CHAPTER 127

NUMERICAL MODELING OF CONSTITUENT TRANSPORT IN BAY SYSTEMS

By R. G. Dean[1] and R. B. Taylor[2]

ABSTRACT

This paper describes the results of a numerical modeling study of the Lower Biscayne Bay system in southeast Florida. The purpose of the study is to predict the effects of cooling water intake and discharge associated with the Turkey Point Power Plant facility, which comprises two fossil-fueled units and two nuclear units. When completed the system will generate 2450 megawatts. One of the original (but since abandoned) operating plans considered would require intake by the plant ranging from 4250 to 10,600 cfs of Bay water for cooling and dilution purposes to be returned via a six-mile canal to the Bay system.

The Lower Biscayne Bay system comprises several bodies of water of 6 to 10 ft. depth which are connected over shallow limestone and mud sills. The numerical model incorporates an area of approximately 36 by 12 nautical miles divided into grid squares of 2 nautical miles on each side.

Available field data are used to calibrate the model. The results of the calibration and predictions of the effects of the plant withdrawal and discharge on the natural bay system flows are presented.

The primary features of interest of the study include: 1) the effect of the plant cooling water requirements on the Bay hydromechanics, including recirculation and flows through small inlets connecting the Bay to the Ocean; and 2) the concentration distributions of conservative constituents in the Bay system as affected by advective and dispersive processes. The numerical procedure consists of a non-dispersive and a dispersive model which are employed sequentially.

INTRODUCTION

This paper presents the background for and some results obtained from two numerical calculation procedures to simulate the tidal, wind-driven and other induced flows and mixing processes in the Biscayne Bay/Card Sound System in Southeast Florida, see Figure 1. The two calculation procedures (or models) are employed sequentially to represent: (1) the non-dispersive hydromechanics of the bay system, and (2) the dispersive and advective transport of a constituent and the exchange with contiguous water systems.

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The numerical models described in this report are based on finite difference representations of the governing equations of motion and continuity and conservation of the constituent. Both dispersive and advective transport are included in the constituent transport considerations.

The non-dispersive numerical model utilizes and extends the techniques developed by Platzman(1), Miyazaki(2), Reid and Bodine(3), and represents an improvement of the numerical model developed by Verma and Dean(4) for the Biscayne Bay area.

For the appropriate geometry of the Bay system, the finite difference representations of the equations of motion and continuity are solved for time-varying forcing functions which can include:(1) ocean tide which could be composed of astronomical and barometric components, (2) wind shear on the surface of the bay system, (3) runoff along the boundaries of the bay, and (4) withdrawal and discharge of water by the Turkey Point Plant at any specified locations. The principal difficulty in applying the available methods to the Biscayne Bay/Card Sound area is that this area is perhaps unique due to the presence of a number of limestone sills, some of which are "laced" by numerous channels. When examined in detail, the variation of hydraulic "admittance" of these various features with tidal stage is quite important in representing the overall hydromechanic response of the bay system. The equations associated with the non-dispersive numerical model were programmed for solution on a digital computer; the results of these computations are Fourier coefficients which represent the time-varying water surface displacements and discharge components throughout the bay system. This output from the non-dispersive program serves as input to the companion dispersive model which predicts the concentrations and transport of a constituent introduced into the bay.

The dispersive model is based on a finite difference formulation of the two dimensional equations for conservation of a constituent. The present version of the model considers only conservative constituents; however, modifications are planned to represent the fate of non-conservative constituents by incorporating exchange mechanisms across the upper and/or lower surfaces to simulate transfer to the atmosphere and bottom sediments, respectively. Of particular interest is the representation of an anisotropic dispersion coefficient based on Elder's(5) study of dispersion in an open channel. This feature is of importance in areas where there is a strong predominance to the current direction.

The present paper does not present the underlying theory or numerical basis in complete detail; for a more complete treatment, the reader is referred to References (6) and (7).

DESCRIPTION OF PHYSICAL SYSTEM

The numerical model incorporates an area of approximately 36 by 12 nautical miles, and extends from the Rickenbacker Causeway (northern limit) to the southern limit of the model, which is located near the causeway between Barnes Sound and Blackwater Sound, see Figure 1. The model extends from the western boundary of the Biscayne Bay/Card Sound system to an

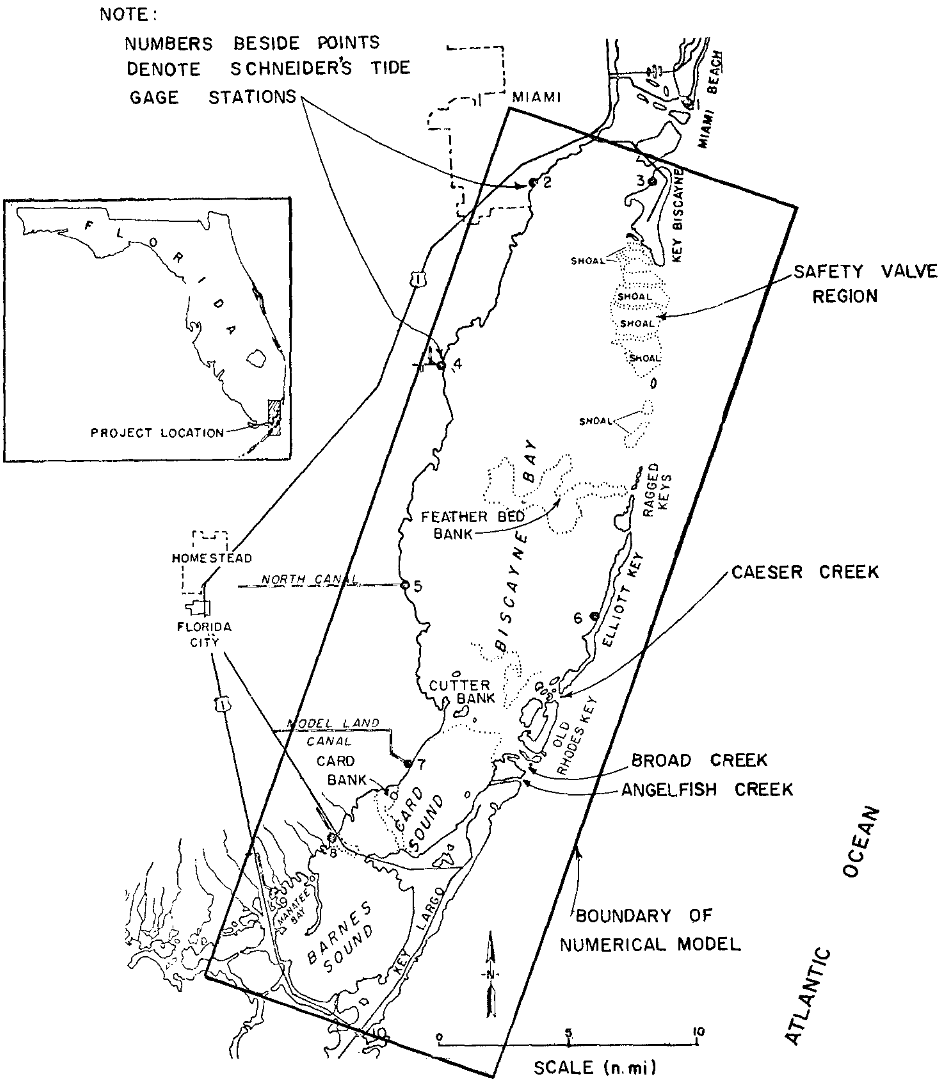

FIGURE 1. AREA INCLUDED IN NUMERICAL MODEL. THIS FIGURE ADAPTED FROM SCHNEIDER.[9]

eastern limit which is approximately 2 miles into the Atlantic Ocean.

The Biscayne Bay system comprises several water bodies which are connected via shallow sills. The primary flow into the Biscayne Bay/Card Sound System occurs through the "Safety Valve" region located at the northeastern limits of Lower Biscayne Bay. This entrance to the bay is approximately 9 nautical miles in length, and is characterized as a shallow limestone sill approximately 1/2 to 2 nautical miles in breadth, and at mean low water is 1 to 3 ft. in depth. The sill is interlaced by approximately 20 channels which, at mean low water, range up to 15 ft. in depth. The other inlets which are responsible for the major part of the remaining flow in and out of the bay system include Bear Cut which communicates with the Atlantic Ocean at the northeast corner of the bay system, the bridge in the Rickenbacker Causeway which communicates with lower Biscayne Bay to the north, and several inlet systems connecting Lower Biscayne Bay and Card Sound to the Atlantic Ocean. These inlets include Caesar Creek, which is located in lower Biscayne Bay between Elliott Key and Old Rhodes Key and transports water in and out of the Bay at this point. At the northern end of Card Sound, there is a series of channels which connect Card Sound to the Atlantic Ocean. These channels are fairly numerous, however, the major channels are Broad Creek and Angelfish Creek.

At the southern limit of Barnes Sound, Jewfish Creek connects Barnes Sound with Blackwater Sound, however, this is a relatively small channel and probably does not affect the region of interest significantly.

The bay system interior may be characterized as a number of shallow basins separated by much shallower limestone sills and mud banks, which affect the hydraulics considerably. Starting at the north end of the bay system, the average mean low water (MLW) depths are on the order of 7 ft. from the Rickenbacker Causeway for a distance of approximately 14 nautical miles to the south where a shallow sill "Feather-Bed Bank" is located. This sill varies considerably in depth, ranging from a mean low water depth of 6 ft. to areas where the sill is exposed; an average depth is on the order of 2 to 3 ft. mean low water. Continuing south from the Feather-Bed Bank a distance of approximately 9 nautical miles, a second limestone sill, "Cutter Bank" is located; this sill separates lower Biscayne Bay from Card Sound. There is also a lateral decrease in the width of the Bay; at this point the width is approximately 3 nautical miles. The depth at Cutter Bank ranges from about 1 to 3 ft. at mean low water. Card Sound is approximately 10 ft. in depth at mean low water and is partially isolated from Little Card Sound by "Card Bank" which is a mud sill of approximately 1 to 3 ft. mean low water depth. Little Card Sound is a small basin which is approximately 8 ft. in depth and is separated from Barnes Sound to the south by a lateral and vertical restriction. The Card Sound bridge and associated causeway result in a clear opening between Card Sound and Barnes Sound of about 2000 ft. The natural sill depth at this location is approximately 3 ft. Barnes Sound has a mean low water depth of 9 ft., and its connection with Blackwater Sound to the south is quite restricted, and occurs through Jewfish Creek. For the purpose of the numerical model described in this study, it is assumed that Barnes Sound and Blackwater Sound are completely isolated from each other.

The major physical characteristics of the Biscayne Bay/Card Sound system are shown in Figure 1.

THEORY AND FINITE-DIFFERENCE REPRESENTATIONS

Because of space limitations, the remaining portion of this paper will emphasize the results obtained from application of the numerical models. In this section, the basis for the theory and finite-difference representations is described briefly, however the reader interested in the details should refer to References (6) and (7).

Non-Dispersive Model - The governing equations for the non-dispersive model are the differential equations of motion and continuity. As in a number of previous studies, it is assumed that the water column is well-mixed, the vertical accelerations are negligible, and the convective accelerations are relatively small. This allows the equations of motion to be integrated over depth and to be expressed in terms of the transport components q_x and q_y and the total instantaneous depth. The bottom and surface stresses are retained in the equations of motion, however the lateral stresses on the water column are considered negligible. Anomalous features such as the shallow sills and inlets to the bay are represented in the form of stress terms, the characteristics of which were determined by calibration. The continuity equation is also integrated over depth to obtain the usual expression for the rate of change of water surface elevation in terms of the divergence of water transport.

The vertically-integrated equations of motion and continuity were cast in finite-difference forms, such that the time-marching solution was based on an explicit time- and space-staggered procedure, with quasi-linearization of the bottom and anomalous features stress terms.

Dispersive Model - The dispersive model is based on the differential equation for conservation of a constituent, c, including constituent transport due to advection and dispersion. The assumption is made that the water column is well-mixed, allowing the governing equation to be integrated over depth. Special features of the method employed in this model include the procedure of representing advective transport and the incorporation of anisotropic turbulent dispersion coefficients, in accordance with the results of Elder(5) and Bowden(8) and limited dye studies in the Bay system of interest.

RESULTS

The results obtained from the numerical calculation procedures are discussed separately under non-dispersive and dispersive sub-categories. However, it should be noted that the dispersive results include water level and transport results from the non-dispersive calculations.

Non-Dispersive Results

Three separate sets of computations were carried out using the non-dispersive model to demonstrate its present capabilities and to gain some insight into future extensions of the model.

Run No. 1 - Two Nautical Mile Grid, Calibration with Schneider's Results, No Wind, No Plant Discharge

The first set of calculations was carried out to calibrate the model and to assess the confidence that could be placed in the use of the model. The grid employed was the 2-mile grid portrayed in Figure 2. The most complete data available for calibration were those collected by J. J. Schneider(9) in 1968, who monitored tidal elevations and set-up in the Biscayne Bay systems at nine locations (Figure 1). In order to calibrate and assess the model, a mean ocean tide of 2.44 ft. range was applied along the seaward grid of the schematized model. This corresponds to the grid line i = 6 as shown in Figure 2. The ocean tide input to the model was a sinusoid having the form

$$\eta = 1.22 \sin \left(\frac{2\pi}{12.4} \frac{t}{3600}\right)$$

in which t is the time in seconds.

In the calculations, which represent a "run" of the numerical model, a time step Δt = 220 sec. was employed. At each time step, the output of the numerical model includes tidal elevations at each of the centerpoints of the grids shown in Figure 2, and also the output includes the transport components (i.e. product of velocity component with total depth) normal to and located at the center of each of the grid lines shown in Figure 2. Figures 3, 4, 5 and 6 present a comparison of the calculations resulting from the numerical model.

Figure 3 presents a comparison of the measured and calculated tidal ranges at the locations of Schneider's tide gage stations. It was found that it was possible to calibrate the model by adjusting the hydraulic characteristics of the inlets and sills in the system so as to obtain agreement generally within 5%.

Figures 4 and 5 present comparisons between computed and measured time lags of the tide for high and low water respectively at Schneider's tide gage stations. Lags shown are with respect to the ocean tide measured at Government Cut. Agreement was generally obtained within $\pm$ 20 minutes except at Station 9.

One interesting phenomenon predicted by the model is the "tidal set-up" in the bay that results from the loss of tidal energy and reflection of tides within the bay. This tidal set-up is manifested as a mean tide elevation above the mean ocean level; this set-up increases toward the lower end of the Bay system. Figure 6 presents a comparison of the measured and computed half-tide planes which represent the set-up. Although the agreement may seem less than desirable, the following should be noted: (1) the magnitude of the quantities are small (maximum of approximately 3") and, (2) the leveling may be questionable. With regard to the latter point, Schneider has concluded the leveling of Tide Gage Location 8 to be in error and has arbitrarily adjusted this level by 0.2' which is almost as great as the maximum set-up.

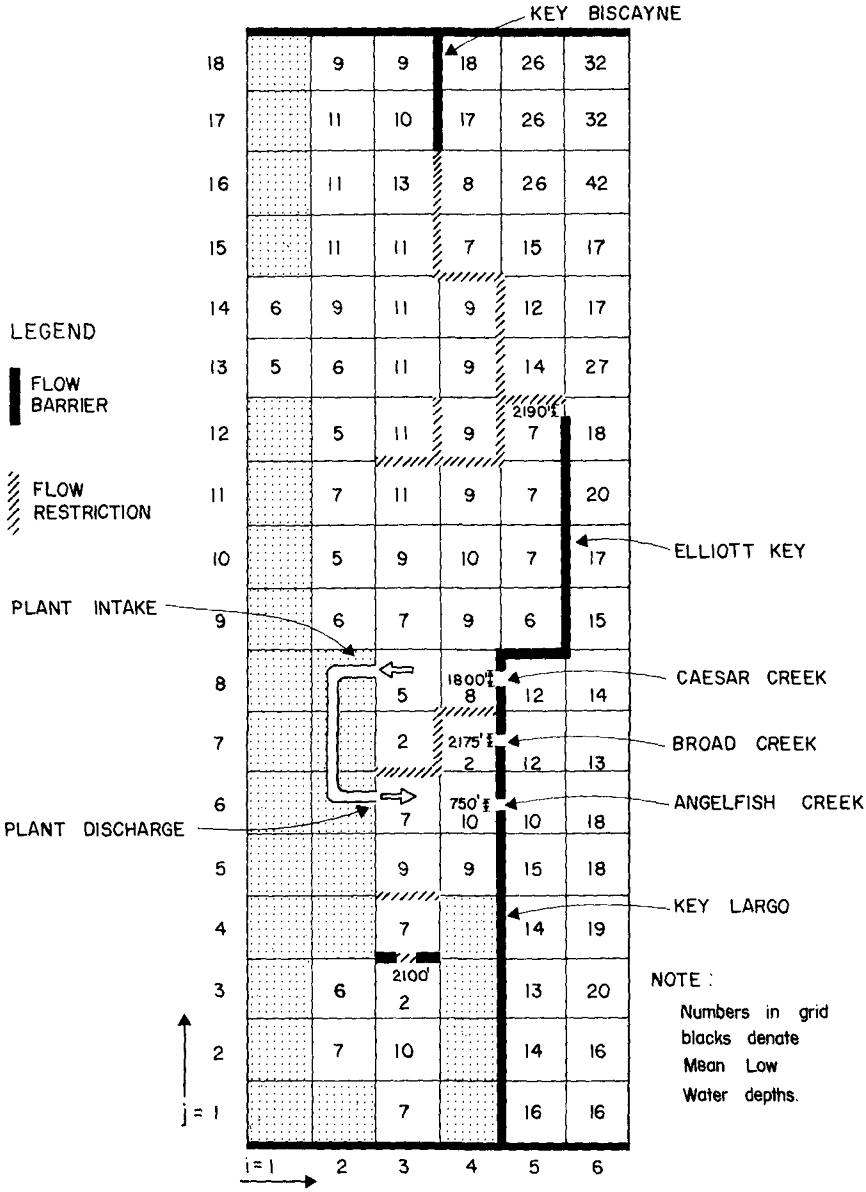

FIGURE 2 TWO MILE GRID SIMULATION OF THE BISCAYNE BAY / CARD SOUND SYSTEM

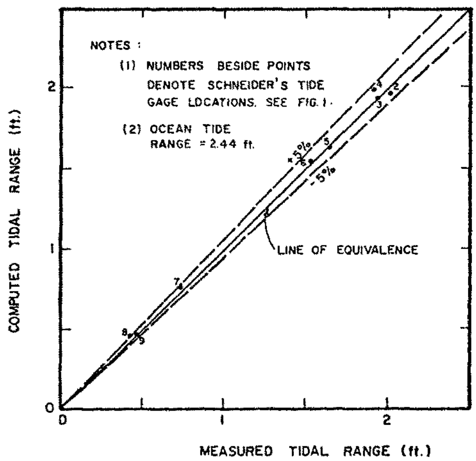

FIGURE 3 COMPARISON OF MEASURED AND COMPUTED TIDAL RANGES.

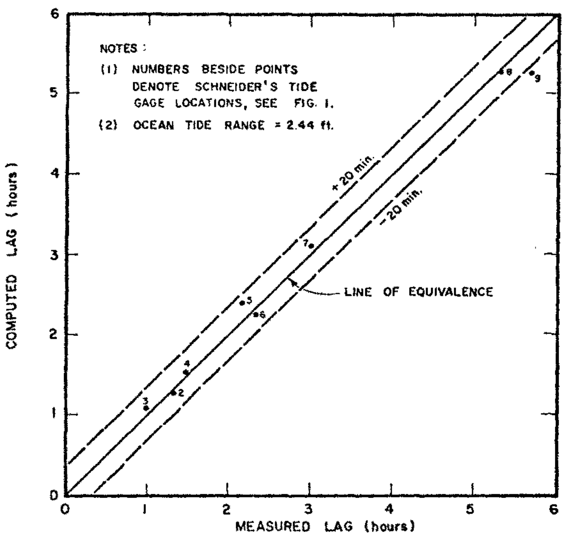

FIGURE 4 COMPARISON OF MEASURED AND COMPUTED TIDAL LAGS FOR HIGH WATER.

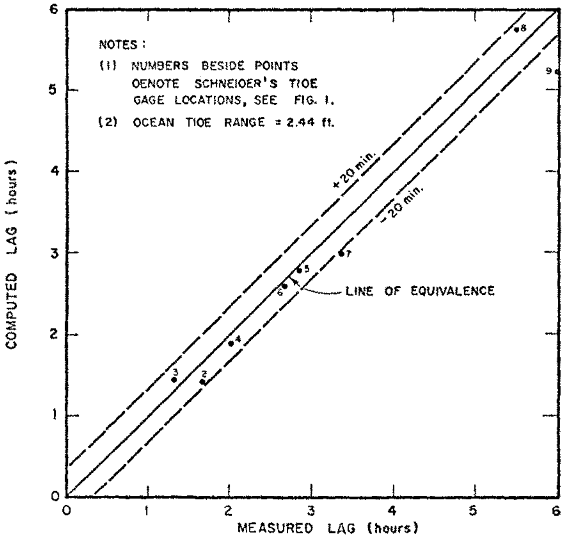

FIGURE 5 COMPARISON OF MEASURED AND COMPUTED TIDAL LAGS FOR LOW WATER.

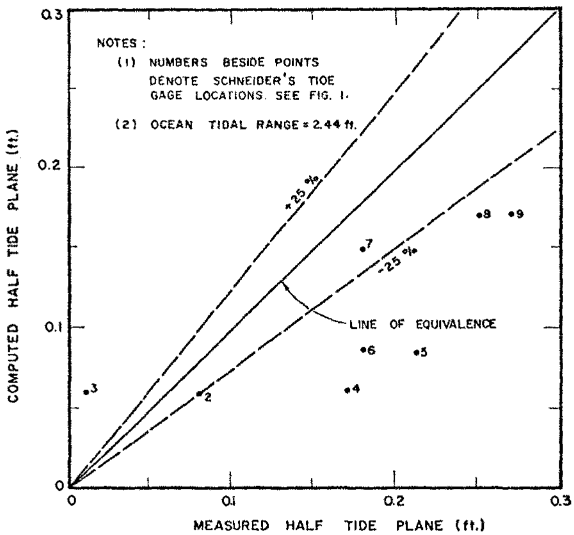

FIGURE 6 COMPARISON OF MEASURED AND COMPUTED HALF TIDE PLANES.

Figure 7 presents isolines of tidal range. The effect of the limestone sills in decreasing the tidal range is very evident from the steep tidal range gradient at these locations. The tidal ranges measured by Schneider at Stations 2-9 are also shown on this figure.

A comparison of mean tidal exchange volumes for Card Sound and the Ocean was made between the results of this model and those of earlier models by Verma and Oean(4), and Taylor(10). The tidal exchange volume was selected as a representative measure of comparison between the various models because the exchange volume represents the total tidal flow through the inlet system over one-half of a tidal cycle and is therefore a better means of comparing the results of the models than is the peak flow rate which can vary considerably with the channel geometry for a given cross-sectional area.

Since the flow rate through an inlet and thus the exchange volume of the bay are roughly proportional to the square root of the amplitude of the ocean tide, the results of Verma and Oean, and Taylor models were adjusted so as to be representative of an ocean tidal range of 2.44 ft., the value used to calibrate the present model.

The comparable tidal exchange volumes of the three models for a tidal range of 2.44 ft. are as follows:

Present Model - 0.59×10^9 ft.^{3}

Verma and Oean - 0.79×10^9 ft.^{3}

Taylor - 0.93×10^9 ft.^{3}

It is believed that the actual value of the tidal exchange volume lies somewhere between 0.6×10^9 and 0.8×10^9 ft.^{3} which would indicate that the results from the previous models are high while the results of this model are slightly low. Support for this is given by O'Brien's relationship(11) between the cross-sectional area of the inlet at its most narrow section and the tidal prism of the bay. Using three inlets having mean water level cross-sectional areas of 2870, 9200, and 8180 ft.^{2} to represent Old Rhodes Channel, Broad Creek and Angelfish Creek, respectively, O'Brien's method yields a tidal exchange volume of 0.74×10^9 ft.^{3} for a tidal range of 2.44 ft.

Maximum discharge values computed at all grid lines in the Bay system indicate a reduction in magnitude of the peak transports in the southern portion of the system and a predominance of the longshore components in the Card Sound Basin.

Run No. 2 - Plant Discharge of 4250 cfs, No Wind, Mean Flow Distribution

Computations were carried out to demonstrate the capability of the model to predict: (1) the effect of a plant discharge of 4250 cfs, (2) the source of the water flowing into the plant, and (3) the disposition of the discharged water. Streamlines are calculated, based on the mean transport components; the streamlines represent the approximate mean flow paths of the water particles. The results are shown in Figure 8 and represent streamlines based on the discharge averaged over a full tidal cycle for zero wind and zero rainfall conditions.

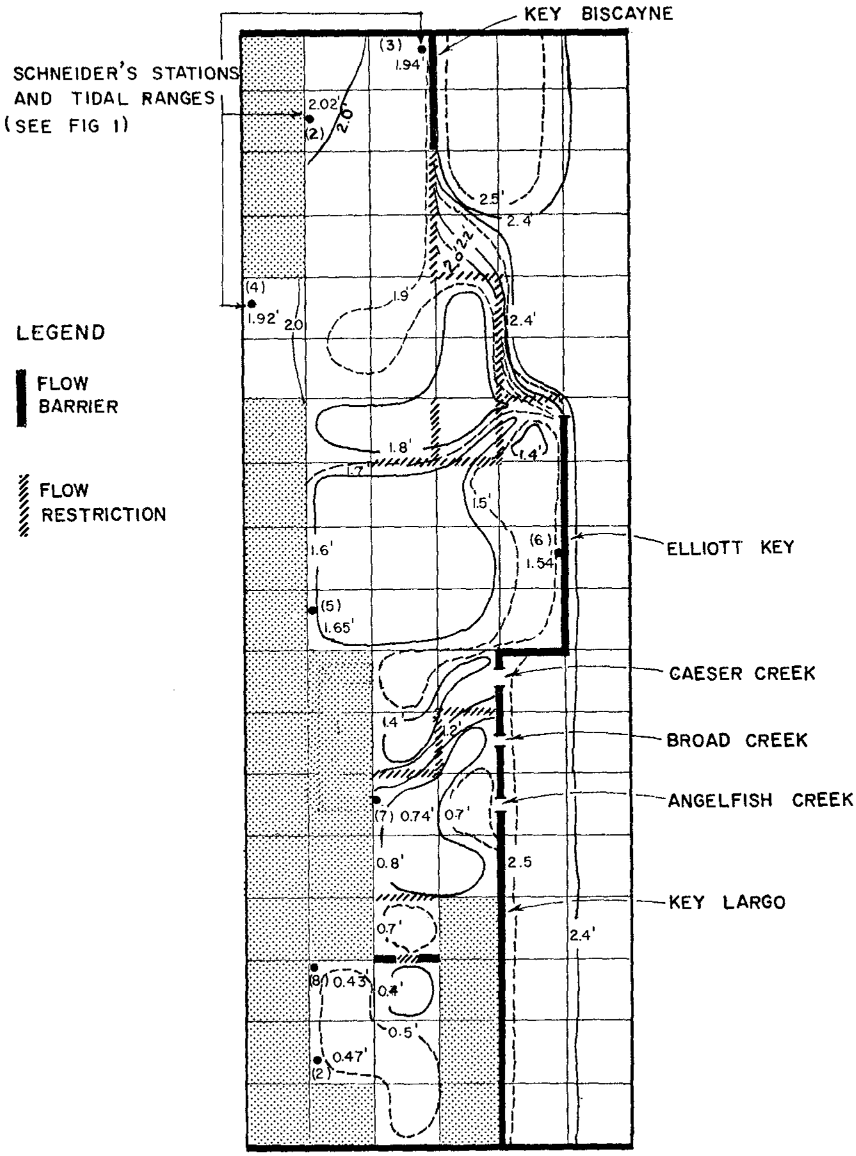

FIGURE 7 ISOLINES OF COMPUTED BAY TIDAL RANGE FOR AN OCEAN TIDAL RANGE OF 2.44 ft.; COMPARISON WITH SCHNEIDER'S DATA.

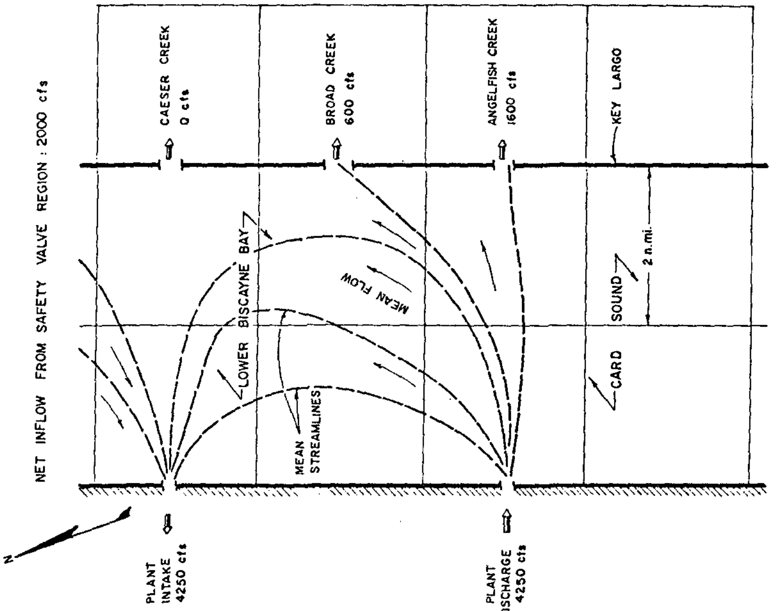

FIGURE 8 MEAN STREAMLINES AND DISCHARGES ASSOCIATED WITH PLANT FLOW OF 4250 c.f.s., WIND CONDITIONS : CALM.

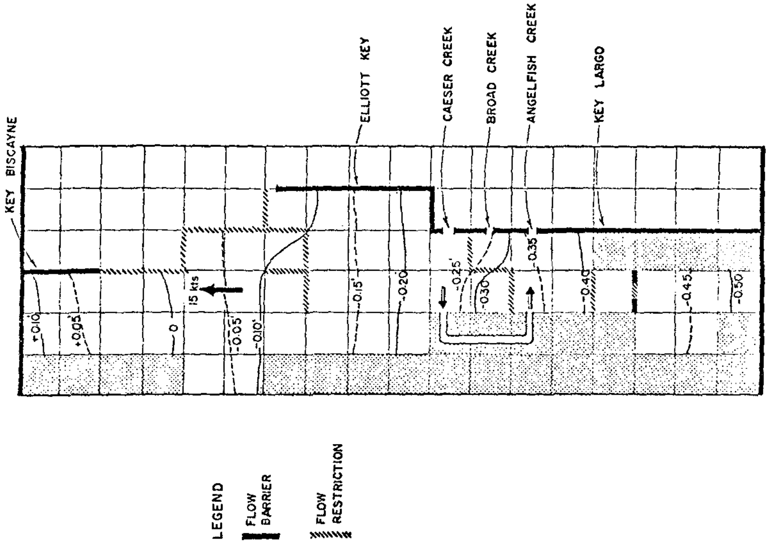

FIGURE 9 CHANGE IN MEAN WATER LEVEL DUE TO A 15 KNOT WIND BLOWING ALONG MAJOR AXIS OF BAY.

From the mean discharge values, it is possible to determine a "dividing streamline" outside of which all water discharge from the Canal terminus at Card Sound is not redrawn into the Plant and inside of which all water is recirculated into the Plant. It is noted that approximately 50% of the water discharged into Card Sound flows from Card Sound to the Atlantic Ocean primarily via Broad and Angelfish Creeks. The remaining 50% is recirculated. To replace the 50% of the Plant flow out of the system, this same amount enters Biscayne Bay, primarily from the "Safety Valve Region", located at the north extremity of lower Biscayne Bay. These results do not reflect the effect of mixing of the Bay water which is treated by the dispersive model.

Run No. 3 - A Steady South-Southwest Wind of 15 Knots

In order to demonstrate the capability of the model in representing forcing functions in addition to the tides, Run No. 3 included the same tide and Plant discharges as Run No. 2, however, a steady wind of 15 knots along the axis of the Bay system was included. Resulting mean streamlines were then computed in a manner identical to that described above for Run No. 2. The associated wind stress applied to the Bay surface was 0.001 lb/ft.^{2}. The major effect of the wind stress resulting from the applied wind is to depress the mean water levels in the southern portions of the Bay and to cause "new ocean water" to be drawn in through Angelfish, Broad, and Caesar Creeks, and to circulate toward the north and for a net amount of water to be displaced out through the Safety Valve region. The change in mean water level due to the wind is shown in Figure 9 . It is noted that the maximum change of -0.5 ft. occurs in the Barnes Sound area.

Figure 10 shows the effect of the south-southwest wind on the mean discharges within Card Sound. Comparison of Figures 8 and 10 shows that without mixing, the plant mass recirculation has increased from 50 to 100% as a result of the wind.

Dispersive Results

Two runs will be presented which employ the companion non-dispersive and dispersive models.

Run No. 1 - Two Nautical Mile Grid,Calibration with Continuous Plant Discharge of 4250 cfs, No Wind

The first set of computations was carried out to: (1) calibrate the dispersive model for net exchange with the ocean, (2) illustrate the capabilities of the model for conditions in which the tides represent the only forces, and (3) to examine the required length of model run to achieve near-equilibrium conditions.

Computed water surface elevations and volumetric flow rates for each grid square as a function of time were obtained from the calibrated non-dispersive model using an ocean tidal amplitude of a = 1.22 ft., zero wind stress (no wind), and a plant discharge of 4250 cfs. These data were then introduced into the dispersive model which used the same grid scheme as the non-dispersive model (Figure 2). The power plant effluent or constituent was considered to have a volumetric concentration level of 1.0 as it entered Card Sound. In order to evaluate the time required to achieve near-equilibrium conditions in the Card Sound Basin, a prototype running time of 333 hours (approximately 14 days) was conducted.

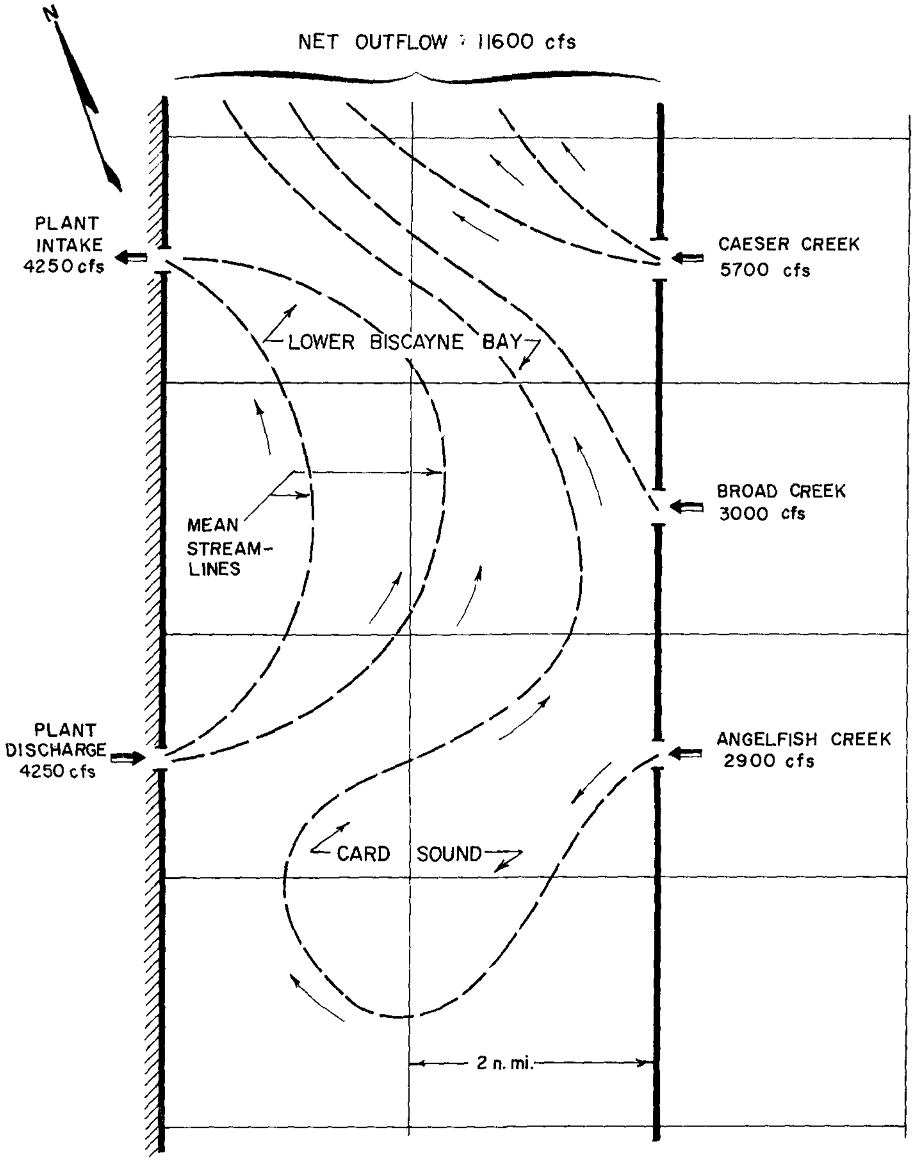

FIGURE 10 MEAN STREAMLINES AND DISCHARGES ASSOCIATED WITH A PLANT FLOW OF 4250 cfs AND A SUSTAINED SSW WIND OF 15 KTS.

For each "run", or set of calculations performed by the model, a time step of Δt = 5000 sec. was used. This is considerably larger than the value of Δt = 220 sec. utilized in the non-dispersive model, but is acceptable due to the more stable nature of the dispersive computation procedure. On the other hand, it will be seen that the dispersive mechanisms approach steady state much more slowly. At each time step, the output of the model includes tidal elevation and constituent concentration levels relative to the discharge point at each of the center points of the grid. Also calculated are velocities and total transport components of the constituent/bay water mixture normal to and located at the center of each of the grid lines shown in Figure 2.

To calibrate the model, values of constituent concentration levels in the ocean grid squares located in the extreme right column and adjacent to Caesar, Broad, and Angelfish Creeks, (6,6), (6,7) and (6,8) were adjusted to achieve the desired degree of mixing between the bay system and the ocean. Based upon limited field data obtained by the Coastal and Oceanographic Engineering Department of the University of Florida using rhodamine dye injection in Broad Creek, the ratio of the mean constituent concentration on the flood tide to the mean constituent concentration in the preceding ebb tide is approximately,

$$\frac{\overline{C}_F}{\overline{C}_E} \approx 0.6$$

The resulting average obtained for use in the model was

$$\frac{\overline{C}_F}{\overline{C}_E} = 0.55$$

which states that during each tidal cycle, there is a 45% renewal of Card Sound water transported to sea on the ebb tide with ocean water. A more detailed description of the procedure is given in Reference (7). Field work is presently in progress to obtain additional data regarding the exchange coefficients associated with the inlets in the lower Biscayne Bay system.

The transport of power plant effluent to and from Card Sound and its contiguous bodies of water for time ranging from 312 to 330 hours for this example is illustrated by the solid curves in Figures 11, 12 and 13. The results obtained from these curves are summarized in Table I.

An inspection of Table I shows that with no wind, Biscayne Bay and the Atlantic Ocean receive nearly equal amounts of constituent, each being greater than the amount received by Barnes Sound. However, these data also show that at a time of 320 hours, there is still a net flow into Barnes Sound which implies that equilibrium has not been attained. This is to be expected since Barnes Sound is essentially a closed end basin, its equilibrium concentration levels should be the same as those at the lower end of Card Sound. Moreover, the weak tidal exchange between these two basins suggests that equilibrium values in Barnes Sound will be approached slowly.

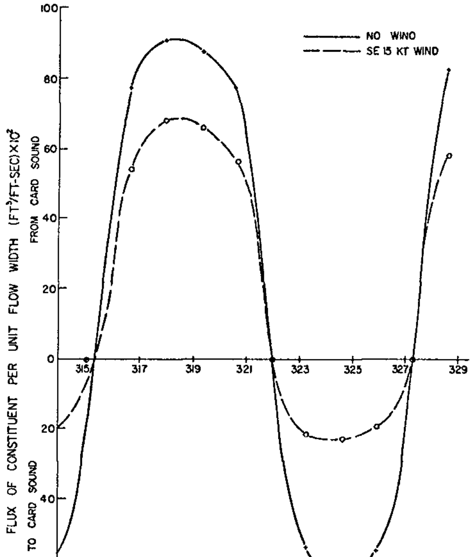

FIGURE 11
EXCHANGE OF CONSTITUENT BETWEEN CARD SOUND AND ATLANTIC OCEAN THROUGH BROAD AND ANGELFISH CREEKS

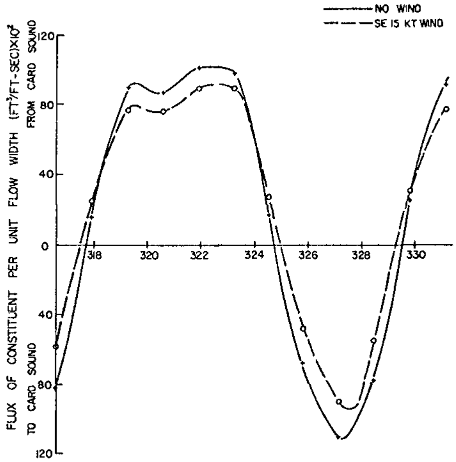

FIGURE 12 EXCHANGE OF CONSTITUENT BETWEEN CARD SOUND AND LOWER BISCAYNE BAY

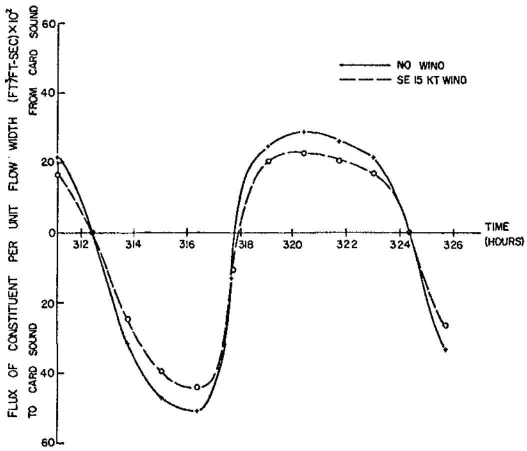

FIGURE 13 EXCHANGE OF CONSTITUENT BETWEEN CARD SOUND AND BARNES SOUND

TABLE I

NET EXCHANGE VOLUMES OF CONSTITUENT BETWEEN CARO SOUND
ANO CONTIGUOUS BOOIES OF WATER FOR CONTINUOUS
PLANT OISCHARGE = 4250 cfs ANO ZERO WINO CONOITIONS
(T = 311 hrs. to T = 330 hrs.)

Contiguous Body of Water	Net Exchange Volume of Constituent (ft^3/ tidal cycle)	Per Cent Constituent Returned with Tide to Card Sound
Atlantic Ocean	9.48×10^7	55%
Lower Biscayne Bay	9.48×10^7	62%
Barnes Sound	2.29×10^7	74%

It should also be noted from Table I that the total net volume of constituent transported out of Card Sound to contiguous bodies of water during one tidal cycle exceeds by approximately 10% the volume of constituent discharges into Card Sound from the power plant during the same period. Realistically this cannot be true since the concentration levels in Card Sound during this period are still increasing. A more precise estimate of an 8% error was obtained using a Δt = 1000 sec. and running the model for the same wind, tide and plant operational conditions. The computed total constituent flux between Card Sound and all contiguous bodies of water is shown in Figure 14. Further investigations have indicated that the improper mass balance of constituent in Card Sound is the result of the technique employed to numerically represent the advective terms in the dispersion equation. The magnitude of this error is approximately 10 per cent.

The distribution of the power plant effluent as predicted by the calibrated dispersive model is illustrated in Figures 15 and 16 for times t = 322 hours. The curves in these figures represent approximate isolines of effluent concentration with values given in parts power plant effluent per 1000 parts bay water. The effects of tidal phase on the distribution of the plant effluent are evident by a comparison of these two figures.

Most of the results presented correspond to problem run times covering the twenty-sixth cycle (approximately 311 to 323 hours) after the initiation of the run, i.e. commencement of the plant discharge. To establish how near the constituent concentration values were to equilibrium and the time at which equilibrium conditions could be expected to be reached, computed maximum constituent concentration levels at two locations in Card Sound, as they occurred during each tidal cycle, were plotted versus time (Figure 17). As indicated by the curve shown in Figure 17 for grid location (3,7), the

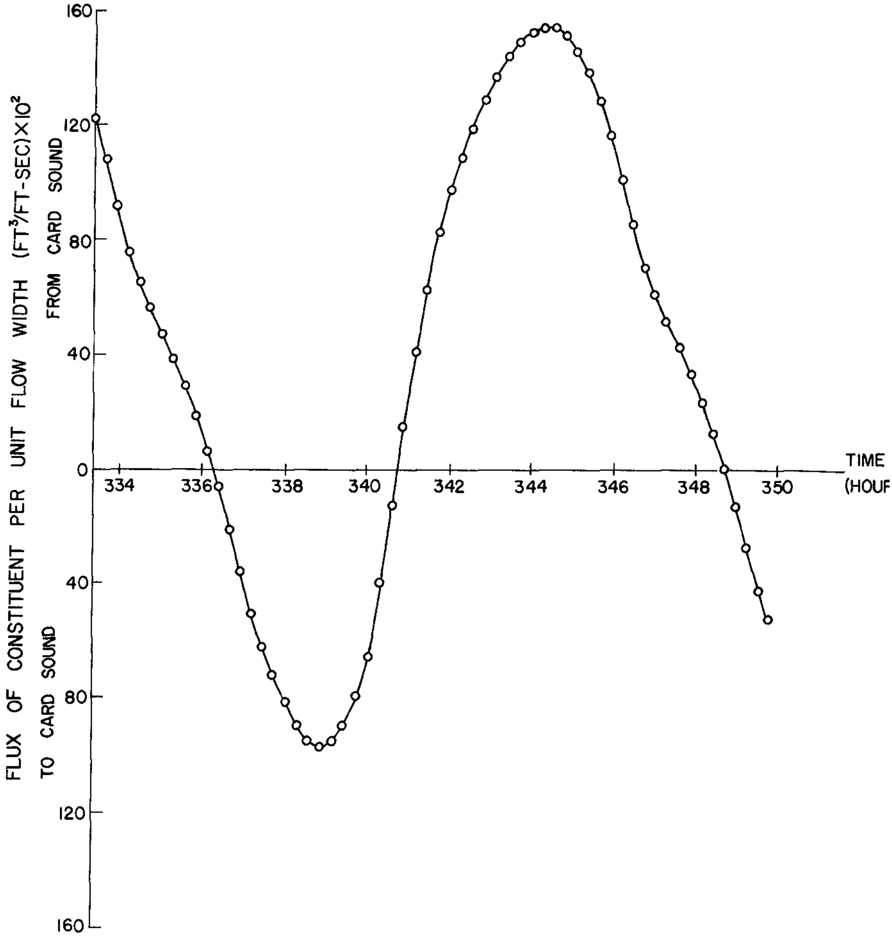

FIGURE 14 TOTAL EXCHANGE OF CONSTITUENT BETWEEN CARD SOUND AND ALL CONTIGUOUS BODIES OF WATER (USING MODEL $\Delta t = 1000$ SECONDS)

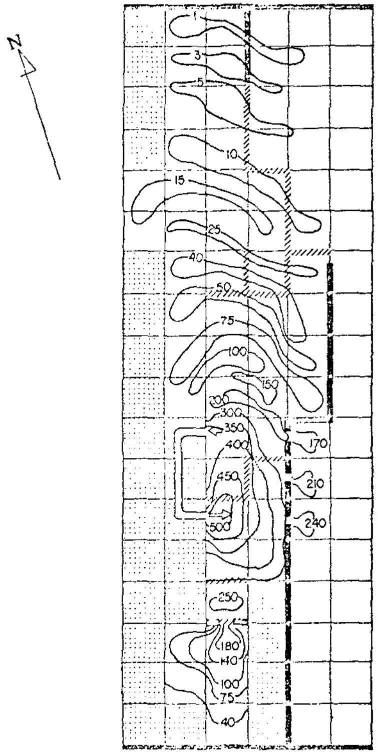

FIGURE 15 ISOLINES OF CONSTITUENT CONCENTRATION (PPT) FOR LOW TIDE AT MODEL LAND CANAL. PROTOTYPE CONTINUOUS DISCHARGE TIME 322 HRS., NO WIND

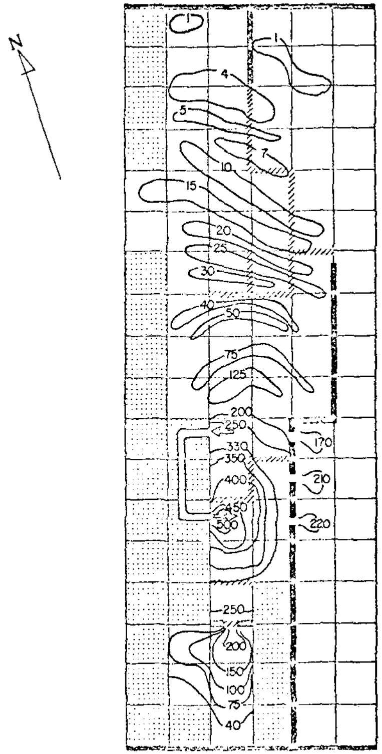

FIGURE 16 ISOLINES OF CONSTITUENT CONCENTRATION (PPT) FOR HIGH TIDE AT MODEL LAND CANAL. PROTOTYPE CONTINUOUS DISCHARGE TIME 329 HRS., NO WIND

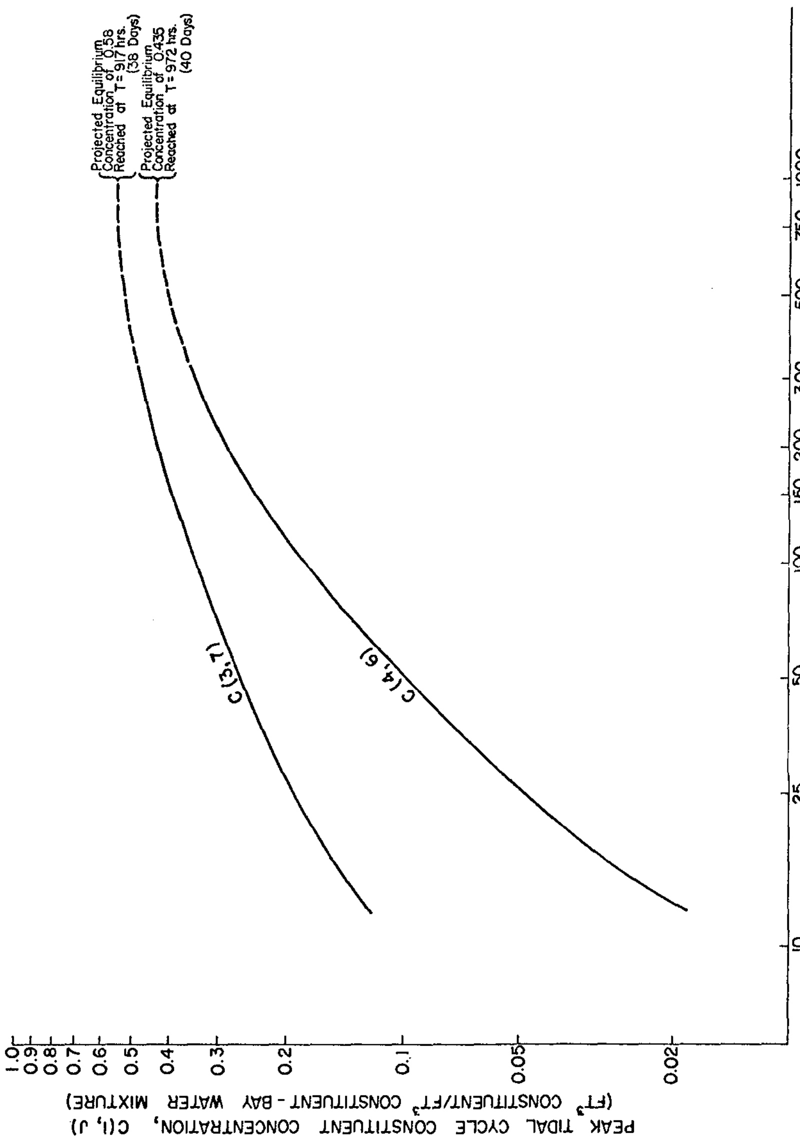

FIGURE 17 PLOT OF CONSTITUENT CONCENTRATION LEVELS AT GRID LOCATIONS (3,7) AND (4,6) VS. PROTOTYPE CONTINUOUS DISCHARGE TIME (NO WIND)

concentration at time T = 330 hours has reached approximately 88% of its extrapolated equilibrium value of 0.55 which is expected to occur 38 days after the commencement of discharge. Similarly, the concentration at grid location (4,6), which corresponds to the region in Card Sound directly east of the discharge canal, for time T = 330 hours has reached approximately 82% of its extrapolated equilibrium value of 0.435. The corresponding equilibrium time for this location is 40 days.

It is evident that the equilibrium time for a particular location in the absence of wind and other climatological variables is dependent upon: (1) the position of the location relative to the discharge point, (2) the presence of predominant currents, and (3) the amount of communication between a basin and adjoining bodies of water. Using these criteria it would be expected that the Card Sound 8asin would reach equilibrium concentration levels first along the western half followed closely by the seaward half. Biscayne 8ay and 8arnes Sound would of course lag Card Sound. Equilibrium conditions in 8arnes Sound, as noted earlier, would be approached very slowly due to the basin's closed nature and the small tides and therefore weak exchange with Card Sound.

Constituent concentration levels existing at the plant intake during the twenty-sixth tidal cycle varied between 28 and 35 per cent, depending on the phase of the tide. If it is assumed that these values are approximately 85 per cent of their equilibrium values (based on the previous discussion) then ultimately a range of 33 to 41 per cent mass recirculation could be expected.

Run No. 2 - Continuous Plant Discharge of 4250 cfs, Steady South-East Wind of 15 Knots

To demonstrate the capability of the dispersive model to describe the effects of varying forcing functions other than the tides, a steady south-east wind of 15 knots was introduced while the other parameters (ocean tide, plant discharge) remained the same. A wind stress of 0.001 lb/ft^2 was applied and surface elevations and volumetric flow rates per unit flow width were computed using the non-dispersive model for each grid element as before. These data were then used as input to the dispersive model which in turn computed the resulting constituent concentration levels, and total transport components of the constituent/bay water mixture as described for Run No. 1.

Due to space limitations, the results of Run No. 2 will be summarized briefly. By comparison of the results of Run Nos. 1 and 2, it was found that the effect of the wind: (1) causes significantly increased mixing of the water from Card Sound with that of the Atlantic Ocean and Lower Biscayne Bay, (2) increases the transport of constituent from Card Sound to Lower 8iscayne 8ay while inhibiting the movement of constituent eastward across Card Sound, and (3) increases slightly the recirculation of the discharged water to the plant intake (from 27-33% for no wind to 28-35% with wind).

SUMMARY

Two numerical models have been developed to represent the non-dispersive and dispersive hydromechanics of a bay system as influenced by tides, winds, runoff and any discharges into the bay system. These models have been applied to the Biscayne Bay/Card Sound System and several examples presented illustrating the application of the model to calculating the behavior of the natural system and the influence of the discharge and withdrawal of water by the Turkey Point, Florida power plant. In particular, the mean flow field and the concentration distribution of a conservative constituent has been investigated. The numerical models provide satisfactory agreement with the limited available field data.

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