MATHEMATICAL SIMULATION CAPABILITIES
IN
WATER RESOURCES SYSTEMS ANALYSIS

LP-16

TEXAS DEPARTMENT OF WATER RESOURCES

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ABSTRACT

Over the last 15 years, a number of computer-based, water resources simulation and optimization models have been developed by the Planning and Development Division of the Department. Descriptions are provided for 29 of these models and their associated computer programs.

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INTRODUCTION

The Texas Department of Water Resources (TDWR) became engaged in 1968 in a research effort jointly funded by TDWR and the Office of Water Resources Research, U.S. Department of the Interior, which has resulted in the development of a series of computer-oriented planning models and attendant usage procedures which can be used to analyze a variety of water resource planning problems and alternatives including many problems identified in the Texas Water Plans of 1968 and 1977. These models and techniques have been developed so as to be functionally interactive in the planning process. Equally important, this research effort has spawned the development of associated techniques, funded entirely with State funds, to provide analytic capabilities for the total spectrum of problems encountered when planning the use of scarce water resources, e.g., ground water management and environmental effects of water resources development.

The descriptions in this report of these models, their potential applications, and their limitations are not intended to be detailed or all-inclusive. Instead, they are introductions to the application of these systems analysis techniques to water resources planning investigations. More detailed information on the models can be obtained from the references cited in the model descriptions, or by contacting the Engineering and Environmental Systems Section of TDWR. In addition, all of the models used by the Texas Department of Water Resources are not discussed in this summary.

The models described are classified into several categories of simulation capabilities. Some of the models are interactive with other models in different categories, and an effort has been made to define in the model descriptions all the possible or necessary model interactions.

The programs described in this document are written in FORTRAN and were generally developed on a UNIVAC 1100 Series Computer. Some difficulties may be enountered with running these programs on IBM computers since the UNIVAC system automatically sets all core storage to zero prior to execution while IBM equipment does not. It is therefore suggested when executing these programs that all core storage locations be set to the number zero prior to execution if the operating system does not do so automatically.

A further description of the application of a number of these models to the analysis of a complete water resources system is provided in TDWR Report 183 and Report LP-75.

The Information Systems and Services Section of TDWR acts as the clearinghouse for the dissemination of all TDWR computer software, data files, and related information. Further information pertaining to the availability of all programs and related documentation described herein may be obtained by contacting the Information Systems and Services Section (Tel: 1-512-475-2661).

Technical Questions pertaining to the computer programs or models should be directed to the Engineering and Environmental Systems Section of the Planning and Development Division (Tel: 1-512-475-4344).

River Basin Analysis

PROGRAM DESCRIPTION

PROGRAM	:	SIMYLD-II is a multi-reservoir simulation model capable of simulating the movement of water through a system of river reaches, pump canals, reservoirs and non-storage river junctions. Water demand to be made on the system can be applied to either the storage or non-storage junctions and the option is available to enter these demands as monthly values or as a total annual demand which will be reduced to monthly demands according to a set of user supplied demand distribution factors. SIMYLD-II also offers the ability to set priorities for meeting water demands and maintaining reservoir storage at each reservoir. An additional capability allows these priorities to change when the hydrologic state of the reservoir system changes between wet, dry, and normal conditions. A second purpose of SIMYLD-II is determination of the firm yield of a single reservoir within a multi-reservoir water resources system. An iterative procedure is used to adjust the demands at the selected reservoir in order to converge on its maximum firm yield at a given storage capacity assuming total systems operation.
INPUT DATA REQUIREMENTS	:	River basin description Reservoir maximum, minimum, and starting capacities Reservoir area-capacity data Reservoir inflow data Reservoir demand data Reservoir evaporation data
SIMULATION MODE	:	Dynamic or static
NUMERICAL SOLUTION	:	The transfer of water through the links in a reservoir system is representative of a typical network flow problem. In SIMYLD-II the optimum allocation of network flows is accomplished through use of the out-of-kilter algorithm.
CORE REQUIREMENTS	:	60K words of storage.
INTERFACE REQUIREMENTS	:	SIMYLD-II is a stand-alone model.

MODEL DEVELOPMENT AND DOCUMENTATION : SIMYLD-II was developed by the Systems Engineering and Development Division of the Texas Water Development Board. The network flow algorithm was developed under contract to the Texas Water Development Board by Dr. Fred Glover, Dr. Darwin Klingman, and Mr. Richard Barr.

The SIMYLD-II Program Documentation and User's Manual is available through the Texas Water Development Board.

Multibasin Simulation and Optimization

PROGRAM DESCRIPTION

PROGRAM	:	AL-V
DESCRIPTION	:	AL-V is a general hydrologic optimization model to be used for analyzing surface water resource systems. It is designed to analyze the simulated multi-period operation of any interconnected configuration of reservoirs, pump canals and pipelines. The capabilities of the AL-V model include the ability (1) to find the minimum cost operating plan for a system of reservoirs, river junctions, canals and river reaches, (2) to find the minimum cost sizing of individual reservoirs, canals, or closed conduits, (3) to determine reservoir operating rules for use in related simulation models and (4) to determine the minimum cost construction sizing and sequencing of a number of water storage and conveyance projects in a multiple purpose river basin system.
INPUT DATA REQUIREMENTS	:	System configuration data Reservoir and canal cost data Reservoir water demand data Reservoir net evaporation rate data Water import data Economic data Hydroelectric power generation data Constraints on flows and storage
SIMULATION MODE	:	Steady state for seasonal or monthly periods
NUMERICAL SOLUTION	:	AL-V uses a generalized network optimization algorithm, with a successive linear approximating technique, to solve for optimal flows in a link-node configuration that is representative of a physical system. This algorithm incorporates network theory in the solution technique with extended capabilities to incorporate consideration of water loss mechanisms which are flow dependent.
CORE REQUIREMENTS	:	60K words of storage.

INTERFACE REQUIREMENTS	:	AL-V is a stand-alone model.
MODEL DEVELOPMENT AND DOCUMENTATION	:	AL-V is an improved version of AL-IV which was itself an enhancement of AL-III originally developed by Water Resources Engineers, Inc. under contract to the Texas Water Development Board. All improvements and modifications to AL-IV were made by Quentin Martin. The network flow algorithms were developed by Dr. Paul Jensen and Dr. Gora Bhaumik of the University of Texas at Austin. Documentation: "Surface Water Resources Allocation Model - AL-V, Program Documentation and User's Manual", by Quentin W. Martin, TDWR, October 1981.

PROGRAM DESCRIPTION

PROGRAM	:	DPSIM-I, Optimal Capacity Expansion Model for Surface Water Resources Systems
DESCRIPTION	:	The DPSIM-I model is a computational procedure utilized in determining the minimum-cost capacity expansion of a general surface water supply system. This program acts as a screening tool to select from a number of development policies, a most likely optimal policy. Such a strategy specifies the capacity sizing and construction sequencing of reservoirs, pump canals, and pipelines in a water supply system. The water requirement and hydrologic conditions within a multi-reservoir system are taken to be subdivided into a series of discrete expansion periods, with expansion in capacity being dictated at the beginning of each period.
INPUT DATA REQUIREMENTS	:	Description and location of reservoirs, demand points, river reaches, canals and pipelines; reservoir area-capacity tables; reservoir and junction inflows, demands and evaporation rates; construction cost-capacity curves for reservoir, canal and pipeline projects; precedent-order relationships for project sequencing; user-designated constraints on project capacity combinations;allowable discrete capacity sizes for projects; economic parameters.
SIMULATION MODE	:	Steady state over each operation simulation period, but dynamic over each staging period.
NUMERICAL SOLUTION	:	A dynamic programming (DP) formulation is used to optimally time and size the construction of new facilities over the various discrete staging intervals. Embedded within the DP procedure is a minimum-cost flow circulation network model which is utilized to establish lower bounds on the operating costs of each of the various alternative development strategies. These lower bounds are computed by solving time-aggregated network flow models consisting of bi-yearly operating periods spanning each staging interval.
CORE REQUIREMENTS	:	60K decimal words of storage on a UNIVAC 1100 Series Computer System. One temporary storage file (tape or disc mass storage device) is required.

INTERFACE REQUIREMENTS	:	The model can perform as a stand-alone procedure; however, DPSIM-I is designed to interact with the AL-IV model within the framework of an optimal capacity expansion algorithm. This interaction is in the form of indirect input/output transfers.
PROGRAM DEVELOPMENT AND DOCUMENTATION	:	DPSIM-I was developed by Dr. Quentin Martin of the Systems Engineering and Development Division of the Texas Water Development Board. Documentation is available in the following publication: "Optimal Capacity-Expansion Model for Surface Water Resources System," Systems Engineering Division, Texas Water Development Board, Austin, Texas, June 1975.

PROGRAM DESCRIPTION

PROGRAM	:	SIM-V
DESCRIPTION	:	SIM-V is a computerized procedure designed to simulate the operation of a large complex surface water storage and transfer system. The SIM-V computer routine allows individual network system elements to be introduced at any point in the simulation time-span. This capability provides the option of investigating various patterns of construction schedules in order that the least costly can be selected for implementation. This capability also allows SIM-V to be used either as a stand-alone procedure or as an extension of any staging analysis. In SIM-V capital costs are entered individually for each system element (canal and reservoir) and system operating costs are computed by the model. In general, the movement of water via the transfer links will be done at a cost which is a known function of the quantity of water flowing and the pumping lift. It is the function of SIM-V to meet system storage requirements, water demands, and hydropower generation target while minimizing the cost of transporting water within the system. No water will be spilled from the system if storage capacity remains in the reservoirs.
INPUT DATA REQUIREMENTS	:	System configuration data Reservoir and canal cost data Reservoir inflow data Reservoir water demand data Reservoir net evaporation rate data Water import data Economic data Hydroelectric power generation data Constraints on flows and storage
SIMULATION MODE	:	Steady state for monthly time period
NUMERICAL SOLUTION	:	Performs the primary task of finding a minimum cost solution to the problem of flow allocation in a capacitated network. In SIM-V the optimum allocation of network flows is accomplished through use of generalized network optimization algorithms coupled with a successive linear approximation procedure.

CORE REQUIREMENTS	:	60K words of storage.
INTERFACE REQUIREMENTS	:	SIM-V is a stand-alone model.
MODEL DEVELOPMENT AND DOCUMENTATION	:	SIM-V is a significantly improved version of SIM-IV which was developed in 1972 by the Systems Engineering and Development Division of the Texas Water Development Board. The network flow algorithms were developed by Dr. Paul Jensen of the University of Texas at Austin. Documentation: "Multireservoir Simulation and Optimization Model - SIM-V, Program Documentation and User's Manual", by Quentin W. Martin, TDWR, December 1981.

Reservoir Operations Analysis

PROGRAM DESCRIPTION

PROGRAM	:	RESOP-II,Reservoir Operating and Quality Routing Program
DESCRIPTION	:	RESOP-IIwas developed to calculate the firm yield of single reservoir sites. It simulates the monthly operation of a reservoir on a hypothetical basis for a given time period. Entire river basins may be operated for firm yield analysis by sequential runs with spills added to the inflow of downstream reservoirs. The program can also simulate the transfer of conservative minerals through a reservoir. The program is currently dimensioned to handle 50 years of data.
NUMERICAL SOLUTION	:	The program allows the user to operate a reservoir with one of three options: Forward Operation, Reverse (iterating forward), or Forward Operation with Quality Routing. The Forward Operations require an annual yield as input and simulates the reservoir operation for that yield. The Reverse Operation allows a gross estimate of the annual yield and then iterates until solution convergence criteria are met - the result being the firm annual yield.
INPUT REQUIREMENTS	:	Control cards for run parameters, monthly distribution factors for annual demand, straight-line segments of the area vs. capacity curve, upstream spills, evaporation data (or lat. and long. for Texas reservoirs), and inflow data. Quality data is also required if quality routing is desired.
CORE REQUIREMENTS	:	Program is essentially machine independent and requires approximately 30,000 words of storage. One input device is needed if the evap. data is not read in from cards.
INTERFACE REQUIREMENTS	:	Stand-along program
MODEL DEVELOPMENT AND DOCUMENTATION	:	The program was developed by TWDB personnel for reservoir firm yield determination. Documentation is available in the following publication: "Reservoir Operating and Quality Routing Program - RESOP-II, " Lewis E. Browder, Report UM-20, TDWR, August 1978.

Irrigation Demand Simulation

PROGRAM DESCRIPTION

PROGRAM : DEMAND-II, Irrigation, Industrial and Municipal Water Demand Model

DESCRIPTION : The program DEMAND-II computes municipal and industrial water requirements for up to ten municipal and industrial districts, and irrigation requirements for up to ten irrigation districts.

The needs of a plant for water are directly proportional to the amount of evaporation. Crop water requirements are calculated by multiplying the pan evaporation by a constant termed "consumptive use coefficient" which reflects the water needs of a particular crop during a particular month for optimum physiological plant growth. The difference between this raw requirement and the amount of rainfall in that month gives the amount of water in the ground that must be available to the plant. The water available in the soil depends on the porosity of the particular soil in which the crop is planted, and the root depth by the porosity gives a figure which represents an effective "soil reservoir". Each combination of soil and crop under consideration has associated with it a soil reservoir. If there is more rain than the crop needs, the surplus will go into the soil reservoir, and when the reservoir is filled to capacity all excess will be lost to the crop. When the reservoir drops below one-half capacity, irrigation water is then called to fill it. The total irrigation demand for one month is the aggregate of the monthly demands of the individual reservoirs. The program also calculates total regional demands for municipal and industrial needs based on monthly fractions of annual demands for each district.

NUMERICAL SOLUTION : The program calculates effective rainfall from actual rainfall by using a second-order polynomial predictive equation. Demands are calculated by doing a mass balance of the system and comparing results with crop requirements throughout the growing season, and with municipal and industrial requirements.

DATA REQUIREMENTS	:	Data required by the model consists of rainfall, evaporation, and runoff series; municipal and industrial demands; information on type of crop per acre, rotation patterns, and consumptive use coefficients.
CORE REQUIREMENTS	:	4,000 decimal words.
INTERFACE REQUIREMENTS	:	Program performs as a stand-alone model.
PROGRAM DEVELOPMENT AND DOCUMENTATION	:	DEMAND-II was developed by the Systems Engineering Division, Texas Water Development Board. The program is documented in the following publication: Texas Water Development Board, "A Completion Report on Stochastic Optimization and Simulation Techniques for Management of Regional Water Resources Systems," Volume IID, Demand II Program Description, December 1970.

PROGRAM DESCRIPTION

PROGRAM	:	DES, Dynamic Economic Simulation Model
DESCRIPTION	:	The Dynamic Economic Simulation Model is a methodology for simulating the demand for and use of irrigation water by several competing users in the face of highly variable rainfall, evapotranspiration, and water supply. The procedure consists of three interlinked submodels: A dynamic programming model that establishes the optimal economic returns and decisions for scheduling the irrigation of one crop in one soil, a linear programming model that selects the optimal cropping patterns for various amounts of soil moisture and water availability, and a dynamic simulation of the changing status of crops and farmer's decisions throughout the growing season. The output of the former two models serves as input into the latter one.
INPUT DATA REQUIREMENTS	:	Historic monthly rainfall and evaporation, yields and consumptive water use requirements for crops, farm water use efficiencies, farm irrigation and crop tillage costs.
SIMULATION MODE	:	Probabilistic and dynamic over a growing season.
NUMERICAL SOLUTION	:	The maximum expected value policy for scheduling the irrigation of one crop in one soil is determined by solving a stochastic dynamic programming (DP) problem. The measures of the condition of the system are crop yield potential, soil moisture and quantity of water available over the remainder of the growing season. The maximum benefit cropping pattern is established by solving a linear programming (LP) problem formulation. The dynamic simulation of a growing season is executed by interfacing the LP and DP solutions with the surface water quantity simulation model SIM-IV.
CORE REQUIREMENTS	:	The DES model consists of a number of stand-alone computer programs, all of which may be executed with under 65K decimal words of storage on a UNIVAC 1100 Series Computer System. At most two external mass storage devices are needed to store the program's outputs.

INTERFACE REQUIREMENTS	: Interaction is required between the various programs in the DES Model. The SIM-IV surface water simulation model is needed in the final dynamic simulation phase.
PROGRAM DEVELOPMENT AND DOCUMENTATION	: DES was developed by Dan Salcedo of the Systems Engineering Division of the Texas Water Development Board. Documentation is available in the following publication: "Dynamic Economic Simulation Model-DES Program Description," Systems Engineering Division, Texas Water Development Board, Austin, Texas, July 1972.

Ground Water Basin Simulation

PROGRAM DESCRIPTION

PROGRAM	: CARIZO, Carrizo Aquifer Digital Model
DESCRIPTION	: CARIZO simulates the change in water levels or piezometric heads throughout the Carrizo-Wilcox Aquifer system over time. The program can operate in either the simulation or the verification mode. In the verification mode, historical recorded piezometric surface elevations are input, comparisons are then made to the appropriate simulated heads to determine errors (difference between simulated heads and recorded heads), and statistical parameters are computed. In the simulation mode, the drawdown from the base year are determined at each node for each year in the simulation period. As the model is presently structured, it can simulate up to a maximum of ten years per run.
INPUT DATA REQUIREMENTS	: CARIZO uses as input, values of transmissibility, storage coefficients, top of aquifer elevations, base of aquifer elevations, initial water table elevations or piezometric heads, pumping rates, and recharge rates.
NUMERICAL SOLUTION TECHNIQUES	: CARIZO uses an iterative alternating direction implicit procedure to solve the finite difference approximation to the differential equations for two-dimensional nonsteady flow of a compressible fluid in a porous medium.
CORE REQUIREMENTS	: CARIZO requires approximately 58000 decimal words of machine storage.
MODEL DEVELOPMENT AND DOCUMENTATION	: CARIZO is based on a program originally developed by George Pinder of the U. S. Geological Survey. Documentation is available in the following publication: "Program Documentation and User's Manual, Carizo Aquifer Digital Model," Texas Water Development Board, Austin, Texas, September 1973.

PROGRAM DESCRIPTION

PROGRAM	:	GWSIM, Groundwater Simulation Program
DESCRIPTION	:	GWSIM is a digital model which simulates the water levels of piezometric heads in a aquifer system at the end of a given time period. The GWSIM program was developed for simulating the Edwards (Balcones Fault Zone) Aquifer in Texas, but the program is very general and could be applied to other aquifer systems. The program allows simulation of a confined aquifer, an unconfined aquifer, or a aquifer containing both types of groundwater conditions. The aquifer may be heterogeneous, in terms of storage and permeability and heterogeneous, anisotropic permeabilities may be used in the simulation. The output from the program is a description of the water levels or piezometric heads throughout the aquifer after a period of time.
INPUT DATA REQUIREMENTS	:	GWSIM uses an input, values of permeability, storage coefficient, top of aquifer elevation, bottom of aquifer elevation,aquifer thickness, land surface elevation, initial water table or piezometric head elevation, and pumping and recharge rate.
NUMERICAL SOLUTION TECHNIQUES	:	GWSIM uses an iterative alternating direction implicit procedure to solve the finite difference approximation to the differential equation governing the non-steady state, two dimensional flow of groundwater in a nonhomogeneous anisotropic aquifer.
CORE REQUIREMENTS	:	GWSIM requires approximately 58,000 decimal words of machine storage.
MODEL DEVELOPMENT AND DOCUMENTATION	:	GWSIM is based on a program written by T. A. Prickett and C. G. Lonnquist of the Illinois State Water Survey. Documentation is available in the following publication: "Program Documentation and Users Manual, GWSIM, Groundwater Simulation Program," Texas Water Development Board, Austin, Texas, May 1974.

PROGRAM DESCRIPTION

PROGRAM	:	IMAGEW-I, Well Field Drawdown Model
DESCRIPTION	:	The IMAGEW-I computer model is a methodology for evaluating the drawdown in water levels produced from pumping from one or more wells in a well field located in either a confined or unconfined homogeneous aquifer. This drawdown can be evaluated at various locations in the aquifer for various elapsed times following the start of pumping. The model assumes that each aquifer is homogeneous and infinite; it is therefore accurate for only a relatively small geographic area surrounding the well field. Image-well theory is utilized to simulate the effects of geohydrologic boundaries.
INPUT DATA REQUIREMENTS	:	Aquifer storage and transmissibility coefficients, pumpage and recharge rates over time, well spatial locations, aquifer characteristics (artesian, water table, leaky, nonleaky), initial water levels.
SIMULATION MODE	:	Steady state in a single time period and dynamic between periods.
NUMERICAL SOLUTION	:	The IMAGEW-I model allows the hydrologist three options when solving for individual well drawdown. Option 1 is the nonleaky artesian aquifer solution derived by Theis. Option 2 utilizes the nonleaky artesian solution with a water table correction derived by Jacob in order to simulate pumping and well drawdown under water-table conditions with no recharge. Option 3 utilizes the modified steady-state solution derived by Walton in order to simulate pumping and well drawdown in water-table conditions with uniform annual recharge.
CORE REQUIREMENTS	:	21K decimal words on a UNIVAC 1100 Series Computer System.
INTERFACE REQUIREMENTS	:	IMAGEW-I is a stand-alone program.
PROGRAM DEVELOPMENT AND DOCUMENTATION	:	IMAGEW-I was developed by William A. White of the Systems Engineering Division and Bill Klemt of the Water Availability Division of the Texas

Water Development Board. Documentation is available in the following publication "Well Field Drawdown Model - IMAGEW-I," Texas Water Development Board, Austin, Texas, February 1973.

Inland Waters Quality Simulation

PROGRAM DESCRIPTION

PROGRAM : DOSAG-I, Stream Quality Routing Model

DESCRIPTION : The purpose of DOSAG-I is to calculate the biochemical oxygen demand and the minimum dissolved oxygen concentration in a particular stream system. If desired, the minimum dissolved oxygen concentration in the stream system may be checked against a pre-specified target level dissolved oxygen concentration. If the minimum dissolved oxygen level is below the target dissolved oxygen level, the program will compute the required amount of flow augmentation to bring the dissolved oxygen level up to the target level in the entire system. The user of the program specifies the locations within the stream system at which dilution water is available for flow augmentation. The program is designed to be run for varying climatic and hydrologic conditions during a twelve month period. Thus, it is possible to enter up to twelve different temperatures and corresponding discharges to each of the headwaters within the stream system being modeled. Derivatives in time representing the carbonaceous and nitrogenous biochemical oxygen demand decay rates and the atmospheric reaeration are combined and integrated to obtain the relationship between dissolved oxygen replenishment and decay within a stream system. Other sources and sinks of dissolved oxygen may be important in various stream systems, but these are not included in DOSAG-I.

NUMERICAL SOLUTION : A LaGrangian solution technique is used to solve the dissolved oxygen equation in the DOSAG-I quality routing model. This solution technique involves using a coordinate system which moves with a particle of water in its path down the stream. At each change in reach and at every junction a simple mass balance is performed to arrive at the biochemical oxygen demand and dissolved oxygen concentrations in the next reach downstream. In this way, the stream is modeled from its upper to its lower end recording its response to all of the pollutional loads imposed on it.

CORE REQUIREMENTS :	4,000 decimal words.
INTERFACE REQUIREMENTS:	DOSAG-I is a stand-alone program.
INPUT DATA REQUIREMENTS :	Physical description of the stream system; reaction rate coefficients and hydraulic properties (depth-velocity-discharge relationships) for each reach; incremental (runoff) flow data; sewage and industrial flow data; mean monthly water temperature; mean monthly headwater flows.
MODEL DEVELOPMENT AND DOCUMENTATION :	The basic code was originally developed by the Federal Water Pollution Control Administration and it was later enhanced by the Texas Water Development Board. The program is documented in the following publication: Texas Water Development Board, "DOSAG-I, Simulation of Water Quality in Streams and Canals," Program Documentation and User's Manual, September 1970.

PROGRAM DESCRIPTION

PROGRAM	:	QNET-I, Multibasin Water Quality Simulation Model
DESCRIPTION	:	The QNET-I water quality model simulates the movement of conservative mineral constituents in water through any network of reservoirs, canals and river reaches. This model utilizes the hydrologic routings computed by the SIMYLD-II surface water quantity simulation procedure to route mineral constituents through a multi-reservoir system. It uses monthly time intervals in its prediction of constituent concentration and can predict quality levels over any number of months. The model assumes that water in each element of a system (reservoirs, canals, and river reaches) is completely mixed over a monthly period and consequently, of uniform quality.
INPUT DATA REQUIREMENTS	:	Output from the SIMYLD-II model provides nearly all the input data requirements via a specially written output file. These data include reservoir contents, stream and canal flows, demands, import quantities, waste returns, and evaporation losses. The remaining input data are quality related, and include initial reservoir qualities and the quality of unregulated reservoir inflows, imported water, and wastewater discharge.
SIMULATION MODE	:	Steady state within each month.
NUMERICAL SOLUTION	:	Mass balances, over both space and time, form the fundamental set of equations solved in QNET-I. In each monthly period, a set of simultaneous linear equations are generated for end-of-month quality concentrations at each mode in the system. These equations are solved iteratively by the Gauss-Siedel method.
CORE REQUIREMENTS	:	Approximately 15K decimal words of storage on a UNIVAC 1100 Series Computer System. Two mass storage files are needed. One file, associated with logical I/O unit 11, provides as input hydrologic data from the SIMYLD-II program. Another file, designated logical unit 13, is used to store as output the computed constituent concentrations.

INTERFACE REQUIREMENTS	:	The SIMYLD-II model provides a storage file of all required hydrologic data for the QNET-I program.
PROGRAM DEVELOPMENT AND DOCUMENTATION	:	QNET-I was developed by staff of the Systems Engineering Division of the Texas Water Development Board. Documentation is available in the following publication: "Multibasin Water Quality Simulation Model QNET-I Program Description," Systems Engineering Division, Texas Water Development Board, Austin, Texas, July 1972.

PROGRAM DESCRIPTION

PROGRAM : QUAL-I, Stream Quality Model

DESCRIPTION : The Stream Quality Model offers selective capabilities to simulate the spatial and temporal variations of several specific water-quality parameters in streams and canals. The parameters simulated by the model are: temperature, carbonaceous and nitrogenous biochemical oxygen demands, dissolved oxygen, and up to three conservative minerals. QUAL-I routes these parameters through a system of streams and canals on an hourly basis for dynamic conditions, or on a daily basis for steady state conditions. It is assumed that the major transport mechanisms, advection and dispersion, are significant only along the main direction of flow (longitudinal axis of the stream or canal). The program allows for inclusion of multiple waste discharges, withdrawals, tributary flows, and incremental runoff. QUAL-I also offers the capability to compute required dilution flows for flow augmentation to meet any prespecified dissolved oxygen level.

The Stream Quality Model is designed to begin the routing calculations from the points farthest upstream (headwaters). As incremental flow and waste inputs or withdrawals are encountered, these are entered into the calculations. The result at the end of the system is a set of simultaneous equations equal in number to the number of computational elements in the system. This set of equations is solved, thus advancing the solution forward in time. This procedure is repeated until steady-state conditions are reached, which is approximately the time required for a water particle at the uppermost point in the system to reach the end of the system.

NUMERICAL SOLUTION : The governing differential equation is solved by an implicit-finite difference approximation technique under the assumption that advection along the primary axis of flow is the primary mode of transport.

INPUT DATA REQUIREMENTS	:	Input data consists of the following items: a) schematic diagram of the stream system describing the following physical properties: location of waste loadings and withdrawals, location of stream and canal junctions, and location and identification of headwater sources available for potential flow augmentation; b) meteorological data; c) reaction rate coefficients; d) input water quality data: biochemical oxygen demands, dissolved oxygen concentrations, temperature, and conservative mineral concentrations; e) hydrologic data: headwater inflows, waste discharges and withdrawals, tributary inflows, incremental flows (runoff) and depth-velocity-discharge relationships.
CORE REQUIREMENTS	:	35,000 decimal words on a UNIVAC 1100 Series Computer System.
INTERFACE REQUIREMENTS	:	QUAL-I performs as a stand-alone model. Interfaces with a reservoir quality model or an estuarine ecological model, if accomplished, are of an input/output nature.
MODEL DEVELOPMENT AND DOCUMENTATION	:	QUAL-I was developed by F. D. Masch and Associates (W. A. White, Project Director) in close collaboration with the Texas Water Development Board. The program is documented in the following publications: Texas Water Development Board, "QUAL-I, Simulation of Water Quality in Streams and Canals," Program Documentation and User's Manual, September 1970. Texas Water Development Board, "Simulation of Water Quality in Streams and Canals," Report 128, May 1971.

PROGRAM DESCRIPTION

PROGRAM	:	QUAL-II, Stream Quality Model
DESCRIPTION	:	QUAL-II is a one-dimensional computer model designed to simulate the spatial and temporal variations in concentration of biotic and abiotic water quality constituents in streams and canals. The following parameters are simulated: chlorophyll - a, nitrogen (ammonia, nitrite, nitrate), phosphorous, carbonaceous BOD, benthic oxygen demand, dissolved oxygen, coliforms, temperature, and three conservative substances. QUAL-II routes these parameters through a system of streams and canals on an hourly basis for dynamic conditions, or on a daily basis for steady state simulations. It is assumed that the major transport mechanisms, advection and dispersion, are significant only along the main direction of flow (longitudinal axis of the stream or canal). The program allows for inclusion of multiple waste discharges, withdrawals, tributary flows, and incremental runoff. QUAL-II also offers the capability to compute required dilution flows for flow augmentation to meet any prespecified dissolved oxygen level. The program includes the complex reactions and major interactions of the nutrient cycles, algae production, benthic oxygen demand, carbonaceous oxygen uptake and their effect on the behavior of dissolved oxygen.
NUMERICAL SOLUTION	:	The set of differential equations representing the whole system are solved simultaneously for each time step (implicit numerical scheme).
INPUT DATA REQUIREMENTS	:	Input data consists of the following items: a) system description identifying numerically the following physical properties: location of waste loadings and withdrawals, stream and canal junctions, and headwaters; b) meteorological data; c) reaction rate coefficients; d) input water quality data for headwater flows and discharges; e) hydrologic data: headwater flows, waste discharges and withdrawals, tributary inflows, incremental flows (runoff), and depth-velocity-discharge relationships.

CORE REQUIREMENTS	:	53,000 decimal words on a UNIVAC 1100 Series Computer System.
INTERFACE REQUIREMENTS	:	QUAL-II performs as a stand-alone model. Interfaces with a reservoir quality model or an estuarine ecologic model, if accomplished, are of aninput/output nature.
MODEL DEVELOPMENT AND DOCUMENTATION	:	QUAL-II was developed by Water Resources Engineers, Inc., under contract with the Environmental Protection Agency. The program is considered an enhanced version of the original Stream Quality Model, QUAL-I. The program is documented in the following publication: Roasner, L. A., J. R. Monser, and D. E. Evenson, "Computer Program Documentation for the Stream Quality Model QUAL-II," prepared for the Environmental Protection Agency, Water Resources Engineers, Inc., May 1973.

PROGRAM DESCRIPTION

PROGRAM	: LAKECO, Lake Ecological Model
DESCRIPTION	: The Lake Ecological Model, LAKECO, is a one-dimensional mathematical model capable of simulating the spatial and temporal variations in concentrations of 19 water quality constituents in a reservoir, and its response to varying meteorological conditions, hydrologic conditions, and to reservoir operational rules. The reservoir is segmented in horizontal homogeneous layers of equal depth and the main driving forces in the model are expressed as surface heat exchange, flow advection, diffusion, and wind mixing. The basic formulation of the model is based on the conservation of mass and energy principles, and the chemical interactions are expressed as first-order kinetic reactions with temperature dependence. The dynamics of the biotic constituents in the model are subject to temperature and dissolved oxygen tolerance limits, nutrient or food availability and predation.
INPUT DATA REQUIREMENTS	: Reservoir physical description; physical, chemical, and biological coefficients; initial hydraulic and water quality conditions in reservoir; and periodic input data which consists of: weather data, reservoir water releases, inflows and quality conditions of inflow waters.
SIMULATION MODE	: Dynamic and steady state.
NUMERICAL SOLUTION	: Partial differential equations are expressed as finite difference approximations and are solved simultaneously over the time step (implicit solution). Simulation time steps of 1 day are used, but input for meteorologic, hydrologic and tributary loading conditions can be updated with as much frequency as every three hours.
CORE REQUIREMENTS	: 50K words of storage. No other hardware is required except a tape drive if storage of output is desired.

INTERFACE REQUIREMENTS: The model performs as a stand-alone model. Interfaces with a Reservoir Operations Model and a Stream Quality Model, if accomplished, are of an input/output nature.

MODEL DEVELOPMENT AND DOCUMENTATION : The Lake Ecological Model was developed by Water Resources Engineers, Inc. Documentation is available in the following publications:

Chen, Carl W. and Gerald T. Orlob, "Ecologic Simulation for Aquatic Environments," Final Report prepared for the Office of Water Resources Research, U. S. Department of the Interior, Water Resources Engineers, Inc., December 1972.

Gaume, A. N., Brandes, R. J., and James H. Duke, Jr., "Computer Program Documentation for the Reservoir Ecological Model TVAECO," prepared for Tennessee Valley Authority, Water Quality Branch, by Water Resources Engineers, Inc., February 1975.

The Hydrologic Engineering Center, U. S. Army Corps of Engineers, "Water Quality for River-Reservoir Systems," Generalized Computer Program 401-100, September 1975.

Estuarine Hydrodynamics,
Salinity and Water Quality
Simulation

PROGRAM DESCRIPTION

PROGRAM : DEM, Dynamic Estuary Model

DESCRIPTION : The Dynamic Estuary Model, DEM, simulates the unsteady flow and dispersional characteristics of both conservative and non-conservative constituents in unstratified estuaries. The model consists of two separate, but compatible programs, the Hydraulics Program and the Transport Program. A hydraulic extract program, in the form of a subroutine of the Hydraulic Program, summarizes the hydraulic output and prepares the appropriate hydraulic input to the Transport Program. In applying the DEM, a network of interconnected channels and junctions is laid out to represent the prototype system. The Hydraulic Program computes the elevation of the water surface at each junction and the velocity and flow in each of the channels entering the junction in response to prescribed tidal excitation and hydrologic inputs. The Transport Model computes the dynamic steady-state concentrations at each junction resulting from a specified set of tidal conditions, inflows, waste discharges, diversions, etc. The model has been applied to the Sabine Lake estuarine system which includes Sabine Lake, Sabine Pass, Port Arthur Canal, Sabine-Neches Canal, and the tidal portions of the Sabine and Neches River channels.

INPUT DATA REQUIREMENTS : The initial application of the model to a new system requires the specification of the physical parameters required to describe the channel and junction network such as channel cross-sectional areas, channel lengths, junction heads, junction surface areas, and bottom friction. Other data includes wind speed and direction, precipitation, evaporation, tidal conditions at the estuary mouth, location, magnitude, and quality of all inflows and withdrawals, and constituent concentrations at the tidal boundary.

NUMERICAL SOLUTION TECHNIQUE	:	The Hydraulics Program uses a modified Runge-Kutta procedure to solve the one-dimensional equation of motion for each channel and the equation of continuity at each junction. The Transport Program uses the results of the Hydraulics Program to solve the one-dimensional mass balance equation at each junction.
CORE REQUIREMENTS	:	The Hydraulics Program requires approximately 30,000 words of machine storage and the Transport Program requires approximately 25,000 words.
MODEL DEVELOPMENT AND DOCUMENTATION	:	The Dynamic Estuary Model was developed by Water Resources Engineers, Inc. Documentation is available in the following publications:
		"Documentation Report FWQA Dynamic Estuary Model," by Kenneth D. Feigner and Howard S. Harris, Federal Water Quality Administration, U. S. Department of the Interior, Washington, D. C., July 1970.
		"Computer Program Documentation for the Dynamic Estuary Model with Application to Sabine Lake Estuarine System." Final report to Texas Water Development Board, by Robert J. Brandes, Allen E. Johnson, Kenneth R. Iceman, and Frank D. Masch, Water Resources Engineers, Inc., Austin, Texas, April 1975.

PROGRAM DESCRIPTION

PROGRAM : ESTECO, Estuarine Ecologic Model

DESCRIPTION : ESTECO is a mathematical model capable of simulating water quality and biological responses of certain types of estuarine systems under the influence of different external inputs, i.e., river inflow quantities and qualities, wastewater return flows and pollutant loadings, local runoff characteristics, tidal behavior, and meteorological conditions. The model simulates the areal distribution of constituent concentrations in a horizontal plane, assuming complete vertical mixing. Hence, the model is most applicable to estuarine systems characterized by large surface areas and relatively shallow depths where wind-induced mixing is prevalent.

The estuarine ecologic model utilizes a two-dimensional (area-wise) Eulerian mesh of square cells to describe the physical character of a prototype system. Constituent concentrations are determined at the center of each cell in the computational grid. In these computations, the effects of various physical chemical and biological processes are accounted for including convective and dispersive transport, inflow/outflow, sedimentation, surface exchange, biodegradation, chemical transformations, photosynthesis, biological uptake, and respiration release. The model simulates sixteen biotic and abiotic constituents most commonly present in the Gulf of Mexico estuarine systems.

INPUT DATA REQUIREMENTS Physical description of the estuary system (grid network); physical, chemical, and biological coefficients; initial hydraulic and water quality conditions; and periodic input data which consists of: meteorological data, tidal net flows across each cell boundary, freshwater inflows and quality conditions of inflow waters.

SIMULATION MODE : The estuarine ecological model is considered a long-term dynamic model with respect to tidal effects, and its primary application is to those problems requiring simulation of ecologic changes which are likely to occur over a period of several months, or even years, rather than during a given tidal cycle.

NUMERICAL SOLUTION	:	Partial differential equations are expressed as finite difference approximations which are solved with an alternating-direction implicit numerical solution scheme.
CORE REQUIREMENTS	:	The machine storage requirements vary depending on the size of the system being modeled and the mesh spacing used. A computational grid of one square-mile cells was used to model San Antonio Bay, Texas, with a core requirement of 50,000 decimal words of memory.
INTERFACE REQUIREMENTS	:	A similarly-structured and compatible tidal hydrodynamics model (i.e.,HYD) first must be applied to the estuarine system to generate a matrix of tidal net flows (across each cell boundary) which in turn, are used by ESTECO to describe the convective transport of constituents.
MODEL DEVELOPMENT AND DOCUMENTATION	:	The estuarine ecologic model was developed by Robert J. Brandes and Frank D. Masch through a study supported by the Texas Water Development Board and the Office of Water Resources Research. Documentation is available in the following publications: Brandes,R.J. and F.D. Masch, "Estuarine Ecologic Model for San Antonio Bay, Texas," Report to the Texas Water Development Board, Water Resources Engineers, Inc., Austin, Texas, 1975. Texas Water Development Board, "Techniques for Evaluating the Effects of Water Resources Development on Estuarine Environments," Report to the office of Water Resources Research, (in preparation).

PROGRAM DESCRIPTION

PROGRAM	: HYD, Tidal Hydrodynamic Model
DESCRIPTION	: The Tidal Hydrodynamic Model, HYD, computes temporal histories of tidal amplitudes and velocities in each of two coordinate (area-wise) directions at discrete points throughout a bay in response to prescribed tidal excitation and hydrologic inputs. The model formulation assumes that the bays are vertically well-mixed, and the tidally generated convection in each of the two area-wise coordinate directions can be represented with vertically itnegrated velocities. HYD has been applied to four bay systems, San Antonio, Matagorda, Corpus Christi-Aransas-Copano, and Galveston.
INPUT DATA REQUIREMENTS	: Basic inputs to HYD include the physiographic details of the bay system such as mean sea level water depths and bay geometry, elevations with respect to mean sea level of the physical features of the bays such as dikes, spoil banks, islands, submerged reefs and barriers, location and magnitude of inflows (rivers, wastewater discharges, etc.), the tidal condition at the estuary mouth (or opening to the ocean), an estimate of bottom friction, wind speed and direction, rainfall, and evaporation.
NUMERICAL SOLUTION	: HYD uses an explicit numerical procedure to solve the basic equations of motion and continuity over a rectangular grid coordinate system with a mesh spacing which is arbitrary provided a time-step is selected which results in a mathematically stable solution.
CORE REQUIREMENTS	: The machine storage requirements vary depending on the size of the system being modeled and the mesh spacing used. The four bay systems on the Texas Gulf Coast which have been modeled require 35,000 to 41,000 words of memory. The computed output can be stored on cards, disc, or tape if desired.
INTERFACE	: HYD performs as a "stand-alone" model, but the coordinate grid system is compatible with the Salinity Transport Model (SAL) and the

Estuarine Ecological Model (ESTECO) and the output of HYD is designed to be used as input to SAL and ESTECO.

MODEL DEVELOPMENT : The HYD models for San Antonio Bay, Matagorda Bay, and Corpus Christi and Aransas Bay were developed by Frank D. Masch and Associates, now with Water Resources Engineers, Inc. Documentation is available in the following publications:

"Tidal Hydrodynamic and Salinity Models for San Antonio and Matagorda Bays, Texas," by Frank D. Masch and Associates, Austin, Texas, report to the Texas Water Development Board, June 1971.

"Tidal Hydrodynamic and Salinity Models for Corpus Christi and Aransas Bays, Texas," by Frank D. Masch and Associates, Austin, Texas, report to the Texas Water Development Board, September 1972.

The HYD Model for Galveston Bay was developed for the Texas Water Quality Board by Tracor, Inc. Documentation is available in the following publication:

"Galveston Bay Project; Hydraulic Model User's Manual," by L. A. Hembree, Jr., G. H. Ward, Jr., A. J. Hays, Jr., Richard Chen, submitted to Texas Water Quality Board, Tracor Document Number T72-AU-9562-U, April 1974.

PROGRAM DESCRIPTION

PROGRAM	:	RIVTID, River/Tidal Hydrodynamic Model
DESCRIPTION	:	The River/Tidal Hydrodynamic Model, RIVTID, is capable of simulating the hydrodynamic response under flood-flow conditions of river/tidal systems subject to unsteady downstream controls. This model considers the distribution of flood flows in two spatial (area-wise) dimensions, and it accounts for inundation of tidal flats and marsh areas, and roadway embankments. RIVTID is capable of interfacing with the Texas Water Development Board's estuarine tidal hydrodynamic models and can be used to "bridge the gap" between these models and the more conventional one-dimensional river flood-routing models. The model has been applied to the Lavaca-Navidad River system including the lower tidal reaches of the Lavaca and Navidad Rivers and a portion of upper Lavaca Bay. It has also been applied to the Guadalupe-San Antonio system including the network of channels, canals, and lakes downstream of the confluence of the Guadalupe and San Antonio Rivers in the vicinity of upper San Antonio Bay.
INPUT DATA REQUIREMENTS	:	The data requirements for application of RIVTID to a river/tidal system include the physiographic details of the area, the tidal conditions at the downstream boundary, magnitude of upstream inflows, an estimate of bottom friction, wind apeed and direction, and evaporation.
NUMERICAL SOLUTION	:	RIVTID uses an explicit numerical procedure to solve the basic equations of motion and continuity over a rectangular grid coordinate system with a mesh spacing which is arbitrary provided a time-step is selected which results in a mathematically stable solution.
CORE REQUIREMENTS	:	The machine storage requirements vary depending on the size of the system being modeled and the mesh size. The Lavaca-Navidad River system and the Guadalupe-San Antonio system each require approximately 35,000 words of memory.

INTERFACE	:	RIVTID performs as a "stand-alone" model but RIVTID is capable of interfacing with the HYD Model.
MODEL DEVELOPMENT AND DOCUMENTATION	:	The River/Tidal Hydrodynamic Model was developed by Water Resources Engineers, Inc. Documentation is available in the following publications:

"Simulation of Flood-Flow Hydrodynamics in River/Tidal Systems," by Robert J. Brandes and F. D. Masch, report to the Texas Water Development Board, Water Resources Engineers, Inc., Austin, Texas, May 1973.

"RIVTID Program Documentation by R. J. Brandes and R. B. Wise, report to the Texas Water Development Board, Water Resources Engineers, Inc., Austin, Texas, May 1973.

"Extension and Refinement of the RIVTID Model, Simulation of Flood-Flow Hydrodynamics in River/Tidal Systems," by Richard B. Wise and R. J. Brandes, Supplemental report Texas Water Development Board, Water Resources Engineers, Inc., Austin, Texas, March 1974.

PROGRAM DESCRIPTION

PROGRAM	:	SAL, Salinity Transport Model
DESCRIPTION	:	The Salinity Transport Model, SAL, uses the output generated by HYD to compute vertically averaged salinities (or any conservative constituent) at the same discrete points over the entire bay system in response to inflow concentration, evaporation, and rainfall. The model formulation assumes that the bays are vertically well-mixed, the tidally generated convection in each of the two area-wise coordinate directions can be represented with vertically integrated velocities, that molecular diffusion is negligible with respect to turbulent diffusion, and dispersion coefficients can be used to represent the composite effects of turbulent diffusion and differential convection. SAL has been applied to four bay systems, San Antonio, Matagorda, Corpus Christi-Aransas-Copano, and Galveston.
INPUT DATA REQUIREMENTS	:	The basic input to SAL includes source concentrations generally measured as total dissolved solids (TDS), the net convective velocities for each cell generated by HYD, dispersion coefficients for each cell, and net evaporation or precipitation. The basic output of SAL is the concentration of salinity or TDS in each computational cell for a given set of inputs. This data can then be reduced to point or bar graphs or to isopleth maps.
NUMERICAL SOLUTION	:	SAL uses a semi-implicit numerical solution scheme to solve the convective-diffusion equation which is based on the principle of mass conservation. SAL uses the same rectangular grid coordinate system as HYD. Since the transport model utilizes net velocities directly from the hydrodynamic model, the grid networks in each model must be identical.
CORE REQUIREMENTS	:	SAL requires approximately 25,000 words of memory. The exact size depends on the system being modeled and the mesh spacing used. The computer output can be stored on cards, disc, or tape if desired.

INTERFACE : SAL can perform as a "stand-alone" model, but it requires convective input at every computational cell. Since this input is not usually available from data collection programs, it must be generated by HYD.

MODEL DEVELOPMENT : The SAL models for San Antonio Bay, Matagorda Bay, and Corpus Christi and Aransas Bay were developed by Frank D. Masch and Associates, now with Water Resources Engineers, Inc. Documentation is available in the following publications:

"Tidal Hydrodynamic and Salinity Models for San Antonio and Matagorda Bays, Texas," by Frank D. Masch and Associates, Austin, Texas, report to the Texas Water Development Board, June 1971.

"Tidal Hydrodynamic and Salinity Models for Corpus Christi and Aransas Bays, Texas," by Frank D. Masch and Associates, Austin, Texas, report to the Texas Water Development Board, September 1972.

The SAL Model for Galveston Bay was developed for the Texas Water Quality Board by Tracor, Inc. Documentation is available in the following publication:

"User's Manual for the Salinity Model of the Galveston Bay System," by L. A. Hembree, Jr. and Richard Chen, submitted to Texas Water Quality Board, Tracor Document Number T72-AU-9561-U, April 1974.

PROGRAM DESCRIPTION

PROGRAM	:	DELTA, River Delta Hydrodynamic and Water Quality Simulation Model.
DESCRIPTION	:	DELTA is a one-dimensional, section-mean model capable of simulating the basic hydraulic and water quality characteristics of complex deltaic systems. Predicated on the approach of Dronkers for the calculation of tides in estuaries and tidal rivers, the model assumes that the momentum of flow patterns are concentrated in the longitudinal components of the channels. The model further assumes that when inundated areas serve principally as volume storage and carry relatively little longitudinal momentum. Through the application of the principles of conservation of longitudinal momentum and contunity, equations are developed that yield hydraulic and water quality information including water surface elevation, channel flow, average channel velocity, adjacent marsh area inundation, depth of marsh inundation, and total time of marsh inundation, as well as the concentrations of selected conservative and nonconservative water quality parameters (selected by the user) at any location within the segmented delta.
INPUT DATA REQUIREMENTS	:	User input requirements include physiographic data such as segment lengths, depths, cross-sectioned areas, bank elevations, and Manning's roughness parameter. In addition the user must supply hydraulic data such as freshwater inflow hydrographs and excitation tides plus initial conditions for water quality parameters. Reaction rates for non-conservative water quality parameters may be changed to accommodate the specific needs of the system.
SIMULATION MODE	:	Temporally and spatially dynamic.

NUMERICAL SOLUTION	:	The governing physical equations are solved by the so-called "leepfrog" method of finite differences where by water depth inundated surface area, lateral channel discharges and water quality constituent concentrations are determined at the center of each segment while longitudinal flow quantities and velocities are determined at the segment boundaries. This solution technique has proven to be quite stable under the wide variety of simulation conditions to which this type of model must be subjected.
CORE REQUIREMENTS	:	Core requirements are a function of the approximately 53K decimal words of core storage are required for execution on a UNIVAC 1100 Series Computer System.
INTERFACE REQUIREMENTS	:	DELTA is a stand-alone program.
PROGRAM DEVELOPMENT AND DOCUMENTATION	:	The DELTA Model was developed by Espey, Huston and Assoc., Inc. with the cooperation of the Texas Department of Water Resources. Documentation is available in the following publication: "User's Manual for Hydrodynamic-Mass Transfer Model of Deltaic Systems," Document No. 7815, Espey, Huston & Assoc., Inc., Austin, Texas, August 1978.

Data Management and Data Generation

PROGRAM DESCRIPTION

PROGRAM	:	FILLIN-I was developed to improve data bases by using a procedure which "fills in" or augments incomplete data sets of various types of hydrologic data. Criteria derived from numerical analysis and variance reduction techniques are used for data augmentation. The procedure is a multi-site data fill-in technique which will analyze monthly time-series data (e.g. streamflow, rainfall, or evaporation data), and fill in missing portions of incomplete record. The program will handle up to 25 data sets of up to 50 years of monthly data each.
NUMERICAL SOLUTION	:	The program extracts the statistical parameters which characterize the multi-size data set (i.e. seasonal means, seasonal standard deviations, single lag-one correlations, and multi-site spatial correlations), and creates a filled data set. This procedure is designed to preserve in the filled-in portion of the records the statistical parameters observed above that existed between the original unfilled portions of the multi-site data set.
INPUT REQUIREMENTS	:	Control cards for run parameters, data type and site names, and the raw data set for each site. Voids in the original data sets must be set to -1.0 for proper handling by the program.
CORE REQUIREMENTS	:	Program is essentially machine independent and requires approximately 45,000 words of storage. A tape drive is also needed if an output tape is desired.
INTERFACE REQUIREMENTS	:	Stand-alone program.
MODEL DEVELOPMENT AND DOCUMENTATION	:	The FILLIN-I program was developed by Water Resources Engineers, Inc., with the cooperation of the Texas Water Development Board. Documentation is available in the following publication: Texas Water Development Board, "A Completion Report on Stochastic Optimization and Simulation Techniques for Management of Regional Water Resource Systems," Volume IIB- Fillin-I Program Documentation, December 1970.

PROGRAM DESCRIPTION

PROGRAM	:	MOSS-IV, Monthly Streamflow Simulation
DESCRIPTION	:	MOSS-IV is a modified version of the Generalized Computer Program HEC-4 developed by the Hydrologic Engineering Center of the U. S. Army Corps of Engineers. The program is designed to fill in hydrologic data at a number of short record locations and to generate synthetic hydrologic data sequences preserving intercorrelation and persistence characteristics, as well as seasonal variations, and other statistical characteristics of the data. Many types of data, such as evaporation, water demand, streamflow, base flow can be processed alone or in combination.
INPUT DATA REQUIREMENTS	:	Up to 10 runoff, rainfall and/or evaporation site gages with a maximum record length of 50 years.
NUMERICAL SOLUTION	:	MOSS-IV is a Markov chain type model with a transferring function of a log Pearson Type III distribution to an approximately Gaussian normal distribution; estimation of the first three moments of the distribution; development of intrasite cross and serial correlations; use of these correlations for filling gaps in historical records or for generating stochastic sequences; and reversing the initial transformation to obtain the filled or generated hydrologic records.
CORE REQUIREMENTS	:	60K words of storage. Three logical storage devices for intermediate operational storage and an additional optional logical unit for card punch or tape output. A Fortran Compiler with very large symbol and label tables is also required.
INTERFACE REQUIREMENTS	:	The model performs as a stand-alone model.
MODEL DEVELOPMENT AND DOCUMENTATION	:	The model MOSS-IV was developed by the Hydrologic Engineering Center, Corps of Engineers,and later modified by the Center for Research in Water Resources, University of Texas at Austin, for the Texas Water Development Board. Documentation is available in the following publication. Leo R. Beard, "Transfer of Streamflow Data Within Texas," CRWR No. 104, Center for Research in Water Resources, University of Texas at Austin, August 1973.

PROGRAM DESCRIPTION

PROGRAM : SEQUEN-I, Sequence Analysis Program

DESCRIPTION : SEQUEN-I analyzes time series sequences of historic filled-in and stochastic hydrologic sequences. It computes various seasonal and statistical parameters for each hydrologic sequence. These parameters include the mean, the standard deviation, the standard error of the mean, the standard error of the standard deviation, and autocorrelation coefficients for various monthly lags. A 10% segment frequency analysis of the data in the sequence is performed on a monthly and annual basis. The program also deos a trend analysis and a Fourier series analysis, for any number of harmonies desired.

INPUT DATA REQUIREMENTS : Filled-in or generated sequence or historical monthly hydrologic data.

NUMERICAL SOLUTION : The trend analysis is done by performing a linear regression analysis on the data set assuming that all the data points are equally spaced in the record. The method of least squares is used to fit an equation of the form

$$x_t = a \pm bt$$

to the observed sequence.

The harmonic analysis fits the data with a model of the form

$$x = \bar{x} + \sum_{i+1}^{m} (A_i \text{Sin } (iwt) + B_i \text{Cos } (iwt)) + r_t$$

The model can be fit to the data set using least squares regression analysis techniques once any time-dependent linear trends have been removed. The assumption of equally spaced data points results in a special case and permits a simple solution method to be used to solve for the harmonic coefficients.

CORE REQUIREMENTS : 30,000 decimal words.

INTERFACE REQUIREMENTS	:	Stand-alone or can be interfaced with MOSS-III.
MODEL DEVELOPMENT AND DOCUMENTATION	:	Program was developed by the Systems Engineering Division, Texas Water Development Board. The program is documented in the following publication: Texas Water Development Board, "Stochastic Optimization and Simulation Techniques for Management of Regional Water Resource Systems, Vol. IIE," January 1972.

Water Resources Systems
Capacity Expansion and Design

PROGRAM DESCRIPTION

PROGRAM	:	CAPEX-I, Pump Station Capacity Expansion Model
DESCRIPTION	:	The CAPEX-I computer model is a procedure designed to determine the minimum present value cost plan for increasing the output capacity of a pump station facility over time. The model selects the optimal number, size, and installation time of pumps and motors and the size of housing structures for the station. Restrictions imposed upon the solution are as follows: (1) all demands for pumping water must be met; (2)a specific size of pumps must produce more than a given percentage of the total output; and (3) the pumps and accessories installed must not exceed the size of the building; and should there be an advantage in staged construction of the building, this advantage will be detected and adopted.
INPUT DATA REQUIREMENTS	:	Pump and motor flow capacities, power sizes, and unit costs; time horizon and time increments for decisions; economic discount rate; pump station size and cost; required rate; pump station size and cost; required flow delivery schedule over time.
SIMULATION MODE	:	Static for each time increment but dynamic between time increments.
NUMERICAL SOLUTION TECHNIQUE	:	The pump installation and sizing problem is represented as a linear integer program. A generalized brand-and-bound algorithm developed by Balas was utilized as the solution technique.
CORE REQUIREMENTS	:	Approximately 35K decimal words of core storage are required for execution on a UNIVAC 1100 Series Computer System.
INTERFACE REQUIREMENTS	:	CAPEX-I is a stand-alone program. It is intended to be utilized to refine the design and associated costs of a single pumping station.
PROGRAM DEVELOPMENT AND DOCUMENTATION	:	CAPEX-I was developed by staff of the Systems Engineering Division of the Texas Water Development Board. Documentation is available in the following publication:

"CAPEX-I Program Description," Systems Engineering Division, Texas Water Development Board, Austin, Texas, January 1972.

PROGRAM DESCRIPTION

PROGRAM	: PIPEX-I, Optimal Capacity Expansion Model for a Water Conveyance Pipeline
DESCRIPTION	: The water pipeline design model PIPEX-I is an automated procedure for determining the least-costly engineering design of a water supply pipeline. It can be utilized to establish for both a fixed or time-varying flow regime, the most economical combination of available pipe diameter, pipe pressure class, number of pumping stations, and installed pumping capacity. The pipeline route is represented by a series of adjacent piece-wise linear segments each having a constant elevation slope. Bounds are required on the water velocities and pressures along each section. The program may be executed in the following modes: (1) <u>Static Design</u>: A time-invarient flow condition is specified along each pipeline section. The minimum-cost static design of a divergent-branched pipeline system (containing no pipe loops), having intermediate flow diversions and intakes, will be obtained. (2) <u>Dynamic Design</u>: A single time-varying set of non-decreasing flows are specified along all pipeline sections. The minimum-cost design over time of a linear (non-branching) pipeline system, with <u>no</u> intermediate flow diversions or intake, will be obtained.
INPUT DATA REQUIREMENTS	: Pipeline elevation-distance data; pipeline route segmentation; location and available sizes of existing and potential pump stations; available pipe diameters, pressure classes, and cost; maximum and minimum water pressure and water velocities; economic parameters; initial pipeline system facilities.
SIMULATION MODE	: Steady-state conditions in a given time period, but variable flows over the various time periods.

NUMERICAL SOLUTION	:	The static and dynamic design problems are solved as dynamic programming formulations.
CORE REQUIREMENTS	:	Approximately 50K decimal words of core storage are required for execution on a UNIVAC 1100 Series Computer System. Four scratch storage files for intermediate calculations.
INTERFACE REQUIREMENTS	:	PIPEX-I is a stand-alone program.
PROGRAM DEVELOPMENT AND DOCUMENTATION	:	PIPEX-I was developed by Quentin Martin of the Systems Engineering and Development Division of the Texas Water Development Board. Documentation is available in the following publications:

"Minimum-Cost Capacity Expansion of a Lineal Water Conveyance Pipeline," by Quentin Martin, Texas Water Development Board, presented at the Joint National TIMS/ORSA Meeting, San Francisco, California, May 10, 1977.

"Pipeline Design Model - PIPEX-I Program Description and Documentation," by Quentin Martin, Texas Water Devleopment Board, Report UM-3, Oct. 1981.

PROGRAM DESCRIPTION

PROGRAM : CANAL-I, Optimal Canal Routing and Design Model

DESCRIPTION : The canal routing and design model CANAL-I is an automated procedure for determining the least-costly route location and engineering design of a water supply canal. It can be utilized to determine, for a fixed flow delivery rate, the most economical location and combination of open channels, embankment dams, pipelines, pump stations, and canal structures. The canal route consists of a series of route sections and junctions and is represented by a directed network. The program computes the optimal steady-state design and route from an over-specified set of potential routes and alternative facilities.

Elevation, water surface, and pressure slopes are required to be constant along individual route sections. Flow is assumed to be delivered to a single terminal junction at a prespecified rate.

Constraints on the design include upper and lower limits on water-surface elevations, water velocity and flow rates; conservation of energy and mass; and subcritical flow in open channels. Upper and lower bounds on water depth, bottom width and water-surface slope for open channels must also be satisfied. Pipe diameters and pressure classes are restricted to available discrete sizes.

The optimal solution specifics, along each route section having a pipeline, the diameter, pressure class, and number of parallel line of pipe installed. Open-channel route sections have specified the water depth, bottom width, and type of lining of the prismatic channel.

INPUT DATA REQUIREMENTS	:	Route elevation-length data; location and available sizes of potential pump stations and embankment dams; location of potential pipelines and open channels; available types of linings for open channels and their characteristics; available pipe diameters and pressure classes; maximum and minimum water surface-elevations, water pressures, and water velocities by section and system; economic parameters; construction cost data for pipelines, open-channels, and canal structures; available sizes of drop structures, spillways, and bridges.
SIMULATION MODE	:	Steady-state (time invariant) conditions corresponding to conditions under ultimate (maximum) delivery rate of water.
NUMERICAL SOLUTION	:	Dynamic programming and network optimization.
CORE REQUIREMENTS	:	Approximately 65K decimal words of core storage are required for execution on a UNIVAC 1100 Series Computer System. Four scratch storage files for intermediate calculations.
INTERFACE REQUIREMENTS	:	CANAL-I is a stand-alone program.
PROGRAM DEVELOPMENT AND DOCUMENTATION	:	CANAL-I was developed by Quentin Martin of the Engineering and Environmental Systems Section of the Texas Department of Water Resources. Documentation is available in the following publication: "Water Conveyance Canal Design Model - CANAL-I", by Quentin W. Martin, Texas Department of Water Resources, Users Manual-21, April, 1979.

Economics Simulation

PROGRAM DESCRIPTION

PROGRAM : ECOSYM, Economic Simulation Model

DESCRIPTION : ECOSYM is a deterministic economic simulation model which makes use of intersectoral relationships of input-output models and relates regional consumption to production and production to resource use. The model simulates industrial sector output, population, employment, unemployment, personal incomes, savings, and taxes, and selected natural resource use. The model is used to analyze economic impacts of a set of water resource development projects. Resource constraints are brought to base in any time period by a set of linear constraints in a Linear Programming formulation. Simulations are on an annual basis and the program handles an input-output transaction table with a maximum of forty-eight processing sectors, twelve household sectors, sixteen primary resources (twelve labor groups and four natural resources), and twelve capital producing sectors.

The economic simulation model utilizes an input-output model framework to describe the interrelationships between various industries within a region. The input-output model provides the link between production and consumption demand. Consumption demand consists of household, government, investment, and export demands. Income elasticity coefficients and past income provide the link to the level and distribution of household consumption in the current time period. Resource use coefficients provide the link between primary resources (labor, water, land, crude petroleum, and natural gas) and the producing industry which uses them. Investment demand is linked to projected final demand through expansion capital coefficients.

NUMERICAL SOLUTION : Given aggregate demand in any time period, the solution for output levels, resource use, and income payments is calculated by solving a set of simultaneous equations with linear constraints. In addition, the simulation model solves a series of consumption, investment, employment, and production equations which relate a variable in the current time period to one or more variables in past time periods.

INPUT DATA REQUIREMENTS	:	For each household group in the model, the following information is necessary: consumption coefficients; natural population growth rate; long-term unemployment factor; ten years of personal disposable income; population, labor available, and labor required from each group in the base year; and taxes. Information for the sectors include: expansion capital matrix, resource matrix, elasticity coefficients matrix, transactions matrix, and final demand for products of each sector.
CORE REQUIREMENTS	:	35,000 decimal words.
INTERFACE REQUIREMENTS	:	ECOSYM requires interfacing with an input-output model.
MODEL DEVELOPMENT AND DOCUMENTATION	:	ECOSYM was developed by the Systems Engineering Division, Texas Water Development Board, partially supported with funds provided by the Office of Water Resources Research, Department of the Interior. The program is documented in the following publication: Texas Water Development Board, "Techniques for Evaluating Market and Non-Market Benefits and Costs of Water Resources Systems - Economic Simulation Model - Program Description," April 1974.

Parameter Estimation Programs

PROGRAM DESCRIPTION

PROGRAM	:	PEP, Parameter Estimation Program
DESCRIPTION	:	The primary purpose of the Parameter Estimation Program is to improve the accuracy and reliability of mathematical models through better calibration. PEP automatically estimates model parameters to minimize the error between simulated variables and field measurements. The parameter estimation algorithm uses mathematical programming to compute model parameters from available measurements of the variables simulated. The calibration problem is expressed as a constrained minimization problem. Parameter estimates are selected by the program so as to minimize a "least squares" error performance function derived from the comparison of measured versus simulated values. The Parameter Estimation Program was designed to be applied to the calibration of parametric mathematical models of physical systems whose output variables are functions of either one or two spatial dimensions and time. However, the program can be applied to any computerized mathematical procedure which computes any variable as a function of any parameter. The only requirements are that the program dimensionality limitations and the data manipulating procedures be compatible with the model.
NUMERICAL SOLUTION	:	The minimization problem subject to inequality constraints is solved by a nonlinear programming technique. The technique used is a modified constrained derivative algorithm. The change in the independent variables from iteration to iteration in the algorithm is constrained by using the Levenberg's constraint technique to limit the search region to a hypersphere about the current solution.
INTERFACE REQUIREMENTS	:	The procedure of parameter estimation is done between executions of a physical simulation model. Therefore, it is required that a linkage between PEP and the simulation program be accomplished in order to do the successive runs required to meet the convergence criteria established by the user. User must provide three subroutines necessary for transfer of information between the simulation program and PEP.

INPUT DATA REQUIREMENTS : Data requirements of PEP are: location in time and space of the measured values of the variable or variables to be used by the program in estimating parameter values; range of values for each parameter to be calibrated; control values specifying type of model to be calibrated and convergence criteria for solution.

CORE REQUIREMENTS : Core requirements vary depending on the core requirements of the model being calibrated. The application of PEP to the Lake Ecological Model, LAKECO, to make simultaneous estimations of three parameters required 55,000 decimal words.

MODEL DEVELOPMENT AND DOCUMENTATION : The Parameter Estimation Program was developed by Water Resources Engineers, Inc., under contract with the Texas Water Development Board. The program is documented in the following publication:

Evenson, D. E., and A. E. Johnson, "Parameter Estimation Program," Program Documentation and User's Manual prepared for Texas Water Development Board, Water Resources Engineers, Inc., December 1975.