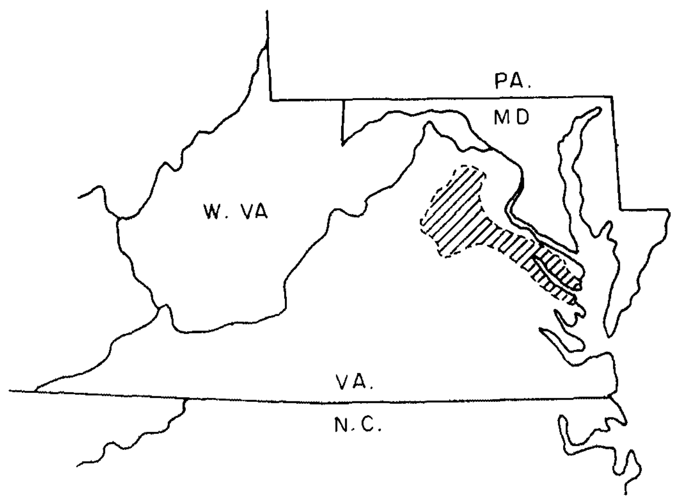
WATER RESOURCE STUDY
SALEM CHURCH RESERVOIR
RAPPAHANNOCK RIVER, VIRGINIA



U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
PUBLIC HEALTH SERVICE
REGION III
CHARLOTTESVILLE, VIRGINIA
MAY 1964

WATER RESOURCE STUDY

SALEM CHURCH RESERVOIR

RAPPAHANNOCK RIVER, VIRGINIA

Study of Potential Needs and Value of
Water Storage for Municipal, Industrial
and Quality Control Purposes

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service, Region III
Charlottesville, Virginia

In Cooperation With The

U. S. DEPARTMENT OF THE ARMY
U. S. Army Engineer District, Norfolk, Virginia

May 1964

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INTRODUCTION

REQUEST AND AUTHORITY

The District Engineer, Corps of Engineers, Washington District, requested by letter dated January 19, 1961, that the Public Health Service restudy the proposed Salem Church Reservoir and revise, if necessary, a Public Health Service report of November 22, 1955. Since the date of request, the responsibility for the Rappahannock River Basin has been transferred to the Norfolk District. The restudy includes an evaluation of water supply and water quality benefits which might accrue from providing storage for regulating flows in the lower Rappahannock River.

This restudy was made under the provisions of the Federal Water Pollution Control Act, Public Law 84-660, and the Federal Water Supply Act, Public Law 85-500, both of which were amended in 1961 by Public Law 87-88. A Memorandum of Agreement dated November 4, 1958, between the Department of the Army and the Department of Health, Education, and Welfare, sets forth the assistance to be provided by the Public Health Service in implementing the Water Supply Act.

PURPOSE AND SCOPE

The objectives of the Public Health Service restudy were: (1) to identify all water uses within the Rappahannock River Basin; (2) to estimate future water uses based upon economic projections; (3) to determine the effects of future waste loads on stream quality under natural flow conditions; (4) to discuss waste treatment and stream flow required to meet established water quality objectives; and (5) to determine benefits which might accrue to reservoir storage for water supplies and water quality control.

Using the above objectives as a basis, the report presents the need for and value of storage for water quality control and water supply. The expected future water requirements in the Basin have been developed for the 100-year period 1970 through 2070. The restudy includes the entire Rappahannock River Basin; however, emphasis was placed on the Fredericksburg, Virginia, area because this is the major population and industrial center within the Basin.

ACKNOWLEDGMENTS

Acknowledgment is gratefully extended to the following agencies and officials for furnishing information necessary in the preparation of this report:

Corps of Engineers, U. S. Army Engineer
District, Norfolk

U. S. Geological Survey
Surface Water Branch
Charlottesville, Virginia

Virginia State Water Control Board

Virginia State Department of Health

Virginia Employment Service

Office of Governor, Virginia Division of
Industrial Development and Planning

Local municipal officials

SUMMARY

1. The Rappahannock River Basin can be divided into three regions, upper, central, and lower, based upon economic, population, and geographic considerations. The upper region is primarily agricultural with scattered towns; the central region containing Fredericksburg is the economic and population center; and the lower region is a narrow strip bordering the estuary with a land and water-oriented economy.

2. The Rappahannock River is approximately 190 miles in length with tidewater extending up to the vicinity of Fredericksburg, a distance of about 107 miles.

3. Above Fredericksburg the Rappahannock River is of good quality for all uses.

4. Present Fredericksburg area municipal and industrial water supplies are withdrawn from the Rappahannock River at the approximate rate of 33 mgd. Fredericksburg's source is above tidewater; whereas, the American Viscose Corporation, the major industry of the area, utilizes the upper estuary.

5. The discharge of untreated and partially treated municipal and industrial wastes into the extreme upper Rappahannock estuary causes, during periods of low-flow, zero dissolved oxygen conditions which extend downstream from the City of Fredericksburg, a distance of 12 to 18 miles. In addition, nuisance conditions exist within the City of Fredericksburg.

6. Oyster beds within the lower Rappahannock estuary are classified as one of the prime areas remaining in the State of Virginia. During the period 1959 to 1963, production had an average value of $2,785,000. Natural spring river discharges cause a salinity-time-temperature condition not normally found in other growing areas which affords control of oyster predators and diseases.

DESCRIPTION

THE AREA

The Rappahannock River Basin is located in eastern Virginia and is bounded on the north and west by the Potomac River Basin; on the east by the Chesapeake Bay; and on the south by the York and James River Basins. The basin includes all of Culpeper, Madison, Rappahannock, and Richmond Counties and parts of Caroline, Essex, Fauquier, Greene, King George, Lancaster, Middlesex, Orange, Spotsylvania, Stafford, and Westmoreland Counties.

The headwaters of the Rappahannock River and its principal tributary, the Rapidan River, lie on the eastern slopes of the Blue Ridge Mountains. The river flows approximately 190 miles in a south-easterly direction across the Piedmont Plateau and the Coastal Plain to enter the Chesapeake Bay. Tidal effects extend up to the "fall line"--a distance of about 107 miles and in the vicinity of Fredericksburg. The total drainage area is approximately 2700 square miles.

Climate within the basin varies with elevation and distance from the Chesapeake Bay. However, the mean annual temperature is about 57° with an average annual rainfall of about 42 inches.

RESERVOIR LOCATION AND DESCRIPTION

The site of the proposed Salem Church Dam is located approximately 5.6 miles upstream from the City of Fredericksburg as shown on Figure 1 (follows page 64). The proposed structure will be a concrete gravity section supplemented with earth dikes or embankments extending from each abutment. There are approximately 1600 square miles of drainage area above the site.

HYDRAULICS

The U.S. Geological Survey maintains several stream gaging stations within the Basin. Continuous flow records are available from October 1907 for a station located 3.8 miles above the City of Fredericksburg on the Rappahannock River. According to the records, flows at this station have varied from a minimum of 5 cfs to a maximum of 140,000 cfs, with a mean discharge of about 1,670 cfs.

THE ECONOMY

PRESENT

The Rappahannock River Basin is located at the southern end of the northeastern megopolis, extending from Boston to Washington, D.C., and lies between the fast growing areas of Washington and Richmond. It is made up of three rather distinct regions based on physiographic and economic characteristics. These regions are shown in Figure 1. The upper region is largely a rural area. However, the main transportation routes between Washington, Charlottesville, and Lynchburg cross the region, and the northern towns on this route have been affected by the growth of the Washington Metropolitan Area. The central region is part of what has been named the Metropolitan Corridor, an area including the four large metropolitan complexes of the State of Virginia-Arlington, Alexandria, and Fairfax; Richmond, Petersburg, and Hopewell; Hampton and Newport News; and the Norfolk-Portsmouth area. The lower region is essentially a rural area, but the land resources and the type of farming differ considerably from the upper region.

Determination of existing population and projection of future Basin population was based on minor civil division boundaries as used in the Census of Population. The civil divisions utilized for this purpose were those which closely approximate the hydrologic boundaries of the Basin. Other economic statistical data is available only on a whole-county basis; therefore, all economic analyses other than population were based on county figures even though the counties may lie partly in other basins.

The economy of the Basin has been undergoing a transition from agriculture to manufacturing and non-commodity employment. This transition is manifested by a 65.8 per cent decline in the farm population from 1940 to 1960; an increase of 11.8 per cent in manufacturing employment's share of the labor force, and an increase of 19.1 per cent in non-commodity employment.

Population

The population of the Basin has increased from about 125,000 in 1940 to about 139,000 in 1960. (See Table 1 and Figure 4.) This is an annual compound increase of 0.5 per cent while the State population has been increasing at an annual rate of 2 per cent and the United States at 1.5 per cent.

Table 1 - Population of the Rappahannock River

Basin by Political Subdivisions

UPPER REGION	1940	1950	1960
Culpeper County	13,365	13,242	15,088
Fauquier County			
Marshall District	3,820	3,043	3,205
Centre District	6,035	6,598	7,995
Lee District	4,001	3,956	4,185
Greene County			
Standardsville District	1,762	1,574	1,672
Ruckersville District	1,666	1,566	1,731
Madison County	8,465	8,273	8,187
Orange County	12,649	12,755	12,900
Rappahannock County	7,208	6,112	5,368
Total	58,971	57,119	60,331
CENTRAL REGION			
Caroline County			
Port Royal District	2,409	1,743	1,812
Bowling Green District	5,514	4,404	4,364
Fredericksburg City	10,066	12,158	13,639
Spotsylvania County			
Chancellor District	2,072	2,547	3,175
Courtland District	3,092	4,834	5,780
Stafford County			
Hartwood District	2,107	2,896	3,205
Falmouth District	3,127	4,033	7,093
Total	28,387	32,615	39,068
LOWER REGION			
Essex County	7,006	6,530	6,690
King George County	5,431	6,710	7,243
Lancaster County	8,786	8,640	9,174
Middlesex County	6,673	6,715	6,319
Richmond County	6,634	6,189	6,375
Westmoreland County			
Washington District	3,372	3,562	3,958
Total	37,902	38,346	39,759
Basin Totals	125,260	128,080	139,158
Virginia Population	2,678,000	3,318,000	3,966,000

Source: Census of Population

The rate of population increase differs among the three regions of the Basin. The population in the lower and upper regions has increased very little while the central region, which is dominated by the City of Fredericksburg, has shown an annual population increase of 1.6 per cent.

As shown in Table 2, the population of the Basin is predominantly rural with only 15.8 per cent of the 1960 population living in small towns and cities. Farm population has been decreasing rapidly in the last 20 years and 78 per cent of the rural population is now rural residential.

Warrenton and Orange are the only population centers of over 2500 people in the upper basin. There are also five small towns in the upper region with a total population of 4594. Culpeper alone accounts for 2400 of these people. In the central region, which includes Fredericksburg, there are two small incorporated towns in Caroline County with a total population of 650 people. In the lower region there are also two small incorporated towns which account for 2163 people.

The Basin has a population density of 39 people per square mile as compared with 100 for the State of Virginia.

Personal Income

Table 3 shows the relative total and per capita income situation of the Basin and the State at different dates. Per capita incomes in both the upper and lower regions of the Basin was considerably below that of the central region in 1960, but even that region was below the state average.

Labor Force and Employment

The civilian labor force in the Basin increased by about 10 per cent between 1940 and 1960 and remained at about 36 per cent of the population.

There has been a considerable change in the proportion of employment in the various categories during the twenty-year period as shown in Figure 2. Commodity employment as a whole has decreased 17.8 per cent from 53.8 to 36 per cent of the labor force. This resulted from the sharp decline in agricultural employment which dropped nearly 38.5 per cent from 52.4 to 14.1 per cent of the labor force. Manufacturing

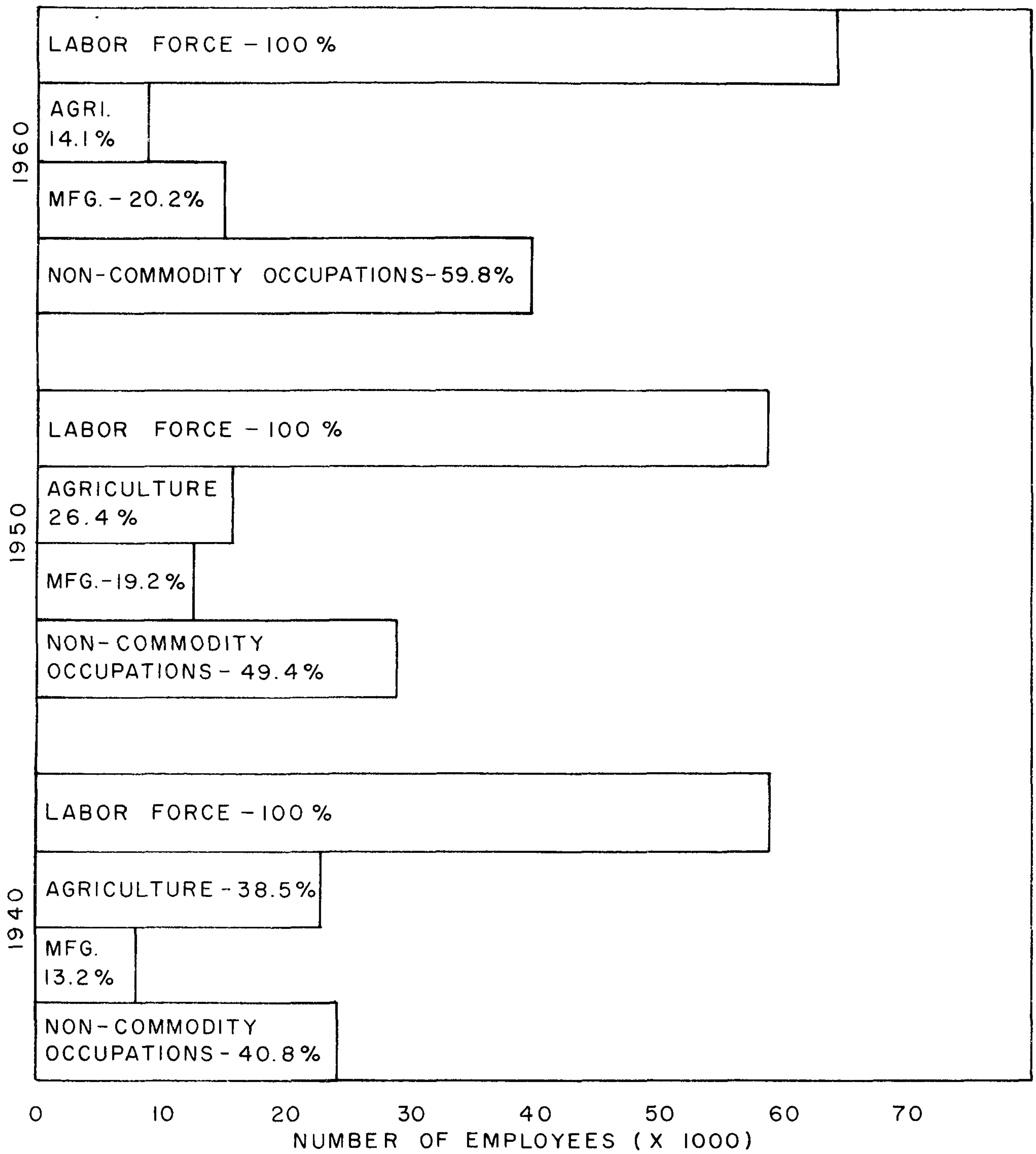
Table 2 - Rappahannock River Basin Population

By Region and By Place of Residence 1940 - 1960*

Area	1940		1950		1960	
	Number	%	Number	%	Number	%
UPPER						
Total Population	67,944	100.0	66,375	100.0	70,324	100.0
Total Rural Population	60,610	89.2	57,340	86.4	59,253	84.3
Farm	45,948	67.6	34,088	51.4	18,206	25.9
Rural Residential	14,662	21.6	23,252	35.0	41,047	58.4
Small Town	7,334	10.8	3,937	5.9	4,594	6.5
Urban	--	0.0	5,098	7.7	6,477	9.2
CENTRAL						
Total Population	43,464	100.0	48,451	100.0	57,059	100.0
Total Rural Population	32,734	75.3	35,549	73.4	42,764	74.9
Farm	22,075	50.8	14,775	30.5	5,515	9.7
Rural Residential	10,659	24.5	20,774	42.9	37,249	65.3
Small Town	664	1.5	755	1.6	656	1.1
Urban	10,066	23.2	12,147	25.1	13,639	24.0
LOWER						
Total Population	44,042	100.0	44,932	100.0	46,843	100.0
Total Rural Population	42,937	97.5	43,137	96.0	44,680	95.4
Farm	27,481	62.4	17,562	39.1	8,880	19.0
Rural Residential	15,456	35.1	25,575	56.9	35,880	76.4
Small Town	1,105	2.5	1,795	4.0	2,163	4.6
Urban	--	0.0	--	0.0	--	0.0
RAPPAHANNOCK BASIN						
Total Population	155,450	100.0	159,758	100.0	174,226	100.0
Total Rural Population	136,281	87.7	136,026	85.1	146,697	84.2
Farm	95,504	61.4	66,425	41.6	32,601	18.7
Rural Residential	40,777	26.2	69,601	43.6	114,096	65.5
Small Town	9,103	5.9	6,487	4.1	7,413	4.3
Urban	10,066	6.5	17,245	10.8	20,116	11.5

*County Data

Source: Census of Population



LABOR FORCE AND EMPLOYMENT
AGRICULTURE, MANUFACTURING, AND NON-COMMODITY OCCUPATIONS
RAPPAHANNOCK RIVER BASIN

FIGURE 2

Table 3 - Personal Income

Virginia and Rappahannock River Basin - 1939, 1958, 1960

Total Income*

Area	1939	1958	% Increase
Virginia	$ 1,128,000,000	$ 6,600,000,000	490
Rappahannock Basin	44,961,000	240,767,000	436

Per Capita Income*

	1939	1958	% Increase
Virginia	$422	$1745	314
Rappahannock Basin	289	1399	384

Per Capita Income**

	1960
United States	$1849
Virginia	1603
Rappahannock Basin	1227
Upper Region	1184
Central Region	1344
Lower Region	1155

* Source: Bureau of Population and Research, University of Virginia, 1958

** Source: 1960 Census of Population

employment made up for part of this decline and non-commodity or service industries increased in importance even more. (See Table 4.)

These changes in the Basin have lagged behind those in the State where by 1960 agricultural employment had declined to only 7.1 per cent of the total labor force and non-commodity employment had increased to 65.5 per cent.

The changes in the different regions of the Basin followed the same pattern but differed in extent. The upper region has a considerably higher percentage of its labor force in agriculture than the other two regions. Non-commodity employment has reached the highest percentage in the central region. This is to be expected with the higher per capita income of the central region. (See Table 5.)

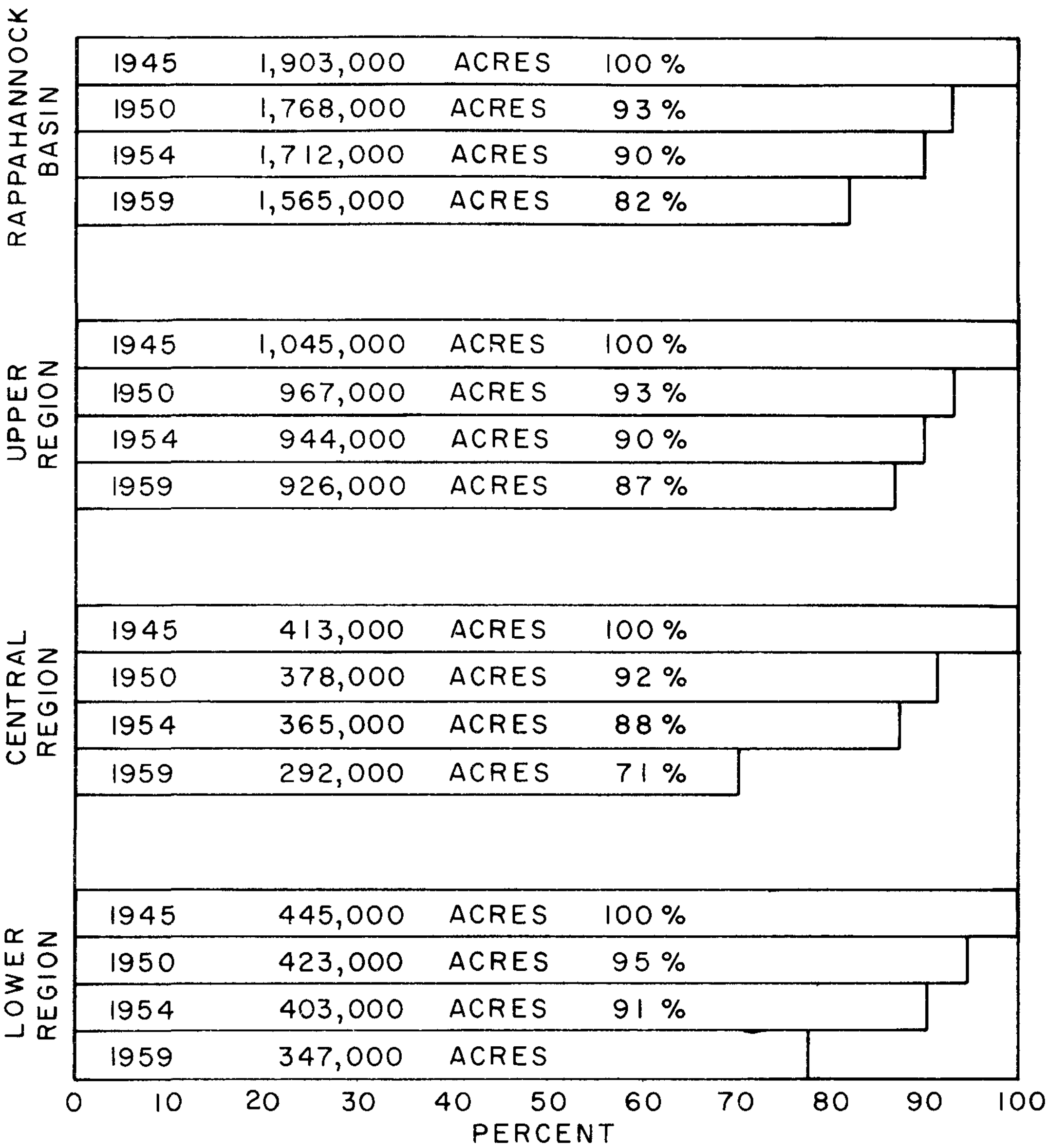
Age of Persons in Labor Force. In each of the three regions of the Basin the percentage of the labor force over 45 years of age was greater than the 33.4 per cent for the State as a whole, while in each of the age groups between 18 and 44 the percentage for the Basin was less than for the State. These relationships indicate that for some time the Basin has not been retaining as large a percentage of the young people maturing into the labor force as the average for the State.

Extractive Industries. The land area and labor force in agriculture have been decreasing as shown in Figure 3. (Per cent of 1945 Farm Acreage in Farms) and Figure 2 (Labor Force and Employment). However, agricultural production has increased due to advances in the technology of farming. (See Table 6, Value of Farm Products Sold.) Livestock, dairying, and poultry products account for 78 per cent of the value of farm products sold in 1959.

Irrigation has not been an important water use in the Basin because of a limited acreage of high value crops such as vegetables.

Logging and sawmilling employed only 5.2 per cent of the labor force even though 56 per cent of the land area was in forest. Table 7 shows that the annual cut of saw timber is exceeding growth, and the annual cut of the total growing stock is only slightly larger than annual cut.

Minerals are a minor resource in the Rappahannock Basin with only about 100 people employed in stone quarries.



PERCENT OF 1945 FARM ACREAGE IN FARMS IN
1950, 1954, AND 1959
RAPPAHANNOCK RIVER BASIN AND REGIONS

FIGURE 3

Table 4 - Number and Per Cent of Employees by Industrial Categories

Rappahannock Basin - 1940, 1950, 1960

Category	1940		1950		1960	
	Number	%	Number	%	Number	%
Labor Force, Civilian	57,249	100.0	57,010	100.0	62,883	100.0
Agriculture	22,013	38.5	15,052	26.4	8,837	14.1
Forest and Fisheries	1,110	1.9	1,230	2.2	948	1.5
Mining and Quarrying	85	0.2	110	0.2	123	0.2
Manufacturing	7,580	13.2	10,955	19.2	12,719	20.2
Logging and Sawmilling	2,558	4.5	4,249	7.5	3,263	5.2
Furniture and Wood Products	230	0.4				
Primary Metals	44	0.1	143	0.3	177	0.3
Fabricated Metals	190	0.3	569	1.0	1,358	2.2
Other Durable Goods	51	0.1	133	0.2	193	0.3
Food and Kindred Products	802	1.4	1,130	2.0	1,628	2.7
Textile Mill Products	774	1.4	828	1.5	565	0.9
Apparel, etc.	808	1.4	848	1.5	1,401	2.2
Printing and Publishing	158	0.3	229	0.4	268	0.4
Chemicals	1,578	2.8	2,320	4.1	2,574	4.1
Other Non-Durable Goods	388	0.7	506	0.9	432	0.7
Construction	3,181	5.6	5,035	8.8	5,565	8.9
Transportation, Communication, Utilities	1,689	3.0	2,543	4.5	2,819	4.5
Trade	4,592	8.0	7,104	12.5	9,683	15.4
Other Services	12,394	21.6	13,474	23.6	19,558	31.1
Commodity Employment	30,788	53.8	27,347	48.0	22,627	36.0
Non-Commodity Employment	23,363	40.8	28,154	49.4	37,628	49.8
Unemployed	3,098	5.4	1,509	2.6	2,628	4.2

Source: Census of Population

Table 5 - Number and Per Cent of Employees by Industrial Categories

For Regions of the Rappahannock Basin - 1940, 1950, and 1960

	1940		1950		1960	
UPPER REGION	Number	%	Number	%	Number	%
Labor Force, Civilian	24,268	100.0	23,242	100.0	25,643	100.0
Agriculture	11,429	47.1	8,687	37.4	5,562	21.7
Fisheries	6	--	12	0.1	16	0.1
Mining	28	0.1	43	0.2	59	0.2
Manufacturing	1,794	7.4	3,102	13.3	3,898	15.2
Commodity Employment	13,257	54.6	11,844	51.0	9,535	37.2
Non-Commodity Employment	9,697	40.0	10,848	46.7	15,292	59.6
Unemployed	1,314	5.4	550	2.4	816	3.2
CENTRAL REGION						
Labor Force, Civilian	16,602	100.0	17,517	100.0	20,416	100.0
Agriculture	4,176	25.2	2,409	13.8	1,153	5.7
Fisheries	28	0.2	51	0.3	40	0.2
Mining	52	0.3	57	0.3	61	0.3
Manufacturing	4,068	24.5	5,023	28.7	5,251	25.7
Commodity Employment	8,324	50.1	7,540	43.0	6,505	31.9
Non-Commodity Employment	7,629	46.0	9,605	54.8	13,145	64.4
Unemployed	649	3.9	372	2.1	766	3.8
LOWER REGION						
Labor Force, Civilian	16,379	100.0	16,251	100.0	16,824	100.0
Agriculture	6,408	39.1	3,956	24.3	2,122	12.6
Fisheries	1,066	6.5	1,167	7.2	892	5.3
Mining	5	--	10	0.1	3	--
Manufacturing	1,718	10.5	2,830	17.4	3,570	21.2
Commodity Employment	9,197	56.2	7,963	49.0	6,587	39.2
Non-Commodity Employment	6,047	36.9	7,703	47.4	9,191	54.6
Unemployed	1,135	6.9	587	3.6	1,046	6.2

Source: Census of Population

Table 6 - Value of Farm Products Sold, Actual and Constant

Dollar Value: Rappahannock River Basin, by Regions

	Value of Products Sold - Actual Dollars			
	1944	1949	1954	1959
Rappahannock Basin	21,821,916	28,128,472	32,817,377	46,793,291
Upper Region	7,842,476	10,992,097	14,532,320	21,043,082
Central Region	9,189,353	11,379,649	11,031,709	17,027,466
Lower Region	4,790,087	5,756,726	7,253,348	8,722,743
	Constant Dollars*			
Rappahannock Basin	11,076,805	11,351,389	13,340,264	19,494,085
Upper Region	3,980,841	4,396,839	5,907,388	8,766,548
Central Region	4,664,516	4,551,860	4,484,390	7,093,642
Lower Region	2,431,448	2,302,690	2,948,486	3,633,895

Source: Census of Agriculture

* Deflated by index of prices paid and received by farmers - USDA 1910-14 = 100

Table 7 - Forest Products Annual Growth and Annual Cut, 1957

	Annual Growth	Annual Cut
Saw Timber	186.9 million board feet	197 million broad feet
Growing Stock	855.1 thousand cords	676 thousand cords

Source: 1957 Forest Survey

Commercial fisheries made a significant contribution to the income of the lower region of the Rappahannock Basin. The oyster harvest, one part of the fishery, according to the Bureau of Commercial Fisheries, had an average value of $2,785,000 from 1959 to 1963 reported for Essex, Richmond, Lancaster and Middlesex Counties. Also, additional value was added for fish caught in the Chesapeake Bay or in the ocean and landed in the counties along the River.

Manufacturing. Manufacturing has been increasing in the Basin, as measured by both number of employees and value added in manufacture. The number of manufacturing employees in the Basin is shown in Table 4. The value added by manufacture as reported by the Census increased from about $29,000,000 in 1954 to $36,000,000 in 1958, but this is far from complete because of the need to withhold data to avoid disclosure of information about an individual company.

The leading manufacturing industries as measured by employment and as reported in the 1960 Census in the order of importance are logging and sawmilling, food and kindred products, apparel, fabricated metals, and furniture and wood products. In the upper region, logging and sawmilling are the leading industries. In the central region, the chemical industry is far the most important, followed by logging and sawmilling. In the lower region, logging and sawmilling and food and kindred products are the most important industries, followed by metal fabrication.

The industry of the Basin is characterized by a large percentage of small establishments in a wide range of industrial groups. In 1958 there were 387 manufacturing establishments in the Basin. Of these, 311 or 80 per cent employed from 1 to 19 employees. (See Table 8 and 9.)

The American Viscose cellophane plant in Spotsylvania County just outside of Fredericksburg (with 2500 employees) overshadows in size all other manufacturing establishments in the Basin. The next largest company has only about 700 employees. The sales of cellophane since 1946 have been increasing at a rate between 5 per cent and 6 per cent per year. However, the production of the Fredericksburg plant has remained constant for a number of years.

Of the other four manufacturing plants in the Basin employing over 250 employees, three are in the textile and apparel industrial groups, and one is in the furniture and fixtures industrial group. Food and kindred products is the only industrial group in the Basin besides chemicals which might be a heavy water user in terms of waste

Table 8 - Distribution of Manufacturing Establishments by Region and by Number of Employees, Rappahannock River Basin, 1958

Number of Employees	Region Upper	Central	Lower	Basin Total	Per Cent of Total
1 - 19	80	95	136	311	80.4
20 - 95	11	15	33	59	15.2
100 - 249	6	4	2	12	3.1
250 and over	3	2	-	5	1.3
	100	116	171	387	100.0

Source: 1958 Census of Manufacturers

discharge and/or water intake. The seventy establishments in this industrial group are small, employing less than 100 employees each. Fifty-one of the seventy establishments were in the lower or tidal estuary section of the Basin.

Non-Commodity Industries. Non-commodity or service employment including construction, transportation, communication, public administration, utilities, trade and other services has increased between 1940 and 1960 from 23,000 employees to 37,600 employees. This represents not only an absolute increase in the number of employees, but also a greater proportion of civilian labor force. In 1940 non-commodity employment made up only 40.8 per cent of the labor force, while in 1960 it made up 59.8 per cent. This compares with 65.5 per cent for the State as a whole in 1960.

Non-commodity employment has consistently been a higher percentage of the labor force in the central region than either the upper or lower regions.

Transportation Facilities. The Rappahannock Basin is crossed by the following major highways: U.S. 1 and 301 North and South through or near Fredericksburg between Washington and Richmond; Routes U.S. 29 and 15 across the upper region through Culpeper; and Route U.S. 17 which runs lengthwise through the Basin and at the southeastern end turns south toward the Norfolk area. There are numerous other Federal, State, and County highways.

The Basin is served by a large number of trucking companies, and by the Southern Railroad across the upper Basin through Orange and Culpeper and the Richmond, Fredericksburg and Potomac Railroad through

Table 9 - Distribution of Manufacturing Establishments by Region and by Industrial Group, Rappahannock River Basin, 1958

	Number of Establishments				
	Region			Basin Total	
Industrial Group	Upper	Central	Lower	Number	Per Cent
Food and Kindred Products	11	8	51	70	18.1
Textile Mill Products	5	-	-	5	1.3
Apparel and Related Products	2	3	1	6	1.6
Lumber and Wood Products	59	96	90	245	63.3
Furniture and Fixtures	6	-	-	6	1.6
Printing and Publishing	8	4	7	19	4.9
Chemicals and Allied Products	1	1	-	2	0.5
Leather and Leather Products	-	1	-	1	0.3
Stone, Clay and Glass Products	3	2	5	10	2.6
Primary Metals	2	-	-	2	0.5
Fabricated Metals	3	1	-	4	1.0
Transportation Equipment	-	-	17	17	4.3
All Groups	100	116	171	387	100.0

Source: 1958 Census of Manufacturers

Fredericksburg. The Chesapeake and Ohio Railroad, an east-west line, connects with the Southern at Orange and with the Richmond, Fredericksburg and Potomac just south of Caroline County.

There are no commercial airports in the area, but complete service is provided at Washington and Richmond.

The interstate highway system, as planned, will enter the Basin in two areas. The North-South Route 95 will cross the Basin near Fredericksburg. East-West Route 66 will cross Fauquier County and connect Washington to the North-South Route 81. This will put Fredericksburg in an even more advantageous position with regard to major highway arteries.

PROJECTED

The location of the Basin and the nature of the labor force are the economic factors which, in conjunction with a continued expansion of the national economy, indicate that the Basin's prospects for growth are good.

The proximity of the nearby large urban areas make the area attractive to industries producing consumer goods, and further development of residential areas for people working outside the Basin is anticipated, together with the service industries which accompany such development.

A labor supply will be available from the release from agriculture and the maturing population; and while training for skilled occupations may be necessary, the educational attainments of the labor force are good.

The Basin is well endowed with a historical heritage and many preserved historical sites, and it has areas with recreational potential along the river and the Bay at its mouth. These assets in conjunction with the fact that the Basin is on the main routes between the population center of the Northeast and the winter resort areas of the South should provide the basis for a considerable expansion in travel and recreation business.

As agricultural and industrial production in the country have become more efficient and as incomes have risen, there has been a steady increase in the employment of service industries. This trend has been apparent in the Rappahannock Basin, but at a slower rate than in the State. In the future, because of the characteristics of the Basin discussed above, there should be a considerable increase in both absolute and percentage employment in non-commodity occupations.

Agriculture will continue to be economically important in the Basin, although the agricultural labor force and the farm population are expected to continue to decline. Livestock numbers will probably continue to increase. The use of irrigation is not likely to expand as the acreage of crops of sufficient value per acre to pay irrigation costs is very limited, and the soil resources of the Basin are not such as to encourage expanded acreage of such crops.

The natural resources of the region will not greatly foster economic growth. There is a possibility that the timber of the Basin can be the basis of some increased wood products manufacturing, as most of the wood is now taken elsewhere to be processed and manufactured into various products. However, current cutting is equal to or greater than current growth, so any increased lumber production is unlikely.

Manufacturing employment has been increasing in the Basin and should continue to do so for some time until automation and other efficiencies in commodity-producing industries make it possible for more people to be released for service employment. The present manufacturing of the Basin is very diversified as to type and the future expansion will probably be in the form of many small diversified industrial operations producing consumer goods. The strategic location of the area in regard to markets and its labor situation should assure this growth.

At least a partial alternative to increased manufacturing employment as a basis for the economic development of the Basin will be increased employment of Basin residents in Washington and Richmond as the interstate highways system is completed and driving time is reduced.

Population and Employment Projections

The expected population growth and the economic development of the region of which the Rappahannock Basin is a part is a basic consideration in making population and employment projections for the Basin. The State of Virginia has been selected as the region with which to relate the Basin, and the population projections of the Basin have been developed through an analysis of the past and expected relationships between the Basin and the State. As a measure of the expected growth in the State population, this report has accepted population projections published by the U.S. Senate Select Committee on Natural Resources.*

*Source: U. S. Senate Select Committee on National Water Resources, Print No. 5, U. S. Government Printing Office, Washington, D.C., 1960, page 6, Table III, Middle Rate of Growth.

Because of the more intensive development of the Fredericksburg urban area, projections for that area are included. The Fredericksburg urban area is defined as the City of Fredericksburg and the four surrounding political districts, Chancellor and Courtland Districts in Spotsylvania County, and Hartwood and Falmouth District in Stafford County.

The Fredericksburg urban area had a population of 32,892 in 1960 of which about 16,840 or 51 per cent were served with municipal water. It is expected that as the population increases, the water supply facilities and sewers will be extended to a greater portion of the area. It is estimated that by 2000, 70 per cent of the urban area population will be served by municipal water systems, and in 2060, 80 per cent will be served by municipal systems.

Population projections for all regions of the Basin and the Fredericksburg urban area are given in Table 10. Figure 4 graphs past and projected population changes.

Labor force and employment projections are given in Table 11 by employment categories for each region. These are based on recent trend relationships between population and labor force and trends in the characteristics of employment and judgment evaluations as to future changes in those characteristics.

Table 10 - Population Projections Rappahannock River Basin

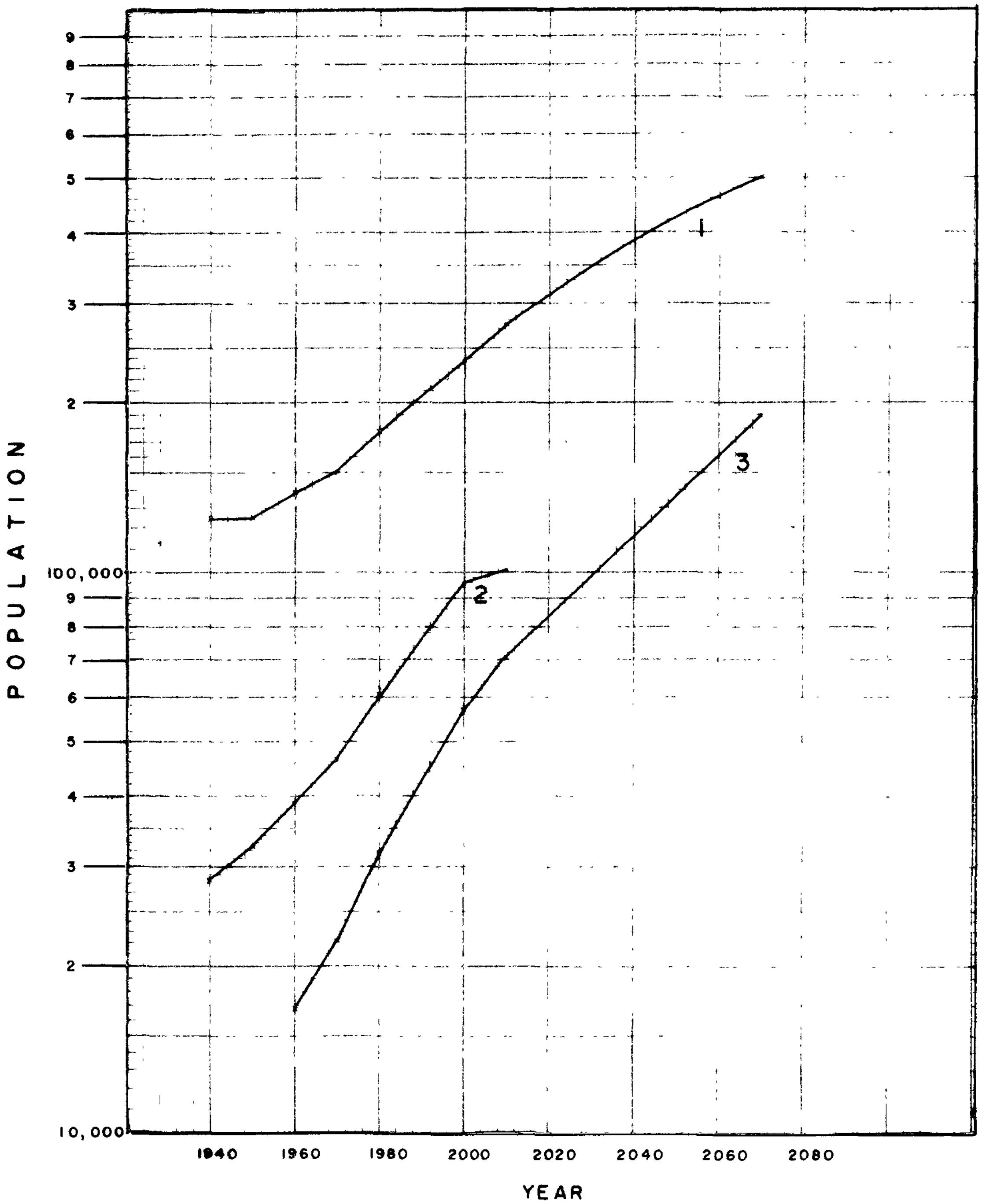
(Minor Civil Division Area)

	1970	1980	2000	2010	2070
Rappahannock Basin	150,700	178,600	239,300	277,800	500,000
Upper Region	63,200	71,500	90,400	101,000	
Central Region	46,700	61,200	95,800	118,800	
Lower Region	40,800	45,900	53,100	58,000	
Fredericksburg Urban Area Population	39,700	52,000	81,400	100,900	240,000
Served with Municipal Water	22,200	31,700	57,000	70,600	190,000

Table 11 - Projected Employment by Occupational Categories

Rappahannock River Basin - Total and by Regions - 1970 - 2010

	1970	1980	2000	2010
Rappahannock Basin				
Labor Force	68,600	81,600	110,100	128,200
Agriculture	7,300	6,400	5,000	4,400
Fisheries	1,000	1,000	1,000	1,000
Mining	200	200	200	200
Manufacturing	13,200	14,100	13,600	13,600
Commodity Employment	21,700	21,700	19,800	19,200
Non-Commodity Employment	44,200	56,700	85,900	103,900
Unemployed	2,700	3,200	4,400	5,100
Upper Region				
Labor Roce	27,100	30,600	38,700	42,800
Agriculture	4,500	3,800	2,800	2,400
Fisheries	-	-	-	-
Mining	100	100	100	100
Manufacturing	4,100	4,300	4,100	3,900
Commodity Employment	8,700	8,200	7,000	6,400
Non-Commodity Employment	17,400	21,200	30,200	34,700
Unemployed	1,000	1,200	1,500	1,700
Central Region				
Labor Force	24,200	31,600	49,200	61,200
Agriculture	1,000	900	800	700
Fisheries	-	-	-	-
Mining	100	100	100	100
Manufacturing	5,500	6,300	6,900	7,900
Commodity Employment	6,600	7,300	7,800	8,700
Non-Commodity Employment	16,600	23,100	39,400	50,100
Unemployed	1,000	1,200	2,000	2,400
Lower Region				
Labor Force	17,300	19,400	22,200	24,200
Agriculture	1,800	1,700	1,400	1,300
Fisheries	1,000	1,000	1,000	1,000
Mining	-	-	-	-
Manufacturing	3,600	3,500	2,600	1,800
Commodity Employment	6,400	6,200	5,000	4,100
Non-Commodity Employment	10,200	12,400	16,300	19,100
Unemployed	700	800	900	1,000



POPULATION OF THE
RAPPAHANNOCK RIVER BASIN
1940, 1950, & 1960 WITH PROJECTIONS TO 2070

LEGEND:

1 TOTAL BASIN
2 CENTRAL REGION
3 FREDERICKSBURG WATER SERVICE DISTRICT

FIGURE 4

PROJECT INVESTIGATION

ESTUARINE STUDIES

During 1959, 1960, and 1961, the Virginia State Water Control Board made a series of sampling runs on the lower Rappahannock River. Seventeen sampling stations were established -- sixteen in tidewater extending from the mouth of the river to the Route 3 bridge in Fredericksburg and one above tidewater and the waste discharges of the Fredericksburg area. Figure 5 shows the location of those stations in the vicinity of Fredericksburg.

Samples were collected using the "same slack" method of tidewater sampling. This method requires that the samples be collected during high and low tides just prior to tide reversal. At such time there is no water movement due to tidal currents.

The following determinations were made on the majority of the samples: temperature, dissolved oxygen, biochemical oxygen demand, pH, solids (total, suspended and settleable), alkalinity, acidity, chlorides and sulfates. The sanitary significance of these determinations and others is discussed below.

Temperature

Temperature controls the solubility of oxygen in water and consequently the saturation level of dissolved oxygen in the stream. The rate of bacterial action is increased or decreased with higher or lower temperatures, respectively.

Dissolved Oxygen

Normally the amount of oxygen dissolved in a stream is limited by the saturation value which is a function of water temperature. In some cases, as a result of the photosynthetic processes of water plants, this value may be exceeded causing "supersaturation". Dissolved oxygen must be present to support fish and other aquatic life, for natural aerobic purification of streams, and to prevent nuisance conditions associated with putrefactive decomposition of waste materials. Values below the saturation level are an indication of the presence of unstable organic substances which demand or utilize oxygen. The gross effect of oxygen demanding substances in a particular stream reach is measured in terms of the deficiency in dissolved oxygen content below the saturation value.

Biochemical Oxygen Demand

The biochemical oxygen demand (usually referred to as B.O.D.) of sewage, sewage effluents, polluted waters or industrial wastes is the amount of oxygen (expressed in mg/l) required to stabilize the decomposable organic matter by aerobic bacterial action. Complete stabilization requires more than 100 days at 20°C., but measurement of BOD based upon such long periods are impractical for use in field investigations. Consequently, a much shorter period of laboratory incubation is used. Incubation for 5 days at 20°C. is normally the recommended procedure because of expediency. Ultimate or complete demands can be reasonably estimated from the 5-day BOD values.

pH

pH is defined as the negative logarithm of the hydrogen ion concentration (in moles per liter). The pH value indicates the relative acidity or alkalinity of a water, with the neutral point at pH 7.0. Values lower than 7.0 indicate the presence of acid salts; whereas, values higher than 7.0 indicate the presence of alkalies or alkaline earth salts.

Solids

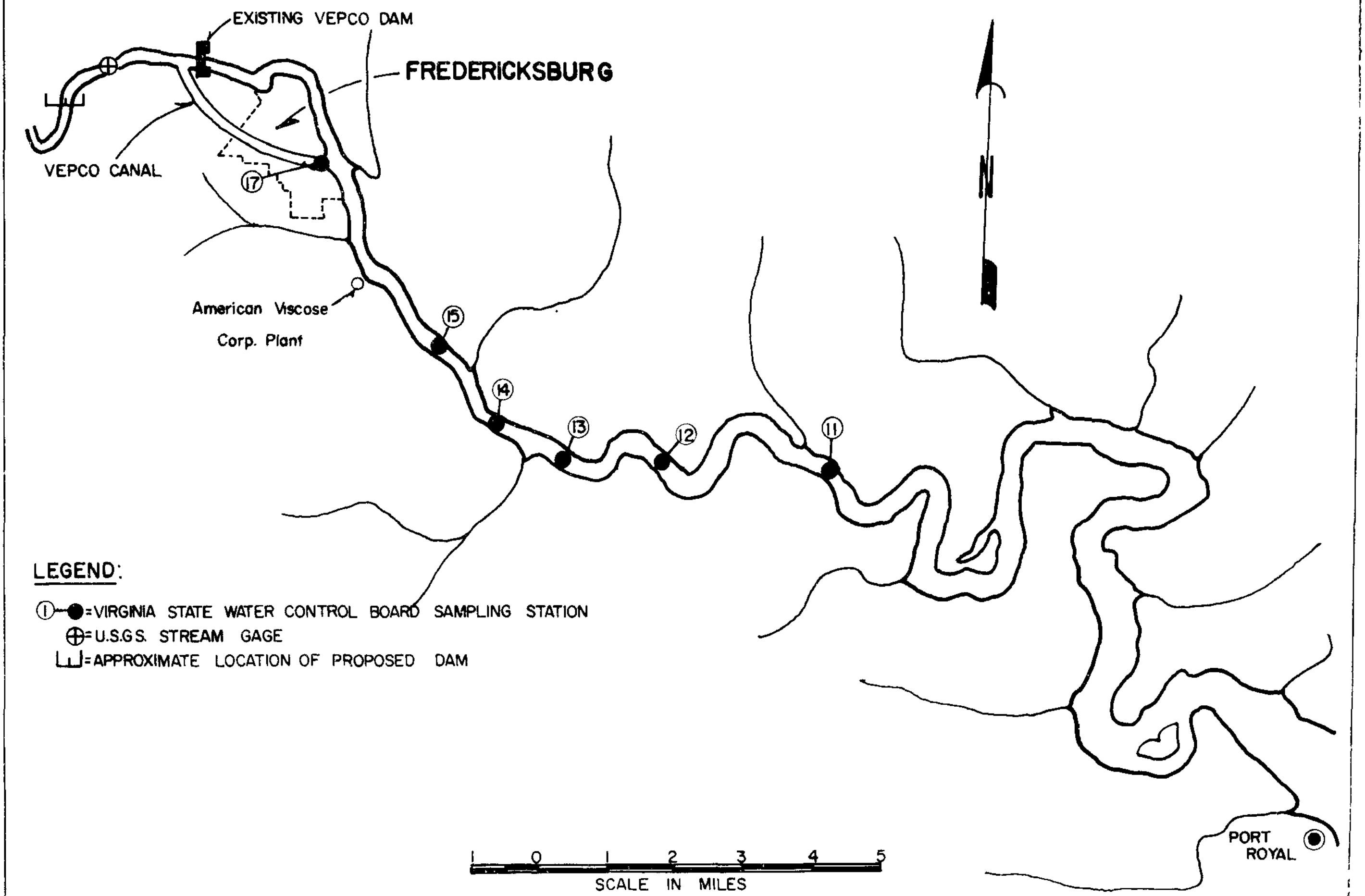
Settleable solids data provide a means for estimating the amount of material that can be expected to settle out in a stream. Suspended solids data may be used to estimate the amount of material which may be swept long distances downstream to be deposited or dissolved, depending on stream conditions.

Alkalinity and Acidity

The alkalinity of water is usually due to the presence of bicarbonates and carbonates. In some waters hydroxide, borate, silicate or phosphate may also contribute to the alkalinity. The acidity of water is normally due to the presence of carbon dioxide, mineral and organic acids, and salts of strong acids and weak bases.

Sulfates

Sulfates are a common decomposition product of organic matter and are also a waste product of several industrial operations. In water supplies sulfates above certain concentrations have undesirable physiological effects in man.



WATER RESOURCES STUDY
RAPPAHANNOCK RIVER BASIN, VIRGINIA

RAPPAHANNOCK
RIVER BASIN

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
PUBLIC HEALTH SERVICE - REGION III
CHARLOTTESVILLE, VIRGINIA
MAY 1964

FIGURE 5

Chloridess

Chlorides are found in practically all natural waters. The analysis can be used as one means of determining the magnitude of sea-water intrusion.

Coliform Organisms

This determination is an indicator of sewage pollution since coliforms are normally found in small numbers in unpolluted streams. Coliform bacteria are present in the intestines of warm-blooded animals and are discharged in large numbers in feces.

Iron and Manganese

The presence of more than trace quantities of iron and manganese will stain porcelain fixtures and laundry. In higher concentrations water is discolored and has a disagreeable taste.

Hardness

The presence of high hardness causes excessive soap consumption in homes and laundries; the formation of water scums and curds in homes, laundries and textile mills; the toughening of cooked vegetables; and the formation of scales in boilers, hot-water heaters, pipes and cooking utensils.

Data Analysis

Tables 16 thru 21 are tabulations of the laboratory results for certain selected sampling stations.

It should be noted that the B.O.D. results are inconsistent for those stations in the vicinity of the American Viscose Corporation outfall. Interference of an unknown nature caused these varying results.

The laboratory results were used to determine the waste assimilation capacity of the upper estuary immediately below the Fredericksburg area. This is the critical reach of the river because of the present waste loads and the expected future area growth. All known physical and chemical variables were considered, including river discharge, tides, deoxygenation and reaeration rates, temperature, dissolved oxygen and waste load.

Figures 6 and 7 are families of curves which indicate the assimilative capacity of the upper estuary for various water temperature and stream discharge conditions with initial dissolved oxygen deficits and 1 and 2 milligrams per liter below saturation, and a minimum dissolved oxygen content of 4 milligrams per liter. These curves are utilized as illustrated by the following example: assuming a water temperature of 20°C and a daily waste load of 7000 lbs. of 5-day B.O.D., the curves (Figure 6) indicate that a discharge of 400 cfs would be required to maintain a minimum D. O. of 4.0 mg per liter within the stream should there exist an initial D. O. deficit of 1.0 mg per liter.

INVENTORIES

Inventories were made in 1963 of water uses, waste discharges and water quality data. This information was obtained from the Virginia Department of Health, Virginia State Water Control Board, local contacts and published reports.

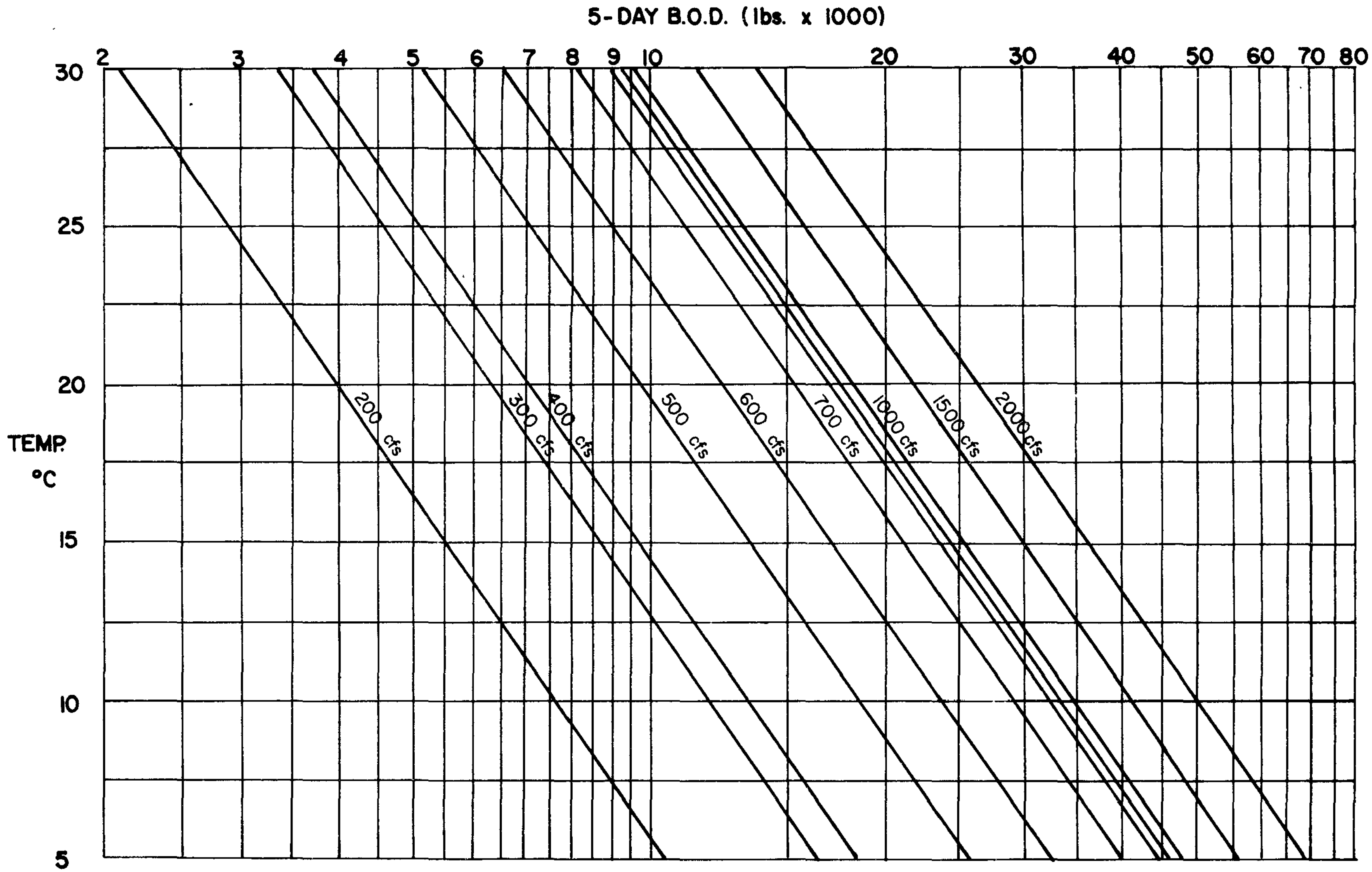
Water Inventory

The water inventory includes data on sources, uses and consumption. Table 23 is a tabulation of the inventory. A summary of these data is given below.

Use	Source	Population Served	Average Consumption (MGD)
Municipal	Surface	21,660	3.12
Municipal	Ground	7,300	0.60
Industrial	Surface	-	30.00

Waste Inventory

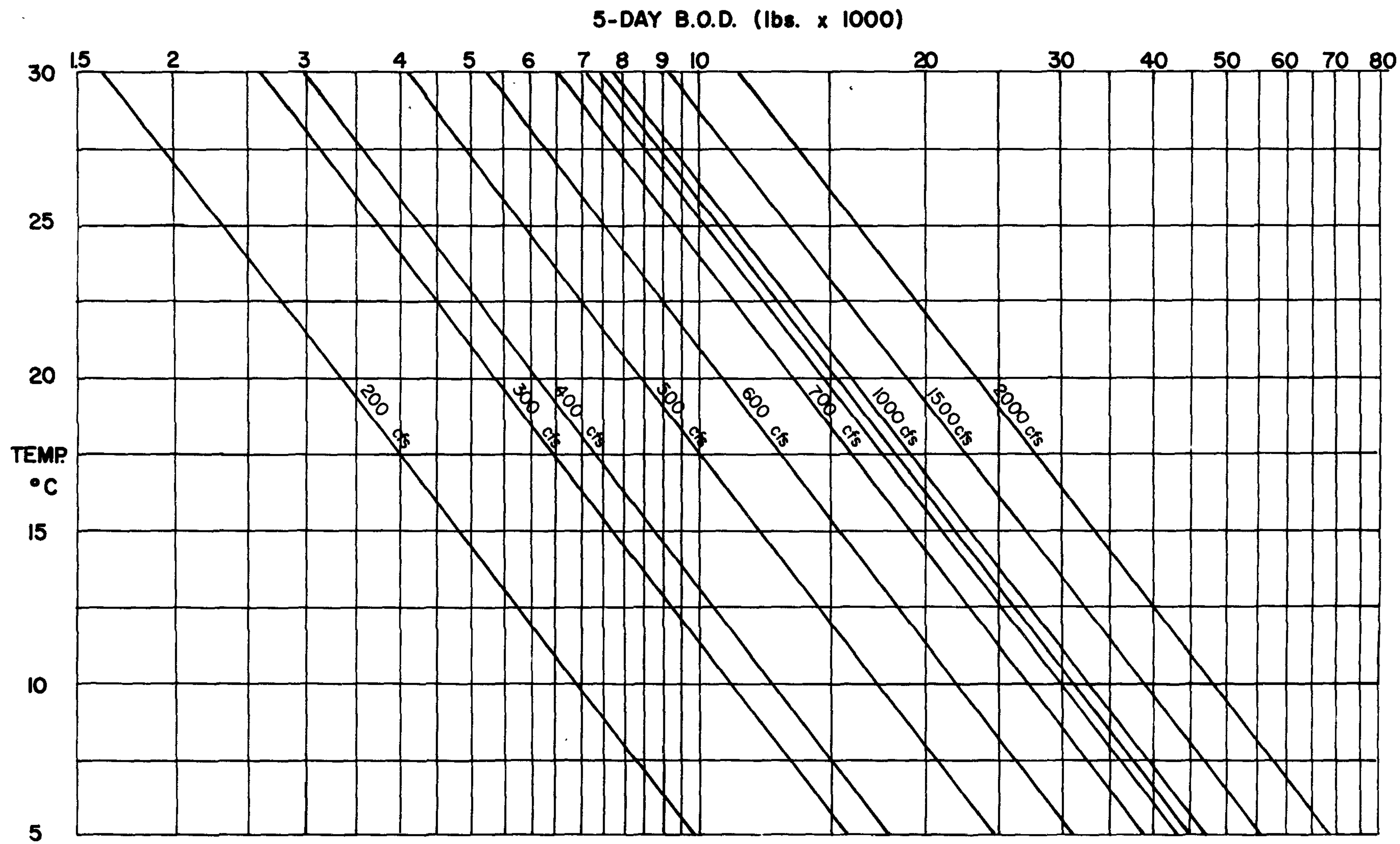
The waste inventory includes such items as sewered population, treatment facilities, and strength of wastes in terms of population equivalents. Table 22 is a tabulation of the inventory. A summary of these data is given as follows:



ASSIMILATIVE CAPACITY OF THE RAPPAHANNOCK RIVER IMMEDIATELY BELOW FREDERICKSBURG FOR VARYING FLOW AND TEMPERATURE CONDITIONS

Minimum D.O. = 4 mg. per liter; Initial D.O. Deficit = 1 mg. per liter

FIGURE 6



ASSIMILATIVE CAPACITY OF THE RAPPAHANNOCK RIVER IMMEDIATELY BELOW FREDERICKSBURG FOR VARYING FLOW AND TEMPERATURE CONDITIONS

Minimum D.O. = 4 mg. per liter; Initial D.O. Deficit = 2 mg. per liter

FIGURE 7

Waste Source	Sewered Population	Population Equivalent Discharged
Municipal	24,380	14,875
Industrial	-	38,800

Surface Water Quality

Data relating to several measures of water quality were collected during a 1951 Public Health Service Field survey of the Rappahannock River.[1] The results of this survey for samples collected at the U.S. Geological Survey gaging station above Fredericksburg are summarized below:

Constituent	Range	Average
Dissolved oxygen (% saturation)	82.1 - 115.7	94
5-Day BOD (mg/l)	0.6 - 1.1	0.8
Coliforms (MPN per 100 ml)	20 - 230	100
Chloride (mg/l)	2 - 5	2.8
pH	6.8 - 7.2	

Samples collected by the U. S. Geological Survey during water year 1956 at the Fredericksburg gaging station gave the following measures of water quality.[2]

Constituent	Range	Average
Iron (mg/l)	0.01 - 0.16	0.09
Chloride (mg/l)	2 - 4.5	2.9
Sulfate (mg/l)	1.9 - 6.3	3.6
Total Hardness (mg/l)	19 - 28	23
pH	6.8 - 7.6	

Field studies in 1959, 1960 and 1961 by the Virginia State Water Control Board produced the following measures of water quality for the Virginia Electric Power Company Canal at Fredericksburg. The canal is assumed to be representative of the river at the gaging station.

Constituent	Range	Average
Dissolved oxygen (% saturation)	28 - 138	92
5-Day BOD (mg/l)	0.4 - 3.4	1.6
Chloride (mg/l)	3 - 30	5
Sulfate (mg/l)	0 - 30	10
Alkalinity, MO (mg/l)	11 - 29	20
pH	6.1 - 6.9	

The results of these independent field surveys indicate that Rappahannock River water above Fredericksburg is of good quality. Further, it appears that the quality of the Rappahannock River at this point has changed very little over the ten-year period covered by these records.

The quality of the Rappahannock River immediately below the Fredericksburg area varies with river discharge and tides. For the lower range of flows (less than 500 to 700 cfs) when the fresh water inflow is not sufficient to overcome the tidal effect (a condition which occurs for extended periods each year), wastes tend to accumulate in the upper estuary. Independent field studies performed by the Public Health Service and the Virginia State Water Control Board indicated that during low flows zones of zero dissolved oxygen extended for as much as 12-18 miles below the Viscose outfall. This condition combined with the actual accumulation of wastes makes the river highly undesirable for most legitimate water uses.

Ground Water Quality

Ground water in the Rappahannock Basin is generally of poor quality having high iron and manganese concentrations, and in some cases, appreciable quantities of hydrogen sulfide. In addition, the water is considered to be corrosive due to low pH and alkalinity combined with a high dissolved carbon dioxide content.

Analyses of several ground water supplies in the basin, performed by the Virginia State Health Department, produced the following data.

Constituent	Range
Iron (mg/l)	0.1 - 7.0
Manganese (mg/l)	0 - 9.0
Hardness (mg/l)	2 - 145
Carbon Dioxide (mg/l)	0 - 70
Chloride (mg/l)	6 - 56
Fluoride (mg/l)	0 - 4.0
pH	6 - 8.5

With few exceptions the iron and manganese content of the ground waters exceed the recommended limits of the Public Health Service Drinking Water Standards. 3/ These standards state that iron and manganese should not be present in a water supply delivered to the consumer in excess of 0.3 mg/1 and 0.05 mg/1, respectively.

Ground Water Availability

No records of major exploration of large scale ground water supplies in the Basin area are available. In the Fredericksburg area numerous domestic wells produce four to five gpm each. Shallow wells, less than 50 feet, yield up to 10 gpm; deeper wells, 100 to 400 feet deep, produce an average of about 15 gpm. These yields will supply adequate water for most domestic and farm needs, but these quantities are not considered sufficient to meet municipal or industrial demands.

Wells in the Piedmont area drilled to depths less than 200 feet yield on the average of 5 to 20 gpm. At greater depths, the quality becomes very poor with no increase in volume. Decreases in production are prevalent during dry periods.

Ground water sources in the Coastal Plain portion of the Basin yield varying quantities depending on location and depth. Generally, the larger yields contain objectionable amounts of bicarbonate and fluoride.

WATER QUALITY OBJECTIVES

There are indications that water requirements in future years will be so great that they can be met only by the most efficient use of all available sources. In addition, the difficulty of maintaining water quality is continually increasing because of the growing quantity and variety of pollutants discharged to water courses. Therefore, current and expected future water uses with accompanying quality requirements must be weighed and quality objectives established to insure efficient development and utilization of water resources.

The Virginia Water Control Board has not established specific water quality objectives for either State-wide or individual stream application. Each waste discharge is considered on its own merits, taking into consideration downstream water uses and assimilative capacity of the receiving waters. However, with certain modifications and/or expansion the following basic criteria are used: (1) dissolved oxygen - not lower than 5 milligrams per liter in the stream; (2) no appreciable settleable or floating solids; (3) no noticeable coloration or discoloration of the receiving stream; (4) toxic substances to be reduced below the toxicity limit of the stream; (5) no appreciable change of pH of the receiving stream; and (6) stream flow for design of sewage treatment facilities equal to minimum average 7-day low-flow occurring on a 10-year frequency.

The Water Control Board has established a dissolved oxygen objective for that reach of the Rappahannock River below the waste discharges of the Fredericksburg area. This objective is to maintain at least average dissolved oxygen concentration of 4 milligrams per liter, with individual minimum values of not less than 3 milligrams per liter. Establishment of the oxygen concentrations was made after consultation with the Virginia Institute of Marine Science. Both agencies believe that river uses will not be contravened by these requirements. In addition, the State has indicated a desire that oxygen-saturated, or near-saturated, water be released from the proposed reservoir in order to continue the present flow of good quality water to the upper estuary at Fredericksburg. Present flows average approximately 92 per cent of dissolved oxygen saturation.

The ability of a stream to assimilate an organic waste load is directly related to the amount of oxygen available at the time of waste introduction. For maximum assimilative efficiency, it is, therefore, necessary that a stream be saturated with oxygen. Lower oxygen values require greater volumes of water to accomplish the same result. Higher dissolved oxygen values in reservoir releases can best be attained through the use of multi-level outlets. Because of vertical stratification in deep impoundments, water quality, in general, decreases with depth. Having the ability to discharge water from several depths allows for selection of water of the best quality and for mixing of waters from various levels. The net result is better control of the discharge to meet downstream quality requirements.

The dissolved oxygen objectives established by the Water Control Board are values which are generally accepted as necessary for maintaining any stream in satisfactory condition for downstream water uses, to protect aquatic life, and to prevent nuisance conditions. These objectives are considered both reasonable and adequate and have been adopted for purposes of this study.

Computations of assimilative capacities to meet established average or minimum dissolved oxygen objectives are necessarily based on average conditions including temperatures and waste loads. Temperature and waste load, however, vary considerably with time, i.e., a 24-hour period. Therefore, even when using a maximum average temperature condition (usually for the summer months) and a known waste load, these normal fluctuations cause variable dissolved oxygen concentrations in the receiving streams for any constant flow condition. In an attempt to satisfy the dissolved oxygen objectives, calculations of assimilative capacity in this report have been based upon a minimum average dissolved oxygen concentration of 4 milligrams per liter. This value was selected recognizing the variables and their effects upon oxygen concentrations. Actual individual values could possibly range from 3 to 5 milligrams per liter.

The optimum in water quality control would be to establish a quality condition suitable for all stream uses and to maintain that condition 100 per cent of the time. Seasonal and even daily variations in natural stream flows render the maintenance of such an objective impractical from engineering and economic standpoints. Since complete quality control is not feasible, particularly in streams receiving large waste volumes, a design low-flow condition is selected with a recurrence frequency which would not render poor water quality more often than would be practical when related to intended uses. Therefore, quality control measures are designed on the basis of maintaining the established minimum quality objectives when stream flows equal a design low-flow condition.

After considering present and expected future uses of the Rappahannock River, the minimum average annual flow with a recurrence frequency of one in 20 years was selected as the design low-flow condition. To determine the probable unregulated flow sequence on a seasonal basis, this annual flow was reduced statistically to monthly flows (See Table 12). This means, statistically, that during approximately one year out of every twenty, there will occur stream flows which will average less than the design flow. A greater recurrence frequency is undesirable from several aspects. Population projections indicate extensive growth in the Fredericksburg area which, with improved water quality, would enhance development of traditionally desirable river front properties for residential, commercial, and recreational uses. Frequent periods of poor quality would suppress river front development for most uses because of the increased risk of nuisance conditions and of damage to floating and adjacent structures because of accelerated corrosion and paint deterioration. Increased frequency would also be harmful to fish and other aquatic life in that normal populations might never exist since recovery following a kill usually requires three to five years.

Table 12 - Minimum Average Uncontrolled Discharge by Months with Recurrence Frequency 1 in 20 Years for Rappahannock River at Fredericksburg

Month	Flow (cfs)
January	624
February	732
March	1122
April	993
May	600
June	419
July	208
August	99
September	99
October	109
November	198
December	301

WATER USES

Water uses within the basin include domestic, municipal, and industrial water supplies, commercial and sport fishing, recreation, agriculture and waste disposal. All of these uses are dependent upon surface waters except for water supplies and agriculture which utilize both surface and ground sources.

The Rappahannock estuary serves as a spawning area for shad and striped bass. The lower estuary, near the Chesapeake Bay, has been called the only prime oyster growing area remaining in the State of Virginia although production is comparatively small in terms of dollar value.

The location of the proposed reservoir will effect only those surface water uses in the vicinity of and downstream from the impoundment. Upstream uses are too far removed to utilize water from the proposed project. The two most significant water users in the basin, the City of Fredericksburg and American Viscose Corporation, have their water intakes and discharge their wastes in the reach of river immediately downstream from the proposed reservoir.

Fredericksburg obtains water from the Virginia Electric and Power Company (VEPCO) Canal which receives its flow from a diversion created by a low-level dam located above the City (Figure 5). The canal supplies water for the Embrey hydroelectric power station and during low-flow periods, the entire river discharge passes through this waterway. At flows less than approximately 50 cfs power generation ceases,and the City is permitted to utilize all available water.

The American Viscose Corporation plant, although obtaining a small portion of its water supply from Fredericksburg, utilizes the upper estuary as its major source of raw water. During low-flow periods, wastes discharged by Fredericksburg and the plant tend to accumulate in the upper estuary and at times, because of tidal action, wastes actually flow upstream. This upstream movement places wastes at the plant intake and causes nuisance conditions within the City of Fredericksburg. Wastes, particularly sulfates within the plant wastes, in the intake water are harmful to the industrial processes making it necessary to employ demineralization equipment on quality critical water. This equipment is placed into operation at river discharges less than approximately 60 cfs.

CONCLUSIONS

1. The proposed Salem Church Reservoir will have no direct effect on upstream areas since upper region communities are too distant for economic utilization of reservoir storage.

2. The proposed upstream water uses will not affect the quality of stored water in the proposed Federal reservoir.

3. The Fredericksburg area will continue to be the center of population and economic growth and will, therefore, continue to have the greatest need for water.

4. Population projections indicate that in the years 1995, 2020, and 2070 there may be 50,650; 90,400; and 190,000 persons, respectively, served by central water and sewer facilities in the Fredericksburg area.

5. By the years 1995, 2020, and 2070, it is estimated that the Fredericksburg Water Service District will have a total water supply requirement of 5.6, 14, and 27 mgd, respectively.

6. Ground water sources within the Fredericksburg area are capable of supplying individual farm, home and small sub-division needs; however, yields are inadequate to meet the concentrated demands of the Water Service District.

7. The water supply design low-flow condition for the Rappahannock River at the point of intake for the City of Fredericksburg is 5.53 mgd, based upon a flow which is expected to occur one day during any 16-year period.

8. The cheapest alternate sources of dependable water supply for the Fredericksburg Water Service District, in the absence of the proposed Federal project, are stage-constructed single-purpose reservoirs. To meet the estimated 2070 needs of 27 mgd will require an annual draft on storage of 3210 acre-feet which will have an annual benefit attributable to the Federal project of $36,500 including operation, maintenance and amortization for 100 years at 3 per cent interest.

9. Industrial water requirements in the year 1995, 2020, and 2070 are estimated to be 37, 45, and 45 mgd, respectively. These requirements, primarily cooling water, are expected to be met using the estuary as the source.

10. The quality objectives used in this report for the Rappahannock River immediately downstream from the Fredericksburg area, which

are in agreement with those established by the Virginia Water Control Board, are to maintain at least a minimum average dissolved oxygen value of 4 milligrams per liter, with individual minimum values of not less than 3 milligrams per liter.

11. The design condition for water quality control is the minimum average annual low-flow having a recurrence frequency of one in twenty years. This annual flow was reduced statistically to monthly flows to determine the probable unregulated flow sequence on a seasonal basis.

12. Expected municipal and industrial waste loads from the Fredericksburg area in the years 1995, 2020, and 2070 are estimated to be 6,500; 7,700; and 8,500 pounds of 5-day BOD, respectively.

13. The Rappahannock River is incapable of assimilating, at design flows, either present or projected residual waste loads after adequate treatment, and meeting the established quality objectives.

14. The cheapest alternate means of meeting the water quality objectives is a combination of modified secondary waste treatment and stage-constructed single-purpose reservoirs. The annual cost of this method, and, therefore, the benefit attributable to annual draft on storage (130,400 acre-feet) for the purpose of water quality control, is $595,500 including operation, maintenance, and amortization for 100 years at an interest rate of 3 per cent.

15. Storage provided within the proposed Salem Church Reservoir for water quality control will produce many intangible benefits by improving conditions in the Rappahannock River for approximately 100 miles from the dam to the Chesapeake Bay. In addition to improved recreational opportunities, the availability of a more uniform quality will be beneficial to fish, aquatic life and wildlife; aesthetic qualities will be improved; and property values will probably be enhanced.

16. The benefits are widespread in scope and appear sufficient in magnitude to warrant the provision of the required volume of storage for water quality control.

17. Water quality in deep impoundments becomes degraded with depth because vertical stratification prevents mixing of surface and bottom waters. It is recommended that multi-level outlets be incorporated in the proposed structure to allow releases from several depths, thereby providing positive control of the discharges to meet particular downstream dissolved oxygen requirements.

WATER REQUIREMENTS FORECASTS

GENERAL

Nationally, total water requirements have spiraled upward during the past 5 or 6 decades. New products and methods as well as the growing demand for manufactured and processed items have magnified industrial water demands. Agriculture utilizes water to create additional tillable lands and to obtain a greater yield per unit of area. Irrigation is already practiced nationwide, and each year the total acreage increases. Metropolitan and urban areas with central water supplies having complex distribution systems, elaborate household plumbing, and air-conditioning, combine with an ever increasing standard of living to place greater demands on our water resources. Total water requirements will continue this upward trend, if for no reason other than the expanding population.

MUNICIPAL AND SERVICE DISTRICT WATER SUPPLIES

A study of 58 municipal systems operated by the American Water Works Company indicates that residential sales of water per service, for the years 1939-59, increased at the rate of approximately two per cent per year.4/ The U.S. Senate Select Committee on National Water Resources, in their Committee Print No. 7, states that in 1954 average municipal water use was 147 gallons per capita per day (gpcd) and that this could conceivably increase to 185 gpcd in 1980 and to 225 gpcd in the year 2000, with a possible leveling off thereafter.5/ This indicates an increase in per capita consumption of approximately 1.1 per cent per year.

Municipal water use rates are affected by the size of the community, its location, habits and standard of living, availability of water, quality and cost of water, existence of sewers, extent and uses of water meters, and other variables. Since the present economy of the Rappahannock Basin is somewhat below the State and national averages and since present water comsumption is considerably lower than the Select Committee average, it is anticipated that per capita water use will increase faster than the mean projections as the area grows through modern urbanization. The annual unit increase for municipal use is projected as 1.5 per cent of the 1960 per capita figure of 80 gallons per capita per day for fifty years. After this time the per capita demand is expected to reach a plateau and continue at a constant rate.

Expanding populations and increasing per capita consumption have made it necessary for a majority of the communities within the upper basin to seek additional sources of water. Surface waters appear to be the only feasible source because of low yields and poor quality of the ground water available within the area. Recently, in order to insure sufficient raw water, the Town of Culpeper made arrangements to utilize a Soil Conservation Service reservoir located upstream from the Town reservoir.

Madison, another upper basin community, is presently making final plans to purchase water supply storage in a proposed Soil Conservation Service reservoir to be constructed near the Town on White Oak Run. The existing well sources are inadequate because of low yields and seasonal fluctuations in the ground water table.

The Town of Warrenton, which obtains its water from the Potomac River Basin and discharges its wastes to the Rappahannock Basin, is now acquiring land to construct a raw water impoundment. Although the reservoir will be in the Potomac Basin, the need for water resource development is apparent in order to meet increasing uses.

Location of communities in the upper basin dictates that water supplies be developed locally. The proposed Federal Reservoir would not, because of distance, be a feasible source of water for these communities.

Lower basin communities are so located that ground water is most likely to continue as the source of supply. In this region surface sources are impractical from the standpoint of both quality and quantity since most surface water in the Coastal Plain is saline and any fresh water is usually completely dependent upon rainfall.

The central basin, and in particular the Fredericksburg area, can effectively utilize the main stem of the Rappahannock River as its source of raw water. In 1960 approximately 16,840 persons in the Fredericksburg urban area were served by central water systems, representing about 51 per cent of the urban population. It is estimated that as the population increases, both water and sewerage facilities will be extended to serve a greater percentage of the populace. By the year 2000, 70 per cent of the urban population will be centrally served and by the year 2060 this will increase to about 80 per cent. For purposes of this report, the area has been designated as the Fredericksburg Water Service District. The remaining portion of the population is expected to be served by individual wells and individual waste disposal systems. The following tabulation gives the project populations, as derived from the economic study, for the Fredericksburg urban area and the Water Service District.

Population Projections-Fredericksburg Area

Year	Urban Population	Service District Population
1960	32,892	16,840
1995	74,000	50,650
2020	124,000	90,400
2070	240,000	190,000

Based on the projected populations and the expected per capita water use,the Fredericksburg Service District will require in the years 1995, 2020, and 2070 an estimated 6, 14, and 27 mgd, respectively.

INDUSTRIAL WATER SUPPLIES

Industries can be classified as two general types, dry and wet. Dry-type industries use little or no water in the manufacturing processes, thereby having no significant waste discharges. Wet industries use varying quantities of water depending on the product, and in numerous cases, water use in the manufacture of identical products will vary from plant to plant.

In the United States between 1900 and 1955 industrial water use increased six-fold, with water use primarily in manufacturing processes and for cooling. There have been many predictions of future industrial needs ranging from very nominal increases to increases of 16 per cent per year. The smaller increases are generally based on growth of existing facilities, whereas the larger predictions are based on the establishment of new plants.

Economic investigations indicate that the natural resources within the region will not support a new wet industry of any magnitude. Therefore, water requirements for industrial growth within the Fredericksburg area are based on nominal increases in water use by existing establishments and allowing for the possible location of light water using industries. Industrial water supply needs are estimated to increase at the rate of 0.2 mgd per year for fifty years after which time the demand is expected to remain constant. It is anticipated that the primary source of industrial supply will be the upper Rappahannock estuary.

Table 13 - Projected Fredericksburg Area Water Supply Requirements

Use	Present	Water Supply Requirements (mgd) 1995	2020	2070
Service District	1.7	6	14	27
Industrial	30.0*	37	45	45
TOTALS	31.7	43	59	72

* Water withdrawn from the estuary.

QUALITY CONTROL REQUIREMENTS

Maximum efficiency in the utilization of water resources can only be attained through the effective control of water quality. Each of the various water uses such as public and industrial water supplies, recreation, fish and wildlife, and waste disposal have differing water quality requirements. With many uses often competing for the water within a single system, quality control, of which waste treatment is an integral part, must be practiced in order that any one use does not cause a quality unsatisfactory for other uses. Water for human consumption has the highest priority; therefore, a good quality must be maintained to meet the demands of public water supplies before being made available for uses of lesser priority.

For purposes of determining the value of storage for water quality control attributable to the proposed Salem Church Reservoir, it is assumed that conventional secondary treatment will be provided for all sources of domestic sewage and its equivalent for industrial wastes. Conventional secondary treatment of domestic sewage within the Fredericksburg area is expected to stabilize approximately 85 per cent of the oxygen-consuming wastes through the year 2020. Although greater waste reductions are presently attainable, it is not reasonable to assume a higher removal when an unknown quantity of organic material will reach the watercourse through individual home disposal systems, storm water sewers, and small sub-division treatment facilities. As the area becomes more densely populated and sewers are extended, more and more of the populated area wastes will receive control treatment. It is expected as this occurs that over-all reduction of the area waste load will increase and that after the year 2020, 90 per cent of the organic material will be stabilized.

For some time the American Viscose Corporation has been engaged in a program to reduce its waste loads discharged to the Rappahannock River. During the past 10 years the company has reduced the organic waste load to the stream by approximately 50% through process modifications and improved housekeeping. In addition, this program has included the separation of waste from the cooling and rinsing waters and collecting them in a concentrated waste flow. There are in effect two effluents being discharged from the plant; one of approximately 24 mgd with a BOD of 6-10 mg/l, and the second of approximately 6 mgd with a BOD of about 120 mg/l. The Virginia Water Control Board has assisted plant personnel in studies which aided in the separation of these wastes.

The Viscose Corporation reports that the wastes in the weak effluent come from rinsing the cellophane in the final steps of manufacture and that there is no known method of preventing the waste from entering the rinse water. Further, there is no known method of treating such a low waste concentration.

Although the company does not now provide any external waste treatment, recent pilot plant studies performed on the more concentrated waste water indicate that the highest degree of waste reduction can be attained using an activated sludge process. Some treatment process changes are necessary, however, including among other things nutrient addition and extended aeration periods which will obtain about an 85% reduction in the oxygen consuming wastes. The 85% reduction is considered to be equivalent to conventional secondary treatment for this waste through the year 2020. It is expected that the industry will continue its current program of in-plant modifications which have already reduced waste loads significantly and after the year 2020 treatment efficiencies of approximately 90% are anticipated. The Virginia Water Control Board has, in fact, instructed the company to continue its efforts to reduce the waste load being discharged.

For the purpose of this investigation, the waste load considered for evaluating water quality control needs is, therefore, the total of the two waste water streams. The total includes that waste load remaining following secondary treatment of the concentrated wastes added to the waste in the less concentrated water.

MUNICIPAL AND INDUSTRIAL WASTE LOADS

Waste loads from domestic sources are estimated to be equivalent to 0.23 pounds of 5-day BOD per person per day. This value is based upon present waste strengths with adjustment for expected future waste loads. Industrial wastes, however, are complicated by many variables. Even the manufacture of any one product, because of different industrial techniques, results in wide variations in quantity and strength of wastes. Future industrial discharges are estimated either by area or by individual plants utilizing available discharge data as a basis for design whenever such data are available.

Within the upper basin (see Figure 1) existing domestic and industrial waste discharges affect only short reaches of stream. Every community having a municipal collection system provides effective secondary treatment, and industries within the area having significant wastes discharge into these community systems. Projections of population and industrial growth in the upper basin indicate that future discharges will not produce significant adverse effects on stream qualities.

The Fredericksburg Service District represents the primary source of domestic wastes within the central basin. Waste loads to the Rappahannock River, as estimated using the District population projections and the expected degree of treatment, are 1,800; 2,600; and 4,400 pounds of 5-day BOD for the years 1995, 2020, and 2070, respectively.

Industrial waste discharges in the Fredericksburg area, as determined from the economic projections, the expected nominal increases in wet manufacturing processes, and the degree of treatment expected, are estimated for the years 1995,2020, and 2070 to be 4,700; 5,100; and 4,100 pounds of 5-day BOD, respectively.

Total waste loads, Service District plus industrial, in the Fredericksburg area, are estimated in the years 1995,2020, and 2070 to be 6,500; 7,700; and 8,500 pounds of 5-day BOD, respectively.

Waste loads in the lower basin (see Figure 1) are not now a problem, nor does an analysis of the economic forecasts indicate that they will be a problem in the future. The area is rural in nature and raw materials are not available for industrial development.

Table 14 - Municipal Service District and Industrial Waste

Loads Discharged Within the Fredericksburg Area

Type Work	Present	Discharge in Pounds of 5-day BOD 1995*	2020*	2070*
Municipal District	2550	1800	2600	4400
Industrial	6600	4700	5100	4100
TOTALS	9150	6500	7700	8500

* Based upon the provision of adequate treatment.

MUNICIPAL AND INDUSTRIAL QUALITY CONTROL REQUIREMENTS

The Rappahannock River below Fredericksburg is incapable of assimilating the projected waste loads at the stream design low-flow condition. Therefore, in addition to adequate waste treatment and in order to meet the established dissolved oxygen objectives, flow regulation is necessary. Maintenance of these objectives will require annual drafts on storage of 97,000; 114,000; and 130,400 acre-feet by the years 1995, 2020, and 2070, respectively.

OYSTERING AREA

The oyster beds within the lower Rappahannock estuary are classified by fisheries experts as one of the prime areas remaining in the State of Virginia because of relatively low infestations of oyster predators and oyster diseases. Representatives of the Virginia Institute of Marine Science and the U. S. Fish and Wildlife Service state that oyster predators and diseases are controlled by a salinity-temperature-time relationship. In general, the relationship is that the lower the salinity and the higher the water temperature, the less the time required to provide effective control. Water temperatures must be greater than 15°C for low salinity concentrations to be effective. At lower temperatures the diseases and predators are nearly dormant and are only slightly affected, while, conversely, at high water temperatures, the oysters themselves could be harmed by low salinities.

Almost yearly during April and May, when the Rappahannock River temperatures first climb above 15°C, high spring run-off occurs which reduces the salinity to a level which kills oyster predators and diseases. Each summer infestation occurs through slow upstream movement and transplanting of young oysters from infested areas; however, the degree of infestation reached prior to cold weather and the dormant stage of the seasonal cycle is such that only a small percentage of the oysters are harmed.

In order to insure continuance of the above natural phenomena, the proposed reservoir should release or pass flows equivalent to nature's April and May river discharges. Information available at this time indicates that satisfactory control of the predators and diseases, a kill of approximately 50 per cent, can be accomplished by about twenty consecutive days of 10 parts per thousand salinity at oyster bed depth (15 feet) at River Mile 14. The U. S. Fish and Wildlife Service and the Virginia Institute of Marine Science are collecting additional data to more accurately fix the required conditions. A more detailed discussion containing actual salinities, time, and flow requirements will be presented in the U. S. Fish and Wildlife Service Report; therefore, more accurate volumes and durations of river discharge and optimum salinities necessary to provide effective disease and predator control should be based on these findings.

Table 15 - Water Supply and Quality Control Requirements for the Fredericksburg Area

Water User and Waste Source	Present		Year 1995		Year 2020		Year 2070	
	Water Supply (mgd)	Quality Control (acre/feet) (1)	Water Supply (mgd)	Quality Control (acre/feet) (1)	Water Supply (mgd)	Quality Control (acre/feet) (1)	Water Supply (mgd)	Quality Control (acre/feet) (1)
Service District	1.7	-	6.0	-	14.0	-	27.0	-
Industrial	30.0 (2)	-	37.0	-	45.0 (2)	-	45.0 (2)	-
TOTALS	31.7	49,900	43.0	100,000	59.0	114,000	72.0	130,400

(1) Quality Control expressed in acre-feet annual draft on storage.

(2) Industrial water withdrawn from estuary.

DISCUSSION OF BENEFITS

AREA CONSIDERED

The location of the proposed Salem Church Reservoir will affect only those water uses within the vicinity of, and downstream from, the City of Fredericksburg. Located within this area are the most significant water uses of the Basin, including the raw water intakes and waste outfalls of Fredericksburg and American Viscose Corporation, as well as the oyster beds of the lower Rappahannock estuary. In addition, economic projections indicate the Fredericksburg area will continue as the Basin leader in population and economic growth and, consequently, will continue to have the greatest need for water.

WATER SUPPLY BENEFITS

Water supply benefits are calculated in terms of costs of obtaining the same quality and quantity of water by the cheapest alternate means which would most likely be developed by the potential users in the absence of the Federal project. Alternates considered in the determination of the value of storage in the proposed Federal reservoir included:

a. Development of ground water sources.

b. Single-purpose water supply reservoirs.

The water supply needs of the Fredericksburg Water Service District are estimated for the years 1995, 2020, and 2070 to be 6, 14, and 27 mgd, respectively.

An investigation of ground water yields within the Fredericksburg area indicates that ground water sources are capable of supplying individual farm, home and small sub-division requirements; however, yields are inadequate to meet the concentrated demands of the Water Service District.

A recent water supply report prepared by Alvord, Burdick, and Howson (Hayes, Seay, Mattern and Mattern), engineering consultants employed by the City of Fredericksburg, indicates the safe gravity yield of the Virginia Electric and Power Company dam (all available flow to the Canal) to be 5.53 mgd[6/]. This estimate was based on the low-flow conditions which occurred in the Rappahannock River in late summer of 1954 and represents a flow which is expected to reoccur one day during any 16-year period. The consultants used this flow as a basis for calculating future raw water storage requirements for the City of Fredericksburg. Since the one in 16-year low-flow condition is reasonable, 5.53 mgd has been taken as the design low-flow for determining additional water requirements necessary to meet future Service District needs. This compares with the minimum recorded flow of 3.2 mgd, which occurred on two successive days in October 1930.

The most feasible alternate sources of dependable water supply, in the absence of the proposed Federal project, are single-purpose water supply reservoirs. These reservoirs must be capable of increasing the design low-flow from 5.53 mgd to the estimated 2020 and 2070 requirements of 14 and 27 mgd, respectively. The following schedule indicates draft on storage needs, dates and costs to meet the estimated future water supply needs.

Total Water Supply Needs	Date of Need (Year)	Need Supplied by Draft on Storage	Annual Draft on Storage (acre-feet)	Construction Date (Year)	Initial Investment	O & M
14 mgd	2020	8.5 mgd	860	1980	$ 680,000	$2000
27 mgd	2070	21.5 mgd	3210	2020	$1,860,000	$5600

The average annual cost of the single-purpose reservoirs amortized at an interest rate of 3 per cent over a 100-year period is $36,500, including operation and maintenance. The annual cost was discounted to 1970 from 1980, the year of first need, to correspond with the probable construction schedule of the proposed Federal project. The annual cost is a measure of the value of storage for water supply in Salem Church Reservoir.

The area around Fredericksburg was investigated, and it was found that there are a number of reservoir sites capable of yielding the required volumes of water. Reservoir costs were computed based upon average unit values derived by the Norfolk District, Corps of Engineers, for construction with the area. In addition, the Corps of Engineers computed the annual draft on storage required to meet future water supply needs. Since the water is expected to be transported within the natural stream bed, no costs will be incurred for transmission.

Adequate volume of water is available to meet the supply requirements of industry because withdrawals are from the tidal portion of the Rappahannock River. A quality problem does exist, however, as is discussed under the section on water uses. The effects of the proposed reservoir on stream quality are given in the following section on water quality control benefits.

WATER QUALITY CONTROL BENEFITS

In the planning of any Federal reservoir, a consideration must be given to inclusion of storage for regulation of stream flow for the purpose of water quality control, except that any such storage and water releases shall not be provided as a substitute for adequate waste treatment. Adequate treatment has been interpreted to be a minimum of conventional secondary treatment for municipal sewage or its equivalent for industrial wastes.

Benefits attributable to storage for stream flow regulation may be tangible, have a measurable dollar value, or may be intangible, with no measurable dollar value. Water quality control by the proposed Salem Church Reservoir will provide many intangible benefits by improving conditions in Rappahannock River for approximately 100 miles from the dam to the Chesapeake Bay. Improved quality will provide increased water-oriented recreational opportunities to an estimated year 2070 Fredericksburg area population of 240,000.

In addition to the recreational benefits, the availability of water of a more uniform quality will be beneficial to fish, aquatic life and wildlife; aesthetic qualities will be improved; and property values will probably be enhanced along the improved reach. There also exists the possibility with the higher regulated summer flows that the oyster predators and diseases will not reach even the limited levels presently attained under natural flow conditions.

It is, therefore, concluded, based on the above, that the benefits are widespread in scope and appear sufficient in magnitude to warrant the provision of the required volume of storage for water quality control.

After conventional secondary treatment of the Fredericksburg area wastes, the waste load discharged to the Rappahannock River will be in excess of the organic load that can be assimilated under the design low-flow conditions. At this design flow the river at Fredericksburg can assimilate during the critical period approximately 2,000 pounds of the 8500-pound BOD load estimated for the year 2070. Assimilative capacity for the critical period was estimated based upon the following criteria:

a. River discharge of 99 cfs (minimum average August discharge with recurrence frequency of 1 year in 20 years).

b. Maximum average temperature of 28.5°C.

c. Initial dissolved oxygen deficit of one milligram per liter. (Equal to approximately 87 per cent of saturation at 28.5°C observed values above Fredericksburg in vicinity of proposed dam site average about 92 per cent).

d. Minimum average dissolved oxygen concentration of 4 milligrams per liter.

Figures 6 and 7 (following page 28) are families of curves giving assimilative capacities for various temperature and flow conditions.

Without stream flow regulation, present poor stream quality conditions with accompanying zero dissolved oxygen values will continue to recur. As the area grows and waste loads increase, quality will worsen. The result will be an increasing reach of stream detrimental to property values, unfit for fish, the source of noxious odors, and of little value for recreational uses. Dependent upon the recurrence frequencies of natural low-flows, degraded stream quality can exist for periods of several days to as long as five months during each year.

Value of Benefits

The value of water quality control storage in a Federal reservoir can be computed in terms of the cost of achieving, in the absence of the Federal project, the established stream quality objectives by the cheapest alternate method. Methods considered included:

1. Complete removal of all pollutants from a portion of the waste load.

2. Storage and regulated release of waste effluents.

3. Combination of modified secondary waste treatment and single-purpose quality control reservoirs.

4. Single-purpose quality control reservoirs.

Complete Removal of All Pollutants - Treatment methods which would economically accomplish substantially complete removal of all pollutants are not presently available. Certain processes are, however, far enough advanced to be considered in comparison with other alternate methods. Freezing and gas hydrate processes for demineralizing sea water can be adopted to reclaiming waste waters by concentrating the dissolved solids to about one per cent by volume. The estimated cost is approximately $0.40 per 1000 gallons and includes the cost of the conventional secondary treatment. Treatment of the Fredericksburg area wastes would have an estimated average annual cost over the 100-year life of the proposed Federal project of approximately $1,100,000, including operation, maintenance, and amortization.

The estimates derived above do not include the costs of treating or disposing of the concentrated solids produced by the processes. Since further treatment results in additive costs to an already expensive method, no further analysis was made.

Storage and Regulated Release of Waste Effluents - Holding ponds can be utilized to store that portion of a waste load which cannot be assimilated during low stream flows for regulated release at a time when the stream stage is higher. Investigations indicate that approximately 1200 acres of holding ponds would be required to store the wastes from the Fredericksburg area. These wastes, however, contain large quantities of sulfate which could create severe problems both during storage and after release to the river. Ground waters could become contaminated through seepage into the water table unless some positive means of sealing were employed. Storage of this waste, which could easily become septic, would result in a biological reduction of the sulfate, producing hydrogen sulfide, an extremely obnoxious gas detectable over a large area. In addition, following any reduction of the sulfate, the waste would be toxic to aquatic life when discharged and have an immediate chemical oxygen demand which in itself could result in low dissolved oxygen conditions.

Holding ponds, because their use will not result in maintaining stream quality objectives, cannot be considered as a feasible alternate method.

Combination of Modified Secondary Treatment and Single-Purpose Reservoir - Provision of modified secondary waste treatment, additional treatment above and beyond conventional secondary, can be expected to increase treatment efficiencies, thereby reducing organic waste loads discharged to a watercourse. Engineering practice has demonstrated that greater efficiencies can be obtained by constructing additional secondary treatment units in series with a conventional plant; however, because of the relatively large cost involved per unit of BOD removal, this method is rarely used. Since wastes from the Fredericksburg area are amenable to further treatment, the following over-all reductions in organic content are expected in comparison to conventional treatment.

Treatment 1970 to Year 2020 Per Cent BOD Removal		Treatment 2020 to Year 2070 Per Cent BOD Removal	
Conventional	Modified	Conventional	Modified
85	90	90	90

Even with the provision of modified secondary treatment, the stream quality objectives cannot be met. In addition to this treatment, an annual draft on storage of 130,400 acre-feet will be required in the year 2070.

The following schedule indicates the storage yields and construction, operation, and maintenance costs required to meet the water quality objectives:

Year Constructed	Modified Treatment*	O & M (per Unit)	Single-Purpose Reservoir	Annual Draft on Storage (Acre-feet)	O & M (per Unit)
1970	$ 759,000	33,700	$ 9,126,000	40,750	$27,300
1995	1,170,000	47,900	7,647,000	30,150	22,900
2020	-	-	10,833,000	51,100	32,700
2045	-	-	1,932,000	8,400	5,800

* ENR Construction Index of 900

As is shown in the above schedule, stage-construction of the combination single-purpose reservoirs and modified treatment have been estimated based upon a 100-year period to correspond with the life of the proposed Federal project. The combination has an estimated annual cost of $595,500 including operation, maintenance, and amortization at 3 per cent.

The area around Fredericksburg was investigated, and it was estimated that there are a number of reservoir sites capable of storing the required volumes of water. Reservoir costs were estimated based upon average unit values derived by the Norfolk District, Corps of Engineers.

Single-Purpose Quality Control Reservoirs - The stream quality objectives can be met through regulating the stream flow by using stage-constructed single-purpose reservoirs. To assimilate the estimated year 2070 waste loads will require after secondary treatment an annual draft on storage of 130,400 acre-feet. The following schedule indicates storage yields and costs:

Year Constructed	Annual Draft on Storage (Acre-feet)	Reservoir Construction Costs	O & M (per Unit)
1970	97,000	$16,005,000	$47,500
1995	17,000	3,910,000	11,700
2020	8,000	1,840,000	5,500
2045	8,400	1,932,000	5,800

Water quality storage within the above single-purpose reservoirs has an estimated annual cost of $640,000 over a 100-year period to correspond with the probable construction date of the proposed Federal project. The annual cost includes operation, maintenance, and amortization at 3 per cent interest.

Summation - Of the four methods discussed above, the combination of modified secondary treatment and single-purpose reservoirs is estimated to be the cheapest alternate means of meeting the stream quality objectives, in the absence of the Federal project. Therefore, the average annual benefit credited to the Salem Church Reservoir for water quality control storage would be $595,500. To accrue this benefit will require an annual draft on storage of 130,400 acre-feet.

The following gives the approximate required drafts on storage by months which will be required by the year 2070:

Month	Draft on Storage (acre-feet)
June	15,650
July	30,000
August	35,200
September	28,700
October	18,250
November	2,600

In earlier discussions it was pointed out that when flows are less than approximately 60 cfs, it is necessary for the American Viscose Corporation to utilize demineralization equipment on a portion of its raw water taken from the Rappahannock River estuary. Demineralization becomes necessary because water quality problems are created by "flood" tides reversing the small flow of the river and carrying wastes upstream to the plant water intake.

River discharges resulting from flow regulation will provide sufficient water volumes to prevent wastes from reaching, through tidal action, the plant intake. Regulated flows would, therefore, serve a dual purpose, but would not provide for the same water additive benefits for quality control. The benefit to improved industrial water quality is an integral and inseparable part of the total benefit attributable to overall quality control.

Table 16 - Tabulation of Survey Results

Virginia State Water Control Board

Station 11

Date	Tide	Temp.	D.O.	B.O.D.	Total Solids	Sulfates	7-Day Avg. River Discharge
8-31-61	L.W.S.	29	3.2	1.6	95	36	497
8-2-61	L.W.S.	28	2.2	3.0	122	38	423
8-7-61	H.W.S.	23	6.4	0.8	303	40	1467
10-5-61	H.W.S.	19	5.0	2.1	141	45	236
7-27-60	L.W.S.	26	3.9	1.2	155	56	273
8-3-60	H.W.S.	30	7.9	2.0	179	54	324
8-9-60	L.W.S.	30	4.0	3.6	151	37	421
9-15-60	H.W.S.	21	5.8	3.0	193	14	2163
9-3-59	L.W.S.	28	3.2	0.0	160	27	543
10-1-59	H.W.S.	21	7.8	-	240	65	631
11-5-50	L.W.S.	14	0.2	0.0	111	14	753

Table 17 - Tabulation of Survey Results

Virginia State Water Control Board

Station 12

Date	Tide	Temp.	D.O.	B.O.D.	Total Solids	Sulfates	7-Day Avg. River Discharge
7-31-61	L.W.S.	28	2.5	2.2	90	38	497
8-2-61	L.W.S.	28	2.6	1.2	125	49	423
8-7-61	H.W.S.	23	6.6	1.6	338	49	1467
10-5-61	H.W.S.	19	2.6	3.6	162	58	236
7-27-60	L.W.S.	26	3.7	1.8	118	42	273
8-3-60	H.W.S.	30	6.2	2.0	188	33	324
8-9-60	L.W.S.	29.5	1.8	1.8	158	48	421
9-15-60	H.W.S.	21	5.9	2.4	135	20	2163
9-3-59	L.W.S.	26	2.8	0.0	120	15	543
10-1-59	H.W.S.	21	7.7	-	298	87	631
11-5-59	L.W.S.	14	8.8	0.0	113	10	753

Table 18 - Tabulation of Survey Results

Virginia State Water Control Board

Station 13

Date	Tide	Temp.	D.O.	B.O.D.	Total Solids	Sulfates	7-Day Avg. River Discharge
7-31-61	L.W.S.	28	2.6	1.8	105	44	497
8-2-61	L.W.S.	27	2.4	1.4	123	43	423
8-6-61	H.W.S.	23	6.6	1.6	262	17	1467
10-5-61	H.W.S.	18	2.4	1.2	161	72	236
7-27-60	L.W.S.	26	3.7	1.6	112	51	273
8-3-60	H.W.S.	30	3.6	1.6	164	32	324
8-9-60	L.W.S.	29.5	2.2	2.8	128	35	421
9-15-60	H.W.S.	21	6.5	1.3	201	21	2163
9-3-59	L.W.S.	28	4.2	0.0	-	16	543
10-1-59	H.W.S.	21	0.0	-	229	73	631
11-5-59	L.W.S.	13.5	10.3	0.0	110	21	753

Table 19 - Tabulation of Survey Results

Virginia State Water Control Board

Station 14

Date	Tide	Temp.	D.O.	B.O.D.	Total	Sulfates	7-Day Avg. River Discharge
7-31-61	L.W.S.	29	2.2	3.2	117	53	497
8-2-61	L.W.S.	27	1.8	1.2	128	43	423
8-7-61	H.W.S.	23	6.2	2.0	236	24	1467
10-5-61	H.W.S.	18	2.6	2.1	171	68	236
7-27-60	L.W.S.	26	2.9	2.4	125	58	273
8-3-60	H.W.S.	30	2.3	0.0	176	62	324
8-9-60	L.W.S.	29.5	2.3	3.2	165	31	421
9-15-60	H.W.S.	21	6.1	2.6	192	31	2163
9-3-59	L.W.S.	28	4.4	0.0	-	21	543
10-1-59	H.W.S.	21	5.7	-	228	49	631
11-5-59	L.W.S.	13.5	11.5	0.0	118	12	753

Table 20 - Tabulation of Survey Results

Virginia State Water Control Board

Station 15

Date	Tide	Temp.	D.O.	B.O.D.	Total Solids	Sulfates	7-Day Avg. River Discharge
7-31-61	L.W.S.	29	3.4	3.4	103	37	497
8-2-61	L.W.S.	29	2.3	5.0	158	63	423
8-7-61	H.W.S.	24	7.0	2.3	178	32	1467
10-5-61	H.W.S.	18	2.2	1.5	195	60	236
7-27-60	L.W.S.	27	1.3	4.4	200	72	273
8-3-60	H.W.S.	30	1.7	2.0	165	45	324
8-9-60	L.W.S.	29.5	3.3	3.0	181	26	421
9-15-60	H.W.S.	21	7.2	1.6	170	17	2163
9-3-59	L.W.S.	28	4.7	1.0	-	34	543
10-1-59	H.W.S.	21	7.4	-	101	13	631
11-5-59	L.W.S.	15.5	10.2	0.0	110	13	753

Table 21 - Tabulation of Survey Benefits

Virginia State Water Control Board

Station 17

Date	Tide	Temp.	D.O.	B.O.D.	Total Solids	Sulfates	7-Day Avg. River Discharge
7-31-61	L.W.S.	20	7.1	3.2	53	4.6	497
8-2-61	L.W.S.	22	7.3	1.2	65	3.9	423
8-7-61	H.W.S.	11	7.0	1.0	188	30.0	1467
10-5-61	H.W.S.	22	9.3	0.8	75	1.8	236
7-27-60	L.W.S.	26	7.2	0.4	88	5.0	273
8-3-60	H.W.S.	21	7.6	0.6	78	9.0	324
8-9-60	L.W.S.	28.5	6.3	1.7	92	7.0	421
9-15-60	H.W.S.	24.5	8.3	1.7	80	11.0	2163
9-3-59	L.W.S.	28	2.2	1.6	-	19.0	543
10-1-59	H.W.S.	22	7.9	-	148	16.0	631
11-5-59	L.W.S.	15.5	13.8	3.4	70	0.0	753

Table 22 - Wastes and Waste Loads - Municipal and Industrial (1963)

Municipality or Industry	Population Served	MGD	Treatment	P. E. Discharged
American Viscose Corporation	-	30.000	None	38,800
Cottage Green Sub-Division	215	0.015	Primary	200
Culpeper	3,500	0.300	Secondary	700
Falmouth S. C.	350	0.350	Primary	225
Ferry Farms Sub-Division	1,000	0.050	Primary	650
Fredericksburg	12,600	1.330	Primary	10,830
Madison	300	0.020	Secondary	100
Orange	3,000	0.300	Secondary	600
Remington	290	0.030	Primary	200
Tappahannock	1,200	0.150	Primary	1,100
Urbanna	125	0.004	Primary	90
Warrenton	1,800	0.220	Secondary	180
Totals	24,380	32.769		53,675

Table 23 - Water Sources and Supplies - Municipal and Industrial (1963)

Municipality or Industry	Population Served	Gallons Per Day	
		Ground	Surface
American Viscose Corporation	-		30,000,000
Bellview Court Subdivision	210	12,000	
Culpeper	3,500		570,000
Ferry Farms Subdivision	1,000	70,000	
Fredericksburg	14,830		2,230,000
Grafton Village Subdivision	190	11,000	
Greenfield Village Subdivision	100	5,000	
Irvington	600	82,000	
Lancaster	90	3,500	
Lively	225	8,500	
Madison	410	17,700	
Orange	3,330		320,000
Port Royal	125	5,000	
Remington	340	12,000	
Saluda	270	10,000	
Sylvania Heights Subdivision	700	40,000	
Tappahannock	1,400	275,000	
Urbanna	550	17,000	
Warsaw	500	20,000	
White Stone	350	13,100	
TOTALS	28,960	601,800	33,120,000

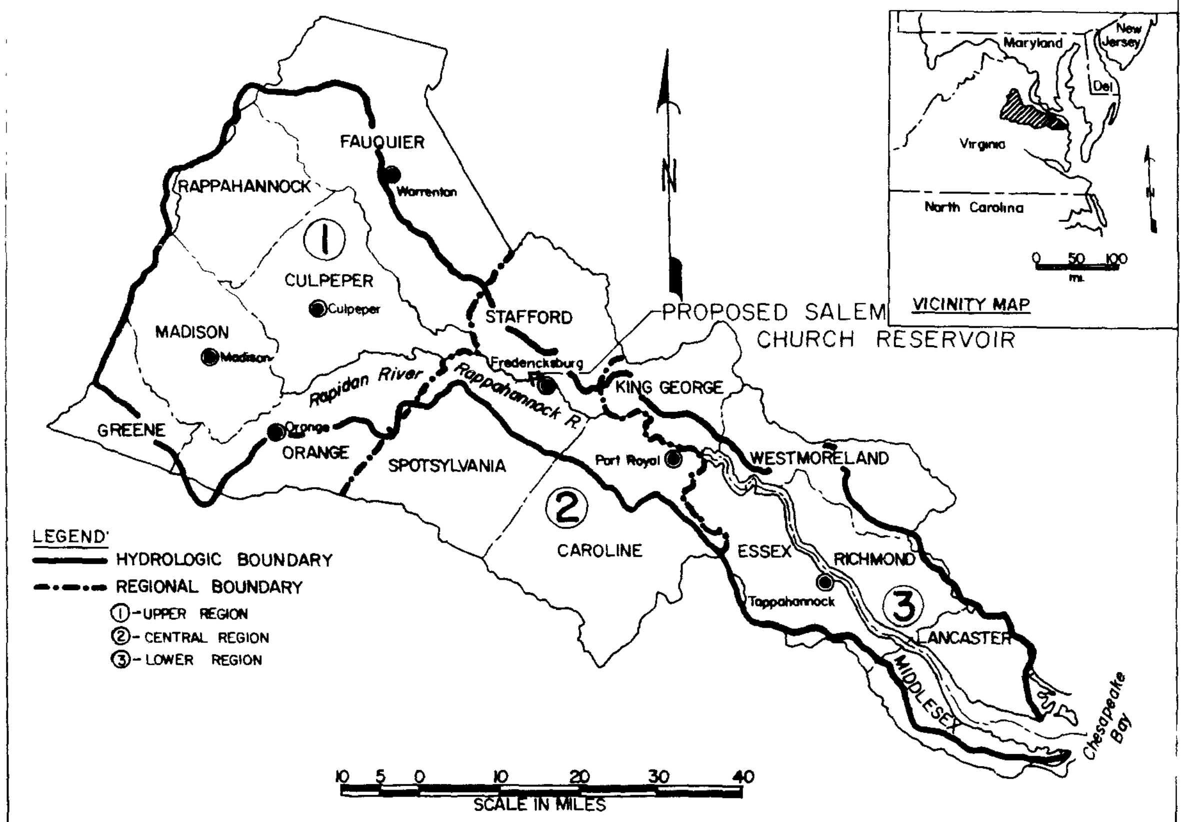


FIGURE 1

WATER RESOURCES STUDY
RAPPAHANNOCK RIVER BASIN, VIRGINIA

RAPPAHANNOCK RIVER BASIN

U S DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
PUBLIC HEALTH SERVICE – REGION III
CHARLOTTESVILLE, VIRGINIA
MAY 1964

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