UPPER TRINITY RIVER BASIN STUDY

USDA - Natural Resources Conservation Service

FINAL REPORT

September 30, 1995

Prepared in Cooperation with the
Tarrant County Water Control and Improvement District Number One

Partial funding was derived from:
Texas Natural Resources Conservation Commission
and
Trinity River Authority
through the
Texas Clean Rivers Act

Texas Water Development Board

WATER RESOURCES ASSESSMENT TEAM
BLACKLAND RESEARCH CENTER
808 EAST BLACKLAND ROAD
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EXECUTIVE SUMMARY

The Texas state office of the Natural Resources Conservation Service (NRCS) established the Water Resource Assessment Team in 1992 and collocated them with the other agencies at the Blackland Research Center in Temple, TX. The major function of that team is to adapt use of the SWAT (Soil and Water Assessment Tool) computer model to small watershed basin water quality applications with ecosystem based data derived from GIS. Modeling for assessment of nonpoint source pollutants and management practices that would affect nonpoint source loadings in streams and receiving waters is a technology of interest to river basin managers throughout the State. Tarrant County Water Control and Improvement District Number One (TCWCID) was first and foremost in collaborating with various federal, state, and local agencies and private consultants to begin the development of this technology.

The Plan of Work was developed in October 1992 for the adaptation of the SWAT basin model to TCWCID's reservoir watersheds and assimilation of GIS data layers needed to drive the model. Cooperative agreements between NRCS, USDA-Agricultural Research Service (ARS), and Texas Agricultural Experiment Station (TAES) set up a team comprised of individuals from the three agencies along with TCWCID staff to carry out the Plan of Work jointly developed for the project.

The SWAT computer process model was developed by USDA-ARS to predict the effect of management on water, sediment, and nutrient yields on large river basins. SWAT was developed by adding reach routing structure to the SWRRBWQ (Simulator for Water Resources in Rural Basins, Water Quality) subbasin simulation model and addition of components for groundwater flow and lateral flow. SWAT is the model developed for the HUMUS (Hydrologic Unit Model for the U.S.) project for the national Natural Resources Conservation Service. TAES has interfaced SWAT with a GIS (Geographic Information System) to provide general model input values. SWAT operates in the UNIX operating system and with the U.S. Army Corps of Engineers GRASS (Geographical Resources Analysis Support System) GIS.

SWAT is intended to be used now and in the future as a tool to assess the nonpoint source pollution (NPS) in watersheds above the TCWCID reservoirs. By identifying the sources and loadings of NPS from subwatersheds or basins, the watershed manager can prioritize the best management practices determined most effective for treatment.

The first overall step was to have SWAT accurately predict flows in a subbasin configuration. This was accomplished by calibrating the model for a five year period (1965-69) to USGS stream flow gauge records. Validation of flow was done by simulating flow for three other five year periods (1970-74, 1975-79 and 1980-84) and comparing to gauge records for the same watershed. Plots of simulation versus measured data indicated R^2 as good as 0.84 on the validation data.

The next step was to accurately predict sediment loadings. Comparisons of simulated sediment loadings were made to measured sediment accumulation in selected reservoirs where data was available. Calibration of the model was done on Richland-Chambers watershed by comparing simulated sediment loadings to a reservoir sediment survey for the period 1988-94. The model validation was accomplished by simulating sediment loadings in the other watersheds. Good results were obtained for all simulations where measured data was available.

The model is predicting nutrients, the loadings being closely related to either flow or sediment. Sampling programs are presently underway to gather data to validate nutrient loadings. It is the plan to eventually have all predicted NPS components validated.

SWAT has been used in some actual alternative development and evaluation of BMP implementation within the project area. Big Sandy Creek is an authorized watershed protection project of NRCS within the Trinity River Watershed where installation of structural measures is underway. TCWCID provided funds for acceleration of implementation of the watershed protection plan. A SWAT model run was used to determine the benefits of these structural measures in retaining sediment loads from their water supply reservoirs. The reduction in sediment loads with a cost factor applied provides justification for the cost-share expenditure.

A similar situation exists in the Mill Creek subbasin of the Richland-Chambers Watershed where SWAT computer simulations of the Mill Creek will be used to evaluate the effectiveness of BMPs being installed. The output data will be used to prioritize which structures provide the greatest benefit/cost ratio and the overall reduction in sediment loads at the basin outlets.

TCWCID staff has been involved and trained throughout the development of this project. They have attended formal workshops on field scale and watershed scale computer models and have provided suggestions on format of input and output structure. They are running the SWAT simulations and using the GIS in their office which assures that the study is not ended as a report gathering dust on a shelf. Their interest and involvement has meant that the end product will be a useful tool for other reservoir and watershed managers.

INTRODUCTION

Sediment and nutrients are being deposited in five water supply reservoirs owned or operated by TCWCID causing water quality and quantity problems. The main concern of the study is to identify significant nonpoint source pollutant (NPS) loadings within the watershed and determine feasible alternatives to lower the rate of reservoir sedimentation and nutrient loading (USDA-SCS, 1992). TCWCID is interested in the effects sediment, nitrogen and phosphorus are having on water quality and on reservoir storage capacity.

Of particular concern is a long-term management plan to reduce the impact of the NPS areas. TCWCID needs to know the potential non-structural measures and structural sites available in the watersheds. Also, they need to know the effect of these structures and land treatment measures on the sediment rates and transport of other NPS pollutants. This includes:

- Erosion, sedimentation, and NPS constituents effects on lake water quality and measures to slow these processes.
- The effect of different intensity rainfall on the transportation of the sediment and NPS to the reservoirs.

Meetings with all parties involved were held to discuss the study concerns and determine the objectives for this study. TCWCID concerns were compared to USDA objectives. The resulting concerns and needs were reduced to the following study objectives:

Identify significant Nonpoint Source Pollution (NPS) areas within the watershed by identifying areas of critical erosion, sources of nutrients and the relative effects of the movement of NPS through the streams and reservoirs.

Coordinate study data and work with other agencies and other studies (Tarrant County WCID, Corps of Engineers (COE), U.S. Geological Survey (USGS), ARS, TAES).

Develop alternative solutions to reduce sediment and NPS problems with priorities.

Propose a management plan to reduce the impact of these NPS areas.

Implement a long-term management plan.

The primary mechanism for accomplishing the needs and objectives of this planning effort was the formulation of the Upper Trinity River Basin Cooperative Study by USDA-NRCS and TCWCID. Funding was provided from various sources including TCWCID, USDA-NRCS, Texas Natural Resource Conservation Commission (TNRCC) through Trinity River Authority (TRA), Texas Water Development Board (TWDB), USDA-ARS, and TAES through cooperative agreements.

A Memorandum of Understanding between TCWCID and USDA-NRCS was also executed in September 1992 to establish a framework to increase cooperation and coordination between the two entities on mutual water quality objectives.

DESCRIPTION OF STUDY AREA

Physical Characteristics

The District's project area is located in the Upper Trinity River Basin in north-central and east-central Texas. It encompasses all or portions of 23 counties. Cedar Creek, Richland-Chambers, Eagle Mountain, Bridgeport, and Benbrook reservoirs and their drainage areas are shown on Figure 1. The five reservoirs control runoff from 6,474 square miles. In addition, Lake Worth and Lake Arlington are included in the project area.

Climate

The climate is subhumid. Average annual precipitation ranges from about 28 inches on the northwestern area of the basin to 39 inches on the southeastern portion of the basin. The entire area is subject to high intensity, short duration thunderstorms during the spring and summer months. Typically, summers are hot and winters are mild with intervals of freezing temperatures as cold fronts pass though the region.

Population

The largest urban population in the basin is within the Dallas-Fort Worth Metroplex. Tarrant County, in which the city of Fort Worth is located, and surrounding area is within the western half of the Metroplex. The estimated 1990 population of Tarrant County alone, Texas' fourth most populous county, is about 1,131,800. It is this population and others living in the surrounding area that is supplied with domestic, municipal, and industrial water from the five reservoirs owned and managed by the Tarrant County WCID. Historic records reveal a remarkable population growth. Demographic data indicates this population growth trend will continue, increasing the needs and requiring additional water.

Soils

The District's watersheds are within portions of the Central Rolling Red Prairies, Cross Timbers, Grand Prairie, and Texas Blackland Prairie Major Land Resource Areas. Soils range from course textured loamy sands in the Cross Timbers to fine textured montmorillonitic clays in the Blackland Prairie. Soil depths vary from very shallow to deep. Upland topography ranges from nearly level to steeply sloping. Much more detailed information on soils is included in the GIS section and Appendix B which lists the major soils occurring within the watersheds.

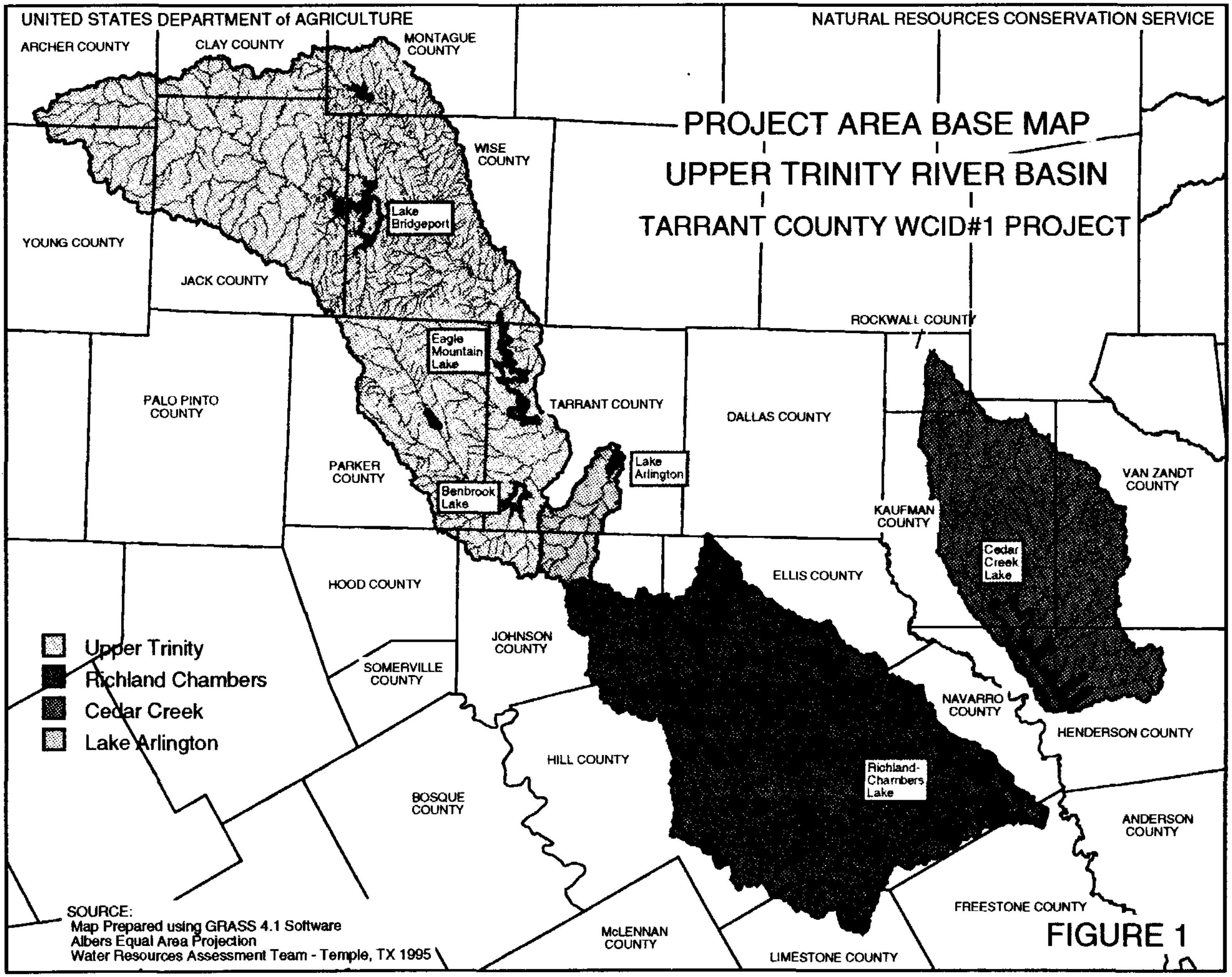
Land Use

Agricultural land uses are dominant in the drainage areas of the five water supply reservoirs comprising the project area. Without adequate treatment and management, soils are subject to accelerated erosion with subsequent increased reservoir sedimentation and related water quantity and quality degradation. Best management practices (BMPs) for alleviating or preventing these problems are unique to each soil, its location, and the circumstances under which the soil is used. With the diversity of soil types, locations, and land uses in the reservoirs' drainage areas it is imperative that proper planning and implementation of BMPs are accomplished. Much more detailed information on land use within the study area is included in the GIS section.

TABLE 1 LAND USE IN TCWCID WATERSHEDS

No.	Description	Acres	Cover
23	Pastureland and Hayland	1,287,470	35.21
32	Range - Brushy	700,677	19.16
21	Agricultural - Cropland	552,980	15.12
31	Range - Open	532,066	14.55
28	Range - Savannah	200,714	5.49
11	Urban and Built-up Land (cities, towns, villages, etc.)	161,505	4.42
51	Water (permanent or predominantly covered)	90,300	2.47
12	Urban - Other (airstrips, farmsteads, landfills, etc.)	60,846	1.66
13	Urban - Highways (outside city limits)	28,061	0.77
52	Water - Farm Ponds	12,978	0.35
81	Pasture (Recreation land)	8599	0.24
64	Pastureland (frequently flooded)	8253	0.23
73	Range (Strip mines, quarries, gravel pits, etc.)	5041	0.14
25	Agricultural - Orchards and Groves	2866	0.08
29	Native Pastureland	2777	0.08
75	Range (River wash, sand bars, etc.)	534	0.01
26	Agricultural - Orchards and Groves (irrigated)	415	0.01
74	Range (Oil waste land, etc.)	306	0.01
22	Agricultural - Irrigated Cropland	69	0
41	Upland Forest	49	0
61	Wetlands	30	0
	TOTAL	3,656,536	100

Source: USDA-NRCS - CBMS Land Use GIS Data Base


UNITED STATES DEPARTMENT of AGRICULTURE
NATURAL RESOURCES CONSERVATION SERVICE
PROJECT AREA BASE MAP
UPPER TRINITY RIVER BASIN
TARRANT COUNTY WCID#1 PROJECT
ARCHER COUNTY
CLAY COUNTY
MONTAGUE COUNTY
WISE COUNTY
YOUNG COUNTY
JACK COUNTY
Lake Bridgeport
ROCKWALL COUNTY
Eagle Mountain Lake
PALO PINTO COUNTY
TARRANT COUNTY
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PARKER COUNTY
Lake Arlington
Benbrook Lake
VAN ZANDT COUNTY
KAUFMAN COUNTY
Cedar Creek Lake
HOOD COUNTY
ELLIS COUNTY
JOHNSON COUNTY
SOMERVILLE COUNTY
Upper Trinity
Richland Chambers
Cedar Creek
Lake Arlington
NAVARRO COUNTY
HENDERSON COUNTY
HILL COUNTY
Richland-Chambers Lake
BOSQUE COUNTY
ANDERSON COUNTY
FREESTONE COUNTY
SOURCE:
Map Prepared using GRASS 4.1 Software
Albers Equal Area Projection
Water Resources Assessment Team - Temple, TX 1995
McLENNAN COUNTY
LIMESTONE COUNTY

FIGURE 1

Dams and Reservoirs

TCWCID owns or operates five major reservoirs within the study area. There are many other ponds and reservoirs within the watersheds ranging from small livestock watering facilities to small municipal reservoirs. All structures included in state or federal inventories are contained in the GIS data base with much of the physical data for each reservoir which is needed for input to the computer model. Table 2 contains data for the five major reservoirs.

TABLE 2 TCWCID MAJOR RESERVOIR DATA

Reservoir	Drainage Area (Square Miles)	Conservation Storage (Acre-Feet)
Benbrook Dam	429	88,200
Bridgeport Dam	1,111	386,420
Eagle Mountain Dam	1,970	190,460
Richland-Chambers Dam	1,957	1,135,000
Cedar Creek Reservoir	1,007	679,200

Table 7 in Appendix C is an extensive listing of all inventory sized reservoirs within the watersheds of the study area. The physical data of most of these reservoirs is in a relational data base. This reservoir data enables the model to reflect the retarding effect on stream flow and sediment.

Sediment survey data was assembled from reservoirs within the TCWCID study area. Some of the surveys were taken at 5 year intervals for several years and others were a one-time survey which can be compared to original storage capacity of a reservoir to calculate accumulated sediment. Accumulated sediment is used in calibration and validation of the model. Table 8 in Appendix C is a listing of those reservoirs for which sediment accumulation data is available along with information on number and dates of surveys.

METHODOLOGY

The study area for this project consists of three watersheds (Figure 1) which include the five major reservoirs owned or managed by TCWCID. Table 3 lists the relative size of these watersheds.

TABLE 3 PHYSICAL DATA ON TCWCID WATERSHEDS

Watershed	Square Miles	Acres	% of Study Area
Upper Trinity	2,601	1,664,500	46.74%
Richland-Chambers	1,957	1,135,000	35.16%
Cedar Creek	1,007	679,200	18.10%

Initially, the watersheds were subdivided into subwatersheds according to the size of each tributary to the main stream. The subwatershed boundaries were digitized from 1:24,000 USGS quad sheets after determining the boundaries on each sheet. This configuration provided about 50 subbasins for the Upper Trinity, 16 for Richland-Chambers, and 18 for Cedar Creek Watersheds. For initial model runs using the 1:250,000 scale GIS data layers for input, this subbasin configuration was adequate. At this point there were several modifications to the SWAT model necessary to accommodate the small watershed applications.

As more detailed GIS data was assembled and the SWAT model development progressed, it was apparent that further subdivision of basins would be necessary to provide the outputs desired. Upper Trinity watershed is divided into 143 subbasins, Richland-Chambers into 20 subbasins, and Cedar Creek into 71 subbasins at the time of this report. Special analysis underway along with the need to establish additional sampling sites on two major tributaries has led to the further subdividing of Cedar Creek watershed.

The first priority for calibration and validation was for stream flow. Availability of measured data to compare model simulations was more prevalent for stream flow. USGS stream flow gauge measurements exist for several years of record at each station.

After the model was working well for flow, the focus turned to sediment loadings from subbasins. Details are presented in the section on calibration and validation of the model. The strategy employed was to take sediment deposition volumes measured in several reservoirs over a span of several years and simulate the watershed with actual weather data for the same period of time. Simulated sediment loadings were then compared to accumulated sediment in the receiving waters.

GEOGRAPHIC INFORMATION SYSTEM

The GIS is an integral part of this overall study. GIS is integrated with SWAT which is a distributed parameter, continuous time, nonpoint source pollution model. Without GIS, the input of physical data would be most time consuming. Integration of GIS also allows visualization and analysis of the input and output of the model. Developers of SWAT chose a public domain raster GIS designed and developed by the Environmental Division of the U.S. Army Construction Engineering Research Laboratory (USA-CERL). GRASS is a general purpose, raster graphic modeling and analysis package and is highly interactive and graphically oriented, providing tools for developing, analyzing, and displaying spatial information. GRASS is used by numerous federal, state, and local agencies and private consultants.

This section of the report outlines the details of the GIS data base assembled for TCWCID. This data base is certainly not considered complete or fixed. As more detailed or more current data becomes available, the TCWCID data base will need to be updated.

Soils

A soils data base describes the surface and upper subsurface of a watershed. Older models only use the soil surface moisture and infiltration parameters to determine rainfall runoff. Models such as EPIC and SWAT use information about each soil horizon. Parameters describing horizon thickness, depth, texture, water holding capacity, dispersion, etc. must be available to the model. These parameters are used to determine a water budget for the soil profile, daily runoff and erosion. Movement of nutrients, pesticides and herbicides on the surface and within the soil horizons are also modeled.

The NRCS soils data base currently available for all of the counties of Texas is the STATSGO 1:250,000-scale soils data base. The 1:250,000-scale USGS topographic map series was used as the base map for the compilation of this data base. The STATSGO data base covers the entire United States and all STATSGO soils are defined in the same way. Therefore, for any area within the United States, the STATSGO data base can be used by models without a great deal of effort to prepare the soil GIS layer. While this data base is usually adequate for predicting erosion from very large watersheds, it usually does not give adequate accuracy for watershed subbasins smaller that the eight digit HUC (Hydrologic Unit Code) or about 1000 square miles. However, it is an excellent tool for initial screening of a large watershed to identify subbasins showing high potential for contributing to non-point source pollution in streams and reservoirs.

Another NRCS soils data base, the SSURGO data base is the most detailed soil data base available. Currently this data base is not available as a vector or high resolution cell (grid) data base. This 1:24,000-scale soils data base is available as printed county soil surveys for over 90% of Texas counties. The tabular data describing the properties of each soil is available in electronic form and a grid GIS with lower resolution has been created. The Computer Based Mapping System (CBMS) or Map Information Assembly Display System

(MIADS) data base was created from 1:24,000 scale soil sheets with a cell resolution of 250 meters (820 feet). Normally, a cell resolution of 20 meters would be used for information taken from a 1:24,000 scale base map to adequately show the detail, but it is a lengthy and costly process. Because this data base has been developed over a period of many years, soil definition and delineation is not very consistent for areas made up of more than one county.

The CBMS data base differs from some grid GIS data bases in that the soil mapping unit ID used to determine the attribute of each cell is the soil that occurs under the center point of the cell instead of the soil that makes up the largest percentage of the cell. This method of cell attribute labeling has the advantage of a more accurate measurement of the various soils in an area. The disadvantage is for any given cell the attribute of that cell may not reflect the soil that actually makes up the largest percentage of that cell.

There is one main difference between the STATSGO and SSURGO data bases. In the SSURGO data base, each soil delineation is a soil which is described a single soil series. In the STATSGO data base, each soil delineation of a STATSGO soil is a made up of more than one soil series. Some STATSGO soils are made up of as many as twenty SSURGO soil series. Usually there is one SSURGO soil series that dominates a STATSGO soil.

Computer models use the soil series name as the data link between the soils GIS layer and the soils properties tabular data base. The SWAT model can use the STATSGO soil name in a GIS soil layer to look up the soil series name that is the dominant series for a specific STATSGO soil. The soils properties tabular data base is a component of the computer model and is not developed by the model user.

During this study, data for the remaining counties needed to complete 1:24,000 scale coverage for soils was assembled. All of the study area is represented by both the 1:250,000 and the 1:24,000 scale soils GIS coverage as shown in Figures 2 and 3 respectively.

Land Use/Cover Classification

Land use and cover affect surface erosion and water runoff in a watershed and are a necessary input of a watershed model.

The USGS Land Use and Land Cover data base is available for all of Texas. This data base was developed from NASA and NHAP (National High-Altitude Photography) high-altitude aerial photographs. The 1:250,000-scale topographic map series was generally used as the base map for the compilation of this data base.

The NRCS 1:24,000-scale Land Use and Land Cover data base is the most detailed land use/cover data base presently available. This data base is available only in CBMS format. Over 90% of Texas counties have been mapped using this format. The CBMS Land Use and Land Cover data base format is the same as the format used for the CBMS soils data base.

During this study, data for the remaining counties needed to complete 1:24,000 scale coverage for land use and land cover was assembled. All of the study area is represented by both the 1:250,000 and the 1:24,000 scale land use GIS coverage as shown in Figures 4 and 5 respectively.

Topographical Data Base

Another data base that describes the surface of a watershed comes in the form of a topographical or DEM (digital elevation model) data base. The DEM data base is a grid representation of elevation contour lines. The only DEM data base that is currently available for all of Texas is the 1:250,000-scale data. This scale corresponds to a cell resolution of three arc seconds or about 100 meters. This data base is usually very adequate for computer models such as SWAT except in very flat watersheds. When using this data base, manual digitizing or scanning to develop subbasin boundaries in a watershed may be necessary.

Where the sub-basin size is less that a few hundred acres or in areas that are almost flat, the more detailed 1:24,000-scale DEM should be used for computer delineation of subbasins. The 1:24,000-scale corresponds to a cell resolution of one arc second or about 30 meters. If this data base is used in watershed modeling, computer time and storage requirements can become an obstacle.

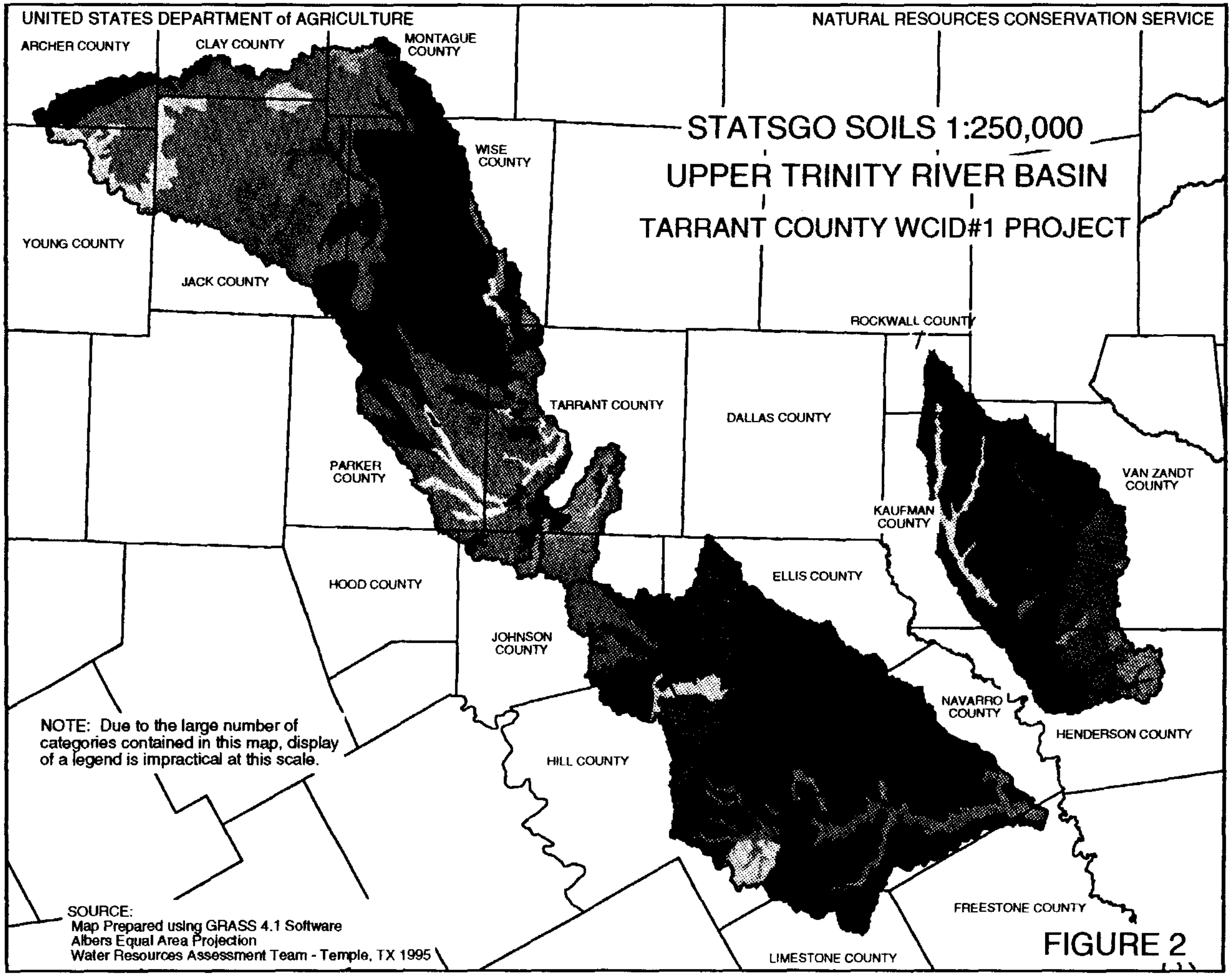
The entire study area is represented only by the 1:250,000 scale GIS coverage for digital elevation models and is displayed in Figure 6. A critical area, the Mill Creek Subwatershed, where additional NRCS planning efforts are underway was digitized from USGS 7.5 minute quadrangle sheets to develop a digital elevation model at a scale of 1:24,000. This GIS coverage is shown in Figure 7.

Historical Climatic Data

Historical climatic data is available from the United States Weather Bureau. The EPIC and SWAT models have built in weather generators that generate daily weather based on historical weather from the nearest weather station. The user can also input daily precipitation and daily maximum and minimum temperatures. Table 4 lists precipitation stations located in or near the watersheds of the study area and the time periods for which data is available for each station.

Historical Stream Flow

Historical stream flow data is available from the USGS records. Historical stream flow data should be compared to model output whenever possible. Stream gauge locations listed in Table 5 includes stream gauge stations located within the watersheds of the study area and the time periods for which data is available for each station.


UNITED STATES DEPARTMENT of AGRICULTURE
NATURAL RESOURCES CONSERVATION SERVICE
STATSGO SOILS 1:250,000
UPPER TRINITY RIVER BASIN
TARRANT COUNTY WCID#1 PROJECT
ARCHER COUNTY
CLAY COUNTY
MONTAGUE COUNTY
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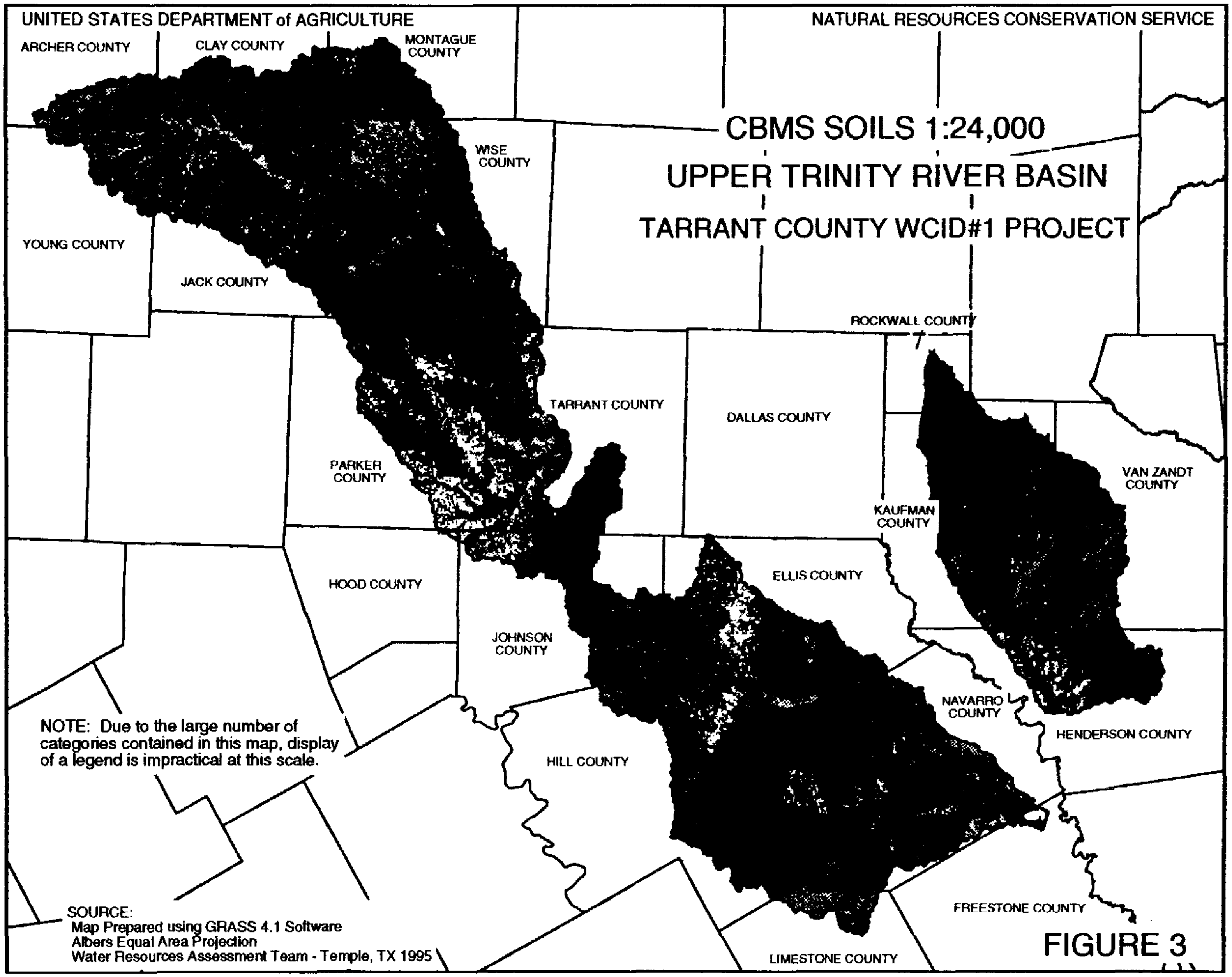
NAVARRO COUNTY
HENDERSON COUNTY
HILL COUNTY
FREESTONE COUNTY
LIMESTONE COUNTY
NOTE: Due to the large number of categories contained in this map, display of a legend is impractical at this scale.
SOURCE:
Map Prepared using GRASS 4.1 Software
Albers Equal Area Projection
Water Resources Assessment Team - Temple, TX 1995

FIGURE 2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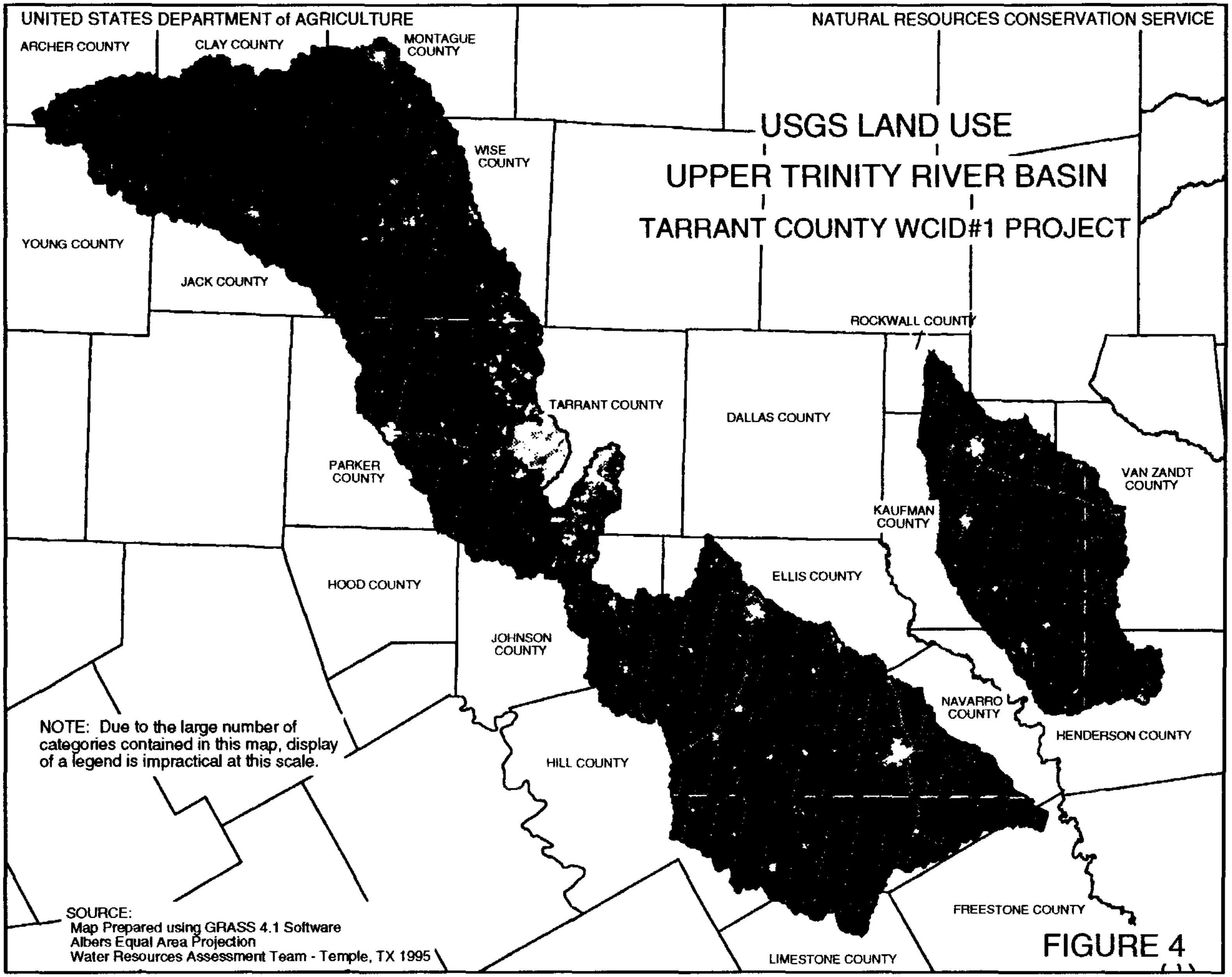
Water Resources Assessment Team - Temple, TX 1995

FIGURE 3



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USGS LAND USE
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CLAY COUNTY
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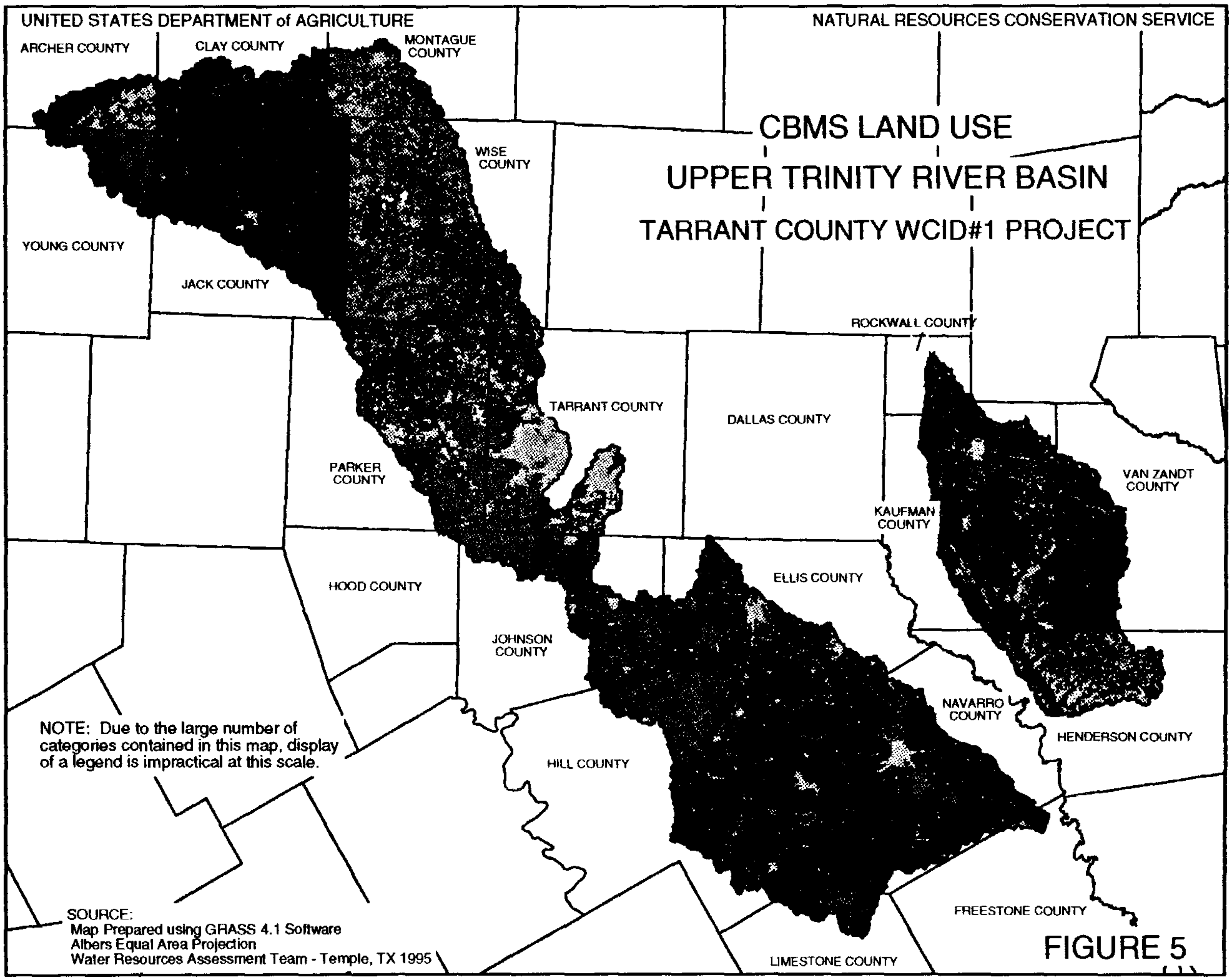
FIGURE 4



UNITED STATES DEPARTMENT of AGRICULTURE
NATURAL RESOURCES CONSERVATION SERVICE
CBMS LAND USE
UPPER TRINITY RIVER BASIN
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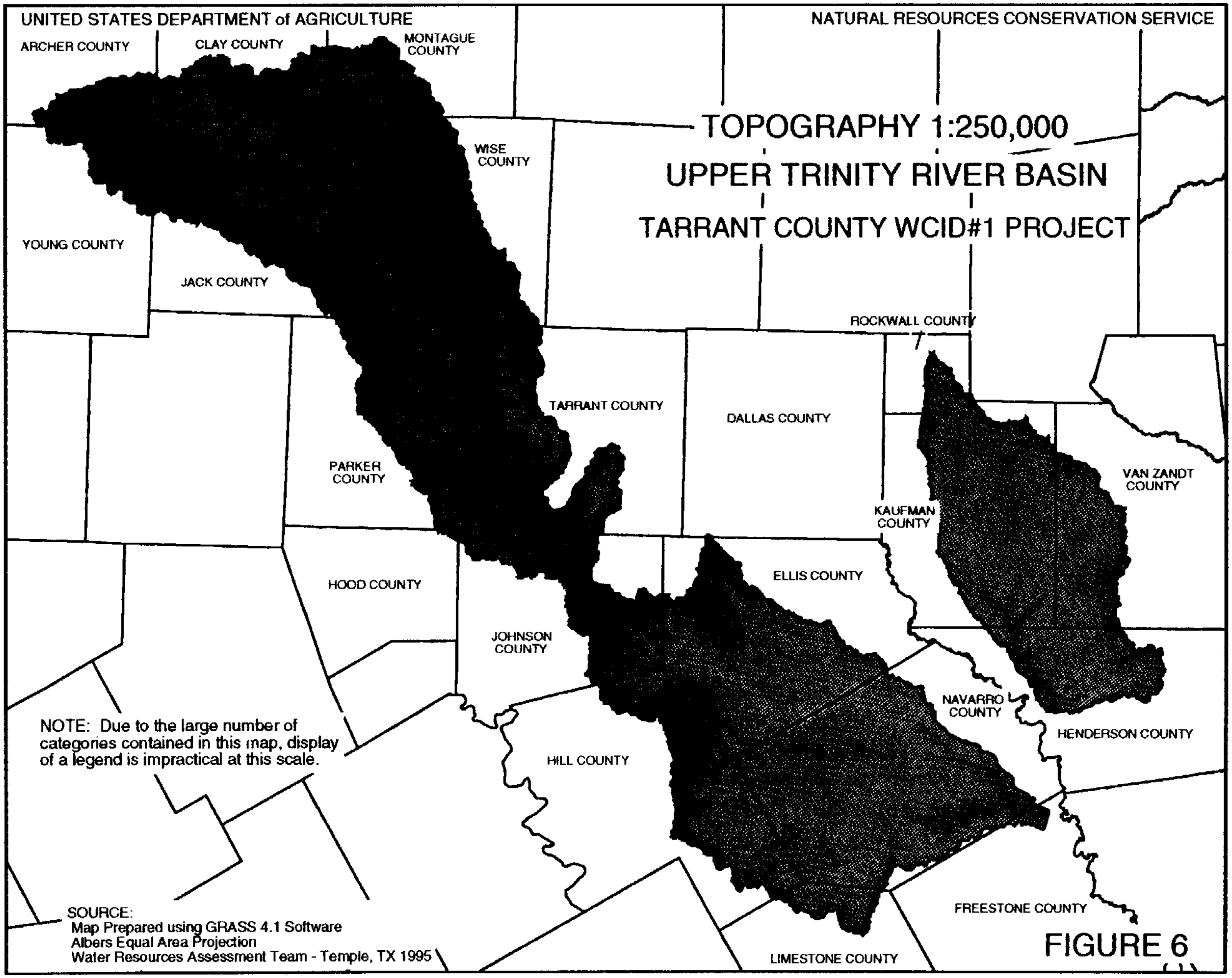
FIGURE 5


UNITED STATES DEPARTMENT of AGRICULTURE
NATURAL RESOURCES CONSERVATION SERVICE
TOPOGRAPHY 1:250,000
UPPER TRINITY RIVER BASIN
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SOURCE:
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Albers Equal Area Projection
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FIGURE 6

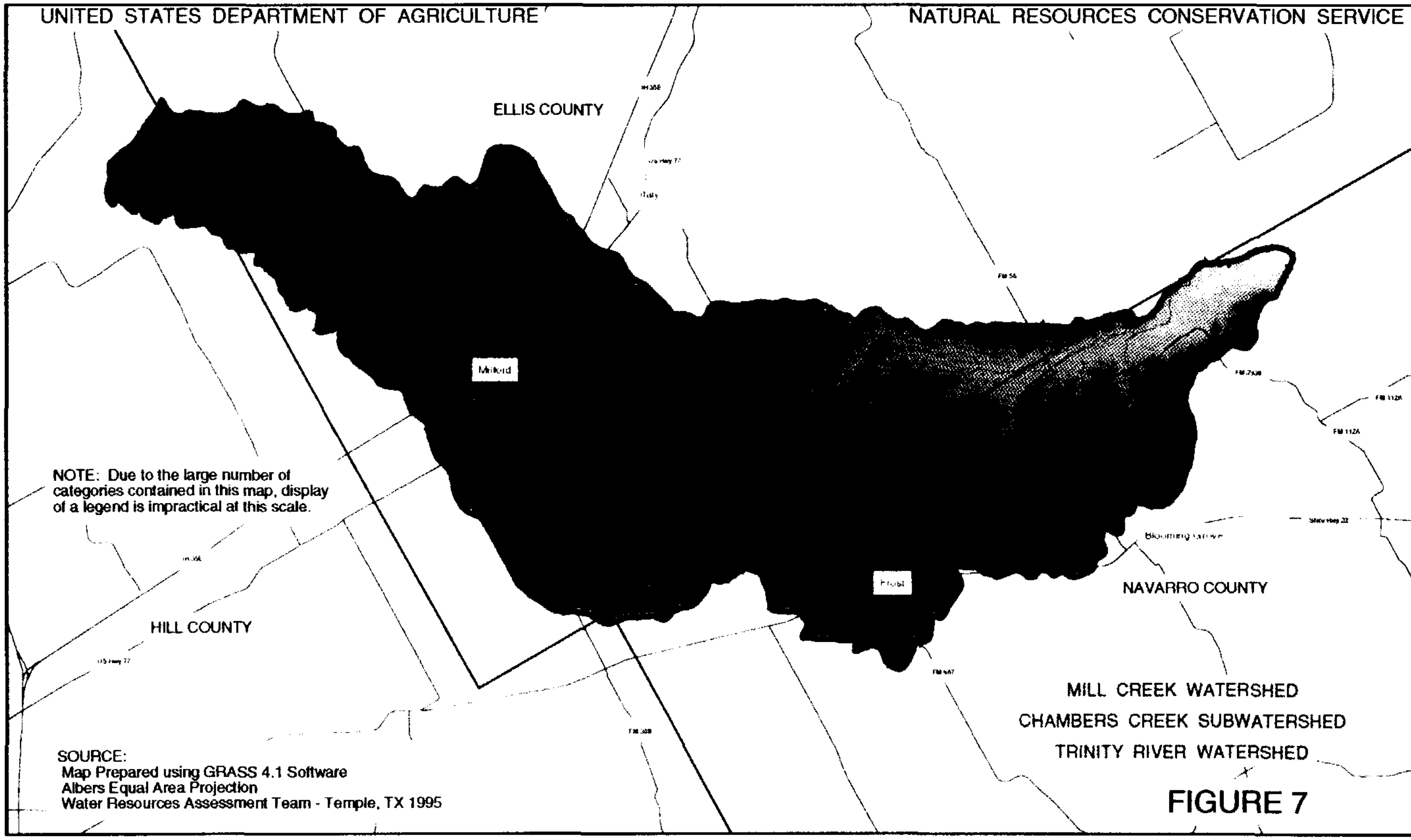

UNITED STATES DEPARTMENT OF AGRICULTURE
NATURAL RESOURCES CONSERVATION SERVICE
ELLIS COUNTY
NOTE: Due to the large number of categories contained in this map, display of a legend is impractical at this scale.
HILL COUNTY
NAVARRO COUNTY
MILL CREEK WATERSHED
CHAMBERS CREEK SUBWATERSHED
TRINITY RIVER WATERSHED
FIGURE 7
SOURCE:
Map Prepared using GRASS 4.1 Software
Albers Equal Area Projection
Water Resources Assessment Team - Temple, TX 1995

TABLE 4 HISTORICAL CLIMATE DATA

STATION NUMBER	STATION NAME	START DATE	END DATE	WATERSHED
480337	ARLINGTON	1960	1993	ARLINGTON
481245	BURLESON 2SSW	1960	1985	ARLINGTON
484761	KENNEDALE 6SSW	1960	1981	ARLINGTON
480404	ATHENS 3SSE	1960	1993	CEDAR
481425	CANTON	1963	1993	CEDAR
482080	CRANDALL	1960	1993	CEDAR
482772	EDOM 3NNW	1959	1993	CEDAR
484483	IRON BRIDGE DAM	1974	1993	CEDAR
484705	KAUFMAN 3SE	1960	1993	CEDAR
484914	LAKE RAY HUBBARD	1977	1993	CEDAR
487358	QUINLAN	1961	1975	CEDAR
480440	AVALON 2NW	1964	1993	RICH CHAM
480518	BARDWELL DAM	1964	1993	RICH CHAM
481800	CLEBURNE	1960	1993	RICH CHAM
482019	CORSICANA	1960	1993	RICH CHAM
482925	ENNIS	1960	1992	RICH CHAM
483047	FAIRFIELD 4E	1960	1993	RICH CHAM
483133	FERRIS	1960	1993	RICH CHAM
483379	FROST	1960	1985	RICH CHAM
484182	HILLSBORO	1960	1993	RICH CHAM
485869	MEXIA	1960	1993	RICH CHAM
487768	ROSS	1960	1976	RICH CHAM
480129	ALEDO 4SE	1960	1993	UPPER TRIN
480271	ANTELOPE	1960	1993	UPPER TRIN
480691	BENBROOK DAM	1960	1993	UPPER TRIN
480984	BOWIE	1960	1993	UPPER TRIN
480996	BOYD	1960	1993	UPPER TRIN
481063	BRIDGEPORT	1960	1993	UPPER TRIN
482096	CRESSON	1960	1993	UPPER TRIN
482334	DECATUR	1960	1993	UPPER TRIN
482677	EAGLE MTN	1977	1993	UPPER TRIN
482678	EAGLE MTN	1960	1975	UPPER TRIN
483247	FORESTBURG	1960	1993	UPPER TRIN
483668	GRAHAM	1960	1993	UPPER TRIN
484517	JACKSBORO	1960	1993	UPPER TRIN
485958	MINERAL WELLS	1960	1984	UPPER TRIN
486636	OLNEY	1960	1993	UPPER TRIN

TABLE 5 HISTORICAL STREAM FLOW GAUGING LOCATIONS

STATION NUMBER	START DATE	END DATE	WATERSHED
8049000	1925	1930	ARLINGTON
8048980	1986	1989	ARLINGTON
8048970	1991	1991	ARLINGTON
8062900	1963	1987	CEDAR
8062800	1963	1987	CEDAR
8062980	1982	1984	CEDAR
8063000	1939	1966	CEDAR
8063003	1983	1984	CEDAR
8062650	1966	1982	CEDAR
8063020	1965	1971	CEDAR
8064600	1972	1983	RICH CHAM
8063500	1939	1988	RICH CHAM
8064500	1939	1984	RICH CHAM
8064100	1984	1989	RICH CHAM
8063800	1964	1988	RICH CHAM
8063100	1961	1988	RICH CHAM
8063200	1956	1972	RICH CHAM
8042700	1956	1981	UPPER TRIN
8042800	1956	1989	UPPER TRIN
8043100	1985	1989	UPPER TRIN
8043500	1908	1930	UPPER TRIN
8044000	1937	1989	UPPER TRIN
8044500	1947	1989	UPPER TRIN
8045850	1980	1987	UPPER TRIN
8046000	1947	1976	UPPER TRIN
8047000	1947	1989	UPPER TRIN
8045500	1917	1934	UPPER TRIN
8047500	1924	1989	UPPER TRIN
8048000	1921	1989	UPPER TRIN
8048543	1977	1991	UPPER TRIN

Geographic and Cartographic Features

The Census Bureau's TIGER (Topologically Integrated Geographic Encoding and Referencing system) files can be converted into a GIS data base by ARC/INFO or GRASS. The resulting GIS layers consist of features such as highways, roads, city streets, streams, rivers and county lines. Names and classification of many of the features are available in the TIGER files. Statistical area boundaries are also included in the TIGER files. The TIGER lines are grouped into county files and available by state for all of the United States. Stream density and road designations may change when crossing county lines. TIGER files are comparable to 1:100,000-scale topographic maps.

Another source of geographic and cartographic features are the 1:100,000-scale USGS DLG (Digital Line Graph) files. These files have recently become available for almost all of Texas. Unlike the TIGER files, 1:100,000-scale DLG files do not contain political boundaries.

A sampling of the TIGER files assembled for TCWCID is illustrated with Figures 8 and 9. A particular layer or layers are added to a graphical display in GRASS as needed for orientation or interpretation of the spatial data.

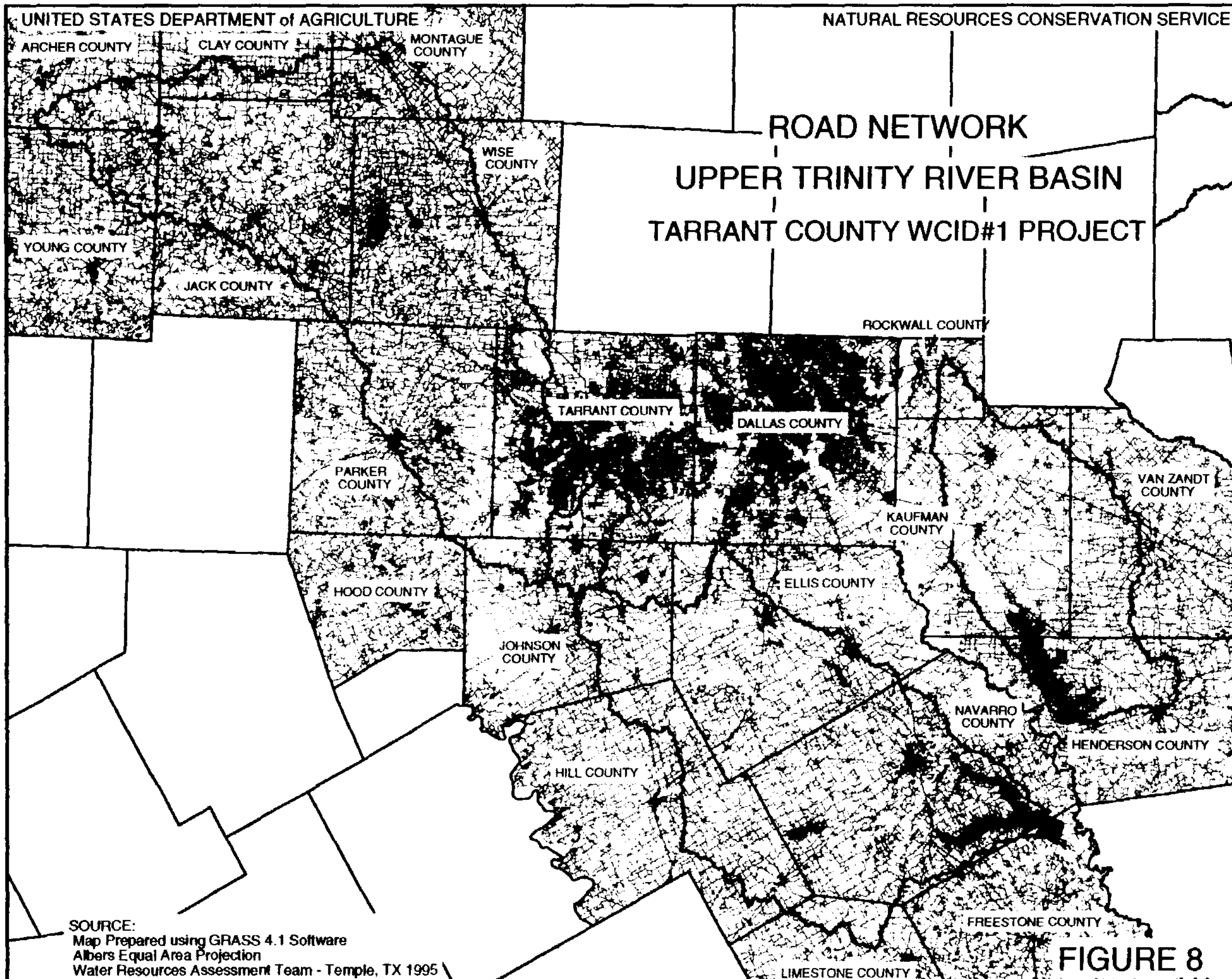
Miscellaneous GIS Data Layers

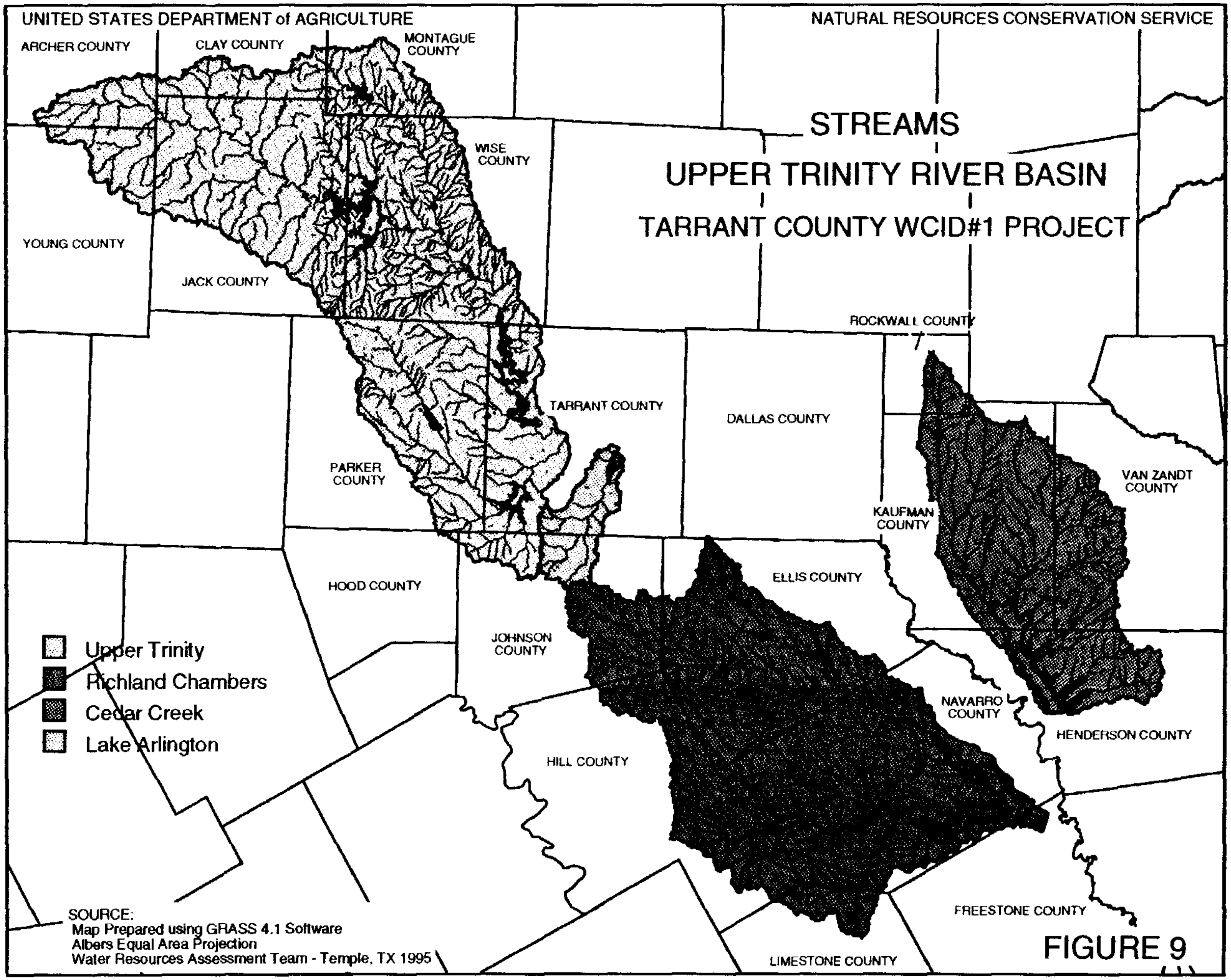
Additional GIS layers were assembled into the TCWCID data base as the data became available from various sources or as the need for a particular spatial coverage was determined.

A combination of the USDA-NRCS and TNRCC data bases which inventoried dams and reservoirs across the state were used to create a single reservoir data base. It consists of both a spatial layer and a relational data base containing all known physical facts about a reservoir such as surface area, drainage area, and storage capacities. Figure 10 is a display of the location of these reservoirs in the study area.

An example of an incomplete spatial layer is Figure 11, showing locations of confined animal feeding operations (CAFO). No agency at the present time has the geographical coordinates of each CAFO. The few locations known within the study area are shown in Figure 11. When this data is gathered it can easily be added to the TCWCID data base. As potential sources of NPS, the location of CAFO's is needed to complete this layer of GIS. TCWCID is in the process of collecting this data at this time.

Location of all types of well locations including gas, oil, and water were obtained from the Texas Railroad Commission. This data was available for most of the counties included in the study area. The counties that were not complete can be added when they become available. There are several different layers according to category of type of well. One such layer is shown in Figure 12.


UNITED STATES DEPARTMENT of AGRICULTURE
NATURAL RESOURCES CONSERVATION SERVICE
ROAD NETWORK
UPPER TRINITY RIVER BASIN
TARRANT COUNTY WCID#1 PROJECT
ARCHER COUNTY
CLAY COUNTY
MONTAGUE COUNTY
WISE COUNTY
YOUNG COUNTY
JACK COUNTY
ROCKWALL COUNTY
TARRANT COUNTY
DALLAS COUNTY
PARKER COUNTY
VAN ZANDT COUNTY
KAUFMAN COUNTY
ELLIS COUNTY
HOOD COUNTY
JOHNSON COUNTY
NAVARRO COUNTY
HENDERSON COUNTY
HILL COUNTY
FREESTONE COUNTY
LIMESTONE COUNTY
SOURCE:
Map Prepared using GRASS 4.1 Software
Albers Equal Area Projection
Water Resources Assessment Team - Temple, TX 1995
FIGURE 8


UNITED STATES DEPARTMENT of AGRICULTURE
NATURAL RESOURCES CONSERVATION SERVICE
STREAMS
UPPER TRINITY RIVER BASIN
TARRANT COUNTY WCID#1 PROJECT
ARCHER COUNTY
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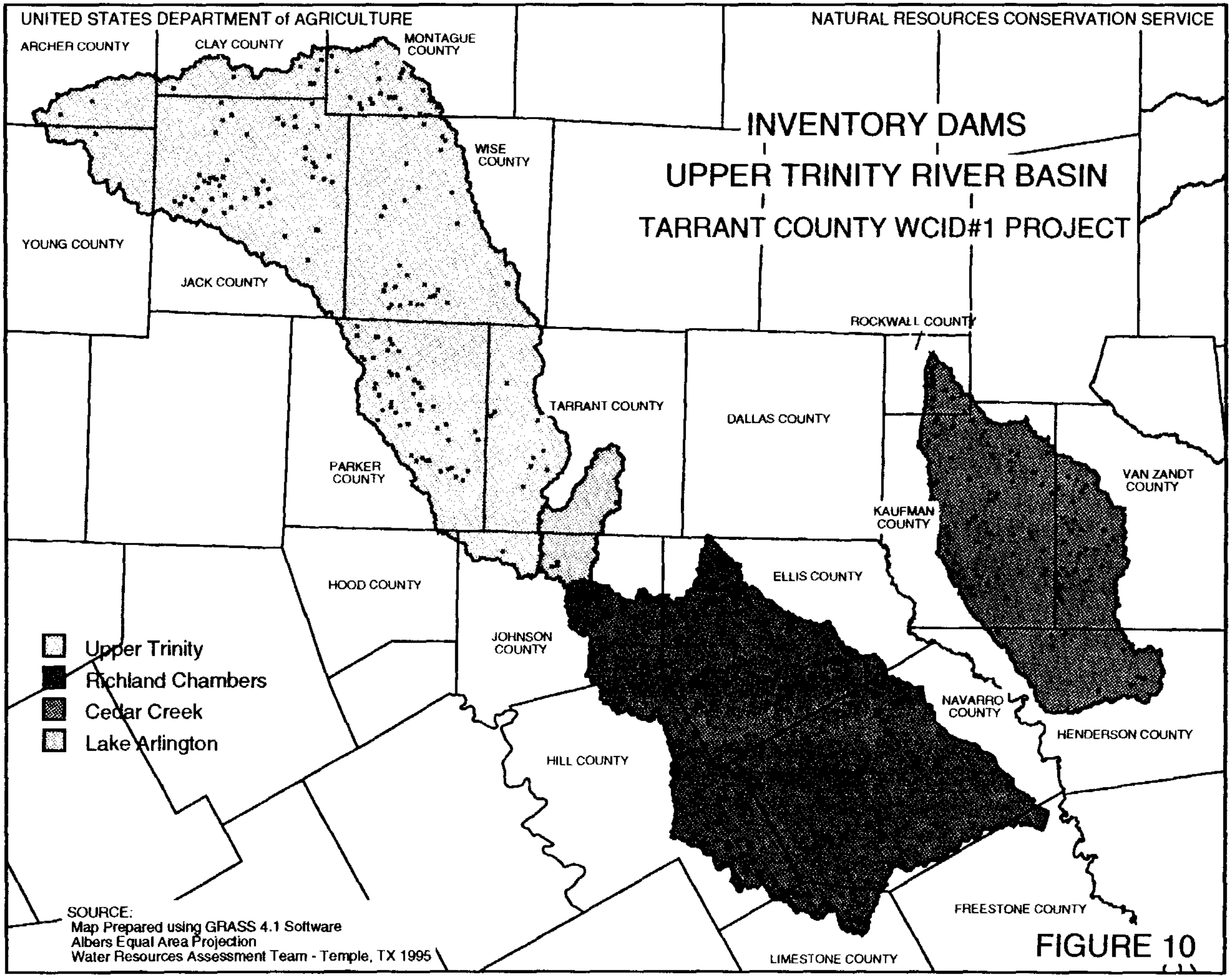
WISE COUNTY
YOUNG COUNTY
JACK COUNTY
ROCKWALL COUNTY
TARRANT COUNTY
DALLAS COUNTY
PARKER COUNTY
VAN ZANDT COUNTY
KAUFMAN COUNTY
ELLIS COUNTY
HOOD COUNTY
JOHNSON COUNTY
NAVARRO COUNTY
HENDERSON COUNTY
HILL COUNTY
FREESTONE COUNTY
LIMESTONE COUNTY
Upper Trinity
Richland Chambers
Cedar Creek
Lake Arlington
SOURCE:
Map Prepared using GRASS 4.1 Software
Albers Equal Area Projection
Water Resources Assessment Team - Temple, TX 1995

FIGURE 9


UNITED STATES DEPARTMENT of AGRICULTURE
NATURAL RESOURCES CONSERVATION SERVICE
INVENTORY DAMS
UPPER TRINITY RIVER BASIN
TARRANT COUNTY WCID#1 PROJECT
ARCHER COUNTY
CLAY COUNTY
MONTAGUE COUNTY
WISE COUNTY
YOUNG COUNTY
JACK COUNTY
ROCKWALL COUNTY
TARRANT COUNTY
DALLAS COUNTY
PARKER COUNTY
KAUFMAN COUNTY
VAN ZANDT COUNTY
HOOD COUNTY
ELLIS COUNTY
JOHNSON COUNTY
NAVARRO COUNTY
HENDERSON COUNTY
HILL COUNTY
FREESTONE COUNTY
LIMESTONE COUNTY
Upper Trinity
Richland Chambers
Cedar Creek
Lake Arlington
SOURCE:
Map Prepared using GRASS 4.1 Software
Albers Equal Area Projection
Water Resources Assessment Team - Temple, TX 1995
FIGURE 10

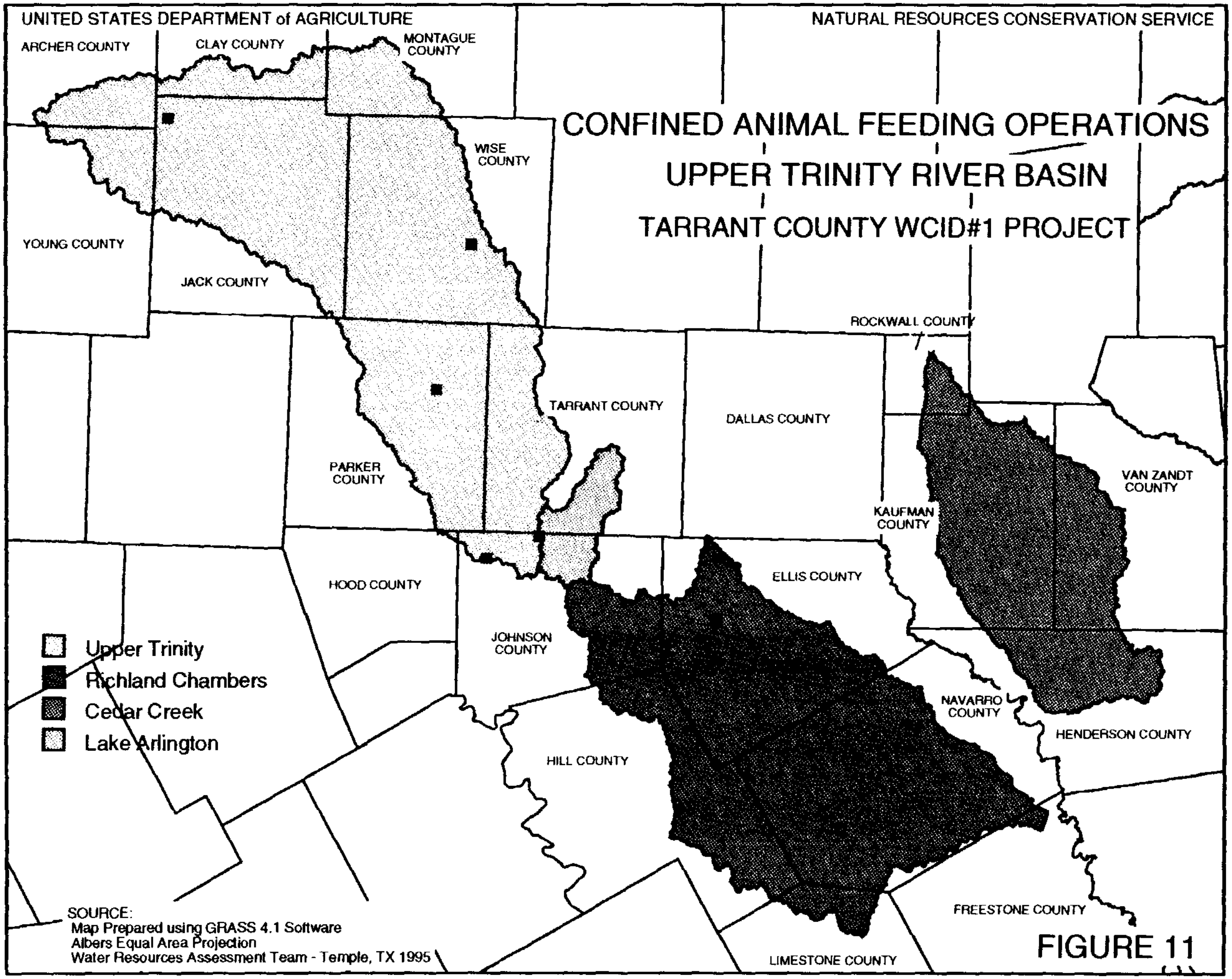

UNITED STATES DEPARTMENT of AGRICULTURE
NATURAL RESOURCES CONSERVATION SERVICE
CONFINED ANIMAL FEEDING OPERATIONS
UPPER TRINITY RIVER BASIN
TARRANT COUNTY WCID#1 PROJECT
ARCHER COUNTY
CLAY COUNTY
MONTAGUE COUNTY
WISE COUNTY
YOUNG COUNTY
JACK COUNTY
ROCKWALL COUNTY
TARRANT COUNTY
DALLAS COUNTY
PARKER COUNTY
KAUFMAN COUNTY
VAN ZANDT COUNTY
HOOD COUNTY
ELLIS COUNTY
JOHNSON COUNTY
NAVARRO COUNTY
HENDERSON COUNTY
HILL COUNTY
FREESTONE COUNTY
LIMESTONE COUNTY
Upper Trinity
Richland Chambers
Cedar Creek
Lake Arlington
SOURCE:
Map Prepared using GRASS 4.1 Software
Albers Equal Area Projection
Water Resources Assessment Team - Temple, TX 1995

FIGURE 11

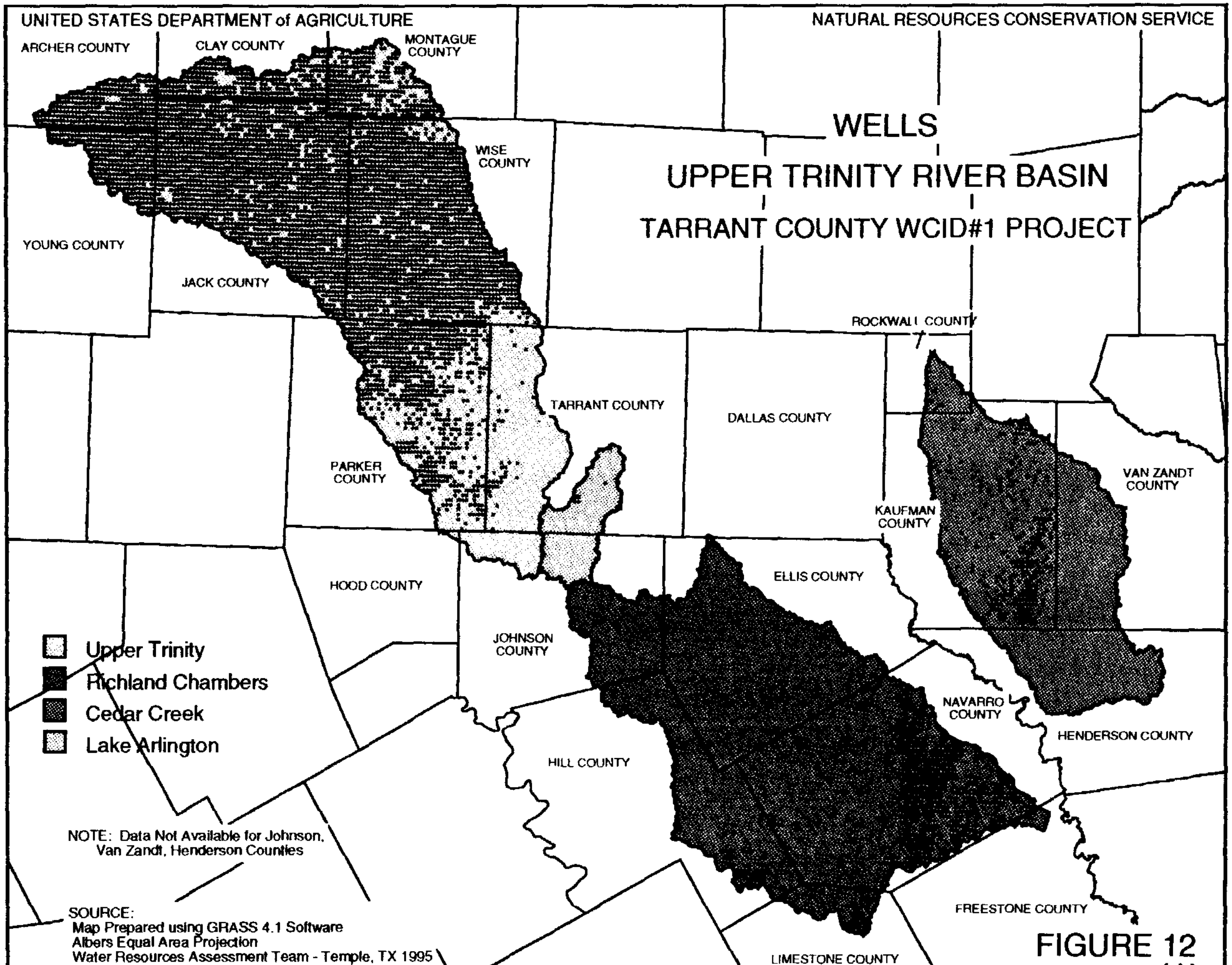

UNITED STATES DEPARTMENT of AGRICULTURE
NATURAL RESOURCES CONSERVATION SERVICE
WELLS
UPPER TRINITY RIVER BASIN
TARRANT COUNTY WCID#1 PROJECT
ARCHER COUNTY
CLAY COUNTY
MONTAGUE COUNTY
WISE COUNTY
YOUNG COUNTY
JACK COUNTY
ROCKWALL COUNTY
TARRANT COUNTY
DALLAS COUNTY
PARKER COUNTY
KAUFMAN COUNTY
VAN ZANDT COUNTY
HOOD COUNTY
ELLIS COUNTY
JOHNSON COUNTY
NAVARRO COUNTY
HENDERSON COUNTY
HILL COUNTY
FREESTONE COUNTY
LIMESTONE COUNTY
Upper Trinity
Richland Chambers
Cedar Creek
Lake Arlington
NOTE: Data Not Available for Johnson, Van Zandt, Henderson Counties
SOURCE:
Map Prepared using GRASS 4.1 Software
Albers Equal Area Projection
Water Resources Assessment Team - Temple, TX 1995
FIGURE 12

Figure 13 indicates the locations of stations where stream flow has been gauged. These locations and the data collected at each station were essential to calibration of the SWAT model.

The location of weather stations is shown in Figure 14. The SWAT model selects appropriate rainfall and temperature data from the nearest weather station to the basin under analysis by the model. Weather stations outside the TCWCID watersheds, yet close enough to influence input data to the model, are included in the GIS data base.

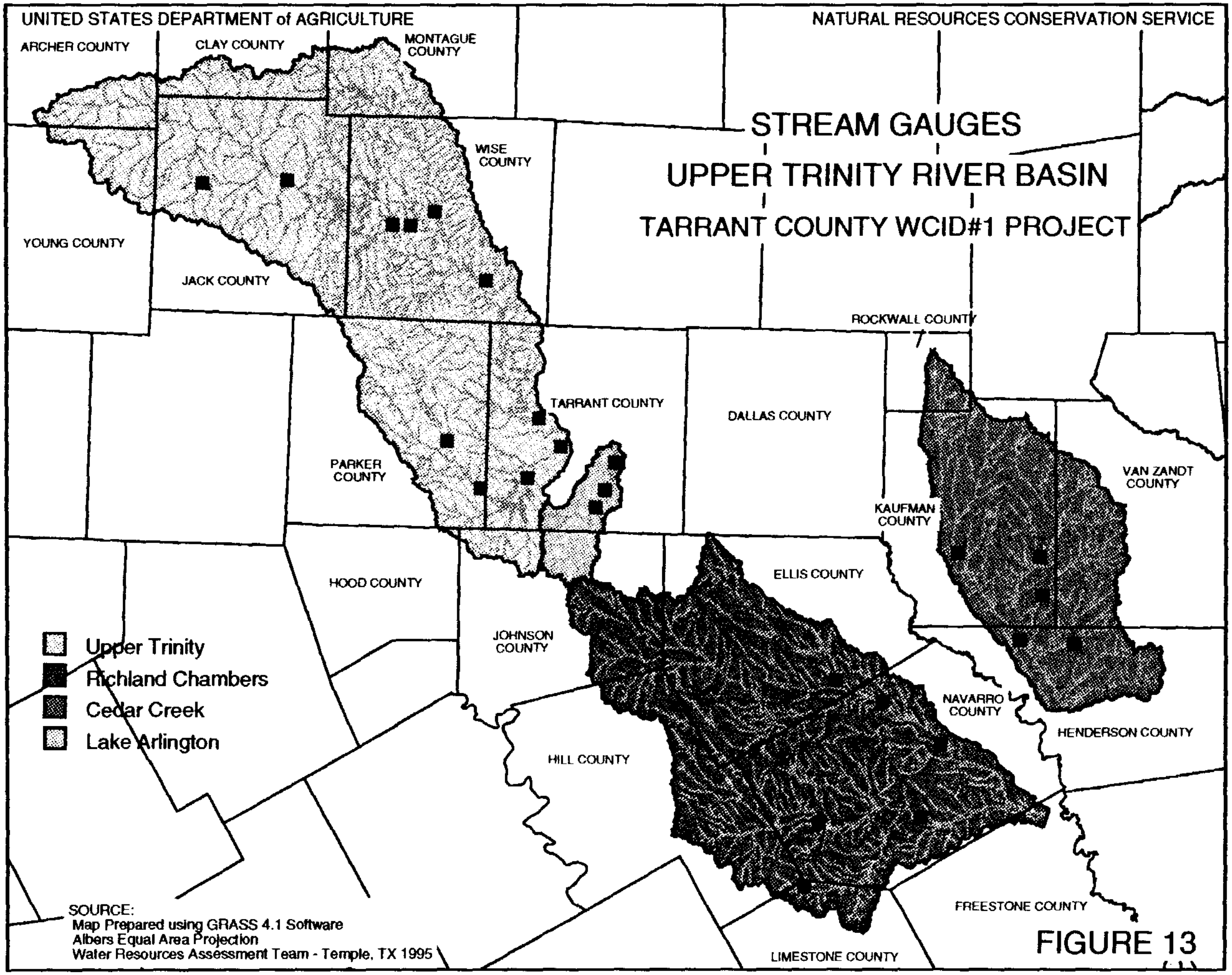
Locations of reservoirs where sediment surveys have been performed are shown in Figure 15. Simulations of watersheds above these reservoirs have been compared to measured sediment accumulation to calibrate the sediment loadings in SWAT.

The Census Bureau population data by census tracts is the basis for the spatial data layer shown in Figure 16. Each symbol or icon represents a population of 1000 people within a census tract. It basically indicates the spatial density of population throughout the study area.

Geology Data

The geologist on the NRCS Water Resources Assessment Team during the early portion of this study digitized the geologic atlas sheets to create a GIS spatial layer of geology formations. The University of Texas Bureau of Economic Geology loaned their original delineations of these atlas sheets which were then scanned by NRCS-WRAT and attributed by the geologist. The geologist also created a relational data base with all pertinent data by mapping I.D.s. Figure 17 displays the spatial layer of the geologic atlas sheets within the study area.

During the same timeframe, another geology GIS data base was made available which displayed land resource geology for the entire state. This layer differs from the atlas sheets in that it deals more with the surface geology and its influence on land resources. Coverage for the study area is shown in Figure 18.



UNITED STATES DEPARTMENT of AGRICULTURE
NATURAL RESOURCES CONSERVATION SERVICE
STREAM GAUGES
UPPER TRINITY RIVER BASIN
TARRANT COUNTY WCID#1 PROJECT
ARCHER COUNTY
CLAY COUNTY
MONTAGUE COUNTY
WISE COUNTY
YOUNG COUNTY
JACK COUNTY
ROCKWALL COUNTY
TARRANT COUNTY
DALLAS COUNTY
PARKER COUNTY
KAUFMAN COUNTY
VAN ZANDT COUNTY
HOOD COUNTY
ELLIS COUNTY
JOHNSON COUNTY
NAVARRO COUNTY
HENDERSON COUNTY
HILL COUNTY
FREESTONE COUNTY
LIMESTONE COUNTY
Upper Trinity
Richland Chambers
Cedar Creek
Lake Arlington
SOURCE:
Map Prepared using GRASS 4.1 Software
Albers Equal Area Projection
Water Resources Assessment Team - Temple, TX 1995

FIGURE 13

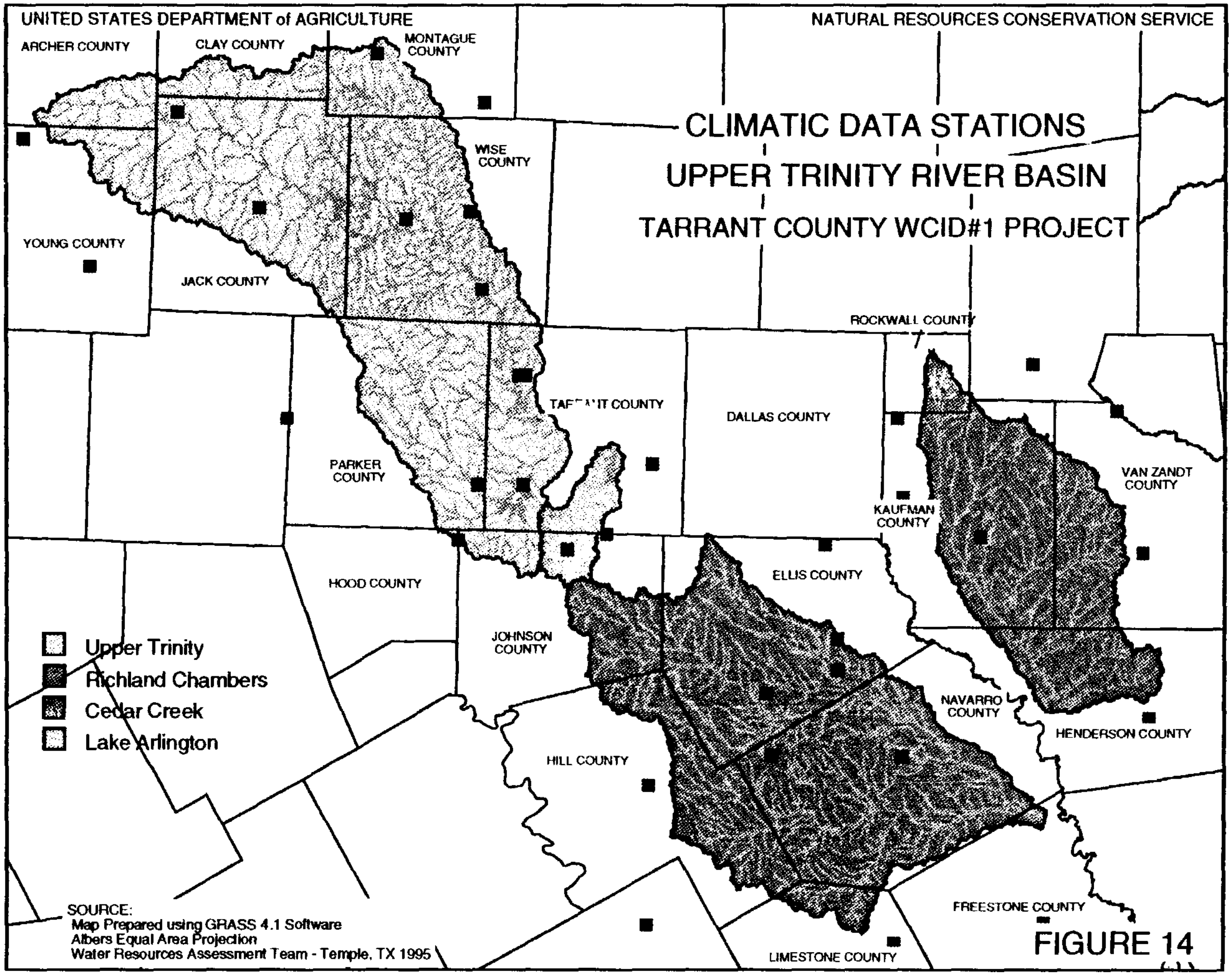
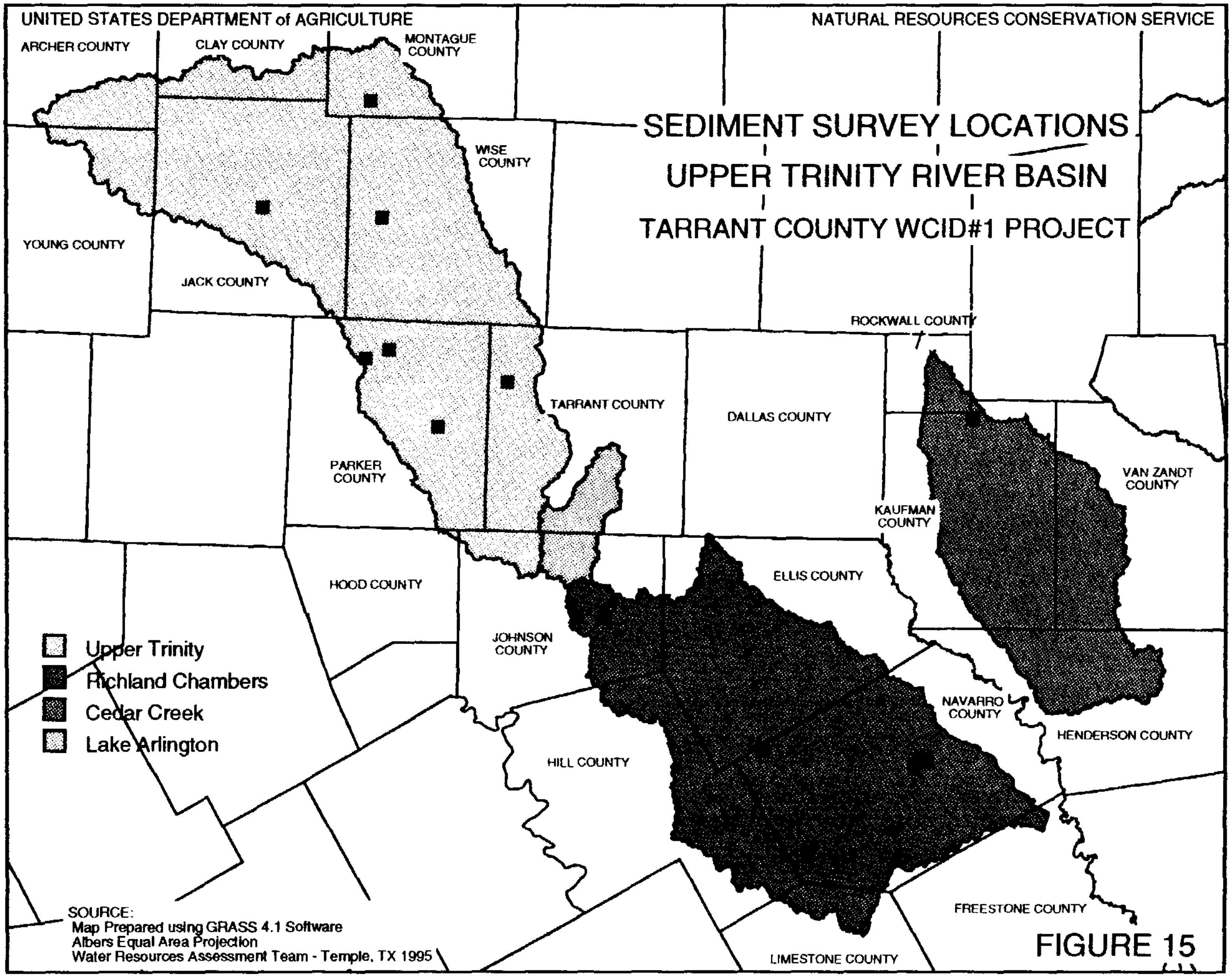
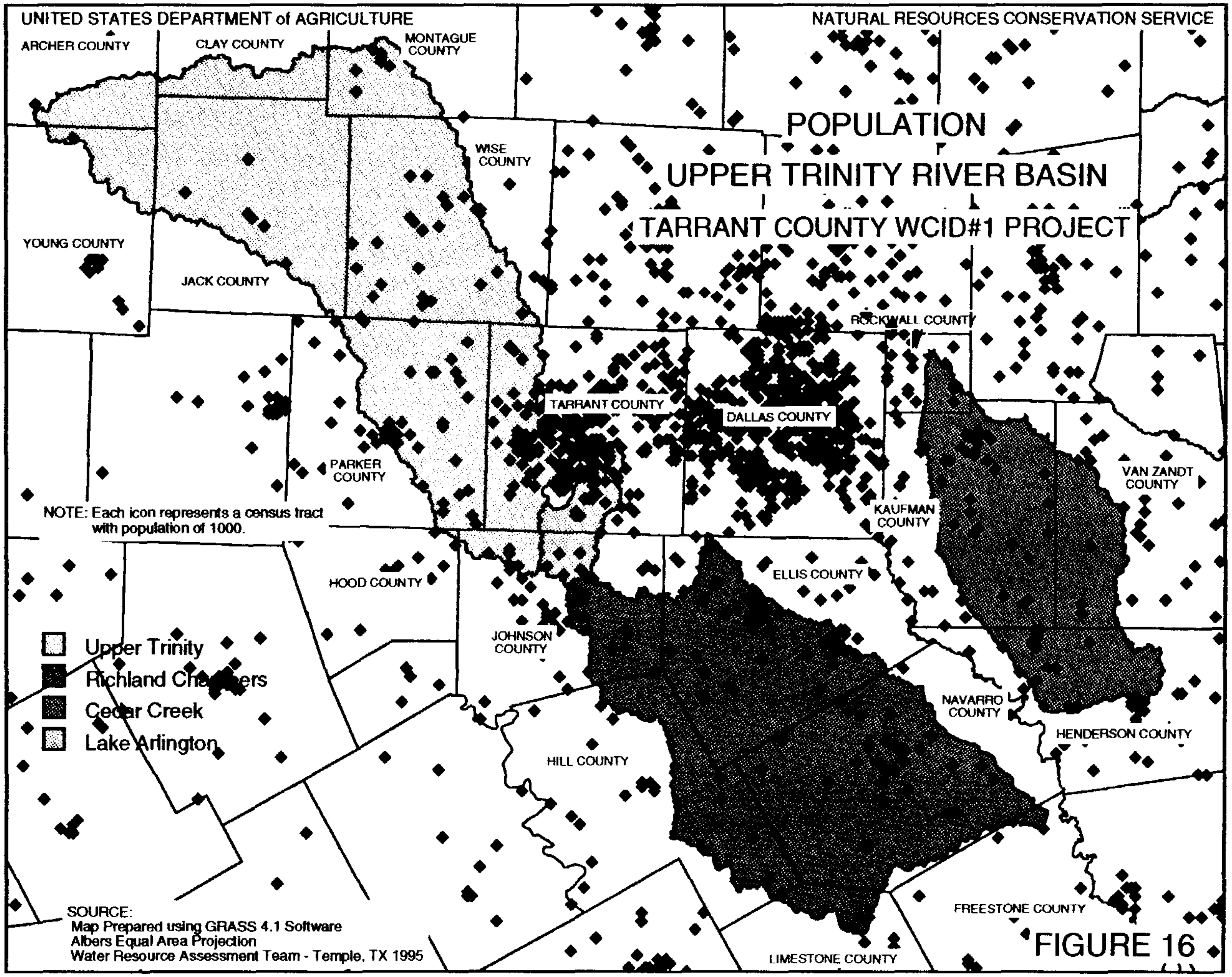
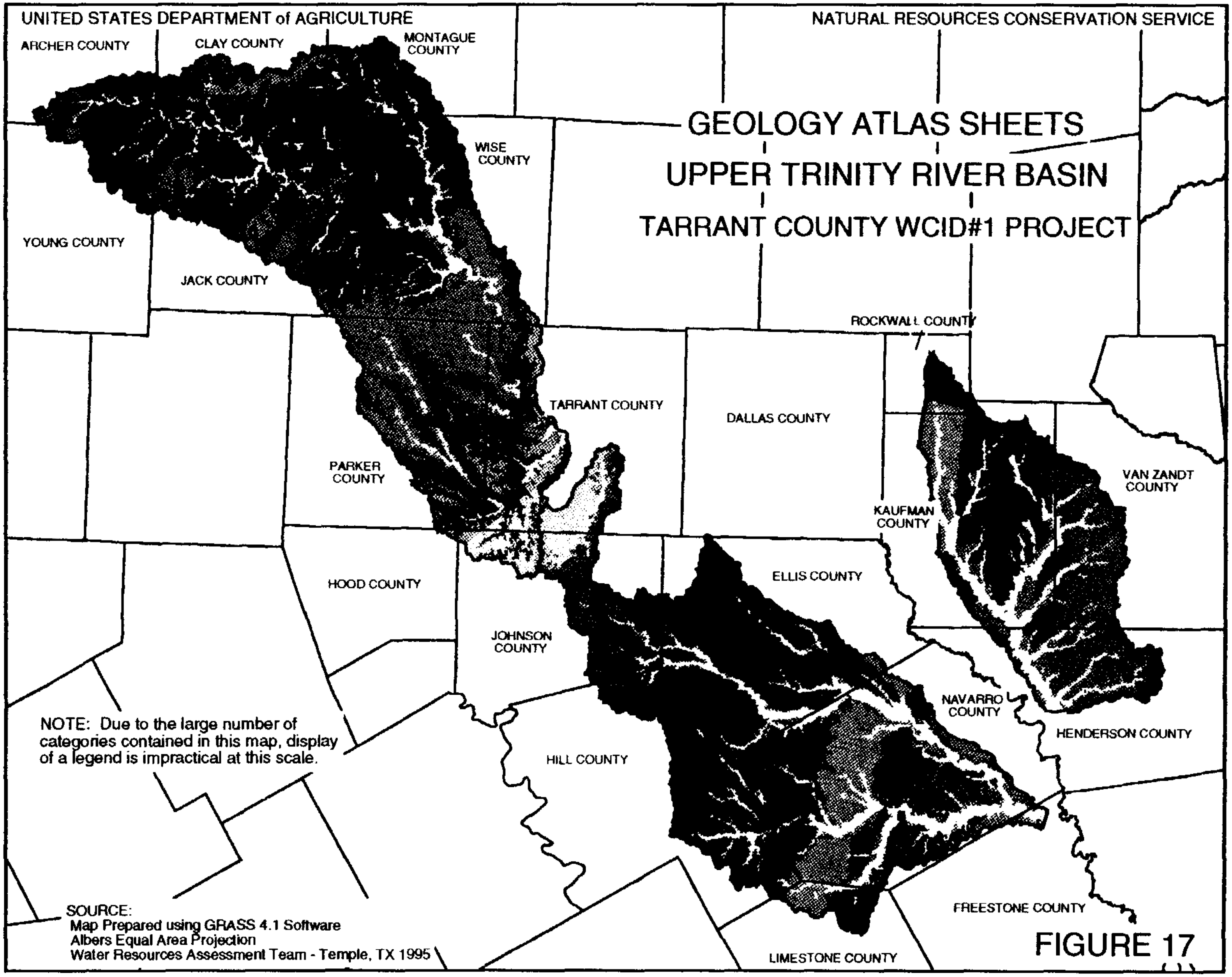

UNITED STATES DEPARTMENT of AGRICULTURE
NATURAL RESOURCES CONSERVATION SERVICE
CLIMATIC DATA STATIONS
UPPER TRINITY RIVER BASIN
TARRANT COUNTY WCID#1 PROJECT
ARCHER COUNTY
CLAY COUNTY
MONTAGUE COUNTY
WISE COUNTY
YOUNG COUNTY
JACK COUNTY
ROCKWALL COUNTY
DALLAS COUNTY
PARKER COUNTY
KAUFMAN COUNTY
VAN ZANDT COUNTY
HOOD COUNTY
ELLIS COUNTY
JOHNSON COUNTY
NAVARRO COUNTY
HENDERSON COUNTY
HILL COUNTY
FREESTONE COUNTY
LIMESTONE COUNTY
Upper Trinity
Richland Chambers
Cedar Creek
Lake Arlington
SOURCE:
Map Prepared using GRASS 4.1 Software
Albers Equal Area Projection
Water Resources Assessment Team - Temple, TX 1995

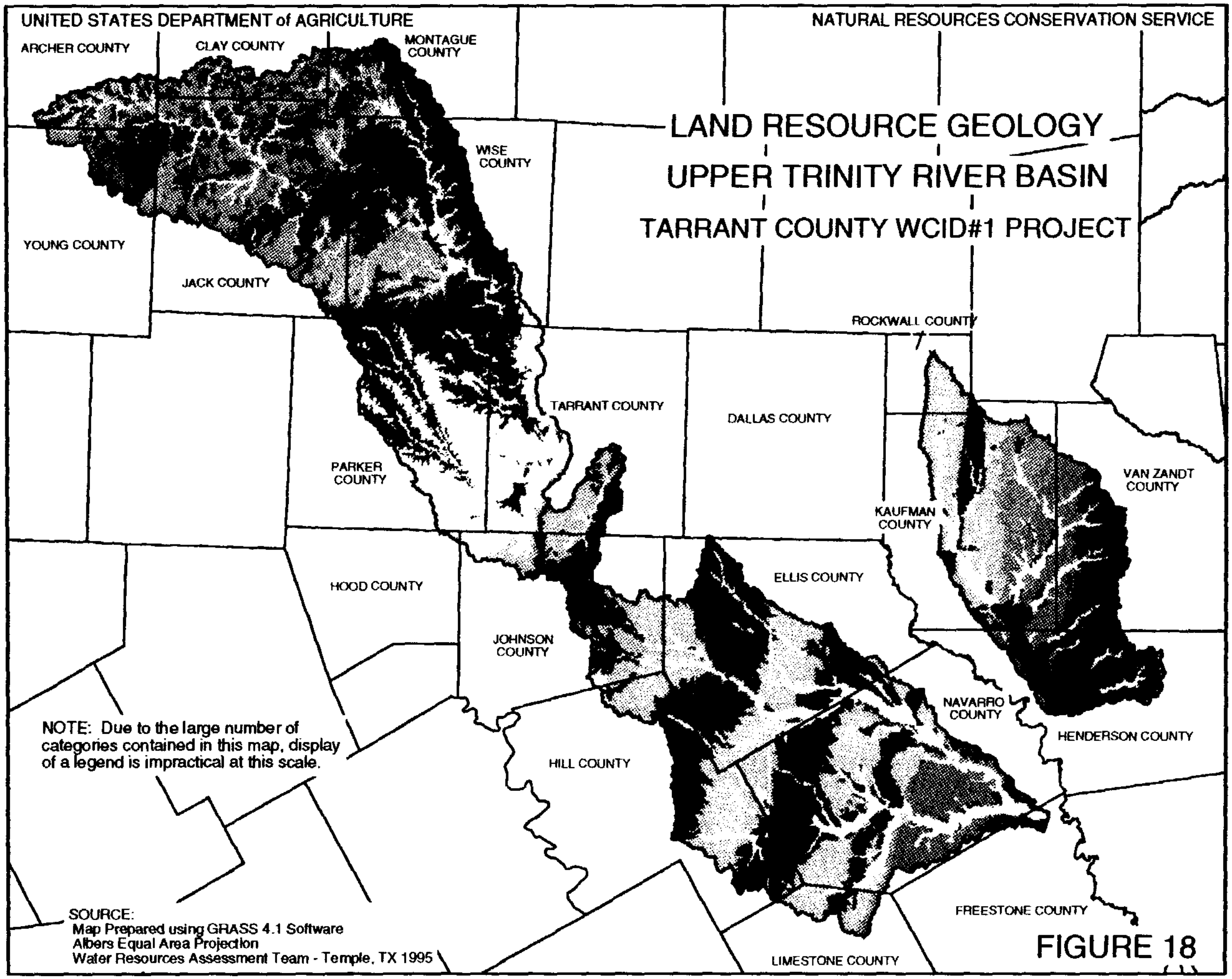
FIGURE 14


UNITED STATES DEPARTMENT of AGRICULTURE
NATURAL RESOURCES CONSERVATION SERVICE
SEDIMENT SURVEY LOCATIONS
UPPER TRINITY RIVER BASIN
TARRANT COUNTY WCID#1 PROJECT
ARCHER COUNTY
CLAY COUNTY
MONTAGUE COUNTY
WISE COUNTY
YOUNG COUNTY
JACK COUNTY
ROCKWALL COUNTY
TARRANT COUNTY
DALLAS COUNTY
PARKER COUNTY
VAN ZANDT COUNTY
KAUFMAN COUNTY
ELLIS COUNTY
HOOD COUNTY
JOHNSON COUNTY
NAVARRO COUNTY
HENDERSON COUNTY
HILL COUNTY
FREESTONE COUNTY
LIMESTONE COUNTY
Upper Trinity
Richland Chambers
Cedar Creek
Lake Arlington
SOURCE:
Map Prepared using GRASS 4.1 Software
Albers Equal Area Projection
Water Resources Assessment Team - Temple, TX 1995
FIGURE 15



UNITED STATES DEPARTMENT of AGRICULTURE
NATURAL RESOURCES CONSERVATION SERVICE
POPULATION
UPPER TRINITY RIVER BASIN
TARRANT COUNTY WCID#1 PROJECT
ARCHER COUNTY
CLAY COUNTY
MONTAGUE COUNTY
WISE COUNTY
YOUNG COUNTY
JACK COUNTY
ROCKWALL COUNTY
TARRANT COUNTY
DALLAS COUNTY
PARKER COUNTY
VAN ZANDT COUNTY
KAUFMAN COUNTY
NOTE: Each icon represents a census tract with population of 1000.
HOOD COUNTY
ELLIS COUNTY
JOHNSON COUNTY
Upper Trinity
Richland Chambers
Cedar Creek
Lake Arlington
NAVARRO COUNTY
HENDERSON COUNTY
HILL COUNTY
FREESTONE COUNTY
LIMESTONE COUNTY
SOURCE:
Map Prepared using GRASS 4.1 Software
Albers Equal Area Projection
Water Resource Assessment Team - Temple, TX 1995
FIGURE 16


UNITED STATES DEPARTMENT of AGRICULTURE
NATURAL RESOURCES CONSERVATION SERVICE
GEOLOGY ATLAS SHEETS
UPPER TRINITY RIVER BASIN
TARRANT COUNTY WCID#1 PROJECT
ARCHER COUNTY
CLAY COUNTY
MONTAGUE COUNTY
WISE COUNTY
YOUNG COUNTY
JACK COUNTY
ROCKWALL COUNTY
TARRANT COUNTY
DALLAS COUNTY
PARKER COUNTY
VAN ZANDT COUNTY
KAUFMAN COUNTY
HOOD COUNTY
ELLIS COUNTY
JOHNSON COUNTY
NAVARRO COUNTY
HENDERSON COUNTY
HILL COUNTY
FREESTONE COUNTY
LIMESTONE COUNTY
NOTE: Due to the large number of categories contained in this map, display of a legend is impractical at this scale.
SOURCE:
Map Prepared using GRASS 4.1 Software
Albers Equal Area Projection
Water Resources Assessment Team - Temple, TX 1995
FIGURE 17


UNITED STATES DEPARTMENT of AGRICULTURE
NATURAL RESOURCES CONSERVATION SERVICE
LAND RESOURCE GEOLOGY
UPPER TRINITY RIVER BASIN
TARRANT COUNTY WCID#1 PROJECT
ARCHER COUNTY
CLAY COUNTY
MONTAGUE COUNTY
WISE COUNTY
YOUNG COUNTY
JACK COUNTY
ROCKWALL COUNTY
TARRANT COUNTY
DALLAS COUNTY
PARKER COUNTY
VAN ZANDT COUNTY
KAUFMAN COUNTY
HOOD COUNTY
ELLIS COUNTY
JOHNSON COUNTY
NAVARRO COUNTY
HENDERSON COUNTY
HILL COUNTY
FREESTONE COUNTY
LIMESTONE COUNTY
NOTE: Due to the large number of categories contained in this map, display of a legend is impractical at this scale.
SOURCE:
Map Prepared using GRASS 4.1 Software
Albers Equal Area Projection
Water Resources Assessment Team - Temple, TX 1995
FIGURE 18

SWAT Model

The Soil and Water Assessment Tool (SWAT) model is the continuation of a long term effort of nonpoint source pollution modeling with the USDA-Agricultural Research Service (ARS). In the early 1970's, in response to the Clean Water Act, ARS assembled a team of interdisciplinary scientists from across the United States to develop a process-based, nonpoint source simulation model. From that effort , a model called CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems) was developed (Knisel, 1980). CREAMS is a field scale model developed to simulate the impact of land management on water, sediment, nutrients, and pesticides leaving the edge of a field. By the early and mid-1980's, several models were being developed with origins from the original CREAMS model.

Several of these efforts involved modifying CREAMS to simulate complex watersheds with varying soils, land use, and management. One effort was the SWRRB (Simulator for Water Resources in Rural Basins) (Williams et al., 1985; Arnold et al., 1990) model. This model was developed to simulate nonpoint source loadings from watersheds. SWRRB is a continuous time (daily time step) model that allows a basin to be subdivided into a maximum of ten subbasins. The major processes included in the model are surface runoff, percolation, return flow, evapotranspiration, transmission losses, pond and reservoir storage, sedimentation, and crop growth. The NRCS (formerly the Soil Conservation Service (SCS)) curve number technique (USDA,1972) was selected for use in predicting surface runoff because:

(a) it is a reliable procedure that has been used for many years in the U.S.;
(b) it is computationally efficient;
(c) the required inputs are generally available; and
(d) it relates runoff to soil type, land use, and management practices.

The use of readily available daily rainfall is a particularly important attribute of the curve number technique. For many locations, rainfall data manipulation and runoff computation are more efficient than similar operations with shorter time increments. Traditionally, the NRCS has used an antecedent rainfall index to estimate three antecedent soil moisture conditions (I-dry, II-normal, III-wet). In reality, soil moisture varies continuously and thus curve number has many values instead of only three. Runoff prediction accuracy was increased by using a soil moisture accounting procedure (Williams and Laseur, 1976) to estimate the curve number for each storm. Although the soil moisture accounting model is superior to the antecedent rainfall method, it does not maintain a water balance and requires calibration with measured runoff data.

The CREAMS daily rainfall hydrology model overcame these deficiencies by linking the curve number technique with evapotranspiration and percolation models. Calibration is not necessary because the CREAMS model is more physically based--the soil water balance is related directly to curve number. Although the CREAMS daily rainfall hydrology model is more advanced than earlier curve number models, it is not applicable to complex basins. The model was developed for use on field-size areas (single land use, soil, and management practice) and does not compute water yield (return flow is neglected).

The CREAMS daily rainfall hydrology model was modified for application to large, complex, rural basins. The major changes involved (which were also incorporated into SWRRB) were (a) the model was expanded to allow simultaneous computations on several subbasins to predict the basin water yield; (b) a return flow component was added; (c) a reservoir storage component was added for use in determining the effects of farm ponds and reservoirs on water and sediment yield; (d) a weather simulation model (rainfall, solar radiation, and temperature) was added to provide for longer term simulations and more representative weather inputs, both temporally and spatially; (e) a better method was developed for predicting the peak runoff rate; (f) a crop growth model was added to account for annual variation in growth; (g) a simple flood routing component was added; (h) components were added to simulate sediment movement through ponds, reservoirs, streams, and valleys; and (i) transmission losses were calculated. Besides water, SWRRB also simulates sediment yield from rural basins using the Modified Universal Soil Loss Equation (MUSLE) (Williams and Berndt, 1977) and a sediment routing model.

In response to needs to simulate stream flow from much larger basins, ROTO (Routing Outputs to Outlet) (Arnold et al., 1995) was developed to take output from multiple SWRRB runs and route the flows through channels and reservoirs. This reach routing approach overcame the SWRRB subbasin limitation by linking multiple SWRRB runs together.

SWAT is a result of the merging of the SWRRB and ROTO models into one basin scale model. The objective in model development was to predict the impact of management (climate and vegetative changes, reservoir management, groundwater withdrawals, and water transfer) on water, sediment, and agricultural chemical yields in large ungauged basins. To satisfy the objective, the model (a) is physically based (calibration is not possible on ungauged basins); (b) uses readily available inputs; (c) is computationally efficient to operate on large basins in a reasonable time; and (d) is continuous time and capable of simulating long periods for computing the effects of management changes. SWAT allows a basin to be divided into hundreds or thousands of grid cells or subwatersheds. It is still a continuous time model (daily time step) that is required to look at long-term impacts of management (i.e., reservoir sedimentation over 50-100 years) and also timing of agricultural practices within a year (i.e., crop rotations, planting and harvest dates, irrigation, fertilizer, and pesticide application rates and timing).

Major enhancements from SWRRB include the following:

- New Input File Structure - The previous SWRRB file structure consisted of one large file with data for all subbasins on weather, soils, land use, topography and management. SWAT files are split into separate files by subbasin and data type. This facilitates more subbasins and simplifies GIS linkages.

- Reach Routing Structure - SWRRB routed from subbasin outlets directly to the basin outlet for simplicity. The new routing structure allows large basins to be simulated, providing more realistic routing. More subbasins can be easily added and GIS linkages and data base management are simplified. A set of commands is used to control the routing. These commands route and add flows through the watershed through reaches and reservoirs. The model reads each command and performs the given hydrologic command.

- Groundwater Component - Total stream flow from large basins is the sum of surface runoff and groundwater flow. Groundwater flow volumes and timing must be simulated to accurately predict stream flow, sediment concentrations, and chemical concentrations in the stream flow. Water percolating past the root zone is assumed to recharge the shallow aquifer. Shallow aquifer components include recharge, revap, flow to the stream, percolation to the deep aquifer, and pumping withdrawals. The shallow aquifer interacts with the stream - channel transmission losses and pond/reservoir seepage replenish it. Once water reaches the deep aquifer it cannot return to the stream.

- Revised Management - SWRRB management files were awkward and only allowed for a three crop rotation. Also, irrigation, nutrient and pesticide application data were in three separate files making cross-checking difficult. Tillage in SWRRB was simplified to handle only four possible options that all occurred at harvest. In SWAT a specific date and specific tillage implement can be selected. SWAT can have an unlimited number of years of rotation.

- Irrigation Water Transfer - SWRRB did not simulate water transfer within a watershed, however, for the large basins simulated by SWAT there may be a need to simulate water transfer. Given the reach routing command structure, it is relatively easy to transfer water within a basin. This can account for irrigation flow paths and could provide a management tool for irrigation management districts and other agencies concerned with irrigation water rights. The algorithm developed here will allow water to be transferred from any reach or reservoir to any other reach or reservoir in the watershed. It will also allow water to be diverted and applied directly to irrigate a subwatershed.

In recent years, there has been considerable effort devoted to utilizing GIS to extract inputs (soils, land use, and topography) for comprehensive simulation models and spatially display model outputs. Much of the initial research was devoted to linking single-event, grid models with raster-based GIS (Srinivasan and Engel, 1991; Rewerts and Engel, 1991). An interface was developed for SWAT (Srinivasan and Arnold, 1993) using the Graphical Resources Analysis Support System (GRASS) (U.S. Army, 1988). The input interface will extract model input data from map layers and associated relational data bases for each subbasin. Soils, land use, weather, management, and topographic data are collected and written to appropriate model input files. The output interface allows the user to display output maps and graph output data by selecting a subbasin from a GIS map.

Flow Calibration and Validation

The Richland-Chambers Watershed was chosen for flow calibration because good weather data is available for this watershed. In addition the watershed contains two reservoirs (Bardwell and Navarro Mills) and about 300 inventory sized ponds and flood prevention dams, providing an opportunity to model ponds and reservoirs.

The 1:24,000 scale soils and land use GIS layers were obtained from the NRCS computer based mapping system. The digital elevation model (DEM) with a scale of 1:250,000 was obtained from the USGS. Subbasin boundaries were delineated on USGS 1:24,000 scale quadrangle maps. The maps were then scanned and digitized to create a watershed basin and subbasin map with 20 subbasins. Data for ponds and reservoirs in the watershed was obtained from NRCS and TNRCC records. Outflow data for Bardwell and Navarro Mills reservoirs was obtained from the COE. Measured daily rainfall and temperatures were obtained from the NRCS climatological data base.

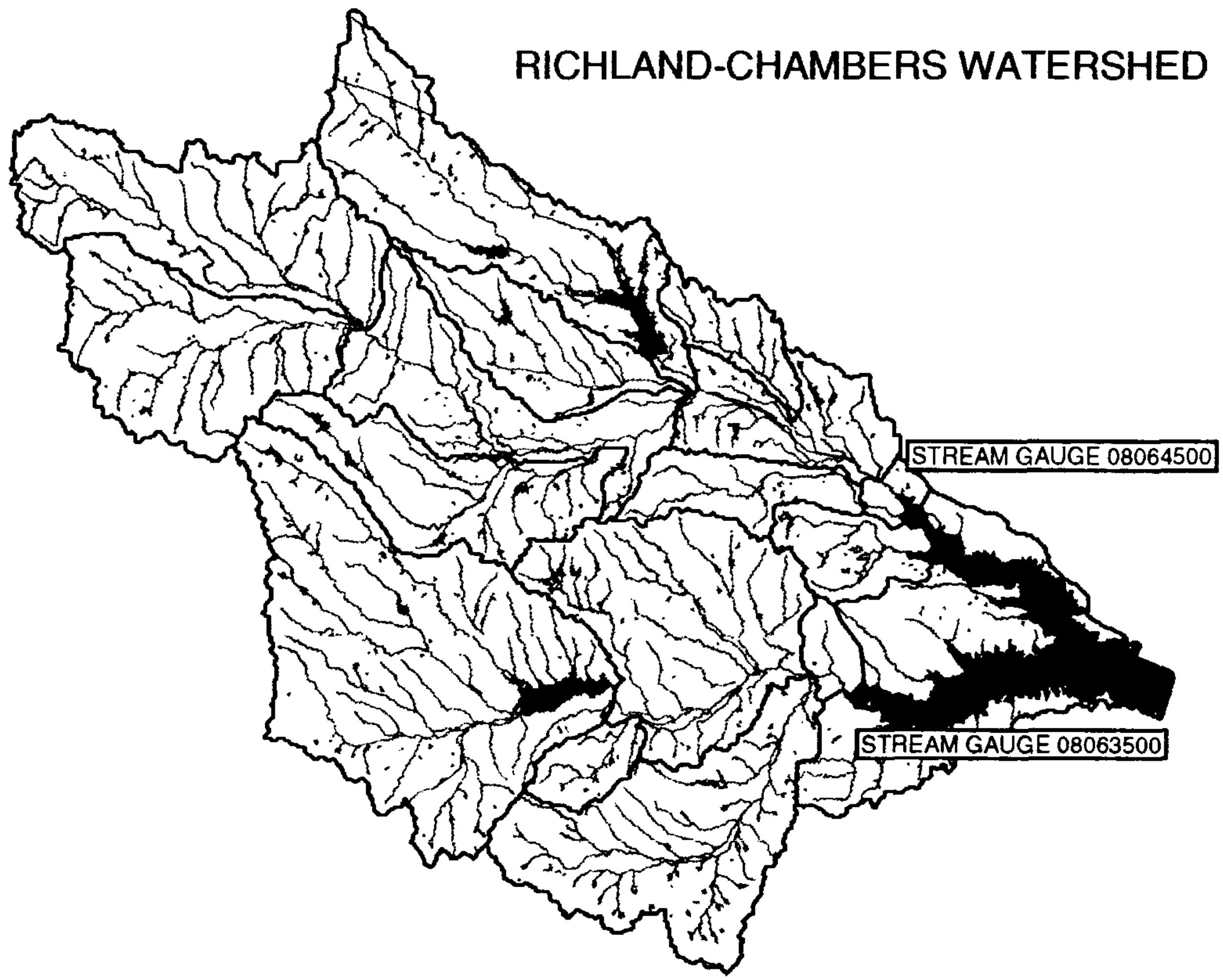
Required inputs for the basin and each subbasin were extracted and formatted using the SWAT/GRASS input interface. The input interface divided each subbasin into a maximum of 30 sub-subbasins. A single land use and soil were selected for each sub-subbasin. The number of sub-subbasins within a subbasin was determined by: (1) creating a sub-subbasin for each land use that equaled or exceeded 5 percent of the area of a subbasin; and (2) creating a sub-subbasin for each soil type that equaled or exceeded 10 percent of any of the land uses selected in (1). Consequently, the interface created 125 sub-subbasins. The soil properties for each of the selected soils were automatically extracted from the model-supported soils data base.

Both weather data and stream gauge data are available for the period 1965 through 1984. The period 1965 through 1969 was chosen for calibration of the SWAT model for stream flow. The runoff curve number, ground water, and revap coefficients were adjusted to give the best results for this time period. The resulting parameters are: curve number reduced 10 percent, ground water height at one meter below the root zone, and revap coefficient equal to 1.0. A map of the Richland-Chambers watershed with stream gauge locations is shown on Figure 19. The statistical analysis for this simulation is shown on Figures 20 and 21. Values of R^2 equal to 0.84 for stream gauge 08064500 and 0.87 for stream gauge 08063500 show a good correlation between observed and simulated values.

For validation, these same parameters were then used for the following five-year simulations: 1970 through 1974, 1975 through 1979, and 1980 through 1984. The results and statistical analyses for these simulations are shown in Figures 22 through 27. Values of R^2 for all simulations exceed 0.80, except for two of the simulations for stream gauge 08063500. These low values may be explained by errors in, or lack of, sufficient stream gauge data, reservoir release data, or weather data for these five-year simulation runs.

UNITED STATES DEPARTMENT of AGRICULTURE

NATURAL RESOURCES CONSERVATION SERVICE



SOURCE:
Map Prepared using GRASS 4.1 Software
Albers Equal Area Projection
Water Resource Assessment Team - Temple, TX 1995

FIGURE 19

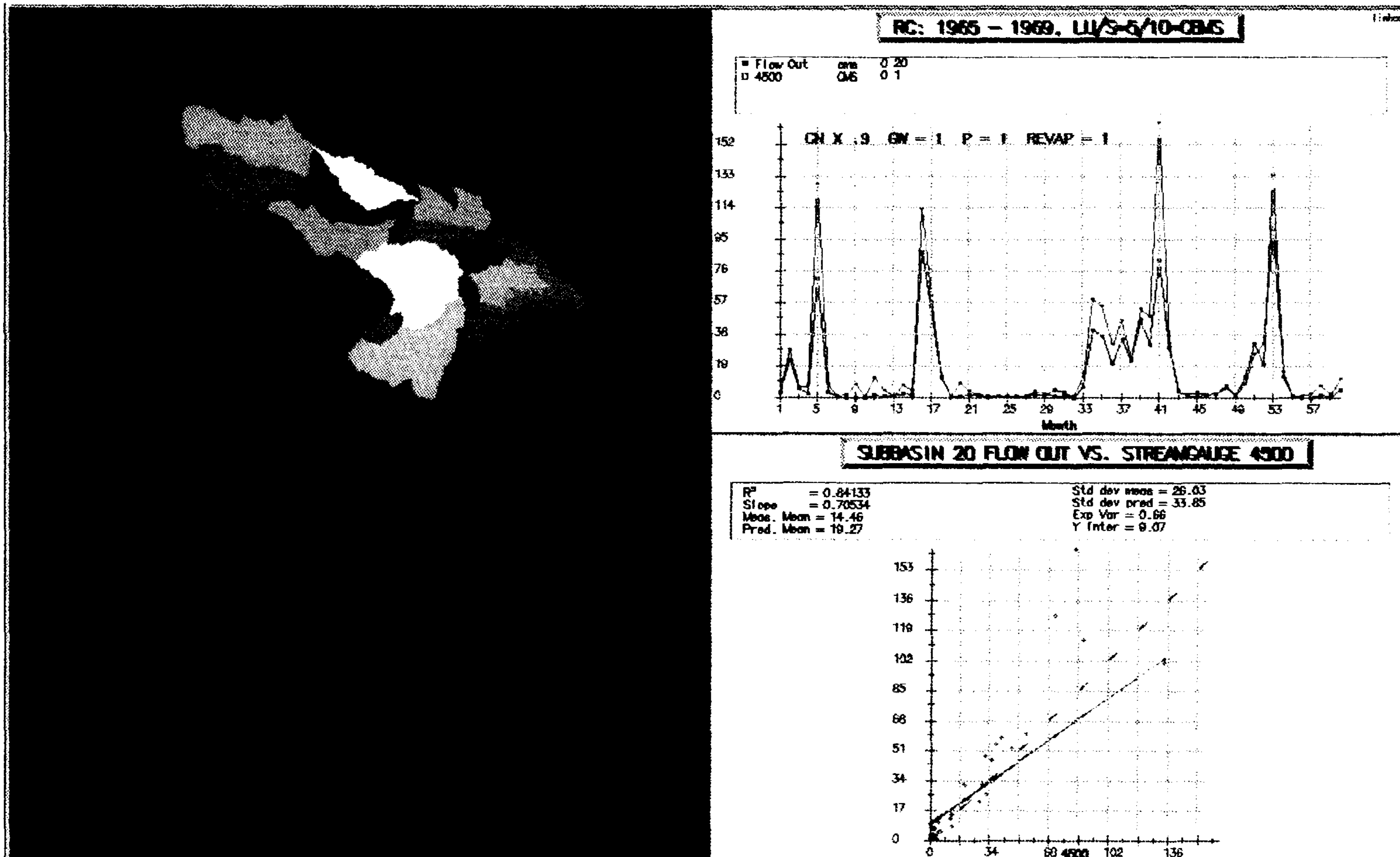


Figure 20. Richland-Chambers Watershed flow calibration (stream gauge 08064500): 1965 to 1969.

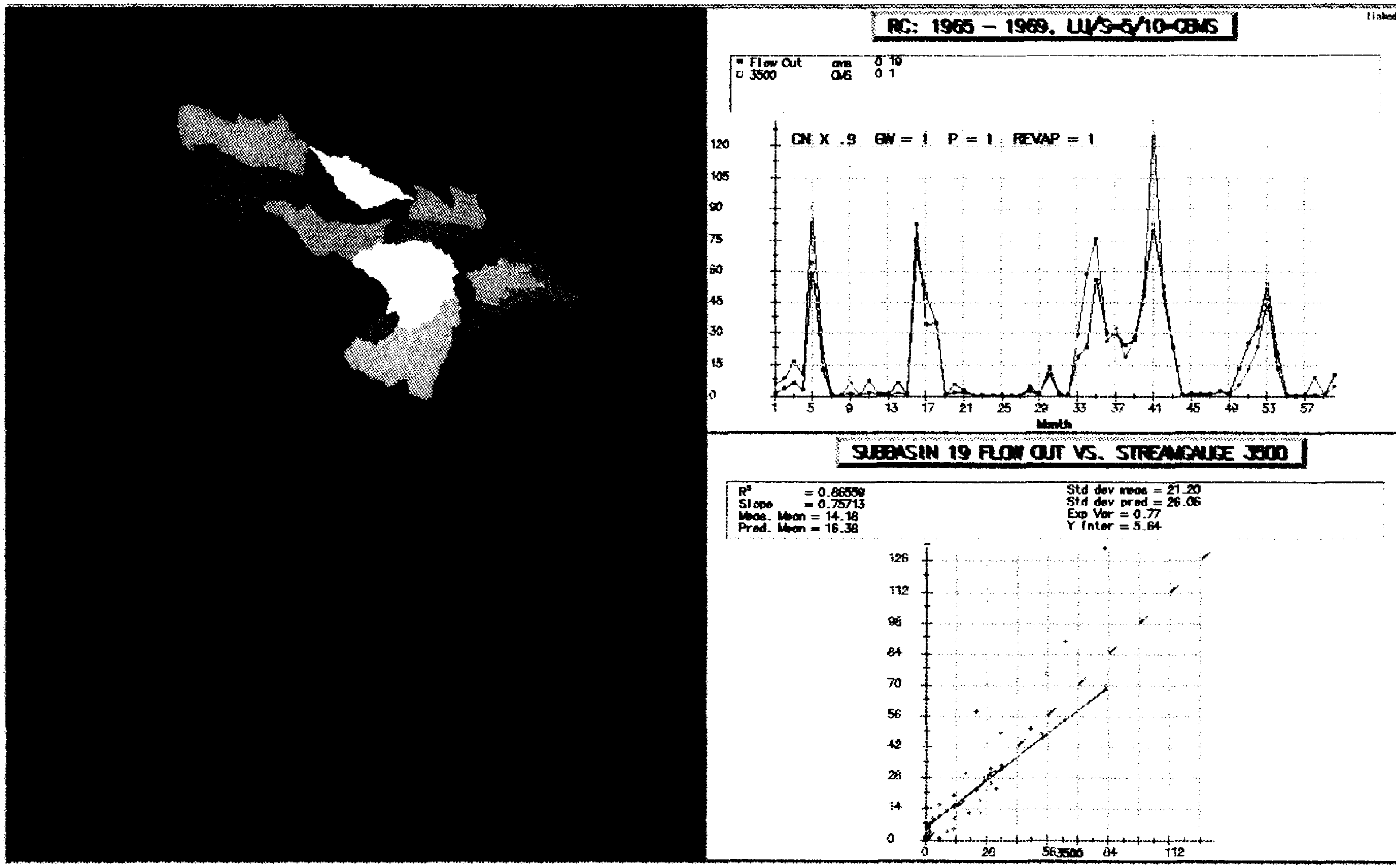


Figure 21. Richland-Chambers Watershed flow calibration (stream gauge 08063500): 1965 to 1969.

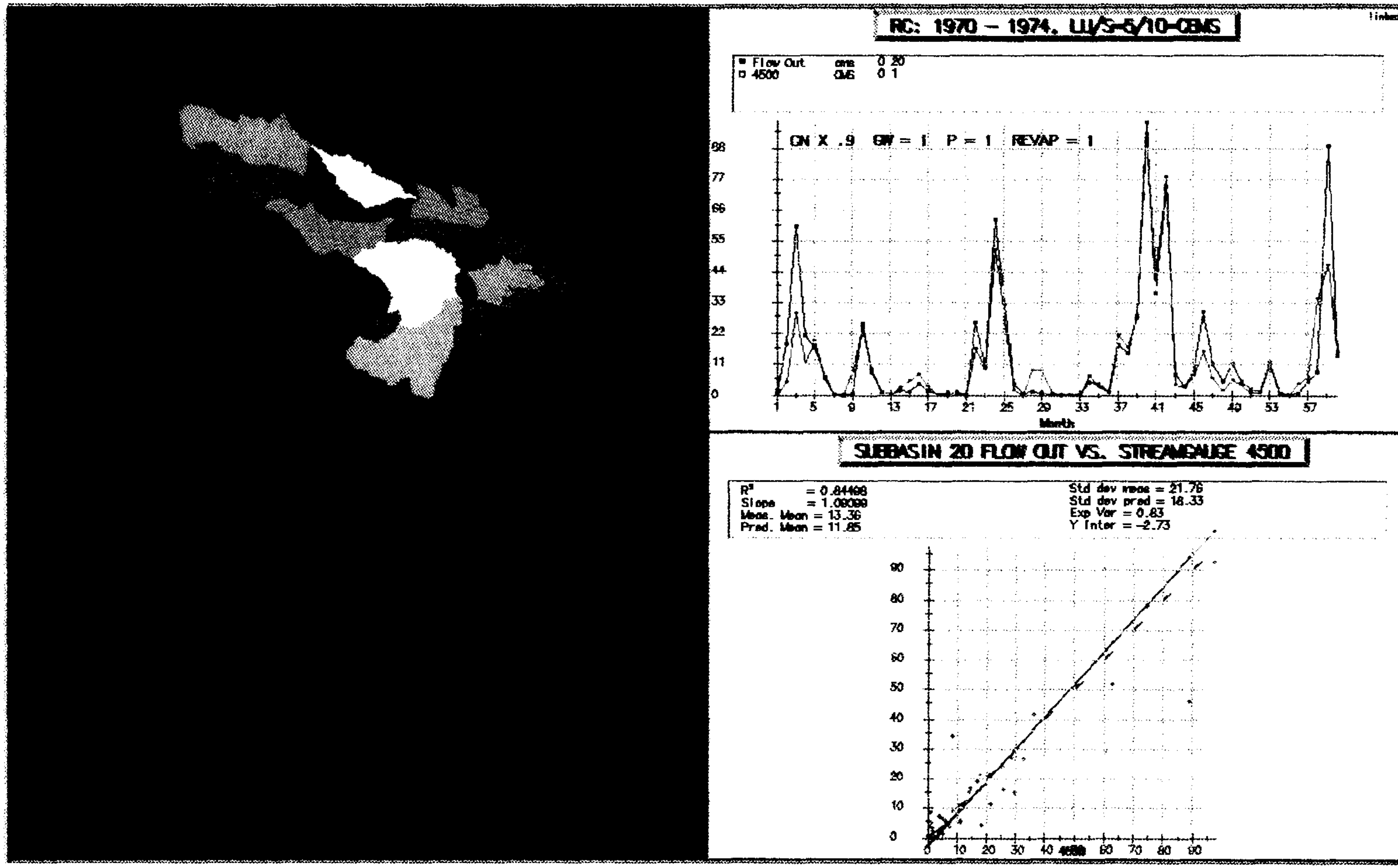


Figure 22. Richland-Chambers Watershed flow validation (stream gauge 08064500): 1970 to 1974.

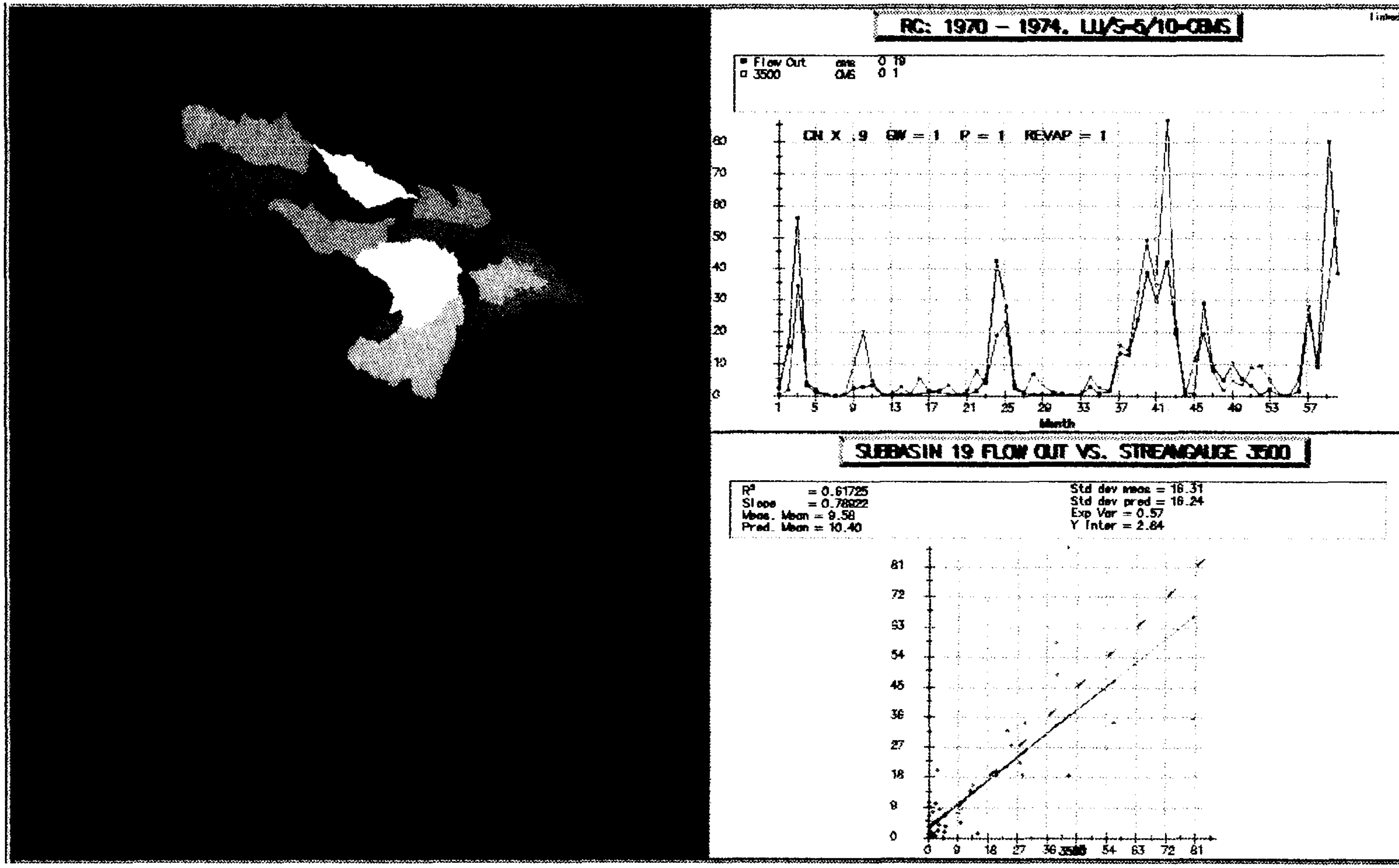


Figure 23. Richland-Chambers Watershed flow validation (stream gauge 08063500): 1970 to 1974.

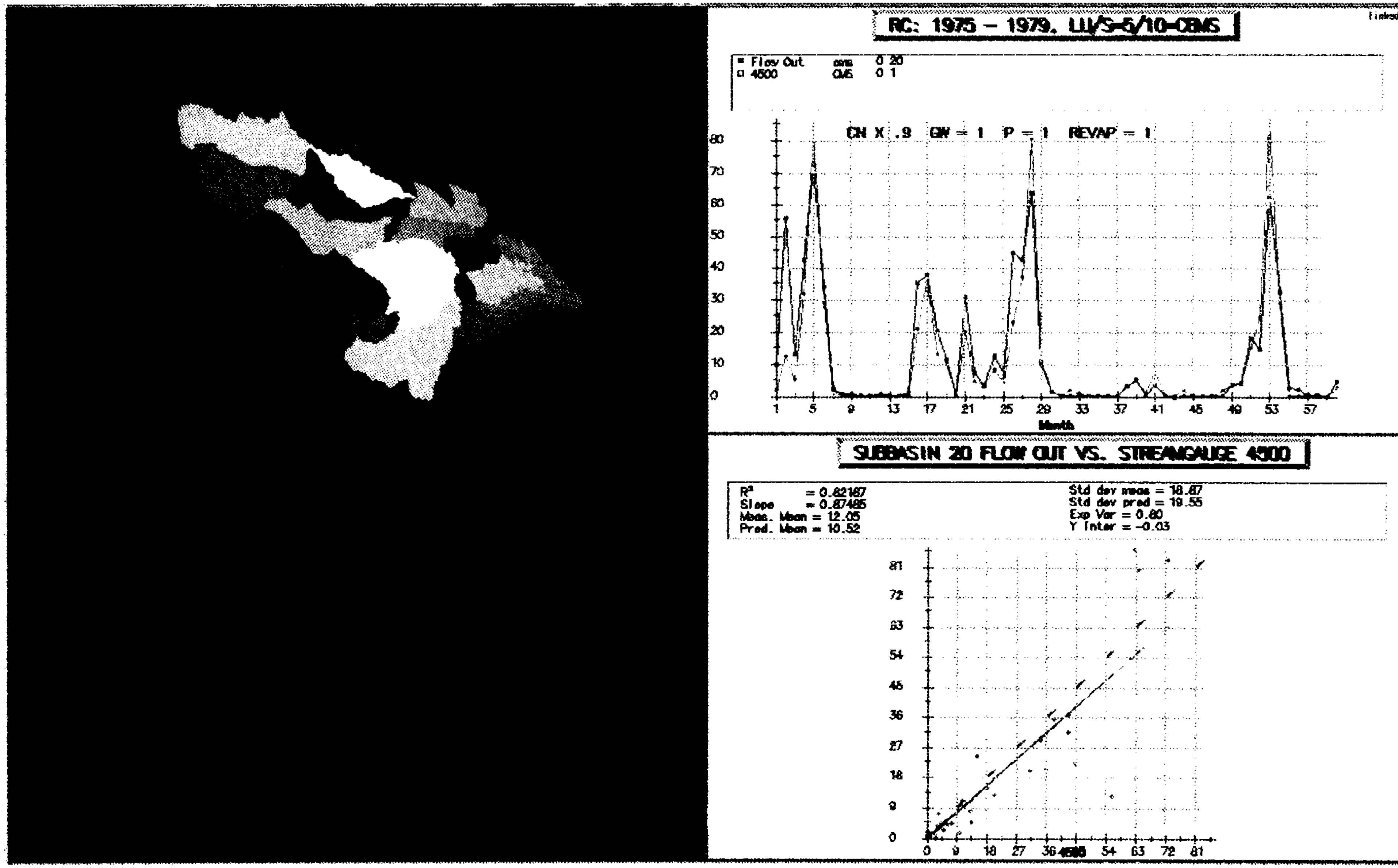


Figure 24. Richland-Chambers Watershed flow validation (stream gauge 08064500): 1975 to 1979.

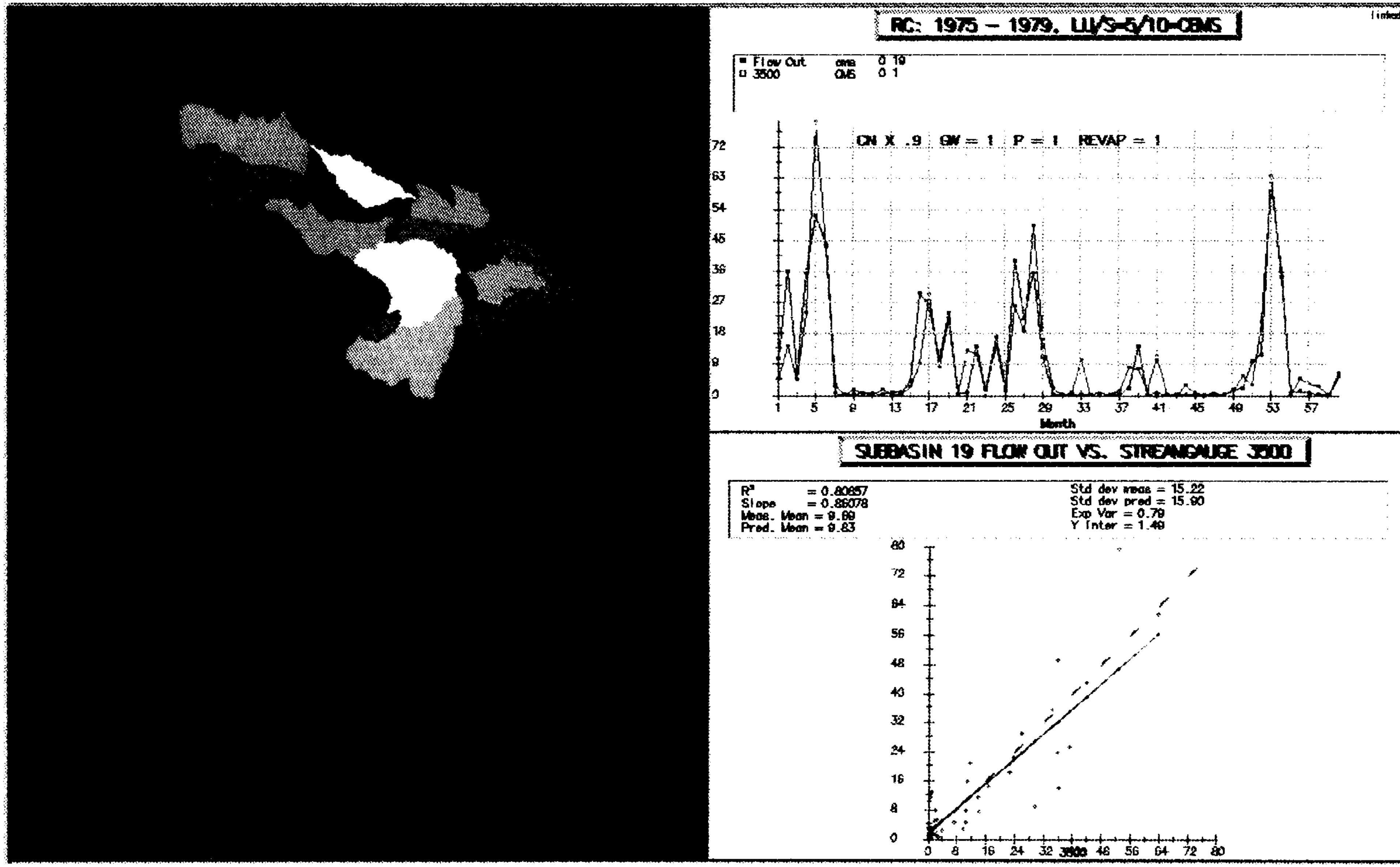


Figure 25. Richland-Chambers Watershed flow validation (stream gauge 08063500): 1975 to 1979.

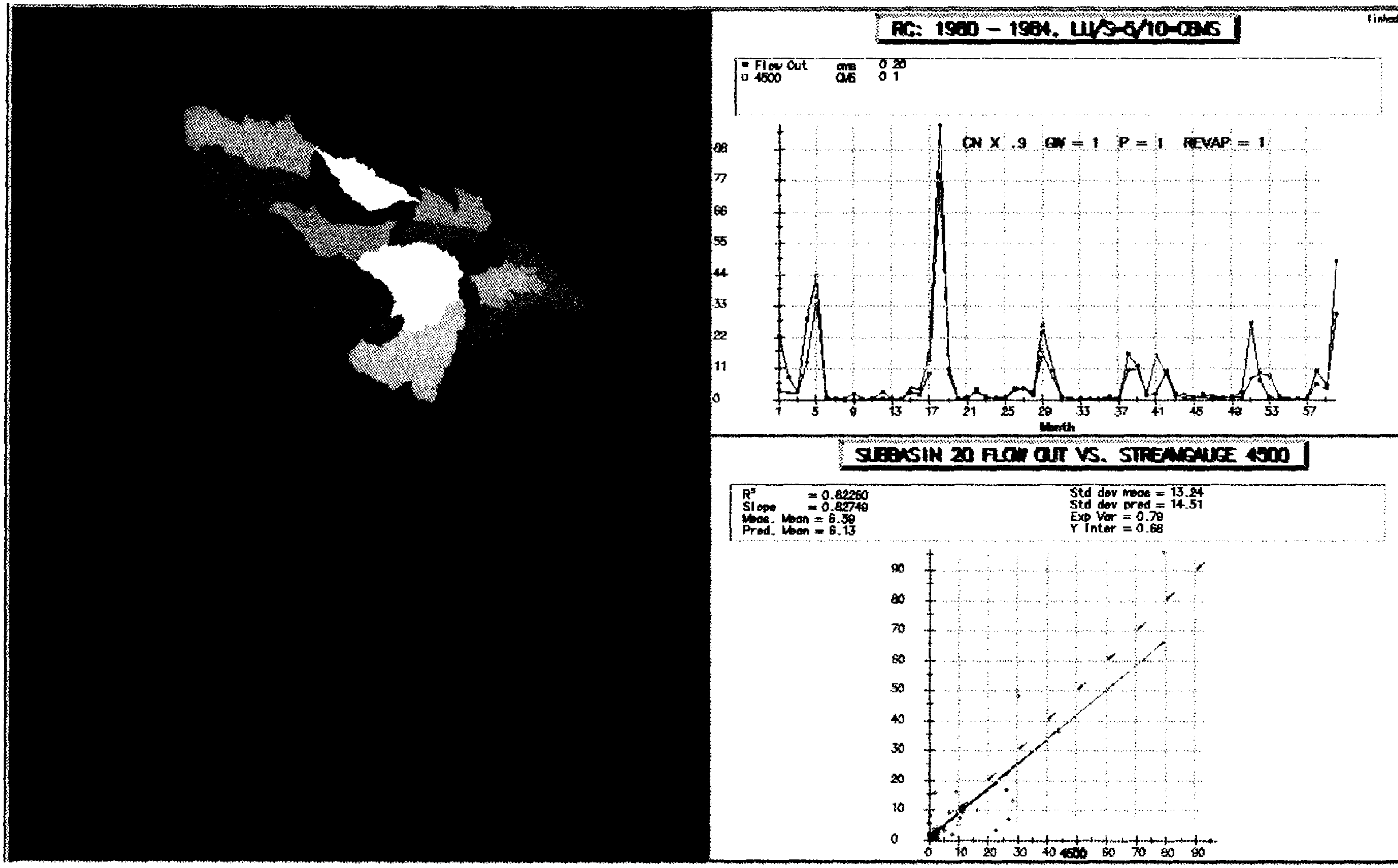


Figure 26. Richland-Chambers Watershed flow validation (stream gauge 08064500): 1980 to 1984.

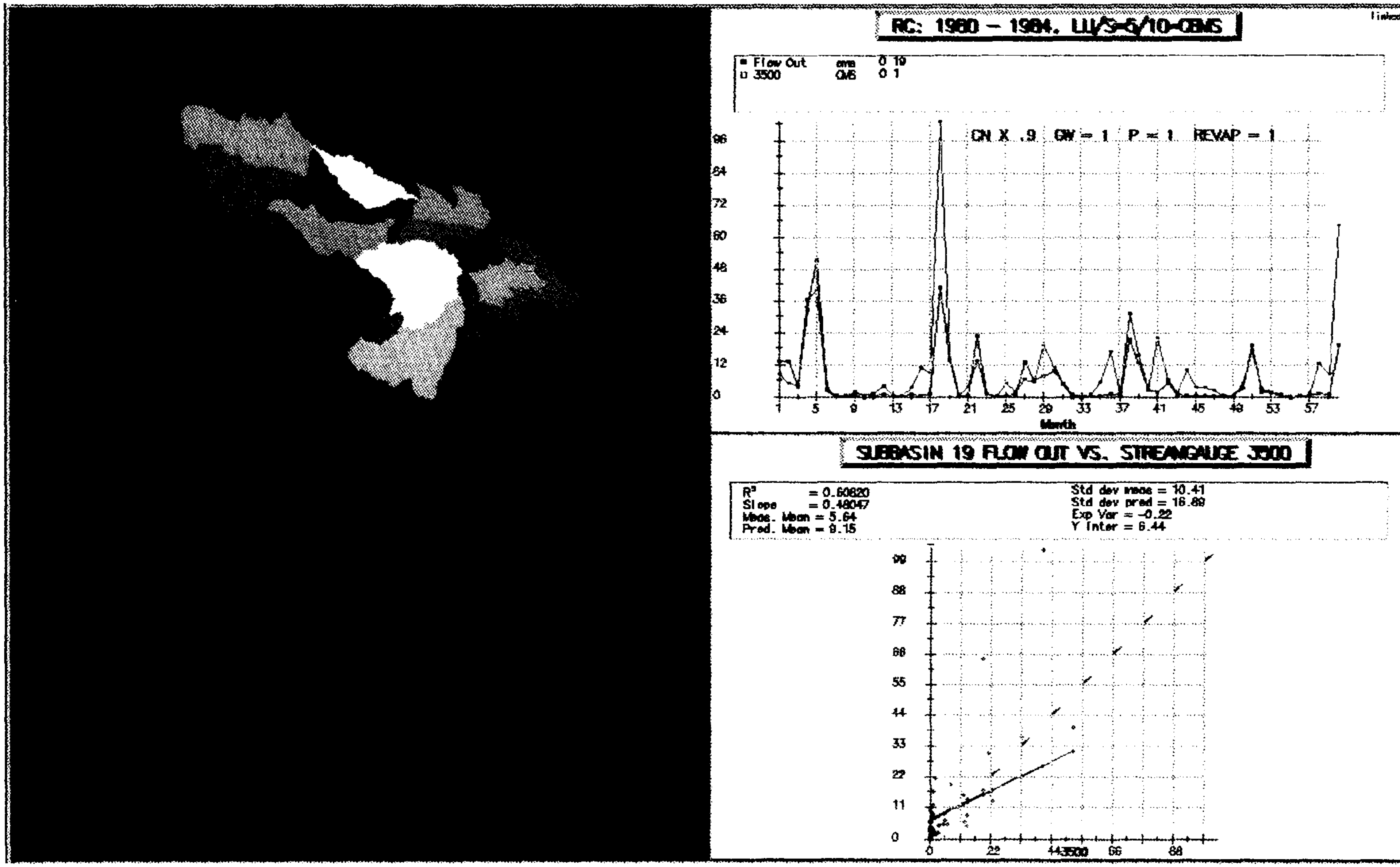


Figure 27. Richland-Chambers Watershed flow validation (stream gauge 08063500): 1980 to 1984.

Sediment Calibration and Validation

The Richland-Chambers watershed was selected for calibration of sediment. A sediment survey was completed on Richland-Chambers Reservoir in December 1994 (Texas Water Development Board, March 1995). A capacity survey was performed during planning and construction, with deliberate impoundment beginning in July 1987. The years 1988 through 1994 were selected for simulation.

The Cedar Creek watershed was selected for validation. A sediment survey was completed on Cedar Creek Reservoir in March 1995.(Texas Water Development Board, July 1995). A capacity survey was performed during planning and construction, with deliberate impoundment beginning in July 1965. The years 1966 through 1994 were simulated for Cedar Creek.

Parameters which affect sediment yield and delivery were adjusted in the Richland-Chambers simulation until simulated sediment was nearly equal to measured sediment. The resulting parameters are as follows:

USLE "P" factor	1.0
Exponential factor for sediment concentration (SPC)	0.008
Exponential factor for stream power equation (SPE)	1.000
Peak Rate Function (PRF)	1.000

The results are shown on Figure 28. Simulated sediment delivery to Richland-Chambers Reservoir is about 38,700,000 tons. Measured sediment is about 36,934,000 tons.

For validation, the same parameters were then used for the Cedar Creek watershed simulation. The results are shown in Figure 29. Simulated sediment delivery to Cedar Creek Reservoir is about 46,200,000 tons. Measured sediment is about 45,901,000 tons.

Additional validation was performed on a small subbasin in Mill Creek watershed, and on lakes Bridgeport and Eagle Mountain in the Upper Trinity watershed. Sediment surveys were performed on Chambers Creek Site 101A (Mill Creek watershed) in years 1960, 1964, 1968, 1974, and 1980. The ten year period of 1965-1974 was chosen for simulation. Sediment surveys were performed on Bridgeport and Eagle Mountain in 1968 and 1988. The 20-year period 1969 through 1988 was chosen for simulation on the Upper Trinity watershed.

The results for Mill Creek are shown on Figure 30. Simulated sediment delivery to Chambers Creek Site 101A is about 39,168 tons. Measured sediment in this reservoir is about 43,045 tons.

It should be noted that the weight of measured sediment for all of the sediment surveys except Chambers Creek Site 101A (Mill Creek watershed) is based on assumed sediment densities. Sediment density was measured during the survey of the Chambers Creek Site 101A, but densities were unavailable for the other sediment surveys.

Validation in the Mill Creek watershed simulations may also be affected by the fact that the 1:250,000 DEM was used for all model runs except for Mill Creek where 1:24,000 DEM was used. The difference in watershed size between Richland-Chambers watershed (1260 sq.mi.) and Chambers Creek Site 101A (2.6 sq.mi.) may also affect this validation.

The results for Upper Trinity are shown on Figure 31. For this watershed it was necessary to set SPC = 0.005. Simulated sediment delivery to Lake Bridgeport is about 15,261,500 tons and measured sediment is about 14,000,000 tons. Simulated sediment delivery to Eagle Mountain Lake is about 19,736,150 tons and measured sediment is about 13,700,000 tons. Simulated and measured sediment do not compare as well for Upper Trinity. This may be related to the fact that Bridgeport and Eagle Mountain are not located at the outlet of the watershed as are Cedar Creek and Richland-Chambers.

In addition, the model inputs for this simulation did not include actual reservoir releases for water supply because of lack of data and time constraints. As a result the simulated reservoir stage could not be balanced against recorded data. This may affect sediment trapping efficiency and discharge volumes to downstream reservoirs (Eagle Mountain is downstream from Bridgeport). Also, the effects of relatively clear water discharge downstream from a reservoir and the associated erosion potential in the stream channel is not clearly known. Another factor is the greater percentage of sandy soils in the Upper Trinity as compared to Cedar Creek and Richland-Chambers, which may influence sediment transport and delivery.

The line plot on Figure 31 lower right quadrant indicates no sediment leaving Eagle Mountain Reservoir. The model did not predict flow below this reservoir for the first 150 or so months and thus the associated sediment was not predicted. Release flows from Eagle Mountain were not available as input for this period of time, thus the flat line indicating no sediment leaving for those 150 months.

The following explanation of a sample graph legend similar to those found in many of the figures is provided for further information:

SEDIMENT YIELD FOR VARIOUS SUBBASINS

* SYLD	Tons/ha	0 2		# SYLD	Tons/ha	0 28
x SYLD	Tons/ha	0 3		+ SYLD	Tons/ha	0 8
o SYLD	Tons/ha	0 21		^ SYLD	Tons/ha	0 10

The legend above would indicate that there are 6 lines on the graph. The symbol preceding "SYLD" indicates the colored icon that identifies a specific line on the graph. "SYLD" indicates that the plot is of sediment yield and the units plotted are tons per hectare. The last numerical digits after the units indicate the subbasin for which the sediment yield is computed. The first line in the above legend would indicate that the line is plotted with an asterisk symbol and is sediment yield in tons per hectare from subbasin number 2.

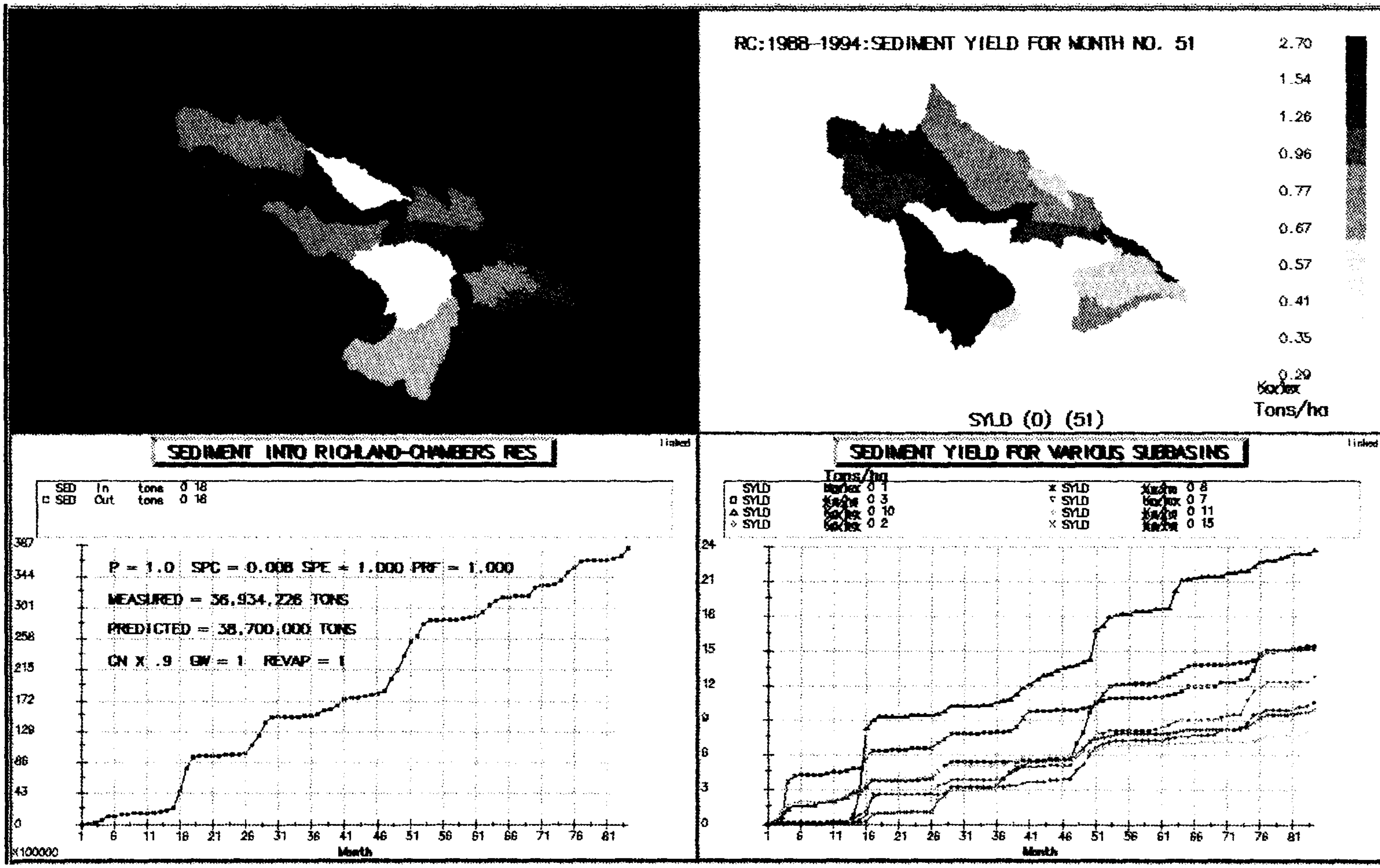


Figure 28. Richland-Chambers Watershed sediment calibration: 1988 to 1994.

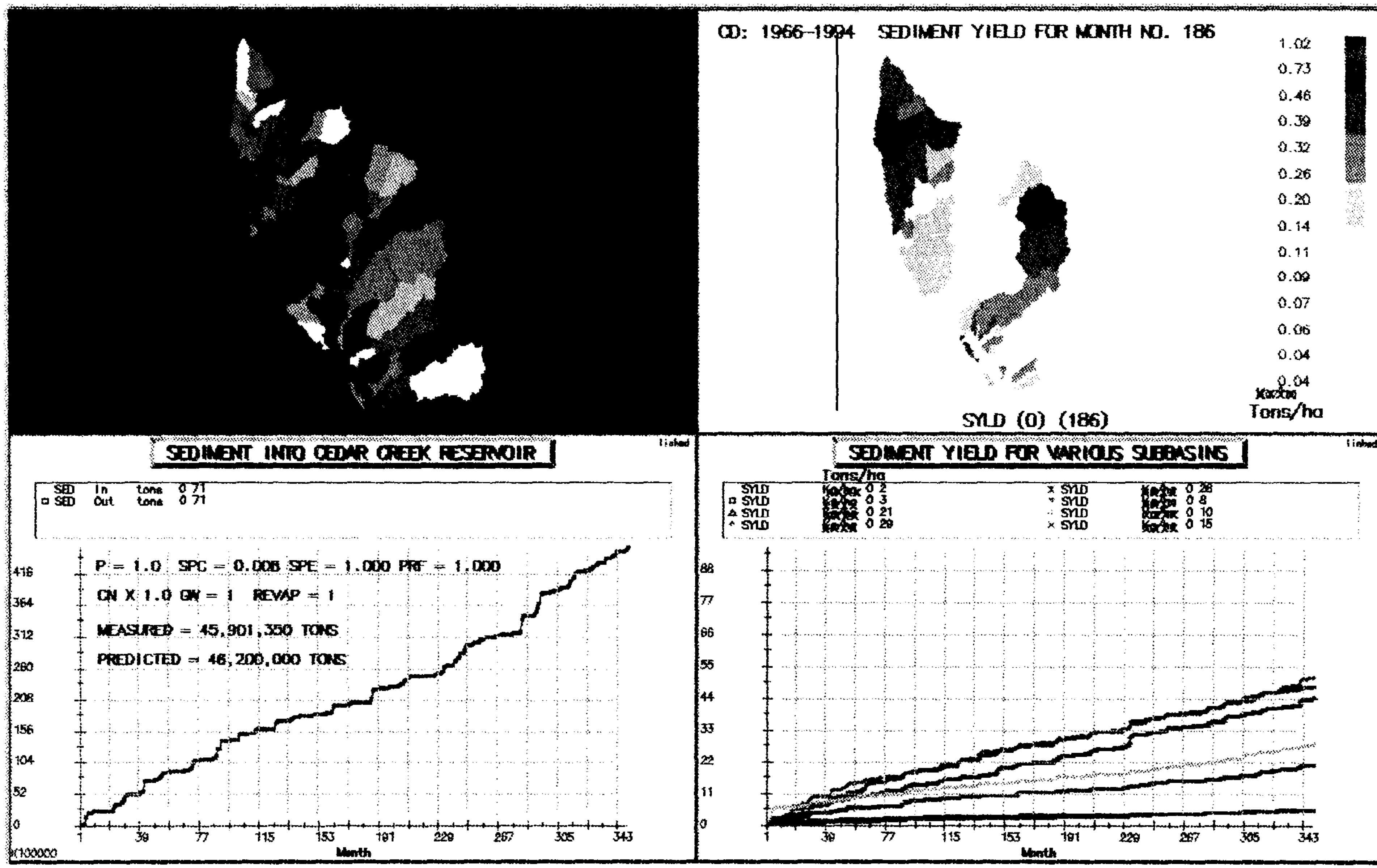


Figure 29. Cedar Creek Watershed sediment validation: 1966 to 1994.

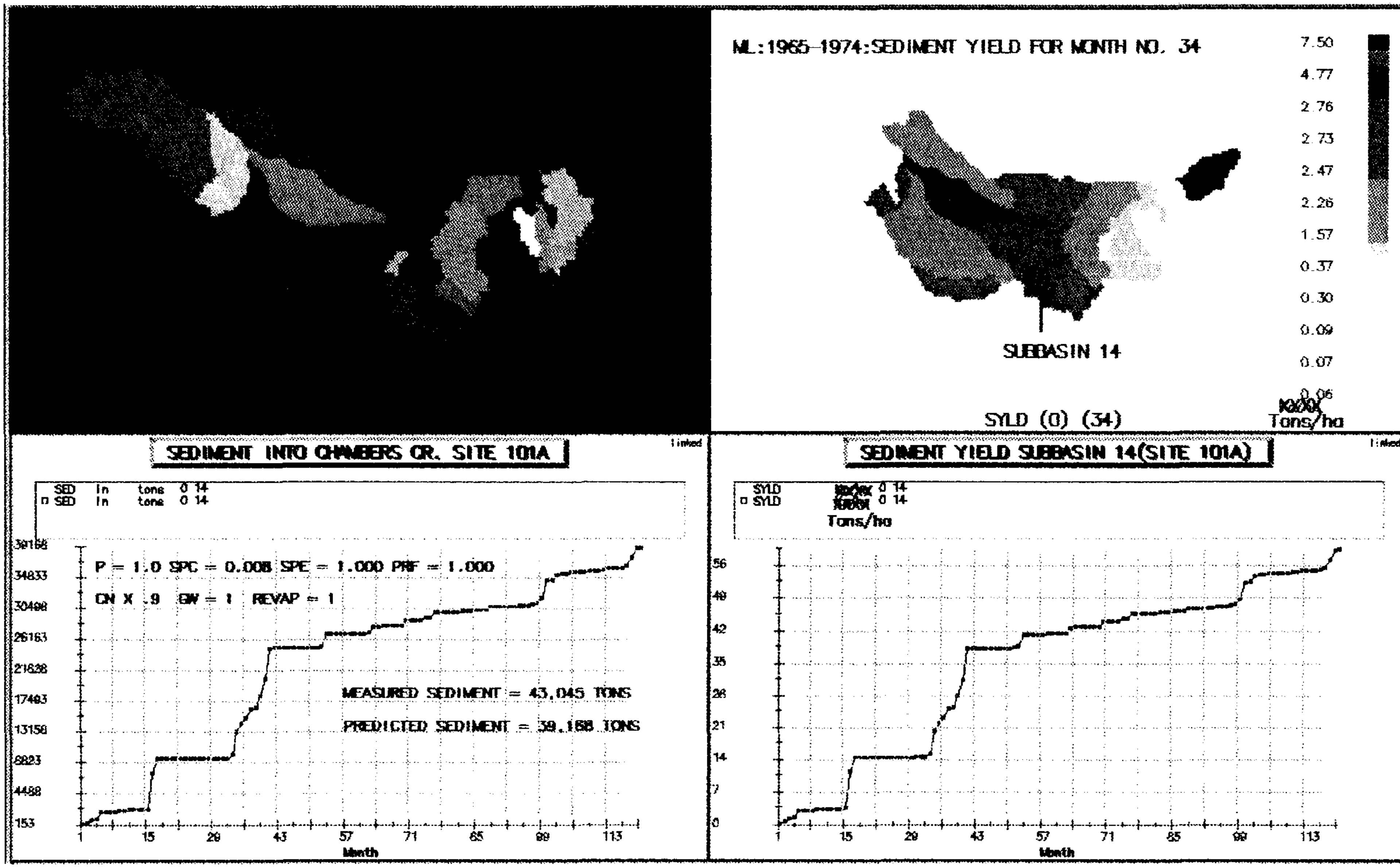


Figure 30. Mill Creek Watershed sediment validation: 1965 to 1974.

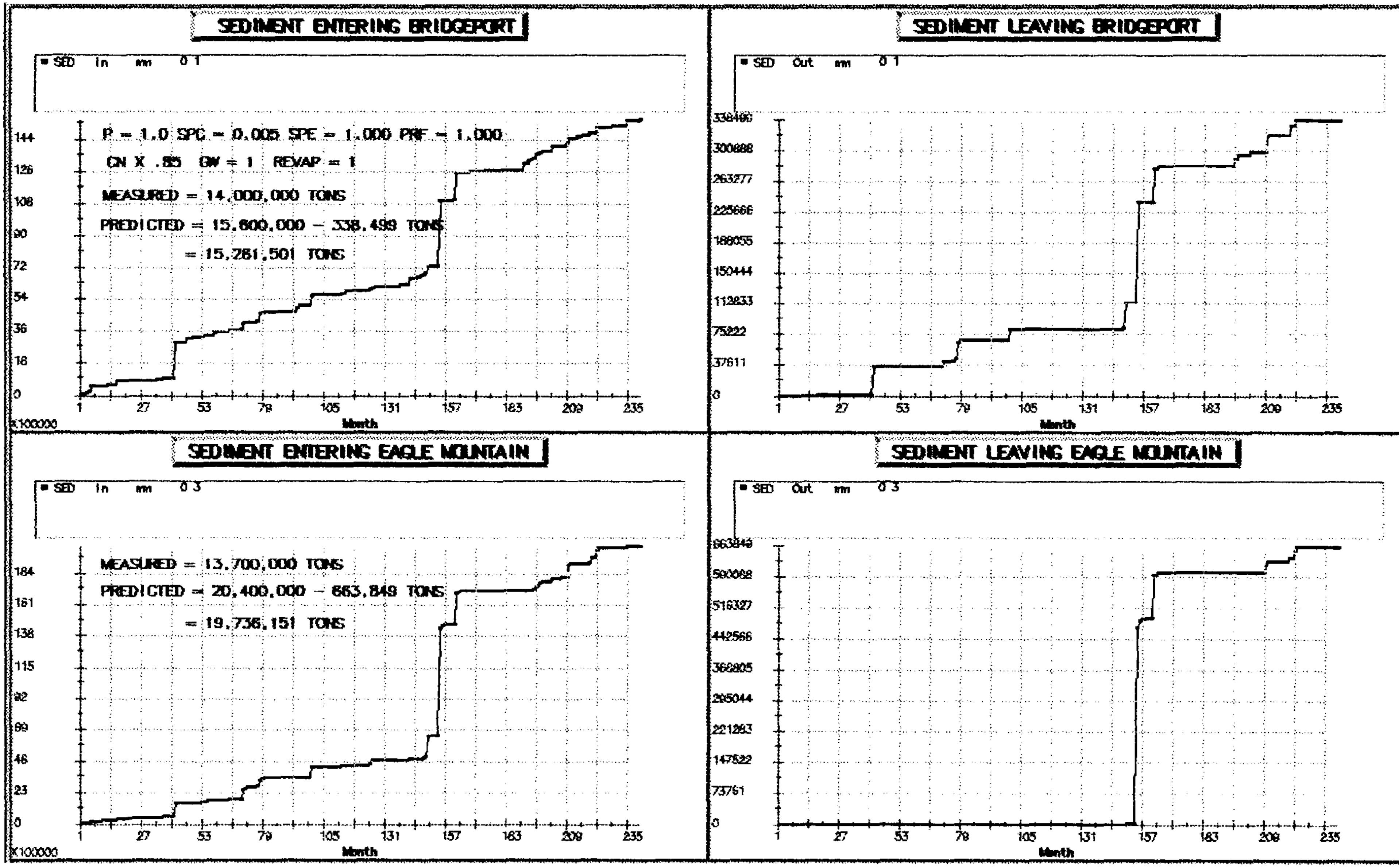


Figure 31. Upper Trinity River Watershed sediment validation: 1969 to 1988.

Nutrient Simulation

The SWAT model will simulate organic and soluble nutrients (nitrogen and phosphorus). TCWCID is in the process of establishing additional monitoring stations to collect nutrient data. Development of these data bases will allow calibration and validation for nutrients to proceed. A sample of SWAT nutrient output for the Richland-Chambers watershed is shown in Figure 32.

Development of Alternative Solutions (BMP's)

Big Sandy Creek is a sub-watershed of the Upper Trinity River Watershed. The location of the watershed relative to Upper Trinity is shown on Figure 33. TCWCID No. 1 has agreed to provide construction funds to NRCS for the installation of eight grade stabilization and flood water retarding structures in Big Sandy Creek. TCWCID staff have used the SWAT model to evaluate the effectiveness of installation of these structures. This planning process allows them to evaluate priorities for funding accelerated implementation of these project works and the cost/benefit ratio for their funding efforts.

Shown on Figure 34 are the existing inventory sized ponds and structures funded by NRCS and others in Big Sandy Creek Watershed. Also shown are the structures that TCWCID No. 1 has agreed to fund.

Figure 35 shows output from two 20-year SWAT simulations on Big Sandy Creek. The first simulation was used to assess sediment load at the outlet from Big Sandy Creek, assuming that only the structures funded by NRCS and others were present. Data for all structures, including the TCWCID funded structures, were included in the second simulation input into the SWAT model. The difference shown is the reduction in sediment loads from Big Sandy Creek Watershed effected by the installation of the TCWCID funded structures. From this data, TCWCID can determine the cost/benefit of participating in cost share of these BMP's in Big Sandy Creek Watershed.

Figure 36 shows the sediment yield for the subbasins in which the TCWCID funded structures will be installed. Similarly, the output data from SWAT can be used to predict the expected reduction in sediment for each individual structure. Using this data TCWCID can calculate cost versus benefits for the eight structures. The construction schedule can also be prioritized based on sediment yield from individual subbasins, or based on expected benefits for individual structures.

The development of the Mill Creek Work Plan occurred at the same time that SWAT was being developed for the TCWCID project. Therefore, currently installed BMP's were not prioritized using SWAT. However, future installation of BMP's in Mill Creek can be prioritized using SWAT predictions for sediment yield. In addition, the benefit to cost of the BMP's can be evaluated. Figure 37 shows the predicted sediment yield from individual subbasins in Mill Creek Watershed. The location of currently installed BMP's is also shown.

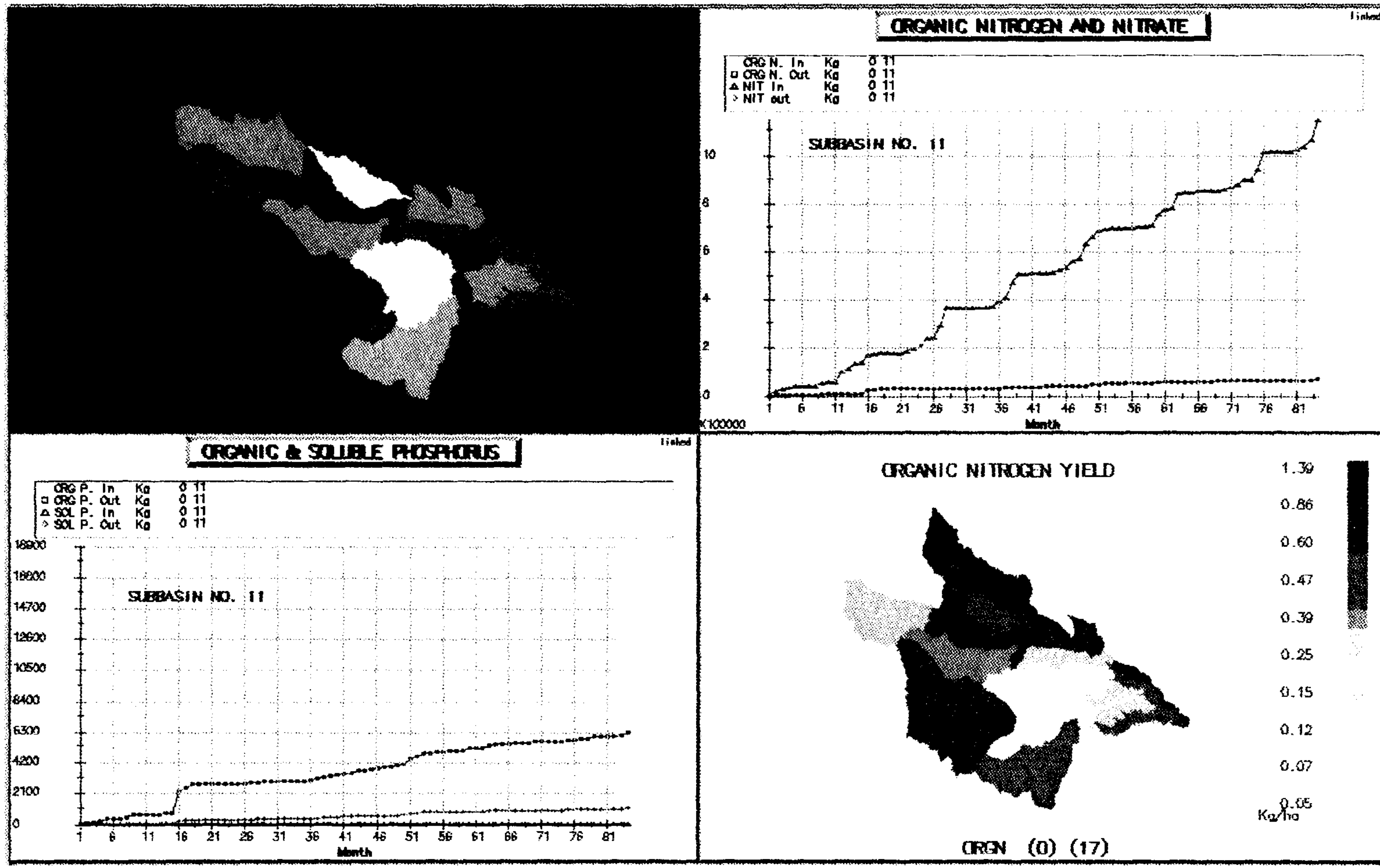


Figure 32. Richland-Chambers Watershed nutrient output from SWAT.

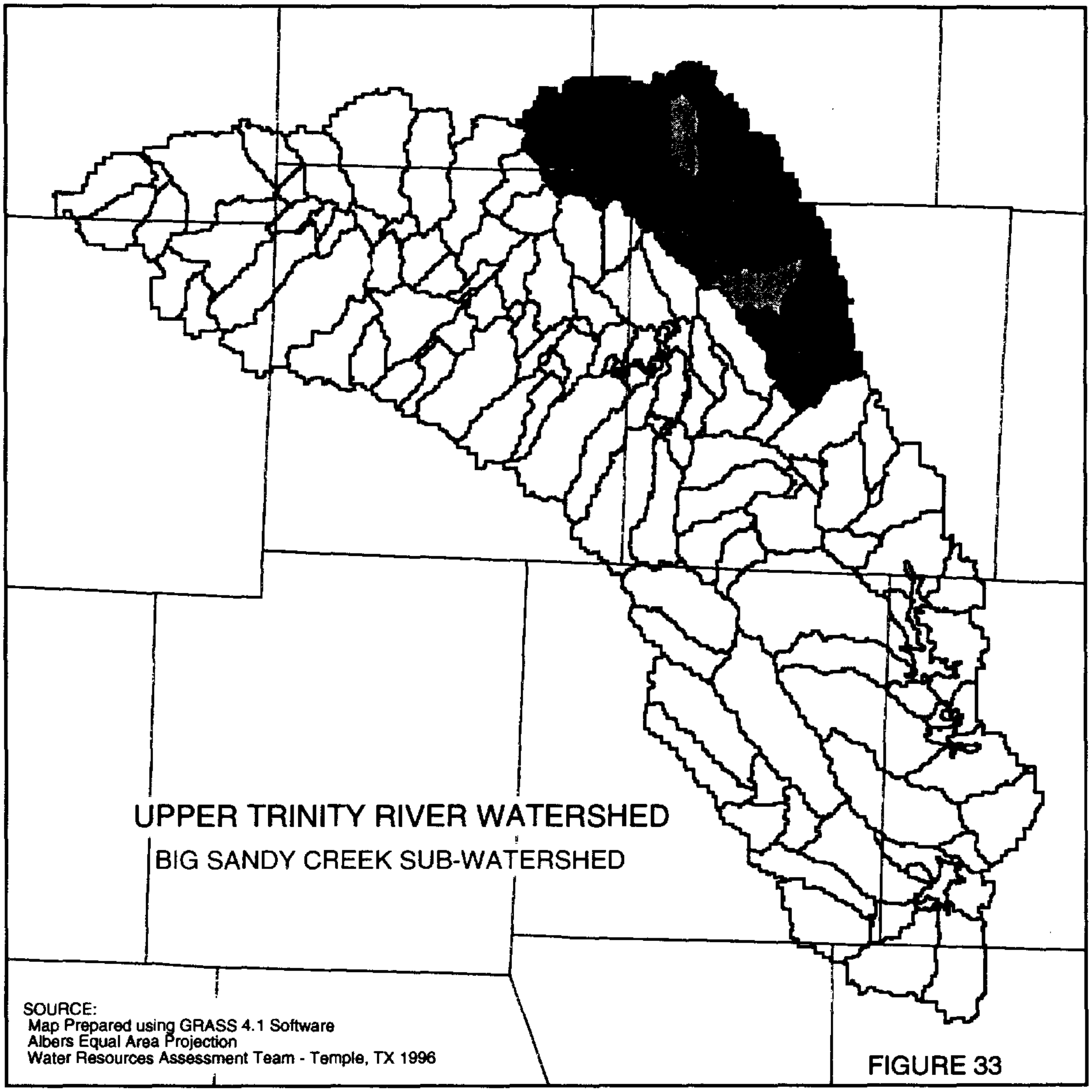
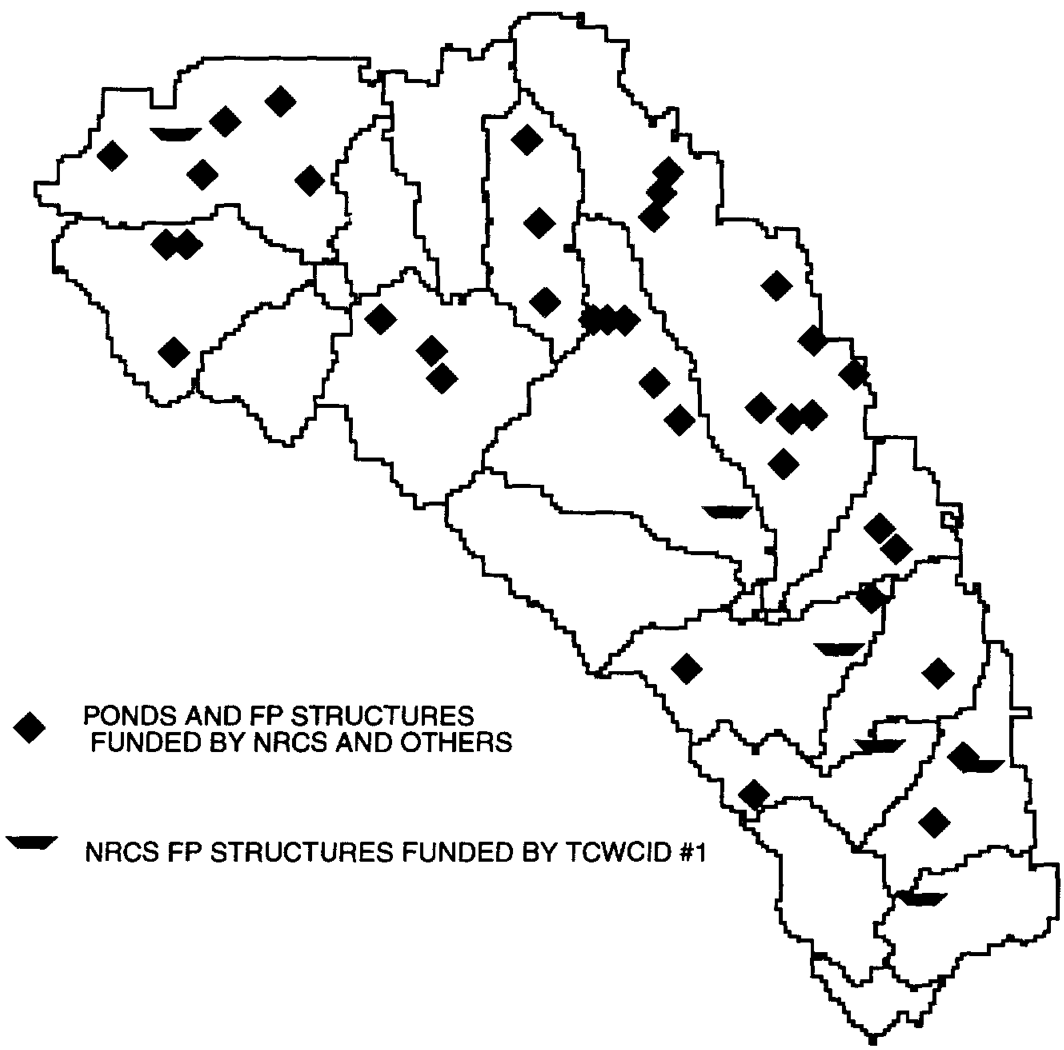

UPPER TRINITY RIVER WATERSHED
BIG SANDY CREEK SUB-WATERSHED
SOURCE:
Map Prepared using GRASS 4.1 Software
Albers Equal Area Projection
Water Resources Assessment Team - Temple, TX 1996

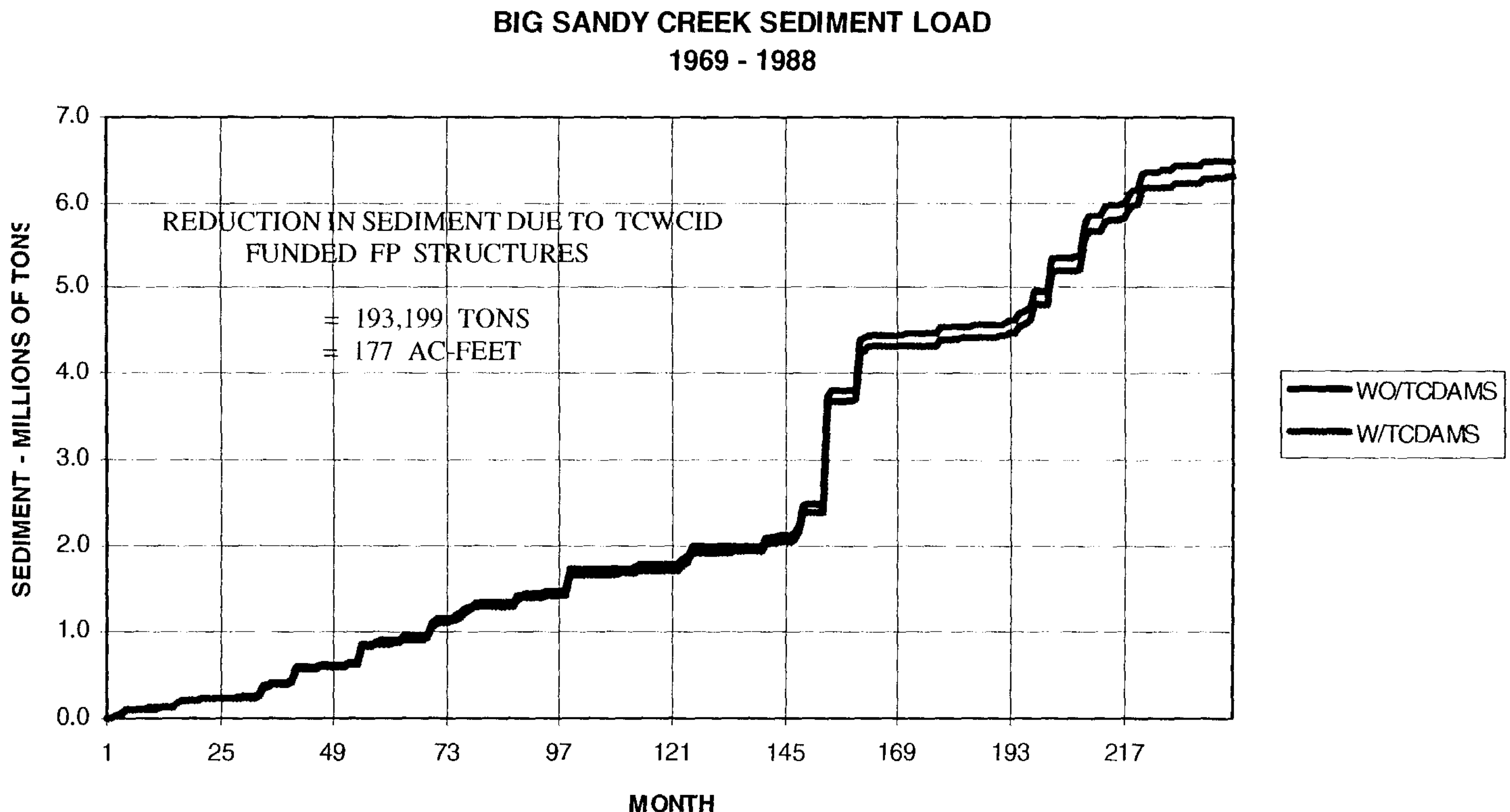
FIGURE 33

BIG SANDY CREEK WATERSHED



SOURCE:
Map Prepared using GRASS 4.1 Software
Albers Equal Area Projection
Water Resources Assessment Team - Temple, TX 1996

FIGURE 34



BIG SANDY CREEK SEDIMENT LOAD
1969 - 1988
REDUCTION IN SEDIMENT DUE TO TCWCID
FUNDED FP STRUCTURES
= 193,199 TONS
= 177 AC-FEET
SEDIMENT - MILLIONS OF TONS
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
1
25
49
73
97
121
145
169
193
217
MONTH
WO/TCDAMS
W/TCDAMS

FIGURE 35

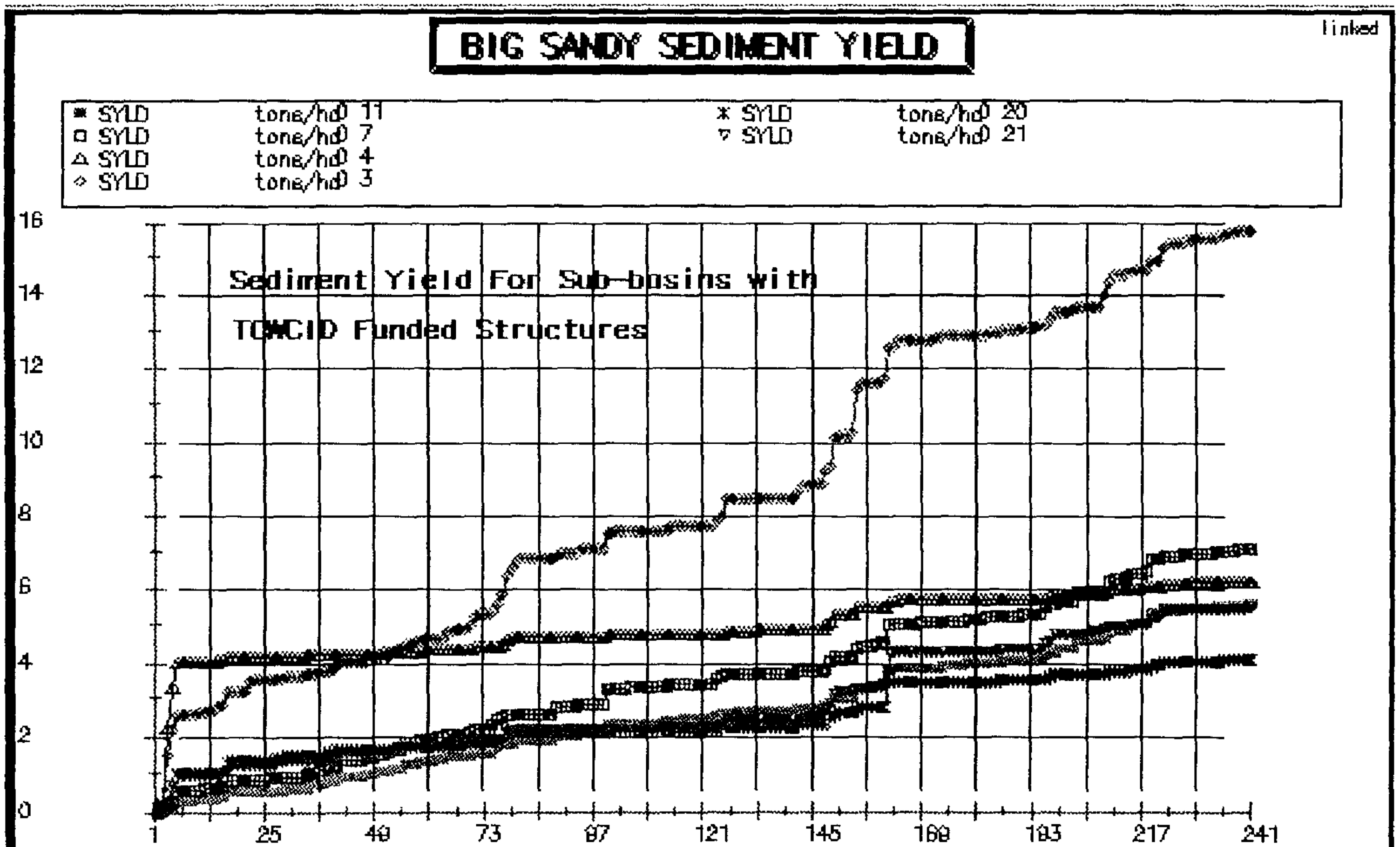

BIG SANDY SEDIMENT YIELD
linked
SYLD tons/ha 11
SYLD tons/ha 7
SYLD tons/ha 4
SYLD tons/ha 3
SYLD tons/ha 20
SYLD tons/ha 21
Sediment Yield For Sub-basins with
TCWCID Funded Structures
16
14
12
10
8
6
4
2
0
1
25
49
73
97
121
145
169
193
217
241
Month

FIGURE 38

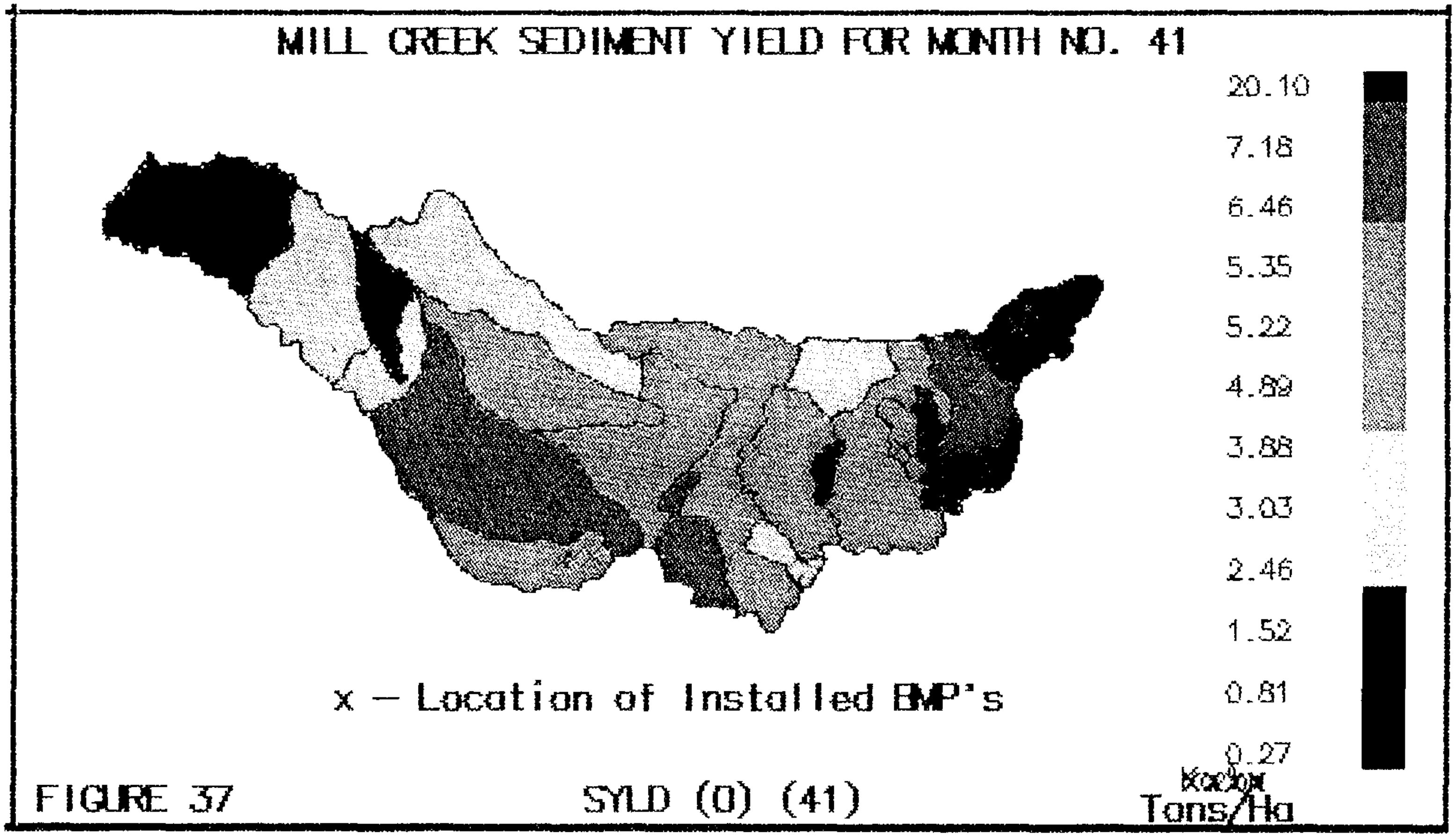

MILL CREEK SEDIMENT YIELD FOR MONTH NO. 41
20.10
7.18
6.46
5.35
5.22
4.89
3.88
3.03
2.46
1.52
0.81
0.27
x – Location of Installed BMP's
SYLD (0) (41)
Tons/Ha

FIGURE 37

SUMMARY AND CONCLUSIONS

Project Results

The results of the study provide information for setting up long range plans for controlling sediment and other nonpoint source (nitrogen and phosphorus) problems in the study area. This study of the watersheds above the TCWCID's reservoirs complements the capability of the model user to evaluate or assess NPS pollutants. Study results provide:

> A method to evaluate BMP's applied in each reservoir's watershed to decrease the amount of sediment and NPS pollutants (nutrients) being transported to the reservoir.
>
> The effect NPS is having on the water quality of each reservoir.
>
> The amount of sediment transported to each reservoir by the various intensity storms and the effect the different alternatives would have on the amount transported.
>
> The relative loadings of NPS pollutants into the streams and reservoirs. Components of the above results are problem maps, project maps, area sediment loadings, and evaluations of alternatives for solving problems.

At the point of current development, SWAT has been effectively applied to small watershed applications with reasonable correlation to measured flow and sediment. It is simulating nutrient loadings, but additional sampling now underway will provide the basis for validation of these constituents.. Current GIS data is suitable for the present level of analysis of the watersheds although it should be a continuous effort to update and add to these data bases.

Use of Study Results

TCWCID has the hardware and software in-house and has a working knowledge of the SWAT model and GIS to utilize the accomplishments of this study. TCWCID staff have worked one-on-one with NRCS, TAES, and ARS staff throughout the project to familiarize themselves with concepts and procedures for running GIS and SWAT. Early in the project, TCWCID staff attended a computer modeling training workshop to learn both field scale and watershed scale computer models, their applications and hands on operation including input and output. A continued partnership between TCWCID and the multi-agency team of NRCS, TAES and ARS will insure future support of the hardware and software. A User's Manual has been jointly developed by NRCS and TCWCID and is included in Appendix D. This manual will continually be updated to reflect changes and enhancements of SWAT and the GIS data.

The study results have already been used to determine the priority of subwatersheds for one implementation plan. Factual data exists for TCWCID to make management decisions regarding the prevention and control of sedimentation and NPS pollution within their reservoirs and the associated watersheds. The District will develop a plan of work to begin implementation of alternative BMP's within the study area

TCWCID has used SWAT modeling and GIS to help develop additional watershed sampling programs in Cedar Creek watershed to analyze specific sediment loading problems associated with that reservoir. The model was used to identify the subbasins with the highest sediment yields containing predominantly colloidal clay particles. In addition, the model was used to located specific sampling sites associated with landuse and soil types to develop the data necessary to validate the model.

In the Richland-Chambers watershed, TCWCID is using SWAT to evaluate the effectiveness of a cooperative BMP implementation program that has been undertaken in the Mill Creek subwatershed. The model will be used to determine reduction in sediment by erosion control structures over a five year period.

Input of point sources of either discharge or withdrawal have not been used at this time even though SWAT has this capability. SWAT currently does not estimate in-stream kinetics on NPS loadings. Because of this, no attempt was made to develop this component of SWAT during this portion of the project.

Conclusions

Several research scientists working on SWAT development are continuing to evaluate such things as spatial variability and improvement of the GIS data bases. It has become apparent in some of these studies that care must be taken in using the 1:250,000 DEM with the small subbasins. Computation of slope lengths and average slope is affected by the DEM and if these computations are not reasonable, the sediment loadings will be inaccurate. The 1:24,000 DEMs are relatively scarce in Texas at present. The need by many entities will lead to eventual development of these DEMs throughout the State which will greatly enhance the topography input to SWAT. Use of SWAT on the smaller watersheds needs to have comparison values of measured data for sediment loadings until ongoing studies can provide the reasonable ranges of use of the 1:250,000 DEM in these cases.

The Mill Creek subwatershed is the beginning of efforts to upgrade all GIS layers to the 1:24,000 scale. A DEM for this area was prepared and the landuse was updated to current conditions, both at 1:24,000. Other targeted or critical areas should have GIS data upgraded as needed.

Another input which needs to be enhanced in the future is that of precipitation data. When simulating smaller watersheds, the density or location of rainfall gauges is critical in duplicating historical events. SWAT's daily time step already has some effect on hydrograph peaks of short duration - high intensity storms since the volume is spread over 24 hours. Supplementing the National Weather Service stations with additional rain gauges will help to define storm volume and areal extent for small watershed areas.

Use of the NEXRAD precipitation data is also a possibility to enhance the definition of a rainfall event over a watershed. The computerized data can indicate the accumulated amounts of rainfall along with the spatial variation of the event over an area. This data can be used in the future to provide precipitation input to SWAT.

Continuing or Future Efforts

A new proposal was developed by USDA - NRCS and TCWCID on August 23, 1993. This study emphasizes the need for integrating watershed, stream and reservoir models to address water quality issues related to NPS pollution. TCWCID desires to use the watershed model with in-stream dynamics added for stream reaches to drive the input to the WASP4 (Water Quality Analysis Simulation Program Version 4) reservoir model (U.S.E.P.A., Ambrose et al.). The model chosen for accomplishing the estimation of the in-stream kinetics is QUAL2E (USEPA). A separate study has adapted the reservoir model specific to the TCWCID reservoirs but input has been derived from sampling of the streams entering the reservoir. Integration of the models would allow "what if?" types of simulations to determine watershed loadings effects on the reservoir.

Once this model integration has been accomplished, the point source loadings will be then included in model runs so that realistic loads are derived from the combination of both point and nonpoint sources and carried through the stream system to the reservoirs.

Model integration and development includes efforts by TCWCID, USDA - NRCS, USDA - ARS, and TAES. The study concentrates initially on the Cedar Creek Reservoir and Eagle Mountain Reservoir with their respective watersheds. Substantial sampling data already exists and a continued, enhanced sampling program is proposed that is specific to the needs of this study. The initial WASP4 modeling efforts have been completed on these same two reservoirs.

TCWCID has been striving for two years to align the teamwork and the financial assistance needed to develop an interface between the SWAT and WASP4 models. Additional features will be added to the combined models to deal with dynamics within tributary or stream reaches along with simulation of the transition zone where tributaries enter the reservoir. The combined model is envisioned as a tool which allows the watershed and/or reservoir manager to assess nonpoint source loadings at the subwatershed level and then track these loadings through the stream network, entry into the reservoir and movement throughout the reservoir. In this way the managers can make informed decisions in the field of water quality as it affects their operations. This project is expected to be completed by December 31, 1995.

Complete development of the new modeling effort will include the nonpoint source loadings and point source loadings from watersheds, full in-stream kinetics, effects of the transition zone at the reservoir coves, and the reservoir reaction to these loadings.

TCWCID has acquired the NEXRAD system for all of the watersheds in the study area. Integration of the precipitation data generated by NEXRAD will be utilized to supplement all precipitation data, especially in ungaged areas or where density of gauges is sparse.

It is expected in order to collect the data needed to calibrate and validate this work, that an additional two years will be required. Once data is collected an additional year to finalize the modeling will be required.

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Appendices

APPENDIX A - CHRONOLOGICAL PROGRESS OF STUDY

December 1993 - Progress During Quarter

Existing GIS layers were depicted in color plotted maps or tables as attachments to the report. The initial SWAT model screening revealed critical areas contributing to non-point source pollution in the streams and reservoirs based on 1:250,000 GIS data. These critical areas received high priority for more intensive assessment. This was done by further subdividing the basins and deriving model input from the more detailed GIS layers that was completed.

Calibration and Validation of WQ Models

Consultation with the ARS model developers was completed regarding plans for calibration and validation of model output. In general, availability of measured data determined the degree of validation that was completed. Measured flow from USGS Stream Gauge records is the most readily available data that can be compared to SWAT predicted flow.

Sediment is the next parameter where limited measurements can be compared to predictions from model simulation. However, the measured data is generally limited to accumulation in reservoirs and not the breakdown of suspended, bedload, etc. within the stream systems. We propose to look at sedimentation studies done on any of the Tarrant County WCID reservoirs as well as two NRCS floodwater retarding structures on Chambers Creek (Sites 37 and 101A). This is to compare these records to a similarly simulated sediment load into the reservoirs for the same period of record.

Other parameters will basically have to wait for sampling and monitoring data. This will build a record for comparison for nutrients, toxics, etc. Records over continuous time do not exist to our knowledge. Any data that is found or becomes available can be used to validate these parameters in SWAT modeling.

Deliverables (11/30/93): Relational Data Bases and GIS Layers

- CBMS soils (1:24,000) for each county were obtained from the soils section of the Soil Conservation Service and processed into a single GIS soils layer. Work was almost completed on the Young County which will complete the map. Mapping was not complete for that portion of Young County within the Upper Trinity, but soil scientists completed the field sheets and provided the data for us to complete the soils series delineations. A color printed map was attached to this progress report with each color delineation representing a specific soil series which will be used by SWAT. The combination of CBMS soils data and the associated land use/land cover cell will accurately depict conditions associated with runoff, erodibility, and effects of any current or future BMP's.

- The CBMS land use map for the project area at a scale of 1:24,000 has also been completed for the entire watershed area. A color printed map was attached to this progress report.

- Geology Land Resources spatial data base at a scale of 1:500,000 has been completed. A printed map was attached to depict this data base layer. The Land Resources descriptions from the Bureau of Economic Geology maps had previously been loaded into the Informix Data Base.

A site location map indicating the station inventory for TNRCC surface water sampling is now complete.

- Several color prints of output screens of the initial SWAT model runs were included to depict only one parameter, sediment, related to water quality. These screens are then partially enlarged with an overlay of the digitized TCWCID sub watersheds to indicate location of areas of low, medium, high, very high loadings of sediment and sediment yield from the basins.

March 1994 - Progress During Quarter

A delay in development of Digital Elevation Models (DEM) for Mill Creek Sub-basin was due to the time it took to obtain stable contour separates for the 7.5' quadrangle sheets from USGS (on order several months). This data should be delivered and development of DEM's complete within the next quarter.

Also there was a delay in obtaining planimetric locations of TNRCC data bases such as segment boundaries, solid waste and wastewater treatment locations. Recent meetings with TNRCC personnel should aid in acquisition of this data as well as other data that agency may make available.

Final efforts are underway to obtain special data bases from other State and Federal agencies. This will include confined animal feeding operations (CAFO) data bases from both TNRCC and EPA. Also included is oil and gas well locations from Texas Railroad Commission. These data bases include all counties of the project area.

All data, computer programs, and simulation models pertinent to the Project were in the process of being loaded onto hardware for further use by TCWCID # 1. This hardware is designed to operate on the stand-alone unit as opposed to all work undertaken at Blackland Research Center which is completely networked.

Simulations were underway using historical climatological data instead of generated weather data. This will allow validation of simulation model results when compared to historical stream flow and sedimentation data.

<u>Deliverables (3/31/94): Relational Data Bases and GIS Layers</u>

- Completed CBMS soils (1:24,000) for each watershed were obtained from the soils section of the Soil Conservation Service and processed into a single GIS soils layer from individual county maps. Work was completed on the Young County portion which now completes the map. A color printed map is attached to this progress report with each color delineation representing a specific soil series which will be used by SWAT.

- Completed CBMS land use/cover (1:24,000) for each watershed were obtained from the soils section of the Soil Conservation Service and processed into a single GIS land use/cover layer from individual county maps. Work was completed on the Young County portion which now completes the map. A color printed map is attached to this progress report with each color delineation representing a specific land use/cover which will be used by SWAT.

- The SSSD Relational Soils Data Base for model input is complete for the project area.

- The Relational Data Base of Climatological Data for the project area is loaded and available to operate SWAT using historical climatological for the periods of record available.

- The data base layer of all reservoirs (TNRCC inventory size) is complete.

- Geologic Atlas Sheets for the entire project area are completed.

- Dr. R. Srinivasan (Texas Agricultural Experiment Station) has completed modification of Model Output Displays requested.

- Initial SWAT Simulations of all three major watersheds in the project area have been completed.

June 1994 - Progress During Quarter

Contour separates were received from USGS for development of Digital Elevation Models (DEM) for Mill Creek Sub-basin. This data has been scanned, edited and is now being attributed. This DEM will be completed in July, 1994.

The process is underway with TNRCC personnel to transfer planimetric locations of TNRCC data bases such as solid waste and wastewater treatment locations to our GIS data base. This is also the case with the 1989 Irrigation Survey of Texas which is being obtained from TWDB.

Special data bases were received from other State and Federal agencies including confined animal feeding operations (CAFO) data bases from both TNRCC and EPA. Also included were oil and gas well locations from Texas Railroad Commission. These data bases include data for all counties of the project area where available.

Simulations are underway using historical climatological data and stream flow records with efforts to calibrate model results. Several changes or modifications of the SWAT model are being made to accommodate the more detailed data bases available for this project.

Deliverables (06/30/94): Relational Data Bases and GIS Layers

- Completed Land Use/Cover Map (1:24,000) for Lake Arlington Watershed which was obtained from the ASCS and SCS office files in Tarrant and Johnson Counties. A color printed map was attached to this progress report with each color delineation representing a specific land use/cover.

- Report of the Lake Arlington Watershed Land Use/Cover Map listing the acreage and percent of total watershed of each category of land use/cover.

- Initial Map of Confined Animal Feeding Operations (CAFO's) within the counties in which the Tarrant County WCID Project Area lies. Many other CAFO's occur in the watershed boundaries but coordinate data is not yet available for these operations. Project partner's will work together to complete the coordinate acquisition for the remaining operations. A color printed map was attached to this progress report with CAFO locations indicated where available.

- Completed Oil and Gas Well Locations Maps (1:24,000) for the project area were depicted with color maps attached to report. There are eighteen (18) layers or maps with each layer indicating a particular class or type of well location. The data was obtained in digital format from Texas Railroad Commission and converted to GIS layers for the project area.

September 1994 - Progress During Quarter

The cooperative irrigation survey (digitized) conducted by Texas Water Development Board and Natural Resources Conservation Service in 1989 has been obtained by WRAT and is now on-line. Additional conversion to GRASS format will be necessary before it can be displayed as part of the Tarrant County WCID GIS.

The digital elevation model (DEM) at 1:24,000 for the Mill Creek watershed was completed. Detailed computer model runs for this sub-watershed have begun using the most detailed data we have available for any portion of the entire project area.

Simulations are underway using historical climatological data and stream flow records with efforts to calibrate model results. Several changes or modifications of the SWAT model have been made to accommodate the more detailed data bases available for this project. Comparison of predicted to measured data is looking much better with the modifications and as the detailed data is incorporated into simulations.

All known sediment surveys on reservoirs within the project area have been located and the pertinent data copied. Once stream flow is calibrated within the SWAT simulations, the sediment survey data will be used to attempt to calibrate sediment delivery predicted by the model.

Deliverables (09/30/94): Relational Data Bases and GIS Layers

- Map indicting locations of reservoirs within the project area which have sediment survey data available. These reservoirs vary from small floodwater retention dams to major reservoirs.
- DEM for Mill Creek subbasin at 1:24,000.
- Color display of output data for the Upper Trinity watershed indicating comparison of predicted vs. measured stream flow. Additional detailed data such as reservoir and pond storage plus more detailed soils analysis should improve the comparison further.

June 1995 - Progress During Quarter

The digital elevation model (DEM) at 1:24,000 for the Mill Creek watershed was corrected from feet to meters as needed by the SWAT model inputs. Detailed computer model runs for this sub-watershed have been used extensively for calibration of sediment. It was also used for adaptation of the SWAT model for very small subbasins. The most detailed data we have available was used for any portion of the entire project area. As new GIS layers were developed for Mill Creek, they have been forwarded to Tarrant County WCID#1. These have included a current land use/cover map and a subbasin map configured to match work being done by the NRCS planning staff on their project work in Mill Creek.

Changes or modifications of the SWAT model have been made to accommodate the more detailed data bases available for this project. Automation of inputs of dams and reservoir data is now complete and work is continuing to automate the selection of specific periods of climatological data without having to manually edit input files.

All available discharges from major reservoirs have been acquired and efforts are ongoing to input the demand and discharges from all reservoirs in the watersheds into model runs.

The configuration of subbasins within Cedar Creek Watershed were revised to allow more detailed analysis of the areas where current and proposed monitoring and sampling stations are located. Cedar Creek Watershed now is divided into 49 subbasins as opposed to the original 18 subbasins. The dam and reservoir data was recompiled to fit the new subbasin boundaries.

The road network data base from Tiger files was completely redone to include the maximum detail including county roads. Agein this will facilitate analysis of sampling stations and overall detail when working in the smallest subbasins.

A new corrected stream network data base layer was also compiled for the project area and made available to Tarrant County WCID#1.

During recent modeling work, there were some errors discovered in the digital elevation map (DEM) which led to improper slope lengths and average slope values computed by the model. A new version of the DEM was obtained and procedures for its use changed to eliminate the problems associated with computing slopes.

As the SWAT model and GIS interface are updated, the new versions are loaded on the Tarrant County WCID#1 workstation.. User manuals are revised and personal assistance provided to TCWCID users. Two updates have been completed during the time period covered by this report.

Deliverables (05/31/95): Relational Data Bases and GIS Layers

- Revised Road Network GIS Layer for Entire Project Area.
- Revised Cedar Creek Watershed Subbasin Delineation (raster).
- Revised Cedar Creek Watershed Subbasin Delineation (vector w/roads & I.D. Numbers).

APPENDIX B - NRCS NATIONAL OFFICIAL SOIL SERIES DESCRIPTIONS

Soils play a substantial role in the processes simulated in the SWAT model. This appendix is included to give the user a uniform description of the soil series properties encountered in the TCWCID study area. This information is found at the Internet Wide World Web address at Iowa State University which houses the NRCS national official soil series descriptions. The internet address is http://www.statlab.iastate.edu/soils/homepage.html.

Only the most prominent soil series found in the study area are included here and the percentage of a particular soil series occurrence within the area is noted in parenthesis after the soil series name. All phases of a soil series name are included within the category of the soil series name.

HOUSTON BLACK SERIES (7.22%)

The Houston Black series consists of very deep, moderately well drained, very slowly permeable soils that formed from weakly consolidated calcareous clays and marls of Cretaceous Age. These soils are on nearly level to moderately sloping uplands. Slopes are mainly 1 to 3 percent, but range from 0 to 8 percent.

TAXONOMIC CLASS: Fine, montmorillonitic, thermic Udic Haplusterts

TYPE LOCATION: Travis County, Texas; from intersection of Farm Road 973 and U. S. Highway 290 in Manor, 3.5 miles east on U. S. Highway 290, 2.4 miles northeast on Farm Road 1100, 1.0 mile northwest and 3.0 miles northeast on Manda Road, 0.5 mile southeast on Lund Road, 900 feet southwest on field road, 105 feet east in pasture.

RANGE IN CHARACTERISTICS: Thickness of the combined A and B horizons is more than 80 inches. The weighted average clay content of the particle size control section is 40 to 60 percent The soil is usually moist, but when dry it has cracks ranging from 0.5 to 4 inches wide extend from the surface to a depth of 12 inches or more Cracks remain open for 90 to 150 cumulative days in most years. Slickensides begin at depths ranging from about 16 to 24 inches below the soil surface. The soil is clayey throughout with dominant textures being clay or silty clay. Some pedons have 15 to 30 percent by volume of siliceous and other pebbles in the upper 12 inches. Dominant textures are clay or silty clay in the upper 12 inches. When dry the surface has a granular mulch about 1/2 inch thick of extremely hard discrete granules. Cycles of microdepressions and microknolls are repeated each 10 to 24 feet. In virgin areas, microknolls are 3 to 18 inches higher than microdepressions. Chromas are less than 1.5 to depths of 30 to 60 inches in the center of microdepressions and 10 to 18 inches in the center of microknolls. The extremes of amplitude or waviness of the boundary between the A and B horizons vary from about 20 to 48 inches from the center of the microknoll to the center of the microdepression.

GEOGRAPHIC SETTING: Houston Black soils are on nearly level to sloping uplands. Slopes range from 0 to 8 percent, but are mainly 1 to 3 percent. The soil formed in calcareous clays and marls mainly of the Taylor Marl geological formation. In places, the substrata are chalks or shales. The climate is warm and subhumid. The mean annual precipitation ranges from 28 to 42 inches and the mean annual temperature ranges from 63 to 70 degrees F. Frost free days range from 220 to 250 days and elevation ranges from 400 to 1000 feet. Thornthwaite annual P-E indices range from 44 to 66.

GEOGRAPHICALLY ASSOCIATED SOILS: These are the Burleson, Branyon, Fairlie, Heiden and Ovan in the same family and the similar Austin and Ferris soils. Burleson, Branyon and Ovan soils are on lower positions. Heiden soils are on similar landscapes with Houston Black. Austin soils are on slightly higher positions. Austin soils are underlain by chalk 20 to 40 inches dry, and prairie soils have chalk at 40 to 60 inches in depth. Ferris soils are on slightly sloping hillsides and have moist color values more than 3.5 and chroma more than 1.5 in the upper 12 inches.

DRAINAGE AND PERMEABILITY: Moderately well drained. Slow to rapid surface runoff. Water enters the soil rapidly when it is dry and cracked, and very slowly when it is moist. Permeability is very slow.

USE AND VEGETATION: Nearly all is cultivated and used for growing cotton, sorghums, and corn. Cotton root rot is prevalent on most areas and limits cotton yields and the use of some legumes in rotations. Native vegetation consists of tall and mid grass prairies of little bluestem, big bluestem, indiangrass, switchgrass, and sideoats grama, with scattered elm, mesquite, and hackberry trees.

DISTRIBUTION AND EXTENT: The Blackland Prairies and eastern part of the Grand Prairies of Texas. The series is extensive.

<u>CROCKETT SERIES</u> (6.34%)

The Crockett series consists of soils that are deep, to weathered shale. They are moderately well drained, and very slowly permeable. These soils are on uplands. They formed in alkaline shales and clays. Slopes are dominantly 1 to 5 percent, but range from 0 to 10 percent.

TAXONOMIC CLASS: Fine, montmorillonitic, thermic Udertic Paleustalfs

TYPE LOCATION: Kaufman County, Texas; 250 feet east of Farm Road 986; 1.5 miles north of post office in Terrell.

RANGE IN CHARACTERISTICS: Solum thickness ranges from 40 to 60 inches. Depth to secondary carbonates ranges from 30 to 60 inches. Some pedons lack visible carbonates. When dry, crack 1/2 to about 2 inches wide extend from the top of the Bt horizon to depths of 2 to 5 feet. If the A horizon is eroded or thin, the soil cracks to the surface. Pressure faces and slickensides range from few to common throughout the Bt horizon and in the BC and C horizon of some pedons. The average clay content of the control section is 40 to 50 percent and the COLE ranges from .07 to .10.

GEOGRAPHIC SETTING: Crockett soils are on broad nearly level to sloping uplands. Slopes range from 0 to 10 percent, but are mostly between 1 and 5 percent. The soil formed in alkaline marine clays and sandy clays, or shale, interbedded with sandier materials mainly of Cretaceous age. The mean annual temperatures ranges from 64 to 70 degrees F. and mean annual precipitation ranges from 32 to 45 inches. Frost free days range from 230 to 275 days and elevation ranges from 200 to 800 feet. Thornthwaite P- E indices ranges from 50 to 75.

GEOGRAPHICALLY ASSOCIATED SOILS: These include the competing Axtell, Bonham, Normangee, and Payne series and the Burleson, Mabank, and Wilson series. Burleson soils are clays with intersecting slickensides. Mabank and Wilson soils are dominated by chromas or 2 or less. Axtell, Bonham, Normangee, and Payne soils are on similar landscapes with Crockett soils. Burleson, Mabank, and Wilson soils are on lower positions.

DRAINAGE AND PERMEABILITY: Moderately well drained. Runoff is slow to rapid. Permeability is very slow.

USE AND VEGETATION: Mainly used for growing cotton, grain sorghums, and small grain, but more than half the acreage is now in pastures. Native vegetation is prairie grasses such as bluestems, indiangrass, switchgrass, and gramas, with scattered elm, hackberry, and mesquite trees.

DISTRIBUTION AND EXTENT: Mainly in the Blackland Prairies of Texas, but minor areas are in Oklahoma. This series is extensive.

<u>WILSON SERIES</u> (3.71%)

The Wilson series consists of very deep, moderately well drained, very slowly permeable soils that formed in alkaline clayey sediments. These soils are on nearly level to gently sloping stream terraces or terrace remnants on uplands. Slopes are mainly less than 1 percent but range from 0 to 5 percent.

TAXONOMIC CLASS: Fine, montmorillonitic, thermic Oxyaquic Vertic Haplustalfs

TYPE LOCATION: Kaufman County, Texas; 4 miles southeast of the intersection of Texas Highway 34 and U. S. Highway 175 in Kaufman, 0.15 mile northeast and 0.2 mile southeast of intersection of county road and U. S. Highway 175, 150 feet southwest in field.

RANGE IN CHARACTERISTICS: Solum thickness ranges from 60 to more than 80 inches. The weighted average clay content of the control section ranges from 35 to 42 percent. When dry cracks 0.4 to about 2 inches wide extend from the top of the Bt horizon to a depth of more than 12 inches. Slickensides or wedged shaped peds begin at a depth of 14 to 26 inches. The surface layer is variable in thickness with a series of micro crests and troughs in the Bt horizon that range from 4 to about 20 feet apart. It is seasonally wet and is saturated in the surface layer and upper part of the Bt horizon during the winter and spring seasons for periods of 10 to 25 days. Redox features are mainly relic. The soil does not have aquic soil conditions in most years.

GEOGRAPHIC SETTING: Wilson soils are on nearly level to gently sloping terraces or remnants there of about 100 to 300 feet above the present streams and includes stream divides in erosional upland. Slope gradients are 0 to 5 percent but dominantly less than 1 percent. The soil formed in alkaline clayey alluvium. Mean annual temperature ranges from 64 to 70 degrees F. and mean annual precipitation ranges from 32 to 45 inches. Frost free days range from 220 to 270 days and elevation ranges from 250 to 700 feet. Thornthwaite P-E indices from 50 to 70.

GEOGRAPHICALLY ASSOCIATED SOILS: These are the competing Mabank and the Bonham, Burleson, Crockett, Houston Black and Normangee series. Mabank soils are on similar positions. Bonham soils have mollic epipedons; Burleson and Houston Black soils are Vertisols; Crockett and Normangee soils have Bt horizons with chroma of more than 2. Bonham, Houston Black, Crockett and Normangee soils are on slightly higher positions above Wilson. Burleson soils are on similar positions.

DRAINAGE AND PERMEABILITY: Moderately well drained. Permeability is very slow. Runoff is low on 0 to 1 percent slopes, medium on 1 to 3 percent slopes, and high on 3 to 5 percent slopes. Very slow internal drainage.

USE AND VEGETATION: Wilson soils are cropped to cotton, sorghums, small grain, and corn. Many areas are now idle or are used for unimproved pasture. Original vegetation was tall prairie grasses, mainly andropogon species, and widely spaced motts of elm and oak trees. Most areas that are not cropped have few to many mesquite trees.

DISTRIBUTION AND EXTENT: Mainly in the Blackland Prairies of Texas, but small areas are in Oklahoma. The soil is extensive, probably exceeding 1,000,000 acres.

TRINITY SERIES (3.39%)

The Trinity series consists of very deep, moderately well drained, very slowly permeable soils on flood plains. They formed in alkaline clayey alluvium. Slopes are typically less than 1 percent, but range from 0 to 3 percent.

TAXONOMIC CLASS: Very-fine, montmorillonitic, thermic Typic Hapluderts

TYPE LOCATION: Kaufman County, Texas; from intersection of old U.S. Hwy. 80 and Farm Road 740 in Forney; 6.1 miles south on Farm Road 740; 0.45 mile south on oil top road which is an extension of Farm Road 740; 54 feet east of fence.

RANGE IN CHARACTERISTICS: Solum thickness is more than 80 inches. Gilgai microrelief is present in undisturbed areas but is subdued with the micro highs 2 to 6 inches higher than the micro lows. When dry, cracks 1/4 to more than 1 inch wide extend to a depth of 20 inches or more for less than 90 cumulative days. Grooved slickensides typically begin at a depth of 16 to 24 inches and increase in number and size with depth. Clay content of the control section ranges from 60 to 80 percent. The soil is slightly alkaline or moderately alkaline and slightly or strongly effervescent throughout.

GEOGRAPHIC SETTING: Trinity soils are on nearly level, wide flood plains of major rivers and streams. Slopes are mainly less than 1 percent but range up to 3 percent. The soil formed in calcareous clayey alluvium. The climate is warm and humid to subhumid. The mean annual precipitation ranges from 34 to 52 inches and mean annual temperatures range from 62 to 70 degrees F. Frost free days range from 230 to 280 days and elevation ranges from 100 to 550 feet. Thornthwaite P-E indices range from 52 to about 70.

GEOGRAPHICALLY ASSOCIATED SOILS: These are the competing Kaufman, Tinn, and Zilaboy series and the Gladewater and Ovan series. Ovan soils have less than 60 percent clay in the particle-size control section, have colors with chroma of 2 or 3 in the A horizon, and have cracks that stay open longer than 90 cumulative days. Gladewater soils have aquic soil conditions within a depth of 20 inches. Gladewater and Zilaboy soils are on slightly lower and wetter positions. Kaufman, Tinn, and Ovan soils are on similar flood plain positions.

DRAINAGE AND PERMEABILITY: Moderately well drained. Runoff is low on 0 to 1 percent slopes and medium on 1 to 3 percent slopes. Permeability is very slow. Flooding is common except where the soil is protected.

USE AND VEGETATION: Most areas are in pasture or planted to crops such as cotton, corn, sorghums, or small grains. Native vegetation is hardwood forest of elm, hackberry, oak, and ash.

DISTRIBUTION AND EXTENT: North Central, Central, and South Central Texas. The series is extensive.

WINDTHORST SERIES (3.02%)

The Windthorst series consists of very deep, moderately well drained, moderately slowly permeable soils that formed in loamy and clayey materials stratified with packsand. These soils are on gently to strongly sloping uplands. Slopes range from 1 to 12 percent.

TAXONOMIC CLASS: Fine, mixed, thermic Udic Paleustalfs

TYPE LOCATION: Parker County, Texas; 5.2 miles southwest of the Parker County Courthouse in Weatherford, Texas, via U.S. Highway 80; 800 feet southwest of the junction with Dennis road in wooded pasture, 150 feet north of U.S. Highway 80.

RANGE IN CHARACTERISTICS: Solum thickness ranges from 40 to about 60 inches. Siliceous or ironstone pebbles range from none to 8 percent by volume in some horizons. Base saturation ranges from 75 to 90 percent, by sum of cations, in some part of the argillic horizon. The average clay content of the control section ranges from 35 to 45 percent.

GEOGRAPHIC SETTING: Windthorst soils are on erosional uplands. Soil areas are convex; slope gradients are dominantly from 3 to 5 percent, but range from 1 to 12 percent. Some of the steeper areas are dissected by gullies. The soil formed in stratified clay, weakly cemented packsands, and loamy materials of Lower Cretaceous age. The climate is dry subhumid. The average annual precipitation ranges from 26 to 32 inches, the mean annual temperature ranges from 62 to 66 degrees F., and Thornthwaite P-E indices from 38 to 52. Frost free period is 220 to 240 days and elevation ranges from 700 to 1300 feet.

GEOGRAPHICALLY ASSOCIATED SOILS: These are the competing Chigley series and the Chaney, Darnell, Demona, Duffau, Keeter, Nimrod, Selden, and Stephenville series. Chaney, Demona, Nimrod, and Selden soils have low chroma wetness mottles in the Bt horizon. In addition, Demona and Nimrod soils have sandy surface layers 20 to 40 inches thick. These soils are in lower positions. Darnell soils are less than 20 inches thick. Darnell, Keeter, and Stephenville soils are on slightly higher positions. Duffau and Stephenville soils have fine-loamy control sections. Keeter soils have fine-silty control sections with sola thickness of 20 to 40 inches.

DRAINAGE AND PERMEABILITY: Moderately well drained; medium to rapid surface runoff; moderately slow internal drainage and permeability.

USE AND VEGETATION: Some areas are cultivated; peanuts, sorghums, and small grains are the main crops. Most areas are in pastures of bermudagrass or in rangeland. Native vegetation is post oak and blackjack oak trees with a ground cover of little bluestem, greenbrier, and annual grasses.

DISTRIBUTION AND EXTENT: North-central Texas and south-central Oklahoma. The soil is of large extent.

WATER (2.55%)

HEIDEN SERIES (2.51%)

The Heiden series consists of soils that are well drained and very slowly permeable ..They are deep to weathered shale. These soils are on nearly level to moderately steep uplands. Slopes are mainly 3 to 8 percent but range from 0.5 to 20 percent.

TAXONOMIC CLASS: Fine, montmorillonitic, thermic Udic Haplusterts

TYPE LOCATION: Bell County, Texas; From the intersection of Texas Highway 36 and Farm Road 436 in Heidenheimer; 0.57 miles southeast on Texas Highway 36; 1 5 feet southwest of fence in cropland.

RANGE IN CHARACTERISTICS: Solum thickness ranges from about 40 to 65 inches. They are thinnest in microknolls or microridges and thickest in centers of microdepressions or microvalleys. Texture throughout the soil is clay or silty clay Weighted average clay content ranges from 40 to 60 percent. Cracks remain open 90 to 150 cumulative days in most years. Slickensides and wedge-shaped peds begin at a depth of 10 to 24 inches. Undisturbed areas have gilgai microrelief with microknolls about 4 to 10 inches above microdepressions. On slopes above 5 percent gilgai are linear with slope.

GEOGRAPHIC SETTING: Heiden soils are on erosional uplands. Slopes are mostly 3 to 8 percent, but range from 0 percent to 20 percent. Surfaces are dominantly convex but plane surfaces occur in some areas of low gradients. Most untilled areas have a microrelief of microvalleys 4 to 12 feet wide and 3 to about 12 inches deep, and microridges about 4 to 12 feet wide that extend up and down slope. The soils formed, mainly, in weakly consolidated Upper Cretaceous formations of calcareous marine sediments, high in montmorillonite clays. The climate is moist subhumid. The mean annual precipitation ranges from 28 to 42 inches and the mean annual temperature ranges from 64 to 70 degrees F. Frost free days range from 225 to 275 days and elevation ranges form 400 to 1000 feet. Thornthwaite annual P-E indices range frcm 44 to 66.

GEOGRAPHICALLY ASSOCIATED SOILS: These are the competing Branyon, Burleson, Crockett, Ellis, Fairlie, Ferris, Houston Black, Lott, McLennan, Ovan and Wilson series. Crockett and Wilson soils have argillic horizons. Ferris Ellis and McLennan soils have color values higher than 3.5 in the upper 12 inches. Lott and McLennan soils have fine silty control sections. Ferris, Ellis, Lott and McLennan soils are on lower more sloping positions. Branyon, Burleson, Crockett, Wilson and Ovan are on lower positions. Houston Black is on similar positions. Fairlie and Lott soils are on slightly higher positions.

DRAINAGE AND PERMEABILITY: Well drained. Permeability is very slow. Runoff is low on 0 to 1 percent slopes, medium on 1 to 3 percent slopes, high on 3 to 5 percent slopes and very high on 5 to 20 percent slopes. Infiltration is rapid when the soil is dry and cracked, but very slow when the soil is wet.

USE AND VEGETATION: Used mainly for pasture and hay. Many areas have been cultivated but are now in grass. Some areas are used for growing grain sorghum and cotton. Grasses are mainly bluestem, buffalograss, and threeawn grass. Scattered mesquite trees occur in places.

DISTRIBUTION AND EXTENT: Central and eastern Texas in the Blackland MLRA (86A). The series is extensive.

ALEDO SERIES (2.37%)

The Aledo series consists of shallow to very shallow, well drained, moderately permeable soils that formed in interbedded limestones and marls of Cretaceous age. These soils are on gently sloping to steep uplands. Slope is mostly less than 8 percent, but ranges from 1 to 40 percent.

TAXONOMIC CLASS: Loamy-skeletal, carbonatic, thermic Lithic Calciustolls

TYPE LOCATION: Parker County, Texas; about 4 miles southeast of the Parker County Courthouse in Weatherford, Texas, on Texas Highway 171, to the intersection of Texas Highway 171 and Farm Road 51; 0.65 mile southeast on Texas Highway 171; south on county road 0.3 mile and south of county road 500 feet in native grass pasture.

RANGE IN CHARACTERISTICS: Solum thickness and depth to limestone bedrock ranges from 9 to 20 inches. Limestone fragments range from 5 to about 50 percent in the A1 horizon and from 40 to 85 percent in the A2 horizon. The control section has from 35 to 65 percent limestone fragments. The fragments are mainly less than 6 inches across, however, some pedons contain a few fragments up to 18 inches across. The calcium carbonate equivalent ranges from 40 to 80 percent. Secondary carbonates as films, threads and soft masses, and pendants on the undersides of fragments range from 5 to 25 percent by volume.

GEOGRAPHIC SETTING: Aledo soils are on convex shallow uplands. Slopes are mainly 3 to 8 percent, but range from 1 to 40 percent. The slopes of 8 to 40 percent are mostly narrow bands or steep breaks within less sloping areas. The soils formed in interbedded limestones and marls, mainly of Cretaceous age. The mean annual temperature ranges from 64 to 68 degrees F. The average annual precipitation ranges from 29 to 36 inches and Thornthwaite annual P-E indices are 44 to 58.

GEOGRAPHICALLY ASSOCIATED SOILS: The are the Bolar, Brackett, Denton, Lewisville, Maloterre, and Purves series. Bolar, Denton, and Lewisville soils have calcic horizons and sola thicker than 20 inches. Brackett soils lack mollic epipedons. Maloterre soils lack mollic epipedons and contain less than 35 percent coarse fragments. Purves soils are clayey and have less than 35 percent coarse fragments.

DRAINAGE AND PERMEABILITY: Well drained; medium to rapid runoff; moderate permeability.

USE AND VEGETATION: Used for rangeland. Vegetation consists of little bluestem, sideoats grama, indiangrass, buffalograss, and occasionally scattered mesquite and motts of live oak trees.

DISTRIBUTION AND EXTENT: North-central Texas, mainly within the Grand Prairie. The series is extensive.

GOWEN SERIES (2.35%)

The Gowen series consists of very deep, well drained, moderately permeable soils that formed in loamy alluvium. These soils are on nearly level flood plains. Slopes are dominantly less than 1 percent, but range up to 2 percent.

TAXONOMIC CLASS: Fine-loamy, mixed, thermic Cumulic Haplustolls

TYPE LOCATION: Erath County, Texas; from the county courthouse in Stephenville, Texas, 21 miles northwest on Texas Highway 108; east on county road 1.6 miles; south on county road 0.2 mile; 100 feet east of road in pasture.

RANGE IN CHARACTERISTICS: Solum thickness is greater than 80 inches. Surface horizons having moist color values of less than 3.5 and evident structure, range in thickness from 24 to about 60 inches. Clay content of the 10- to 40-inch particle-size control section ranges from 20 and 35 percent, and more than 15 percent is coarser than very fine sand. Reaction ranges from neutral to moderately alkaline. The soil is noncalcareous above 50 inches.

GEOGRAPHIC SETTING: These soils are on nearly level and gently sloping flood plains. Slopes range from 0 to 2 percent. They formed in loamy alluvium derived dominantly from noncalcareous soils. Flooding occurs at intervals ranging from one or more times a year to once in about every five years unless protected. Mean annual temperature ranges from 64 to 70 degrees F., and mean annual precipitation ranges from 28 to 40 inches. Frost free days range from 230 to 270 days and elevation ranges from 200 to 950 feet. The Thornthwaite indices range from 30 to about 60.

GEOGRAPHICALLY ASSOCIATED SOILS: These include the Bosque, Bunyan, and Frio series. Bunyan soils do not have mollic epipedons. All of these series are in similar landscape postions.

DRAINAGE AND PERMEABILITY: Well drained. Permeability is moderate. Runoff is negligible; In some areas during the winter months a water table is at a depth of 4 to 7 feet.

USE AND VEGETATION: Most of the soil is farmed to peanuts, sorghums, cotton, and pecan orchards. Areas that flood frequently are used mainly for bermudagrass pastures and pecan orchards. Scattered hackberry, elm, and pecan trees occur in most areas.

DISTRIBUTION AND EXTENT: The soil is mainly in the mixed post oak and prairie areas of central Texas and in adjoining areas of Oklahoma. The series is of moderate extent.

TRUCE SERIES (2.19%)

The Truce series consists of soils that are deep to weathered shale. These well drained, slowly permeable soils formed in residuum weathered from shale. These soils are on gently sloping to steep, convex uplands. Slopes are typically 1 to 5 percent, but range from 1 to 40 percent.

TAXONOMIC CLASS: Fine, mixed, thermic Udic Paleustalfs

TYPE LOCATION: Erath County, Texas; from the junction of Interstate 20 and Texas Highway 108, 0.95 mile south on Texas Highway 108, then 75 feet east of highway right-of-way in native range, this point being about 22 miles north-northwest of Stephenville, Texas.

RANGE IN CHARACTERISTICS: Solum thickness ranges from 40 to 60 inches. Fragments of sandstone and ironstone mainly 3 to 24 inches across cover 0 to 20 percent of the soil surface. The argillic horizon is clay, sandy clay, or clay loam with clay content of 35 to about 55 percent. Fragments of sandstone and ironstone mainly less than 10 inches across comprise 0 to 5 percent by volume.

GEOGRAPHIC SETTING: Truce soils usually have convex surfaces. Typically, they are on gently sloping stream divides with slopes of 1 to 5 percent. However, slopes range to 40 percent when the soil is sloping to steep along hillsides. These soils formed in materials weathered from shales interbedded with thin discontinuous layers of sandstone of Pennsylvanian age. Mean annual precipitation ranges from 24 to 32 inches; and mean annual temperatures range from 63 to 66 degrees F. Frost free days range from 210 to 240 days and elevation ranges from 1,000 to 1,800 feet. Thornthwaite annual P-E indices range from 36 to 50.

GEOGRAPHICALLY ASSOCIATED SOILS: These are the competing Bonti series and the Exray, Owens, Shatruce, and Thurber series. Bonti soils are above mainly on ridgetops with plane slopes. Exray soils have sola less than 20 inches to sandstone bedrock, and are above mainly on ridgetops. Owens soils are more alkaline, lack argillic horizons, and are in positions similar to Truce soils. Shatruce soils are 20 to 40 inches thick over shaly clay and are above on bouldery escarpments. Thurber soils have clay loam surface layers, secondary carbonates within 28 inches of the surface, and are below on nearly level or gently sloping positions.

DRAINAGE AND PERMEABILITY: Well drained. Runoff is rapid; Permeability is slow.

USE AND VEGETATION: Mostly used as rangeland. A few small areas are cropped to small grains and sorghums. Climax vegetation is an open post oak savannah with tall and mid grasses such as indiangrass, big and little bluestem, and sideoats grama. Most areas contain other woody plants such as blackjack oak and elm with invading mesquite, cedar, and lotebush. Present herbaceous vegetation consists mainly of sideoats grama, Texas needlegrass, hairy grama, threeawns, sand dropseed, and other low producing perennials and annuals with western ragweed, Engelmann-daisy, bundleflower, prairie clover, primrose, and gayfeather.

DISTRIBUTION AND EXTENT: North Central Prairie and West Cross Timbers of Texas. The series is extensive.

EXRAY SERIES (1.99%)

The Exray series consists of shallow, well drained, moderately slowly permeable soils that formed in residuum of weathered sandstone interbedded with clay. These upland soils have slopes ranging from 1 to 20 percent.

TAXONOMIC CLASS: Clayey, mixed, thermic Lithic Rhodustalfs

TYPE LOCATION: Erath County, Texas; from the county courthouse in Stephenville, Texas; 17 miles north-northwest on Texas Highway 108, east 0.1 mile on county road and 50 feet south of road in wooded pasture.

RANGE IN CHARACTERISTICS: The solum thickness and depth to bedrock ranges from 10 to 20 inches. The average clay content from the soil surface to bedrock is more than 35 percent when the solum is less than 14 inches thick. Fragments of sandstone and ironstone cover 0 to 50 percent of the surface. The fragments range from less than 3 inches across to about 48 inches across. Fragments in the solum range from 0 to 25 percent by volume and are mainly less than 10 inches across. There are a few chert pebbles in some pedons.

GEOGRAPHIC SETTING: Exray soils are gently sloping to moderately steep with plane to slightly convex surfaces. They are on hills or ridges over hard sandstone mainly of

Pennsylvanian age. Slopes are 1 to 5 percent on ridgetops, but range to 20 percent on slopes below ridgetops. Average annual precipitation is 26 to 32 inches, and Thornthwaite annual P-E indices are 36 to 50. Mean annual temperature is 64 to 67 degrees F. Frost free period is 230 to 240 days and elevation ranges from 1000 to 1800 feet.

GEOGRAPHICALLY ASSOCIATED SOILS: These are the competing Bonti series and Owens, Shatruce, Shavash, Truce, and Vashti series. Bonti soils are on similar landscapes. Owens soils are more alkaline, lack argillic horizons and are typically on south-facing slopes or strongly convex knolls. Shatruce soils are 20 to 40 inches thick over shaley clay and are on bouldery hillsides. Shavash soils have sandy surface layers, a loamy control section, and are on narrow ridgetops slightly higher than Exray soils. Truce soils have sola thicker than 20 inches, and are on lower slopes. Vashti soils have sola thicker than 20 inches, a loamy control section, and are on stream divides.

DRAINAGE AND PERMEABILITY: Well drained; rapid runoff; moderately slow permeability and internal drainage.

USE AND VEGETATION: Used almost exclusively as rangeland. Native vegetation is mainly bluestem, indiangrass, sideoats grama, sand lovegrass, ragweed, blackjack, and post oak.

DISTRIBUTION AND EXTENT: Mainly in the savannah areas of north-central Texas. The series is of moderate extent.

AXTELL SERIES (1.78%)

The Axtell series consists of very deep, moderately well drained, very slowly permeable soils on Pleistocene terraces. The soil formed in slightly acid to alkaline clayey sediments. Slopes are dominantly 0 to 5 percent, but range up to 12 percent.

TAXONOMIC CLASS: Fine, montmorillonitic, thermic Udertic Paleustalfs

TYPE LOCATION: Navarro County, Texas; from the intersection of State Highway 22 and Farm Road 55 in Blooming Grove; 1.1 miles south on Farm Road 55; 3.8 miles west-southwest on county road to flood prevention structure; 250 feet west of the west channel below flood prevention structure; 100 feet north in post oak timber. Latitude 32 degrees, 02 minutes 33 seconds N, Longitude 96 degrees, 43 minutes 57 seconds W.

RANGE IN CHARACTERISTICS: Solum thickness is more than 80 inches. The boundary between the A and Bt horizons is abrupt over the subsoil crests and clear over the subsoil troughs, and the texture change is abrupt. The solum contains 0 to 5 percent siliceous pebbles, with some pedons containing up to 35 percent pebbles on and in the surface layer. Depth to secondary carbonates ranges from 30 to 60 inches in most pedons. The control section is clayey with average clay content ranging from 38 to 50 percent. COLE ranges from 0.07 to 0.10 in the upper 20 inches of the Bt horizon and the potential linear extensibility is greater than 2.5 inches in the upper 50 inches of the soil. COLE ranges from 0.07 to 0.10 in the upper 20 inches of the Bt horizon and the potential linear extensibility is greater than 2.5 inches in the upper 50 inches of the soils.

GEOGRAPHIC SETTING: Axtell soils are on broad, nearly level to strongly sloping stream terraces and terrace remnants about 50 to 300 feet above the present streams. Also included are terrace remnants on stream divides in erosional uplands. These sediments are mainly of Pleistocene Age. Slopes are mainly between 0 and 5 percent, but range to 12 percent. The soil formed in clayey alluvium. The mean annual temperature ranges from about 64 to 68 degrees F., and mean annual precipitation ranges from 32 to 42 inches. Frost free days range from 240 to 270 days and elevation ranges from 200 to 600 feet. Thornthwaite P-E indices ranges from 54 to 66.

GEOGRAPHICALLY ASSOCIATED SOILS: These are the competing Crockett and Tabor series and the Lufkin, Rader, and Wilson series. Crockett soils are on slightly higher upland positions. Lufkin and Wilson soils are in similar or slightly lower positions and are dominated by colors with chroma 2 or less. Tabor soils are on positions similar Axtell. Rader soils are on similar or slightly lower positions, and have fine-loamy control sections.

DRAINAGE AND PERMEABILITY: Moderately well drained; runoff is low on slopes less than 1 percent, medium on slopes of 1 to 3 percent, high on slopes of 3 to 5 percent, and very high on slopes of 5 to 12 percent; very slow permeability.

USE AND VEGETATION: Mostly cultivated in the past, but now in pasture. Some areas are farmed to corn, grain sorghum, or small grains. Native vegetation is post oak, blackjack oak, hickory, red cedar, greenbriar; grasses include mid and tall grasses such as little bluestem, big bluestem, indiangrass, panicum and paspalum.

DISTRIBUTION AND EXTENT: Mainly in east-central Texas, but small areas are in Oklahoma. This soil is moderately extensive.

BONTI SERIES (1.76%)

The Bonti series consists of moderately deep, well drained, moderately slowly permeable soils formed in residuum of interbedded sandstone and clayey materials. These upland soils have slopes ranging from 1 to 40 percent.

TAXONOMIC CLASS: Fine, mixed, thermic Ultic Paleustalfs

TYPE LOCATION: Erath County, Texas; 14.5 miles northwest of Stephenville on Texas Highway 108, 4.5 miles northeast on Farm Road 1715, 4.4 miles north on county road (1.4 mile north of Russel Chapel Cemetery), 100 feet west in wooded pasture.

RANGE IN CHARACTERISTICS: Solum thickness and depth to bedrock range from 20 to 40 inches. Fragments of sandstone and ironstone cover from 0 to 50 percent of the surface. The fragments range from less than 3 to 48 inches across. Fragments in the solum range from 0 to 25 percent by volume and are mainly less than 10 inches across.

GEOGRAPHIC SETTING: Bonti soils are gently sloping to steep with plane or slightly convex surfaces. They are on hills or ridges over sandstone bedrock mainly of Pennsylvania age. Slopes are usually 1 to 5 percent on ridgetops but range to 40 percent along hillsides. Mean annual temperature is 64 to 67 degrees F., mean annual precipitation is 26 to 32 inches. Frost free period is 215 to 230 days, and elevation ranges form 1200 to 1700 feet. Thornthwaite annual P-E index ranges from 38 to 50.

GEOGRAPHICALLY ASSOCIATED SOILS: These include the competing Shatruce and Truce series and the Exray, Owens, and Vashti series. Shatruce soils are on bouldery escarpments. Truce soils are on lower, convex slopes. Exray soils are less than 20 inches deep to sandstone bedrock and are intermingled with Bonti soils. Owens soils are clayey throughout, are less than 20 inches deep over shale, and mainly are on convex knolls and south-facing escarpments. Vashti soils have fine-loamy control sections and are above stream divides.

DRAINAGE AND PERMEABILITY: Well drained, rapid runoff; moderately slow permeability and internal drainage.

USE AND VEGETATION: Used mainly as rangeland. Native vegetation is mainly little and big bluestem, indiangrass, sideoats grama, Arizona cottontop, sand lovegrass, switchgrass, ragweed, blackjack, and post oak.

DISTRIBUTION AND EXTENT: North-central Texas. The series is of moderate extent.

TABLE 6 OCCURRENCE OF SOIL SERIES IN STUDY AREA

Tarrant County WCID#1 Study Area Soils

Description	Acres	Percent Cover
HOUSTON BLACK	262086	7.22
CROCKETT	230034	6.34
WILSON	134592	3.71
TRINITY	123184	3.39
WINDTHORST	109503	3.02
WATER	92374	2.55
HEIDEN	90912	2.51
ALEDO	85882	2.37
GOWEN	85427	2.35
TRUCE	79339	2.19
EXRAY COMPLEX	72153	1.99
AXTELL	64591	1.78
BONTI	63950	1.76
EDDY	63090	1.74
BURLESON	60510	1.67
DUFFAU COMPLEX	58633	1.62
AUSTIN	56389	1.55
PULEXAS	52761	1.45
SHATRUCE	52652	1.45
WEATHERFORD COMPLEX	52435	1.44
FERRIS COMPLEX	51150	1.41
WOODTELL	47899	1.32
CROSSTELL	47384	1.31
LUFKIN COMPLEX	46949	1.29
ALEDO COMPLEX	45614	1.26
KEETER	45259	1.25
SANGER	43559	1.20
VENUS	40822	1.12
BASTSIL	40683	1.12
CHANEY	38893	1.07
BLUEGROVE	37954	1.05
KAUFMAN	36295	1.00
FERRIS	35187	0.97
HOUSTON COMPLEX	35167	0.97
FRIO	33487	0.92
DUFFAU	33378	0.92
BRACKETT	32402	0.89
MABANK	32360	0.89
STEPHEN	31492	0.87
CONA	31244	0.86
FREESTONE	30601	0.84
SELDEN	29938	0.83

Description	Acres	Percent Cover
JOLLY COMPLEX	5169	0.14
BERNALDO	4744	0.13
NAVO COMPLEX	4527	0.12
WINDTHORST AND DUFFAU SOILS	4468	0.12
PAYNE	4122	0.11
WHITESBORO	4103	0.11
LINDALE	4022	0.11
CUTHBERT	3963	0.11
LESON	3944	0.11
PITS	3825	0.11
ANOCON-STONEBURG ASSOCIATION	3766	0.10
BIROME COMPLEX	3627	0.10
CISCO	3627	0.10
DELEON	3489	0.10
KNOCO COMPLEX	3449	0.10
MAY	3192	0.09
BOSQUE	3173	0.09
WESWIND	3153	0.09
CHATT	3074	0.08
SUMTER	3034	0.08
BLANKET	2994	0.08
TABOR	2787	0.08
HUNT	2758	0.08
LOTT	2669	0.07
HOUSTON AND ELLIS	2649	0.07
CHICKASHA	2639	0.07
LUCKENBACH	2550	0.07
TONKAWA	2481	0.07
BONHAM	2471	0.07
LINDY	2332	0.06
PATILO-HEATON	2323	0.06
ARENTS	2204	0.06
MEDLIN	2125	0.06
CALLAHAN	2066	0.06
LUFKIN	2046	0.06
TILLMAN	1977	0.05
BUNYAN	1908	0.05
MANGUM COMPLEX	1898	0.05
WAURIKA COMPLEX	1888	0.05
LEAGUEVILLE COMPLEX	1779	0.05
GRANDFIELD	1749	0.05
WINTERS	1689	0.05

Tarrant County WCID#1 Study Area Soils

Description	Acres	Percent Cover
TINN	25985	0.72
WOLFPEN	24967	0.69
PURVES	21893	0.60
SET	21537	0.59
OWENS	19581	0.54
DARNELL COMPLEX	19442	0.54
LAMAR	19125	0.53
WINDTHORST COMPLEX	18918	0.52
NAHATCHE	18493	0.51
THURBER	17168	0.47
HENSLEY	16862	0.46
BOLAR	16686	0.46
LEWISVILLE	16428	0.45
PONDER	15992	0.44
BONTI COMPLEX	15983	0.44
ANOCON	15568	0.43
GASIL	15420	0.42
PICKTON	15340	0.42
NIMROD	14984	0.41
STEPHENVILLE	14530	0.40
RENFROW COMPLEX	14401	0.40
WESTFORK	13728	0.38
BALSORA	13560	0.37
HASSEE	13541	0.37
PALOPINTO	13501	0.37
KAMAY	12522	0.35
SUNEV	12355	0.34
NORMANGEE	12256	0.34
KRUM	12237	0.34
SLIDELL	11910	0.33
ROWDEN	11841	0.33
SILAWA	11524	0.32
WISE	11099	0.31
MALOTERRE COMPLEX	10962	0.30
DERLY COMPLEX	10931	0.30
DENTON	10368	0.29
KEMP	10289	0.28
BRANYON	9765	0.27
RADER	9420	0.26
VERNON	8885	0.24
YAHOLA AND BUNYAN	8787	0.24
BROKEN ALLUVIAL LAND	8421	0.23
FERRIS AND HEIDEN	8174	0.23
BLUEGROVE ASSOCIATION	7986	0.22
SANDOW	7571	0.21

Description	Acres	Percent Cover
BOLAR COMPLEX	1611	0.04
STONEBURG ASSOCIATION	1571	0.04
MARKLEY COMPLEX	1492	0.04
TREADWAY	1255	0.03
GRAVEL PITS	1235	0.03
BASTROP	1205	0.03
MINGO	1177	0.03
HAPLUSTALFS	1147	0.03
OKEMAH	1137	0.03
WILSON COMPLEX	1029	0.03
JACKSBORO	988	0.03
SAN SABA	959	0.03
DUTEK	920	0.03
CULP	899	0.02
GULLIED LAND	810	0.02
KONAWA	742	0.02
KIRVIN	702	0.02
STIDHAM	702	0.02
ROTAN	682	0.02
BAZETTE	623	0.02
VASHTI	563	0.02
AQUILLA	544	0.01
OVAN	525	0.01
NEBGEN COMPLEX	523	0.01
WICHITA	464	0.01
SPECK	445	0.01
COVING COMPLEX	435	0.01
SLICKSPOTS	405	0.01
SEAWILLOW	395	0.01
GALLIME	346	0.01
KONSIL	336	0.01
ASPERMONT	306	0.01
MINWELLS	297	0.01
THROCK	297	0.01
GREDGE COMPLEX	287	0.01
SAGERTON	287	0.01
DEPORT	267	0.01
BIROME	257	0.01
EUFAULA	237	0.01
ENGLE	198	0.01
GROESBECK	188	0.01
TABOR COMPLEX	188	0.01
HOLLISTER	178	0.00
LARUE	178	0.00
BLUM	119	0.00

Tarrant County WCID#1 Study Area Soils

Description	Acres	Percent Cover
ELLIS AND HOUSTON	7492	0.21
PURSLEY	7453	0.21
PORT-WHEATWOOD COMPLEX	7364	0.20
ELLIS CLAY	7353	0.20
URBAN LAND	6909	0.19
EDGE	6752	0.19
SILSTID	6692	0.18
COBB COMPLEX	6632	0.18
STYX	6593	0.18
AUFCO	6514	0.18
DEANDALE	6484	0.18
VERNON	5832	0.16
ALTOGA	5664	0.16
SOMERVELL COMPLEX	5426	0.15
SUBTOTAL	3472310	95.69

Description	Acres	Percent Cover
ELROSE	119	0.00
TRAVIS	119	0.00
DALCO	89	0.00
JUSTIN	79	0.00
OIL-WASTE LAND	79	0.00
WHEATWOOD	79	0.00
WEYMOUTH	69	0.00
CALLISBURG	59	0.00
LAVENDER COMPLEX	59	0.00
YOMONT	50	0.00
DOUGHERTY COMPLEX	30	0.00
CROCKETT COMPLEX	20	0.00
CLAY PITS	10	0.00
EUFAULA COMPLEX	10	0.00
TOTAL	3628785	100

APPENDIX C - TABLES OF DATA FOR STUDY AREA

TABLE 7 TCWCID INVENTORY SIZED RESERVOIR LISTING

COUNTY	LAT.	LONG.	ID	FED ID	NAME
ARCHER	33.4500	98.5867		TX00999	BRIDWELL LAKE DAM
ARCHER	33.4200	98.6683		TX00998	CALVIN LAKE DAM
CLAY	33.5500	97.9933	SCS	TX02873	BIG SANDY CREEK WS SCS SITE 5A
CLAY	33.5283	98.0033	SCS	TX02865	BIG SANDY CREEK WS SCS SITE 4
CLAY	33.5000	98.0100	SCS		BIG SANDY CREEK WS SCS SITE 1B
CLAY	33.5000	98.0197	SCS		BIG SANDY CREEK WS SCS SITE 1A
CLAY	33.5350	98.0467	SCS	TX02864	BIG SANDY CREEK WS SCS SITE 2
CLAY	33.5100	98.2200		TX02866	BURNS LAKE DAM
CLAY	33.4817	98.3767		TX04679	ANTELOPE FIELD LAKE DAM
ELLIS	32.2567	96.5333	SCS	TX01284	CHAMBERS CREEK WS SCS SITE 126
ELLIS	32.2683	96.5583	SCS	TX01283	CHAMBERS CREEK WS SCS SITE 125
ELLIS	32.2367	96.5850	SCS	TX01233	CHAMBERS CREEK WS SCS SITE 121A
ELLIS	32.2483	96.6317	SCS	TX01228	CHAMBERS CREEK WS SCS SITE 29
ELLIS	32.2667	96.6333		TX00001	BARDWELL DAM
ELLIS	32.3233	96.6583		TX01286	LAKE CLARK DAM
ELLIS	32.3417	96.6850	SCS	TX01288	CHAMBERS CREEK WS SCS SITE 20
ELLIS	32.2517	96.6950	SCS	TX01289	CHAMBERS CREEK WS SCS SITE 118
ELLIS	32.2450	96.6983	SCS	TX01232	CHAMBERS CREEK WS SCS SITE 117
ELLIS	32.2150	96.7133	SCS	TX01231	CHAMBERS CREEK WS SCS SITE 116
ELLIS	32.2367	96.7150	SCS	TX01230	CHAMBERS CREEK WS SCS SITE 115
ELLIS	32.3533	96.7183	SCS	TX01287	CHAMBERS CREEK WS SCS SITE 19
ELLIS	32.1867	96.7267	SCS	TX01229	CHAMBERS CREEK WS SCS SITE 95
ELLIS	32.2333	96.7500	SCS	TX01252	CHAMBERS CREEK WS SCS SITE 89
ELLIS	32.1783	96.7550	SCS	TX01249	CHAMBERS CREEK WS SCS SITE 94
ELLIS	32.2233	96.7600	SCS	TX01248	CHAMBERS CREEK WS SCS SITE 110
ELLIS	32.2283	96.7700	SCS	TX01247	CHAMBERS CREEK WS SCS SITE 109
ELLIS	32.3200	96.7733	SCS	TX04523	CHAMBERS CREEK WS SCS SITE 24
ELLIS	32.1833	96.7750	SCS	TX06184	YOUNGBLOOD GSS
ELLIS	32.2317	96.7800	SCS	TX01246	CHAMBERS CREEK WS SCS SITE 108
ELLIS	32.1350	96.7833	SCS	TX01320	CHAMBERS CREEK WS SCS SITE 102
ELLIS	32.2667	96.7850	SCS	TX01253	CHAMBERS CREEK WS SCS SITE 113
ELLIS	32.3333	96.7867	SCS	TX01254	CHAMBERS CREEK WS SCS SITE 23
ELLIS	32.1800	96.7867	SCS	TX01250	CHAMBERS CREEK WS SCS SITE 93
ELLIS	32.2433	96.7983	SCS	TX01245	CHAMBERS CREEK WS SCS SITE 107
ELLIS	32.2333	96.8000	SCS	TX05787	CHAMBERS CREEK WS SCS SITE 108A
ELLIS	32.2800	96.8033	SCS	TX01256	CHAMBERS CREEK WS SCS SITE 111 & 112
ELLIS	32.3417	96.8050		TX01255	SOUTH PRONG DAM

COUNTY	LAT.	LONG.	ID	FED ID	NAME
ELLIS	32.1983	96.8150	SCS	TX01251	CHAMBERS CREEK WS SCS SITE 92
ELLIS	32.2400	96.8183	SCS	TX04526	CHAMBERS CREEK WS SCS SITE 106
ELLIS	32.1083	96.8283	SCS	TX01234	CHAMBERS CREEK WS SCS SITE 101C
ELLIS	32.1267	96.8433	SCS	TX01244	CHAMBERS CREEK WS SCS SITE 100
ELLIS	32.1750	96.8583	SCS	TX06179	MRS. LUCRETIA WARD COUCH
ELLIS	32.4033	96.8600		TX01282	WAXAHACHIE COUNTRY CLUB LAKE DAM
ELLIS	32.1250	96.8667	SCS	TX06181	JOHN S. MACKINNON
ELLIS	32.4133	96.8667	SCS	TX01280	CHAMBERS CREEK WS SCS SITE 14
ELLIS	32.4083	96.8667		TX01279	KATY LAKE DAM
ELLIS	32.0917	96.8700	SCS	TX01235	CHAMBERS CREEK WS SCS SITE 99
ELLIS	32.3917	96.8783	SCS	TX01275	CHAMBERS CREEK WS SCS SITE 15
ELLIS	32.4183	96.8850	SCS	TX01274	CHAMBERS CREEK WS SCS SITE 13
ELLIS	32.4350	96.8967	SCS	TX01272	CHAMBERS CREEK WS SCS SITE 11
ELLIS	32.4517	96.8967	SCS	TX01271	CHAMBERS CREEK WS SCS SITE 10
ELLIS	32.4167	96.9017	SCS	TX01273	CHAMBERS CREEK WS SCS SITE 12
ELLIS	32.4267	96.9100	SCS	TX01270	CHAMBERS CREEK WS SCS SITE 9
ELLIS	32.2383	96.9167	SCS	TX01238	CHAMBERS CREEK WS SCS SITE 86
ELLIS	32.2617	96.9200	SCS	TX01257	CHAMBERS CREEK WS SCS SITE 84
ELLIS	32.4583	96.9233		TX04268	DIAMOND J RANCH DAM NO 2
ELLIS	32.2317	96.9267		TX01240	BELL BRANCH RANCH DAM
ELLIS	32.4900	96.9300	SCS	TX01263	CHAMBERS CREEK WS SCS SITE 2A
ELLIS	32.4417	96.9300	SCS	TX01318	CHAMBERS CREEK WS SCS SITE 8
ELLIS	32.2483	96.9317	SCS	TX01319	CHAMBERS CREEK WS SCS SITE 83
ELLIS	32.0717	96.9317	SCS	TX01236	RICHLAND CREEK WS SCS SITE 44
ELLIS	32.4650	96.9317	SCS	TX01264	CHAMBERS CREEK WS SCS SITE 2F
ELLIS	32.3850	96.9333	SCS	TX01277	CHAMBERS CREEK WS SCS SITE 17
ELLIS	32.2633	96.9350	SCS	TX01258	CHAMBERS CREEK WS SCS SITE 82
ELLIS	32.5000	96.9367	SCS	TX01316	CHAMBERS CREEK WS SCS SITE 2B
ELLIS	32.2167	96.9383	SCS	TX01237	CHAMBERS CREEK WS SCS SITE 85B
ELLIS	32.5050	96.9450	SCS	TX01317	CHAMBERS CREEK WS SCS SITE 1
ELLIS	32.1400	96.9483	SCS	TX01241	CHAMBERS CREEK WS SCS SITE 98A
ELLIS	32.3000	96.9483	SCS	TX01260	CHAMBERS CREEK WS SCS SITE 80
ELLIS	32.4483	96.9500	SCS	TX01269	CHAMBERS CREEK WS SCS SITE 7
ELLIS	32.2533	96.9533	SCS	TX01259	CHAMBERS CREEK WS SCS SITE 81
ELLIS	32.4550	96.9567	SCS	TX01268	CHAMBERS CREEK WS SCS SITE 6
ELLIS	32.1483	96.9650	SCS	TX01242	CHAMBERS CREEK WS SCS SITE 98
ELLIS	32.4900	96.9667	SCS	TX01266	CHAMBERS CREEK WS SCS SITE 4
ELLIS	32.4100	96.9700	SCS	TX01276	CHAMBERS CREEK WS SCS SITE 16
ELLIS	32.3267	96.9750	SCS	TX01261	CHAMBERS CREEK WS SCS SITE 56
ELLIS	32.2600	96.9750	SCS	TX04525	CHAMBERS CREEK WS SCS SITE 79D
ELLIS	32.4917	96.9800	SCS	TX01265	CHAMBERS CREEK WS SCS SITE 3

COUNTY	LAT.	LONG.	ID	FED ID	NAME
ELLIS	32.4083	96.9800		TX01278	HI VIEW RANCH LAKE DAM
ELLIS	32.4550	96.9800	SCS	TX01267	CHAMBERS CREEK WS SCS SITE 5
ELLIS	32.2517	96.9867	SCS	TX01262	CHAMBERS CREEK WS SCS SITE 79B
ELLIS	32.2483	96.9967	SCS	TX01239	CHAMBERS CREEK WS SCS SITE 79A
ELLIS	32.1817	96.9983	SCS	TX01243	CHAMBERS CREEK WS SCS SITE 97
ELLIS	32.2517	97.0017	SCS	TX01307	CHAMBERS CREEK WS SCS SITE 77
ELLIS	32.3383	97.0050	SCS	TX01306	CHAMBERS CREEK WS SCS SITE 55
ELLIS	32.3167	97.0050		TX01308	WILEMON LAKE DAM
ELLIS	32.3900	97.0050		TX01311	CAMP HOBILITZELLE LAKE DAM
ELLIS	32.2383	97.0133	SCS	TX01227	CHAMBERS CREEK WS SCS SITE 78
ELLIS	32.3533	97.0200	SCS	TX01304	CHAMBERS CREEK WS SCS SITE 53
ELLIS	32.3333	97.0333		TX06182	ODOS MATTHEWS JR.
ELLIS	32.3217	97.0400	SCS	TX01305	CHAMBERS CREEK WS SCS SITE 54
ELLIS	32.2400	97.0500	SCS		CHAMBERS CREEK WS SCS SITE 75C
ELLIS	32.2650	97.0517	SCS	TX01303	CHAMBERS CREEK WS SCS SITE 75B
ELLIS	32.3783	97.0800	SCS	TX04524	CHAMBERS CREEK WS SCS SITE 49A
ELLIS	32.3950	97.0800	SCS	TX06183	M. G. WILSON DAM
ELLIS	32.5667	97.0833	SCS	TX01285	CHAMBERS CREEK WS SCS SITE 20A
FREESTONE	31.9667	96.1417		TX06316	RICHLAND CREEK DAM
HENDERSON	32.2517	95.8483		TX00226	LEE LAKE DAM
HENDERSON	32.2550	95.8600		TX00224	COX LAKE DAM
HENDERSON	32.2383	95.8800		TX06396	VALLEY VIEW LAKE DAM
HENDERSON	32.3117	95.9017		TX00223	THOMAS LAKE DAM
HENDERSON	32.2283	95.9650		TX04395	FOREST GROVE DAM
HENDERSON	32.3583	96.0000	SCS	TX05948	CEDAR CREEK WS SCS SITE 143A
HENDERSON	32.3467	96.0500		TX05217	ABERNATHY LAKE DAM
HENDERSON	32.1800	96.0683		TX00237	JOE B. HOGSETT DAM
HENDERSON	32.3217	96.0833		TX00239	JOHN SANTERRE LAKE DAM
HENDERSON	32.3433	96.0850		TX00240	MABANK CITY LAKE DAM
HENDERSON	32.3500	96.2233		TX09090	WILLIAMS DAM
HILL	31.8283	96.7317	SCS	TX00434	RICHLAND CREEK WS SCS SITE 6
HILL	31.8200	96.7317	SCS	TX00433	RICHLAND CREEK WS SCS SITE 6A
HILL	31.7967	96.7783	SCS	TX00426	RICHLAND CREEK WS SCS SITE 3
HILL	31.8100	96.7883	SCS	TX00425	RICHLAND CREEK WS SCS SITE 2
HILL	31.8217	96.7917	SCS	TX00427	RICHLAND CREEK WS SCS SITE 1
HILL	31.8250	96.8250		TX00424	HUBBARD LAKE NO 1 DAM
HILL	31.8333	96.8300		TX04850	HUBBARD LAKE NO 5 DAM
HILL	31.8267	96.8300		TX04399	HUBBARD LAKE NO 3 DAM
HILL	31.8300	96.8317		TX00423	HUBBARD LAKE NO 4 DAM
HILL	31.8600	96.8450	SCS	TX04235	RICHLAND CREEK WS SCS SITE 94
HILL	31.9417	96.8517	SCS	TX061[illegible]6	MUESSE GSS

COUNTY	LAT.	LONG.	ID	FED ID	NAME
HILL	31.8967	96.8567	SCS	TX04232	RICHLAND CREEK WS SCS SITE 89
HILL	32.0033	96.8567	SCS	TX00437	RICHLAND CREEK WS SCS SITE 49
HILL	31.8850	96.8567	SCS	TX04233	RICHLAND CREEK WS SCS SITE 90
HILL	31.8383	96.8600	SCS	TX04234	RICHLAND CREEK WS SCS SITE 93
HILL	31.8733	96.8650	SCS	TX04754	RICHLAND CREEK WS SCS SITE 91A
HILL	31.8167	96.8800	SCS	TX04473	RICHLAND CREEK WS SCS SITE 92A
HILL	31.9033	96.8800	SCS	TX04231	RICHLAND CREEK WS SCS SITE 88
HILL	31.9267	96.8833	SCS		MCNIEL DAM
HILL	31.9917	96.8833	SCS	TX00431	RICHLAND CREEK WS SCS SITE 58
HILL	31.8233	96.8850	SCS	TX04631	RICHLAND CREEK WS SCS SITE 92C
HILL	32.0367	96.8883	SCS	TX00443	RICHLAND CREEK WS SCS SITE 48
HILL	31.9833	96.8900	SCS	TX00432	RICHLAND CREEK WS SCS SITE 66
HILL	31.9000	96.8917	SCS	TX05775	RICHLAND CREEK WS SCS SITE 87A
HILL	32.0433	96.9000	SCS	TX00442	RICHLAND CREEK WS SCS SITE 46
HILL	32.0200	96.9100	SCS	TX00438	RICHLAND CREEK WS SCS SITE 57
HILL	31.9000	96.9117	SCS	TX04230	RICHLAND CREEK WS SCS SITE 86
HILL	32.0567	96.9133	SCS	TX00440	RICHLAND CREEK WS SCS SITE 45
HILL	31.9617	96.9200	SCS	TX04630	RICHLAND CREEK WS SCS SITE 71A
HILL	31.9717	96.9317	SCS	TX04713	RICHLAND CREEK WS SCS SITE 68
HILL	31.9500	96.9333	SCS	TX05774	RICHLAND CREEK WS SCS SITE 70
HILL	31.9017	96.9367	SCS	TX04229	RICHLAND CREEK WS SCS SITE 83
HILL	31.9850	96.9383	SCS	TX04712	RICHLAND CREEK WS SCS SITE 65
HILL	31.9000	96.9467	SCS	TX04228	RICHLAND CREEK WS SCS SITE 82
HILL	31.8783	96.9483	SCS	TX06195	STAPLETON & HANZLICEK DAM
HILL	31.9300	96.9617		TX05410	KEMPSHAFER LAKE DAM
HILL	31.8950	96.9633	SCS	TX04227	RICHLAND CREEK WS SCS SITE 81
HILL	31.8983	96.9783	SCS	TX04226	RICHLAND CREEK WS SCS SITE 80
HILL	32.0000	96.9883	SCS	TX00441	RICHLAND CREEK WS SCS SITE 63
HILL	32.1233	96.9950	SCS	TX00439	RICHLAND CREEK WS SCS SITE 42
HILL	32.0600	97.0000		TX05409	ISENBERG LAKE DAM
HILL	32.1317	97.0017	SCS	TX00461	RICHLAND CREEK WS SCS SITE 41
HILL	31.9067	97.0033	SCS	TX04225	RICHLAND CREEK WS SCS SITE 78
HILL	32.0800	97.0033	SCS	TX00454	RICHLAND CREEK WS SCS SITE 56
HILL	32.0283	97.0067	SCS	TX00451	RICHLAND CREEK WS SCS SITE 62
HILL	32.0867	97.0083	SCS	TX00452	RICHLAND CREEK WS SCS SITE 55
HILL	32.0933	97.0150	SCS	TX00448	RICHLAND CREEK WS SCS SITE 53
HILL	32.0383	97.0183	SCS	TX00444	RICHLAND CREEK WS SCS SITE 61
HILL	32.1533	97.0233	SCS	TX00463	RICHLAND CREEK WS SCS SITE 39
HILL	32.0867	97.0250	SCS	TX00447	RICHLAND CREEK WS SCS SITE 54
HILL	32.1367	97.0300	SCS	TX00462	RICHLAND CREEK WS SCS SITE 40
HILL	32.0533	97.0333	SCS	TX00445	RICHLAND CREEK WS SCS SITE 60

COUNTY	LAT.	LONG.	ID	FED ID	NAME
HILL	32.0967	97.0333	SCS	TX00449	RICHLAND CREEK WS SCS SITE 52
HILL	32.1083	97.0367	SCS	TX00453	RICHLAND CREEK WS SCS SITE 50
HILL	32.1017	97.0383	SCS	TX00450	RICHLAND CREEK WS SCS SITE 51
HILL	32.0517	97.0400	SCS	TX00446	RICHLAND CREEK WS SCS SITE 59
HILL	31.9883	97.0417	SCS	TX04714	RICHLAND CREEK WS SCS SITE 72
HILL	32.1550	97.0450	SCS	TX00466	RICHLAND CREEK WS SCS SITE 38
HILL	32.1517	97.0650	SCS	TX00464	RICHLAND CREEK WS SCS SITE 37
HILL	32.1767	97.1000	SCS	TX00465	CHAMBERS CREEK WS SCS SITE 72A
HILL	32.2333	97.1100	SCS	TX00460	CHAMBERS CREEK WS SCS SITE 74
HILL	32.2350	97.1267		TX06191	HOPPER GSS
HILL	32.1917	97.1267	SCS	TX00457	CHAMBERS CREEK WS SCS SITE 72
HILL	32.2372	97.1319	SCS		SANDLIN DAM
HILL	32.2439	97.1375	SCS	TX06193	E.W. WRIGHT JR. DAM
HILL	32.1950	97.1850	SCS	TX00456	CHAMBERS CREEK WS SCS SITE 67A
HILL	32.2167	97.1850	SCS	TX04224	CHAMBERS CREEK WS SCS SITE 68
HILL	32.1983	97.1867	SCS	TX00459	CHAMBERS CREEK WS SCS SITE 67B
HILL	32.2300	97.2017	SCS	TX00458	CHAMBERS CREEK WS SCS SITE 65A
JACK	33.2917	97.9583		TX03192	GRACE LAKE DAM NO. 1
JACK	33.3450	97.9683		TX05532	CHERRYHOMES LAKE DAM
JACK	33.2967	97.9800		TX05534	GRACE LAKE DAM NO. 2
JACK	33.1883	97.9933	SCS	TX06243	JUD CRAMER DAM
JACK	33.1883	97.9967	SCS	TX06244	JUD CRAMER WEST DAM
JACK	33.4083	98.0000	SCS	TX06240	JERRY HAYS DAM
JACK	33.3233	98.0033	SCS	TX03203	WEST FORK ABOVE BRIDGEPORT WS SCS 11
JACK	33.3017	98.0100	SCS	TX03204	WEST FORK ABOVE BRIDGEPORT WS SCS 12
JACK	33.3317	98.0100	SCS	TX03202	WEST FORK ABOVE BRIDGEPORT WS SCS 9
JACK	33.4567	98.0150		TX05531	GRAY LAKE DAM
JACK	33.1250	98.0183		TX05544	ANNIN LAKE DAM
JACK	33.3400	98.0300	SCS	TX03201	WEST FORK ABOVE BRIDGEPORT WS SCS 6
JACK	33.3633	98.0300		TX03193	CRAFT LAKE DAM
JACK	33.4067	98.0567	SCS	TX03213	WEST FORK ABOVE BRIDGEPORT WS SCS 3
JACK	33.4283	98.0583	SCS	TX03214	WEST FORK ABOVE BRIDGEPORT WS SCS 3B
JACK	33.1733	98.0783		TX04406	THOMAS CHERRYHOMES LAKE DAM
JACK	33.4117	98.0883	SCS	TX03212	WEST FORK ABOVE BRIDGEPORT WS SCS 2
JACK	33.4233	98.1033	SCS	TX03211	WEST FORK ABOVE BRIDGEPORT WS SCS 1
JACK	33.2433	98.1197		TX06399	LOST CREEK DAM
JACK	33.2733	98.1217		TX05523	WORTHINGTON LAKE NO 1 DAM
JACK	33.2900	98.1367		TX05549	WORTHINGTON LAKE NO. 3 DAM
JACK	33.2350	98.1400		TX03186	LAKE JACKSBORO DAM
JACK	33.1317	98.1417		TX05524	H. RICHARDS LAKE DAM
JACK	33.2633	98.1517		TX05547	WORTHINGTON LAKE NO. 2 DAM

COUNTY	LAT.	LONG.	ID	FED ID	NAME
JACK	33.2733	98.1533		TX03207	WORTHINGTON LAKE DAM
JACK	33.3883	98.1817		TX03209	CAMPSEY DAM
JACK	33.2533	98.1850	SCS	TX03205	NORTH CREEK WS SCS SITE 18
JACK	33.2317	98.2200	SCS	TX03185	NORTH CREEK WS SCS SITE 20
JACK	33.4283	98.2233		TX03210	GARNER LAKE DAM
JACK	33.3333	98.2333	SCS		JW QUICK POND
JACK	33.2583	98.2367	SCS	TX03206	NORTH CREEK WS SCS SITE 21
JACK	33.2200	98.2367	SCS	TX03184	NORTH CREEK WS SCS SITE 19
JACK	33.2967	98.2417		TX05551	PRUNTY LAKE DAM
JACK	33.4167	98.2467		TX05538	BALL LAKE DAM
JACK	33.2783	98.2500	SCS	TX03200	NORTH CREEK WS SCS SITE 17
JACK	33.4533	98.2517		TX05541	ELLENBURG LAKE DAM
JACK	33.2917	98.2583	SCS	TX03208	NORTH CREEK WS SCS SITE 31
JACK	33.3900	98.2633		TX05542	SMITH LAKE DAM
JACK	33.2950	98.2683	SCS	TX03194	NORTH CREEK WS SCS SITE 13
JACK	33.2483	98.2700	SCS	TX04302	NORTH CREEK WS SCS SITE 23
JACK	33.2933	98.2750	SCS	TX03195	NORTH CREEK WS SCS SITE 14
JACK	33.2817	98.2783	SCS	TX03197	NORTH CREEK WS SCS SITE 16
JACK	33.2250	98.2867		TX05528	DEARING LAKE DAM
JACK	33.2867	98.2900	SCS	TX03196	NORTH CREEK WS SCS SITE 15
JACK	33.2233	98.2900	SCS	TX03188	NORTH CREEK WS SCS SITE 22
JACK	33.3000	98.3033		TX05539	MARTIN LAKE DAM
JACK	33.2733	98.3067	SCS	TX03199	NORTH CREEK WS SCS SITE 30
JACK	33.2467	98.3217	SCS	TX03191	NORTH CREEK WS SCS SITE 28A
JACK	33.2533	98.3417	SCS	TX03198	NORTH CREEK WS SCS SITE 26
JACK	33.2367	98.3517	SCS	TX03190	NORTH CREEK WS SCS SITE 25
JACK	33.2417	98.3667	SCS	TX03189	NORTH CREEK WS SCS SITE 24
JOHNSON	32.3517	97.1017	SCS	TX06198	RELVEA DAM
JOHNSON	32.3133	97.1033		TX04336	BUCK RANCH LAKE NO 4 DAM
JOHNSON	32.2500	97.1167	SCS		WOLFE DAM 1
JOHNSON	32.2500	97.1217	SCS		WOLFE DAM 2
JOHNSON	32.3833	97.1333	SCS		CHAMBERS CREEK WS SCS SITE 46A
JOHNSON	32.2917	97.1417	SCS	TX03602	CHAMBERS CREEK WS SCS SITE 64A
JOHNSON	32.3367	97.1500	SCS	TX03603	CHAMBERS CREEK WS SCS SITE 44A
JOHNSON	32.3450	97.1600	SCS	TX03611	CHAMBERS CREEK WS SCS SITE 44
JOHNSON	32.3900	97.1883	SCS	TX03615	CHAMBERS CREEK WS SCS SITE 43A
JOHNSON	32.2883	97.1950	SCS	TX03606	CHAMBERS CREEK WS SCS SITE 60
JOHNSON	32.3233	97.2083	SCS	TX03609	CHAMBERS CREEK WS SCS SITE 58
JOHNSON	32.4217	97.2233	SCS	TX03614	CHAMBERS CREEK WS SCS SITE 32
JOHNSON	32.2800	97.2283	SCS	TX03607	CHAMBERS CREEK WS SCS SITE 62
JOHNSON	32.3100	97.2283	SCS	TX03608	CHAMBERS CREEK WS SCS SITE 59

COUNTY	LAT.	LONG.	ID	FED ID	NAME
JOHNSON	32.2617	97.2300	SCS	TX03604	CHAMBERS CREEK WS SCS SITE 63
JOHNSON	32.3750	97.2383	SCS	TX03612	CHAMBERS CREEK WS SCS SITE 42
JOHNSON	32.3306	97.2383	SCS	TX03610	CHAMBERS CREEK WS SCS SITE 57
JOHNSON	32.2867	97.2383	SCS	TX03605	CHAMBERS CREEK WS SCS SITE 61
JOHNSON	32.4200	97.2483	SCS	TX03613	CHAMBERS CREEK WS SCS SITE 31
JOHNSON	32.3667	97.2500	SCS		CHAMBERS CREEK WS SCS SITE 12
JOHNSON	32.2950	97.2517	SCS	TX03593	CHAMBERS CREEK WS SCS SITE 61A
JOHNSON	32.4250	97.2583	SCS	TX03600	CHAMBERS CREEK WS SCS SITE 30
JOHNSON	32.2917	97.2611	SCS	TX06199	LANMAN DAM
JOHNSON	32.3667	97.2617	SCS	TX06200	MCNAUGHTO GSS NO 1
JOHNSON	32.4050	97.2783	SCS	TX03599	CHAMBERS CREEK WS SCS SITE 35
JOHNSON	32.3667	97.2800	SCS	TX03592	CHAMBERS CREEK WS SCS SITE 38
JOHNSON	32.3933	97.2967	SCS	TX03598	CHAMBERS CREEK WS SCS SITE 34
JOHNSON	32.4117	97.3017	SCS	TX03595	CHAMBERS CREEK WS SCS SITE 33
JOHNSON	32.3817	97.3067	SCS	TX03597	CHAMBERS CREEK WS SCS SITE 36
JOHNSON	32.3750	97.3083	SCS	TX03596	CHAMBERS CREEK WS SCS SITE 37
JOHNSON	32.4167	97.3150	SCS	TX03601	CHAMBERS CREEK WS SCS SITE 33A
JOHNSON	32.4917	97.3583		TX04797	MOUNTAIN VALLEY DAM NO 1
JOHNSON	32.4850	97.3583		TX04798	MOUNTAIN VALLEY DAM NO 2
JOHNSON	32.4817	97.3717		TX09005	MOUNTAIN VALLEY LAKE NO 3 DAM
JOHNSON	32.5125	97.5000	SCS	TX06197	DANIEL DAM
JOHNSON	32.5083	97.5000		TX03617	CLARK DAM
KAUFMAN	32.4683	96.0767	SCS	TX03333	CEDAR CREEK WS SCS SITE 130B
KAUFMAN	32.6467	96.0850	SCS	TX03348	CEDAR CREEK WS SCS SITE 96
KAUFMAN	32.7333	96.0967	SCS	TX03346	CEDAR CREEK WS SCS SITE 92
KAUFMAN	32.4850	96.1017	SCS	TX04521	CEDAR CREEK WS SCS SITE 120
KAUFMAN	32.5250	96.1067	SCS	TX04480	CEDAR CREEK WS SCS SITE 117
KAUFMAN	32.4750	96.1083	SCS	TX04522	CEDAR CREEK WS SCS SITE 121A
KAUFMAN	32.6650	96.1117	SCS	TX03347	CEDAR CREEK WS SCS SITE 95A
KAUFMAN	32.6900	96.1297	SCS		CEDAR CREEK WS SCS SITE 94B
KAUFMAN	32.6900	96.1350	SCS	TX04479	CEDAR CREEK WS SCS SITE 94C
KAUFMAN	32.5533	96.1367		TX03337	CIRCLE K DAM NO 2
KAUFMAN	32.5633	96.1417		TX03336	CIRCLE K DAM NO 1
KAUFMAN	32.4767	96.1650		TX05206	NOLAN LAKE DAM
KAUFMAN	32.7283	96.1733	SCS	TX03341	CEDAR CREEK WS SCS SITE 87A
KAUFMAN	32.5167	96.1833	SCS		CEDAR CREEK WS SCS SITE 122A
KAUFMAN	32.5583	96.1833		TX04264	WEST LAKE DAM
KAUFMAN	32.6700	96.1867		TX03345	TONKERSLEY LAKE DAM
KAUFMAN	32.7350	96.1900	SCS	TX03342	CEDAR CREEK WS SCS SITE 88
KAUFMAN	32.6950	96.1917	SCS	TX03344	CEDAR CREEK WS SCS SITE 90
KAUFMAN	32.7150	96.1933	SCS	TX03343	CEDAR CREEK WS SCS SITE 89

COUNTY	LAT.	LONG.	ID	FED ID	NAME
KAUFMAN	32.4250	96.2000		TX03332	KEMP LAKE DAM
KAUFMAN	32.6450	96.2233	SCS		CEDAR CREEK WS SCS SITE 55B
KAUFMAN	32.4683	96.2250	SCS	TX04520	CEDAR CREEK WS SCS SITE 85
KAUFMAN	32.6383	96.2283	SCS	TX06203	BAXTER DAM
KAUFMAN	32.7283	96.2400	SCS	TX04633	CEDAR CREEK WS SCS SITE 50C
KAUFMAN	32.6317	96.2417	SCS	TX03339	CEDAR CREEK WS SCS SITE 58
KAUFMAN	32.5617	96.2433	SCS	TX03334	CEDAR CREEK WS SCS SITE 76
KAUFMAN	32.6483	96.2450	SCS	TX03338	CEDAR CREEK WS SCS SITE 57
KAUFMAN	32.5333	96.2467	SCS	TX03335	CEDAR CREEK WS SCS SITE 77A
KAUFMAN	32.6317	96.2467	SCS	TX03340	CEDAR CREEK WS SCS SITE 59
KAUFMAN	32.4533	96.2500	SCS	TX04519	CEDAR CREEK WS SCS SITE 84
KAUFMAN	32.7500	96.2500	SCS		CEDAR CREEK WS SCS SITE 47A
KAUFMAN	32.7783	96.2583		TX03373	PORTER LAKE DAM
KAUFMAN	32.5850	96.2600	SCS	TX03350	CEDAR CREEK WS SCS SITE 60
KAUFMAN	32.8100	96.2667		TX03374	TAWAKONI BALANCING RESERVOIR LEVEE
KAUFMAN	32.4667	96.2667	SCS	TX05784	CEDAR CREEK WS SCS SITE 82
KAUFMAN	32.7667	96.2667	SCS	TX05807	CEDAR CREEK WS SCS SITE 46REV
KAUFMAN	32.4700	96.2750	SCS	TX04518	CEDAR CREEK WS SCS SITE 83
KAUFMAN	32.5433	96.2783	SCS	TX03349	CEDAR CREEK WS SCS SITE 61
KAUFMAN	32.5967	96.2817		TX03352	KAUFMAN CITY LAKE DAM 2
KAUFMAN	32.4833	96.2833	SCS	TX05783	CEDAR CREEK WS SCS SITE 68A
KAUFMAN	32.5967	96.2867		TX03351	KAUFMAN CITY LAKE DAM 1
KAUFMAN	32.4300	96.2883	SCS	TX04924	CEDAR CREEK WS SCS SITE 73REV
KAUFMAN	32.4467	96.2883	SCS		CEDAR CREEK WS SCS SITE 72
KAUFMAN	32.8000	96.2917		TX03376	TERRELL COUNTRY CLUB LAKE DAM
KAUFMAN	32.6750	96.3000	SCS	TX06204	LESTER MAY ESTATE GSS
KAUFMAN	32.5833	96.3000	SCS	TX05806	CEDAR CREEK WS SCS SITE 43A
KAUFMAN	32.4467	96.3050	SCS	TX04517	CEDAR CREEK WS SCS SITE 71
KAUFMAN	32.4650	96.3133	SCS	TX04516	CEDAR CREEK WS SCS SITE 70
KAUFMAN	32.4767	96.3250	SCS	TX04515	CEDAR CREEK WS SCS SITE 69
KAUFMAN	32.4983	96.3317	SCS	TX04514	CEDAR CREEK WS SCS SITE 68
KAUFMAN	32.5000	96.3333	SCS		CEDAR CREEK WS SCS SITE 67A
KAUFMAN	32.4800	96.3367		TX03329	WELLS DAM
KAUFMAN	32.7883	96.3400		TX03375	ROBERTS LAKE DAM
KAUFMAN	32.7217	96.3450		TX03372	NORTH HAVEN CONSTRUCTION CO LAKE
KAUFMAN	32.5500	96.3500	SCS		CEDAR CREEK WS SCS SITE 64R
KAUFMAN	32.5183	96.3500	SCS	TX04513	CEDAR CREEK WS SCS SITE 66 DAM
KAUFMAN	32.5617	96.3550	SCS	TX04511	CEDAR CREEK WS SCS SITE 63
KAUFMAN	32.5267	96.3550	SCS	TX04512	CEDAR CREEK WS SCS SITE 65
KAUFMAN	32.5750	96.3567		TX05205	STARBRAND LAKE DAM
KAUFMAN	32.5933	96.3783	SCS	TX06207	FERGUSON DAM

COUNTY	LAT.	LONG.	ID	FED ID	NAME
KAUFMAN	32.6717	96.3817	SCS	TX04509	CEDAR CREEK WS SCS SITE 31
KAUFMAN	32.8050	96.3833		TX03377	CEDAR CREEK WS SCS SITE 15
KAUFMAN	32.7667	96.3850	SCS	TX03378	CEDAR CREEK WS SCS SITE 19
KAUFMAN	32.6300	96.3867	SCS	TX04510	CEDAR CREEK WS SCS SITE 33
KAUFMAN	32.6650	96.3883	SCS	TX04335	CEDAR CREEK WS SCS SITE 32
KAUFMAN	32.7967	96.3883	SCS	TX03379	CEDAR CREEK WS SCS SITE 18
KAUFMAN	32.7567	96.4050		TX03380	CEDAR CREEK WS SCS SITE 21A
LIMESTONE	31.7800	96.5517	SCS	TX01069	RICHLAND CREEK WS SCS SITE 25
LIMESTONE	31.7667	96.5667	SCS	TX01068	RICHLAND CREEK WS SCS SITE 24
LIMESTONE	31.7400	96.5717	SCS	TX01056	RICHLAND CREEK WS SCS SITE 22
LIMESTONE	31.7633	96.5750	SCS	TX01072	RICHLAND CREEK WS SCS SITE 23
LIMESTONE	31.7383	96.5800	SCS	TX01057	RICHLAND CREEK WS SCS SITE 21
LIMESTONE	31.7750	96.5867	SCS	TX01065	RICHLAND CREEK WS SCS SITE 17
LIMESTONE	31.7350	96.5900	SCS	TX01058	RICHLAND CREEK WS SCS SITE 20A
LIMESTONE	31.7633	96.5933	SCS	TX01066	RICHLAND CREEK WS SCS SITE 18
LIMESTONE	31.7950	96.5933	SCS	TX01064	RICHLAND CREEK WS SCS SITE 13
LIMESTONE	31.7367	96.6000	SCS	TX01059	RICHLAND CREEK WS SCS SITE 20
LIMESTONE	31.7533	96.6033	SCS	TX01067	RICHLAND CREEK WS SCS SITE 19
LIMESTONE	31.7900	96.6167	SCS	TX01071	RICHLAND CREEK WS SCS SITE 16A
LIMESTONE	31.7883	96.6233	SCS	TX01070	RICHLAND CREEK WS SCS SITE 16
LIMESTONE	31.7617	96.6433		TX01073	CITY OF COOLIDGE LAKE NO 2 DAM
LIMESTONE	31.7617	96.6450		TX01074	CITY OF COOLIDGE LAKE NO 1 DAM
LIMESTONE	31.7783	96.6633	SCS	TX01075	RICHLAND CREEK WS SCS SITE 10
LIMESTONE	31.7550	96.6783	SCS	TX01076	RICHLAND CREEK WS SCS SITE 9C
LIMESTONE	31.7550	96.6833	SCS	TX01077	RICHLAND CREEK WS SCS SITE 9B
LIMESTONE	31.7667	96.6983	SCS	TX01078	RICHLAND CREEK WS SCS SITE 9A
LIMESTONE	31.7833	96.7050	SCS	TX01079	RICHLAND CREEK WS SCS SITE 8
LIMESTONE	31.7850	96.7233	SCS	TX01080	RICHLAND CREEK WS SCS SITE 7
LIMESTONE	31.7883	96.7383	SCS	TX01081	RICHLAND CREEK WS SCS SITE 5
LIMESTONE	31.7917	96.7417	SCS	TX01082	RICHLAND CREEK WS SCS SITE 4A
LIMESTONE	31.7933	96.7517	SCS	TX01063	RICHLAND CREEK WS SCS SITE 4
MONTAGUE	32.7492	97.5692	SCS	TX04908	FARMERS CREEK WS SCS SITE 1
MONTAGUE	33.4533	97.6883	SCS	TX06082	WINN GSS
MONTAGUE	33.4667	97.7083	SCS		BIG SANDY CREEK WS SCS SITE 104
MONTAGUE	33.4350	97.7183	SCS	TX06078	FERGUSON GSS
MONTAGUE	33.4389	97.7333	SCS		BIG SANDY CREEK WS SCS SITE 108
MONTAGUE	33.4650	97.7467		TX00700	BIG SANDY WS SCS SITE 22A
MONTAGUE	33.4233	97.7667	SCS		BIG SANDY CREEK WS SCS SITE 14
MONTAGUE	33.5333	97.7800	SCS	TX06083	T. PRICE DAM
MONTAGUE	33.5250	97.7833	SCS	TX00766	BIG SANDY CREEK WS SCS SITE 18
MONTAGUE	33.4483	97.7850	SCS	TX04900	BIG SANDY CREEK WS SCS SITE 13C

COUNTY	LAT.	LONG.	ID	FED ID	NAME
MONTAGUE	33.5150	97.7867	SCS	TX00767	BIG SANDY CREEK WS SCS SITE 20
MONTAGUE	33.4733	97.8000	SCS	TX04899	BIG SANDY CREEK WS SCS SITE 13A
MONTAGUE	33.4733	97.8083	SCS	TX00696	BIG SANDY CREEK WS SCS SITE 13
MONTAGUE	33.4733	97.8150	SCS	TX00697	BIG SANDY CREEK WS SCS SITE 12
MONTAGUE	33.4800	97.8383	SCS	TX00698	BIG SANDY CREEK WS SCS SITE 11
MONTAGUE	33.5117	97.8417	SCS	TX00765	BIG SANDY CREEK WS SCS SITE 10
MONTAGUE	33.5450	97.8483		TX00768	MOSE JOHNSON LAKE DAM
MONTAGUE	33.4583	97.8583		TX05940	BOWIE RESERVOIR DAM
MONTAGUE	33.4683	97.8650		TX00699	AMON G CARTER DAM
MONTAGUE	33.4483	97.8867	SCS	TX00695	BIG SANDY CREEK WS SCS SITE 8
MONTAGUE	33.4592	97.8917		TX05802	BIG SANDY CREEK WS SCS SITE 8A
MONTAGUE	33.4717	97.9167	SCS	TX06051	GAINES LAKE
MONTAGUE	33.5267	97.9517	SCS	TX00770	BIG SANDY CREEK WS SCS SITE 6
MONTAGUE	33.5583	97.9667	SCS	TX00769	BIG SANDY CREEK WS SCS SITE 5B
NAVARRO	32.0633	96.3717	SCS	TX02562	CHAMBERS CREEK WS SCS SITE 141
NAVARRO	32.1333	96.3750		TX05161	WHEELOCK LAKE DAM
NAVARRO	32.0667	96.3800	SCS	TX02563	CHAMBERS CREEK WS SCS SITE 140
NAVARRO	32.0767	96.4033		TX02568	LAKE HALBERT DAM
NAVARRO	32.0817	96.4233		TX02566	MAGNOLIA LAKE DAM
NAVARRO	32.0617	96.4367		TX02565	BEATON LAKE DAM
NAVARRO	32.1600	96.4400	SCS		CHAMBERS CREEK WS SCS SITE 130B
NAVARRO	32.2100	96.4600	SCS	TX02572	CHAMBERS CREEK WS SCS SITE 129
NAVARRO	32.0750	96.4650		TX02567	MOBIL PIPELINE LAKE DAM
NAVARRO	32.2067	96.4700	SCS	TX02574	CHAMBERS CREEK WS SCS SITE 128
NAVARRO	31.9233	96.4750	SCS	TX04753	RICHLAND CREEK WS SCS SITE 36 REV
NAVARRO	32.2017	96.4783		TX02573	JOHNSTON LAKE DAM
NAVARRO	32.2417	96.4917		TX02575	RICE LAKE DAM
NAVARRO	32.1267	96.4950		TX05155	ALLISON SOUTH LAKE DAM
NAVARRO	32.1050	96.4983	SCS	TX02564	CHAMBERS CREEK WS SCS SITE 139
NAVARRO	32.1400	96.5000	SCS		CHAMBERS CREEK WS SCS SITE 136A
NAVARRO	31.9517	96.5050		TX02647	CARROLL LAKE DAM
NAVARRO	32.1300	96.5067		TX02601	CORSICANA COUNTRY CLUB LAKE
NAVARRO	31.8583	96.5067	SCS	TX02625	RICHLAND CREEK WS SCS SITE 30
NAVARRO	32.1383	96.5117		TX05112	ALLISON LAKE DAM
NAVARRO	31.8450	96.5150	SCS	TX02626	RICHLAND CREEK WS SCS SITE 29
NAVARRO	31.9200	96.5167	SCS	TX02644	RICHLAND CREEK WS SCS SITE 35
NAVARRO	32.1617	96.5167	SCS		CHAMBERS CREEK WS SCS SITE 124C
NAVARRO	31.9133	96.5183	SCS	TX02645	RICHLAND CREEK WS SCS SITE 34
NAVARRO	32.2433	96.5183	SCS	TX04528	CHAMBERS CREEK WS SCS SITE 127A
NAVARRO	31.9050	96.5200	SCS	TX02648	RICHLAND CREEK WS SCS SITE 33
NAVARRO	32.1217	96.5267	SCS	TX04529	CHAMBERS CREEK WS SCS SITE 136

COUNTY	LAT.	LONG.	ID	FED ID	NAME
NAVARRO	32.2150	96.5300	SCS	TX02603	CHAMBERS CREEK WS SCS SITE 121E
NAVARRO	31.8417	96.5300		TX02620	BUTLER LAKE DAM
NAVARRO	32.1717	96.5317	SCS	TX04527	CHAMBERS CREEK WS SCS SITE 124A-1
NAVARRO	32.1833	96.5333	SCS	TX05788	CHAMBERS CREEK WS SCS SITE 124B
NAVARRO	32.0183	96.5333	SCS	TX04632	RICHLAND CREEK WS SCS SITE 143A
NAVARRO	32.2217	96.5433	SCS	TX02604	CHAMBERS CREEK WS SCS SITE 121D-2
NAVARRO	31.8150	96.5467	SCS	TX02627	RICHLAND CREEK WS SCS SITE 26
NAVARRO	32.2250	96.5500	SCS	TX02605	CHAMBERS CREEK WS SCS SITE 121D-1
NAVARRO	31.9367	96.5517	SCS	TX02652	RICHLAND CREEK WS SCS SITE 118
NAVARRO	31.8933	96.5533	SCS	TX02646	RICHLAND CREEK WS SCS SITE 32
NAVARRO	31.8167	96.5550	SCS	TX02628	RICHLAND CREEK WS SCS SITE 26A
NAVARRO	32.0800	96.5567	SCS	TX02583	RICHLAND CREEK WS SCS SITE 140
NAVARRO	32.1867	96.5567	SCS	TX02597	CHAMBERS CREEK WS SCS SITE 124
NAVARRO	32.2300	96.5600	SCS	TX02606	CHAMBERS CREEK WS SCS SITE 121C
NAVARRO	32.0633	96.5633	SCS	TX02584	RICHLAND CREEK WS SCS SITE 138
NAVARRO	31.8500	96.5633	SCS	TX02621	RICHLAND CREEK WS SCS SITE 15
NAVARRO	31.8700	96.5667	SCS	TX02624	RICHLAND CREEK WS SCS SITE 31
NAVARRO	32.0417	96.5750	SCS	TX02585	RICHLAND CREEK WS SCS SITE 137A
NAVARRO	32.0583	96.5767	SCS	TX02582	RICHLAND CREEK WS SCS SITE 137G
NAVARRO	32.1950	96.5783	SCS	TX02599	CHAMBERS CREEK WS SCS SITE 123A
NAVARRO	32.1883	96.5800	SCS	TX02598	CHAMBERS CREEK WS SCS SITE 123B
NAVARRO	31.9700	96.5917	SCS	TX02649	RICHLAND CREEK WS SCS SITE 129
NAVARRO	32.1983	96.5933	SCS	TX02602	CHAMBERS CREEK WS SCS SITE 122A
NAVARRO	31.8300	96.5967	SCS	TX02623	RICHLAND CREEK WS SCS SITE 14
NAVARRO	32.1983	96.5983	SCS	TX02600	CHAMBERS CREEK WS SCS SITE 122B
NAVARRO	32.0250	96.6033	SCS	TX04588	RICHLAND CREEK WS SCS SITE 136 REV
NAVARRO	31.9033	96.6050	SCS	TX02650	RICHLAND CREEK WS SCS SITE 116
NAVARRO	31.8400	96.6067	SCS	TX02622	RICHLAND CREEK WS SCS SITE 14A
NAVARRO	32.1750	96.6133	SCS	TX06294	THORNTON LAKE DAM
NAVARRO	32.0483	96.6167	SCS	TX04272	RICHLAND CREEK WS SCS SITE 135D
NAVARRO	32.1967	96.6167	SCS	TX02607	CHAMBERS CREEK WS SCS SITE 121
NAVARRO	31.8983	96.6217	SCS	TX02651	RICHLAND CREEK WS SCS SITE 115
NAVARRO	31.8150	96.6283	SCS	TX02632	RICHLAND CREEK WS SCS SITE 12
NAVARRO	32.0367	96.6283		TX05162	COX LAKE DAM
NAVARRO	32.1800	96.6300	SCS		CHAMBERS CREEK WS SCS SITE 120B
NAVARRO	32.0667	96.6333	SCS	TX04271	RICHLAND CREEK WS SCS SITE 135B
NAVARRO	32.0833	96.6450	SCS	TX04270	RICHLAND CREEK WS SCS SITE 135A
NAVARRO	31.9017	96.6467	SCS	TX02635	RICHLAND CREEK WS SCS SITE 114
NAVARRO	32.0633	96.6567	SCS	TX04269	RICHLAND CREEK WS SCS SITE 134
NAVARRO	32.1600	96.6600	SCS		CHAMBERS CREEK WS SCS SITE 120A
NAVARRO	31.9817	96.6650	SCS	TX02640	RICHLAND CREEK WS SCS SITE 127

COUNTY	LAT.	LONG.	ID	FED ID	NAME
NAVARRO	31.9067	96.6650	SCS	TX02636	RICHLAND CREEK WS SCS SITE 113
NAVARRO	32.1367	96.6717	SCS	TX02596	CHAMBERS CREEK WS SCS SITE 119B
NAVARRO	32.1467	96.6750	SCS	TX02595	CHAMBERS CREEK WS SCS SITE 119A
NAVARRO	31.9883	96.6767	SCS	TX02641	RICHLAND CREEK WS SCS SITE 126
NAVARRO	31.8950	96.6833	SCS	TX02638	RICHLAND CREEK WS SCS SITE 111
NAVARRO	31.8933	96.6867	SCS	TX02634	RICHLAND CREEK WS SCS SITE 110
NAVARRO	31.9133	96.6900	SCS	TX02637	RICHLAND CREEK WS SCS SITE 112
NAVARRO	31.8867	96.6933	SCS	TX02642	RICHLAND CREEK WS SCS SITE 109
NAVARRO	31.9350	96.6983	SCS	TX02643	RICHLAND CREEK WS SCS SITE 105
NAVARRO	31.9500	96.7000		TX00009	NAVARRO MILLS DAM
NAVARRO	32.0283	96.7017	SCS	TX02591	RICHLAND CREEK WS SCS SITE 124
NAVARRO	31.8750	96.7067		TX02630	LAKE DAWSON DAM
NAVARRO	32.0600	96.7067	SCS	TX02590	RICHLAND CREEK WS SCS SITE 123
NAVARRO	31.8750	96.7067	SCS		RICHLAND CREEK WS SCS SITE 107B
NAVARRO	32.1217	96.7083	SCS	TX02586	CHAMBERS CREEK WS SCS SITE 105B
NAVARRO	31.8850	96.7117	SCS	TX02633	RICHLAND CREEK WS SCS SITE 108
NAVARRO	31.8667	96.7133	SCS	TX02629	RICHLAND CREEK WS SCS SITE 107A
NAVARRO	32.1183	96.7217	SCS	TX02592	CHAMBERS CREEK WS SCS SITE 105A
NAVARRO	32.0550	96.7267	SCS	TX02587	RICHLAND CREEK WS SCS SITE 121
NAVARRO	31.8700	96.7350	SCS	TX02631	RICHLAND CREEK WS SCS SITE 106A
NAVARRO	32.1383	96.7367	SCS	TX02594	CHAMBERS CREEK WS SCS SITE 104A
NAVARRO	32.0550	96.7433	SCS	TX02589	RICHLAND CREEK WS SCS SITE 120
NAVARRO	32.0433	96.7500	SCS	TX02588	RICHLAND CREEK WS SCS SITE 119A
NAVARRO	32.1350	96.7500	SCS	TX02593	CHAMBERS CREEK WS SCS SITE 104B
NAVARRO	32.1200	96.7700	SCS	TX02613	CHAMBERS CREEK WS SCS SITE 103B
NAVARRO	32.0967	96.8250	SCS	TX02608	CHAMBERS CREEK WS SCS SITE 101A
NAVARRO	32.0133	96.8267	SCS	TX02609	RICHLAND CREEK WS SCS SITE 101
NAVARRO	32.0233	96.8333	SCS	TX02612	RICHLAND CREEK WS SCS SITE 100A
NAVARRO	32.0183	96.8433	SCS	TX02611	RICHLAND CREEK WS SCS SITE 98A
NAVARRO	32.0383	96.8533	SCS	TX02610	RICHLAND CREEK WS SCS SITE 99
NAVARRO	32.0500	96.8783	SCS	TX02614	RICHLAND CREEK WS SCS SITE 47
PARKER	32.7667	97.5767		TX04938	WALSH LAKE DAM
PARKER	32.6817	97.5950		TX04941	PETITFILS LAKE DAM
PARKER	32.6617	97.6067		TX01188	LAKE MONTEX DAM
PARKER	32.6683	97.6250		TX01187	LAKE MULLET DAM
PARKER	32.6883	97.6367		TX05988	SANDPIT DAM
PARKER	32.7483	97.6450	SCS	TX01183	CLEAR FORK TRINITY RIVER WS SITE 23
PARKER	32.6850	97.6450		TX01182	MEEKER LAKE DAM
PARKER	32.7800	97.6517		TX01223	MOORE LAKE DAM
PARKER	32.6800	97.6650		TX04940	RUFE EVANS LAKE DAM
PARKER	32.7717	97.6750		TX01222	LAKE WEATHERFORD DAM

COUNTY	LAT.	LONG.	ID	FED ID	NAME
PARKER	32.8183	97.6867	SCS	TX01220	CLEAR FORK TRINITY RIVER WS SITE 21
PARKER	32.7017	97.6950	SCS	TX01186	CLEAR FORK TRINITY RIVER WS SITE 33
PARKER	32.7017	97.7033	SCS	TX01185	CLEAR FORK TRINITY RIVER WS SITE 32
PARKER	32.7067	97.7133	SCS	TX01184	CLEAR FORK TRINITY RIVER WS SITE 31
PARKER	32.8583	97.7167	SCS	TX01218	CLEAR FORK TRINITY RIVER WS SITE 18
PARKER	32.8100	97.7167	SCS	TX01221	CLEAR FORK TRINITY RIVER WS SITE 22A
PARKER	32.8217	97.7217	SCS	TX01219	CLEAR FORK TRINITY RIVER WS SITE 19
PARKER	32.8683	97.7250	SCS	TX01215	CLEAR FORK TRINITY RIVER WS SITE 16
PARKER	32.7017	97.7283		TX04939	MONCRIEF LAKE DAM
PARKER	32.8733	97.7350	SCS	TX01216	CLEAR FORK TRINITY RIVER WS SITE 16A
PARKER	32.8450	97.7383	SCS	TX01217	CLEAR FORK TRINITY RIVER WS SITE 17
PARKER	32.7133	97.7400		TX05561	LAKE MONCRIEF DAM
PARKER	32.7800	97.7517	SCS	TX01199	CLEAR FORK TRINITY RIVER WS SITE 30
PARKER	32.8983	97.7533	SCS	TX01213	CLEAR FORK TRINITY RIVER WS SITE 14
PARKER	32.7767	97.7717	SCS	TX01226	CLEAR FORK TRINITY RIVER WS SITE 29
PARKER	32.9333	97.7767	SCS	TX01207	CLEAR FORK TRINITY RIVER WS SITE 8
PARKER	32.8833	97.7800	SCS	TX01214	CLEAR FORK TRINITY RIVER WS SITE 15
PARKER	32.8033	97.7850	SCS	TX01198	CLEAR FORK TRINITY RIVER WS SITE 28
PARKER	32.9483	97.7950	SCS	TX01205	CLEAR FORK TRINITY RIVER WS SITE 6
PARKER	32.8833	97.7950	SCS	TX01212	CLEAR FORK TRINITY RIVER WS SITE 13
PARKER	32.8150	97.7967	SCS	TX01197	CLEAR FORK TRINITY RIVER WS SITE 27
PARKER	32.8250	97.7967	SCS	TX01196	CLEAR FORK TRINITY RIVER WS SITE 26
PARKER	32.8900	97.8017	SCS	TX01211	CLEAR FORK TRINITY RIVER WS SITE 12
PARKER	32.9583	97.8017	SCS	TX01204	CLEAR FORK TRINITY RIVER WS SITE 5
PARKER	32.9350	97.8067	SCS	TX01206	CLEAR FORK TRINITY RIVER WS SITE 7
PARKER	32.8083	97.8183	SCS	TX06273	E.A. PATTERSON & E.A. PATTERSON JR.
PARKER	32.8400	97.8267	SCS	TX01195	CLEAR FORK TRINITY RIVER WS SITE 25A
PARKER	32.7867	97.8300		TX01191	SUNSHINE DAM
PARKER	32.9617	97.8317	SCS	TX01203	CLEAR FORK TRINITY RIVER WS SITE 4
PARKER	32.8633	97.8367	SCS	TX01193	CLEAR FORK TRINITY RIVER WS SITE 24
PARKER	32.9633	97.8383	SCS	TX01202	CLEAR FORK TRINITY RIVER WS SITE 3
PARKER	32.8533	97.8383	SCS	TX01194	CLEAR FORK TRINITY RIVER WS SITE 25
PARKER	32.9183	97.8450	SCS	TX01210	CLEAR FORK TRINITY RIVER WS SITE 11
PARKER	32.9150	97.8667	SCS	TX01209	CLEAR FORK TRINITY RIVER WS SITE 10
PARKER	32.9200	97.8733	SCS	TX01208	CLEAR FORK TRINITY RIVER WS SITE 9
PARKER	32.9650	97.8867	SCS	TX01200	CLEAR FORK TRINITY RIVER WS SITE 1
PARKER	32.9850	97.8867	SCS	TX01201	CLEAR FORK TRINITY RIVER WS SITE 2
ROCKWALL	32.8200	96.3117	SCS	TX00790	CEDAR CREEK WS SCS SITE 16A
ROCKWALL	32.8133	96.3383	SCS	TX00791	CEDAR CREEK WS SCS SITE 16
ROCKWALL	32.848[illegible]	96.3400	SCS	TX00792	CEDAR CREEK WS SCS SITE 13
ROCKWALL	32.8667	96.3600	SCS	TX00793	CEDAR CREEK WS SCS SITE 11

COUNTY	LAT.	LONG.	ID	FED ID	NAME
ROCKWALL	32.8050	96.3833	SCS	TX03377	CEDAR CREEK WS SCS SITE 15
ROCKWALL	32.9150	96.3900	SCS	TX00811	CEDAR CREEK WS SCS SITE 1A
ROCKWALL	32.8850	96.3917	SCS	TX00816	CEDAR CREEK WS SCS SITE 5
ROCKWALL	32.8467	96.3933	SCS	TX00794	CEDAR CREEK WS SCS SITE 9
ROCKWALL	32.8917	96.3933	SCS	TX00815	CEDAR CREEK WS SCS SITE 4
ROCKWALL	32.8967	96.3933	SCS	TX00814	CEDAR CREEK WS SCS SITE 3
ROCKWALL	32.8717	96.3950	SCS	TX00818	CEDAR CREEK WS SCS SITE 7
ROCKWALL	32.8267	96.3950	SCS	TX00795	CEDAR CREEK WS SCS SITE 14A
ROCKWALL	32.9133	96.3950	SCS	TX00812	CEDAR CREEK WS SCS SITE 1B
ROCKWALL	32.8783	96.3950	SCS	TX00817	CEDAR CREEK WS SCS SITE 6
ROCKWALL	32.9050	96.3967	SCS	TX00813	CEDAR CREEK WS SCS SITE 2
TARRANT	32.7217	97.1983		TX00776	LAKE ARLINGTON DAM
TARRANT	32.6183	97.2033		TX05215	EAST BALANCING RESERVOIR DAM
TARRANT	32.6200	97.2083		TX05216	WEST BALANCING RESERVOIR DAM
TARRANT	32.6867	97.3900		TX04796	WILLOW CREEK LAKE DAM
TARRANT	32.7267	97.3983		TX00777	LAKE COMO DAM
TARRANT	32.7917	97.4150		TX00785	LAKE WORTH DAM
TARRANT	32.7117	97.4267		TX00778	LUTHER LAKE DAM
TARRANT	32.6950	97.4317		TX09003	RIDGLEA COUNTRY CLUB DAM
TARRANT	32.6500	97.4500		TX00003	BENBROOK DAM
TARRANT	32.8700	97.4967		TX00779	EAGLE MOUNTAIN DAM
TARRANT	32.8083	97.5283		TX00781	HAYWIRE LAKE NO 1 DAM
VANZANDT	32.5517	95.9267	SCS	TX02893	CEDAR CREEK WS SCS SITE 123
VANZANDT	32.5367	95.9400	SCS	TX02844	CEDAR CREEK WS SCS SITE 124
VANZANDT	32.5700	95.9517		TX02845	COTTON LAKE DAM
VANZANDT	32.4933	95.9567	SCS	TX02798	CEDAR CREEK WS SCS SITE 134
VANZANDT	32.5283	95.9733	SCS	TX02847	CEDAR CREEK WS SCS SITE 126
VANZANDT	32.6667	95.9750		TX02852	HAMILTON LAKE DAM
VANZANDT	32.4617	95.9933	SCS	TX02797	CEDAR CREEK WS SCS SITE 135B
VANZANDT	32.5283	95.9967	SCS	TX02846	CEDAR CREEK WS SCS SITE 127
VANZANDT	32.6633	95.9967	SCS	TX02848	CEDAR CREEK WS SCS SITE 104
VANZANDT	32.4600	96.0017	SCS	TX02814	CEDAR CREEK WS SCS SITE 135A
VANZANDT	32.6517	96.0083	SCS	TX02828	CEDAR CREEK WS SCS SITE 105
VANZANDT	32.5700	96.0100	SCS		CEDAR CREEK WS SCS SITE 111F
VANZANDT	32.5167	96.0150	SCS	TX02818	CEDAR CREEK WS SCS SITE 128
VANZANDT	32.6750	96.0217	SCS	TX02827	CEDAR CREEK WS SCS SITE 103
VANZANDT	32.4833	96.0250	SCS	TX02808	CEDAR CREEK WS SCS SITE 135C
VANZANDT	32.5900	96.0300	SCS	TX02820	CEDAR CREEK WS SCS SITE 109
VANZANDT	32.6283	96.0317	SCS	TX02829	CEDAR CREEK WS SCS SITE 105A
VANZANDT	32.5683	96.0350	SCS	TX02822	CEDAR CREEK WS SCS SITE 113
VANZANDT	32.5183	96.0383	SCS	TX02819	CEDAR CREEK WS SCS SITE 129

COUNTY	LAT.	LONG.	ID	FED ID	NAME
VANZANDT	32.6800	96.0450	SCS	TX02826	CEDAR CREEK WS SCS SITE 102
VANZANDT	32.4733	96.0450	SCS	TX02809	CEDAR CREEK WS SCS SITE 136
VANZANDT	32.5833	96.0500		TX02824	BOBBITT LAKE DAM
VANZANDT	32.5433	96.0533	SCS	TX02823	CEDAR CREEK WS SCS SITE 114
VANZANDT	32.4867	96.0567	SCS	TX02815	CEDAR CREEK WS SCS SITE 130A
VANZANDT	32.5950	96.0583	SCS	TX02821	CEDAR CREEK WS SCS SITE 110
VANZANDT	32.4167	96.0600	SCS	TX02813	CEDAR CREEK WS SCS SITE 140
VANZANDT	32.4217	96.0600	SCS	TX02812	CEDAR CREEK WS SCS SITE 139
VANZANDT	32.4517	96.0633	SCS	TX02810	CEDAR CREEK WS SCS SITE 137
VANZANDT	32.4750	96.0667	SCS	TX02816	CEDAR CREEK WS SCS SITE 131
VANZANDT	32.4450	96.0683		TX02817	RICHARDS LAKE DAM
VANZANDT	32.4267	96.0683	SCS	TX02811	CEDAR CREEK WS SCS SITE 138
VANZANDT	32.6583	96.0700	SCS	TX02825	CEDAR CREEK WS SCS SITE 101
WISE	33.5500	97.0217	SCS		BIG SANDY WS SCS SITE 125A
WISE	33.0817	97.4967	SCS	TX05065	BIG SANDY WS SCS SITE 44
WISE	33.0850	97.5000	SCS	TX05062	BIG SANDY WS SCS SITE 43
WISE	33.2083	97.6317	SCS	TX06293	J.E. HAYNES DAM
WISE	33.3000	97.6333	SCS		BIG SANDY WS SCS SITE 32
WISE	33.2733	97.6467	SCS	TX05835	BIG SANDY WS SCS SITE 36
WISE	33.2417	97.6500	SCS		BIG SANDY WS SCS SITE 37
WISE	33.0400	97.6550	SCS	TX01486	SALT CREEK & LATERALS WS SCS SITE 10
WISE	33.3833	97.6667	SCS		BIG SANDY WS SCS SITE 24D
WISE	33.3917	97.6750	SCS	TX05834	BIG SANDY WS SCS SITE 24B
WISE	33.3633	97.6783	SCS		BIG SANDY WS SCS SITE 26
WISE	33.0667	97.6783	SCS	TX01487	SALT CREEK & LATERALS WS SCS SITE 21
WISE	33.0550	97.6867	SCS	TX01484	SALT CREEK & LATERALS WS SCS SITE 8B
WISE	33.0533	97.6917	SCS	TX01482	SALT CREEK & LATERALS WS SCS SITE 8
WISE	33.0517	97.6983	SCS	TX01483	SALT CREEK & LATERALS WS SCS SITE 8A
WISE	24.3333	97.7000	SCS		BIG SANDY WS SCS SITE 24A
WISE	33.4367	97.7083	SCS		BIG SANDY WS SCS SITE 110
WISE	33.0767	97.7133	SCS	TX01485	SALT CREEK & LATERALS WS SCS SITE 9
WISE	33.0350	97.7200	SCS	TX01481	SALT CREEK & LATERALS WS SCS SITE 7
WISE	33.4167	97.7217	SCS		BIG SANDY WS SCS SITE 23A
WISE	33.2833	97.7333	SCS		BIG SANDY WS SCS SITE 28
WISE	33.0350	97.7333		TX01480	SALT CREEK & LATERALS WS SCS SITE 6
WISE	33.0383	97.7500	SCS	TX01492	SALT CREEK & LATERALS WS SCS SITE 5
WISE	33.0967	97.7600	SCS	TX04720	SALT CREEK & LATERALS WS SCS SITE 14
WISE	33.3333	97.7667	SCS		BIG SANDY WS SCS SITE 25A
WISE	33.2550	97.7700		TX01497	PERCH HILL PLANT DAM
WISE	33.0317	97.7783	SCS	TX01491	SALT CREEK & LATERALS WS SCS SITE 4
WISE	33.4317	97.7783		TX01498	BIG SANDY WS SCS SITE 14

COUNTY	LAT.	LONG.	ID	FED ID	NAME
WISE	33.1167	97.7800	SCS	TX04721	SALT CREEK & LATERALS WS SCS SITE 15
WISE	33.0717	97.7900	SCS	TX01495	SALT CREEK & LATERALS WS SCS SITE 22
WISE	33.0333	97.8000	SCS	TX01489	SALT CREEK & LATERALS WS SCS SITE 1
WISE	33.0250	97.8067	SCS	TX01490	SALT CREEK & LATERALS WS SCS SITE 2
WISE	33.0750	97.8150	SCS	TX01493	SALT CREEK & LATERALS WS SCS SITE 13
WISE	33.0633	97.8200	SCS	TX01494	SALT CREEK & LATERALS WS SCS SITE 12
WISE	33.2400	97.8217		TX04392	LONE STAR INDUSTRIES DAM
WISE	33.2200	97.8300		TX01496	BRIDGEPORT DAM
YOUNG	33.2750	98.5100		TX05521	NEWMAN LAKE DAM
YOUNG	33.3817	98.5750	SCS	TX05893	YOUNG COUNTY COMM. CT. C.A.T. NO. 1
YOUNG	33.3950	98.6750		TX03948	CAMPBELL LAKE DAM

TABLE 8 RESERVOIRS WITH AVAILABLE SEDIMENT SURVEYS IN STUDY AREA

Reservoir or Lake	County	Drainage Area Sq.Mi.	Reservoir Capacity As Built - AcFt	Years of Surveys
Amon G. Carter	Montague	103.00	15,805.75	1967, 1970
Beaton Lake	Navarro	0.82	319.00	1949
Bridgeport Lake	Wise	1,111.00	386,559.00	1968, 1988
Cedar Creek	Henderson	1,007.00	679,200.00	1995
Dawson City Lake	Navarro	1.16	N/A	1956, 1963, 1984
Eagle Mountain Lake	Tarrant	1,970.00	189,522.00	1968, 1988
Halbert Lake	Navarro	9.48	8,012.00	1949
Magnolia Lake	Navarro	0.43	756.00	1949
Richland-Chambers Lake	Navarro	1,957.00	1,135,000.00	1995
Weatherford Lake	Parker	109.00	21,233.61	1973
Chambers Creek SCS 37	Johnson	2.05	68.13	1964, 1969, 1974, 1980
Chambers Creek SCS 42	Johnson	30.94	566.12	1976
Chambers Creek SCS 101A	Navarro	2.58	326.68	1964, 1968, 1974, 1980
Clear Fork of Trinity SCS 7	Parker	2.55	175.00	1969, 1974, 1978
Clear Fork of Trinity SCS 10	Parker	4.30	210.94	1963, 1968, 1973, 1980

APPENDIX D - TECHNICAL PAPERS RELATED TO STUDY

HYDROLOGIC MODELING OF TEXAS GULF BASIN USING GIS

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ABSTRACT

Geographic Information System (GIS) has been successfully integrated with distributed parameter, continuous time, non-point source (NPS) pollution model SWAT (Soil and Water Assessment Tool). The integration has proven to be effective and efficient for data collection, and to visualize and analyze the input and output of simulation models. The SWAT-GIS system is being used to model the hydrology of 18 major river systems in the United States as part of the project called the Hydrologic Unit Model for the United States (HUMUS). This paper focuses on the integration of SWAT (basin scale hydrologic model) with the Geographical Resources Analysis Support System (GRASS-GIS) and a Relational Data Base Management System. The system is then applied to the Texas Gulf river basin. Input data layers (soils, land use, and elevation) were collected at a scale of 1:250,000 from various sources. The average monthly simulated and observed streamflow records from 1970-1979 are presented for the 6-digit basins defined by the United States Geological Survey (USGS) in the Texas Gulf basin.

INTRODUCTION

The Texas Gulf basin covers more than 80% of the State of Texas (170.8 million acres). Ninety seven percent of the state is nonfederal land; of this, range land is the largest with 61%. The terrain and climate features are diverse: desert mountains in the western part of the state have precipitation rates of 10 inches per year, and the forest cover in the eastern section have rainfall rates of 60 inches a year. In an average rainfall year, it is estimated that about 42% of the precipitation falling on Texas is evaporated directly back into the atmosphere, and about 47% is lost through plant transpiration. Only little over one percent of the precipitation that falls actually recharges aquifers, and the remaining 10% runs off to become stream flow in rivers and tributaries (Texas State Soil and Water Conservation Board, 1991). Domestic, industrial, recreation, power generation, fish industries and rural agriculture water demands depend on the fresh water supply from streams, reservoirs and groundwater. Given the relatively high cost of distributing water from reservoirs, and limited supplies, agriculture most often rely on groundwater for irrigation or depend totally on rainfall.

Paper presented in: *Second International Conference/Workshop on Integrating GIS and Environmental Modeling*, Breckenridge, Co.

There are 15 major river basins and eight coastal basins in Texas, of which 18 major basins contribute their water yield into the Gulf of Mexico. There are approximately 3700 streams and tributaries, and 80,000 linear miles of stream bed. The United States Geological Survey (USGS) has divided the 18 basins into approximately 22 (Figure 1) sub-water resource regions called 6-digit hydrologic unit areas (HUA). For this study only 18 of the 22 sub-water resource regions were selected. The four others were located along the coast and had inadequate detail to meet the model input requirements. Because of the importance of freshwater, an understanding of how potential alterations in climate, land use and other hydro-meteorological parameters may affect water resources is needed. The Resources Conservation Act (RCA) of 1977 requires the Department of Agriculture to appraise the status, condition, and trends in the uses and conservation of non-federal soil, and water related natural resources. This study accomplishes some of the issues related to the RCA appraisal of 1997 through the Hydrologic Unit Model of United States (HUMUS) (Srinivasan et.al,1993).

In the past, erosion and runoff estimates were predicted using empirically derived equations including the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) and SCS curve number method (USDA, 1972). More recently, runoff, soil erosion and chemical movement models have been based on the major processes of soil erosion and water movement such as the detachment and transport of particles by rainfall and runoff (Beasley et al., 1980, Young et al., 1989). Existing soil erosion models such as Erosion Productivity Impact Calculator (EPIC) (Williams et al., 1984), Chemicals, Runoff, Erosion from Agricultural Management Systems (CREAMS) (Knisel, 1980), Water Erosion Prediction Project (WEPP) (Foster and Lane, 1987), Areal Nonpoint Source Watershed Environment Response Simulation (ANSWERS) (Beasley et al., 1980), AGricultural NonPoint Source (AGNPS) (Young et al., 1989), Simulator for Water Resource Rural Basin (SWRRB) (Arnold et al., 1990), TOPOMODEL (Beven and Kirkby, 1979), and Soil and Water Assessment Tool (SWAT) (Arnold et al., 1993), provide users with analytical tools that allow them to predict runoff and erosion characteristics of slopes, fields, watersheds, and channels. These models also allow evaluation of management practices that influence certain factors contributing to runoff and erosion and provide significant insight into the processes of soil erosion. However, they have a number of limitations that restrict their use.

The factors that have limited the use of simulation models as management tools include: large data and input parameter requirements, parameters that are difficult to estimate or obtain, uncertainty in inputs, and lack of technical assistance to analyze the overwhelming amount of model outputs. Researchers have successfully shown that integration of simulation models with spatial databases and expert systems can significantly reduce the time and resources required to develop input and interpret output from simulation models (Arnold and Sammons, 1989, Heatwole, 1990, Shanholtz and Zhang, 1989, Srinivasan and Engel, 1992, Rewerts and Engel, 1991). Further they have used several forms of graphical tools including GIS to visualize spatially and/or temporally varying data such as runoff and sediment yield (Bingner, 1989, Srinivasan and Engel, 1992).

Geographic Information Systems (GIS) are disigned to collect, manage, store and display spatially varying data. Several NPS simulation models including ANSWERS, AGNPS, TOPOMODEL and SWAT, have been integrated/interfaced with GIS to enhance the use and utility of the models (Srinivasan and Engel, 1992, Rewerts and Engel, 1991, Srinivasan et al., 1993, Chairat and Delleur, 1993). This paper describes an application of an integrated SWAT/GRASS model to the Texas Gulf river basin. The results were reported at 6-digit hydrologic units (Figure 1).

THE SWAT MODEL

SWAT was developed to predict the effect of alternative management decisions on water, sediment, and chemical yields with reasonable accuracy for ungaged rural basins. The model was developed by modifying the SWRRB model for application to large and complex river basins. Major changes from SWRRB involved (a) expanding the model to allow simultaneous computations on several hundred subwatersheds and (b) adding components to simulate lateral flow, ground water flow, reach routing transmission losses, and sediment and chemical movement through ponds, reservoirs, streams and valleys. SWAT operates on a daily time step and is capable of simulating 100 years or more. Major components of the model include hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides, ground water and lateral flow, and agricultural management.

The SWAT model offers significant advantages over the combined SWRRB/ROTO model. SWAT offers distributed parameter and continuous time simulation, flexible watershed configuration, irrigation and water transfer, lateral subsurface flow, groundwater flow, and lake water quality components. The distributed parameter, continuous time feature was achieved by developing new routing structure. SWRRB routed from subbasin outlets directly to the basin outlet for simplicity. The new routing structure in SWAT is required to allow large basins to be simulated, provide more realistic routing, allow for more subbasins to be easily added, and simplify GIS linkages and database management. A set of commands is used to control the channel routing which route and add flows through the watershed through reaches and reservoirs. The model reads each command and performs the given hydrologic command.

Total streamflow from large basins is the sum of surface runoff and groundwater flow. Groundwater flow volumes and recession periods must be simulated to accurately predict streamflow, sediment concentrations, and chemical concentrations in the streamflow. Water percolating past the root zone is assumed to recharge the shallow aquifer. Shallow aquifer components include recharge, groundwater evaporation, flow to the stream, percolation to the deep aquifer, and pumping withdrawals. The shallow aquifer also interacts directly with the streams and reservoirs through transmission losses and seepage. A detailed description of the model, and model inputs can be found in Arnold et al. (1993).

Since SWAT was developed for large basins, a component to simulate water transfer between subbasins was developed. Given the reach routing command structure, it is relatively easy to transfer water within a basin. This can account for irrigation flow paths and could provide a management tool for irrigation management districts and other agencies concerned with irrigation water rights. The algorithm developed here will allow water to be transferred from one reach or reservoir to any other in the watershed. It will also allow water to be diverted and applied as irrigation directly in a subwatershed.

THE SWAT-GIS INTEGRATED SYSTEM

The GIS tool chosen was GRASS (Shapiro et al., 1992), a public domain raster GIS designed and developed by the Environmental Division of the U.S. Army Construction Engineering Research Laboratory (USA-CERL). GRASS is a general purpose, raster graphic modeling and analysis package and is highly interactive and graphically oriented (both 2-D and 3-D), providing tools for developing, analyzing, and displaying spatial information. GRASS is being used by numerous groups federal, state, local agencies, and private consultants.

A toolbox rationale was utilized in providing a collection of GIS programs to assist with the data development and analysis requirements of the SWAT model. The SWAT-GRASS input interface programs and other tools are written in C language and are integrated with the GRASS libraries. The SWAT model is written in FORTRAN 77 language and both the interface and model run under the UNIX environment. The input-interface tools assist with preparation and extraction of data from the GIS database for use in the SWAT model (Figure 2). The input interface (Srinivasan and Arnold, 1993) consists of three major divisions, 1) the project manager; 2) tools to extract and aggregate inputs for the model; and 3) tools to view, edit and check the input for the model. The function of the project manager is to interact with the user to collect, prepare, edit and store basin and subbasin information to be formatted into a SWAT input file.

The extract and aggregate step uses a variety of hydrologic tools (Srinivasan and Arnold, 1993). The GIS layers that are required at this step include: subbasin, soils, elevation, land use, pesticide application, and weather network. In addition the reservoirs, inflow, pond and lake data can be collected directly from the user. In the third step the user can either view, edit or check the data extracted from the previous phase by using a subbasin number as input. There are about 15 different data forms that can be modified by the user. The developed interface reduces the data collection and manipulation phase of watershed simulations (Rosenthal, et al., 1993). The interface allows rapid modification of the various management practices and prepares the data for subsequent model runs. The interface can also be used to perform sensitivity analysis by modifying the GIS data layers and/or choosing different aggregation methods for various input data.

DATA BASES

The most critical component of the SWAT-GIS integrated system is the collection of data required to run the simulation models. To model the 6-digit hydrologic unit areas of the Texas Gulf for example, the required information were historical weather, soil properties, topography, natural vegetation, cropped areas, irrigation, state and county boundaries, reservoir (stage-flow) data, and agricultural practices (Figure 2). The SWAT model data requirement can be classified as spatial and relational. The spatial databases include: topography, land use, soils, state and county boundaries, hydrologic unit area (watershed boundaries), stream network, weather station locations, geology maps, and stream gauge stations (Figure 2). The relational databases are: national resources inventory (NRI), national agricultural statistical survey (NASS), state soil survey database (SSSD), weather parameters, stream flow and reservoir operation data, and agricultural census data (Ag Census).

USGS developed spatial data were used for this study at 1:250,000 scale. The DEM (Digital Elevation Model), LULC (land use and land cover), and streamgauge data were obtained from USGS and were processed in Albers Equal Area (AEA) projection for the study area. Several quads of 1^o by 1^o DEM and 1^o by 2^o LULC were processed, and patched together into one map using several of the GRASS GIS procedures. The soil layers called STATSGO (USDA, 1992) were obtained from SCS, and the attribute databases were loaded into an INFORMIX relational database manager. The DEM, LULC and STATSGO soils layers are at a scale of 1:250,000. Other relational databases such as NRI, NASS, Ag Census were analyzed for periodic intervals of 5 to 10 years. Historic stream flow from USGS stream gauge stations, and weather information were used for the simulation. When weather data (daily precipitation and temperature) were unavailable weather parameters were simulated using a stochastic weather generator (Arnold et al., 1990). The streamflow values predicted from SWAT simulations were validated against the historical streamflows using USGS streamgauges at the outlet of each 6-digit HUA.

SWAT-GIS APPLICATION ON TEXAS GULF RIVER BASINS

The GIS integrated water quality SWAT model was applied to the 6-digit HUA (Figure 1). In this paper results from two 6-digit HUA covering the *Seguin* (120100) and *Naches* (120200) river (Figure 1) basins are presented. Each river basin spans multiple climatic zones and widely varying soils and landuse. Also, each basin contains major reservoirs. The GIS layers obtained from USGS for land use (LULC, 200 m square grid) and DEM (1 m vertical interval, 3 arc-second data) at a scale of 1:250000 were assembled in the AEA projection. The STATSGO soils survey layer (1:250000 scale) was obtained from the SCS and soil attributes were loaded into an INFORMIX relational database manager. From the USGS water body layer at a scale of 1:2,000,000 the reservoirs were identified and inputs for the reservoirs were created for the SWAT model using the SWAT-GIS integrated system. In order to use the SWAT-GIS integrated system, first the river basin was subdivided into multiple subbasins, using the DEM layer as an input into the GRASS *r.watershed* program. Thus, *Seguin* and *Naches* river basins were subdivided into 115 and 116 subbasins respectively.

Using the SWAT-GIS integrated system, the required inputs for each of the subbasins within each basin were extracted and formatted. The extracted information included, soils, land use, topographic, weather generator, rain and temperature gauges, reservoir, and groundwater attributes. Table 1 gives additional information about the basins. In addition using the SWAT-GIS integrated system the routing structure (Arnold, 1993) needed to run the model was automatically developed using the flow path data created during the extraction of topographic attributes. This procedure also detects and automates the routing procedures if any reservoir or inflow data exist in any of the subbasins. The system allows the user to edit errors that occured when extracting the routing structure using either the keyboard or through a graphical user interface. The SWAT-GIS integrated system helps users to model a river basin and saves several orders of magnitude in time compared to several man weeks and months depending on the size and variability of a basin. Since detailed reservoir operation rules were difficult to simulate, average monthly measured USGS streamflow data from the reservoir outlet were used as input to the model. The SWAT model was then run for 10 years in both river basins for the period of 1970-79 and average monthly output were stored from the model for validation.

It is important for simulation models to produce frequency distributions that are similar to measured frequency distributions. Close agreement between means and standard deviations indicates that the frequency distributions are similar. Generally, simulated values compared well with measured values at the outlet of the river basin, with average monthly predicted flows 5% (Table 2) higher than measured flows. The standard deviations between measured and predicted compared well (within 2%) (Table 2). Figures 3 and 4 show the close agreement of seasonal trends of average monthly observed and predicted streamflow for 1970-79 (120 months) for *Seguin* and *Naches* river basins respectively. Approaching Nash-Sutcliffe coefficient of 1 is an indication of well predicted system by the simulation model. In both the basins the SWAT model does predict very close to the observed data (Table 2). It is important to note that at the outlet of each reservoir, measured streamflow data were used as input to SWAT, which could help account for the relatively close agreement with observed data. However, considering the extreme spatial variability above and below the reservoir, the model was still able to predict streamflow reasonably close to observed values.

SUMMARY AND CONCLUSION

The SWAT (Soil and Water Assessment Tool) model was integrated with the GRASS (Geographic Resources Analysis Support System) GIS tool to develop a continuous time, distributed parameter modeling tool to assist with management of runoff, erosion, pesticide, and nutrient movement in large basins. The integrated system assists with development of SWAT input from GIS layers. The system is currently being evaluated for several watersheds within the Texas Gulf. Preliminary results suggest that the integrated SWAT/GIS model significantly reduces the time required to obtain input data, and simplifies model operation. One of the limitations of the modeling system was its inability to mimic the complex reservoir operation rules and attempts are being made to improve this in the SWAT model.

The integrated SWAT-GIS system was applied to the Texas Gulf USGS defined 6-digit hydrologic unit areas (HUA). Results from two of the river basins (*Seguin* and *Naches*) were reported in this paper. SWAT model inputs including data on soils, topography, land use, and weather were automatically derived from map layers and associated databases using the integrated GIS system. Simulated average monthly stream flows were in close agreement (within 5%) with observed flows for both the river basins.

ACKNOWLEDGEMENTS

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Table 1. 6-digit HUA Basin Characteristics

6-digit number Name	120100 Seguin River	120200 Naches River
Drainage Area (km^2)	24469.2	25161.0
Length of main channel (km)	604.0	440.7
Average main channel slope (%)	0.0001	0.0001
Average overland slope (%)	0.002	0.002
Number of subbasins	115	116
Number of weather stations	6	6
Number of weather generator stations	11	5
Number of reservoirs	2	1

Table 2. 6-digit HUA Basin Statistics between Observed and Predicted average monthly streamflow values at the outlet of the river basins for the period of 1970-79.

6-digit number Name	120100 Seguin River	120200 Naches River
Measured mean ($\frac{m^3}{sec}$)	228.89	207.43
Predicted mean ($\frac{m^3}{sec}$)	230.59	218.45
Measured std. dev.	205.28	192.68
Predicted std. dev.	201.70	194.58
R^2	0.866	0.831
Regression slope	0.947	0.903
Nash Sutcliffe	0.863	0.818
Number of Observations	120	120

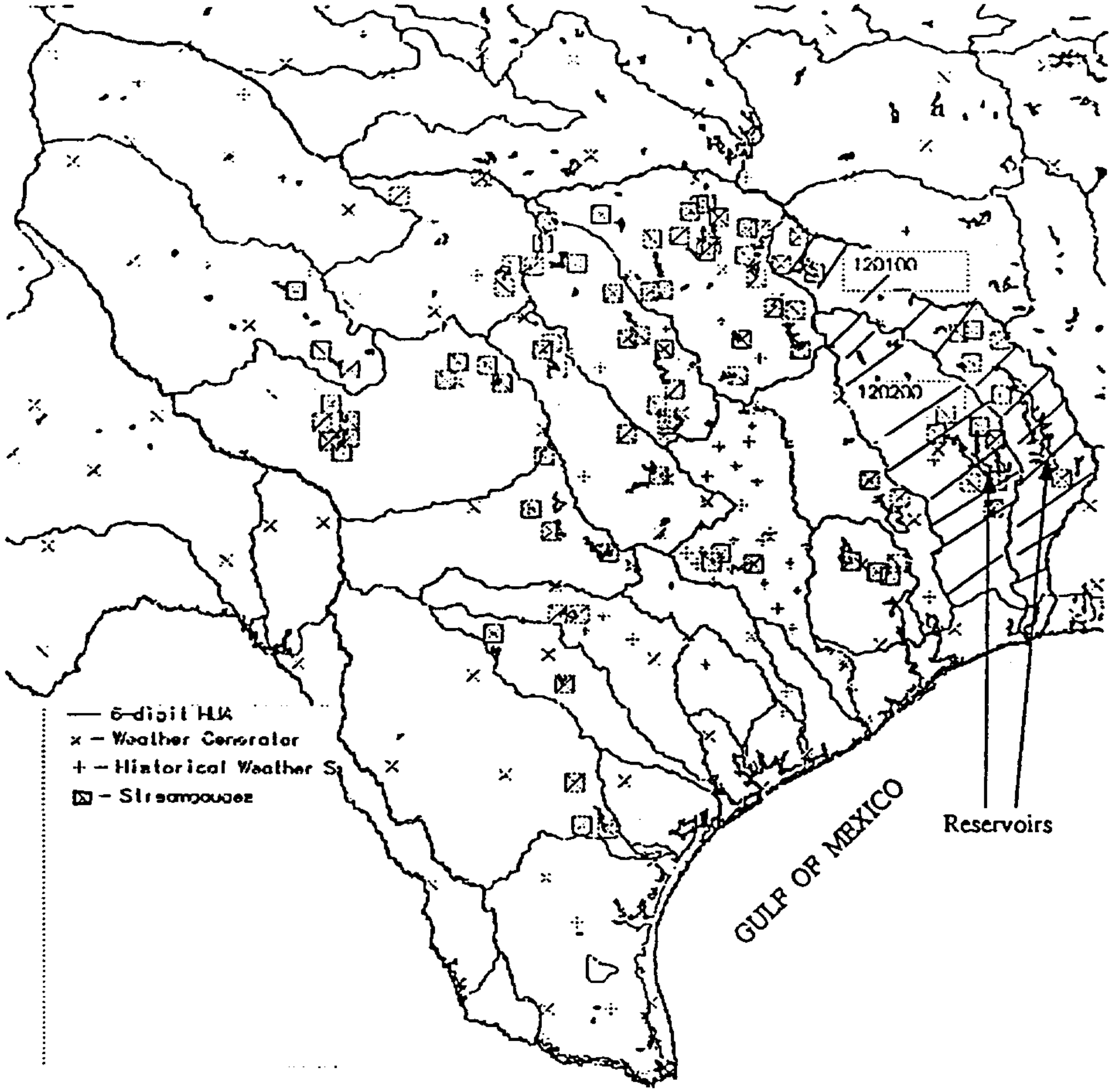

Figure 1. Texas Gulf 6–digit HUA Layer with Water bodies, Weather and Streamgague Locations

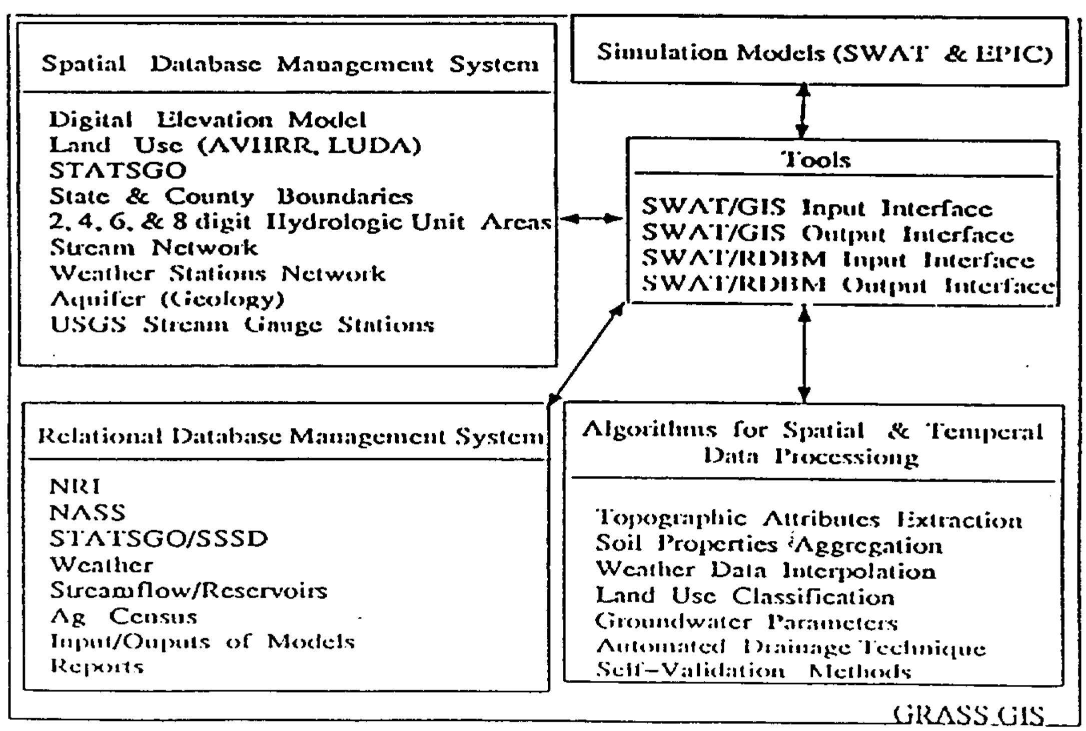

Figure 2. Schematic View of SWAT-GIS Integrated System

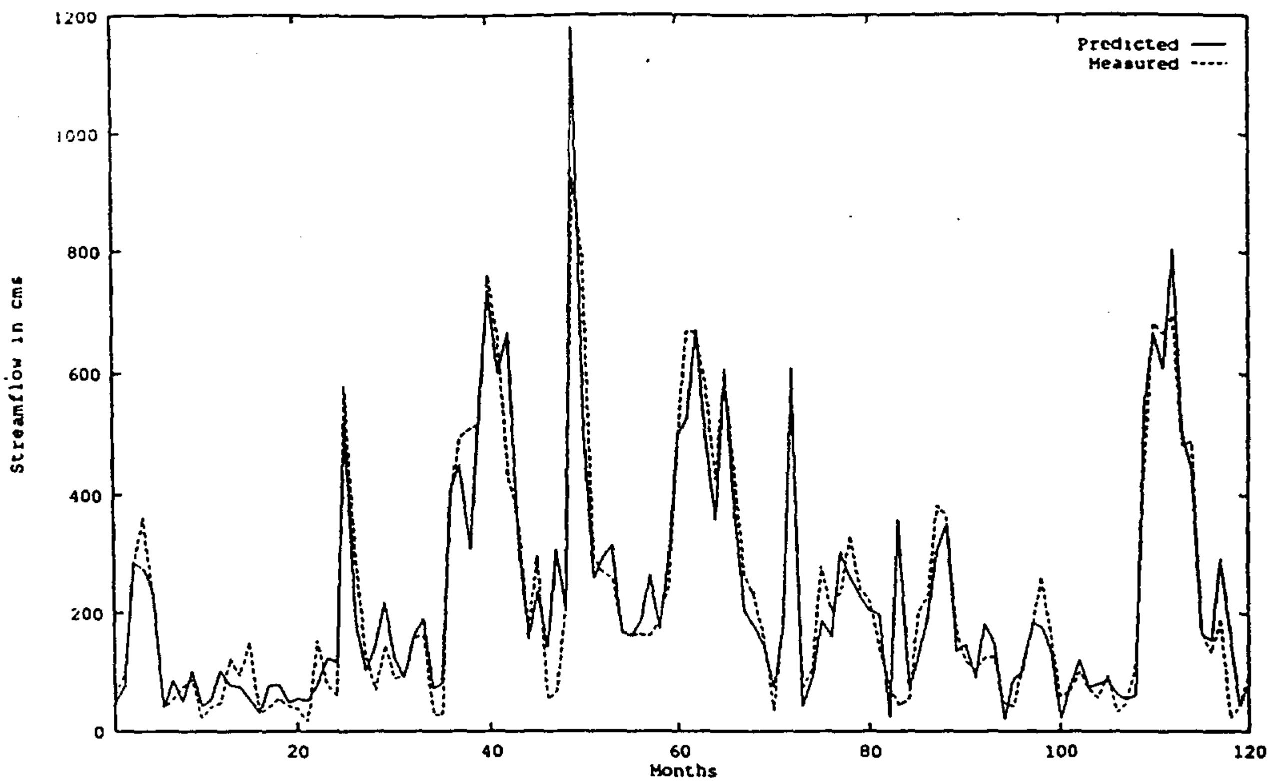

Figure 3. Predicted and measured streamflow ($\frac{m^3}{sec}$) for the *Seguin* river basin for 120 months (1970-79).

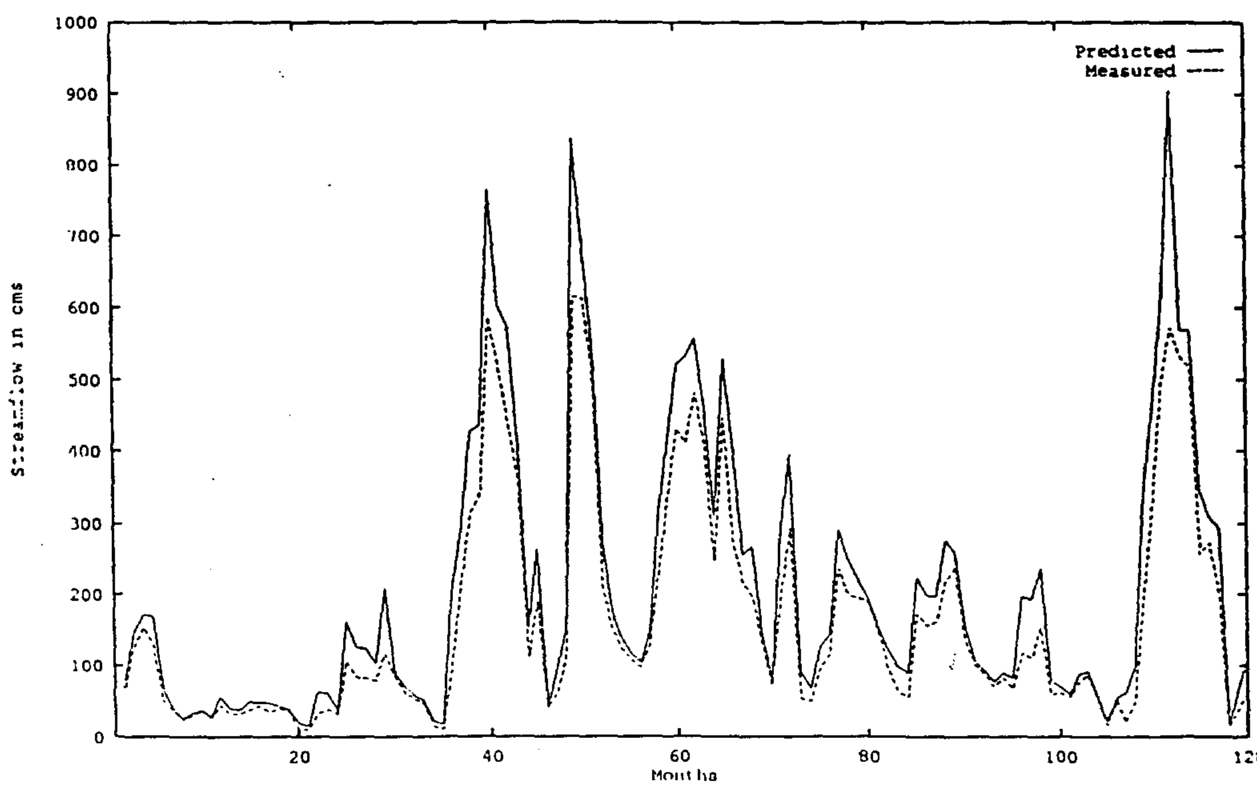

Figure 4. Predicted and measured streamflow ($\frac{m^3}{sec}$) for the *Naches* river basin for 120 months (1970-79).

IMPACT OF RESERVOIRS ON A BASIN SCALE MODEL

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ABSTRACT

Reservoirs are studied for their impact on overland runoff prediction, and baseflow. Three reservoirs from the Texas gulf coast were selected for overland runoff calculations, and ten reservoirs were selected for baseflow analysis. It is found that a simple target volume approach to reservoir regulation reasonably predicts the outflow from a reservoir, and that baseflow days are not as significantly affected by water levels in reservoirs as they are by the underlying geology. A ratio is introduced to gauge reservoir operating procedures from readily available data on stream flow rates and reservoir capacities.

INTRODUCTION

From a modeling perspective, reservoirs cause difficulty in calibration of watershed analyses because they act as external forcing functions on natural hydrological processes. Even if the stream flow has been successfully routed through a large watershed or river basin, the calculations at the outlet could fail if reservoir operations aren't properly accounted. Reservoir uses vary from sediment entrapment, to flood control, to irrigation of farms. Water reaches a reservoir from surrounding watersheds directly by overland runoff and by subsurface flow via soil and geological strata. We shall be solely interested in watersheds on the order of natural river basin scales. This study was undertaken as part of a larger study of the Hydrological Unit Model of the United States (HUMUS, Srinivasan et al., 1993a). The HUMUS project uses GIS, and the Soil and Water Assessment Tool (SWAT) model which combines the basin scale SWRRB model and the ROTO routing models (Arnold, 1992). The emphasis of this paper will be on using readily available data on stream flow and dam dimensions to gauge monthly outflow rates. The objectives of this paper are:

1 Determine the impact of reservoirs on runoff prediction by the SWAT model.

2 Determine the impact of reservoirs on baseflow days.

IMPACT OF RESERVOIRS ON RUNOFF CALCULATIONS

The reservoir component of SWAT attains a seasonal target discharge based on potential evapotranspiration (PET) of water in the reservoir, and precipitation flowing overland and subsurface into the reservoir. The input requirements consist of the monthly overland flow into the reservoir from the surrounding subbasins, the monthly potential evapotranspiration, the monthly target volume of the reservoir, the drainage areas of the subbasins contributing water to the reservoir, and the hydraulic conductivity of the soil media underlying the reservoir.

Since SWAT runs on a daily time step, the monthly data is decomposed to daily values by dividing the predicted monthly discharges by the number of days in a month. SWAT also gives the option of using daily outflow readings from a stream gauge located on the spill side of the reservoir.

Three of the twenty two six digit level hydrological units from the Texas Gulf coast basin were selected for study of major reservoirs (Figure 1). The USGS hydrological unit or natural river basin specifications vary from two digits to fourteen digits: two digits being the coarsest, and the fourteen digits being the finest. In the river basin called Nueces labeled 121101 by the USGS, there is the Wesley E. Seale dam with a storage capacity of 0.38 km^3 (308,700 acre-feet), located near Mathis, Texas. Storage capacity is the volume of water in the reservoir at the principal spillway level. In the Sabine river basin labeled 120100, there are two reservoirs named Iron Bridge and Toledo Bend, located near Wills Point, Texas and Burkeville, Texas respectively. Iron Bridge has a storage capacity of 1.15 km^3 (936,200 acre-feet), and Toledo Bend has a storage capacity of 6.29 km^3 (5,102,000 acre-feet). In the Neches river basin, the Sam Rayburn reservoir is located near Lufkin, Texas with a capacity of 6.92 km^3 (5,610,00 acre-feet).

The SWAT input data for each of the reservoirs are shown in Tables 1, 2, and 3. The Neches and Sabine river basins were calibrated in a previous study (see Srinivasan et al., 1993b). Since the Nueces river basin is still being calibrated, the Wesley Seale dam and reservoir was not used in runoff calculations, but was used instead in the determination of flow-capacity ratios discussed below. The target storage volume of each reservoir for every month of the year is based on a fraction of the principal spillway volume. At the beginning of each month, SWAT estimates the expected monthly outflow rate necessary to equal the target storage volume, and averages the monthly expected outflow rate over the number of days in the month. The governing equation is given by:

$$V_{est.} = V_{init.} - V_{in} - ET\ loss.$$

Where, $V_{est.}$ is the estimated monthly flow from the reservoir, $V_{init.}$ is the initial storage volume in the reservoir (at beginning of each month), and V_{in} is the direct runoff to the reservoir. Typically, a dam has area-capacity rating curves that translate height of water in the reservoir to volume and surface area. The outflow from the reservoir is then added to stream flow that has been routed upstream of the reservoir. It was assumed that for the Texas gulf coast, as a percent of spillway volume that there are higher volumes of water in the reservoir during winter months, and lower volumes during summer months. Realistically of course operating rules vary by location and time of year. The Sam Rayburn reservoir for example, operates upon consideration of water demanded by authorities down stream, maintenance of water levels in adjacent dams, and the flood pool level of the reservoir.

The monthly runoff directly reaching the reservoir from the basins surrounding the reservoir were obtained from data on total monthly precipitation and land management using the modified SCS curve number method (Arnold et al., 1990). The landuse management from the Land Use Land Cover (LULC) map from the USGS, was found to be rangeland and pasture. Sam Rayburn and and Toledo Bend have the same runoff values since they had the same rain gauge closest them. The potential ET for each reservoir was obtained from the handbook of Hargraves (1979) for the city closest the reservoir. For Toledo Bend,the closest city with PET readings was New Orleans, Lousiana; for Iron Bridge it was Shreveport, Lousiana; for Sam Rayburn it was New Orleans, Lousiana. The seepage rate and the hydraulic conductivity for all three reservoir and dams were both assumed to be 0.001 meters/day. The number of subbasins surrounding the reservoirs and their total drainage areas were as follows: Toledo Bend, 23 subbasins for 3,350 km^2; Iron Bridge, 5 subbasins for 1,223 km^2; and, Sam Rayburn, 9 subbasins for 2,238 km^2.

Figures 2, 3, and 4 show the predicted and measured monthly outflow from each of the forementioned reservoirs. Simulations were done from 1970 to 1979. However, to avoid biases of initial conditions, outflow from 1974 through 1976 is reported. Overall, SWAT is able to track the trend of the measured stream flow on the spill side of the Toledo Bendand Sam Rayburn reservoirs. The disagreement with measured values for Iron Bridge may be due to the smaller capacity whereby outflow is more sensitive to daily operating procedures than are larger reservoirs like Sam Rayburn or Toledo Bend. There are difficulties in predicting outflow for winter months probably because target volumes during this period are not as assumed. When other fractions of principal spillway volumes close to 3.0 were tried, results similar to those shown were obtained.

FLOW-CAPACITY RATIO

Is it possible to use just the measured inflow and outflow rates to infer operating procedures or rules of reservoirs ? To answer this question, the four reservoirs were examined for their flow to capacity ratios (R_c) using:

$$R_c = \frac{100\Delta t\left[\left|q_{in} - q_{out}\right|\right]}{V_p}.$$

Where, q_{in} is inflow, q_{out} is outflow, Δt is the time period of interest, and V_p is the maximum storage capacity of the dam. Here, Δt was taken as one month. The ratio means and standard deviations by month from twenty years worth of data, from 1970 to 1989, are shown in figures 5, and 6.

The higher means and standard deviations of the ratio implies that there is more regulation of the dams. Note from the figures that higher mean values show correspondingly higher standard deviations. The figures imply more regulation of flow during summer months than during winter months. This may indicate that reservoirs operate to keep water at principal spillway levels during summer months. The higher values for Toledo Bend from January to March may be because it provides water for both Eastern Texas and Southern Lousiana and is sensitive to a confluence water demanded from the two states.

IMPACT OF RESERVOIRS ON BASEFLOW DAYS

Baseflow days is the time period within which recharge water that has infiltrated through the soil profile and past the root zone reaches streams by subsurface flow. Mathematically, baseflow days can be obtained by determining the number of days it takes for baseflow to decline by log cycle. Nathan and McMahon (1990), and White and Sloto (1991) have studied automated methods of hydrograph separation for Queensland, Australia and Pennsylvannia, USA, respectively. In this study, we used the automated method discussed by Nathan and McMahon (1990) to separate baseflow from surface runoff, and then transformed the baseflow data to a semi-log coordinate system. The data reported here were obtained on further refinement by "skimming" the bottom of all the recession periods on the semi-log plots. Table 4 shows ten reservoirs from different parts of the state of Texas that were analyzed for baseflow days. The cells with a "-" in them indicate that there was no data available to calculate baseflow days. The geological information was obtained from depths varying from 150 feet to 200 feet below the dams (Dowell and Petty; 1971, 1973, 1974). Except for the Leon, Palo Pinto, and San Angelo reservoirs, the number of baseflow days before the reservoir was built is not drastically different from those after. It can thus be concluded that baseflow days are not strongly influenced by the water head level in the reservoirs. The discrepancy for Leon, and Palo Pinto is probably due to the smaller reservoir capacities which cause vagaries in stream gauge readings because of higher sensitivities to regulation of reservoirs. The conclusion that baseflow days are not significantly affected by water levels in the reservoirs can also be made by comparing the seventh column where baseflow days were computed with the complete data (before and after the dam was built) with the baseflow days calculated from stream flow on the inlet side of the dams. Except for the Wesley Seale reservoir, there is no significant disagreement between the complete data baseflow days at the outlet and the baseflow days at the inlet. Since no geology information is available for Wesley Seale, it is difficult to suspect geology; however, the discrepancy may be due to the heterogeneity of geology i.e., the stream gauges on the inlet side and outlet sides may be located in two different geological media. The contribution of geology toward baseflow days can be seen on comparing the Toledo Bend and Sam Rayburn reservoirs with the others. Since these two reservoirs have porous sand, silty clay, and sandstone geological media, the baseflow days are lower than for the other reservoirs. We thus conclude that baseflows are affected more by the underlying geology of the reservoirs than they are by water levels.

ACKNOWLEDGEMENTS

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Figure 1. Loci of Toledo Bend, Iron Bridge, Sam Rayburn, and Wesley Seale Reservoirs and dams.

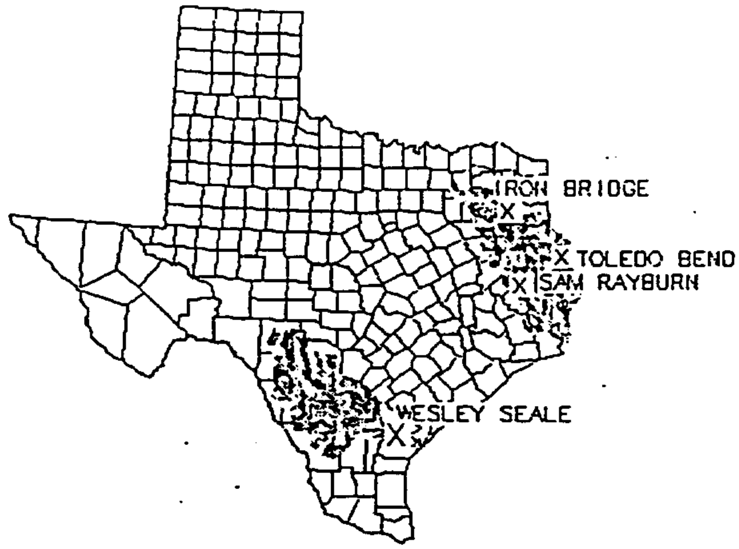

Table 1. SWAT INPUT DATA FOR IRON BRIDGE RESERVOIR.

Direct Runoff (mm)	PET (mm)	Target
1.8	49	2.0
7.0	60	2.0
8.5	96	2.0
15.0	125	1.8
20.0	172	1.5
5.0	200	1.5
2.5	214	1.2
2.0	197	1.2
12.0	152	2.0
9.0	113	2.0
6.0	64	2.0
8.0	49	2.0

Table 2. SWAT INPUT DATA FOR TOLEDO BEND RESERVOIR.

Direct Runoff (mm)	PET (mm)	Target
24.4	62	2.0
4.2	72	2.0
9.2	108	2.0
9.2	137	1.8
13.0	171	1.5
14.0	184	1.5
3.8	189	1.2
6.6	178	1.2
25.0	143	2.0
10.0	113	2.0
12.0	72	2.0
13.0	59	2.0

Table 3. SWAT INPUT FOR SAM RAYBURN RESERVOIR.

Direct Runoff (mm)	PET (mm)	Target
24.4	62	1.8
4.2	72	1.8
9.2	108	1.8
9.2	137	1.8
13.0	171	1.5
14.0	184	1.5
3.8	189	1.0
6.6	178	1.0
25.0	143	2.0
10.0	113	2.0
12.0	72	2.0
13.0	59	2.0

Figure 2. Monthly outflow from the Toledo Bend Reservoir (Capacity: 6.29 km^3).

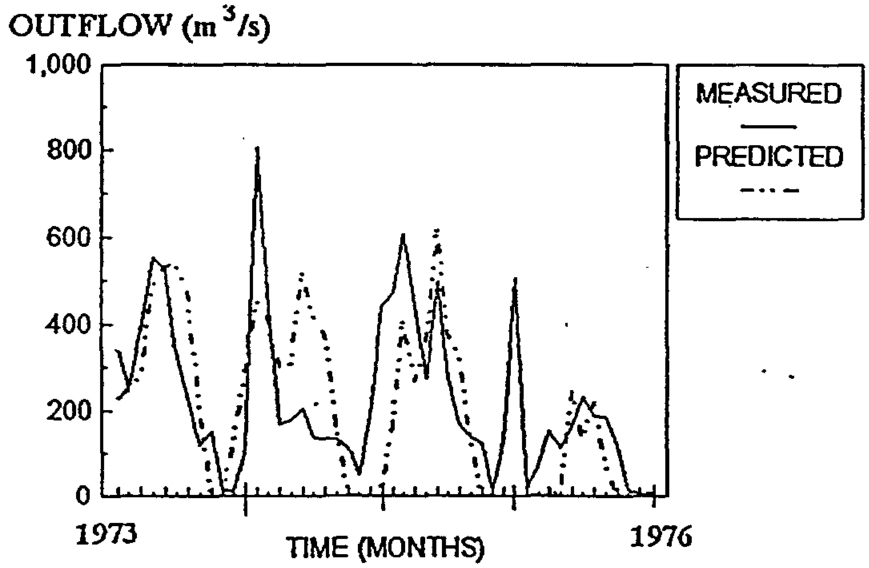

Figure 3. Monthly outflow from the Iron Bridge Reservoir (Capacity: 1.15 km^3).

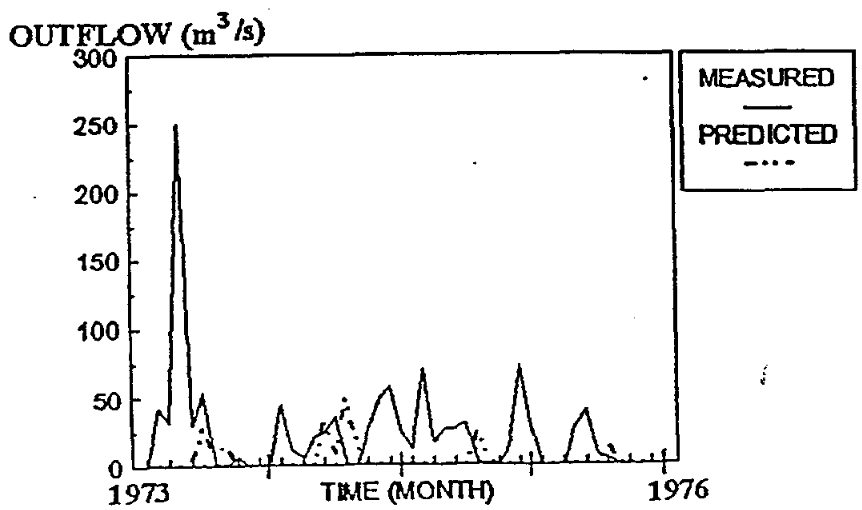

Figure 4. Monthly outflow from the Sam Rayburn Reservoir (Capacity: 6.92 km^3).

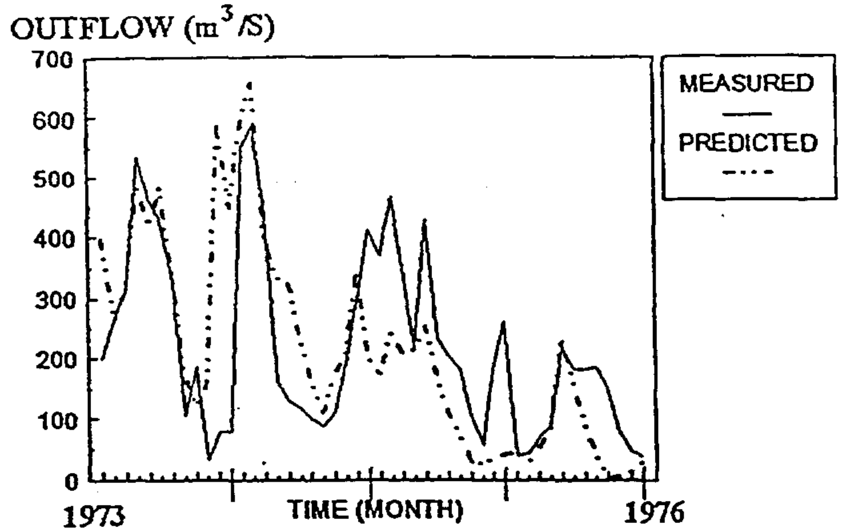

Figure 5. Mean values of the flow-capacity ratio.

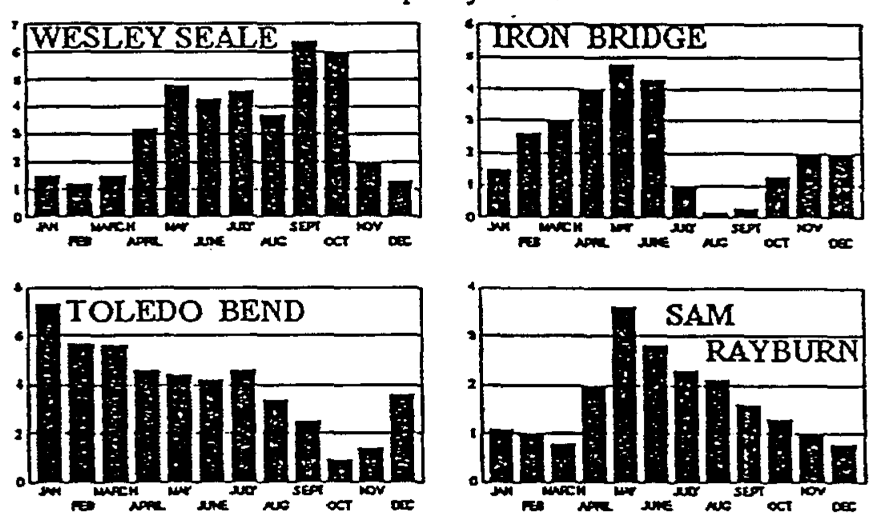

Figure 6. Standard deviations of the flow-capacity ratio.

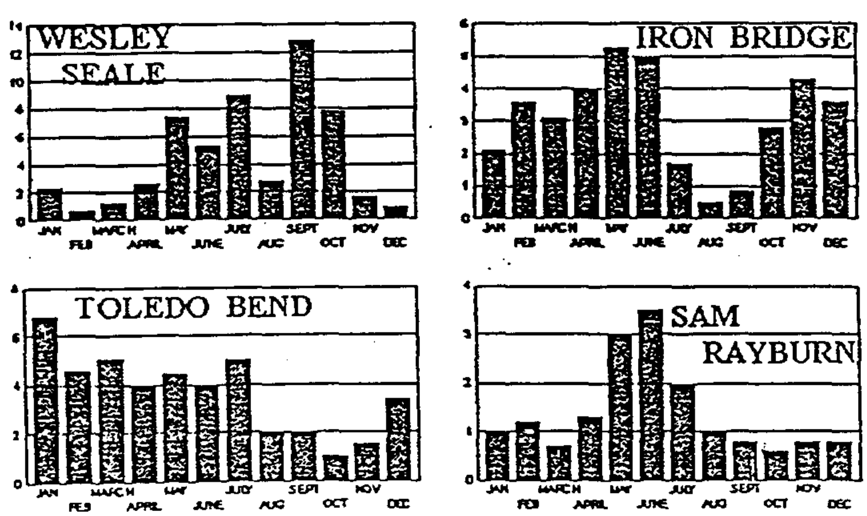

Table 4. BASEFLOW DAYS FOR TEN RESERVOIRS IN THE TEXAS GULF COAST.

Name	Built (year)	Capacity (km^3)	Inlet of Dam	Before Dam	After Dam	Comp. Data	Geology [1]
Leon	1954	0.05	16	14	23	20	SC-HGSh
Hubbard	1962	0.71	23	13	8	16	SC-ShSa
Whitney	1951	2.59	12	7	10	11	Li-Sh(alt.)
Palo Pinto	1964	0.05	17	24	9	23	SaS-Sh
W. Seale	1958	0.38	22	10	7	10	N/A
Belton	1954	2.31	18	15	9	19	Li-Sh
Robert Lee	1969	0.82	20	26	-	26	ClSi-SSh
San Angelo	1951	0.86	31	21	33	31	Cal-C-Sh
Toledo	1969	6.29	8	8	6	8	S-SiC
S. Rayburn	1965	6.92	10	7	-	7	Si-Sa-C

[1]S=Sand;C=Clay;Sa=Sandstone;Cal=Caliche;Sh=Shale;HGSh=Hard,Gray Shale;Cl=Clayley;Li=Limestone;Si=Silt;alt.=Alternate layers;N/A=Not available

Small Watershed Modeling and Assessment Using GIS

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Tarrant County WCID Number One

Introduction

A five-year cooperative project between Tarrant County Water Control and Improvement District Number One (District) and the USDA-Soil Conservation Service (SCS) began in October 1992. Tarrant County WCID controls five major reservoirs supplying water to Fort Worth and several other Metroplex communities and industries. The methodology being developed in this project is being used by several entities to meet requirements of Texas Senate Bill 818 that requires river basin assessments of water quality every two years.

Partners in the project are using the SWAT (Soil and Water Assessment Tool) model developed by USDA-Agricultural Research Service (ARS). Scientists with Texas Agricultural Experiment Station (TAES) have developed the interface between the Geographic Information System (GIS) databases and SWAT to provide required model inputs.

Intent of the project is to assess water quantity and quality under current and projected management conditions. Results will detect critical areas contributing to sedimentation and related nonpoint source water quality problems in drainage areas of the reservoirs.

Presented to Association of State Floodplain Managers, Comprehensive Watershed Management, 18th Annual Conference-May 8-13, 1994, Tulsa, Oklahoma

Description of Study Area

The Upper Trinity River Basin is located in north and east-central Texas (Figure 1). It encompasses all or portions of 19 counties. Five major reservoirs owned and/or managed by Tarrant County WCID control runoff from 6,474 square miles and serve a population of 1.5 million people with municipal, industrial, and recreation water. The reservoirs include Lake Bridgeport, Eagle Mountain Lake, Lake Benbrook, Richland-Chambers Lake, and Cedar Creek Lake (1992b).

Agricultural land uses are dominant in the basin and without adequate treatment and management, soils are subject to accelerated erosion. Best management practices (BMPs) for alleviating water quality problems are unique to each soil type, location and land use. Large amounts of sediment are being deposited in the water supply reservoirs, depleting water storage volume and increasing treatment costs..

Concept of Projects through Partnership

The Texas SCS Water Resource Assessment Team (WRAT) was formed in late 1992 and co-located with the ARS and TAES laboratory to accommodate transfer of SWAT modeling technology. Responsibility for the Upper Trinity Watershed Project was assigned to WRAT. Emphasis for the SCS team has been to develop projects involving small watersheds and to use the SWAT model and GIS applications at levels of greater detail. Partnerships on the Upper Trinity Cooperative Study have to date involved SCS, ARS, TAES, Tarrant County WCID, Texas Water Development Board, Trinity River Authority, and Texas Natural Resources Conservation Commission for at least some portion of the project. Many other agencies have been involved in development of GIS data layers. There is widespread interest in development of the SWAT technology for non-point assessment of small watersheds and large river basins.

Geographic Information System

The Soil Conservation Service uses the US Corps of Engineers' raster based Geographic Resources Analysis Support System (GRASS), a public domain GIS (1991). Simulations using SWAT are being performed in UNIX on the SUN workstation platform. INFORMIX is the relational database management system used by SCS. Most of the work involving GIS at the ARS/TAES laboratory has been with a base scale of 1:250,000 which is readily available for most if not all the United States. These GIS layers are the foundation for the HUMUS (Hydrologic Unit Model for the United States) project, a cooperative effort between SCS, ARS, and TAES at the Temple, TX laboratory. The purpose of the HUMUS project is to assist in the Resource Conservation Act (RCA) assessment of the status and condition of water resources of the nation under current and projected management conditions. SWAT model technology was originally developed for the HUMUS assessments.

The WRAT staff has assembled or developed most of the GIS layers at a scale of 1:24,000 for use in modeling the smaller watersheds. Collection of this data is the most critical element to model the watersheds (Srinivasan et al. 1993c). Basic layers and/or relational databases include information on soils, land use, topography, watershed or basin boundaries. Other databases include historical streamflow and weather data, political boundaries, point sources, confined animal feeding operations, oil and gas well locations, agricultural statistics and census data, and geology. The GIS interface also allows the user many graphic displays for viewing model output. Choices include single and multiple line graphs, pie charts, bar graph, scatter plot, comparative map generation, and statistics.

The Swat Model and GIS

SWAT is a basin-scale, continuous time water quality model integrated with a GIS to extract input data to simulate basin hydrology and conditions. Development of SWAT involved combining a routing procedure to the SWRRB (Arnold, 1990) simulation model. This allows loadings at sub-basin outlets to be routed through the stream network on a real time basis to the receiving reservoir or point of interest. Integration of GIS and SWAT eased the task of providing input for hundreds of sub-basins and multiple simulations.

Srinivasan and Arnold (1993a) applied the integrated system to simulate the upper portion of the Seco Creek basin by subdividing the area into 37 subbasins. They found that average monthly streamflow agreed with measured monthly streamflow values for the period January 1991 through August 1992.

SWAT has a unique feature that allows the output of other model runs to be imported at stream routing nodes throughout the watershed simulation. A simulation using very detailed data for a small subbasin of the watershed can be integrated into a general assessment of the entire watershed above a reservoir. This can indicated the targeted basin's effects on loadings at a basin outlet or reservoir. SWAT can handle other features such as point sources of water inflow/outflow and can accommodate irrigation diversions, return flows, wastewater treatment outfalls, and other municipal or industrial permitted uses. To be a realistic simulation of the watershed, the model must handle both nonpoint sources and all permitted point sources as well as water transfers in or out of the basin. Thus predicted streamflow can be compared to measured streamgauge records in the GIS.

The need for assessments of smaller areas with high level of detail requires that greater detail of GIS databases be available. The HUMUS project (Srinivasan et al., 1993b), as an example, used the STATSGO (1992a) soils geographic database (1:250,000 scale base) as one of the GIS layers in simulating entire river basins. STATSGO polygons represent soils associations that may include 20-30 individual soil series. The SCS soils and land use/cover for the Upper Trinity Project is a full coverage of the CBMS (computer based mapping system 1:24,000 scale) data that will provide more detail in the GIS layer and model input. Each soils polygon in CBMS represents an individual soil series. A link from the spatial data to the relational soils database provides soil properties for each soil to SWAT model input.

Use of SWAT and GIS by Tarrant County WCID

Plans for the Upper Trinity Project extend far beyond making a few simulations and preparing a report for the bookshelf. Tarrant County WCID will receive the working simulation model and complete GIS database for their project area on hardware to be used in their office.. Updating of both the model and databases are to be an ongoing process. The District intends to initially use the SWAT model as a management tool to help develop future sampling programs for the assessment of the watersheds that feed its reservoirs. It is anticipated that this and other models will be applied to the District's watersheds to help determine the areas contributing to sedimentation of reservoirs or nonpoint source pollutant loadings. As these programs are developed, the data generated will be used to supplement the ongoing work and ultimately provide a validated model designed around site specific areas. The District's future intention for use of this model will be to link this watershed model with the District's reservoir model to help evaluate the benefits to their reservoirs from implementation of BMPs in the associated watersheds.

Summary and Conclusion

The SWAT (Soil and Water Assessment Tool) and GRASS GIS integrated as a modeling tool can guide management decisions regarding runoff, sediment, nutrient and pesticide loadings for small watersheds. This tool allows assessment or evaluation of effects from a watershed based on hydrologic and hydraulic boundaries consistent with basic principles and standards for planning treatment alternatives in water resource projects.

The integration of the water quality model and GIS reduces significantly the time to prepare input data for models and simplifies model operation. As GIS layers become readily available, the effort to simulate current versus projected management will involve minimum timeframes and personnel.

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A SPATIAL DECISION SUPPORT SYSTEM FOR ASSESSING AGRICULTURAL NONPOINT SOURCE POLLUTION[1]

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Abstract: A spatial decision support system (SDSS) was developed to assess agricultural nonpoint source (NPS) pollution using an NPS pollution model and geographic information systems (GIS). With minimal user interaction, the SDSS assists with extracting the input parameters for a distributed parameter NPS pollution model from user-supplied GIS base layers. Thus, significant amounts of time, labor, and expertise can be saved. Further, the SDSS assists with visualizing and analyzing the output of the NPS pollution simulations. Capabilities of the visualization component include displays of sediment, nutrient, and runoff movement from a watershed. The input and output interface techniques/algorithms used to develop the SDSS, along with an example application of the SDSS, are described.
(KEY TERMS: distributed nonpoint source pollution modeling; GIS; decision support-system; Universal Soil Loss Equation; integration; visualization.)

INTRODUCTION

In the past, erosion estimates were commonly predicted using empirically derived equations including the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978). More recently, soil erosion and chemical movement models have been based on the major processes of soil erosion and water movement such as the detachment and transport of particles by rainfall and runoff (Beasley et al., 1980; Young *et al.*, 1985). Existing soil erosion models such as EPIC (Erosion Productivity Impact Calculator) (Williams *et al.*, 1984), CREAMS (Chemicals, Runoff, Erosion from Agricultural Management Systems) (Knisel, 1980), WEPP (Water Erosion Prediction Project) (Foster and Lane, 1987; Lane and Nearing, 1989), ANSWERS (Areal Nonpoint Source Watershed Environment Response Simulation) (Beasley *et al.*, 1980), and AGNPS (AGricultural NonPoint Source) (Young *et al.*, 1987 and 1989) provide users with analytical tools that allow them to predict erosion characteristics of slopes, fields, watersheds, and channels. These models also allow evaluation of management practices that influence certain factors contributing to erosion and provide significant insight into the processes of soil erosion. However, they have a number of limitations that restrict their widespread use.

Factors that have limited the use of simulation models as management tools include large data and input parameter requirements, parameters that are difficult to estimate or obtain, and uncertainty in inputs. Researchers have successfully shown that integration of simulation models with spatial databases and coded expertise to minimize input required from the user was consistent and complete enough in generating input data files for the simulation models (Arnold and Sammons, 1989; Heatwole, 1990; Shanholtz and Zhang, 1989).

Another major factor limiting the use of simulation models is a lack of assistance in analyzing the model results. The complex programs used to study erosion prediction can provide an overwhelming amount of data for analysis in even a small watershed. Use of graphics to visualize the spatially varying data and time dependent data such as runoff or sediment yield at the outlet can greatly enhance the ability of conservation managers to conduct further analysis and to make proper decisions (Bingner, 1989; Shoup and Becker, 1985; Barringer *et al.*, 1987).

One of the strongest reasons to implement an automated approach to resource planning is the ability to

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change questions, scenarios, or assumptions quickly and easily. Within a short time (especially compared to the time it would take to do manual calculations for a new query and then hand-draft maps), a complex analysis can be performed, using a combination of simple GIS analyses such as map overlays and boolean operations in GIS. Geographic Information Systems (GIS) are tools to collect, manage, store and display spatially varying data.

This paper is focused to achieve the following objectives:

- Develop methods to extract the input data from GIS for an NPS model using a hydrologic toolbox.
- Develop methods for visualizing agricultural nonpoint source pollution simulation results such as erosion, runoff, and chemical movement estimates.
- Demonstrate and discuss the benefits of the methods developed in the above objectives using an example data set.

BACKGROUND INFORMATION

Bekdash et al. (1991) performed best management practices (BMPs) evaluations using a linkage between GIS and the CREAMS model. The authors suggested that interpolation of maps for the delineation of stream channels and the watershed boundary is time consuming and felt that a systematic approach of extracting the required data is the right way of addressing the problem. Panuska *et al.* (1991) integrated two terrain-enhancing programs, TAPES-C and TAPES-G (Moore, 1988), into the AGNPS pollution model to automate the input of data including slope, slope length, channel slope and flow direction. Sasowsky and Gardner (1991) used a raster-based GIS to extract inputs for the Simulation of Production and Utilization of Rangelands (SPUR) model, a quasi-physically based surface runoff model in which a watershed is configured as a set of stream segments and contributing areas. Rewerts and Engel (1991) integrated a watershed simulation (ANSWERS) with a raster GIS. Their Project Manager can be used to gather information from the user, extract data from a GIS, create an ANSWERS input file, and read ANSWERS output into new GIS layers. The authors estimated that the time required to prepare an input data set for the ANSWERS model could be significantly reduced by using the Project Manager, possibly by 7 to 10 times.

Hession (1990) suggested that once the base coverage exists in a GIS, it is merely a two- to three-hour process to build a new AGNPS input file for a different cell size, a different subwatershed, or updated land use conditions. In comparison, to build a new AGNPS input file at a different cell resolution using manual techniques, the process must essentially b started from scratch. Further, Hession (1990) statec that it takes from three person days for a 200 hectare (500 acre) watershed to one person month for a 9,300 hectare (23,000 acre) watershed to prepare input data for an AGNPS run. These estimates are based on a cell size of 16 hectares (40 acres).

DEVELOPMENT OF SDSS

Due to the difficulties in using NPS pollution models, an alternative approach suggested by various researchers is to collect or derive the necessary data from a spatial data base (i.e., a GIS). The NPS pollution model and the GIS used for the SDSS were AGNPS (Young *et al.,* 1985) and GRASS (Geographical Resources Analysis Support System) (U.S. Army, 1987). The following sections describe the NPS pollution model, the GIS, their integration, and supporting tools (i.e., the hydrologic toolbox). The hydrologic toolbox is a collection of procedures that describe the interactions between various hydrologic parameters and was developed within the GRASS GIS environment. Thus, any hydrologic models that use thes parameters can utilize the hydrologic toolbox.

Integration Approach

The user's view of the SDSS and interactions between different components of the system are shown in Figure 1. The components include the input interface to the NPS pollution model, output interface (*Visualization*) to the NPS pollution model, and the hydrologic toolbox to facilitate the input/output interfaces to this and other models. All components in this system are modular and interact through the GIS tool, which serves as the core of the system. By keeping the components of the spatial decision support system modular, one can use any of the components as a stand-alone module, in combination with other modules, or add/modify new/existing components.

NPS Pollution Model

The distributed parameter model AGNPS was used in the development of the SDSS. The AGNPS model was developed to serve as a land management tool fo estimating sediment and nutrient yields in surface water runoff from agricultural lands and to compare

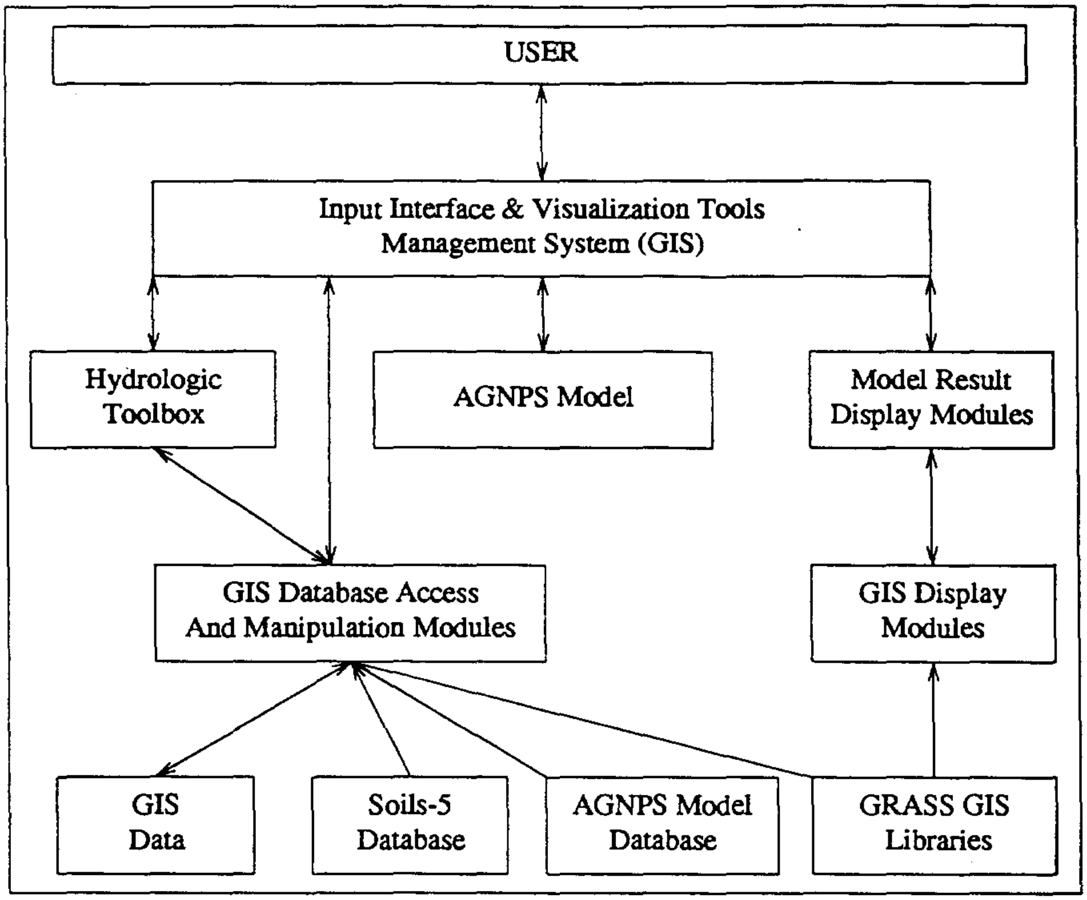

Figure 1. User's View of SDSS.

the potential impacts of various land management strategies on the quality of surface water runoff (Young *et al.*, 1985). AGNPS is used to estimate changes in concentrations of sediment, nutrients (N, P), and chemical oxygen demand (COD) in runoff waters from agricultural watersheds (Young *et al.*, 1985). It is a storm (event-based) model, uses distributed parameter inputs, and operates on a cell basis (uniform square areas subdividing the watershed). The primary advantage of this distributed parameter approach is the potential for providing a more accurate picture of the hydrologic and pollutant transport system under alternative management conditions. The AGNPS model has been modified to run on UNIX platforms (Srinivasan, 1992), which helps its integration with the GRASS GIS tool. GRASS is a public domain raster GIS designed as a general purpose, raster graphic modeling and analysis package initially developed for land and environmental planners at military installations. GRASS is also capable of some vector GIS operations, image processing, and graphics production. GRASS data layers can be transported to and from several other GIS platforms.

Hydrologic / Other GIS Based Tools

Several hydrologic GIS-based and/or other generic tools were used in developing the NPS pollution-GIS tool interfaces (AGNPS-GRASS links) to keep the SDSS structure as modular as possible (Figure 1). The following tools are used either in the AGNPS-GRASS input interface or the AGNPS-GRASS output interface (*Visualization Tool*). These tools can be classified into one of two categories: (1) hydrologic tools (*r.cn, r.soils5,* and *r.fill.direct*); or (2) other generic tools (*d.rast.arrow, d.rast.number, d.rast.zoom,* and *d.rast.edit*). These tools can be used as stand-alone modules or can be integrated with other modules or tools within a GIS environment.

r.cn

The Soil Conservation Service curve number (SCS CN) procedure is used to predict runoff volume from watersheds. *r.cn* is the curve number tool written in the 'C' language and incorporated as a tool in the GRASS GIS. *r.cn* generates a curve number map for a watershed based on four layers (Hydrological soil group, Hydrologic condition, Management practice, and Land use) of information using the rules stipulated by the SCS Hydrology Handbook (USDA, 1972) and can convert from AMC (antecedent soil moisture condition) II to either AMC I or III (Arnold et al., 1990).

r.soils5

r.soils5 extracts soils information from the Soils-5 database for a GRASS soil series layer and creates layers for the soil properties of interest. The Soils-5 database (Goran, 1983) is a national database providing hundreds of soil properties for each soil series. *r.soils5* allows the user to classify a soil series layer with Soils-5 database information and can be directly used as input for many hydrologic models.

r.fill.direct

Digital elevation models (DEMs) can be used to derive a wealth of information about the morphology of a land surface using neighborhood operations to calculate slope, aspect, and shaded relief (Klingebiel *et al.*, 1988) and points of inflection (Peucker and Douglas, 1975). From past research, it has been recognized that depressions, areas surrounded by higher elevation values in the DEM data, are the nemesis of hydrologic flow routing.

r.fill.direct was developed to generate a depressionless DEM data layer and unique flow direction (aspect) layer based on work by Jenson and Domingue (1988). The resulting depressionless elevation layer can further be manipulated to derive slopes and other topographic attributes required by hydrologic models.

d.rast.arrow

d.rast.arrow is a GRASS GIS tool that displays arrows on aspect maps to indicate flow directions. *d.rast.arrow* is designed to help the user better visualize surface water flow direction indicated by an aspect cell map. The *d.rast.arrow* tool is used in the *Visualization Tool* to show the flow and routing direction used in AGNPS. An arrow can point in one of eight directions for AGNPS.

d.rast.num

d.rast.num is a GRASS GIS tool to display cell category numbers on maps. After displaying a cell map, the *d.rast.num* program may be run to draw the corresponding cell value over each cell to indicate to which category that cell belongs. The *d.rast.num* tool is used in the *Visualization Tool* to show the cell number map, since AGNPS keeps track of its data through cell numbers.

d.rast.zoom

d.rast.zoom is an interactive GRASS GIS tool to zoom in or zoom out on a cell map displayed on the graphics monitor. This tool is used in the *Visualization Tool* to allow one to closely view outputs for an area of interest.

d.rast.edit

d.rast.edit is a graphical raster map editor in the GRASS GIS tool. The *d.rast.edit* program facilitates editing cell values in a layer using the mouse cursor on the graphic display monitor. Within the *d.rast.edit* program, previously defined tools (*d.rast.arrow*, *d.rast.zoom*, and *d.rast.num*) can be invoked, allowing one to edit a flow direction map and view the corrected map. This tool can be used in both AGNPS-GRASS input and output interfaces to change cell values for an area to study the effects on the output of the model.

AGNPS-GRASS INPUT INTERFACE

The major objective of the AGNPS-GRASS input interface is to minimize the user interaction in preparing the input data for the AGNPS model and to minimize the number of user supplied/developed GIS database layers. Figure 2 shows a schematic of the AGNPS-GRASS input interface. Of the 22 input parameters required by the AGNPS model for each cell (Table 1), the interface prepares the input data from 7 GIS database layers (see Figure 2) and a watershed layer that shows the watershed boundary. A few parameters, such as rainfall amount and its corresponding energy intensity value, are needed for the whole watershed and therefore are obtained from the user. The major asset of the GIS approach is its flexibility, data analysis capabilities, data preparation

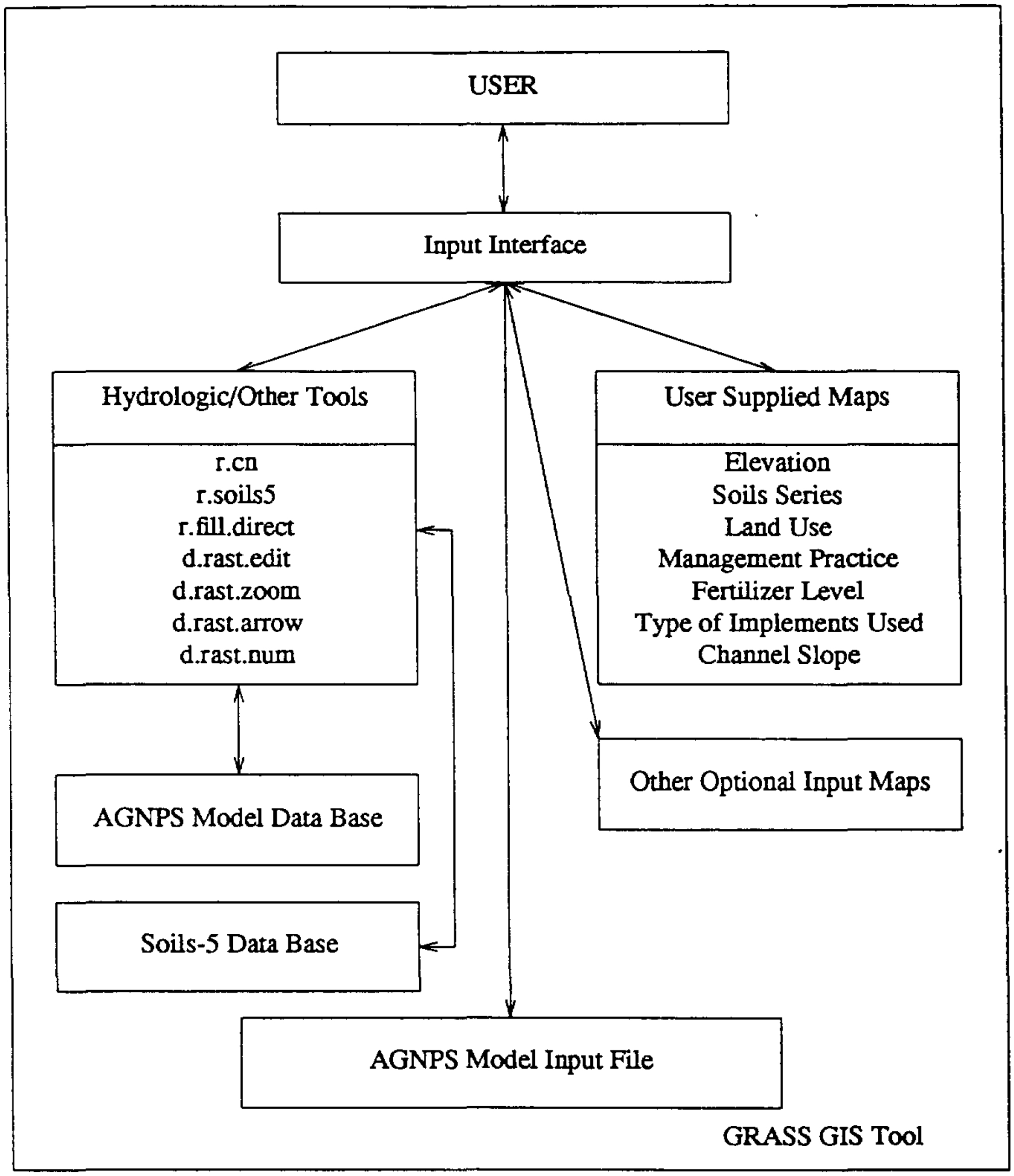

Figure 2. Schematic of the AGNPS-GRASS Input Interface.

capabilities, potential for reuse, and ease of updating as compared with a manual approach.

The AGNPS manual is the primary source for determining input values. Even though the AGNPS user's manual and the Soils-5 data base provide most of the input data needed by the model, considerable expertise is still required for selecting parameters. The AGNPS-GRASS input interface (see Figure 2) development for extracting 22 input parameters (see Table 1) for the AGNPS model was done using programs written in the 'C' language and using GRASS subroutines to manipulate the GRASS GIS data layers directly. Extraction of the 22 parameters using the input layers and GIS procedures are summarized in Table 1, and a more detailed description can be found in Srinivasan (1992). To obtain default values for input parameters, either the AGNPS User's Manual suggested procedures or tables are used.

TABLE 1. List of AGNPS Cell Input Parameters, Descriptions, Input Layers, and GIS Procedures.

No.	AGNPS Parameters	Descriptions	Input Layers/GRASS Tools
1	Cell number	A cell number layer is generated in GRASS	watershed
2	Number of cells into which it drains	An aspect layer	elevation/r.fill.direct
3	SCS curve number	Curve number	land use, management, hydrologic condition, and hydrologic soil group/r.cn
4	Average slope percent	Overland slope	elevation/r.slope.aspect
5	Slope shape factor	Overland flow shape; assumed to be uniform	
6	Average field slope length	Derived using unit stream power theory (Moore and Burch, 1986a, 1986b)	aspect and elevation
7	Average channel slope (percent)	User input, else 50 percent of overland slope	channel slope
8	Average channel side slope (percent)	Use soil texture information	soils/r.soils5
9	Mannings *n*	Use standard table	soil texture and land use
10	USLE K factor	Use soils-5 database	soils/r.soils5
11	USLE C factor	Use SCS technical guide	C factor
12	USLE P factor	Use SCS technical guide	P factor
13	Surface condition constant	Use AGNPS Manual	land use and management
14	Aspect	An aspect layer	elevation/r.fill.direct
15	Soil texture	Use soils-5 database	soils/r.soils5
16	Fertilization level	Use field information	nutrient levels
17	Incorporation factor	AGNPS Manual	management
18	Point source indicator	User provided	
19	Gully source level	User provided	
20	Chemical oxygen demand	AGNPS Manual	land use
21	Impoundment factor	User provided	
22	Channel indicator	User provided	

AGNPS-GRASS OUTPUT INTERFACE (*VISUALIZATION TOOL*)

The complex programs used to study erosion prediction can provide an overwhelming amount of data for analysis in even a small watershed. Graphical displays of the results have proven to be a more effective and efficient way of interpreting results and in making decisions than scanning through pages of numerical output in the form of tables. Visual displays can convey more data in a short time period than other methods. AGNPS provides detailed output; however, users often cannot make use of it due to a lack of analytical and visual aid tools.

Primary output given by AGNPS for watersheds being analyzed includes estimates of runoff volume, peak flow rate at the watershed outlet, area-weighted erosion for both upland and channel areas, sediment delivery ratio, sediment enrichment ratio, mean sediment concentration, and total sediment yield for each of five sediment particle size classes. A nutrient analysis is also available that includes N, P, and COD mass per unit area for both soluble and sediment adsorbed phases.

The *Visualization Tool* allows the user to display sediment, runoff and chemical movement in a watershed and produces simple statistics of both inputs and outputs of the AGNPS model for a cell or an average for an area. This tool greatly assists the decision making process. With visualization capabilities such as those described here, distributed parameter NPS models become more useful. More information about the *Visualization Tool* interface can be found in Srinivasan (1992).

The interface for visualizing and analyzing (Figure 3) the results of the AGNPS model was implemented using the GRASS GIS tool and programs written in the 'C' language. Initially the visualization interface generates 17 GIS layers (Table 2) from the ASCII output files of an AGNPS run. The layers generated can be saved for future evaluation of output.

The inputs required for the *Visualization Tool* include the watershed boundary map, the cell size, the flow direction (aspect) layer for the watershed, and the ASCII AGNPS input and output file names. Once data are extracted, a menu (see Figure 3) wit choices as described in Table 3 is used to begin the decision making process based on the model results.

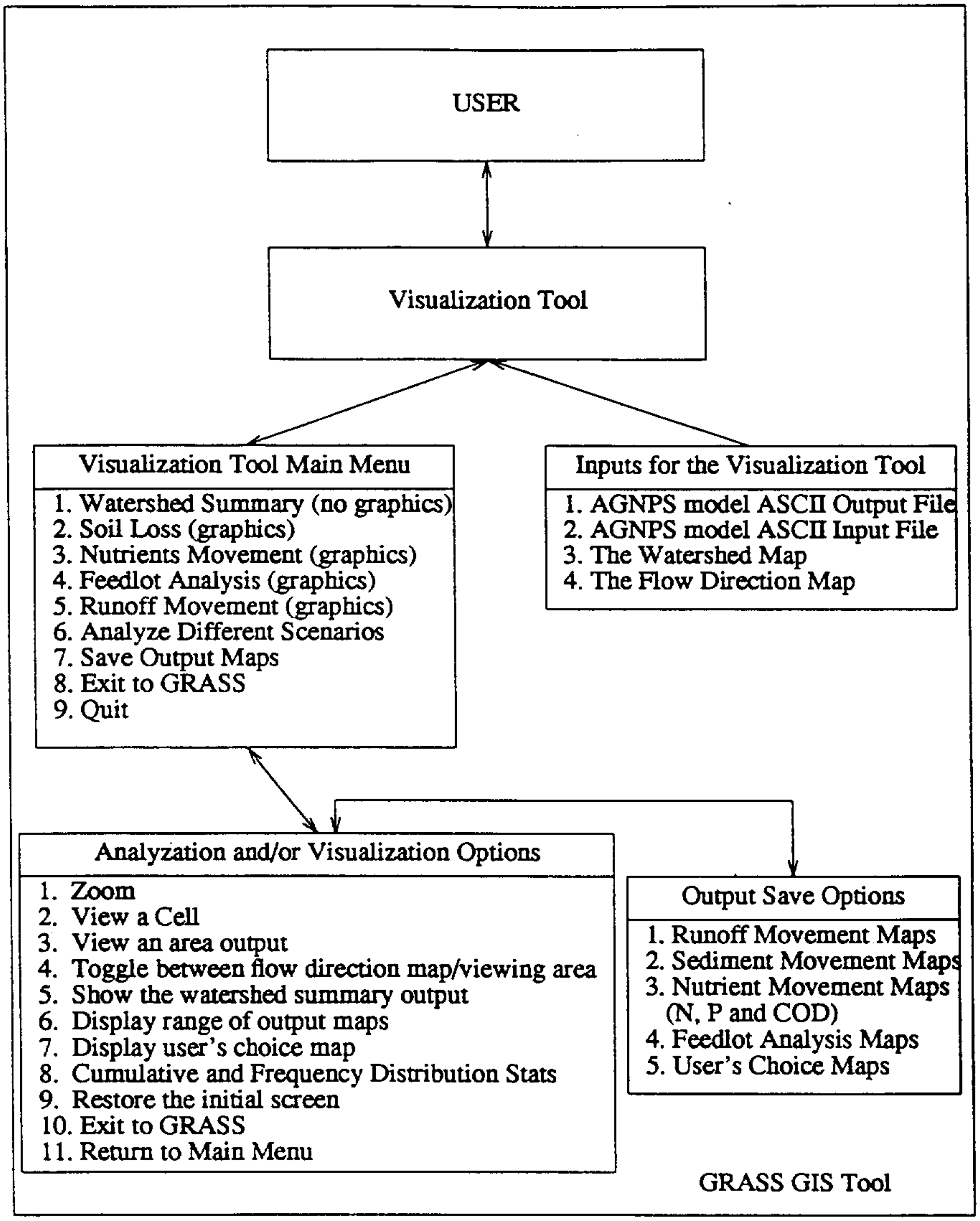

Figure 3. Schematic of the AGNPS-GRASS Output Interface (Visualization Tool).

The *Visualization Tool* splits the screen into various screens to display the output of the model. The number of windows created depends on the type of output displayed. The tool always reserves an ASCII terminal (non graphics) for interacting with the user. The first screen (see Figure 3) provides various options including a watershed summary (no graphics) and spatially distributed soil loss, nutrients, runoff, and feedlot movement output (graphics) of a watershed.

VISUALIZATION TOOL OPTIONS

Option 1 (see Figure 3) displays the watershed summary for soil loss, runoff and nutrient movement at the watershed outlet in the non-graphics window. Options 2-5 (see Figure 3) move to the next screen (Figure 3) where the appropriate options are displayed. The display screen layout for option 2 (see

Figure 3), soil loss, is shown in Figure 4. The top row windows display the output maps (see Table 2). A legend for each of the output maps is displayed, showing the color and the numerical value associated with it. The right hand top corner window displays the watershed map with cell numbers by laying a grid on top for reference using the *d.rast.num* program. Below this cell number map, the aspect map of the watershed with arrows pointing in the flow directions is displayed using the *d.rast.arrow* program. In the bottom row, two windows display the input and output statistics for a cell or area in the left and right windows respectively. The left bottom window shows cell inputs. For example, for soil loss (see Figure 4), the bar chart shows the amount of erosion, deposition and sediment movement in tons for a cell or average values for a group of cells. Cell statistics, including accumulation area in acres, percentage of deposition, and weighted average erosion are displayed. The *Analyze Different Scenarios* option (see Figure 3) allows one to visualize and analyze a different simulation for the same resolution as the current scenario. Table 3 summarizes the spatially distributed input and output options.

TABLE 2. AGNPS Output Maps Created Using Visualization Tool.

AGNPS Output	Maps Generated
Hydrology Output	Cell number Runoff generated Runoff from upstream Runoff to downstream
Sediment Output	Erosion Deposition Sediment leaving the cell
Chemical Output	Nitrogen associated with sediment (generated) Nitrogen associated with sediment (leaving) Nitrogen associated with runoff (generated) Nitrogen associated with runoff (leaving) Phosphorus associated with sediment (generated) Phosphorus associated with sediment (leaving) Phosphorus associated with runoff (generated) Phosphorus associated with runoff (leaving) COD associated with runoff (generated) COD associated with runoff (leaving)

TABLE 3. Spatially Distributed Output Options and Descriptions (*Visualization Tool*).

Option No.	Option Name	Description
1	Zoom	Adjusts viewing region of maps displayed; allows zooming in or zooming out.
2	View a cell	Displays a selected cell's input and output statistics in the bottom row of windows (Figure 4).
3	View an area output	Displays a selected area's average input and output statistics in the bottom row of windows (see Figure 4).
4	Toggle option	Toggles between the current viewing area within the watershed and the flow direction map.
5	Watershed summary	Displays the summary at the outlet of the watershed for all the outputs in the ASCII (nongraphics) window.
6	Display ranges of output	Displays output layers (see Table 2) for a specified range of values (see Figure 3) and allows the maps to be saved.
7	Display user's choice o:`maps	Displays the user's choice of maps.
8	Cumulative and frequency distribution	Displays the cumulative and frequency distribution area curves for any of the output variables.

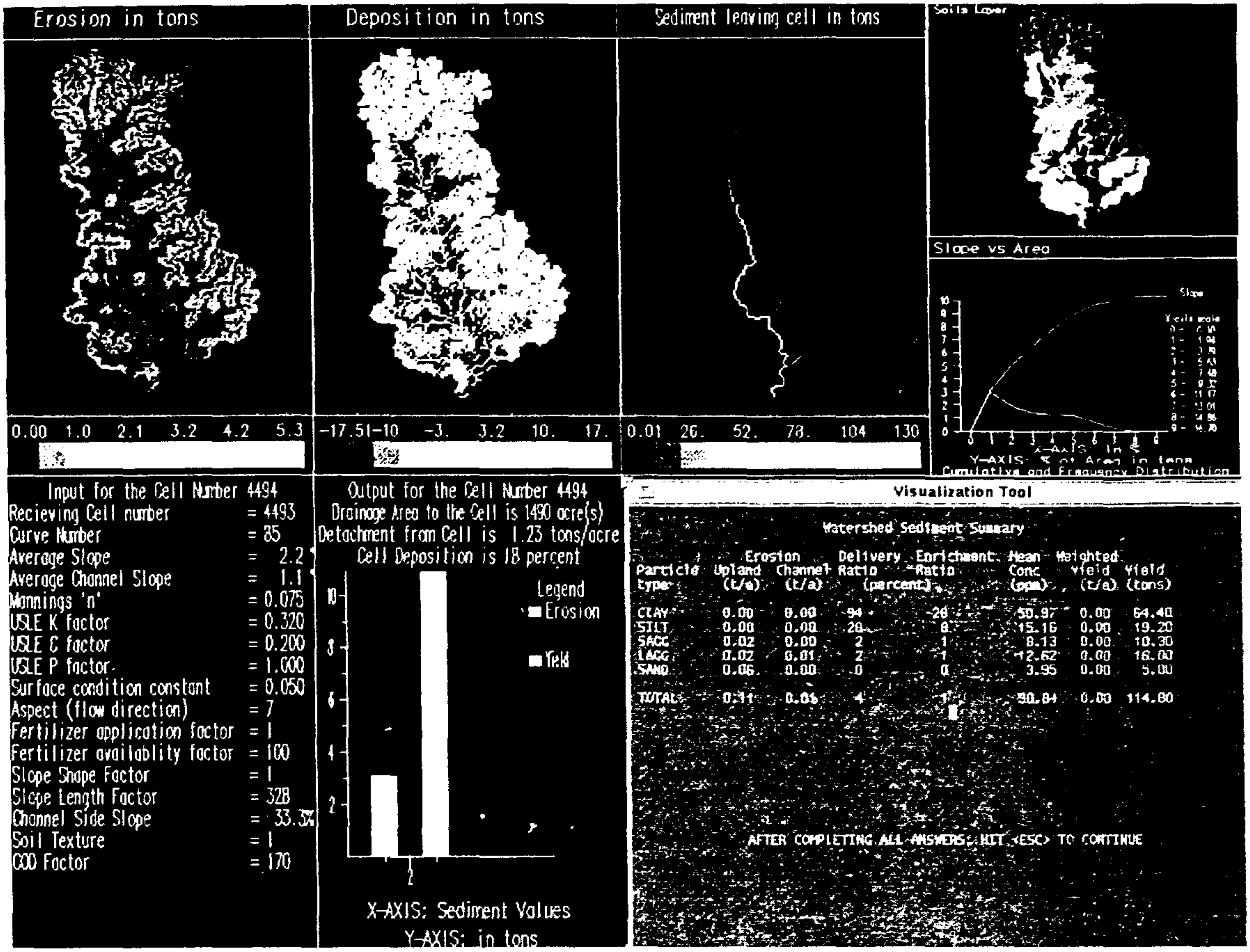

Figure 4. Sediment Output Screen of Visualization Tool for Seco Creek Watershed.

APPLICATION OF THE SDSS

The SDSS was applied to several watersheds, including the upper drainage basin of the Seco Creek watershed located in south central Texas (see Figure 4). The total area of the basin is 11,641 hectares. The basin was modeled using a square 1 hectare grid (100 X 100m). To date, the AGNPS model has not been applied to a basin this large with such a small cell size because the PC-version of the AGNPS model is limited to 1900 cells. More than 98 percent of the Seco Creek basin is rangeland. The base GIS layers were digitized by the SCS-Fort Worth GIS center. The elevation contours were digitized at a 1:24000 scale from USGS 7.5 minute maps. The field boundary map and soils map were also digitized at 1:24000 scales from county records. From the three base layers, the remaining layers were created/ reclassed to model the basin using the SDSS. The soils in the watershed are primarily the Tarrant soil series, which has a high clay content. The basin has been monitored by the USGS since 1966. Unfortunately, the water quality data were sampled once every 90 days. Hence, only the simulated runoff outputs were compared to the USGS average daily flow records.

Table 4 shows the simulated versus observed runoff flow and their mean values for 13 storms that were modeled using the SDSS. The runoff values at the outlet of the watershed were generally underpredicted. One of the reasons attributed to the underprediction was that the rainfall was assumed by the model to be uniform across the watershed. However, in this application, only one weather station was located near the outlet of the watershed. Of the events simulated, the model tended to underpredict during the winter season and either overpredict or more closely predict values during the summer season (see Table 4). The R^2 of observed and simulated runoff was 0.64, and the slope of the regression line was 0.588. The standard deviations of measured and predicted runoff were 4.86 mm and 3.56 mm, respectively.

TABLE 4. Observed and Simulated Runoff Results for the Upper Seco Creek Watershed.

Date	Rainfall (mm)	AMC	Runoff Observed (mm)	Runoff Predicted (mm)
09/14/90	40.6	I	0.07	0.01
05/02/91	59.4	I	4.69	0.26
07/21/91	51.1	I	0.87	0.09
11/17/91	38.1	II	1.51	0.77
12/19/91	53.1	II	1.74	2.10
12/20/91	52.6	III	17.60	9.74
01/26/92	39.1	I	1.76	0.01
02/03/92	47.8	II	2.63	1.60
03/03/92	29.2	I	0.16	0.01
03/04/92	39.1	III	7.25	4.08
03/27/92	84.3	I	6.82	1.46
06/07/92	41.9	III	2.66	5.73
06/09/92	52.1	III	8.51	9.94
		Mean	4.33	2.74

The Antecedent Soil Moisture Condition (AMC) has significant influence on the runoff prediction, and it is difficult to observe the runoff from an individual storm when the duration is more than a day. In addition, the base flows were also included in the observed data. There could be a better match between observed and simulated if the base flow from individual storms was removed and then compared. The purpose of this application was to demonstrate the capabilities of the SDSS using existing spatially distributed data and not to validate the AGNPS model.

One of the major advantages of the SDSS is its capability to simulate several hundred scenarios within a short time. In this application, a lack of monitoring of all the constituents at the outlet and at various locations within the watershed prevented performing a detailed validation of the AGNPS model. The concept of spatially distributed modeling is evolving and more careful monitoring has to be planned to validate spatial predictions. However, the integrated system presented is intended for the comparison of management and land use practices, and it is likely that the users will often make only a best estimate of the prevailing conditions for a single event.

Figures 4 and 5 show the sample outputs from the *Visualization Tool*, described schematically in Figure 3. Figure 4 shows the sediment movement results of the December 20, 1991, event. The upper three windows show simulated erosion, deposition and yield movement within the watershed. The right most window on the top row shows the soils layer for the watershed. The bottom two windows in Figure 4 show the input and output statistics of cell 4494 (see Figure 4) from the AGNPS model. The ASCII window shows the sediment delivered to the outlet of the watershed and particle size distributions of the sediment. The information, as shown in Figure 4, helps managers spatially identify problem areas and can help them understand the causes by providing information about the model inputs. Once problem areas are identified, land use, management, and structural practices can be proposed to rectify them, and the practices' effectiveness can be simulated using the decision support tool. In Figure 5, two simulation results were compared and displayed. For the same event, the outputs due to range and crop conditions were simulated and the runoff outputs were displayed. The bottom two windows show average statistics for a selected area in one of the top row windows for both simulations. The bottom right two windows show the difference in runoff for the current (range condition) and the selected (cropped condition) land uses. It is believed that the *Visualization Tool* will be a powerful tool for assisting decisionmaking processes by manipulating and displaying NPS pollution model input and output data graphically in a quick and easy manner.

SUMMARY AND CONCLUSIONS

A spatial decision support system (SDSS) was developed that consists of input, output (*Visualization*), and simulation model components. The SDSS is a loosely integrated system using the AGNPS (AGricultural NonPoint Source) pollution model and the GRASS GIS tool. Several additional GIS tools were developed that can be used either to derive inputs or visualize outputs of various nonpoint source pollutions models, including AGNPS. The SDSS can be used to assist with management of runoff, erosion, and nutrient movement in agricultural watersheds.

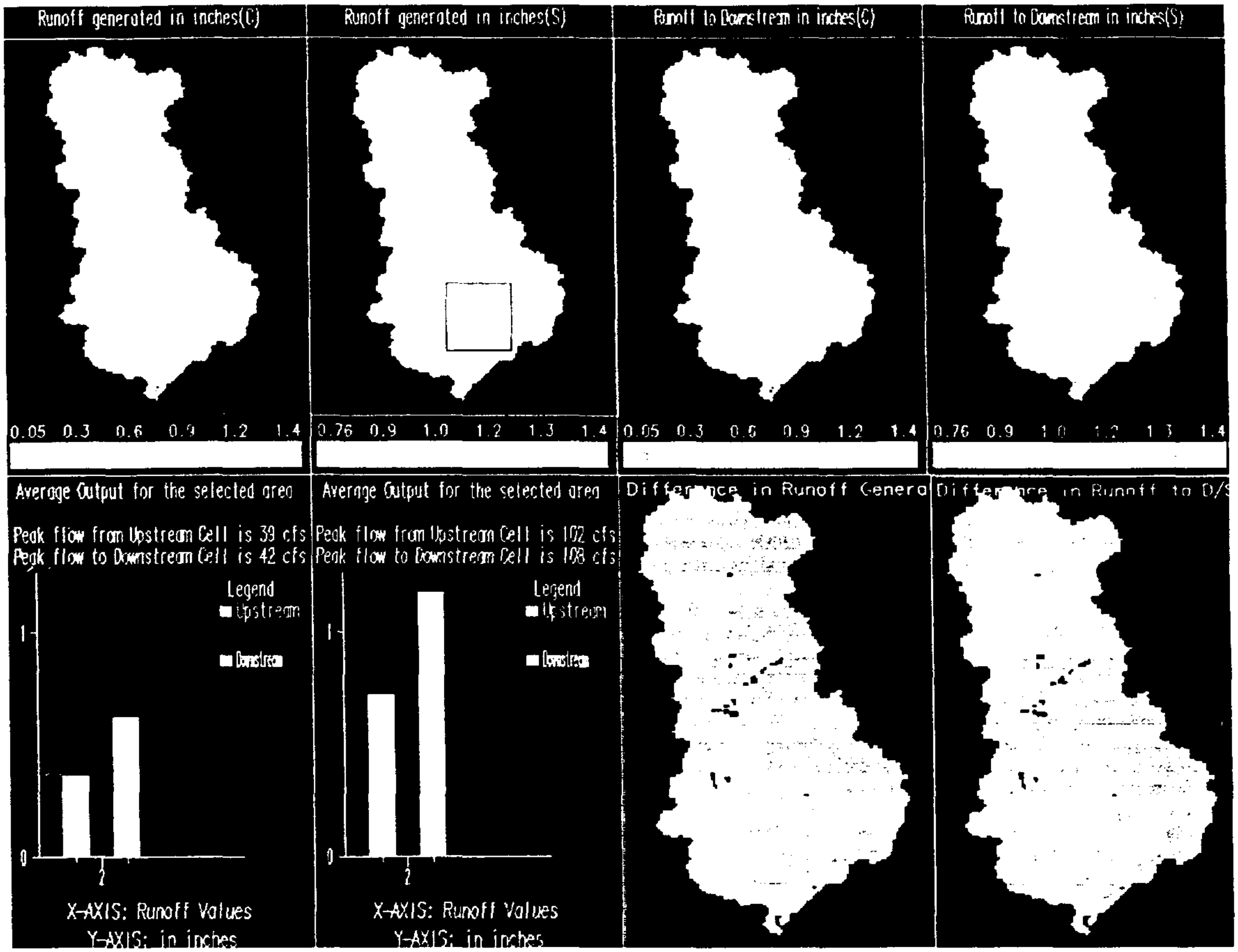

Figure 5. Runoff Output Screen of Two Scenarios in Visualization Tool for Seco Creek Watershed.

The integrated system assists with development of AGNPS input from GIS layers, running of the model, and interpretation of the spatially varying results. The system is currently being evaluated on numerous watersheds within the United States, Portugal, and Australia, and preliminary results suggest that the integrated GIS/AGNPS model significantly reduces the time required to obtain the data needed by AGNPS, simplifies operation of AGNPS, and most importantly, allows the identification of problem areas very quickly. Once problem areas are identified, land use, management and structural practices can be proposed to rectify them, and the practices' effectiveness can be simulated using the decision support tool. The SDSS was applied to the Seco Creek, Texas, watershed and simulated runoff values were compared with the observed values.

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INTEGRATION OF A BASIN-SCALE WATER QUALITY MODEL WITH GIS[1]

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ABSTRACT: Geographic Information Systems (GIS) have been successfully integrated with distributed parameter, single-event, water quality models such as AGNPS (AGricultural NonPoint Source) and ANSWERS (Areal Nonpoint Source Watershed Environmental Response Simulation). These linkages proved to be an effective way to collect, manipulate, visualize, and analyze the input and output date of water quality models. However, for continuous-time, basin large-scale water quality models, collecting and manipulating the input data are more time-consuming and cumbersome due to the method of disaggregation (subdivisions are based on topographic boundaries). SWAT (Soil and Water Assessment Tool), a basin-scale water quality model, was integrated with a GIS to extract input data for modeling a basin. This paper discusses the detailed development of the integration of the SWAT water quality model with GRASS (Geographic Resources Analysis Support System) GIS, along with an application and advantages. The integrated system was applied to simulated a 114 sq. km upper portion of the Seco Creek Basin by subdividing it into 37 subbasins. The average monthly predicted streamflow is in agreement with measured monthly streamflow values.

(KEY TERMS: geographic information systems; water quality; distributed parameter modeling; natural resource databases; Soil and Water Assessment Tool (SWAT); basin scale modeling.)

INTRODUCTION

The spatially and temporally distributed nature of hydrological processes often limits identification and assessment of water quality and quantity. Once water quality problems are identified, several proven techniques are available to minimize the problems. Models are often used to evaluate the best available alternative control measures. Type, scale, and level of application of these models depend on the kind of questions to be answered. This is due to the site-specific nature of water quality problems, which often renders general rules or solutions infeasible.

Models are effective tools for identifying problem areas of water quality. Some widely-used models include EPIC (Williams *et al.*, 1983), ANSWERS (Beasley *et al.*, 1980), WEPP (Foster and Lane, 1987), CREAMS (Knisel, 1980), AGNPS (Young *et al.*, 1989), SWRRB (Arnold *et al.*, 1990), and ROTO (Arnold, 1990). Models and decision support systems are often used to identify water quality problem areas and to evaluate the effectiveness of hypothetical solutions. However, the use of these models is limited because:

- Each model addresses specific issues in water quality areas along with a set of assumptions, and input requirements vary significantly. For example, models are either non-spatially distributed (EPIC, CREAMS), or spatially distributed (ANSWERS, AGNPS, SWRRB); single-event (AGNPS, ANSWERS, or continuous-time scale (EPIC, CREAMS, SWRRB, ROTO); field-scale (WEPP, EPIC, CREAMS), or watershed/basin-wide (ANSWERS, AGNPS, SWRRB).

- Multiple goals may be site-specific and vary within a study area, requiring a combination of techniques or models to address the problems. Simultaneously simulating water quality and quantity characteristics in different parts of the study area, for example, falls beyond the scope of most models.

- The amount of time, expertise, and cost required for acquiring input data, running the models, and analyzing the results are growing, with complexity level varying across the models. For example, as the models begin to address several water quality and quantity concerns, the information needed to execute

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the models has increased significantly (a simple model like USLE requires only six inputs, while a spatially-distributed, single-event model like AGNPS requires 22 inputs for each cell or grid within a study area). The data need can vary significantly between and within models, depending on the questions to be answered, thereby tremendously increasing the cost, time, and complexity of analyzing results.

The integration of a Geographic Information System (GIS) with distributed parameter models can eliminate many of the limitations associated with the use of these models.

In recent years, GIS has played a role in natural resources modeling and proved to be an effective tool in using NPS (nonpoint source) pollution models. Srinivasan and Engel (1991a, 1991b) integrated the AGNPS model with the Geographic Resources Analysis Support System (GRASS) (U.S. Army, 1988) GIS to extract inputs to run the AGNPS model and to display and facilitate analysis of model output. Rewerts and Engel (1991) integrated the ANSWERS model with the GRASS GIS to build inputs to run the model. Both AGNPS and ANSWERS are single-event distributed-parameter models that require a watershed to be divided into square grids and resample like a raster-based GIS, where the data are stored in a grid-like array. There are significant differences between the single-event and continuous-time distributed models, both in methods of extracting inputs and methods of analyzing and displaying outputs, due to the time component involved in continuous-time modeling. Growing numbers of researchers are exploring the role of GIS in hydrologic and water quality modeling (e.g., Tim *et al.*, 1991; Chen *et al.*, 1993; Chairat and Delleur, 1993).

Continuous-time, distributed-parameter models consider the basin or watershed divided into subbasins based on topography, soil, and land use and thus preserve the spatially-distributed parameters and homogeneous characteristics within a subbasin. Collection of inputs for such models is often difficult due to the level of aggregation and the nature of spatial distribution. The objective of this study was to develop a GIS interface to automate inputs to a continuous-time, distributed-parameter model called the Soil and Water Assessment Tool (SWAT) (Arnold, 1992).

THE SWAT MODEL

SWAT was developed to predict the effect of alternative management practices on water, sediment, and chemical yields from ungaged rural basins. The model was developed by modifying the SWRRB model for application to large, heterogeneous rural basins. Major changes to SWRRB include: (a) expanding the model to allow simultaneous computations on several hundred subwatersheds (the upper limit is 2500 subbasins), and (b) adding components to simulate lateral flow from the soil profile (0-2 m), ground water flow from the shallow aquifer (2-25 m), reach routing transmission losses, and sediment and chemical movement through ponds, reservoirs, streams, and valleys. SWAT operates on a daily time step and is capable of simulating 100 years or more. Major components of the model include surface hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides, ground water and lateral flow, and agricultural management. Srinivasan *et al.* (1993) used the SWAT model to simulate water and sediment movement for the 18 major river basins of the U.S.

The SWAT model offers significant advantages over the combined SWRRB/ROTO model (Arnold, 1990). SWAT offers distributed-parameter and continuous-time simulation, flexible watershed configuration, irrigation and water transfer, lateral flow, groundwater flow, and lake water quality components. The distributed-parameter, continuous-time feature was achieved by developing a new routing structure. SWRRB routes from subbasin outlets directly to the basin outlet for simplicity. The new routing structure in SWAT is required to allow large basins to be simulated, provide more realistic routing, allow for more subbasins to be easily added, and simplify GIS linkages and database management. A detailed description of the model and model inputs is found in Arnold *et al.* (1993).

SWRRB did not simulate water transfer within a watershed; however, for the large basins simulated by SWAT, there may be a need to simulate water transfer. Given the reach routing command structure, it is relatively easy to transfer water within a basin. This feature can account for irrigation flow paths and could provide a management tool for irrigation management districts and other agencies concerned with water rights. The algorithm developed here will allow water to be transferred from any reach or reservoir to any other reach or reservoir in the watershed. It will also allow water to be diverted and applied directly to irrigate a subwatershed.

SWAT MODEL INPUT DATA REQUIREMENTS

The SWRRB input file structure consisted of one large file with data for all the subbasins on weather, soils, land use, topography, and management (Arnold

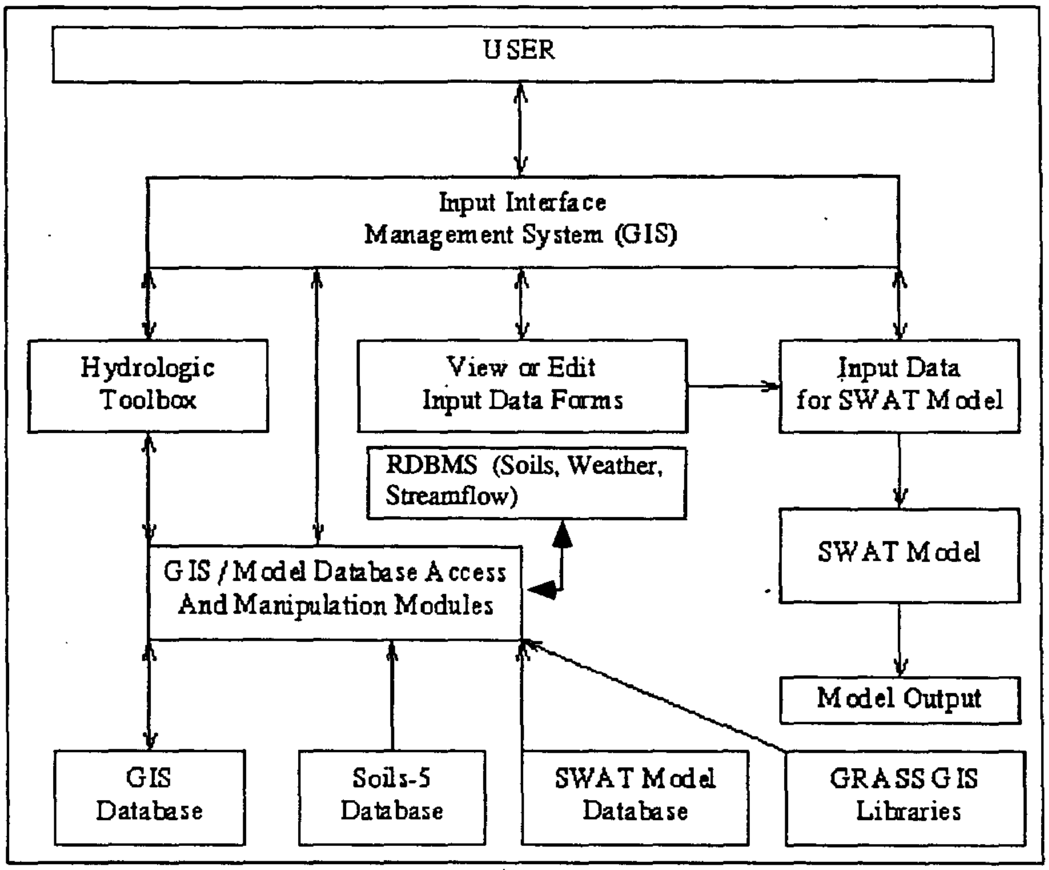

Figure 1. User's View of SWAT/GRASS Input Interface.

Maddock (1953). However, if W and D at various locations of the basin are known, the constants can be computed and used to derive the mean dimensions of the channel for each subbasin and for the entire basin.

r.topo.att

This program estimates overland slope and slope length for each subbasin and for the entire basin from a DEM layer. The neighborhood algorithm, which proved to be the most appropriate for distributed hydrologic modeling (Srinivasan and Engel, 1991d), is used to estimate overland slope for each grid. The estimated slopes are aggregated at the basin and subbasin levels using the weighted average technique. The unit stream power theory (Srinivasan and Engel, 1991d), is used to estimate overland slope length and aggregated using either the weighted average or the mode method.

r.auto_wshd

This program is used to delineate a watershed/basin boundary from an outlet point. This program uses the elevation layer and allows the user to zoom in to a display site location (for example, a stream gauge station) and select a point graphically. It then creates a watershed layer with the selected outlet location. The results obtained depend very much on the quality of the elevation layer. The *r.auto_wshd* uses the principle of the watershed program developed within GRASS GIS.

r.fill.dir

This program was developed to generate a depressionless DEM data layer and unique flow direction (aspect) layer based on work by Jenson and Domingue (1988). The resulting depressionless elevation layer can be further manipulated to derive watershed boundary, slopes, and other topographic attributes required by hydrologic models. The various modules that were developed are GRASS programs and can be ncorporated easily for other hydrologic models requiring these inputs and aggregation methods.

Model Database Access Tools

The *get_soil* module extracts the soil properties required by SWAT from the model-supported soils database. Further, a link has been established to extract soil properties from a relational database management system for the SCS-developed STATSGO (USDA-SCS, 1992). The *get_weather* program generates weather parameters for SWAT based on latitude and longitude. Similarly, the *get_crop* program creates the crop and pesticide parameters for SWAT based on the type of crop and pesticide information. Details of how these modules are used in the interface development are discussed in the later sections.

Methods of Aggregation

The major difference in extracting inputs for distributed basin-scale models (SWAT, SWRRB) and distributed watershed-scale models (AGNPS, ANSWERS) is the methods of aggregation to extract the input parameters. The distributed watershed-scale model divides the study area into square grids and extracts input for each square grid, which is similar to a raster-based GIS. A distributed basin-scale model divides the basin into subbasins by the homogeneity of soil, crop, and topographic features. Due to the heterogeneous distribution of the above-mentioned three types of data over space, the subbasins within a watershed were delineated by using topography within the GIS context. This requires tools to aggregate inputs at both basin and subbasin levels for the model. The method of aggregation varies and depends on the type of input. The general methods to aggregate data are mean, mode (dominant), weighted average, discrete or segment average, and geometric mean. The mean and weighted average methods use the absolute mean and area weighted mean method. The mode method uses the dominant features within the area of interest. The discrete or segment average method uses an averaging technique within discrete groups of data and finally averages over all the groups. The geometric mean uses the statistical geometric mean method to aggregate an input. This method is useful to keep continuity of an input aggregation. Use of different methods of aggregation for various inputs are discussed in later sections.

DEVELOPMENT OF INPUT INTERFACE

The input interface was developed on principles similar to those detailed in Rewerts and Engel (1991), where the ANSWERS model was integrated with GRASS GIS. The interface programs and other tools are written in C language and are integrated with the GRASS libraries. The SWAT model is written in FORTRAN 77 language, and both the interface and model run under the UNIX environment. Figure 12 shows a user's view of the input interface structure, the various components involved, and its interaction within the input interface for the SWAT model. The interface consists of three major divisions: (1) implementing a project manager; (2) extracting and aggregating input for the model; and (3) viewing, editing, and checking the input for the model. The function of the project manager is to interact with the user to collect, prepare, edit, and store basin and subbasin information to be formatted into a SWAT input file. Most of the SWAT input data are derived from GRASS raster layers.

The project manager consists of a series of steps that are to be completed to prepare the SWAT inputs. All steps may be run again by the user so that previously-entered parameters can be changed. As the user completes each step, the project manager retains the pertinent information in the user's GRASS database. This allows the user to work with a project in increments if necessary. Multiple, concurrent simulation projects are facilitated, each being identified by a project name and stored. The project manager can be used to either copy or delete an existing project. The four basic layers needed to extract inputs for the SWAT model include a basin layer (which includes the subdivisions of subbasins), an elevation layer, a soils layer, and a land use layer. The basin layer can be derived by using either *r.watershed* or *r.auto_wshd* program in GRASS by using the elevation layer as input. The following sections describe how each input datum is extracted and aggregated from GIS layers and other model databases.

Basin Attributes

This is the first step before attempting to extract any other input. Using a given basin layer, the program calculates area, resolution, and geographic coordinate boundaries for the basin and for each subbasin. The fraction of each subbasin within the basin is also estimated.

Soil Attributes

This option extracts and aggregates soil properties for each subbasin by using a soil layer and the *get_soil* program, which writes the soil attribute data in the SWAT model format. In addition, the interface supports a relational soil database such as STATSGO (USDA-SCS, 1992), where each soil association polygon identifier has several attributes. If the STATSGO database is used, the interface will link into the relational database to extract the necessary soil attributes in the model format. The program masks each subbasin and changes the region to fit that subbasin so that the program can function efficiently. The soil layer should contain the soil series name as category label. The soil series categories are aggregated for each subbasin by using either the mode (dominant) or weighted average aggregation method. While using the weighted average method, the soil properties are averaged; however, this weighted average approach is not applicable for all the properties of soils due to their discreteness. The default method of aggregation uses the mode (dominant) approach. The *get_soil* module uses the soil series name as input and extracts data from a model-supported soils database derived from the Soils-5 (Goran, 1983) database.

Topographic Attributes

The topographic features required by the entire basin and each subbasin are gathered using an elevation layer. By masking the entire basin and each subbasin, the stream length, stream slope, and stream dimensions are estimated using the *r.stream.att* tool along with proper aggregation methods. The drainage area is computed for each subbasin along with the drainage aspect of which subbasin flows into which subbasin. This information is later used to automate the routing structures for SWAT. The starting and ending node of the stream for the basin and each subbasin are estimated. Using the *r.topo.att* tool, overland slope and slope length are estimated and aggregated by the weighted average or mode (dominant) method. The channel characteristic factors USLE K, USLE C, Mannings 'n,' and USLE P are estimated using a standard table and the information obtained in the topographic attributes extraction processes.

Land-Use Attributes

The land-use attributes are extracted using a knowledge-based approach, where a set of rules along with a model-supported crop database are incorporated in the programs that automate inputs required by the model using a land-use layer. The land-use layer contains crop rotation information, which is used with the latitude and longitude coordinates of each subbasin to predict the planting date, harvest date, type of crop, nutrient application rates, and time of application. The *get_crop* program is used to extract the land-use attributes. The aggregation method used here is mode (dominant).

Automated Irrigation and Nutrient Applications

The user has the choice of irrigation and applying nutrients automatically whenever the plant system reaches the critical limit set by the user. In addition, the user has the option of entering actual dates and amounts of irrigation and nutrients applied.

Weather Attributes

Weather generator attributes are generated using the *get_weather* program based on 1200 weather stations across the U.S. where monthly generator attributes have been developed. The *get_weather* program requires the latitude and longitude of the basin. The latitude and longitude coordinates for the center of the basin are computed using the basin layer and the projection conversion tool supported by USGS. The weather generator attribute files can be created for the entire basin or for each subbasin.

Rain and Temperature Gauges

A raster or site layer showing the location of rain and temperature gauges is used to assign the rain and temperature data files to each subbasin. If there is no rain or temperature gauge in a subbasin, the interface chooses the closest one. The rain and temperature gauge files are given as category labels in the layer, and the input files contain daily maximum and minimum temperatures and rainfall values.

Reservoir and Inflow / Withdraw Input

Reservoirs can be simulated at the outlet of any subbasin. Also, measured or simulated flows can be added to the inlet or outlet of any channel. This option can be used interactively using a graphics screen and the basin layer to point and choose the subbasin to build reservoir or inflow/withdraw data.

On selection of a subbasin, the program draws different symbols for reservoirs and inflows, asks the user for pertinent information, and saves it into the model format. The user also has options to add, delete, or modify the reservoir or inflow data. The interface automatically updates the routing command file if it finds a reservoir or inflow/withdraw inputs.

Computed Routing Structure

This option allows the user to automatically create the routing command file for the model. An algorithm was developed to take the flow path (flow direction) data developed in the topographic attributes option and generate the command file required by the model to route and add flow through the basin. To use this option, the user must have completed the Basin Attributes and Topographic Attributes options. This module also detects and automates the routing procedures if any reservoir or inflow data exist in any of the subbasins. Possible errors are checked while creating the routing structure, such as more than one outlet from the basin, or two basins flowing into each other, or a circularity of flow detected in the system. The interface will allow the user to edit the errors by using either keyboard or graphical interface.

Ground Water Parameters

Ground-water parameters are created for each subbasin using the alpha layer. Alpha is the parameter required to lag the ground-water flow as it leaves the shallow aquifer to return to the stream (Arnold *et al.*, 1993).

In addition, the user can overlay any raster, vector, or site map along with displaying the basin number layout on the graphical screen. The status for each option is shown on the screen following the completion of that step. When the user collects the data incrementally, steps already "done" need not be "rerun." Once the steps are completed, the user can move on to the next phase by choosing option 1, which extracts all the data and saves into the SWAT model format under the project directory located in the current "LOCATION" model element directory (the location where GIS data elements are stored in GRASS GIS).

In this phase the user can either view, edit, or check the data extracted from the previous phase by using a subbasin number as input. The user may either use a graphic monitor to point and choose or type the subbasin number from an "ASCII" window. There are about 15 different data forms that can be modified by the user. The developed interface is believed to reduce the data collection and manipulation time by several orders. The interface allows speedy modification of the various management practices and prepares the data for subsequent model runs. The interface can also be used to examine the model or to perform sensitivity analysis by modifying the GIS data layers and/or choosing different aggregation methods for various input data.

APPLICATION

The GIS integrated water quality model was applied to the upper portion of Seco Creek watershed (Figure 2), located in south central Texas. The basin is approximately 114 sq. km. The Seco Creek watershed is predominantly rangeland (98 percent of the area). The base GIS layers were digitized by the SCS-Fort Worth GIS center. The elevation contours were digitized at the 1:24000 scale from USGS 7.5 minute maps. The field boundary map and soils map were also digitized at 1:24000 scales from county records. The soils in the watershed are primarily the Tarrant soil series, which has a high clay content. The basin has been monitored by the USGS since 1966; however, water quality data were sampled once every 90 days. Consequently, only simulated streamflow was compared to USGS average daily flow records. Measured daily rainfall and temperatures were obtained from January 1991 through August 1992 from unpublished data for the watershed. Thus, monthly simulated streamflow data from SWAT was compared to monthly measured streamflow data for the 20-month run. Using the digitized contour layer, the basin and 37 subbasin boundaries (see Figure 2) were delineated using the *r.watershed* command in GRASS. The required inputs for the basin and for each subbasin were extracted and formatted using the SWAT/GRASS input interface. The integrated system (SWAT/GRASS) helped to prepare the inputs to the SWAT model in four hours, which would take normally a few weeks of man-days for the same size of watershed. Before running the watershed command, the DEM was filtered using the *r.fill.direct* tool, which uses the Jenson and Domingue (1988) smoothing algorithm. The predominant soil was selected for each subbasin using the model (dominant) approach, and its soil properties were automatically extracted from the model-supported Soils-5 database (Goran, 1983). SCS-digitized land cover data was used for land use information in the system.

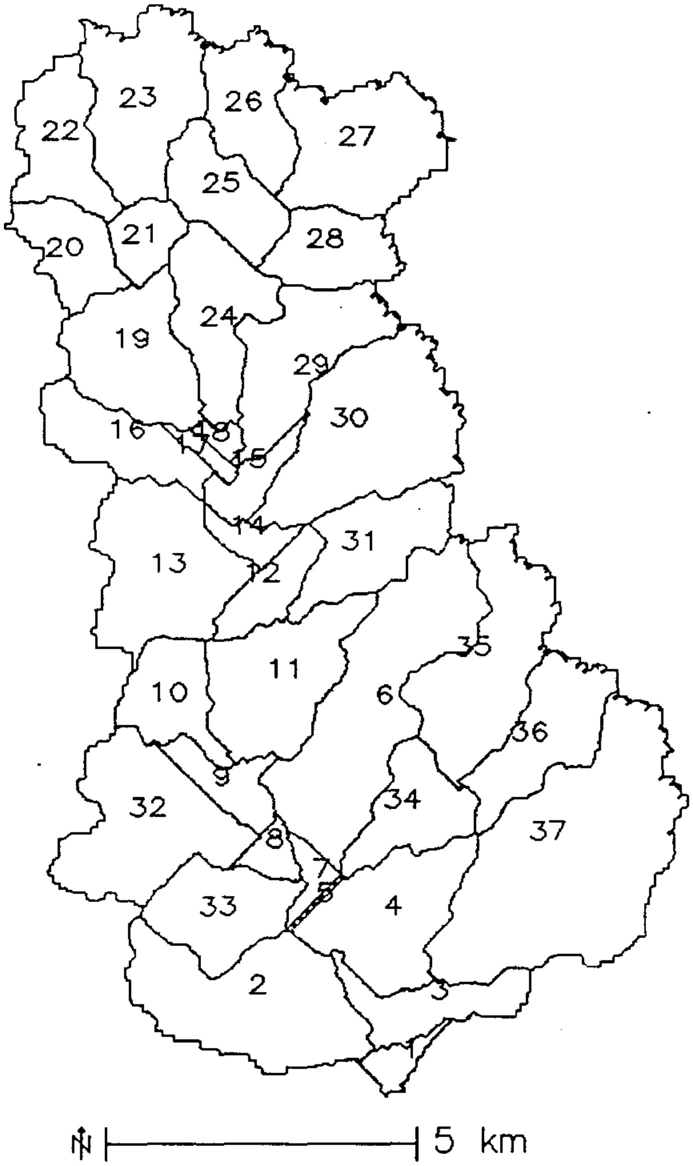

Figure 2. Basin and Subbasin Map of Upper Seco Creek Watershed.

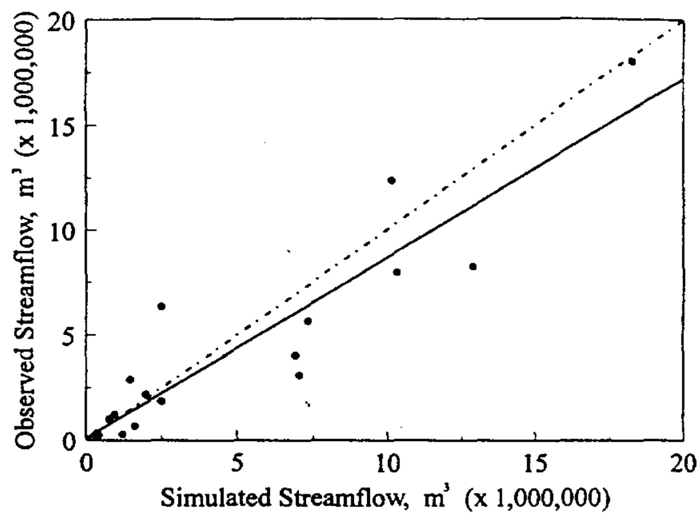

Figure 3. Observed vs. Simulated Average Monthly Streamflow Regression Chart for the 20-Month Period (January 1991 to August 1992).

RESULTS

Generally, simulated values compared well with measured values, with average monthly predicted flows 12 percent lower than measured flows (Figure 3). A common criticism of simulation models is that they do not simulate extremes well and thus underpredict standard deviations. Measured and predicted standard deviations compared well (within 8 percent). An R^2 of 0.86 also indicated a close relationship between measured and predicted values. Statistics are valuable criteria, but a graph often sheds considerable insight to the goodness-of-fit. Measured versus predicted monthly streamflow are plotted in Figure 3. A regression line and line-of-perfect-fit (1:1) are plotted with the regression points.

Seasonal trends can easily be visualized by plotting measured and predicted monthly values against time. The measured and predicted monthly surface runoff for the 20-month period (Figure 4) showed that there were no general tendencies to over- or underpredict during certain seasons of the year. SWAT also simulates the major hydrologic components for each subbasin. Figure 5 presents precipitation, surface runoff, ground-water flow, percolation past the root zone, and evapotranspiration for subbasin 37. Although measured data are seldom available to validate the individual components, it is important that the components are reasonable to ensure a realistic simulation.

SUMMARY AND CONCLUSION

Much of the initial research in utilizing GIS (Geographic Information Systems) to automate model input was devoted to linking single-event, grid models. In this study, a GIS input interface tool was developed for a continuous-time model that uses subwatershed boundaries based on natural flow paths. The SWAT (Soil and Water Assessment Tool) model was integrated with the GRASS (Geographic Resources Analysis Support System) GIS tool to develop a continuous-time, distributed-parameter modeling tool to assist with management of runoff, erosion, pesticide, and nutrient movement in large basins. The integrated system assists with development of SWAT input from GIS layers. The system is currently being evaluated for several watersheds

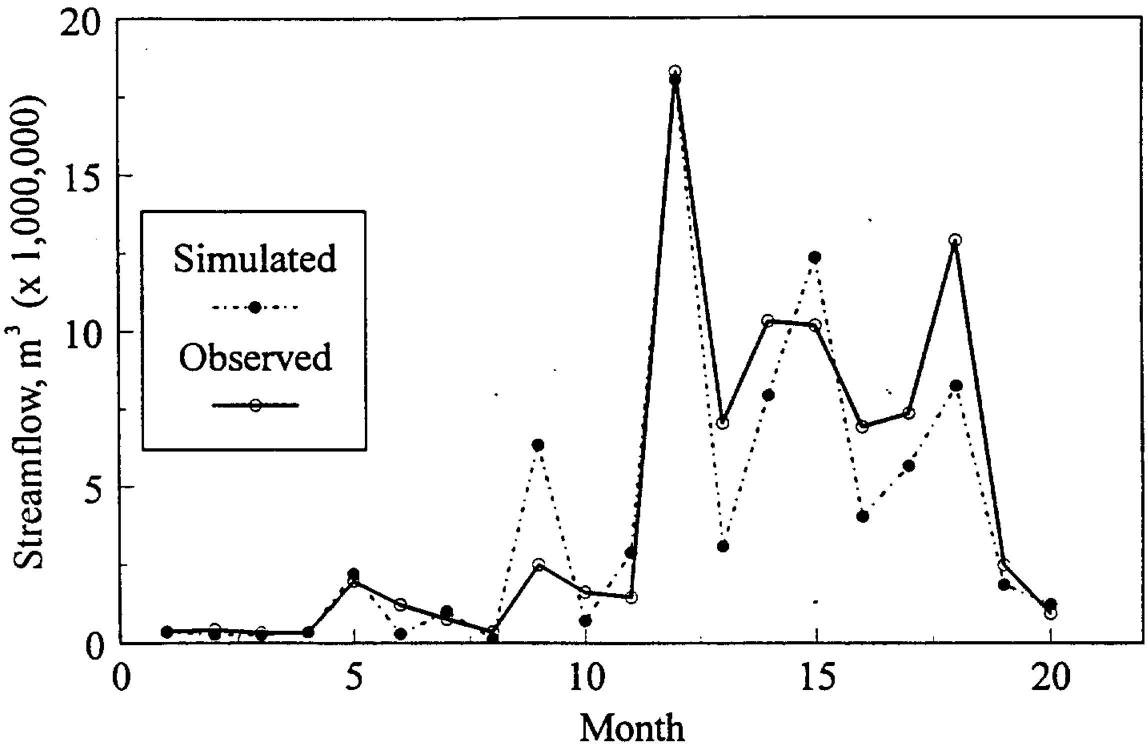

Figure 4. Observed and Simulated Average Monthly Streamflow in Cubic Meters for 20-Month Period (January 1991 to August 1992).

around Texas and midwest regions. Preliminary results suggest that the integrated SWAT/GIS model significantly reduces the time required to obtain input data and simplifies model operation. Once the problem areas are identified, land use, management, and structure practices can be proposed to reduce the problem, and the practices' effectiveness can be simulated for several years using the integrated system. While developing the integrated system, many other hydrologic and model specific tools were developed which could be used as stand-alone modules to collect data for other models that use similar input. We believe this approach will further enhance the usability and utility of the model.

The integrated SWAT/GRASS system was applied to a 114 sq. km basin within the Seco Creek basin located in the south central part of Texas. The basin was divided into 37 subbasins. SWAT model inputs including data on soils, topography, land use, and weather were automatically derived from map layers and associated databases by using the integrated GIS system. Simulated average monthly stream flows were in close agreement (within 12 percent) with observed flows. Regression line slope (1.00) and R^2 (0.86) also indicate relatively good agreement. Currently the SWAT/GRASS system has been used to validate sediment and nutrients from several monitored watersheds (Srinivasan *et al.*, 1993).

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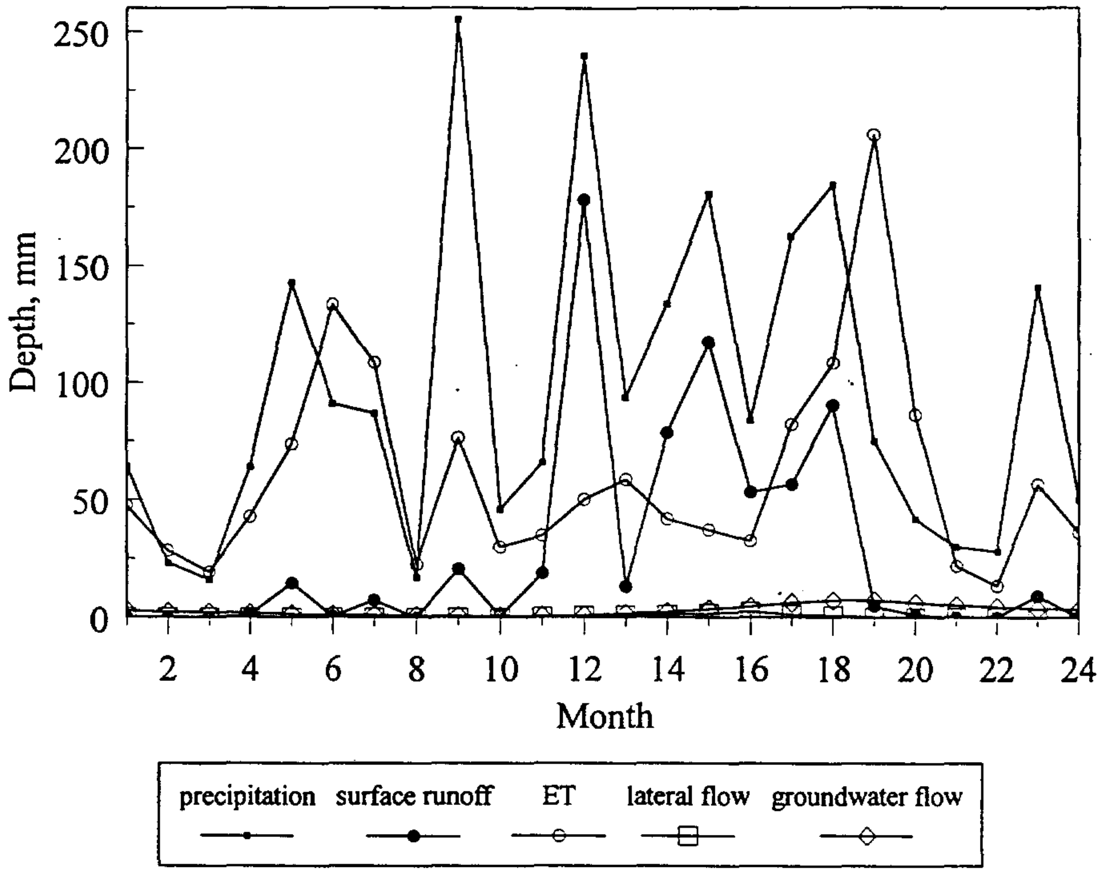

Figure 5. Simulated Water Budget (depths) for Subbasin No. 37 for 20-Month Period (precipitation, surface runoff, ground-water flow, percolation, and ET).

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SMALL WATERSHED ASSESSMENT USING THE SWAT MODEL

by

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A USDA-SCS Team in Texas is using the SWAT/GIS integrated system developed by USDA-ARS and Texas Agricultural Experiment Station at Temple, TX for assessment of nonpoint source pollution for small watersheds. Simulations for different cropping systems, management techniques, and other best management practices (BMP's) can provide a basis for making watershed management decisions.

Nonpoint source model, GIS geographic info systems, Hydrologic modeling, Watershed modeling, Water resources planning

SMALL WATERSHED ASSESSMENT USING THE SWAT MODEL

F. Charles Baird and R. Srinivasan

Introduction

USDA-SCS State Conservationist in Texas, Harry W. Oneth, established the Water Resource Assessment Team (WRAT) in October 1992 with an objective to transfer the latest water resources computer modeling technology to the SCS in Texas and to other end users throughout the State. This technology is currently based and under development at the Blackland Research Center (Texas Agricultural Experiment Station) and Grassland, Soil and Water Research Laboratory (USDA - Agricultural Research Service). Cooperative projects have been developed to date between SCS and three other partners:

Tarrant County Water Control and Improvement District Number One
Brazos River Authority
Lower Colorado River Authority

Partners in the project are using the SWAT (Soil and Water Assessment Tool) model developed by USDA-Agricultural Research Service (ARS). Scientists with Texas Agricultural Experiment Station (TAES) have developed the interface between the Geographic Information System (GIS) databases and SWAT to provide required model inputs and to graphically display the output data.

Intent of the projects is to assess water quantity and quality under current and projected management conditions using SWAT and GIS. Results will indicate critical areas contributing to sedimentation and related nonpoint source water quality problems which can be addressed by best management practices (BMPs). These BMPs applied on private lands would provide benefits to the landowner as well as to the downstream watershed and/or reservoir manager.

General Description of Study Areas

Tarrant County WCID owns and/or manages five major reservoirs supplying water to Fort Worth and several other Metroplex communities and industries. The watersheds are within the Upper Trinity River Basin and encompass all or portions of 19 counties (Figure 1). The reservoirs control runoff from 14,800 km^2 (5,700 $mile^2$) and serve a population of 1.5 million people with municipal, industrial, and recreational water. The reservoirs include Lake Bridgeport, Eagle Mountain Lake, Lake Benbrook, Richland-Chambers Lake, and Cedar Creek Lake (USDA-SCS, 1992).

The Brazos River Authority (BRA) project involves a drainage area contributing to a tributary of the Brazos River known as the Bosque River. The Bosque River is the contributing watershed to Lake Waco immediately above the confluence with the Brazos River. The watershed area covers 4,300 km^2(1,650 $mile^2$) in portions of six counties. Nonpoint source pollutants from an area with a high concentration of confined animal feeding operations is of concern to the BRA.

The Lower Colorado River Authority (LCRA) project area entails 10,160 km^2 (3,925 $mile^2$) of the lower Colorado River beginning immediately below Austin, Texas. Assessment of nonpoint source pollutants is emphasized in this project, especially those originating from cropland.

Agricultural land uses are dominant in all the basins and without adequate treatment and management, soils are subject to accelerated erosion. Best management practices (BMPs) for alleviating water quality problems are unique to each soil type, location and land use. Large amounts of sediment are being deposited in the water supply reservoirs, depleting water storage volume and increasing treatment costs..

Geographic Information System

The Soil Conservation Service uses the US Corps of Engineers' raster based Geographic Resources Analysis Support System (GRASS), a public domain GIS (U.S. Army COE). Simulations using SWAT are being performed in UNIX on the SUN workstation platform. INFORMIX is the relational database management system used by SCS. Most of the developmental work involving GIS at the ARS/TAES laboratory has been with a base scale of 1:250,000 which is readily available for most if not all the United States. These GIS layers are the foundation for the HUMUS (Hydrologic Unit Model for the United States) project (Srinivasan, et.al. 1993a), a cooperative effort between SCS, ARS, and TAES at the Temple, TX laboratory. The purpose of the HUMUS project is to assist in the Resource Conservation Act (RCA) assessment of the status and condition of water resources of the nation under current and projected management conditions. SWAT model technology was originally developed for the HUMUS project.

The WRAT staff has assembled or developed most of the GIS layers at a scale of 1:24,000 for use in modeling the smaller watersheds. Collection of this data is the most critical element to model the watersheds (Srinivasan, et. al. 1993b). Basic layers and/or relational databases include information on soils, land use, topography, watershed or basin boundaries. Other databases include historical streamflow and weather data, political boundaries, point sources, confined animal feeding operations, oil and gas well locations, agricultural statistics and census data, and geology. The GIS interface also allows the user many graphic displays for viewing model output. Choices include single and multiple line graphs, pie charts, bar graph, scatter plot, comparative map generation, and statistics.

The SWAT Model and GIS

SWAT is a basin-scale, continuous time water quality model integrated with a GIS to extract input data to simulate basin hydrology and conditions. Development of SWAT involved combining a routing procedure to the SWRRB (Arnold, et.al.) simulation model.

This allows loadings at sub-basin outlets to be routed through the stream network on a real time basis to the receiving reservoir or point of interest. Integration of GIS and SWAT eased the task of providing input for hundreds of sub-basins and multiple simulations.

Srinivasan and Arnold (1994) applied the integrated system to simulate the upper portion of the Seco Creek basin by subdividing the area into 37 subbasins. They found that average monthly streamflow agreed with measured monthly streamflow values for the period January 1991 through August 1992.

SWAT has a unique feature that allows the output of other model runs to be imported at stream routing nodes throughout the watershed simulation. A simulation using very detailed data for a small subbasin of the watershed can be integrated into a general assessment of the entire watershed above a reservoir. This can indicate the targeted basin's effects on loadings at a basin outlet or reservoir. SWAT can handle other features such as point sources of water inflow/outflow and can accommodate irrigation diversions, return flows, wastewater treatment outfalls, and other municipal or industrial permitted uses. To be a realistic simulation of the watershed, the model must handle both nonpoint sources and all permitted point sources as well as water transfers in or out of the basin. Thus predicted streamflow can be compared to measured streamgauge records in the GIS.

The need for assessments of smaller areas with a high level of detail requires that greater detail of GIS databases be available. The HUMUS project as an example, uses the STATSGO (USDA-SCS, 1992b.) soils geographic database (1:250,000 scale base) as one of the GIS layers in simulating entire river basins. STATSGO polygons represent soils associations that may include 20-30 individual soil series. The SCS soils and land use/cover for the Water Resource Assessment Team projects is a coverage of the CBMS (computer based mapping system 1:24,000 scale) data that will provide more detail in the GIS layer and model input. Each soils polygon in CBMS represents an individual soil series. A link from the spatial data to the relational soils database provides soil properties for each soil to the SWAT model input.

Use of SWAT and GIS in Small Watersheds

Initially, SWAT was run on the small watersheds in much the same manner as for the HUMUS Project. As more detailed GIS data was developed, the subbasins were reduced in size to work toward more reasonable representation of actual conditions. The initial SWAT screenings were conducted with subbasins averaging about 6750 ha (16,670 acre) for the projects; since the divisions of subbasins are critical for sediment or nonpoint source pollutants; subbasins were subdivided to areas averaging about 70 ha (174 acre) for detailed assessment (Figure 2). The assessment team will not likely get more detailed in their work than this latter scenario.

The partners intend to initially use the SWAT model as a management tool to help develop sampling programs for the assessment of the watersheds required by Texas Senate Bill 818. It is anticipated that this and other models will be applied to the watersheds to help determine the areas contributing to sedimentation and nonpoint source pollutant loadings. As these programs are developed, the data generated will be used to supplement the ongoing work and ultimately provide a validated model designed around site specific areas.

Summary and Conclusion

The SWAT (Soil and Water Assessment Tool) and GRASS GIS integrated as a modeling tool can guide management decisions regarding runoff, sediment, nutrient and pesticide loadings for small watersheds. This tool allows assessment or evaluation of effects from a watershed based on hydrologic and hydraulic boundaries consistent with basic principles and standards for planning treatment alternatives in water resource projects.

The integration of the water quality model and GIS reduces significantly the time to prepare input data for models and simplifies model operation. As GIS layers become readily available, the effort to simulate current versus projected management will involve minimum timeframes and personnel.

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SMALL WATERSHED MODELING AND ASSESSMENT USING THE SWAT AND GIS

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WACO, TX
MARCH 3, 1995

ABSTRACT

The integration of a Geographic Information System (GIS) with distributed parameter water quality models such as SWAT (Soil and Water Assessment Tool) has eliminated limitations associated with the use of such models in the past. Applications range from assessment of large river basins across the country to small watersheds and subbasins on a regional basis. It is necessary to use databases and GIS layer scales appropriate with the purpose of the analysis.

This paper discusses the use of SWAT and GIS in several small watersheds throughout the State to evaluate the effectiveness of alternative management and control practices related to water quality. Readily available sampling and recorded data within these watersheds facilitated the comparison of predicted and measured quantities. Measured data is normally found only on much larger stream basin area.

Many agencies and groups are currently developing GIS layers basic to the input data needs of most water quality models. As the gaps in GIS data layers and measured parameter databases are filled, the use of a model such as SWAT can provide comprehensive analysis with a minimum of personnel resources.

INTRODUCTION

Agencies and boards responsible for water quality management in streams and reservoirs under their jurisdiction are desperate for tools to help them in assessment and evaluation. Several projects in recent years have led to development of models for evaluating management decisions and carrying out control measures and how each affects water quality parameters. Many computer models have been developed within the last few years, but several address only specific issues in water quality along with a given set of assumptions. Input requirements can vary significantly and require many hours, days, or weeks of time to prepare inputs.

BACKGROUND ON THE SWAT MODEL

SWAT (Soil and Water Assessment Tool) was developed as a result of a national scale cooperative project known as HUMUS (Hydrologic Model for the United States) funded by USDA - Natural Resources Conservation Service. Partners in the project are USDA-Agricultural Research Service (ARS) and Texas Agricultural Experiment Station (TAES) at the Temple, TX research laboratory. The purpose of the HUMUS project is to assist in the Resource Conservation Act (RCA) assessment of the status and condition of water resources of the nation under current and projected management conditions (Srinivasan, et.al. 1993b).

SWAT is a basin-scale, continuous time water quality model integrated with a GIS to extract input data to simulate basin hydrology and conditions. Development of SWAT involved combining a routing procedure to the SWRRB (Arnold, 1990) simulation model. This allows loadings at sub-basin outlets to be routed through the stream network on a real time basis to the receiving reservoir or point of interest. Integration of GIS and SWAT eased the task of providing input for hundreds of sub-basins and multiple simulations.

SWAT has a unique feature that allows the output of other model runs to be imported at stream routing nodes within the watershed simulation. This allows output data from field scale EPIC simulations to be integrated with simulation of the entire basin. This building block concept allows flexibility in assessment of best management practices from a very detailed level for part of the basin to be analyzed for its effects within the whole basin. SWAT can handle other features such as point sources of water inflow or outflow and can accommodate such features as irrigation diversions and return flows, wastewater treatment plant outfalls, and other municipal and industrial permitted uses. To be a realistic simulation, the model must handle not only nonpoint sources but all permitted point sources of flow as well.

GEOGRAPHIC INFORMATION SYSTEM

The Natural Resources Conservation Service uses the US Corps of Engineers' raster based Geographic Resources Analysis Support System (GRASS), a public domain GIS (1988). Simulations using SWAT are being performed in UNIX on the SUN workstation platform. INFORMIX is the relational database management system used by NRCS. Most of the developmental work involving GIS at the ARS/TAES laboratory has been with a base scale of 1:250,000 which is readily available for all the United States. These GIS layers of the four basic inputs of soils, landuse, topography and climatological data are the foundation for the HUMUS assessments. The soils layer is the NRCS STATSGO database and landuse is the USGS GIRAS database.

More detailed data of large areas is scarce to non-existent in digital format at present. The WRAT staff has assembled or developed most of the GIS layers at a scale of 1:24,000 for use the ongoing project watersheds. Collection of this data is the most critical element to model the watersheds (Srinivasan et al. 1993c). Basic layers and/or relational databases include information on soils, land use, topography, watershed or basin boundaries. Other databases include historical streamflow and weather data, political boundaries, point sources, confined animal feeding operations, oil and gas well locations, agricultural statistics and census data, and geology. The GIS interface also allows the user many graphic displays for viewing model output. Choices include single and multiple line graphs, pie charts, bar graph, scatter plot, comparative map generation, and statistics.

ONGOING PROJECTS

USDA-NRCS State Conservationist in Texas, Harry W. Oneth, established the Water Resource Assessment Team (WRAT) in October 1992 with an objective to transfer the latest computer modeling technology from the Temple research laboratory to the NRCS in Texas and to other end users throughout the State. By collocating the WRAT staff at with the ARS and TAES scientists, all parties would benefit by the close working relationship and feedback in both directions for improving the model and interfaces for use by the end-users.

Cooperative watershed management projects have been developed to date between NRCS and three other partners (Figure 1):

Tarrant County Water Control and Improvement District Number One
Brazos River Authority
Lower Colorado River Authority

Intent of the projects is to assess water quantity and quality under current and projected management conditions using SWAT and GIS. Results will detect critical areas contributing to sedimentation and related nonpoint source water quality problems which can be addressed by best management practices (BMPs). These BMPs applied on private lands would provide benefits to the landowner as well as to the watershed and/or reservoir manager.

Another NRCS project, the Seco Creek Watershed Demonstration Project is making use of models and GIS (Figure 2). The demonstration project was established as a result of President George Bush's recommendation to Congress for the USDA Water Quality Initiative. The models will be used to evaluate the use of best management practices' potential to reduce transport of agricultural chemicals and sediment, improve ground water and downstream surface water quality, and improve the quality and availability of vegetative cover. The project will demonstrate and encourage voluntary adoption of best management practices that will reduce nonpoint source water pollution from rangeland and cropland.

Watershed Areas and Setting

Tarrant County WCID owns and/or manages five major reservoirs supplying water to Fort Worth and several other Metroplex communities and industries. The watersheds are within the upper Trinity River Basin and encompass all or portions of 19 counties (Figure 3). The reservoirs control runoff from 14,800 km^2 (5,700 $mile^2$) and serve a population of 1.5 million people with municipal, industrial, and recreational water. The reservoirs include Lake Bridgeport, Eagle Mountain Lake, Lake Benbrook, Richland-Chambers Lake, and Cedar Creek Lake (1992b).

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The Lower Colorado River Authority (LCRA) project area entails 10,160 km^2 (3,925 $mile^2$) of the lower Colorado River beginning immediately below Austin, Texas. Assessment of non-point source pollutants is emphasized in this project and management of cropland in particular.

The Seco Creek Watershed comprises an area of 690 km^2 (267 $mile^2$) in Bandera, Medina, and Uvalde Counties in South Central Texas. It is situated about 50 miles west-northwest of San Antonio and overlies the Edwards Aquifer that is a rapidly recharged aquifer (Lemon, et.al.). Water enters directly into the formation through fractured limestone, sinkholes and open caves. Consequently the potential exists for pesticides, nutrients, and sediments that might be present in the surface water to move directly into the aquifer. Management of land in the Seco Creek Watershed is critical to the protection of the aquifer.

SWAT APPLICATIONS

Srinivasan and Arnold (1993) applied the integrated system to simulate the upper portion of the Seco Creek basin (Figure 1) by subdividing the area into 37 subbasins. They found that average monthly streamflow was in agreement with measured monthly streamflow values for the period January 1991 through August 1992.

Data is available for Seco Creek Watershed at both the 1:250,000 and 1:24,000 scales for the basic four GIS layers. A comparison is being made of model output from simulations using these two extremes in data detail along with trials of mixed scales. This exercise will suggest sensitivity of model results with the scale of GIS layers (Arnold, 1992). The end result would be to prioritize development of GIS layers that are critical for model results. Thus resources are not wasted developing a detailed layer that may affect simulation output only slightly.

SUMMARY AND CONCLUSION

The SWAT (Soil and Water Assessment Tool) and GRASS GIS integrated as a modeling tool can guide management decisions regarding runoff, sediment, and nutrient loadings for small watersheds. This tool allows assessment or evaluation of effects from a watershed based on hydrologic and hydraulic boundaries consistent with basic principles and standards for planning treatment alternatives in water resource projects.

The integration of the water quality model and GIS reduces significantly the time to prepare input data for models and simplifies model operation. As GIS layers become readily available, the effort to simulate current versus projected management will involve minimum timeframes and personnel.

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1 Introduction

Hydrologic models can be broadly divided into lumped parameter models and distributed parameter models. The lumped parameter approach considers the whole catchment as a single entity and maps the input rainfall excess to an output hydrograph. Though computationally efficient, this approach doesn't explicitly account for spatial variabilities present with in the catchment. Chief among this type of model is the USLE (Wischmeier and Smith, 1978). Distributed models divide the catchment into a number of smaller areas (which could be square elements or subcatchments), which are assumed to be uniform with respect to the hydrologic parameters. Hydrology is simulated within each of these elements and the output routed to the outlet. Hence these models take into consideration spatial variability of the watershed. Examples of these include the AGNPS (AGricultural Non-Point Source Pollution) model (Young et al., 1987), ANSWERS (Aerial Nonpoint Source Watershed Response Simulation) (Beasely et al., 1977) and SWAT (Soil and Water Assessment Tool) (Arnold et al., 1993). Considerable time and effort are required to acquire the data, run the models and interpret resulting information. Integration with a GIS can eliminate many of these problems. Several models have been integrated with GIS which include AGNPS and GRASS GIS by Engel et al. (1992), ANSWERS and GRASS (Rewerts and Engel, 1991), and SPUR and ERDAS (Sasowsky and Gardner, 1991).

As noted before, these models either discretize the watershed into smaller elements by overlaying a square grid (ANSWERS or AGNPS) or into various subbasins (SWAT and SPUR). With the integration of these models with a GIS, it is possible to divide the watershed into a large number of elements since the GIS automatically generates the input. Hence we can consider the spatial variability to the level of detail supported by the data. However, as the number of such elements increase, so does the computation time. It is not clear from studies to date that the effect of increasing input levels of detail improves the accuracy of the simulated output. For effective use of the above tools, it is necessary to be able to discretize the watershed to an appropriate level of detail. A gross discretization may lead to poor simulation results whereas very fine discretization would require far more input data and significantly increased computation time and space (which may be important for large watersheds comprised of hundreds of subbasins) with no or little increase in accuracy. This study tries to address some of these problems.

2 Objectives

1. Quantify the effect that level of discretization has on the accuracy of output obtained.

2. Examine the impact of using a virtual basins approach as compared to

using the dominant soil and landuse within a subbasin.

3. Determine whether the Representative Elementary Area (REA) in the context of hydrologic modeling can be used to determine the appropriate size of subbasin.

3 Relevant Literature and Methodology

SWAT (Soil Water Assessment Tool), a continuous daily time step model developed by Arnold et al. (1993), was obtained by adding a new routing structure to the SWRRB model (Arnold et al., 1990; Williams et al., 1985) so as to remove the restriction of only being able to simulate 10 subwatersheds in the case of SWRRB. The new routing structure of SWAT routes and adds flows down through the basin reaches and reservoirs. Apart from this, changes were incorporated to simulate lateral flow, ground water flow, reach routing transmission losses, and sediment and chemical movement through ponds, reservoirs, streams and valleys. SWAT is capable of simulating hundreds of subwatersheds for periods of 100 years or more. The major components of the model include hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides, ground water and lateral flow, and agriculture management. Additional details about the model can be found in Arnold et al. (?).

SWAT allows for considerable flexibility in watershed discretization. The watershed can be divided into cells and/or subwatersheds. Different parts of the watershed can be divided differently. The dominant soil and landuse within each subbasin is considered to be the soil and landuse of the subbasin. However, in order to account for multiple soil and landuse combinations, the concept of virtual subbasins was incorporated into SWAT. Instead of assuming the dominant soil and landuse to be the soil or landuse of the subbasin, each subbasin is discretized into virtual areas (referred to as virtual basins), each having a unique soil and landuse combination without reference to their spatial positioning within the subbasin. This is similar to the concept of Hydrologic Response Units (HRU's) given by Maidment (1991). The hydrologic response is generated within each of these virtual areas and then the weighted average (by area) of the response from these virtual subbasins is taken to be the output of the subbasin. Since there can be large numbers of such combinations, a threshold is set. Only soil and landuse combinations forming a proportion larger than that of the threshold are considered. The threshold is arbitrary and is set by the user.

Wood et al. (1988) developed the concept of representative elementary area (REA) which they refer to as the fundamental building block of catchment modeling. They argue that for smaller areas, actual patterns of variability of topography, soil or rainfall lead to differences in the output even though the underlying distribution is the same. As larger and larger areas are considered, more and more of the variability is sampled and then finally an area is obtained whose hydrologic response can be considered to be the net effect of the individual point hydrologic responses within the subbasin or basin. So a basin with all its variation in soils, topography, weather, etc. can be represented by these REA's without much loss in quality of the output. This concept of the REA seems very promising in large scale basin modeling. Thus, we will determine if the concept of REA can be applied to a catchment scale model integrated with a GIS.

To prove the existence of REA, Wood et al. (1988) discretized the Coweta River experimental catchment in North Carolina, which had an area of 17 km^2, into 3, 19, 39 and 89 subcatchments by the method described by Band and Wood (1986). In order to be able to emulate point hydrologic response which can be then averaged to form the basin hydrologic response, they applied the modified and distributed version of TOPMODEL (Beven and Kirkby, 1979) and (Beven, 1986) within each 30m pixel comprising the catchment. Then pixel output was aggregated to form the subbasin response. The subbasin responses then arranged in increasing order of their areas and a running average of 15 subcatchments moving in steps of 5 was taken. The mean area within each window was plotted against the mean average response. The graphs indicated that the areal response stabilized at around 1 km^2. The size was the same for all the outputs studied. They concluded the REA for this catchment was 1 km^2. They made further studies and remarked that the size of the REA is governed primarily by the topography. Soil and rainfall variability, even though responsible for the difference between the subcatchments, didn't have a major role in determining the size of the REA.

In the above study, variability in only soil, rainfall and topography were studied. Large catchments, in addition to the above, have landuse variability to consider. Moreover, the biggest promise of REA exists in determining the appropriate size of the subbasin to be considered for obtaining satisfactory results. For a model like SWAT, more subbasins greatly increase the computation time. If the model has to be run in 30 m pixels in order to generate the output, the number of runs to be made will be the same even if the catchment is divided into 10 subcatchments instead of 50.

Gupta and Waymire (1983) encourage the use of coarse grained dynamics operating at a higher scale for basin-scale response as opposed to detailed dynamic specification at the continuum scale. Existence of REA at these coarser scales also needs to be studied. Since for these studies, basin scale models like SWAT are most likely to be used, it is reasonable to use such models for study of the existence of the REA. Also in the previous study, the results weren't validated with observed data. One could be more confident with the concept of REA if it could be shown that the hydrologic response generated at the REA scale matches observed data or at least does better or nearly the same as that generated at smaller or larger scales.

4 Methodology

A watershed in Texas of size 4297 km^2 was used in this study. It has originally about 40 subbasins and mostly composed of agriculture and range land. Using the "r.watershed" tool within the GRASS GIS and the DEM, the watershed was discretized into 4, 8, 14, 20, 24, 29, 35, 40 and 54 subbasins. Measured stream flow data was available at two locations within the watershed. Since both these gages are not located at the outlet of the subbasin, the simulated flow draining into the basin where the gage was located was extracted and compared with the output. Statistics used in the comparison apart from the Coefficient of Determination include the Coefficient of Efficiency of Nash and Sutcliffe (1971) and Residual mass curve coefficient given by Aitken (1973). A coefficient of efficiency of 1 indicates perfect agreement. If the results are highly correlated but biased, then the coefficient of efficiency will be less than the coefficient of determination (Aitken, 1973). The mass residual coefficient has an advantage over the coefficient of efficiency in that it measures the relationship between the sequence of flows and not just the relationship between the individual flow events.

Simulations were made both for the dominant case where the dominant soil and landuse within the basin was considered to be the soil and landuse of each subbasin and the virtual basin approach where a threshold of 10% for landuse and 5% for soil was used. The threshold indicates that landuses which form at least 10% of the subbasin area and soils which form at least 5% of the area within each of the selected landuses will be taken as virtual basins. Results for both these cases are presented here. Output data was available for year 1965 to 1974 and 1975 to 1984. So two different simulations were made for these different time periods and the results compared. A single simulation was not done for both these time periods since the rain gage data available was different between the both. No calibration whatsoever was attempted throughout the study, so only the impact of spatial variability can be studied.

It is clear from above that when the percent of landuse and soil are considered to be the basis of forming a virtual basin, within a particular basin configuration a smaller area is considered to be a virtual basin within a smaller subbasin compared to a larger subbasin. For example if two of the basins within a basin configuration are of sizes 10000 ha and 5000 ha, a landuse occupying an area of more than 1000 ha will be potential virtual basin candidate in the case of first subbasin while a landuse of 500 ha will be for the second subbasin. Landuses which form 500 ha or more of the first subbasin will be totally neglected. To avoid this the original interface was modified so that the absolute area rather than the proportion of the area, to be the basis for virtual basin formation. For example if a threshold of 500 ha was set all soil and landuse combinations within the subbasins of areas 500 ha or more will be considered as a virtual basin irrespective of size of subbasin it is located in.

Using the above modification SWAT simulations were made for different basin configurations using different thresholds ranging from 100 ha to 2000 ha. The statistics obtained for all the above results are presented in the results section.

In order to study the existence of the representative elementary areas of Wood, the procedure followed by Wood et al. was used. SWAT simulations were made for the various configurations mentioned above. Runoff from each of the these subbasins with different configurations was listed in order of increasing area. Then a moving average of 15 subbasins with a window of 5 was taken and the average area Vs the average runoff within each window was plotted.

This is similar to the procedure followed by Wood et al., but there are a couple of major differences between these two approaches. Wood et al. made TOPMODEL simulations within each of the pixels comprising the subbasins and then integrated the results of each of these pixels to form the subbasin level output. No routing was considered between the subbasins. They considered TOPMODEL since they wanted a hydrologic model "that can be parameterized at point scale so that the average response of every catchment and subcatchment can be considered to be identical to the average of all the point responses within it". By virtue of virtual subbasins, SWAT considers the impact of different soils and landuses within the subbasins. Hence, the subbasin level output can be considered to be the average response due to the various soils and landuses present within the basin. Increasing the size of the subbasin amounts to incorporating more and more of this variability or in other words, sampling more and more of the spatial variability and hence at a certain stage, according to Wood's argument, the average response should stablize. However, the number of virtual basins within a subbasin depends on threshold set by the user.

5 Results

The results obtained due to the above studies are presented next. Various statistics including mean, standard deviation, coefficient of efficiency, coefficient of determination and mass residual coefficient are presented. Results are presented for both gages 5000 and 5200. As noted above both these gages are upstream of the outlet. So the number of basins draining into the basin having these gages is different from the total number of basins in the watershed. In the results the number of basins draining into these gages is shown. Mostly coefficient of efficiency is used as a measure of accuracy of the simulated results even though other measures generally followed the same trend.

First the results obtained when the dominant approach was considered will be discussed. The results are given in Tables 1 to 4 for two different stream gages (5000 and 5200) and two different time periods (1965 - 1974 and 1975 - 1984). From the tables it is seen that in general, the results improved as the number of basins increased. Results were consistently better for configurations having more than 17 basins in case of gage 5000 and 19 in case of gage 5200 both of which occur with the basin configuration having more than 24 subbasins. As mentioned before the number of basins given in the gages represent the number of basins flowing into the gage rather than the total number of basins in the particular configuration under consideration. However, for configurations below this, the results some times are not consistent with some configurations doing extremely well. For example using the basin configuration having just 1 basin for gage 5000, the results are very good with a coefficient of efficiency of 0.57 in case of gage 5000 and a coefficient of efficiency of 0.70 in case of gage 5200. This is just due to lucky combinations giving rise to good results. For example using the 6 basin configurations which results in 5 basins flowing into 5200 and 2 into 5000, the coefficient of efficiency is -0.15 in the first case and 0.72 in the second case for years 1975-84. This indicates that not much confidence could be placed on these results. Hence, using a dominant approach 24 basins or more seems to be giving satisfactory results.

Table 1: Results Obtained when Runoff Simulated using Different Basin Configurations for Years 1965 to 1974 for Gauge 5000 Using the Dominant Soil and Landuse

Basin Configuration	Statistics							
	MeObs[a] cms	MeSim[b] cms	StdObs[c] cms	StdSim[d] cms	COD[e]	Slope[f]	COE[g]	MRC[h]
28	5.89	5.97	11.20	9.63	0.68	0.96	0.68	0.26
24	5.89	6.35	11.20	10.01	0.66	0.91	0.65	0.15
20	5.89	6.17	11.20	9.92	0.67	0.93	0.67	0.20
18	5.89	6.15	11.20	9.87	0.67	0.93	0.67	0.21
17	5.89	6.22	11.20	9.96	0.67	0.92	0.67	0.23
12	5.89	8.02	11.20	12.01	0.58	0.71	0.45	0.08
7	5.89	6.89	11.20	10.55	0.61	0.83	0.58	0.08
5	5.89	10.90	11.20	16.40	0.50	0.48	-0.27	-0.36
2	5.89	3.52	11.20	7.61	0.62	1.16	0.56	-0.02
1	5.89	3.65	11.20	8.01	0.62	1.10	0.57	-0.08

[a]Mean of Observed Results
[b]Mean of Simulated Results
[c]Standard Deviation of Observed Results
[d]Standard Deviation of Simulated Results
[e]Coefficient of Determination
[f]Slope of the Regression Line
[g]Coefficient of Efficiency
[h]Mass Residual Coefficient

The results obtained using the virtual basin approach is presented in Tables 5 to 8 for gages 5000 and 5200 and time periods 1965 - 1974 and 1975 - 1984. These results are obtained by taking 10% for landuse and 5% for soil as the threshold

Table 2: Results Obtained when Runoff Simulated using Different Basin Configurations for Years 1965 to 1974 for Gauge 5200 Using the Dominant Soil and Landuse

Basin Configuration	Statistics							
	MeObs[a] cms	MeSim[b] cms	StdObs[c] cms	StdSim[d] cms	COD[e]	Slope[f]	COE[g]	MRC[h]
35	7.24	6.71	13.75	11.10	0.72	1.05	0.71	0.46
25	7.24	7.71	13.75	12.35	0.67	0.91	0.66	0.33
22	7.24	7.48	13.75	12.31	0.67	0.91	0.66	0.35
20	7.24	7.56	13.75	12.33	0.67	0.91	0.66	0.35
19	7.24	7.64	13.75	12.40	0.66	0.90	0.66	0.38
14	7.24	9.44	13.75	14.46	0.60	0.73	0.49	0.27
8	7.24	8.42	13.75	13.11	0.62	0.83	0.59	0.26
7	7.24	12.39	13.75	19.05	0.52	0.52	-0.05	-0.07
5	7.24	11.03	13.75	18.27	0.61	0.59	0.24	-0.13

[a]Mean of Observed Results
[b]Mean of Simulated Results
[c]Standard Deviation of Observed Results
[d]Standard Deviation of Simulated Results
[e]Coefficient of Determination
[f]Slope of the Regression Line
[g]Coefficient of Efficiency
[h]Mass Residual Coefficient

values. First concentrating on the results for time period 1975 to 1984, the coefficient of efficiency increased from 0.01 to 0.65 for gage 5000 and from -0.64 to 0.59 for gage 5200. This is again expected with more number of subbasins indicating that more spatial variability is picked up. Since proportion of area is used as the basis for forming a virtual basin, when the simulation is done for 54 basins, the average basin size is smaller and hence more virtual basins or more soil landuse combinations are picked up, on the other hand having just 4 basins, the basins are quite large and hence fewer combinations are picked up since a larger area has to be occupied by a soil landuse combination to be considered as a virtual basin.

As discussed above the interface has been changed for making the absolute values as the basin for virtual basin configuration as compared to proportion of the virtual basin. The results obtained for various thresholds for all the configurations are given in Tables 9 through 18. These results clearly indicate that as the set threshold increases, so does decrease the accuracy of the results. For example for year 1965 to 1974 and the output at gage 5200, the coefficient of efficiency increased from 0.37 when 2000 ha was used as the threshold to 0.65 has when 100 ha was used as the threshold when the number of basins draining into

Table 3: Results Obtained when Runoff Simulated using Different Basin Configurations for Years 1975 to 1984 for Gauge 5000 Using the Dominant Soil and Landuse

Basin Configuration	Statistics							
	MeObs[a] cms	MeSim[b] cms	StdObs[c] cms	StdSim[d] cms	COD[e]	Slope[f]	COE[g]	MRC[h]
28	3.10	3.99	8.11	10.08	0.80	0.72	0.66	0.58
24	3.10	4.38	8.11	10.16	0.79	0.71	0.63	0.51
20	3.10	4.12	8.11	9.94	0.79	0.72	0.66	0.61
18	3.10	4.10	8.11	9.99	0.79	0.72	0.66	0.61
17	3.10	4.17	8.11	10.05	0.79	0.72	0.65	0.60
12	3.10	5.31	8.11	11.35	0.75	0.62	0.38	0.38
7	3.10	4.65	8.11	10.73	0.78	0.67	0.54	0.45
5	3.10	7.42	8.11	13.35	0.66	0.49	-0.32	0.06
2	3.10	2.55	8.11	8.71	0.76	0.81	0.72	0.58
1	3.10	2.64	8.11	9.05	0.76	0.78	0.70	0.60

[a]Mean of Observed Results
[b]Mean of Simulated Results
[c]Standard Deviation of Observed Results
[d]Standard Deviation of Simulated Results
[e]Coefficient of Determination
[f]Slope of the Regression Line
[g]Coefficient of Efficiency
[h]Mass Residual Coefficient

this gage was 35. This is because more number of soil and landuse combinations are picked up at a lower threshold. This is observed at all configurations. On the other hand, across the different configurations as the number of basins increased the configuration at which best results occurred changed. For example at 100ha threshold all most all basins except the one with 5 basins provided best results, but at a threshold of 300 and 500 ha best results were obtained at 25 number of basins and at a threshold of 2000 the best results were at 14 basins. The reason is not surprising if it is noted that at higher threshold, for basin configurations with more number of basins (hence smaller average basin size) the number of combinations above the threshold is less, hence less number of combinations are picked up. For example number of soil and landuse combinations above 2000 ha may be minimal in all the 54 basins, since size of most would be very close to that, hence this will essentially lead to choosing the dominant soil landuse combination.

Table 4: Results Obtained when Runoff Simulated using Different Basin Configurations for Years 1975 to 1974 for Gauge 5200 Using the Dominant Soil and Landuse

Basin Configuration	Statistics							
	MeObs[a] cms	MeSim[b] cms	StdObs[c] cms	StdSim[d] cms	COD[e]	Slope[f]	COE[g]	MRC[h]
35	4.19	4.48	9.96	11.85	0.73	0.72	0.62	0.67
25	4.19	5.24	9.96	11.95	0.72	0.71	0.58	0.62
22	4.19	4.91	9.96	11.53	0.69	0.72	0.58	0.70
20	4.19	4.98	9.96	11.63	0.69	0.71	0.58	0.70
19	4.19	5.05	9.96	11.73	0.69	0.71	0.57	0.69
14	4.19	6.18	9.96	12.99	0.66	0.62	0.37	0.56
8	4.19	5.57	9.96	12.41	0.70	0.67	0.52	0.60
7	4.19	8.34	9.96	15.17	0.59	0.50	-0.16	0.36
5	4.19	7.75	9.96	16.73	0.70	0.50	-0.15	0.32

[a]Mean of Observed Results
[b]Mean of Simulated Results
[c]Standard Deviation of Observed Results
[d]Standard Deviation of Simulated Results
[e]Coefficient of Determination
[f]Slope of the Regression Line
[g]Coefficient of Efficiency
[h]Mass Residual Coefficient

Table 5: Results Obtained when Runoff Simulated using Virtual Basin Approach for Basin Configurations for Years 1965 to 1974 for Gauge 5000, Using Proportion of Area as the Basis of Virtual Basin Formation

Basin Configuration	Statistics							
	MeObs[a] cms	MeSim[b] cms	StdObs[c] cms	StdSim[d] cms	COD[e]	Slope[f]	COE[g]	MRC[h]
28	5.89	6.46	11.20	10.63	0.61	0.82	0.58	0.02
24	5.89	9.42	11.20	15.15	0.55	0.55	0.09	-0.73
20	5.89	7.01	11.20	11.29	0.60	0.77	0.54	-0.01
18	5.89	9.30	11.20	15.08	0.56	0.55	0.10	-0.67
17	5.89	6.73	11.20	10.93	0.61	0.80	0.56	0.0[illegible]
12	5.89	6.74	11.20	11.01	0.60	0.79	0.56	0.01
7	5.89	7.02	11.20	11.27	0.60	0.77	0.54	-0.03
5	5.89	8.51	11.20	13.41	0.58	0.64	0.33	-0.03
2	5.89	8.45	11.20	13.84	0.66	0.66	0.43	0.54
1	5.89	9.55	11.20	15.35	0.55	0.54	0.05	-0.18

[a]Mean of Observed Results
[b]Mean of Simulated Results
[c]Standard Deviation of Observed Results
[d]Standard Deviation of Simulated Results
[e]Coefficient of Determination
[f]Slope of the Regression Line
[g]Coefficient of Efficiency
[h]Mass Residual Coefficient

Table 6: Results Obtained when Runoff Simulated using Virtual Basin Approach for Basin Configurations for Years 1965 to 1974 for Gauge 5200, Using Proportion of Area as the Basis of Virtual Basin Formation

Basin Configuration	Statistics							
	MeObs[a] cms	MeSim[b] cms	StdObs[c] cms	StdSim[d] cms	COD[e]	Slope[f]	COE[g]	MRC[h]
35	7.24	7.64	13.75	12.83	0.64	0.85	0.62	0.24
25	7.24	11.27	13.75	18.38	0.51	0.54	0.04	-1.60
22	7.24	8.00	13.75	13.28	0.63	0.82	0.60	0.22
20	7.24	10.85	13.75	17.89	0.52	0.55	0.11	-1.39
19	7.24	7.90	13.75	13.13	0.63	0.83	0.61	0.23
14	7.24	7.85	13.75	13.14	0.63	0.83	0.61	0.24
8	7.24	8.18	13.75	13.56	0.63	0.80	0.58	0.21
7	7.24	9.68	13.75	15.68	0.61	0.68	0.45	0.21
5	7.24	13.02	13.75	21.49	0.67	0.52	-0.06	0.14

[a]Mean of Observed Results
[b]Mean of Simulated Results
[c]Standard Deviation of Observed Results
[d]Standard Deviation of Simulated Results
[e]Coefficient of Determination
[f]Slope of the Regression Line
[g]Coefficient of Efficiency
[h]Mass Residual Coefficient

Table 7: Results Obtained when Runoff Simulated using Virtual Basin Approach for Basin Configurations for Years 1975 to 1974 for Gauge 5000, Using Proportion of Area as the Basis of Virtual Basin Formation

Basin Configuration	Statistics							
	MeObs[a] cms	MeSim[b] cms	StdObs[c] cms	StdSim[d] cms	COD[e]	Slope[f]	COE[g]	MRC[h]
28	3.10	4.29	8.11	9.60	0.77	0.74	0.65	0.64
24	3.10	4.51	8.11	9.74	0.76	0.73	0.62	0.60
20	3.10	4.63	8.11	9.95	0.76	0.71	0.60	0.60
18	3.10	4.50	8.11	9.85	0.76	0.72	0.62	0.61
17	3.10	4.43	8.11	9.71	0.77	0.73	0.63	0.62
12	3.10	4.42	8.11	9.80	0.76	0.72	0.62	0.61
7	3.10	4.66	8.11	10.00	0.76	0.71	0.59	0.58
5	3.10	5.75	8.11	11.31	0.72	0.61	0.32	0.46
2	3.10	5.83	8.11	11.65	0.71	0.58	0.23	0.40
1	3.10	6.48	8.11	12.42	0.69	0.54	0.01	0.29

[a]Mean of Observed Results
[b]Mean of Simulated Results
[c]Standard Deviation of Observed Results
[d]Standard Deviation of Simulated Results
[e]Coefficient of Determination
[f]Slope of the Regression Line
[g]Coefficient of Efficiency
[h]Mass Residual Coefficient

Table 8: Results Obtained when Runoff Simulated using Virtual Basin Approach for Basin Configurations for Years 1975 to 1984 for Gauge 5200, Using Proportion of Area as the Basis of Virtual Basin Formation

Basin Configuration	Statistics							
	MeObs[a] cms	MeSim[b] cms	StdObs[c] cms	StdSim[d] cms	COD[e]	Slope[f]	COE[g]	MRC[h]
35	4.19	5.06	9.96	11.44	0.70	0.73	0.59	0.69
25	4.19	5.37	9.96	11.80	0.70	0.71	0.56	0.66
22	4.19	5.25	9.96	11.69	0.70	0.71	0.57	0.68
20	4.19	5.23	9.96	11.69	0.70	0.71	0.58	0.68
19	4.19	5.19	9.96	11.57	0.70	0.72	0.58	0.68
14	4.19	5.14	9.96	11.65	0.70	0.71	0.58	0.68
8	4.19	5.38	9.96	11.93	0.70	0.70	0.55	0.66
7	4.19	6.47	9.96	13.22	0.66	0.61	0.34	0.59
5	4.19	8.98	9.96	18.50	0.67	0.44	-0.64	0.10

[a]Mean of Observed Results
[b]Mean of Simulated Results
[c]Standard Deviation of Observed Results
[d]Standard Deviation of Simulated Results
[e]Coefficient of Determination
[f]Slope of the Regression Line
[g]Coefficient of Efficiency
[h]Mass Residual Coefficient

Table 9: Results Obtained when Runoff Simulated using Virtual Basin Approach for Basin Configurations for Years 1965 to 1974 for Gauge 5000, Using 100 ha as the Threshold

Basin Configuration	Statistics							
	MeObs[a] cms	MeSim[b] cms	StdObs[c] cms	StdSim[d] cms	COD[e]	Slope[f]	COE[g]	MRC[h]
28	5.89	5.57	11.20	9.58	0.64	0.93	0.64	0.07
24	5.89	5.63	11.20	9.45	0.64	0.95	0.64	0.09
20	5.89	5.57	11.20	9.43	0.64	0.95	0.64	0.08
18	5.89	5.54	11.20	9.39	0.64	0.96	0.64	0.07
17	5.89	5.50	11.20	9.32	0.64	0.96	0.64	0.08
12	5.89	5.36	11.20	9.19	0.64	0.98	0.64	0.07
7	5.89	5.63	11.20	9.34	0.64	0.96	0.64	0.08
5	5.89	5.61	11.20	9.32	0.65	0.97	0.65	0.08
2	5.89	5.62	11.20	9.33	0.63	0.96	0.63	0.10
1	5.89	5.75	11.20	9.99	0.63	0.89	0.62	0.05

[a] Mean of Observed Results
[b] Mean of Simulated Results
[c] Standard Deviation of Observed Results
[d] Standard Deviation of Simulated Results
[e] Coefficient of Determination
[f] Slope of the Regression Line
[g] Coefficient of Efficiency
[h] Mass Residual Coefficient

Table 10: Results Obtained when Runoff Simulated using Virtual Basin Approach for Basin Configurations for Years 1965 to 1974 for Gauge 5200, Using 100 ha as the Threshold

Basin Configuration	Statistics							
	MeObs[a] cms	MeSim[b] cms	StdObs[c] cms	StdSim[d] cms	COD[e]	Slope[f]	COE[g]	MRC[h]
35	7.24	6.75	13.75	11.68	0.66	0.95	0.65	0.27
25	7.24	6.90	13.75	11.72	0.66	0.96	0.66	0.28
22	7.24	6.55	13.75	11.35	0.66	0.98	0.66	0.27
20	7.24	6.66	13.75	11.43	0.66	0.98	0.66	0.28
19	7.24	6.63	13.75	11.37	0.66	0.98	0.66	0.28
14	7.24	6.49	13.75	11.24	0.66	1.00	0.66	0.28
8	7.24	6.71	13.75	11.48	0.66	0.97	0.66	0.27
7	7.24	6.71	13.75	11.45	0.67	0.98	0.66	0.28
5	7.24	10.27	13.75	16.91	0.66	0.66	0.44	0.20

[a]Mean of Observed Results
[b]Mean of Simulated Results
[c]Standard Deviation of Observed Results
[d]Standard Deviation of Simulated Results
[e]Coefficient of Determination
[f]Slope of the Regression Line
[g]Coefficient of Efficiency
[h]Mass Residual Coefficient

Table 11: Results Obtained when Runoff Simulated using Virtual Basin Approach for Basin Configurations for Years 1965 to 1974 for Gauge 5000, Using 200 ha as the Threshold

Basin Configuration	Statistics							
	MeObs[a] cms	MeSim[b] cms	StdObs[c] cms	StdSim[d] cms	COD[e]	Slope[f]	COE[g]	MRC[h]
28	5.89	6.11	11.20	10.32	0.62	0.85	0.60	0.01
24	5.89	5.83	11.20	9.72	0.63	0.92	0.63	0.06
20	5.89	5.91	11.20	9.93	0.63	0.89	0.62	0.04
18	5.89	5.90	11.20	9.90	0.63	0.90	0.62	[illegible]
17	5.89	5.80	11.20	9.75	0.63	0.91	0.63	[illegible]
12	5.89	5.55	11.20	9.47	0.63	0.94	0.63	0.06
7	5.89	5.72	11.20	9.50	0.64	0.94	0.63	0.07
5	5.89	5.56	11.20	9.29	0.64	0.97	0.64	0.08
2	5.89	5.66	11.20	9.39	0.63	0.95	0.63	0.10
1	5.89	5.80	11.20	10.07	0.63	0.88	0.62	0.05

[a]Mean of Observed Results
[b]Mean of Simulated Results
[c]Standard Deviation of Observed Results
[d]Standard Deviation of Simulated Results
[e]Coefficient of Determination
[f]Slope of the Regression Line
[g]Coefficient of Efficiency
[h]Mass Residual Coefficient

Table 12: Results Obtained when Runoff Simulated using Virtual Basin Approach for Basin Configurations for Years 1965 to 1974 for Gauge 5200, Using 200 ha as the Threshold

Basin Configuration	Statistics							
	MeObs[a] cms	MeSim[b] cms	StdObs[c] cms	StdSim[d] cms	COD[e]	Slope[f]	COE[g]	MRC[h]
35	7.24	7.29	13.75	12.47	0.64	0.88	0.62	0.23
25	7.24	7.16	13.75	12.09	0.65	0.92	0.65	0.26
22	7.24	6.88	13.75	11.88	0.65	0.93	0.65	0.25
20	7.24	7.04	13.75	11.97	0.65	0.93	0.65	0.26
19	7.24	6.95	13.75	11.83	0.65	0.94	0.65	0.27
14	7.24	6.70	13.75	11.56	0.66	0.96	0.65	0.27
8	7.24	6.84	13.75	11.66	0.65	0.95	0.65	0.27
7	7.24	6.70	13.75	11.44	0.66	0.98	0.66	0.28
5	7.24	10.35	13.75	17.03	0.66	0.66	0.43	0.19

[a]Mean of Observed Results
[b]Mean of Simulated Results
[c]Standard Deviation of Observed Results
[d]Standard Deviation of Simulated Results
[e]Coefficient of Determination
[f]Slope of the Regression Line
[g]Coefficient of Efficiency
[h]Mass Residual Coefficient

Table 13: Results Obtained when Runoff Simulated using Virtual Basin Approach for Basin Configurations for Years 1965 to 1974 for Gauge 5000, Using 300 ha as the Threshold

Basin Configuration	Statistics							
	MeObs[a] cms	MeSim[b] cms	StdObs[c] cms	StdSim[d] cms	COD[e]	Slope[f]	COE[g]	MRC[h]
28	5.89	6.86	11.20	11.27	0.59	0.76	0.52	-0.04
24	5.89	6.30	11.20	10.30	0.62	0.85	0.60	0.04
20	5.89	6.55	11.20	10.74	0.60	0.81	0.56	-0.01
18	5.89	6.37	11.20	10.49	0.61	0.83	0.58	0.0[illegible]
17	5.89	6.30	11.20	10.38	0.61	0.84	0.59	0.02
12	5.89	5.64	11.20	9.64	0.63	0.92	0.63	0.04
7	5.89	5.73	11.20	9.52	0.63	0.94	0.63	0.07
5	5.89	5.56	11.20	9.30	0.65	0.97	0.64	0.08
2	5.89	5.64	11.20	9.41	0.63	0.95	0.63	0.10
1	5.89	5.78	11.20	10.08	0.63	0.88	0.62	0.05

[a]Mean of Observed Results
[b]Mean of Simulated Results
[c]Standard Deviation of Observed Results
[d]Standard Deviation of Simulated Results
[e]Coefficient of Determination
[f]Slope of the Regression Line
[g]Coefficient of Efficiency
[h]Mass Residual Coefficient

Table 14: Results Obtained when Runoff Simulated using Virtual Basin Approach for Basin Configurations for Years 1965 to 1974 for Gauge 5200, Using 300 ha as the Threshold

Basin Configuration	Statistics							
	MeObs[a] cms	MeSim[b] cms	StdObs[c] cms	StdSim[d] cms	COD[e]	Slope[f]	COE[g]	MRC[h]
35	7.24	7.29	13.75	12.47	0.64	0.88	0.62	0.23
25	7.24	7.16	13.75	12.09	0.65	0.92	0.65	0.26
22	7.24	6.88	13.75	11.88	0.65	0.93	0.65	0.25
20	7.24	7.04	13.75	11.97	0.65	0.93	0.65	0.26
19	7.24	6.95	13.75	11.83	0.65	0.94	0.65	0.27
14	7.24	6.70	13.75	11.56	0.66	0.96	0.65	0.27
8	7.24	6.84	13.75	11.66	0.65	0.95	0.65	0.27
7	7.24	6.70	13.75	11.44	0.66	0.98	0.66	0.28
5	7.24	10.35	13.75	17.03	0.66	0.66	0.43	0.19

[a] Mean of Observed Results
[b] Mean of Simulated Results
[c] Standard Deviation of Observed Results
[d] Standard Deviation of Simulated Results
[e] Coefficient of Determination
[f] Slope of the Regression Line
[g] Coefficient of Efficiency
[h] Mass Residual Coefficient

Table 15: Results Obtained when Runoff Simulated using Virtual Basin Approach for Basin Configurations for Years 1965 to 1974 for Gauge 5000, Using 500 ha as the Threshold

Basin Configuration	Statistics							
	MeObs[a] cms	MeSim[b] cms	StdObs[c] cms	StdSim[d] cms	COD[e]	Slope[f]	COE[g]	MRC[h]
28	5.89	7.80	11.20	12.67	0.55	0.66	0.37	-0.16
24	5.89	7.37	11.20	11.76	0.57	0.72	0.47	-0.08
20	5.89	7.46	11.20	12.08	0.56	0.69	0.43	-0.13
18	5.89	7.27	11.20	11.80	0.57	0.72	0.46	-0.1[illegible]
17	5.89	7.20	11.20	11.68	0.57	0.72	0.47	-0.1[illegible]
12	5.89	6.70	11.20	11.15	0.58	0.77	0.53	-0.07
7	5.89	6.15	11.20	10.06	0.62	0.87	0.60	0.05
5	5.89	5.86	11.20	9.73	0.64	0.92	0.63	0.06
2	5.89	5.42	11.20	9.20	0.63	0.97	0.63	0.09
1	5.89	5.56	11.20	9.89	0.63	0.90	0.62	0.04

[a]Mean of Observed Results
[b]Mean of Simulated Results
[c]Standard Deviation of Observed Results
[d]Standard Deviation of Simulated Results
[e]Coefficient of Determination
[f]Slope of the Regression Line
[g]Coefficient of Efficiency
[h]Mass Residual Coefficient

Table 16: Results Obtained when Runoff Simulated using Virtual Basin Approach for Basin Configurations for Years 1965 to 1974 for Gauge 5200, Using 500 ha as the Threshold

Basin Configuration	Statistics							
	MeObs[a] cms	MeSim[b] cms	StdObs[c] cms	StdSim[d] cms	COD[e]	Slope[f]	COE[g]	MRC[h]
35	7.24	9.02	13.75	14.92	0.58	0.70	0.45	0.08
25	7.24	8.63	13.75	14.04	0.61	0.76	0.54	0.17
22	7.24	8.42	13.75	14.03	0.59	0.76	0.52	0.14
20	7.24	8.43	13.75	13.90	0.60	0.77	0.54	0.16
19	7.24	8.37	13.75	13.78	0.60	0.77	0.54	0.16
14	7.24	7.86	13.75	13.26	0.61	0.81	0.58	0.18
8	7.24	7.28	13.75	12.29	0.64	0.89	0.63	0.25
7	7.24	7.03	13.75	11.95	0.66	0.93	0.65	0.27
5	7.24	10.24	13.75	17.05	0.65	0.65	0.42	0.17

[a]Mean of Observed Results
[b]Mean of Simulated Results
[c]Standard Deviation of Observed Results
[d]Standard Deviation of Simulated Results
[e]Coefficient of Determination
[f]Slope of the Regression Line
[g]Coefficient of Efficiency
[h]Mass Residual Coefficient

Table 17: Results Obtained when Runoff Simulated using Virtual Basin Approach for Basin Configurations for Years 1965 to 1974 for Gauge 5000, Using 2000 ha as the Threshold

Basin Configuration	Statistics							
	MeObs[a] cms	MeSim[b] cms	StdObs[c] cms	StdSim[d] cms	COD[e]	Slope[f]	COE[g]	MRC[h]
28	5.89	8.47	11.20	13.49	0.53	0.60	0.25	-0.29
24	5.89	8.68	11.20	13.58	0.53	0.60	0.23	-0.28
20	5.89	8.99	11.20	14.24	0.52	0.57	0.13	-0.37
18	5.89	8.92	11.20	14.09	0.52	0.57	0.15	-0.35
17	5.89	8.92	11.20	14.07	0.52	0.57	0.15	-0.3[illegible]
12	5.89	8.30	11.20	13.45	0.53	0.61	0.26	-0.29
7	5.89	8.40	11.20	13.33	0.53	0.61	0.26	-0.27
5	5.89	8.28	11.20	13.16	0.54	0.63	0.30	-0.23
2	5.89	6.90	11.20	11.47	0.58	0.74	0.50	-0.06
1	5.89	7.06	11.20	12.29	0.57	0.69	0.44	-0.15

[a]Mean of Observed Results
[b]Mean of Simulated Results
[c]Standard Deviation of Observed Results
[d]Standard Deviation of Simulated Results
[e]Coefficient of Determination
[f]Slope of the Regression Line
[g]Coefficient of Efficiency
[h]Mass Residual Coefficient

Table 18: Results Obtained when Runoff Simulated using Virtual Basin Approach for Basin Configurations for Years 1965 to 1974 for Gauge 5200, Using 2000 ha as the Threshold

Basin Configuration	Statistics							
	MeObs[a] cms	MeSim[b] cms	StdObs[c] cms	StdSim[d] cms	COD[e]	Slope[f]	COE[g]	MRC[h]
35	7.24	9.61	13.75	15.66	0.56	0.66	0.37	0.00
25	7.24	10.43	13.75	16.77	0.55	0.61	0.26	-0.05
22	7.24	9.50	13.75	15.67	0.57	0.66	0.39	-0.04
20	7.24	9.75	13.75	15.69	0.56	0.66	0.38	-0.02
19	7.24	9.74	13.75	15.66	0.57	0.66	0.38	-0.01
14	7.24	9.11	13.75	15.05	0.58	0.69	0.45	0.03
8	7.24	9.24	13.75	15.23	0.56	0.68	0.41	0.02
7	7.24	9.13	13.75	15.04	0.58	0.70	0.45	0.07
5	7.24	11.47	13.75	19.00	0.63	0.58	0.19	0.02

[a] Mean of Observed Results
[b] Mean of Simulated Results
[c] Standard Deviation of Observed Results
[d] Standard Deviation of Simulated Results
[e] Coefficient of Determination
[f] Slope of the Regression Line
[g] Coefficient of Efficiency
[h] Mass Residual Coefficient

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APPENDIX E - USER'S GUIDE TO SWAT, GRASS, GIS AND UNIX

WATER RESOURCE ASSESSMENT TEAM

USER'S GUIDE

FOR

SWAT, GRASS, GIS, UNIX

(TCWCID#1 VERSION)

REVISED 9/96

This manual will be updated and re-distributed every time significant contributions are made o procedures change.

Conventions:

Commands to be typed at the DOS or UNIX prompt are in ***bold italics***.
Commands that are given by clicking on an icon are <u>underlined</u>.
Parenthesis are used in commands to show items that you must decide on.
To describe mouse/window operations the following conventions will be used:

[rb] = click right mouse button
[lb] = click left mouse button
[pp] = click on push pin with left mouse button

TABLE OF CONTENTS

DOS COMMANDS

COMPRESSING FILES WITH pkzip:

Usage: *pkzip (options) (path):(zip filename) (source path):(filename)*
Options: *-rp* saves directory structure

RESTORING ZIPPED FILES:

Usage: *pkunzip (options) (path):(zipped filename)*
Options: *-d* restores directory structure

To see usage and definition of options, type: *pkzip* or *pkunzip*

PIPE-QU.EXE Converts "pipe" (¦) in a data file to double quotes for direct import to 123. Output file will contain numbers and will have a .prn extension. Numbers may be converted to values by removing the ' at the beginning of the range.

UNIX COMMANDS (Sun OS)

GENERAL

CHANGE YOUR PASSWORD:

Login, then type: *passwd*
You will be prompted to change your password.
Then type: *exit*

COPY A FILE:

	cp	(Copies files)
Usage:	*cp (filename) (filename)*	
	cp (path/filename) .	(copies to pwd)

SEE CPU USAGE:

	ps -auxr	(Shows CPU usage)
or	*ps*	"
or	*top*	"
or	*ps -aux*	To determine what process are currently running

KILL A PROCESS:

	kill (job number)	(to kill the job)
or	*kill -9 (job number)*	(a sure kill)

PRINT A FILE:

	lpr	(Default printer)
Usage:	*cat (filename) ¦ lpr*	
	lpr (filename)	SparcLaser printer (default)
	lpr -Plpcolor (filename)	Color Tektronix printer
	lpr -h -Plpcolor (filename)	To turn off the banner page

KILL A PRINT JOB:

lpq	(Lists jobs in print queue)
lprm (job#)	(Kills job#)

DISPLAY YOUR PATH:

pwd (Shows current working directory)

DISPLAY A FILE:

	cat	(Lists a file)
Usage:	*cat (filename)*	
Alternate:	*more (filename)*	

DUMP A WINDOW TO A BITMAP FILE:

xwd -out (filename) (dumps a window to a bitmap file)
Click in the window you wish to save

RECALL A WINDOW DUMPED TO A BITMAP FILE:

xwud -in (filename) (To recall the window)

TO DUMP A WINDOW TO THE PRINTER:

xwd ¦ xwd2ps ¦ lpr -P(printer name) then click on window to print
(This command takes about 10 minutes to process)

SEE YOUR DISK QUOTA:

df (reports free disk space by drive partitions)

MAKE GLOBAL CHANGES IN A FILE USING vi

:g/XXXXXX/s//YYYYYY/ Where XXXXXX is the old string and YYYYYY is the new string

REBOOT THE SUN WORKSTATION

reboot Type this command from a root login.

or Press the "stop" button and the "A" button at the same time.
Then type *sync* and hit return.

RUN A JOB IN THE BACKGROUND

(command name) &	to run a job in the background
control z	to stop a job
bg	to place a stopped job in the background and restart
fg	to bring a job forward
jobs	to list jobs running in the background
fg % (job number)	to bring one of the several running jobs forward

TAKE A SNAPSHOT OF A WINDOW ON THE SCREEN

1) Open the operating system snapshot window
2) Click on 'region'
3) Click on 'hide window'
4) Click on 'snap'
5) Use mouse to move to upper left of area to snapshot within the window and press left button AND HOLD IT DOWN. Drag frame to surround the area to snapshot and PRESS the center button to select the frame
   Program responds: "snap succeeded"
6) Click on save
7) Enter a file name with the extension .sun
8) Click on save
   Program responds: "save succeeded"

PRINT A SNAPSHOT

1) From your home directory (cd ~) type: *xv*
2) [rb] in "xv" window1
3) Load filename.sun (file of your choice)
4) Make color adjustments as desired. (Can be saved back as .sun with new colors)
5) [lb] on save; [lb] on postscript format; [rb] on OK
6) Save to a filename.ps filename; [rb] on OK
7) Make paper size and adjustment within "xv"; [rb] on OK; [rb] on Quit
8) To send to printer:

Type:	***lpr -h -Plpcolor (filename.ps)***	Tektronix Color Printer
or:	***lpr (filename.ps)***	SparcLaser Printer

COMPRESSING UNIX FILES

gzip (filename)	compresses unix files and adds .gz extension
gzip -d (filename.gz)	unpacks compressed files
zip (filename.zip) (source filename)	compresses unix files; compatible with the DOS version "pkzip"
unzip (filename.zip)	unpacks zipped files; compatible with the DOS version "pkunzip"

UNIX SCRIPT FILES AND PROGRAMS

FILE: *siteconv* LOCATION: */home/tcwd*

This script file was used to convert the TNRCC Well Site Database into GRASS site files. The site files contain latitude, longitude, and site ID information. Each site file represents a different type of well location (i.e., gas well, abandoned well, water well, etc.,). The script file 'siteconv' converted the database latitude and longitude (recorded in centiseconds) into GRASS "aea" format.

Script files are written specific to a type of database format, the variations in database formats and units result in the need to customize script files for that particular database. The format followed by the source files and used by 'siteconv' is shown below:

-35060838	12046716	07
(long)	(lat)	(site id)

Before running the siteconv program, be sure to make a backup of the file you are working on.
To run the program type: ***siteconv (filename)***

PROGRAM HIGHLIGHTS:

Line #

4 Taking input file and converting it from centisecond format to decimal equivalent,(%f) represents floating decimal; (%s) represents string variable. The ($#) represents an column in the data file, whether the entity is decimal or string. (Centiseconds to decimal equiv. = {####### / 360,000}

7 Providing information to conversion program regarding desired projection and necessary coordinate reference information. For our work at WRAT we are using a Prime Meridian Longitude of -96 deg. and a Standard Latitude of +23 deg., this may vary with application in other regions of the U.S.(verify before changing).

10 Use of GRASS program to convert ASCII data into GRASS format. We use "aea" projection and "clark 66" spheroid representation. CRITICAL: THE PROGRAM READS LONGITUDE 1ST AND LATITUDE 2ND, INCLUDE (-) OR (+) SIGN WITH THE DATA.

12 The longitude, latitude, and following number or string must be delineated between each other by a (¦) symbol, this was performed here.

14/16 These commands move the output file to users workspace and subdirectory.

FILE: *cafo.conv* LOCATION: */home/tcwd*

This script file was used to convert the Texas CAFO Database into GRASS site files. The site files contain latitude, longitude, and site ID information. Each site file represents a different type of CAFO location (i.e., dairy, feedlot, poultry, or swine operation). The script file 'cafo.conv' converted the database latitude and longitude (recorded in D:M:S) into GRASS "aea" format.

Script files are written specific to a type of database format, the variations in database formats and units result in the need to customize script files for that particular database. The format followed by the source files and used by 'cafo.conv' is shown below:

-2945520	3356230	operation type, ID, operator
(long)	(lat)	(site id)

Before running the program be sure to make a backup of the file you are working on.

To run the program type: *cafo.conv (input filename)*

PROGRAM HIGHLIGHTS:

Line #

4 Taking input file and formatting spaces between the D:M:S data so the values can be converted to a decimal equivalent; (%d) represents integer variable and (%S) represents a string variable , ($#) represents an column in the data file, whether the entity is decimal or string.

7 Converting D:M:S to decimal equivalent.

10 Providing information to conversion program regarding desired projection and necessary coordinate reference information. We are using a **Prime Meridian Longitude of -96 deg.** and a **Standard Latitude of +23 deg.**

13 Use of GRASS program to convert ASCII data into GRASS format. We use "aea" projection and "clark 66" spheroid representation. **CRITICAL: THE PROGRAM READS LONGITUDE 1ST AND LATITUDE 2ND, INCLUDE (-) OR (+) SIGN WITH THE DATA.**

15 The longitude, latitude, and following number or string must be delineated between each other by a (¦) symbol, this was performed here.

17/18 These commands move the output file (in GRASS format) to users workspace and subdirectory.

FILE: *tarr.gps* LOCATION: */home/tcwd*

This script file was used to convert the output from the TCWCID global positioning system in a spreadsheet ASCII format into the correct format and actually create a GRASS site map of the data. The site files contain latitude, longitude, and site ID information.

The TCWCID GPS coordinates are in degrees and decimal minutes.

The format followed by the source files and used by 'tarr.gps' is shown below:

97 36.42	33 09.99	operation type, ID, operator
(long)	(lat)	(site id)

Before running the program be sure to make a backup of the file you are working on.

To run the program type: *tarr.gps (filename)*

****

FILE: *dms.cnvt* LOCATION: */home/tcwd*

This script file was used to convert TCWCID spreadsheet data in ASCII format into the correct format and actually create a GRASS site map of the data. The site files contain latitude, longitude, and site ID information.

The TCWCID GPS coordinates are in degrees, minutes, seconds format.

The format followed by the source files and used by 'dms.cnvt' is shown below:

97 36 42 33 09 59 operation type, ID, operator
(long) (lat) (site id)

Before running the program be sure to make a backup of the file you are working on.

To run the program type: *dms.cnvt (filename)*

****

FILE: *stream.cnvt* LOCATION: */home/tcwd*

This script file was used to renumber the first column of data in the streamgauge records after the user has stripped out unwanted months or years of data. This step is necessary to convert the file into the format required by the SWAT model.

To run the program type: *stream.cnvt (input filename) (output filename)*

Note: The input filename can be repeated as output filename if desired.

FILE: *in.flow* (Converts stream gauge records to inflow input format for SWAT)
USAGE: *in.flow (input filename) (# of years of data) > (output filename)*
EXAMPLE: *in.flow 08063100 10 > inflow.3100*
LOCATION: ???????

FILE: *convert.climate*
LOCATION: */wrat3/dybala/bin*

This script file was used to convert the CDBS (climatic database, Portland, Oregon) temperature and precipitation files. These files contain precipitation, maximum, and minimum temperature for different reporting stations. They are downloaded by modem and arrive in ASCII format with each water year contained in tabular format. Each table is arranged in columns by month and there is a separate table in the file for each water year.

Convert.climate uses a "C"" program written by B. Sheng. It is named **transrl** and is located in **/wrat3/dybala/bin/**. Convert.climate prompts the user for a filename (without the .extension) and asks whether it is a temperature or a precipitation file. It then invokes transrl and (in the case of temperature files) pastes the output files into a single file.

The program file 'transrl' converts the database English units into metric units. Transrl also reformats the water year and monthly tabular format into a two or three column format. The months and days are represented in the output file by a five-digit number. The first two digits of this number represent the calendar year and the last three digits represent the consecutive day in the calendar year (i.e., 89265, is the 265th day of 1989).

Before running the climate.convert script, be sure to make a backup of the file you are working on.

To run the program type: *convert.climate*

PROGRAM HIGHLIGHTS:

The first prompt that will come up on the screen after invoking the script is "What Climatic File do you want to convert to SWAT format?". Type in the filename without the .extension.

The script will return "Does the Climatic File contain (T)emperature or (P)recipitation?". Type in a single letter (T ,t ,P, or P). The climatic file will be converted to the format required by the SWAT model. Climate.convert will then prompt "Do more?". If you wish to convert more files, answer with a single letter (Y); if not, type in a (N).

UNIX SCRIPT FILES AND PROGRAMS (cont'd)

FILES: *convert.strm* *and* *convert.strm1*

LOCATION: */wrat3/dybala/bin*

These script files are used to convert USGS streamgage files to a format that is usable in the SWAT model. The USGS files contain daily discharges in cubic feet per second for different USGS gages. They are downloaded from the Internet via Mosaic and arrive in UNIX ASCII format. Convert.strm uses a routine written by B. Sheng.

Some basic instructions for using Mosaic to retrieve these USGS records are as follows:

1. Type in mosaic from your UNIX prompt.
2. Click on File
   Open URL
   http://txwww.cr.usgs.gov:80/nwis1/ (address of URL)
3. Click on experimental nwis1 interface
4. Select by Basin and (or) by USGS HUC and (or) by County
5. Select a station type (Surface Water)
6. Select by text string (i.e., 08211520)
7. Click on Find Stations
8. Select Discharge, in CFS
   Type in a Starting Date and an End Date for Data in windows.
9. Select Return Graph
10. Click on Get Data
11. Click on Retrieve the data here
12. Click on Save As (bottom of Mosaic Page)
13. Type in a filename for data (i.e., oso8894.str) and select Plain Text
    File name should indicate beginning and ending year of data saved.
14. Use the Back button to navigate back to request form for more inquiries
15. To leave the program, click on File
    Exit
    Yes

An example of this file format is shown below.

```
# The data you have obtained from this automated
# U.S. Geological Survey database have not received
# Director's approval and as such are provisional
# and subject to revision. The data are released
# on the condition that neither the USGS nor the
# United States Government may be held liable for
# any damages resulting from its use.
# Furthur information can be obtained using this URL
# URL="http://txwww.cr.usgs.gov/~jabisese/txnwis/provisional.html"
```

```
#
# This data was retreived using this URL
# URL="http://txwww.cr.usgs.gov/~jabisese/cgi-bin/nwis1_server"
# Data for USGS station 08211520
# DISCHARGE, IN CFS
#
date    value
d       n
01/01/1988    2.10
01/02/1988    2.60
01/03/1988    2.60
01/04/1988    2.40
01/05/1988    2.70
01/06/1988    2.80
01/07/1988    3.20
01/08/1988    3.10
01/09/1988    3.20
01/10/1988    2.70
01/11/1988    2.10
01/12/1988    1.80
01/13/1988    2.00
01/14/1988    1.90
    .
    .
    .
12/25/1994    2.30
12/26/1994    2.20
12/27/1994    2.30
12/28/1994    841.00
12/29/1994    370.00
12/30/1994    68.00
12/31/1994    28.00
```

The script file 'convert.strm' converts the database CFS units into CMS units. Convert.strm also aggregates the daily values into a monthly value and reformats the date. The months and years are represented in the output file by a four-digit number. The first two digits of this number represent the calendar year and the last two digits represent the month of the calendar year (i.e., 8901, is the January of 1989).

The script file 'convert.strm1' performs some cleanup to a streamgage file after it has been merged with another streamgage file that is existing on our system. Basically, it realigns the columns and renumbers the consecutive number located in the first column of the data file.

Before running the convert.strm script, be sure to make a backup of the file you are working on.

To run the program type: *convert.strm datafile begin_year end_year output.file*
(For example, *convert.strm oso8894.str 1988 1994 08211520.ext*)

PROGRAM HIGHLIGHTS:

File: convert.strm

```
******************************************************************************
# This file is used to convert USGS stream gage data from a daily CFS
# value to a monthly CMS value with a date in the format of YYMM.  This
# script file will divide by the number of days in the month that have a
# value associated with them (zero or positive value). Written by B. Sheng
# TJD
#
#USAGE:  convert.strm  datafile  begin_year  ending_year output.file
```
convert.strm $1 $2 $3 $4

```
#!/bin/csh -f
```

```
tail +20 $1 | awk 'BEGIN{FS="/"} {printf("%s %s %s\n",$1,$2,$3)}' > ttt_temp
```
This command cuts off the header from the input file (tail ...)
The input file is indicated by the $1 which refers to the first entry of the command line after invoking the script (i.e., datafile).
It pipes the resulting data to the awk statement where the field seperator is set to a "/". This seperates the date into three seperate columns.
The result is directed to a temporary file.

```
set list=(1 2 3 4 5 6 7 8 9 10 11 12)
```
This line sets up a list of tweleve months.

```
set b=$2
```
This initiates the variable b to the beginning year ($2) from the command line.

```
set e=1
```
This line gives the starting point for a sequential number to be plotted as the first column of the final file.

```
while ($b <= $3)
```
A conditional statement which askes if the year is less than or eqal to the ending year given in the command line ($3).

foreach j ($list)

For each month in the list, perform the following steps:.

set a=$j

Let a=each month of the year

set c=0

Initiates daily cfs value at zero for the loop.

set d=0

Initiates day counter to zero for the loop.

cat ttt_temp ¦ awk '{if($1=='$a'&&$3=='$b'&&$4>=0){ c+=$4; d++ }} END{if(d!=0) printf("%3d %10.2f %d%.2d\n",'$e',c*0.02831685/d,'$b%100','$a'); else printf("%3d %10.2f %d%.2d\n",'$e',c,'$b%100','$a')}' >> $4

This lineperforms a number of functions. The cat command "reads in" the tempory file and pipes the results to the awk command for each iteration of the loop. The first portion {if($1=='$a'&&$3=='$b'&&$4>=0) of the awk command is conditional (if the value for the month equals that set by the list for this iterration AND the value for the year is equal to that set by the begining year (for the first iteration) AND the value for cfs is greater than or equal to zero (a non-null value), THEN

{ c+=$4; d++ }} translates to add the value of c (initiated at 0) to daily cfs value ($4) and store the sum in c AND add 1 to the day counter (d)., THEN

END{if(d!=0) translates to another conditional statement if day counter is not equal to zero,

printf("%3d %10.2f %d%.2d\n",'$e',c*0.02831685/d,'$b%100','$a') translates to print the formatted results of a sequential number (e), summation of daily cfs values for the month (converted to cms before summed), the date in the form YYMM, ELSE

printf("%3d %10.2f %d%.2d\n",'$e',c,'$b%100','$a')} is the formatted print command that is a result of the day counter equalling zero, in which case, print formated results of the same information with the exception of the the daily cfs (or cms) value is not arithmetically manipulated and returns a zero, THEN

>> $4 append the results of the loop to the output.file ($4).

NOTE: The ttt_temp file is in the form

MM	*DD*	*YYYY*	*value*
$1	*$2*	*$3*	*$4*

@ e++

Increment the sequential number by one before continuing loop.

```
end
```
End the internal loop.

```
@ b++
```
Increment the year value by one and test if it is less than or equal to the end year.

```
end
```

```
rm ttt_temp
```
****

The result of the convert.strm script is an output file in the following format:

```
1     0.06 8801
2     0.05 8802
3     0.03 8803
4     0.04 8804
5     0.12 8805
6     0.06 8806
7     0.17 8807
8     0.12 8808
9     0.60 8809
10    0.34 8810
11    0.04 8811
12    0.04 8812
13    0.06 8901
14    0.07 8902
15    0.04 8903
   .
   .
80  0.07 9408
81  0.18 9409
82  3.07 9410
83  0.07 9411
84  1.69 9412
```

This is the same format as the streamgage files stored in /wrat2/wrat/data/texas/streamgauges that are used during a SWAT run. In order to append one of these existing files with additional information that you downloaded via the Internet, perform the following steps.

1. Copy a streamgage file from /wrat2/wrat/data/texas/streamgauges to your working directory.
2. vi this file (i.e., vi 08211520.mon)
3. Navigate to the last line in the file (0G).

4. :r filename (to read in the additional information downloaded above, for example, :r 08211520.ext)
5. Compare overlapping values (if any) for agreement, delete any unnecessary lines, or make any other desired edits.
6. :wq (Write and Quit vi editor).
7. Run convert.strml on the saved file as follows:
   Type in convert.strml
   You will be prompted for a file name - Type it in.
   Convert.strml will then prompt "Do more?". If you wish to convert more files, answer with a single letter (Y); if not, type in a (N).
8. Convert.strml yields a new file with the same name as the input filename with the addition of a .add extension.
9. Once you are satisfied with this new file, you should move it to your directory of streamgage files for SWAT.

cpio TAPE COMMANDS

COPY (WRITE) A FILE TO TAPE OR DISK:

cpio -ocBv > /dev/rmt/0 (Exabyte tape)
o = copy out (write)
c = use an ASCII header
B = use large blocks
v = verbose
> = direct output to following device

EXTRACT (READ) A FILE FROM TAPE OR DISK:

cpio -icBuvd < /dev/rmt/0 (Exabyte tape)

i = copy in (read)
u = unconditionally replace
d = if makes or corrects directories if needed
(file name) Specific file to be extracted

READ (LIST) WHAT IS A TAPE OR DISK:

cpio -icBuvdt < /dev/rmt/0 (Exabyte tape)
mt -f /dev/rmt/0 rewind (Mounts and rewinds tape)

MOUNT AND REWIND THE TAPE:

mt -f /dev/rmt/0 rewind (Mounts and rewinds tape)
mt -f /dev/rmt/0n stat (Status of tape files)

ARCHIVE (SAVE) SELECTED FILES TO THE TAPE:

*ls ¦ *.ras ¦ cpio -ov > /dev/rmt/0* (Saves all files with .ras ext.)

RECOVER ARCHIVED (SAVED) FILES FROM THE TAPE:

cpio -icdB < /dev/rmt/0 (Reads archived files)

tar COMMANDS (for help type: ***help tar***)

COPY (WRITE) A FILE TO TAPE OR DISK:

tar cvf /dev/rmt/0 (filename)	(Exabyte tape)
tar cvf /dev/rfd0 (filename)	(Sun OS floppy)

c = create
v = verbose
f = Device to be used

COPY EVERYTHING OFF OF A TAPE OR DISK (READ THE DISK):

tar xvf /dev/rmt/0	(Exabyte tape)
tar xvf /dev/rfd0	(Sun OS floppy)

x = extract (read)

READ (LIST) WHAT IS ON A TAPE OR DISK:

tar tvf /dev/rmt/0	(Exabyte tape)
tar tvf /dev/rfd0	(Sun OS floppy)

t = tell me the contents of the tape (list it)

ADDITIONAL HINTS ON USING THE TAPE DRIVES:

The 8 mm tape drives can read 2 gig and 5 gig formats.
They can write only to 5 gig format.

Tape drives on a Sun have 'rewind on close' and 'no rewind on close' device files.
- 5 gig, 'no rewind on close' is /dev/rmt/0n.
- 5 gig, 'rewind on close' is /dev/rmt/0.
- 2 gig, 'no rewind on close' is /dev/nrst0.
- 2 gig, 'rewind on close' is /dev/rst0.

ADDITIONAL HINTS ON USING THE TAPE DRIVES (cont'd):

Using the 'no rewind on close' allows you to write multiple files to a single tape.

mt positions the tape and reports on the status of it.
cpio takes the list of files to copy out from standard input.
tar takes the file/directory list from the command line.

examples:

I want to copy directory 'thisstuff/' to 5 gig tape.

Check tape status *mt -f /dev/rmt/0n stat*

Exabyte EXB-8500 8mm tape drive:
sense key(0x0)= no sense residual= 0 retries= 0
file no= 0 block no= 0

(the file numbers reported are 0 based)

I want to skip the first file on the tape:

mt -f /dev/rmt/0n fsf 1
mt -f /dev/rmt/0n stat
Exabyte EXB-8500 8mm tape drive:
sense key(0x0)= no sense residual= 0 retries= 0
file no= 1 block no= 0

Using cpio -- (argument B means 5120 bytes per block -- default 512
[more efficient method of storage])
find thisstuff -print ¦ cpio -ocB -O /dev/rmt/0n

Using tar -- (20 is the number of 512 byte chunks per block on tape)
tar cbf 20 /dev/rmt/0 thisstuff

I want to copy in the entire directory structure from the first file on the tape that is in tar format (Use the 'o' argument on the command line for tar to make you the file owner when you are extracting).

mt -f /dev/rmt/0 rewind
tar xovbf 20 /dev/rmt/0n

I want to copy in the 'data' directory structure from the second file on the tape that is in tar format (used 'no rewind device' on last command).

tar xovbf 20 /dev/rmt/0n data

ADDITIONAL HINTS ON USING THE TAPE DRIVES (cont'd):

I want to copy in the entire directory structure from the first file on the tape that is in cpio format (Use the 'd' (directories created) and 'u' (overwrite) to copy in files from cpio format; if the tape was written with the 'B' option, it must be read with the 'B' option).

mt -f /dev/rmt/0 rewind
cpio -icvBdu -I /dev/rmt/0n

I want to copy in the 'data' directory structure from the second file on the tape that is in cpio format (used 'no rewind device' on last command).

cpio -icvBdu -I /dev/rmt/0n data

Read the man pages for other options on mt, find, tar and cpio.

RESTORING FROM BACKUP TAPES - Commands used.

mt -f /dev/rmt/0 rewind	rewind the tape
mt -f /dev/rmt/0n fsf 4	move to fourth file on the tape without rewinding
mt -f /dev/rmt/0n stat	give the status of the tape without rewinding
/usr/lib/fs/ufs/ufsrestore iv	run ufsrestore interactively
ufsrestore>?	list available commands
ufsrestore>ls	list directories or files on the tape
ufsrestore>cd irene	change to directory named irene on the tape
ufsrestore>add stream	add "stream" to list of directories to extract from tape
ufsrestore>extract	extract all files in directory named "stream"

If you are asked to specify next volume # enter a "1".
If asked whether to set owner/mode '.' answer "n".

Assuming you were in /wrat4/bednarz/temp when you started *ufsrestore*, the files in /irene/stream will be copied to /wrat4/bednarz/temp/irene/stream. The owner of the extracted files will be the same as the owner of /wrat4/bednarz/temp.

ufsrestore>quit — to quit ufsrestore; tape is automatically rewinded

For additional help type: *man ufsrestore*

MOUNT & UNMOUNT CDROM:
Place a cd in cdrom drive, then type:

volcheck	(Mount CDROM drive)
df	(To find path to access CDROM disk)
cd	(Return to home directory)
eject cd	(Unmount CDROM drive and eject CD)

UNIX DISKETTE COMMANDS

LOAD DOS 5.25 DISKETTE:
Converts DOS format to UNIX
Make a directory to load to then give the command:
mcopy 'b:'* .

FORMAT A DISKETTE IN THE SUN:

fdformat -d format a disk in DOS format (after formatting, eject and reload floppy, then type *volcheck* and *df*)

SAVE FILES TO A DISKETTE ON THE SUN:

*ls *.ras ¦ cpio -ov > /dev/rfd0* (Saves files to Sun diskette)

WRITE/READ DOS DISKETTES ON THE SUN:

Insert diskette in drive "A" and type:

volckeck	mounts floppy drive
df	shows path to floppy directory; you can then copy to it or from it (example: /floppy/unnamed_floppy#1)

USING dd TO WRITE AND READ DISKETTES

dd if=(filename) of=/dev/rfd0	(Write on the sun diskette)
dd if=/dev/rfd0 of=(filename)	(Read the dd diskette)

GRASS

STEPS TO CREATE A NEW RASTER MAP FROM PART OF AN OLD MAP

A. By reclass of categories

1) Create a temporary work file with the vi editor. This file will contain the old category number with its new category number.

Ex.

12338955=1
33221155=2
55446644=3

2) Create an output file that has the new categories in it but is not a map that can stand alone by itself.

r.reclass input=(filename of original file) output=(New filename) <(filename of temporary file created in step 1)

3) Make a new stand alone map

r.resample (This runs interactively. It takes the output file of step 2 as input and produces a new file which you must name.)

4) remove the file created in step 2

g.remove (This reclass file is no longer any good because it can not be displayed if the original file is no longer available.)

B. By pulling out a certain area

1) Use the *r.mask* command to set a mask on a certain area, watershed, etc. This will cause only the area picked in the mask to be shown on the screen when a map is displayed.

2)Use the r.resample command to make this new map. The only data within this new map will be that which occurs within the masked area.

CREATE A MASK ON ANY EXISTING RASTER MAP

Make a mask of the new area (a mask is an outline that can be placed over other maps). Only one of these can exist in memory at a time.

r.mask (Runs interactively. Can be made on any raster map)

1) Remove current mask

2) Create a new mask
   a. Enter new map name

RE-SET THE REGION

g.region save=(mapset name) n= s= e= w= (from v.digit)

SUPERIMPOSE 2 VECTOR MAPS IN v.digit

Make sure both maps are in aea projection and available (in the current mapset or by link)

v.digit	(on map within bigger map)
Z	(Zoom if needed)
C	(Customize)
O	(Select the overlay map - the bigger one)

PRINT A GRASS RASTER MAP

A. The background in your graphics monitor must be white to get a good print. To get this white background, you will need to type:
d.erase white
d.rast -o (filename)

B. Now you will need to click on the background of the monitor to get the Workspace menu, here under Programs you need to choose Snapshot. Now move the snapshot menu away from your graphics display. Before setting the window click in the snapshot menu the "hide window during capture" button. In the Snapshot screen click on Region and then Snap, use the left mouse key to set the window you want. You will have to hold on to the left key once you have started your window, once you have gotten the window you want press the middle key on the

PRINT A GRASS RASTER MAP (cont'd)

mouse. This will set the window and you are now ready to click on the save button. In naming your window file, you must add a .sun extension.

C. You are now through with the Snapshot screen.

D. You can now output this file to the printer

PRINT A RASTER MAP LARGER THAN 8.5 X 11 ON PRINTER

This procedure divides the raster map into quadrants and prints each quadrant on a separate sheet of paper, to be taped together after printing.

1) Put in proper size paper in printer

2) vi the file "quadvect" (do this only if a vector is plotted)

vect (vector map name)	
color black	Color of vector line
width 1	Width of vector line
hcolor white	Color of highlite on either side of vector line
hwidth 1	Width of highlite on either side of vector line
end	Required if vect and it's options used

verbose 0

3) Start grass4.1

Type the command: *ps.select*

Select "tekA" for 8.5 x 11 paper or "tekB" for 11 x 17 paper.

Hit return to choose the default for the rest of the questions.

4) Give the command:

psquada (raster file name) 4 90 dummy quadvect

where:

PRINT A RASTER MAP LARGER THAN 8.5 X 11 ON PRINTER (cont'd)

(raster file name)	the raster map to print
4	the number of quadrants to print (2.4.6.8)
90	rotation factor where 0 is not rotated and 90 is.
dummy	required file name
quadvect	optional if vector file to be overlaid on raster map (must substitute "dummy2" here if vector file NOT to be painted)

The output of this command (for this example) will be 4 files named:

(raster file name)0.ps
(raster file name)1.ps
(raster file name)2.ps
(raster file name)3.ps

These 4 files will be automatically sent to the color printer. If you do not wish them to be printed automatically, use vi to comment out (place a # in col 1) of the statement in the psquada command that begins with rsh txwrat lpr (etc) or make another copy of the command with a different name with this line deleted. You could call it psquadm (for manual printer output).

Put # in front of colortable y to leave out legend (2 different lines)

OTHER GRASS COMMANDS

d.what.rast	Shows what the cell is
v.to.rast	Converts vector map to raster (Must set region and d.vect map first)
r.report	Set mask first (r.mask) trinity = upper_tr_ws (Upper trinity) Richland/chambers = Cedar =

Note: cats directory contains description and linkfiles (1 for each map)
Make 1 copy for each map after generating it. Must cover the entire map if it is a sectional map.

USE THE DISPLAY ON ANOTHER MACHINE

setenv DISPLAY rcproj:0.0	where rcproj is the name of your machine; allows you to run a monitor after remote logging into another machine.

LEGEND SHORTCUT

This shortcut will leave out the categories that are not represented in your current map when doing a legend.

1. Set your frame on your monitor just like before: ***d.frame -c***

2. Instead of typing ***d.legend***, type in: ***d.newl***

   The GRASS tool is interactive to set text and background color, etc.

CONVERT LAT/LONG TO COORDINATES

Type:	*m.geo*	
Hit <return> twice		
Select type of conversion:	*2*	for lat/long to coordinates
Select projection:	*3*	for "aea"
Select spheriod:	*8*	for "clark66"

Last prime meridian and standard parallel will be displayed and should be -96.00 and +23.00 respectively. If not indicate that you want to change them and enter:

Meridian Longitude value: *-96*
Parallel Latitude: *+23*

You will then be prompted for your lat/long values in degrees, minutes, seconds format:

Example: Enter	***+33 10 00***	for latitude
	-96 36 25	for longitude

The results should be displayed as follows:

Longitude	Latitude	Easting	Northing	Zone
-97 36 24.9985	+33 10 0.0012	-148917.03	1123112.31	None

You will then be prompted to enter another lat/long, or you can exit the program by hitting return at that point.

INPUT TIGER FILES

1. Download individual county files from Exabyte tape to your workspace.

    a. Create a subdirectory in your $HOME location named tiger.
    mkdir tiger
    b. Change into the newly created directory.
    cd tiger
    c. Load Exabyte tape and rewind to the beginning.
    mt -f /dev/rmt/0 rew
    d. Browse the filenames on the tape.
    tar tvf /dev/rmt/0n
    e. Extract files from the tape to your tiger directory.
    tar xvf /dev/rmt/0n tiger48/gzip/xxx
    where xxx = the 3 digit FIPS code for the county
    f. Unzip all files.
    *gunzip **

2. Move selected unzipped tiger files into grass4.0. For this process to operate properly you must be running GRASS and be in a GRASS location with utm coordinates.

    a. To create a GRASS location with utm coordinates (example):

    Location: UTM14
    Projection: (1)UTM14
    Mapset: PERMANENT
    Region: N=39000000 S=2990000 RES=200
    E=700000 W=480000 RES=200
    Zone: 14

    b. Make a subdirectory in $LOCATION named tiger. Change into this directory and move the applicable files (located in $HOME/tiger/..) to here.
    mkdir tiger
    cd tiger
    mv $HOME/tiger/.... .
    cd ..

INPUT TIGER FILES (cont'd)

3. Run v.in.tiger.scs interactively on these files. You will need to know two file names for this procedure. One file will have a .1 extension and the other will have a .2 extension (ex. t48001.1, t48001.2). The 001 represents the county fips code. You will also need to know the cfc code for the particular data that you want. The cfc codes are given in the tiger manual. An example of this is A2 gets you all the Secondary Roads for the particular county that you are working with. If you want the county boundary you will type in BOU as the cfc code.

v.in.tiger.scs
trg48___.f41
tgr48___.f42
newfilename.rds
A NOTE: cfc code A is for all roads, highways, etc.
{CR}
{CR}
{CR}
{CR}

4. Exit UTM14 location and change to Albers Equal Area projection location (texas).

a. Establish a link to UTM14 location:
cd $LOCATION
cd ..
ln -s /wrat3/dybala/data/utm14/PERMANENT utm14

b. Add UTM14 to your mapset list with *g.mapsets*:
g.mapsets
+ __
cd $LOCATION

5. Run *v.proj* on *newfilename.rds*:
v.proj
newfilename.rds
{CR}
utm14
{CR}
PERMANENT
{CR}

INPUT TIGER FILES (cont'd)

6. Run *v.support* on *newfilename.rds*:

   v.support
   newfilename.rds
   1
   {CR}
   {CR}
   2
   {CR}
   {ESC}
   {ESC}

7. Clean up your workspace and delete unnecessary files. You can remove all zip files from $HOME/tiger directory with *rm -irf* * and you can also remove all files from utm14's $LOCATION/tiger directory.

8. Use *v.patch* in aea location to patch newly formed vector maps together.

9. Just remember the same cfc code will not get the same exact information every time for different counties. In other words the tiger data is not labeled consistently. Example: cfc code H2 will get you all of the streams for one county but will only get part of the streams in another county.

EXPORT A MAP TO GRASS

Acquire	(Select map from list)
Output_data	
export	
Click mouse on title block of screen	
Select an export format: 6. dlg3	
Enter export file name	
Enter ATTRIBUTE CODE	: 3 for both 1 for pairs
Enter Coord type	: 2 for utm
Enter a SET NUMBER	: Set No. = 0
(export file is created in /ltplus/export)	

Move the file to the proper dlg directory under your current mapset.

or

Select export format	: 5. digit
Enter export file name	
Enter attribute code	: (1=OB) ONLY, 3 both obj and attr)
Enter COORD type.	: Choose 2 for utm
Enter a SET NUMBER	: Set No. = 0

1 to 3 exports file will now be created in /ltplus/export. These 3 files have the extensions: acii, att, and cat). These files must be moved to a sub-directory called dig_ascii under the appropriate mapset.

Start GRASS

cd $LOCATION

v.import

1 for ASCII DLG file (3 to import digit files)

(Take all the defaults)

Run v.proj to convert utm maps to aea projection (utm14 and utm15)
Run v.patch to patch aea maps together then:
Run v.support on composite map
Run v.digit on composite map

1. v.support (Enter file name) - Set region resolution 30 x 30
   1 to build topology
2. v.to.rast - old filename - new filename
3. r.support

Mask on the map before converting a raster map to a dem with r.surf.contour. This will

EXPORT A MAP TO GRASS (cont'd)

accelerate the process. You may want to use r.buffer to create a mask outside of the watershed boundary.

Then convert GRASS raster map to dem:

r.surf.contour (Note: this will take time-several days in some cases)

The safest way to run the above command is in the background mode. After starting r.surf.contour, hit <ctrl Z> to suspend the process, and then type in *bg* to place it in the background. This will allow you to logout of the machine without terminating the process, and it will also protect you from small power outages which may kill an xterm (but not the server since it has a power backup).

An alternative (and faster) method to r.surf.contour to create a DEM is to use *s.surf.tps* on the raster map.

First, you have to create a site file from the raster map. You can do this by running r.stats on the raster as follows:

r.stats -1zg oldfilename | awk '{printf("%f|%f|#%d\n",$1,$2,$3)}' > newfilename

(newfilename is a site file created from the raster map of the contour lines)

s.surf.tps (Run interactively)

Use a mask to set the region. s.surf.tps gives you the opportunity to create a number of new files including DEM, aspect, slope, etc. Take defaults for items such as tension, smoothing, etc. You are given the opportunity to multiply units by a conversion factor (such as feet to meters) when interacting with s.surf.tps.

You can use *r.mapcalc* to change units on a DEM from feet to meters.

For example, to change the units on a raster map named willow.dem from feet to meters and write the changes to a new map layer called willow.dem.meters:

r.mapcalc willow.dem.meters='willow.dem.3048'*

CONVERT GRASS VECTOR MAP TO ASCII

v.out.ascii input=(grass vector filename) ouput=(filename.asc) creates ascii file

CONVERT GRASS ASCII FILE TO DXF

v.out.dxf input=(filename.asc) output=(filename.dxf)

DEVELOP REPORT OF SITES IN A WATERSHED

Before starting be sure the region is set and there are no masks.
Type *s.menu*

1	(Read a site list such as tx_reservoirs)
2	(Mask the list on the watershed)
3	(Save, use a new filename)
4	(Check for Duplicates)
8	(Run reports)
0	(Just include the site itself)
1	(Site characteristics report)

Then you can view or print the report. You can also mask on individual subbasins and run reports for each subbasin. The new site file can be plotted using ***d.sites***.

**** This command works only in GRASS4.1**

CHANGE COLORS IN A RASTER MAP

cd to "colr" directory
Type: ***vi (raster map filename)***
The file is in the following format: category #:red:green:blue
To change colors, refer to a color chart and change appropriate numbers.

GRASS

SUGGESTIONS FOR RUNNING r.watershed ON AN EXISTING WATERSHED TO REDEFINE THE SUBBASINS

You need to first mask on an area slightly larger than the watershed in order to get accurate basins from the dem. To do this run *r.grow* on the existing watershed and extend the watershed boundary about 500 meters. *r.grow* extends the boundary one cell at a time, so you may have to run r.grow several times. Then mask on the new watershed. Before running *r.watershed*, set the resolution of the region to match the resolution of the dem (the resolution for tx_dem.fill.aea is 100 meters).

Type: *r.grow*

(raster filename)	(Name of existing watershed map to be grown)
(raster filename)	(Name of new extended watershed map or temporary map)
y	(Should result be a 0/1 map?)
d.rast (filename)	(Plot the new extended watershed map)
r.mask	(Mask on the new extended watershed map)
g.region	
1	(Modify the current region directly - change resolution to match the resolution of the dem that you are using (30 m))
d.erase	(To set the new region)
r.watershed	
y	(Do you want to use the fast mode?)
y	(If not enough RAM, should slow mode be used?)
12_dem.aea	(Name of elevation map layer)
<hit return>	(No depression map layer)

Select the units for the basin threshold and the size for the exterior drainage basins. I used 4000 hectares and got a pretty good map.
Next enter the name of the new watershed basin map (**filename.bas**) and accumulation map (**filename.acc**).
Ram can produce several maps not necessary for r.watershed to function. These are optional.
Map layers for the lumped parameter hydrologic/soil erosion model are not needed - hit return to continue.
For methods of tabulating basin information, enter "3".
The program will now create the new watershed map.

g.region	(To re-set the resolution to your normal resolution)
r.support	(To create or update supporting files for the raster map)
r.poly	(To create a vector map of the subbasins)
v.support	(To create or update supporting files for the vector map)

GRASS

DETERMINE AVERAGE SLOPE FOR A SUBBASIN

g.remove MASK	remove any existing masks
g.region rast=(basin map)	set region to basin map which contains the selected subbasin
d.erase	
r.slope.aspect	
input=*(dem)*	
output=*(filename).slp*	
(filename).asp	
no	Do zero values represent true elevation?
yes	Report in percent?
1	Select "1" for meters
no	Do you want to specify minimum value of slope for which aspect is computed?
r.mask	mask on selected subbasin
r.average	
input base map=*(basin map)*	
input cover map=*(filename).slp*	
output map=*(filename).aveslp*	
no	Are the vlaues to be looked up from the cats file?
d.rast (filename).aveslp	Plot the average slope map.
d.what.rast	Click on the selected subbasin to get average slope; subtract "1.0" to
get	true average slope.

DETERMINE WEIGHTED SLOPE OF A SUBBASIN(SIMILAR TO WEIGHTED CN)

r.weighted.cn	
input = *(filename).slp*	
output = *(filename).wgtslp*	
d.rast (filename).wgtslp	Plot the weighted slope map.
d.what.rast	Click on the selected subbasin to get weighted slope; subtract "1.0"
to	get true weighted slope.

THE SWAT MODEL

TO RUN SWAT MODEL

Note: Always use a "shell tool" when working with swat or swat input.

a) Establish necessary links by: (Do this ONE time)

create a sub-directory under your home directory called data
create a sub-directory under data called some name (dataset name)
cd to the dataset directory
Give the link (ln) command for each link you wish to establish. Keep in mind that each link name will become a mapset in GRASS. xxxxxx is whatever name you wish to call the mapset.

Example:
ln -s wrat2/wrat/data/texas/PERMANENT xxxxxxx
ln -s /brc20/srin/data/US.aea/PERMANENT xxxxxx

Links to the /wrat2/wrat directory are the permanent project files.

STEPS TO RUN THE SWAT MODEL

1. Start GRASS in a xterm or shelltool (not a cmdtool) and start a monitor

2. Start swatgrass *swatgrass*

3. From swatgrass prompt type: *swat_input94.4.routeadd* or *swat_input94.4*

4. Make your choice to either create a new run file, to work on an existing file.

5. You must have access to a raster basin file prior to running SWAT! If basin map was created using ***r.watershed***, you must run ***wshd2to1*** which properly renumbers subbasins for swat.

6. From the SWAT menu extract input from the appropriate layers.

THE SWAT MODEL (cont'd)

Interface operation notes:
Text or menu options that can be completed by hitting the <ESC> key . This type of interface is used for menus or for entering tables of parameters. All menus have a default answer of Exit (0), so that by simply hitting <ESC> one may leave the program's menus. The following keystroke guide is helpful to know when using the parameter entry worksheets that use this interface:

<RETURN> moves the cursor to next prompt field.
<CTRL-K> moves the cursor to previous prompt field.
<CTRL-H> moves the cursor backward non-destructively within the field.
<CTRL-L> moves the cursor forward non-destructively within the field.
<CTRL-A> writes a copy of the screen to a file named "visual_ask" in your home directory.
<CTRL-C> where indicated (on bottom line of screen) can be used to cancel operation.

7. Process the layers in the following order: 3,4,5,6,7,8,9,10,11,13,14,1. Options 2 and 12 are normally not used.

8. For WRAT SWAT runs use the following for these layers:

	1:250,000	1:24,000
4>land use	*tx_lulc_recl.aea*	*trin.mod.landuse*
5>soils	*tx_statsgo.aea*	*trin.mod.soil*
6>topographic	*12_dem.aea*	
9>rain & temp site file	*tarrcnty.pcp*	*tarrcnty.pcp*
10>groundwater	*alpha.aea, us.heath.bfd.new*	

NOTES:
Step 4 - The landuse categories in the cats file must have the same four-letter format as shown in the crop.dat file.
Step 5 - If you get error messages that specific soil names cannot be found, you will need to edit the soil cats file. Select a soil name with properties similar to the soil name that could not be found, and substitute that soil name in the cats file. The selected soil name must be included in the soils data files.
Step 6 - **Be sure that the dem extends beyond the boundaries of the basin map and that the units of the dem is meters.**

9a. Manual Input of Pond Data.

For layer #11, enter data for SCS watershed dams and other farm ponds as ponds. The model accepts a maximum of one pond for each subbasin. If you have several ponds in a subbasin, you must add the data together to get one composite pond for that subbasin.

Enter principle spillway and emergency spillway storage in watershed millimeters. Enter principle spillway and emergency spillway surface area in hectares. If there is no principle spillway, assume that the principle spillway storage and surface area is equal to 95% of the emergency spillway storage and surface area.

Additional suggestions:

Initial pond volume:	75 to 100% of the normal storage.
Seepage through dam:	0
Initial sediment concentration	350
Normal sediment concentration	350
Hydraulic conductivity of pond bottom:	0.08
Starting month of non-flood season:	6
Ending month of non-flood season:	9
No. of days to bring flood to normal storage:	10 for SCS watershed dams 1 for farm ponds

9b. Automatic Input of pond data.

To automatically input pond data, you must have a site file and a corresponding data file for the ponds. The site file must be in the following format:

-36258.560000|1093840.220000|TX00811 ROCKWALL SCS CEDAR CREEK WS SITE 1A

Only the coordinates and the ID number are critical. After that, the description can be anything. The data file must be in the following format:

(watershed name)

NAT ID	DR AREA (HECT)	PS S A (HECT)	PS STOR (HECT-M)	ES S A (HECT)	ES STOR (HA-M)
TX00811	445.2	13.0	13321.9	63.7	65499.4

The first three lines of the file are ignored. Data for each pond must begin with the ID number followed by the data in the order as shown. Data must be in metric units. The drainage area must be greater than "0". However if there are ponds in series, the total drainage area should be entered for the pond at the lower end of the series, and the drainage areas of upstream ponds may be entered as an insignificant value (such as 0.1).

From the swat_input menu select option 11 (Input Reservoir...Menu). From the Reservoir Menu select option 7. Answer the questions as follows:

Do you want to automate the inputs from a pond site file y/n....................*(y)*
Reservoir Site Map...*(site file name)*
Enter the name and path where the reservoir information file is stored....*(path/data file name)*
Enter the percentage of principle spillway storage as initial volume...........*(recommend 75 %)*
Enter the beginning month of non-flood season...*(6)*
Enter the ending month of non-flood season..*(9)*
Enter the average number of days to bring a flood to normal storage........*(10)*

Swat_input will then extract the data for each pond and sum the data by subbasin. One composite pond for each subbasin with ponds will be created.

9c. Large reservoirs on the main stem of the stream network should be individually input as reservoirs (option 1). To input reservoirs select option 1 from the Input Reservoir...Menu. Enter data as follows:

EXAMPLE:

FORM 15 (RESERVOIR DATA)

Month the Reservoir became operational	1__
Year the Reservoir became operational (Simulation year)	66_
Reservoir Operation Rules 0. Simulate with Principle Outflow	
Reservoir Operation Rules 1. Use measured Outflow	
2. Simulatied controled Outflow-Target release	0
Total reservoir surface area at emergency spillway (ha)	2444___
Runoff volume from reservoir catchment area	
required to fill emergency spillway (ha-meters)	17269__
Total reservoir surface area at principal spillway (ha)	1445___
Runoff required to fill to principal spillway (ha-meters)	6772__
Initial reservoir volumes (ha-meters)	6772__
Average principal spillway release rate (m**3/s/km**2)	0___
Seepage through dam (m**3/day)	0_____
Initial sediment concentration in reservoirs(ppm)	350____
Normal sediment concentration in reservoirs (ppm)	350____
Hydraulic conductivity of reservoir bottoms (mm/hr)	0.08_

If release rates for the reservoir are available, an outflow data file for the reservoir may be loaded into swat. To do this enter "4" for Reservoir Operation Rules and add the outflow data file name (example: bw6669.flw) to the *.res file in the following format (vi the *.res file after exiting the pond and reservoir input menu):

```
(line 1)    Reservoir Data 1 2
(line 2)     1 66 4  2444.0 17269.0  1445.0  6772.0  6772.0    0.0    0.0  350.0  350.0    0.1
(line 3)     0      0.   bw6669.flw
(line 4)    (blank line)
(line 5)    (blank line)
(line 6)    (blank line)
            ~
            ~
```

The outflow data file must be in the project directory and should be in the following format (daily values):

```
GATED FLOW-BARDWELL LAKE, 1966-1969, CMS
   0.00    66001
   0.00    66002
   0.00    66003
......etc.
```

10. Menu item 13 provides options for adjusting CN, USLE P factor, and revap storage.

AFTER COMPLETING ALL APPLICABLE STEPS

11. Under option 1 you will need to select number 1 for Form 1 and 2. Under Form 1 you will get two screens. The first one will look similar to the following. The suggested answers to these questions are shown.

Form 1			Suggested Response
1 Title ________________________________			
2 Program Control Codes			
Number of years of runoff simulation		______	10
Beginning Year of Simulation		______	80
Number of Subareas in basin		______	
Printout frequency Monthly(0);Daily(1);Annual(2)		______	0
Will Rainfall be:			
Read in single rain gauge for entire basin	(1)		
Simulated single rain gauge for entire basin	(2)		
Read in one main gauge for each subbasin	(3)		
Simulated for multiple rain gauges	(4)	______	3
Will the max & min temperatures be :			
Read in single in max & min for entire basin	(1)		
Simulated single max & min for entire basin	(2)		
Read in max & min each subbasin	(3)		
Simulated for each subbasin	(4)	______	3
Number of times random number generator cycles before simulation begins			0

On the second screen, the only items that should be answered are "Reach outlet number..." and "ET method..." (use Penman-Montieth)

12. To remove all data from a project run, you should use option 4 from the SWAT/Grass Project Manager.

13. When you are through entering the data you can select option 0 to get out of the program. At this time you should have been through all the options except numbers 2 and 12.

14. Now you should be ready to move on to the model. First type:
    cd $LOCATION

15. Next type: *cd swat*

16. Now type: *ls*
    This gives you the different names of projects that can be run.

17.	Now type:	*cd (project name)*	
18.	To run the model type:	*swat*	(maximum of 500 sub-subbasins)
		swat.750	(maximum of 750 sub-subbasins)
		swat.1100	(maximum of 1100 sub-subbasins)

19. After the model has run type: *d.newsplit (project name).rch*

You will now get a screen which will ask for the following:

Filename to be converted	________	(project name.rch)
# of basins	________	(#of subbasins in watershed)
# of years	________	10
# of months to group together	________	120

20. If you used dominant soil and landuse for each subbasin type:
d.newsplit (project name).sbs
If you used multiple soil and landuse (sub-subbasin concept) type:
d.newsplit (project name).bsb
You will again get the screen mentioned above, just answer it the same way.

If you wish to plot the reservoir output file type:
d.newsplit (project name).rsv

Filename to be converted	________	(project name.rsv)
#of basins	________	(# of reservoirs in watershed)
#of years	________	10
#of months	________	120

21. Then you type: *d.grsgraph graph.def*

22. Now you should see a screen labeled "Create Definition File" looking like this model

	____________________
Name of data file 1.	____________________
Name of data file 2.	____________________
Name of data file 3.	____________________
Name of data file 4.	____________________
Name of data file 5.	____________________
Name of data file 6.	____________________
Path to data files.	____________________
Name of basin file.	____________________
Name of vector file.	____________________
Name of site file.	
Name of print device.	____________________

You should answer the blanks like this:

model		swat
Name of data file 1.		(project name).rch(# basins)sout(# months)
Name of data file 2.		(project name).rch(# basins)mout(# months)
Name of data file 3.		(project name).bsb [or sbs](# basins)sout(# months)
Name of data file 4.		(project name).bsb [or sbs](# basins)mout(# months)
	or	(project name).rsv(#reservoirs)sout(#months)
Name of data file 5.		(file name for measured data, such as stream flow)
Name of data file 6.		(file name for measured data, such as stream flow)
Path to data files.		.
Name of basin file		(name of basin raster file)
Name of vector file		(name of vector file you want overlaid - (optional)
Name of site file		(***** This is optional *****)
Name of print device		lpr -Pbrcsun2 (***** This is optional *****)

Definitions:
(project name).rch(# basins)sout(# months) = reach routed monthly output for a subbasin
(project name).rch(# basins)mout(# months) = reach routed output for a selected month for a subbasin
(project name).sbs or bsb(# basins)sout(#months) = monthly output for an individual subbasin
(project name).sbs or bsb(#basins)mout(#months) = output for a selected month for an individual subbasin

NOTE - If you have already run d.grsgraph once for the same file name you will not get this screen because this information is already saved in a file. To edit the graph.def file, type: ***d.grsgraph graph.def -e***

23. When the graphics display changes and says choose a file, click on the one you want. You will then be able to choose from a menu on the right side of the graphics screen, you will want to choose 'Link to Map'.

24. Next you will get to choose a graph type of your choice. Now you can choose what you want to compare on your graph. Once your map is shown and it says "DONE" just below the map, click on the subbasin you want and you will get a graph of the chosen data..

25. To exit, click on the 'esc' button at the bottom of the screen.

26. To get the graphics screen to change back to a full screen you need to type: ***d.frame -e***

27. To run *xg*, first get out of swatgrass. Then type:
xhost +
swatgrass
Then change directory to your swat project directory and type:
xg graph.def

INSTRUCTIONS FOR RUNNING SWAT WITH DAILY OUTPUT

1. Start swat_input94.3.

2. **Do not try to run more than one year of data when using daily output!** Input data for each option as you normally would.

3. After completing input options 3 through 14, select option 1. Then select Form 1 and input data as follows:

Number of years of runoff simulation	1
Beginning year of simulation	1982
Number of subareas in basin	(enter number)
Printout frequency Monthly(0);Daily(1);Annual(2)	1

Complete the rest of Form 1 as you normally would.

Run the swat model.

It is not necessary to run d.newsplit after running the swat model if you only wish to look at the data files.

After running the swat model, cat the following files to look at daily output:

(project name).sbs	if using dominant soil and landuse
(project name).bsb	if using multiple soil and landuse
(project name).rch	for reach routed data

Descriptions of the data in these files is given in "Watershed Modeling and GIS with SWAT and GRASS".

When running daily output, your project files will get extremely large and you may run out of storage. For large watersheds like Upper Trinity, you may have to extract the subbasins that you are interested in and run the model only on those subbasins. Another option is to use dominant soil and landuse to reduce the size of the files.
Currently one year is the minimum period of time that you can run the swat model. Jeff and Srini are working on an option to run a period of time of less than one year.

THE SWAT MODEL (cont'd)

INPUTTING ACTUAL WEATHER DATA INTO THE SWAT MODEL

1. Steps 3 through 6 must be run prior to running swat_inp to input weather data (steps 8 and 9).

2. It is not necessary to edit the weather files. SWAT will automatically extract the data for the time period that you are modeling.

3. The data in this file should run from 1960 to 1990 (or present). If there is a short period of no data or individual missing data for the time table you are modeling the weather generator in step 8 of swat_inp will fill in that time for you.

4. To find out which weather stations are in or around the watershed you are modeling you will need to display the sites file of the weather stations in that area and then ask which sites are in your area (d.sites then d.what.site). The file you will need to display is the one titled XXXXXX.pcp where XXXXXX is the 6 digit HUA that you are working in. When you are doing the d.what.site command record the 6 digit number occurring right after the northing is listed. This number will usually start with 48.

5. When running swat_inp choose option 9 (Extract Rain and Temperature Gauges). You must still run option 8 of swat_inp even though you have actual weather..

6. When choosing option 9 you will be asked if you have a raster map with the temp. and rainfall. Answer no.

7. Next you will be asked if you have a site file for the temp. and rainfall. Answer yes.

8. It will then ask you for the filename. The filename will be XXXXXX.pcp , the XXXXXX represents the 6 digit hua that you are working with.

   Example: for Cedar Creek within the Trinity River Basin it would be 120301.pcp

9. You will now be asked for a path, this path is where you put the files you retrieved above, probably in your home directory or in a subdirectory possibly named climate and then with additional subdirectories for different watersheds.

STREAMFLOW DATA

1. Determine the streamgauge I.D. number that you intend to compare.

2. The time period covered by the stream gauge should match the simulation time period in order to plot correctly against predicted values of the model. You may after stripping the unneeded months of data need to run the script file named "stream.cnvt" to renumber the left column in sequential order beginning with "1".

3. Next you need to copy this file to the location of your model run. Example:
   cd $LOCATION ***cd swat*** ***cd (model run name)***

4. Now you need to add this to the graph.def file when you create it. If you already have a graph.def file, you will need to edit it (***d.grsgraph1 graph.def -e***) for your particular run. Where the file asks for Name of datafile 5, insert the filename of the file you created in the step above. Answer these questions like this example:

Model Name	swat
Name of datafile 1.	cedar.rch53sout120
Name of datafile 2.	cedar.rch53mout120
Name of datafile 3.	cedar.sbs53sout120 or cedar.bsb53sout1120
Name of datafile 4.	cedar.sbs53mout120 or cedar.bsb53mout120
Name of datafile 5.	cdr.650
Name of datafile 6.	cdr.800
Path to data files.	.
Name of basin file.	(raster basin filename)
Name of vector file.	OPTIONAL
Name of site file.	OPTIONAL
Name of 'print' device.	OPTIONAL

When you use the esc key to get out of this input mode you will be prompted to save the same files The last one you will be asked to save will be one called swat.(your stream gauge filename) like the one shown below.

There isn't a Model Definition File for "swat.650".

Press <esc> to Create a Model Definition File for this filename.
Press `q` then press <esc> to quit.
C_

Just push the esc key and then you will see the following. The bold letters or numbers represent how this screen should be answered.

COMPARING STREAMFLOW DATA (cont'd)

Definition File =swat.650 Current Data File =cdr.650

Create Model Definition File - (continued)

Number of Columns	**02**
Starting Line number of data	**01**
Delimiter SPACE COMMA NONE	**SPACE**
Number of datasets per group	**001_**
Number of lines in a dataset	**00120**
Groups per file	**001**

Now you will see this screen, again the bold letters represent how this screen should be answered.

Create Model Definition File - (continued)
Define data type for each column

Data types Available: ASC_SCI_NOTATION, ASC_FLOAT, ASC_INT and CAT_LABEL

	Data Type	Label	Units
Column 1	**ASC_INT_____**	**month_____**	**none_____**
Column 2	**ASC_FLOAT___**	**08062650___**	**cms______**

The Label for Column 2 can be what ever you want it to be, the numbers shown above represent a particular stream gauge number.

5. Now you should be able to type in ***d.grsgraph graph.def*** and display the actual stream gauge data.

CALIBRATING SEDIMENT

There are two ways to calibrate or adjust sediment yields predicted by the model:

1. Adjust the "P" factor with option 13 of the SWAT input menu.
   "P" should normally be between 0.5 and 1.0

2. Adjust the stream channel routing parameters in the *.bsn file.
   The three routing parameters to adjust are: SPC = 0.005 to 0.015
   SPE = 1.000 to 2.500
   PRF = 1.000 to 2.000

CALIBRATING SEDIMENT (cont'd)

The format of the *.bsn file is f8.3 as shown below:
Basin DATA
5079.400 1.000 1.000 0.500 0.000 0.005 1.000 1.000

The last 3 numbers are SPC, SPE, and PRF in that order.

Note: For subbasins covered by water (such as Cedar Creek Reservoir - 67,68,69,70,71) set k = 0.000 in the *.rte file for those subbasins. This will eliminate channel erosion in those subbasins.

TRANSFERRING FILES ON INTERNET VIA FTP

To Export Files to Another Agency: (ex. USGS)

1. Place the file in proper directory as follows:

rlogin brcserv0	
cd /ftp/ftp/pub/outgoing	
mkdir [directory name]	ex. mkdir usgs
cd usgs	
cp [path/filename] .	ex. cp /wrat2/baird/tx.e00 .

2. Notify other party to access and retrieve file as follows:

ftp brcsun0.tamu.edu	
anonymous	at request for login
[email address]	at request for password
cd /ftp/pub/outgoing/usgs	
bin	
get [filename]	
exit	

For another agency to export files to us:

ftp brcsun0.tamu.edu	
anonymous	at request for login
[email address]	at request for password
cd /ftp/pub/incoming	
bin	
put (filename)	
exit	

ROOT COMMANDS

The following commands are all to be done from "root" login!

1. To shut down the workstation to turn it off or move it - type: ***halt***

2. Tape Backup of Systems

   A. Sun Workstation

   Login as "Root" and load unprotected tape in tape drive.

cd /	change directory to root
./backall	to back up original drives
./backuptroy	to back up "troy" hard drive

   NOTE: The 5 GB tapes will only back up one of the three systems (either original sun drives, troy, or laptop).

   B. Tadpole Notebook

   Login as root and load unprotected tape in tape drive.

cd /	change directory to root
./backall	to back up the "/" and "/usr2" partitions

3. To reboot workstation - type: ***reboot***

FILES AND DIRECTORIES

The original TCWCID setup has the basic GRASS directory and file structure although naming of some directories is at the discretion of the user. Refer to the GRASS manual for required directory and file structure.

File names can be up to 80 characters long. However, creating names more than 12 to 15 characters long becomes cumbersome when accessing the files. It is suggested that the file name be suggestive of the file contents if possible. Capital letters should not be used in directory names. Capitals are not recommended in file names except where required by the application program which uses the file (e.g. PERMANENT is required by GRASS).

Some WRAT file naming conventions have evolved and are listed below. Final GIS files and data for each of the TCWCID Project is stored in /data/data/base and /data/data/state. Under these directories is a directory (mapset) for permanently stored files.

Example:

Tarrant County Project data is stored in:	/data/data/base/PERMANENT
Statewide project data is stored in:	/data/data/state/PERMANENT

Within the mapsets and directories, some file naming conventions have been adopted to ease the identification of contents. These conventions include the following as part of the filename or as file extension:

Filename Use	Represents
aea	map is in albers equal area conic projection
bas	subbasins as determined by r.watershed, or methods other than digitizing
bnd	basin or watershed boundary map
db	database file
dem	digital elevation map
dlg	digital line graph
mod	map used for model input
quad	7.5 minute quad sheet
rd	roads vector map
recl	reclassed map
res	reservoir
str	streams vector map
utm	map is in universal transverse mercator projection
wshed	subbasins delineated by digitizing

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APPENDIX F - LIST OF ACRONYMS AND ABBREVIATIONS

ARS	Agricultural Research Service
ASAE	American Society of Agricultural Engineers
BMP	Best Management Practice
BOD	Biochemical Oxygen Demand
CAFO	Confined Animal Feeding Operation
CBMS	Computer Based Mapping System
CERL	Construction Engineering Research Laboratory
cfs	Cubic Feet per Second
CFSA	Consolidated Farm Services Agency
cfu	Colony Forming Units
CO_2	Carbon Dioxide
$CO(NH_2)_2$	Urea
COD	Chemical Oxygen Demand
COE	Corps of Engineers
CREAMS	Chemicals, Runoff, and Erosion from Agricultural Management Systems model
CRP	Clean Rivers Program
CRWR	Center for Research in Water Resources
DEM	Digital Elevation Model
DLG	Digital Line Graph
DO	Dissolved Oxygen
EPIC	Erosion Productivity Impact Calculator
ERS	Economic Research Service
ft	Feet
GIS	Geographic Information System
GLEAMS	Groundwater Loading Effects of Agricultural Management Systems
GRASS	Graphical Resources Analysis Support System
HUC	Hydrologic Unit Code
in	Inch
m	Meter
m^3	Cubic Meter
μg/l	Micrograms per Liter
mg/l	Milligrams per Liter
mgd	Million Gallons per Day
mi^2	Square Mile
mld	Million Liters per Day
MUSS	Soil loss from water erosion using small watershed MUSLE options (t/ha)
N	Nitrogen
N_2	Nitrogen Gas
NASA	National Aeronautics and Space Administration
NEXRAD	Next Generation Weather Radar
NHAP	National High Altitude Photography

LIST OF ACRONYMS AND ABBREVIATIONS (cont'd)

NH_3	Ammonia Nitrogen
NH_4+	Ammonia Nitrogen (variant)
NO_2	Nitrite
NO_3	Nitrate
NOAA	National Oceanic and Atmospheric Administration
NPS	Nonpoint Source
NRCS	Natural Resources Conservation Service
OP	Orthophosphate
PO_4	Phosphate
Precip	Precipitation
Q	Surface runoff (mm)
RCWP	Rural Clean Water Program
ROTO	Routing Outputs To Outlets model
SCS	Natural Resources Conservation Service (formerly Soil Conservation Service)
SURGO	Soil Survey Geographic Data Base
STATSGO	State Soil Geographic Data Base
SWAT	Soil and Water Assessment Tool
SWRRB	Simulator for Water Resources in Rural Basins
TAES	Texas Agricultural Experiment Station
TAEX	Texas Agricultural Extension Service
TAMU	Texas A&M University
TCWCID	Tarrant County Water Control and Improvement District No. 1
TDS	Total Dissolved Solids
TDWR	Texas Department of Water Resources
TIGER	Topologically Integrated Geographic Encoding and Referencing System
TKN	Total Kjeldahl Nitrogen
TN	Total Nitrogen
TNRCC	Texas Natural Resources Conservation Commission
TP	Total Phosphorus
TRA	Trinity River Authority
TSS	Total Suspended Solids
TSSWCB	Texas State Soil and Water Conservation Board
TWC	TNRCC (formerly Texas Water Commission)
TWDB	Texas Water Development Board
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey