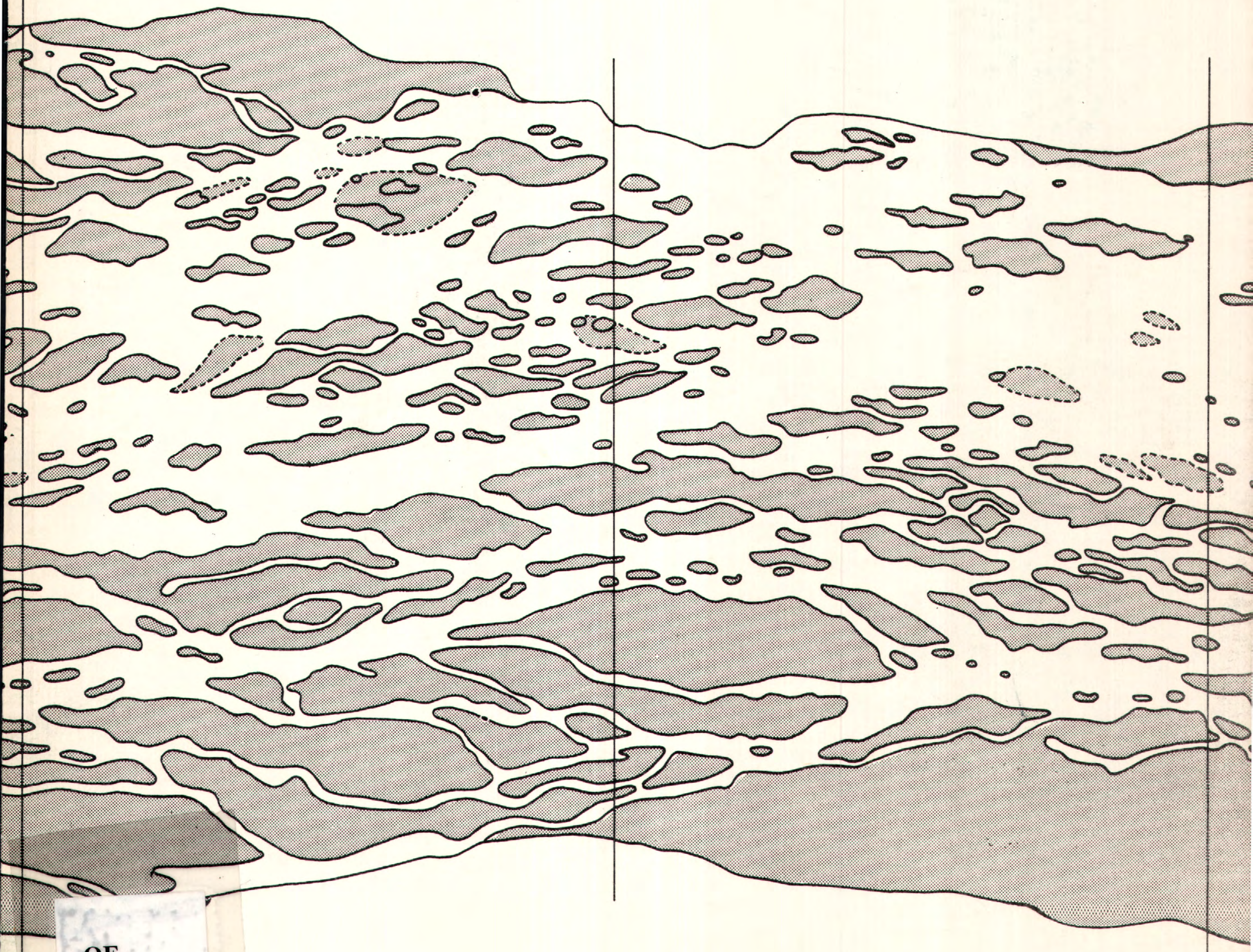
SIMULATED HYDROLOGIC EFFECTS OF POSSIBLE GROUND-WATER AND SURFACE-WATER MANAGEMENT ALTERNATIVES IN AND NEAR THE PLATTE RIVER, SOUTH-CENTRAL NEBRASKA



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Cover illustration--A 2-km reach of the Platte River channel near Kearney, Nebraska, from an aerial photograph taken in 1957.

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By Alan W. Burns

U.S. GEOLOGICAL SURVEY

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METRIC CONVERSIONS

Inch-pound units used in this report may be converted to metric (SI) units by using the following conversion factors:

Multiply inch-pound units	*By*	*To obtain metric units*
acre	0.0040	square kilometer
acre-foot (acre-ft)	1,233	cubic meter
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year
cubic foot per second (ft^3/s)	28.3162	liter per second
foot (ft)	.3048	meter
foot per day (ft/d)	.3048	meter per day
inch per year (in/yr)	25.4	millimeter per year
mile (mi)	1.609	kilometer
foot squared per day (ft^2/d)	.093	meter squared per day

SIMULATED HYDROLOGIC EFFECTS OF POSSIBLE GROUND-WATER AND SURFACE-WATER MANAGEMENT ALTERNATIVES IN AND NEAR THE PLATTE RIVER, SOUTH-CENTRAL NEBRASKA

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ABSTRACT

Digital-computer models were developed and used to simulate the hydrologic effects of hypothetical water-management alternatives on the wetland habitat area near Grand Island, Nebr. Areally distributed recharge to and discharge from the aquifer system adjacent to the Platte River between Overton and Grand Island were computed for four hypothetical water-management alternatives: (1) current conditions; (2) increasing the acreage irrigated by surface water by about 270,000 acres; (3) increasing the acreage irrigated by ground water by about 270,000 acres, replacing as much subirrigated area as possible; and (4) increasing the acreage irrigated by ground water by about 270,000 acres without replacing subirrigated areas. Using stream-aquifer response functions, the stream depletions resulting from the computed aquifer recharge and discharge, averaged over a 50-year planning period, were 125,000, 53,000, 174,000, and 177,000 acre-feet per year, respectively.

Frequency curves of the stage in the river near the wildlife habitat area were computed from the 50-year sequences of monthly streamflows for each of the management alternatives. The differences in the stage-frequency curves were minimal for the four water-management alternatives.

For comparative purposes, three additional water-management alternatives were simulated which had direct effects on the streamflow entering the study area: (1) Assume an importation of 240,000 acre-feet per year for irrigation of 100,000 acres downstream from the study area; (2) assume a diversion of 240,000 acre-feet per year for irrigation of 100,000 acres upstream from the study area; and (3) assume a reservoir or diversion which would store or divert any incoming monthly streamflow greater than 2,000 cubic feet per second. The average streamflow for the current-conditions simulation was 1,274 cubic feet per second, whereas the average for each of these hypothetical management alternatives was 1,606, 1,045, and 1,102 cubic feet per second, respectively. Translating these different streamflow sequences to stage-frequency curves indicates a much greater change in stream stage than the four water-management alternatives previously evaluated.

INTRODUCTION

This study is part of the Platte River Study, a multidisciplinary study being conducted by agencies of the U.S. Department of the Interior concerned with the critical habitat of the whooping crane and other migratory waterfowl along the Platte River in central Nebraska. Hydrologic investigations have been an important subset of the Platte River Study and have attempted to identify the hydrologic system as it relates to the habitat, and thus how water-management alternatives could affect the habitat. This particular report presents the simulations of the hydrologic effect on the river caused by potential water-management alternatives in and near the Platte River between Overton and Grand Island, Nebr.

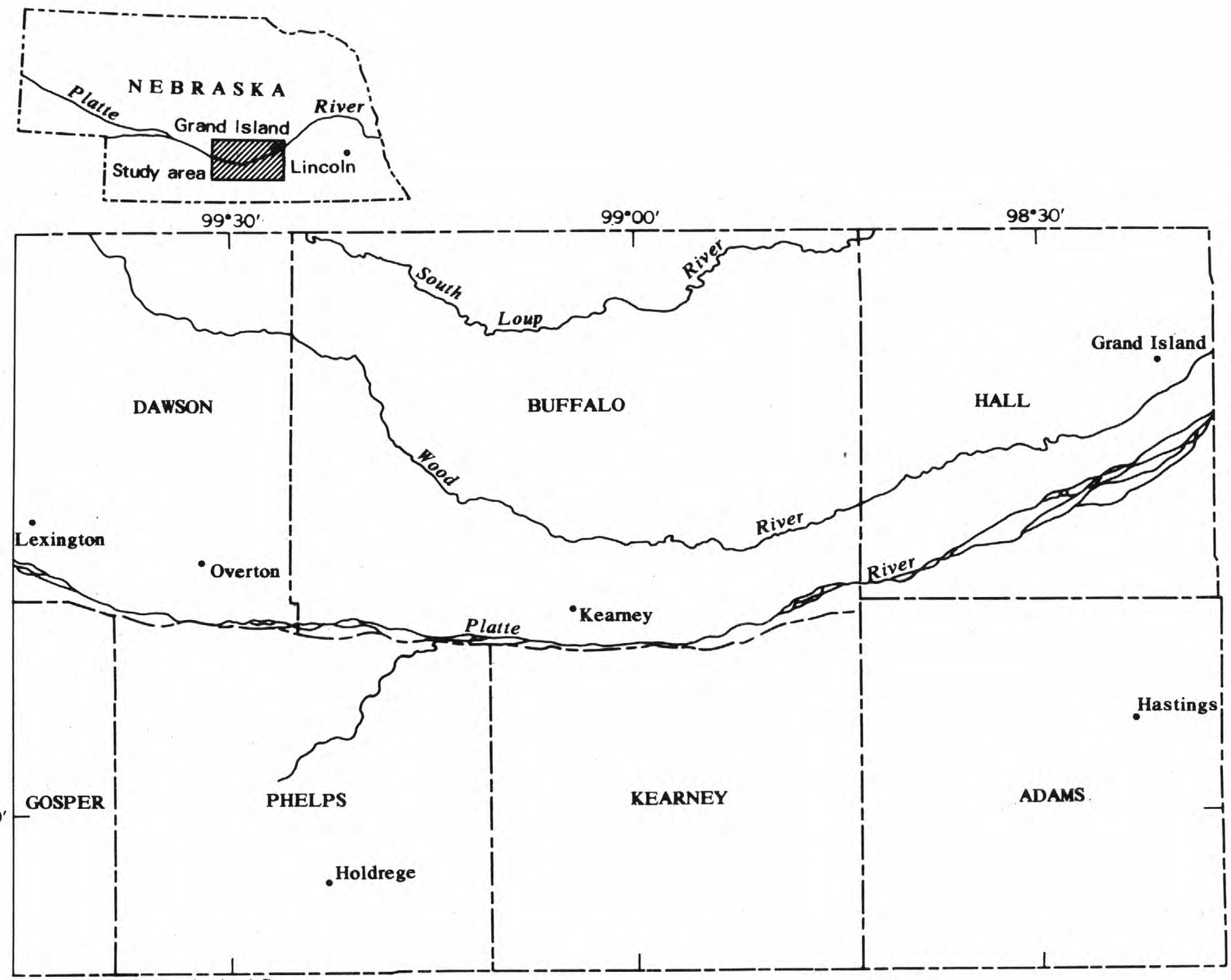
Purpose and Scope

The purpose of the part of the Platte River Study described in this report was to determine the range of effects on the streamflow and stage of the river near the habitat area due to possible water-management practices in a 70-mile reach of the river upstream from the habitat area. The analysis considered only hypothetical water-management alternatives rather than actual proposed projects. A 50-year planning period was used to be compatible with the rest of the Platte River Study. The area of analysis was limited to the reach of the Platte River between the two gaging stations at Overton and Grand Island (fig. 1). The area extended outward from the river to a distance at which the effects of water management would be negligible during the 50-year period. This report does not consider the effect of water management on the habitat areas directly, nor does it directly consider effects of additional ground-water diversions upstream from Overton. (However, it does provide information that can be used with other reports in this study to do such an evaluation.)

The primary objective of this substudy was to determine the effects of possible ground-water development between Overton and Grand Island on the streamflow of the Platte River. Secondary objectives were to compare the effects of possible ground-water developments to similar irrigation developments using surface water and to compare the effects of these possible developments, which are transmitted through the aquifer system to the river, to the effects of developments which would directly affect the incoming streamflow at Overton. This report is a brief discussion of a rather brief and general analysis for a topic that could involve considerably greater effort to evaluate in more detail.

Background and Approach

The hydrologic system in this reach of the Platte River is typical of the entire Platte River drainage system throughout the Great Plains. Surface water is hydraulically connected to the ground water in the adjacent aquifers. The diversion of streamflow for irrigation, the withdrawal of ground water for irrigation, the return flow of excess irrigation applications, and the ground-water use by native and agricultural phreatophytes are components of this highly complex and integrated hydrologic system. Within a certain area of influence controlled by geologic boundaries, ground-water



Base from U.S. Geological Survey
1:500 000 State base map, 1965

0 10 20 30 MILES

0 10 20 30 KILOMETERS

Figure 1.--Location of study area.

withdrawals that are consumptively used will deplete the streamflow in the Platte River either by reducing return flow or by inducing infiltration from the river to the aquifer. Recharge in excess of withdrawals will augment streamflow either by increasing return flow or by reducing infiltration from the river to the aquifer.

Based on information available from previous studies, the study area was partitioned into subareas, each of which can be characterized by the response of the river to changes in water-management practices that are transmitted through the aquifer system. Scenarios of possible water-management alternatives then were selected, and the effects of those alternatives on the river were simulated.

DESCRIPTION OF STUDY AREA

The study area for this report is shown in figure 1. It includes those areas for which land-use data were available and where water use will affect the flows in the Platte River. Much of this area is on the south side of the Platte River where both the surface water and ground water flow away from the Platte River. This area is included in the study area because there is no hydrologic boundary which would prevent water withdrawals or accretions from affecting the flows of the Platte River. This area is generally flat. Normal precipitation is about 23 in/yr, with almost half of that occurring from April through June. The primary use of the land is for agriculture, with corn being the predominate crop.

The Platte River flows through this region, providing an important source of water for both agricultural use and for wildlife. The river-bottom area is wide, and the river generally is shallow and extensively braided in sandy channels through the bottom area. These features contribute to a closely connected stream-aquifer system. Other prominent surface waters in this region include the Wood River and the many irrigation canals that tend to parallel the Platte River.

Large volumes of ground water occur in the Quaternary deposits adjacent to the Platte River and in the underlying Tertiary Ogallala Formation. The Quaternary deposits include various units of alluvial and eolian deposits. The Ogallala Formation, which contains an extensive aquifer from Texas to South Dakota, underlies most of the Quaternary deposits in this area. Below the Ogallala Formation is the Cretaceous Pierre Shale or the Niobrara Formation, which serves as the bottom of the aquifer system.

All of these deposits can be considered a single unconfined aquifer system (Lappala, Emery, and Otradovsky, 1979, p. 18), consisting of clay, silt, sand, and gravel. The saturated thickness of the aquifer ranges from 100 to 360 ft. The transmissivity ranges from 5,000 to 30,000 ft^2/d, and the specific yield probably ranges from about 0.10 to 0.20.

Irrigation is an important aspect of agriculture in this area. Surface water diverted from the Platte River is delivered to the farms by extensive canal systems. In many areas, the water table is close enough to land surface for natural subirrigation to occur. In these areas, roots of the crops (or native riparian vegetation) grow deep enough to get water directly from the aquifer. In other areas, ground water is pumped for irrigation from wells using high-capacity pumps.

STREAM-AQUIFER INTERACTION

The effects of losses from the ground-water system by pumpage or subirrigation and the effects of gains by recharge from precipitation or excess irrigation applications are transmitted through the aquifer system to the river as accretions or depletions to streamflow. Withdrawals from the aquifer do not necessarily cause direct losses of water from the river; for example, ground-water withdrawals may not cause river water to enter the aquifer but rather may just reduce the amount of ground water that previously had been entering the river.

The magnitude and timing of the effects of these stresses (pumpage or recharge) which are transmitted through the aquifer to the river depend upon the transmissive properties of the aquifer (transmissivity); the storage properties of the aquifer (specific yield for this water-table aquifer); the hydraulic connection between the stream and aquifer; and the distance from the point of stress to the stream. Procedures to describe these response functions can be derived from the theory of ground-water hydraulics. The general form of a response of a straight stream in perfect connection to an ideal aquifer to a stress on the ground-water system is:

$$q/Q = erfc \sqrt{\frac{x^2 S_y}{4Tt}}$$

where:

- q is the instantaneous rate of depletion or accretion from the stream measured at time t, in cubic feet per second;
- Q is the rate of stress on the ground-water system, in cubic feet per second;
- $erfc$ is the complementary error function;
- x is the distance from the point of stress to the stream, in feet;
- S_y is the specific yield of the aquifer under water-table conditions;
- T is the transmissivity of the aquifer in feet squared per day; and
- t is the time since the stress was commenced, in days.

The assumptions necessary in the derivation of this function and the definition of an ideal aquifer are:

(1) the aquifer is semi-infinite, homogeneous, and isotropic,
(2) the transmissivity is constant with time,
(3) the water is released instantaneously from storage,
(4) the stream is straight, hydraulically connected to the aquifer, and fully penetrating,
(5) the water temperature is the same in the stream and aquifer and is constant with time,
(6) the stress is continuous and steady, and
(7) the stress affects the entire saturated thickness instantaneously.

A curve illustrating this response function for a given set of parameters is shown in figure 2. This curve indicates that the rate of stream depletion (accretion) would be 25 percent of the pumping (injection) rate after 6 months, 50 percent after 18 months, and 75 percent after 80 months.

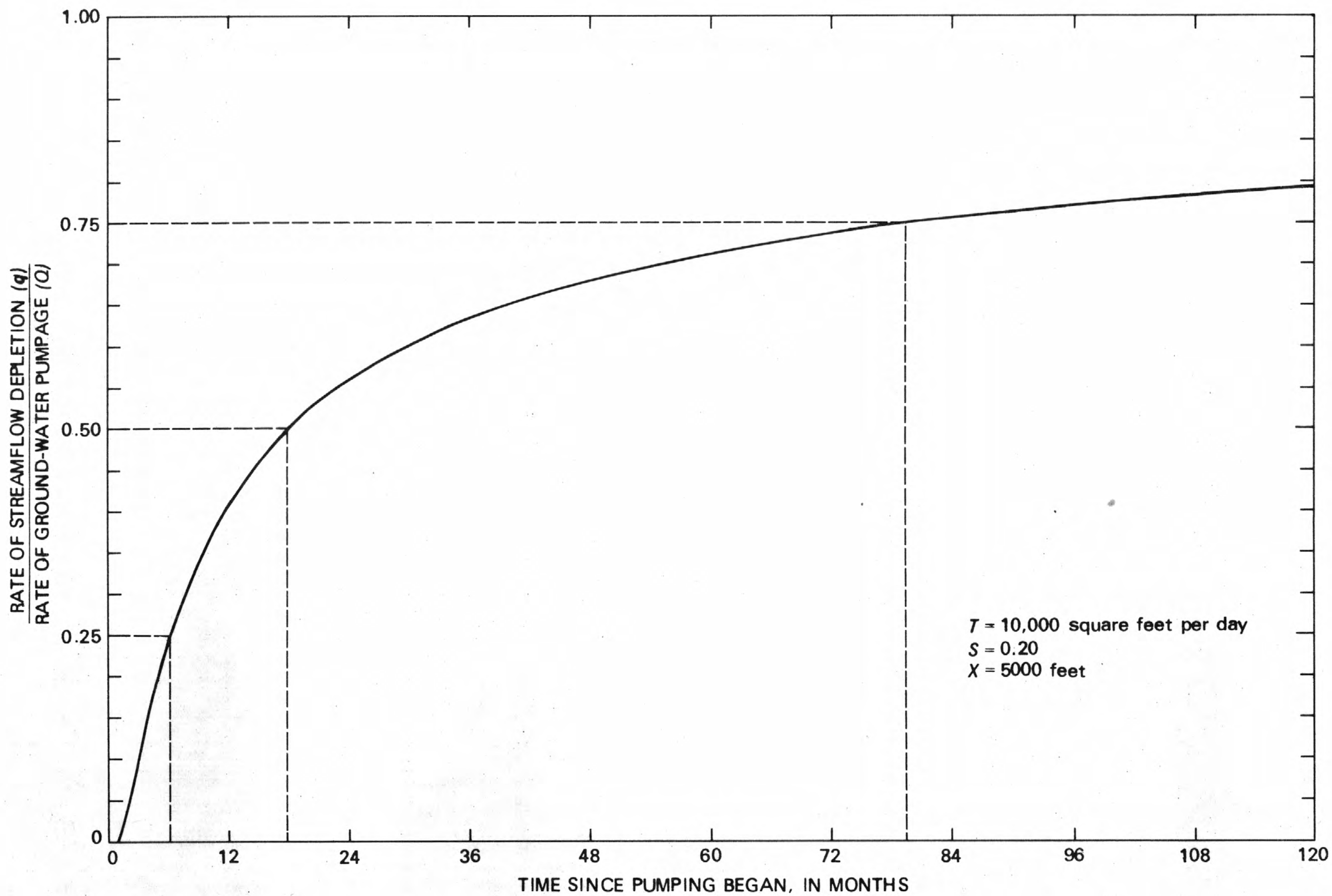


Figure 2. -- Stream-aquifer response function.

Equation 1 is typically integrated over time to evaluate the volume of stream response to the volume of the stress. The solution of this integration is:

$$\frac{v}{Qt} = \left(\frac{x^2 S_y}{2Tt}+1\right) erfc\left(\sqrt{\frac{x^2 S_y}{4Tt}}\right) - \sqrt{\frac{x^2 S_y}{4Tt}}\, \frac{2}{\sqrt{\pi}}\, e^{-\left(\frac{x^2 S_y}{4Tt}\right)} \qquad (2)$$

where v is the volume depleted from the stream through time t.

Jenkins (1968a) has developed a "lumped" parameter known as the SDF (stream depletion factor), that uniquely characterizes a response curve. The SDF is equal to the distance squared times the specific yield divided by the transmissivity ($x^2 S_y/T$) for the idealized assumptions stated earlier. Response curves of the integrated equation (2) for different SDF values are shown in figure 3. These curves indicate the percent of the volume pumped (or injected) that comes from (or goes to) the stream. Using an SDF value of 100 as an example, streamflow would be depleted by about 8 percent of the first month's pumpage, by about 40 percent of the first 6-months' pumpage, by about 65 percent of the first 30-months' pumpage, and by about 92 percent of the first 50 years of pumpage.

The SDF becomes a very important parameter when evaluating stream-aquifer interactions for large regions. Using a detailed, distributed parameter, digital ground-water flow model, arbitrary points within the model can be stressed and the response of the stream to those stresses can be simulated. Using a type-curve analysis similar to that used in fitting aquifer-test data to theoretical curves, a theoretical curve is fit to the simulated stream-depletion values and the respective SDF values are assigned to each of the points in the model. Thus all the vagaries of boundary conditions, variable transmissivities and a sinuous river can be accounted for with the SDF parameter within the limits of resolution of the corresponding digital model.

The curves in figures 2 and 3 are for a continuous stress. A representation of the response data which proves more useful for analysis with time-varying stresses are discrete *unit* response functions (figures 4-8) for unit periods of stress, such as a month. These step functions represent the percent by volume that stream depletion (or accretion) is of a monthly stress and the continuing future effects beyond the termination of the stress. Notice the differences between the magnitude of the peak of the response curves for different SDF values (see figure 9, which demonstrates the differences in scales of figures 4-8) and the differences in time when the peak occurs. Using an SDF value of 10, for example, streamflow would be depleted by about 50 percent of the monthly pumpage during the month that the pumpage occurred and by about 24 percent of the pumpage (which has now ceased) during the following month. On the other hand, for an SDF value of 1,000, the maximum monthly stream depletion would be only about 3 percent of the pumpage, and it would occur about 5 months after the pumpage had ceased. The extreme example is for an SDF value of 100,000, in which the maximum monthly stream depletion would be only about 0.07 percent of the pumpage and would occur about 45 years after the one month of pumping.

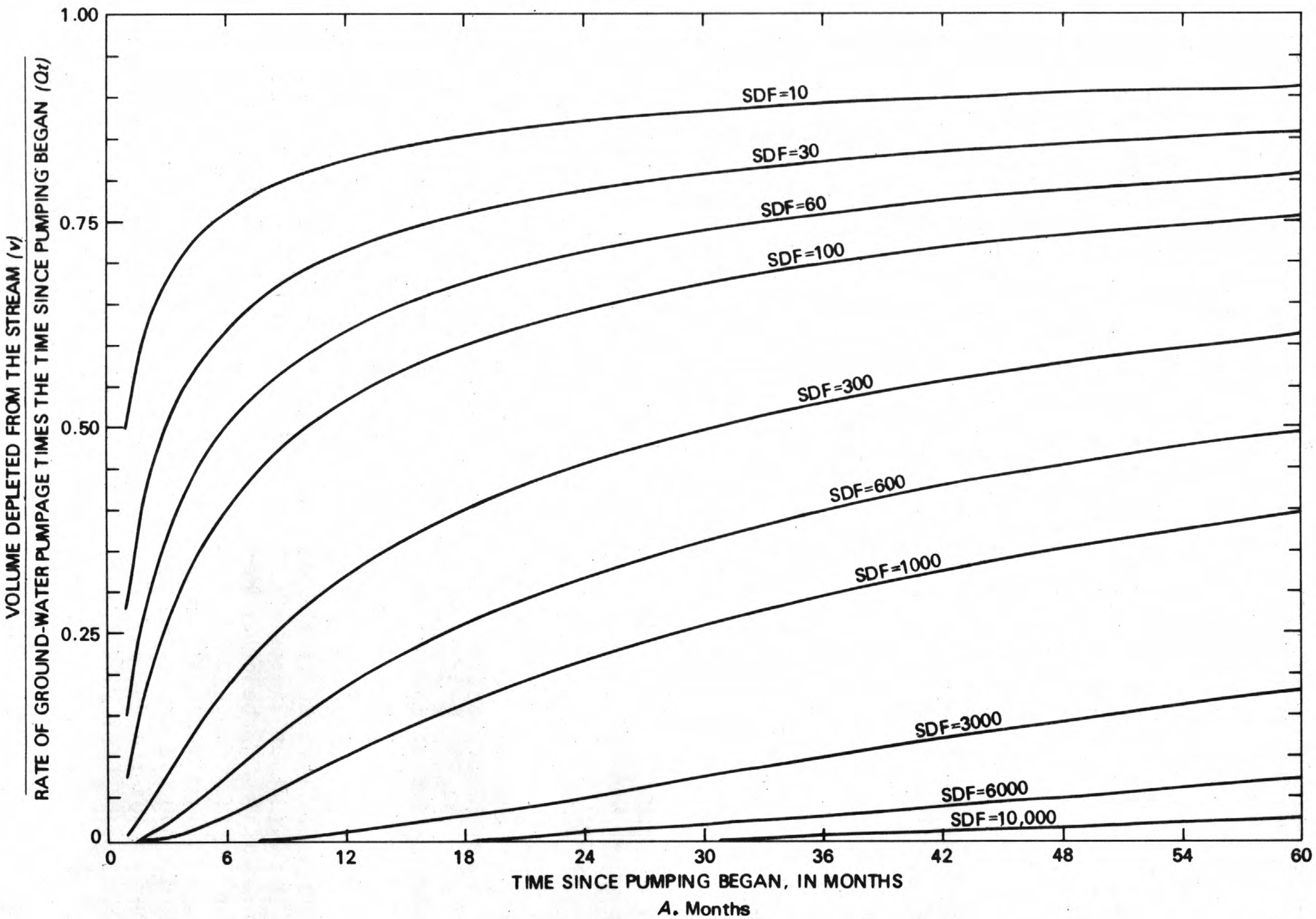


Figure 3. -- Stream-depletion factor (SDF) response functions. $= \frac{a^2 S}{T}$

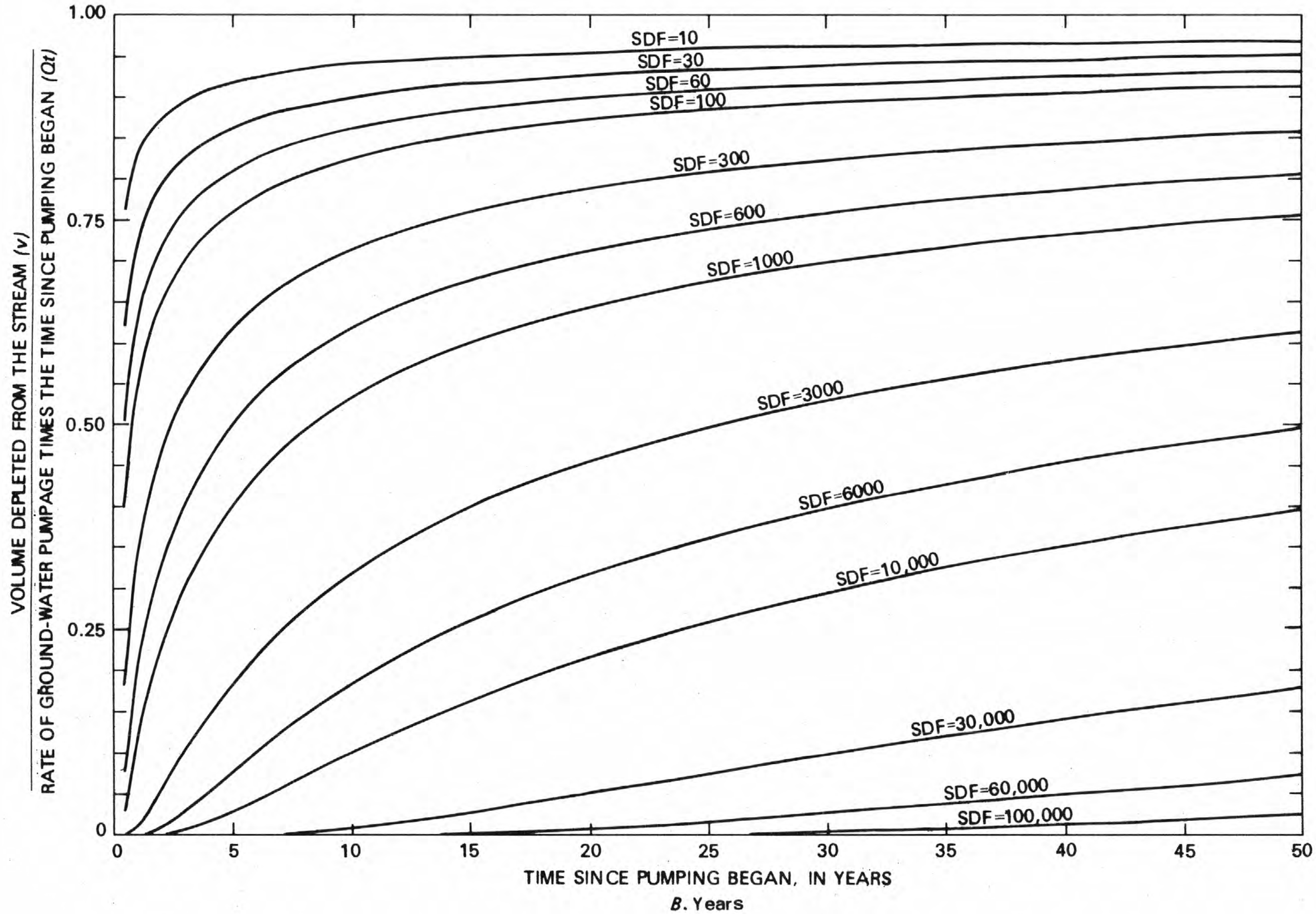
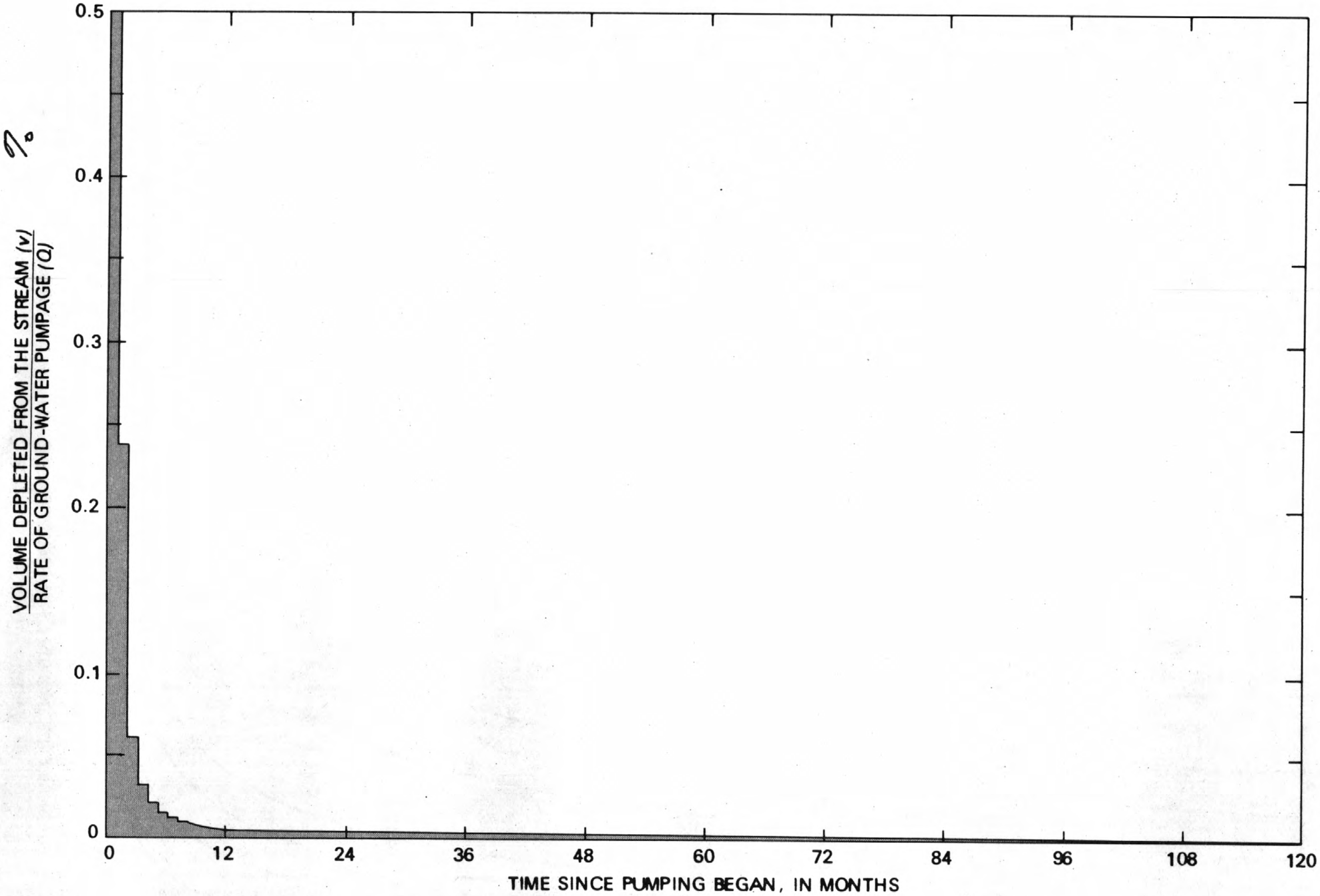


Figure 3. -- Stream-depletion factor (SDF) response functions -- Continued.



75% of effect (volumetric) in first month

Figure 4.--Unit response function for stream-depletion factor (SDF) = 10 days.

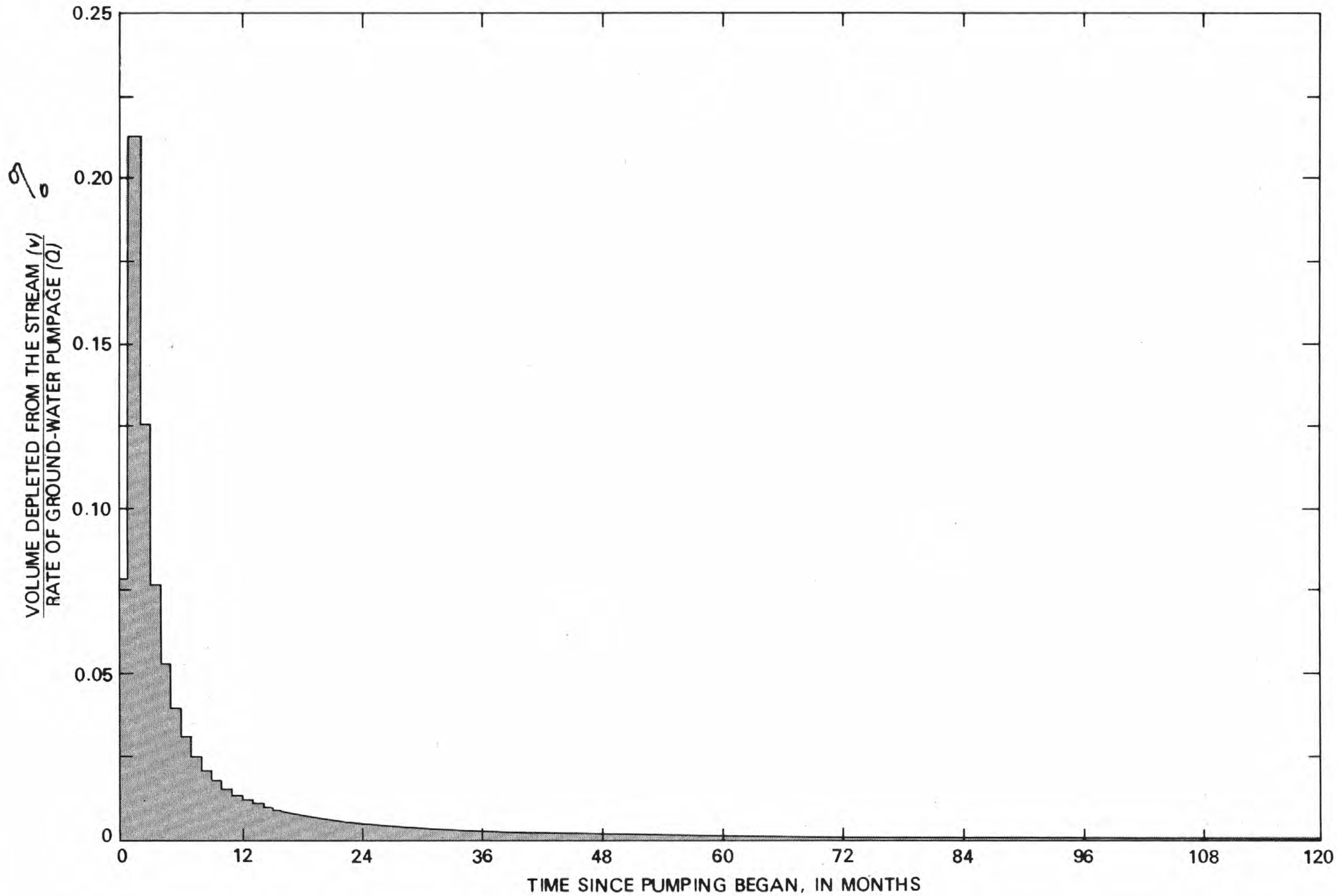


Figure 5.--Unit response function for stream-depletion factor (SDF)=100 days.

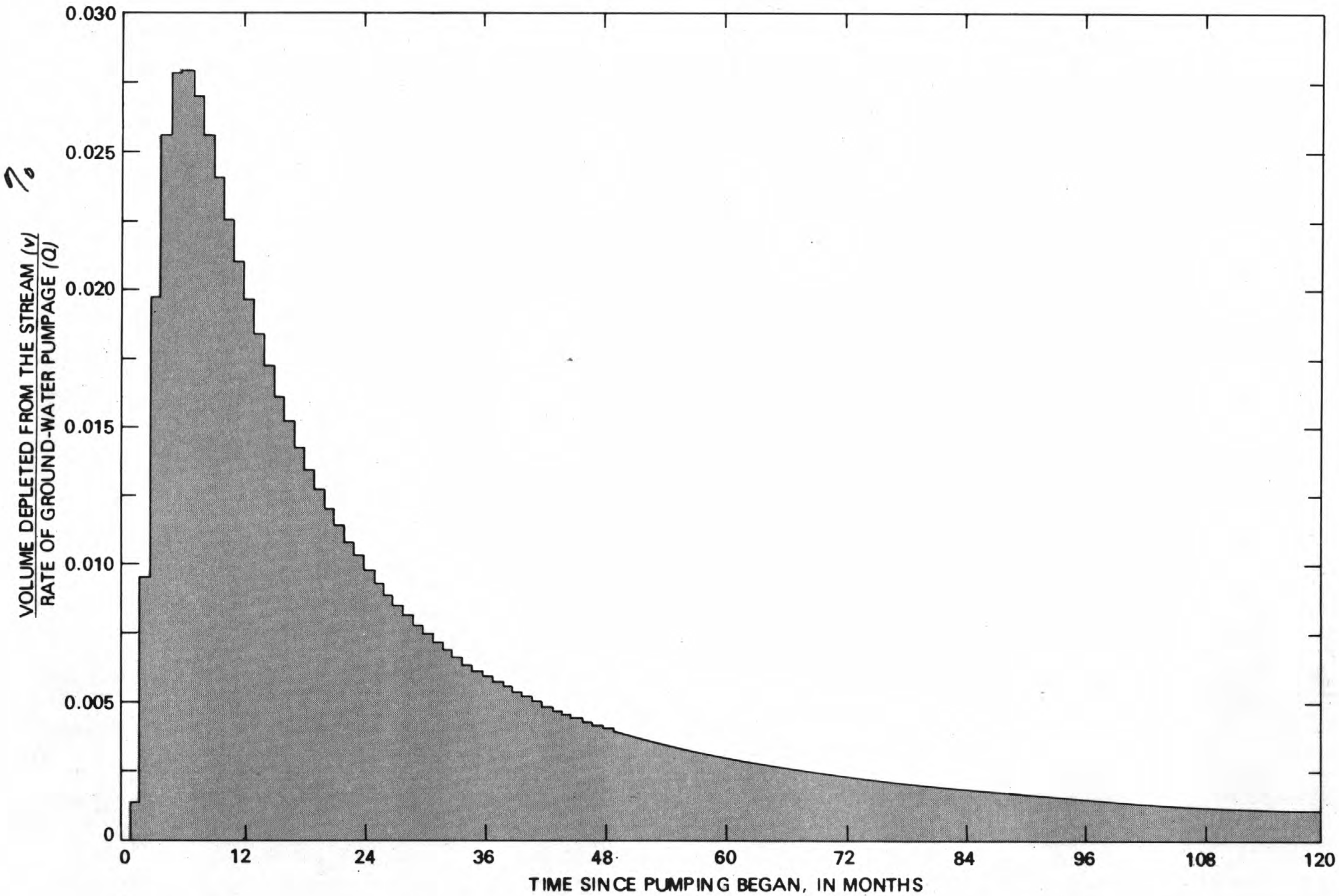


Figure 6. -- Unit response function for stream-depletion factor (SDF)=1000 days.

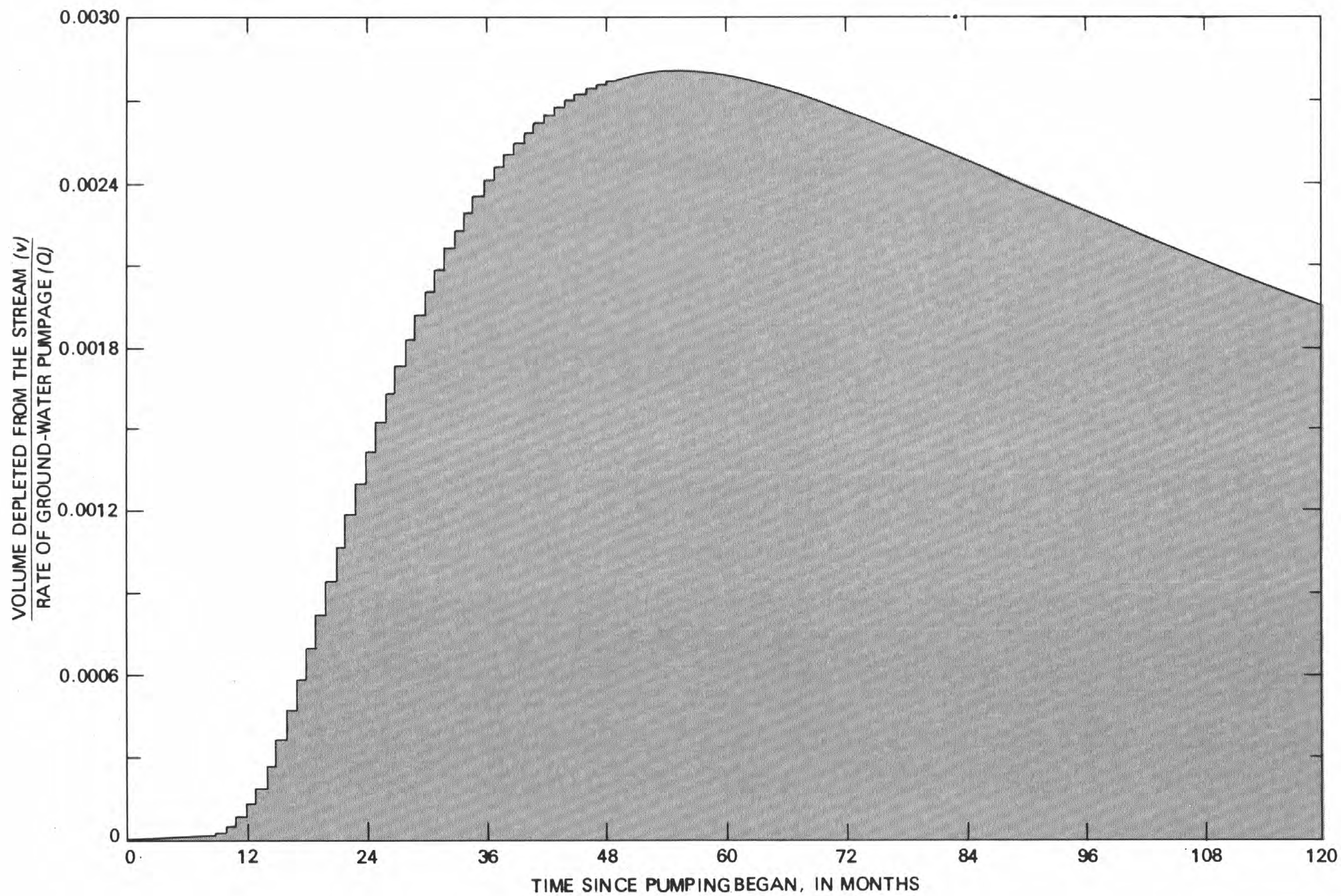


Figure 7.--Unit response function for stream-depletion factor (SDF) = 10,000 days.

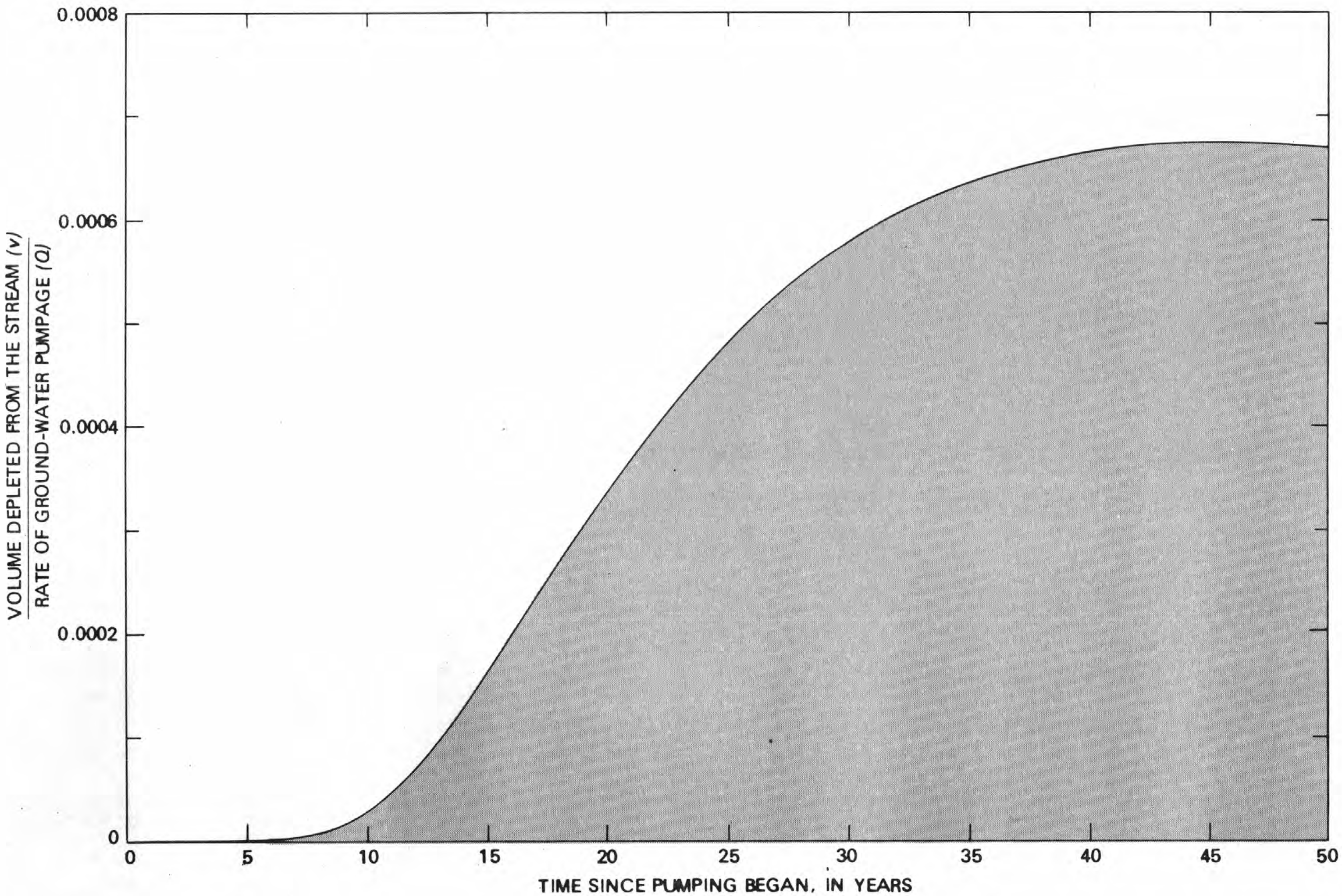


Figure 8. -- Unit response function for stream-depletion factor (SDF) = 100,000 days.

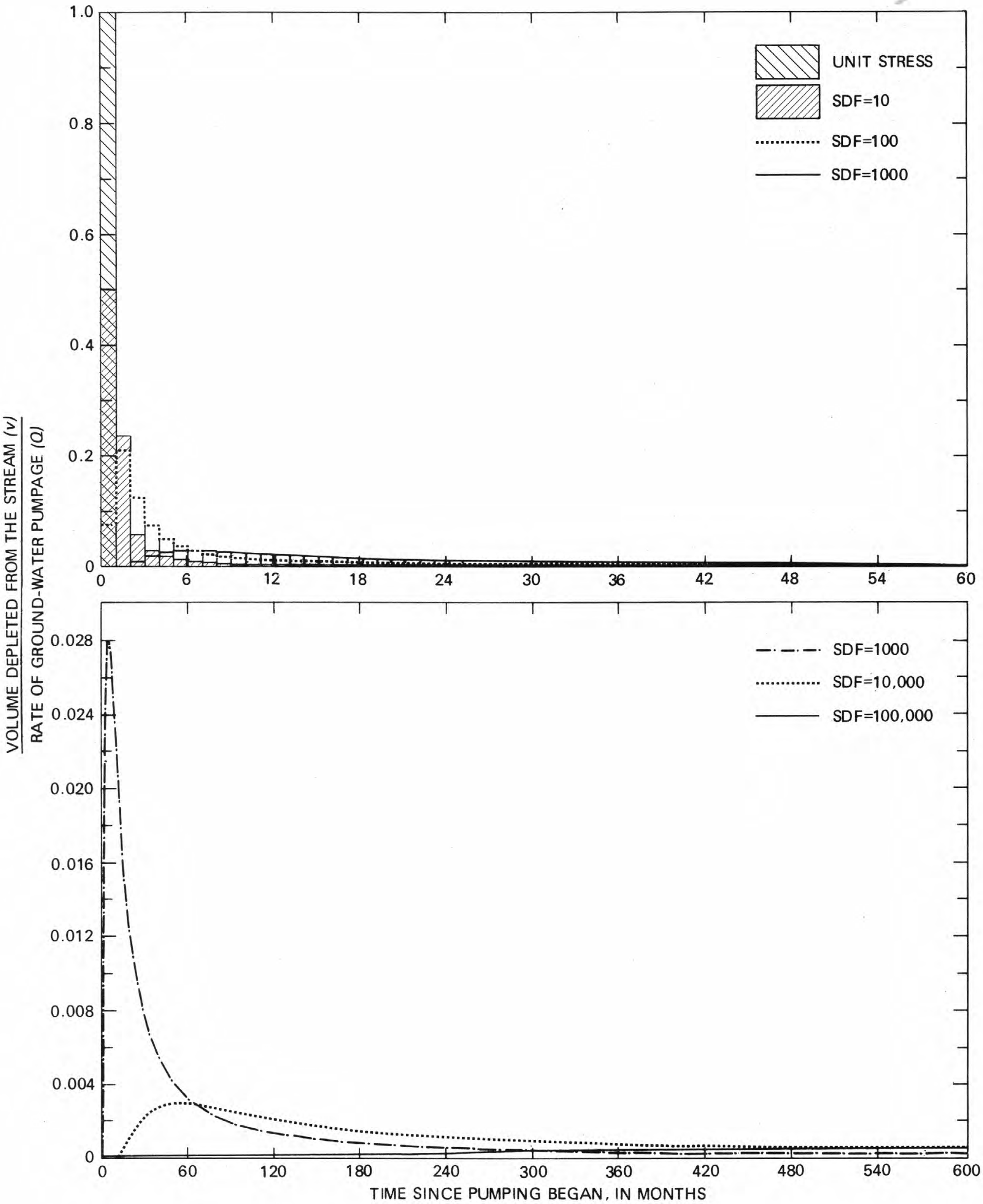


Figure 9.--Relative scales for various values of the stream-depletion factor (SDF).

The unit response function [$U(k)$] and a time series of aquifer stresses [$Q(k)$] are used with the discretized version of the convolution equation (Eagleson and others, 1966, p. 756-757) to compute the time series of stream depletions (or accretions) [$Q(i)$] at time i:

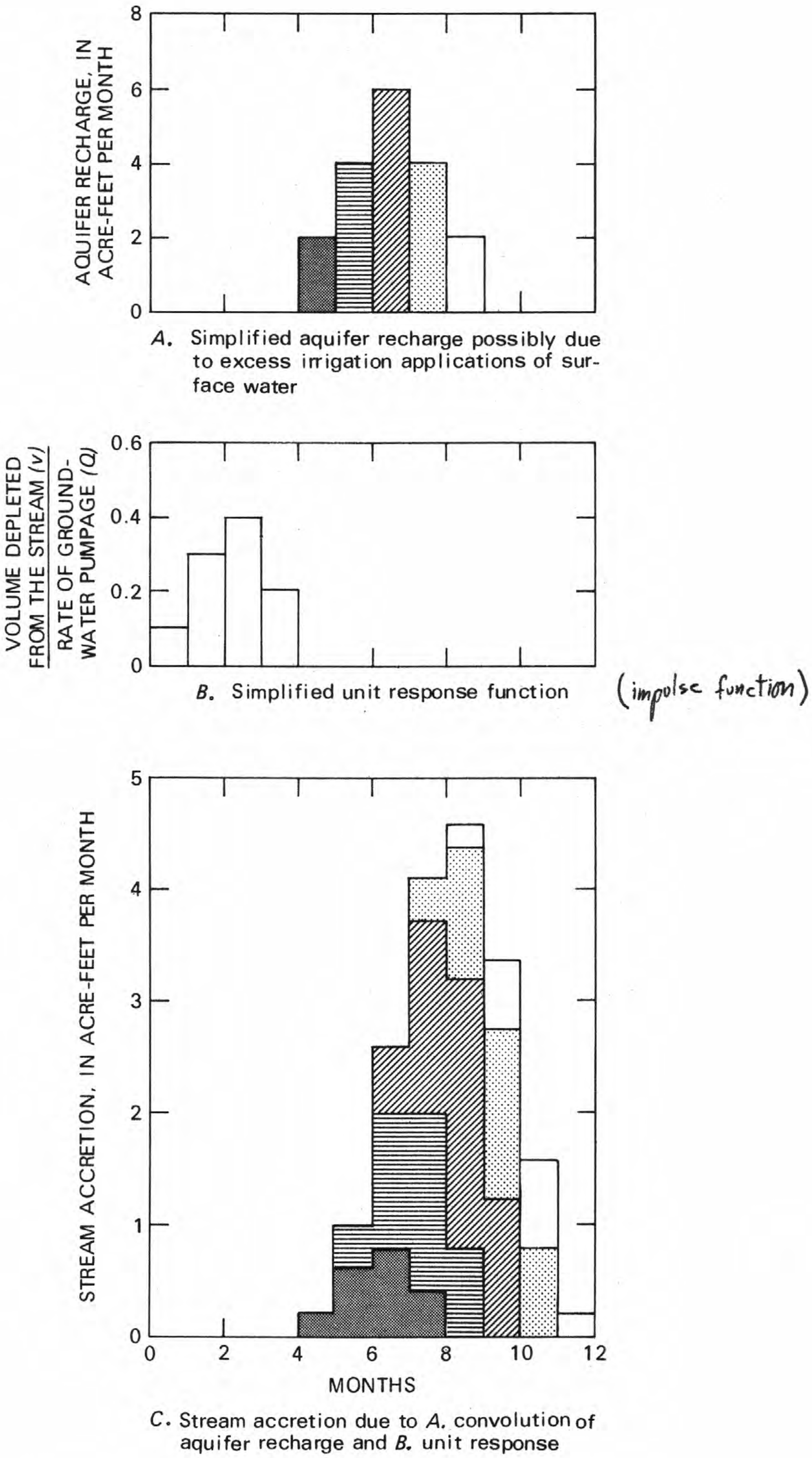
$$q(i)=\sum_{k=1}^{i} Q(k)\cdot U(i-k+1). \qquad (3)$$

This computation is shown in figure 10, where the time series of stream accretions due to aquifer recharge for each month are added to the stream accretions due to the aquifer recharge in each subsequent month, resulting in the total stream accretions.

COMPUTATION OF STREAM DEPLETIONS

The SDF values computed for this study were primarily based on the ground-water model used for the Missouri River Basin Commission Level B Study (Lappala, Emery, and Otradovsky, 1979). The model of the Middle Platte reach of the Upper Platte subbasin of the Level B study extended east and west beyond the area of interest for this current study, using a constant grid network with nodes 2.5 mi by 2.5 mi. For the Level B Study, the southern extent of the modeled area was the approximate ground-water divide between the Platte River and the Republican River or Blue River. To account for this arbitrary boundary, the Level B model maintained a constant gradient along the boundary. The effect of this assumption was simulation of equal rates of development (withdrawal or recharge) on both sides of the boundary of the modeled area. This current study considered a more realistic distribution of potential development in the area south of the ground-water divide and thus could not use the arbitrary boundary previously used for the Level B Study. The constant gradient boundary conditions in the Level B model were removed and the data set for that model was used with another similar ground-water flow model (Taylor, 1971) for this study.

Taylor's model simulates the stream response to a single pumping well, and fits the simulated response to the theoretical response at the point where the response is 28 percent of the pumpage. This point is where the pumping period is equal to the SDF value on the theoretical curve (see Jenkins, 1968b). The SDF values for the study area south of that covered by the Level B data set were computed for three cross sections. Aquifer characteristics were estimated based on the geologic cross sections published by Johnson (1960). These cross sections were extended south beyond the limit of land-use data such that the arbitrarily chosen no-flow boundary would have minimal effect on the SDF values computed along the cross section. The SDF values were then contoured and bands of equal SDF values were assigned the mean SDF value between the contour intervals (fig. 11).



A. Simplified aquifer recharge possibly due to excess irrigation applications of surface water

B. Simplified unit response function

C. Stream accretion due to *A.* convolution of aquifer recharge and *B.* unit response

Figure 10.--Illustration of the convolution of the aquifer recharge with unit response function to yield stream accretion.

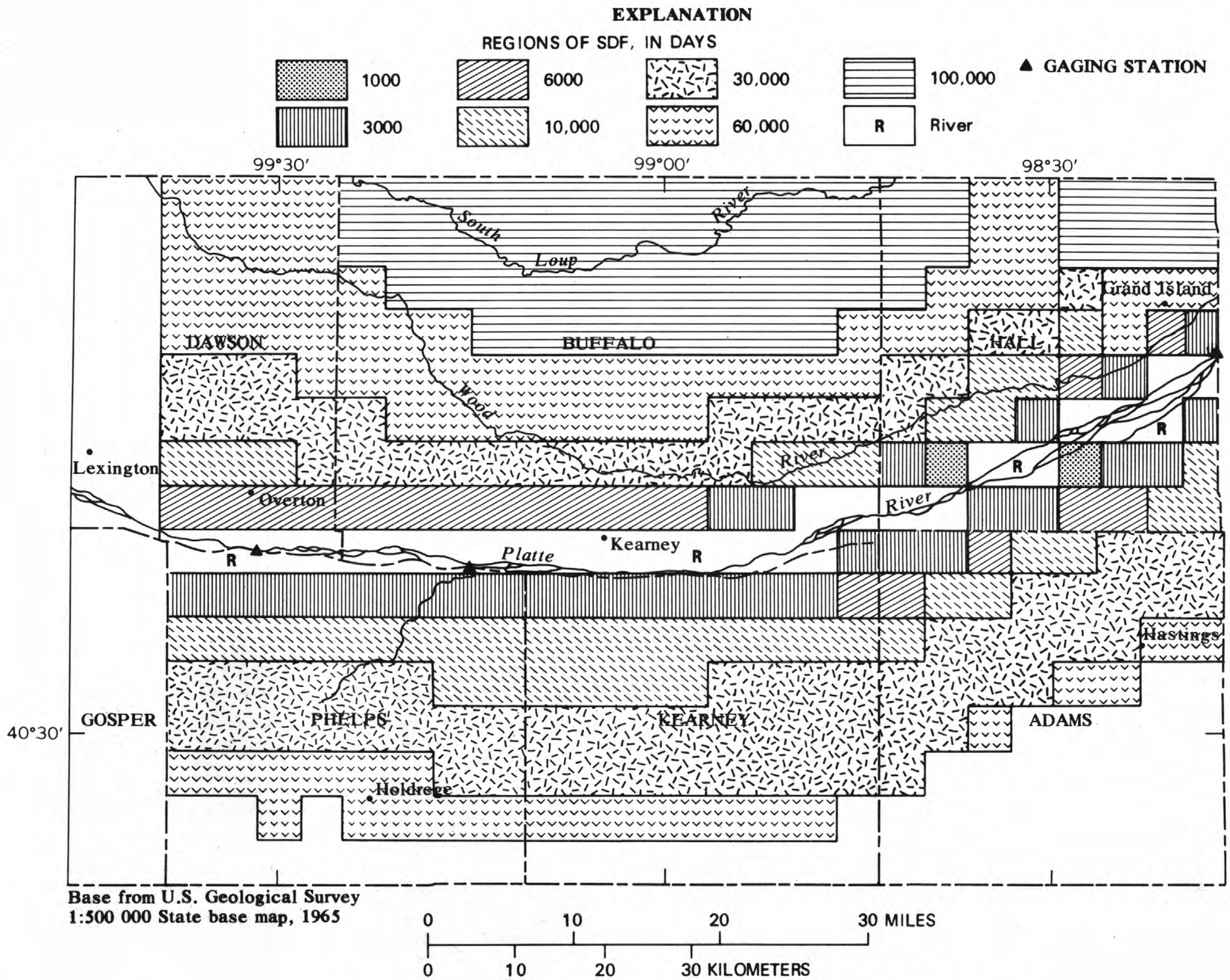


Figure 11.-- Stream-depletion factor (SDF) regions, in days.

Data enumerating the total acreage, number of wells, acreage irrigated by surface water, soil type, irrigable acreage, and subirrigated acreage for quarter townships (5,760 acres for most quarter townships) were provided by the U.S. Bureau of Reclamation (Fred Ostradovsky, written commun., 1981). An SDF-band value was assigned to each quarter township. When discretizing the area by quarter townships, the distances were such that no SDF value less than 1,000 existed except within quarter townships which intersected the river. An assumed distribution of SDF values was assigned to each quarter township which is intersected by the river. This assumed distribution was based on an average location of the river within a quarter township. This assumed distribution was the same for every quarter township which intersected the river, and thus the acreages and number of wells for some of the bands in table 1 are identical.

Table 1.--*Well and acreage data by stream depletion factor (SDF) bands*

Band	SDF value	Total acreage	Wells	Acreage irrigated with surface water	Irrigable acreage	Sub-irrigated acreage
1	10	17,000	114	314	7,400	15,200
2	30	8,800	55	157	3,700	7,600
3	60	8,800	55	157	3,700	7,600
4	100	19,000	123	340	8,000	16,500
5	300	29,400	191	523	12,300	25,400
6	600	29,400	191	523	12,300	25,400
7	1,000	35,000	248	419	17,400	28,200
8	3,000	176,000	1,260	6,630	102,000	59,200
9	6,000	97,900	719	1,210	64,400	21,200
10	10,000	248,000	1,600	29,700	182,000	8,900
11	30,000	488,000	2,480	62,400	309,000	1,600
12	60,000	445,000	1,990	3,220	190,000	6,400
13	100,000	319,000	954	926	77,200	8,200

To compute the depletion of streamflow from the Platte River between the Overton gage and Grand Island gage due to stresses in the aquifer, the net ground-water recharge for the area within each SDF band was calculated. A computer model (see appendix) was developed to calculate the monthly net ground-water recharges within each SDF band and then convolute them with their respective response functions. The amount of net ground-water recharge in an area is a function of the soil type, available soil moisture, the amount of irrigation water applied and precipitation on the land surface, the plants' consumptive use, and the amount of water withdrawn from the aquifer. To determine the amount of water recharged to or withdrawn from the aquifer, four basic land-irrigation categories were identified within the study area: Dryland (for nonirrigated land), irrigated land using surface water, irrigated land using ground water, and subirrigated areas.

The amount of land characterized by each of these land categories was determined for each SDF band and each of four soil types (see table 2 for brief description) from the data which was summarized in table 1. Net ground-water recharge rates (in feet per month) were computed for each of the four soil types by the U.S. Bureau of Reclamation (Fred Otradovsky, written commun., 1981), using a soil-moisture model. Lappala and others (1979) described the soil-moisture model as follows:

"Net ground-water recharge was computed with a water-balance model of the soil zone developed by the Nebraska Reclamation Office, U.S. Bureau of Reclamation, Grand Island, Nebr. The model operates on a monthly basis and is adapted from the daily irrigation scheduling program developed by Jensen and others (1969). The soil zone was modeled as a lumped system for a given topography, soil type, and crop distribution. Inputs and outputs from the soil zone are shown in figure 12. Inputs to the model are monthly values of precipitation and potential evapotranspiration (ET). Potential ET was computed using the Jensen-Haise method (Jensen and others, 1969). Runoff was abstracted from precipitation using monthly rainfall-runoff relationships derived from data obtained by the Agricultural Research Service at Rosemont, Nebr. (U.S. Department of Agriculture, 1956-68). These relationships considered soil type, slope, crop cover, and farming practices.

"Outflow from the soil zone consisted of gravity drainage and ET. Gravity drainage, or assumed recharge to the water table, occurred when infiltration from precipitation and applied irrigation water exceeded ET plus soil-moisture-retention capacity. Net ground-water recharge for land irrigated with ground water was equal to recharge from precipitation plus irrigation seepage minus total ground-water withdrawal. For land irrigated with surface water, net ground-water recharge was equal to recharge from precipitation plus seepage losses. Potential ET was computed for Grand Island, Nebr., by using air temperature and solar radiation (Jensen and others, 1969). Relative humidity, elevation, and crop type were used to adjust potential ET to obtain actual consumptive use. Four major crop types were used for this study: Row crops, small grains, alfalfa, and pasture. Annual net recharge to the water table and ground-water withdrawals were computed using typical cropping patterns for these crops under dryland conditions and irrigation with ground water and surface water."

Table 2.--*Average net ground-water recharge rates, by irrigation category and soil type, 1941-77*

[Computed from U.S. Bureau of Reclamation soil moisture model. Data are in feet per year]

Soil type	Dryland	Land irrigated with		Subirrigated land
		Ground water	Surface water	
Bottomland-----	0.27	-0.42	1.10	-1.05
Terrace land---	.13	-.47	.62	-----
Silty uplands--	.13	-.81	.56	-----
Sandy uplands--	.40	-.27	.83	-----

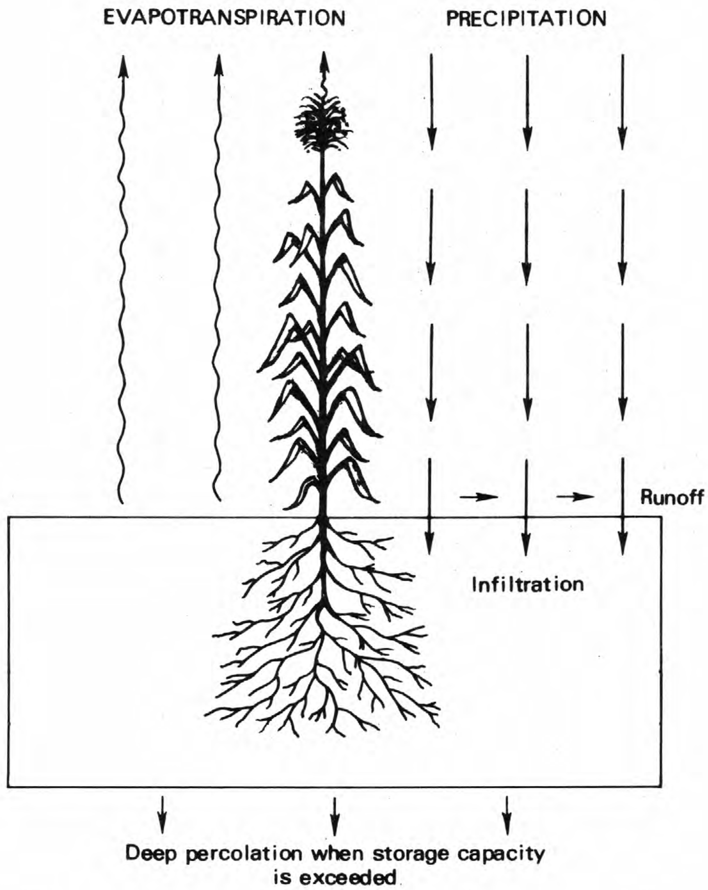


Figure 12.--Simulated components of the soil zone. (Modified from Lappala and others, 1979, p.45.)

Annual average net ground-water recharge rates for each soil type and land category computed from these data are shown in table 2. Data provided by U.S. Bureau of Reclamation (table 1) had to be supplemented with additional soil data and well-pumping data. Soil types for much of the southern part of the study area were assigned using the U.S. Soil Conservation Service maps for Phelps (U.S. Department of Agriculture, 1973) and Adams (U.S. Department of Agriculture, 1974) Counties. To compute acreage irrigated by ground water, the acreage irrigated per well was needed. This acreage value was assumed to vary according to SDF band and county (table 3) and was computed to match countywide data provided by the U.S. Bureau of Reclamation.

The 37 years of net ground-water recharge rates provided by the U.S. Bureau of Reclamation had to be extended to provide the needed 50 years of data. This extension was computed by multiple regression using two terms for the sine and cosine of time to compute a seasonality factor and monthly precipitation at Kearney. The model then was run for two consecutive 50-year periods to generate estimates of current streamflow depletions. The first 50-year sequence (an approximation of 1880-1930 conditions) was based on the assumption that there was no ground-water pumpage, no surface-water irrigation on the south side of the river, and that all of the quarter townships intersected by the river were naturally subirrigated. Also, subirrigated acreage was increased from current conditions in all other SDF bands. The second 50-year sequence (an approximation of 1930-80 conditions) was based on the assumption of instantaneous implementation of the Tri-County project, which is on the south side of the river and accounts for most of the acreage irrigated by surface water in the study area. The number of wells was assumed to increase linearly from zero to the present total, and the number of subirrigated acres was assumed to decrease linearly to the present number. Estimates of the net ground-water recharge over the study area and the resultant stream depletion are shown in figure 13. Estimates of streamflow depletion were computed by averaging the last 5 years of data and are shown on the first line of table 4. The average stream depletion of 32,300 acre-ft/yr compares favorably with the 38,800 acre-ft/yr computed for the 1931-78 point-flow study of the U.S. Bureau of Reclamation (Fred Otradovsky, written commun., 1981).

Table 3.--*Acres irrigated per well, by SDF band and county*

[SDF, stream depletion factor; USBR, U.S. Bureau of Reclamation]

SDF band	Acres north of river	Acres south of river
1-6---	40	40
7-9---	40	80
10-13--	50	100

County	Acres computed using SDF band data	Acres computed using USBR county data
Adams----	98	92
Buffalo--	47	61
Dawson---	46	46
Hall-----	47	56
Kearney--	93	92
Phelps---	93	77

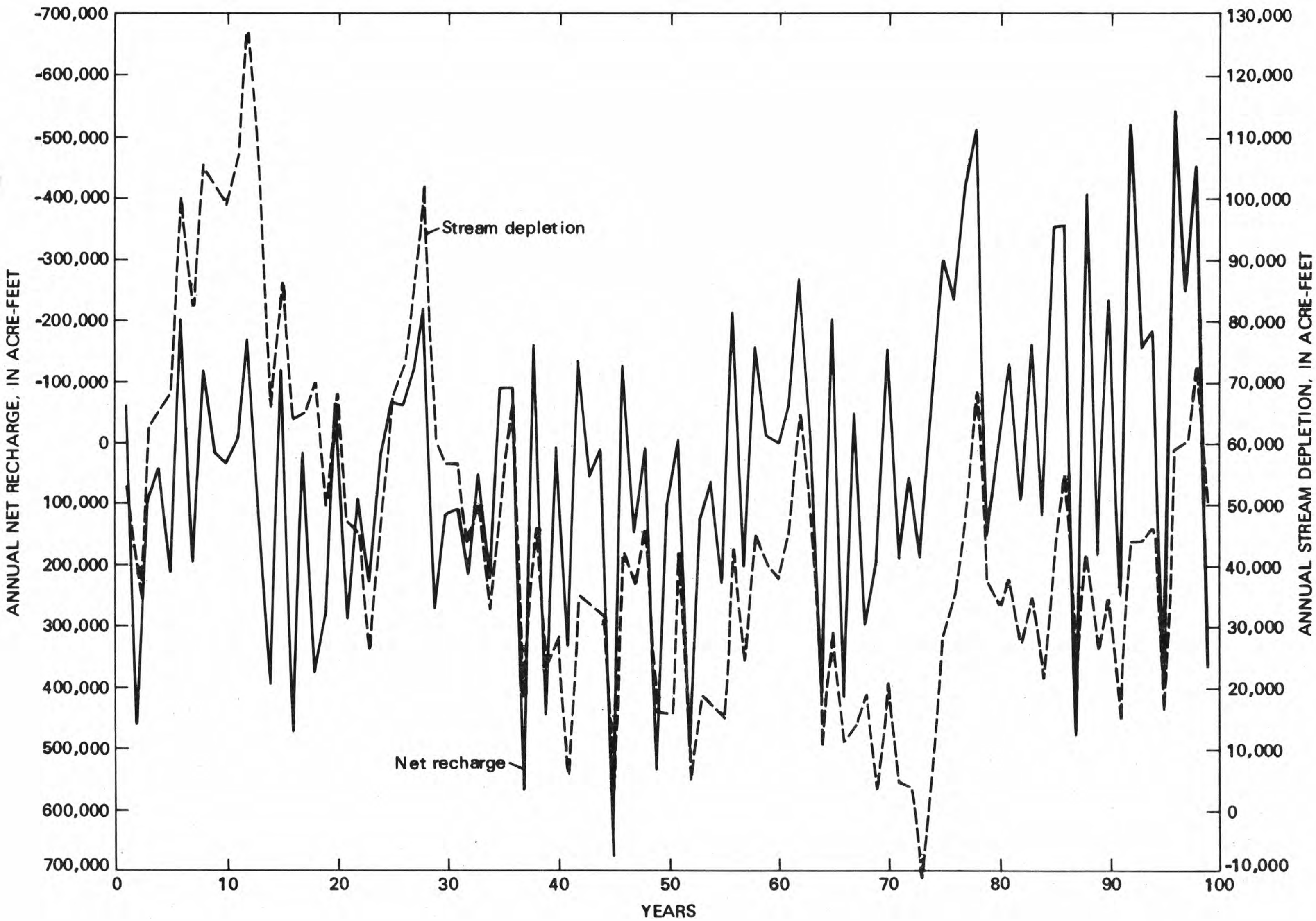


Figure 13.-- Annual net ground-water recharge and annual stream depletion.

Table 4.--*Acreages and stream depletion for current and predicted conditions*

Water management activity	Areas, in acres				Average streamflow depletion for the last 5 years, in thousands of acre-feet													50-year average
	Dryland	Surface-water irrigated	Ground-water irrigated	Sub-irrigated	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total	
1930-1980 conditions.	([1])	([1])	([1])	([1])	3.9	3.1	2.3	0.9	1.1	3.2	7.0	9.1	8.8	7.9	6.4	5.1	59.1	32
Continue current practices.	944,000	106,000	617,000	197,000	10.4	9.5	8.8	7.4	7.6	9.6	13.3	15.4	15.0	14.1	12.6	11.4	135	125
Surface-water development.	716,000	378,000	617,000	154,000	3.1	2.6	1.9	0.5	0.4	1.8	4.4	5.9	5.8	0.3	4.4	3.7	39.8	53.2
Ground water replacing subirrigation.	742,000	106,000	889,000	128,000	16.6	15.8	15.1	13.5	13.3	15.0	19.2	21.8	21.2	20.0	18.6	17.6	207.7	174
Ground-water development.	716,000	106,000	889,000	154,000	16.9	16.0	15.4	13.8	13.6	15.3	19.6	22.2	21.6	20.4	19.0	17.9	212	177

[1]Varies with time.

Four water-management alternatives for the area between Overton and Grand Island were simulated to identify possible ranges of future streamflow depletions: (1) Continue current management practices, (2) irrigate all remaining irrigable land with surface water, (3) irrigate all remaining irrigable land with ground water, replacing areas of subirrigation, and (4) irrigate all remaining irrigable land with ground water. Each of these conditions was assumed to start instantaneously and was modeled for a 50-year period following the 100-year sequence discussed earlier. The distribution of acreage, the average stream depletion, and the average monthly stream depletion occurring in the last 5 years of the 50-year sequence is shown in table 4 for each alternative.

The four alternatives simulated resulted in a range of stream depletions. If the current water-management practices continue, the predicted 50-year average stream depletion would be 125,000 acre-ft/yr. If the available 270,000 acres of irrigable land were irrigated with some imported source of water, the average depletions would be reduced to 53,200 acre-ft/yr. If that same acreage were irrigated with ground water, replacing where possible subirrigated acreage, the depletions would average 174,000 acre-ft/yr. If the existing subirrigated areas were not replaced by the new irrigated acreage, the stream depletion would average 177,000 acre-ft/yr.

EFFECTS OF WATER-MANAGEMENT ALTERNATIVES ON STREAM STAGE

Changes in the streamflow and stage of the Platte River will affect ground-water levels in wildlife-refuge areas along the Platte River (Hurr, 1981). To relate the effects of changes in stream discharge due to management practices to the stream stage along the habitat area, a relationship between stream discharge and stream stage was developed. The stage-discharge rating tables for the gaging stations, Platte River near Cozad, near Overton, near Odessa, and near Grand Island were all fit to regression lines. The general form of the equation is:

$$h=aQ^b \qquad (4)$$

where

h is river stage above zero flow, in feet;
Q is river discharge in cubic feet per second; and
a and b are regression coefficients.

The relationship for the Cozad station differed from the other sites because two channels are present there, but the regression coefficients for the other sites (table 5) were remarkably similar. Based on these results, a generalized description of the stage-discharge relationship for the habitat area was modeled as:

$$h=0.033Q^{0.5} \qquad (5)$$

As a tool to evaluate the effects of various water-management alternatives, a frequency curve of predicted stream stage along the habitat area was computed. The historical streamflow data for the Platte River near Overton was used for the period 1941-77. To extend this record to the same 50-year sequence used for the net ground-water recharge rates (see section on "Computation of Stream Depletions"), the monthly flows were regressed with the monthly flows for the South Platte River at Julesburg.

Table 5.--*Regression coefficients for stage-discharge relationships for the Platte River*

Station	Regression coefficients a	Regression coefficients b
Platte River near Overton----------------------------------	0.038	0.479
Platte River near Odessa-----------------------------------	.040	.484
Platte River near Grand Island-----------------------------	.020	.549
Platte River near Cozad (channel 1)------------------------	.414	.333
Platte River near Cozad (channel 2)------------------------	.186	.382

Historically, flow diversions between the gages near Overton and Grand Island have been made by the Kearney Canal and Elm Creek Canal. The Elm Creek Canal, abandoned in 1963, was not considered in this analysis of future conditions. Much of the water diverted to the Kearney Canal is used for power production and is returned to the river. The net amount diverted, as modeled, was based on the monthly average data provided by the U.S. Bureau of Reclamation point-flow study (Fred Otradovsky, written commun., 1981). Thus the streamflow used to compute the frequency curve of stream stage along the habitat area is the historical Overton streamflow (1,270 ft^3/s average), less the average Kearney Canal diversion (23,000 acre-ft/yr), less the stream depletion computed for each water-management activity (see table 4) for 50-year average. The frequency curves were computed not only for the entire year (fig. 14), but also for the different "hydrologic seasons" applicable to the habitat area. These seasons include September through February (fig. 15), March through April (fig. 16), and May through August (fig. 17). As can be seen in these figures, the various management alternatives have only minimal effect on the stage of the river.

Some hypothetical water-management alternatives which would affect streamflow directly were selected to compare their effects with the effects of the four water-management alternatives previously discussed. The alternative water-management alternatives which affect the upstream inflow to the study area include: (1) Increase current flows in the Platte River by importing the water needed to irrigate 100,000 acres (average flow is 1,610 ft^3/s); (2) decrease current flows in the river by diverting the water needed to irrigate 100,000 acres (simulated flow is 240,000 acre-ft/yr; average flow is 1,040 ft^3/s); and (3) decrease current flows in the river by storing or diverting all monthly flow that exceeds 2,000 ft^3/s (average flow is 1,100 ft^3/s). All of these flows were adjusted by subtracting the monthly average Kearney Canal diversion and the predicted stream depletion based on current conditions, previously discussed in the section on "Computation of Stream Depletions," to compute the frequency curves of stream stage. The annual frequency curves are shown in figure 18, and the frequency curves for the three hydrologic seasons--in figures 19, 20, and 21, respectively. Though no quantitative analysis of the stage-frequency curves was made, it is obvious that there is a much greater deviation among these sets of curves than for the previous sets of curves.

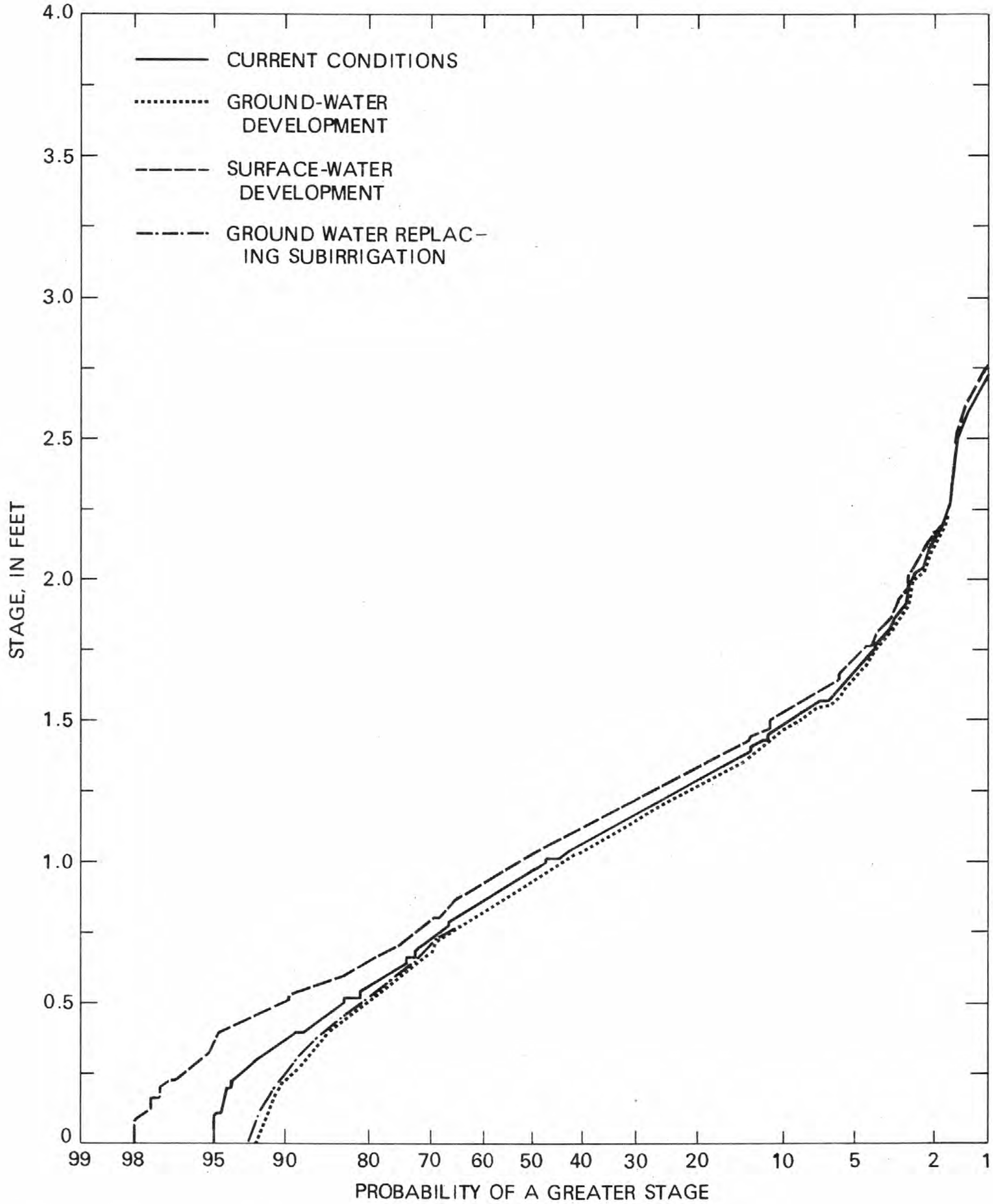


Figure 14.--Annual stream-stage frequency curves for four water-management alternatives affecting stream depletion.

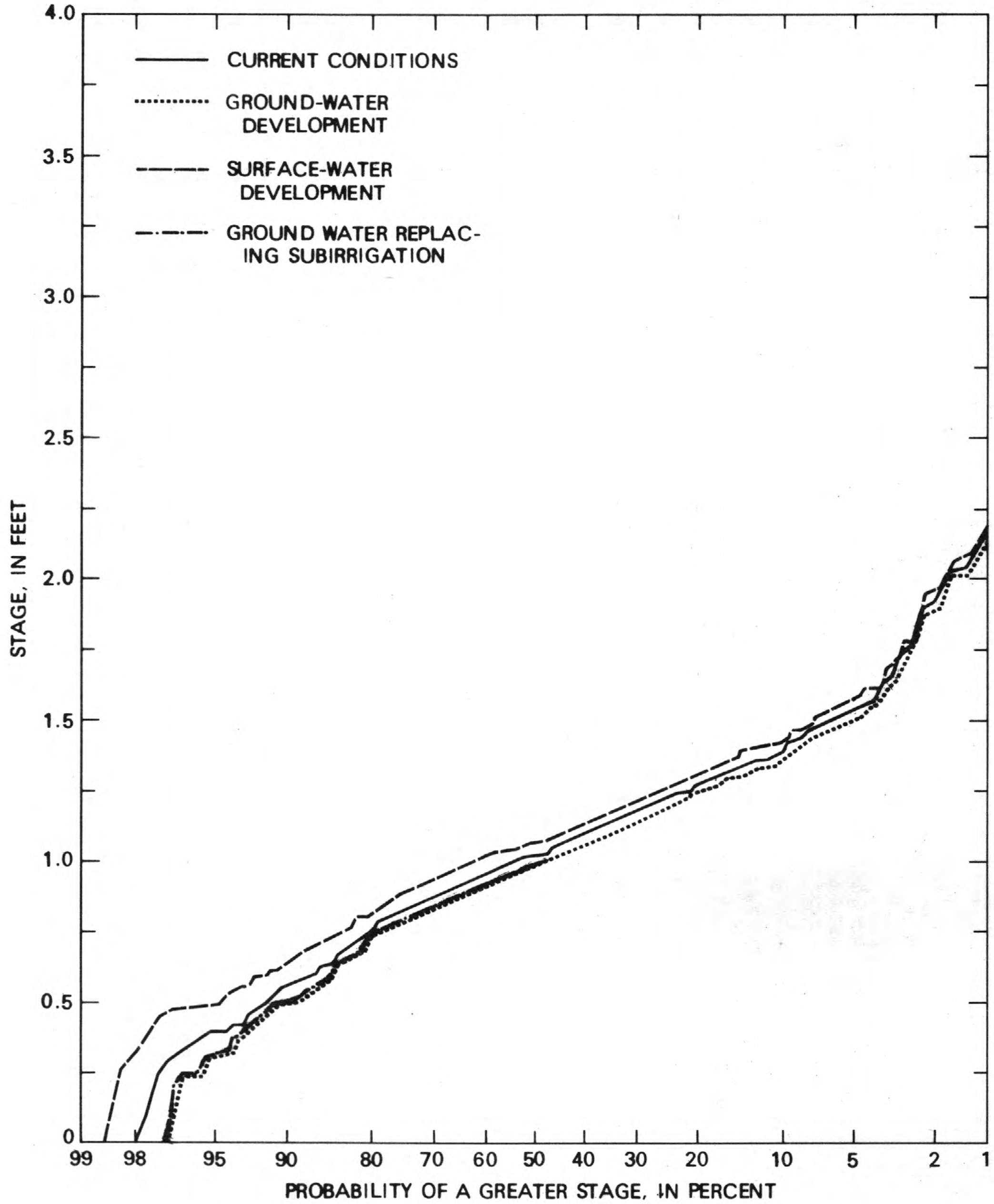


Figure 15.--September through February stream-stage frequency curves for four water-management alternatives affecting stream depletion.

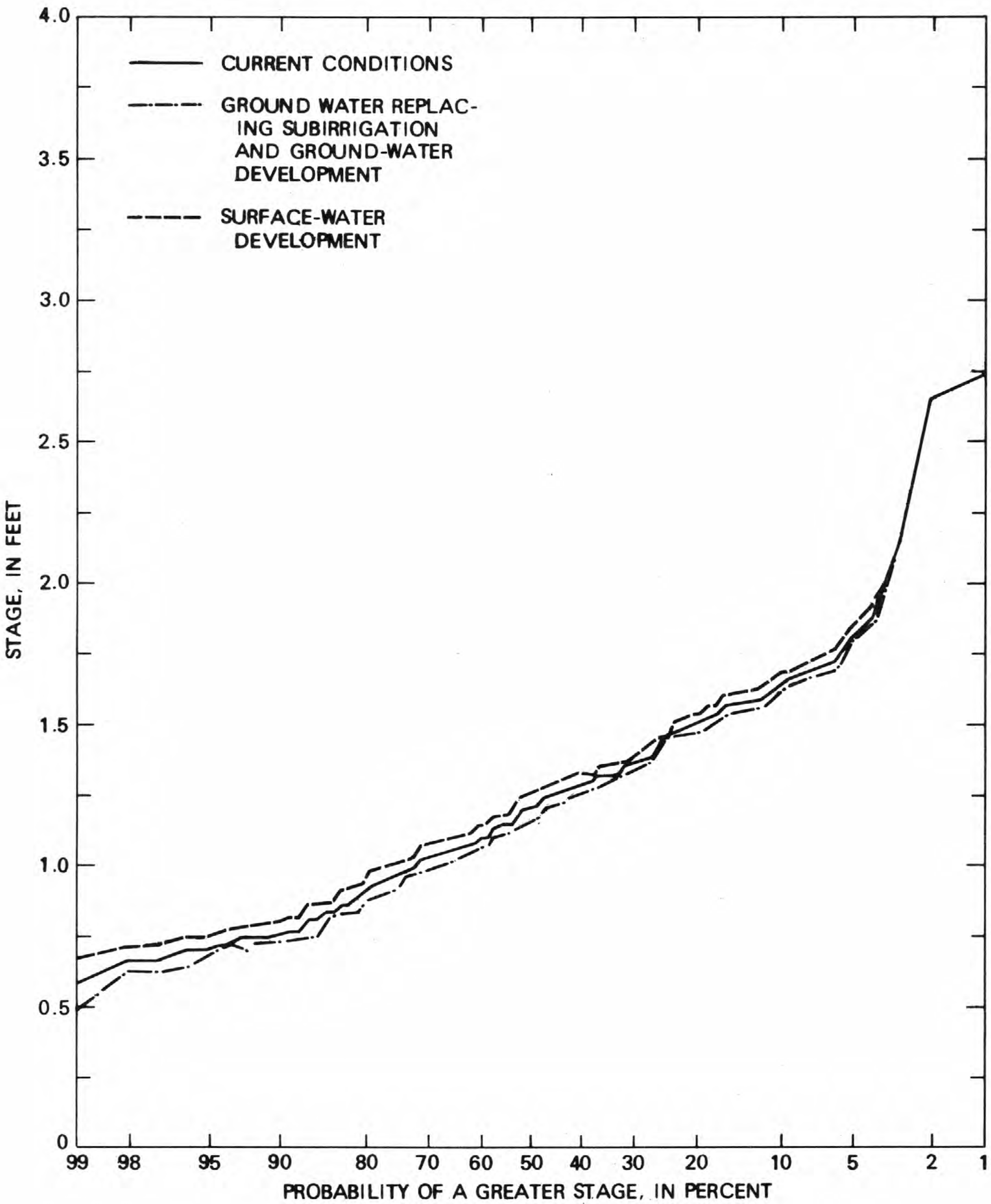


Figure 16.--March through April stream-stage frequency curves for four water-management alternatives affecting stream depletion.

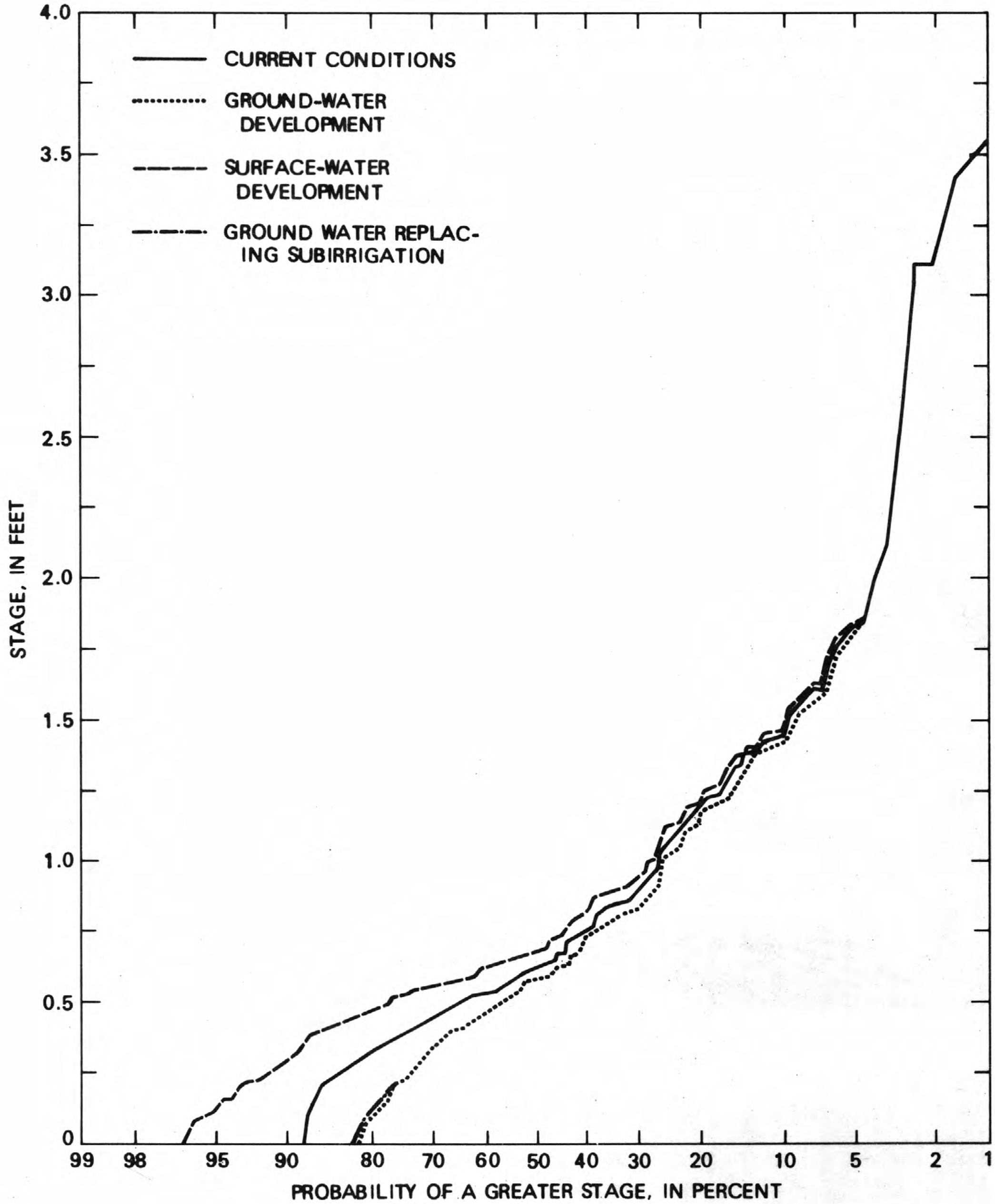


Figure 17.--May through August stream-stage frequency curves for four water-management alternatives affecting stream depletion.

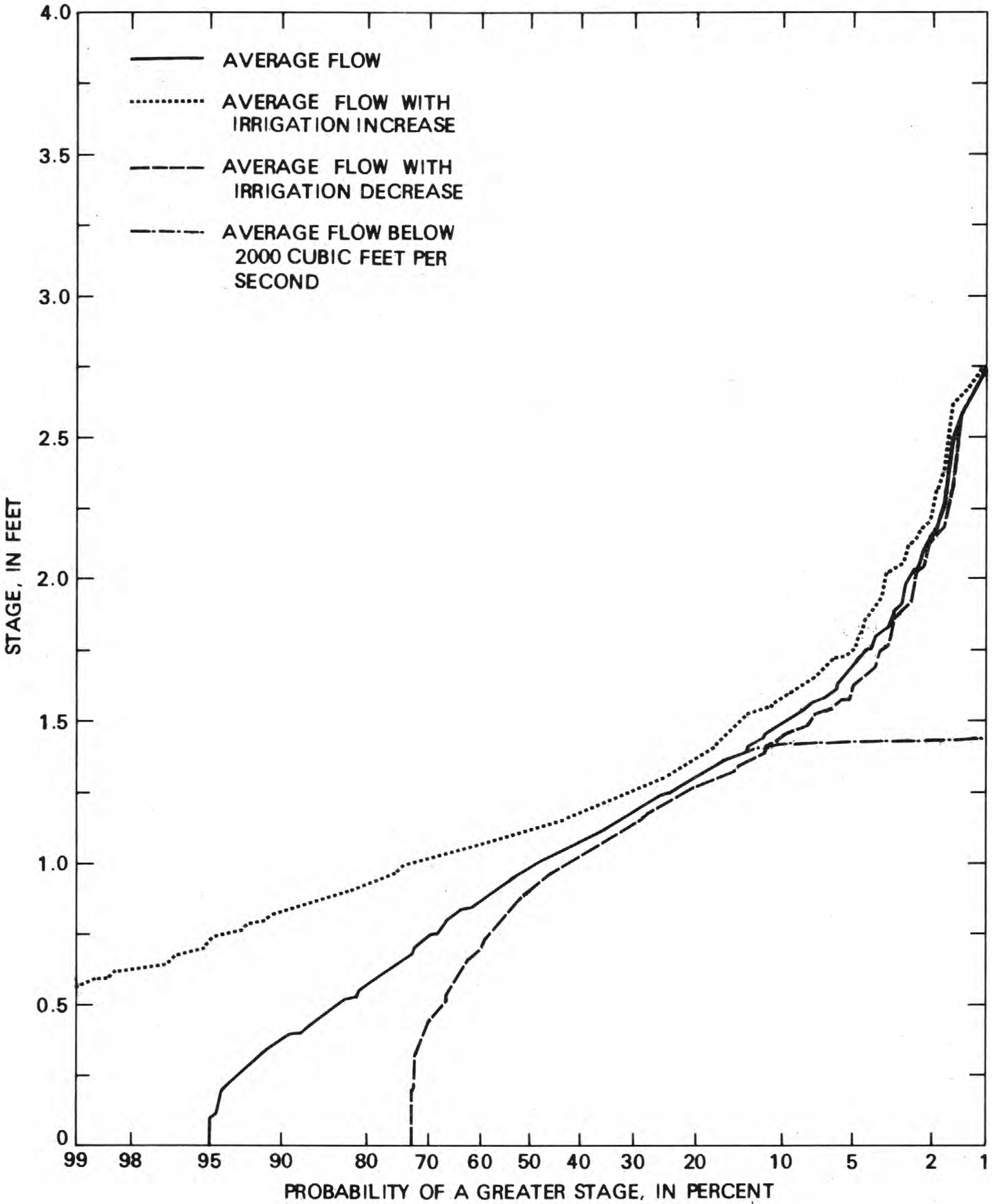


Figure 18.-- Annual stream-stage frequency curves for four water-management alternatives directly affecting upstream flow.

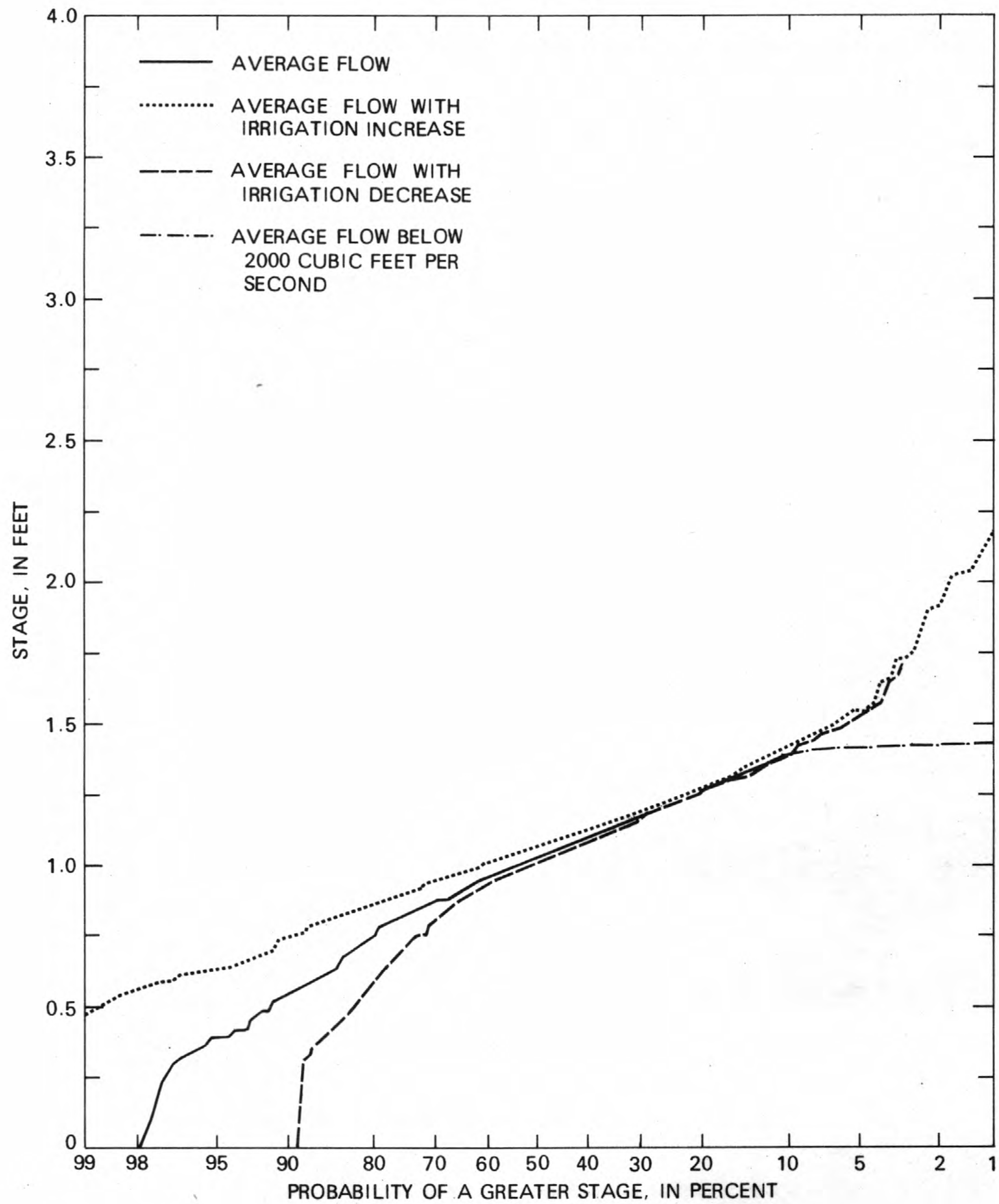


Figure 19.--September through February stream-stage frequency curves for four water-management alternatives directly affecting upstream flow.

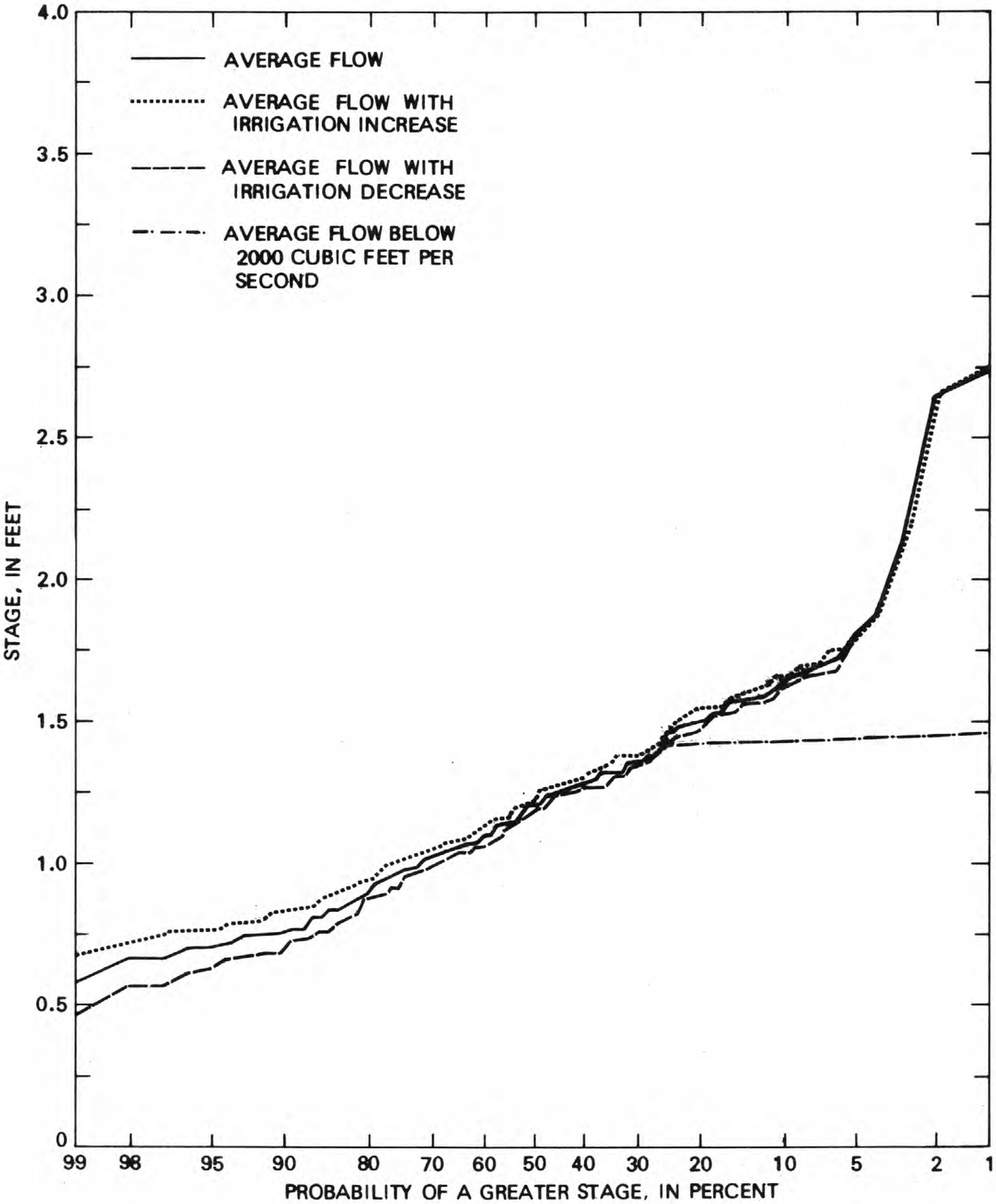


Figure 20.--March through April stream-stage frequency curves for four water-management alternatives directly affecting upstream flow.

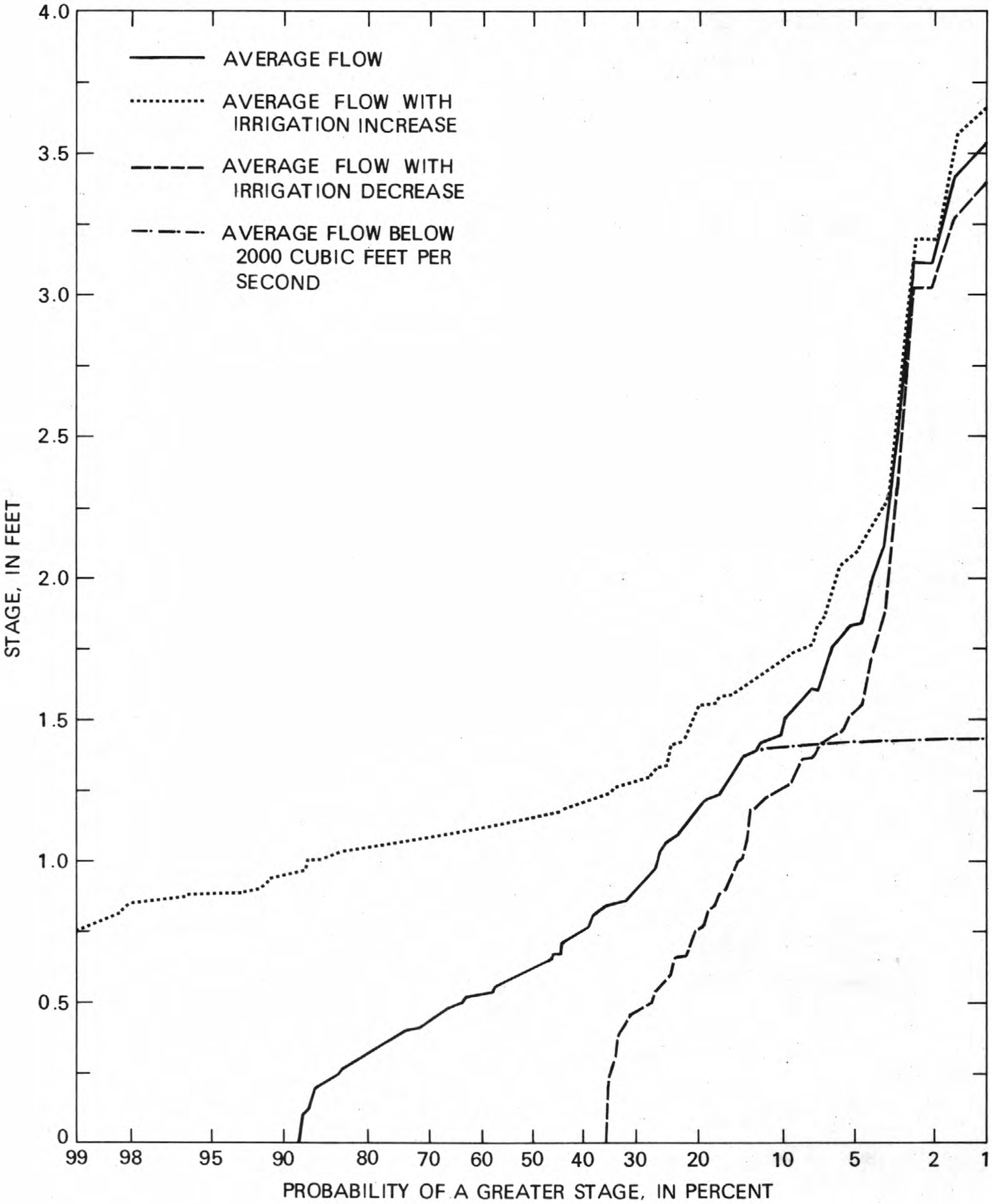


Figure 21.--May through August stream-stage frequency curves for four water-management alternatives directly affecting upstream flow.

CONCLUSIONS

The effects of water-management practices in the area of the Platte River between Overton and Grand Island caused an average of about 32,300 acre-ft/yr of simulated stream depletion over the last 50 years. This depletion would increase to about 124,900 acre-ft/yr over a 50-year period, even if no changes occur in the water-management activities due to the delayed effects of the historical increase in ground-water pumpage to the current level. Adding about 270,000 acres of new surface-water irrigated acreage would reduce the depletions to an average of 53,200 acre-ft/yr over a 50-year period. If ground water were used to irrigate about 270,000 acres of irrigable land, some in areas of current subirrigation, the computed 50-year average depletion would be increased to 174,000 acre-ft/yr. If the increased ground-water irrigated areas did not replace subirrigated areas, the computed 50-year depletion would average 177,000 acre-ft/yr. The hydrologic effect of these possible water-management alternatives would be minimal on the stage of the river along the habitat area, as shown by the frequency curves. The effects of importing or diverting the 240,000 acre-ft/yr necessary to irrigate 100,000 acres, or storing or diverting all high flows in excess of 2,000 ft^3/s, would be much more significant to the river stage, as shown in the frequency curves.

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_____ 1974, Soil Survey of Adams County, Nebraska, 102 p.

APPENDIX

Fortran Model to Compute Stream Depletion

```
      PROGRAM PLTRSP(INPUT,OUTPUT,TAPE1,TAPE2,TAPE3,TAPE4,
     1 TAPE5=INPUT,TAPE6=OUTPUT)
C
      DIMENSION IBAND(125),ISOIL(125),KOUNTY(125),ACRES(125),NWS(125),
     1 CANALS(125),SUBS(125)
      DIMENSION ETDRY(600,4),ETSW(600,4),ETGW(600,4),ETSUB(600)
      DIMENSION PERSUB(13),ACPRWL(6,13),PRESNT(12),FIX(12)
      DIMENSION UNIT(13,600)
      DIMENSION STRMDP(601)
C
C         ETDRY  - NET RECHARGE FOR DRYLAND
C         ETSW   - NET RECHARGE FOR SURFACE WATER IRRIGATION
C         ETGW   - NET RECHARGE FOR GROUND WATER IRRIGATION
C         ETSUB  - NET RECHARGE FOR AREAS OF SUBIRRIGATION
C
C         PERSUB - PERCENTAGE ADJUSTMENT OF SUBIRRIGATED AREAS (BY BAND)
C         ACPRWL - ACREAGE PER WELL (BY BAND AND COUNTY)
C         PRESNT - 5 YEAR AVERGE OF CURRENT MONTHLY STREAM DEPLETION
C
C         UNIT   - STREAM RESPONSE TO AQUIFER STRESS (BY MONTH AND BAND)
C         STRMDP - FUTURE STREAM DEPLETION
C
C         IBAND  - SDF BAND NUMBR
C         ISOIL  - SOIL TYPE NUMBER
C         KOUNTY - COUNTY NUMBER
C         ACRES  - TOTAL ACREAGE
C         NWS    - NUMBER OF WELLS
C         CANALS - ACREAGE IRRIGATED BY SURFACE WATER
C         SUBS   - ACREAGE THAT IS SUBIRRIGATED
C
      DATA PRESNT /12*0./
      DATA DPMAX /15./ , AVGULD /10./ , AVGBLD /5./
      DATA FIX /1.,1.,1.,1.,1.,1.,.9,.8,.9,1.,1.,1./
C
      READ (5,1000) NMONTH,N
      READ (5,1010) PERSUB
      DO 5 I = 1,6
    5 READ (5,1010) (ACPRWL(I,J),J=1,13)
C
      DO 10 I = 1,N
      READ (1,1020) IBAND(I),KOUNTY(I),ISOIL(I),ACRES(I),NWS(I),
     1 CANALS(I),SUBS(I)
   10 CONTINUE
C
      DO 12 J=1,4
   12 READ (2,1030) (ETDRY(I,J),I=1,NMONTH)
      DO 14 J=1,4
   14 READ (2,1030) (ETGW(I,J),I=1,NMONTH)
      DO 16 J=1,4
   16 READ (2,1030) (ETSW(I,J),I=1,NMONTH)
```

```
      READ (2,1030) (ETSUB(I),I=1,NMONTH)
      DO 18 I = 1,NMONTH
      IM = (I-1)/12
      IM = I - IM*12
   18 ETSUB(I) = ETSUB(I)*FIX(IM)
C
      READ (3) UNIT
C
C          MODEL THE PERIOD 1879-1928
C
      DO 80 IMONTH = 1,NMONTH
      R = 0.
      DRY = 0.
      SW = 0.
      SB = 0.
      GW = 0.
      DO 60 I = 1,N
      DEPTH = AVGULD
      TTLAC = ACRES(I)
      CANAL = 0.
      IF (KOUNTY(I) .EQ. 5 .OR. KOUNTY(I) .EQ. 6) GO TO 20
      CANAL = CANALS(I)
      TTLAC = TTLAC - CANAL
   20 IB = IBAND(I)
      IF (IB .LT. 8) GO TO 30
      SUB = SUBS(I)*PERSUB(IB)
      IF (SUB .GT. TTLAC) GO TO 30
      GO TO 40
   30 SUB = TTLAC
      DEPTH = AVGBLD
   40 TTLAC = TTLAC - SUB
      IS = ISOIL(I)
      DEPTH = DPMAX - (DPMAX-DEPTH)*SUB/ACRES(I)
      RCHGNT = TTLAC*ETDRY(IMONTH,IS) + CANAL*ETSW(IMONTH,IS) +
     1 SUB*ETSUB(IMONTH)*(DPMAX-DEPTH)/DPMAX
      R = R + RCHGNT
      DRY = DRY + TTLAC
      SW = SW + CANAL
      SB = SB + SUB
      DO 50 IK = 1,NMONTH
      STRMDP(IK) = STRMDP(IK) - RCHGNT*UNIT(IB,IK)
   50 CONTINUE
   60 CONTINUE
      WRITE (6,2000) IMONTH,DRY,SW,GW,SB,R,STRMDP(1)
      DO 70 IK = 1,NMONTH
      STRMDP(IK) = STRMDP(IK + 1)
   70 CONTINUE
   80 CONTINUE
C
C          MODEL THE PERIOD 1929-1978
```

```
C
      DO 150 IMONTH = 1,NMONTH
      R = 0.
      DRY = 0.
      GW = 0.
      SW = 0.
      SB = 0.
      DO 120 I = 1,N
      DEPTH = AVGULD
      K = KOUNTY(I)
      TTLAC = ACRES(I)
      CANAL = CANALS(I)
      TTLAC = TTLAC - CANAL
      IB = IBAND(I)
      IGW = (IMONTH -1)/12
      XGW = IGW + 1
      GWAC = (XGW/50.)*NWS(I)*ACPRWL(K,IB)
      IF (GWAC .GT. TTLAC) GWAC = TTLAC
      TTLAC = TTLAC - GWAC
      IF (IB .LT. 8) GO TO 90
      SUB = SUBS(I)*PERSUB(IB)**((50.-XGW)/49)
      GO TO 100
   90 SUB = SUBS(I) - (TTLAC-SUBS(I))*(XGW-50.)/49.
      DEPTH = AVGBLD
  100 IF (SUB .GT. TTLAC) SUB = TTLAC
      TTLAC = TTLAC - SUB
      IS = ISOIL(I)
      DEPTH = DPMAX - (DPMAX-DEPTH)*SUB/ACRES(I)
      RCHGNT = TTLAC*ETDRY(IMONTH,IS) + CANAL*ETSW(IMONTH,IS) +
     1 GWAC*ETGW(IMONTH,IS) + SUB*ETSUB(IMONTH)*(DPMAX-DEPTH)/DPMAX
      R = R + RCHGNT
      DRY = DRY + TTLAC
      SW = SW + CANAL
      GW = GW + GWAC
      SB = SB + SUB
      DO 110 IK = 1,NMONTH
      STRMDP(IK) = STRMDP(IK) - RCHGNT*UNIT(IB,IK)
  110 CONTINUE
  120 CONTINUE
      IM = IMONTH + NMONTH
      WRITE (6,2000) IM,DRY,SW,GW,SB,R,STRMDP(1)
      IF (IMONTH .LT. 541) GO TO 130
      IJ = (IMONTH-1)/12
      IJ = IMONTH - IJ*12
      PRESNT(IJ) = PRESNT(IJ) + STRMDP(1)
  130 DO 140 IK = 1,NMONTH
      STRMDP(IK) = STRMDP(IK + 1)
  140 CONTINUE
  150 CONTINUE
      DO 160 IMONTH = 1,12
```

```
      PRESNT(IMONTH) = PRESNT(IMONTH)/5.
      WRITE (6,2000) IMONTH,PRESNT(IMONTH)
  160 CONTINUE
      WRITE (4) STRMDP
      STOP
 1000 FORMAT (2I5)
 1010 FORMAT (13F4.0)
 1020 FORMAT (I4,2I7,F10.0,I6,F9.0,11X,F12.0)
 1030 FORMAT (4X,12F7.2)
 2000 FORMAT (I5,5F8.0,G15.7)
      END
```