SIMULATION OF THE EFFECTS OF MANAGEMENT ALTERNATIVES ON THE STREAM-AQUIFER SYSTEM, SOUTH FORK SOLOMON RIVER VALLEY BETWEEN WEBSTER RESERVOIR AND WACONDA LAKE, NORTH-CENTRAL KANSAS

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CONVERSION FACTORS

For those readers who would prefer to use the International System (SI) of Units rather than the inch-pound units given in this report, the following conversion factors are presented:

Multiply inch-pound unit	By	To obtain SI unit
inch	25.40	millimeter
foot	0.3048	meter
acre	4,047	square meter
square mile	2.590	square kilometer
acre-foot	1,233	cubic meter
foot per second (ft/s)	0.3048	meter per second
foot per day (ft/d)	0.3048	meter per day
foot per year (ft/yr)	0.3048	meter per year
cubic foot per second (ft^3/s)	0.4719	liter per second
gallon per minute (gal/min)	0.06308	liter per second
cubic foot per square foot (ft^3/ft^2)	0.3048	cubic meter per square meter

SIMULATION OF THE EFFECTS OF MANAGEMENT ALTERNATIVES ON THE STREAM-AQUIFER, SOUTH FORK SOLOMON RIVER VALLEY BETWEEN WEBSTER RESERVOIR AND WACONDA LAKE, NORTH-CENTRAL KANSAS

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ABSTRACT

The South Fork Solomon River valley between Webster Reservoir and Waconda Lake, north-central Kansas, has an area of about 100 square miles, of which 10,000 acres are used for agriculture. Extensive irrigation uses both surface- and ground-water supplies. Shortages of surface water, particularly during 1972 and 1978 when no surface water was available for irrigation, have required the extensive development of irrigation wells to meet irrigation-water demand.

A two-dimensional digital model of transient ground-water flow was applied to investigate the potential effects on the stream-aquifer system of seven management alternatives, proposed by the U.S. Bureau of Reclamation, to determine which might make best use of surface water and ground water. These alternatives included proposals to conserve surface-water supplies by lining the Osborne Irrigation Canal with clay, replacing the lateral canals with pipe, removing phreatophytes, decreasing surface-water use by 75, 50, or 25 percent and replacing it with ground-water sources, and continuing 1978 ground-water use and 1970-78 average surface-water use until the end of the 20th century.

Results were assessed by comparison of drawdowns of hydraulic head in the alluvial aquifer and base flow for each simulation. As listed in order of the smallest to the greatest potential effects on the system relative to drawdown and base flow, the alternatives are: (1) Removal of one-half of the phreatophytes; (2) continuation of 1978 ground-water withdrawals and average 1970-78 surface-water supply; (3) replacement of the lateral canals with pipe; (4) lining the Osborne Irrigation Canal with clay; (5) decrease of surface-water use by 25 percent and replacement of it with ground water; (6) decrease of surface-water use by 50 percent and replacement of it with ground water; and (7) decrease of surface-water use by 75 percent and replacement of it with ground water. The removal of one-half of the phreatophytes would result in a decrease in average drawdown in the alluvial aquifer to about 1.74 feet and an increase in base flow of the Solomon River to about 12.3 cubic feet per second. The decrease of surface-water supply by 75 percent and a corresponding increase in ground-water withdrawal would result in an increase in drawdown in the aquifer to about 2.5 feet and a decrease in base flow to about 6.8 cubic feet per second.

INTRODUCTION

Agricultural irrigation uses both surface- and ground-water supplies from the stream-aquifer system of the South Fork Solomon River valley between Webster Reservoir and Waconda Lake, north-central Kansas. Releases from Webster Reservoir, at the upstream end of this reach, supply as much as one-half of the water used for irrigation. During the 1970's there were shortages of water in Webster Reservoir, particularly during 1972 and 1978 when no stored water was available for irrigation. Since the early 1970's, use of irrigation wells in the study area has increased substantially to compensate for the shortage of surface water.

Location and Description of Study Area

The study area, as shown in figure 1, is about 100 square miles in Rooks and Osborne Counties in north-central Kansas. About 15.6 percent of the area (10,000 acres) is cultivated in cropland. The valley floor is nearly flat with some terraces along the valley sides. The valley is underlain by an alluvial, unconfined aquifer consisting of interbedded sand, gravel, silt, and clay of Pleistocene age lying on relatively impermeable Cretaceous rocks. The alluvial aquifer has virtually no

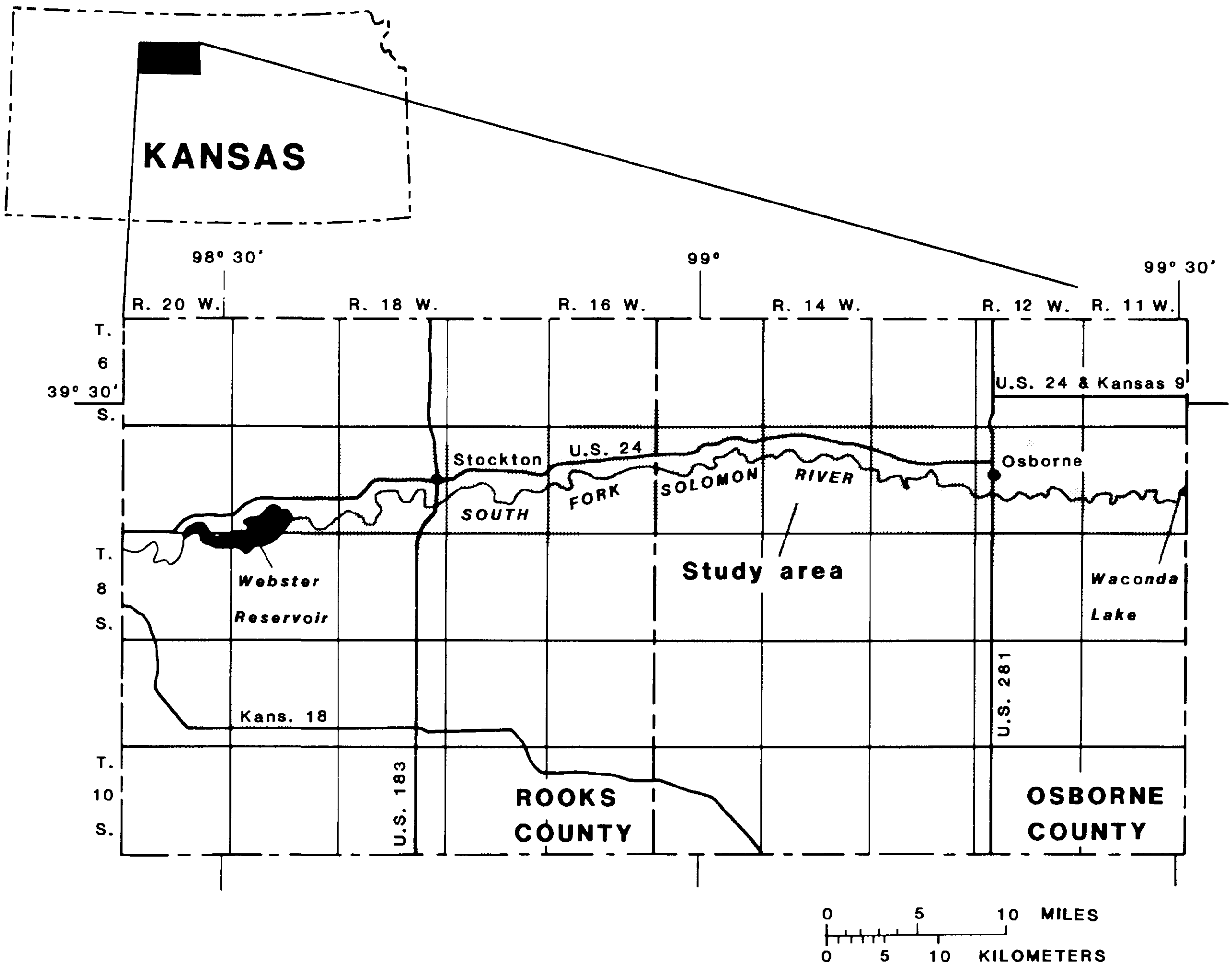

Figure 1.--Location of study area.

lateral hydraulic connection to the adjacent upland, which is the regionally important Ogallala Formation of late Tertiary age. Average annual precipitation in the study area is about 24 inches. Average annual lake evaporation is about 50 inches.

Purpose and Scope

The purpose of this study was to analyze the simulated effects of several different management alternatives proposed by the U.S. Bureau of Reclamation on the potentiometric surface of the alluvial aquifer (average drawdown) and base flows in the South Fork Solomon River using the computer model documented in Burnett and Reed (1982). Changes in appropriate model sources and sinks were utilized to simulate the following hypothetical management alternatives:

1. Lining the remaining 84 percent of the Osborne Irrigation Canal with clay to decrease leakage by infiltration,

2. Replacing 70 percent of the canal laterals with pipe,

3. Removal of one-half of the phreatophytes along the stream,

4. Decreasing the availability of the surface water to the canal system by 75 percent and increasing ground-water pumpage to compensate,

5. Alternative 4 with 50-percent less surface water,

6. Alternative 4 with 25-percent less surface water,

7. Continuation of 1978 conditions--ground-water withdrawal at 1978 rate and surface-water supply to the canal at 1970-78 average rate.

Previous Investigations

The geohydrology and a digital computer model of the stream-aquifer system in South Fork Solomon River valley between Webster Reservoir and Waconda Lake were described in an initial report by Burnett and Reed (1982). The report was a cooperative study with the U.S. Bureau of Reclamation and the Kansas Geological Survey. The digital computer model developed by Burnett and Reed (1982) to simulate two-dimensional ground-water flow in the stream-aquifer system from 1970 to 1978 was used in this study for further simulations.

DESCRIPTION OF THE STREAM-AQUIFER SYSTEM

In the reach between Webster Reservoir and Waconda Lake, the South Fork Solomon River stream-aquifer system may be considered as an interactive unit isolated from the regional Ogallala Formation. Streamflow is controlled by releases from Webster Reservoir. Tributaries within the reach are small. Reservoir releases normally are made only for irrigation purposes; therefore, low flows in the reach accrue from seepage as the river intercepts the water table in the alluvial aquifer.

The aquifer consists of unconsolidated, interbedded sand, gravel, silt, and clay of Pleistocene age deposited in a channel eroded into relatively impermeable Cretaceous rocks. Maximum saturated thickness[1] is about 50 feet near the center of the channel. Drillers' logs of the alluvium are recorded in Stullken (1980). The configuration of the base of the alluvial deposits is shown on plate 1 of Burnett and Reed (1982). In addition, that report contains maps showing the potentiometric surface of water in the alluvial aquifer during 1970 and 1979.

Hydraulic conductivity[2] for the aquifer ranged from 40 to 500 ft/d, based on estimations made and described in Burnett and Reed (1982). They also estimated specific yield[3] of the aquifer to range from 0.15 to 0.25.

The stream, canals, and underlying aquifer interact as a system. Conceptually, flow enters the system from reservoir releases and direct precipitation. Small, but accountable contributions also come from terrace deposits near the downstream end of the reach and from the alluvium of a few of the tributaries. The reservoir releases are transported about 17 miles downstream in the river to a diversion dam. A canal system then distributes the diverted flow to the flood plain north of the river. All of these surface-water conveyances overlie the aquifer and tend to leak water to it. The river also receives water from the aquifer, but the canals cannot because they are elevated above the water table. Flow is removed from the system by evapotranspiration from phreatophytes along the stream banks, consumptive use of ground water and surface water by irrigation, and streamflow out of the reach.

The alluvial aquifer can yield water to or accept water from the river depending on the position of the potentiometric surface of the aquifer relative to the streambed. The canals are above the potentiometric surface at all times and, during irrigation season, leak flow to the aquifer at constant rates. Withdrawals of ground water for irrigation and municipal use can cause water-level changes in the aquifer and changes in the rates and direction of stream-aquifer flow.

DESCRIPTION OF CALIBRATED STREAM-AQUIFER MODEL

The model used in this study is a two-dimensional, finite-difference solution developed by Trescott and others (1976). It was adapted, calibrated, and described for use in the study area by Burnett and Reed (1982). The model features and their relation to physical land features are shown on plate 1.

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1 Saturated thickness is the thickness of aquifer material that is saturated by water (Lohman and others, 1972).

2 Hydraulic conductivity is the volume of water at the existing kinematic viscosity that will move through a porous medium in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow (Lohman and others, 1972).

3 Specific yield is the ratio of the volume of water that rock or soil, after being saturated, will yield by gravity to the volume of the rock or soil (Lohman and others, 1972).

Numerous assumptions need to be made to describe a complex stream-aquifer system for this model. The aquifer is numerically described in the model as being laterally and vertically homogeneous with the coordinate axes co-linear with the principal components of the hydraulic-conductivity tensor. Flow rates for recharge to and discharge from the model (that is, precipitation, evapotranspiration, well discharges) are constant with time within each pumping period of the model.

Model boundaries or interfaces are treated in numerous ways. The upstream end of the reach, Webster Reservoir, was considered to be a constant-head boundary, using the assumption that the reservoir would always contain enough water to maintain leakage through the dam. The downstream end was considered a constant-head boundary, assuming a constant level in Waconda Lake. Most of the north and south sides of the valley were modeled as no-flow boundaries, representing the impermeable valley walls of bedrock. Inflow from alluvium of tributaries was modeled as constant heads, assuming no development or seasonal changes in the water levels of the tributary alluvium and that the calibrated model reasonably modeled ground-water gradients at those locations. There are 12 of these tributary inflows.

The stream-aquifer interface was modeled as if the two units were separated by a permeable membrane 0.6- to 12-feet thick, with a hydraulic conductivity of 0.0000013 ft/s. Water can flow either way through the interface depending on hydraulic-head values in the stream and aquifer. The leak option of the model computing this flow assumes that the hydraulic head of the river remains constant throughout each time step of the simulated period.

Withdrawals by irrigation and municipal wells were treated as constant fluxes (flows which do not change regardless of hydraulic-head gradients). Locations of these wells are noted on plate 4 of Burnett and Reed (1982) and in Stullken (1980). Their aggregate quantity is itemized in model budgets later in the report. The number of large-capacity wells increased from 12 during 1970 to about 93 during 1978. Typical irrigation-well yields range from 200 to 750 gal/min within the study area. Methods for determining irrigation-well rates are based on acres from water-right applications. Acreage irrigated by ground water only received 1.0 ft/yr, and acreage irrigated by both surface water and ground water withdrew 0.5 ft/yr from ground water.

Because ground-water development was not significant prior to 1970, the model was calibrated to simulate the changing (transient) conditions in the aquifer beginning March 1970 and continuing to January 1979. Nineteen pumping periods were used in making the transient simulations from 1970 to 1979. Basically, the pumping periods were set up to simulate two pumping periods per year--one pumping period simulating the nonirrigation season from September through May and another period simulating the irrigation season from June through August.

Leakage from the Osborne Irrigation Canal (main canal--not laterals) was treated as a constant flux (recharge wells) during the irrigation periods. The annual leakage loss noted by operations records was apportioned equally among all main-canal nodes. The assumptions used were that the water level in the canal remained the same during the irrigation period and that infiltration to the aquifer was by unsaturated vertical flow, such that the hydraulic gradient is a function of canal water level only. The annual leakage loss noted by operations records was apportioned equally among all main-canal nodes.

Evapotranspiration was simulated as a constant flux (withdrawal wells) along the course of the river using a withdrawal rate estimated from figures calculated for the North Fork Solomon River by Jorgensen and Stullken (1981, p. 28). The aggregate rate used was 4.76 ft^3/s during irrigation periods and 1.10 ft^3/s during nonirrigation periods.

Recharge from precipitation was applied at a uniform rate across the modeled area during each pumping period. The calibrated rate is 5 to 15 percent of the annual precipitation and ranges from 0.8 inch during 1976 to 4.3 inches during 1973, averaging 2.0 inches throughout the calibration period.

The model calibration used a hydraulic conductivity for the aquifer of 130 ft/d (0.0015 ft/s) and a specific yield of 0.20. All values noted were derived from and documented in Burnett and Reed (1982).

MODIFICATIONS TO CALIBRATED STREAM-AQUIFER MODEL

Modifications to the two-dimensional, finite-difference model developed by Trescott and others (1976) were necessary in order to make the simulations of the various proposed management alternatives. In the original two-dimensional model, the coding is such that when well nodes are desaturated, simulations stop with a message indicating which node or nodes have gone dry. Although this procedure is satisfactory for model-calibration simulations, changes were made to the model so that simulations would continue after nodes containing pumping wells had been desaturated during the projection period. This was accomplished by assigning zero pumping rates to those wells located in the desaturated nodes. The model program was coded so that future pumping rates (after the 1978-79 nonirrigation period) would be read from separate files containing the updated pumping values for each particular management simulation.

An additional program modification was made to reactivate dry nodes during each time step by arbitrarily assigning a saturated thickness of 2 feet to those nodes. This modification was made to allow the nodes to remain active and, thus, to receive recharge, return flow, and ground-water flows from surrounding nodes. Well pumpage in nodes that actually went dry, however, remained zero. Also, modifications were made to allow the constant-flux values, representing canal leakage and surface-water return, to remain active after a node goes dry.

RESULTS OF SIMULATED MANAGEMENT ALTERNATIVES

"Monthly water-distribution" reports by the U.S. Bureau of Reclamation provided the data to develop relationships for net surface-water supplied versus main canal loss, lateral canal loss, and final farm delivery. The relationship of net surface-water supply to main canal loss is shown in figure 2. The relationship of net surface-water supply to lateral canal loss is shown in figure 3, and the relationship of net surface-water supply to farm delivery of water for irrigation is shown in figure 4. A summary of components used in the model simulations is shown in table 1. Values in table 1 for ground-water pumpage are beginning values for the projection, as pumpage is decreased when nodes go dry. Modification of values for each alternative are explained in the discussions for that alternative.

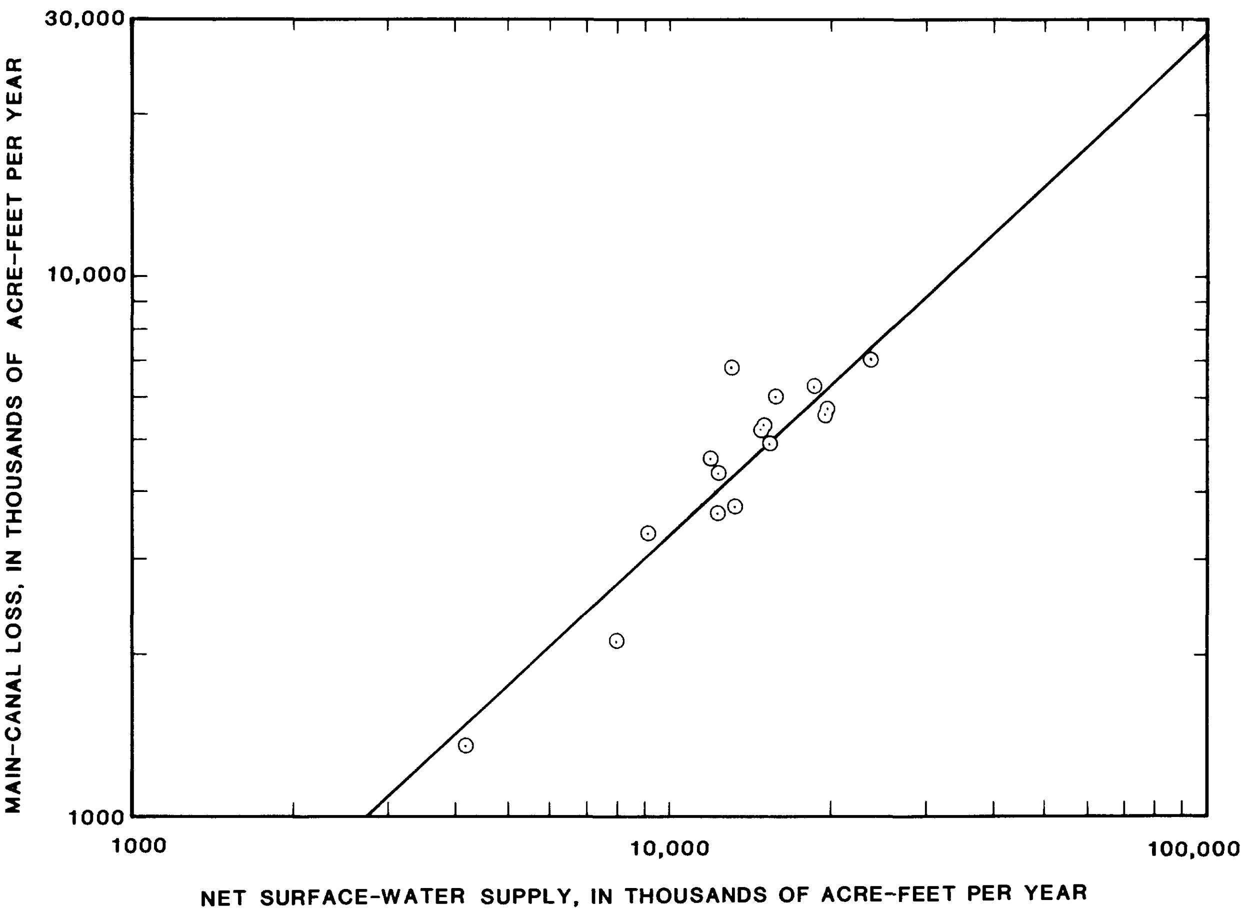

Figure 2.--Relationship between net surface-water supply and main-canal loss.

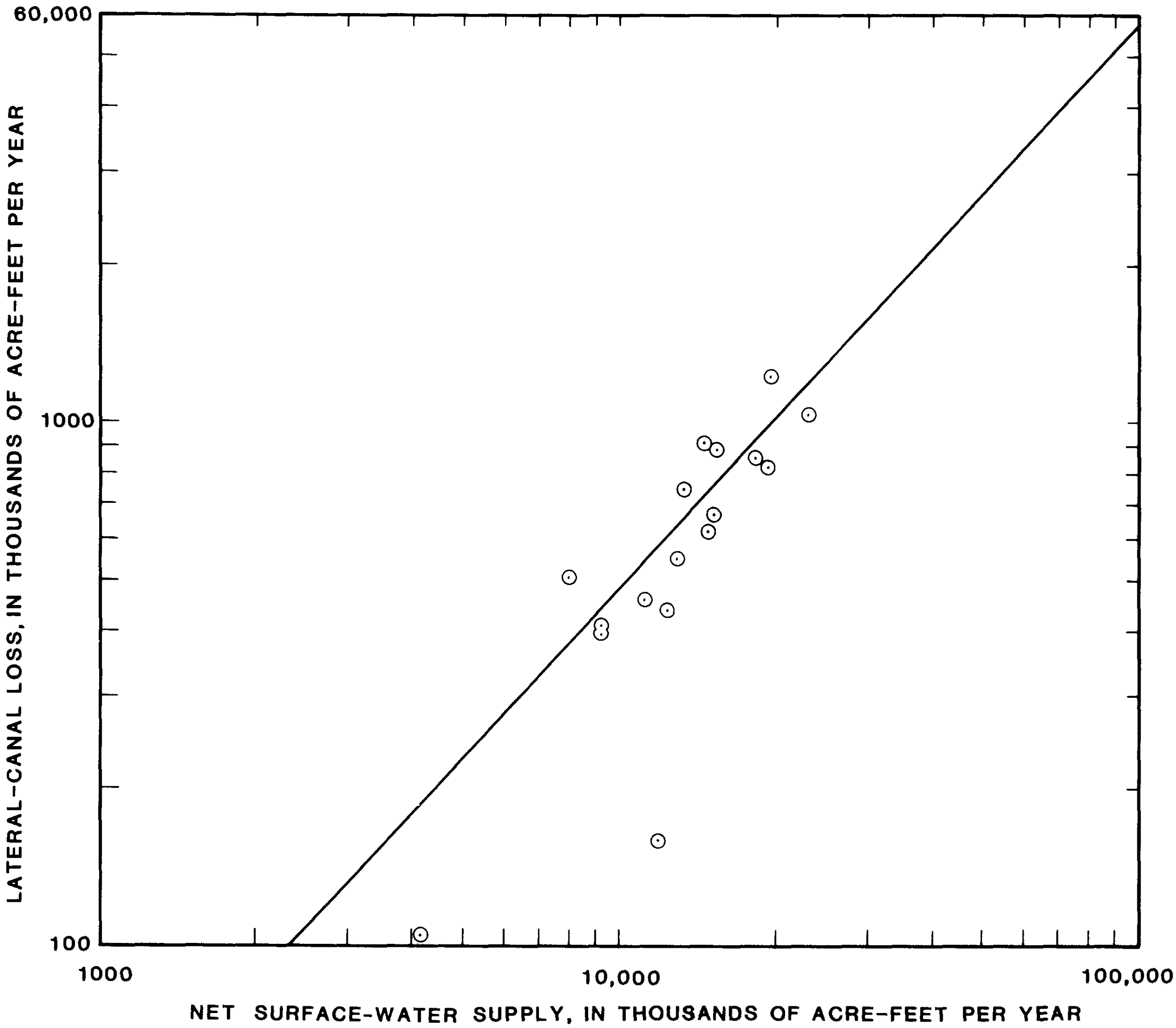

Figure 3.--Relationship between net surface-water supply and lateral-canal loss.

All management schemes are simulated by the model beginning with the 1979 irrigation season. As determined from U.S. Bureau of Reclamation records, the 1970-78 average net surface-water supply of 11,375 acre-feet per year is used as a reference surface-water supply for the simulations. Recharge from precipitation is set to approximate the average 1970-78 rate of 13.85 ft^3/s for the irrigation periods and 11.84 ft^3/s for the nonirrigation periods (from Burnett and Reed, 1982). Evapotranspiration is held constant at 4.76 ft^3/s for the irrigation periods and at 1.10 ft^3/s for the nonirrigation periods, except for alternative 3. Return flow to the aquifer from surface- and ground-water irrigation is computed as 10 percent of the quantities applied.

Management alternative 1 involved simulating the hydraulic heads and effects on streamflow in the South Fork Solomon River resulting from lining the remaining 84 percent of the Osborne Irrigation Canal with clay. The location of the main canal and the nodes used to simulate the interaction between the canal and the ground-water system are shown on plate 1.

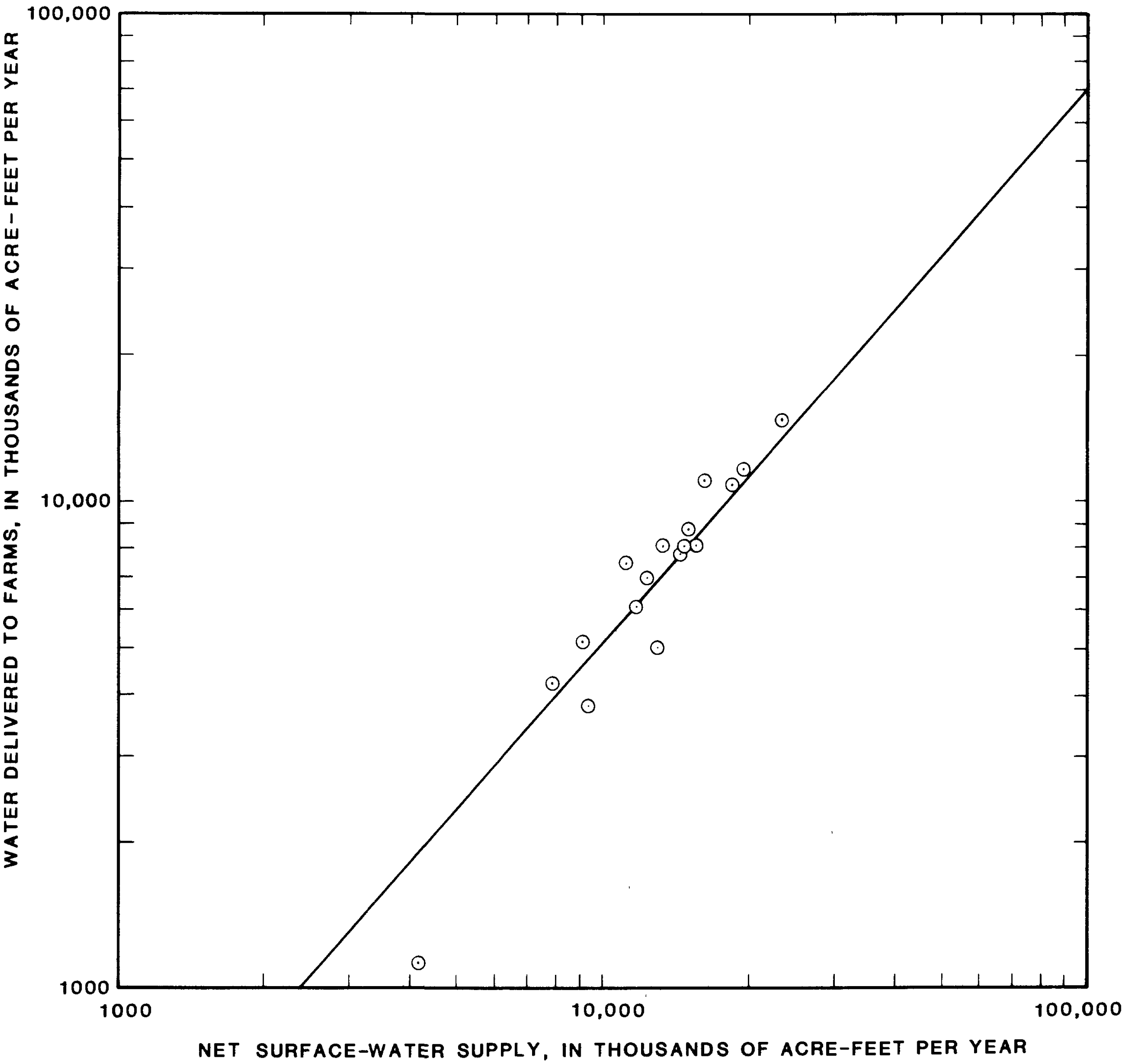

Figure 4.--Relationship between net surface-water supply and farm delivery.

According to calculations made by the U.S. Bureau of Reclamation (oral commun., 1979), infiltration losses of 15.0 ft^3/s or 2,678 acre-feet of water for the 90-day irrigation season (assuming a seepage rate of 0.2 ft^3/ft^2 per day) could be saved by lining the remaining sections of the canal with clay. Including the effects of dry years (1972 and 1978) to compute an average annual water savings to add into the model, a savings of 11.6 ft^3/s was calculated and used for making the simulation. Alternative 1 was simulated by decreasing constant-flux values assigned to the nodes representing the canal by 11.6 ft^3/s. Sixty-one nodes were used to represent the main canal, and thus each flux value assigned to each node was decreased by 0.19 ft^3/s.

Table 1.--*Component flows simulated for irrigation periods using management alternatives 1 to 7*

[Values are in acre-feet per year]

Management alternative	Net surface-water supply	Surface-water farm delivery	Ground-water pumpage	Main- and lateral-canal losses
1	11,375	7,890	6,220	2,280
2	11,375	6,190	7,910	3,960
3	11,375	5,800	8,300	4,350
4	2,845	1,410	12,680	1,250
5	5,688	2,650	11,450	2,240
6	8,530	4,260	9,850	3,285
7	11,375	5,800	8,300	4,350

In addition, it was assumed that while a saving of 11.6 ft^3/s could be salvaged from infiltration and, therefore, applied and used on irrigated land, a decrease of 11.6 ft^3/s from the ground-water-withdrawal rate also could be accomplished. This decrease of ground-water-withdrawal rates from 1978 pumpage was assumed to be evenly distributed to nodes used to simulate ground-water pumping for irrigation purposes.

Inasmuch as 79 nodes were used to simulate ground-water withdrawal, 0.15 ft^3/s was subtracted from the pumping rate for each node containing one or more irrigation wells. It was assumed that changes in irrigation practices would not occur within the period simulated and that the availability of surface water would remain the same.

The simulations of average drawdown for all alternatives within the modeled area (total storage change divided by model area divided by storage coefficient) are shown in figures 5 and 6. The effects on base flow within the study area for all alternatives for 1980-2000 are shown in figure 7. Average drawdown at the end of the nonirrigation periods (May 31) for alternative 1 would have a maximum value of about 1.97 feet by 2000 (fig. 5). Base flow at the end of the nonirrigation season (May 31) would have a maximum value of about 11.0 ft^3/s by 2000 for alternative 1 (fig. 7). Projected rates for the final two periods of alternative 1 are shown in table 2.

Management alternative 2 involved simulating hydraulic heads and the effects on streamflow of replacing 70 percent of the existing canal laterals with pipe. Based on lateral-loss figures from 1970 through

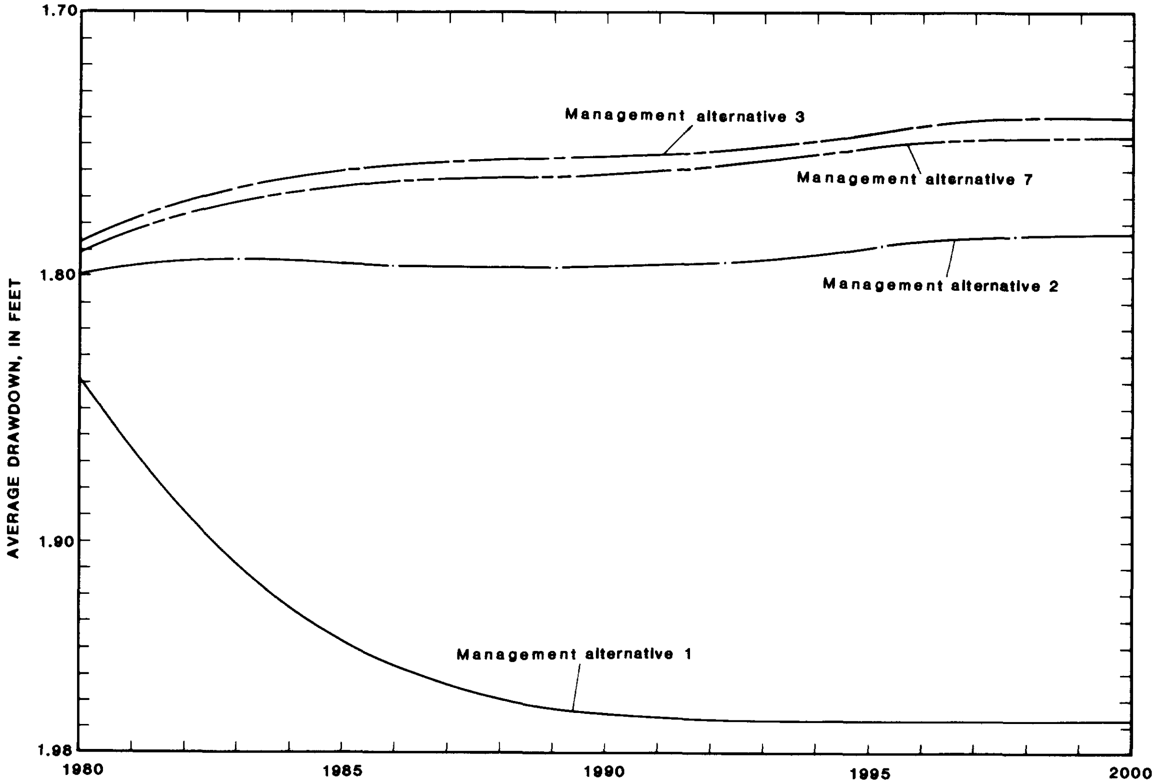

Figure 5.--Average drawdown on May 31 versus time for management alternatives 1, 2, 3, and 7, 1980-2000.

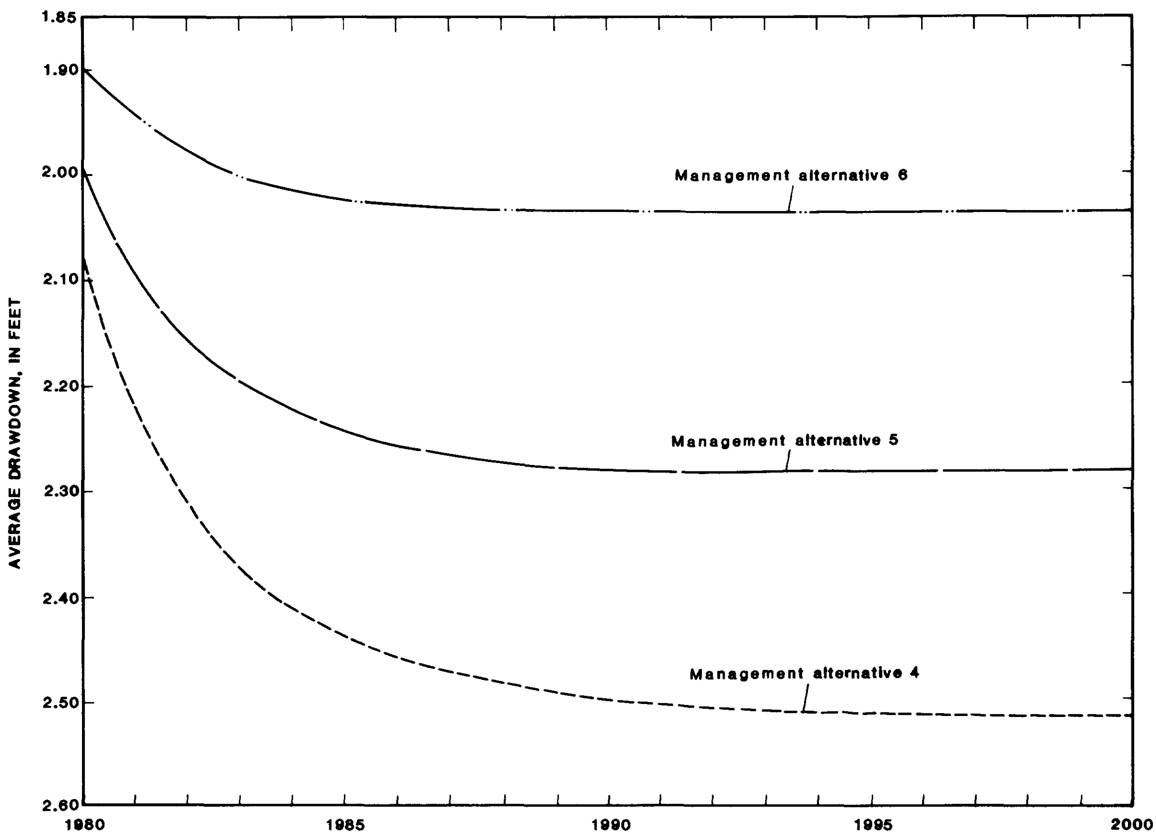

Figure 6.--Average drawdown on May 31 versus time for management alternatives 4, 5, and 6, 1980-2000.

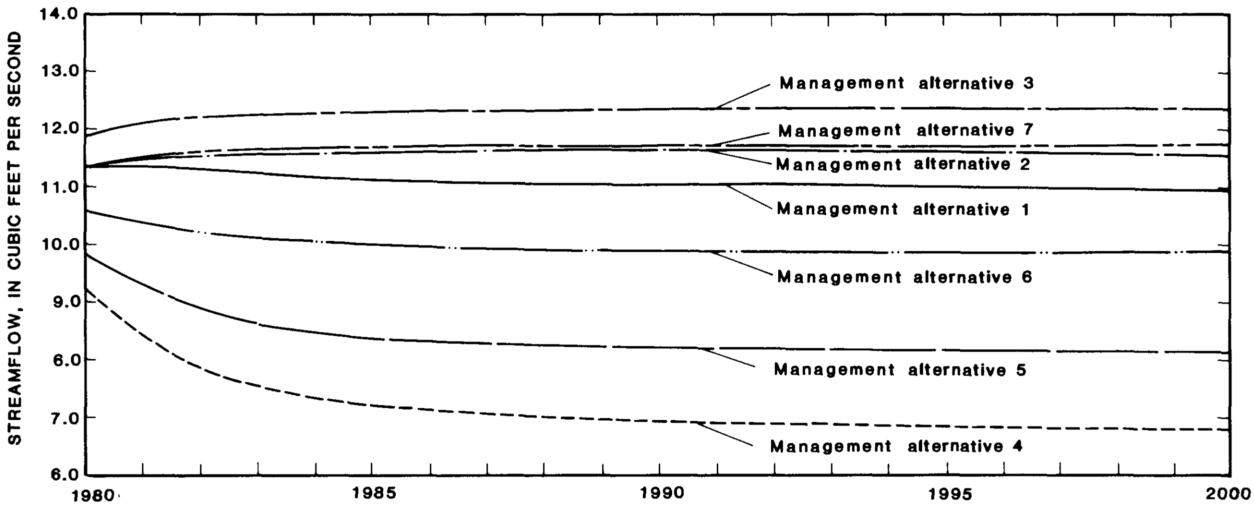

Figure 7.--Simulated streamflow on May 31 versus time for all management alternatives, 1980-2000.

Table 2.--*Projected rates of flow at the end of the irrigation and nonirrigation periods during 2000 for management alternative 1, based on lining the remaining 84 percent of the main canal*

	Rates of flow (cubic feet per second)	
	Irrigation period	Nonirrigation period
Inflow components		
Recharge from precipitation	+13.84	+11.67
Leakage from Osborne Irrigation Canal	+12.78	0.0
Subsurface inflow	+ 1.98	+ 1.89
Recharge from surface-water irrigation	+ 4.42	0.0
Recharge from ground-water irrigation	+ 2.96	0.0
Outflow components		
Ground-water evapotranspiration	-4.76	-1.10
Subsurface outflow	-0.41	-0.42
Discharge from wells (municipal and irrigation wells)	-30.99	-1.42
Net river leakage	+2.53	-10.99
Change in storage	-2.35	+0.37

1978 (U.S. Bureau of Reclamation, written commun., 1979), an average of 555 acre-feet of water per irrigation season has been lost in the laterals. Assuming that no leakage would occur in the replacement pipe and that replacing 70 percent of the existing laterals with pipe would result in a 70-percent savings, 389 acre-feet of water or 2.20 ft^3/s per season would be saved. Consequently, alternative 2 was modeled by decreasing constant-flux values assigned to the nodes simulating the canal laterals by 2.20 ft^3/s. Sixty-one nodes were used to simulate the canal laterals, and thus each flux value assigned to each node was decreased by 0.036 ft^3/s.

It was assumed that a savings of 2.20 ft^3/s could be salvaged from infiltration and, therefore, applied to the land, resulting in savings of 2.20 ft^3/s of ground-water pumpage. Decreases in ground-water-withdrawal rates were assumed to be equal at all nodes used to simulate ground-water pumping for irrigation purposes. Inasmuch as 79 nodes were used to simulate ground-water withdrawal, each pumping-node value was decreased by 0.028 ft^3/s from 1978 rates.

The simulations of average drawdown for alternative 2 within the modeled area are shown in figure 5, and the effects on base flow within the study area for 1980-2000 are shown in figure 7. Average drawdown at the end of nonirrigation pumping periods (May 31) would decrease to about 1.78 feet by 2000 (alternative 2, fig. 5). Base flow at the end of the nonirrigation season (May 31) would have a maximum value of about 11.5 ft^3/s by 2000 (alternative 2, fig. 7). Projected rates of flow for the final two periods are shown in table 3.

Table 3.--*Projected rates of flow at the end of the irrigation and nonirrigation periods during 2000 for management alternative 2, based on replacement of 70 percent of the lateral canals with pipe*

	Rates of flow (cubic feet per second)	
Inflow components	Irrigation period	Nonirrigation period
Recharge from precipitation	+13.84	+11.67
Leakage from Osborne Irrigation Canal	+22.17	0.0
Subsurface inflow	+ 2.04	+ 1.90
Recharge from surface-water irrigation	+ 3.47	0.0
Recharge from ground-water irrigation	+ 3.89	0.0
Outflow components		
Ground-water evapotranspiration	-4.76	-1.10
Subsurface outflow	-0.40	-0.42
Discharge from wells (municipal and irrigation wells)	-38.85	-1.42
Net river leakage	+5.97	-11.59
Change in storage	-7.37	+0.96

Management alternative 3 simulated the resulting hydraulic heads and effects on base flows by assuming the removal of one-half of the phreatophytes within the study area. In the calibrated model, evapotranspiration from ground water was simulated by pumping wells placed along the stream course. The effect of phreatophyte removal was simulated by decreasing the pumping rates of these wells by 50 percent for both irrigation and nonirrigation pumping periods.

The simulations of average drawdown for alternative 3 within the modeled area are shown in figure 5, and the effects on base flow within the study area for 1980-2000 are shown in figure 7. Average drawdown at the end of nonirrigation pumping periods (May 31) would decrease to 1.74 feet by 2000 (alternative 3, fig. 5). Base flow at the end of the nonirrigation season would have a maximum value of about 12.3 ft^3/s by 2000 (alternative 3, fig. 7). Projected rates of flow for the final two periods are shown in table 4.

Management alternatives 4, 5, and 6 simulated the resulting hydraulic heads and effects on streamflows by assuming a decrease of surface supply by 75, 50, and 25 percent, respectively, of the average 1970-78 use, while increasing 1978 ground-water pumpage a similar quantity to compensate for the decrease in surface water. These alternatives were simulated by decreasing the constant-flux values assigned to the nodes representing canal-boundary conditions and decreasing surface-water irrigation returns.

Table 4.--*Projected rates of flow at the end of the irrigation and nonirrigation periods during 2000 for management alternative 3, based on removal of one-half of the phreatophytes*

	Rates of flow (cubic feet per second)	
Inflow components	Irrigation period	Nonirrigation period
Recharge from precipitation	+13.84	+11.67
Leakage from Osborne Irrigation Canal	+24.37	0.0
Subsurface inflow	+ 2.05	+ 1.90
Recharge from surface-water irrigation	+ 3.25	0.0
Recharge from ground-water irrigation	+ 4.04	0.0
Outflow components		
Ground-water evapotranspiration	-2.38	-0.55
Subsurface outflow	-0.42	-0.42
Discharge from wells (municipal and irrigation wells)	-41.85	-1.42
Net river leakage	+5.21	-12.40
Change in storage	-8.11	+1.22

It was assumed that uniform loss occurred along the main canal and laterals, and therefore the total loss was distributed equally among the 61 nodes that were used to simulate the canal and laterals. Surface-water return was distributed equally among the 61 nodes representing this process.

Results of alternatives 4, 5, and 6 for simulated average drawdown and base flow within the modeled area are shown in figures 6 and 7, respectively. The average drawdown at the end of the nonirrigation periods (May 31) by 2000 throughout the modeled area would increase to maximum values of 2.52 feet for alternative 4 (75-percent decrease), 2.28 feet for alternative 5 (50-percent decrease), and 2.03 feet for alternative 6 (25-percent decrease), as shown in figure 6. Base flow at the end of the nonirrigation periods (May 31) would have decreased by 2000 to a maximum value of about 6.8 ft^3/s for alternative 4, about 8.2 ft^3/s for alternative 5, and about 9.9 ft^3/s for alternative 6, as shown in figure 7. Projected rates of flow for the final two pumping periods for alternatives 4, 5, and 6 are found in tables 5, 6, and 7, respectively.

Table 5.--*Projected rates of flow at the end of the irrigation and nonirrigation periods during 2000 for management alternative 4, based on a 75-percent decrease of the 1970-78 average surface-water supply*

	Rates of flow (cubic feet per second)	
Inflow components	Irrigation period	Nonirrigation period
Recharge from precipitation	+13.84	+11.67
Leakage from Osborne Irrigation Canal	+ 7.00	0.0
Subsurface inflow	+ 2.25	+ 1.94
Recharge from surface-water irrigation	+ 0.79	0.0
Recharge from ground-water irrigation	+ 4.97	0.0
Outflow components		
Ground-water evapotranspiration	-4.76	-1.10
Subsurface outflow	-0.39	-0.42
Discharge from wells (municipal and irrigation wells)	-51.09	-1.42
Net river leakage	+11.06	-6.77
Change in storage	+16.33	-3.90

Management alternative 7 consisted of simulating hydraulic heads and effects on base flow by continuing the 1978 irrigation and nonirrigation pumpage conditions and 1970-78 average surface-water usage to the year 2000. Results of alternative 7 for average drawdown and effects on base flow within the study area for 1980-2000 are shown in figures 5 and 7, respectively. The average drawdown at the end of the nonirrigation pumping periods (May 31) would decrease to a maximum value of about 1.75 feet by 2000, as shown in figure 5. Base flow at the end of the non-irrigation periods (May 31) would increase to a maximum value of about 11.8 ft^3/s by 2000, as shown in figure 7. Projected rates of flow for the final two pumping periods are found in table 8.

Of the seven management alternatives, alternative 7, which simulates continued 1978 pumpage and 1970-78 average surface-water supply, can be referred to as "continued conditions," and as such provides a relative reference to compare the other alternatives. This alternative would result in a rise in water levels during the first few pumping periods that can be recognized as an increase in simulated recharge and surface-water supply relative to comparable model inputs used in the latter years of the model calibration. This response also is apparent in alternatives 2 and 3, but is not apparent in alternatives 1, 4, 5, and 6, as the increases in hydrologic stresses for these alternatives override this effect. Magnitudes of sources, changes in withdrawals because of nodes going dry, and resulting drawdowns depend somewhat on the spatial distribution of the modified stresses applied for each alternative.

Table 6.--*Projected rates of flow at the end of the irrigation and nonirrigation periods during 2000 for management alternative 5, based on a 50-percent decrease of the 1970-78 average surface-water supply*

	Rates of flow (cubic feet per second)	
Inflow components	Irrigation period	Nonirrigation period
Recharge from precipitation	+13.84	+11.67
Leakage from Osborne Irrigation Canal	+12.56	0.0
Subsurface inflow	+ 2.20	+ 1.93
Recharge from surface-water irrigation	+ 1.49	0.0
Recharge from ground-water irrigation	+ 4.64	0.0
Outflow components		
Ground-water evapotranspiration	-4.76	-1.10
Subsurface outflow	-0.40	-0.42
Discharge from wells (municipal and irrigation wells)	-47.85	-1.42
Net river leakage	+7.94	-8.17
Change in storage	+10.34	-2.49

Table 7.--*Projected rates of flow at the end of the irrigation and nonirrigation periods during 2000 for management alternative 6, based on a 25-percent decrease of the 1970-78 average surface-water supply*

	Rates of flow (cubic feet per second)	
Inflow components	Irrigation period	Nonirrigation period
Recharge from precipitation	+13.84	+11.67
Leakage from Osborne Irrigation Canal	+18.39	0.0
Subsurface inflow	+ 2.13	+ 1.92
Recharge from surface-water irrigation	+ 2.39	0.0
Recharge from ground-water irrigation	+ 4.30	0.0
Outflow components		
Ground-water evapotranspiration	-4.76	-1.10
Subsurface outflow	-0.39	-0.42
Discharge from wells (municipal and irrigation wells)	-44.36	-1.42
Net river leakage	+4.98	-9.93
Change in storage	+ 3.48	-0.72

Table 8.--*Projected rates of flow at the end of the irrigation and nonirrigation periods during 2000 for management alternative 7, based on 1970-78 average surface-water supply and 1978 ground-water withdrawal*

	Rates of flow (cubic feet per second)	
Inflow components	Irrigation period	Nonirrigation period
Recharge from precipitation	+13.84	+11.67
Leakage from Osborne Irrigation Canal	+24.37	0.0
Subsurface inflow	+ 2.05	+ 1.90
Recharge from surface-water irrigation	+ 3.25	0.0
Recharge from ground-water irrigation	+ 3.88	0.0
Outflow components		
Ground-water evapotranspiration	-4.76	-1.10
Subsurface outflow	-0.40	-0.42
Discharge from wells (municipal and irrigation wells)	-40.23	-1.42
Net river leakage	+3.69	-11.77
Change in storage	-5.69	+1.14

Comparison of the results of the seven alternatives indicate that a decrease in surface-water supply, along with a corresponding increase in ground-water withdrawal, would have the greatest effect on water levels and on base flow. A base-flow difference of about 5 ft^3/s is indicated between alternatives 4 and 7, and a difference of about 3 ft^3/s is indicated between alternatives 4 and 6. The least base flow that would occur at the end of the nonirrigation seasons is 6.8 ft^3/s in alternative 4. However, during the irrigation periods, the Solomon River becomes a loosing stream in all management alternatives, with losses ranging from 2 to 11 ft^3/s. Elimination of one-half of the phreatophytes would result in an increase in base flow of 0.6 ft^3/s relative to alternative 7.

SUMMARY AND CONCLUSIONS

Projection simulations were made based on management alternatives proposed by the U.S. Bureau of Reclamation involving: (1) The clay-lining of 84-percent of the Osborne Irrigation Canal, (2) the replacement of 70 percent of the canal laterals with pipe, (3) the removal of one-half of the phreatophytes along the stream, (4) decreasing surface-water use by 75 percent and replacing it with ground water, (5) decreasing surface-water use by 50 percent and replacing it with ground water, (6) decreasing surface-water use by 25 percent and replacing it with ground water, and (7) the future continuation of 1978 conditions of ground-water pumpage and 1970-78 average surface-water use.

Results of the projections were reported in terms of the effects on average drawdown in the alluvial aquifer within the model area and effects on base flow in the Solomon River at the end of the nonirrigation periods (May 31). Alternative 1, in which lining of the remaining 84 percent of the main canal was simulated, would result in an average drawdown of about 1.97 feet, and a base flow of about 11 ft^3/s by the year 2000. Alternative 2, in which 70 percent of the laterals were replaced with pipe, would result in an average drawdown of about 1.78 feet and a base flow of about 11.5 ft^3/s by 2000. Alternative 3, in which removal of one-half of the phreatophytes was simulated, would result in an average drawdown of about 1.74 feet and a base flow of about 12.3 ft^3/s by 2000. Alternative 4, in which the surface-water supply was decreased by 75 percent and ground-water withdrawal was increased to compensate, had the greatest effect on the aquifer. This alternative indicated that about 2.5 feet of average drawdown would occur by 2000 and that base flow would decrease to about 6.8 ft^3/s. Alternatives 5 and 6 were similar to projection 4 except that the surface-water supply was simulated at a 50-percent decrease for alternative 5 and a 25-percent decrease for alternative 6. Alternative 5 would result in an average drawdown of about 2.3 feet and a base flow of about 8.2 ft^3/s by 2000. Alternative 6 would result in an average drawdown of about 2 feet and a base flow of about 9.9 ft^3/s by 2000. Alternative 7, in which 1978 pumpage and 1970-78 average surface-water supplies were simulated, would result in an average drawdown of about 1.75 feet and a base flow of about 11.8 ft^3/s by 2000. In comparing alternatives 1, 2, 3, and 7, there are relatively small differences in the effects on the aquifer system from these options.

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