CHESAPEAKE AND DELAWARE CANAL
AFFECTS ENVIRONMENT

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American Society of Civil Engineers
National Water Resources Engineering Meeting

Phoenix, Arizona

14 January 1971

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by

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INTRODUCTION

The Chesapeake and Delaware Canal is a man-made waterway connecting the upper Chesapeake Bay with the Delaware Bay. It constitutes a vital link in a short water route between the ports of Philadelphia and Baltimore, and more importantly, between the ports of New York City and Baltimore. General cargo vessels transiting the North Atlantic Ocean usually call at two American ports, one being New York City. The round trip route Europe - New York City - Baltimore is significantly shortened by the C and D Canal, and maritime interests in Baltimore consider the canal to be essential to the economy of that port.

Figure I shows the location of the C and D Canal with respect to the upper Chesapeake Bay and the Delaware Bay. Figure 2 is an enlarged map of the canal itself and the near approaches to the two ends of the canal. Note that the eastern end of the canal enters directly into the Delaware Bay, via a channel formed by two short jetties. The western approach to the canal from the Chesapeake Bay is via a tributary tidal waterway, the Elk River.

The canal started in 1829 as a private barge canal with locks, two at the Delaware end, and one at the Chesapeake end. For the most part, natural tidal and non-tidal waterways were connected by short dredged sections to form this original canal. In 1927, the C and D Canal was converted to a sea-level canal, with a controlling depth of 14 feet, and a width of 150 feet. In 1938 the canal was deepened to 27 feet, with a channel width of 250 feet. Channel side slopes were dredged at 2.5:1, thus making the total width of the waterway at least 385 feet in those segments representing new cuts or having shore spoil area dykes rising above sea level. However, there were significant segments of the 27-foot canal passing through shallow flooded areas, or through tidal marshes, and the shoreline in these areas was not well defined.

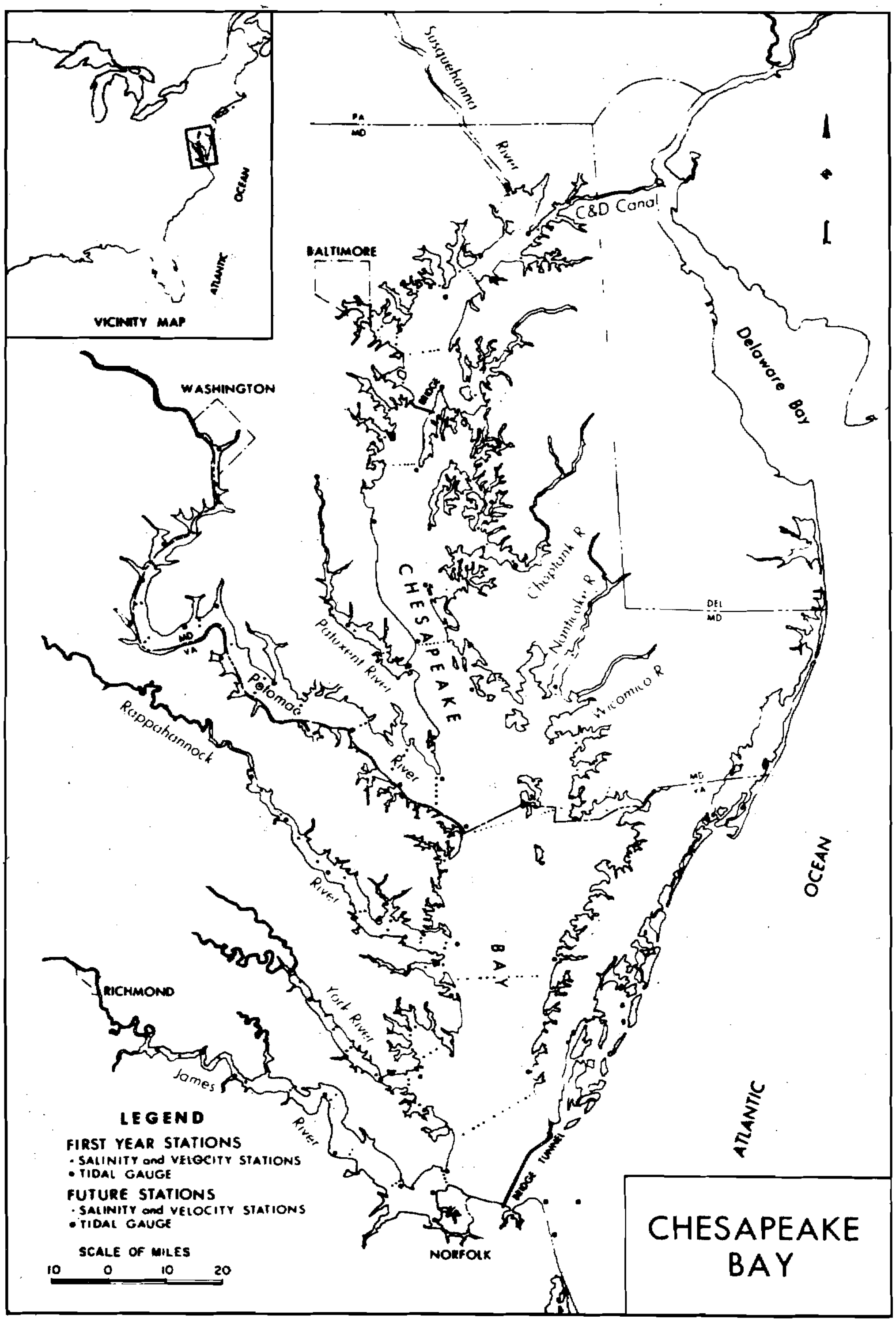

Figure I

Location of C and D Canal with respect to the upper Chesapeake Bay and Delaware Bay

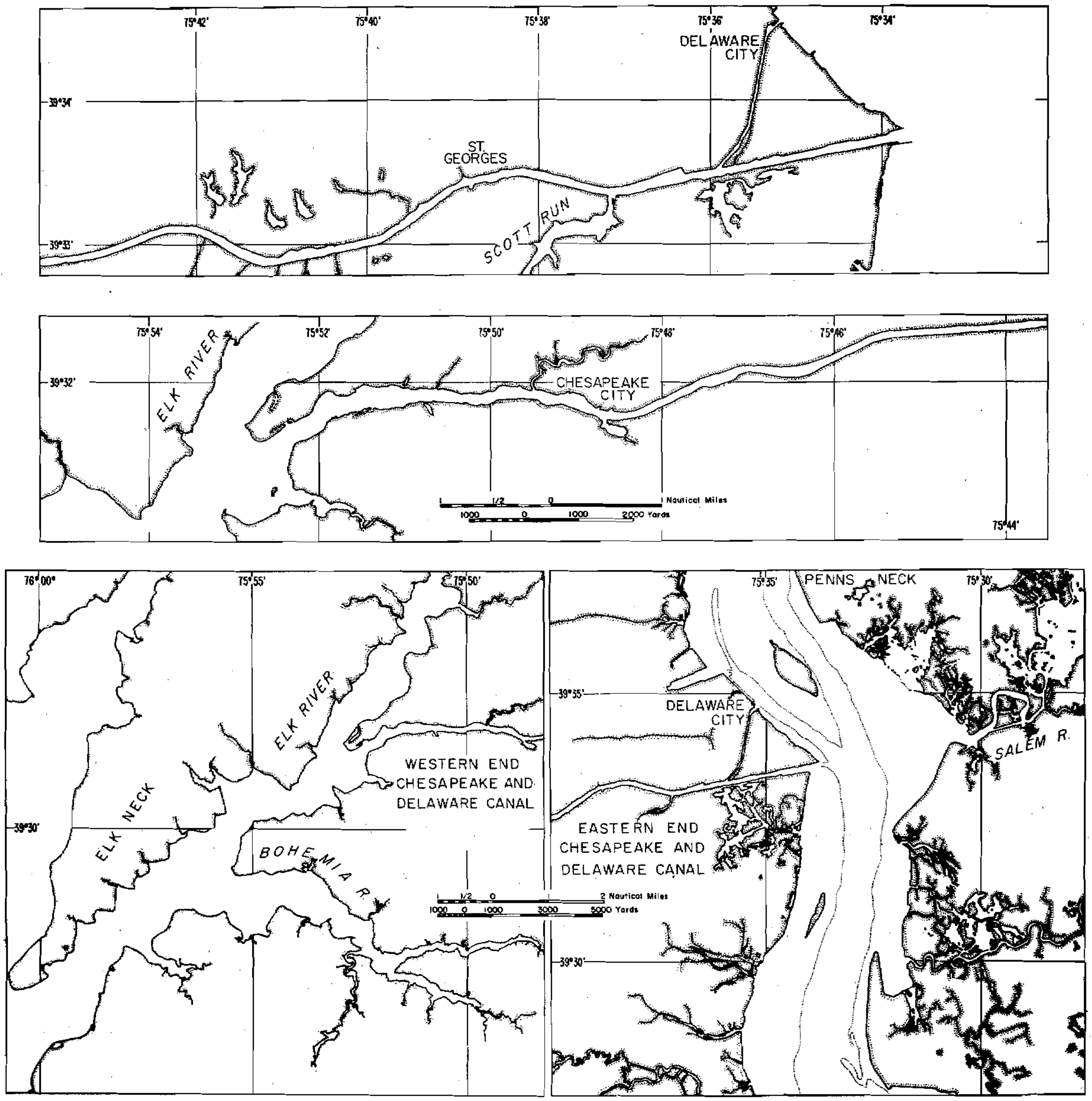

Figure II

Enlarged map of C and D Canal and near approaches to the two ends of the canal

In 1954 Congress authorized a further enlargement of the Chesapeake and Delaware Canal to a depth of 35 feet and a channel width of 450 feet. This authorization also provided for the deepending of the navigation channel in the upper Chesapeake Bay between the port of Baltimore and the western end of the canal. Very soon after initiation of actual work on the project in 1963, concern was expressed by students of the environment, by natural resources agencies, and by conservation groups as to the possible detrimental effects of disposal of dredged spoil, particularly from the dredging of the approach channel in the upper Chesapeake Bay, and a study of these effects was undertaken by the Chesapeake Biological Laboratory with funds provided by the U. S. Army Corps of Engineers. However, concern for the possible effects of the strictly hydraulic changes resulting from this project were not widely expressed until the spring of 1970.

This concern was first centered on the biological effects of possible changes in the temporal and spacial distribution of salinity in the upper Chesapeake Bay as a consequence of a projected increase in the diversion of fresh water from the upper Chesapeake Bay through the canal to the Delaware Bay. The results of computations based on existing knowledge have permitted a first approximation of the salinity changes which will likely occur and some estimation of possible biological effects of these changes. These tentative conclusions, however, require confirmation. More recently, concern has been directed towards the possible ecological consequences of changes in the flow regime and salinity patterns in the canal itself, and in the close proximity to the two ends of the canal as a result of the present enlargement of the canal. Of particular concern are the possible effects on eggs and larvae forms of estuarine fish, since the western end of the canal is known to be an important nursery area for striped bass, and possibly other anadromous forms.

PHYSICAL HYDROGRAPHY

The fact that there was a net flow of water from the Chesapeake Bay to the Delaware Bay through the C and D Canal had long been known, but unfortunately only by relatively few people. The Philadelphia District of the U. S. Army Corps of Engineers conducted an extensive study of the flow in the then recently completed 27-foot deep, 250-foot wide canal in 1938. An unpublished but comprehensive report entitled "Tides and Currents in the Chesapeake and Delaware Canal" prepared by Clarence F. Wicker (Wicker 1938), then of the Philadelphia District, Corps of Engineers, gave the results of an analysis of the series of tidal height and current measurements collected in the 1938 field study. This report showed that there was a net eastward-directed flow through the canal, superimposed on a very much larger oscillatory tidal flow. Of the 14 sections studied in the report by Mr. Wicker, the three sections nearest the Delaware end of the canal showed a net eastward-directed flow of from 65×10^6 to 67×10^6 cubic feet over the normal tidal period of 12.42 hours, or a mean eastward flow of about $1500\ ft^3 \cdot sec^{-1}$. The remaining 11 sections showed a net eastward flow over a tidal period ranging from 38×10^6 to 46×10^6 cubic feet, with an average for the eleven sections of $42.1 \times 10^6\ ft^3$, corresponding to a mean eastward discharge of $950\ ft^3 \cdot sec^{-1}$.

While we believe the Philadelphia District of the U. S. Army Corps of Engineers would have made this report available to anyone who requested it, concerned scientists and officials in Maryland were not aware of its existence at the time that plans for the enlarged canal were announced. One of us first became aware of this 1938 study by chance in January, 1968, as a result of inquiries to the Corps as to the possible reasons for certain anomalous results noted by two members of the staff of the Chesapeake Bay Institute in the studies they had conducted on the hydraulic model of the Delaware Bay, located at the U. S. Army Corps of Engineers Waterways Experiment Station in Vicksburg, Mississippi. The Philadelphia District made a copy of the report of the 1938 study available to us.

This report has served as the primary source of basic data used to obtain the several estimates of the probable increase in diversion of flow from the Chesapeake Bay to the Delaware Bay through the enlarged C and D Canal which have been made by the Corps of Engineers and by others. Early estimates made by the Corps and by one of us differed by a considerable amount. The latest projections of the possible net flow through the new canal, based on more careful appraisal are in essential agreement.

Average Net Flow Through the C and D Canal

The 1938 study of the 27-foot canal showed the following pertinent features regarding the tide and current regime in the canal.

(a) Because of the much longer travel route from the ocean to the western terminus of the canal via the Chesapeake Bay than in the case of the eastern terminus via the Delaware Bay, the tides at Courthouse Point at the western end of the canal occur more than ten hours later than the tide at Reedy Point at the eastern end of the canal.

(b) The tidal curve at the Delaware end of the canal is nonsymmetrical, with the time interval of rise significantly shorter than the time interval of fall, and the duration of high water longer than the duration of low water. The tidal curve at the Chesapeake end of the canal is much more nearly symmetrical.

(c) The mean tide range at the Delaware end of the canal is 5.4 feet, as compared to only 2.2 feet at the Chesapeake end of the canal.

(d) There was a net difference in the mean tide level between the two ends of the canal, with mean water level at the Chesapeake end of the canal standing approximately 0.3 foot above the mean water level at the Delaware end of the canal.

(e) The resulting tidal current regime in the canal is shown to be primarily hydraulic in character, the magnitude of the currents at any time being dependent on the elevation difference at the two ends of the canal.

(f) Based upon simultaneous current velocity measurements at three sections (Chesapeake City Bridge and Reedy Point Bridge on the main canal, and Fifth Street Bridge on the Branch Canal), coupled with cubature observations, velocity curves at some 14 cross-sections along the canal were determined and presented in graphical form in the subject report. Various pertinent properties of the tidal flow in the canal are summarized as a function of distance along the canal in graphical form. Of particular pertinence to the matter under consideration here is the plot of total eastward and westward flow through each section, in cubic feet per tidal cycle, presented in Figure 18 of the subject report. These data show that there was a net eastward flow through all sections of the canal. The three sections nearest the Delaware end of the canal show a net eastward directed flow of from 65×10^6 to 67×10^6 cubic feet over the tidal cycle of 12.42 hours, or a mean eastward flow of about 1500 cfs. These three stations are apparently influenced by flow through the Branch Canal and are probably not representative of the net flow from the Chesapeake to the Delaware. The remaining 11 sections show a net eastward flow over a tidal cycle ranging from 38×10^6 to 46×10^6 ft^3, with an average for the 11 sections of 42.1×10^6 ft^3, corresponding to a mean eastward discharge of 950 cfs. However, giving greater weight to those sections at which actual velocity observations were made, my best estimate of the probable net non-tidal flow through the 27-foot canal is 1000 cfs, directed eastward.

Effects of Enlargement on Net Flow

An estimate can be made of the probable increase in net eastward flow through the canal from the Chesapeake to the Delaware for the enlarged canal, using the above results from the study of the 27-foot deep canal. The procedure for this estimation is based on the assumption that the characteristics of the tidal height curves in the waters of the Chesapeake and Delaware Bays adjacent to the ends of the canal are not significantly influenced by the enlargement of the canal. Consequently, the head difference between the two ends of the canal, as a function of time over the tidal cycle, will remain the same for the new, enlarged canal as for the 27-foot deep canal. The velocities at any section, and at any time, in the enlarged canal will then equal the velocities which prevailed in the 27-foot deep canal multiplied by the 2/3 power of the ratio of the hydraulic radii of the two canal configurations.

The cross-sectional area of the 27 foot deep, 250 wide canal, with 2.5:1 side slopes, was 8,572 ft^2. The area of the enlarged 35 foot deep, 450 foot wide canal, with 2.5:1 side slopes, will be 18,812 ft^2. The ratio of the area of the enlarged 35-foot canal to the area of the old 27-foot canal is then 2.20. The wetted parameter of the 27-foot canal is 395 feet, and that of the 35-foot canal is 638 ft. The hydraulic radius of the 27-foot canal is then 21.7 ft., and that of the 35-foot canal is 29.5 ft. The ratio of the velocities in the 35-foot canal to that in the 27-foot canal is equal to the 2/3 power of the ratio of the hydraulic radii, and hence is 1.23. The ratio of the discharge through any cross-section for the 35-foot canal to that for the 27-foot canal is then the product 1.23 x 2.20 or 2.70.

The results of applying these considerations to the known tidal velocity and tidal flows for the 27-foot canal, to obtain the corresponding estimates for the 27-foot canal, are given in Table I.

Table I

Summary of Tidal Velocity and Tidal Flow Characteristics for the 27-foot canal, and Projections for the 35-foot canal.

		27-ft Canal	35-ft Canal	Ratio 35/27
Cross Sectional Area, ft^2		8,572	18,812	2.20
Ave. "Maximum" tidal Velocity, $ft \cdot sec^{-1}$	Eastward	2.90	3.57	1.23
	Westward	2.28	2.80	1.23
Mean Tidal Velocity $ft \cdot sec^{-1}$	Eastward	1.85	2.28	1.23
	Westward	1.45	1.78	1.23
Ave. "Maximum" Tidal Discharge, $ft^3 \cdot sec^{-1}$	Eastward	24,860	67,120	2.70
	Westward	19,540	52,760	2.70
Mean Tidal Discharge $ft^3 \cdot sec^{-1}$	Eastward	15,830	42,740	2.70
	Westward	12,440	33,590	2.70
Ave. Net Non-Tidal Flow, $ft^3 \cdot sec^{-1}$	Eastward	1,000	2,700	2.70
Ave. Duration, Tidal Flow, hours	Eastward	5.90	5.90	1.00
	Westward	6.52	6.52	1.00
Excursion During 1/2 Tidal Cycle, ft	Eastward	3.93×10^4	4.84×10^4	1.23
	Westward	3.41×10^4	4.20×10^4	1.23
Net Non-Tidal Excursion per Tidal Cycle, ft	Eastward	5.2×10^3	6.4×10^3	1.23

It is pertinent to note that while the volume rate of flow through the 35-foot canal will be increased to a value 2.70 times that for the 27-foot canal, the velocities, as well as the tidal excursions during each phase of the tidal flow, and the net non-tidal excursion, in the 35-foot canal will be increased, on the basis of this preliminary projection, to values only 1.23 times these parameters for the 27-foot canal. Changes in the actual velocities and in the length of the tidal excursions and the net non-tidal excursion may be of greater ecological significance than changes in the volume rate of flow.

The above estimates are made for the long term average tidal conditions. We know that there are relatively large seasonal and shorter term variations in the tidal properties at the two ends of the canal. The effects of these fluctuations on the net flow through the canal are not known. Short term variations in the flow regime may be of considerable ecological significance, and studies of such variations are an important part of a study of the canal now underway.

Somewhat over 90% of the length of the canal has now been widened to the present project channel width of 450 feet, and about 60% of the length of the canal has been deepened to 35 feet. Studies now underway in the canal thus cover a transition period. Even so, much can be learned about the probable ultimate consequences of this project on the estuarine ecology of the waterway and of the adjacent Chesapeake Bay and Delaware Bay. For example, the likelihood that the net non-tidal flow through the canal has shown and will show large short term transient variations is supported by a 10-day series of current meter observations made at the Reedy Point Bridge in October, 1969. Data for 17 complete tidal cycles from this series have been analyzed. Over these 17 tidal cycles (approximately nine days), the average net flow was, as expected, eastward, with an average transport of 1,950 $ft^3 \cdot sec^{-1}$. However, over shorter intervals of time the net flow was almost as often directed towards the west as toward the east. This is seen in the tabulation given in Table II. This Table shows that out of the 17 full tidal cycles, the net flow was directed to the eastward for 9 cycles, to the west for 6 cycles and was essentially zero for 2 cycles.

Salinity Distribution in the Canal

Salinity surveys almost always show a gradient of increasing salinity from the Chesapeake end of the canal to the Delaware end. Over much of the year the salinity at the Chesapeake end of the canal either equals that of fresh water or is only slightly higher than that of the fresh water inflow to the Bay. Table III gives typical values for the salinity at surface and bottom, at Turkey Point at the western end of the canal, at three positions along the canal, and at two positions in the Delaware Bay near the eastern end of the canal. The salinity distributions are given for periods of high river inflow to the Chesapeake Bay and the Delaware Bay; for periods of low river inflow to these estuaries; and for average conditions. Note that during periods of high fresh water inflow, there is virtually no vertical variation in salinity at the eastern end and over most of the length of the canal. For periods of low fresh water inflow, and even for average conditions, a slight but significant vertical gradient exists in the canal.

This characteristic horizontal and vertical salinity gradient suggests that, in order to satisfy continuity requirements for salt, there may be a net flow through the canal from the Chesapeake to the Delaware to balance the diffusive flux of salt in the opposite direction. This net flow requirement exists irrespective of the hydraulic flow requirements associated with the variation in tidal amplitude and phase between the two ends of the canal. The deepening and widening of the canal will tend to increase the vertical gradient in salinity, and intensify the tendency for a two-layered net non-tidal flow pattern, with a westward flowing upper layer and an eastward flowing deeper layer.

Table II

Net Non-Tidal Flow Through the C and D Canal as Determined from Continuous Current Meter Observations Over a 17 Tidal Cycle Period in October, 1969

Tidal Cycle Interval		Net Flow ($ft^3 \cdot sec^{-1}$)
0-2	(2)	0
2-5	(3)	8430 Eastward
5-6	(1)	790 Westward
6-9	(3)	10250 Westward
9-12	(3)	10530 Eastward
12-13	(1)	3950 Westward
13-16	(3)	7100 Eastward
16-17	(1)	3160 Westward

Table III

Typical Variation of Salinity in ‰ Through the C and D Canal

		Position (See Notes Below)					
		A	B	C	D	E	F
High River Flow Period	Surface	0.11	0.27	0.32	1.39	1.00	1.90
	Bottom	0.11	0.27	0.33	1.45	1.30	2.93
Low River Flow Period	Surface	4.30	5.98	6.05	7.80	5.46	7.39
	Bottom	9.41	6.10	6.18	8.46	7.55	10.44
Average River Flow	Surface	0.83	1.28	1.60	3.16	2.30	3.48
	Bottom	1.70	1.30	1.76	3.47	3.07	5.08

A. Turkey Point. Junction of Chesapeake Bay and Elk River. For practical purposes western end of Chesapeake and Delaware Canal.

B. Chesapeake City Bridge (2 miles east of junction of C and D Canal and Elk River).

C. Summitt Bridge (4 miles east of junction of C and D Canal and Elk River).

D. Reedy Point. East end of C and D Canal (8 miles east of junction of C and D Canal and Elk River).

E. Channel, Delaware Bay, directly east of entrance to C and D Canal.

F. Channel, Delaware Bay, 5 miles south of junction of C and D Canal.

Salinity Distribution in the Upper Chesapeake Bay

A one-dimensional time-dependent numerical model of the salinity pattern in the upper Chesapeake Bay was recently developed by Mr. William Boicourt, a graduate student in the Chesapeake Bay Institute. This model was verified using salinity data collected during the period when C and D Canal had a channel depth of 27 feet and a channel width of 250 feet. This computer model was run to compute the weekly average salinity as a function of distance along the axis of the Chesapeake Bay and as a function of time for an eleven year period 1958 through 1968. The primary time dependent input term is the fresh water inflow to the Bay from the Susquehanna River. Computations over the eleven year period were made using the observed river flow, and also using the observed river flow less 1700 cfs, representing the additional fresh water diversion expected to occur through the enlarged canal. Thus one set of computed salinity values represented conditions in the upper Chesapeake Bay associated with the 27 foot deep, 250 foot wide canal, while the second set represented conditions in the upper Chesapeake Bay associated with the 35 foot deep, 450 foot wide canal.

Table IV summarizes the results of these computations at three positions in the upper Chesapeake Bay. Note that the enlargement of the canal has very little effect on the salinities during the spring period of high fresh water inflow; that is, during the period of annual minimum salinities. During years of higher than average fresh water inflow to the Bay, the additional diversion of fresh water through the canal has only a small effect on even the maximum annual salinities. The effect of enlargement of the canal on the salinity distribution in the upper Chesapeake Bay is most pronounced during unusually dry years, during that part of the year when the river discharge was lowest, and the salinities were at a maximum.

Table IV

Summary: Minimum and Maximum Weekly Mean Salinities, Upper Chesapeake Bay, for 11 Year Period 1958 thru 1968. A: For 27-Foot Canal; B: For 35-Foot Canal.

	Turkey Point		Pooles Island		Bay Bridge	
	A	B	A	B	A	B
Range, Minimum Salinities	0.10	0.10	0.42	0.43	6.84	6.90
	0.22	0.23	2.33	2.44	9.92	10.52
Ave., Minimum Salinities	0.13	0.13	1.14	1.19	8.60	8.79
Range, Maximum Salinities	1.14	1.30	7.05	7.61	15.21	15.39
	3.67	5.87	13.30	16.07	18.37	18.53
Ave., Maximum Salinities	2.14	2.94	9.00	11.58	17.23	17.61

BIOLOGICAL EFFECTS

From the preceding portion of this paper, the following biologically significant hydrographic results of enlargement of the canal are expected:

1. Net transport through the canal will increase about 170%, from about 1000 cfs to about 2700 cfs.

2. In the Canal:

   a. Maximum and mean velocity will increase by about 23%.

   b. Length of the tidal excursions in both the eastward and westward directions, and also of the net non-tidal excursion, will be extended by about 23%.

   c. Saline waters from the Delaware Bay will intrude farther toward the Chesapeake, and stratification will be strengthened.

   d. Tidal and turbulent exchange of waters at the two ends of the Canal will be increased.

   e. Turbidity may be increased as the result of increased velocities.

3. In the Chesapeake Bay system:

   a. Salinities in the upper Bay will be increased during seasons of low fresh water input (normally late summer and fall) and will be virtually unchanged during periods of high river inflow (winter and spring)

   b. At the Bay Bridge, maximum salinity change will be less than 0.5‰ over a natural salinity range of 6.8‰ to 18.4‰. South of the Bay Bridge, where natural salinities are higher, the effects of enlargement of the Canal will be even less.

4. In the Delaware River:

   a. Input of clean water from the Chesapeake Bay will be increased.

   b. Salinities will be reduced, but no estimates are yet available of the temporal and spacial distribution of these changes.

From these changes, we expect that the principal biological effects will result from the increased transport of organisms from the Chesapeake system to the Delaware, modification of the biological habitat in the canal, and altered salinities in some seasons in portions of the Chesapeake and Delaware estuarine systems. There may, of course, be others, perhaps including improvement or damage to the general water quality of some areas.

The previous portion of this paper has shown that the flow pattern and the water exchange between the Chesapeake and Delaware are highly variable. From the biological point of view, it is frequently inadequate to deal, as the physical hydrographer does effectively, with average conditions, net transport, and integrated patterns. While these can be very useful, biological effect and responses are very often caused by the short-term extreme conditions, which do not appear in summary expressions. The biological pertinent environment for fish eggs, for instance, may be that available during a very short spawning period which is determined by complex physiological sequences. Mortality or debility can be caused by quite brief exposure to intolerable environmental stresses. Even in the notoriously variable environment of the estuary, where all successful species have impressive adaptations for tolerating change, the estimation of average conditions will not provide accurate or adequate predictions of biological response.

With this caveat and the reservations it implies, it is still desirable (and frequently necessary in view of increased concern for and requirement of environmental evaluation) to assemble pertinent background information, develop best estimates of the ecological effects of such an environmental modification, and use them to assist in decisions affecting public resources. In this portion of this report, the background information and tentative prediction of biological effects presented at the 1970 hearings on the C and D Canal enlargement are summarized. (Committee on Public Works, 1970)

Background Information

The Chesapeake Bay has been the subject of extensive biological research, especially since the mid-1940's, and the Delaware River and estuary have also been studied in part. No project has, however, been directed toward full understanding of the biological effects of creating or enlarging the canal. The most pertinent data were produced in a recent extensive study of the gross physical and biological effects of overboard spoil disposal in the upper Chesapeake involving the approaches to the canal (Chesapeake Biological Laboratory, 1970). This study was conducted over a period of three years under a contract with the U. S. Bureau of Sport Fisheries and Wildlife, funded by its Philadelphia District of the U. S. Army Corps of Engineers. The scientists involved observed some of the effects of salinity changes on important Bay species. In relation to the canal, there was an especially significant dividend from the work of Mr. William Dovel, who studied fish eggs and larvae. He and others were interested in the Canal, and bootlegged regular trips and sampling activities in that body of water to learn how it might be related to the specific Chesapeake area under study. This curiosity produced what is now the only available data on some of the most important biological characteristics of the Canal. It has been possible to assemble related data and a considerable element of experienced judgment by scientists[1] to produce the following summary:

1. The Canal contains a rich supply of small crustaceans and the highest densities of eggs and larvae of striped bass that we have seen anywhere in the Chesapeake system. Many other species of juvenile fish were found in the Canal in recent years.

1. Special appreciation is expressed to David G. Cargo, William Dovel, Elgin Dunnington, Edgar H. Hollis, Ted S. Y. Koo, Hayes T. Pfitzenmeyer and to the Delaware Department of Natural Resources for data and opinions.

2. A small number of young striped bass tagged in Chesapeake Bay moved to Delaware Bay, and the pattern of recovery suggests that the C and D Canal is the principal route for escapement of fish from Maryland out of the Chesapeake.

3. A small number of larger striped bass tagged in Chesapeake Bay moved, apparently through the Canal, to Delaware Bay.

4. Commercial fishing for striped bass is carried out in the Canal each winter.

5. Several shad tagged in Delaware Bay were recaptured in the upper Chesapeake.

6. Many species of marine fish migrate into Chesapeake Bay each year. The upper limit of migration is apparently controlled by salinity in summer and fall.

7. The low-salinity area of the upper Chesapeake, including the approach to the Canal, is an exceptionally important spawning and nursery area for many species of young fish.

8. Many bottom species produce larvae which are carried up the Bay in deeper water.

9. Salinity controls the up-Bay limits of oysters, clams, many other bottom species, and of some of the most serious predators and parasites of these species, including the oyster drill and the protozoan Minchinia nelsoni or MSX.

10. Salinity also affects the distribution of sea nettles, setting the up-Bay limit at about 7 parts per mille for the large summer medusae and at about 5 ‰ for the over-wintering polyps.

11. The environment of the upper Chesapeake is violent and varies greatly throughout the year and from year to year.

The Estimated Biological Effects of Enlargement

A. In the Canal:

1. Increased flow and velocity will probably affect the success of striped bass eggs and larvae, but it is impossible to predict whether the change will be favorable or unfavorable.

Comment: The large crops of eggs and larvae now present are an accidental by-product of creating the Canal. Since there has been no study to determine the optimal conditions for them, we do not know whether they will be further enhanced or reduced.

2. Movements of fish between the Chesapeake and Delaware Bays may be increased.

Comment: Perhaps more striped bass will move to Delaware Bay, but it is possible that shad and other species in the Delaware will respond as they would to a new tributary and move into the Canal in larger numbers.

B. In Chesapeake Bay:

NOTE: It is appropriate to note that Dr. Pritchard predicts

(a) little change in Bay salinities during late winter, spring and early summer, (b) greatest increase in fall, (c) maximum effect in low salinity areas, and (d) almost no effect below the Severn River.

1. Several marine fish, probably including the croaker, silver perch, spot, butterfish and puffer, will move slightly farther up-Bay in the summer and fall.

2. The success of spring-spawning fish (striped bass, shad, perch, herring and others) will probably be little affected.

3. Several species of small benthic molluscs will penetrate farther up-Bay each fall, but be killed each spring to about the same position they occupied prior to Canal enlargement.

4. Oysters above the Chesapeake Bay Bridge will improve slightly in growth and condition during fall. The up-Bay limit near Pooles Island will not change, however, since it is apparently controlled by spring flows.

5. The oyster enemies Minchinia nelsoni (MSX) and drills will not be affected, since they are restricted to higher salinities than those at the Severn River. Another parasite, Dermocystidium marinum, might be slightly favored if the density of oysters increases.

6. Sea nettles may be increased in areas north of the Bay Bridge. They may appear slightly earlier, intrude somewhat farther up the Bay, be more abundant in some areas, and disappear earlier in the fall.

7. Sea nettle polyps will apparently retain the same distribution pattern, since they are probably limited by low spring salinities.

8. Other responses, which cannot now be predicted, will occur. In general, the species limited by spring salinities will be affected little or not at all. Those controlled by fall salinity will shift farther up the Chesapeake.

These tentative estimates are obviously subject to correction and refinement. They have, however, been useful in suggesting the nature and magnitude of the effects of enlargement of the Canal, and especially in designing the research program required for improved prediction of effects and decision on optimal management of the Canal.

RESEARCH PROGRAM

The Corps of Engineers has developed a six-phase study program related to Canal enlargement. This program was developed, in part, as a response to the concern expressed at the Congressional hearings and the information provided at these hearings (Committee on Public Works, 1970, p. 301). The program comprises:

1. "Field measurements and studies of tides, currents and salinities in the Canal and its approaches by the Philadelphia District.

2. "Construction and testing of a hydraulic model (of the Canal) by the Waterways Experimental Station.

3. "Mathematical model studies by the Waterways Experimental Station.

4. "Hydraulic model tests by the Waterways Experimental Station of control structures to determine their effectiveness in controlling flows.

5. "Preliminary design of several types of control structures by the Philadelphia District.

6. "Ecological studies to be performed by a qualified agency, firm or institution, using data developed from the model studies and field investigations."

It is appropriate to emphasize that this is a highly interdisciplinary program. Continuous exchange and interaction will be required among engineers in theoretical and applied fields, physical hydrographers, specialists in hydraulic and mathematical modeling, biologists conducting field surveys and laboratory experiments, and decision-makers in various public agencies. Each will contribute to and depend upon the concurrent efforts or other professional groups. As a brief example, the hydraulic model of the Canal will be highly useful for estimating changes in net flow and in the time dependent flow pattern; for cross-checking with theoretical models for mutual improvement; for

for estimating the movements of fish eggs and larvae by the use of simulating particles; for suggesting the effects of various types of possible flow-control structures; and for testing of new ideas which will emerge after this specific study program is completed.

Responsibilities for the program have been established and the studies have begun. The Philadelphia District of the Corps is making field measurements in the Canal and has begun the design of possible flow control structures. The staff of the Waterways Experiment Station has added the Canal, from Turkey Point on the Chesapeake to Reedy Point on the Delaware, to the Delaware Bay and River Model with which it has long experience. WES has also imbarked upon mathematical analysis of all available data to develop useful models of the Canal and nearby estuarine areas.

The ecological studies were initiated in October, 1970 under a contract between the Philadelphia District of the Corps of Engineers and the University of Maryland. The University is prime contractor for its work, and L. E. Cronin is program coordinator; but the entire program will be conducted as an inter-institutional effort, making complementory use of the special facilities, location, and professional competencies of The Johns Hopkins Chesapeake Bay Institute; the University of Maryland's Chesapeake Biological Laboratory; and the University of Delaware's College of Marine Studies. This program includes:

1. Hydrographic Program - by the Chesapeake Bay Institute. Dr. Donald W. Pritchard, Principal Investigator.

   a. Studies of the time variations in the distribution of salinity in the Canal and adjacent estuarine approaches.

   b. Direct current measurements of flow patterns within the Canal and of net flow through the Canal.

   c. Measurements of division of flow at Turkey Point.

2. Ecological Program - by Chesapeake Biological Laboratory, Dr. Ted S. Y. Koo, Principal Investigator; and Delaware College of Marine Studies, Drs. Frank C. Daiber and Victor Lotrich, Co-principal Investigators.

   a. Analysis of fish eggs and larvae in the Canal and its approaches (CBL).

   b. Effects of environmental variations on fish eggs and larvae (CBL).

   c. Use of the Canal by juvenile and adult fish (CBL and DCMS).

   d. Biological survey in the Canal and its approaches and estimation of the effects of changes (CBL and DCMS).

These projects will variously require one to three years for completion. Since dredging for enlargement of the Canal is now partially completed, specific agreement has been made for an exceptionally thorough progress report and analysis on or before 30 September 1972 to assist the decision and plans which must be developed at that time.

SUMMARY

The Chesapeake and Delaware Canal is a rather dramatic example of an engineering activity which has created a new biological environment as it provided a new shipping route. Heightened public concern was focused on the environmental effects fourteen years after authorization and seven years after initiation of the project for enlargement of the Canal. Data and opinions assembled from many sources have permitted helpful first estimates of the physical and biological effects of enlargement. Extensive interdisciplinary, and multi-institutional research have been established to parallel the final portion of the dredging program. Assurance has been given that decisions on the structure and operation of the Canal will take full advantage of the new biological and environmental knowledge.

The future will determine the accuracy of our preliminary estimates and the success of this effort to achieve the best possible balance between shipping interests and important biological values of this artificial Canal and near-by estuarine waters. The results will be of exceptional local importance and may stimulate or assist in understanding other areas of interaction between engineering and man's environment.

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