Water Quality and Hydrology in the Fort Belvoir Area Virginia, 1954-55

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1586-A

Prepared in cooperation with the Atomic Energy Commission and the U.S. Army Engineers, and published with the permission of the Commission

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By C. N. DURFOR

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WATER QUALITY AND HYDROLOGY IN THE FORT BELVOIR AREA, VIRGINIA

By C. N. Durfor

ABSTRACT

This report summarizes the results of an investigation of water quality and hydrology in the Fort Belvoir, Va., area for the period August 1954 to September 1955. It summarizes and evaluates information about the water resources of this area that are pertinent to the choice of location and operation of an Army nuclear power reactor. The quantity, quality, nature, and use of the local water that might be affected by the location and operation of a reactor in the area were subjects of investigation. Variations in the quality of the water caused by variation in streamflow, tidal effects, and pollution were important facets of the investigation.

During extended periods of low streamflow in the Potomac River (usually in the late summer months), salty water moves upstream from Chesapeake Bay and increases the dissolved solids content of the surface waters adjacent to Fort Belvoir. When the streamflow is low the concentration of dissolved solids in the water near the river bottom exceeds that near the surface.

The waters in Gunston Cove usually contain more dissolved oxygen than those in the Potomac River. During the summer, the content of dissolved oxygen in the cove waters frequently exceeds 100 percent of saturation.

Surface floats that were released on a flood tide in Gunston Cove moved toward the inner portion of the cove in the same direction as the wind and the tide. The maximum average velocity of these floats was 0.65 feet per second. On an ebb tide, many surface floats that were released in Gunston Cove moved toward the inner portion of the cove in the direction of the wind, in opposition to the direction of the tidal movement. Floats released near the mouth of the cove on the same tide, moved with the tide out of the cove through a narrow pass at the end of a submerged sandbar extending from the Fort Belvoir shoreline. The maximum average velocity of the floats in the pass on this ebb tide was 0.85 feet per second. Measurements of subsurface flow direction indicate that the water in the deeper part of Gunston Cove tended to move toward Accotink Bay on the flood tide and out of the cove into the Potomac River on the ebb tide. The water 150–500 feet offshore from the reactor site tended to move toward Accotink Bay on the flood tide and toward Pohick Bay on the ebb tide, whereas waters 30 feet from the Fort Belvoir shoreline tended to move counterclockwise during part

of the time. In Gunston Cove the maximum measured flood velocity was 0.48 feet per second, and the maximum ebb velocity was 0.71 per second.

During periods of low streamflow, pollutants that enter the Potomac River at Fort Belvoir may move as much as 5.5 miles upstream on a flood tide and as much as 5 miles downstream on an ebb tide. At higher flow rates movement of pollutants is less upstream and greater downstream. The time required to flush the 10-mile reach of the Potomac River adjacent to Fort Belvoir varies from a day or two at high-flow rates to several weeks at low-flow rates.

INTRODUCTION

PURPOSE AND SCOPE OF THE INVESTIGATION

This report summarizes the findings of an investigation of quality of water of the Potomac River in the vicinity of Fort Belvoir, Va., during the period August 1954–September 1955. The investigation was requested by Mr. A. E. Gorman of the Atomic Energy Commission and Maj. J. A. Bacci of the U.S. Army Engineers. They requested that information of the type indicated by the following questions be obtained before installation and operation of a small package-power reactor at Fort Belvoir.

1. How do the physical and chemical characteristics of the water in Gunston Cove affect its use as a cooling agent?
2. How would the hydrologic conditions in this cove affect use of the water for condenser cooling and for disposal of liquid wastes?
3. How would disposal of reactor wastes and cooling water in the cove affect the physical and chemical characteristics of the cove water?
4. What hydrologic factors would be involved in any planned or accidental release of radioactive wastes from the reactor?

The investigation included assembly and review of earlier data on the quality of water in the area; collection and analysis of water samples from the Potomac River and Gunston Cove and the streams flowing into it; collection of water temperature data; measurement of subsurface movement of waters in Gunston Cove; and evaluation of these data. This report is concerned principally with study and interpretation of these data and analysis of what might be expected in years when different hydrologic conditions may prevail.

The chemical analysis of water samples was supervised by D. E. Weaver. Records of water discharge and drainage areas in Maryland and Virginia were furnished by the district offices of the U.S. Geological Survey at College Park, Md., and Charlottesville, Va., respectively. Information concerning ground-water movement in the Potomac River basin was furnished by P. M. Johnston. This investigation was conducted under the general supervision of W. F. White.

LOCATION OF FORT BELVOIR

The reactor area at Fort Belvoir is on a peninsula in the Potomac River about 20 miles south of Washington, D.C., and about 7 miles upstream from Indian Head, Md. (see fig. 1). The peninsula is

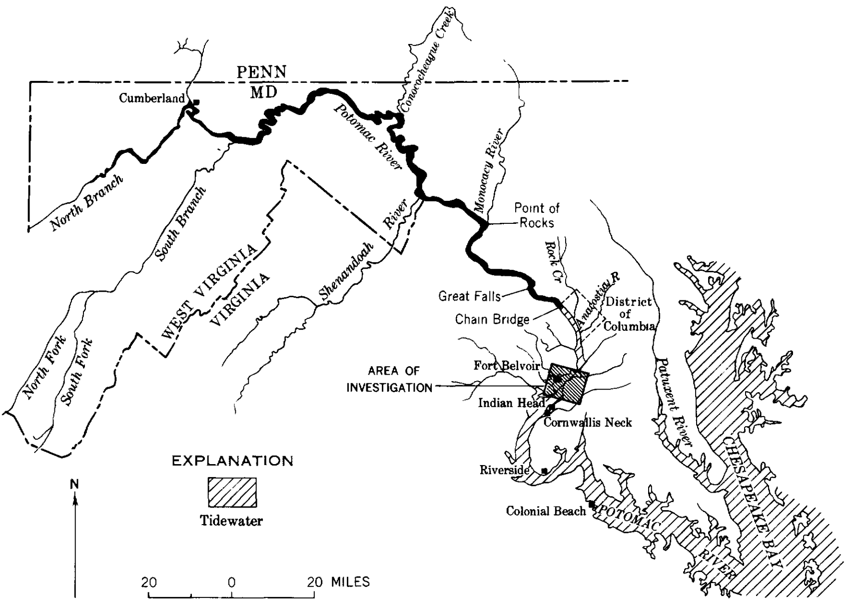

FIGURE 1.—Index map of the Potomac River drainage basin, showing area of investigation.

bordered on the northeast by Dogue Creek, on the east by the Potomac River, and on the southwest by Gunston Cove. Accotink and Pohick Creeks discharge fresh water into the tidal flats of the inner portion of Gunston Cove. Figure 2 shows at a larger scale the area outlined in figure 1 and the location of the sites at which water samples were collected.

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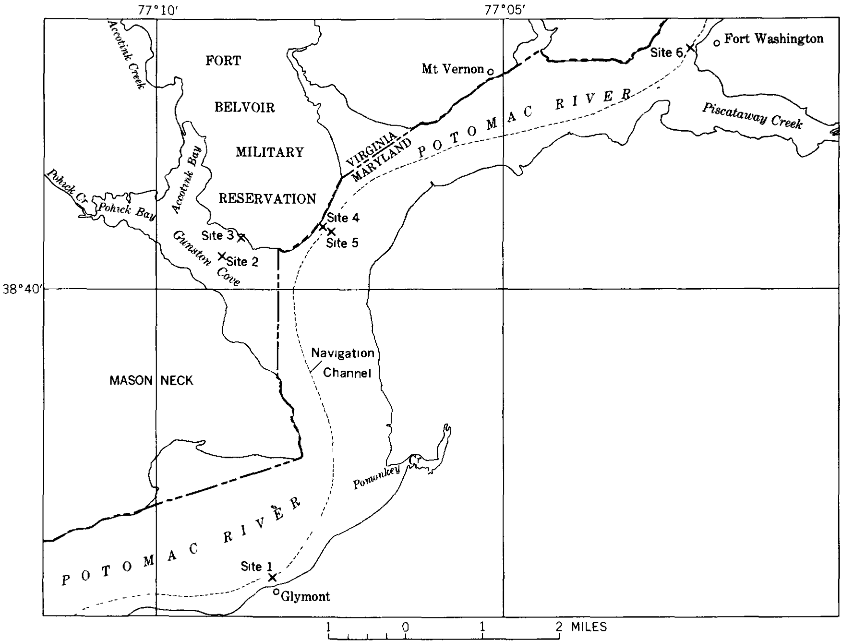

FIGURE 2.—Map of the Fort Belvoir area in the Potomac River basin, showing sites at which water samples were collected.

PREVIOUS INVESTIGATIONS

Prior to 1916, most of the investigations of the Potomac River relating to water quality were confined to that reach of the river above Washington, D.C. In 1916, the U.S. Public Health Service evaluated the sanitary and bacteriological conditions of the Potomac River between Washington, D.C., and Fort Lookout, Va., and measured the movement of floats over several tidal cycles between Chain Bridge and Colonial Beach, Va. In 1917, Messrs. J. W. Sale and W. W. Skinner investigated the vertical distribution of dissolved oxygen and the precipitation of suspended solids by salt water in the reach of the river between Washington, D.C., and Fort Lookout. In 1933, the U.S. Public Health Service investigated the disposal of sewage in the Potomac River below Washington, D.C. This report contains results of daily determinations of temperature, alkalinity, dissolved oxygen, and biochemical oxygen demand at 10 locations between Three Sisters Island and Fort Washington.

In 1949, the Chesapeake Bay Institute of the Johns Hopkins University started an investigation of the distribution of dissolved oxygen, temperature, and salinity in Chesapeake Bay. The data from each series of sampling runs and an atlas of the salinity and temperature distribution have been printed. In a report published in February 1954, Golian and others have discussed the environmental aspects of the Naval Research Laboratory, which is located in the southernmost part of the District of Columbia. For many years various government installations along the banks of the Potomac River have been analyzing the river water for those chemical constituents of interest to them. White and Durfor (1954) prepared an inventory of these data, which was released in the open files by the Geological Survey. In 1955, Paul M. Johnston (written communication) discussed ground water conditions with special reference to the effect of accidental spillage of radioactive waste at a reactor site at Fort Belvoir, Va.

HYDROLOGIC FEATURES OF THE POTOMAC RIVER WATERSHED

MAIN STEM

ABOVE THE HEAD OF TIDEWATER

The North Branch and South Branch Potomac River originate in the Appalachian Mountains of West Virginia and Virginia and flow in an easterly and northeasterly direction, respectively, to their junction at a point 21 miles southeast of Cumberland, Md. (see fig. 1). From there, the Potomac River flows east and then southeasterly through the Piedmont Plateau 170 miles to the Fall Line at Great Falls. This flashy, nonnavigable part of the Potomac River is the natural boundary between Maryland and West Virginia, Maryland and Virginia, and the District of Columbia and Virginia. The fall of the river from the confluence of the two branches to the Fall Line at Great Falls is 521 feet. The total drainage area of the Potomac River above Great Falls is 11,460 square miles. At Little Falls (approximately 0.3 mile upstream from Chain Bridge) the river cascades over irregular rocky shelves. From this point the Potomac River, here subject to tidal action, continues in a southeasterly direction for a distance of 117 miles across the Coastal Plain to Chesapeake Bay.

The discharge rates of the Potomac River are a factor in establishing the pattern of chemical quality, the circulation pattern, and the flushing characteristics. The discharge rates of this stream are measured at Point of Rocks, located about 90 miles above Washington, D.C., and at a point above Chain Bridge near Washington, D.C. The lowest 7-day discharge and the lowest 30-day discharge at the Point of Rocks gage for each year between 1895 and 1954 are shown on figure 3. A duration curve for the daily discharge at the gage above

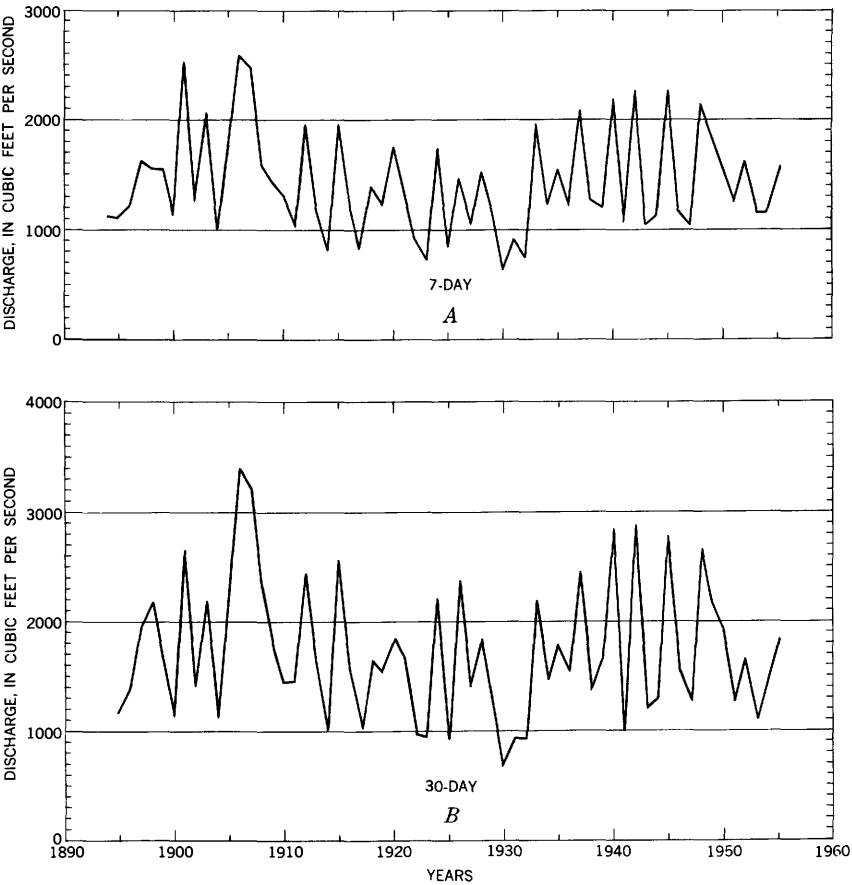

Figure 3.—Potomac River at Point of Rocks, Md., 1895–1954. ***A***, **Annual lowest 7-day discharge ;** ***B***, **Annual lowest 30-day discharge.**

Chain Bridge near Washington, for the period 1931 through 1954, has been constructed (see fig. 4). This curve indicates the percentage

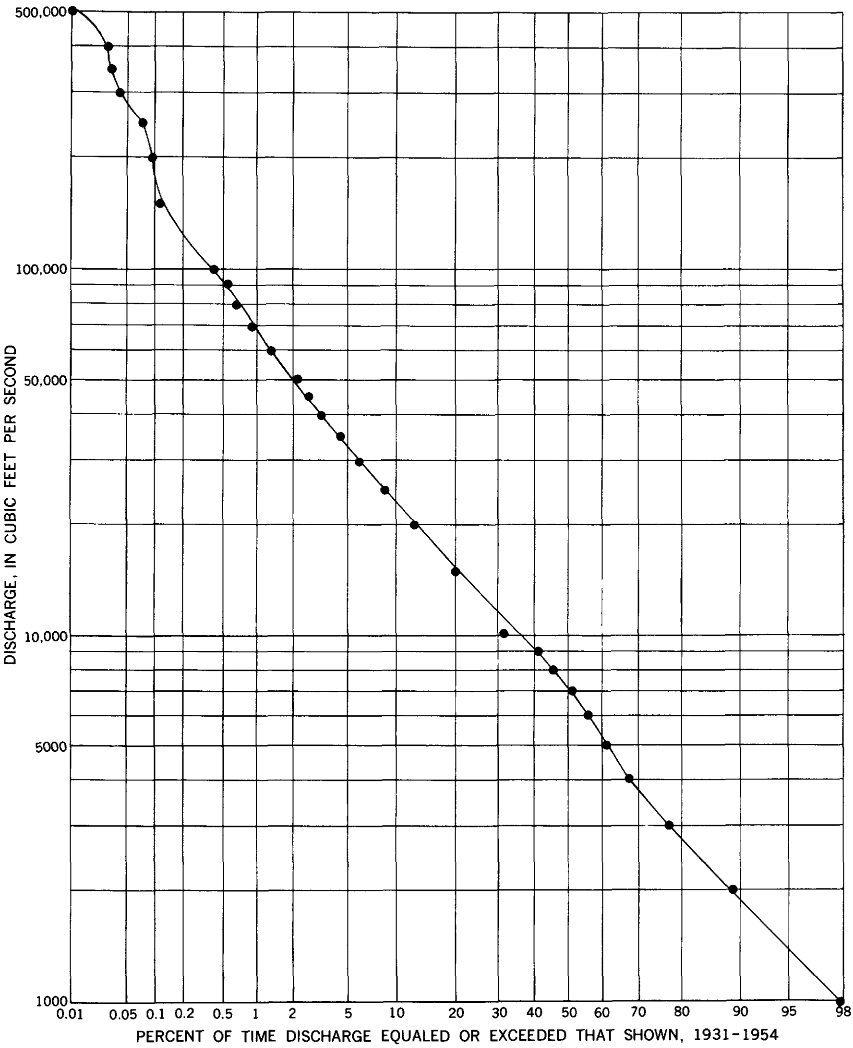

FIGURE 4.—Duration curve of daily flow, Potomac River near Washington, D.C., 1931–54.

of time various flow rates at the gaging station have been equaled or exceeded, irrespective of their chronological sequence of occurrence. For example, the flow rate at the gage near Washington equaled or exceeded 2,000 cfs (1293 mgd) 88 percent of the time. The Department of the Army diverts water for the public supply of the District of Columbia from the Potomac River at the Washington Aqueduct located just above Great Falls. The mean daily diversion at Washington Aqueduct for the period October 1951 to September 1952 was 328 cfs. However, the amount of diversion varies throughout the year, depending upon the needs of the municipal water supply. The discharge figures shown in figure 4 represent the flow of the river downstream from the diversion and do not include water diverted for municipal use.

The streamflow of the Potomac River above Chain Bridge, near Washington, varies in a cyclic manner throughout the year. The minimum monthly discharge and the mean monthly discharge for the period 1931 to 1954 have been plotted on figure 5. The higher

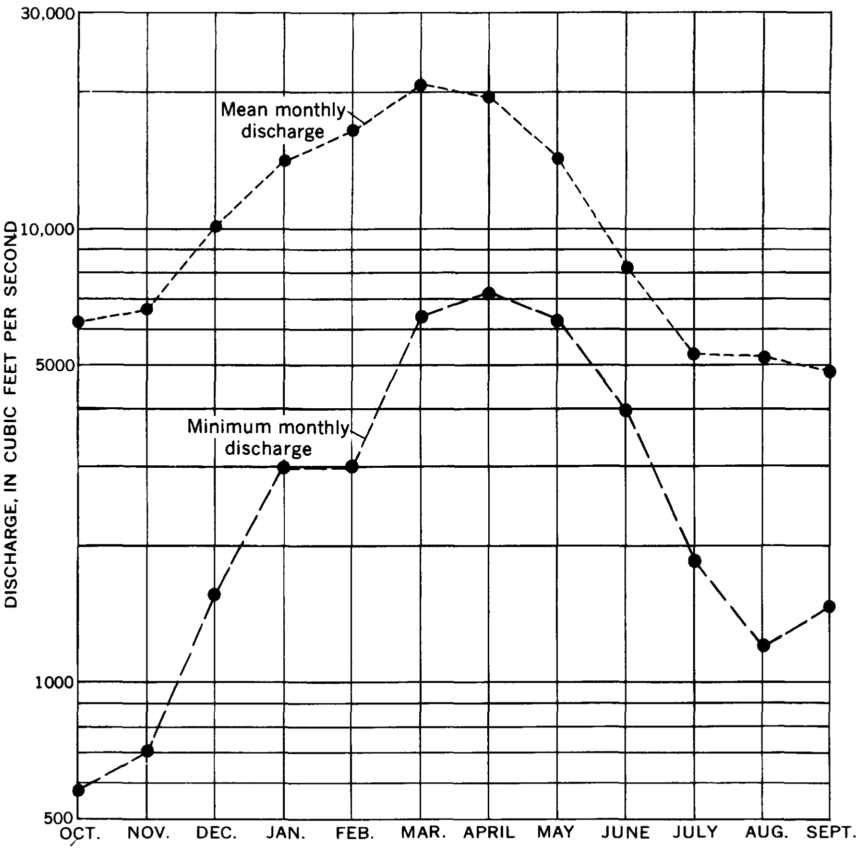

FIGURE 5.—Minimum monthly and mean monthly discharge of the Potomac River near Washington, D.C., 1931–54.

discharge rates of the Potomac River occur during the period February through May. The discharge rates usually decrease after May and a period of low-flow occurs during the period July through

November. The times of maximum and minimum discharges in the Potomac River may vary from year to year. For example, the minimum monthly flow during the period of record reached a low of 583 cfs in October of 1931, and the maximum monthly mean discharge (44,100 cfs) occurred in October 1943.

BELOW THE HEAD OF TIDEWATER

In the vicinity of Fort Belvoir the normal downstream flow of the river is periodically interrupted by the flood tide, and the direction of water movement is then upstream until ebb tide, when the water flows downstream until the next flood tide. In the Potomac River the tide passes through two cycles in approximately 24 hours and 50 minutes. Successive high and low tides occur about one-half hour later each 12-hour cycle, or about 50 minutes later each succeeding day. Times and heights of high and low water at Washington Channel are predicted by the U.S. Coast and Geodetic Survey and are published annually in "Tide Tables, East Coast, North and South America." The high tide of the Potomac River at Gunston Cove occurs about 50 minutes sooner than in the Washington Channel; the high tide at Glymont occurs one hour and 10 minutes sooner than in the Washington Channel. In the latter part of September 1955, a water-stage recorder was installed in Gunston Cove. The observed times of high and low tides in Gunston Cove closely approximate the times of high and low tides predicted by the "Tide Tables." In the Potomac River near Fort Belvoir and in Gunston Cove the ebb tide lasts longer than the flood tide.

The location of the deeper portions of the Potomac River accords with the normal pattern of a flowing stream; that is, the navigation channel lies nearest the outer bank of the river bends. Thus the navigation channel lies close to the Maryland shore at Fort Washington and Glymont, and close to the Virginia shore in the reach of the river between Dogue Creek and Hallowing Point. At Fort Belvoir the river is about 1 mile wide, and the center of the navigation channel is about 600 feet from the shoreline of Fort Belvoir. The navigation channel, which is about 600 feet wide, ranges in depth from 30 to about 60 feet at mean low water; the river decreases gradually in depth from about 15 feet at a distance of 2,000 feet off-shore at Fort Belvoir to about 1½ feet near the Maryland shore. A large submerged sandbar extends about 80 percent of the distance across the mouth of Gunston Cove. At mean low water, the depth of the water in this cove ranges from 3 feet at its mouth to 6 or 7 feet in the large oval depression in the center of the cove. This shallow tidal cove has an area of about 3.5 square miles.

INFLUENCE OF TRIBUTARY RUNOFF AND GROUND-WATER DISCHARGE ON POTOMAC RIVER DISCHARGE

TRIBUTARY RUNOFF

The waters of the Potomac River near Washington, D.C., are augmented by waters from the Anacostia River and numerous smaller tributaries. The navigable tidal section of the Potomac River, between Chain Bridge and Fort Belvoir, has a drainage area of 2,920 square miles. The following streams enter this tidal river above Fort Belvoir: Rock Creek, Anacostia River, Four-Mile Run, Oxon Run, Hunting Creek, Broad Creek, Swan Creek, Piscataway Creek, Little Hunting Creek, Dogue Creek, Accotink Creek, and Pohick Creek. The drainage area between Washington, D.C., and Fort Belvoir is only about 4 percent of the total drainage area of the Potomac River above Fort Belvoir.

Accotink Creek has a drainage area of less than 50 square miles and empties into a tidal flat known as Accotink Bay, which unites with Gunston Cove (see fig. 2). Since May 1949, the U.S. Geological Survey has operated a water-stage recorder on this stream near Accotink Station, Virginia. The maximum daily streamflow at the gaging station during the period of record was 1,240 cfs; the minimum daily streamflow was 2.5 cfs. Pohick Creek, also, has a drainage area of less than 50 square miles, and it empties into another tidal flat known as Pohick Bay, which unites with Gunston Cove. Continuous records of streamflow on Pohick Creek are not available. Miscellaneous measurements of Pohick Creek near Springfield, Va., were made between 1947 and 1954.

GROUND-WATER DISCHARGE

Discharge of ground water into the Potomac River occurs in variable amounts, depending upon the nature of the aquifers and the gradient from the water table to the river. From its headwaters to Memorial Bridge in the District of Columbia (approximately 4.5 miles below Chain Bridge), the river flows in a valley cut in consolidated bedrock though minor deposits of recent alluvium border the stream in places. Discharge of ground water from the alluvium is probably more rapid than from bedrock, but of shorter duration owing to the small area involved. In the consolidated rocks the movement of ground water into the river is probably rather slow except possibly where the river passes over limestone, which in some places may be cavernous.

Below Memorial Bridge the river flows over the unconsolidated sands, gravels and clays of the Coastal Plain. The sands and gravels are much more permeable than the clays and the consolidated rocks, hence discharge of ground water into the river is more rapid and in larger quantities in the Coastal Plain than in the Piedmont Plateau.

FIELD STUDIES

INVESTIGATIONS OF CHEMICAL QUALITY

Water samples were collected from Gunston Cove near the Fort Belvoir shoreline and 2,000 feet from the shoreline opposite the proposed site of the rèactor. Since the water from the Potomac River could have a pronounced effect on the chemical quality of the water in the cove, samples of the river water were collected 30 feet offshore at Fort Belvoir and from the navigaation channel near Gunston Cove. The river was sampled about 5 miles above Fort Belvoir, near Fort Washington, because this location was believed to represent the maximum upstream point of travel on the flood tide from Fort Belvoir. The river water was sampled approximately 4 miles below Fort Belvoir near Glymont. This location is at the first bend in the river below Fort Belvoir and was considered to be the maximum downstream point of travel on an ebb tide. Accotink and Pohick Creeks discharge into the inner portion of Gunston Cove. In order to evaluate the effects of the water from these creeks, water samples were taken of the streams above the influence of tide water on the same days that samples were taken from the Potomac River. See figure 2 and the following table for locations of all water sampling sites.

Locations of sampling sites on the Potomac River and on Accotink and Pohick Creeks

Site	*Location*
1	Potomac River at Glymont, 4 miles downstream from Fort Belvoir and 1½ miles upstream from Indian Head, Md.
2	Gunston Cove, 2,000 feet offshore from reactor site at Fort Belvoir.
3	Gunston Cove, 30 feet offshore from reactor site at Fort Belvoir.
4	Potomac River, 30 feet offshore from point 300 yards below U.S. Bureau of Fisheries dock at Fort Belvoir.
5	Potomac River, 400 feet offshore from point 300 yards below U.S. Bureau of Fisheries dock at Fort Belvoir.
6	Potomac River at Fort Washington, 5 miles upstream from Fort Belvoir.
7	Accotink Creek at the intersection of U.S. Route 1.
8	Pohick Creek at the intersection of U.S. Route 1.

It was assumed that the analyzed samples of Potomac River water taken at high tide represent the water of the greatest concentration of dissolved solids during a tidal cycle, and the analyzed samples taken

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at low tide represent water of the least concentration of dissolved solids during the tidal cycle. During most of the year, when changes in chemical quality of the Potomac River were slight, water samples were taken monthly; when the chloride concentration of the Potomac River near Fort Belvoir exceeded 25 ppm, water samples were collected weekly.

Samples of the Potomac River obtained for comprehensive chemical analysis were collected just below the surface in one-liter Pyrex bottles. Other samples of water near the bottom were taken with a Foerst sampler and collected in 370-ml pressure-closure bottles for partial chemical analysis.

From September 14, 1954, to July 1, 1955, comprehensive analyses were made once a month of the surface-water samples collected at high and low tide at each sampling site on the Potomac River. During the period July 1, 1955, through September 30, 1955, comprehensive analyses were made of the surface-water samples having the largest and the smallest content of dissolved solids (as indicated by the specific conductance) collected at the six sampling locations during the sampling day. A partial analysis was made of the other 10 water samples. The comprehensive analysis consisted of determination of color, pH, specific conductance, silica, iron, lithium, sodium, potassium, calcium, magnesium, bicarbonate, sulfate, chloride, fluoride, nitrate, dissolved solids, hardness, and turbidity. The partial analysis consisted of determination of pH, specific conductance, chloride, bicarbonate, and turbidity. Because the waters of the Accotink and Pohick Creeks were not expected to change radically in chemical quality, comprehensive analyses of these waters were made less frequently than for the Potomac River.

The temperature and dissolved oxygen content of the waters in the vicinity of Fort Belvoir were expected to vary with depth and with location. These variations would help to establish the circulation pattern of water in the vicinity of Fort Belvoir. Samples of the Potomac River for the determination of dissolved oxygen were collected just below the surface of the water at each of the six sampling locations, and near the bottom in Gunston Cove. These samples were collected with the standard dissolved oxygen sampler and stabilized as recommended in "Standard Methods for Examination of Water, Sewage and Industrial Wastes" (Am. Pub. Health Assc., 1955). Water temperature was measured using an underwater thermometer calibrated in 0.2°F. The thermometer has a thermistor for a sensing element and responds rapidly.

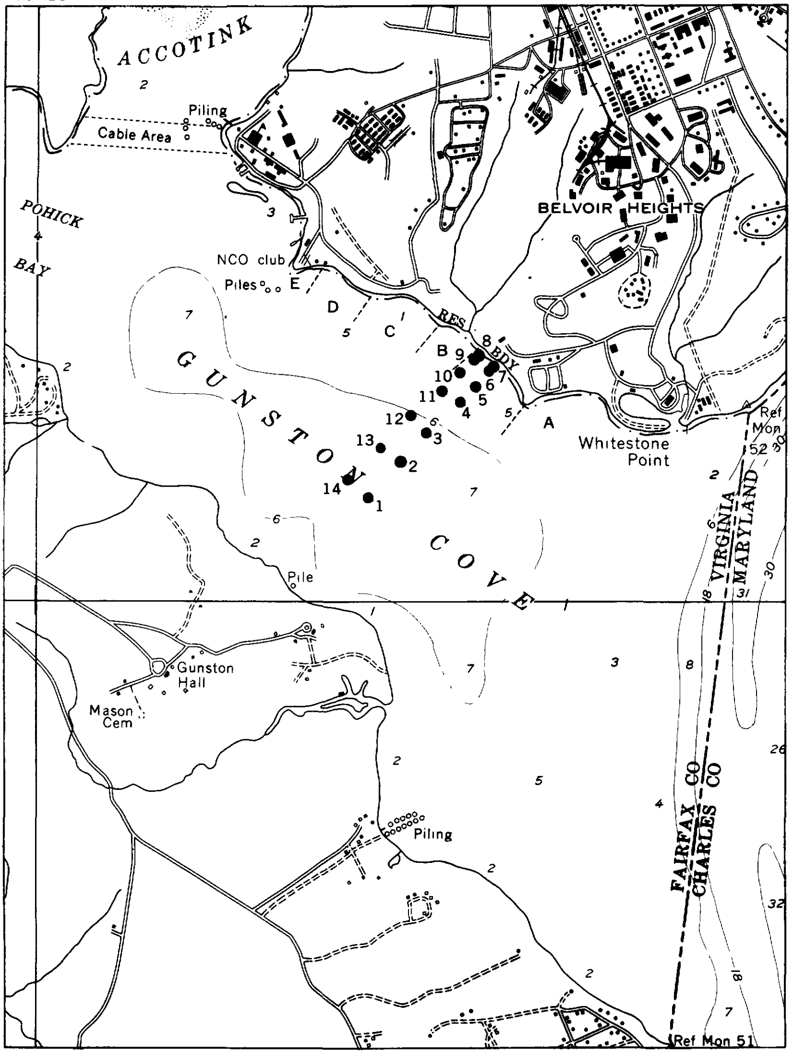
SURFACE FLOAT INVESTIGATIONS IN GUNSTON COVE

A study of the chemical quality data indicated a need for more intensive studies of the circulation pattern of the water in Gunston Cove. Two float studies were made to evaluate the flow pattern of the surface water. The floats were constructed of 1½- by 2- by 8-inch Douglas fir that had been water sealed and oven dried. To keep the floats in a vertical position a metal slug was attached to the bottom of the wooden float. The top of the float extended about ½ inch above the surface of the water. Attached to the top of the float was a 6-inch-square, numbered, and colored pennant, which was free to turn with the wind. About 15 of these floats were distributed throughout the cove on the change of the tide. When these floats were grounded or when it was apparent that additional floats would be needed to supplement the data being obtained, more floats were set out at strategic points during the ebb or flood tide. The movements of these floats throughout one flood and one ebb tide were recorded by observers stationed at three locations on the banks of Gunston Cove. One man in a boat located the floats at various intervals and communicated the approximate position to the observers on shore, who located the exact position with transits. Observations of the movement of these surface floats on a flood tide were carried out on June 29, 1955, and on an ebb tide on July 25, 1955.

SUBSURFACE HYDROLOGIC INVESTIGATIONS IN GUNSTON COVE

A study of the data on chemical quality and the data obtained from the float investigations indicated a need for concentrated study of the subsurface movement of water in Gunston Cove. This study consisted of measurements of current velocity, current direction, water depth, specific conductance, and chloride concentration two hours before and after a high and a low tide on nine days between August 3, 1955 and September 2, 1955. The 332d Engineer Survey Liaison Detachment of the U.S. Army Reserve assisted in this investigation by making observations beginning 7:30 p.m. on August 27, 1955, continuing through the night, and ending at 2:02 p.m. on August 28, 1955. The data obtained by this unit were incorporated into the Geological Survey data.

Measurements were made on a line normal to the Fort Belvoir shore near the projected site of the intake line, and on a line normal to the Fort Belvoir shore 250 feet upstream from the first line. The location of each of the observation points (14 in number) are shown on figure 6. Measurements were made 1 foot below the water surface and 1 foot above bottom at all locations. The times of observations were planned so that the observations at location 7 (50 feet from shore) were made 2 hours before or after a high and a low tide. The majority of the observation runs were made during the daylight hours. The "Tide Tables, East Coast" of the U.S. Coast and Geodetic Survey were used to predict the times of high and low tides in Gunston Cove.



Base from U. S. Geological Survey Belvoir, Va.–Md. 7½-minute quadrangle, 1956

2000 0 2000 FEET

DEPTH CURVES AND SOUNDINGS IN FEET
DATUM IS MEAN LOW WATER

Figure 6.—Map of Gunston Cove, Va., showing location of observation sites 1 to 14 and temperature ranges *A* to *E* during hydrologic investigation of 1954–55. Measurements were made of velocity, current direction, temperature, and specific conductance of the water at various depths.

Water velocity was measured with a standard Price low-velocity current meter using equipment for a regular boat measurement of discharge with a Type A reel and a 30-pound weight suspended 0.5 feet below the meter. The depth of the water was measured by lowering the 30-pound weight to the bottom of the cove and reading the depth directly from the calibrated counter on the Type A reel. To stabilize the boat, anchors were utilized fore and aft. Readings of velocity and current direction were made after the boat became stationary. The direction of flow was measured by the following method. A string was attached to the tailfin of the 30-pound weight suspended below the current meter. As the current meter and the weight were lowered into the water, the tailfins oriented themselves in the direction of the flowing water. When the string from the tailfins assumed a stable position, it was pulled taut. The magnetic azimuth of an imaginary line through two points on the water surface formed by the cable supporting the current meter and the string attached to the tailfin was recorded. A standard Navy compass was used to indicate magnetic directions which were recorded to the nearest 10°. An average current direction was recorded when the flow direction vacillated. All magnetic current direction readings were converted to degrees from due north.

At each of the 14 observation points specific conductance was measured 1 foot below the surface of the water and 1 foot above the bottom of the cove. Water samples were collected that were representative of the range of specific conductance encountered during each observation run. The specific conductance and chloride concentration of these samples were determined in the laboratory. The underwater thermometer was used to measure the water temperature near the bottom and 1 foot below the surface.

CHEMICAL AND PHYSICAL CHARACTERISTICS OF THE POTOMAC RIVER

ABOVE THE HEAD OF TIDEWATER, AT GREAT FALLS

The Potomac River at Great Falls has been sampled by personnel from the Dalecarlia Filtration Plant for many years. Partial chemical analyses were made on the daily samples and comprehensive chemical analyses were made on the monthly composite sample. The river at Great Falls usually contains less than 200 ppm of dissolved solids and less than 15 ppm of chloride. Usually the hardness of the river is less than 150 ppm; the bicarbonate is less than 110 ppm; the calcium and the sulfate are each less than 40 ppm and the magnesium and nitrate are each less than 10 ppm.

HEAD OF TIDEWATER TO FORT WASHINGTON

In addition to the regular weekly or monthly sampling by the personnel of the District of Columbia Sewage Treatment Plant, the water of the Potomac River between Three Sisters Island (2½ miles downstream from Chain Bridge) and Fort Washington was sampled on special field trips by the Geological Survey. When the discharge of the Potomac River is above average the changes in chemical character of the river between Great Falls and Fort Washington are insignificant. During periods of low flow the salty water from Chesapeake Bay intrudes as far upstream as Three Sisters Island and lowers the pH of the water and bicarbonate content and increases the chloride and dissolved solids.

VICINITY OF FORT BELVOIR

Chloride data from 1930 to 1944 and recent continuous conductivity records (calibrated from 0–520 ppm Cl) of the Potomac River at Indian Head, Md., were furnished by personnel of the Naval Powder factory.

INFLUENCE OF RIVER DISCHARGE

The concentration of dissolved material in the Potomac River near Fort Belvoir varies with stream flow. At low flow rates the dissolved solids content is high, and at high flow rates the dissolved solids content is low. At most discharge rates the concentration of dissolved solids increases in a downstream direction.

The amount of each chemical constitutent in the water of the Potomac River varies with location and the flow rate of the river. When the flow rate of the river is above average, the amount of dissolved material does not vary greatly but the concentrations of the individual constituents occur in slightly different proportions. In figure 7 the concentrations in equivalents per million (epm) of the major constituents found in water of the Potomac River on March 10, 1955, at Glymont, Gunston Gove, Fort Belvoir, and Fort Washington (sites 1, 2, 5, and 6 on fig. 2) have been plotted. The mean daily discharge for this date was 37,600 cfs. At this flow rate the calcium content exceeded the chloride, indicating that the waters in this reach of the river were of the same chemical character as the water entering the head of tidewater near Little Falls.

When the flow rate decreased, during the late summer, the concentration of dissolved material increased. The concentrations of the major ions in the water of the Potomac River on October 6, 1954, also have been plotted on figure 7. The mean daily discharge for this date was 1,290 cfs. The increases in concentration were caused primarily

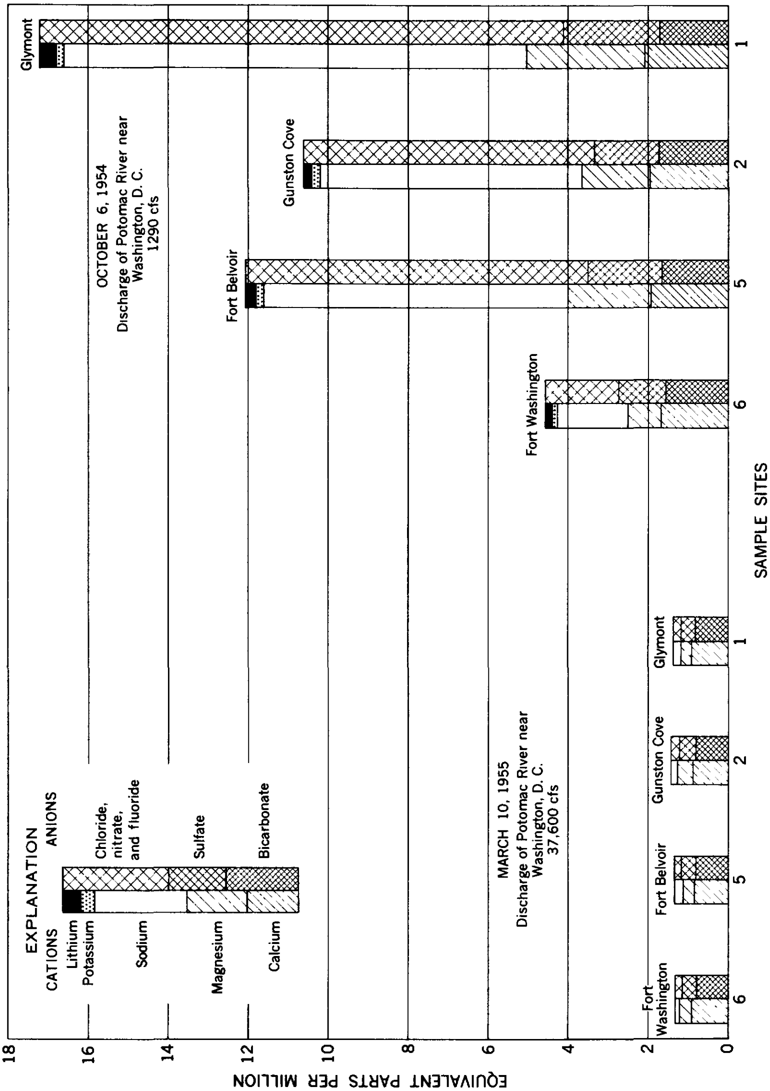


FIGURE 7.—Chemical character of the Potomac River water in the Fort Belvoir area, October 6, 1954, and March 10, 1955.

by the encroachment of salty water from Chesapeake Bay. The greater the distance downstream, the greater the increase in concentration and more pronounced the change in composition. From figure 7 it can be noted that at the extreme downstream station (site 1) the ratio of sodium to calcium is about 5:1; whereas, at the extreme upstream station (site 6) the ratio of sodium to calcium is slightly over 1:1. The ratio of chloride to bicarbonate also increases as the bay is approached. Thus, the water at the downstream locations had a tendency to take on the chemical characteristics of ocean water and the water at the upstream location was more like the water at Great Falls.

During periods of sustained low flow the concentration of dissolved solids in this tidal river below Fort Washington slowly increases to a high level. Between 1895 and 1954 the lowest mean 7-day discharge and the lowest mean 30-day discharge of the Potomac River occurred in 1930 (see fig. 3). An analysis of the chloride data of the Potomac River at Indian Head reveals that the maximum chloride on record occurred during the summer of 1930. Chloride concentrations at Indian Head during the salt-water invasions of 1930 and 1954, and chloride concentrations at Fort Belvoir during the salt-water invasions of 1954, are plotted on figure 8. It has been estimated from this graph that about 2 months are required for the chloride at Indian Head to move from the minimum values to the plateaus of high chloride in 1930 and 1954. Since this program of investigation started during the salt-water invasion of 1954, the time interval for chloride at Fort Belvoir to reach the plateau of high chloride can be estimated to be of the same duration.

After these high chloride concentrations are reached, the variation in maximum daily chloride is small compared to the total chloride concentration. It can be noted from the graph that the plateau of high chloride was considerably higher in 1930 than during the same period in 1954. The mean discharge of the Potomac River for July, August, September, and November of 1930 was considerably lower than the mean discharge for the same period of time in 1954. The maximum chloride content on record at Indian Head during 1930 was 3,700 ppm and in 1954 it was 1,300 ppm. Since there have been longer periods of sustained lower flow in the Potomac River (as in 1930) than in 1954, it is not unreasonable to assume that chloride concentrations greater than the maximum chloride concentration on record during 1954 at Fort Belvoir could be expected in the future.

When the flow rate increases slowly after periods of sustained low flow, the concentration of dissolved material decreases slowly. Between December 1930 and March 1931, the discharge rate gradually

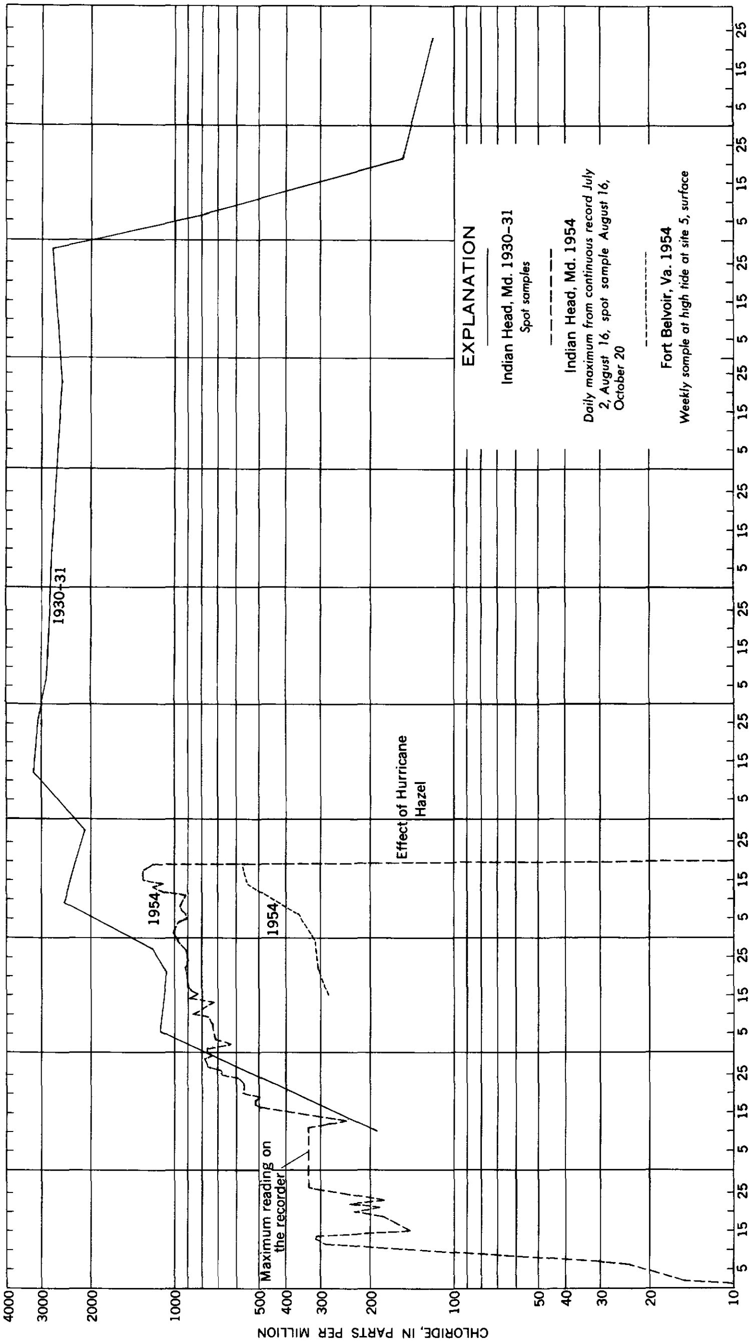


FIGURE 8.—Chloride concentration of the Potomac River water at Fort Belvoir, Va., and Indian Head, Md., 1930–54.

increased to about 5,000 cfs with little or no decrease in the chloride content at Indian Head. In April of the same year, the discharge rate rose from about 5,000 cfs to slightly higher than 25,000 cfs in about 30 days and there was a corresponding decrease in chloride from 2,500 ppm to 150 ppm in the same period of time. When the stream flow of this river increases rapidly, the dissolved solids content decreases rapidly. On October 19, 1954, for example, the chloride content at Indian Head was 1,200 ppm; but the large amount of runoff associated with hurricane Hazel rapidly increased the discharge and flushed this reach of the river so effectively that on October 20, 1954, only 13 ppm of chloride was recorded. This phenomenon is illustrated on figure 8.

INFLUENCE OF STAGE OF TIDE AND DEPTH OF WATER

The amount of dissolved materials present in the reach of the river between Fort Washington and Glymont varies with the stage of the tide. On the flood tide the salty water from Chesapeake Bay moves upstream until high-water slack. On the ebb tide the salty water from the preceding flood tide (mixed with the upstream fresh water) retreats downstream until low-water slack. Since the current strength in the navigation channel is stronger than in the more shallow parts of the river, the advance and retreat of salty water is more rapid in the navigation channel. Most of the year the variation in concentration of dissolved materials with depth is negligible in this reach of the river. During periods of salt water invasion the concentration of dissolved materials near the river bottom exceeds that near the surface.

ESTIMATION OF CHEMICAL QUALITY FROM SPECIFIC CONDUCTANCE

Specific conductance is a measure of the ability of water to conduct a current of electricity as a result of the ionization of dissolved salts. The specific conductance of water is the reciprocal of the electrical resistance of 1 cubic centimeter of the water, between electrodes each 1 square centimeter in area, and is expressed in micromhos. The specific conductance can be used as a measure of the concentration of dissolved salts, because the electrical conductivity increases in direct proportion to the concentration of dissolved solids. For this reach of the river the numerical value of specific conductance in micromhos measured at 25°C is approximately 1.8 times the weight of dissolved solids, in parts per million.

The measurement of specific conductance is more rapid and convenient than chemical analyses of water and was used to eliminate

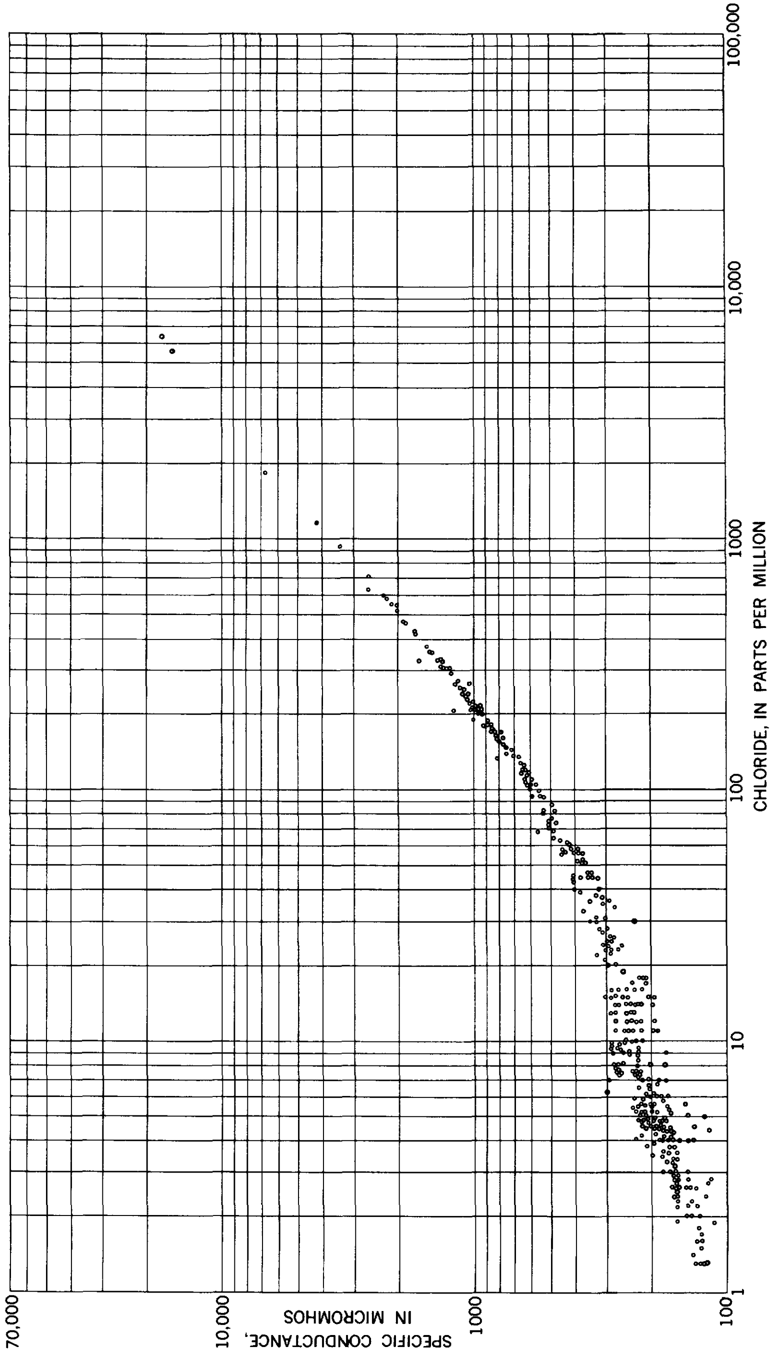


FIGURE 9.—Relation between specific conductance and chloride concentration.

many chemical determinations. Specific conductance was used to estimate the concentration of many chemical constituents. The relation between specific conductance and chloride is shown in figure 9. When the specific conductance of Potomac River water exceeds a value of 600 micromhos, the relation between specific conductance and the chloride is approximately a straight line when plotted on a logarithmic scale. Below a specific conductance of 600 micromhos (100 ppm of chloride) the relation between the chloride concentration and conductivity is more complex.

The relations between specific conductance and several other dissolved constituents in these waters are similar to the specific conductance-chloride relations, and can be used to estimate the concentration of these other ions. However, the relations between the specific conductance and the concentration of the various ions present are not precise and may vary with time, location in the reach, discharge, and other factors. The specific conductance relations stated above pertain to the Potomac River between Fort Washington and Glymont during the period of this investigation and do not represent the conditions existing at Accotink and Pohick Creeks.

RANGE OF OBSERVED CHEMICAL CONSTITUENTS AND TURBIDITY

As stated previously, comprehensive analyses were not made of each sample collected. However, the more important chemical determinations were made on all samples. Table 1 shows the concentrations of the more important constituents of samples of maximum and minimum specific conductance from the Potomac River at each sampling location. The maximum concentration of dissolved solids in the river water occurred at high tide and near the bottom, and the minimum concentration occurred at low tide.

Table 2 shows the maximum and minimum turbidity of the surface water at the sampling sites on the Potomac River. In general, the turbidity of the waters is low and reaches a maximum during periods of flood water. Since the water at these locations was not sampled during a flood, the maximum turbidity indicated in these tables may be low.

TABLE 1.—*Maximum and minimum values in the specific conductance and partial chemical analyses of water of the Potomac River at Fort Washington, Fort Belvoir, and Glymont*

[Based on weekly or less frequent sampling. For location of sampling sites, see fig. 2]

Sampling site	1 Glymont	4 Fort Belvoir (30 ft offshore)	5 Fort Belvoir (400 ft offshore)	6 Fort Washington
Maximum				
Date	Oct. 6, 1954	Oct. 14, 1954	Oct. 14, 1954	Oct. 14, 1954.
Stage of tide	High	High	High	High.
Depth (feet)	68	3	55	70.
Specific conductance (micromhos at 25° C)	4,180	1,480	2,090	827.
Hardness as $CaCO_3$ (ppm)	472	226	330	164.
Bicarbonate (ppm)	101	100	99	101.
Chloride (ppm)	1,160	355	545	168.
Nitrate (ppm)	3.1	2.5	2.0	4.1.
pH	7.2	7.1	7.2	8.0.
Turbidity (ppm)	28	7.0	30	35.
Minimum				
Date	Mar. 10, 1955	Mar. 10, 1955	Mar. 10, 1955	Mar. 24, 1955.
Stage of tide	Low	Low	Low	Low.
Depth (feet)	65	6	50	Top.
Specific conductance (micromhos at 25° C).	142	139	133	134.
Hardness as $CaCO_3$ (ppm)	64	60	57	64.
Bicarbonate (ppm)	55	55	53	47.
Chloride (ppm)	2.2	2.6	1.8	2.4.
Nitrate (ppm)	4.2	4.2	4.5	3.5.
pH	7.4	7.5	7.5	7.4.
Turbidity (ppm)	192	87	80	182.

TABLE 2.—*Turbidity of the Potomac River at Fort Washington, Fort Belvoir, and Glymont*

[Based on weekly or less frequent sampling. For location of sampling sites, see fig. 2]

Sampling site	Date	Maximum turbidity at surface (ppm)	Discharge at Chain Bridge (cfs)	Date	Minimum turbidity at surface (ppm)	Discharge at Chain Bridge (cfs)
1 Glymont	Mar. 24, 1955	276	90,600	Sept. 15, 1954	5.1	1,080
2 Gunston Cove, 2,000 feet offshore	do	71	90,600	do	4.8	1,080
3 Gunston Cove, 30 feet offshore	Oct. 21, 1954	80	17,300	do	5.8	1,080
4 Fort Belvoir, 30 feet offshore	Mar. 24, 1955	119	90,600	Oct. 14, 1954	4.3	1,080
5 Fort Belvoir, 400 feet offshore	do	182	90,600	Sept. 15, 1954	5.0	1,330
6 Fort Washington	do	182	90,600	do	4.3	1,080

GUNSTON COVE

TRIBUTARY INFLUENCE

The chemical quality of the Accotink and Pohick Creeks, which discharge into the northeastern and northwestern tidal flats of Gunston Cove, did not change appreciably during the period of investigation. Figure 10 is a time series of bicarbonate, chloride, hardness,

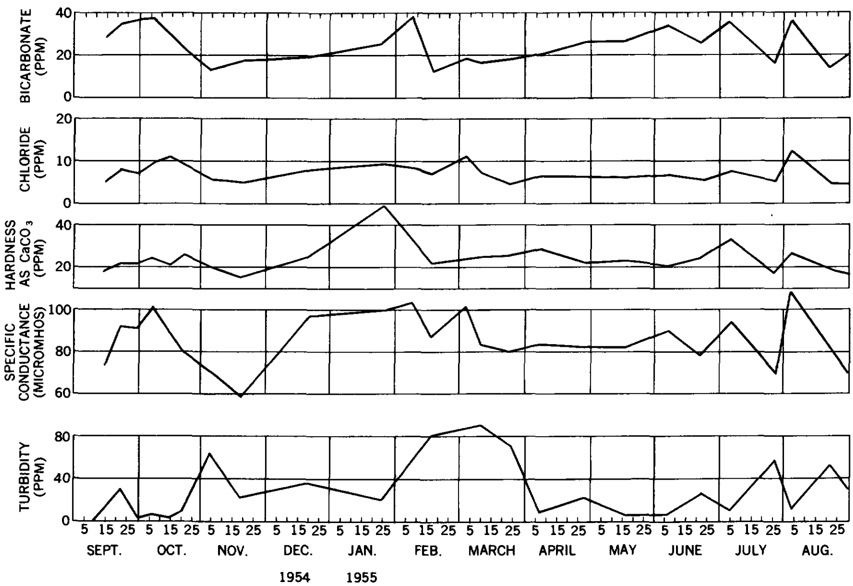


FIGURE 10.—Chemical quality of the water of Accotink Creek, September 1954–August 1955.

turbidity, and conductivity of the Accotink Creek throughout the period of this investigation. Accotink Creek had a maximum recorded hardness of 50 and a minimum recorded hardness of 14. The Pohick Creek had a maximum recorded hardness of 34 and a minimum recorded hardness of 10. When the streamflow of these streams is low, the concentration of the dissolved solids in Gunston Cove is considerably higher than the concentrations of the dissolved solids of either stream. The small amount of water added to the cove by these streams is insufficient to change the chemical quality of Gunston Cove. When the streamflow of the Potomac River is high, these streams do not contribute enough water to alter the composition of the waters in this cove.

Table 3 shows the concentrations of the more important constituents in samples of the water of maximum and minimum specific conductance from Gunston Cove, Accotink Creek, and Pohick Creek. During the period of the investigation the maximum observed concentration of iron in the water of Gunston Cove was 1.5 ppm and the maximum observed concentration of manganese was 0.22 ppm. No samples were taken of Accotink or Pohick Creek during a flood period, hence it is possible that the chemical constituents of these streams may be lower than the determination shown in table 3.

TABLE 3.—*Maximum and minimum values in the specific conductance and partial chemical analyses of water in Gunston Cove, Accotink Creek, and Pohick Creek*

[Based on weekly or less frequent sampling. For location of sampling site, see fig. 2]

Sampling site	2 Gunston Cove, 2,000 feet offshore	3 Gunston Cove, 30 feet offshore	7 Accotink Creek at U.S. Route 1	8 Pohick Creek at U.S. Route 1
Maximum				
Date	Oct. 14, 1954	Oct. 14, 1954	Oct. 6, 1954	Nov. 4, 1954.
Stage of tide	High	High		
Depth (feet)	8	4		
Specific conductance (micromhos at 25° C.).	1,370	1,330	101	81.8.
Hardness as $CaCO_3$ (ppm)	216	212	24	22.
Bicarbonate (ppm)	120	102	37	18.
Chloride (ppm)	328	320	9.2	7.0.
Nitrate (ppm)	2.6	2.4	.4	1.7.
pH	7.1	7.3	7.0	6.9.
Turbidity (ppm)	26	56	6.2	5.4.
Minimum				
Date	Mar. 24, 1955	Mar. 10, 1955	Nov. 19, 1954	Mar. 24, 1955.
Stage of tide	Low	High		
Depth (feet)	Top	3		
Specific conductance (micromhos at 25° C.).	118	143	58.3	59.3.
Hardness as $CaCO_3$ (ppm)	47	61	15	17.
Bicarbonate (ppm)	38	52	17	12.
Chloride (ppm)	4.4	3.0	5.0	3.6.
Nitrate (ppm)	1.8	4.0	.4	1.2.
pH	7.4	7.1	6.6	7.4.
Turbidity (ppm)	55	82	22	45.

TIDAL INFLUENCE

On a flood tide, salty water moved up the Potomac River and into the shallow water of Gunston Cove. The movement of salty water in the cove was not as rapid as in the river. On an ebb tide in the river the salty water from the previous flood tide and the up-stream fresh water with which the salty water had come into contact, retreated seaward. As a result, the ratio of the specific conductance at high tide to the specific conductance at low tide greatly exceeds 1.0 in the river. On the ebb tide in the cove the salty water from the previous flood tide, which had been diluted with fresh water from the river or other considerable tributaries entering the bay, retreated out of the cove. As a result, the ratio of the specific conductance at high tide to the specific conductance at low-water slack approached a value of 1.0 in the cove (see table 4 and fig. 2). At high-water slack the mineral content of the cove water was usually less than adjacent river water. At low-water slack the mineral content of the cove water usually exceeded the adjacent river water.

TABLE 4.—*Specific conductance of water in the Potomac River and Gunston Cove*

[For location of sampling sites, see fig. 2]

Sampling site	(2) Gunston Cove, 2,000 feet from shore			(5) Potomac River at Fort Belvoir, 400 feet from shore		
	Specific conductance, in micromhos					
Date	High tide	Low tide	Ratio of high tide to low tide	High tide	Low tide	Ratio of high tide to low tide
1954						
Sept. 15	964	614	1.57	959	512	1.87
Sept. 22	863	769	1.14	1,140	497	2.30
Sept. 29	878	877	1.00	1,170	630	1.85
Oct. 6	1,070	1,000	1.07	1,310	814	1.61
Oct. 24	1,320	1,230	1.07	1,660	814	2.04

As the streamflow increased, the chloride content of the river water and the cove water decreased. The chloride content of the cove water decreased at a slower rate than that of the river water. In the cove the chloride content at low-water slack exceeded the chloride content at high-water slack, indicating that the water with more dissolved material in the cove was diluted by the water with less dissolved material brought into the cove by the river on the flood tide. A survey of chloride content of the Potomac River, adjacent to Fort Belvoir and Gunston Cove, was made on November 23, 1954, after the navigation channel had been flushed of chloride. The results of this investigation, which are plotted on figure 11, indicate that the navigation channel is flushed of chloride first, the chloride in the shallow sections of this reach of the river are diluted at a slower rate, and the chloride remains in Gunston Cove for the longest period of time.

DISSOLVED OXYGEN

The amount of oxygen dissolved in water is a significant factor in relation to corrosion of pipes and vessels in contact with the water or wet steam. The dissolved oxygen content of the water in the Potomac River and Gunston Cove is also an index of the capacity of the stream to assimilate pollution. If the amount of oxygen consumed exceeds the oxygen produced, the oxygen content of the water may be depleted to the point where animal and plant life cannot survive and putrefaction occurs.

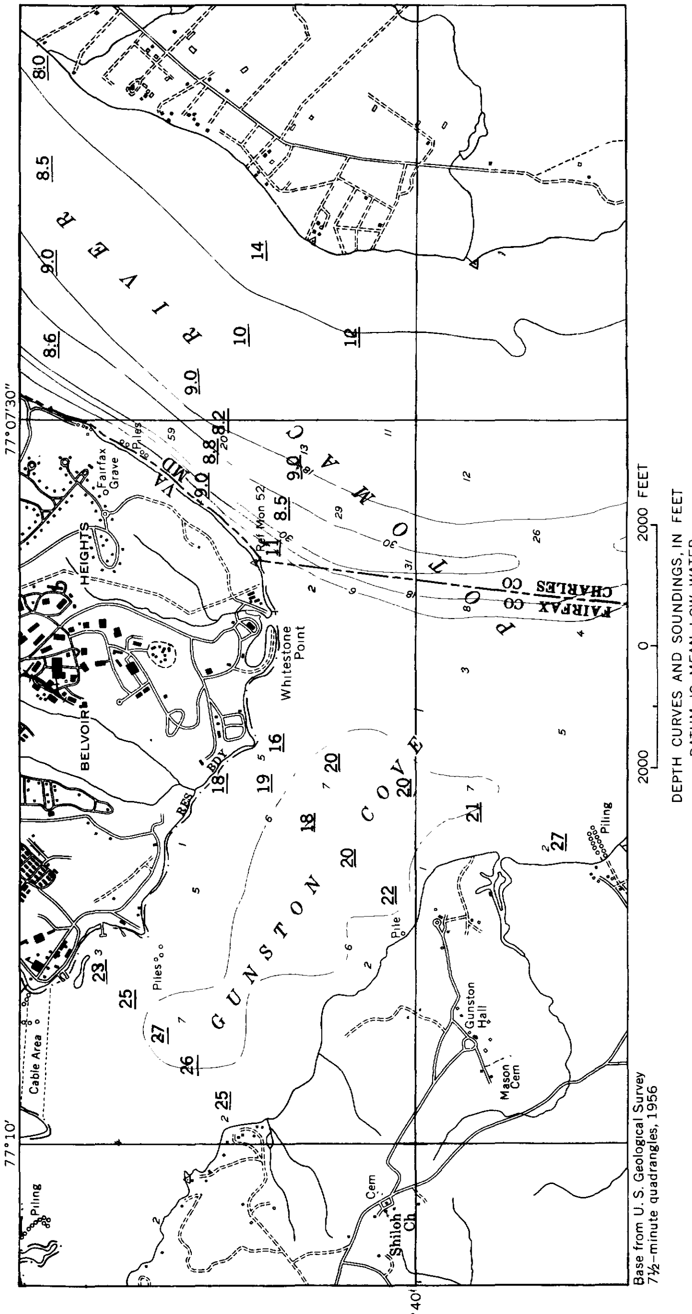


FIGURE 11.—Map showing salinity survey of the Potomac River in the vicinity of Fort Belvoir, Va., November 23, 1954. Underscored figures indicate chloride concentration in parts per million.

Between September 15, 1954, and July 1, 1955, determinations were made of the dissolved oxygen content of the surface waters at the six sampling locations on the Potomac River and of the bottom water of Gunston Cove approximately 2,000 feet offshore. Because the samples could not be analyzed for dissolved oxygen at the sampling location, they were stabilized as recommended in "Standard Methods for the Examination of Water, Sewage and Industrial Wastes," and were then placed in a refrigerated container and analyzed at a later time in the laboratory by the Alsterbury (azide) modification of the Winkler method.

The amount of oxygen present in the water in the Potomac River and Gunston Cove is dependent upon the following factors:

1. *The mechanical adsorption of oxygen from the air into the water.*—The oxygen at the water interface slowly diffuses into the water below the surface. The greater the agitation of these waters, the greater the rate of oxygen mixing in the water.

2. *The amount of oxygen produced by submerged green plants.*—During the summer, oxygen-producing plants in the Fort Belvoir area account for much of the dissolved oxygen in the water. During the warmer months, the dissolved oxygen exceeded 100 percent saturation at all stations. During the winter, oxygen-producing plants are dormant or nonexistent, and the main source of oxygen is the atmosphere. The percent saturation does not exceed 100 during the winter.

3. *The amount of oxygen consumed by oxygen-using bacteria in organic matter.* The biochemical oxygen demand (BOD) is a measure of the amount of oxygen being consumed by those organisms which require oxygen. Since the biochemical oxygen demand was not measured, the total amount of oxygen produced or absorbed cannot be calculated. Between September 1954 and June 1955 the minimum observed value of dissolved oxygen in Gunston Cove was 3.0 ppm, which was 32 percent saturation.

4. *The amount of sunlight and the turbidity of the water when algae are active.*—Sunlight increases the activity of oxygen-producing plants during the summer; thus, the amount of dissolved oxygen in the water is greater in the afternoon than in the morning. When the day is cloudy or overcast, or for some reason the water becomes turbid, less oxygen is produced and the dissolved oxygen content may decrease because of oxygen consumers in the water.

5. *The tidal stage.*—On the rising tide the shallow water of Gunston Cove, which is usually high in dissolved oxygen content, is

flooded with water from the river channel, which is lower in dissolved oxygen content. On the ebb tide the water from Gunston Cove, which is usually high in dissolved oxygen content, moves out into the main channel, which is lower in dissolved oxygen content. In Gunston Cove, the rise in percent saturation is not as great during the day when the low tide occurs in the morning as when the high tide occurs in the morning.

WATER TEMPERATURE

The heat exchanger system of the proposed reactor has been designed to operate with a specific temperature differential between the cove intake water and the condenser effluent. If the cove water temperature exceeds the temperature for which the heat exchanger has been designed, the efficiency of the heat exchanger will be reduced and larger amounts of cooling water will be required. To obtain maximum efficiency, the intake pipe must be located at the coolest water in the cove and at a position where the warmer effluent water will not influence the intake water to the reactor. It would not be practical to locate the intake at a great distance from the reactor.

Between September 15, 1954, and October 1, 1955, the temperatures of the water in the Potomac River, Gunston Cove, Accotink Creek, and Pohick Creek were measured when water samples were collected. The water temperatures were measured with a sensitive underwater thermometer at 10-foot intervals where the depth of the water exceeded 10 feet. Where the water depth did not exceed 10 feet, the temperature was measured at 2-foot intervals. Water temperature measurements were made at high tide and low tide, irrespective of the time of day, and may not represent the maximum or minimum water temperatures for the day.

During selected days between August 31, 1955, and September 7, 1955, the temperatures of the water in Gunston Cove, 1 foot above the bottom and 1 foot below the surface, were measured at 7 locations, from a point 50 feet from the Fort Belvoir shore to a point in the middle of the cove (see fig. 6). On the same days, water-temperature profiles were made from the spit of land projecting into water near Whitestone Point to a point near the Non-Commissioned Officers Club. On each water-temperature profile run, the temperature of the water 100 feet and 150 feet from the Fort Belvoir shoreline was measured near the bottom and 1 foot below the surface at each of the five temperature ranges indicated on figure 6.

The temperature of the Potomac River water varies with the season. Weekly observations of the water temperature at Fort Washington for the past 5 years indicate that the maximum river temperatures occurred in July and August, and the minimum river temperatures occurred from the latter part of December until the middle of February (see fig. 12). The maximum observed water temperature in Gunston Cove, during the period of investigation, was 93.6°F on August 3, 1955; in some winters Gunston Cove has been covered with a layer of ice.

During the summer and winter the daily maximum water temperature in Gunston Cove usually exceeded the daily maximum water temperature in the Potomac River and the daily minimum water temperature in Gunston Cove was usually less than the daily minimum water temperature in the Potomac River. When the Potomac River water temperature was rapidly decreasing (in autumn) the daily minimum water temperature in the river usually exceeded the daily maximum water temperature in Gunston Cove. In spring, the daily maximum temperature of the river water was usually less than the daily minimum temperature of cove water.

At most observation sites in the Potomac River and Gunston Cove, the temperature of the surface waters exceeded the temperature of the bottom waters. The maximum recorded temperature differences in Gunston Cove was 7.5°F. The larger temperature differences with depth occurred in the late afternoon, on sunny days. The lowest temperatures of water in the cove were usually about 500–800 feet from the reactor site.

MOVEMENT OF WATER IN THE POTOMAC RIVER AND GUNSTON COVE

In the Potomac River the average ebb currents are either more rapid or of a longer duration than the flood current. It is difficult to obtain precise values for the net tidal movement because the net movement on one tide cycle is generally much less than the movement on the flood or on the ebb tide. A study of circulation in tidal rivers is complex, and only in recent years has there been any intensive investigation of the movement. Neither the methods used for the study of nontidal river flow nor those applicable to currents and circulation in the open sea can be used in evaluation of the flow in estuaries.

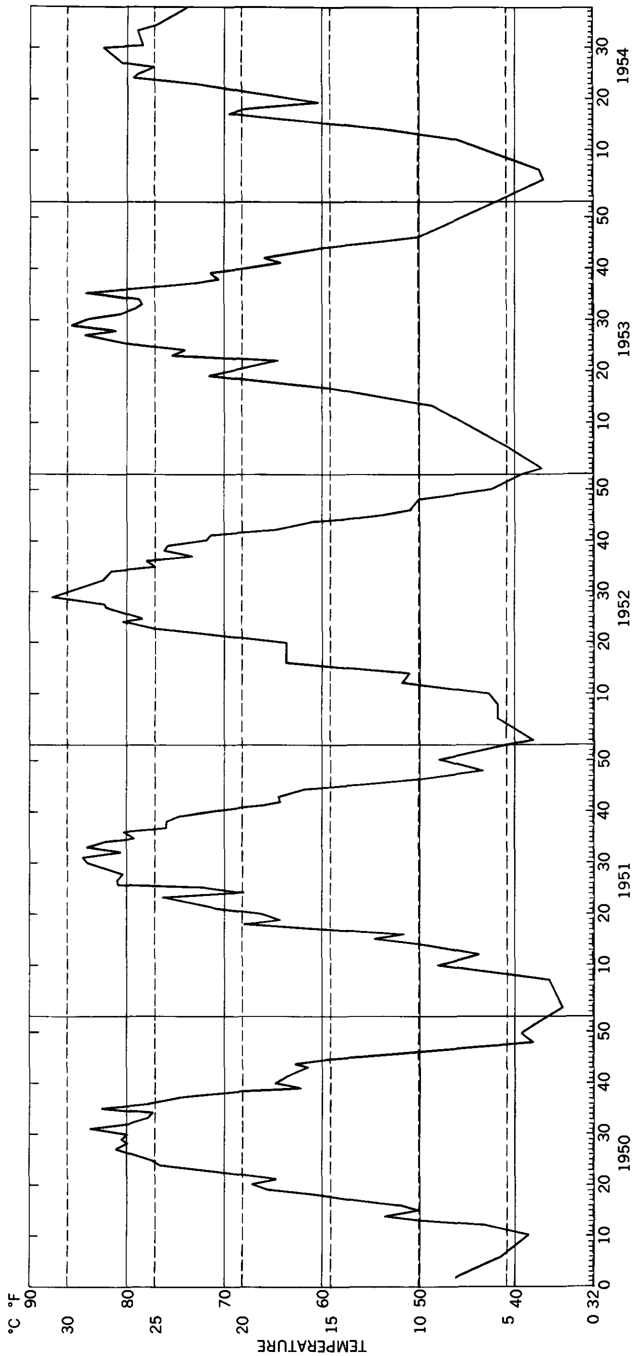


FIGURE 12.—Potomac River water temperature at Fort Washington, Md., 1950–54. Data based on once-a-week observations furnished by the District of Columbia.

In this report, several methods of estimating the tidal characteristics—such as travel time of water, flushing time, and extent of travel on the ebb and flood tides are discussed and illustrated. Under no conditions should any one method be selected as the method for the determination of a particular characteristic, for these methods cannot be expected to give precise answers. It is not expected that one would look at a graph and say, "It will take 8 days for water to move from Chain Bridge to Fort Belvoir if the discharge rate is 10,000 cfs." These calculations are only to be used to obtain orders of magnitude.

TIDAL CAPACITIES

The tidal capacities of the Potomac River are constantly changing with tide, fresh-water inflow, and changing topographic features. Mean low water has been defined by the Coast and Geodetic Survey as the average height of low water over a 19-year period. The tide in the Potomac River is semidiurnal and all low-water heights are included in the average. Soundings in the Potomac River are based on the mean low water as a reference datum. In a similar manner, mean high water is the average height of the high water over a 19-year period. The shoreline contours on U.S. Geological Survey maps represent the approximate line of mean high water.

The amount of fresh water entering the tidal section of the Potomac River is measured above Chain Bridge. For many years the time and height of the tides in the Potomac River have been measured at the Washington Channel. The U.S. Coast and Geodetic Survey correlated the time and height of the tide at Washington Channel with the time and height of the tide at various locations in the estuary. Soundings of the river have been carried out by the Coast and Geodetic Survey, the Army Engineers, and the Geological Survey.

The low-tide capacity of the Potomac River is the volume of water in the Potomac River at mean low water; it was estimated in the following manner. The Potomac River between Chain Bridge and Cornwallis Neck was subdivided into 12 sections. The low-tide volume of each section was calculated. The distance from Chain Bridge to the seaward edge of each section was plotted against the accumulative low-tide volume of the river to the seaward location of each section. Figure 13 is a plot showing the accumulative low-tide volume of water from Chain Bridge to various locations in the reach of the river from Chain Bridge to Cornwallis Neck.

The high-tide capacity of the Potomac River was calculated by repeating the above process and substituting the depth at mean high

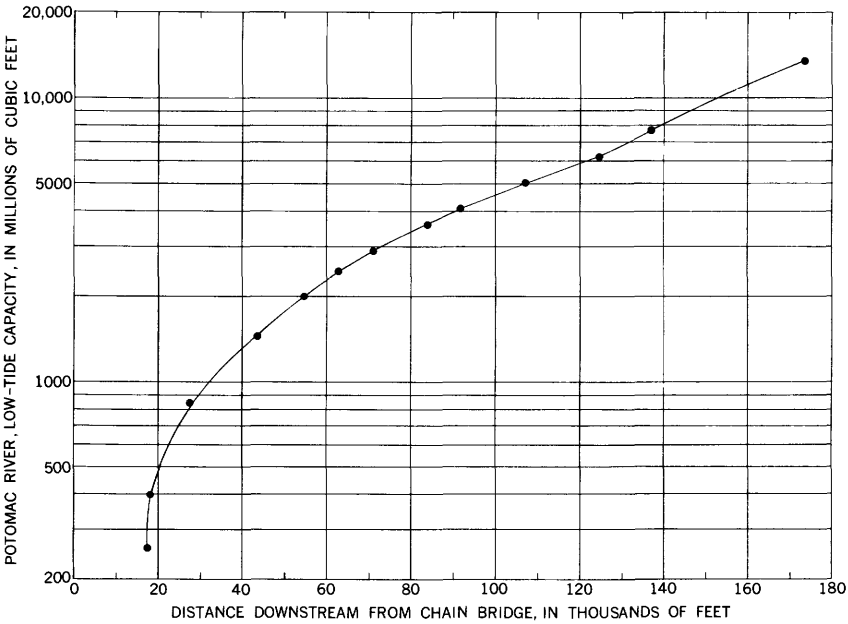


FIGURE 13.—Low-tide capacity curve of the Potomac River between Chain Bridge and Cornwallis Neck.

water for the depth at mean low water. The depth at mean high water is calculated by adding the mean tidal range to the depth at mean low water. In the Potomac River the tidal range varies with location; for example, at Washington Channel the mean tidal range is 2.9 feet, and at Gunston Cove the mean tidal range is 2.0 feet. The intertidal volume of each segment was obtained by subtracting the mean low-water volumes of each segment from the mean high-water volumes. The accumulative intertidal volume of the river at various locations is plotted against the river distance downstream from Chain Bridge (see fig. 14).

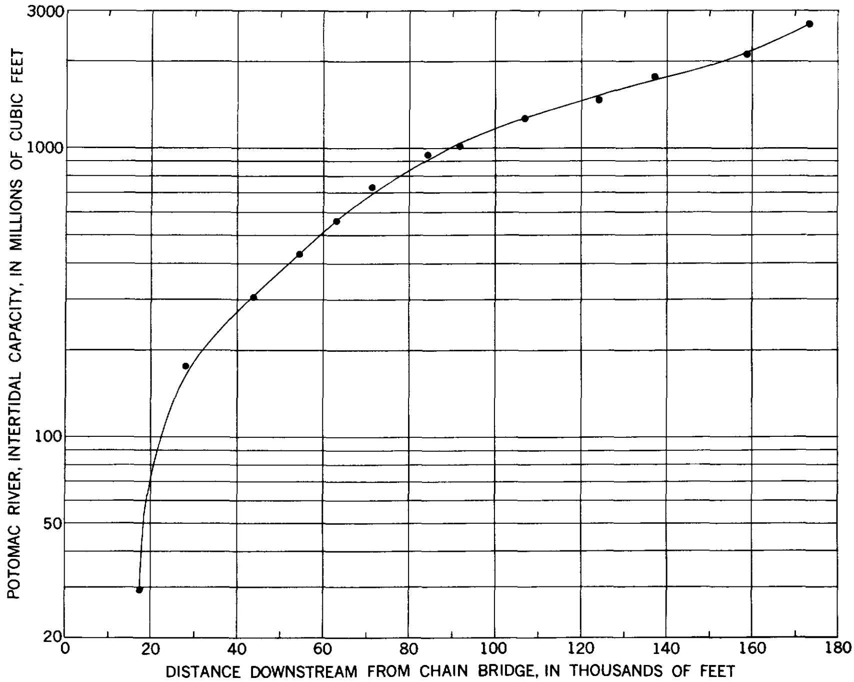


FIGURE 14.—Intertidal capacity curve of the Potomac River between Chain Bridge and Cornwallis Neck.

The low-tide and intertidal capacity curves (fig. 13 and 14) are based on mean low-water and mean high-water levels and mean tidal ranges. In 1955 the range of low tides in the Washington Channel was predicted to be 0.7 feet above to 0.7 feet below mean low water and the range of high tide was predicted to be 0.9 feet above to 0.8 feet below mean high water. When the tide rises above the mean tide, the tidal capacity curves in figures 13 and 14 will be displaced upward; when the tide falls below the mean tide, these curves will be displaced downward. When the tidal range is greater than the mean tidal range, the intertidal capacity curve (fig. 14) will be displaced upward; when the tidal range is less than the mean tidal range, the intertidal capacity curve will be displaced downward.

TIME OF TRAVEL OF WATER

ESTIMATED FROM MEAN RIVER VOLUME AND DISCHARGE

As the Potomac River is tidal in this area, the downstream flow is periodically interrupted by the upstream movement of water. If the upstream tidal movement of water is ignored, the time of travel of water from Chain Bridge to any point downstream can be more easily estimated. Klegerman and Niles,[1] estimate the time of travel of water by the following method: It is assumed that the mean volume of water in the Potomac River is the arithmetic mean of the volume of water at mean low tide and at mean high tide. The time of travel is computed by subdividing the accumulative volume of the river at a location by the fresh-water discharge rate. The time of travel from Chain Bridge to Fort Washington, Fort Belvoir, and Glymont has been computed for various flow rates by this method. The results of these computations have been plotted on figure 15. This method of computation may give a reasonable estimate of the time of travel of water from Chain Bridge to some point downstream when there is no upstream tidal movement of water. However, the error of estimation increases with distance downstream. At these downstream locations the tides have greater influence on the movement of water and retard the downstream movement.

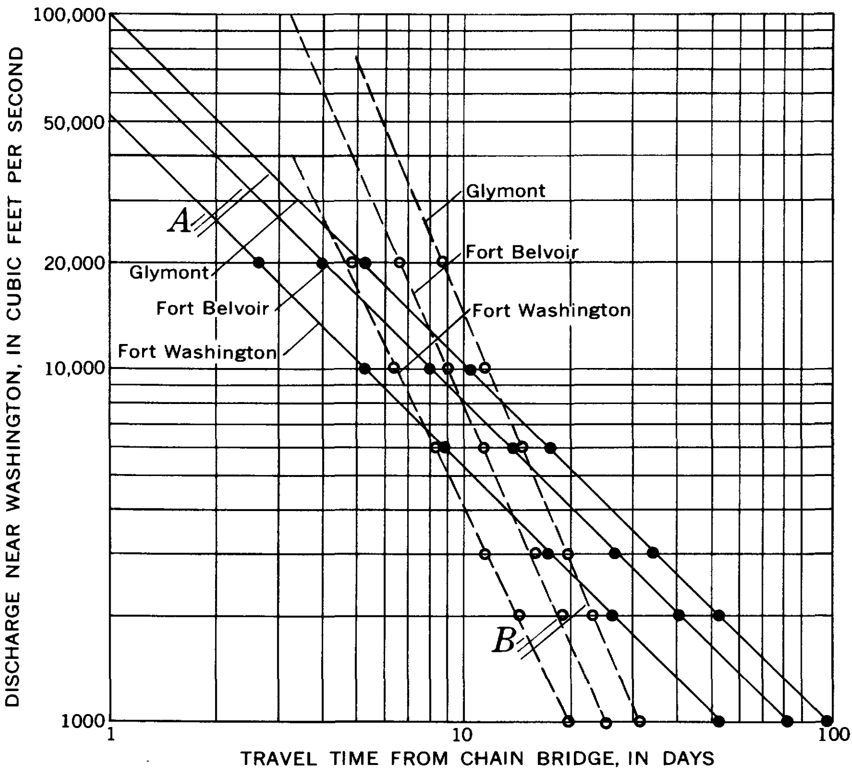


FIGURE 15.—Relation of time of travel of Potomac River water from Chain Bridge to Fort Washington, Fort Belvoir, and Glymont to discharge. *A*, Based on method suggested by Klegerman and Niles; *B*, based on method suggested by B. H. Ketchum.

[1] Klegerman, M. H., and Niles, T. M., 1954, a pollution study of the Potomac River: Paper presented before the Sanitary Engineering Division, Am. Soc. Civil Engineers, Atlanta, Ga.

ESTIMATED FROM RIVER-WATER EXCHANGE RATIO

In 1951, B. H. Ketchum, of the Woods Hole Oceanographic Institute, proposed a novel technique for estimating the average time required for water in an estuary to move from an upstream location to a downstream location. This method can be used for estimating the mean age of water and the flushing time at various flow rates. In this procedure the Potomac River between Chain Bridge and Cornwallis Neck is divided into consecutive volume segments. The length of each segment should be equal to the excursion of a water particle on the flood tide and should be the maximum distance in which complete mixing of water added during a tidal cycle can be expected. The high-tide volume of each segment is equal to the low-water volume of the adjacent seaward segment. The segment nearest the head of tidewater (segment 0) is of such a length that the river discharge per tidal cycle is just sufficient to raise the water level from low to high tide. Since the entire rise on the flooding tide in this segment is contributed only by river flow, there will be no net exchange of water between the segment nearest the head of tide (segment 0) and the next adjacent seaward section (segment 1) but on the ebb tide a volume equal to the river flow per tidal cycle escapes from segment 1. The quotient of the intertidal volume of any segment by the high-water volume of that segment represents the fraction of water and dissolved solids removed from any segment on the ebb tide and is called the exchange ratio (r).

The river water in each segment is a mixture of waters that have accumulated during an infinite number of tidal cycles. The mean age of river water in any segment is the average time required for the river water to pass through the segment. The water entering each successive downstream segment has been in the estuary for a progressively longer period of time. The total travel time of water, through segment n, is the sum of the mean age of water in each segment through which the river water must pass.

Table 5 illustrates the manner in which the travel time of water at various locations between Chain Bridge and Cornwallis Neck has been computed by this method for an assumed flow rate of 1,000 cfs. near Washington, and an assumed average tidal range.

TABLE 5.—*Calculation of time of travel of Potomac River water (discharge 1,000 cfs)*

[R=Volume of river water introduced per tidal cycle. P=Segment intertidal volume. V=Segment low-tide volume. $r=\frac{P}{P+V}$, Exchange ratio; the fraction of water removed from the section during ebb tide. $\frac{1}{r}=\frac{P+V}{P}$, Mean age of water in the segment]

Segment No.	0	1	2	3	4	5	6	7	8	9
Seaward boundary thousands of feet from Chain Bridge	19	28.5	42.5	56.5	74.0	94.5	116.5	135.5	151.0	166.5
Segment midpoint do	9.5	23.8	35.5	49.5	65.2	84.2	105.5	126.0	143.2	158.8
V_D millions of cubic feet	400	444.6	570	737	895	1,173	1,505	1,835	2,135	2,415
P_D do	44.6	125.4	167	158	278	332	330	300	280	410
V_D+P_D do	444.6	570.0	737	895	1,173	1,505	1,835	2,135	2,415	2,625
ΣV_D do	400	844.6	1,415	2,152	3,047	4,020	5,725	7,560	9,695	12,110
ΣP_D do	44.6	170	292	460	738	1,070	1,400	1,700	1,980	2,390
R million cubic feet per tide cycle	44.6									
Mean age tidal cycle	9.99	4.55	4.40	5.67	4.23	4.53	5.56	7.12	8.62	6.40
Mean age days	5.17	2.36	2.28	2.94	2.20	2.36	2.88	3.70	4.47	3.32
Total travel time do	5.17	7.53	9.81	12.25	14.95	17.31	20.19	23.89	28.36	31.68

A flow of 1,000 cfs is equivalent to 44.6 million cubic feet per tidal cycle (R). The duration of a tidal cycle is 12 hours and 25 minutes or 0.519 days. The length of segment 0 is so chosen that intertidal capacity (P_0) is just equal to the river discharge (R), then $P_0=44.6$. From figure 14, $P_0=44.6$ at 19,000 feet from Chain Bridge. From figure 13, the low-tide volume at 19,000 feet from Chain Bridge (V_0) is 400 million cubic feet. The high-tide volume of this segment (V_0+P_0) is 400+44.6=444.6 million cubic feet. This hightide volume (V_0+P_0) is the low-tide capacity of the adjacent seaward segment (V_1). The sum of the low-tide volume of segment 0 and the next adjacent seaward segment is 400+444.6=844.6 million cubic feet. From figure 13, this accumulative volume is found 27,500 feet downstream from Chain Bridge, at which location the accumulative intertidal volume (P) is 170 million cubic feet (from fig 14). The accumulative intertidal volume of the river, including this segment (170 million cubic feet), minus the accumulative intertidal volume of the upstream segments, is the intertidal volume of the segment (125.4 million cubic feet). The segmentation of the estuary and the determination of the low-tide volume and the intertidal volume of the segments are continued in a like manner.

The mean age of water in each segment (in tidal cycles) is found by dividing the high-tide volume by the intertidal volume. To convert mean age in tidal cycles to mean age in days, multiply by 0.519. The travel time of water since it entered tidewater near Washington, D.C. is found by totalizing the mean age of water in every segment. The travel time of river water between Chain Bridge and Cornwallis Neck decreases as the discharge rate increases. The relation between the discharge rate and the travel time of water at Fort Washington, Fort Belvoir, and Glymont has been illustrated on figure 15.

ESTIMATED FROM FLOAT OBSERVATIONS

From August 4, 1913, to October 23, 1914, the U.S. Public Health Service carried out a series of float observations on the Potomac River between Chain Bridge and Colonial Beach. Each float consisted of a block of wood, 12 by 12 by 24 inches, set on top of a piece of 4- by 4-inch timber, 6 feet long. On the lower end of the 4- by 4-inch timber were placed at right angles with one another 4 vanes made of sheet metal. The floats were submerged until the top was about even with the surface of the water. The floats were placed into the water at 14 locations between Chain Bridge and the entrance to Chesapeake Bay. The movement of these floats was observed day and night by a crew in a boat. The results of these observations were published by Cummings (1916) in "Investigation of the Pollution and Sanitary Conditions of the Potomac Watershed."

The Potomac River is a wide, shallow estuary with a narrow, deep navigation channel. The movement of water, as defined by these floats, approximated the average rate of movement of the upper 6 feet of water in the navigation channel, during the period of observation of the floats. The floats did not define the movement of water in the more shallow sides of the channel.

FLUSHING TIME

The ebb and flow of the tide limit the flushing abilities of the Potomac River. Liquid waste waters introduced into the river at Fort Belvoir on the flood tide may travel upstream and then move into the shallow parts of the river, where they linger until diluted by succeeding tidal movements. Thus, polluting material added on the flood tide may pass the point of introduction several times before being flushed from the immediate area. Flushing time is the time required for the river water with its contained pollution to move through an area and has been calculated by the following methods.

ESTIMATED FROM RIVER-WATER EXCHANGE RATIO

The time required to flush out the area between Fort Washington and Glymont has been determined by the method of B. H. Ketchum. Using the graph of figure 15, the time of travel of water to Fort Washington was subtracted from the time of travel of water to Glymont for specific discharges. Figure 16 illustrates the time required

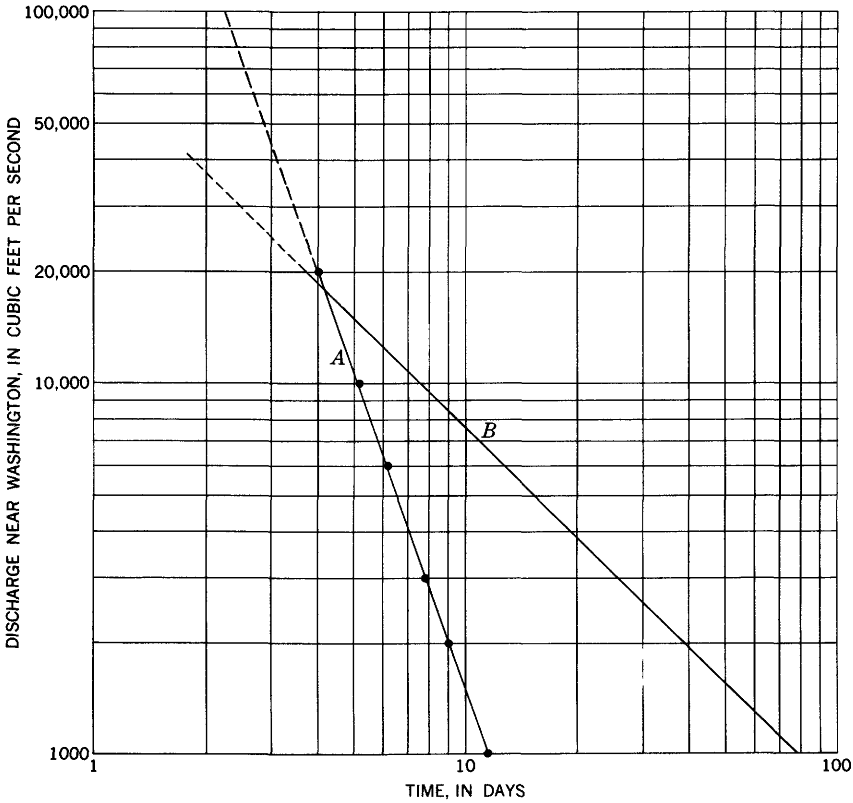


FIGURE 16.—Time required to flush the area between Fort Washington and Glymont. *A*, Based on method suggested by B. H. Ketchum; *B*, based on method suggested by Klegerman and Niles.

to flush out the area between Fort Washington and Glymont at various discharges. The flushing capacity of the estuary is greater at the higher discharge rates.

ESTIMATED FROM ACCUMULATIVE RIVER VOLUME AND DISCHARGE

The time necessary to flush out an area has been computed by a method suggested by Klegerman and Niles. In this method the accumulative low-tide capacity and high-tide capacity are plotted against the distance downstream from Chain Bridge (see fig. 17). It is assumed that, at zero fresh-water inflow, water on the flood tide will move upstream a distance equivalent to the horizontal distance between the low-tide capacity curve and the high-tide capacity curve. As the flow increases, the displacement upstream on the flood tide decreases and the displacement downstream on the ebb tide increases.

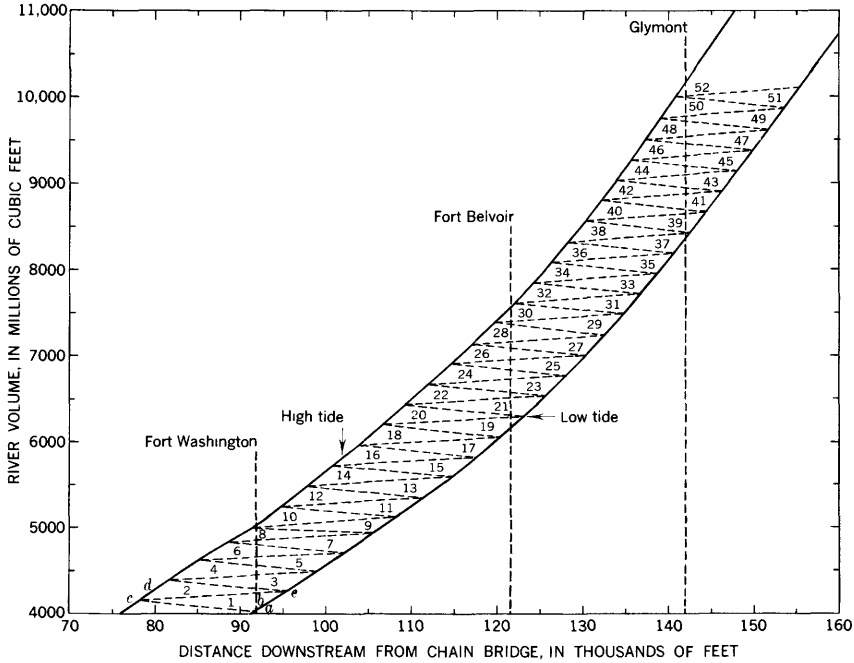


Figure 17.—Estimation of the time required to flush the area between Fort Washington and Glymont at a discharge rate of 6,000 cfs, based on method suggested by Klegerman and Niles.

With a fresh-water inflow of 6,000 cfs, or 134 million cubic feet in 6 hours and 12½ minutes, the displacement upstream is less than at zero inflow. To estimate the time necessary to flush out the area between Fort Washington and Glymont at this flow rate, the following procedure is used. From *a*, a distance equivalent to 134 million cubic feet (*b*) is measured vertically upward. The intersection of the high-tide capacity curve with the horizontal projection of point *b* is the location of the upstream displacement on the flood tide (*c*). On the following theoretical ebb tide, the displacement is calculated using *c* as a starting point. A distance equivalent to 134 million cubic feet is measured vertically upward (*d*). The intersection of the low-tide capacity curve with the horizontal projection of point *d* is the location of the downstream displacement on the ebb tide (*e*). The remainder of this graph has been constructed in a similar manner. According to the graph, the tide has reversed 52 times from the time the water started at Fort Washington until it was completely below Glymont.

Assuming an average of 6 hours and 12½ minutes for each tide reversal, it took 23 days for water at Fort Washington to be flushed clear beyond Glymont at a discharge rate of 6,000 cfs. The time required to flush out the area between Fort Washington and Glymont at various flow rates, as computed by this method, is indicated on figure 16.

Klegerman and Niles (op. cit.) state, "Actually, the tidal movement is more extensive—probably not less than two or three times the theoretical area after a few tidal cycles." Also, "The extent of the river over which pollution is dispersed and mixed is undoubtedly much greater than shown." Assuming the above statements by the authors of the method are correct, it follows that the estimation of 13 days to flush out this area, when the discharge rate is 6,000 cfs, is high. On figure 17, it appears that pollution added on the flood tide at Fort Belvoir will pass its point of introduction about 9 times before it passes completely out of the area. Although the estimate of 9 passes may be high, the fact is clearly demonstrated that the pollutant may remain in the area over several tide cycles.

EXTENT OF TRAVEL ON EBB AND FLOOD TIDE

In the Potomac River, under normal circumstances, water moves upstream on the flood tide and downstream on the ebb tide. During periods of high discharge, water does not have a chance to move upstream on the flood tide but continues to move downstream until the upstream force of the flood tide exceeds the downstream force. During a normal tide cycle the water in the channel moves upstream or downstream a greater distance than the water in the more shallow portions of the river. The possibility of waste introduction requires a knowledge of the extent of movement of pollution from Fort Belvoir on ebb and flood tides.

ESTIMATED FROM WATER VELOCITY

If continuous cross-sectional measurements of the velocity were made, the displacement on a flood or ebb tide could be determined. Maximum flood velocity and the maximum ebb velocity at the Chesapeake Bay entrance have been predicted for each tide cycle in the "Current Tables" of the Coast and Geodetic Survey. Water velocity at Fort Belvoir is estimated to be 0.8 as great as the water velocity at Chesapeake Bay entrance. The water velocity data obtained from these tables have been used in the following example to illustrate the method of determining displacement on the flood tide.

The variation in water velocity with time can be represented by a cosine curve, which means that the maximum velocity in the channel is $\frac{\pi}{2}$ times the mean velocity in the channel,

$$V_{max}=\frac{\pi}{2}\times\bar{v}_{channel}, \qquad (1)$$

in which V_{max}=maximum water velocity in the channel (ft per sec), and $\bar{v}_{channel}$=mean water velocity in the channel (ft per sec).

The channel velocity is assumed to be one-third larger than the mean velocity of the cross section. This assumption could be proven by actual measurements in this estuary as it has been proven in other estuaries. Thus, equation 1 becomes

$$\bar{v}_{cross\ section}=\frac{3}{2}\times\frac{V_{max}}{\pi}, \qquad (2)$$

in which $\bar{v}_{cross\ section}$=mean water velocity in the cross section (ft per sec).

The water velocity data in the "Current Tables" are published in the unit of knots. Since a knot equals approximately 1.7 feet per second, equation 2 becomes

$$\bar{v}_{cross\ section}=\frac{1.7\times 3\times V_1}{2\times\pi}, \qquad (3)$$

$$=0.81\ V_1$$

in which V_1=maximum water velocity in the cross section (knots).

The distance a particle travels is a product of its velocity and the elapsed time.

Thus, $$S=vt, \qquad (4)$$

in which s=tide displacement (feet) and t=duration of flood or ebb (seconds).

The duration of a flood tide is assumed to be ¼ of a lunar day (24 hours, 50 minutes) or 22,350 seconds. When equations 3 and 4 are combined, and 22,350 (seconds) are substituted for the time (t), S becomes $$S=18{,}000\ V_1$$

In the "Current Tables" it is stated that the predicted maximum flood velocity is 1.7 knots at Chesapeake Bay entrance. Thus, the displacement upstream on a flood tide at this water velocity is:

$$S = 18{,}000 \times 0.8 \times 1.7,$$

or,

$$S = 24{,}000 \text{ (feet)}.$$

This predicted maximum ebb velocity is 2.1 knots at Chesapeake Bay entrance, and thus the displacement downstream on a tide cycle at this water velocity is approximately 30,000 feet.

This method of computation gives the order of magnitude of displacement on a flood or ebb tide and is based upon the following predictions by the Coast and Geodetic Survey (Current tables, issued annually):

1. Water velocity at Chesapeake Bay entrance.
2. Ratio of water velocity at Chesapeake Bay entrance to water velocity at Fort Belvoir.
3. Channel velocity ⅓ larger than the mean velocity of the cross section.

The water velocity predictions are based on average discharge during certain portions of the year. To verify these predictions by direct velocity measurements at Fort Belvoir or at Chesapeake Bay entrance would be extremely costly and time consuming. Unusual hydrologic conditions such as a freshet make these predictions of questionable value.

ESTIMATED FROM CHLORIDE CONTENT OF WATER

The displacement on the ebb tide and flood tide can be computed when the chloride content of the Potomac River is known at high-water slack and low-water slack. In the reach of the Potomac River affected by saline invasion the maximum chloride content during a tide cycle is found at high-water slack and the minimum chloride content is found at low-water slack. In this river the chloride concentration increases as Chesapeake Bay is approached.

The chloride data from 5 days of sampling at high-water slack and low-water slack were used to compute the extent of travel on ebb and flood tide in the following manner. Using chloride concentrations as the ordinate and distance downstream from Chain Bridge as the abscissa, the chloride concentration at several locations on the Potomac River on successive high-water slack and low-water slack tide were plotted. When the high tide occurred in the afternoon, a horizontal line was drawn from Fort Belvoir on the low-tide chloride curve to the point on the high-tide chloride curve. The distance between the two curves indicated the displacement on the flood tide. Extent of travel on the ebb tides were computed in a similar manner. Table 6 is a summary of computations of tidal displacements at Fort Belvoir.

TABLE 6.—*Tidal displacement at Fort Belvoir*

Date (1954)	Displacement on an ebb tide (feet)	Displacement on a flood tide (feet)	Discharge near Washington (cfs)
Sept. 15	17, 000	------------	1, 140
Sept. 29	16, 000	------------	1, 370
Oct. 6	------------	15, 000	1, 0 0
Oct. 14	------------	16, 000	1, 370

This method could not be used for estimating displacements when saline invasion of the water in the Fort Belvoir area was not present. During 1955, the chloride content of the water near Fort Belvoir was too low to be of significant value in estimating displacements.

FLOAT OBSERVATIONS

In 1913 and 1914, the U.S. Coast and Geodetic Survey, at the request of the Public Health Service, conducted a series of float measurements in the navigation channel of the Potomac River to evaluate the movement of water. The construction of these floats was previously discussed under "Time of Travel of water." The float studies were conducted in the vicinity of Fort Belvoir in June 1914. The discharge of the river at Point of Rocks, Md., varied from 2,120 cfs to 4,840 cfs. These floats were introduced at Marshall Hall, just upstream of Fort Belvoir, and traveled 5 to 5½ miles upstream on the flood tide, and 6½ to 7 miles downstream on the ebb tide; the floats moved in the navigation channel in the higher current velocities. These values of tidal displacement can be assumed to represent the extreme distance that pollution, introduced at Fort Belvoir, would be displaced on an ebb or flood tide at these discharge rates.

ESTIMATED FROM MEAN RIVER VOLUME AND DISCHARGE

In the section under "Flushing time" the method for estimating the displacement from Glymont by low-tide and high-tide capacity curves has been discussed. These capacity curves were used to determine the extent of travel from Fort Belvoir on the ebb and flood tide.

These displacements from Fort Belvoir at various rates of fresh-water inflow are illustrated in figure 18. When the discharge reaches

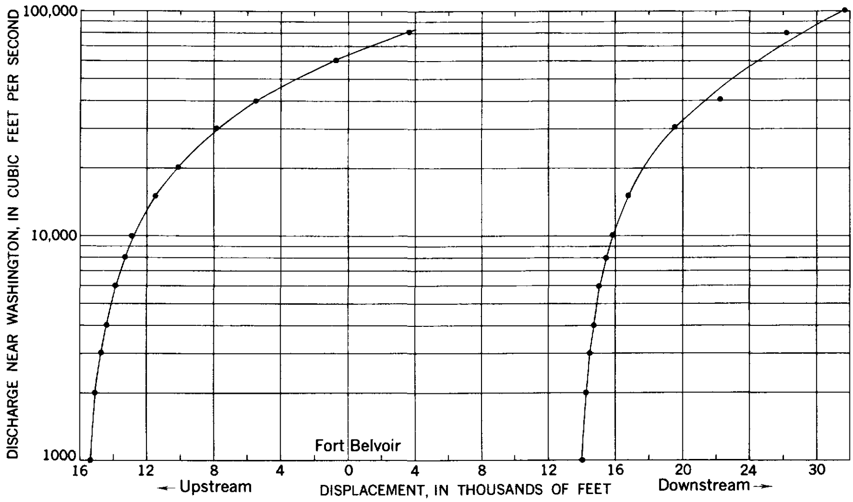


FIGURE 18.—Effect of discharge upon tidal displacement.

64,000 cfs or above, the movement of river water at Fort Belvoir will be downstream regardless of the stage of the tide. These computations are based on mean tidal ranges and mean river-volume capacity curves. At tidal ranges in the Potomac River greater than mean, the displacement will be greater upstream and downstream. At tidal ranges in the Potomac River less than mean, the displacement will be less.

SURFACE FLOAT OBSERVATIONS IN GUNSTON COVE

The data obtained from the investigations of the movement of the surface floats in Gunston Cove on a flood tide and on an ebb tide have been translated to figures 19 and 20. These float studies gave indications of the average movement of the upper 8-inch layer of the waters in Gunston Cove on different phases of the tidal cycle. The observed positions of these floats were plotted on an enlarged map of Gunston Cove. Straight lines were drawn between the observed locations of these floats; but these straight lines may not represent the actual line of movement of the floats between the times of observation. The time of observation of each float is also indicated on the charts. This time may not represent the time at which the float reached its observed position, because the floats may have grounded at some time prior to the observation of the float.

Figure 19 is the plot of the movements of surface floats on a flood tide in Gunston Cove on June 29, 1955. On this tide the floats moved in a northerly direction toward the inner portions of the cove. From

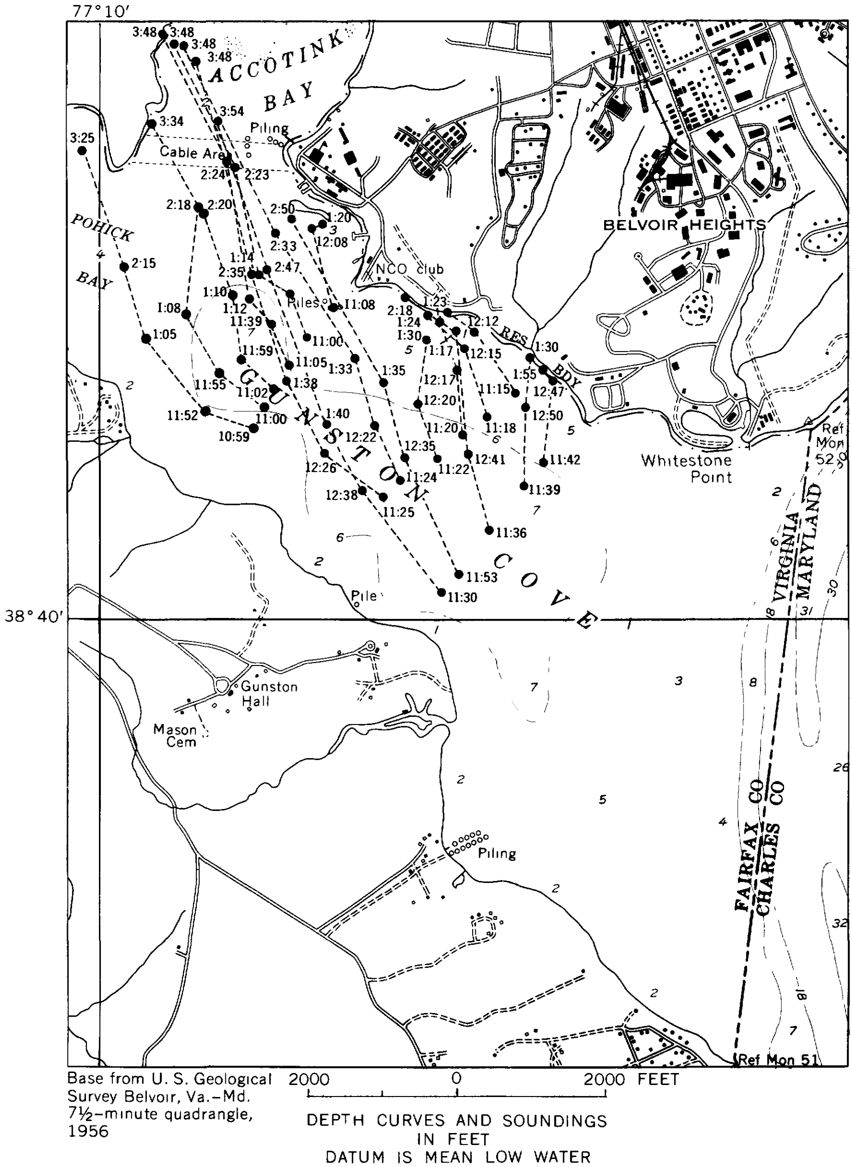


FIGURE 19.—Flow-pattern map of Gunston Cove, Va., showing times of arrival of floats on a flood tide, June 29, 1955. High tide, 4:02 p.m.; low tide, 10:20 a.m. Data by U.S. Geological Survey.

the plotted positions and the time interval between the observations the average velocities were calculated. The maximum average velocity (0.65 feet per second) of the surface floats and some of the larger average velocities occurred when the floats moved into the shallow portion of Gunston Cove. Although the wind early in the day opposed the tidal movements of the water, at no time did the floats tend to move out of the cove on this flood tide; the average velocities of the floats increased when the direction of the wind and of the tidal movement were not opposed.

Figure 20 is the plot of the movements of the surface floats on an ebb tide in Gunston Cove on July 25, 1955. On this tide the surface floats released in the inner portion of Gunston Cove moved in the direction of the Fort Belvoir shoreline and in the general direction of Accotink Bay, but only one float was observed near the mouth of Accotink Bay; the surface floats tended to move in the same general direction as the movement of the wind on the day of the test. The floats released near the mouth of Gunston Cove moved out of the cove into the Potomac River; these floats moved in a direction opposite to the direction of the wind at the time of observation. The maximum average velocity (0.85 fps) and the larger velocities during the flow-pattern study were found in the middle of the pass at the end of the submerged sandbar projecting from Whitestone Point.

SUBSURFACE DIRECTION OF FLOW AND VELOCITY IN GUNSTON COVE

SUBSURFACE DIRECTION OF FLOW

The movement of water in Gunston Cove is affected by the movement of the water in the tidal Potomac River near Fort Belvoir. According to the "Current Tables, Atlantic Coast," the direction of the flood current at strength of current at Hallowing Point, which is located at the south tip of the mouth of Gunston Cove, is 340° true. The majority of the current-direction measurements made on the flood tide indicate that the water in the deeper parts of Gunston Cove moves toward Accotink Bay and the northern end of Pohick Bay. At times water moves toward Accotink Bay on the first part of the tidal cycle and then shifts toward Pohick Bay on the latter part of the tidal cycle.

On the ebb tide the movement of water is from Accotink Bay and Pohick Bay toward the mouth of this cove and into the Potomac River. During the greater portion of the investigation the movement of the water in the deeper part of the cove (500 ft. from the Fort Belvoir shoreline and out) could be attributed directly to tidal action.

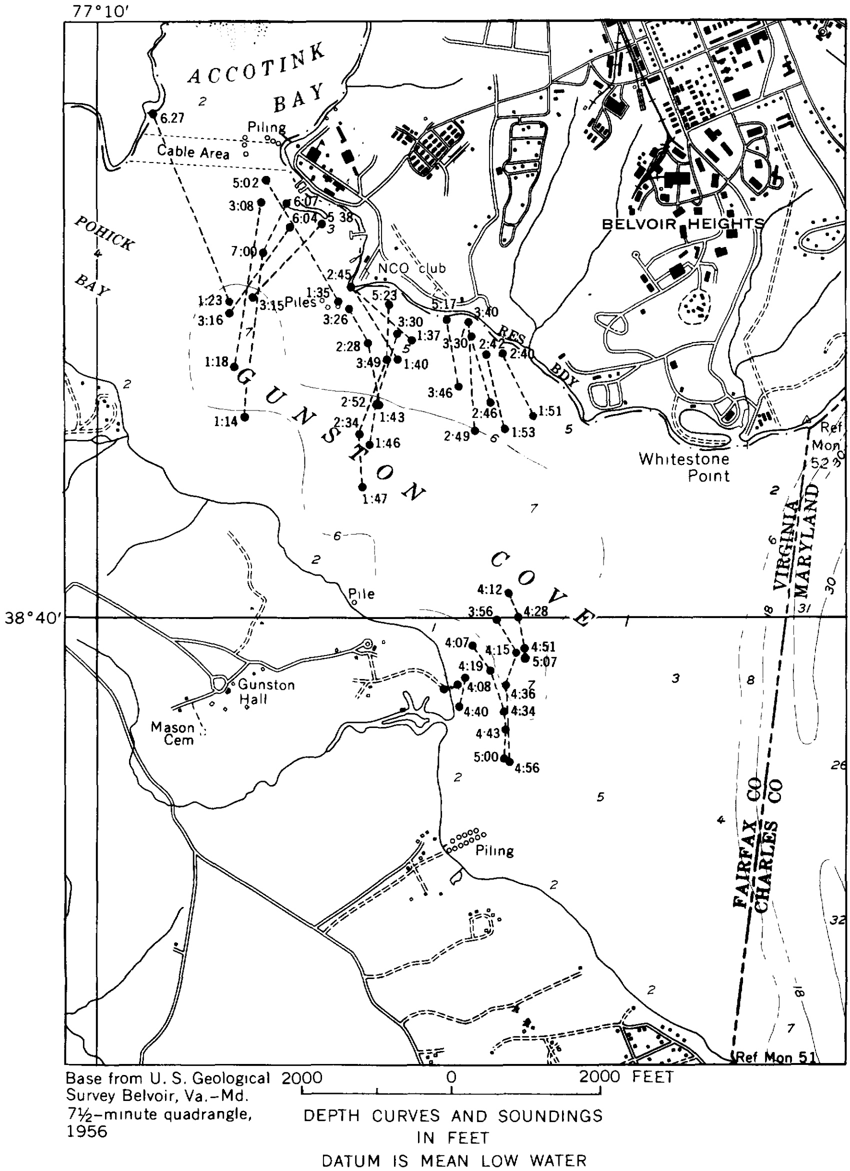


FIGURE 20.—Flow-pattern map of Gunston Cove, Va., showing times of arrival of floats on an ebb tide, July 25, 1955. High tide, 12:34 a.m., low tide, 7:21 p.m. Data by U.S. Geological Survey.

The movement of the water near the Fort Belvoir shore is complex and variable, as it is affected by the shoreline, the wind, and the tidal action. A swale discharges a small amount of fresh water into the cove near the projected site of the reactor. There appears to be a counterclockwise movement of the cove water near this swale. At times, the water close to the Fort Belvoir shore moves toward the shoreline on the flood tide and away from the shoreline on the ebb tide. During a large part of the time, the cove water 150–500 feet offshore moves toward Accotink Bay on the flood tide and toward the mouth of Gunston Cove on the ebb tide.

The water just below the surface appears to be influenced by wind action. Infrequently, the water near the bottom moves in the direction of the tide and the water just below the surface moves in the opposite direction. The direction of the current just below the surface was the resultant of the movement of water at the surface and the movement of the water near the bottom.

SUBSURFACE VELOCITY

In Gunston Cove, the current increases for a period of about 3 hours after slack water until the maximum current velocity is reached. The velocity then decreases for another period of about 3 hours when slack water is again reached, and the current begins a similar cycle in the opposite direction. The measurements of current strength during this investigation were made about 2 hours before and after a high and low tide: Thus, it is not unreasonable to assume that some of the current velocities measured may represent the maximum flood and ebb currents during the tide cycle. The maximum current velocities observed in this investigation were: flood current—0.48 fps just below the surface and 0.45 fps near the bottom; ebb current—0.71 fps just below the surface and 0.64 fps near the bottom.

In "Tide and Currents in New York Harbor," published by the U.S. Coast and Geodetic Survey, it is stated: "In general, it may be said that the velocity of the tidal current decreases from the surface to the bottom . . . but the effect of wind and fresh water inflow may bring considerable variation in the vertical velocity distribution." The majority of the current velocity measurements indicated that the movement of water just below the surface exceeded the water movement just above the cove bottom. The water velocity just below the surface was usually within 0.1 foot per second of the water velocity near the bottom when the top and bottom current directions were similar. The more the current direction of the waters just below the surface varied from the current direction of the bottom water, the greater the variation of the current velocities through the vertical. The velocity of the water in the deeper part of the cove usually exceeded the velocity of the water near the shore.

SUMMARY AND CONCLUSIONS

The chemical quality of the water in Gunston Cove, near the location of the proposed reactor site, is affected by the water from the adjacent Potomac River and by the stage of tide in this cove. The chemical quality of the Potomac River at Fort Belvoir is affected by the stage of tide, the amount of fresh-water inflow, and the duration of low discharge rates of fresh-water inflow. During the larger part of the time the chemical quality of the Potomac River, which is similar to the quality of water in Gunston Cove, would not adversely affect the use of the water in Gunston Cove as a cooling agent.

After extended periods of low streamflow, the salty water from the lower Potomac River and Chesapeake Bay moves on the flood tide into the vicinity of Fort Belvoir; and into Gunston Cove. During these periods of invasion of saline water the chemical character of the water near Fort Belvoir is altered; hardness, chloride, and dissolved solids increase. When the streamflow near Washington was less than 10,000 cfs and the saline water was advancing upstream near Fort Belvoir, the dissolved solids concentration of the water in Gunston Cove was less than the dissolved solids concentration of the water in the adjacent Potomac River. At such times the dissolved solids concentration of the waters in this cove did not change appreciably between high tide and low tide.

The advance of saline water in the Potomac River near Fort Belvoir during the 1954 investigation was halted by increases in the streamflow. Sudden heavy increases in the streamflow rapidly flushed the salty water downstream below Fort Belvoir. Salty water in Gunston Cove was moved out of the cove at a slower rate than the Potomac River adjacent to Fort Belvoir, and the concentration of dissolved solids of the water in the cove then exceeded the concentration in the adjacent river. In the fall of 1954, salty water remained in Gunston Cove for several week after the water in the adjacent Potomac River was free of salty water.

The temperature of the water in Gunston Cove varied in a cyclic manner throughout the period of investigation and also varied with location and depth. A water temperature of 94° F was observed in Gunston Cove on August 9, 1955, near the site of the proposed reactor. The coincidence of low-flow periods and high air temperature may result in periods when the water temperatures in this cove may exceed the maximum water temperature observed. In the winter of 1954, the water in the cove was covered with a layer of ice. In the summer of the investigation, the warmer water of the cove was at the surface and close to the Fort Belvoir shoreline; the cooler water was offshore and near the bottom. The daily maximum water temperature of the cove was usually observed in the late afternoon. The stage of tide in Gunston Cove appeared to have little effect upon the water temperature.

The dissolved oxygen content of the water in Gunston Cove is influenced by the absorption of oxygen from the air into the water, the presence of aquatic life, the amount of sunlight, and, to a small extent, the stage of tide. In the summer, the dissolved oxygen content of the water in this cove often exceeded 100 percent saturation. In other seasons of the year, when aquatic life was not active, the dissolved oxygen content was high but did not exceed 100 percent saturation. A minimum dissolved oxygen content of 32 percent was observed in the spring of 1955.

During the major part of this investigation the turbidity of the water in Gunston Cove was less than 10 ppm. At greater than average rate of fresh-water inflow the turbidity increased. The maximum observed turbidity in the cove in the vicinity of the proposed reactor site was 80 ppm. Since the rate of movement of water in the cove is not great and water samples were collected during or after periods of high fresh-water inflow, it is reasonable to assume that the turbidity values in this cove will not greatly exceed 80 ppm.

The time required to flush the reach of the river basin between Fort Washington and Glymont of pollution is dependent upon the (*a*) streamflow, (*b*) the range of tide, and (*c*) the duration of low streamflow. At extensively high discharge rates, the effect of tide is strongly reduced and the movement of water may be entirely downstream on the predicted flood tide; at high rates of streamflow, this reach of the river may be flushed of pollutants in less than a day; and at low discharge rates pollutants may linger in this reach for many weeks.

The movement of water in Gunston Cove is related to the rate of streamflow of the Potomac River, the range and stage of tide, and the direction and intensity of prevailing winds. At the surface, the movement of water is influenced by wind action; as the depth increases, the effect of wind action decreases.

The introduction of small quantities of reactor waste cooling water should not directly alter the chemical characteristics of the water of this tidal basin. If the warmer condenser waste waters were distributed uniformly throughout the water of the cove, there would be little difficulty in the dissipation of heat. Local areas of warmer water in the vicinity of the discharge lines could alter the normal environs of aquatic life to the extent that chemical and physical changes may occur in the water.

Successful disposal of planned or accidental release of radioactive wastes from the reactor into Gunston Cove will depend upon several factors:

Density of the effluent.—If the density of the effluent is similar to the density of the water, the dispersal of the effluent will be influenced by those phenomena which normally control the movement of water in this cove. The lower the density of the effluent, the greater influent the movement of the surface water will have upon the ultimate disposition of the pollutant. The greater the density of the effluent, the greater the tendency for the effluent to seek the bottom of the cove and perhaps remain undispersed as a slow-moving body.

Affinity for sediment.—The greater the affinity for sediment, the greater the tendency for the radioactive wastes from the reactor to be adsorbed on the sediment. The movement of this adsorbed pollutant will then be governed by those phenomena—such as intensity of fresh-water inflow, particle size and type of suspended material, stream contour, temperature, chloride concentration—which influence the movement of sediment.

Stage of tide.—If reactor wastes or other pollutants are introduced into the cove, the direction of movement and extent of movement may be governed by the stage of tide. For example, if polluting wastes are introduced as the tidal water from the Potomac River begins to flood into Gunston Cove, they will probably move in the direction of Accotink Bay or Pohick Bay and will continue to do so for as long as six hours. If pollutants are introduced at a later time on the same flood tide, the extent of travel to the inner part of the cove will be less.

Discharge rate.—The volume of water in Gunston Cove available for dilution of pollutants increases as the discharge rate of the Potomac River and its tributaries increases. During periods of high streamflow the introduced pollutants may not advance upstream but move rapidly downstream, or they may temporarily be pocketed in Gunston Cove. During periods of low streamflow the pollutants may move upstream on a flood tide as far as Fort Washington. On the succeeding ebb tide the greater part of this polluting material will be displaced in a downstream direction. Polluting material which may have lingered on the sides of the estuary at an upstream point could be carried farther upstream on succeeding flood tides. However, each succeeding tide should tend to reduce the concentration of the pollutants.

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