Regional Water Supply Management Decision Support Tools for the San Antonio Region

Phase II
Technical Report

submitted to the
General Managers Oversight Panel

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1.1 Background

Water resources in the San Antonio region consist primarily of surface waters of the Nueces, San Antonio and Guadalupe River basins and groundwater of the Edwards aquifer. As increased demands have been placed on these water resources, competition over their allocation has also escalated. The western agricultural sector is in competition for water with the rapidly growing San Antonio/Bexar County metropolitan sector. To the east in the aquifer system, the Cities of New Braunfels and San Marcos with water dependent economies, view themselves at being at a disadvantage due to an inability to assure long-term spring flows.

Superimposed on the east-west conflicts are north-south conflicts between recharge and servicing downstream water rights. These rights exist in the lower reaches of the Nueces, San Antonio and Guadalupe Rivers as well as undefined bay and estuary requirements. In this arena of increasing conflicts, the region urgently needs sound water management to address the requirements of each of the individual competing demands and to allocate a fair and equitable supply to each.

To assist regional managers in the decision-making process in this complex and competitive environment, the Center for Water Research (CWR) at the University of Texas at San Antonio (UTSA) has undertaken a project to design, test, and implement a Decision Support System (DSS) for regional water supply management. For purposes of this project, a Decision Support System is defined as

> an interactive, PC-based system that incorporates existing regional models, a comprehensive database and a user interface to provide objective information for defensible decisions in unstructured problems.

Although many types of information systems could be designed, a Decision Support System is the management tool of choice for this application because it operates at a management level and is an extension of the management function. In contrast with some other systems, a DSS does not make decisions. Rather, is enhances the managers capability to extract information from large volumes of data and to evaluate complex "what-if" scenarios.

1.2 Project History

The Center for Water Research at the University of Texas at San Antonio initiated work in 1991 on a multi-phase research project to design, test and implement decision support tools for regional water management. Phase I, entirely funded by the Texas Water Development Board (TWDB), focused on the preparation of a comprehensive study design in collaboration with a General Managers Oversight Panel comprised of representatives from the San Antonio Water Board, Waste Water Department of the City of San Antonio, Alamo Conservation and Reuse District, San Antonio River Authority, Guadalupe-Blanco River Authority, Edwards Underground Water District, Canyon Regional Water District, Nueces River Authority, Bexar Metropolitan Water District, and the Texas Water Development Board.

While Phase I was in progress, the San Antonio Water System was formed by consolidating the City Water Board, Alamo Conservation and Reuse District, and the Department of Wastewater of the City of San Antonio into a single entity. Prior to this consolidation, the General Managers of both the Water Board and the Reuse District were members of the General Manager's Oversight Panel. In addition, during Phase I, the Bexar Metropolitan Water District participated as a separate entity. During Phase II Bexar Metropolitan Water District was represented by the Canyon Regional Water Authority.

Phase I, which was completed in August 1991, provided the detailed study design for subsequent work in the form of a proposal to the Texas Water Development Board. The goal of the project described in the proposal was "to design, produce, test and implement a decision support system consisting of databases and analytical tools that provide area water managers, and the public, with the capability to examine alternative water resource management strategies." Basic to this goal is the adoption, for PC use, of existing regionally specific, computational hydrologic models and production, also for PC use, of specific screening models.

Phase II was jointly funded by the Texas Water Development Board, the San Antonio Water System, the Guadalupe-Blanco River Authority, the San Antonio River Authority, the Edwards Underground Water District, and the Canyon Regional Water Authority. The Phase II objectives defined in the proposal were as follows:

1. To gather, maintain, and make available region-specific hydrologic models. Such models to be maintained a the CWR and accessible to regional users who may wish to make multiple runs or investigate "what if" scenarios. The models would also be adapted for PC use. (The latter was an effort expected to extend beyond Phase II.)

2. To identify, develop, and make available PC compatible screening models, including demographic, demand, hydrologic, cost, economic and environmental assessment models.

3. To test sensitivity and analytical operation of models and tools developed to assure their usefulness to water managers in the region.

4. To develop a recommended set of hardware, a procedures manual, other materials, training, etc. to ensure that each user has the on-site operating capability to utilize the tools and resources being developed in Phase II.

5. To identify, obtain, maintain, and make available on a current basis the data and information necessary to support the use of the models identified in objectives 1) and 2).

6. To design and implement an on-going extension program to inform the region's interests of the work being done.

7. To prepare a plan for establishing the UTSA Center for Water Research as the entity responsible for maintaining and enhancing these databases and models through a partnership agreement with the State of Texas, regional water management entities and other regional water interests.

Phase II work could actually be divided into two parts. In a chronological sense, the first part of the research consisting of work on objectives 1, 3, and 5 covered the period from May 1992 through October 1992. Over this approximately 6-month period, it became increasingly obvious that the PC versions of the regional hydrologic models alone were not appropriate for a management oriented DSS.

In November 1992, the General Managers Oversight Panel was briefed on a geobased approach to the DSS with access to the regional models through pre- and post-processors. Following this presentation at the monthly Panel meeting, the course of work was altered, focusing on the pre- and post-processor approach. While this was a significant change in the direction of the research, a simple demonstration was prepared to illustrate these concepts using the Edwards Aquifer model, GWSIM-IV. Because of the seemingly wide acceptance of this redirection, the second half of the project work, November 1992 to date, has focused on modification of the I/O and operational characteristics of the models for pre- and post-processor interfaces. It is in the context of this redirected effort that this report has been prepared.

1.3 Phase II Activities

Although Phase II research followed what appeared to be two separate avenues, the project never lost sight of the main goal to provide management level DSS tools. As a result of the redirection and change in form of the project deliverables, change and modification to the original seven project objectives were also necessary. Some were altered, others deferred and some may no longer be necessary. The following discussion summarizes the details of work on each specific objective and documents the set of circumstances leading up to the change in project activities.

1.3.1 Initial Phase II Work. The Phase II work began with collection and evaluation of the regional surface and ground-water models and supporting data. This is work corresponding to Phase II objectives 1, 3 and 5. Several available computer models for the Edwards Aquifer were acquired and evaluated to determine the most appropriate as a management tool based on computational accuracy, ease of execution, completeness with respect to goals of this project and availability of documented case studies. The Texas Water Development Board's GWSIM-IV was the model of choice for the Edwards Aquifer. The Texas Water Development Board's SIMYLD-II as implemented for the Guadalupe and San Antonio River Basins by the firm Espey Huston and Associates and the Edwards Underground Water District's Recharge Model implemented for the Nueces River Basin by HDR Inc. are the only operable surface water models utilized in the region, and therefore were selected for the DSS. Detailed discussions and evaluation of these models are contained in Chapters 5 and 6 of the report.

Sensitivity and model testing for the DSS, referred to in Phase II objective 3, is different from classical sensitivity testing. When computer models are developed by others and offered for distribution, the user can only assume that they have been subjected to a sensitivity analysis. The verified model should satisfactorily react to changes in modeling parameters in an expected and reasonable way. Model testing and verification are a standard procedures for the development of engineering software. Application of these procedures to the GWSIM-IV and SIMYLD-II models was confirmed by Mr. Steve Densmore at a General Managers Oversight Panel meeting. For the DSS, sensitivity analysis addresses the question of whether the regional models, when ported to the PC environment, produce results similar to those obtained from their accepted mainframe counterparts within acceptable accuracy. To illustrate, monthly spring flows were computed by the Center for Water Research for the 1947-1959 drought and recovery period for each of ten spring locations and compared with similar results obtained from the Texas Water Development Board mainframe run for the same period. Figures 1.1 and 1.2 show these correlations at Comal and San Marcos Springs, respectively. Table 1.1 summarizes the correlation coefficients obtained for each of five flowing spring locations. Perfect correlation would be indicated by a coefficient of 1.000. Table 1.1 shows near perfect correlation at each location. In view of other uncertainties in the model and aquifer properties, the results from the PC run may be considered identical to the State's mainframe run.

A second measure of model sensitivity in DSS analysis was obtained by comparing monthly spring flows computed from a continuous 13-year run (e.g. 1947-1959) with spring flows computed during each of the 13 individual years beginning with heads computed at the end of the previous year. Figures 1.3 and 1.4 illustrate these correlations for Comal and San Marcos Springs, respectively. The second column of Table 1.1 lists the correlation coefficients obtained from this second set of comparisons at each of the five flowing springs. The results from the two methods of analysis correlate so well that they may be considered identical.

Initial objective number 5 deals primarily with the acquisition of data to support the implementation of selected

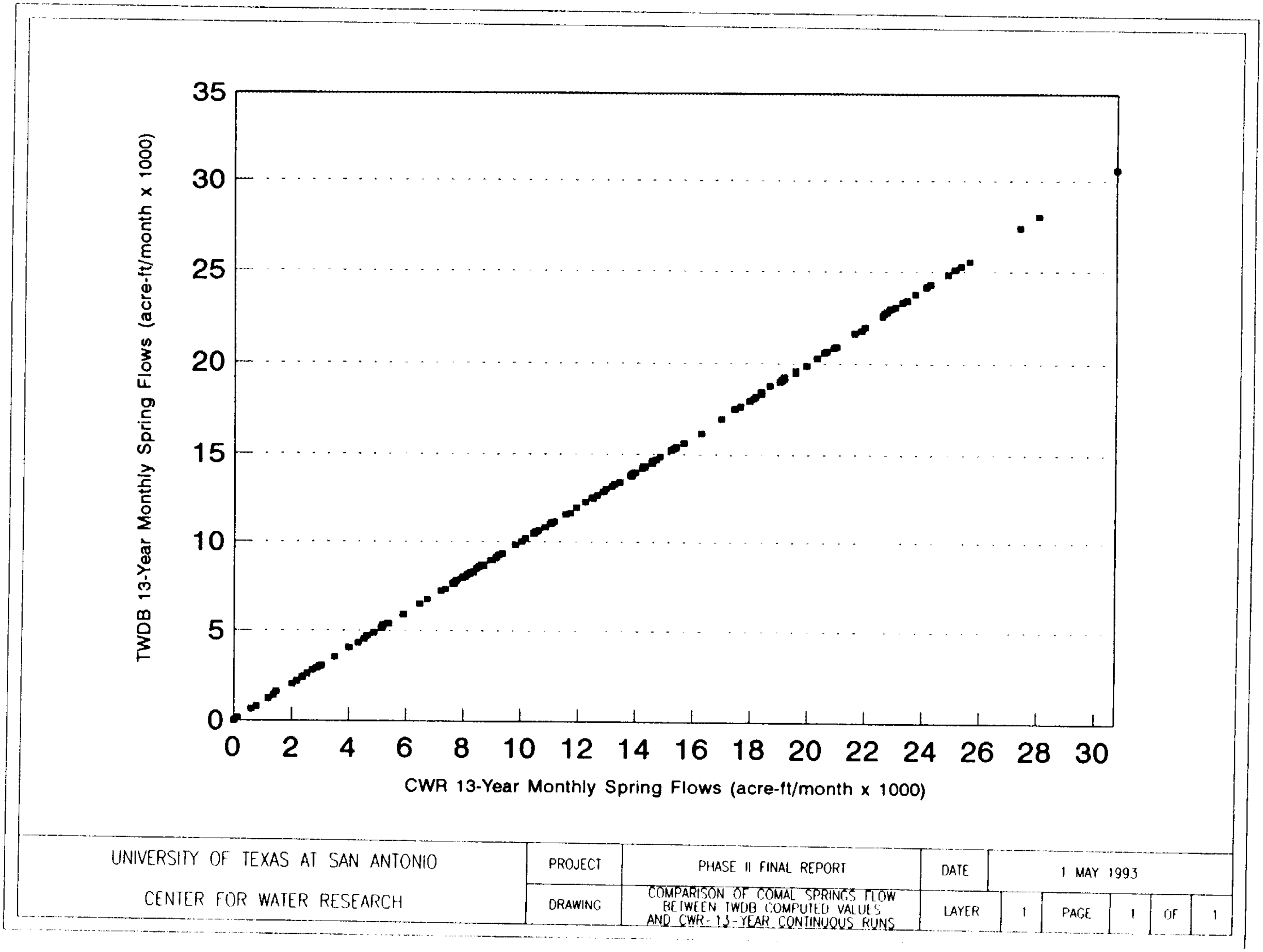
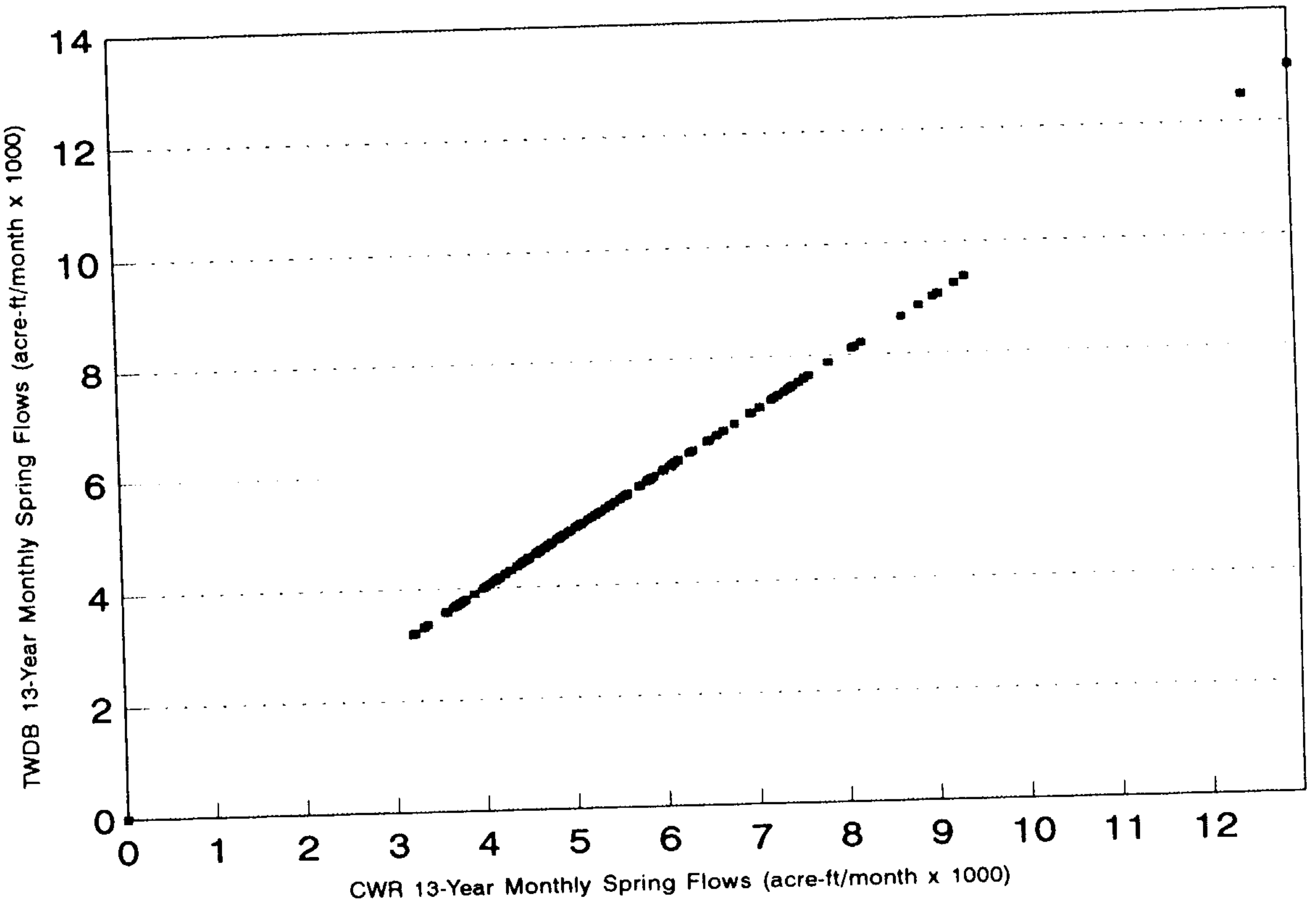


Figure 1.1 TWDB Computed Comal Spring Flow Versus CWR Computed Comal Spring Flow; Continuous 13-Year Simulation 1947-1959



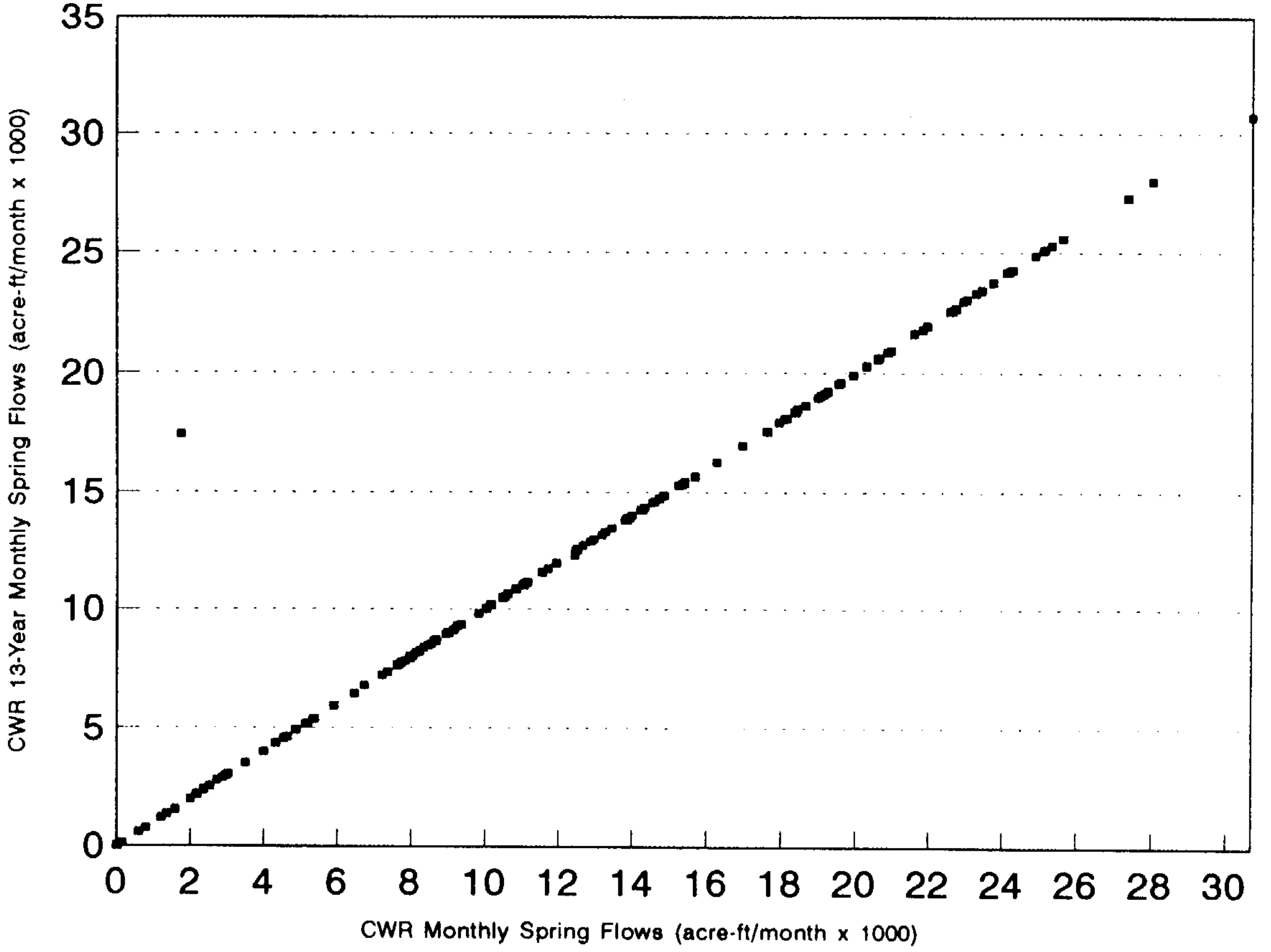
UNIVERSITY OF TEXAS AT SAN ANTONIO	PROJECT	PHASE II FINAL REPORT	DATE	1 MAY 1993				
CENTER FOR WATER RESEARCH	DRAWING	COMPARISON OF SAN MARCOS SPRINGS FLOW BETWEEN TWDB COMPUTED VALUES AND CWR 13 YEAR CONTINUOUS RUNS	LAYER	1	PAGE	1	OF	1

Figure 1.2 TWDB Computed San Marcos Flow Versus CWR Computed San Marcos Spring Flow; Continuous 13-Year Simulation, 1947-1959

Spring	TWDB Continuous 13-Year Simulation Versus CWR Continuous 13-Year Simulation	CWR Continuous 13-Year Simulation Versus CWR Annual Simulation
Leona North	0.999889	0.9999419
Leona West	0.9997322	0.9998997
Comal	0.9999849	0.9857031
San Marcos	0.9999999	0.9999998
San Pedro	0.9999999	0.9999999

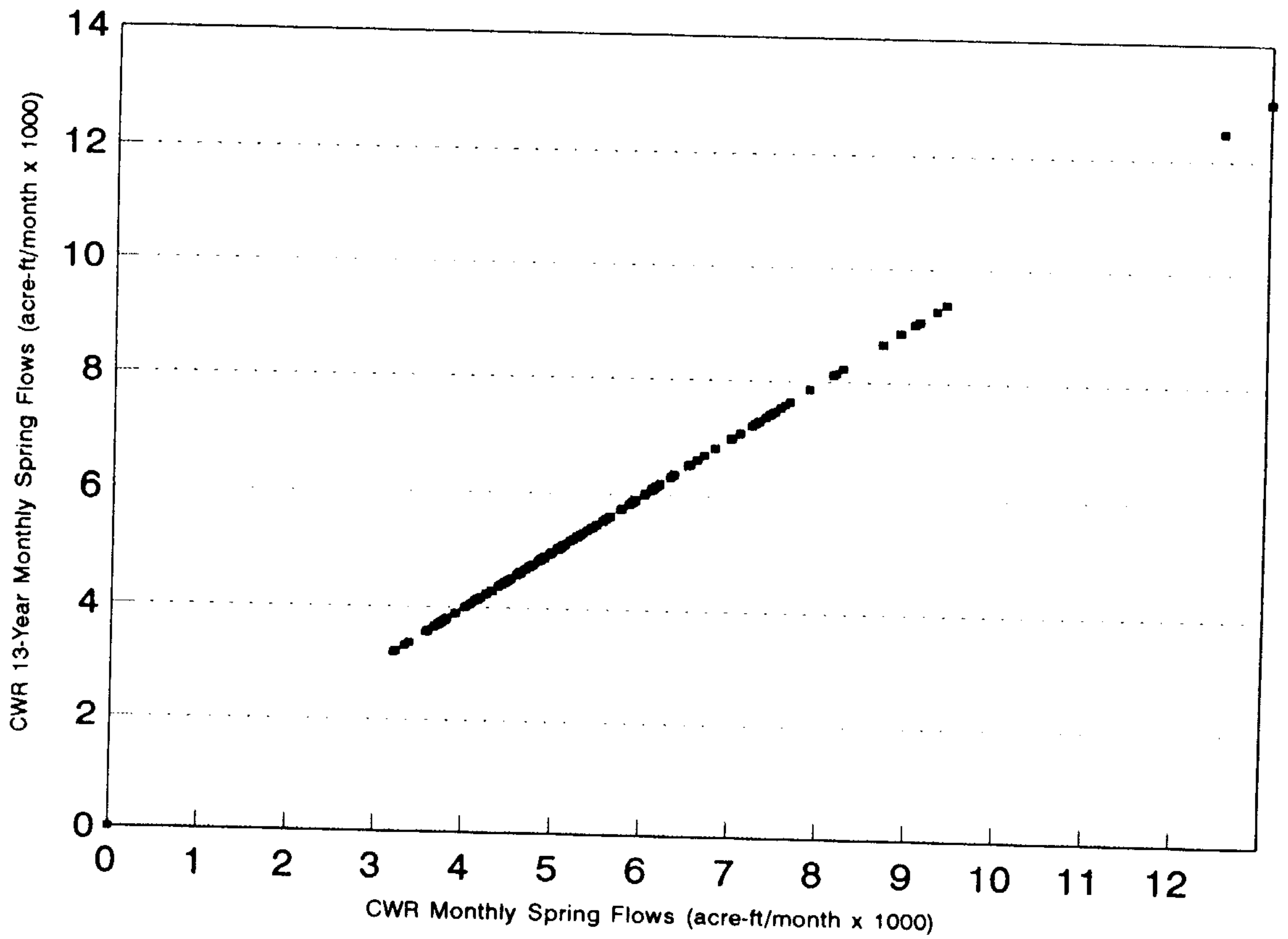
UNIVERSITY OF TEXAS AT SAN ANTONIO	PROJECT	PHASE II FINAL REPORT	DATE	1 MAY 1993				
CENTER FOR WATER RESEARCH	DRAWING	CORRELATION COEFFICIENTS FOR GWSIM RUN COMPARISONS	LAYER	1	PAGE	1	OF	1

Table 1.1 Correlation Coefficients for Comparisions Between GWSIM-IV Runs; 1947-1959 Sequence



UNIVERSITY OF TEXAS AT SAN ANTONIO	PROJECT	PHASE II FINAL REPORT	DATE	1 MAY 1993				
CENTER FOR WATER RESEARCH	DRAWING	COMPARISON OF COMAL SPRINGS FLOW BETWEEN CWR-13-YEAR CONTINUOUS AND CWR-ANNUAL RUNS	LAYER	1	PAGE	1	OF	1

Figure 1.3 CWR 13-Year Continuous Computed Comal Springs Flow Versus CWR Computed Spring Flow on Annual Basis, 1947-1959



UNIVERSITY OF TEXAS AT SAN ANTONIO	PROJECT	PHASE II FINAL REPORT	DATE	1 MAY 1993				
CENTER FOR WATER RESEARCH	DRAWING	COMPARISON OF SAN MARCOS SPRINGS FLOW BETWEEN CWR-13-YEAR CONTINUOUS AND CWR-ANNUAL RUNS	LAYER	1	PAGE	1	OF	1

Figure 1.4 CWR 13-Year Continuous Computed San Marcos Spring Flow Versus CWR Computed Spring Flow on Annual Basis, 1947-1959

models. At the time of acquisition of the GWSIM-IV model from the Texas Water Development Board, a complete data set consisting of monthly pumping and recharge data for each of the model's 2480 cells was provided for the 1947-1959 drought and recovery period. More recently, the project was able to obtain period of record recharge data by cell and by month for 1934-1991. Pumpage data was not available for the entire period-of-record, however the State has provided pumping distribution by cell, by month, and by water use for 1989. Pumpage data is provided for three applications; municipal and industrial, domestic and stock, and irrigation. The 1989 pumpage distribution can be applied to any period of record provided an average annual aggregated pumpage is specified. Attempts to acquire the complete recharge and pumpage data set for the 1978-1989 model verification period have been unsuccessful.

Complete data sets were provided for both the SIMYLD-II and Nueces River Basin recharge models, including regulated and unregulated stream flows for major stream systems in the models, estimates of flows from ungauged areas, reservoir area-capacity, demands and monthly demand distributions, import distribution, reservoir operating criteria for average dry and wet periods, evaporation data at proposed existing projects, water rights, diversion rights, and monthly recharge in the Nueces River Basin. The Center has been unable to acquire water rights data by electronic media from the Texas Water Commission, after submitting several requests. Still other data that have been incorporated into data files consists of water supply, recharge and pumpage data. Much of this data was obtained directly from the South Texas Technical Data Review Panel final report. The content of this report was far short of what the DSS project anticipated. To date, no attempt has been made to reformat this data for input to the models.

1.3.2 Modification of Project Objectives. Progress in the project up to the end of October 1992 included acquisition, testing, and downloading of regional models to the PC environment. Results indicated that even when operated at the PC level, the input and output files were still very large, very complex, and varied from model to model. Despite significant efficiencies obtained in run times, the time required to prepare input data sets and analyze output was prohibitive. As the Center focused its efforts on model implementation for management, it became increasingly clear that this complexity would limit the application of the models for management purposes and could endanger the achievement of basic project goals. Strict requirements for content, units, and format of input data dictated a separate, lengthy input data preparation process for each run. The models, in their original form, provide output data which can only be accessed in hard copy or by scanning a massive output file on disc. The input and output files for a complete GWSIM-IV run, for example, are 6.47 MB and 1.15 MB, respectively. This output file takes two hours to print on a line printer, and the input file would require about 11.6 hours. In other words, a single complete run with GWSIM-II, while requiring only about 12 minutes to run on a PC 486, could still require up to nearly 14 hours to run, document and analyze. Further documentation of run for other models is shown in Table 1.2. Since development of management scenarios requires multiple model runs, exercising the decision-making capabilities of the software in its present form on a continuous basis would be a full time job for at least one person.

The complexity of the models and the input/output data structures in their present forms would preclude an understanding of model capabilities and efficient independent implementation of the models and database by the managers. To make efficient use of the models, the manager or his staff would need to study them carefully and become thoroughly familiar with the computational procedures, capabilities, and limitations of each model, and to determine the proper input data necessary to perform the computations successfully. This effort would be hampered by the

Table 1.2 Model Run Times, Output File Sizes and Print Times

MODEL	RUN TIME H:MM:SS.HH	FILE	SIZE (BYTES)	PAGES [1]	PRINT TIME [2]
SIMYLD-II	0:03:34.87	SIMYLD.IN	327,799	71	35.2 minutes
		SIMYLD.OUT	3,346,515	481	6.0 hours
HDR	0:00:15.92	input:			
		NDATAL	281,607	38	30.3 minutes
		outputs:			
		MAXREL	12	1	-
		OFLOWS	13,272	1	85.6 minutes
		OQADJ	36,288	21	3.9 minutes
		OQCHK	6,888	1	44.4 minutes
		OQTLD	6,888	1	44.4 minutes
		ORCHRG	13,272	1	85.6 minutes
		OSYSOP	122,304	21	13.2 minutes
GWSIM-IV	0:01:03.00 S	INPUT.SM	687,179	129	73.9 minutes
	0:12:36.22 L	INPUT.LG	6,473,531	497	11.6 hours
		MODOUT.SM	77,564	18	8.3 minutes
		MODOUT.LG [3]	1,147,705	249	2.0 hours

[1] 66 lines per page, no page breaks

[2] 155 characters/second

[3] This file takes two hours to print at 156 characters per second, and is the benchmark for all print calculations. Based on MSDOS TYPE command from a 486/46 computer with fast access hard drive, feeding an Epson-FX 1050 dot matrix printer through a serial port.

lack of complete, formal users manuals for the GWSIM-IV and the Nueces River Basin models. Implementation of the models and database at the management level would require the services of a high-level technical professional, the cost of which would be prohibitive. To thoroughly understand and effectively implement the software, a senior level hydraulic engineer and/or computer specialist would probably be needed. This person would be supported by at least one technician to key in data and maintain the system.

The regional models and data files that reside on PC computers at the Center can be operated by Center staff for the client agencies, however, implementation of the software for decision support applications requires a significant effort simply because of the input/output requirements described above. Similarly, it is expected that major training efforts would still be required simply to explain to the managers the model capabilities, input data requirements, and the impact of input data changes on output format and analysis.

As a result of the above evaluations, the Center determined that the original objective of delivering PC versions of the models and databases directly to the managers for their use would not be a practical solution to the need for efficient water management tools. At the same time, further investigation by the Center produced an alternate solution to the problem. Pre- and post-processors to the models and database would minimize the requirements for full user understanding of the model computational procedures and database structure, and would eliminate the burden of preparing lengthy input data sets and analyzing stacks of output.

1.3.3 Execution of Remaining Phase II Objectives. Once the decision had been made to enhance the system capabilities by the addition of pre- and post-processors, the project proceeded to fulfill its original objectives in the context of providing a more complete understanding of the problem. Plans for development of the processor-based Decision Support System were also prepared. To complete Phase II, the remaining original objectives (2, 4, 6, and 7) and were addressed to varying extents during the remaining six months as follows:

Screening models - Some of the screening models enumerated in the proposal (e.g. demographic and cost models) were found to reside at local planning agencies, such as AACOG. Some of the analysis, reduction and display capabilities of other screening models (e.g. stochastic analysis and display of computational software output) are included in the PC-compatible support software described in Chapter 7 of the report.

Recommended procedures - Minimum specifications for the hardware on which the system will operate were developed (Section 4.2), and technical descriptions of the model input and output are provided in Appendices B, C and D.

Extension activities - These activities have been ongoing since the beginning of the project. They include monthly meetings with the managers group, meetings with individual managers, presentations to agency boards of directors, demonstrations of simulated Decision Support System capabilities, media presentations and presentations of technical papers.

Information resources - Establishment of formal and informal interaction channels between the Center and the state and other public and private water entities; and development of a structure for collection, maintenance and dissemination of water-related information are ongoing.

1.4 Capabilities

One of the major goals of the project was to make the computational power of the regional models directly available to the managers for planning purposes. Although not in its final form, the present system does make the capabilities available to the managers through collaboration with the Center. Managers with what-if scenarios relating to system management and development of local water use rules may bring their questions to the Center. Center staff would then develop the input data files for the models, execute the programs and reduce the output to a form useable by the manager. Although this process would be completed in a matter of days, it still is probably the most efficient method for obtaining water system analysis for planning purposes. With future development of the processor-based Decision Support System, the analysis time would be reduced to a matter of minutes, and the programs could be executed by the manager in his office, or at the Center in collaboration with staff.

Regional water data can also be accessed through the Center. Although a significant amount of raw data does exist, it resides, in various formats at various locations. The Center has assembled this data in file format at a single location. The Center staff can retrieve data as requested by the managers, and can format, process, display and output the data according to the requirements of the managers. Additional data sets not included in the present system can also be assembled, upon request.

Support software is also available to provide routine water-related computations, data reduction, analysis and display. Generic surface-water and ground-water models may be executed at the center for analysis of special cases or for comparison with the regional models. Reduction and analysis packages provide special functions which enhance understanding of the output from regional and generic models. Reduction and display software provide special techniques for displaying the data which facilitate understanding of results.

In summary, the capabilities provided to the manager at the conclusion of Phase II put him in a planning position which is much more favorable than at the beginning of the project. The manager now has, close at hand, a system which can, in a relatively short time, provide a reliable answer to water-related planning questions. The need for timely response to planning questions will be fully resolved by development of the processor-based Decision Support System.

1.5 Deliverables

The Phase II project deliverables are basically those specified in the proposal; the regional water models and data in a PC environment. Executable versions of the GWSIM-IV ground-water model, and the SIMYLD and HDR surface-water models, compiled in a DOS environment, are included on floppy discs with this report. "Read Me" files explaining how to load the programs, and sample input data files are also included on the discs. Appendices B, C and D contain descriptions of the model routines, and input and output formats. The software will run on a DOS-based 386 or 486 computer, configured according to the specifications in Chapter 4. Verification of proper execution of the models on the managers' system can be obtained by comparison with base run outputs available at the Center.

Regional water data in flat ascii file format is also included on floppy disc with this report. The files were obtained from the Report of the Technical Data Review Panel, and are listed by table number from the report. Additional data for developing GWSIM-IV input files over the period of record (1934-1990) is available upon request at the Center.

Perhaps the most important project deliverable is a blueprint for the development of the processor-based Decision Support System. In addition to the report, software and data generated by Phase II, the project work provided an understanding of the needs of the manager group and the capabilities of hardware and software, enabling the CWR staff to determine precisely the necessary configuration of the DSS. With this information in hand, the Center staff has been able to define a clear path to the design of a Decision Support System which is probably the only workable solution to the information needs of the manager group.

The purpose of this report is to provide a detailed description of the work completed to date, to present the results of Phase II and to outline the direction for continuing work on this multi-phase project that promises to be an extraordinarily useful tool for water managers and informed citizens in the region. The continuation of this major research project will utilize the unique resources offered by the growing University of Texas at San Antonio interdisciplinary graduate programs in engineering, hydrology, hydrogeology and environmental science.

The goals of the project have been achieved to date in the context of close and continued collaboration between the Center for Water Research and the regional water agencies. On-going interaction has taken the form of regular monthly General Manager's Oversight Panel meetings, presentations to agency boards and direct conversations between CWR staff and agency personnel. Maintaining a strong focus of the overall goal of the project; **to provide the tools that the individual managers need to operate their systems more effectively**, has produced a clear vision of the Decision Support System, which is the only viable solution to their needs. It is anticipated that continued cooperation will strengthen the technical work now in progress and assure that the results of the future project work will play an important part in providing for the needs of all water users in the region.

2.0 LITERATURE SURVEY

Technical work began with a comprehensive survey of the literature related to Decision Support Systems. Such systems aid the decision maker in reaching technically acceptable conclusions by providing quick and efficient access to data and analytical capabilities pertinent to the problem at hand. DSS's have been used in electric power generation and distribution, space exploration, biotechnology, and financial and investment services.

This literature survey was initiated with a search for information on generic DSS's before narrowing the focus to systems with specific applications to water resources. The literature portrays a field of endeavor which, although not in the fully mature stage, provides adequate guidance for the system development being undertaken by the project. The results of this work and that done under subsequent phases to add valuable contributions to the literature relating to the development of decision support applications development.

2.1 Decision Support Systems Literature

A DSS, for the purposes of this work, is defined as an interactive, computer-based, system that incorporates a user interface, model base, and data base to provide objective information to support decisions for relatively *unstructured* problems. It does not make the decisions nor does it limit the responsibility of the decision maker through artificial intelligence or expert experience.

Historically many different systems have been developed to assist in making decisions. Decision support is one of the more recent developments. Because of the shared goal of more effective decision-making, labels and definitions are often overlapping. Several different systems exist, including Artificial Intelligence

(AI), Expert Systems (ES), Decision Support Systems (DSS), Spatial Decision Support Systems (SDSS), Operations Research (OR) and Multi-Objective Optimization Systems (MOOS).

Essential to a DSS is that it "meet the needs requirement of supporting the user"[2.1] and that it "support semistructured and unstructured decision-making tasks" [2.2]. Another component of a DSS that is commonly accepted is that it be computer-based. A working definition put forward by Walsh is that it "can be any computer system, hardware and software, designed to support decision makers interactively in thinking about and making decisions about relatively *unstructured* problems" [2.3].

Operation Research and Multi-Objective Optimization both are intended to provide the "best" solution to relatively *structured* problems. Operation research has been described as "a systematic approach for scientifically studying well *structured* problems that can be modeled using quantitative mathematical techniques" [2.4].

By contrast, Expert Systems attempt to incorporate the expertise of an individual or individuals into a computer so that the expertise and experience can be passed on to others. A user of the system could be relatively inexperienced in decision-making and still make effective decisions by being guided by the system. A more exact definition is as follows: "expert systems, a branch of artificial intelligence, can be defined as computer programs that embody the knowledge, experience, and expertise of one or more experts in some domain, and that apply this knowledge to make inferences about the domain [2.5]". "The information and reasoning paths in an expert's mind can be represented in an expert system and used either by the expert or another user who needs this expertise. The expertise becomes codified and transferable, and the process of decision-making becomes documentable" [2.6].

Researchers at The University of Texas at Austin have worked on developing such an expert system. In a paper presented in the Journal of Water Resource Planning and Management, [2.7] they explain a model using the Corpus Christi area as an example. Although accurate in its processing, the model does not fully meet the criteria for decision support because it is only able to give an "optimal answer" and is unable to assist decision-making by providing "what if" scenarios.

The natural extension of a DSS is a Spatial Decision Support System (SDSS). SDSS integrates DSS and Geographic Information Systems (GIS) to form a new system that assists in making decisions that relate to problems with a spatial dimension [2.8, 2.9]. A GIS organizes geobased data in an interval data base and displays them in a flat-map or three-dimensional screen format. The data may be subdivided into layers for display and analysis purposes. The Spatial Decision Support System is the ultimate goal of this project and appears to be the most promising of the technologies available to meet the needs of the client water agencies.

The system being developed in this study is intended to provide water managers and others within the study area with tools for accessing information and doing analysis to assist their decision-making processes. As such, the Decision Support System will include a user interface, model base and data base. The data base includes all data available (pumping, recharge, stream flows, etc.) for the study area. The model base consists of models that are already in use including: GWSIM-IV for the Edwards aquifer, SIMYLD-II for the San Antonio and Guadalupe River basin, and the Nueces River Basin Model for recharge.

When completed, the SDSS will be a computer-based system that will give information to support decisions for relatively *unstructured* problems. Rather than being a system that simply gives an optimization within certain parameters, it will give the objective outcome of "what if" situations. A manager will be able to use the system to find an effective and technically defensible solution within the soft parameters of political obligations and public support.

2.2 Water Management Decision Support Systems

In 1964, Governor John Connally requested a comprehensive water plan for the State of Texas. By 1969 the Texas Water Development Board had adopted the Texas Water Plan: "a flexible guide for the orderly development, conservation, and management of the State's water and related land resources to meet the needs of the people of Texas to the year 2020" [2.9]. Although the Texas Water Plan was not approved by the voters, benefits have been derived from the plan. Because of the immense scale of this project, computer-oriented methodologies were developed for handling large masses of data and for modeling inter- and intra-basin water allocations and resource development. This approach initially utilized "eight interrelated computer programs (four data management programs and four simulation/optimization programs) and a procedure for using these programs" [2.10]. The Texas Water Development Board has published other reports on optimization and simulation [2.11, 2.12].

Decision Support Systems are now being applied to several facets of water management and water resource planning. Of particular interest is the use of a computer model developed in Colorado to determine the yield of a proposed reservoir on the Cache la Poudre River. The model, MODSIM, evolved from SIMYLD-II [6.3], a river basin simulation model produced by the Texas Water Development Board. It simulates the operation of a large network of twenty reservoirs with the purpose of evaluating potential yields of a single proposed reservoir in combined operation with existing facilities [2.13]. For the Qu'Appelle River basin in

Canada, DSS is being implemented to determine operating policies of a multi-reservoir system while recognizing conflicting demands [2.14]. Decision support is also being utilized for the Trent River in Canada, primarily to determine releases from thirty-six reservoirs necessary to satisfy downstream demands [2.15].

Other examples of micro-computers in water control and data base management include an operational forecasting model for the Columbia River Basin. Although initially designed to be used on a mainframe computer it has recently been updated to run on a PC. The stream model, SSARR, is "designed as a once through [analysis] for providing time-series simulations of all natural and man-caused effects on runoff, water levels, and water utilization as a complete system analysis which can be used for forecasting stream flows and scheduling reservoir regulation" [2.16].

Another example is the computer support system for the Tennessee Valley Authority (TVA) Reservoir, which has been in use for almost 14 years for collecting and modeling hydrologic data. Their Water Resources Management Information (WATERMAIN) provides support for operations of this integrated multipurpose reservoir system. TVA is also planning a Reservoir Operations Branch Enhanced Computer System (ROBECS) that will be capable of a better response to the related water resources issues and demands [2.17].

In the United Kingdom, several water supply and management entities such as the Grafham Water Supply Scheme, the Wolverhampton Scheme, the London Water Ring Main, and the River Derwent Supply Scheme have implemented graphical and optimization models to fully automate the control for water supply and management. The computer-aided design and evaluation programs are used for systems analysis and simulation, systems optimization and scheduling, and demand analysis and prediction [2.18].

In South Florida, the Operations Assistant and Simulated Intelligence System (OASIS) was being considered in 1988. "OASIS is an advisory system that monitors and displays hydrologic and meteorologic data, incorporates a versatile data plotting package, and features an advisor expert system for the operation of water control facilities within the South Florida Water Management District" [2.19, 2.20]. Since then a comprehensive GIS-based system has been developed for assessing the status of surface-water and ground-water resources, and determining what procedures are necessary to manage these resources. Similarly, the expert system being developed at the University of Texas at Austin will calculate water supply deficits over a specified planning horizon. This system, however, goes one step further, and suggests "efficient and cost effective" solutions [2.5].

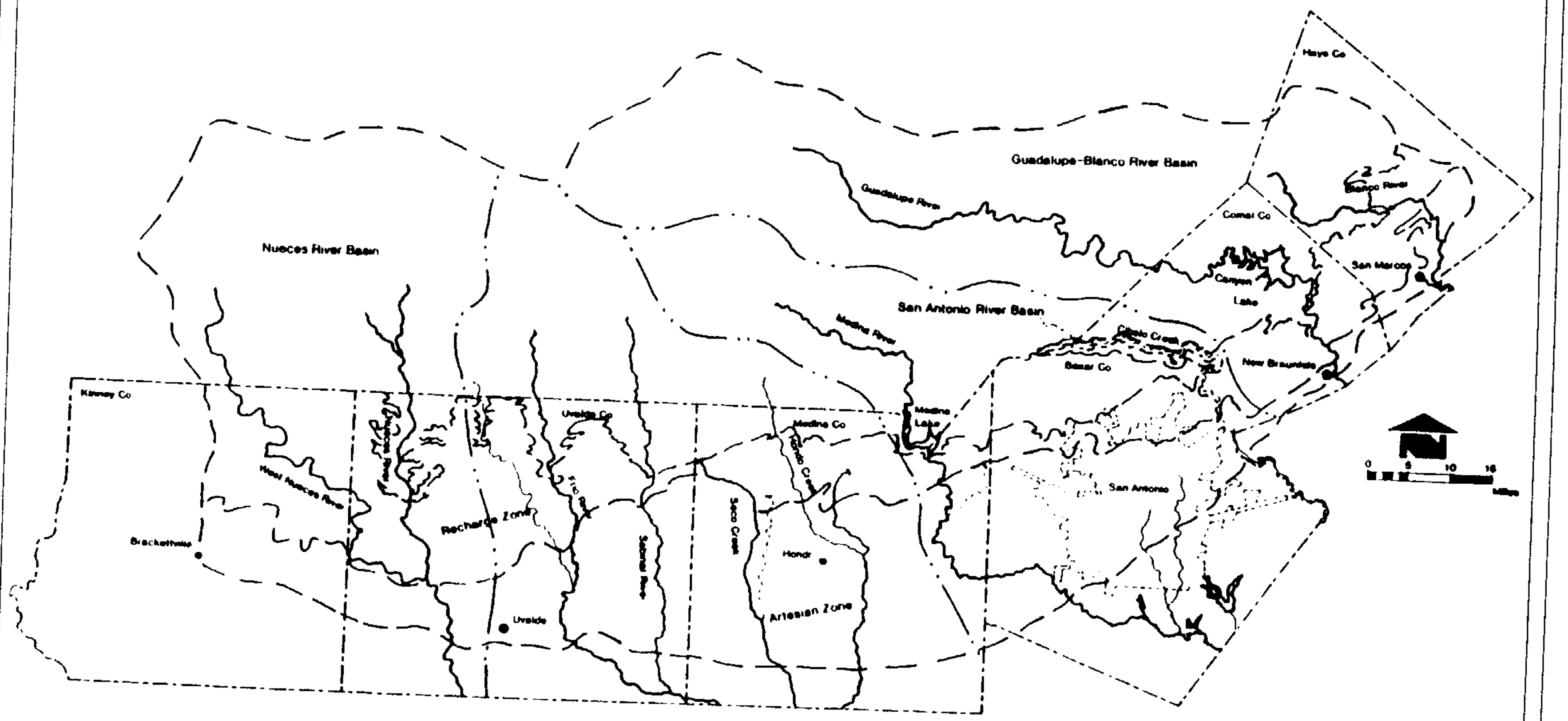
Computer systems are being increasingly utilized to provide information to assist in effective decision-making. The emerging importance of Decision Support Systems is now recognized by many professional groups. At the twentieth Anniversary Conference of the Water Resources Planning and Management Division of the American Society of Civil Engineers, a day-long session will be devoted to Computer-Aided Decision Support Systems, with several other sessions involving the application of Decision Support Systems to various water resources quantity and quality problems.

3.0 REGIONAL WATER SYSTEM OVERVIEW

The focus of this study is the development of management tools for operation of the water supply system for the San Antonio region. This system is composed of three major surface-water subsystems (the Nueces, San Antonio and Guadalupe/Blanco River basins) and the Edwards aquifer (Figure 3.1). The water budgets within each unit are usually analyzed separately with existing numerical models, but the dynamics of the interactions between units are lost and interbasin impacts are not determined. The individual regional models must ultimately be incorporated into a management system which reflects the realities of the interactive operation of the total water resource system.

A thorough understanding of the operational characteristics of each of the hydrologic units is necessary before undertaking the integration of existing regional models. The physical properties of the individual units are detailed in Appendix A.

Major management and operating plans for the region described cannot be undertaken without recognizing of the inter-relation between the three river basins and the Edwards aquifer. Jurisdictional boundaries are relatively simple to establish, especially for surface basins. Similarly, boundaries of the Edwards aquifer including both the unconfined (recharge) and artesian portions are readily defined by its geological characteristics. Unfortunately, the hydrology within the four major regional water resources entities does not respect the political boundaries defining the various jurisdictions.



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	DRAWING	HYDROLOGIC COMPONENTS FOR THE SAN ANTONIO REGION STUDY	LAYER	1	PAGE	1	OF 1

Figure 3.1 Hydrologic Components for the San Antonio Region Study

Some of the connectivities between the basins are readily manifested and easily recognized by the non-technical public. Heavy rains in the Nueces River basin produce recharge which is reflected within a matter of days as increases in well levels in Bexar County and elsewhere. Unusually high rainfalls and associated high ground water levels in 1991-92 caused normally dry springs to flow (e.g., San Pedro Springs). In contrast, low rainfalls and excessive pumping during several preceding years have led to reduced flows in some springs and caused others to cease to flow all together.

Interactions between surface-water basins in the region are much more limited than interactions between ground water and surface water. The only direct inter-basin surface-water interaction is at the confluence of the San Antonio River and the Guadalupe River a short distance above their entry into the San Antonio Bay. Although the impact of the combined flow upon San Antonio Bay is significant, upstream flows in the individual rivers are affected only minimally by conditions at the confluence.

The operational dynamics of a hydrological system are complex, and involve interactions between the ground water, surface water and the atmosphere. From a regional modeling standpoint, these interactions can be simplified somewhat to take into account only the major interactions between ground water and surface water, including recharge spring contributions to base flow, irrigation pumping and municipal use. The major conduit of interaction between the subregions within the study area is the Edwards aquifer, which conveys water from west to east. The proper management of this resource by effective application of decision support tools is therefore fundamental to simultaneously satisfying the water needs throughout the area.

The operation of the Edwards aquifer and its interactions with surface water may be simplified to help clarify the understanding of this complex resource and to aid in the preparation of management scenarios in the DSS. The dominant operational components of the aquifer are recharge and agricultural withdrawals in the west, major municipal withdrawals in the mid-section and spring flows in the east. The western recharge section serves as a storage tank for the system, while the artesian section to the east acts as a pressurized conduit, distributing the recharge to users and rivers to the east.

The connectivities between hydrologic components described above demonstrate that while each user is extracting water from an individual well or surface-water body, all users are clearly sharing a geographically extensive water resource conjunctively. That is, what one user extracts is not available to his neighbor or others downstream. The present challenge is to manage the shared resource efficiently so that all users are satisfied. This can be done by determining the location, time and flow rate of withdrawals throughout the region that will maintain an operationally acceptable head distribution. In particular, under the present constraints, the head distribution throughout the system must support minimum spring flow levels at Comal and San Marcos Springs.

The management challenge of satisfying simultaneously the general requirements throughout the region and the specific requirements at the Comal and San Marcos Springs can only be met by implementing a region-specific management Decision Support System. This system will permit the analysis of the large volumes of data governing the operation of the regional water system, and the efficient synthesis of a solution from the data. The challenge is significant, however the solution is well within the capabilities of the type of system that put men on the moon.

4.0 DATA MANAGEMENT SYSTEM

A solid database is a key component in a technical management system. The role of the data management system in the DSS to is organize and make available the data necessary for implementation of the regional models, and to organize and store the results of model runs. The database is the foundation of the computational component of the DSS. If the data input to the regional models is not accurate, the output from the models is of no value to the manager, and will only increase misinformation and contribute to confusion.

4.1 Data System Development

The database for the DSS provides access for separate inquiries and manipulation of the physical data required by the models. The basic system containing water-related data for the region has been implemented under Phase II work. Stand-alone data files are now accessed through standard dBase protocols. The Phase III system will access the data through specially interface software to provide the following functions:

- Extraction of data for use by the model pre-processors.
- Data lookup functions
- Limited data manipulation and analysis
- Archiving of new data produced by model post-processors

Ideally, the development of a database system to meet the above objectives should parallel the implementation of the regional models. By preparing both simultaneously insures compatibility. Because model development for the region have preceded the stand alone database development, the following steps in the data system development process are required:

1. Design
    - Define the objectives
    - Identify required data
    - Design the database
2. Implementation
    - Develop a data dictionary
    - Acquire the required data
    - Convert the data to proper format
    - Enter the data into the database
    - Update the data dictionary
3. Maintain the database

Each of the above three stages is covered in the following sections.

4.2 Database Design

As Salzberg noted, "The hardest part of designing a database is finding out exactly what is needed and what is known. This should be the most time-consuming part of designing" [4.1]. The data required must be identified as to subject, format, units of measure, frequency of reporting, and range of values. Data sources must be identified. A system must be designed to prevent unnecessary duplication of data, and to catalog data attributes, including source, content and reliability. Once the data are identified and located, a process is initiated to develop the most useable method of storing the data and to provide efficient access and manipulation. Only when the above steps have been completed can the data actually be integrated into the system. It is not unusual to find that the available data are in a format that is not directly useable for modeling or even for first-level analysis. Converting these data requires the expenditure of time and resources [4.1].

The design of the database within Phase II work has been driven by many factors, including the frequency of use of the data, the format of the data, and the capabilities of the access software. Currently, water data for the DSS is stored in a simple, non-hierarchical format. As the unique requirements of the models and access software become further defined in Phase III, the database will be altered to meet these needs.

The hierarchical system of data storage was chosen as the preferred structure for the DSS. In almost all projected cases, data retrieval is based on one or two primary criteria, usually location and time period. Each data hierarchy is contained within either a single datafile, or a cross-indexed set of data files. The structure for data extraction and processing will be determined by the amount of data available in each hierarchy, and by the requirements of the access and modeling software.

The design prototype system operates in the following minimum computational environment:

Hardware:

- Intel 80386 processor with 80387 math co-processor or 80486 processor, or equivalent
- High-speed mass storage, preferably SCSI interface, with a minimum access time of 25 milliseconds, seek time of 4 milliseconds, and data throughput of 100 kilobytes per second
- CD-ROM data input device, on system development and prototype equipment only. Eventually, CD-ROM capability may be added to "production" units.
- Not less than 4 megabytes (4,096,000 bytes) of accessible system memory
- VGA color monitor
- 101-key extended keyboard

Mouse support, digitizer and high-resolution monitors are not included in the basic system. These options could be added at a later date.

Software:

The operating system is MicroSoft's MS-DOS, version 5.0A. Command processing functions for the prototype system are provided by the 4DOS Command Processor version 4.01D, from J. P. Software. The 4DOS processor was chosen due to its enhanced batch file language and internal functions, allowing for faster system prototyping. Extended memory management (EMM) is provided by QEMM version 6.0, by QuarterDeck Software. EMM is required for system development but not required by the final system. Multi-tasking is conducted under DesqView version 2.4. Database development and maintenance are done by dBASE IV version 1.5, from Borland/Ashton -Tate. Additional software will be developed using several compiled 3GL and 4GL languages, including (but not limited to) FORTRAN, C, PASCAL, and Assembler.

4.3 Database Implementation

Once the database has been finally designed, and the data collected and converted, total data entry into the database can be completed. This is usually, barring design changes, the shortest part of the database creation process. Entry of the basic data to the dBase system has already been accomplished under Phase II. Further data collection and entry will be completed under Phase III. In many instances, this procedure can be automated, reducing the need for manual oversight.

Once all the data have been acquired, updated, and finalized, the data dictionary can be created. This dictionary will be an automated or manual record, which indicates the source, reliability and format of the data. The data dictionary can also include information regarding the updating and disposition of the data. No matter how well-designed the database and its supporting files, the need for clearly defined objectives, good management and qualified operating personnel is not eliminated [4.2].

The report of the Technical Data Review Panel (TDRP) was considered initially as a potential primary source of raw data for the DSS. The goal of the panel was to identify areas of agreement and disagreement regarding the accuracy and reliability of technical data [4.3]. The panel did not, however, attempt to resolve those disagreements to produce a final, complete and verified set of data. In several instances, data from different sources are presented, with some obvious variations and inconsistencies. Furthermore, the data are presented in a summary format, usually showing only annual figures. In some instances, these records are incomplete. As a result, the TDRP report is useful primarily as a general description of the types of data available and must be supplemented with data from other sources to provide a complete, reliable source of input to the regional models.

Basic streamflow and meteorological data are most easily acquired through EarthInfo, Inc., of Boulder, Colorado [4.4]. EarthInfo markets a database of raw environmental information, including daily and peak streamflows, quarter-hour and hourly rainfall data, and climatic summaries. These data are available on CD-ROM discs, in history-to-date and annual update forms. This product includes software for converting the EarthInfo files into several popular database formats, in addition to plain ASCII text files.

While some data on reservoirs, evaporation, pumpage and recharge are contained within the regional model input files, these data should be updated and verified for final incorporation into the DSS system database. Efforts are currently underway to locate and acquire these data for inclusion in the database system supporting the regional models.

4.4 Maintenance of the Database

Maintenance of the database files will be conducted solely by the CWR, using the commercial package dBASE IV version 1.5. Limiting change functions to the CWR all but eliminates the possibility of data corruption by the addition of unverified data, or system breakdown due to file format changes. The CWR's Master Data Files are available to the users of the system.

Routine maintenance of the final data files will be performed on a regular basis. This maintenance will include, but is not limited to, updating the files as new data become available, modifying the files as support software is improved and new capabilities added, and recovering files that become damaged.

5.0 GROUND-WATER MODELS

5.1 Model Evaluations

Four numerical models of the Edwards aquifer were reviewed in the early stages of this project. These models were reasonably well documented, however some gaps in the information were encountered. All of the models reviewed compute head levels and spring flows as a function of recharge and pumpage. Common features include horizontal grid representation of the flow system, averaging of system parameters within grid elements, boundary conditions specified at the perimeter of the grid, and for the finite-difference models, division of the time element of the analysis into major and minor time steps.

5.1.1 GWSIM-IV Finite Difference Model. GWSIM-IV is a numerical model which simulates ground-water flow and ground-water quality (mass transport). It may be operated strictly as a flow program, or may compute water flow and quality in the same run. The basic solution technique was developed by T.A. Prickett and C. G. Lonnquist of the Illinois State Water Survey [5.1] and was later modified by personnel of the Texas Department of Water Resources [5.2 and 5.3]. The GWSIM-IV program is maintained at the Texas Water Development Board, where current applications include modeling of aquifer management strategies. The model has now been adapted by the CWR staff at UTSA for execution in the PC environment.

The program computes hydraulic heads (water levels), storage, flows between elements, spring flows and concentrations of a conservative constituent (only when mass transport options are implemented) at the end of a specified time period. The ground-water flow solution, which may be executed independent of the ground-water quality solution, is based on the relationship governing non-steady state, two-dimensional flow in a non-homogeneous, isotropic artesian aquifer [5.1]:

$$\frac{\partial}{\partial x}\left(T\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(T\frac{\partial h}{\partial y}\right)=S\,\frac{\partial h}{\partial t}+Q \qquad (5.1)$$

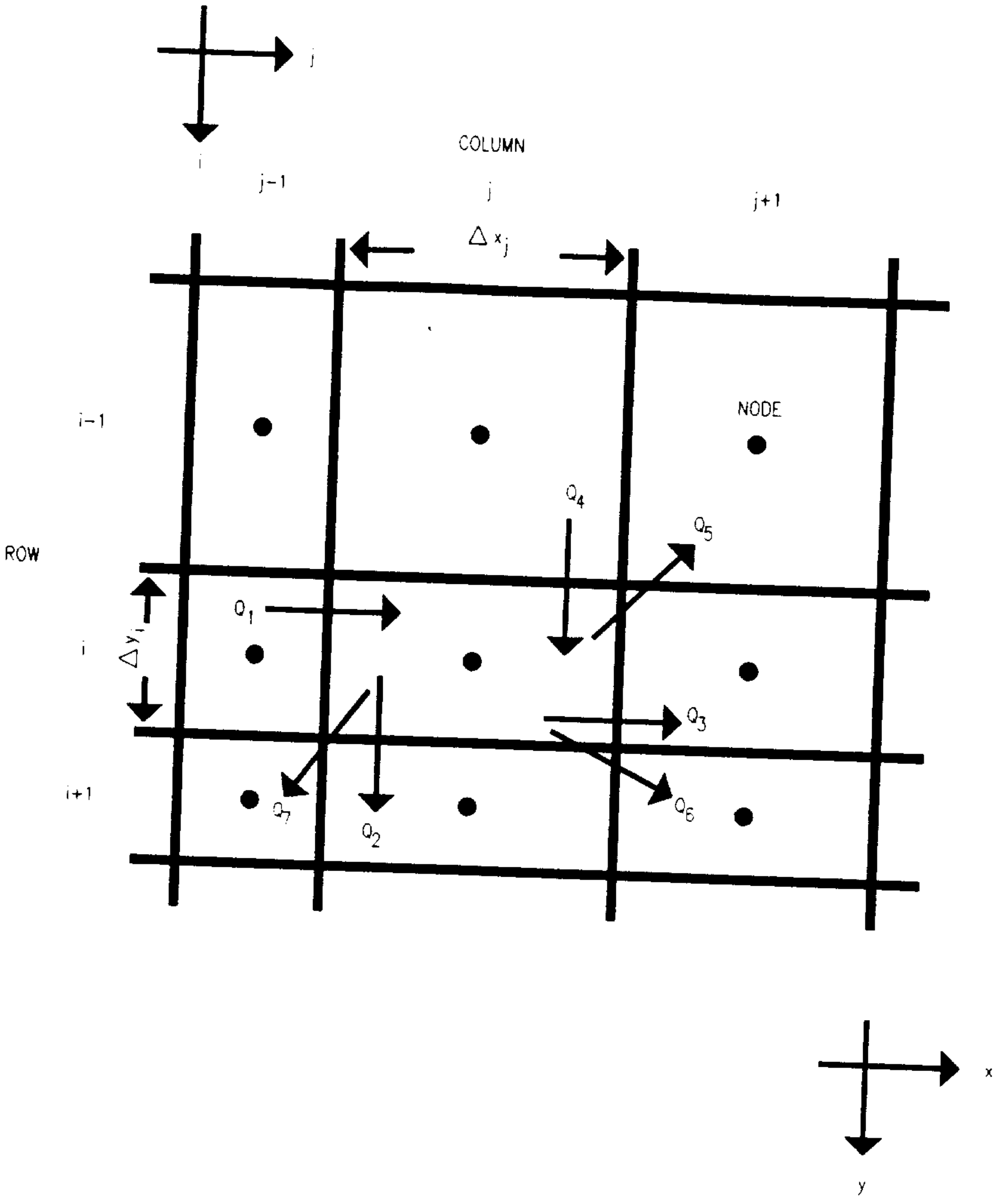
where T = aquifer transmissivity $[L^2/T]$
h = hydraulic head $[L]$
t = time $[T]$
S = aquifer storage coefficient
Q = net ground-water flux per unit area $[L/T]$
x,y = rectangular coordinates $[L]$

Equation 5.1 cannot be solved for the system in closed form, however, a numerical approximation may be obtained by a finite difference approach using the iterative alternating direction implicit (IADI) procedure [5.4 and 5.5]. The computational framework for the development of the solution(s) is as follows:

(1) The real continuous-parameter aquifer system is replaced by a rectangular finite-element grid representation. The distributed parameters in the real aquifer are replaced by representative values at the center of each grid element (Figure 5.1). The operational characteristics of a typical grid element include the horizontal and vertical (row and column) dimensions, dx and dy; the hydraulic function of the cell (no-flow, water table or artesian); the cell (aquifer) thickness; and the flows, Q, entering and leaving each cell.

(2) The relationships in Equation 5.1 are written in finite difference form for each element in the grid.

(3) The unsteady component of the real system behavior over time is reproduced by dividing the total time of simulation into major time steps. The aquifer parameters (transmissivity, anisotropy, etc.) and the operational characteristics (recharge, pumpage, etc.) are specified for each major step. The flow equations are then solved iteratively for the



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DRAWING	GRID ELEMENTS FOR FINITE DIFFERENCE ANALYSIS	LAYER	1	PAGE	1	OF	1

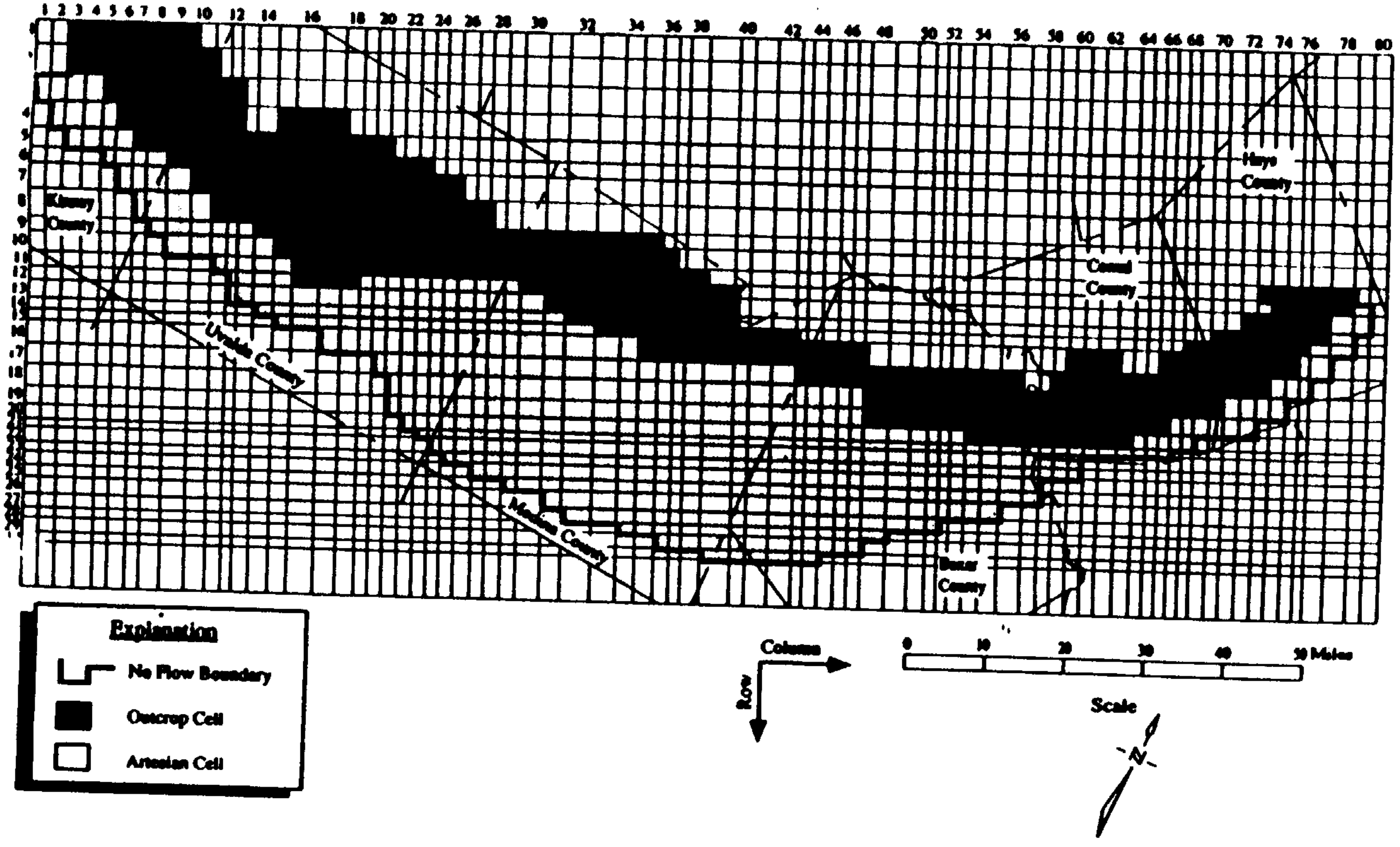
Figure 5.1 Grid Elements for Finite Difference Analysis [5.2]

hydraulic head within the major step. The solution then proceeds to the next time step and repeats the process.

Inputs to the program are defined within data sets corresponding to a menu of program options. The orientation and geometry of the finite-difference grid and the hydraulic properties of each conducting cell (top, bottom, transmissivity, anisotropy and storage) are first defined. The initial head distribution and the distribution of recharge and withdrawals are also input. The total study period is subdivided into major time steps, and the heads in each cell and springflows are computed iteratively. The program output includes an echo of input system and computational parameters, a summary of iteration parameters, and the heads, spring flows, river flows, leakage, changes in storage and mass balances for individual time steps. The details of program structure, inputs and outputs are presented in Appendix B.

The current version of the program provides an accurate simulation of aquifer flow on an annual basis from realistic monthly recharge and pumpage data sets. It incorporates information developed in the Maclay-Land study [5.6] including effects of faults and anisotropy, appropriate values of transmissivity, storage coefficients and major geologic controls on the aquifer.

The capabilities and limitations of the model as a management tool have been demonstrated in recent case studies executed by the Texas Water Development board [5.7]. In these studies, the aquifer was represented by a rectangular grid (Figure 5.2) with 31 rows and 80 columns. The primary flow (grid) axis is oriented in an east northeast direction. The model grid is composed of water table cells (the "recharge zone" of the aquifer), artesian cells (the "artesian zone" of the aquifer) and no-flow cells, which represent cells which are not hydraulically connected with the aquifer. The no-flow cells form a continuous impermeable boundary along the



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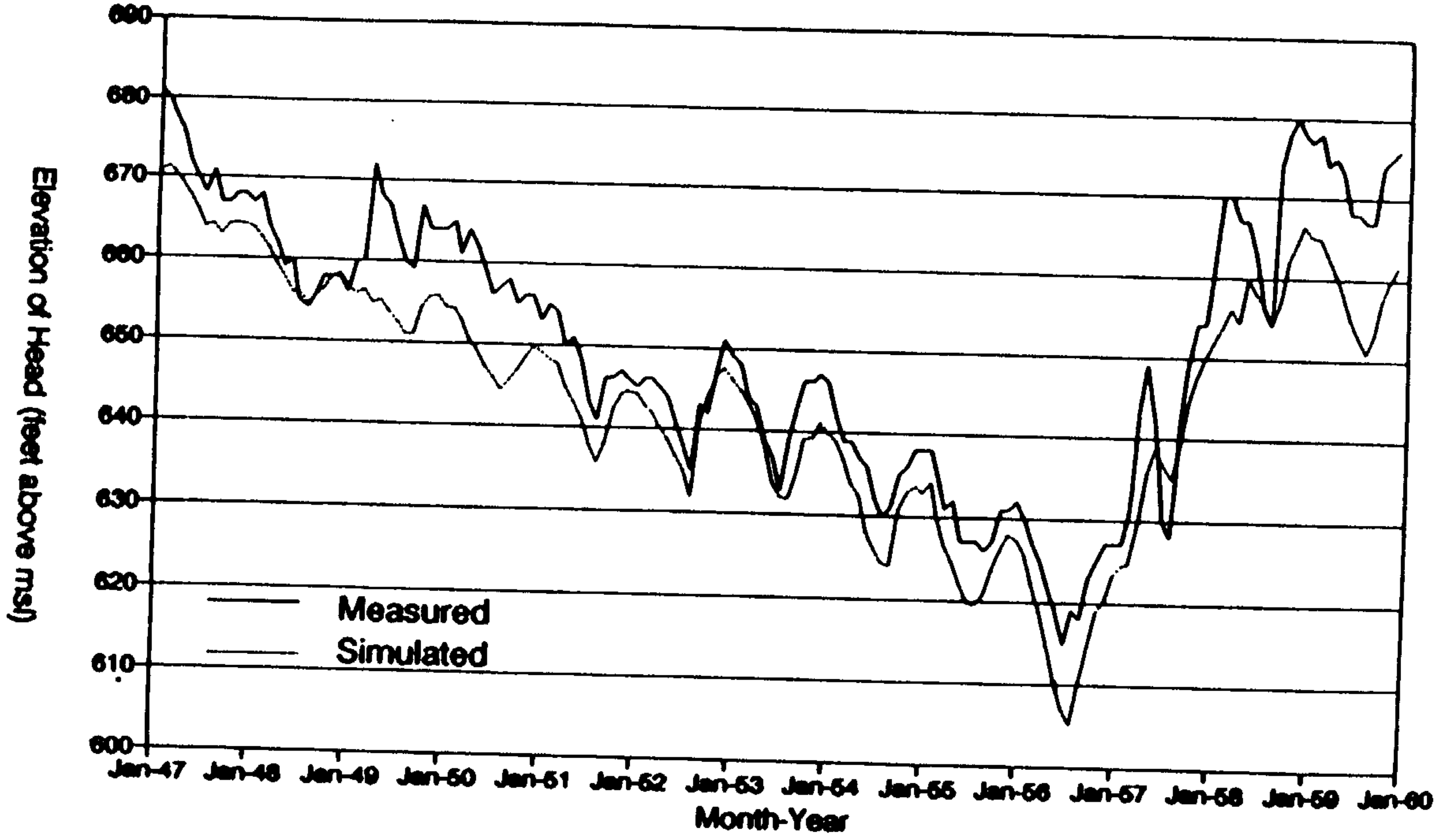
	DRAWING	FINITE DIFFERENCE GRID FOR THE GWSIM-IV MODEL OF THE EDWARDS AQUIFER	LAYER	1	PAGE	1	OF	1

Figure 5.2 Finite Difference Grid for the GWSIM-IV Model of the Edwards Aquifer [5.7]

northern edge of the recharge zone, representing the interface between the Edwards and Trinity aquifers. The no-flow cells along the southern extreme of the artesian zone represent the aquifer contact with the highly saline water below the "bad water line". In the present model, leakage is permitted across three boundary artesian cells in the southeast corner of Uvalde County.

The measured indicator well levels (CY-26 and J-17 located near Fort Sam Houston) and flow at Comal and San Marcos springs were compared with the computed values from 1947 through 1959 and from 1978 through 1990 with 1 month major time steps. Reasonably good agreement was obtained for the indicator wells and Comal Springs (Figures 5.3 and 5.4). Agreement for San Marcos Springs was not as good (Figure 5.5), because of the difficulties in modeling the multiple sources of flow of San Marcos Spring, which include local recharge, leakage from the Blanco River and Trinity aquifer (Glen Rose), and perhaps leakage from the Guadalupe River. In addition to model calibration, the effects of various management scenarios on well levels and spring flows were computed.

The results of the TWDB study demonstrate the value of the model as a management tool. Present management strategies focus on the relationships between well levels and flow of Comal Springs, which are reproduced with acceptable accuracy by the model. San Marcos Springs flow is not reproduced as accurately. The model is effective in reproducing flow patterns over broad areas, however it is not appropriate for detailed investigations where the area of the study site is of the same magnitude as the area of an individual cell. For example, the model in its present form would not be appropriate for studying movement of the bad water line within several hundred feet of San Marcos Springs.



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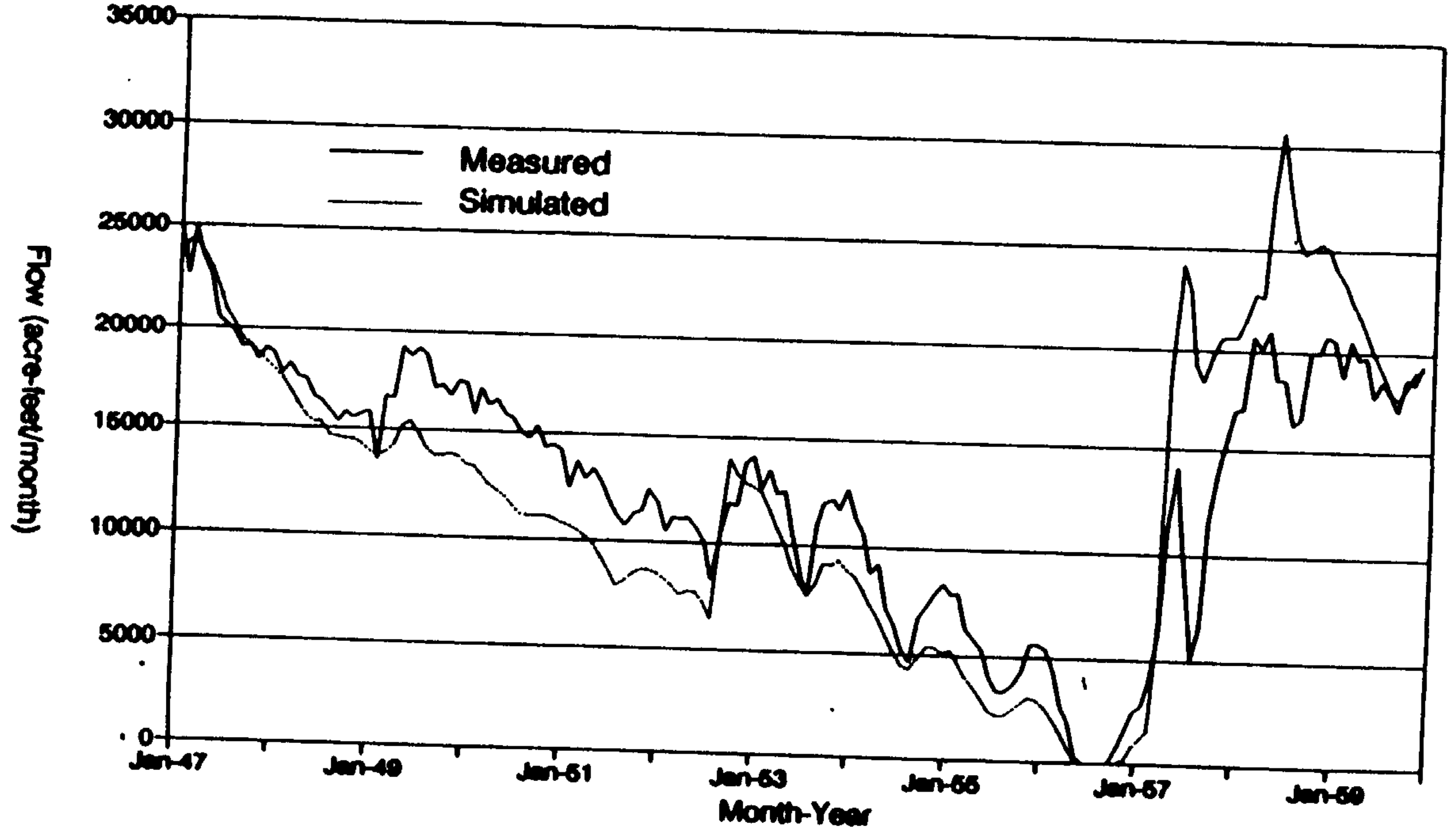
CENTER FOR WATER RESEARCH	DRAWING	SIMULATED VERSUS MEASURED WATER LEVELS COMPUTED BY GWSIM-IV, WELL CY-26 (68-37-20)	LAYER	1	PAGE	1	OF	1

Figure 5.3 Simulated Versus Measured Water Levels Computed by GWSIM-IV, Well CY-26 (68-37-20) [5.7]



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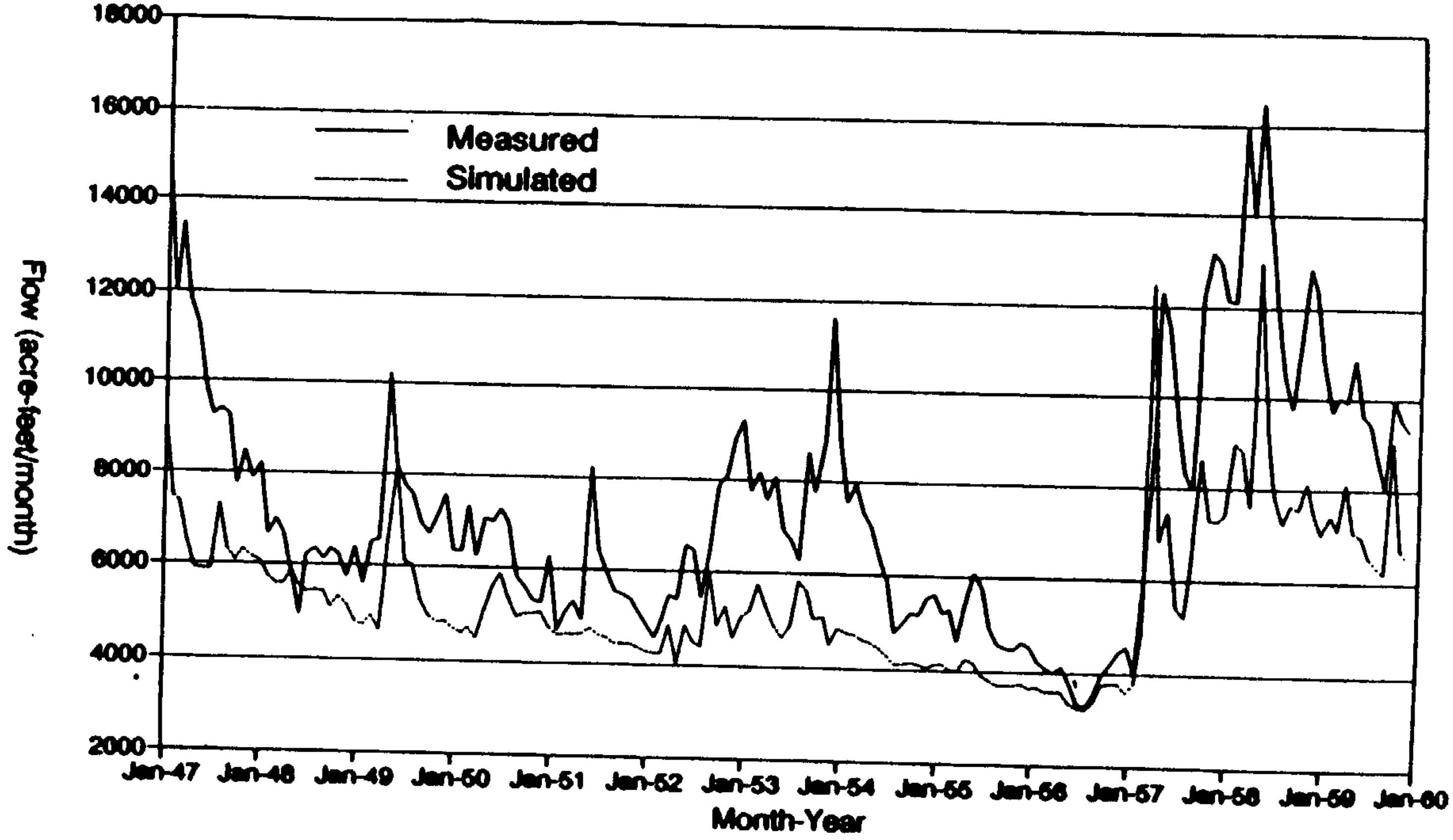
CENTER FOR WATER RESEARCH	DRAWING	SIMULATED VERSUS MEASURED COMAL SPRINGS FLOWS COMPUTED BY GWSIM-IV	LAYER	1	PAGE	1	OF	1

Figure 5.4 Simulated Versus Measured Comal Springs Flows Computed by GWSIM-IV [5.7]



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CENTER FOR WATER RESEARCH	DRAWING	SIMULATED VERSUS MEASURED SAN MARCOS SPRINGS FLOWS COMPUTED BY GWSIM-IV	LAYER	1	PAGE	1	OF	1

Figure 5.5 Simulated Versus Measured San Marcos Springs Flows Computed by GWSIM-IV [5.7]

Of the models surveyed, GWSIM-IV is the only one with the ability to determine water quality as a function of initial concentrations and contaminant inflow. This capability is not being utilized in the present study because attention is focused on the quantity component of water supply. As development continues in north Bexar County and adjacent areas, the study of potential contamination sources and impacts on water quality will become increasingly important. The ability to compute ground-water flow and mass transport in a single program which has already been calibrated to the Edwards aquifer is a significant asset to the project.

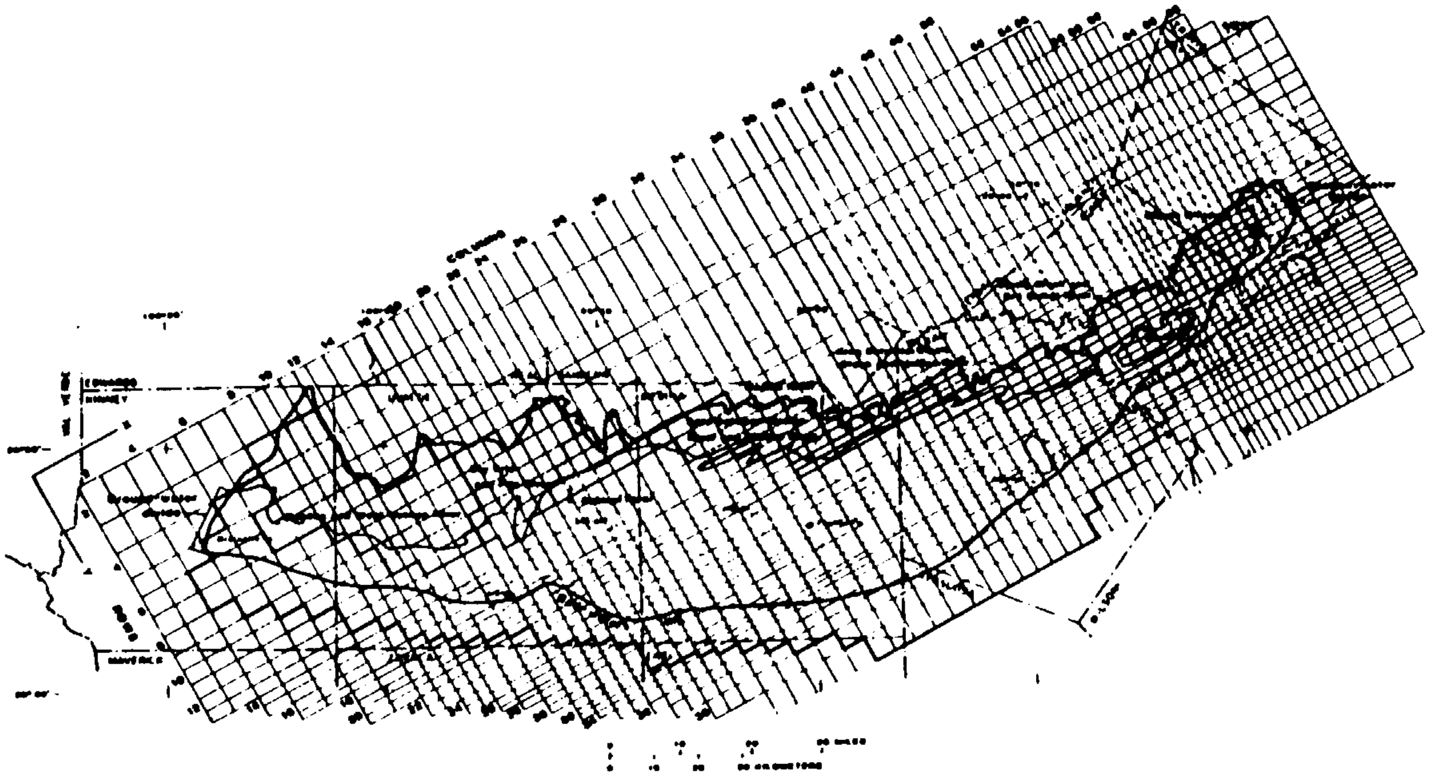
5.1.2 Maclay-Land Finite Difference Model. During the 1970s, a cooperative effort between the USGS and the San Antonio City Water Board led to the development of a mathematical simulation of the Edwards aquifer. The model is a modification of a general-purpose, two dimensional finite-difference ground-water flow model originally developed by Trescott et al. in 1976 [5.6 and 5.8]. The original code was modified to provide added features relevant to investigation of regional flow in the Edwards aquifer, such as the capability to evaluate the impact of Balcones faulting on the flow regime of the aquifer.

The model was developed and validated by R.W. Maclay and L.F. Land in the early 1980s to expand understanding of and modeling capabilities for storage and flow concepts within the Edwards. Specific objectives of the model preparation for investigation of the Edwards included a) determination of the effects of faults on flow, storage and regional anisotropy; b) quantification of aquifer transmissivity, anisotropy and storage coefficient; c) determination of the major geologic controls on the aquifer; and d) testing of different hypotheses regarding the rate and direction of regional ground-water flow.

The Maclay-Land model is based on the same theoretical framework as the hydraulic section of the GWSIM-IV model. It computes vertically averaged two-dimensional flow in a non-homogeneous, isotropic artesian aquifer. The differential equation describing the dynamics of ground-water flow (Equation 5.1) is identical for this model, and the techniques for generation and solution of the finite difference equations are also similar.

Several modifications of the generalized Trescott model were required to adequately represent the Edwards aquifer. An option was added to allow variation in transmissivity and anisotropy values for individual cells. In addition, modifications were made that restricted flow along one flow axis at selected locations. This provided simulation of flow restrictions caused by barrier faults. Other modifications included changing weighting of recharge/discharge within flow basins and expanding detail of regions to which hydraulic parameters were applied.

The program is reasonably well-documented, although documentation containing all of the recent revisions to the software is not currently available. Input to the program is similar in content to the hydraulic section of GWSIM-IV, and includes hydraulic system parameters, computational options and time step control parameters. The rectangular finite difference grid for the Maclay-Land Edwards aquifer model (Figure 5.6) had 40 rows and 72 columns. Rows were oriented N65E to approximate the alignment of the normal faults west of Cibolo Creek. The grid was divided into 26 sub-regions, and anisotropy was varied within the regions to determine effects on regional flow. By varying anisotropies, individual sub-regions could act as barriers or conduits, thus reproducing actual flow conditions within the aquifer more accurately.



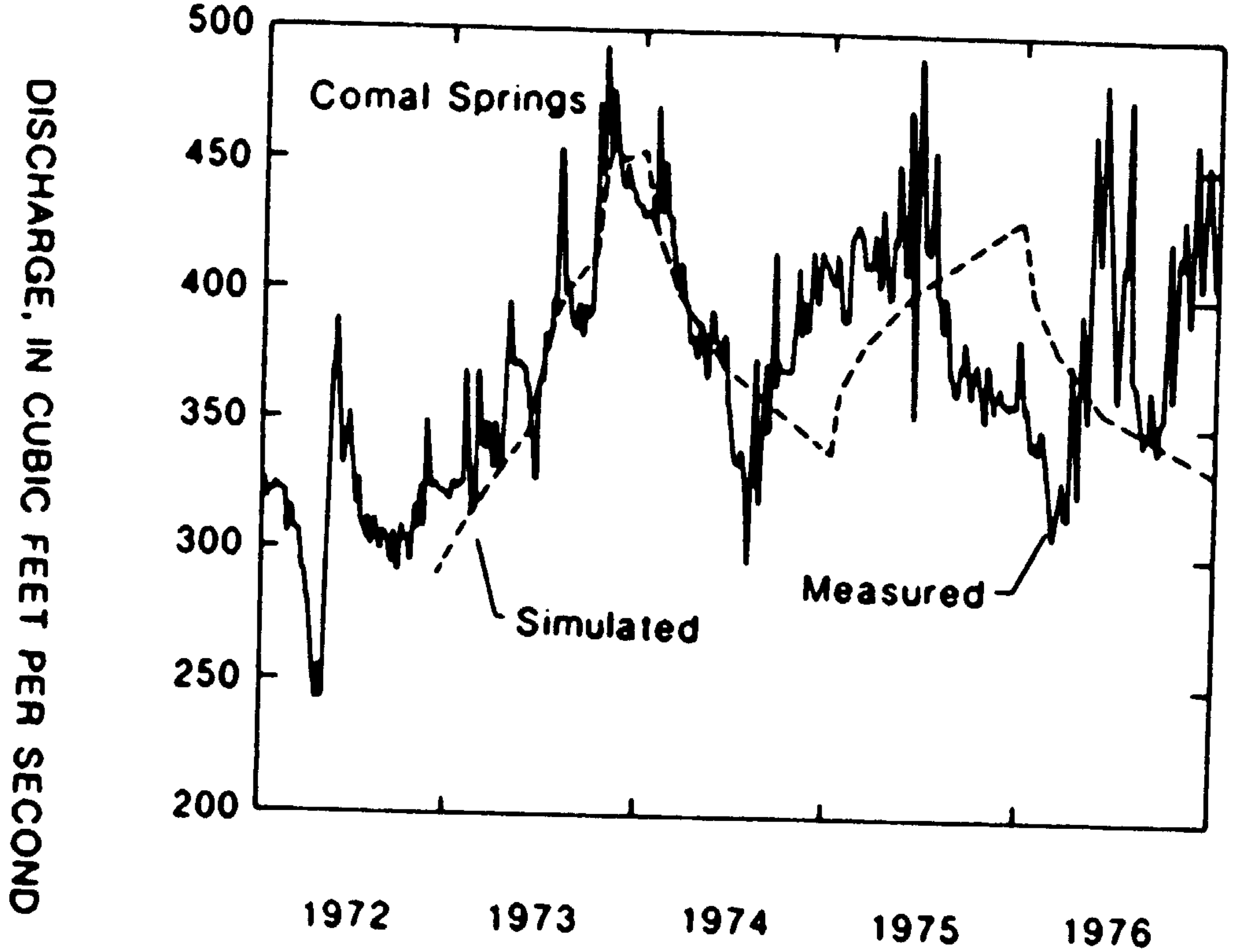
UNIVERSITY OF TEXAS AT SAN ANTONIO	PROJECT	PHASE II FINAL REPORT	DATE	1 MAY 1993				
CENTER FOR WATER RESEARCH	DRAWING	FINITE DIFFERENCE GRID FOR THE MACLAY-LAND MODEL OF THE EDWARDS AQUIFER	LAYER	1	PAGE	1	OF	1

Figure 5.6 Finite Difference Grid for the Maclay-Land Model of the Edwards Aquifer [5.6]

After a series of calibration and simulation runs, the set of model input parameters best reproducing measured regional flow was selected. Model results for these data reproduce Comal and San Marcos springs flow volumes reasonably well over the test period (Figures 5.7 and 5.8). The computed variation of flow over time tracks the measured values well for the first half of the computational period, but then appears to lag the measured flow by approximately six months during the latter half of the computations. Conclusions obtained from the study include the following: a) high transmissivity estimates (>100 ft^2/sec) were confirmed, b) two essentially independent areas of regional flow were identified and c) barrier faults have a significant impact on flow direction , storage, water levels, and springflow.

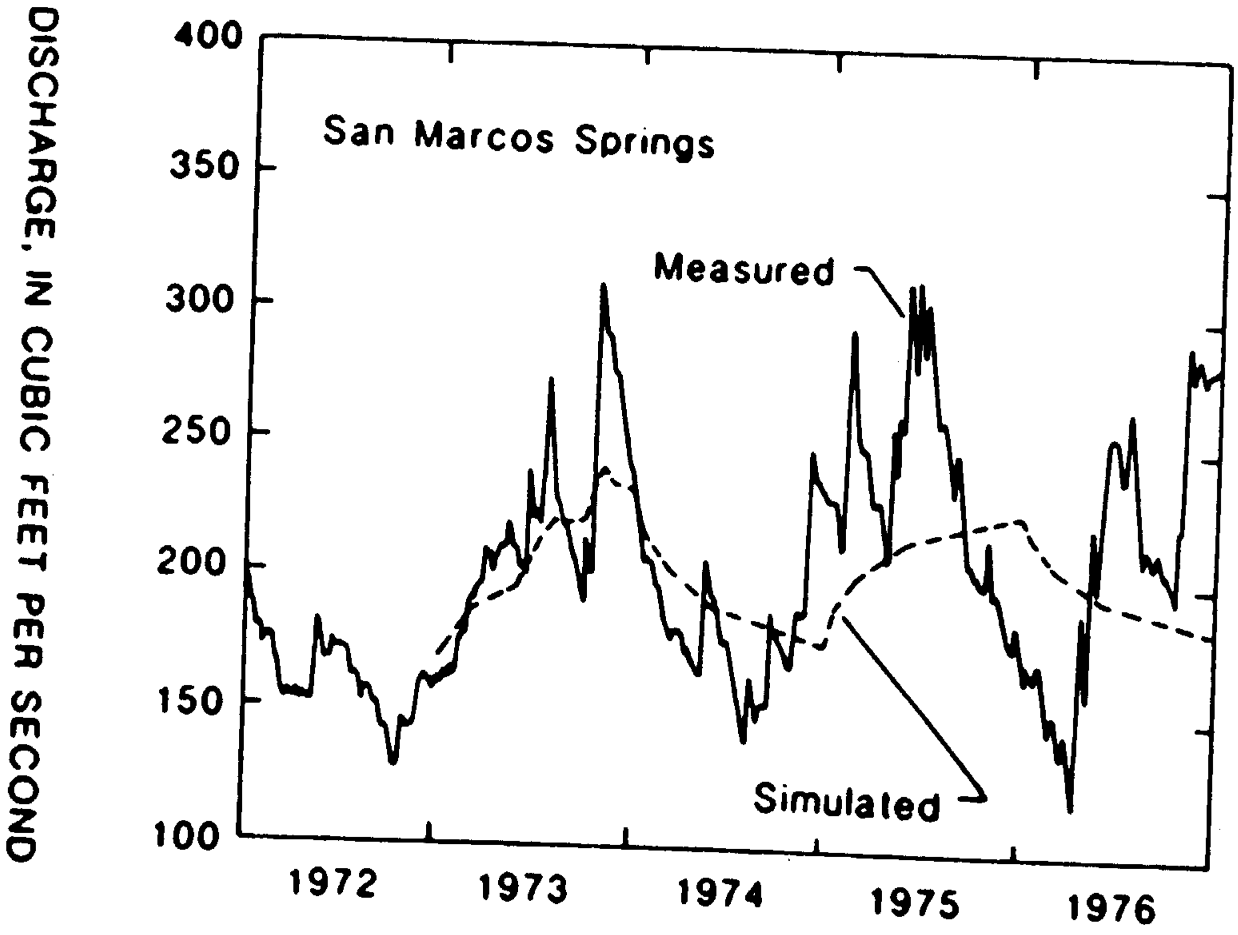
The Maclay-Land model demonstrates flexibility in representing the effects of geologic parameters on regional flow within the aquifer. Computed spring flows are a reasonably good approximation of total measured flows, and exercising the various options for varying aquifer parameters helps the investigator to understand the effects of these changes on aquifer performance. These results are of value for comparison with the results of other models, and some of the results of the Maclay-Land work have been incorporated into the GWSIM-IV and USGS models. The differences between the time sequence of measured and computed spring flows (approximately 6 months) indicate that the model in its present form may not be appropriate for direct application as a management tool.

5.1.3 EMSP Finite Difference Model. The Edwards Management Simulation Program (EMSP) was developed from the PLASM model [5.1] as a ground-water management tool for the Edwards aquifer by the Texas Water Commission. PLASM is a two-dimensional model for computation of nonsteady ground-water flow in an artesian or water-table heterogeneous anisotropic aquifer system, based on equation



UNIVERSITY OF TEXAS AT SAN ANTONIO	PROJECT	PHASE II FINAL REPORT	DATE	1 MAY 1993				
CENTER FOR WATER RESEARCH	DRAWING	SIMULATED VERSUS MEASURED COMAL SPRINGS FLOWS COMPUTED BY THE MACLAY-LAND MODEL	LAYER	1	PAGE	1	OF	1

Figure 5.7 Simulated Versus Measured Comal Springs Flows Computed by the Maclay-Land Model



UNIVERSITY OF TEXAS AT SAN ANTONIO	PROJECT	PHASE II FINAL REPORT	DATE	1 MAY 1993					
CENTER FOR WATER RESEARCH	DRAWING	SIMULATED VERSUS MEASURED SAN MARCOS SPRINGS FLOWS COMPUTED BY THE MACLAY-LAND MODEL	LAYER	1	PAGE	1	OF	1	

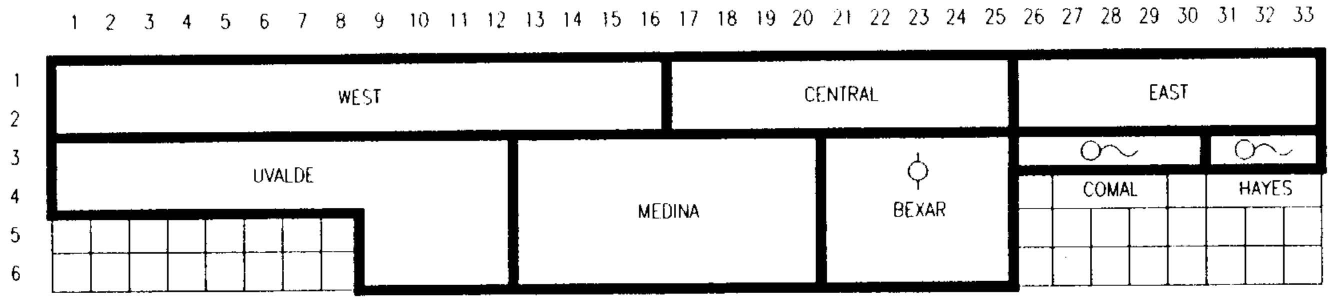
Figure 5.8 Simulated Versus Measured San Marcos Spring Flows Computed by the Maclay-Land Model [5.6]

5.1. As such, the theoretical framework of the model is similar to that of GWSIM-IV and the Maclay-Land model.

The original PLASM general-purpose analytical model was written in FORTRAN IV. It was modified by the Texas Water Commission into a management simulation model for the Edwards aquifer for execution in the PC environment in the BASIC language [5.9]. The program input includes three data files. The EDWARDS.PLA file contains the aquifer physical data, including transmissivities, storage coefficients, hydraulic conductivities, heads and geometry. The data in this file has been generated by calibrating the program with respect to measured head levels and spring flows, and therefore cannot be modified. The finite element grid for the model (Figure 5.9) is much coarser than those employed in the other models (a 6 x 33 grid with eight computational units). The HISTORY.DAT file contains quarterly historic recharge and pumpage data for the years 1934 through 1988. Pumpage data for 1934 through 1980 are derived from the years 1980 through 1988, reflecting withdrawal conditions which are more severe than the actual pumpage for those years. This input file is a starting point for management scenario runs, and may be modified to fit special needs. The EMSP.MGT file defines the management scenario for analysis by the model, and is modified for each run. Data are input interactively in response to screen prompts.

The model performs three types of simulations: aquifer storage and recovery, conservation reduction and drought management. The simulations may be performed separately or in combination. Output is in a tabular format.

The major advantage of the EMSP model is that it is simple and easy to execute. The computational mesh is, however, very coarse, and the physical parameter data set is inflexible. In addition, analytical capabilities are limited to several simple scenarios.



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CENTER FOR WATER RESEARCH	DRAWING	FINITE ELEMENT GRID FOR THE EMSP MODEL	LAYER	1	PAGE	1	OF	1

Figure 5.9 Finite Element Grid for the EMSP Model

With the advent of high-end micro computers, larger models such as GWSIM-IV and the Maclay-Land models, can execute the same scenarios efficiently and in much greater detail, thereby eliminating the need for simpler codes to execute management scenarios.

5.1.4 USGS Finite Element Model. A multi-layer finite-element model of the Edwards and Trinity aquifers is currently being developed by the United States Geological Survey in Austin [5.10] under the Edwards-Trinity Regional Aquifer Systems Analysis (RASA) project. Work on the model is on-going, with formal release anticipated in approximately two years. The study area covers 10,000 square miles and is bounded by the Colorado River on the north (a head-dependent source/sink), the "bad-water line" on the southeast, and the drainage divides of the Pedernales, Guadalupe and Nueces Rivers. It is represented by a two-layer finite-element grid with approximately 7,000 elements. The model is divided vertically into five computational units.

The major computational advantage of the finite-element method with respect to the finite difference models discussed above is its ability to areally vary aquifer anisotropy. Finite-difference models are based on a rectangular grid with fixed element coordinate axes for the whole model mesh. In the finite-element model, element geometry and orientation may vary throughout the model, permitting replication of local deviations from regional patterns of anisotropy in the flow sections of the model, and more accurate duplication of irregular boundaries. The penalty paid for more accurate representation of geologic details in the finite-element formulation is a much more intensive effort required in the preparation of input and computation of results. In particular, since the element numbers are sequential, a change in the configuration of one element in the mesh requires re-numbering of the whole mesh. Special routines therefore are required to prepare the data [5.11].

Because of its detailed analytical capabilities, the model is particularly valuable in determining flow patterns within the aquifer. Preliminary results indicate that flows enter the Edwards aquifer from the lower and middle Trinity (Glen Rose) aquifer in the Hill Country and Edwards Plateau at a total rate of approximately 400 ft^3/sec. Flow is controlled by location of recharge, location of barrier faults, and elevation of discharge features (Leona, San Antonio, San Pedro, Hueco, Comal and Barton Springs, major well fields and seeps). The model simulates flow volumes from major springs within the correct order of magnitude, but the timing of the transient response is not adequate.

The USGS finite-element model, because of its more sophisticated analysis capabilities, presents an opportunity to develop a more accurate model of the flow within the Edwards aquifer and interactions between the aquifer and surface waters. The enhanced capabilities of the software also require increased effort in preparing data and analyzing results. If this software can be made portable to the PC environment, in the future it may provide us with enhanced capabilities for managing the aquifer.

5.2 Model Selection

5.2.1 Selection Criteria. The Edwards aquifer models were evaluated objectively for adequacy of documentation with respect to program inputs, outputs and applications examples; ease of program execution; ease of application to management studies (organization, input and output, execution times); accuracy of results with respect to target operational parameters (water levels and spring flows); and opportunities for enhancement of the software for integration in future management investigations.

5.2.2 Model Evaluation and Selection. The EMSP program, although simple to operate as a management tool, had limited flexibility in determining physical data for the model and in computation of aquifer interaction and response. In particular, the very coarse finite-difference grid does not permit sufficiently detailed analysis to account for significant normal variations in flow parameters. Inputs to the model are not easily modified. As a result this model was eliminated as a candidate for the primary aquifer computational model.

Studies produced with the Maclay-Land model have demonstrated that it is capable of reproducing aquifer flow volumes with reasonable accuracy, although the time variation of flow is out-of-phase with the measured data in calibration runs. The inability of the model to accurately reproduce the time component of flow detracts significantly from its potential as a stand-alone management tool. The program is reasonably well documented, and permits an adequate degree of detail in reproducing local effects for applications to regional modeling. The special capabilities of the program, summarized in Figure 5.10, include the ability to accurately reproduce the effects of fault-associated geologic structure by aligning the grid major axis in a northeast direction. These capabilities make it a valuable analysis system to support the development of future computational tools for management applications.

The USGS finite-element program is the most analytically sophisticated of the models considered. It includes not only the Edwards aquifer, but also the Trinity aquifer to the north, which provides significant flow input to the Edwards. In addition, the finite-element mesh provides an accurate model of irregular boundaries and changes in flow direction from one cell to the next. It is the only model considered which is capable of analyzing a multi-layered system. The model is capable of reproducing measured flow with reasonable accuracy, although some difficulty was reportedly encountered with accurately reproducing the time variation of flow [5.11]. No simulation runs are available for

The USGS Maclay-Land Edwards Aquifer Model

[USGS water supply paper 2336-A]

BACKGROUND

- General finite-difference model (developed by Trescott et al. 1975)
- Modified by Maclay and Land to provide capability of representing barrier faults (structural controls within the aquifer)

MODELING OBJECTIVES

- Develop realistic monthly recharge and pumpage data sets for an accurate aquifer simulation
- Incorporate information developed by the USGS, including:
  - Effects of faults and anisotropy.
  - Appropriate values of transmissivity, anisotropy and storage coefficient.
  - Major geological controls on the aquifer.

STUDY FINDINGS

- Independent areas of flow exist within the aquifer affected by locations of barrier faults
- Barrier faults in unconfined zones have a significant impact on storage
- High transmissivity values do exist
- Storage coefficients:
  unconfined : 0.05
  confined : 0.0001

INPUT REQUIREMENTS

- Grid design; axis orientation, cell size and shape
- Estimates of:
  - Aquifer properties (transmissivity, storage, and geometry)
  - Distribution of initial head values
  - Recharge and discharge
- Subdivision of study period into major time and minor time subintervals

SOLUTION CHARCTERISTICS

- Finite difference solution is capable of simulating unconfined flow, confined flow, or both
- Aquifer may be heterogeneous, anisotropic and irregular
- Recharge and Discharge may vary spatially and temporarily

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DRAWING	MACLAY-LAND ATTRIBUTES	LAYER	1	PAGE	1	OF	2

Figure 5.10 Summary of Maclay-Land Model Attributes

MATHEMATICAL MODEL

FOR A CONFINED SYSTEM:

$$\frac{\partial}{\partial x}\left(T\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(T\frac{\partial h}{\partial y}\right)=S\,\frac{\partial h}{\partial t}+Q$$

Where:
T = Aquifer transmissivity
h = Head
S = Aquifer storage coefficient
Q = Net groundwater flux per unit area

AQUIFER REPRESENTATION

- Four boundary conditions
- Structural basis for grid orientation
- Accumulated data for parameter estimates

MODEL BOUNORIES

- Updip limit of recharge zone
- Transition between fresh and saline zones
- Ground-water divides in west and northeast

GRID ORIENTATION

- Grid is oriented N65E to coincide with the faults of the Balcones fault zone, but preference is given to fault orientations west of Cibolo Creek to optimize computations
- Structural controls aligned with a grid axis

IDENTIFIED PROBLEMS

- Grid is coarse
- Flow across boundries not accounted for
- Total storage should include hydraulically connected formations

OTHER CONSIDERATIONS

- Assignment of variables
- Grid alignment with respect to transmissivity

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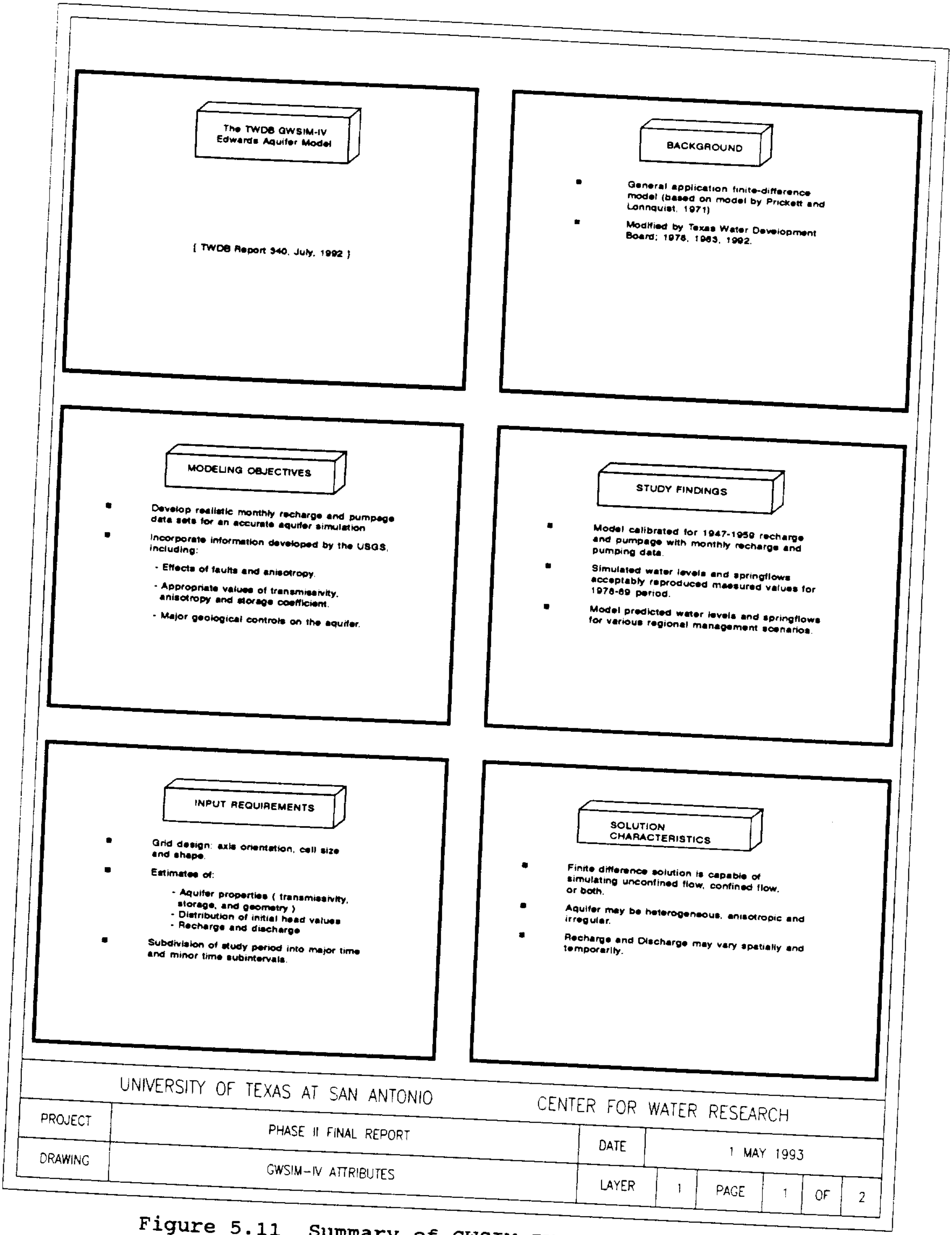
Figure 5.10 Summary of Maclay-Land Model Attributes (con't)

review because the model documentation has not been released by the U.S.G.S. The future release of this program should provide the user with a powerful tool for evaluation of aquifer flow under detailed management scenarios, and applications results will undoubtedly be included in the future management support system.

Of the models reviewed, the GWSIM-IV program, summarized in Figure 5.11, provided the broadest range of capabilities in its present form coupled with the ability to reproduce water levels and spring flows with reasonable accuracy. It is the only software with a fully-developed reference manual, which, although in draft form, provided a complete description of input and execution options and requirements.

The program is particularly well-adapted to management studies, with straightforward options for modifying blocks of data within the finite difference grid. Monthly operational data sets (recharge, pumpage, spring flow) have also been prepared so the program can accurately compute the seasonal variations in flow, and can be calibrated with respect to monthly system discharges. The mass transport section of the program determines water quality changes based on the flows computed in the hydraulic section of the model. This capability should prove valuable in the future, when increased population in the study region will make maintenance of water quality a key management issue.

In consideration of the attributes of all the models considered, the GWSIM-IV program proved to be the most complete in terms of the overall goals and technical requirements of the project. It is well-documented, technically accurate and has a robust set of input and output options. This model provides a solid base on which to build the ground-water component of the Decision Support System. With additional input from the results of analyses by the other programs, and modifications to integrate execution of the model into the framework of the overall Decision Support System, GWSIM-IV will supply useful information on aquifer function throughout the life of the project.



The TWDB GWSIM-IV
Edwards Aquifer Model

[TWDB Report 340, July, 1992]

BACKGROUND

- General application finite-difference model (based on model by Prickett and Lonnquist, 1971)
- Modified by Texas Water Development Board; 1976, 1983, 1992.

MODELING OBJECTIVES

- Develop realistic monthly recharge and pumpage data sets for an accurate aquifer simulation
- Incorporate information developed by the USGS, including:
  - Effects of faults and anisotropy.
  - Appropriate values of transmissivity, anisotropy and storage coefficient.
  - Major geological controls on the aquifer.

STUDY FINDINGS

- Model calibrated for 1947-1959 recharge and pumpage with monthly recharge and pumping data.
- Simulated water levels and springflows acceptably reproduced measured values for 1978-89 period.
- Model predicted water levels and springflows for various regional management scenarios.

INPUT REQUIREMENTS

- Grid design: axis orientation, cell size and shape.
- Estimates of:
  - Aquifer properties (transmissivity, storage, and geometry)
  - Distribution of initial head values
  - Recharge and discharge
- Subdivision of study period into major time and minor time subintervals.

SOLUTION
CHARACTERISTICS

- Finite difference solution is capable of simulating unconfined flow, confined flow, or both.
- Aquifer may be heterogeneous, anisotropic and irregular.
- Recharge and Discharge may vary spatially and temporarily.

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DRAWING	GWSIM-IV ATTRIBUTES	LAYER	1	PAGE	1	OF	2

Figure 5.11 Summary of GWSIM-IV Model Attributes

MATHEMATICAL MODEL

FOR A CONFINED SYSTEM:

$$\frac{\partial}{\partial x}\left(T\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(T\frac{\partial h}{\partial y}\right)=S\,\frac{\partial h}{\partial t}+Q$$

Where:
T = Aquifer transmissivity
h = Head
S = Aquifer storage coefficient
Q = Net groundwater flux per unit area

SOLUTION PROCEDURES

- Interactive Alternating-Direction implicit (IADI) procedure.
- Reduces total set of nodal finite-difference equations for each time step (based on eqn (1)) to several smaller sets, which are solved iteratively.
- Head predictor algorithm (for each major time step) and iteration parameters.
- Iteration parameters aid convergence.

MODEL BOUNDARIES

- Updip limit of recharge zone on north.
- Transition between fresh and saline zones on south.
- Ground-water divides on west and north-east.

GRID GENERATION

- Grid is oriented east-west.
- Cell sizes adjusted to optimize computational accuracy.
- 5 possible transmissivity ranges and 4 ranges of anisotropy for each cell.

IDENTIFIED PROBLEMS

- Grid is relatively coarse, therefore model is not appropriate for detailed site-specific studies.
- Grid orientation does not correspond to major geological features.
- Flow across boundaries does occur.
- Total storage should include hydraulically connected formations.

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DRAWING	GWSIM-IV ATTRIBUTES	LAYER	1	PAGE	2	OF	2

Figure 5.11 Summary of GWSIM-IV Model Attributes (con't)

6.0 SURFACE-WATER MODELS

Modeling of surface water in the region has received far less intensive study than has modeling of the Edwards aquifer, and as a result, fewer models are available. Analytically surface water is somewhat easier to model because the two major parameters, streamflow and reservoir yields are readily known. Still, these modeling efforts are constrained by lack of stream gauge data, problems in estimating recharge, and uncertainties in demands and return flows.

Only two regional surface-water models were available for this project. The Guadalupe-San Antonio River basin model is an adaptation of the Texas Water Development Board is SIMYLD-II by Espey-Huston, Inc. [6.1, 6.2]. The original SIMYLD-II model is further supported by a published user manual [6.3].

The surface-water model developed for the Nueces River basin by HDR Engineering, Inc [6.4] was part of a comprehensive study to determine the potential for increased recharge and its effects on downstream uses. Although this work is now being extended to the Guadalupe-Blanco and San Antonio basins, the model has no documented record of previous application and no user manual.

6.1 Guadalupe and San Antonio River Basins -- SIMYLD-II

SIMYLD-II is a river basin simulation model developed in 1972 by Carlos D. Puentes et al. of the Systems Engineering Division of the Texas Water Development Board [6.3]. The model provides the water resource planner with a means of analyzing the hydrologic operation of multiple reservoirs within a single or multiple basin system. The model has been used by the Texas Water Rights Commission to adjudicate water rights in the Cypress Creek basin, to support planning for the proposed Coastal Canal and to determine yields for existing and proposed reservoirs in the Nueces River basin [6.1].

The model has also been furnished to planning and management agencies outside of Texas. SIMYLD-II was the basis for the development of MODSIM, a model used in the Cache la Poudre Project in Colorado to simulate the operation of a large network containing 20 reservoirs, 70 nodes and 80 links [6.5]. In addition, Espey, Huston and Associates, Inc. implemented SIMYLD-II in their Water Availability Study of the Guadalupe and San Antonio River basins [6.2].

The capabilities of SIMYLD-II are two-fold. First, it simulates the operation of a river basin system under user-specified demands and hydrologic conditions. Second, it determines the firm yield of a selected reservoir within the system based on the specified conditions.

The physical system is represented as a network of nodes and links. Figure 6.1 represents the system with proposed storage and conveyance facilities at that time of the Espey-Huston report (1986). Nodes are either storage junctions (reservoirs) or non-storage junctions (stream confluences, canal/stream intersections). Inflows and demands along the system are grouped at nodes. Links represent connecting river reaches, canals and pipelines. Minimum and maximum capacities of links are set by the user. Input for each node includes monthly demands, monthly unregulated inflows, and annual import amounts (and their monthly distributions). Inputs for each reservoir include the reservoir operating rules, initial capacity, monthly evaporation data and area-capacity data. Details of program structure, input and output for SIMYLD-II are provided in Appendix C.

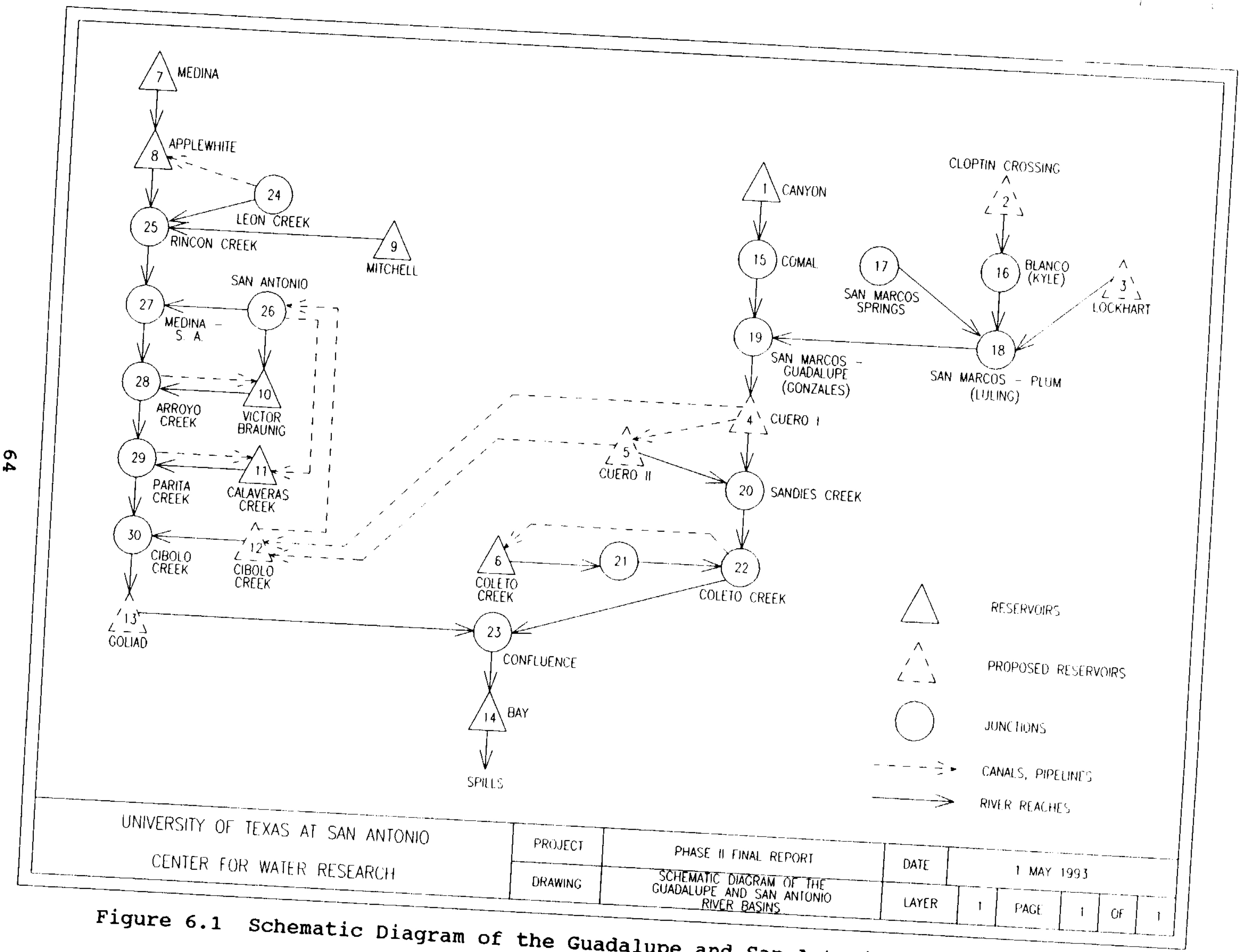


Figure 6.1 Schematic Diagram of the Guadalupe and San Antonio River Basins

The model provides end-of-month storage values, spills from the system, internal spills, transfer amounts, surface area, evaporation loss, demands met and shortages incurred for each reservoir for selected years. For non-storage nodes the model gives monthly shortages. The model provides monthly flows and yearly average flows in the system's river reaches and canals. The maximum flow in each link for the period of simulation is also given. Annual and period of simulation summaries are generated including yearly totals and averages.

The model has several features which provide flexibility for planning applications. Monthly storage levels can be varied during the year since the operating rules of a reservoir are input as a percentage of reservoir capacity to be held in storage at the end of each month. Demands and demand priorities and certain hydrologic conditions can be varied as well. The ability to change a storage junction to a non-storage junction by setting its capacity to zero provides flexibility to the model. A water system can be analyzed with any combination of proposed reservoirs without the need to reconfigure the physical network or restructure the input database. For example, the Guadalupe-San Antonio River basin system could be analyzed with only Cloptin Crossing in place by setting the capacities of other proposed reservoirs to zero (Figure 6.1). Reservoirs that are "turned off" simply act as non-storage nodes where the same inflows and demands are allocated. With this capability and by varying demands and inflows at selected nodes, a system can be analyzed under many different scenarios. The system, as it currently exists (Figure 6.2), is analyzed through this capability. Espey, Huston and Associates, Inc. simulated numerous scenarios for the Guadalupe-San Antonio system by varying springflows at Comal and San Marcos springs, return flows from the City of San Antonio, and water-rights development options.

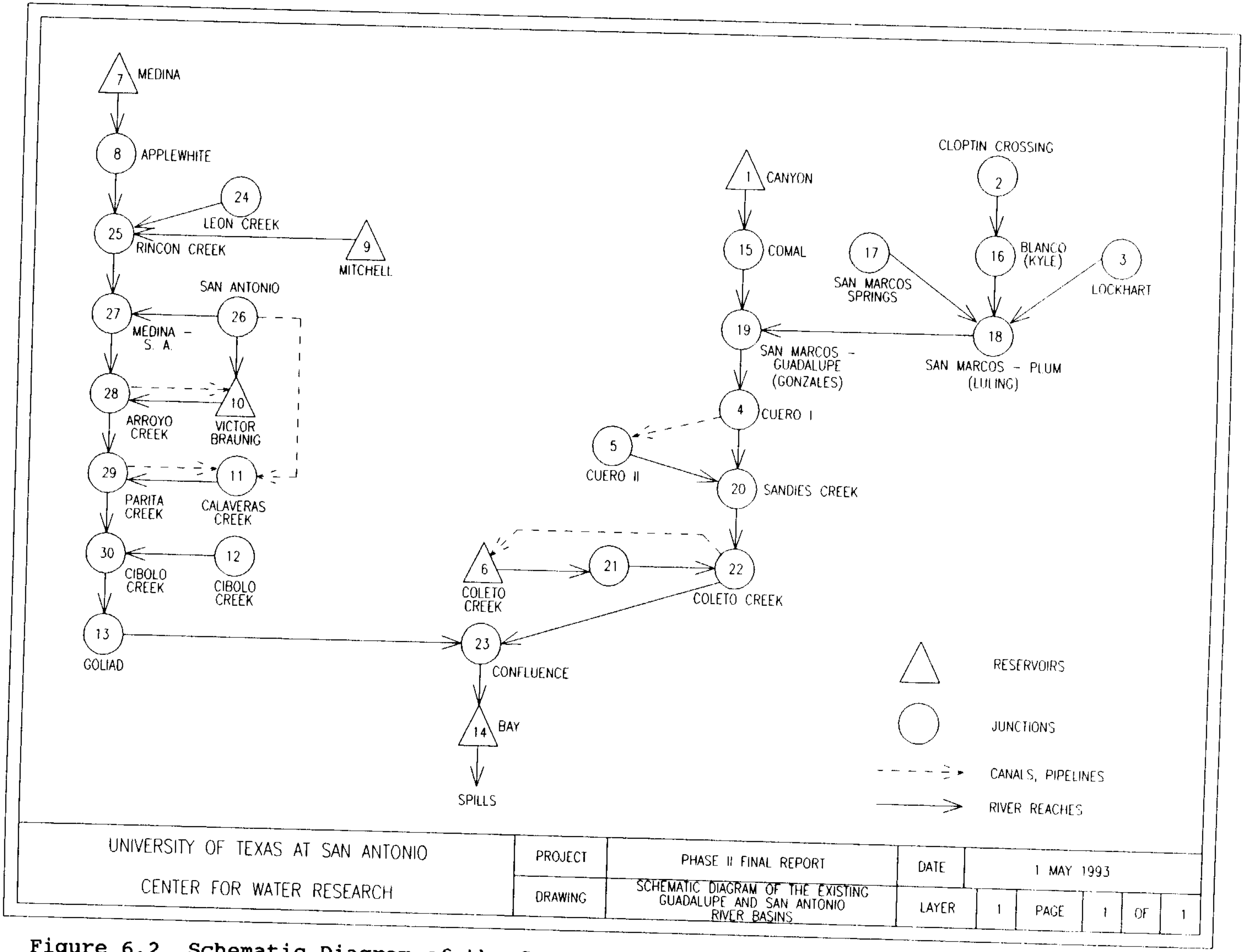


Figure 6.2 Schematic Diagram of the Current Guadalupe and San Antonio River Basins

In its present form the model has two major shortcomings. First, it accounts only for surface water with indirect or no linkage to ground water. Second, the model is lacking pre- and post-processors which would greatly facilitate management of the large volumes of input and output data.

SIMYLD-II has been adapted to operate in the DOS environment and is presently installed on a high-level PC at the Center for Water Research. Espey, Huston and Associates, Inc. has provided the input database for the Guadalupe-San Antonio river basin system for the period of record from 1940 to 1982. The Center for Water Research can analyze the Guadalupe-San Antonio River basin system under existing conditions and also for any other combination of the proposed reservoirs illustrated in Figure 6.1. The addition of a proposed reservoir or new conveyance not included in the present input data structure would require compilation of all operating data for the reservoir, reconfiguration of the physical network and reconstruction of an input data file which would require calculation of unregulated inflows and compilation of demand data for each node in the new configuration.

6.2 Nueces River Basin -- HDR Model

Development of the Nueces River Basin-HDR model was incorporated historical records of streamflow, precipitation and water use for the period 1934 through 1989. This model uses a monthly timestep. Calculations are made in an upstream to downstream sequence, starting at the headwaters of the Nueces River, and continuing through the Frio River confluence, and finally downstream to the Nueces Estuary. The model reports flows at all designated control point locations, which are usually co-located with USGS stream gauges. Other control points are located at stream intersections and upstream and downstream of the Edwards aquifer recharge zone.

The model requires several input data types, including natural streamflow, historical diversions, monthly water demand factors, and downstream delivery factors at each control point. The demand and delivery factors must be calculated externally to the model.

The model simulates the effects of existing and potential recharge projects on water availability and downstream impacts. Diversion and storage rights are included. The model reports results in a series of output files, each identified with a specific location or purpose, described in detail in Appendix D.

7.0 SUPPORT SOFTWARE

In addition to the database system and regional models described in Sections 4.0, 5.0, and 6.0, numerous programs are available to support the development and operation of the DSS. This computational support network makes possible the efficient preparation of information for the database and regional models, operation of the computer system, and analysis and display of data and model results. Some of the programs have capabilities parallel to those of the regional models, and can be used for verification purposes. Much of the software discussed on the following pages is available for use at the CWR. Other programs are readily available, on an as-needed basis, from government and commercial suppliers.

7.1 Ground-Water Models

In addition to the Edwards aquifer models reviewed in Section 5.0, numerous general-application ground-water models are available to perform similar functions (Table 7.1). These programs are classified by their method of representing the aquifer and solution technique: finite-difference, finite element and analytic element. The finite-difference solutions are mostly based on the original work of the Illinois Water Survey [7.1]. The most numerous and most widely used of the solutions is the MODFLOW program [7.2], which has been modified extensively since its introduction by the U.S. Geological Survey. Other popular programs include MT3D, MODMOC-3D, Princeton Transport Code (PTC), TWODAN, and FEPER [7.3, 7.4, 7.5, 7.6, 7.7]. MT3D is a finite difference mass transport model designed to work with MODFLOW. MODMOC-3D combines the mass transport code MOC [7.8] and ground- water flow model MODFLOW into one program. The PTC also models transport but the finite element mesh allows for irregular element shapes rather than the rectangular elements required by the finite-difference codes. TWODAN is a steady-state two-dimensional analytical element ground-water flow model without a fixed grid. This computational scheme permits great flexibility. FEPER is a data pre-and postprocessor for finite difference and finite element programs.

Of the programs described above, the MODFLOW, MT3D, PTC, and FEPER programs are installed on the CWR computers. The MODFLOW program and the companion mass transport routine MT3D [7.1, 7.2] were previously implemented in a detailed study of contaminant transport in the Balcones Escarpment region of the Edwards aquifer in 1992 [7.9].

Table 7.1 Ground Water Models

Model	Origin/Source	Attributes/Capabilities
<u>Finite Difference</u>		
MODFLOW, ver.3.2	U.S. Geological Survey	Two and three dimensional ground-water flow analysis. Modular structure.
MT3D	S.S. Papadopulos & Associates	Three dimensional contaminant transport model. Includes advection, dispersion and chemical reactions in ground-water systems. Modular format (MODFLOW companion software)
MODMOC-3D	Aquifer Simulation, Inc.	Simulates ground-water flow and solute transport. (Combines MODFLOW and MOC from USGS)
<u>Finite Element</u>		
PTC (Princeton Transport Code)	Princeton University	Finite element analyis of ground-water flow and contaminant transport
<u>Analytic Element</u>		
TWODAN	Charles Fitts	Analytic solutions for aquifer head and flow that satisfy the governing flow equations and specified boundary conditions. Flexible.

Table 7.1 Ground Water Models (cont’)

Model	Origin/Source	Attributes/Capabilities
<u>Processor</u>		
FEPER	ENVIRON Corp.	Data pre- and postprocessor for finite difference and finite element codes.

7.2 Surface-Water Models

General purpose surface models have been developed primarily by government agencies (Table 7.2). The U.S. Army Corps of Engineers Hydrologic Engineering Center in Davis, California, has generated a series of programs covering flood hydrographs (HEC-1), water surface profiles (HEC-2), reservoir system analysis (HEC-3), monthly streamflow simulation (HEC-4), simulation of flood control (HEC-5), scour and deposition in rivers and reservoirs (HEC-6), and flood frequency analysis (HECWRC) [7.10, 7.11, 7.12, 7.13, 7.14, 7.15, 7.16]. Other programs have been produced by the Texas Water Commission for surface runoff and sediment yield (HYMO), hydrology (STORM) and available surface water (WAPAM) [7.17, 7.18, 7.19], the United States Soil Conservation Service for hydrology (TR-20), hydrology of small watersheds (TR-55), and water surface profiles (WSP-2) [7.20, 7.21, 7.22]; and by the Texas Water Development Board for the yield of reservoirs (RESOP-II) [7.23]. Many of these programs are available in enhanced versions from commercial suppliers. The TR-20 [7.21] model was installed on the CWR computer system as part of the Balcones Escarpment contaminant transport study.

Table 7.2 Surface Water Models

Model	Origin/Source	Attributes/Capabilities
HEC-1	United States Army Corps of Engineers	Flood hydrographs.
HEC-2	United States Army Corps of Engineers	Water surface profiles
HEC-3	United States Army Corps of Engineers	Reservoir system analysis for conservation
HEC-4	United States Army Corps of Engineers	Monthly streamflow simulation.
HEC-5	United States Army Corps of Engineers	Flood control and conservation.
HEC-6	United States Army Corps of Engineers	Scour and deposition in rivers and reservoirs
HECWRC	United States Army Corps of Engineers	Flood frequency analysis
HYMO	Texas Water Commission	Surface runoff and sediment yield.
STORM	Texas Water Commission	Runoff from urban and non-urban watersheds (quantity and quality).
WAPAM	Texas Water Commission	Surface-water availability and allocation

Table 7.2 Surface Water Model (cont')

Model	Origin/Source	Attributes/Capabilities
TR-20	Soil Conservation Service	Hydrology
TR-55	Soil Conservation Service	Hydrology for small watersheds
WSP-2	Soil Conservation Service	Water surface profiles
RESOP-II	Texas Water Development Board	Firm yield of single reservoir sites.
Storm Water	Environmental Protection Agency	Urban storm-water runoff and combined Management sewer overflow
SWMM	Environmental Protection Agency	Storm-water management
SWRRBWK	U.S. Department of Agriculture	Rural basin hydrology and related processes

7.3 Utility Software

In addition to the computational models described above, a wide range of programs are available to perform utility operations. Computational support software assists in developing and modifying code by compiling and debugging software [7.27, 7.28, 7.29, 7.30, 7.31, 7.32]. Other programs pre- and post-process the data for the numerical models [7.33, 7.34, 7.35]. System software enhance the computational capabilities of the computer system [7.36, 7.37, 7.38, 7.39, 7.40, 7.41, 7.42]. Statistical packages [7.43, 7.44] determine the quality (reliability) of the results of deterministic models, display special relations between system parameters, and generate mathematical expressions for these relationships. Data reduction and display packages [7.45, 7.46] filter and enhance the data, and display it in a meaningful graphic format. Word processing software packages [7.47, 7.48, 7.49, 7.50, 7.51] prepare information for presentation and distribution.

Table 7.3 Utility Software

Model	Origin/Source	Attributes/Capabilities
<u>Software Development</u>		
WATCOM FORTRAN	Watcom Computer	FORTRAN Compiler
LAHEY FORTRAN	Lahey Computer Systems, Inc.	FORTRAN Compiler
MS FORTRAN	Microsoft Corp.	FORTRAN Compiler
C/TURBO C	Borland International	C Compiler
TURBO Assembler	Borland International	Assembly Compiler
TURBO Debugger	Borland International	Program analysis and decompiler.
<u>Pre/Postprocessors</u>		
FILLIN-I	Texas Water Development Board	Improves databases by augmenting incomplete sets of various types of hydrologic data.
PEP	Texas Water Development Board	Improves the accuracy and reliability of mathematical models through better calibration.
SEQUEN-I	Texas Water Development Board	Analyzes historic filled-in and stochastic hydrologic time sequences.

Table 7.3 Utility Software (cont')

Model	Origin/Source	Attributes/Capabilities
<u>System Software</u>		
MS DOS	Microsoft Corp.	Disk operating system.
4 DOS	JP Software Inc.	Command processor.
PATHMINDER	Westlake Data Corp.	Operating system shell.
QEMM	Quarterdeck	Memory mangement.
DESQVIEW	Quarterdeck Office Systems	Multi-tasking environment.
DISK MANAGER	Ontrack Computer Systems	Hard Disk installation and maintenance.
Norton Utilities	Symantec	System management and maintenance.

Table 7.3 Utility Software (cont')

Model	Origin/Source	Attributes/Capabilities
<u>Statistical/Analytical</u>		
MATLAB	The Mathworks, Inc.	Scientific and engineering numeric computation.
HYPERSIGNAL	The Metagraphics Software Corporation	Digital signal processing.
<u>Data Reduction/Display</u>		
SURFER	Golden Software, Inc.	Graphic display
GRAPHER	Golden Software, Inc.	Graphic display

Table 7.3 Utility Software (cont')

Model	Origin/Source	Attributes/Capabilities
<u>System Support</u>		
Autosketch	Autodesk, Inc.	Computer assisted drafting.
Wordperfect	Wordperfect Corp.	Word processor.
Wordstar	Wordstar, Inc.	Word processor.
FORMTOOL	BLOCPublishing	Form design utility.
Harvard Graphics	Software Publishing Corp.	Presentation graphics.

The following is a list of owner companies and their trademarks which have been referred to in Section 7.0:

Autodesk: AUTOSKETCH
BLOCPublishing: FORMTOOL
Borland International, Inc.: TURBO PASCAL
Golden Software, Inc.: SURFER, GRAPHER
JP Software, Inc.: 4DOS
Lahey Computer Systems, Inc.: LAHEY P77L
The Mathworks, Inc.: MATLAB
Metagraphics Software Corp.: HYPERSIGNAL
Micropro International Corp.: WORDSTAR
Microsoft Corporation: MICROSOFT, MS FORTRAN, MS DOS
On Track Computer Systems: DISK MANAGER
Quarterdeck Office Systems: DESQVIEW, QEMM
SPS Software Publishing: HAVARD GRAPHICS
Symantec: NORTON UTILITIES
Westlake Data Corp.: PATHMINDER
Wordperfect Corp.: WORDPERFECT

8.0 DECISION SUPPORT SYSTEM IMPLEMENTATION

8.1 Implementation Objectives

As stated in Section 1.0, the primary objective of the project is to provide decision support tools to help managers predict the effects of their planning decisions. To do this job effectively, the manager must be able to convert available data into information that is understandable and applicable to the problem at hand. The first step in this process is gathering and assessing the potential components of the Decision Support System presently available, including technical literature, water-related data, support software and regional models. This part of the work has been completed under phase II of the project. The components are then processed to eliminate redundant elements, ensure their compatibility with one another, and make them easily accessible to the user. The major part of this work is complete. Finally, components are integrated into a single user-friendly Decision Support System. This step has been completed to the point of preparation of a prototype DSS system in Phase II, and will be finished in Phase III.

Once the prototype DSS has been assembled and tested, continued support will be necessary to train the client users on the system and assist them in extracting information from the system and in preparing and testing their inquiries for different management scenarios. In this way, the information needs specific to the individual clients will be serviced.

8.2 System Components

The Decision Support System is based on two major components: the database and the regional models. A broad and detailed database covering demographics, recharge, pumpage, spring flow and water rights has been assembled from local, state and national sources as part of Phase II. Remaining database development work includes filtering data from diverse sources to remove repeated or unnecessary values; coordinating the data to assure that all values are in common units and context; and structuring the data within the framework of the interrelational database. The units, format and structure of the data must also be made compatible with the input requirements of the regional models.

The regional models for the Nueces River basin, the San Antonio/Guadalupe River basin and the Edwards aquifer were assembled, tested, implemented in the PC environment and documented as part of Phase II work. The individual programs are efficient and accurate models of the components of the regional water system. Full implementation of the Decision Support System will ultimately require developing computational interactions between the models to represent the physical interactions between the components in the real system.

A solid foundation for the Decision Support System has been constructed from verified hydrologic data and from tested and documented regional models. The present (Phase II) system capabilities are as follows:

- Retrieve and review data from the TDRP on the dBase system
- Execute the GWSIM-IV, SIMYLD-II and HDR/NRB models using period-of-record input files and subset of these files
- Analyze subsets of the TDRP data and investigate the performance of regional water system components in response to special requests by the client agencies.

Work in Phase III consists of converting the data to useful information through model runs and analysis, and making the information directly accessible to the client user.

8.3 System Structure

The structure of the DSS is defined from the perspective of the user and his needs. At this stage of system development, the user of the DSS must deal with dBase protocol for extracting information from the database and with complex input and output structures for implementing the regional models. The time required for these operations is significant, and maintaining a clear focus on the objectives of the work in the face of distractions from system interface mechanics is difficult. The Decision Support System will replace the multiple input/output structures with a single user friendly (level 1) interface (Figure 8.1), and thereby eliminate a significant part of the burden on the user in the analysis process.

The user interface is accessible through a character-oriented on-screen query system which extracts the information necessary for a data search or model run from the user. The system then converts the user-supplied information into commands and input data for the database and/or the regional model through their respective (level 2) interface systems. The database and model interfaces translate query system commands into commands to the database and models, and assembles input files for the models from database files (pre-processing). The system executes the routines, then generates output files from the routines (post-processing) as specified by the user. The output files are then passed to the user interface system and displayed in tabular or graphical format. The output files may be saved on disc for future analysis.

The support software (Section 7.0) supplement the database and models by providing statistical analysis of the data and graphical output options. These capabilities are also accessed through the user interface system. A batch mode capability for the system will be implemented in parallel with the interactive screen interface

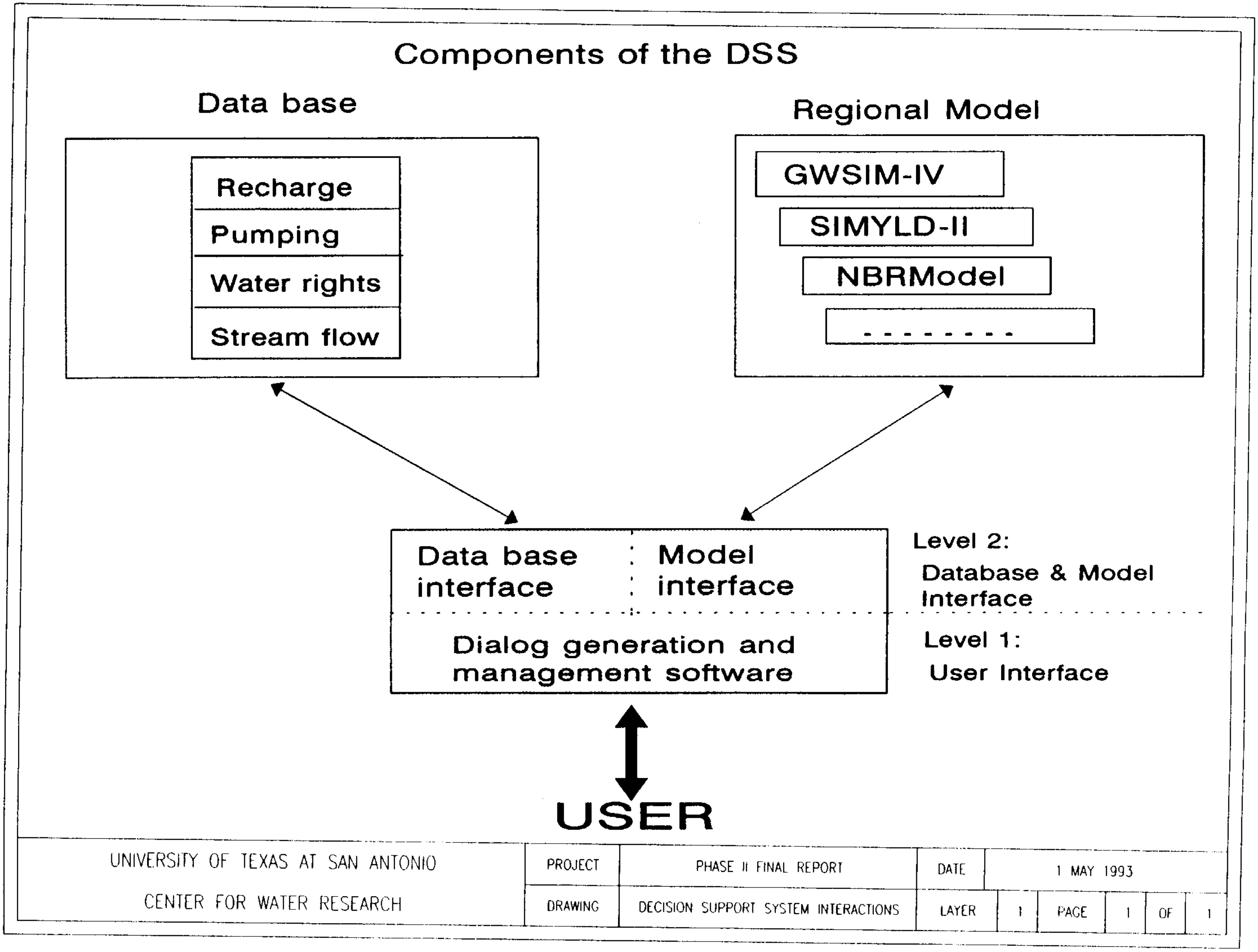


Figure 8.1 Decision Support System Interactions

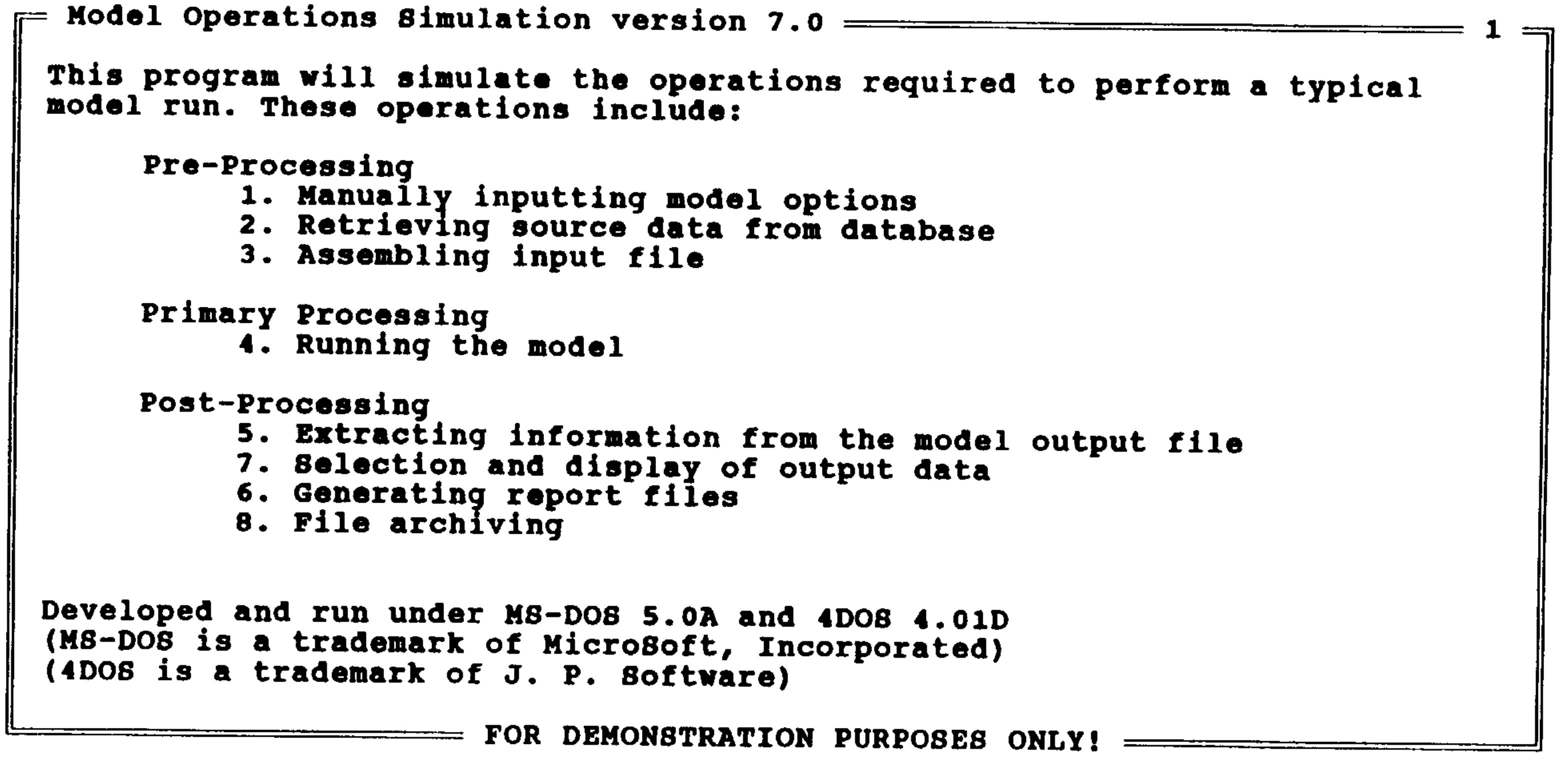
to permit efficient execution of large and/or repetitive system runs.

To access the system, the user chooses between database inquiry and model execution. For database inquiry, the system asks for the type of data, statistical analysis type (if any) and output format. The system retrieves the data, performs the specified analyses, and outputs information on-screen in tabular or graphical format, to the printer for hard copy and/or to disk for archiving.

For model execution, the system asks for the type of model run, then requests the source of data (database, stand-alone files or screen input), and steps the user through data file generation and/or modification, if necessary. The interface system runs through the list of program options (Figure 8.2) until all the necessary input data (including output format and medium) are complete. The system then performs all data preparation and translation operations and executes the model, with system prompts on the screen indicating the progress of the work. At the conclusion of model execution, the system displays prompts for accessing the various components of the model output. Output can then be displayed, printed or archived for future analysis, or it can be transferred to other regional model pre-processors.

8.4 Decision Support System Simulation

A prototype of a section of the user-driven DSS was prepared in Phase II to investigate the procedures required to develop and implement the interactive component of the system, and to demonstrate capabilities of the system to the client group. The GWSIM-IV model was selected for the simulation because the input data sets are configured to permit efficient modification of the data, and because of interest shown by the clients in the rela-



```
╒═ Model Operations Simulation version 7.0 ═══════════════════════════ 1 ═╕

 This program will simulate the operations required to perform a typical
 model run. These operations include:

      Pre-Processing
           1. Manually inputting model options
           2. Retrieving source data from database
           3. Assembling input file

      Primary Processing
           4. Running the model

      Post-Processing
           5. Extracting information from the model output file
           7. Selection and display of output data
           6. Generating report files
           8. File archiving


 Developed and run under MS-DOS 5.0A and 4DOS 4.01D
 (MS-DOS is a trademark of MicroSoft, Incorporated)
 (4DOS is a trademark of J. P. Software)

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UNIVERSITY OF TEXAS AT SAN ANTONIO	PROJECT	PHASE II FINAL REPORT	DATE	1 MAY 1993				
CENTER FOR WATER RESEARCH	DRAWING	PROGRAM DESCRIPTION OF DECISION SUPPORT SYSTEM SIMULATION	LAYER	1	PAGE	1	OF	1

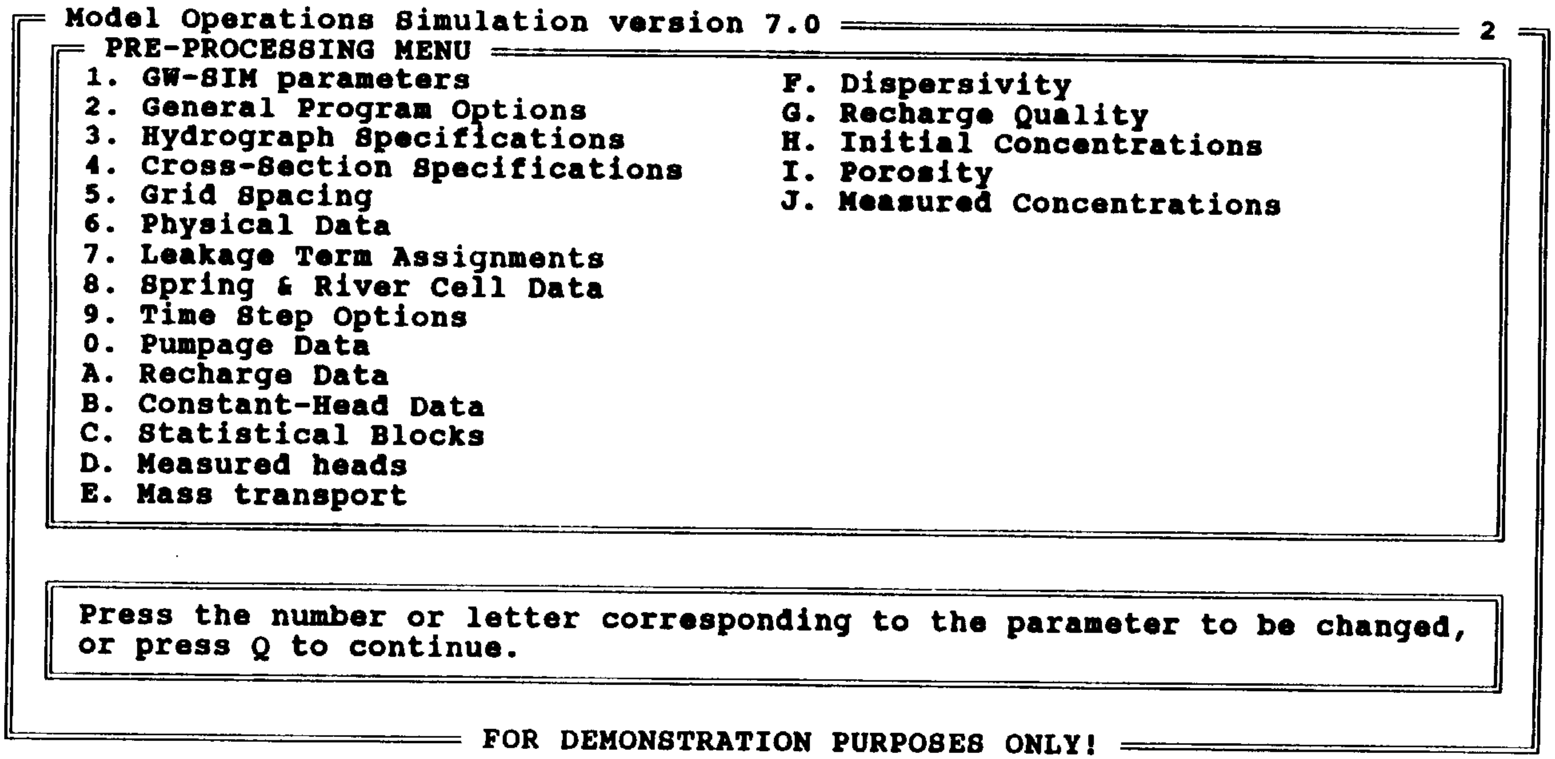
Figure 8.2 Program Options for Decision Support System Simulation

tionship between recharge, pumpage and spring flow computed by the program.

The simulation system focused on the GWSIM-IV time step input data options 4 and 7, which permit the pumpage and recharge values within a rectangular block of grid cells to be multiplied by a constant. This capability allows the user to develop and execute scenarios investigating the effects of pumpage and recharge on spring flow. Groups of grid cells corresponding to the five counties in the region were identified, and a pre-processor code for GWSIM-IV was prepared which changes the pumpage and/or recharge in each county by a user-specified amount.

An interactive, menu-driven user interface program was developed which allows the user to specify the changes in pumpage or recharge by county with a few keystrokes, and obtain a graphical display of flow at ten selected spring locations corresponding to the pumpage and recharge chosen in a matter of minutes. Each run covers one calendar year within the 1947 to 1959 drought sequence. The first major time step in each single-year run starts with head values for the entire grid computed in the 1947 to 1956 calibration run for the last month in the previous year. The results of single-year runs have been verified by comparison with the results of computations for the total calibration period.

The interactive program starts with a list of available pre-processing and post-processing options, which represent the total capabilities of the complete (Phase III) system (Figure 8.2). For simulation purposes, all of the options except simulation option 3 are active. The user chooses simulation option 1 on the main menu to access a screen listing of the GWSIM-IV PRE-PROCESSING MENU (Figure 8.3). The user then selects the GW-SIM PROGRAM PARAMETERS option (Figure 8.4) from the menu to access the listing of physical parameters for the model. These parameters correspond to the



```
Model Operations Simulation version 7.0                                  2
  PRE-PROCESSING MENU
  1. GW-SIM parameters                      F. Dispersivity
  2. General Program Options                G. Recharge Quality
  3. Hydrograph Specifications              H. Initial Concentrations
  4. Cross-Section Specifications           I. Porosity
  5. Grid Spacing                           J. Measured Concentrations
  6. Physical Data
  7. Leakage Term Assignments
  8. Spring & River Cell Data
  9. Time Step Options
  0. Pumpage Data
  A. Recharge Data
  B. Constant-Head Data
  C. Statistical Blocks
  D. Measured heads
  E. Mass transport

  Press the number or letter corresponding to the parameter to be changed,
  or press Q to continue.

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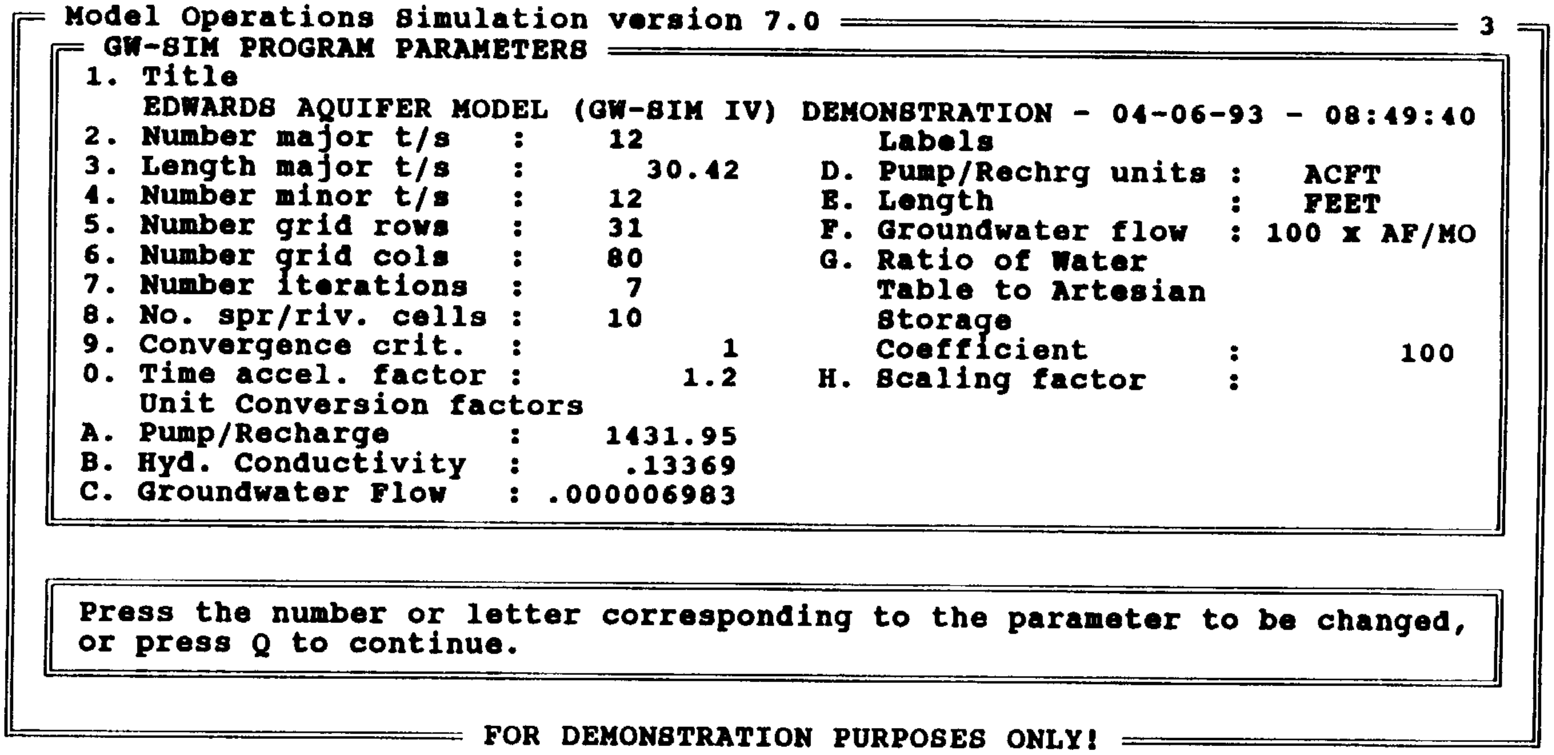
UNIVERSITY OF TEXAS AT SAN ANTONIO	PROJECT	PHASE II FINAL REPORT	DATE	1 MAY 1993					
CENTER FOR WATER RESEARCH	DRAWING	PRE-PROCESSING MENU FOR DECISION SUPPORT SYSTEM SIMULATION	LAYER	1	PAGE	1	OF	1	

Figure 8.3 Preprocessing Menu for Decision Support System Simulation



```
Model Operations Simulation version 7.0                                    3
 GW-SIM PROGRAM PARAMETERS
  1. Title
     EDWARDS AQUIFER MODEL (GW-SIM IV) DEMONSTRATION - 04-06-93 - 08:49:40
  2. Number major t/s   :    12               Labels
  3. Length major t/s   :      30.42      D. Pump/Rechrg units :   ACFT
  4. Number minor t/s   :    12           E. Length            :   FEET
  5. Number grid rows   :    31           F. Groundwater flow  : 100 x AF/MO
  6. Number grid cols   :    80           G. Ratio of Water
  7. Number iterations  :     7              Table to Artesian
  8. No. spr/riv. cells :    10              Storage
  9. Convergence crit.  :         1          Coefficient       :        100
  0. Time accel. factor :       1.2       H. Scaling factor    :
     Unit Conversion factors
  A. Pump/Recharge      :    1431.95
  B. Hyd. Conductivity  :      .13369
  C. Groundwater Flow   : .000006983

 Press the number or letter corresponding to the parameter to be changed,
 or press Q to continue.

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UNIVERSITY OF TEXAS AT SAN ANTONIO	PROJECT	PHASE II FINAL REPORT	DATE	1 MAY 1993					
CENTER FOR WATER RESEARCH	DRAWING	GWSIM-IV PROGRAM PARAMETERS FOR DECISION SUPPORT SYSTEM SIMULATION	LAYER	1	PAGE	1	OF	1	

Figure 8.4 GWSIM-IV Program Parameters for Decision Support System Simulation

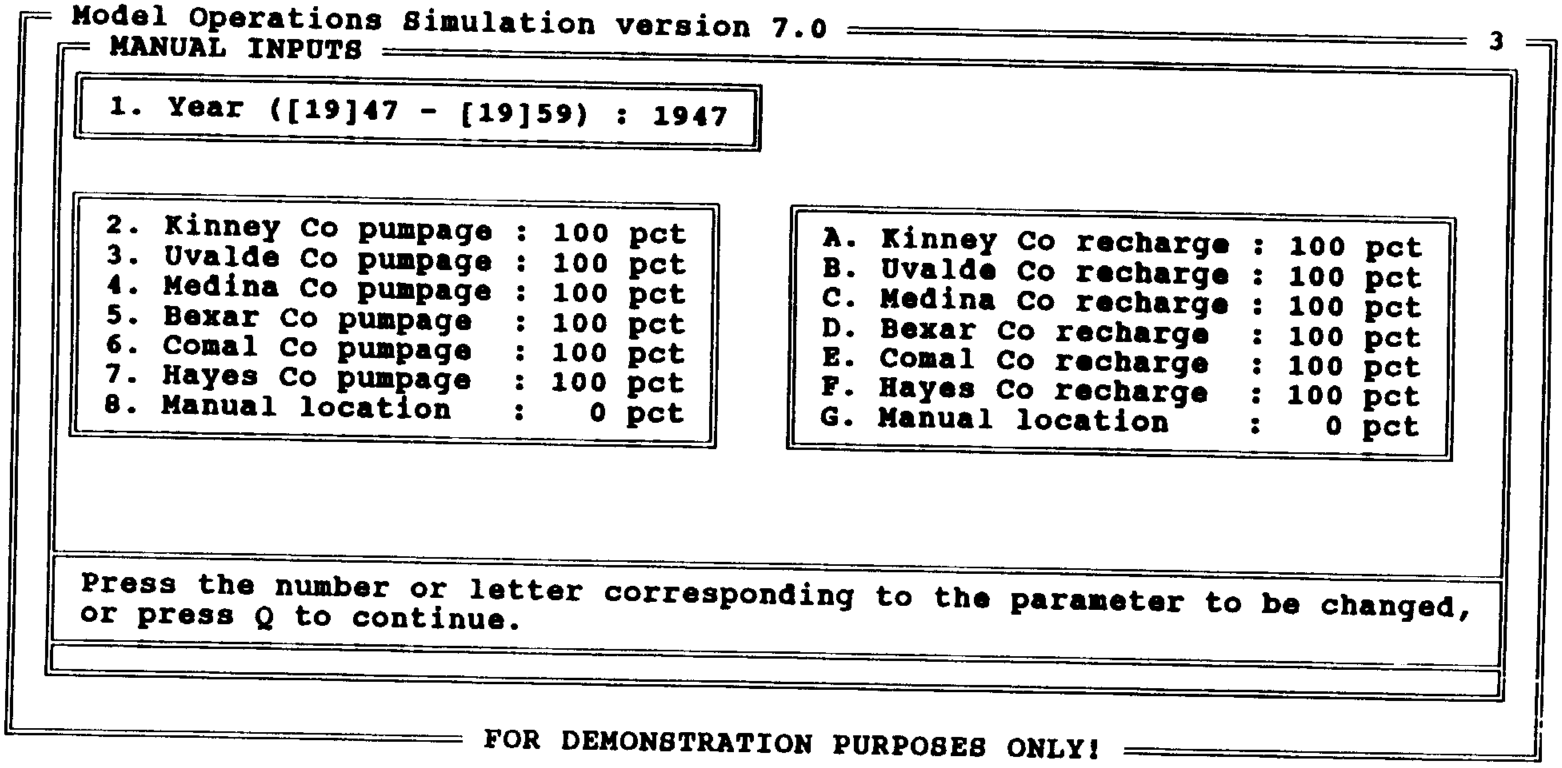
GWSIM-IV data set 2, which sets the model parameters that correspond to all major time steps in the model run. All parameters except the title are fixed for the purposes of the simulation.

The last simulation input screen accessed is the pumpage and recharge menu (Figure 8.5), which represents part of the data corresponding to items 10 and A on the PRE-PROCESSING MENU. The user selects the year within the period of record that he would like to run and assigns a percentage of historical pumping and recharge to each county. The GWSIM-IV pre-processor then converts the data from the screen menus to input files for GWSIM-IV and runs the model program. Finally, plots of the flows at the ten spring locations are displayed on the screen (Figure 8.6).

The preparation and implementation of the simulation system shows the feasibility of developing a DSS which processes efficiently the management scenarios prepared by members of the client group. Execution of the GWSIM-IV model has shown that it is flexible and stable under various operation conditions. The simulation indicates that the San Antonio Region DSS is potentially a powerful tool for converting data into meaningful management information.

8.5 Spatial Decision Support System

The Decision Support System described above will significantly increase the efficiency of access to the database and models for the user who is not familiar with the input and output requirements for the individual routines. While the computer will still handle input and output in a tabular manner, quick and complete understanding of its hydrologic system requires that input and output be displayed in a geographical context. Since the region of concern is geographically defined, every item of data has an



```
Model Operations Simulation version 7.0                                        3
 MANUAL INPUTS
  1. Year ([19]47 - [19]59) : 1947

  2. Kinney Co pumpage : 100 pct        A. Kinney Co recharge : 100 pct
  3. Uvalde Co pumpage : 100 pct        B. Uvalde Co recharge : 100 pct
  4. Medina Co pumpage : 100 pct        C. Medina Co recharge : 100 pct
  5. Bexar Co pumpage  : 100 pct        D. Bexar Co recharge  : 100 pct
  6. Comal Co pumpage  : 100 pct        E. Comal Co recharge  : 100 pct
  7. Hayes Co pumpage  : 100 pct        F. Hayes Co recharge  : 100 pct
  8. Manual location   :   0 pct        G. Manual location    :   0 pct

 Press the number or letter corresponding to the parameter to be changed,
 or press Q to continue.

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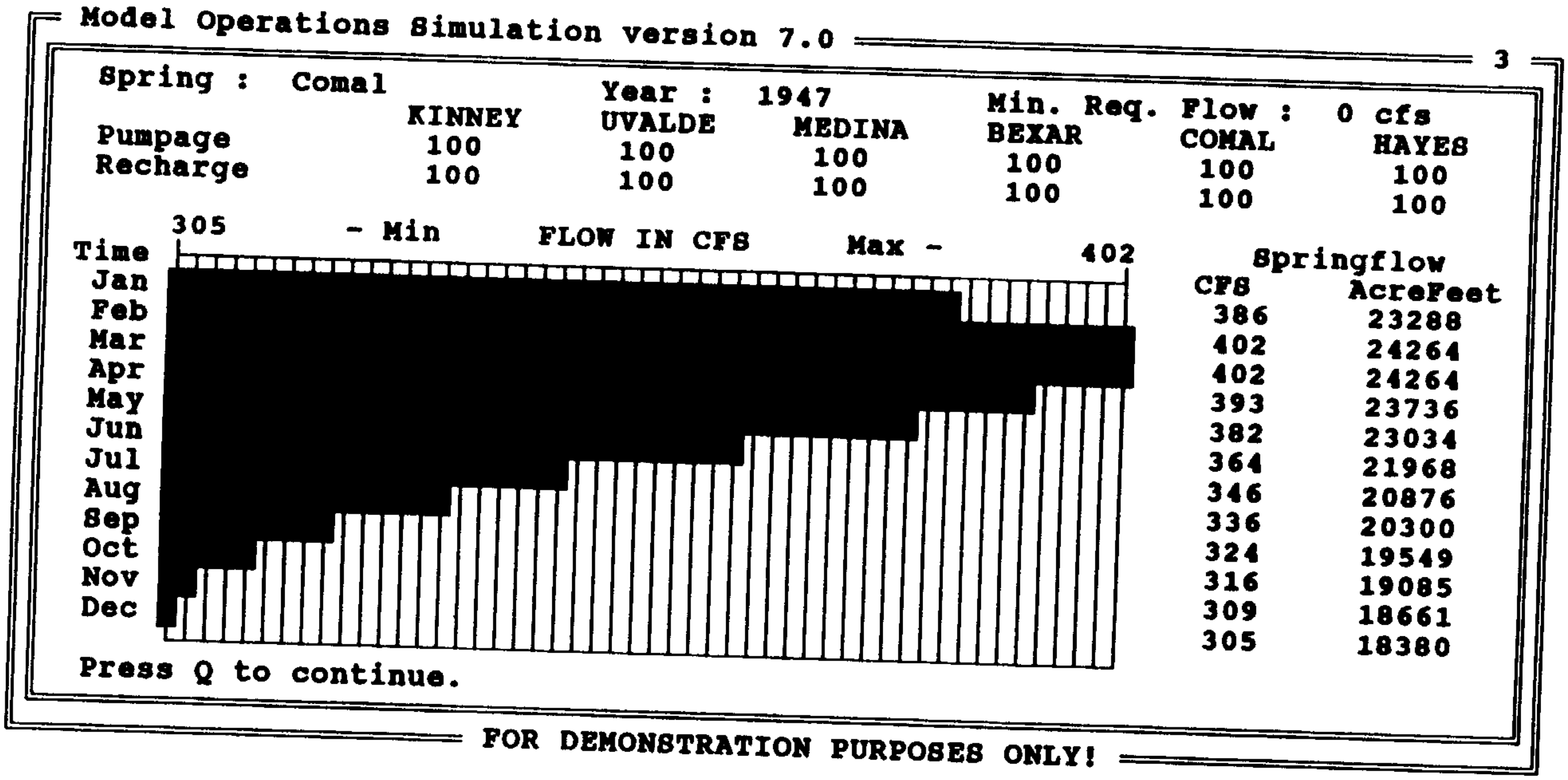
UNIVERSITY OF TEXAS AT SAN ANTONIO	PROJECT	PHASE II FINAL REPORT	DATE	1 MAY 1993				
CENTER FOR WATER RESEARCH	DRAWING	PUMPAGE AND RECHARGE INPUT MENU FOR DECISION SUPPORT SYSTEM SIMULATION	LAYER	1	PAGE	1	OF	1

Figure 8.5 Pumpage and Recharge Input Menu for Decision Support System Simulation



```
Model Operations Simulation version 7.0                                    3
Spring :  Comal
                          Year :  1947            Min. Req.  Flow :  0 cfs
                 KINNEY   UVALDE    MEDINA    BEXAR     COMAL      HAYES
Pumpage           100      100       100       100       100        100
Recharge          100      100       100       100       100        100
        305      - Min    FLOW IN CFS    Max -      402
Time                                                        Springflow
Jan                                                      CFS     AcreFeet
Feb                                                      386      23288
Mar                                                      402      24264
Apr                                                      402      24264
May                                                      393      23736
Jun                                                      382      23034
Jul                                                      364      21968
Aug                                                      346      20876
Sep                                                      336      20300
Oct                                                      324      19549
Nov                                                      316      19085
Dec                                                      309      18661
                                                         305      18380
Press Q to continue.
              FOR DEMONSTRATION PURPOSES ONLY!
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UNIVERSITY OF TEXAS AT SAN ANTONIO	PROJECT	PHASE II FINAL REPORT	DATE	1 MAY 1993				
CENTER FOR WATER RESEARCH	DRAWING	COMAL SPRINGS FLOW PLOT FROM DECISION SUPPORT SYSTEM SIMULATION	LAYER	1	PAGE	1	OF	1

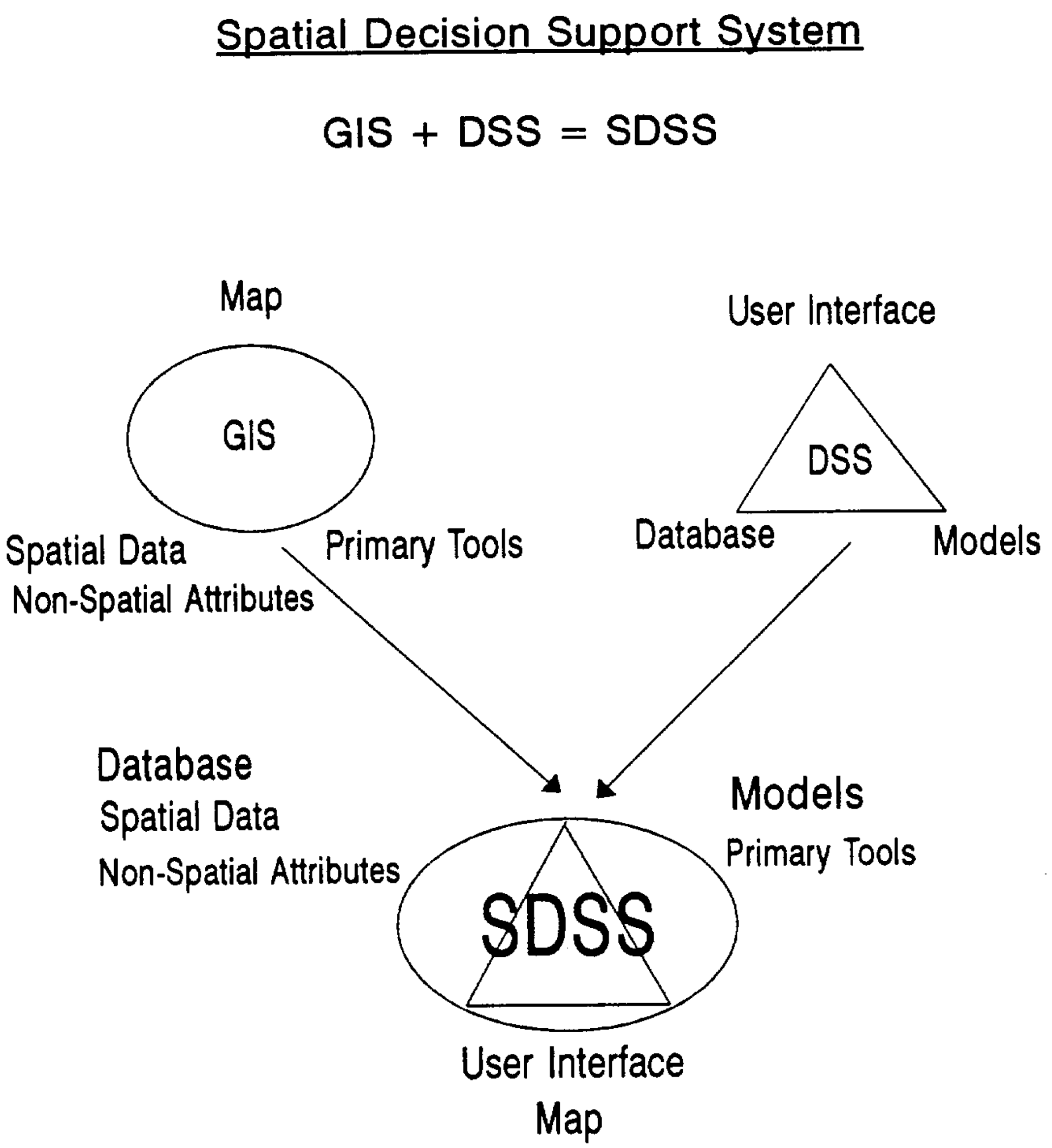
Figure 8.6 Comal Springs Flow Plot for Decision Support System Simulation

associated spatial location; otherwise they have no meaning. Similarly, the regional models that describe the systems do so geographically. In other words, every cell in the ground-water model and the nodes and control points in the surface-water model are spatially defined. Concurrently, results generated by the model are determined at these same locations and again have no meaning unless their locations are defined.

The Phase III level of development for the Decision Support System includes the integration of a Geographic Information System (GIS) into the user interface so that large, geographically-distributed data sets may be entered, displayed and modified by keystrokes and/or mouse on a flat map screen display (Figures 8.7, 8.8). This system is defined as a Spatial Decision Support System (SDSS). Suitable systems for geographic data input and display of data have already been developed [8.1], and are available at reasonable cost for implementation in the PC environment. Sophisticated color graphics display systems significantly enhance the efficiency of information transfer between the Decision Support System and the user, and between the user and his associates.

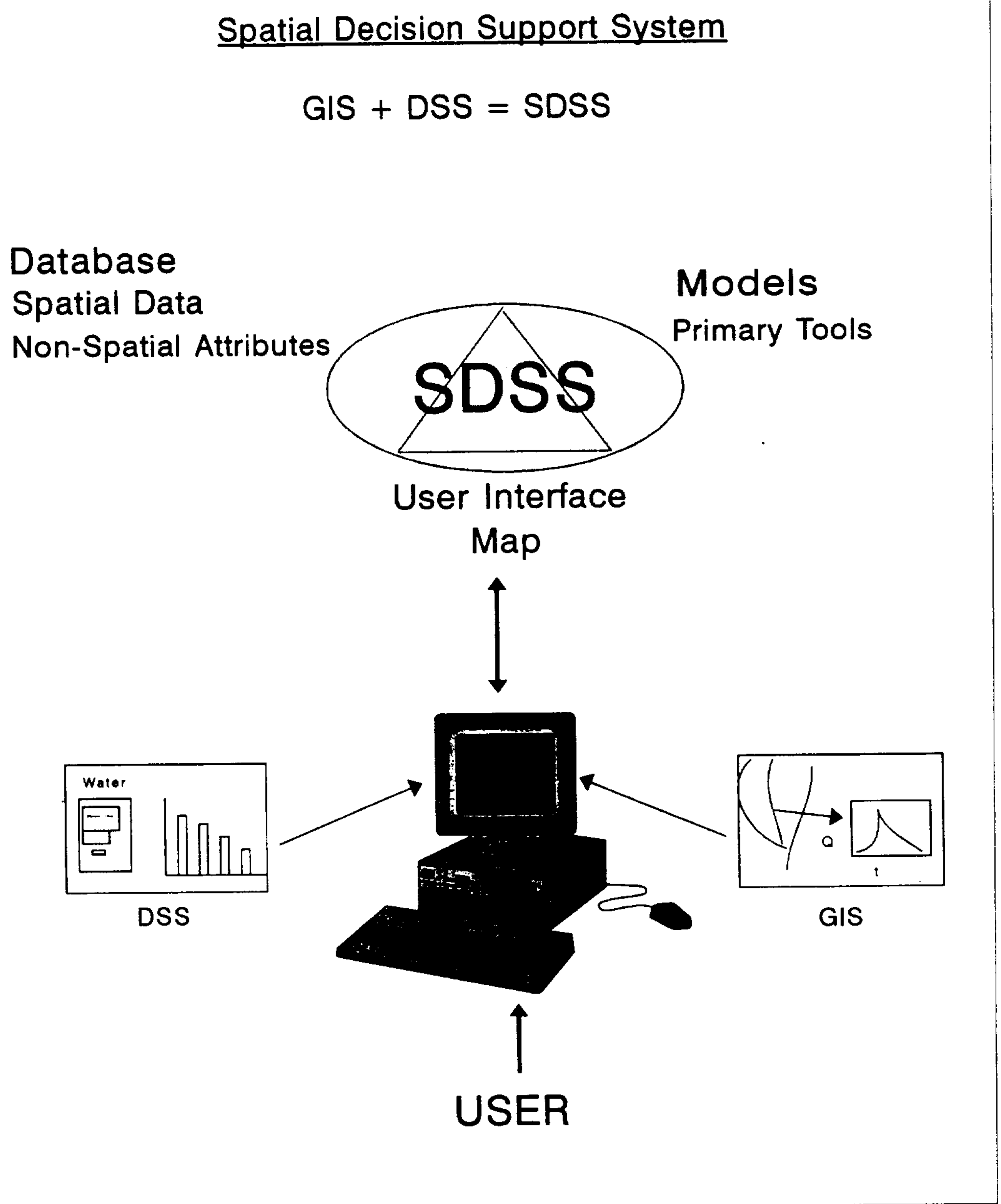
Further enhancements of the capabilities of these systems will be implemented during the development of the Spatial Decision Support System, increasing the display and communication power of the system. With these technological advances, a system which will meet all the information needs of the client group can be developed in a reasonable time frame and at a reasonable cost in light of the multiple benefits to the users.

The GIS and System Control Software (SCS) (Figure 8.9, 8.10) are the operational core of the SDSS. They allow access to the data retrieval and computational capabilities of the database and models in response to user commands.



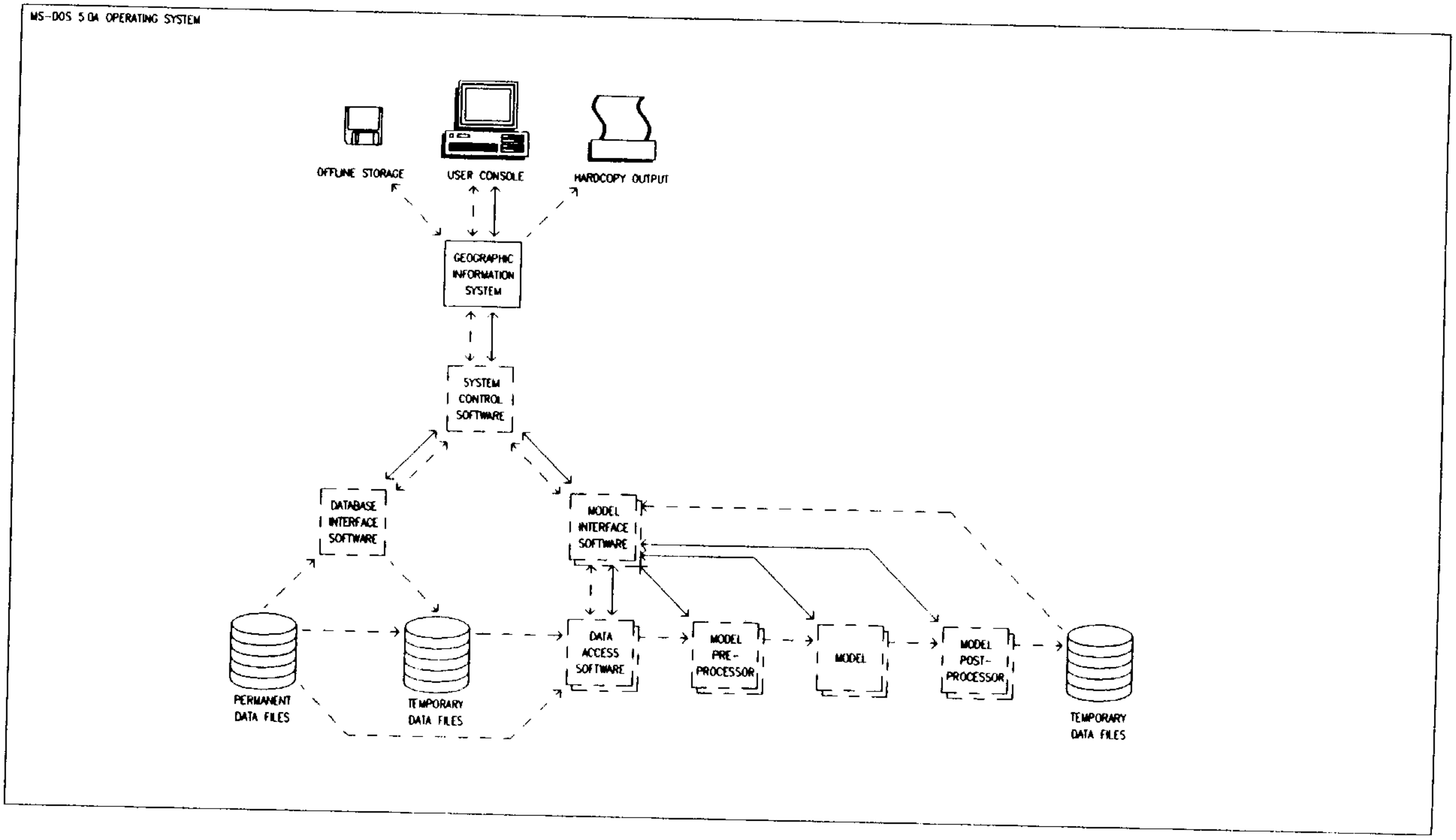
UNIVERSITY OF TEXAS AT SAN ANTONIO			CENTER FOR WATER RESEARCH				
PROJECT	PHASE II FINAL REPORT	DATE	1 MAY 1993				
DRAWING	SDSS CONCEPTS	LAYER	1	PAGE	1	OF	1

Figure 8.7 Spatial Decision Support System Concepts



UNIVERSITY OF TEXAS AT SAN ANTONIO		CENTER FOR WATER RESEARCH					
PROJECT	PHASE II FINAL REPORT	DATE	1 MAY 1993				
DRAWING	SDSS INTERACTIONS	LAYER	1	PAGE	1	OF	1

Figure 8.8 Spatial Decision Support System Interactions



KEY TO SYMBOLS: COMMERCIAL SOFTWARE | DEVELOPED SOFTWARE | DATA PATH - - → | COMMAND PATH ——→

MS-DOS is a trademark of Microsoft Corporation

UNIVERSITY OF TEXAS AT SAN ANTONIO CENTER FOR WATER RESEARCH	PROJECT	PHASE II FINAL REPORT	DATE	1 MAY 1993			
	DRAWING	OPERATIONAL COMPONENTS OF THE SPATIAL DECISION SUPPORT SYSTEM	LAYER	1	PAGE	1	OF 1

Figure 8.9 Operational Components of the Spatial Decision Support System

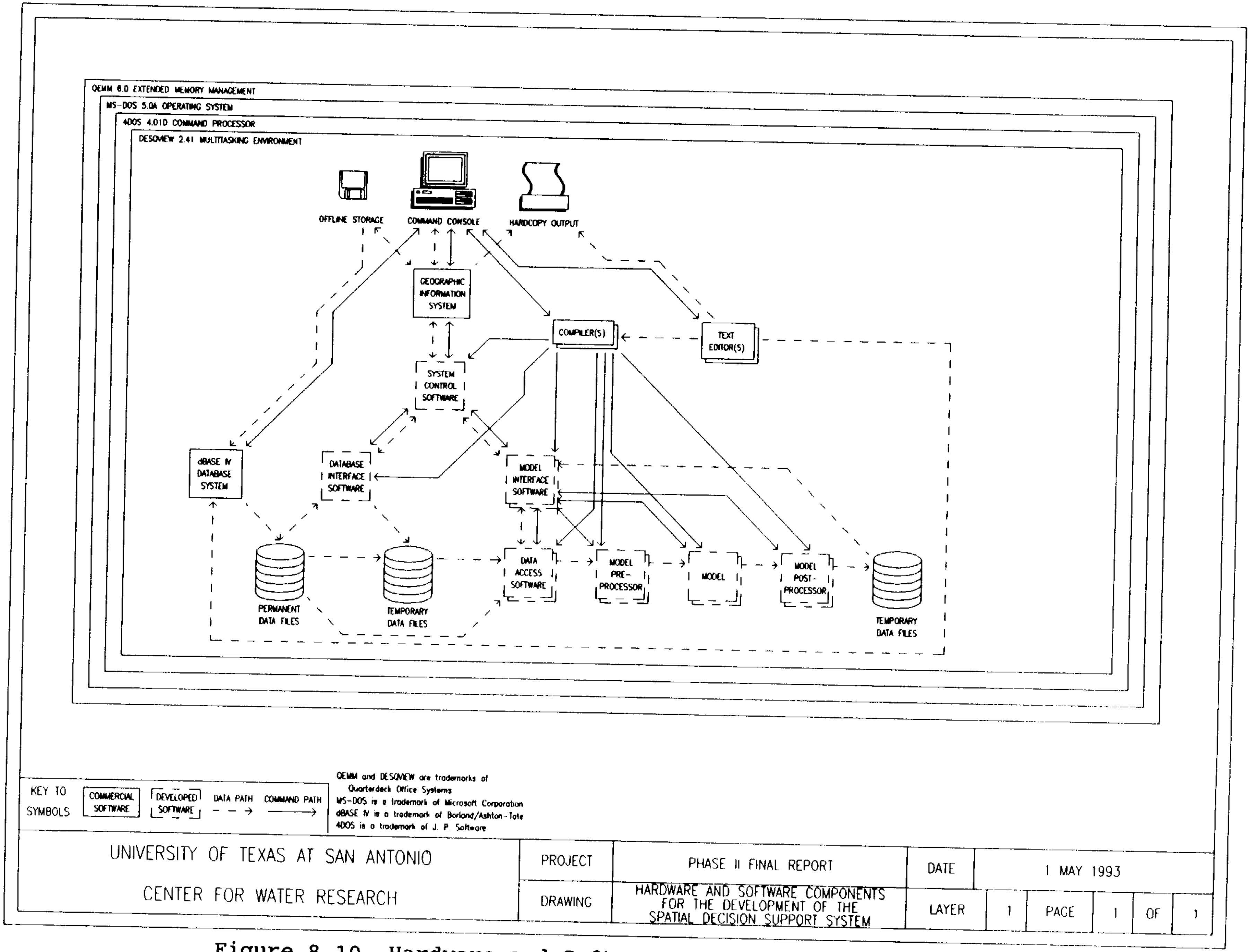


Figure 8.10 Hardware and Software Components in the SDSS

9.0 CONCLUSIONS

The overall objective of this project is the development of a comprehensive Decision Support System for the San Antonio Region which will allow water managers to efficiently process large volumes of data and to evaluate solutions to local and regional water needs. The first step toward this goal, which has been accomplished under Phase II, included identifying, assembling, testing and documenting the components for the system, and preparing the basic Decision Support System (DSS). This basic system contains all the components and performs all the functions of the final comprehensive system, but many of the system interactions must still be performed manually. The fundamental difference between the present system and the final product is the speed and ease of data retrieval and model computations in response to user requests.

The activities in Phase II leading up to the establishment of the basic DSS are as follows:

- Establishment of the database from the information provided by the Technical Data Review Panel of the South Central Texas Region and other sources
- Review, selection and documentation of numerical models for the Nueces, San Antonio and Guadalupe/Blanco River basins and the Edwards aquifer
- Investigation of the mechanisms of hydrological interaction between the river basins and between the river basins and the aquifer
- Preparation of preliminary and exemplary pre- and postprocessors for the GWSIM-IV program which permit execution of the model for a single calendar year or any other time increment within the period of record, as dictated by the user

- Demonstration of some of the basic DSS functions including extracting data from the database, preprocessing the data, running the GWSIM-IV program, postprocessing the data and storing output data in the database, in response to instructions directed through the user interface.

As a result of experience gained during the Phase II work, the following findings were indicated:

- The Decision Support System (DSS) is the tool of choice for satisfying water management needs in the San Antonio region. Decision Support is an interactive, computer based system that incorporates a user interface, database, and computational models to provide objective information to support a relatively unstructured decision making process. As such, the DSS allows the manager freedom to choose inputs to his scenarios, and to vary the conditions under which his management scenario will operate.

- The DSS is simple to use at the management level. The pre-and post processors for the database and models and the user interface eliminate the need to become familiar with the details of program input and output structures.

- The DSS is an extension of the water manager's major function: to process available data for synthesis of defensible solutions. The DSS greatly enhances the efficiency of the data processing, and provides solid documentation of the procedures followed to reach management decisions.

- The most effective embodiment of the DSS for this regional application is a Spatial Decision Support System (SDSS), which incorporates the extensive graphical display capabilities of the Geographic Information System (GIS) into the pre- and postprocessing functions to increase the efficiency of information transfer between the DSS and the user.

Phase II work has made great strides toward completion of the DSS. The task of completing the development and implementation of the DSS remains for Phase III. This management system, with continued support and development, will serve the needs of the San Antonio region well into the next century.

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APPENDICES

APPENDIX A

THE WATER SYSTEM FOR THE SAN ANTONIO REGION

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THE WATER SYSTEM FOR THE SAN ANTONIO REGION

The water system for the San Antonio region is composed of three major surface water subsystems (the Nueces, San Antonio and Guadalupe/Blanco River basins) and the Edwards Aquifer. The physical properties of the individual units are outlined below.

A.1 The Edwards Aquifer

A.1.1 Regional Hydrogeology and Flow. The Edwards aquifer within the San Antonio region is composed of the Georgetown Formation and the Person and Kainer Formations of the Edwards Group. It is bounded on the west and east by ground-water divides in Kinney and Hays counties, on the north by the Balcones fault zone and on the south by the "bad water" line (Figure A.1).

The aquifer consists of 400 to 600 feet of thin- to massive-bedded carbonate rock with layers of high porosity and permeability rock separated by layers with low permeability [A.1]. At some locations porous layers are connected hydraulically by faults and fractures. High angle normal faults also serve as local flow barriers when impermeable layers are displaced vertically across permeable layers. The aquifer is confined at the base by the Glen Rose Formation and the upper confining layer is the Del Rio clay (Figure A.2).

The aquifer is confined laterally by its outcrop area in the Balcones fault zone to the north and by the bad water line to the south. Significant inflow, estimated at 400 ft^3/sec by the USGS, may occur along the northern edge of the Balcones fault zone, where the Edwards aquifer has been downfaulted against the lower permeability rock of the Glen Rose Formation. The quantity, location and direction of this flow are currently being studied.

Recharge to the Edwards aquifer occurs where rocks of the Georgetown Formation and the Edwards group outcrop in the Balcones fault zone. Streams crossing the outcrop zone lose substantial quantities of flow through their channels as recharge to the aquifer. All major streams in the region, except the Guadalupe, contribute a significant part of their flow to recharge (Table A.1). Some streams normally maintain flow only in their upper reaches, with all base flow being lost to the highly permeable limestone. Streams to the west of San Antonio are the major contributors to recharge (approximately 70% of the total). The highly permeable stream channels present numerous opportunities for enhancement of recharge. The feasibility of developing additional recharge structures is being actively investigated at this time. Some additional recharge to the saturated zone occurs in interstream areas through direct precipitation infiltration.

Table A.1 - Average Annual Stream Contributions to the Edwards Aquifer Recharge [A.3]

Basin	Annual Recharge (Acre Feet)
Nueces	102,600
Frio-Sabinal	149,300
Seco-Hondo-Medina	154,400
Helotes-Salado	65,200
Cibolo-Dry Comal	105,200
Guadalupe	(No significant recharge)
Blanco	35,800
Total	**612,500**

Water entering the unconfined aquifer in the west generally flows south into the confined zone (Figure A.3). This pattern of regional flow is interrupted locally by faults. High-angle normal faulting may juxtapose two permeable layers of distinct geologic origin, or a permeable layer and an impermeable one (Figure A.4). In addition, rotation of the fault blocks with respect to one another in the fault plane (Figure A.5) may cause lateral discontinuity in the transmission characteristics between layers.

Once in the artesian zone of the aquifer, water moves eastward through high permeability materials under low gradients and discharges from wells and springs (Table A.2). During an average year, the majority of the flow issues from Comal Springs. Spring water flows from channels developed in faults under hydraulic pressure generated by the elevated hydraulic heads to the west of the springs (Figure A.6).

Table A.2 - Average Annual Discharge from Major Springs in the Edwards Aquifer [A.5]

Spring	Annual Discharge (Acre Feet)
Leona Springs (Uvalde)	7,040 (1940 - 1965)
San Antonio/San Pedro Springs (San Antonio)	(Discontinuous)
Comal Springs (New Braunfels)	204,907 (1928-1991)
San Marcos Springs (San Marcos)	119,500 (1957-1991)

Several hundred high-yield wells in Uvalde, Medina, Bexar Comal and Hays Counties also discharge water from the aquifer for agricultural, industrial and municipal use. The cities of Uvalde, D'Hanis, Hondo, Castroville, San Antonio, San Marcos and Kyle rely solely on the Edwards aquifer for their municipal water supplies.

The San Antonio metropolitan region accounts for approximately 50% of the pumpage from the aquifer (Table A.3). The remainder is used by the smaller municipalities and agriculture.

Table A.3 - 1989 Pumpage Totals for the Edwards Aquifer, by County [A.6]

County	Discharge (acre-feet)
Bexar	293,000
Comal	27,800
Hays	13,000
Kinney	2,600
Medina	70,500
Uvalde	136,800
Total	**543,700**

A.1.2 Operational Characteristics One of the distinguishing characteristics of the Edwards aquifer is its high flow capacity. This capacity is reflected in the very low hydraulic gradients associated with the flow; the excellent response correlation between water levels in widely-spaced wells, and between wells and spring flows; the high levels of sustained spring output (averaging between 100 ft^3/sec and 500 ft^3/sec total); the short response time between major rainfall events and changes in well levels; and the uniform water quality and temperature throughout the aquifer.

The geologic conditions contributing to high flow capacity in the aquifer were graphically demonstrated when blind catfish were netted from a 1,500 foot well south of San Antonio, indicating the presence of interconnected cavernous openings at that depth.

Rates of springflow and well discharge (Figure A.7) vary significantly from year to year and from one month to the next primarily due to rainfall conditions. The rate of flow from Comal Springs correlates directly with well levels in Bexar County, which in turn reflect recharge and pumpage rates. Figure A.8 shows an approximately linear relationship between the water level in observation well J-17 in Bexar County and flow from Comal Springs. Flow in the more remote San Marcos Springs, by comparison, does not correlate well with San Antonio well levels. Discharge from the San Marcos springs reflects the effects of a substantial local component of recharge.

Another important characteristic of the aquifer is its ability to store and supply water. The yield obtained lowering the water level by 1 foot in the unconfined (water level) zone of the aquifer is on the order of 1000 times greater than the yield in the confined (artesian) zone. The relatively large areal extent of the high-yield unconfined zone in the western part of the aquifer and the high transmissivity of the confined zone are largely responsible for the productive capacity of the aquifer which can only be described as highly prolific.

The high storage capacity of the aquifer is reflected in the stability of the volume of available water in the aquifer over time (Figure A.9) and the historic stability of well levels (Figure A.10) throughout the period of record (1934 to 1991). These quantities have remained relatively stable despite high withdrawal and low recharge rates during years of severe drought in the mid-1950's and ever-increasing pumping from 1950 to the present. Over the long term the ratio of pumpage to spring flow has increased steadily (Figure A.7) and the total discharge (spring flow and pumpage) has also increased, however the impact on the amount of water in storage has been negligible. Recharge (Figure A.11) varies drastically from one year to the next.

A.2 Nueces River Basin

The Nueces River basin covers an area of 16,950 square miles and is bounded on the north by Colorado River basin, on the east by both the San Antonio River basin and the San Antonio-Nueces coastal basin, on the west by the Rio Grande River basin and on the south by the Nueces-Rio Grande coastal basin (Figure A.12). It extends from Edwards County to Nueces Bay and encompasses parts of the Edwards Plateau and the West Gulf Coastal Plain physiographic regions [A.8]. The Balcones Escarpment crosses the northern part of the basin through Medina, Uvalde and Kinney counties and forms the boundary between the two physiographic regions. All or parts of 22 counties are in the Nueces River basin including: Atascosa, Bandera, Bee, Dimmit, Duval, Edwards, Frio, Jim Wells, Karnes, Kinney, LaSalle, Live Oak, Nueces, Maverick, Medina, McMullen, Real, San Patricio, Uvalde, Webb, Wilson, and Zavala Counties.

The Nueces River originates in Edwards County at an elevation of approximately 2,400 feet. It flows southeast for 315 miles to the Nueces Bay [A.8]. Major tributaries are the Frio and Atascosa Rivers. The Frio River begins in Real County and joins the Nueces River south of Three Rivers. The Sabinal, Dry Frio, and Leona Rivers, and the San Miguel and Hondo Creeks are the principal tributaries of the Frio River. Flow in streams on the Edwards Plateau is provided by springs and precipitation in the area. As the streams cross the Balcones Fault zone they lose much of their flow to the Edwards Aquifer.

Choke Canyon, located on the Frio River above Three Rivers, is the largest reservoir in the Nueces River basin with a capacity of about 690,000 acre-feet [A.9]. The water is primarily for municipal, industrial and recreational use [A.10]. Lake Corpus Christi, located on the Nueces River near Mathis, has a capacity of about 298,000 acre-feet and supplies water primarily for municipal and industrial use. In Medina County there are reservoirs on the Seco, Parker and Verde Creeks. These reservoirs were designed as recharge enhancement structures.

As of 1984 average annual runoff in the Nueces River basin ranged from 145 acre-feet/year/square mile at Laguna to 38 acre feet/year/square mile at Bracketville [A.11]. The Nueces River discharges an average of 634,000 acre-feet/year into Nueces Bay [A.12].

A.3 San Antonio River Basin

The San Antonio River basin covers an area of approximately 4,180 square miles and is bounded on the north by the Guadalupe River basin and on the south by both the Nueces River basin and the San Antonio-Nueces Coastal basin. The San Antonio River basin extends from Bandera County to the Guadalupe and San Antonio River confluence near San Antonio Bay (Figure A.13). It encompasses parts of the Edwards Plateau and the West Gulf Coastal Plain. The Balcones Escarpment crosses the basin through northern Medina and Bexar Counties and forms a boundary between the two physiographic regions [A.13]. The basin includes most of Bexar, Wilson, and Karnes Counties and portions of Bandera, Kendall, Goliad, Guadalupe, and Medina Counties.

The Medina River begins in northwest Bandera County at an elevation of 2,300 feet, flows southeast and joins the San Antonio River south of the city of San Antonio at an elevation of 410 feet. It is 146 miles long and is the primary stream that drains the Edwards Plateau portion of the basin [A.14]. The San Antonio River is 238 miles long and originates in the City of San Antonio. It flows southeast and joins the Guadalupe River approximately 11 miles upstream of San Antonio Bay at the Refugio/Calhoun county line. Another major tributary of the San Antonio River is Cibolo Creek. It originates in Kendall County at a elevation of more than 2,000 feet, flows southeasterly across the Balcones Escarpment and connects with the San Antonio River in Karnes County at an elevation of 223 feet. Cibolo Creek is 147 miles long. As these streams cross the Balcones Fault zone, all of Cibolo Creek base flow and most of the Medina River base flow enters the Edwards Aquifer [A.13]. Salado Creek which originates in northern Bexar County, joins the San Antonio River on the south side of the city of San Antonio. Other tributaries include Leon, Calaveras, and Escondido Creeks.

Medina Lake on the Medina River is the largest reservoir in the San Antonio River basin and has a capacity of 254,000 acre feet. Some of its storage is recharged to the Edwards aquifer. The rate of recharge is function of the lake elevation. The water is used primarily for irrigation within the Nueces River basin. Olmos Reservoir located on Olmos Creek in the city of San Antonio has a storage capacity of 15,500 acre-feet, but is empty except when used for flood control [A.13]. The waters of Calaveras Lake and Braunig Lake which have capacities of 80,000 and 30,000 acre feet respectively are used for cooling at thermal electric powerplants [A.15].

As of 1984 average annual runoff in the San Antonio river basin ranged from 122 acre-feet/year/square mile at Goliad to 209 acre-feet/year/square mile at Elmendorf [A.11]. The San Antonio River discharges an average of 502,000 acre-feet/year into the Guadalupe River [A.12].

A.4 Guadalupe-Blanco River Basin

The Guadalupe-Blanco River basin covers and area of 6,070 square miles and is bounded on the north by the Colorado River basin, on the east by both the Lavaca River basin and the Lavaca Guadalupe Coastal basin, on the west by a small portion of the Nueces River basin and on the south by the San Antonio River basin (Figure A.14). It extends from Kerr County eastward to Hays and Comal Counties thence southeastward to San Antonio Bay. The basin encompasses parts of the Edwards Plateau and the West Gulf Coastal Plain. The Balcones Escarpment crosses the basin through Hays and Comal Counties and separates the two physiographic regions [A.16]. All or parts of 13 counties lie within the basin. These are Bastrop, Blanco, Caldwell, Comal, DeWitt, Fayette, Goliad, Gonzales, Guadalupe, Hays, Kendall, Kerr, and Victoria.

The headwaters of the Guadalupe River are in Kerr County at an elevation of 2,360 feet. From there the river, which is 250 miles long, flows eastward to Gonzales, then southeastward to Guadalupe Bay of the San Antonio Bay system. The Blanco and San Marcos Rivers are the principal tributaries to the Guadalupe River [A.11]. The Blanco River originates in northern Kendall County and flows southeastward to Hays County where it joins the San Marcos River near San Marcos. The San Marcos River originates at the springs in San Marcos, flows southeastward and joins the Guadalupe River near the city of Gonzales. Plum Creek is a tributary of the San Marcos River. Other major tributaries to the Guadalupe River include Johnson, Peach, Sandies, and Coleto Creeks, and the Comal River.

The largest reservoir on the Guadalupe River is Canyon Lake which has a conservation storage capacity of about 390,000 acre feet [A.15]. The reservoir is used for flood control, recreation, municipal and industrial use within the basin and for export to other basins [A.16]. Coleto Creek Reservoir in located in Victoria and Goliad counties has a capacity of about 35,000 acre-feet and is operated as a cooling pond for electric power generation [A.15, A.17]. Lake McQueeny, Lake Dunlap, and H-4 Reservoir with capacities of 5,000, 5,900, and 6,700 acre-feet are located below New Braunfels. These and three smaller reservoirs (H-5, TP-4, and TP-5) on the Guadalupe River are used for hydroelectric power [A.16].

As of 1984 average annual runoff in the Guadalupe-Blanco River basin ranged from 273 acre-feet/year/square mile at Victoria to 158 acre-feet/year/square mile at Comfort [A.11]. The Guadalupe River discharges an average of 2,342,000 acre-feet/year into the Guadalupe Bay. This includes the flow from the San

Antonio River. The average flow of the Guadalupe at the San Antonio River confluence is about 1,800,000 acre-feet/year [A.12].

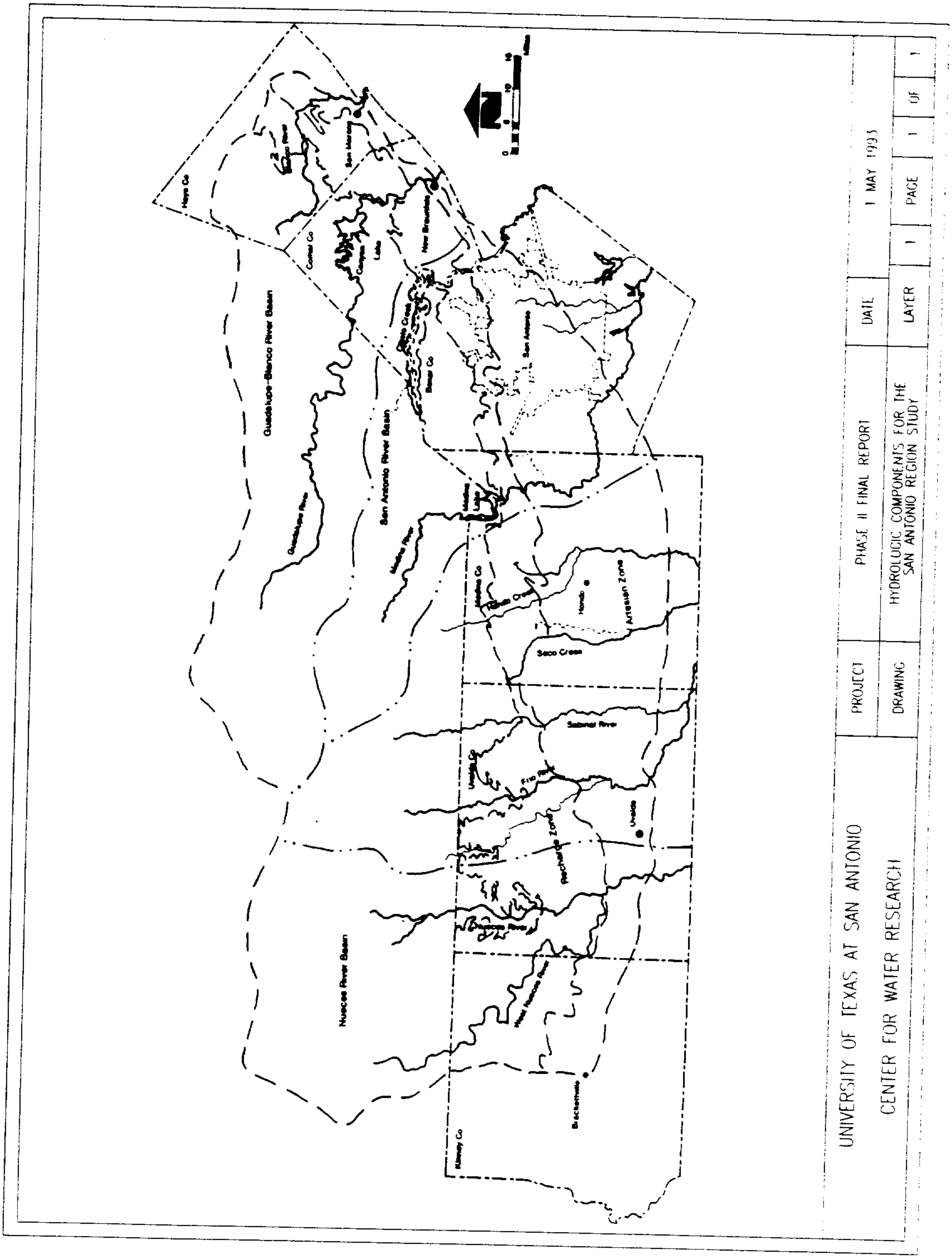


Figure A.1 - Hydrologic Components for the San Antonio Region Study

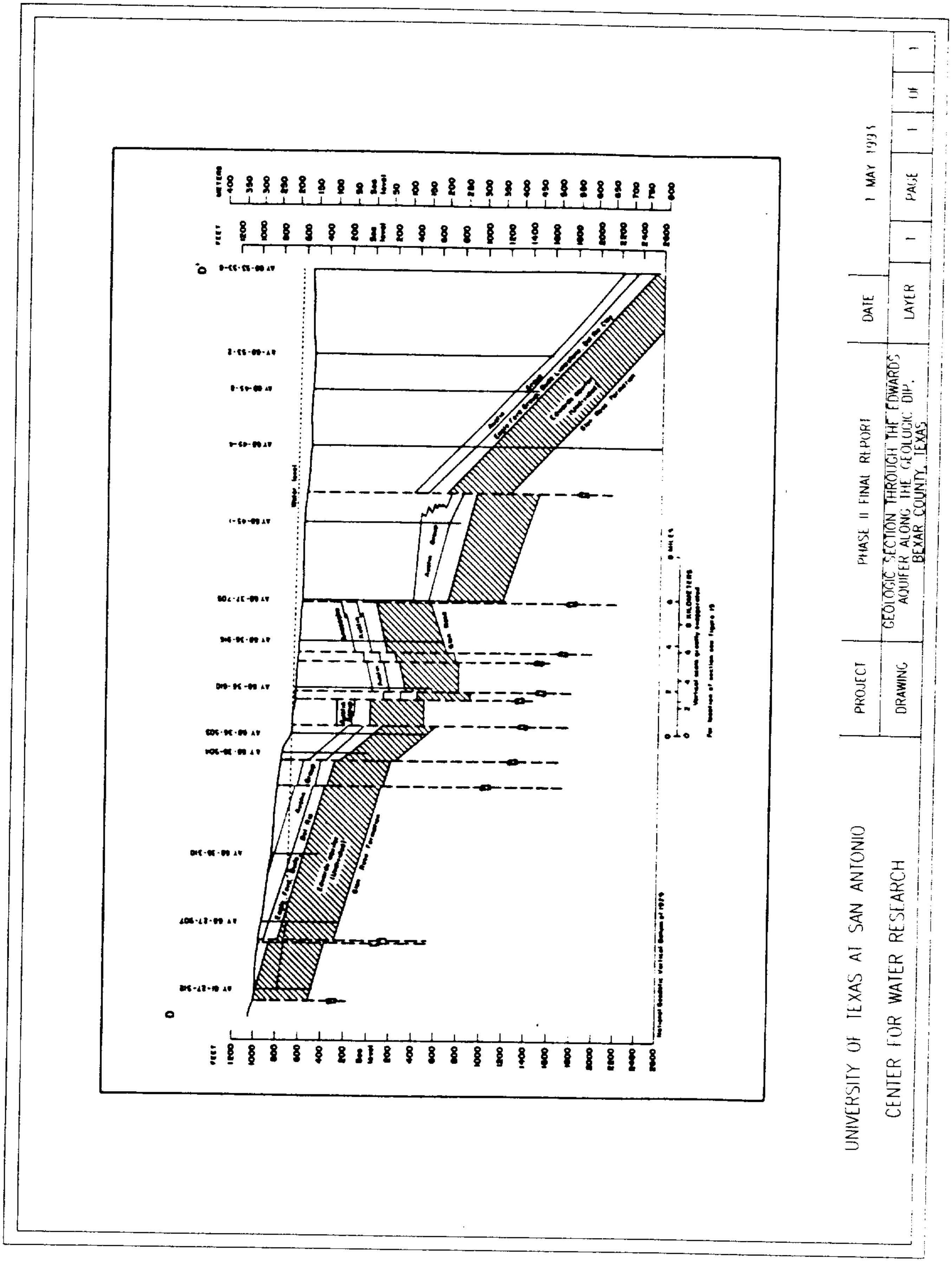


Figure A.2 - Geologic Section Through the Edwards Aquifer Along the Geologic Dip, Bexar County, TX [A.1]

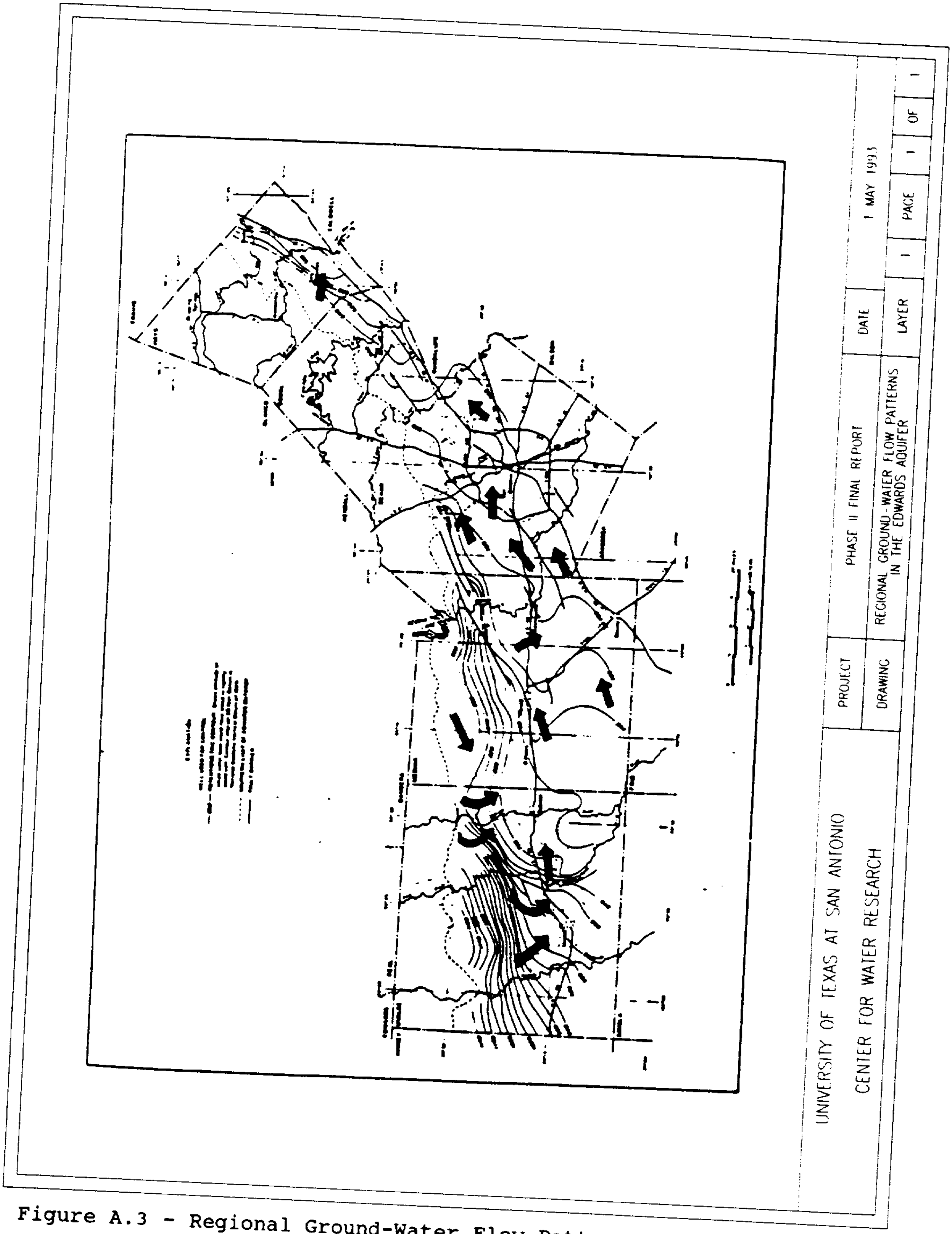
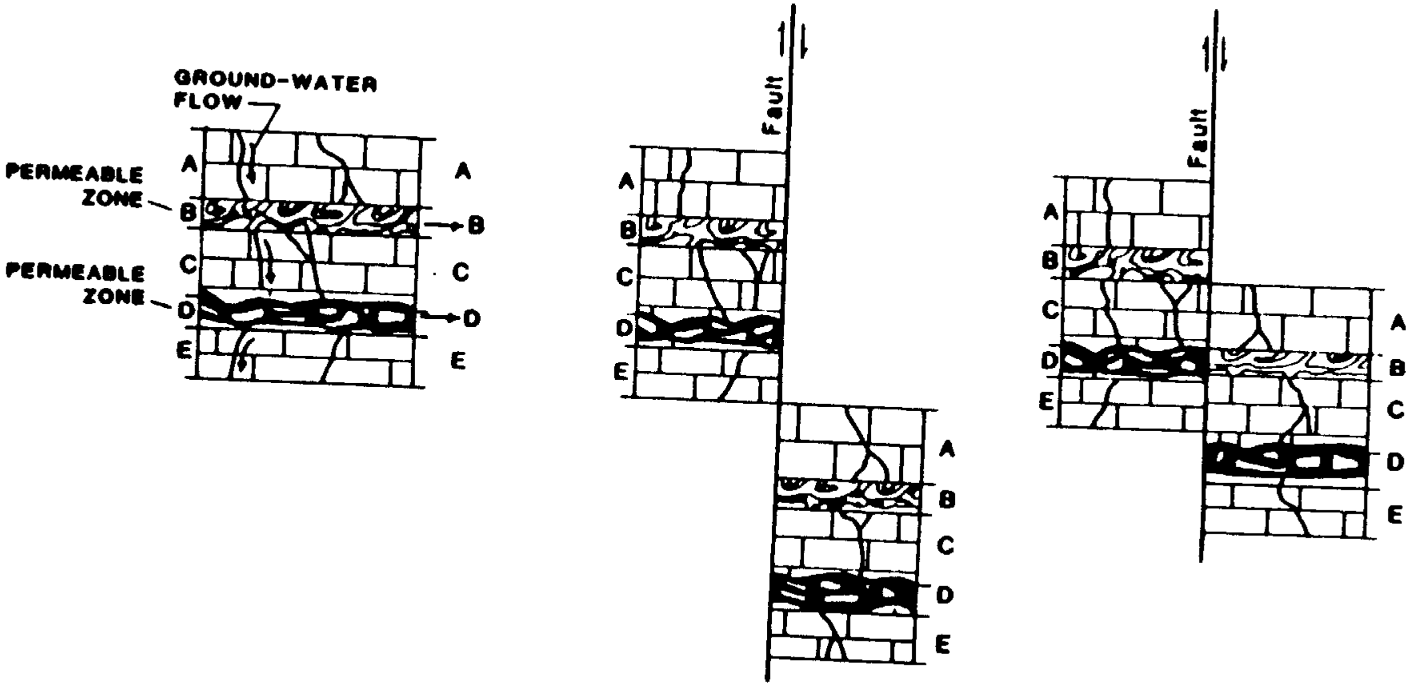


Figure A.3 - Regional Ground-Water Flow Patterns in the Edwards Aquifer [A.2]



UNFAULTED SECTION

BARRIER FAULT--Aquifer completely separated by a normal fault. Ground-water flow is greatly impeded. Leakage through confining unit allows some flow

BARRIER FAULT--Aquifer partially separated by a normal fault, but limited hydraulic connection across fault is maintained. Ground-water flow is impeded

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Figure A.4 - Schematic Section Perpendicular to a Displaced Fault Demonstrating Effects on Conductivity [A.4]

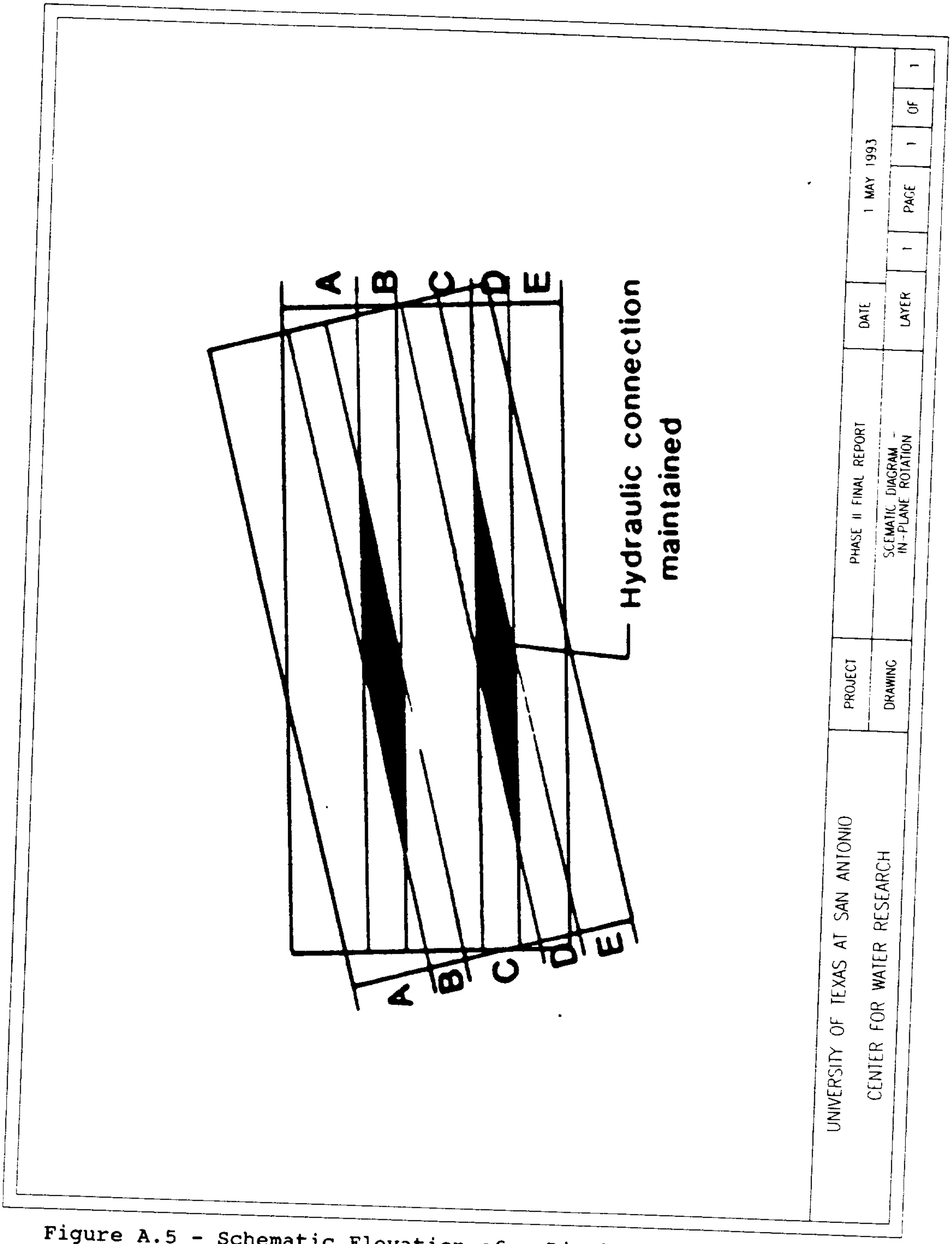


Figure A.5 - Schematic Elevation of a Displaced Fault Showing Effects of In-Plane Rotation of Fault Blocks [A.4]

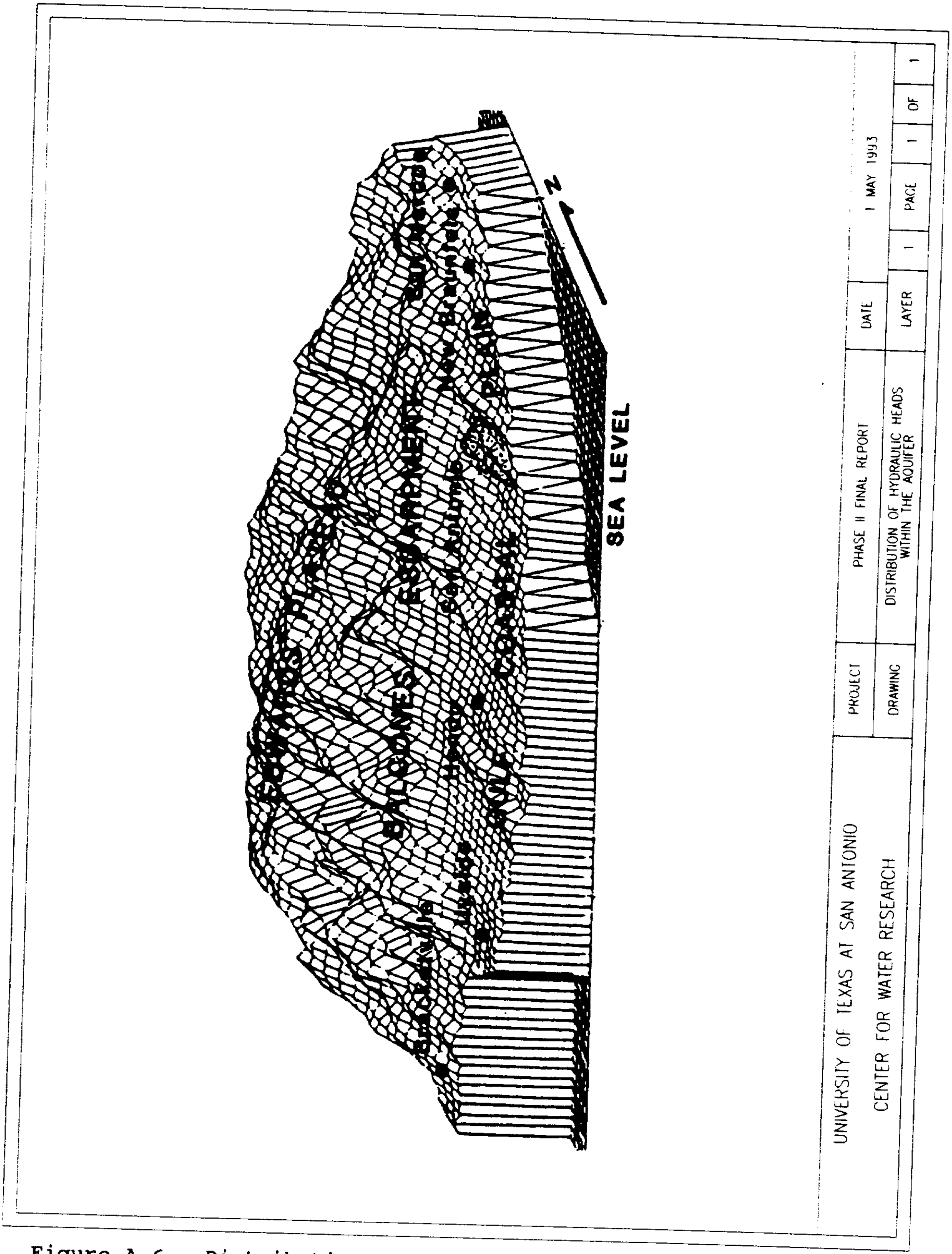


Figure A.6 - Distribution of Hydraulic Heads Within the Aquifer [A.7]

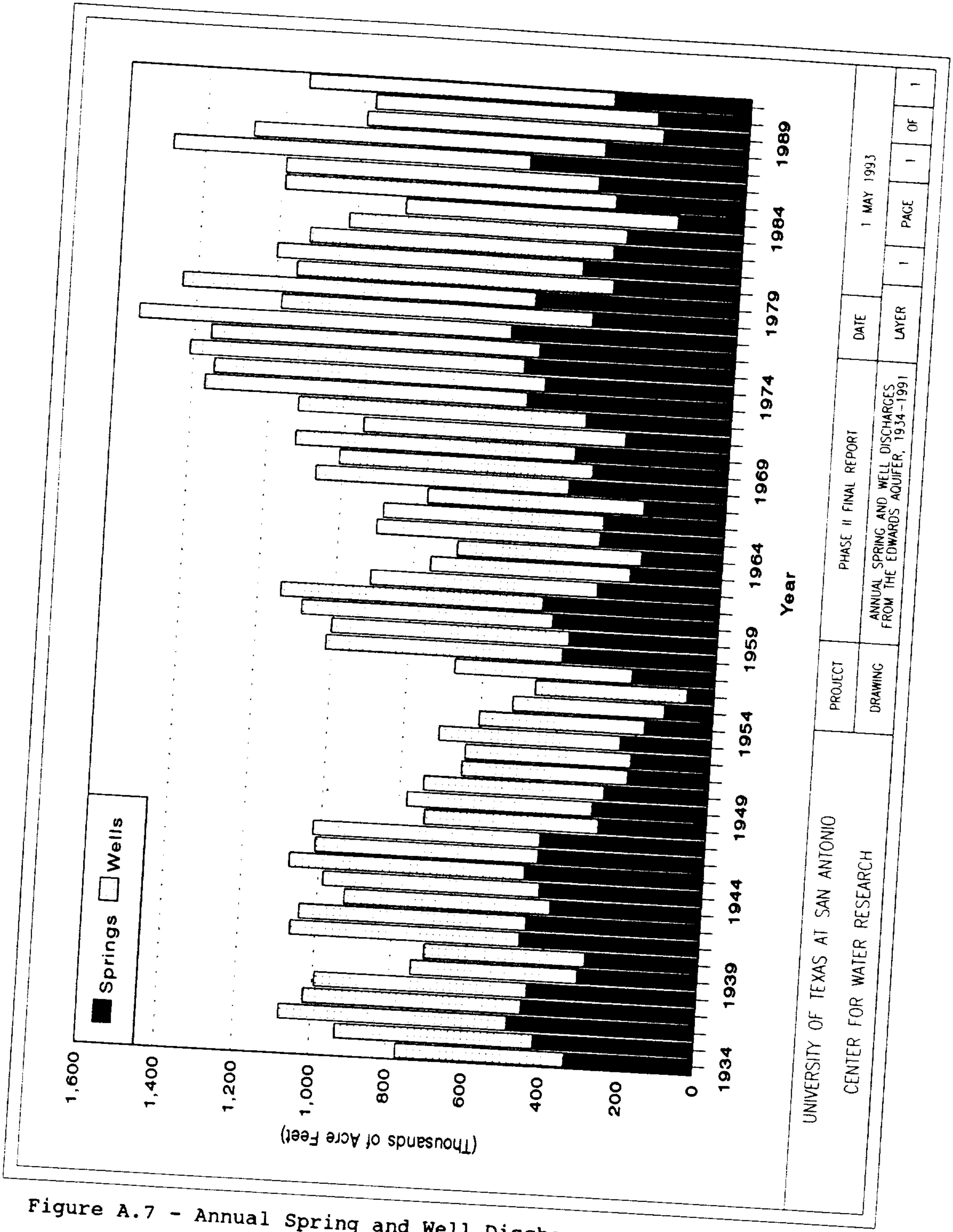
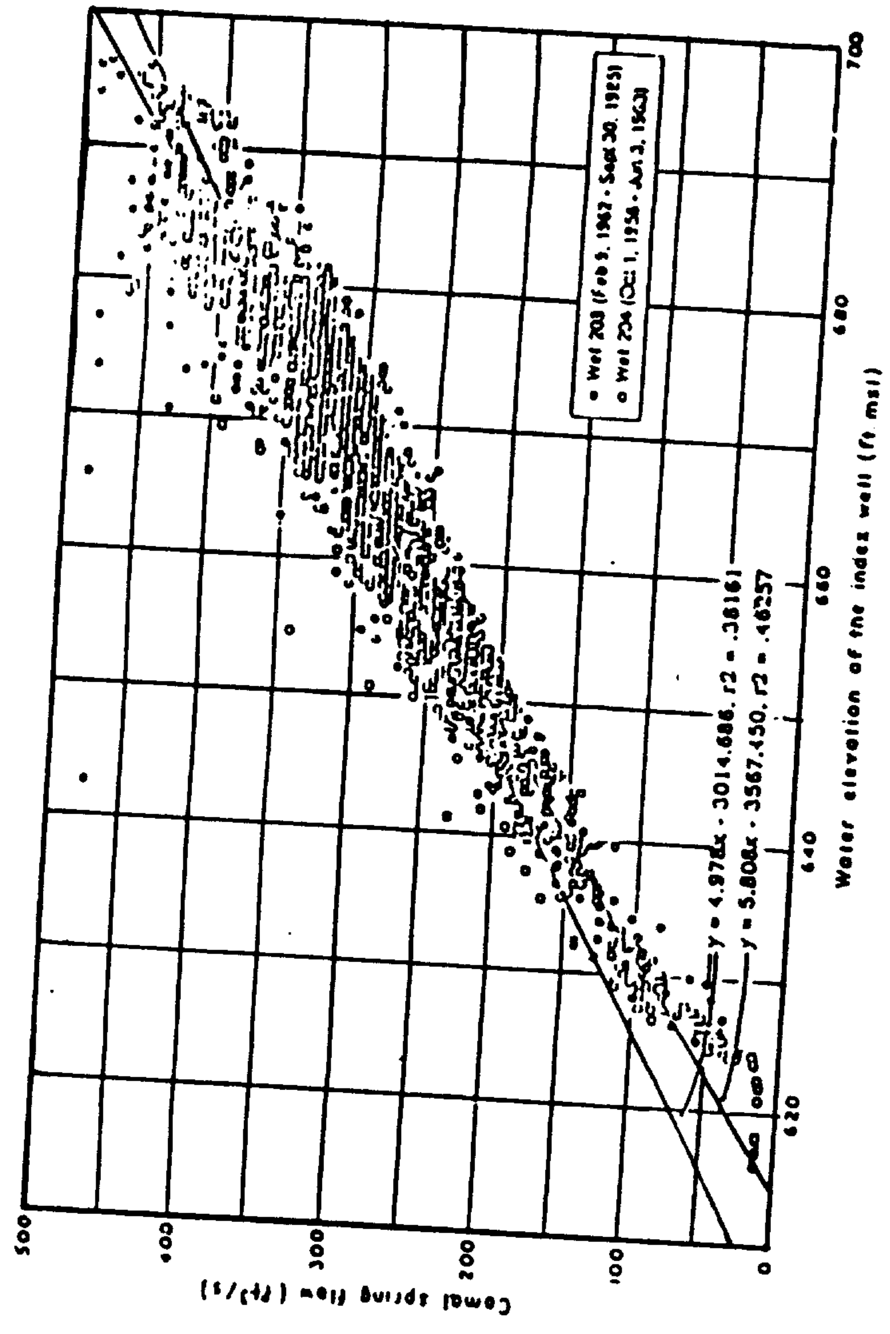


Figure A.7 - Annual Spring and Well Discharges from the Edwards Aquifer, 1934 to 1991 [A.5]



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		PAGE	1 OF 1

Figure A.8 - Comal Springs Flow Versus Water Levels at Well J-17, 1956 through 1985 [A.5]

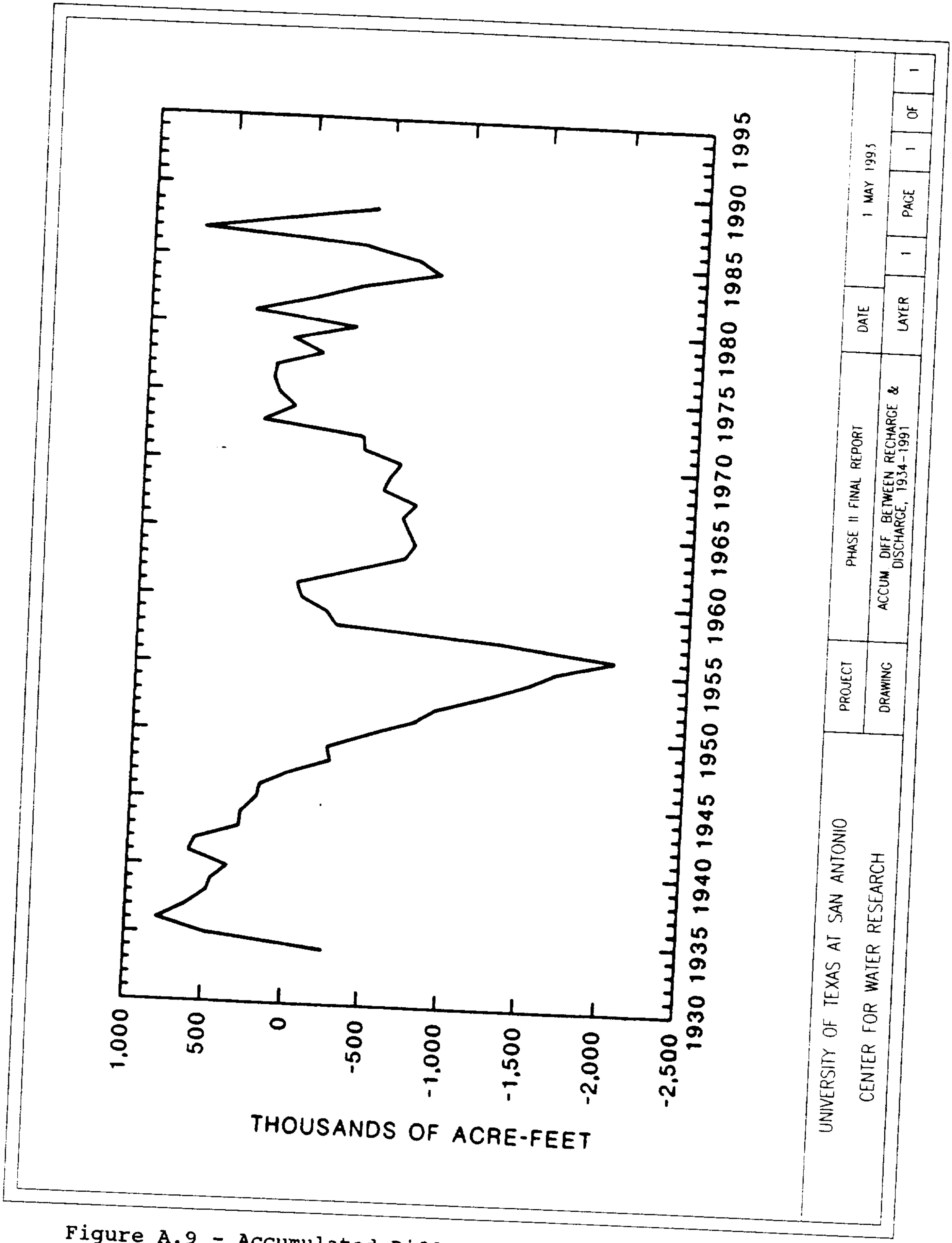


Figure A.9 - Accumulated Difference Between Recharge and Discharge in the Edwards Aquifer, 1934 to 1991 [A.5]

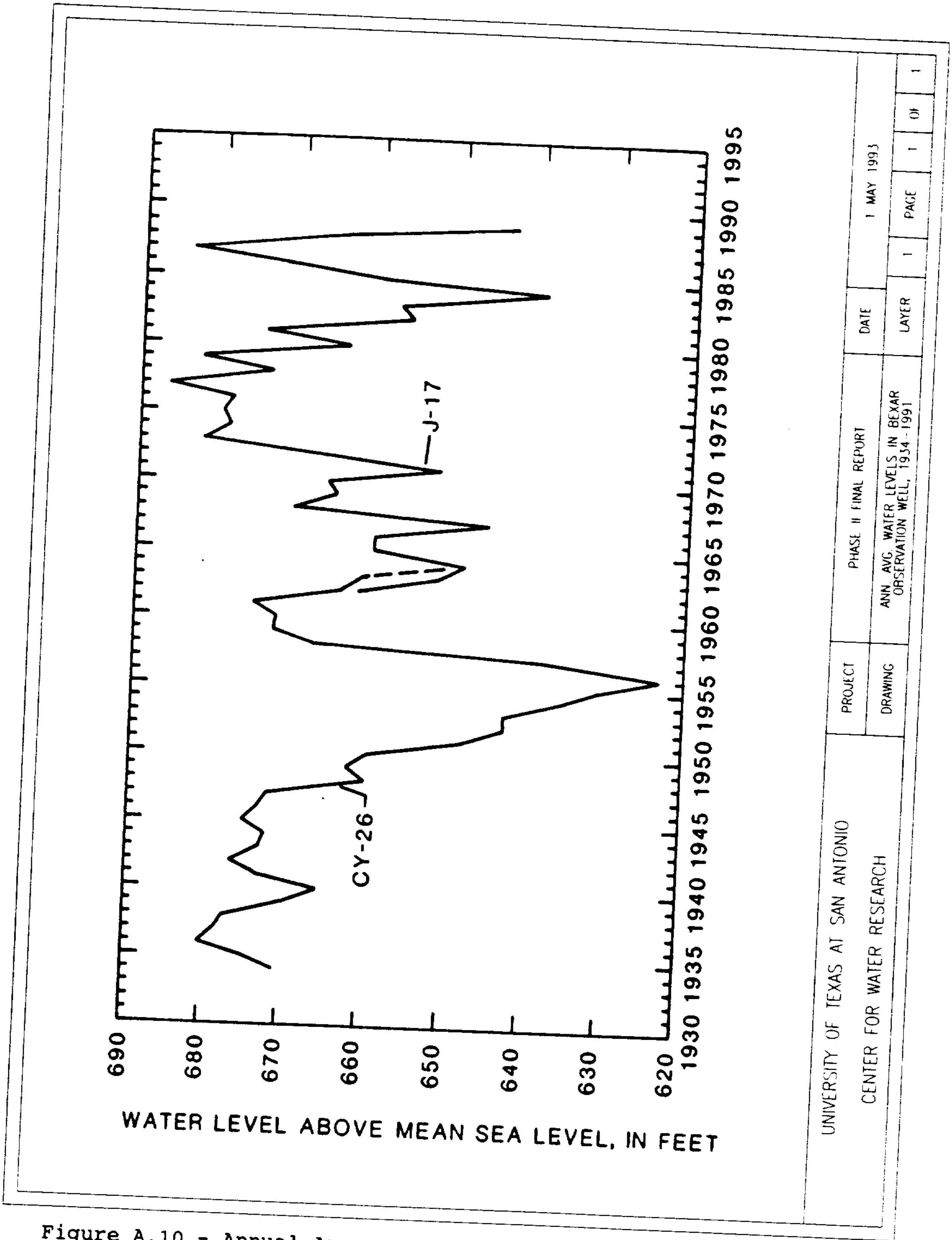


Figure A.10 - Annual Average Water Levels in the Bexar County Observation Well, 1934 to 1991 [A.5]

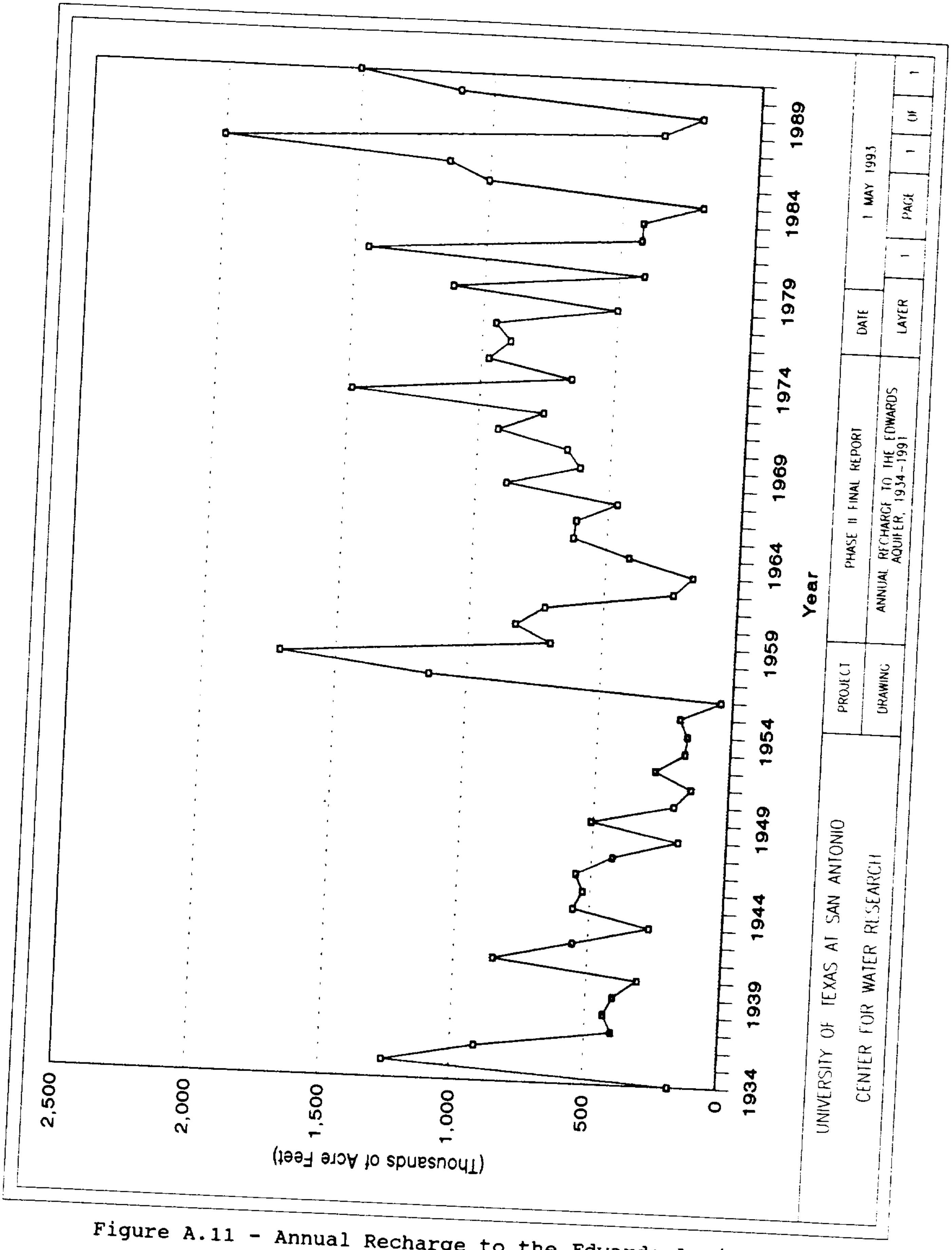


Figure A.11 - Annual Recharge to the Edwards Aquifer, 1934 to 1991 [A.5]

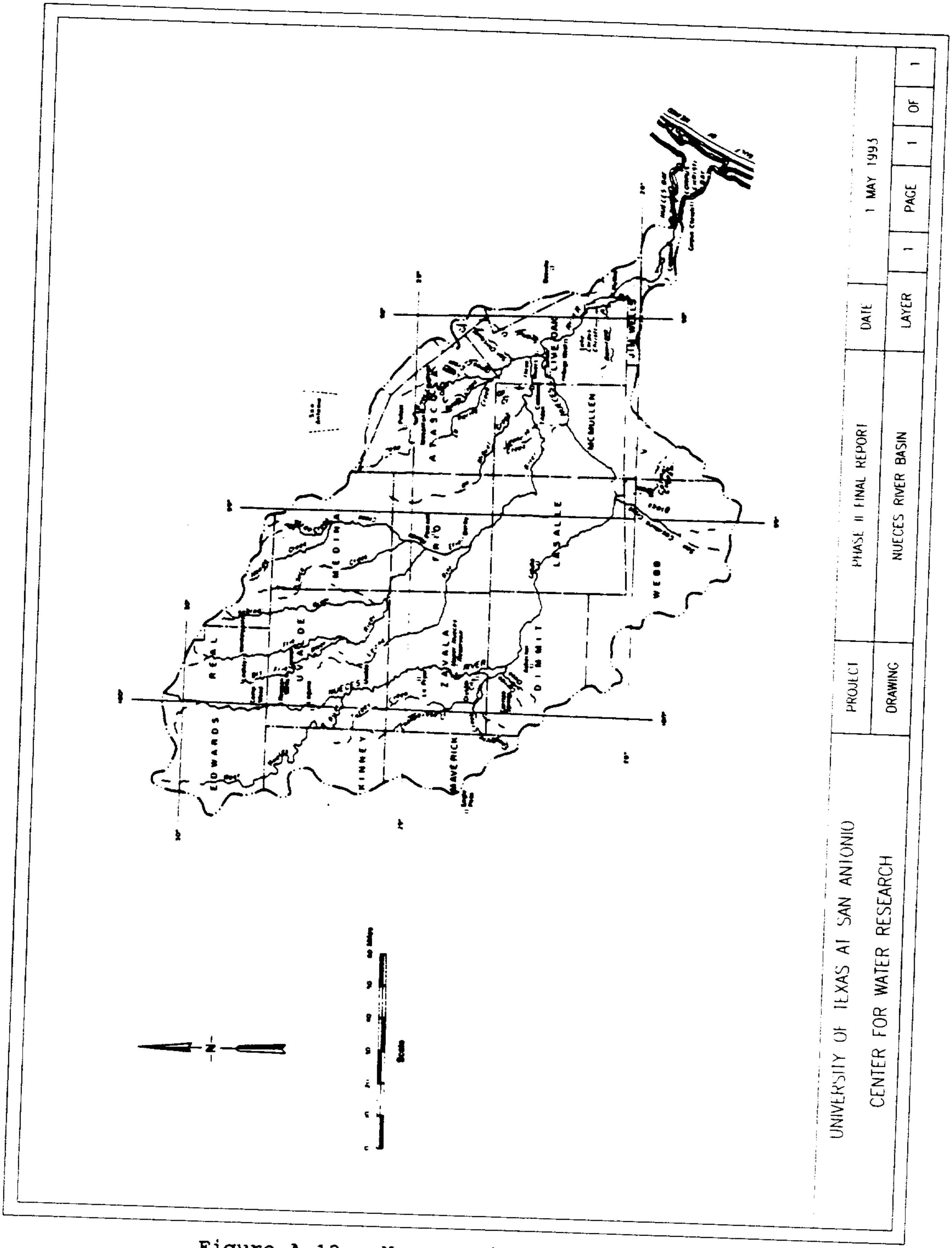


Figure A.12 - Nueces River Basin [A.8]

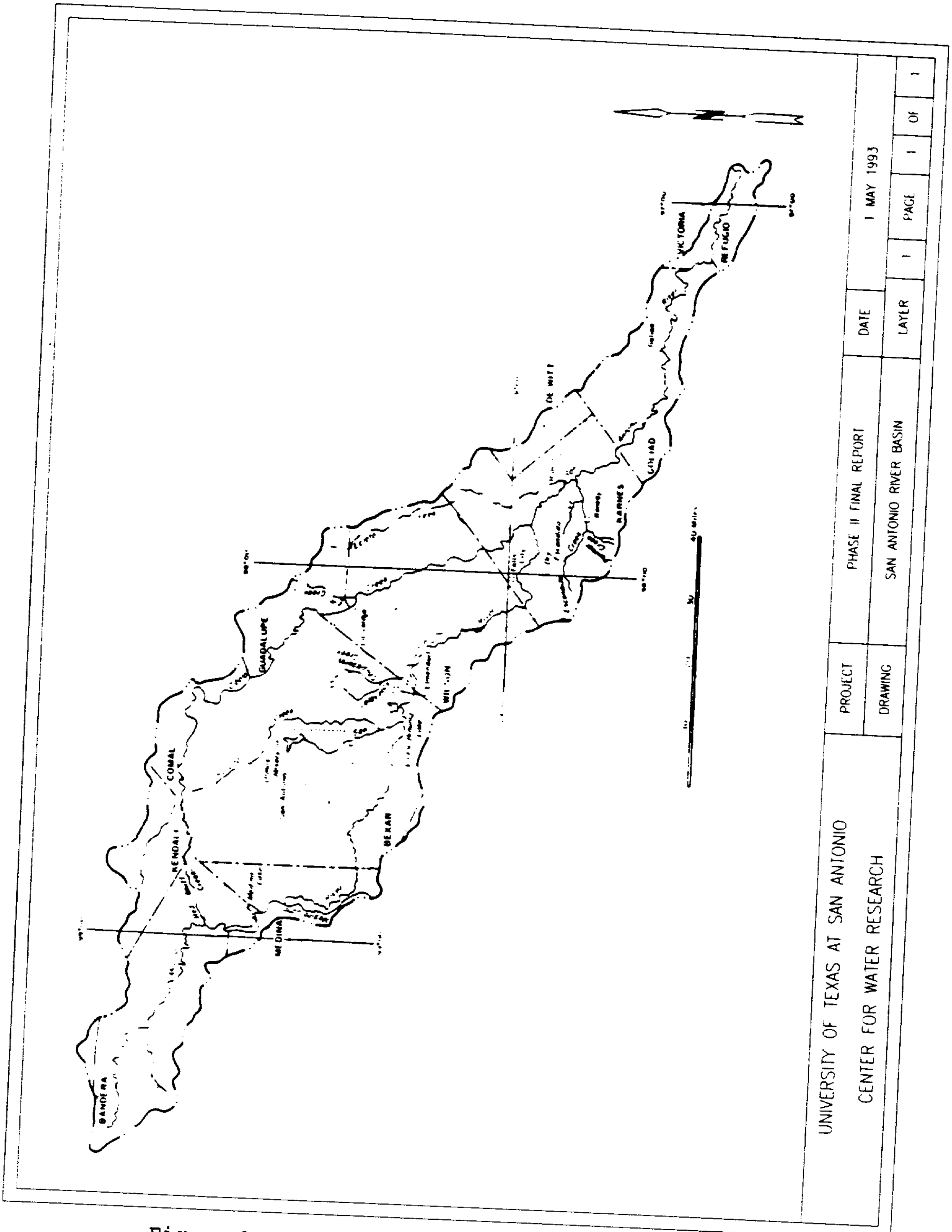


Figure A.13 - San Antonio River Basin [A.13]

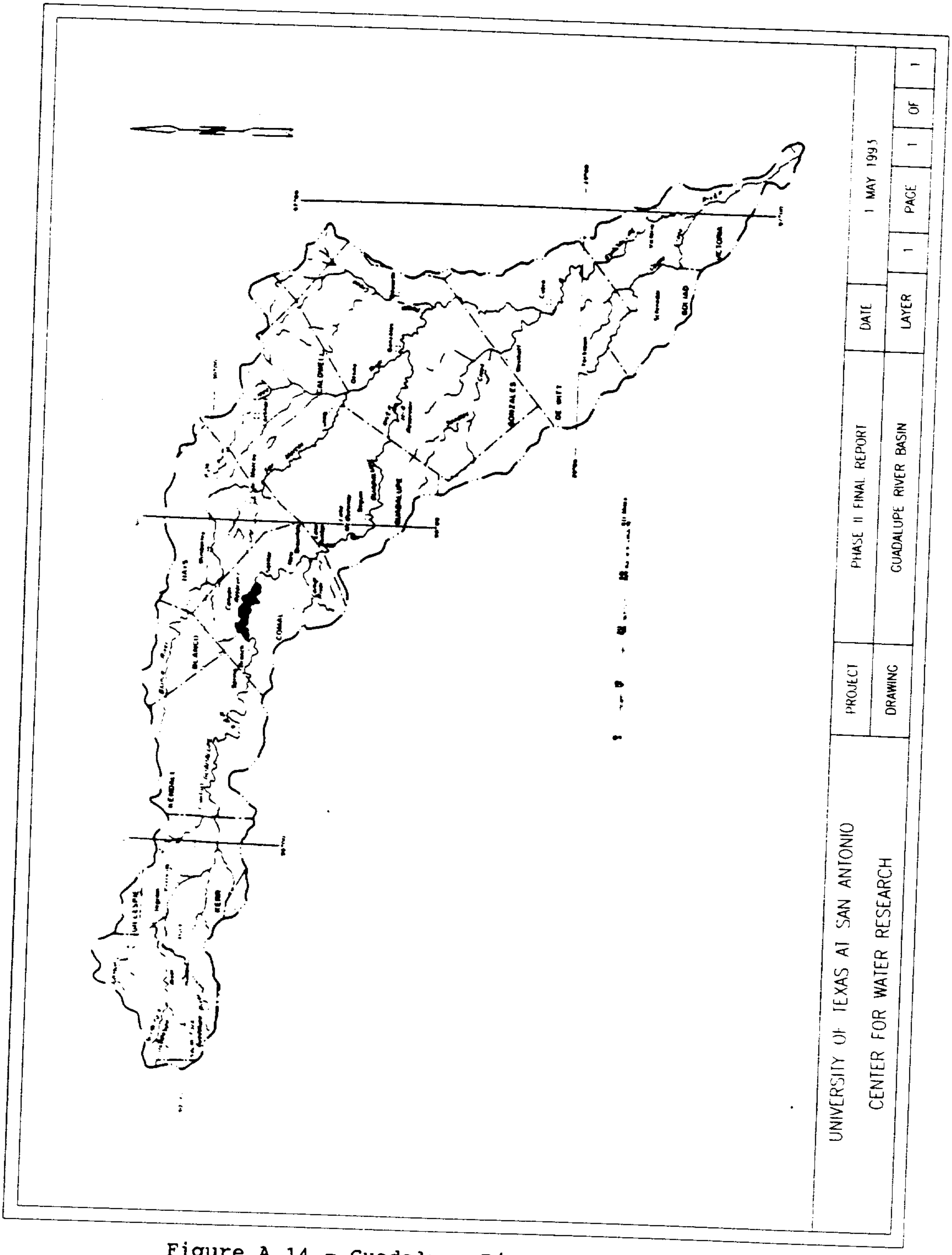


Figure A.14 - Guadalupe River Basin [A.16]

APPENDIX B

TECHNICAL DESCRIPTION OF GWSIM-IV MODEL

APPENDIX B

TECHNICAL DESCRIPTION OF GWSIM-IV MODEL

B.1 PROGRAM DESCRIPTION

The GWSIM-IV model is written in FORTRAN 77. It is composed of a main program (EXEC) which performs administrative functions for the computational process and subroutines which handle specific input, computational and output functions. Subroutines are divided broadly between general purpose routines, those that determine the aquifer flow (hydrologic) and those that compute mass transport (quality). The general purpose routines are OUTPUT, PLOTH, PLOTS and XSECT. The hydrologic routines are CALIB, FLUX, GETPMP, HYDRO, PHYSDT, SOLVE and SUMFLO. The quality routines are QREAD, QSOLVE, and QUAL. The connectivities between the various routines are shown in Figure B.1.

B.1.1 EXEC Routine

The EXEC program reads basic data and calls subroutines to perform input, computational and output tasks. It modifies and corrects variables, as required, during each time step and dimensions the majority of the arrays. If a finite difference grid with more than 31 rows or 31 columns is required, the array declaration must be changed in this program.

B.1.2 SUMFLO Routine

This subroutine calculates the groundwater flux across cell boundaries by Darcy's Law, utilizing the average head for the time period. The routine stores flows on disc during the execution of the hydrologic section of the program and reads the flows in the mass transport section.

B.1.3 QSOLVE Routine

This routine solves the system of equations for concentrations using the iterative alternating direction implicit (IADI) procedure. A user-supplied error criterion terminates the iterative sequence for each time step.

B.1.4 XSECT Routine

This subroutine produces a printer plot of a water level profile. Measured water levels are also printed, if available. The profiles may be along rows and/or along columns.

B.1.5 PLOTS Routine

This routine produces plots of simulation errors or head (quality) changes similar to those produced by Subroutine PLOTH. Simulation error or difference is equal to the simulated head level minus observed head level. Statistics are printed which may be used to compare the head differences. The mean, standard deviation, maximum and minimum values for the simulated head, observed head (if an error map is produced) or beginning head (if a head change map is produced), and difference in head are printed. The nodes with the maximum and minimum values are identified by row and column numbers. The mean and standard deviation of the absolute value of the head value is also printed. The covariance and regression coefficient are printed, but these values have meaning only when an error map is produced. These two values indicate the goodness-of-fit between the simulated and observed water level.

The subroutine only considers cells with non-zero observed head levels. This permits reading a set of observed head levels (Data Set 22) which contains only measured well levels. Normally, Data Set 22 contains measured values for all active cells, with most values obtained from a contour map of head levels.

B.1.6 PLOTH Routine

This routine produces print plots of head, saturated thickness or water quality. A letter will be printed for each active cell in the system to indicate the parameter value for that cell. The range of values corresponding to each letter is printed with statistics to indicated the distribution of the parameter.

Two plot scaling options are available. If the plotting scale factor read in Data Set 2 is zero, the maps will be printed with uniform cell spacing. No lines or spaces are skipped during the printing, and a compact map is produced. If the scale factor is not equal to zero, non-uniform grid spacings will be printed.

If the scale factor is greater than zero, the program attempts to print the information based on that scale. For example, if the factor equals 1000, the maps will be printed with 1000 length units per inch. If the grid spacings are such that more than one row (or column) occurs at a printing position, only the highest numbered row (or column) is shown. The plot will be segmented if necessary to produce a plot at the desired scale. As safety features, the plot will not be completed if the distance separating the first and last columns or first and last rows is more than 50 times the scale factor. The resulting plot may be no wider or longer than 50 inches.

If the scale factor is negative, the program computes the smallest scale factor that allows all data to be plotted. The maximum plot size is still 50 inches.

B.1.12 FLUX Routine

This subroutine prints a map of groundwater flows between nodes at the end of a time step. The maps are printed if either Time Step Option 12 or 17 is enabled. Both should not be enabled for the same time step. The appropriate units conversion factor and label must be read in Data Set 2.

Two maps are produced. The first map shows flow between columns and is labeled "Direction 1". For a cell subscripted i,j, the value printed is for flow from cell i,j to cell i,j+1. The second map, labeled "Direction 2", shows flow between rows. For a cell subscripted i,j the flow is from cell i,j to cell i+1, j. A negative number represents reversal of flow, i.e., from cell i,j+1 to cell i,j.

B.1.13 GETPMP Routine

This subroutine is called for each major time step, to read the pumpage and recharge data. It computes the net withdrawal rate, Qi, j, in units of cubic length per day.

B.1.14 QUAL Routine

This subroutine reads data related to mass transport and calls mass transport related subroutines. The majority of the mass transport modeling is performed by this subroutine.

B.1.15 OUTPUT Routine

This subroutine prints the majority of the model output. The mass balances are also computed in this routine. Many of the plotting routines are called from OUTPUT.

B.2 INPUT FILE

GWSIM-IV permits great flexibility in the construction of the data set. The user may specify the format of input blocks, the method of assigning the physical parameters of the system, and the form of inputs to the system. The content and format of program input and the output may be tailored to fit the user's needs. The computational procedures performed by the program, the format of the input data, and the form of the output are specified by the user through program options at the beginning of the input stream.

The basic input parameters for hydrologic modeling are:

1. Finite difference grid spacings
2. Node type
3. Land surface elevation
4. Top of aquifer elevation

5. Base of aquifer elevation
6. Saturated thickness
7. Initial head (water level elevation)
8. Hydraulic conductivity
9. Storage coefficient
10. Leakage terms
11. Pumpage and recharge rates

B.2.1 Features/Description

The following is a list of the data sets in the input stream, in the order that they are read by the program. The program options corresponding to each data set are also shown.

Data Set	Title	Read Switch
1	Title	Always
2	Parameters	Always
3	General program options	Always
4	Hydrograph specifications	Optional - GPO 1
5	Cross section specifications	Optional - GPO 2
6	Grid Spacing	Always
7	Physical Data	Always
8	Physical data corrections	Optional - GPO 6
9	Physical data adjustments	Optional - GPO 7
10	Leakage term assignment	Optional - GPO 11
11	Leakage term adjustments	Optional - GPO 12
12	Spring/River data	Optional

The following data sets may be read for each major time step

13	Time step options	Always
14	Pumpage for all cells	Optional - TSO 2
15	Pumpage by block	Optional - TSO 3
16	Pumpage adjustments	Optional - TSO 4
17	Recharge for all cells	Optional - TSO 5
18	Recharge by block	Optional - TSO 6
19	Recharge adjustments	Optional - TSO 7
20	Heads for constant head cells	Optional - TSO 24
21	Limits for statistical blocks	Optional - TSO 27
22	Measured heads	Optional - TSO 22
23	Mass Transport Title	Optional - GPO 15
24	Mass transport Options	Optional - GPO 15

The following data sets are read only if General Program Option 15 is enabled

25	Dispersion coefficients for all cells	Optional - MTO 1
26	Dispersion coefficients by block	Optional - MTO 3
27	Dispersion coefficient adjustments	Optional - MTO 4
28	Recharge quality for all	Optional - MTO 5

	cells	
29	Recharge quality by block	Optional - MTO 7
30	Recharge quality adjustments	Optional - MTO 8
31	Initial concentrations for all cells	Optional - MTO 14
32	Initial concentrations by block	Optional - MTO 17
33	Initial concentration adjustments	Optional - MTO 18
34	Porosity for all cells	Optional - MTO 21
35	Porosity by block	Optional - MTO 23
36	Porosity adjustments	Optional - MTO 24
37	Measured concentrations	Optional - MTO 14

Notes:
GPO = General Program Option (Data Set 3)
TSO = Time Step Option (Data Set 13)
MTO = Mass Transport Option (Data Set 24)

Data Sets 1 through 12 may be read only once, whereas the remainder of the sets may be read for each major time step. Many of the data sets are read only if the corresponding program option is enabled. Data Sets 23 through 37 are read only for mass transport computations (General Program Option 15 enabled).

If the user does not specify the format for a particular input block, the data will be read according to the default format specified by the program. The user may, however, override the default format by adding 5 to the value of the option that controls the data set. A record containing the new format then becomes the first line of the data set.

Card images of the input data sets are shown in Figure B.2.

B.2.2 DataSet 1 Description

This data set consists of one record, containing a title for the model run. This title is alphanumeric, and is limited to eighty characters.

Variable	Columns	Format	Description
TITLE	1-80	20A4	Title of Run

Table B.1 - Listing of DataSet 1 (Example)

```
      0         1         2         3         4         5         6         7         8
      1...5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0

   1 :  EDWARDS AQUIFER MODEL - TWDB MONTHLY REVERIFICATION,1947-1959
```

B.2.3 DataSet 2 Description

This data set consists of three records which contain various program parameters, as described below.

Variable	Columns	Format	Description
Record One			
NSTEPS	1-5	I5	Number of major time steps
NSP	6-10	I5	Number of minor time steps
NR	11-15	I5	Number of rows in grid
NC	16-20	I5	Number of columns in grid
NPARM	21-25	I5	Number of iteration parameters
NSPRG	26-30	I5	Number of spring or river cells
Record Two			
DELMAJ	1-10	F10.0	Length of major time step (days)
ERROR	11-20	F10.0	Convergence criterion
TIMACL	21-30	F10.0	Time acceleration factor
PMPFCT	31-40	F10.0	Units conversion factor for pumpage and recharge
PMPNAM	41-46	A6	Label to indicate pumpage and recharge units
XLGTNM	47-52	A6	Label to indicate length units
FLXNAM	53-64	A6	Label to indicate units for ground-water flow maps
Record Three			
PERFCT	1-10	F10.0	Units conversion factor for hydraulic conductivity
FLXFCT	11-20	F10.0	Units conversion factor for ground-water flow maps
STRFCT	21-30	F10.0	Ratio of water table to artesian storage coefficient
SCALE	31-40	F10.0	Scaling factor for

plotting head changes, heads, saturated thicknesses, and cross sections.

Table B.2 - Listing of DataSet 2 (Example)

```
        0    1    2    3    4    5    6    7    8
        1...5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0

   1 :   12   12   31   80    7   10
   2 :     30.42        1       1.2    1431.95  ACFT   FEET100'S AF/MO
   3 :    .13369.000006983      100
```

B.2.4 DataSet 3 Description

This one-line data set contains the General Program Options. If the option is set to 0, then the function controlled by that option will not be performed. A setting between 1 and 5 enables the function, and a setting of 6 or greater indicates that the function will utilize a user-specified format.

The General Program Options are fully defined in the program's documentation; they will be simply listed here. Although allowance is made in the program for thirty-five General Program Options, only fifteen are currently available for use.

Option	Function
1	Print hydrographs
2	Print cross-sections
3	Read constant grid spacings
4	Write grid spacings
5	Read default physical data
6	Read physical data corrections
7	Adjust parameters
8	Write physical data
9	Plot initial water levels
10	List and plot initial saturated thickness
11	Read leakage terms assignment
12	Read leakage terms adjustment
13	Write leakage terms
14	Calculate steady-state heads
15	Compute mass transport

Variable	Columns	Format	Description
OPT(X)	1-35	35I1	Program options

Table B.3 - Listing of DataSet 3 (Example)

```
          0         1         2         3         4         5         6         7         8
          1...5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0

      1 :   5 5    8
```

B.2.5 DataSet 4 Description

This dataset is used to define the cells for which hydrographs are to be printed, and is controlled by General Program Option 1. Up to twenty-five cells may be so defined. Data set 4 may contain one or two records, depending on the number of cells selected.

Variable	Columns	Format	Description
Record One			
NSAVE	1-3	I3	Number of cells for which hydrographs are to be printed
ISAVE(1)	4-6	I3	Row number of first identified cell
JSAVE(1)	7-9	I3	Column number of first identified cell
ISAVE(2)	10-12	I3	Row number of second identified cell
JSAVE(2)	13-15	I3	Column number of second identified cell
The sequence continues through:			
ISAVE(13)	76-78	I3	Row number of thirteenth identified cell
Record Two			
JSAVE(13)	1-3	I3	Column number of thirteenth identified cell
ISAVE(14)	4-6	I3	Row number of fourteenth identified cell
JSAVE(14)	7-9	I3	Column number of fourteenth identified cell

The sequence continues through:

JSAVE(25)	72-75	I3	Column number of twenty-fifth identified cell

No data set example is available.

B.2.6 DataSet 5 Description

This dataset is used to define the specification for cross section outputs, and is controlled by General Program Option 2. Up to twenty-five rows and columns may be defined. Data set 5 contains two records, the first consisting of the columns for which cross-sections are requested and the second specifying the rows for which cross-sections are requested.

Variable	Columns	Format	Description
Record One			
NCOLS	1-3	I3	Number of columns for which cross-sections are requested
MCOLS(1)	4-6	I3	First column to be cross-sectioned
MCOLS(2)	7-9	I3	Second column to be cross-sectioned

The sequence continues through the last column

MCOLS(25)	75-78	I3	Twenty-fifth column to be cross-sectioned
Record Two			
NROWS	1-3	I3	Number of rows for which cross-sections are requested
MROWS(1)	4-6	I3	First row to be cross-sectioned
MROWS(2)	7-9	I3	Second row to be cross-sectioned

The sequence continues through the last column

MROWS(25)	76-78	I3	Twenty-fifth row to be cross-sectioned

No data set example is available.

B.2.7 DataSet 6 Description

This data set defines the grid spacings and is read if General Program Option 3 is enabled. The unit for grid spacing is length.

If GPO-3 is equal to 1 (or 6, if a user-specified format is added as record 1), constant spacings are read. The spacings in the X-direction (columns) are read 15 values per card, with 5 spaces per value. Y-values (rows) are read in a similar fashion. The data is read in a similar fashion if the user has specified a format (GPO-3 equal to 6), with the number of specifications per card controlled by the format chosen. The unit for grid spacing is length.

The default format is:

Variable	Columns	Format	Description
HA	1-5	F5.0	Grid spacing in X-direction (between columns)
HB	6-10	F5.0	Grid spacing in Y-direction (between rows)

Table B.4 - Listing of DataSet 6 (Example)

```
      0         1         2         3         4         5         6         7         8
      1...5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0

  1 : (10X,10F7.0)
  2 :            10560. 10560. 12672. 12144.  9504. 11352.  8712. 13464. 15840. 13200.
  3 :            10296.  6864. 10560. 12672. 12144. 16896. 14256. 12144.  8448.  8976.
  4 :             9504.  9504.  8976.  8184.  8976. 11088.  8976. 10296. 10032. 16104.
  5 :            13464. 19536. 16368. 11880. 12144.  9504.  7656. 11616. 19272.  9504.
  6 :            14256. 15312.  7128.  9768. 10560.  8448.  8712. 15840. 14256. 11352.
  7 :             7392.  6864.  9504. 10032. 12144. 14520. 10560.  8448.  9504.  9504.
  8 :             9240. 11616. 10560.  8448.  7392.  7392.  7392.  7392. 10032.  8976.
  9 :            10032. 10032.  8976.  9504.  8184.  6336. 12672. 14520. 10032. 10560.
 10 :            13992. 17952. 16896. 15840. 12144.  8712. 14256. 15576.  7920. 11352.
 11 :             8712.  7656. 11088.  6600.  6336. 13464. 11880. 12672. 11088.  8448.
 12 :             4752.  8976.  6336.  8184.  6864.  9504.  7392.  5808.  8184.  5808.
 13 :            26400.
```

B.2.8 DataSet 7 Description

This data set contains the information necessary to physically describe the area being modeled. This data set can be read in two ways. If a single default set of information is to be applied to all cells in the model (GPO-5 equals 1), then the following format is used and only one card is read. A different format may be used by adding 5 to the value of General Program Option 5 and inserting a format statement as record 1.

Variable	Columns	Format	Description
K	5	I1	Node type declaration *
B(1)	6-10	F5.0	Land surface elevation
B(2)	11-15	F5.0	Top of aquifer elevation
B(3)	16-20	F5.0	Base of aquifer elevation
B(4)	21-25	F5.0	Saturated thickness
B(5)	26-30	F5.0	Initial head (water level)
B(6)	31-35	F5.0	Hydraulic conductivity in X direction
B(7)	36-40	F5.0	Hydraulic conductivity in Y direction
B(8)	41-45	F5.0	Storage coefficient **

* Possible node type declarations are as follows:

Flag	Node Type
1	Water Table
2	Artesian
3	Exterior

** Read if the node type is Artesian

If 5 is added to General Program Option 5, physical data values are read for each cell (one record per cell) by a user-specified format. Variable names for this case are as follows:

Variable	Description
NR	Row Number (I)
NC	Column Number (J)
FLAG(NR,NC)	Node type declaration
SURF(NR,NC)	Land surface elevation
TOPAQ(NR,NC)	Top of aquifer elevation
BOTLEL(NR,NC)	Base of aquifer elevation
THIK(NR,NC)	Saturated thickness
H(NR,NC)	Initial Head (water level)
P(NR,NC,1)	Hydraulic conductivity in X-direction
P(NR,NC,2)	Hydraulic conductivity in Y-direction
SF1(NR,NC)	Storage Coefficient

Table B.5 - Listing of DataSet 7 (Example)

```
     0        1         2         3         4         5         6         7         8
     1...5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0

 1 : (6X,I3,5F9.3,2F8.1,F10.5)
 2 :   1  1  3    5.000     .000     .000     .000    0.000      .0      .0    .06000
 3 :   1  2  3    5.000     .000     .000     .000    0.000      .0      .0    .06000
 4 :   1  3  1 1250.000 1250.000 1125.000  100.000 1189.258    63.0    15.0    .06000
 5 :   1  4  1 1350.000 1350.000 1140.000   93.000 1202.271    38.0    15.0    .06000
 6 :   1  5  1 1390.000 1390.000 1150.000   90.000 1224.700    25.0    15.0    .06000
 7 :   1  6  1 1560.000 1560.000 1180.000   66.000 1256.711    13.0    15.0    .06000
 8 :   1  7  1 1500.000 1500.000 1180.000   70.000 1285.246    10.0    15.0    .06000
 9 :   1  8  1 1370.000 1370.000 1175.000   84.000 1307.210    13.0    15.0    .06000
10 :   1  9  1 1480.000 1480.000 1210.000   70.000 1328.571      .0    15.0    .06000
11 :   1 10  3    5.000     .000     .000     .000    0.000      .0      .0    .06000
```

B.2.9 DataSet 8 Description

This data set contains corrections to the physical data and is read if General Program Option 6 is enabled. The format of this dataset is user-configurable by adding 5 to the value of GPO-6. If used, this dataset consists of a variable number of records, with a minimum number of two. The last record must be blank.

Variable	Columns	Format	Description
II	1-5	I5	First row of grid segment
III	6-10	I5	Last row of grid segment
JJ	11-15	I5	First column of grid segment
JJJ	16-20	I5	Last column of grid segment
K	21-25	I5	Nodal type declaration
B(1)	26-30	F5.0	Land surface elevation
B(2)	31-35	F5.0	Top of aquifer elevation
B(3)	36-40	F5.0	Base of aquifer elevation
B(4)	41-45	F5.0	Saturated thickness
B(5)	46-50	F5.0	Initial head (water level)
B(6)	51-55	F5.0	Hydraulic conductivity in X-direction
B(7)	56-60	F5.0	Hydraulic conductivity in

B(8)	61-65	F5.0	Y-direction Storage Coefficient *

* If the nodal declaration is Artesian (2), the storage coefficient must be multiplied by 1,000,000 prior to coding.

No example data set is available.

B.2.10 DataSet 9 Description

This data set contains factors to adjust the initial values of hydraulic conductivity and storage coefficient and is read if General Program Option 7 is enabled. One record is required for each adjustment, which is applied to a specified section of the grid.

Maps of the parameters may also be printed. If the option equals 1, no maps are printed; if it equals 2, hydraulic conductivity and transmissivity maps in both directions are printed; if it equals 3, a storage coefficient map is printed; and if it equals 4, all maps are printed.

Variable	Columns	Format	Description
II	1-5	I5	First row of grid segment
III	6-10	I5	Last row of grid segment
JJ	11-15	I5	First column of grid segment
JJJ	16-20	I5	Last column of grid segment
K	21-25	I5	Parameter identifier *
HA	26-35	F10.0	Adjustment Value **

* If the parameter identifier is 1 or -1, hydraulic conductivity in X-direction is modified. If the identifier is 2 or -2, hydraulic conductivity in Y-direction is modified. If the identifier is 3, the storage coefficient is modified.

Additionally, if the identifier is -1 or -2, new hydraulic conductivities are calculated by dividing the adjustment value by the saturated thickness. Thus, the adjustment value becomes a transmissivity value.

** If the adjustment value is non-negative, the present value of the parameter is multiplied by the adjustment value, and adjustments are cumulative. If the adjustment value is negative, the absolute value of the adjustment is assigned to all cells in the defined grid section.

No example data set is available.

B.2.11 DataSet 10 Description

This data set contains leakage terms to be assigned to some or all cells in the grid and is read if General Program Option 11 is enabled. There are three possible conditions of General Program Option 11.

If GPO-11 equals 1, leakage terms are read for all cells. Only data sub-set 1 is read.

If GPO-11 equals 2, leakage terms are read for all cells, followed by block replacements of leakage terms. Data sub-sets 1 and 2 are read.

If GPO-11 equals 3, only block replacements (data sub-set 2) are read.

A different format may be used by adding 5 to GPO-11, and placing a format statement as the first record of the data (sub-) set.

In all cases, the last record must be blank.

Variable	Columns	Format	Description
Sub-set 1			
B(I,J)	11-17	F7.0	Reference head for cell (I,J)
G(I,J)	18-24	F7.0	Slope for cell (I,J)
B(I,J)	25-31	F7.0	Reference head for cell (I,J+1)
G(I,J)	32-38	F7.0	Slope for cell (I,J+1)
B(I,J)	39-45	F7.0	Reference head for cell (I,J+2)
G(I,J)	46-52	F7.0	Slope for cell (I,J+2)
B(I,J)	53-59	F7.0	Reference head for cell (I,J+3)
G(I,J)	60-66	F7.0	Slope for cell (I,J+3)
B(I,J)	67-73	F7.0	Reference head for cell (I,J+4)
G(I,J)	74-80	F7.0	Slope for cell (I,J=4)

The values are read a row at a time, with five pairs of values on each card.

The units of reference head are length, and must agree with the units used in Data Set 7. The units of slope are volume per major time step per unit of length, and they are converted to cubic length per day per length by the conversion factor in Data Set 2. The slope values may be read on a per unit area per day basis (i.e. feet per day per foot) instead of acre-feet per year per foot. This is accomplished by placing a negative sign before the slope values read in this data set.

Sub-set 2

II	1-5	I5	First row of grid segment
III	6-10	I5	Last row of grid segment
JJ	11-15	I5	First column of grid segment
JJJ	16-20	I5	Last column of grid segment
HA	21-30	F10.0	Reference head
HB	31-40	F10.0	Slope

Table B.6 - Listing of DataSet 10, Sub-set 2 (Example)

```
     0        1         2         3         4         5         6         7         8
     1...5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0

1 :  (4I3,2F5.0)
2 :   18 19 21 21 630.  6.25
3 :   20 20 22 22  630 6.25
4 :   0
```

B.2.12 DataSet 11 Description

This data set is read if General Program Option 12 is enabled. All or some of the leakage terms read in Data Set 10 are multiplied by these values. The data set is further divided into two data sub-sets, following the same restrictions and formats as Data Set 10, and are read the same way except that, instead of the input values being assigned to the cells, the input values multiply those values previously read in Data Set 10.

No example data set is available.

B.2.13 DataSet 12 Description

This data set contains row and column numbers, reference heads, and slope terms for cells declared to be spring or river cells. This data set is read if variable NSPRG on line one of Data Set 2 is greater than 0.

For a spring cell, flow will be from the cell as long as the calculated head for the cell is higher than the reference head. If the calculated head falls below the reference head, there will be no flow.

For a river cell, there will be flow out of the cell if the calculated head is greater than the reference head, otherwise, flow will be into the cell. A river cell is designated by coding the slope as a negative number.

At the end of each major time step, the total flow volume is printed for each spring/river cell.

Variable	Columns	Format	Description
I	1-5	I5	Row number for cell
J	6-10	I5	Column number for cell
RD(I,J)	11-20	F10.0	Reference head
R(I,J)	21-30	F10.0	Slope

Table B.7 - Listing of DataSet 12 (Example)

```
      0         1         2         3         4         5         6         7         8
      1...5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0

 1 :  (2I5,2F10.0)
 2 :     20   64  620.      2611.7
 3 :     17   74  574.       887.0
 4 :     13   14  863.        58.2
 5 :     13   15  858.         6.4
 6 :     14   14  862.         6.4
```

B.2.14 DataSet 13 Description

This one-line data set contains the Time Step Options plus the parameters needed to adjust the time step size (see Time Step Option 1) and a comment field.

The Time Step Options are fully defined in the program's documentation; they will be simply listed here.

Option	Function
1	Change time step parameters
2	Read pumpage for each cell
3	Read pumpage by block
4	Pumpage adjustments
5	Read recharge for each cell
6	Read recharge by block
7	Recharge adjustments
8	unused
9	Store pumpage and recharge rates
10	Retrieve pumpage and recharge rates
11	List pumpage and recharge rates
12	Plot flows - minor

13	List heads - minor
14	Save heads
15	Save physical data
16	List heads - major
17	Plot flows - major
18	List head changes during this step
19	Plot head changes during this step
20	List head changes through this step
21	Plot head changes through this step
22	Compare measured heads
23	Plot cross-sections
24	Read constant heads
25	List and plot saturated thickness
26	Plot heads
27	Read limits for statistical blocks

Variable	Columns	Format	Description
OPT(X)	1-27	I1	Value for Option X
NSP2	31-35	I5	Number of minor time steps for this step if Time Step Option 1 is enabled
DELMJI	36-45	F10.0	Length of this major time step, in days, if Time Step Option 1 is enabled.
TIMAC1	46-55	F10.0	Time step acceleration factor for this major time step if Time Step Option 1 is enabled
B(J)	56-79	A4	Comment to describe time step

Table B.8 - Listing of DataSet 13 (Example)

```
    0         1         2         3         4         5         6         7         8
    1...5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0

1 : 010010000000000000000000000
```

B.2.15 DataSet 14 Description

This data set contains a pumpage value for each cell in the system and is read if Time Step Option 2 is enabled. The data are read by rows, with ten cell values per record. The first ten characters of each record are not read, and may be used to describe the record. A user-defined format may be used if 5 is added to TSO-2, and a format record is added as data set record 1. The units are volume per major time step (i.e. acre-feet per year). They are converted to cubic length per day by the conversion factor in Data Set 2.

Variable	Columns	Format	Description
Q(I,J)	11-17	F7.0	Value for column 1 (11, 21, etc)
Q(I,J)	18-24	F7.0	Value for column 2 (12, 22, etc)
Q(I,J)	25-31	F7.0	Value for column 3 (13, 23, etc)
Q(I,J)	32-38	F7.0	Value for column 4 (14, 24, etc)
Q(I,J)	39-45	F7.0	Value for column 5 (15, 25, etc)
Q(I,J)	46-52	F7.0	Value for column 6 (16, 26, etc)
Q(I,J)	53-59	F7.0	Value for column 7 (17, 27, etc)
Q(I,J)	60-65	F7.0	Value for column 8 (18, 28, etc)
Q(I,J)	66-73	F7.0	Value for column 9 (19, 29, etc)
Q(I,J)	74-80	F7.0	Value for column 10 (20, 30, etc)

Table B.9 - Listing of DataSet 14 (Example)

```
         0         1         2         3         4         5         6         7         8
         1...5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0

  1 :    147PMP 11    .00    .00    .34    .34    .25    .25    .17    .34    .42    .00
  2 :    147PMP 12    .00    .00    .00    .00    .00    .00    .00    .00    .00    .00
  3 :    147PMP 13    .00    .00    .00    .00    .00    .00    .00    .00    .00    .00
  4 :    147PMP 14    .00    .00    .00    .00    .00    .00    .00    .00    .00    .00
  5 :    147PMP 15    .00    .00    .00    .00    .00    .00    .00    .00    .00    .00
  6 :    147PMP 16    .00    .00    .00    .00    .00    .00    .00    .00    .00    .00
  7 :    147PMP 17    .00    .00    .00    .00    .00    .00    .00    .00    .00    .00
  8 :    147PMP 18    .00    .00    .00    .00    .00    .00    .00    .00    .00    .00
  9 :    147PMP 21    .00    .00    .42    .42    .34    .34    .25    .50    .59    .42
 10 :    147PMP 22    .00    .00    .00    .00    .00    .00    .00    .00    .00    .00
 11 :    147PMP 23    .00    .00    .00    .00    .00    .00    .00    .00    .00    .00
 12 :    147PMP 24    .00    .00    .00    .00    .00    .00    .00    .00    .00    .00
 13 :    147PMP 25    .00    .00    .00    .00    .00    .00    .00    .00    .00    .00
 14 :    147PMP 26    .00    .00    .00    .00    .00    .00    .00    .00    .00    .00
 15 :    147PMP 27    .00    .00    .00    .00    .00    .00    .00    .00    .00    .00
 16 :    147PMP 28    .00    .00    .00    .00    .00    .00    .00    .00    .00    .00
```

B.2.16 DataSet 15 Description

This data set contains pumpage rates for all cells in a specified region of the grid and is read if Time Step Option 3 is enabled. The units in this data set are the same as those used in Data Set 14. The last record of this data set must be blank. A user-specified format may be used if 5 is added to TSO-3 and a format statement is added as record 1.

Variable	Columns	Format	Description
II	1-5	I5	First row of grid segment
III	6-10	I5	Last row of grid segment
JJ	11-15	I5	First column of grid segment
JJJ	16-20	I5	Last column of grid segment
HA	21-30	F10.0	Pumpage rate

No example data set is available.

B.2.17 DataSet 16 Description

This data set contains pumpage adjustment factors which will multiply the pumpage rates for all cells in a specified region of the grid and is read if Time Step Option 4 is enabled. The last record of this data set must be blank. A user-specified format may be used if 5 is added to TSO-4 and a format statement is added as record 1.

Variable	Columns	Format	Description
II	1-5	I5	First row of grid segment
III	6-10	I5	Last row of grid segment
JJ	11-15	I5	First column of grid segment
JJJ	16-20	I5	Last column of grid segment
HA	21-30	F10.0	Pumpage adjustment factor

No example data set is available.

B.2.18 DataSet 17 Description

This data set contains a recharge value for each cell in the system and is read if Time Step Option 5 is enabled. The data are read by rows, with ten cell values per record. The first ten characters of each record are not read, and may be used to describe the record. A user-defined format may be used if 5 is added to TSO-5 and a format record is added as data set record 1. The units are volume per major time step (i.e. acre-feet per year). They are converted to cubic length per day by the conversion factor in Data Set 2.

Variable	Columns	Format	Description
RHG(I,J)	11-17	F7.0	Value for column 1 (11, 21, etc)
RHG(I,J)	18-24	F7.0	Value for column 2 (12, 22, etc)
RHG(I,J)	25-31	F7.0	Value for column 3 (13, 23, etc)
RHG(I,J)	32-38	F7.0	Value for column 4 (14, 24, etc)
RHG(I,J)	39-45	F7.0	Value for column 5 (15, 25, etc)
RHG(I,J)	46-52	F7.0	Value for column 6 (16, 26, etc)
RHG(I,J)	53-59	F7.0	Value for column 7 (17, 27, etc)
RHG(I,J)	60-65	F7.0	Value for column 8 (18, 28, etc)
RHG(I,J)	66-73	F7.0	Value for column 9 (19, 29, etc)
RHG(I,J)	74-80	F7.0	Value for column 10 (20, 30, etc)

Table B.10 - Listing of DataSet 16 (Example)

```
     0         1         2         3         4         5         6         7         8
     1...5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0

 1 : RECHR 11      0.0    0.0   32.0   31.0   24.0   36.0   28.0   43.0   40.0    0.0
 2 : RECHR 12      0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
 3 : RECHR 13      0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
 4 : RECHR 14      0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
 5 : RECHR 15      0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
 6 : RECHR 16      0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
 7 : RECHR 17      0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
 8 : RECHR 18      0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
 9 : RECHR 21      0.0    0.0   41.0   39.0   31.0   37.0   28.0   44.0   51.0   43.0
10 : RECHR 22      0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
11 : RECHR 23      0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
12 : RECHR 24      0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
13 : RECHR 25      0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
14 : RECHR 26      0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
15 : RECHR 27      0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
16 : RECHR 28      0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
```

B.2.19 DataSet 18 Description

This data set contains recharge rates for all cells in a specified region of the grid and is read if Time Step Option 6 is enabled. The units in this data set are the same as those used in Data Set 15. The last record of this data set must be blank. A user-specified format may be used if 5 is added to TSO-6 and a format statement is added as record 1.

Variable	Columns	Format	Description
II	1-5	I5	First row of grid segment
III	6-10	I5	Last row of grid segment
JJ	11-15	I5	First column of grid segment
JJJ	16-20	I5	Last column of grid segment
HA	21-30	F10.0	Recharge rate

No example data set is available.

B.2.20 DataSet 19 Description

This data set contains recharge adjustment factors which will multiply the recharge rates for all cells in a specified region of the grid and is read if Time Step Option 7 is enabled. The last record of this data set must be blank. A user-specified format may be used if 5 is added to TSO-7 and a format statement is added as record 1.

Variable	Columns	Format	Description
II	1-5	I5	First row of grid segment
III	6-10	I5	Last row of grid segment
JJ	11-15	I5	First column of grid segment
JJJ	16-20	I5	Last column of grid segment
HA	21-30	F10.0	Recharge adjustment factor

No example data set is available.

B.2.21 DataSet 20 Description

This data set contains the heads at the end of major Time Steps or changes in head during the major time step for constant-head cells, and is read if Time Step Option 24 is enabled.

If data are to be read for all cells, (TSO-24 value of 1 or 2), the data are to be read in the same manner as Data Set 14.

If values are to be read for a specified region of the grid (TSO-24 value of 3 or 4), the data are read in a manner similar to Data set 15.

If TSO-24 equals 1 or 3, the value read is a specified head for the area involved.

If TSO-24 equals 2 or 4, the value read is a change in head for the area involved.

Adding 5 to TSO-24 allows a user-specified format to be used, which is added as record 1.

If TSO-24 is equal to 3 or 4 (or 8/9), then the last record of the data set must be blank.

Variable	Columns	Format	Description
TSO-24, value 1 or 2			
B(I,J)	11-17	F7.0	Value for column 1 (11, 21, etc)
B(I,J)	18-24	F7.0	Value for column 2 (12, 22, etc)
B(I,J)	25-31	F7.0	Value for column 3 (13, 23, etc)
B(I,J)	32-38	F7.0	Value for column 4 (14, 24, etc)
B(I,J)	39-45	F7.0	Value for column 5 (15, 25, etc)
B(I,J)	46-52	F7.0	Value for column 6 (16, 26, etc)
B(I,J)	53-59	F7.0	Value for column 7 (17, 27, etc)
B(I,J)	60-65	F7.0	Value for column 8 (18, 28, etc)
B(I,J)	66-73	F7.0	Value for column 9 (19, 29, etc)
B(I,J)	74-80	F7.0	Value for column 10 (20, 30, etc)
B(I,J)	11-17	F7.0	Value for column 1 (11, 21, etc)
TSO-24, value 3 or 4			
II	1-5	I5	First row of grid segment
III	6-10	I5	Last row of grid segment
JJ	11-15	I5	First column of grid segment
JJJ	16-20	I5	Last column of grid segment

HA	21-30	F10.0	Head or change in head

No example data set is available.

B.2.22 DataSet 21 Description

This data set contains the row and column numbers which delineate a section of the grid for which the statistical data are to be calculated and read if Time Step Option 27 is enabled. Up to sixty blocks may be so identified. Adding 5 to TSO-27 allows a user-specified format to be read as record 1. The last record of the data set must be blank.

Variable	Columns	Format	Description
IRWC(J,NBLK)	1-5	I5	First row of grid segment
IRWC(J,NBLK)	6-10	I5	Last row of grid segment
IRWC(J,NBLK)	11-15	I5	First column of grid segment
IRWC(J,NBLK)	16-20	I5	Last column of grid segment

No example data set is available.

B.2.23 DataSet 22 Description

This data set contains measured (observed) heads at the end of the major time step and is read if Time Step Option 22 is enabled. These heads are compared to the simulated heads. The data are read in the same manner as DATA Set 14. Adding 5 to TSO-22 allows a user-specified format to be read as record 1.

Variable	Columns	Format	Description
H(I,J)	11-17	F7.0	Value for column 1 (11, 21, etc)
H(I,J)	18-24	F7.0	Value for column 2 (12, 22, etc)
H(I,J)	25-31	F7.0	Value for column 3 (13, 23, etc)
H(I,J)	32-38	F7.0	Value for column 4 (14, 24, etc)
H(I,J)	39-45	F7.0	Value for column 5 (15, 25, etc)
H(I,J)	46-52	F7.0	Value for column 6 (16, 26, etc)
H(I,J)	53-59	F7.0	Value for column 7 (17, 27, etc)
H(I,J)	60-65	F7.0	Value for column 8 (18, 28, etc)

H(I,J)	66-73	F7.0	Value for column 9 (19, 29, etc)
H(I,J)	74-80	F7.0	Value for column 10 (20, 30, etc)

No example data set is available.

B.2.24 DataSet 23 thru 37

Since this phase of the project was not involved in water quality calculations, the mass transport options were not investigated. General descriptions of data sets 23 thru 37 may be found in the program documentation.

B.3 OUTPUT FILE

The program output is divided into two basic sections, corresponding to the two major computational operations: groundwater flow (hydrologic) analysis and mass transport analysis. Within each of these computational sections, the first part of the output echoes the input data, including the system parameters which remain constant during the computation process and the control options chosen by the user. The second part shows the results of computations for each major time step, at a level of detail determined by the control options enabled. Due to the number of possible output formats, individual sections will not be described in detail in this report.

B.3.1 Features/Description

The output data section for each major time step in the flow computations contains two parts: a log of the computation procedures for the minor time steps and a summary of the final iterative computation results for the major time step. The echo of the options chosen for the time step is first displayed. The number of days simulated, the equivalent number of major time steps completed, the sum of changes in head for the last iteration and the number of iterations to convergence are printed for each minor time step in block form. If the number of iterations is equal to 51 for a minor time step, the procedure may not have converged because of an exceedingly small error criterion or an error in the physical data.

Spring and river cell flow data follows the minor time step output. It includes the row and column number of the cell, the head at the spring, and the total flow for the time step, which is calculated by summing the flows for each of the minor time steps. Grid-wide totals of pumpage, recharge, constant-head inter-cell flow, change in storage, springflow, river flow and leakage are also listed for the step and as cumulative totals through the step. Finally, the mass balance is printed for the major step and cumulatively for all steps. The size of the mass balance terms give an indication of the quality of the numerical solution.

The program produces symbolic maps of head, saturated thickness and quality, and maps of changes in these values with the mean and standard deviation of the data. An error map with covariance and regression coefficient may also be printed. The map data is printed cell-by-cell in the rectangular format corresponding with the finite-difference grid. The grid plot may be scaled to produce the proper aspect ratio for each cell.

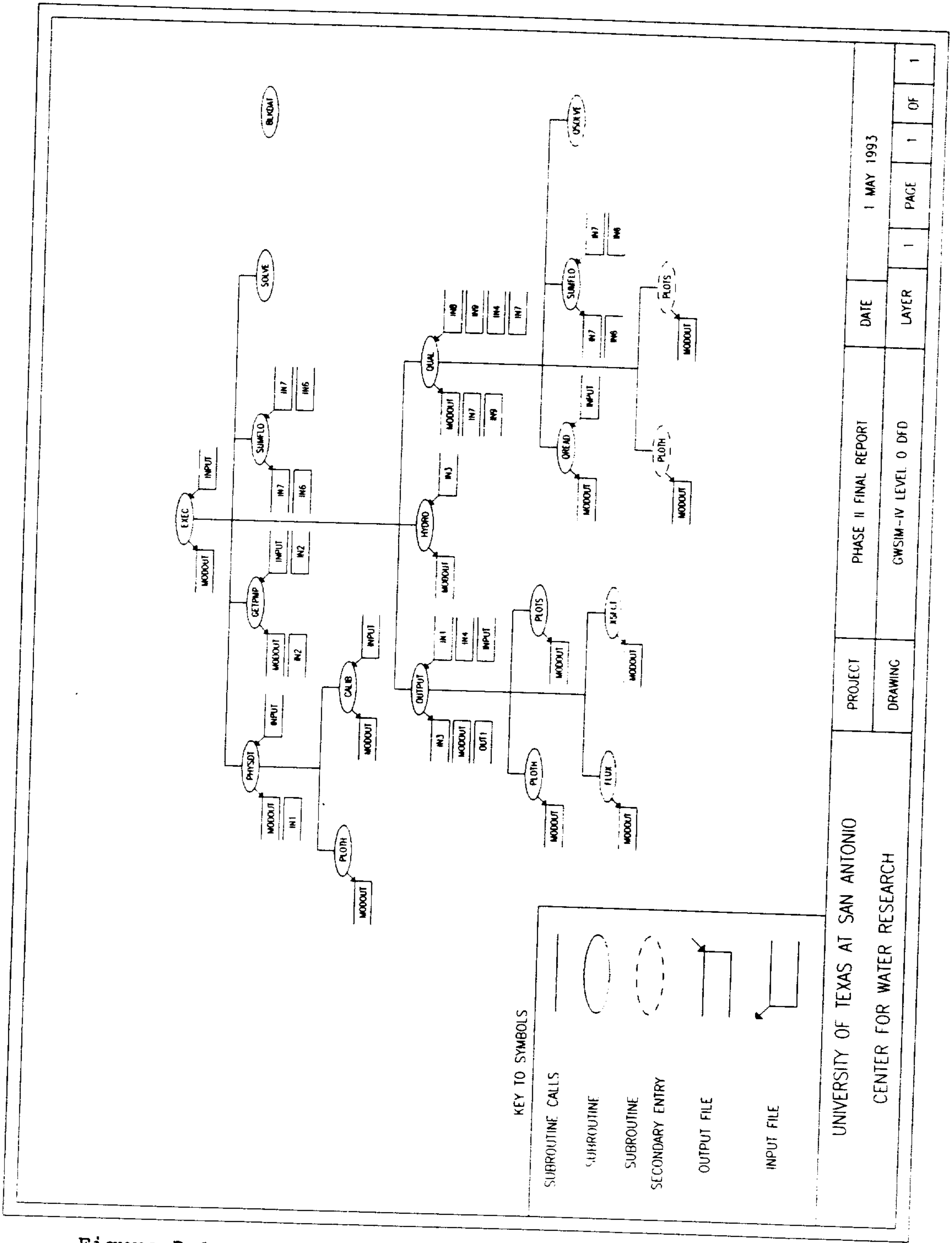


Figure B.1 - GW-SIM IV Level 0 Data Flow Diagram [B.1]

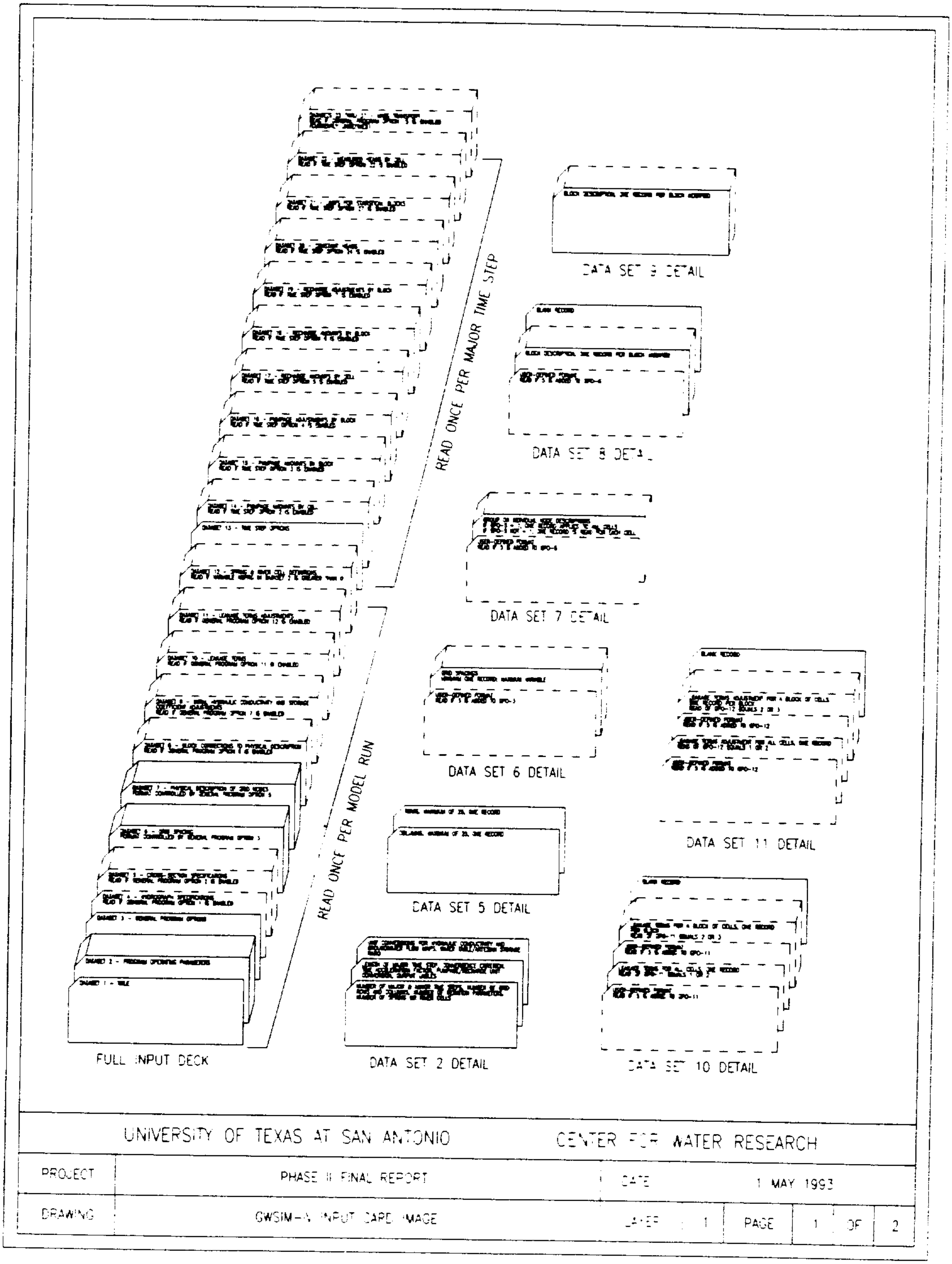
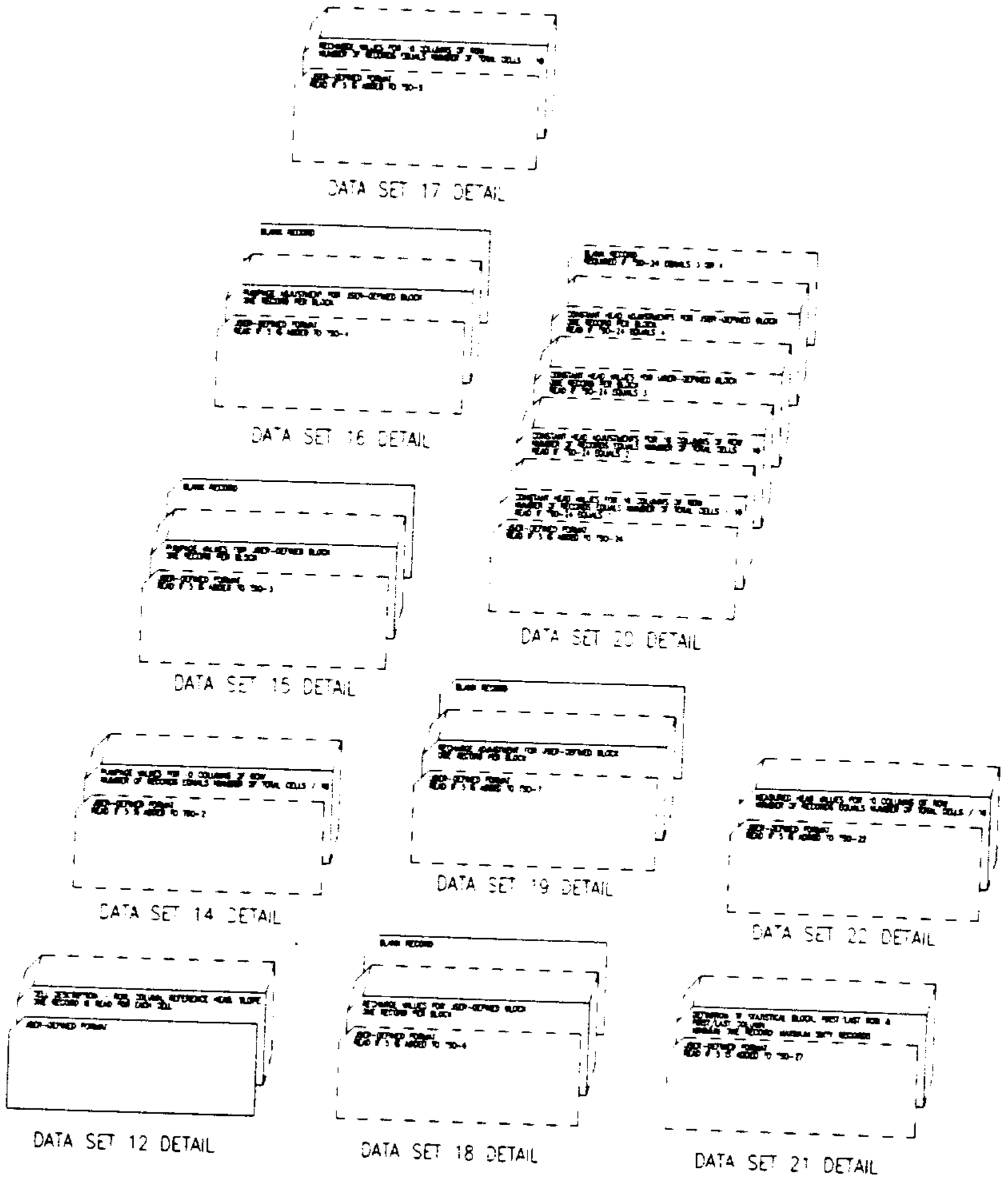


Figure B.2a - GW-SIM IV Input Card Deck Image [B.2]



UNIVERSITY OF TEXAS AT SAN ANTONIO			CENTER FOR WATER RESEARCH				
PROJECT	PHASE II FINAL REPORT	DATE	1 MAY 1993				
DRAWING	GWSIM-IV INPUT CARD IMAGE	LAYER	1	PAGE	2	OF	2

Figure B.2b - GW-SIM IV Input Card Deck Image [B.2]

APPENDIX C

TECHNICAL DESCRIPTION OF SIMYLD-II MODEL

APPENDIX C

TECHNICAL DESCRIPTION OF SIMYLD-II MODEL

C.1 PROGRAM DESCRIPTION

The SIMYLD-II model is designed to simulate the hydrologic operation of a system of interconnected reservoirs within a basin, or a multi-basin water resource system.

Since part of the input to the model is a detailed physical configuration of the area to be modeled, SIMYLD-II is essentially location-independent; it can be used to model several different locations without requiring modification of the source code and recompilation of the model.

SIMYLD-II is capable of performing two functions. The first is to provide planners/managers a simulation of the operation of a system subject to a specified sequence of demands and hydrology. In this mode, the model simulates the movement of water in a system of reservoirs, rivers and conduits on a monthly basis while striving to meet a set of specified demands in a given order of priority.

The second function of SIMYLD-II is to determine the firm yield of a reservoir within the system. "Firm yield" is defined, for the purposes of this model, as the maximum demand at a reservoir that can be met with 'acceptable' shortages. By operating the storage facilities as parts of an interconnected system, the firm yield of any given reservoir can be increased appreciably over that available if the reservoir is operated independently.

Figure C.1 shows the relationships of the program modules and files.

C.1.1 MAIN Routine

The MAIN routine of SIMYLD-II is the central control point, from which other subroutines are accessed. Although the files used by the model are opened or initialized by MAIN, it performs no read/write or computational functions.

C.1.2 ADJUST Routine

The ADJUST subroutine is used to modify the annual demands in firm yield calculations based on greatest shortage incurred during period of simulation.

C.1.3 CARDS Routine

The CARDS subroutine reads in all input data except for monthly inflows, demands, and evaporation data.

C.1.4 DATA1 Routine

If variable monthly data (inflow, demand, and evaporation) are being used, they are read into the model by the DATA1 subroutine. The subroutine also creates a temporary scratch file for storage of information that will be used by other subroutines.

DATA1 also includes two additional entry points.

Entry point DATA2 allows the simulation to read one year's worth of data from the scratch file.

Entry point RULE determines monthly operating rule criteria of a preselected subsystem of reservoirs and passes this information to subroutine OPRATE.

C.1.5 OPRATE Routine

The OPRATE subroutine is the heart of the model. It sets initial arrays, bounds on arcs, upper and lower constraints on links, and yearly and monthly loops. It also calculates arc bounds, unit flow costs, final reservoir storage, monthly evaporation, average and maximum link flow and all yearly totals. Most calls to other operating subroutines are made from OPRATE.

C.1.6 AREA Routine

The AREA subroutine determines the reservoir surface area as a function of volume by linear interpolation of area-capacity data .

C.1.7 OUT1 Routine

The OUT1 subroutine creates the first part of the three-part output report, which consists of all input variables read in by the CARDS subroutine.

C.1.8 OUT2 Routine

The second part of the output report is created by the OUT2 subroutine. This part consists of detailed monthly system operations for selected years.

C.1.9 OUT3 Routine

The final part of the output report is created by the OUT3 subroutine. It is called from the MAIN routine when the simulation is concluded. This report section includes summaries of yearly data for each node by year and each year by node, totals of all nodes for each year for the period of simulation, and maximum and average flows in links.

C.1.10 SETNET Routine

The setup of the configuration of the system network of nodes and links is performed by the SETNET subroutine.

C.1.11 SUPERKIL Routine

The SUPERKIL subroutine is the primary cost-analysis section of the model. It finds the minimum cost flow in the network based on the user-specified ranking.

C.1.12 RIGHT Routine

The RIGHT subroutine, and it's LEFT entry point, perform part of the arc labeling procedure required by the SUPERKIL subroutine.

C.2 INPUT FILE

Due to the non-location-specific nature of SIMYLD-II, the input file is an integral part of the simulation, as well as being a source of data used by the model. The input file consists of the information required to accurately define the physical area being modeled, plus the actual monthly data for inflows, demands and evaporation at each junction of the model.

C.2.1 Features/Description

The following is a list of the data sets that comprise the input file, in the order that they are accessed by the model.

Data Set	Title
1	Title of simulation run
2	Parameters
3	System node descriptions
4	Spill reservoirs
5	Reservoir area-capacity tables
6	Demands, rank & demand distribution
7	Import amount and distribution
8	Sub-system definitions
9	Average conditions
10	Unit conversion factors
11	Reservoir operating criteria
12	Link information and system configuration
13	Junction unregulated inflows
14	Junction demand data
15	Reservoir evaporation data

Card images of the input data sets are shown in Figure C.2.

C.2.2 DataSet 1 Description

This data set consists of one record, containing a title for the model run. This title is alphanumeric, and is limited to eighty characters.

Variable	Columns	Format	Description
TITLE(I)	80	20A4	Title array for simulation run

Table C.1 - Listing of DataSet 1 (Example)

```
      0         1         2         3         4         5         6         7         8
      1...5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0

  1 :                  SAN ANTONIO AND GUADALUPE COMBINED SIMULATION
```

C.2.3 DataSet 2 Description

This dataset contains the information used by the program to begin setting up the physical format of the area to be modeled. It contains one record.

Variable	Columns	Format	Description
NJ	11-15	I5	Number of nodes (reservoir and non-storage junctions) in the system
NRES	16-20	I5	Number of reservoirs in the system
NL	21-25	I5	Number of links in the system
NR	26-30	I5	Number of river reaches in the system
NYEAR	31-35	I5	Number of years to simulate
ND	36-40	I5	Number of nodes in the system
NS	41-45	I5	Number of spill nodes in the system
IYEAR	46-50	I5	Calendar year simulation starts
IMP	51-55	I5	Node number where import occurs
IYLD	56-60	I5	Yield node number

			at which Firm Yield is to be determined
IFRM	61-65	I5	Begin detailed yearly printout at this year
ITOY	66-70	I5	End detailed yearly printout at this year
TAPE1	71-75	A4	Indicates whether monthly data is to be read in from cards or tape (preset to 1)
CPCT	76-80	F5.0	Tolerance for Firm Yield determination *

* Entered as a decimal fraction of 1. Preset to 0.10.

Table C.2 - Listing of DataSet 2 (Example)

```
   0         1         2         3         4         5         6         7         8
   1...5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0

1 : PARAMETERS   30   30   40   29   43   30   1 1940            1   43   1 0.02
```

C.2.4 DataSet 3 Description

This dataset describes the system nodes. Reservoirs are entered first, followed by non-storage junctions. There is one record per node/junction.

Variable	Columns	Format	Description
RNAME	1-8	2A4	Node name
J	11-15	I5	Assigned node number
RCAP(J)	16-25	I10	Node maximum cap.
RMIN(J)	26-35	I10	Node minimum cap.
FSTART(J)	36-45	I10	Node starting capacity

Table C.3 - Listing of DataSet 3 (Example)

```
   0         1         2         3         4         5         6         7         8
   1...5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0

1 : CANYON         1   369507         0   369507
```

C.2.5 DataSet 4 Description

This dataset identifies the spill reservoirs. The reservoirs are listed in an order indicating the preference of spill locations. Up to 14 reservoirs may be listed on the one record in the dataset.

Variable	Columns	Format	Description
SP(1)	11-15	I5	First spill reservoir
SP(2)	16-20	I5	Second spill reservoir

The pattern continues through SP(14).

Table C.4 - Listing of DataSet 4 (Example)

```
    0        1         2         3         4         5         6         7         8
    1...5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0

1 : SPILLS      14
```

C.2.6 DataSet 5 Description

Dataset 5 contains the area-capacity descriptions for each of the reservoirs in the system. Each reservoir requires six records, with each record containing three pairs of area/capacity points.

Variable	Columns	Format	Description
J	11-15	I5	Reservoir number
ACTAB(J,1,1)	16-25	I10	Point 1 (4, 7, etc) area
ACTAB(J,1,2)	26-35	I10	Point 1 (4, 7, etc) capacity
ACTAB(J,2,1)	36-45	I10	Point 2 (5, 8, etc) area
ACTAB(J,2,2)	46-55	I10	Point 2 (5, 8, etc) capacity
ACTAB(J,3,1)	56-65	I10	Point 3 (6, 9, etc) area
ACTAB(J,3,2)	66-75	I10	Point 3 (6, 9, etc) capacity

Table C.5 - Listing of DataSet 5 (Example)

```
0        1         2         3         4         5         6         7         8
1...5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0

1 : AC CANYON   1        0        0      134      765      403     3378   1
2 : AC CANYON   1      650     7000      850    10600      160    26000   2
3 : AC CANYON   1     1830    32000     2040    37500     2450    51000   3
4 : AC CANYON   1     3080    74000     3650    97500     4200   122000   4
5 : AC CANYON   1     4440   134000     4820   156000     5164   176927   5
6 : AC CANYON   1     5850   216000     6900   281000     8240   369507   6
```

C.2.7 DataSet 6 Description

This dataset contains the total demands, rank (priority) for each of the three system status conditions (average, wet & dry) and demand distribution (by month) for each demand junction. There is one record per junction, as specified by variable ND in DataSet 2.

Variable	Columns	Format	Description
J	11-13	I3	Node number
DEM(J)	14-21	I8	Annual demands at node
DEMR(J,K)	22-30	3I3	Ranking of node's demands for the three subsystem states
DEMD(J,K)	31-78	12F4.0	Node demand monthly distribution

Table C.6 - Listing of DataSet 6 (Example)

```
0        1         2         3         4         5         6         7         8
1...5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0

1 : CANYON      1   37500 42 42 42.069.063.072.074.081.095.115.114.093.080.071.073
```

C.2.8 DataSet 7 Description

Annual import amounts and monthly distribution are contained in this dataset. Each record contains the information for one node. If no imports are used, a blank record must be supplied.

Variable	Columns	Format	Description
IMP	11-15	I5	Node number where import occurs
IMPRT	16-25	I10	Annual import amount
DIMP(I)	31-78	12F4.0	Monthly import distribution

Table C.7 - Listing of DataSet 7 (Example)

```
      0    1    2    3    4    5    6    7    8
      1...5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0

   1 : IMPORT
```

C.2.9 DataSet 8 Description

This dataset identifies the reservoirs to be used in determining the system states: average, wet and dry. It contains one record.

Variable	Columns	Format	Description
NSRS	11-15	I5	Number of reservoirs in subsystem
JESVOL(I)	16-80	13I5	List of reservoirs in subsystem

Table C.8 - Listing of DataSet 8 (Example)

```
      0    1    2    3    4    5    6    7    8
      1...5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0

   1 : SUB SYSTEM    4    1    6   10   11
```

C.2.10 DataSet 9 Description

This dataset identifies the lower and upper limits for the average system state, as a percentage of the capacity of the subsystem identified in DataSet 8. It contains one record.

Variable	Columns	Format	Description
AVRGLO	11-20	F10.0	Low bound for subsystem average storage

AVRGHI	21-30	F10.0	High bound for subsystem average storage

Table C.9 - Listing of DataSet 9 (Example)

```
      0         1         2         3         4         5         6         7         8
      1...5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0

   1 : AVERAGE ST          .50        .90
```

C.2.11 DataSet 10 Description

This single-record dataset contains the units to be used in the model. If the value of any unit is less than or equal to zero, the model will automatically default to a value of 1.

Variable	Columns	Format	Description
CONFLO	11-20	F10.0	Multiplier to convert flow units to monthly volume
CONINF	21-30	F10.0	Multiplier to convert read-in inflows to system units
CONDEM	31-40	F10.0	Multiplier to convert read-in demands to system units

Table C.10 - Listing of DataSet 10 (Example)

```
      0         1         2         3         4         5         6         7         8
      1...5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0

   1 : FACTORS              1.         1.         1.
```

C.2.12 DataSet 11 Description

This dataset specifies the reservoir operating rules to be used by the simulation. Three records are used for each reservoir, corresponding to the three possible system states: average, wet and dry. each record identifies the reservoir, assigns a rank (priority) to the reservoir for maintaining water in storage for the given state, and a percentage indicating the percent of maximum storage desired to be in storage at the end of each month.

Variable	Columns	Format	Description
J	11-15	I5	Reservoir number
OPRP(L,J)	26-30	I5	Ranking of reservoir storage for subsystem state
OPRR(L,J,I)	31-78	12F4.0	Monthly operation rules for subsystem state

Table C.11 - Listing of DataSet 11 (Example)

```
     0         1         2         3         4         5         6         7         8
     1...5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0

1 :   RES         1 1 AVERAGE  470.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
2 :    OP         1 2  DRY     470.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
3 :  RULES        1 3 WET      470.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
```

C.2.13 DataSet 12 Description

This dataset describes the system links. River reaches should be listed first, followed by pump canals. There is one record for each link.

Variable	Columns	Format	Description
L	10-15	I5	Assigned link number
LNODE(L,1)	16-20	I5	Node at beginning of link
LNODE(L,2)	21-25	I5	Node at end of link
CMAX(L)	26-35	I10	Maximum capacity of transfer for link
CMIN(L)	36-45	I10	Minimum capacity of transfer for link

Table C.12 - Listing of DataSet 12 (Example)

```
     0         1         2         3         4         5         6         7         8
     1...5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0

1 : CAN-COMAL     1    1   15   9000000        0
```

C.2.14 DataSet 13 Description

This dataset contains the monthly or seasonal values for inflow to each junction. There is one record per year per junction, and the records must be in order.

Variable	Columns	Format	Description
W(I,J,K)	21-80	12F8.0	Junction unregulated inflow data

Table C.13 - Listing of DataSet 13 (Example)

```
   0       1       2       3       4       5       6       7      88      9
   1...5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....01...5....0....5.
    10      11      12      13      14      15      16
   ...0....5....0....5....0....5....0....5....0....5....0....5....0

1 : FLOW.1       1940   4776.   6346.   9532.  22168.  16486.  20505.  12690.   5307.   3385.   3469.
  :   15082.  48549.
2 : FLOW.1       1941  17198.  74593.  72436. 100262. 129737.  42983.  30826.  15857.  18313.  28813.
  :   16101.   1342.
3 : FLOW.1       1942  11440.   9796.   9408.  41833.  51265.  15868.  11011.   8180.  36624.  41412.
  :   23271.  19595.
```

C.2.15 DataSet 14 Description

This dataset contains the monthly or seasonal values for demands at each junction. There is one record per year per junction, and the records must be in order.

Variable	Columns	Format	Description
D(I,J,K)	21-80	12F8.0	Junction demand data

Table C.14 - Listing of DataSet 14 (Example)

```
   0       1       2       3       4       5       6       7      88      9
   1...5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....01...5....0....5.
    10      11      12      13      14      15      16
   ...0....5....0....5....0....5....0....5....0....5....0....5....0

1 : DEMD.15      1940  21915.  22522.  26563.  36391.  32327.  38969.  30736.  21671.  19267.  19753.
  :   31244.  50666.
2 : DEMD.15      1941  36698.  67728.  72434.  75969.  79934.  70326.  58564.  40504.  39408.  52136.
  :   37737.  34746.
```

C.2.16 DataSet 15 Description

This dataset contains the annual evaporation rates for each reservoir, on a monthly or seasonal basis. Decimal points must be included in the values. There is one record per year per reservoir, and the records must be in order.

Variable	Columns	Format	Description
E(I,J,K)	21-80	12F8.0	Reservoir evaporation data

Table C.15 - Listing of DataSet 15 (Example)

```
    0        1         2         3         4         5         6         7         8
    1...5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0

1 : EVAP.CANYN      1940  0.09 0.01 0.25 0.17 0.28-0.12 0.49 0.69 0.60 0.20-0.20-0.11
2 : EVAP.CANYN      1941  0.04-0.12-0.11-0.12 0.04 0.02 0.48 0.62 0.31 0.12 0.23 0.13
3 : EVAP.CANYN      1942  0.17 0.15 0.29-0.13 0.11 0.38 0.07 0.42-0.02-0.05 0.21 0.16
```

C.3 OUTPUT FILE

The output file provided by SIMYLD is presented in three parts, each with a specific purpose.

C.3.1 Features/Description

The first part of the output file provides a complete printing of the input variables that control the simulation.

The second section contains detailed monthly system operations for selected years. At the end of each simulation year, OPRATE determines if the year should be printed. If so, detailed monthly information for each reservoir for each year is printed including initial storage, unregulated inflows, internal upstream and downstream spills, demand, surface area, evaporation rate and loss, shortages incurred, transfer amounts, system losses (spills), end-of-month content and operating rules. Totals for the year are also printed. Detailed monthly information for each non-storage node for each year is printed including demand, shortage, and unregulated flow. Totals for the year are also printed. Detailed information for each link for each year is printed consisting of the monthly flow in the link and the yearly average.

The final report section provides a summary by year for each node and a second summary by node for each year. Totals for each node for the simulation period are also given in the second summary. The information consists of beginning and ending storage, unregulated inflow, demands, shortages, evaporation loss, and system loss (spills). A total of all nodes for each year of the simulation period is also provided. This includes simulation period totals and averages. In addition, a summary of average flow in each link and maximum observed flow in each monthly interval are given.

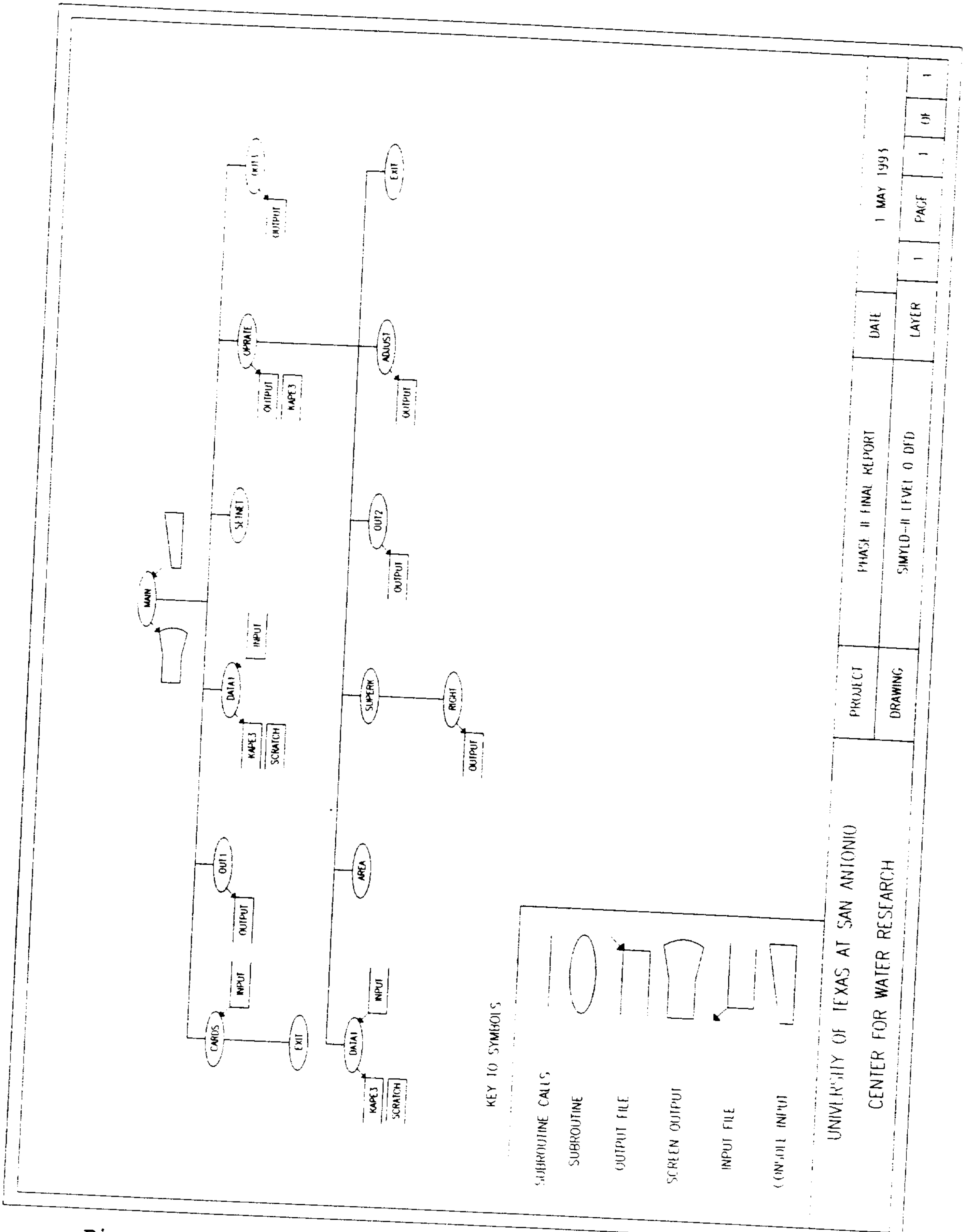


Figure C.1 - SIMYLD II Level 0 Data Flow Diagram [C.1]

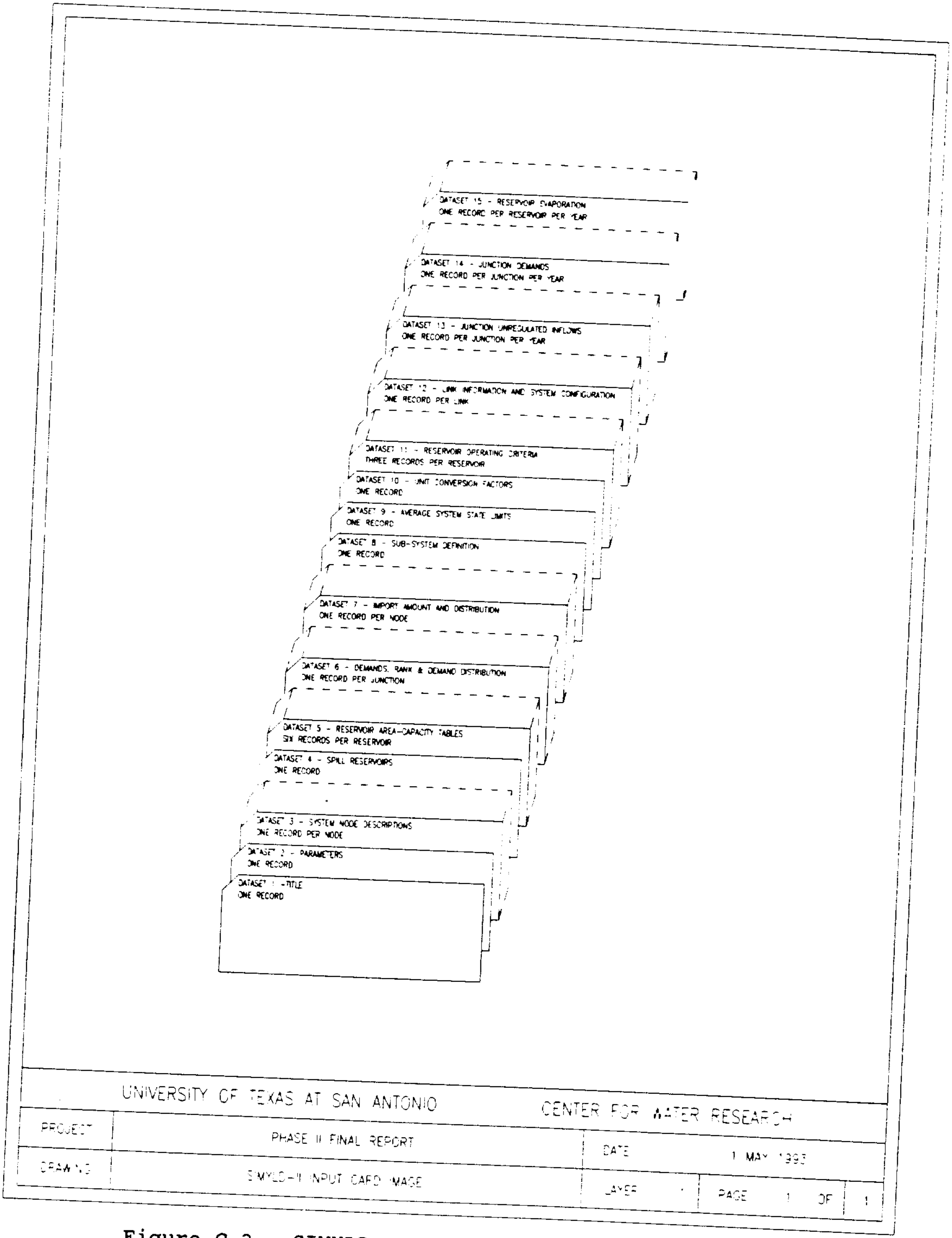


Figure C.2 - SIMYLD II Input Card Deck Image [C.2]

APPENDIX D

TECHNICAL DESCRIPTION OF HDR/NRB MODEL

APPENDIX D

TECHNICAL DESCRIPTION OF HDR/NRB MODEL

D.1 PROGRAM DESCRIPTION

The HDR Engineering Nueces River Basin model (HDR/NRB) is based on the Nueces River Basin area of south central Texas. It is designed to calculate historical recharge of the Edwards Aquifer, asses the potential effects of recharge dams, and evaluate the current and projected firm yield of the Choke Canyon/Lake Corpus Christi system.

HDR/NRB operates on a monthly time step, and simulates operations in an upstream-to-downstream order. During these operations, it considers recharge, channel losses, water rights and the effects of selected reservoirs.

The version of the model evaluated by the Center for Water research is specifically designed for this particular geographic area, although the model itself is written in such a way as to allow for modification to be used for other areas.

Figure D.1 diagrams the relationships of the model routines and files.

D.1.1 MAIN Routine

The MAIN routine of HDR/NRB is the central control point, from which other subroutines are accessed. In addition, the MAIN routine prompts the user to enter the number of a control point for which a report of the maximum available water rights release is generated.

D.1.2 READIN Routine

The READIN subroutine accesses the input file and reads in the input data.

D.1.3 GOLDEN Routine

The GOLDEN subroutine uses proven algorithms to calculate firm yields. As such, it is the calculation heart of the model.

D.1.4 FLOWS Routine

The FLOWS routine simulates streamflow effects for each step of the simulation.

D.1.5 WRR Routine

This subroutine calculates the effects and requirements of water rights releases.

D.1.6 RCHRG Routine

Recharge calculations are handled in this subroutine.

D.1.7 RRESOP Routine

Recharge reservoir operations are simulated in this subroutine.

D.1.8 SYSOP Routine

The effects of non-recharge reservoirs are calculated in this subroutine.

D.1.9 PHASE4 Routine

The PHASE4 subroutine handles the application of system operations policy.

D.1.10 STORARE Routine

Area calculations from storage specifications are dealt with by the STORARE subroutine.

D.2 INPUT FILE

The input file contains the information necessary for HDR/NRB to perform it's calculations. It includes data on demands, evaporation, reservoir types, diversions and natural flows.

D.2.1 Features/Description

The following is a list of the data sets that comprise the input file, in the order that they are accessed by the model.

Data Set	Title
1	Program parameters (general)
2	Program parameters (CC/LCC system)
3	Monthly demands
4	Evaporation
5	Control point specifications
6	Control point parameters

7	Upstream control point lists
8	Water rights
9	Diversion rights
10	Natural flows
11	Type 1 reservoir data 1
12	Type 1 reservoir data 2
13	Type 2 reservoir data

Card images of the input data sets are shown in Figure D.2.

D.2.2 DataSet 1 Description

This data set consists of one record, containing the general program parameters. These include the number of control points and reservoirs, length of the simulation, number of evaporation data sets and a water rights control (mode) switch.

Variable	Columns	Format	Description
NCP	1-5	I5	Number of control points
NRES	6-10	I5	Number of reservoirs
NRCR	11-15	I5	Number of control points for which recharge is calculated
NYRS	16-20	I5	Length of simulation in years
NNE	21-25	I5	Number of net evaporation sets
IWR	26-30	I5	Water rights mode switch
IYLD	31-35	I5	Non-functional; reserved for later modifications

Table D.1 - Listing of DataSet 1 (Example)

```
      0    1    2    3    4    5    6    7    8
      1...5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0

 1 :     29    6   12   56    7    1    0
```

D.2.3 DataSet 2 Description

This dataset contains the information used by the program to control the operation of the Choke Canyon/Lake Corpus Christi system, plus a convergence criterion. It consists of one record.

Variable	Columns	Format	Description
SYSDEM	1-10	F10.0	Annual CC/LCC diversion, in acre-feet
IOP	11-20	I10	Non-functional; default is 1
XLCC	21-30	F10.2	Lake Corpus Christi target level in feet above MSL
CONV	31-40	F10.0	Convergence criterion

Table D.2 - Listing of DataSet 2 (Example)

```
     0        1         2         3         4         5         6         7         8
     1...5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0

 2 :    219899.         1     76.00        1.
```

D.2.4 DataSet 3 Description

This dataset contains the monthly demand factors for each of the four reaches in the area. Each reach demands are further subdivided by demand type: municipal, industrial, irrigation and mining. There are a total of sixteen records in this dataset.

Variable	Columns	Format	Description
DMF(N,M,J)	1-72	12F6.2	Monthly demands by percent

Table D.3 - Listing of DataSet 3 (Example)

```
     0        1         2         3         4         5         6         7         8
     1...5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0

 3 :   5.70  5.33  6.32  8.00  9.19  9.68 11.41 13.43 11.00  7.22  6.52  6.20
 4 :   7.29  6.84  7.93  8.38  8.80  8.99 10.14  9.98  8.43  8.11  7.56  7.55
 5 :   3.75  4.22  6.93  8.60 12.28 16.07 16.07 14.36  7.93  4.01  3.23  2.55
 6 :   8.30  8.30  8.30  8.30  8.40  8.40  8.40  8.40  8.30  8.30  8.30  8.30
 7 :   6.82  6.57  7.37  8.12  7.67  9.01 10.75 10.95  9.17  8.07  7.93  7.57
 8 :   7.29  6.84  7.93  8.38  8.80  8.99 10.14  9.98  8.43  8.11  7.56  7.55
 9 :   7.97  7.40 10.02  9.90  9.26 11.25  9.11  7.03  6.59  8.52  7.27  5.68
10 :   8.30  8.30  8.30  8.30  8.40  8.40  8.40  8.40  8.30  8.30  8.30  8.30
11 :   6.82  6.57  7.37  8.12  7.67  9.01 10.75 10.95  9.17  8.07  7.93  7.57
12 :   7.29  6.84  7.93  8.38  8.80  8.99 10.14  9.98  8.43  8.11  7.56  7.55
13 :   6.15  6.63  7.63 11.45 13.21 11.78 10.20  8.98  6.20  5.17  6.24  6.36
14 :   8.30  8.30  8.30  8.30  8.40  8.40  8.40  8.40  8.30  8.30  8.30  8.30
```

```
15 :   7.24  6.64  8.05  8.43  8.72  9.05 10.27 10.24  8.38  8.14  7.45  7.39
16 :   7.29  6.84  7.93  8.38  8.80  8.99 10.14  9.98  8.43  8.11  7.56  7.55
17 :   3.75  3.94  3.45 12.59 21.08 19.08  8.43  6.13  6.21  4.90  6.49  3.95
18 :   8.30  8.30  8.30  8.30  8.40  8.40  8.40  8.40  8.30  8.30  8.30  8.30
```

D.2.5 DataSet 4 Description

Evaporation data is read on a monthly basis, with one record per year for each evaporation point.

Variable	Columns	Format	Description
EVNT(N,I,J)	21-80	12F5.2	Net evaporation in feet

Table D.4 - Listing of DataSet 4 (Example)

```
          0         1         2         3         4         5         6         7         8
          1...5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0

19 : EVAP               1934 -0.25 0.21 0.17-0.03 0.41 0.67 0.52 0.62 0.42 0.41-0.10-0.03  3.02
20 : EVAP               1935  0.18 0.00 0.15 0.13 0.03-0.50 0.52 0.71-0.75 0.24 0.17-0.14  0.74
21 : EVAP               1936  0.14 0.15 0.14 0.25-0.27-0.03 0.24 0.52 0.18 0.24 0.14 0.11  1.81
22 : EVAP               1937  0.10 0.17 0.17 0.38 0.28 0.48 0.52 0.61 0.61 0.48 0.30-0.67  3.43
23 : EVAP               1938  0.13 0.13 0.26 0.11 0.27 0.59 0.76 0.52 0.50 0.53 0.35 0.00  4.15
24 : EVAP               1939  0.08 0.16 0.31 0.46 0.34 0.25 0.60 0.39 0.31 0.41 0.20 0.15  3.66
```

D.2.6 DataSet 5 Description

Dataset 5 contains the specifications for each control point, including the reservoir type, recharge calculation and reservoir simulation switches, partner area control point identification for ungaged recharge calculations, and the evaporation set identification number. One record is read for each control point.

Variable	Columns	Format	Description
KRRES(K)	1-5	I5	Reservoir type *
KRCR(K)	6-10	I5	Recharge calculation switch
KRES(K)	11-15	I5	Reservoir simulation switch
KRCRP(K)	16-20	I5	Partner area control point number
NESET(K)	21-25	I5	Evaporation set number

*   0 - no structure; 1 - Type 1, 2 - Type 2; 3 - Type 2 existing

Table D.5 - Listing of DataSet 5 (Example)

```
        0        1        2        3        4        5        6        7        8
        1...5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0

411 :      0    0    0    0    3          CP1
```

D.2.7 DataSet 6 Description

This dataset contains various calculation factors, which must be determined prior to file creation. In addition, the number of upstream control points, reach identification and number of upstream water sources are included. Each control point is represented by a single record in this dataset.

Variable	Columns	Format	Description
DLVF(K)	1-10	F10.4	Downstream delivery factor
WRF(K)	11-20	F10.4	Local water rights factor
PARF(K)	21-30	F10.4	Partner area factor
NUSCP(K)	31-35	I5	Number of upstream control points
IDRCH(K)	36-40	I5	Reach ID
NWRS(K)	41-45	I5	Number of upstream sources for water rights releases

Table D.6 - Listing of DataSet 6 (Example)

```
        0        1        2        3        4        5        6        7        8
        1...5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0

412 :      .9535    1.0000    1.0000    0    1    0
```

D.2.8 DataSet 7 Description

This dataset identifies, by number, the upstream control points for the current control point. It is read only if variable NUSCP(K) in DataSet 6 is greater than zero.

Variable	Columns	Format	Description
KUS(K,N)	1-45	15I3	Upstream control point numbers

Table D.7 - Listing of DataSet 7 (Example)

```
      0        1         2         3         4         5         6         7         8
      1...5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0

531 :   1  2
```

D.2.9 DataSet 8 Description

Each water source identified by variable NWRS(K) in DataSet 6 is defined by a record in this dataset. The record contains the source ID number and delivery factor.

Variable	Columns	Format	Description
KWRS(K,N)	1-5	I5	Source ID number
WRDLVF(K,N)	6-15	F10.4	Delivery factor

No example dataset is available.

D.2.10 DataSet 9 Description

Each control point has diversion rights for municipal, industrial, irrigation and mining use associated with it. These rights are defined in this dataset.

Variable	Columns	Format	Description
WR(K,M)	1-40	4I10	Diversion rights in acre-feet

Table D.8 - Listing of DataSet 9 (Example)

```
      0        1         2         3         4         5         6         7         8
      1...5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0

413 :       1015       168      5200         0
```

D.2.11 DataSet 10 Description

Natural flows over the recharge zone in acre-feet are listed in this dataset. There is one record per year per control point.

Variable	Columns	Format	Description
If recharge calculation switch is disabled, or partner area control point is less than or equal to zero			
QN(K,I,J)	5-111	12I9	Natural flows by month
If recharge calculation switch is enabled, and partner area control point is greater than zero			
QL(K,I,J)	5-111	12I9	Natural flows by month

Table D.9 - Listing of DataSet 10 (Example)

```
      0    1    2    3    4    5    6    7    8
      1...5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0.....
      8  9    10   11
      6....0....5....0....5....0....5..

414 : 1934     1993     1933     2315     2777     3440     1623     1009      694      554
    :      529      495      645    18006
```

D.2.12 DataSet 11 Description

Each reservoir in the model must be specified. This function is provided by DataSet 11 if the reservoir simulation switch is enabled or if the recharge reservoir type is 1. There is one record in this dataset.

Variable	Columns	Format	Description
NLEV	1-10	I10	Number of elevation-area-contents levels
STOR1(K)	11-20	I10	Initial reservoir storage in acre-feet
CONSTOR(K)	21-30	I10	Conservation storage in acre-feet
DSTOR(K)	31-40	I10	Dead storage in acre-feet
RCRATE(K)	41-50	F10.0	Direct recharge rate in acre-feet/month
RCREL(K)	51-60	F10.0	Recharge release rate in acre-feet per month

Table D.10 - Listing of DataSet 11 (Example)

```
       0        1         2         3         4         5         6         7         8
       1...5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0

2495 :         12    237473    237473        59        0.        0.
```

D.2.13 DataSet 12 Description

The elevation-area-contents levels referred to in DataSet 11 are defined in this dataset. There is one record per level.

Variable	Columns	Format	Description
E(K,L)	1-10	F10.2	Elevation in feet
A(K,L)	11-20	F10.0	Area in acres
C(K,L)	21-30	F10.0	Contents in acre-feet

Table D.11 - Listing of DataSet 12 (Example)

```
       0        1         2         3         4         5         6         7         8
       1...5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0

2496 :      46.00         0         0
2497 :      54.00         7        46
2498 :      58.00        10        80
2499 :      62.00       163       427
2500 :      66.00       689      2133
2501 :      70.00      1206      5924
2502 :      74.00      3292     14920
2503 :      78.00      5565     32636
2504 :      82.00      8467     60700
2505 :      86.00     13674    104982
2506 :      90.00     16635    165601
2507 :      94.00     19251    237473
```

D.2.14 DataSet 13 Description

If the reservoir is a Type 2, as identified by variable KRRES(K), then normal and dead capacities are read from DataSet 13. There is one record in this dataset.

Variable	Columns	Format	Description
CONSTOR(K)	1-10	I10	Normal pool in acre-feet

DSTOR(K)	11-20	I10	Dead pool in acre-feet

No example dataset is available.

D.3 OUTPUT FILE

The HDR Engineering Nueces River Basin Model (HDR) creates several output files, each reporting on a specific function of the model. These are described below.

D.3.1 Features/Description

Output files OQTLD and OQCHK are identical in structure, and contain flows at Tilden (OQTLD) and Choke Canyon (OQCHK). The units are acre-feet. Each file contains one line for each year modeled, and each line contains one value for each month, plus an annual total. Column totals/averages are not calculated.

Output file OQADJ is a scratch file used to pass data between sections of the program. It can be safely ignored and deleted.

File ORCHRG contains a recharge summary by control point; the units are acre-feet. There is one line for each year of the model. The first column lists a count of years; each successive column lists the recharge by control point.

Output file OFLOWS contains the annual flow at each control point, in acre-feet per year. There is one line for each year of the model. The first column lists a count of years; each successive column lists the flow by control point.

The MAXREL file contains the maximum water rights release for the control point specified at the manual input step described in D.1.1. This figure is in acre-feet.

The final file, OSYSOP, is a summary of the operating parameters of Choke Canyon/Lake Corpus Christi. There are two lines for each month of the model. Each line contains:

Control point number (26 for Choke Canyon, 29 for Lake Corpus Christi)
Year being modeled
Month of the year
Beginning storage in acre-feet
Inflow in acre-feet
Net evaporation loss in acre-feet
Release amount in acre-feet
Spill amount in acre-feet
Ending storage in acre-feet
Ending surface elevation, in feet above MSL
Modified flow rate, in acre-feet

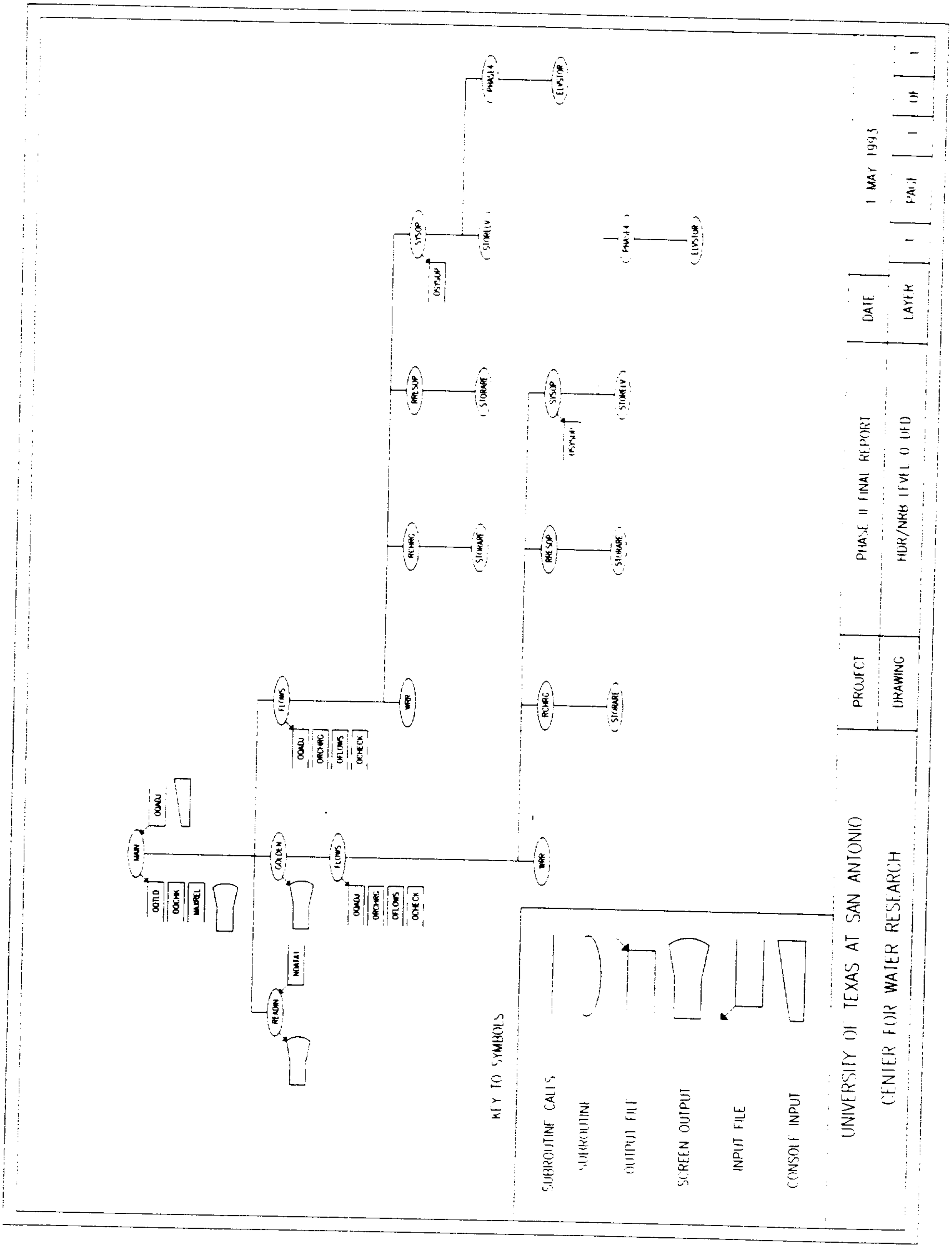


Figure D.1 - HDR/NRB Level 0 Data Flow Diagram [D.1]

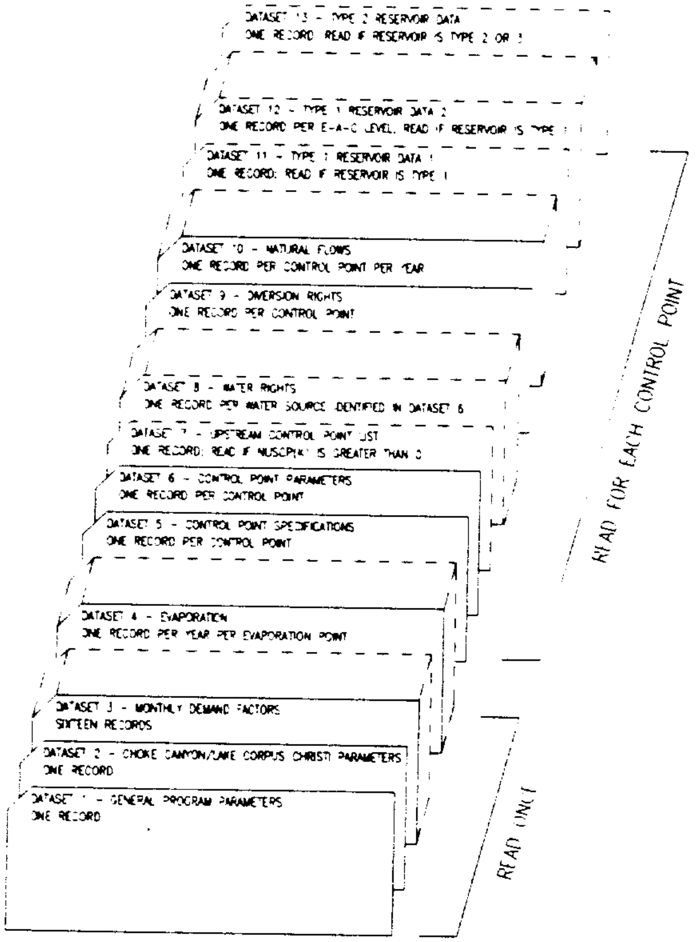


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Figure D.2 - HDR/NRB Input Card Deck Image [D.2]

REFERENCES

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LISTS OF TABLES AND FIGURES

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