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HYDROLOGIC MODEL OF GUAYANILLA BAY, PUERTO RICO

Michael A. Chartock

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CENTER FOR ENERGY AND ENVIRONMENT RESEARCH
UNIVERSITY OF PUERTO RICO — U S DEPARTMENT OF ENERGY

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TABLE OF CONTENTS

APPENDICES

EXECUTIVE SUMMARY

I. Objectives and Purpose: A hydrologic model is developed to account for the average water flow patterns in Guayanilla Bay as a guide to understand the function of the bay, to identify controls over bay processes, to describe important data uncertainties, and to inform decisions on the effective uses of the bay.

II. Wind, tidal forces, industrial pumping and freshwater input are the major external forces affecting the bay, although each of the bay's five major compartments are unique in the extent to which these forces dominate. Precipitation, evaporation and ship activity affect the water budget to a much lesser degree. Bottom topography or bathymetry of the bay is the most critical feature controlling the flux of water and the unique characteristics of the bay compartments.

III. Biological processes control the rate of exchange between several compartments. Mangroves are important in the thermal cove and Southeast Bay compartments. Seagrasses are important in the Western Bay, Southeastern Bay and Central Bay as they affect sill depth and wind drift.

IV. Wind drift and equilibrating (subsurface) return flows are both the largest flows and those associated with the greatest uncertainty. 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 most beneficial studies for predicting the physical behavior of Guayanilla Bay.

V. Management options affecting the bay can influence the bay's productivity, use as a port, and the characteristics of water used for power plant cooling. Wind, geomorphology, and intake and discharge location have the greatest control over power plant cooling water intake temperature. Sills between bay compartments and the freshwater from surface and groundwater 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 sedimentation rates and stabilize bottom topography. Thus, management decisions in development of the bay can be informed by a hydrologic model to sustain and enhance productive uses in an efficient manner.

RESUMEN

I. Objetivos y propósito: Se desarrolla un modelo hidrológico que considera el patrón del flujo promedio de las aguas de la Bahía de Guayanilla. El mismo sirve de guía para comprender el funcionamiento de la bahía, identifica lo que controla sus procesos, describe las icentidumbres relacionadas con datos importantes e informa qué decisiones deben tomarse para su uso efectivo.

II. El viento, las fuerzas de las mareas, el bombeo de agua para usos industriales y el agua dulce aportada por los ríos constituyen las fuerzas externan mayores que afectan la bahía aunque cada uno de sus cinco divisiones principales (comportamientos) son únicas en el modo de estas fuerzas ejercer su influencia. La precipitación pluvial, la evaporación y el tránsito marítimo afectan el sistema hidrológico en un grado menor. La topografía submarina y la batimetría de la bahía son los factores mas críticos en el control del flujo de agua en la bahía, siendo además características de naturaleza única en los compartimientos que componen la misma.

III. La estructura biológica afecta la hidrología de la bahía mediante el control de las tazas de intercambio entre sus distintas secciones o compartimientos. El manglar es importante en los compartimientos enmarcados por la caleta termal y el sureste de la bahía. Las praderas de fanerógamas son importantes en las secciones delimitadas por el oeste, sureste y la parte central de la bahía donde éstas afectan la profundidad del umbral de la bahía y el material acarreado por los ventisqueros.

IV. Los flujos de agua resultantes de la taza de amontonamiento por los ventisqueros y retorno al equilibrio son los dos tipos más grandes de corrientes que a su vez están más sujetos a inconsistencias o vaguedad. De acuerdo a este estudio, sería beneficioso llevar a cabo una investifación para caracterizar las corrientes provenientes de amontonamiento de agua por los ventisqueros a traves del umbral de bahías llanas junto a una evaluación de flujos resultantes de contracorrientes de equilibrio en canales profundos. De esta manera se podría predecir el comportamiento físico de la Bahía de Guayanillla.

V. Las opciones o alternativas de manejo que afectarían la bahía podrían muy bien influenciar su productividad, su uso como puerto y las características del agua a usarse para enfriamiento en las centrales generatrices. Su geomorfología y la velocidad del viento ejercen un mayor control sobre la temperatura del agua a usarse para enfriamiento. Los umbrales entre los distintos compartimientos de la bahía y el agua dulce de superficie y niveles freáticos de las cuencas pluviales de los ríos Yauco y Guayanilla tienen un mayor control sobre la productividad biológica (desde el punto de vista hidrológico). El desarrollo de puertos podría ser afectado por corrientes marinas y comunidades biológicas que controlen las tazas de sedimentación y estabilicen la topografía submarina. De esta manera las decisiones y el desarrollo de la bahía podrían ser influenciadas por la información generada por un modelo hidrológico de manera que se puedan sostener y aumentar sus usos productivos de una manera eficiente en cuanto al costo.

HYDROLOGIC MODEL OF GUAYANILLA BAY

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1.0 INTRODUCTION

The hydrologic flux among geographic areas 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 (Kumel and Hadjitheodorou, 1970; Goldman, 1979), industrial cooling water pumping, and groundwater flow. Storm surges and ship traffic affect the water budget less frequently or on a smaller scale.

This paper describes a hydrologic model of Guayanilla Bay, Puerto Rico (Fig. 2). The model accounts for the mass balance of water among five major hydrologic subdivisions (or compartments) of the bay, describing daily flux as an average of events that occur on an hourly, daily, monthly, and seasonal basis. It is useful for understanding the relative importance of different flows, their respective controls, and their effect on habitat types and industrial uses within the bay. The model 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 describe environmental and economic processes in Guayanilla Bay and its surroundings that are formulated at the Marine Ecology Division, Center for Energy and Environment Research, Mayaguez, Puerto Rico.

Guayanilla 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. Compartment boundaries are defined by submerged bars, jetties, headlands, seagrass beds, cays and dredge spoil banks. Sills shallower than 0.7 m are indicated in Fig. 2 and are critical for isolating several bay compartments. Openings, including channels and pipes or other industrial structures, facilitate communication between the compartments. This communication or "interface" between compartments occurs along the exposure between sub-areas, 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 movement in the bay: tides, wind drift, runoff, groundwater, and pumping of industrial cooling water. Additionally, shipping and storm surges can occasionally affect coastal water flow. Quantification of these parameters in the following sections provides the basis for developing the generalized annual hydrologic budget model presented in this paper.

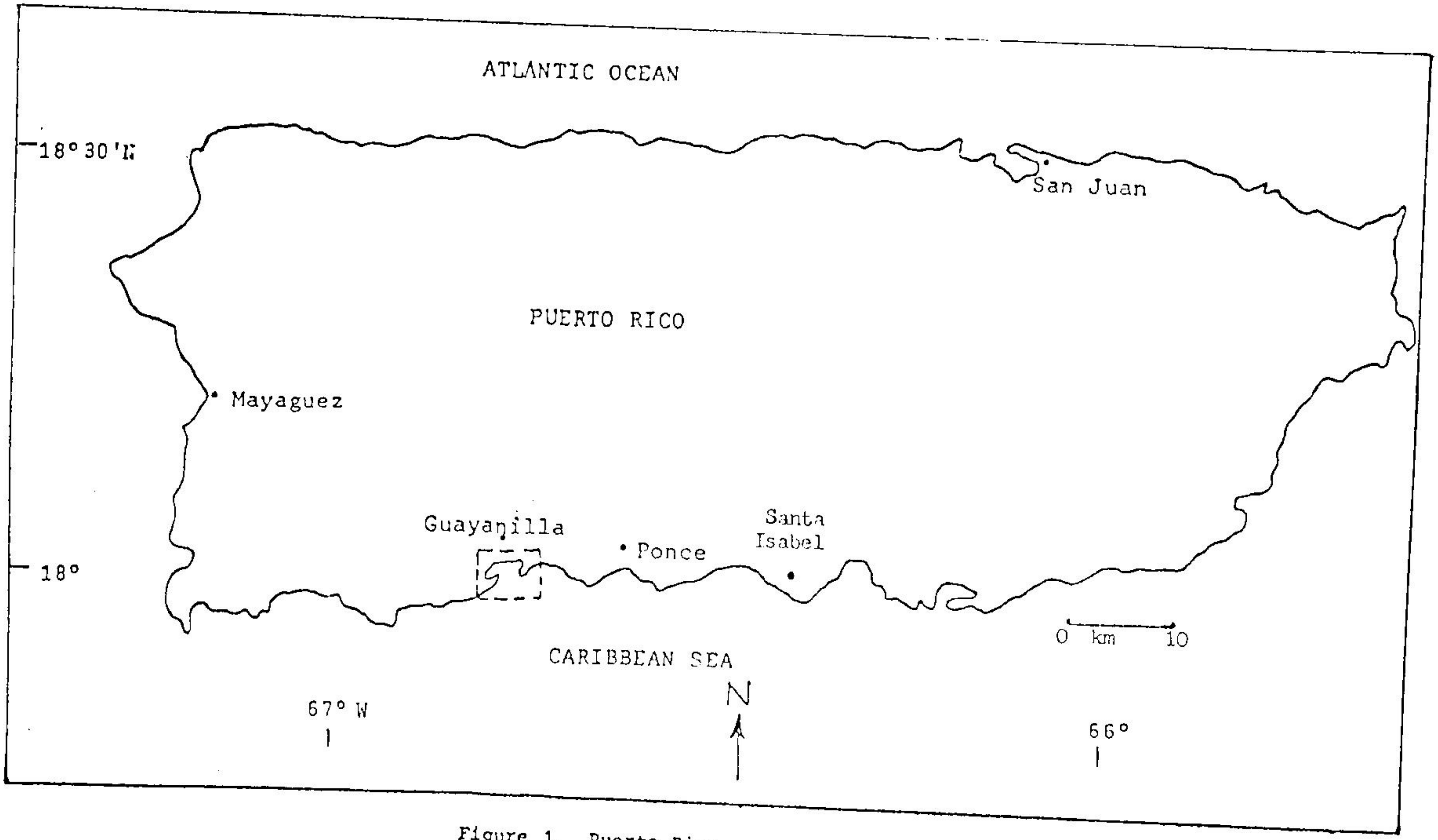

Figure 1. Puerto Rico

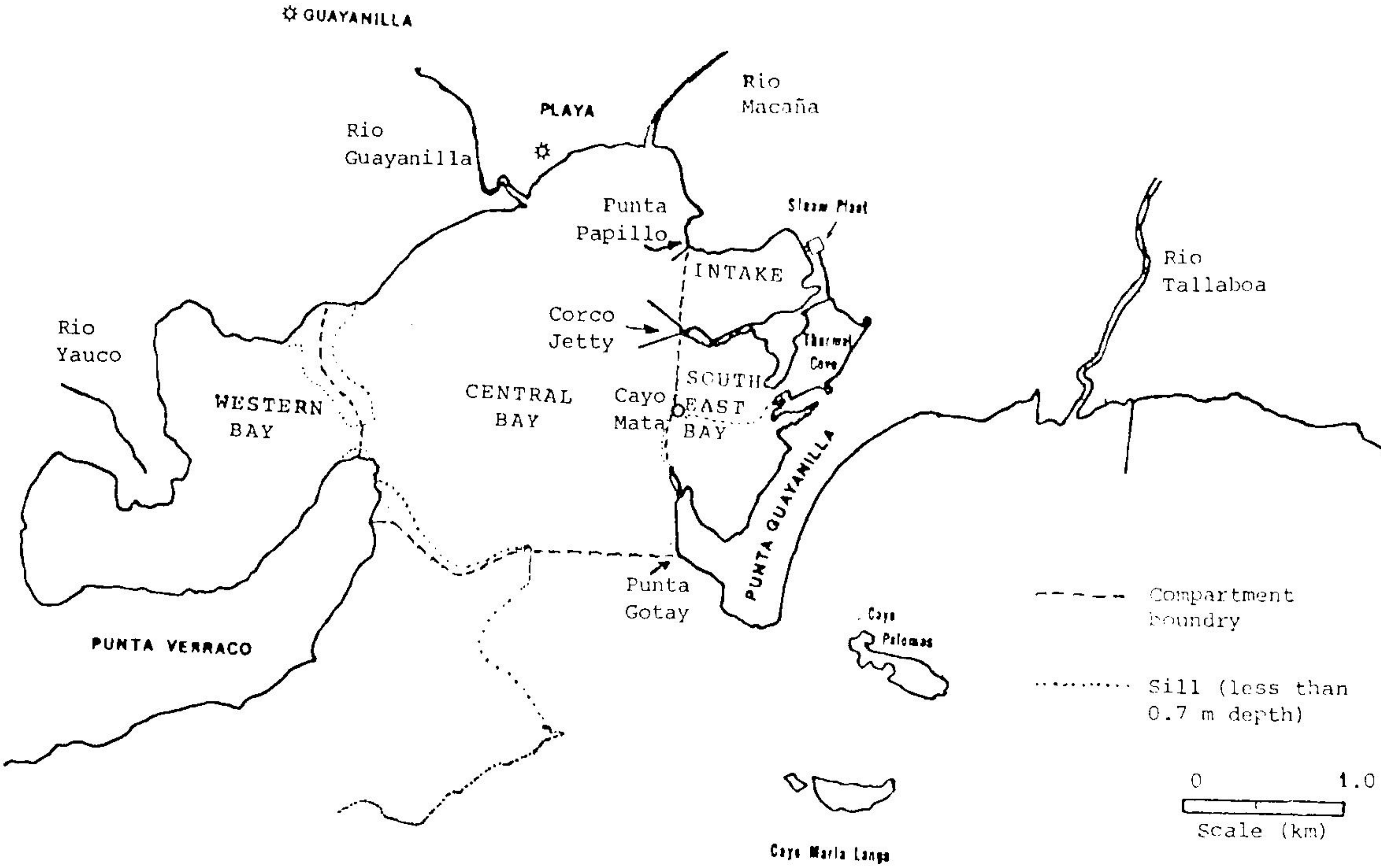

Fig. 2 Guayanilla Bay

TABLE 1

Characteristics of Guayanilla Bay Compartments

Compartment	Area (km^2)	Max. depth (m)	Mean depth (m)	Volume ($10^6 m^3$)	Exposure and Communication: Direction	Length	Mean depth (m)	Section area (m^2)	Dominant Margin Type
Western Bay	3.06	3.5	1.08	3.30	East	1170	1.10	1,290	Mangroves
Central Bay	4.33	19.2	8.72	37.6	South	2280	7.62	17,290	Seagrasses
					West	1170	1.10	1,290	
					East[a]	512	5.23	2,680	
					East[b]	585	1.87	1,090	
					East[c]	549	7.9	4,340	
Intake	0.38	9.1	3.55	1.35	West	512	5.23	2,680	Gravel and rock
Thermal Cove	.24	3.7	2.19	0.52	West	42	1.83	77.0	Mangroves and rock
Southeast Embayment	.81	14.0	1.92	1.56	West[b]	535	1.87	1,093	Seagrasses rocky shore
					West[c]	549	7.92	4,340	
					East	42	1.83	77.0	
Total	8.82	--	--	44.33	--	--	--	--	-

a. Corco Jetty to Punta Pepillo
b. From Cayo Mata to Punta Gotay
c. From Cayo Mata to Corco Jetty
d. Communicates to thermal cove by industrial pumping.

2.1 TIDES

The tidal range at Guayanilla Bay varies between 15 to 45 cm (EQB, 1972) with a daily average range of 30 cm.[1] Based on this range, flux for the bay is 2.65 x 10^6 m^3 daily. Tidal flux is a small proportion of Central Bay volume (7%). However, tidal flux is a large proportion of the water volume of the Western Bay (28%), and is significant in the other shallow-water compartments. The Western Bay may be the most "powerful" in terms of productivity and respiration (Chartock, in preparation) so that the exchange of materials through tidal forces is critical for the bay system.

2.2 WIND DRIFT

Surface water movement in Guayanilla Bay has a significant influence 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 oceanic studies (Lange and Huhnerfuss, 1979). In shallow bays with limited fetch, Goldman estimates that drift in the upper (2-3 meters) mixed layer is approximately 1% in South Coastal Caribbean Bays, as supported by studies during 1977 through 1979 (Goldman, 1979). This is in near agreement with estimates of 2-3% for fetches of 4 to 10 km summarized by Von Arx (1968). Estimates of surface water movement induced by wind at Guayanilla Bay tabulated in Table 2 are based on average 24 hrs. wind velocity of 2.9 m/sec (see Appendix A). The average vector of the wind is easterly, shifting from the southeast (120°) to the northeast (60°) on a diurnal basis.

Water movement at the Caribbean interface is affected by circadian and seasonal variation in wind direction. This effect is due 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 is not yet verified with drift bottle studies (Goldman, 1979). Thus, wind vector fluctuations must be accounted for to estimate flows. As summarized in Appendix A, two directions of wind predominate: northeast (60°) at night, and most of the day during winter months (January through March); and southeast (120°) during the day most of the year. The northeast component is dominate approximately 50% of the time, and the southeast component is dominant 60% of the time. These two average wind vectors are included in the wind drift data summarized in Table 2. As indicated in Table 2, the volume of flow from wind drift is most significant for the exposed Central Bay where surface water drifts into the bay during the day and exits at night.

The wind driven flow entering the bay is 2.92 x 10^6 m^3 and the flow driven out the bay is 1.95 x 10^6 m^3 daily. These quantities compare with the 2.65 x 10^6 m^3 per day moving by tidal forces (see Section 3.0). However, the wind driven circulation of the bay is a critical variable for the exchange of water in Guayanilla Bay since this factor fluctuates seasonally and daily, and may control upwelling (see Section 2.6).

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[1] National Oceanic and Atmospheric Administration data from Ponce. Confirmed with selected monthly measurements at Guayanilla Bay (Chartock, in preparation).

TABLE 2

Hydrologic Flux Summary[a]
(10^6 m^3 per day)

Compartment	Compartment Volume	Flux			
		Tidal	Wind[c] (Summary)	Industrial Pumping	Runoff and Groundwater
Western Bay	3.30	0.918	1.82	-	0.072
Central Bay	37.6	2.65[b]	8.59	-	0.150
Intake	1.35	0.114	3.33	2.16	.008
Thermal Cove	0.52	0.071	.167	2.16	.002
Southeast Embayment	1.56	.244	4.09	-	-
Total	44.33	2.65[a]	-	-	.232

a. Data tabulated are aggregate flows. Separate flows among compartments are presented in Table 5.

b. The total flux of the bay system passes through the Central Bay (volume of Central Bay changes 1.30 x 10^6 m^3 during a tidal cycle).

c. Wind drift estimate of deeper channels based upon movement of upper 3m of water at 1% of wind velocity (2.9 m/sec). For shoals or sills where this depth was less than 3 m average sill depth was used. See Appendix B for detailed wind drift data.

2.3 INDUSTRIAL PUMPING

Hydrologic budgets of the intake, thermal cove, and southeast embayment are affected significantly by the Costa del Sur Oil-fired Power Plant, which operates by once-through sea water cooling. When all six units (boilers) are on-line, the cooling water flow is 37.6 m^3/sec. This plant operates with a power factor of approximately 80% so that estimated pumping is 2.16 x 10^6 m^3 per day. This pumping alone exchanges the volume of the thermal cove five times daily.

2.4 RUNOFF AND GROUNDWATER

The Western Bay receives runoff from the Yauco River Watershed, and the Central Bay receives runoff from the Guayanilla and Macaña Rivers. The Yauco River is impounded at the Luchetti Reservoir, and some flow is diverted out of the watershed. The river valleys in all the watersheds in Fig. 3 are developed for irrigated agriculture, primarily sugar cane. Runoff is highest in June through November, and low from December through May. The average annual streamflow for the Guayanilla River, measured approximately two km upstream from the bay discharge, is 29.6 x 10^6 m^3 per year; for the Yauco River is 13.5 x 10^6 m^3 per year; and for the Macaña River is 9.8 x 10^6 m^3 per year (Crooks, et al., 1968). Summary data for watershed flows are included in Appendix B. Potential water entering bay compartments from groundwater and runoff is 26.3 x 10^6 m^3 per year to the Western Bay and 54.3 x 10^6 m^3 per year to the Central Bay.[1] Actual freshwater entering is likely to be somewhat less due to domestic freshwater use and evaporation in agriculture.

The geological structure of Guayanilla Bay is heterogeneous with a karst topography in Miocene Limestone that outcrops at the surface (Morelock, et al., 1979). A variety of marine and alluvial sediments occur at the surface. Both the limestone and unconsolidated sediments serve as aquifers, and the allivium has been extensively developed for irrigation supply.

Groundwater influx into the bay has been estimated from average groundwater flow along the south coast of Puerto Rico. A daily average discharge of 2.1 m^3 per linear foot of shoreline has been estimated (Puerto Rico Water Resources Authority, 1972). This estimated value is within a factor of 0.5 of the groundwater flow from the watersheds above Guayanilla Bay estimated by the U.S. Geological Survey (Crooks, 1968).

The freshwater flow is small as an annual average, approximately 8.8% of the tidal flux, but seasonal variation and individual storm events can make this a very important factor, with some measurements of peak runoff of 1.4 x 10^6 m^3 per day for the Guayanilla and Yauco Rivers

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[1] These data are based on 66% evaportranspiration losses of water entering the lower basin, based on similar losses in U.S.G.S. upper basin measurements.

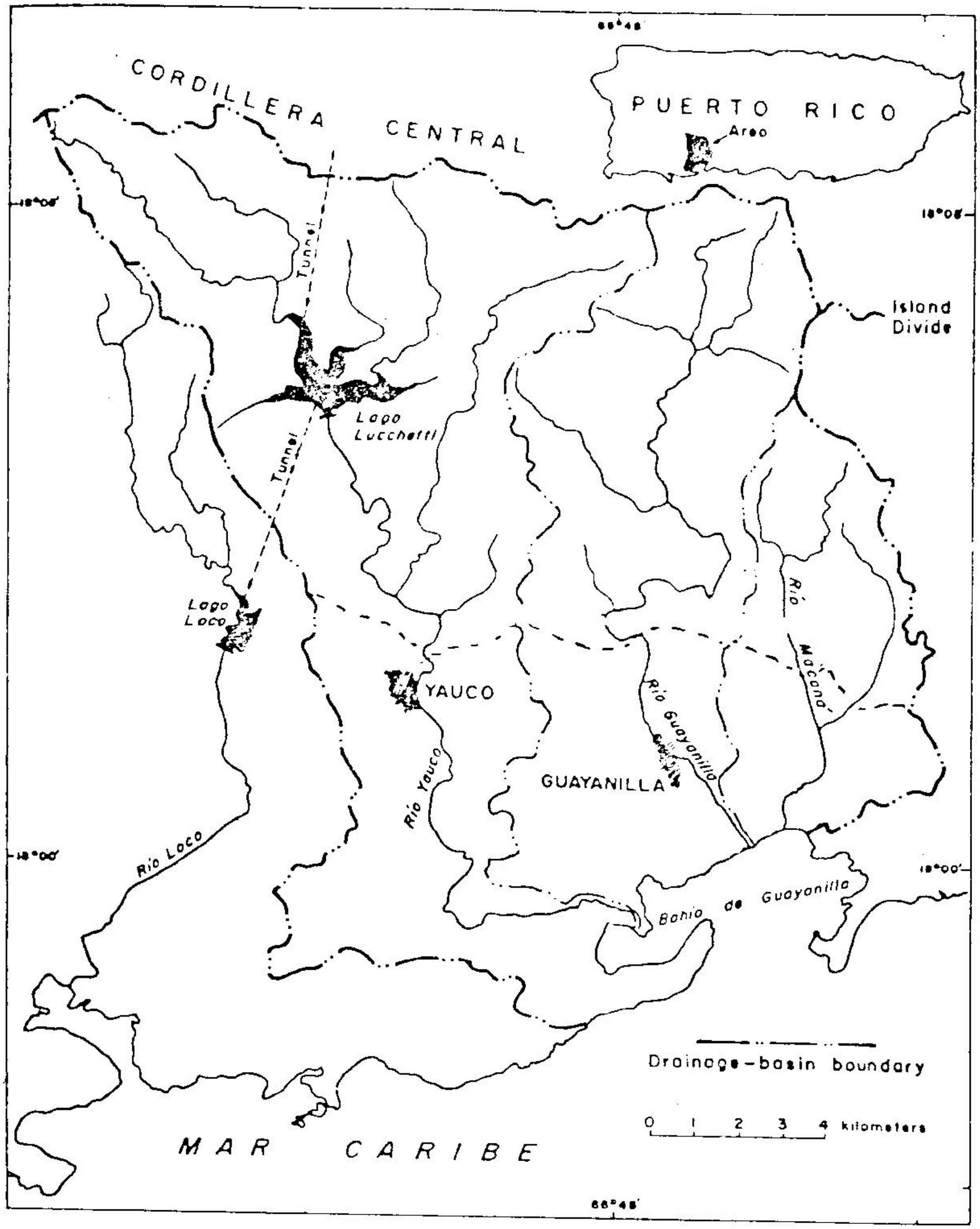

Fig. 3 Guayanilla Bay Watershed (Modified from Crooks, et. al. 1968 p. 12).

(almost one-half the tidal flux during high rainfall periods).[1] The freshwater flux is also important for maintaining the brackish water conditions of the Western Bay, and this is a critical physical factor in structuring the biotic community and its energy flow patterns.

2.5 OTHER SOURCES

Four other sources of hydrologic flux occur: precipitation, evaporation, storm surges (storm tides), channel dredging, and ship traffic. These sources of flux, however, are either small or infrequent. Direct precipitation from the annual average rainfall of 90 cm in the relatively arid coastal environment (Cintrón, Lugo, Pool and Morris, 1978) results in an addition of 79,400 m^3 of water annually, divided among bay compartments according to surface area. Most of this addition occurs from May through October. This flux is about three orders of magnitude smaller than categories shown in Table 2.

Annual pan evaporation is 79.9 inches at Ponce, with very similar values at Guanica and Sabana Grande (Staff, National Oceanic and Atmospheric Administration, personal communication November, 1979). This results in a flux of 18 x 10^6 m^3 annually or approximately 49,000 m^3 daily from the entire bay (see Table 3).

Storm surges accompany the tropical depressions, storms, and hurricanes that frequent the Caribbean. The hurricane force winds and storm surge contacts Puerto Rico an average of once every six years (Puerto Rico Water Resources Authority, 1972). These storms have different intensities, but a maximum expected storm surge along the south coast would result in about 3 m storm tide (Puerto Rico Water Resources Authority, 1972). This tidal stand would pass during a two to four hour period and result in a displacement of 26 x 10^6 m^3 about one-half the volume of the bay.

The large container ships and tankers entering Guayanilla Bay displace approximately 100,000 metric tons, or 48,000 m^3. An average of one tanker enters and leaves the bay daily (Puerto Rico Port Authority Staff, personal communication, 1980). This exchange occurs at the interface between the Central Bay and the coastal water. Thus, water movement due to tankers traffic is similar in magnitude to evaporation water flux, although very localized.

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[1] Much greater rainfall occurs during tropical storms. Uncontrolled runoff from the three drainage basins can be equivalent to 1.9 x 10^7 (10 cm of rainfall over a 24 hour period in the drainage basin). This is about 0.4 times the volume of the bay. Much of this runoff would be released within a one day period (Gregg Morris, personal communication).

TABLE 3

Water Flux from Precipitation and Evaporation
(10^3 m^3 per day)

Location	Direct Precipitation	Evaporation
Western Bay	7.47	16.9
Central Bay	10.69	23.9
Intake	0.94	2.11
Thermal Cove	0.58	1.31
Southeast Embayment	2.00	4.49
Total	21.7	49.00

Propeller pumping by 2,000 horsepower tugboats displaces water across the bay - coastal water interface. The tugboats have a thrust that moves 29,900 m^3 per minute. Approximately four tugboats per day transit the mouth of the bay, each crossing in an average of five seconds over the Central Bay - coastal interface. This results in an estimated localized movement of 10,000 m^3 of water in each direction.

2.6 EQUILIBRATING FLOWS

Equilibrating flows are established in the bay that maintain the volume of compartments. Equilibrating flows are the result of gravitational force that results in flow to establish a uniform (level) geopotential 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. In 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 movement of bottom water has been substantiated by drogue and temperature studies (Goldman, 1979). The size of equilibrating flows are mass balance estimates of counter currents. They are based on the assumption that the average daily volumes of the Guayanilla Bay compartments 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 is substantiated by observations of the extension of turbid Western Bay water that moves 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 compartments. 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 flows are listed in Table 5, including the origin or source compartment when the source of flow is within the Guayanilla Bay system. 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, is dominated by both tidal flow and wind. Wind drives about 10% more water into the bay (J4) than tide, but tides flush much more water from the bay (J1) than does wind (J3). The magnitude of the equilibrating flow out of the bay is directly related to wind velocity.

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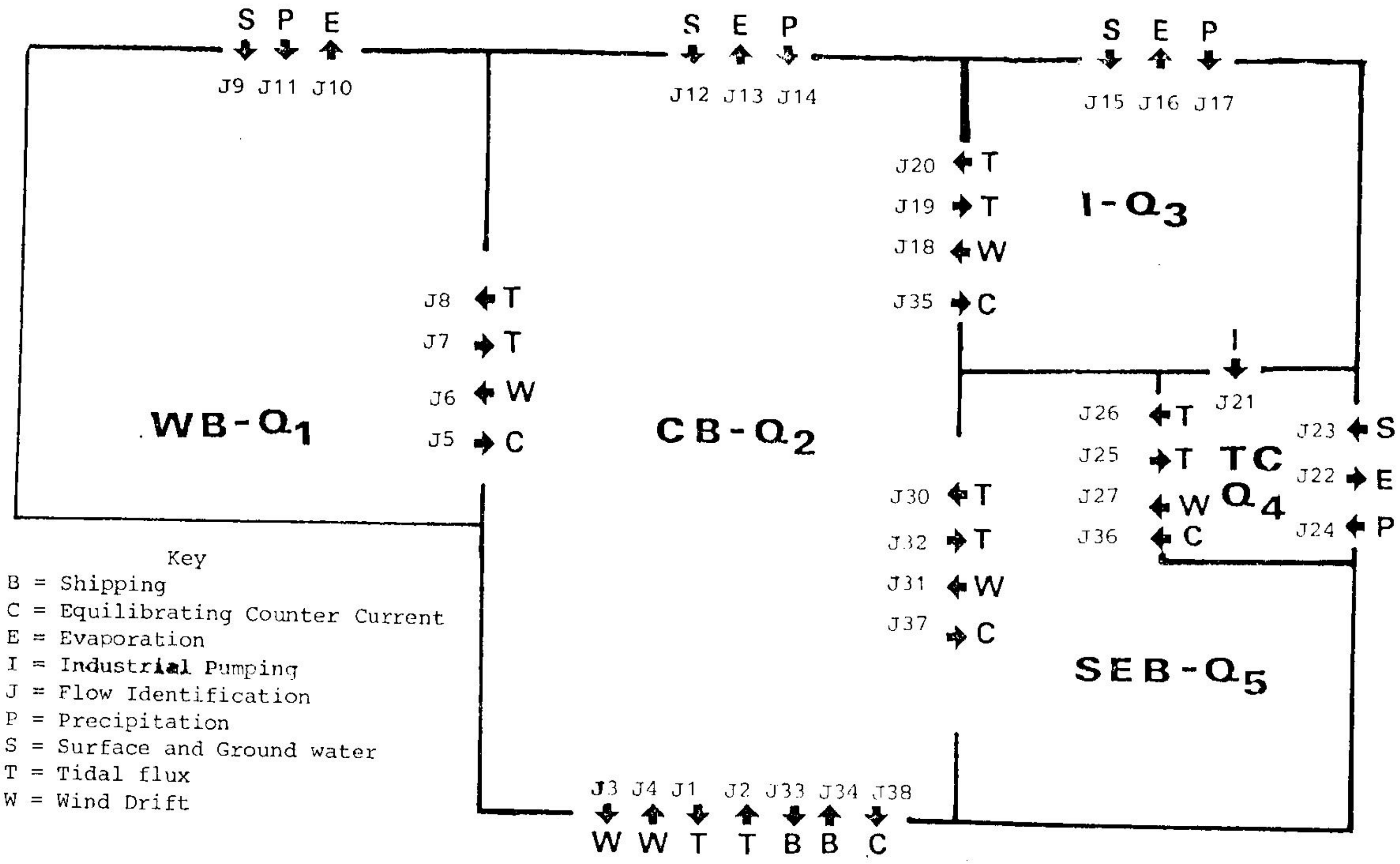

Fig. 4. Schematic of Guayanill Bay System (flows refer to Table 5)

TABLE 4

External Energy Sources

Energy Source	Name	Notes
I_1	Tide	30 cm sea elevation change
I_2	Wind	average 2.9 m/sec
I_3	Streamflow and Groundwater	87×10^6 m^3 per year from watershed
I_4	Precipitation	90 cm/year
I_5	Evaporation	200 cm/year
I_6	Shipping	60,000 m^3/day
I_7	Industrial pumping	2.16×10^6 m^3/day

TABLE 5

System Flow Rates and Transfer Co-efficients

Flow	Transfer Co-efficient (BASIC)[a]	Type	Source Bay [b]	Sink Bay [b]	Source Volume (10^6 m^3)	Flow Rate	Transfer Co-efficient Value
J1	K1	Tide	CB	CAR	37.6	2.65	0.070
J2	K2	Tide	CAR	CB	--	2.65	2.65
J3	K3	Wind	CB	CAR	37.6	1.95	0.052
J4	K4	Wind	CAR	CB	--	2.92	2.92
J5	K5	Equilibrium	WB	CB	3.30	1.892	0.57
J6	K6	Wind	CB	WB	37.6	1.82	0.048
J7	K7	Tide	WB	CB	3.30	0.918	0.278
J8	K8	Tide	CB	WB	37.6	0.918	0.024
J9	K9	Stream/Ground	--	WB	--	0.072	0.072
J10	KA	Evaporation	WB	--	3.30	0.0169	0.005
J11	KB	Rainfall	--	WB	--	0.007	0.007
J12	KC	Stream/Ground	--	CB	--	0.150	0.15
J13	KD	Evaporation	CB	--	37.6	0.024	0.0006
J14	KE	Rainfall	--	CB	--	0.011	0.011
J15	KF	Groundwater	--	I	--	0.008	0.008
J16	KG	Evaporation	I	--	1.35	0.002	0.0015
J17	KH	Rainfall	--	I	--	0.0009	0.0009
J18	KI	Wind	I	CB	1.35	3.33	2.47
J19	KJ	Tide	CB	I	37.6	0.114	0.003
J20	KK	Tide	I	CB	1.35	0.114	0.084
J21	KL	Pumping	I	TC	1.35	2.60	1.93
J22	KM	Evaporation	TC	--	0.52	0.0021	0.004
J23	KN	Groundwater	--	TC	--	0.002	0.002
J24	KO	Rainfall	--	TC	--	0.0006	0.0006
J25	KP	Tide	SEB	TC	1.56	0.071	0.045
J26	KQ	Tide	TC	SEB	0.52	0.071	0.136
J27	KR	Wind	TC	SEB	0.52	.167	0.321
J28	KS	Evaporation	SEB	--	1.56	.00045	0.0002
J29	KT	Precipitation	--	SEB	--	.0002	0.0002
J30	KU	Tide	CB	SEB	37.6	.244	0.0065
J31	KV	Tide	SEB	CB	1.56	.244	0.156

TABLE 5 (continued)

Flow	Transfer Co-efficient (BASIC)[a]	Type	Source Bay	Sink Bay	Source Volume (10^6 m^3)	Flow Rate	Transfer Co-efficient Value
J32	KW	Wind	SEB	CB	1.56	4.349	2.78
J33	KX	Shipping	CAR	CB	--	0.058	0.0015
J34	KY	Shipping	CB	CAR	37.6	0.058	0.058
J35	KZ	Equilibrium	CB	I	37.6	5.9231	0.157
J36	L1	Equilibrium	TC	SEB	0.52	2.4335	4.67
J37	L2	Equilibrium	CB	SEB	37.6	1.7483	0.0465
J38	L3	Equilibrium	CB	CAR	37.6	1.7467	0.0313

a. Co-efficient is a two digit code used in BASIC program to specify the transfer Co-efficient value (see Appendices C and D).

b. CAR = Carribean; CB = Central Bay; I = Intake Bay; SEB = Southeast Bay; TC = Thermal Cove; WB = Western Bay.

The interrelationship among causal forces and storages that determine system behavior is provided in the system equations in Table 6 and shown in the energy circuit diagram 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 also provided. Appendix D lists a model 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 or 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 movement 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 industrial pumping. For example, changing the intensity of industrial pumping dramatically alters the degree of upwelling in both the Intake and Southeast Bays. The effect of decreased pumping on the Southeast Bay would be to substitute coastal water for the surface waters originating in the Intake and thermal cove areas. The amount of water upwelling in the Southeast embayment would nearly double if the industrial pumping ceased. The implication of selected management 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 estimates of system parameters are based on measurement of relatively stable characteristics such as shoreline dimensions and bathymetry. However, many system parameters are not directly measurable, are stochastic (with a high degree of variability), or must be inferred (e.g. the equilibrating flows). One purpose of the model is to identify parameters that critically affect system behavior but that are poorly understood.

Summarized below are selected descriptions of the reliability of model data and some observations that substantiate fundamental interrelationships.

4.1 STORAGE VOLUME

Compartment sizes are based on measurements from National Oceanic and Atmospheric Administration Navigational Charts.[1] These have been

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[1] National Oceanic and Atmospheric Administration. June 3, 1978 11th Edition. Charts No. 25681 Bahía de Guayanilla and Bahía de Tallaboa.

TABLE 6

System Equations[a]

1. Q_1 = Western Bay (WB) Volume

$$\dot{Q}_1 = K_9 I_3 - K_a I_5 Q_1 + K_b I_4 + K_8 I_1 Q_2 - K_7 I_1 Q_1 + K_6 I_2 Q_2 - K_5 Q_1$$

2. Q_2 = Central Bay (CB) Volume

$$\begin{aligned}\dot{Q}_2 = {} & K_2 I_1 - K_1 I_1 Q_2 - K_3 I_2 Q_2 + K_4 I_2 + K_5 Q_1 - K_6 I_2 Q_2 + K_7 I_1 Q_1 - K_8 I_1 Q_2 \\ & + K_c I_3 - K_d I_5 Q_2 + K_e I_4 + K_i I_2 Q_3 - K_j I_1 Q_2 + K_k I_1 Q_3 - K_z Q_2 \\ & + K_w I_2 Q_5 - K_u I_1 Q_2 + K_v I_1 Q_5 - L_2 Q_2 - L_3 Q_2 + K_x I_6 - K_y I_6 Q_2\end{aligned}$$

3. Q_3 = Intake Embayment (I) Volume

$$\dot{Q}_3 = K_f I_3 - K_g I_5 Q_3 + K_h I_4 - K_i I_2 Q_3 + K_j I_1 Q_2 - K_k I_1 Q_3 + K_z Q_2 - K_l I_7 Q_3$$

4. Q_4 = Thermal Cove (TC) Volume

$$\dot{Q}_4 = K_l I_7 Q_3 - K_m I_5 Q_4 + K_n I_3 + K_o I_4 + K_p I_1 Q_5 - K_q I_1 Q_4 - K_r I_2 Q_4 - L_1 Q_4$$

5. Q_5 = Southeast Embayment (SEB) Volume

$$\begin{aligned}\dot{Q}_5 = {} & K_q I_1 Q_4 - K_p I_1 Q_5 + K_r I_2 Q_4 - K_s I_5 Q_5 + K_t I_4 + K_u I_1 Q_2 - K_v I_1 Q_5 \\ & - K_w I_2 Q_5 + L_2 Q_2 + L_1 Q_4\end{aligned}$$

---

a. $\dot{Q}$ = rate of change of Q

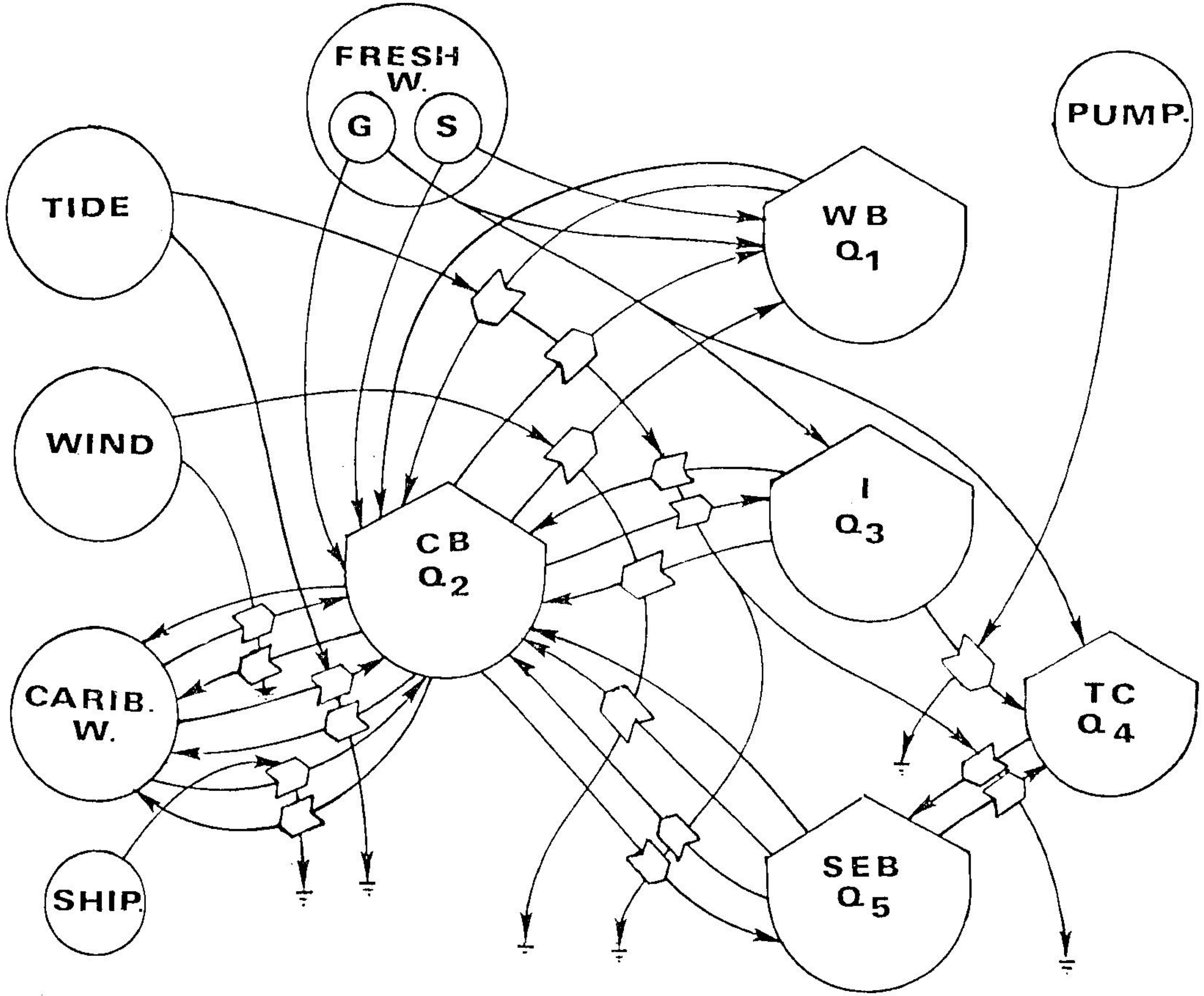

Fig. 5 Energy Circuit Diagram (evaporation not shown). Sources (circles) of water or energy interact(wide arrow-shaped symbols) to control flows (lines with small arrows) of water to compartments (storage tanks).

selectively verified by depth soundings of the bay during Fall, 1979. Field trip checks on the geographic boundries have been provided by reviewing areal photographs and by cruising along the shoreline to verify land - mangrove boundries. Map measurements are probably accurate within one percent. Average depths of bay compartments are based on map measurements of five transects in each compartment, with an estimated error range of 3%. Overall compartment size errors is within 5%.

4.2 CURRENTS

Verification of water movements 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, detailed confirmation of wind-current relationships have not been made. Related studies of wind drift indicate variation of 10 to 50% of actual values (Lange and Huhnerfuss, 1979).

The existence of all equilibrium currents has been substantiated with drogue studies (Goldman, 1978). In addition, the general relationship between wind velocity and the magnitude of equilibrium (return) flows is substantiated by observations; for example, of the extension of turbid Western Bay water into the Central Bay. Wind and current velocity relationships are also substantiated by multi-depth drogue observations (Goldman, 1978).

4.3 FRESHWATER INPUT

Surface water inputs have annual variation of ± 40% of the mean annual flow. Although large yearly variation in runoff occurs, the long term average yearly runoff values used in this report are probably representative within 10-20%.

Groundwater flow data are subject to considerable uncertainty. However, total freshwater influx can be verified independently by calculating dilution of Caribbean water in the bay. Dilution of Western Bay waters occurs to the range of 28 to 33 parts per thousand salinity. Total freshwater flow data used in this report are consistent with this range of salinity given the rates of tidal and wind driven water flux (see Table 7). Salinity stratification and mixing data have not been evaluated, however, and error range is uncertain.

5.0 MANAGEMENT IMPLICATIONS AND CONCLUSIONS

Guayanilla Bay is a complex, multicompartment estuary with distinctive sub-areas. From a physical standpoint, the hydrology is affected by numerous separate forces that collectively characterize the bay. From a biological standpoint the bay compartments also function distinctly, but are highly interdependent (Chartock, in preparation). The hydrologic behavior of the bay can be managed to affect its biological properties and human uses as an "Industrial Marine Ecosystem" (Tilly, 1979).

TABLE 7

Relationship of Salinity to Flushing in Western Bay[a]

Salinity in Western Bay (°/°°)	Fraction of Fresh H_2O	Accumulated Volume of Freshwater (m^3)	Flushing Time
28	.188	622,000	8.635
29	.1594	526,000	7.3067
30	.13	430,000	5.97
31	.10	334,000	4.6
32	.07	237,000	3.3
33	.04	143,000	2.0

[a] Assumes that the Central Bay has a salinity of 34.5 parts/thousand, and that the volume of the Western Bay of 3.3×10^6 m^3 and total freshwater input is 72,000 m^3 per day.

5.1 MANAGEMENT OF BATHYMETRY

The relative isolation of the Western Bay from the Central Bay can be modified by dredging the shallow sill that separates these compartments, as one example of a management action. The sill depth and width parameters influence the strata of water that enter or leave bay compartments and the source of water for equilibrating return flows. The channel, for example, that penetrates the sill near Punta Verraco provides for the equilibrating flow of deeper, poorly oxygenated water out of the Western Bay to the Central Bay, and may be one factor maintaining the oxygen concentration in the eutrophic Western Bay (Chartock, in preparation) that sustains a small commercial fishery (Cole, 1976). Thus, effects of alternative dredging plans on the transfer coefficients for wind driven currents and for equilibrium return flows should be evaluated with the models such as the one described here.

Dredging is a continuing process used by industry in Guayanilla Bay to maintain adequate port conditions. Suspended materials in shallow waters moved by the wind drift are a major source of sediment that is transported in the bay. The sediment budget of the bay can be managed to reduce or divert sediment sources to minimize dredging expenditures. Managing biological populations that stabilize the bottom may also be a mechanism to avoid or minimize costly dredging programs. The model described here only provides an initial framework for sediment management. A detailed sediment budget is needed to implement an effective stabilization program.

5.2 WATERSHED MANAGEMENT

Groundwater and surface water flows are important for maintaining the biological and physical characteristics of the Western Bay such as community composition, productivity, turbidity, and total particulate matter.

The freshwater flow is dependent on surface and subsurface development of the watershed (U.S.G.S., 1968). For example, increased groundwater pumping coupled with severe drought, can result in sea water intrusion from the bay into the alluvial sediments in the Guayanilla Valley. Development of storage and groundwater recharge capacity in the three rivers that enter Guayanilla Bay, needs to be evaluated as a mechanism to both maintain 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 in an evaluation based on the model presented here, but the dramatic changes produced by periodic floods require additional model parameters.

5.3 INDUSTRIAL INTAKES AND DISCHARGES

Industrial pumping enhances upwelling at the boundary between the Intake and Central Bays, and reduces upwelling at the mouth of the Southeast

Bay. Although water characteristics are modified in the bay system by this industrial application (López, 1979), the hydrologic flow between the tropical surface water mass along the coast and Central Bay water is not affected. This water exchange is critical in affecting the physical and biological characteristics of the bay. Alternative industrial intake and discharge locations must be compared against the hydrologic exchanges within the bay and between the bay and the coast. For example, options to locate the Costa del Sur Power Plant discharge outside of Guayanilla Bay (in the adjacent Tallaboa Bay) would eliminate the equilibrium return flow (J-38 in Table 5) from the Central Bay, and greatly increase the amount of coastal water entering the bay with the potential for substantial change in the bay's physical and biological characteristics. In this regard, the total bay system's hydrologic input-output budget is more like a natural system in its present configuration than with some alternative approaches. The point here is not that alternatives are better or worse, but that the outcomes need to be quantitively compared for the entire bay when evaluating management options.

5.4 POWER PLANT COOLING

One major use of the bay as a resource is to maintain or improve the thermal efficiency of the Costa del Sur Power Plant. The cool bay water is a valuable resource; it serves as the heat sink that dissipates heat from the fossil fuel power plant. Heated water from the thermal cove and Southeast Bay typically does not return to the intake, primarily because of upwelling caused by the combination of surface wind and pumping. However, if pumping alone were functioning (i.e. if there were no upwelling), surface water would enter the power plant pulling in water that has just left the Southeast Bay. Thus, even small wind velocities isolate surface waters at an average of 28° from subsurface waters at an average of 26°, this significantly improves power plant efficiency. (This may represent a reduction in cost of $5,000 to $10,000 daily, depending on fuel costs.)

Because water exchanges are affected by wind and bathymetry, managers of the bay should be careful in adjusting bathymetry or topography that can affect the wind regime, especially on the eastern margins of the bay where wind effects are most closely coupled with man's uses and where wind fetch is short and potentially effected by shoreline modification.

5.5 RESEARCH IMPLICATIONS

A wide range of research has been conducted in Guayanilla Bay to characterize the physical and biological structure of the bay and the influence of industrialization (González, 1979). The model summarized here can be used to review this research against the needs of understanding the function of the bay, and to inform planning and decision making by industrial, governmental, public and private interest groups.

Although all of the flow parameters used in this model are subject to uncertainty, some are more critical than others to understanding the bay's function. The most critical includes the magnitude of wind drift across shallow sills and the extent of equilibrium flows. Other important flows are the surface water, groundwater and the response of individual compartments to variation in tide height. However, it is unlikely that a modest research effort on these latter categories would produce much benefit to decision makers. In contrast, a research project with the objective of understanding wind and equilibrium flows would be a modest activity and result in a verification of the critical hydrologic aspects of Guayanilla Bay ecosystem models.

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APPENDIX A

Wind Drift Data Supplement

Wind Speed and Direction

Wind speed data used in this report are based on 8 years of observations taken at Santa Isabel Airport during the period 1946-1953. These indicated an annual mean wind speed of 2.9 m/sec. A less comprehensive set of data for Tallaboa Bay, (adjacent to Guayanilla Bay) show that winds recorded over the one year period beginning June 1, 1975, and ending May 31, 1976, averaged 2.8 m/sec, when corrected from the 250 ft measurement level to a level 10 m above the ground.[1] Wind vector data are summarized in Table A-1. Table A-2 summarizes the basis for wind drift flows between compartments based on direction of exposure, depth, and the vector of wind velocity.

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[1] Puerto Rico Water Resources Authority, 1976. South Coast Power Plant Complex. p. 42.

TABLE A-1

WIND STATISTICS

Santa Isabel Airport
Santa Isabel, Puerto Rico

	Mean Wind Speed m/sec	Direction
January	3.0	ENE
February	2.8	NE
March	3.4	ESE
April	3.2	SE
May	2.9	SE
June	3.2	SE
July	3.3	SE
August	3.1	E
September	2.6	E
October	2.4	N
November	2.3	NE
December	2.3	NE

Based on the period 1946-1953.

Sources: Puerto Rico Water Resources Authority 1976. "South Coast Power Plant Complex" Table 4. 2-1.

TABLE A-2
Wind Drift Data[a]

Compartment	Direction	Width (m)	Depth Affected by Wind (m)	Sectional Area for Drift[g]	Uncorrected Flow[h] ($10^6 m^3$/day)	Wind Vector Corrected Flow[i] ($10^6 m^3$/day)
Western Bay	East (N section)	270	1.26	340	2.10	1.82
	East (Mid sill)	720	0.30	216		
	East (S section)	182	1.55	282		
Central Bay	South	1010	3.0	3020	7.55	1.95
	(night)	1100	.87	957	2.20	1.95
	South	1010	3.0	3020	7.55	
	(day)	1100	.87	957	2.20	2.92
	West	(see W.B. above)			2.10	1.82
	East[a]	512	3.0	1540	3.85	3.33
	East[b]	585	.61	1090	0.89	.77
	East[c]	549	3.0	1650	4.13	3.58
Intake	West	512	3.0	1540	3.85	3.33
Thermal Cove	West[d]	42	1.83	770	.191	.17
Southeast Embayment	West[e]	585	.61	1090	0.89	.77
	West[f]	549	3.0	1650	4.13	3.58
	East	42	1.83	770	.19	.17

---

[a] Values in table are rounded to 3 significant digits.

Footnotes to TABLE A-2

a. Channel between Cayo Mata and Commonwealth Oil Refining Corporation (CORCO) Jetty.

b. Channel between Punta Gotay and Cayo Mata.

c. Channel between CORCO, Jetty and Punta Papillo.

d. Communication from east side of Intake embayment is through forced pumping to thermal cove.

e. Deep portion of channel from Punta Gotay to reef midway to Punta Verraco.

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

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

h. Wind drift calculation is based on velocity of wind driven water through channel. Movement of water is estimated at 1% of average wind speed (2.9 m/sec), and direction (easterly). Wind drift occurs in the upper three meters unless a sill is present, in which case the average sill height is used.

i. Wind direction 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, 1979). To account for component of wind drift through embayment exposure, cosine of velocity component and time duration corrections have been made for wind vector corrected daily flow. For most exposures, this results in a 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).

APPENDIX B

Surface and Groundwater Data

TABLE B-1. Annual rainfall on the three principal river basins, 1961 and long-term average.

River Basin	Drainage Area Km^2	Weighted Rainfall cm 1961	Weighted Rainfall cm Long-term
Río Yauco			
Upper basin, (excluding Lago Lucchetti diversion)	39.1	132	163
Lower basin	41.2	74	94
Entire basin, (excluding Lago Lucchetti)	80.3	101	127
Río Guayanilla			
Upper basin, above stream station	47.9	185	196
Lower basin	29.5	81	99
Entire basin	77.4	145	160
Río Macaná			
Upper basin	19.5	188	175
Lower basin	13.7	96	114
Entire basin	33.2	150	150
Three basins, (excluding Lago Lucchetti)			
Upper basins	50.2	168	180
Lower basins, the Guayanilla-Yauco area	85.5	79	99
Three basins	191.7	127	145

Source: Modified from Crooks *et al.* 1968

TABLE B-2

Annual amount of water received by the Guayanilla-Yauco River basins, 1961-63 and long-term average.

Source of water	Amount, 10^6 m^3			
	1961	1962	1964	Long term Average
Rainfall on upper basins				
Río Yauco (does not include drainage area above Lucchetti Dame)	52	49	83	64
Río Guayanilla	89	74	117	94
Río Macaná	37	28	36	33
Total rainfall on upper basins	178	151	236	191
Streamflow entering lower basins				
Río Yauco (above first diversions)	20	11	14	14
Río Guayanilla (gaging station)	27	11	27	29
Río Macaná	11	6	10	10
Total streamflow entering lower basins	58	28	51	53
Rainfall on lower basins				
Río Yauco	29	29	38	38
Río Guayanilla	23	25	29	29
Río Macaná	12	15	17	15
	64	69	84	82
Water reaching lower basins	122	97	135	135

Source: Modified from Crooks *et al.* 1968

APPENDIX C

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

```
100  HOME
110  VTAB 12
120  PRINT "A HYDROLOGIC MODEL OF GUAYANILLA BAY,PR."
130  VTAB 15
140  PRINT "                    BY"
150  PRINT "          MICHAEL A. CHARTOCK"
160  PRINT
170  PRINT "CENTER FOR ENERGY & ENVIRONMENT RESEARCH"
180  PRINT "UNIVERSITY OF PUERTO RICO & U.S. D.O.E."
190  PRINT "             JANUARY  1980"

200  REM
210  REM
230  REM  PLEASE READ REM STATEMENTS FOR SPECIFICATION OF PROGRAM VARIABLES
240  REM   TO OPERATE:LOAD PROGRAM AND ENTER RUN: TO PRINT SPECIFY PRINTER LO
CAT
ION (E.G. PR#2) AND ENTER RUN
250  REM  BAY COMPARTMENT SIZES IN SECTION 400
260  REM  STATEMENT 690 SPECIFIES T, THE TIME INCREMENT, NOW SET FOR 24 HRS
270  REM  INTEGRATION ACCOMPLISHED ON HOURLY INTERVALS(900 AND 1200);THEN PRI
NTI
NG INDICATES DAILY VALUES
280  REM  ENERGY SOURCES DO NOT VARY IN THIS VERSION (SET TO 1 IN 910 - 960)
290  REM  MODEL TAKES TIME TO EQUILIBRATE(SEE RESULTS) AS INITIAL COMPARTMENT
 SI
ZE IS MEAN LOW WATER,WITHOUT BEING
300  REM  ENERGIZED BY THE ENERGY SOURCES.
410 Q1 = 3.30
420 Q2 = 37.6
430 Q3 = 1.35
440 Q4 = 0.52
450 Q5 = 1.56
690  LET T = 24
700  LET K1 = (2.65 / 37.6) / T
701  REM  TIDE FROM CB TO CARIBB.
703  LET K2 = (2.65) / T
704  REM  TIDE FROM CARIB TO CB
706  LET K3 = (1.95 / 37.6) / T
707  REM  WIND FROM CB TO CARIB
710  LET K4 = (2.92) / T
711  REM  WIND FROM CARIB TO CB
720  LET K5 = (1.8821 / 3.30) / T
721  REM  COUNTER CURRENT FROM WB TO CB
723  LET K6 = (1.82 / 37.6) / T
724  REM  WIND FROM CB TO WB
726  LET K7 = (.918 / 3.30) / T
727  REM  TIDE FROM WB TO CB
730  LET K8 = (.918 / 37.6) / T
731  REM  TIDE FROM CB TO WB
735  LET K9 = (0.072) / T
737  REM  FRESHWATER TO WB
740 KA = (0.0169 / 3.30) / T
```

```
741  REM  EVAPORATION FROM WB
745  LET KB = (0.007) / T
746  REM  RAINFALL INTO WB
750  LET KC = (0.15) / T
751  REM  FRESHWATER TO CB
755  LET KD = (.024 / 37.6) / T
756  REM  EVAPORATION
760  LET KE = (.011) / T
761  REM  RAINFALL TO CB
765  LET KF = (0.008) / T
766  REM  GROUNDWATER TO INTAKE
770  LET KG = (.002 / 1.35) / T
771  REM  EVAPORATION FROM INTAKE
775  LET KH = 0.0009 / T
776  REM  RAINFALL TO INTAKE
780  LET KI = (3.33 / 1.35) / T
781  REM  WIND FROM INTAKE
785  LET KJ = (.114 / 37.6) / T
786  REM  TIDE FROM CENTRAL BAY TO INTAKE
788  LET KK = (.114 / 1.35) / T
789  REM  TIDE FROM INTAKE TO CB
790  LET KL = (2.60 / 1.35) / T
791  REM  PUMPING FROM INTAKE TO TC
795  LET KM = (.0021 / .52) / T
796  REM  EVAPORTATION FROM TC
800  LET KN = (00.0020) / T
801  REM  GROUNDWATER TO TC
805  LET KO = (0.0006)
806  REM  RAINFALL TO TC
810  LET KP = (.071 / 1.56) / T
811  REM  TIDE FROM SEB TO TC
815  LET KQ = (.071 / .52) / T
816  REM  TIDE FROM THE THERMAL COVE TO SEB
820  LET KR = (.167 / .52) / T
821  REM  WIND FROM THERMAL COVE TO SEB
825  LET KS = (.0004 / 1.56) / T
826  REM  EVAPORATION FROM SEB
830  LET KT = (.0002) / T
831  REM  PRECIPITATION TO SEB
835  LET KU = (.244 / 37.6) / T
836  REM  TIDE FROM CB TO SEB
840  LET KV = (.244 / 1.56) / T
841  REM  TIDE FROM SEB TO CB
845  LET KW = (4.3498 / 1.56) / T
846  REM  WIND FROM SEB TO CB
850  LET KX = (.058 / 37.6) / T
851  REM  SHIPPING OUT OF BAY
855  LET KY = (.058) / T
856  REM  SHIPPING INTO BAY
860  LET KZ = (5.9231 / 37.6) / T
861  REM  COUNTERCURRENT FROM CB TO INTAKE
865  LET L1 = (2.4335 / .52) / T
866  REM   COUNTERCURRENT FROM TC                      TO SEB
870  LET L2 = (1.7483 / 37.6) / T
```

```
871   REM  COUNTERCURRENT FROM CB TO SEB
875   LET L3 = (1.1767 / 37.6) / T
876   REM  COUNTERCURRENT FROM CB TO CARIB
900   FOR I = 1 TO 24
910   LET I1 = 1
920   LET I2 = 1
925   LET I3 = 1
930   LET I4 = 1
950   LET I5 = 1
960   LET I6 = 1
970   LET I7 = 1
1000   IF C = 0 THEN  GOTO 3000
1100Q  + (K9 * I3) - (KA * I5 * Q1) + (KB * I4) + (K8 * I1 * Q2) - (K7 * I1
* Q1) + (K6 * I2 * Q2) - (K5 * Q1) + Q1
1110 AQ2 = (K2 * I1) - (K1 * I1 * Q2) - (K3 * I2 * Q2) + (K4 * I2) + (K5 * Q1
) -
 (K6 * I2 * Q2) + (K7 * I1 * Q1) - (K8 * I1 * Q2) + (KC * I3) - (KD * I5 * Q2
) +
 (KE * I4)
1115 BQ2 = (KI * I2 * Q3) - (KJ * I1 * Q2) + (KK * I1 * Q3) - (KZ * Q2) + (KW
 *
I2 * Q5) - (KU * I1 * Q2) + (KV * I1 * Q5) - (L2 * Q2) - (L3 * Q2) + (KY * I6
) -
 (KX * I6 * Q2)
1118 Q2 = AQ2 + BQ2 + Q2
1120 Q3 = (KF * I3) - (KG * I5 * Q3) + (KH * I4) - (KI * I2 * Q3) + (KJ * I1
* Q
2) - (KK * I1 * Q3) + (KZ * Q2) - (KL * I7 * Q3) + Q3
1130 Q4 = (KL * I7 * Q3) - (KM * I5 * Q4) + (KO * I4) + (KP * I1 * Q5) - (KQ
* I
1 * Q4) + (KN * I3) - (KR * I2 * Q4) - (L1 * Q4) + Q4
1150 Q5 = (KQ * I1 * Q4) - (KP * I1 * Q5) + (KR * I2 * Q4) - (KS * I5 * Q5) +
 (K
T * I4) + (KU * I1 * Q2) - (KV * I1 * Q5) - (KW * I2 * Q5) + (L2 * Q2) + (L1
* Q
4) + Q5
1200   NEXT I
1650   GOTO 4050
3000   PRINT : PRINT
3900   PRINT "                           TABLE OF COMPARTMENT VOLUMES"
3950   PRINT "                            (MILLIONS OF CUBIC METERS)"
3960   PRINT
3970   PRINT "----------------------------------------------------------------------
---
--------"

4000   PRINT "DAY   WESTERN BAY   CENTRAL BAY   INTAKE BAY   THERMAL COVE  SO
UTH
EAST BAY"
4010   PRINT "----------------------------------------------------------------------
---
--------"

4050   LET C = C + 1
4100   PRINT C;"      ";Q1;"     ";Q2;"     ";Q3;"     ";Q3;"     ";Q5
5000   GOTO 900
```

A HYDROLOGIC MODEL OF GUAYANILLA BAY,PR.
BY
MICHAEL A. CHARTOCK

CENTER FOR ENERGY & ENVIRONMENT RESEARCH
UNIVERSITY OF PUERTO RICO & U.S. D.O.E.
JANUARY 1980

TABLE OF COMPARTMENT VOLUMES
(MILLIONS OF CUBIC METERS)

DAY	WESTERN BAY	CENTRAL BAY	INTAKE BAY	THERMAL COVE	SOUTHEAST BAY
1	3.3	37.6	1.35	1.35	1.56
2	3.30013766	37.6066268	1.35017663	1.35017663	1.56400456
3	3.30066248	37.6166165	1.35053281	1.35053281	1.56474789
4	3.30134473	37.6253608	1.35085475	1.35085475	1.56514932
5	3.30203102	37.6329315	1.35113338	1.35113338	1.5654868
6	3.30266643	37.6395234	1.35137577	1.35137577	1.56577946
7	3.30323609	37.6452796	1.35158734	1.35158734	1.56603464
8	3.30373995	37.6503128	1.3517723	1.3517723	1.56625761
9	3.30418301	37.6547163	1.35193411	1.35193411	1.56645263
10	3.30457162	37.6585699	1.35207571	1.35207571	1.56662327
11	3.30491207	37.6619427	1.35219963	1.35219963	1.56677262
12	3.30521019	37.6648947	1.3523081	1.3523081	1.56690333
13	3.30547118	37.6674786	1.35240304	1.35240304	1.56701773
14	3.30569964	37.6697402	1.35248614	1.35248614	1.56711788
15	3.30589963	37.6717198	1.35255887	1.35255887	1.56720553
16	3.30607467	37.6734526	1.35262254	1.35262254	1.56728225
17	3.30622789	37.6749692	1.35267826	1.35267826	1.5673494
18	3.306362	37.6762968	1.35272704	1.35272704	1.56740818
19	3.30647939	37.6774588	1.35276974	1.35276974	1.56745963
20	3.30658214	37.6784759	1.35280711	1.35280711	1.56750467
21	3.30667208	37.6793662	1.35283982	1.35283982	1.56754409
22	3.3067508	37.6801455	1.35286845	1.35286845	1.56757859
23	3.30681971	37.6808275	1.35289351	1.35289351	1.56760879
24	3.30688002	37.6814246	1.35291545	1.35291545	1.56763523
25	3.30693282	37.6819472	1.35293465	1.35293465	1.56765837
26	3.30697903	37.6824046	1.35295146	1.35295146	1.56767862
27	3.30701947	37.6828049	1.35296617	1.35296617	1.56769635
28	3.30705488	37.6831554	1.35297905	1.35297905	1.56771186
29	3.30708587	37.6834622	1.35299032	1.35299032	1.56772545
30	3.30711299	37.6837307	1.35300018	1.35300018	1.56773734
31	3.30713674	37.6839657	1.35300882	1.35300882	1.56774774
32	3.30715751	37.6841714	1.35301638	1.35301638	1.56775685
33	3.30717571	37.6843515	1.35302299	1.35302299	1.56776482
34	3.30719163	37.6845091	1.35302878	1.35302878	1.5677718
35	3.30720556	37.6846471	1.35303385	1.35303385	1.56777791
36	3.30721776	37.6847678	1.35303829	1.35303829	1.56778326
37	3.30722844	37.6848735	1.35304217	1.35304217	1.56778794

DAY	WESTERN BAY	CENTRAL BAY	INTAKE BAY	THERMAL COVE	SOUTHEAST BAY
38	3.30723779	37.684966	1.35304557	1.35304557	1.56779203
39	3.30724597	37.685047	1.35304855	1.35304855	1.56779562
40	3.30725313	37.6851179	1.35305115	1.35305115	1.56779876
41	3.3072594	37.6851799	1.35305343	1.35305343	1.5678015
42	3.30726489	37.6852342	1.35305543	1.35305543	1.56780391
43	3.30726969	37.6852818	1.35305717	1.35305717	1.56780601
44	3.30727389	37.6853234	1.3530587	1.3530587	1.56780786
45	3.30727757	37.6853598	1.35306004	1.35306004	1.56780947
46	3.30728079	37.6853917	1.35306121	1.35306121	1.56781088
47	3.30728361	37.6854195	1.35306224	1.35306224	1.56781211
48	3.30728607	37.685444	1.35306313	1.35306313	1.5678132
49	3.30728824	37.6854653	1.35306392	1.35306392	1.56781414
50	3.30729013	37.6854841	1.35306461	1.35306461	1.56781497
51	3.30729178	37.6855004	1.35306521	1.35306521	1.56781569
52	3.30729323	37.6855148	1.35306573	1.35306573	1.56781633
53	3.30729449	37.6855273	1.35306619	1.35306619	1.56781689
54	3.3072956	37.6855383	1.3530666	1.3530666	1.56781737
55	3.30729658	37.6855479	1.35306695	1.35306695	1.5678178
56	3.30729742	37.6855563	1.35306726	1.35306726	1.56781817
57	3.30729817	37.6855637	1.35306753	1.35306753	1.5678185
58	3.30729882	37.6855701	1.35306777	1.35306777	1.56781878
59	3.30729939	37.6855758	1.35306798	1.35306798	1.56781903
60	3.30729989	37.6855807	1.35306816	1.35306816	1.56781925
61	3.30730032	37.685585	1.35306832	1.35306832	1.56781944
62	3.30730071	37.6855888	1.35306845	1.35306845	1.56781961
63	3.30730104	37.6855921	1.35306858	1.35306858	1.56781975
64	3.30730133	37.685595	1.35306868	1.35306868	1.56781988
65	3.30730159	37.6855975	1.35306877	1.35306877	1.56781999
66	3.30730181	37.6855997	1.35306886	1.35306886	1.56782009
67	3.307302	37.6856016	1.35306893	1.35306893	1.56782018
68	3.30730218	37.6856034	1.35306899	1.35306899	1.56782025
69	3.30730233	37.6856048	1.35306904	1.35306904	1.56782032
70	3.30730246	37.6856061	1.35306909	1.35306909	1.56782038
71	3.30730257	37.6856072	1.35306913	1.35306913	1.56782043
72	3.30730267	37.6856083	1.35306917	1.35306917	1.56782047
73	3.30730276	37.6856091	1.3530692	1.3530692	1.56782051
74	3.30730283	37.6856098	1.35306923	1.35306923	1.56782054
75	3.3073029	37.6856105	1.35306925	1.35306925	1.56782057
76	3.30730296	37.6856112	1.35306928	1.35306928	1.5678206
77	3.30730301	37.6856116	1.35306929	1.35306929	1.56782062
78	3.30730306	37.685612	1.35306931	1.35306931	1.56782063
79	3.30730309	37.6856123	1.35306932	1.35306932	1.56782065
80	3.30730312	37.6856127	1.35306933	1.35306933	1.56782067
81	3.30730315	37.685613	1.35306934	1.35306934	1.56782068
82	3.30730318	37.6856134	1.35306936	1.35306936	1.56782069
83	3.30730321	37.6856138	1.35306937	1.35306937	1.56782071
84	3.30730324	37.685614	1.35306938	1.35306938	1.56782072
85	3.30730326	37.685614	1.35306938	1.35306938	1.56782073
86	3.30730327	37.6856141	1.35306938	1.35306938	1.56782073
87	3.30730327	37.6856141	1.35306938	1.35306938	1.56782073
88	3.30730327	37.6856141	1.35306938	1.35306938	1.56782073
89	3.30730327	37.6856141	1.35306938	1.35306938	1.56782073
90	3.30730327	37.6856141	1.35306938	1.35306938	1.56782073

APPENDIX D

Listing of Computer Program with Hourly Tidal and Wind Variation and Table of Compartment Results

```
100  HOME
110  VTAB 12
120  PRINT "A HYDROLOGIC MODEL OF GUAYANILLA BAY,PR."
125  PRINT "VERSION B: PRINTS OR PLOTS HOURLY VOLUME"
130  VTAB 15
140  PRINT "                  BY"
150  PRINT "        MICHAEL A. CHARTOCK"
160  PRINT
170  PRINT "CENTER FOR ENERGY & ENVIRONMENT RESEARCH"
180  PRINT "UNIVERSITY OF PUERTO RICO & U.S. D.O.E."
190  PRINT "             JANUARY  1980"
200  REM  REFER TO DAILY VERSION (APPENDIX C) FOR ADDITION NOTATION
210  REM  STATEMENTS 490 OR 1600 CONTROL PRINT OR PLOT OPTION
220  REM  TO PLOT CHANGE 1600 TO "GOTO 6000" AND DELETE STATEMENT 490
230  REM  SECTION 900 CONTROLS HOURLY CHANGES OF WIND AND TIDE
240  REM  MANIPULTION OF VARIABLES PERMITS AN EVALUATION OF CONTROLS ON SYSTE
M B
EHAVIOR.
250  REM  SEE APPENDED TABLE FOR BEHAVIOR OF PRESENT CONFIGURATION. NOTE REDU
CTI
ON OF VOLUME OF CENTRAL BAY FROM NORTHEAST WIND IN MORINING FOLLOWED BY FURTH
ER
REDUCTION BY TIDE IN AFTERNOON.
410 Q1 = 3.30
420 Q2 = 37.6
430 Q3 = 1.35
440 Q4 = 0.52
450 Q5 = 1.56
490  GOTO 690
500  HOME
600  REM  GRAPHICS SECTION
610  HGR
620  HCOLOR= 7
690  LET T = 24
700  LET K1 = (2.65 / 37.6) / T
701  REM  TIDE FROM CB TO CARIBB.
703  LET K2 = (2.65) / T
704  REM  TIDE FROM CARIB TO CB
706  LET K3 = (1.95 / 37.6) / T
707  REM  WIND FROM CB TO CARIB
710  LET K4 = (2.92) / T
711  REM  WIND FROM CARIB TO CB
720  LET K5 = (1.8821 / 3.30) / T
721  REM  COUNTER CURRENT FROM WB TO CB
723  LET K6 = (1.82 / 37.6) / T
724  REM  WIND FROM CB TO WB
726  LET K7 = (.918 / 3.30) / T
727  REM  TIDE FROM WB TO CB
730  LET K8 = (.918 / 37.6) / T
731  REM  TIDE FROM CB TO WB
```

```
735  LET K9 = ( 0.072 ) / T
737  REM  FRESHWATER TO WB
740 KA = ( 0.0169 / 3.30 ) / T
741  REM  EVAPORATION FROM WB
745  LET KB = ( 0.007 ) / T
746  REM  RAINFALL INTO WB
750  LET KC = ( 0.15 ) / T
751  REM  FRESHWATER TO CB
755  LET KD = ( .024 / 37.6 ) / T
756  REM  EVAPORATION
760  LET KE = ( .011 ) / T
761  REM  RAINFALL TO CB
765  LET KF = ( 0.008 ) / T
766  REM  GROUNDWATER TO INTAKE
770  LET KG = ( .002 / 1.35 ) / T
771  REM  EVAPORATION FROM INTAKE
775  LET KH = 0.0009 / T
776  REM  RAINFALL TO INTAKE
780  LET KI = ( 3.33 / 1.35 ) / T
781  REM  WIND FROM INTAKE
785  LET KJ = ( .114 / 37.6 ) / T
786  REM  TIDE FROM CENTRAL BAY TO INTAKE
788  LET KK = ( .114 / 1.35 ) / T
789  REM  TIDE FROM INTAKE TO CB
790  LET KL = ( 2.60 / 1.35 ) / T
791  REM  PUMPING FROM INTAKE TO TC
795  LET KM = ( .0021 / .52 ) / T
796  REM  EVAPORTATION FROM TC
800  LET KN = ( 00.0020 ) / T
801  REM  GROUNDWATER TO TC
805  LET KO = ( 0.0006 )
806  REM  RAINFALL TO TC
810  LET KP = ( .071 / 1.56 ) / T
811  REM  TIDE FROM SEB TO TC
815  LET KQ = ( .071 / .52 ) / T
816  REM  TIDE FROM THE THERMAL COVE TO SEB
820  LET KR = ( .167 / .52 ) / T
821  REM  WIND FROM THERMAL COVE TO SEB
825  LET KS = ( .0004 / 1.56 ) / T
826  REM  EVAPORATION FROM SEB
830  LET KT = ( .0002 ) / T
831  REM  PRECIPITATION TO SEB
835  LET KU = ( .244 / 37.6 ) / T
836  REM  TIDE FROM CB TO SEB
840  LET KV = ( .244 / 1.56 ) / T
841  REM  TIDE FROM SEB TO CB
845  LET KW = ( 4.3498 / 1.56 ) / T
846  REM  WIND FROM SEB TO CB
850  LET KX = ( .058 / 37.6 ) / T
851  REM  SHIPPING OUT OF BAY
855  LET KY = ( .058 ) / T
856  REM  SHIPPING INTO BAY
860  LET KZ = ( 5.9231 / 37.6 ) / T
861  REM  COUNTERCURRENT FROM CB TO INTAKE
```

```
865  LET L1 = (2.4335 / .52) / T
866  REM   COUNTERCURRENT FROM TC                          TO SEB
870  LET L2 = (1.7483 / 37.6) / T
871  REM  COUNTERCURRENT FROM CB TO SEB
875  LET L3 = (1.1767 / 37.6) / T
876  REM  COUNTERCURRENT FROM CB TO CARIB
880  REM  GRAPHICS SECTION A
900  REM  CALCULATES STORAGE VALUES
903  LET HR = HR + 1
910  LT I1 = ( COS ((HR / 12.5) * 3.1414))
915  IF HR = 25 THEN HR = 0
918  LET HW = HW + 1
920  IF HW > 12 THEN I2 = 1.25:K3 = 0
925  IF HW < 12 THEN I2 = .75:K4 = 0
928  IF HW = 24 THEN HW = 0
930  LET I4 = 1
950  LET I5 = 1
960  LET I6 = 1
970  LET I7 = 1
1000  REM  TIDE SWITCH
1010  IF I1 =  > 0 THEN K1 = 0:K7 = 0:KK = 0:KR = 0:KV = 0
1020  IF I1 < 0 THEN K2 = 0:K8 = 0:KJ = 0:KQ = 0:KU = 0
1030  LET I1 =  ABS (I1)
1100 Q1 =  + (K9 * I3) - (KA * I4 * Q1) + (KB * I5) + (K8 * I1 * Q2) - (K7 *
I1
* Q1) + (K6 * I2 * Q2) - (K5 * Q1) + Q1
1110 AQ2 = (K2 * I1) - (K1 * I1 * Q2) - (K3 * I2 * Q2) + (K4 * I2) + (K5 * Q1
) -
 (K6 * I2 * Q2) + (K7 * I1 * Q1) - (K8 * I1 * Q2) + (KC * I3) - (KD * I5 * Q2
) +
 (KE * I4)
1115 BQ2 = (KI * I2 * Q3) - (KJ * I1 * Q2) + (KK * I1 * Q3) - (KZ * Q2) + (KW
*
I2 * Q5) - (KU * I1 * Q2) + (KV * I1 * Q5) - (L2 * Q2) - (L3 * Q2) + (KY * I6
) -
 (KX * I6 * Q2)
1118 Q2 = AQ2 + BQ2 + Q2
1120 Q3 = (KF * I3) - (KG * I5 * Q3) + (KH * I4) - (KI * I2 * Q3) + (KJ * I1
* Q
2) - (KK * I1 * Q3) + (KZ * Q2) - (KL * I7 * Q3) + Q3
1130 Q4 = (KL * I7 * Q3) - (KM * I5 * Q4) + (KO * I4) + (KP * I1 * Q5) - (KQ
* I
1 * Q4) + (KN * I3) - (KR * I2 * Q4) - (L1 * Q4) + Q4
1150 Q5 = (KQ * I1 * Q4) - (KP * I1 * Q5) + (KR * I2 * Q4) - (KS * I5 * Q5) +
 (K
T * I4) + (KU * I1 * Q2) - (KV * I1 * Q5) - (KW * I2 * Q5) + (L2 * Q2) + (L1
* Q
4) + Q5
1600  GOTO 3500
1990  PRINT "TIME: ";C
2000  PRINT Q1
2010  PRINT Q2
2030  PRINT Q3
2040  PRINT Q4
2050  PRINT Q5
2090  PRINT
3000  GOTO 900
3500  IF C = .> 1 THEN  GOTO 4100
3600  PRINT : PRINT
3900  PRINT "        TABLE OF HOURLY COMPARTMENT VOLUMES"
3910  PRINT "            (MILLIONS OF CUBIC METERS)
390 RN "------------------------------------------------------------
-"
```

```
4000  PRINT "HR  WESTERN BAY  CENTRAL BAY  INTAKE BAY  THERMAL COVE  SOUTHEAS
T B
AY"
4010  PRINT "----------------------------------------------------------------
---

--------"
4100  PRINT C;"  ";Q1;"     ";Q2;"     ";Q3;"     ";Q4;"    ";Q5
4200  LET C = C + 1
5000  GOTO 700
6000  REM  PLOT SECTION
6200  LET TP = TP + 1
6210  HPLOT TP, - (Q1 * 30) + 159
6220  HPLOT TP, - (Q2 * 4) + 159
6230  HPLOT TP, - (Q3 * 30) + 159
6240  HPLOT TP, - (Q4 * 30) + 159
6250  HPLOT TP, - (Q5 * 30) + 159
6900  IF TP = 279 THEN TP = 0
6905  VTAB 22
6910  PRINT Q1,Q2,Q3,Q4,Q5
7000  GOTO 700
10000  END
```

TABLE OF HOURLY COMPARTMENT VOLUMES
(MILLIONS OF CUBIC METERS)

HR	WESTERN BAY	CENTRAL BAY	INTAKE BAY	THERMAL COVE	SOUTHEAST BAY
0	3.31509012	37.4871998	1.38820076	.530515493	1.61000969
1	3.32601808	37.3782888	1.41922517	.541499076	1.65659704
2	3.33082038	37.2690165	1.44394364	.552336374	1.69949199
3	3.32793933	37.1557085	1.46311097	.562595577	1.73845475
4	3.31632204	37.0354331	1.47740285	.571985998	1.77333031
5	3.29548752	36.9061308	1.48744365	.580326668	1.80408407
6	3.26543433	36.7675761	1.49372137	.582353012	1.83466274
7	3.22693439	36.6203743	1.49678778	.585049901	1.85911637
8	3.18140852	36.4651306	1.49723335	.587995078	1.87834393
9	3.13074755	36.303268	1.49564133	.590842676	1.89335103
10	3.07714829	36.1369394	1.49257703	.593316765	1.90520909
11	3.02293538	36.0601365	1.48917336	.595256321	1.91519
12	3.00689173	36.255342	1.41107134	.58656671	1.81548423
13	2.99408014	36.4250956	1.35097161	.574493472	1.72981575
14	2.98633067	36.5779306	1.30519311	.560757799	1.65640433
15	2.98516269	36.721257	1.27083113	.546523618	1.59380932
16	2.99171412	36.8612337	1.24558528	.532564344	1.54079432
17	3.00669462	37.0026565	1.22762103	.519381979	1.49624209
18	3.03053226	37.1488088	1.2154824	.516150633	1.45219254
19	3.06348121	37.3002135	1.2080333	.512903131	1.41673104
20	3.10467643	37.4576262	1.20425214	.50991846	1.38851746
21	3.15272778	37.6206225	1.20325943	.507365314	1.36627799
22	3.20579987	37.7877652	1.20429008	.505329444	1.34879846
23	3.26172001	37.956811	1.20667669	.503834236	1.33493153
24	3.27983223	37.8091586	1.26973808	.507663535	1.40142702
25	3.29592838	37.6728872	1.32181294	.515035911	1.46285167
26	3.30776221	37.5429529	1.3643853	.524472384	1.5194609
27	3.31337342	37.4147741	1.39870526	.534883407	1.57133186
28	3.31121064	37.2844046	1.42584619	.545481321	1.61847218
29	3.30022959	37.1486864	1.44675103	.555711817	1.66090101
30	3.27995948	37.0053702	1.46226835	.565200735	1.69870506
31	3.25046243	36.8538115	1.47309107	.568637922	1.73598823
32	3.21252578	36.694472	1.47992178	.572716	1.76700911
33	3.16756391	36.5279465	1.48347205	.576976427	1.79261991
34	3.11745972	36.3556545	1.48442896	.581053751	1.81377543
35	3.0644015	36.270993	1.48404597	.584711602	1.83168606
36	3.04742005	36.4510543	1.4083172	.577877992	1.74334548

Appendix D Table Continued.

37	3.03149328	36.604397	1.34966975	.567620016	1.66669712
38	3.01870665	36.7391152	1.30465153	.555581929	1.60040639
39	3.01092739	36.8625613	1.27054388	.542874301	1.54343608
40	3.00970544	36.9811806	1.2451998	.53023597	1.49490936
41	3.01620249	37.1003388	1.22691312	.518149554	1.45402408
42	3.03114536	37.2241765	1.21431358	.506922737	1.42000235
43	3.05496929	37.3553578	1.20631065	.505382329	1.38533471
44	3.08791789	37.4938005	1.20205464	.503736374	1.35821021
45	3.1291207	37.6399769	1.20073094	.50222662	1.33741183
46	3.17718084	37.793228	1.20162221	.501004498	1.32176712
47	3.2302556	37.9519203	1.20409033	.500151727	1.31014764
48	3.24789338	37.7994323	1.26734325	.504492851	1.37785798
49	3.26593897	37.6621395	1.31987265	.512294416	1.44113593
50	3.282001	37.5349787	1.36313467	.522126388	1.50014553
51	3.29383721	37.413116	1.39833673	.532930206	1.55485184
52	3.29948963	37.2921337	1.42649673	.543934627	1.60513037
53	3.29740738	37.1682143	1.448493	.554590192	1.65085292
54	3.28654501	37.0383028	1.46510458	.564518777	1.6919506
55	3.26642898	36.9002333	1.47704228	.57347504	1.728456
56	3.23712669	36.7535337	1.48487177	.576170301	1.76444969
57	3.19942391	36.5987348	1.48920226	.579470467	1.79408771
58	3.15472816	36.4364442	1.49067045	.582955278	1.81824207
59	3.10491368	36.359339	1.49049808	.586332097	1.83807969
60	3.08896261	36.5446847	1.4143414	.57943315	1.75023246
61	3.0717998	36.6998557	1.35504199	.569289559	1.67306549
62	3.05563535	36.8325442	1.30920086	.557471628	1.60550439
63	3.04258483	36.9500422	1.27414863	.545028186	1.54675403
64	3.03454085	37.0590704	1.24778608	.532648188	1.4961569
65	3.0330736	37.1655723	1.22845474	.520775731	1.45310479
66	3.03935982	37.2745113	1.21483243	.509690606	1.41698742
67	3.05413618	37.3897027	1.20584955	.499563738	1.38716588
68	3.07783667	37.5135014	1.20065301	.499004231	1.3563343
69	3.11068533	37.645514	1.19857992	.498318416	1.33267931
70	3.15180737	37.7860767	1.19895053	.497713737	1.31502536
71	3.19980019	37.9344208	1.20115326	.497322491	1.30223105
72	3.21456048	37.7752328	1.26426593	.502003102	1.3691144
73	3.23213325	37.634691	1.31694623	.510061495	1.43233194
74	3.25013994	37.5079724	1.36063713	.520119128	1.4919893
75	3.26619569	37.3902291	1.39651534	.531153013	1.54796533
76	3.27806288	37.2767968	1.4255537	.542413736	1.60002495
77	3.28378622	37.1633921	1.44857309	.553362027	1.64790693
78	3.28181558	37.0463063	1.46628629	.563620324	1.69139269
79	3.27110432	36.9225735	1.47933322	.572936274	1.73035599
80	3.25117606	36.790103	1.4883077	.58115536	1.76479504
81	3.22210602	36.6485959	1.4936679	.582993415	1.79876029
82	3.18467877	36.4986483	1.49594383	.585462191	1.82631996
83	3.14029409	36.4321267	1.4963075	.588208833	1.84856134
84	3.12769347	36.6265114	1.42009193	.580968744	1.76147203
85	3.11162428	36.7877277	1.36046029	.570747363	1.68398218
86	3.09427024	36.9228052	1.31406168	.559030993	1.61525015
87	3.07787067	37.0386819	1.27827254	.54679604	1.55470769
88	3.06456704	37.1420573	1.25103908	.534670573	1.50191136
89	3.0562739	37.2391818	1.23074935	.523049265	1.45644898
90	3.05457901	37.3356214	1.21612933	.512173606	1.41788514

Appendix D Table Continued.

91	3.0606721	37.4360334	1.20615899	.50218669	1.38573339
92	3.07529829	37.5439819	1.20000533	.493169701	1.35944558
93	3.09889013	37.6615751	1.19700203	.493564064	1.33186994
94	3.13165379	37.7881608	1.19663306	.493778956	1.31117752
95	3.1727104	37.9239682	1.19832454	.494001959	1.29622029
96	3.18240851	37.7550524	1.2610447	.499130608	1.36145816
97	3.19715463	37.6077875	1.31361334	.507507716	1.42381842
98	3.21472648	37.4778136	1.35747786	.517814506	1.48337772
99	3.23275365	37.3605198	1.39380294	.529073208	1.53996121
100	3.24885794	37.2512243	1.42353172	.540566367	1.59325025
101	3.26080666	37.1453937	1.44744087	.551774682	1.64287447
102	3.26664755	37.0388501	1.46618647	.562329922	1.68848308
103	3.26483156	36.9279711	1.48034274	.571979923	1.72980068
104	3.25431134	36.809863	1.4904331	.580562955	1.76666713
105	3.23460803	36.6824969	1.49695339	.587989008	1.79906212
106	3.20580843	36.5457281	1.50027194	.588966948	1.83101258
107	3.16869677	36.4914595	1.50145137	.590677974	1.85670154
108	3.16160127	36.6971088	1.42551719	.58275832	1.771571
109	3.14895801	36.8673956	1.36586387	.572203384	1.69479837
110	3.13275708	37.0084622	1.31918024	.560409122	1.62575233
111	3.11520981	37.1266138	1.28288196	.548271663	1.56408035
112	3.09858118	37.2282197	1.25495546	.536349074	1.50955213
113	3.08503559	37.3195278	1.23383131	.524976688	1.46195874
114	3.07650711	37.406425	1.21828096	.514347534	1.42105262
115	3.07459918	37.4941812	1.20733282	.504566967	1.38651623
116	3.08051312	37.5872094	1.20020448	.495688625	1.35794994
117	3.09500154	37.6888708	1.19624896	.487737167	1.3348717
118	3.11849544	37.8010666	1.1949466	.489025822	1.31025407
119	3.15118449	37.9229202	1.19589654	.490062611	1.29225486
120	3.15394366	37.7418385	1.25798982	.495790956	1.35510761
121	3.16368123	37.5847688	1.31018577	.504587846	1.41585559
122	3.17846703	37.4480173	1.35395363	.515200281	1.47457589
123	3.19608788	37.3274333	1.39046346	.526703617	1.53107021
124	3.2141815	37.2185685	1.42064721	.538421559	1.58496968
125	3.23037651	37.1168688	1.4452526	.549864484	1.63582254
126	3.24244536	37.0179028	1.46489214	.560682978	1.68317026
127	3.2484391	36.9175754	1.48008386	.570633657	1.72660627
128	3.24681015	36.8123332	1.49128595	.579554685	1.76582216
129	3.23651075	36.6993416	1.49892419	.587348602	1.80064009
130	3.21706	36.5766231	1.50341229	.593970296	1.83103194
131	3.1885591	36.5354216	1.50564235	.59416321	1.8611914
132	3.18877367	36.7537044	1.4303165	.585148619	1.77931464
133	3.18170961	36.9353747	1.37095734	.573928775	1.70443068
134	3.16899634	37.0855318	1.32428214	.561804906	1.63608728
135	3.15264895	37.2096211	1.28773636	.549587159	1.57412598
136	3.13490312	37.3134026	1.25933874	.537756335	1.51851853
137	3.11804673	37.4028132	1.23755579	.526579815	1.46925778
138	3.10426477	37.4837526	1.22119921	.516192668	1.42629027
139	3.0955089	37.5618232	1.20934216	.506652691	1.38947925
140	3.09339669	37.6420596	1.20125095	.497976333	1.35858897
141	3.09913991	37.7286775	1.19633006	.490160989	1.33328262
142	3.11349785	37.8248713	1.19407867	.483197829	1.31312834
143	3.13689976	37.9323672	1.19409228	.485302863	1.29120053
144	3.13126795	37.7375061	1.25535943	.491833322	1.35095964