	10,350	7,144

1/ Assuming a 65 percent rate of irrigation efficiency, gross water demand, in billion gallons per year:

	1980	2000	2020
	1,218	3,317	3,581

Attachment C. Table 6-C-23
Future Irrigation Water Requirements
State Virginia Subarea No. 6

Crop	Seasonal Net Irrig. Requirements (in/ac)	1980		2000		2020	
		Projected Acres	Seasonal NIR (ac-ft)	Projected Acres	Seasonal NIR (ac-ft)	Projected Acres	Seasonal NIR (ac-ft)
Wheat							
Rye							
Oats							
Barley							
Corn (grain)							
Silage							
Sorghum (grain)							
Fruits & Nuts							
Vegetables							
Hay							
Soybeans							
Peanuts							
Cotton							
Tobacco							
Irish Potatoes							
Sweet Potatoes							
Nursery & Other	9.95	60	50	100	42	200	166
Total 1/		77	50	100	42	200	166

1/ Assuming a 65 percent rate of irrigation efficiency, gross water demand, in billion gallons per year:

	1980	2000	2020
	25,091	41,709	83,092

Attachment C. Table 6-C-24
Future Irrigation Water Requirements
State Virginia Subarea No. 7

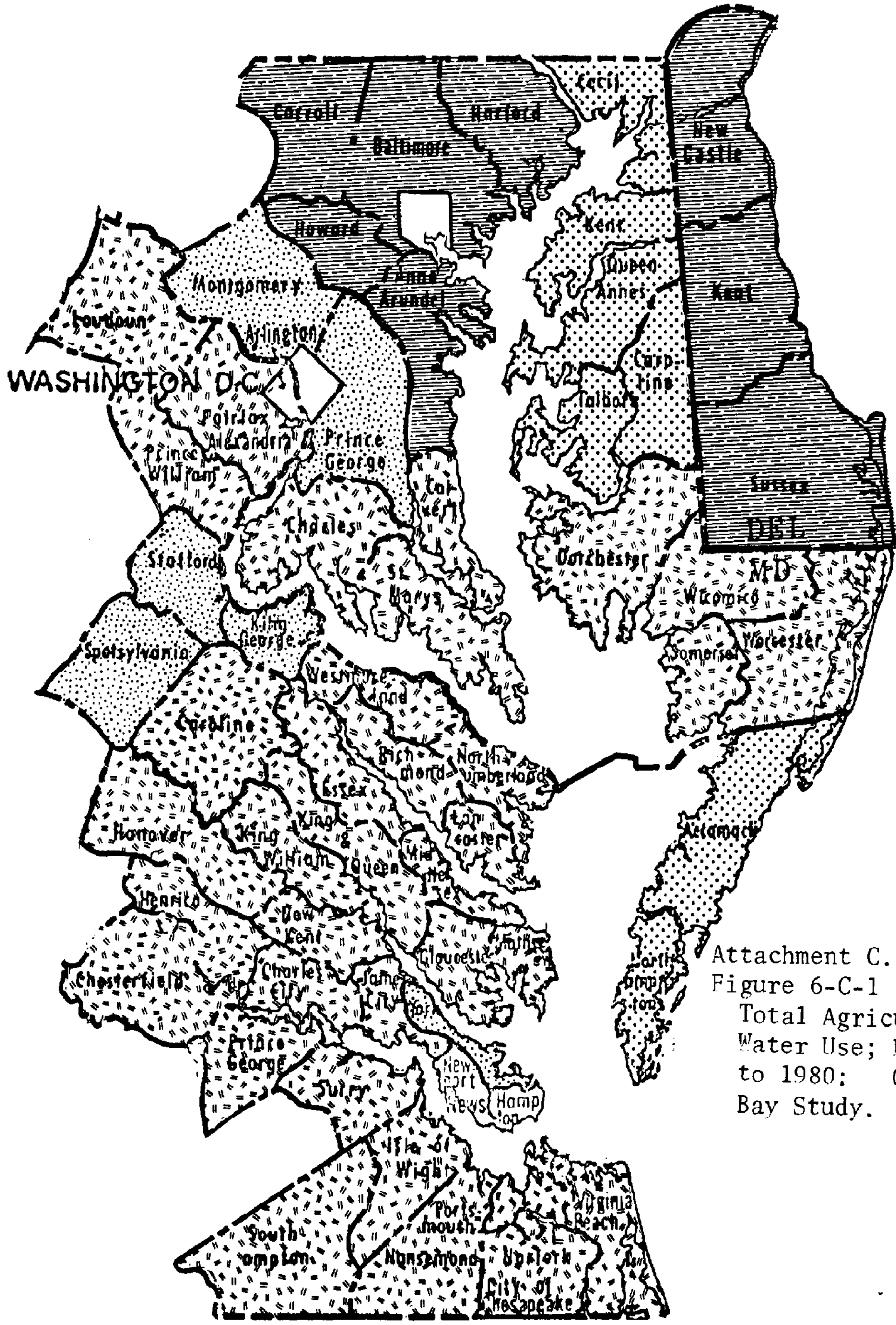
Crop	Seasonal Net Irrig. Requirements (in/ac)	1980		2000		2020	
		Projected Acres	Seasonal NIR (ac-ft)	Projected Acres	Seasonal NIR (ac-ft)	Projected Acres	Seasonal NIR (ac-ft)
Wheat							
Rye							
Oats							
Barley							
Corn (grain)	7.95	260	172	360	239	300	199
Silage							
Sorghum (grain)							
Fruits & Nuts							
Vegetables	3.33	500	139	500	139	250	69
Hay	8.32	90	62	0	0	0	0
Soybeans							
Peanuts							
Cotton							
Tobacco							
Irish Potatoes							
Sweet Potatoes							
Nursery & Other	8.32	2,260	1,567	2,100	1,456	2,300	1,595
Total 1/		3,110	1,940	2,822	1,834	2,850	1,863

1/ Assuming a 65 percent rate of irrigation efficiency, gross water demand, in billion gallons per year:	1980	2000	2020
	972,665	919,552	933,889

Attachment C. Table 6-C-25
Future Irrigation Water Requirements
State Virginia Subarea No. 8

Crop	Seasonal Net Irrig. Requirements (in/ac)	1980		2000		2020	
		Projected Acres	Seasonal NIR (ac-ft)	Projected Acres	Seasonal NIR (ac-ft)	Projected Acres	Seasonal NIR (ac-ft)
Wheat							
Rye							
Oats							
Barley							
Corn (grain)	8.56	1,000	713	13,060	9,316	8,000	5,707
Silage	6.06	360	182	1,000	505	1,000	505
Sorghum (grain)							
Fruits & Nuts	8.73	30	22	100	73	150	109
Vegetables	3.40	400	113	500	142	300	85
Hay	8.73	180	131	1,000	728	1,000	728
Soybeans							
Peanuts	7.55	500	315	2,000	1,258	2,500	1,573
Cotton							
Tobacco							
Irish Potatoes							
Sweet Potatoes							
Nursery & Other	8.73	200	146	860	626	2,000	1,455
Total 1/		2,670	1,622	18,520	12,648	14,950	10,162

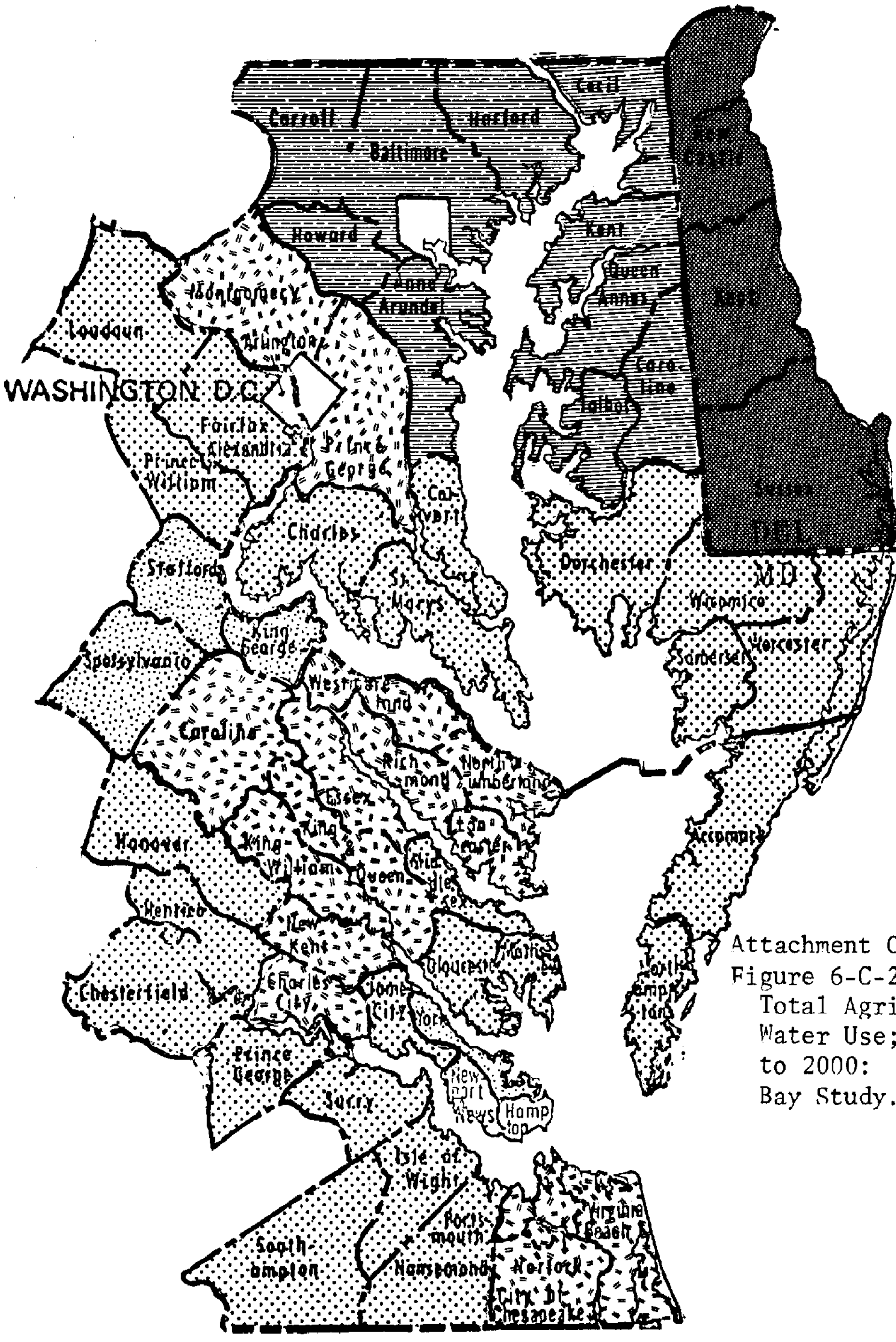
1/ Assuming a 65 percent rate of irrigation efficiency, gross water demand, in billion gallons per year:	1980	2000	2020
	812,998	6,340	5,094



Attachment C.
Figure 6-C-1
Total Agricultural Water Use; Projections to 1980: Chesapeake Bay Study.

Million Gallons

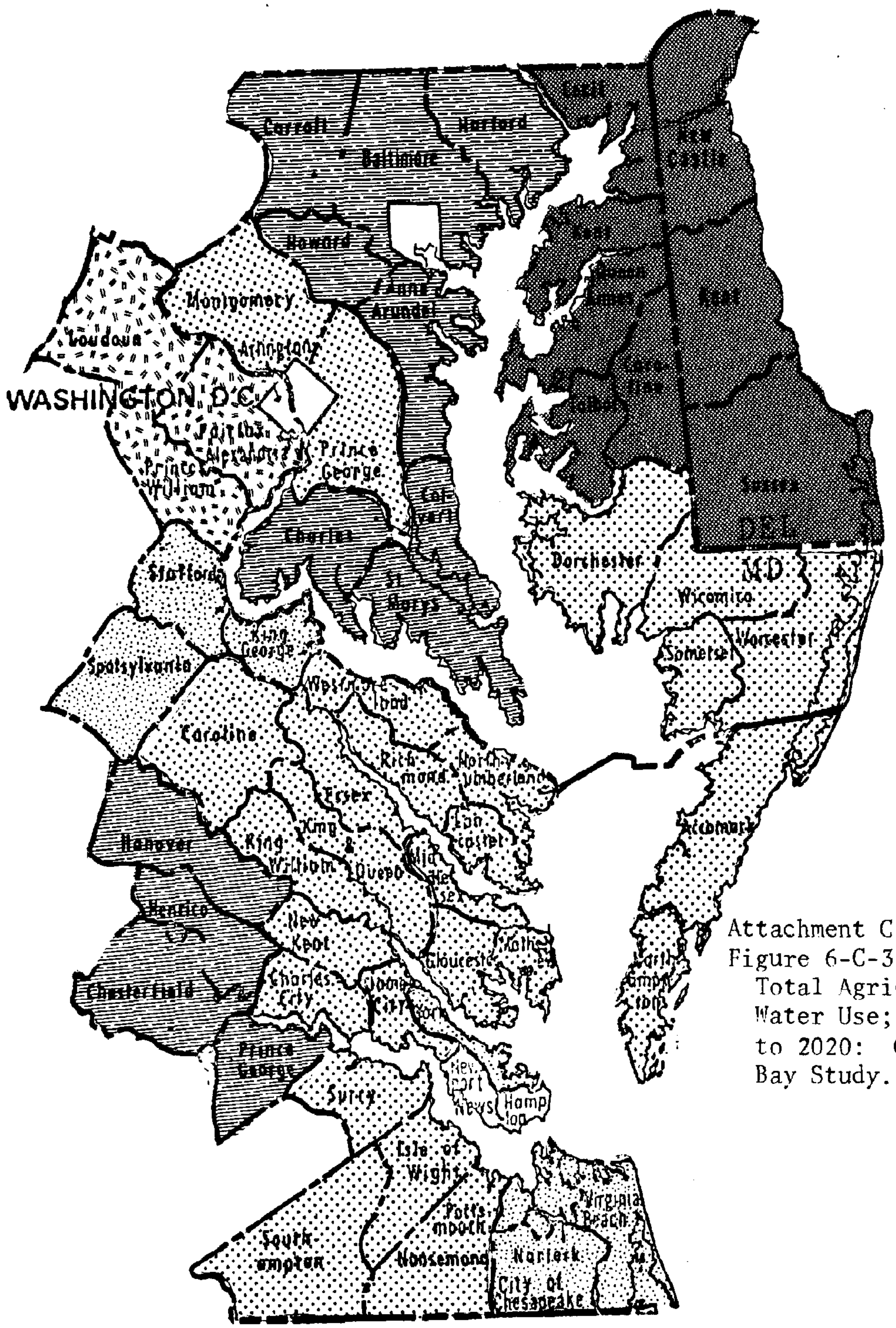
(dotted)	0-1999
(dashed)	2000-5999
(dense dots)	6000-9999
(horizontal lines)	10,000-19,999
(solid dark)	20,000+



Attachment C.
Figure 6-C-2
Total Agricultural Water Use; Projections to 2000: Chesapeake Bay Study.

Million Gallons

- 0-1999
- 2000-5999
- 6000-9999
- 10,000-19,999
- 20,000+



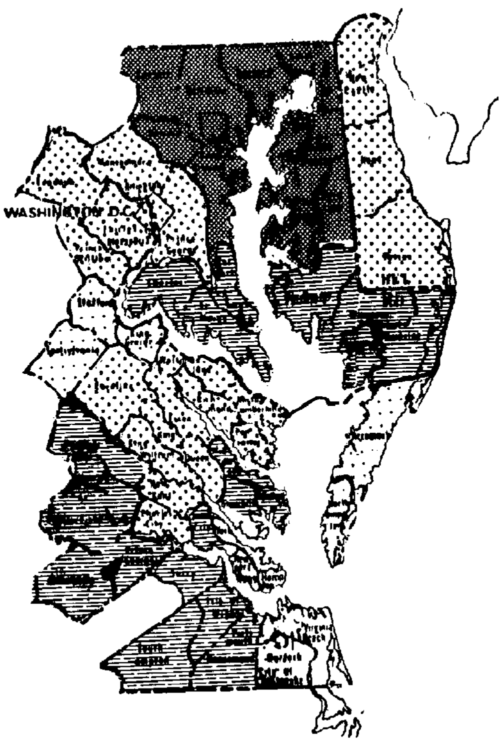
Attachment C.
Figure 6-C-3
Total Agricultural Water Use; Projections to 2020: Chesapeake Bay Study.

Million Gallons

	0-1999
	2000-5999
	6000-9999
	10,000-19,999
	20,000+

Attachment C.
Figure 6-C-4
Annual Domestic Water, Farm Population. Projections to 1980, 2000, and 2020: Chesapeake Bay Study.

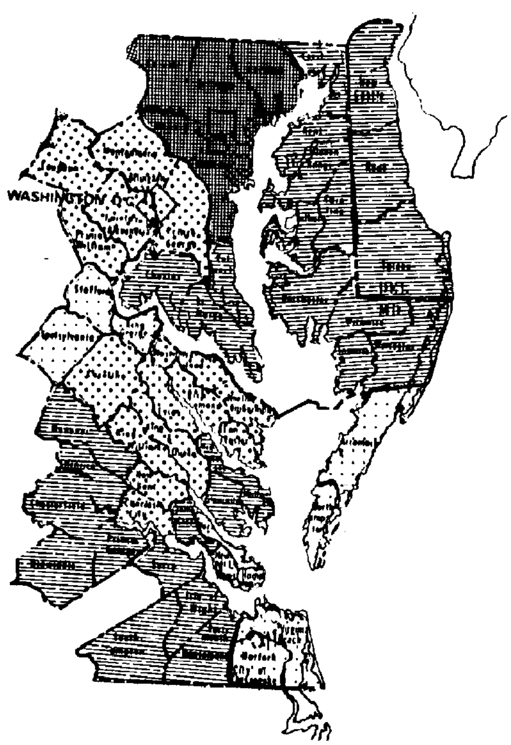
1980



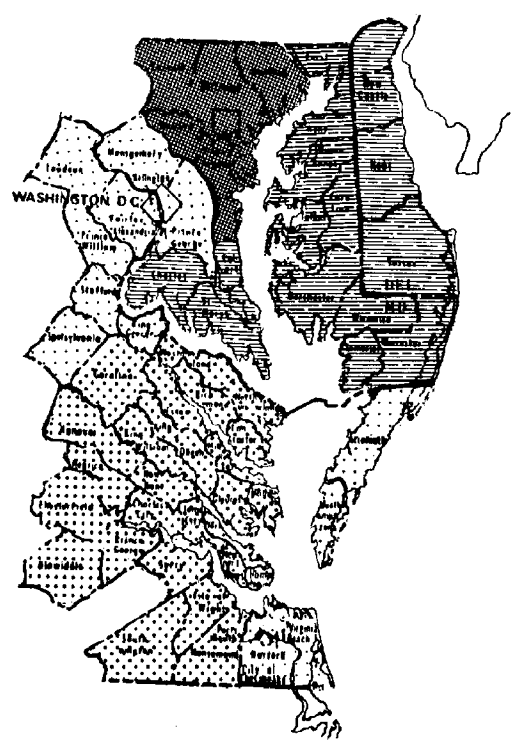
Million Gallons

(light stipple)	0-40.9
(dotted)	41-99.9
(lined)	100-159.9
(dark)	160+

2000

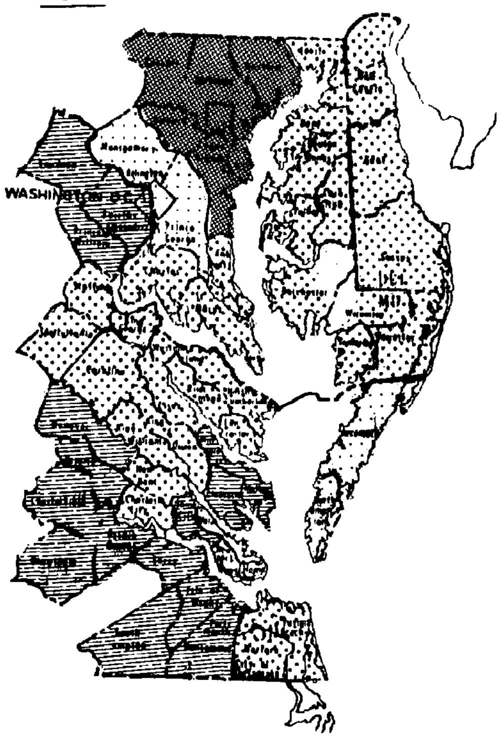


2020



Attachment C.
Figure 6-C-5
Annual Domestic Water Use, Non-Farm Residual Population. Projections to 1980, 2000, and 2020: Chesapeake Bay Study.

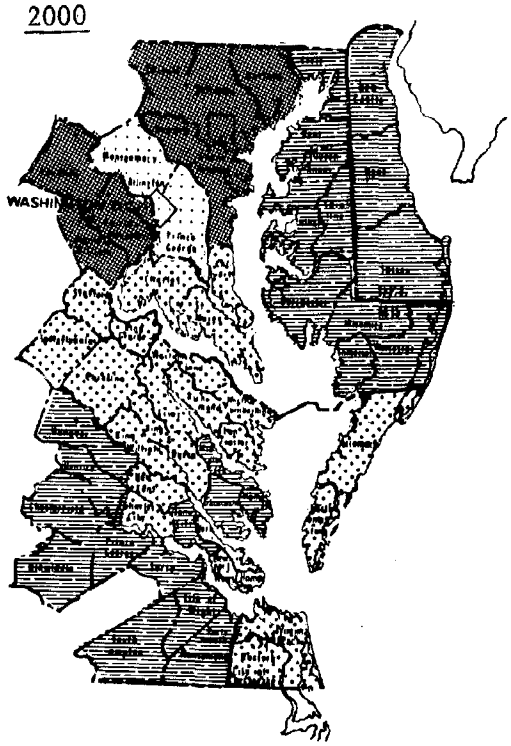
1980



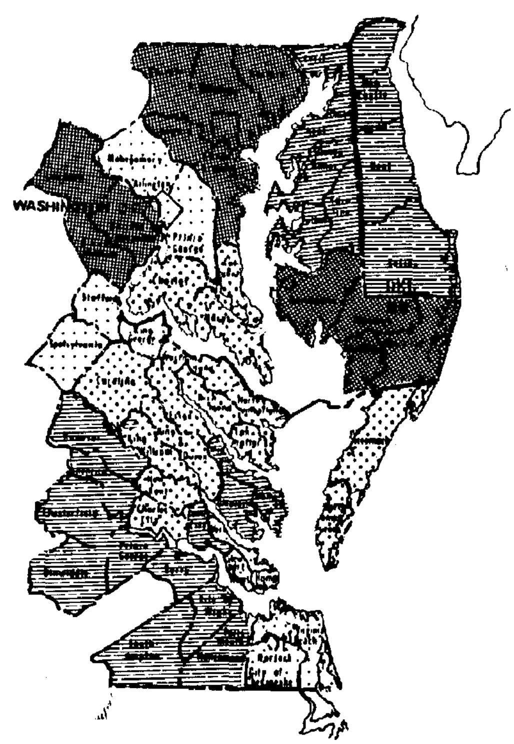
Million Gallons

(light dots)	0-999
(dense dots)	1000-2499
(horizontal lines)	2500-3999
(dark crosshatch)	4000+

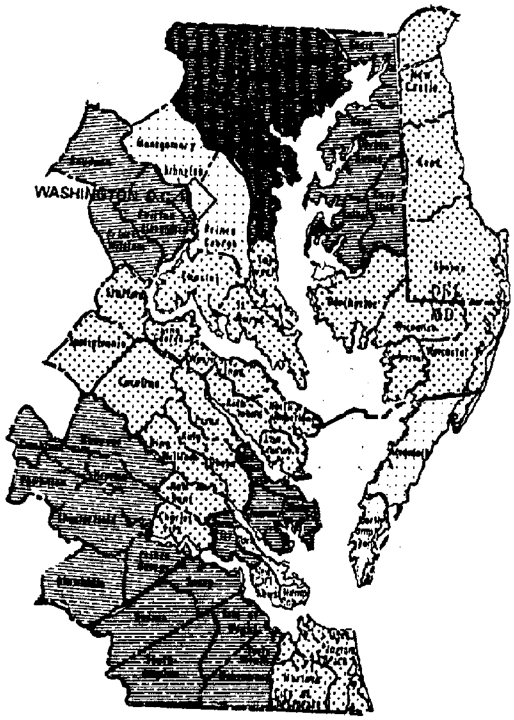
2000



2020

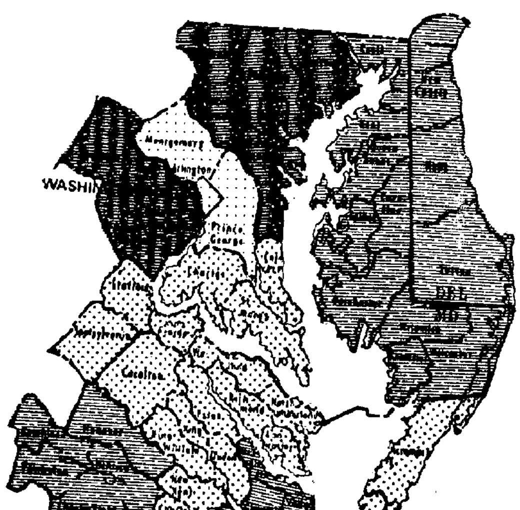


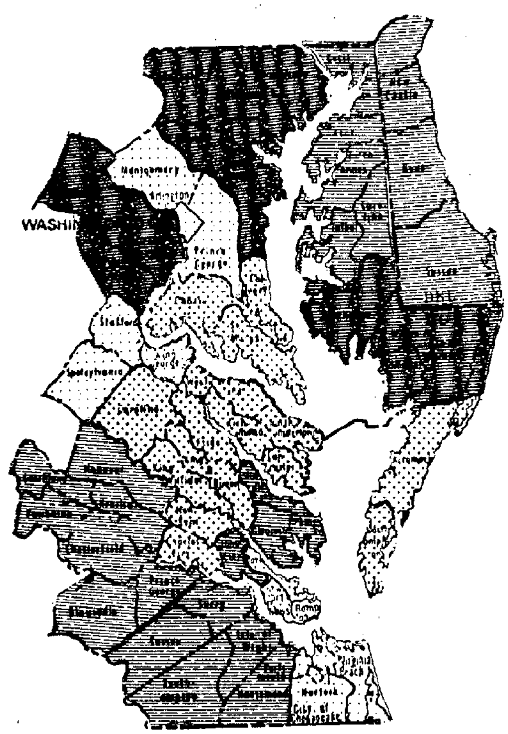
Attachment C.
Figure 6-C-6
Annual Domestic Water Use, Residual Population. Projections to 1980, 2000, and 2020: Chesapeake Bay Study.



Million Gallons

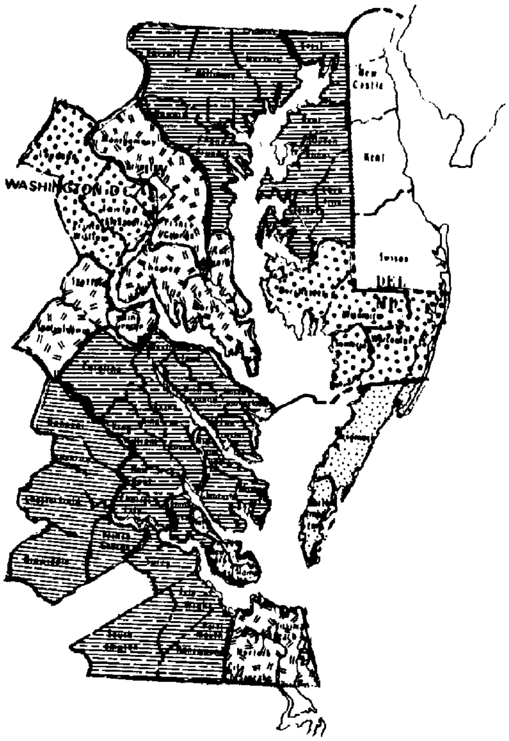
- 0-999
- 1,000-2,499
- 2,500-3,999
- 4,000+





Attachment C.
Figure 6-C-7
Livestock Numbers[1/], Projections to 1980, 2000, and 2020: Chesapeake Bay Study.

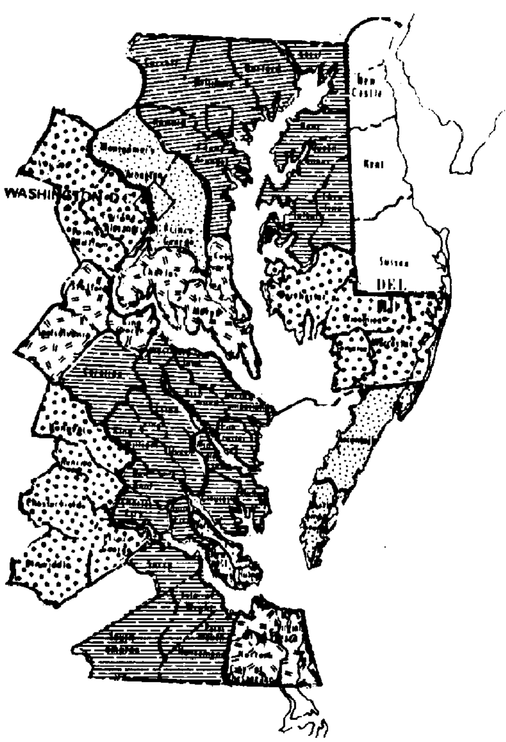
1980



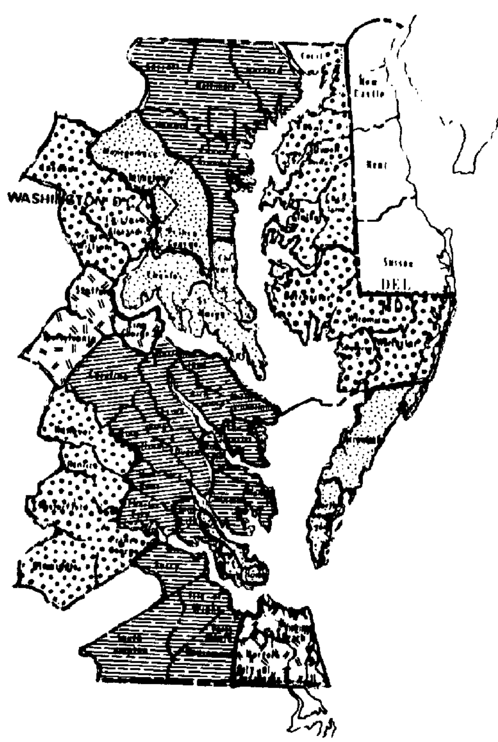
(fine dots)	0-29,999
(dashes)	30,000-59,999
(coarse dots)	60,000-99,999
(horizontal lines)	1000,000+

1/ Excludes milk cows, poultry; includes backup herds.

2000

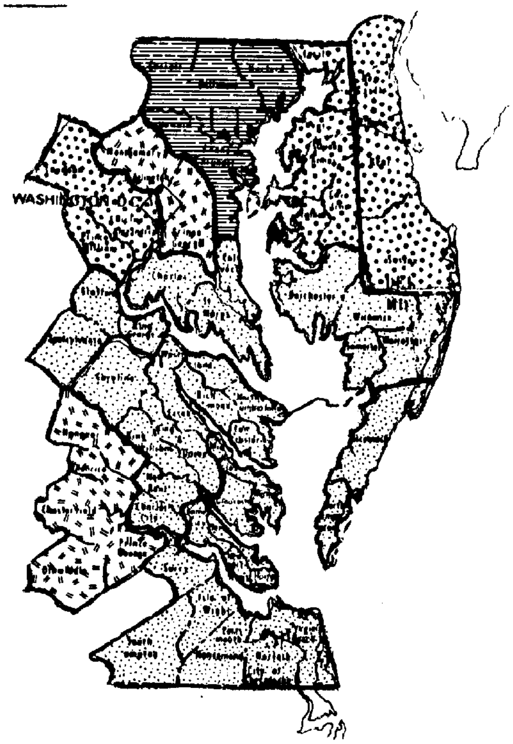


2020



Attachment C.
Figure 6-C-8
Milk Cow Numbers[1/],
Projections to 1980,
2000, and 2020:
Chesapeake Bay Study.

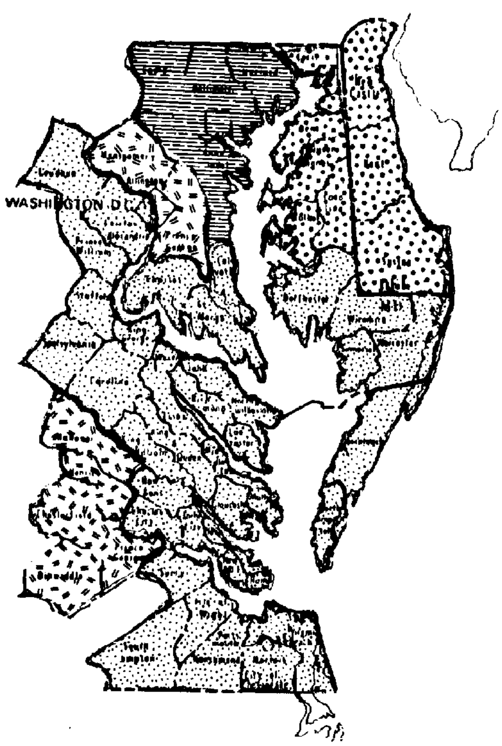
1980



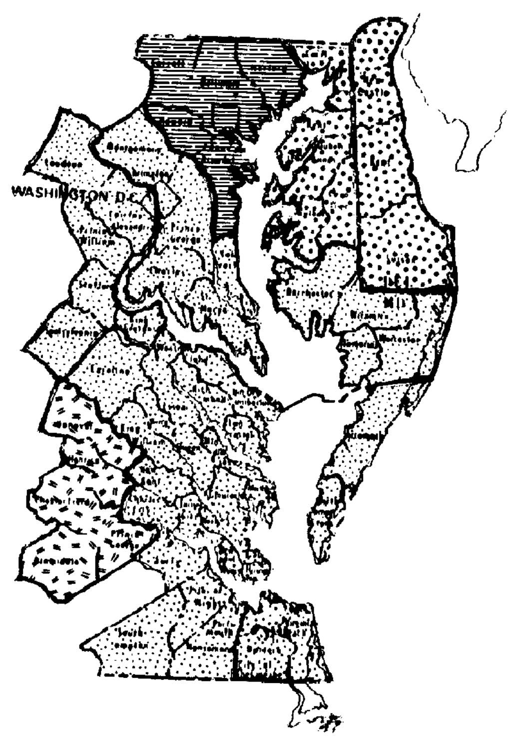
- 1-4999
- 5000-9999
- 10,000-49,999
- 50,000+

1/ Includes backup herd

2000

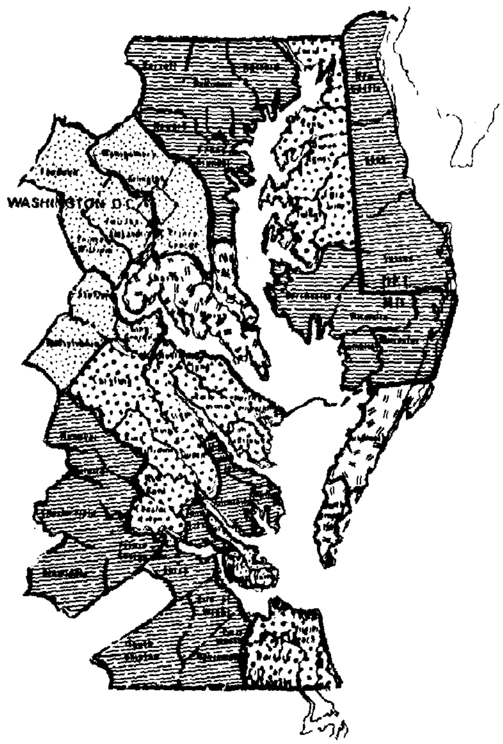


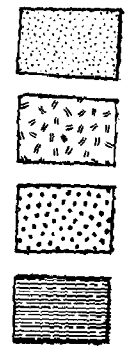
2020



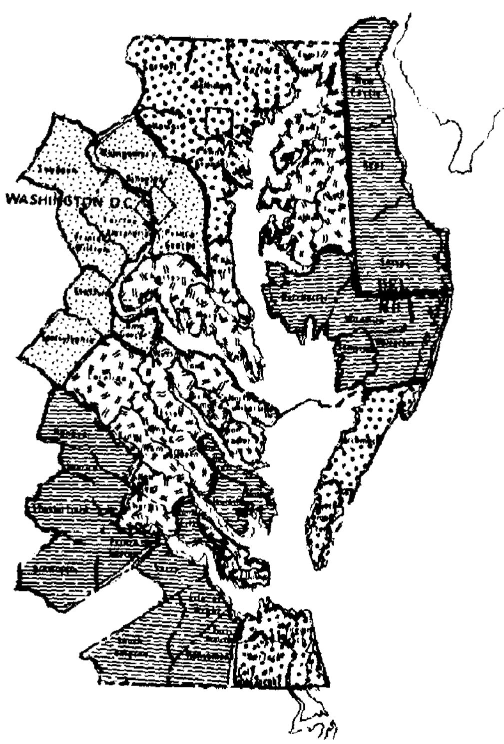
Attachment C.
Figure 6-C-9
Poultry Numbers. Projections to 1980, 2000, and 2020: Chesapeake Bay Study.

1980

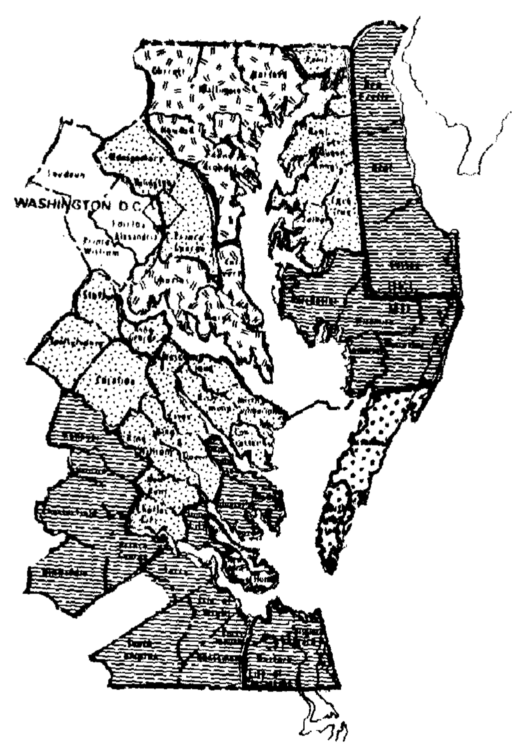




2000

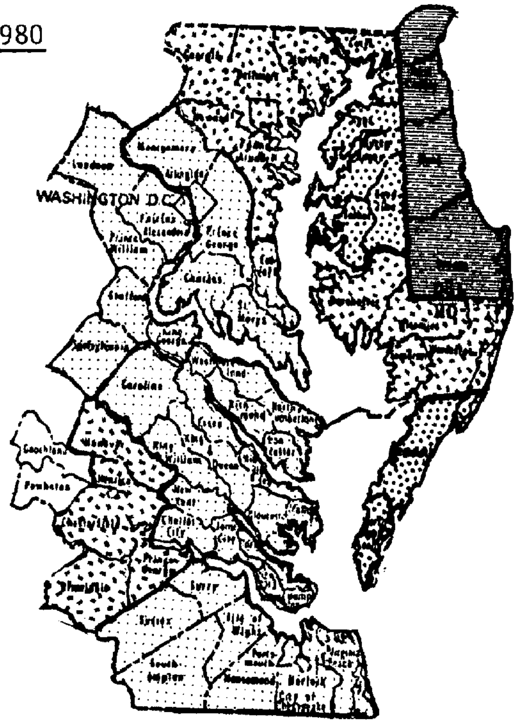


2020



Attachment C.
Figure 6-C-10
Total Irrigated Acreage; Projections to 1980, 2000, and 2020: Chesapeake Bay Study.

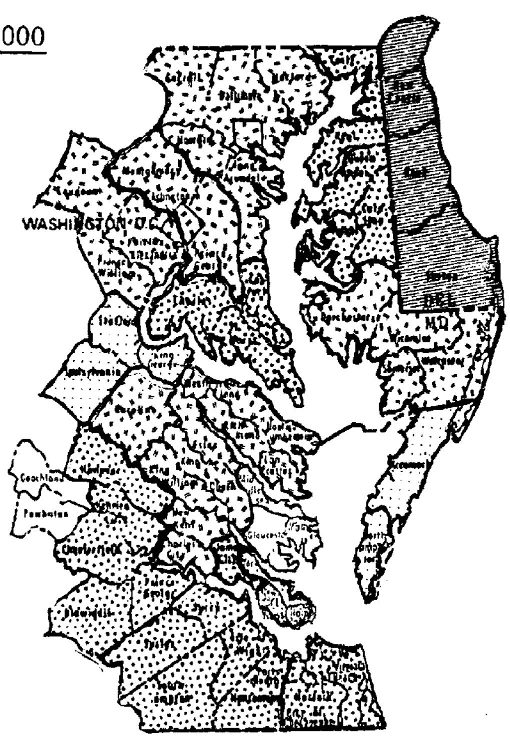
1980



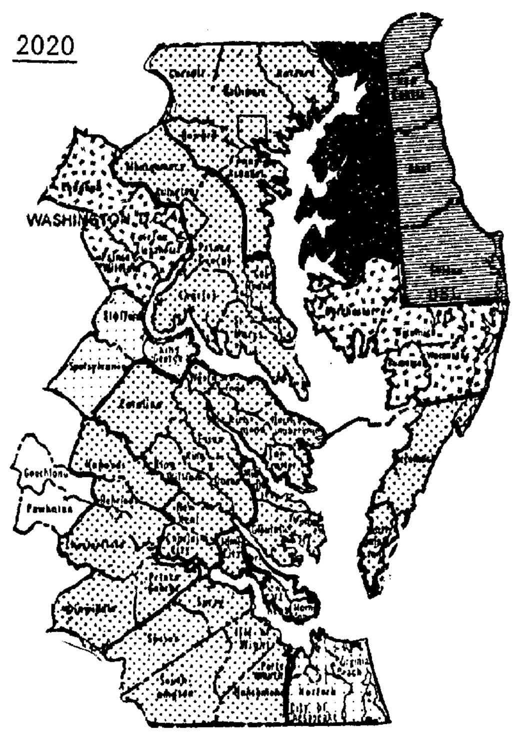
Acres

- 1-4999
- 5000-9999
- 10,000-49,999
- 50,000-99,999
- 100,000+

2000

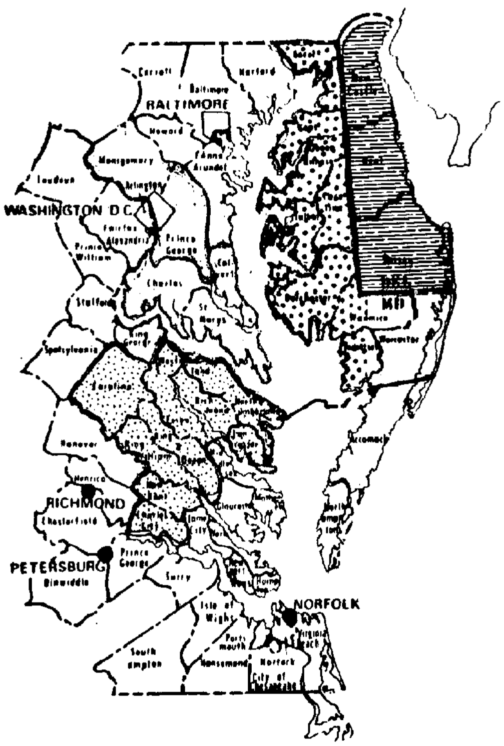


2020



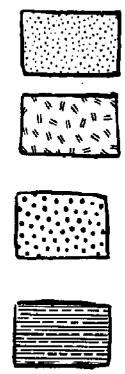
Attachment C.
Figure 6-C-11
Irrigated Acreage, Food Grains. Projections to 1980, 2000, and 2020: Chesapeake Bay Study.

1980



KEY

Acres



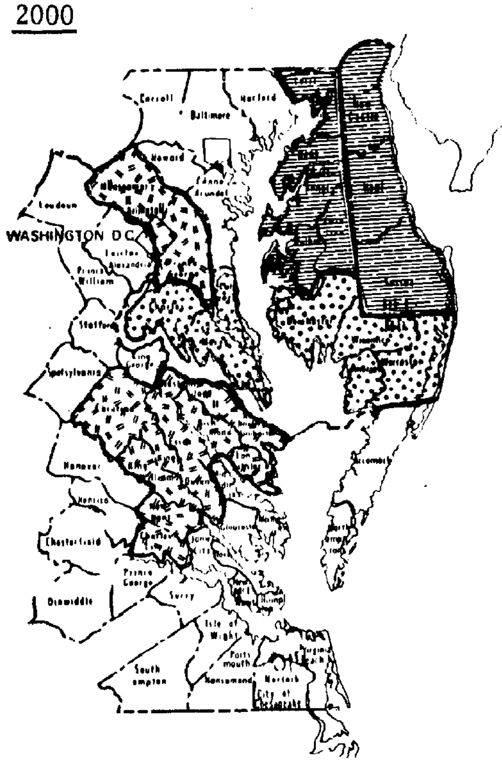
1-499

500-999

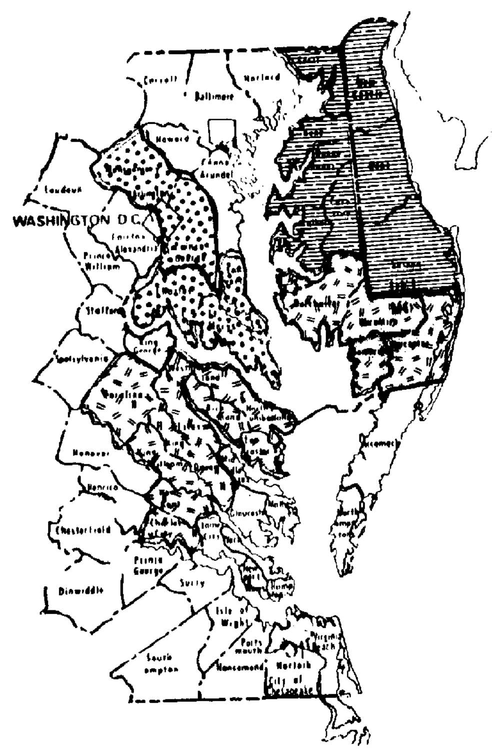
1000-4999

5000+

2000

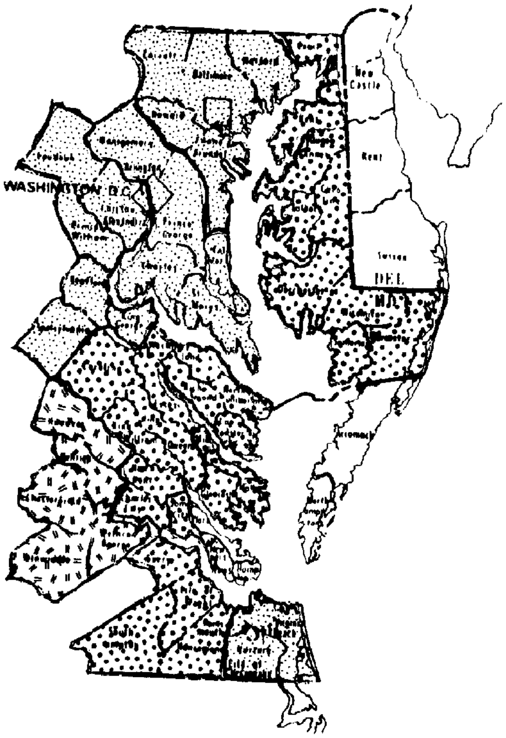


2020



Attachment C.
Figure 6-C-12
Irrigated Acreage, Feed Grains. Projections to 1980, 2000, and 2020: Chesapeake Bay Study.

1980

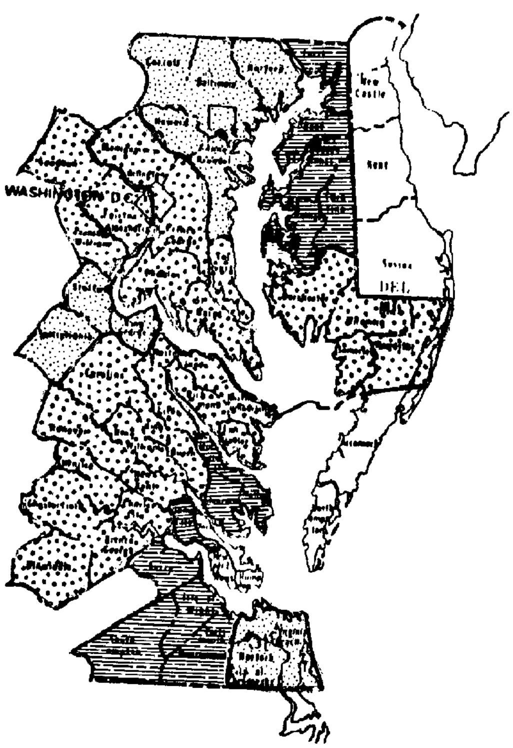


KEY

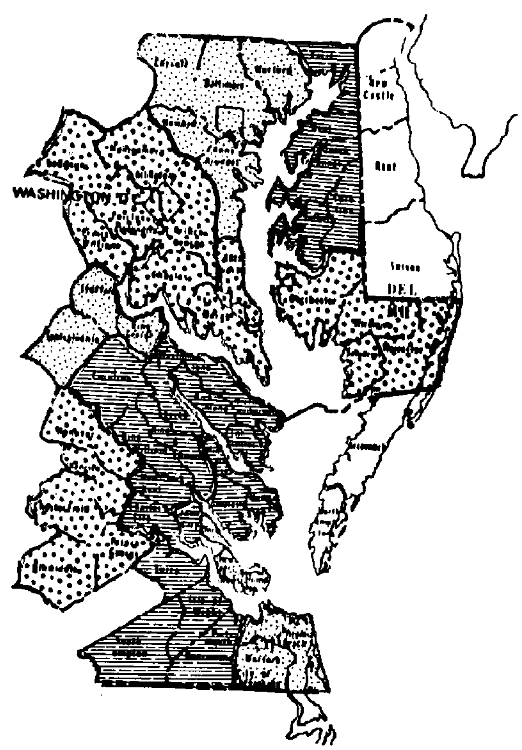
Acres

- 1-799
- 800-999
- 1000-4999
- 5000+

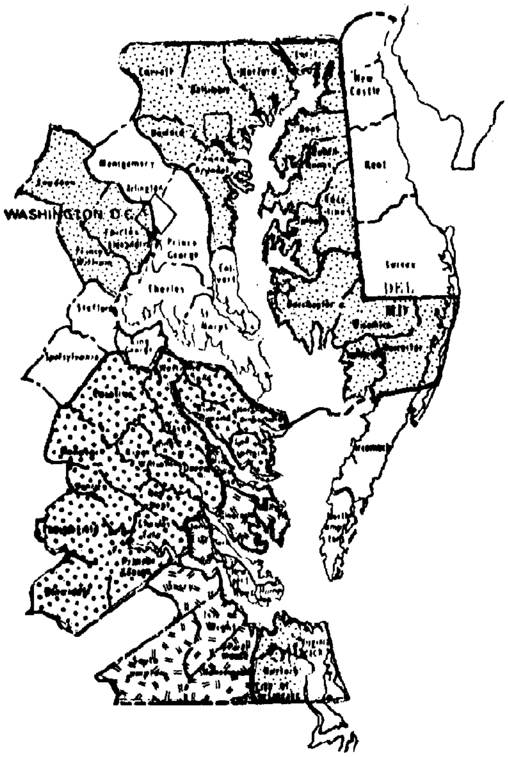
2000



2020



1980

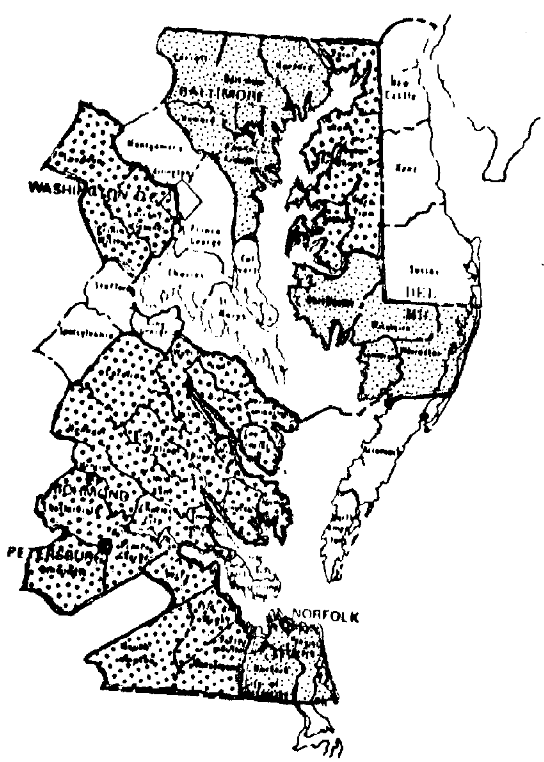


Attachment C.
Figure 6-C-13
Irrigated Acreage, Roughage, Projections to 1980, 2000, and 2020: Chesapeake Bay Study

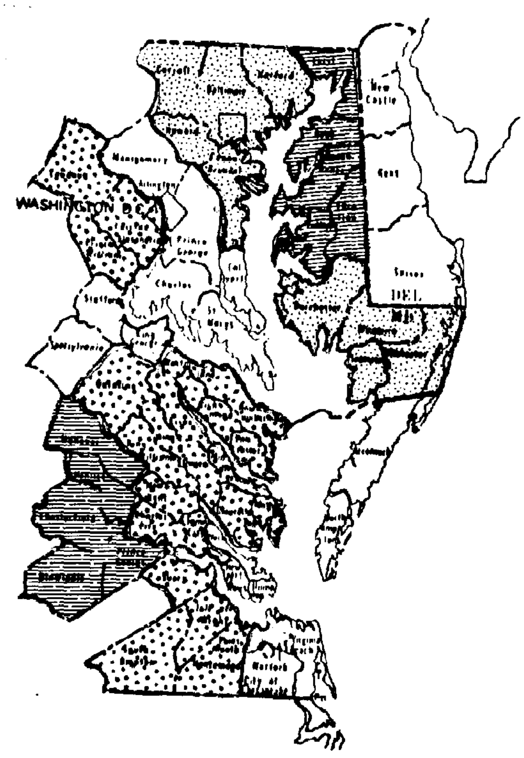
KEY

Acres	
	1-499
	500-999
	1000-4999
	5000+

2000



2020



Attachment D:

Fertilizer and Livestock Waste Impacts --Tables.

Attachment D.

Table 6-D-1--Recommended per acre application rates, fertilizer, herbicide and insecticide by crop and yield, Chesapeake Bay Study

Crop	Yield	N	P_2O_5	K_2O	Lime	Herbicide 1/	Insecticide 1/
		Pounds					
Wheat	35 bu.	50	60	60	667	0	0
	50-60 bu.	100	70	70	667	0	0
Rye	30 bu.	50	60	70	667	0	0
Corn	75 bu.	85	60	60	667	2½	0
	100 bu.	110	80	80	667	2½	0
	125 bu.	135	100	100	1,000	2½	0
	150 bu.	160	120	120	1,000	2½	0
Silage	12 tons	90	60	90	667	2½	0
	15 tons	112	75	112	1,000	2½	0
	20 tons	150	150	150	1,000	2½	0
Sorghum	*	90	60	60	667	0	0
Oats	50 bu.	40	50	50	500	0	0
	55 bu.	50	60	60	500	0	0
Barley	50 bu.	50	60	60	667	0	0
Fruits and nuts 2/							
Del.		40	41	40	0	24	9
Md.		78	94	25	0	24	9
Va.		244	58	53	0	24	9
Vegetables 2/							
Del.		35	71	70	0	8	5
Md.		86	101	100	0	8	5
Va.		30	51	70	0	8	5
Hay	1-1.5 tons	20	40	40	0	0	0
Soybeans	25-30 bu.	10	50	50	1,000	1	0
Peanuts	*	0	0	31	0	7	3
Tobacco	1100 lbs.	40	80	160	500	0	0
	1300-1400 lbs.	60	120	240	500	0	0
Irish potatoes	175 cwt.	150	200	200	0	16	6
Sweet potatoes	350 bu.	75	150	300	250	11	4

*Yield unspecified.

1/ Pounds of active ingredients.

2/ For fruits and nuts and vegetables, aggregate application rates were determined from historical use by appropriate state subregion, as listed in Fertilizer Use in the United States, By Crops and Areas, 1964 Estimates, Statistical Bulletin No. 408, USDA. 1967.

Source: Farm Data Manual, Planning Data for Farming in Maryland, Information Series Number 6, Cooperative Extension Service, University of Maryland. 1970.

Attachment D.

Table 6-D-2--Annual Fertilizer Requirements, Chesapeake Bay Study: 1970, 1980, 2000, and 2020.

State and Subarea	1970	1980		2000		2020	
	Requirement	Requirement	Percent Change 1/	Requirement	Percent Change 1/	Requirement	Percent Change 1/
	Tons	Tons		Tons		Tons	
CHESAPEAKE BAY							
N	63,750.9	72,569.8	13.8	74,383.4	16.7	77,582.4	21.7
P_2O_5	68,716.5	78,307.3	14.0	76,906.1	11.9	78,758.1	14.6
K_2O	73,223.7	83,487.0	14.0	86,279.6	17.8	82,485.1	12.6
Lime	711,012.3	763,947.9	7.4	765,825.6	7.7	736,763.5	3.6
Herbicide 2/	2,514.5	2,494.9	-0.8	2,067.1	-17.8	1,898.8	-24.5
Insecticide 2/	589.7	573.6	-2.7	434.9	-26.3	366.0	-37.9
DELAWARE							
N	10,971.0	9,375.1	-14.5	10,189.8	-7.1	10,399.0	-5.2
P_2O_5	12,824.8	12,824.1	0.0	13,163.2	2.6	13,351.8	4.1
K_2O	12,954.9	13,059.0	0.8	13,415.4	3.6	13,329.9	2.9
Lime	146,309.2	143,266.7	-2.1	150,366.7	2.8	140,900.0	-3.7
Herbicide 2/	523.8	462.3	-11.7	469.6	-10.3	477.2	-8.9
Insecticide 2/	133.5	152.4	14.2	159.1	19.2	168.3	26.1
MARYLAND							
Study Area							
N	31,252.1	42,268.8	35.3	47,713.9	52.7	53,436.7	71.0
P_2O_5	31,067.4	39,288.0	26.5	42,295.7	36.1	46,574.7	49.9
K_2O	32,836.9	41,526.5	26.5	46,087.3	40.4	48,770.3	48.5
Lime	309,892.1	344,821.9	11.3	388,127.2	25.2	397,790.6	28.4
Herbicide 2/	984.7	1,068.0	8.5	944.1	-4.1	923.0	-6.3
Insecticide 2/	190.8	165.2	-13.4	106.9	-44.0	74.0	-61.2
Subarea 1							
N	7,036.8	8,318.4	18.2	6,630.9	-5.8	5,947.2	-15.5
P_2O_5	6,768.0	7,666.9	13.3	6,162.4	-8.9	5,516.4	-18.5
K_2O	7,270.9	8,271.3	13.8	6,958.3	-4.3	6,323.1	-13.0
Lime	51,250.4	49,061.5	-4.3	41,603.1	-18.8	41,253.1	-19.5
Herbicide 2/	211.1	199.4	-5.5	149.7	-29.1	119.8	-43.2
Insecticide 2/	51.4	44.4	-13.6	29.7	-42.2	20.4	-60.3
Subarea 2							
N	13,206.8	19,578.4	48.2	22,977.5	74.0	28,917.1	119.0
P_2O_5	12,206.6	17,115.3	40.2	19,400.4	58.9	24,461.7	100.4
K_2O	12,435.0	17,524.7	40.9	19,886.1	59.9	24,492.3	97.0
Lime	126,873.7	155,137.5	22.3	198,770.8	56.7	211,625.0	66.8
Herbicide 2/	395.9	480.2	21.3	469.4	18.6	489.6	23.7
Insecticide 2/	74.8	70.6	-5.6	50.8	-32.1	36.7	-50.9
Subarea 3							
N	7,561.7	11,026.4	45.8	15,153.2	100.4	16,266.7	115.1
P_2O_5	8,270.9	10,554.2	27.6	13,086.2	58.2	13,515.8	63.4
K_2O	8,441.2	10,765.9	27.5	13,688.5	62.2	13,715.3	62.5
Lime	98,700.8	106,541.7	7.9	122,078.3	23.7	122,864.6	24.5
Herbicide 2/	296.2	316.1	6.7	279.4	-5.7	279.6	-5.6
Insecticide 2/	57.0	44.6	-21.8	23.4	-58.9	14.4	-74.7
Subarea 4							
N	1,707.4	1,511.4	-11.5	1,096.9	-35.8	718.2	-57.9
P_2O_5	1,781.9	1,653.8	-7.2	1,160.6	-34.9	810.0	-54.5
K_2O	2,048.8	1,911.1	-6.7	1,336.4	-34.8	955.8	-53.3
Lime	14,175.0	12,819.8	-9.6	8,861.5	-37.5	6,228.1	-56.1
Herbicide 2/	43.2	36.1	-16.4	20.9	-51.6	13.2	-69.4
Insecticide 2/	6.1	4.5	-26.2	2.2	-63.9	1.3	-78.7
Subarea 5							
N	1,739.3	1,834.2	5.5	1,855.5	6.7	1,587.4	-8.7
P_2O_5	2,039.9	2,297.9	12.6	2,486.1	21.9	2,270.8	11.3
K_2O	2,641.1	3,053.6	15.6	4,218.0	59.7	3,283.7	24.3
Lime	18,892.1	21,261.5	12.5	16,813.5	-11.0	15,819.8	-16.3
Herbicide 2/	37.6	36.1	-4.0	24.7	-34.3	20.7	-44.9
Insecticide 2/	1.5	1.1	-26.7	0.8	-46.7	1.3	-13.3

Attachment D.

Table 6-D-2-- Annual Fertilizer Requirements, Chesapeake Bay Study: 1970, 1980, 2000, and 2020. (Cont.)

State and Subarea	1970 Requirement	1980 Requirement	1980 Percent Change 1/	2000 Requirement	2000 Percent Change 1/	2020 Requirement	2020 Percent Change 1/
	Tons	Tons		Tons		Tons	
VIRGINIA							
N	21,527.8	20,925.9	-2.8	16,479.6	-23.4	13,746.7	-36.1
P_2O_5	24,824.3	26,195.2	5.5	21,447.2	-13.6	18,831.6	-24.1
K_2O	27,431.9	28,901.5	5.4	26,776.8	-2.4	20,384.9	-25.7
Lime	254,811.0	275,859.4	8.3	227,331.7	-10.8	198,072.9	-22.3
Herbicide 2/	1,006.0	964.5	-4.1	653.5	-35.0	498.6	-50.4
Insecticide 2/	265.4	256.1	-3.5	168.9	-36.4	123.7	-53.4
Study Area 1							
N	3,515.8	3,090.4	-12.1	2,548.4	-27.5	2,218.7	-36.9
P_2O_5	5,396.8	5,331.1	-1.2	4,659.3	-13.7	4,350.4	-19.4
K_2O	6,371.4	6,214.7	-2.5	5,666.7	-11.1	5,142.7	-19.3
Lime	25,265.4	38,175.0	51.1	39,323.7	55.6	41,743.7	65.2
Herbicide 2/	378.8	323.8	-14.5	251.2	-33.7	212.4	-43.9
Insecticide 2/	160.2	133.4	-16.7	97.8	-39.0	77.5	-51.6
Study Area 2							
N	2,159.0	1,889.4	-12.5	1,190.4	-44.9	898.4	-58.4
P_2O_5	2,112.3	2,072.4	-1.9	1,428.2	-32.4	1,136.6	-46.2
K_2O	2,324.1	2,216.0	-4.7	1,510.7	-35.0	1,176.7	-49.4
Lime	14,568.7	10,074.0	-30.9	5,929.2	-59.3	4,158.3	-71.5
Herbicide 2/	54.6	37.8	-30.8	21.2	-61.2	13.6	-75.1
Insecticide 2/	7.9	6.2	-21.5	4.8	-39.2	3.8	-51.9
Study Area 3							
N	916.0	953.4	4.1	932.4	1.8	1,110.7	21.3
P_2O_5	1,003.2	1,094.7	9.1	1,052.0	4.9	1,360.5	35.6
K_2O	1,062.0	1,187.8	11.8	1,167.8	10.0	1,361.6	28.2
Lime	9,099.4	9,194.8	1.0	7,975.0	-12.4	8,108.3	-10.9
Herbicide 2/	18.9	16.9	-10.6	13.5	-28.6	13.2	-30.2
Insecticide 2/	0.7	0.8	14.3	0.4	-42.9	0.4	-42.9
Study Area 4							
N	2,615.2	2,457.2	-6.0	2,329.1	-10.9	2,018.7	-22.8
P_2O_5	2,919.5	3,127.0	7.1	2,859.0	-2.1	2,489.7	-14.7
K_2O	3,369.6	3,568.5	5.9	3,306.3	-1.9	2,924.4	-13.2
Lime	31,608.7	35,969.8	13.8	32,936.5	4.2	28,883.3	-8.6
Herbicide 2/	84.4	93.0	10.2	72.9	-13.6	63.6	-24.6
Insecticide 2/	14.2	17.8	25.4	14.2	0.0	12.5	-12.0
Study Area 5							
N	5,961.3	6,057.6	1.6	4,933.2	-17.2	4,080.3	-31.6
P_2O_5	6,632.6	7,292.8	10.0	6,069.5	-8.5	5,079.4	-23.4
K_2O	6,752.1	7,449.2	10.3	8,779.7	30.0	5,098.3	-24.5
Lime	89,419.6	94,711.5	5.9	75,652.7	-15.4	63,264.6	-29.2
Herbicide 2/	157.3	146.1	-7.1	97.8	-37.8	69.5	-55.8
Insecticide 2/	8.6	6.2	-27.9	3.1	-64.0	1.5	-82.6
Study Area 6							
N	69.6	95.6	37.4	112.4	61.5	110.1	58.2
P_2O_5	73.7	94.1	27.7	126.5	71.6	134.6	82.6
K_2O	87.1	108.9	25.0	427.7	391.0	135.4	55.5
Lime	695.0	692.7	-0.3	210.2	-69.8	443.7	-36.2
Herbicide 2/	3.0	3.5	16.7	3.3	10.0	2.6	-13.3
Insecticide 2/	1.0	1.0	0.0	1.0	0.0	0.7	-30.0
Study Area 7							
N	2,297.3	2,090.2	-9.0	1,368.4	-40.4	900.7	-60.8
P_2O_5	2,563.1	2,229.1	-13.0	1,327.9	-48.2	836.9	-67.3
K_2O	2,638.4	2,257.1	-14.5	1,465.6	-44.5	841.7	-68.1
Lime	31,449.2	26,787.5	-14.8	13,320.2	-57.6	7,594.8	-75.9
Herbicide 2/	64.2	48.2	-24.9	24.0	-62.6	15.9	-75.2
Insecticide 2/	10.6	6.8	-35.8	3.4	-67.9	3.0	-71.7
Study Area 8							
N	3,993.6	4,292.1	7.5	3,065.3	-23.2	2,409.1	-39.7
P_2O_5	4,123.1	4,954.0	20.2	3,924.6	-4.8	3,443.4	-16.5
K_2O	4,827.2	5,899.3	22.2	4,452.5	-7.8	3,704.2	-23.3
Lime	52,705.0	60,254.2	14.3	51,984.4	-1.4	43,876.0	-16.8
Herbicide 2/	244.8	295.3	20.6	169.7	-30.7	107.8	-56.0
Insecticide 2/	62.2	84.0	35.0	44.2	-28.9	24.3	-60.9

1/ Percent changes from 1970 requirement.

2/ Herbicide and Insecticide measured in pounds of effective ingredients.

Attachment D.

Table 6-D-3-- Manure production and characteristics per 1000 pounds live weight1/

Item	Units	Dairy		Beef		Swine		Sheep	Poultry	
		Cow	Heifer	Stocker 400-700	Feeder over 700 lb.	Feeder	Breeder	Feeder	Layer	Broiler
Raw Waste (RW)2/	lb/day	82.	85.	90.	60.	65.	50.	40.	53.	71.
	Feces/Urine ratio	2.2	1.2	1.8	2.4	1.2		1.0		
Total Solids (TS)	lb/day	10.4	9.2	11.5	6.9	6.0	4.3	10.	13.4	17.1
	% of RW	12.7	10.8	12.8	11.6	9.2	8.6	25.	25.2	25.2
Volatile Solids	lb/day	8.6			5.9	4.8	3.2	8.5	9.4	12.0
	% of TS	82.5			85.	80.	75.	85.	70.	70.
BOD_5	lb/day	1.6			1.6	2.1	1.3	0.9	3.5	-
	% of TS	16.5			23.	33.	30.	9.0	27.0	-
COD	lb/day	9.1			6.6	5.7	5.2	11.8	12.0	-
	% of TS	88.0			95.	95.	90.	118.	90.	-
TKN	lb/day	.41	.31	.40	.34	.45		.45	.72	1.16
	% of TS	3.9	3.4	3.5	4.9	7.5		4.5	5.4	6.8
P	lb/day	.073	.036		.11	.15		.066	.28	.26
	% of TS	.7	3.9		1.6	2.5		.66	2.1	1.5
K	lb/day	.27			.25	.30		.32	.31	.36
	% of TS	2.6			3.6	4.9		3.2	2.3	2.1

1/ Actual values may vary from these values due to differences in ration, age, and management practices.

2/ Feces plus urine

Source: American Society of Agricultural Engineers, data adapted from Structures and Environment Committee 412 report AW-D-1, Revised 6-14-73.

Attachment D.

Table 6-D-4- Annual Livestock & Poultry, Wastes and Pollutants, Chesapeake Bay Study; 1970, 1980, 2000, and 2020. 1/

State and Subarea	1970	1980		2000		2020	
	Pollutant	Pollutant	Percent Change 1/	Pollutant	Percent Change 1/	Pollutant	Percent Change 1/
	Thousand Tons	Thousand Tons		Thousand Tons		Thousand Tons	
CHESAPEAKE BAY							
Raw Waste- - -	37,288.8	20,313.4	-45.5	18,854.0	-49.4	18,885.0	-49.4
Total Solids -	4,478.6	2,468.2	-44.9	2,292.5	-48.8	2,304.0	-48.6
Volatile Solids	2,429.9	1,189.6	-51.0	1,073.0	-55.8	1,059.2	-56.4
BOD_5 - - - - -	635.1	302.1	-52.4	270.5	-57.4	261.7	-58.8
COD- - - - - -	2,710.5	1,321.9	-51.2	1,189.7	-56.1	1,169.7	-56.8
TKN- - - - - -	193.8	103.3	-46.7	95.3	-50.8	94.8	-51.1
P- - - - - - -	41.2	18.3	-55.6	16.3	-60.4	15.7	-61.9
K- - - - - - -	96.7	45.0	-53.5	40.4	-58.2	39.4	-59.3
DELAWARE							
Raw Waste- - -	2,846.2	1,555.2	-45.4	1,159.8	-59.3	870.0	-69.4
Total Solids -	348.9	193.9	-44.4	143.1	-59.0	106.7	-69.4
Volatile Solids	202.8	118.5	-41.6	95.4	-53.0	72.2	-64.4
BOD_5 - - - - -	54.1	30.7	-43.3	25.0	-53.8	20.0	-63.0
COD- - - - - -	227.5	132.3	-41.8	106.4	-53.2	81.2	-64.3
TKN- - - - - -	15.4	8.6	-44.2	6.5	-57.8	5.0	-67.5
P- - - - - - -	3.5	1.9	-45.7	1.5	-57.1	1.3	-62.9
K- - - - - - -	7.9	4.4	-44.3	3.5	-55.7	2.8	-64.6
MARYLAND							
Raw Waste- - -	20,585.8	11,071.3	-46.2	10,584.5	-48.6	10,805.0	-47.5
Total Solids -	2,486.0	1,350.7	-45.7	1,289.0	-48.1	1,315.7	-47.1
Volatile Solids	1,321.8	672.4	-49.1	642.4	-51.4	675.4	-48.9
BOD_5 - - - - -	331.9	153.6	-53.7	142.3	-57.1	144.5	-56.5
COD- - - - - -	1,464.6	733.5	-49.9	696.4	-52.5	727.9	-50.3
TKN- - - - - -	105.3	54.5	-48.2	51.5	-51.1	52.0	-50.6
P- - - - - - -	21.3	8.9	-58.2	8.0	-62.4	8.0	-62.4
K- - - - - - -	51.3	23.9	-53.4	22.5	-56.1	23.2	-54.8
Study Area 1							
Raw Waste- - -	10,745.8	5,788.3	-46.1	6,060.9	-43.6	6,703.1	-37.6
Total Solids -	1,307.3	714.8	-45.3	747.8	-42.8	825.9	-36.8
Volatile Solids	671.7	337.5	-49.8	353.7	-47.3	407.9	-39.3
BOD_5 - - - - -	162.3	72.0	-55.6	72.0	-55.6	80.6	-50.3
COD- - - - - -	739.2	364.8	-50.6	379.2	-48.7	435.3	-41.1
TKN- - - - - -	54.1	27.9	-48.4	28.7	-47.0	31.5	-41.8
P- - - - - - -	10.3	4.0	-61.2	3.9	-62.1	4.3	-58.3
K- - - - - - -	25.5	11.5	-54.9	11.8	-53.7	13.3	-47.8
Study Area 2							
Raw Waste- - -	5,564.5	3,167.2	-43.1	2,800.2	-49.7	2,618.2	-52.9
Total Solids -	664.7	381.7	-42.6	336.3	-49.4	314.1	-52.7
Volatile Solids	374.3	212.0	-43.4	192.3	-48.6	186.5	-50.2
BOD_5 - - - - -	92.7	47.4	-48.9	42.4	-54.3	40.3	-56.5
COD- - - - - -	413.5	230.6	-44.2	208.5	-49.6	201.5	-51.3
TKN- - - - - -	28.3	15.5	-45.2	13.7	-51.6	12.7	-55.1
P- - - - - - -	5.8	2.7	-53.4	2.3	-60.3	2.2	-62.1
K- - - - - - -	14.4	7.5	-47.9	6.7	-53.5	6.4	-55.6
Study Area 3							
Raw Waste- - -	1,212.8	726.2	-40.1	690.7	-43.0	649.6	-46.4
Total Solids -	146.7	85.4	-41.8	79.9	-45.5	74.7	-49.1
Volatile Solids	89.4	46.2	-48.3	41.1	-54.0	36.3	-59.4
BOD_5 - - - - -	28.3	15.1	-46.6	14.1	-50.2	12.6	-55.5
COD- - - - - -	104.1	53.3	-48.8	47.5	-54.4	41.8	-59.8
TKN- - - - - -	7.2	4.2	-41.7	4.0	-44.4	3.7	-48.6
P- - - - - - -	1.9	1.0	-47.4	0.9	-52.6	0.9	-52.6
K- - - - - - -	3.8	2.0	-47.4	1.9	-50.0	1.7	-55.3

Attachment D.

Table 6-D-4- Annual Livestock & Poultry, Wastes and Pollutants, Chesapeake Bay Study; 1970, 1980, 2000, and 2020. 1/ (Cont.)

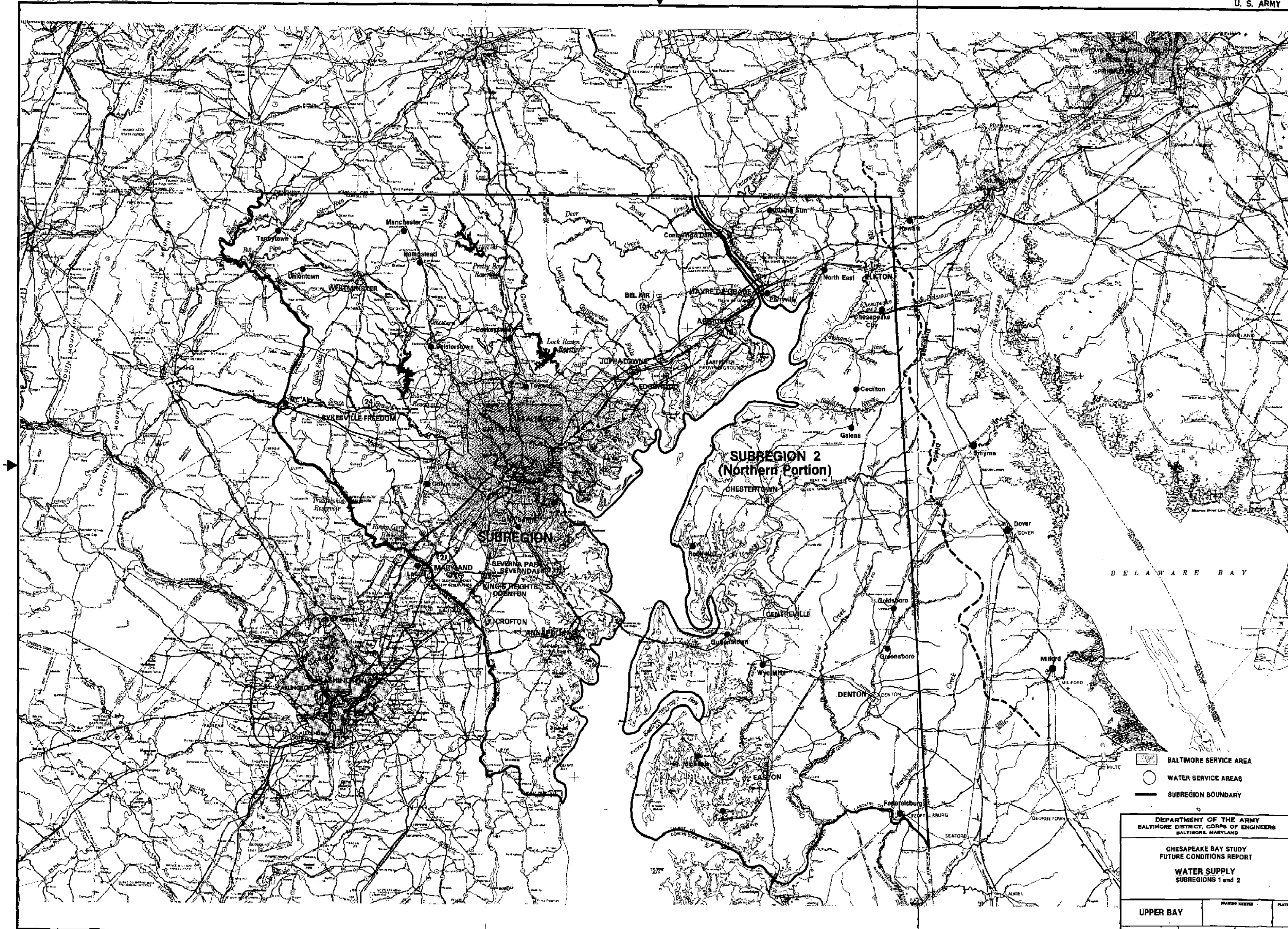
State and Subarea	1970 Pollutant	1980 Pollutant	1980 Percent Change 1/	2000 Pollutant	2000 Percent Change 1/	2020 Pollutant	2020 Percent Change 1/
	Thousand Tons	Thousand Tons		Thousand Tons		Thousand Tons	
Study Area 4							
Raw Waste	2,198.1	966.5	-56.0	616.1	-72.0	413.7	-81.2
Total Solids	265.1	118.2	-55.4	75.5	-71.5	50.8	-80.8
Volatile Solids	135.3	55.6	-58.9	34.8	-74.3	23.5	-82.6
BOD_5	33.5	12.3	-63.3	7.5	-77.6	4.9	-85.4
COD	149.4	60.3	-59.6	37.7	-74.8	25.4	-83.0
TKN	11.1	4.7	-57.7	3.0	-73.0	2.0	-82.0
P	2.2	0.7	-68.2	0.4	-81.8	0.3	-86.4
K	5.3	2.0	-62.3	1.2	-77.4	0.8	-84.9
Study Area 5							
Raw Waste	864.5	423.1	-51.1	416.6	-51.8	420.3	-51.4
Total Solids	102.1	50.6	-50.4	49.6	-51.4	50.1	-50.9
Volatile Solids	51.2	21.2	-58.6	20.5	-60.0	21.1	-58.8
BOD_5	15.1	6.7	-55.6	6.3	-58.3	6.1	-59.6
COD	58.3	24.5	-58.0	23.6	-59.5	23.9	-59.0
TKN	4.6	2.2	-52.2	2.2	-52.2	2.2	-52.2
P	1.0	0.4	-60.0	0.4	-60.0	0.4	-60.0
K	2.2	0.9	-59.1	0.9	-59.1	0.9	-59.1
VIRGINIA							
Raw Waste	13,856.8	7,686.9	-44.5	7,109.7	-48.7	7,209.9	-48.0
Total Solids	1,643.7	923.6	-43.8	860.4	-47.7	881.7	-46.4
Volatile Solids	905.3	398.7	-56.0	335.3	-63.0	311.7	-65.6
BOD_5	249.1	117.9	-52.7	103.2	-58.6	97.2	-61.0
COD	1,018.4	456.1	-55.2	386.8	-62.0	360.6	-64.6
TKN	73.1	40.2	-45.0	37.3	-49.0	37.7	-48.4
P	16.4	7.6	-53.7	6.7	-59.1	6.4	-61.0
K	37.6	16.7	-55.6	14.4	-61.7	13.4	-64.4
Study Area 1							
Raw Waste	264.3	156.2	-40.9	173.2	-34.5	195.3	-26.1
Total Solids	31.9	19.1	-40.1	21.4	-32.9	24.5	-23.2
Volatile Solids	18.0	8.0	-55.6	8.0	-55.6	8.1	-55.0
BOD_5	5.5	3.0	-45.5	3.1	-43.6	3.2	-41.8
COD	20.8	9.7	-53.4	9.8	-52.9	9.9	-52.4
TKN	1.5	0.9	-40.0	1.0	-33.3	1.1	-26.7
P	0.4	0.2	-50.0	0.2	-50.0	0.2	-50.0
K	0.8	0.4	-50.0	0.4	-50.0	0.4	-50.0
Study Area 2							
Raw Waste	4,369.0	2,011.9	-54.0	1,530.9	-65.0	1,263.1	-71.1
Total Solids	526.3	247.9	-52.9	189.9	-63.9	157.3	-70.1
Volatile Solids	272.1	84.8	-68.8	51.2	-81.2	35.8	-86.8
BOD_5	69.1	19.8	-71.3	12.4	-82.1	8.9	-87.1
COD	301.7	92.8	-69.2	56.3	-81.3	39.5	-86.9
TKN	22.3	9.6	-57.0	7.3	-67.3	6.0	-73.1
P	4.5	1.2	-73.3	0.8	-82.2	0.6	-86.7
K	10.9	3.2	-70.6	2.0	-81.7	1.4	-87.2
Study Area 3							
Raw Waste	1,230.7	643.8	-47.7	696.5	-43.4	798.3	-35.1
Total Solids	148.0	79.0	-46.6	86.3	-41.7	98.8	-33.2
Volatile Solids	79.2	28.1	-64.5	26.1	-67.0	26.0	-67.2
BOD_5	20.3	7.0	-65.5	6.5	-68.0	6.7	-67.0
COD	87.9	31.1	-64.6	29.0	-67.0	28.8	-67.2
TKN	6.3	3.1	-50.8	3.4	-46.0	3.8	-39.7
P	1.3	0.4	-69.2	0.4	-69.2	0.4	-69.2
K	3.2	1.1	-65.6	1.0	-68.8	1.0	-68.8

Attachment D.

Table 6-D-4-- Annual Livestock & Poultry, Wastes and Pollutants, Chesapeake Bay Study; 1970, 1980, 2000, and 2020. 1/ (Cont.)

State and Subarea	1970 Pollutant	1980 Pollutant	1980 Percent Change 1/	2000 Pollutant	2000 Percent Change 1/	2020 Pollutant	2020 Percent Change 1/
	Thousand Tons	Thousand Tons		Thousand Tons		Thousand Tons	
Study Area 4							
Raw Waste	2,658.8	1,293.7	-51.3	942.0	-64.6	773.3	-70.9
Total Solids	314.8	156.0	-50.4	112.5	-64.3	92.2	-70.7
Volatile Solids	178.9	79.9	-55.3	65.5	-63.4	59.6	-66.7
BOD_5	48.4	23.0	-52.5	19.3	-60.1	17.6	-63.6
COD	200.4	91.0	-54.6	75.0	-62.6	68.2	-66.0
TKN	14.0	7.0	-50.0	5.2	-62.9	4.4	-68.6
P	3.2	1.5	-53.1	1.2	-62.5	1.1	-65.6
K	7.3	3.2	-56.2	2.7	-63.0	2.4	-67.1
Study Area 5							
Raw Waste	2,092.0	1,185.5	-43.3	1,125.5	-46.2	1,071.6	-48.8
Total Solids	246.0	138.4	-43.7	129.4	-47.4	122.6	-50.2
Volatile Solids	139.2	63.2	-54.6	57.8	-58.5	53.8	-61.4
BOD_5	39.4	19.9	-49.5	18.7	-52.5	17.6	-55.3
COD	157.4	72.9	-53.7	66.8	-57.6	62.2	-60.5
TKN	11.2	6.3	-43.8	5.9	-47.3	5.6	-50.0
P	2.6	1.3	-50.0	1.2	-53.8	1.1	-57.7
K	5.9	2.8	-52.5	2.6	-55.9	2.5	-57.6
Study Area 6							
Raw Waste	143.3	165.0	15.1	220.7	54.0	298.1	108.0
Total Solids	17.6	21.0	19.3	28.3	60.8	38.2	117.0
Volatile Solids	8.5	10.1	18.8	12.3	44.7	15.5	82.4
BOD_5	2.2	2.2	0.0	2.7	22.7	3.3	50.0
COD	9.5	11.1	16.8	13.4	41.1	16.9	77.9
TKN	0.7	0.8	14.3	1.1	57.1	1.5	114.3
P	0.1	0.1	0.0	0.2	100.0	0.2	100.0
K	0.3	0.3	0.0	0.4	33.3	0.5	66.7
Study Area 7							
Raw Waste	737.9	481.9	-34.7	406.2	-45.0	359.8	-51.2
Total Solids	84.9	58.0	-31.7	49.7	-41.5	45.3	-46.6
Volatile Solids	51.7	32.1	-37.9	27.3	-47.2	25.2	-51.3
BOD_5	15.1	10.2	-32.5	9.5	-37.1	9.2	-39.1
COD	58.8	37.4	-36.4	32.5	-44.7	30.4	-48.3
TKN	4.0	2.8	-30.0	2.5	-37.5	2.3	-42.5
P	1.0	0.7	-30.0	0.6	-40.0	0.6	-40.0
K	2.2	1.4	-36.4	1.2	-45.5	1.1	-50.0
Study Area 8							
Raw Waste	2,360.6	1,748.7	-25.9	2,014.7	-14.7	2,450.4	3.8
Total Solids	274.3	204.1	-25.6	243.0	-11.4	302.8	10.4
Volatile Solids	157.7	92.4	-41.4	87.1	-44.8	87.7	-44.4
BOD_5	49.0	32.8	-33.1	31.1	-36.5	30.8	-37.1
COD	181.8	110.0	-39.5	104.0	-42.8	104.6	-42.5
TKN	13.1	9.7	-26.0	11.0	-16.0	13.0	-0.8
P	3.3	2.2	-33.3	2.1	-36.4	2.1	-36.4
K	7.0	4.3	-38.6	4.1	-41.4	4.0	-42.9

1/ Percent change from 1970 polluntants.


SUBREGION 2
(Northern Portion)
SUBREGION
BALTIMORE SERVICE AREA
WATER SERVICE AREAS
SUBREGION BOUNDARY
DEPARTMENT OF THE ARMY
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CHESAPEAKE BAY STUDY
FUTURE CONDITIONS REPORT
WATER SUPPLY
SUBREGIONS 1 and 2
UPPER BAY
D E L A W A R E   B A Y
Manchester
Hampstead
Taneytown
Uniontown
WESTMINSTER
BEL AIR
HAVRE DE GRACE
ABERDEEN
North East
ELKTON
Chesapeake City
Cecilton
Galena
CHESTERTOWN
JOPPATOWNE
EDGEWOOD
SYKESVILLE-FREEDOM
Mt. Airy
Columbia
SEVERNA PARK
SEVERNDALE
KINGS HEIGHTS
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Smyrna
Dover
Milford

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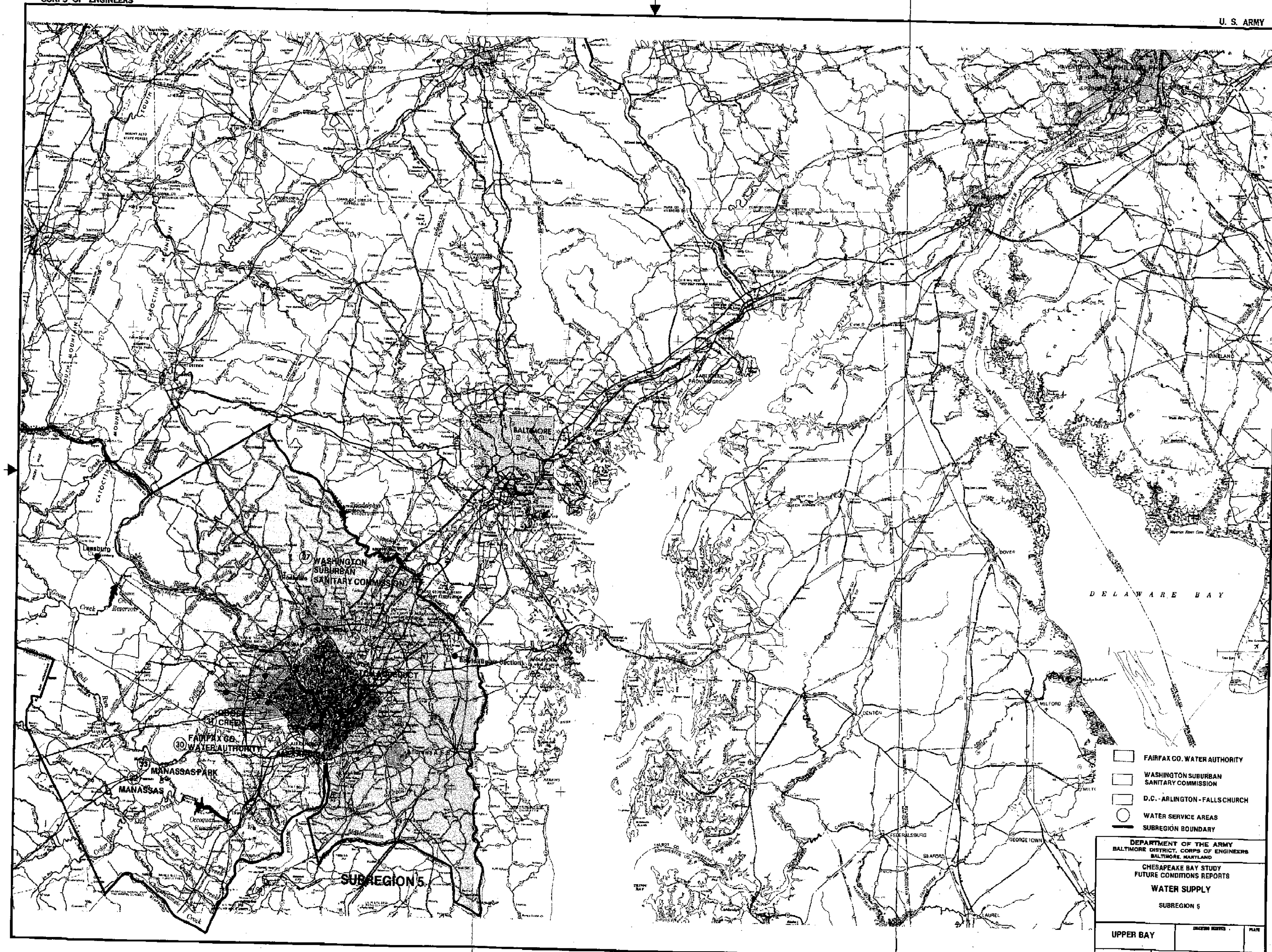

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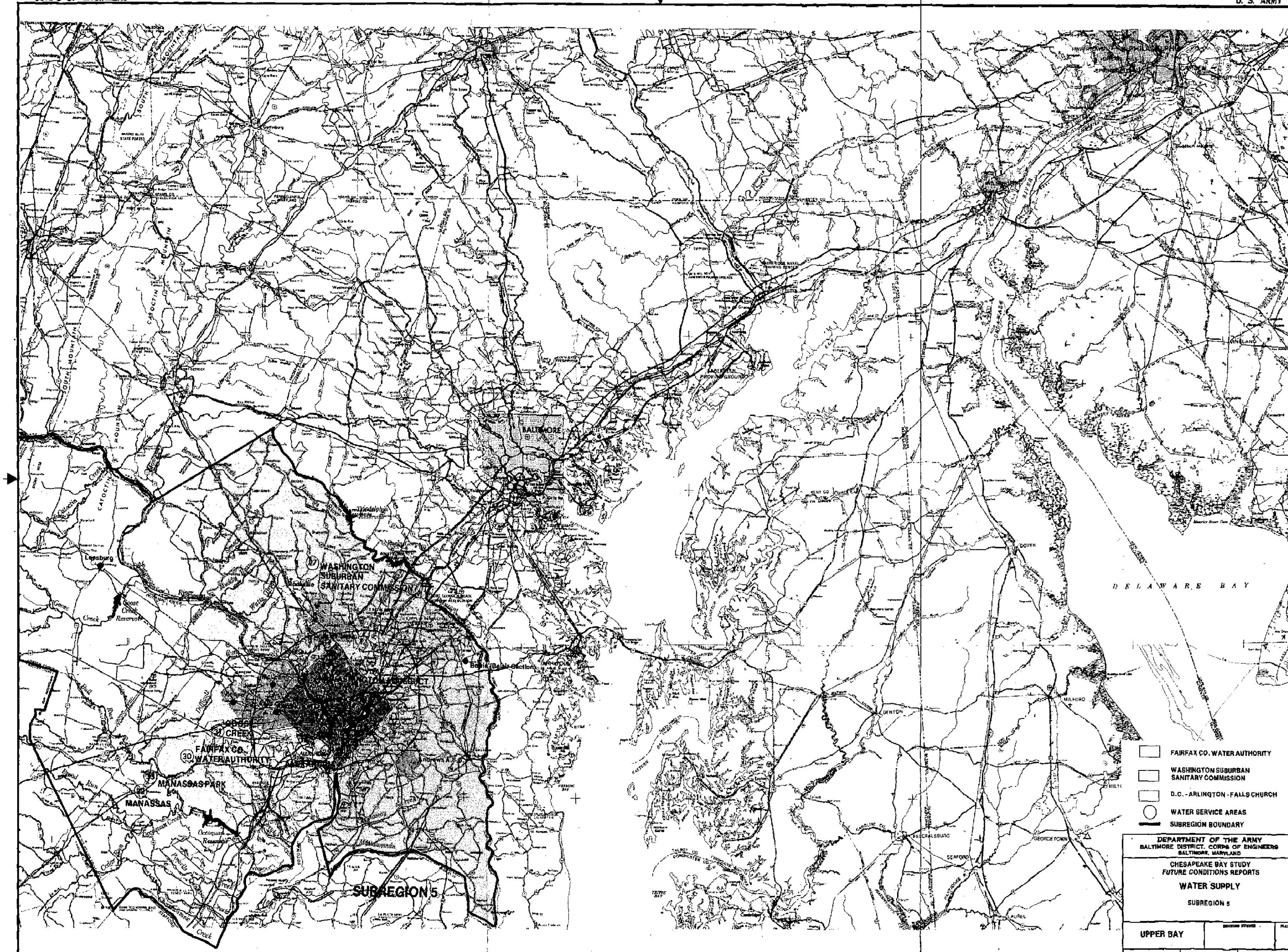
CHESAPEAKE BAY STUDY
FUTURE CONDITIONS REPORTS

WATER SUPPLY

SUBREGION 5

UPPER BAY

PLATE 5-2



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FUTURE CONDITIONS REPORTS
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SUBREGION 5

UPPER BAY

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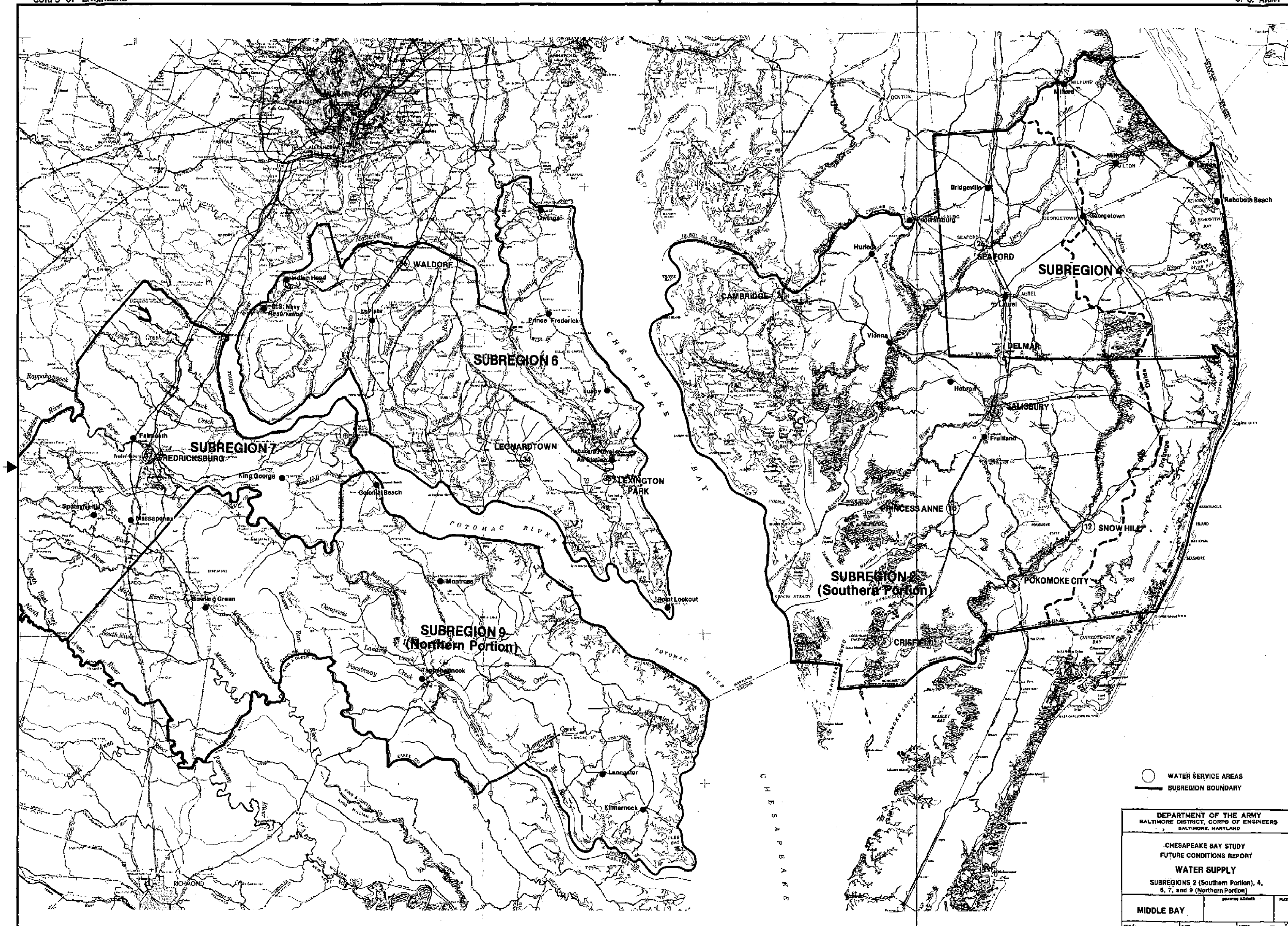

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CHESAPEAKE BAY STUDY
FUTURE CONDITIONS REPORT
WATER SUPPLY
SUBREGIONS 2 (Southern Portion), 4, 6, 7, and 9 (Northern Portion)

MIDDLE BAY

PLATE 5-3

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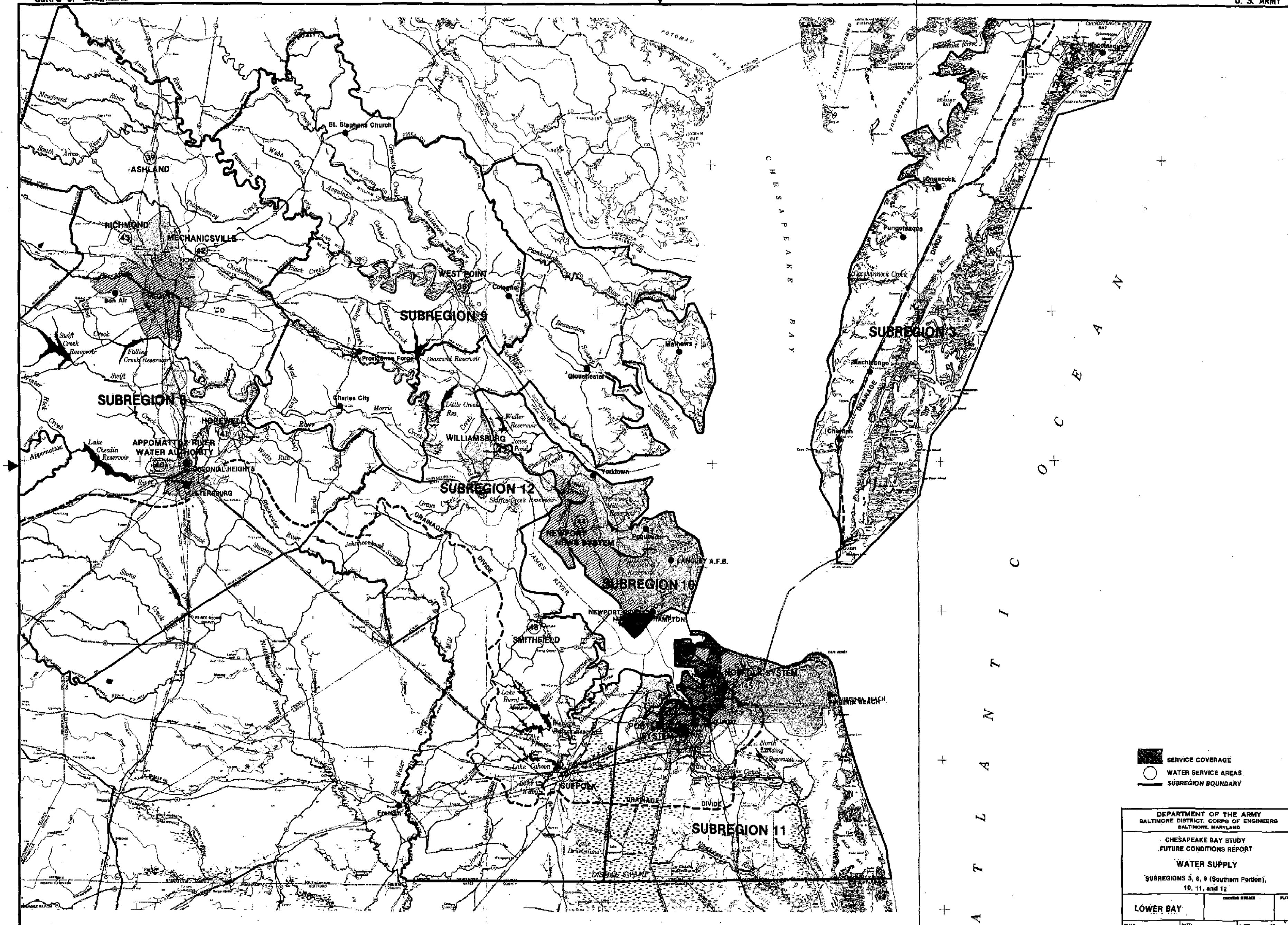

PLATE 5-4