CITY OF VIRGINIA BEACH, VIRGINIA

DRAINAGE CANAL
NORTH BAY TO RUDEE INLET

ENGINEERING STUDY

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FEBRUARY 1967

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February 10, 1967

Mr. W. Russell Hatchett, City Manager
City of Virginia Beach
Municipal Building
Virginia Beach, Virginia

Dear Sir:

Pursuant to your authorization and instruction, and a Resolution of the City Council of Virginia Beach dated July 25, 1966, we have carried out a study of the possible effects of the construction of a waterway connecting Back Bay with the Atlantic Ocean through Rudee Inlet. The results of the study are contained in the Report presented herewith.

In connection with those particular phases of the study which related to tidal hydraulics, we engaged the services of Clarence F. Wicker, P.E., Consulting Engineer, Girard Trust Building, Philadelphia, Pennsylvania, with whose findings we have concurred.

We will be glad to discuss the Report in detail at your convenience.

We take this occasion to express our appreciation of the important assistance given us in the work by agencies of the City and of the State and Federal Governments, and by interested individuals.

Very truly yours,

LANGLEY, McDONALD AND OVERMAN

By: George E. Langley
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SUMMARY

By resolution dated July 25, 1966, the City Council of Virginia Beach authorized an Engineering study to determine the possible effects of the construction of a tidal waterway connecting Back Bay (North Bay) with the Atlantic Ocean through Rudee Inlet and to report on the study.

The entire purpose of the study and report is summarized as follows:

(a) to determine, in the light of ordinary engineering and economic considerations, the best location, dimension, and arrangement of a new waterway between North Bay and Rudee Inlet which reasonably satisfy the needs described elsewhere, namely to improve drainage, permit small boat traffic, and possibly increase within reasonable limits the salinity of the Back Bay waters and at the same time reduce the turbidity of these waters. No attempt has been made in the study to discriminate as to the relative importance of these several functions;

(b) to determine the likely effects of such a waterway upon the environmental features of adjacent lands and water bodies. The ultimate ecologic effects of any environmental changes are outside the scope of the study and must be determined by others.

The report sets out in general terms the physiographic character of the Virginia Beach area and some of the major developments which led to the consideration of the tidal waterway mentioned, whose threefold functions are described above.

The criteria developed as the study progressed for the determination of location, dimensions and arrangement of the waterway with respect to the three separate functions of drainage, boat passage and salinity and turbidity control are described in the report.

Four separate locations or routes between the terminal points mentioned were investigated. These are described in the report and delineated on the drawings which accompany it. The factors affecting location are discussed. These include military reservations, lakes, land uses, and others.

The normal and extreme variations in tidal rise in the ocean at Rudee Inlet and the variations in water level in Back Bay are considered. Data on these phenomena are presented. An assumed tide level of 6.0 feet above Mean Sea Level in the ocean at Rudee Inlet is discussed in relation to higher levels which may occur on occasion and in relation to water levels in Back Bay and at Sewells Point.

The effects of the contemplated waterway are analyzed in detail. The tidal regimen which will prevail in such a waterway is described and its effect in lowering and raising the water level in Back Bay (North Bay and Shipps Bay) is analyzed. Such effects are shown to be negligible under normal tide conditions, but a little more severe under extreme conditions which induce tidal rises in the ocean at Rudee Inlet to 6.0 feet above Mean Sea Level and higher.

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consequence of the contemplated waterway project are likely to be either sea water from extremely high ocean tides or an even larger mixed volume of sea water and storm runoff occurring when an extremely high wind tide coincides with heavy precipitation. In either case, the intrusion of sea water into the Back Bay water body by a course which was not open to it in the natural state will be a major element of the consequences of that project.

C. In the light of the judicial principle prevailing in Virginia that surface water is the "common enemy" to be defended against with all due consideration of other rights and public interests; and of the complex nature of the rights and interests involved which include the common law rights of property owners to defend against surface water; the right and duty of the municipality to facilitate such defense; the right of other property owners to be protected against the effects of drainage diversion and the municipality's duty in that connection; the property rights as well as the more eminent rights of the United States in connection with the two Naval facilities which could be affected; the rights of the Commonwealth in connection with its military establishment at Camp Pendleton, and of its people in the preservation and utilization of the wildlife resources of the area, to say nothing of a number of other rights which may spring from the statutory powers of cognizant regulatory agencies of the City, State, and Federal Governments.

D. In addition to the cost of the excavation of the Canal, other items of construction cost that would be encountered include:

(a) clearing of timber within the Canal proper and the disposal areas,

(b) rights of way and disposal areas,

(c) construction of cul-de-sacs at highway terminations and new road connections at certain locations,

(d) structures for drainage and small boat passage,

(e) construction of a minimum of three multi-box culverts or medium level bridges at highway locations. A medium level bridge in this instance would be considered as having a vertical clearance of 16 feet at mean high water.

The report contains the following recommendations:

1. It is recommended that if the benefits to be derived from improved drainage, the provision for small boat traffic and a method of artifically introducing salt water into Back Bay are sufficient to justify the cost. and in the absence of an unfavorable legal opinion, a drainage canal be designed and constructed along either Alternate Route A or Route C, in accordance with the general plans which are included in this report.

2. It is recommended that if the waterway is built, controlled sluiceways be provided in connection with Lake Tecumseh and Redwing Lake and a program for their operation be established.

3. It is recommended that provision be made for regular tide gage and salinity readings in selected locations in the waterway and in Back Bay including North Bay and Shipps Bay.

4. It is recommended that a tide gate be provided in the waterway between South Birdneck Road and General Booth Boulevard. This would be closed under extreme high tidal conditions in Lake Rudee and might be closed at times when the salinity in Back Bay reached detrimental proportions. A program for the operation of this gate would have to be established.

5. It is recommended that a supplemental report be made after an investigation and study of existing bubble curtains and the most efficient and economical method of providing a tide gate.

SECTION 1. GENERAL STATEMENT

The present day City of Virginia Beach includes all of the former County of Princess Anne, some 270 square miles.

The area lies in the Coastal Plain Physiographic Province of the United States, and in the commonly designated Tidewater section of Virginia. Its site is in a nearly level plain of considerable physiographic extent which is, in this locality, divided into the Princess Anne and Dismal Swamp terraces. Both of these are of marine origin. Their surfaces are gently undulating to level. The Princess Anne Terrace, bordering the Atlantic Ocean and Chesapeake Bay ranges in elevation from sea level to about 15 feet. The Dismal Swamp Terrace, ranging to a maximum elevation of about 25 feet forms the central and western parts of the area. The terraces are separated by a low escarpment which has been obliterated to a large extent by local erosion and by land improvement but which is readily discernable in many places on the ground as well as on topographic maps.

Dissection of these surfaces is neither complete nor thorough. Many large areas have no natural surface drainage. Most of the natural drainageways reach sea level within a few miles of their source. No part of the area is more than 8 miles from a point at sea level.

Until recent years the area development was to a large extent agriculture oriented. The consolidation on January 1, 1963 of the original City of Virginia Beach with Princess Anne County coincided roughly with the

culmination of a period of intensified urbanization in many parts of the former county. At the present time agriculture remains an important element in the economy but the agricultural capability of lands no longer regulates the market value of real estate.

Nevertheless, many of the considerations which formerly dictated that local government make provision for the needs of an agricultural industry still prevail, and will for some time in the future. Among such provisions is the continued improvement of imperfect natural drainage. This is, of course, essential for continuing suburban and urban development as well as for agriculture.

Boating as a recreational pursuit and the boating industry as an economic factor are becoming increasingly important in the City of Virginia Beach. The planning agencies of the City have attached great significance to proposals which have been put forward for many years to interconnect the waterways of the Albemarle-Currituck-Pamlico Sound system with the Atlantic Ocean through Rudee Inlet and with Chesapeake Bay through the Lynnhaven River waterways and Lynnhaven Inlet. Such proposals have far reaching implications which are examined in this report.

Most of the southeast quarter of the present City is occupied by Back Bay and its tributary bays, all of which are merely an extension of Currituck Sound, and by the barrier beaches which are associated with this extended lagoon system. The Back Bay Game Refuge includes 4,589 acres of the bays and barrier beaches. Back Bay has long been a celebrated and

important recreational asset by reason of its abundant wildfowl and fish feeding capability. Ecological disturbances among the aquatic plant life in recent years which have led to great reductions in wildfowl and fish populations are attributed to the reduced salinity of Bay waters and to increased sediments born by waterways draining into the Bay. The gravity of this situation is recognized by authorities on fish and wildlife, by sportsmen's groups, and by the Governing Body of Virginia Beach.

On April 27, 1964, motivated by the foregoing and other long range planning considerations, the City Council created the Virginia Beach Dredging Commission and empowered it to conduct dredging operations which would lead to environmental improvements within the City, utilizing for this purpose dredging equipment purchased by the City. Among the projects which the Commission undertook was that of dredging the first segment of the connecting waterways mentioned. This segment was to begin in North Bay and to follow a location recommended by field representatives of the U. S. Soil Conservation Service.

By May 5, 1966, substantial progress had been made on this project. It was deferred at that time, however, to permit a re-evaluation of the possible effects of the tidal interconnection between the various water bodies. The nature of these possible effects is described in another section of this Report, this being a primary purpose of the Report.

The entire purposes of this Report and the Engineering study which it follows are:

(a) to determine, in the light of ordinary engineering and economic considerations, the best location, dimension, and arrangement of a new waterway between North Bay and Rudee Inlet which reasonably satisfy the needs described above, namely to improve drainage, permit small boat traffic, and possibly increase within reasonable limits the salinity of the Back Bay waters and at the same time reduce the turbidity of these waters. No attempt has been made in the study to discriminate as to the relative importance of these several functions;

(b) to determine the likely effects of such a waterway upon the environmental features of adjacent lands and water bodies. The ultimate ecologic effects of any environmental changes are outside the scope of the study and must be determined by others.

SECTION 2. CRITERIA FOR FUNCTIONAL PLANNING

Because of the dual and possibly three fold function of the contemplated waterway described in a preceding section, and because of the practical requirement that its cost, while not limited by strict considerations of calculable benefits and their relation to the estimated costs, must be kept within reasonable and tolerable bounds, rigid criteria were not adopted initially in the study, but were developed following preliminary analysis of several alternative approaches.

The essential criteria as finally developed are summarized with respect to each of the stated functions in the following:

A. Drainage

1. The drainage area contributing surface runoff to any one of the alternative waterway routes would be approximately 10,500 acres.

2. The canal cross section would have to be adequate to convey surface runoff at rainfall rates which would be determined for a ten year frequency from Steel's formulas based on Yarnell's data. Initially, consideration was given to rates associated with much lower frequencies, up to 50 years. It was found, however, that the cost of a waterway to accommodate such rates would undoubtedly be greater than the anticipated benefits would justify and that the possibility of serious damage resulting from the occasional overloading of the waterway would not be great.

3. Since the present and future development in the drainage areas contributing runoff to the several routes would be materially the same, a uniform coefficient of runoff was adopted, this being 0.43. This reflects an anticipated ultimate land use having the following assumed characteristics and proportions:

Commercial and Industrial	10%
Multi-family Residential	15%
Single family and Duplex Residential	55%
Parks	20%

B. Boating

The waterway dimensions adopted for purposes of this study were developed with respect to boating requirements by the methods set forth in Report No. 3 of the Corps of Engineers Committee on Tidal Hydraulics, "Evaluation of Present State of Knowledge of Factors Affecting Tidal Hydraulics and Related Phenomena - May, 1965". The width of the travel lanes should be about 160% of the beam of the design vessel, the medial strip between these lanes should be 80% of the beam of the design vessel, and the clearances between the outer edges of the travel lane and the bottom of the canal prism should be 60% of the beam of the design vessel. The sum of these factors is 520% of the beam of the design vessel. According to the paper in ASCE Waterways and Harbors Journal, Vol 90 WW3,

"Small Craft Harbors Development", the median average of this range of beams, 10.5 feet, is taken as the beam of the design vessel. Applying this to the 520% factor derived above yields 55 feet as the bottom width of the canal prism, and this is rounded to 60 feet. The side slopes of the canal prism are assumed to be 1 vertical on 2 horizontal.

C. Salinity and Turbidity Regulation

The Back Bay-Currituck Sound Data Report on Fish Studies, 1958 - 1964, prepared by the Bureau of Sport Fisheries and Wildlife, the North Carolina Wildlife Resources Commission and the Virginia Commission of Game and Inland Fisheries suggests certain conclusions as to optimum salinity for the sustenance of native wildlife. These are construed to indicate 10 to 12 percent of sea water salinity. For the purposes of this study 10 percent is taken as the optimum level.

Definitive criteria for tolerable turbidity have not been found. It is generally held, however, that any turbidity is detrimental to wildlife sustenance, directly or indirectly. Obviously any natural water body must be subject at some time and in some degree to turbidity. Since this is a condition which cannot be averted altogether it can only be evaluated in relative terms, and its importance can only be determined by others.

Detailed data and discussion of salinity and turbidity are found in the work mentioned above and a companion work titled Back Bay-Currituck Sound Data Report on Environmental Factors, prepared by the Bureau of Sport Fisheries and Wildlife, the North Carolina Wildlife Resources Commission and the Virginia Commission of Game and Inland Fisheries.

SECTION 3. LOCATION

The alternative locations discussed in this report are controlled by factors described above and by others not heretofore mentioned.

The area between North Bay and Rudee Inlet is occupied to a large extent by the U. S. Navy's Fleet Anti-Air Warfare Training Center (FAAWTC Dam Neck), by the U. S. Amphibious Base, and by the Virginia National Guard Reservation (Camp Pendleton), all of which are indicated on Plate I. The same area contains three small lakes, each of which lies partly in one or the other of the military reservations mentioned. The lakes are remnants of the former lagoon. The largest is Lake Tecumseh, formerly called Salt Pond, Redwing Lake, formerly called Fresh Pond, and Lake Christine.

Lake Rudee and Lake Wesley, on the other hand, comprise the small estuary of Owl's Creek and are not associated with the former lagoon. Rudee Inlet, through which Owl's Creek drains to the Ocean, is functionally a small river mouth, as distinguished from the tidal inlets which are essential features of the lagoon-barrier beach complex extending southward through the Carolinas.

Lake Tecumseh is the receiving body for the effluent from a sewage treatment plant at FAAWTC, Dam Neck. Redwing Lake does not receive any treatment plant effluent, nor does Lake Christine. Effluents from Camp Pendleton are discharged in emergencies into Lake Rudee, or more properly, into the Southern Fork of Owl's Creek.

The configuration of these lakes and the military reservations creates an important group of location factors including the necessity to provide adequate control of water levels in them to avoid flooding on the one hand and excessive drawdown on the other; and the necessity to avert the development of excessive small boat traffic in these lakes abutting the military reservations.

Highways affecting the location of the various routes studied are shown on the accompanying drawings.

Gow type borings have been made at selected locations of the proposed routes. Logs of these borings are shown on Plate IV.

Anticipated construction costs have not been a controlling factor in route determination. In this connection consideration will have to be given eventually to the character of the material which will be excavated not only as an element of construction cost but because any substantial quantities of granular material will have collateral value as building material or beach nourishment material depending on their location.

Detailed studies and estimates of right-of-way costs were not included. In each of the several locations, however, careful consideration was given to the agricultural soil classifications prevailing along the way. It will be found in this locality that the closest correlation exists between the U. S. Department of Agriculture soil types and the agricultural value of land, and further, that the same close correlation exists between the agricultural values and the highest and best land use concepts associated with development

planning programs. In short, in this locality, the lands having the highest elevations have the highest values and are best suited for contemporary uses. Potential damage to or proposed acquisition of such lands has been avoided wherever possible.

Portions of the routes studied transverse the southeast approach zone of the U. S. Naval Air Base at Oceana, but this circumstance is not seen as a factor affecting location.

The waterway locations delineated in this report are described briefly as follows:

Route A

Beginning at North Bay, thence following Hell Point Creek, Ashville Bridge Creek, by-passing Lake Tecumseh to the southwest; thence along Scopus Marsh Creek; thence by land cut in a northerly direction to Malbon Swamp; thence along Malbon Swamp, by-passing Redwing Lake to the west; thence by land cut in a northwesterly direction to Owl's Creek, passing west of the Commonwealth of Virginia Military Reservation (Camp Pendleton) to Lake Rudee.

Alternate Route A

Same as Route A, except by land cut from Scopus Marsh Creek in a northerly direction to the by-passing of the west shore of Redwing Lake. This route is to the east of Route A.

Route B

Beginning at North Bay, thence following Hell Point Creek, Ashville

Bridge Creek; thence along the west shore of Lake Tecumseh and passing to the west of the United States Fleet Anti-Air Warfare Training Center, Dam Neck Military Reservation to the south shore of Redwing Lake; thence in a northerly direction across Redwing Lake and passing through the properties of the United States Fleet Anti-Air Warfare Training Center and Naval Amphibious Base (Lovett's Marsh) to the south shore of Lake Christine; thence in a northwesterly direction through Lake Christine; thence by land cut to Lake Wesley.

Route C.

Beginning at North Bay, thence following Hell Point Creek, Ashville Bridge Creek; thence along the west shore of Lake Tecumseh and passing to the west of the United States Fleet Anti-Air Warfare Training Center, Dam Neck Military Reservation to the south shore of Redwing Lake; thence in a westerly direction along the south shore of Redwing Lake; thence following the same route as Route A to Lake Rudee.

SECTION 4. TIDES

In addition to all the definitive criteria which can be adduced to guide the planning of a waterway whose intended functions have been described, one matter is of paramount importance. This is the possible total effect of altering, by calculated measures, the tidal regimen which has prevailed in the state of nature and which has largely controlled the land forms and the social and economic development as well as the plant and animal ecology in this coastal environment.

There have, of course, been many radical changes in tidal circulation in the waters involved, but these have been associated with natural disturbances such as the breaching of the barrier beaches in severe storms. While the gradual evolution of drainage improvements in the past has undoubtedly had its effect, it appears that the construction, maintenance and modification of the Chesapeake and Albemarle Canal have been the calculated measures which have had the most profound effects on Back Bay and the connected water bodies. These effects have been debated for forty years or more and divergent views of them are still to be found.

Every effort has been made in this study to provide the means to evaluate the likely results of the contemplated alteration of the tidal regimen. It cannot be asserted, however, that deviations from anticipated effects will not occur and that their consequences may not be damaging.

This being the case, it will devolve upon the governing body to make the final judgement, in practical terms, between undoubted risk of altering existing conditions and the undoubted benefits which will result.

In a contemplated waterway connecting Back Bay and the Atlantic Ocean through Rudee Inlet, astronomic tides by themselves are not of sufficient magnitude to induce an excessive hydraulic gradient in either direction. Back Bay as a detached body does not have its own measurable astronomic tide. Fluctuations in its level are associated with ocean tides propagated through the Sound System and with rainfall and wind. Recorded variations in surface level in Back Bay are summarized on Plate III. The lowest level in the period of record as shown is 2.7 feet below Mean Sea Level occurring in March, 1962. The highest is 2.3 feet above Mean Sea Level occurring in September, 1964. A low water level of - 1.0 MSL has been exceeded five times in the 4.7 year period of record. A high water level of + 2.0 MSL has been exceeded twice in the same period.

Tide levels in the Ocean at Virginia Beach, (Rudee Inlet), as shown on Plate III, fall within the limits of + 6.7 and - 4.1 MSL, during a 4.7 year period of record. Other records indicate a rise to + 7.4 MSL. The normal range of astronomic tides is from + 1.7 to - 1.7 MSL. The radically higher and lower tides shown are associated with winds. Plate III shows in addition to the variations in inferred high and low tide levels at Rudee Inlet and the changes in water level in Back Bay, the wind conditions with which all these are associated. The tides at Rudee Inlet are inferred from

the daily records of the U.S.C. and G.S. tide gauge at Sewells Point in Hampton Roads. While the astronomic tides at Virginia Beach are related to those at Sewells Point by a predictable relationship to which numerical values are assigned, the wind tides are not and many anomalous variations will be found. The fact is, however, that when the highest tides occur in the Ocean at Rudee Inlet, the highest generally occur also at Sewells Point. There is reason to believe that the stillwater rise in these extreme high tides at Rudee Inlet is probably a little greater than it is at Sewells Point. No recording tide gauge has been maintained continuously along the Ocean front anywhere near Virginia Beach for long periods of time. Sporadic data are available but these do not generally reflect extremes of wind conditions and tidal surge because such tide gauges as had been installed were carried away under such conditions. Analysis of all available data on the Ash Wednesday Storm of March 6-7, 1962 suggests a possible rise at Virginia Beach to about 7.7 feet above MSL but this cannot be verified by direct gauge reading. The maximum tide of record at Sewells Point was at 8.0 feet above MSL on August 23, 1933. No record is known of the tide at Virginia Beach on that occasion.

Consideration of the frequency of these extreme high tides and analysis of the mechanics of tidal surges suggests that a high tide at Virginia Beach at Elevation 6.0 feet above Mean Sea Level might be expected to occur at somewhat, but not precisely, the same frequency as that assumed for the design rainfall.

SECTION 5. THE PROJECT AND ITS EFFECTS

The contemplated water way, whose location, dimensions and arrangement were established in consideration of all of the matters heretofore discussed, and whose effects are to be discussed, is that planned to follow Route A, as shown on the drawings accompanying this report. This waterway is referred to interchangeably as a canal. The effects of a waterway along any of the other locations can readily be related to those of Route A.

A. Tidal regimen of canal

Route A was analyzed in detail. It appears that Route B will not be acceptable because of objections by the Defense Department and the Commonwealth of Virginia. Route C and Alternate Route A are variations of Route A. The flows in this water way will vary during normal fresh water inflows from slack water to a maximum in the southward direction to slack water to a maximum in the northward direction and finally back to slack water before southward flow. The durations of flows in the alternating directions and their magnitudes will be a function of the varying elevations of the ocean and of North Bay. North Bay does not have a measurable astronomic tide at present because of the great distance of this portion of the lagoon system tributary to Oregon Inlet from that inlet. Its level is subject to fluctuations due to meteorological factors. Available records show the weekly extremes of North Bay which are tabulated below:

Year	High Extremes	Low Extremes	Mean of Extremes
1962	+ 1.09 MSL	+ 0.46 MSL	+ 0.78 MSL
1963	+ 0.77	+ 0.18	+ 0.48
1964	+ 1.07	+ 0.28	+ 0.68
1965	+ 1.06	+ 0.41	+ 0.74
Averages	(+ 1.00)	(+ 0.33)	(+ 0.67)

The mean range of tide at Rudee Inlet (Virginia Beach, Outer Coast) according to the U. S. Coast and Geodetic Survey is 3.4 feet. MHW is approximately at + 1.7 MSL and MLW is approximately at - 1.7 MLW.

If the geometry of the proposed canal is such as to affect the levels of North Bay as a result of the transmission of the tidal prism, the regimen of the canal will be dependent on the tide in the ocean and the derived tide in North Bay. The relationship between the derived tide in North Bay and the tidal prism, assuming that the tide in North Bay rises and falls simultaneously throughout the Bay, is expressed by the following:

$$\frac{Q}{a} = h$$

where Q is the tidal prism in cubic feet
a is the mean surface area of the Bay
h is the range of tide in the Bay

North Bay and Shipps Bay are virtually one continuous body of water having a surface area of 185,000,000 square feet. In fact, Shipps Bay in turn is connected via a number of passes to the immense lagoon system to the south, but as a preliminary step to the analysis it is assumed that North Bay-Shipps Bay is an independent body.

In a canal of the length involved here, which is small relative to the wave length of the tide propagating therein, it is not necessary to undertake the very involved methods of analyses that are based on harmonics; a

steady-state analysis will suffice. The tide graph in the ocean at Rudee Inlet was derived, an average difference of elevation between a fixed water surface in North Bay and in the ocean during inflow and outflow was derived. It was ascertained, taking North Bay at + 0.67 ft. MSL, that the average difference of elevation during inflow to North Bay was 0.65 ft. and the corresponding difference of elevation during outflow would be 1.47 ft. Assuming Manning's "n" as 0.025, the average discharge during inflow is 547 cfs and the average discharge during outllow from North Bay is 668 cfs. The duration of inflow would be 4.6 hours, and the total volume of inflow is then 4.6 x 3600 x 547 cfs = 9,070,000 cf. Similarly, the duration of outflow is 7.8 hours, making the total volume of outflow from North Bay = 7.8 x 3600 x 668 cfs = 18,750,000 cf.

Thus, the effect of 9,070,000 cf inflow to North Bay via the Route A canal would raise the elevation of North Bay-Shipps Bay

$$\frac{9,070,000}{185,000,000} = +0.05 \text{ ft.}$$

and the volume of outflow would lower the surface

$$\frac{18,750,000}{185,000,000} = -0.10 \text{ ft.}$$ from that at the end of the inflow, for a net lowering during one tide cycle of 0.05 ft. As pointed out before, North Bay-Shipps Bay is not an isolated entity; it connects freely with a very large lagoon system to the south and it is a certainty that the tidal prism transmitted to and from the lagoons via the proposed canal would have no appreciable effect on water surface elevations in these lagoons,

including the portion of North Bay at the end of the proposed canal.

The average velocity of the inflow corresponding to a mean range of tide at Rudee Inlet would be 0.73 fps and that of the outflow, 1.03 fps. These values are based on the elevation of North Bay = +0.67 MSL. Higher elevations in North Bay will reduce the velocity of the inflowing current and increase the velocity of the outflowing current, but not to such extent as to consititute a navigational difficulty. The velocities in the Route B canal will be somewhat greater than those computed for the Route A canal, but the differences are not of significance to boat operators. In short, any one of the routes studied is feasible from a navigational standpoint.

Materially different effects are seen when the assumptions as to rainfall and tides described in Sections 2 and 4 are applied instead of those mentioned in the foregoing.

It was considered, for the reasons mentioned in Section 4, that the ocean stage to be assumed should be +6.0 MSL although it is clear that the March 1962 maximum stage was about +7.7 MSL at Virginia Beach, according to Corps of Engineers data. This decision was made because the March 1962 storm is so rare an event. Low water -1.0 MSL was assumed for North Bay because this seemed likely to be an accompaniment of +6.0 MSL in the ocean.

Corps of Engineers data on the predicted and observed stages at Fort Norfolk were studied to ascertain the effects of the surge on the astronomic tidal fluctuations. Relationships were found between the rates of rise and fall of the surge and the astronomic tides; a rising surge increases the

amount of tidal rise as a function of the rate of rise of the surge, and a rising surge decreases the amount of tidal fall, again as a function of the rate of rise. Similar relationships were determined when the surge is falling. It was assumed that a mean astronomic tidal range of 3.4 feet would prevail during a surge that culminated at the time of high tide. The peak elevation of the surge at that time would be:

$$+6.0 \text{ MSL} - \frac{3.4}{2} = +4.3 \text{ MSL}$$

Using the relationships determined between the rate of rise of the surge and the astronomic tidal rise, it was determined that the rise which culminated in a peak elevation of the combined tide and surge of +6.0 MSL began at elevation +2.3 MSL, and coincidentally the ensuing fall terminated at +2.3 MSL also. The tidal period of 12.42 hours appears to be valid for the rise from +2.3 MSL through +6.0 MSL and back to +2.3 MSL according to the record of the March 1962 storm. The assumption made in the studies described above that the analysis could be made on the basis of a steady state condition is equally valid here. On this basis, a preliminary estimate was made of the maximum discharge during the +2.3, +6.0 +2.3 MSL tidal cycle with -1.0 MSL in North Bay of 2350 cfs. The mean discharge during the tidal cycle was also computed as 1720 cfs. The 1720 cfs flow for 12.42 hours would raise the level of Shipps Bay-North Bay 0.4 feet assuming no flow to the lagoons to the south of Shipps Bay. It is virtually certain that there would be a flow to these lagoons, and that it probably would be equal

to the inflow from the proposed canal, thus -1.0 MSL is assumed to be the constant level in North Bay. New backwater curves were then computed backwards from the Ocean towards North Bay and it was found that both of these ended at -1.0 MSL at North Bay, thereby confirming the values determined in the initial investigation. The following table summarizes the results.

Station	Maximum Stage MSL	Maximum Velocity fps	Average Stage MSL	Average Velocity fps
Ocean	+6.00	1.65	+4.15	1.41
521+00	+5.04	1.85	+3.78	1.53
421+00	+4.98	1.93	+3.40	1.67
321+00	+4.40	2.12	+2.92	1.82
204+00	+3.50	2.44	+2.20	2.15
104+00	+2.00	3.04	+1.13	2.50
54+00	+0.75	3.70	+0.32	2.89
North Bay	-1.00	5.10	-1.00	3.74
Averages		2.73		2.21

The maximum elevations in the canal adjacent to Lake Tecumseh and Redwing Lake corresponding to +6.00 MSL in the ocean and -1.0 MSL in North Bay would be +3.7 and +4.8 MSL respectively. The average elevations would be +2.3 and +3.4 MSL respectively.

B. Salinity.

It is not to be concluded that the effects of the proposed canal on the salinity in North Bay-Shipps Bay will be negligible, from the findings above stated as to the effects of the canals' tidal prisms on water surface elevations. Because of the great difference between the salinities of the ocean and North Bay, there will be a density flow towards the Bay. The ocean salinity is

assumed to be 35.01 ppt (parts per thousand). The salinity information pertaining to North Bay and four of the bays to the south for a period of years is tabulated below:

Years	North Bay Salinity ppt	Shipps Bay Salinity ppt	Redhead Bay Salinity ppt	Sand Bay Salinity ppt	Back Bay Salinity ppt	Source
1925-33	-	-	-	-	3.33	(1)
1952	0.81	-	-	-	1.05	(2)
1953	0.59	-	-	-	1.00	(2)
1954	0.73	-	-	-	0.98	(2)
1955	0.81	-	-	-	1.96	(2)
1965-66	3.21	3.26	2.23	2.71	2.05	(3)

Key to sources of above information:
(1) Virginia Game Preservation Commission
(2) U. S. Army Engineer District, Norfolk
(3) City of Virginia Beach, Virginia

The large increase in salinity of North Bay in 1965-66 as compared to 1955 may be due in part to the drought that prevailed in the later period, but it is probable that the salt water pumping plant that was placed in operation in May 1965 for the transfer of ocean water to Shipps Bay was the chief cause of the difference. It is to be noted that the salinity in Back Bay in 1965-66 was only slightly higher than that in 1955. The meteorology of Back Bay area is similar to that of North Bay area. The average of the four years 1952-55 is 0.72 ppt, and this is taken as the salinity of North Bay without the pumping plant.

The regimen of a canal connecting North Bay with the ocean at Rudee Inlet, with North Bay having a salinity of 0.72 ppt, would be similar to that of an estuary. The net discharge from North Bay towards the ocean during

a tide cycle is analagous to the upland discharge into an estuary. The difference between 18,750,000 cf outflow and 9,070,000 of cf inflow is 9,680,000 cf and this is the net outflow in 12.42 hours (the length of a tidal cycle). The average rate is

$$\frac{9,680,000 \text{ cf}}{12.42 \times 3600} = 216 \text{ cfs.}$$

The relationship between the total fresh water discharge per tidal cycle and the tide prism in this case is such as to indicate that a stratified salinity regimen will exist in the canal. The line of the interface will be at its highest elevation at the ocean end of the canal, thence it will become lower in elevation as North Bay is approached. The flow below the interface will be salt water of salinity approaching that of the ocean, and the direction of flow always will be towards North Bay. The water above the interface will be fresh and the direction of flow will reverse in consonance with the tides. The length of the salinity "wedge" may be determined by the equation derived by Keulegan (Eq. 11.10. "Estuary and Coastline Hydrodynamics, 1966" edited by A. T. Ippen):

$$\frac{L_o}{H} = 6\left(\frac{V_\Delta \cdot H}{\nu}\right)^{1/4}\left(\frac{2\ V_r}{V_\Delta}\right)^{-5/2}$$

where L_o is the length of the wedge in feet
H is the mean depth in feet at MSL
V_Δ is the densimetric velocity in feet per second
ν is the kinematic viscosity in lb-sec^2/ft^4
V_r is the average velocity of flow just upstream of the wedge

$$V_\Delta = \sqrt{\frac{\Delta e}{e_m} gH}$$

where Δe is the difference between the densities of fresh water and sea water

e_m is the average of the densities of fresh water and sea water

g is the acceleration due to gravity

H is the mean depth in feet at MSL

Taking 20°C (68°F) as the temperature of the water:

e	at salinity 0.72 ppt	=	0.99879
$\Delta e + e$	at salinity 35.01	=	1.02480
	Δe	=	0.02601
	and e_m	=	1.01180

$$V_\Delta = \sqrt{\frac{0.02601 \times 32.2 \times 8.98}{1.1180}} = 2.72$$

The value of ν at 68°F is 0.000011.

Inserting these values in the equation as shown on page 22, and taking $H = 8.98$.

$$L_o = 8.98 \times 6.0 \left(\frac{2.72 \times 8.98}{0.000011}\right)^{1/4} \left(\frac{2 \times 0.308}{2.72}\right)^{-5/2}$$

$$= 86,000 \text{ ft.}$$

As the length of the canal is 62,000 feet, the above computation shows that there will be a salt water-fresh water interface throughout the length of the canal. Its elevation at the ocean end of the canal is determined as follows:

$$\frac{h_{sl}}{H} = 1 - 0.628 \left(\frac{2\ V_r}{V_\Delta}\right)^{2/3}$$ according to Keulegan equation 11.16 (from the above reference)

where h_{sl} is the height of the salinity wedge above the bottom at the mouth

H
V_r are as defined above
V

$$\frac{h_{sl}}{H} = 1 - 0.628 \left(\frac{2 \times 0.308}{2.72}\right)^{2/3} = 0.767$$

Keulegan offers experimental values of h_{sl}/H for various values of $2V_r/V_\Delta$. From the table in the same reference, h_{sl}/H for $2V_r/V_\Delta = 0.226$ is 0.703.

Taking the average of 0.767 and 0.703 = 0.735, and applying this to the depth at the entrance at MSL = 9.70 ft., the height of the salinity wedge is

$$9.70 \times 0.735 = 7.12 \text{ ft. above the bottom.}$$

With this as the starting point, and remembering that the length of the wedge is 86,000 feet, it can be shown that the height of the wedge at the North Bay end of the canal is 1.98 feet.

The average velocity of the flow below the interface is computed below, using equation 26.9 page 26-5 Street Handbook of Fluid Dynamics.

$$\bar{u} = \sqrt{\frac{8\, g'\, h_2\, s}{f\, (1 + a)}}$$

where $\bar{u}$ is the average velocity of the current below the interface

$g' = g \dfrac{\Delta e}{e}$

f = D'Arcy friction factor = 0.033 corresponding to Mannings "n" = 0.025 = a factor taken as 0.43

h_2 = The height of the wedge at the North Bay end

s = Slope of the bottom of the canal.

Evaluation of the above equation using the proper figures results in the finding that the average velocity of the current in the wedge is 0.103 fps. The area of the portion of the canal below the wedge at the North Bay end of the canal is 253 sq. ft., and the discharge of salt water into North Bay is then 253 sq. ft. x 0.103 fps. = 26 cfs. It now remains to determine the effects of a constant discharge of 26 cfs, into North Bay on the salinity of that body of water.

Data on the volumes of sea water pumped into Shipps Bay-North Bay per month and the corresponding average salinities in these bays were available for analysis. At first, the pumping rate was of the order of 500 to 700 x 10^6 gallons per month, but later the rate was reduced to about 400 x 10^6 and finally to about 250 x 10^6 gallons per month. The salinity of North Bay-Shipps Bay increased steadily to a maximum then it decreased somewhat in accordance with the decreased pumpage. The salinity in North Bay-Shipps Bay is a function of the fresh water inflow, the volume of sea water introduced by the pumping plant, outflow of the waters of North Bay-Shipps Bay to the lagoons to the south, and evaporation. This is a very complicated regimen, but an approximation of the effects of the pumping plant on salinity can be made as follows: It is noted that the salinity in North Bay-Shipps Bay tended to stabilize for appreciable periods during two different pumping rates. These are tabulated below:

Av. Pumpage Rate GPMo.	cfs	Salinity as % of ocean salinity
0.394 x 10^9	20.3	11.83
0.250 x 10^9	12.9	7.85
0	0	0.21

This table indicates that if the pumpage rate of water of ocean salinity is maintained at one of the rates indicated, the inflow of salt water will balance the inflow of fresh water, evaporation, and the outflow of water from North Bay-Shipps Bay. By extrapolation, it may be concluded that the 26 cfs inflow from

the canal, computed above, will raise the salinity of North Bay-Shipps Bay to approximately 15% of that of sea water which is above the optimum of 10%. If marine biologists in fact find it difficult to accept a salinity in North Bay-Shipps Bay of 15% of that of sea water, then it will be necessary to construct a salinity barrier in the canal. This may consist of a lock or gate or a bubble curtain. The lock plan is well-recognized as being entirely practical though costly. The bubble curtain plan has been used in Holland. These are discussed more fully later in this section.

Increased salinity is desirable in North Bay-Shipps Bay area. The artificial introduction of sea-water by pumping from the ocean and its associated expense could be discontinued if a direct connection with Rudee Inlet were effected. Average salinity readings, Secchi disk readings and amount of sea water pumped is delineated on Appendix I. Individual salinity and Secchi disk station readings are given in Appendix II.

C. Turbidity

There will be no tidal flow in the canal during excavation until it is completed. According to the computations of current velocities in the canals during normal fresh water inflow conditions, it is unlikely that an appreciable volume of sediment will be transported to North Bay; the velocities of flow are too low to keep any but the finest fractions in transport. However, the canal will intercept and discharge large quantities of rainfall runoff, and it is usual that these inflows will carry sediment to the canal. The question to be resolved is whether the flow during high rainfall runoffs will be towards North Bay.

An assumption was made that all flow would be towards the ocean for a trial analysis. The inflow rate was first computed corresponding to a 10-year rainfall and runoff coefficients varying from 0.5 to 0.9 depending on the nature of the expected development of the tributary area of 10,500 acres. Calculations are based upon full development of the watershed. The value derived was 8,818 cfs as the peak rate of discharge. It was noted that the inflow could be apportioned along the length of the canal as a uniform variation without introducing appreciable error, and this was done in the backwater computation made for the trial analysis. It was quickly perceived that the elevation of water surface in the canal increased beyond that of North Bay, and it was concluded that a more reasonable assumption would be to divide the total inflow into two equal parts and compute backwater curves from each end towards the middle, using again a uniform reduction of the quantities as the mid point is approached. The backwater computations, using Mannings "n" as 0.025, from the two ends towards the middle resulted in substantially the same elevation of water surface at the mid point of the canal, namely +6.0 MSL. This assumption is considered to be reasonable, and it is concluded that the 10-year rainfall will cause a peak discharge into North Bay of about 4,571 cfs. A condition could arise when the entire Back Bay watershed contributing storm runoff to the canal under full development criteria would flow toward North Bay. This condition would be brought about by a hurricane with heavy rainfall. A tide gate would be closed to prevent tidal flooding to the south thus preventing any storm runoff to

Rudee Inlet. This would cause a peak discharge into North Bay of 7,656 cfs. The proposed cross section of the canal would have to be enlarged to prevent flooding of the low areas. Lesser rainfalls will produce smaller peak discharge, but it is likely that all but very light rains will cause flows into North Bay. Without doubt, North Bay will shoal adjacent to the end of the canal, and the turbidity of North Bay-Shipps Bay may be adversely affected by the proposed canal during times of large rainfalls. The drainage area tributary to North Bay will be decreased by the construction of the canal predicated upon the average water surface elevations in Lake Rudee and North Bay. The opportunities for settlement of suspended solids before transport to North Bay may be increased. Insufficient data are available to make a quantitative estimate of the average annual volume of sediment to be transported to North Bay by the proposed canal.

The absence of grass in North Bay is largely due to colloidal particles being suspended in the waters of the Bay thus preventing the penetration of sunlight to the bottom. Introduction of sea water to provide a 10% - 12% salinity has been proven as an aid in the settling to the bottom of these particles. However, until such time as the particles become a permanent part of the bottom, any wind of 15 miles per hour or more brings about wavelets which in turn cause the water to roil and the particles become suspended once more. Large amounts of colloidal particles were introduced into North Bay when a private developer commenced a hydraulic dredging project. Later this was much improved when a dike was constructed

entirely around the project in such a manner that the dredge used and re-used the same water in its operation. It is desirable to utilize a clamshell or drag-line type of construction equipment for excavation, where feasible. Where a hydraulic dredge is utilized, it is necessary to close direct water access to North Bay temporarily, and make provision for storm runoff without upland flooding.

Consideration has been given to the desirability of providing a sedimentation basin at the confluence of the canal and North Bay. To be effective, it was calculated to require the dredging of some 40 acres, 20 feet deep. However, it was concluded that the amount of colloidal particles placed in suspension by the dredging operation would exceed the latter benefits.

D. Tide Gates.

Current velocities in the proposed canal corresponding to normal conditions will not be a problem to navigation. During extraordinary rainfalls, the velocity of flow will be such that navigation may be difficult, but these events are so rare as to be of little practical consequence. In any event, it is impracticable to control these flows by means of "tide gates" because the structure would tend to void the beneficial effects of the canal as a drainage facility. Consequently, tide gates are not required to control current velocities due to storm runoff.

It will be necessary to place a barrier in the canal somewhere between South Birdneck Road and General Booth Boulevard. The barrier may be in the form of an operable tide gate or gates of a size equal to the

cross-sectional area of the canal. Upon the occurrance of a hurricane tide of +6.0 in Lake Rudee, it has been calculated that the level of water in the canal at Redwing Lake would be +4.8, and at Lake Tecumseh +3.7. Obviously, flooding would occur and damage could result. This condition could be brought about by the permitting of water from one watershed to enter into another watershed. To avoid the liability, the tide gates would be closed when the tide level in Lake Rudee reached +3.5. The closing mechanism could be automatically operated by electric motors, float actuated or by manually operated doors actuated by an alarm system telegraphed to the nearest police or fire station.

E. Salinity Barrier

Details of bubble curtains used in Holland are not available, but they are understood to consist of a number of pipes placed normal to the canal on the bottom, containing holes through which air is pumped. It is not known how much air is required to create sufficient turbulence to break up the salinity wedge which would be expected to exist in the proposed canal under normal conditions of fresh water discharge. Although there has been considerable thought given to this method of preventing salinity intrusions in estuaries, or more likely, minimizing their extent, so far as is known full scale tests have not been made in the United States. It is conceivable that a bubble curtain could be used in conjunction with a tide gate such that the tide gate could be left in an open position and the curtain made operable in the event of a high salinity condition occurring in North Bay.

F. Sluiceway in Lake Tecumseh

It would appear that construction of the Route Alternate A or C canals would deprive Lake Tecumseh of most of its supply of water and there is little doubt that this will result in stagnation. It would be desirable to provide a sluiceway in the canal adjacent to the lake for the purpose of permitting a flow into the lake of such magnitude as to assure good water quality. This would doubtless be a variable quantity depending on rainfall and evaporation. The area of Lake Tecumseh is 11,500,000 sq. ft. If it is found to be desirable to raise the level of the lake by one foot in 24 hours, the average rate of inflow must be 132 cfs. A sharp crested weir about 22 feet in length would discharge this quantity of water under a head of 1.5 feet. No reason is seen to make the sluice larger than this.

An adjustable planked sluiceway should be constructed in Lake Tecumseh. There would be times when no flow to Lake Tecumseh would be required and others when the desirable flow might be less than the maximum competence for a 1.5 foot head. It is also possible that it might be desirable to permit a flow from the Lake into the canal, which could be accomplished when the canal is at a lower level than the Lake. The sluice should be so constructed that the of the top of the gate in its lowest position is at approximately MSL. The elevation of the top of the gate in its highest position should be that computed for this location by means of a backwater analysis using the 10-year rainfall. This elevation should be set at approximately +2.0. Redwing Lake could be handled in a similar manner.

G. Pollution in Lake Tecumseh

Consideration has been given to the existence of a sewage treatment plant located in Lake Tecumseh and operated by the U. S. Navy. The plant was designed for an equivalent population of 3,000 persons at a flow rate of 300,000 GPD, providing primary and secondary treatment with BOD reduction of 85% and with a chlorinated effluent. The plant was originally designed and constructed in 1952 with a capacity of 150,000 GPD. It was expanded in 1963 to the present 300,000 GPD capacity. The present flow into the plant is approximately 250,000 GPD and is in operator-attendance continuously. A Chlorine residual of at least 2.0 PPM is maintained in the effluent. Water samples were taken at three locations shown on the plan sheets and as tabulated in Appendix III. Tests made on the treated sewage effluent shows a Bio-Chemical Oxygen Demand (BOD) of 24 ppm. This is considered a satisfactory test. The other water samples taken in Redwing Lake, Ashville Bridge on Sand Bridge Road and Lake Tecumseh also are satisfactory. Under the present operating conditions of the sewage treatment plant there is no danger in the pollution of North Bay.

H. Security of Naval Station

The future security of the Fleet Anti-Air Warfare Training Center (FAAWTC, Dam Neck) was considered. Since the proposed canal would lie outside the present boundaries of the Station and no direct connection would exist between the canal and Lake Tecumseh or Redwing Lake, it was concluded that security of the Center would not be affected.

I. Continuance of Salt Water Pumping Station

If a canal is constructed between North Bay and Rudee Inlet with a bottom width of 60 feet and a depth of 8.0 feet referred to local mean low water, there will be no need for continuing operation of the salt water pumping station.

J. Planes of Local Mean High and Low Water in the Canal

Mean high water will vary uniformly from +1.7 MSL at Rudee Inlet to +0.67 at the North Bay end of the canal; mean low water will also vary uniformly from -1.7 MSL at Rudee Inlet to +0.67 at the North Bay end. The bottom elevation of a canal 8 foot deep referred to local mean low water will vary uniformily from an elevation of -9.7 MSL at the ocean to -7.33 MSL at the North Bay end.

K. Change in City Ordinance

The present City Code of Virginia Beach, Section 6-41, states, in part, that the Dredge Commission may not operate within the present boundaries of the Rudee Inlet Authority or the Virginia Beach Erosion Commission. If it is desired to utilize the hydraulic dredge operated by the Virginia Beach Dredge Commission North of South Birdneck Road, it will be necessary to change the wording of Section 6-41.

L. Corps of Engineers Permit

The present permit issued December 22, 1965, to construct a canal from North Bay northwardly follows a route through Lake Tecumseh and Redwing Lake and it does not include a connection of salt water with fresh water. A revised permit should be requested.

SECTION 6. CONCLUSIONS

The results of the analyses presented in the report in connection with tidal exchanges, salinity and other phenomena can be expected to be verified by observation only when observed conditions satisfy the assumptions made for the analyses. Such assumptions are within the range of natural conditions which will occur at times, but the frequency of occurrence cannot be predicted.

A waterway designed to serve the threefold purpose of improving drainage and providing for future drainage needs, of permitting the operation of small craft throughout its length and of providing a means of regulating water quality in Back Bay will be a complex facility. Its operation will likewise be complex.

From the analysis presented in Section 4, it is seen that the largest volumes of water introduced into Back Bay as a consequence of the contemplated waterway project are likely to be either sea water from extremely high ocean tides or an even larger mixed volume of sea water and storm runoff occurring when an extremely high wind tide coincides with heavy precipitation. In either case, the intrusion of sea water into the Back Bay water body by a course which was not open to it in the natural state will be a major element of the consequences of that project.

In Virginia, it is understood that the judicial principle prevails that surface water is the "common enemy", and may be defended against by land owners by any means, provided damage to others does not ensue.

The right to defense does not permit that drainage or surface water be collected by an owner and discharged on the property of another which had not hitherto been affected by it. In short, diversion of surface water from one watershed to another would not be easily defensible within the meaning of the judicial principle, in any instance where damage occurs.

By the extension of the principle to actions by a political jurisdiction it would be inferred that a municipality does not have the right to make drainage improvements which serve the public interest in one watershed but which could damage or impair the public interest in another watershed In such a case, if adequate and assured measures could be provided to guard against such possible damage, then the right to make improvements could undoubtedly be shown.

In this case, the nature of the public interest involved is complex. It includes the common law rights of property owners to defend against surface water; the right and duty of the municipality to facilitate such defense; the right of other property owners to be protected against the effects of drainage diversion and the municipality's duty in that connection. the property rights as well as the more eminent rights of the United States in connection with the two Naval facilities which could be affected, the rights of the Commonwealth in connection with its military establishment at Camp Pendleton, and of its people in the preservation and utilization of the wild-life resources of the area, to say nothing of a number of other rights which may spring from the statutory powers of cognizant regulatory agencies

of the City, State, and Federal Governments.

Every effort has been made in this work to utilize the best knowledge available in evaluating the possible effects of the contemplated waterway. However, since the fundamental question is one whose answer turns on conditions of tide and rainfall about whose magnitude only assumptions can be made on the basis of records which are in some respects inadequate and about whose frequency even less certain assumptions can be made, such an evaluation must be stated with appropriate reservations.

Moreover, the state of technical knowledge of the phenomena involved is such at the present time that, even with the most complete data, an unqualified opinion would scarcely be justified.

The contemplated waterway, as has been stated, would be constructed in a single program which would include the excavation of the canal and the construction of whatever accessory facilities were necessary to provide adequate control A fundamental conclusion reached in these studies is that, unless full control of the intrusion of tidal waters into the Back Bay watershed through the waterway can be maintained, some segment or segments of the public interest would be adversely affected at some time and under some conditions. Such adverse effects might include excessive alteration of the salinity level of Back Bay; excessive alteration of water level and water quality in Lake Tecumseh and Redwing Lake; backwater flooding of private property along the canal route, and others which may be inferred from the substance of the Report.

The single program concept, based on the three functional purposes of improved drainage, small boat passage and changed salinity in Back Bay may involve the introduction on a large scale of either fresh or salt water from one watershed and drainage system into another watershed and drainage system. It appears that a large scale alteration may have important legal aspects.

On the other hand, it appears that improvement of drainage to accommodate contemporary and future development is not only permitted, but is mandatory for a municipality. As a practical matter, it does not appear that any objection to a watershed drainage project could be sustained under the Virginia legal principle even though part of the water volume were placed in another watershed, damage therefrom notwithstanding, provided reasonable precaution is taken to guard against such damage. In order to accommodate the computed surface runoff in the Back Bay watershed under the full development criteria, without diverting half of the volume into Owl's Creek, the proposed cross-sectional area of the canal in the Southern section would have to be enlarged in order to prevent flooding to a high level.

It is apparent that the introduction of salt water into the canal system will have to be controlled. It is also apparent that drainage structures will be necessary to maintain a reasonable lake level in the two affected lakes.

In addition to the cost of the excavation of the Canal, other items of construction cost that would be encountered include:

(a) clearing of timber within the Canal proper and the disposal areas,

(b) rights of way and disposal areas,

(c) construction of cul-de-sacs at highway terminations and new road connections at certain locations,

(d) structures for drainage and small boat passage,

(e) construction of a minimum of three multi-box culverts or medium level bridges at highway locations. A medium level bridge in this instance would be considered as having a vertical clearance of 16 feet at mean high water.

SECTION 7. RECOMMENDATIONS

In view of the conclusions reached as to the feasibility of the contemplated waterway, when considered in its threefold function the recommendations presented here are simple, but qualified in some respects.

1. It is recommended that if the benefits to be derived from improved drainage, the provision for small boat traffic and a method of artifically introducing salt water into Back Bay are sufficient to justify the cost, and in the absence of an unfavorable legal opinion, a drainage canal be designed and constructed along either Alternate Route A or Route C in accordance with the general plans which are included in this Report.

2. It is recommended that if the waterway is built controlled sluiceways be provided in connection with Lake Tecumseh and Redwing Lake, and a program for their operation be established.

3. It is recommended that provision be made for regular tide gage and salinity readings in selected locations in the waterway and in Back Bay, including North Bay and Shipps Bay.

4. It is recommended that a tide gate be provided in the waterway between South Birdneck Road and General Booth Boulevard. This would be closed under extreme high tidal conditions in Lake Rudee and might be closed at times when the salinity in Back Bay reached detrimental proportions. A program for the operation of this gate would have to be established.

5. It is recommended that a supplemental report be made after an investigation and study of existing bubble curtains and the most efficient and economical method of providing a tide gate.

AVERAGE SALINITY, SECCHI DISK
AND SEA WATER PUMPED

MONTH	STA. 6,8,9 NORTH BAY %SALINITY	SECCHI	STA. 1,5,7,10,11,12 SHIPPS BAY %SALINITY	SECCHI	STA. 2,13,14 RED HEAD BAY %SALINITY	SECCHI
May 1965	2.1	16"	2.2	14"	1.9	12"
June	4.7	19"	4.6	18"	2.7	20"
July	6.3	25"	7.0	27"	3.8	23"
Aug.	11.3	23"	11.3	25"	5.7	23"
Sept.	12.8	21"	13.1	21"	7.3	19"
Oct.	13.9	19"	13.2	22"	6.6	21"
Nov.	12.4	24"	11.9	24"	7.1	26"
Dec.	13.1	26"	12.5	26"	6.3	20"
Jan. 1966	NO REMARKS					
Feb.	9.3	16"	9.3	17"	7.7	16"
March	7.3	11"	8.7	16"	7.5	13"
April	10.4	14"	10.9	12"	8.2	13"
May	10.1	14"	10.5	13"	8.9	15"
June	8.4	27"	8.5	25"	7.2	20"
July	8.5	26"	8.3	22"	7.9	22"
Aug.	6.9	23"	7.3	25"	6.1	24"
Sept.	8.4	19"	8.6	19"	6.6	19"
Oct.	10.4	21"	10.3	20"	6.7	19"

(CONTINUED)
AVERAGE SALINITY, SECCHI DISK
AND SEA WATER PUMPED

MONTH	STA. 3,4,15,16,17,18 SAND BAY %SALINITY	SECCHI	STA. 19,20,21,22 BACK BAY %SALINITY	SECCHI	SEA WATER INTRODUCED INTO BACK BAY GALLONS	
May 1965	4.0	17 "	NO	READING	600,000,000	5/26-6/26
June	4.9	21 "	NO	READING	93,000,000	6/27-6/30
July	4.9	23 "	2.7	NO READING	537,000,000	
Aug.	7.0	24 "	3.4	25 "	662,750,000	
Sept.	8.8	21 "	4.0	21 "	570,750,000	
Oct.	9.1	22 "	5.0	21 "	233,000,000	
Nov.	9.0	26 "	5.3	28 "	377,500,000	
Dec.	9.6	28 "	6.5	27 "	436,000,000	
Jan. 1966	NO	REMARKS			241,000,000	
Feb.	8.5	21 "	7.7	16 "	179,000,000	
March	8.9	18 "	6.9	17 "	528,000,000	
April	10.6	12 "	7.5	14 "	237,000,000	
May	8.6	18 "	7.2	23 "	24,000,000	
June	7.4	25 "	7.2	29 "	300,000,000	
July	6.6	24 "	6.5	27 "		
Aug.	7.6	26 "	5.9	28 "	249,000,000	
Sept.	8.2	19 "	5.9	20 "	500,500,000	
Oct.	8.2	18 "	5.9	20 "	318,000,000	

	(1)		(2)		(3)		(4)		(5)	
DATE	SECCHI	% SALINITY	SECCHI	% SALINITY	SECCHI	% SALINITY	SECCHI	% SALINITY	SECCHI	% SALINITY
7/1/65	15"	7.8	21"	5.4	19"	2.8	18"	7.2	28"	9.0
7/6/65	29"	5.5	24"	3.8	24"	3.0	20"	2.9	20"	4.5
7/12/65	28"	5.5	30"	5.3	23"	2.3	23"	2.3	29"	6.2
7/19/65	28"	6.1	26"	5.7	23"	4.2	25"	3.4	33"	8.9
7/22/65	24"	7.9	23"	5.9	23"	4.3	23"	13.4	27"	10.8
7/29/65	26"	7.3	26"	5.5	23"	2.7	23"	2.5	26"	7.5
8/2/65	28"	8.1	23"	5.3	23"	3.0	24"	2.9	25"	11.4
8/6/65	25"	8.9	24"	6.5	28"	3.2	29"	6.7	31"	11.7
8/9/65	21"	9.3	20"	8.0	20"	2.5	21"	2.6	24"	8.3
8/13/65	24"	10.9	26"	8.9	21"	4.4	22"	5.7	25"	12.6
8/16/65	25"	12.5	23"	9.3	25"	9.6	28"	15.9	27"	12.6
8/23/65	28"	13.1	26"	11.4	26"	6.5	26"	6.3	30"	14.6
8/27/65	23"	10.9	21"	8.9	22"	4.5	24"	4.5	26"	13.0
8/30/65	19"	11.7	19"	7.4	22"	7.3	21"	12.1	22"	13.0
9/8/65	20"	12.3	20"	9.8	21"	6.7	25"	20.7	12"	15.2
9/16/65	23"	12.6	21"	10.8	20"	3.4	19"	3.3	19"	4.1
9/22/65	22"	12.9	24"	11.8	18"	4.2	24"	3.5	27"	12.4
9/30/65	19"	12.3	23"	11.7	25"	7.9	24"	19.8	20"	13.7
10/6/65			23"	5.4	19"	7.0	17"	16.0	22"	20.1
10/12/65			24"	7.4	23"	8.0			27"	12.9
10/15/65							30"	6.7		
10/22/65	18"	10.8	19"	8.1	20"	7.3	19"	10.3	16"	13.3
11/8/65	24"	11.7	22"	9.3	30"	7.1	21"	7.3	21"	9.3
11/19/65	16"	10.8	28"	6.9	24"	8.7	20"	14.8	17"	12.6
11/26/65	24"	10.6	33"	7.3	34"	7.9	30"	10.2	27"	13.7
12/11/65	22"	10.2	19"	6.9	26"	9.3	27"	9.8	30"	15.0
2/15/66		9.63		8.85		8.09		8.24		9.46
2/21/66	19"	8.54	16"	7.30	19"	8.70	24"	9.16	16"	7.92
3/2/66	13"	8.38	11"	7.30	15"	8.24	17"	9.01	16"	9.95
3/21/66	17"	8.24	18"	8.07	22"	8.70	19"	11.19	20"	10.58
4/4/66	10"	9.63	15"	9.16	11"	9.95	12"	11.80	15"	11.34
4/11/66		12.42		9.63		10.88		12.74		13.05
5/3/66	15"	10.41	13"	9.78	21"	7.92	19"	9.01	13"	10.41
6/7/66	27"	8.54	21"	7.76	23"	7.76	25"	7.76	29"	8.70
7/22/66	27"	8.6	17"	8.9	27"	6.6	15"	6.9	21"	7.7
8/15/66	25"	6.9	24"	6.3	25"	6.0	25"	6.0	24"	8.9
8/29/66		8.6		6.0		8.0		10.6		8.6
9/8/66	16"	9.1	15"	7.1	16"	6.9	15"	10.3	14"	9.7

	(6)		(7)		(8)		(9)		(10)	
DATE	SECCHI	% SALINITY	SECCHI	% SALINITY	SECCHI	% SALINITY	SECCHI	% SALINITY	SECCHI	% SALINITY
7/1/65	24"	7.0	22"	7.5	22"	6.6	21"	6.7	18"	6.0
7/6/65	24"	5.7	26"	7.0	25"	7.2	28"	7.3	29"	7.6
7/12/65	29"	6.8	31"	7.0	25"	3.9	28"	4.1	30"	5.0
7/19/65	31"	8.2	33"	7.6	25"	7.5	24"	5.5	25"	6.6
7/22/65	24"	6.2	24"	7.1	22"	6.3	10"	3.6	24"	6.6
7/29/65	28"	9.8	29"	8.9	27"	8.3	25"	7.7	26"	8.9
8/2/65	27"	10.4	25"	8.5	20"	8.9	14"	7.7	23"	8.8
8/6/65	31"	12.0	31"	11.5	22"	9.4	21"	8.8	22"	9.5
8/9/65	26"	10.2	19"	10.6	19"	11.4	18"	11.4	19"	10.0
8/13/65	25"	11.7	24"	11.1	23"	11.1	22"	9.5	23"	10.6
8/16/65	27"	11.1	25"	10.9	24"	9.7	23"	8.7	23"	10.6
8/23/65	30"	15.6	29"	15.9					27"	15.5
8/27/65	27"	17.4	24"	13.9	22"	12.3	22"	12.7	25"	13.6
8/30/65	24"	13.0	22"	13.4	21"	13.2	20"	12.8	20"	12.8
9/8/65	20"	12.9	18"	13.8	17"	13.4	13"	12.8	18"	13.9
9/16/65	23"	11.3	21"	13.4	25"	11.6	20"	12.1	21"	13.1
9/22/65	28"	12.0	27"	14.0	30"	14.4	27"	13.5	26"	13.5
9/30/65	16"	13.1	19"	13.7	16"	13.3	13"	13.5	15"	13.8
10/6/65	19"	16.7	23"	14.6	19"	14.2	23"	13.9	19"	13.7
10/12/65	22"	14.0	30"	13.4	15"	12.6	30"	13.7	30"	13.4
10/22/65	17"	13.8	19"	12.8	15"	13.4	15"	13.1	16"	13.1
11/8/65	28"	11.4	33"	11.9	35"	11.9	33"	12.6	28"	12.5
11/19/65	19"	12.6	18"	12.7	16"	12.8	17"	12.6	17"	12.8
11/26/65	30"	12.3	27"	12.3	29"	12.5	38"	13.3	29"	12.7
12/11/65	27"	13.6	26"	12.6	27"	12.6	23"	13.1	24"	12.6
2/15/66		10.88		10.11		9.63		9.95		10.25
2/21/66	15"	8.24	17"	9.16	17"	8.38	15"	8.38	16"	9.01
3/2/66	15"	9.78	15"	8.24	7"	5.28	8"	4.97	16"	7.92
3/21/66	18"	9.01	20"	9.46	13"	7.92	7"	6.99	17"	8.85
4/4/66	15"	11.34	11"	10.62	14"	10.88	12"	9.63	12"	9.63
4/11/66		11.03		11.19		10.25		9.10		10.62
5/3/66	15"	10.25	15"	10.58	13"	10.41	13"	9.46	13"	10.58
6/7/66	29"	9.01	23"	8.24	29"	8.07	23"	8.24	23"	8.70
7/22/66	25"	8.3	25"	8.3	25"	8.6	27"	8.6	27"	8.6
8/15/66	27"	7.7	24"	6.6	22"	7.1	20"	4.3	26"	5.4
8/29/66		8.6		7.7		7.1		6.6		6.6
9/8/66	16"	9.7	17"	9.1	16"	7.7	19"	7.7	18"	7.4

	(11)		(12)		(13)		(14)		(15)	
DATE	SECCHI	% SALINITY	SECCHI	% SALINITY	SECCHI	% SALINITY	SECCHI	% SALINITY	SECCHI	% SALINITY
7/1/65	19"	5.9	19"	6.9	23"	3.1	16"	3.1	18"	3.5
7/6/65	30"	6.8	28"	6.9	23"	2.8	24"	3.1	21"	3.3
7/12/65	32"	6.3	30"	6.2	23"	2.3	21"	2.6	26"	2.3
7/19/65	30"	5.5	26"	6.1	23"	2.6	23"	3.8	25"	4.6
7/22/65	24"	5.4	23"	7.9	22"	4.3	22"	3.3	25"	14.2
7/29/65	23"	7.7	29"	8.8	23"	3.0	21"	3.0	23"	3.0
8/2/65	26"	7.8	25"	9.0	23"	3.0	17"	3.0	23"	6.5
8/6/65	26"	8.8	26"	9.6	23"	3.2	19"	3.1	26"	9.6
8/9/65	24"	8.9	20"	10.6	19"	3.5	19"	4.1	22"	4.7
8/13/65	26"	9.5	23"	10.7	20"	3.3	26"	4.4	20"	6.2
8/16/65	27"	10.1	25"	11.6	25"	5.9	25"	4.7	22"	15.4
8/23/65			29"	13.7	23"	5.7	22"	7.4		
8/27/65	24"	11.7	27"	13.7	20"	4.1	25"	4.9	25"	7.8
8/30/65	19"	11.1	20"	13.7	19"	5.0	19"	5.4	22"	9.4
9/8/65	15"	13.6	20"	15.1	19"	7.3	21"	6.0	23"	23.0
9/16/65	21"	14.5	22"	13.4	16"	3.7	18"	4.1	20"	4.0
9/22/65	29"	14.0	27"	13.6	17"	4.2	14"	5.4	26"	6.7
9/30/65	15"	13.4	19"	13.7	20"	6.9	15"	5.6	27"	20.0
10/6/65	23"	11.0	22"	13.1			15"	4.5	22"	14.5
10/12/65	30"	10.9	27"	12.9	23"	6.9			23"	8.0
10/15/65							23"	5.1		
10/22/65	16"	13.0	18"	12.8	21"	7.4	21"	7.6	19"	11.0
11/8/65	24"	11.5	33"	12.1	27"	7.2	23"	6.3	19"	9.3
11/19/65	21"	11.7	20"	11.8	23"	7.0	22"	6.4	21"	13.7
11/26/65	33"	11.1	27"	12.2	30"	8.0	34"	5.5	30"	11.2
12/11/65	25"	12.3	26"	12.1	22"	6.3	18"	5.6	27"	11.0
2/15/66		9.46		9.78		8.38		7.45		8.85
2/21/66	13"	8.54	21"	9.16	18"	7.30	14"	6.84	25"	8.85
3/2/66	15"	7.76	12"	7.15	9"	7.61	10"	6.21	16"	8.85
3/21/66	16"	8.38	20"	9.16	16"	8.09	12"	7.45	18"	9.95
4/4/66	13"	9.63	10"	10.11	11"	7.45	13"	7.45	17"	10.62
4/11/66		10.88		11.19		7.61		7.45		12.74
5/3/66	11"	10.58	13"	10.58	17"	8.38	15"	7.92	15"	9.63
6/7/66	25"	8.24	23"	8.54	19"	7.15	19"	6.68	27"	7.3
7/22/66	23"	9.1	21"	7.4	25"	7.7	23"	6.9	27"	6.6
8/15/66	26"	6.3	26"	6.3	24"	6.0	25"	6.3	24"	6.6
8/29/66		7.7		8.0		6.6		5.4		10.6
9/8/66	17"	7.7	16"	8.3	16"	6.3	17"	6.3	16"	9.4

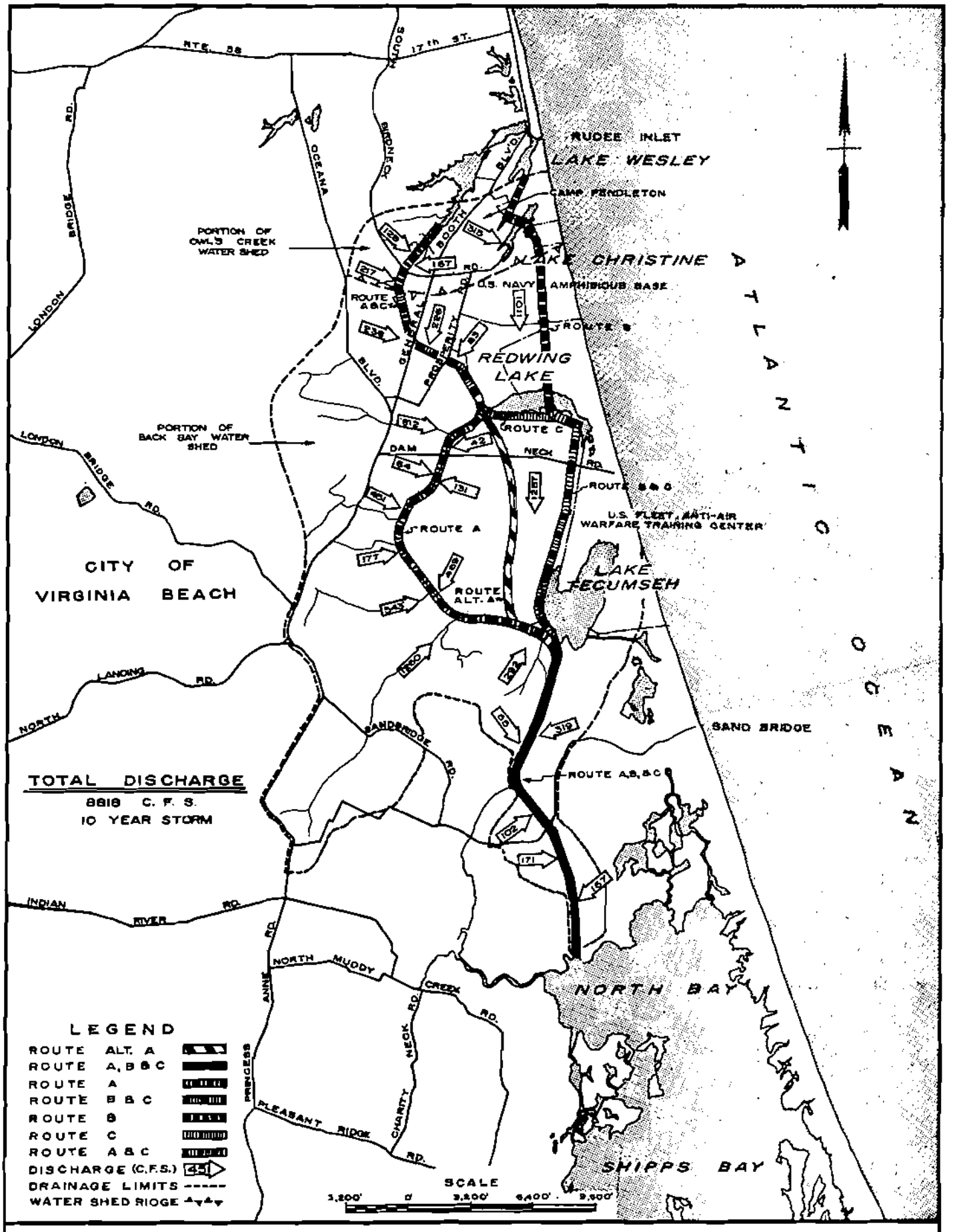
	(16)		(17)		(18)		(19)		(20)	
DATE	SECCHI	% SALINITY	SECCHI	% SALINITY	SECCHI	% SALINITY	SECCHI	% SALINITY	SECCHI	% SALINITY
7/1/65	25"	9.8								
7/6/65	23"	3.6	19"	2.3	21"	2.3	19"	2.3		
7/12/65	26"	2.9								
7/19/65	25"	6.2								
7/22/65	28"	16.7	25"	2.4	26"	3.1	27"	3.0		
7/29/65	23"	4.6								
8/2/65	25"	6.8								
8/6/65	30"	10.9								
8/9/65	22"	4.6								
8/13/65	24"	10.3								
8/16/65	28"	15.5	25"	3.0	25"	3.0	28"	3.2		
8/23/65	26"	8.3								
8/27/65	26"	8.3	23"	3.2	26"	3.0	26"	3.1	22"	4.0
8/30/65	23"	16.2	19"	4.1	20"	3.8	20"	4.1		
9/8/65	18"	17.4	21"	4.3	20"	4.3	20"	4.3	15"	4.5
9/16/65	17"	3.4	24"	3.5	22"	3.4	22"	4.5	22"	4.0
9/22/65	21"	7.3								
9/30/65	18"	17.2	20"	4.6	18"	5.0	20"	4.6	20"	5.1
10/6/65	19"	15.4	19"	8.0	19"	7.3	17"	4.7		
10/12/65	23"	10.9	23"	6.9						
10/15/65					30"	4.9	23"	5.1	23"	4.6
10/22/65	20"	10.9	16"	5.5	17"	5.6	17"	5.6	17"	6.1
11/8/65	21"	8.6	25"	6.3	27"	5.7	28"	5.9	23"	5.4
11/19/65	18"	14.1	22"	7.4	23"	6.6	24"	6.3	19"	5.7
11/26/65	29"	10.8	32"	6.5	35"	5.7	36"	5.8	28"	5.7
12/11/65	29"	12.6	29"	7.7	29"	7.0	29"	7.2	19"	6.4
2/15/66		9.32		7.76		7.76		8.07		7.45
2/21/66	25"	9.01	19"	8.70	16"	7.92	16"	8.54	13"	7.30
3/2/66	17"	9.32	15"	7.15	19"	6.84	16"	6.99		6.36
3/21/66	21"	12.42	19"	7.30	19"	7.15	14"	6.99	15"	7.15
4/4/66	14"	13.82	10"	7.92	10"	6.84	10"	6.68		
4/11/66		12.74		9.10		8.01		8.33		
5/3/66	15"	11.34	17"	7.15	17"	6.52	13"	7.15	15"	7.15
6/7/66	25"	7.45	25"	7.15	25"	6.99	25"	7.30	21"	6.99
7/22/66	17"	6.6	25"	6.3	31"	6.6	27"	6.6	27"	6.6
8/15/66	25"	7.7	27"	6.3	30"	6.3	27"	6.3	21"	6.3
8/29/66		11.4		6.0		6.0		6.0		5.4
9/8/66	16"	9.7	15"	6.3	16"	6.3	17"	6.0	10"	6.0

MISSING

WATER SAMPLES - DRAINAGE CANAL

	Redwing Lake	Lake Tecumseh	Ashville Bridge Creek
Determination:(Standard Methods- APHA, AWWA, WPCE)	PPM	PPM	PPM
Total Dissolved Solids @105°C	219	330	680
Total Hardness, as $CaCO_3$	66	108	160
Calcium Hardness, as $CaCO_3$	34	48	66
Magnesium Hardness as $CaCO_3$	32	60	94
Calcium, as Ca	13.6	19.2	26.4
Magnesium as Mg	7.7	14.6	22.8
Alkalinity (Phenolpthalein) as $CaCO_3$	0	0	0
Alkalinity (Total) as $CaCO_3$	20	18	32
Carbonate Alkalinity as $CaCO_3$	0	0	0
Bicarbonate Alkalinity as $CaCO_3$	20	18	32
Hydroxides as OH	0	0	0
Carbon Dioxide as CO_2	5.1	9	12
Carbonates as CO_3	0	0	0
Bicarbonates as HCO_3	12.2	11	19.5
Chlorides as Cl	54	89	234
Iron as Fe	1.1	0.76	0.76
Manganese as Mn	0	0	0
Sulfate as SO_4	45	63	75
Fluorides as Fl	0	0	0
Silica as SiO_2	0	0	0
Copper as Cu	1.2	0	0.8
Phosphate (Total) as PO_4	0.4	2.4	0.4
Color, Standard Platinum Cobalt Scale	30	20	20
Odor	0	0	0
Ph (Laboratory)	6.9	6.6	6.7
Turbidity, Silica Scale	0	0	0
B.O.D.	1.1	2.4	1.1

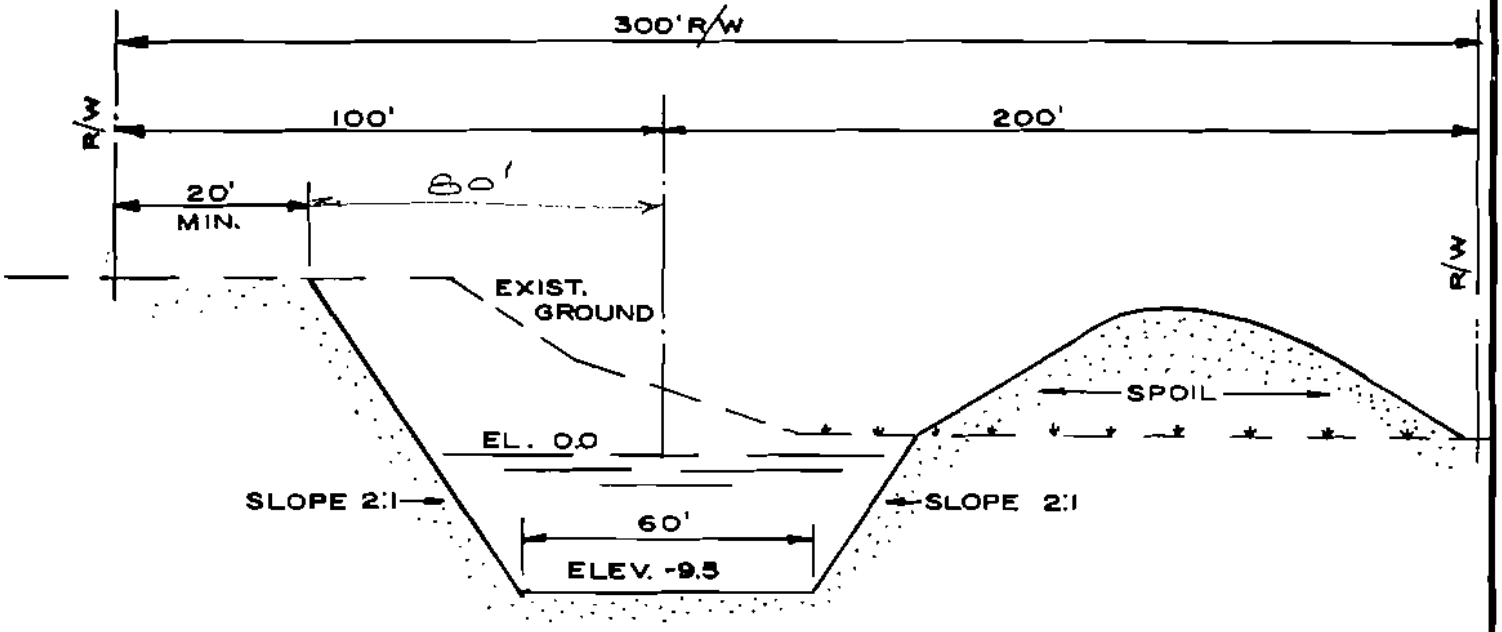
Stuart C. Crawford
Consulting Chemist



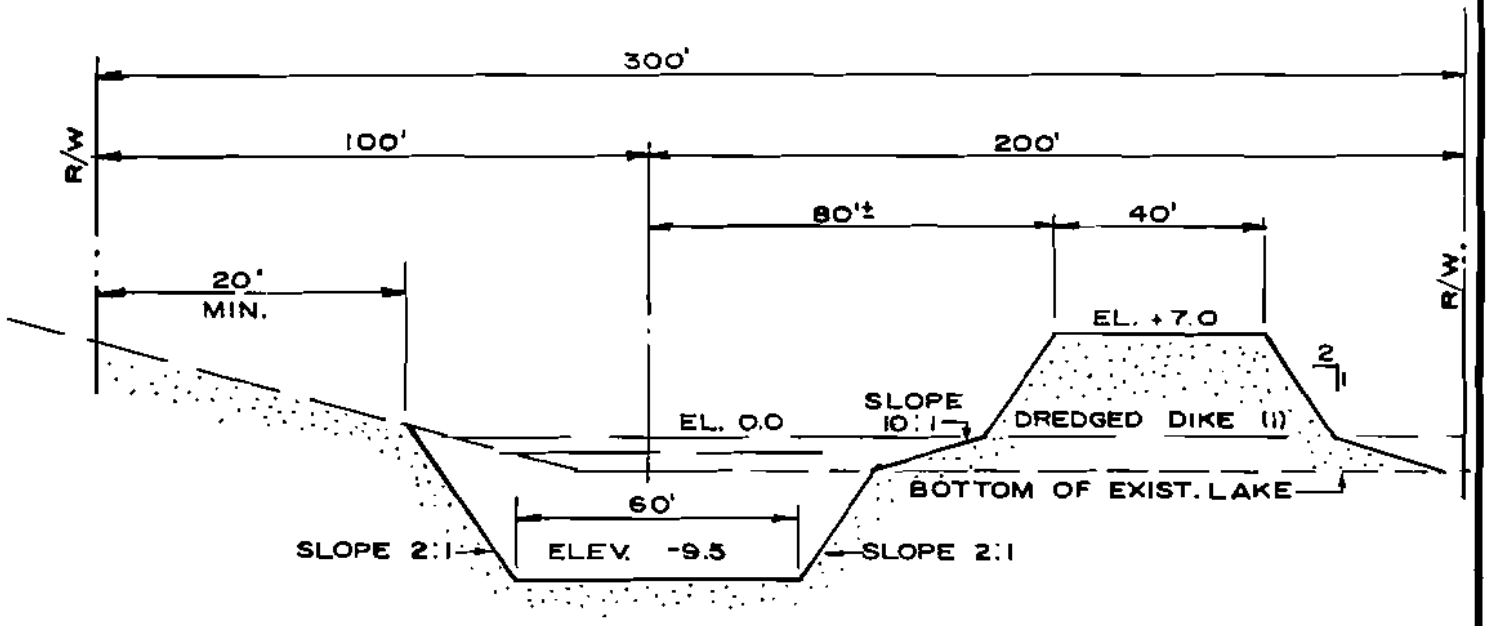
LANGLEY, McDONALD & OVERMAN.
CONSULTING ENGINEERS

STORM DRAINAGE CONTRIBUTION

PLATE I



SECTION THRU SWAMP OR HIGH GROUND



SECTION THRU OR ADJACENT TO LAKE

TYPICAL SECTIONS

(1) CANAL TO BE DREDGED BY BUCKET METHOD OR BY HYDRAULIC DREDGE. IF HYDRAULIC DREDGE, DIKE TO BE PUMPED AHEAD OF DREDGE AND DRESSED TO HEIGHT SHOWN WITH SMALL EARTHMOVER.

(2) VERTICAL CONTROL: MEAN SEA LEVEL = 0.0