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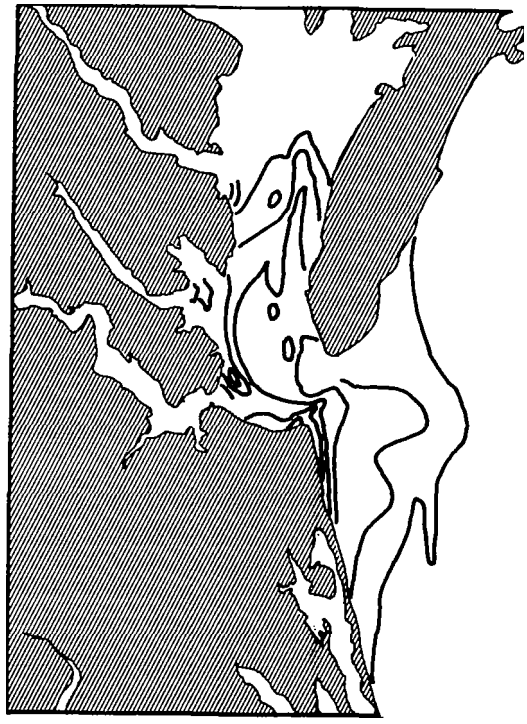
Chesapeake Bay Plume Study

Superflux 1980



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A BENCHMARK MULTI-DISCIPLINARY STUDY OF THE INTERACTION BETWEEN THE CHESAPEAKE BAY AND ADJACENT WATERS OF THE VIRGINIAN SEA

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Estuaries are by definition coastal bodies of water emptying into the seas or oceans of the world through semi-restricted openings within which the salt water from the sea is diluted by freshwater from land drainage (ref. 1). Such systems, especially large ones, behave like semi-enclosed brackish water reservoirs and have physical, chemical, geological, and biological features different from those of the ocean into which they open and flow and from the freshwater streams which empty into them. Generally speaking, uncontaminated estuaries are extremely fertile, producing large quantities of animal and plant materials (i.e. total biomass) each biological year. Consequently, they are sites of many highly productive and valuable inshore fisheries and the spawning areas or nursery grounds of many species of finfish which range the waters of the continental shelves of the Earth's oceans. They also shelter many plants and invertebrates of ecological or economic significance.

The sheltered waters and extensive tidal shorelines of estuaries also provide ports, industrial and residential sites, recreational opportunities, and tourist attractions. Because of these attractions and amenities, estuarine shorelines are usually the first places to be populated when countries are colonized from the sea or when agricultural and economic development occurs, and they grow rapidly. Urban and industrial development in such areas is common. Consequently multiple-use problems involving conflict among the many users are common in heavily populated areas and they inevitably increase as populations grow. During periods of growing international commerce, estuarine shorelines often experience explosive growth and utilization and natural or traditional uses are "pinched" even further.

In the United States, a look at the major population centers of the East, Gulf, and West coasts demonstrates the accuracy of these statements. Some examples include Boston on the Charles estuary, New York City on the Hudson, Philadelphia, Chester and Wilmington on the Delaware, the principal urban areas of Baltimore, Washington, Richmond-Hopewell and the Hampton Roads complex in the Chesapeake Bay region, Charleston on the estuarine portions of the Ashly and Cooper Rivers and their confluence, New Orleans on the Mississippi, Corpus Christi and San Francisco on the bays of the same names, and the Seattle-Tacoma complex on Puget Sound. Many more could be cited, and this situation applies the world over.

Because of their social and economic importance and associated multiple-use development and management problems, as well as their internal physical, geological, chemical, and biological complexities, estuaries have become the

objects of much scientific study and technological advancement over the last thirty years in the United States and many other countries.

The Chesapeake Bay, the largest estuary in the United States, exemplifies this last point. At present a large array, probably the largest on any similar body of water in the world, of scientific and technological specialists and institutions is engaged in investigation of its natural and socially-related phenomena and problems, and a great deal has been discovered in the last three decades. For example, the Chesapeake Bay Bibliography series (refs. 2 to 6) contains over 6610 entries.

Despite the efforts and the knowledge developed by recent and extant scientists and institutions and their predecessors, much of scientific, technological, and managerial importance remains to be learned. It is not yet possible to answer many of the critical questions which would allow determination of cause and effect or prediction and management.

A number of reasons account for our continuing relative ignorance of certain important features. Estuaries are naturally complex and dynamic, subject to changes of great magnitude, violence, and suddenness in the catastrophic events experienced. They are also subject to the lesser, but still significant, fluctuations which occur over long periods of time, such as dry years, wet years, and years of average annual rainfall, as well as to the smaller but more frequent daily, monthly, and seasonal changes.

Not only has nature made certain estuaries especially large and/or complex, dynamic, complicated, and extremely difficult to grasp, understand, and manipulate, but society has superimposed its own complicating and dynamic effects, all of which make the task of understanding and controlling estuarine environments and resources even more difficult. At times it may seem impossible to develop adequate understandings of such natural systems using traditional means of field sampling (or laboratory observation), analysis, and deduction or induction which have stood the scientific method in such good stead over the years of recorded human history. Only in recent years have techniques of sampling and analysis, e.g. automated samples, instrumented buoys, high-speed computers, sensitive micro-analytical techniques, hydraulic models, wide-area remote sensing, and accurate navigation and positioning developed the power and scope to give encouragement that such systems may soon be better understood.

For some years, science administrators and scientists interested in understanding large systems like the Chesapeake have dreamed of being able to plan and mount large-scale multi-disciplinary field and laboratory efforts designed to gather, analyze, and synthesize biological, chemical, geological, physical, and even socio-economic data taken at the same time (or nearly so) over the entire length and breadth of the Bay, or large segments of it. They have also wished to understand the interactions between the Chesapeake and its tributaries, especially the principal ones, and those between the Bay and the adjacent waters of the Atlantic. Comprehensive synoptic and simultaneous studies of the passage or flux of energy, chemicals, biological entities, turbidity, and other factors into, through, and out of the estuarine system

have been particular dreams. The goal has been to develop a comprehensive understanding in sufficient detail to enable accurate explanation, precise prediction and, hopefully, wiser use and manipulation.

The Chesapeake Bay drains large expanses of four states - New York, Pennsylvania, Maryland and Virginia - and lesser portions of West Virginia and Delaware (fig. 1). Principal inflow from the Susquehanna system provides approximately 50% of all the fresh water entering the system. The rest is provided by the Potomac (18%) and the James (14%), with the remaining (18%) coming from all of the other rivers of the eastern shores (fig. 1). The Bay is 156 n. mi. long and 25.6 n. mi. wide at its widest and encompasses 11.5×10^9 m^2 (2 841 650 acres) of surface area with a volume of 74×10^9 m^3 (11.6 cubic miles) of water. Though its deepest spots in the natural channels are quite deep (i.e. 53 m (175 ft)) it is essentially a shallow body of water, averaging about 8 m (27 ft) in depth in its main body. Including the tributaries, it averages 6 m (21 ft) in depth (ref. 7). Its shallowness renders it subject to violent stirrings by wind. Its waters are frequently quite turbid as a consequence of wind action, river flow, and runoff. Normally the tide ranges about 1 m (3 ft).

Like all great estuaries with a large but varying volume of freshwater inflow, the Chesapeake experiences wide fluctuations in its physical and chemical parameters, which vary considerably at any one spot in the water column. They also fluctuate up and down the Bay and between day and night, as well as seasonally and annually on a regular or sometimes irregular basis (refs. 8 to 11).

Fluctuations in salinity are especially significant indicators of such variability and its importance. Figures 2, 3, and 4, depicting salinity at specific locations and depths and by years, show this quite clearly. For example, figures 2 and 3 compare salinities in several different years at comparable locations in the James and York estuaries. During periods of drought over the drainage basin, higher salinity ranges far up these tidal tributaries. During the extremely dry period of the mid-1960's it moved some 21.7 n. mi. inland, up the tidal James, reaching to the city of Hopewell and threatening municipal and industrial water supplies (fig. 4). Figure 4 also shows that the distribution of the male and female blue crabs (Callinectes sapidus) was affected since there is some sorting by sex of that species with the females remaining in higher salinity waters. Such salinity-related destructions affect a number of economically and ecologically important estuarine species. Similar changes occurred in the main stem of the Bay proper, as shown in figure 5 which depicts salinities during normal (1968) and wet (1972) years at the surface and bottom at the same stations.

The extremely wet years occurred when two tropical storms (i.e. former Gulf coast hurricanes), Camille (August 1969) and Agnes (June 1972), visited the basin. These episodes generally caused marked reductions in salinities throughout the Bay, but the responses were complex and scientifically interesting (ref. 12). An immediate aftermath of Agnes was large-scale freshwater mortalities over the vulnerable low-salinity upstream oysterbeds of the basin. A long-term effect of these salinity changes was a marked reduction in the

abundance of the two oyster-eating snails, Urosalpinx cinerea and Eupleura caudata, and a number of mortality-causing oyster disease organisms. Thus, long-term recovery and survival of oyster populations on higher-salinity beds have been much better than formerly since Agnes visited the area in 1972, at least until 1980-81 when two dry years began to allow salinities in those same places to increase.

The Agnes episode also provided scientists with an opportunity to investigate for the first time the details of the effects of such Bay-wide catastrophic events. An entire volume resulted from the multi-institutional, multi-disciplinary investigations that took place (ref. 12). Agnes not only affected the Chesapeake but also produced low salinities far out over the shelf waters around the mouth of the Chesapeake, mostly northward, as shown in figures 6 and 7 (ref. 12).

Many other important features of the Bay also vary. For example, the currents at any one spot in the system also vary daily and seasonally and, at times, annually. The amount of fresh water entering the system at any one time, in relation to the salt water from the ocean, influences not only salinity (especially) and temperature but currents as well. Other physical features such as turbidity (due to sediment-laden land runoff from above and below the fall line, plankton productivity, and resuspension of particulates from the bottom), color, and transparency are also affected by freshwater inflow from contributing streams and from adjacent highland and lowland areas. Estuarine chemistry is likewise affected by rainfall, temperature, sediment influx and resuspension, biological processes, and other factors, including the chemical contributions from society's many industrial, domestic, and agricultural activities. Additionally, chemical oxygen demand (COD), biological oxygen demand (BOD), nutrients, trace metals, many toxicants, and many other chemicals and chemically-related phenomena are influenced by rainfall and runoff and injections from point-source or non-point-source discharges.

Biological systems within the estuary are influenced directly, indirectly, and inter-reactively by all the physical, chemical, and geological factors mentioned above. Hence, biological productivity may be affected favorably or adversely by changing nutrient levels and types or by toxicants (usually adversely), salinity, temperature, turbidity, transparency, and other factors.

As indicated above, salinity is important to estuarine biological systems since many species are themselves directly salinity-dependent or salinity-limited. Most are indirectly affected as well; for example, the several pathogens and predators (i.e. MSX, Dermocystidium, and other diseases, and the oyster drills Urosalpinx cinerea and Eupleura caudata which damage oysters) may be allowed (or caused) to invade oyster beds previously protected by low salinities when drought causes an increase in the salinity levels in the waters over those beds. Conversely, extremely low salinities caused by a surfeit of freshwater inflow can kill oysters in those same previously productive beds. Many similar fluctuations can occur in the populations of other changeable species of ecological and economic significance.

Scientists have long been interested in the physical, chemical, geological, and biological interactions between the Chesapeake Bay and the waters of the nearby littoral and shelf regions. The integrity and productivity of the Bay is closely dependent upon the Atlantic waters which enter within the approximately 15.6-n.-mi.-wide mouth between Cape Henry and Cape Charles. The tremendous volume of salty ocean water (about 32 parts per thousand of salts at the Bay mouth) obviously influences salinities far into the Bay, and waterborne ocean sediments, animals, and plants play a strong role in productivity of the system. Conversely, the coastal and nearby shelf waters of the Chesapeake Bight of the Mid-Atlantic Bight are known to be greatly influenced by fresh water from the nearby Chesapeake and Delaware Bays. It remains to be determined how much influence each system has on the other, how far these interacting influences extend southward (around Cape Hatteras into the Carolinas) and northward (off of Maryland, Delaware, and New Jersey), what their seaward distribution is, how they change, and what influence the estuarine-generated water, sediments, detritus, contaminants, and biological systems have on coastal and shelf waters.

To understand such complex and dynamic systems and answer the questions involved in developing such understanding involves large-scale, multidisciplinary field and laboratory research efforts. It also involves carrying out such studies over long periods of time because many natural phenomena exhibit not only short-period but long-period variability and studies must be of sufficient duration and extent to cover such periodicities. For example, one must cover normal or average periods as well as abnormal or extreme periods in order to understand the ups and downs of fishery populations, since population levels can be markedly influenced by extremes in physical, chemical, or even biological aspects of their habitats.

In 1979 scientists and employees from a number of scientific institutions joined in a multi-institutional, multi-disciplinary study of the lower Chesapeake Bay and adjacent coastal and shelf waters. The project, called Superflux, the field phases of which were carried out during the period from March to October of 1980, involved personnel from the National Aeronautics and Space Administration's Langley Research Center and Wallops Flight Center; the Virginia Institute of Marine Science (VIMS); Chesapeake Bay Institute of the Johns Hopkins University; the National Marine Fisheries Service of the National Oceanic and Atmospheric Administration (NOAA), Northeast Fisheries Center; NOAA's National Ocean Survey and Atlantic Marine Center; Research Triangle Institute; the College of Marine Studies of the University of Delaware; Old Dominion University; the U.S. Navy (Oceana Naval Air Base, Little Creek Amphibious Base, and the Naval Academy); the Environmental Protection Agency; the U.S. Coast Guard; Anne Arundel Community College; the Department of Natural Resources of the State of Maryland; and the University of Miami.

As frequently happens in scientific research, unforeseen events conspired to make Superflux of special interest. A severe drought (which markedly reduced rainfall and hence river flow) over the entire East Coast throttled the outflow of the major tributaries entering the Mid-Atlantic Bight. For example, rainfall dropped to extremely low levels and riverflow into the Chesapeake was reduced to the lowest since 1966-67, when the salt water

intrusion zone moved upstream some 21.7 n. mi. into the James and other tributaries. That this unusual natural event should occur at a time when scientific forces were marshalled and active in the three segments of Superflux was especially notable.

The severity of the drought which occurred during the Superflux experiments offered an unusual opportunity to observe rainfall-dependent phenomena Bay-wide and in synoptic fashion during an extreme condition. In this sense, the measurements made during Superflux will serve as a benchmark for future monitoring of this area. The results of these experiments demonstrated the influence of extreme low-flow conditions on the mouth of the Chesapeake and the nearby Atlantic using remote sensing techniques and sea truth observations during periods of high and normal flow.

The Superflux experiments were also marked by a notable degree of interdisciplinary scientific and technical coordination, from data collection all the way to analysis and interpretation. Several times in the past, scientists have attempted to plan and carry out large-scale sea truth observations to compare them with the observations made by remote sensing instruments. Attempts have been made to correlate surface and subsurface oceanographic measurements with remote-sensing passes from low, intermediate, and high altitudes as well as satellite overflights. Superflux marks the most successful effort to date in bringing about such a coordinated effort between marine scientists and remote sensing scientists.

Future efforts in ocean research and development should devote high priority to large-scale, multi-disciplinary examinations of estuarine, coastal, and near-shore oceanic regions. Much remains to be learned in order to allow proper scientific understanding, prediction and management. Remote sensing techniques should again be paired with large-scale, synoptic observations of the several important natural and economically- and socially-related phenomena to develop new understandings and predictive models of estuarine and coastal waters in order to enable reasonable selections and sound management and economic decisions. Science and economics will both be served by the resulting improved understanding.

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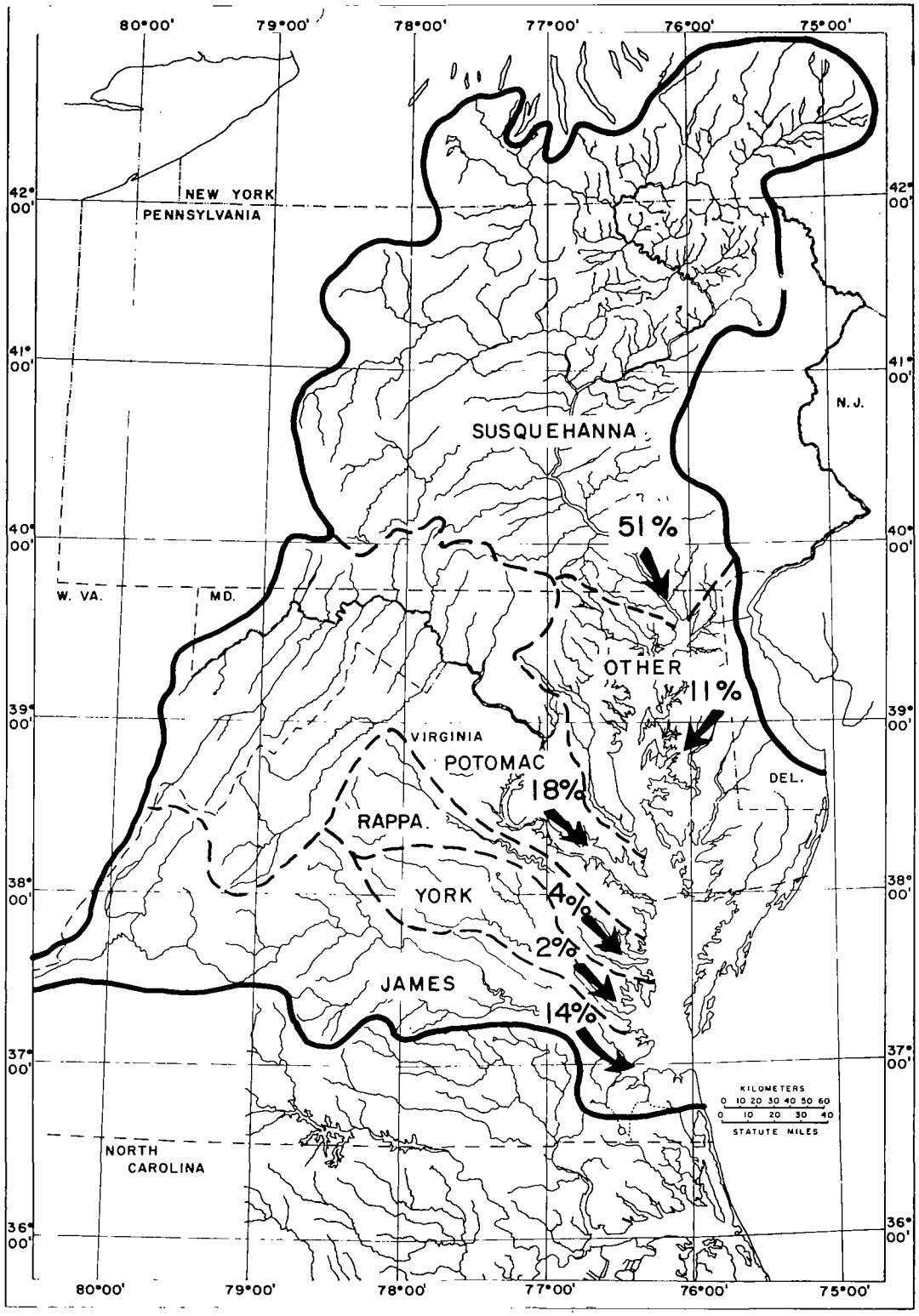

Figure 1.- Chesapeake Bay drainage basin showing sub-basins and approximate freshwater contribution by major tributaries.

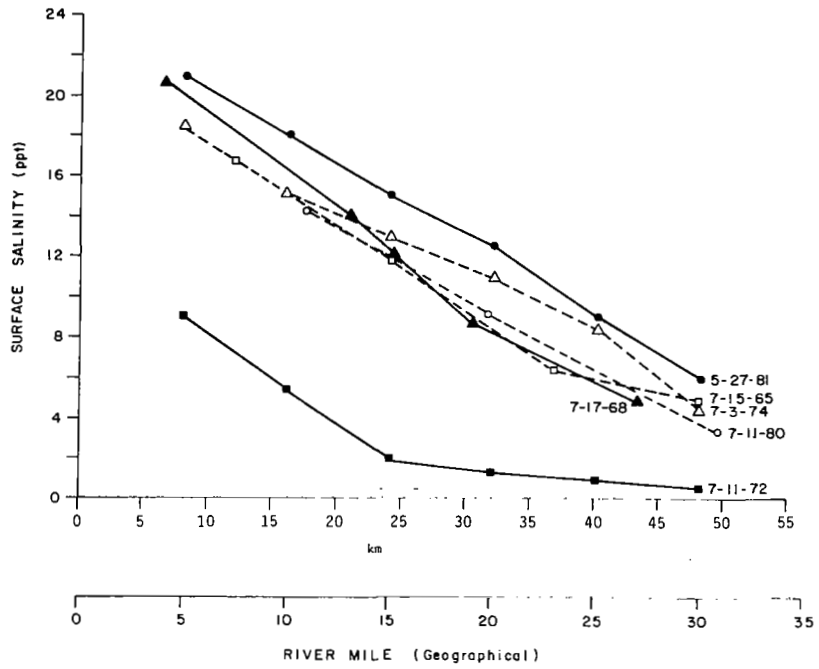

Figure 2.- Surface water salinity of the James River by river mile during periods of high rainfall (1972, tropical storm Agnes), normal rainfall (July 1968), and drought (1965, 1974, and 1980-1981).

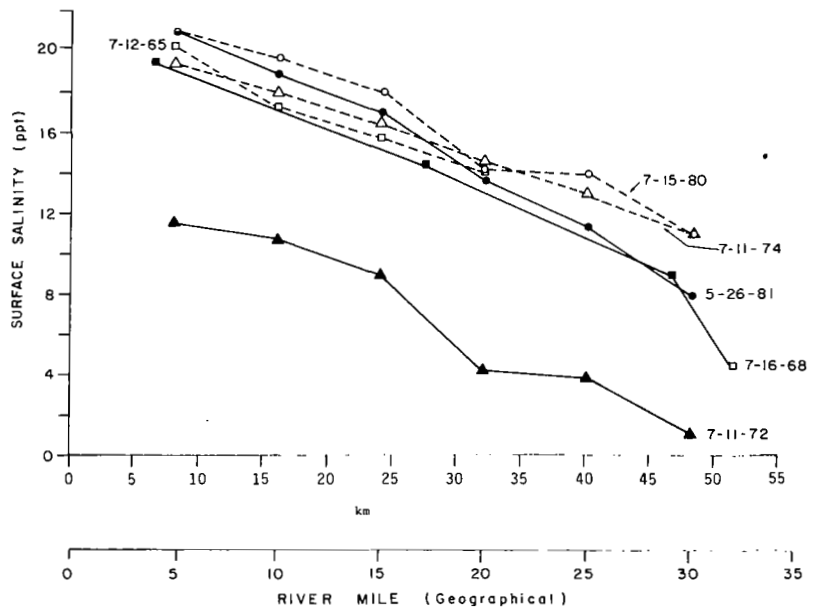

Figure 3.- Surface water salinity of the York River by river mile during periods of high rainfall (1972, tropical storm Agnes), normal rainfall (July 1968), and drought (1965, 1974, and 1980-1981).

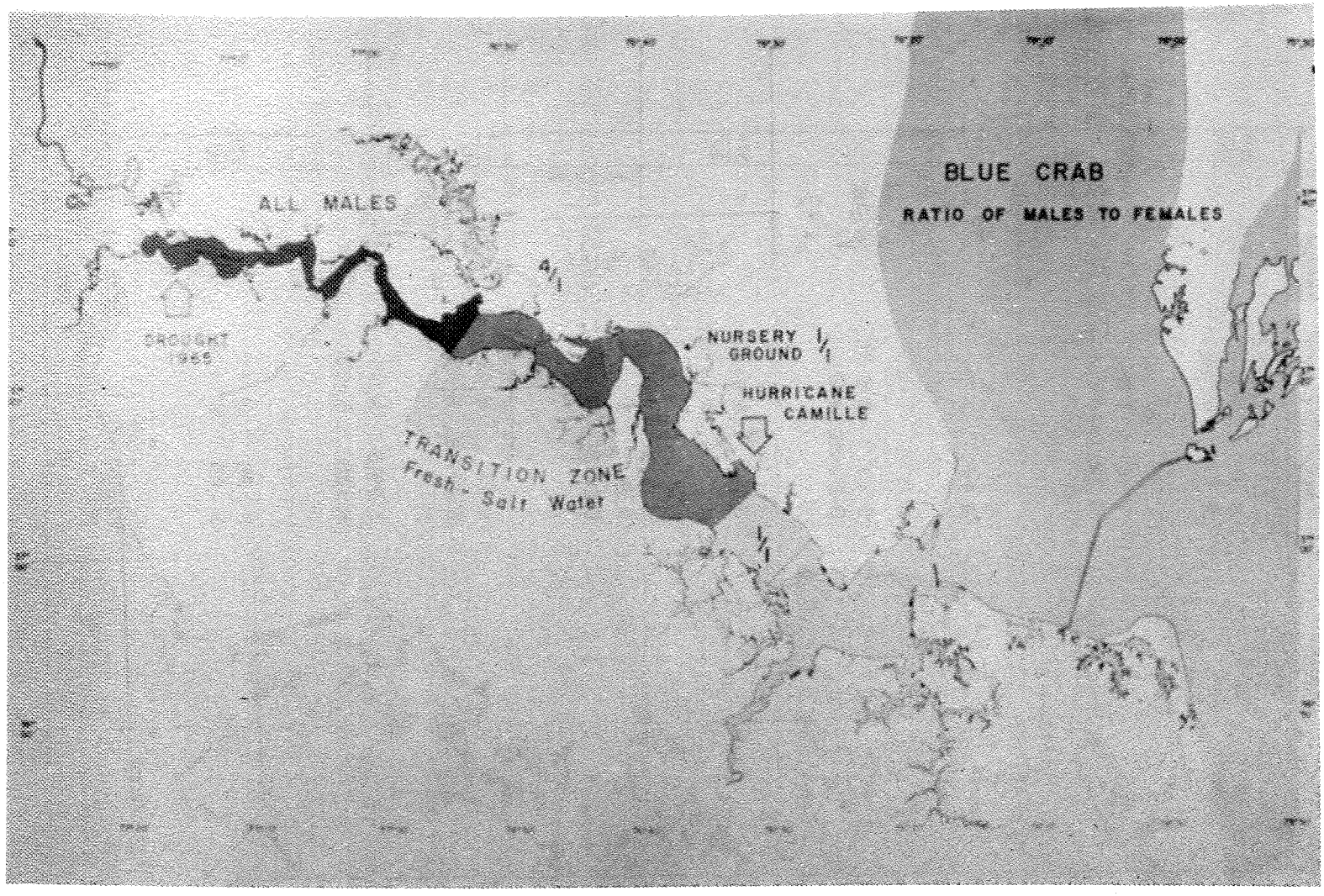

Figure 4.- Influence of drought (1965) and high rainfall (tropical storm Camille, August 1969) on the salinity transition zone and on the ratio of male to female blue crabs in the James River.

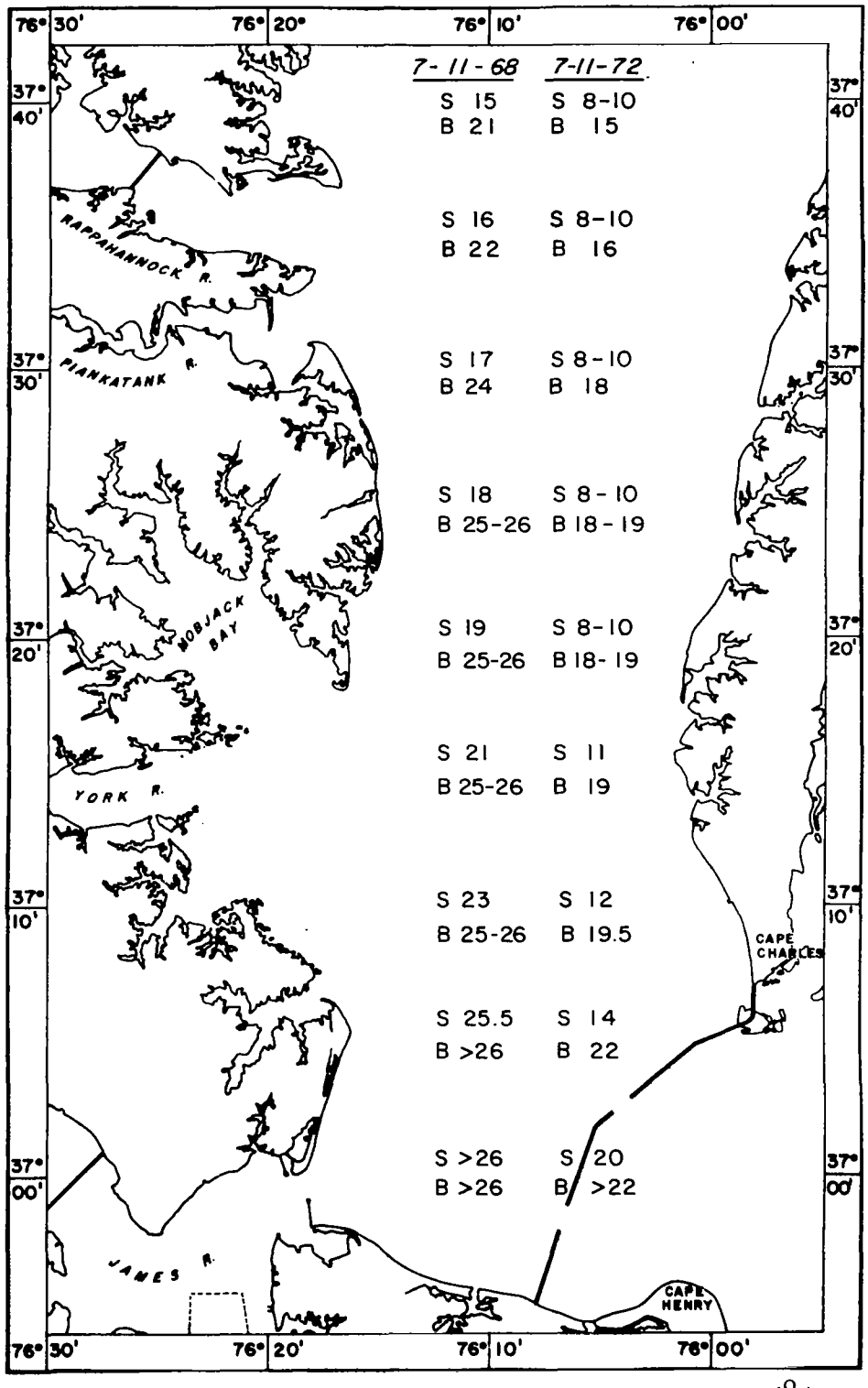

Figure 5.- Distribution of salinity in parts per thousand (^{o}/oo) at the same locations in the Chesapeake Bay during July, 1968 (average to below-average rainfall period) and July 1972 (high rainfall period, tropical storm Agnes).

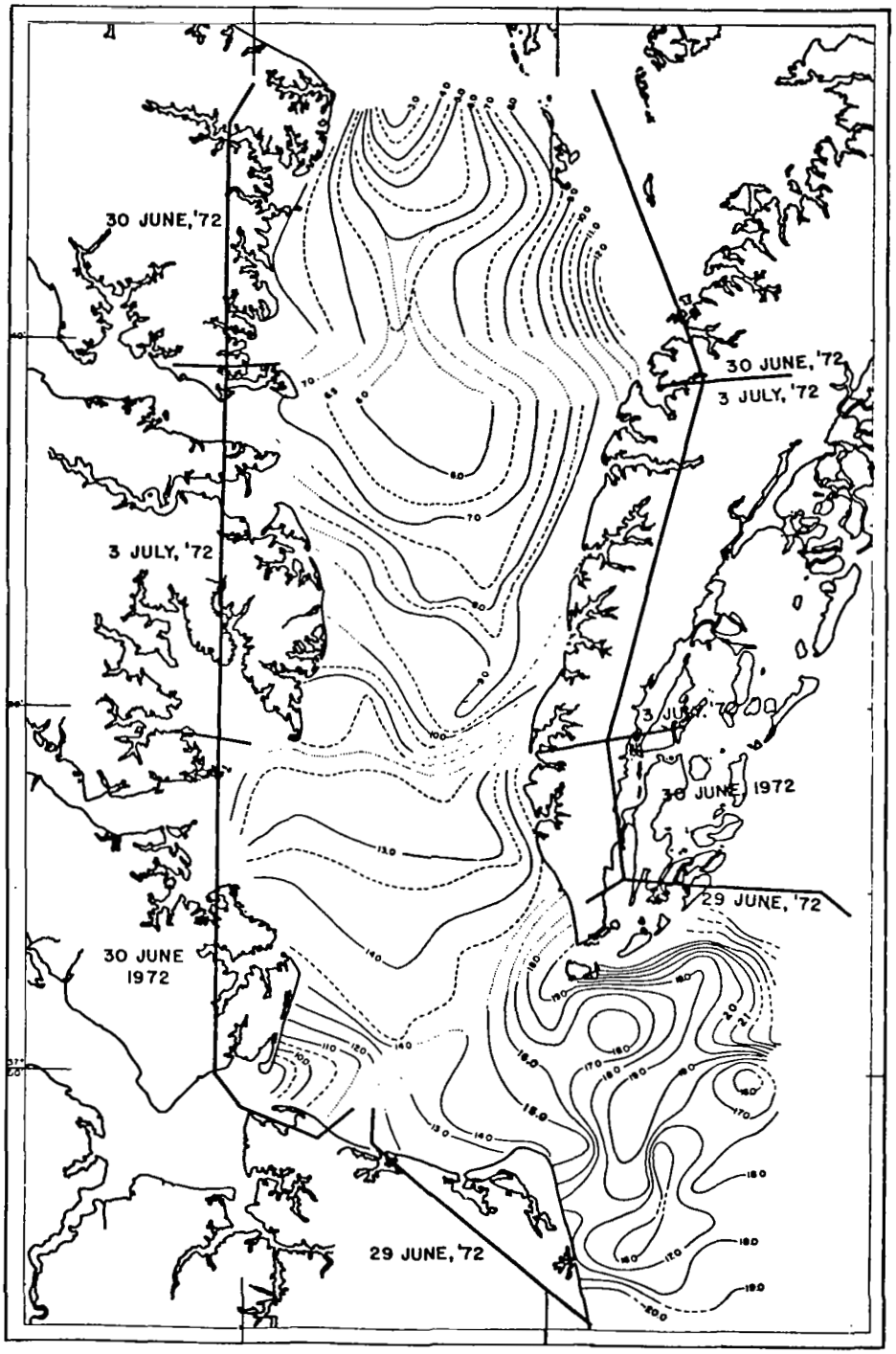

Figure 6.- Surface salinities in the lower Chesapeake Bay one week (June 29 to July 3, 1972) after passage of tropical storm Agnes through the region (June 21 and 22, 1972) (from ref. 12).

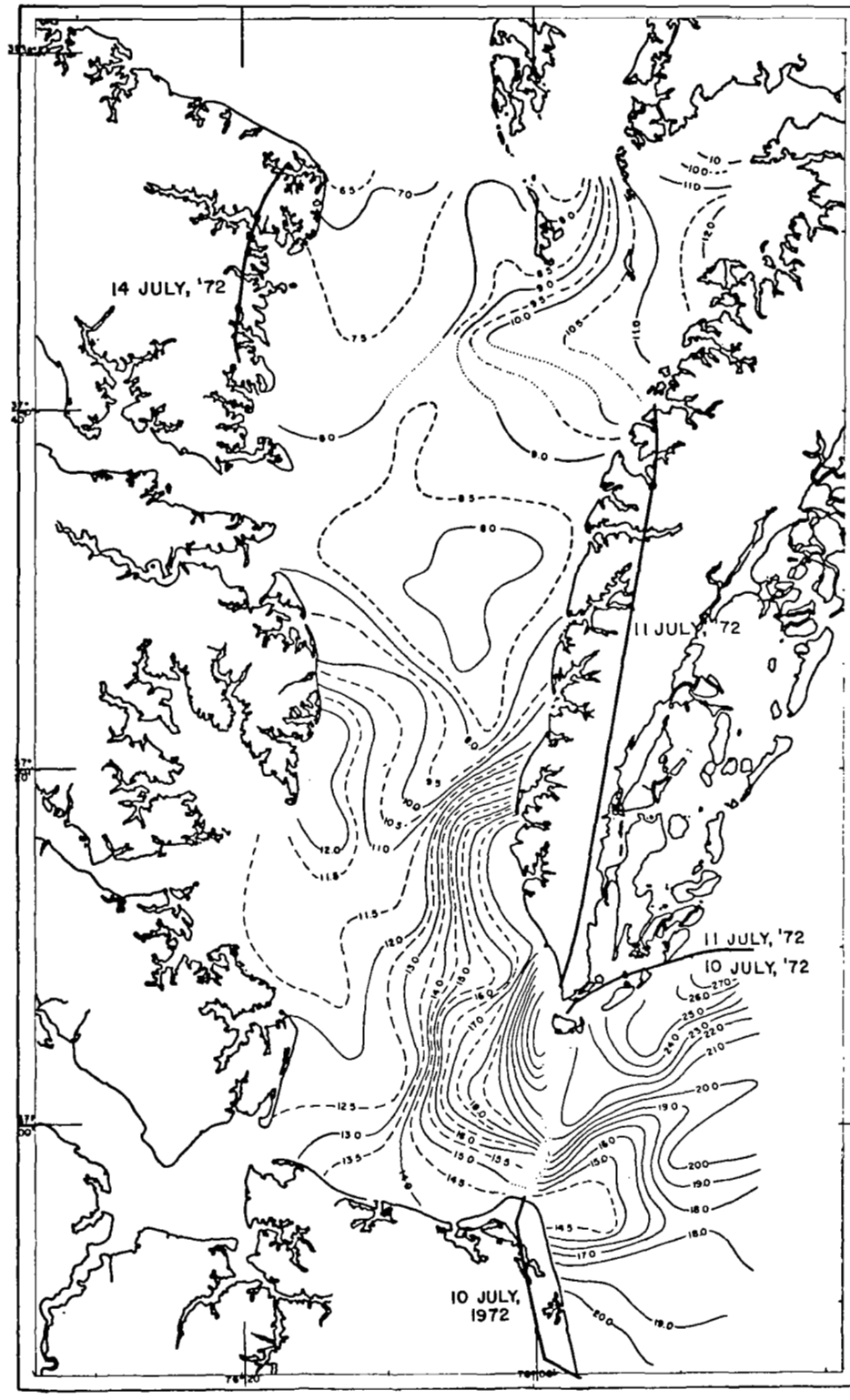

Figure 7.- Surface salinities in the lower Chesapeake Bay two weeks (July 10-14, 1972) after passage of tropical storm Agnes through the Chesapeake Bay region (June 21 and 22, 1972) (from ref. 12).