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Lower Republican River Basin:
Stream-Aquifer Study
First Year Report

by

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Disclaimer

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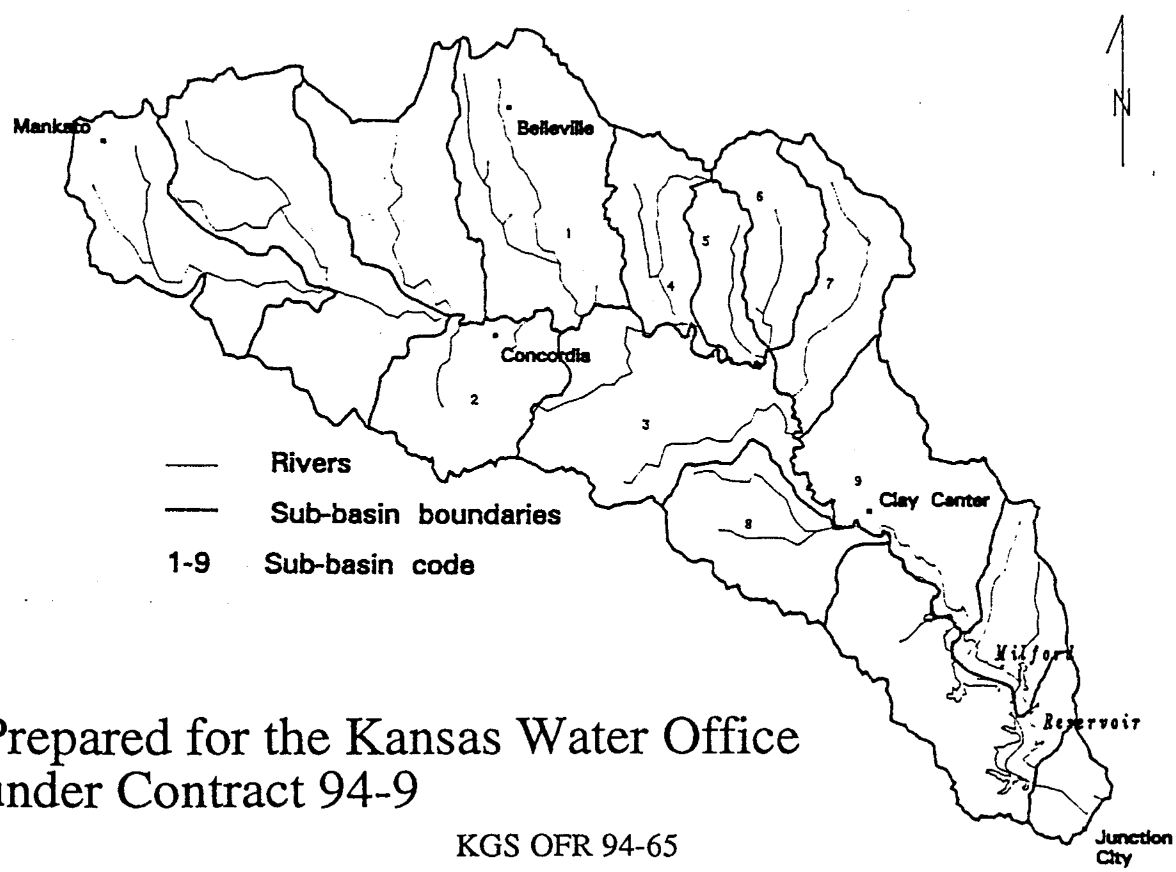

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TABLE OF CONTENTS

List of Figures

List of Tables

1. INTRODUCTION

Since 1988, flows in the Republican River have been low relative to historic levels. Low flow conditions are especially pronounced in the reach between Concordia and Clay Center. This reach is in an area where large groundwater appropriations exist, therefore the impact of ground water pumpage on streamflow should be assessed. As there are competing interests for the water and finite amounts of the resource, decisions balancing ground water rights and surface water benefits must be made. The former relate to the administration of water rights for irrigation, the latter primarily to minimum streamflow standards and to desired inflows to the Milford Reservoir.

The purpose of the Republican River Stream/Aquifer Study is to assess the impact of selective administration of water rights in the reach between Concordia and Clay Center on the streamflow at Clay Center, which is used as the control point for the inflows into Milford Lake. The basis for this assessment is the evaluation of the hydrologic balance for the study area, for which we have employed the model SWAT. The SWAT model is designed to assist in the management of water resources by evaluating the effects of landuses, irrigation alternatives, etc. The study area is divided into subbasins based on the natural stream network.

This report describes the methods used to model hydrologic processes included in SWAT, the input parameters and data required and the model's output, and results of the initial modeling phase. We present preliminary model application results on parameter estimation, model calibration and sensitivity analysis, and evaluate the water balance for the basin.

2. OBJECTIVES OF THIS STUDY

The goal of this study is to develop a PC-based model capable of assisting personnel of the Kansas Water Office and of the Division of Water Resources to manage the water resources of the Lower Republican River Basin. While it is clearly essential that such a model be parsimonious (computationally and in terms of data needs) and usable with modest training, it is equally important that it be physically sound. The study area is located between Concordia and Clay Center where large ground water appropriations exist, therefore the stream-aquifer interaction under the influence of well pumping should be evaluated. Therefore, given information on hydromorphology, precipitation, temperature, solar radiation, streamflow, surface reservoir releases and ground water withdrawals, etc., a watershed model should be able to estimate recharge, evapotranspiration, surface runoff, ground water discharge and soil moisture deficits. The recharge distribution data obtained from the watershed model will be used subsequently in the established USGS ground water model MODFLOW (McDonald and Harbaugh, 1988) to simulate aquifer dynamics of the basin.

3. HYDROLOGIC MODEL SELECTION

3.1 Model Classification: Scientific Criteria

Numerous mathematical hydrologic models have been developed in the past three decades. These models can be classified according to the following six criteria: (Ozga-Zielinska, 1976) 1. model structure and modeling subject; 2. role of the time factor; 3. cognitive value of a model; 4. character of results obtained; 5. applied approach and methods of solution; 6. properties of operator functions.

The first criterion, model structure and modeling subject, relates to what part or parts of the hydrologic cycle are included in the model and their level of abstraction in the model. The following four levels can be identified: (a) individual processes, (b) component models, (c) integrated watershed models, and (d) global watershed models. In our study, only the third category is considered. An integrated watershed model consists of a set of linked component models along with an operator that apportions the flow of water to the individual components in the proper order.

According to the second classification criterion, the role of the time factor, models can be classified as static or dynamic. Static models include various empirical equations and regression models in which time is not an independent variable. Dynamic models require differential equations with time as an independent variable and thus can show the time variability of output. Also, according to the time frame simulated, models can be characterized as event or continuous simulation models. An event model is one that represents a single runoff event occurring over a period of time ranging from an hour, more or less, to several days. A continuous watershed model is one that operates over an extended period of time determining flow rates and conditions during both runoff periods and periods of no surface runoff. Michaud and Sorooshian (1994) compared three event models from simple to complex distributed models on a midsized semiarid watershed and concluded that when calibration was performed, the accuracy of the complex distributed model was similar to that of the simple distributed model. Without calibration, the complex distributed model was more accurate than the simple distributed model. The spatially lumped model performed very poorly.

Three categories result when the third classification criterion, cognitive value of a model, is considered: (a) physically-based models, (b) conceptual models, and (c) trend models. Physically-based models are those in which the governing physical laws and the model structure are well-known and can be described by the equations of mathematical physics. Conceptual models may be utilized when the model structure and physical laws are unknown or the physically-based model is so complicated that it is more appropriate to greatly simplify the model behavior (Brutsaert, 1986).

The character of results obtained or output of a model (the fourth criterion) can be classified as stochastic or deterministic. If any of the variables in a mathematical model are regarded as random variables having distributions in probability, then the model is stochastic. If all of the variables are considered to be free from random variation, then the model is deterministic (Clarke, 1973).

The fifth classification criterion (applied approach and methods of solution) overlaps somewhat with the third criterion (cognitive value of the model), but introduces a different terminology. Systems can be referred to either as "black box" systems or "white box" systems. The black box approach treats the system as a system operator which transforms input into output. The white box approach implies that the physical laws and nature of the system are well understood and can be synthesized into a system operation without recourse to observations of input and output.

The last classification criterion is related to mathematical properties of the operator function. Models may be classified as linear or nonlinear, lumped or distributed and stationary or nonstationary. According to Clarke (1973), usage of the term linear has two meanings. A model is linear in the systems theory sense if the principle of superposition is valid. An alternative meaning of linearity is linearity in the statistical sense. Lumped models do not explicitly take into account spatial variability of inputs, outputs or parameters and usually are represented by an ordinary differential equation or a set of linked ordinary differential equations. Distributed models include spatial variations in inputs, outputs, and parameters and often consist of a set of linked partial differential equations. A deterministic operator is stationary if its form and parameters are invariant in time; otherwise it is nonstationary. A stochastic model is stationary if its properties do not change with absolute time.

In the following, only dynamic watershed models are considered in accordance with the objectives of the Lower Republican River Basin study.

As will be discussed in the following, several alternative models could be used in our study. Objective methods of choosing the best model have not yet been developed, so this choice remains a part of the art of hydrologic modeling. Dawdy and Lichty (1968) suggest four general criteria that can be used to choose between alternative models: (a) accuracy of prediction, (b) simplicity of the model, (c) consistency of parameter estimates, and (d) sensitivity of results to changes in parameter values.

Accuracy of prediction of system outputs is obviously very important. It is desirable that models developed by research be tested in such a manner that error statistics are known. All other factors being equal, the model with minimum bias and error variance would be superior.

Simplicity refers to the number of parameters that must be estimated and the ease with which the model can be explained to clients or public bodies. Again, all other factors being equal, one should choose the simplest model. Consistency of parameter estimates is an important consideration in developing conceptual models using parameters estimated by optimization techniques. If the optimal parameters are very sensitive to the particular period of record used, or if they vary widely between similar watersheds, the model will probably be unreliable. Finally, models should not be too sensitive to input variables that are difficult to measure.

3.2 Practical Model Selection Criteria

Measured streamflow from a watershed is the sum of surface runoff, lateral flow from the root zone, and return flow from the shallow aquifer (Figure 1). Few models attempt to simulate all these components; however, several watershed-scale models have been developed to simulate the surface and root zone. These include spatially detailed, single-event models such as ANSWERS (Beasley et al., 1980) and AGNPS (Young et al., 1987), and continuous time models such as HSPF (Johansen et al., 1984) and SWRRB (Arnold et al., 1990).

We examined a number of candidate models, some of which are briefly described below. We put emphasis on physically-based, continuous simulation, distributed and agriculturally-oriented models. Thus we exclude from the descriptions the previously mentioned single event models, as well as rangeland-oriented models such as ERHYM (Wight, 1987) and SPUR (Wight and Skiles, 1987).

There are a number of other specific criteria for selecting a model, which include but are not limited to:

1. Objective compatibility;
2. Major process components;
3. Watershed scale;
4. Landuse conditions;
5. Time scale of simulation ;
6. Data collection difficulty;
7. Software availability;
8. Expertise requirement;
9. Computer resource requirement;
10. Time frame requirement.

In order to accomplish the objectives of this study, based on the above mentioned criteria the selected model should be: (1) distributed at the watershed scale, allowing the basin to be subdivided; (2) physically-based; (3) designed to accept readily available inputs to allow general use over large regions; (4) continuous in time to allow simulation of land management factors such as crop rotations, tillage, reservoir operation, etc.; (5) computationally efficient to allow simulation of a variety of management strategies without excessive cost; (6) capable of simulating long periods for use in frequency analysis; and (7) "validated" over a wide range of hydrologic regimes.

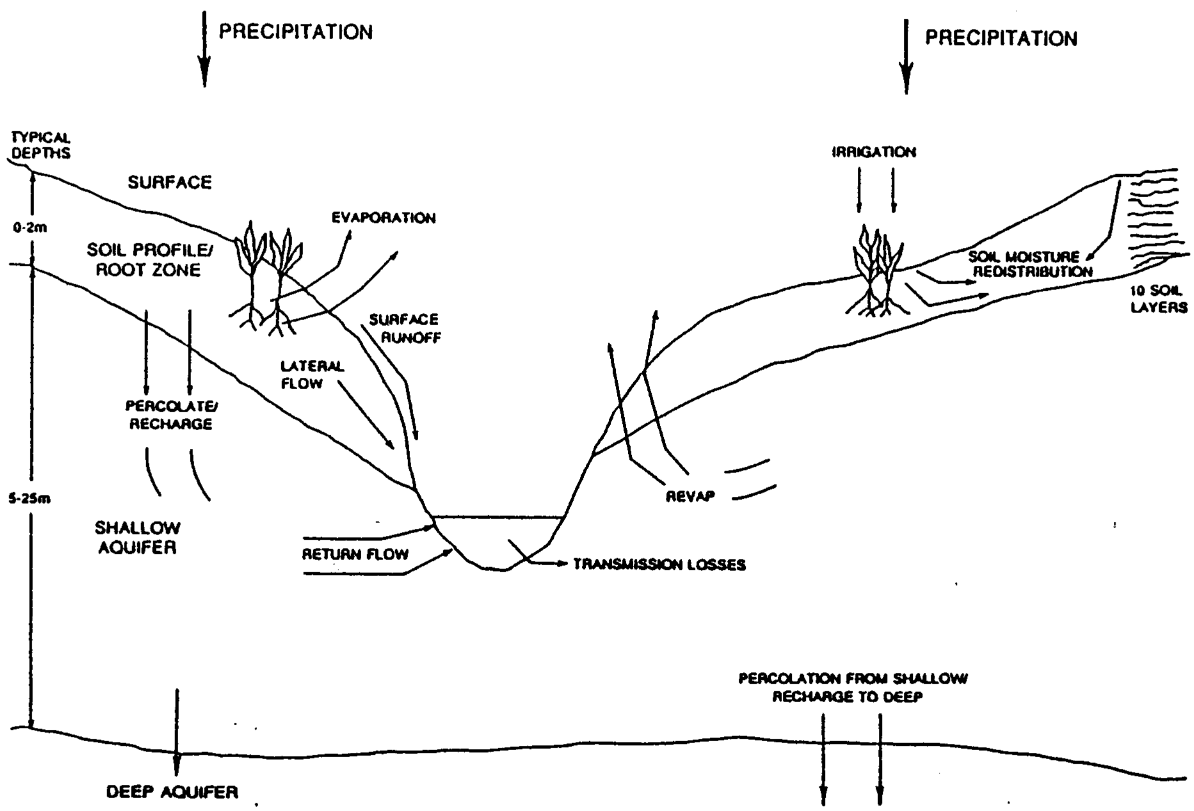


Fig. 1 - Hydrologic Balance

3.3 Summaries and Assessment of Selected Models

SHE (Abbott et al., 1986) European Hydrologic System Model (Système Hydrologique Européen)

Model Summary Description: SHE is a physically based, distributed-parameter catchment modeling system. The model considers the major hydrologic processes which govern water movement through a catchment, namely: snowmelt, canopy interception, evapotranspira- tion, overland flow, channel flow, and unsaturated and saturated subsurface flow. Spatial variability of hydrologic processes is described by using a rectangular grid of (x, y) points in the horizontal plane with vertical variation in properties represented by a series of horizontal planes of various depths.

SHE is applicable to a wide range of hydrologic processes and can be applied to a variety of hydrologic problems, including irrigation schemes, determination of landuse changes, water development studies, groundwater contamination, erosion and sediment transport, and flood prediction.

Summary Critique: SHE applications have been performed on mainframe computers. Applications of the program on PCs are limited due to the large number of computations that must be made. Because of its intensive data and computing requirements this model has not been considered suitable for our application.

TOPMODEL (Beven and Wood, 1983) TOPography-Based Hydrologic MODEL

Model Summary Description: TOPMODEL is a topography-based hydrologic model derived from the variable contributing area theory. The inputs of the model are the hourly rainfall and potential evaporation, and the distribution of the topographical index derived from the digital terrain map of the catchment. The outputs are the hourly average and local soil moisture deficits below saturation, and the hourly discharge, separated into two components (surface runoff on the saturated area, and subsurface flow/groundwater discharge).

Summary Critique: Because, in addition to the high temporal resolution input data requirements, vegetation and land management factors are not explicitly considered in this model it has not been considered further.

HSPF (Johanson et al., 1980) Hydrological Simulation Program-Fortran

Model Summary Description: The Hydrologic Simulation Program - Fortran (HSPF) model simulates both watershed hydrology and water quality. It allows an integrated simulation of land and soil contaminant runoff processes with in-stream hydraulic and sediment-chemical interactions. The program provides a time history of runoff rate, sediment load, and nutrient and pesticide concentration, along with a time history of water quality and quantity at specific points in a watershed.

HSPF computes a continuous hydrograph of stream flow at the basin outlet. Input is a continuous record of precipitation and evaporation data. Rainfall is distributed into interception loss, rainfall on impervious areas which contributes directly to runoff, and an infiltrated portion.

The program user must supply parameters for each of the various processes. More than 20 parameters are needed to describe merely the hydrological parameters, some of which cannot be directly measured (such as the various soil moisture parameters). Without calibration data, it can be difficult to verify the flows computed by this model.

Summary Critique: Although this model seems to meet a number of our requirements, it has been mainly applied to urban, as opposed to agricultural watersheds, and that seems to be its strength. A drawback of this model is that several parameters of the model are not physically based, therefore they cannot be estimated from readily available information. In addition, the model is so large that it is more suitable for execution on mainframe computers. For these reasons we have not pursued it further.

SPAW (Saxton et al., 1974) The Soil-Plant-Air-Water Model

Model Summary Description: SPAW was developed to provide daily soil water estimates on cultivated cropland in the Midwest. The model computes daily estimates of runoff, actual evapotranspiration and deep percolation.

Summary Critique: This agricultural and soil-physics-based model requires too detailed unsaturated soil physical and plant parameters which are not available, and thus this model is not considered further.

VSMB (Baier et al., 1979) Versatile Soil Moisture Budget

Model Summary Description: VSMB calculates the water budget of the soil within the rooting zone of the crop from evapotranspiration, precipitation, and deep drainage.

Summary Critique: This is not a distributed parameter model. Its strength lies in a detailed representation of the root zone processes. It has been implemented on a watershed scale by Sophocleous and McAllister (1987, 1990). However it lacks streamflow routing routines and was reserved as a standby model. Its major advantage is its simplicity.

CREAMS (Knisel, 1980) Model for Chemical, Runoff, and Erosion from Agricultural Management Systems

Model Summary Description: CREAMS is a well known field-scale model for chemical, runoff, and erosion from agricultural management systems which was developed to estimate runoff,

erosion and sediment transport, plant nutrient and pesticide yield from field-sized catchments.
Summary Critique: This model, designed for the field plot scale, is the precursor to more suitable watershed-scale models such as SWAT/SWRRB, which will be discussed in more detail later.

SWRRB (Williams et al., 1985, Arnold et al., 1990) Simulator for Water Resources in Rural Basins

Model Summary Description: SWRRB was developed to predict the effect of management decisions on water and sediment yields with reasonable accuracy for ungaged, rural basins. It is the precursor to SWAT, which will be described in more detail next.
Summary Critique: It does not have ground water flow, lake water quality and irrigation transfer components; also, its routing structure is unrealistic.

SWAT (Arnold et al., 1993) Soil and Water Assessment Tool

SWAT (Soil and Water Assessment Tool) is a partially physically based, linked surface-subsurface watershed model. The objective in model development was to predict the effect of management decisions (climate and vegetative changes, groundwater withdrawals, reservoir management, and water transfer) on water, sediment, and chemical yields with reasonable accuracy for river basins. The major processes are: 1) precipitation; 2) snowmelt; 3) infiltration; 4) evapotranspiration; 5) surface runoff; 6) routing; 7) erosion; 8) chemical movement; 9) groundwater flow and lateral flow; 10) irrigation water transfer; 11) lake water quality; 12) reservoir (pond) component. Figure 2 shows the system simulated and the hydrologic components.

SWAT was developed by adding some components, e.g., ground water flow, to the spatially detailed, continuous time model, SWRRB, which was developed by modifying the CREAMS daily rainfall model for application to large, complex, rural basins.

The model allows considerable flexibility in watershed configuration and discretization, and is operated continuously on a daily time step. Watersheds can be subdivided into subbasins. The divisions may be based on stream network, soils, landuse, tillage operations, elevation, temperature, rainfall, etc. Sediment and associated chemicals are then routed to the basin outlet. A different rain gauge may be assigned to each subbasin. Also, in the vertical direction the model is capable of working with any variation in soil properties -- the soil profile can be divided into a maximum of 10 layers. Figure 2 gives a complete flow chart of all the hydrologic components simulated by SWAT.

SWAT input and output files are split into separate files by subbasin and data type. This input data structure facilitates the use of several subbasins in the modeling and simplifies GIS linkages. SWAT has also been used by Bureau of Indian Affairs and Texas River Authorities.

Based on the criteria and the analysis of model candidates, SWAT is the state of the art in this field and is selected to model the Lower Republican River basin. This model is intended for general use and accepts readily available inputs. Inputs for the surface water model are easily obtained and weather, soils, crops, and pesticide databases for the USA are supplied to users. Groundwater inputs are also relatively easy to obtain and are similar in similar hydrogeological regions.

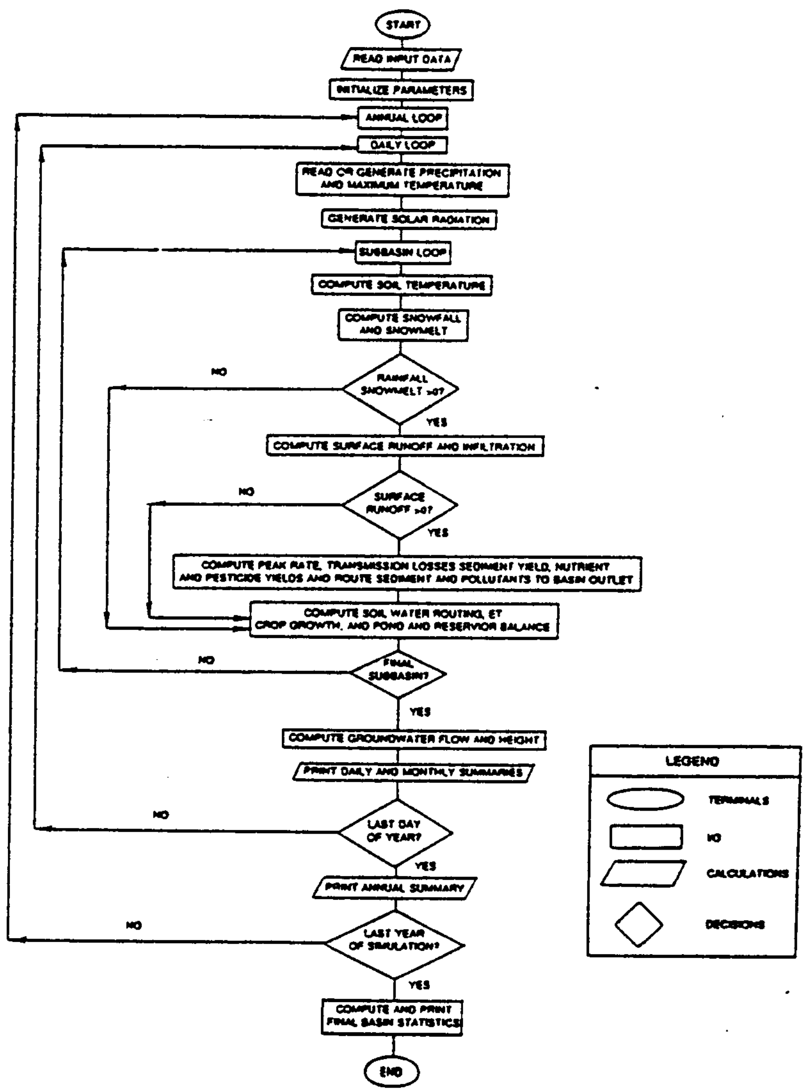


Fig. 2 - SWAT Model Operation Flow Chart

4. DETAILED DESCRIPTION OF SWAT

4.1 Model Processes

SWAT (Soil and Water Assessment Tool, Arnold et al., 1993) is a partially physically based, linked surface-subsurface watershed model. The objective in model development was to predict the effect of management decisions (climate and vegetative changes, groundwater withdrawals, reservoir management, and water transfer) on water, sediment, and chemical yields with reasonable accuracy for river basins.

A brief description of the major components of the model is presented here. Those processes, such as sedimentation, nutrients, and pesticides, that are not used in this project are omitted. Detailed descriptions of the processes are presented in the SWRRB documention reference by Arnold et al. (1990) from which our descriptions have been summarized.

4.1.1 Hydrologic Processes

Surface Runoff

Surface runoff from daily rainfall is predicted using a procedure similar to that of the CREAMS runoff model, option one (Knisel, 1980). As in the CREAMS model, runoff volume is estimated using a modification of the SCS curve number method (U.S. Department of Agriculture, Soil Conservation Service, 1972). The curve number varies non-linearly from condition 1 (dry) at wilting point to condition 3 (wet) at field capacity, and approaches 100 at saturation. The SWAT model also includes a provision for estimating runoff from frozen soil.

Peak runoff rate predictions are based on a modification of the Rational Formula. The runoff coefficient is calculated as the ratio of runoff volume to rainfall. The rainfall intensity during the watershed time of concentration is estimated for each storm as a function of total rainfall using a stochastic technique. The watershed time of concentration is estimated using Manning's formula, considering both overland and channel flow.

Percolation

The percolation component of SWAT uses a storage routing technique to predict flow through each soil layer in the root zone. Downward flow occurs when field capacity of a soil layer is exceeded if the layer below is not saturated. The downward flow rate is governed by the saturated conductivity of the soil layer. Upward flow may occur when a lower layer exceeds field capacity. Movement from a lower layer to an adjoining upper layer is regulated by the soil water to field capacity ratios of the two layers. Percolation is also affected by soil temperature. If the temperature in a particular layer is $0^{o}C$ or below, no percolation is allowed from that layer.

Lateral Subsurface Flow

Lateral subsurface flow is calculated simultaneously with percolation. A non-linear function of lateral flow travel time is used to simulate the horizontal component of subsurface flow. The magnitudes of the vertical and horizontal components are determined by simultaneous solution of the two governing equations.

Evapotranspiration

Potential evapotranspiration is estimated by the Priestley-Taylor method. Required inputs are daily maximum and minimum air temperature and solar radiation. The model computes soil and plant evaporation separately.

Snow Melt

The SWAT snow melt component is similar to that of the CREAMS model (Knisel, 1980). If snow is present, it is melted on days when the maximum temperature exceeds $0^{o}C$, using a linear function of temperature. Melted snow is treated in the same way as rainfall for runoff and percolation estimation, but rainfall energy is set to 0.0 and peak runoff rate is estimated assuming uniformly distributed rainfall for a 24 h duration.

Transmission Losses

Many semiarid watersheds have alluvial channels that abstract large volumes of streamflow. The abstraction, or transmission losses, reduce runoff volumes as the flood wave travels downstream. SWAT uses Lane's method, described in Chapter 19 of the Soil Conservation Service (SCS) Hydrology Handbook (USDA Soil Conservation Service, 1972), to estimate transmission losses. Channel losses are a function of channel width and length and flow duration. Both runoff volume and peak rate are adjusted when transmission losses occur.

Ponds and Reservoirs

Farm pond storage is estimated as a function of pond capacity, daily inflows and outflows, seepage, and evaporation. Ponds are assumed to have only emergency spillways. Required inputs are capacity and surface area. Surface area below capacity is estimated as a non-linear function of storage. Reservoirs are treated similarly except they have emergency and principal spill- ways. Thus, required inputs include volume and surface area at both spillway elevations and the principal spillway release rate.

Flood Routing

The flood routing structure of SWAT routes and adds flow down through the watershed through reaches and reservoirs. A set of commands are used to control routing and adding the flows down through the watershed. The basic commands are subbasin, route, routres, transfer, add, routsub, recall, save, and finish.

4.1.2 Weather

The weather variables necessary for driving SWAT are precipitation, air temperature, and solar radiation. If daily precipitation data are available, they can be input directly to SWAT. If not, the weather generator can simulate daily rainfall and temperature. Solar radiation is always simulated. One set of weather variables may be simulated for the entire basin, or different weather may be simulated for each subbasin.

Precipitation

The SWAT precipitation model is a first-order Markov chain model. Thus, input to the model include monthly probabilities of receiving precipitation if the previous day was dry and if the previous day was wet. Given the wet-dry state, the model determines stochastically whether precipitation occurs or not. When a precipitation event occurs, the amount is determined by generating from a skewed normal daily precipitation distribution. The amount of daily precipitation is partitioned between rainfall and snowfall using average daily air temperature.

Air Temperature and Solar Radiation

Daily maximum and minimum air temperature and solar radiation are generated from a normal distribution corrected for wet-dry probability state. The correction factor is used to provide more deviation in temperatures and radiation when weather changes and for rainy days. Conversely, deviations are smaller on dry days. The correction factors are calculated to insure that long-term standard deviations of daily variables are maintained. Monthly values of daily standard deviations of maximum and minimum temperature are input. Monthly values of daily standard deviations (SDs) of solar radiation are estimated by assuming that the difference between mean and maximum daily radiation is 4SDs.

Soil Temperature

Daily average soil temperature is simulated at the center of each soil layer. Since air temperature is provided by the weather component of SWAT, the soil temperature model should be capable of using these air temperatures as drivers. A linear relationship is used to relate the bare soil surface temperature, the maximum and the minimum daily air temperature, and a damping factor is used to vary the temperature as soil depth changes.

The soil surface temperature is also affected by residue and snow cover. This effect is simulated by lagging the predicted bare surface temperature using a weighting factor.

4.1.3 Crop Growth

The crop model in SWAT is a simplification of the EPIC crop model. SWAT uses EPIC concepts of phenological crop development based on daily accumulated heat units, harvest index for partitioning grain yield, Monteith's approach for potential biomass, and water and temperature stress adjustments. However, the detailed EPIC root growth and nutrient cycling models are not included. A single model is used for simulating all the crops considered. SWAT is capable of simulating crop growth for both annual and perennial plants. Annual crops grow from planting date to harvest date or until the accumulated heat units equal the potential heat units for the crop. Perennial crops maintain their root systems throughout the year, although the plant may become dormant after frost.

4.1.4 Agricultural Management

Irrigation

The SWAT user has the option to simulate dryland or irrigated agricultural areas. If irrigation is indicated, one must also specify the runoff ratio (volume of water leaving the field/volume applied) and a plant water stress level to start irrigation. The plant water stress factor ranges from 0.0 to 1.0 (1.0 means no stress and 0.0 means no growth).

Tillage and Residue

The SWAT tillage component was designed to partition the above-ground biomass at harvest. A portion of the biomass is incorporated into the soil while the remainder is left on the soil surface as residue. Once the residue is incorporated, it has no impact on the model. Also no change is made in bulk density due to tillage. The residue is set at harvest according to the tillage practices chosen. The residue decays throughout the remainder of the year (harvest to next harvest) as a function of soil water content and soil temperature. Inputs include dates, tillage, crop, and pesticide codes (relating to the numbers in the CROP.DAT, TILL.DAT, and PEST.DAT files), and application amounts.

4.1.5 Groundwater Model Component

The main objective of the linked model developed in SWAT is to predict the impact of management changes on total water supplies. The model is intended for general use where extensive field-work to obtain inputs is not feasible. Thus, the groundwater component must use readily available inputs. Also, it must have sophistication and technology similar to those of the other components of the simulation model. A detailed numerical model is not justified for this situation and thus a relatively simple, yet realistic model was developed.

The system simulated by the model consists of four control volumes that include (1) the surface, (2) the soil profile or root zone, (3) the shallow aquifer, and (4) the deep aquifer, Figure 1. Contributions to streamflow are surface runoff, lateral flow from the soil profile, and return flow from the shallow aquifer. The percolation from the soil profile is assumed to recharge the shallow aquifer. Once the water percolates to the deep aquifer it is lost from the simulated system and cannot return. The detailed mathematical equations for the surface and soil profile are given by Arnold et al. (1990), and the shallow and deep aquifer models are described by Arnold et al. (1993).

4.2 Data Requirements

4.2.1 Weather Data

1) Station information: Number of stations; Station number, names, and locations.
2) Precipitation data for each station: Daily rainfall of all stations; TP-40 (Hershfield, D. M., 1962. Rainfall frequency Atlas of the United States for durations from 30 minutes to 24 hours and return periods from 1 to 100 years. U.S. Dept. Commerce Tech. Paper No. 40. 115pp.) 10-year frequency 0.5 hour rainfall; TP-40 10-year frequency 6 hour rainfall; Monthly maximum 0.5 hour rainfall.
3) Temperature data: Daily temperature; Average monthly maximum temperature; Average monthly minimum temperature.
4) Solar radiation data: Monthly average daily solar radiation.

4.2.2 Basin Data

1) Area in each subbasin.
2) Main channel length in each subbasin.
3) Average channel slope in each subbasin.
4) Average main channel width in each subbasin.
5) Effective hydraulic conductivity of channel alluvium.
6) Channel Manning N values.
7) Overland flow N values.
8) Sediment concentration in return flow.
9) Average slope length for each subbasin.
10) Average slope steepness for each subbasin.

4.2.3 Stream Flow Data

1) Station information: Number of stations; Station number, names, and locations.
2) Monthly flow rate data in each station.
3) Daily flow rate data in each station.

4.2.4 Pond Data

1) Fraction of each subbasin that flows into ponds.
2) Total surface area of all ponds in each subbasin.
3) Runoff volume from pond catchment area to fill ponds.
4) Initial pond volumes.
5) Initial sediment concentration in ponds.

6) Normal sediment concentration in ponds.
7) Hydraulic conductivity of pond bottoms.

4.2.5 Reservoir Data

1) Fraction of each subbasin that flows in reservoirs.
2) Total reservoir surface area at emergency spillway.
3) Runoff volume from reservoir catchment area required to fill emergency spillway.
4) Total reservoir surface area at principal spillway.
5) Runoff required to fill to principal spillway.
6) Initial reservoir volumes.
7) Average principal spillway release rate.
8) Initial sediment concentration in reservoirs.
9) Normal sediment concentration in reservoirs.
10) Hydraulic conductivity of reservoir bottoms.

4.2.6 Soil Data

1) Number of soils.
2) Soil series name.
3) Number of soil layers.
4) Depth to bottom of each layer.
5) Bulk density.
6) Available water capacity.
7) Saturated conductivity.
8) Clay content.
9) Maximum rooting depth.

4.2.7 Crop Data

1) Planting date.
2) Harvest date.
3) Vegetation: Annual or Perennial.
4) Tillage: fall or spring plow, conservation or zero tillage.

4.2.8 Irrigation Data

1) Are the crops irrigated.
2) Water stress when irrigation applied.
3) Irrigation runoff ratio.

4.2.9 Well and Water Rights Data

1) Number of wells, and locations.
2) Pumping rates.

4.2.10 Routing data

4.3 Input Data Files

SWAT input files are grouped by subbasin and data type. The first group of data is the input data files for the entire basin, and the second group is the input data files for each of the subbasins. There are two types of data files in the first group: user provided files and data base files. For user provided files the file names can be defined by users but the extension must be maintained. The following is a simple description of each of the files.

4.3.1 Basin Input Files

A. Data Base Files

1. CROP.DAT

This is the crop data base input file. It contains crop specific parameters that are input to the model. When a crop is specified to be planted in the management (.mgt) file, the crop parameters for that crop are taken from CROP.DAT. The crop parameters include biomass conversion factor, harvest index, optimum and base temperatures, maximum leaf area, maximum root depth and several others.

2. TILL.DAT

This is the tillage data base input file. It contains mixing efficiencies for over 70 tillage operations that can be selected in the management (.mgt) file.

3. PEST.DAT

This is the pesticide data base input file. It contains pesticide parameters for over 80 pesticides that can be selected in the management (.mgt) file. The pesticide parameters include the soil partition coefficient, washoff fraction, foliar and ground half-lifes, and water solubilities.

B. User Provided Files

4. *.COD

This is the input control code file. It contains the number of years of simulation, beginning year, print codes, weather generation control codes, and several others. All the inputs are common to the entire basin and not subbasin dependent.

5. *.BSN

This is the general basin input file. It contains inputs that are relevant to the entire basin that include drainage area, baseflow factors, and initial soil water contents.

6. *.WGN

This is the weather generator input file. It contains monthly parameters that are required for generating daily amounts of precipitation, maximum and minimum temperatures, and solar radiation. Many of the parameters are required by the model even if measured precipitation and temperature data are used.

7. *.LWQ

This is the lake water quality input file. It contains parameters for the lake toxic balance and for the lake phosphorus balance.

8. *.FIG

This is the watershed configuration input file. It contains the routing commands SWAT uses to route and add flows through a watershed. The commands include subbasin, route, routres, transfer, add, routsub, recall, save, and finish.

9. *.STA

This is the measured data input file from a gaged station. It contains monthly measured flow and sediment yield data. The model reads in the data and compares to simulated model output. Then SWAT reports several statistics on the comparison including means, standard deviations, and R-squared.

10. *.RES

This is the reservoir input file. This file contains reservoir input data including surface area and storages for emergency and principal spillways, release rates, and normal sediment concentrations.

4.3.2 Subbasin Input Files

1. *.SUB

This is the general subbasin input file. This file contains general inputs specific to each subbasin that include area, curve number, land and channel slopes and lengths, USLE erosion control practice factor P, and initial residue cover.

2. *.RTE

This is the subbasin routing input file. This file contains information on channel dimensions (length, slope, width, depth, etc.) for the main channel through the subbasin.

3. *.PND

This is the pond input file. This file contains pond input data including surface area and storages, conductivity of the pond bottoms, and normal sediment concentrations.

4. *.CHM

This is the chemical input file. This file contains data on initial pesticide concentrations in the soil and on the foliage along with initial nutrient concentrations in the soil.

5. *.SOL

This is the soils input file. This file contains soil data including bulk density, available water capacity, saturated conductivity, particle sizes, organic carbon, and maximum rooting depth. Each soil can have a maximum of 10 soil layers.

6. *.MGT

This is the management input file. This file contains input data for management operations for planting, harvest, irrigation applications, nutrient applications, pesticide applications, and tillage operations. Users can schedule the operations by month and day or by heat units. Inputs include dates, tillage, crop, and pesticide codes (relating to the numbers in the CROP.DAT, TILL.DAT, and PEST.DAT data base files), and application amounts. The maximum number of years of rotation is currently set at 40 and can be easily increased.

7. *.MCO

This is the management code input file. This file contains input data for automatic management operations for irrigation and fertilization. The user can input stress level to trigger irrigation or fertilization and SWAT will automatically boost soil levels to specified amounts.

8. *.GW

This is the groundwater input file. This file contains aquifer data including a recession parameter, specific yield, a revap coefficient, and a deep aquifer percolation coefficient.

9. *.PCP

This is the measured precipitation input file. There are four choices for rainfall input: 1) Read in single rain gage for entire basin, in this case, there is only one precipitation input file for the entire basin; 2) Read in one rain gage for each subbasin, in this case, each of the subbasins must have one measured precipitation input data file, and the files contain daily rainfall values in mm and each day is stored on one line; 3) Simulated single rain gage for entire basin; 4) Simulated for multiple rain gages; in the last two cases, no precipitation input file is necessary to run the simulation.

10. *.TMP

This is the measured temperature input file. There are also four choices for temperature input: 1) Read in single maximum and minimum temperature for entire basin, in this case, there is only one temperature input file for the entire basin; 2) Read in maximum and minimum temperature for each subbasin, in this case, each of the subbasins must have one measured temperature input data file, and the files contain daily maximum and minimum temperature values in Celsius and each day's maximum and minimum temperature are stored on one line; 3) Simulated single maximum and minimum for entire basin; 4) Simulated for each subbasin; in the last two cases, no temperature input file is necessary to run the simulation.

There is one file named FILE.CIO which contains all of the names of the input and output files for an application. It must always be called FILE.CIO and must always be present in every SWAT application.

All of the example input files can be seen in the **Appendix X**.

4.4 Model Output Files

1. *.STD

This is the standard output file. It first lists several input variables for inspection, including the random number generator seeds, the rainfall and temperature input code, monthly rainfall generator parameters, weather generator variables, basin hydrology and sedimentation inputs, pond, reservoir and routing data, soil and crop data, etc. It then prints precipitation, surface runoff, subsurface flow, water yield, percolation, transmission losses, ET, sediment yield, and soil water content. These values are basin composite values, weighted by subbasin area. They may be printed daily or monthly, as desired by the user, and summed for the entire year. Finally, all average annual values are listed and balance errors are printed.

2. *.STB

This is the subbasin output file. It reports output for each subbasin by month and year for over 50 variables related to water, sediment, nutrients and crops.

3. *.RCH

This is the reach output file. It reports output for each routing reach by month and year for water, sediment, and nutrients entering , leaving and being deposited in the channel reaches.

4. *.RSV

This is the reservoir output file. It reports output for each reservoir by month and year for water and sediment entering, leaving and being deposited in the reservoir.

5. *.LQO

This is the lake water quality output file. It reports output by month for the lake water quality parameters simulated by the model that includes pesticide concentrations, pesticide balance components, total phosphorus, and chlorophyll concentrations.

6. *.PSO

This is the pesticide output file. It reports output by month for soluble and sorbed pesticide yields for each subbasin.

7. *.EVE

This is the event output file. For each runoff event, the model outputs results to this file, including runoff sediment and nutrient yields. This file can then be read by another SWAT run, thus allowing modeling of large basins to be split into several individual SWAT runs.

5. ESTABLISHMENT OF DATABASES

The modeling effort was supported by data organized in a geographic information system data base and in a hydrologic data base. These databases are outlined in subsections 5.1 and 5.2 and presented in graphical form in subsection 5.3.

5.1 Geographic Information System (GIS) Database

A Geographic Information Systems (GIS) data base was developed, primarily for the purpose of preparing input parameters for the hydrologic model SWAT. Since SWAT is a largely physically based, spatially distributed watershed model, it is critical to have spatially distributed data, and more important, the analytical functions to manipulate these data in order to extract desired parameters. GIS, by providing precisely these data and these capabilities, played an important role in this project in the detailed modeling of spatial variability of hydrologic processes. These tasks would otherwise have been a very time consuming and therefore costly component of hydrologic modeling, especially when areal features are involved.

To the extent permitted by data availability, GIS data were gathered for most of the spatial parameters of the SWAT model. These data provide spatial distribution of climate, channel morphology, ground water table, and basin conditions such as basin topography, landuse, soils, hydrography, and geology (bedrock elevation). Other necessary data include township and range reference systems and administrative boundaries. The specific data files are detailed by data themes in a later section. All GIS data were made available in Arc/Info (workstation version 6.0 or higher) format, which is compatible with the state-wide GIS data base. Each GIS coverage contains default attributes such as ID, area, perimeter for polygon coverages, and ID, left and right polygon IDs, beginning and ending node IDs, and length of the line for line coverages. All the final coverages are in Albers projection. Besides GIS data coverages, there are also several text files in the data base, which were developed particularly for generating maps to display different data themes.

The model parameters were extracted through various GIS procedures, depending upon the nature of the parameters. In this study, length and areal measurements were frequently needed, such as stream lengths and sizes of subbasin, landuse, and soil polygons. These values were calculated automatically and stored as part of attributes when a GIS coverage was created. GIS overlay functions were used to obtain composite parameters such as soil properties in a subbasin, where a soil coverage was overlaid with a basin boundary coverage. With appropriate areal weights calculated by GIS procedures, spatial averages of soil parameters were estimated for each subbasin and used as input for the hydrologic model. Using relational data base functions, attributes from different data sources were linked and manipulated to derive required parameters for the model; in particular, soil parameters were derived from multiple sources. For spatial data that were only available at point locations, such as precipitation and temperature, spatial interpolation based on the Thiessen polygon technique was used to extend point data to polygons, so that areal weights could be extracted.

Detailed descriptions of GIS coverages, organized by parameter categories, are given below. For each coverage, the available information of data source, scale, coverage type (point, line, or polygon), and map projection are provided. File names are **bold faced**; among these, GIS coverages are indicated in **UPPER CASE**.

SOILS:

Soils data were initially obtained from DASC at the soil association level for the entire state of Kansas. Overlay functions were applied to extract an area that covers the Lower Republican River Basin. Several soil attributes were linked from multiple data sets by soil association ID and added into the attribute table. Subbasin boundaries were overlaid with the soils; the proportions of soil associations within each subbasin were then computed and used as areal weights for a series of soil parameters required by the hydrologic model. The basic information of GIS coverages and text files related to soils data is as follows:

SOILASSOC
description: generalized soil survey at the soil association level
geographic area: entire Kansas
source: State Soil Geographic Data Base (STATSGO) , DASC
scale: 1:250,000
coverage type: polygon
projection: Lambert conformal
attributes: MUID (soil association ID)

REPUBHUC_SOIL
a subset of SOILASSOC within the Lower Republican River Basin, in Lat/Long projection.
attributes: MUID

REPSOIL
a modified coverage of REPUBHUC_SOIL, whose lat/long projection was changed into Albers projection and more attribute items were added to the items in REPHUC_SOIL.

additional attributes: MUID, soil component code (1-16), percentage of components, soil phase number, soil layer number, soil layer depth (low and high), soil texture, clay content (low and high), available water capacity (low and high), bulk density (low and high), permeability (low and high), and soil association names.

HUC11SOIL

an overlaid coverage of REPSOIL and HUC-11 subbasin boundary coverage REPH11. Attribute items are the combination of the two coverages.

awcu.aml - macro language file to display soil available water capacity by value range
awc2.aml - macro language file to display available water capacity by MUID polygons
awc.shd - shade set used by the aml files
awcu.key - key file used by the aml files

BASEMAPS:

Basemap information was obtained from DASC or was digitized off USGS 1:100,000 or 1:250,000 topo quads. The base maps contain administrative boundaries, township, range, and section systems, and major streams and water bodies. These coverages were included in the data base primarily for mapping and reference purposes.

COUNTY

description: county boundaries of eight counties that cover the lower Republican River Basin
geographic area: an area including the Lower Republican River Basin
source: Kansas Cartographic Database (KCD), DASC
scale: 1:24,000 -1:100,000
coverage type: polygon, line
projection: Albers
attributes: line attributes: DLG#, KCD#; polygon attributes: county name, county abbreviation, KS code for county, FIPS#, FIPS code

REPCOUNTY

a subset of COUNTY, within the Lower Republican River Basin, clipped by basin boundary coverage REPBOUND

CSEATS
description: 5 county seat locations in the Lower Republican River Basin
geographic area: the Lower Republican River Basin
source: digitized off USGS 1:250,000 Manhattan and Beloit quads
scale: 1:250,000
coverage type: point
projection: Albers
attributes: county names, county seat names

REPSECT
description: section corner points
geographic area: the Lower Republican River Basin
source: Kansas Cartographic Database (KCD), DASC
scale: 1:24,000 - 1:100,000, intended scale of use
coverage type: point
projection: Albers
attributes: the default items

REPTOWNR
description: Township and Range lines
geographic area: the Lower Republican River Basin
source: Kansas Cartographic Database (KCD), DASC
scale: 1:24,000 - 1:100,000
coverage type: line
projection: Albers
attributes: the default items

MTICS
description: the master tic file
geographic area: an area surround the Lower Republican River Basin
source: generated from a text file
scale: N/A
coverage type: tic
projection: lat/long
attributes: none

basemap.aml - macro language file to display base maps

LANDUSE/LAND COVER:

Landuse and land cover data were developed from classified Thematic Mapper (TM) images (1989-1990). A total of ten categories of landuse/land cover were identified, five urban categories and four rural in addition to a miscellaneous category. The five urban categories were combined into one unit in this study. The areal weights can be extracted by overlaying the landuse/landcover coverage with the subbasin boundary coverage. The weighted landuse data can be used as input parameters for landuse management files of the hydrologic model.

REPHUC_LANDC

description: landuse/landcover

geographic area: the Lower Republican River Basin

source: landuse classification from Thematic Mapper (TM) (original), DASC

scale: 30mx30m resolution of original image, approximately 1:100,000 for the classified data

coverage type: polygon

projection: lat/long

attributes: landuse code, detailed definition of the code is in the associated text files with abbreviated county names and the suffix "lan".

REPLANDC

a modified coverage of REPHUC_LANDC, whose lat/long projection was changed into Albers.

The following are text files associated with the landuse/land cover coverages, two files for each county; one contains the definition of landuse code and a classification accuracy matrix, the other (.doc) provides basic information of the data.

cdlan; cdlan.doc

cylan; cylan.doc

dklan; dklan.doc

gelan; gelan.doc

jwlan; jwlan.doc

mclan; mclan.doc

mslan; mslan.doc
rllan; rllan.doc
rplan; rplan.doc
wslan; wslan.doc

lanc.aml - macro language file to produce landuse map - plotter version
landcolor.aml - macro language to display landuse map - color printer version
luse1.key - key file used by lanc.aml
luse2.key - key file used by landcolor.aml

HYDROGRAPHY:
WATERSHED BOUNDARIES

Watershed boundary coverages (plus a gauging station coverage) were used as part of the base maps for mapping and reference purposes. The areas of the entire basin and subbasins were used as input parameters for basin and subbasin input files of the hydrologic model. The HUC-11 subbasin boundary coverage was extremely important in computing areal weights for soils, climate, and landuse attributes for each subbasin. The areal weights were extracted by overlaying the subbasin boundary coverage with other coverages of interest.

REPHUC_BOUND
description: boundary line of the Lower Republican River Basin, which is identified by the USGS Hydrologic Unit Code (HUC) with 8 digits
geographic area: Lower Republican River Basin
source: SCS (original), DASC
scale: 1:100,000
coverage type: polygon
projection: lat/long
attributes: HUC-8 code

REPBOUND
a modified coverage of REPHUC_BOUND, whose lat/long projection was changed to Albers

REPH11
description: subbasin boundaries of the Lower Republican River Basin, the subbasins are identified by the Hydrologic Unit Code (HUC) with 11 digits

geographic area: Lower Republican River Basin
source: SCS (original), DASC
scale: 1:100,000
coverage type: polygon
projection: Albers
attributes: HUC-11 code, SWAT subbasin code

GAGSTAT
description: gauging station locations
geographic area: the Lower Republican River Basin
source: USGS
scale: N/A
coverage type: point
projection: Albers
attributes: gauging station names

subbasin.aml - macro language file to display subbasins

STREAMS

Streams, especially lengths of various portions of the streams, were used as input parameters for subbasin and routing files of the hydrologic model. In conjunction with topographic data, stream lengths were used to compute channel slopes as input parameters for the subbasin and routing files of the model. In addition, average slope length, also required by the subbasin input file of the model, was derived based on spatial data of streams, topography, and basin boundaries.

STRMS
description: all streams in the USGS 1:100,000 quads: Smith Center, Concordia, Clay Center, Manhattan, and Blue Rapids
geographic area: the Lower Republican River Basin
source: digitized from USGS 1:100,000 topo quads
scale: 1:100,000
coverage type: line
projection: Albers
attributes: the default items

PSTREAMS

a subset of STRMS, only the primary streams are included.

WATER BODIES

Areas of water bodies such as reservoirs and ponds were required input parameters for reservoir and ponds input files of the hydrologic model.

RESVR

description: boundary line of Milford Reservoir
geographic area: Milford Reservoir in the Lower Republican River Basin
source: digitized off 1:250,000 USGS Manhattan quad
scale: 1:250,000
coverage type: polygon
projection: Albers
attributes: the default items

PONDS

description: boundary lines of ponds
geographic area: the Lower Republican River Basin
source: digitized off 1:250,000 USGS Beloit and Manhattan quads
scale: 1:250,000
coverage type: polygon
projection: Albers
attributes: the default items

WELLS

Well data, especially groundwater elevations, were primarily used for groundwater input files of the hydrologic model.

REPWL77

description: water elevation contour lines, 1982
geographic area: within the flood plain of the Lower Republican River
source: L.E. Dunlap, 1982. Geohydrology of principal aquifers in the Republican River Basin, Kansas. USGS Open File Report 82-79.
scale: 1:250,000

coverage type: line
projection: Albers
attributes: elevation (identical to coverage-ID)

wl77.aml - macro language file to display groundwater elevations (1977)

WATER RIGHTS:

Water rights data were used to estimate irrigation related parameters for landuse management input files of the hydrologic model.

WTRGHT
description: well locations showing attributes related to water rights
geographic area: inside and surrounding the Lower Republican River Basin
source: Division of Water Resources (original data), USGS(Arc/Info coverage)
scale: N/A
coverage type: point
projection: Albers
attributes: file-ID, township, range, section, DWR-ID, quarter system of sections, DWR filed office code, DWR basin code, DWR stream code, GMD code, DWR alluvial valley code, DWR special use area code, county code, number of wells in battery, test date, test rate, water source (ground vs. surface), water use code, permit overlap code, permit status code, county FIPS code, and water use-abbreviations.
DWR - Board of Agriculture, Division of Water Resources, State of Kansas
GMD - Ground Water District

wtrt.aml - macro language file to display water right locations.

BEDROCK ELEVATION:

REPBEDRCK
description: contour lines of bedrock elevation
geographic area: within the flood plain of the Lower Republican River
source: L.E. Dunlap, 1982. Geohydrology of principal aquifers in the Republican River Basin, Kansas. USGS Open File Report 82-79.
scale: 1:250,000
coverage type: line
projection: Albers

attributes: elevation (identical to coverage-ID)

bedrck.aml - macro language file to display bedrock elevations

ELEVATION:

Elevation data, in combination with other information such as stream lengths and basin boundaries, were used primarily for computing channel slopes and average slope length for subbasin and routing files of the hydrologic model.

BELOITLAT
description: lattice from USGS 1:250,000 3 arc second interval DEM - Beloit East
geographic area: 39N to 40N, -98W to -99W degrees
source: USGS DEM, DASC
scale: 1:250,000
coverage type: lattice
projection: lat/long
attributes: elevation

MANHATLAT
description: lattice from USGS 1:250,000 3 arc second interval DEM - Manhattan West
geographic area: 39N - 40N, -97W - -98W degrees
source: USGS DEM, DASC
scale: 1:250,000
coverage type: lattice
projection: lat/long
attributes: elevation

REPUBLAT
a combination of BELOITLAT and MANHATLAT

REP_HYPSO
description: hypsography
geographic area: the Lower Republican River Basin, incomplete due to lack of data at DASC
source: USGS DLG 1:100,000, DASC
scale: 1:100,000

coverage type: line
projection: lat/long
attributes: USGS classification code (major, minor, 1,2,3), minor2 carries elevation

REPHYPSO
a modified coverage of REP_HYPSO, whose lat/long projection was changed into Albers

elev.aml - macro language file to display basin hypsography.

CLIMATE:

Climate coverages contain locations of meteorological stations. Attached to each station are the availability codes of several attributes such as daily precipitation, and daily maximum and minimum temperature measurements. Thiessen polygon interpolation was applied to the coverages in order to extend point data to polygon data that cover the entire study area. The subbasin boundary coverage was overlaid with the Thiessen polygons so that the proportions of Thiessen polygons within each subbasin were computed and used as areal weights for climatic parameters of the hydrologic model.

NCDCSTAT
description: NCDC meteorological station locations in Kansas
geographic area: entire Kansas
source: National Climatic Data Center (NCDC)
scale: N/A
coverage type: point
projection: Albers
attributes: data source, station ID, station name, beginning and ending observation dates, availability of precipitation, maximum temperature, minimum temperature, evaporation, snow, and hourly data.

NCDCPCP
a subset of NCDCSTAT, it contains all stations state-wide which have precipitation records.

NCDCP9
a subset of NCDCSTAT, it contains only 9 major stations within and surrounding the Lower Republican River Basin that have precipitation records.

NCDCTEMP
a subset of NCDCSTAT, it contains all stations state-wide that have temperature records.

THSSNPCP
a Thiessen polygon coverage that is the spatial interpolation of NCDCPCP (state-wide precipitation point coverage) using a Thiessen polygon technique.

THSSNP9
a Thiessen polygon coverage that is the spatial interpolation of NCDCP9 (a 9-precipitation station point coverage) using a Thiessen polygon technique, covering the Lower Republican River Basin.

THSSNTEMP
a Thiessen polygon coverage that is the spatial interpolation of NCDCTEMP (state-wide temperature point coverage) using a Thiessen polygon technique.

HUC11PCP
a polygon coverage that is the combination of THSSNPCP (a state-wide Thiessen polygon coverage of precipitation stations) and the HUC-11 boundary coverage REPH11.

HUC11P9
a polygon coverage that is the combination of THSSNP9 (a Thiessen polygon coverage of precipitation of the Lower Republican River Basin) and HUC-11 boundary coverage REPH11.

HUC11TEMP
a polygon coverage that is the combination of THSSNTEMP (a state-wide Thiessen polygon coverage of temperature stations) and HUC-11 boundaries.

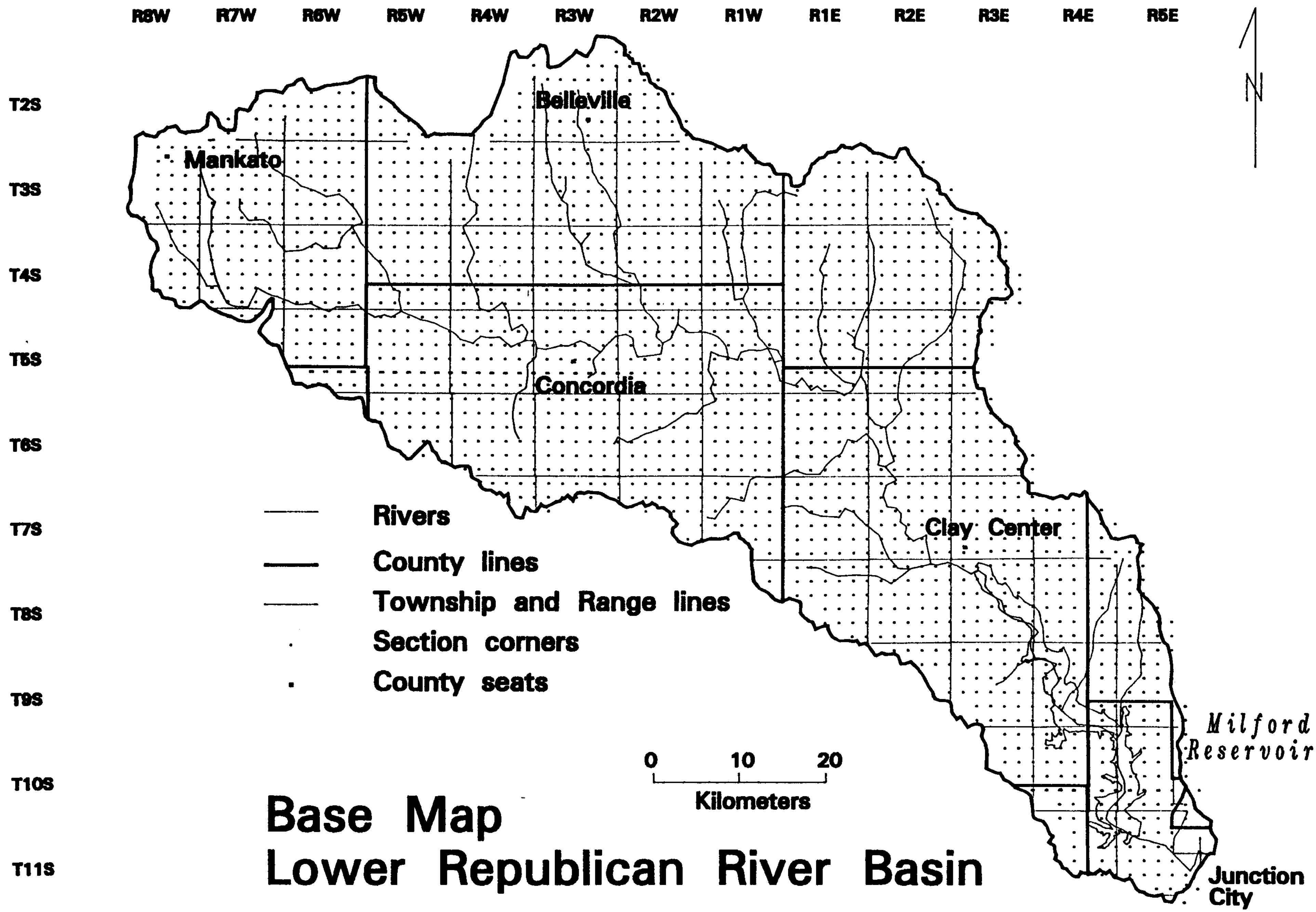
huc11p9.aml - macro language file to display precipitation Thiessen polygons and subbasin boundaries
huc11temp.aml - macro language file to display temperature Thiessen polygons and subbasin boundaries

The GIS data base has been summarized in a series of maps. The base map of the Lower Republican River Basin is shown in Figure 3. Figure 4 shows the division of the basin into nine (9) subbasins is shown. The topography map of the basin is shown in Figure 5. The precipitation and temperature measuring stations (weather stations) with the corresponding Thiessen polygons are indicated in Figures 6 and 7, respectively. Figure 8 presents the distribution of available soil water capacity. Landuse is shown in Figure 9. The distribution of water rights over the basin is given in Figure 10. The groundwater table, from 1977 data, is contoured as shown in Figure 11; the bedrock elevation contours are shown in Figure 12.

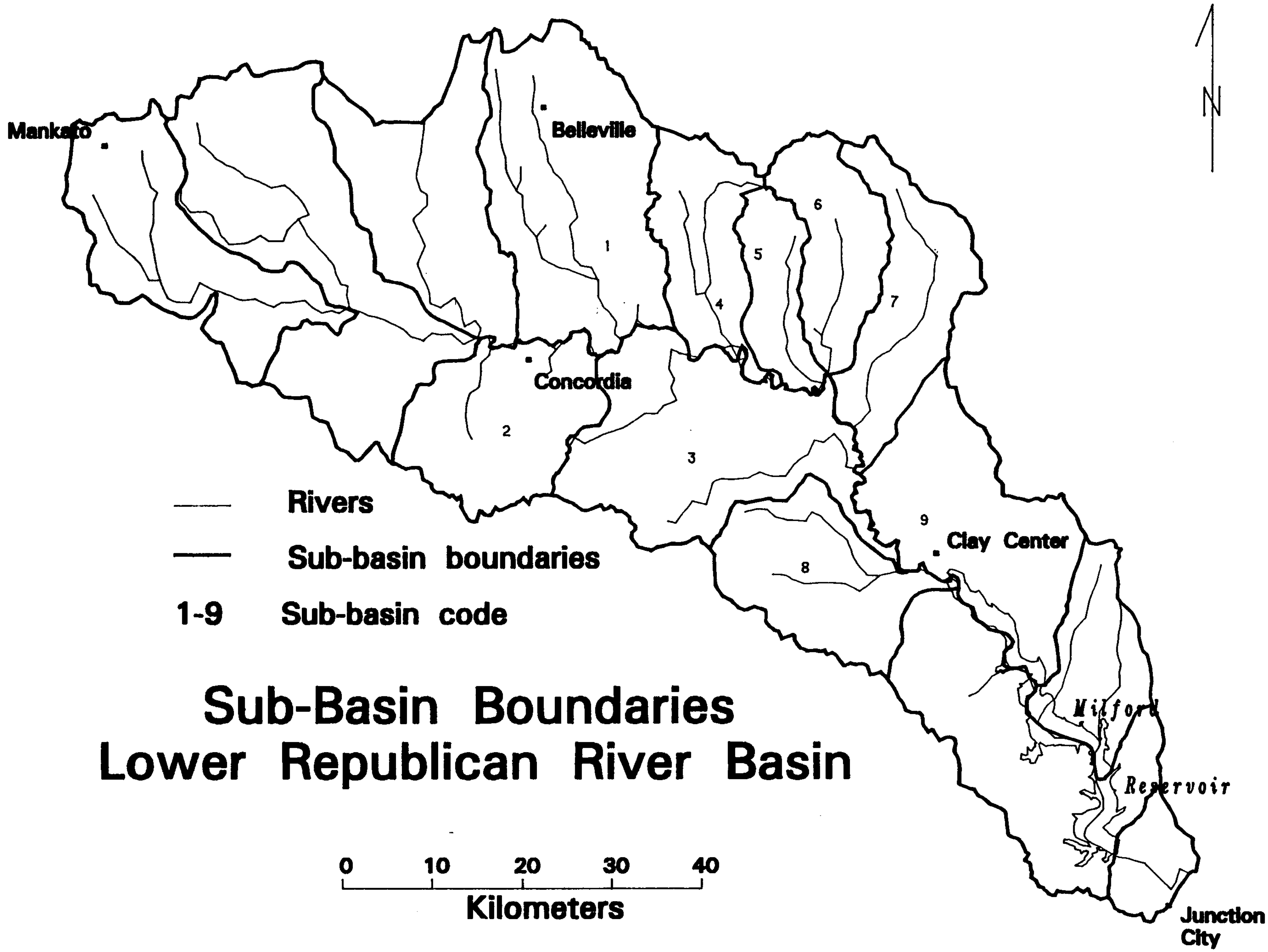
5.2 Hydrologic Database

The hydrologic data base consists of time series of the hydrologic input and output, precipitation and streamflow. The streamflow hydrographs observed at the Concordia and Clay Center gauging stations are shown in Figure 13 for the periods of record. The difference in discharge between those two stations is the "streamflow gain," to which we will refer in Section 6 Results: Parameter Estimation and Sensitivity Analysis; the streamflow gain will be compared to the "basin yield" computed by the SWAT model. Annual precipitation and streamflow for the corresponding gauging stations at Concordia and at Clay Center are expressed as water depths over the basin and are shown in Figures 14 and 15. Water rights (surface water, groundwater and total) and appropriations are also presented graphically in Figures 16-18. Figure 19 contrasts the evolutions of total water appropriations in the Lower Republican River Basin with the mean annual streamflow at Clay Center. Two different ordinate scales are used in Figures 16-19. We note the doubling of appropriations since the severe drought of the mid-1950s. The streamflow at Clay Center shows a weak statistical downward trend; the annual discharge has remained rather stable, exhibiting variations that are primarily climate-driven.

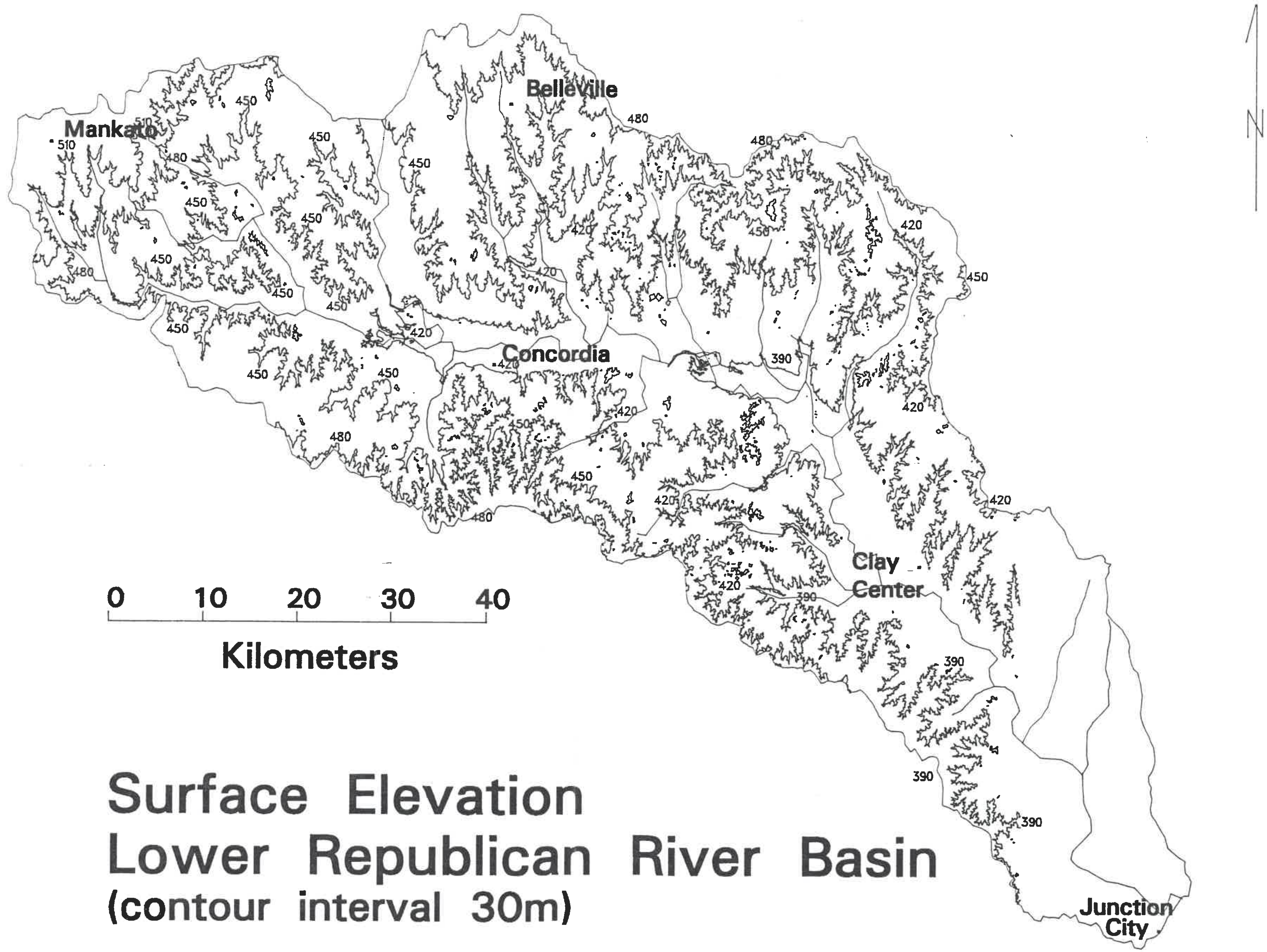
5.3 Graphical Presentation of Data: Maps and Hydrologic Series



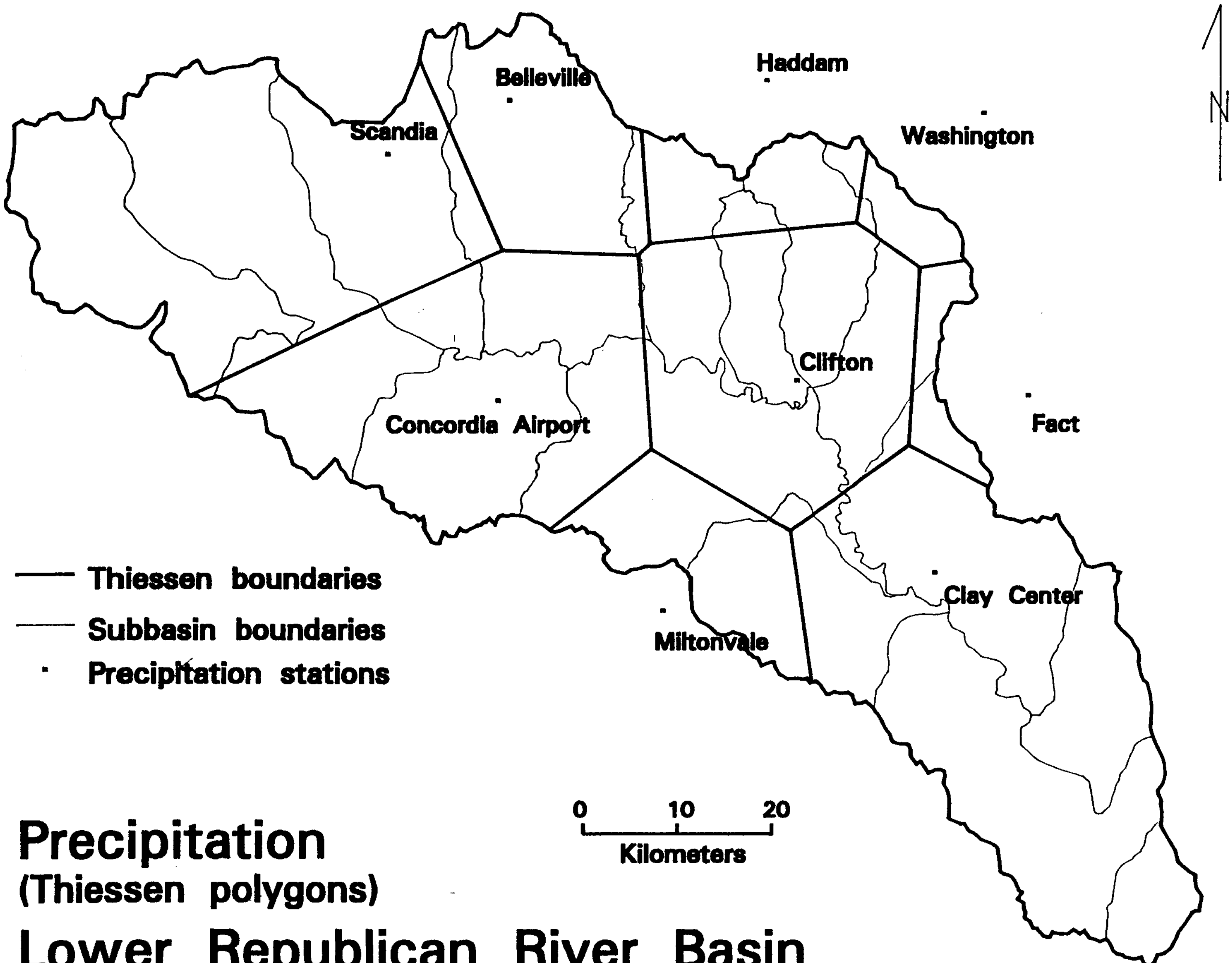
Base Map
Lower Republican River Basin



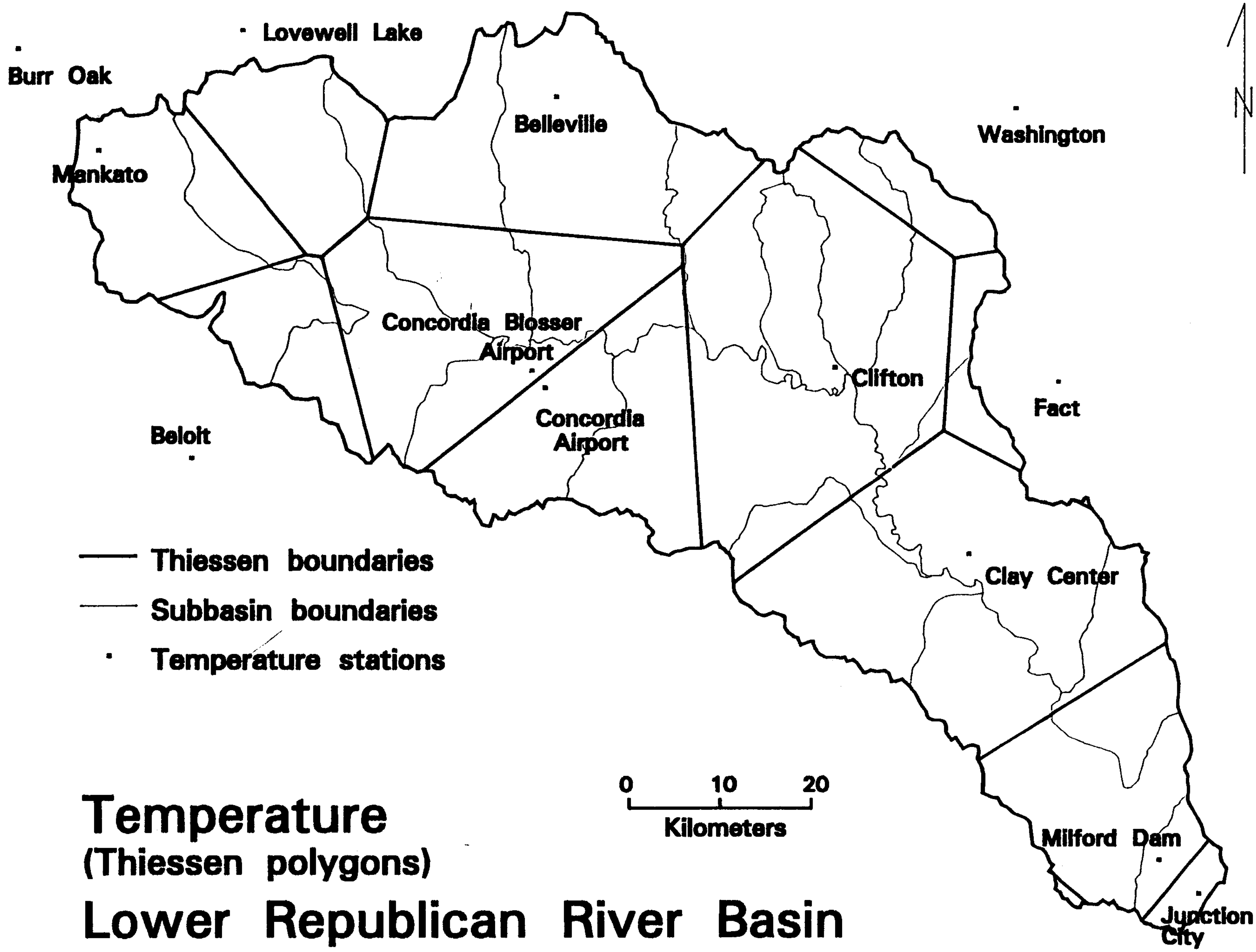
Sub-Basin Boundaries
Lower Republican River Basin



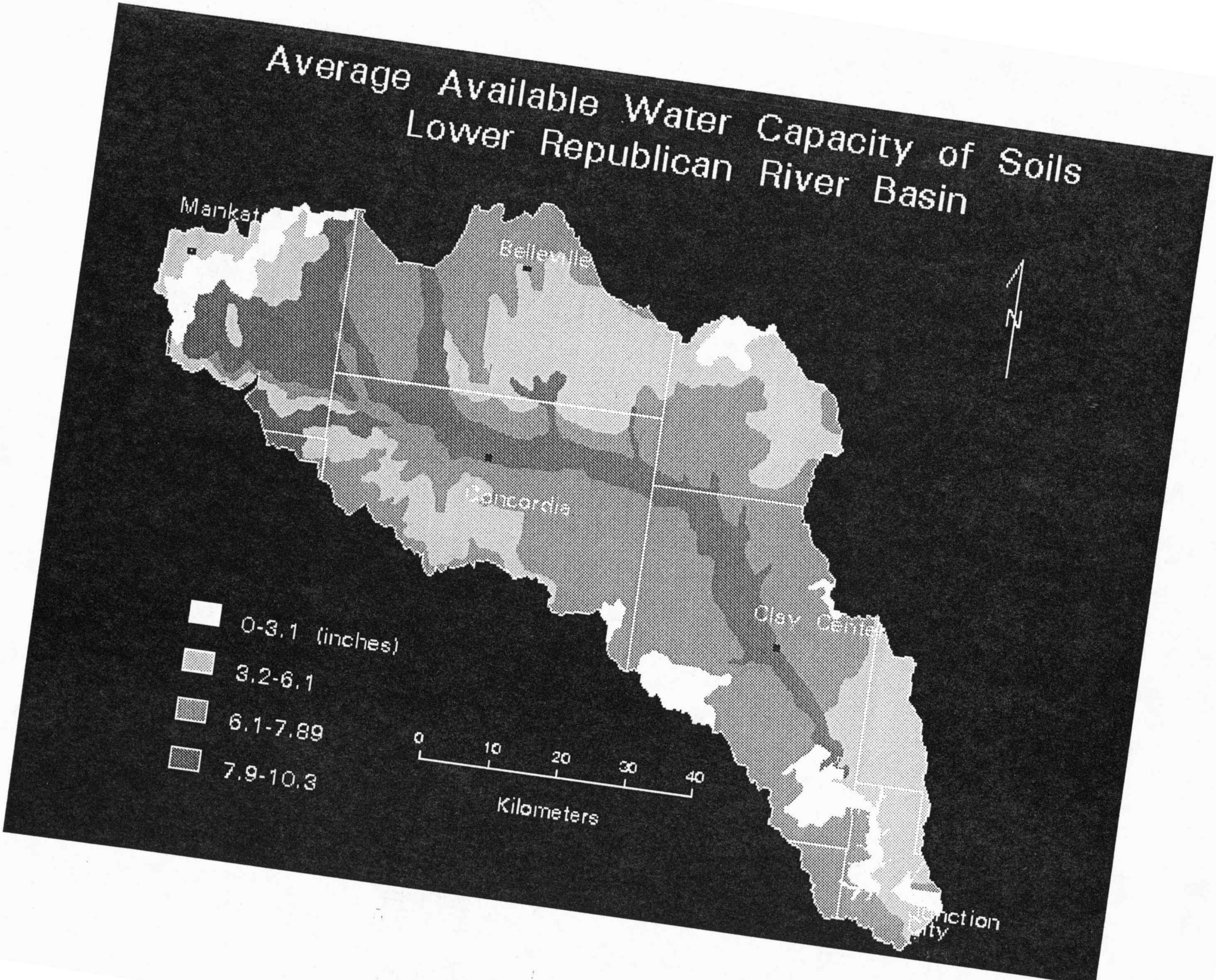
Surface Elevation
Lower Republican River Basin
(contour interval 30m)

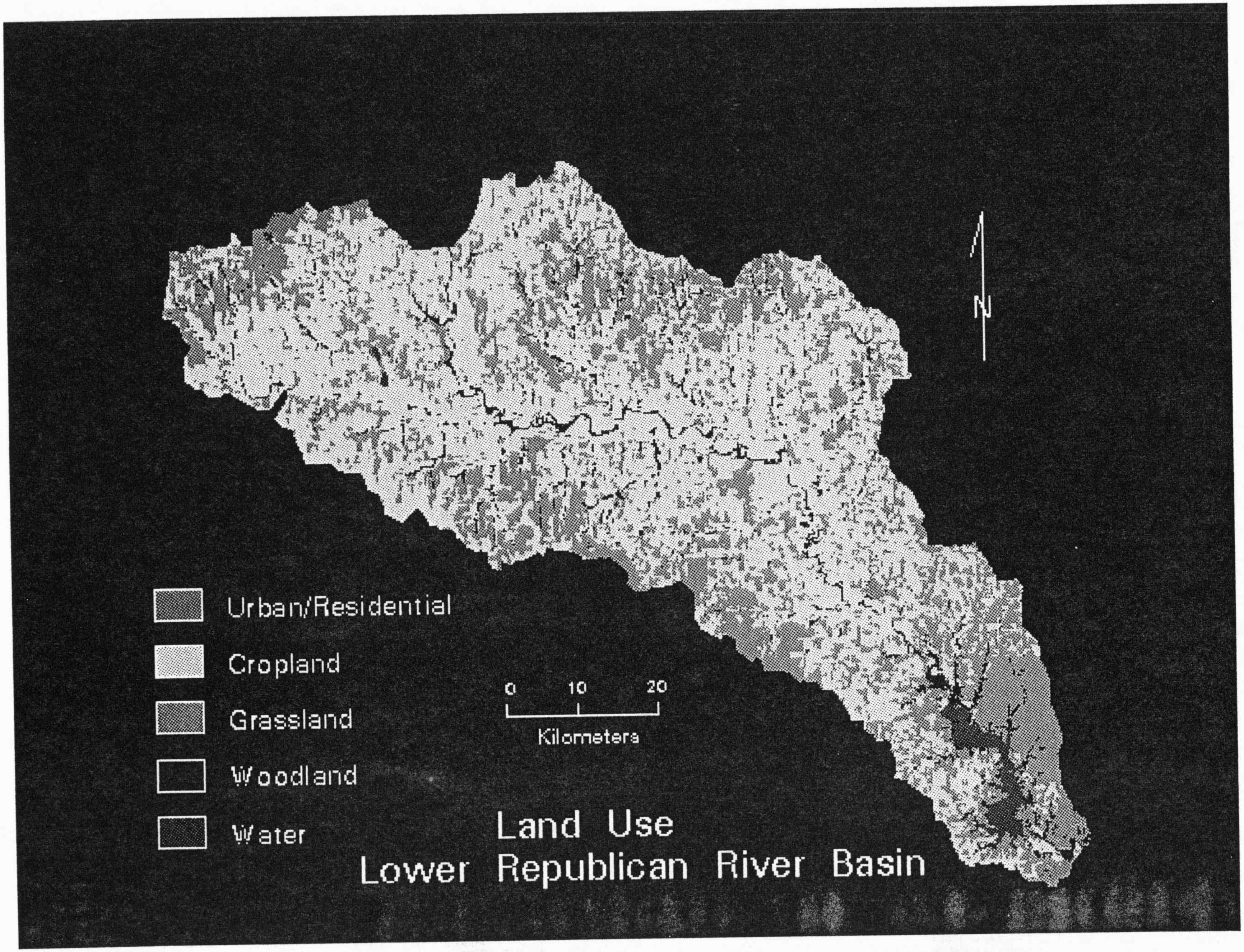


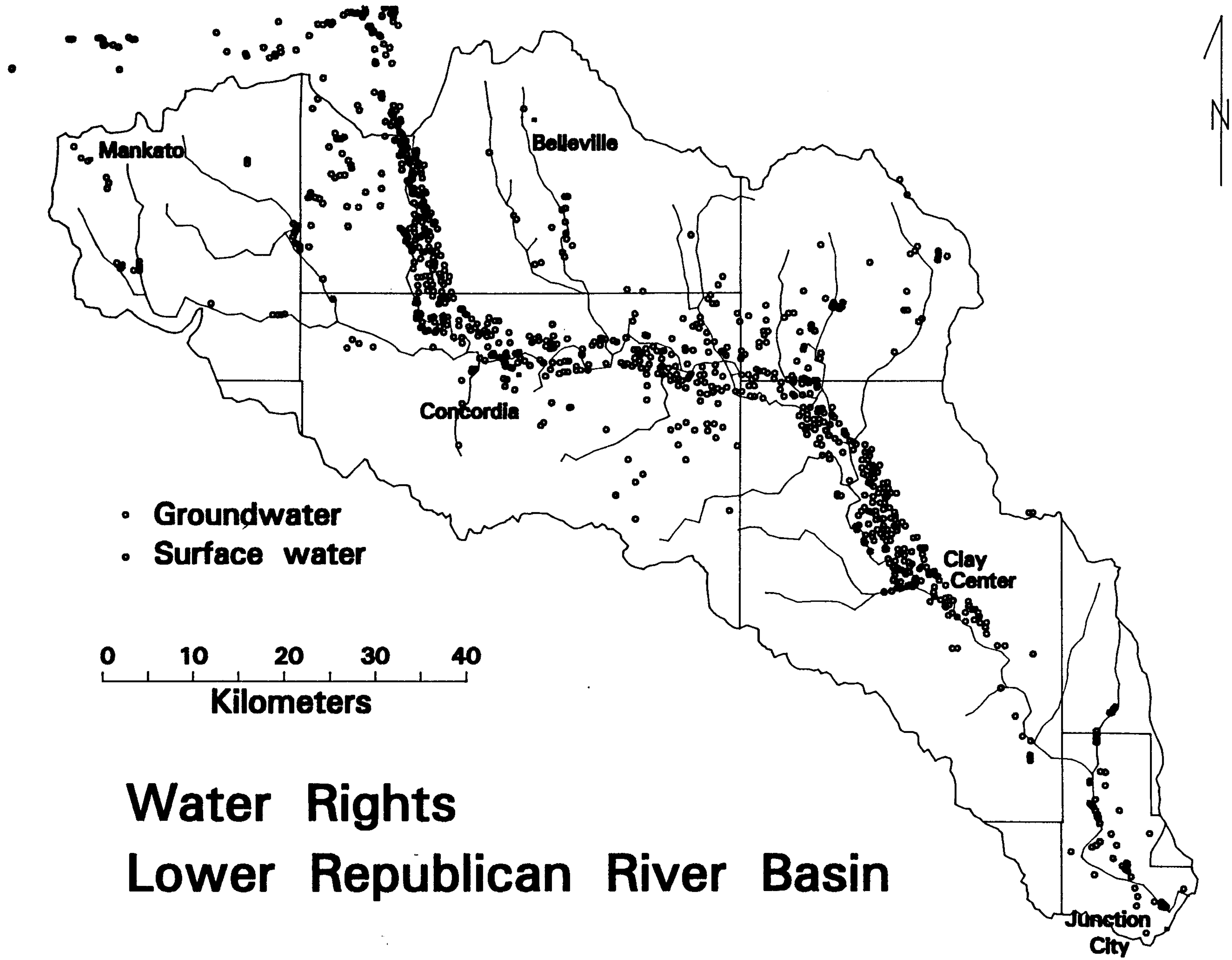
Precipitation
(Thiessen polygons)
Lower Republican River Basin



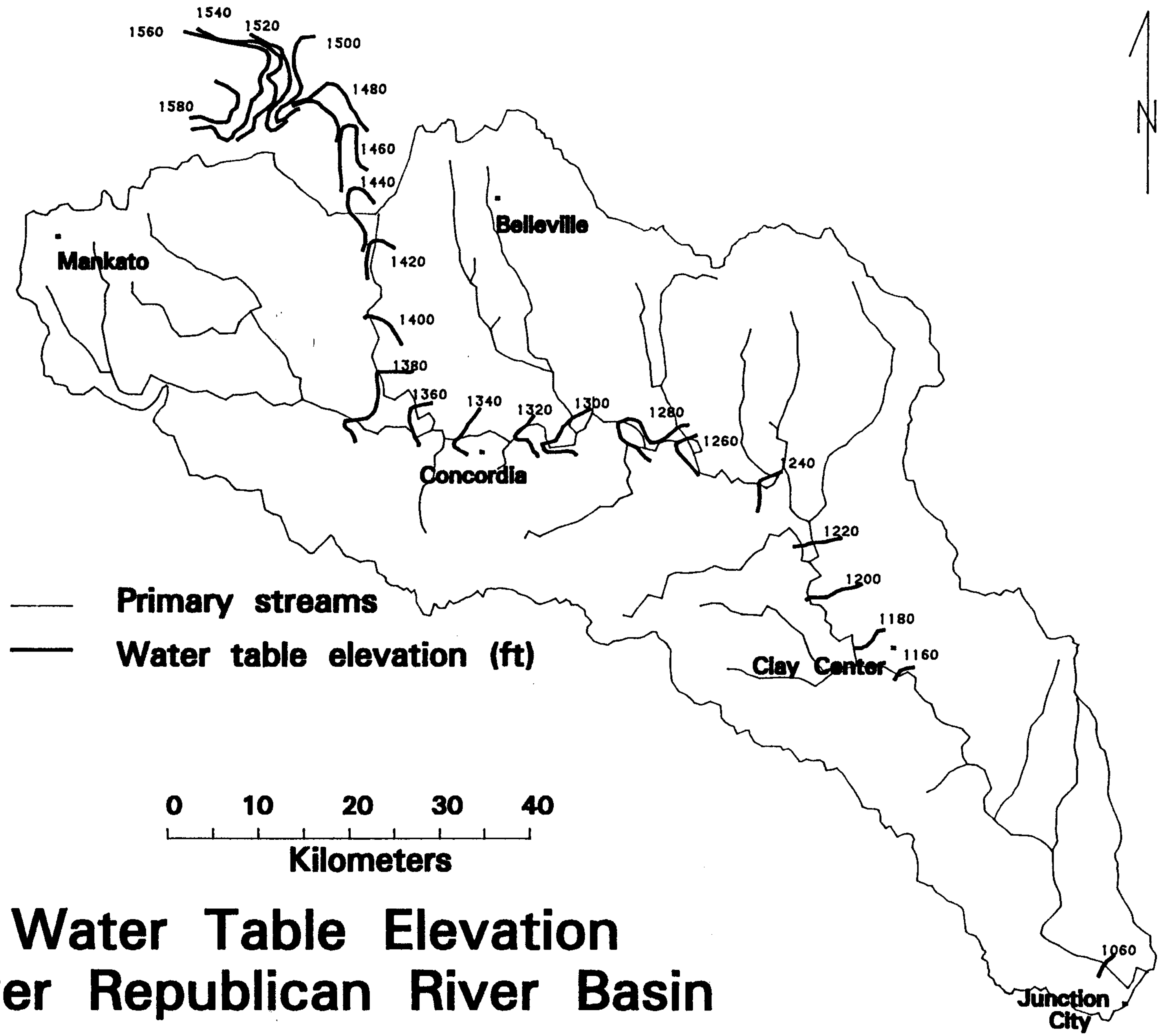
Temperature
(Thiessen polygons)
Lower Republican River Basin


Average Available Water Capacity of Soils
Lower Republican River Basin
Belleville
Concordia
Clay Center
N
0-3.1 (inches)
3.2-6.1
6.1-7.89
7.9-10.3
0
10
20
30
40
Kilometers

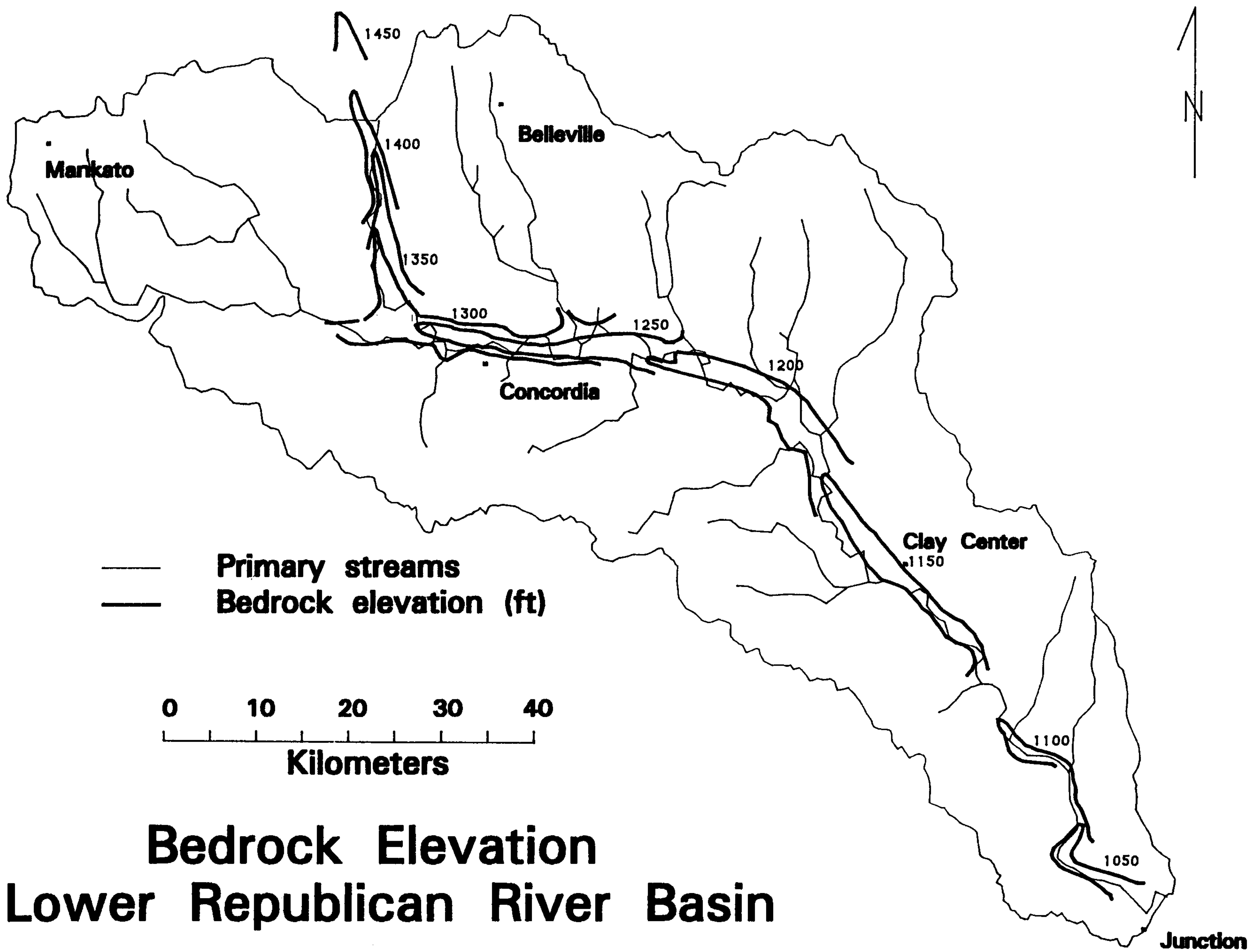

Urban/Residential
Cropland
Grassland
Woodland
Water
0 10 20
Kilometers
N
Land Use
Lower Republican River Basin



Water Rights
Lower Republican River Basin



Water Table Elevation
Lower Republican River Basin



Bedrock Elevation
Lower Republican River Basin

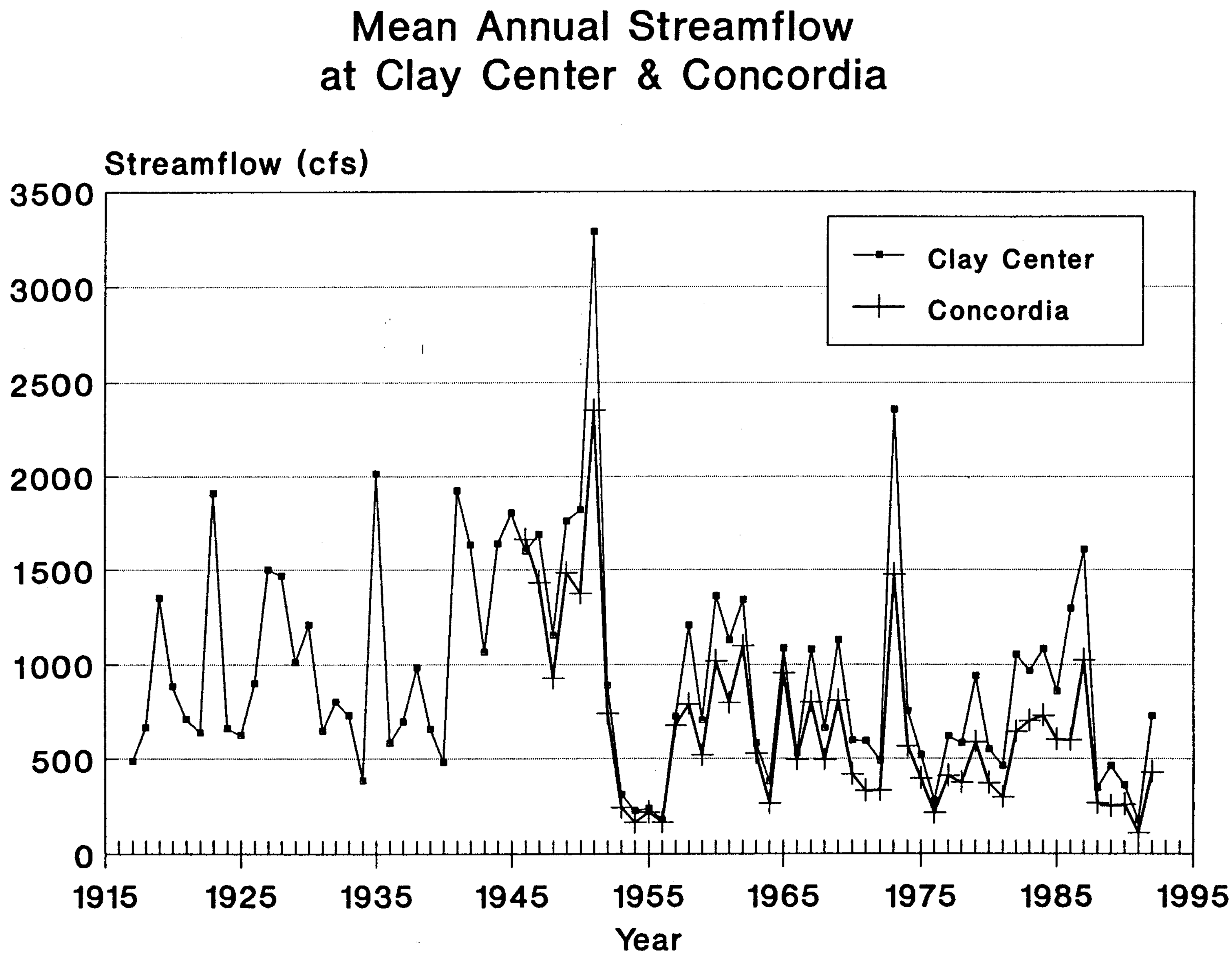


Fig. 13 - Annual Streamflow Hydrographs at Concordia & Clay Center

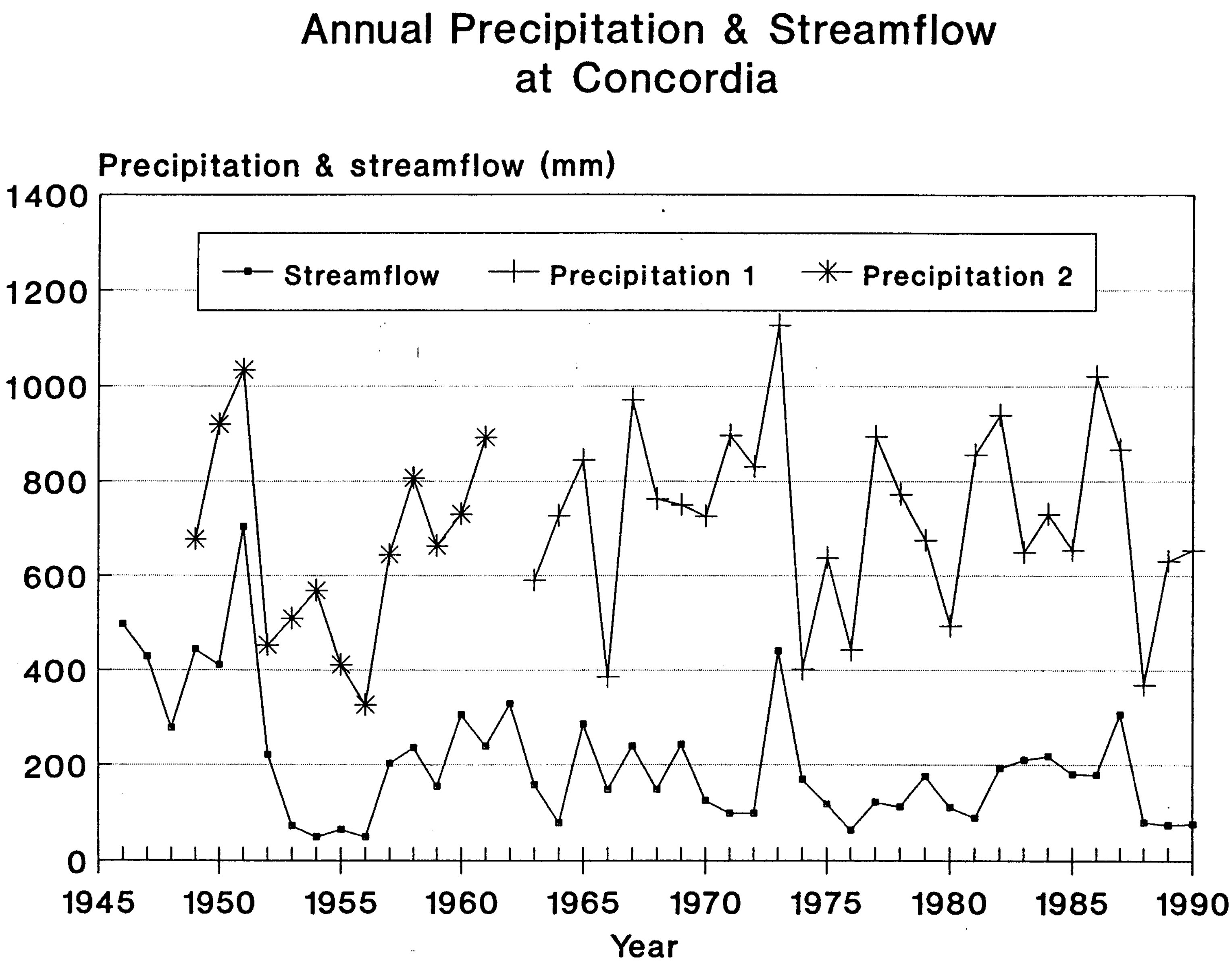


Fig. 14 - Annual Precipitation & Streamflow at Concordia

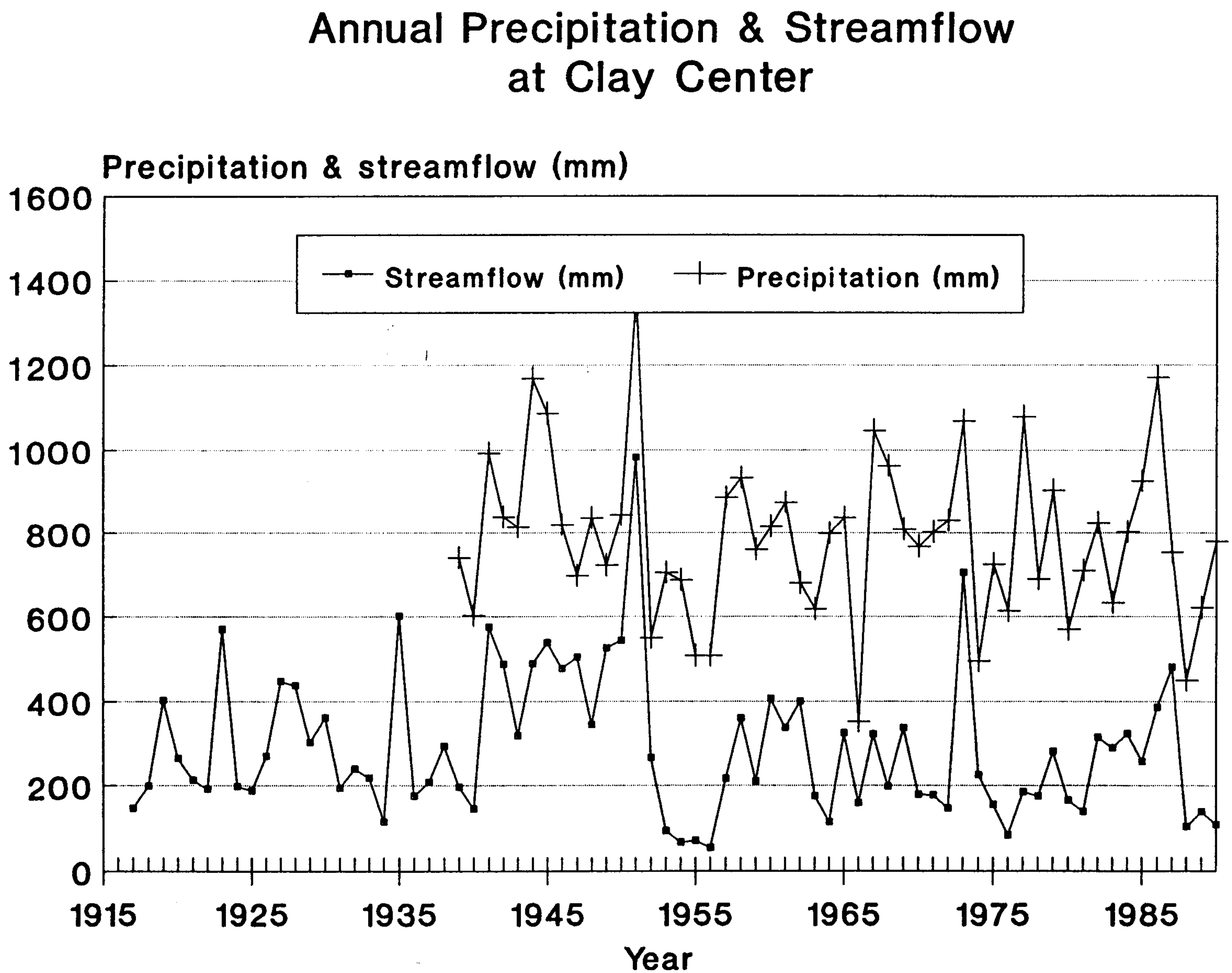


Fig. 15 - Annual Precipitation & Streamflow at Clay Center

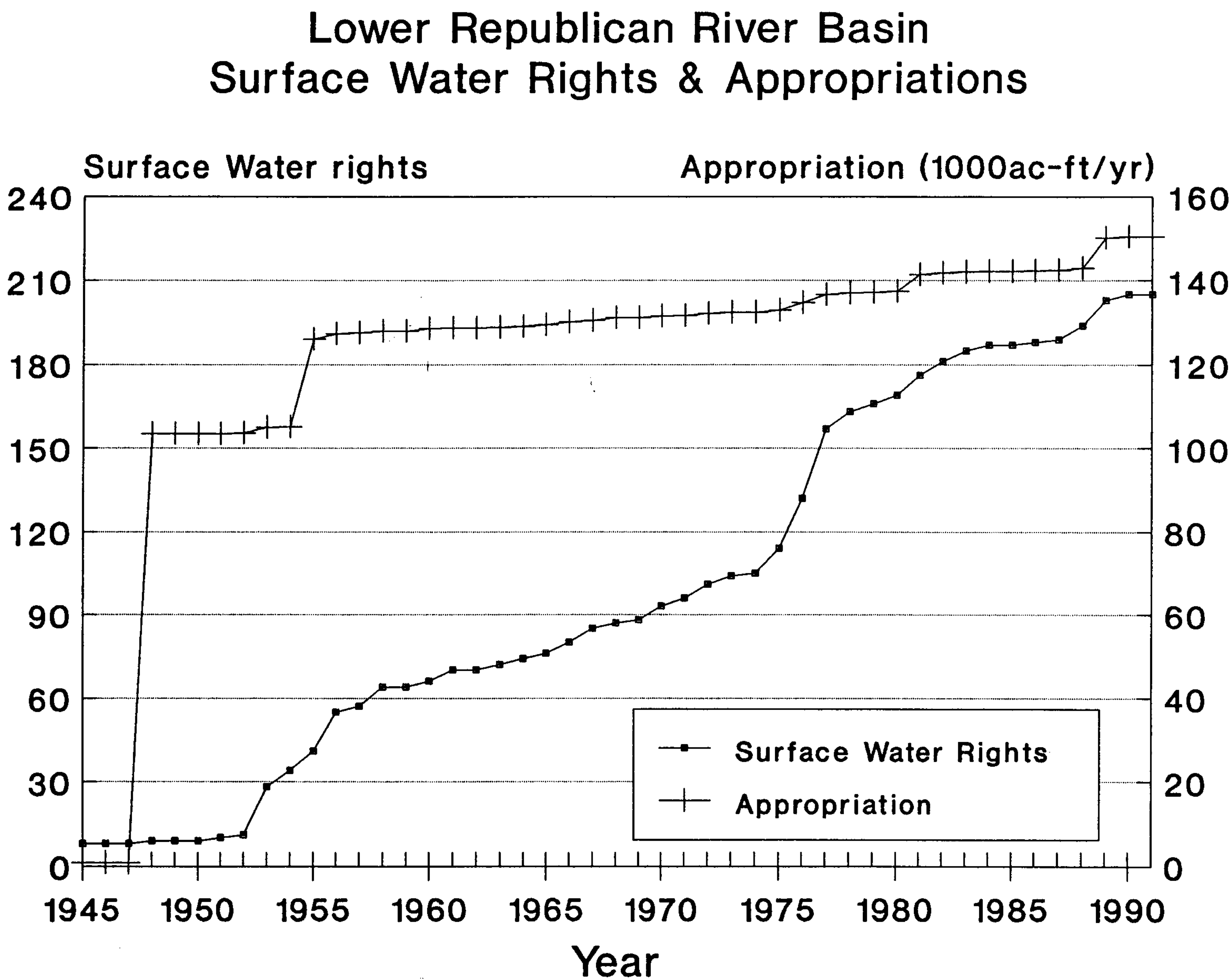


Fig. 16 - Surface Water Rights & Appropriations

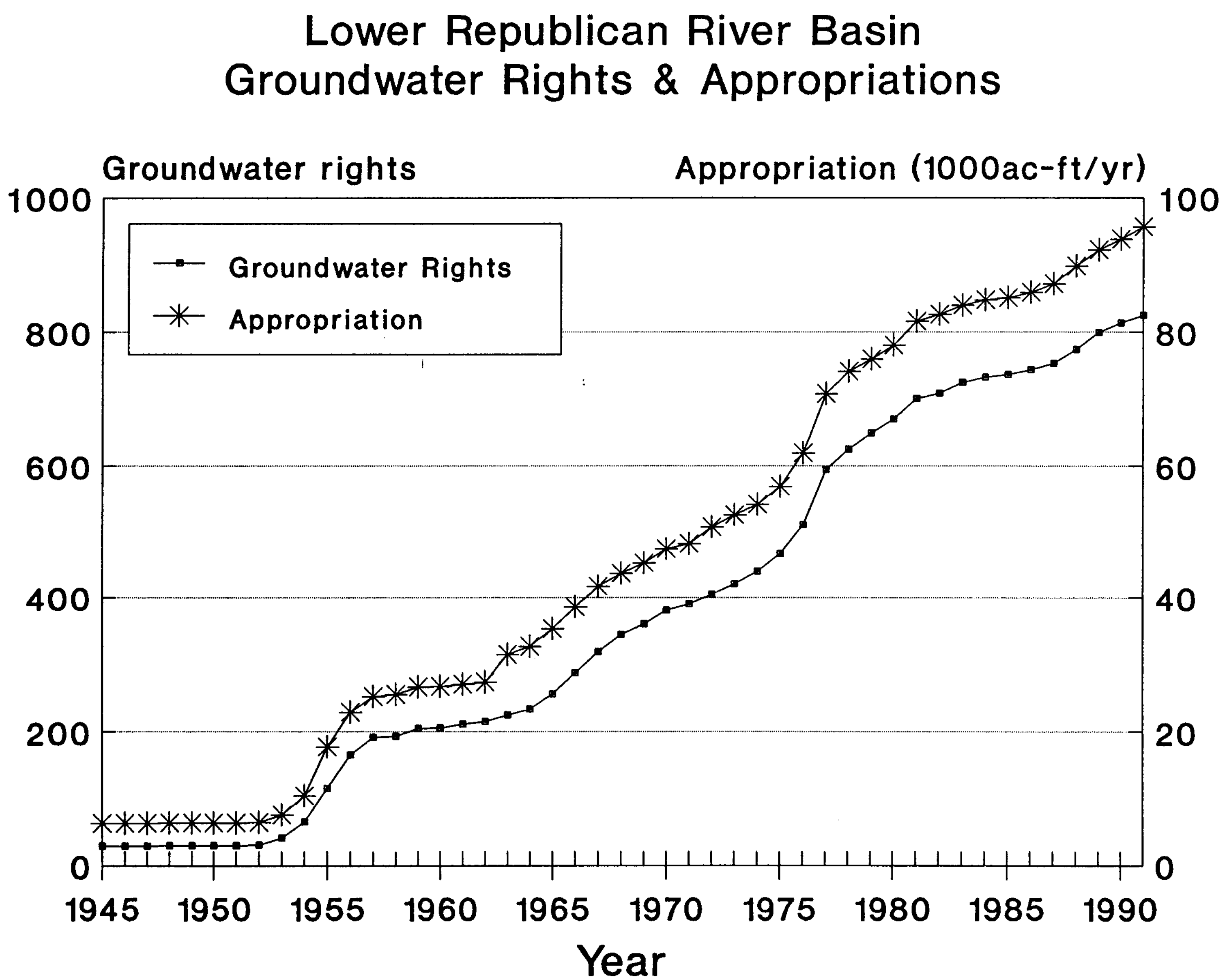


Fig. 17 - Groundwater Rights & Appropriations

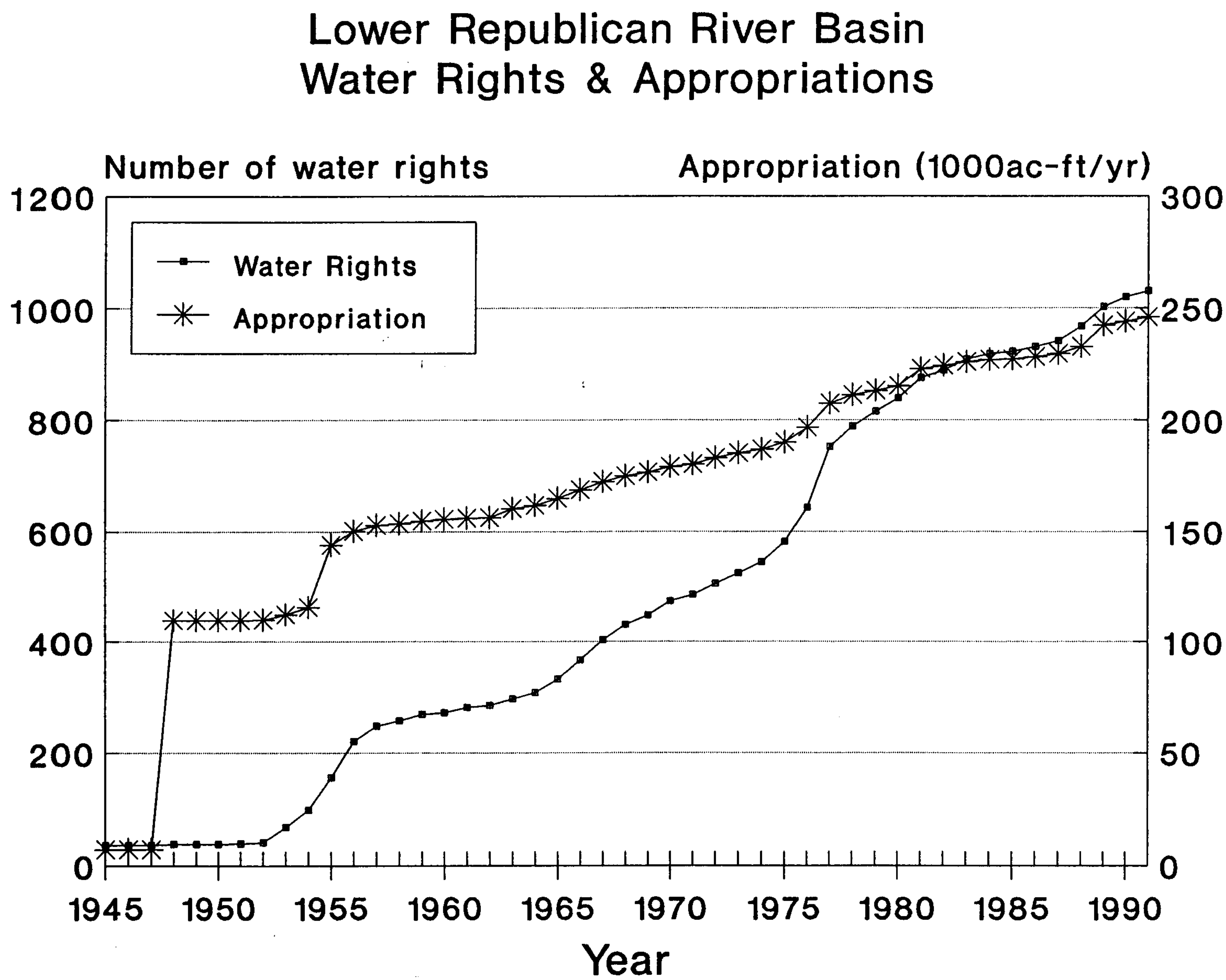


Fig. 18 - Surface & Ground-water Rights & Appropriations

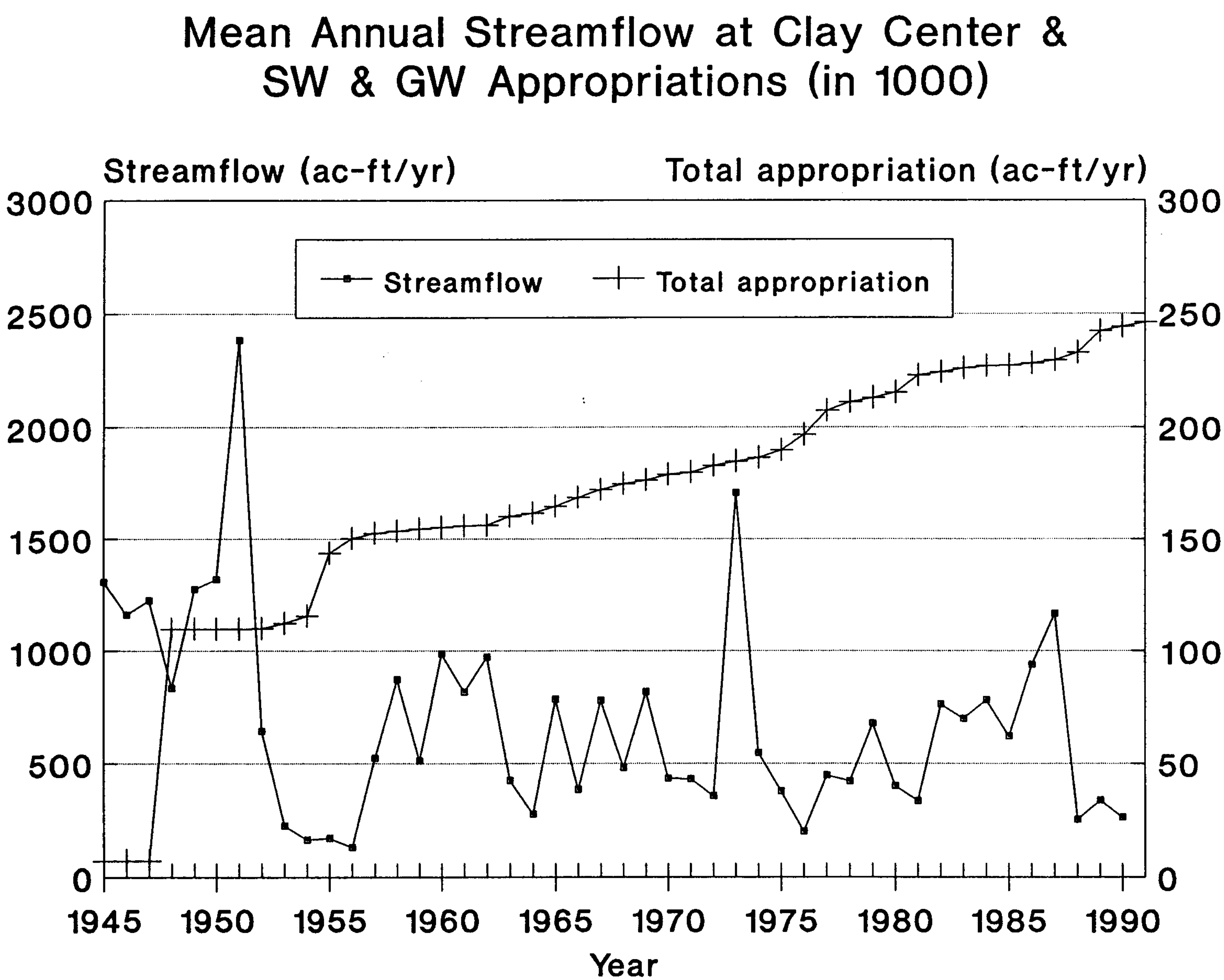


Fig. 19a - Mean Annual Streamflow at Clay Center & Total Appropriations (different scale)

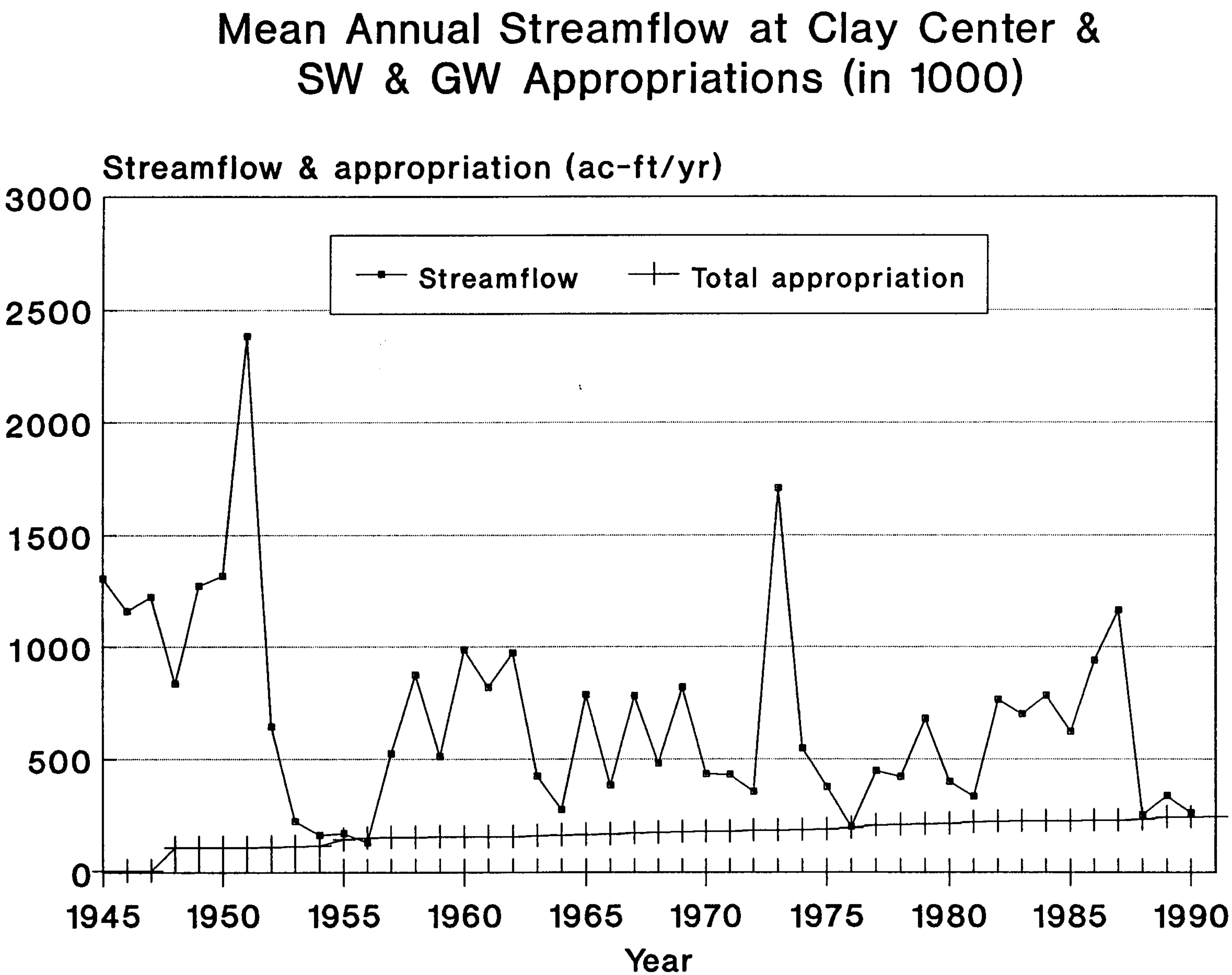


Fig. 19b - Mean Annual Streamflow at Clay Center & Total Appropriations (same scale)

6. RESULTS: PARAMETER ESTIMATION AND SENSITIVITY ANALYSIS

The data required to run SWAT can be classified into different categories according to several criteria; however, they can be divided broadly into two groups based on the sources from which they are derived: measurements and estimates.

Some of the parameters required by SWAT cannot be measured from the field or obtained from historical records, therefore they have to be estimated. Examples of such parameters are basin lag time and groundwater reaction factor. In some other cases the parameters can be determined only by an experienced hydrologist because such parameters are empirical. In these cases, sensitivity analysis could be used to identify those parameters that affect the model output significantly and select them accordingly. We have employed this approach in the Republican River Basin modeling study. Examples of such parameters are the groundwater delay factor and the water stress factor. The SCS curve number is a composite parameter that can be estimated roughly from land surface and crop cover characteristics, and antecedent soil moisture conditions. This section describes some of the parameter estimation procedures.

6.1 Basin Lag Time, BRT (days)

The subsurface contribution to streamflow does not occur immediately after precipitation, because it takes time for the precipitation to percolate through the soil column and reach the water table and from there to travel laterally through the aquifer to the stream. Basin lag time lags the subsurface contribution to streamflow relative to precipitation. If basin lag time is zero, all subsurface flow reaches the subbasin outlets on the day it occurs as precipitation. According to the data input format description, judgment is required to set basin lag time to as many days as subsurface flow from a precipitation event is expected to contribute to streamflow. A procedure is developed here to estimate this parameter when both monthly precipitation and streamflow data are available: 1) First, calculate the cross correlation coefficients for lags = 0, 1, 2, ..., m, where m is the largest time lag, in months, which depends on the basin characteristics, primarily size and soil type. 2) Then, plot these correlations versus the lags; this graph shows that the correlation first decreases with time lag and then increases to a second peak. Physically, the first one or two monthly correlations indicate the dependence between precipitation and surface runoff, and the second peak reflects the correlations between precipitation and subsurface flow. Therefore, the second peak time lag can be used as the estimate of the basin lag time (days). An example of this procedure from the Lower Republican River Basin is shown in Figure 20, in which the second peak is broad and therefore somewhat ill-defined.

6.2 Groundwater Reaction Factor, α(days^{-1})

Because base flow is groundwater discharge, a base flow recession curve can be used to estimate the time rate of aquifer discharge to the stream system after recharge. The reaction factor is a direct index of the intensity with which the groundwater outflow responds to changes in recharge. Arnold et al. (1993) suggested an equation which relates the reaction factor to the number of days for base flow recession to pass through one log cycle, BFD. This equation is based on a conceptual representation of the aquifer as a linear reservoir:

$\alpha = 2.3/BFD$ (days^{-1})

Several flood streamflows that occured in the Lower Republican River basin during 1986 and 1988 are plotted in Figures 21a to 21d, and the number of days for base flow recession to pass through one log cycle ranges from 5 to 7. Substituting BFD = 5, 6, and 7 into the above equation yields α in the range of 0.30 to 0.50 (days^{-1}).

6.3 Water Stress Factor - WSF (-)

The water stress factor is computed as the ratio of plant water use (from all soil layers) to predicted pant transpiration rate. The value of water stress factor is the plant water stress level at which irrigation begins. The WSF ranges from 0 to 1 (1 means no stress and 0 means no growth). If only supplemental irrigation is desired, WSF should be set to a low value, for example, 0.10. The low value allows the plants to be stressed severely before water is applied. WSF should be set to a high level, say, 0.90, to assure little plant water stress (typical of drip irrigation). The amount of irrigation water applied is sufficient to bring the soil root zone to field capacity. In Figure 22 we show two different water factor scenarios: WSF=0.2, high stress scenario, i.e. soil moisture is allowed to be depleted severely before large amounts of water are applied relatively infrequently, and WSF=0.61, low stress scenario, when only low soil moisture deficits are allowed and small amounts of water are applied relatively frequently.

6.4 Groundwater Delay Factor, δ(days)

The groundwater delay time or drainage time of the aquifer is a function of a given geometry as well as permeability. This value is part of the basin lag time which affects only the timing of the return flow and not the total volume.

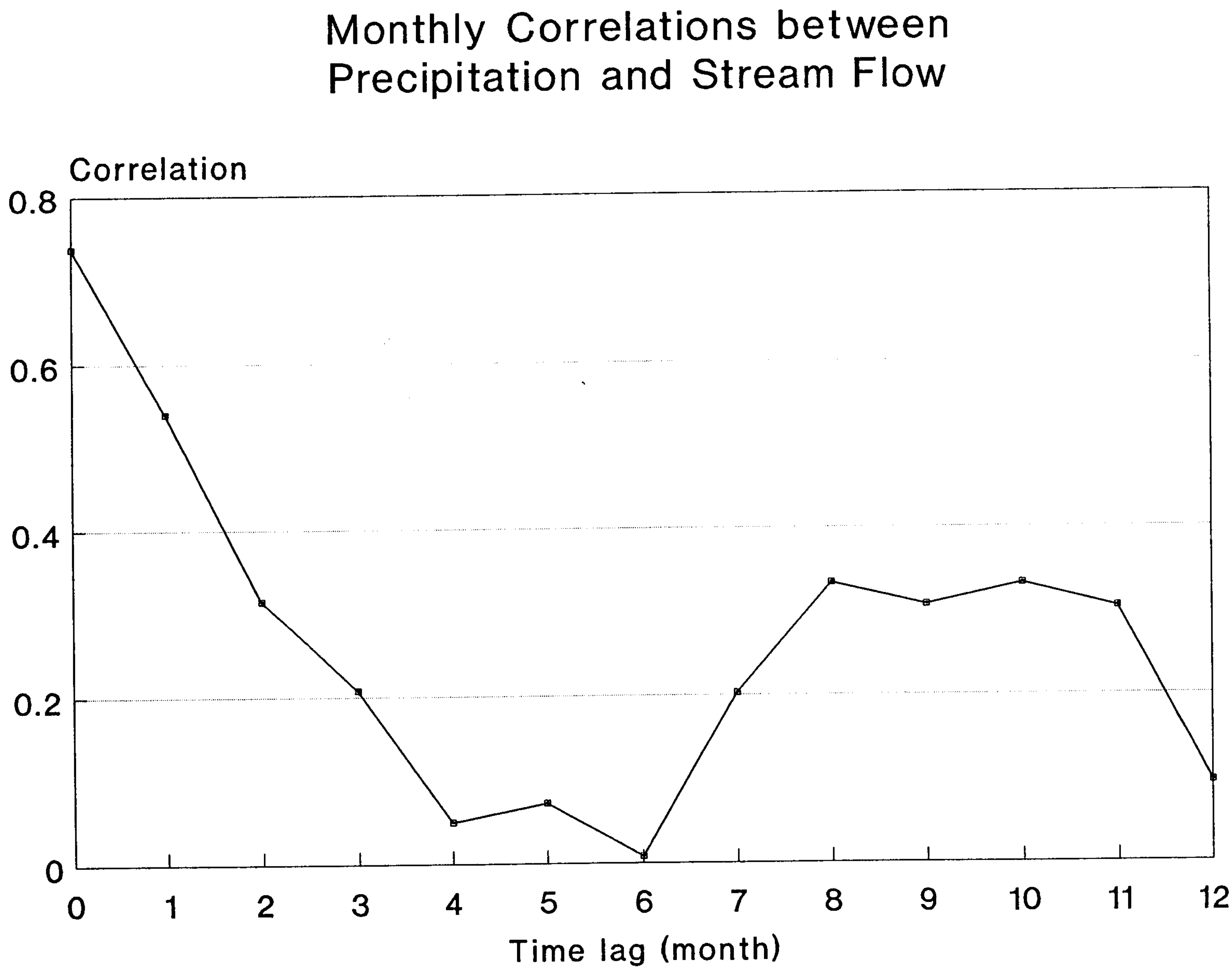


Fig. 20 - Monthly Correlations between Precipitation and Streamflow

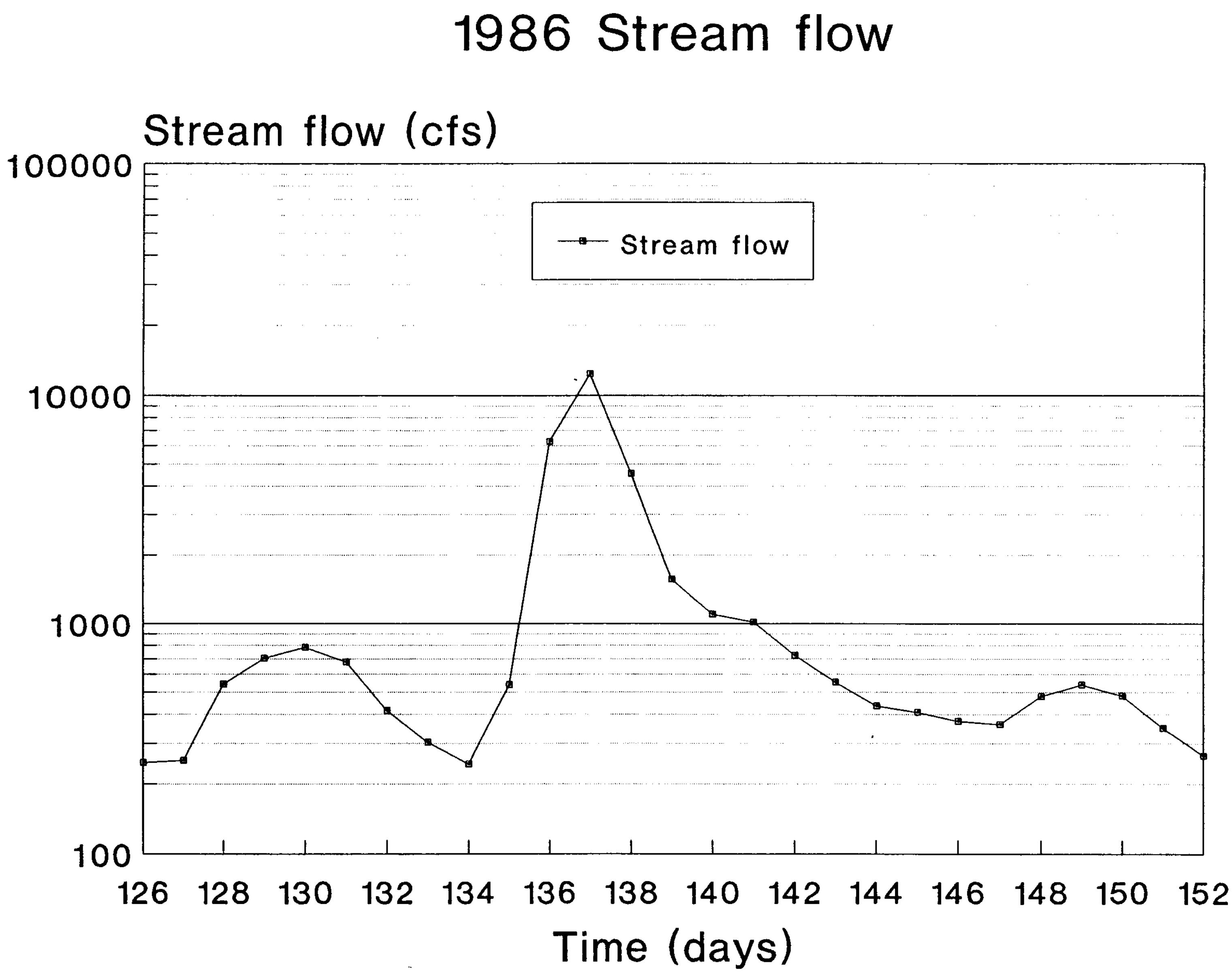


Fig. 21a-d - Semilogarithmic Plots of Streamflow Hydrograph

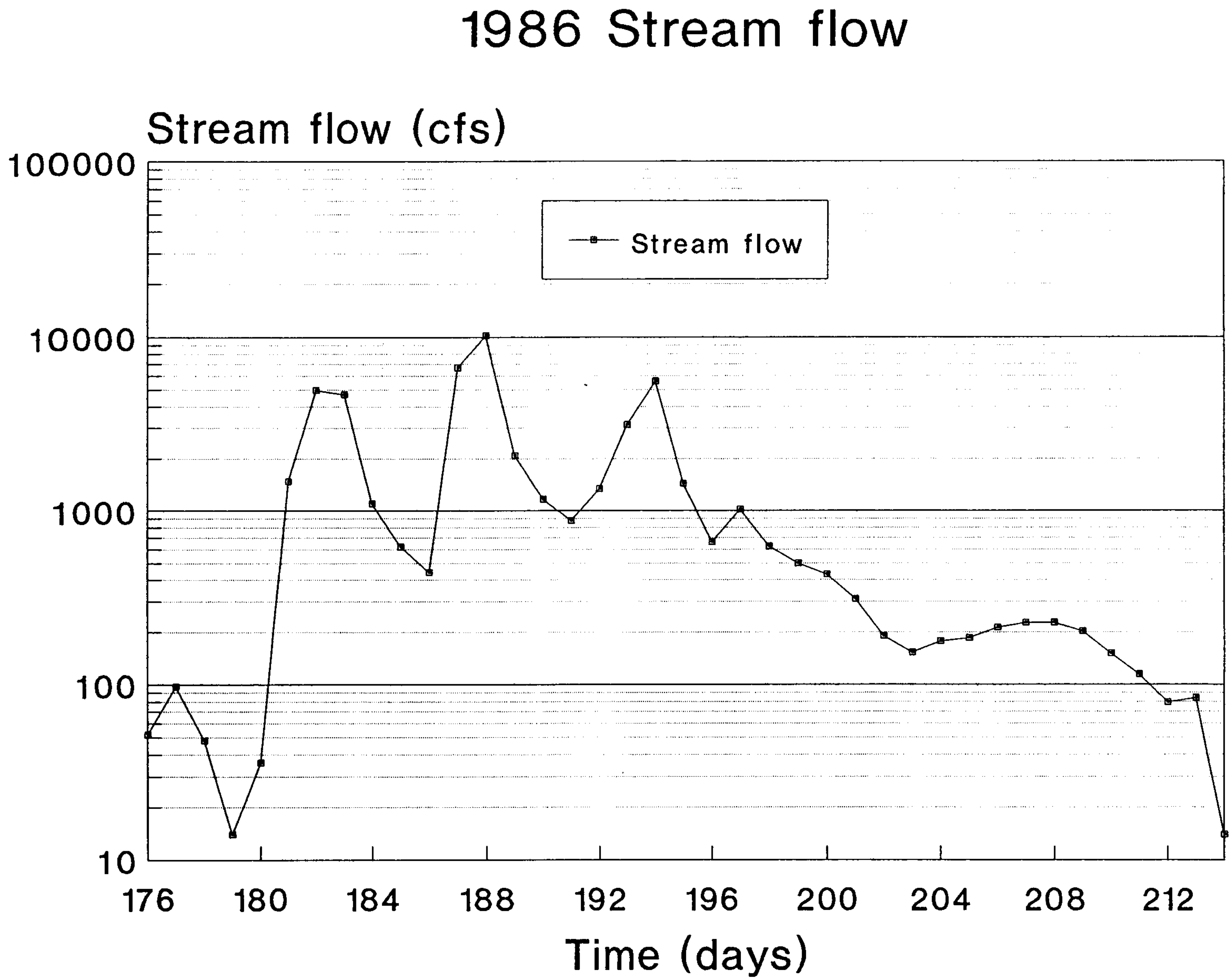


Fig. 21a-d - Semilogarithmic Plots of Streamflow Hydrograph

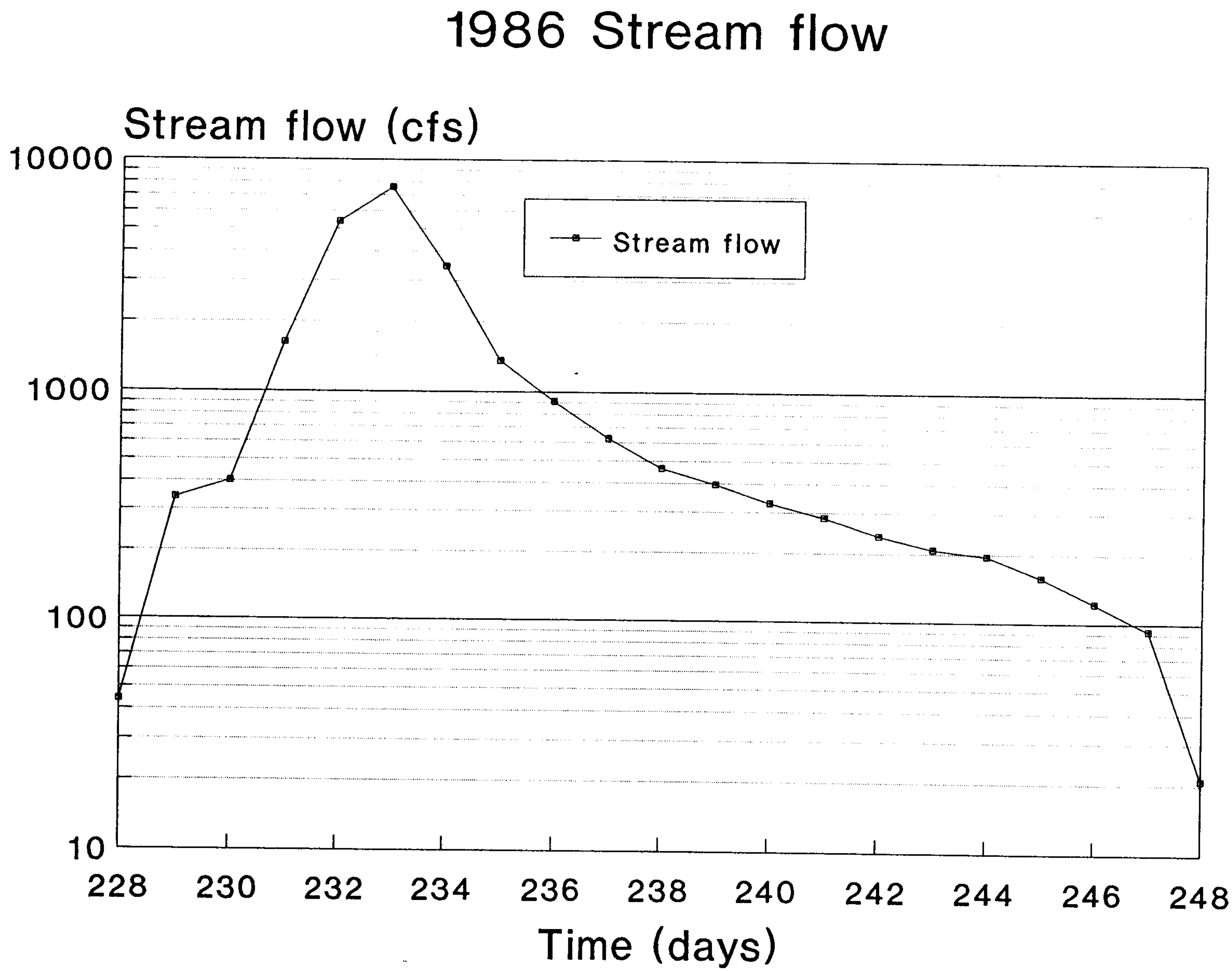


Fig. 21a-d - Semilogarithmic Plots of Streamflow Hydrograph

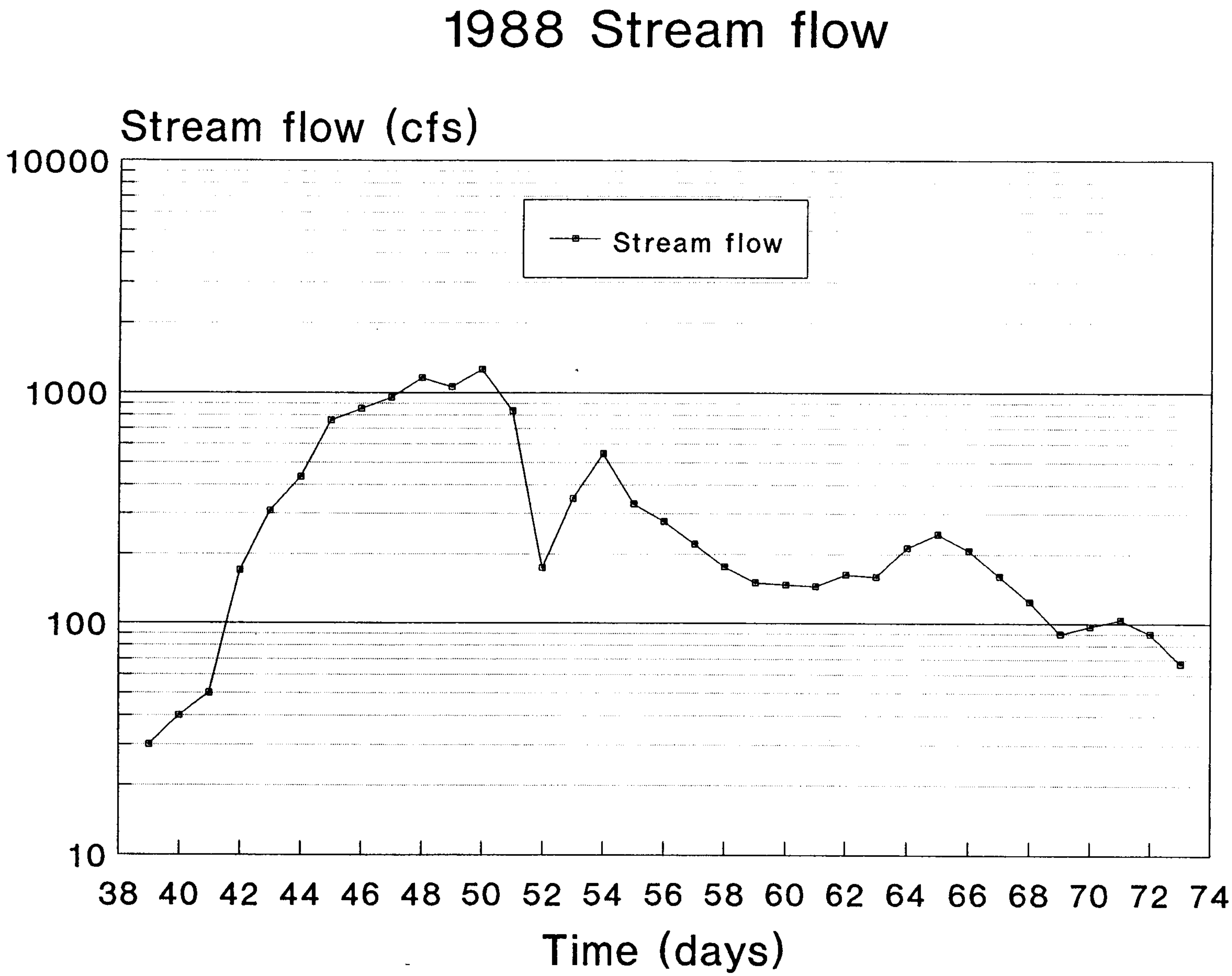


Fig. 21a-d - Semilogarithmic Plots of Streamflow Hydrograph

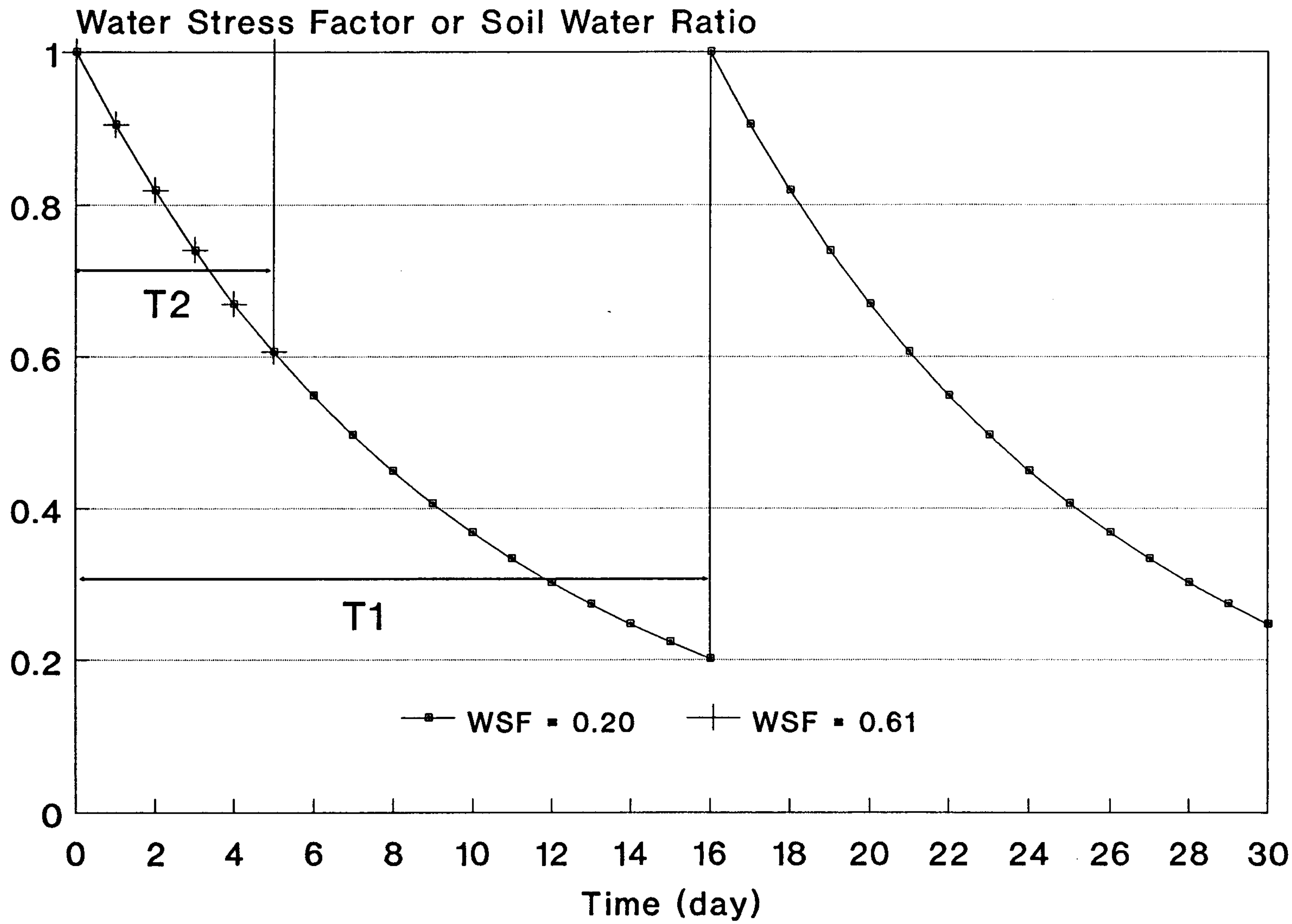


Fig. 22 - Water Stress Factors for two different Irrigation Scheduals

6.5 Sensitivity Analysis

An important characteristic of a model is its sensitivity to variations or uncertainty in input parameters. Sensitivity analysis defines quantitatively the dependence of a selected model performance measure, e.g. basin yield, on a specific parameter; the degree of dependence (sensitivity) is manifested in the model response to a range of values given to a parameter, while all other parameters are held constant. The sensitivity analysis was performed for the time period 1986-1990; this time period includes a very dry year (1988), two moderately dry years (1989, 1990), a wet year (1986) and a year close to the average conditions (1987). All computations are carried out with a daily time step; for comparison purposes, results are aggregated monthly and annually. The sensitivity analysis is based on the following parameters: WSF, landuse, SCS curve number (CN), groundwater reaction factor, δ, and groundwater delay factor, α.

The following definitions and summary statistics are used in the comparison of results presented in Tables 1-3; all results are given as water depth averaged over the basin area. Graphical presentation of monthly and annual time series of measured streamflow gain and computed basin yield is shown in Figures 24-48 following Tables 1-3.

Measurement: the "measurement" data are defined as the difference between the streamflows measured at Clay Center and Concordia ("gain"); this definition is used because SWAT models a stream that is contained completely within the basin.

Water Yield: total output at Clay Center computed by the model;

r_m: monthly correlation between measured gain and computed water yield;

r_y: annual correlation between measured gain and computed water yield;

Mean Q_{dif}: the monthly mean differences between measured gain and computed water yield;

Std Q_{dif}: the standard deviations of the monthly differences between measured gain and computed water yield;

Y_{meas}: the annual average of measured gain;

Y_{comp}: the annual average of computed water yield.

Water Stress Factor: The following four WSF values are tested: 0.00, 0.15, 0.25, and 0.35. The results are shown in Table 1. The first column of results in Table 1 gives the monthly correlations between the measured and the computed water yield, the second column gives the annual correlations. The third column shows the monthly mean differences between measured gain and computed water yield, the fourth column shows the corresponding standard deviations. The annual averages of measured gains and computed water yields are shown in the last two columns. Table 1 shows that when WSF = 0.25 both r_m and r_y have large values (>0.95), mean Q_{dif} and STD Q_{dif} have the smallest values, and Y_{meas} and Y_{comp} are the closest. Therefore, WSF =

0.25 is selected as the standard case and outlined in bold face in Table 1.

Landuse: Four different landuses are simulated: wheat, grassland, range, and corn. Wheat is the standard case; it is based on data taken from Farm Facts for 1983. Table 1 shows that the computed water yields are very sensitive to landuse.

SCS Curve Number: The runoff curve number is the SCS antecedent moisture condition 2 curve number (CN2). Three numbers are tested: 70, 75, and 78. The value of 75 is the standard case. Table 1 shows that the computed annual mean water yield and the correlations with the gain increase with increasing curve number values, and that the differences are significant. We note here that SWAT is capable of modeling a continuous variation of the curve number .

Groundwater Delay Factor, δ: Three values are tested: 50, 100, and 150 days. The value of 100 days is the standard case. Table 1 shows that the model output is not very sensitive to this parameter.

Groundwater Reaction Factor, α: The reaction factor is a direct index of the intensity with which the groundwater outflow responds to changes in recharge. As mentioned above, the range of this parameter should be 0.30 to 0.50 days^{-1}. Three values are tested: 0.30, 0.40, and 0.50 days^{-1}. The value of 0.40 days^{-1} is the standard case. Table 1 shows that the model output is also not very sensitive to this parameter; therefore the fact that a precise value for α could not be determined from the data (broad second peak) is no cause for concern.

In Table 2, results for Mean Q_{dif} and STD Q_{dif} are presented for all 5 years shown aggregated in Table 1, as well as separately for wet and for dry years; years at which measured mean annual streamflow at Clay Center exceeds 500cfs are considered wet, otherwise are considered dry. Results of the monthly mean differences between measured gain and computed water yield (Mean Q_{dif}) indicate that simulations of the dry years were relatively better than simulations of the wet years. The reason for this outcome is that the year 1988, which was used for calibration, is a dry year. In general, however, the Mean Q_{dif} of the aggregated years is closer to zero and therefore better than either the wet or the dry years separately. An indication that the simulation results are reasonable is that Mean Q_{dif} values for wet years are insensitive to the water stress factor (WSF), while Mean Q_{dif} values for dry years are quite sensitive to WSF, as expected.

In Table 3 we show statistics of runs in which the simulation extended over a single year, in contrast to the statistics shown in Tables 1 and 2, which are derived from 5-year simulations.

In the 5-year simulations, the WSF was kept constant, as required by the code. However, the value of the optimal WSF is climate-dependent and therefore should be variable from year to year. In order to investigate how varying the WSF affects simulation results for individual years we performed individual annual simulations with variable WSF. Optimality is characterized by best agreement between Y_{meas} and Y_{comp} (annualized gain and yield), which relate directly to the annual simulations with WSF values fixed for one year at a time.

Table 1

Sensitivity Analysis Statistics
Main Parameters; Results Aggregated for All Years
Modeling period: 1986 - 1990

Case No.	r_m	r_y	Mean Q_{dif} (mm)	STD Q_{dif} (mm)	Y_{meas} (mm)	Y_{comp} (mm)
WSF* = 0.00	0.87	0.96	0.85	7.06	100.28	90.09
WSF = 0.15	0.87	0.96	0.81	7.07	100.28	90.52
WSF = 0.25	**0.91**	**0.95**	**-0.10**	**5.20**	**100.28**	**101.62**
WSF = 0.35	0.87	0.91	-1.34	7.42	100.28	116.40
Wheat	**0.91**	**0.95**	**-0.10**	**5.20**	**100.28**	**101.62**
Grassland	0.76	0.82	-1.21	8.56	100.28	114.81
Range	0.82	0.96	1.27	7.21	100.28	85.06
Corn	0.82	0.97	2.07	7.15	100.28	75.45
SCS No.=70	0.89	0.93	0.50	5.80	100.28	94.22
SCS No.=75	**0.91**	**0.95**	**-0.10**	**5.20**	**100.28**	**101.62**
SCS No.=78	0.92	0.97	-0.67	5.22	100.28	108.28
δ**= 50	0.90	0.96	-0.03	5.89	100.28	100.66
δ= 100	**0.91**	**0.95**	**-0.10**	**5.20**	**100.28**	**101.62**
δ= 150	0.91	0.95	-0.16	5.06	100.28	102.25
α*** = 0.30	0.91	0.95	-0.10	5.20	100.28	101.49
α= 0.40	**0.91**	**0.95**	**-0.10**	**5.20**	**100.28**	**101.62**
α= 0.50	0.91	0.95	-0.12	5.20	100.28	101.70

*WSF - Value of water stress factor when irrigation begins
δ** - Groundwater delay (days)
α*** - Reaction factor for groundwater $(days)^{-1}$
Text in bold lines refers to the standard case.

Table 2

Sensitivity Analysis Statistics

Main Parameters; Results Segregated by Wet and Dry Years

Modeling period: 1986 - 1990

Case No.	Mean Q_{dif} (mm)			STD Q_{dif} (mm)		
	All	Wet	Dry	All	Wet	Dry
WSF* = 0.00	0.85	-0.41	1.69	7.06	9.69	4.31
WSF = 0.15	0.81	-0.41	1.63	7.07	9.69	4.36
WSF = 0.25	**-0.10**	**-0.44**	**0.11**	**5.20**	**6.75**	**3.81**
WSF = 0.35	-1.34	-0.41	-1.96	7.42	9.69	5.21
Wheat	**-0.10**	**-0.44**	**0.11**	**5.20**	**6.75**	**3.81**
Grassland	1.21	1.14	-2.78	8.56	11.87	4.69
Range	1.27	3.26	-0.06	7.21	9.83	4.24
Corn	2.07	4.22	0.63	7.15	9.84	3.93
SCS No.=70	0.50	0.29	0.65	5.80	7.65	4.13
SCS No.=75	**-0.10**	**-0.44**	**0.11**	**5.20**	**6.75**	**3.81**
SCS No.=78	-0.67	-1.13	-0.36	5.22	6.76	3.83
δ**= 50	-0.03	-0.46	0.25	5.89	8.10	3.74
δ= 100	**-0.10**	**-0.44**	**0.11**	**5.20**	**6.75**	**3.81**
δ= 150	-0.16	-0.20	-0.14	5.06	6.47	3.84
α*** = 0.30	-0.10	-0.42	0.11	5.20	6.74	3.82
α= 0.40	**-0.10**	**-0.44**	**0.11**	**5.20**	**6.75**	**3.81**
α= 0.50	-0.12	-0.45	0.10	5.20	6.75	3.81

*WSF - Value of water stress factor when irrigation begins

δ** - Groundwater delay (days)

α*** - Reaction factor for groundwater $(\text{days})^{-1}$

Text in bold lines refers to the standard case

Years in which measured mean annual streamflow at Clay Center exceeds 500cfs are considered wet, otherwise are dry.

Table 3

Sensitivity Analysis Statistics: Water Stress Factor

Case No.	Mean Q_{dif} (mm)	STD Q_{dif} (mm)	Y_{meas} (mm)	Y_{comp} (mm)
1986				
WSF = 0.15	1.74	7.79	209.21	188.30
WSF = 0.25	1.74	7.79	209.21	188.30
WSF = 0.35	1.74	7.79	209.21	188.30
WSF = 0.45	1.74	7.79	209.21	188.30
WSF = 0.55	0.30	7.44	209.21	205.56
WSF = 0.65	0.41	7.45	209.21	204.29
1987				
WSF = 0.15	-2.14	2.62	175.33	200.51
WSF = 0.25	-2.14	2.62	175.33	200.51
WSF = 0.35	-2.14	2.62	175.33	200.51
WSF = 0.45	-2.52	3.08	175.33	205.55
WSF = 0.55	-2.38	2.94	175.33	203.94
WSF = 0.65	-2.85	3.38	175.33	209.58
1988 Used for calibration in 1-year runs				
WSF = 0.15	0.08	2.40	23.13	22.19
WSF = 0.25	-0.02	2.44	23.13	23.38
WSF = 0.35	-0.02	2.45	23.13	23.42
WSF = 0.45	-0.02	2.45	23.13	23.42
WSF = 0.55	0.03	2.42	23.13	22.76
WSF = 0.65	-0.02	2.45	23.13	23.39
1989				
WSF = 0.15	3.08	8.10	63.09	26.16
WSF = 0.25	1.72	6.36	63.09	42.46
WSF = 0.35	0.31	4.79	63.09	59.37
WSF = 0.45	-0.63	3.69	63.09	70.63
WSF = 0.55	-0.52	3.57	63.09	69.31
WSF = 0.65	0.49	4.19	63.09	57.20

1990

WSF = 0.15	0.49	3.16	30.62	24.79
WSF = 0.25	-0.57	4.01	30.62	37.52
WSF = 0.35	-1.69	5.67	30.62	50.94
WSF = 0.45	-1.25	5.29	30.62	45.67
WSF = 0.55	-0.72	4.67	30.62	39.26
WSF = 0.65	-0.32	4.16	30.62	34.48

Results indicate that optimal WSF values vary annually. For example, in 1986 WSF=0.55 yields best agreement between Y_{meas} and Y_{comp}, because 1986 was a wet year not requiring heavy irrigation. In contrast, 1988 (used for calibration) is a dry year and the optimal WSF=0.25, which minimizes the difference Y_{meas} and Y_{comp} and implies heavy irrigation. In Figure 23 we plot the differences between Y_{meas} and Y_{comp} for various Water Stress Factors for 1990, from which we conclude that the model indicates optimality under both a high and a low WSF value; the correct solution can be determined from data on actual irrigation schedule and crop types for the given year. In this particular case, monthly streamflows indicate that WSF=0.2 is optimum. Note that although the single-year simulations elucidate the variability of WSF with climate, their results are more dependent upon the assumed initial conditions than those of the five-year runs.

Model output for the various scenarios simulated in the five-year runs is graphed in monthly steps in Figures 24-35 and aggregated on an annual basis in Figures 36-48. In the individual runs, all parameters were given their optimal values, except the one that was allowed to vary in order to observe the model's performance and sensitivity to that parameter. The results aggregated annually are intended to summarize model behavior. The temporal resolution in monthly steps is instructive of the model's ability to track changing meteorological forcing.

The following set of parameters, found to be optimal, define our standard for the sensitivity analysis: WSF=0.25, landuse=wheat, SCS CN=75, α=0.4 days^{-1}, δ=100 days; the simulation of the standard case is shown in Figure 26 in the context of the WSF sensitivity test and is not repeated with each parameter variation. The detailed simulations also confirm that WSF should be variable; for example, for 1987 (months 13-24, Figure 26) the model matches observations well using WSF=0.25; however for 1989 (months 37-48, Figure 27) WSF=0.35 gives a better match than WSF=0.25, while in 1990(months 49-60, Figure 25) WSF=0.15, or less, appears optimal. Landuse should also be modeled as varying annually; the graphs show that wheat (standard case, Figure 26) is optimal for 1987, but for 1989 corn, or range, or grassland, (Figures 28-30) is better. The results for year 1988 (Figure 26, months 25-36) are mixed: 1) the exponential decline of basin yield from 1987 continues while the measured streamflow gain increases at month 26 (this may be explained by unaccounted irrigation return flows, which may have been significant relative to the basin yield in the dry year 1988; see analysis of storage balance in subsection 6.6); 2) the next rise in streamflow gain, which occured in 1988 (month 31), is tracked but is overpredicted.

By observing the model behavior during periods of sharp declines of streamflow gains we see that the model is unable to track the basin response very well. However, the model has been able to follow the pattern of streamflow gains reasonably well over the period 1986-1990. As already discussed, monthly results shown in Figures 31-36 indicate that basin behavior is less sensitive to the parameters SCS CN, α and δ. Annual results are summarized in Figures 36-48.

Finally, the overall hydrologic balance for the basin, over the five years of simulation, offers a means of checking the modeling effort with regard to gross errors ("blunders"). SWAT outputs the terms of surface and subsurface water balances separately, from which the overall balance for the basin can be established.

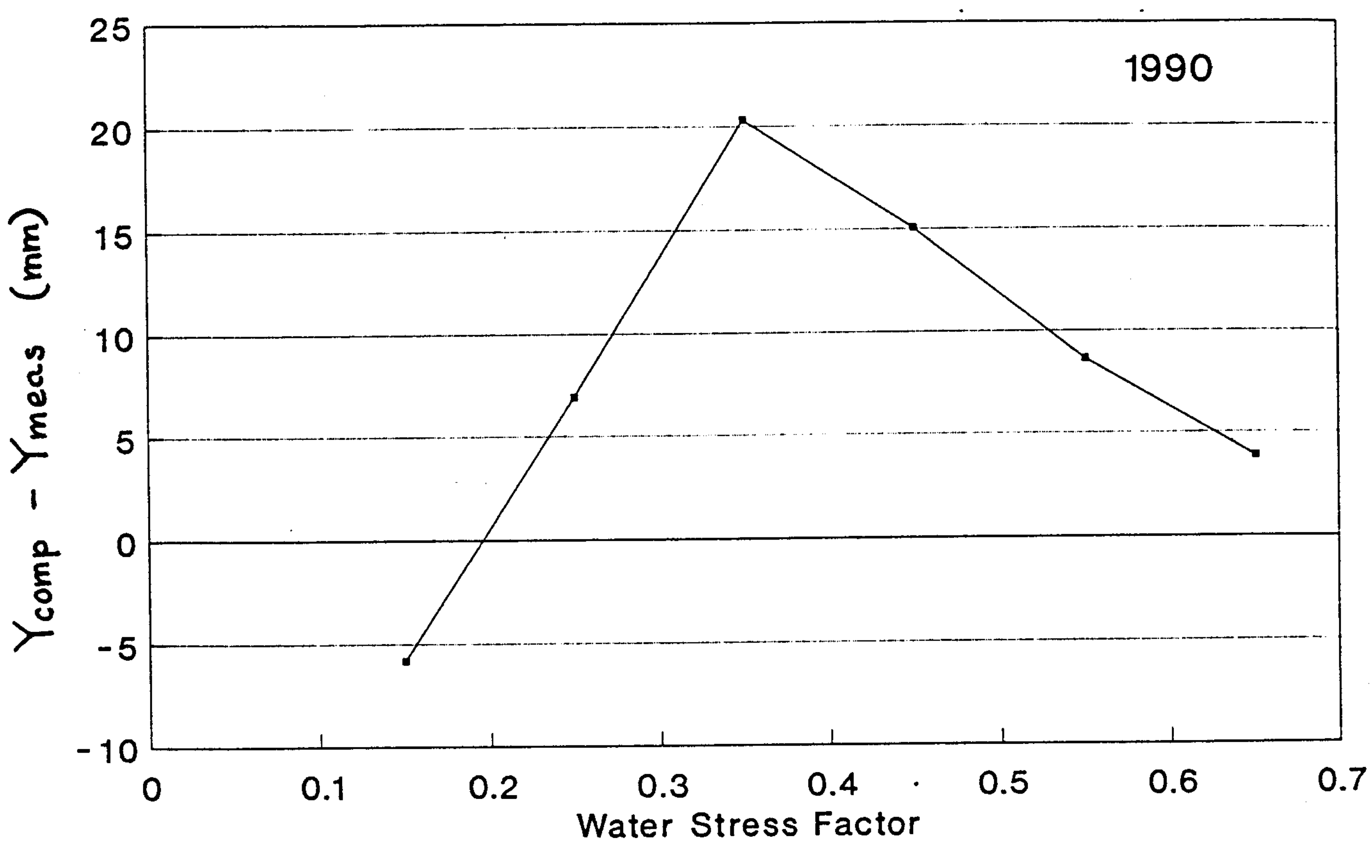


Fig. 23 - Water Stress Factor vs Difference of Streamflow Gain and Basin Yield

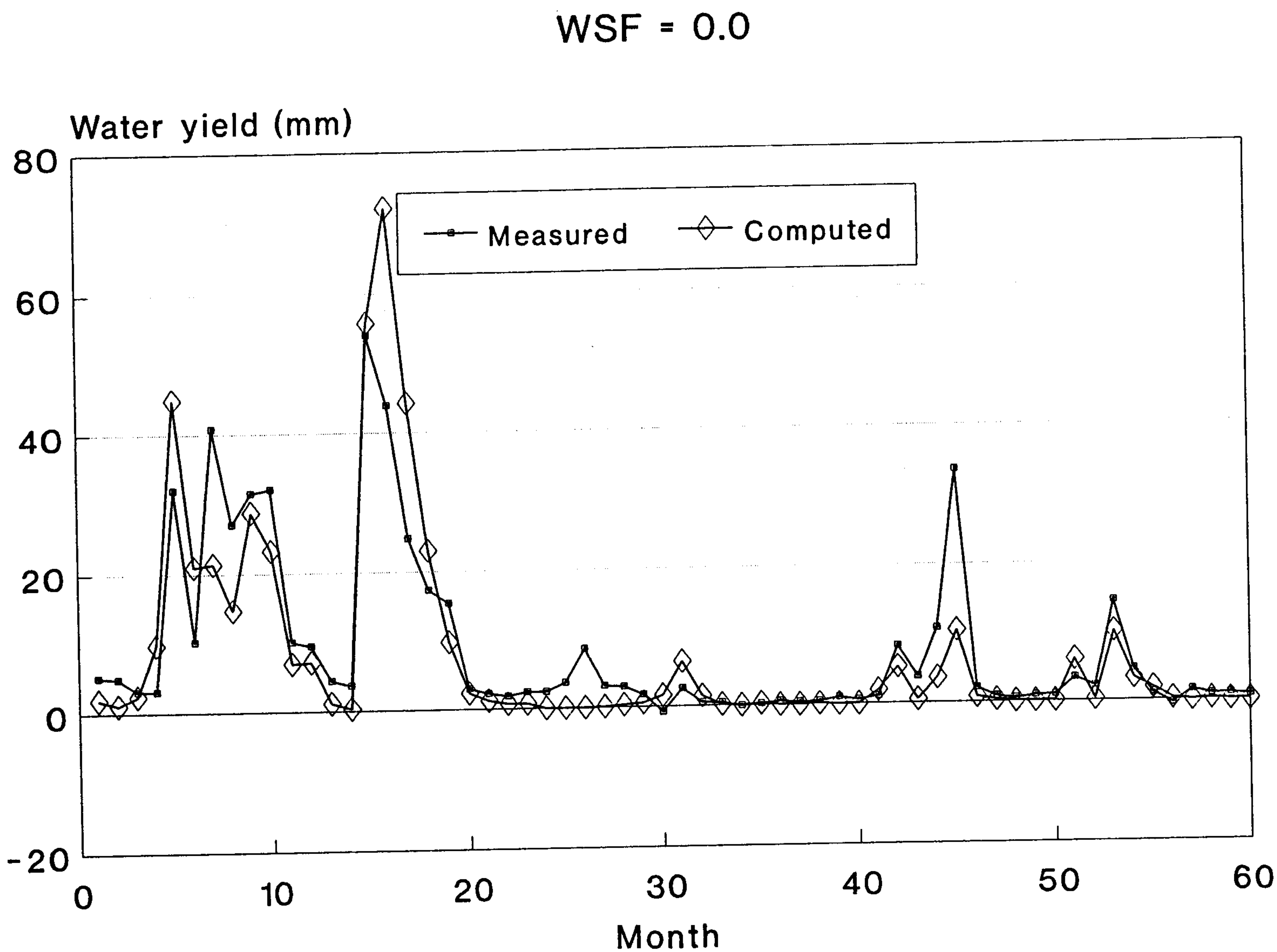


Fig. 24 - Model Calibration; Sensitivity to WSF: monthly data, WSF=0

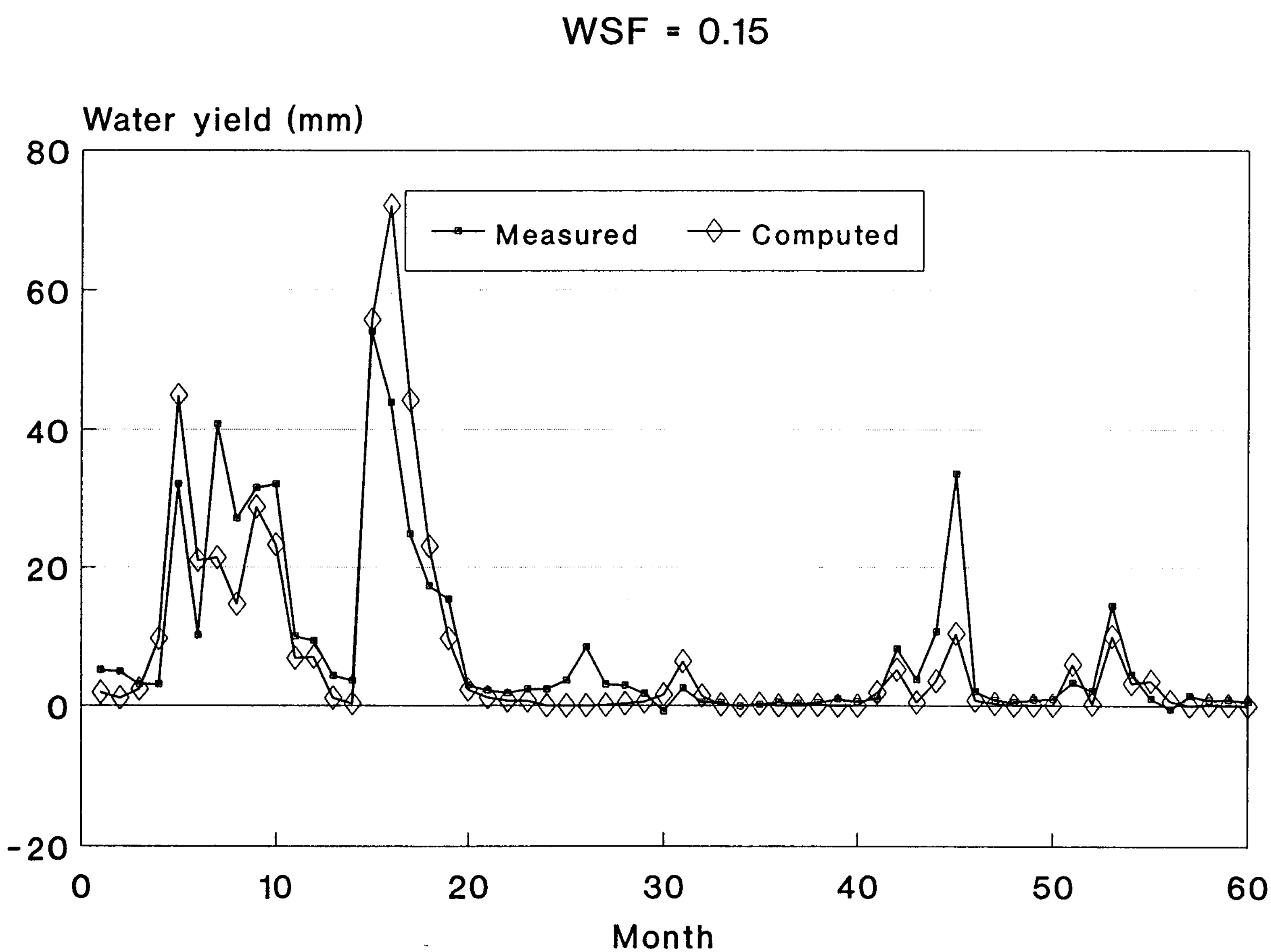


Fig. 25 - Model Calibration; Sensitivity to WSF: monthly data, WSF=0.15

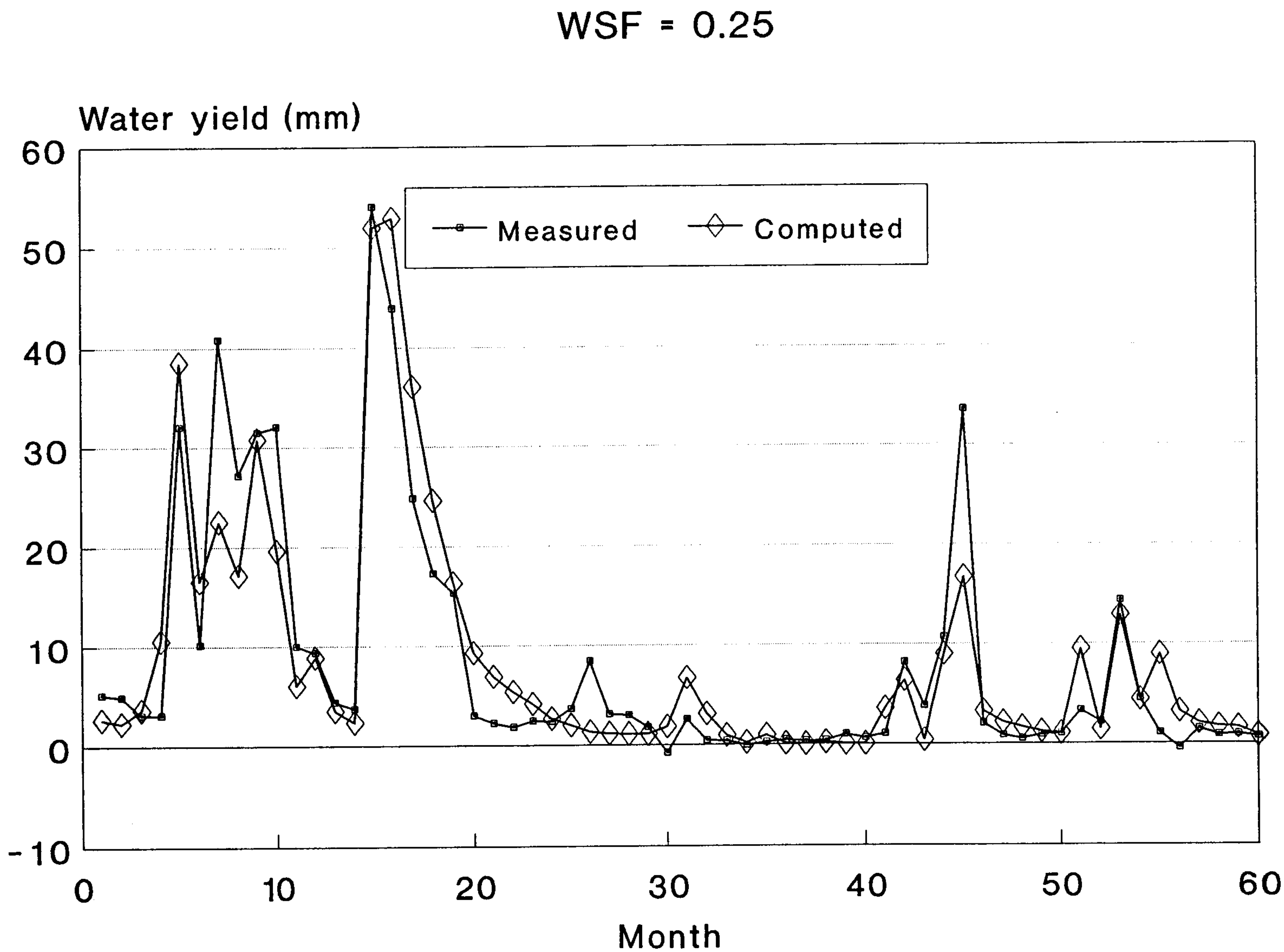


Fig. 26 - Model Calibration; Sensitivity to WSF: monthly data, WSF=0.25

(standard case: WSF=0.25, Landuse=Wheat, SCS CN=75, δ=100days, α=0.4days^{-1})

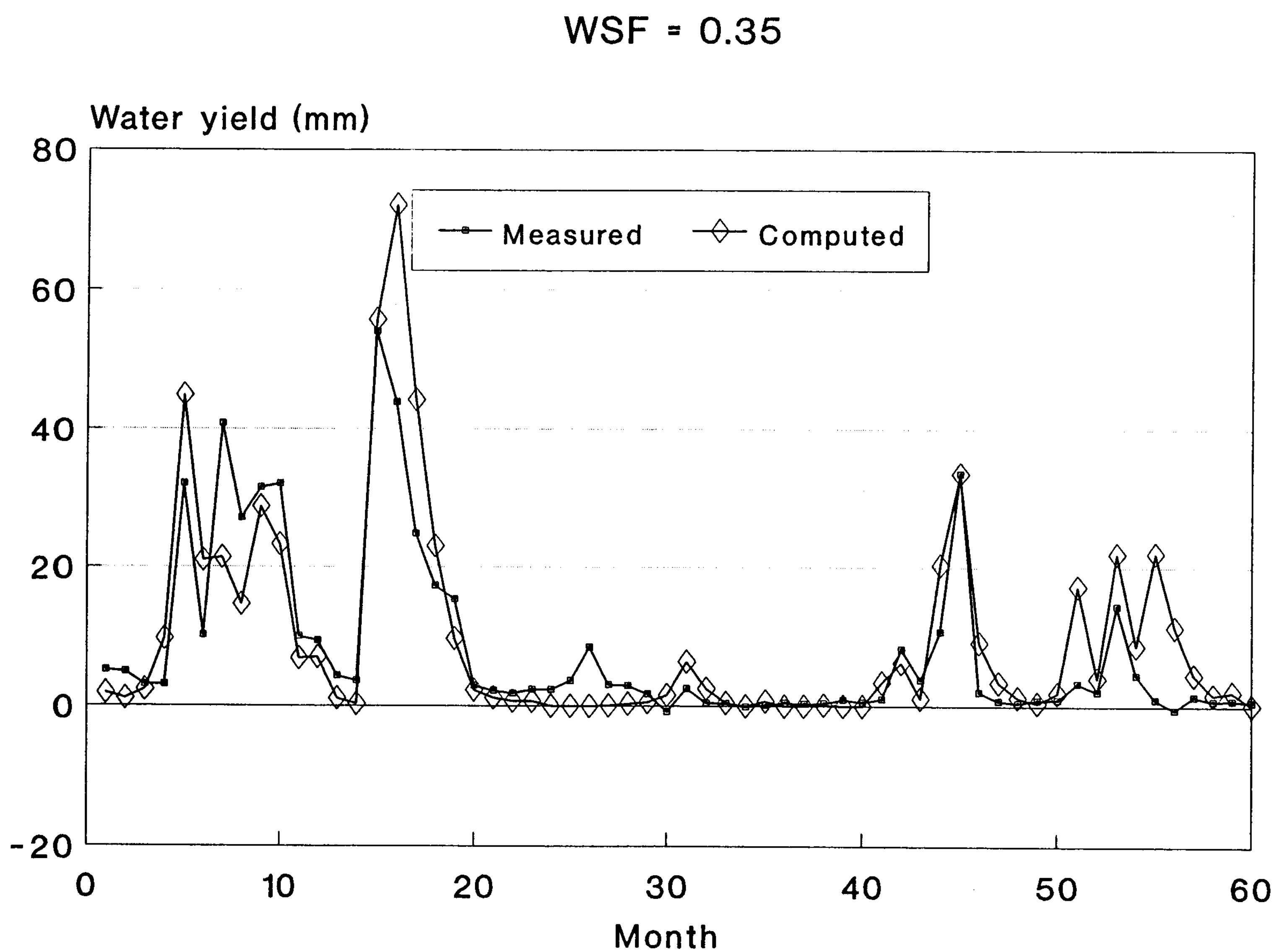


Fig. 27 - Model Calibration; Sensitivity to WSF: monthly data, WSF=0.35

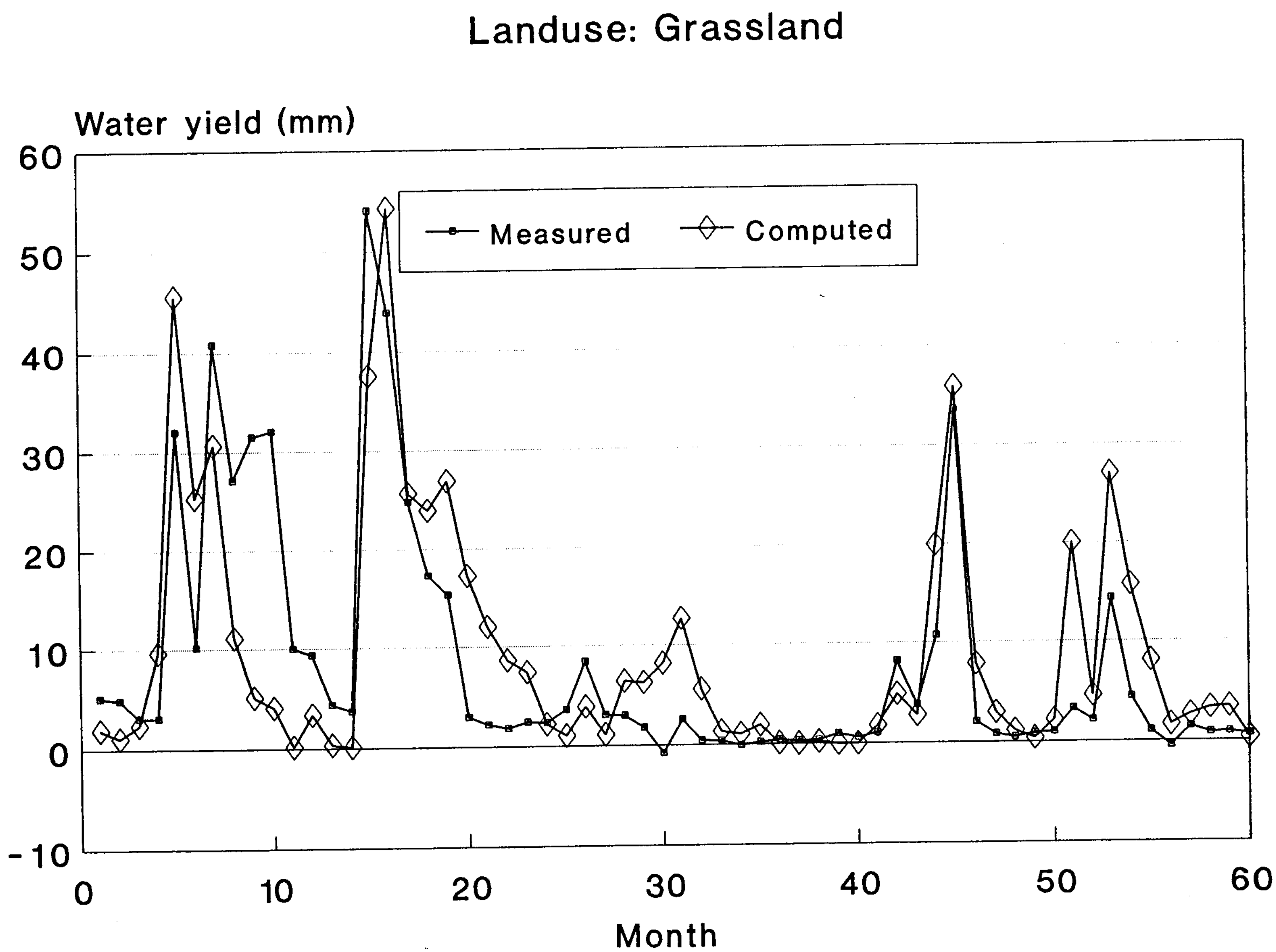


Fig. 28 - Model Calibration; Sensitivity to Landuse: monthly data, Grassland

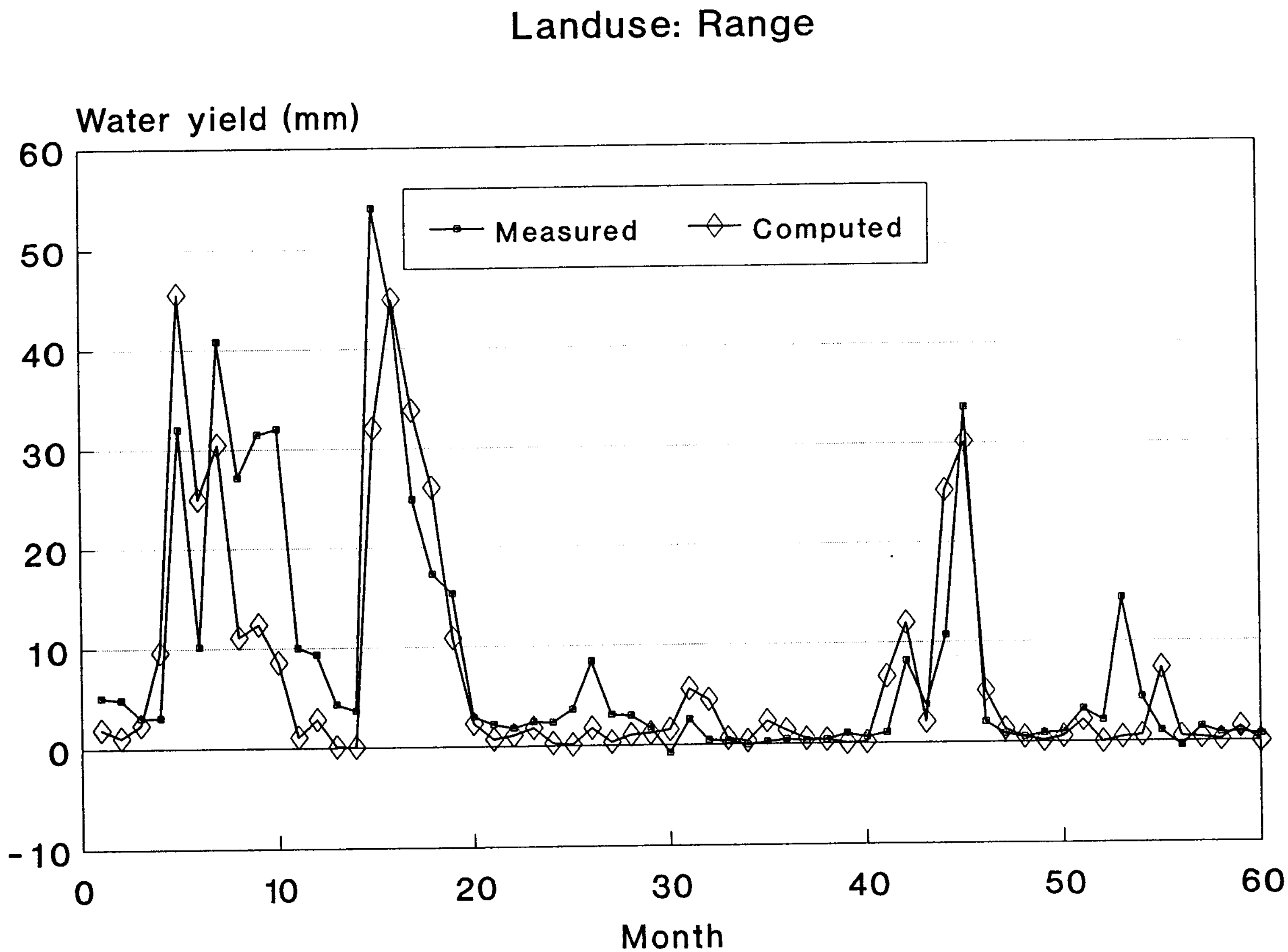


Fig. 29 - Model Calibration; Sensitivity to Landuse: monthly data, Range

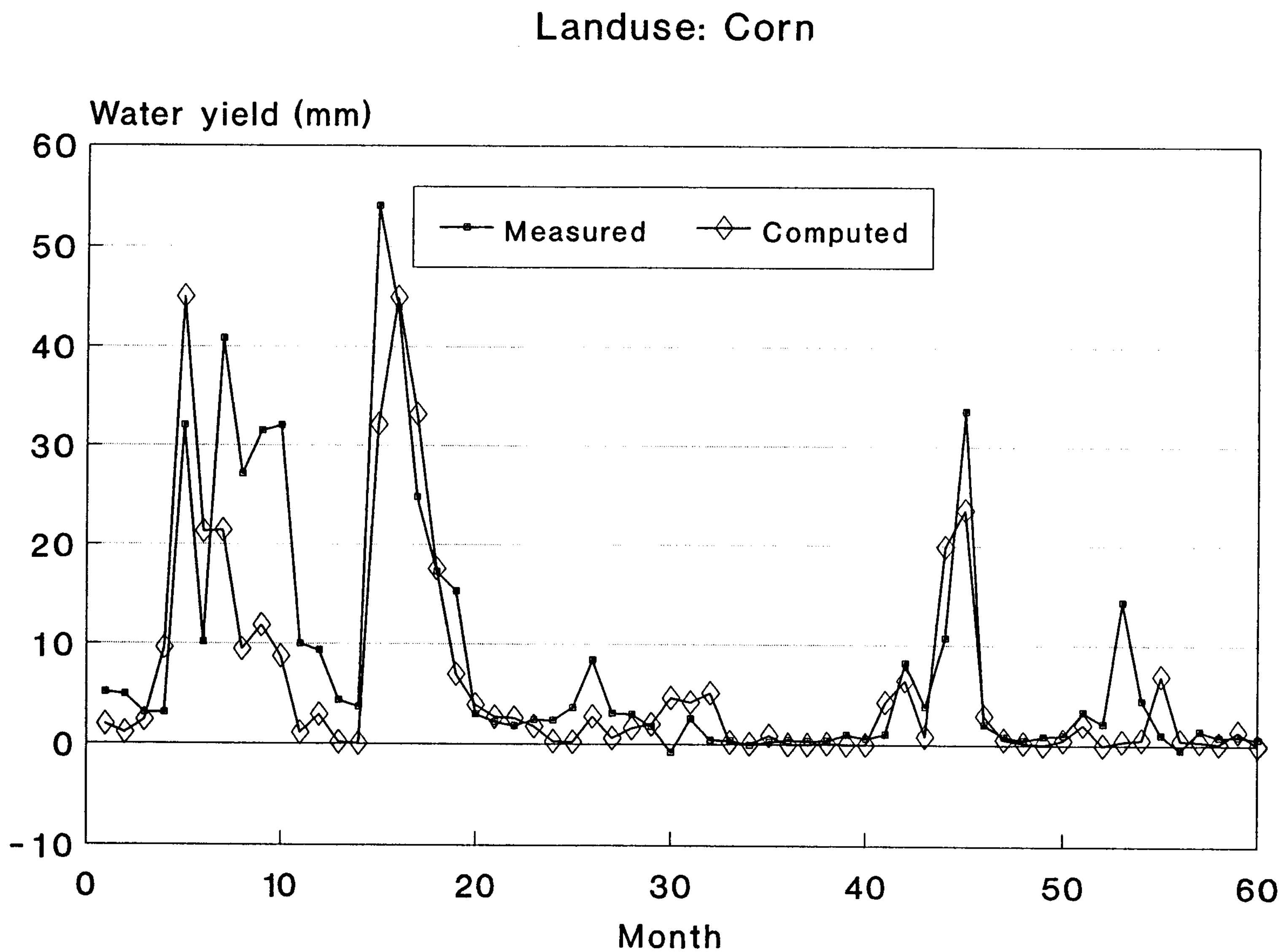


Fig. 30 - Model Calibration; Sensitivity to Landuse: monthly data, Corn

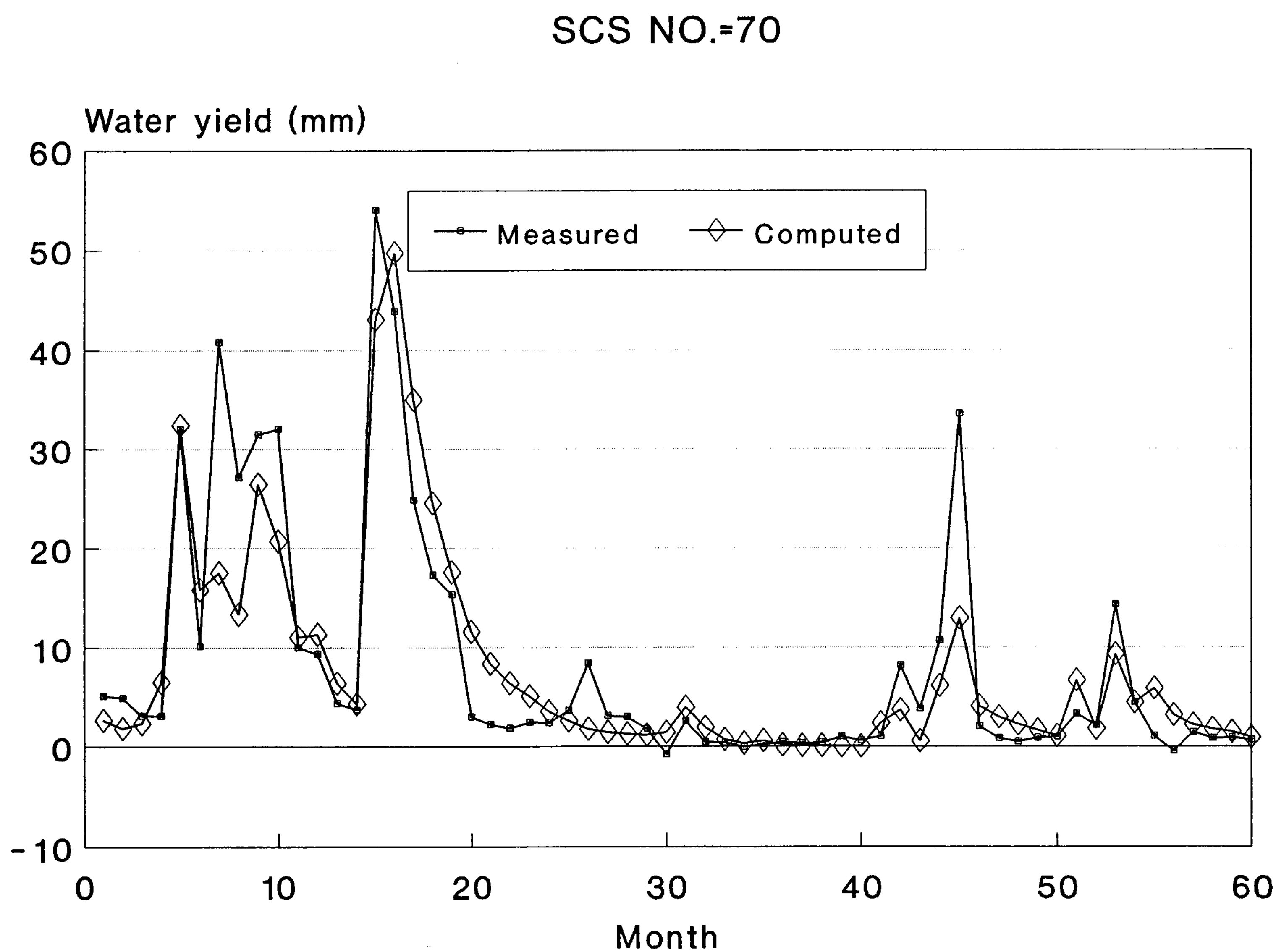


Fig. 31 - Model Calibration; Sensitivity to SCS CN: monthly data, SCS CN=70

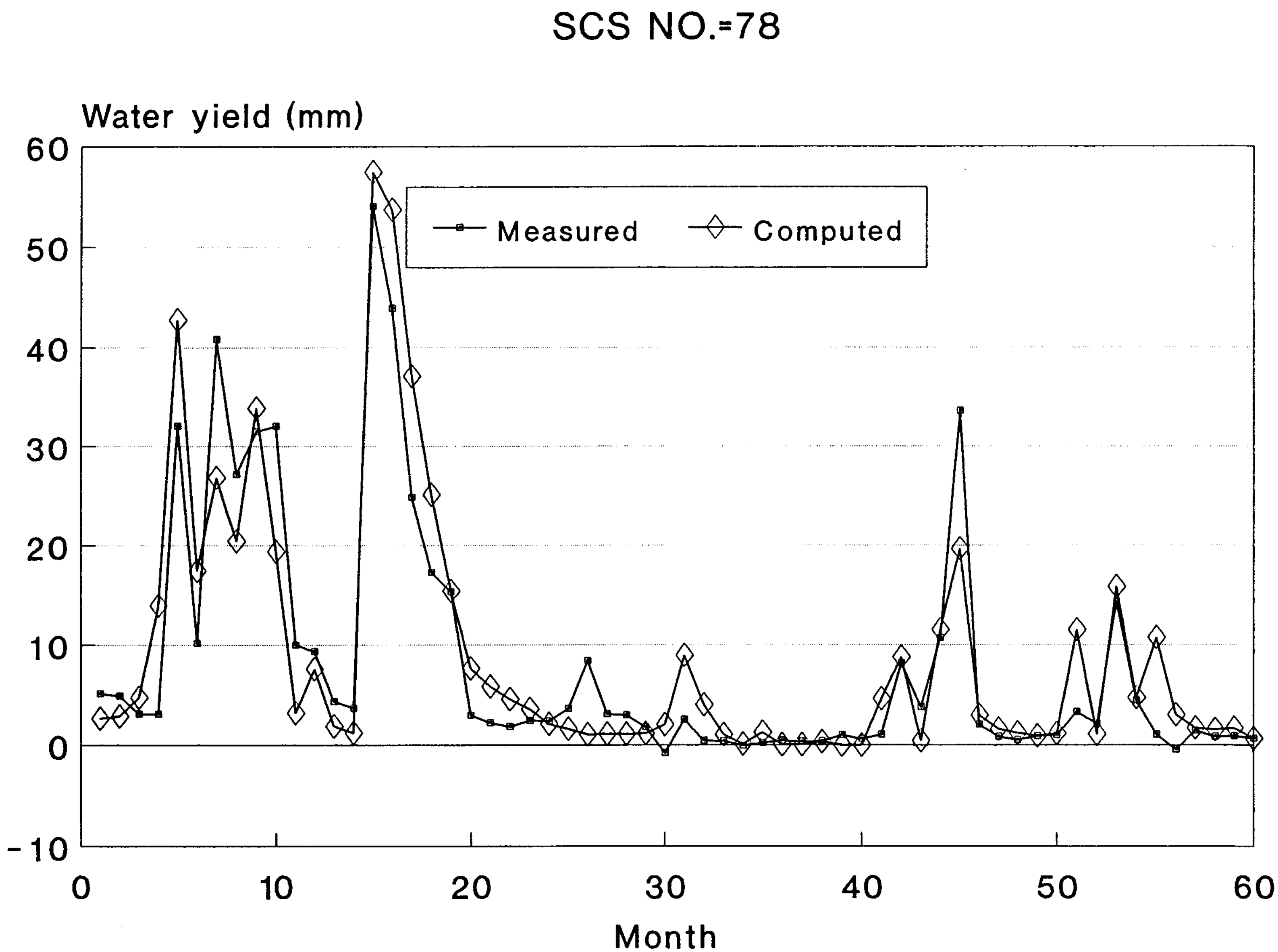


Fig. 32 - Model Calibration; Sensitivity to SCS CN: monthly data, SCS CN=78

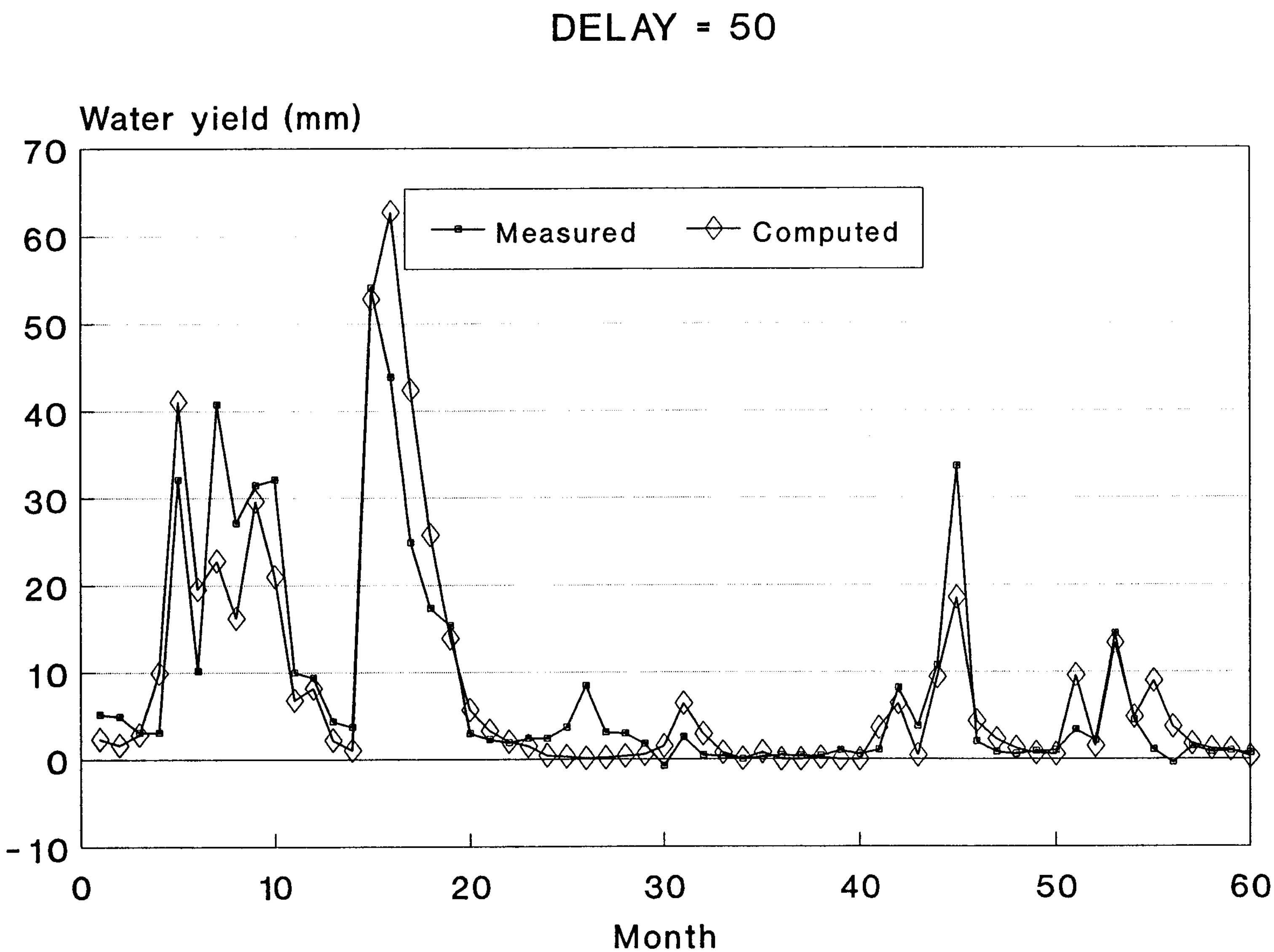


Fig. 33 - Model Calibration; Sensitivity to Groundwater Delay Factor δ: monthly data, δ=50days

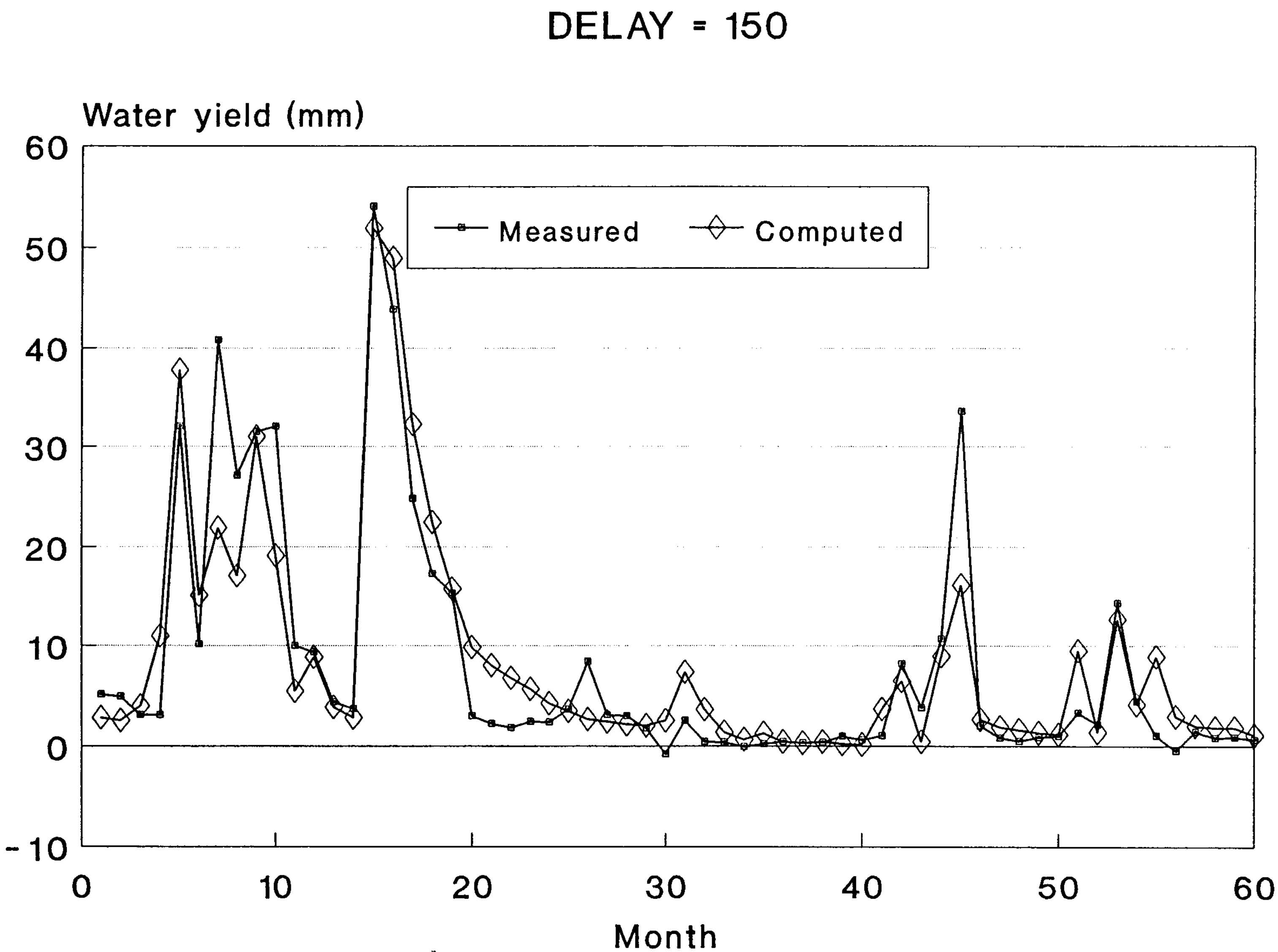


Fig. 34 - Model Calibration; Sensitivity to Groundwater Delay Factor δ: monthly data, δ=150days

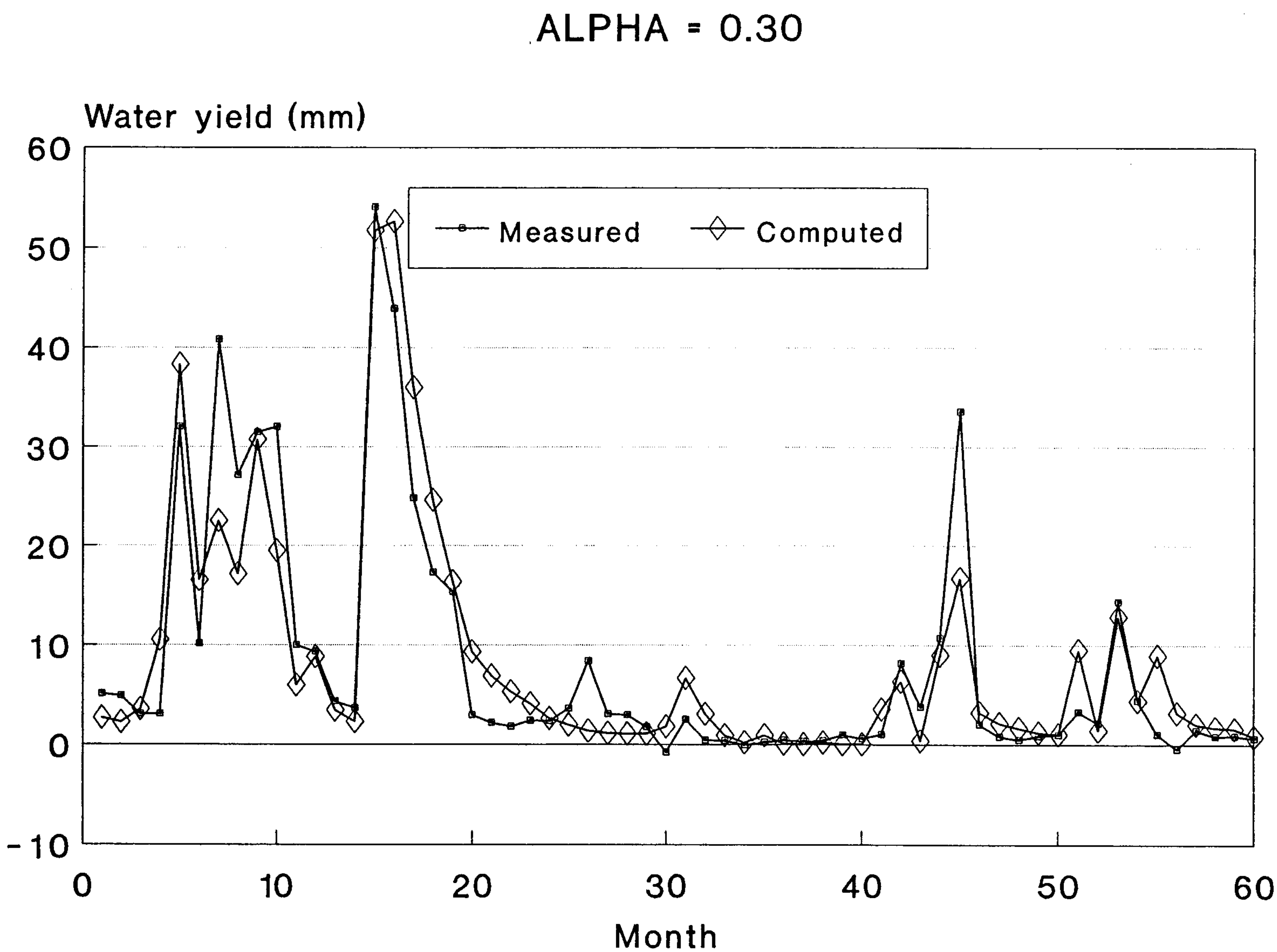


Fig. 35 - Model Calibration; Sensitivity to Groundwater Reaction Factor δ: monthly data, α=0.3 days^{-1}

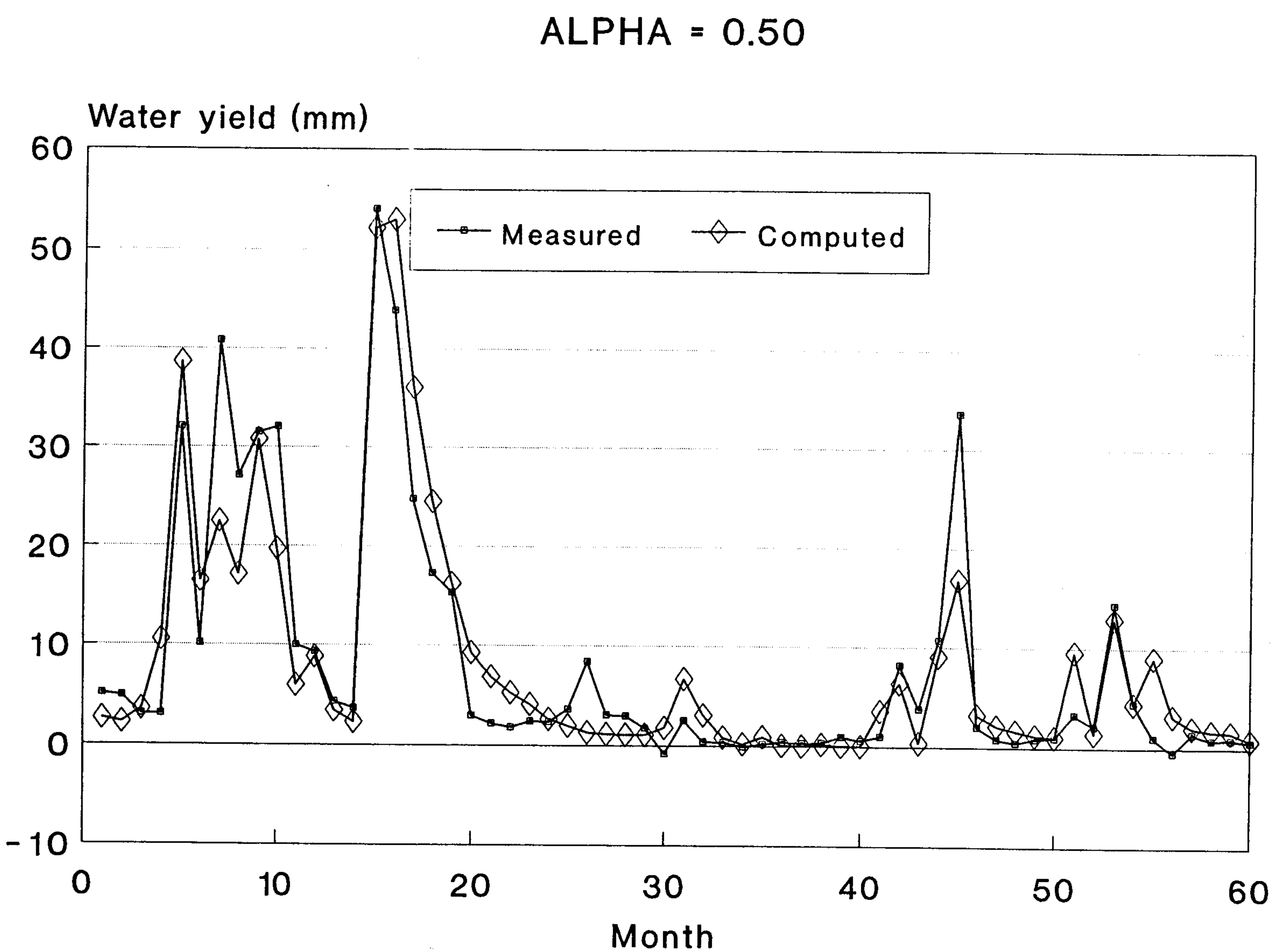


Fig. 35 - Model Calibration; Sensitivity to Groundwater Reaction Factor δ: monthly data, α=0.5 days^{-1}

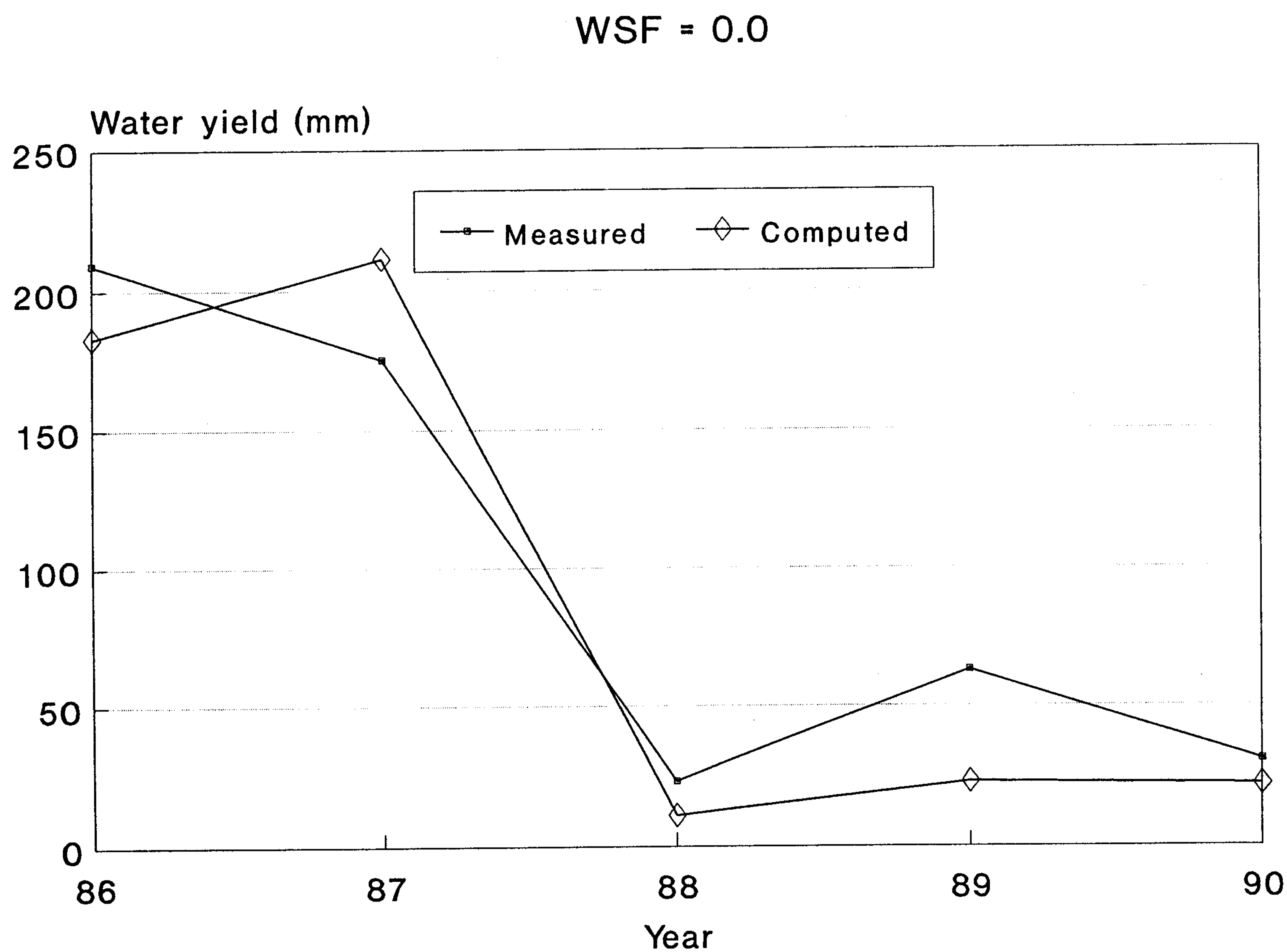


Fig. 36 - Model Calibration; Sensitivity to WSF: annual data, WSF=0

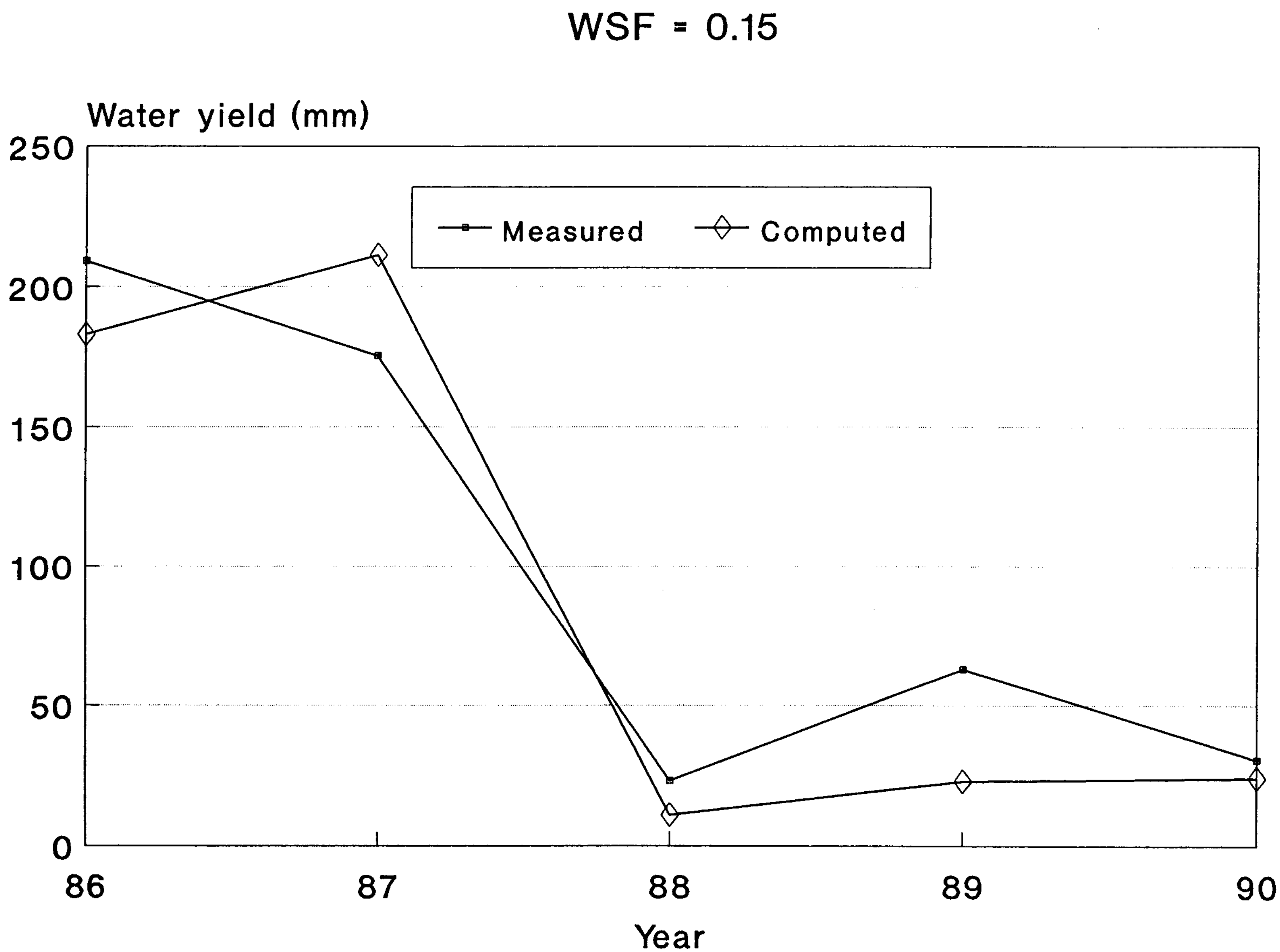


Fig. 37 - Model Calibration; Sensitivity to WSF: annual data, WSF=0.15

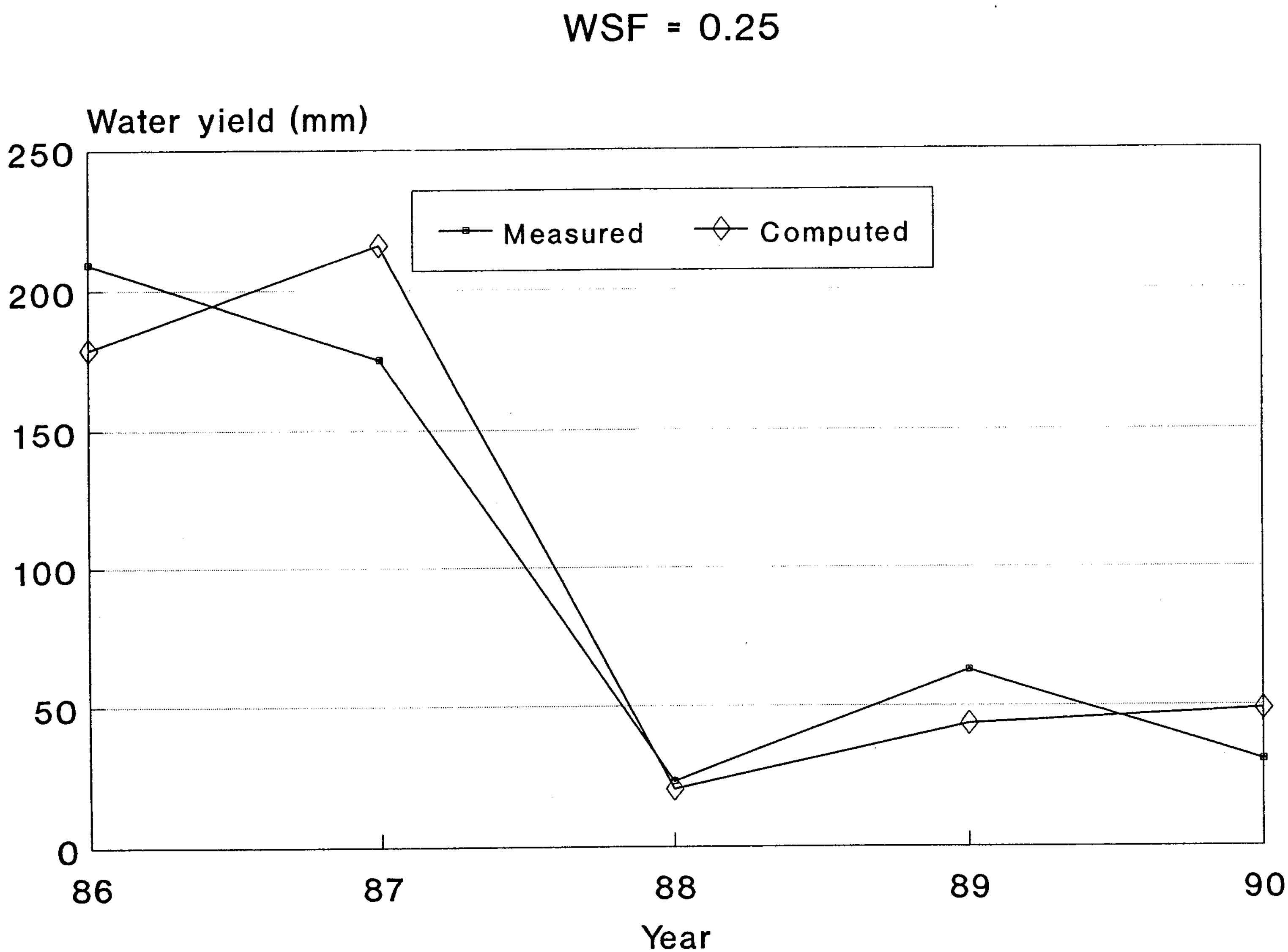


Fig. 38 - Model Calibration; Sensitivity to WSF: annual data, WSF=0.25

(standard case: WSF=0.25, Landuse=Wheat, SCS CN=75, δ=100days, α=0.4days^{-1})

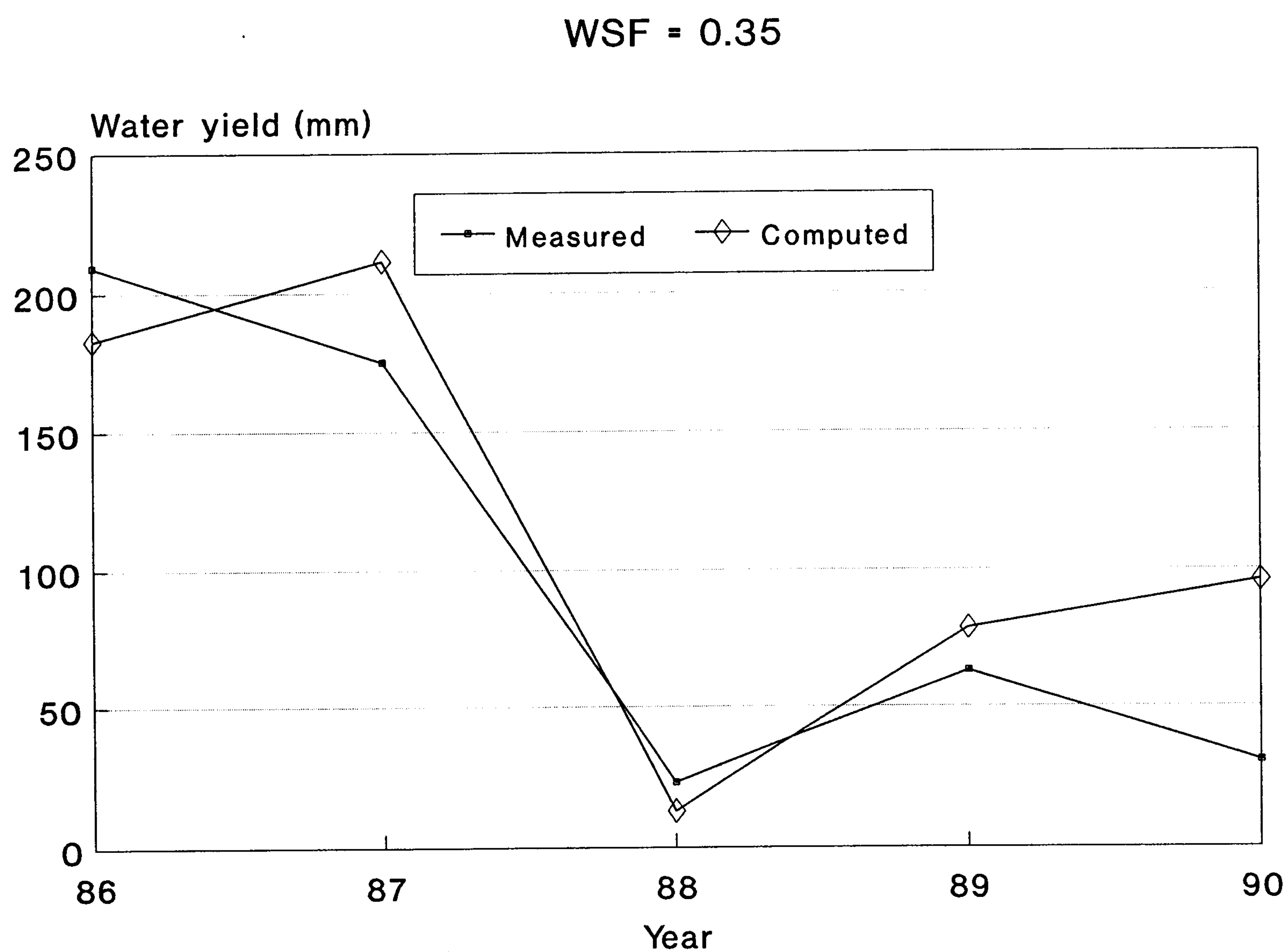


Fig. 39 - Model Calibration; Sensitivity to WSF: annual data, WSF=0.35

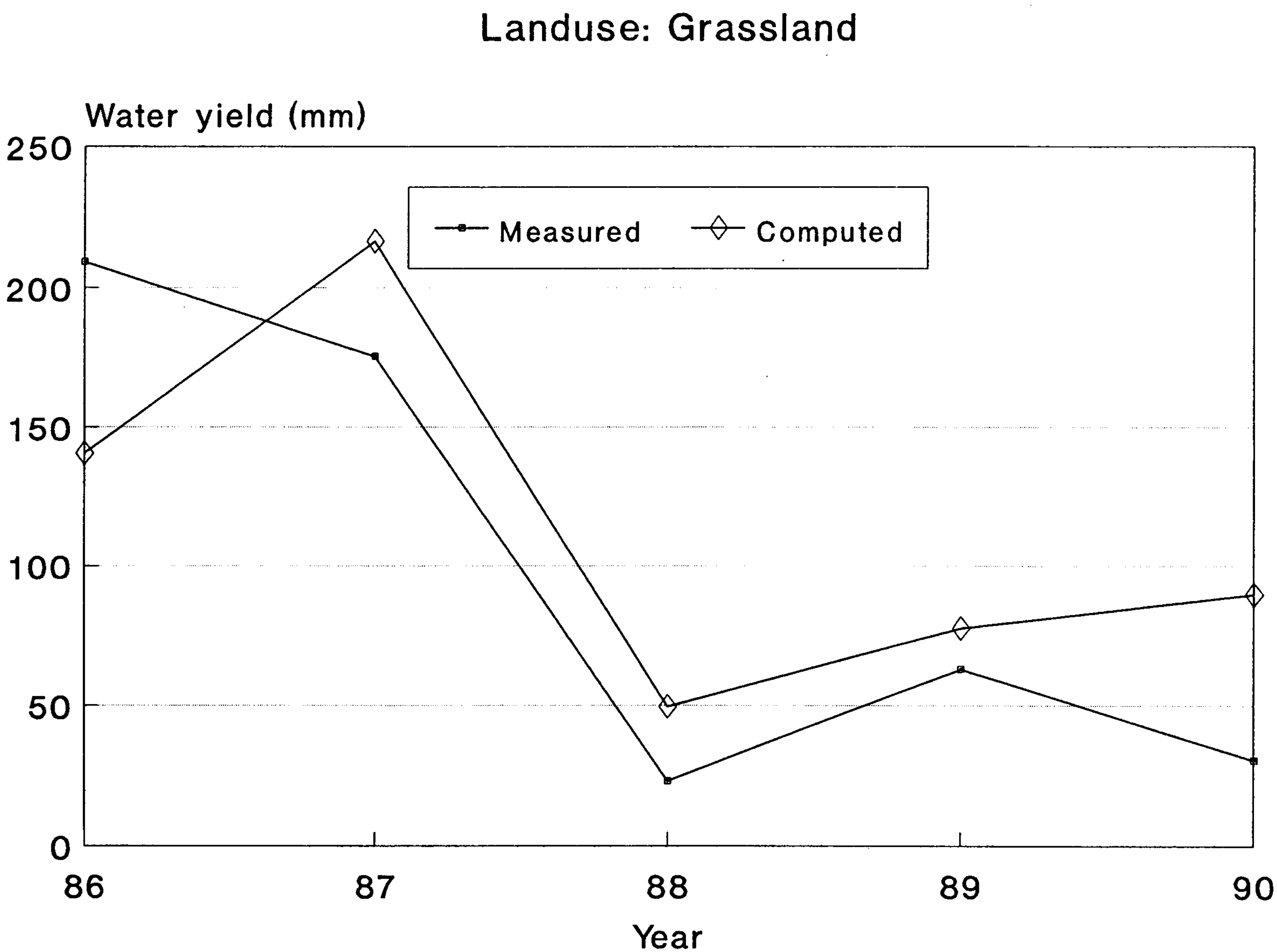


Fig. 40 - Model Calibration; Sensitivity to Landuse: annual data, Grassland

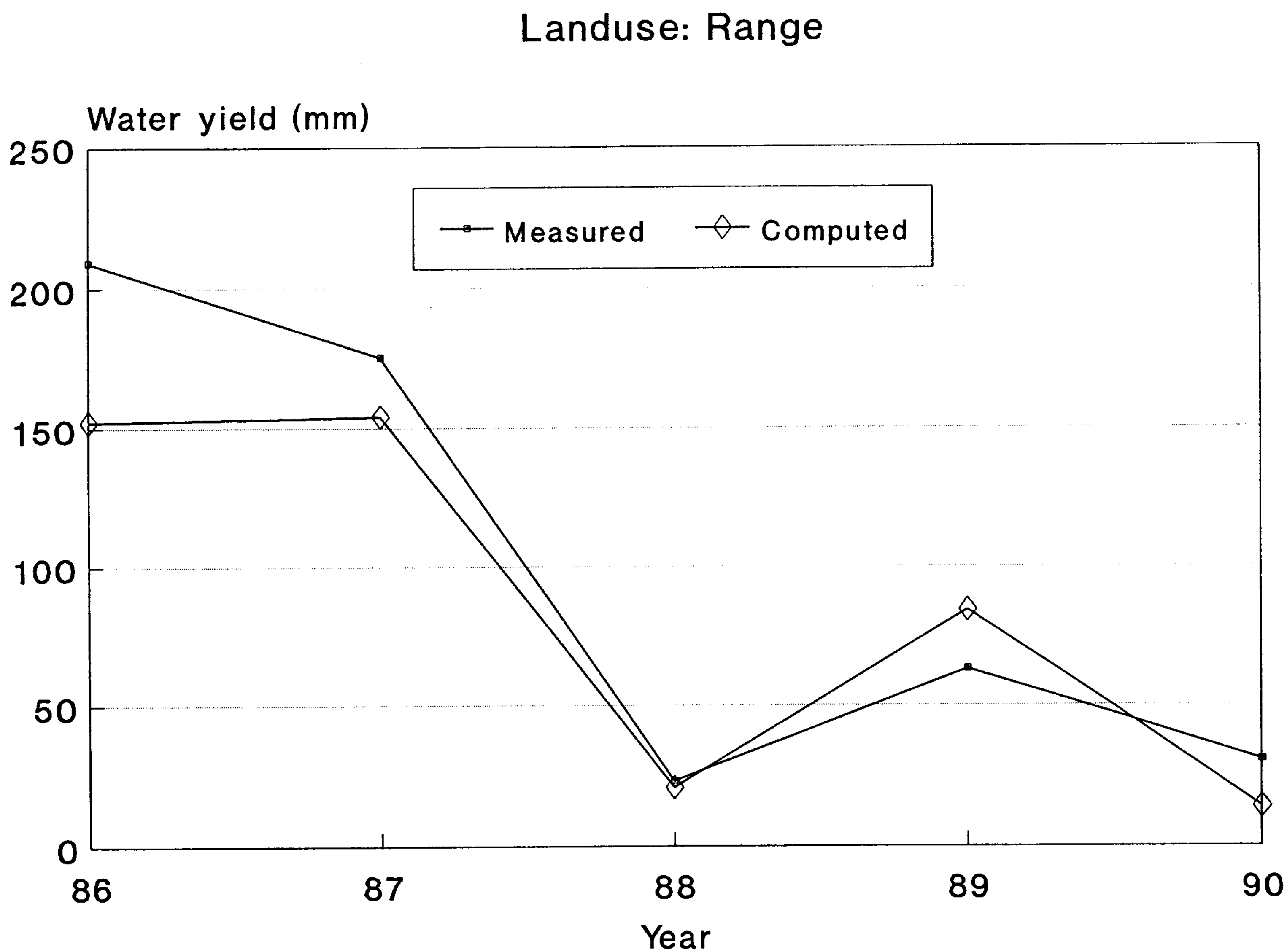


Fig. 41 - Model Calibration; Sensitivity to Landuse: annual data, Range

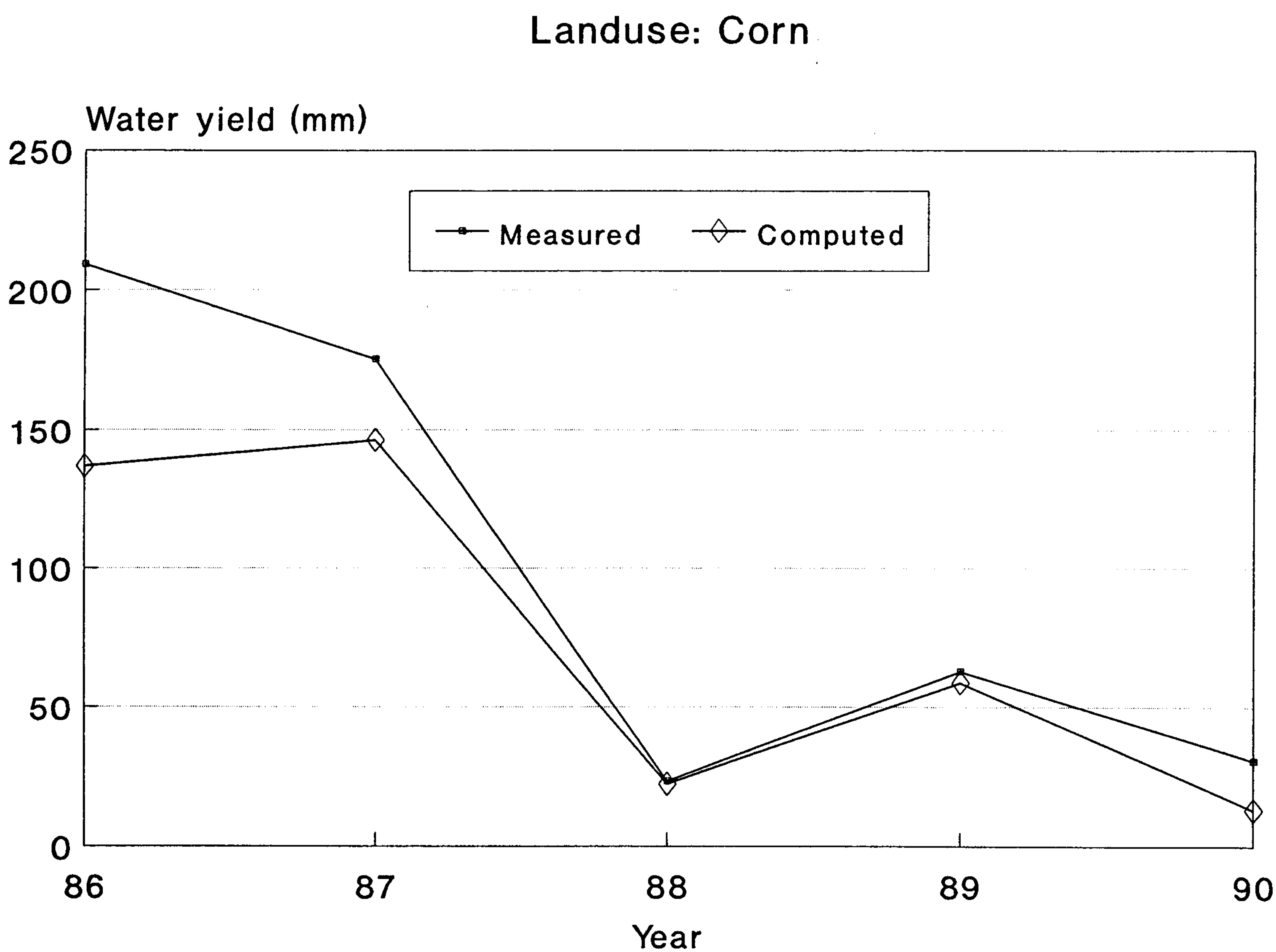


Fig. 42 - Model Calibration; Sensitivity to Landuse: annual data, Corn

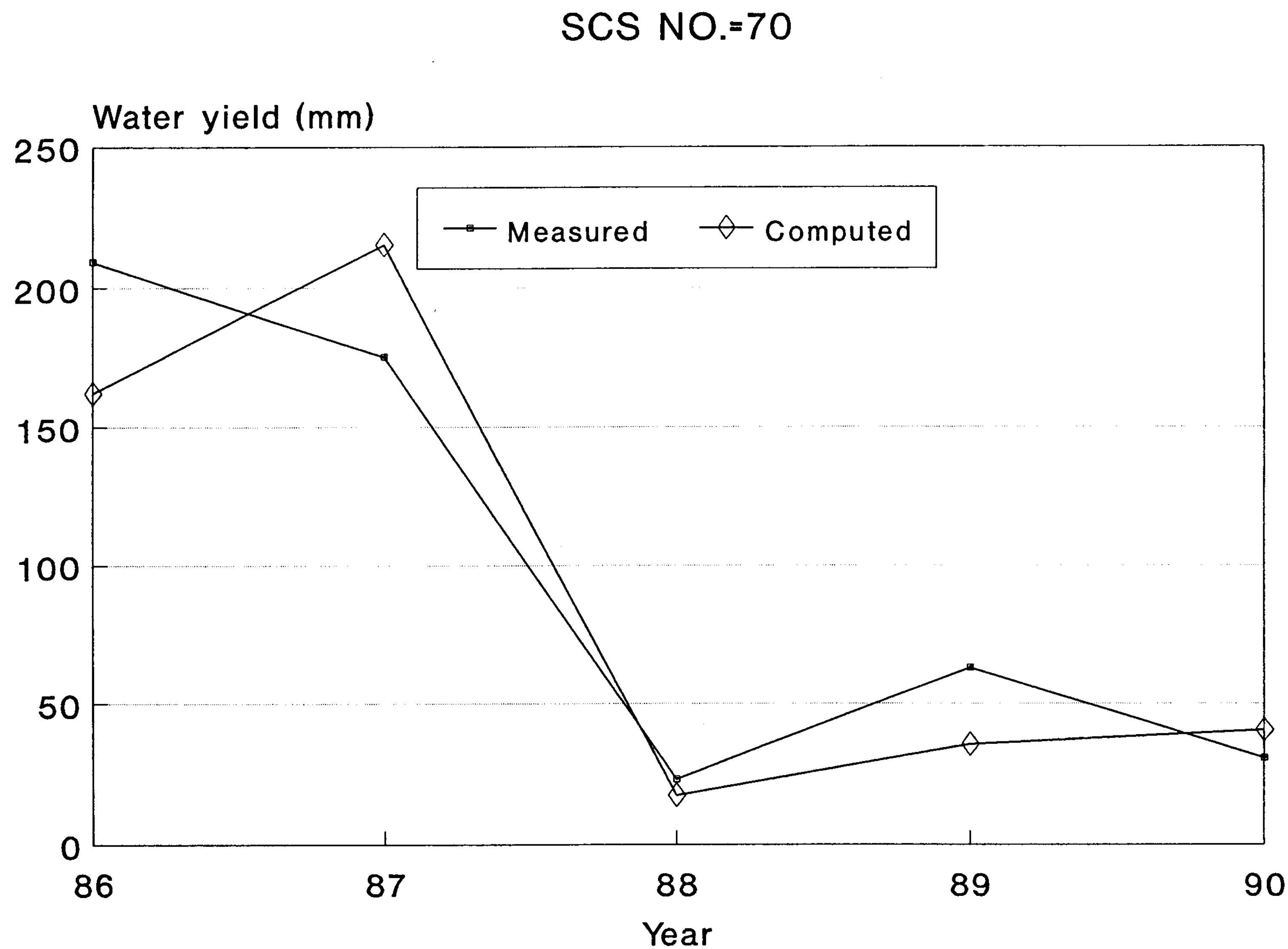


Fig. 43 - Model Calibration; Sensitivity to SCS CN: annual data, SCS CN=70

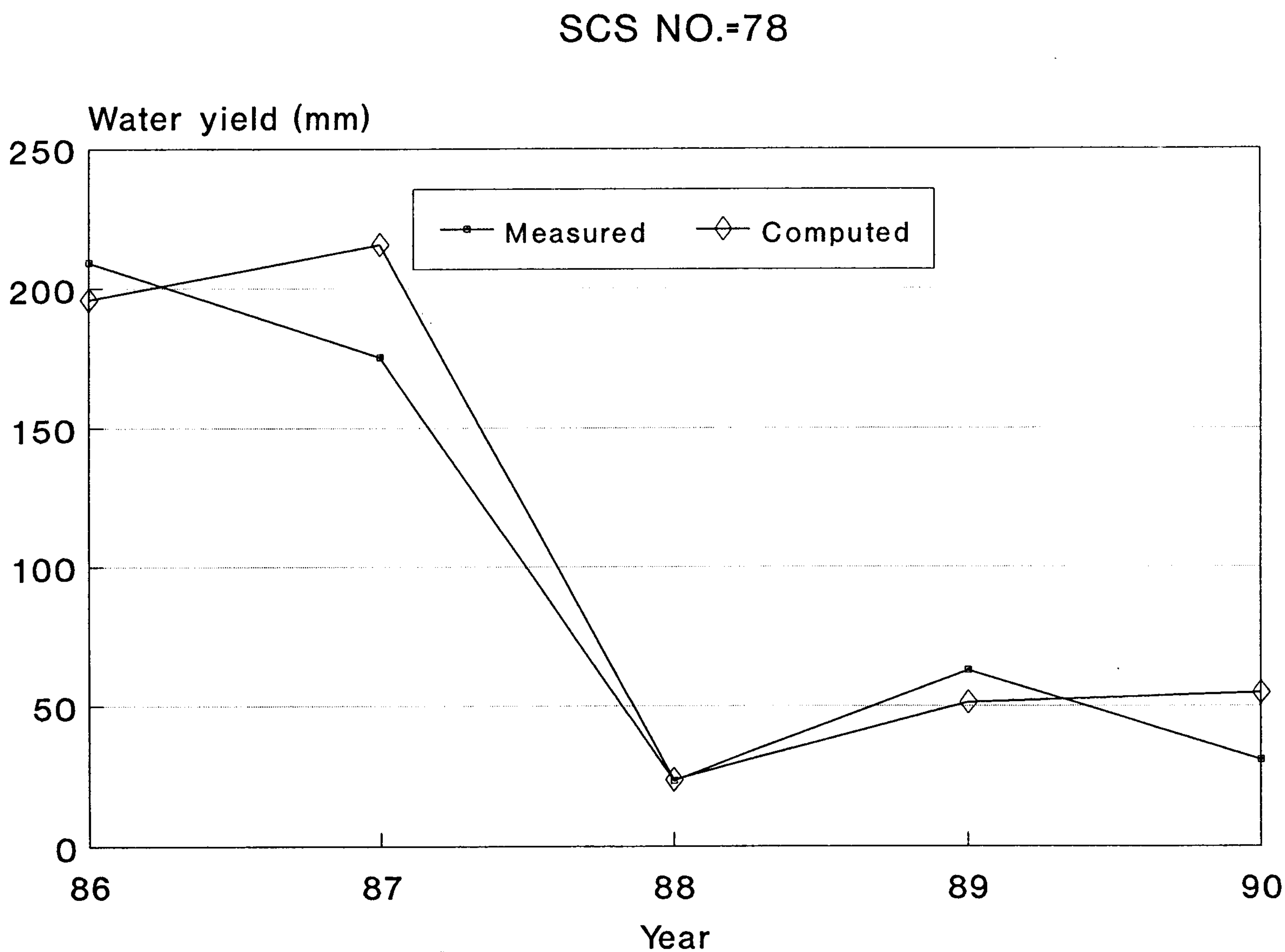


Fig. 44 - Model Calibration; Sensitivity to SCS CN: annual data, SCS CN=78

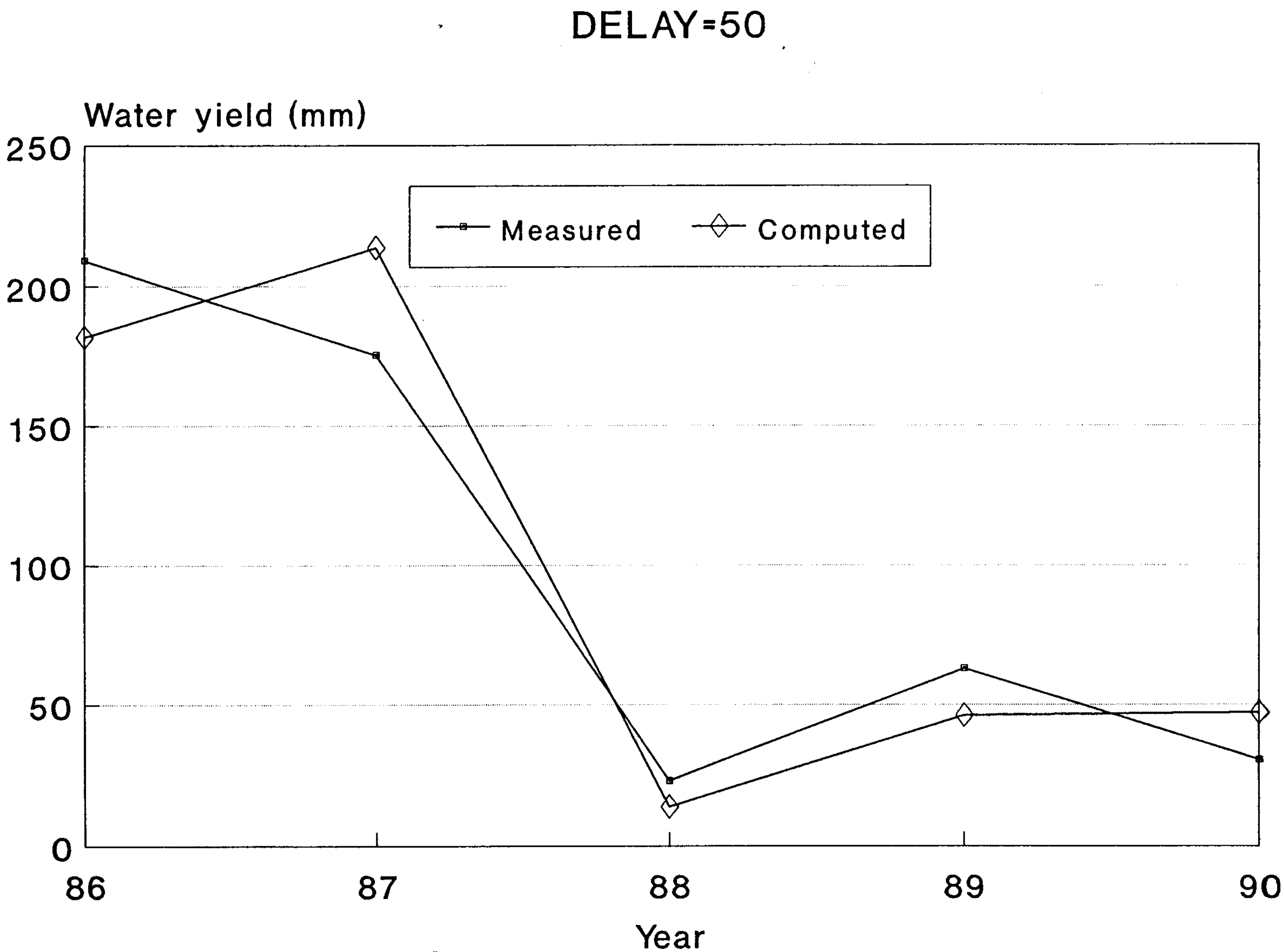


Fig. 45 - Model Calibration; Sensitivity to Groundwater Delay Factor δ: annual data, δ=50days

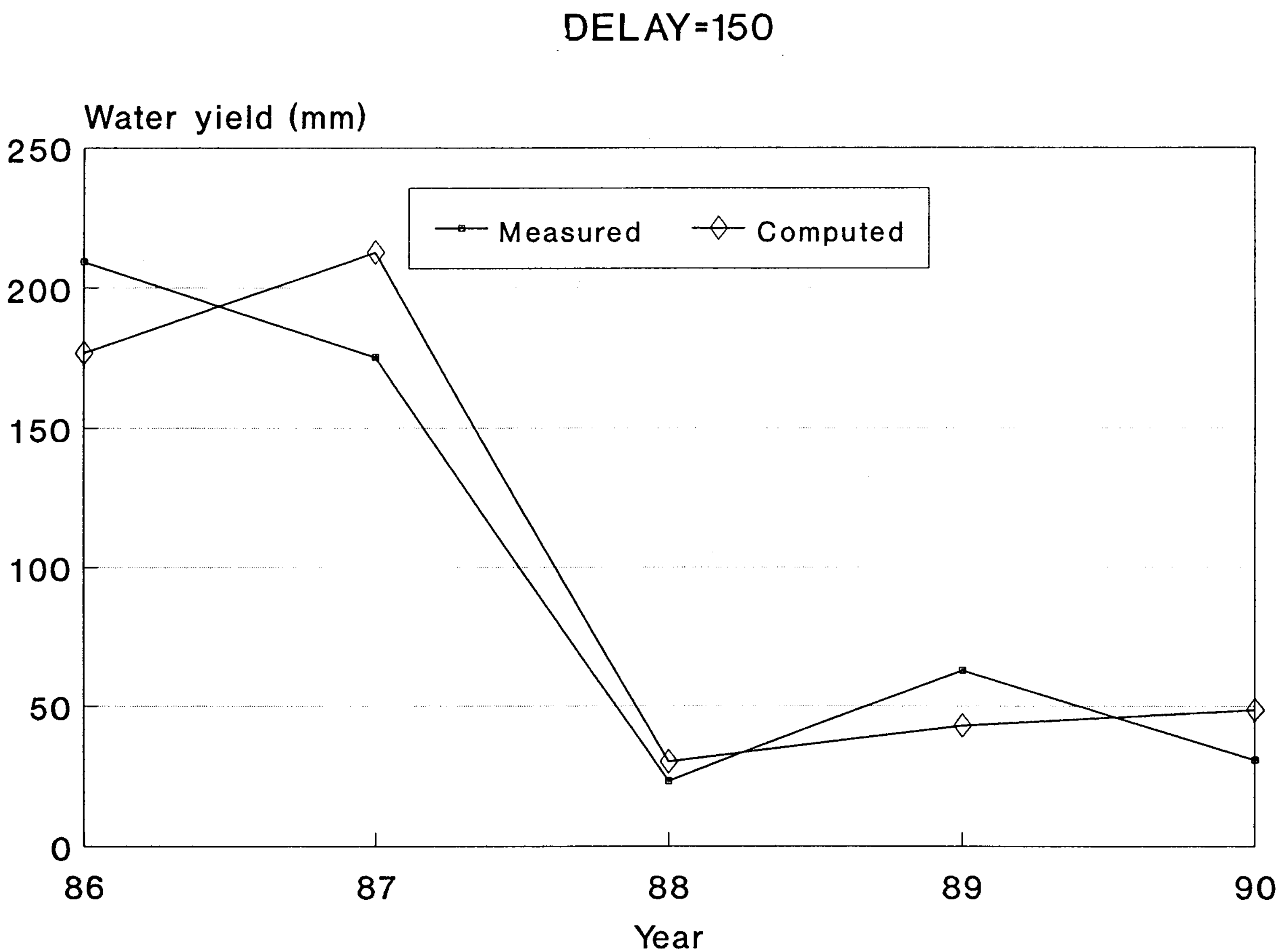


Fig. 46 - Model Calibration; Sensitivity to Groundwater Delay Factor δ: annual data, δ=150days

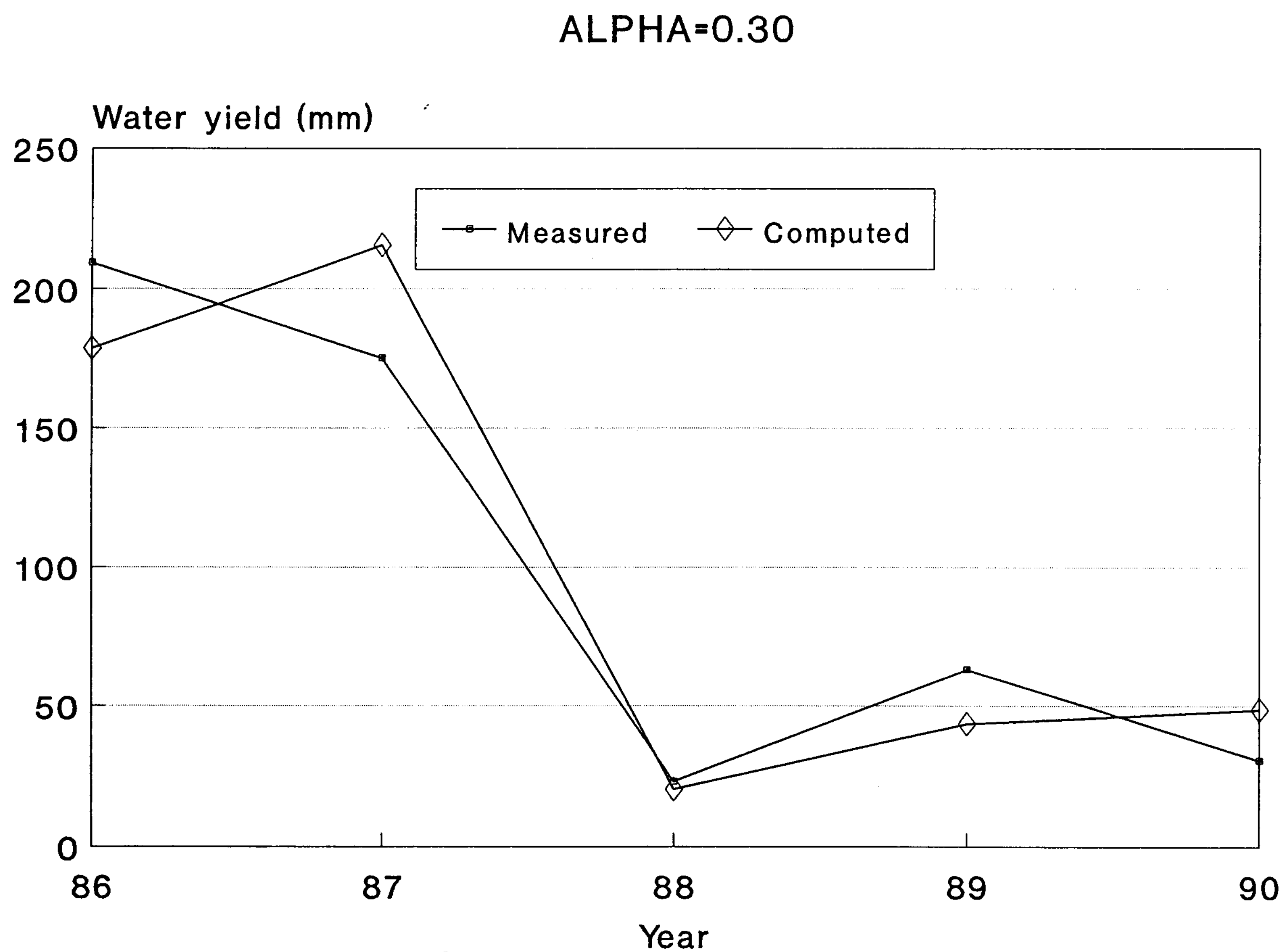


Fig. 47 - Model Calibration; Sensitivity to Groundwater Reaction Factor δ: annual data, α=0.3 days^{-1}

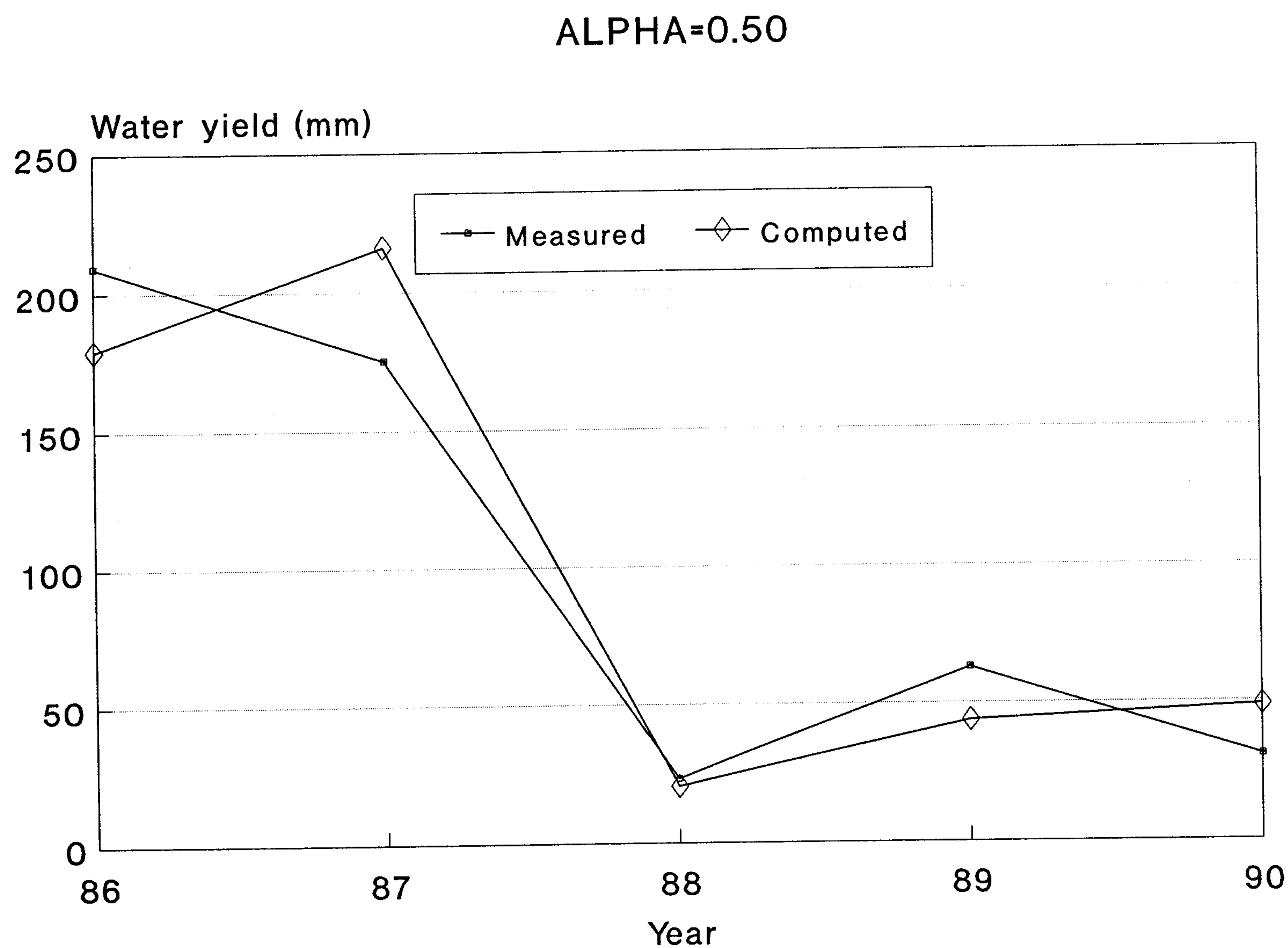


Fig. 48 - Model Calibration; Sensitivity to Groundwater Reaction Factor δ: annual data, α=0.5 days^{-1}

6.6 Hydrologic Balance

An inherently difficult problem arises in the assessment of the modeling accuracy of the hydrology of a watershed: the water that enters the basin as (measured) precipitation (P, input) is subjected to several operations prior to reaching the basin outlet as streamflow, where it can be measured in order to establish a quantitative estimate of modeling accuracy; these operations are also partly affected by the meteorological forcing (itself an input function): e.g., temperature and wind effects on evapotranspiration. The state of the system is not observed at intermediate stages of the generation of what the SWAT developers term the basin water yield, that is the streamflow (Q) at the basin outlet generated from precipitation that fell on the basin. The water yield, Q, consists of the sum of the surface runoff, the lateral subsurface flow (interflow), the return flow (baseflow) and any seepage losses through the bed of alluvial channels, termed "transmission losses" in SWAT, (as well as losses to ponds and reservoirs, if present), as shown in Figure 1. Each of these quantities is affected by a number of interacting processes, and none of them is measured directly. It is thus clear that precipitation passes through various "filters" before it becomes streamflow; moreover, the amount that percolates into the "deep aquifer" (deep percolation) is lost to the system.

When the water yield is viewed in the context of an overall water balance, additional quantities appear that are also not known directly through measurements; some of these are major, e.g. evapotranspiration (ET). It is therefore difficult to develop robust estimates of modeling accuracy, nevertheless, it is important that a system-wide balance be established. The overall water balance for the basin reads as follows, where the quantities are expressed as water depths (mm) accumulated over the time period for which the balance is determined:

$$P = ET + \text{revaporation (from shallow GW)} + \text{deep percolation} + Q + \Delta(\text{storage})$$

In this balance the term "revaporation" accounts for water that travels from the shallow aquifer to the soil profile, from which it is returned to the atmosphere by evapotranspiration; however, currently SWAT does not include it in the soil water balance, and does not account for it in the ET term. The common assumption that the change of storage is zero is based on the rationale that over several years storage gains and losses balance out; however, this is not so over the span of only five years employed in this study, therefore we have

$$\Delta(\text{storage}) = [P] - [ET + \text{revaporation (from shallow GW)} + \text{deep percolation} + Q]$$

For the five-year calibration run, the average annual water balance terms, all computed by the model and rounded to the nearest mm, are (see also Fig. 49):

IN: Precipitation P = 732mm; irrigation water = 30mm

OUT: losses: Evapotranspiration ET = 688mm

losses revaporation = 34mm

losses deep percolation = 36mm and

water yield Q= surface runoff + lateral subsurface flow (interflow) + return flow (baseflow)-transmission losses= 67mm + 1mm + 37mm - 3mm = 102mm.

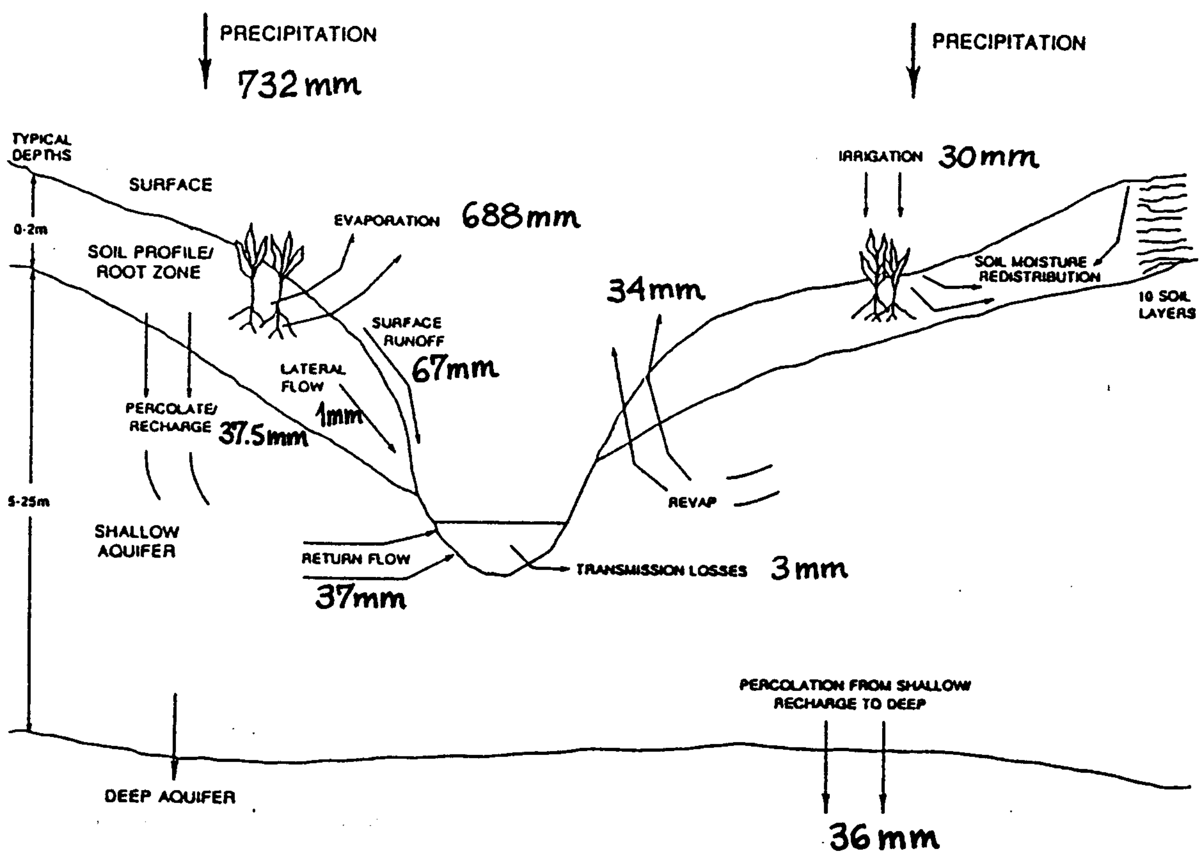


Fig. 49 - Components of the Water Balance

Therefore, the outflows (ET+revaporation+deep percolation+Q) exceed the input (precipitation, P) by 128mm, or by about 17% of the input (P). This result must be corrected by (properly) including in the balance the irrigation water that the model "generates" based on the concept of the water stress factor, which is not accounted in the aforementioned water balances. In our case the annual average amount of this water is approximately 30mm (30.35mm), which reduces the deficit to 98mm, or about 13%. If one considers additionally that during the time period 1986-1990 conditions were rather dry, some amount of storage depletion should be expected to have occurred, i.e. $\Delta(\text{storage})<0$. This will, most likely, reduce the storage balance error to under 10%, which is an acceptable margin of error for this type of work.

The following storage balances for the two sub-systems that are modeled by SWAT in detail, the shallow aquifer portion of the basin and the soil profile (root zone), Figure 49, reveals the composition of the storage depletion. The balance for the shallow aquifer reads:

$$\Delta(\text{storage})_{\text{shallow aquifer}} = \text{recharge} + \text{percolation} - \text{revaporation} - \text{return flow} - \text{deep percolation} + \\ + \text{transmission losses}$$

$$\Delta(\text{storage})_{\text{shallow aquifer}} = 37.5\text{mm} + 3.2 - 34.4\text{mm} - 37.2\text{mm} - 36.0\text{mm} + 2.8\text{mm} = -64.1\text{mm}$$

A similar calculation for the soil profile yields:

$$\Delta(\text{storage})_{\text{soil}} = (\text{net precipitation}) - \text{ET} - \text{recharge} - \text{percolation} - \text{lateral flow}$$

where (net precipitation)=precipitation P-surface runoff=731.8mm - 66.6mm=665.2mm, so that

$$\Delta(\text{storage})_{\text{soil}} = 665.2 - 688.2 - 37.5 - 3.2 - 0.6 = 665.2 - 729.5 = -64.3\text{mm}$$

Modeling consistency can be checked partially by first correcting the thus calculated $\Delta(\text{storage})_{\text{soil}}$ =-64.3mm for the applied irrigation water of +30.35mm, which gives $\Delta(\text{storage})_{\text{soil}}$ = -34mm, and by then comparing the corrected result with the storage deficit computed by SWAT via soil moisture accounting, which is -135mm over five years or -27mm per year (on the average; individual years have different soil moisture balances). We note that the soil moisture accounting procedure includes irrigation volumes. From this comparison, -34mm versus -27mm, we conclude that the soil profile (root zone) component of SWAT works well.

Finally, the sum of the two storage changes (deficits) consitutes the overall storage change (deficit), excluding the 30.35mm of irrigation water. As was shown above, this deficit is -128mm; this figure is confirmed here, thus also indicating overall internal model consistency:

$$\Delta(\text{storage}) = \Delta(\text{storage})_{\text{shallow aquifer}} + \Delta(\text{storage})_{\text{soil}} = -64.3 - 64.1 = -128.4\text{mm}$$

With irrigation water supply, the two deficit calculations yield 98mm and 98.1mm. The discrepancies are due to the overall storage balance having been calculated using integers, while the terms in the partial storage balances are stated to the first decimal.

Reviewing the various terms of the balances, we note that evapotranspiration, ET, is by far the largest with 688mm, followed by the water yield, Q, with 102mm. However, the water yield is a composite quantity; its dominant term is the surface runoff (67mm), which explains why landuse is so important a parameter. We also note that the relatively high value of revaporation (34mm) is, probably, the result of placing the shallow aquifer's water table only 2m from the ground surface, SWAT's recommended maximum depth to water table; however, relevant data for the Lower Republican River Basin are scarce.

Furthermore, the value for deep percolation (36mm) could be somewhat high. Deep percolation is modeled as a true "loss" for the system; it depends on a single model parameter, the percolation coefficient, which is not physically based and which determines deep percolation as a fraction of recharge to the shallow aquifer. In the absence of direct measurements, additional sensitivity analysis should be employed to test this modeling component. In general, the groundwater component of SWAT is simplistic, in contrast to the detailed modeling of the soil profile. Simulation of the aquifer conditions in the Lower Republican River Basin in the second year of study with MODFLOW, which uses the physical groundwater flow equations, should give much more reliable results.

7. SUMMARY and CONCLUSIONS

In the first year of study we have compiled the data necessary for the analysis and modeling of the hydrologic behavior of the Lower Republican River Basin. This information has been organized in two data bases, a geographic data base and a hydrologic data base. The former has been manipulated with the GIS software package Arc/Info to provide appropriate coverages which have been displayed as maps of the quantities of interest. Estimates of several hydrologic modeling parameters have been developed by additional mathematical manipulations of these data.

After careful screening of the field of basin-scale hydrologic models, we have selected the Soil and Water Assessment Tool model (SWAT) for this study. SWAT is, largely, a physically based model. In addition to the parameters of the model that could be determined directly from measurements of the physical properties of the basin, we have estimated the remaining parameters indirectly by using hydrologic judgement and directly by comparing the model's predictions with the streamflow record.

We have performed a rather comprehensive sensitivity analysis using data for the period 1986-1990. We have found that the water stress factor, a measure of irrigation scheduling, affects basin yield most strongly, followed by landuse (crop type) and the SCS curve number. The model was found to be insensitive to groundwater-related parameters. From the modeling results we conclude that the most sensitive parameters, water stress factor and landuse, should be time-variable (at least annually), not constant during the simulation. The model's performance may be also judged reasonable based on the analysis of the basin-wide storage balance, as well as the separate storage balances for the soil profile and for the shallow aquifer. The dominant terms of the overall balance are evapotranspiration and water yield. This set of initial results are encouraging.

Next year's effort should concentrate on two areas: 1) refinement of the basin-wide hydrologic modeling effort, including the SWAT code modification to accommodate temporal variability of such parameters as water stress factor (accomplished this year in a preliminary fashion) and landuse, and 2) initiation of the aquifer modeling study with MODFLOW. Completion of these objectives will lead to the final project phase in which the models will be used to assess and evaluate alternate water management scenarios for the Lower Republican River Basin.

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APPENDIX

Soil data and Water Rights data

SOIL SURVEY OF
CLAY COUNTY, KANSAS

SOIL ASSOCIATION & Soil Series	%	Depth (in.)			% Clay	Permiability. (in/hr)			% pass. no.200 (0.074m	Available water capacity (in/in)			Moist Bulk Density (g/cm3)		
						min.	max.	avg.		min.	max.	avg.	min.	max.	avg.
Crete-Hobbs	54														
Crete: Cr,Cs	80	0	7	3.5	23.5	0.60	2.00	1.30	97.5	0.16	0.18	0.17	1.2	1.4	1.3
		7	36	21.5	43.5	0.06	0.60	0.33	97.5	0.18	0.2	0.19	1.1	1.3	1.2
		36	60	48	32.5	0.20	2.00	1.10	97.5	0.18	0.2	0.19	1.2	1.4	1.3
Hobbs:Hn,Ho	6	0	7	3.5	22.5	0.60	2.00	1.30	92.5	0.21	0.24	0.225	1.2	1.4	1.3
		7	60	33.5	22.5	0.60	2.00	1.30	90	0.18	0.22	0.2	1.2	1.4	1.3
Minor soils	14														
Crete-Lancaster-Hedville	15														
Crete:Ct	30	0	7	3.5	31	0.20	0.60	0.40	97.5	0.21	0.23	0.22	1.2	1.4	1.3
		7	31	19	47	0.06	0.60	0.33	97.5	0.12	0.2	0.16	1.1	1.3	1.2
		31	60	45.5	32.5	0.20	2.00	1.10	97.5	0.18	0.22	0.2	1.2	1.4	1.3
Lancaster:Lh*,Lc	30	0	9	4.5	19	0.60	2.00	1.30	75	0.17	0.22	0.195	1.35	1.45	1.4
		9	35	22	26.5	0.60	2.00	1.30	52.5	0.15	0.19	0.17	1.35	1.5	1.43
		35													
Hedville	10	0	14	7	15	0.60	2.00	1.30	52.5	0.09	0.14	0.115	1.35	1.5	1.43
		14													
Minor soils	30														
Muir-Eudora	15														
Muir:Mu	50	0	22	11	22.5	0.60	2.00	1.30	92.5	0.2	0.23	0.215	1.3	1.45	1.38
		22	60	41	26.5	0.60	2.00	1.30	92.5	0.18	0.22	0.2	1.3	1.5	1.4
Eudora:Er,Eu	20	0	8	4	11.5	0.60	2.00	1.30	79	0.2	0.24	0.22	1.3	1.5	1.4
		8	60	34	11.5	0.60	2.00	1.30	79	0.17	0.22	0.195	1.35	1.5	1.43
Minor soils	30														
Crete-Kipson-Sogn	11														
Crete:Cx	53	0	6	3	31	0.20	0.60	0.40	92.5	0.21	0.23	0.22	1.2	1.4	1.3
		6	28	17	47	0.06	0.60	0.33	95	0.12	0.2	0.16	1.1	1.3	1.2
		28	60	44	32.5	0.20	2.00	1.10	92.5	0.18	0.22	0.2	1.2	1.4	1.3
Kipson:Ks*	16	0	8	4	31	0.60	2.00	1.30	45	0.17	0.2	0.185	1.3	1.4	1.35
		8	18	13	26.5	0.60	2.00	1.30	32.5	0.15	0.2	0.175	1.35	1.5	1.43
		18													
Sogn	9	0	12	6	31	0.60	2.00	1.30	85	0.17	0.22	0.195	1.15	1.2	1.18
		12													
Minor soils	22														
Geary-Holder	5														
Geary:Gc,Gf,Gh	78	0	10	5	21	0.60	2.00	1.30	89	0.22	0.24	0.23	1.3	1.4	1.35
		10	36	23	31	0.60	2.00	1.30	91.5	0.17	0.2	0.185	1.35	1.5	1.43
		36	60	48	26	0.60	2.00	1.30	91.5	0.15	0.19	0.17	1.3	1.4	1.35
Holder	10	0	12	6	21	0.60	2.00	1.30	95	0.22	0.24	0.23	1.4	1.6	1.5
		12	36	24	31.5	0.60	2.00	1.30	97.5	0.18	0.2	0.19	1.2	1.4	1.3
		36	60	48	22.5	0.60	2.00	1.30	95	0.2	0.22	0.21	1.4	1.6	1.5
Minor soils	12														

SOIL SURVEY OF
CLOUD COUNTY, KANSAS

SOIL ASSOCIATION & Soil Series	%	Depth (in.)			% Clay	Permiability. min.	max. (in/hr)	avg.	% pass. no.200 (0.074m	Available water capacity min.	max. (in/in)	avg.	Avg. Bulk Density Moist (gr/cu.cm)	Dry
Crete-Hastings-Hobbs	16													
Crete: Cr,Cs,Ct,Cu	70	0	14	7	92.5	0.2	0.6	0.4	92.5	0.16	0.18	0.17	1.30	1.41
		14	34	24	95	0.2	0.6	0.4	95	0.18	0.2	0.19	1.20	1.41
		34	60	47	92.5	0.2	0.6	0.4	92.5	0.18	0.2	0.19	1.30	1.41
Hastings:Hb,Hc,Hd	15	0	12	6	92.5	0.2	0.6	0.4	92.5	0.17	0.19	0.18		1.41
		12	24	18	95	0.2	0.6	0.4	95	0.18	0.2	0.19		1.41
		24	44	34	92.5	0.2	0.6	0.4	92.5	0.17	0.19	0.18		1.41
Hobbs:Ho	5	0	20	10	90	0.6	2	1.3	90	0.17	0.19	0.18	1.30	1.41
		20	40	30	90	0.6	2	1.3	90	0.18	0.2	0.19	1.30	1.41
		40	60	50	90	0.6	2	1.3	90	0.18	0.2	0.19	1.30	1.41
Minor soils	10													
Kipson-Hastings-Armo	20													
Kipson:Kp	33	0	10	5	45	0.6	2	1.3	45	0.14	0.16	0.15	1.35	1.41
		10	20	15	50	0.6	2	1.3	50	0.14	0.16	0.15	1.40	1.41
		20												1.41
Hastings:Hb,Hc,Hd	28	0	12	6	92.5	0.2	0.6	0.4	92.5	0.17	0.19	0.18		1.41
		12	24	18	95	0.2	0.6	0.4	95	0.18	0.2	0.19		1.41
		24	44	34	92.5	0.2	0.6	0.4	92.5	0.17	0.19	0.18		1.41
Armo:Ar	17	0	10	5	87.5	0.6	2	1.3	87.5	0.16	0.18	0.17	1.25	1.41
		10	40	25	92.5	0.6	2	1.3	92.5	0.16	0.18	0.17	1.30	1.41
		40	60	50	82.5	0.6	2	1.3	82.5	0.16	0.18	0.17	1.30	1.41
Minor soils	22													
Crete-Longford-Hedville	25													
Crete: Cr,Cs,Ct,Cu	42	0	14	7	92.5	0.2	0.6	0.4	92.5	0.16	0.18	0.17	1.30	1.41
		14	34	24	95	0.2	0.6	0.4	95	0.18	0.2	0.19	1.20	1.41
		34	60	47	92.5	0.2	0.6	0.4	92.5	0.18	0.2	0.19	1.30	1.41
Longford:Lm,Ln,Lo	28	0	16	8	85	0.2	0.6	0.4	85	0.17	0.19	0.18		1.41
		16	46	31	87.5	0.2	0.6	0.4	87.5	0.18	0.2	0.19		1.41
		46	60	53	70	0.2	0.6	0.4	70	0.17	0.19	0.18		1.41
Hedville:He	5	0	16	8	50	0.6	2	1.3	50	0.11	0.13	0.12	1.40	1.41
		16												
Minor soils	25													
Hastings-Crete-Hord	20													
Hastings:Hb,Hc,Hd	45	0	12	6	92.5	0.2	0.6	0.4	92.5	0.17	0.19	0.18		1.41
		12	24	18	95	0.2	0.6	0.4	95	0.18	0.2	0.19		1.41
		24	44	34	92.5	0.2	0.6	0.4	92.5	0.17	0.19	0.18		1.41
Crete:Cr,Cs,Ct,Cu	30	0	14	7	92.5	0.2	0.6	0.4	92.5	0.16	0.18	0.17	1.30	1.41
		14	34	24	95	0.2	0.6	0.4	95	0.18	0.2	0.19	1.20	1.41
		34	60	47	92.5	0.2	0.6	0.4	92.5	0.18	0.2	0.19	1.30	1.41
Hord:Hr	10	0	22	11	90	0.6	2	1.3	90	0.17	0.19	0.18	1.35	1.41
		22	42	32	90	0.6	2	1.3	90	0.18	0.2	0.19	1.40	1.41
		42	60	51	90	0.6	2	1.3	90	0.18	0.2	0.19	1.40	1.41
Minor soils	15													

SOIL ASSOCIATION & Soil Series	%	Depth (in.)			% Clay	Permiability. (in/hr)			% pass. no.200 (0.074m	Available water capacity (in/in)			Avg. Bulk Density (gr/cu.cm)	
						min.	max.	avg.		min.	max.	avg.	Moist	Dry
Lancaster-Hedville	4													
Lancaster:Lh	50	0	20	10	60	0.6	2	1.3	60	0.11	0.13	0.12	1.3	1.41
		20	28	24	70	0.6	2	1.3	70	0.16	0.18	0.17	1.4	1.41
		28	36	32	57.5	0.6	2	1.3	57.5	0.1	0.12	0.11	1.4	1.41
Hedville:He	20	0	16	8	50	0.6	2	1.3	50	0.11	0.13	0.12	1.4	1.41
		16												
Minor soils	30													
Muir-Carr-Humbarger	10													
Muir:Mr	35	0	18	9	82.5	0.6	2	1.3	82.5	0.17	0.19	0.18		1.41
		18	42	30	90	0.6	2	1.3	90	0.18	0.2	0.19		1.41
		42	60	51	82.5	0.6	2	1.3	82.5	0.17	0.19	0.18		1.41
Carr:Ca,Cb	25	0	18	9	45	0.6	2	1.3	45	0.12	0.14	0.13		1.63
		18	48	33	37.5	0.6	2	1.3	37.5	0.1	0.12	0.11		1.63
		48	60	54	32.5	0.6	2	1.3	32.5	0.06	0.1	0.08		1.63
Humbarger:Hu	10	0	10	5	70	0.6	2	1.3	70	0.16	0.18	0.17		1.41
		10	22	16	87.5	0.6	2	1.3	87.5	0.17	0.19	0.18		1.41
		22	48	35	72.5	0.6	2	1.3	72.5	0.18	0.2	0.19		1.41
		48	60	54	22.5	0.6	2	1.3	22.5	0.1	0.12	0.11		1.41
Minor soils	30													
Detroit-Sutphen-Bridgepor	2													
Detroit:De	30	0	12	6	92.5	0.06	0.2	0.13	92.5	0.17	0.19	0.18	1.3	1.41
		12	36	24	95	0.06	0.2	0.13	95	0.18	0.2	0.19	1.4	1.31
		36	60	48	92.5	0.06	0.2	0.13	92.5	0.18	0.2	0.19	1.4	1.41
Sutphen:St	15	0	32	16	92.5	<.06			92.5	0.18	0.2	0.19		1.31
		32	60	46	90	<.06			90	0.18	0.2	0.19		1.31
Bridgeport:Br	15	0	14	7	90	0.6	2	1.3	90	0.16	0.18	0.17		1.41
		14	22	18	95	0.6	2	1.3	95	0.16	0.18	0.17		1.41
		22	40	31	87.5	0.6	2	1.3	87.5	0.16	0.18	0.17		1.41
		40	60	50	95	0.6	2	1.3	95	0.16	0.18	0.17		1.41
Minor soils	40													
Roxbury-New Cambria-Mc	3													
Roxbury:Rx	40	0	20	10	90	0.6	2	1.3	90	0.17	0.19	0.18	1.37	1.41
		20	42	31	90	0.6	2	1.3	90	0.18	0.2	0.19	1.42	1.41
		42	60	51	90	0.6	2	1.3	90	0.17	0.19	0.18	1.42	1.41
New Cambria:Nc	10	0	12	6	92.5	0.06	0.2	0.13	92.5	0.18	0.2	0.19	1.35	1.41
		12	40	26	95	0.06	0.2	0.13	95	0.18	0.2	0.19	1.4	1.31
		40	60	50	92.5	0.06	0.2	0.13	92.5	0.18	0.2	0.19	1.4	1.41
McCook:Mc	10	0	15	7.5	92.5	0.6	2	1.3	92.5	0.12	0.16	0.14	1.35	1.41
		15	40	27.5	80	0.6	2	1.3	80	0.12	0.14	0.13	1.3	1.41
		40	60	50	75	0.6	2	1.3	75	0.12	0.14	0.13	1.3	1.41
Minor soils	40													
	97													

NOTES: 1.Data was not available for %Clay so values were estimated .(Unified system was used which defines clay as the soil material passing no.200 sieve.)

2.Data was not available for bulk dry densities. Values were estimated by using table-- from "Introduction to Geotechnic Engineering" by Covacs.

3.Data for Moist Bulk Densities was also not available. The values used, are those of the same soil series in other counties, where values are given.

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WATER RIGHTS SUMMARY

Year	No.	Qapp.(ac-ft/yr)
1945	36	7094.42
1946	36	7094.42
1947	36	7094.42
1948	38	109696.7
1949	38	109696.7
1950	38	109696.7
1951	39	109728.7
1952	41	109966.7
1953	68	112405.4
1954	98	115542.4
1955	156	143819.4
1956	220	150249.7
1957	248	152764.7
1958	257	153518.7
1959	269	154673.3
1960	272	155312.3
1961	281	155902.3
1962	285	156154.3
1963	297	160305.3
1964	308	161753.3
1965	332	164798.7
1966	367	168701.7
1967	403	172244.2
1968	431	174831.3
1969	448	176469.3
1970	474	178998.8
1971	486	179987.8
1972	506	183002.7
1973	525	185004.5
1974	545	186691.5
1975	581	189868.6
1976	643	196720.3
1977	752	207428.8
1978	788	211138.0
1979	815	213153.2
1980	839	215437.1
1981	876	223048.5
1982	889	224479.8
1983	909	226077.2
1984	919	227033.9
1985	923	227348.8
1986	931	228209.5
1987	942	229639.5
1988	968	232838.0
1989	1002	242296.4
1990	1019	244187.2
1991	1030	246021.4

SURFACE WATER RIGHTS SUMMARY

Year	No.	Qapp.(ac-ft/yr)
1945	8	885.50
1946	8	885.50
1947	8	885.50
1948	9	103407.81
1949	9	103407.81
1950	9	103407.81
1951	10	103439.81
1952	11	103588.81
1953	28	104938.71
1954	34	105192.71
1955	41	126101.71
1956	55	127357.71
1957	57	127573.71
1958	64	128010.71
1959	64	128010.71
1960	66	128574.71
1961	70	128831.71
1962	70	128831.71
1963	72	128889.71
1964	74	129153.71
1965	76	129489.61
1966	80	130175.61
1967	85	130573.61
1968	87	131189.77
1969	88	131240.77
1970	93	131576.77
1971	96	131766.77
1972	101	132208.83
1973	104	132422.83
1974	105	132483.83
1975	114	132924.83
1976	132	134745.33
1977	157	136680.13
1978	163	137046.63
1979	166	137219.63
1980	169	137408.13
1981	176	141437.13
1982	181	141845.13
1983	185	142111.13
1984	187	142244.13
1985	187	142244.13
1986	188	142334.13
1987	189	142415.13
1988	194	142992.13
1989	203	150066.13
1990	205	150336.13
1991	205	150336.13

SURFACE WATER RIGHTS DATA

FILE-ID	TOWN	RANGE	SEC	QUALIFIERS#	CNTY	SRC	USE		AREAnet	Qnet
Prior to 1945										
VCD000900	05S	02W	29	27254600	15	S	3		432	258.00
VCD000900	05S	02W	29	46004260	15	S	3		432	258.00
VJW000900	02S	09W	31	NESWNE	45	S	3		50	37.00
VJW001000	02S	10W	23	30704070	45	S	3		184	60.00
VJW001000	02S	10W	23	33804495	45	S	3		184	60.00
VJW001000	02S	10W	23	48752820	45	S	3		184	60.00
VJW001000	02S	10W	23	33554820	45	S	3		184	60.00
VRP001100	04S	05W	32	32002650	79	S	5	*	0	446.00
VJW001200	01S	06W	06	57003500	45	S	3	*	209	15.50
VJW001200	01S	07W	01	48500350	45	S	3	*	209	15.50
VJW001200	01S	07W	01	36000850	45	S	3	*	209	15.50
VRP001300	01S	05W	05	17801600	79	S	3	*	65	34.00
VRP001400	02S	05W	02	NESWNE	79	S	3	*	50	25.00
VRP001600	02S	05W	13	NWSWSW	79	S	3	*	10	10.00
1948										
A00038500	01S	06W	11	NW	45	S	3		1	102522.31
1951										
A00080500	02S	09W	31	37003120	45	S	3	*	32	32.00
A00080500	02S	09W	31	49705070	45	S	3	*	32	32.00
1952										
A00102800	10S	04E	08	NWSESE	14	S	3		99	149.00
A00102800	10S	04E	08	SWSESE	14	S	3		99	149.00
A00102800	10S	04E	17	NWNENE	14	S	3		99	149.00
A00102800	10S	04E	17	SWNENE	14	S	3		99	149.00
1953										
A00122600	02S	07W	07	SWNWNW	45	S	3		91	45.00
A00148700	01S	05W	06	17004060	79	S	3		165	33.00
A00148700	01S	06W	01	21452110	45	S	3		165	33.00
A00151600	09S	05E	29	SENESW	81	S	3	*	156	50.00
A00151600	09S	05E	29	NWNWSE	81	S	3	*	156	50.00
A00151600	09S	05E	29	SENESW	81	S	3	*	156	50.00
A00151600	09S	05E	29	SESWSW	81	S	3	*	156	50.00
A00151600	09S	05E	29	SWSESW	81	S	3	*	156	50.00
A00157500	02S	05W	12	25501920	79	S	3		115	102.00
A00164400	01S	06W	03	SESESE	45	S	3		84	100.00
A00164700	02S	06W	14	SENWNW	45	S	3		120	70.00
A00164700	02S	06W	14	NESWNW	45	S	3		120	70.00
A00164700	02S	06W	15	SWSENE	45	S	3		120	70.00
A00167900	01S	05W	34	NCSWNW	79	S	3	*	72	82.00
A00167900	01S	05W	34	NCSENW	79	S	3	*	72	82.00
A00174200	01S	07W	01	NENENW	45	S	3		80	142.00
A00174500	03S	04W	06	12863590	79	S	3		115	70.00
A00183200	03S	04W	06	NCW2SENW	79	S	3		169	212.00
A00183200	03S	04W	06	SENWNW	79	S	3		169	212.00
A00183200	03S	04W	06	NENWNW	79	S	3		169	212.00
A00186300	02S	05W	13	SWNWSW	79	S	3		90	140.00
A00186300	02S	05W	13	NWSWSW	79	S	3	*	90	140.00
A00186500	02S	06W	14	NWNWNE	45	S	3		43	30.00

A00190000	02S	05W	02	NESWNE	79	S	3	*	58	47.90
A00195700	01S	07W	02	SWNWSW	45	S	3		120	106.00
A00195700	01S	07W	03	SWNESE	45	S	3		120	106.00
A00197600	01S	05W	33	NWNESE	79	S	3	*	40	30.00
A00204100	08S	02E	14	SWNESW	14	S	3		77	30.00
A00204600	01S	06W	06	57003500	45	S	3	*	0	60.00
A00204600	01S	07W	01	48500350	45	S	3	*	0	60.00
A00204600	01S	07W	01	36000850	45	S	3	*	0	60.00
1954										
A00209700	05S	02E	07	36404225	101	S	3		122	46.00
A00209700	05S	02E	07	40403550	101	S	3		122	46.00
A00209700	05S	02E	07	43403900	101	S	3		122	46.00
A00209700	05S	02E	07	46453300	101	S	3		122	46.00
A00209700	05S	02E	07	34153625	101	S	3		122	46.00
A00209700	05S	02E	07	52403600	101	S	3		122	46.00
A00209800	05S	02E	07	36400800	101	S	3		116	42.00
A00209800	05S	02E	07	51900450	101	S	3		116	42.00
A00209800	05S	02E	07	40650750	101	S	3		116	42.00
A00209800	05S	02E	07	36251900	101	S	3		116	42.00
A00226600	02S	09W	31	49705070	45	S	3	*	0	16.00
A00226600	02S	09W	31	NW	45	S	3		0	16.00
A00226600	02S	09W	31	NW	45	S	3		0	16.00
A00226600	02S	09W	31	37003120	45	S	3	*	0	16.00
A00238000	05S	02E	07	34151250	101	S	3		23	22.00
A00238000	05S	02E	07	29991600	101	S	3		23	22.00
A00266800	05S	03W	29	18001850	15	S	3		316	83.00
A00266800	05S	03W	29	25004000	15	S	3		316	83.00
A00266800	05S	03W	29	25005150	15	S	3		316	83.00
A00266800	05S	03W	28	19804850	15	S	3	*	316	83.00
A00266800	05S	03W	29	14001120	15	S	3		316	83.00
A00266800	05S	03W	28	26405100	15	S	3		316	83.00
A00266800	05S	03W	28	32005100	15	S	3		316	83.00
A00280600	02S	05W	36	44002600	79	S	3		105	45.00
A00280600	02S	05W	36	49002900	79	S	3		105	45.00
1955										
A00404100	10S	04E	36	SENENE	31	S	3		518	777.00
A00404100	10S	05E	31	NWSESW	31	S	3		518	777.00
A00404100	11S	05E	06	SWSWNE	31	S	3		518	777.00
A00404100	10S	04E	36	SENENE	31	S	3		518	777.00
A00404100	10S	05E	31	SWSESW	31	S	3		518	777.00
A00404100	11S	05E	06	NENENW	31	S	3		518	777.00
A00404100	10S	05E	31	NENWSW	31	S	3		518	777.00
A00404100	10S	05E	31	NWSWNW	31	S	3		518	777.00
A00404100	10S	04E	36	NWNENE	31	S	3		518	777.00
A00443000	01S	06W	01	SWNWSW	45	S	3	*	135	124.00
A00449700	04S	06W	12	NWSESE	45	S	3		106	23.00
A00449700	04S	06W	12	04001300	45	S	3	*	106	23.00
A00454400	01S	05W	34	SWSWNE	79	S	3		90	135.00
A00454400	01S	05W	34	SWSENE	79	S	3		90	135.00
A00454400	01S	05W	35	SWSWNW	79	S	3		90	135.00
A00457200	05S	02W	24	SENENW	15	S	3		87	90.00
A00457200	05S	02W	23	NCSWNW	15	S	3		87	90.00

A00467300	02S	06W	18	51000600	45	S	3		0	19700.00
A00477700	02S	07W	07	NWSENW	45	S	3		0	60.00
1956										
A00502400	05S	03W	30	NCSW	15	S	3		96	144.00
A00506600	10S	05E	06	SWNENW	31	S	3		64	65.00
A00506600	10S	05E	06	SWSENW	31	S	3		64	65.00
A00522400	10S	05E	06	SWSESW	31	S	3		182	150.00
A00522400	10S	05E	06	SWNESW	31	S	3		182	150.00
A00551500	01S	06W	02	38301915	45	S	3		217	131.00
A00551500	01S	06W	02	21501450	45	S	3		217	131.00
A00551500	01S	06W	02	53801090	45	S	3		217	131.00
A00551500	01S	06W	02	53800825	45	S	3		217	131.00
A00551500	01S	06W	02	54500650	45	S	3		217	131.00
A00567900	08S	02E	12	09000100	14	S	3	*	329	83.00
A00567900	08S	02E	12	04000350	14	S	3	*	329	83.00
A00581300	11S	05E	07	SWNWSE	31	S	3		101	150.00
A00581300	11S	05E	18	NWNWNW	31	S	3		101	150.00
A00581300	11S	05E	07	SWSESW	31	S	3		101	150.00
A00596100	08S	02E	13	36001650	14	S	3	*	106	122.00
A00596100	08S	02E	13	37001050	14	S	3	*	106	122.00
A00596100	08S	02E	13	34802940	14	S	3	*	106	122.00
A00596100	08S	02E	13	41000400	14	S	3	*	106	122.00
A006226A	09S	05E	29	SESWSW	81	S	3	*	0	140.00
A006226A	09S	05E	29	SWSESW	81	S	3	*	0	140.00
A006226A	09S	05E	29	SENESW	81	S	3	*	0	140.00
A006226A	09S	05E	29	NWNWSE	81	S	3	*	0	140.00
A006226A	09S	05E	29	SENESW	81	S	3	*	0	140.00
A00622700	02S	06W	16	35204000	45	S	3		61	42.00
A00622700	02S	06W	16	44004440	45	S	3		61	42.00
A00623100	04S	04W	17	NESWSW	79	S	3		60	87.00
A00632500	05S	04W	10	SWSWSW	15	S	3		47	24.00
A00633600	04S	04W	17	NWNESW	79	S	3		0	0.00
A00653200	02S	05W	36	52002900	79	S	3		12	56.00
A00659100	04S	04W	17	36304780	79	S	3		62	62.00
A00659100	04S	04W	18	48350215	79	S	3		62	62.00
1957										
A00708800	01S	05W	15	NENESW	79	S	3		180	137.00
A00708800	01S	05W	15	SESENW	79	S	3		180	137.00
A00728000	01S	06W	01	SWNWSW	45	S	3	*	0	79.00
1958										
A00781700	02S	08W	12	08603400	45	S	3	*	162	112.50
A00781700	02S	08W	11	15500100	45	S	3	*	162	112.50
A00788300	02S	08W	12	08603400	45	S	3	*	0	21.50
A00788300	02S	08W	11	15500100	45	S	3	*	0	21.50
A00790900	01S	05W	34	NCSENW	79	S	3	*	54	60.00
A00790900	01S	05W	34	NCSWNW	79	S	3	*	54	60.00
A00790900	01S	05W	33	NWNESE	79	S	3	*	54	60.00
A00791000	01S	06W	03	NENWNE	45	S	3		61	70.00
A00791000	01S	06W	03	NCNENE	45	S	3		61	70.00
A00791100	01S	06W	03	NWSESE	45	S	3		0	76.00
A00791100	01S	06W	03	SWSENE	45	S	3		0	76.00
A00792000	04S	04W	20	NESWNE	79	S	3		171	33.00

A00792000	04S	04W	20	NENENW	79	S	3		171	33.00
A00793100	01S	05W	05	17801600	79	S	3	*	0	64.00
1960										
A00841000	04S	06W	13	44201915	45	S	3		118	120.00
A00841000	04S	06W	13	37052200	45	S	3		118	120.00
A00851300	04S	05W	32	32002650	79	S	5	*	0	444.00
1961										
A00859400	02S	04W	18	NESWSW	79	S	3		40	46.00
A00863100	01S	05W	26	27972870	79	S	3		406	171.00
A00879700	03S	08W	26	18061795	45	S	3		90	40.00
A00880300	05S	05W	04	12504280	15	S	5		0	0.00
1963										
A00953000	03S	08W	35	51140932	45	S	3		123	34.00
A00953000	03S	08W	35	30711454	45	S	3		123	34.00
A00960700	04S	04W	07	01600920	79	S	3		1	24.00
1964										
A00992800	06S	02E	29	SESENW	14	S	3		179	152.00
A00992800	06S	02E	29	NENWNW	14	S	3		179	152.00
A01041800	02S	04W	31	00502600	79	S	3		0	112.00
1965										
A01127900	10S	05E	18	01150560	31	S	4	*	0	42.90
A01149500	01S	05W	26	25703930	79	S	3	*	227	293.00
1966										
A01163200	01S	05W	15	21504900	79	S	3		228	324.00
A01186900	02S	08W	09	NWSENW	45	S	3		0	135.00
A01186900	02S	08W	09	NWSWNW	45	S	3		0	135.00
A01226700	04S	05W	07	NESWSE	79	S	3		51	76.00
A01242500	05S	02W	29	25004554	15	S	3		245	151.00
A01242500	05S	02W	32	42902180	15	S	3		245	151.00
1967										
A01286600	01S	05W	35	38403500	79	S	3	*	80	120.00
A01287300	01S	05W	35	29503650	79	S	3		225	31.00
A01293700	04S	03W	26	33405095	79	S	3		29	120.00
A01296600	02S	08W	24	34302970	45	S	3		31	40.00
A01324500	01S	05W	26	25703930	79	S	3	*	155	87.00
1968										
A01536000	08S	02E	11	NWNWSE	14	S	3		80	382.16
A01536000	08S	02E	11	SESESW	14	S	3		80	382.16
A01536000	08S	02E	14	NENWNE	14	S	3		80	382.16
A01536000	08S	02E	11	NWSWNE	14	S	3		80	382.16
A01536000	08S	02E	11	NENENW	14	S	3		80	382.16
A01536000	08S	02E	14	NENENE	14	S	3		80	382.16
A01552900	04S	06W	24	CNNWNE	45	S	3		155	234.00
A01552900	04S	06W	24	NWNENE	45	S	3		155	234.00
A01552900	04S	06W	24	SENENE	45	S	3		155	234.00
A01552900	04S	06W	24	SESENE	45	S	3		155	234.00
1969										
A01623400	02S	05W	04	NWNWNW	79	S	3		34	51.00
1970										
A01700300	04S	06W	12	04001300	45	S	3	*	0	113.00
A01700300	04S	06W	12	18002600	45	S	3		0	113.00
A01707800	09S	04E	09	52705150	14	S	3		35	42.00

A01710900	08S	02E	14	27001700	14	S	3		201	88.00
A01710900	08S	02E	14	26400500	14	S	3		201	88.00
A01710900	08S	02E	14	26800250	14	S	3		201	88.00
A01763900	08S	02E	15	13200990	14	S	3		59	65.00
A01768600	05S	04W	27	52505210	15	S	3		25	28.00
1971										
A01798600	02S	05W	05	43550065	79	S	3	*	41	17.00
A01798600	02S	05W	05	49151220	79	S	3	*	41	17.00
A01813400	01S	05W	06	19654090	79	S	3		158	165.00
A01852600	02S	05W	02	20950595	79	S	3		0	8.00
A01852600	02S	05W	02	26451350	79	S	3		0	8.00
A01852600	02S	05W	02	34902505	79	S	3		0	8.00
1972										
A01898700	01S	05W	10	09905000	79	S	3		44	45.00
A91903000	09S	03E	24	38001000	14	S	2		0	3.06
A01912400	04S	05W	03	26054555	79	S	3		130	128.00
A01936200	05S	01E	25	SESENW	101	S	3		177	187.00
A01936200	05S	01E	25	NCN2SESW	101	S	3		177	187.00
A01949300	01S	05W	18	14851485	79	S	3		96	79.00
1973										
A02000400	01S	05W	26	04003700	79	S	3		50	75.00
A02000500	01S	05W	35	26454455	79	S	3		188	90.00
A02086900	01S	04W	21	19152440	79	S	3		3	49.00
1974										
A02230200	05S	02E	26	33003300	101	S	3		319	61.00
1975										
A02338200	03S	02W	31	11904060	79	S	3		15	25.00
A02357000	01S	05W	25	04601190	79	S	3		26	7.00
A02393800	02S	03W	34	09903540	79	S	3		57	87.00
A02397700	04S	03W	09	NWSENE	79	S	3		86	132.00
A02397700	04S	03W	09	N2NWNE	79	S	3		86	132.00
A02444800	03S	05W	28	33000066	79	S	3		132	13.00
A02444800	03S	05W	28	31681915	79	S	3		132	13.00
A02444900	03S	05W	31	05280065	79	S	3		57	55.00
A02444900	03S	05W	31	05282510	79	S	3	*	57	55.00
A02457600	04S	03W	24	22500360	79	S	3		238	69.00
A02457600	04S	02W	19	04005478	79	S	3		238	69.00
A02473900	03S	04W	30	52700345	79	S	3		18	27.00
A02501200	04S	05W	10	08584026	79	S	3		40	26.00
A02501200	04S	05W	10	06604026	79	S	3		40	26.00
1976										
A02544300	05S	03E	18	NWSWNW	101	S	3		135	135.00
A02544300	05S	03E	18	NCW2NENW	101	S	3		135	135.00
A02556800	01S	05W	35	16304655	79	S	3		0	74.00
A02574500	02S	05W	01	05003750	79	S	3		251	348.00
A02574500	02S	05W	11	07000100	79	S	3		251	348.00
A02574500	02S	05W	12	52753300	79	S	3		251	348.00
A02598300	08S	02E	13	34802940	14	S	3	*	85	103.00
A02598300	08S	02E	13	41000400	14	S	3	*	85	103.00
A02598300	08S	02E	13	37001050	14	S	3	*	85	103.00
A02598300	08S	02E	13	36001650	14	S	3	*	85	103.00
A02613800	06S	04W	11	00450445	15	S	3		111	166.50

A02638100	05S	03W	28	30351750	15	S	3		138	51.00
A02638100	05S	03W	28	34650595	15	S	3		138	51.00
A02699600	03S	05W	31	05282510	79	S	3	*	65	36.00
A02699600	03S	05W	31	22451830	79	S	3		65	36.00
A02699600	03S	05W	31	14501765	79	S	3		65	36.00
A02708100	04S	06W	13	24102780	45	S	3		193	98.00
A02712100	07S	02E	29	37501100	14	S	3	*	0	30.00
A02714800	04S	05W	05	36302700	79	S	3		141	210.00
A02714900	03S	05W	32	00503890	79	S	3		138	83.00
A02718000	03S	05W	09	NCS2S2SE	79	S	3		74	90.00
A02718000	03S	05W	09	SWSWSE	79	S	3		74	90.00
A02774500	01S	05W	22	52504420	79	S	3		83	81.00
A02774500	01S	05W	22	33663960	79	S	3		83	81.00
A02774500	01S	05W	22	25403600	79	S	3		83	81.00
A02783200	03S	05W	28	NWNESW	79	S	3		30	60.00
A02793900	02S	06W	12	04102115	45	S	3		49	22.00
A02814200	01S	05W	21	NWSWSW	79	S	3		55	55.00
A02817000	02S	05W	20	09902705	79	S	3		77	65.00
A02817100	01S	06W	24	03750420	45	S	3		86	113.00
1977										
A02892500	01S	05W	27	SENWNE	79	S	3		50	75.00
A02899400	11S	05E	08	45003750	31	S	4		0	7.67
A02901000	03S	05W	12	13861320	79	S	3		150	135.00
A02909500	02S	06W	10	NCE2SW	45	S	3		56	84.00
A02915200	01S	06W	25	SENWNW	45	S	3		40	60.00
A02917300	01S	05W	20	06950495	79	S	3		10	9.00
A02917300	01S	05W	20	09000180	79	S	3		10	9.00
A02917400	01S	05W	21	19143960	79	S	3		373	134.00
A02917400	01S	05W	21	03302145	79	S	3		373	134.00
A02917400	01S	05W	21	16805050	79	S	3		373	134.00
A02917600	01S	05W	20	05303000	79	S	3		93	112.00
A02921700	03S	05W	09	NWNESW	79	S	3		60	90.00
A02921700	03S	05W	09	SESESW	79	S	3		60	90.00
A02934800	01S	05W	29	18154390	79	S	3		102	99.00
A02937500	03S	05W	09	NESESE	79	S	3		0	20.72
A02957100	03S	05W	22	32303990	79	S	3		66	58.75
A02957100	03S	05W	22	04602800	79	S	3		66	58.75
A02957100	03S	05W	22	15202970	79	S	3		66	58.75
A02971300	02S	04W	07	12605020	79	S	3		37	37.50
A02980500	03S	05W	35	25082970	79	S	3		38	40.00
A02984900	04S	03E	21	05005200	101	S	3		166	153.00
A03017500	01S	05W	34	31351385	79	S	3		0	98.00
A03017600	01S	05W	27	NENWSE	79	S	3		101	150.00
A03022800	02S	06W	11	12202520	45	S	3		121	57.00
A03025800	01S	06W	05	26002600	45	S	3		136	76.00
A03039400	08S	02E	13	37001050	14	S	3	*	0	20.00
A03039400	08S	02E	13	36001650	14	S	3	*	0	20.00
A03039400	08S	02E	13	34802940	14	S	3	*	0	20.00
A03039400	08S	02E	13	41000400	14	S	3	*	0	20.00
A03049800	03S	03W	18	NESESE	79	S	3	*	120	180.00
A03049900	03S	03W	18	NESESE	79	S	3	*	7	10.15
A03050900	03S	04W	06	NCE2NWNW	79	S	3		77	116.00

A03052700	01S	05W	05	02002600	79	S	3		40	53.00
A03065700	02S	12W	05	46902780	92	S	3		13	59.00
A03065700	02S	12W	05	38401360	92	S	3		13	59.00
1978										
A03144000	06S	03W	12	05905140	15	S	3		69	20.00
A03144700	01S	05W	22	09604880	79	S	3		85	83.00
A03149300	01S	06W	03	06303730	45	S	3		182	120.00
A03175300	02S	05W	34	01300290	79	S	3		149	70.50
A03219300	03S	05W	28	NWSWNW	79	S	3		26	40.00
A03225000	02S	05W	05	41582937	79	S	3		184	33.00
A03225000	02S	05W	05	42904820	79	S	3		184	33.00
1979										
A03265500	02S	05W	05	49151220	79	S	3	*	0	30.00
A03265500	02S	05W	05	43550065	79	S	3	*	0	30.00
A03268300	02S	05W	34	18250925	79	S	3		0	123.00
A03311000	04S	03W	12	06604200	79	S	3		73	20.00
1980										
A03396100	01S	06W	01	07255205	45	S	3	*	81	122.00
A03452000	07S	02E	29	37501100	14	S	3	*	0	47.00
A03476400	09S	03E	04	20300940	14	S	3		64	19.50
A03476400	09S	03E	04	20002730	14	S	3		64	19.50
1981										
A03543800	02S	05W	32	40924785	79	S	3		40	45.00
A03543900	02S	05W	31	06601320	79	S	3		50	45.00
A03544000	03S	05W	17	27370521	79	S	3		75	94.00
A03561000	11S	05E	21	20002950	31	S	5		0	3500.00
A03572300	01S	05W	15	21004900	79	S	3		130	203.00
A03572400	01S	05W	35	38403500	79	S	3	*	35	52.00
A03574900	07S	02E	28	41804900	14	S	3		0	90.00
1982										
A03587600	01S	06W	35	00203290	45	S	3		55	40.00
A03596900	01S	06W	01	07255205	45	S	3	*	0	142.00
A03597100	04S	05W	01	29203080	79	S	3		164	140.00
A03601100	04S	05W	32	32002650	79	S	5	*	0	0.00
A03636400	10S	05E	18	01150560	31	S	4	*	0	86.00
1983										
A03653900	01S	05W	22	42803780	79	S	3		41	53.00
A03653900	01S	05W	22	31803780	79	S	3		41	53.00
A03685700	04S	02W	06	20804900	79	S	3		63	65.00
A03693100	03S	04W	19	51501330	79	S	3		32	48.00
A03693200	03S	05W	36	38002450	79	S	3	*	120	100.00
1984										
A03699200	09S	04E	31	42240844	14	S	3		84	35.00
A03714800	07S	02E	33	31002750	14	S	3		70	98.00
1986										
A03831500	02S	05W	25	12005260	79	S	3		60	90.00
1987										
A03870300	01S	05W	22	04751900	79	S	3		54	81.00
1988										
A03872900	03S	04W	19	20500550	79	S	3		70	105.00
A03900700	03S	05W	25	39002600	79	S	3		160	240.00
A03900900	03S	04W	20	24003000	79	S	3		0	0.00

A03905100	04S	05W	19	40002500	79	S	5		0	0.00
A03916900	08S	02E	12	09000100	14	S	3	*	0	232.00
A03916900	08S	02E	12	04000350	14	S	3	*	0	232.00
1989										
A03919100	03S	04W	06	00204420	79	S	3		0	42.00
A03923900	03S	05W	01	13201320	79	S	3		84	125.00
A03926000	02S	05W	25	08002750	79	S	3		97	81.00
A03926400	05S	04W	36	27500550	15	S	3		204	306.00
A03926400	05S	04W	36	18001800	15	S	3		204	306.00
A03926400	05S	04W	36	27401450	15	S	3		204	306.00
A03929900	05S	03W	30	06002225	15	S	3		40	60.00
A03930300	11S	05E	17	10003000	31	S	5		0	5895.00
A03937800	02S	05W	06	03002500	79	S	3		38	50.00
A03949900	05S	02W	24	39602340	15	S	3		120	180.00
A03954900	08S	03E	07	01003200	14	S	3		223	335.00
1990										
A03985800	07S	02E	33	00860972	14	S	3		241	150.00
A03985900	07S	02E	33	39303225	14	S	3		80	120.00

-- The two numerical values indicate distance in ft North and West of the Southeast section corner, respectively. Directional symbols indicate appropriate quarter sections.

* -- indicates overlap.

GROUND WATER RIGHTS SUMMARY

Year	No.	Qapp.(ac-ft/yr)
1945	28	6208.92
1946	28	6208.92
1947	28	6208.92
1948	29	6288.92
1949	29	6288.92
1950	29	6288.92
1951	29	6288.92
1952	30	6377.92
1953	40	7466.71
1954	64	10349.71
1955	115	17717.71
1956	165	22892.03
1957	191	25191.03
1958	193	25508.03
1959	205	26662.61
1960	206	26737.61
1961	211	27070.61
1962	215	27322.61
1963	225	31415.59
1964	234	32599.59
1965	256	35309.09
1966	287	38526.09
1967	318	41670.61
1968	344	43641.61
1969	360	45228.61
1970	381	47422.11
1971	390	48221.03
1972	405	50793.93
1973	421	52581.70
1974	440	54207.74
1975	467	56943.77
1976	511	61975.00
1977	595	70748.75
1978	625	74091.37
1979	649	75933.62
1980	670	78028.97
1981	700	81611.41
1982	708	82634.72
1983	724	83966.09
1984	732	84789.78
1985	736	85104.73
1986	743	85875.43
1987	753	87224.43
1988	774	89845.93
1989	799	92230.33
1990	814	93851.15
1991	825	95685.36

GROUND WATER RIGHTS DATA

FILE-ID	TOWN	RANGE	SEC	QUALIFIERS#	CNTY	SRC	USE	AREAnet	Qnet
Prior to 1945									
VCD000100	05S	01W	26	34951700	15	G	4	0	110.00
VCD000100	05S	01W	26	35351700	15	G	4 *	0	110.00
VCD000100	05S	01W	26	35201700	15	G	4 *	0	110.00
VGE0001MU	10S	05E	19	SESE	31	G	4 *	0	9.21
VGE0001IR	10S	05E	19	SESE	31	G	3 *	0	9.21
VJW000100	05S	07W	12	NENE	45	G	4	0	10.74
VCY000100	06S	01E	02	42003600	14	G	4	0	61.40
VCY000100	06S	01E	02	42003550	14	G	4	0	61.40
VGE000200	12S	05E	01	48504500	31	G	4 *	0	1764.40
VGE000200	11S	05E	35	06501000	31	G	4 *	0	1764.40
VGE000200	12S	05E	01	50504350	31	G	4 *	0	1764.40
VGE000200	12S	05E	01	50704150	31	G	4 *	0	1764.40
VJW000200	03S	06W	21	SENW	45	G	4	0	36.82
VJW000200	03S	06W	21	NESW	45	G	4	0	36.82
VCD000300	07S	02W	15	46003050	15	G	4 *	0	9.21
VCD000300	07S	02W	15	45003050	15	G	4 *	0	9.21
VJW000300	04S	08W	25	SESENW	45	G	4	0	55.23
VJW000300	04S	08W	25	SWNESE	45	G	4	0	55.23
VJW000300	04S	08W	25	SWNESE	45	G	4	0	55.23
VJW000300	04S	08W	25	NWNESE	45	G	4	0	55.23
VJW000300	04S	07W	30	SWSWSE	45	G	4	0	55.23
VJW000300	04S	07W	30	SESESE	45	G	4	0	55.23
VJW000300	04S	07W	30	NESENE	45	G	4	0	55.23
VJW000300	04S	08W	25	NESWSE	45	G	4	0	55.23
VJW000300	04S	07W	30	NENESE	45	G	4	0	55.23
VJW000300	04S	07W	30	SENESE	45	G	4	0	55.23
VCY000300	07S	02E	03	00504920	14	G	4	0	10.74
VCD000400	05S	03W	33	30752769	15	G	4	0	1044.00
VCD000400	06S	03W	05	11010711	15	G	4	0	1044.00
VCD000400	05S	03W	32	38020122	15	G	4	0	1044.00
VCD000400	05S	03W	32	48670474	15	G	4	0	1044.00
VCD000400	06S	03W	09	51622492	15	G	4	0	1044.00
VCD000400	05S	03W	32	47580046	15	G	4	0	1044.00
VCD000400	06S	03W	05	35170073	15	G	4	0	1044.00
VWS000400	05S	02E	12	NWNESW	101	G	4 *	0	2.30
VWS000400	05S	02E	12	NWNESW	101	G	4 *	0	2.30
VCY000400	08S	03E	07	27500500	14	G	4	0	521.71
VCY000400	08S	03E	08	16503250	14	G	4	0	521.71
VCY000400	08S	03E	07	22000350	14	G	4	0	521.71
VCY000400	08S	03E	08	31003800	14	G	4	0	521.71
VCD000500	05S	05W	22	11000100	15	G	4	0	21.20
VCD000500	05S	05W	22	25002550	15	G	4	0	21.20
VRP000500	01S	04W	31	27504900	79	G	4 *	0	18.41
VJW000500	03S	08W	22	35805180	45	G	4	0	79.79
VJW000500	03S	08W	16	22302710	45	G	4	0	79.79
VJW000500	03S	08W	22	24802730	45	G	4	0	79.79

VCY000500	07S	04E	20	SWSENE	14	G	4		0	7.67
VCY000500	07S	04E	21	SWSWNW	14	G	4		0	7.67
VRP000600	03S	04W	17	16400560	79	G	4	*	0	43.00
VRP000600	03S	04W	17	10700630	79	G	4	*	0	43.00
VRP000600	03S	04W	17	10600530	79	G	4	*	0	43.00
VJW000600	02S	09W	23	34304020	45	G	4		0	30.68
VJW000600	02S	09W	23	38003900	45	G	4		0	30.68
VRP000700	03S	05W	16	SWSESE	79	G	4		0	18.40
VCD000800	05S	04W	09	NESWSW	15	G	3	*	40	60.00
VCY000800	06S	01E	01	32505230	14	G	2		0	114.77
VCD001100	05S	02W	25	NWNWSW	15	G	3	*	160	100.00
VCY0012RE	08S	03E	08	27005000	14	G	5	*	0	20.00
VCY0012RE	08S	03E	08	27405160	14	G	5	*	0	20.00
VCY0012IN	08S	03E	08	27405160	14	G	2	*	0	1841.33
VCY0012IN	08S	03E	08	27005000	14	G	2	*	0	1841.33
VJW001300	02S	10W	34	NENWSE	45	G	4		0	9.20
VJW001300	02S	10W	34	NENESE	45	G	4		0	9.20
VRP001800	04S	04W	21	NENESW	79	G	3	*	80	112.00
VWS002800	05S	01E	32	NCS2N2SW	101	G	3		82	87.50
1948										
A00039900	05S	04W	15	NENWNE	15	G	3		80	80.00
1952										
A00090500	08S	02E	11	43501150	14	G	3		300	89.00
1953										
A00115200	05S	02W	25	SWNESE	15	G	3		125	110.00
A00129900	06S	01E	01	34005230	14	G	2		0	79.79
A00150500	05S	02W	22	NWNESW	15	G	3	*	127	78.00
A00154500	05S	03W	36	NENWNE	15	G	3	*	98	98.00
A00164000	04S	04W	20	26102180	79	G	3	*	46	69.00
A00170900	05S	02W	26	SENWNE	15	G	3		160	97.00
A00170900	05S	02W	26	SENENE	15	G	3		160	97.00
A00171300	05S	04W	16	NWSENW	15	G	3	*	383	146.00
A00177300	04S	04W	08	NESENE	79	G	3		168	150.00
A00187900	03S	04W	21	SENESW	79	G	3		120	131.00
A00187900	03S	04W	21	NWNWSW	79	G	3		120	131.00
A00196200	08S	02E	02	NESWSW	14	G	3		225	130.00
1954										
A00217300	03S	04W	18	CWNENE	79	G	3		80	100.00
A00218100	10S	04E	08	SWSESE	14	G	3		0	0.00
A00220700	05S	04W	09	NESWSW	15	G	3	*	40	53.00
A00222000	03S	04W	17	NENWNW	79	G	3		80	100.00
A00224400	04S	04W	27	NWSESE	79	G	3		140	165.00
A00224500	04S	04W	33	NCW2SE	79	G	3		109	105.00
A002247D2	03S	04W	08	07255170	79	G	3		77	78.00
A002247D1	03S	04W	07	07601500	79	G	3		80	122.00
A00230100	05S	04W	16	SWNESW	15	G	3	*	0	86.00
A00230100	05S	04W	16	NWSENW	15	G	3	*	0	86.00
A00231800	05S	04W	21	NECRNENW	15	G	3		137	88.00
A00238900	03S	04W	32	20600960	79	G	3		161	153.00
A00240300	04S	04W	33	SWNENE	79	G	3		117	95.00
A00246000	10S	04E	05	SESE	14	G	3		86	119.00
A00252400	04S	04W	29	SENWSE	79	G	3	*	95	90.00

A00254900	05S	04W	04	SENWNE	15	G	3		116	170.00
A00262700	04S	04W	09	NWNESW	79	G	3		126	179.00
A00264100	08S	03E	35	NCNE	14	G	3	*	209	120.00
A00264500	03S	04W	17	26303840	79	G	3	*	171	81.00
A00279000	08S	02E	01	52501470	14	G	3	*	129	85.00
A00281200	03S	04W	17	16400560	79	G	4	*	0	3.00
A00281200	03S	04W	17	10700630	79	G	4	*	0	3.00
A00281200	03S	04W	17	10600530	79	G	4	*	0	3.00
A00298300	06S	01W	04	32205200	15	G	3	*	76	75.00
A00313600	07S	02E	18	NWNWNE	14	G	3		140	218.00
A00313600	07S	02E	18	SWNENE	14	G	3		140	218.00
A00313600	07S	02E	18	SWNWNE	14	G	3		140	218.00
A00313600	07S	02E	18	SWNENE	14	G	3		140	218.00
A00320900	05S	04W	08	SENESE	15	G	3		220	330.00
A00320900	05S	04W	08	NESESE	15	G	3		220	330.00
A00322600	06S	02E	33	12501700	14	G	3		330	268.00
1955										
A00338900	05S	02W	25	SWSWSW	15	G	3	*	160	120.00
A00339000	05S	02W	25	NWNWSW	15	G	3	*	0	65.00
A00346700	06S	01E	24	SENWNE	14	G	3		83	120.00
A00354100	05S	02W	36	SESWNW	15	G	3	*	45	67.50
A00380300	06S	01E	13	38402340	14	G	3		240	175.00
A00389600	04S	03W	01	SENESE	79	G	3		80	72.00
A00391100	05S	03W	35	NWNWNE	15	G	3	*	359	222.00
A00391100	05S	03W	36	NENWNW	15	G	3	*	359	222.00
A00398300	01S	05W	20	NWNWNE	79	G	3		70	90.00
A00402300	06S	01E	24	NWSWNW	14	G	3		130	195.00
A00412400	01S	05W	05	NWNWNW	79	G	3		94	120.00
A00416100	08S	03E	28	NWNESE	14	G	3		120	178.00
A00418700	05S	02W	25	NCSWNW	15	G	3		152	228.00
A00419300	10S	04E	24	SWNESE	31	G	2		0	900.00
A00419300	10S	04E	24	NWNESE	31	G	2		0	900.00
A00420200	06S	01E	02	CNNWSE	14	G	3		220	144.00
A00425000	01S	05W	20	23952260	79	G	3	*	50	50.00
A00430300	10S	05E	30	NESWSW	31	G	3		180	80.00
A00431600	11S	04E	14	NCSWNE	31	G	3		130	210.00
A00432000	04S	02W	07	24005100	79	G	3		98	46.00
A00437100	04S	04W	16	NWSWNE	79	G	3		45	34.00
A00437900	07S	03E	31	NCS2	14	G	3		227	70.00
A00438800	05S	04W	16	NCS2SE	15	G	3		79	82.00
A00442300	08S	03E	27	48500580	14	G	3	*	67	29.00
A00444300	06S	01E	02	NWSWNE	14	G	3		94	128.00
A00444800	05S	04W	16	SENWSW	15	G	3		38	40.00
A00445800	04S	04W	04	44903100	79	G	3		160	133.50
A00446300	05S	01W	30	CEW2NE	15	G	3		113	14.00
A00446300	05S	01W	30	NWSWNE	15	G	3		113	14.00
A00450900	03S	04W	33	NWNWSE	79	G	3		130	195.00
A00451800	05S	03W	36	NENWNW	15	G	3	*	0	81.00
A00451800	05S	03W	35	NWNWNE	15	G	3	*	0	81.00
A00455700	05S	02W	32	NWNWSW	15	G	3		75	48.00
A00457500	05S	01W	31	CESENW	15	G	3		102	107.00
A00457800	04S	04W	16	SWNWNE	79	G	3		23	33.00

A00457900	04S	04W	34	25162186	79	G	3	*	99	100.00
A00458600	06S	02E	30	NENWSE	14	G	3		160	220.00
A00458800	04S	04W	09	43092551	79	G	3		80	120.00
A00459400	05S	01W	32	SESWSW	15	G	3		140	180.00
A00459600	04S	04W	04	30704420	79	G	3		110	139.00
A00459700	04S	04W	17	12570817	79	G	3		90	135.00
A00459800	04S	04W	08	01001320	79	G	3		312	300.00
A00459900	04S	04W	21	NENESW	79	G	3	*	75	219.00
A00460000	04S	04W	34	51402742	79	G	3		217	208.00
A00460100	04S	04W	09	SWNWNW	79	G	3		148	222.00
A00460100	04S	04W	09	SENENW	79	G	3		148	222.00
A00460900	06S	01E	02	22004450	14	G	3		95	130.00
A00461100	05S	02W	32	NWNWSE	15	G	3		170	212.00
A00463600	05S	02W	25	SWSWSW	15	G	3	*	0	330.00
A00463600	05S	02W	25	NWNWSW	15	G	3	*	0	330.00
A00465500	07S	02E	22	13202610	14	G	3		80	120.00
A00468400	05S	04W	03	CSSESE	15	G	3		52	78.00
A00470400	06S	01W	01	NWSWSW	15	G	3		80	120.00
A00470500	05S	01W	30	NWSWSE	15	G	3		126	189.00
A00471400	06S	01W	02	48501370	15	G	3		63	49.00
A00481900	05S	04W	24	14505080	15	G	3		80	120.00
A00492000	06S	02E	29	15000600	14	G	3	*	210	100.00
1956										
A00497500	06S	01E	03	26402040	14	G	3		145	177.00
A00499100	05S	02W	34	NWNENE	15	G	3	*	180	240.00
A00506700	04S	04W	17	NENESE	79	G	3		109	120.00
A00511300	03S	04W	29	NCNWSE	79	G	3	*	130	51.00
A00511300	03S	04W	29	NWNWSE	79	G	3	*	130	51.00
A005114ST	03S	04W	18	NWSENE	79	G	6	*	0	0.00
A005114IR	03S	04W	18	NWSENE	79	G	3	*	80	32.00
A00512000	05S	02W	26	CWE2SE	15	G	3		74	111.00
A00521300	06S	01E	04	26401320	14	G	3	*	535	160.00
A00544300	04S	04W	34	13201320	79	G	3		39	60.00
A00547500	06S	02E	30	NESENW	14	G	3		198	141.00
A00563400	05S	04W	14	NWNESE	15	G	3		267	262.00
A00563400	05S	04W	14	SWNENE	15	G	3		267	262.00
A00565400	01S	05W	18	NWNWNE	79	G	3		80	120.00
A00565800	05S	01W	32	NWSWNE	15	G	3		70	51.00
A00572000	07S	02E	27	12805200	14	G	3		173	70.00
A00578800	05S	03W	24	10502600	15	G	3		60	56.00
A00584700	05S	04W	03	NCW2SWSE	15	G	3		80	97.00
A00587500	09S	03E	01	SWSWNE	14	G	3		75	105.00
A00587600	09S	04E	06	SWSWNW	14	G	3		181	195.00
A00592400	03S	04W	20	50000740	79	G	3		113	76.50
A00593000	01S	06W	02	12003960	45	G	3		92	50.00
A00594300	08S	03E	06	NWNWSE	14	G	3		69	103.50
A00595500	08S	03E	06	SENENW	14	G	3		160	163.00
A00598500	05S	03W	35	NWNWNE	15	G	3	*	0	143.00
A00598500	05S	03W	36	NENWNW	15	G	3	*	0	143.00
A00601100	06S	01E	25	CWSE	14	G	3		200	55.00
A00602000	05S	03W	33	NWNENE	15	G	3		40	60.00
A00602500	05S	03W	20	SWNWSE	15	G	3		210	159.00

A00605000	04S	04W	10	NENWSW	79	G	3		75	47.00
A00605000	04S	04W	10	SWNWSW	79	G	3		75	47.00
A00605900	07S	02E	26	NWSESW	14	G	3		212	155.00
A00607100	05S	04W	13	SENESE	15	G	3		95	67.50
A00607200	05S	01W	32	SWSWNW	15	G	3		172	189.00
A00612600	01S	06W	12	13901520	45	G	3		160	107.00
A00617000	01S	05W	07	46204620	79	G	3		132	37.00
A00625900	05S	01W	31	NWSESW	15	G	3		84	75.00
A00630200	05S	04W	15	26100060	15	G	3	*	99	96.00
A00631200	01S	04W	17	NWNWNE	79	G	3		155	232.50
A00632200	04S	04W	08	51001200	79	G	3	*	100	30.00
A00632600	05S	04W	15	CENESW	15	G	3		138	83.00
A00633400	06S	02E	33	NCNE	14	G	3		0	120.00
A00639900	05S	01W	33	44653300	15	G	3		80	90.00
A00641500	05S	01W	28	39601188	15	G	3		155	100.00
A00641800	06S	01E	01	NESWSW	14	G	3		30	34.00
A00642000	04S	04W	22	NWNESW	79	G	3		80	114.00
A00643000	04S	04W	22	SWSWSW	79	G	3		40	60.00
A00644600	06S	02E	30	46055170	14	G	3		75	91.00
A00645100	01S	04W	19	SWNWNW	79	G	3		50	75.00
A00652500	05S	02W	22	NWNESW	15	G	3	*	0	59.52
A00654100	04S	04W	21	NENESW	79	G	3	*	0	78.80
A00654100	04S	04W	21	NWNESW	79	G	3		0	78.80
A00655200	04S	04W	16	NENWSW	79	G	3		292	275.00
A00655200	04S	04W	16	SWSENW	79	G	3		292	275.00
A00658000	04S	04W	08	NWNESE	79	G	3	*	0	0.00
A00658300	05S	02W	35	NWSWNE	15	G	3		92	100.00
1957										
A00662300	05S	02W	36	SENWNE	15	G	3		40	60.00
A00667100	05S	04W	10	NENENW	15	G	3		30	45.00
A00667700	07S	02E	03	CWNWNE	14	G	3		34	34.00
A00670600	05S	03W	17	SWNWNE	15	G	3		126	83.00
A00671100	04S	04W	22	NCNENW	79	G	3		145	50.00
A00671200	04S	04W	21	CNNESE	79	G	3		66	73.00
A00676200	04S	03E	19	CWNW	101	G	3		163	45.00
A00680800	03S	04W	06	01002490	79	G	3		0	60.00
A00684000	06S	01E	04	26401320	14	G	3	*	0	44.00
A00692300	07S	02E	15	SWNESE	14	G	3	*	141	107.00
A00694300	08S	03E	21	NCSW	14	G	3		220	96.00
A00695600	05S	03W	21	SWNESW	15	G	3		60	17.00
A00701500	05S	02W	36	SWSWNE	15	G	3		84	126.00
A00701700	05S	02W	21	28001300	15	G	3		101	111.00
A00704100	06S	01E	06	NCNE	14	G	3		140	110.00
A00704200	05S	01W	31	NCN2SWNE	15	G	3		122	159.00
A00704300	05S	01W	32	NCSWSE	15	G	3		159	175.00
A00705700	05S	04W	17	NENENE	15	G	3	*	78	40.00
A00712000	08S	03E	28	36002759	14	G	3	*	145	103.00
A00718200	01S	04W	18	NESENW	79	G	3		90	75.00
A00718500	06S	01W	12	50001850	15	G	3		124	186.00
A00730900	05S	04W	03	SWNWNW	15	G	3		227	73.00
A00732900	05S	06W	11	NCSWSW	45	G	3		76	114.00
A00735800	01S	04W	21	NWSENW	79	G	3		74	80.00

A00749900	05S	04W	03	40001900	15	G	3		158	170.00
A00756100	05S	01E	32	NWNWSW	101	G	3		73	63.00
1958										
A00770600	07S	02E	14	CWNW	14	G	3		160	165.00
A00778600	06S	01E	08	CWSWSWNW	14	G	3		236	152.00
1959										
A00800200	05S	02W	34	NWNENE	15	G	3	*	0	70.00
A00801500	01S	04W	08	NCN2	79	G	3		115	97.00
A00804100	03S	04W	29	38801340	79	G	3		120	112.00
A00805000	04S	04W	34	25162186	79	G	3	*	0	50.00
A00808200	05S	01W	15	13204620	15	G	3		228	285.00
A00808200	05S	01W	15	33003960	15	G	3		228	285.00
A00810500	06S	01E	13	NENWSE	14	G	3		160	112.00
A00815300	05S	02W	31	SENWSW	15	G	3		140	41.00
A00818500	05S	01W	13	NESENE	15	G	3	*	160	33.00
A00819400	06S	01W	04	32205200	15	G	3	*	0	34.58
A00819500	05S	01E	32	SWNWSE	101	G	3		0	39.00
A00827000	03S	04W	29	NCNWSE	79	G	3	*	5	183.00
A00827000	03S	04W	29	NWNWSE	79	G	3	*	5	183.00
A00829200	08S	03E	35	NCNE	14	G	3	*	0	98.00
1960										
A00844700	04S	04W	22	NWSWSE	79	G	3		48	75.00
1961										
A00858600	03S	04W	17	26303840	79	G	3	*	0	0.00
A00868800	05S	01W	20	SWSENW	15	G	3		0	29.00
A00878500	03S	04W	28	NWNESW	79	G	3		140	200.00
A00878600	08S	03E	27	NCE2NW	14	G	3		92	42.00
A00882900	04S	04W	09	46251300	79	G	3	*	97	62.00
1962										
A00900800	05S	01W	30	38503850	15	G	3		134	94.00
A00902600	03S	04W	33	26502615	79	G	3	*	100	43.00
A90906500	05S	03W	33	32073364	15	G	A		0	25.00
A00906700	08S	03E	17	CNNWNE	14	G	3		62	90.00
1963										
A00910500	05S	03W	36	N2SWSE	15	G	3		107	84.00
A00910500	05S	03W	36	SENESE	15	G	3		107	84.00
A00912100	05S	01W	25	20105165	15	G	3		89	102.00
A00920300	06S	01E	01	30504980	14	G	2		0	65.98
A00934300	04S	04W	22	27005260	79	G	3		40	133.00
A00935700	08S	03E	35	SWNESE	14	G	3		120	165.00
A00937900	04S	04W	04	23252230	79	G	3		128	192.00
A00938000	04S	04W	04	NCSWSE	79	G	3		150	128.00
A00948700	04S	04W	33	CNNESE	79	G	3		194	166.00
A00949200	06S	01E	23	SESWNW	14	G	3		155	157.00
A00965800	12S	05E	01	50704150	31	G	4	*	0	2900.00
A00965800	12S	05E	01	48504500	31	G	4	*	0	2900.00
A00965800	12S	05E	01	50504350	31	G	4	*	0	2900.00
A00965800	12S	05E	02	52000500	31	G	4	*	0	2900.00
A00965800	11S	05E	35	06501000	31	G	4	*	0	2900.00
1964										
A00985900	05S	01W	11	NWNWNW	15	G	3		153	190.00
A00985900	05S	01W	11	NWNENW	15	G	3		153	190.00

A00988900	05S	02W	19	SESWNW	15	G	3		168	187.00
A00997300	06S	01E	08	NWNWSE	14	G	3		83	110.00
A01004400	06S	01E	14	SWNWSE	14	G	3		145	244.00
A01020900	03S	04W	32	38601310	79	G	3		186	95.00
A01023700	04S	03W	26	NCN2	79	G	3		117	53.00
A01043400	07S	02E	03	CWNWNW	14	G	3		80	120.00
A01055500	05S	01W	03	13201320	15	G	3		156	123.00
A01058500	06S	01W	04	39353155	15	G	3		80	62.00
1965										
A01068600	06S	01E	13	NCW2	14	G	3		168	152.00
A01074000	05S	04W	11	SESENE	15	G	3		182	150.00
A01074000	05S	04W	11	SESENE	15	G	3		182	150.00
A01074100	05S	04W	02	SENESW	15	G	3		325	148.00
A01074100	05S	04W	02	SENESW	15	G	3		325	148.00
A01086900	06S	02E	33	NENENE	14	G	4		0	30.20
A01096900	05S	01W	23	SENWSW	15	G	3		113	102.00
A01097200	06S	01E	25	37503170	14	G	3	*	222	155.00
A01101800	06S	01E	01	SENWSW	14	G	3		86	129.00
A01108900	06S	01W	22	NESWNE	15	G	3		115	128.00
A01111500	05S	04W	12	SWSWNW	15	G	3		25	37.50
A01112400	06S	01E	10	NWSWNE	14	G	3		138	165.00
A01114300	06S	01W	11	E2W2NWNW	15	G	3		116	39.00
A01116500	06S	01W	03	26352540	15	G	3		217	202.00
A01129600	04S	04W	27	SECRSWNE	79	G	3		0	32.00
A01133500	04S	04W	09	00502660	79	G	3		249	163.00
A01135200	06S	01W	03	NWSENW	15	G	3		114	171.00
A01137000	04S	04W	04	20461960	79	G	3		0	97.00
A01140000	03S	04W	17	10700630	79	G	4	*	0	20.00
A01140000	03S	04W	17	16400560	79	G	4	*	0	20.00
A01140000	03S	04W	17	10600530	79	G	4	*	0	20.00
A01144300	07S	02E	23	NWNWSE	14	G	3		240	133.00
A01146200	06S	01E	23	SENESW	14	G	3		108	162.00
A01147400	05S	02W	01	40303590	15	G	3		177	61.80
A01147500	05S	01E	30	SWNWSW	101	G	3	*	220	112.00
A01150200	04S	01W	35	NCNE	79	G	3		209	320.00
1966										
A01153300	01S	04W	31	NWNENW	79	G	3		91	74.00
A01153300	01S	04W	30	NCSESW	79	G	3		91	74.00
A01153600	04S	04W	04	12703000	79	G	3		72	122.00
A01155500	04S	04W	35	NWNWSW	79	G	3		80	120.00
A01156900	04S	01W	35	NESESW	79	G	3		137	160.00
A01159800	05S	01W	25	NWNWNW	15	G	3		100	94.00
A01162000	04S	04W	08	01002905	79	G	3		0	173.00
A01167400	06S	01W	23	NESWNW	15	G	3		158	76.00
A01172000	05S	01W	16	NWNWNW	15	G	3		160	93.00
A01180100	04S	04W	09	CWSENE	79	G	3		96	50.00
A01181400	04S	04W	04	03300460	79	G	2		0	70.00
A01183200	06S	01W	04	45352630	15	G	3		160	116.00
A01184500	03S	04W	20	41253760	79	G	3		138	135.00
A01184700	06S	01E	03	NCW2NE	14	G	3		98	90.00
A01185100	03S	04W	21	13005255	79	G	3		78	117.00
A01186300	08S	03E	26	NWNESW	14	G	3		177	131.00

A01186800	02S	08W	09	NESWNW	45	G	3		119	43.00
A01187400	05S	04W	12	NCSW	15	G	3		116	44.00
A01188700	04S	04W	09	NENWNE	79	G	3		117	143.00
A01197500	05S	01W	34	05352620	15	G	3		115	173.00
A01197600	05S	01W	28	NENWNW	15	G	3		415	108.00
A01199000	05S	03W	17	NWSESW	15	G	3		103	77.00
A01199800	01S	04W	17	NCW2SW	79	G	3		108	48.00
A01206600	01S	04W	18	09803950	79	G	3		114	172.00
A01215200	05S	01E	07	SWSWSE	101	G	3		80	103.00
A01226900	06S	01E	06	SENESE	14	G	3		248	95.00
A01226900	06S	01E	06	SWNWSE	14	G	3		248	95.00
A01227800	01S	04W	29	SENENE	79	G	3		80	72.00
A01237700	01S	04W	18	07062186	79	G	3		177	68.00
A01248900	01S	04W	03	SESESW	79	G	3		115	155.00
A01249800	05S	01E	30	NWSWNW	101	G	3		0	121.00
A01249800	05S	01E	30	SWNWSW	101	G	3	*	0	121.00
A01249900	05S	02W	21	18355240	15	G	3	*	40	60.00
A01250700	07S	02E	22	CWE2SE	14	G	3		99	114.00
1967										
A01260400	06S	01E	23	24802600	14	G	3		76	103.00
A01266600	06S	01W	11	NENWNE	15	G	3		65	56.00
A01282300	05S	02W	22	17502600	15	G	3		127	100.00
A01284700	01S	04W	17	51803670	79	G	3		160	209.00
A01288300	01S	04W	31	33353265	79	G	3		152	34.00
A01288300	01S	04W	31	26503795	79	G	3		152	34.00
A01294100	06S	01W	29	NCSE	15	G	3		160	161.00
A01294200	06S	01W	21	13400695	15	G	3		65	57.00
A01296100	05S	02W	36	SESWNW	15	G	3	*	0	0.00
A01300300	06S	03W	23	SWSENW	15	G	3		84	38.00
A01300900	07S	02E	27	06000051	14	G	3		140	135.00
A01301100	05S	04W	13	19902650	15	G	3		149	160.00
A01309100	05S	02W	21	31703000	15	G	3		150	105.00
A01313400	01S	05W	21	39953300	79	G	3		92	75.00
A01316700	03S	04W	33	15353695	79	G	3		122	155.00
A01317700	06S	01E	02	39404290	14	G	3		34	51.00
A01322800	05S	02W	35	NCN2NW	15	G	3		77	98.00
A01330100	05S	01E	08	NCNE	101	G	3	*	125	93.00
A01338400	05S	03W	19	01501130	15	G	3		69	103.00
A01338500	05S	04W	13	48501624	15	G	3		82	116.00
A01341400	01S	03W	01	57003450	79	G	3		335	240.00
A01346200	06S	04W	26	NESWSE	15	G	3		81	46.00
A01357200	01S	06W	22	26003520	45	G	3		156	52.00
A01363100	05S	01W	22	SENWSE	15	G	3		95	142.00
A01367800	02S	08W	11	33303670	45	G	4		0	245.51
A01367800	02S	08W	11	39604580	45	G	4		0	245.51
A01367800	02S	08W	11	39405200	45	G	4		0	245.51
A01373300	06S	01W	11	SESESW	15	G	3		31	16.00
A01397500	02S	12W	05	17041464	92	G	3		359	137.00
A01397500	02S	12W	05	17763720	92	G	3		359	137.00
A01397500	02S	12W	05	18005210	92	G	3	*	359	137.00
A01401700	05S	02W	14	39601980	15	G	3		120	67.00
A01415000	05S	02W	20	06500660	15	G	3		148	204.00

A01418800	05S	06W	11	07101580	45	G	3		151	38.00
A01418800	05S	06W	11	06902815	45	G	3		151	38.00
A01425400	05S	01W	26	30350710	15	G	3		0	0.00
A01425500	05S	01W	22	NENWNE	15	G	3		126	108.00
1968										
A01430100	06S	01E	13	37853635	14	G	3		85	92.00
A01440500	03S	04W	32	40902195	79	G	3		0	100.00
A01443600	02S	10W	28	SESESE	45	G	4		0	6.14
A01450600	03S	04W	18	51802600	79	G	6		0	44.36
A01450600	03S	04W	18	51803200	79	G	6		0	44.36
A01461800	03S	04W	18	26100200	79	G	3		72	46.00
A01463100	07S	02E	27	40801260	14	G	3		80	40.00
A01463100	07S	02E	27	28401260	14	G	3		80	40.00
A01466300	07S	02E	21	NESENE	14	G	3		73	57.00
A01483500	05S	03W	23	36003895	15	G	3		197	32.00
A01494500	07S	02E	25	CNS2NW	14	G	3		80	75.00
A01501700	08S	02E	12	NWNESW	14	G	3		0	0.00
A01512800	02S	12W	04	SWSESE	92	G	3		118	64.00
A01515000	07S	02E	36	NWNENE	14	G	3		90	90.00
A01517600	01S	04W	18	39601200	79	G	3		80	120.00
A01517700	01S	04W	19	33994884	79	G	3		37	56.00
A01535200	05S	04W	15	NESWNW	15	G	3		72	107.00
A01537500	06S	01W	20	NCSW	15	G	3		160	124.00
A01539600	01S	05W	14	02401360	79	G	3		97	73.00
A01547400	01S	04W	05	00701715	79	G	3		92	123.00
A01550400	03S	04W	17	20554948	79	G	3		0	60.00
A01555400	11S	05E	10	47500250	31	G	2		0	66.20
A01565000	11S	05E	28	NENWNE	31	G	3		117	125.00
A01572300	06S	01E	07	NWNWNW	14	G	3		63	120.00
A01579100	07S	02E	23	NWSWSE	14	G	3		0	51.00
A01579500	07S	02E	20	23200030	14	G	3	*	160	115.00
A01588900	06S	02E	19	NESWNE	14	G	3		80	72.30
A01594900	01S	05W	24	23102790	79	G	3		120	112.00
1969										
A01613000	07S	02E	11	SWNWSW	14	G	3		197	104.00
A01619700	06S	01E	10	SESWNE	14	G	3		69	63.00
A01621500	07S	02E	09	NESWNE	14	G	3		120	133.00
A01632300	05S	04W	02	37623754	15	G	3		0	120.00
A01640100	08S	02E	01	14802630	14	G	3		110	129.00
A01642200	05S	01W	31	06301485	15	G	3		0	30.00
A01643900	04S	04W	35	41604490	79	G	3		59	75.00
A01645300	07S	02E	04	39601320	14	G	3		115	139.00
A01649000	06S	01W	10	NESWNE	15	G	3		128	94.00
A01660400	01S	05W	14	02750050	79	G	3		78	117.00
A01661100	07S	02E	03	NWSWNW	14	G	3		77	131.00
A01664000	01S	04W	31	13553925	79	G	3		102	68.00
A01665500	01S	04W	17	17152610	79	G	3		136	90.00
A01683500	03S	04W	20	38900740	79	G	3		0	93.00
A01687000	01S	04W	20	38754555	79	G	3		78	56.00
A01687100	01S	04W	21	14500660	79	G	3		174	145.00
1970										
A01688700	07S	01W	24	NCN2NW	15	G	3		75	26.50

A01692700	04S	02W	18	36954885	79	G	3		58	57.00
A01699700	07S	02E	26	NESWNE	14	G	3		47	80.00
A01700500	06S	01E	36	SWSWNE	14	G	3		100	194.00
A01700600	06S	02E	31	SWNWSW	14	G	3		130	220.00
A01702900	07S	02E	15	SWNESE	14	G	3	*	42	64.00
A01707700	08S	03E	22	12751800	14	G	3		99	150.00
A01707700	08S	03E	22	25502100	14	G	3		99	150.00
A01709700	07S	02E	03	NWNWSW	14	G	3		85	140.00
A01709800	07S	02E	36	NESWSW	14	G	3		70	99.00
A01713600	05S	04W	10	06201408	15	G	3		104	81.00
A01716000	06S	01E	26	51802560	14	G	3	*	115	130.00
A01718300	08S	03E	26	26003440	14	G	3		38	57.00
A01718500	04S	04W	09	46251300	79	G	3	*	0	38.00
A01724600	08S	02E	12	NWNWNE	14	G	3		139	210.00
A01733800	04S	04W	27	40205200	79	G	3		76	97.00
A01744400	05S	01E	29	51503960	101	G	3	*	160	154.00
A01744700	05S	02W	02	47503960	15	G	3		83	70.00
A01751300	08S	03E	26	SWSESE	14	G	3		40	60.00
A01757600	04S	04W	27	26004600	79	G	3		150	104.00
A01766000	07S	02E	09	32600600	14	G	3		36	51.00
A01767500	04S	04W	34	39272211	79	G	3		0	111.00
1971										
A01771000	06S	01W	22	12401440	15	G	3		70	105.00
A01783700	02S	06W	06	12504545	45	G	4		0	2.82
A01783700	02S	06W	06	12504750	45	G	4		0	2.82
A01787000	05S	01E	34	00502620	101	G	3	*	106	69.00
A01823600	05S	02W	36	08002510	15	G	3		65	98.10
A01841600	07S	02E	04	14803280	14	G	3		160	125.00
A01841600	07S	02E	04	25200100	14	G	3		160	125.00
A01852500	02S	05W	02	12001050	79	G	3		202	227.00
A01854300	07S	02E	26	26805240	14	G	3		70	69.00
A01862700	04S	04W	27	39004560	79	G	3		73	43.00
A01863000	08S	03E	26	02003200	14	G	3		0	60.00
1972										
A01882300	05S	04W	17	NENENE	15	G	3	*	40	100.00
A01884000	01S	04W	19	16802870	79	G	3		145	197.00
A91900500	04S	04W	05	40201320	79	G	9		0	314.99
A91900600	04S	04W	05	39201280	79	G	9		0	0.00
A91908900	01S	04W	20	12002300	79	G	9	*	0	449.99
A01926900	01S	06W	23	35355190	45	G	4		0	124.50
A01931700	01S	04W	04	07903465	79	G	3		275	155.00
A01937600	05S	04W	05	00330066	15	G	3		9	33.00
A01937900	08S	03E	20	32501650	14	G	3		227	232.00
A01938400	05S	03W	17	SWNENW	15	G	3		120	143.00
A01960300	07S	02E	23	51804350	14	G	3		302	453.00
A01968500	07S	02W	01	13853960	15	G	3		160	149.00
A01978500	06S	01W	11	SWNWNW	15	G	3		0	110.00
A01981200	05S	04W	09	15304430	15	G	4		0	31.42
A01983000	06S	01E	26	51802560	14	G	3	*	46	80.00
1973										
A02012800	01S	04W	15	49851315	79	G	3		132	180.00
A02022900	03S	02W	31	10565180	79	G	3		25	2.00

A02039400	01S	04W	16	13203960	79	G	3		132	198.00
A02040600	08S	03E	26	38803900	14	G	3		30	30.00
A02073200	07S	02E	21	39603960	14	G	3		149	135.00
A02074300	06S	02E	18	14804040	14	G	3		175	114.00
A02085400	07S	02E	35	39603960	14	G	3		156	94.00
A02085500	06S	02E	28	13402660	14	G	3		160	66.40
A02087000	07S	02E	29	25500700	14	G	3		163	54.00
A02087200	08S	03E	26	52005080	14	G	3		60	74.00
A02114100	05S	02W	21	06603250	15	G	3		80	67.00
A02117900	05S	01E	31	04402500	101	G	3		238	282.00
A02119400	07S	02E	28	06602640	14	G	3		160	147.00
A02141400	05S	02E	12	NWNWSW	101	G	4		0	15.37
A02141400	05S	02E	12	NWNESW	101	G	4	*	0	15.37
A02141400	05S	02E	12	NWNESW	101	G	4	*	0	15.37
A02152500	07S	02E	34	12000605	14	G	3		204	264.00
A02152500	07S	02E	34	SESE	14	G	3		204	264.00
A02165200	06S	01W	02	13505240	15	G	3		70	65.00
1974										
A02184400	08S	03E	22	NCN2SWSE	14	G	3		36	54.00
A02192200	08S	03E	20	12800020	14	G	3		85	85.00
A02192300	08S	03E	21	07605048	14	G	3		90	90.00
A02221000	06S	01E	24	SWNWSW	14	G	3		100	160.00
A02224700	08S	03E	28	27804050	14	G	3		80	120.00
A02229100	05S	04W	15	07103990	15	G	3		72	87.00
A02238700	05S	05W	27	47804360	15	G	4		0	101.60
A02246700	05S	01E	20	13103960	101	G	3		156	83.00
A02270900	03S	04W	33	40253745	79	G	3		146	146.00
A02279600	07S	02E	34	38000100	14	G	3		95	98.00
A02279700	07S	02E	34	08400050	14	G	3		29	22.00
A02284500	05S	01E	29	51503960	101	G	3	*	0	49.00
A02284600	03S	04W	07	49502030	79	G	3		68	102.00
A02286300	05S	01E	14	NWSESE	101	G	2		0	6.14
A02286300	05S	01E	14	SWNESE	101	G	2		0	6.14
A02286300	05S	01E	14	NWNESE	101	G	2		0	6.14
A02293700	06S	02W	21	13551355	15	G	3		158	148.00
A02298300	07S	02E	26	NENWSE	14	G	3		78	110.00
A02298500	07S	02E	22	40604120	14	G	3		65	80.00
A02316000	10S	05E	18	SWSWSE	31	G	4		0	55.30
A02322800	05S	02W	30	02505250	15	G	3		331	29.00
A02322800	05S	02W	30	03003960	15	G	3	*	331	29.00
1975										
A02338100	06S	01E	25	16804340	14	G	3		140	180.00
A02339400	07S	02E	14	CNNW	14	G	3		153	75.00
A02341500	07S	02E	22	NCN2NE	14	G	3		62	70.00
A02346200	08S	03E	16	NCW2SWNW	14	G	3		39	59.00
A02357100	01S	05W	25	52155150	79	G	3		195	75.00
A02357100	01S	05W	25	17803560	79	G	3		195	75.00
A02357100	01S	05W	25	34304158	79	G	3		195	75.00
A02369000	05S	04W	13	08151980	15	G	3	*	55	82.50
A02373000	05S	01W	28	39603950	15	G	3		0	141.00
A02380400	11S	05E	35	07000650	31	G	4		0	0.00
A02380400	11S	05E	35	15001250	31	G	4		0	0.00

A02380400	12S	05E	01	48504500	31	G	4	*	0	0.00
A02380400	11S	05E	35	05000200	31	G	4		0	0.00
A02380400	12S	05E	01	50704150	31	G	4	*	0	0.00
A02380400	11S	05E	35	06501000	31	G	4	*	0	0.00
A02380400	12S	05E	01	50504350	31	G	4	*	0	0.00
A02380400	12S	05E	02	52000500	31	G	4	*	0	0.00
A02380400	11S	05E	35	11000950	31	G	4		0	0.00
A02380400	11S	05E	35	02501000	31	G	4		0	0.00
A02382000	05S	04W	22	52001280	15	G	3		85	90.00
A02390500	07S	02E	35	08001260	14	G	3		77	91.00
A02390600	07S	02E	15	52003150	14	G	3		158	219.00
A02394000	01S	04W	04	NCSE	79	G	3		166	215.00
A02394100	01S	04W	10	NCNW	79	G	3		140	184.00
A02405300	03S	04W	06	13000990	79	G	3		84	76.00
A02411600	05S	01W	03	26300280	15	G	3		0	50.00
A02419800	06S	01W	23	25401315	15	G	3		200	109.00
A02420005	10S	05E	32	NWNESE	31	G	1		0	1.53
A02433600	05S	03W	24	39703930	15	G	3		136	29.00
A02433600	05S	03W	24	39703795	15	G	3		136	29.00
A02440000	01S	06W	22	09252530	45	G	3		154	105.00
A02440700	05S	02W	35	39505250	15	G	3		92	109.00
A02442900	05S	02W	33	46201250	15	G	3		106	135.00
A02457300	05S	01E	10	13201960	101	G	3		154	180.00
A02475800	01S	05W	14	48502740	79	G	3		50	25.00
A02480400	01S	04W	17	12901290	79	G	3		65	90.00
A02494600	01S	05W	10	30033498	79	G	3		114	60.00
A02526800	05S	01E	30	08005180	101	G	3		101	96.00
A02533600	05S	02W	21	26802500	15	G	3		177	189.00
1976										
A02549000	05S	02W	32	28702440	15	G	3		118	147.00
A02561700	04S	05W	03	NENESE	79	G	3		160	240.00
A02571300	01S	05W	23	42750085	79	G	3	*	72	88.00
A02583900	02S	08W	11	19503640	45	G	4		0	99.40
A02583900	02S	08W	11	12703520	45	G	4		0	99.40
A02583900	02S	08W	11	17002820	45	G	4		0	99.40
A02586700	01S	06W	22	NENESW	45	G	4		0	479.05
A02586700	01S	06W	22	NENESW	45	G	4		0	479.05
A02587900	05S	03W	23	23101220	15	G	3		107	45.00
A02595500	06S	01W	05	38301185	15	G	3		119	105.00
A02595600	06S	01W	05	36602650	15	G	3		140	103.00
A02595700	06S	01W	02	05303100	15	G	3		80	105.00
A02613700	06S	04W	11	00450445	15	G	3		15	11.00
A02618900	01S	05W	17	03962178	79	G	3		78	77.00
A02637100	05S	03W	07	01000530	15	G	3		71	41.00
A02637200	05S	01E	20	13201320	101	G	3		160	121.00
A02657100	05S	04W	24	34525260	15	G	3		184	85.00
A02662200	04S	02W	19	46102620	79	G	3		133	52.00
A02662900	03S	04W	17	NCW2NWNW	79	G	3		0	10.00
A02673400	05S	03W	21	52153955	15	G	3		16	11.00
A02679100	04S	01E	24	46003000	101	G	3		229	290.00
A02685500	07S	02E	23	15003850	14	G	3	*	111	74.60
A02686800	05S	02W	11	13101320	15	G	3		80	90.00

A02691800	05S	04W	05	11720430	15	G	3		81	109.00
A02697100	04S	02E	28	NCN2S2NE	101	G	3		92	138.00
A02710100	06S	01W	26	40903695	15	G	3		155	51.00
A02712000	07S	02E	28	46201340	14	G	3	*	127	107.00
A02715600	11S	05E	21	45002960	31	G	4		0	151.00
A02715600	11S	05E	21	46803300	31	G	4		0	151.00
A02725200	06S	02W	35	13153930	15	G	3		160	99.00
A02725800	01S	04W	18	52000660	79	G	3		160	96.00
A02732000	03S	04W	07	29471287	79	G	3	*	120	73.00
A02742000	01S	04W	21	41250675	79	G	3		135	132.00
A02748400	01S	06W	21	24654025	45	G	3		160	114.00
A02749600	01S	04W	15	13503830	79	G	3		160	108.00
A02754900	05S	03W	29	31824573	15	G	3		92	56.00
A02758900	05S	03W	18	08502280	15	G	3		98	83.00
A02767400	05S	01E	17	00702300	101	G	3		160	117.00
A02776800	05S	03W	36	24755080	15	G	3		77	65.00
A02776900	06S	02W	18	40603860	15	G	3		146	17.00
A02776900	06S	02W	18	41253365	15	G	3		146	17.00
A02777100	05S	03W	34	52603800	15	G	3		162	252.00
A02779200	05S	01W	12	13201310	15	G	3		132	132.00
A02781100	06S	01E	14	42201330	14	G	3		65	94.00
A02781200	06S	01E	14	42203740	14	G	3		76	114.00
A02794000	06S	02E	32	48201720	14	G	3		254	103.06
A02797600	04S	04W	04	37403460	79	G	3		0	106.50
A02799800	06S	02E	33	12603750	14	G	3		0	79.62
A02813300	05S	01E	32	NWSESE	101	G	3		255	360.00
A02813300	05S	01E	33	NWSESW	101	G	3		255	360.00
1977										
A02830400	04S	04W	20	39902375	79	G	3		4	165.00
A02840600	01S	06W	14	38300360	45	G	3		140	160.00
A02843200	01S	06W	18	21800100	45	G	4	*	0	166.05
A02843200	01S	06W	18	16800100	45	G	4	*	0	166.05
A02843200	01S	06W	18	11800100	45	G	4	*	0	166.05
A02845200	01S	06W	17	13201320	45	G	3		136	173.00
A02854300	06S	01W	04	06303930	15	G	3	*	80	75.00
A02865500	04S	02E	24	NWNESE	101	G	3		240	240.00
A02865500	04S	02E	24	NCS2	101	G	3		240	240.00
A02868200	04S	04W	27	12875200	79	G	3		0	113.00
A02875300	03S	04W	21	00304225	79	G	3		77	90.00
A02883800	06S	02E	33	26801250	14	G	3		0	9.00
A02883900	07S	02W	11	39601320	15	G	3		160	168.00
A02886500	06S	02E	33	39602680	14	G	3		105	94.00
A02892300	07S	02E	10	16501180	14	G	3		60	84.00
A02892400	07S	02E	10	34321346	14	G	3		108	162.00
A02897800	01S	06W	15	37291386	45	G	3		90	127.00
A92903200	07S	02E	04	10002000	14	G	2	*	0	18.01
A02908000	05S	03W	19	49503370	15	G	3		86	77.00
A92909800	08S	03E	07	48001250	14	G	A		0	81.01
A02912400	05S	03W	18	32541298	15	G	3	*	130	68.00
A02912800	04S	02W	18	16204540	79	G	3		71	35.00
A02917200	01S	05W	20	23952260	79	G	3	*	0	4.00
A02917500	01S	05W	21	40260396	79	G	3		67	66.00

A02917500	01S	05W	21	36301420	79	G	3		67	66.00
A02921300	05S	03W	19	NCW2NW	15	G	3		70	181.00
A02921500	03S	02E	36	11703870	101	G	3		132	121.00
A02928800	05S	04W	12	10003200	15	G	3		0	76.00
A02929600	01S	05W	18	46703880	79	G	3		85	45.00
A02936300	04S	04W	16	13501320	79	G	3		148	159.00
A029365D2	04S	04W	16	26000680	79	G	3		60	78.00
A029365D1	04S	04W	15	52403580	79	G	3		30	42.00
A02949800	06S	01E	13	33102400	14	G	3		0	185.00
A02956400	02S	04W	31	16503550	79	G	3		110	134.00
A02956500	02S	04W	31	14001300	79	G	3	*	100	150.00
A02957500	08S	03E	17	25003840	14	G	3		150	201.00
A02958700	05S	04W	08	52500890	15	G	3		90	52.00
A02959800	06S	01E	14	25403920	14	G	3		175	210.00
A02959900	06S	01E	24	52005180	14	G	3		60	55.00
A02968100	03S	04W	06	20461056	79	G	3		0	22.00
A02968100	03S	04W	06	13551915	79	G	3		0	22.00
A02971400	06S	04W	02	30700630	15	G	3		50	57.00
A02973000	04S	04W	32	09900050	79	G	3		159	89.00
A02976000	02S	12W	05	13534150	92	G	3		0	39.00
A02982200	01S	06W	15	39602775	45	G	3		91	113.00
A02984800	05S	02W	31	36211254	15	G	3		81	46.00
A02984800	05S	02W	31	21621257	15	G	3		81	46.00
A02985200	05S	01W	29	26503820	15	G	3	*	145	39.00
A02987800	01S	06W	15	26002670	45	G	3		160	210.00
A02993400	06S	01E	03	35404020	14	G	3	*	107	144.00
A02995500	01S	04W	23	34501330	79	G	3	*	72	26.50
A02998300	01S	06W	24	52004060	45	G	3		60	90.00
A03004100	04S	04W	28	32901250	79	G	3		175	93.00
A03007500	01S	06W	13	25704090	45	G	3		144	216.00
A03007600	06S	01E	11	34104130	14	G	3		150	184.00
A03007700	08S	02E	01	40004250	14	G	3		176	95.00
A03007700	08S	02E	01	18504250	14	G	3		176	95.00
A03007800	07S	02E	14	51801860	14	G	3		0	101.00
A03007900	06S	02E	31	30004990	14	G	3		119	165.00
A03009600	01S	04W	29	38002480	79	G	3	*	400	230.00
A03015800	06S	02E	20	SWSWSW	14	G	3		7	87.96
A03015800	06S	02E	29	NENWSE	14	G	3		7	87.96
A03015800	06S	02E	20	NWSWSW	14	G	3		7	87.96
A03015900	07S	02E	03	20803490	14	G	3		158	171.00
A03022500	07S	02W	23	NCSE	15	G	3		132	140.00
A03024000	01S	04W	31	27504900	79	G	4	*	0	134.72
A03027100	05S	01W	34	33003300	15	G	3		37	36.00
A03028000	01S	04W	29	38002480	79	G	3	*	0	77.00
A03028700	05S	03W	13	28854325	15	G	3		102	25.00
A03028700	05S	03W	13	28704140	15	G	3		102	25.00
A03028700	05S	03W	13	30354240	15	G	3		102	25.00
A03031200	05S	02W	25	SWSWNE	15	G	3		158	237.00
A03031200	05S	02W	25	CWNWNE	15	G	3		158	237.00
A03036000	05S	04W	11	01305150	15	G	3		71	27.00
A03036100	03S	04W	29	39501990	79	G	3		0	68.00
A03036300	03S	04W	33	26502615	79	G	3	*	0	73.00

A03036400	03S	04W	32	21201914	79	G	3		0	113.00
A03036500	03S	04W	33	15204820	79	G	3		24	33.00
A03037300	04S	03E	29	48853255	101	G	4		0	172.80
A03037300	04S	03E	29	43503270	101	G	4		0	172.80
A03052600	05S	03W	27	11505180	15	G	4		0	306.80
A03054800	05S	04W	15	26100060	15	G	3	*	0	0.00
A03054900	04S	04W	20	26102180	79	G	3	*	28	0.00
A03056900	05S	03W	18	00404250	15	G	3		115	132.00
A03060900	06S	01W	25	13251325	15	G	3		130	120.00
A03066000	05S	05W	26	51800230	15	G	3		317	131.00
A03073800	01S	04W	19	NWNWSE	79	G	3		83	125.40
A03076900	05S	03W	23	23753895	15	G	3		0	70.00
A03084600	06S	01W	03	26755150	15	G	3		76	102.00
A03084700	07S	02E	21	52602990	14	G	3		15	23.00
A03084800	07S	02E	24	00505080	14	G	3		0	60.00
A03093300	05S	06W	11	NESESE	45	G	3		30	0.00
A03097500	06S	01W	21	40503900	15	G	3		130	123.00
A03098500	06S	01W	05	32203970	15	G	3		123	132.00
A03104200	08S	03E	21	SWSWNE	14	G	3		0	25.50
A03109800	05S	03W	18	01001230	15	G	3		79	114.00
A03110800	05S	02W	35	NCN2NE	15	G	3		60	90.00
1978										
A03118200	05S	02W	21	31352650	15	G	3		0	52.00
A03124000	03S	04W	17	26303840	79	G	3	*	0	117.00
A03124500	05S	01E	10	13004000	101	G	3		160	194.00
A03133700	08S	02E	12	NCE2SWNW	14	G	3		147	220.50
A03133700	08S	02E	12	SWSWNE	14	G	3		147	220.50
A03133700	08S	02E	12	CWSWNE	14	G	3		147	220.50
A03135000	11S	05E	08	SESWSE	31	G	4		0	0.15
A03145900	06S	01E	07	31501580	14	G	3		0	94.00
A03146100	05S	01E	01	13001320	101	G	3		132	73.68
A03164800	05S	02W	26	SESENE	15	G	3		10	12.00
A03167700	05S	01E	02	39203910	101	G	3		132	140.00
A03173000	08S	03E	19	28000150	14	G	4		0	0.97
A03176200	05S	02E	01	39203930	101	G	3		110	81.00
A03176900	01S	04W	27	39603960	79	G	3		190	88.00
A03177300	01S	04W	16	35001320	79	G	3		167	180.00
A03177900	05S	04W	16	52500600	15	G	3		74	98.00
A03178000	05S	04W	15	39501250	15	G	3		120	120.00
A03188200	04S	01W	16	28902100	79	G	4	*	0	12.27
A03188200	04S	01W	16	29402110	79	G	4	*	0	12.27
A03190000	05S	01W	35	39603960	15	G	3	*	153	72.00
A03199000	05S	01W	15	52004026	15	G	3		0	57.00
A03205200	11S	05E	21	NESENW	31	G	3		100	150.00
A03205200	11S	05E	21	SENENW	31	G	3		100	150.00
A03205800	01S	06W	23	35795233	45	G	4	*	0	23.05
A03205800	01S	06W	22	33800300	45	G	4	*	0	23.05
A032108HD	03S	04W	29	04103050	79	G	9	*	0	568.00
A032108IN	03S	04W	29	04103050	79	G	2	*	0	38.00
A03223200	06S	02E	19	32904700	14	G	3		160	180.00
A03232700	06S	02E	18	NCSESW	14	G	3		98	147.00
A03244100	08S	03E	27	48500580	14	G	3	*	0	67.00

A03250100	01S	04W	21	13204060	79	G	3		140	195.00
A03250800	06S	01E	04	39603935	14	G	3		90	135.00
A03251100	08S	03E	20	44003850	14	G	3	*	47	19.00
A03251200	08S	03E	17	06004100	14	G	3	*	0	23.00
A03252600	03S	04W	28	39603960	79	G	3		160	185.00
1979										
A03255000	11S	05E	35	16003900	31	G	2		0	0.25
A03262700	05S	01W	35	CEW2SW	15	G	3		80	120.00
A03262900	01S	04W	15	21500100	79	G	3		160	45.00
A03272800	05S	01W	13	NESENE	15	G	3	*	0	207.00
A03272900	05S	01E	26	41303950	101	G	3		120	20.00
A03272900	05S	01E	26	52503660	101	G	3		120	20.00
A03276900	05S	01E	30	NWNESW	101	G	3		0	97.00
A03285500	05S	01E	23	51605050	101	G	3	*	160	49.00
A03292200	05S	01W	33	08601920	15	G	3		111	152.00
A03313600	07S	02E	23	36202550	14	G	3		160	117.00
A03322100	01S	06W	12	39002675	45	G	3		115	30.00
A03322100	01S	06W	12	36602675	45	G	3		115	30.00
A03342700	06S	02E	18	41803960	14	G	3		68	69.00
A03342800	07S	02E	10	14302590	14	G	3		61	92.00
A03342900	08S	03E	27	07703190	14	G	3		121	62.00
A03354900	01S	04W	03	30005000	79	G	3		66	64.00
A03355500	05S	01E	34	52500900	101	G	3		40	40.00
A03357700	05S	01E	17	39801230	101	G	3		160	82.00
A03364000	07S	02E	10	22694856	14	G	3		143	183.00
A03364100	07S	02E	11	37505150	14	G	3		128	192.00
A03364200	06S	01E	11	39401300	14	G	3	*	160	87.00
A03364300	03S	04W	20	40501200	79	G	3		24	30.00
A03365700	04S	04W	17	39401125	79	G	3		127	23.00
A03365700	04S	04W	17	31004000	79	G	3		127	23.00
A03365900	04S	04W	08	51001200	79	G	3	*	0	12.00
A03369300	01S	04W	29	40001350	79	G	3		0	46.00
A03370100	05S	04W	03	SWNWSE	15	G	3		0	23.00
1980										
A03382300	11S	05E	34	33754640	31	G	3		82	81.00
A03386000	11S	05E	34	61503600	31	G	3		35	35.00
A03386100	11S	05E	28	NESESE	31	G	3	*	97	97.00
A03401300	05S	04W	13	08151980	15	G	3	*	13	19.00
A03401900	01S	04W	20	52603300	79	G	3		80	120.00
A03407700	01S	04W	04	27401580	79	G	4		0	53.70
A03408300	01S	04W	29	NWSWNE	79	G	3	*	0	293.00
A03408700	10S	04E	05	NWNESW	14	G	4		0	165.72
A03408700	10S	04E	05	NWNESW	14	G	4		0	165.72
A03408700	10S	04E	05	NWNESW	14	G	4		0	165.72
A03420300	04S	04W	33	43002500	79	G	3		38	38.00
A03425300	04S	03E	20	SESESW	101	G	4		0	125.21
A03427500	02S	07W	07	36002700	45	G	3		0	136.00
A03437800	04S	03E	20	SENESW	101	G	4		0	58.61
A03437900	04S	03E	20	NENESW	101	G	4		0	58.61
A03458300	11S	05E	19	SESWSW	31	G	4		0	1.50
A03462800	04S	04W	32	38800120	79	G	3		158	160.00
A03462900	04S	04W	29	39601320	79	G	3	*	129	107.00

A03469900	05S	01W	34	03604300	15	G	3		120	128.00
A03474900	05S	03W	34	39301755	15	G	3	*	144	112.00
A03474900	05S	03W	34	40451950	15	G	3	*	144	112.00
A03475800	06S	02W	12	13202700	15	G	3		160	36.00
A03483400	07S	03E	31	CWE2SW	14	G	3		0	135.00
A03483500	07S	03E	31	CWE2W2SE	14	G	3		0	135.00
1981										
A03486000	05S	01E	16	49500110	101	G	3	*	134	80.00
A03486200	01S	04W	20	11502600	79	G	3		77	40.00
A03496400	07S	02E	27	NWSWSE	14	G	3		130	180.00
A03508600	03S	02E	26	12801300	101	G	3		132	107.00
A03511400	05S	03W	22	39602050	15	G	3		155	76.00
A03517700	01S	05W	27	NESESW	79	G	3		76	114.75
A03521900	02S	12W	05	18005210	92	G	3	*	0	80.00
A03526100	05S	03W	18	SWSWNW	15	G	3		80	120.00
A03528800	06S	01E	01	NESWNW	14	G	3		0	143.00
A03530900	05S	01E	17	00500600	101	G	3		0	118.00
A03532400	05S	01W	16	NCN2SE	15	G	3		188	85.00
A03545200	06S	03W	23	39962739	15	G	4		0	35.29
A03548700	04S	04W	34	13105250	79	G	3		0	125.00
A03552600	07S	02E	08	42503090	14	G	3		12	10.00
A03560700	11S	05E	21	36204950	31	G	5		0	330.00
A03560800	11S	05E	21	27203920	31	G	5		0	330.00
A03560900	11S	05E	21	23503670	31	G	5		0	330.00
A03561200	05S	04W	03	24805235	15	G	3		0	63.00
A03566100	06S	01E	14	00202440	14	G	3		0	131.50
A03568700	05S	01E	35	28502200	101	G	4		0	128.90
A03569900	06S	01E	15	12000050	14	G	3		50	48.00
A03572500	01S	04W	30	07004500	79	G	3		15	22.00
A03572600	01S	04W	31	44003400	79	G	3		31	36.00
A03572700	01S	05W	36	47002000	79	G	3		19	12.00
A03572800	01S	05W	25	01000100	79	G	3		0	22.00
A03578900	07S	02E	04	36003800	14	G	3		73	109.00
A03579000	06S	02E	31	39600050	14	G	3		136	201.00
A03579300	06S	01E	04	00701500	14	G	3		0	255.00
A03579400	06S	01E	09	29000080	14	G	3		0	170.00
A03582500	03S	04W	17	12801190	79	G	3		53	80.00
1982										
A03586700	02S	09W	23	38383920	45	G	4		0	14.11
A03594400	05S	04W	23	35643036	15	G	3		37	50.00
A03596800	01S	06W	13	52205260	45	G	3		89	107.00
A03604400	02S	04W	06	52303970	79	G	3	*	37	57.00
A03605500	05S	01W	16	26800240	15	G	3		0	195.00
A03606000	08S	03E	07	44003800	14	G	4		0	368.20
A03611200	05S	04W	22	52504373	15	G	3		59	86.00
A03634300	01S	06W	20	39601350	45	G	3		128	146.00
1983										
A03649400	05S	01W	26	35201700	15	G	4	*	0	49.96
A03649500	05S	01W	26	35351700	15	G	4	*	0	0.00
A03650200	07S	02W	15	45003050	15	G	4	*	0	3.84
A03650300	07S	02W	15	46003050	15	G	4	*	0	3.84
A03657000	05S	03W	25	46405210	15	G	3	*	111	151.00

A03658300	04S	04W	29	39601320	79	G	3	*	0	19.00
A03659300	07S	02E	27	26603590	14	G	3		160	160.00
A03659800	04S	04W	33	39603870	79	G	3		136	192.00
A03662000	02S	12W	05	13201320	92	G	3		0	105.00
A03665300	02S	12W	09	35450100	92	G	4		0	101.73
A03665300	02S	12W	09	37000100	92	G	4		0	101.73
A03665300	02S	12W	09	36250100	92	G	4		0	101.73
A03668900	06S	01E	23	25001300	14	G	3		61	99.00
A03673200	06S	01W	04	06303930	15	G	3	*	0	45.00
A03682300	01S	05W	14	25402275	79	G	3		0	73.00
A03686300	07S	02E	16	44002800	14	G	3		158	221.00
A03693000	03S	04W	18	38600100	79	G	3		0	88.00
A03693300	03S	04W	19	51800100	79	G	3		79	19.00
1984										
A03697700	04S	04W	21	39601320	79	G	3		157	86.00
A03699000	04S	04W	28	51904320	79	G	3		82	67.00
A03714700	07S	02E	26	39602660	14	G	3		60	90.00
A03718000	07S	02E	03	00504760	14	G	4		0	39.28
A03742000	01S	06W	18	11800100	45	G	4	*	0	112.47
A03742100	01S	06W	18	16800100	45	G	4	*	0	112.47
A03742200	01S	06W	18	21800100	45	G	4	*	0	112.47
A03750900	04S	04W	21	39504880	79	G	3		157	204.00
1985										
A03780700	12S	05E	10	09920915	31	G	5		0	0.30
A03790900	01S	05W	23	42750085	79	G	3	*	0	12.00
A03800700	05S	03W	20	43235230	15	G	3		220	105.00
A03805600	01S	06W	23	35795233	45	G	4	*	0	197.66
A03805600	01S	06W	22	33800300	45	G	4	*	0	197.66
1986										
A03812300	06S	01E	05	45505150	14	G	3		103	103.00
A03816000	05S	03W	34	40451950	15	G	3	*	0	95.44
A03816000	05S	03W	34	39301755	15	G	3	*	0	95.44
A03823900	08S	03E	17	06004100	14	G	3	*	0	15.00
A03824000	08S	03E	20	44003850	14	G	3	*	0	13.00
A03824400	05S	02W	21	18355240	15	G	3	*	72	108.00
A03830300	07S	02E	15	39800700	14	G	3		50	68.00
A03838100	08S	03E	08	13152620	14	G	4		0	368.26
1987										
A03851500	05S	03W	19	40001500	15	G	3		0	225.00
A03852500	06S	01E	24	12501000	14	G	3		128	192.00
A03853400	08S	02E	01	52501470	14	G	3	*	0	110.00
A03853500	08S	02E	02	46500100	14	G	3		75	113.00
A03853600	07S	03E	31	52004840	14	G	3		91	131.00
A03853700	08S	02E	02	39501200	14	G	3		67	102.00
A03856000	04S	04W	16	41901300	79	G	3		80	120.00
A03856500	08S	03E	27	13000020	14	G	3	*	27	147.00
A03863700	07S	02E	16	17950059	14	G	3		70	100.00
A03868000	07S	02E	21	39601320	14	G	3		72	109.00
1988										
A03872400	07S	02E	22	09603940	14	G	3		136	180.00
A03875400	05S	01W	35	39603960	15	G	3	*	0	158.00
A03879900	02S	04W	06	52303970	79	G	3	*	40	60.00

A03881800	06S	01E	03	35404020	14	G	3	*	0	17.00
A03882800	03S	04W	18	10000680	79	G	3		50	75.00
A03884500	02S	04W	06	39002050	79	G	3		132	150.00
A03891900	05S	01E	34	00502620	101	G	3	*	62	87.00
A03892400	08S	02E	11	37400205	14	G	3		0	320.00
A03900800	03S	04W	20	26003100	79	G	3		70	165.00
A03903100	07S	02E	20	23200030	14	G	3	*	0	95.00
A03903700	07S	02E	15	17002640	14	G	3		101	152.00
A03903800	07S	02E	11	00305250	14	G	3		0	0.00
A03906900	01S	06W	11	00702740	45	G	3		55	82.50
A03908400	06S	01W	10	12004100	15	G	3		210	315.00
A03909000	07S	02E	22	26403980	14	G	3		80	120.00
A03910100	08S	03E	28	36002759	14	G	3	*	0	115.00
A03910600	06S	01E	06	52404950	14	G	3		84	127.00
A03911900	11S	06E	30	08303800	31	G	3		0	0.00
A03912900	03S	04W	20	12001770	79	G	3		107	105.00
A03913500	03S	04W	07	29471287	79	G	3	*	0	100.00
A03914600	06S	01W	05	13201320	15	G	3		132	198.00
1989										
A03918300	06S	03W	05	38751250	15	G	3		35	35.00
A03920400	05S	03W	23	03501330	15	G	3		0	120.00
A03924400	03S	04W	17	00204010	79	G	3		64	96.00
A03928600	06S	01W	10	41004200	15	G	3		132	198.00
A03930600	07S	02E	34	51501250	14	G	3		0	61.40
A03931600	01S	05W	10	32005200	79	G	3		0	21.00
A03931700	01S	05W	10	49805200	79	G	3		26	39.00
A03934200	08S	02E	02	17002150	14	G	3		45	68.00
A03934300	08S	03E	21	42003850	14	G	3		238	117.00
A03934400	08S	03E	21	40005160	14	G	3		0	117.00
A03935400	07S	02E	28	46201340	14	G	3	*	0	85.00
A03937000	05S	04W	03	19800660	15	G	3		38	57.00
A03938000	06S	02W	01	11202640	15	G	3		107	150.00
A03938400	05S	03W	24	17005000	15	G	3		0	156.00
A03942000	05S	04W	02	13505250	15	G	3		0	220.00
A03942500	02S	05W	13	39601320	79	G	3		130	195.00
A03944800	07S	02E	23	15003850	14	G	3	*	0	92.00
A03948900	06S	01W	33	14003850	15	G	3		134	200.00
A03950000	05S	02W	24	01600100	15	G	3		0	0.00
A03950000	05S	02W	24	00400100	15	G	3		0	0.00
A03950000	05S	02W	24	00800100	15	G	3		0	0.00
A03950000	05S	02W	24	01200100	15	G	3		0	0.00
A03950900	07S	02E	15	39705230	14	G	3		68	102.00
A03953900	03S	04W	07	21000350	79	G	3		60	90.00
A03956300	02S	04W	31	16803300	79	G	3		0	0.00
A03957700	08S	03E	07	50003300	14	G	4		0	0.00
A03972000	05S	03W	35	01001640	15	G	4		0	0.00
A03981300	05S	03W	25	50003980	15	G	3		110	165.00
1990										
A03982000	01S	04W	07	08650040	79	G	3		67	69.80
A03982700	06S	01E	24	37593496	14	G	3		0	0.00
A03984100	06S	01E	24	52403455	14	G	3		30	43.00
A03986300	05S	03W	18	32541298	15	G	3	*	0	128.00

A03987200	05S	03W	22	18101040	15	G	3		183	170.00
A03987200	05S	03W	22	18800970	15	G	3		183	170.00
A03987200	05S	03W	22	19500900	15	G	3		183	170.00
A03987200	05S	03W	22	17401110	15	G	3		183	170.00
A03990500	05S	03W	22	30150035	15	G	3		0	72.00
A03991100	05S	01E	20	39501950	101	G	3		136	195.00
A03992400	05S	04W	04	37255000	15	G	3		40	82.00
A03993200	05S	03W	24	10103960	15	G	3		46	45.00
A04006400	08S	02E	01	08001450	14	G	3		0	0.00
A04006700	06S	01W	20	25601260	15	G	3		133	198.00
A04008600	05S	01E	13	04365217	101	G	6		0	21.02
A04008600	05S	01E	13	01325154	101	G	6		0	21.02
A04009700	07S	02E	27	00305240	14	G	3		0	189.00
A04010900	01S	07W	02	40002725	45	G	3		131	196.00
A04016100	07S	02E	34	39604630	14	G	3		142	212.00
1991										
A04020600	01S	05W	36	21502790	79	G	3		114	100.00
A04020600	01S	05W	36	20002790	79	G	3		114	100.00
A04020600	01S	05W	36	16402790	79	G	3		114	100.00
A04044900	05S	01W	27	33501100	15	G	3		0	95.00
A04045000	04S	01W	16	28902100	79	G	4	*	0	0.61
A04045000	04S	01W	16	29402110	79	G	4	*	0	0.61
A04045800	01S	04W	20	12002300	79	G	2	*	0	97.00
A88911500	08S	02E	02	24004750	14	G	2		0	335.00
A889116HD	05S	03W	26	07263564	15	G	9	*	0	413.50
A889116IN	05S	03W	26	07263564	15	G	2	*	0	67.50
A889117HD	08S	02E	02	24004750	14	G	9	*	0	0.00
A889117IN	08S	02E	02	24004750	14	G	2	*	0	25.60
A889118IN	03S	04W	29	13863762	79	G	2	*	0	0.00
A889118HD	03S	04W	29	13863762	79	G	9	*	0	700.00

-- The two numerical values indicate distance in ft North and West of the Southeast section corner, respectively. Directional symbols indicate appropriate quarter sections.

* -- indicates overlap.