TR-17
1969

Texas Water Resources Institute
make every drop count

Development of Optimization Systems Analysis Technique for Texas Water Resources

R.W. Hann

Texas Water Resources Institute

Texas A&M University

RESEARCH PROJECT TECHNICAL COMPLETION REPORT

Project Number A-004-TEX

May, 1965 - June, 1968

Agreement Numbers

14-01-0001-704, 14-01-0001-814, 14-01-0001-989, 14-01-0001-1412

DEVELOPMENT OF OPTIMIZATION SYSTEMS ANALYSIS TECHNIQUE FOR TEXAS WATER RESOURCES

Principal Investigator

Roy W. Hann, Jr., P.E.

The work upon which this publication is based was supported in part by funds provided by the United States Department of the Interior, Office of Water Resources Research, as authorized under the Water Resources Research Act of 1964.

Technical Report No. 17
Water Resources Institute
Texas A&M University

February 1969

Table of Contents

List of Tables

List of Figures

List of Illustrations

ABSTRACT

This report summarizes the results of the research project Development of Optimization - Systems Analysis Techniques for Texas Water Resources.

Several analytical models which were obtained and modified for use in evaluating water resource problems are described. A method for evaluating the optimum blend of water from two or more reservoirs to meet several concurrent quality criteria is presented.

The special importance of estuarine analysis methods relating to water quality is outlined and two models are presented one for a steady state dispersion of wastes in partially mixed estuaries and the other an optimization scheme using linear systems analysis to determine the optimum waste loads into an estuarine system under a variety of constraints.

Interbasin transfer of water is examined and one plan evaluated to demonstrate the use of analytical models for streamflow evaluation, field determination and reservoir simulation.

The use of a Leontif input-output model to predict economic growth as a function of resource use is developed and an example presented using the area affected by the Blackburn Crossing Reservoir in East Central Texas.

Principal Investigator
Roy W. Hann, Jr., Ph.D.

DEVELOPMENT OF OPTIMIZATION - SYSTEMS ANALYSIS TECHNIQUES FOR TEXAS WATER RESOURCES

Technical Report #17
Water Resources Institute
Texas A&M University

February 1969

Key Words: Water Quality*/Estuaries*/Simulation/ Optimization*/Reservoir Management/ Economic Analysis

SECTION I

Introduction

During the summer of 1965 a research effort was initiated through the Texas Water Resources Institute intitled Development of Optimization - Systems Analysis Techniques for Texas Water Resources. This report summarized the work carried out by the research staff.

The active project staff throughout the project consisted of the project director Roy. W. Hann, Jr. (Civil Engineer) who was funded 1/4 time, and Dr. Warren Trock (Agricultural Economist) who was also funded 1/4 time. Through most of the project period, Dr. Hann and Dr. Trock were each assisted by a 1/2 time masters level research assistant.

The broad objective of the project was stated to be "to develop realistic techniques to evaluate complex Texas problems in river basin management through the utilization of both engineering and economic principals."

The efforts carried out during the course of the project may generally be divided into four general areas.

The first is the collection or development of analytical methods for use in the analysis of water resource systems. Computer programs for six analyses were obtained and modified for use, first on the 7094 Computer and later on the IBM 360 Computer. These programs for the analysis of streamflow records, simplified reservoir simulation and streamflow simulation are described in Section II along with other analysis methods investigated or used.

The second general area is the development of analytical methods for the solution of water resource problems associated with bays and estuaries. This problem area is a particularly critical one in Texas inasmuch as inter-basin diversion schemes will substantially modify the estuarine environment and the response of the estuaries to environmetal pollution. The activities initiated by this project which are described in Section III have led to the establishment by Texas A&M University of a major research program in this area.

Early in the project the project director noted the relative ease by which waters from the Red River could be diverted into the Trinity, Neches, and Sabine basins. It was hypothesized that the diversion of a unit firm yield to the head waters of these streams would free several units of firm yield near the mouth of the basins and thus make previously proposed diversion plans calling for transporting water parallel to the gulf coast more acceptable. The investigation of the possible plan which is discussed in Section IV proved to be an interesting example problem in which to demonstrate the use of some of the analytical techniques outlined previously.

The fourth area recognized the importance of economics in water resources planning and conversly, the importance of water in stimulating broad base economic development. In Section V, the Leontief input - output method of economic analysis is used to evaluate the economic impact of water resources development. The study is based on the area affected by the Blackburn Crossing Reservoir on the Upper Neches River.

A list of project publications and a summary of accomplishments round out the final report.

Section II

Analytical Models

The engineering staff of the project devoted a major effort to the development, acquisition and modification, and testing of analytical methods for use in water resource management. This section describes the activities of the staff in this area.

Cooperation with the Hydrologic Engineering Center of The Corps of Engineers:

Early in the project it became evident that with the level of manpower available to the engineering effort that greater project accomplishment could be obtained by reviewing the analytical methods developed by others and adapting them for use in solving Texas problems.

Early project efforts led to the project director becoming closely associated with the staff of the Hydrologic Engineering Center of The Corps of Engineers in Sacramento, California. This organization was established in late 1964 is charged with developing analytical techniques for the U.S. Army Corps of Engineers. By working closely with this large group of engineers and scientists the project staff was able to bring to bear a much larger scale program than would have been possible by developing all methodology with the project staff effort.

Several major computer programs were obtained from the HEC and modified for use by the project staff. Four of the modified programs are documented in the appendix to this report. Initial modification involved reprogramming the programs to run on the Texas A&M University 7094 computer and later reconversion to the 360 computer was necessary.

The programs which were converted and used are described briefly below. The modified user manuals are presented as appendices 1 through 4 for the first four programs. The other programs listed have been modified but extensive documentation (and testing) was not completed in the project period.

The coordination with the HEC extended well beyond the limit of program acquisition.

In 1966 the project director attended a two-week course offered by the Hydrologic Engineering Center and presented a one day session in Water Quality Aspects of Water Resources. The Center Director, Leo R. Beard, also presented a seminar at Texas A&M University. In 1967 the project director again presented a one day program on Water Quality Aspects of Water Resources to a HEC training program and visited the HEC staff to coordinate program development. In 1968 Texas A&M University presented (under contract) a two-week course entitled Water Quality Aspects of Water Resource Management for the HEC. This was the first training course of any type which was contracted by this agency to any University. This program led to the presentation of a similar course for the Bureau of Reclamation. Each of these courses was attended by 35 participants from the contracting agency and 8 representatives from other federal and state agencies.

The project director was also asked to prepare (on a contract basis) an extensive publication entitled Water Quality Aspects of Water Resources Planning for Developing Countries for the HEC.

Converted Programs.

A. Reservoir Yield Program:

The Reservoir yield program performs any number of multipurpose routings under indentical conditions for a single reservoir with optional delivery to pipe line or river or both and with maximum and minimum flow controls at the reservoir and, ir desired, at one downstream control point. Power generation at the reservoir and quality control at the downstream control point are optional. The year is devided into any number of periods (dimensioned up to 15) of equal or unequal lenth. Maximum and minimum permissible storages and all other quantities can be specified as uniform or varying each period with similar or dissimilar patterns each year. An optional minimum storage above the absolute minimum can be specified at which shortages in withdrawals from storage are declared, increasing linearly to 100 percent at the absolute minimum storage.

The multipurpose reservoir program follows closely the procedures commonly used in hand computation. Where a direct solution is not possible, successive approximations are made. This is in evaporation and power computation, where the first approximation based on reservoir stage at the beginning of each period is used to establish an approximate average stage for the period, on which the next approximations of evaporation and power are based. Outlet capacity is approximated onceonly on the basis of reservoir stage at the start of each period. No delay or routing of outflows to the downstream control point is made. Provision is made for an optional buffer zone at the bottom of the conservation pool.

The reservoir routing is made by first searching for the largest of the minimum flow requirements for all purposes and the smallest of the maximum permissible flow. The former will control if there is no conflict and the latter if there is. These controls are overridden by flows necessary to empty or fill the conservation pool. Absolute control is exercised by full reservoir and empty reservoir limitations. If storage at the start of a period is within the bottom buffer zone, release from the reservoir (over and above inflow minus evaporation) is reduced by the proportion of empty space in the buffer zone. Releases are first assigned to the pipeline and the remainder to the river.

Specific details of the program such as power and water quality formulas and input and output formats can be noted in the appendix.

B. Partial Duration-Independent Low Flow Events.

The Partial Duration-Independent Low Flow Event program, will compute the data necessary to plot a partial duration curve depicting independent low flow events for a given period of monthly stream flows. Up to twenty durations may be specified in one computer run with partial duration plotting data being determined for each. Storagy-yield relations can subsequently be determined from the output of this program.

The method used in determining a partial duration series is similar to that described in "Handbook of Applied Hydrology", 1964 edition, by, V.T. Chow, and in ASCE Sanitary Engineering Division publication 3283, September 1962, "Reservoir Mass Analysis by A Low-Flow Series" by John B. Stall.

Flow volumes are accumulated each month in accordance with a given duration for the entire period of record. That is, each cumulative value represents the flow for the current month plus the summation of previous flows for a number of months equal to the duration minus one. In the program this volume is converted to an average rate of flow in cfs regardless of the input units. The array is then successively scanned to lacate low-flow events in an ascending manner. These events are selected without regard to the calendar year and in such a manner as to assure their chronological independence. The effective number of years of record is determined and is subsquently used in cumputing the exceedence frequency addition Program details, input and output instructions and a sample problem using the Neches River Basin is shown in the appendix.

C. Simplified reservoir yeild.

Simplified Reservoir Yield Program is used to determine surface water reservoir yield. The program predicts the expected low yield during a drought period as determined from the low flow events described previously.

The program is a modification of Gooch's simplified method for determination of surface water reservoir yield. The design drought concept is used to compute the yields. The primary factors associated with the severity of drought which enter into the computations are duration of drought, overall runoff during drought period, and net reservoir surface evaporation.

To determine the yield by means of a single-interval estimate covering the entire critical drought period, expression

$$Y = .97 \frac{C}{N} + R - (E * A)$$

is used where:

Y = Yield in acre-feet/year

C = Reservoir capacity, in acre-feet

N = Drought duration in years

R = Minimum probable runoff for the corresponding duration in acre-fee/year

E= Average rate of reservoir surface evaporation in feet/year and

A= Average of the reservoir areas at the beginning and end of the critical period.

An example shown in the appendix demonstrates the use of the program in evaluation a reservoir site an the San Bernard River.

D. Monthly Streamflow Analysis

The program is designed to compute from observed unregulated monthly stream flows or previously generated synthetic monthly streamflows at a group of related stations, statistics of the observed synthetic flows or for comparison with the statistics of the observed streamflows. For each station and each of the twelve months, the program computes the mean, standard deviation and skew coefficient. These statistics are also computed from annual flows at each station. In addition, the program is designed to compute the inter-station and serial gross correlation coefficients between both monthly and annual observed streamflows. The program will estimate any missing correlation coefficients on the basis of other pertinent correlative values. The program will handle stations having non-concurrent and/or discontinuous streamflow records.

This program was actually modified twice as the HEC developed updated versions.

E. Monthly Streamflow Simulation

The purpose of the Monthly Streamflow Program is to generate synthetic (or simulated) monthly streamflows for a group of related stream-gaging stations, having the same statistical characteristics as the observed flows. The synthetic flows are based on a series of normally-distributed random standard deviates and on the logarithmic means, standard deviations, skew coefficients,and gross correlation coefficients computed from the observed records in The Monthly Streamflow Analysis Program.

Considerable effort was expended in the coversion of this program, but extensive delays occurred in debugging and testing due to the difference in random number generators. As a result of the delays only historical records were used in project test examples and additional time was not alloted for program documentation.

F. Multireservoir Simulation Program:

The HEC Multibasin Multipurpose Simulation Program was converted but adequate data to simulate the Neches River basin could not be obtained in time to demonstrate the use of the program. It is expected that the program will be used extensively in future research. The reader is referred to HEC program 23-J2-6253 for further information.

Watershed Models.

Early in the project a Fortran version of the Stanford Watershed Model was obtained and studied. Although after study it was found that its size constraints made it impractical for problems of Texas basin scale the program was made available to other campus researchers. A problem oriented language entitled HYMO has been developed by a student of the project director for use in watershed runoff determination by the Agricultural Research Service. Publication is pending.

Linear Systems Mixing Problem.

During the course of the project a linear systems analysis scheme presented by Robt Brazier of the AEC for optimizing the selection of two or more water supplies was observed to be suitable for evaluating the blend of water from several reservoirs to meet downstream quality objectives.

The project director was aware that the HEC considered only one quality parameter in the multireservoir-multipurpose simulation program (HEC-Reservoir Systems Analysis-Conservation Program) and recognized this methodology as suitable for including múltiple quality parameters in the analysis.

Let us assume that two reservoirs are available to supply a water source and that the relative qualities and water cost are as given below:

	Supply Fraction	Cost $/Acreft	CL^-	$SO_4^=$	TDS
Reservoir A	X_1	3.8	50	100	200
Reservoir B	X_2	2.0	330	250	1000

The cost shown is actually needed only if the total cost of the water is to be figured. Otherwise only a dummy cost showing that the use of reservoir A over B is preferred is necessary.

Let it also be assumed for the purposes of the problem that no more than 75% of the project demand can be furnished by reservoir A and no more than 80% can be furnished by Reservoir B and that the desired quality standard at the mixing point is 200 mg/l chloride, 300 mg/l sulfate and 700 mg/l Total Dissolved Solids. It is now possible to write an objective function for the "cost" which we would like to minimize. i.e.

$$3.8 \ X_1 + 2.0 \ X_1 = Z$$

where Z is the function to be minimized

A set of linear equations can now be written for the acceptable quality criteria. i.e.

For Chloride

$$50 \ X_1 + 330 \ X_2 \quad 200$$

For Sulfate

$$100 \ X_1 + 250 \ X_2 \quad 300$$

For TDS

$$200 \ X_1 + 1000 \ X_2 \quad 700$$

and addition constraints evaluated. i.e.

$$X_1 \geq 0 \qquad X_2 \geq 0$$ i.e. No negative flows in river

$$X_1 \leq .75 \qquad X_2 \leq .85$$ i.e. Supply constraints

$$X_1 + X_2 = 1$$ i.e. Total flow must equal demand.

The objective function and the restraints are first degree polynomials and are therefore linear. The programming requirement, that the variables be non-negative, corresponds to the physical situation where it is agreed to not pump water back into one of the sources, which seems entirely reasonable.

Since the problem has only the two variables x_1 and x_2 the problem can be considered as two dimensional and graph of the functions in a plane may be drawn. This is shown in figure 2-1 where each of the restraints are represented by a straight line on the graph. In the case of the inequality restraints, the allowable solution must lie in the area bounded by one of the lines. The total effect is to require that any solution which satisfies all restraints must be somewhere in the cross hatched area on the graph. The one equality restraint is more restrictive, it requires that all solutions lie on the line $X_1 + X_2 = 1$. Therefore, any point on the line joining A and B represents a mix with the desired properties. However, only one point can be the least cost point. It can quickly be found. Point

B (X_1 = .75, X_2 = .25) gives Z = .75 (3.8) + .25 (2.0) = 3.35 another possible combination is X_1 = .7, X_2 = .3 this gives Z = .7 (3.8) + .3 (2.0) = 3.26. This illustrates the fact that the objective function decreases steadily as one progresses from B toward A and in fact the least cost solution is at point A(X_1 = .467, X_2 = .533) which gives Z = .467 (3.8) + .533 (2.0) = 2.84. It will be found that the optimum solution will always be on the boundary of the region which contains all the allowable solutions. Point B is actually the maximum cost solution. Similar problems could be handled in the same way with almost any number of inequality restraints. This is not true of equality restraints. In fact, a second quality restraint is permissible only if the two lines intersect somewhere in the region of allowable solutions, in which case there is only one possible solution.

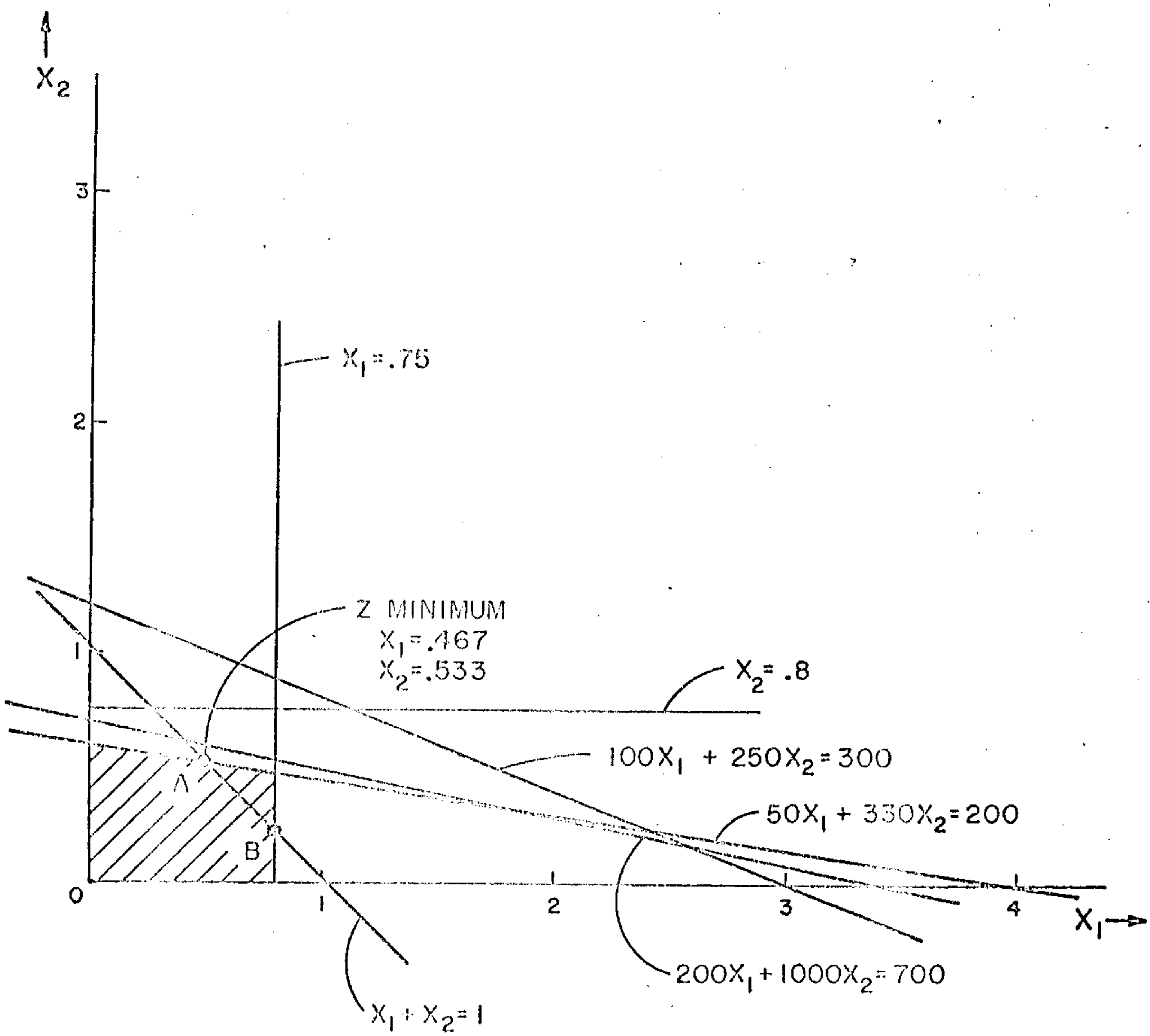
Problems with three or more quality variable can best be treated by purely mathematical means. The Simplex Method for the solution of linear equation systems has worked quite well.

The methodology shown above has been presented to the HEC for possible inclusion in their system model.

The analytical models described above have been widely used in water resources education on the Texas A&M University campus. The HEC programs have been used extensively in the graduate Water Resources Course CE 664 and in the Graduate Civil Engineer Computer Analysis and Design Course CE 680. They were also used in conjunction with the Corps of Engineers and Bureau of Reclamation training programs presented on the Texas A&M University campus.

FIG. 1.-1

GRAPHICAL SOLUTION OF THE BLENDING PROBLEM



Special lectures demonstrating these methods have been presented at the University of Texas, the University of Oklahoma, and at New Mexico State University during the course of the project.

Section III

Estuarine Models

Estuaries are an important part of the water resource picture in the State of Texas. The Sabine Estuary, Galveston Bay, Matagorda Bay, San Antonio Bay, Aransas Bay, Corpus Christi Bay, Baffin Bay and other estuaries are major spawning grounds and habitats for the aquatic life of the Texas Gulf Coast and are of great interest to commercial and sport fishermen, recreational interests and the public at large.

The major water resource plans being comtemplated for the State of Texas will drastically modify the fresh water inflow into these estuaries and may thus modify their salinity structure and water quality. These plans call for upstream water storage and substantial interbasin transfer. The problem is magnified by the tremendous industrial complex which has developed and is developing on these estuaries and the environmental modification and environmental pollution which they are causing.

During the course of this project the project director initiated a seed research effort dealing with the development of mathematical models dealing with the water quality in estuaries. The models already developed and those to be developed will become tools by which the effect of inflow modification, changes in effluent levels, and changes in other environmental parameters may be evaluated by those responsible for both the quantity and quality aspects of water resource management.

Only the project directors effort was funded under this project. Other personnel and facilities were provided from a variety of University and Federal funding sources. However, it is in this area that some of the most important contributions of the project have been made.

Initial project success has been such that considerable funding has been received to continue and expand this activity. The Houston Ship Channel was chosen as the primary area of study because of importance of this waterway and drastic condition of its water quality. Data for model verification was obtained from a combination of previously published data, data collected from unpublished sources and from Texas A&M University field operations. The technical writeup of the computer programs uses data from the San Bernard Estuary which was used in testing the improved computer model in problem oriented language form.

Methodology

The goals of this activity are to develop analytical models of various levels of sophistication which will permit the evaluation of water quality at various locations in an estuarine system.

The initial activity described herein is the development of a steady state estuarine model which uses a finite difference methodology.

The analytical model and accompanying computer program is quite flexible in that various parameters may vary from segment to segment and in that an adjustment is made to evaluate the effect of stratification.

The analysis considers for each segment such parameters as:

1. Length, depth, volume, and area;
2. Water temperature;
3. Coefficient of deoxygenation;
4. Upper and lower level salinities;
5. Quality and quantity of local inflow;
6. Current ebb velocity, ebb time, flood velocity, and flood time;
7. Waste loadings and associated decay patterns.

Stratification is handled by evaluating a parameter called "Degree of Stratification" which describes the relative trend of the estuary between the extremes of being highly stratified or homogeneous.

The evaluation of the quality in a partially mixed estuary between the two extremes is made by considering the estuary as being made up of part homogeneous estuary and part highly stratified estuary as indicated by the degree of stratification term. For example, a degree of stratification of 0.3 indicates the estuary behaves as if it were 0.3 highly stratified and 0.7 homogeneous. The relative fraction is then applied to the general mixing equation and the resultant dispersion curves to arrive at the desired answer for the water quality in the estuary.

Calculations for waste patterns in a homogeneous estuary are based on the generally accepted steady state formula for dispersion in a system with one-dimensional flow:

$$C = C_o e^{-jX}$$

where

$$j = \frac{U}{2E}\left[1 + \sqrt{1 + \frac{4EK_d}{U_1^2}}\right]$$

or

$$j = \frac{U}{2E}\left[1 - \sqrt{1 + \frac{4EK_d}{U_1^2}}\right]$$

and

E = Dispersion coefficient

C = Waste concentration

C_o = Concentration at outfall

X = Distance

U_1 = Advective velocity in the homogeneous estuary

K_d = Removal coefficient

The plus sign is used if X is positive or downstream and the negative is used where X is negative or upstream.

The solution for the highly stratified estuary in the direction of flow takes the form

$$C = C_o e^{jX}$$

where

$$j = -\frac{Kd}{U_2}$$

and K_d = Removal

X = Distance

U_2 = Advective velocity in the highly stratified estuary

No material will be upstream of the discharge source.

These equations are used with segment to segment correction for dilution and volume change and results combined (for partially mixed estuaries) to determine the profiles for the unit waste loads. At this point the analysis diverges depending on whether it is desired to calculated dispersion patterns for known loads or to set quality standards and determine optimum allowable loads.

The loads from the individual discharges are now superimposed to give the total dispersion pattern. This concept may be understood more clearly by referring to Figure 3-1. The bell shaped curves represent the relative concentration in each of n segments resulting from the injection of a unit waste loading into one of the segments. For example, a_{11} represents the total mass of the pollutant in segment 1 resulting from the infection of a unit waste loading into segment 1. Value a_{21} represents the total mass in segment 2 resulting from the injection of a unit waste loading into segment 1. Likewise, a_{24} represents the relative concentration in segment 2 resulting from the infection of a unit waste loading into segment 4.

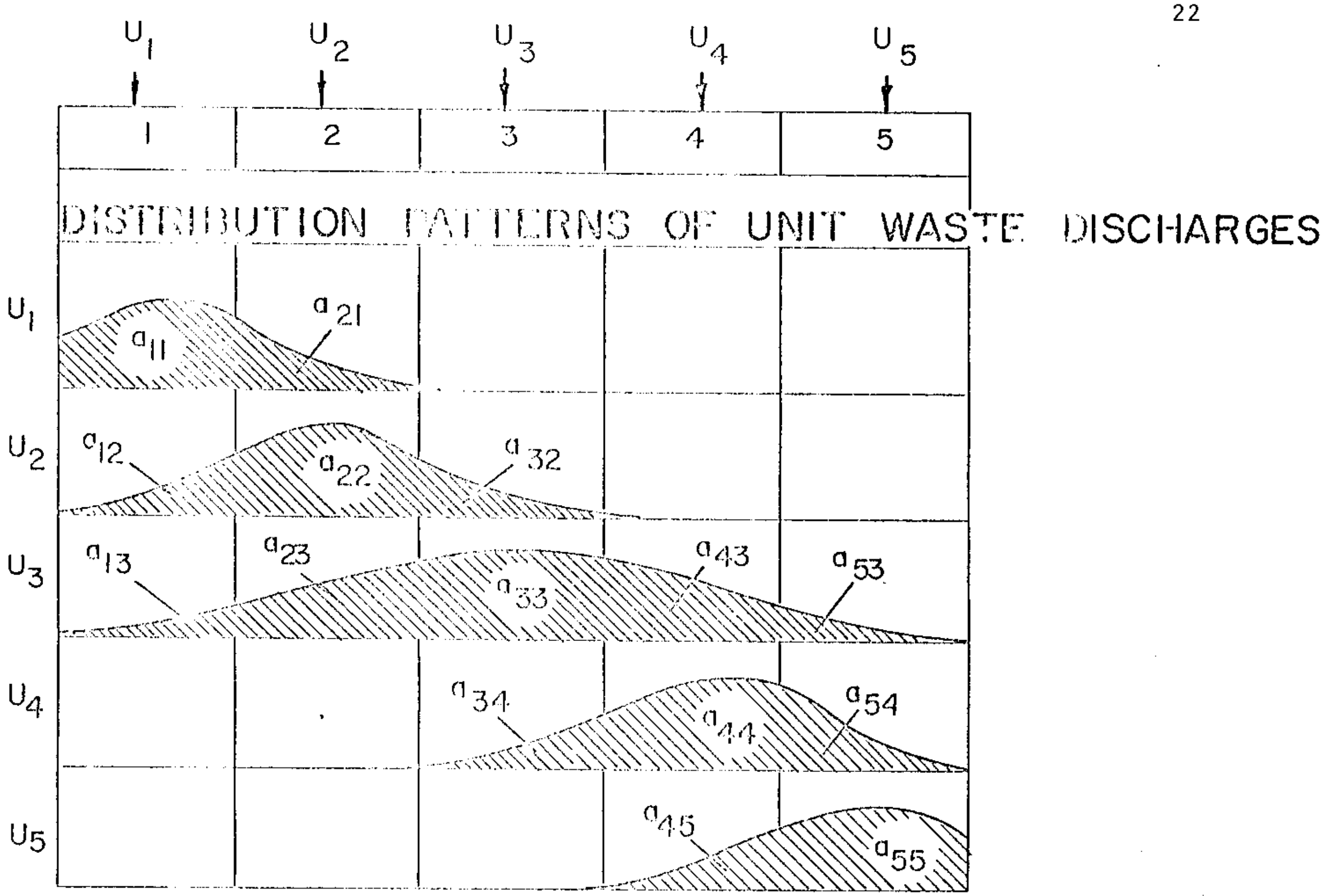
These terms are called the unit loading coefficients.

Once the unit loading coefficients have been calculated, modified, and weighted according to the degree of stratification, the total waste load ultimately appearing in each segment may be computed if actual initial waste loadings into each segment are known. In Figure 3-1 D_1, D_2, D_3,............,D_n represent actual waste loadings injected into each of segments, 1, 2, 3, ..., n, respectively. The total waste load ultimately appearing in a given segment is simply the sum of wastes appearing in the segment. For example, the total waste load in segment 1, $WLOAD_1$, is given by

$$WLOAD_1 = a_{11} D_1 + a_{12}D_2 + a_{13}D_3 + ... + a_{1n}D_n.$$

This equation states that the total waste load in segment 1 is equal to the amount of actual waste injected into segment 1 that remains in segment 1, plus the amount of actual waste injected into segment 2 that appears in segment 1, plus the amount of actual waste injected into segment 3 that appears in segment 1, etc. The terms D_1, D_2, etc. represent waste loadings expressed as a constant rate (weight per unit time). The terms $WLOAD_1$, $WLOAD_2$, etc. represent the total waste loads (weight) that will appear in the given segments under steady-state conditions. By carrying out the preceding analysis for each segment, formulation is now available to determine the amount of waste present at any point in the estuary for a given pattern of waste discharges and physical conditions.

One major advantage which this method develops is that each waste discharge is analysed separately. Since different wastes materials which



SOLUTION EQUATIONS

$$a_{11}D_1 + a_{12}D_2 + a_{13}D_3 = WLOAD_1$$

$$a_{21}D_1 + a_{22}D_2 + a_{23}D_3 = WLOAD_2$$

$$a_{32}D_2 + a_{33}D_3 + a_{34}D_4 = WLOAD_3$$

$$a_{43}D_3 + a_{44}D_4 + a_{45}D_5 = WLOAD_4$$

$$a_{53}D_3 + a_{54}D_4 + a_{55}D_5 = WLOAD_5$$

ILLUSTRATION 3-1

IDEALIZED ESTUARY
WITH 5 SEGMENTS

are measured by a common parameter often have different decay and sedimentation rates the advantage accrues by being able to evaluate the individual dispersion curves prior to superimposing the loads.

The computer program for the dispersion model is described in detail in the appendix of this report. The version which is presented is an improved version over the one developed during this project time period. it was deemed wise to include to most current version in this report.

The major change has been in the use of the "Problem Oriented Language" approach to the input and output of data and the inclusion of sediment removal. Although the program is usable for any pollutant material following a first order reaction rate (and is easily modified to other rate patterns), it has been used in practice primarily to develop quality profiles for organic material measured as biochemical oxygen demand and to compute the resultant dissolved oxygen profile. The input data to the program includes the number of segments.; segment length; salinity in receiving basin;for each segment - depth, area, volume (homogeneous estuary), coefficient of deoxygenation, temperature of water, upper salinity, lower salinity, local inflow, salinity of local inflow, dissolved oxygen in local inflow, ebb velocity, ebb time, flood velocity, flood time, depth, area, volume (highly stratified estuary); volume of a portion of receiving basin; and initial waste loading applied to each segment.

The output from this model includes the initial waste loading applied to each segment, and the ultimate waste load and dissolved oxygen appearing in each segment.

In order to demonstrate the applications of the model, crude data pertaining to the Houston Ship Channel at Houston, Texas, were gathered from various sources. Data concerning certain physical characteristics of the cross-section of the estuary were obtained from plotted channel cross-sections made by the U.S. Army Corps of Engineers. Initial waste loadings being applied to the estuary were obtained from unpublished files of the Texas State Department of Health. Tidal characteristics were obtained from data gathered by the Corps of Engineers. Inflows into each segment were obtained from a special report by the U.S. Geological Survey. Upper and lower salinities were determined from data collected by the Corps of Engineers. River quality standards for oxygen were used, based on requirements set by the Texas Water Pollution Control Authority. The remaining data were either estimated or allowed to vary between certain values for various applications of the models. For examples, a coefficient of deoxygenation of 0.231 per day was used throughout; whereas a water temperature of 15°C was used for winter analyses and 30°C was used for summer analyses.

Figure 3-2;3 are plots of observed BOD values and calculated BOD values for the medium flow summer and winter conditions. The differences in peak value may be attributed to deviation between actual waste loads and permit values, sampling and laboratory methods and in the assumption of decay coefficients, temperatures and salinities. Field programs presently underway will permit a more rigorous verification of the modeling techniques.

Linear Systems Analysis

For purposes of water quality management it would be desirable to be

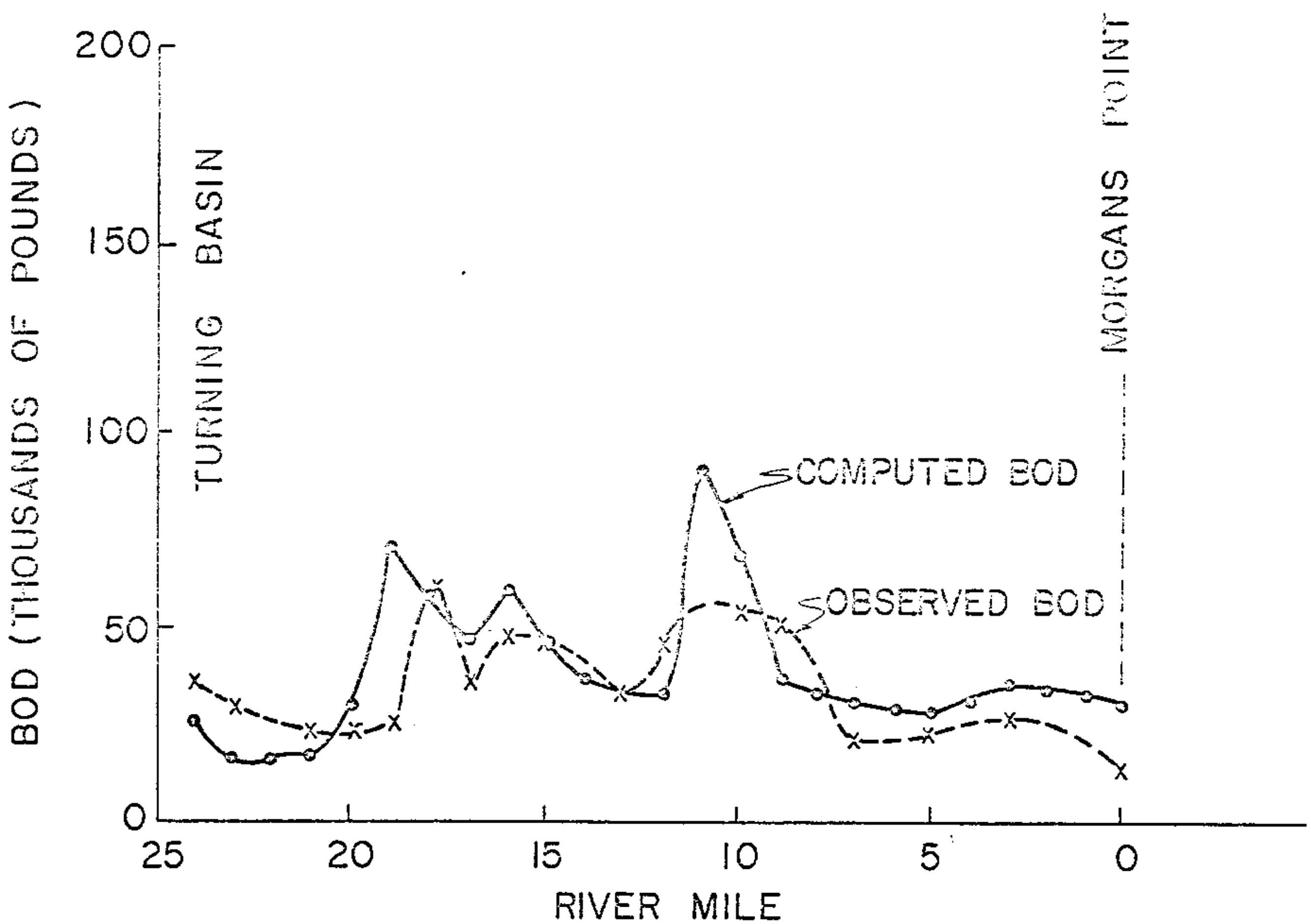


ILLUSTRATION 3-2

OBSERVED BOD VS. COMPUTED BOD
FOR MEDIUM FLOW SUMMER CONDITION
PERMIT WASTE LOADING REDUCED BY 25 PERCENT

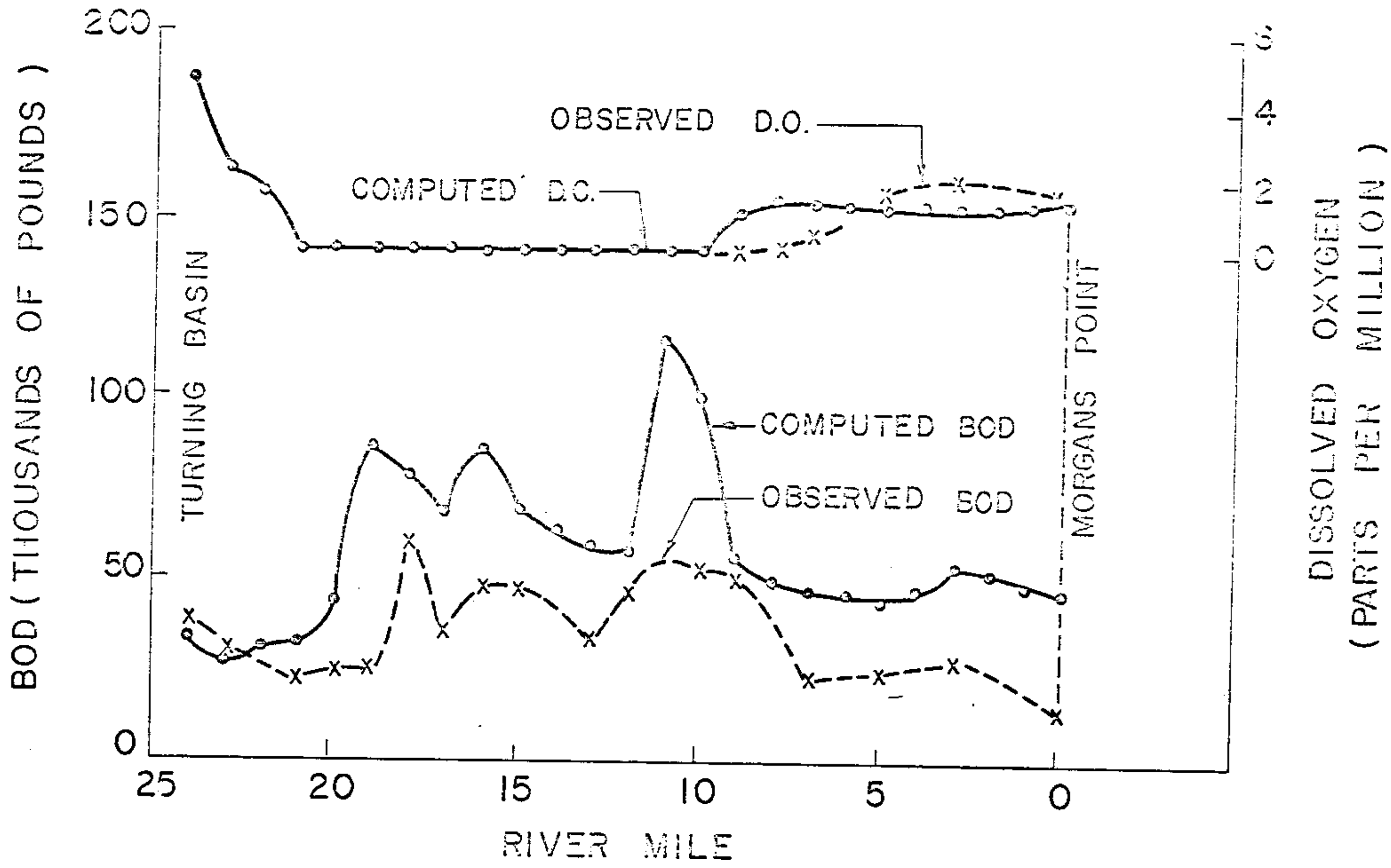


ILLUSTRATION 3-3

OBSERVED BOD VS. COMPUTED BOD
FOR MEDIUM FLOW WINTER CONDITION
PERMIT WASTE LOADING REDUCED BY 25 PERCENT

able to "work backwards" from set water quality criteria to allowable waste loadings. The equations developed as part of the dispersion model show promise in permitting this type of analysis to be made.

This method requires that for each segment there be calculated the total waste capacity for a given waste which is allowed under the quality criteria.

Where organic material (as BOD) is the pollutant material the total waste capacity (TWC) is equal to the sum of the oxygen resource per day divided by the estimated weighted decay factor

$$\text{i.e. } TWC_N = \frac{AO_N}{K_{1_N}}$$

where TWC = total waste capacity of the segment

AO_N = daily oxygen resource from atmospheric and mechanical aeration and inflow

and K_{1_N} = the decay constant for the accumulated waste in the segment

It is then possible to modify the equations for the total waste in each segment as shown in Figure 3-1 as shown below.

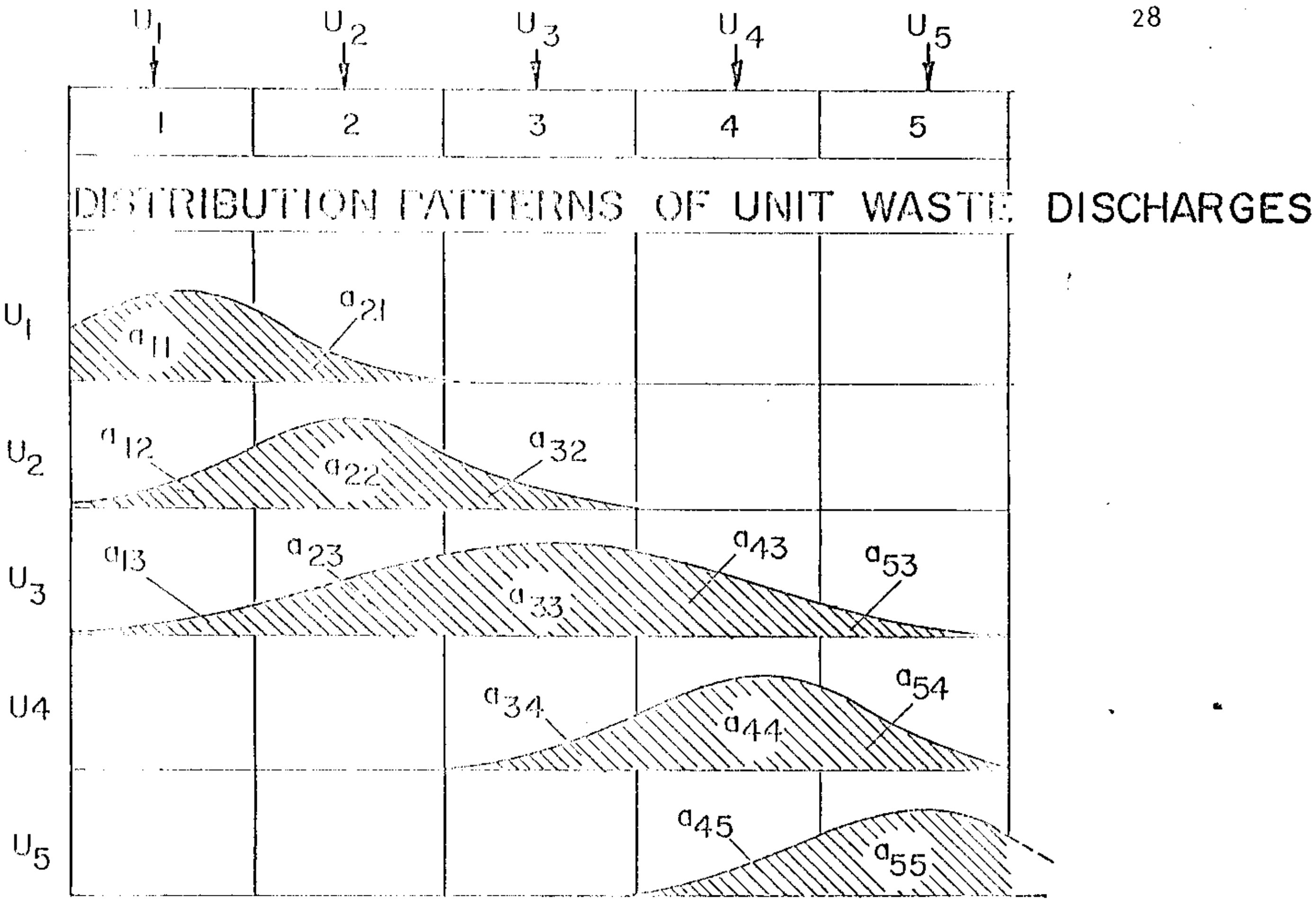
$$a_{11} D_1 + a_{12} D_2 + a_{13} D_3 + \dots\dots\dots\dots + a_{1n} D_n \leq TWC_1$$

$$a_{21} D_1 + a_{22} D_2 + a_{23} D_3 + \dots\dots\dots\dots + a_{2n} D_n \leq TWC_2$$

$$a_{31} D_1 + a_{32} D_2 + a_{33} D_3 + \dots\dots\dots\dots + a_{3n} D_n \leq TWC_3$$

$$\vdots$$

$$a_{n1} D_1 + a_{n2} D_2 + a_{n3} D_3 + \dots\dots\dots\dots + a_{nn} D_n \leq TWC_n$$



SOLUTION EQUATIONS

$$a_{11} D_1 + a_{12} D_2 + a_{13} D_3 \leq TWC_1$$

$$a_{21} D_1 + a_{22} D_2 + a_{23} D_3 + \leq TWC_2$$

$$a_{32} D_2 + a_{33} D_3 + a_{34} D_4 + \leq TWC_3$$

$$a_{43} D_3 + a_{44} D_4 + a_{45} D_5 \leq TWC_4$$

$$a_{53} D_3 + a_{54} D_4 + a_{55} D_5 \leq TWC_5$$

ILLUSTRATION 3-4
IDEALIZED ESTUARY
WITH 5 SEGMENTS

The unknown values in this set of equations are D_1, D_2, D_3, . . . D_n, i.e. The initial waste loadings which may be injected into each segment in order not to violate the quality standard.

In some cases, the equal signs may be used in Equation (2), and the resulting simultaneous equations may be solved directly for the unknown allowable waste loadings. Treating Equations (2) as inequalities, there exist an infinite number of solutions for the unknown values. The problem thus becomes one of finding an optimum solution to the equations in order to maximize or minimize some objective function. Illustration 3-4 demonstrates the modified equation with the appropriate "less than" or "equal" signs.

The most simple objective function is that the total waste load to the system is to be maximized without violating the linear equations.

i.e.

$$TLOAC = D_1 + D_2 + D_3 . . . . D_n$$

Figure 3-5- shows such an analysis for a set of quality parameters for the Houston Ship Channel. The example shows that the optimum loading is 38,441. lbs BOD/day. If equal loading per segment were an additional constraint only 5591. lbs/day would have been allowed.

Other objective functions which provide for minimum cost of waste treatment, maximum and minimum loads for particular segments, and equity requirements such as equal required treatment for similar industries have been hypothesized but not programmed.

The analytical models for estuarine analysis shown herein are not polished or complete and much modification and improvement is needed before they will be true engineering tools. They do, however, show great

INFLOW INTO FIRST SEGMENT = 61.00 CUBIC FEET PER SECOND.

MAXIMUM BOD ALLOWED BEYOND LAST SEGMENT OF ESTUARY = 3.00 PARTS PER MILLION.

ALLOWABLE INITIAL WASTE LOADING

SEGMENT	QUALITY STANDARD FOR OXYGEN (PARTS PER MILLION)	SIMULTANEOUS SOLUTIONS	OPTIMUM SOLUTION	OTHER POSSIBLE SOLUTIONS		
1	2.0	654.24	654.05	252.44	223.65	196.56
2	2.0	91.38	90.61	227.19	223.65	216.22
3	2.0	877.14	871.58	204.47	223.65	237.84
4	2.0	72.43	58.19	184.03	223.65	261.62
5	2.0	1437.28	1397.28	165.62	223.65	287.78
6	2.0	482.59	439.93	149.06	223.64	316.56
7	2.0	497.55	389.94	134.16	223.65	348.22
8	2.0	1248.10	1122.70	120.74	223.65	383.04
9	2.0	609.53	336.91	108.67	223.65	421.34
10	2.0	3544.21	2303.98	97.80	223.65	463.48
11	2.0	439.25	0.	88.02	223.65	509.83
12	2.0	1946.45	722.93	79.22	223.65	560.81
13	2.0	1610.10	0.	71.30	223.65	616.89
14	2.0	2969.57	0.	64.17	223.65	678.58
15	2.0	3111.31	0.	57.75	223.65	746.44
16	2.2	132691.74	0.	51.97	223.65	821.08
17	2.4	-144176.51	6818.17	46.78	223.65	903.19
18	2.6	-10928.13	0.	42.10	223.65	993.51
19	2.8	4558.53	2758.48	37.89	223.65	1092.86
20	3.0	6767.98	0.	34.10	223.65	1202.14
21	3.2	7878.05	0.	30.69	223.65	1322.36
22	3.4	-14535.31	0.	27.62	223.65	1454.59
23	3.6	26499.87	0.	24.86	223.65	1600.05
24	3.8	-13958.52	0.	22.37	223.65	1760.06
25	4.0	4113.77	20477.06	20.14	223.65	1936.06
TOTALS		18502.59	38441.82	2343.15	5591.16	19331.11

LOW FLOW, SUMMER CONDITION

FIGURE 3-5
Answers From Linear Systems Analysis

promise and their development has keyed a large coordinated program for estuarine analysis.

Section IV

Evaluation of Interbasin Transfer

As part of the initial project research plan it was stated that "the availability of water and the most economical disbursement of this water on the basin and interbas in scale needs extensive study".

Early in the project the project staff observed the relative ease by which Red River water could be diverted from the Lake Texhoma area into the Trinity, Neches and Sabine River basins. In earlier times a diversion of Red River water would not have been considered but recent proposals indicate that within the time period that a diversion plan could be executed the quality of the water in the basin would be improved to the point where a receiving basin would welcome a firm yield source with origin in the Red River.

Although the development of water resource plans was beyond the scope of this project, the development of analysis methods suitable to evaluate such plans was well within the project scope.

As a result the research staff chose to pursue the methodology and analysis of related factors necessary to evaluate one part of a Red River diversion scheme. Specifically the study involves a general study of the physical features and economic base of the source basin and one possible receiving basin, namely, the Neches River Basin. The results of this study are published in detail as a masters thesis entitled A Study to determine the Feasibility of Diverting a Portion of the Red River into the Trinity, Neches and Sabine River Basins by John H. Cook.

The methodology followed in the development of Cook's Thesis will be briefly described herein but the reader is requested to obtain the thesis for detailed information.

The possible diversion scheme is shown in schematic form in Figure 4-1 and in plan in Figure 4-2.

In brief the plan involved the pumping of Lake Texhoma water into the Trinity River Basin where it would flow into Lake Lavon. From Lake Lavon it would be diverted into Lake Tawakoni and subsequently pumped from Sabine River Channel into the headwaters of the Neches River. Thus diversions could be made to any one of the three receiving basins.

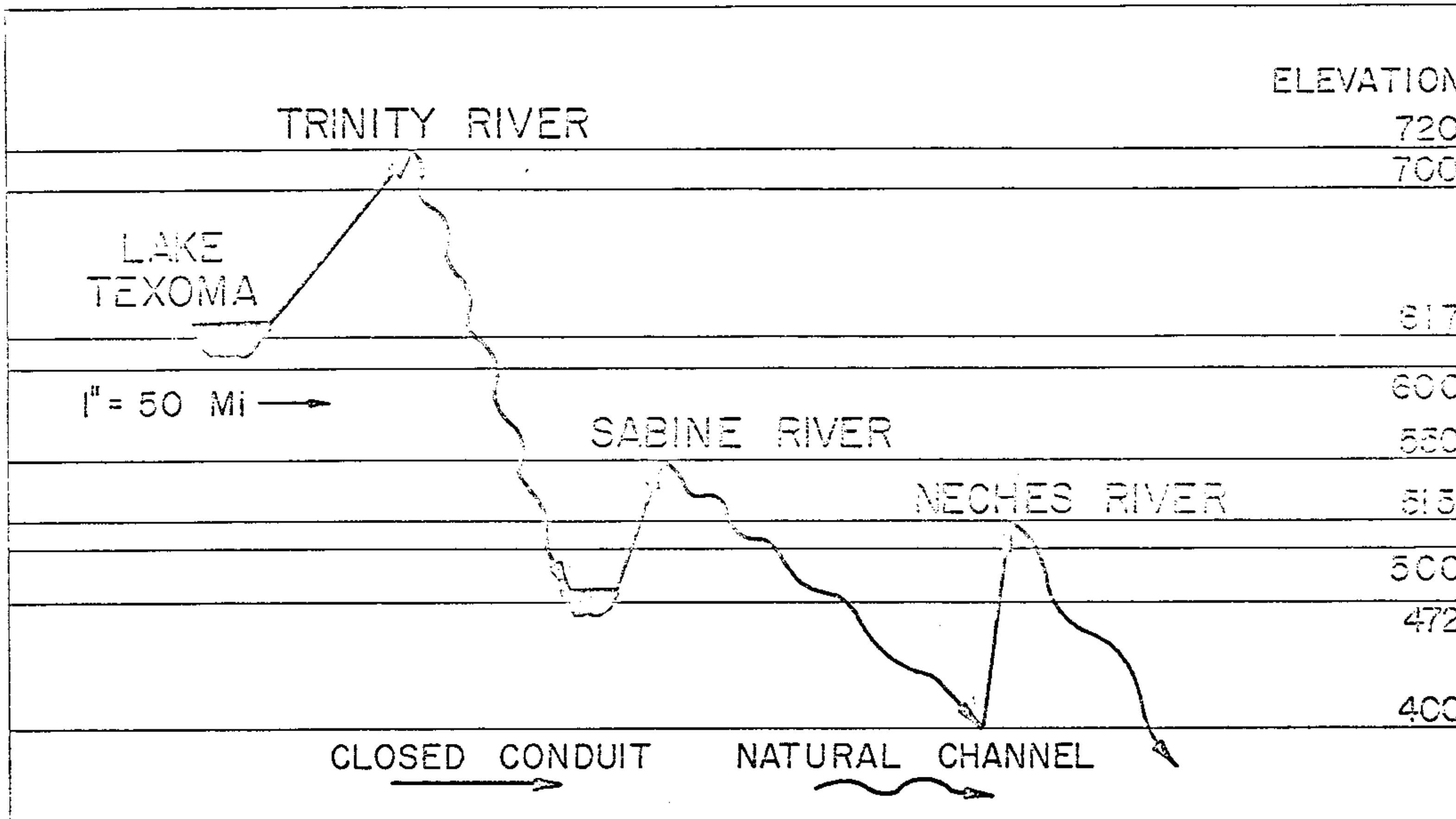
A general economic review was made of the source basin and receiving basins to identify important facets of the basin economics and to identify present and future water use segments.

An analysis was made of the water resource of the Red River basin above Denison Dam and of the Neches River basin. The Neches was chosen as the receiving basin to be studied in order to coordinate with the economic input-output analysis carried out by the economic staff of the project with regard to the most upstream major Neches River Reservoir, namely, the Blackburn Crossing Reservoir.

The analysis made of both the source and receiving basins included a general study of basin rainfall and evaporation, ground water and general runoff, floods, and quality aspects of the surface water.

Three detailed analysis were carried out in the source basin to evaluate the maximum firm yield which could be satisfied by Lake Texhoma under given statistical probabilities of non fulfillment.

It was first necessary to determine the inflow into Lake Texhoma. A computer model was developed which took the flows from upstream gaging stations, made corrections for areas below the gages, made corrections for

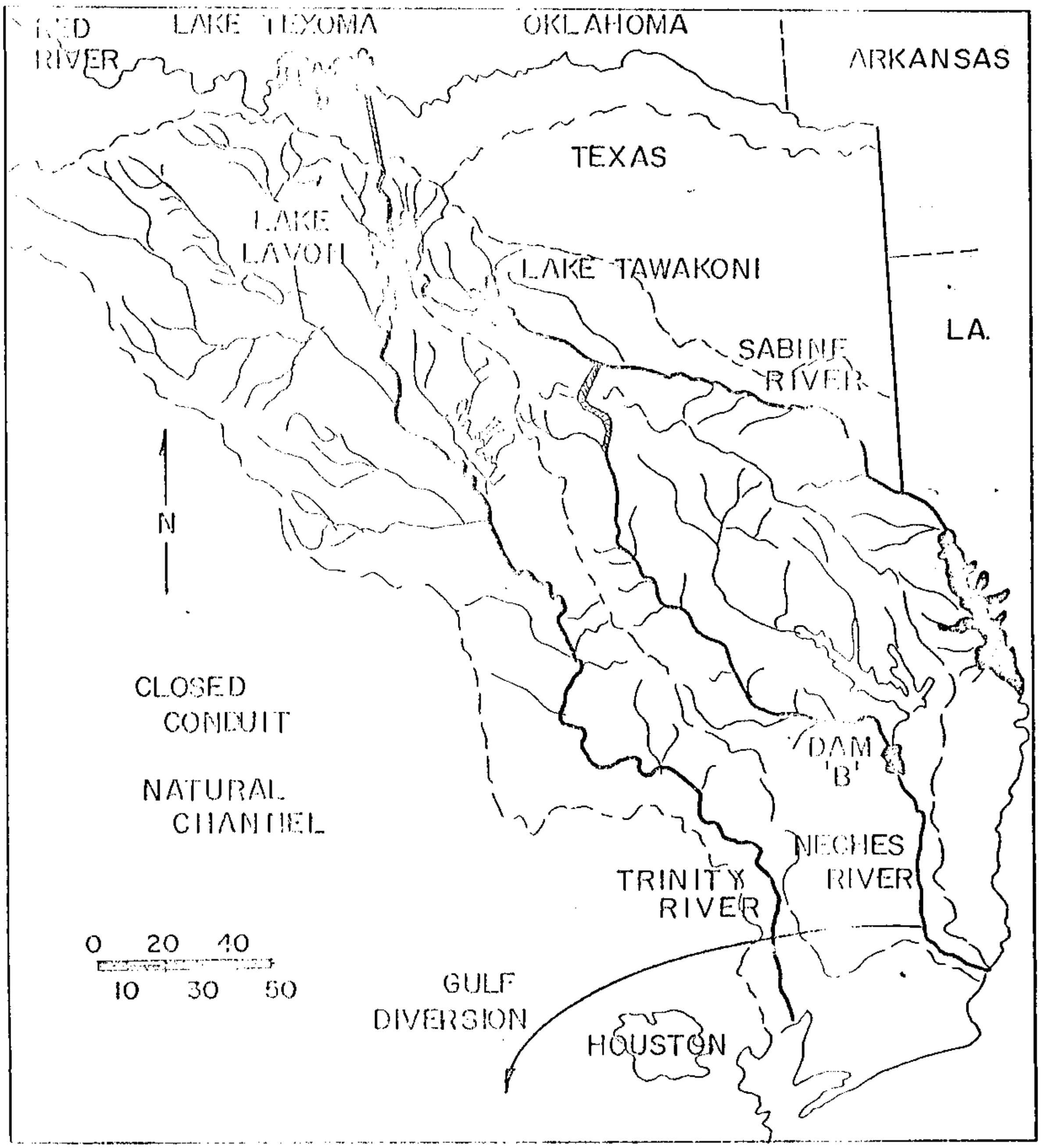


DIVERSION SCHEMATIC

FIGURE 4-1

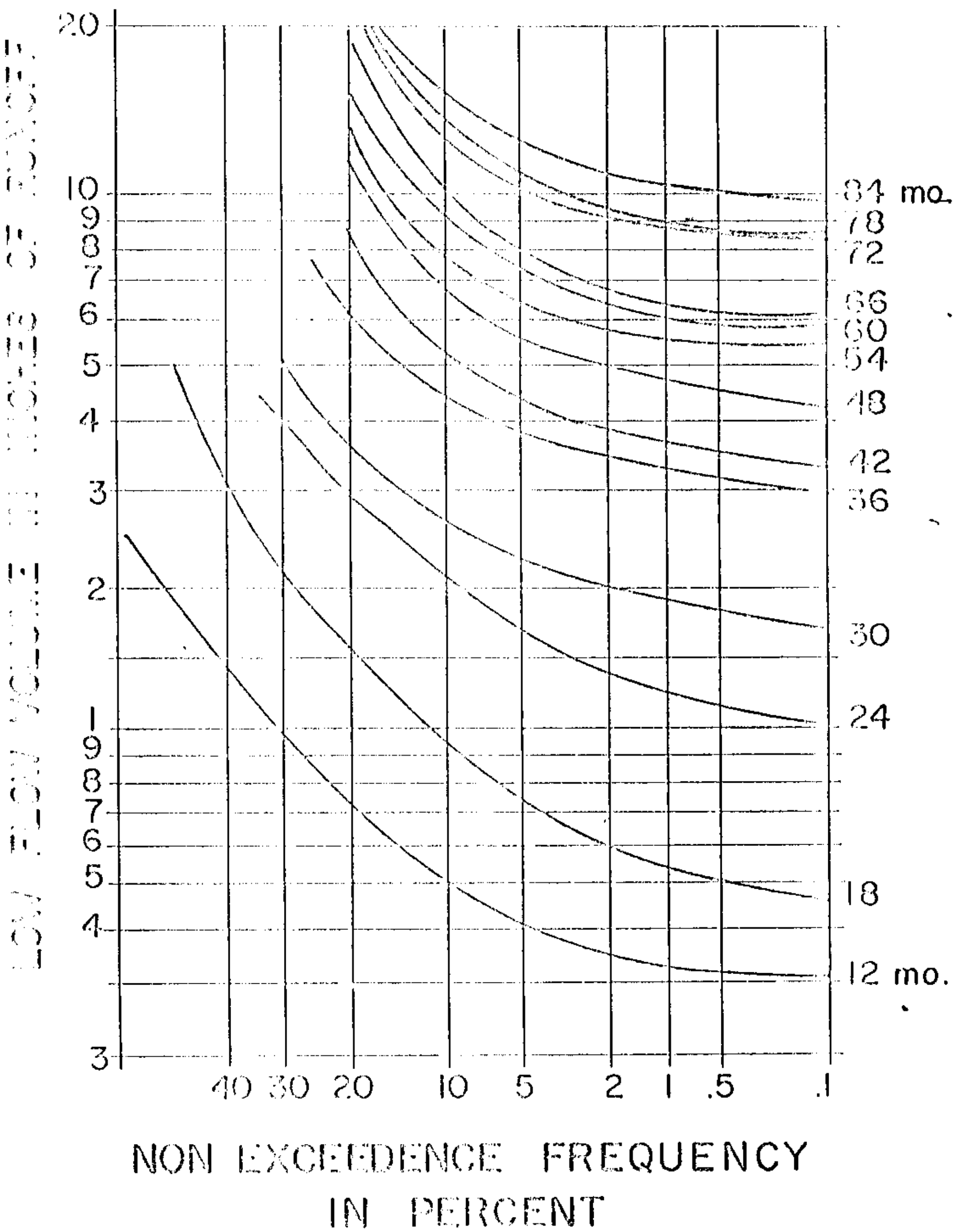
PROPOSED DISTRIBUTION SYSTEM

FIGURE 4-2



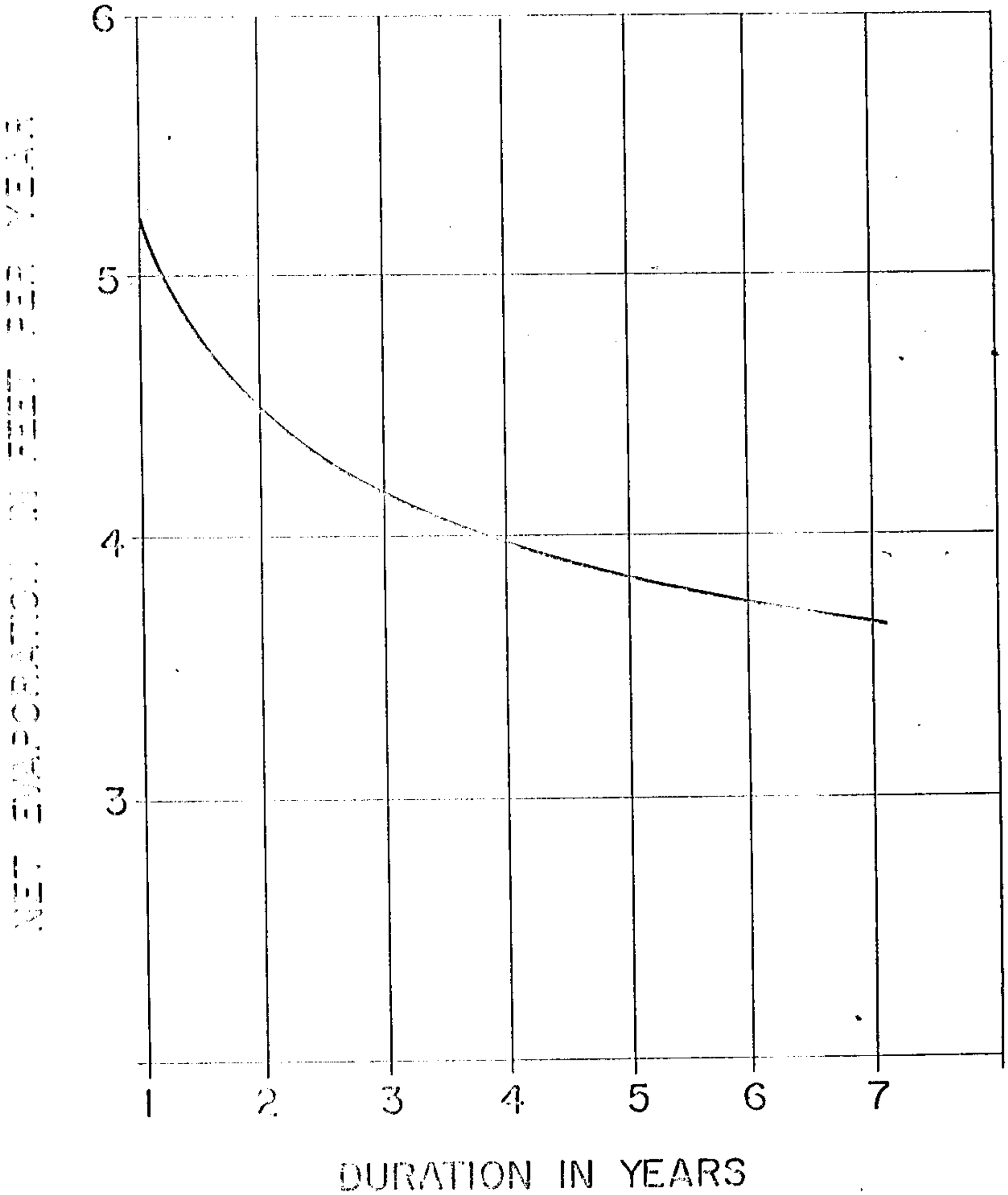
LOW FLOW EVENTS
RED RIVER AT
LAKE TEXOMA

FIGURE 4-3



MAXIMUM NET EVAPORATION AT LAKE TEXOMA

FIGURE 4-4



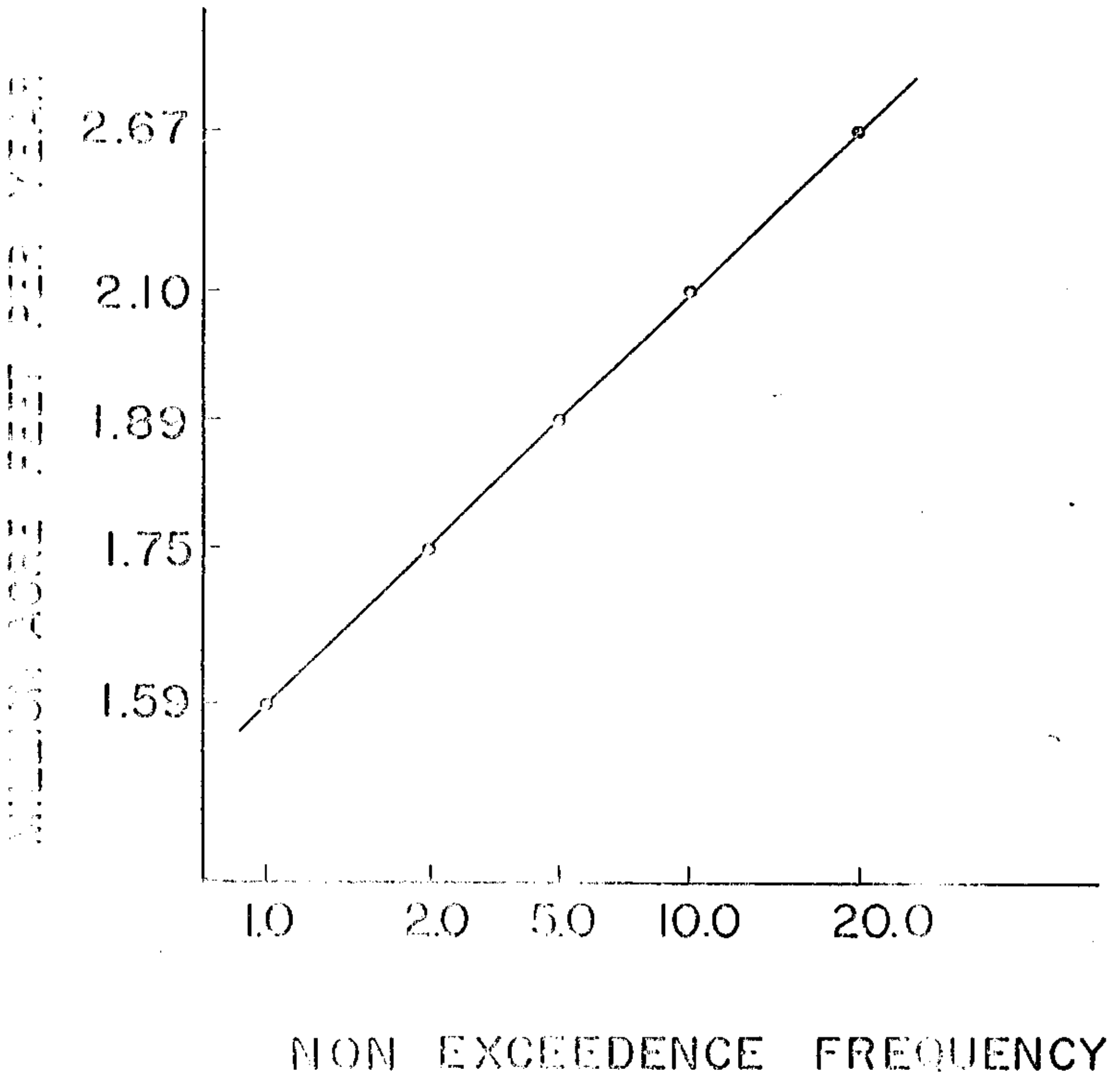


FIGURE 4.5

YIELD OF LAKE TEXOMA
USING
SIMPLIFIED YIELD PROGRAM

control exerted by existing reservoirs, and produced reasonable inflow values. The independent low flow event computer program was then used to determine critical drought periods with various probabilities of occurrences. The low flow periods and related flows were then used with basin evaporation as input to the simplified reservoir yield program to determine the yield to be expected based on given non-exceedence frequencies.

Figure 4-3 shows the runoff expected for various time periods and non-exceedence frequencies for Lake Texhoma. Figure 4-4 shows the evaporation curve used for Lake Texhoma. Figure 4-5 shows the yield expected from Lake Texhoma based on different non-exceedence frequencies.

In the receiving basin an analysis was made of the yield to be expected at various stages of development without supplementation for the Blackburn Crossing reservoir. The methodology is similar to that for Lake Texhoma except the inflow may be computed more simply.

Many political and socio-economic factors must be considered in any diversion scheme. An attempt was made to identify and discuss those which related to this particular plan. Foremost were the problems of interstate allocation of Red River waters, the discrepancies between future water needs for a basin when computed by those within or without the basin and the hope by many in West Texas to reverse the Red River flow to bring Mississippi water to the Texas high plains.

Section V

Economic Evaluation

The economics staff of the project elected to chose the region affected by the Blackburn Crossing Reservoir on the Neches River to demonstrate the use of the Leontif input-output analysis to interrelate the relationship between water as a resource and economic activity in a region. The readers attention is called to Technical Report #12 of the Texas Water Resources Institute for a more detailed description of the methodology presented herein.

Objectives

The needs of water resource planners for projections of economic activity by planning areas has stimulated the application of new techniques of regional economic analysis. Many of these techniques rely heavily on the computer for analysis of the large amounts of population, employment, and industrial output data.

The regional input-output model is one important new method that has been developed by econometricians and regional analysts for projecting regional economic activity. The first objective of this study was to build an input-output model of the economic activity of the watershed under study.

Once input-output models have been built, it is important that the relationship between various sectors of the economy and water use be built into these models. The second objective of this study, then, was to determine the relationship between the use of water as a resource and the economic activity of the various sectors.

A third objective of this study was to estimate the influence of an additional water supply on the level of economic activity in the watershed. Since a development of this resource is underway, a method of estimation of impact is useful.

As a preliminary to the study pertinant data such as the location, physiography and geology, water resources, human resources, energy resource, transportation facilities, and political entities were evaluated.

THE WATERSHED MODEL

The watershed model was conceived to examine the interdependence between the various sectors and industries of the watershed economy. Basically the input-output model is a general theory of production. The problem is to determine the levels of production in each sector which are required to satisfy the given level of total output.

The static closed model is based upon three fundamental assumptions. These are that:

1. Each group of commodities is supplied by a single production sector.
2. The inputs to each sector are a unique function of the level of output of that sector.
3. There are no external economies on diseconomies.

The economy consists of n + 1 sectors of these; one sector - that representing final demand - is autonomous. The remaining n sectors are non-autonomous, and structural interrelationships can be established among them.

Basic Mathematical Formulation

The model may be described as in the following equations in which X is the gross output of sector i, where i denotes a non-autonomous sector, x_{ij} the output of the producing industry i purchased by the non-autonomous sector j and Y_i is final demand for sector i.

Under the assumptions of input-output theory:

$$X_i = \sum_{j=1}^{n} x_{ij} + Y_i \text{ for all } X_i \text{ where } i = j.$$

An open system may be described mathematically as follows, in which i and j = 1, 2, 3, ... n.

$$X_1 = x_{11} + x_{12} + \ldots x_{ij} + \ldots x_{in} + Y_1$$
$$X_2 = x_{21} + x_{22} + \ldots x_{2j} + \ldots x_{2n} + Y_2$$
$$X_3 = x_{31} + x_{32} + \ldots x_{3j} + \ldots x_{3n} + Y_3$$
$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$
$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$
$$X_i = x_{i1} + x_{i2} + \ldots x_{ij} + \ldots x_{in} + Y_i$$
$$X_n = x_{n1} + x_{n2} + \ldots x_{nj} + \ldots x_{nn} + Y_n.$$

Constant technical coefficients are assumed for all X_i industries as in the following equation, $A_{ij} = \frac{x_{ij}}{X_j}$.

Substituting this equation into the above equation and transposing we have;

$$X_i - \sum_{j=1}^{n} A_{ij}X_j = Y_i$$

This equation is representative of the distribution of output of the sectors. The system may be written in matrix form as in X - AX = Y, in which X is a column sector of outputs, A is the matrix of technical coefficients, and Y is a column sector of final demands. Solving for the outputs required from each sector to deliver a specified final demand gives: $X = (I - A)^{-1}$ Y in which I is an identity matrix of the same dimension as A.

Interpretation of this solution is as follows:
Given final demand for the area products Y, and the matrix of interdependency coefficients matrix, the change in required output from each watershed area sector can be determined. Each interdependency coefficient $(I-A)^{-1}$, specific outputs are required of each area industry X.

Consequently, given a change in final demand for the watershed area products, and the interdependency coefficients matrix, the change in required output from each watershed area sector can be determined. Each interdependency coefficient (A_{ij}) must therefore be interpreted as showing the output required of industry i in response to one dollar's worth of final demand for products of industry j.

The Flow Tables

Table 5.1 is a partial table of goods and services within the study area by sector of origin and destination. The entries in each row of Table 5.1 lists by producers' prices the amount of a sector output consumed by itself and each of the other sectors in the economy. Each column of Table 5.1 represents a sector's input structure.

Technical Coefficients

Table 5.2 shows a partial table of the direct purchases of each sector from every other sector per dollar of output in 1958. All entries in Table 5.2 can be calculated directly from Table 5.1. Each entry in Table 5.2 shows the value of goods and services required from the row sector per dollar of output by the column sector.

Interdependence Coefficients

Table 5.3, a partial matrix of interdependence coefficients for the study area, was computed from Table 5.2. The unique characteristic of this matrix is that indirect and circular relationships between sectors, as well as the direct relationships are summarized. Each coefficient shows the direct and indirect requirements for products of the row sector per dollar of delivery to final demand of products of the column sector.

Table 5.1 Interindustry Flows of Goods and Services, Dollar Values, by Sector of Origin and Destination, Watershed Study Area, 1958

	1	2	3	4	5	6
	Livestock Products	Other Ag. Products	Ag. Forestry Products	Mining	Con- struction	Food Products
1. Livestock & Livestock Products	3,027,858	444,474	602,911	0	137,527	7,780,568
2. Other Agricultural Products	4,709,898	184,504	1,521,090	0	0	2,295,921
3. Agricultural Forestry Products	351,459	228,964	4,547	0	0	0
4. Mining: Pet. & Natl. Gas	4,892	17,368	0	168,554	559,397	5,923
5. Construction	167,075	98,276	996	2,123,491	5,477	111,601
6. Food & Kindred Products	2,104,807	734	73,870	0	9,736	5,210,945

Table 5.2 Technical Coefficients, Watershed Economy, Watershed Study Area, 1958

	Livestock Products	Other Ag. Products	Ag. Forestry Products	Mining	Con-struction	Food Products
1. Livestock & Livestock Products	.16093	.07268	.13924	0.	.00226	.24959
2. Other Agricultural Products	.25033	.03017	.35129	0.	0.	.07365
3. Agricultural Forestry Products	.01868	.03744	.00104	0.	0.	0.
4. Mining: Pet. & Natl. Gas	.00026	.00284	0.	.00219	.00985	.00019
5. Construction	.00888	.01607	.00023	.02759	.00009	.00358
6. Food & Kindred Products	.11187	.00012	.01706	0.	.00016	.16716

Table 5.3 Interdependency Coefficients, Watershed Economy, Watershed Study Area, 1958

	1	2	3	4	5	6
	Livestock Products	Other Ag. Products	Ag. Forestry Products	Mining	Con-struction	Food Products
1. Livestock & Livestock Products	1.28261	.10888	.22434	.00549	.00610	.39493
2. Other Agricultural Products	.35972	1.07919	.43387	.00734	.00722	.20465
3. Agricultural Forrestry Products	.03817	.04342	1.02235	.00209	.00775	.01655
4. Mining: Pet. & Natl. Gas	.00562	.01273	.00680	1.01606	.02701	.00417
5. Construction	.02977	.04248	.02327	.05451	1.01396	.02110
6. Food & Kindred Products	.17569	.02117	.05393	.00330	.00338	1.25632

Impact of Water Development

Once the input-output model has been constructed for the watershed area for a base period and the functional relationship between water as a resource requirement and total output is determined, this model can be used to forecast the impact on the watershed economy of increases in the supply of water available to industries.

A forecast of output by industry sector in the watershed study area was made for 1963, using (1) the functional relationship between water and output established for 1958 and (2) estimates of water use in 1963, developed in the same manner as were the estimates for 1958. Output per acre foot of water use in 1958 for each water using sector were multiplied by the estimated water use for each sector in 1963. For those sectors not using water as a resource requirement, estimates of output based on published data were used. The results of the forecast are found in Table 5.4.

Here it can be seen that total water use in 1958 amounted to 3400 acre feet and total output was $870,450, 529. In 1963, total use of water had increased to 6293 acre feet and total output to $1,220,732,585. This forecast compares favorably with total output estimated independent of water use. (See Table 5.5) As with the estimates of output in the watershed for 1958, output by sector was estimated from value-added data. The total for all sectors was found to be $1,124,722, 532. This indicates that the estimate of output based on water use was a bit high, some $96,010,053 or 8.5%.

Although not outlined in this report special studies were made to define flow table accuracies, examine the productivity associated with the water resource, and evaluate source and magnitude in evaluating productivity.

Table 5.4 Estimated Output Based on Water Use, Watershed Study Area, 1963

	Sector	Output, 1958 (Dollars)	Water Use, 1958 (Acre Feet)	Output per Acre Ft., 1958 (Dollars)	Water Use 1963 (Acre Feet)	Estimated Output 1963 (Dollars)
1.	Livestock	18,814,754				16,823,739
2.	Other Ag. Prod.	6,115,495				5,460,520
3.	Ag. Forestry Prod.	4,330,014				3,871,814
4.	Mining - Pet. & Natl. Gas	76,965,974	478	161,016	470	75,677,520
5.	Construction	60,852,521				35,728,952
6.	Food & Kindred Prod.	31,173,397	506	61,607	540	33,267,780
7.	Apparel, etc.	13,801,684				17,857,892
8.	Lumber & Wood	11,485,396	175	65,630	193	12,666,590
9.	Wood Containers	4,564,862	27	169,068	260	43,957,680
10.	Household Furn.	2,404,491	2	1,202,245	161	5,646,904
11.	Other Furniture	1,098,951			17	1,206,431
12.	Printing & Publishing	5,229,032	38	137,606		7,748,973
13.	Chemicals, Paints, etc.	18,198,522	262	69,460	569	39,522,740
14.	Pet. & Natl. Gas Refining	23,378,219	770	30,361	733	22,254,613
15.	Rubber & Plastic Products	2,004,980	42	47,737	215	10,263,455
16.	Glass Products	5,358,579	57	94,010	92	8,648,920
17.	Stone & Clay Products	6,588,707	129	51,075	856	43,720,200
18.	Primary Metals	39,539,865	520	76,038	938	71,323,644
19.	Heatg. & Plumbg.	10,979,308	137	80,140	279	22,359,060
20.	Const. Machy.	1,141,336	3	380,445	7	2,663,115
21.	Machine Shops, etc.	646,460	11	58,769	13	763,997
22.	Service Ind. Mach.	15,116,725	122	123,907	335	41,508,845
23.	Household Appl.	5,707,299	67	85,183	404	34,413,932
24.	Aircraft Repair & Pts.	1,385,569	14	98,969	1	98,969
25.	Motor Equip.	1,164,720			5	884,543
26.	Misc. Mfg.	2,972,308	40	74,307	205	15,232,935
27.	Trade	238,544,394				301,596,192
28.	Finance	86,582,540				127,658,216
29.	Real Estate	155,585,427				193,202,041
30.	Personal Services	18,719,000				24,694,000
	Total	$870,450,529	3,400		6,293	1,220,732,585

Table 5.5 Comparison of Output Estimates for 1963, Watershed Study Area

	Sector	Output Based on Water Use (Dollars)	Output Based on Value Added (Dollars)
1.	Livestock & Livestock Products	16,823,739	16,823,739
2.	Other Agricultural Products	5,460,520	5,460,520
3.	Agricultural Forestry Products	3,871,814	3,871,814
4.	Mining	75,677,520	75,735,814
5.	Construction	35,728,952	35,728,952
6.	Food & Kindred Products	33,267,780	37,195,955
7.	Apparel, etc.	17,857,892	17,857,892
8.	Lumber & Wood Products	12,666,590	15,233,441
9.	Wooden Containers, etc.	43,957,680	11,595,904
10.	Household Furniture	5,646,904	5,646,904
11.	Other Furniture & Fixtures	1,206,431	1,206,431
12.	Printing & Publishing	7,748,973	7,748,973
13.	Chemicals, Paints, Varnish, etc.	39,522,740	16,836,459
14.	Petroleum Refining, etc.	22,254,613	28,043,491
15.	Rubber& Plastic Products	10,263,455	16,859,411
16.	Glass & Glass Products	8,648,920	8,508,469
17.	Stone & Clay Products	43,720,200	13,626,523
18.	Primary Metals	71,323,644	50,348,036
19.	Heating, Plumbing, etc.	22,359,060	14,898,806
20.	Construction & Related Machinery	2,663,115	1,375,309
21.	Machine Shops, Metalwork, etc.	763,997	771,207
22.	Service Industry Machinery	41,508,845	27,914,572
23.	Household Appliances	34,413,932	51,081,862
24.	Aircraft Repair & Parts	98,969	157,099
25.	Motor Equipment & Vehicles	884,543	884,542
26.	Miscellaneous Manufacturing	15,232,935	12,169,957
27.	Trade	301,596,192	301,596,192
28.	Finance	127,658,216	127,658,216
29.	Real Estate	193,202,041	193,202,041
30.	Personal Services	24,694,000	24,694,000
	Totals	1,220,732,585	1,124,722,532

The results of this study show that the technique of forecasting economic development based on input-output analysis and the water-use-output relationship is a reliable and reasonably accurate technique. It is proposed that the technique can be used to evaluate the economic impact of water resources development on small watershed area.

Section VI

List of Publications

The following publications were derived in whole or in part from the research effort funded by this project.

Thesis

1. Cook, John Henry. "A Study to Determine the Feasibility of Diverting a Portion of the Red River Into the Trinity, Neches and Sabine River Basins". May 1968.
2. Canion, Robert Larry. "Input Output as a Method of Evaluation of the Economic Impact of Water Resource Development". May 1968.
3. Evett, Jack W., "A One-Dimensional, Steady State, Nonidealized Technique for Estuarine Analysis and Its Application to the Houston Ship Channel". May 1968.

WRI Technical Reports

Report #12. "Input Output as a Method of Evaluation of the Economic Impact of Water Resource Development".

Presentations to National and Regional Meetings

1. "Waste Dispersion Patterns in the Houston Ship Channel", Hann, Roy W., Jr., presented to the Texas Section, American Society of Civil Engineers, Houston, Texas, April 18, 1968.
2. "An Approach to Analyzing Water Quality in the Houston Ship Channel", Hann, Roy W., Jr., Proceedings of the 12th Water for Texas Conference, November, 1967.

3. "Institutional Factors in Water Development", Trock, Warren, L., Proceedings of the 12th Water for Texas Conference, November, 1967.

4. "The Concept of Waste Assimilation Capacity as a Useful Tool in Water Resources Management", Hann, Roy W., Jr., presented to the National Meeting ASCE, Dallas, Texas, February, 1967.

5. "The Houston Ship Channel - A Complex Problem in Estuarine Analysis", Hann, Roy W., Jr., Evett, Jack B., and Tyer, Bobby G., presented to the Texas Section, American Society of Civil Engineers, Austin, Texas, October, 1966.

6. "Computerized Evaluation of Liquid Wastes Assimilation in River Systems", Hann, Roy W., Jr., 58th National Meeting, American Institute of Chemical Engineers, Dallas, Texas, February, 1966.

7. "Digital Computers; A Promising Tool for State Water Resources Agencies", Hann, Roy W., Jr., Proceedings, Joint Meeting Rocky Mountain Division of AWWA and WPCF, Albuquerque, New Mexico, October, 1965.

Printed Lectures

1. "Computer Applications in Water Quality Management", Hann, Roy W., Jr., presented to the Water Quality Management Training Course, Austin, Texas, April, 1968.

2. "Simulation and Load Evaluation Models in Water Quality Management of Tidal Estuaries", Hann, Roy W., Jr., presented to an Environmental Engineering Seminar, University of Oklahoma, April, 1968.

3. "Systems Analysis in Water Resources Management and in Management of Tidal Estuaries", Hann, Roy W., Jr., presented to a Water Resources Seminar, Las Alamos, New Mexico, January, 1968.

4. "Water Quality Aspects of Reservoir System Analysis", Hann, Roy W., Jr., presented to the U.S. Army Corps of Engineers Seminar, "Reservoir Systems Analysis", Omaha, Nebraska, April, 1967.

5. "Aquatic Systems Analysis in Water Resources Planning and Management", Hann, Roy W., Jr., presented to the New Mexico Water and Sewage Works Short School, Las Cruces, New Mexico, April, 1966.

6. "Water Quality Aspects in Planning and Managing Water Resource Systems", Hann, Roy W., Jr., presented to the U.S. Army Corps of Engineering Seminar, "Storage Yield and Streamflow Simulation", Sacramento, California, January, 1966.

Other

"Work Plan for the Development of a Comprehensive Water Quality Management Program for Galveston Bay and Its Tributaries", Appendix A, Roy W. Hann, Jr., et.al., Water Resources Research Committee of Texas, College Station, Texas, October, 1966.

Section VII

Summary

This project furnished the seed funding and direction for what has become a major research effort to solve Texas Water Resource Problems.

Although the project level was not high in terms of manpower, significant results were achieved by the project staff and many of the ideas which had their birth as part of this broad effort have led to significant funded research projects and a large number of independent thesis projects.

The analytical methods for water resource analysis described in Section II have been used extensively in two graduate courses at Texas A&M University and are being made available to state and federal agencies upon request. The Agricultural Research Service is using a watershed runoff model which is the outgrowth of these methods as presented in one of the graduate courses. Additional theses projects on multibasin simulation await interested graduate students.

The priority which Texas places on her Bays and Estuaries and the need to evaluate the effect of fresh water inflow modification and environmental pollution management has spurred the development of the estuarine models which had their initial formulation as part of this project. Projects with funding of over one half million dollars over a four year period have been initiated under the direction of the project director of this project. These projects call for further development of analytical techniques for estuarine analysis and provide for a field effort to collect the necessary data to verify the analytical methods. The project director participated in the development of the Galveston Bay work plan which is being used by the Texas Water Quality board to guide estuarine studies.

Interbasin transfer was considered in this project because of the statewide interest in such plans and because it gave a real and existing problem for which to demonstrate the use of some of the analytical methods developed or reprogrammed by the project staff.

The project staff's interest in interbasin transfer was prior to the announcement of the States' Interbasin transfer plans in the preliminary version of the Texas Water Plan. Following that report with its more large scale transfer the staff shifted its emphasis to problems on which it felt they could have more impact. It is interesting to note that the latest version of the Texas Water Plan returned to the concept of a Gulf Coast Canal which this project diversion plan made more feasible.

The project stimulated a close cooperation between the project staff and federal and state agencies. Close contact with the Hydrologic Engineering Center of the Corps of Engineers prevented duplication of effort, participation on the part of the project staff as student and faculty in Corps training courses and eventually led to the presentation by Texas A&M University of special two week courses entitled Water Quality Aspects of Water Resource Planning for the Corps of Engineers and the Bureau of Reclamation. Representatives of the Federal Water Pollution Control Administration, The Texas Water Development Board, the Texas Water Quality Board and The Texas Parks and Wildlife Department also participated in these courses and thus learned of our efforts and used methodology developed by this project. Although the project stayed within the general framework of the project objectives, there was some deviation through the course of the project from initially stated sub-objectives. This was necessitated by the level of funding, changes in staff personnel, and staff interests and competenness. The significant accomplishments of the project are as a result of working with real Texas water resources problems in which lay within the scope of the staff competencies.

The Appendices are not included in this report. If information contained in one of them is desired, it can be obtained from Dr. Roy W. Hann, Jr., Environmental Engineering Division, Civil Engineering Department, Texas A&M University, College Station, Texas.