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CONTINUOUS SIMULATION OF SURFACE AND SUBSURFACE FLOWS
IN CYPRESS CREEK BASIN, FLORIDA, USING
HYDROLOGICAL SIMULATION PROGRAM-FORTRAN (HSPF)

by

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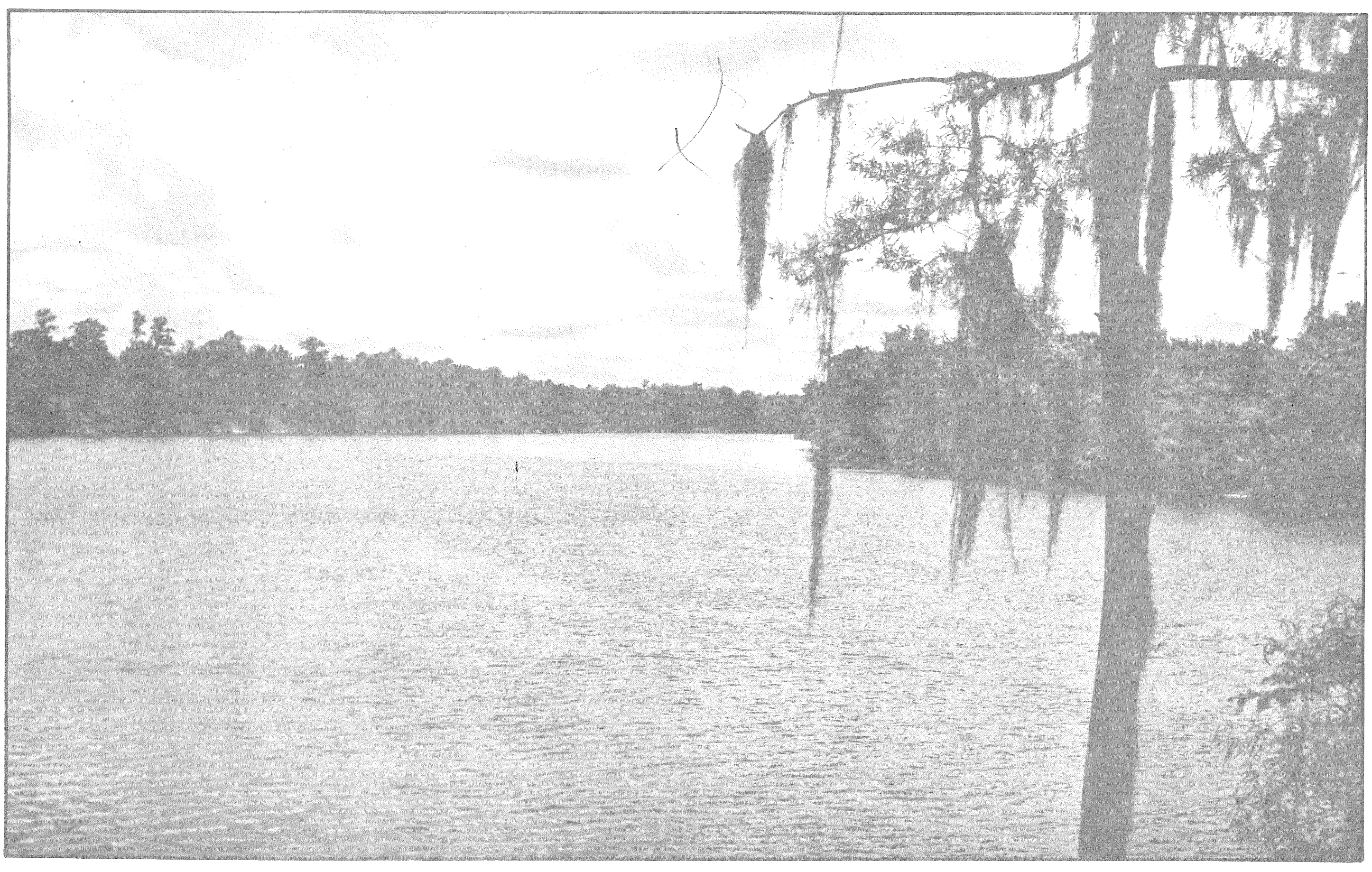

UNIVERSITY OF FLORIDA

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CAROLINE NANCY HICKS

A THESIS PRESENTED TO THE GRADUATE SCHOOL
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LIST OF SYMBOLS

ABS	=	absolute value function
CV	=	coefficient of variation
D	=	stream stage
D_d	=	drainage density
E	=	expected value
ET_A	=	actual evapotranspiration
ET_p	=	potential evapotranspiration
K_1	=	coefficient for converting PE into ET_p
K_2	=	coefficient for converting ET_p into ET_A
ln	=	natural logarithm function
L_s	=	stream length
mgd	=	million gallons per day
msl	=	mean sea level
n	=	number of data points
n_e	=	effective number of data points
PE	=	pan evaporation
R	=	correlation coefficient
r	=	correlation coefficient, lagged one day
RE	=	relative error
RMSE	=	root mean square error

SA	=	surface area
SDEV	=	standard deviation
t	=	t-test statistic for significance
V	=	stream volume

Abstract of Thesis Presented to the Graduate School
of the University of Florida in Partial Fulfillment
of the Requirements for the Degree of
Master of Engineering

CONTINUOUS SIMULATION OF SURFACE
AND SUBSURFACE FLOWS IN CYPRESS CREEK
BASIN, FLORIDA, USING HYDROLOGICAL SIMULATION
PROGRAM-FORTRAN (HSPF)

By
Caroline Nancy Hicks
August, 1985

Chairman: James P. Heaney
Cochairman: Wayne C. Huber
Major Department: Environmental Engineering Sciences

A calibrated HSPF model for Cypress Creek Watershed north of Tampa, Florida, is presented. Recent development in the watershed has caused the Southwest Water Management District to become concerned about long-term effects on runoff volume and leakance to deep groundwater in the watershed. The model is used to predict average monthly streamflow and total annual streamflow.

Goodness of fit criteria for such prediction are discussed. Simple statistical methods and graphical comparison techniques are chosen for use in calibration. Estimation of the HSPF parameter values for the basin is discussed. Predicted monthly streamflows are compared to measured monthly stream flows. The predicted mean monthly streamflow for the calibration period shows a relative error of less than 2 percent.

A parameter sensitivity analysis proves the active groundwater recession rate to be the most sensitive parameter. Tests to determine correlation between predicted soil storages and shallow well elevations show that the behavior of the active groundwater zone of HSPF is significantly correlated to fluctuations of the surficial aquifer.

A verification of the model is performed during a period of severe drought. HSPF is found to over-predict flows after successive months of drought due to its inability to simulate the drawdown of a threshold storage volume in the surficial aquifer. The model predicts mean monthly flow for the verification period with a relative error within 4.1 percent.

James P. Heaney
Chairman

CHAPTER I

INTRODUCTION

Cypress Creek Watershed, located north of Tampa, Florida in Pasco County (Figure 1-1) has undergone extensive development over the last decade. Landowners in the basin have modified the surface drainage, and the West Coast Regional Water Supply Authority (WCRWSA) has established a 30 mgd capacity wellfield in the center of the watershed, pumping from the deep groundwater aquifer. Within the same time period, recurrent droughts have been a particular problem. In 1984 the Water Resources Research Center (WRRC) at the University of Florida contracted to undertake an extensive study of the watershed under the sponsorship of the Southwest Florida Water Management District (SWFWMD).

Previous studies of the basin include seven years of hydro-biological monitoring of the Cypress Creek wellfield by the SWFWMD, Biological Research Associates, and Conservation Consultants, Inc. (Rochow, 1983). Two models for simulation of steady state groundwater flow for a 932 square mile area containing Cypress Creek wellfield and nine other municipal wellfields were developed by the USGS: a two dimensional model (Hutchinson et al., 1981) and a quasi-three-dimensional model (Hutchinson, 1984). In

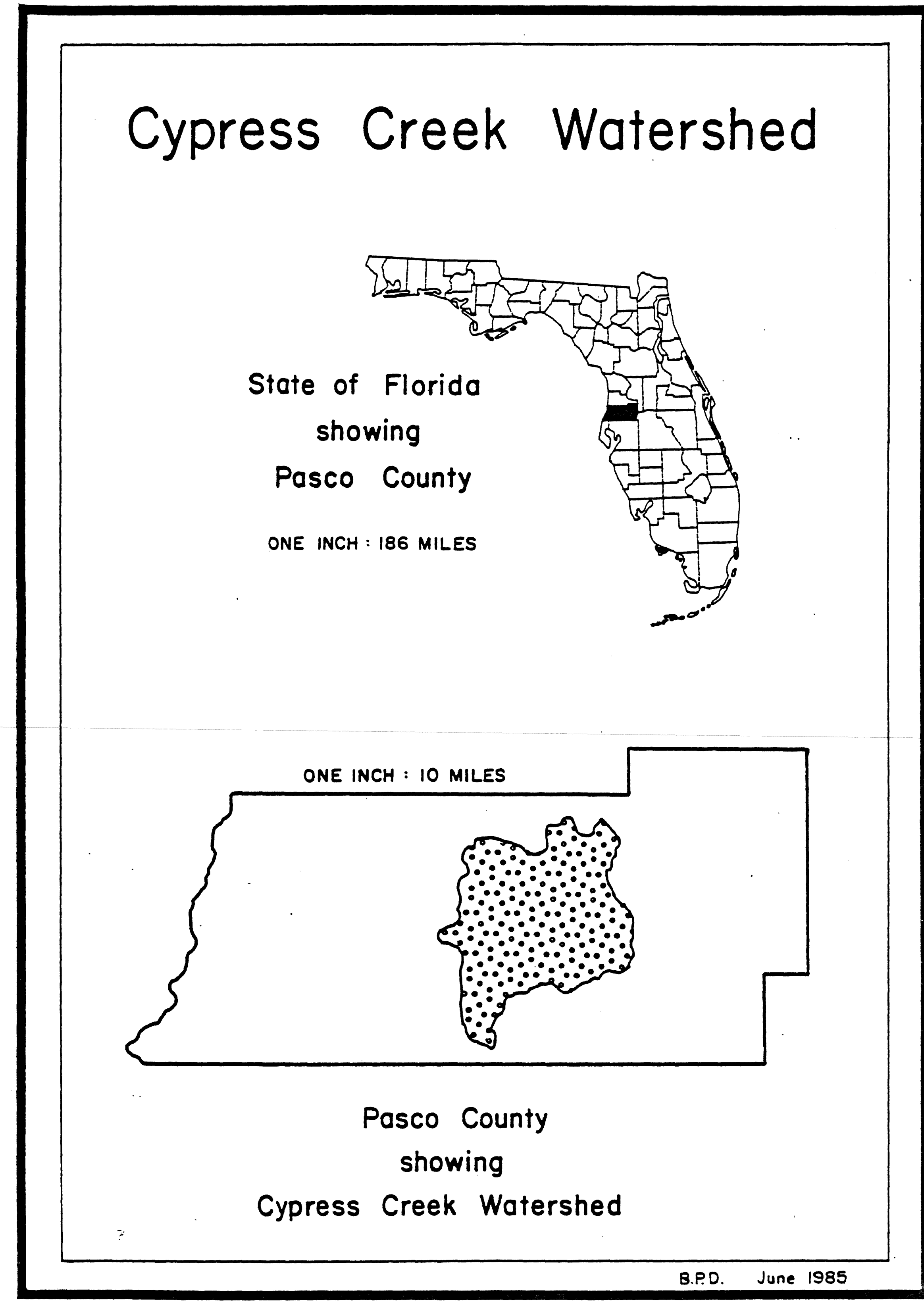

Figure 1-1 General Location of the Study Area

addition, a model patterned after the Prickett-Lonnquist aquifer simulation model is currently maintained by SWFWMD. Previous studies have been inconclusive as to the effects of either drainage development or deep aquifer pumping on the surface hydrology of the basin.

The objectives of the current study by the WRRC are to determine any possible effects on the surface hydrology of the basin of both on-going drainage development and deep aquifer pumping. One goal of the study was to develop a hydrologic simulation model of the surface hydrology of Cypress Creek watershed. The model would be used in part to determine whether either the total runoff volume or the volume of leakance to deep groundwater of Cypress Creek Watershed had decreased over the period of development, and if so, could this decrease be accounted for on the basis of annual rainfall levels alone.

To answer these questions, a long term continuous simulation model was needed in order to span the period prior to wellfield operation (pre-1976) to the present. A groundwater model could best simulate deep aquifer pumpage, but could not as accurately capture the effects of continuous changes in surface drainage. The fact that the Prickett groundwater model of the basin was already in operation at the SWFWMD was an added consideration. For these reasons, it was decided that a surface model could best allow for the examination and comparison of hydrographs and stages before and after various hydrologic modifications and conditions, which might include surface drainage, deep aquifer pumping, general development in the watershed, and droughts.

A comprehensive runoff model review performed by Huber and Heaney (Basta et al., 1982) describes criteria used in selecting an appropriate runoff model. Given the aforementioned characteristics desired in the model for this study, HSPF (Hydrological Simulation Program-Fortran) was chosen. The initial release of HSPF was prepared by Hydrocomp Incorporated. The revised version used for this project, Release 7.0, was prepared by Anderson-Nichols and Company and obtained through the Environmental Protection Agency's (EPA) Environmental Research Laboratory in Athens, Georgia (Johanson et al., 1981). HSPF is a long-term continuous simulation model which is both well documented and well supported. It was expected that HSPF could simulate the surface hydrology well, although that proved challenging for the swamp conditions existing in Cypress Creek Watershed.

Once the model was chosen, some thought had to be given as to what would constitute an acceptable simulation or "fit" of the actual hydrologic conditions at Cypress Creek Watershed. The subject of this thesis is the calibration and goodness of fit of the HSPF model subsequently developed as a part of the WRRC research for the Cypress Creek project. Chapter II describes the study area and its water budget components. A detailed look at the calibration procedure itself is given in Chapter III, which encompasses the machinations of HSPF. Chapter IV will discuss some of the many methods available for analysis of goodness of fit, and will explain why the particular methods used for this study were appropriate based on the questions the simulation was designed to answer. Chapter V is an analysis of the simulation's goodness of fit, based on this calibration. The summary and conclusions are presented in Chapter VI along with suggestions for further research.

CHAPTER II

DESCRIPTION OF STUDY AREA

General Location

Cypress Creek Watershed (CCW) is located in west-central Florida, Pasco County, between U.S. Highway 41 to the west and Interstate 75 to the east (Figure 2-1). The watershed outlet is on Cypress Creek, just south of State Road 54. From its outlet, the watershed extends northward for about 14 miles. Cypress Creek runs north to south through CCW, draining 117 square miles of sandy ridges, flatwoods, hammocks, and swamps. This region of highland ridges separating broad valleys enjoys a climate characterized by long, warm, relatively humid summers, and mild, dry winters.

The Wellfields

Cypress Creek wellfield is situated in the center of Cypress Creek Watershed, just south of State Road 52 (Figure 2-1). The wellfield consists of 1272 acres owned by the City of St. Petersburg and 2623 acres owned by Southwest Florida Water Management District (SWFWMD) for a total of 3895 acres. In 1974 the City of St. Petersburg transferred rights to the development of a wellfield on City property in

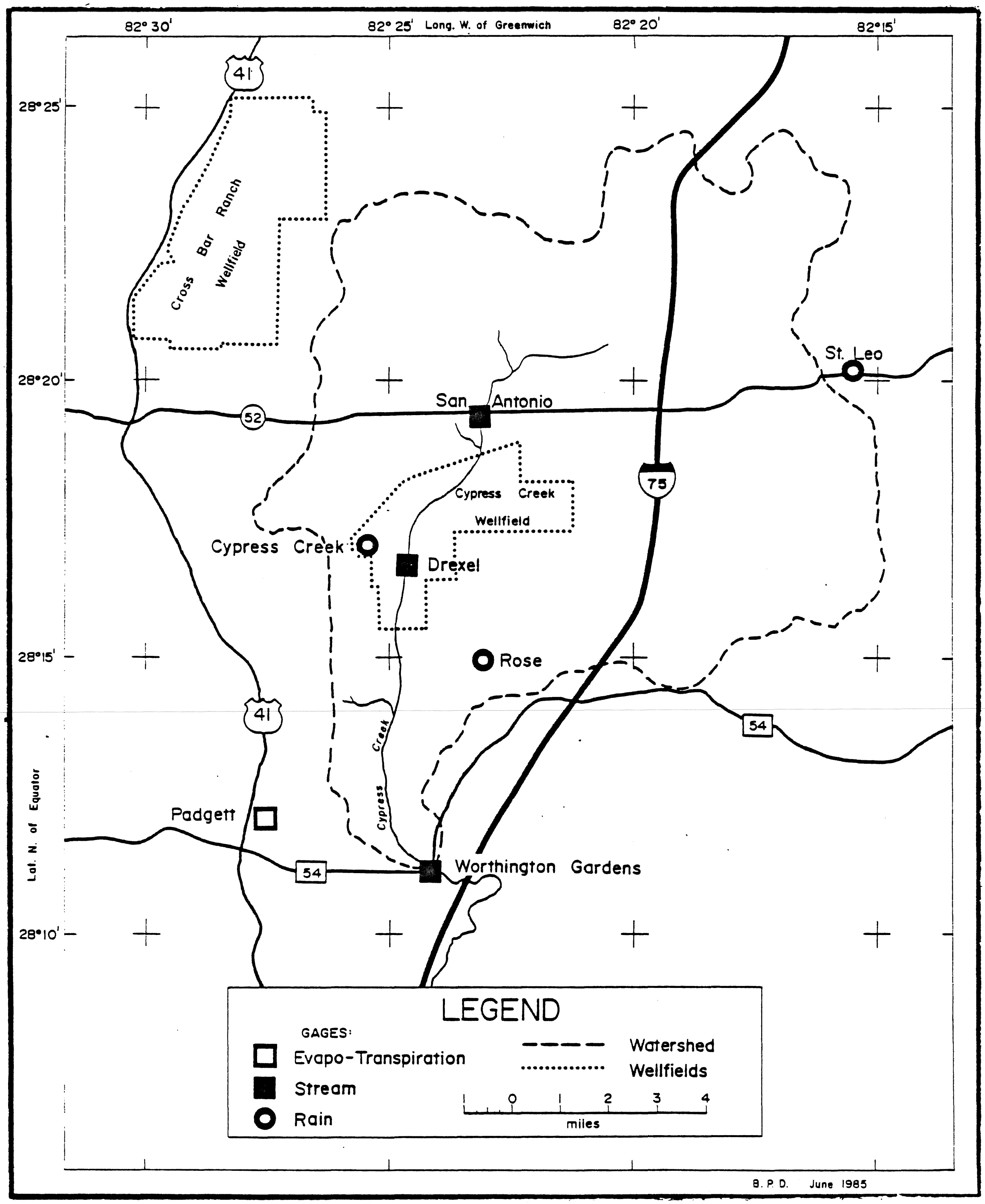

Figure 2-1 Cypress Creek Watershed, and Cypress Creek and Cross Bar Ranch Wellfields, North of Tampa, Florida

the Cypress Creek area to the West Coast Regional Water Supply Authority (WCRWSA). A consumptive use permit was issued to WCRWSA in March 1978 for withdrawals of 30 mgd average annual and 30 mgd maximum daily from ten 700-foot deep wells. In September 1979 three additional 700-foot deep wells were authorized and constructed. The consumptive use permit was later modified to permit withdrawal of an average of 30 mgd annually and a maximum of 40 mgd daily from the thirteen wells. The wells are generally located in the central part of the property, east of Cypress Creek (SWFWMD, 1982).

Northwest of Cypress Creek wellfield lies more than 8000 acres of land which make up Cross Bar Ranch wellfield (Figure 2-1). This wellfield extends five miles south from its northern boundary which is one mile south of the Pasco-Hernando County line. The western boundary is the Seaboard Coast Line Railroad; from this boundary the property extends east for two to three miles. Pinellas County purchased the property in 1976 and transferred the wellfield development rights to WCRWSA in November 1977. A consumptive use permit was issued to WCRWSA by SWFWMD in February 1980 to pump groundwater from 17 wells. Withdrawals were authorized for a combined average annual of 30 mgd and a maximum daily of 45 mgd (Legette et al., 1981).

The centers of the two wellfields are approximately 8.5 miles apart. Property boundaries are about four miles apart at their closest points; however, under present development plans the closest production wells in the two wellfields will be about six miles apart (Leggette et al., 1978).

Soils and Land Use

Physiography

The physiography of Cypress Creek Watershed and Pasco County is characterized by discontinuous highland ridges separated by broad valleys; the ridges are above the deep aquifer's potentiometric surface, but the valleys are below it (i.e., subject to flowing wells). Numerous shallow lakes are found in the valleys. Extending westward from State Road 581 to two miles east of the Pasco County coastline is an area described as the Gulf Coastal Lowlands. Including the majority of the Cypress Creek Watershed, this is a region of flatwood and grassy sloughs, with elevations in the watershed portion ranging from 50 to 80 feet msl. The lowlands rise to meet the Brooksville Ridge region which extends from SR 581 eastward. Elevations in the Brooksville Ridge portion of the watershed reach over 200 feet msl.

Geology

The geology of central Pasco County can be described as an upper or surficial zone of soils and a lower zone of consolidated rock. The surficial zone consists of unconsolidated deposits of sand and clay of the Pleistocene and Halocene ages and ranges from 20 to 40 feet in thickness

(SWFWMD, 1982). Between the sand and the consolidated rock is a clay layer ranging generally from 2 to 25 feet in thickness which acts as a semipermeable confining layer (Ryder, 1978). Underlying the surficial zone is the consolidated rock of the Floridan Aquifer: Tampa, Suwannee, Ocala, and Avon Park limestone formations. In Cypress Creek wellfield within CCW, the Tampa limestone is approximately 40 feet thick. Beneath this are about 80 feet of the Suwannee, 140 feet of the Ocala, and about a 700 feet layer of Avon Park limestone (Ryder, 1978). A generalized geologic column in the Cypress Creek wellfield is shown in Figure 2-2 (Ryder, 1978).

Soils

Seven general soil associations are found in the study area; all but one association contain at least two distinct soils. The exception is the soil of the Big Cypress Swamp. A summary of the characteristics of each association is presented in Table 2-1. The location of each association is pictured in Figure 2-3. Detailed soils information may be found in Soil Survey of Pasco County (Stankey, 1982).

Soil Moisture Capacity

Heaney et al. (1985) have estimated the soil moisture capacities of the Cypress Creek watershed soils. Three approaches to estimating soil moisture capacity were compared: available water capacity data for soil horizons taken from soil interpretation records prepared by the Soil

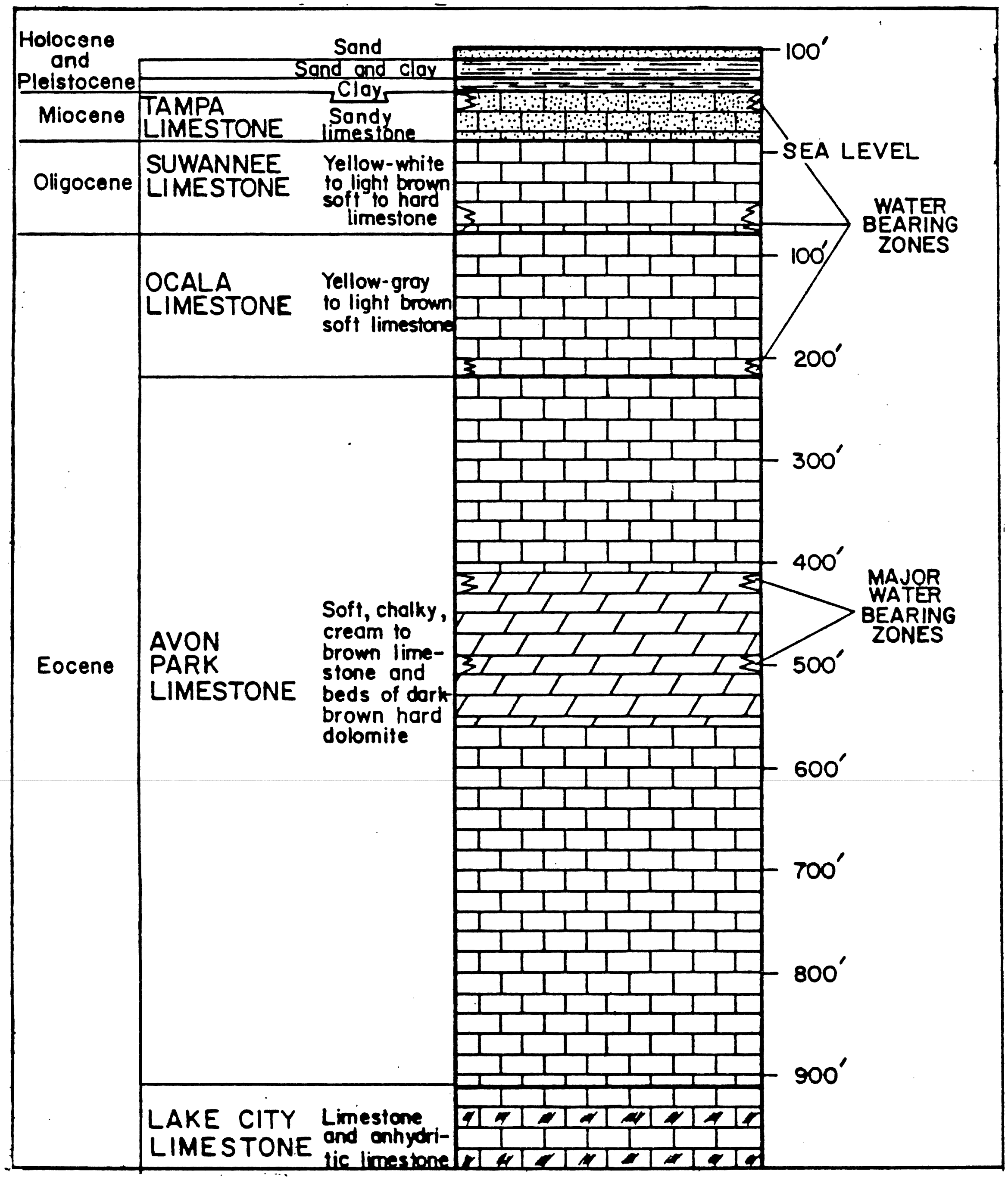

Figure 2-2 Generalized Geologic Column in the Cypress Creek Wellfield (Ryder, 1978)

Table 2-1

Soil Associations of Cypress Creek Watershed (Stankey, 1982)

Soil Association	Map Area	Topography	Slope	Drainage	Profile	Limitations to Development	% of Total Area
1) Tavares Sparr Adamsville	4	Upland ridges	Nearly level to sloping	Moderately well drained and somewhat poorly drained	Sandy throughout; some are sandy to a depth of 40"-80" and loamy below	Wetness poor filtration sandiness	14.4
2) Smyrna Sellers Myakka	8	Flatwood and depressions	Nearly level	Poorly drained and very poorly drained	Sandy throughout, some have a dark colored subsoil within 30" depth some have a dark colored surface layer	Wetness ponding poor filtration sandiness	9.8
3) Chobee	11	Swamp and river flood plains	Nearly level	Very poorly drained	Dark colored loamy surface layer less than 20" thick over calcareous loamy materials	Flooding wetness slow percolation	14.6
4) Tavares Adamsville Narcooosee	1	Upland ridges	Nearly level to gently sloping	Moderately well drained and somewhat poorly drained	Sandy throughout; some have a dark colored surface layer within 25" depth	Wetness poor filtration sandiness	3.6
5) Pomona EauGallie Sellers	9	Flatwoods and depressions	Nearly level	Poorly drained and very poorly drained	Dark colored and sandy within 30" depth; some are sandy throughout with a thick dark colored surface layer	Wetness ponding slow percolation sandiness	41.8
6) Nobelton Blichton Flemington Variant	7	Upland ridges	Nearly level to sloping	Somewhat poorly drained and poorly drained	Sandy to a depth of less than 40" and loamy or clayey below	Wetness slow percolation	5.6
7) Basinger Wauchula	10	Flatwoods and depression	Nearly level to gently sloping	Poorly drained	Some are sandy throughout; some have dark-colored, sandy subsoil within 30" depth and are loamy below	Wetness poor filtration sandiness	10.2

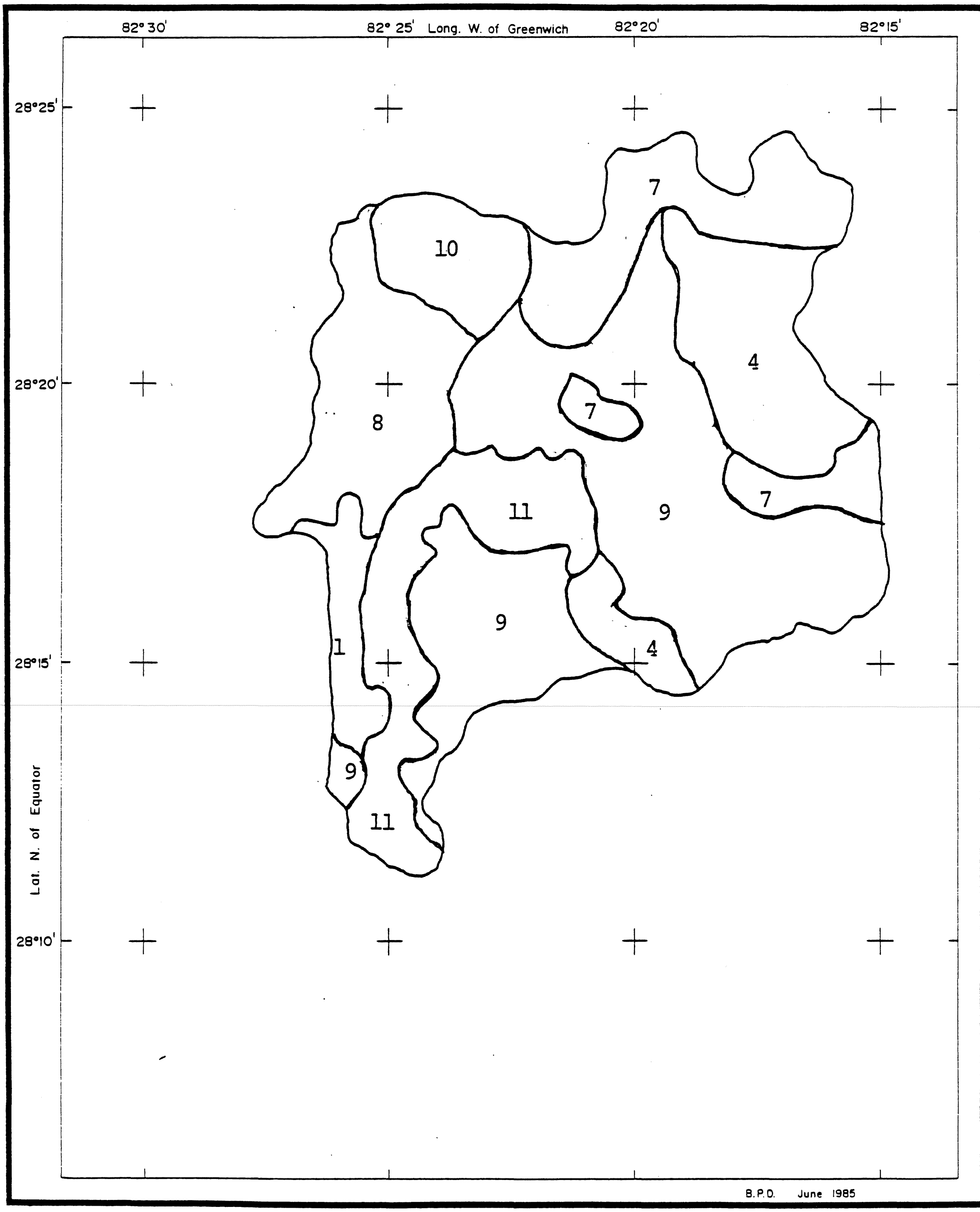

Figure 2-3 Location of Soil Associations within Cypress Creek Watershed

Conservation Service (SCS); water table rise from measured storm events; and storage curves prepared by the South Florida Water Management District (SFWMD) and the Agricultural Research Service (ARS) based on the depth to the water table.

The analysis produced the following estimates of soil moisture storage:

Method	Estimate, in/in
soils inventory	.08-.10
water table rise	.13-.15
storage curves	.12

These estimates are quite close to each other. According to Heaney et al. (1985), the first two approaches should be weighted more heavily because they were based on site specific data. An average of .11 in/in was recommended.

Land Use

Land use in the area is limited mostly to forestry and pasture, due to the sandy, poorly drained nature of the soils. There is some potential for growing citrus, hay, grass, clover, and soybeans, but successful agricultural use depends on having some type of water control system to remove excess water in the wet season and to provide irrigation in the dry season.

The timber present is primarily longleaf and slash pine with some oak, gum, and cypress. On soils with forestry potential, however, lumbering is limited by seedling mortality and the difficulties involved in moving equipment in and out of wooded, often swampy, areas.

Some general statistics for Pasco County indicate the limitations on land use. In 1969, 60 to 80 percent of county land was farmland, but only 10 to 20 percent of farmland was in harvested crops (Wood and Fernald, 1974). The majority of all farmland was used as pasturage for livestock. In 1980, 34 percent of county land was in forest, but only 18 percent of forest land was owned by forest industries (Terhune, 1983).

Aside from Cypress Creek wellfield, development in CCW is located chiefly in the lower basin, and consists mainly of trailer parks and small residential subdivisions. The creek serves as the western boundary for a system of lakes being developed into residential waterfront communities.

Rainfall

Gages

Hourly rainfall values for the period 1944-1979, archived by the National Weather Service, are available on magnetic tapes at the University of Florida for eight stations regionally, as shown in Figure 2-4. Of these eight, St. Leo is closest to CCW. All NWS stations also record additional climatological data (e.g., temperature),

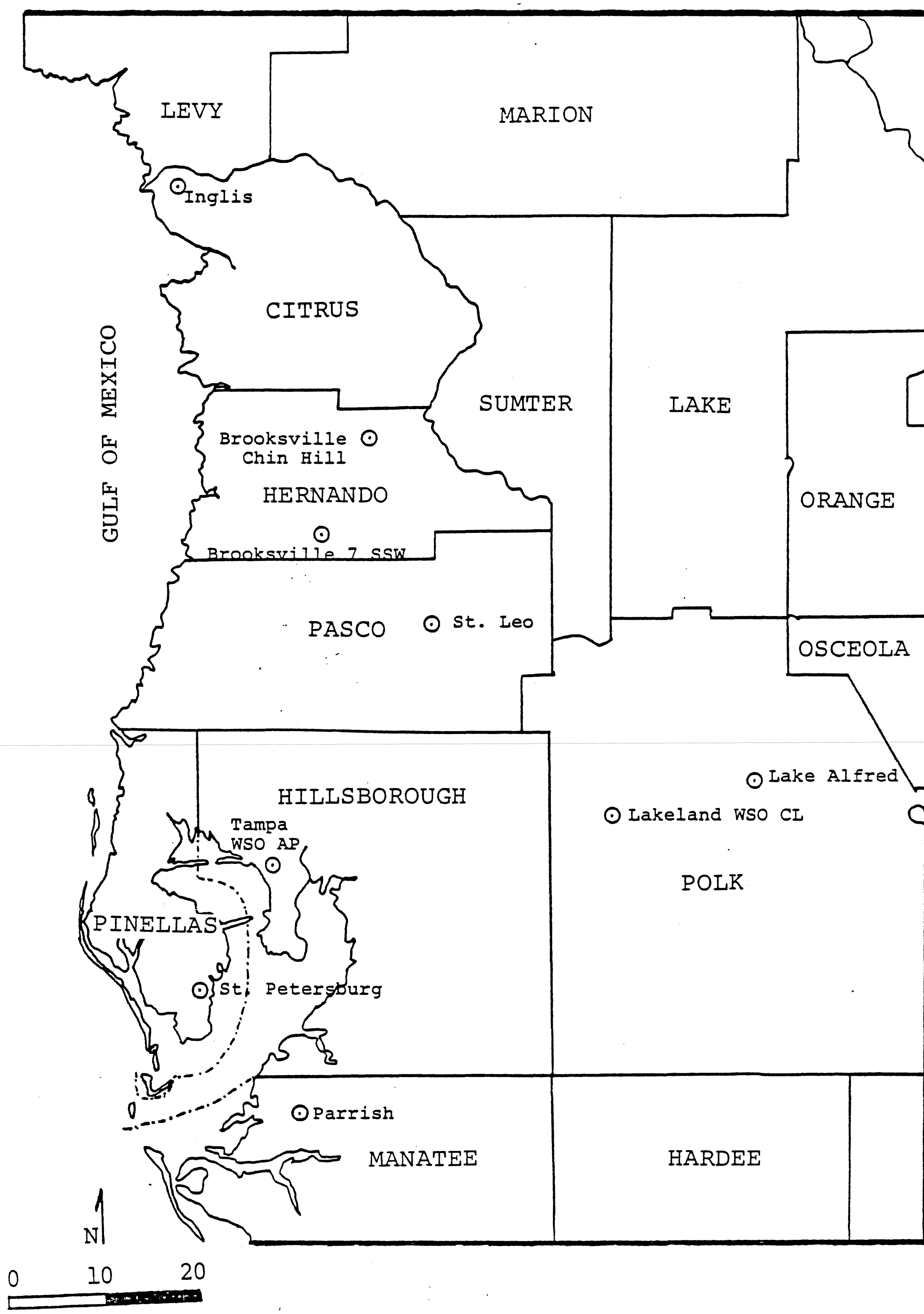

Figure 2-4 Hourly Precipitation Stations near Cypress Creek

and their records may be updated beyond 1979 from the monthly NWS Climatological Data for Florida.

In addition to St. Leo, daily precipitation data are recorded at six locations near CCW: Crews Lake, SWFWMD (Brooksville), Gower's Tower, Cypress Creek, Rose and South Pasco. These locations are shown in Figure 2-5. The Cypress Creek and Rose locations are within the watershed boundary; these two locations plus St. Leo are the nearest three gages to CCW, as shown in Figure 2-1.

Descriptive Statistics

Annual rainfall values for Cypress Creek, Rose and St. Leo are shown in Table 2-2 and St. Leo data are plotted in Figure 2-6. The table and figure both illustrate the widely ranging rainfall values typical of Florida precipitation. The average, standard deviation, maximum and minimum values for the three stations are also shown in Table 2-2; however, confidence limits on such values will be wide for Cypress Creek and Rose with only seven years of data at these two stations. For a detailed time series analysis of the relationship between rainfall at St. Leo and runoff at the Worthington Gardens and Sulphur Springs gages on Cypress Creek, the interested reader is referred to the work of Heaney et al., 1985.

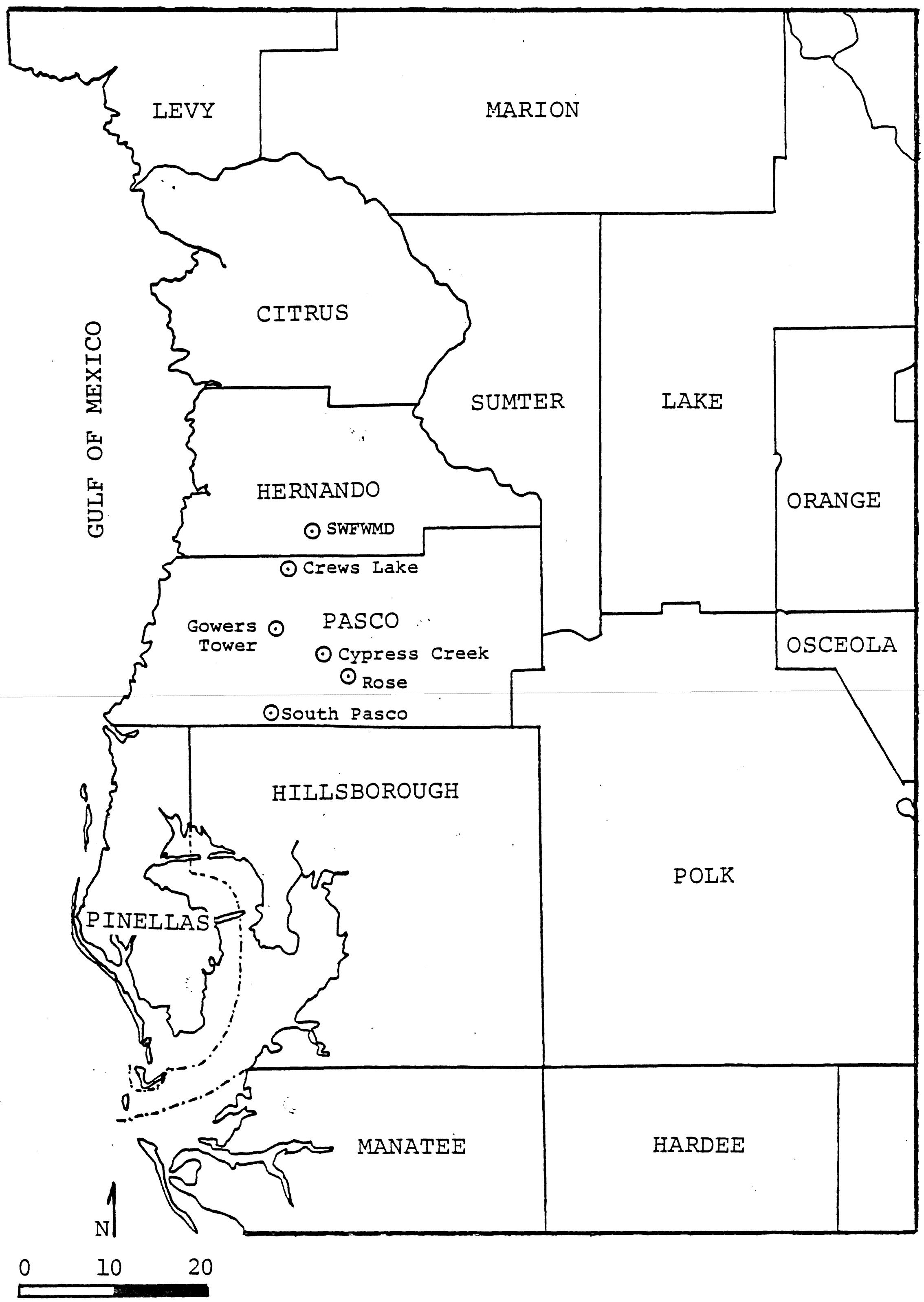

Figure 2-5 Daily Precipitation Stations near Cypress Creek

Table 2-2

Annual Rainfall (inches) and Descriptive Statistics
in the Vicinity of the Cypress Creek Watershed

Year	St. Leo	Cypress Creek	Rose
1931	45.15		
1932	40.49		
1933	64.97		
1934	69.85		
1935	57.55		
1936	55.85		
1937	60.73		
1938	49.16		
1939	50.90		
1940	43.87		
1941	60.05		
1942	60.09		
1943	63.30		
1944	54.30		
1945	81.93		
1946	51.79		
1947	68.46		
1948	51.33		
1949	63.91		
1950	57.35		
1951	50.12		
1952	42.62		
1953	81.13		
1954	45.02		
1955	41.37		
1956	45.41		
1957	58.83		
1958	56.16		
1959	70.41		
1960	75.34		
1961	36.61		
1962	45.90		
1963	61.00		
1964	59.68		
1965	57.82		
1966	53.46		
1967	43.47		
1968	46.31		
1969	65.75		
1970	52.93		
1971	52.27		
1972	50.31		
1973	58.38		

Table 2-2 (cont.)

Annual Rainfall (inches) and Descriptive Statistics in the Vicinity of the Cypress Creek Watershed

Year	St. Leo	Cypress Creek	Rose
1974	60.75		
1975	49.87		
1976	47.14		
1977	49.66	50.32	47.19
1978	50.75	60.37	54.35
1979	66.95	61.12	70.33
1980	43.03	43.89	47.27
1981	52.87	56.49	45.45
1982	72.45	65.61	64.04
1983	75.89	70.78	65.20
n	53	7	7
Avg.	56.05	58.37	56.26
Std. Dev.	10.6	9.1	10.2
Max.	81.93 (1945)	70.78 (1983)	70.33 (1979)
Min.	36.61 (1961)	43.89 (1980)	45.45 (1981)

RAINFALL AT ST. LEO, 1931 – 1983

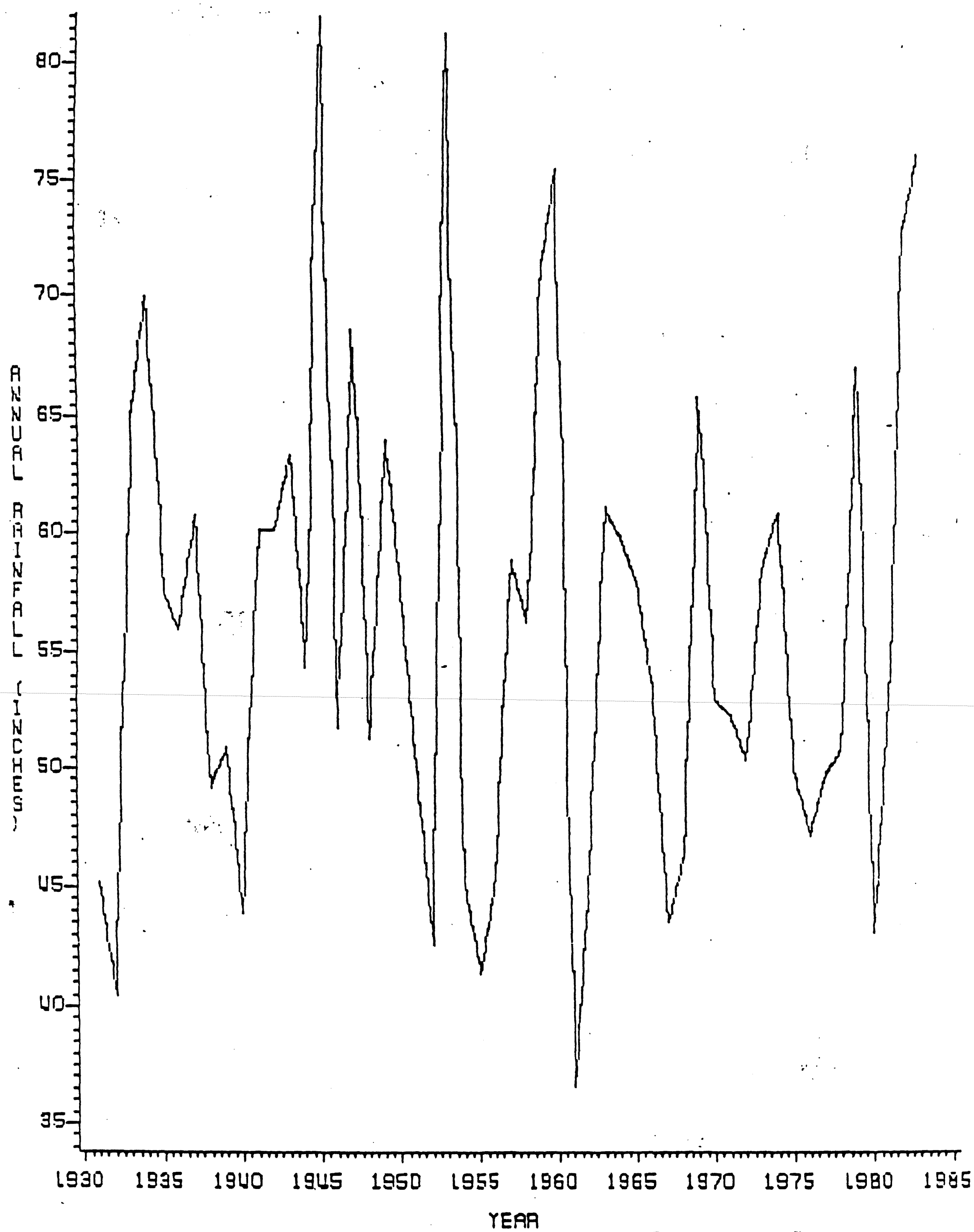

Figure 2-6 Time History of Annual Precipitation at St. Leo Rain Gage

Seasonal Distribution

Hughes et al. (1971) report a mean annual rainfall for west-central Florida of about 55 inches (1931-1955), with about 45 percent (25 inches) occurring during the summer (June, July, August). Average fall, winter and spring totals are about 13, 7 and 10 inches, respectively. Using the 53 year record at St. Leo (1931-1983), average monthly values are shown in Figure 2-8.

Evapotranspiration

Pan Evaporation Data

Evapotranspiration (ET) may occur from plant and ground surfaces, from the soil zone which is beneath the land surface but above the water table, and directly from the water table. In west-central Florida the maximum potential ET from a free water surface is 46 to 50 inches annually, but actual ET is limited by the depth of the water table below ground and below plant root zones (Hutchinson, 1984).

The nearest pan evaporation station to the Cypress Creek Watershed is at Lake Padgett just outside the western boundary of the watershed (Figure 2-1). Data are available for only twelve years of record, 1972 to 1983, including four years of incomplete or missing data; the mean annual pan evaporation for the eight complete years is 55.7 inches. The average monthly pan evaporation is shown in Table 2-3.

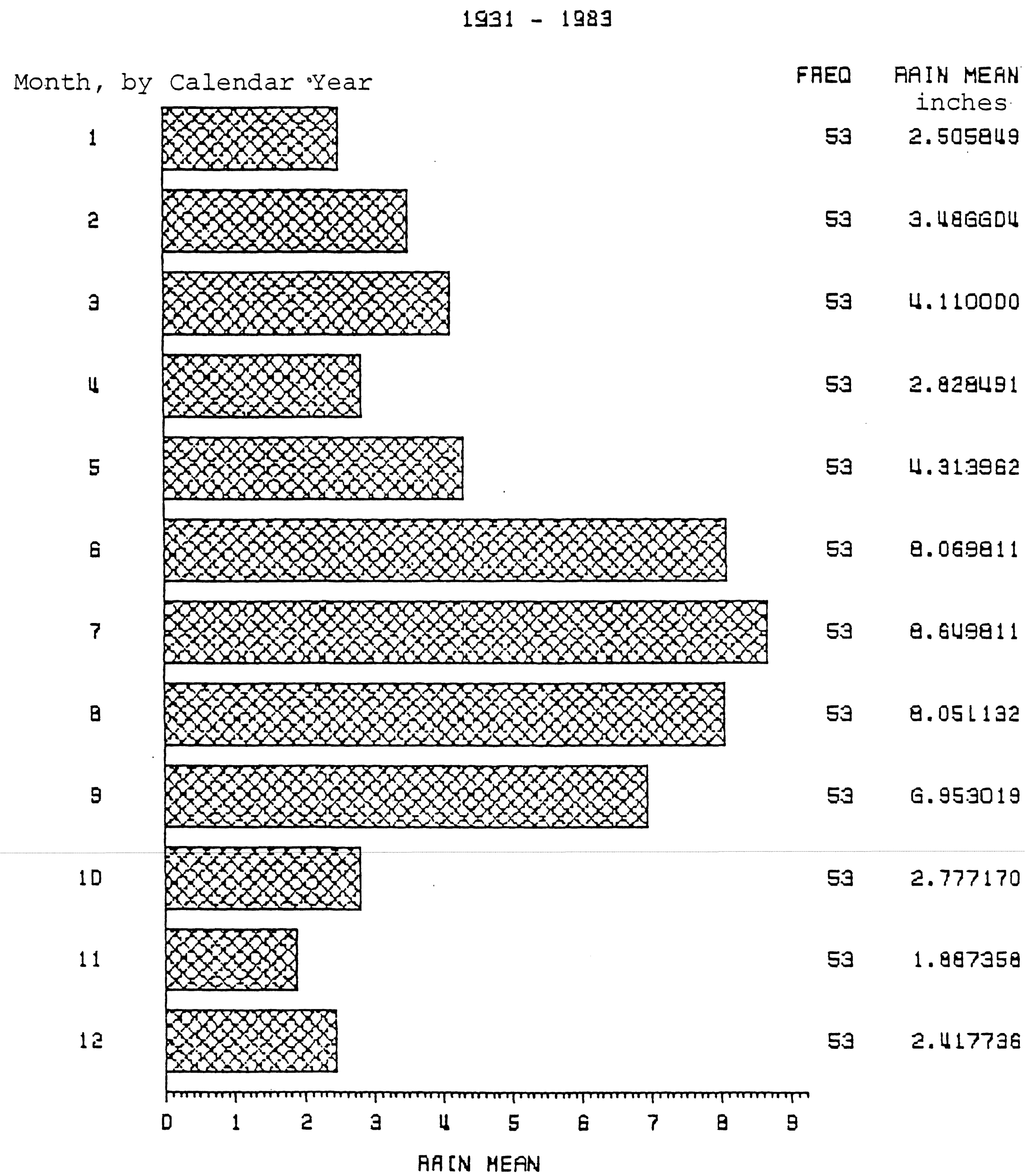

Figure 2-7 Monthly Rainfall Distribution at St. Leo

Table 2-3

Monthly Pan Evaporation at Lake Padgett (inches)

Month	Mean	SDEV
January	2.74	0.38
February	3.19	0.61
March	4.99	0.46
April	6.15	0.41
May	6.55	0.88
June	5.86	0.93
July	5.44	0.91
August	5.25	0.57
September	4.73	0.87
October	4.70	0.53
November	3.23	0.29
December	2.70	0.27
Annual	55.75	4.07

A longer period of record is available at the Lake Alfred station in Polk County, located about 40 miles southeast of Cypress Creek (Figure 2-4). Sixteen complete years of record are present during the 20-year period 1965 to 1984. The mean annual pan evaporation for these years is 70.5 inches.

An evaporation analysis of Lake Alfred annual pan evaporation data examines the relationship of evaporation to rainfall, wind, and temperature (Heaney et al., 1985). Over the eighteen years of data analyzed, no significant correlation was found between any of these parameters at the 95% confidence level.

Evapotranspiration Calculation

Pan evaporation cannot be used directly as the actual evapotranspiration data in a modeling system. The actual evapotranspiration used is calculated as follows (Gibney, 1983):

$$ET_A = K_1 * K_2 * PE \qquad (2-1)$$

where

ET_A = actual evapotranspiration, inches,

K_1 = coefficient converting PE into potential evapotranspiration, (ET_p),

K_2 = coefficient converting ET_p into ET_A, and

PE = pan evaporation, inches

A recent University of Florida study suggests a value of 0.70 for K_1 in Florida (Jones et al., 1983). A value of

0.89 for K_2 is suggested by another study in southern Florida (Khanal, 1980). For South Florida, Gibney (1983) suggests multiplying pan data by (0.7 * 0.89) for actual ET from pervious land segments. For the Lake Padgett period of record (1972-1983) this would put actual ET in the range of 32 to 40 in/yr.

Other estimates of actual evapotranspiration give a higher range of values. Hutchinson (1984) cites a base rate of 25 to 35 inches per year. This base rate includes ET from plant surfaces, bare land, and the unsaturated zone (above the water table but beneath land surface). Evapotranspiration from the water table accounts for another 15 in/yr. Using Hutchinson's values, total evapotranspiration could be in the range of 40 to 50 in/yr.

Surface Water

Cypress Creek

Cypress Creek, the focus of this study, is a tributary of the Hillsborough River. The total drainage area of the creek is about 160 square miles at its confluence with the Hillsborough River, but the area of the watershed above the gaging station at State Road 54 (Worthington Gardens) is 117 square miles. This forms a practical lower boundary for the study area. Along its upper reaches, Cypress Creek runs chiefly through agricultural land, developed into pasture and citrus groves. Urban developments are located in the southern portion of CCW. The remaining areas of the watershed are low-lying swamps and wetlands.

Three gaging stations are located on the creek within CCW; their tributary characteristics are shown in Table 2-4 and their locations shown in Figure 2-1. The outlet of the study area is the Worthington Gardens gage at SR 54, where discharge averages 41 cfs annually. An additional gage is located at Sulphur Springs, about seven miles south of the study area boundary. Table 2-4 summarizes the characteristics of Cypress Creek at the four gages.

The stream bed between state roads 52 and 54 is ill-defined, running through swamps and rarely reaching an average depth greater than three feet. Between the San Antonio and Worthington gages, the creek is about 12.7 miles long. Above the San Antonio station there is often no flow; the length of this reach is somewhat indeterminate, but the major portion of the flow is probably carried in one to two miles. Between the San Antonio gage and the Cypress Creek watershed outlet at the Worthington Gardens gage, land elevation drops from 70 to approximately 50 feet msl.

Lakes

Many lakes are near the Cypress Creek Watershed; most of the lakes within its boundaries are located in its northwest portion. Among the larger lakes are Big Fish Lake, New River Pond, Oakes Pond and King Lake. These four

Table 2-4

Characteristics of Subcatchments in Cypress Creek
Basin North of Tampa, Florida
(Murphy, 1978) (USGS, 1982)

Station	Location	USGS ID #	Drainage Area (mi)	Average Annual Discharge (cfs)	Average Annual Discharge (in/yr)	Total Stream Length, Station to Mouth (mi)	Period of Record
San Antonio	SR 52	02303400	56.0	19.9	4.83	25	December, 1962 to current year
Drexel	50 ft upstream from wellfield access road	02303408	73.2	---	---	22	January, 1977 to September, 1981 (discontinued)
Worthington Gardens	SR 54	02303420	117	41.0	4.76	14	June, 1974 to current year
Sulphur Springs	SR 581	02303800	160	87.7	7.44	2.5	October, 1964 to November, 1983

lakes are indicated on Figure 2-8 from which an impression may be gathered of the large number of nearby lakes. SWFWMD stage data for the ten lakes listed in Table 2-5 are available. These ten lakes are also indicated in Figure 2-8. Additional quantity and quality information for some of the regional lakes is given by Dickinson et al. (1982) and Huber et al. (1982).

Water Quality

Results of routine monitoring of temperature, conductivity and chloride values along Cypress Creek by the USGS are available roughly on a monthly basis for gaging locations at SR 52 (San Antonio), Worthington Gardens and Sulphur Springs. Sampling at Worthington Gardens began in May 1966 and at the other two locations in February 1964. These data have not been analyzed during this project.

Synoptic sampling for 18 water quality parameters was conducted by Conservation Consultants, Inc. (1981) during October 1979 and April 1980 at six lakes and three stream locations near the Cypress Creek wellfield. Biological sampling was also conducted at various times and locations. No relationship between pumping and minor anomalies in biota was established and none of the regional lakes sampled were considered eutrophic.

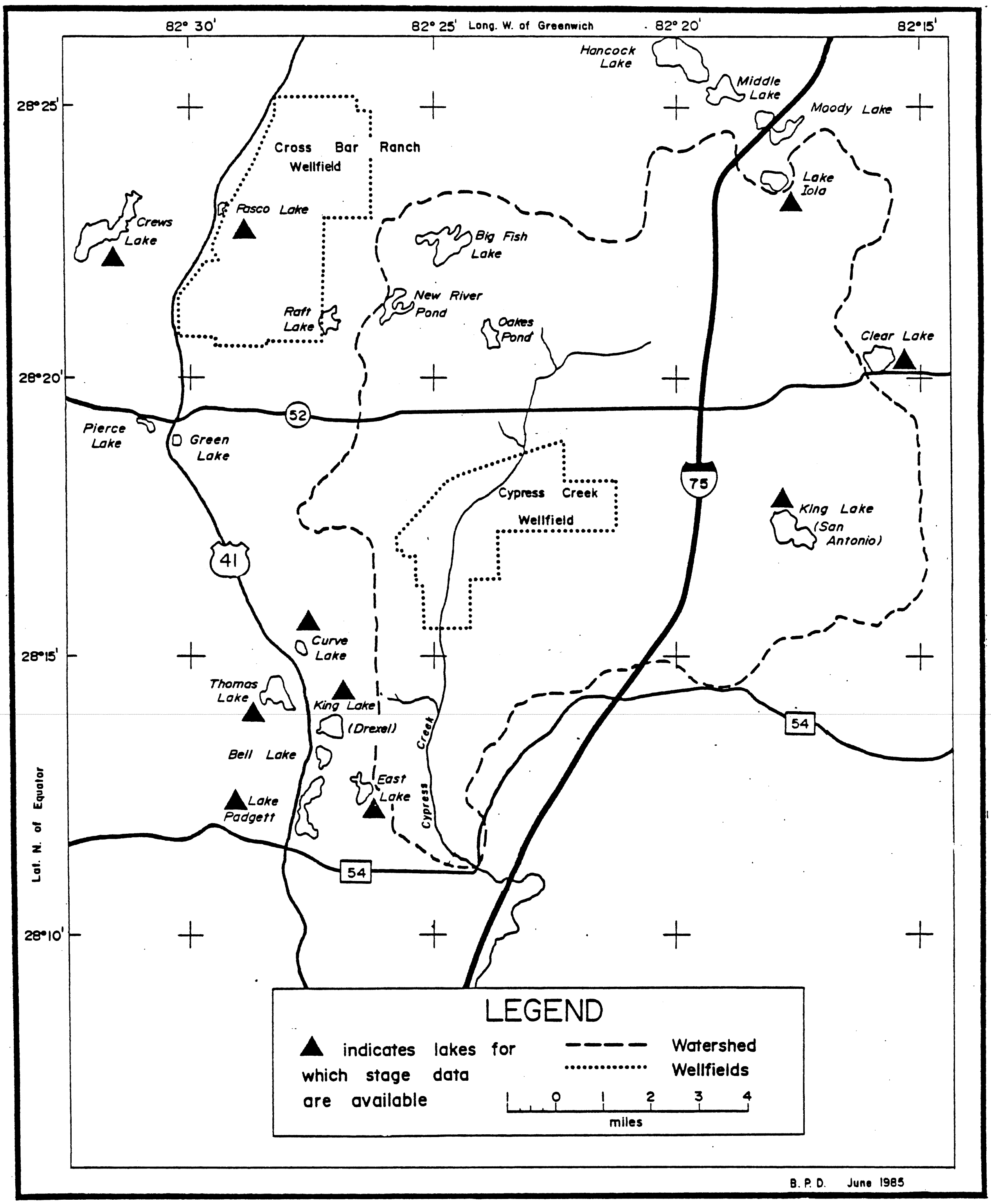

Figure 2-8 Major Lakes in Cypress Creek Watershed, Some with Stage Data

Table 2-5

Lake Stage Data for 10 Lakes in
the Cypress Creek Area

Lake	Period of Record	Average Stage (ft msl)
Crews Lake	1964 - 1983	50.7
Pasco Lake	1976 - 1983	*
Lake Iola	1965 - 1983	*
Curve Lake	1976 - 1983	75.5
Clear Lake	1965 - 1983	*
King Lake (Drexel)	1976 - 1983	71.8
Lake Padgett	1964 - 1983	69.7
King Lake (San Antonio)	1977 - 1983	*
East Lake	1976 - 1983	77.2
Lake Thomas	1971 - 1983	*

* not available

Groundwater

Aquifers

As described earlier (see Figure 2-2), the hydrologic system of the area can be represented as an unconfined surficial aquifer separated from the underlying Floridan aquifer by a relatively impermeable confining bed. The underlying limestone is pitted with sinkholes and underground streams and caverns. Groundwater flows southwest, toward the Gulf of Mexico and Tampa Bay. The potentiometric surface is affected by rainfall, surface and subsurface runoff, evapotranspiration, leakage to or from the Floridan aquifer, pumpage, and changes in storage in the surficial and Floridan aquifers. Definitions of aquifer parameters are found in Freeze and Cherry (1979).

The surficial aquifer in the Cypress Creek area is as much as 30 feet thick. Transmissivity ranges from 50 to 6000 gallons per day foot (gpd/ft), and the average specific yield in this area is 0.2 (SWFWMD, 1982). Transmissivity for the Floridan aquifer ranges from 200,000 to 400,000 gpd/ft with the zones of greatest transmissivity occurring from 350 to 650 feet below land surface. The specific storage for the Floridan aquifer in this area is approximately 0.0009 (SWFWMD, 1982).

Both downward and upward aquifer leakage occurs in the study area. The Floridan aquifer is recharged about six inches annually by downward leakage from the surficial aquifer; however, in areas such as Big Cypress Swamp in CCW about one inch of water per year leaks upward from the Floridan to the surficial aquifer (Hutchinson, 1984).

Groundwater Quality

Groundwater quality has been monitored within Cypress Creek wellfield since 1978. A monitoring well at a zone 300 feet below the production zone has been regularly analyzed for chloride, sulfate, and total dissolved solids levels. Data analyses up to 1982 indicate that water quality has either stabilized or improved in this well (SWFWMD, 1982).

Wellfield product water has been monitored since 1977. Table 2-6 shows chloride (Cl) and sulfate (SO_4) concentrations over six years of record. The values show that the concentrations of these ions have remained stable throughout this period (SWFWMD, 1982).

Simulation of the Study Area

This general description of Cypress Creek Watershed is provided to establish the character of the region which the hydrologic model attempts to simulate mathematically. A detailed description of the relationships between the rainfall, evaporation, land use, and soils data and specific parameters used by HSPF is provided in Chapter III where calibration of the model is discussed.

Table 2-6

Sulfate and Chloride Concentration (mg/L) in
Cypress Creek Wellfield Product Water (SWFWMD, 1982)

	1977		1978		1979		1980		1981		1982	
	SO_4	Cl	SO_4	Cl	SO_4	Cl	SO_4	Cl	SO_4	Cl	SO_4	Cl
January				12.5	25	12.5	19	13.0	19	11.0	25	14.0
February				12.5	21	12.5	21	12.5	22	12.5	23	13.0
March				11.0	21	12.0	21	13.0	17	12.5	17	13.6
April			22.5	12.5	20	11.5	22	12.5	18	13.0	24	13.5
May		13.5	15	11.0	20	13.5	23	12.5	21	12.5	23	13.5
June		13.0	19	11.0	26	13.0	27	13.0	20	13.0	27	13.0
July		13.5	16	12.5	26	13.5	26	12.5	20	13.0	--	----
August		12.5	30	11.8	25	13.5	24	12.5	17	13.5	24	12.5
September		13.5	22	11.8	25	12.5	19	12.5	18	14.5	19	13.5
October		12.4	23	11.8	18	12.5	27	12.5	18	14.0	19	13.5
November		13.3	22	13.3	25	14.0	26	13.0	--	13.5	--	----
December		14.0	25	12.5	21	12.0	22	12.5	20	13.0		

CHAPTER III

STREAMFLOW SIMULATION WITH HSPF

Calibration Period and Hydrologic Data

HSPF

The Hydrological Simulation Program-Fortran, or HSPF, is one of the most flexible models used in water resources evaluation (Donigian et al., 1983). This program is an outgrowth of the Stanford Watershed Model, developed by Stanford University, and since extended and refined. HSPF has the capability of simulating both surface and groundwater hydrology in a study area over an extended period of time, e.g., ten to twenty years. Estimates of each component of the hydrologic cycle obtained using this model often fit the observed values well; however, HSPF can only simulate the effects on an aquifer of human activities, such as pumpage, rather crudely. The accurate modeling of such activities might best be achieved by coupling HSPF with a groundwater simulation model.

Calibration Period

For the initial hydrologic calibration of the HSPF model three types of data were needed: rainfall records from all of the gages within the watershed, representative pan evaporation data for the area, and measured runoff volumes to compare to simulated volumes. Two rain gages, Rose and Cypress Creek, are located in the central and southeastern portions of the watershed, each with about 8 years of record (See Table 2-2). One rain gage with over 50 years of record exists at St. Leo, just outside the eastern boundary of the watershed (See Figure 2-1). Unfortunately, Rose, one of the short term gages, has many weeks of missing data. Comparative plots of the daily records at the three gages show little correlation. Simulation of Cypress Creek watershed is very sensitive to differences in rainfall record. In order to take advantage of the three available gages, ten months of data missing for Rose were filled in using the St. Leo record: Jan.-May 1976, Sept.-Oct. 1976, Oct.-Nov. 1978 and Nov. 1983.

A pan evaporation station exists at Lake Padgett just to the west of the watershed (see Figure 2-1). The period of record extends from 1972 to present. Longer records are obtainable at Lake Alfred, over 40 miles away.

Three streamflow gages are located in the Cypress Creek drainage area. Closest to the headwaters is San Antonio with runoff and stage data from 1963 to present. Within the wellfield area is Drexel, with records from 1977 to the present. The watershed outlet at Worthington Gardens has discharge data from 1974 to the present and stage data from about 1970 to the present (see Figure 2-1).

Stream data are crucial to calibration, being the only means of comparing simulated and measured runoff volumes. The initial plan had been to calibrate during the pre-pumping period and then test the model with pumping under way. Most of the discharge data, however, exist only for years after pumping was initiated (1976). Another issue in choosing the calibration period was the availability of rainfall data. Data from two gages, St. Leo and Cypress, are both available from 1977 to the present. For pre-1977 runs, the data are restricted to the gage at St. Leo. The HSPF user's manual recommends using three to five consecutive years of above average rainfall from the maximum possible number of representative gages (Johanson et al., 1981). Cypress was above average only in 1978, 1979, 1982 and 1983. For the period from 1977 to the present, St. Leo was above average only in 79, 82, and 83.

Considering all data problems, the water years 1978-1980 were selected as the three years for calibration. This afforded calibration at three reaches of Cypress Creek during two above average years of rainfall as recorded by a gage within the watershed. These years also correspond to the early period of wellfield operation.

Segmenting the Watershed

The first step taken after HSPF was installed and running was to become familiar with the workings of the system. After careful study of the HSPF User's Manual

(Johanson et al., 1981) and other available documentation (Donigian et al., 1978, 1983, 1984), several sample runs were made using programs and data provided in the manual. When the results of these test runs could be interpreted and understood reasonably well, similar problems were set up based on an initial, simple model of the Cypress Creek watershed.

Initially, the watershed was divided into three areas corresponding to the three stream gages. The tributary area for each gage was given in the description of the USGS gages. A test program from the HSPF user's manual was altered to characterize three reaches and three permeable land segments. The data and parameters given with the sample run were used until enough was learned about input of data to the Time Series Store (TSS) of HSPF to create files of real data. When sufficient data on the study area had been amassed, the current version of six permeable (PERLND) segments was developed using USGS topographic maps, and Pasco County soils data (See Figure 3-1). The Creek remained divided into three reaches, and the land was subdivided so that each segment fed into only one reach. The area of each segment was digitized along what were considered its approximate boundaries until the land areas contributing to each stream gage summed to the correct area. The divisions are straight lines because on such a large watershed (117 mi^2) all distinctions are approximate. The

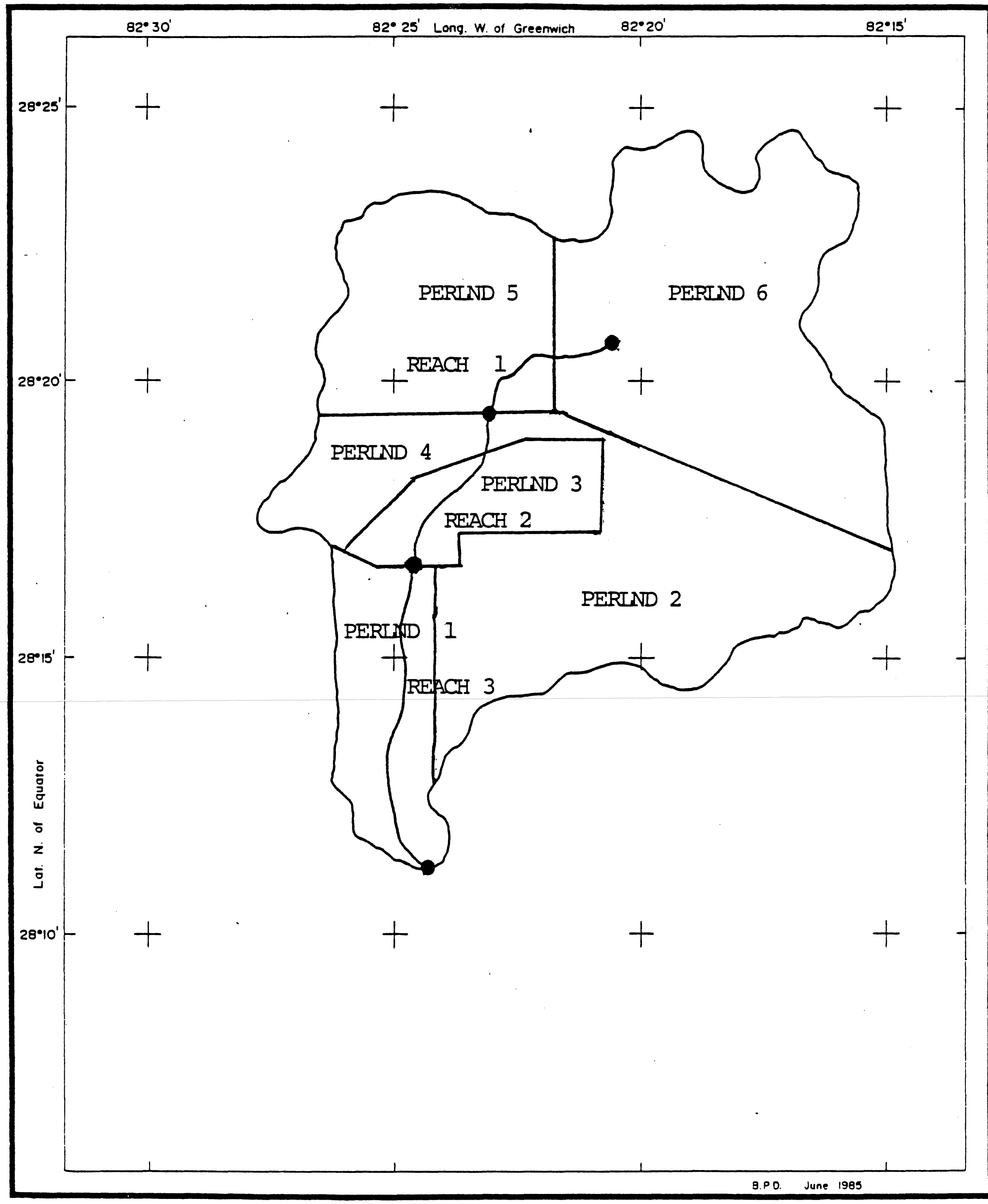

Figure 3-1 Relation of PERLNDs and REACHes in Cypress Creek Watershed

area of each subcatchment, called PERLNDs in HSPF, is shown in Table 3-1 which also indicates the predominant land use in each PERLND.

Area Adjustment

Initial calibration runs consistently overestimated runoff. Runoff from land segments 5 and 6 was routed through REACH 1, becoming part of runoff volume. Annual and monthly values of runoff volume were compared to monthly and annual volumes calculated from the San Antonio gage discharge data. Measured and simulated values were compared in three forms: tables, hydrographs, and double mass curves. The simulated volumes were consistently high by thousands of acre-ft. Various measures were tried to reduce runoff estimates, but when the reasonable limits of estimated storage, deep percolation and ET were strained, a new line of thought was brought to bear on the problem.

Looking at the topographical map of the basin, doubts were raised as to whether the entire area of PERLND 5 actually contributed runoff to Cypress Creek. The northwest corner of the basin is thickly dotted by lakes; some runoff must contribute to lake storage. Where county road 583 crosses state road 52 and continues northward to the edge of the basin, a change in land elevation could be discerned. The road travels for the most part at 80 feet in elevation while land to the east and west falls away to 75 feet. A hypothesis was that the western lake region of PERLND 5 did

Table 3-1

Soil Associations and Land Use by PERLND in
Square Miles (Heaney et al., 1985)

Soil Group PERLND	1	2	3	4	5	6	TOTAL
1	3.54			0.63			4.17
4		2.84			0.2	13.76	16.8
7					0.99	10.86	11.85
8				5.51	6.14		11.65
9	1.34	25.6	1.96	2.55	5.9	11.58	48.93
10					6.53		6.53
11	7.32	3.16	6.55	0.04			17.07
TOTAL	12.2	31.6	8.51	8.73	19.76	36.2	117
Avg. Storage Cap., in/in	0.09	0.08	0.10	0.08	0.12	0.09	
Upper Zone, in	5	5	5	5	5	5	
Lower Zone, in	7	31	7	19	55	55	
UZSN, in	0.4	0.35	0.45	0.35	0.25	0.3	
LZSN, in	0.56	1.86	0.7	1.52	3.3	4.4	

NOTES:

1. Soils data taken from Pasco County soils map
2. Storage capacity and infiltration rates taken from SCS Soils Sheets
3. UZSN is water storage in upper soil zone
4. LZSN is water storage in lower soil zone
5. Land use by PERLND

PERLND	Land Use
1	Swamp
2	Most thickly settled and cultivated region
3	Wellfield portion of the swamp
4	Improved pasture
5	Improved pasture
6	Upland ridges

6. Estimate of LZSN in PERLND 1 changed to .70 due to programming problems

not contribute runoff to Cypress Creek except during extremely wet years. It was decided to try calibration of PERLND 5 with this area, 8.6 square miles, as non-contributing area to REACH 1. This leaves 11.2 mi^2 of PERLND 5 which was thought to contribute runoff, or 7168 acres. This value for land area brings runoff and storage volumes into acceptable ranges, and also reduces ET.

Routing of Input Time Series

In HSPF, each subcatchment may be assigned its own rainfall and evaporation record. Because of the importance of rainfall record, three gages were used for calibration. Cypress Creek rainfall data was routed to PERLNDs 3, 4 and 5. St. Leo rainfall was used for the eastern PERLNDs, 2 and 6. The problem of missing data at Rose resulted in the use of its record for only the most proximate subcatchment, PERLND 1. Simulation is not as sensitive to the input pan evaporation data; data from the closest station, Lake Padgett, were used for all six subcatchments.

The calculation of evapotranspiration from the subcatchments in HSPF includes ET from plant surfaces and plant transpiration from soil storages and baseflow (see section on Evapotranspiration). To simulate evaporation in the REACHes from standing water surfaces in Big Cypress Swamp, the pan evaporation data from Lake Padgett were routed to REACHes 2 and 3.

The Reaches

A reach in HSPF is an open or closed channel, consisting of a single zone between two nodes. Flow through a reach is uni-directional. Runoff from a PERLND plus outflow from any feeding reach enters a reach as inflow at a single point, the upstream node. A reach may have outflow, however, from up to five exits. Precipitation and evaporation may occur within a reach.

To create the F-Tables (the stream characterizations in HSPF), volume, surface area, and discharge as a function of stage had to be defined (see Table 3-2 and Figure 3-1). The lengths of each gaged reach were known with its contributing area (Murphy, 1978) but the volume and area of Cypress Swamp were unknown, since the swamp has no definable banks. To create a surface area-stage relationship, therefore, the area within a topographic contour surrounding the stream was digitized; this area could then be related to a particular stream stage depending on the datum of the corresponding stream gage. For example, the datum for the San Antonio gage (REACH 1) was 70 feet mean sea level (msl). Digitization gave the area around the stream at the 75 foot contour and this surface area was related to a stage of five feet. REACH 1 was in such a flat area that only two contours existed, so for this reach interpolation was necessary between contours.

Table 3-2

Summary of REACH Characteristics, Cypress Creek

REACH	Length, miles	Depth, feet	Surface Area, acres	Storage Volume, ac-ft	Discharge ft^3/sec
1	3.3	0	0	0	0
		0.5	0.22	0.06	0.67
		1	1.27	0.64	3.5
Bee Tree Branch		2	7.2	7.2	16.3
to San Antonio		3	19.9	29.8	63
		4	40.9	81.8	178
		5	71.6	179	400
		6	113	339	760
		7	116	582	1325
2	4.7	0	0	0	0
		2.8	102	142	0
		2.9	109	158	1.8
San Antonio		3.0	117	176	4.5
to Drexel		3.2	134	214	12.8
		3.4	152	258	22.5
		3.7	181	335	42.5
		4.2	236	495	88
		4.7	298	699	150
		5.7	444	1266	350
		6.7	621	2081	660
3	8.0	0	0	0	0
		2.8	221	309	0
		3	249	374	0.63
Drexel		4	410	820	10
to Worthington		5	603	1509	30
Gardens		6	828	2483	67
		7	1081	3784	128
		8	1362	5450	220
		10	2005	10027	510
Total	16.0				

Notes:
1. REACH lengths: No. 1 -- USGS station data,
   Nos. 2 & 3 -- Murphy (1978)
2. Stage-area relationship from USGS contour maps
3. Volume = 0.5 * Stage * Surface Area
4. Stage-discharge relationship from USGS rating curves

To develop the F-Table relationships, simple linear regressions were used to relate stage to surface area. The data were first transformed by taking the natural logarithm:

$$\ln(SA) = m * \ln(D) + b \qquad (3\text{-}1)$$

where
- ln = natural logarithm function,
- SA = the stream surface area in acres,
- D = the stream stage in feet,
- m = the slope of the regression line, and
- b = the vertical axis intercept.

The raw data for equation 3-2 for each reach were provided by the digitization between contours discussed previously. The data and the resulting regression equations are shown in Table 3-3. For volume, each reach was modeled as:

$$V = 1/2\ D * SA \qquad (3\text{-}2)$$

where
- V = stream volume in acre-ft,
- D = stream stage in feet, and
- SA = stream surface area in acres.

The stage-to-discharge relationship for each F-Table was developed from USGS rating curves. Rating curve number eleven at San Antonio, rating curves one and two at Drexel, and curve number four at Worthington Gardens were used for REACHes 1, 2, and 3 respectively. The F-Tables for all three reaches showing stage, surface area, volume and discharge, are given in Table 3-2.

The initial condition for each reach was entered as the volume of water in acre-ft present in the reach on the day prior to the beginning of calibration, Sept. 30, 1979. This volume was derived by taking the stage measured at each

Table 3-3

Development of Stage-Surface Area Relationships for the REACHes

Reach 1, Datum = 70 ft msl

Contour ft msl	Stage D, ft	Surface Area, SA acres
73	3	18.37
75	5	84.48
78	8	213.04

Equation 3-2, REACH 1

$$\ln(SA) = 0.23754 + 2.50571 \ln(D) \quad (3\text{-}3)$$

Initial Volume, Sept. 30, 1978: 0.36 ac-ft

Reach 2, Datum = 54 ft msl

Contour ft msl	Stage D, ft	Surface Area, SA acres
60	6	514.23
65	11	1706.15
70	16	3289.26
75	21	7496.79

Equation 3-2, REACH 2

$$\ln(SA) = 2.48274 + 2.07603 \ln(D) \quad (3\text{-}4)$$

Initial Volume, Sept. 30, 1978: 118.6 ac-ft

Reach 3, Datum = 42 ft msl

Contour ft msl	Stage D, ft	Surface Area, SA acres
50	8	1235.08
55	13	3126.72
60	18	7287.42
65	23	8260.79
70	28	11,498.62
75	33	14,382.92

Equation 3-2, REACH 3

$$\ln(SA) = 3.61416 + 1.73259 \ln(D) \quad (3\text{-}5)$$

Initial Volume, Sept. 30, 1978: 530.1 ac-ft gaging station on this date and converting it to volume using equations 3-3 through 3-5. These equations and the initial volumes calculated are listed in Table 3-3.

Calibration Parameters

The Water Balance

The HSPF component which controls the hydrologic simulation of the basin is called PWATER. In section PWATER the overall water balance for each time step can be represented as follows:

$$PERS = SUPY - TAET - PERO - IGWI \qquad (3\text{-}6)$$

where

PERS = total moisture stored in the various storage zones of the model, inches,
SUPY = moisture supplied to the land segment as rain (or snow), inches,
TAET = actual evapotranspiration taking place over the land segment, inches,
PERO = runoff from the land segment, inches, and
IGWI = water lost by percolation through the confining layer to deep groundwater, inches.

Figure 3-2 shows the overall hydrologic cycle in terms of the HSPF simulation.

Simulation with HSPF requires three types of daily hydrologic data: rainfall records, pan evaporation and streamflow data. The first two time series are required input to the model and serve as driving forces. The streamflow data are required for calibration and verification of simulated runoff volumes. The rainfall data become the moisture supply SUPY; the pan evaporation data serve as an upper bound on estimation of actual

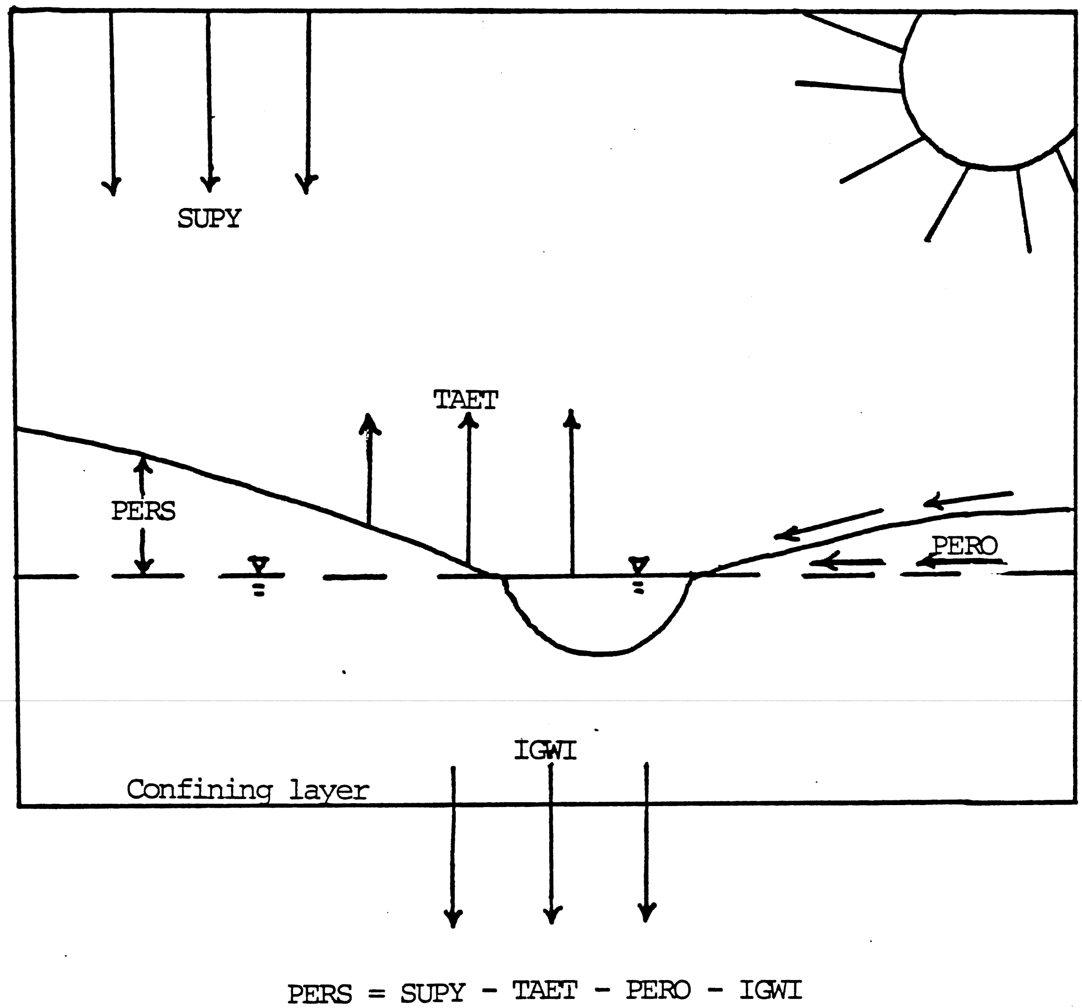

Figure 3-2 The Hydrologic Cycle of HSPF

evapotranspiration by model input parameters. The streamflow data are compared to the runoff time series, PERO, once it has been transformed into streamflow in the reaches and reservoirs simulation block of the model, RCHRES.

The overall water balance for each land segment is subdivided by the model into inflows, outflows, and storages occurring in six surface and subsurface storage zones: interception storage (CEPS), surface storage (SURS), interflow storage (IFWS), upper zone storage (UZS), lower zone storage (LZS), and active groundwater storage (AGWS). Figure 3-3 shows the relative position of each of these zones and Figure 3-4 diagrams the various inflows and outflows from each zone.

In section PWATER, 25 parameters are used to describe the water flows and storages in each zone. Given that Cypress Creek Watershed is divided into six permeable land segments or subcatchments, designated as PERLND 1 through PERLND 6 (Figure 3-1), 150 parameters must be assigned numbers that are physically meaningful. Suggestions for parameter values according to watershed location and land use can be found in the user's manual for the Agricultural Runoff Management (ARM) Model (Donigian et al., 1978). The parameters can be grouped into six areas dealing with water retention or flow: interception, soil storage, evapotranspiration, recession rates, infiltration, and

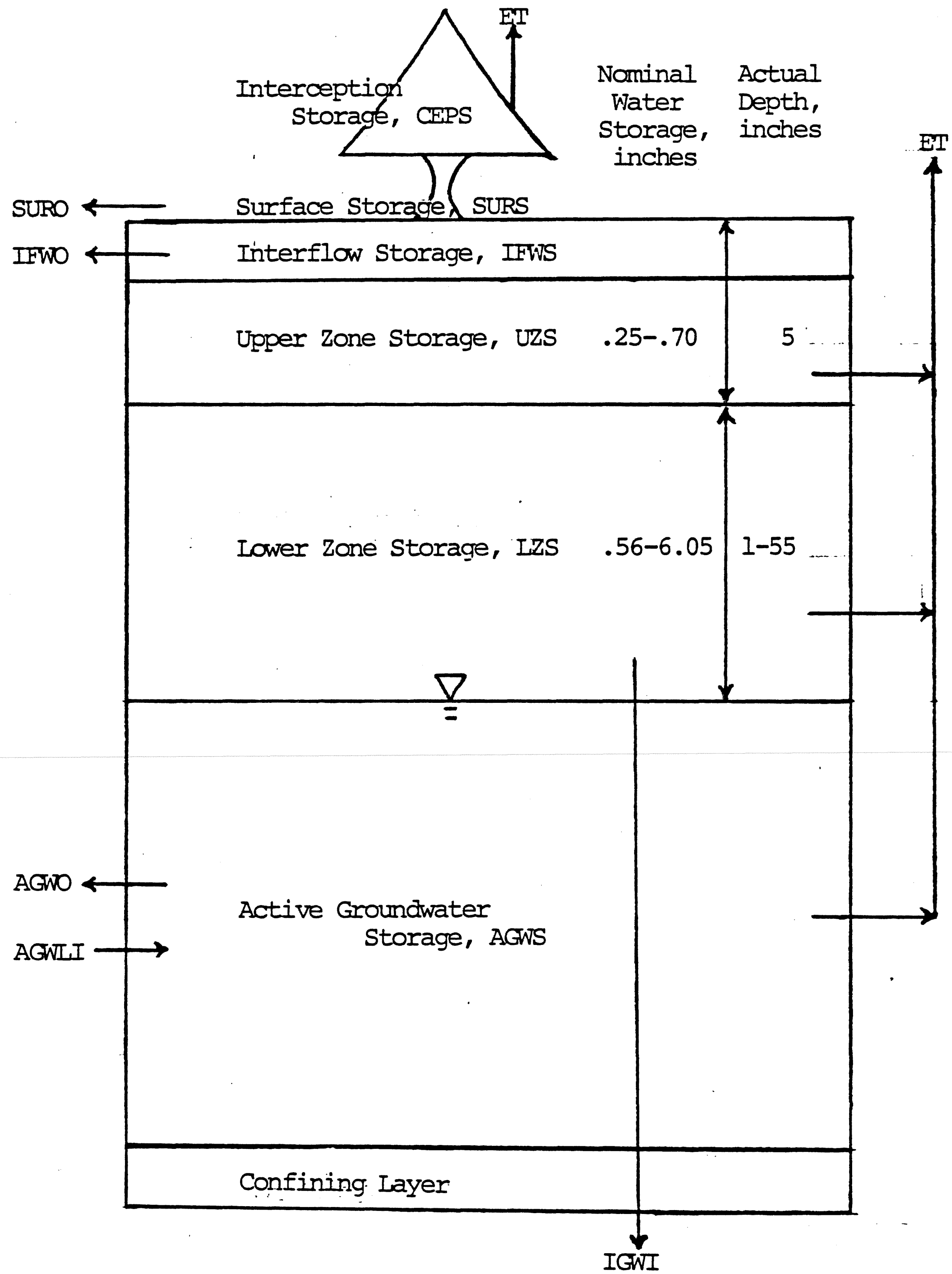

Figure 3-3 Relation of Storage Zones for PERLNDs in HSPF

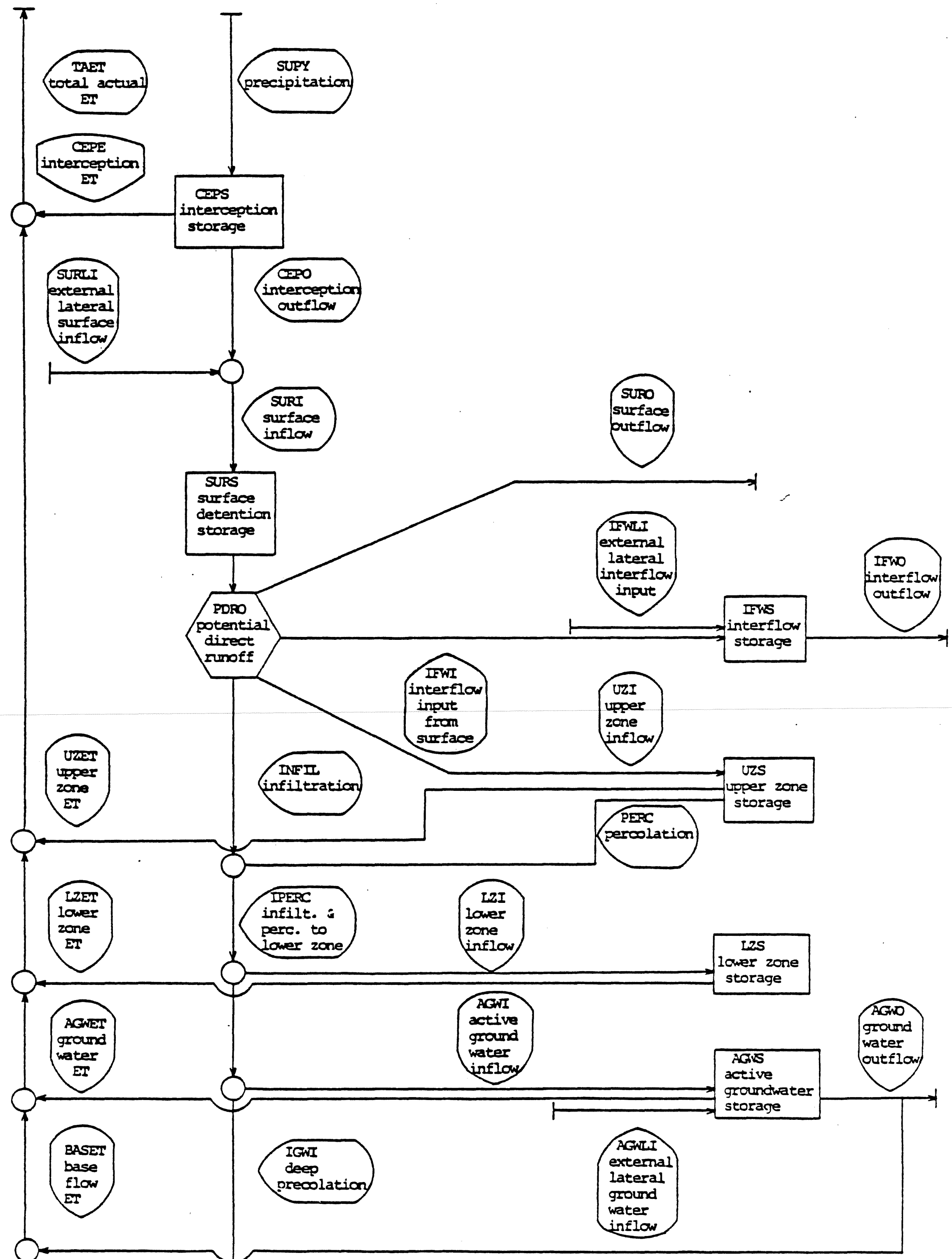

Figure 3-4 Flow Diagram of Water Movement and Storages in Section PWATER of HSPF (adapted from Johanson et al., 1981)

lateral transport. Table 3-4 lists the parameters by group and gives a brief description of their function. Several equations and definitions of variables in those equations used in discussion of the input parameters are taken from the User's Manual for HSPF (Johanson et al., 1981).

Interception

The interception zone consists of water retained in storage above the overland flow plane, chiefly by vegetative cover. The water balance equation for interception is:

$$CEPS = SUPY - CEPE - CEPO \quad (3\text{-}7)$$

where

CEPS = interception storage for the time step, inches,
SUPY = moisture supply, i.e., rainfall input in time series fashion, inches,
CEPE = evapotranspiration from interception storage, inches, and
CEPO = interception outflow to the surface zone, inches.

The water retained in interception storage never reaches the overland flow plane. The amount retained is determined by the input interception parameter CEPSC, the maximum possible interception, and the amount held in storage at the beginning of the time step. The initial value for CEPS at the start of the simulation period is estimated from values output for CEPS during earlier calibration runs. Water retained in interception storage is removed by evaporation, as discussed in a later section, Evapotranspiration. Any moisture exceeding this input interception capacity during the time step overflows

Table 3-4

HSPF Parameter Descriptions

Parameter	Units	Description	Method of Estimation
Interception:			
CEPSC	in	Interception storage capacity	Heimburg (1976)
CEPS	in	Interception state storage	Initial calibration runs
Soil Storages:			
UZSN	in	Upper zone nominal storage	SCS soil storage capacities
LZSN	in	Lower zone nominal storage	
SURS	in	Surface state storage	Initial calibration runs
IFWS	in	Interflow state storage	
UZS	in	Upper zone state storage	
LZS	in	Lower zone state storage	
AGWS	in	Active groundwater state storage	
Evapotranspiration:			
FOREST		Fraction winter forest transpiration	Forest estimates derived from Seaburn and Robertson, Inc. (1977) and values from ARM manual
LZETP		Lower zone ET parameter	
AGWETP		Fraction ET from active GW storage	
BASETP		Fraction ET from active GW outflow	
Recession Rates:			
KVARY	1/in	Groundwater recession behavior parameter	Gaschnig et al. (1981) and calibration
AGWRC	1/day	Active groundwater recession rate	
IRC	1/day	Interflow recession rate	
GWVS	in	Index to groundwater slope	
Infiltration:			
INFILT	in/hr	Index to mean infiltration rate	Stankey (1982)
INFILD		Ratio max/min infiltration rate	
INFEXP		Exponent in infiltration equation	
INTFW		Interflow inflow parameter	ARM manual
DEEPFR		Fraction of GW to deep aquifer	Set to reflect estimates by Ryder (1982) and Hutchinson (1984)
Lateral Transport:			
LSUR	ft	Length of overland flow plane	Calculation of drainage density, Eagleson (1970)
SLSUR		Average surface slope	Topographic measurements
NSUR		Manning's n for overland flow	ARM manual

interception storage to reach the overland flow plane or surface storage zone. The following expected values for the parameter CEPSC are found in the ARM manual:

grassland	0.10 in/event
cropland	0.10-0.25 in/event
light forest cover	0.15 in/event

A study by Heimburg (1976) of north central Florida cypress domes provides the best available information for evaluating the interception capacity of foliage in Cypress Creek watershed. Heimburg found the maximum interception to be about 0.15 inches of rainfall per event. Maximum interception is defined as the fully saturated condition of canopy and stems. This value agrees with the CEPSC value of 0.15 inches suggested in the ARM User's Manual for land segments with light forest cover. The same value was used for all six PERLND segments.

Soil storages

Zones. Once water has reached the overland flow plane it must pass through one or more of the five soil storage zones of the surficial aquifer (Figure 3-3). Some of the more important parameters affecting runoff volumes are the water storage capacities for the unsaturated soil zones. Surface storage (SURS) is depression storage on the surface. Interflow storage (IFWS) contains water that flows below the surface to streams and other surface water bodies. The upper zone storage (UZS) is the upper few inches of the unsaturated zone from which water infiltrates to lower zone storage (LZS) or leaves as evapotranspiration. From the lower zone water may also evapotranspire or percolate into active groundwater storage (AGWS). Active groundwater may become runoff, evapotranspiration, or deep percolation.

The input state storages were determined during initial calibration runs. State storages (CEPS, SURS, IFWS, UZS, LZS, AGWS) are input to simulate moisture conditions at the beginning of the calibration period. Reasonable values are estimated from storages output by the model for the same time of month in a similarly wet or dry year. The state storages used reflect conditions on Sept. 30, 1977, the day before the simulation began. The values were estimated from state storages output by the model on Sept. 30, 1978.

Interflow zone. Interflow is a lateral flow occurring just beneath the surface. If vertical percolation is retarded by a shallow, semi-permeable soil layer, interflow can be a major component of total runoff. The balance for the interflow zone is:

$$IFWS = IFWI + IFWLI - IFWO \qquad (3\text{-}8)$$

where

IFWS = interflow storage, inches,
IFWI = interflow input from the surface zone, inches,
IFWLI = optional lateral inflow from a time series, inches, and
IFWO = interflow outflow to reaches/reservoirs, inches.

Evapotranspiration does not occur from interflow. Part of the potential direct runoff (PDRO) from the surface zone is sent into the interflow zone as IFWI. This flow is combined with the time series flow IFWLI, if any, to make up total interflow inflow, INFLO. The amount of inflow which becomes outflow is determined as follows:

$$IFWO = (IFWK1*INFLO) + (IFWK2*IFWS) \qquad (3\text{-}9)$$

where

IFWO = interflow outflow, in/interval,
INFLO = inflow into interflow storage, in/interval, and
IFWS = interflow storage at the start of the interval, inches.

The terms IFWK1 and IFWK2 are defined by:

$$IFWK1 = 1.0-(IFWK2/KIFW) \qquad (3\text{-}10)$$
$$IFWK2 = 1.0-EXP(-KIFW) \qquad (3\text{-}11)$$
$$KIFW = -ALOG(IRC) * DELT60/24.0 \qquad (3\text{-}12)$$

where

IRC = interflow recession parameter,
DELT60 = number of hr/interval,
24.0 = number of hours per day,
EXP = Fortran exponential function, and
ALOG = Fortran natural logarithm function.

INTFW is the parameter affecting the interflow component of runoff. It is used to compute a variable, RATIO, which is used to determine how much of the potential direct runoff (PDRO) from the surface storage zone is routed to the interflow zone, i.e.,

$$RATIO = INTFW * (2.0**LZRAT) \qquad (3\text{-}13)$$

where

INTFW = interflow inflow parameter, and
LZRAT = ratio of actual to nominal lower zone storage, LZS/LZSN.

Values of INTFW usually range from 0.5 to 5.0; the ARM manual suggests 2.0 for South Florida. This value was used for all six subcatchments. The only input parameter required for the determination of interflow is the recession parameter, IRC. The method used to estimate this parameter is discussed in the section under <u>Recession Rates</u>. As previously stated, the state storage IFWS is determined during early calibration for the beginning of the simulation period and then is an output of the model.

<u>Upper zone storage</u>. The upper zone water balance is defined by:

$$UZS = UZI - UZET - PERC \qquad (3\text{-}14)$$

where

UZS = upper zone storage, inches,
UZI = a fraction of potential direct runoff (PDRO) from the surface zone, inches,
UZET = evapotranspiration from the upper zone, inches, and
PERC = moisture lost as percolation from the upper to the lower zone, inches.

UZET is discussed in the Evapotranspiration section. Calculation of both UZI and PERC depends on the ratio

$$UZRAT = UZS/UZSN \qquad (3\text{-}15)$$

where UZRAT is the ratio of actual upper zone storage (UZS) to nominal upper zone storage (UZSN). The determination of nominal storages is considered in the section on nominal storage.

Inflow to the upper zone (UZI) is determined by the variable FRAC:

$$FRAC = (0.5/(UZRAT-1)**(2*UZRAT-3) \qquad (3\text{-}16)$$

where FRAC is the fraction of the potential direct runoff (PDRO) from the surface zone which is retained by the upper zone storage, resulting in upper zone inflow UZI. The upper zone inflow added to upper zone storage at the start of the interval is the total water available for percolation.

Percolation from the upper zone is a function of the ratio UZRAT and of the ratio

$$LZRAT = LZS/LZSN \tag{3-17}$$

where LZRAT is the ratio of actual lower zone storage (LZS) to nominal lower zone storage (LZSN). UZRAT minus LZRAT must be greater than 0.01 for percolation to occur.

$$PERC = 0.1*INFILT*UZSN*(UZRAT-LZRAT)**3 \tag{3-18}$$

where

PERC = percolation from the upper zone, in/interval, and
INFILT = infiltration parameter, in/interval,

and the other variables are as previously defined. Estimation of the INFILT parameter is discussed in the section on infiltration.

Lower zone. The lower zone has only one inflow and one outflow:

$$LZS = LZI - LZET \tag{3-19}$$

where

LZS = lower zone storage, inches,
LZI = inflow to the lower zone, inches, and
LZET = evapotranspiration from the lower zone, inches.

Evapotranspiration is discussed in a later section. Inflow to the lower zone is a fraction of the combined flows of infiltration from the surface zone and percolation from the upper zone. This fraction depends on LZRAT, the ratio of actual to nominal lower zone storage.

$$LZFRAC = 1.0 - LZRAT*(1.0/(1.0 + INDX))**INDX \tag{3-20}$$

when LZRAT is less than one. When LZRAT is greater than one

$$LZFRAC = (1.0/(1.0 + INDX))**INDX \tag{3-21}$$

and

INDX = 1.5*ABS(LZRAT - 1.0) + 1.0 (3-22)

where

LZFRAC = fraction of infiltration plus percolation entering LZS,

LZRAT = LZS/LZSN, and

ABS = function for determining absolute value.

The determination of the nominal lower zone storage is discussed in the section on nominal storages.

Groundwater storages. The fraction of direct infiltration plus percolation which is not directed to lower zone storage is all that remains of the initial moisture supply, SUPY. This remainder will either be inflow to active groundwater storage or lost to the simulation as deep percolation to inactive groundwater. Active groundwater storage may lose water through both evapotranspiration and runoff, i.e.,

AGWS = AGWI + AGWLI - AGWO - AGWET (3-23)

where

AGWS = active groundwater storage, inches,

AGWI = active groundwater inflow, inches,

AGWLI = optional lateral inflow from a time series, inches,

AGWO = active groundwater outflow to reach or reservoir, inches, and

AGWET = evapotranspiration from active groundwater storage, inches.

The amount of infiltration plus percolation which is lost to inactive groundwater storage is determined by the parameter DEEPFR. DEEPFR is entered as a fraction between 0 and 1.0; multiplied by the remainder of infiltration plus percolation, this portion becomes IGWI, deep percolation through the confining layer. When this fraction has been extracted, the remaining water is active groundwater inflow, AGWI. The estimation of DEEPFR is discussed in the section on infiltration parameters.

Active groundwater outflow, AGWO, is calculated using three recession parameters:

$$AGWO = KGW * (1.0 + KVARY * GWVS) * AGWS \quad (3\text{-}24)$$
$$KGW = 1.0 - (AGWRC) ** (DELT60/24.0) \quad (3\text{-}25)$$

where

AGWO = active groundwater outflow, in/interval,
KVARY = parameter which makes active groundwater storage to outflow relation nonlinear, 1/inches,
GWVS = index to groundwater slope, inches,
AGWS = active groundwater storage at the start of the interval, inches,
AGWRC = daily recession rate of groundwater flow, and
DELT60 = hr/interval.

The method of estimation of AGWRC, KVARY, and GWVS is discussed in the section on recession rates. Inflow to active groundwater is added each interval to GWVS, but GWVS is also decreased by three percent once a day, creating a variable energy gradient that depends on past active groundwater storage. The use of a value of KVARY greater than zero allows variable recession rates.

The determination of deep percolation (IGWI) and active groundwater outflow (AGWO) disposes of all water supplied to the simulation through the various precipitation and lateral inflow time series.

Nominal Storages in Unsaturated Zones

Nominal storages for the upper and lower unsaturated zones are two of the most important parameters for determination of runoff. To calculate the nominal storage capacities, the soil groups occurring in the basin were determined from the Soil Survey of Pasco County (Stankey, 1982), and the percent of each soil group occurring in each of the six land segments was estimated. SCS Soil Interpretation Sheets provide soil storage capacities for soils in each soil group. The SCS sheets divide the capacities into two horizons. The upper horizon consists of the first five inches of soil, and the lower horizon consists of the soil between the five inch depth and the water table. It was decided that these two horizons would correspond well to the HSPF upper and lower zone storage blocks (Figure 3-3).

The horizon storage capacity information for each soil group was combined. Each group was then weighted as a percentage of its occurrence in each land segment and the storage capacities for each horizon were multiplied by the weights to determine total storage capacity horizons for each land segment. The final HSPF nominal storage capacities were obtained by multiplying by the soil zone depths, five inches for the upper zone horizon and the remaining inches between the five inch depth and the average water table depth for the lower zone horizon. Average depth to the water table was obtained for each soil group from the SCS soils data. The upper zone storage capacities ranged from 0.25 to 0.70 inches. Lower zone storage capacities ranged from 0.56 to 6.05 inches. For each land segment the minimum capacity for the upper or lower horizon was used because HSPF allows overfill for soil storages; the nominal capacities input into the model are indicators, not maximum capacities. In PERLND 1, the minimum lower zone capacity of 0.56 inches caused programming errors, so this value was adjusted to 0.70 inches. The estimated nominal storage capacities for the upper and lower zones are presented in Table 3-1.

Evapotranspiration

Potential evapotranspiration is input to the model as a time series. Actual evapotranspiration is calculated as a function of the moisture storages in four storage zones, of the outflow from the active groundwater zone, and of the potential evapotranspiration. The five sources of actual ET are discussed in the order ET is taken.

$$TAET = BASET + CEPE + UZET + AGWET + LZET \quad (3\text{-}26)$$

where

TAET = total actual evapotranspiration, inches,
BASET = ET from active groundwater outflow, inches,
CEPE = ET from interception storage, inches,
UZET = ET from upper zone storage,
AGWET = ET from active groundwater storage, inches, and
LZET = ET from lower zone storage, inches.

Locations of ET outflows are shown in Figures 3-3 and 3-4. Active groundwater outflow (AGWO), or baseflow, provides the first source from which ET is taken. The parameter BASETP specifies the fraction of potential ET which can be withdrawn from this outflow, if any outflow exists. This withdrawal from AGWO is BASET. Remaining potential ET then acts as a demand on interception storage (CEPS). No parameter governs this flow; the entire volume of storage will be used as CEPE unless demand is less than storage.

The third source of actual ET is the upper zone storage (UZS). Again, no ET parameter is used; rather, the demand depends on the ratio of actual storage to nominal storage, UZS/UZSN. Actual ET from this zone is designated UZET. Remaining potential exerts a demand on active groundwater storage (AGWS). This demand is regulated by the input parameter AGWETP. AGWETP is the fraction of the remaining potential ET that is drawn from AGWS if there is enough storage to supply the demand. ET supplied from this zone is AGWET.

The last ET source is the lower zone (LZS). The parameter, LZETP, represents the effect of transpiration by vegetation. To simulate varying vegetative type and root depth over the land segment, LZETP is used to calculate a linear probability density function for ET demand from the lower zone, or

$$RPARM = (0.25/(1.0-LZETP))*(LZS/LZSN)*DELT60/24.0 \qquad (3-27)$$

where

RPARM = maximum ET opportunity in in/interval,
LZETP = lower zone ET parameter,
LZS = current lower zone storage, inches,
LZSN = lower zone nominal storage, inches, and
DELT60 = hr/interval.

Evapotranspiration from the lower zone is output as LZET. The input potential ET is adjusted for effects of seasonal transpiration by the parameter FOREST. FOREST is an estimate of the forested acreage in a subcatchment which will transpire in winter. In Florida, this acreage includes pines, citrus, and cutover flatwoods being repopulated by scrub pine. Data for estimating this fraction for the swamp were available in the form of vegetative covering acreage for the area roughly corresponding to PERLNDs 1 and 3 (Seaburn and Robertson, Inc. 1977). For 6125 acres of swamp (Table 3-5), the acreage in cutover flatwoods, pine flatwoods, and citrus groves was divided by total forested acreage to obtain a ratio of 0.4 for FOREST. This estimate was then applied to all six PERLNDs.

A similar calculation was used for a parameter affecting actual evapotranspiration from the lower zone (LZETP). The fractional area of the watershed covered by forest can be taken as an estimate of LZETP. Total forest area divided by total area was calculated to be 0.83 or 83%. A value of 0.8 was used for LZETP for PERLNDs 1 and 3. The ARM manual suggests a range from 0.25 for open land and grassland to 0.7-0.9 for heavy forest. For PERLNDs 2,4,5 and 6 a medium value of 0.4 was chosen.

The active groundwater evapotranspiration parameter AGWETP controls ET drawn from active groundwater storage. This parameter is set during calibration in order that total

Table 3-5

Vegetation and Land Use for Swamp Area Encompassing PERLNDs 1 and 3

Land Use	Area, acres	
Forest		
Transpiring in winter		
Cutover flatwoods	1257	
Pine flatwoods	380	
Citrus grove	227	
Total		1864
Other		
Hardwood-cypress	2760	
Cypress ponds	332	
Mesic-xeric oak	70	
Mesic hardwood	69	
Total		3321
Total Forest		5085
Non-Forest		
Marsh	68	
Improved pasture	304	
Developed	668	
Total		1040
TOTAL		6125

FOREST = Transpiring/Total Forest
= 1864/5085
= 0.4

LZETP = Total Forest/Total
= 5085/6125
= 0.8

Acreage data from Table 1, Seaburn and Robertson, Inc. (1977)

ET simulated reflects the best estimate of actual ET for the area. If higher values of ET were desired than could be obtained using LZETP and AGWETP, the baseflow evapotranspiration parameter BASETP was used to subtract water as ET from a land segment's baseflow runoff to a stream. Table 3-6 summarizes the evapotranspiration parameters.

Recession Rates

The function governing groundwater recession can be either a linear function or a power function as selected by the modeler using KVARY. By default KVARY = 0, making the groundwater recession rate a linear function. Increasing KVARY creates a non-linear relation between groundwater outflow and storage increasing baseflow during wet periods and decreasing it during dry periods without altering the actual baseflow volume. For all segments this parameter was left at zero. When KVARY equals zero, no estimate for the index to groundwater slope, GWVS, is required. The description of hydrograph separation techniques in Hydrology for Engineers (Linsley et al., 1982) provides a good description of the baseflow recession curve.

The interflow recession rate and the groundwater recession rate can be found using equations 3-28 and 3-29:

$$IRC = Q^i_{t+1}/Q^i_t \qquad 0 \leq IRC \leq 1 \qquad (3\text{-}28)$$

$$AGWRC = Q^a_{t+1}/Q^a_t \qquad 0 \leq AGWRC \leq 1 \qquad (3\text{-}29)$$

Table 3-6

Evapotranspiration Parameters

Parameter	PERLND 1	2	3	4	5	6
FOREST	0.4	0.4	0.4	0.4	0.4	0.4
LZETP	0.8	0.4	0.8	0.4	0.4	0.4
AGWETP	0.6	0.6	0.6	0.6	0.6	0.6
BASETP	0.1	0	0.5	0.5	0	0

where IRC is the interflow recession rate, AGWRC is the active groundwater recession rate, Q_t^i is the interflow discharge on any day, and Q_t^a is the groundwater discharge on any day. IRC is used in the discussion of the interflow zone. AGWRC, KVARY, and GWVS are discussed in the section on groundwater storages.

The ARM manual states that these parameters are "close to 0.0 for small watersheds that only experience runoff during or immediately following storm events". In the Cypress Creek Watershed, however, subsurface flow is a major component of stream flow; therefore the expected value of these parameters was relatively high (near 1). In a study by Gaschnig and others (1981) where the development of an expert system for use with HSPF is discussed, a formula for AGWRC is offered based on soil type and geology and corrected for soil slope:

$$AGWRC = 1.0 - (Y*(1.0-X)) \qquad (3\text{-}30)$$

where

X = a factor determined by soil type and geology, and
Y = a factor determined by soil slope.

For the Cypress Creek watershed with its sandy soils of moderate to rapid permeability, a range of 0.90 to 0.92 is suggested for X. For slopes between 0.001 and 0.01, Y takes on a value of 1.0. Using equation 3-30 with these values, AGWRC would range from 0.90 to 0.92. The simulation is extremely sensitive to AGWRC, however, and during calibration only significantly higher values of AGWRC produced acceptable results. The parameter AGWRC was set at 0.985 for PERLND 3 through 6 and at 0.945 for PERLNDs 1 and 2. Lower values caused the release of too much water as runoff from active groundwater storage.

Interflow was not a significant component of runoff for the simulation. The parameter for interflow recession, IRC, was set at the value of 0.9. The simulation showed little sensitivity to changes in the value of IRC at the daily time step used in the model.

Infiltration

Infiltration is the movement of water into the soil under the forces of gravity and capillarity. The rate at which water penetrates the surface is called the infiltration rate (Eagleson, 1970). In HSPF, the index to the soil infiltration rate is INFILT. The infiltration rate of a soil at a given time depends on the current soil moisture conditions and surface water availability. HSPF accounts for these effects by using a ratio of the amount of water currently in lower zone storage to the lower zone nominal storage capacity to compute a mean infiltration capacity.

$$IBAR = INFILT/(LZS/LZSN)^{**}INFEXP \qquad (3\text{-}31)$$

where

IBAR = mean infiltration capacity, in/interval,
INFILT = infiltration parameter, in/interval,
LZS = lower zone storage, inches,
LZSN = lower zone nominal storage, inches, and
INFEXP = exponent parameter greater than one.

The value of IBAR is used to separate moisture leaving the surface zone into moisture which infiltrates (INFIL) and moisture which is potential direct runoff (PDRO). These flows are described in the sections on the surface, interflow, and upper zones. INFILT is also used to compute the amount of water which percolates out of upper zone storage; this calculation is presented in the section on the upper zone.

The ARM manual suggested a range for INFILT of 0.01 to 1.0 in/hr for soils with runoff potential ranging from low to high. Better estimates were available in the form of soil permeability data for Pasco County soils. Soil permeabilities (hydraulic conductivities) for each soil type were obtained from the Soil Survey of Pasco County, Florida (Stankey, 1982). Permeability ranges from 2.0 in/hr to over 20 in/hr over the six land segments. The minimum rate was input for each land segment except in the case of PERLND 6 where it was necessary to indicate a wider range of permeabilities. The extent of the infiltration range is determined by parameter INFILD, the ratio of maximum to minimum infiltration rate. The maximum value which INFILD can assume is 2.0 and this was the value used to indicate the wide range of infiltration rates occurring in each land segment. The exponent in the infiltration equation, INFEXP, was given its default value of two. The parameter INTFW, which governs the amount of water going into the interflow zone, is discussed in the section Interflow zone.

Percolation from the surficial aquifer to the deep aquifer is governed by DEEPFR. The action of this parameter is discussed in the section Groundwater Storage. Moisture which percolates through the confining layer into inactive groundwater storage is lost to the HSPF simulation.

DEEPFR was set during calibration to reflect estimates of the annual leakance of water through the confining layer. A digital model of predevelopment flow by Ryder (1982) estimated a downward leakance of five inches per year with no pumping. Also, Hutchinson (1984) estimated that pumping 133 mgd increased leakance to about nine inches per year. These studies provide a range for leakance of 5-9 in/yr for the calibration period. Starting with DEEPFR set to zero, this parameter was gradually increased during calibration until the amount of deep percolation output annually by the model was brought within the given range. DEEPFR for PERLND 1 was assigned a zero value because it is expected to be an area of net recharge from the Floridan to the surficial aquifer. HSPF has no capability, however, for simulation of an upward flow from a deep groundwater aquifer. Figure 3-5 (SWFWMD, 1984) shows a generalized map of Floridan aquifer recharge and discharge for Pasco County. Table 3-7 provides

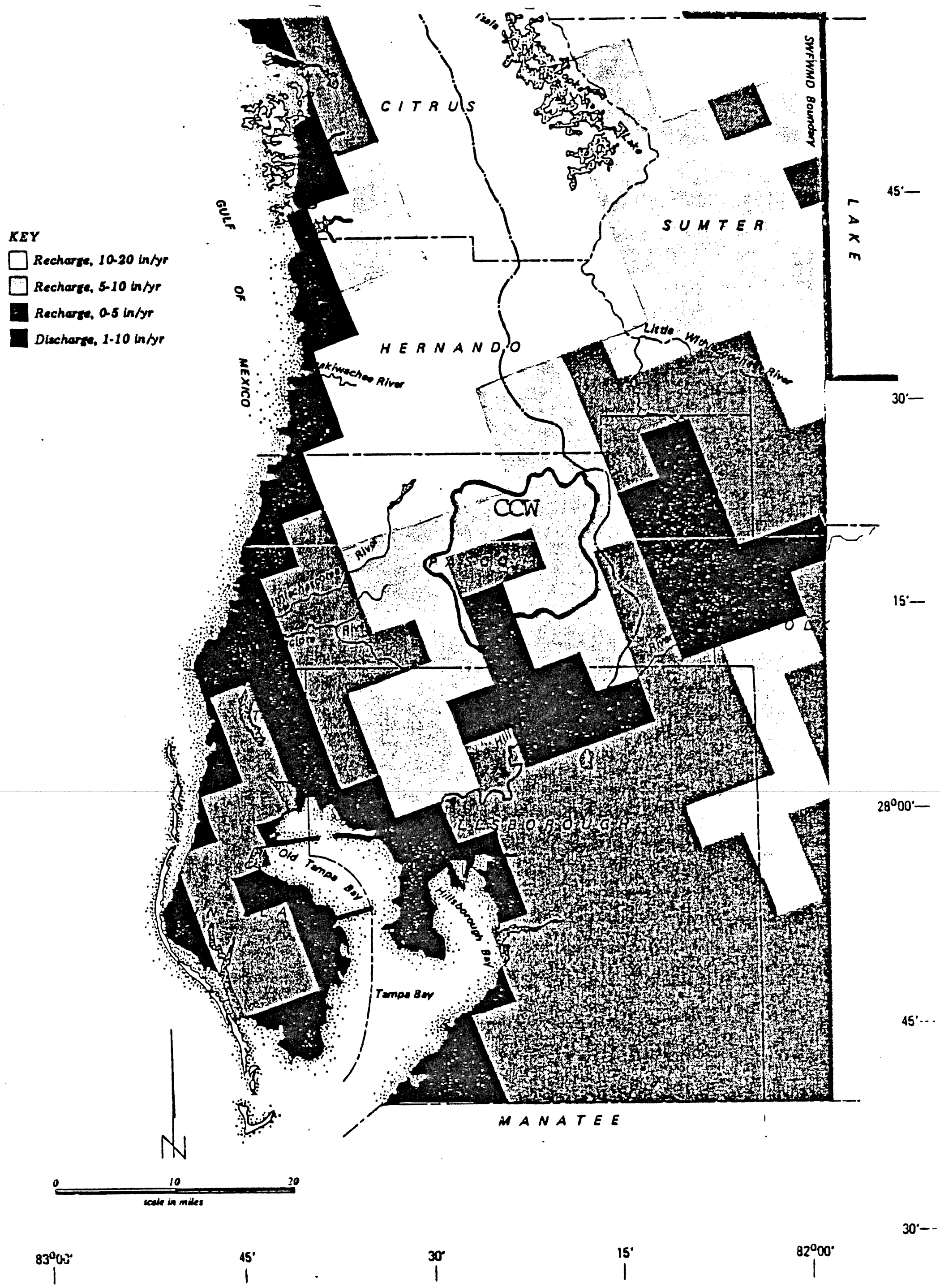

Figure 3-5 Distribution of Floridan Aquifer Recharge and Discharge, as Determined by a Calibrated Model of Predevelopment Flow (Ryder, 1982)

Table 3-7

Infiltration Parameters

Parameter	PERLND 1	2	3	4	5	6
INFILT in/hr	2.0	6.0	2.0	6.0	6.0	10.0
INFEXP	2.0	2.0	2.0	2.0	2.0	2.0
INFILD	2.0	2.0	2.0	2.0	2.0	2.0
INTFW	2.0	2.0	2.0	2.0	2.0	2.0
DEEPFR	0.0	.20	.20	.20	.25	.30

a summary of the infiltration parameters for the six subcatchments.

Lateral Transport

Overland flow in HSPF is calculated using the Chezy-Manning equation and an empirical relation between surface detention storage and surface outflow depth. Three surface flow parameters are needed: NSUR, LSUR, and SLSUR. The flow equation for SURSM < SURSE is:

SURO = DELT60*SRC*(SURSM*(1.0+0.6(SURSM/SURSE)**3))**1.67 (3-32)

For SURSM $\geq$ SURSE

SURO = DELT60*SRC*(SURSM*1.6)**1.67 (3-33)

where

SURO = surface outflow, in/interval,
DELT60 = hr/interval,
SRC = routing variable, described below,
SURSM = mean surface detention storage over the time interval, inches, and
SURSE = equilibrium surface dentention storage for current supply rate, inches.

Equilibrium surface detention storage is given by:

SURSE = DEC*SSUPR**0.6 (3-34)

where

DEC = routing variable, described below, and
SSUPR = rate of moisture supply to overland flow surface.

The routing variables, DEC and SRC, are calculated using lateral transport input parameters.

DEC = 0.00982*(NSUR*LSUR/SQRT(SLSUR))**0.6 (3-35)

SRC = 1020.0*(SQRT(SLSUR)/(NSUR*LSUR)) (3-36)

where

NSUR = Manning's n for overland flow plane,
LSUR = length of the overland flow plane in ft, and
SLSUR = slope of the overland flow plane.

LSUR approximates the length of travel to a stream channel. This length of overland flow can be estimated using equations (3-37) and (3-38) (Eagleson, 1970):

$$LSUR = 1/2\ D_d^{-1} \quad (3\text{-}37)$$

$$D_d = SA/\Sigma L_S \quad (3\text{-}38)$$

where D_d is the drainage density, SA is the area of the catchment, and L_S is the stream length draining the catchment. In a study of the Kissimmee river basin by Huber et al. (1976), drainage densities computed for natural areas ranged from 1.17 to 2.58 mile^{-1}. A low range is characteristic of humid areas with low relief. The drainage density for each of the six subcatchments was approximated by dividing the length of Cypress Creek draining each PERLND by the area of each PERLND. Drainage densities ranged from 0.0912 to 0.9016 mile^{-1}, corresponding to an LSUR range of 2930 to 29,000 feet (see Table 3-8).

SLSUR is the average slope of overland flow. For the Cypress Creek basin, Murphy (1978) lists a range of slope of 1.2 to 5.0 ft/mi, or 0.003 to 0.0009. Values for the simulation were derived from measurements made on topographic maps. The difference in elevation between two points was divided by the distance between the two points; the final slope was the average of six calculations for each land segment. SLSUR ranged from 0.002 to 0.013. Table 3-9 shows the elevation and slope range for each PERLND segment.

Table 3-8

Calculation of Drainage Density and Overland Flow Length (LSUR) for Six PERLNDs

PERLND	Area	Stream Length	D_d	LSUR
	mi^2	mi	1/mi	ft
1	12.2	11.0	0.902	2930
2	31.6	11.0	0.348	7580
3	8.5	4.7	0.553	4770
4	8.7	4.7	0.540	4890
5	11.2*	3.3	0.295	8960
6	36.2	3.3	0.091	29000

* see page 40.

Table 3-9

Elevation and Slope for Six PERLNDs

PERLND	Max. Elev. ft.	Min. Elev. ft.	Max. Slope	Min. Slope	Average Slope*
1	85	50	.0200	0	.005
2	170	55	.0400	.0013	.013
3	82	60	.0100	.0011	.005
4	80	70	.0100	.0025	.007
5	110	75	.0058	.0008	.002
6	232	80	.0156	.0088	.013

* Average slope is the average of six measurements made in each PERLND.

Manning's n for overland flow is represented by the parameter NSUR. Chow (1959) gives a range of Manning's n for flood plains of 0.025 to 0.150; the n value increases as brush density increases and increases as depth of flow decreases. For Cypress Creek basin, therefore, high to very high coefficients are expected. The ARM manual suggests values that vary considerably from published channel values due to extremely small depths of overland flow.

Approximate values from the manual are:

smooth, packed surface	0.05
normal roads and parking lots	0.10
disturbed land surfaces	0.15
turf	0.25
heavy turf and forest litter	0.35

PERLNDs 2,4,5 and 6 were assigned the turf value for NSUR of 0.25; the swamp segments, PERLNDs 1 and 3 were given the higher value of 0.35.

Summary of Parameter Estimates

Table 3-10 lists the twenty five parameter estimates for each of the six PERLNDs.

Sensitivity Analysis

An analysis was done covering the five parameters to which the simulation had proved most sensitive during calibration. These five parameters were: the active groundwater recession constant, AGWRC, the parameter controlling leakance to deep groundwater, DEEPFR, two parameters determining evapotranspiration, LZETP and AGWETP,

Table 3-10

Parameter Estimates for Six PERLNDs

Parameter	Units	Description	Assumed Value by PERLND 1	2	3	4	5	6
Interception:								
CEPSC	in	Interception storage capacity	0.15	0.15	0.15	0.15	0.15	0.15
CEPS	in	Interception state storage	0	0	0	0	0	0
Soil Storages:								
UZSN	in	Upper zone nominal storage	0.4	0.35	0.45	0.35	0.25	0.3
LZSN	in	Lower zone nominal storage	0.7	1.86	0.7	1.52	3.3	4.4
SURS	in	Surface state storage	0	0	0	0	0	0
IFWS	in	Interflow state storage	0	0	0.001	0	0	0
UZS	in	Upper zone state storage	0.001	0.001	0.073	0.025	0.017	0.001
LZS	in	Lower zone state storage	1.4	3.5	1.414	2.24	3.994	5.428
AGWS	in	Active groundwater state storage	3.2	1.4	7.002	7.401	2.26	2.24
Evapotranspiration:								
FOREST		Fraction winter forest transpiration	0.4	0.4	0.4	0.4	0.4	0.4
LZETP		Lower zone ET parameter	0.8	0.4	0.8	0.4	0.4	0.4
AGWETP		Fraction ET from active GW storage	0.6	0.6	0.6	0.6	0.6	0.6
BASETP		Fraction ET from active GW outflow	0.1	0	0.5	0.5	0	0
Recession Rates:								
KVARY	1/in	Groundwater recession behavior parameter	0	0	0	0	0	0
AGWRC	1/day	Active groundwater recession rate	0.945	0.945	0.985	0.985	0.985	0.985
IRC	1/day	Interflow recession rate	0.9	0.9	0.9	0.9	0.9	0.9
GWVS	in	Index to groundwater slope	0	0	0	0	0	0
Infiltration:								
INFILT	in/hr	Index to mean infiltration rate	2	6	2	6	6	10
INFILD		Ratio max/min infiltration rate	2	2	2	2	2	2
INFEXP		Exponent in infiltration equation	2	2	2	2	2	2
INTFW		Interflow inflow parameter	2	2	2	2	2	2
DEEPFR		Fraction of GW to deep aquifer	0	0.2	0.2	0.2	0.25	0.3
Lateral Transport:								
LSUR	ft	Length of overland flow plane	2928	7584	4774	4887	8960	28960
SLSUR		Average surface slope	0.005	0.013	0.005	0.007	0.002	0.013
NSUR		Manning's n for overland flow	0.35	0.25	0.35	0.25	0.25	0.25

and the lower zone nominal storage, LZSN. According to Donigian and others (1984), hydrographs for selected storm events are sensitive to other parameters such as UZSN, INTFW, and INFILT. The simulation of annual and monthly runoff volumes however, was not sensitive to adjustment in these parameters. Simulation runs over the northwestern subcatchment, PERLND 5, were used to quantify the sensitivity to the five parameters analyzed. The sensitivity of the parameters in the other five subcatchments is expected to be similar because the same mechanisms are involved. The results listed in Table 3-11 document the effects on the annual average runoff (PERO), deep percolation (IGWI), and evapotranspiration (TAET) for the three water years of calibration, Oct. 1977 to Sept. 1980.

The most dominant parameter is AGWRC which showed significant effects on runoff after changes in value of ± 0.5 percent. LZETP and DEEPFR affected both runoff and deep percolation after changes at the ± 10 percent level. At the same level, AGWETP significantly altered runoff, while LZSN created only slight alterations in runoff.

An in-depth look was taken at the three parameters causing the more significant effects. Both subcatchments contributing runoff to REACH 1 were used in six simulations. Each parameter was tested separately by adjusting its value by the same percentage in both PERLND 5 and PERLND 6. After

Table 3-11

Sensitivity Analysis for Five Parameters over PERLND 5 Using Annual Averages, Oct. 1977 - Sept. 1980

Parameter	% Diff.	Deep Percolation in	Deep Percolation % Diff.	Runoff in	Runoff % Diff.	Evapotranspiration in	Evapotranspiration % Diff.
Best fit		6.323		5.599		44.296	
AGWRC = 0.980	-0.5	6.227	-1.5	6.242	11.0	43.791	-1.1
AGWRC = 0.990	0.5	6.468	2.3	4.687	-16.0	45.005	1.6
AGWRC = 0.975	-1.0	6.160	-2.6	6.723	20.0	43.410	-2.0
AGWRC = 0.995	1.0	6.701	6.0	3.249	-42.0	46.132	4.1
DEEPFR = 0.225	-10	5.726	-9.4	5.985	6.9	44.486	0.4
DEEPFR = 0.275	10	6.911	9.3	5.222	-6.7	44.106	-0.4
DEEPFR = 0.188	-25	4.828	-24	6.583	18	44.755	1.0
DEEPFR = 0.313	25	7.791	23	4.673	-17	43.808	-1.1
LZETP = 0.36	-10	6.753	6.8	6.071	8.4	43.278	-2.3
LZETP = 0.44	10	5.914	-6.5	5.140	-8.2	45.280	2.2
LZETP = 0.30	-25	7.419	17	6.816	22	41.700	-5.9
LZETP = 0.50	25	5.328	-16	4.501	-20	46.681	5.4
AGWETP = 0.54	-10	6.209	-1.8	5.952	6.3	44.081	-0.5
AGWETP = 0.66	10	6.429	1.7	5.278	-5.7	44.489	0.4
AGWETP = 0.45	-25	6.021	-4.8	6.569	17	43.688	-1.4
AGWETP = 0.75	25	6.581	4.1	4.848	-13	44.739	1.0
LZSN = 2.97	-10	6.391	1.1	5.762	2.9	44.187	-0.3
LZSN = 3.63	10	6.260	1.0	5.455	-2.6	44.385	0.2
LZSN = 2.48	-25	6.505	2.9	6.053	8.1	43.969	-0.7
LZSN = 4.13	25	6.175	-2.3	5.260	-6.1	44.489	0.4

each change the average monthly flow volume, the standard deviation, the peak monthly flow volume, and the total volume discharged over the three years of simulation were compared to the actual values and to the values produced by the "best fit" parameters listed in Table 3-10. The results are shown in Table 3-12. The prediction of standard deviation of monthly flow and the prediction of peak flow were only improved at the expense of close prediction of the total and average monthly flow volumes.

Judging the Calibration

The sensitivity analysis shows that a change in one parameter may improve one aspect of the calibration though reducing the match or "goodness of fit" of another aspect. As this chapter has described, values for parameters were chosen after extensive research; those values considered the best fit values based on this study were not changed in the calibration process. Other parameters not readily measurable, such as AGWRC and DEEPFR, were fine tuned over many simulations. The value chosen as the "best fit" would be based on judgements made in this modeling process. In order to make decisions on changing parameter values during calibration of the model, it was necessary to decide what goodness of fit criteria would be used to judge the "best fit" set of parameters. The topic of goodness of fit is addressed in the next chapter, Chapter IV.

Table 3-12

Sensitivity Analysis on Flow Volume Statistics
for REACH 2, Sept. 1977 - Oct. 1980
(Flows in Acre-ft)

	Sum of Flow	Mean Flow	RE	SDEV	CV	Peak Month Flow
Actual Flow	34986	971.8		1584.3	1.63	7793
Best Fit	34566	960.2	1.2%	1325.5	1.38	5330
<u>Parameter Changes</u>						
AGWRC - 0.5%	38799	1077.7	10.9%	1538.7	1.43	6284
AGWRC + 0.5%	28643	795.6	18.1%	1042.5	1.31	4046
DEEPFR - 10%	37233	1034.2	6.4%	1404.5	1.36	5630
DEEPFR + 10%	31963	887.9	8.6%	1246.9	1.40	5030
LZETP - 10%	37555	1043.2	7.3%	1385.0	1.33	5574
LZETP + 10%	31709	880.8	9.4%	1263.8	1.44	5073

CHAPTER IV

GOODNESS OF FIT

Continuous simulation of hydrologic processes by hydrologic models such as HSPF provides valuable information for water resource management and for hydrological planning and design. In order for confidence to be placed in the management and design decisions based on the simulated results however, the simulation must pass some pre-determined test of reliability. Maalel (1983a) expresses the hydrologic model mathematically as:

$$y = g(x,\theta) \qquad (4\text{-}1)$$

where y is the dependent variable and $y = (y_1, y_2, \ldots, y_n)$, x is the independent variable and $x = (x_1, x_2, \ldots, x_n)$, and n is the number of measurements. The parameters are $\theta = (\theta_1, \theta_2, \ldots, \theta_p)$ and p is the number of parameters. Reliability is then defined as follows (Maalel, 1983a, p. 9):

> thus, the reliability will be the probability that the model $g(x,\theta)$ will perform adequately in predicting the behavior of the system over a given range of observations and within specified confidence limits.

Parameter Estimation

Reliability depends on the success of a model's predictions of system behavior; successful prediction depends on whether the parameters chosen give the "best fit" to the data. The selection of a best fitting set of parameters is complicated however, because variation of the parameters of the system within some predicted range may produce approximately the same output. According to Fiering and Kuczera (1982), this leads to the use of lumped parameters which are no longer physically measurable, but must be adjusted using statistical parameter estimation techniques.

The use of statistical techniques to compare the relative "goodness of fit" of various sets of estimated parameters forces the hydrologic modeler to decide at the onset of model calibration which statistical measures will be deemed the most significant in evaluating parameter adjustment. A wide variety of parameter estimation methods are available, but each method contains some particular bias in prediction. The modeler must first define his problem. A continuous model of streamflow, for example, may emphasize the close prediction of total annual flow volumes, average monthly flow volumes, peak flows, low flows, or certain specified flow events, but the equally successful prediction of each of these flow statistics using the same set of parameters is highly improbable. For this reason the modeler must decide which flow statistic is the most relevant as input to the managerial or design decision for which the simulation data is required.

For the Cypress Creek Watershed study, the hydrologic simulation was to address the problem of predicting the annual and monthly flow volumes; interest lay in what watershed developments or hydrologic events had the most impact on the long-term behavior of Cypress Creek. Given this definition of the modeling problem, the next step was to determine which parameter estimation method would more readily lend itself to goodness of fit analysis for total annual and average monthly flows. The following section presents some of the parameter estimation techniques that were considered.

Goodness of Fit Criteria

Equation (4-1) can be modified to include an error term to account for disturbances or errors which are a part of the modeling process (Maalel, 1983a):

$$y = g(x,\theta) + e \qquad (4\text{-}2)$$

where $e = e(_1, e_2, \ldots, e_n)$ is the deviation of the fitted value $g(x,\theta)$ from the measured value, y, and

$$e_i = y_i - g(x_i,\theta). \qquad (4\text{-}3)$$

The term e_i is called the residual (Neter and Wasserman, 1974).

If the modeling process were ideal then the actual value, y_i, would equal the fitted value, $g(x_i,\theta)$, and a plot of the actual values versus the fitted values would yield a straight line at a 45 degree angle from the vertical; the relationship between observed and predicted values would be linear. The modeling process is not an ideal one however, and the presence of the residuals produces a scattering of points on such a plot. Linear curve fitting techniques draw a straight line of best fit through these scattered data points by minimizing some function of the residual, e_i. The values predicted by the linear regression model have a relation to the actual values defined by:

$$y_i = E(y_i) + \varepsilon_i \qquad (4\text{-}4)$$

where y_i is the actual value, $E(y_i)$ is the expected value of y_i predicted by the regression model, and ε is the error term for this curve-fitting technique, that is, ε is the function of e that the model seeks to minimize.

If the curve-fitting technique chosen is appropriate for the simulation analysis, the properties of the residual e_i should reflect the properties of ε (Neter and Wasserman, 1974). The minimizing function for each type of linear curve-fitting however, creates its own bias in the parameter estimation process.

Hirsch and Gilroy (1984) describe the method of least squares as the most well known and widely used method of parameter estimation. The method defines the line of best fit as one that minimizes the sum of the squares (SS) of the residuals, e_i, from the equation (4-3) (Maalel, 1983a):

$$SS = \sum_{i=1}^{n} e_i^2 = \sum_{i=1}^{n} [y_i - g(x_i, \theta)]^2 \qquad (4\text{-}5)$$

This method gives equal weight to all observations, meaning the variance or the standard error is assumed constant (Maalel, 1983b). The assumption that the error term is constant introduces a bias toward outliers, especially since it is the square of the error term that is minimized.

Automatic parameter determination routines utilizing the method of least squares have been incorporated into single segment models of the Stanford Watershed Model, the parent version of HSPF (Linsley et al., 1982). Parameter adjustment over successive iterations produces an optimum set of parameter values. For a multisegmented basin, such as the one developed for the Cypress Creek study, with all segments having different parameters, the number of iterations increases exponentially and computation time becomes prohibitively large.

The drawback to the least squares method created by the squared error term occurs in other curve-fitting approaches. Hirsch and Gilroy (1984) describe a method called the line of organic correlation which seeks to minimize the sum of the squared geometric means of horizontal and vertical distances, i.e., the sum of the areas of the right triangles formed by the horizonal and vertical lines from the data point to the line. Here again the squaring of the error term favors the prediction of outliers or peak values over the correct prediction of average values.

If the error terms are not normally distributed, a system of weights can be computed to reduce the effect of outliers on the line of best fit. Maalel (1983a) suggests a method which seeks to minimize a weighted sum of squares (WWS):

$$WSS = \sum_{i=1}^{n} w_i e_i^{2} = \sum_{i=1}^{n} w_i \ (y_i - g(x_i,\theta))^2 \qquad (4\text{-}6)$$

where the weights w are equal to the inverse of the variance of the residual ($1/SDEV_e^{2}$). This type of weighting leads to least-variance estimates if the model $g(x,\theta)$ is linear in the parameters.

The method of least absolute value (LAV) estimation also tends to avoid the bias in estimation introduced by squaring the error term. Gentle (1978) describes the LAV technique as one which seeks to minimize the sum of the absolute deviations of the observed values from those predicted by the model. The absolute value term (AV) to be minimized is:

$$AV = \sum_{i=1}^{n} ABS(e_i) = \sum_{i=1}^{n} ABS((y_i - g(x_i, \theta)) \qquad (4\text{-}7)$$

In a comparison of the LAV approach with other methods, Maalel (1983b) stated that the LAV method had the largest bias of estimates and the largest standard errors.

Graphical Comparison

Thomann (1982) recommends qualitative comparison of observed data and computed values as the most direct and easily understood measures of model fit. Graphical presentations are clear and concise indicators of model performance. A scattergraph of observed values, y_i, versus values computed by the model, $g(x_i, \theta)$, plots one set of values against the other. The plot yields a scattering of points which is analyzed for its approximation to the ideal 45 degree line. As parameter adjustments are made, the subsequent scattergraphs can be compared to determine whether outlying data points are moving closer to or farther from the desired line as described by equation (4-1).

For visual comparison of the adjusted parameter's effect on prediction of flow timing, peaks, and valleys, a simple hydrograph may be used. The hydrograph of observed flows versus time can be overlain by a hydrograph of the predicted flow versus time. Relative goodness of fit of any set of parameters is determined by which set yields a predicted hydrograph that most closely matches the actual hydrograph.

The double mass curve is an effective graphical technique for averaging a model's performance over the long-term. A mass curve is a plot of continuously summed variable against time. A double mass curve is a plot of one continuously summed variable versus a second continuously summed variable over the same time period. For a double mass curve of the observed values and the model's predicted values the plot is a connected line of the data points:

$$(a,b) = (\sum_{n} y, \sum_{n} g(x,\theta)) \qquad (4\text{-}8)$$

where n is the number of measurements. Any parameter estimation results in a better fit if the double mass curve approximates more closely a straight line at 45 degrees from the vertical.

Simple Descriptive Statistics

Two of the principle characteristics of statistical distributions are central tendency, the grouping of observations about a central value, and variability, the dispersion or spread of the observations (Viessman et al., 1977). For a model of good fit, the measures of central tendency and variability for the fitted values are expected to display similar characteristics to these measures for the observed values.

The most familiar measure of central tendency is the mean, the first moment about the origin. The statistical mean is defined as:

$$\bar{x} = (1/n) \sum_{i=1}^{n} x_i \qquad (4\text{-}9)$$

where n is the number of observations and x = y for the observed values or $x = g(x,\theta)$ for the predicted values.

Thomann (1982) describes several methods of comparing the statistical means. The relative error is:

$$RE = ABS\ (\overline{y} - \overline{g(x,\theta)})/y \qquad (4\text{-}10)$$

where $\overline{y}$ represents the observed mean and $\overline{g(x,\theta)}$ is the computed mean. The relative error gives no measure of variability in the data but is useful because it is an easily understood comparison. The statistic behaves poorly at the upper tail where $y > g(x,\theta)$ because the maximum possible relative error is 100 percent.

The root mean square error, a statistically well behaved measure, is defined as follows:

$$RMSE = [\sum_{i=1}^{n} (y_i - g(x_i,\theta))^2 \ / \ n]^{1/2} \qquad (4\text{-}11)$$

The root mean square error represents a type of relative error when expressed as a ratio to a mean value over time.

The statistical variance is a measure of the range of values and is the second moment taken about the mean (Viessmann et al., 1977).

$$SDEV^2 = (1\ /(n-1)) \sum_{i=1}^{n} (x_i - \overline{x})^2 \qquad (4\text{-}12)$$

where again x may represent either the observed or the predicted values, y or $g(x,\theta)$. The square root of the variance is called the standard deviation, SDEV. The units are the same as those for the statistical mean, so the standard deviation is more easily interpreted than the variance. If the standard deviation of the fitted values is similar to the standard deviation of the observed values, the model is successful in predicting the variability shown by the actual data. If the modeler is more interested in the prediction of average values however, the standard deviation may be of little use in assessing goodness of fit.

Another expression useful in comparing the relative variability between the model and the actual data is the coefficient of variation, CV:

$$CV = SDEV/\overline{x} \qquad (4\text{-}13)$$

where SDEV = the standard deviation and $\overline{x}$ = the mean. If the coefficients of variation for the actual values and the fitted values are close together then the variables are considered to behave similarly provided the means and the standard deviations are not much larger or smaller, when compared between the two data sets.

Choice of Methods

As discussed in Chapter III, the simulation for this study requires the estimation of 25 parameters for each of six catchments, or a total of 150 parameters. Given this large number of parameters, it is impossible to use an automatic parameter estimation procedure because of the prohibitively large number of combinations to be examined. Thus, a trial-and-error procedure must be used with the analyst supplying "reasonable" guesses as to the expected values of the parameters. These estimates can be refined based on the results of the calibration runs. The reliability of a parameter estimate depends on the available data base for this parameter as well as its importance in the simulation. As the sensitivity of the simulation to any parameter is demonstrated during calibration, the data base is expanded to produce an improved estimate of that parameter. If this trail-and-error procedure were formalized, it would be possible to devise an "expert system" for this particular problem. Gashnig et al. (1981) showed how such a system could be developed for the HSPF model. They interviewed Dr. Norman Crawford, one of the developers of the HSPF model, and encoded some of his experience with parameter estimation techniques for the model into a computer based expert system.

In this study of Cypress Creek, the author had little prior knowledge as to the proper values of the parameters. However, as a knowledge base was gathered and experience with the model gained, she became the best expert on how to calibrate this model. The emphasis of this study was on total and average flow prediction, which argued against the use of methods which would more heavily weight outliers; thus, standard regression analysis was avoided. Accordingly, the selected methods for calibrating the model are based on straightforward comparisons of the measured

versus simulated flows, using graphical techniques and simple descriptive statistics. Parameter estimates are "reasonable" if they do not deviate too far from their expected values. These techniques will be used in Chapter V to demonstrate the goodness of fit of the simulation.

CHAPTER V

ANALYSIS OF MODEL FIT

Water Budget Comparison

Initial Estimates

The hydrologic output from running section PWATER in HSPF distributes the input precipitation from the Time Series Store into four blocks: storage, runoff, percolation to deep groundwater, and actual evapotranspiration. Before running the model some estimate of the expected annual range for each of these values was needed.

Estimates for expected values for runoff in the Cypress Creek basin are in the range from 6 to 9 in/yr (Murphy, 1978), and groundwater modeling of the Cypress Creek wellfield and nine other municipal wellfields in the area (Hutchinson, 1984) gives an average of 10 in/yr for the area, with no pumping. This suggests a runoff range of 6-10 in/yr. Percolation to deep groundwater is expected to range from 5-9 in/yr (See <u>Infiltration</u> section, Chapter 3), and evapotranspiration may range from 40-50 in/yr (Hutchinson, 1984).

Model Estimates

The weighted average annual evapotranspiration over the six PERLNDS was 43 inches for the three years of calibration, Oct. 1977 - Sept. 1980, well within the range suggested. Average pan evaporation input for this same time period was 55 inches. This produces an evaporation coefficient of 0.78 for the Cypress Creek basin, a high value for South Florida compared to the suggested value of 0.62 (see Chapter 2, Evapotranspiration). The weighted average volume of runoff for the six subcatchments was 7.3 inches annually and the weighted average volume of deep percolation was 5.3 inches annually. The runoff volume falls within the low end of the estimated range. The percolation volume is 0.3 inches greater than the lowest estimate. The weighted average rainfall input over the basin during the three years of simulation was 54.5 inches; this value is below the average at all three rain gages (see Table 2-2). This fact could account for the low runoff and percolation averages predicted by the model for this period.

Comparison of Predicted and Measured Runoff

Annual and Monthly Runoff Volume

Once parameters reflecting the best available data about the watershed were chosen for the six land segments, some method for comparing simulated streamflow against measured streamflow was needed. As discussed in Chapter IV, the goal was to match average volume rather than high or low extremes. Starting at San Antonio, daily Cypress Creek discharge data were used to compare measured and simulated annual and mean monthly discharge volumes. Tables 5-1, 5-2, and 5-3 show the simulated and measured values, indicating which water years were being over- or under-predicted and to what extent. Three plots were generated using the Statistical Analysis System (SAS) on the University of Florida computers. The first was a scattergraph of monthly measured volumes versus monthly simulated volumes (Figures 5-1, 5-2, and 5-3). A good fit would occur if the scatter of points approximated a 45 degree line. Next, a hydrograph was prepared of the monthly volumes versus time, with measured and simulated values overlaid (Figures 5-4, 5-5, and 5-6). Here, the objective would be to match timing and volume of flow, and peaks if possible. The third plot was a double mass curve of measured versus simulated values, again looking for a 45 degree line (Figures 5-7, 5-8, and 5-9). The results for the calibrated model of the basin are shown in Figures 5-1 through 5-9.

A simple statistical comparison of the measured and simulated monthly flow volumes is shown in Table 5-4. The model works well in predicting monthly flow volumes over the long term; relative error (RE) for the mean flows is well within the 2 percent range for all three reaches. The variability of the modeled flow is less than that for actual flow, as can be seen by comparing the values for standard deviation and coefficient of variation (CV).

Table 5-1

Measured and Simulated Volumes of Streamflow, REACH 1

Water Year	Month	Measured Flow acre-ft	Simulated Flow acre-ft
1978	Oct.	1,107.0	1,106.1
	Nov.	84.5	20.0
	Dec.	312.3	111.5
	Jan.	1,063.0	676.1
	Feb.	2,338.0	1,720.0
	March	2,528.0	2,386.0
	April	139.8	103.7
	May	304.9	327.2
	June	223.1	354.0
	July	651.6	1,453.4
	Aug.	2,533.0	3,279.4
	Sept.	239.1	977.8
		11,524.3	12,515.2
1979	Oct.	11.1	385.1
	Nov.	0.0	5.1
	Dec.	0.0	28.9
	Jan.	84.2	734.7
	Feb.	149.4	439.5
	March	670.1	618.2
	April	11.3	0.9
	May	2,742.0	2,439.5
	June	89.2	586.1
	July	18.4	113.8
	Aug.	3,418.0	2,943.2
	Sept.	7,793.0	5,330.4
		14,986.7	13,625.4
1980	Oct.	4,217.0	4,693.3
	Nov.	562.8	1,598.8
	Dec.	377.4	593.8
	Jan.	369.5	92.9
	Feb.	300.2	26.4
	March	435.2	42.2
	April	339.4	21.2
	May	99.0	55.4
	June	101.1	8.0
	July	799.1	436.7
	Aug.	779.6	669.3
	Sept.	94.6	187.2
		8,474.9	8,425.2

Table 5-2

Measured and Simulated Volumes of Streamflow, REACH 2

Water Year	Month	Measured Flow acre-ft	Simulated Flow acre-ft
1978	Oct.	1,278.6	1,306.7
	Nov.	115.4	34.7
	Dec.	391.6	206.8
	Jan.	1,426.2	1,091.3
	Feb.	3,509.1	2,476.6
	March	3,762.1	2,682.6
	April	133.3	153.1
	May	25.8	236.7
	June	3.6	292.7
	July	588.9	1,267.7
	Aug.	5,194.5	4,001.5
	Sept.	258.8	1,394.2
		16,687.9	15,144.6
1979	Oct.	12.9	619.2
	Nov.	0.0	11.7
	Dec.	0.0	0.0
	Jan.	40.0	927.6
	Feb.	50.0	632.5
	March	483.2	643.6
	April	0.0	5.5
	May	2,864.6	2,252.1
	June	54.7	795.0
	July	0.0	116.5
	Aug.	2,938.4	2,558.4
	Sept.	8,507.1	5,787.2
		14,950.9	14,349.3
1980	Oct.	5,274.4	5,684.1
	Nov.	287.3	1,912.0
	Dec.	144.5	715.8
	Jan.	215.2	60.7
	Feb.	104.7	39.2
	March	177.7	10.1
	April	259.4	0.0
	May	0.0	0.0
	June	0.0	0.0
	July	84.8	208.0
	Aug.	562.5	686.7
	Sept.	3.7	180.5
		7,114.2	9,497.1

Table 5-3

Measured and Simulated Volumes of Streamflow, REACH 3

Water Year	Month	Measured Flow acre-ft	Simulated Flow acre-ft
1978	Oct.	2,391.3	2,248.8
	Nov.	383.1	640.7
	Dec.	1,137.3	430.6
	Jan.	3,835.9	1,995.1
	Feb.	8,495.2	5,303.6
	March	10,388.9	8,204.0
	April	590.1	1,642.8
	May	1,309.4	1,006.6
	June	38.7	1,116.2
	July	3,073.7	3,289.5
	Aug.	15,306.8	11,163.0
	Sept.	1,249.3	5,205.3
		48,199.7	42,246.2
1979	Oct.	306.8	1,297.0
	Nov.	2.2	296.8
	Dec.	17.8	51.8
	Jan.	1,868.8	2,356.6
	Feb.	1,110.5	2,848.1
	March	3,049.1	2,283.7
	April	104.1	539.5
	May	13,339.6	7,313.9
	June	642.5	4,843.0
	July	10.5	747.6
	Aug.	3,903.5	7,039.4
	Sept.	17,668.5	17,213.7
		42,023.9	46,831.1
1980	Oct.	13,278.2	14,620.4
	Nov.	1,237.4	3,488.3
	Dec.	663.9	1,704.5
	Jan.	519.4	455.2
	Feb.	948.9	137.0
	March	1,340.1	18.1
	April	2,010.7	48.2
	May	104.5	91.9
	June	10.7	244.2
	July	2,165.4	723.7
	Aug.	2,846.2	4,112.8
	Sept.	555.0	1,346.0
		25,680.4	26,990.3

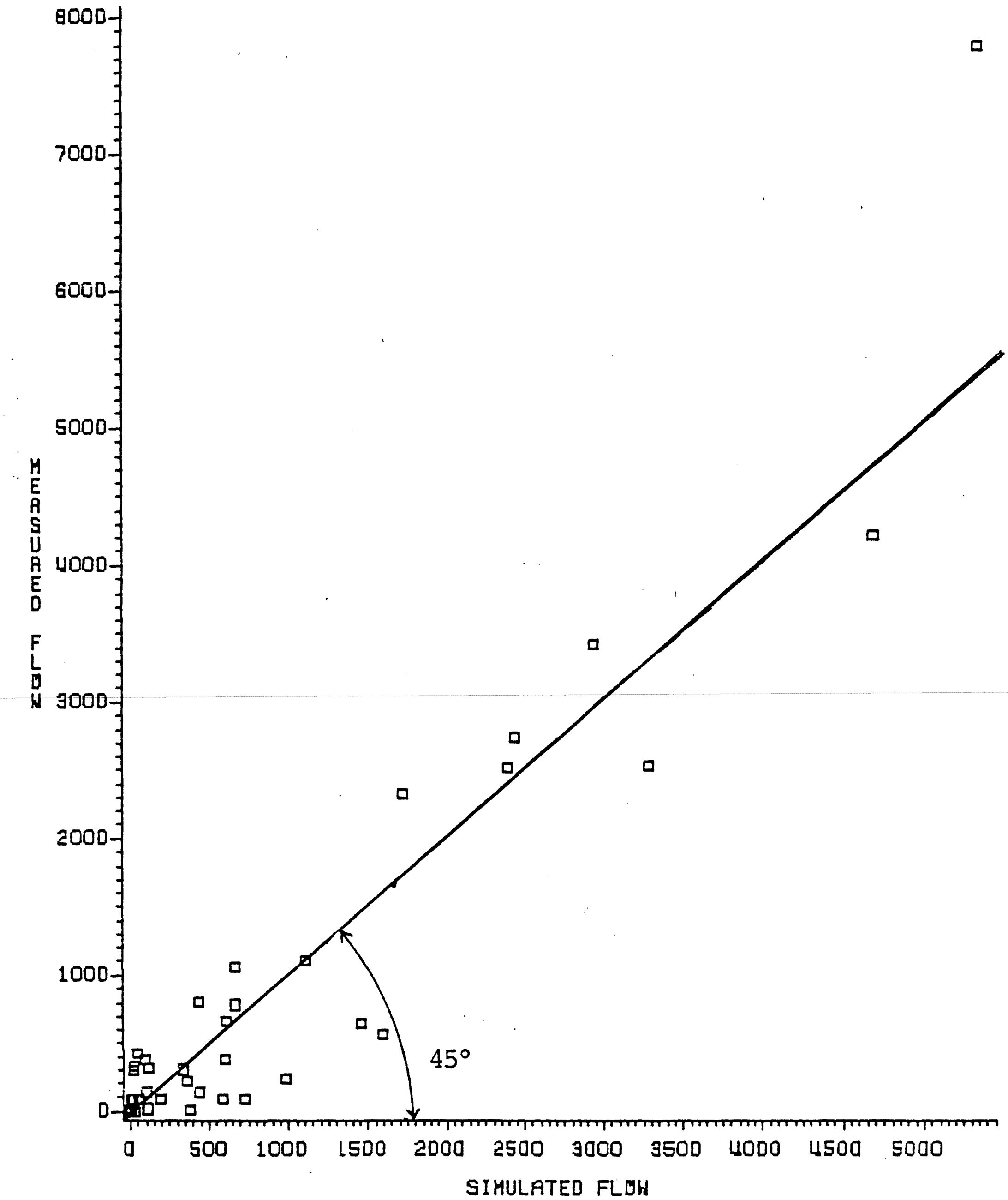

Figure 5-1 Scattergraph of Measured and Simulated Flows, REACH 1, Volumes in Acre-ft, Oct. 1977 - Sept. 1980

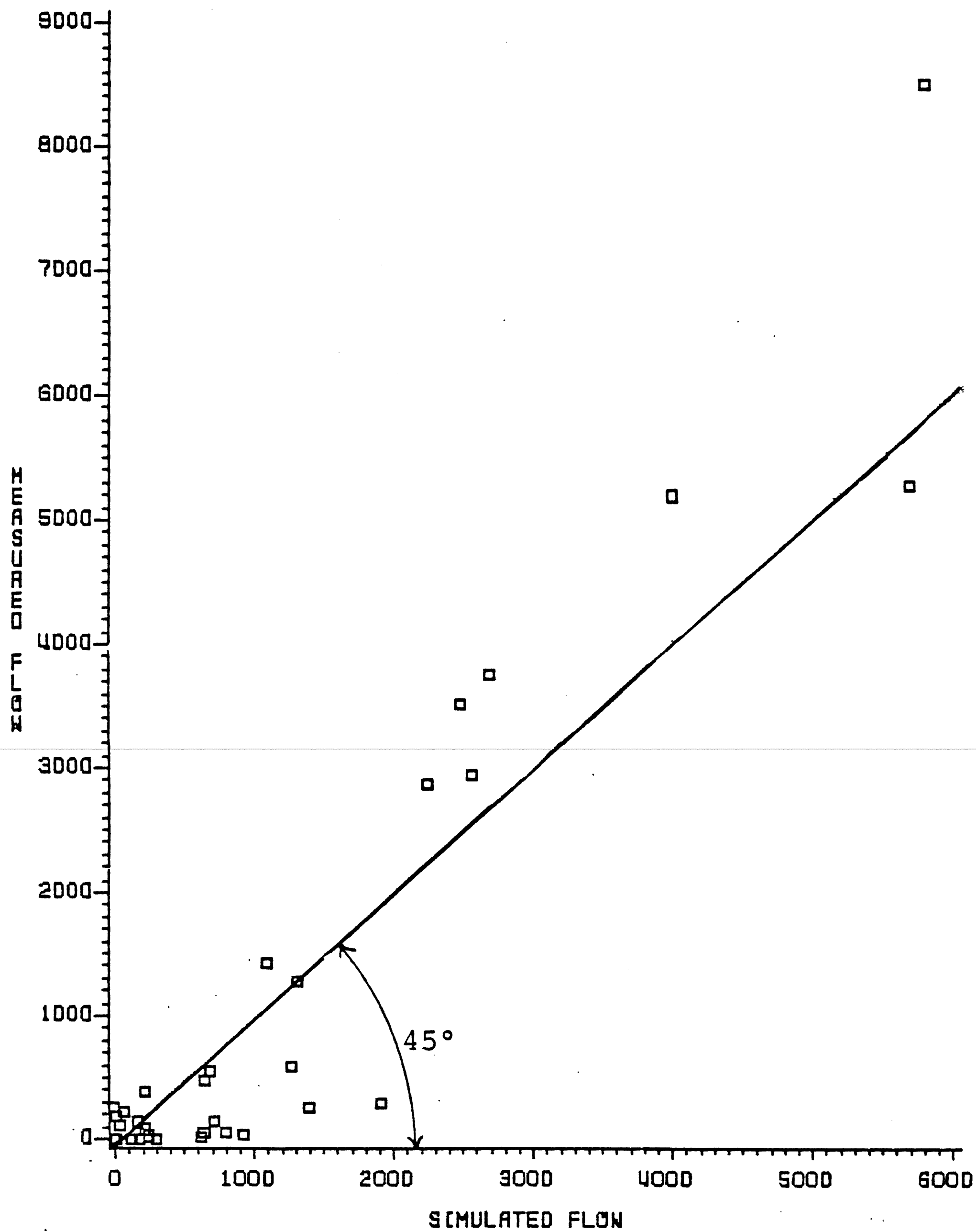

Figure 5-2 Scattergraph of Measured and Simulated Flows, REACH 2, Volumes in Acre-ft, Oct. 1977 - Sept. 1980

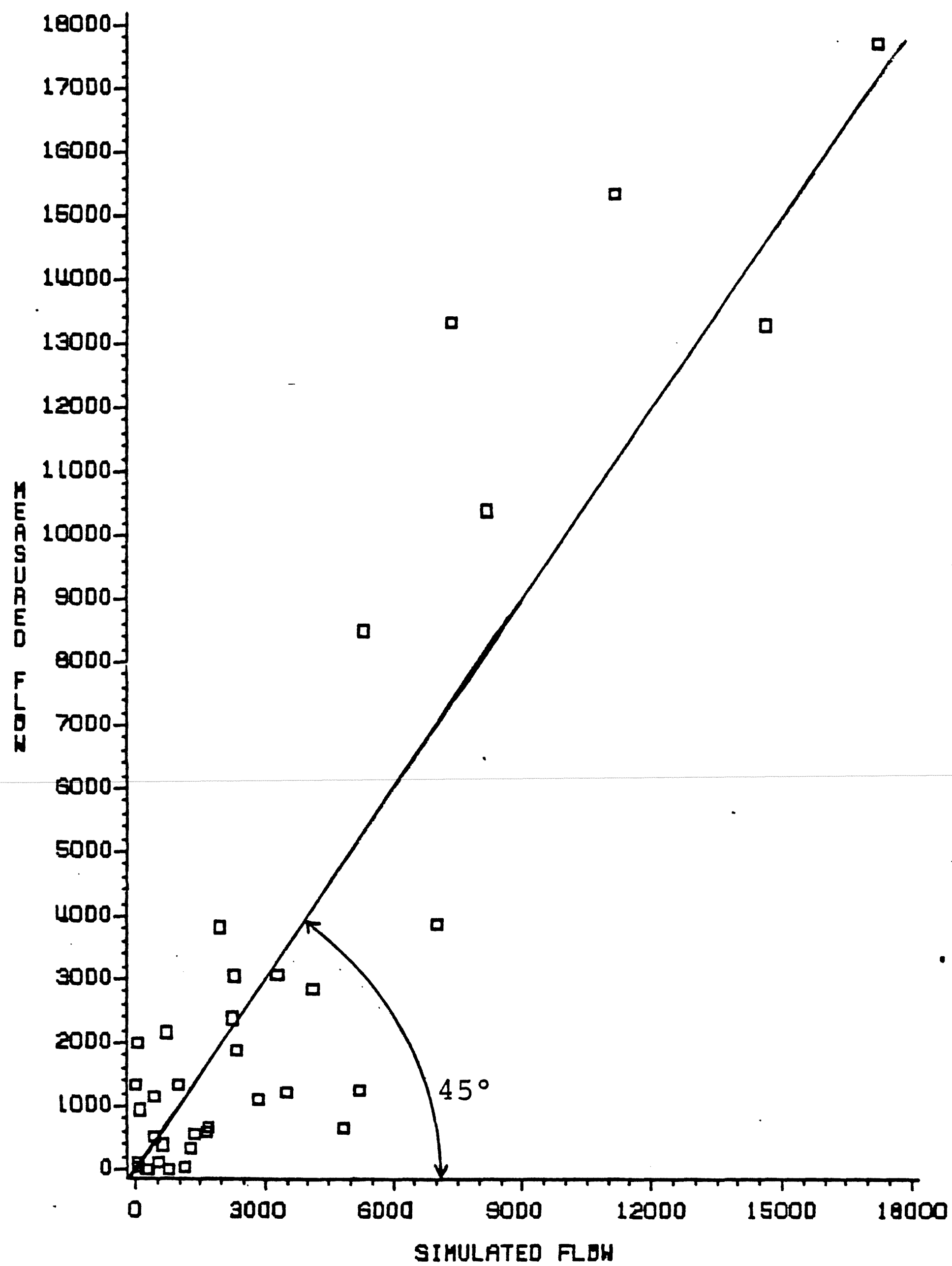

Figure 5-3 Scattergraph of Measured and Simulated Flows, REACH 3, Volumes in Acre-ft, Oct. 1977 - Sept. 1980

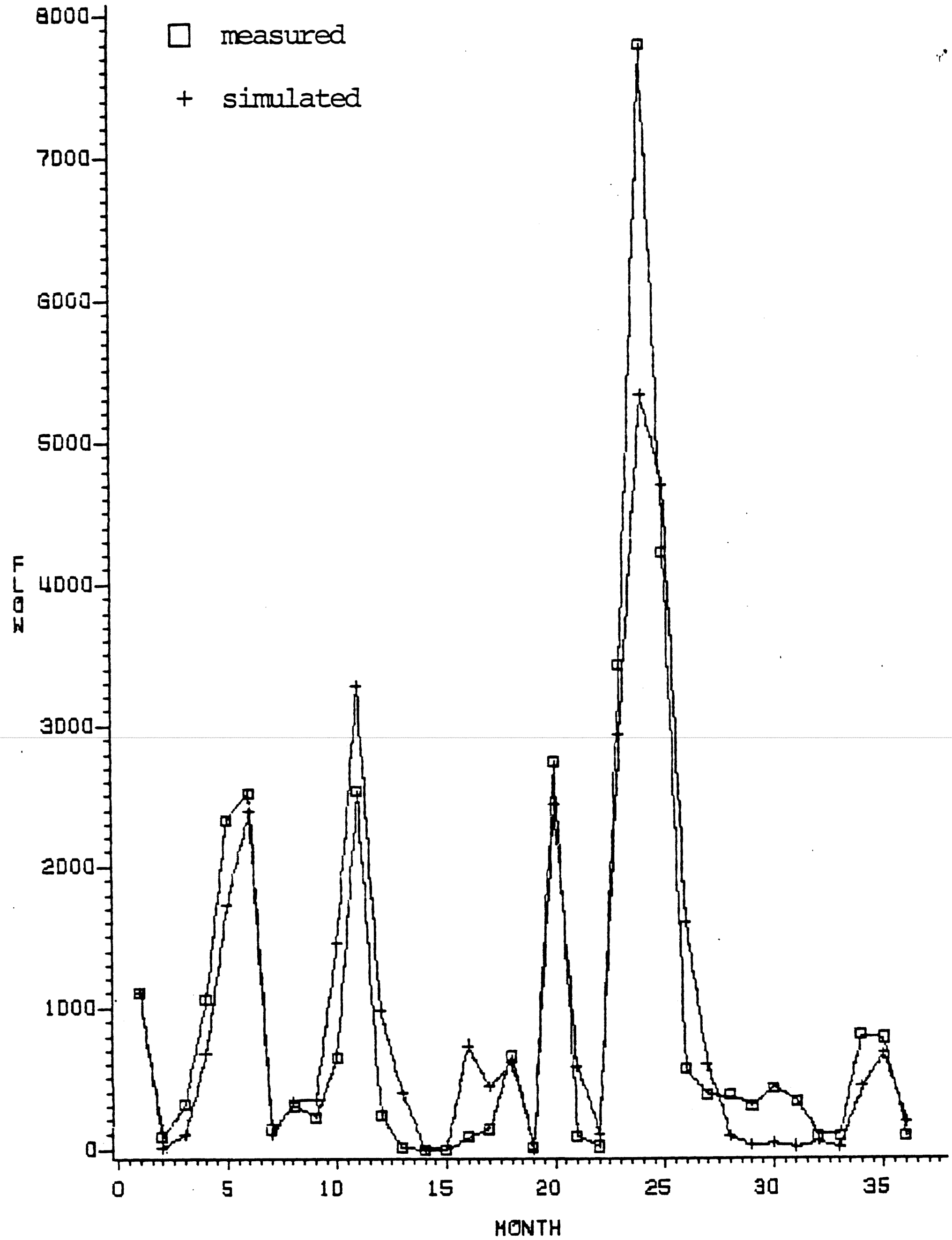

Figure 5-4 Hydrograph of Measured and Simulated Flows, REACH 1, Volumes in Acre-ft, Oct. 1977 - Sept. 1980

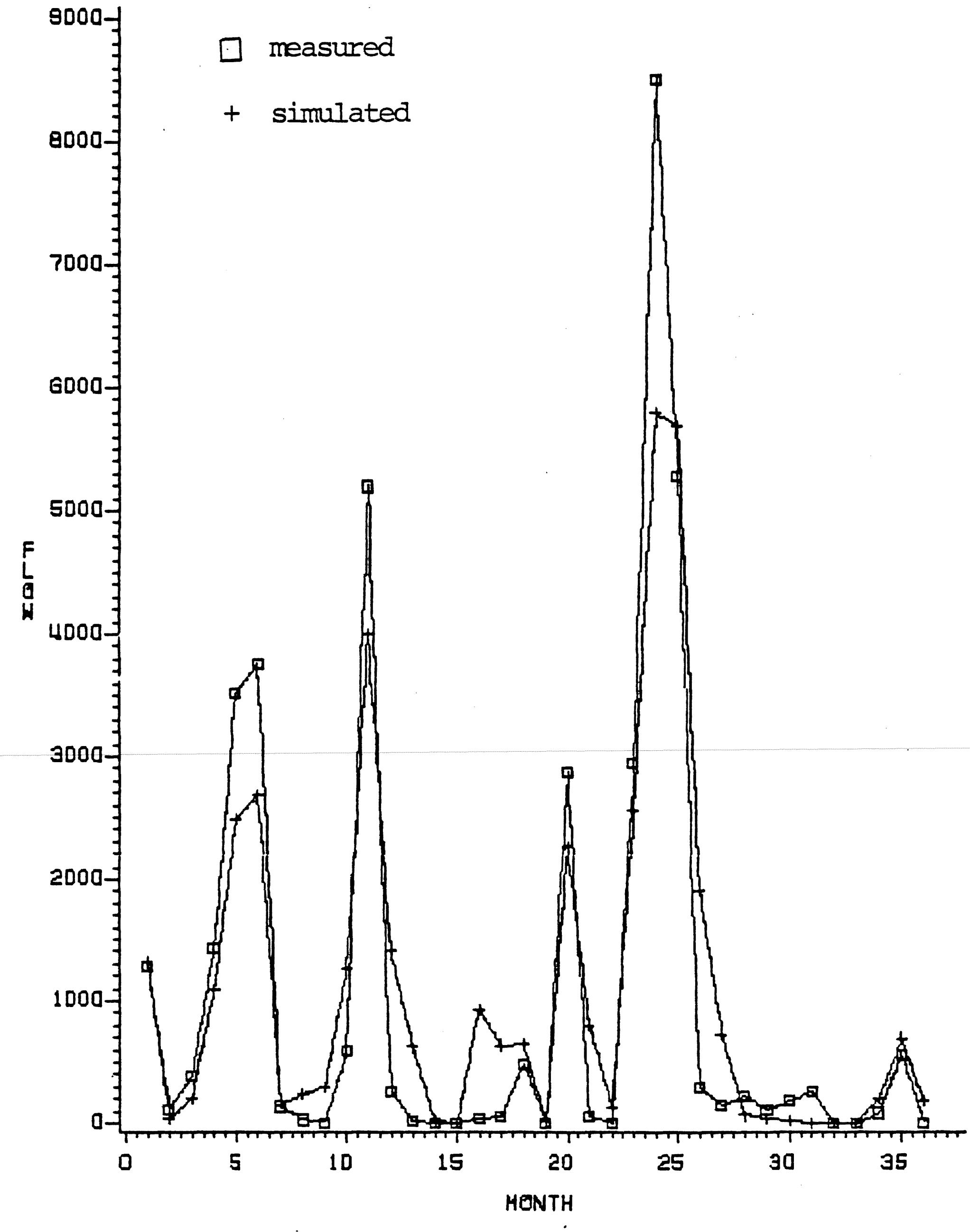

Figure 5-5 Hydrograph of Measured and Simulated Flows, REACH 2, Volumes in Acre-ft, Oct. 1977 - Sept. 1980

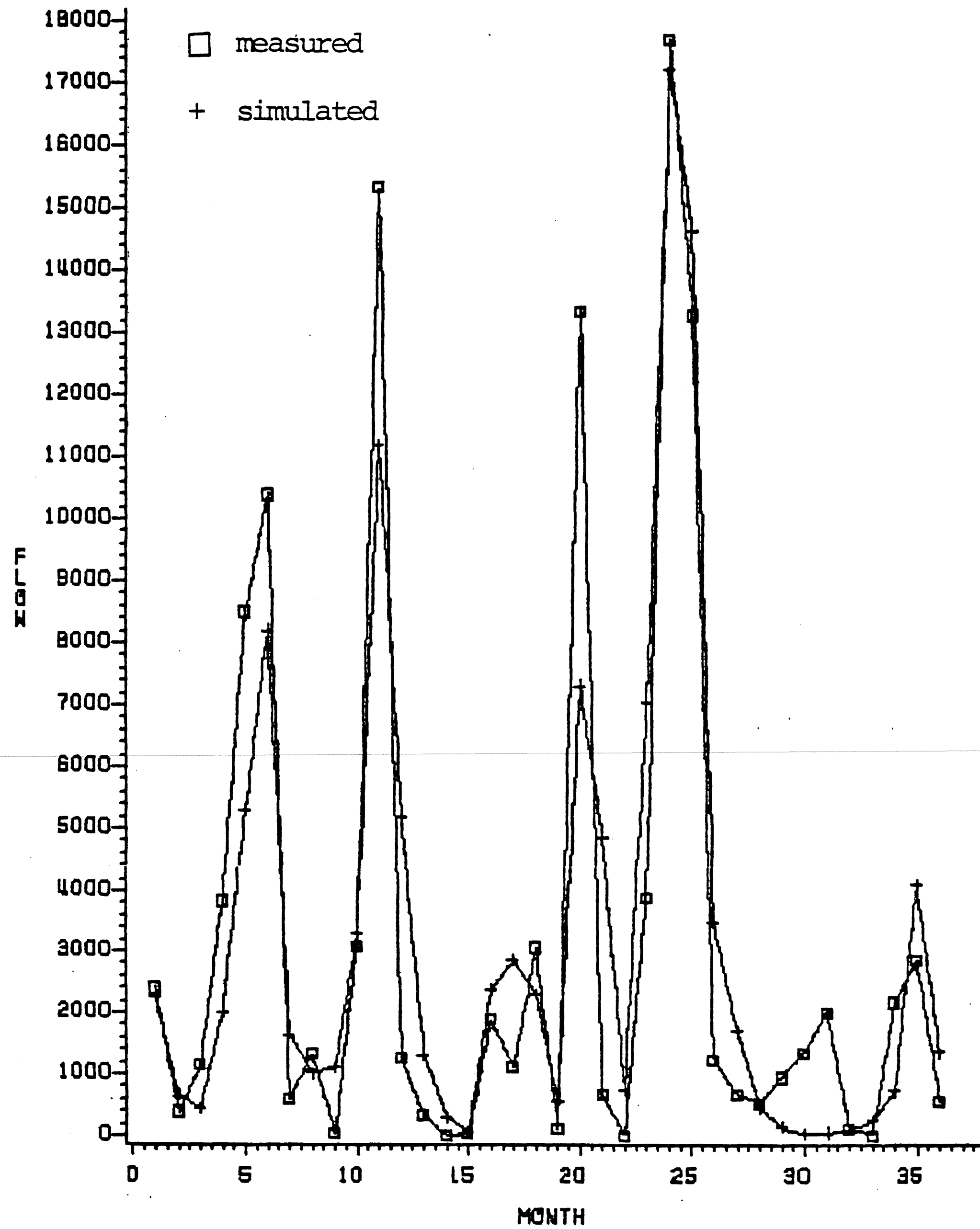

Figure 5-6 Hydrograph of Measured and Simulated Flows, REACH 3, Volumes in Acre-ft, Oct. 1977 - Sept. 1980

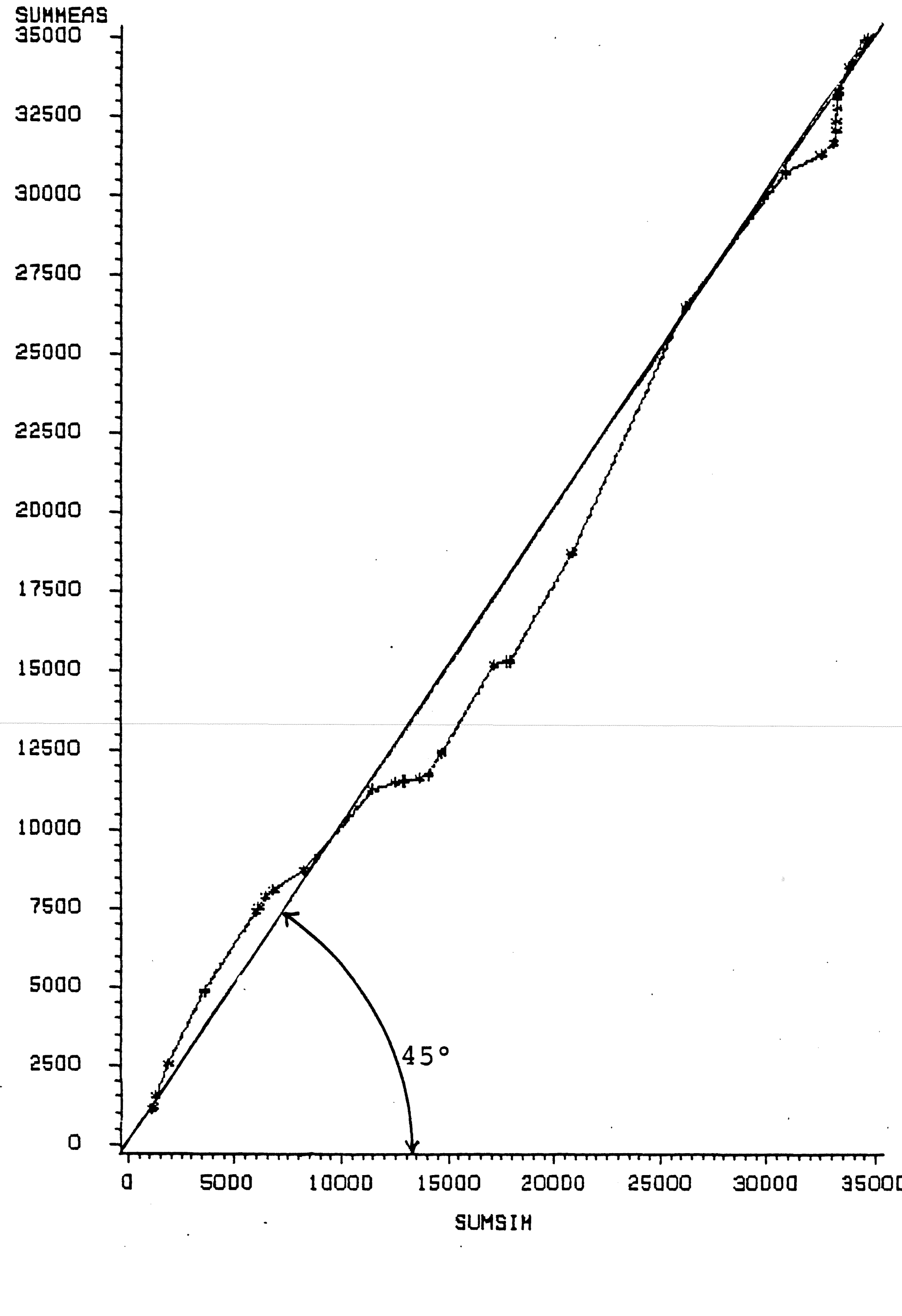

Figure 5-7 Double Mass Curve of Measured and Simulated Flows, REACH 1, Volumes in Acre-ft, Oct. 1977 - Sept. 1980

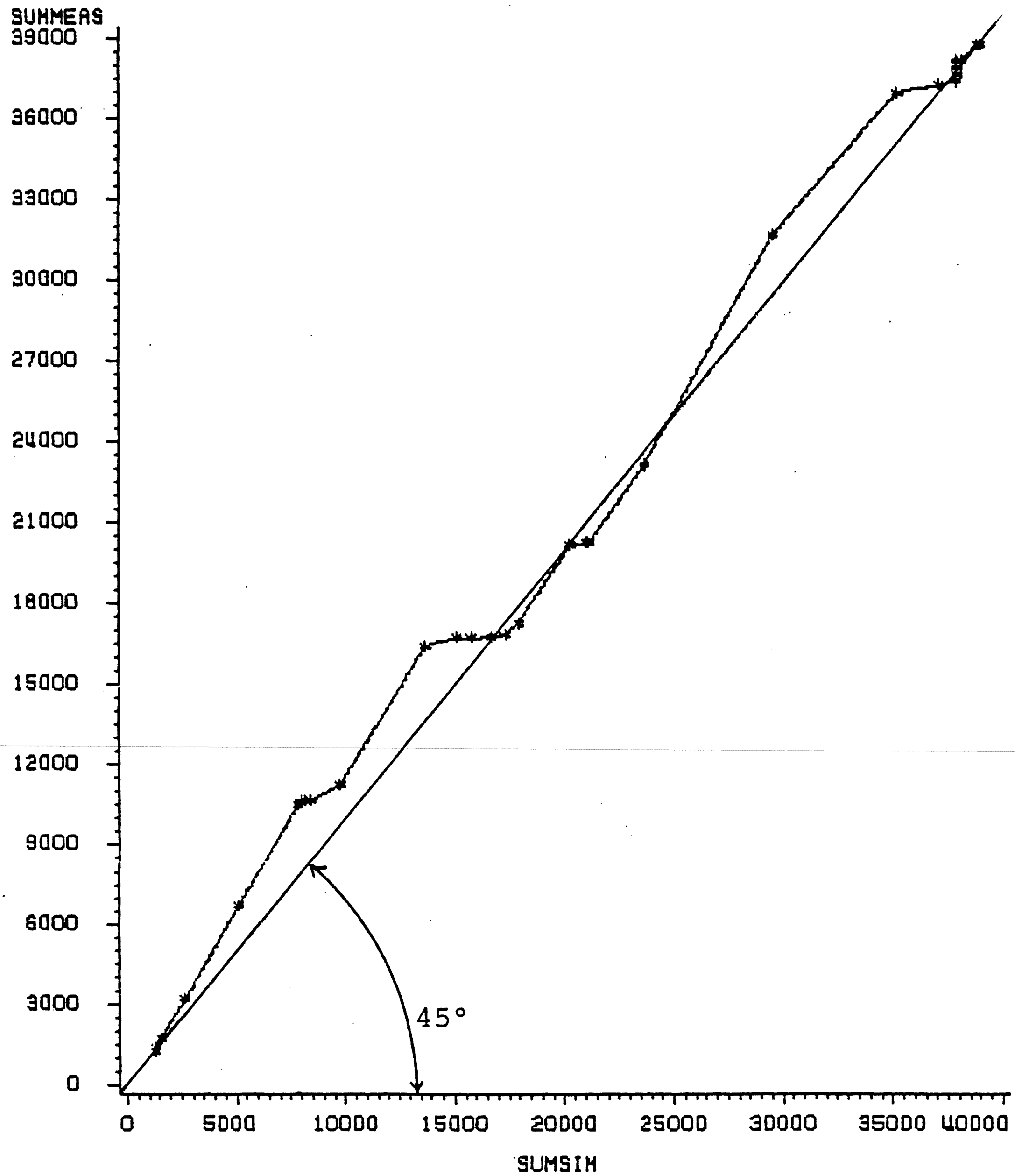

Figure 5-8 Double Mass Curve of Measured and Simulated Flows, REACH 2, Volumes in Acre-ft, Oct. 1977 - Sept. 1980

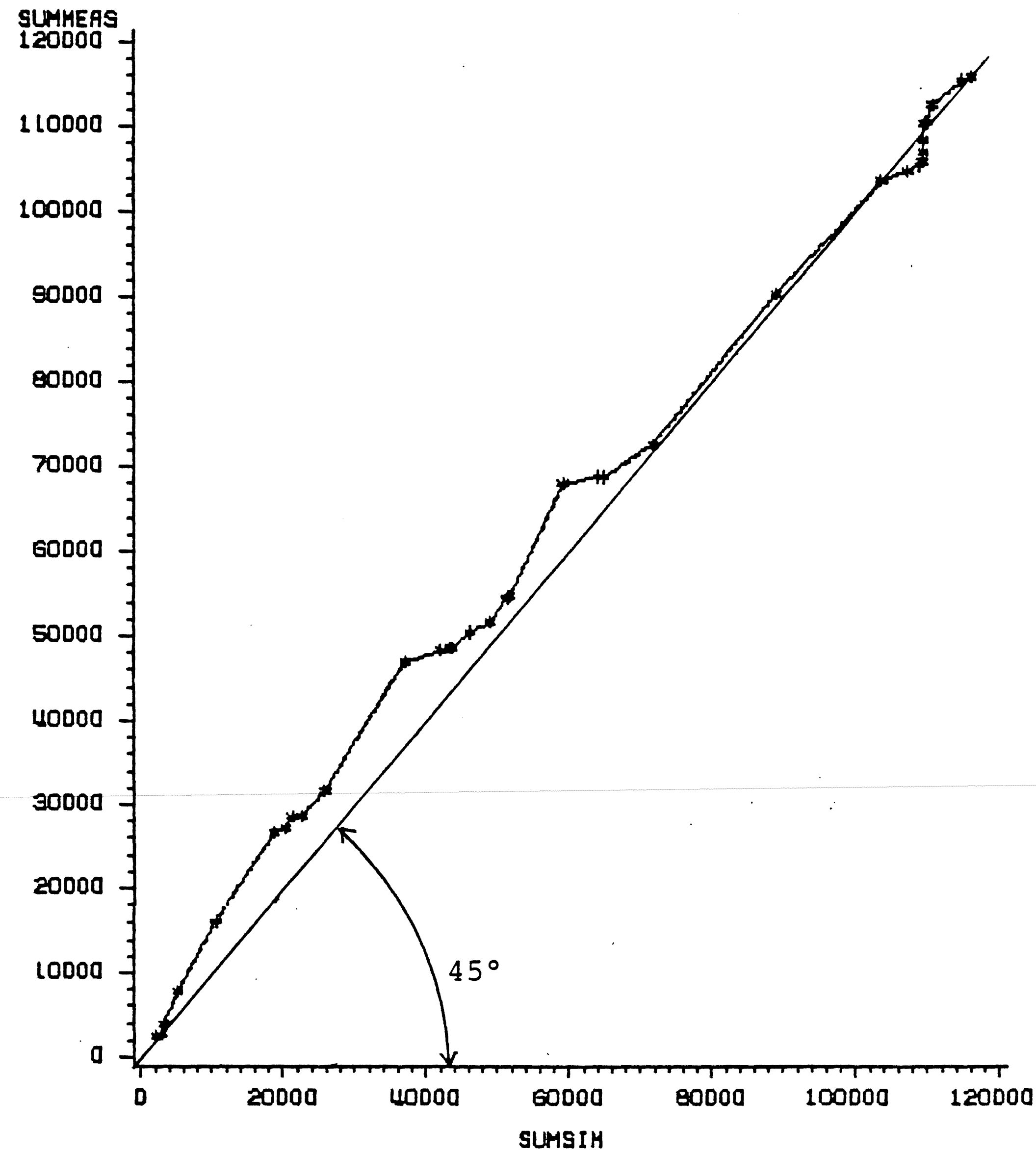

Figure 5-9 Double Mass Curve of Measured and Simulated Flows, REACH 3, Volumes in Acre-ft, Oct. 1977 - Sept. 1980

Table 5-4

Statistics for Monthly Flow Volume Prediction, REACHes 1, 2 and 3, Oct. 1977 - Sept. 1980

Reach		Volumes in acre-feet Sum	Mean	SDEV	CV	RE
1	measured	34986	972	1584	1.6	
	simulated	34566	960	1326	1.4	1.2%
2	measured	38753	1076	1956	1.8	
	simulated	38991	1083	1499	1.4	0.6%
3	measured	115924	3220	4766	1.5	
	simulated	116068	3224	4109	1.3	0.1%

Extreme Flow Prediction

A comparison of the average, peak, and zero flows measured at the San Antonio, Drexel, and Worthington Gardens gages with the values predicted by the simulation of the three analogous reaches shows that the simulation is more successful at predicting average flows than the range of flows from zero to peak. Tables 5-5, 5-6, and 5-7 contain the results. The statistics for monthly average flow (cfs) are the same as those for monthly average flow (ac-ft) in Table 5-4; only the units of flow differ.

Days of no flow were predicted for all REACHes; there was over-prediction of no-flow days for REACH 1 and under-prediction of no-flow days for REACHes 2 and 3. The percentage of days recorded as having zero flow at Worthington Gardens is very small; therefore, the relative error in prediction of no-flow days at REACH 3 is not significant.

For the ten days of greatest peak flow, the timing of the predicted peak flows is very close to that of the actual peaks for all three REACHes, with the longest lag time occurring at the downstream reach, REACH 3. The range of predicted peak flow is very small however, compared to the actual peak flow range. Accurate prediction of daily flows is not expected however, since the model was calibrated using a daily time step and comparisons of monthly flows.

Table 5-5

Comparison of Extreme Flows at REACH 1 and at San Antonio, Oct. 1977 - Sept. 1980

	Monthly Daily Flow (cfs)				Days of No Flow	
	Mean	SDEV	CV	RE	Total Days	% No-Flow Days
SAN ANTONIO	16.1	26.4	1.6		121	11
REACH 1	15.9	21.8	1.4	1.2	221	20

Ten Highest Measured Peak Flows and Corresponding Predicted Peak Flows

SAN ANTONIO		REACH 1	
Date	Discharge (cfs)	Date	Discharge (cfs)
Feb. 12, 1978	45	Feb. 12, 1978	30
Feb. 20, 1978	83	Feb. 22, 1978	51
March 11, 1978	78	March 11, 1978	58
Aug. 15, 1978	85	Aug. 14, 1978	67
May 11, 1979	180	May 11, 1979	71
Aug. 15, 1979	92	Aug. 16, 1979	62
Aug. 26, 1979	132	Aug. 27, 1979	86
Sept. 4, 1979	61	Sept. 3, 1979	86
Sept. 16, 1979	268	Sept. 17, 1979	92
Sept. 30, 1979	500	Sept. 30, 1979	118

Average value of ABS(San Antonio peak flow - REACH 1 peak flow)
= 85 cfs
SDEV = 115 cfs

Average value of ABS(days between measured and predicted peaks)
= 0.7 days
SDEV = 0.7 days

Table 5-6

Comparison of Extreme Flows at REACH 2 and at Drexel, Oct. 1977 - Sept. 1980

	Monthly Daily Flow (cfs)				Days of No Flow	
	Mean	SDEV	CV	RE	Total Days	% No-Flow Days
DREXEL	17.8	32.6	1.8		405	37
REACH 2	17.9	24.8	1.4	0.6	276	25

Ten Highest Measured Peak Flows and Corresponding Predicted Peak Flows

DREXEL		REACH 2	
Date	Discharge (cfs)	Date	Discharge (cfs)
Feb. 19, 1978	157	Feb. 24, 1978	70
March 4, 1978	86	March 6, 1978	50
March 10, 1978	148	March 13, 1978	60
Aug. 10, 1978	274	Aug. 8, 1978	50
Aug. 16, 1978	192	Aug. 21, 1978	86
May 12, 1978	168	May 16, 1979	58
Aug. 27, 1979	142	Aug. 29, 1979	82
Sept. 17. 1979	258	Sept. 19, 1979	98
Sept. 24, 1979	261	no peak	--
Oct. 1, 1979	430	Oct. 1, 1979	143

Average value of ABS(Drexel peak flow - REACH 2 peak flow)
= 129 cfs
SDEV = 81 cfs

Average value of ABS(days between measured and predicted peaks)
= 2.8 days
SDEV = 1.6 days

Table 5-7

Comparison of Extreme Flows at REACH 3 and
at Worthington Gardens, Oct. 1977 - Sept. 1980

	Monthly Daily Flow (cfs)				Days of No Flow	
	Mean	SDEV	CV	RE	Total Days	% No-Flow Days
W. GARDENS	53.3	78.8	1.5		80	7
REACH 3	53.4	67.9	1.3	0.2	19	2

Ten Highest Measured Peak Flows and Corresponding Predicted Peak Flows

W. GARDENS		REACH 3	
Date	Discharge (cfs)	Date	Discharge (cfs)
Jan. 24, 1978	112	Jan 31., 19788	65
Feb. 23, 1978	308	Feb. 28, 1978	153
March 13, 1978	306	March 14, 1978	161
Aug. 6, 1978	309	no peak	--
Aug. 14, 1978	455	Aug. 19, 1978	222
May 11, 1979	640	May 22, 1979	195
May 26, 1979	120	May 27, 1979	199
Sept. 2, 1979	206	Sept. 7, 1979	287
Sept. 17, 1979	364	Sept. 19, 1979	286
Oct. 3, 1979	588	Oct. 3, 1979	354

Average value of ABS(W. Gardens peak flow - REACH 3 peak flow)
= 166 cfs
SDEV = 125 cfs

Average value of ABS(days between measured and predicted peaks)
= 4.1 days
SDEV = 3.5 days

Soil Storage Analysis

Zone Utilization

The six soil storage zones of HSPF are not fully utilized in the simulation of Florida conditions. Water infiltrates rapidly into the sandy soil and outflow to Cypress Creek is generally lateral outflow from the surficial aquifer. This makes the active groundwater storage zone the most important zone in runoff simulation.

Evaporation in the model involves three of the zones: interception, the lower zone (the root zone), and the active groundwater zone. Storage of water over the course of a day takes place for the most part in the lower and active groundwater zones. Tables 5-8 through 5-10 provide a summary of the involvement of each zone in storage, evaporation and runoff in the simulation on an average daily basis over the water year Oct. 1978 - Sept. 1979.

Simulation of Soil Storage

As the previous analysis shows, the active groundwater and lower zones are the two most active zones in the HSPF simulation. The average daily simulated storage from these two zones and daily shallow well elevations were compared to determine if the behavior of water in the HSPF zones reflects the actual behavior of groundwater in Cypress Creek Watershed.

The water year October 1978 through September 1979 was chosen for analysis because it was the most active of the

Table 5-8

Average Daily Storage by Zone for Six PERLNDs,
Oct. 1978 - Sept. 1979

PERLND		Total Storage PERS in/day	Interception Storage CEPS in/day	Surface Storage SURS in/day	Upper Zone Storage UZS in/day	Interflow Storage IFWS in/day	Lower Zone Storage LZS in/day	Active Groundwater Storage AGWS in/day
6	Avg. Daily	5.88	0.004	0	0.004	0	4.79	1.08
	Range	0.90-12.11	0.0-0.07	0	0.001-0.05	0	0.90-11.08	0.0-6.24
	Percentage	100					81	18
5	Avg. Daily	5.55	0.004	0	0.004	0	4.58	0.97
	Range	0.56-14.06	0.0-0.05	0	0.001-0.08	0	0.56-9.21	0.0-6.24
	Percentage	100					83	17
4	Avg. Daily	6.17	0.002	0	0.002	0	3.38	2.75
	Range	0.31-12.98	0.0-0.10	0	0.001-0.204	0.0-0.007	0.31-9.86	0.0-9.47
	Percentage	100					55	45
3	Avg. Daily	4.36	0.001	0	0.007	0.002	1.79	2.47
	Range	0.01-10.73	0.0-0.10	0	0.001-0.884	0.0-0.508	0.006-7.10	0.0-8.79
	Percentage	100					41	57
2	Avg. Daily	2.67	0.003	0	0.012	0.002	1.81	0.85
	Range	0.02-12.48	0.0-0.050	0.0-0.007	0.001-0.608	0.0-0.081	0.02-4.14	0.0-7.65
	Percentage	100					68	32
1	Avg. Daily	3.06	0.004	0	0.044	0.035	1.95	1.02
	Range	0.006-12.15	0.0-0.068	0.0-0.001	0.001-0.820	0.0-1.170	0.005-10.91	0.0-6.70
	Percentage	100				1	64	33

Table 5-9

Average Daily Evapotranspiration by Zone for Six PERLNDs, Oct. 1978 - Sept. 1979

PERLND		Total ET, TAET in/day	Interception ET, CEPE in/day	Upper Zone ET, UZET in/day	Lower Zone ET, LZET in/day	Active GW ET, AGWET in/day	Baseflow ET, BASET in/day
6	Avg. Daily	0.114	0.033	0	0.052	0.029	---
	Range	0.022-0.231	0.0-0.150	0.0-0.002	0.0-0.157	0.0-0.143	---
	Percentage	100	29		46	25	---
5	Avg. Daily	0.124	0.034	0.001	0.051	0.039	---
	Range	0.057-0.232	0.0-0.150	0.0-0.023	0.0-0.171	0.0-0.143	---
	Percentage	100	27		41	31	---
4	Avg. Daily	0.136	0.029	0.002	0.033	0.037	0.036
	Range	0.036-0.234	0.0-0.150	0.0-0.058	0.0-0.180	0.0-0.121	0.0-0.084
	Percentage	100	21		24	27	26
3	Avg. Daily	0.139	0.030	0.006	0.033	0.037	0.034
	Range	0.0-0.239	0.0-0.150	0.0-0.168	0.0-0.235	0.0-0.140	0.0-0.077
	Percentage	100	22	4	24	27	24
2	Avg. Daily	0.097	0.033	0.002	0.038	0.023	---
	Range	0.0-0.230	0.0-0.150	0.0-0.164	0.0-0.151	0.0-0.143	---
	Percentage	100	34	2	39	24	---
1	Avg. Daily	0.112	0.027	0.007	0.045	0.027	0.007
	Range	0.0-0.239	0.0-0.150	0.0-0.180	0.0-0.236	0.0-0.134	0.0-0.024
	Percentage	100	24	6	40	24	6

Table 5-10

Average Daily Runoff and Deep Percolation by Zone
for Six PERLNDs, Oct. 1978 - Sept. 1979

PERLND		Total Runoff, PERO in/day	Surface Outflow, SURO in/day	Interflow IFWO in/day	Active GW Outflow, AGWO in/day	Deep Percolation, IGWI in/day
6	Avg. Daily	0.014	0	0	0.014	0.025
	Range	0.0-0.094	0	0	0.0-0.094	0.0-1.945
	Percentage	100			100	
5	Avg. Daily	0.016	0	0	0.016	0.021
	Range	0.0-0.095	0	0	0.0-0.095	0.0-0.482
	Percentage	100			100	
4	Avg. Daily	0.006	0	0	0.006	0.022
	Range	0.0-0.076	0	0	0.0-0.076	0.0-0.369
	Percentage	100			100	
3	Avg. Daily	0.005	0	0.002	0.003	0.021
	Range	0.0-0.066	0	0.0-0.053	0.0-0.066	0.0-0.684
	Percentage	100		40	60	
2	Avg. Daily	0.047	0	0	0.046	0.020
	Range	0.0-0.432	0	0.0-0.009	0.0-0.423	0.0-1.923
	Percentage	100			99	
1	Avg. Daily	0.053	0	0.004	0.049	---
	Range	0.0-0.356	0	0.0-0.123	0.0-0.356	---
	Percentage	100		8	92	

three water years of calibration. The average daily storages were obtained for the lower and active groundwater zones of each PERLND; these averages were divided by the average soil porosity of 0.11 to obtain total depth of storage. The well elevations used were daily data from shallow well 4-S, located approximately 1.5 miles east of the San Antonio stream gage near state road 52. All analyses were conducted using Statistical Analysis Systems (SAS) on University of Florida computers.

Figures 5-10 through 5-15 plot the three time series for each PERLND. The well elevations, ELEV, are in inches of water above 64 feet msl. LZS represents inches of lower zone storage and AGWS represents inches of active groundwater storage.

After plotting, correlations were run using the three time series for each PERLND. All correlation coefficients were reported to have significance above the 95% confidence limit. This high significance level could be due to a serial correlation effect. To determine the extent of serial correlation between two time series with an equal number of observations, n, the effective number of data points, n_e, is given by (Kite, 1977):

$$n_e = n \frac{(1-r_x r_y)}{(1+r_x r_y)} \qquad (5\text{-}1)$$

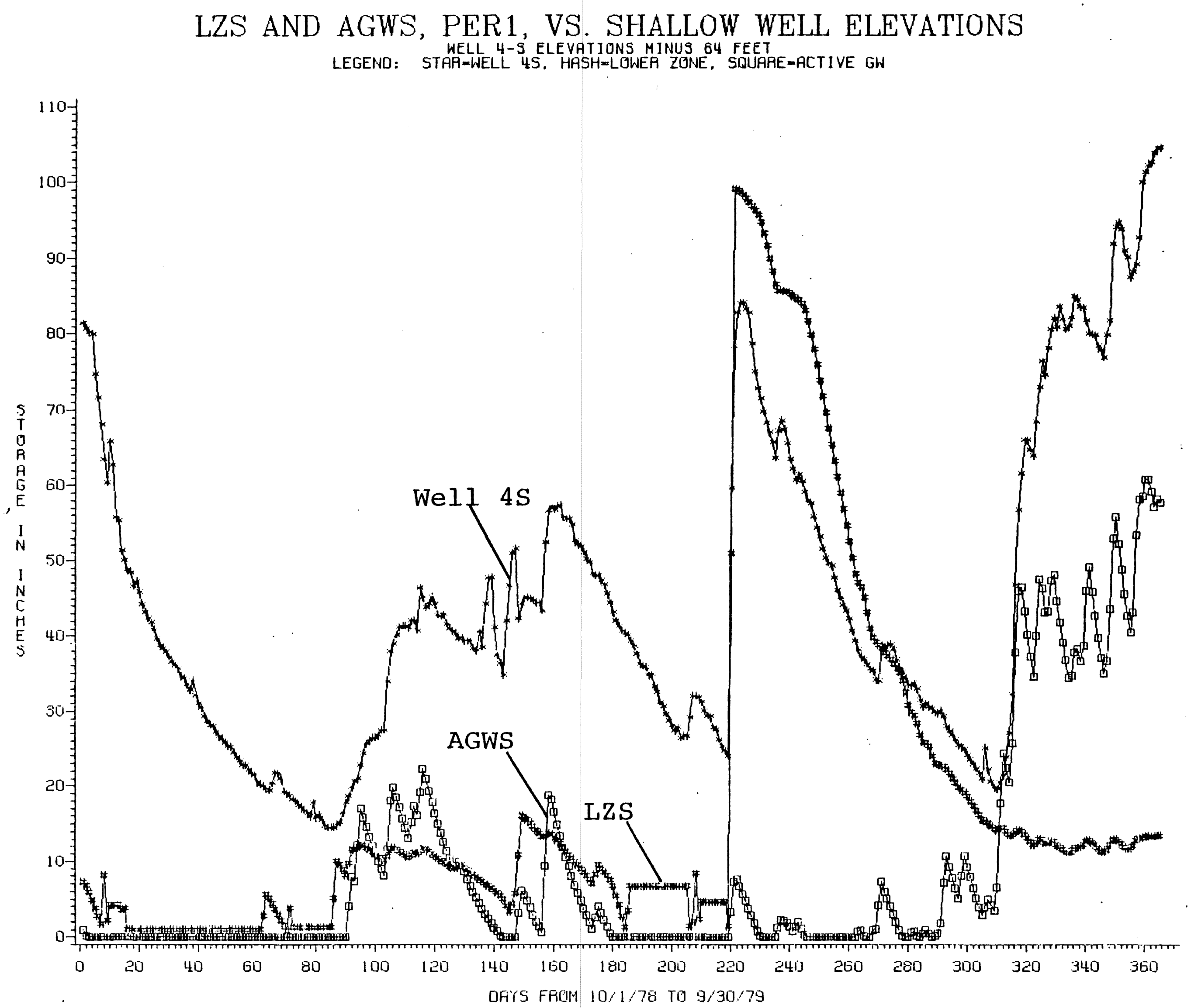

Figure 5-10 Comparison of Soil Storages and Shallow Well Elevations, PERLND 1

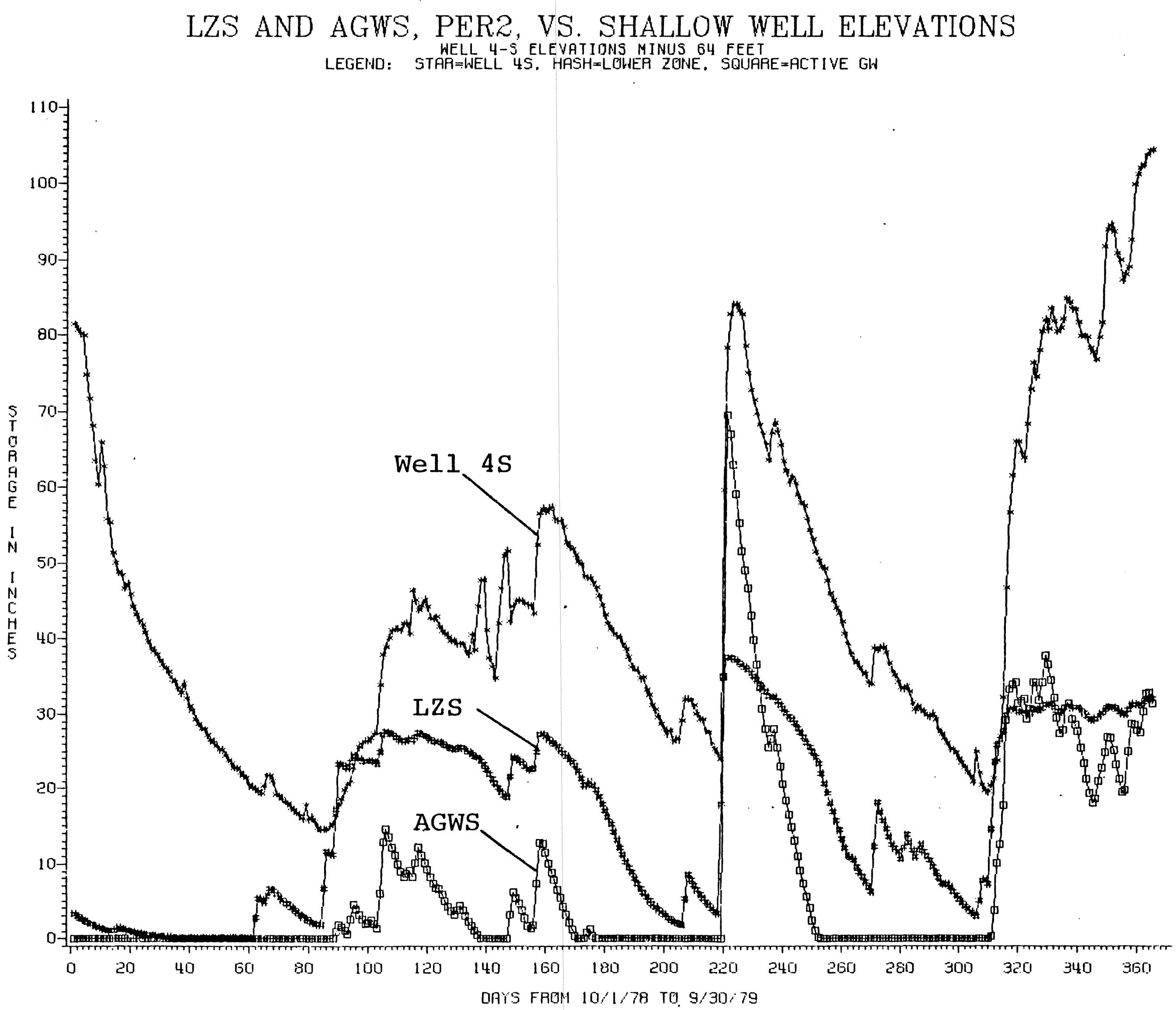

Figure 5-11 Comparison of Soil Storages and Shallow Well Elevations, PERLND 2

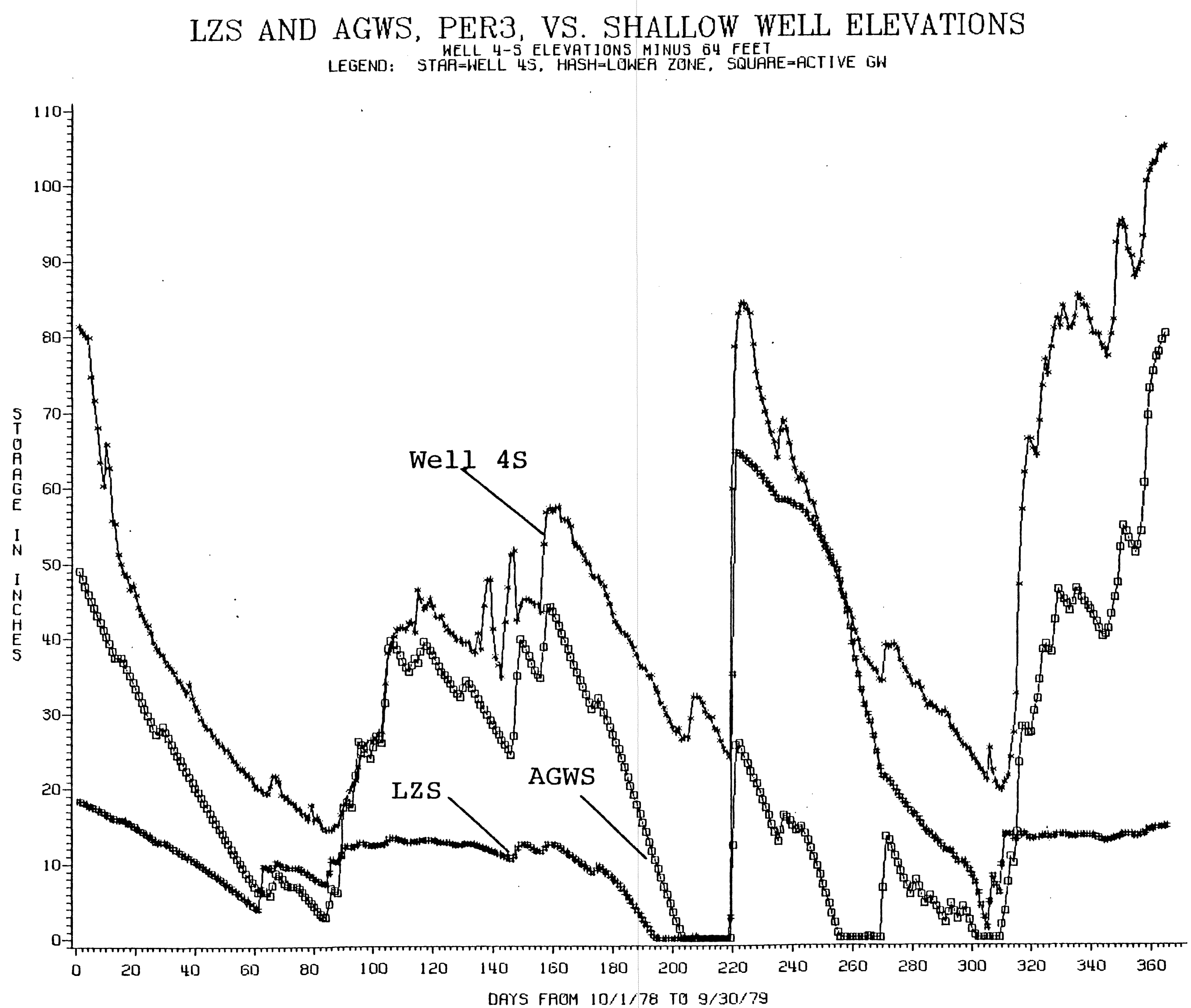

Figure 5-12 Comparison of Soil Storages and Shallow Well Elevations, PERLND 3

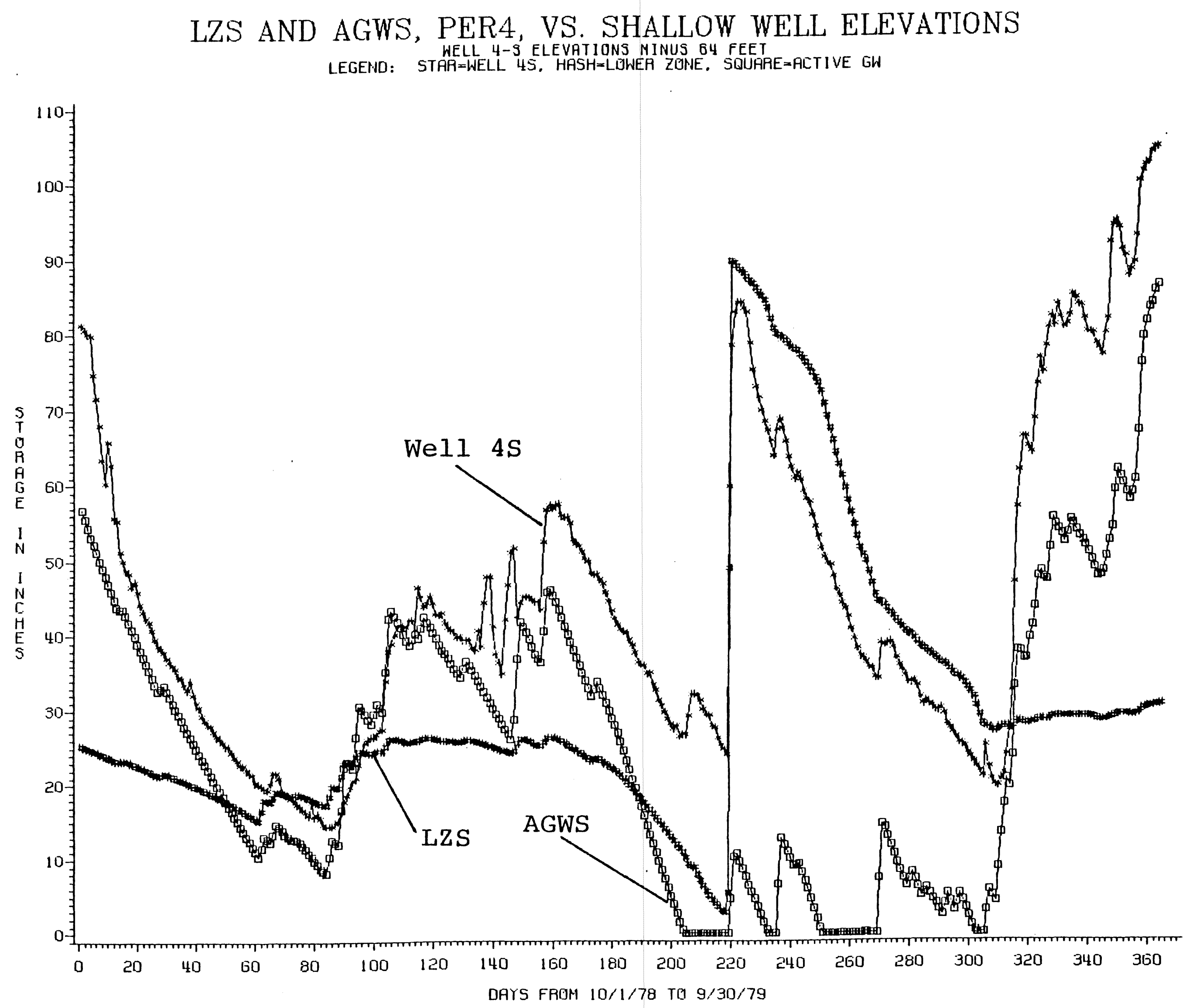

Figure 5-13 Comparison of Soil Storages and Shallow Well Elevations, PERLND 4

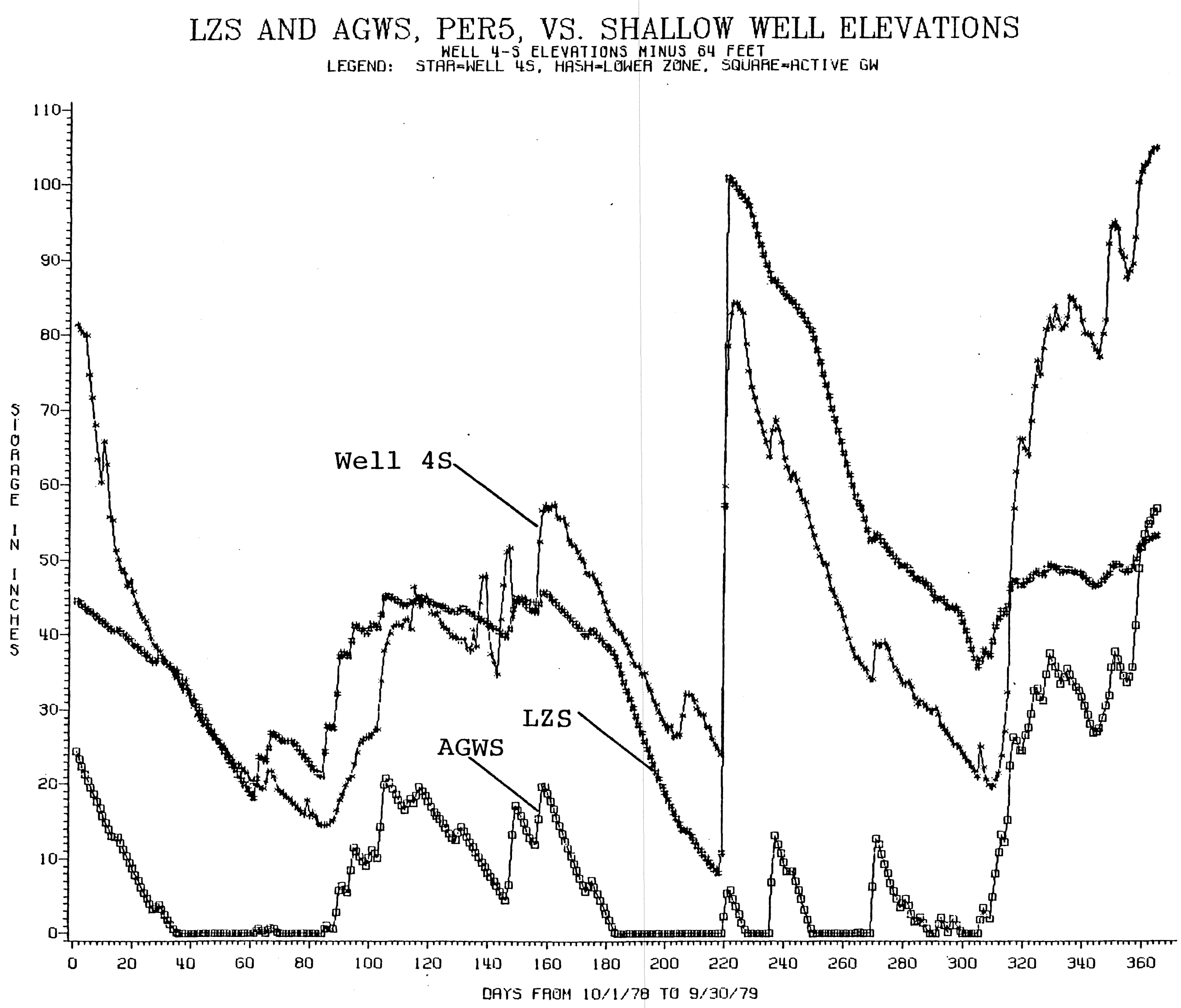

Figure 5-14 Comparison of Soil Storages and Shallow Well Elevations, PERLND 5

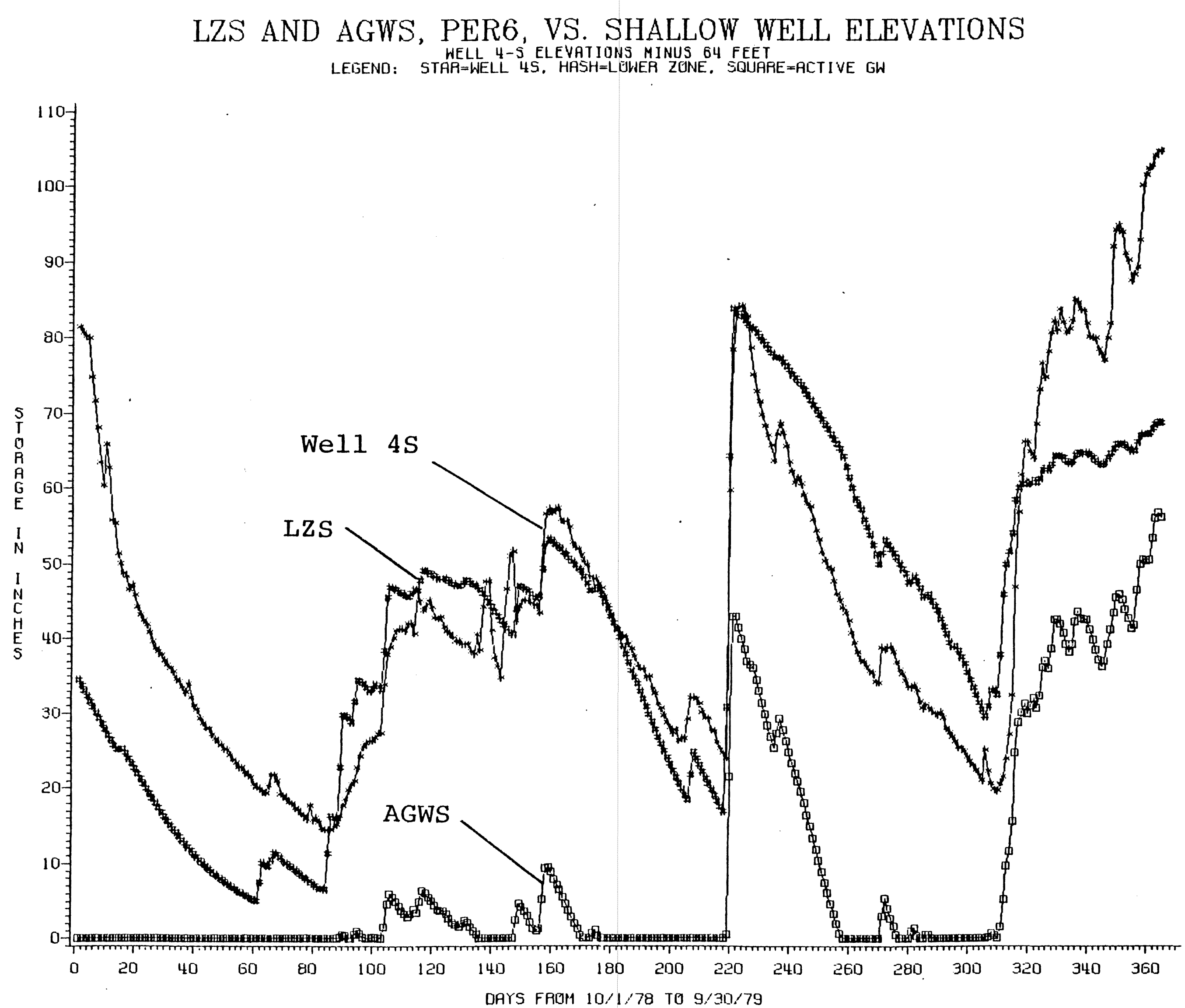

Figure 5-15 Comparison of Soil Storages and Shallow Well Elevations, PERLND 6

where

r_x = the correlation coefficient of time series x against itself, lagged one day, and
r_y = the correlation coefficient of time series y against itself, lagged one day.

Using the value n_e thus computed, the t-test for significance is performed whereby a calculated value of t is compared to t at n_e-2. The value t_{n_e-2} is taken from tables.

$$t_{calc} = R\,[(n_e-2)/(1-R^2)]^{1/2} \qquad (5\text{-}2)$$

where

t_{calc} = the calculated t value for comparison,
R = the correlation coefficient between time series x and y, and
n_e = effective value of n.

If t_{calc} is greater than t_{n_e-2} then the two time series do show significant correlation. If the value of t_{calc} is less than t_{n_e-2} then the two time series being compared are not significantly correlated, and any correlation previously shown is interpreted as being due to serial correlation.

The results of the significance test for well elevation (ELEV), lower zone storage (LZS) and active groundwater storage (AGWS) are presented in Table 5-11. The t values tabulated are those for a 95% confidence interval. Five of the six PERLNDs show a significant correlation between the behavior of the HSPF active groundwater zone and the actual groundwater behavior represented by the shallow well elevation data. This suggests that soil storage simulation using HSPF is a good model of physical behavior in Florida

Table 5-11

Significance Test for Correlation between
Soil Storages and Shallow Well Elevations

PERLND	n	Lag-1 coef., r		Correlation coef., R		n_e	t_{n_e-2}	t_{calc}	Significance
6	365	ELEV	0.975618	LZS vs ELEV	0.74325	7	2.571	2.484	no
		LZS	0.990326	AGWS vs ELEV	0.85564	9	2.365	4.374	yes
		AGWS	0.978422	LZS vs AGWS	0.69595	6	2.776	1.938	no
5	365	ELEV	0.975618	LZS vs ELEV	0.57813	8	2.447	1.736	no
		LZS	0.981754	AGWS vs ELEV	0.77593	10	2.306	3.479	yes
		AGWS	0.970358	LZS vs AGWS	0.17679	9	2.365	1.277	no
4	365	ELEV	0.975618	LZS vs ELEV	0.39979	8	2.447	1.068	no
		LZS	0.985240	AGWS vs ELEV	0.64327	9	2.365	2.223	no
		AGWS	0.978267	LZS vs AGWS	-0.27988	7	2.571	-0.652	no
3	365	ELEV	0.975618	LZS vs ELEV	0.41307	7	2.571	1.014	no
		LZS	0.987428	AGWS vs ELEV	0.74530	10	2.306	3.162	yes
		AGWS	0.974972	LZS vs AGWS	-0.05361	7	2.571	-0.120	no
2	365	ELEV	0.975618	LZS vs ELEV	0.65651	7	2.571	1.946	no
		LZS	0.987620	AGWS vs ELEV	0.75526	9	2.365	3.049	yes
		AGWS	0.977019	LZS vs AGWS	0.73793	7	2.571	2.445	no
1	365	ELEV	0.975618	LZS vs ELEV	0.33050	7	2.571	0.858	no
		LZS	0.985901	AGWS vs ELEV	0.67693	10	2.306	2.601	yes
		AGWS	0.969982	LZS vs AGWS	-0.10539	9	2.365	-0.280	no

watersheds under normal conditions. In the absence of good streamflow data, well elevation data could be used as an additional means of calibrating an HSPF hydrologic model.

Verification

Testing the Model

Water years 1981 and 1982 were chosen for verification of the model. Two factors influenced this choice. The first concerned the availability of rainfall data. Complete rainfall records for the three gages used during calibration exist only for the years 1977 through 1983. At least two continuous years of data were needed for verification. The second reason was the occurrence of a severe drought during 1981. Simulation of the period Oct. 1980 through Sept. 1982 would provide a severe test of the model. The parameter values input were the same as those listed in Table 3-10 with the exception of the initial state storages. The state storages used were values output by the model for a run ending Sept. 30, 1980. The initial stream volumes were calculated using Cypress Creek stage data for the same data and equations 3-2 through 3-5. These values are listed in Table 5-12.

Streamflow records were available from the San Antonio and Worthington Gardens gages for both years of verification, but at Drexel only the first twelve months of data were recorded, from Oct. 1980 to Sept. 1981. The

Table 5-12

Initial State Storages Used in Verification

	CEPS in	SURS in	UZS in	IFWS in	LZS in	AGWS in
PERLND						
1	0	0	0.001	0	0.011	0
2	0	0	0.001	0	1.134	0
3	0	0	0.001	0	2.530	1.578
4	0	0	0.001	0	1.740	1.265
5	0	0	0.001	0	3.120	0.006
6	0	0	0.001	0	3.476	0

REACH	Volume ac-ft
1	0.0
2	20.4
3	309.4

results of the verification are given in Tables 5-13 through 5-15. Scattergraphs, hydrographs, and double mass curves are shown for REACHes 1 and 3 in Figures 5-16 through 5-21. Graphical comparisons for REACH 2 and Drexel flows are not shown; of the twelve data points available for plotting, eight were zero flows.

During the verification period, the model again proved successful in predicting total and average flow volumes. At San Antonio the relative error for mean flow was 0.7%; for Worthington Gardens the relative error was 4.1%. The standard deviations for REACHes 1 and 3 were again significantly less than that of the respective measured data. Over-prediction of flow in REACH 2 was caused by the high flows predicted after the drought, a problem in all three REACHes.

Zero or low flows were predicted for all three REACHes during the first eight months of verification. A discrepancy occurs beginning in June of 1981 with the return of rainfall to the basin. The model predicts very high flows in Cypress Creek from June to October of 1981, following rainfall ranging from 4 to 13 inches per month during the months of June, July, August and September. High flows would be expected with this level of rainfall if the watershed were not recovering from a severe drought.

Many attempts were made to reduce the high flows; parameter values were changed, the contributing area was

Table 5-13

Verification Values for REACH 1, Oct. 1980 - Sept. 1982

	Descriptive Statistics, Flow in Acre-ft				
	Sum	Mean	SDEV	CV	RE
Measured	24208	1009	1899	1.9	
Simulated	24377	1016	1279	1.3	0.7%

Water Year	Month	Measured Flow acre-ft	Simulated Flow acre-ft
1981	Oct.	16.9	34.2
	Nov.	0	18.4
	Dec.	0	3.9
	Jan.	0	0.2
	Feb.	5.3	2.8
	March	0	0.7
	April	0	0
	May	0	0
	June	0	132.3
	July	0	501.2
	Aug.	35.3	2272.9
	Sept.	421.5	3451.9
		479.0	6418.5
1982	Oct.	97.6	923.0
	Nov.	0	54.0
	Dec.	133.4	211.8
	Jan.	2150.1	2388.4
	Feb.	844.2	1323.4
	March	1914.8	1086.2
	April	548.2	266.4
	May	175.2	56.8
	June	5218.5	1878.2
	July	1810.9	3300.3
	Aug.	3348.1	3061.8
	Sept.	7487.6	3408.6
		23,728.6	17,958.9

Table 5-14

Verification Values for REACH 2, Oct. 1980 - Sept. 1982

Water Year	Month	Measured Flow acre-ft	Simulated Flow acre-ft
1981	Oct.	0	0
	Nov.	0	0
	Dec.	0	0
	Jan.	0	0
	Feb.	0	0
	March	2.5	0
	April	0	0
	May	0	0
	June	0	0
	July	0	331.2
	Aug.	39.1	2308.0
	Sept.	341.2	4395.0
		382.8	7034.2
1982	Oct.	--	1359.2
	Nov.	--	77.3
	Dec.	--	87.8
	Jan.	--	2351.2
	Feb.	--	1322.7
	March	--	1055.1
	April	--	294.2
	May	--	0
	June	--	1702.0
	July	--	4124.5
	Aug.	--	4002.2
	Sept.	--	4743.5
			21,119.7

Table 5-15

Verification Values for REACH 3, Oct. 1980 - Sept. 1982

	Descriptive Statistics, Flow in acre-ft				
	Sum	Mean	SDEV	CV	RE
Measured	72755	3031	4832	1.6	
Simulated	69802	2908	3690	1.3	4.1%

Water Year	Month	Measured Flow acre-ft	Simulated Flow acre-ft
1981	Oct.	10.2	0.6
	Nov.	13.7	0
	Dev.	34.8	0
	Jan.	13.9	0
	Feb.	593.7	0
	March	482.0	0
	April	108.5	0
	May	0	0
	June	1.0	24.1
	July	0.3	1022.6
	Aug.	3113.7	5907.7
	Sept.	4558.0	11482.5
		8,929.8	18,437.5
1982	Oct.	461.5	4391.9
	Nov.	20.2	685.2
	Dec.	175.1	221.3
	Jan.	4562.0	5963.1
	Feb.	2054.9	3927.1
	March	5111.4	2785.3
	April	1470.3	1265.9
	May	130.8	280.7
	June	14255.2	5817.9
	July	8528.9	11067.1
	Aug.	9588.0	7570.7
	Sept.	17466.4	7387.6
		63,824.7	51,363.9

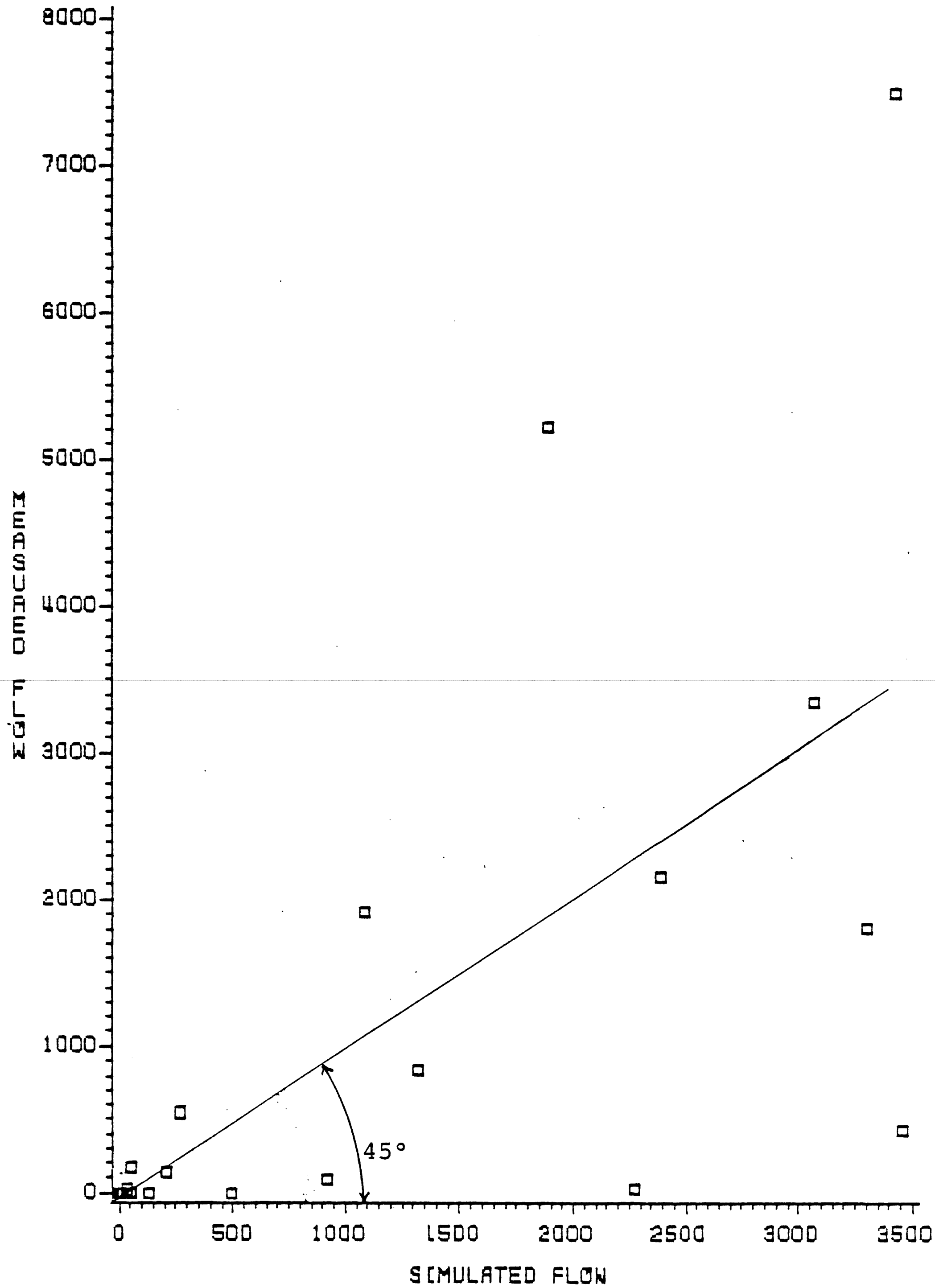

Figure 5-16 Scattergraph of Measured and Simulated Flows, REACH 1, Volumes in Acre-ft, Oct. 1980 - Sept. 1982

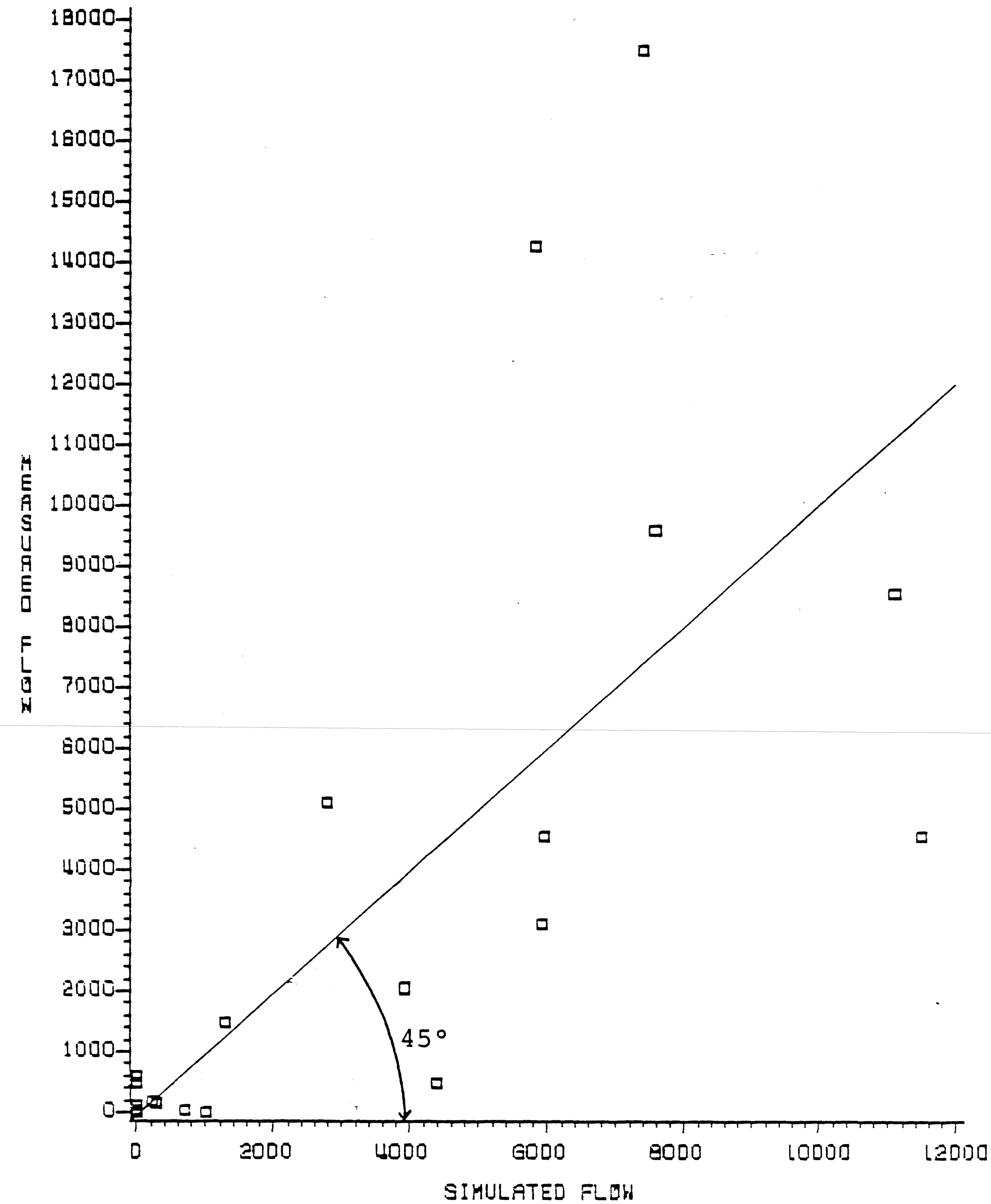

Figure 5-17 Scattergraph of Measured and Simulated Flows, REACH 3, Volumes in Acre-ft, Oct. 1980 - Sept. 1982

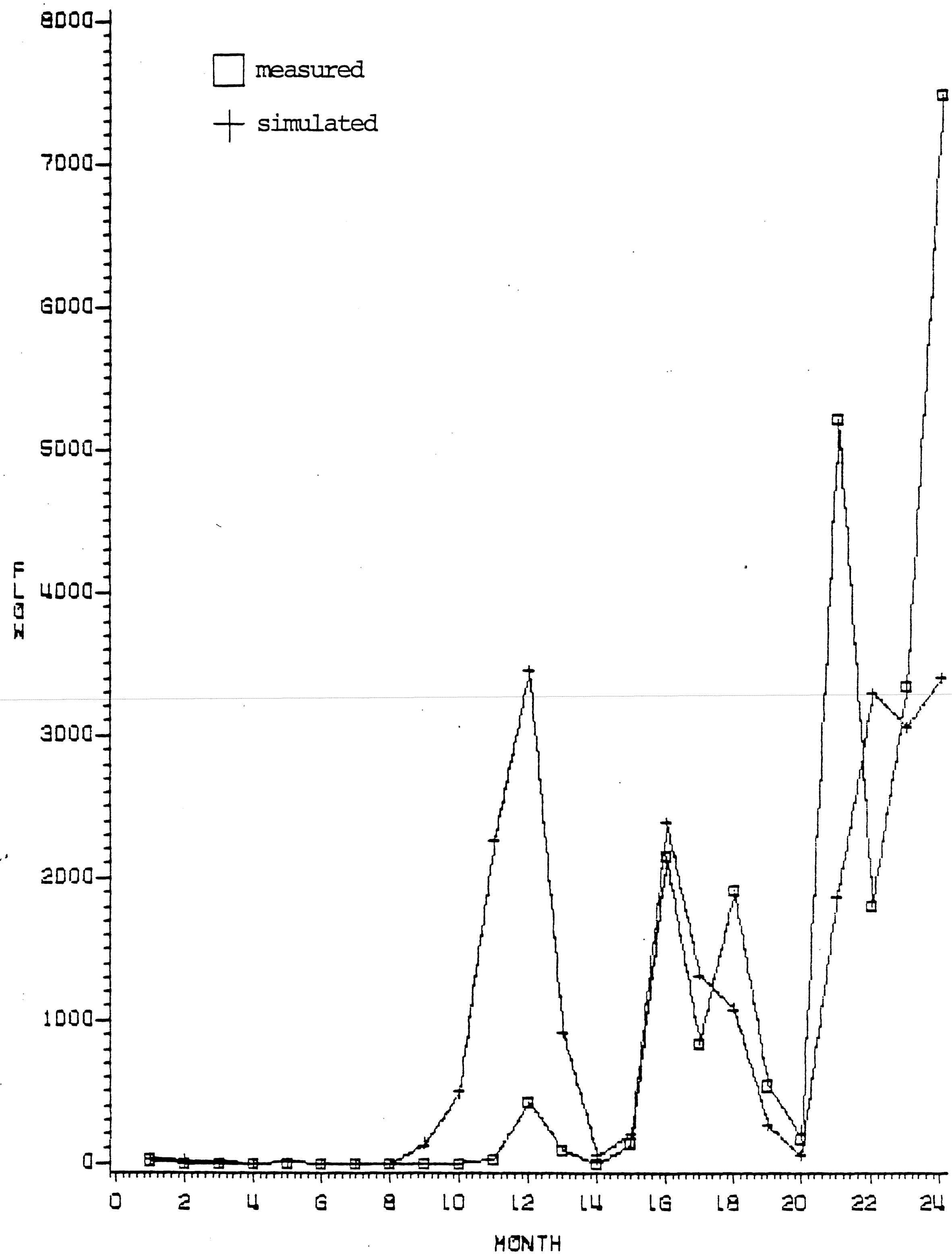

Figure 5-18 Hydrograph of Measured and Simulated Flows, REACH 1, Volumes in Acre-ft, Oct. 1980 - Sept. 1982

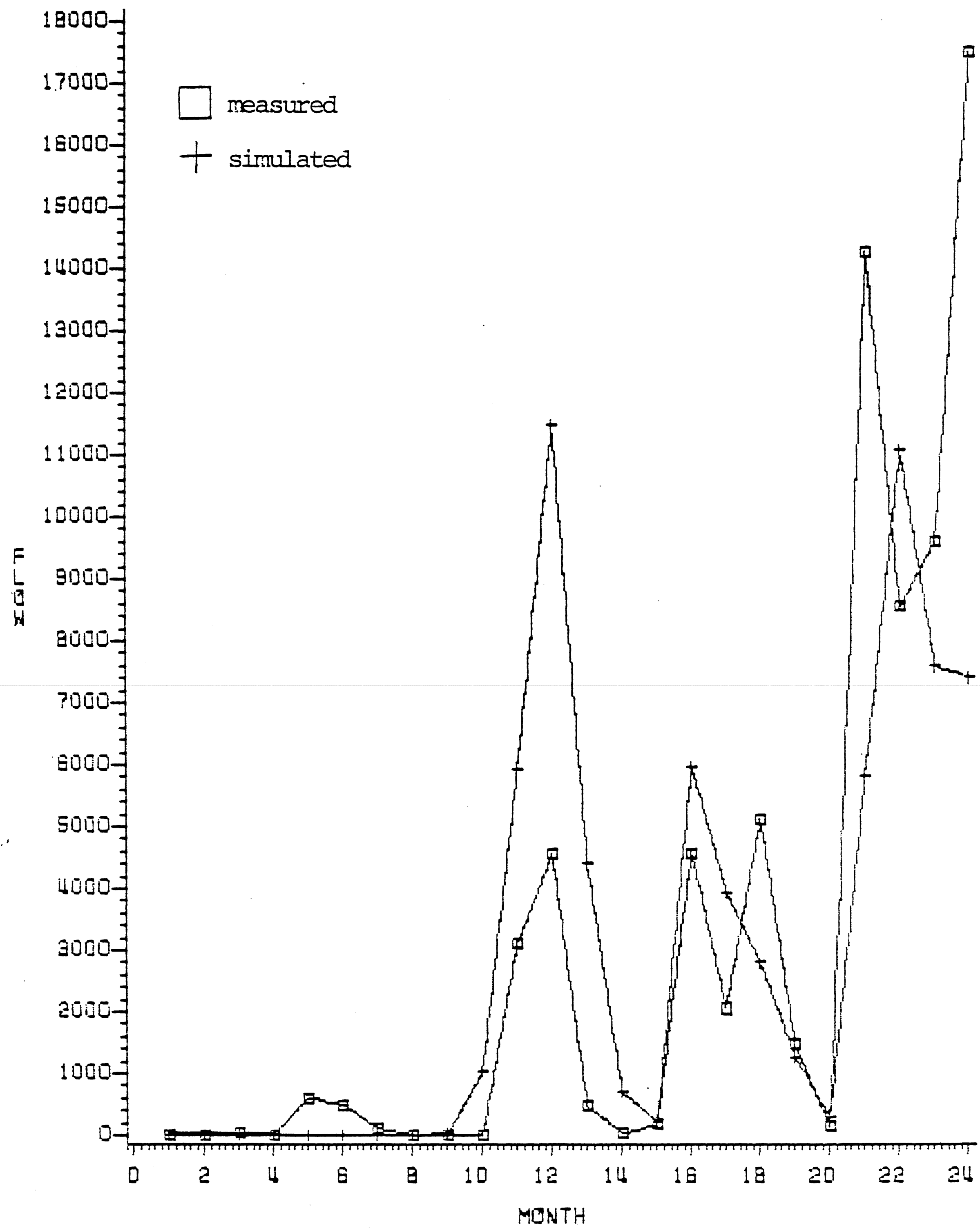

Figure 5-19 Hydrograph of Measured and Simulated Flows, REACH3, Volumes in Acre-ft, Oct. 1980 - Sept. 1982

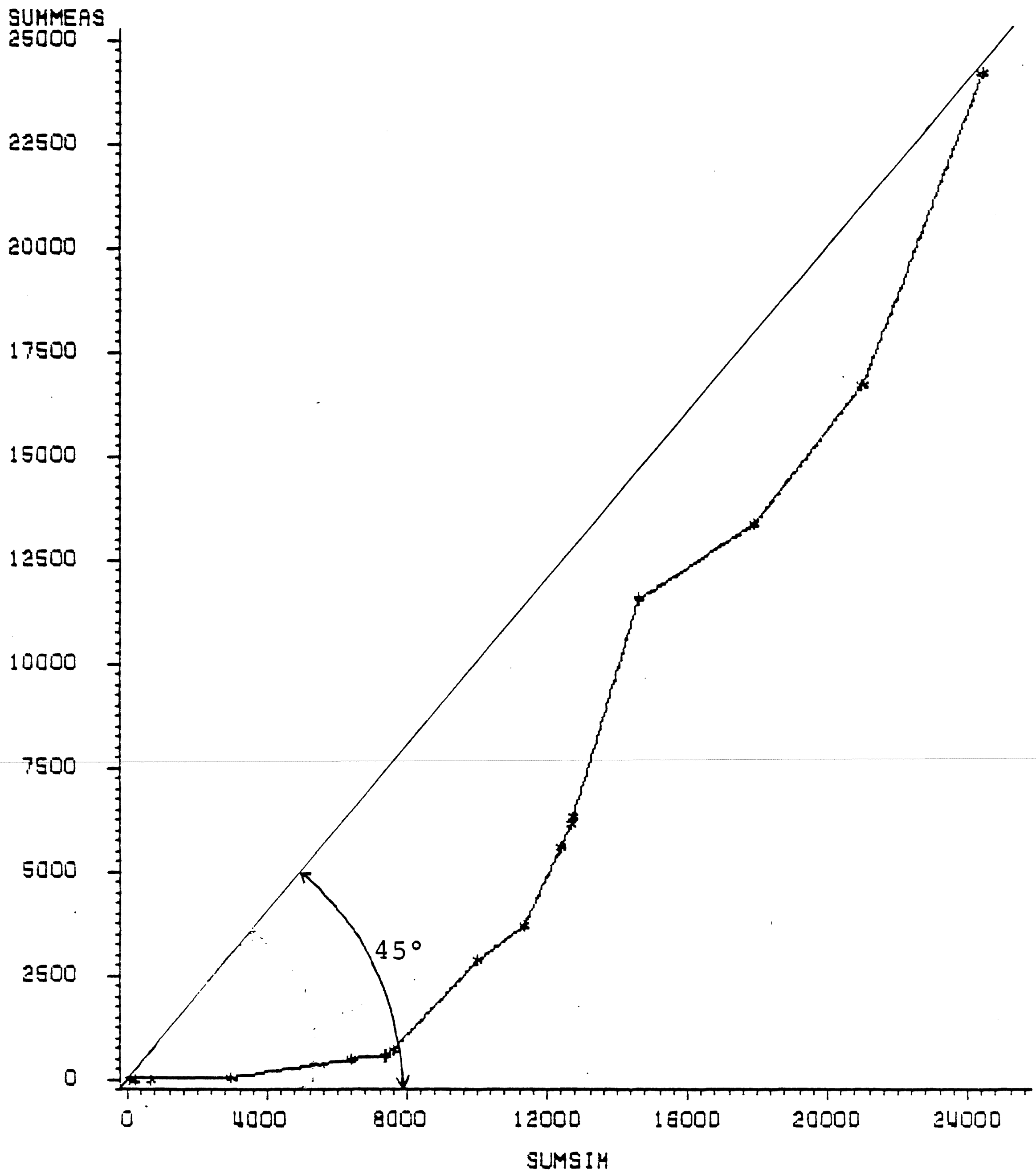

Figure 5-20 Double Mass Curve of Measured and Simulated Flows, REACH 1, Volumes in Acre-ft, Oct. 1980 - Sept. 1982

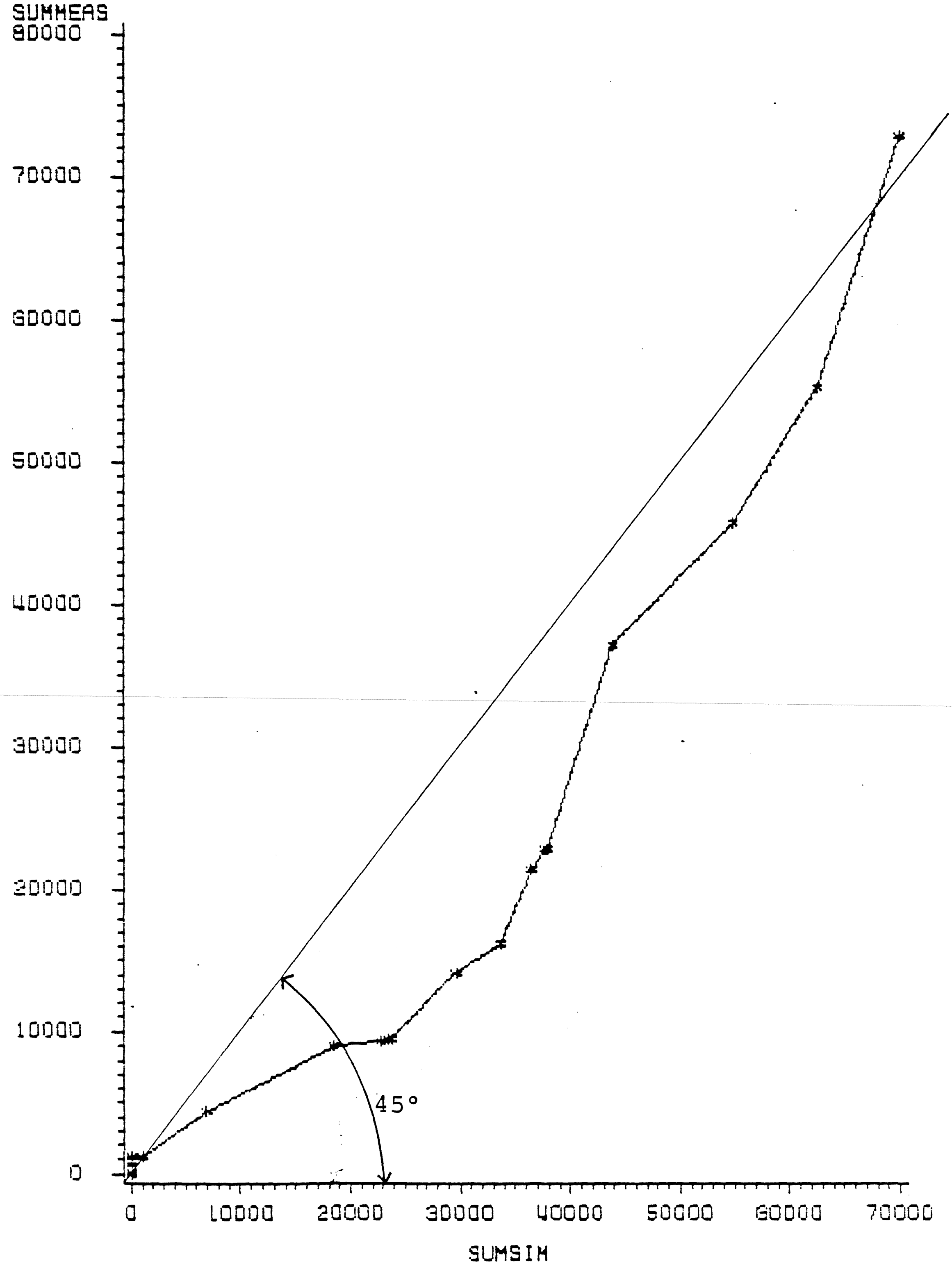

Figure 5-21 Double Mass Curve of Measured and Simulated Flows, REACH 3, Volumes in Acre-ft, Oct. 1980 - Sept. 1982

reduced, and the volume-discharge relationships in the F-Tables were adjusted. None of the remedial efforts produced a significant effect on the level of post-drought flow.

The physical behavior of the watershed which the model was not successfully simulating was the depletion of the surficial aquifer during successive dry months. If rainfall is not available to replenish the surficial aquifer, evapotranspiration and leakance to deep groundwater can reduce the water table level until it drops below the level of the stream bed. When rainfall occurs after such a depletion, water must fill the surficial storage to the threshold level of the stream bed before runoff will be observed.

After consultation with Anderson-Nichols & Co., who currently maintain the HSPF model for the EPA, it was clear that HSPF alone could not simulate this depletion of the surficial aquifer. The active groundwater storage zone of the model does not recognize a threshold level of storage below which outflow will not occur. Any water entering the active groundwater storage zone must eventually leave as either evapotranspiration or outflow to a stream; no minimum level of storage is maintained.

For simulation of watershed behavior during a drought, two options are suggested to supplement HSPF. The first option is to output the active groundwater storage and outflow time series, AGWS and AGWO, to a separate computer file. These two time series could then be manipulated using simple algorithms which would subtract water for threshold storage and recalculate the outflow produced by groundwater recession. The resulting time series could then be input to the model for continuation of simulation.

An alternative is the use of a groundwater model to predict the behavior of the surficial aquifer during droughts. Simulation of streamflow using HSPF could be continued at that point in time when the groundwater model predicts that the level of the surficial aquifer has risen to the threshold level necessary for runoff.

Table 5-16 compares streamflow at San Antonio with well elevations for the period of verification. The well used is shallow well 4-S near the San Antonio stream gage. During months of little or no streamflow, the average well elevation is significantly below the level reached during months of normal to high flow. The combined area of PERLNDs 5 and 6 which produces runoff is 30,336 acres. The maximum and minimum average well elevations at which an average of zero flow occurred are 65.8 feet and 63.6 feet respectively. Using an average soil porosity of 0.11 inch per inch for the basin, an idea of the threshold volume of surficial aquifer storage for REACH 1 can be obtained:

$$30{,}336 \text{ acres} * (65.8 - 63.6)\text{ft} * 0.11 = 6341 \text{ acre-ft.} \quad (5\text{-}3)$$

The over-prediction of flow for REACH 1 for the first five

Table 5-16

Well 4-S Elevation and San Antonio Streamflow Comparison

Well 4-S Statistics, 1977 - 1982				ft msl
n	Mean Elev.	SDEV	Min. Elev.	Max. Elev.
1493	68.6	2.5	63.4	74.6

Comparison, Oct. 1980 - Sept. 1982

Month	Avg. Flow cfs	Avg. Elev. ft msl
Oct. 1980	0.27	66.9
Nov.	0	65.8
Dec.	0	65.0
Jan. 1981	0	63.9
Feb.	0.10	63.5
Mar.	0	63.6
Apr.	0	*
May	0	*
June	0	*
July	0	*
Aug.	0.57	64.3
Sept.	70.8	65.8
Oct.	1.59	64.7
Nov.	0	64.7
Dec.	2.17	64.1
Jan. 1982	35.0	67.5
Feb.	15.2	67.8
Mar.	31.1	69.0
Apr.	9.21	68.5
May	2.85	66.8
June	87.7	70.2
July	29.5	71.2
Aug.	54.5	71.4
Sept.	126	72.2

* indicates missing data

months after the drought, June through October 1980, was 6,824 acre-feet.

Assessing Performance

HSPF was originally designed and tested using streams in areas where flow is continuous, not the intermittant flow observed in Cypress Creek over the last decade. Despite the performance of the model when severe drought conditions were encountered, however, the model predicted total and average monthly flow volumes with a relative error of 4.1 percent or less, for the two REACHes where data permitted comparison. This is the long-term behavior this study sought to simulate; the goodness of fit criteria described in Chapter IV have been satisfied. Reservations are held regarding monthly flow prediction in the short-term, especially following successive months of zero flow. It is believed this model of Cypress Creek watershed can be used to simulate trends or averages for any component of the water budget over the long-term. For successful short-term prediction, calibration using a smaller time step is recommended. An additional suggestion for improving the calibration is discussed in Chapter VI.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Objectives

Recent developments and droughts in Cypress Creek Watershed are of concern to the Southwest Water Management District. This study is one part of an investigation conducted by the Water Resources Research Center of the University of Florida to determine what effects if any such developments and hydrologic conditions are having on the long-term behavior of runoff, deep percolation and other components of the water budget in CCW. The purpose of this study was to simulate the surface hydrology of the basin using HSPF, to develop appropriate criteria for judging the goodness of fit of such a model, and to use these criteria to assess the performance of the calibrated model. Prior to the accomplishment of these tasks, all relevant data concerning the watershed had to be amassed and analyzed.

The Study Area

Cypress Creek Watershed is 117 square miles of sandy ridges, flatwoods, hammocks, and swamps. Cypress Creek itself is a stream of intermittant flow which expands along most of its course into Big Cypress Swamp. A wellfield located in the watershed and operated by the West Coast Regional Water Supply Authority pumps a maximum of 40 mgd daily and an average of 30 mgd annually from thirteen wells. Local landowners are responsible for extensive surface drainage development in the basin. The watershed contains areas of recharge to the deep Floridan aquifer and areas where discharge from the Floridan takes place.

Hydrologic Simulation

Hydrological Simulation Program-Fortran (HSPF) was the model used for continuous simulation of the surface hydrology of the watershed. In HSPF the water balance is calculated using the inflows, outflows, and storages of six storage zones. Cypress Creek Watershed was divided into six subcatchments draining into three reaches. The area contributing flow to each reach was taken from USGS data for Cypress Creek. During the three-year calibration period, predicted monthly streamflow for each reach was compared to measured streamflow. When possible, parameter values were set using actual data from the watershed. The simulation proved most sensitive to changes in the active groundwater recession parameter, AGWRC, which was set at values determined by calibration.

Goodness of Fit

The calibrated model is to be used to predict changes over the long-term in the behavior of such components of the water budget as runoff and percolation to deep groundwater. Therefore, goodness of fit criteria were needed which would favor correct prediction of total and average flow rather than high or low extreme flows. The criteria should also be readily understandable and non-controversial. For these reasons, simple statistical measures and graphical comparisons were chosen to analyze the performance of the model during calibration.

Model Performance

The weighted average annual values predicted for the water budget components over the calibration period were all within the estimated ranges. The mean monthly flow predicted for each reach showed a relative error of less than 2 percent. The variability of the modeled flows was less than that of the actual flows.

An analysis of the activity in the six storage zones of HSPF proved the active groundwater and lower zones to be the two most active zones during simulation. In a comparison of the storage volume fluctuation in these two zones to actual shallow well elevations, the activity of the groundwater zone was significantly correlated to the measured fluctuations of the surficial aquifer.

The verification of the model was done for a two year period which included nine months of severe drought. For the months following the drought the model predicted flows much greater than measured flows. After consultation with Anderson-Nichols & Co., who maintain HSPF for the EPA, it was decided that HSPF has no capacity to simulate the restoration of a threshold storage volume to the surfical aquifer needed before runoff can commence. In spite of this problem with the model, the mean monthly flow over the period of verification was predicted with a 4.1 percent or less relative error for the two reaches where measured flow was available for comparison.

Suggestions for Further Research

Improving the Calibration

The best recommendation for improving the calibration of this HSPF model of Cypress Creek Watershed is to ascertain the actual area contributing discharge at each stream gaging station. A case was made in Chapter III for regarding a portion of the northwest subcatchment as non-contributing area based on lake storage, surface elevations, and the presence of a roadbed, as shown on a USGS topographic map of the area.

It is believed that similar arguments could be made for considering as non-contributing area much of the land located east of I-75 in the watershed, if fieldwork were done to assess actual groundwater flow patterns.

If the area projected as contributing flow were too great, the active groundwater recession rate (AGWRC) must be set at values approaching one to prevent flow from leaving active groundwater storage too quickly. A higher recession constant would result in less variation in predicted monthly flow over time, thereby affecting model performance in simulation of actual high and low flows. If less area were contributing, the same total flow volume could be simulated with greater flow variation, using a smaller value for the recession rate.

<u>Linkage with a Groundwater Model</u>

Simulation of a Florida watershed with HSPF offers interesting possibilities for linkage to a groundwater model of the watershed. The HSPF time series of leakance to deep groundwater, IGWI, could be output in a time-step suitable for use as input leakance values to a groundwater model. Conversely, this time series could be generated externally by the groundwater model and input into HSPF to observe any alterations in the overall water balance.

For simulation of the effects of deep groundwater on the surfical aquifer, a groundwater model might be used to calculate some percentage of the daily pumpage acting to drawdown active groundwater storage. HSPF can accept negative flows through the time series AGWLI (active groundwater lateral inflow). Negative flows computed by the groundwater model could reduce active groundwater storage in HSPF via this external time series.

Another linkage was suggested in Chapter V: the use of a groundwater model to simulate surfical aquifer behavior during droughts. After the drought the groundwater model would predict at what time the surfical aquifer had returned to a threshold storage volume, and streamflow flow simulation by HSPF could then be continued.

A Version of HSPF for Florida

In the zone utilization analysis of Chapter V, the lower zone storage and active groundwater storage proved to be the most important soil zones for storage, outflow to streams, and evapotranspiration. Interception storage was a significant contributor of ET. Figure 6-1 shows a suggested version of the HSPF pathways in section PWATER which could be the basis for a simplified model for the simulation of hydrologic conditions in many Florida watersheds. (Actual pathways are shown in Figure 3-4). If algorithms were added requiring a threshold storage volume in the active groundwater zone before outflow could take place, hydrologic behavior could be simulated even during Florida's cyclic dry periods.

An Expert System for HSPF

As discussed in Chapter IV, hydrology has entered the realm of expert systems. An expert system is a computer

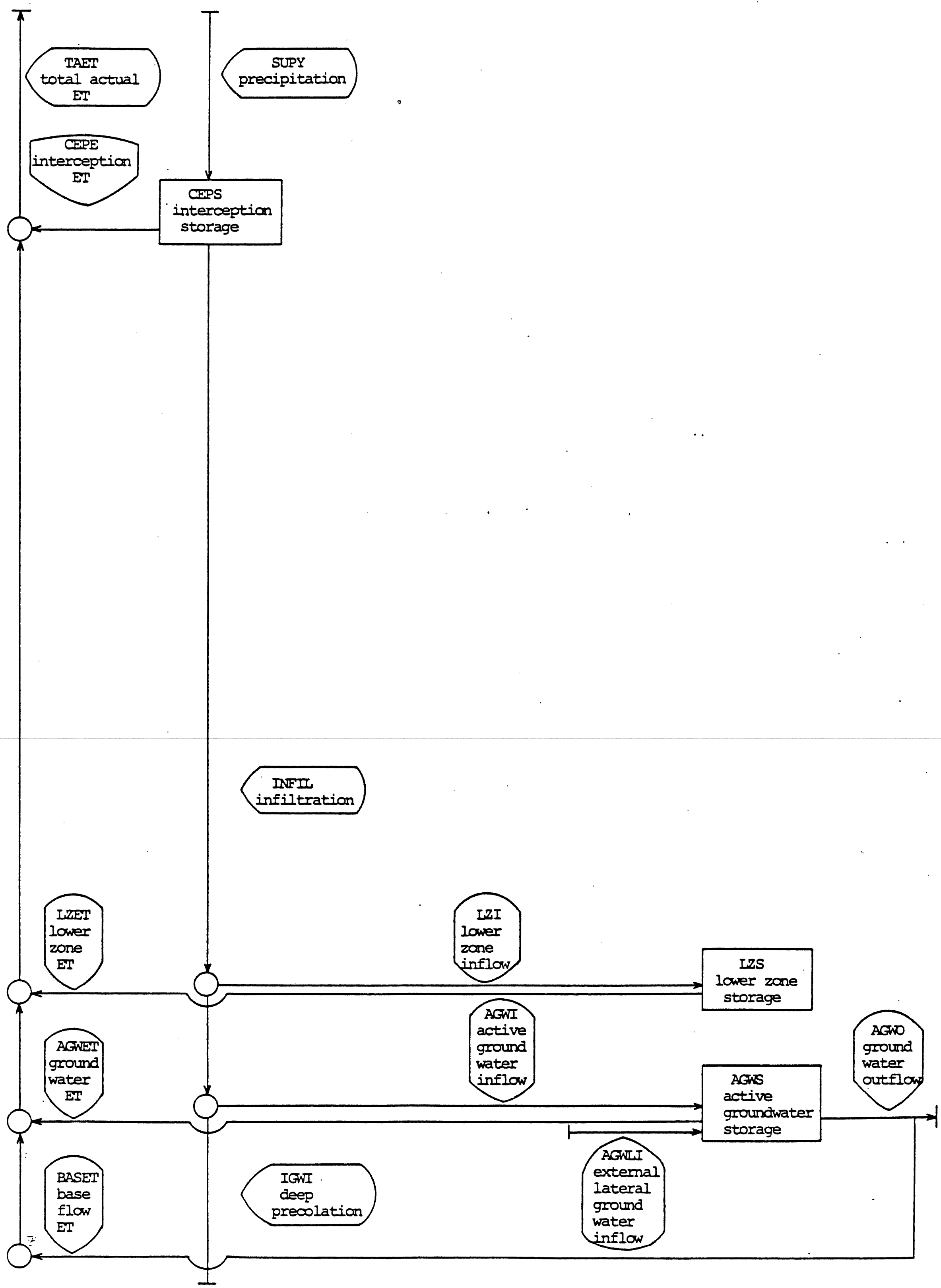

Figure 6-1 Flow Diagram of Water Movement and Storages Suggested for a Simplified Version of Section PWATER in HSPF

base of experience and knowledge in some body of work which enables a professional in the field to make intelligent decisions upon responding to a simple menu of questions and answers about field data and the confidence placed in those data. The data collection and analysis influencing calibration decisions as documented in Chapter III of this thesis are representative of the information encoded during the development of a computer based expert system for hydrologic simulation. The knowledge of parameter values documented in this study could serve as the groundwork for the database expansion required as the next step in the development of such an expert system.

APPENDIX
LISTING OF HSPF INPUT DATA

```
TSSM                  TSSPL=    15
  SHOWSPACE
END TSSM
RUN
GLOBAL
  Running a network of 6 Land-segments and 3 Rchres's
  START       1977/10/01         END     1980/09/30
  RUN INTERP OUTPUT LEVEL     3
  RESUME     0 RUN      1
END GLOBAL
OPN SEQUENCE
    INGRP                 INDELT 24:00
      PERLND        5
      PERLND        6
      PERLND        3
      PERLND        4
      PERLND        1
      PERLND        2
      RCHRES        1
      RCHRES        2
      RCHRES        3
      DISPLY        1
      DISPLY        2
      DISPLY        3
    END INGRP
END OPN SEQUENCE
PERLND
  ACTIVITY
    #thru# ATMP SNOW PWAT  SED PSTE PWTG PQAL MSTL PEST NITR PHOS TRAC ***
    1    6    0    0    1
  END ACTIVITY
  PRINT-INFO
    #thru#            PFLAG ***
    1    6                5
  END PRINT-INFO
  GEN-INFO
    #thru#      Name          NBLKS                  Printout  ***
    5      LAND-SEGMENT FIVE      1                    6
    6      LAND-SEGMENT SIX       1                    6
    3      LAND-SEGMENT THREE     1                    6
    4      LAND-SEGMENT FOUR      1                    6
    1      LAND-SEGMENT ONE       1                    6
    2      LAND-SEGMENT TWO       1                    6
  END GEN-INFO
  TABLES FOR SECTION PWATER ***
  PWAT-PARM1
    #THRU# CSNO RTOP ***
```

```
    1    6    0    1
  END PWAT-PARM1
  PWAT-PARM2
    #THRU#*** FOREST        LZSN     INFILT       LSUR      SLSUR      KVARY      AGWRC
    5           0.40         3.3        6.0      8960.       .002          0      0.985
    6           0.40         4.4       10.0     28960.     .0130           0      0.985
    3           0.40        0.70        2.0      4774.       .005          0      0.985
    4           0.40        1.52        6.0      4887.       .007          0      0.985
    1           0.40        0.70        2.0      2928.       .005          0      0.945
    2           0.40        1.86        6.0      7584.       .013          0      0.945
  END PWAT-PARM2
  PWAT-PARM3
    #THRU#*** PETMAX      PETMIN     INFEXP     INFILD     DEEPFR     BASETP     AGWETP
    5                                                        0.25                   .6
    6                                                        0.30                   .6
    3                                                        0.20       0.50        .6
    4                                                        0.20       0.50        .6
    1                                                         0.0       0.10         .6
    2                                                        0.20        0.0         .6
  END PWAT-PARM3
  PWAT-PARM4
    #THRU#***  CEPSC        UZSN       NSUR      INTFW        IRC      LZETP
    5            .15        0.25        .25        2.0        .90        .40
    6            .15        0.30        .25        2.0        .90        .40
    3            .15        0.45        .35        2.0        .90        .80
    4            .15        0.35        .25        2.0        .90        .40
    1            .15        0.40        .35        2.0        .90        .80
    2            .15        0.35        .25        2.0        .90        .40
  END PWAT-PARM4
  PWAT-STATE1
    #THRU#***   CEPS        SURS        UZS       IFWS        LZS       AGWS       GWVS
    5                                 0.017                 3.994       2.26
    6                                 0.001                 5.428       2.24
    3                                 0.073      0.001      1.414      7.002
    4                                 0.025                 2.24       7.401
    1                                 0.001                 1.40       3.20
    2                                 0.001                 3.50       1.40
  END PWAT-STATE1
END PERLND
RCHRES
  ACTIVITY
    #thru# HYDR ADCA CONS HEAT  SED  GQL OXRX NUTR PLNK   PH ***
    1    3    1
  END ACTIVITY
  PRINT-INFO
    #thru#PFLAG ***
    1    3    6
  END PRINT-INFO
```

```
  GEN-INFO
    #thru#        Name          NEXITS    Unit flags    Print-files ***
     1       Reach 1                 1    1    1    1    6    0
     2       REACH 2                 1    1    1    1    6    0
     3       REACH 3                 1    1    1    1    6    0
  END GEN-INFO
  HYDR-PARM1
    #thru#           Flags                                       ***
            V  A  A              ODFVFG            CDGTFG        ***
          CON  1  2            1  2  3  4  5     1  2  3  4  5   ***
     1    3    1  1            4
  END HYDR-PARM1
  HYDR-PARM2
    #thru#     FTABNO         LEN ***
     1            100         3.3
     2            101         4.7
     3            102         8.0
  END HYDR-PARM2
  HYDR-INIT
    #THRU#        VOL ***
                AC-FT ***
     1            .36
     2          118.6
     3          530.1
  END HYDR-INIT
END RCHRES
FTABLES
  FTABLE    100
  Rows/cols ***
    9    4
      DEPTH      SAREA        VOL      DISCH ***
         FT      ACRES    ACRE-FT      FT3/S ***
        0.0        0.0        0.0        0.0
        0.5       0.22       0.06       0.67
        1.0       1.27       0.64       3.50
        2.0       7.20       7.20       16.3
        3.0      19.89      29.84         63
        4.0      40.90      81.80        178
        5.0      71.55     178.86        400
        6.0     112.98     338.93        760
        7.0     166.24     581.84       1325
  END FTABLE100
  FTABLE    101
  ROWS/COLS ***
   11    4
      DEPTH      SAREA        VOL      DISCH ***
         FT      ACRES    ACRE-FT      FT3/S ***
        0.0        0.0        0.0        0.0
```

```
      2.8        101.5       142.1         0.0
      2.9        109.2       158.3         1.8
      3.0        117.2       175.7         4.5
      3.2        134.0       214.3        12.8
      3.4        151.9       258.3        22.5
      3.7        181.1       335.0        42.5
      4.2        235.6       494.7        88.0
      4.7        297.5       699.2       150.0
      5.7        444.1      1265.6       350.0
      6.7        621.1      2080.9       660.0
  END FTABLE101
  FTABLE    102
  ROWS/COLS ***
    9    4
     DEPTH       SAREA         VOL       DISCH ***
        FT       ACRES     ACRE-FT       FT3/S ***
       0.0         0.0         0.0         0.0
       2.8       221.0       309.4         0.0
        3.       249.0       373.6         .63
        4.       410.0       819.9         10.
        5.       603.5      1508.6         30.
        6.       827.6      2482.9         67.
        7.      1081.0      3783.5        128.
        8.      1362.4      5449.5        220.
       10.      2005.4     10027.1        510.
  END FTABLE102
END FTABLES
DISPLY
  DISPLY-INFO1
    #thru#***        Title                       TRAN PIVL DIG1 FIL1  PYR DIG2 FIL2 YRND
    1         REACH1  DISCHARGE (AC-FT)          SUM     0               1    2         9
    2         REACH2  DISCHARGE (AC-FT)          SUM     0               1    2         9
    3         REACH3  DISCHARGE (AC-FT)          SUM     0               1    2         9
  END DISPLY-INFO1
END DISPLY
EXT SOURCES
<-Volume-> <Member> SsysSgap<--Mult-->Tran <-Target vols> <-Grp> <-Member->  ***
<Name>   # <Name> # tem strg<-factor->strg <Name>   #   #        <Name> # #  ***
TSS     21 PRECIP   ENGL                   PERLND   1        EXTNL  PREC
TSS     30 PRECIP   ENGL                   PERLND   3   5    EXTNL  PREC
TSS     29 PRECIP   ENGL                   PERLND   2        EXTNL  PREC
TSS     29 PRECIP   ENGL                   PERLND   6        EXTNL  PREC
TSS     31 PETDAT   ENGL                   PERLND   1   6    EXTNL  PETINP
TSS     31 PETDAT   ENGL                   RCHRES   2   3    EXTNL  POTEV
END EXT SOURCES
NETWORK
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Target vols> <-Grp> <-Member->  ***
<Name>   #        <Name> # #<-factor->strg <Name>   #   #        <Name> # #  ***
```

```
PERLND   5 PWATER PERO          597.      RCHRES    1      EXTNL  IVOL
PERLND   6 PWATER PERO         1930.0     RCHRES    1      EXTNL  IVOL
PERLND   3 PWATER PERO         453.2      RCHRES    2      EXTNL  IVOL
PERLND   4 PWATER PERO         463.8      RCHRES    2      EXTNL  IVOL
PERLND   1 PWATER PERO         650.4      RCHRES    3      EXTNL  IVOL
PERLND   2 PWATER PERO        1684.7      RCHRES    3      EXTNL  IVOL
RCHRES   1 HYDR   ROVOL                   RCHRES    2      EXTNL  IVOL
RCHRES   2 HYDR   ROVOL                   RCHRES    3      EXTNL  IVOL
RCHRES   1 HYDR   ROVOL                   DISPLY    1      INPUT  TIMSER
RCHRES   2 HYDR   ROVOL                   DISPLY    2      INPUT  TIMSER
RCHRES   3 HYDR   ROVOL                   DISPLY    3      INPUT  TIMSER
END NETWORK
END RUN
```

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BIOGRAPHICAL SKETCH

Caroline Nancy Hicks was born on May 15, 1958, in Clarkesville, Georgia, in the corner of northeast Georgia that she considers the most beautiful part of a beautiful state. Here she was "raised right" by Dr. and Mrs. L. G. Hicks, Jr., a method of upbringing which accounts, in part, for her sisterly devotion to Murphy, Claire, Argen, and Laurie. She graduated from Habersham Central High School in 1976. She settled in Gainesville, Florida, in 1977 where she played with the bluegrass band, Red and Murphy & Co., for eight years. While in Gainesville, she attended the University of Florida, graduating as a Phi Beta Kappa initiate with a Bachelor of Arts in economics, with high honors, in 1979. In 1983 she entered the graduate program in the Department of Environmental Engineering, emerging as a Tau Beta Pi initiate with a Master of Engineering degree in August, 1985.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Engineering.

James P. Heaney, Chairman
Professor of Environmental
Engineering Sciences

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Engineering.

Wayne C. Huber, Co-Chairman
Professor of Environmental
Engineering Sciences

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Engineering.

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This thesis was submitted to the Graduate Faculty of the College of Engineering and to the Graduate School, and was accepted as partial fulfillment of the requirements for the degree of Master of Engineering.

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