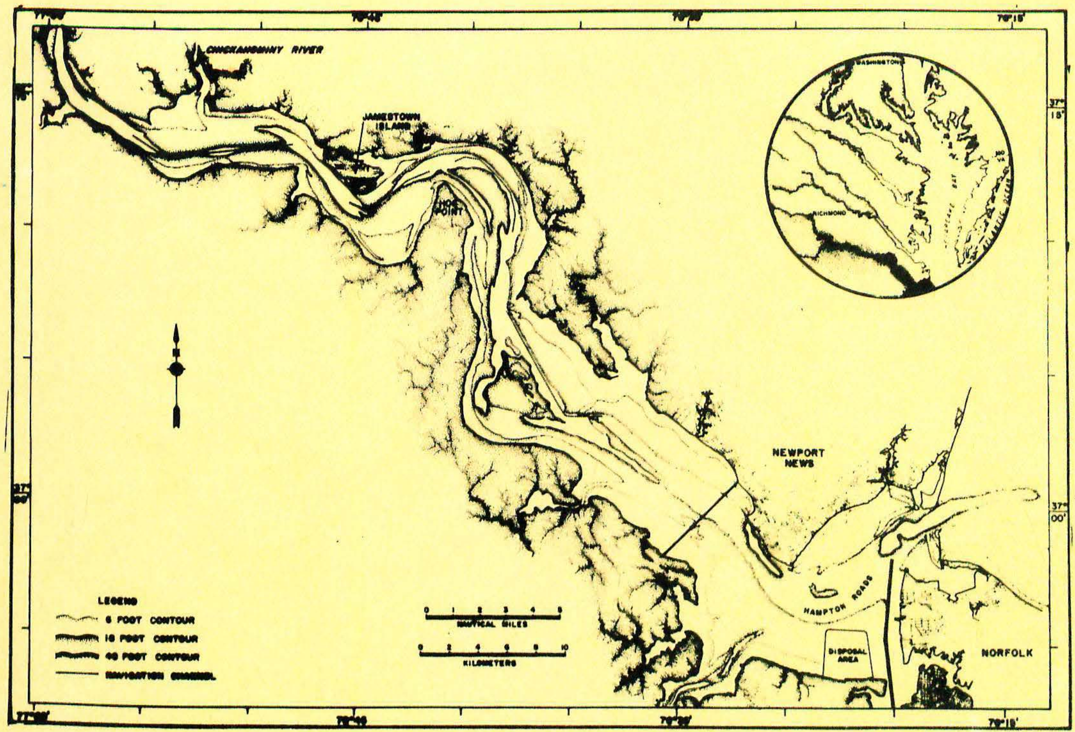
Dr. Andrews

J. D. Andrews

FINAL REPORT

OPERATION JAMES RIVER



AN EVALUATION OF PHYSICAL AND BIOLOGICAL EFFECTS OF THE PROPOSED JAMES RIVER NAVIGATION PROJECT

by WILLIAM J. HARGIS, JR.
Chief Scientist, OJR

Special Scientific Report in Applied Marine Science & Ocean Engineering, No. 7
VIRGINIA INSTITUTE OF MARINE SCIENCE, Gloucester Point, Virginia

FINAL REPORT
ON
RESULTS OF OPERATION JAMES RIVER
(An Evaluation of the Physical and Biological Effects of the Proposed James River Navigation Project)

by
William J. Hargis, Jr.
Chief Scientist

December 1966

Special Report in Applied Marine Science

and Ocean Engineering No. 7

of the

Virginia Institute of Marine Science

Gloucester Point, Virginia

ABSTRACT
OF THE
FINAL REPORT
ON
RESULTS OF OPERATION JAMES RIVER

(An Evaluation of the Physical and Biological Effects
of the Proposed
James River Navigation Project)

by
William J. Hargis, Jr.
Chief Scientist

A comprehensive study of the physical and biological characteristics of the James Estuary has been carried out by oceanographers of the Virginia Institute of Marine Science under contract with the Virginia Commission of Fisheries. This research project, under way for three years, has been directed especially to the effects of the proposed James River Navigation Project channel dredging on physical features--*i.e.*,the structure and dynamics, of the estuary, and indirectly on oyster production. Five separate phases were carried out under the project (called Operation James River). These involved: 1) accumulation and study of relevant literature and data, 2) research into the physical characteristics of the James, itself, 3) studies of oysters and related organisms in the field, 4) research on relevant marine organisms under laboratory conditions, and 5) studies of "before

and after" effects of channel dredging on the salinity and currents in the especially-constructed hydraulic model.

OJR has produced much new knowledge of the biological, chemical, geological and physical characteristics of the tidal James which is of great value scientifically and also will be of value in the future development of the James River Basin. Of greater immediacy, the physical studies indicate clearly that the proposed channel deepening *will cause changes* in the salinity and current regimes of the estuary. Biological research, however, shows that these physical changes *will have no significant effect* on the production of seed or market oysters in the James Estuary. If conducted properly, the dredging will not affect other marine populations significantly. Future proposals for alterations in the physical, chemical and geological characteristics of tidal James should be evaluated just as carefully.

FINAL REPORT
ON
RESULTS OF OPERATION JAMES RIVER

(An Evaluation of the Physical and Biological Effects
of the Proposed
James River Navigation Project)

by

William J. Hargis, Jr.,
Chief Scientist

INTRODUCTION

Physical and Biological Oceanography of the James Estuary

The James Estuary is a complicated physical system, usually classified by oceanographers as an horizontally-stratified, mixing-type estuary. (The word estuary denotes that portion of a tidal tributary where sea salts mix with fresh water from land runoff.) Stratification is due principally to difference in density between water masses. Heavier salt water, originating in the ocean is concentrated in lower levels of the estuary while the lighter, less-dense fresh water, entering from the upland parts of the basin, flows down the estuary along the surface. Movement of the fresher water layer is gravity induced. Salt water of a particular salinity level intrudes farther up-estuary in the lower layers than in the surface layers and salinities are usually lower over the shoals than in the deeper water. Salinities are often higher on one side (in the James the NE or Newport News side) than on the other.

Mixing between the two layers is caused by movement (advection) and agitation by tidal action and other turbulence-producing (stirring action) phenomena and by the tendency of miscible liquids to mix. This mixing of water causes the saltier water from below to be carried into the fresher layers above where it is further mixed and diluted and carried seaward. Loss of this salt water from the lower layer causes more salt water to flow into the estuary from the ocean as replacement. Thus, an up-estuary moving current is established and maintained in the lower layer. This complex relationship is presented in simplified fashion in Figure 1.

These structural and dynamical physical aspects of water masses in the estuary may vary depending on 1) amount of freshwater inflow from upland drainage, 2) geometry of the estuarine basin (*i.e.*, bottom and shoreline topography and orientation), and 3) salinity of bay or ocean waters at the mouth.

The biota of the James estuary is also quite complex, consisting of free-living and attached species that may be bottom dwelling (benthonic), floating (planktonic), or swimming (nektonic). Plant and animal populations living in an estuary must be adapted to the highly variable conditions of salinity, temperature, pressures, light penetration and other physiologically important chemical and physical conditions existing there.

The economically important oyster has become well-adapted to estuarine conditions. Because they cannot move after setting, oysters can escape predators and diseases or other unfavorable conditions only by passive defense mechanisms, such as closure or immune responses, or by the protection afforded by such ecological conditions as low salinity. It is widely recognized that post-spat or adult Atlantic oysters (<u>Crassostrea virginica</u>) can tolerate lower salinity regimes than can most of the major predators and diseases which destroy or weaken them (Galtsoff, 1964 and many others.) Pre-setting or larval oysters are planktonic and wholly or partially dependent on estuarine currents to carry them from the spawning areas to the setting places.

It is clear, therefore, that the success of oyster populations and the dependent oyster fishery is directly related to continuance of favorable salinity and current patterns in the estuary. Especially apparent is the need to evaluate each proposed long-term change in the geometry of the bottom and sides and in freshwater inflow in the light of the possible physical and biological (and eventually--economic) effects.

An interesting sidelight of this research has been the development of considerable evidence /Nichols, personal communication, Hargis (1965) and Marshall (1954)/ that oystering practices, themselves, have made significant changes in the bottom geometry of the estuary by removing far more shell and other materials from the bars than have been replaced by the oysters, replenishment programs and geological processes. Most oyster shoals show lowering at a rate greater than two feet per 30 years since 1900. Some shoals have been lowered up to eight feet. It is likely that some of the materials removed from the oyster bars has been deposited in the depressions between them as a result of the oystermen culling off the rocks. If continued, this likely will result in smoothing of the bottom. According to our calculations about 43,000,000 cubic yards of material has been removed or moved around by tonging activities. Though this deepening occurred in the shoals rather than in the channel or deeper parts and hence has not had the same hydraulic effect as channel deepening will have, it has produced significant changes in bottom geometry. Circulation and salinity distribution in relation to the bottom undoubtedly have also been altered. The most important point here is that the activities of resource users, like oyster fishermen and gravel and shell miners, also must be considered in future considerations of resource-use in the James Estuary.

The James River Navigation Project

For some years, it has been considered desirable to deepen and widen the shipping channel in the tidal James from its mouth to Deepwater Terminal near Richmond from the present controlling depth of 25 feet to 35 feet with a width of 300 feet at the bottom. Because this proposed channel project, called the James River Navigation Project (JRNP), would make a permanent change in the geometry of the basin and in the salinities and currents in the estuarine portion of the system, which might affect the production of oysters, it was deemed necessary to determine the nature, extent and biological significance of these changes. Accordingly, the General Assembly of 1964 requested the Virginia Commission of Fisheries to conduct a study of the physical and biological consequences of the proposed channel deepening (JRNP).[1]

---

[1] Events leading to this action have been summarized by the U.S. Army Corps of Engineers in their Report of 1962 and by Hargis in his pre-engineering studies of 1962a and 1962b.

The Commission of Fisheries contracted with the Virginia Institute of Marine Science to plan and execute the investigation. Accordingly, VIMS oceanographers designed the large-scale study called Operation James River (OJR). The proposal for this study was submitted to the Commission by memorandum of 23 June 1964 (Hargis, 1964). VIMS oceanographers had already begun preliminary research in the fall of 1963 to expedite developments.

Operation James River

As it finally developed, Operation James River was organized in five parts:

1. Historical Phase--location, accumulation and study of relevant data and scientific and technical publications; see Bibliography for some of these source materials.
2. Physical Phase, Field--detailed study of the physical, chemical and geological systems operating in the tidal James.
3. Physical Phase, Laboratory--examination of "before and after" effects of channel dredging in an especially constructed hydraulic model of the entire tidal James system.
4. Biological Phase, Field--study of oyster and related communities in the estuary.
5. Biological Phase, Laboratory--studies of physiological responses of oyster predators and oyster larvae and analogous larvae under controlled laboratory conditions.

A more complete discussion of the plan of research in OJR may be found in Appendix I.

Much public attention has been focussed on the hydraulic model itself. Though large and expensive pieces of scientific equipment or "hardware" always demand notice, it is important to stress that research is done by people--scientists, working according to a plan or to plans on carefully posed questions. As should be apparent (above and below), the hydraulic model work was only a small part of Operation James River. Though the model experiments provided the predictability of "before and after" studies, biological research in the field and laboratory and oceanographic work in the James Estuary, itself, have supplied the main evidence for the conclusions reached herein.

Hydraulic Model Studies

Data for design, construction and verification of the hydraulic model were provided after extensive field studies by VIMS oceanographers, who also played a major role in planning other phases of model research.

The Summary Report of the Waterways Experiment Station (WES, 1966) was delivered to VIMS on 10 October 1966. This provided the results of the analyses of model studies as conducted by WES engineers, along with their conclusions of the physical effects of channel deepening.

Data from the model have been in VIMS hands since results of the studies began developing. Physical oceanographers at the Institute have, using model data obtained directly from WES, conducted their own calculations of salinity and current effects as indicated by the "before and after" studies. Hence, a thorough evaluation of model results separate from that of WES engineers (WES, 1966) has been made by VIMS scientists.

Resumé of the Status of OJR, with Acknowledgments

Most of the program of OJR has been completed. Analyses of the effects of the JRNP channel dredging on the salient features of salinity and current patterns and corresponding biological effects are complete as possible.

It is important to note that all VIMS research departments and most of its scientists have been involved. Members of the Virginia Commission of Fisheries, the Virginia Water Resources Commission and the Virginia Water Control Board provided valuable assistance. Also participating were the Federal Water Pollution Control Administration (funds for chemical studies and mathematical model work), the Norfolk District Engineer of the Corps of Engineers (financial assistance with the hydraulic model), the U. S. Coast and Geodetic Survey (vessels and personnel for studies of currents), and the U. S. Army Transportation Corps at Fort Eustis (vessels and personnel for field operations). Engineers of the Waterways Experiment Station of the Corps of Engineers helped design certain "prototype" studies and designed, built, and verified the model. The author served throughout as Operations Chief. Most of the actual research was conducted under the respective VIMS Senior and Associate Oceanographers and to them much credit is due. Analyses of the results have been a "community" effort though the author has been and is finally responsible as Chief Scientist.

In the report presented below, the phrase "personal communication" used after a scientist's name indicates that a draft report on research accomplished during OJR has been provided and contains the supporting evidence.

THE PROBLEMS

Early discussions of the possible adverse effects of channel deepening on marine organisms involved the following aspects:

1. Possible interference with fish and crab and other biological populations in the tidal James by dredge-induced sedimentation and by hydrographic changes.
2. Destruction of oyster bottoms by sedimentation.
3. Mechanical destruction of productive oyster bars by removal and sloughing.
4. Interference with transport and setting of oyster larvae and spat by changes in circulation patterns.
5. Interference with survival of attached oysters by changes in salinity patterns.

It was early determined that effects of sedimentation and interference by dredging on fish, crabs, oysters and other estuarine organisms could be minimized by judicious timing of dredging operations and careful placement of spoil. Extensive studies of sedimentation and of spatial and temporal distribution of fish and crabs and benthic organisms, conducted during OJR, confirmed these determinations (Joseph, personal communication, and Van Engel, personal communication).

The possible cost of mechanical destruction of productive oyster bars, certain to occur, was considered to be clearly a calculable engineering problem and did not receive further attention.

The remaining questions of the possible effects of changes in salinity and current patterns resulting from dredging proved most serious and consequently were those to which OJR, hence this report, was directed.

In terms of oyster production, the critical questions were:

1. Will salinity changes resulting from JRNP channel dredging affect survival and quality of seed oysters, or oyster production?
2. Will changes in circulation, such as mixing, currents and net transport, affect spatfall appreciably?

A great mass of data has been developed around the many components of these two primary questions. Considerable other fundamentally and technically valuable information was also gathered. Only the most important relevant data are cited in this Engineering Report. The rest will be made available in a larger, more comprehensive scientific monograph now being prepared.

RESULTS OF OPERATION JAMES RIVER

PRELIMINARY CONSIDERATIONS

Since 1960, characteristics of oyster production in the James have changed. The disease known as MSX, which began in 1959, has reduced setting by eliminating brood oysters in the lower estuary. Drought conditions in 1964, 1965 and 1966 have further altered the picture. As a result, the James produces less seed (markedly reduced) and more market oysters (markedly increased) than formerly.

It must be emphasized, however, that we are here concerned primarily with the effects of changes in salinities and current regimes in years of "normal" seed and market oyster production (as contrasted with the poor post-MSX seed-producing years of 1962, 1963, 1964, 1965 and 1966). It is anticipated that the system will return to "normal" as breeding populations recover from MSX. Hence, remarks below refer to pre-MSX or "normal" conditions unless otherwise specified. Based upon past experience, normal rainfalls are certain to return.

BIOLOGICAL STUDIES

Oyster Productivity

Under normal conditions, production of oysters is greatest in the area between the James River Bridge and Skiffes Creek (Fig. 2).

The most complete and accurate records of actual oyster (seed and market) production in the James River have been gathered by the Virginia Commission of Fisheries. Unfortunately, these records go back only to 1960, hence do not cover pre-MSX years. According to estimates provided by Mr. Charles Bagnell, the Commission's Conservation and Repletion Officer, and his associate, Mr. Tillage Rowe, it has been possible to divide the lower James Estuary into five zones of comparative productivity according to percentage of oysters produced. This provided the basis for the productivity chart presented in Figure 3, which shows that since 1960 1) 70 per cent of total production in the James occurred in the Burwell Bay reach, with about 40 per cent produced on the northern side of the Rocklanding Shoal Channel and 30 per cent south of the channel, and 2) 15 per cent occurred between Wreck Shoal and Browns Shoal Rock. During this same period oyster rocks in the area around and below the James River Bridge produced about 10 per cent and the area from Horsehead Bar to Deepwater Shoals only about 5 per cent.

In pre-MSX years, the relative positions of areas 2 (southwestern side of the Rocklanding Shoal Channel in Burwell Bay) and 3 (off and below the mouth of Warwick River) are reversed (according to Dr. Andrews, personal communication) and the latter area outproduces the former by a considerable margin. Hence, the general area of importance to us includes that reach of the estuary from James River Bridge to Deepwater Shoal with most production coming from the Burwell Bay Shoals and those immediately below. Little regular production occurs above the Mulberry Point region.

Spatfall or Setting

The best spatfall data are those gathered by the VIMS Malacology Department. Those for pre-MSX years are presented in Figure 4. According to Dr. Andrews' data, seasonal spatfall or spat survival in these "normal" years (1931 and 1944-1960--17 years), as judged from the numbers of spat counted per bushel (Sp/Bu) on natural cultch dredged from each bar, was heaviest on the "offshore" or "channelward" rocks in that reach of the river extending from Blunt Point Rock (1,074 Sp/Bu to 1,162 Sp/Bu) to Horsehead Rock (1,241 Sp/Bu), with greatest seed production at Wreck Shoal (1,368 Sp/Bu). Rainbow Rock (1,033 Sp/Bu), Point of Shoal Rock (288 Sp/Bu) and Deepwater Shoal (808 Sp/Bu) also produced noticeable amounts of seed in these 17 years. These figures indicate survival as well as spatfall since spat on natural cultch on the bottom are exposed for their entire lives to all the natural agents acting on oysters in the regions of setting.

Weekly counts from shellbags placed in James River are especially indicative of actual spatfall but do not reflect survival, since the spat-bearing cultch is removed from the water at the end of each week for counting--to be replaced by fresh shellbags. They are the best available indicators, however, of larval occurrence in the seed area and initial spatfall. Weekly shellbag counts clearly show that in pre-MSX years setting was heaviest on the down-estuary and channelward rocks (Andrews, personal communication). This is undoubtedly the general pattern of spatfall in normal years.

Survival of Spat

Spat survival depends upon freedom from attack and destruction by predators and parasites and from debilitating or lethal environmental conditions such as excessive fresh water. In most years initial setting is heavier down-estuary and channelward, as has been reported above. Because predators and diseases are heaviest and most active down-estuary, survival is lowest there. Survival increases progressively up-estuary as pests are reduced and their effects diminished in lower salinities. On the other hand, survival at the upper end of the seed area (above Mulberry Point) becomes highly irregular due to a periodic exposure to excessive fresh water during years of extremely high spring runoff. Optimal conditions for setting and survival occur in the middle of the area around Burwell Bay. Wreck Shoal rocks and bars in the vicinity are regularly the most productive.

Predators and Diseases

Because of the importance of predation and disease in survival of oysters in the estuary, considerable effort has been devoted in OJR to studies of distribution, survival, reproduction and destructiveness of screwborers or drills and flatworms and distribution and lethality of pathogens. Oysters are more tolerant of salinity variations than are these pests. Previous studies have shown that the major predators and pathogens are generally confined to the lower reaches of the major seed-producing area (Fig. 5).

Extensive studies of the three oyster predators known to occur in the James were conducted during OJR. Results (Haven, personal communication) indicated that two, the rough oyster drill (Eupleura caudata) and the oyster leech (Stylochus ellipticus), are not serious in the seed area. Accordingly, the smooth drill or screwborer (Urosalpinx cinerea) is the predator accorded most attention.

Of the two diseases studied (MSX caused by Minchinia nelsoni and dermocystidiasis caused by Dermocystidium marinum), MSX has proved most serious in the area above the James River Bridge. Hence, most attention is given to this pathogen.

Studies in the laboratory (Haven, personal communication) provided confirmation of earlier work (L. Wood, personal communications, Carriker, 1955, and others) that salinities of around 10 parts per thousand (o/oo) and less are lethal to active drills. Field studies (Haven, personal communications) confirmed earlier determinations (Andrews, 1964b) that the low salinities prevailing in early spring (February to April or May) provide the most significant control on upriver distribution of drills.

Studies of MSX distribution and its lethality during OJR (Andrews, personal communication) indicate that early spring low salinities also control the upriver intrusion and lethality of MSX because oysters are able to "throw off" the pathogen when spring salinities, to which they are exposed, fall to about 10 o/oo.

Whaley and Hopkins (1952) and Stroup and Lynn (1963) presented the most comprehensive salinity data for the 12 years (1949-1961) preceding the outbreak of MSX and the present prolonged drought period. During this 12-year period, the salinity patterns controlled predator and parasite distribution in the James and established the upriver limits of drills, MSX and "dermo" as represented in Figure 5.

Natural Salinity Experiments

Conveniently, higher than usual salinities occurred for the period 1963-1966 while OJR was in progress due to the prolonged drought over the greater Chesapeake Basin. As a result, the effects of the naturally increasing salinities on the upriver distribution of drills and MSX and on the lethality of the latter were observed directly.

In the late summer of 1965 salinities were from 2 o/oo to around 4 o/oo higher than in 1964 in the area from Brown Shoal to Wreck Shoal. Comparison of OJR salinity data with summer salinity averages as presented in Stroup and Lynn (1963) indicates salinities for 1965 to have been much higher (by as much as 5 o/oo to 6 o/oo) in the same area than for the period preceding 1961.

Monitoring natural populations of oysters and drills in the field and studying imported experimental populations in trays (Haven, personal communications, and Andrews, personal communication) during the same period yielded the following results:

1) Drills increased in abundance near and just above Brown Shoal but did not move appreciably upriver

during the three-year drought period when salinities increased quite markedly during summer, as described immediately above.

2) Though MSX extended its range farther into the seed area during 1964 (reaching well into Wreck Shoal), it did not advance appreciably as salinities continued increasing in 1965 and 1966 and mortalities were not significantly increased. It was observed that MSX was lost from oysters every year in spring (April and May) during periods of high river flow.

Larval Transport

In a meeting of the American Society of Limnology and Oceanography in 1952, Bousfield (1955) suggested that barnacle larvae are carried upstream in the Miramichi Estuary by net up-estuary transport in the lower, higher salinity layer. Pritchard (1953) pointed out that the same up-estuary transport system may be important in carrying oyster larvae in the James Estuary. Even before these two formally published studies, biological oceanographers wondered about the mechanisms whereby weakly-swimming, tiny fish larvae might get upriver against the prevailing outward flow then believed to exist. Oyster biologists have also sought explanations for the regular repopulation of up-estuary oyster bars periodically destroyed by abnormal freshets.

For many years, VIMS scientists have noted the fact that in pre-MSX years spatfall was heavier down-estuary than up-estuary and heavier channelward than shoreward, indicating that oyster larvae probably originated down-estuary and were carried up-estuary by movements of water masses, perhaps in the inward flowing lower salt layer--the "subway".

Again, Nature has provided us with convincing evidence that such is the case, generally speaking. In 1959, MSX attacked oysters in the Hampton Roads area and effectively reduced the populations of adults living there to less than 85 per cent of their former numbers. In 1961 and subsequent years spatfall, as measured by numbers of spat per shell on cultch in shellbags, diminished markedly and remained at levels lower than ever before in the previous thirty years. This reduction has continued through 1966 (Andrews, 1964a, and Andrews and Wood, in press) while MSX effects have persisted (though they seem to be showing signs of reduction lately). According to all available evidence, most of the spat produced in normal or pre-MSX years in James River originate as larvae below the James River Bridge. Thus, earlier ideas of the importance of the up-estuary transport system in carrying oyster larvae to areas where they not only can set but survive well have been confirmed by strong evidence. (These observations, however, did not serve to establish or deny the relative importance, dominance, of the lower, saltier layer in the up-estuary transport system.)

This affirmation and the remaining question of the relative role of the lower layer in the process made it especially necessary to examine the factors affecting larval transport and setting with extreme care. The spatfall and oyster production data presented above have proven to be especially important in this (Figs. 2, 3, and 4).

In preparing to determine the biological effects of possible reductions inret transport and net current velocities, it was necessary to review results of previous studies of larval behavior, larval transport and spatfall, such as Andrews (1951 and 1954), Bousfield (1955), Haskin (MS of 1963), Loosanoff (1932), Galtsoff (1964) and Pritchard (1953). Spatfall and larval distribution data (Andrews, personal communications and L. Wood, personal communications) gathered during OJR were also utilized.

Larval Samples

Larval samples made during OJR have not been carefully analyzed as yet due to difficulties in developing adequate techniques for reliable sample preparation and counting. However, preliminary results do not create doubt of the importance of the up-estuary moving water masses in carrying oyster larvae originating down-estuary to the seed area. More importantly, dye studies in the hydraulic model, reported more completely below, strongly support this hypothesis.

Larval Production, Spatfall and Survival

It also became important to investigate the relationships between spawning and spatfall, spatfall and survival, and natural spatfall and seed production much more carefully during OJR. The results were very interesting and relevant to our problem.

Oyster reproduction has been shown to be an extremely wasteful process (Galtsoff, 1964, and Andrews, personal communication). Each market-size oyster (two to three years old) may produce as many as 100 million eggs in a season. Even yearling females produce millions of ova. Males produce many more sperm. Though much spawning material is wasted before fertilization occurs in the water, many planktonic (floating or weakly-swimming) larvae are produced. Because of the large numbers of filter-feeding animals which feed voraciously on estuarine plankton populations in the estuaries at times when larvae are in the water, it is certain that many more larvae are produced than ever set. Continuing with this line of investigation, VIMS records were searched for data which would provide some quantitative estimate of the efficiency of the system. A study already done at VIMS by Dr. Andrews in 1947-1953 contained relevant information. Review of the data presented in the paper by Andrews (1954) dealing with setting characteristics of Virginia oysters indicated that considerable difference existed between numbers of larvae setting and numbers of spat surviving on natural cultch on seed-producing oyster bars in the James Estuary.

In his experiments, Andrews used 1) shellbags that were lifted and counted weekly throughout the entire setting season, 2) shellbags that were left in place throughout the setting season, and 3) natural cultch dredged from the bottom at the end of the setting season. Weekly shellbag counts provided the best evidence available of concentrations of larvae available to set on the various seed bars studied, because effects of predation were largely eliminated by their being removed from the water after less than a week's exposure to predators. Seasonal shellbag counts indicated the numbers that could have set and survived had the natural cultch been arranged on the bottom in small mounds as was the experimental cultch--in the shellbags. And the spat counts from natural cultch showed actual spat survival and seed and market oyster production. Results are presented in Table I.

Predators and diseases presumably had little effect on these estimates since they are not significant on Wreck Shoal. Other factors, of course, operate to reduce survival on natural cultch.

TABLE I

Setting Records - Wreck Shoal

(Number of spat per shell - Modified from Andrews, 1954)

Year	Total Spat Weekly Bags	Spat Seasonal Bags	Reduction Factor	Spat Nat. Cultch	Reduction Factor
1947	313	13	25X	3.6	3X
1948	308	9	44X	3.5	2X
1949	215	15	14X	7.4	2X
1951	80	8	10X	6.4	1.3X
1952	80	6	13X	3.8	1.5X

In 1951 and 1952, years of lowest total spatfall, as measured by weekly shellbags, the numbers of larvae available in the vicinity of the seed bars to set (as indicated by this method) exceeded actual seed production in the same locations by 13-fold and 15-fold, respectively. In 1948 spatfall was 88 times greater than actual seed production on natural cultch and in 1949, 28 times greater. Obviously, many more larvae were available during these five years than were required to produce commercially useful sets on natural cultch. Since the amount of "overproduction" of larvae, as evidenced by "wastage" in the above observations, is undoubtedly much higher than even these data indicated--because of losses during periods immediately before and during setting--it is clear that the numbers of larvae available to set in the seed area during most seasons greatly exceeded those needed to produce a commercial catch.

Andrews (1954) contended that competition after setting is a factor reducing survival. Whether this has been definitely demonstrated is not entirely clear. However, there is no doubt that many more larvae and spat are produced than are needed to produce economic sets in normal years.

Results of Dye Studies

Oyster larvae are capable of some "self-directed" motion--they can swim, but their swimming ability is quite weak. It is certain that movement of the water masses in which they find themselves plays a major role in their dispersion or transport in the James Estuary.

To examine the role of up-estuary currents in transport of oyster larvae in the James, two studies employing dye to simulate larvae were carried out in the model at Vicksburg by VIMS scientists (MacIntyre, personal communication). Dye was released at two points in the lower estuary. One release point was Hampton Bar, southeast of Hampton Creek, and the other was at the mouth of the Nansemond River off Pig Point (Figure 6). Water samples were taken at various stations upriver from the points of release at specified time intervals for fluorometric analysis. Color photographs were also made. From these observations, 1) time of passage or movement, 2) extent of dispersion, and 3) concentrations of dye (larvae) versus time and sampling location were determined. Releases were made at both 3,200 cfs and 1,000 cfs with the channel in its present condition. Dye release studies were not made with the JRNP channel deepened.

Results showed that the dye moved up-estuary from the Hampton Bar and Pig Point release points more efficiently at 1,000 cfs than at 3,200 cfs. For example, after a period of time equalling 7 "prototype" days, concentrations (at slack before ebb) at a point in the channel in Burwell Bay were 10-30 parts per billion (ppb) at 3,200 cfs and 20-120 ppb at 1,000 cfs. On the north shoal in Burwell Bay, they went from 10-30 ppb at 3,200 cfs to 30-100 ppb at 1,000 cfs, and on the south shoal 10-30 ppb (3,200 cfs) to 30-110 ppb (1,000 cfs).

The most important result of these experiments was the demonstration that dye (simulating larvae) moved upstream more efficiently at 1,000 cfs, a model flow regime under which stratification was lower and net transport in the lower layers reduced. The 1,000 cfs model flow experiment represented the low flow conditions prevailing in the James River in August and September when spatfall is at its highest for the entire setting season (June to October).

Laboratory experiments indicate (Powell, personal communication) that larvae are normally viable (living) for periods of from 14 to 20 "prototype" days after spawning. Some live as long as 24 to 25 days in the laboratory. Dye arrived at Burwell Bay about 7 "prototype" days after release. Concentrations did not diminish markedly over a 14-day period in Burwell Bay. Furthermore, dye extended up-estuary beyond Deepwater Shoal by a considerable amount, indicating that in nature larvae clearly may be carried beyond or "overshoot" the seed rocks. This "overshoot" of dye (larvae) extended well beyond the last productive seed bed at Deepwater Shoal all the way to Jamestown Island, a distance of 9-10 miles (Fig. 2). Quantity of dye or "overshoot" to

Hog Point above Deepwater Shoal amounted to about half the concentration at Burwell Bay. Assuming that larvae would be transported in fashion similar to dye, it can be concluded from these experiments that considerable numbers of larvae are normally carried beyond the productive oyster bars by the up-estuary transport system.

Examination of spatfall data, also, indicates that "overshoot" occurs. As can be seen in Figure 4, Deepwater Shoal received an effective set (survival) of about 60 per cent (808 Sp/Bu) of that received at Wreck Shoal (1,368 Sp/Bu), the most productive rock, during the 17 years of study. In addition, our studies indicated that larvae are carried to the seed areas in about 7 days leaving from 7 to 13 days for them to be "sloshed" and to swim around in the vicinity of the rocks before they must set or die. This is ample time to cover any slight slow-down that might occur from reduction in the transport system and assure that larvae will be viable when they reach the setting area.

PHYSICAL STUDIES--LABORATORY

("Before and After" Model Experiments)

General Experimental Considerations

The magnitude and direction of salinity and current changes resulting from channel deepening were studied in the hydraulic model at the Waterways Experiment Station (WES). Three different river flow conditions were used in the "steady-state" technique. These were 1) 11,500 cfs at Richmond--representing "spring high flows", 2) 3,200 cfs--representing average May to December flows, and 3) 1,000 cfs--representing extreme low flows of August and September. These flows were chosen after study of average monthly rainfalls for the 57-year period of recorded discharges at Richmond (Nichols, 1964b). Freshwater inflow normally prevailing during seasonal periods of biological significance was also considered carefully in selection of experimental flows.

Measurements of salinity and current velocity were made in the model estuary at specified transects, stations and depths with the channel as it is now (with the Newport News deepening which will be completed by the time JRNP develops) as the "before" condition and with the "JRNP" channel deepening as the "after" condition. Determinations of spatial and quantitative changes and of the direction of change in 1) salinity, 2) level of no-net-motion, and 3) currents and net transport were made from data obtained in these studies.

Salinity Changes

These experiments indicate (Figs. 6, 7, 8) the following changes in distribution of salinity:

1. At 11,500 cfs (Fig. 6), salinity will increase (move up-estuary) in the lower levels of the channel and decrease (move down-estuary) in the upper layers of the channel and over the shoals (hence over the oyster grounds) on both sides of the estuary.
2. At 3,200 cfs (Fig. 7), salinity will increase (move up-estuary) in the lower levels of the channel, decrease (move down-estuary) in the upper layers of the channel and over the NE shoals (Newport News side--the most productive

bars in pre-MSX years) and increase (move up-estuary) over the SW shoals (Portsmouth side).

3. At 1,000 cfs (Fig. 8), salinity will increase (move up-estuary) over the shoals as well as in the channel at all depths.

Figure 10 shows where these changes will take place in the "upriver-downriver" or longitudinal axis of the estuary with relation to the bottom area affected and the vertical distribution of water masses exhibiting the changes indicated. Since salinities at the bottom over the shoals are those affecting survival of spat and seed, most changes in the lower and upper layers over the channel are not very important.

Figures 10, 11, and 12 indicate the areas on the bottom where increases will occur at levels above +0.5 o/oo. Magnitude of observed changes (both increases and decreases) in all salinity experiments ranged from -0.9 o/oo to +1.3 o/oo (this last in the channel at the James River Bridge), with most of the point salinity changes falling between -0.4 o/oo and +0.7 o/oo. Most of the increases noted were below +0.8 o/oo and situated in or near the channel.

At high flow conditions (11,500 cfs) model data indicated that no increases occurred in the channel greater than +0.7 o/oo--most were below +0.6 o/oo. Furthermore, during these high flows freshening ranging from -0.1 o/oo to -0.8 o/oo occurred on all shoals where oysters and their pests live.

The 3,200 cfs tests represented intermediate flows. Increases noted in the shoals around Rocklanding Channel (Fig. 7) as a result of the deepening were not higher than +0.8 o/oo (at the extreme up-estuary end). Most increases were around or below +0.6 o/oo. Salinities over most of the shoals, especially those NE of the channel (normally the most productive bars), diminished slightly.

Effects of Salinity Changes on Oyster Production

The various biological and physical salinity studies presented above indicated the following:

1. Permanent changes in salinities of from +2.0 o/oo to as much as +5.0 o/co are required before significant up-estuary movement of pests and diseases can be expected.
2. At none of the flow conditions studied did salinities increase on the oyster shoals by more than +0.8 o/oo. The average increase noted was much less.
3. JRNP channel dredging will not increase salinities prevailing during the high flow regimes of late winter and early spring over the oyster rocks. In fact, freshening will result.

Since drill distribution is controlled chiefly by salinities at high spring flow conditions, which will not increase on the oyster shoals, no significant ingress of drills (or diseases) into the seed-producing areas will result from channel deepening. The slight resultant decreases in salinity on the shoals, ranging from about -0.8 o/oo at Brown Shoal to -0.6 o/oo at Wreck Shoal, may produce slight decreases in both disease and predator effects, but no clear benefit can be claimed since the changes are so small and will only serve to offset slight advances in pest levels allowed by increased salinities on the SW shoals by increased salinities during summer and fall.

Comparison of the salinity changes noted above with the biological evidence gathered during the studies of Haven (personal communication) and Andrews (personal communication) indicates that salinity increases of considerably greater magnitude would be required before patterns of drill and disease distribution in the James Estuary will be markedly affected in normal years.

Based upon the best evidence available at the present time, no significant increase in predation or disease in the oyster beds of the James Estuary is expected to result from salinity changes caused by channel deepening.

Since disease-caused mortality of seed is not a serious factor in normal years, no increase in deaths due to MSX and "dermo" will occur as a result of salinity changes induced by JRNP channel deepening.

To summarize--results of OJR confirm the fact that there is closer correlation between spring flows (low shoal salinities or the 11,500 cfs situation) and predator control than for any other period and flow condition of the year. /Andrews (1964b) has even suggested that the extreme high spring flows that normally occur only during "wet years" are sufficient to control drills./ Hence, spring salinity conditions are most closely related to drill and MSX distribution. Since this is so and no changes are expected in the salinity regime during this period (no major changes are expected at any of the normal flow levels), no significant reduction in spat survival and seed production will occur from salinity changes due to JRNP channel deepening.

Effects of Channel Deepening on Circulation in the James Estuary

Present knowledge and theories of circulation in estuaries like the James indicate that in general deepening the channel should 1) reduce the total volume of water moving up-estuary in the lower, saltier layer and 2) reduce the total volume of water moving down-estuary in the upper, fresher layer by reducing the mixing between the two differing masses of water. A reduction in rate of movement of the water masses or net non-tidal current velocities should also occur. Because of the presumed importance of net transport in the lower layer (volume of water moving up-estuary) in moving oyster larvae, "before and after" studies of the relevant physical phenomena were made in the model utilizing techniques of current measurement and salinity observations. The resultant data were analyzed carefully by VIMS oceanographers.

Estimates of changes in direction and magnitude of net transport and net non-tidal current velocity were developed in two ways (Nichols, Ruzecki and MacIntyre, personal communications) as follows:

1. By use of WES current velocity data in calculations of "before and after" levels of no-net-motion and water transport at the important experimental sections in the model estuary, and
2. By computation from WES salinity data of "before and after" levels of no-net-motion and water transport at sections across the model estuary

located as follows: a) one mile below James River Bridge, b) Browns Shoal, c) Jail Point (Wreck Shoal), d) middle of Burwell Bay, and e) Mulberry Point (Horsehead Bar). These sections were selected because of the importance of this reach of the river in spatfall and seed production.

These studies of the changes in water mass movements due to deepening indicated that the vertical location of the level of no-net-motion will be altered somewhat, while reduction in net transport and net non-tidal current velocities also will take place. Since analyses of data derived by both techniques agree, there is little doubt of these conclusions. Further, these results agree in general with those deduced from theory and existing knowledge.

These reductions in net (non-tidal) up-estuary transport in the lower layer at the 3,200 cfs flow condition will be on the order of less than 20 per cent in net transport (at Jail Point). Net current velocities will also be reduced by less than 30 per cent. At the same transect, net (non-tidal) transport in the upper layer will be reduced by less than 18 per cent and net (non-tidal) current velocity by less than 13 per cent in the upper layer. Because of limitations in the model operations during this series of studies, it is clear that these estimates of the degree or amount of reduction in net (non-tidal) transport and net (non-tidal) current velocities are quite high, in fact maximal, and that the actual changes in the James itself will be of significantly lesser magnitude.

Effects of Current Changes on Oyster Production

According to VIMS spatfall data, successful setting occurs most frequently in the James Estuary during late August and September. This is a seasonal period when freshwater inflows are very low and when stratification is least and mixing is greatest. Therefore, the net transport system in the lower layers is at its weakest for the entire spawning period (June to October). Nevertheless, the model studies, described above indicate that up-estuary transport of dye does occur at this flow and further that up-estuary transport of these particles is more efficient at low flows than at higher flows prevailing at other earlier times of the year. This is quite interesting because it tends to cast doubt on earlier theories that net transport in the lower saltier layers, the "subway", is the most important system for moving oyster larvae in the James. And it helps to explain why spatfall is best in the estuary at low flow conditions of late summer even though spawning occurs during most of the summer.

The reduction in net transport and net current velocities during the higher flow conditions prevailing earlier in summer (as represented by the 3,200 cfs tests) will undoubtedly affect the transport of oyster larvae. Larvae will be transported up-estuary in the lower layers less efficiently but, at the same time, washed down-estuary at a slower rate in the upper layers where oyster shoals occur. /On being washed down-estuary, larvae tend to be carried away from the most productive (highest survival) rocks./ Hence, detrimental effects of diminished up-estuary transport during intermediate flow conditions of early or mid-summer would be minimized, perhaps even balanced, by the decreased losses down-estuary. As indicated above, these effects of channel deepening on transport will be minimal to non-existant during seasonal periods when spatfall is highest in the James because flows are generally at their lowest for the year then and mixing is greatest and the two-layered system is extremely weak.

The dye studies described above indicated that significant "overshoot" of larvae-simulating dye masses occurred at 1,000 cfs. Further, these experiments indicated that larvae (as represented by dye particles) reach the setting areas with half or more of their effective larval life remaining and hence that the slight net velocity reductions mentioned above very likely would have no significant effect on viability of larvae reaching the seed beds.

Productivity estimates made for pre-MSX and post-MSX periods and discussed more fully above (Fig. 3) show that the area most likely to be affected by any slight reduction in larval transport that might occur--the reach above Horsehead Rock--produces less than 5 per cent of all oysters produced in the estuary. Furthermore, this production is irregular. As stated elsewhere, significant reductions are not expected because larval transport will not be significantly affected during the period of heaviest setting. (It is important to note that great variability in larval production, larval transport, and spatfall exists in normal years and that minor changes in larvae or spat upwards or downwards will be undetectable or indistinguishable from scientific or economic productivity data.)

Studies of spatfall and its relations with larval availability, and of spatfall and seed production, described above, show that far more larvae are available to set than are needed to produce an economically significant set. It is safe to conclude that slight reductions in net transport and velocity of transport of larvae resulting from JRNP will have no significant effect on production of young (or old) oysters.

All factors considered, it must be concluded that changes in current patterns resulting from JRNP channel dredging will have no significant effect on seed or market oyster production in the James Estuary.

CONSIDERATIONS OF OTHER POSSIBLE EFFECTS OF CHANNEL DEEPENING

During the long dialogue over the channel deepening (Corps of Engineers, 1962 and 1965, and Hargis, 1962a and 1962b), various interests have raised other questions regarding the possible detrimental effects of activities associated with or resulting from channel dredging, such as disruption of activities of finfish and crabs, bottom "burial" by spoil disposal operations, excess sedimentation and mechanical destruction of productive "bottoms." Studies of distribution of finfish and larvae during OJR indicate that dredging, if properly conducted, should cause little temporary damage and that long-term damage would be insignificant. The same can be concluded for crabs.

If managed well, spoil disposal will cause little damage. Studies of VIMS relating to ecological effects of spoil disposal on bay bottoms indicate that repopulation by benthic organisms is swift and that few significant lasting changes in species compostion usually result provided spoil piles are not too deep. Hence, if economically valuable mollusc beds are avoided, no permanent damage will result.

Care should be taken by engineers to avoid depositing spoil in areas whence the spoil materials will be retransported by currents to cause construction and maintenance problems. Dr. Nichols' studies of sedimentation processes in the James system, undertaken as part of OJR, will be useful in determining where such problems will occur and serve to verify sediment patterns in the model. The hydrographic model could be utilized to determine most suitable spoil practices.

Mechanical destruction of a limited amount of productive oyster seed bars cannot be avoided if JRNP channel dredging is carried out. Earlier estimates of the U. S. Army Corps of Engineers indicate that a total of 65 acres of oyster-producing bars (of variable productivity) would be removed or sloughed away.

POSTLOGUE

Though this study was directed specifically at the possible physical and biological effects of the channel deepening to be carried out under the James River Navigation Project as described by the U. S. Army Corps of Engineers, it is increasingly apparent that the tidal James, including the James Estuary, is an extremely complex system. The results of Operation James River research emphasized that engineering projects and other of men's activities can have marked as well as insidious effects on the physical and biological characteristics of the estuary. Alterations in the shoreline, as with bulkheading and filling to extend the land into the estuary (e.g., Craney Island), or in the bottom, as with channel or long shore dredging and in-water spoil disposal, can change salinity, current and sedimentation patterns. Alterations of freshwater inflow as by upriver dams or water supply diversions, even in other Chesapeake Bay tributaries, can have even more marked effects. Pollution, presently extremely high in the upper freshwater reaches of the tidal James but not in the estuarine portions (Brehmer and Haltiwanger, 1966), might also affect biological productivity in the estuary if allowed to worsen.

It is important, therefore, that future proposals involving engineering projects (including further channel deepening) and increased pollution in the freshwater portions of the tidal James be carefully evaluated for possible effects on biological, chemical, geological and physical characteristics in the estuary as has been done in this case with JRNP.

CONCLUSIONS

Studies conducted by VIMS biological, chemical, geological and physical oceanographers as part of Operation James River indicate the following:

1. Changes in the physical characteristics of the James Estuary will result from the James River Navigation Project.
2. These changes will involve small increases and decreases in salinity and decreases in net transport and currents at different freshwater flow conditions and in different parts of the estuary as noted above.

3. Salinity changes will not be large enough to have significant effect on survival of spat and hence on either seed or adult oyster production.
4. Circulation or current pattern changes will have no significant effects on setting or seed production.
5. No significant disruption of activities of finfish and crabs, plankton or benthos will result if the work is carefully planned and conducted.
6. Some mechanical destruction of oyster "bottoms" will inevitably result.
7. It is recommended that appropriate agencies and scientific groups be consulted as the James River Navigation Project is put into effect.
8. Future engineering projects in the James River Basin, such as dams, channels, spoil disposal, shoreline alterations and other developments, should be carefully evaluated whether in upland reaches or on tidal waters for their impact on other reaches of the river.

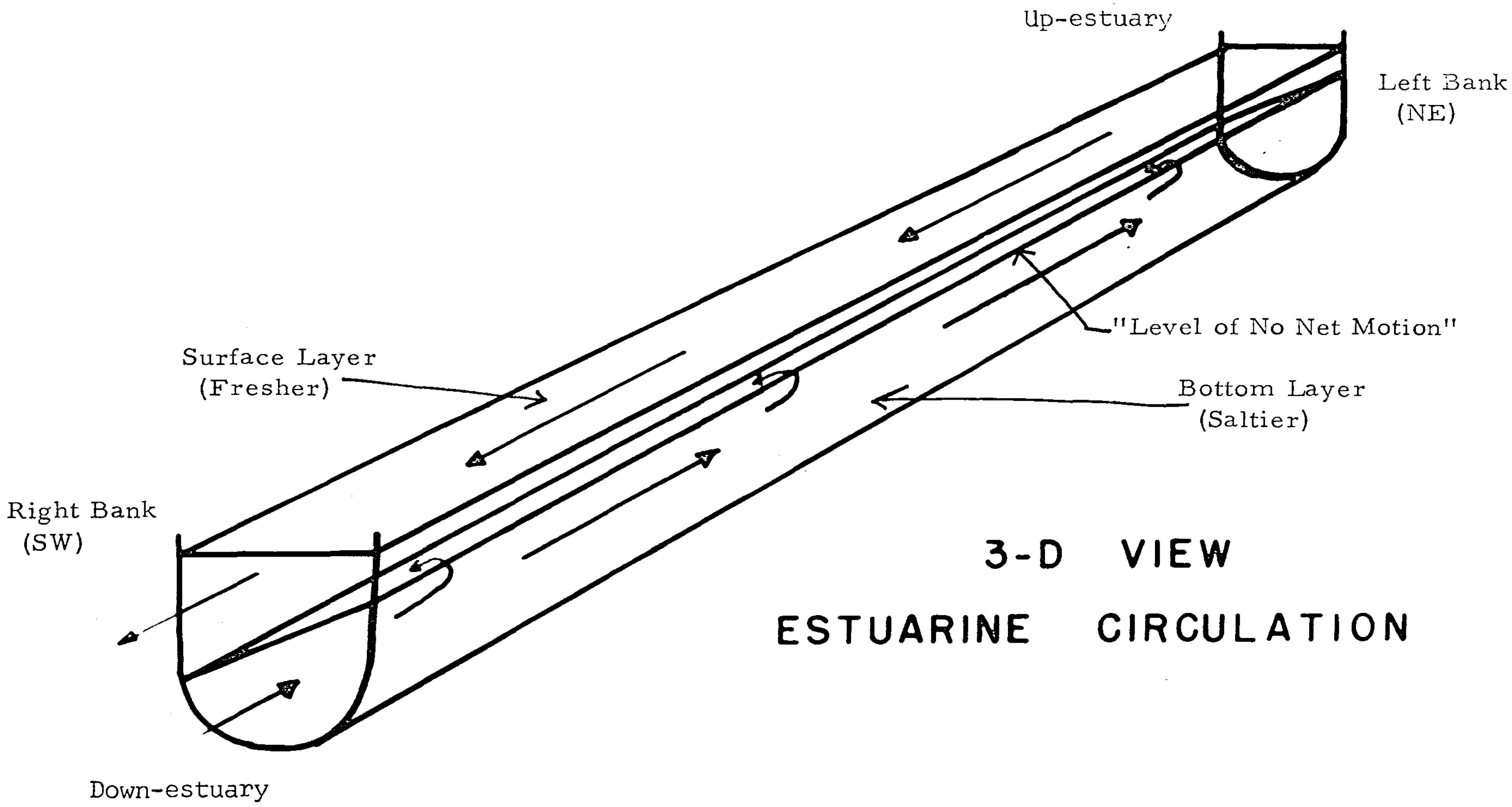


FIGURE 1

Schematic Diagram of
Estuarine Circulation
Showing Major Components
of Circulation in the
James Estuary

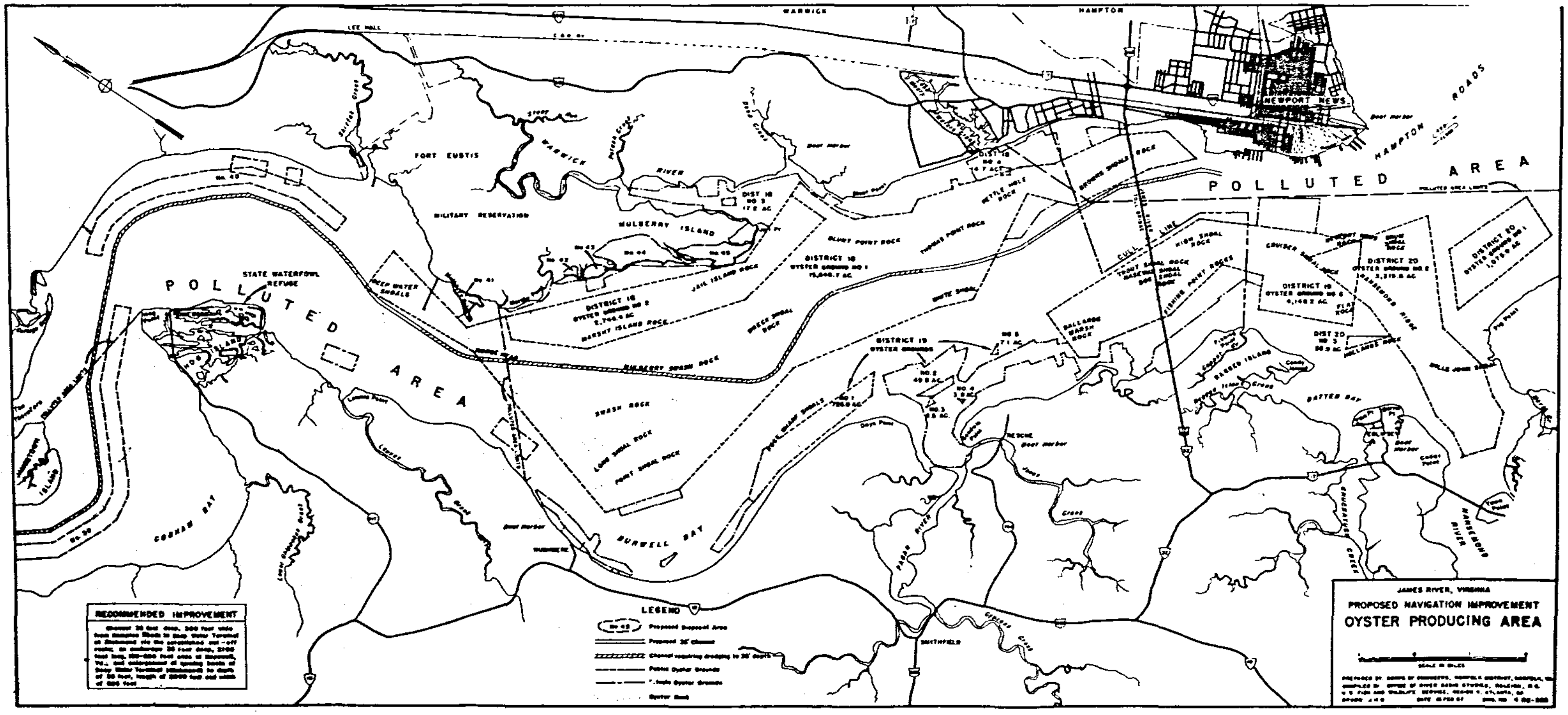
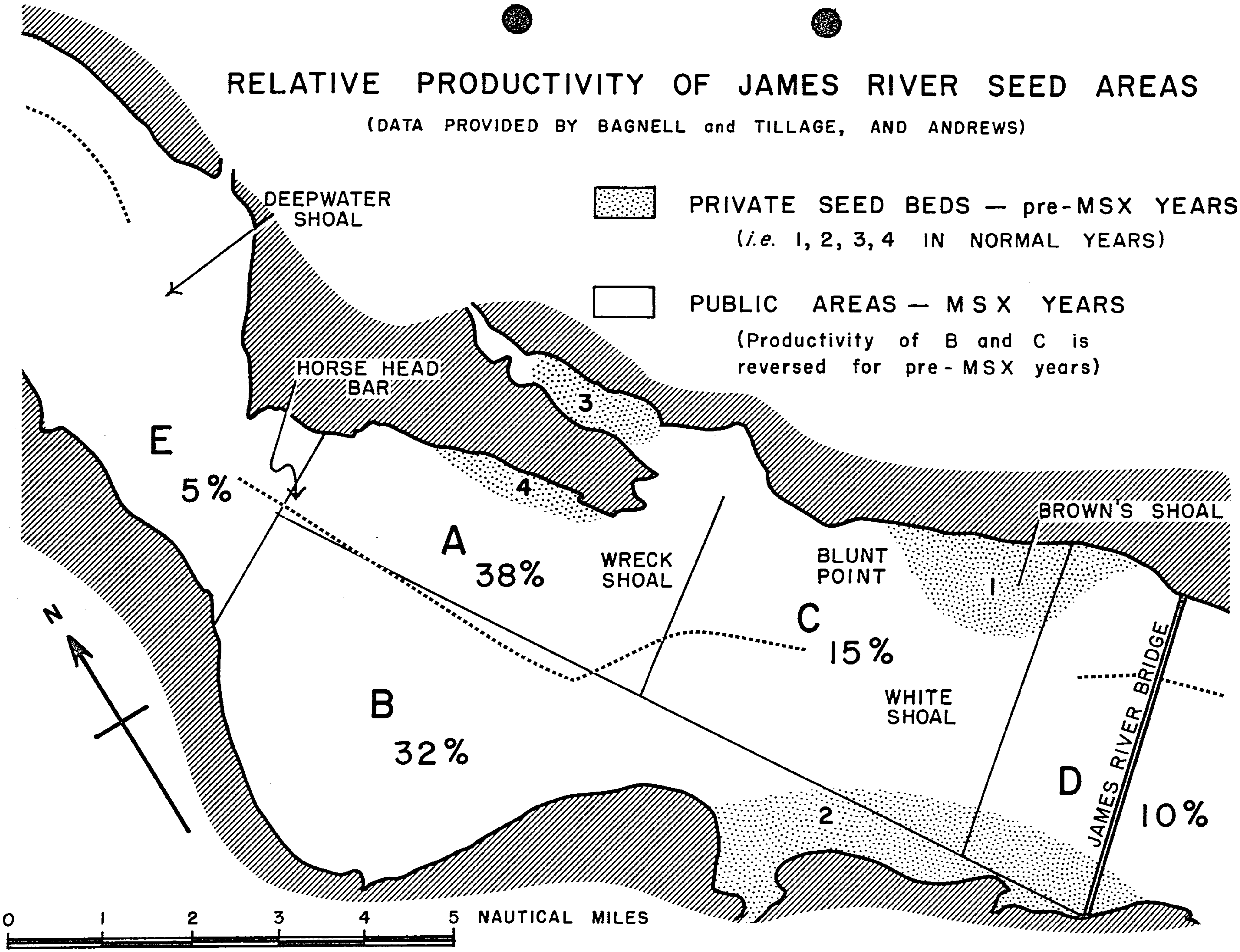


FIGURE 2

Oyster Producing Area
of Estuarine Portion
James River

(From Corps of Engineers, 1962)



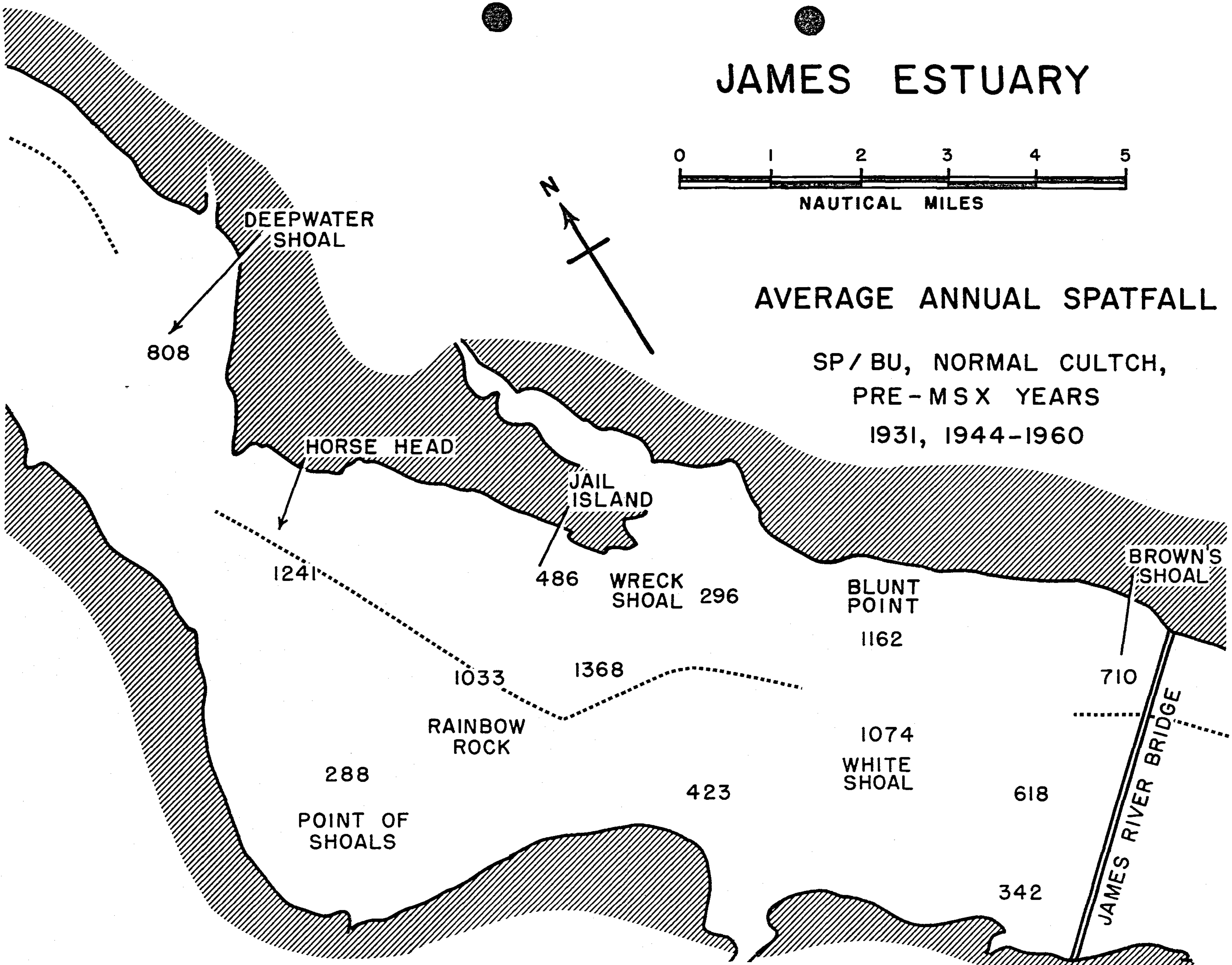
RELATIVE PRODUCTIVITY OF JAMES RIVER SEED AREAS

(DATA PROVIDED BY BAGNELL and TILLAGE, AND ANDREWS)

░ PRIVATE SEED BEDS — pre-MSX YEARS
(*i.e.* 1, 2, 3, 4 IN NORMAL YEARS)

☐ PUBLIC AREAS — MSX YEARS
(Productivity of B and C is reversed for pre-MSX years)

FIG. 3



JAMES ESTUARY

AVERAGE ANNUAL SPATFALL

SP / BU, NORMAL CULTCH,
PRE-MSX YEARS
1931, 1944-1960

FIG. 4

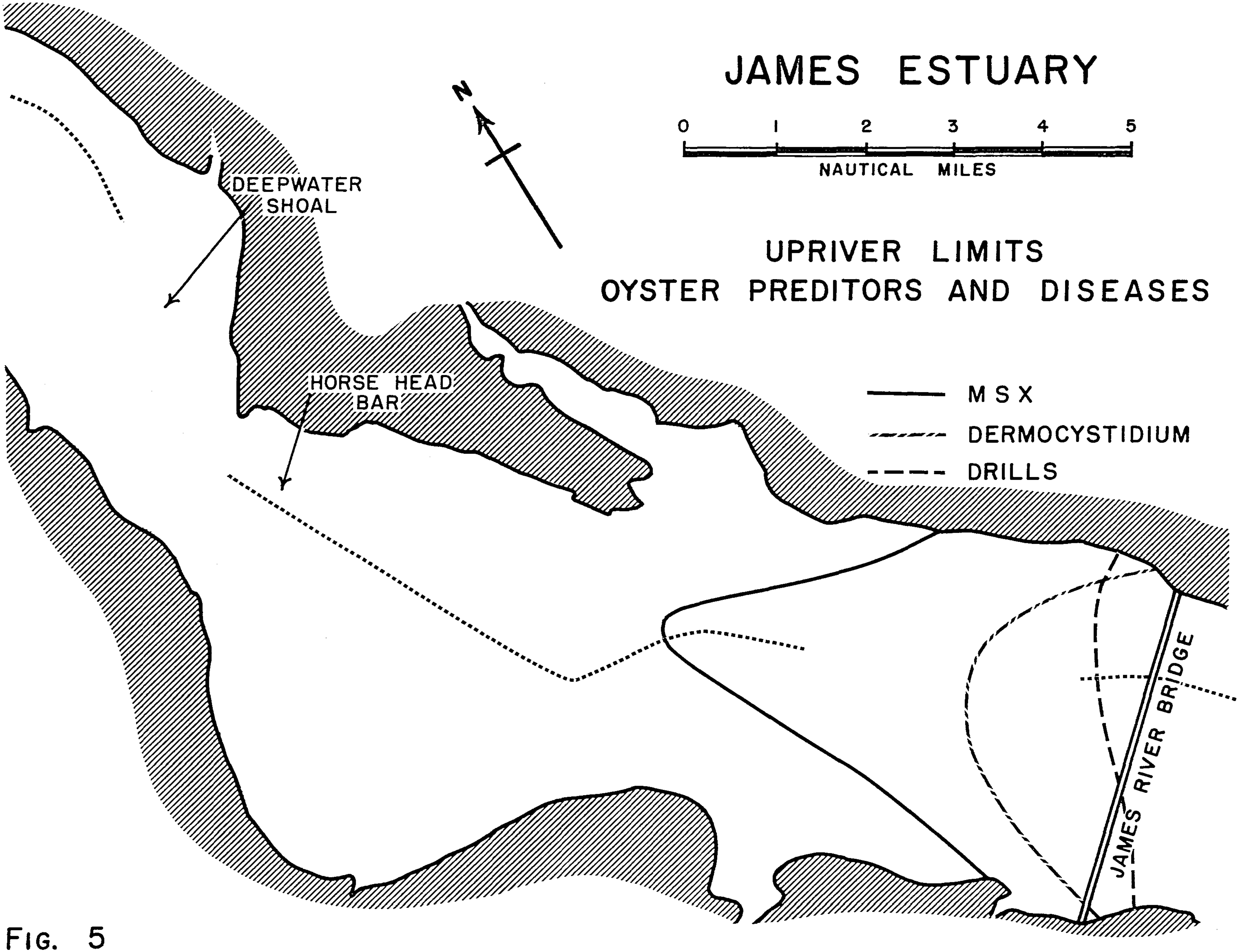

JAMES ESTUARY
0
1
2
3
4
5
NAUTICAL MILES
N
UPRIVER LIMITS
OYSTER PREDITORS AND DISEASES
DEEPWATER SHOAL
HORSE HEAD BAR
MSX
DERMOCYSTIDIUM
DRILLS
JAMES RIVER BRIDGE

FIG. 5

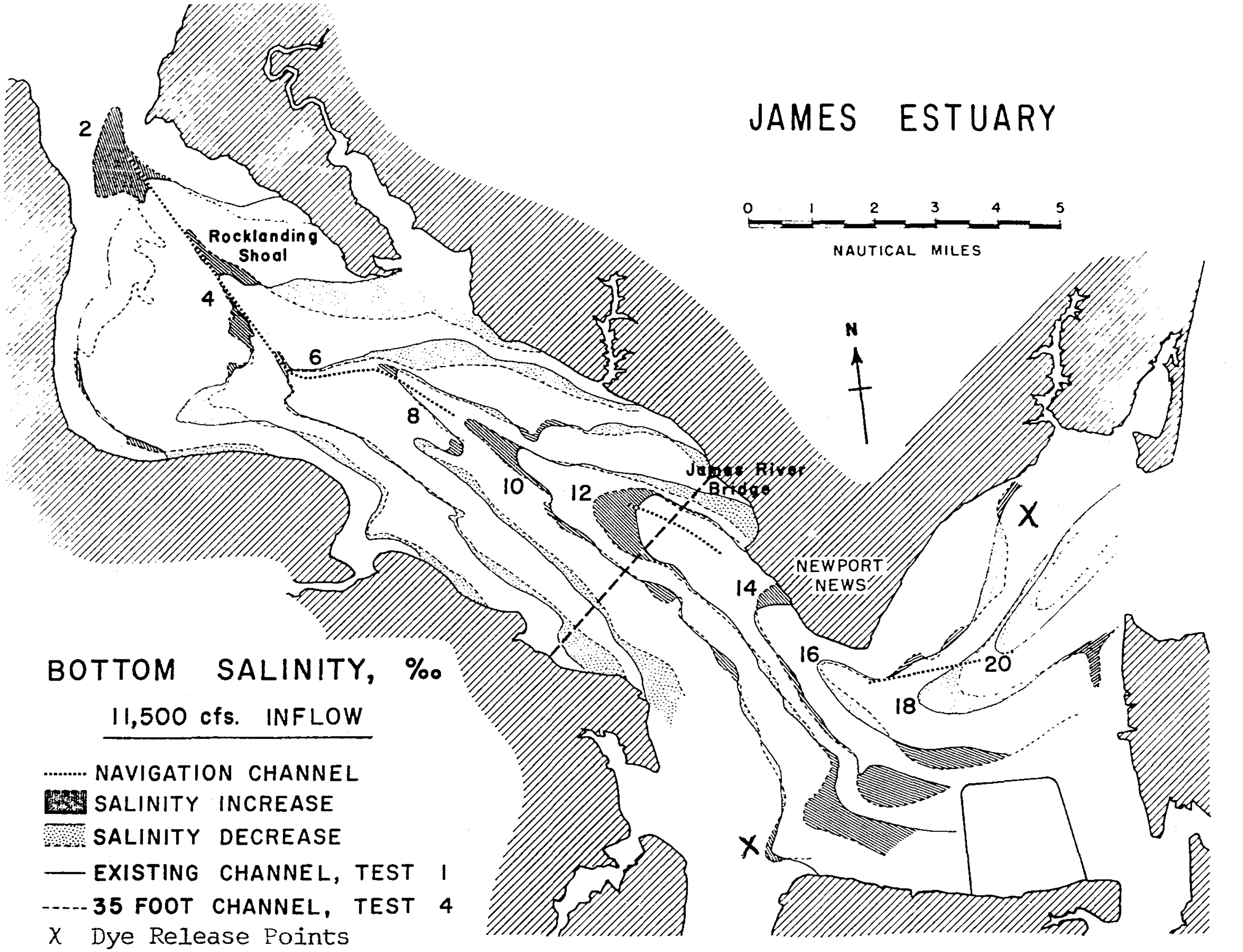


Fig. 6. Distribution of bottom isohalines before and after deepening at 11,500 cfs steady inflow, Richmond.

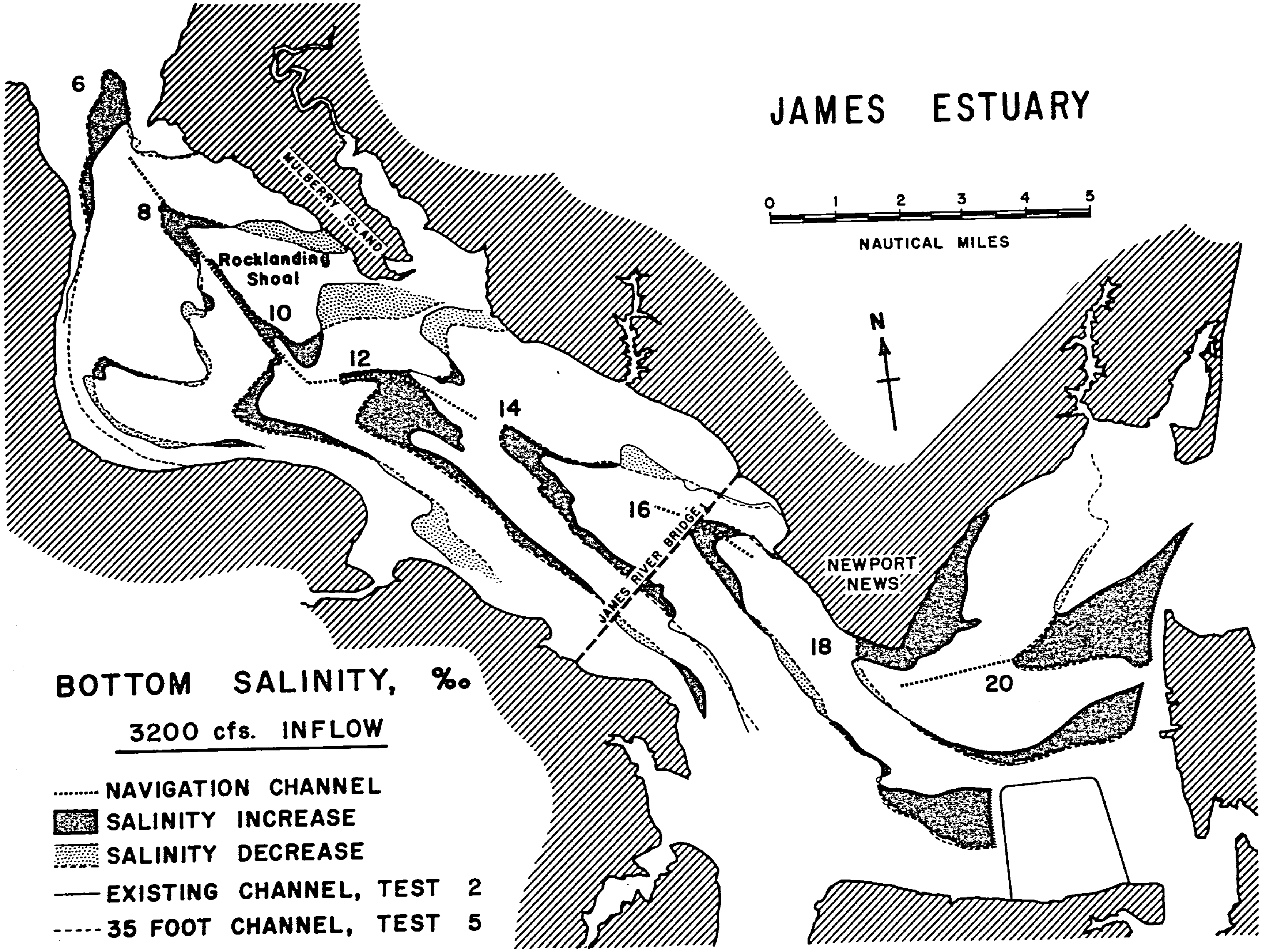

JAMES ESTUARY
0 1 2 3 4 5
NAUTICAL MILES
N
MULBERRY ISLAND
Rocklanding Shoal
JAMES RIVER BRIDGE
NEWPORT NEWS
6
8
10
12
14
16
18
20
BOTTOM SALINITY, ‰
3200 cfs. INFLOW
NAVIGATION CHANNEL
SALINITY INCREASE
SALINITY DECREASE
EXISTING CHANNEL, TEST 2
35 FOOT CHANNEL, TEST 5

FIG. 7

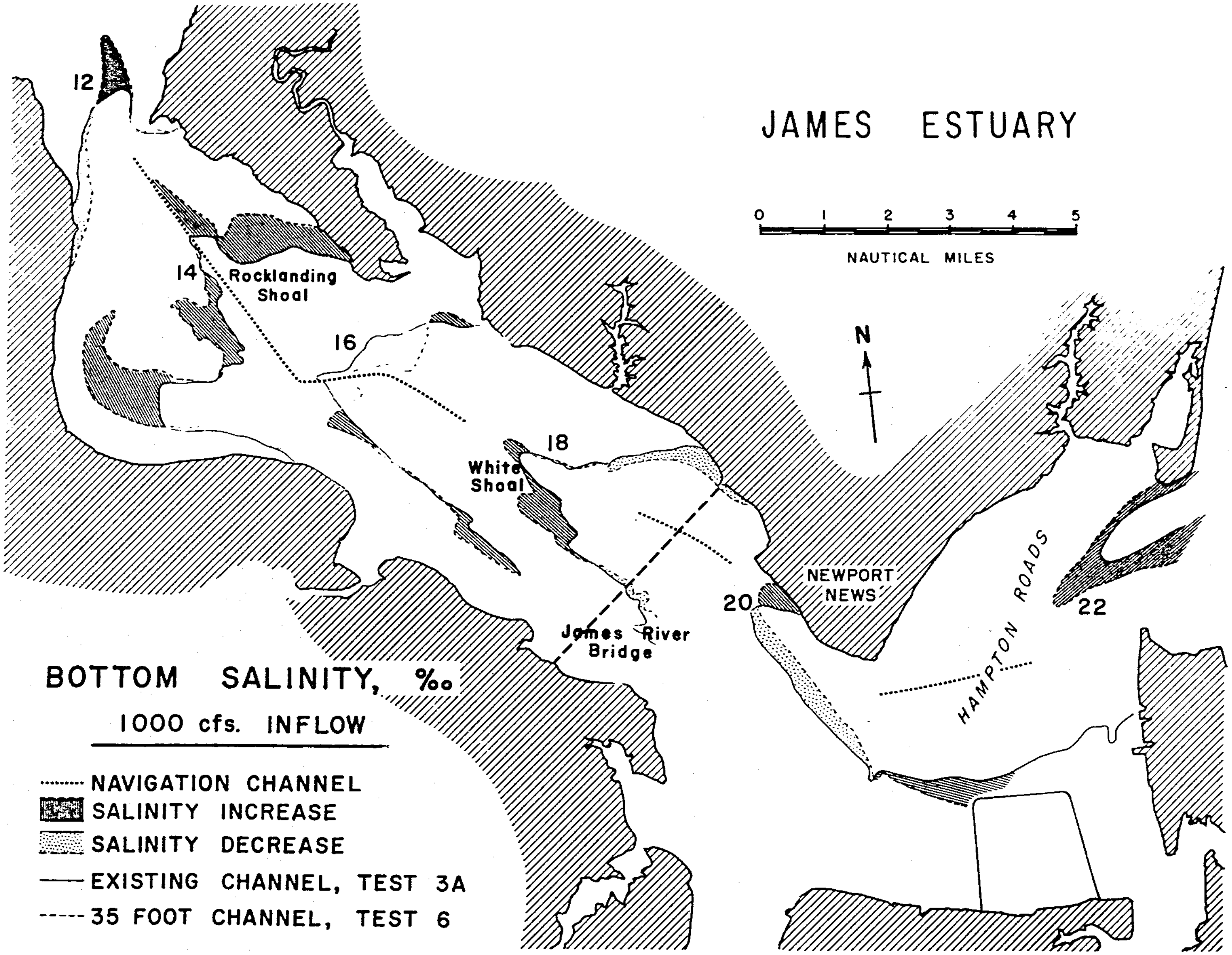


Fig. 8. Distribution of bottom isohalines before and after deepening at 1,000 cfs steady inflow, Richmond.

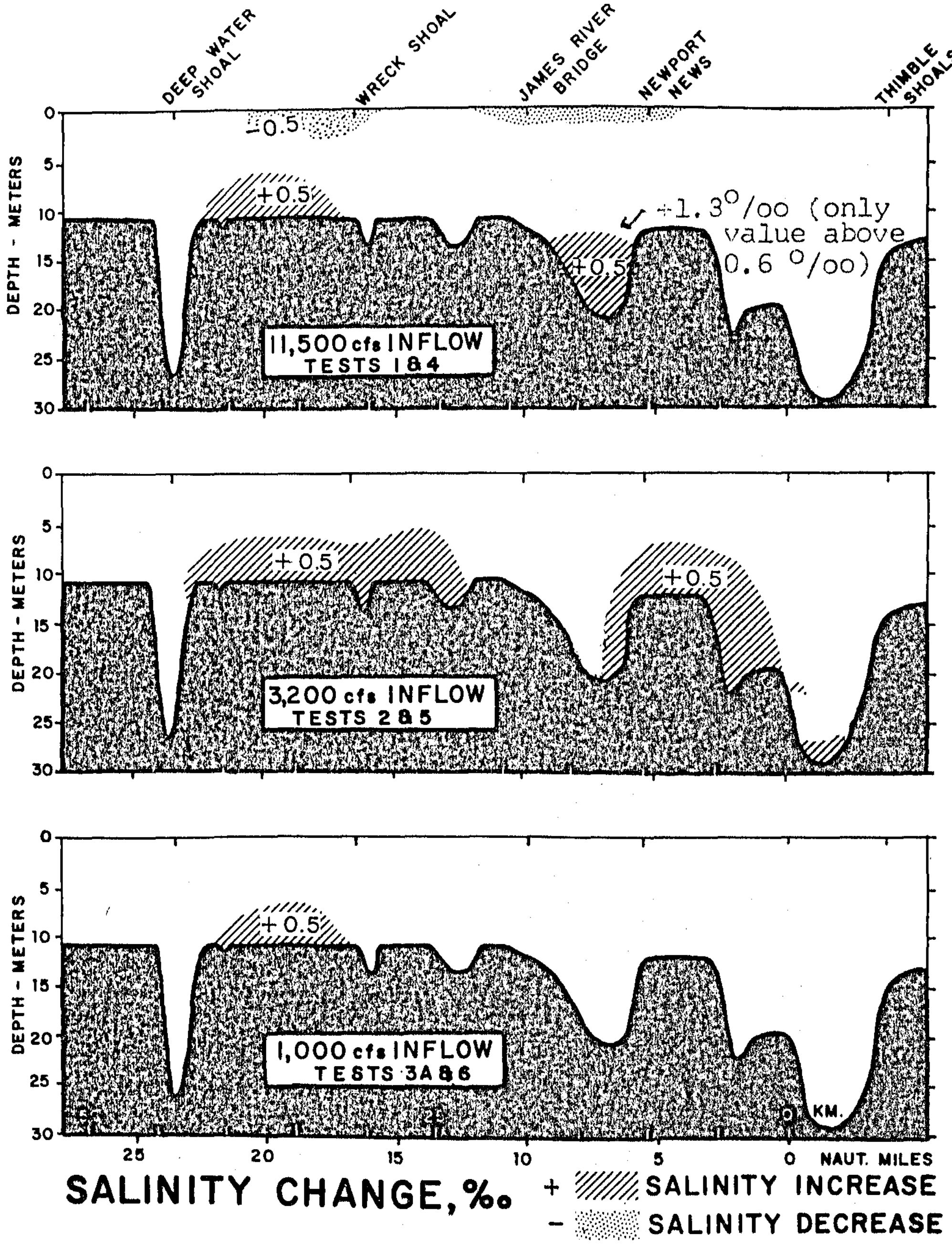


Fig. 9. Profile of James Estuary and differences of salinity due to deepening the 35-foot channel. Shaded areas represent areas where differences are greater than + or - 0.5 °/oo.

A. For 11,500 cfs steady inflow at Richmond, Tests 1 and 4. No changes greater than +0.6
B. For 3,200 cfs steady inflow at Richmond, Tests 2 and 5. No changes greater than +0.8
C. For 1,000 cfs steady inflow at Richmond, Tests 3A and 6. No changes greater than +0.7

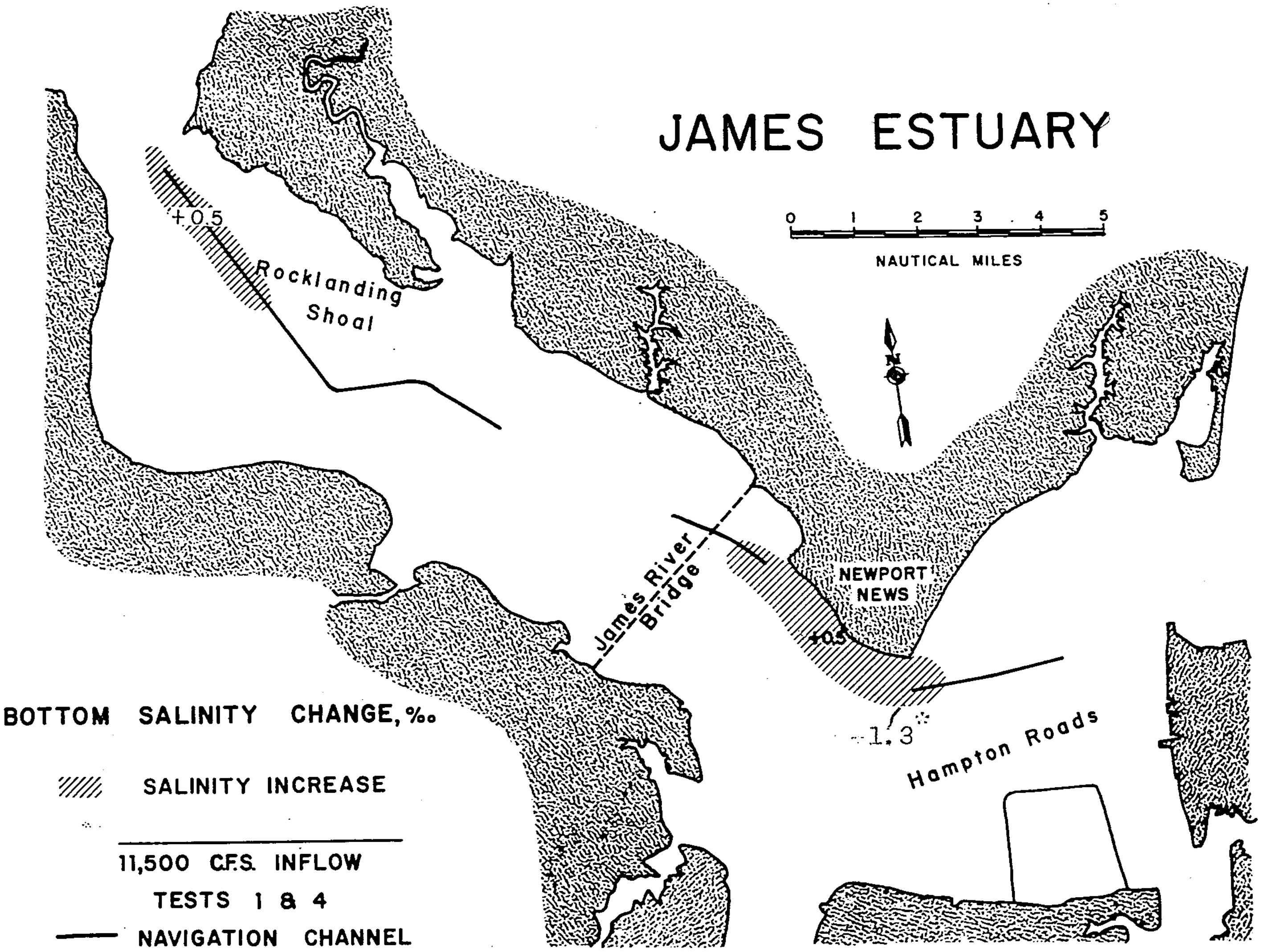


Fig. 10. Areas where bottom salinity increases more than + 0.5 ^{o}/oo after deepening, shaded, for 11,500 cfs steady inflow, Richmond. No change greater than 0.7 ^{o}/oo except where indicated*.

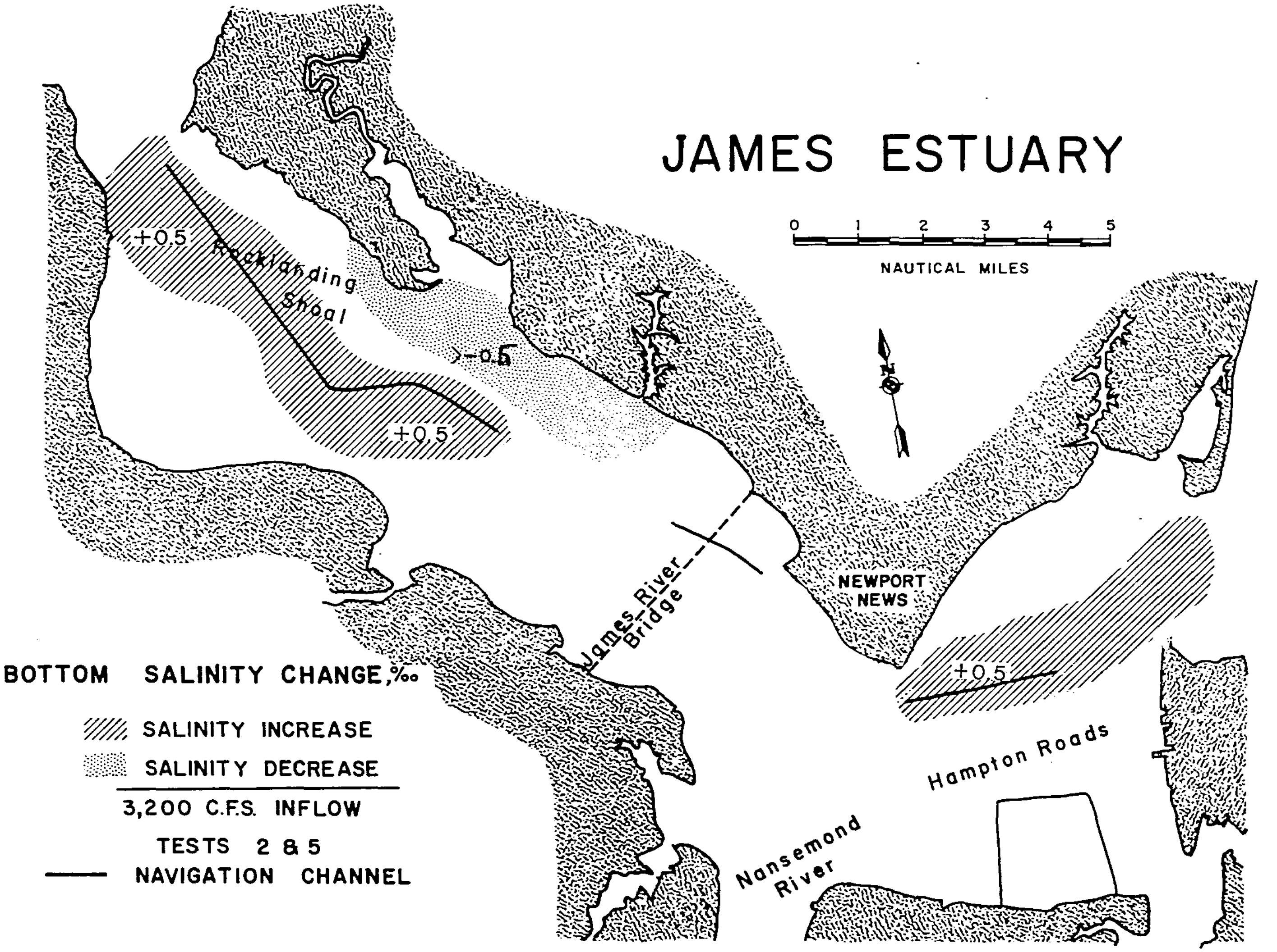


Fig. 11. Areas where bottom salinity increases more than + 0.5 °/oo after deepening, shaded, for 3,200 cfs steady inflow at Richmond. No changes greater than +1.0 °/oo noted.

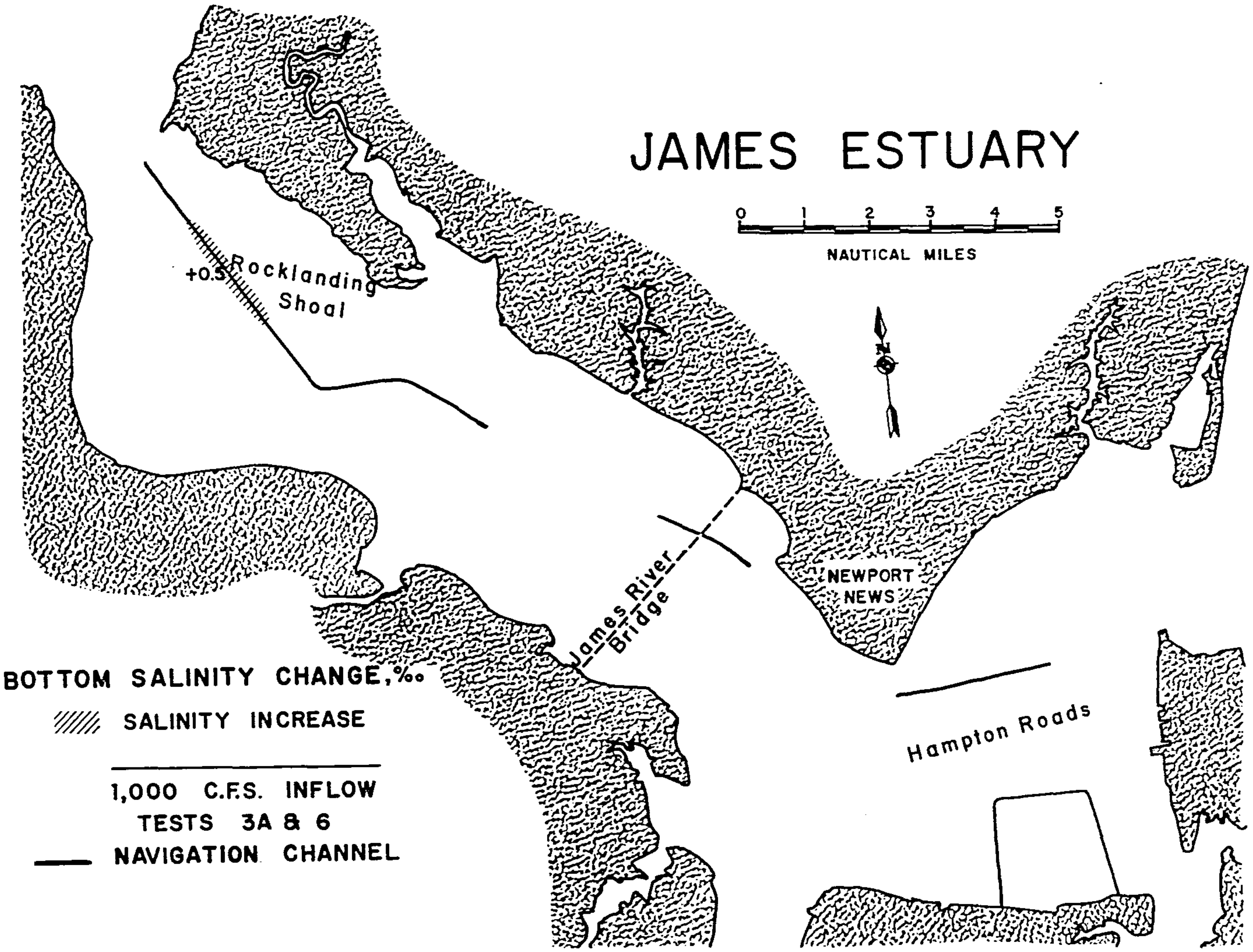


Fig. 12. Area where bottom salinity increases more than + 0.5 $^{o}/_{oo}$ after deepening, shaded, for 1,000 cfs steady inflow at Richmond. No changes greater than +0.6 $^{o}/_{oo}$ noted.

BIBLIOGRAPHY

Andrews, J. D. 1951. Seasonal patterns of oyster setting in the James River and Chesapeake Bay. Ecology 32:752-758. VIMS Contr. 34.

Andrews, J. D. 1955. Setting of oysters in Virginia. Proc. Natl. Shellfish. Assoc. 45(1954):38-46. VIMS Contr. 53.

Andrews, J. D. 1964a. Oyster mortality studies in Virginia. IV. MSX in James River public seed beds. Proc. Natl. Shellfish. Assoc. 53(1962):65-84. VIMS Contr. 155.

Andrews, J. D. 1964b. Effects of river flow regulation by Salem Church Dam on marine organisms. Rept. to U. S. Bureau of Sport Fisheries and Wildlife, U. S. Fish and Wildl. Serv. 16 p.

Andrews, J. D. 1966. Oyster mortality studies in Virginia. V. Epizootiology of MSX, a protistan pathogen of oysters. Ecology 47: 19-31. VIMS Contr. 193.

Andrews, J. D., and J. L. Wood. 1967 Oyster mortality studies in Virginia. VI. History and distribution of Minchinia nelsoni (MSX), a pathogen of oysters, in Virginia. In Press. VIMS Contr. 225.

Bousfield, E. L. 1955. Ecological control of distribution of barnacle larvae in the Miramichi Estuary. Nat. Mus. Canada, Bull. 137. 69 p.

Brehmer, M. L., and S. O. Haltiwanger. 1966. A biological and chemical study of the tidal James River. Final Rept., Contract PH 86-65-86, Fed. Water Pollution Control Administration.

Carriker, M. R. 1955. Critical review of biology and control of oyster drills Urosalpinx and Eupleura. U. S. Fish and Wildl. Serv., Sci. Rept.-Fish. 148. 150 p.

Cline, C. H., and W. E. Maloney. 1960. Field report, James River dye dispersal tests. U. S. Navy Hydrographic Office, Informal Oceanogr. MS 1-60. 38 p.

Galtsoff, P. S. 1964. The American oyster, Crassostrea virginica. U. S. Fish and Wildl. Serv., Fish. Bull. 64. 480 p.

Hargis, W. J. Jr. 1962a. History and current status James River navigation project. VIMS mimeo rept. 9 p.

Hargis, W. J. Jr. 1962b. Current knowledge on the hydrography and biology of the estuarine portion of James River. VIMS mimeo rept. 7 p.

Hargis, W. J. Jr. 1964. Operation James River. VIMS mimeo rept. 10 p.

Hargis, W. J. Jr. 1965. Multidisciplinary research on an estuarine engineering project, p. 45-66. In Seminar on Multidisciplinary Research as an Aid to Public Policy Formation. Virginia Polytechnic Institute, Water Resources Research Center Bulletin 2.

Hargis, W. J. Jr. 1966. Investigation of oyster larvae and spat and certain environmental factors in an horizontally stratified estuary. Final Rept. on Proj. 3-7-R, PL 88-309, U. S. Bur. Comm. Fish. 68 p.

Haskin, H. H. 1964. The distribution of oyster larvae. Univ. Rhode Island, Narragansett Mar. Lab., Occas. Publ. 2:76-80.

Ippen, A. T. 1966. Estuary and coastline hydrodynamics. McGraw Hill Book Co., New York. 744 p.

Loosanoff, V. L. 1932. Observations on propagation of oysters in James River and Corrotoman rivers and the seaside of Virginia. Va. Comm. Fish., Newport News. 46 p.

Marshall, N. 1954. Changes in the physiography of oyster bars in the James River, Virginia. Va. Jour. Sci. 5:173-181. VIMS Contr. 52.

Nichols, M. M. 1964a. Provisional inventory of hydrographic data James River 1927-1963. OJR Spec. Study Rept. 1. VIMS, Gloucester Pt., Va. 4 p.

Nichols, M. M. 1964b. James River hydrographic summary. OJR Spec. Study Rept. 2. VIMS, Gloucester Pt., Va.

Nichols, M. M. 1964c. Hydrographic data for the James River estuary cruises 0004 - 0014. OJR Spec. Study Rept. 3. VIMS, Gloucester Pt., Va.

Nichols, M. M. 1966a. Summary of James River slack water runs 1963-1966. OJR Spec. Study Rept. 4. VIMS, Gloucester Pt., Va.

Nichols, M. M. 1966b. Report of progress on Project 3-7-R for the period 1 July 1965 - 30 June 1966. OJR Spec. Study Rept. 5. VIMS, Gloucester Pt., Va.

Pritchard, D. W. 1953. Distribution of oyster larvae in relation to hydrographic conditions. Proc. Gulf Caribbean Fish. Inst. 6:123-132.

Stroup, E. D., and R. J. Lynn. 1963. Atlas of salinity and temperature distribution in Chesapeake Bay 1952-1961 and seasonal averages 1949-1961. The Johns Hopkins Univ., Ches. Bay Inst., Graphical Summary Rept. 2. 410 p.

U. S. Army Waterways Experiment Station /WES/. 1966. Effects of a proposed 35-foot channel to Richmond on currents and salinities over the seed oyster beds in James River. Hydraulic Model Study. Summary Report. Vicksburg, Miss. 24 p. 6 tables and 24 figs.

U. S. Congress, 87th, 2d sess. /Corps of Engineers/. 1962. James River, Virginia. House Document 586. 182 p.

U. S. Congress, 89th, 1st sess. /Corps of Engineers/. 1965. Channel to Newport News, Norfolk harbor and Thimble Shoal channel, Virginia. House Document 187. 333 p.

Virginia Institute of Marine Science. 1964. Data report cruise 0003. OJR Spec. Study Rept. 6. VIMS, Gloucester Pt., Va.

Virginia Institute of Marine Science. 1964. Data report cruise 0001. OJR Spec. Study Rept. 7. VIMS, Gloucester Pt., Va.

Virginia Institute of Marine Science. 1964. Data report cruise 0002. OJR Spec. Study Rept. 8. VIMS, Gloucester Pt., Va.

Virginia Institute of Marine Science. 1965. Data report Operation KITE and Operation TAIL, James River 1965. OJR Spec. Study Rept. 9. VIMS, Gloucester Pt., Va.

Whaley, H. H., and T. C. Hopkins. 1952. Atlas of the salinity and temperature distribution of Chesapeake Bay 1949-1951. The Johns Hopkins Univ., Ches. Bay Inst., Graphical Summary Rept. 1.

APPENDIX I

Hargis, William J., Jr. 1965. Multidisciplinary research on an estuarine engineering project. Seminar on Multidisciplinary Research as an Aid to Public Policy Formation. V.P.I. Water Resources Research Center Bull. No. 2. p. 45-66. VIMS Contr. 234.

MULTIDISCIPLINARY RESEARCH ON AN ESTUARINE ENGINEERING PROJECT

by

William J. Hargis, Jr.
Director of Virginia Institute of Marine Science

INTRODUCTION

Other participants of this conference have considered, in stimulating fashion, various problems concerned with development of adequate methods for using and conserving water resources. All seem to agree that every effort must be expended to establish and employ the soundest decision-making procedures possible. Clearly, the setting of goals for water resource-use programs must be placed on an objective, practical, scientific basis. Thus, the latest technique of Systems Analysis or Operations Research should be utilized to achieve the most satisfactory evaluations and arrays of recommended decisions in the least possible time.

Dr. Thomann pointed out that to make the Systems Analysis approach work in water resources management, several types of reliable information are needed. Among those suggested by him and Dr. Sherwani are psychological, sociological, and political data to facilitate establishment of meaningful, adequate goals and these must be accompanied by more adequate economic data and engineering evaluations and more significant data about the resources themselves. Limitations of knowledge in any of these areas place constraints on the efficacy of the results of Systems Analysis and consequently on the choices offered decision makers.

I concur in this evaluation. Increased resource-oriented psychological and sociological research is necessary. We <u>must</u> establish valid scientific bases for setting goals for resource management programs and these can only be in the psychological and sociological requirements of humans. One cannot help wondering why this necessity is not, even yet, adequately recognized by state and federal governments, which support most resource research.

Though economic evaluations are the most easily made, continuing economic research is needed. In making forecasts, economic studies must be accurate and include realistic appraisals of all uses to which resources are and can be put, including aesthetic applications. Otherwise, value judgments will continue to be inadequate.

Especially critical is the lack of knowledge about structure and dynamics, and the inherent requirements and limitations of the natural resources we seek to manage. Often ignorance in this area is so pervasive as to prevent recognition of problems (costs) likely to develop if water resources are utilized in a particular manner, for example, if a vast construction job such as deepening of an entire tidal river or establishment of a large number of reservoirs throughout a large watershed is carried out. To make realistic value judgments, we must recognize all present and future problems. For every problem unrecognized the likelihood of a wrong choice or untoward result increases. Cost-benefit ratios can only be as good as the costs and benefits considered.

To date, development of resource systems, for example, river basins, has proceeded in piecemeal fashion with resource-use plans and construction of projects and legislative and executive regulations promulgated in provincial, myopic fashion. As these developments have increased in number, magnitude and complexity, cries of anguish from areas, persons, communities or industries whose desires and activities were adversely affected, and the ensuing conflicts waged at every level and with every weapon imaginable, have forcefully indicated the complex nature of these resource systems and the complex and often conflicting needs, desires and goals of the users.

DIFFICULTIES OF SCIENTIFIC MANAGEMENT OF WATER RESOURCES

It is not always possible to wait until one can decide from a vantage point of complete, and completely reliable, information from all fields to make resource-use decisions. Society's needs are often urgent. Therefore, many, or even most, decisions will be based on imperfect knowledge. However, it is important to know the limiting essentials, whatever they are, and have as much detail as possible.

It is important to recognize that the amount of detail that specialists must unearth or develop is dictated by the intricacies of the problems presented to them by decision-makers.

The problem of necessary detail may be quite troublesome in ways other than in setting limits on the efficacy of decisions. It can affect the relationships between scientists and managerial groups, who wonder why scientists do not know more. For example, in discussions of problems with these groups, it is not unusual for scientists to be asked, plaintively, "Why don't you already have the information we are asking for? You've been working on it for over 20 years!" Usually, reasonable examination discloses that early work was either poorly supported or was satisfactory to the simpler problems of the time.

Other difficulties arise to trouble both managers and scientists -- often inapplicable or inconsequential questions asked in the past led to inadequate results. It is easier to ask productive questions about resources when the phenomenon under study is understood. It is in this context that wide-ranging basic research studies generally prove especially valuable in resource problems because they provide information which enables scientists to focus on the real problems quickly.

Also quite serious and equally frustrating to scientists and managers alike is the lack of stability in the resource systems under scrutiny. Changes in resource systems, some slow and some rapid, are caused by: 1) natural, progressive or regressive evolutions, 2) natural random fluctuations, 3) changes brought about by increasing use by society, and 4) changes brought about by varying uses by society. For example, the tidal James is no longer the same as it was when the current, large-scale field and laboratory studies involved in VIMS' Operation James River (discussed below) were begun in the early spring of 1964, only two short years ago. Changes have been wrought on the structure and the dynamics of the James by such factors as increased contamination, severe and long-lasting droughts, major depth changes in the Hampton Roads area by harbor dredging, alteration of freshwater input by increasing freshwater withdrawals and diversions, and increasing wetland destruction. This changeability makes it difficult to evaluate the reliability and significance of information more than a few months old. Many resource scientists would like, for quite obvious reasons, to see a moratorium established on man-made alterations within the system under study while detailed scientific studies are going on -- obviously an impossible dream. Fortunately, there are techniques of compensating for these changes, for example, by developing and utilizing scale and mathematical modeling capabilities.

As society's awareness of the problems has grown, more enlightened efforts to solve them have evolved. Increasingly, but still far too slowly, the tremendous power and capability of Science and Technology are being brought to bear in Resource Management efforts -- Prometheus, the giant, is being unchained.

RESOURCE INFORMATION NECESSARY

Data from many fields are necessary to proper evaluation, planning and management of natural resources. Of greatest importance is the necessity to have basic, accurate information about the potentials of the natural resources, themselves. Without information concerning the nature, requirements and limitations of the resources being considered, management's plans and regulations for development, exploitation and conservation of natural resources may be ineffectual -- even detrimental. It can be categorically stated that management activities which ignore the basic nature of the resources, themselves, are unlikely to succeed except through happenstance. Hence, there is great need for accurate information about the chemical, biological, geological, and physical nature of our important resource systems, but these are quite often complex and difficult to study. Let us consider the James River as a specific example of complexity and discuss the role of natural and man-made interactions.

The James River Basin, Virginia's largest and most valuable aquatic resource system, offers an excellent example of a natural resource system under pressure of development by many interests, some of which are actually or potentially destructive or in conflict. Clearly, it is an inherently complicated system and can be used to illustrate many facets of the difficulties involved in management of water resources. The tidal James is now under close scrutiny of a determined, multidisciplined study on some of its mysteries -- a scientific assault for the purpose of developing information useful to those faced with making the decision on channel deepening.

THE JAMES RIVER BASIN

The James River system is composed of two major segments: 1) that portion above the fall line at Richmond (the Upland region) (tributaries entering below Richmond are ignored) and 2) that below the fall line (the Tidewater region), see Fig. 1. Though quite complex themselves, the freshwater montane and piedmont portions comprising the Upland are simpler in structure and dynamics than those of Tidewater. Tidewater James is, itself, divisible into two, or three parts -- depending on how far seaward one wishes to follow the system. These parts are: 1) the fresh-tidal, 2) the estuarine, and 3) the coastal. Structurally and dynamically, each part is different, the parts interact, and the boundaries of each are mobile, moving inland and seaward in response to tidal cycles and variations in river flows and bottom and shoreline geometry.

To illustrate the differences between these different reaches of the James, we might assume the roles of riverside observers examining the river from various vantage points from above Richmond to Hampton Roads. Looking out over the James at Bremo Bluff, we would see that the water flows one way, downstream. We would, therefore, decide that wastes dumped into this portion of the James would be carried away by the rapidly moving fresh water. We would be right, of course, but downstream users would suffer if our wastes had not been handled properly.

Another observer looking at the James at Curles Neck would also note that, with the exception of the ebb and flow of the tides, the fresh water has a net downstream flow. As

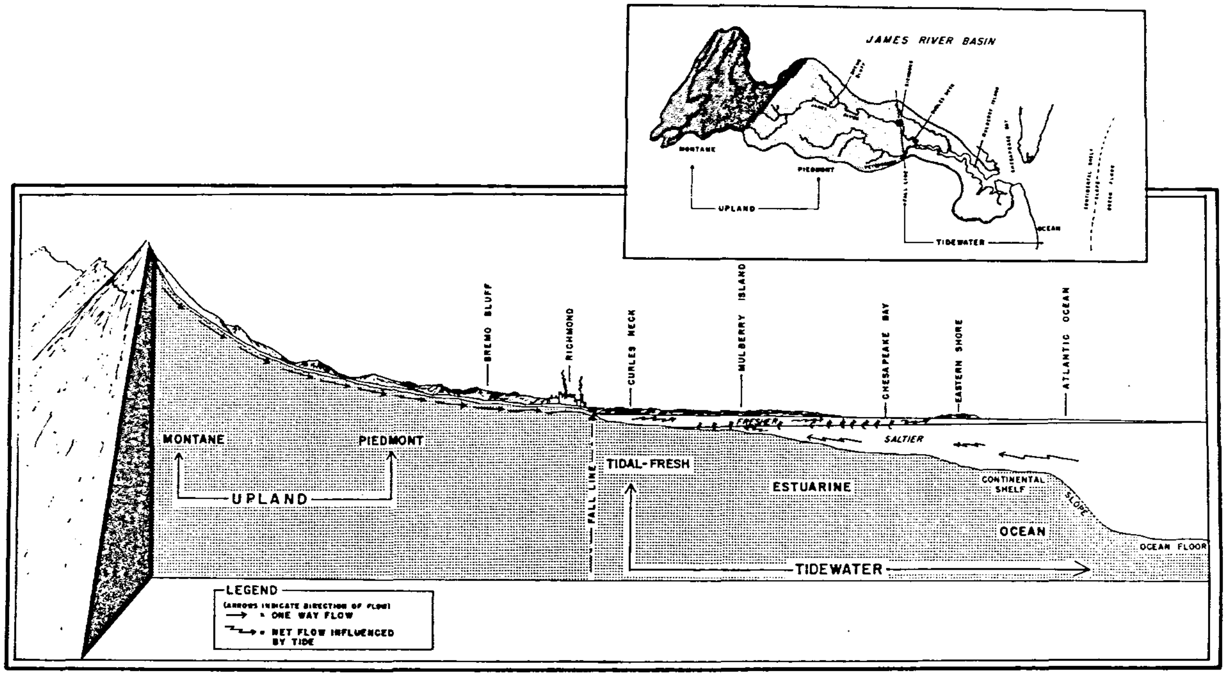


Fig. 1. The James River Basin showing regions, parts and places mentioned in text. Diagrammatic representation depicts the flow characteristics of the different parts of the Upland and Tidewater region. (Courtesy of U.S. Waterways Experiment Station, Vicksburg, Mississippi.)

a result, he might conclude that wastes dumped into this section of the river would be carried away. He might further conclude that a considerable volume of waste could be handled by the obviously vast quantities of water in this tidal reach. In both conclusions he would only be partially correct. Tidal oscillations slow the process of transport considerably and wastes tend to oscillate back and forth with the tide. For this reason, the value of the vast quantities of water in mixing and carrying away wastes is reduced because dilution and dispersion are not as rapid as in a one-way system and downstream movement is slow. For example, during periods of low, freshwater discharges a month or more may be required to transport wastes thirty to forty miles. As a result, it is not as difficult as it would seem to overload an estuary. The upper tidal portions of the James and Potomac offer excellent examples of overloading with wastes.

We move downstream to Carter's Grove or Mulberry Island and again look out over the estuarine portion of the James. Here the James is vast -- millions upon millions of gallons of water. Again the water exposed to view has a net downstream flow. Surely one might think that wastes discharged here would cause no problems but would be diluted swiftly by the great quantities of water and carried away by the net downstream movement. However, in this we could be very wrong. Not only do tidal oscillations slow the movement of water as at Curles Neck but here the James is usually two-layered, really two streams, one under the other. The uppermost system or layer is fresher and lighter and has a net flow downstream; the lower system is saltier and heavier and has a net flow upstream. Thus, wastes introduced into this lower layer would not go downstream but have a net flow upstream. It is this two-layered system that raises especial difficulties with the proposed Tidewater projects.

The James River Navigation Project

As an example of the complex factors involved, we can examine the long considered James River Navigation Project which many in Virginia hold to be an highly desirable developmental project intended to enable deep draft vessels to reach farther inland with greater loads and hence improve the economics of shipping to inland areas. Probably a more important economic objective is the possible opening of the James to increasing industrialization.

This project will deepen the channel from its present 25-foot depth to 35 feet, from the James River Bridge, just above Hampton Roads, to Richmond, some 98 statute miles inland.

In 1955, when the project was first seriously proposed, few objections were raised. Later, on realization of the close relationship between the structure and dynamics of the upstream-flowing, salt layer in the estuarine portion and the 1) successful setting and survival of oyster larvae, and 2) successful survival and growth of oyster spat in the river, a new economic factor was introduced. According to the latest and most widely held ideas, the bulk of the oyster larvae contributing to the successful seed areas in the James are spawned in Hampton Roads and are carried upstream in the salt layer where they set on shell piles in the traditional seed areas above the James River Bridge off Mulberry Island (Fig. 1). In these seed areas the spat, as oysters are called after setting, survive and grow to seed size because predators and diseases are controlled by low salinity.

As a result of relatively recent studies of the circulation of estuarine and coastal waters, it became apparent to estuarine scientists that the water in the lower salt layer has a net upstream movement and that this current carries larvae of many other animals to their setting areas. It was also clear from long-term observations that survival of oyster spat on the seed beds is due to restriction of the activities of oyster predators and diseases by the low salinities prevailing in these areas. Further, it is evident that changes in the structure and dynamics of the estuarine portion will result from alterations in the density differences normally existing between the fresher layer (originating upstream) and the saltier layer (originating in the ocean). In an estuary like the James, which is an horizontally stratified but partially mixed estuary, an increase in the volume of salt water, a certain result of dredging, will increase stratification, reduce mixing between the two layers and increase the distance upstream that salt water of a particular concentration intrudes. It also will reduce the rate of flow of the upstream moving current in the lower layer. These modifications could reduce the setting and survival of seed oysters in an area on which, in normal years, the major portion of the oyster industry of Virginia is directly dependent for most (70 to 80 per cent) of its seed. The resulting change in production of seed oysters and probable reduction in the productivity of the oyster industry could cause an economic loss of sizable proportions to the Commonwealth and constitute a significant project cost.

Though many factors undoubtedly played strong roles in the decision, Virginia officially decided to delay approval of the James River Navigation Project until a scientific study could be carried out to determine the effects of channel modification on the oyster industry. The General Assembly of 1964, appropriated funds and ordered the Commission of Fisheries to conduct the necessary research and report on the relationships between the channel deepening as proposed and seed oyster production in the James estuary.

Operation James River

In order to comply with this legislative directive, the Commission of Fisheries contracted with the Virginia Institute of Marine Science to plan and carry out the studies and make the analyses. In turn, VIMS designed and initiated a comprehensive research project involving cooperation between scientific disciplines and engineering technologies. This research project, called Operation James River (OJR), began with an analysis of the problem (accomplished in 1963) and will end with a report to the General Assembly and Governor in 1967. A much more comprehensive technical report embodying all of the vast amount of scientific data produced by OJR will be presented to the scientific community later.

Since the ultimate problem revolved around setting and survival of oyster larvae and spat, the interactions between oysters and their important biological associates and the physical characteristics of their environment were considered initially.

For an area to qualify as a good seed-producing area, the following conditions are necessary:

1) Adequate brood stock must be present.
2) Oyster larvae (spawn) must be able to survive and develop to setting stage.
3) Larvae must be transported from spawning to setting areas.
4) Larvae must encounter suitable substrate for setting at the propitious time in their life history.
5) Larvae must be able to set and enter spat phase.

6) Spat must survive and develop into seed.
7) Seed should be free of diseases and suitable for transplanting to growing areas.

Survival and development of parental stocks and oyster larvae and spat depend upon the suitability of a number of physical and biological factors such as 1) currents adequate to transport larvae, 2) satisfactory food, 3) suitable salinity, temperature and dissolved oxygen, 4) adequate cultch suitably located, and 5) relative freedom of larvae and spat from predators and disease organisms.

In order to determine whether the proposed James River Navigation Project would have an adverse effect on oyster seed production, it was considered necessary that all of these factors be examined.

Thus, the large-scale operation, OJR, was designed to secure information concerning the interaction between the physical attributes of the estuary such as 1) surface and subsurface currents, 2) lateral and vertical movements of water masses, 3) salinity, 4) temperature, 5)geometry, 6) light, and 7) other factors; and biological activities such as 1) the spawning of oysters, 2) the transport and survival of oyster larvae, and 3) the setting, survival and condition of spat or seed. Important corollary information has also been sought on sedimentation, on spatial and temporal distribution and abundance of plankton, bottom organisms, predators and disease organisms of oysters and on dispersal and diffusion of actual and possible contaminants of all types.

The operation has been carried out in five phases. Order of priority of these phases was determined by the time requirements of each phase; for example, the time required in construction and verification and testing of an hydraulic model made it necessary to secure the prototype data for model design (data from the river, itself) as quickly as possible in 1964.

Larvae and spat, predators and diseases have special times to spawn, set, migrate, reproduce and infect. These, often rigidly timed, biological events imposed rigid scheduling limitations on the work.

Accordingly, the operation was planned and is being carried out in five programs. These are:

A. Compilation of Existing Data

Accumulation, evaluation and analysis of all existing physical and biological data about the James (and other pertinent estuaries) and the important animals and plants therein was begun in 1963 and is continuing. Considerable information has been unearthed and new insights into biological and physical processes in the James estuary are developing.

B. Physical Studies of the Estuary

Careful examination of the present physical factors operating in the estuary are underway or completed. These have involved:

1. Regular physico-ecological cruises of the estuary studying temperature, salinity and oxygen at several critical places. These cruises have been underway since March of 1964 and many of their data have been summarized.
2. Special studies designed to examine different critical areas and special aspects of the dynamics of the estuary were planned and executed. These involved:

a. Occupation of stations arranged to study dynamics of currents, salinities and temperatures over extended periods of time.

b. Completion of extensive transects designed to show the relations between channel and shoal waters at critical areas like Wreck, White and Brown shoals.

c. Dye studies (using Rhodamine B and fluorometric analytical equipment) to follow currents and movement and dispersal of dye-tagged water masses.

3. Surveys to gather data to be used in construction and verification of the hydraulic model and in other modeling techniques have been conducted, completed and transmitted to the Hydraulics Division of the U.S. Army Engineers, Waterways Experiment Station at Vicksburg, Mississippi. These studies involved as many as nine boats and 40 men and considerable equipment. As a result of these field surveys, extensive and valuable data have been gathered which will not only be useful in the model work but in evaluating older theories of structure and dynamics of the estuary.

C. Physical Studies in the Laboratory (scale model)

In order to permit controlled evaluations of the effects of the channel deepening on the distribution of isohalines (areas of equal salinity) and the structure and dynamics of the tidal James under various conditions, an hydraulic model of the tidal James has been designed, constructed and verified and will soon be in experimental use.

This facility will allow us to vary conditions of river flow, salinity, channel depth and position, siltation and contamination and, above all, achieve predictability of dynamic structure and function of the estuary.

D. Biological Studies in the Estuary

A partial list of specific biological investigations being carried out is:

1. Spatial and temporal distribution of oyster spat in the estuary.
2. Spatial and temporal distribution of oyster and analogous larvae.
3. Location of primary parental or brood stocks (sources of spawn) for James seed area.
4. Spatial and temporal distribution of oyster drills (a predator) and their effects on spat and adult oysters.
5. Spatial and temporal distribution of MSX and Dermocystidium (diseases) and their effects on spat, seed and adult oysters.
6. Spatial and temporal distribution of plant and animal plankton.
7. Spatial and temporal distribution of bottom organisms.
8. Spatial and temporal distribution of young and adult fishes and crabs (other important marine and estuarine species).

These studies have been designed to show not only the seasonality, numbers and distribution of the organisms involved but also to disclose relationships of these factors to salinity, currents, oxygen, etc. All phases are underway at this time,

Fig. 2. Showing building housing the James River hydraulic model and the water supply facility. (Courtesy of U.S. Waterways Experiment Station, Vicksburg, Mississippi.)

Fig. 3. James River hydraulic model showing two different stages of construction. (Courtesy of U.S. Waterways Experiment Station, Vicksburg, Mississippi.)

Fig. 4. James River hydraulic model showing Hampton Roads (looking seaward) with Newport News on the left and Norfolk on right. (Note Craney Island Disposal Area intruding on right and tidal programmer upper left.) (Courtesy of U.S. Waterways Experiment Station, Vicksburg, Mississippi.)

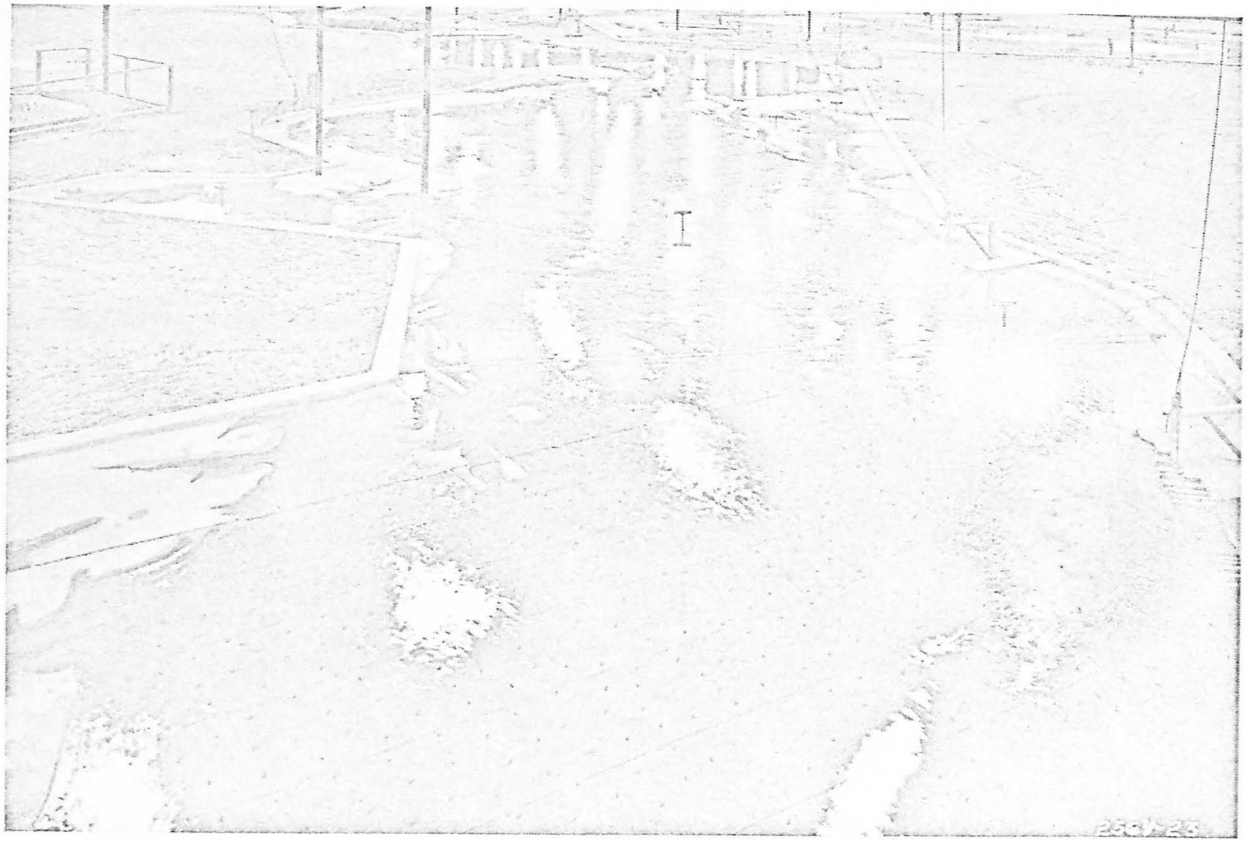


Fig. 5. James River Hydraulic Model looking upriver from Hampton Roads to seed beds above James River Bridge in center foreground. (Dark spots on bottom are adjustable roughness simulators and resistance units. Réserve fleet included in center background.) (Courtesy of U.S. Waterways Experiment Station, Vicksburg, Mississippi.)

Fig. 6. James River hydraulic model showing Rocklanding Shoal Channel Reach, off Mulberry Island, without water. Model channel is dredged by removing molded channel blocks. (Courtesy of U.S. Waterways Experiment Station, Vicksburg, Mississippi.)

with greatest emphasis on those pertaining directly to oyster larvae and spat, their food, predators and diseases.

E. Biological Studies in the Laboratory

In order to better establish the relationship between oyster larvae, spat, drills and other predators and diseases and competitors and analogous larvae, carefully designed controlled studies of their responses to the various environmental variables, e.g., salinity, temperature, light, oxygen, currents, are being carried out in the laboratory. Some of these studies are underway and will be terminated in the fall.

From these studies we expect to be able to give a much more accurate appraisal of the impact of the proposed James River Navigation Project and succeeding engineering or industrial projects on the biota of the estuary. A very valuable bonus will be the improved understanding of the physical and biological environment of the tidal James.

SUMMARY

As a result of earlier work, the James is now a classic in marine science. When Operation James River, a massive, multidisciplinary study, is completed, the James will be one of the best known estuaries in the world. Furthermore, we will be in a much better position to study and evaluate the effects of increased 1) industrial and domestic wastes, 2) siltation, 3) river flow alterations, 4) wetlands destruction and other man-made changes on the intended use of this natural resource. The data will be much more adequate for use in Systems Analysis or Operations Research procedures. In addition, the data and conclusions will be available to those responsible for decisions which will result in the fuller utilization of this great but not limitless resource for the maximum benefit of our present and future society. In view of the importance of the James River Basin to Virginia, significant advantages should accrue.