WATER MOVEMENT

By
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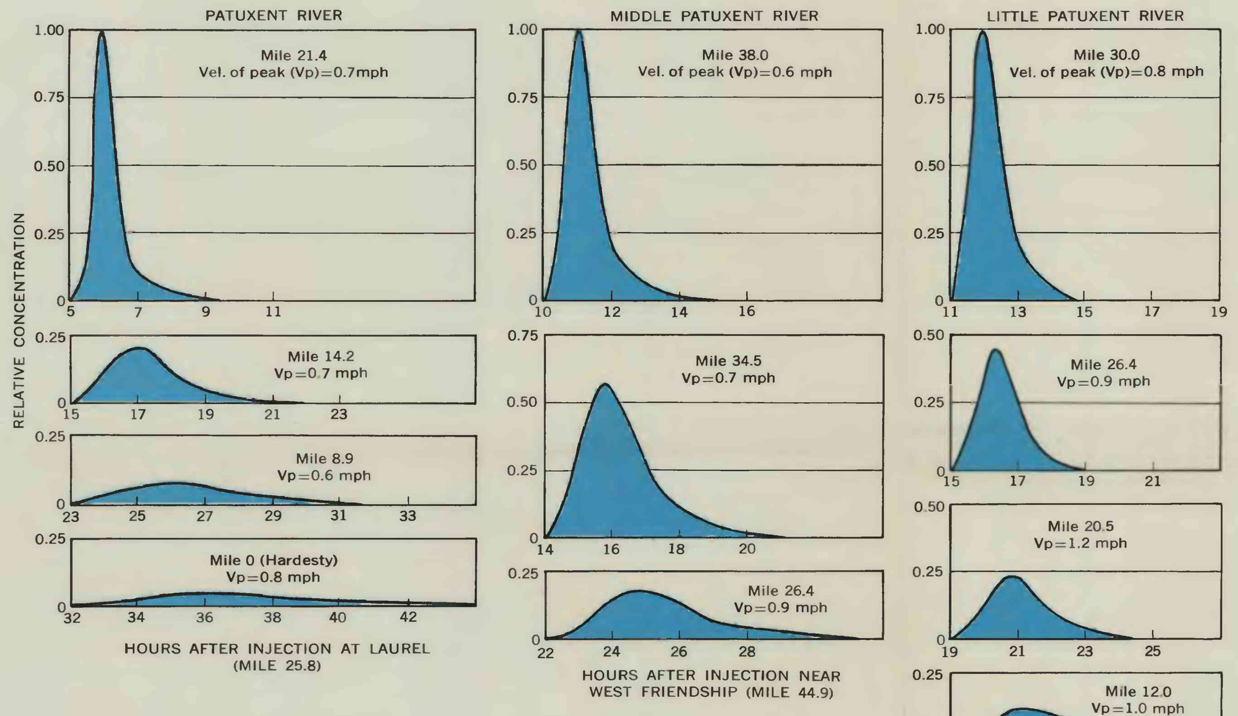
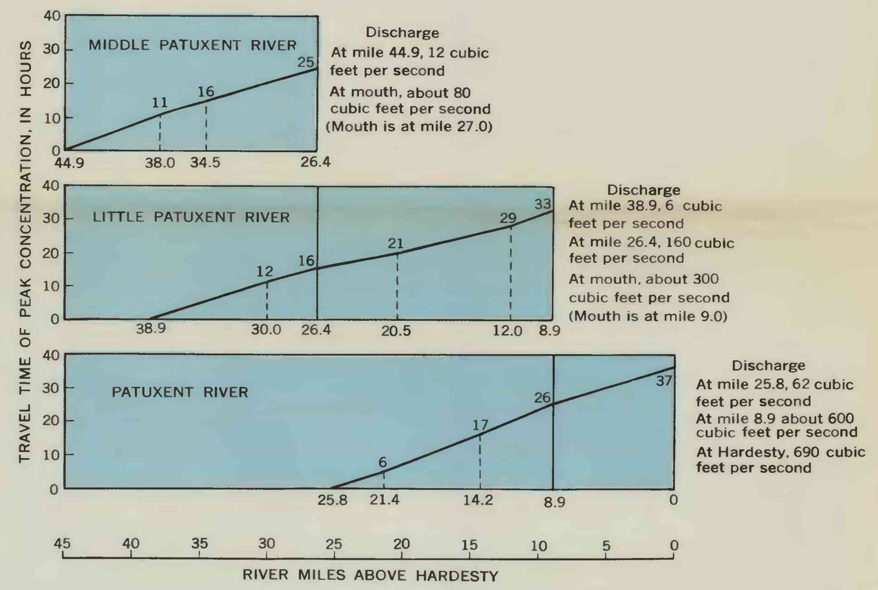
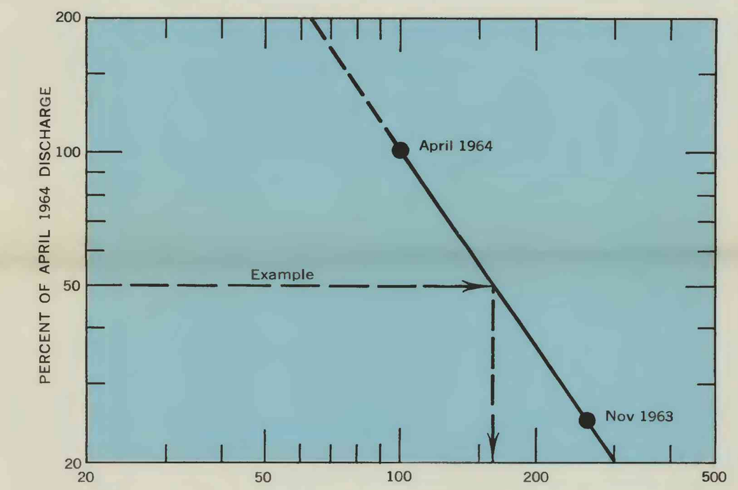


TIME-CONCENTRATION CURVES, SHOWING INCREASING PASSAGE TIME AND DECREASING CONCENTRATIONS AT SUCCESSIVE SAMPLING SITES FOR EACH OF THREE DYE INJECTIONS, APRIL 6-8, 1964. CONCENTRATIONS ARE GIVEN AS RATIOS TO THE PEAK CONCENTRATION AT THE FIRST SAMPLING SITE ON EACH STREAM

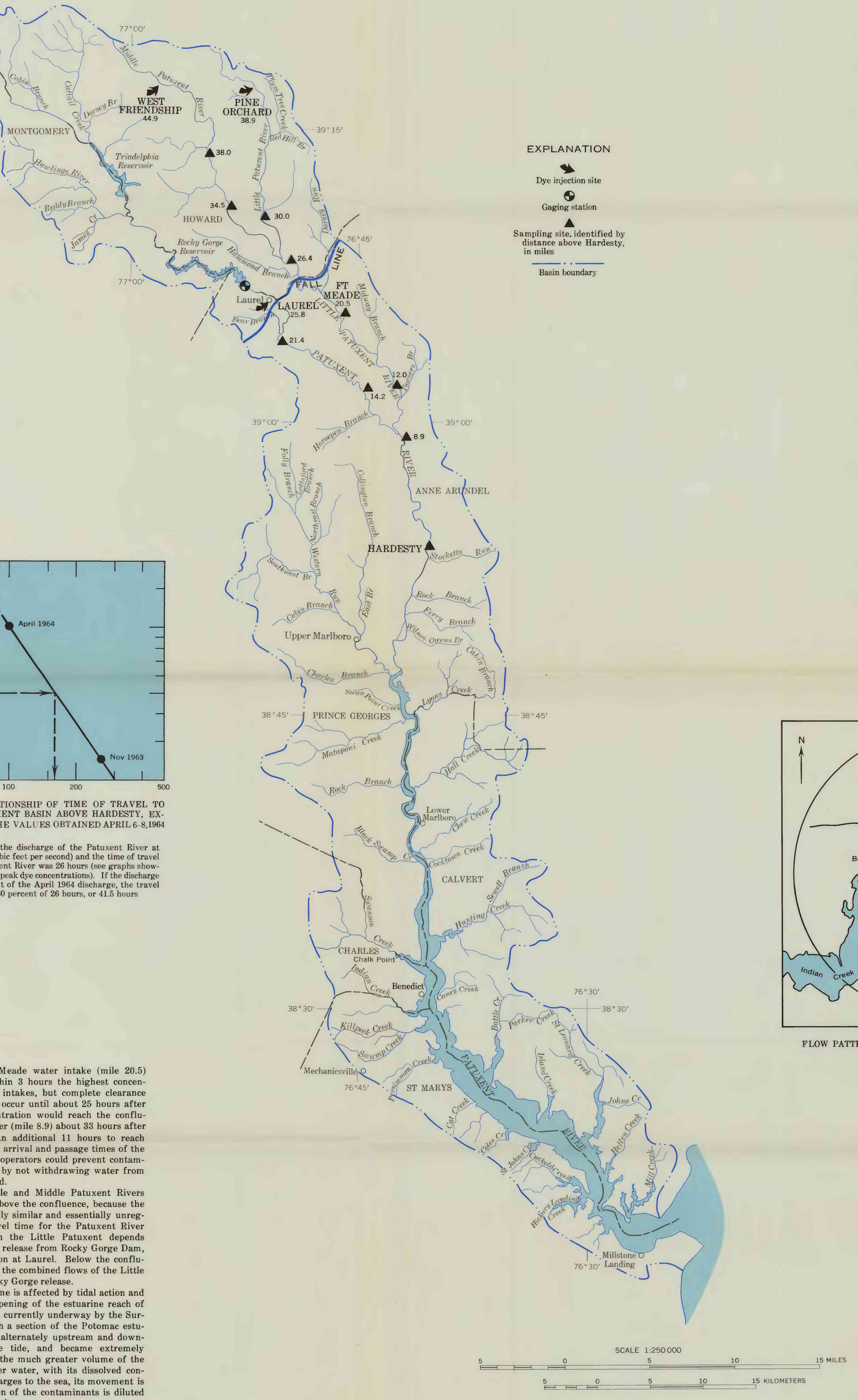


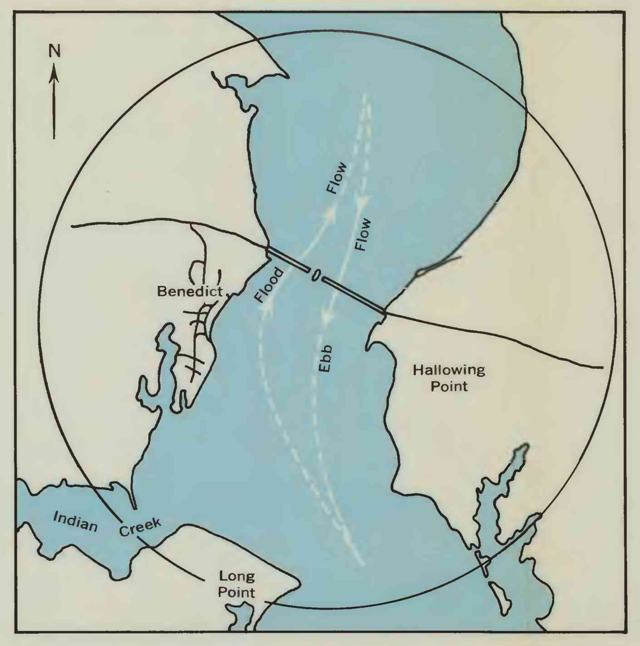
CUMULATIVE TIME OF TRAVEL OF PEAK DYE CONCENTRATIONS FROM INJECTION SITES TO DOWNSTREAM SAMPLING SITES ON EACH OF THREE STREAMS, APRIL 6-8, 1964



APPROXIMATE GENERAL RELATIONSHIP OF TIME OF TRAVEL TO DISCHARGE FOR THE PATUXENT BASIN ABOVE HARDESTY, EXPRESSED AS PERCENT OF THE VALUES OBTAINED APRIL 6-8,1964

Example: For the April 1964 measurement the discharge of the Patuxent River at Laurel (mile 25.8) was 62 cfs (cubic feet per second) and the time of travel from Laurel to the Little Patuxent River was 26 hours (see graphs showing cumulative time of travel of peak dye concentrations). If the discharge at Laurel is 31 cfs, or 50 percent of the April 1964 discharge, the travel time is estimated to be about 160 percent of 26 hours, or 41.5 hours





FLOW PATTERNS OF INCOMING AND OUTGOING TIDES AT BENEDICT, MARYLAND

WATER MOVEMENT IN THE PATUXENT ESTUARY

The Patuxent estuary meanders for a distance of about 50 miles between Chesapeake Bay and Hardesty—the approximate upstream limit of tidal action. During periods of low streamflow, salt water with chloride concentrations over 50 ppm (parts per million) intrudes as far as Lower Marlboro, about 35 miles above the mouth. The estuary varies in width from a maximum of 2.5 miles near its mouth to barely 100 feet at Hardesty. Its depth does not decrease uniformly upstream; the wide areas usually are more shallow than the constricted parts.

Chalk Point near Benedict is the site of an electric powerplant that uses estuarine water for cooling. Many studies of the environmental and ecological relationships of the area have been in progress since 1962 to establish the natural base from which to record local changes resulting from the discharge of heated effluent into the estuary. These include research efforts by scientists associated with Johns Hopkins, Lehigh, American and Maryland Universities, Maryland state agencies, and the U. S. Geological Survey.

Some of the studies conducted by the U. S. Geological Survey were the definition of the velocity and flow pattern and a computation of the inflow-outflow exchange of water in the Benedict Bridge area. The data on flow patterns, velocity, and volume of water in the Benedict area of the Patuxent estuary contribute to the research efforts of the above-mentioned institutions in several ways: (1) Definition of the flow pattern aids in the understanding of heat dissipation from the powerplant effluent, (2) definition of the flow pattern also contributes to the delineation of fish migrations and spawning grounds, and to the composition of population complexes and densities of other aquatic life, (3) knowledge of the amount of water exchanged by tidal action may be applied to the capacity of the estuary to assimilate heat and wastes without detrimental effects to the biota, and (4) comparison of the tidal inflows and outflows aids in identifying local salinity patterns and furthers understanding of the responses of the local biota to altered environmental conditions.

Simultaneous stage, velocity, and directional measurements of flow were made at 17 points representative of cross-sectional areas of the channel at Benedict Bridge during a complete tide cycle on August 5 and 6, 1964.

Measurement and velocity of water during flood and ebb tide conditions throughout a 17-hour period are illustrated. The arrows, which indicate the direction of flow and velocity, are spaced at equal-area intervals to represent the amount of water flowing through a section that extends laterally from a given arrow half way to adjoining arrows. The bridge and the vertical area of the water in the cross section of the channel is positioned directly above the flow direction record.

The velocity and height of tide at Benedict show greatest variations when the fresh water input of the river is minimal. During August 5 and 6 the flow of the river was quite low; about 90 percent of the time it is higher than on these dates. The estuary at Benedict Bridge is about 3,000 feet wide and its maximum depth is about 35 feet. The average cross-sectional area of the water is about 40,000 square feet; from low slack tide to high slack tide the area of the cross section changed from about 35,000 to 46,000 square feet. The normal range in tides at Benedict is 1.6 feet; during periods of high winds and extremely high tides, the height of the tide may reach an additional 3 feet. The maximum measured velocity, about 1.8 feet per second, occurred during flood tide in the deepest part of the cross section just west of the draw bridge at about 11:00 p.m., on August 5. The maximum average velocity of the flooding tide across the estuary was about 1.2 feet per second. The volume of water moving past the bridge during maximum flow was about 48,000 cubic feet per second.

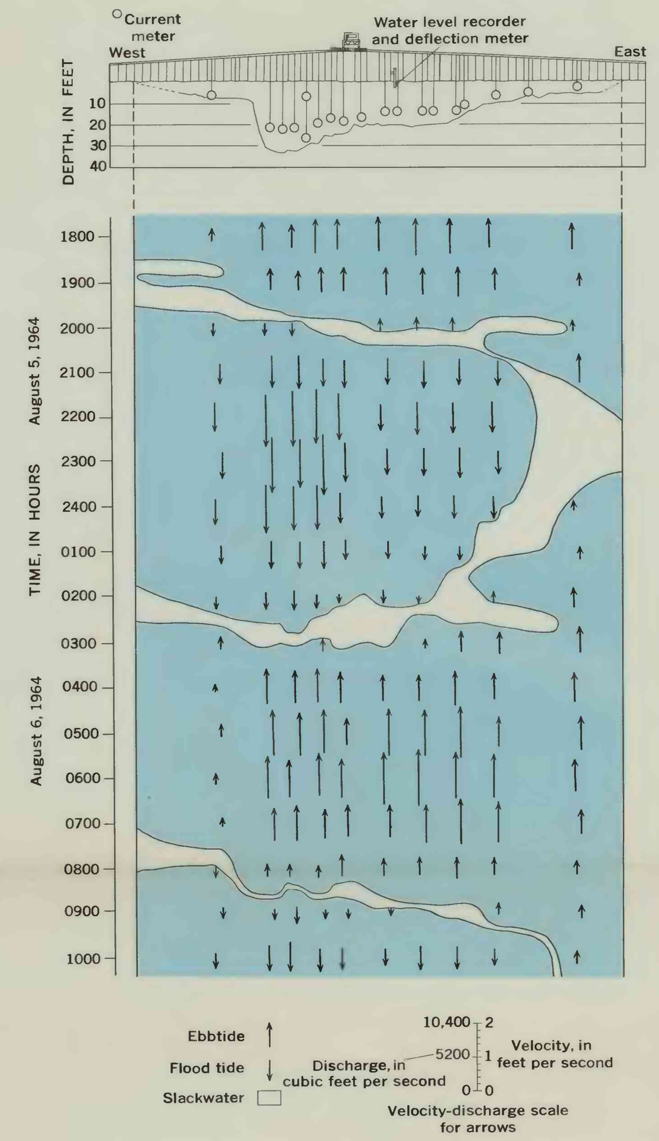
The shape of the channel is a controlling factor of the flow pattern during tidal interchange. During flood tide highest velocities were observed and the greatest volume of water flowed upstream just west of the draw bridge, passing under the bridge where the channel is deepest. For a period of 30 to 45 minutes, while the tide was flooding on the west side, the water in the extreme eastern portion of the estuary remained slack. During ebb tide the highest velocities and greatest volume of water were observed under the eastern half of the bridge. Apparently the tidal interchange of water in the area of Benedict Bridge rotates in a west to east pattern as shown.

During one tide cycle measured on August 5 and 6, 1964, about 5.4 billion gallons of water (about 726 million cubic feet) flowed upstream past Benedict Bridge and returned seaward on the outgoing tide. The mean gage height at Benedict during both incoming and outgoing tides was the same. When higher tides occur, haphazardly because of wind action, or progressively because of the lunar and seasonal tidal cycles, more water moves upstream than downstream; the excess is considered to enter into storage in the estuary and the shoreline of the estuary. A one-foot increase in mean gage height at Benedict is estimated to be equivalent to over 300 million cubic feet of water in storage above Benedict. This storage is depleted when sequential tides are progressively lowered and the mean gage height decreases. The fresh water runoff during the measured period, estimated to be about 9 million cubic feet, was only a small part of the water that moved seaward past Benedict.

SELECTED REFERENCES

Buchanan, T. J., 1964, Time of travel of soluble contaminants in streams: Am. Soc. Civil Engineers Proc., v. 90, no. SA3, Paper 3932, 12 p.

Wilson, J. R., Jr., and Forrest, W. E., 1965, Potomac River time-of-travel measurements: Lamont Geol. Observatory Symposium on Diffusion in Oceans and Fresh Waters, Palisades, N. Y., 1964 Proc., p. 1-18.



MOVEMENT AND VELOCITY OF WATER IN PATUXENT RIVER ESTUARY AT BENEDICT, MARYLAND, AUGUST 5 AND 6, 1964

INTRODUCTION

Surface water movement in the Patuxent River basin takes place in two different hydraulic regimens: freshwater stream channels, and the estuary. Above Hardesty, water movement in the basin is independent of tidal action, and time-of-travel measurements are used to describe the movement and dilution of soluble materials. In the estuary large quantities of water move upstream and downstream with the tides, and the analysis of water movement is more difficult. Results of studies of both aspects of surface water movement are described on this sheet for observations made in 1963 and 1964.

TIME OF TRAVEL IN THE PATUXENT RIVER BASIN

Time of travel is a term used to describe the rate and pattern of movement of water and its content of dissolved solids. Time of travel was measured in several fresh-water reaches of the Little Patuxent, Middle Patuxent, and Patuxent Rivers above Hardesty in November 1963 under typical autumn low-flow conditions, and in April 1964 during the spring rainy season. Fluorescent dye was added to the streams and water samples were collected at frequent intervals at selected downstream sites and tested for the dye. (Buchanan, 1964). Both time of travel and information about the dilution (dispersion) of dissolved materials are determined from the time-distribution of dye concentrations in the samples. The results are applicable only to problems concerning soluble contaminants. In a given situation suspensions tend to have longer travel times and large waves tend to have shorter travel times than solutes. The travel time of floating materials may be erratic, depending upon water-surface currents and wind action.

The longitudinal dispersion patterns, or time-concentration curves, are shown for the April 1964 measurement. Had a different amount of dye been used, the relative shapes of the curves would be about the same, as long as the volume of dye used was very small in comparison with the volume of water in the reach. Had the discharge been different, the relative shapes of the curves also would be different. The cumulative travel times were obtained from the time-concentration curves.

Stream discharge is the principal factor affecting time of travel; time of travel is shorter when discharge is high than when discharge is low. The approximate general relationship is shown of time of travel to discharge for the Patuxent River basin, on the basis of the two measurements. This relationship may be used, with caution, to obtain estimated travel times for discharges different than those listed. Discharge may be determined from the gaging stations on the Little Patuxent and Patuxent Rivers by measurement or estimation at any desired location.

An important application of time-of-travel information is in the prevention of water-supply contamination. Arrival and passage times at any point as far downstream as Hardesty, where flow is affected by tidal fluctuations, can be predicted by referring to the graph showing cumulative time of travel. If for example toxic materials were accidently spilled into the Little Patuxent River at Pine Orchard (mile 38.9 is where U. S. Highway 40 crosses the river), with discharge conditions similar to those listed, the leading edge would arrive at Ft. Meade water intake (mile 20.5) about 19 hours later. Within 3 hours the highest concentrations would be past the intakes, but complete clearance of the chemicals would not occur until about 25 hours after the spill. The peak concentration would reach the confluence with the Patuxent River (mile 8.9) about 33 hours after the spill and would take an additional 11 hours to reach Hardesty. Anticipating the arrival and passage times of the toxic material, water plant operators could prevent contamination of the water supply by not withdrawing water from the stream during this period.

Travel times in the Little and Middle Patuxent Rivers usually will be equivalent above the confluence, because the two streams are hydraulically similar and essentially unregulated. However, the travel time for the Patuxent River above the confluence with the Little Patuxent depends largely on the magnitude of release from Rocky Gorge Dam, just above the gaging station at Laurel. Below the confluence travel time depends on the combined flows of the Little Patuxent River and the Rocky Gorge release.

Below Hardesty travel time is affected by tidal action and by the broadening and deepening of the estuarine reach of the river. In another study, currently underway by the Survey, dye was traced through a section of the Potomac estuary. The dye cloud moved alternately upstream and downstream in response to the tide, and became extremely dispersed as it mixed with the much greater volume of the estuary. Although the river water, with its dissolved contaminants, ultimately discharges to the sea, its movement is slowed and the concentration of the contaminants is diluted as the water passes through the estuary.

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WATER RESOURCES OF THE PATUXENT RIVER BASIN, MARYLAND

By
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