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HYDROLOGIC MODEL OP GUAYANILLA BAY, PUERTO RICO

Michael A. Chartock

February 1980

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Table of Compartment Size Results.

D. Listing of Computer Program (hourly

and Table of Compartment Size Results sss eet ee

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XECUTIVE SUIARY

Objectives and furpese: hyarolegic model is developed to

Account foF tne average water flow patterns in Guayanilla Bay

a5 a guide to understand the function of the Lay, to idontsey

controls over nay processes, to qurcribe ImOrtant data un~

certainties, and tt inform decisions ua the effective uses

of the bay.

Wind, tide? forces, industrial pursing an frenmwator input are

The Fajor externa? Forces affecting tha bay, although each of the bay's five major compartimnts are unigue in the extent to which these forces dominate. Prozipitation, evaporation and Ship activity affect the water budget to a much lesser degree. Bottom topegraphy or bathynetry of the bay is the most critical Feature controlling the flux of water and the sigue charac~ teristics of the tay compartrents.

Biologica! procesace control the rate of exchenge between several compartments. Mancroves aze important in the tnermal cove and Southeast Bay compartrents. Seagrasses are important zn the Western Bay, Southeastern Bay and Central bay as they affect

SILL depth ane wind drift,

Wind drift and equilsbratine (wudsurtace) return flows are both The largest flows and those aesociated with the greatest un- certainty. Based on this study a research effort to characterize wind drift flow rates across shallow bay sills, together with

an evaluation of equilibrating return flows in? deeper channels would be the nost beneficial studies for predicting the physical behavior ef Guayanilla Say.

Managenant options affecting the bay can influence the bay's

Productivity, use ae a port, and the characteristics of water

?used for powor plant cooling. Wind, gconorphology, and intake

?and discharge location have the greatest control over power plant

Cooling water intake tonserature, sills between bay compartnents

and the freshwater from surfece and aroundwater of the Yauco and

Guayanilla River watersheds have the greatest control over

biological productivity (from a hydrologic standpoint). Currents,

and biological communities could be managed to control sedinentation

Fates and stabilize bottom topography. ?Thus, managenent decisions

in development of the bay can be informed by'a hydrologic model

to sustain and enhance productive uses in an efficient manner.

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Resumes

Gbjetivos y propésite: se desarrollu un models hidrolSsico gue con Siaera ei patron de! flujo prowedio fe las agues de la sahfe de Guayanilla, £1 misno sirve de gufa pare corsrende® el funciona siento de 12 bahia, identifsea Io que cuntrola sus procesas, describe ac icentidusres relacionadas con datos importantes © in-

forma qué decisiones deben tomarse rare eu so efactiva,

EL viento, las fuerzas de lat mareas, cl bonbeo de agua para usos industrialer y el agua dulce aportads por los rfos constituyen las fuorzas exterran mayores que afectan 1s bahia aunaue cada uno de S88 cinco divisiones principales (compartanicntos) son gnicas en el modo de estas fucrzas cjercer su influencia. ta precipitacséa pluvial, le eveporacién y el tréneito morftine afectan ¢] sistema hidrolégico en un grado menor. La topogragta subrarina y la bati-netrfa de la buhfa son los Factores nas erfticor en el control del Muse de agua en 1a bahia, siendo adenix caracturfeticas de natura leza fnica en las comartinientos que eonponen ia misma.

La estructura biolégica afecta 1a hidrolcefa de 1s bahfa mediante el control de las tazas de intercarbio entre sus distintas seeciones

© conpartimientos. £1 manclar es inportante en los compartinientos ennareados por la caleta ternal y el sureste de 1s bahfa. las pre: @eras de faneréganas son inportantes en las secciones delinitadas por el oeste, sureste y 1a parte central de la banfa donde Getas afectan Ia profundided dol umbral ce la bahfa y el material acarreado por los ventisqueres.

Los flujos de agua resultentes de 12 taza de anontonaniento por les ventisqueros y retorno al equilibrio son los dos tipos rie grandes de corrientes que a su vez estin més sujetos a inconsistencias © vagueéad. De acuerdo a este estudio, serfa beneficioso llevar @ cabo una investifacién para caracterizar las corrientes provenientes de anontonaniento de agua por los ventisqueros a traves Gel wibral ge banfas Uaras junte a una evaluacién de flujos resultantes de contracorrientes de equilibrio ex canales profundos. De esta manera se podrfa predecir el comporsanionto fisico de 1a Bahia de Guayanitita, Las opciones 0 alternativas de manejo que afectarfan 1a bahfa podrfan

muy bien influeneiar eu productividad, su uso cono puerto y las

caracteristicas del agua a usarse para enfrianiento en las centrales

generatrices. Su geonorfologia y 1s velocidad del viento ejercen

lun mayor control sobre la tenperatura del agua a usarse para enfri-

aniento. Los unbrales entre los distintos conpartinientos de la

banfa y e1 agva dulce de suverficie y niveles freaticos de las cuen=

eas pluviales de los fos Yauco y Guayanilla tienen un mayor control

sobre la productividad biol6gica (desde el punto de vista hidrolégico) «

BL desarrollo de puertos podria ser afectedo por corrientes marinas

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Y comunidades biol6gicas que controlen 1as tazas de sedlmentacién

¥ evtabilicen la toposratfa submarina. be arta rancra las deci~

Siones y el desarrollo de a bahia podrfar, scr influenciadas por

3a informacién generada por un motel hidroléqico de manera gue Se

Puedan sostener y aunentar sus uros productivo> de una manera

eficiente en cuanto al costo.

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HYDROLOGIC MODEL, OF GUAYANILLA ERY

Michael A. Chartock

Marine Ecology Division

Center for Energy and Environnent Research,

College Station

Mayaguez, P.R. 00708

1.0 nerRopucTroN

The hydrologic flux among geographic arcas is an important process mediating the transfer of energy and materials in the coastal zone. In the coastal bays of southern Puerto Rico this flux is affected primarily by wind drift, tides, runoff (Xunel and ladjathwodorou, 1970; Golénan, 1979), industrial cooling water punping, and groundvater flow. Storm Surges and ship traffic atfect the water budget lees frequently or on a snaller seal

This paper describes a hydrologic model of Guayanilla Bay, Puerto Rico (ig. 2). The model accounts for the macs balance of wacer among five major hydrologic subdivisions (or compartments) of the bay, describing @aily flux as an average of everte that occur on an hocrly, daily, monthly, and seasonal basis. It is useful for understanding the relative importance Of eifserent flows, their respective controls, and their effect on habitat types and industria} uses within the bay. The mde! is based on the information summarized below and appended, and should provide a reference for acquiring improved data for more accurate prediction and management applications. This model is one part of a series of models that deseribe environmental and economic processes in Guayanilla Bay and its surroundings that are formulated at the harine Ecology Division, center for Energy and Environment Research, Mayaguez, Puerto Rico.

Guayanitle Bay is located on the south coast of Puerto Rico (Fig. 1) and consists of the five sub-areas (compartments) shown in Fig. 2 and characterized in Table 1. Conparement boundaries are defined by sub merged bars, jetties, headlands, seagrass beds, cays and dredge spoil Danks. Sills shallower then 0.7 m are indicated in Pig. 2 and are critical for isolating several bay conpartrents. Openings, including channels and pipes or other industrial structures, facilitate communication between the compartnents. This communication or "interface" between compartments, eccurs along the exposure between subareas, and is in part dependent on depth characteristics (see Table 1 and Section 2) +

2.0 SOURCES OF WATER MOVEMENT

Five primary factors affect water movenent in the bay: tides, wind @rite, runoff, groundwater, and punping of industrial cooling water. Aasitfonally, ?shipping ané storm eurges can oceasionally effect coastal water flow. ?Quantification of these parancters in the following sections provides the basis for developing the generalized annual hydrologic budget, Rodel presented in this paper.

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2.1 Tapes

The tidad range at Guayanilla Bay varies between 15 to 45 cm

(ge, 1972) with a daily everage range of 30 am.) Based on this range,

£10x for the bay is 2.65 x 10" m3 daily. Tidal flux is a small proportion

Of Central Bay volun: (78). However, tidal flux is a large proportion

Of tho water volune of te Western Bay (20+), and is significant in

the other shallowwater compartmints. The Hestern Bay may be the nost. "powerful" in terms of productivity and respiration (Chartock, in pre paration) so that the exchange of materials through tida! forces is critical for the bay system.

2.2 WIND DRIFT

Surface water novenent in Guayanilla Bay has a significant inflvence from the wind (Goldman, 1979). Surface wind drift has been reported as 2.6 to 5.8 ¥ of wind velocity based on a review of 16 coastal and eceenic studies (Lange and Wuhnorfuss, 1979). In shallow bays with Limites fetch, Goldman estimates that drift in the upper (2-3 meters) mixed layer is approximately 1¥ in South Coastal Caribhoan Bays, a2 supported oy studies during 1977 through 1979 (Goldman, 1979). ?This is in near agreement with estinates of 2-34 for fetchoc of 4 to 10 km summarized by Von AEX (1960), Estimates of surface water movenent induced by wind at Guayanilla Say tabulated in Table 2 are based on average 24 hre. wind velocity of 2-9 m/sec (see Appendix A). The average vector of the wind is easterly, shifting

fom the southeast (120°) to the northeast (60°) on @ diurnal basis.

Water movenent at the Caribbean interface is affected by circadian fan seasonal variation in wind ¢irection. This effect is dve to the southern exposure of the Central Bay - Caribbean interface and results

in switching the wind drift in and out of the bay. This switching te not yet verified with drift bottle seuases (Goldman, 1973). Thus. wind Vector fluctuations mst be accounted for to estimate flows. As surnarized in Appondix 4, to directions of wind predoninate: northeast (60°) at Right, and most of the day during winter months (January through March) 1 fand southeast (120°) during the day most of the year. The northeast component is dominate approximately?50% of the tine, and the southeast ?component is cominant 60% of the tine. These two average wind vectors are included in the wind drift data surmarized in Table 2. As indicated in Table 2, the volune of flow from wind dzift is most significant for

the excosed Central Bay where surface water drifts into the bay Guring

the éay and exits at night.

The wind driven flow entering the bay is 2.92 x 108 m3 and the flow ariven out the bay is 1.95 x 106 m9 daily. ?These quantities compare with the 2.65 x 108 m} per day moving by tidal forces (see Section 3-0), Howe ever, the wind driven circulation of the bay is a critical variable for he exchange of water in Guayanilla Bay since this factor fluctuates sea sonally and dailv, and may control upwelling (see Section 2.6)

Watioval Oceanic and Atmospheric Adniniscration data from Ponce. Confirwed with selected monthly measurements at Guayanilla Bay (Chartock, in preperation) -

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TABLE 2

hydrologic Flux Sumary®

(108 n? per day)

Compartment Wind ngustrial Wano®® and

Compartment Vortine ?tidal {Surmary) Puncing Groundvater

Western Bay 3.30 og 1.82 - 0.072

central pay 37.6 2.65% 3.89 - 0.150

Intake 1.38 oma a3 te 008

Therma cove 0.52 oor 67216 002

Southeast 1.56 1246 4.08, - -

Exbayent

?total 44.33 aes = - 202

Data tabulated are aggregate flow. Separate flows anong compartments:

are presented in Table 5.

b, The tote {lux of the bay system passes through the Central Bay

(volume of Central Bay changes 1.30 * 106 m) uring s tial cycle).

ce Mind drift estimate of deeper channels based upon movenont of upper

Sn of water at 1% of wind velocity (2.9 a/sec). For shoals or sills

where this depth was less than 3 m average sill depth was used, See Appendix

B for detailed wing drift aca.

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2.3 INDUSTRIAL PuMPING.

Hydrologic budgets of the intake, thermal cove, and southeast en boynont are affected uignificantly by the Costa del Sur Ofi-fired Power Plant, which operates by once=through sea water cooling. iien all six units? (boilers) are on-line, the cooling water flow is 37.6 m/sece

Tais plant operates with a power factor of approximately Got so that estimated pumping is 2.16 x 10% m9 per day. This pumping alone exchanges the volune of the thermal cove five times daily.

2.4 RUNOFF AND GROUND

R

?re Western Bay receives runof? from the Yauco River Watershed, and the Contral Bay receives runoff fron the Cuayanitla and Hacafa, RIVET. The Yauco River is impounded at the Luchetti Reservolr, and some flow ia diverted out of the watershed, The river valleys in all the watersheds in Fig. 2 are developed for irrigated agriculzute, prinarily suger canes Runoff is highest in June through Novenber, and low from Ducesber through May. The average annual streanflow for the Guayanille Rives, measured approxinately two kn upstream from the bay discharge, is 29c6 108 m3 per year: for tie Yauco River is 13.5 x 10° a? per years and for the dacaia River i 9.8 x 106 m! per year (Crooks, ef wiv 1968). Sumary @ata for watershed flows are included in Appendix Be Potential wager entering bay compartments from groundwatar and runoéf is 26+3 x 108 mo por year to the Nestern Say and 54.3 x 106 = por year to the Central Bay.| Actual freshwater entering is Iikely to lu somewhat less ave to donestic freshwater use and evaperation in agriculture:

The geological structure of Gusyonilla Ray is heterogeneous with a karst topography in Miocene Limestone that outcrops at the surface (Worelock, et al., 1979). A variety of marine and alluvial sediments occur et the surface. Both the Limestone and unconsolidated sediments serve as aquifers, and the alliviun hae been extensively developed for irrigation supply.

Groundwater influx into the bay has been estimated from average grouévater flow along the south coast of Puerto Rico. A daily average Gischarge of 2.1 m3 per Linear foot of shoreline has been eatimared (euerto Rico Water Resources Authority, 1972). This estimated value 4s within a factor of 0.5 of the groundwater flow from the watersheds above Guayanilia Bay estimated by the U.S. Geological Survey (Crooks, 1968)

?The freshwater flow is small as an annual average, approximately 8.08 of the tidal flux, but seasonal variation and individual storm events can make this a very important factor, with sone measurements of eek runoff of 1.4 x 106 m per day for the Guayanilla and Yauco Rivers

?Rises Gata are Pased Gh ou evaportrancpiration losses of water entering the lower basin, based on similar loaves in U.S.G-3. upper basin measurements.

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(almost one-hal£ the tidal flux during hich rainfall perisa:).) te

freshwater flux is also smportant for mairtaininy the brackish water conditions of the Western Bay, and thi: in a critical physical factor in structuring the biotic community and its energy flow patterns.

2.5 OTHER souRces

Four other sources of ivarclegic f1ur occur: precipitation, evacor Bion, storm surges (storm tides), channel dredging, end ship traffic, ?These sources of flux, however, are either small of infrequent. Direct Precipitasion fron the annus average rainfall of 30 cm in the rClatively arid coastal environnant (Cintrén, tugo, Pool ana sorris, 1978) results

in an addition of 7,409 mi of water annuslly, divided among bay compartments according to surface area. Most of this addition occurs from May through October. This flux is abcut three orders of macnitude smaller than categories shown in Table 2,

Aznual pan evaporation is 19.9 inchwe at Ponce, with very sinilar Values at Guanica and Sabana Grande (Seat, National Occanse end Atmos~ pheric Administration, personal communication tlovensur, 1379). thin Eerults in a flux of 18 x 10° md annually cr aperoaimavely 49,000 mi Gaily from the entire bay (see Table 1)

Storm surges accompany the tropical depressions, storms, and hurri~ canes that frequent the Caribbean. The hurricane force wines and storm Sarge contacts Puerto Rico an average of once «very six years (Puerto Rico Water Resources Authority, 1972). These storms have different intensities, Dut a aoximun expected stom surge along the cout coast would result in about 3m storm tide (Puerto Rico water Resources Authority, 1972). Tals tical stend woul! pass duping a two to four hour period and result in a displacement of 26 x 10° m? about one-half the volune of the bay.

The large container ships and tankers entering Guayanilla Bay dis~ place approxinately 100,000 metric tons, or 48,000 m3, An average of

fone tanker enters and leaves the bay daily (Puerto Rico Port Authority Staff, personal communication, 1980). This exchango occurs av the intor- face between the Central Bay and the coastal water. Thus, Water movenant due to tankers traffic is similar in magnitude to evaporation water fli, although very localized.

?Wish Greater rainfall Occurs during tropical storms. Uncontrolled

runoff from the three drainage basins can be equivalent to 1.9 x 107

(10 om of rainfatt over a 24 hour period in the drainage basin). This

As about 0.4 tines the volune of the bay. Much of this runoff would

be released within a one day period (Gragg Morris, personal communication) «

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Water Flux from Precipitation and Evaporation

(003 m per dey!

Direct

Location Precipitation Evaporation

Western Bay 2. 16.9

central say 10.60) 23.9

Intake 0.94 an

?Thermal cove 0.58 nat

Southeast Embayment 2.00 4.49

Total 20.7 49.00

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Propeller pumping by 2,000 horsepower tugboats displaces water

across the bay - coastal water interface. ?The tusboats have a thrust

that moves 29,900 m? per minute. Approximately four tusboats per day

transit the mouth of the bay, each crossing in an avorage of five seconds

?over the Central Bay - coastal interface, This results in an estimated

Localized movenent of 10,000 m3 of water in each direction.

2.6 EQUILIBRATING FLOWS

bguilibrating flows are established in the bay that maintain the volune of compartnents. fquilibrating flows are the result of gravi~ tational force that results in flow to establish a uniforn (level) geo-potential surface. For example industrial pumping reduces the volume of the Intake Bay so that water flows into the Intake Bay from the Central Bay to re-establish equilibrium. tn this case, surface water of the Intake Bay is moved by wind into the Central Bay, and an equilibrating flow is the cool bottom water from the Central Bay. This novenent of bottom water has been substantiated by Grogue and temperature studies (Golénan, 1979). The size of equilibrating flows are nass balance estimates of counter currents. They are based on the assumption that the average daily volumes of the Guayanilla Bay compartnents are constant, (see Section 3).

Increased easterly winds force surface water into the Western Bay. A bottom equilibrating current from the Western Bay is established as a counterflow that exits a narrow channel near Punta Verraco, resulting) in an outflow of turbid Western Bay water into the Central Bay. this Flow 4e substantiated by observations of the extension of turbid Western Bay water that noves east into the Central Bay and then south along Punta Verraco.

3.0 MODEL AND PROPERTIES

?The model of the bay storages and flows is shown in schematic form in Fig. 4, indicating the inputs and discharges of water and the flows among compartnents. The external energy sources are listed in Table 4 with a summary description of the magnitude and type of force described in the previous section. The flovs are listed in Table 5, including the origin or source compartnent when the source of flow is within the Guayanilla Bay aysten. The transfer coefficient, or proportion of the source compartment that flows each day, is also provided. The largest flow is an upwelling equilibrating counter current flowing into the Intake Bay, largely the result of westward wind drift and industrial pumping. Generally, wind driven currents and equilibrating flows are the largest flows between compartments.

?the exchange of water in and out of the system as a whole, however, As dominated by both tidal flow and wind, Wind drives about 108 sore water into the bay (J4) than tide, but tides flush much more water from the bay (31) than does wind (93). The magnitude of the equilibrating flow out of the bay is directly related to wind velocity.

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TABLE 4

External Energy Sources

Energy

source Name Notes

1 Tide 30 em sea

' elevation change

> win average 2.9 m/sec

: Streamflow and 87 x 106 m? per

Groundvater year from water~

shea

Precipitation 90 en/year

Evaporation 200 en/year

I, Shipping 60,000 m3/day

ty Industria? pumping 2.16 x 108 m3/eay

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?The intereelationship anong causal forces and storages that determine

syston behavior is provided in the system equations in Table 6 and shown

in the energy circuit diagran in Fig. 5 (Odum, 1971), Appendix C contains

the hydrologic model written in BASIC with annual average values used for

external energy sources. ?The simulation results are aleo provided. AP pendix D lists a nodel that includes 24 hour wind direction shift and

25 hour tidal day. The equations and computer model can be used to predict responses to changes in either the external energy sources oF

the physical and biological characteristic that determines the transfer rates within the Guayanilla Bay system.

Examples of biological properties that control system behavior are the mangrove forests and seagrass beds that control the rate of water movenent across channels. Mangroves determine channel width and the seagrass beds stabilize bottoms and reduce wind driven currents (Scoffin, 1970).

Many of the physical and biological structures controlling hydraulic flux have been manipulated by dredging, constructions of jetties, and by industria? pumping. For example, chanaing the intensity of inévstrial punping Graratically alters the degree of upwelling in both the Intake

and Southeast Bays. the effect of decreased punping on the Southeast

bay would be to substitute coastal water for the surface waters originating din the Intake and thermal cove areas. The anount of water upwelling in the Southeast exbaynent would nearly double if the industrial pumping ceased. The inplication of selected managenent options for effective use of the bay is briefly described in Section 5 and in the Executive Summary.

4.0. MODEL VERIFICATION

Much of the data used to develop estinates of system parancters are based on measurement of relatively stable characteristics such es shore Line dimensions and bathymetry. Howover, many system parancters are not @irectly measurable, are stochastic (with a high degree of variability), Or mist be inferred (e.g. the equilibrating flows). One purpose of the model is to identify paraneters that critically affect system behavior but that are poorly understood.

Sunmarized below are selected descriptions of the reliability of model dats and some observations that substantiate fundamental inter relationships.

4.1) STORAGE VOLUME

Compartment sizes are based on meagurerents from National Oceanic and Atmospheric Administration Navigational charts.1 These have been

?Wational Oceanic and Rtrospheric Administration, June 3, 1978 11th

Edition. Charts No. 25681 Bahia de Guayanilla and Bahfa de Tallaboa.

---Page Break---

TABLE 6

Syston Equations @

eS

1.) = Western Bay (WE) Volume

BTS KTR RT, + RTO, - T,0, + mGt,2, =H

2. Q) = Central Bay (cP) Yolune

2 Raby = ByTWRy = KyTyOy + Katy + MyPy ~ KeIgO> + RTO, ~ KyI\O,

1 Ey = Fabsa * Mel * KT, - 570 TO, ~ BOD

TBaRaPs Bur @y * BYERS ~ by@ ? 150) + Kt, - K,1,0, 7 Intake Enbayment (I) Volume

BS Mets MyTeO) + Ty MI) KE, - KI, + HO, ~ KIO

4.0, = Thermal cove (72) Volune

~RebSRe IST Maly TKS = ATW, - TO, = Tyg

5. Southeast Ebayment (SES) Voluse

BS MGR NES REM RTOS HRT, KT) = KTR,

RRs * 1h) 440,

a. O= rate of change of 9

7

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---Page Break---

selectively verified by depth soundings of the bay during Pall, 1979.

Field trip checks on the geographic Soundsice have buen Proviged by

reviewing areal photograplis and by cruising along the shoreline to

verify land - mangrove inundries. aj measurements are Trobably accurate

within one percent. Average dejehs cf Lay compartments are based on

map reacurenents of fin. tronsests in each cortartmnt, with an estimated

error range of 2. Overs] compartment cine error is within Ste

2 coRREntS

Verification of water movonents is based on drogue, current meter, and dye studies of current velocity, These studies substantiate wind velocity and surface current measurements in open water areas. However, Getailed confirmation of wind-current relationships have not been made. Related studies of wind drift indicate variation of 10 to 300 of actual values (Lange and Muhnerfurs, 1979).

?The existence of all uautlibriun currents has peen substantiated with drogue studies (Goldman, 1976). In addition, the gunezal re lationship between winé velocity and the magnitude of equilibriue (return) Hows is substantiated by observations; for example, of the extension of turbid Western Bay water inte the Central Bay. Wind and current velocity relationships are also substantiated by multi-depth @rogue observations (Goldman, 1972).

4.2 FE

SSHWATER INPUT

Surface water inputs have annual vaviation of + 406 of the mean enoual flow. Although large yearly veriation in runof£ cecurs, the tong term average yearly runc!f values used in this report are probably representative within 10-20%.

Growndwacer flow gata are subject to considerable uncertainty. Wiowever, total freshwater influx can be verified independently by calculating dilution of Caribbean water in the ay. Dilution of Western Bay waters occurs to the range of 28 to 33 perts per thousand salinity, Total freshwater Tloe data used in thio report are consistent with thio range of salinity given the rates of tidal and wind Griven water flux (sce Table 7). Salinity stratification and mixing data have not been evaluated, however, and error ranae is uncertain,

5.0 MANAGEMENT IMPLICATIONS AND CONCLUSIONS

Goayanitia Bay ix a complex, multicompartnent estuary with distinctive sub-areas. From a physical standpoint, the hydrology is affected by

Runerous Separate forces that collectively characterize the bay. Prom

a biological standpoint the bay compartments also function distinctly,

but are highty interdependent (Chartock, in preparation). The hydrologic

behavior of the bay can be managed to affect its biological properties

and human uses az an "Industrial Marine Ecosystem? (Tilly, 1979) +

1?

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ante 7

Relationship of Salinity to Flushing in Western Bay?

a

Salinity ia accunulated

Western Bay Fraction of Volume of Flushing

(feed Fresh 1,0 Freshwater ?Tame

es

28 186 622,000 5.635

23 1598 $26,000 7.3067

20 29 430,000 5.97

2 10 334,000 46

32 237,000 33

3 108 143,000 2.0

Central Pay aas a salinity of 34.5 parts/thousand,

and that the voluto of the Sestumn Bay of 3.3 x 100 Bo ena roves

freshwater input is 72,000 m? per day

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5.1 MANAGEMENT OF

?The relative ssolation of the Western Bay fron the Central Bay can by modifica by dredging the shallew il that separates chess conpartnent®, as onc cxsmle of a menaqument action. The sill depth and widsh parancters influence the strata of water that enter oF leave Bay compartmnts and ths source of water for oguilibreting return flows. The channel, for example, that penetrates tne sil] near Punta Verrace Provides for the equilibratins flow of accper, poorly oxygenated water Out of the Wostern Hay to the Central Nay, ana nay be one factor maine taining the oxyyen concentration in the autrorhie Western bay {Chertocks preparation) that sustains 2 nnall commercial fishery (cole; 1976), Thus, effects of alternative dredging plans on the transfer coefficients for wind driven currents and fer equilibriun return flows should be evaluated with tho models such as the one describee heres

Dredging is a continving process ured by industry in Guayantlla Bey to maintain adequate rort conditions. Suspended nacerials in shallow waters moved by the wind drift are a major source of sediment that te Eransperted in the bay. The sediment buugot of the bay can be managed to reduce or divert sediment sources to minimize dredging expendi teress

Banagine biological yopulations that stahilize the bottom ray also Bo a Rechaniam to avoid o minimize costly éredging programs. The model des scrived here orly provides an initial franewr! for sediment manssencets A detailed sedinent budget is needed to implenent an effective stable ization program,

5.2. WATERSHED waacrMeNT

Groundwater and surface water flovs are inportant for maintaining the biological an¢ physical characteristics of the Western aay such ae comunity composition, productivity, turbidity, and total particulate matter.

The freshwater flow is dependent on surface and subsurface develop pont of the watevshed (U.5.G.8., 1968). For example, imeroaned ground. water pumping coupled with severe drought, can result in sea water ine trusion from the bay into the alluvial sediments in the Guayanilia Valley. Development of storage and groundvate: recharse capacity im the three rivers that enter Gcayanilla Say, noeds to be evaluated as a mechentom,

fo both naintain continued groundwater use and sustain brackish water

conditions in the Western Bay. Periodic floods affect the shoreline and

bathymetric characteristics, especially in the Western Bay. Management

Of the long term average flows of freshwater can easily be included tm

?an evaluation based on the model prosented here, but the dramatic changes

Produced by periodic floods require additional ?model parancters.

5.2 INDUSTRIAL INTAKES AND DISCHARGES

Industrial pumping enhances upwelling at the boundary between the

Intake and Central Says, and reduces upwolling at the mouth Of the Southeast

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Bay. Although water charactorsstien are medified in the bay

aysten by this industria} aps svarion (Ayes, 117%), tw mydrolecce

flow bettwer tha trupreut arta veto sai aleng the Goast and central

TEE water Se not atfvctrd. This aster uxsnuoge ie exitieal dn affecting

FR Pysicad and tictosicai characteristics uf the bay. Alteonacion industriel intake ad dischaxge 2ccazions must ?x compared eoatane the pigrologic exchanges within th. bay ard Setwocn the Bay ené oe coanee rer sfamelny option to decate Ue Corea del Sur Power Plant dischecge Spbside of Cuoyanilla bay Un th> aGjacent Tullabos Bay) woud elinioate She cetlivoun rosur, flow (o-3s in Tabie 3) fron eke central Se greatly increas the amount of coastal water ontering the bay wien ton Pogential for subscantial change in the ?Eay'y ;hysteal and biologees Gheracteristice- In this regard, che total Buy systen's nycrolonie smPutmourput budget ir move like a natcral eygten in ive torent seme figuration than with sone alternative uproaciices ?The achat hereon Rot that altvrnatives aru better or worsu, Dut that the oueconee mend seen geamestwely compared for the entize bay when evaleating eanseee rent opt.

Onc mator Use of tne bay as & rosourse is to naintain oF smprove

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scale Southeaee ay tutlcaily aaue soe return to the aneake, sieerily

Mace wee, Sg metting caused 7 the consination of surtace wind and Paeetg,

Soreaee age Gein alone weze functioning (ive, £2 there were ao umelingg),

TEE tne BURE MOSIE enter che power plant pulling in water that has free

Jefe the Southeast say, Thus, even small wind velocities peo

ser geet ?ASSES aE a average of 2A" from subsurface waters at an avorete

cepreecne ME, giamisicantly inprovze poxer plant efficiency. ?Tania aoe

FETSeet 8 Fecustion in cose of $5,000 20 $10,000 dally, depending a fuel costs.)

Because water exchanges are affected ty wind and bathynetry, managers of, thebay should be careful in adjusting hathymetey or toneetetiy? erat mnnea ERE Ne Wied regime, especially on the eartern narsine of the fey where wind ofsects are post closely coupled with man's aves ang utce wind fetch is short and potentially effected by shoreline oa feation.

5.5 RESEARCH TuPLIcATTONS

Aouige Fang of rescarch has been conducted in Guayantlla Bay to Shefacterize the physica? and biological structure of the say ange ehe Abgtwence of industrialization (Gonediez, 1979). ?The model susmerkeed nore an be used to review this research against the needs of anne Ekphaing the function of the bay, and to inform planning ana Gocvcion

Baking by industrial, governsontal, publie and private interest seoseae

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eters used in this node) are subject

fe mecttainty, som: are more eri seat than others to widcrseenden eae

bay's function. Thy mart eritical anzluacn the aagnitude of wine artes

acrous shallow 2121 extent of equilibrium flows. Other important

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Sedinente by Marine Vegetation in Binini Lagoon, Eahanas. Journal of Sedinentary Petrology. Vol. 40(1): 249-273.

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APPENOTX A

Wind Leite Data supplenent

Wind Speed ang

Wind speed data used in this report are based oh 8 years of ?observations taken at Santa Zsabel Airsort during the period 1946-1953. These indicated an annual moan wind speed of 3.5 n/eee, a Less comprehensive set of data for Tallaboa bay, (adjacent to Gueyanilla Bay) show that winds recorded over the one year period beginning Sune 1, 1975, and ending may 31, 197%, averaged 208 w/ces, when

erecta fron the 250 ft measurement level to @ level 19 m above the ground.' Wind vector data are summarized in Tare Ae}. Table Re? Sunmarizes the basis for wind drife flows getween corpartments based on direction of exposure, depth, and the vector of wind velocity,

?Fucrto Bice Water Resources Authority, 1976. South Coast Pousr Plane

Complex. p. 42.

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TABLE At

wine stanistics

Senta Isabel Airport

Santa Isabel, Purrto Rico

Yeah wind creed

B/sec Direction

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peril 2.2 se

Yay 2.9 SE

sure 3.2 se

outy 3.3 se

August at zg

September 2.6 e

october, 24 ?

Novenber 23 Ne

December, 23 ne

Based on the period 1946-1953.

Sources: Puerto Rico Water Resources Authority 1976. "South coast

Power Plant Complex? Table 4. 2-1.

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Footnotes to TABLE Ac2

f

Channel between Cayo Mata and Commonwealth O12 Refining

Corporation {CORCO) Jetty.

Channel between Punta Gotay and Cayo Mata.

Channel between CORCO, Jetty ané Punta Papilio.

Communication from east side of Intake embayment is through

forced punping to thermal cove.

Deep portion of channel from Punta Gotay to reef midway

to Punta Verraco.

Shallow portion of channel between reef (see @ above) and Punta Verraco.

Sectional area for wind drift is the width times sill depth or 3m, whichever is shallower.

Wind drift calculation is based on velocity of wind driven weter through channel. Movenent of water is estimated at

18 of average wind speed (2.9 m/sec), and direction (easterly) « Wand drift occurs in the upper ehree meters unless a sill ie Present, in which case the average sill height is used.

Wind @izection has an annual average component of 120° for 60¥ of the year, and 60° for 40% of the year based on diurnal and Seasonal variations in Appendix B (and summarized by the National Weather Service, 1978). To account for component of wind drire through enbaynent exposure, cosine of velocity component and

time duration corrections have been made for wind vector corrected @aily flow. For most oxposures, this results ina 0-866 correction factor. For the southern exposure of the Central Bay, the correction factor is 0.2 for flows to the south and 0.3 for flows to the north (e.g. cosine of angle of wind incidence normal to

the exposure of the bay multiplied by duration of the wind).

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APPENDIX 8

Surface and Groundwater Data

TABLE 8-1. Annual rainfall on the three principal river basins,

1961 and long-term average.

sn

Drainage Weighted Rainfall

Area cr

River Basin xn? 1961 tong-term

Rio aves

Upper basin, (excluding Lago 39.1 132 163

Lucehetti diversion)

Lower basin %

Entire basin, (excluding Lago 101 127

Lucchetti)

fo Guayanst1a

Upper basin, above stream station tes 196

Lower basin 8 9

Entire basin 145 160

Rio macané

Upper basin 19.5 198 15

Lower basin 33.7 36 6

Entire basin 332 150 150

?Three basins, (

?Euccherss)

Upper basins 50.2 168 180

Lower basins, the Guayanilla~

99

145

Source: Modified from Crooks et al. 1968

29

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TABLE B+?

Annual amount of water received by the Cuayanilla-Yauco River basins,

4961-63 and long-term average.

amount, 10° m?

Source of water a

iverase

Rainfall on upper basing

Rio Yauco (does not include 82 a) os

Grainage area above Lvccheets

ane)

Rio Guayanitla 89 m4 9

Rio Macand 31 B38

?Total rainfail on upper basins 178 151236 191

Streantiow entering lower basins

Rio Yauco (above first diversions) 20 n 16 4

Rio Guayaniila (gaging station) 27 " 2 2

Ro macan ace £ 2 10

?Total sereanflow entering 58 OST 33

ower besine

Rainfall on tower basins

Rio Yauco 2 2 oe 30

nfo Guayaniite 23 2 2 2

Rio Macand 42 BON 15

ee so @

Water reaching lower basins 12 971s 135

Source.

Modified from crooks et al. 1968

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Listing of Computer Program (in BASIC) with Energy Sources Constant

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A HYDROLOGIC MODEL OF GUAYANILLA BAYPRe

By

MICHAEL A. CHARTOCK,

CENTER FOR ENERGY & ENVIRONMENT RESEARCH

UNIVERSITY OF PUERTO RICO & U.S. D.0.E.

January 1960

TABLE OF COMPARTHENT VOLUMES

(HTLLTONS OF CUBIC METERS >

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Limting of Conpvter Progean with Hourly Tidal and Wind Yariaeton

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200 REM REFER TO DAILY VERSION (APPENDIX C) FOR ADDITION NOTATION
349 REM STATEMENTS 490 Of 1600 CONTROL PRINT OR PLOT OPTION

320 REM TO'PLOT CHANCE T600°T0 ?GOTO Good! AND DELETE STATEMENT 490

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15 TF WR = 25,

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928 TE WW = 24 THEN Hu

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950 LET 15 = 4

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Th #02) ~ (KY BTL x05) ~ (KU E12 #05) + C42 a a2d ECL

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TABLE OF HOURLY COMPARTMENT VOLUKES*

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CHTLLIONS OF CUBIC RETERS

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