MODELING THE EFFECT OF SOIL AND WATER CONSERVATION PRACTICES ON WATERSHED YIELDS IN CENTRAL AND EASTERN KANSAS

by

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CHAPTER 1

Introduction

The consumption of water in the United States is growing at an annual rate of about one percent. By the year 2000 the Water Resources Council estimates annual consumption of water will be 151 million acre-feet or 27 percent above current (1975) levels. While agriculture is now, and into the forseeable future, the largest single consumer of water; municipal and industrial use amounts to 17 percent of the current total demand and its share will increase to perhaps 30 percent by the year 2000 (U.S. Water Resources Council, 1978). Keeping these trends in mind, the engineer/resources planner must ask where is this water to come from?

Kansas is an interesting, if incomplete, microcosm of the nation. Western Kansas is an irrigation-intensive agricultural area, dependent upon partially depleted ground water resources to maintain current crop production levels. On the other hand, much of Eastern Kansas lacks substantial ground water reserves, except for alluvial aquifers, and is more dependent upon surface waters to satisfy water needs. Moreover, agriculture in the Eastern part of the state involves little irrigation; municipal and industrial use constitutes the major water demand.

Figure 1 vividly demonstrates the differences between the two halves of the state. This figure shows the thirteen planned or completed Federal reservoirs in the state for which the Kansas Water Resources Board has agreed to repay the cost of providing municipal

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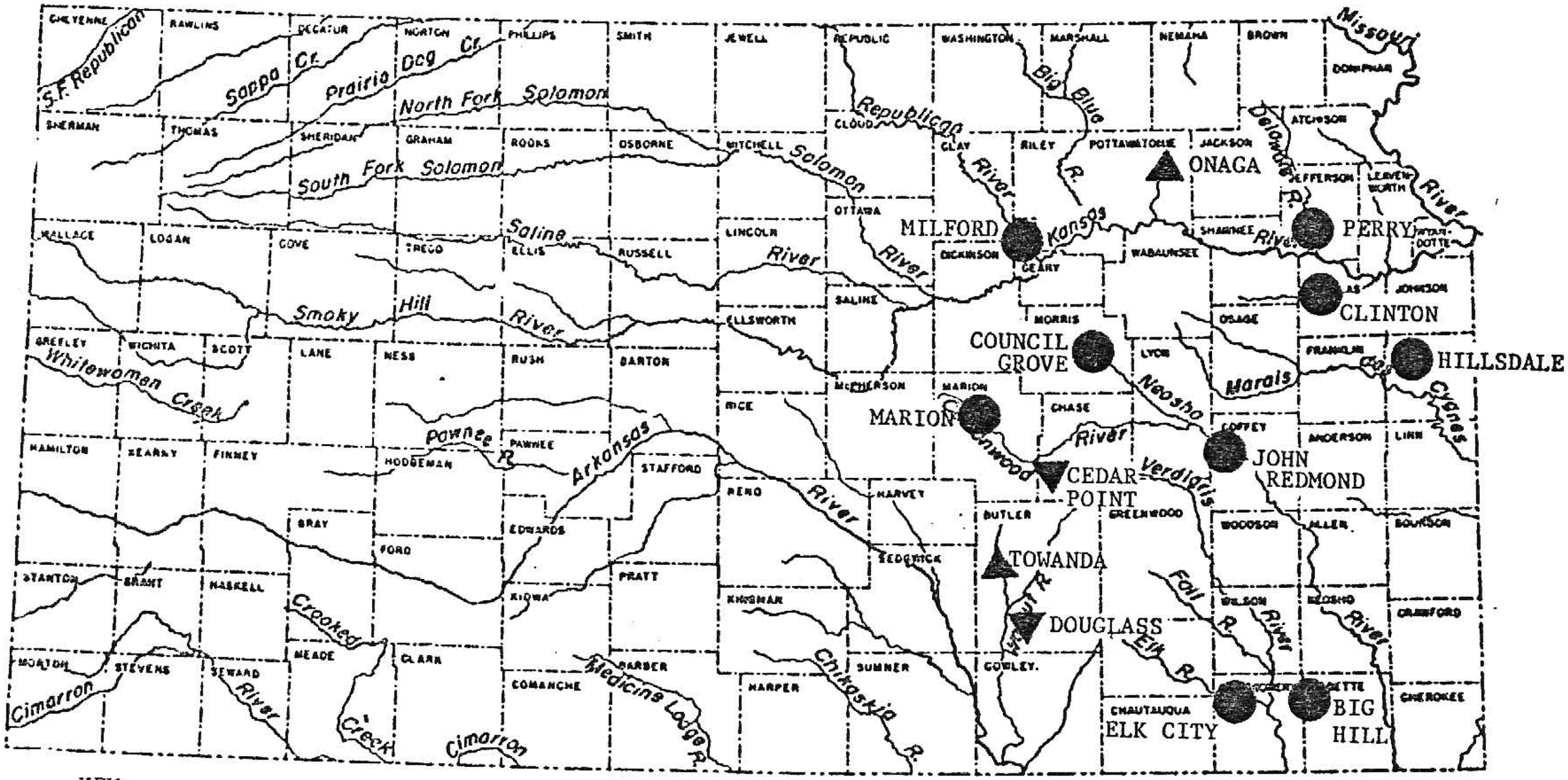


KEY:

● Reservoir completed or under construction

▼ Reservoir scheduled for future construction

Figure 1--Locations of Federal reservoirs for which the State of Kansas has made assurances to repay the cost of providing water supply storage. Taken from The Kansas State Water Plan: Water Plan and Storage Program 1979-1980. Report by the Kansas Water Resources Board, 1980; pp 3.

and industrial water supply storage (as of 1980). Clearly the Eastern portion of Kansas will rely heavily upon surface water to fulfill future water needs.

Because agricultural land constitutes 58 percent of the total land area of the country, and 94 percent of the more agrarian state of Kansas, the use and condition of agricultural land may have a profound effect upon the quantity and quality of surface water yield. Previous work (Berry, 1981 and Koelliker et.al., 1981) has demonstrated that improved soil and water conservation practices have contributed to the failure of several Western Kansas reservoirs, constructed primarily to provide irrigation water, by substantially reducing surface yields. Because the basic philosophy of most conservation measures is to "hold the raindrop where it falls" this may not be a suprising conclusion. However, the question arises, what will be the effects of improved conservation measures on Eastern Kansas reservoirs which are an important component of future water supply systems?

Statement of Purpose

The objectives of the work detailed in this thesis are two-fold. The first is to investigate the effects that agricultural soil and water conservation practices have upon watershed yields in Central and Eastern Kansas. This investigation is to be done using a previously developed hydrologic model. Similar studies have been conducted for a watershed in Western Kansas (Berry, 1981 and Koelliker et.al., 1981).

The second objective is to evaluate this model over a wider range of climatic conditions than has been done heretofore. This evaluation was previously recommended by Berry (1981).

To accomplish these goals three small watersheds, which are gaged by the United States Geological Survey (USGS), were chosen.

These basins were selected to provide a fairly uniform geographical representation of Central and Eastern Kansas. Each watershed was modeled for both historic and projected land-use practices and levels of conservation measures. The results of this modeling were compared to USGS reports of annual flow volume at the gaging sites to determine how well the model simulated the operation of the watersheds. When a satisfactory correlation between the model and the "real world" was reached, the models of the historic and projected watershed conditions were compared to evaluate the effect of improved conservation practices on water yields.

The conservation measures of interest in this study are ponds, terraces, and to a lesser extent, improved residue management techniques. Of course, ponds reduce watershed yields by impounding runoff and storing it for future use. Terraces, on the other hand, are primarily a soil conservation practice. However, terracing increases the length of the flow path, increasing the opportunity for water to infiltrate into the soil, and so reducing surface runoff. Residue is also a soil conservation measure which slows the rate of water movement (by increasing the surface roughness) and so decreases surface runoff.

CHAPTER 2

Overview of the Model

The model used to simulate these three watersheds was initially developed at Kansas State University as "FROMKSU," a model to simulate the operation of feedlot runoff control systems using a digital computer (Zovne and Koelliker, 1979). The model evolved until the current watershed yield version was developed. This model is composed of two computer programs, a potential yield program ("POTYLD"), and a depletion program ("DEPLETE"). These two programs are documented elsewhere (particularly Koelliker et.al., 1981) but an understanding of both the model's operation and limitations is necessary before attempting to draw conclusions based upon the model's results. So, the major facets of the model, how they interact, and the limitations they impose will be discussed here. This discussion is not intended to be a user's guide to the computer programs. However, in Appendix D, there is a short description of alterations (from what is presented by Koelliker et.al., 1981) made to the computer programs for this study.

Operation

The POTYLD program simulates a watershed by performing a daily water balance, using historical weather data, on a representative pond and as many as eighteen "plots." These plots are used to represent various portions of the watershed sharing similiar characteristics (i.e. areas of the watershed composed of similiar soils, which are terraced and planted to corn might be represented by a single plot). For each plot the model maintains a record of precipitation, interception storage, runoff, evapotranspiration, water lost below the root zone, and the soil moisture in the root zone. These accounts are updated on a daily basis during the simulation.

A variety of factors are used to define each plot. Particularly, to simulate each plot the program must be provided with the crop grown, the crop's growing season, the type of soil, the runoff characteristics of the plot, and the area represented by the plot which drains into the pond. Using the growing season dates, the program determines monthly values of "crop coefficients" for each simulated crop using a modified Blaney-Criddle procedure. These coefficients modify the computed daily potential evapotranspiration to determine the actual evapotranspiration from each crop. As currently implemented these crops may be simulated: wheat, corn, grain sorghum, soybeans, alfalfa, and pasture.

The soil type is defined for each plot as one of the Soil Conservation Service (SCS) irrigation design groups. These twelve groups of soils have varying infiltration rates, water holding capacities, and available root zone depths (U.S. Department of Agriculture, 1975[b]). For purposes of modeling, each soil group has an available root zone of four feet except for those that SCS has determined have a shallower available depth. Short descriptions of each group are given in Table 1. For modeling purposes each soil is divided into two zones--upper and lower. The upper zone is always one foot in depth while the lower zone accounts for the remainder of the soil profile.

The runoff characteristics of the plot are defined by SCS runoff curve numbers. The curve number method will be examined in some detail momentarily.

TABLE 1

Descriptions of Soil Conservation Service
Irrigation Design Groups as used in POTYLD program

Design Group	
1	Deep soils with silt loam or silty clay loam surface layers and slowly permeable clay subsoils. Three foot available rooting depth with approximately 12.2 inches available water capacity. Surface infiltration rate is about 0.1 inch per hour.
2	Deep soils with silty clay or clay surface layers and subsoils; infiltration and permeability are very slow. Three foot available rooting depth with approximately 9.3 inches available water capacity. Surface infiltration rate is about 0.1 inch per hour.
3	Deep soils with silt loam, loam, clay loam, or silty loam surface layers and moderately slowly permeable clay loam, silty clay loam, or silty clay subsoils. Five foot (four in model) available rooting depth with approximately 31.7 inches available water capacity. Surface infiltration rate is about 0.3 inch per hour.
4	Moderately deep soils with silt loam, clay loam or silty clay loam surface layers with moderately slowly permeable clay loam or silty clay subsoils. Only 2.5 foot available rooting depth with approximately 11.9 inches available water capacity. Surface infiltration rate is about 0.3 inch per hour.
5	Deep soils wih silt loam, loam, clay loam, or silty clay loam surface layers and subsoils. Permeability is moderate to moderately slow. Five foot (four in model) available rooting zone with about 35.6 inches available water capacity. Surface infiltration rate is about 0.5 inch per hour.
6	Moderately deep soils with silt loam or loam surface layers and loam, clay loam, or silty clay loam subsoils that are moderately permeable. Three foot available rooting zone with about 13.0 inches available water capacity. Surface infiltration rate is about 0.5 inch per hour.
7	Deep soils with silt loam, loam or very fine sandy loam surface layers and moderately permeable subsoils of medium texture. Five foot (four in model) available rooting zone with about 29.1 inches available water capacity. Surface infiltration rate is about 1.0 inch per hour.

TABLE 1

Continued

Design Group	
8	Moderately deep soils with silt loam, loam or very fine sandy loam surface layers and moderately permeable clay loam, loam or silt loam subsoils. A 2.5 foot rooting zone with about 11.5 inches of available water capacity. Surface infiltration rate is about 1.0 inch per hour.
9	Deep soils with fine sandy loam and loam surface layers and moderately rapidly permeable subsoils. Five foot (four in model) available rooting zone with about 26.9 inches of available water capacity. Surface infiltration rate is about 1.5 inches per hour.
10	Moderately deep soils with sandy loam to loam surface layers and moderatley rapid to rapidly permeable sand subsoils. A five foot (four in model) rooting zone with about 15.3 inches of available water capacity. Surface infiltration rate is about 1.5 inches per hour.
11	Deep soils with loamy fine sand or loamy sand surface layers and moderatley rapid to rapidly permeable subsoils. A five foot (four in model) rooting zone with an available water capacity of about 16.3 inches. Surface infiltration is about 2.0 inches per hour.
12	Deep and rapidly permeable soils with fine sand to sand surface layers and subsoils. A five foot (four in model) rooting zone with approximately 11.7 inches of available water capacity. Surface infiltration is about 3.0 inches per hour.

Taken from Irrigation Guide and Irrigation Planners Handbook.
U.S. Department of Agriculture, Soil Conservation Service.
Salina, Kansas; 1975, pp 3-7 thru 3-18.

The pond is modeled as an inverted, truncated pyramid. The only dimensions required are the length and width of the base of the pond, the slope of the pond's sides, and the maximum depth of water in the pond before the pond overflows. The modeler must choose these dimensions so that the relationships between water depth in the pond and both storage volume and surface area are similiar to those relationships in a "typical" pond in the simulated basin. Finally, an estimate of the daily seepage rate from the pond must be provided.

At this point a general outline of the model's procedures will be given to provide the reader with a "feel" for the model. That will be followed by a more detailed discussion of each component of the simulation which will dwell in more detail on the analytical procedures used. A sketch of the model's operation is given in Figure 2.

On any given day of the simulation one of two things may happen--it will either rain or not rain (or snow). The logic of the model is altered depending upon whether or not precipitation occurs. In the simpler case of no precipitation, there is no surface runoff. (Note however, that melting of any snow on the ground--snowpack--may produce runoff.) In this case, for each plot the amount of water held in interception storage (if any) is reduced by the computed amount of evaporation for the day. Then, the amount of evapotranspiration lost by the growing crop is computed and the soil moisture account is reduced by that amount. If instead the crop is dormant or the plot is fallowed, then the evaporation from bare soil is calculated and the soil moisture account reduced by that amount. Finally, the pond volume is reduced by the amount of lake evaporation computed for that day and the quantity of seepage lost from the pond.

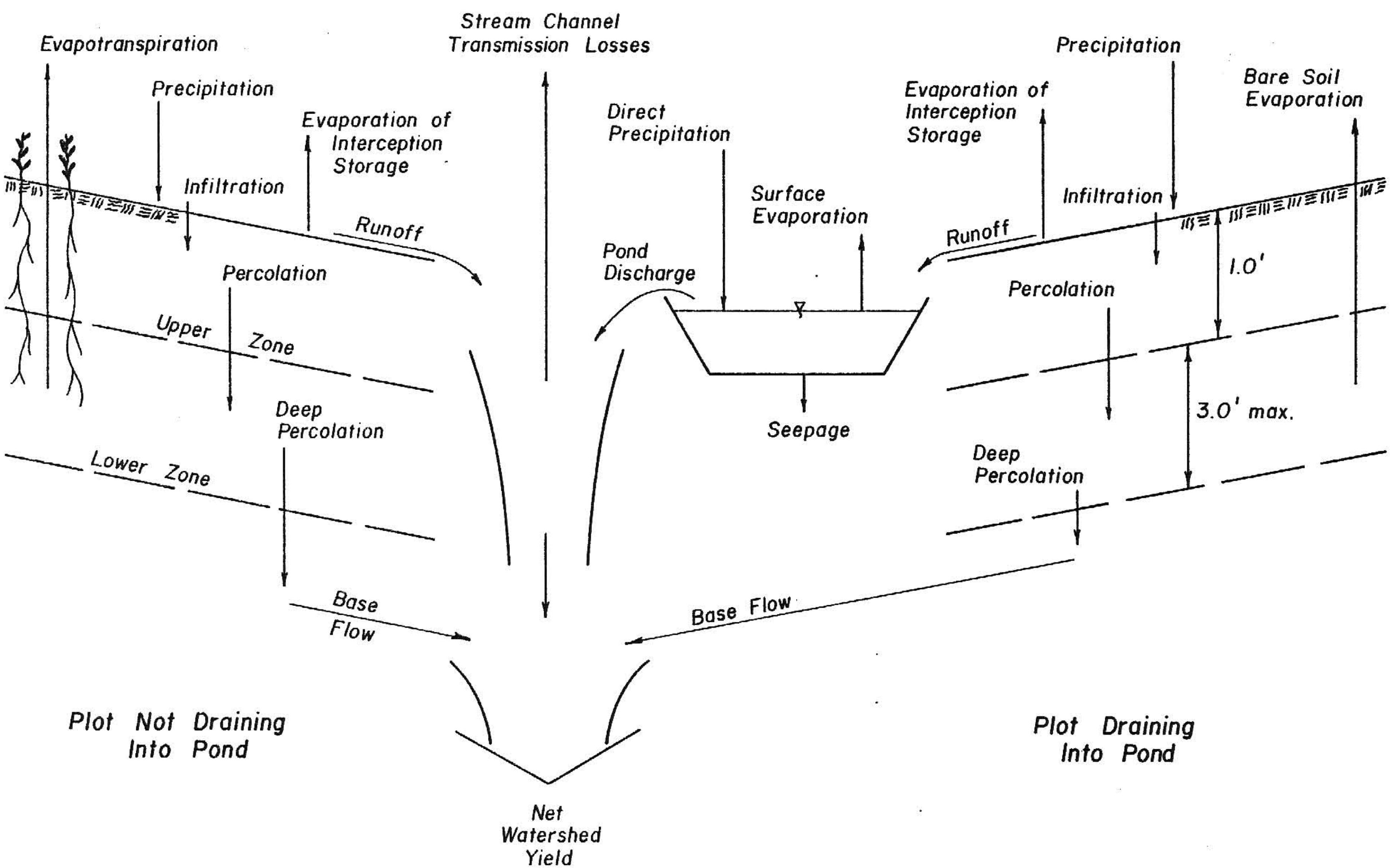


Figure 2--Schematic Diagram of the Model. Revised from Figure 7, page 22, "Modeling Reduced Water Yields into Webster Reservoir Due to Changing Land Use Practices," by Berry, 1981.

On the other hand, if precipitation does occur on the simulated day, the model first determines if the precipitation falls as rain or snow. Snow is added to any existing snowpack and the model procedes as if no precipitation had occurred. In the case of rain the amount of runoff (if any) and interception storage are computed for each plot. If there happens to be snow on the ground, the amount of snow melted by the falling rain and atmospheric conditions is determined and added to the precipitation amount before any runoff calculations are done. Melting of snow by warm air temperatures alone may also produce runoff. (Snowpack is also reduced by sublimation.) The amount of water not accounted for by runoff and interception storage infiltrates into the soil profile. The program then distributes this water within the profile, filling the upper zone to capacity and spilling any excess into the lower zone. Now, as with the no precipitation case, the amount of evapotranspiration of the crop or, if no crop is growing, the amount of bare soil evaporation is removed from the soil moisture account. Then the water remaining in the soil profile is re-evaluated and any water in excess of the soil's holding capacity is lost as deep percolation. Finally, the pond volume is decreased by lake evaporation and seepage as before, and increased by the amount of runoff from the plots which drain into the pond and the amount of precipitation falling directly on the pond surface. If the pond's storage capacity is exceeded the quantity of water discharged is computed.

At this point the day's run is concluded and all of the accounts are updated. If it is the end of the month, a monthly summary is saved and if it is the end of the year, the annual summary is computed, printed and the accounts closed in preparation for the next year's run.

To accomplish the steps outlined above, POTYLD uses quantitative procedures adopted from several sources. Each of these will be discussed in more detail.

The daily precipitation amount is taken from the records of the U.S. Weather Service station being used to drive the model (this record is usually stored on magnetic tape). Each day's precipitation is considered to be an event seperate from other days' precipitation. The form of the precipitation is determined by averaging the maximum and minimum temperatures reported for the simulated day. If this average temperature is greater than 32 degrees (Fahrenheit) the model assumes that the precipitation occurs as rain; if not, snow is the assumed form. These three data, precipitation, maximum and minimum temperature, are the only daily data required by the program.

Runoff is determined from daily rainfall (and melted snow) amounts, and each plot's runoff characteristics and antecedant soil moisture conditions using the SCS precipitation excess equation. This equation is:

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \qquad (1)$$

$$\text{and } Q = 0 \quad \text{if } P < 0.2S$$

where Q is the runoff, P is the precipitation amount, and S is an estimate of the potential abstraction (all in inches). The potential abstraction is the sum of the initial abstraction and the limiting amount of infiltration that can occur after runoff begins. The initial abstraction is the quantity of water which must accumulate (filling small depressions, wetting exposed surfaces, etc.) before runoff can begin. The value 0.2S in the numerator of the runoff equation is an estimate of the initial abstraction (USDA, Soil Conservation Service Technical Release No. 55, 1975[a]). The value of S is given by:

$$S = \frac{1000}{CN} - 10 \tag{2}$$

where CN is the SCS runoff curve number. Thus, the curve number defines the runoff characteristics of each plot. Actually, three curve numbers are provided for each plot; one for each of three antecedant soil moisture conditions (which are roughly dry, average, and wet). The soil moisture level in the upper zone determines which of these curve numbers is used on any given day. Values of curve numbers for various soil types, crops, conservation practices, and hydrologic conditions are readily available. An abbreviated list is found on Table 2.

If it has rained, recall that the next quantity computed is the interception storage. This is the small amount of rain water which is puddled on impervious surfaces, and adheres to leaves and the like. The quantity computed is removed from the volume of water that did not runoff. A maximum of 0.1 inch is allowed to remain is the interception storage account. This account is depleted by evaporation until it is emptied.

Evapotranspiration calculations include the computation of potential evapotranspiration, and evaporation from the pond surface and from bare soil. These computations are done once for each simulated day using a modified Penman's equation. The data required by the model to perform these calculations are the average daily temperature and several long-term monthly data including the average relative humidity, wind speed, ratio of actual to potential sunshine,

TABLE 2
SCS Runoff Curve Numbers

Land-use and Conservation Practice	Hydrologic Condition	Hydrologic Soil Group		
		B	C	D
Row crops				
Straight rows	Poor	81	88	91
Straight rows	Good	78	85	89
Contoured	Poor	81	88	91
Contoured	Good	78	85	89
Contoured and terraced	Poor	74	80	82
Contoured and terraced	Good	71	78	81
Small grains				
Straight rows	Poor	76	84	88
Straight rows	Good	75	83	87
Contoured	Poor	74	82	85
Contoured	Good	73	81	84
Contoured and terraced	Poor	72	79	82
Contoured and terraced	Good	70	78	81
Close-seeded legumes				
Straight rows	Poor	77	85	89
Straight rows	Good	72	81	85
Contoured	Poor	75	83	85
Contoured	Good	69	78	83
Contoured and terraced	Poor	73	80	83
Contoured and terraced	Good	67	76	80
Pasture or range				
	Poor	79	86	89
	Fair	69	79	84
	Good	61	74	80
Woods				
	Poor	66	77	83
	Fair	60	73	79
	Good	55	70	77

Taken from Engineering Field Manual. USDA, Soil Conservation Service; pp. 9.2, Table 9.1.

and mid-monthly intensity of solar radiation. Also, two constants related to the geographic location of the basin are required as are coefficients related to wind movement and crop reflectance. The basic equation is:

$$PET = \frac{\Delta}{\Delta + \gamma} R_n + \frac{\gamma}{\Delta + \gamma} E_a \qquad (3)$$

where PET is the potential evapotranspiration (millimeters of water/day), delta (Δ) is the slope of the saturated vapor pressure--temperature curve, gamma (γ) is the psychromatric constant, Rn is the net solar radiation, and Ea is an estimate of convection losses. The soil heat flux term (generally represented by G) usually present in this equation is neglected in the model.

Each of the terms in this equation are calculated from the data provided to the program. The modifying ratios are defined by:

$$\frac{\Delta}{\Delta + \gamma} = 0.039T^{0.673} \qquad (4)$$

and note:

$$\frac{\gamma}{\Delta + \gamma} = 1 - \frac{\Delta}{\Delta + \gamma} \qquad (5)$$

where T is the average daily temperature (degrees Fahrenheit). The convective loss term and the net solar radiation term are computed from the daily average temperature, monthly average relative humidity, percent sunshine, wind velocity, and the various constants provided by the modeler (for details see Zovne and Koelliker, 1979). The bare soil and lake evaporation are computed in the same manner as the potential evapotranspiration except for simple modifications of the net radiation term and, in the case of lake evaporation, the convective loss term.

Actual evapotranspiration is determined by multiplying the potential evapotranspiration by the Blaney-Criddle crop coefficient and a term which accounts for soil moisture limitations on crop transpiration. This factor, defined by Kanemasu (quoted in Koelliker et.al., 1981) is equal to one until the available soil moisture level is less than 0.3 of the soil's maximum available water capacity. At this point the factor is reduced linearly to zero at the soil's permanent wilting point (i.e. no evapotranspiration can occur if the soil moisture level is at or below the permanent wilting point).

Evaporation from bare soil is modeled by another procedure developed by Kanemasu (quoted in Koelliker et.al., 1981). Bare soil evaporation is taken to occur in two stages--the first stage occurring when the soil is wet. Under this condition the computed bare soil evaporation rate is used. The second stage occurs when the hydraulic properties of the soil begin to limit the rate of evaporation. This is modeled to occur at a point when the soil moisture in the upper zone falls below a certain limiting value (which is programmed into the model for each soil type). When this occurs, evaporation is computed by an equation by Ritchie (quoted in Koelliker et.al., 1981) which relates the amount of evaporation to the soil's hydraulic properties and the time elapsed since stage two evaporation began.

This concludes the review of the POTYLD program. Clearly, this is an incomplete outline of the program. For a more detailed discussion refer to Koelliker et.al. (1981) or Zovne and Koelliker (1979).

The next step after a successful POTYLD run is the use of the DEPLETE program. DEPLETE computes the annual surface yield of the watershed and an estimate of the amount of depletion of the surface yield by conservation practices. The POTYLD program provides yearly precipitation excess amounts from each plot and the pond, and the basic data regarding the plots themselves. The modeler must provide DEPLETE with annual land-use (as represented by POTYLD plots) proportions thoughout the basin, the watershed's total area, and for each plot the plot which represents that plot's base (no conservation measures) condition. The depletion caused by conservation measures is simply the difference between the precipitation excesses POTYLD determined for the treated and untreated plots. The depletion due to ponds is the difference between the actual pond yield as reported by POTYLD and the potential yield from the pond watershed which DEPLETE computes from precipitation excess amounts provided by POTYLD.

Finally, a procedure is used to estimate downstream yields by deducting stream transmission losses from the precipitation excess quantities computed by DEPLETE. This method uses a relationship between the ratio of annual precipitation to a long-term estimate of potential evapotranspiration (using Thornthwaite's temperature method) and a transmission loss factor defined as the ratio of annual upstream runoff to downstream runoff (Sharp et.al., 1966). This relationship is shown graphically in Figure 3. This transmission loss factor is then used to reduce the upstream yield from DEPLETE to account for losses which occur in stream channels because of phreatophytes and other items not accounted for by POTYLD. This estimate of downstream yield is the final result provided by the model.

Limitations

As occurs with any model, the procedures and methods used in this model entail a variety of limitations. These limitations must be kept in mind when attempting to come to any conclusions regarding the basins simulated by the model. Several of the limitations inherent in the POTYLD program deserve a close look.

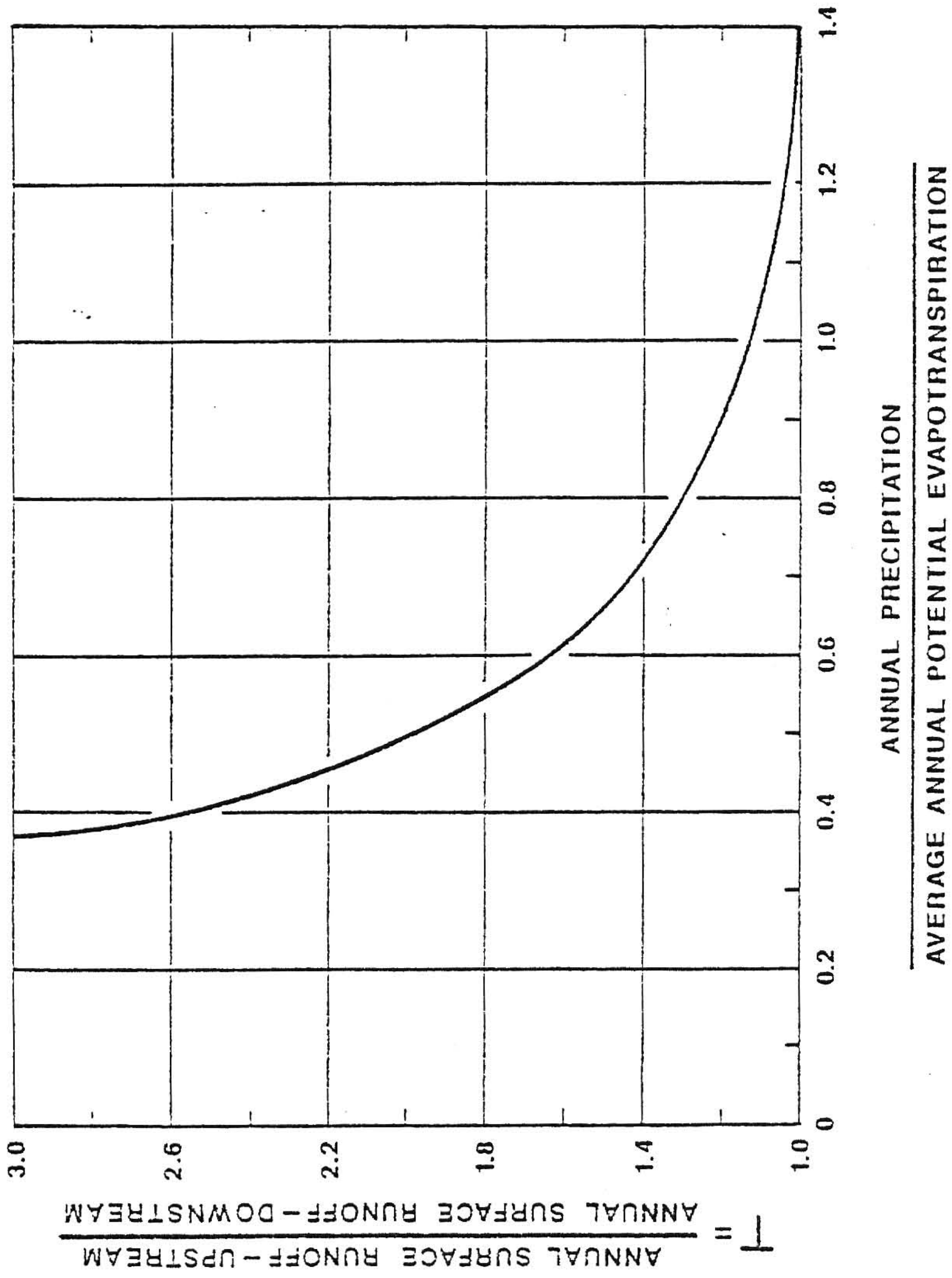


Figure 3--Transmission Loss Factor as a function of the ratio of annual precipitation to Thornthwaite's estimate of annual potential evapotranspiration. Taken from "Development of a Procedure for Estimating the Effects of Land and Watershed Treatment on Streamflow," Sharp et.al., 1966; Figure 10, page 20.

One of these is the relatively small number of plots available. Even a small watershed is an incredibly complex array of different soils, plants, geological features, soil and water conservation practices, other farming practices, and other natural and man-made features--all of which may affect the hydrologic regime. A certain amount of "averaging" must be done by the modeler in order to simulate this complex with the simple tools available.

A second, more debilitating problem is that of weather data. There are relatively few weather stations in Kansas which take daily rainfall data and fewer which take daily temperature data, both required by the POTLYD program. When modeling a small watershed one must be considered lucky to have any weather station within the confines of the basin. Further, one cannot expect a single station to adequately represent the rainfall over an entire watershed on a day-to-day basis. In fact, Thornthwaite considered it necessary to have a rain gage for every nine square miles of watershed in order to get a reasonably good approximation of the intensity and areal distribution of precipitation over a basin (quoted in Sharp et.al., 1966). Accepting this estimate, the smallest watershed used in this study (the 56 square mile Wolf Creek basin) would require six rain gages, well distributed within the watershed, to give an adequate picture of rainfall. The model was actually run with one gage located outside of the drainage area.

Another limitation is that of using monthly climatological data (relative humidity, solar radiation, etc.) for computations of evapotranspiration. As will be shown, the use of long-term monthly averages tends to reduce the variability of evaporation reported by the model compared to that recorded in the vicinity of the watersheds modeled. Since evaporation and transpiration are major terms in the water budget, the impact may be substantial. One would expect that computed watershed yields would also be less variable than the actual yields, which is the case.

Other limitations that might be mentioned include the lack of Blaney-Criddle crop coefficients for anything except cash crops or "tame" pasture. Any portion of the watershed which is not planted to the crops available in the model must be either ignored as insignificant or modeled as one of the available crops.

The modeling of a "typical" pond involves several shortcomings. The concept of a "typical" pond itself is one. The relationships between stage and storage as well as surface area vary widely even in small watersheds with uniform geologic conditions. Even more dramatic is the variation in pond drainage areas. Whether or not a single "representative" pond can adequately simulate the effects of all of the ponds in a watershed is open to question. Neither is it feasible to develop a prismatoid which has the same stage-surface area and stage-storage volume relationships as a pond constructed by damming a small valley.

These limitations were accepted by the authors of POTYLD in order to develop a model both practical and usable over a wide range of conditions. Most of these limitations are difficult to alleviate although some improvements might be made (as has been done throughout the development of the model). However, the modeler must at all times remain aware of these limitations because ultimately the modeler will wish to make some conclusions regarding the "real world" based upon simulation results.

CHAPTER 3

Modeling the Watersheds

Several criteria were used in the selection of the watersheds to be modeled. First, in order to verify the model's ability to simulate the watershed, the stream gaging station at the sites selected had to have been in operation for some period of time. From the relatively small list of sites meeting this requirement, sites were chosen on the basis of the quality of the records at the gaging station, the proximity of the watershed to a weather station with sufficient record available, the watershed size (keeping the drainage area small permitted a more detailed analysis of the basin), and the geographical distribution over the Central and Eastern part of Kansas. Also, an attempt was made to eliminate sites which were not predominately agricultural and those with unique characteristics which might effect water yields but not be amenable to modeling. These considerations led to the selection of three USGS gaging stations:

1. No. 8559, Wolf Creek near Concordia
2. No. 1805, Cedar Creek near Cedar Point
3. No. 1840, Lightning Creek near McCune

Each of the watersheds defined by these stations will be discussed individually (their locations within the state are shown in Figure 4). However, the basic procedures used to describe the watersheds for the model are essentially the same and will be mentioned first.

The first step was to define the watersheds' land use characteristics. This involved determining, on a yearly basis, the crops grown, the acreage of each crop within the watershed, and the level of

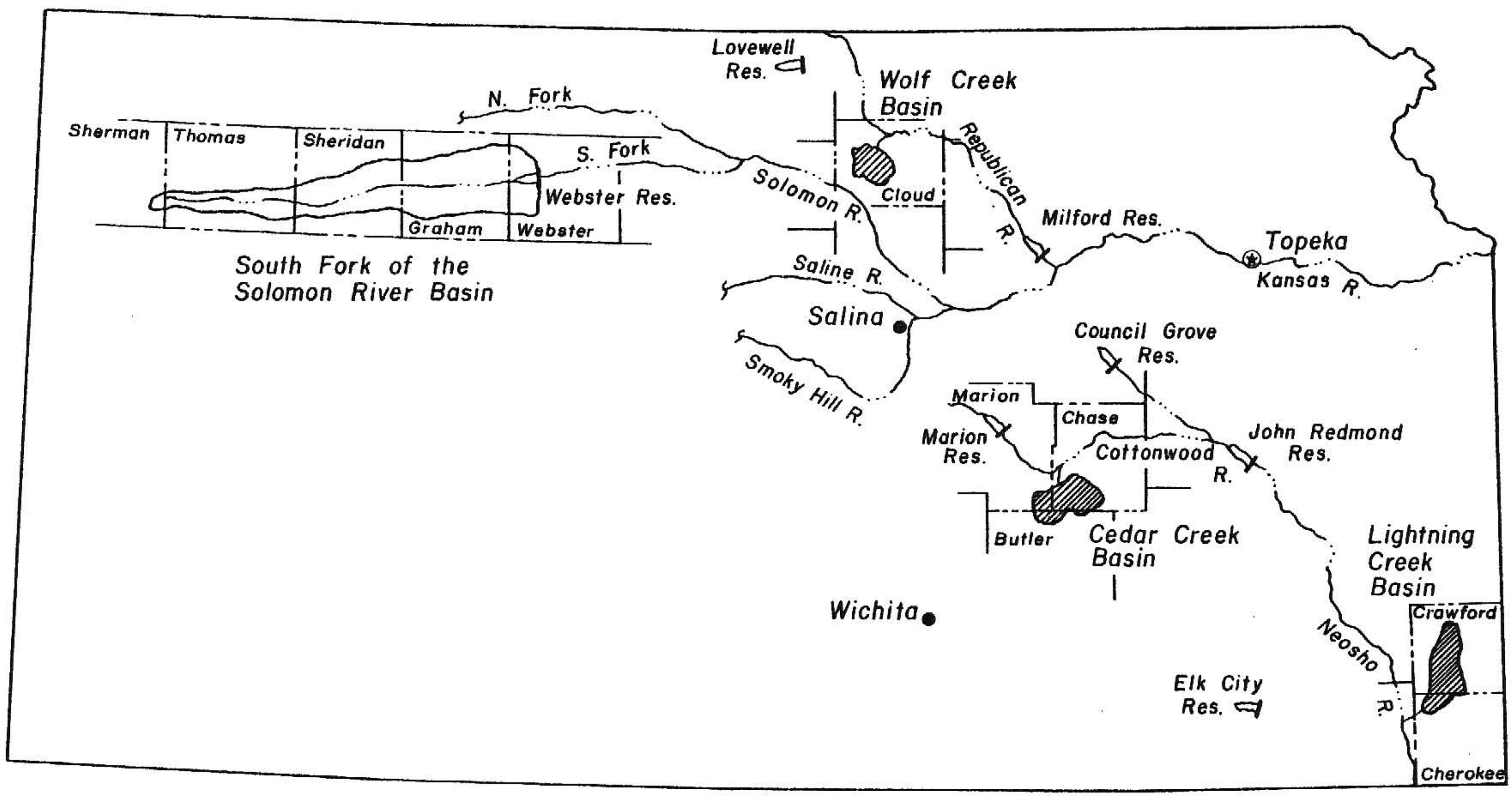


Figure 4--Map Showing Location of Modeled Watersheds

applied conservation practices. Crop data are available from annual reports by the Kansas State Board of Agriculture on a county basis. Therefore, the mix of crops for each basin was assumed to be the same as indicated by these data for the county containing the major portion of the watershed. To some degree this assumption was verified by examination of aerial photographs.

Because the vast majority of non-cultural practices (ponds, diversions, terraces, and waterways primarily) are built with monetary assistance from the Federal government, the level of conservation measures was estimated from records kept by the Agricultural Stabilization and Conservation Service (ASCS). The ASCS has responsibility for Federal agricultural cost-sharing programs. These data, too, are kept on a county-wide basis and the same assumptions made for the crop data were accepted for the applied conservation data. The practices accounted for include only terracing and ponds. These are the practices of major concern in the Eastern portion of the state. Since ASCS payments for cultural practices on cropland (maintainence of residue levels chiefly) are spotty or non-existant, depending upon the county, they could not be included. Other practices such as diversion terraces and grass waterways, while part and parcel of conservation systems, have little effect upon the hydrologic characteristics of a watershed, when compared to that of terraces and ponds, and so were not analyzed. Aerial photographs and USGS 7 1/2 minute quadrangle maps were used to adjust the level of practices applied from that estimated from ASCS records.

These data are reported by ASCS as miles of terraces and number of ponds installed. The model actually requires an estimate of the area protected by terraces. Fortunately, for about eight years, ASCS provided estimates of the area treated by terracing as well as the miles installed. From these eight years a conversion factor (from miles to acreage) was developed. A similiar conversion factor could be determined using some representative land slope for each county and SCS terrace design procedures.

The number of ponds installed, on the other hand, can be used in the model directly. However, a variety of further data regarding the ponds and their drainage area characteristics is also required. These include the average size of pond drainage areas, the average pond dimensions, and the average land-use within the ponds' drainage areas.

The drainage area used for the "typical" pond, as modeled in the POTYLD program, was determined by averaging the drainage areas (determined from USGS quadrangle maps) of about 30 ponds randomly selected from the entire watershed.

Stage-storage volume relationships for about 30 possible pond sites were also derived from quadrangle maps. This data was plotted as stage versus storage volume and a single "average" curve was estimated. Then, various combinations of base width, length, and side slope were tried until one matching the "average" curve was found. The maximum storage volume in the pond was determined by estimating the sediment yield from the pond watershed (see Kansas Water Resources Board, 1971) over a period of 50 years. From this volume and the stage-storage volume curve previously determined the maximum water height in the pond before discharge occurs was determined (this is a procedure similiar to that used by SCS in Kansas to determine the elevation of a drain pipe when designing stockwater ponds). The final parameter concerning the "typical" pond is the rate of seepage from the pond. For lack of any substantial data a rate of 1/16 inch was chosen for all three watersheds simulated.

The first estimate of the land-use in the pond watershed was the same as that made for the basin as a whole. However, examination of aerial photographs indicated that the proportions of pasture should be increased and of row crops, particularly, decreased. The pond watershed land-use characteristics were modified to reflect this fact.

The next major consideration was determination of soil types. Using Soil Surveys of the county containing the major portion of the watersheds the predominant SCS irrigation group or groups within the watershed were determined. The Soil Surveys also aided in estimating land-use restrictions of various soils which affected which soil types were assigned to various plots. To estimate SCS runoff curve numbers, the hydrologic soil group for each plot was necessary. The hydrologic soil group is an indication of the infilitration rate of the soil--the higher a soil's infiltration rate, the less potential it has to produce runoff. Because each plot's soil type was usually an average of several soils the hydrologic soil group tended to be a composite.

Finally, each plot's runoff curve numbers were selected for "average" antecedant soil moisture conditions from tables published by SCS. The "dry" and "wet" moisture condition curve numbers were determined from a table of conversions from the average conditions, also published by SCS.

At this point, the simulated basin and its "typical" pond are defined for the model. Calibration of the model is the next step. Before describing the calibration and use of the model however, some details regarding each of the simulated watersheds will be presented.

Wolf Creek

As shown on the drainage area map (Figure 5), the 56 square mile Wolf Creek watershed is located south of Concordia in Cloud County, Kansas. Wolf Creek is a tributary of the Republican River, joining that river about four miles downstream of the gaging station which defines the watershed.

The closest Weather Service office maintaining the data required by POTYLD is located at Concordia and Concordia's daily weather data records were used to drive the model. The closest evaporation data stations (as shown in Figure 4) are Lovewell and Milford Reservoirs. The available streamflow records restrict the simulation period to 1963 through 1978.

Land-use within the watershed has been relatively consistent throughout the simulated period. About 40 percent of the basin is dedicated to pasture; wheat is raised on 35 percent, while grain sorghum, corn, and alfalfa take up most of the remaining area. The only noticable trends in cropping patterns throughout the period modeled are a slight reduction in alfalfa acreage and a substantial reduction in corn acreage in favor of grain sorghum.

From examination of aerial photographs the number of ponds reported by ASCS was found to be about 50 percent low. This may be due to non-uniform distribution of ponds thoughout the watershed or to the construction of a large number of ponds without Federal assistance. For modeling purposes the actual pond count for 1971 (the date of the aerial photographs) was used and the number of ponds in other years was increased over the reported number by the same proportion.

For purposes of modeling two simplifying assumptions were made. First, while roughly 20 percent of the wheat acreage in Cloud County

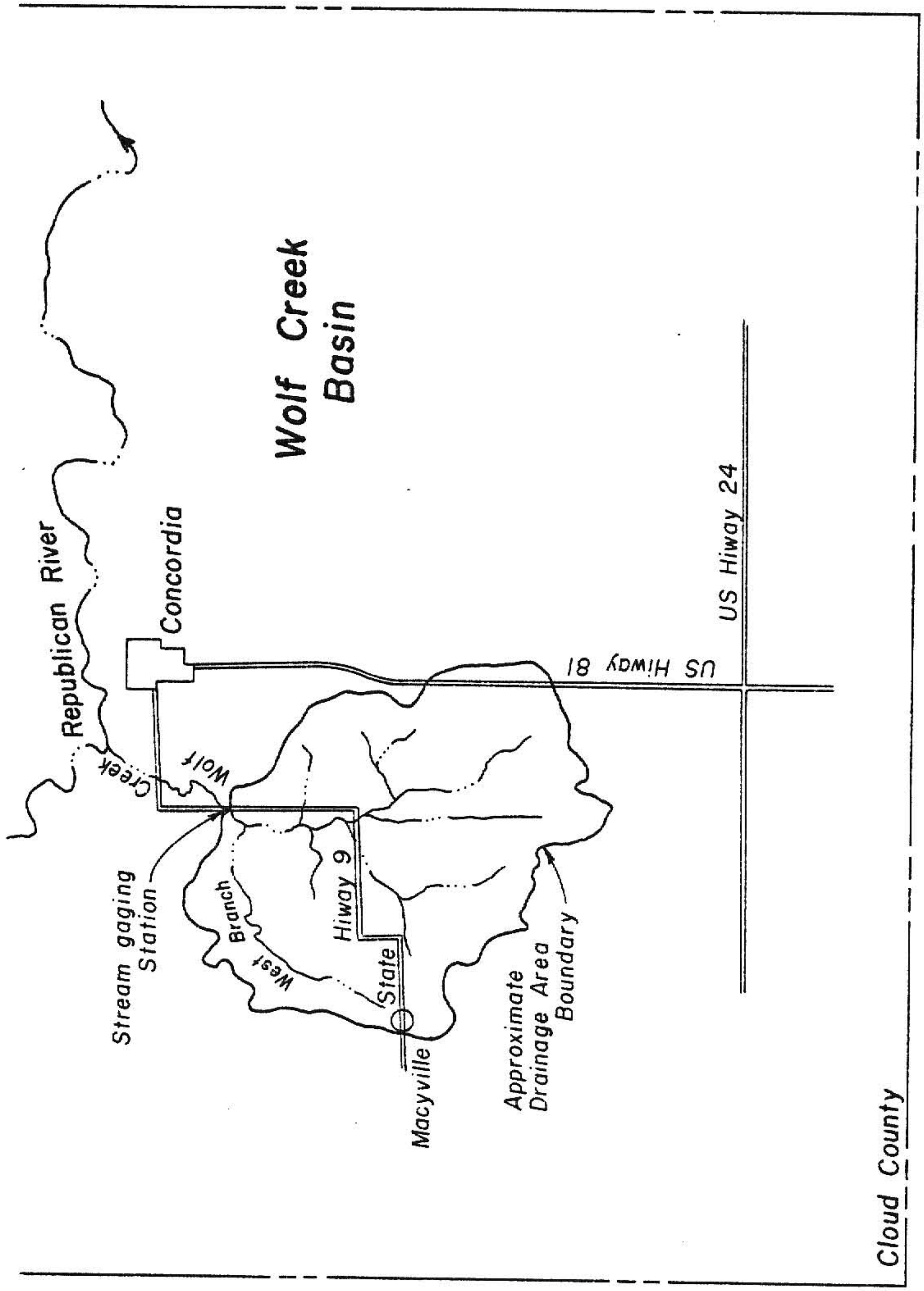


Figure 5--Drainage Area Map--Wolf Creek
Taken from USGS 1:250,000 ratio contour maps.

is in a wheat/fallow rotation, all of the wheat acreage in the Wolf Creek watershed was assumed to be planted annually. Generally, wheat/fallow rotation should be restricted to the drier, western portion of the county. Second, all of the terraces in the watershed were arbitrarily assigned to be on wheat ground. The assumption made here is that the substantial portion of the row crops (corn and sorghum) are found on alluvial soils which are not as likely to be terraced as are upland soils. This reduces the number of plots required to simulate the basin.

The geology of the area is quite typical of central Kansas. The lower reaches of Wolf Creek lie in a sand and silt alluvium while the upper reaches cut through Upper Cretaceous deposits including the Dakota Sandstone, Graneros shale, and Greenhorn limestone. The shales underlying the uplands in all three formations are generally impervious (State Geological Survey of Kansas, 1929). In Cloud County, prior to the advent of large-scale well pumping for irrigation use, the quantity of water recharged to the groundwater reservoir and the amount of water discharged from the groundwater reservoir were thought to be in equilibrium (State Geological Survey, 1959). Because only minimal pumping is evident in the Wolf Creek area this assumption was extended to the period of the simulation.

Cedar Creek

The Cedar Creek basin (shown in Figure 6) has an area of approximately 110 square miles. The major portion of the watershed lies in southwestern Chase County with the Turkey Creek branch in Marion County and some of the basin's uplands located in Butler County. Cedar Creek is a tributary of the Cottonwood River and the gaging station defining the watershed is located about six miles

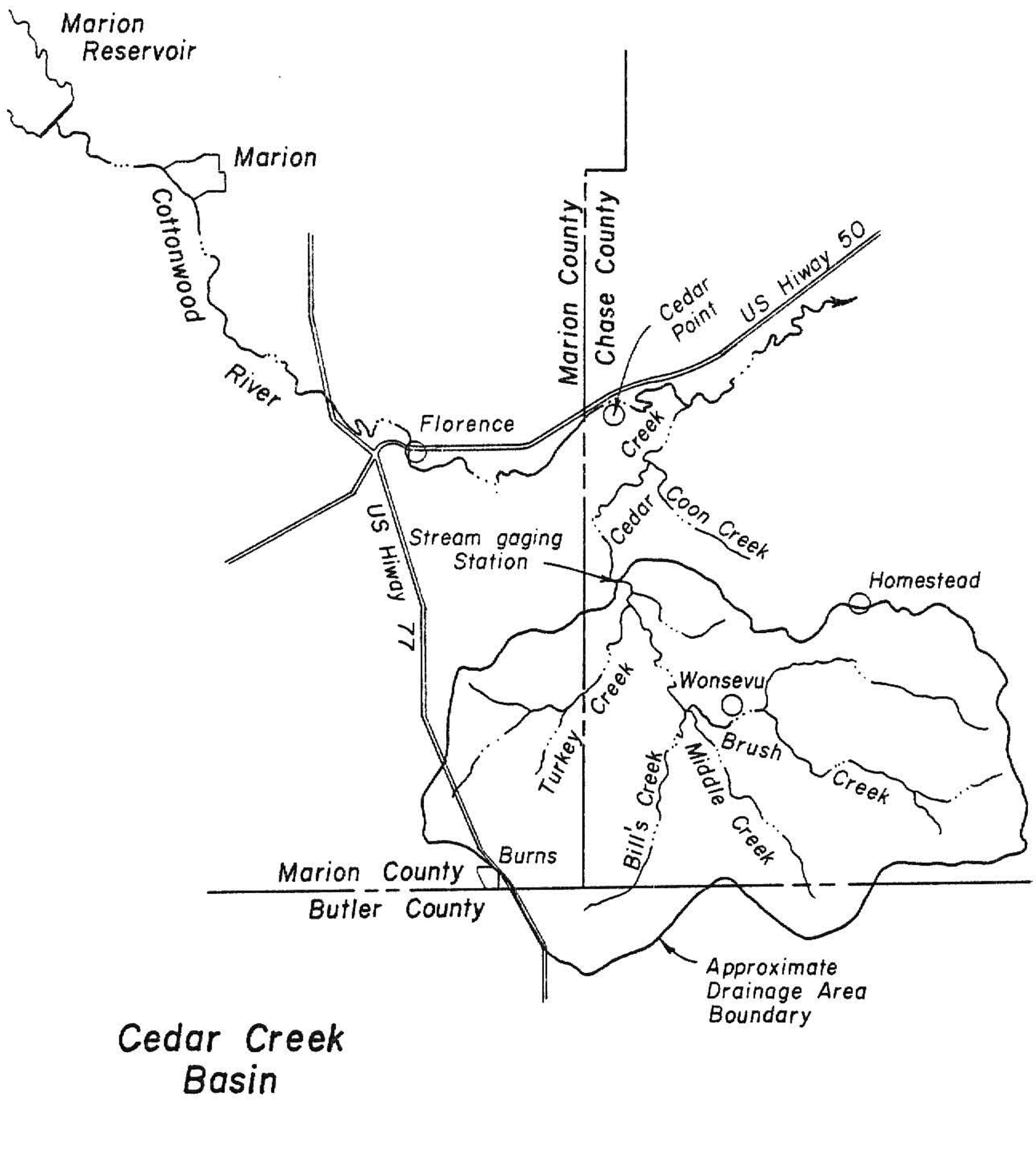


Figure 6--Drainage Area Map--Cedar Creek
Taken from USGS 1:250,000 ratio contour maps.

upstream of the juncture between the two. Referring to Figure 1, notice that the location of the proposed Cedar Point Reservoir is in the vicinity of the gaging station.

The closest Weather Service station fulfilling the model's requirements is at Florence and the model was driven with that station's data. The closest evaporation data stations are at Marion Reservoir and Council Grove Reservoir. Because the weather records at Florence prior to 1950 are not very complete, the simulation period was restricted to 1950 through 1978.

Land-use within the watershed is predominantly pasture and range. Roughly 85 percent of the basin is pasture or range land while the remainder is a mix of wheat, sorghum, alfalfa, and modest acreages of soybeans and corn. The trends in planting practice over the simulation period show a tendancy towards changing corn acreage to soybeans and to reduce pasture land by increasing the acreage of alfalfa. These trends are of only minor effect upon the overall land-use patterns, however.

As with the Wolf Creek basin, the historic amount of terracing was assumed to be entirely on wheat ground. This reduces the number of plots required in the model. Also, given the large area of pasture land, two pasture plots were used to model more effectively variations of soil types within the basin.

The Cedar Creek watershed is geologically the most uniform of the three basins modeled in this study. The entire drainage area lies in a delineated ground-water region named the Cedar Creek Area (which lies in the physiographic region named the Flint Hills Uplands). The chief aquifers in the region are limestone members of the Chase Group (the Fort Riley, Towanda, and Winfield limestones). Wells and the few springs in the area have very small yields--commonly on the order of 5 to 10 gallons per minute. Streams and their related alluvial aquifers generally maintain a state of equilibrium (State Gelogical Survey, 1951).

Lightning Creek

The Lightning Creek drainage area is located in the Southeastern counties of Crawford and Cherokee (see Figure 7). The gaging station itself is located in Cherokee County but most of the 197 square mile watershed is in Crawford County. Lightning Creek is a tributary of the Neosho River and enters that river about 8 miles downstream of the gaging station.

The closest Weather Service station with complete data for POTYLD is at Girard on the eastern edge of the drainage area. However, as modeling of this basin proceded, it became obvious that Girard's precipitation record did not adequately represent precipitation over the basin. To help improve the model, precipitation data from McCune, on the western edge of the basin near the watershed outlet, were combined with Girard's temperature data (temperature data is not taken as McCune). This assembled record for McCune was also used to drive the model and the results from both stations were combined so that Girard represented 54 percent of the basin and McCune the rest. This change had significant effect upon the results because, for the simulated period, McCune's average annual precipitation was 2.3 inches less that Girard's. The only evaporation data in the area is taken at the Elk City Dam, well to the west of the watershed. Because of a long break in the stream gaging record prior to 1961, only the period 1961 through 1978 was modeled.

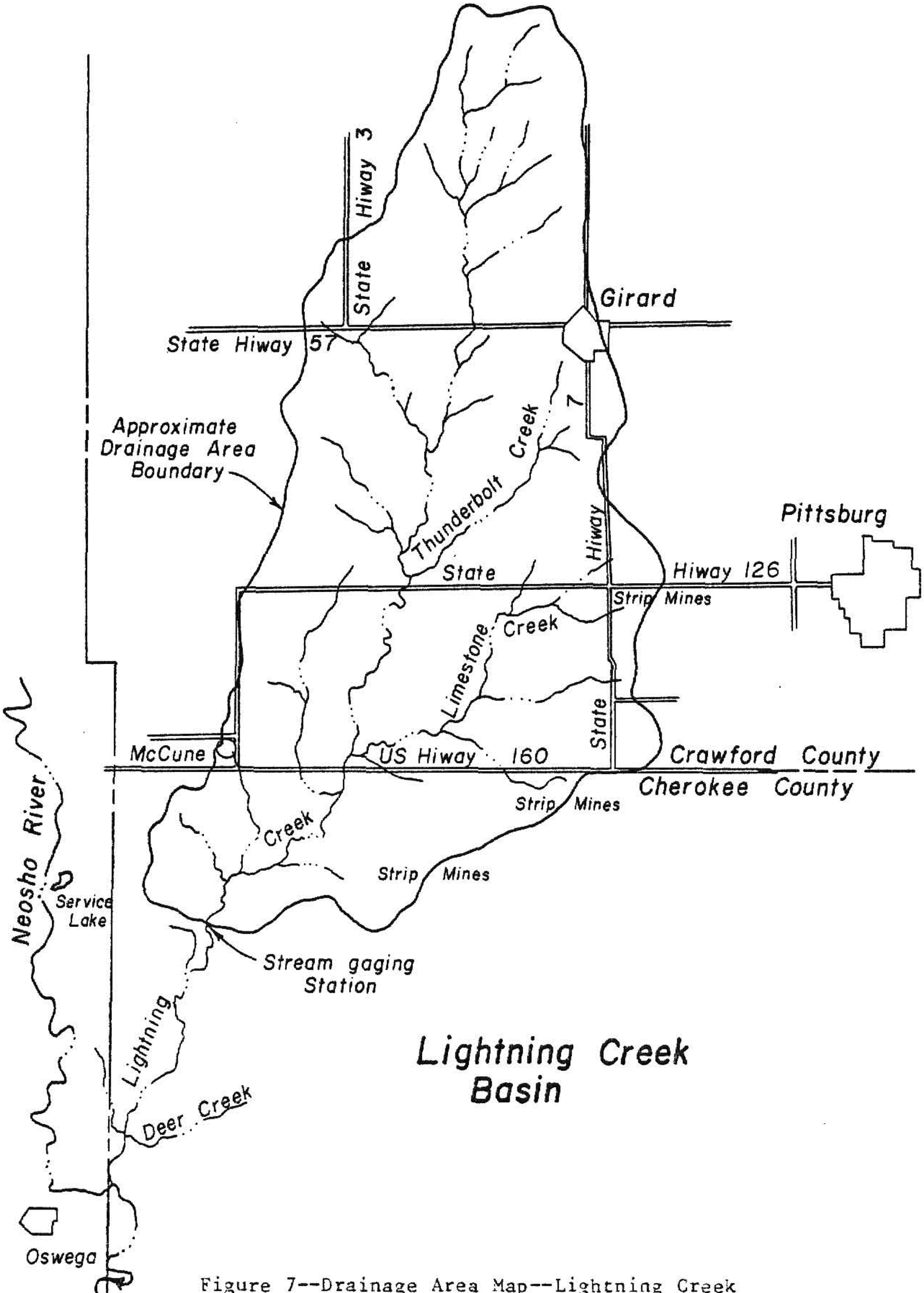


Figure 7--Drainage Area Map--Lightning Creek
Taken from USGS 1:250,000 ratio contour maps.

Land-use within the watershed is quite diverse. About 40 percent of the basin is pasture land while the remainder is split between wheat (about 13 percent), grain sorghum (10 percent), corn (7 percent), and soybeans (20 percent). Aerial photographs indicated that roughly 10 percent of the watershed is best described as wooded. Crop production trends during the simulation period are more dramatic than for either of the other watersheds. Wheat acreage has decreased moderately and corn acreage has fallen dramatically in favor of grain sorghum and there has been a slight increase in pastured land.

Because of the more diverse cropping patterns and a variety of soil types, several assumptions were made in modeling the Lightning Creek watershed. The amount of terraces were divided in a 50:25:25 ratio of wheat:corn:sorghum (although after 1971 the increase in sorghum acreage necessitated biasing this ratio in favor of terracing sorghum rather than corn). In an attempt to account for widely varying soils, there are two soybean plots as well as two pasture plots. Finally, a third "pasture" plot was added to attempt to account for the substantial wooded area in the basin. This plot's evapotranspiration characteristics are the same as for pasture but the runoff curve numbers are those of woodlands.

Geologically the Lightning Creek basin is quite complex and not well studied. The eastern portion of the area contains numerous strip mines (coal). The effect of these upon the hydrologic regime is difficult to determine and much of the area draining into strip mines was actually removed from the model watershed. This reduced the modeled drainage area to 191.25 square miles. Otherwise, the basin is underlain by limestones, sandstones, and associated shales with generally gentle relief. While surface drainage is reported as good, subsurface drainage is relatively poor (U.S. Department of Agriculture, 1973). Examination of USGS quadrangle maps indicates that the outlet of the watershed is quite flat and even the surface drainage appears to be mediocre in this area.

The data used to model each of these watersheds are summarized in Appendix B.

CHAPTER 4

Model Calibration

Because this model has been devised to function over a broad range of conditions, it is necessary to calibrate the model for the specific climatic/geographic area of interest. Despite the large number of variables in the model, only three are available for calibration. These are the two geographical coefficients of the Penman evapotranspiration equation and, to some degree, the SCS runoff curve numbers. The first step in calibration for each watershed was to match the model's long-term average lake evaporation with that reported at stations in the area. This was accomplished by varying the Penman geographical coefficients until satisfactory correlation with reported lake evaporation averages was achieved. The final results of these calibration runs are shown on Table 3 for all the watersheds. These calibration runs involved only use of the POTYLD program.

The reasons for comparing lake evaporation to nearby evaporation stations rather than to the long-term lake evaporation reported by the Weather Service (Weather Service Technical Paper No. 37, 1959) were that the simulated periods are relatively short and are not the same periods used by the Weather Service in establishing the long-term evaporation estimates. So, any substantial deviation of the simulated period evaporation amounts from the long-term average can be better accounted for by using data from the actual period modeled. For Wolf

TABLE 3

Lake Evaporation Data

Location	Period of Record	Average Annual Evaporation (inches)	Standard Deviation (inches)
Wolf Creek Basin model	1964-1978	45.8	0.99
Lovewell Reservoir	1964-1978	43.4	3.70
Milford Reservoir	1966-1978	47.9	3.60
Long-term Estimate	-	53.0	-
Cedar Creek Basin model	1965-1978	48.9	0.76
Marion Reservoir	1966-1978	50.0	3.83
Council Grove Lake	1964-1978	47.6	3.58
Long-term Estimate	-	53.5	-
Lightning Creek Basin model	1964-1978	49.3	0.45
Elk City Dam	1964-1978	41.7	3.30
Long-term Estimate	-	49.0	-

In each case the long-term estimate is taken from maps in Weather Service Technical Paper No. 37. Also taken from this paper were the pan coefficients for each location and estimates of the percentage of annual lake evaporation which occurs between the months of May and October (the normal period during which pan evaporation data is taken).

Creek and Cedar Creek, with nearby evaporation stations both to the east and west of the watersheds, this worked well.

For Lightning Creek however, this procedure was finally rejected and the lake evaporation was matched to the long-term average instead. There were several reasons for doing so. First, Elk City Reservoir (the nearest source of evaporation data) is rather distant from the watershed and there is no station within a reasonable distance to the east. In this part of Kansas the annual rainfall approaches the annual evaporation rate and it becomes more important to closely match the actual evaporation to the model's estimate. Further, the initial model runs made with coefficients matched to Elk City Reservoir's evaporation rate led to watershed yields far in excess of, although still highly correlated to, those reported by USGS. In light of this, and in order to get a model of Lightning Creek which was of some use, the geographic coefficients were changed so that the model's lake evaporation matched the long-term average reported by the Weather Service.

Having matched the evaporation rates, the model was run with the watersheds previously described. The annual watershed yields estimated by these runs were compared to those reported by USGS. For Wolf Creek this initial run indicated good agreement with the USGS data. For Cedar Creek and Lightning Creek, further adjustments were indicated. These adjustments were made by slightly varying SCS curve numbers for some of the plots. Because the plots altered were each a composite of differing soil types and differing cultural practices, it is not reasonable to insist that the curve numbers indicated by SCS tables are unvarying. The curve numbers used in the final simulation of historic conditions are presented in Appendix B.

Initially, the surface runoff determined by the model was the the only component of streamflow used to compare with USGS reports. In Appendix C are plots of USGS versus model watershed yields, where the model yields are from surface runoff only. As indicated by these plots the correlation between the two is fair for all three watersheds. However, the curve numbers used to achieve this correlation are slightly higher than reasonable (except for Lightning Creek). Also, in the eastern portion of the state, base-flow becomes an important component of streamflow. So, an estimate of base-flow was made by computing the volume of water lost as "deep percolation" (from POTYLD results) for the watershed as a whole.

The geology of all of the basins indicates this is a reasonable assumption. In all cases there are relatively impervious shales impeding the downward movement of water. For Wolf Creek and Cedar Creek the geology is relatively uncomplicated and the percolation losses may be the best estimate of base-flow. In Lightning Creek, the more complex geology (especially the poor underdrainage conditions) may have some effect upon the contribution of soil water to base-flow. However, no adjustment of this estimate of base-flow was made for this study.

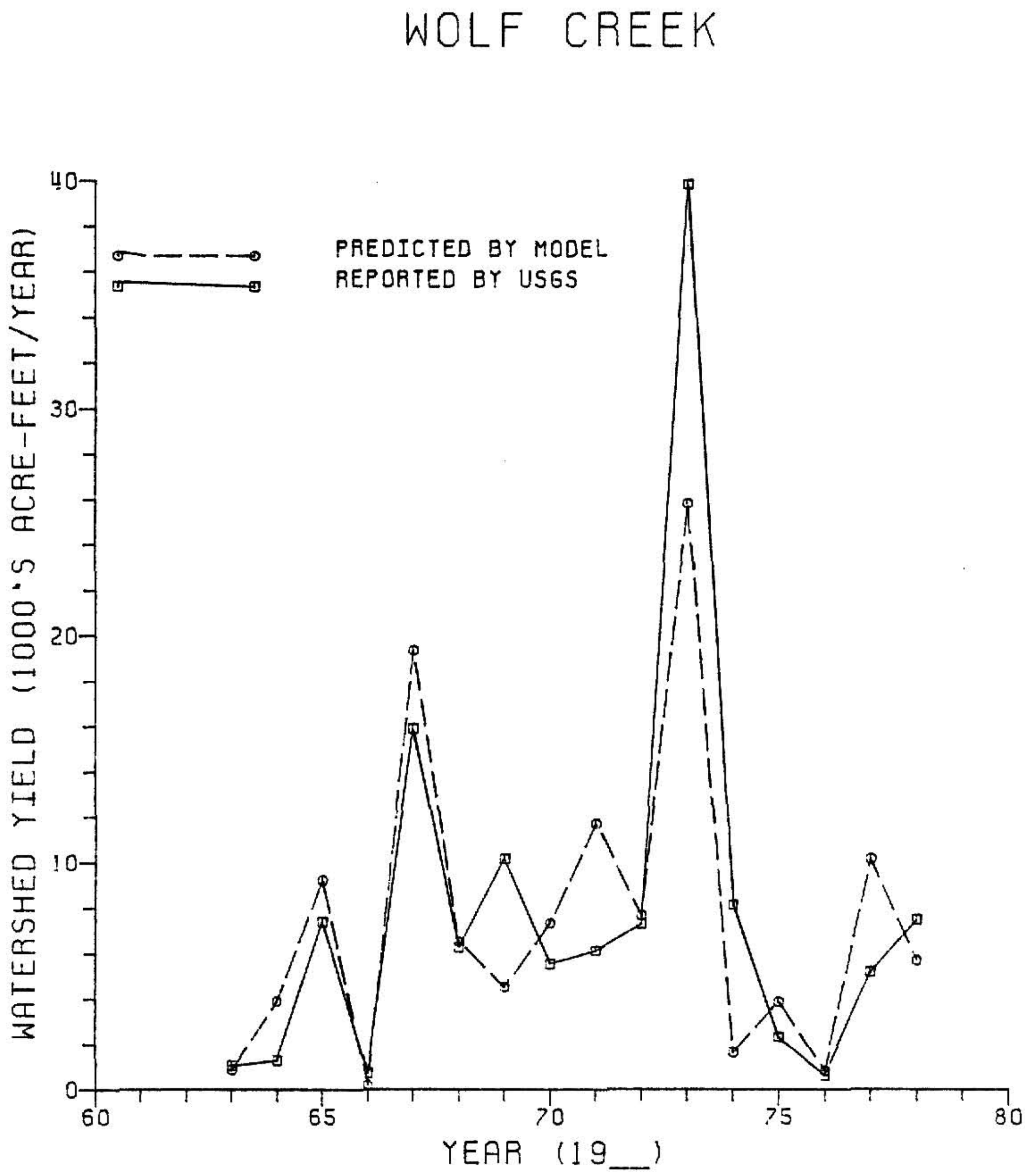
For all the watersheds, the addition of this base-flow estimate reduced the SCS curve numbers to more reasonable values and improved the correlation of the model's results to the yields reported by USGS. The composition of stream flow resulting from this estimate is summarized in several tables found in Appendix B. A computer statistical package (SAS Institute, Inc.; 1980) was used to compare the model's results to USGS reports. The correlation coefficients (an indication of the linear relationship between the two--usually represented by an "r") are shown below:

Wolf Creek	r = 0.87
Cedar Creek	r = 0.85
Lightning Creek	r = 0.94

In all cases the values of r indicate a strong linear relationship between reported and modeled yields.

Graphical comparisons between the model's results and reported yields are shown on the following pages. For each watershed, a plot of watershed yield (both modeled and USGS) versus time is given, followed by a plot of model yields versus reported yields. In this plot the "expected line" indicates the line that would result if the model perfectly simulated the reported yield from the basin. The "regression line" is the least-squares best fit line obtained from the data and the data points are plotted as well. Obviously, the closer these two lines are to each other, and the closer the data points are to the line, the better the model simulates the watershed.

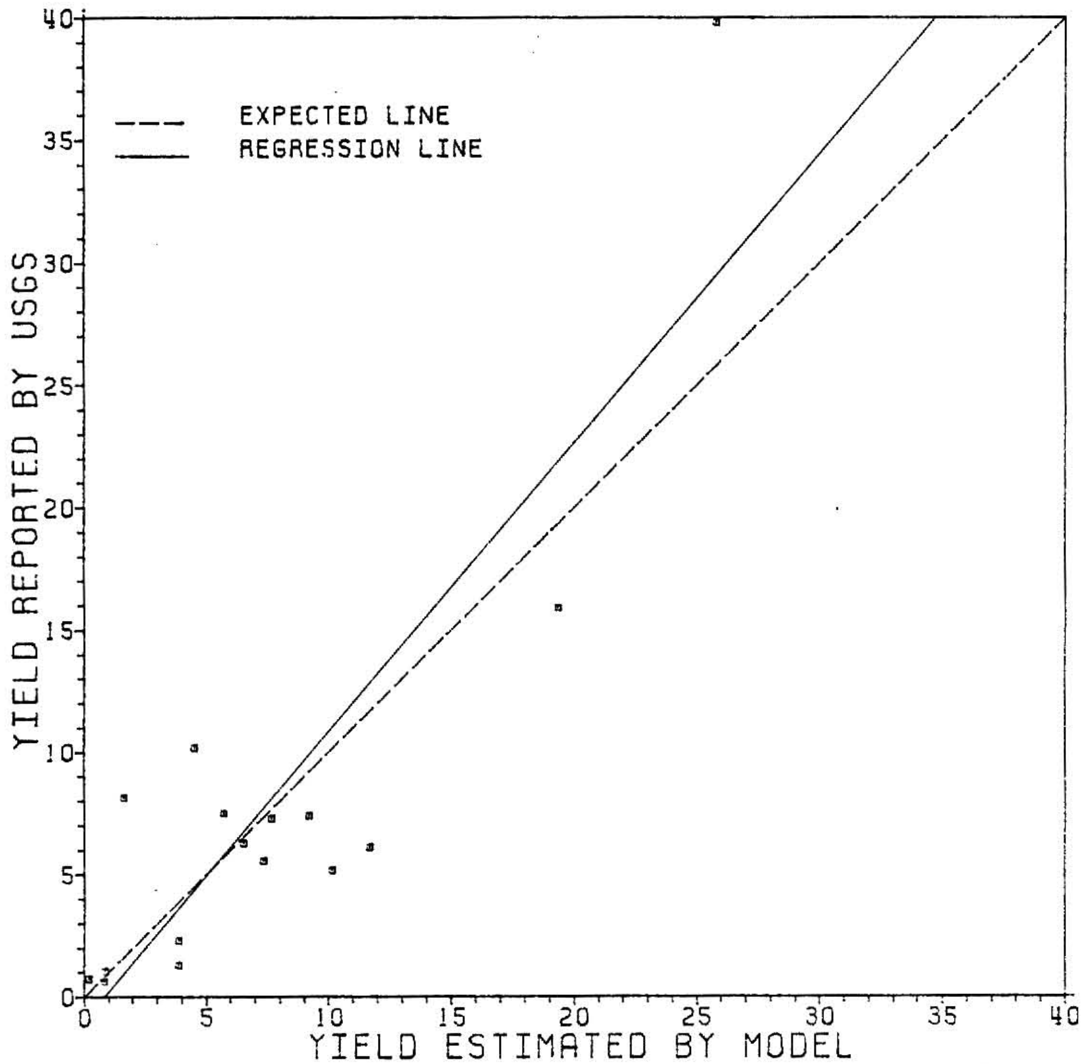
Continuing to refer to these plots, further statistical tests were done. These tests indicated for Wolf Creek and Cedar Creek that the value of the intercept was not statistically different from zero and simultaneously that the value of the slope of the line was not statistically different from one, at a 95 percent confidence level. That is to say that the model results are not statistically different from the reported yields. For Lightning Creek the intercept was significantly larger that zero while the slope was not significantly different from one. Examination of the plot indicates that the model reports a consistently high water yield in dry years but a low yield in wet years. The use of the deep percolation volume as an estimate of base-flow, while it improves the linear correlation between model



PREDICTED AND REPORTED WATERSHED YIELDS
FOR 1963 THRU 1978
--MODELING WITH A BASE-FLOW ESTIMATE--

Figure 8

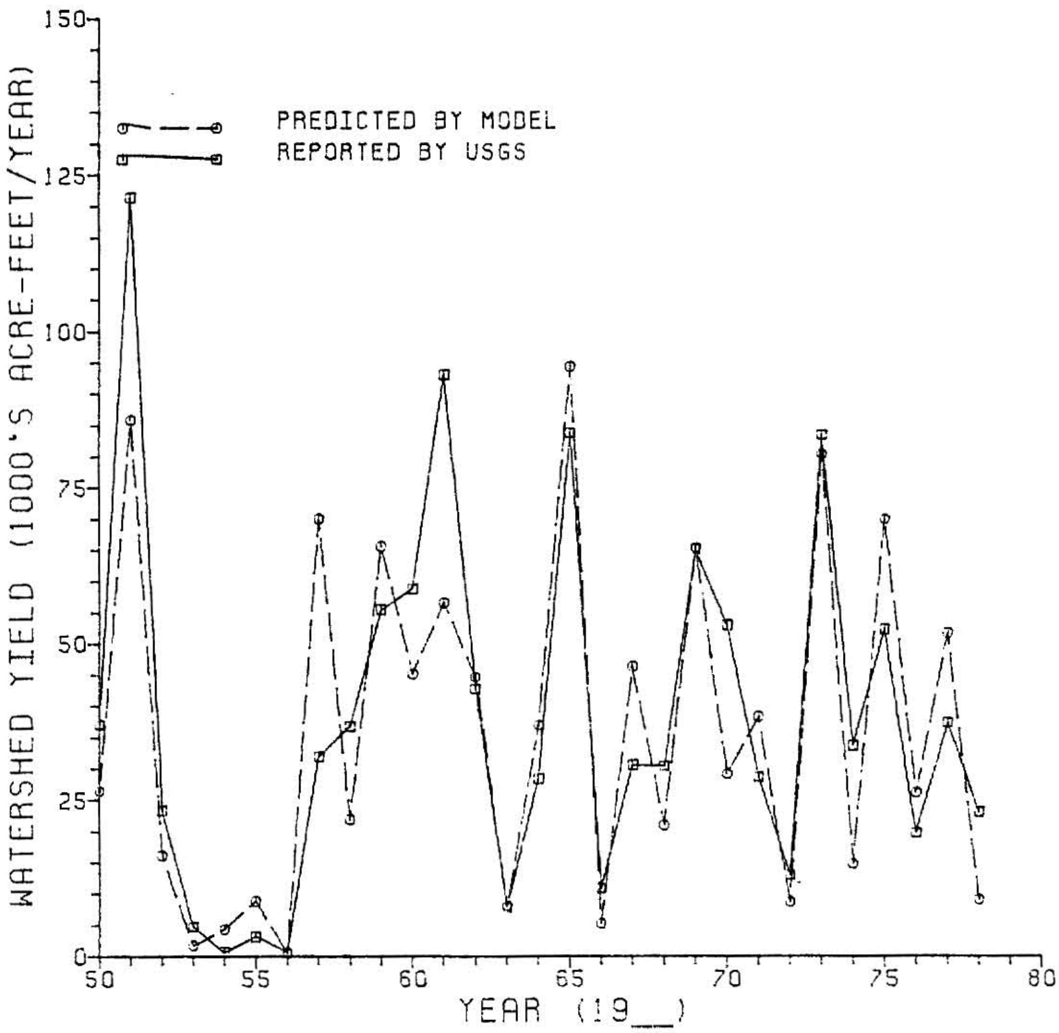
WOLF CREEK



WATERSHED YIELD ESTIMATED BY MODEL
COMPARED TO THAT REPORTED BY USGS
--MODELING WITH A BASE-FLOW ESTIMATE--
(UNITS ARE 1000'S OF ACRE-FEET/YEAR)

Figure 9

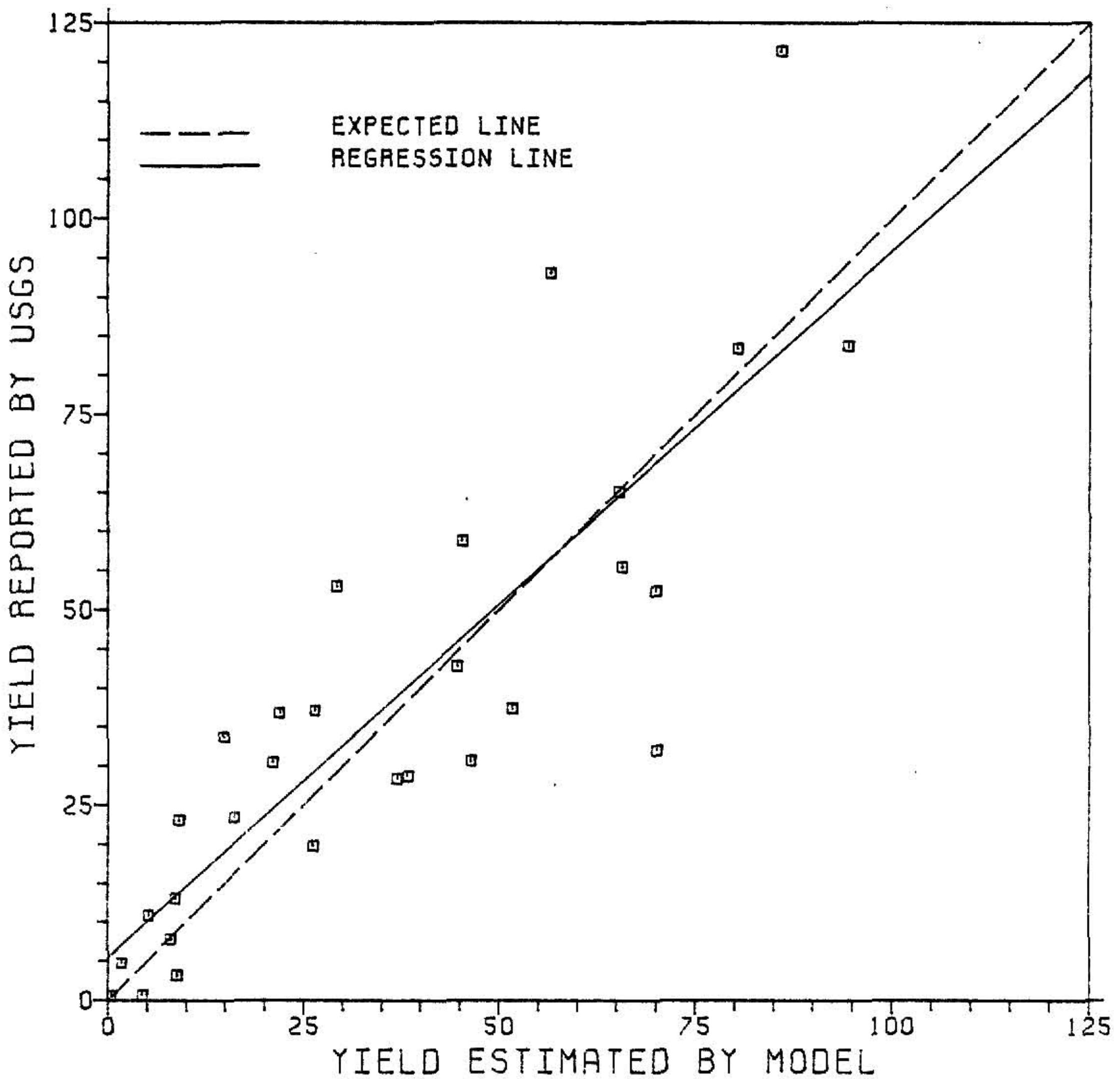
CEDAR CREEK



PREDICTED AND REPORTED WATERSHED YIELDS
FOR 1950 THRU 1978
--MODELING WITH A BASE-FLOW ESTIMATE--

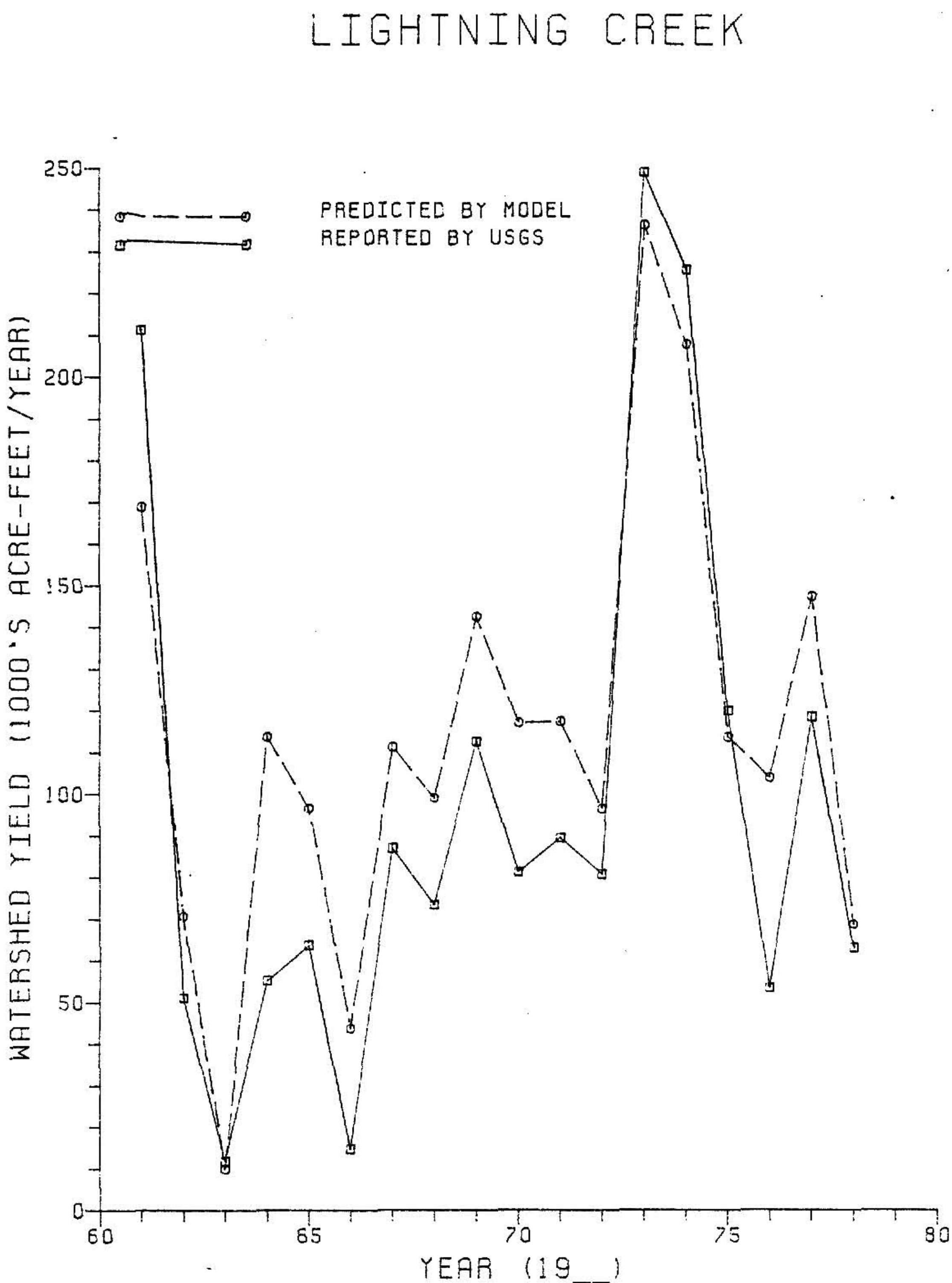
Figure 10

CEDAR CREEK



WATERSHED YIELD ESTIMATED BY MODEL
COMPARED TO THAT REPORTED BY USGS
--MODELING WITH A BASE-FLOW ESTIMATE--
(UNITS ARE 1000'S OF ACRE-FEET/YEAR)

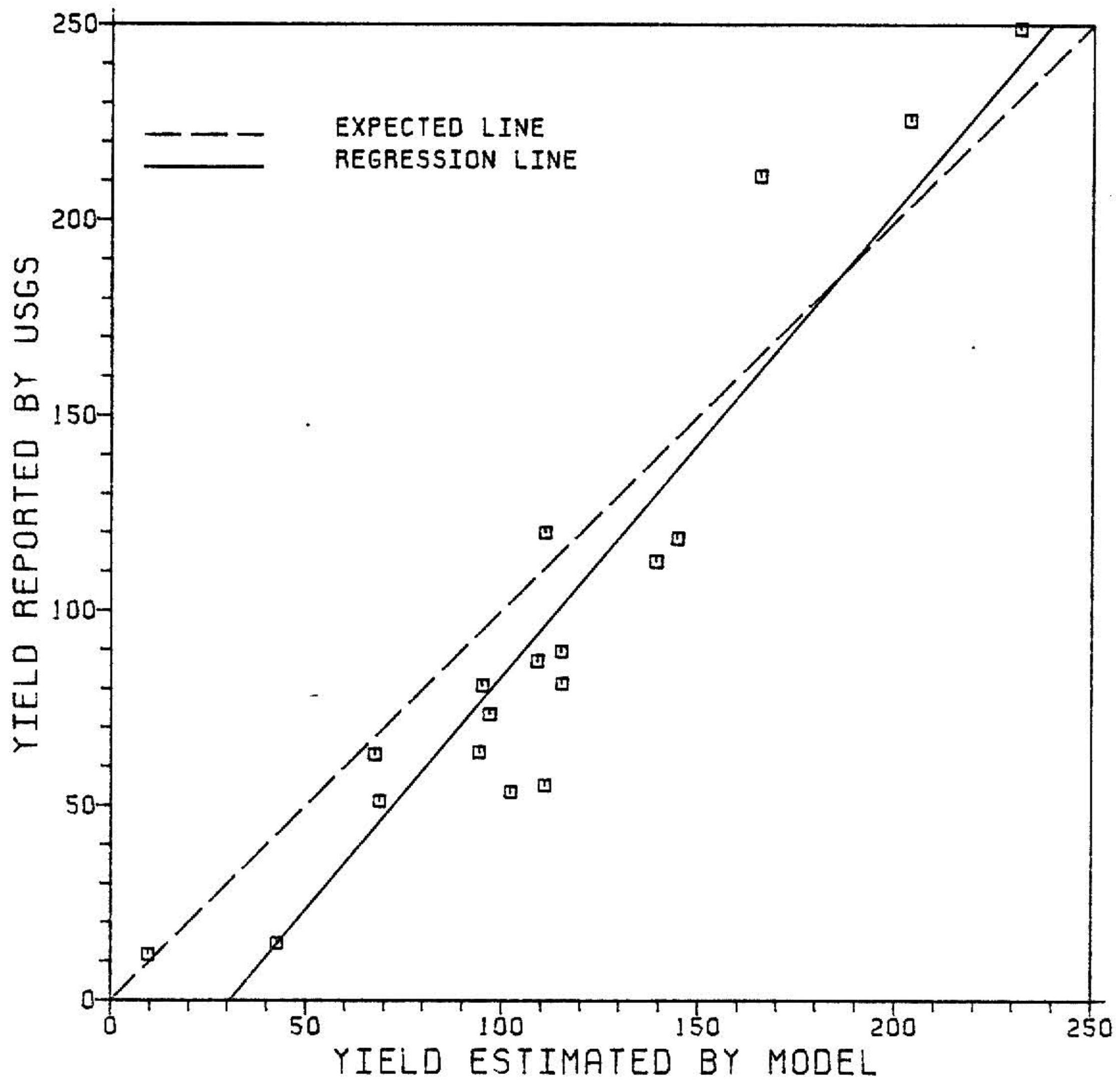
Figure 11



PREDICTED AND REPORTED WATERSHED YIELDS
FOR 1961 THRU 1978
--MODELING WITH A BASE-FLOW ESTIMATE--

Figure 12

LIGHTNING CREEK



WATERSHED YIELD ESTIMATED BY MODEL
COMPARED TO THAT REPORTED BY USGS
--MODELING WITH A BASE-FLOW ESTIMATE--
(UNITS ARE 1000'S OF ACRE-FEET/YEAR)

Figure 13

and USGS yields, also tends to overestimate the long-term average watershed yield. This is probably due to geologic factors that are not accounted for in modeling the basin. The results of the statisticial tests performed are summarized in Table 4.

TABLE 4
Summary of Analysis of Statistical Significance of Model Results

Watershed	Correlation Coefficient	F/Probability of having a value > F: Test 0	Test 1	Simultaneous
Modeling without a base-flow estimate				
Wolf Creek	0.76	0.18/0.67	0.29/0.60	0.14/0.87
Cedar Creek	0.83	0.89/0.35	1.36/0.25	0.68/0.51
Lightning Creek	0.86	4.19/0.057	3.71/0.072	2.10/0.16
Modeling with a base-flow estimate				
Wolf Creek	0.87	0.28/0.61	0.98/0.34	0.54/0.59
Cedar Creek	0.85	1.25/0.27	0.79/0.38	0.63/0.54
Lightning Creek	0.94	7.08/0.017	3.12/0.096	4.77/0.024

F is the computed test statistic. The probability of having a value greater than F is the basis for accepting or rejecting the tested hypothesis. The hypothesis tested are:

Test 0 is testing whether or not the Y-intercept (of the plot of model yields versus USGS reported yields) is significantly different from zero (which is the expected value of the intercept).
Test 1 tests whether or not the slope of the line is significantly different from the expected value of one.
Simultaneous is testing the two hypothesis above, simultaneously.

If the probability of having a value greater that F is less than the accepted level of signficance (0.05 for this study) then the modeled yields differ significantly from the yields reported by USGS. Notice that only Lightning Creek modeled with a base-flow estimate tests as having a significant difference between the two yields.

CHAPTER 5

Modeling the Impact of Conservation Measures

With a calibrated model capable of matching historic stream flow records, it is possible to examine the effects of soil and water conservation measures on watershed yields. Because the DEPLETE program was written specifically for this task, the calibration (historic conditions) runs have already provided some data. For historic conservation conditions, the program has estimated depletions caused by farm ponds and terraces (the only practices modeled).

In addition to the historic yield reductions estimated by DEPLETE, it would be interesting to evaluate the depletions that would have occurred if some future level of conservation measures had been applied to the watershed during the simulated period. The ability to do so is the power of a simulation model.

To accomplish this requires only an estimate of the future level of installed conservation practices. For this study, an estimate was made using data from the SCS Kansas Conservation Needs Inventory of 1969 (which actually used a 1967 data base). The purpose of this publication was to provide estimates of the amount of conservation that was still required in each county of Kansas in order to reduce soil loss throughout the county to the "acceptable" level of 5 tons/acre/year. Again, for modeling purposes, the data for the county containing the major portion of the watershed was used for each basin. The model watershed created using this data is one with the "ideal" level of soil and water conservation practices installed. As such it is not by any means likely to occur in the near future; but, in some sense, it exhibits the land-use conditions with the most severe yield depleting potential which could be expected to develop in the basin. The data derived from the Conservation Needs Inventory are summarized in Table 5.

The number of ponds estimated for each watershed for the projected land-use conditions is approximately the number estimated in the last year of the historic simulation. The reason for this is that Kansas has witnessed a dramatic reduction in the number of farm ponds built in the past several years. There are a variety of reasons for this reduction; the poor overall condition of the farm economy, the realization that ponds are often not the most efficient nor reliable method of storing water, the considerable increase in the cost of dam construction, and the fact that many of the best pond sites have already been used. For these reasons, and considering that for each watershed as a whole new ponds must, to some degree, replace storage lost to sediment accumulation in older ponds, the number of ponds estimated for the projected conditions is only slightly above 1978 levels.

Finally, it is necessary to adjust the runoff curve numbers to account for the increase in applied conservation measures. For some plots this is relatively easy because the "good" hydrologic condition (see Table 2) is equivalent to the best conservation and farming practice condition. So, the improved conditions curve number can be taken directly from tables of curve numbers. However, notice on Table 5 that improved residue practices are a substantial portion of the conservation needed to adequately protect the watershed. To estimate the reductions in curve numbers for wheat, sorghum, corn, and soybean

TABLE 5

Projected Level of Applied Conservation Measures

Item	Percentage of the Total Watershed Area		
	Wolf Creek	Cedar Creek	Lightning Creek
Cropland	67	16	60
Adequately treated	25	5	10
Needing:			
Improved residue only	2	6	13
Terraces	37	4	32
Other	3	1	5
Pasture and Rangeland	33	84	30
Adequately treated	8	44	3
Needing:			
Protection from overgrazing	23	33	4
Improved cover	1	4	10
Reestablished cover	1	3	13
Forest Land	*	*	10
Adequately treated	-	-	2
Not adequately treated	-	-	8

* For Wolf Creek and Cedar Creek basins the small amount of wooded area was placed in the Pasture and Rangeland catagory. From The Conservation Needs Inventory: Kansas; USDA, Soil Conservation Service; Salina, KS, 1969.

plots due to improved residue management, Figure 14 (taken from Rawls and Onstad, 1978) was consulted. Description of the plots used in the "projected conditions" runs are tabulated in Appendix B (improved residue management is noted as "mulched" in these tables).

On the following pages the model results for the projected conditions simulations are plotted in time series with the historic runs. After this plot for each watershed is a bar graph showing the depletion of the basin's potential yield for both the historic and projected land-use conditions. The data shown graphically here are also tabulated in Appendix B.

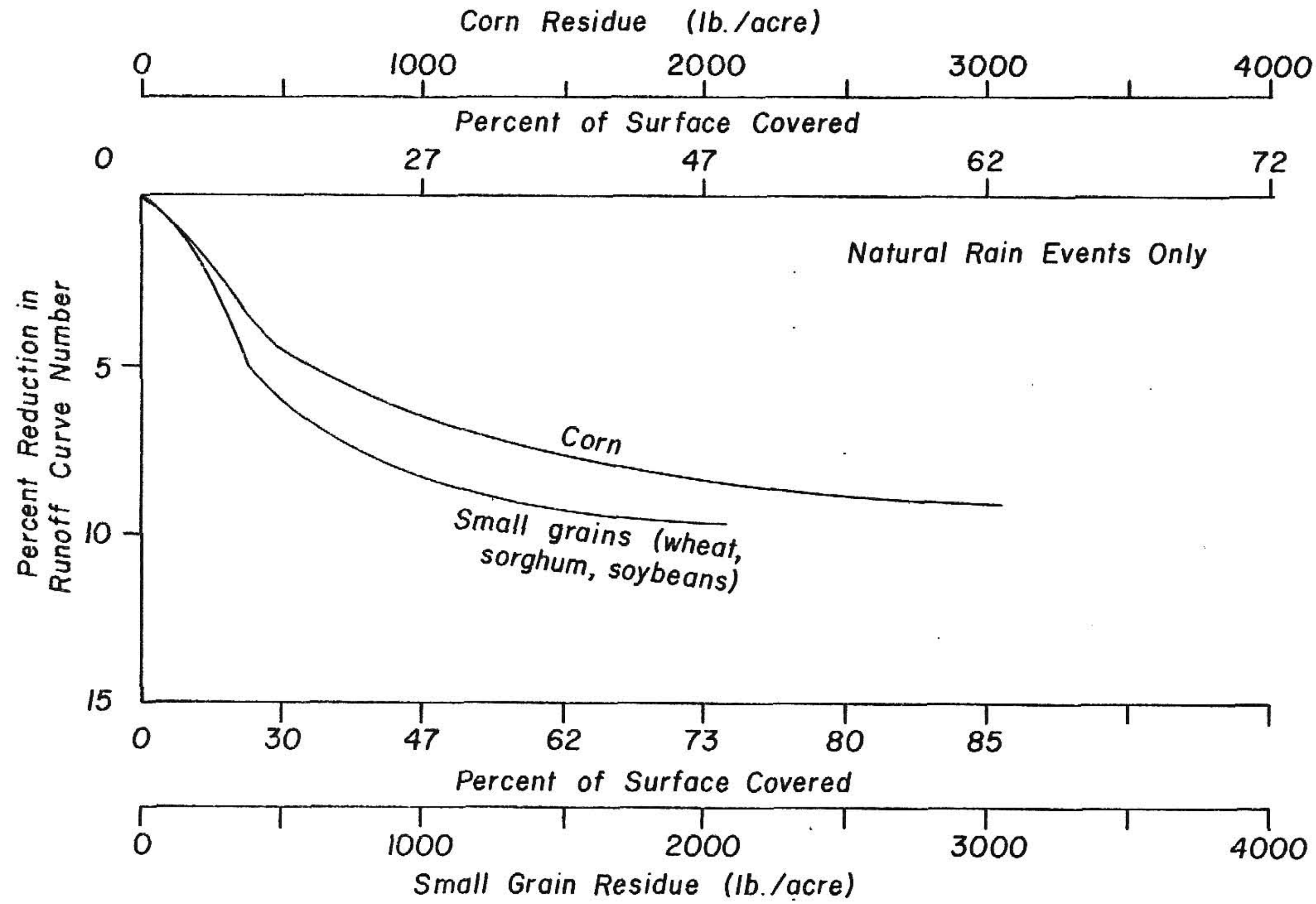
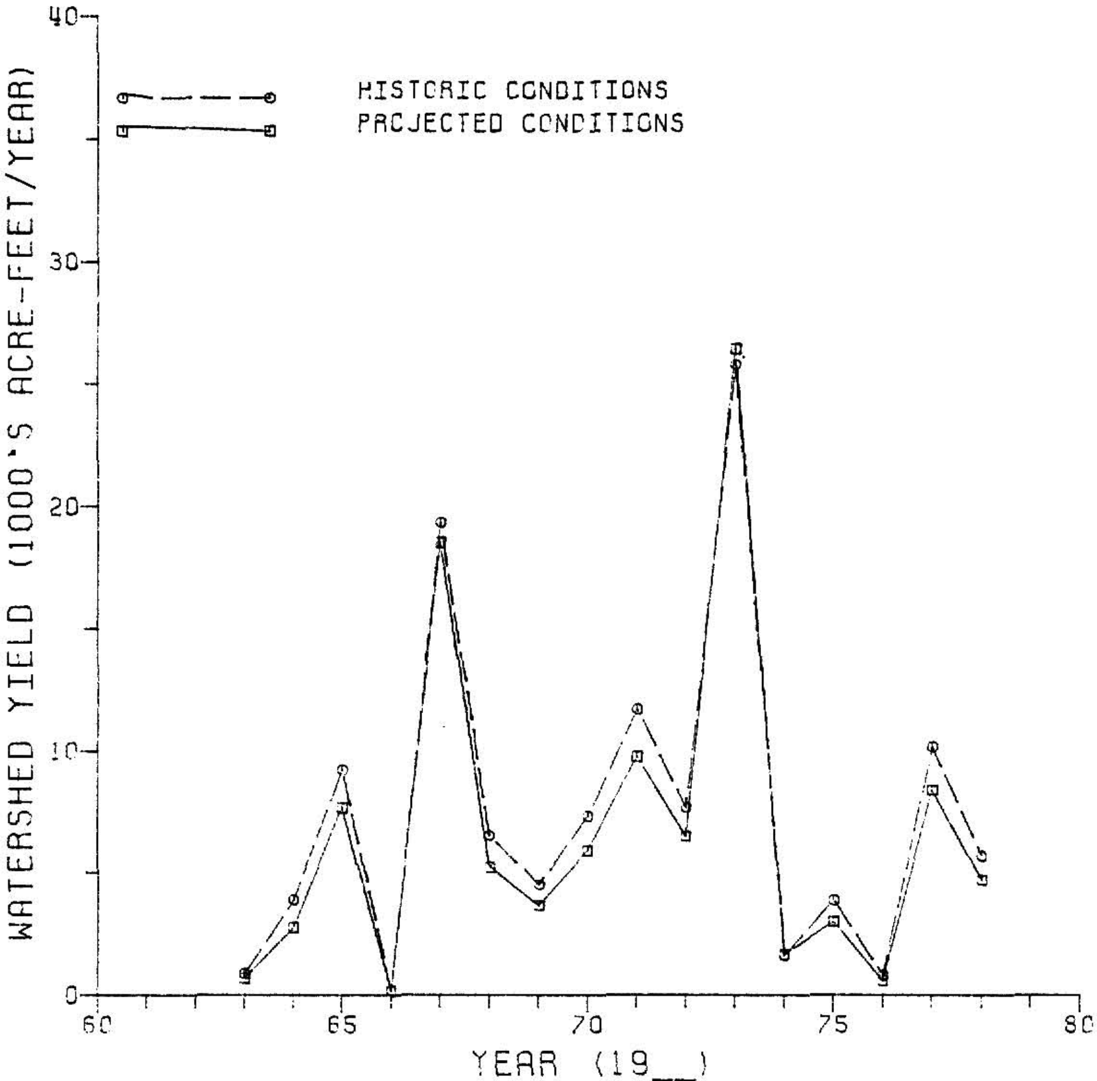


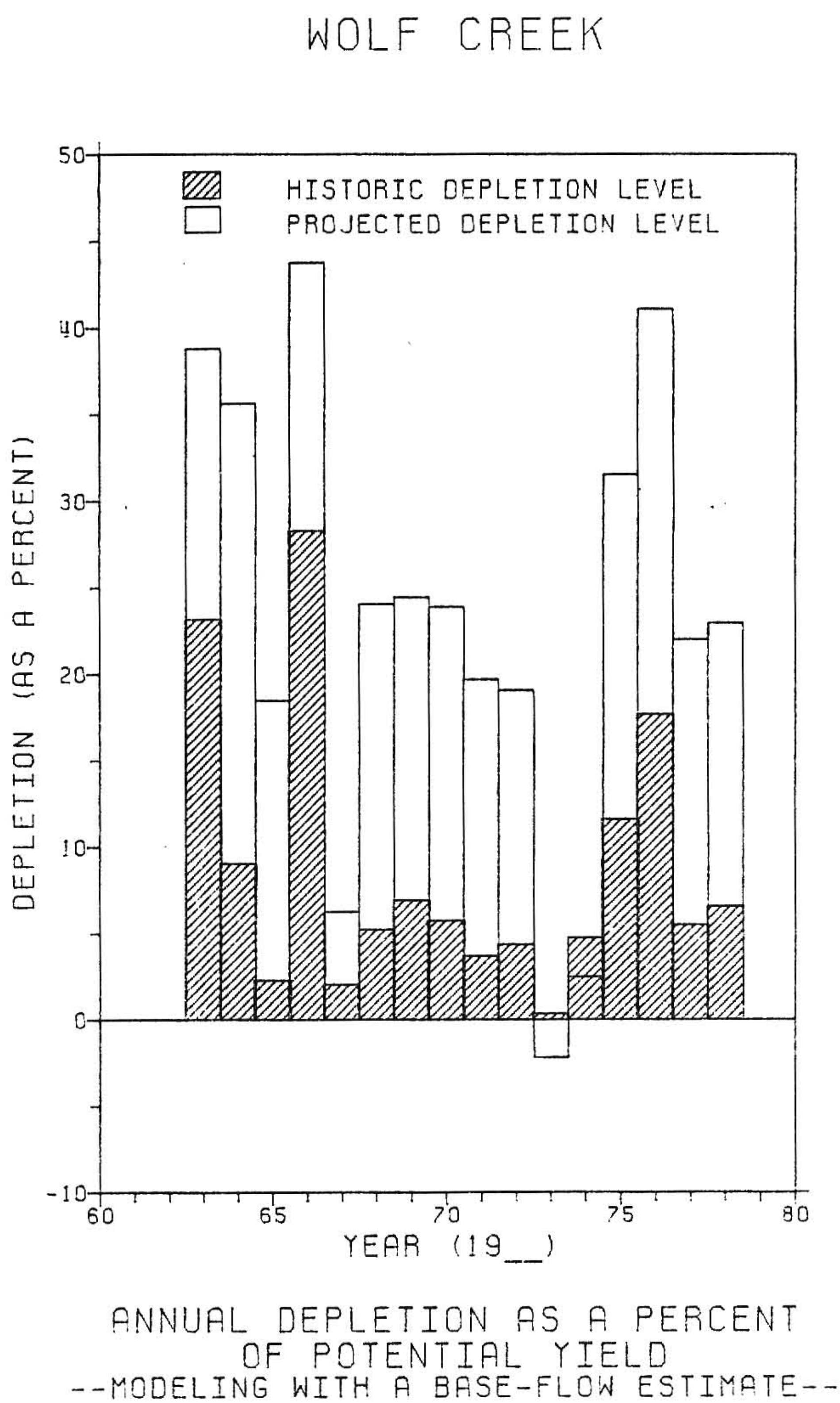
Figure 14--Reduction of SCS Runoff Curve Numbers as a function of crop residue levels. Taken from "Residue and Tillage Effects on SCS Runoff Curve Numbers," Rawls and Onstead, 1978; Figures 3 and 4.

WOLF CREEK



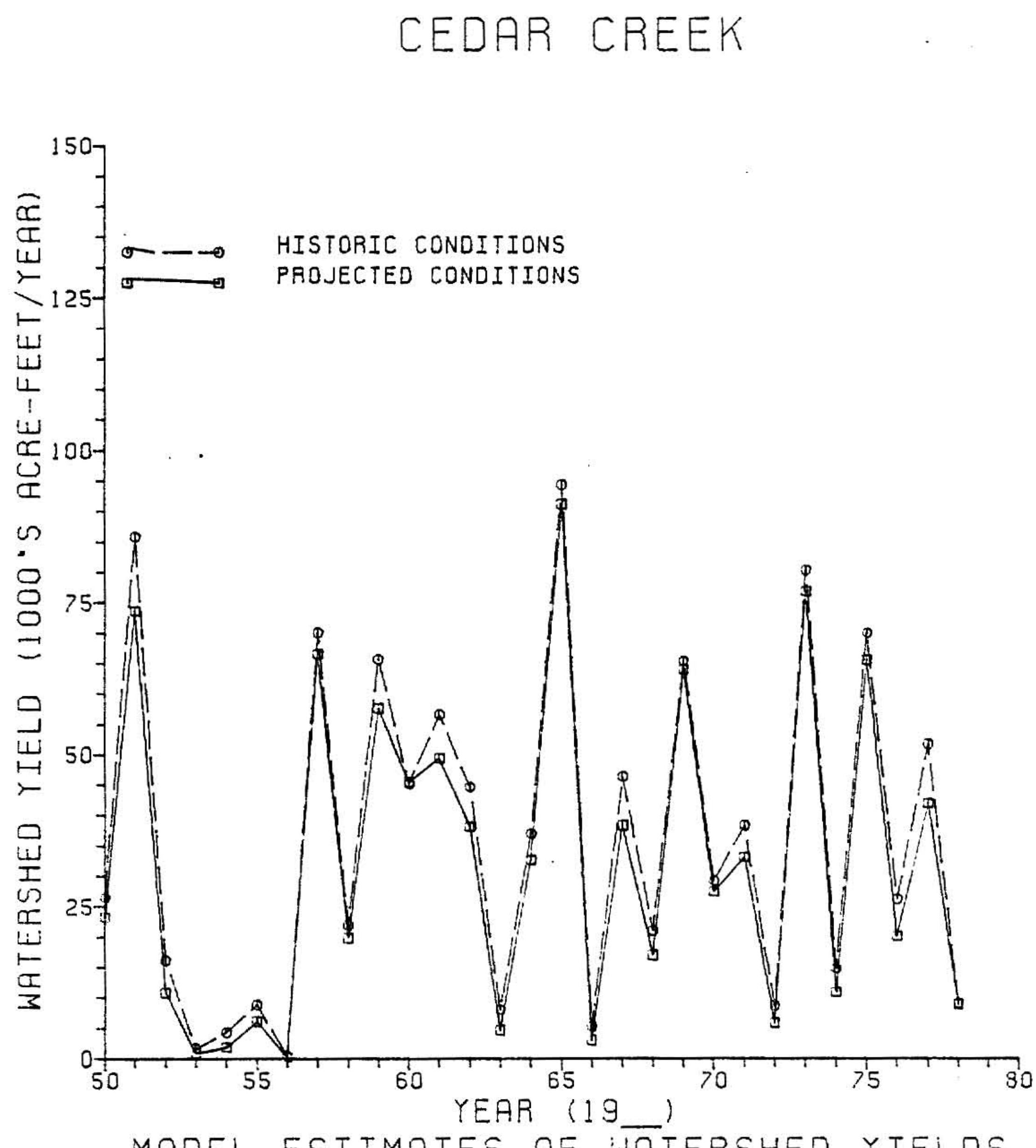
MODEL ESTIMATES OF WATERSHED YIELDS
HISTORIC AND PROJECTED LAND USE
CONDITIONS AND CONSERVATION PRACTICES
--MODELING WITH A BASE-FLOW ESTIMATE--

Figure 15



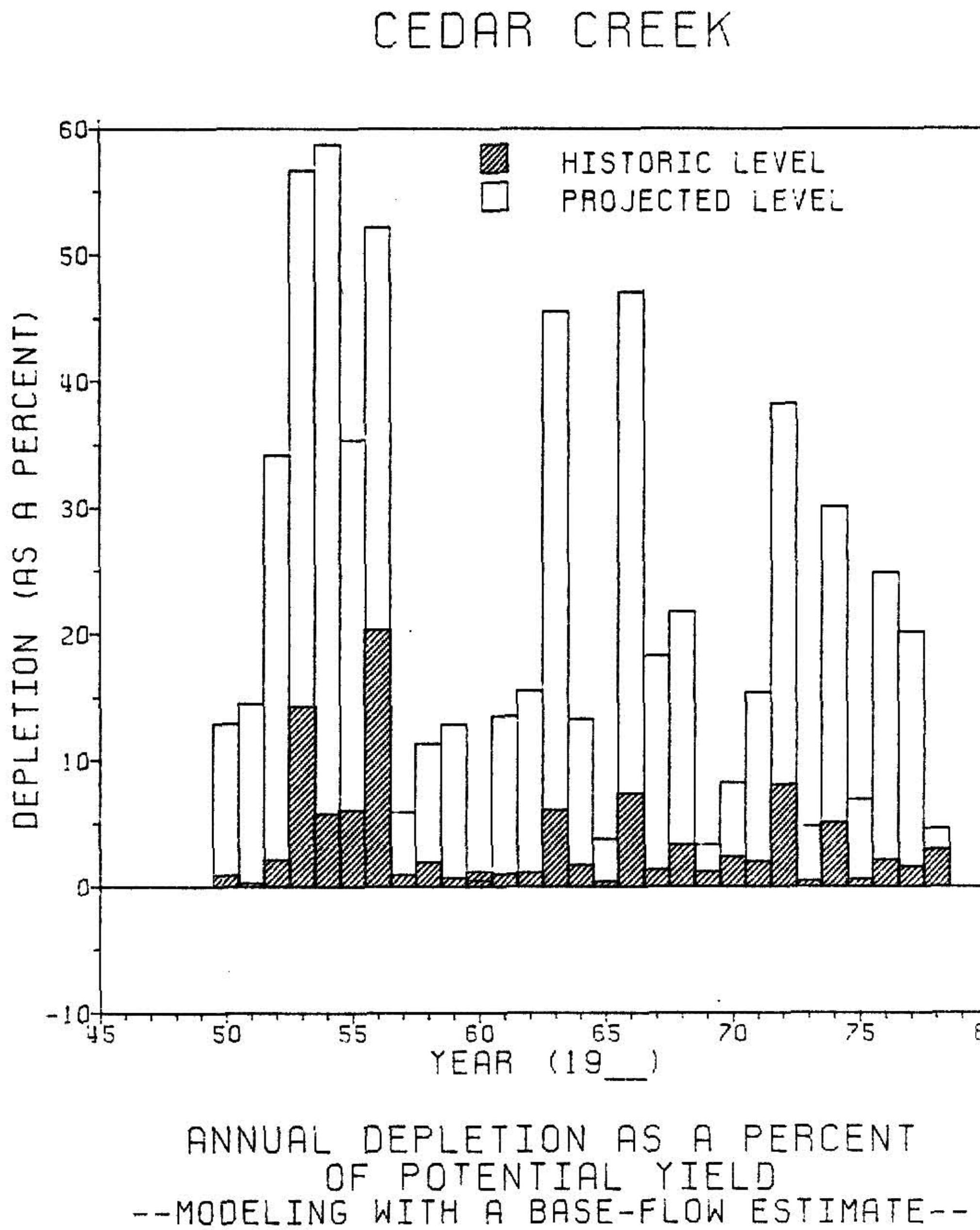
WOLF CREEK
HISTORIC DEPLETION LEVEL
PROJECTED DEPLETION LEVEL
DEPLETION (AS A PERCENT)
50
40
30
20
10
0
-10
60
65
70
75
80
YEAR (19__)
ANNUAL DEPLETION AS A PERCENT
OF POTENTIAL YIELD
--MODELING WITH A BASE-FLOW ESTIMATE--

Figure 16



MODEL ESTIMATES OF WATERSHED YIELDS
HISTORIC AND PROJECTED LAND USE
CONDITIONS AND CONSERVATION PRACTICES
--MODELING WITH A BASE-FLOW ESTIMATE--

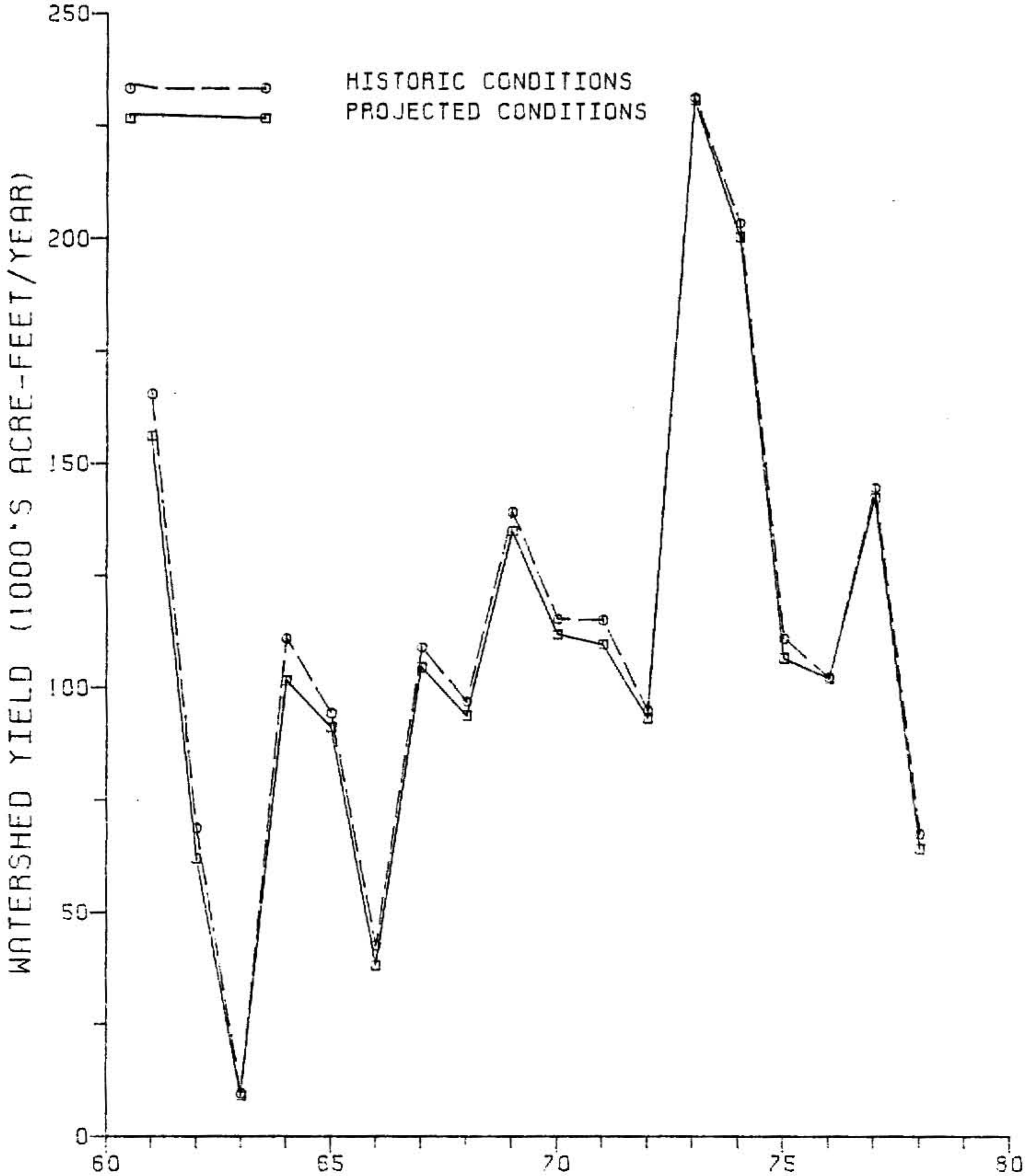
Figure 17



CEDAR CREEK
HISTORIC LEVEL
PROJECTED LEVEL
DEPLETION (AS A PERCENT)
60
50
40
30
20
10
0
-10
45
50
55
60
65
70
75
80
YEAR (19__)
ANNUAL DEPLETION AS A PERCENT
OF POTENTIAL YIELD
--MODELING WITH A BASE-FLOW ESTIMATE--

Figure 18

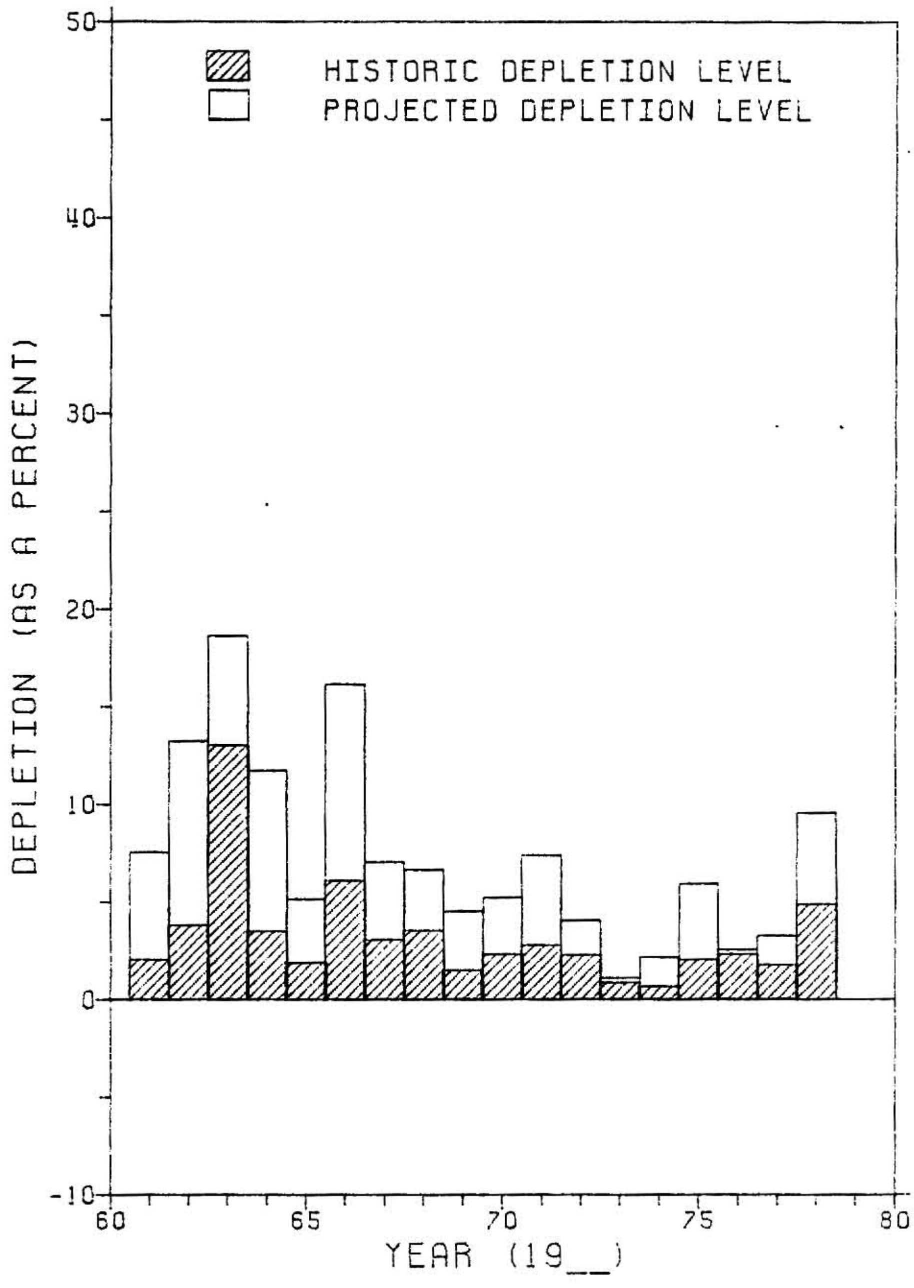
LIGHTNING CREEK



MODEL ESTIMATES OF WATERSHED YIELDS
HISTORIC AND PROJECTED LAND USE
CONDITIONS AND CONSERVATION PRACTICES
--MODELING WITH A BASE-FLOW ESTIMATE--

Figure 19

LIGHTNING CREEK



ANNUAL DEPLETION AS A PERCENT
OF POTENTIAL YIELD
--MODELING WITH A BASE-FLOW ESTIMATE--

Figure 20

CHAPTER 6

Discussion of Results

The results obtained in this study will be examined on an individual watershed basis first, and then a few general observations will be made. Table 6, on the following page, summarizes the long-term average watershed yields from the simulation runs.

Wolf Creek

As indicated by the previously noted correlation coefficient (r = 0.87), tests of significance, and by examining Figure 8, annual watershed yields computed by the model compare favorably with those reported by the USGS. The model does display a marked inability to duplicate yields for the extremely wet year 1973.

Perhaps of greater interest are the yield depletion results. Being the most westerly of the three basins, and so the most arid, Wolf Creek shows the greatest potential for depletion. This is shown on the table of long-term depletion amounts (Table 6). From Figure 16 note that the very dry years of 1963, 1966, and 1976 show historic depletion levels hovering around 20 percent of the potential yield and projected depletions pushing 40 percent. Even the moderate period of 1968 through 1972, with approximately average yields, shows depletion levels historically of roughly 5 percent and for projected conditions of close to 20 percent. These results are similiar to those obtained by Berry for the drainage area of Webster Reservoir (Berry, 1981 and Koelliker et.al., 1981), except that depletion levels are not as severe for the Wolf Creek basin. Still, the yield reductions

TABLE 6

Modeled Long-term Watershed Yield Averages

	Historic Conditions Yield	Projected Conditions Yield	Potential Yield
Wolf Creek			
Ac.-Ft./Yr.	7,445	6,596	7,763
In./Yr.	2.5	2.2	2.6
Depletion of Potential Yield (%)	4.1	15.0	-
Cedar Creek			
Ac.-Ft./Yr.	36,317	32,240	36,830
In./Yr.	6.2	5.5	6.3
Depletion of Potential Yield (%)	1.4	12.5	-
Lightning Creek			
Ac.-Ft./Yr.	112,320	108,426	114,980
In./Yr.	11.0	10.6	11.3
Depletion of Potential Yield (%)	2.3	5.7	-

predicted for Wolf Creek for the projected land-use conditions could seriously hamper operations of a water-supply structure below the watershed.

Cedar Creek

As with Wolf Creek, the correlation coefficient, signficance tests, and the time-series plot (Figure 10) all show a good agreement between the modeled (historic conditions) watershed yields and USGS stream gaging records. Again, the model was unable to match the extremely wet year, 1951 in this case.

The yield depletion results for Cedar Creek (Figure 18) show the dramatic effects that the projected land-use conditions would have had during the drought period of 1953 through 1956; averaging almost a 50 percent reduction in the watershed's potential yield throughout the period. As with Wolf Creek, this basin shows extremely high depletion levels during dry years, although less so for historic conditions; but from Table 6 note that the long-term depletion under projected conditions is less than that for Wolf Creek.

The explanation for the large increase in depletion percentages from historic to projected conditions (when compared to those for Wolf Creek and Lightning Creek) is found in the land-use patterns. Roughly 85 percent of the Cedar Creek basin is pasture or range land. With no data at hand, pastured land was modeled at a constant condition throughout the simulated period (i.e. no improvements in grazing practices were accounted for). This is unlike the treatment of cropland which could, for example, be converted gradually from unterraced to terraced ground through the simulation period. Because of the large proportion of pasture and range (roughly twice the percentage found in the other two basins), the effects of improving the hydrologic condition of the pasture plots from "fair" (historic condition estimate) to "good" (projected conditions) is much more obvious at Cedar Creek than it is at the other two basins. Notice, on Table 2, the large drop in curve numbers between "fair" and "good" condition pasture and range land. Since decreasing the curve number decreases the runoff computed by the SCS Runoff Equation (Equation 1), it conversely increases the depletion amounts--in relatively arid regions at any rate.

Lightning Creek

The Lightning Creek model is both the best and worst of the simulations. The linear correlation (r = 0.97) is by far the highest of the three, but the significance tests (Table 4) indicate a considerable bias in the model. This bias also appears in Table 6 in the considerable difference between the reported and modeled long-term average watershed yield. However, despite almost uniformly high estimates of yield, the model still underestimated the watershed yield for the wet years of 1961 and 1973 (Figure 12).

Examination of the yield depletion results (Figure 20) shows the reduced influence of conservation measures on water yields when compared to depletions in the other basins. Even in the dry year of 1963, the projected conditions depletion level is estimated at only 18 percent. However, the effects are the same as those shown by Wolf Creek and Cedar Creek. The depletion percentage is highest in dry years and reduced in wet ones. The projected long-term depletion for Lightning Creek (Table 6) of less than 6 percent further demonstrates the muted influence of conservation treatment on yields for this basin. This is in large part due to the higher annual precipitation amounts for this area--the most humid part of Kansas.

General Observations

These three models have several points in common. The most obvious is the inability of the models to match reported watershed yields for extremely wet years. For Wolf Creek and Lightning Creek the year 1973 exemplifies this, while 1951 demonstrates the point at Cedar Creek. This is probably accounted for by several factors. One of these is the inability to completely represent the precipitation regime throughout a drainage area using only one or two rain gages.

Another reason is the lack of variability in evaporation estimates made by the model. From Table 3, the difference between the standard deviations of the model and of the reporting evaporation stations is obvious. This indicates that the model will overestimate evaporation (and transpiration as well) in wet years, when evaporation can be expected to be depressed to a degree, and underestimate in dry years. This effect is not obvious in dry years but it appears that in wet years runoff quantities are being underestimated in favor of excessive evapotranspiration losses.

Another common feature of these models are the characteristics of yield depletions. In general, during dry periods the volume of water depleted by conservation practices is low but it is a substantial percentage of the potential watershed yield. Thus, at Cedar Creek, there are occasions when the depletion under projected watershed conditions is over 50 percent of the potential yield. Conversely, during wet years the volume of water depleted is much larger but that volume is a smaller fraction of the potential yield. Therefore, from the point of view of those dependant upon the basin for water supply, the major reductions in yields (on a percentage basis) attributable to conservation practices occur at the worst time--during dry years.

Related to this is the effect of ponds upon yields. As noted in Tables 7, 12, and 17 (Appendix B), during dry years ponds account for a much larger fraction of the total depletion losses than they do during wet years. Essentially, the soil, as a water-holding reservoir, has a greater capacity than do small ponds. This becomes apparent during wetter years as the ponds' storage capacities are taxed and they discharge excess water while the soil continues to store water without "discharge." Of course in quite wet years the water storage capacity of the soils, too, is exceeded and percolation below the root zone occurs.

The reduction in depletion percentages moving from west to east is in large part because of the increase in rainfall amounts from west (roughly 15 inches annually) to east (a little over 40 inches annually). This is because conservation practices deplete downstream yields by increasing the amount of water held in a basin's water storage "reservoirs" (ponds, too, but most importantly the soil itself). They do so by increasing the opportunity for surface water to infiltrate into the soil from where crops remove it by transpiration. But ponds and the soil profile have only limited holding capacities and growing crops can transpire water at only a limited rate. Therefore, in humid regions were the amount of precipitation approaches the potential evapotranspiration volume, conservation practices will continue to increase infiltration into the soil but the soil's water holding capacity is more likely to be exceeded and so water is lost below the root zone (deep percolation in the POTYLD program). At least some of this water will reappear downstream as base-flow. In other words, moving from arid regions to more humid ones, conservation practices tend merely to trade reduced surface runoff for increased sub-surface contributions to stream flow.

One final comment concerning the depletion effects of small ponds needs to be made. In previous work (Berry, 1981 and Koelliker et.al., 1981), it was noted that ponds reduced the yield from their drainage areas by an average of 53 percent in the Webster Reservoir watershed. This substantually agreed with previous work by Sauer and Masch (1969). The pond reductions in the watersheds modeled here were substantually (on the order of 50 percent) below that predicted by the relationship between average annual runoff and the depleting potential of ponds presented by Sauer and Masch. In part, this discrepancy is due to a difference in pond design between the Webster basin study and the work presented here. In Western Kansas farm ponds are generally built with only an earth-cut spillway around one end of the dam embankment. Moving towards more humid areas, SCS design criteria begins to force the more frequent use of a drain pipe (or trickle tube) to provide some protection to the earth spillway by reducing the frequency of use. Since water above the drain pipe is not held in the reservoir long enough for evaporation to have a substantial effect, the inclusion of a drain pipe effectively reduces the size of the modeled pond. This reduces the ponds potential to deplete the yield from its watershed.

CHAPTER 7

Conclusions and Recommendations

Conclusions

A study of the effects of soil and water conservation practices upon watershed yields has been made which supplements and extends previous work by examining these effects in the more humid eastern portion of Kansas. This work indicates that conservation measures have a substantive effect upon watershed yields in this part of the state and that in the future this effect will probably increase. While the impact of conservation practices upon watershed yields decreases progressing from west to east, it is still large enough to be of concern when planning water supply facilities dependant upon surface water yields.

Recommendations

One refinement to the model seems to be indicated by the results of this work. It is not easily accomplished nor is it actually guaranteed to improve the model substantially. However, since the problem of minimal data cannot generally be resolved for a daily simulation model, making better use of data available is the only means of improving model results.

This refinement is to improve the variability of the evaporation term. Because this term is used in the calculation of potential evapotranspiration as well as bare soil and lake evaporation, it has the largest impact upon the water budget of any single factor in the model. The lack of variability in the computed lake evaporation, compared to the reported values, is in large part due to the use of long-term monthly average climatological data. An interesting experiment would be to rewrite the POTYLD program to use the daily data available at a limited number of first-order stations (Concordia being one of them) and compare the results obtained with the results from the current version and with "real-world" data. If sufficient improvement is indicated by trial runs with the stations reporting the data required, a data base could be developed for use with other stations reporting only limited weather data (in much the same way as the monthly climatological data was produced in the first place). While this data base would be produced by interpolating between the first-order stations, it would possibly be superior to the current procedure and certainly no worse.

Such a model would be easier for the user to use in that the climatological data would no longer be user-supplied (as envisioned, the user would merely need to supply the location of the modeled basin relative to the network of first-order weather stations, by providing latitude and longitude for example). However, this refinement is not without disadvantages. Aside from the work required to rewrite the program in the first place, the computer run-time would no doubt be substantially increased as would the storage requirements for the data used in any given run.

APPENDIX A

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APPENDIX B

Summary of Data Used in Modeling

and

Tabulation of Results

TABLE 7

Watershed Yield Summary
Wolf Creek Basin

Year	Reported Yield (Ac.Ft.)	Potential Yield (Ac.Ft.)	Historic Conditions Yield (Ac.Ft.)	Historic Conditions Dep* (%)	Projected Conditions Yield (Ac.Ft.)	Projected Conditions Dep* (%)
1963	1,050	1,116	857	95	683	58
64	1,280	4,270	3,883	84	2,749	31
1965	7,390	9,417	9,202	79	7,677	18
66	713	258	185	94	145	57
67	15,890	19,738	19,335	77	18,504	18
68	6,260	6,876	6,516	80	5,221	22
69	10,160	4,841	4,506	80	3,658	27
1970	5,530	7,772	7,325	78	5,915	23
71	6,110	12,142	11,693	75	9,751	17
72	7,290	8,018	7,667	71	6,489	17
73	39,810	25,881	25,794	50	26,452	7
74	8,130	1,699	1,618	91	1,657	46
1975	2,300	4,369	3,862	86	2,991	36
76	615	978	805	87	576	37
77	5,180	10,745	10,185	86	8,382	24
78	7,480	6,086	5,687	85	4,690	27
Mean	7,824		7,445			
Standard Deviation	9,429		6,924			

*Note: "Dep" is the percentage of the total depletion volume which was accounted for by ponds in the watershed.

TABLE 8

POTYLD Plot Descriptions
Wolf Creek Basin

Plot	Description*	Curve Numbers Antecedant Moisture Condition			Growing Season Dates
		I	II	III	
1	Terraced wheat [3]	55	74	88	9/20 - 7/05
2	Contoured wheat [3]	59	77	89	9/20 - 7/05
3	Contoured sorghum [3]	62	79	91	6/20 - 10/20
4	Contoured corn [3]	63	80	91	5/15 - 10/20
5	Pasture [3]	48	68	84	4/01 - 10/31
6	Contoured alfalfa [3]	54	73	87	4/01 - 10/31
The following plots were added for the Projected Conditions run.					
7	Mulched wheat [3]	57	75	88	9/20 - 7/05
8	Terraced sorghum [3]	57	75	88	6/20 - 10/20
9	Improved pasture [3]	42	62	79	4/01 - 10/31

*The number in brackets represents the Irrigation Design Group for the plot.

TABLE 9

Land Use Conditions
Wolf Creek Basin

Year	Total No. of Ponds	Percentage of the basin represented by plot: 1	2	3	4	5	6	7	8	9
1963	110	4	30	12	7	39	8	0	0	0
64	114	5	30	12	5	39	9	0	0	0
1965	118	5	31	11	5	39	9	0	0	0
66	124	6	30	12	4	40	8	0	0	0
67	127	6	33	11	4	38	8	0	0	0
68	130	6	32	11	4	39	8	0	0	0
69	135	7	28	12	6	39	8	0	0	0
1970	140	7	25	15	5	40	8	0	0	0
71	142	7	22	18	4	41	8	0	0	0
72	144	8	21	15	5	42	9	0	0	0
73	146	8	24	18	4	40	6	0	0	0
74	146	8	26	17	4	39	6	0	0	0
1975	147	8	31	15	3	38	5	0	0	0
76	147	8	26	13	3	43	7	0	0	0
77	148	8	31	14	2	41	4	0	0	0
78	149	8	27	15	2	43	5	0	0	0

Following is the land use condition within the watershed's "typical" pond drainage area:

Pond	-	3	26	7	0	56	8	0	0	0

Following is the Projected Conditions land use for the basin as a whole:

All	150	29	6	3	4	0	8	4	8	38

Following is the land use condition within the watershed's "typical" pond drainage are for the Projected Conditions model:

Pond	-	23	3	2	0	0	8	3	5	56

COMPONENTS OF ANNUAL WATERSHED YIELD ESTIMATES

WOLF CREEK
Historic conditions

YEAR	ANNUAL PRECIP (In.)	YIELD FROM DEPLETE (Ac.Ft.)	TRANSMISSION LOSS FACTOR	SURFACE YIELD (Ac.Ft.)	DEEP PERCOLATION (Ac.Ft.)	ANNUAL YIELD (Ac.Ft.)
1963	23.25	1,118	1.31	857	0	857
1964	28.61	4,445	1.14	3,883	0	3,883
1965	33.24	9,797	1.08	9,080	122	9,202
1966	15.16	368	1.98	185	0	185
1967	38.24	17,323	1.04	16,590	2,745	19,335
1968	30.01	7,297	1.12	6,516	0	6,516
1969	29.53	5,082	1.13	4,506	0	4,506
1970	28.55	8,393	1.15	7,325	0	7,325
1971	35.28	12,414	1.06	11,693	0	11,693
1972	32.71	8,213	1.08	7,574	93	7,667
1973	44.42	18,298	1.03	17,849	7,945	25,794
1974	15.82	497	1.89	262	1,356	1,618
1975	25.12	4,767	1.23	3,862	0	3,862
1976	17.43	1,373	1.71	805	0	805
1977	35.23	10,781	1.06	10,152	0	10,152
1978	30.36	6,338	1.11	5,687	0	5,687

Average annual precipitation for the period = 28.94 inches

Average annual potential evapotranspiration = 30.0 inches

Average annual surface yield after transmission losses = 6,677 Acre-Feet

Average annual deep percolation loss
(i.e. best estimate of base-flow) = 766 Acre-Feet

Average annual estimate of total yield = 7,443 Acre-Feet

Table 10

COMPONENTS OF ANNUAL WATERSHED YIELD ESTIMATES

WOLF CREEK
Projected conditions

YEAR	ANNUAL PRECIP (In.)	YIELD FROM DEPLETE (Ac.Ft.)	TRANSMISSION LOSS FACTOR	SURFACE YIELD (Ac.Ft.)	DEEP PERCOLATION (Ac.Ft.)	ANNUAL YIELD (Ac.Ft.)
1963	23.25	820	1.31	628	55	683
1964	28.61	2,985	1.14	2,608	141	2,749
1965	33.24	7,869	1.08	7,293	384	7,677
1966	15.16	287	1.98	145	0	145
1967	38.24	14,621	1.04	14,002	4,502	18,504
1968	30.01	5,847	1.12	5,221	0	5,221
1969	29.53	4,061	1.13	3,601	57	3,658
1970	28.55	6,605	1.15	5,765	150	5,915
1971	35.28	10,233	1.06	9,639	112	9,751
1972	32.71	6,614	1.08	6,099	390	6,489
1973	44.42	14,784	1.03	14,421	12,031	26,452
1974	15.82	328	1.89	173	1,484	1,657
1975	25.12	3,692	1.23	2,991	0	2,991
1976	17.43	983	1.71	576	0	576
1977	35.23	8,902	1.06	8,382	0	8,382
1978	30.36	5,227	1.11	4,690	0	4,690

Average annual precipitation for the period = 28.94 inches

Average annual potential evapotranspiration = 30.0 inches

Average annual surface yield after transmission losses = 5,390 Acre-Feet

Average annual deep percolation loss
(i.e. best estimate of base-flow) = 1,207 Acre-Feet

Average annual estimate of total yield = 6,596 Acre-Feet

Table 11

TABLE 12

Watershed Yield Summary
Cedar Creek Basin

Year	Reported Yield (Ac.Ft.)	Potential Yield (Ac.Ft.)	Historic Conditions Yield (Ac.Ft.)	Historic Conditions Dep* (%)	Projected Conditions Yield (Ac.Ft.)	Projected Conditions Dep* (%)
1950	37,100	26,726	26,473	55	23,269	7
51	121,400	86,116	85,854	46	73,601	3
52	23,360	16,480	16,130	73	10,843	10
53	4,720	1,966	1,685	94	851	20
54	640	4,620	4,353	89	1,905	18
1955	3,170	9,384	8,814	91	6,065	24
56	551	500	398	86	239	9
57	31,970	70,691	70,041	66	66,522	5
58	36,810	22,355	21,917	76	19,818	10
59	55,450	66,084	65,615	69	57,591	7
1960	58,820	45,742	45,192	81	45,533	6
61	93,090	57,148	56,572	65	49,405	4
62	42,760	45,175	44,663	63	38,148	4
63	7,800	8,547	8,029	89	4,655	16
64	28,400	37,606	36,970	74	32,605	7
1965	83,780	94,767	94,363	62	91,189	3
66	10,860	5,634	5,218	85	2,984	13
67	30,650	46,979	46,347	77	38,368	7
68	30,480	21,728	21,012	75	16,988	9
69	65,140	66,106	65,335	59	63,922	4
1970	52,980	29,894	29,190	69	27,424	9
71	28,700	39,091	38,307	68	33,072	6
72	13,010	9,418	8,656	82	5,816	17
73	83,430	80,673	80,134	62	76,794	3
74	33,760	15,571	14,779	83	10,878	11
1975	52,290	70,355	69,955	62	65,494	3
76	19,720	26,769	26,201	67	20,098	5
77	37,330	52,584	51,735	69	41,959	5
78	23,070	9,348	9,070	86	8,920	7
Mean	38,319		36,317			
Standard Deviation	29,630		27,861			

*Note: "Dep" is the percentage of the total depletion volume which was accounted for by pond in the watershed.

TABLE 13

POTYLD Plot Descriptions
Cedar Creek Basin

Plot	Description*	Curve Numbers Antecedant Moisture Condition I	II	III	Growing Season Dates
1	Terraced wheat [4]	63	80	91	10/01 - 6/25
2	Contoured wheat [4]	68	84	93	10/01 - 6/25
3	Contoured sorghum [4]	72	86	94	5/10 - 10/20
4	Contoured corn [4]	72	86	94	5/10 - 10/20
5	Pasture [4]	64	81	92	3/20 - 11/10
6	Contoured alfalfa [4]	64	81	92	3/20 - 11/10
7	Contoured soybeans [4]	72	86	94	5/20 - 10/25
8	Pasture (D soils) [1]	72	86	94	4/01 - 10/31
The following plots were added for the Projected Conditions run.					
9	Terraced and mulched wheat [4]	60	78	90	10/01 - 6/25
10	Terraced sorghum [4]	63	80	91	5/10 - 10/20
11	Mulched corn [4]	67	83	93	5/10 - 10/20
12	Improved pasture [4]	57	75	88	3/20 - 11/10
13	Improve pasture (D soils) [1]	63	80	91	3/20 - 11/10

*The number in brackets designates the Irrigation Design Group for the plot.

TABLE 14

Land Use Conditions
Cedar Creek Basin

Year	Total No. of Ponds	Percentage of the basin represented by plot: 1	2	3	4	5	6	7	8	9	10	11	12	13
1950	62	2	2	3	3	78	3	0	9	0	0	0	0	0
51	70	2	1	3	2	80	3	0	9	0	0	0	0	0
52	78	2	3	3	3	78	2	0	9	0	0	0	0	0
53	86	2	3	3	2	78	3	0	9	0	0	0	0	0
54	94	2	2	4	1	79	3	0	9	0	0	0	0	0
1955	100	2	2	4	1	79	3	0	9	0	0	0	0	0
56	104	2	2	3	1	80	3	0	9	0	0	0	0	0
57	106	2	2	3	1	79	4	0	9	0	0	0	0	0
58	107	2	2	4	2	78	3	0	9	0	0	0	0	0
59	109	2	2	4	1	79	3	0	9	0	0	0	0	0
1960	111	2	2	5	2	77	3	0	9	0	0	0	0	0
61	113	2	2	5	1	77	3	1	9	0	0	0	0	0
62	116	2	1	4	2	78	3	1	9	0	0	0	0	0
63	121	2	2	4	2	77	3	1	9	0	0	0	0	0
64	125	2	2	3	2	78	4	0	9	0	0	0	0	0
1965	130	2	2	3	2	77	4	1	9	0	0	0	0	0
66	134	2	2	3	2	76	5	1	9	0	0	0	0	0
67	139	2	2	3	2	76	5	1	9	0	0	0	0	0
68	140	3	1	4	2	75	5	1	9	0	0	0	0	0
69	142	3	1	3	2	76	5	1	9	0	0	0	0	0
1970	145	3	1	3	2	77	4	1	9	0	0	0	0	0
71	148	3	0	4	2	77	4	1	9	0	0	0	0	0
72	151	3	0	3	2	78	4	1	9	0	0	0	0	0
73	156	3	1	3	2	75	5	2	9	0	0	0	0	0
74	158	3	2	3	2	75	5	1	9	0	0	0	0	0
1975	160	3	3	4	2	74	4	1	9	0	0	0	0	0
76	162	3	4	3	2	73	4	2	9	0	0	0	0	0
77	162	3	3	3	1	74	5	2	9	0	0	0	0	0
78	162	3	1	4	1	73	6	3	9	0	0	0	0	0

Following is the land use condition for the watershed's "typical" pond drainage area:

Pond	-	2	2	4	0	80	4	0	8	0	0	0	0	0

Following is the Projected Conditions land use for the basin:

All	165	0	0	1	0	0	5	3	0	4	2	2	74	9

Following is the land use condition for the watershed's "typical" pond drainage area for the Projected Conditions model:

Pond	-	0	0	0	0	0	0	4	0	0	4	4	80	8

COMPONENTS OF ANNUAL WATERSHED YIELD ESTIMATES

CEDAR CREEK
Historic conditions

YEAR	ANNUAL PRECIP (In.)	YIELD FROM DEPLETE (Ac.Ft.)	TRANSMISSION LOSS FACTOR	SURFACE YIELD (Ac.Ft.)	DEEP PERCOLATION (Ac.Ft.)	ANNUAL YIELD (Ac.Ft.)
1950	28.33	31,038	1.19	26,096	377	26,473
1951	50.59	87,258	1.02	85,510	344	85,854
1952	27.53	19,522	1.21	16,130	0	16,130
1953	19.24	2,766	1.64	1,685	0	1,685
1954	19.41	7,080	1.63	4,353	0	4,353
1955	22.50	12,441	1.41	8,814	0	8,814
1956	18.78	669	1.68	398	0	398
1957	44.96	64,728	1.03	62,849	7,192	70,041
1958	30.99	15,305	1.13	13,490	8,427	21,917
1959	41.27	68,208	1.04	65,484	131	65,615
1960	36.36	44,721	1.07	41,787	3,405	45,192
1961	39.04	50,163	1.05	47,674	8,898	56,572
1962	40.20	44,638	1.05	42,663	2,000	44,663
1963	21.95	11,588	1.44	8,029	0	8,029
1964	33.30	40,647	1.10	36,921	49	36,970
1965	46.08	93,228	1.03	90,743	3,620	94,363
1966	21.29	7,748	1.48	5,218	0	5,218
1967	40.88	47,815	1.04	45,834	513	46,347
1968	31.16	22,831	1.13	20,174	838	21,012
1969	39.98	60,377	1.05	57,648	7,687	65,335
1970	29.00	29,784	1.17	25,378	3,812	29,190
1971	36.81	38,925	1.07	36,491	1,816	38,307
1972	26.12	10,805	1.25	8,622	34	8,656
1973	43.11	61,073	1.04	59,007	21,307	80,314
1974	26.84	18,182	1.23	14,779	0	14,779
1975	39.22	69,247	1.05	65,872	4,083	69,955
1976	26.89	32,101	1.23	26,125	76	26,201
1977	43.33	52,928	1.03	51,171	564	51,735
1978	21.47	13,361	1.47	9,070	0	9,070

Average annual precipitation for the period = 32.64 inches

Average annual potential evapotranspiration = 31.9 inches

Average annual surface yield after transmission losses = 33,725 Acre-Feet

Average annual deep percolation loss
(i.e. best estimate of base-flow) = 2,592 Acre-Feet

Average annual estimate of total yield = 36,317 Acre-Feet

Table 15

COMPONENTS OF ANNUAL WATERSHED YIELD ESTIMATES

CEDAR CREEK
Projected conditions

YEAR	ANNUAL PRECIP (In.)	YIELD FROM DEPLETE (Ac.Ft.)	TRANSMISSION LOSS FACTOR	SURFACE YIELD (Ac.Ft.)	DEEP PERCOLATION (Ac.Ft.)	ANNUAL YIELD (Ac.Ft.)
1950	28.33	21,604	1.19	18,164	5,105	23,269
1951	50.59	68,379	1.02	67,009	6,592	73,601
1952	27.53	13,050	1.21	10,783	60	10,843
1953	19.24	1,397	1.64	851	0	851
1954	19.41	3,049	1.63	1,875	30	1,905
1955	22.50	8,561	1.41	6,065	0	6,065
1956	18.78	402	1.68	239	0	239
1957	44.96	46,050	1.03	44,713	21,809	66,522
1958	30.99	9,305	1.13	8,201	11,617	19,818
1959	41.27	59,405	1.04	57,032	559	57,591
1960	36.36	34,673	1.07	32,398	13,135	45,533
1961	39.04	34,397	1.05	32,690	16,715	49,405
1962	40.20	29,500	1.05	28,195	9,953	38,148
1963	21.95	6,719	1.44	4,655	0	4,655
1964	33.30	30,628	1.10	27,820	4,785	32,605
1965	46.08	77,953	1.03	75,875	15,314	91,189
1966	21.29	4,430	1.48	2,984	0	2,984
1967	40.88	35,766	1.04	34,284	4,084	38,368
1968	31.16	14,381	1.13	12,708	4,280	16,988
1969	39.98	42,599	1.05	40,674	23,248	63,922
1970	29.00	23,105	1.17	19,687	7,737	27,424
1971	36.81	26,479	1.07	24,823	8,249	33,072
1972	26.12	6,849	1.25	5,465	351	5,816
1973	43.11	44,261	1.04	42,763	34,031	76,794
1974	26.84	11,576	1.23	9,409	1,469	10,878
1975	39.22	53,324	1.05	50,725	14,769	65,494
1976	26.89	23,105	1.23	18,804	1,294	20,098
1977	43.33	36,295	1.03	35,090	6,869	41,959
1978	21.47	8,727	1.47	5,924	2,996	8,920

Average annual precipitation for the period = 32.64 inches

Average annual potential evapotranspiration = 31.9 inches

Average annual surface yield after transmission losses = 24,824 Acre-Feet

Average annual deep percolation loss
(i.e. best estimate of base-flow) = 7,416 Acre-Feet

Average annual estimate of total yield = 32,240 Acre-Feet

Table 16

TABLE 17

Watershed Yield Summary
Lightning Creek Basin

Year	Reported Yield (Ac.Ft.)	Potential Yield (Ac.Ft.)	Historic Conditions Yield (Ac.Ft.)	Historic Conditions Dep* (%)	Projected Conditions Yield (Ac.Ft.)	Projected Conditions Dep* (%)
1961	211,200	168,815	165,390	26	156,068	9
62	51,020	71,468	68,733	34	62,007	11
63	11,770	11,000	9,566	53	8,954	24
64	55,190	115,020	110,974	33	101,508	12
1965	63,690	96,067	94,243	28	91,124	10
66	14,700	45,363	42,590	39	38,036	13
67	87,000	112,439	108,989	25	104,499	10
68	73,400	100,438	96,869	29	93,744	10
69	112,600	141,275	139,173	17	134,874	6
1970	81,250	117,989	115,254	23	111,825	8
71	89,450	118,368	115,040	23	109,612	8
72	80,720	97,123	94,916	28	93,168	10
73	249,000	233,396	231,349	8	230,808	2
74	225,600	204,782	203,446	13	200,353	4
1975	120,000	113,243	110,913	24	106,510	8
76	53,380	104,678	102,238	21	102,017	6
77	118,500	147,177	144,548	20	142,347	6
78	63,040	70,998	67,525	35	64,206	14
Mean	97,862		112,320			
Standard Deviation	67,387		52,790			

*Note: "Dep" is the percentage of the total depletion volume which was accounted for by ponds in the watershed.

TABLE 18

POTYLD Plot Descriptions
Lightning Creek Basin

Plot	Description*	Curve Numbers Antecedant Moisture Condition I	II	III	Growing Season Dates
1	Terraced wheat [1]	63	80	91	10/01 - 6/25
2	Contoured wheat [1]	70	85	94	10/01 - 6/25
3	Terraced sorghum [1]	63	80	91	5/20 - 10/25
4	Contoured sorghum [1]	75	88	95	5/20 - 10/25
5	Terraced corn [1]	63	80	91	5/15 - 10/20
6	Contoured corn [1]	75	88	95	5/15 - 10/20
7	Contoured soybeans [2]	70	85	94	5/15 - 10/30
8	Contoured soybeans (C soils) [3]	64	81	92	5/15 - 10/30
9	Pasture [1]	66	82	92	3/20 - 11/10
10	Pasture (C soils) [5]	59	77	89	3/20 - 11/10
11	Woods [5]	40	60	78	3/20 - 11/10
The following plots were added for the Projected Conditions runs.					
12	Terraced soybeans [3]	59	77	89	5/15 - 10/30
13	Mulched soybeans [2]	63	80	91	5/15 - 10/30
14	Improved pasture [1]	62	79	91	3/20 - 11/10
15	Improved woods [5]	35	55	74	3/20 - 11/10
16	Improved pasture (C soils) [5]	55	74	88	3/20 - 11/10

*The number in brackets represents the Irrigation Design Group for the plot.

TABLE 19

Land Use Conditions
Lightning Creek Basin

Year	Total No. of Ponds	Percentage of the basin represented by plot: 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1961	214	5	13	2	2	2	7	6	15	26	12	10	0	0	0	0	0
62	225	5	8	2	2	2	8	7	17	27	12	10	0	0	0	0	0
63	235	5	8	2	2	3	9	6	16	27	12	10	0	0	0	0	0
64	252	6	10	2	3	3	8	5	12	29	12	10	0	0	0	0	0
1965	261	6	9	2	3	3	8	6	15	26	12	10	0	0	0	0	0
66	268	6	7	2	3	3	8	5	14	30	12	10	0	0	0	0	0
67	278	6	10	3	2	3	5	6	14	29	12	10	0	0	0	0	0
68	282	6	7	3	2	3	6	6	15	30	12	10	0	0	0	0	0
69	286	7	5	3	4	3	4	6	15	31	12	10	0	0	0	0	0
1970	292	7	4	3	8	3	3	6	14	30	12	10	0	0	0	0	0
71	301	7	6	3	15	3	2	5	12	25	12	10	0	0	0	0	0
72	316	7	4	4	9	3	2	6	14	29	12	10	0	0	0	0	0
73	331	7	2	5	10	3	0	7	18	26	12	10	0	0	0	0	0
74	338	7	6	5	9	3	0	6	15	27	12	10	0	0	0	0	0
1975	348	7	3	5	12	3	0	6	14	28	12	10	0	0	0	0	0
76	356	7	7	5	8	3	0	5	11	32	12	10	0	0	0	0	0
77	359	7	4	5	9	3	0	5	12	33	12	10	0	0	0	0	0
78	364	5	0	7	9	3	0	6	16	32	12	10	0	0	0	0	0

Following is the land use conditions within the watershed's "typical" pond drainage area:

Pond	-	5	5	4	4	4	4	5	13	34	11	11	0	0	0	0	0

Following is the Projected Conditions land use for the basin as a whole:

All	375	9	0	15	0	3	0	0	0	0	0	0	15	6	30	10	12

Following is the land use condition within the watershed's "typical" pond drainage area for the Projected Conditions model:

Pond	-	9	0	9	0	6	0	0	0	0	0	0	13	7	34	11	11

COMPONENTS OF ANNUAL WATERSHED YIELD ESTIMATES

LIGHTNING CREEK
Historic conditions--McCune precipitation

YEAR	ANNUAL PRECIP (In.)	YIELD FROM DEPLETE (Ac.Ft.)	TRANSMISSION LOSS FACTOR	SURFACE YIELD (Ac.Ft.)	DEEP PERCOLATION (Ac.Ft.)	ANNUAL YIELD (Ac.Ft.)
1961	49.47	119,434	1.02	116,693	35,744	152,437
1962	31.32	47,640	1.14	41,709	259	41,968
1963	20.06	11,301	1.61	7,006	0	7,006
1964	40.12	90,294	1.05	85,857	907	86,764
1965	35.43	66,583	1.09	61,274	8,821	70,095
1966	30.83	29,920	1.15	25,991	81	26,072
1967	42.64	99,727	1.04	95,863	5,801	101,664
1968	38.33	76,909	1.06	72,387	9,654	82,041
1969	42.76	90,242	1.04	86,783	18,002	104,785
1970	43.43	131,217	1.04	126,477	14,940	141,417
1971	44.35	101,707	1.03	98,311	14,473	112,784
1972	38.40	99,517	1.06	93,707	19,242	112,949
1973	52.82	140,959	1.02	138,266	76,662	214,928
1974	48.09	147,344	1.03	143,644	40,173	183,817
1975	36.95	59,534	1.07	55,494	23,652	79,146
1976	40.27	118,528	1.05	112,789	12,900	125,689
1977	51.08	127,176	1.02	124,520	26,416	150,936
1978	35.44	64,250	1.09	59,132	20,444	79,576

Average annual precipitation for the period = 40.10 inches

Average annual potential evapotranspiration = 32.7 inches

Average annual surface yield after transmission losses = 85,884 Acre-Feet

Average annual deep percolation loss
(i.e. best estimate of base-flow) = 18,232 Acre-Feet

Average annual estimate of total yield = 104,115 Acre-Feet

Table 20

COMPONENTS OF ANNUAL WATERSHED YIELD ESTIMATES

LIGHTNING CREEK
Historic conditions--Girard precipitation

YEAR	ANNUAL PRECIP (In.)	YIELD FROM DEPLETE (Ac.Ft.)	TRANSMISSION LOSS FACTOR	SURFACE YIELD (Ac.Ft.)	DEEP PERCOLATION (Ac.Ft.)	ANNUAL YIELD (Ac.Ft.)
1961	52.13	152,357	1.02	149,346	27,078	176,424
1962	39.66	87,561	1.05	83,059	8,474	91,533
1963	22.31	15,972	1.45	10,981	765	11,746
1964	45.14	131,489	1.03	127,375	4,223	131,598
1965	42.02	98,975	1.04	94,917	19,897	114,814
1966	32.92	60,391	1.12	54,074	2,586	56,660
1967	44.39	114,576	1.03	110,764	4,465	115,229
1968	40.64	106,941	1.05	101,946	7,554	109,500
1969	48.79	142,978	1.02	139,551	28,915	168,466
1970	37.55	86,315	1.07	80,814	12,154	92,968
1971	46.03	109,023	1.03	105,844	11,118	116,962
1972	38.89	71,828	1.06	67,839	11,715	79,554
1973	59.99	167,555	1.02	165,055	80,283	245,338
1974	53.58	171,000	1.02	167,846	52,322	220,168
1975	45.32	100,882	1.03	97,771	40,203	137,974
1976	32.09	78,711	1.13	69,699	12,562	82,261
1977	48.35	128,168	1.03	125,006	14,100	139,106
1978	33.87	48,461	1.10	43,889	13,371	57,260

Average annual precipitation for the period = 42.43 inches

Average annual potential evapotranspiration = 32.7 inches

Average annual surface yield after transmission losses = 99,765 Acre-Feet

Average annual deep percolation loss
(i.e. best estimate of base-flow) = 19,544 Acre-Feet

Average annual estimate of total yield = 119,309 Acre-Feet

Table 21

COMPONENTS OF ANNUAL WATERSHED YIELD ESTIMATES

LIGHTNING CREEK
Projected conditions--McCune precipitation

YEAR	ANNUAL PRECIP (In.)	YIELD FROM DEPLETE (Ac.Ft.)	TRANSMISSION LOSS FACTOR	SURFACE YIELD (Ac.Ft.)	DEEP PERCOLATION (Ac.Ft.)	ANNUAL YIELD (Ac.Ft.)
1961	49.47	94,801	1.02	92,625	53,343	145,968
1962	31.32	34,437	1.14	30,150	2,837	32,987
1963	20.06	7,228	1.61	4,481	263	4,744
1964	40.12	76,053	1.05	72,316	6,789	79,105
1965	35.43	52,555	1.09	48,364	19,482	67,846
1966	30.83	20,978	1.15	18,224	1,368	19,592
1967	42.64	84,272	1.04	81,007	15,904	96,911
1968	38.33	62,175	1.06	58,519	20,391	78,910
1969	42.76	73,146	1.04	70,342	32,145	102,487
1970	43.43	111,724	1.04	107,688	30,228	137,916
1971	44.35	80,327	1.03	77,645	31,751	109,396
1972	38.40	84,376	1.06	79,450	32,323	111,773
1973	52.82	115,914	1.02	113,700	101,942	215,642
1974	48.09	124,403	1.03	121,279	57,289	178,568
1975	36.95	47,463	1.07	44,242	34,162	78,404
1976	40.27	104,106	1.05	99,065	23,510	122,575
1977	51.08	105,216	1.02	103,018	48,608	151,626
1978	35.44	51,804	1.09	47,678	27,509	75,187

Average annual precipitation for the period = 40.10 inches

Average annual potential evapotranspiration = 32.7 inches

Average annual surface yield after transmission losses = 70,544 Acre-Feet

Average annual deep percolation loss
(i.e. best estimate of base-flow) = 29,991 Acre-Feet

Average annual estimate of total yield = 100,535 Acre-Feet

Table 22

COMPONENTS OF ANNUAL WATERSHED YIELD ESTIMATES

LIGHTNING CREEK
Projected conditions--Girard precipitation

YEAR	ANNUAL PRECIP (In.)	YIELD FROM DEPLETE (Ac.Ft.)	TRANSMISSION LOSS FACTOR	SURFACE YIELD (Ac.Ft.)	DEEP PERCOLATION (Ac.Ft.)	ANNUAL YIELD (Ac.Ft.)
1961	52.13	122,825	1.02	120,398	44,274	164,672
1962	39.66	70,697	1.05	67,062	19,665	86,727
1963	22.31	10,206	1.45	7,017	5,523	12,540
1964	45.14	110,753	1.03	107,288	13,304	120,592
1965	42.02	79,192	1.04	75,945	35,008	110,953
1966	32.92	49,789	1.12	44,581	9,166	53,747
1967	44.39	99,385	1.03	96,078	14,885	110,963
1968	40.64	89,238	1.05	85,070	21,311	106,381
1969	48.79	122,474	1.02	119,539	42,925	162,464
1970	37.55	70,367	1.07	65,883	23,717	89,600
1971	46.03	87,860	1.03	85,298	24,498	109,796
1972	38.89	57,290	1.06	54,108	23,212	77,320
1973	59.99	138,229	1.02	136,167	107,560	243,727
1974	53.58	146,414	1.02	143,713	75,197	218,910
1975	45.32	80,946	1.03	78,450	52,003	130,453
1976	32.09	66,241	1.13	58,656	25,848	84,504
1977	48.35	109,151	1.03	106,458	27,985	134,443
1978	33.87	39,052	1.10	35,367	19,484	54,851

Average annual precipitation for the period = 42.43 inches

Average annual potential evapotranspiration = 32.7 inches

Average annual surface yield after transmission losses = 82,615 Acre-Feet

Average annual deep percolation loss
(i.e. best estimate of base-flow) = 32,531 Acre-Feet

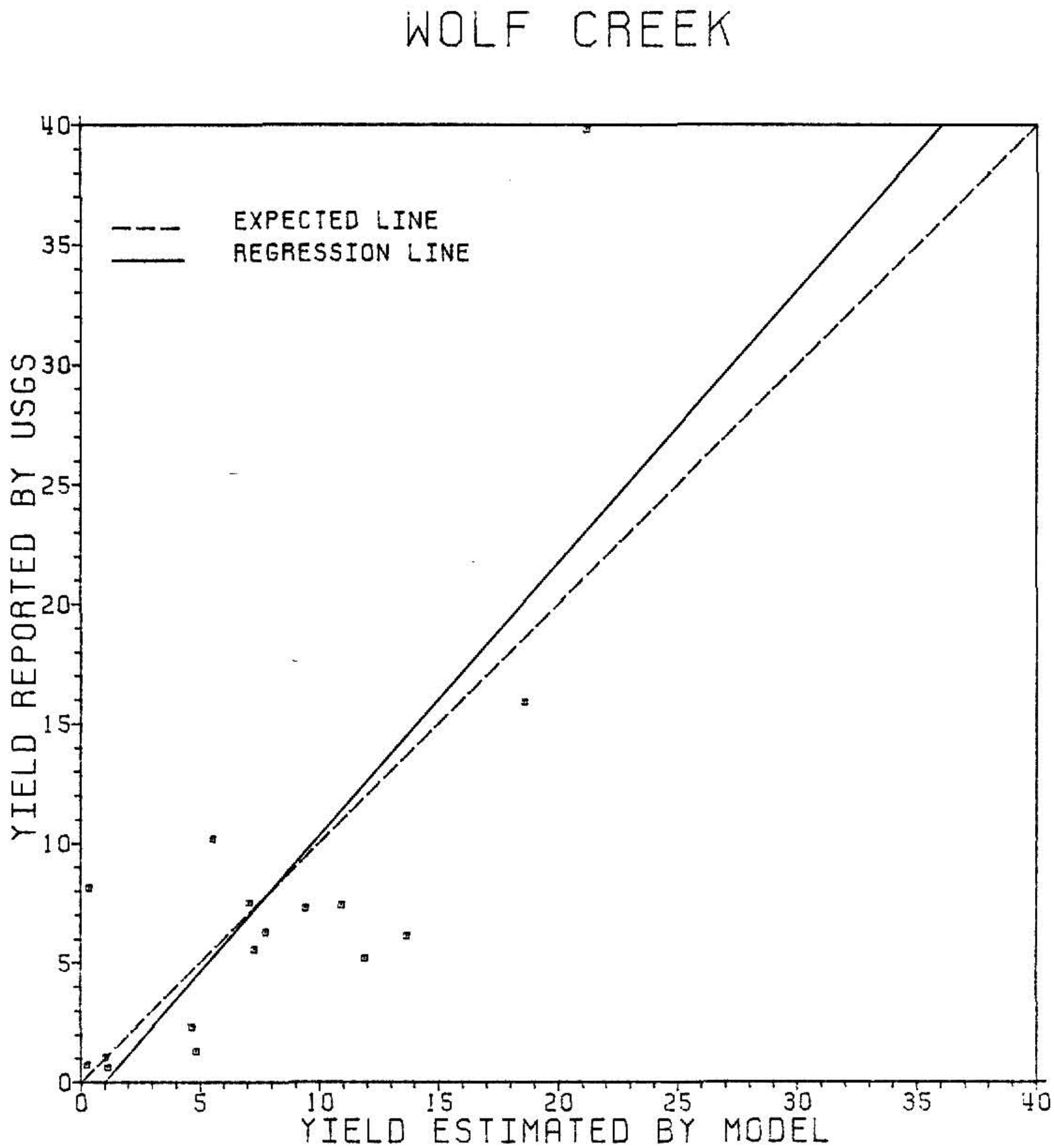
Average annual estimate of total yield = 115,147 Acre-Feet

Table 23

APPENDIX C

Plots of Model Yield versus that Reported

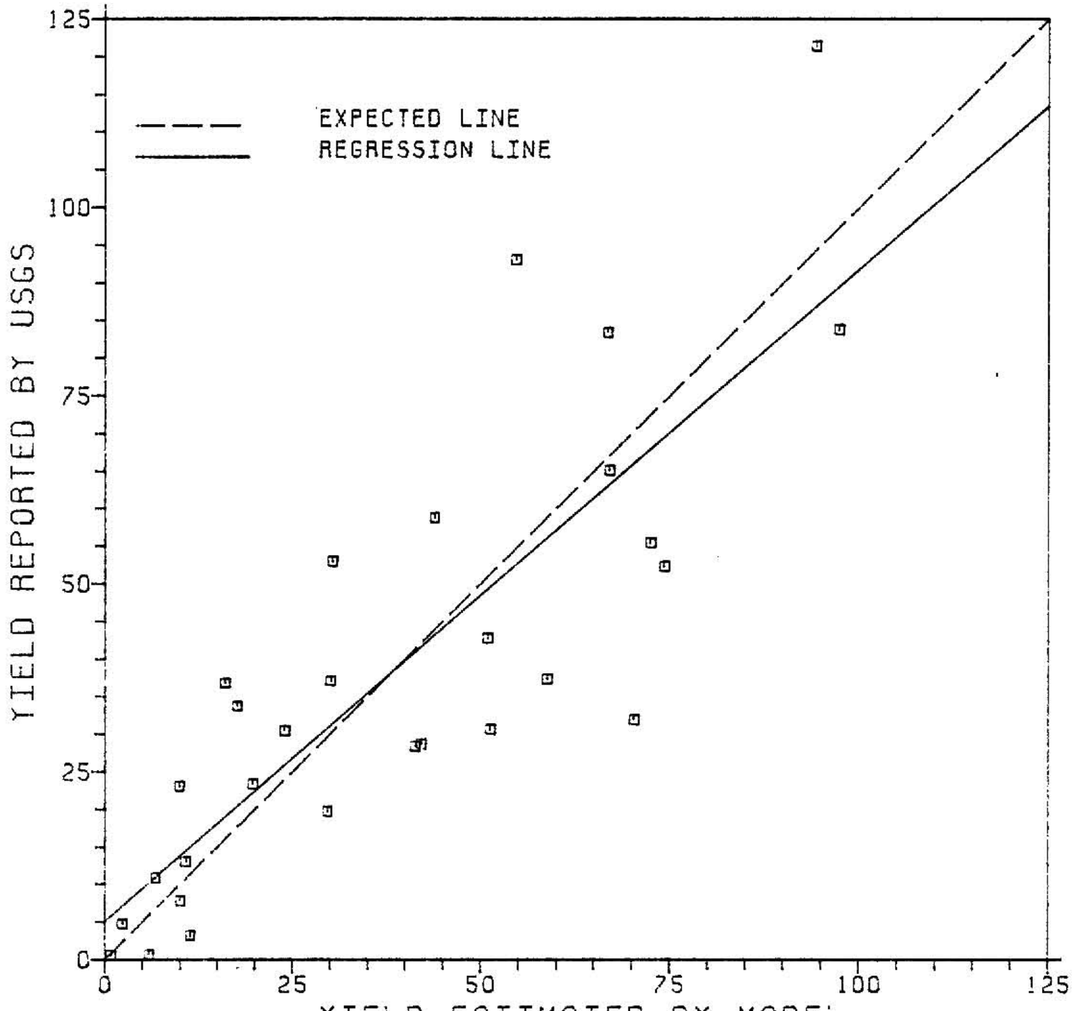
by USGS for the No Base-flow Model



WATERSHED YIELD ESTIMATED BY MODEL
COMPARED TO THAT REPORTED BY USGS
--MODELING WITHOUT A BASE-FLOW ESTIMATE--
(UNITS ARE 1000'S OF ACRE-FEET/YEAR)

Figure 21

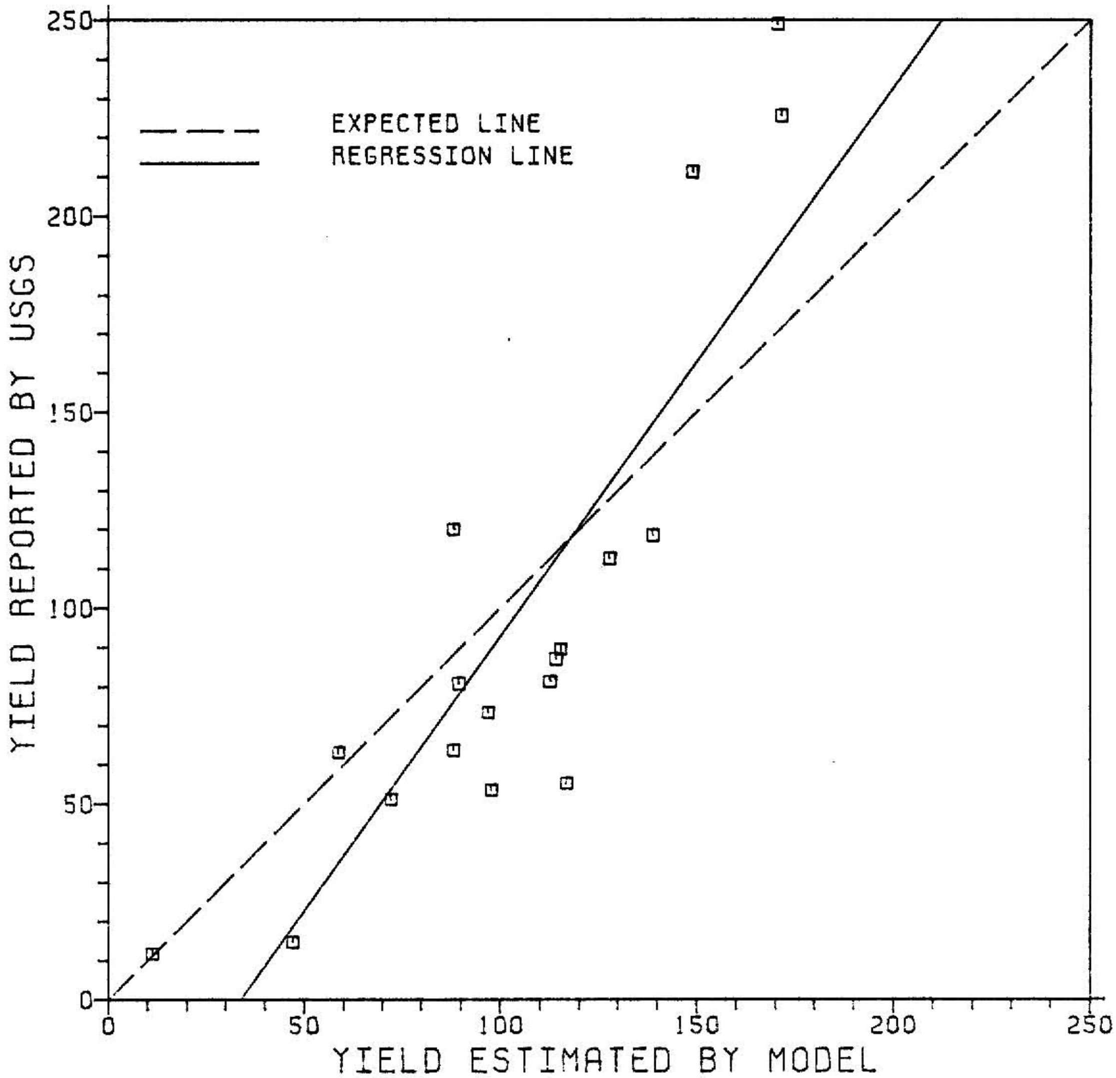
CEDAR CREEK



WATERSHED YIELD ESTIMATED BY MODEL
COMPARED TO THAT REPORTED BY USGS
--MODELING WITHOUT A BASE-FLOW ESTIMATE--
(UNITS ARE 1000'S OF ACRE-FEET/YEAR)

Figure 22

LIGHTNING CREEK



WATERSHED YIELD ESTIMATED BY MODEL
COMPARED TO THAT REPORTED BY USGS
--MODELING WITHOUT A BASE-FLOW ESTIMATE--
(UNITS ARE 1000'S OF ACRE-FEET/YEAR)

Figure 23

APPENDIX D

Summary of Modifications Made to the

Computer Programs for this Study

Alterations to the POTYLD Program

In September, 1982, a few corrections and alterations of the Potential Yield program (POTYLD) were made. The following list briefly describes these changes and the changes themselves are shown on the attached sheets. Most of these changes are easily found because the new lines lack line numbers (on the right-hand side of the listing).

Runs made with this updated model indicate that the changes made have only a moderate influence on the model's results. Although the numerical results may be altered, conclusions drawn from runs of older versions of POTYLD should not be adversely affected by these changes.

Main Program

1. Page 3: Lines PY 1720 and 1730 were revised to provide a more reasonable initial soil moisture. Note that a line was added before PY 1720 also.

2. Page 4: Line PY 2650 was revised and line PY 2290 removed to eliminate MSTART (month to start the simulation run) from the variable list. The model does not function properly unless MSTART is 1, so MSTART has been replaced by 1. MSTART is in NAMELIST OMEGA; to remove it revise line PY 680. MSTART need not be removed from this NAMELIST since it will not be used.

3. Page 4: Line PY 2840 was removed and lines PY 2850 and 2880 thru 2900 were revised, since MSTART was removed from the program.

4. Page 5: Lines PY 3450 and 3460 were corrected. The wrong index had previously been used. This revision alters the program's output.

Subroutine CROPCO

5. Page 6: Line CRP 160 was revised to eliminate the data portion of the statement (related to the next item).

6. Page 6: Between lines CRP 290 and 300 a DO-loop was added to place zeroes in all arrays local to CROPCO at each call to the subroutine. Previously, some spurious crop coefficients existed in the KCROP array because this was not done. This change alters the program's output.

Subroutine IART

7. Page 7: Line IA 150 was modestly revised--.LT. becomes .LE. There is little apparent change in the programs's output due to this alteration.

Subroutine SNOWRT

8. Page 8: Between lines SNO 100 and 110 a line was added. There is little change in the output caused by this addition.

```
      DO 120 J=1,12
  120 KCROP(7,J) = 0.0
      DO 130 II=1,NPLOTS
      IF (POND(II).NE.1) DA = DA+AREA(II)
      TPAREA = TPAREA+AREA(II)
      T(II) = 0.0
      EO(II) = 0.0
      IAET(II) = 0.0
      DSRNFF(II) = 0.0
      AINTER(II) = 0.0
      AAETRS(II) = 0.0
      ACHSOM(II) = 0.0
      DSPERC(II) = 0.0
C     *****  THE FOLLOWING LINE WAS ADDED IN SEPTEMBER, 1982
      SOIL = ISOIL(II)
C     *****   FOLLOWING 2 LINES REVISED SEPTEMBER, 1982
      SMLZ(II) = 0.5*AVLFCL(SOIL) + PWPLZ(SOIL)

      SMUZ(II) = 0.5*AVLFCU(SOIL) + PWPUZ(SOIL)
      SMGWZ(II) = 6.30
      SMPD(II) = SMLZ(II)+SMUZ(II)
C     *****   ESTABLISH FALLOW SUBAREAS FOR BEGINNING OF SIMULATION
  130 IF (ROTATE(II).EQ.2) ICRCP(II) = 7
C     *****   PUNCH VALUE OF DA FOR DEPLETE
      IF (OUTPUT.GT.2) WRITE (7,140) DA
  140 FORMAT (F10.2)
      YEARS = YEND-YSTART+1
C     *****
C     *****   PRINT INPUT PARAMETERS
C     *****
```

```
C     *****
C     *****   ***** ENTER MONTHLY LOOP *****
C     *****
C     *****  MONTHLY LOOP ALTERED IN SEPTEMBER, 1982 TO ELIMINATE
C     *****  MSTART FROM THE VARIABLE LIST (NAMELIST OMEGA).
C     *****   FOLLOWING LINE REVISED IN SEPTEMBER, 1982
      DO 710 NM=1,12
C     *****
C     *****   ESTABLISH CROP ROTATIONS FOR WHEAT
      DO 290 II=1,NPLOTS
      IROT = ROTATE(II)
      GO TO (290,270,280), IROT
C     *****   IROT=2 FOR A WHEAT HARVESTING YEAR ('WHEAT YEAR')
  270 IF (NM.GT.MGSEP(II)) ICROP(II) = 7
      GO TO 290
C     *****   IROT=3 FOR A WHEAT PLANTING YEAR ('FALLOW YEAR')
  280 IF (NM.GE.MGSBP(II)) ICROP(II) = INCROP(II)
  290 CCNTINLE
C     *****   READ DAILY METEORCLOGICAL DATA FOR ONE MONTH
  300 READ (4,310,END=970) KAN,STIND,YEAR,MONTH,(PREC(I),I=1,31),(TMAX(I
     1),I=1,31),(TMIN(I),I=1,31)
  310 FORMAT (I2,I4,2I2,31F4.2,62F3.0)
      IF (STIND.NE.INDST) GO TO 300
      IF (YEAR.LT.YSTART-1900) GO TO 300
      IF (YEAR.GT.YEND-1900) GO TO 970
C     *****  A LINE WAS REMCVED AT THIS POINT IN SEPTEMBER, 1982
C     *****   FOLLOWING LINE REVISED IN SEPTEMBER, 1982
      IF (MONTH.GT.NM.AND.YEAR.EQ.(YSTART-1900)) GOTO 320
      GO TO 340
  320 IPLLS1 = YSTART+1
C     *****   FOLLOWING 3 LINES REVISED SEPTEMBER, 1982
      WRITE (6,330) MONTH,YSTART,IPLUS1
  330 FORMAT (///'MONTHLY WEATHER DATA STARTS IN ',I2,'/',I4,'.  THE SIM
     1ULATION PERIOD WILL START IN 01/',I4,'.')
      YSTART = YSTART+1
      GO TO 300
  340 NDIM(2) = 28
      IF (NM.EQ.2.AND.TMAX(29).LT.900) NDIM(2) = 29
      NDAYS = NDIM(NM)
```

```
C       *****                                                          PY 3350
C       *****    ***** ENTER SUBAREA LOOP *****                        PY 3360
C       *****                                                          PY 3370
        DO 580 JJ=1,NPLOTS                                             PY 3380
C       *****                                                          PY 3390
        STRNOF = 0.0                                                   PY 3400
        CROP = ICROP(JJ)                                               PY 3410
        SOIL = ISOIL(JJ)                                               PY 3420
        KROPKU = KCROP(CROP,NM)                                        PY 3430
        ZSMUZ = SMUZ(JJ)                                               PY 3440
C       *****    FOLLOWING 2 LINES REVISED SEPTEMBER, 1982
        ZPWPUZ = PWPUZ(SOIL)                                           PY 3450
        ZAVFCU = AVLFCU(SOIL)                                          PY 3460
        RCN1 = RCNI(JJ)                                                PY 3470
        RCN2 = RCNII(JJ)                                               PY 3480
        RCN3 = RCNIII(JJ)                                              PY 3490
        ZFCU = FCU(SOIL)                                               PY 3500
        ZIAET = IAET(JJ)                                               PY 3510
        ZSM = SM(JJ)                                                   PY 3520
        IF (RAIN) 370,370,360                                          PY 3530
C       *****    SUBROUTINE RNCFRT EVALUATES PRECIPITATION EXCESS USING PY 3540
C       *****     THE SCS EQUATION.                                    PY 3550
```

```
C     MONTH AND DAY GROWING BEGINS ANC ENDS, NUMBER OF DAYS IN EACH
C     MONTH, AND THE MEAN MCNTHLY AVERAGE TEMPERATURES IN FAHRENHEIT
C     DEGREES.
      INTEGER CROP,DGSB,DGSE
      INTEGER NDIM(12),SHIFT
C     FOLLOWING LINE REVISEC IN SEPTEMBER, 1982
      REAL MID(12),DBMD(12),ACC(12),PCGS(12)
      REAL MMAT(12),KT(12),KCROP(7,12),PCGS1(12)
C     ACC=ACCUMULATIVE DAYS IN GROWING SEASON
C     MGSB=MONTH GROWING SEASCN BEGINS EXPRESSED NUMERICALLY IE 1-12
C     DGSB=DAY GROWING SEASCN BEGINS EXPRESSED NUMERICALLY
C     MGSE=MONTH GROWING SEASON ENDS EXPRESSED NUMERICALLY IE 1-12
C     DGSE=DAY GROWING SEASCN ENDS EXPRESSED NUMERICALLY
C     MID=MEDIAN DATES OF THE MONTHS IN THE GROWING SEASON
C     DBMD=DAYS BETWEEN MID DATES
C     PCGS=PERCENT OF GROWING SEASON REACHED AT MID DATES
C     MMAT=MEAN MONTHLY AVERAGE TEMPERATURES
C     MGSB1=TEMPORARY STORAGE FCR MGSB
C     MGSE1=TEMPORARY STORAGE FOR MGSE
C     PCGS1=TEMPORARY STORAGE FOR PCGS
C
C     THE FOLLOWING LOOP (DC 5) WAS ACDED IN SEPTEMBER, 1982 TO ZERC
C     THE ARRAYS LCCAL TO CROPCC FOR EACH CALL TO THE SUBROUTINE.
      DO 5 I=1,12
      PCGS(I) = 0.0
      PCGS1(I) = 0.0
      MID(I) = 0.0
      DBMD(I) = 0.0
      ACC(I) = 0.0
    5 CONTINUE
      MGSB1 = MGSB
      MGSE1 = MGSE
      IF (MGSB.GT.MGSE) GO TO 10
```

```
      IA = 0.1
      IASTOR = IAET-PET
C     *****   FOLLOWING LINE REVISED IN SEPTEMBER, 1982
      IF (KRCPKO.LE.0.0) IASTOR = IAET-PETBS
      IF (IASTOR.GT.0.1) IASTOR = 0.1
      IF (IASTOR.LE.0.0) IASTOR = 0.0
      IF (IA.GT.P) IA = P
      IF ((IA+IASTOR).GE.0.1) IA = 0.1-IASTOR
      XIAET = IAET+IASTOR
      RETURN
      END
```

```
      SUBROUTINE SNOWRT (PRECIP,WATER,PACK,PET,TEMPAV,SNOVAP)
C     *****
C     *****   SUBROUTINE SNOWRT CALCULATES THE MOISTURE ADDED TO THE
C     *****    SUBAREA DUE TO MELT OF THE SNOWPACK
C     *****
      REAL M,MA,MR
      M = 0.0
C     *****   SNOVAP=DEDUCTION FROM THE MOISTURE STORED IN THE
C     *****    SNOWPACK DUE TO SUBLIMATION (INCHES)
      IF (PACK.GT.0.1) SNOVAP = PET
C     *****  THE FOLLOWING LINE WAS ADDED IN SEPTEMBER, 1982
      IF (SNOVAP.GT.PACK) SNOVAP=PACK
      PACK = PACK-SNOVAP
      IF (SNOVAP.GT.0.0) PET = 0.0
      IF (TEMPAV-32.) 10,10,20
   10 IF (PRECIP) 70,70,30
   20 IF (PACK) 90,90,40
   30 PACK = PACK+PRECIP
      WATER = 0.0
      GO TO 90
C     *****   MA=SNOWMELT DUE TO ATMOSPHERIC CONDITIONS (INCHES)
   40 MA = 0.05*(TEMPAV-34.)
      IF (MA.LT.0.0) MA = 0.0
      IF (PACK-MA) 60,60,50
C     *****   MR=SNOWMELT DUE TO RAIN (INCHES)
   50 MR = (PRECIP*(TEMPAV-32.))/144
```

MODELING THE EFFECTS OF SOIL AND WATER CONSERVATION PRACTICES ON WATERSHED YIELDS IN CENTRAL AND EASTERN KANSAS

by

MATHIAS A. SCHERER III

B.S., Kansas State University, 1979

AN ABSTRACT OF A MASTER'S THESIS

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MASTER OF SCIENCE

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1983

ABSTRACT

Future water supply plans for Eastern Kansas involve a considerable increase in the use of existing and future surface reservoirs. Studies have indicated that similiar reservoirs in Western Kansas, built for irrigation water supply, have suffered significant reductions in inflow caused by the increased application of soil and water conservation measures upstream of the structures. This points to a need to examine the possibility and extent of similiar effects upon Eastern Kansas drainage basins.

A previously developed hydrologic model has been used to simulate three small watersheds in Central and Eastern Kansas. These simulations indicate that changes in conservation practices have reduced potential long-term watershed yields by as much as 4.1 percent. The conservation practices with substantial impact include small farm ponds, terraces, and cultural practices which leave plant residue on the surface. Future improvements in conservation practices may increase yield depletions to as high as 15 percent in Central Kansas and 5.7 percent in the Southeastern corner of the state. Under these future land-use conditions, single, dry year depletions of as much as 59 percent in Central Kansas and 19 percent in Eastern Kansas were modeled. This indicates that conservation measures will have an appreciable impact upon reservoir operations in the more humid, eastern portions of Kansas, although they will not be as severe as those predicted for the drier, western part of the state.