DRE-90

MEMORANDUM REPORT

On

Mathematical Models in Water Resources Planning

July, 1979

MEMORANDUM REPORT

JULY 1979

MATHEMATICAL MODELS IN WATER RESOURCES PLANNING

SOUTH FLORIDA WATER MANAGEMENT DISTRICT

A MEMORANDUM REPORT

JULY 1979

MATHEMATICAL MODELS IN WATER RESOURCES PLANNING

By

Ashok N. Shahane
Water Resources Division
Resource Planning Department
South Florida Water Management District
West Palm Beach, Florida 33402

TABLE OF CONTENTS

INTRODUCTION

During the last ten years, the South Florida Water Management District has utilized several mathematical models to aid its increasing statutory responsibility in areas of water resource planning, regulation and operation. These mathematical models are basically procedures that incorporate numerous mathematical equations and flowcharts representing the interactions of key processes and variables of the water system in south Florida. The primary purpose of this report is to provide an executive summary of the mathematical models that are considered in water resources planning functions of the Water Resources Division of the District.

To bring both brevity and completeness to the extent possible, a specific format is adopted in this report. It is hoped that a brief description of the model, followed by the current status, district areas of its application, and a list of documentation reports will adequately expose the water resources managers, executives, leaders and professionals to the modeling work of the District in water resources planning.

It should be noted that there are some models that have been attempted by the Division staff but they are not included in this report because of their either short term status or "an early developmental stage" status, or the routine status. This category of sideline models includes contour plotting program, the frequency analysis programs, the dynamic ecosystem model, steady state surface water quality model, wind driven circulation model and spectral model. Currently there are several models for which detailed technical documentation reports are planned. For any additional technical details, the reader is requested to get in touch with the Division Director or the Department Director.

1. LINEAR OPTIMIZATION MODEL

Description: Considering (a) cost effectiveness, (b) flood protection, (c) water supply performance, and (d) environmental impact as guidelines, the general framework of this linear programming model optimizes the operational cost of various water management schemes using constraints such as hydrologic balance, storage capabilities and regulation schedules, equipment and facility limitations, flood control requirements and environmental limitations. The decision variables of the model are (1) the optimum amount of water backpumped on a monthly basis and (2) the amount of water delivered to meet service area requirements.

Areas of Application: Three planning basins in the Lower East Coast of south Florida: West Palm Beach basin (C-51), Hillsboro basin (C-14), and Tamiami basin (C-4); Lake Okeechobee Planning area.

Status: Ready to use.

Documentation Reports:

1. "Multi-objective Evaluation Methodology", Water Use and Supply Development Plan, Vol. IIIA, Lower East Coast Planning Areas, Technical Exhibits "A-H", pp. 2-136 to 2-146, April 1977.

2. Marban, J., "A Linear Programming Model of the Water Resources in Southeast Florida", proceedings of the ASCE Water Resources Planning and Management Division Specialty Conference on Water Systems '79 at Houston, Texas, February 1979.

Contact Person: Jorge Marban

2. CLAD MODEL (CONCENTRATION, LOADING AND DISCHARGE MODEL)

Description: Using rainfall, land use information, historical discharge records, land use pollutant accumulation rates and general basin descriptive parameters, the model estimates the quantity and quality of water discharged from a basin from some projected land use. Some of the water quality parameters considered in the model include (a) suspended and settleable solids, (b) biochemical oxygen demand (BOD), (c) total nitrogen, (d) orthophosphate, and (e) total phosphate.

Areas of Application: It is applicable to any basin. Current District applications are for Western part of West Palm Beach basin, western part of Tamiami basin with Snapper Creek and the Hillsboro basin.

Status: Ready to use.

Documentation Reports:

1. "Urban Stormwater Runoff; STORM", Hydrologic Engineering Center of the United States Crops of Engineers, January 1975.

2. Foy, Jay "Concentration, Loading and Discharge Model (CLADM) and its Applications", documentation report (under preparation).

Contact Persons: Ashok Shahane and Jorge Marban.

3. THE RECEIVING WATER QUANTITY MODEL

Description: This is an adapted and modified version of the receiving water quantity part of the EPA stormwater management model. It is applied to investigate the hydraulic impact of various backpumping schemes. Various modifications to the original EPA model are in relation to Manning's roughness coefficient, depth of flow, width of hypothetical channels through marsh areas, rainfall input, seepage rate and use of the Monte Carlo technique for model area computations. Using geometrical data of the link-node network, rainfall, evaporation, inflows, outflows, seepage function and Manning's 'n' for marshland, the model estimates stages at various node points. Comparison of these simulated stages with recorded stages indicates satisfactory correlations during wet seasons implying that the model can be a useful tool to examine the impact of additional inflow resulting from backpumping.

Areas of Application: Three conservation areas of south Florida.

Status: Ready to use.

Documentation Reports:

1. Lin, Steve, "The Application of the Receiving Water Quantity model to the Conservation Areas of South Florida", a documentation report (under preparation).

Contact Person: Steve Lin

4. THE WATER QUALITY PLANNING MODEL

Description: This model is based on the useful concepts of the receiving water quality portion of the EPA stormwater management model. For the given link-node representation of conservation areas, this model uses the velocities, discharges and other hydraulic parameters in conjunction with the historical and future loadings of the chemical constituents to generate daily concentrations of these coefficients at selected points called nodes. The model is first calibrated for the available chloride field data of 1974. The response of the model to wet and dry conditions is then examined by simulating possible concentrations of chlorides for four years of 1968-71. After reasonable results from these runs, the model is then used to estimate the spatial and time distribution of chlorides under historical and backpumping conditions. Due to the limited water quality data base, the model is demonstrated only for chlorides at the present time.

Areas of Application: Three conservation areas of south Florida.

Status: The model needs additional calibration and validation data.

Documentation Reports:

1. Shahane, A. N. and Maloy, J. R., "The Water Quality Planning Model", a paper presented to the International Conference on Ecological Modelling at Copenhagen, Denmark, August 1978.

2. "Water Quality Modelling", Water Use and Supply Development Plan; Vol. IIIA, Lower East Coast Planning Areas, Technical Exhibits I-K, pp. 3-1 to 3-96, April 1977.

Contact Person: Ashok Shahane.

5. LEC AQUIFER HYBRID MODEL

Description: Using the unsteady groundwater flow equation in two dimensions, an analog model is set up based on the electrical equivalence of the same equation. Finite difference expression of the equation is represented by resistors and capacitors with 1 mile resolution in square grids. Basic input data to the analog simulator includes wellfields and canals of the aquifer, land use, and ground elevation. To use the model, rainfall, canal flows, pumpages, and stage data have to be converted to equivalent electrical units and set up in time sequences. Output of this model includes groundwater elevation at every node point and areal evapotranspiration, storage and outflows. The model is being used in on-going programs in the areas of drought analysis, wellfield development, seepage estimations and saltwater intrusion studies.

Areas of Application: Lower East Coast with Biscayne Aquifer and some part of shallow aquifer in Palm Beach County.

Status: Ready to use.

Documentation Reports:

1. Shih, G., "Use of Hybrid Computer Models in Resource Planning", In-Depth Report of South Florida Water Management District, Vol. 3, No. 2, February 1976, p. 12.

2. Shih, G. and McVeigh, F., "A Hybrid Computer System for Groundwater Modelling", ASCE 26th Annual Hydraulic Division Specialty Conference, University of Maryland, August 9-11, 1978.

3. Lin, S. and Shih, G., "Management Possibilities of Drought Moderation

in Southeast Florida", AGU 1979 Spring Meeting, May 28 - June 1, Washington, D.C.

4. "Lower East Coast Aquifer Studies", Water Use and Supply Development Plan, Vol. IIIA, Lower East Coast Planning Areas, Technical Exhibits "A-H", pp. 1-1 to 1-82, April 1977.

Contact Persons: Steve Lin, Alan Fox and George Shih.

6. THE OPERATIONAL WATER QUANTITY MODEL

Description: Essential components of the operational water quantity model include a sub-basin model, routing model and their combination. Using the rainfall input, initial stage conditions and basin parameters, the sub-basin model estimates the amounts of overland flow, sub-surface flow, surface storage, sub-surface storage, water losses and the streamflows contributed by each of the 19 sub-basins of the upper and lower Kissimmee basin. An iterative type routing model is then designed to distribute the simulated streamflows through the primary conveyance system of lakes, canals and channelized river managed by gate operations at the controlling structures. The developed methodology for combining the sub-basin model with the routing model is demonstrated for the Kissimmee River system for the year 1970 by considering 21 canals, 14 lakes, and 14 control structures.

The final outcome of the model relates to simulated lake stages, water levels at tailwater and headwater sides of the controlling structures and simulated discharges through controlling structures every 3 hours for the full year of 1970. The comparison of simulated values with the corresponding historical data indicates the "working" of all individual pieces of the operational water quantity model.

It is felt that information provided directly by the model, and secondary information generated in developing the model, forms an extensive data base which may be useful in current as well as future management studies and operations of the Kissimmee basin, although several steps are necessary before the model is finally put "on line" for operation.

Areas of Application: Kissimmee River basin.

Status: It requires additional calibration beginning with independent field checks on stage-storage-discharge curves.

Documentation Reports:

1. Shahane, Berger and Hamrick, "The Development of an Operational Water Quantity Model", Technical Publication #77-5 of South Florida Water Management District, November 1977.

2. Shahane, Berger and Hamrick, "Computer Program Documentation for the Operational Water Quantity Model", Technical Supplement to Technical Publication #77-5, South Florida Water Management District, November 1977.

Contact Person: Ashok N. Shahane.

7. AN INPUT-OUTPUT MODEL (WATER BUDGET ANALYSIS)

Description: The basic hydrologic equation of "Inflow-outflow = storage change" is used to estimate stage hydrographs. In this model, historical stages, historical releases, regulation schedules and water demands are used to calibrate and to assess operational aspects of the model. The output of the model includes stage hydrographs for the simulation period, stage duration curves, regulatory releases, releases to meet demands and the amount of demand satisfied.

Areas of Application: It is applicable to any basin, planning area or a watershed. District applications are for Lake Okeechobee, Kissimmee drawdown studies and Boney Dike Marsh.

Status: Ready to use.

Documentation Report:

1. "Evaluation of Lake Okeechobee Storage Alternatives", Water Use and Supply Development Plan, Vol. IIIB, Lake Okeechobee Planning Area, pp. 5-7 to 5-13, April 1977.

Contact Persons: Steve Lin, Paul Trimble and Jorge Marban.

8. THE HYDRAULIC BACKWATER MODELS

Description: Two versions (namely the District backwater program and HEC-2) are widely used for district applications. Both versions use the Bernoulli's theorem for estimating total energy at each cross-section Manning's formula for computing the friction head loss between two consecutive cross-sections; and average friction slope for a reach is determined in terms of the average of the conveyance at the two ends. The differential equation of gradually varied flow and a numerical scheme are utilized in both versions to obtain upstream or downstream stages of the canal for a given discharge, and canal cross-sectional data.

A. The District Backwater Program: A single section representation (SR) method is applied to compute conveyance for the given channel cross-section. The composite technique for varied roughness coefficient (CTR) is then used to estimate mean velocities and head losses for each section. This version is limited to a prismatic channel. Computations for head loss through Bridges, culverts, weirs, dams etc. are not included in this version.

B. HEC-2 Program: The multiple section representation (MR) method is used to compute conveyances. The CTR method is then applied to estimate mean velocities and head losses. This version is not limited to prismatic channel, and it is capable to handle the subcritical and supercritical flow conditions because of various hydraulic structures such as bridges, culverts, weirs, embankments and dams. This version also computes the critical depth at each cross section:

These two programs have been used (a) to establish stage-storage-discharge relationships, (b) to obtain water surface profiles for floods of different frequency levels, and (c) to delineate the encroachment line on the flood plain area under various water management schemes with an extensive use of HEC-2.

Areas of Application: It is applicable to any canal; current District applications are for 21 canals of the Kissimmee basin, Shingle Creek, West Palm Beach Canal (C-51), Hillsboro Canal (C-14) etc.

Status: Ready to use.

Documentation Reports:

1. Shih, S. F. (Tony), "FCD Backwater Profile Computations", a memorandum report of Central and Southern Florida Flood Control District, September 1975.

2. Shahane, Berger and Hamrick, "The Development of the Operational Water Quantity Model", Technical Publication #77-5, South Florida Water Management District, November 1977.

3. Lin, Lane and McCann, "Floodplain Management Studies of the Shingle Creek Basin", Technical Publication #79-1, South Florida Water Management District, West Palm Beach, FL, April 1979.

Contact Persons: Steve Lin and Ashok Shahane

9. SYNTHETIC RAINFALL AND RUNOFF DATA GENERATORS

Description: A generalized type of statistical model called a synthetic data generator is developed to broaden the existing limited data base. The synthetic runoff data generator is based on the M^{th} order autoregressive model introduced by Thomas and Fiering of Harvard University. The synthetic rainfall data generator includes periodicity more explicitly in terms of fourier series. Initially, statistical parameters (such as mean, regression coefficients, fourier coefficients, standard deviations, autocorrelations) are estimated using historical data. These synthetic generators are then applied to generate 100 to 400 years of monthly data, the statistical characteristics of which are similar to historical data.

Areas of Application:

1. Monthly streamflows at S-65E in the Kissimmee basin.

2. Monthly rainfall in the Kissimmee basin.

3. Monthly stages of Lake Okeechobee.

4. Areal and Point monthly rainfall in Palm Beach, Broward and Dade Counties for 400 years.

Status: Synthetic rainfall generator will be ready in July 1979. The synthetic runoff generator is ready to use.

Documentation Reports:

1. Shih, S. F., "Synthetic Data Generator - A Joint Distribution Technique", Technical Publication #76-1, South Florida Water Management District, West Palm Beach, FL, February 1976.

2. Shahane, A. N., Shih, S. F., and McGraw, R., "Areal Rainfall Analyses and Syntheses for Lower East Coast of South Florida", (a documentation report is under preparation).

Contact Person: Ashok Shahane.

10. AREAL RAINFALL PROGRAM

Description: This computer program was developed as a part of an in-house project on statistical data analysis and synthesis (Program No. 8018). It is designed to handle long term rainfall records at Weather Bureau stations, District stations, city and county stations. Using the Monte Carlo method and a simple averaging method, the program computes daily and monthly areal rainfall for Palm Beach, Broward and Dade Counties. The Monte Carlo method generates several thousand random numbers which are assigned systematically to various raingages or node points. The ratio of the number of random points assigned to a raingage and the total number of random points falling in the area is the Theissen coefficient for that raingage. These Theissen coefficients are multiplied by the rainfall values to obtain daily and monthly areal rainfall. Coordinates of boundary points and rainfall stations are main inputs in addition to the point rainfall values. Binary search techniques, sort programs, and bit pattern concepts have made this computer program more efficient and manageable on an in-house computer facility - HP 3000.

Areas of Application: Any planning area or watershed with current applications in the following areas:

1. Lower east coast (drought analysis, aquifer simulation and synthetic generator).
2. Istokpoga basin.

Status: Ready to use.

Documentation Report:

1. Shahane, A. N., Shih, S. F. and McGraw, R., "Areal Rainfall Analyses and Syntheses for Lower East Coast of South Florida", (documentation report under preparation).

Contact Person: Ashok Shahane and Tom MacVicar.

11. IRRIGATION WATER REQUIREMENT PROGRAM

Description: This program uses weighted pan coefficients to estimate potential evapotranspiration based on the amount of land devoted to each crop. The crop water requirement is then computed as an equivalent to evapotranspiration. ET deficit and ET surplus are estimated as the differences between evapotranspiration and actual rainfall. This program has been used to compute supplemental water use.

Areas of Application: Any agricultural area with current District applications for for

1. Everglades agricultural area.
2. Lower east coast.
3. Lower west coast.

Status: Ready to use.

Documentation Report:

1. Mierau, R., "Supplemental Water Use in the Everglades Agricultural Area", Technical Publication #74-4, South Florida Water Management District,

West Palm Beach, FL, June 1974.

Contact Person: Ronald Mierau

12. HOLEY LAND RESERVOIR MODEL

Description: The sensitive issue of returning agricultural runoff on a marsh type storage area is examined through the model which is based on input-output computations. The model estimates rainfall, seepage, evaporation, irrigation water requirements, agricultural runoff, channel capacities, flow redirection and pump capabilities that are related to the hydrology of the storage area. These estimates are then subjected to a routing procedure which provides stage hydrographs on a monthly basis for six different regulation schedules. The output of the model is utilized in estimating the amount of agricultural runoff presently pumped to Lake Okeechobee that can be diverted to the conservation areas and to determine the impact of these diversions on Lake Okeechobee storage. In addition, the stages of water in the storage area, as determined by the model for the period 1963-73, are used to assess the hydrologic, ecologic and economic impact of the storage area.

Area of Application: Holey Land reservoir in the southern part of the Everglades agricultural area in south Florida.

Status: Ready to use.

Documentation Report:

1. "Investigation of Backpumping Reversal and Alternate Water Retention Sites in Miami Canal and North New River Canal Basins of the Everglades Agricultural Area", a report of the South Florida Water Management District prepared for the special project for the prevention of eutrophication of Lake Okeechobee, December 1975.

Contact Person: Ronald Mierau.

13. NUBBIN SLOUGH DIVERSION MODEL

Description: The basic purpose of the model is to determine the effects of structural changes and changes in operating criteria on the flow to Lake Okeechobee from Nubbin Slough - Taylor Creek, the impact on the FP&L reservoir, and changes in St. Lucie Canal flow. The framework of the model takes into account (a) design capacities of the channels, (b) seepage estimates as a function of stages in the FP&L reservoir, (c) evaporation estimates, (d) flow and stage routing procedures for various combinations of conveyance routes, (e) regulation schedules of Lake Okeechobee and the FP&L reservoir, and (f) several water management schemes and runoff generated in the St. Lucie canal basin. Using a set of daily inflows and outflows (including rainfall, evaporation, seepage, regulatory and nonregulatory discharges) and the net storage change, hydrologic and economic criteria of diversion flows under various management schemes are used to assess the amount and distribution of diversion flows for a given day or month. The procedure of the model is useful in reservoir management and operations for multi-purpose use and for assessing the impact of related water management schemes from both a quality and quantity view.

Area of Application: Nubbin Slough area, coupled with Florida Power & Light Company reservoir near Lake Okeechobee.

Status: Ready to use.

Documentation Reports:

1. Mierau, R., "Nubbin Slough Diversion Alternatives", a memorandum of the South Florida Water Management District, June 9, 1978.

2. Mierau, R., "FP&L Reservoir Routing", a memorandum of the South Florida Water Management District, October 28, 1977.

3. Mierau, R., "Revised St. Lucie Canal Flow Estimates for Lake Okeechobee Water Budget", a memorandum of South Florida Water Management District, West Palm Beach, Florida, March 24, 1976.

Contact Person: Ronald Mierau

14. UNCERTAINTY ESTIMATION PROGRAMS

Description: With observed variables randomly spaced as the only input, the process estimates the variable and its associated uncertainty at any point of the regular grid suitable for contour mapping. Weighted least square or Kriging procedures are used to obtain unbiased minimum variance estimates.

Area of Application: Any areal distributed variable.

Status: Ready to use; some refinements are in progress.

Documentation Report: In preparation

Contact Person: George Shih

15. CSU STATISTICAL PACKAGE

Description: Colorado State University (CSU) statistical package has several programs that are useful to hydrologists and water managers. The statistical package that is adapted to the District's HP 3000 computer includes (a) ARIMA models, (b) disaggregation models, (c) correlation models for filling and extending data, (d) trend and cyclic analyses of time series, (e) several "goodness of fit" tests, and (f) Fourier series program. Although these programs are currently set up for monthly series, they can be easily modified to any other time step. Any time series data such as rainfall, evaporation, evapotranspiration, seepage, runoff, water quality, etc., etc., can be an input to these programs. The output from these programs include several estimated statistical parameters for various models using the observed data. The "goodness of fit" tests provide a quantitative basis for testing the adequacy of the selected model and statistical estimations.

Areas of Application: Correlation models are used for monthly rainfall series of the lower west coast.

Status: ARIMA model, "goodness of fit" tests and filling data programs are ready to use; other statistical programs need some additional checking.

Documentation Report:

1. Salas, Yevjevich, Boes, Delleur, Schaake, Croley, Benzeden and Smith, "Lecture notes for the computer workshop in statistical hydrology", July 17-21, 1978, Hydrology and Water Resources Program, Dept. of Civil Engg., Colorado State University, Fort Collins, Colorado.

Contact Person: Ron Mierau

16. MESH GENERATION PROGRAM

Description: The main purpose of this program is to divide a given area into several small areas called elements. These elements could be triangular, quadrilateral or any other desired shape. These elements are used in the finite element method for solving differential equations of surface and groundwater movements.

Currently there are two versions of this program. One is adapted to the CDC 3100 and the other is available on the HP 3000. Although these programs are based on similar principles and input data, the nature of output is slightly different. A program on CDC 3100 uses x and y coordinates of the boundary points of the area and the output includes a number of triangular elements in a counter-clockwise order with x and y coordinates of the left side, right side and apex nodes of each element. Considering the trade off between core limitation and level of resolution, an input parameter (which is called number of passes) is used. For example, Pass No. 1 requires a maximum of 200 input elements; Pass No. 2 specifies 100 input elements, etc., etc. There are four passes that are used in this program.

A computer program that is available on the HP 3000 also uses boundary points but it can generate either triangular or quadrilateral elements. In addition to the nodes of the element and their position coordinates, connectivity data indicating the connective features of the elements are provided.

Areas of Application: Finite element method for the aquifers of the District

Status: Ready to use.

Documentation Reports:

1. Engineering production program No. E086 of CDC 3100, Data Processing Division, South Florida Water Management District.

2. Segerlind, L. J., "Applied Finite Elements Analysis", Chapter 18, John Wiley & Sons, Inc., 1976.

Contact Persons: Don Paich, Tom MacVicar and George Shih.

17. HYDRODYNAMIC SURFACE WATER MODEL

Description: Hydrodynamic equations, based on continuity and momentum, are solved by the method of characteristics. Compatibilities between overland flow and channel flow are checked within the internal boundaries. Input parameters include rainfall, area dimensions, slopes, channel cross sections, and roughness of surfaces and channels. The output variables include depth, velocity and discharge at grid points.

Areas of Application: Lower west coast.

Status: In progress.

Documentation Report:

1. Chen, C. L. and Chow, V. T., "Hydrodynamics of Mathematically Simulated Surface Runoff", Hydraulic Engineering Series No. 18, Dept. of Civil Engineering, University of Illinois, Urbana, Illinois, August 1968.

Contact Persons: George Shih and Paul Trimble