Evapotranspiration Before and After Clearing Phreatophytes, Gila River Flood Plain, Graham County, Arizona

GEOLOGICAL SURVEY PROFESSIONAL PAPER 655-P

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By R. C. CULLER, R. L. HANSON, R. M. MYRICK, R. M. TURNER, *and* F. P. KIPPLE

GILA RIVER PHREATOPHYTE PROJECT

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PREFACE

This report is the last of the U.S. Geological Survey Professional Paper 655 Series describing the hydrologic and environmental studies associated with the Gila River Phreatophyte Project. The following is a list of the publications originating from this project:

SURVEY PUBLICATIONS

Culler, R. C., and others, 1970, Objectives, methods, and environment—Gila River Phreatophyte Project, Graham County, Arizona: U.S. Geological Survey Professional Paper 655-A, p. A1-A25.

Burkham, D. E., 1970, Precipitation, streamflow, and major floods at selected sites in the Gila River drainage basin above Coolidge Dam, Arizona: U.S. Geological Survey Professional Paper 655-B, p. B1-B33.

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______1981, Evapotranspiration from rapidly growing young saltcedar in the Gila River Valley of Arizona: U.S. Geological Survey Open-File Report 81-485, 26 p.

______1981, Evapotranspiration from forage grass replacing native vegetation in the Gila River Valley, Arizona: U.S. Geological Survey Open-File Report 81-1018, 38 p.

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JOURNAL ARTICLES

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CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS

Multiply English unit	*by*	*To obtain metric (SI) unit*
Inches (in.)	25.4	Millimeters (mm)
Feet (ft)	.3048	Meters (m)
Miles (mi)	1.609	Kilometers (km)
Square feet (ft^2)	.0929	Square meters (m^2)
Acres	.4047	Hectares (ha)
Square miles (mi^2)	2.590	Square kilometers (km^2)
Acre-feet (acre-ft)	1233	Cubic meters (m^3)
Acre-feet (acre-ft)	1.233×10^{-3}	Cubic hectometers (ha^3)
Cubic feet per second (ft^3/s)	.02832	Cubic meters per second (m^3/s)
Acre-feet per square mile (acre-ft/mi^2)	4.761×10^{-4}	Cubic hectometers per square kilometer (ha^3/m^2)

SCIENTIFIC NAMES AND COMMON EQUIVALENTS

Common name	*Scientific name*
arrowweed	*Pluchea sericea* (Nutt.) Coville
baccharis	*Baccharis* species
Bermuda grass	*Cynodon dactylon* (L.) Pers.
catclaw	*Acacia greggii* Gray
cottonwood	*Populus fremontii* Wats.
creosotebush	*Larrea tridentata* (DC.) Coville
mesquite	*Prosopis juliflora* (Swartz) DC.
red willow	*Salix laevigata* Bebb.
Russian olive	*Elaeagnus angustifolia* L.
saltcedar	*Tamarix chinensis* Lour.
saltgrass	*Distichlis stricta* (Torr.) Rydb.
seepweed	*Sueda torreyana* Wats.
seepwillow	*Baccharis glutinosa* Pers.
whitethorn	*Acacia constricta* Benth.
willow	*Salix* species

EQUATIONS

Equation No.

(1) $$ET = Q_I - Q_O + Q_T + \Delta C + \bar{P} + \Delta\bar{M}_S + \Delta\bar{M}_I + \Delta\bar{M}_C + G_B + G_I - G_O + \Delta\bar{M}_{TC}$$

(2) $$\bar{P} = \left(\sum_{j=1}^{n} A_j P_j\right) \bigg/ \sum_{j=1}^{n} A_j$$

(3) $$\Delta\bar{M}_{zt} = \left[\sum_{j=1}^{n} (\Delta M_{zjt} A_j)\right] \bigg/ \sum_{j=1}^{n} A_j$$

(4) $$\Delta M_{ztj} = M_{zj(t-1)} - M_{zjt}$$

(5) $$\Delta\bar{M}_C = -\Delta\bar{h}\, S'A$$

(6) $$G = i\,T\,W\,D$$

(7) $$\epsilon_{ET_s} = \left[\epsilon^2_{Q_I} + \epsilon^2_{Q_O} + \epsilon^2_{Q_T} + \epsilon^2_{\Delta C} + \epsilon^2_{\bar{P}} + \epsilon^2_{\Delta\bar{M}_S} + \epsilon^2_{\Delta\bar{M}_I} + \epsilon^2_{\Delta\bar{M}_C} + \epsilon^2_{\Delta\bar{M}_{TC}}\right]^{1/2}$$

(8) $$\epsilon_{ET_b} = \left[\epsilon^2_{G_B} + \epsilon^2_{G_I} + \epsilon^2_{G_O}\right]^{1/2}$$

(9) $$\epsilon_{ET} = \left[\epsilon^2_{ET_s} + \epsilon^2_{ET_b}\right]^{1/2}$$

(10) $$PET = (0.014t - 0.37)R$$

(11) $$ET' = ET - \bar{P} - \Delta\bar{M}_S$$

(12) $$U = f\,k$$

(13) $$k = k_o + k_p\,V$$

(14) $$V = \sum_{v=1}^{4} A_v \left[C_v/100 + (C_v/100)^x\right]/\,2$$

(15) $$\Delta_{min} = \sum_{t=1}^{321} \left[(ET_t - U_t)\right] /\,321$$

(16) $$k_p = \frac{ET' - f\,k_o}{f\,V}$$

(17) $$\bar{s}\Delta = \left[\frac{\sum_{t=1}^{N} \Delta_t^2 \quad \left(\sum_{t=1}^{N} \Delta_t\right)^2 /\,N}{N-1}\right]^{1/2}$$

(18) $$\bar{s}\Delta = \left(\sum_{m=1}^{12} s\Delta_m^2\right)^{1/2}$$

(19) $$k = k_o + k_{cw}A_{cw}$$

(20) $$k = k_o + k_p\,V + k_{cw}A_{cw}$$

SYMBOLS

A Area of reach or surface area assigned to a sample point.
A_j Area assigned to rain gage j or to soil-moisture hole j.
A_v Fraction of total area having a canopy cover falling in density class v.
a_o Intercept of the relation defined in unnumbered equation page P38.
a_I Slope of the relation defined in unnumbered equation page P38.
B Subscript denoting "basin fill."
BC Subscript for f, k, k_o, k_p, and U denoting that the Blaney-Criddle PET equation was used to determine f in equation 12.
b Bias error.
C Subscript denoting "capillary zone of soil profile."
ΔC Change in Gila River channel storage.
C_v Average cover density in class v.
cw Subscript for consumptive use coefficient for cottonwood and willow, in equations 19 and 20.
D Total number of days in a budget period.
Δt Difference between measured and computed ET for a given budget period, equation 17.
ET Evapotranspiration measured by the water budget.
ET' Evapotranspiration measured by the water budget with P and $\bar{M}_S$ removed.
f Climatic factor.
G Downvalley ground-water flow through the alluvium.
G_B Inflow of ground water from "basin fill."
G_I Downvalley ground-water inflow.
G_O Downvalley ground-water outflow.
Δh Average ground-water level change.
i Downvalley ground-water slope (ft/ft).
I Subscript denoting "inflow" or "intermediate zone of soil profile."
JH Subscript for f, k, k_o, k_p, and U denoting that the Jensen-Haise PET equation was used to determine f in equation 12.
j Sample point—i.e., precipitation gage or soil-moisture access hole.
k Consumptive use coefficient which is dependent on the kind and quantity of vegetation.
k_o Consumptive use coefficient for no phreatophyte cover.
k_p Increase in the consumptive use coefficient for phreatophyte cover, dominated by saltcedar.
m Subscript denoting month in equation 18.
M Moisture content of soil.
$\Delta\bar{M}_S$ Average change in moisture content in the unsaturated soil zone immediately below the land surface.
ΔM_I Average change in moisture content in the unsaturated intermediate zone located between the overlying soil zone and the underlying capillary zone.
ΔM_C Average change in moisture content in the capillary zone located below the intermediate zone and within the zone of water-table fluctuations.
ΔM_{TC} Lateral ground-water movement through the capillary zone between the flood plain and adjacent terrace area.
M_{jzt} Soil-moisture content in zone z of hole j at the end of budget period t.
ΔM_{zjt} Change in soil-moisture content in zone z of hole j at the end of budget period t.
ΔM_{zt} Average weighted change in moisture content in zone z of the reach during period t.
n Total number of sample points in a reach.
N Total number of budget-period evaluations of ET or ET' for a month.
o Subscript for consumptive use coefficient k denoting no phreatophytes.
O Subscript denoting "outflow."
P Average precipitation on the area.
P_j The accumulated precipitation at gage j for the budget period, in inches.
P Precipitation.
p Monthly percentage of daytime hours of the year used in equation 12 to determine f_{BC}.
PET Potential evapotranspiration.
PAN Subscript for f, k, k_o, k_p, and U denoting that pan evaporation was used to determine f in equation 12.
p Subscript for consumptive use coefficient k denoting phreatophytes dominated by saltcedar.
Q_I Gila River inflow.
Q_O Gila River outflow.
Q_T Tributary inflow.
R Subscript for k, k_o, k_p, and U denoting that the solar radiation equation was used to determine f in equation 12.
s Subscript denoting a sampling type of error.
s Standard deviation.
$s\Delta$ Standard deviation of differences.
S Subscript denoting "soil zone of soil profile."
S' Apparent specific yield.
t Temperature or subscript denoting a given budget period.
T Transmissivity or subscript denoting "tributary."
U Computed evapotranspiration.
v Subscript denoting a given cover density class.
V Numerical descriptor of phreatophyte cover on a given area.
W Width of saturated alluvium.
x Exponent in equation 15.
z Subscript denoting a given soil-moisture zone.
ϵ Measurement error in water-budget component.
Δ_{min} Minimum average difference between measured and computed evapotranspiration for all accepted budget periods.

GILA RIVER PHREATOTYPE PROJECT

EVAPOTRANSPIRATION BEFORE AND AFTER CLEARING PHREATOPHYTES, GILA RIVER FLOOD PLAIN, GRAHAM COUNTY, ARIZONA

By R. C. CULLER, R. L. HANSON, R. M. MYRICK, R. M. TURNER, and F. P. KIPPLE

ABSTRACT

The conveyance of ground water to or from a river channel and down its valley is an important hydraulic function of the alluvium underlying that river's flood plain. In the arid southwestern States, evapotranspiration from a flood plain can result in a significant reduction in the quantity of water conveyed to downstream users. A large part of this evapotranspiration is transpiration from deep rooted plants, called phreatophytes, which obtain most of their water from the saturated zone and capillary fringe. Phreatophyte control, consisting of the removal of the phreatophytes and substitution of plants having a lower consumptive use and higher economic value, has been proposed for and applied to large areas of flood plain in an attempt to reduce the conveyance losses. The relatively high consumptive use by phreatophytes has been documented by numerous studies, but the actual reduction in evapotranspiration resulting from the application of phreatophyte control on the flood plain of a major river has never been measured.

The U.S. Geological Survey initiated the Gila River Phreatophyte Project in 1962 with the following objectives: (1) develop methods of analyzing the hydrology of a flood plain; (2) determine the evapotranspiration and the change in evapotranspiration resulting from the application of phreatophyte control on a flood plain typical of areas of existing or proposed application; (3) develop methods of extrapolating results to other areas; and (4) evaluate the reliability of the results. The project site consisted of 15 miles (mi) or 24 kilometers (km) of the Gila River flood plain in southeastern Arizona, subdivided into four contiguous reaches. The areas of the reaches ranged from 1,400 to 2,300 acres or 570 to 930 hectares (ha). In 1962, the vegetation consisted mainly of saltcedar and mesquite of variable heights and densitites of cover. Removal of the phreatophytes was done in stages beginning in 1967 and completed in 1971. Postclearing attempts to establish grass were unsuccessful because of heavy grazing and adverse weather conditions, but annual plants did provide temporary cover when shallow soil moisture was available during the growing season.

Evapotranspiration was evaluated for each reach as the residual in a water-budget equation consisting of twelve components measuring all inflow and outflow of water through each reach, for budget periods of two or three weeks, during the study period 1963 through 1971. Evaluations were made for 414 budget periods. Measurement errors in the water budget are important because the accuracy of the evapotranspiration data is dependent on the quantity of water measured as inflow and outflow rather than on the magnitude of the evapotranspiration. The errors in each component and in the total budget were evaluated and the maximum potential evapotranspiration before and after clearing was computed. Acceptance criteria based on measurement errors and potential evapotranspiration were used to establish acceptable maximum and minimum evapotranspiration values and maximum errors in these values. Applying these tests to the water-budget evaluations provided 321 acceptable evapotranspiration values.

The accepted evapotranspiration data were fitted to four previously developed and widely used empirical evapotranspiration equations by use of an optimization program. Optimum fitting was achieved when the average difference between measured (accepted) and computed evapotranspiration for each accepted budget period was minimized. An analysis of variablity between measured and computed values indicated a possible error in the annual values computed by empirical equations of 15 percent before clearing and 25 percent after clearing.

Annual evapotranspiration on the project area averaged 43 inches (in.) or 1,090 millimeters (mm) before clearing, and ranged from 56 in. (1,420 mm) for dense stands of phreatophytes to 25 in. (630 mm) on areas of no phreatophytes. The removal of phreatophytes resulted in a reduction in evapotranspiration averaging 19 in. (480 mm) per year and ranged from 14 in. (360 mm) on reach 1 to 26 in. (660 mm) on reach 3 because of the difference in the density of phreatophytes. This reduction is temporary and would not apply after permanent replacement vegetation became established. A flood plain without phreatophytes is in an artificial condition, and the water requirements for maintaining this condition will depend on the land-management practices applied.

A logical replacement of phreatophytes would be a cover of forage grasses. For this reason the consumptive use of water for various grasses was computed with empirical equations using previously published parameters derived for optimum production of grasses under irrigation near Mesa, Ariz. The computations indicated a consumptive use greater than the evapotranspiration from the Gila River flood plain before removing the phreatophytes. Assuming that these grasses could be established, it can be postulated that the consumptive use would be less than under irrigation, production would be less than optimum, and some water would be salvaged. Data to confirm or disprove this postulation must await further studies.

INTRODUCTION

The principal source of water in the southwestern United States is the relatively high precipitation falling on headwater areas. Use of this water is largely confined to cities and irrigated farms in the arid low lands. Water is transported from source to user through a conveyance system consisting of channels and flood plains of rivers and their tributaries. The efficiency of this conveyance system is reduced by phreatophytes, which are deep-rooted plants growing on the flood plains and drawing their moisture from ground water. The flood plain serves two functions in the hydraulic system of a drainage basin: (1) it conveys surface flows that exceed the capacity of the river channel and (2) it conveys subsurface flows to or from the river channel and down the valley through the underlying alluvium. Because of the abundant water supply and fertile soil, the flood plain is an ideal environment for the production of plants. Dense thickets of phreatophytes now cover many of the flood plains in the southwestern United States, retarding the movement of flood water over the surface of the flood plain and causing greater flood damage. The high consumptive use of water by the phreatophytes constitutes a withdrawal from the subsurface flow and results in a reduction in the quantity of water available downstream. The scarcity of water in the southwestern United States has prompted a search for additional approaches to water management.

Phreatophyte control, consisting of the removal of the phreatophytes and their replacement with other types of vegetation, has been proposed and applied at numerous sites. The intended benefits from phreatophyte control are: reduced flood damage, reduced evapotranspiration, and greater economic return from the site by the production of more valuable vegetation. Nonbiologic problems caused by the removal of phreatophytes include an increase in flood-plain erosion and in downstream silt load should the replacement vegetation not become well established. Also, phreatophytes provide a wildlife habitat and a greenbelt of luxuriant vegetation in otherwise sparsely vegetated areas, and loss of these features must be considered. A comprehensive discussion of the problems of managing the phreatophyte habitat has been presented by Horton and Campbell (1974). Quantitative data showing benefits and detriments are necessary to determine the desirability of applying phreatophyte control to any particular site. The prediction of the quantity of water diverted from phreatophyte use is of primary importance in planning phreatophyte control; the quantity thus saved is equivalent to the amount by which evapotranspiration is changed following vegetation modification.

In 1962, before initiating this study, the Geological Survey examined the available data on evapotranspiration. The high consumptive use of water by various species of phreatophytes had been measured at several locations. Blaney and others (1942) reported an annual use of 4.68 feet (ft) or 1.43 meters (m) by saltcedar planted in tanks at Carlsbad, New Mexico, where the average depth to water was 4 ft (1.2 m). Gatewood and others (1950) measured evapotranspiration from 9,303 acres or 3,765 hectares (ha) of the Gila River flood plain near Safford, Arizona. A total of 28,000 acre-feet (acre-ft) or 34.5 cubic hectometers (hm^3) was used during the 12-month period ending September 30, 1944. During this period estimates were obtained of the total water use for various species of phreatophytes growing in tanks (Gatewood and others, 1950) and evapotranspiration was evaluated at several ground-water well sites by means of the transpiration-well method developed by White (1932). These studies showed that the observed annual use of water for 100-percent volume density was 7.2 ft (2.2 m) for saltcedar, 4.7 ft (1.4 m) for baccharis, 6.0 ft (1.8 m) for cottonwood, and 3.3 ft (1.0 m) for mesquite. Methods of extrapolating these data to the heterogeneous vegetation on a typical flood plain were neither developed nor tested. Phreatophyte control was not performed on any of these sites and changes in evapotranspiration were not measured.

The determination of the quantity of water that could be saved requires an estimate of evapotranspiration both before and after the application of phreatophyte control. The postclearing condition of the flood plain is only temporary unless some form of regular maintenance is performed to prevent reinvasion by phreatophytes. Large areas of privately owned flood plain have been cleared to provide agricultural land. In this case, the postclearing evapotranspiration depends on the crop planted. Phreatophyte control projects are generally planned to convert the phreatophyte areas to grass in order to minimize the cost of maintenance and to provide an economic benefit in the form of forage. Ideally, the replacement vegetation should minimize consumptive use, maximize forage production, and resist invasion by phreatophytes. The types of vegetation which will completely satisfy these criteria in the flood-plain environment have not been identified and the density of grass species that can be established is not predictable. Thus, an estimation of evapotranspiration for the postclearing conditions with a beneficial replacement vegetation on the flood plain cannot reliably be made.

An evaluation of available evapotranspiration data indicates that several deficiencies exist when applying these data to present water-management problems. In an attempt to correct these deficiencies the following objectives were established for the Gila River Phreatophyte Project: (1) develop methods of analyzing the hydrology of a flood plain; (2) determine the evapotranspiration and the change in evapotranspiration resulting from phreatophyte control on a flood plain; (3) develop methods of extrapolating results to other areas; and (4) evaluate the reliability of the results. The water budget was selected as the primary method of measuring evapotranspiration from flood-plain areas.

The criteria for selecting a study site were set by the objectives and the methods of measurement. The site requirements included the following: (1) hydraulic characteristics suitable for evapotranspiration measured by the water-budget method; (2) a large area of dense phreatophytes; (3) authorization to apply phreatophyte control; and (4) uniform land management. A reach of the Gila River flood plain within the San Carlos Indian Reservation was selected as the best site available. Continuous records of the flow of the Gila River through the reach were available for the preceding 33 years (Burkham, 1970); changes in the channel and flood plain had been observed since 1929 (Burkham, 1972), and the vegetation had been repetitively mapped since 1914 (Turner, 1974). Phreatophyte control on this reach, as proposed by the Corps of Engineers, was authorized by Congress in Public Law 85-500 (U.S. Congress, 1958) and approved on July 3, 1958 as part of the project entitled, "Gila River channel improvements between Camelsback Reservoir site and Salt River, Arizona." A formal agreement was made on May 28, 1962 between the U.S. Geological Survey and the San Carlos Apache Indian Tribe, with the approval of the Bureau of Indian Affairs, for the use of reservation lands for the project.

Evapotranspiration was measured by the water-budget method during the period March 1963 through September 1971. The phreatophytes were not disturbed until December 1964. Removal of the phreatophytes was done in stages and was completed in March 1971. The volume of water lost to evapotranspiration was measured for 414 two- or three-week budget periods on four contiguous reaches of the study area. Evapotranspiration was related, by use of empirical equations, to potential evapotranspiration and to the type of vegetation. Error analyses of the components of the water budget, prepared by Burkham and Dawdy (1970) and Hanson and Dawdy (1976), were used to evaluate the reliability of the results.

PERSONNEL AND ACKNOWLEDGMENTS

The project was planned and activated under the general supervision of Thomas Maddock, Jr. and F. E. Clark, former chiefs of the General Hydrology Branch and G. E. Harbeck, Jr., research hydrologist. From 1967 to 1972 general supervision was provided by R. W. Stallman, research coordinator, Rocky Mountain Region, and since 1972 by P. C. Benedict, research coordinator, Western Region. The study was under the direct supervision of R. C. Culler, project chief, from 1962 to 1973. R. L. Hanson became project chief in 1973. Collection of records and analysis of data on surface water, sedimentation, and chemical quality of water were under the supervision of H. M. Babcock, district chief, Water Resources Division in Arizona. The authors of this report were responsible for processing and interpretation of data used in this analysis.

Extensive cooperation and assistance were provided by the San Carlos Agency, C. J. Rieves and T. B. White, superintendents; by the San Carlos Irrigation Project, M. D. Young, general engineer, Bureau of Indian Affairs; and by the San Carlos Apache Tribe, Marvin Mull, Tribal Council President.

DESCRIPTION OF THE STUDY AREA

The study area is located on the Gila River flood plain within the San Carlos Indian Reservation, Graham County, in southeastern Arizona. The area extends from the U.S. Highway 70 bridge near Bylas, 15 miles (mi) or 24 kilometers (km) downstream, to the mouth of Hackberry Draw, which is within the San Carlos Reservoir and is located 11 mi (18 km) upstream from Coolidge Dam. The flood plain ranges from 3,500 to 5,500 ft (1,100 to 1,700 m) in width and has an average downvalley slope of 0.0016. The Gila River is normally confined to a meandering channel about 110 ft (34 m) wide and 7 ft (2 m) deep. Terraces up to 25 ft (8 m) in height border the flood plain throughout most of the reach. The channels of numerous tributary streams are graded to the flood plain and fanshaped deltas are formed at the mouth of each stream. The flood plain ranges in elevation above mean sea level from 2,460 to 2,585 ft (750 to 788 m). The Santa Teresa Mountains to the south and the Gila Mountains to the north reach elevations of 8,200 and 5,000 ft (2,500 and 1,500 m), respectively.

The upstream extension of the study area was

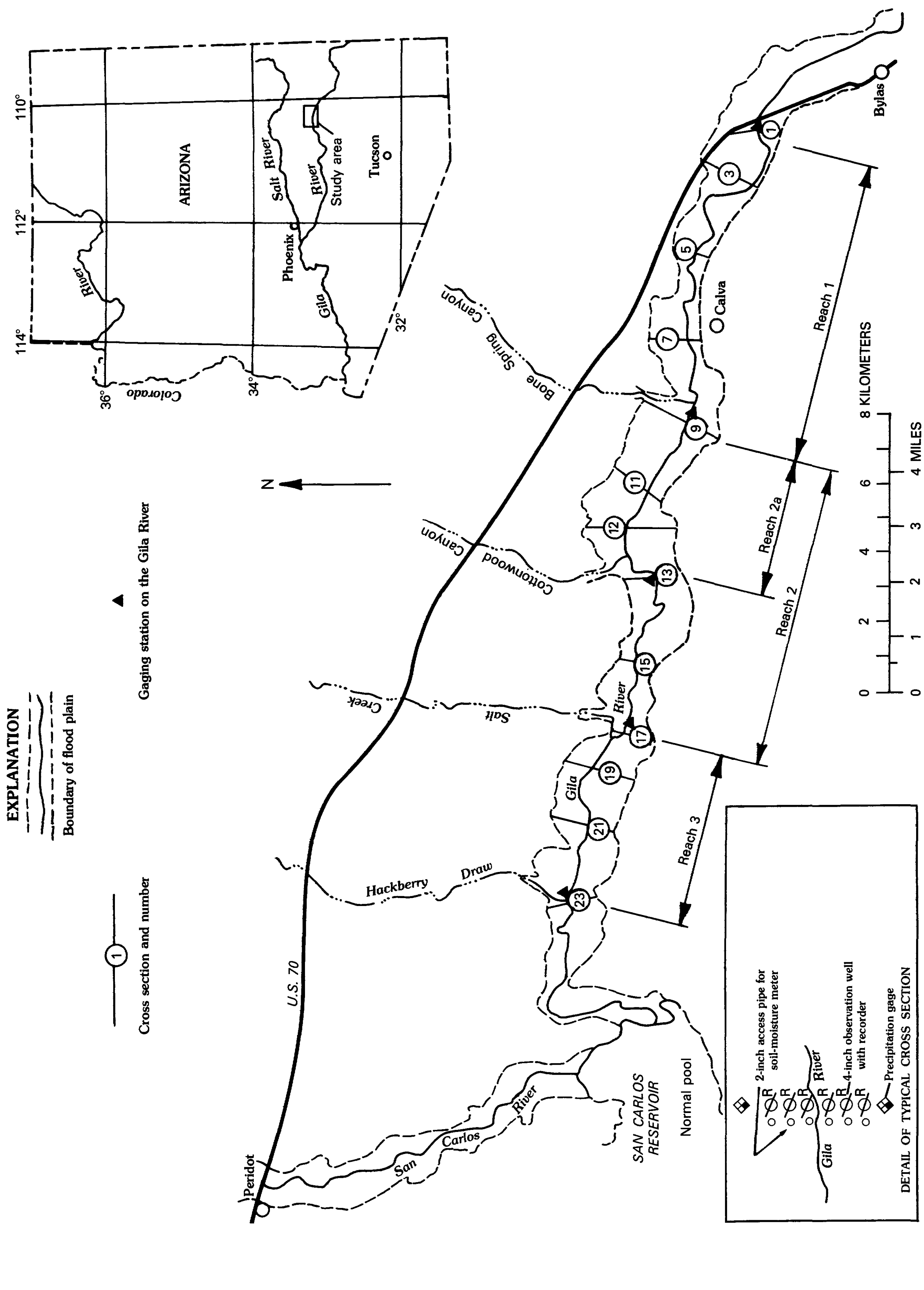

FIGURE 1.—Map showing Gila River Project area and instrument location.

limited by irrigated farm land on the flood plain above the Bylas bridge on U.S. Highway 70. Downstream, the area was limited by possible inundation by the San Carlos Reservoir. Although no part of the study area had been flooded by the reservoir since 1944, the project was designed to preclude total interruption of the study by high water levels in the reservoir. The study area included 5,500 acres (2,200 ha) and was initially subdivided into three reaches (fig. 1). The upper reach, designated reach 1, is above the maximum water level which can occur in the San Carlos Reservoir. This reach extends from the U.S. Highway 70 bridge downstream to the mouth of Bone Spring Canyon. Reach 2 extends from the mouth of Bone Spring Canyon to the mouth of Salt Creek. In 1966, the lower part of reach 2 was inundated by reservoir water resulting in the designation of the upper half of reach 2 as an additional reach (2a). Reach 3 includes the area between the mouths of Salt Creek and Hackberry Draw. This reach was flooded by the reservoir in January 1966 which terminated the collection of data there because the Gila River channel was plugged with sediment.

Topographic maps of the project area include plane-table surveys by the Soil Conservation Service in 1914-15 to a scale of 1:12,000 with 5 ft (1.5 m) contours. All of the project area except 1 mi (1.6 km) of reach 1 at the upstream end was included in a 1947 map of the San Carlos Reservoir by the Corps of Engineers at a scale of 1:7,200 with 5 ft (1.5 m) contours. Topographic maps to a scale of 1:62,500 with 80 ft (24.4 m) contours were published by U.S. Geological Survey (USGS) as the Bylas Quadrangle in 1960 and the San Carlos Reservoir Quadrangle in 1962. Provisional unedited USGS 7½ minute quadrangle maps to a scale of 1:24,000 with 40 ft (12.2 m) contours were also available. Vertical control for project surveys were tied to U.S. Coast and Geodetic Survey (C&GS) bench mark elevations above mean sea level (supplementary adjustment of 1937) by third order leveling. Horizontal control was established by third order triangulation from C&GS monuments to relate project surveys and the Arizona Zone East Grid System.

Prior to the beginning of this project aerial photography was available for 1935, 1942, 1947, and 1954. Black-and-white, color, or color-infrared aerial photography ranging in scale from 1:900 to 1:120,000 was obtained on 76 dates between March 1962 and November 1972. Vegetation, channel changes, inundation by the reservoir, and clearing progress were observed by ground surveys and the use of aerial photographs.

Access to the flood plain was provided by roads crossing the flood plain along 13 cross sections at about 1 mi (1.6 km) intervals as shown in figure 1. All instrumentation was located along the cross sections to minimize the area of phreatophytes disturbed by the installation and servicing of equipment. Repetitive surveys were made along the cross sections to measure erosion or deposition on the flood plain and changes in the river channel.

GEOLOGY

The Gila River flood plain at the project site is within the Safford basin, a typical basin-and-range downfaulted sediment-filled trough between uplifted ranges as described by Davidson (1961). Two water-bearing sedimentary units, identified as basin-fill and alluvial deposits, are included in the valley fill as described in detail by Weist (1971).

The basin fill, divided into a silt and sand facies and a limestone facies, consists mainly of a very fine sand and silt that is partly cemented. The beds dip gently from north to south into a poorly defined axial area slightly south of the Gila River. The basin-fill deposits extend to a depth of about 1,000 ft (300 m)

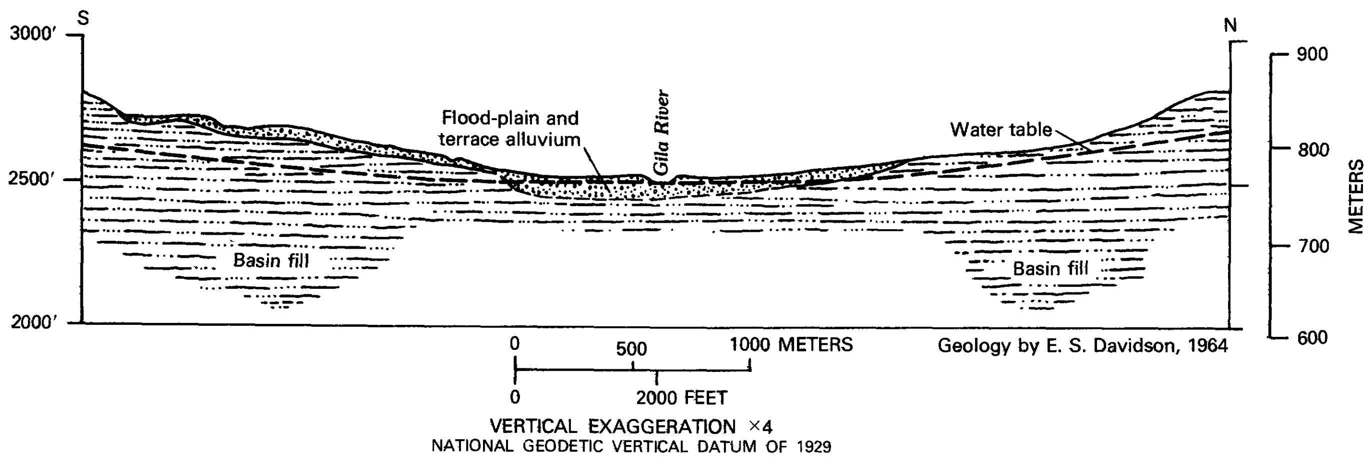

FIGURE 2.—Geologic section (diagrammatic) across the study area.

and reach a width of 10 mi (16 km). Water enters the basin fill along the outer boundaries of the formation and along tributary stream channels and flows toward the center of the valley where it is discharged into the overlying alluvial deposits. The basin fill contains water generally under artesian pressure, but because it is fine grained, it yields only a few gallons per minute to wells.

Alluvial deposits occur in the channels cut into the basin fill by the Gila River and its tributaries. The deposits are divided into terrace alluvium, which underlies the entire Gila River flood plain, and the flood-plain alluvium, which overlies the terrace alluvium and occupies the central part of the flood plain. These two units consist of poorly sorted lenticular deposits of sand, gravel, and some silt and form a single aquifer. Figure 2 shows a typical geologic cross section of the study area.

The soils on the project are a heterogeneous complex of alluvium ranging from clay to cobbles and are constantly relocated by erosion and deposition. All tributaries to the project area are graded to the flood plain and not to the river channel. Flows in these tributaries are infrequent and consist primarily of high peak discharges carrying large quantities of sediment which are deposited in alluvial fans on the flood plain. Flood flows in the Gila River redistribute these deposits on the flood plain creating a heterogeneous and frequently changing soil surface. Soil texture profiles at a number of sites in the project area have been described by McQueen and Miller (1972).

CLIMATE

The project area is classified as semiarid by Thornthwaite (1948, pl. 1A). Mean annual precipitation is about 12 in. (305 mm). Longterm climatological data are available and have been summarized by Sellers and Hill (1974) for National Weather Service stations at San Carlos Reservoir, 20 mi (32 km) west; San Carlos, 20 mi (32 km) northwest; and Safford, 35 mi (56 km) east of the project. The mean annual precipitation for the 30-year period 1941–70 ranges from 8.43 in. (214 mm) at Safford to 14.15 in. (359 mm) at San Carlos Reservoir. The seasonal distribution of precipitation and temperature is similar at all stations and is shown in table 1 as mean monthly totals at San Carlos Reservoir for the period of study and the longterm record 1941–70.

Burkham (1970) has described in detail the types of storms which produce runoff. The seasonal distribution of precipitation can be divided into two periods which have distinctly different types of storms. About 40 percent of the annual precipitation occurs as late afternoon thunderstorms during the four-month period July through October. That rainfall is of high intensity, short duration, and covers small areas. Moist tropical air, usually from the Gulf of Mexico, enters east-central Arizona during this period and the storms are triggered by orographic uplift and high surface temperatures. Winter precipitation is very erratic from year to year although it is generally less violent and of longer duration than the summer rains. Cold season precipitation is normally associated with cyclonic storms that develop in the North Pacific Ocean and move eastward over the continent. These storms usually remain too far north to bring more than strong winds and cloudy conditions to the area. However, when they follow a more southerly track and intensify off the coast of southern California, significant quantities of precipitation can occur. The maximum monthly precipitation for December at San Carlos Reservoir was 8.53 in. (217 mm) in 1965; the December mean of 1.77 in. (45 mm) has been surpassed 16 times in the 42 year period 1931 through 1972. Drought conditions are most prevalent in May and June when the average monthly precipitation at San Carlos Reservoir is less than 0.25 in. (6.4 mm); the total precipitation for both months has been zero in nine years during the period 1931–72.

Temperature extremes range from 10° Fahrenheit (F) or -12° Celsius (C) to 115°F (46°C). Each of the seven months from April to October has experienced maxima exceeding 100°F (38°C) and minimum temperatures below freezing have been observed in all months except June through September. Mean daily temperatures range from 32°F (0°C) to 60°F (16°C) in winter and 65°F (18°C) to 100°F (38°C) in summer. The average diurnal temperature variation exceeds 29°F (16°C) in both winter and summer as shown in table 1. The estimated mean monthly relative humidity

TABLE 1.—*Climatological data for San Carlos Reservoir*

	Temperature °F means				Precipitation (inches) means	
	1941-1970			March 1963-June 1973	1941–1970	March 1963-June 1973
Month	Daily Maximum	Daily Minimum	Monthly	Monthly	Monthly	Monthly
January	58.4	32.6	45.5	45.2	1.58	0.90
February	63.9	35.6	49.8	49.2	1.01	1.07
March	68.8	40.0	54.4	54.3	1.46	1.22
April	78.6	47.9	63.3	61.6	.48	.38
May	88.0	56.8	72.4	72.0	.22	.20
June	97.1	65.9	81.5	80.6	.24	.10
July	99.8	73.2	86.5	86.8	1.81	1.77
August	97.1	71.3	84.2	83.9	2.32	2.83
September	93.7	64.8	79.3	78.0	1.28	1.60
October	83.1	52.6	67.9	67.7	1.08	.54
November	69.2	39.9	54.6	55.9	.90	1.45
December	59.7	33.4	46.6	45.8	1.77	2.71
Annual average	79.8	51.2	65.5	65.1	1.18	1.23
Annual total					14.15	14.77

ranges from 23 to 64 percent with the minima occurring at 1800 hours in either May or June and the maxima occurring at 0600 hours in August. Annual pan evaporation averaged 97 in. (2,460 mm). Average total monthly wind movement ranged from 650 mi (1,050 km) in December to 1,250 mi (2,010 km) in July at the San Carlos Reservoir station.

The preceding climatic data are based upon long-term records from National Weather Service stations in the vicinity of the project area. The climate near the ground on the project area differs to some extent from these data because of the moderating effect induced by the high phreatophyte transpiration. In dense thickets of phreatophytes during the growing season, the diurnal variation in temperature is reduced and the relative humidity is maintained at a high level. Another local influence, cold air draining from the adjacent mountains onto the valley floor, can produce extremely low minimum temperatures in winter.

VEGETATION

At the time the project began in 1962, the moist conditions prevailing along the flood plain had promoted a dense growth of phreatophytes. This vegetation comprised mainly saltcedar and mesquite. Cottonwood, seepwillow, seepweed, and arrowweed were also present (Turner, 1974). On the uplands above the flood plain grew low, open stands of creosote-bush, mesquite, catclaw, and whitethorn.

The vegetation of the study area was mapped on aerial photographs at a scale of 1:7,100 (plate 1). Two major vegetation types, saltcedar and mesquite, were recognized. Within these two types, irregular parcels of apparently homogeneous vegetation were outlined on the photographs. Canopy cover estimates were made photogrammetrically (Turner, 1974). Average plant heights were determined for each parcel from field observations. Canopy cover values were grouped into four cover classes: 1–25 percent, 26–50 percent, 51–75 percent, and 76–100 percent. The following height classes were recognized: for saltcedar, 0–6.5 ft (0–2.0 m), 6.6–13 ft (2.0–4.0 m), and greater than 13 ft (4.0 m); for mesquite 0–7 ft (0–2.1 m) and greater than 7 ft (2.1 m).

The method devised for describing the hydrologic parameters of the study area utilized a grid system of quadrangles each 2,000 ft (610 m) on a side (fig. 3). The quadrangles were further subdivided into one hundred square plots, each 200 ft (61 m) on a side with an area of 0.918 acre (0.372 ha). The plots were assigned vegetative descriptors based upon the canopy coverage and height classes of the parcel into which each quadrangle fell. Table 2 gives the number of plots in reach 3 that fell within the vegetative classes noted above. Where the vegetation comprised only ephemeral plants, the parcel was regarded as bare ground. In a few instances the plots fell within parcels of upland vegetation. The upland vegetation

TABLE 2.—Number of 1-acre plots in Reach 3 characterized by combinations of species (*mesquite and saltcedar*), canopy-cover class, and *height class. Values apply only to the area of flood-plain alluvium.*

	SALTCEDAR												MESQUITE								
CANOPY COVER	A			B			C			D			A		B		C		D		
HEIGHT	1	2	3	1	2	3	1	2	3	1	2	3	1	2	1	2	1	2	1	2	TOTAL
QUADRANGLE[1]:																					
29-1	-	3	-	-	-	-	-	-	-	-	9	-	-	8	-	-	-	-	-	-	20
29-2	-	9	1	-	13	-	-	19	-	-	33	16	-	4	-	2	-	-	-	3	100
29-3	-	1	-	-	-	-	-	3	-	-	8	-	-	-	-	-	-	-	-	-	12
30-1	-	1	-	-	-	-	-	-	-	-	1	-	-	-	-	10	-	-	-	-	12
30-2	-	2	-	-	6	-	-	-	-	-	75	6	-	1	-	2	-	-	-	8	100
30-3	-	3	-	-	20	-	-	-	-	-	65	-	-	-	-	-	-	-	-	-	88
30-4	-	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-	4
31-2	-	-	-	-	-	-	-	-	-	-	46	34	-	-	-	-	-	-	-	-	80
31-3	-	1	-	-	13	-	-	-	-	-	85	1	-	-	-	-	-	-	-	-	100
31-4	-	-	-	-	-	-	-	-	-	-	56	-	-	-	-	-	-	-	-	-	56
32-2	-	1	-	-	-	-	-	-	-	-	3	8	-	-	-	-	-	-	-	-	12
32-3	-	2	-	-	18	-	-	-	-	-	72	8	-	-	-	-	-	-	-	-	100
32-4	-	-	-	-	-	-	-	-	-	-	80	-	-	-	-	-	-	-	-	-	80
33-2	-	-	-	1	-	-	-	-	-	-	10	1	-	-	-	-	-	-	-	-	12
33-3	-	-	-	-	-	-	-	-	3	-	97	-	-	-	-	-	-	-	-	-	100
33-4	-	-	-	-	-	-	-	-	1	-	31	-	-	-	-	-	-	-	-	-	32
34-1	-	-	-	-	-	-	1	-	-	-	23	-	-	-	-	-	-	-	-	-	24
34-2	-	-	-	-	-	-	-	-	-	-	31	69	-	-	-	-	-	-	-	-	100
34-3	-	-	-	-	-	-	-	-	43	-	50	7	-	-	-	-	-	-	-	-	100
34-4	1	-	-	-	-	-	-	-	-	-	15	-	-	-	-	-	-	-	-	-	15
35-1	-	-	-	-	-	-	-	-	-	-	20	-	-	-	-	-	-	-	-	-	20
35-2	-	-	-	-	-	-	-	-	-	-	42	58	-	-	-	-	-	-	-	-	100
35-3	3	2	1	-	17	-	-	-	10	-	31	12	-	-	-	-	-	-	-	-	76
36-2	-	-	-	-	-	-	-	-	-	-	55	29	-	-	-	-	-	-	-	-	84
36-3	-	-	6	-	-	-	-	1	-	-	62	7	-	-	-	-	-	-	-	-	76
37-2	-	-	-	-	-	-	-	-	-	-	20	-	-	-	-	-	-	-	-	-	20
37-3	-	-	-	-	-	-	-	15	-	-	27	-	-	-	-	-	-	-	-	-	42

Canopy coverage, in percent—Class A, 1-25 percent; Class B, 26-50 percent; Class C, 51-75 percent; Class D, 76-100 percent.

Height, in feet: Saltcedar—Class 1, 0-6.5 ft; Class 2, 6.5-13.0 ft; Class 3, 13.0+ ft.
Mesquite—Class 1, 0-7 ft; Class 2, 7+ ft.

[1] See figure 3

TABLE 3.—*Area from which vegetation was cleared on project reaches during 7 years*

Calendar year	ACRES CLEARED				
	Reach 1	Reach 2	Reach 2a	Reach 3	TOTAL
1964	360				360
1966	268				268
1967	1,040				1,040
1968				1,440[1]	1,440[1]
1969			1,374		1,374
1970		114			114
1971		819			819
TOTAL	1,668	933	1,374	1,440	5,415

[1] Vegetation killed by inundation.

was not classified further. Tables similar to table 2 were prepared for each reach and the data for all reaches are summarized in table 9 (see "Use of *ET* data for defining a prediction equation").

Removal of all flood-plain vegetation was a treatment condition incorporated into the experimental design of this research program. The vegetation removal or "clearing" is described in detail by Park, Culler, and Turner (1978) and will be discussed here in general terms only. Root plows were used to cut the roots of the phreatophytes below the crown. The debris was collected and piled into windrows for burning. Cleared areas were left fallow for one year to locate areas of re-establishment by phreatophytes. These areas were cleared a second time. Most of the vegetation was removed during the period from 1966 through 1971. The acreage cleared, the location, and associated clearing dates are given in table 3. As vegetation removal progressed, the vegetative descriptors for each plot were changed to reflect the new unvegetated condition. The vegetative condition of the project area will be defined as: (1) preclearing—conditions on the flood plain before clearing began; (2) partial clearing—conditions during the period of clearing; (3) postclearing—conditions after the phreatophytes were removed.

Postclearing attempts to establish grass were unsuccessful because of heavy grazing and adverse weather conditions. Bermuda grass established itself in some areas and various annual plants appeared for a few weeks each year.

SURFACE WATER

Discharge in the Gila River, as inflow at the upstream end of a reach and as outflow at the downstream end, is the largest and most variable component in the water budget. Long-term records of the flow of the Gila River are available in the annual reports of the U.S. Geological Survey for the Calva gaging station at cross-section 9 in the project area. The drainage area above this station is 11,470 square miles (mi^2) or 29,707 square kilometers (km^2) and the average annual discharge for the period 1929–72 was

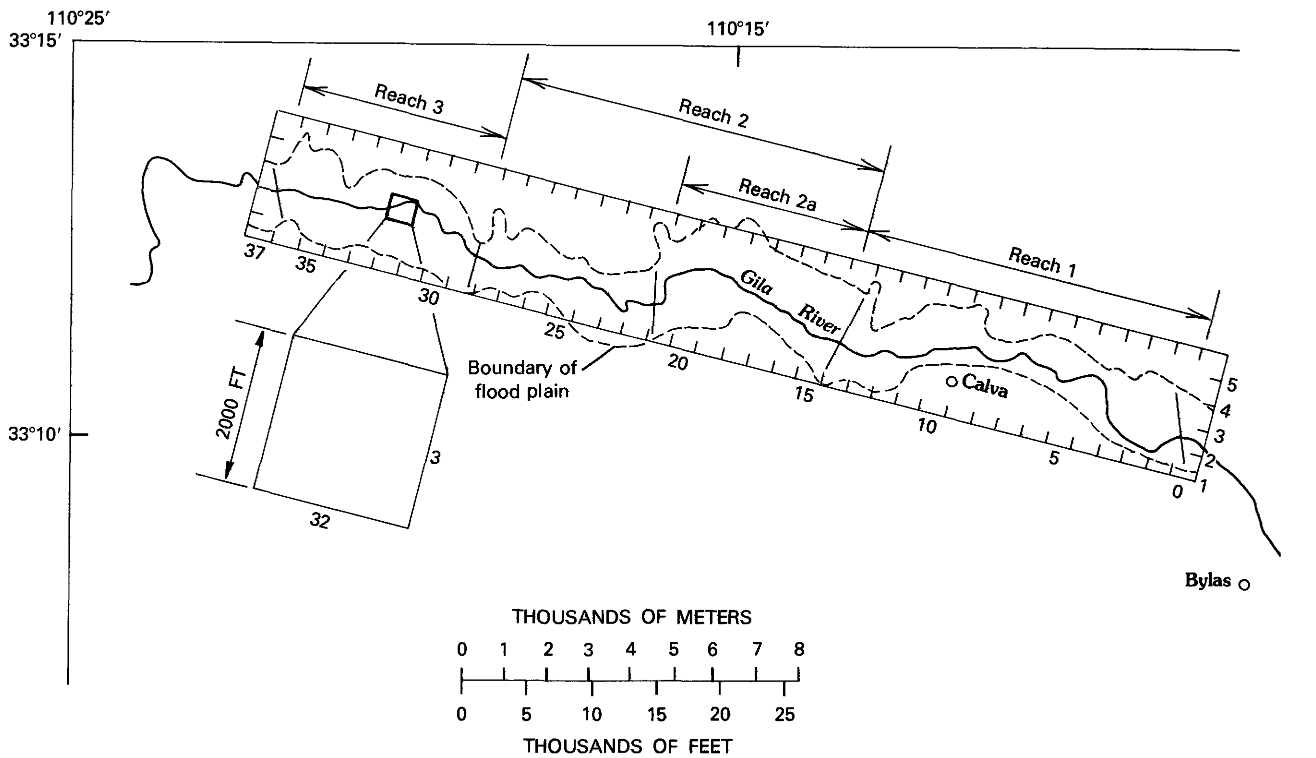

FIGURE 3.—Map of study area showing grid network and the system for numbering quadrangles used in describing vegetation cover.

181,100 acre-ft (223 hm^3). Flow in the Gila River is highly variable, as indicated by the annual discharges for the period of record which ranged from 20,870 acre-ft (25.7 hm^3) in 1956 to 804,100 acre-ft (991 hm^3) in 1941. Instantaneous flow ranged from zero, which occurred many times, to 40,000 cubic feet per second (ft^3/s) or 1,133 cubic meters per second (m^3/s) on August 13, 1967. The post-1914 peak flow occurred on January 20, 1916, and was estimated to exceed 100,000 ft^3/s (2,800 m^3/s).

Burkham (1970) in a comprehensive analysis of runoff in the Gila River above Coolidge Dam shows that major flows are confined to two distinct periods because of the seasonal distribution of precipitation. Runoff from July through October is produced by convective storms and the discharge is highly variable with numerous flood peaks of short duration. High sustained flows occur in winter from snowmelt and frontal storms. May and June are ordinarily the months of extremely low flows although discharge can be very low in any month. A particularly low runoff year occurred in 1956 when the total monthly discharge was zero at the Calva gaging station in June, and from September through December.

Diversions of the Gila River above the project area are used for metallurgical treatment of ores, for municiple use, and for irrigation of about 69,000 acres (28,000 ha).

The tributary streams to the Gila River in the study area drain about 260 mi^2 (673 km^2) and individually range in size from 0.1 to 39 mi^2 (0.3 to 100 km^2). Burkham (1976) gives a complete description of these tributaries including the seasonal runoff for the period of 1963–71. The basins are long and narrow and drain the north slopes of Mount Turnbull and the south slopes of the Gila Mountains. The channel slopes range from 2 percent near the river to more than 40 percent at the higher elevations of Mount Turnbull. All tributaries are ephemeral and most of the flow is the result of summer thunderstorms. High rates of discharge occur for short periods, generally a few hours or less, and many tributaries do not flow every year. The channels are graded to deltas on the flood plain and many flows seep into the alluvium without reaching the Gila River channel.

GROUND WATER

The 1,000 ft (300 m) thick underlying basin-fill unit described previously is recharged on the high mountain slopes adjoining the flood plain and because of its low permeability is an artesian aquifer under the flood plain. Weist (1971, fig. 8) mapped contours of the potentiometric surface in the basin fill and found this surface to be subparallel to the land surface on the steep valley slopes. The depth to water in wells 2.5 mi (4 km) from the flood plain was 360 ft (100 m). Ground-water movement in the basin fill is downslope toward the Gila River and slightly downstream to the west. The water in the basin fill is under sufficient artesian pressure to rise above the water table in the overlying alluvium and water movement is always from the basin fill to the alluvium.

The alluvial deposits have a relatively high permeability. Water in the alluvium is unconfined and is recharged from the basin fill, downvalley movement of ground water in the alluvium, overbank flooding from the Gila River, surface flow from the channels of tributary streams which spread over the flood plain, and precipitation falling on the flood plain. Discharge from the alluvial aquifer is by downvalley underflow, transpiration by phreatophytes and other vegetation, and evaporation from the soil. The Gila River channel is hydraulically connected to the alluvial aquifer and water can move either to or from the aquifer.

The depth to ground water on the flood plain ranges from 5 ft (1.5 m) near the river to 20 ft (6.1 m) near the outer boundaries of the flood plain. On the adjacent terraces the depth to water is from 20 to 40 ft (6 to 12 m). During high reservoir-water levels in the San Carlos Reservoir the ground-water level rises to the ground surface near the river in the downstream part of the study area. Aquifer tests (Hanson, 1972) show that the average storage coefficient is 0.15 and the average transmissivity is 28,000 square feet (ft^2) or 2,600 square meters (m^2) for the alluvium. The average downvalley slope of the ground-water table is 0.0016 and the resulting downvalley subsurface flow averages 5.1 acre-ft (0.0073 hm^3) per day.

MAN'S INFLUENCE

The observed influence of man on the project area began as early as 800 years ago with the construction of pueblos by members of the Salado culture (J. E. Ayres, Arizona State Museum, oral commun., 1974). Remains of these houses are in evidence on the terrace south of the Gila River in the vicinity of Calva and at Dewey Flat. These sites were surveyed in 1959 and the more important ones were excavated. In 1966, prior to clearing, the area was resurveyed for archeological sites under the direction of J. E. Ayres, Assistant Archeologist, Arizona State Museum, University of Arizona. These prehistoric residents may have raised crops on the flood plain but any lasting effect was quite insignificant. Cultivation of the project area in historic times has not been extensive.

About 170 acres (69 ha) were farmed on Dewey Flat in about 1870 (Bureau of Indian Affairs records, San Carlos Agency, unpub. data). At Calva, 65 acres (26 ha) were cultivated in the 1930's (BIA, San Carlos Agency), and an area of 360 acres (146 ha) near the Bylas highway bridge was cleared and leveled for flood irrigation by diversion from the river in the fall of 1964. Only 65 acres (26 ha) of this area were continuously farmed during the period 1965–71.

The historical changes in natural flood-plain vegetation have been described by Turner (1974). Man has caused changes in both prehistoric and historic times by the deliberate burning of the vegetation to improve grazing or to flush animals from the dense thickets. The frequency of burning cannot be determined nor can its long-term effect on the vegetation be defined. Man is responsible for triggering a significant change in the dominant species of the flood-plain vegetation by the introduction of saltcedar. This exotic and prolific plant was not found on the project area in 1914, but has since invaded and dominated the area. Removal of the riparian vegetation by the phreatophyte control project, as described by Park, Culler, and Turner (1978), produced a dramatic change in the vegetation which in turn produced a significant change in the evapotranspiration of the area.

The construction of the San Carlos Reservoir has altered the flood-plain topography and the river channel. The flood plain in reach 1 is wholly above the effect of reservoir backwater and is gently sloping toward the entrenched river channel with terraces along the outer boundaries. The flood plain in reach 3, however, contains large deposits of reservoir sediment, eliminating the cross-valley slope toward the river, obscuring the adjacent terraces, and reducing the channel conveyance so that natural levees have developed. The reduction in channel conveyance has in turn caused complete plugging of the channel by debris (Kipple, 1977).

The construction of levees and bridges has produced local irregularities on the flood plain. In 1907, a 2,000 ft (610 m) fill was built across the Gila River at the railroad bridge 1 mi (1.6 km) above the mouth of the San Carlos River. The bridge was abandoned in 1928. This fill constricts the river channel and has increased the sediment deposition on the upstream side of the fill (Kipple, 1977). A replacement railroad bridge upstream near Calva (cross-section 9) confines the low water channel to the south side of the flood plain and the Bylas highway bridge at the upstream end of the project area near section 1 confines the channel to the north side of the flood plain. A 2,000 ft (610 m) levee was constructed in 1964 on the north bank of the river below the highway bridge to protect the farm land in the project area. The floods of December 22, 1965 and August 13, 1967 overflowed the levee and caused some erosion and sediment deposition.

METHOD OF ANALYSIS

The determination of evapotranspiration (ET) of phreatophytes from a flood plain by the water-budget method requires that all significant movement of liquid water into and out of the flood plain be measured. Twelve liquid-water components have been defined as significant in the water budget of the Gila River flood plain. An equation expressing these components is

$$ET = Q_I - Q_O + Q_T + \Delta C + \bar{P} + \Delta\bar{M}_S + \Delta\bar{M}_I + \Delta\bar{M}_C + G_B + G_I - G_O + \Delta\bar{M}_{TC} \quad (1)$$

where

- ET = evapotranspiration from the area,
- Q_I = surface inflow of the Gila River,
- Q_O = surface outflow of the Gila River,
- Q_T = surface inflow from tributaries bordering the area,
- ΔC = change in Gila River channel storage,
- $\bar{P}$ = average precipitation on the area,
- $\Delta\bar{M}_S$ = average change in moisture content in the unsaturated soil zone located immediately below the land surface,
- $\Delta\bar{M}_I$ = average change in moisture content in the unsaturated intermediate zone located between the overlying soil zone and the underlying capillary zone,
- $\Delta\bar{M}_C$ = average change in moisture content in the capillary zone located below the intermediate zone and within the zone of water-table fluctuations,
- G_B = ground-water inflow vertically upward into the alluvium from the underlying basin fill,
- G_I = ground-water inflow downvalley through the saturated alluvium,
- G_O = ground-water outflow downvalley through the saturated alluvium, and
- $\Delta\bar{M}_{TC}$ = lateral ground-water movement through the capillary zone between the flood plain and adjacent terrace area.

ET determined with equation 1 will henceforth be referred to as "measured ET."

One factor not considered in the water-budget equation which may be significant during some budget periods is surface depression storage. Reliable field measurements of depression storage were not possible. However, the only time this factor appears to be significant is during periods of high flow in the

Gila River when the error in the measurement of the Q_T and Q_O components and the resultant ET are large.

The water-budget equation can be solved for any given length of period, if that period is long enough for measurable changes to occur in the components. However, the budget period must also be short enough to permit detection of seasonal variations in ET. Other factors considered in the selection of the budget-period length (for this study) included the time and cost in data collection and the frequency with which data could be measured without redundancy of information. Because of these considerations, budget periods of 14 and 21 days were used—the length depending on the frequency with which soil-moisture and precipitation measurements could be obtained. Except for basin-fill inflow, which was assumed constant, all other components of the water budget were recorded continuously and could, therefore, be evaluated for any length of budget period.

COLLECTION AND CONVERSION OF BASIC DATA

The project was instrumented for the independent measurement of each component in the water budget. The collection and conversion of data for these components are described in the following pages. The errors involved in computing the individual components and in evaluating ET as the residual in the budget equation were analyzed and described by Burkham and Dawdy (1970) and Hanson and Dawdy (1976).

GILA RIVER STREAMFLOW

Measurements of discharge were required at the upstream and downstream ends of each reach. A gaging station, Gila River at Calva, has been in operation since 1929 at cross-section 9. Additional gaging stations were installed at cross-sections 1, 17, and 23 in 1963. A gaging station was also established at cross-section 13 in June 1966 following inundation of the stations at cross-section 17 and 23 from backwater in San Carlos Reservoir. A continuous record of river stage was obtained at each gaging station and a stage-discharge relation was established and maintained by repetitive current-meter discharge measurements.

The gain or loss of flow within a reach of the river is the difference between the measured inflow and outflow. Generally, this difference is a small fraction of the flow passing through the reach and accurate discharge records are essential to obtain reliable measures of gain or loss. Burkham and Dawdy (1970) analyzed the accuracy of the measured discharge and developed criteria to predict the error in flow volumes. The magnitude of this error is a function of both the quantity of flow and the accuracy of the stage-discharge relation. The Gila River channel is subject to considerable scour and fill; thus, good definition of the stage-discharge relation requires frequent discharge measurements. The frequency of measurements ranged from one week in the winter to three per week in the summer with additional measurements during floods.

Records of daily discharge are complete for the study period at cross-sections 1 and 9. The gaging station at cross-section 13 was in operation after June 1966 but the discharge record is incomplete during floods and during the first six months of 1968 when backwater affected the stage-discharge relation. No streamflow data in excess of 3,500 ft^3/s (99 m^3/s) were obtained at cross-section 17 and the data are incomplete during periods in 1966, 1968, and 1969 because of backwater from the reservoir. A stage-discharge relation could not be established for flows exceeding about 500 ft^3/s (14 m^3/s) at cross-section 23. The channel at this station was completely plugged in 1964 as shown in figure 4 and the station was relocated 1,000 ft (305 m) downstream on an excavated channel. The station records were not used after July 1965 because of renewed inundation from the reservoir and plugging of the excavated channel. The channel plugging process is described by Kipple (1977).

The mean annual discharge, the maximum and minimum discharge, and the total annual discharge for the gaging station at cross-section 9 for each water year (October 1 to September 30) during the period of study are given in table 4. The variability in monthly discharge at this station during the study period is shown in figure 5.

CHANGE IN CHANNEL STORAGE

The water stored in the channel within a reach is computed as the product of the average cross-sectional area of the stream and the channel length. Discharge measurement notes provided the data necessary to compute the cross-sectional area at the time of measurement. These data were used to develop an area-stage relation for the cross sections at the ends of the reaches. The recorded stages provided the data for determining the cross-sectional area at the beginning and end of each budget period. Average cross-sectional area for the reach is the average of the areas for each end of the reach. Change in channel storage (ΔC in equation 1) during a budget period is

TABLE 4.—*Annual and extreme discharges of the Gila River at Calva, cross-section 9, during the study period*

Water year	Mean annual (ft³/s)	Extremes (ft³/s) Maximum	Minimum	Total annual (acre-ft)
1963	242	3,240	0	175,100
1964	130	3,060	0	94,390
1965	126	4,700	0	90,960
1966	737	39,000	11	533,400
1967	205	40,000	9.1	148,400
1968	798	8,960	21	579,300
1969	83.6	1,160	3.7	60,560
1970	43.1	982	2.6	31,220
1971	82.6	7,470	1.2	59,770
1972	243	7,160	4.0	176,400

the difference between the channel storage at the beginning and end of the budget period.

TRIBUTARY INFLOW

The discharge from the numerous tributaries to the Gila River within the project area is an input to the water budget. The method of measuring the flow from these tributaries was designed on the following assumptions and criteria: (1) the total discharge during a water-budget period from all tributaries to a reach would be required; (2) although the smallest water-budget period would be two weeks, longer water-budget periods might be used; (3) significant amounts of runoff occur only during the months of July through October; (4) tributaries contribute surface flow to the study reach for only a small part of the time and this flow is assumed to be a small part of the total volume of water included in a water budget for most periods; (5) accurate records of flow for each tributary would not be required; (6) the water-budget computations could be omitted for periods of excessive discharge from tributaries; and (7) periods of no flow in the tributaries would be accurately defined.

The location of tributary basins and gaging installations are shown in the report describing the measurement of tributary streamflow (Burkham, 1976). Gages were installed on streams draining 235 mi² (608 km²) of the total 260 mi² (673 km²) of area tributary to the project area. Continuous recording gages were established on streams draining the 10 largest basins, which included 54 percent of the tributary area. Six other recording gages were located at sites selected on the basis of the physiography and orientation of the basins. Crest-stage gages were established on 47 other tributary streams. Stage recorders were operated during the July through October runoff season and the crest-stage gages were regularly inspected during this 4-month period. Tributary runoff data were obtained from 1963–72 for reaches 1 and 2. The discharge of the Gila River at cross-section 23 could not be measured during periods of tributary discharge, therefore, flows from the tributaries to reach 3 were not used.

A stage-discharge relation was computed for each tributary gaging station using the standard-step method as described by Burkham (1976). The initial intent was to verify these relations by using current-meter and slope-area measurements of discharge. This plan was later discarded when it became apparent that this refinement of the stage-discharge relation could not be justified because of the limited significance of tributary runoff in the water budget and because of the difficulties involved in making verification measurements. Thus, only a few current-meter and slope-area measurements of floodflow were obtained.

Runoff from tributaries having recording gages was computed by applying the stage-discharge rela-

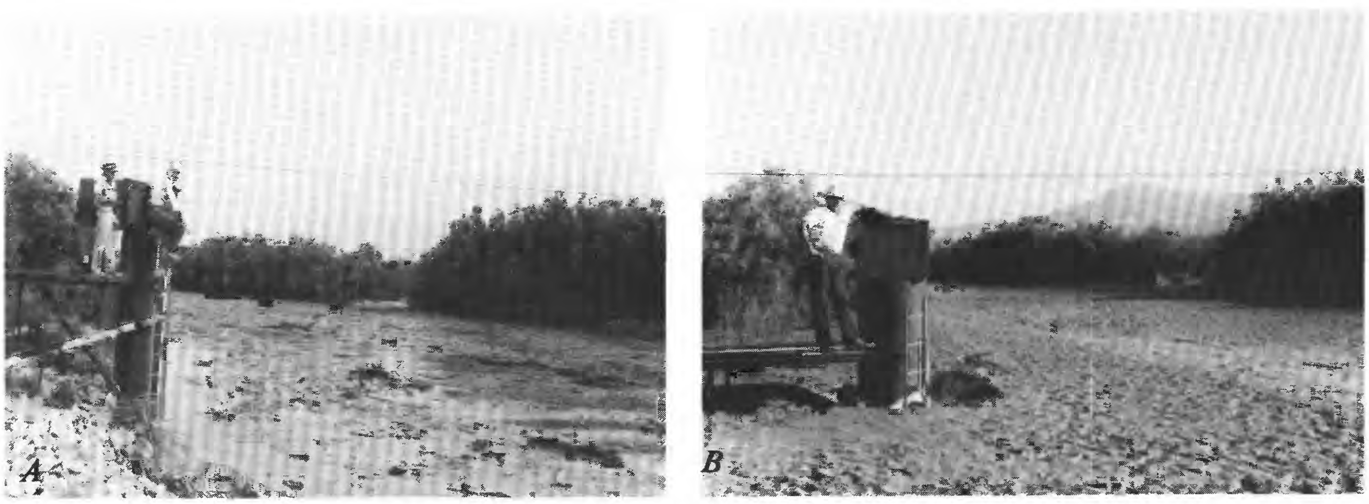

FIGURE 4.—Views looking upstream at the gaging station and channel at cross-section 23 on July 15, 1964 (upper photo) and on September 6, 1964 (lower photo) after deposition from channel plugging had filled the channel.

tions to the recorded gage heights. Discharge data from watersheds near the project area having drainage areas of less than 100 mi² (259 km²) were used to develop a relation between peak discharge and

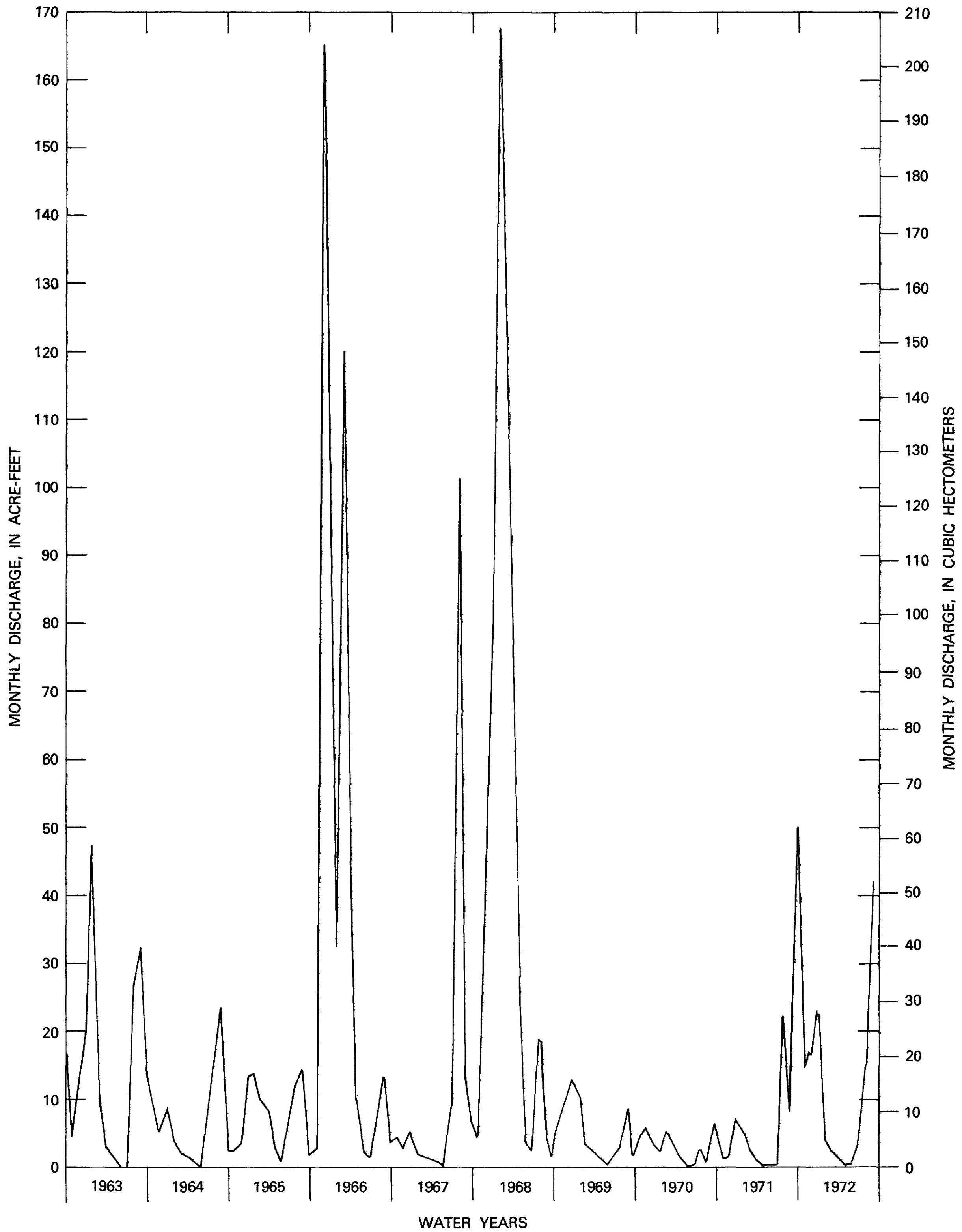

FIGURE 5.—Monthly discharge of the Gila River at Calva, Arizona.

volume of storm runoff. The volume of runoff from each storm event was then obtained by applying the discharge-volume relation using the peak discharge computed for those tributaries with crest-stage gages.

Average seasonal runoff from tributaries to reaches 1 and 2 for the period 1963-71 was 1,370 acre-ft (1.69 hm^3) or 9 acre-ft per mi^2 (0.0043 hm^3 per km^2). The seasonal runoff to reach 1 ranged from a minimum of 40 acre-ft (0.049 hm^3) in 1970 to a maximum of 1,620 acre-ft (2.00 hm^3) in 1967. For reach 2, the seasonal runoff ranged from 90 acre-ft (0.11 hm^3) in 1970 to 2,220 acre-ft (2.74 hm^3) in 1971. The largest runoff from an individual storm occurred on August 5 and 6, 1967 and totaled 280 acre-ft (0.35 hm^3) in reach 1 and 690 acre-ft (0.85 hm^3) in reach 2. The highest peak discharge on an individual tributary was estimated as 8,000 ft^3/s (227 m^3/s) during the storm. On a unit area basis, the maximum peak discharge was 2,300 ft^3/s per mi^2 (25 m^3/s per km^2) on July 16-17, 1967. There was no flow in any of the tributary streams during 96 percent of the days in a year.

PRECIPITATION

Precipitation falling on the project area is an inflow component of the water budget. The limited areal extent of the summer storms required a relatively dense network of rain gages to provide an adequate sample for the computation of the volume of precipitation. Three types of gages were used: float-actuated digital recorders, weighing recorders, and nonrecording wedges. Recording gages were installed at the ends of each reach and wedge gages were located at the ends of each cross section as shown in figure 1. The distance between gages is about 1 mi (1.6 km). Hourly data were recorded by the digital gages and the weighing gage charts were interpreted for one-hour intervals. Wedge gages were read every 2 to 3 weeks when soil-moisture measurements were made, to obtain the precipitation accumulated during a budget period.

Precipitation records for wedge gages are complete for reach 1 from September 1963 through September 1971, for reach 2 from October 1963 through September 1971, and for reach 3 from June 1964 through February 1966. The recording gages were operated from January 1964 to September 1971, except for periods of instrument malfunction.

Data from the wedge gages were used to compute the volume of precipitation for a budget period. Occasionally the precipitation at a gage was not obtained. In such instances, the precipitation was estimated using observed data from nearby wedge gages or from the recording gages. Representative portions of the project area were assigned to each wedge gage by a modification of the Thiessen Method (Thiessen, 1911). The total accumulated precipitation for a budget period was computed as an average weighted value from

$$\bar{P} = \left(\sum_{j=1}^{n} A_j P_j\right) \Big/ \sum_{j=1}^{n} A_j \qquad (2)$$

where

$\bar{P}$ = the average weighted precipitation for the budget period, in inches,

P_j = the accumulated precipitation at gage j for the budget period, in inches,

A_j = the area assigned to gage j, in acres, and

n = total number of gages in a reach.

Hanson and Dawdy (1976) analyzed the measurement errors associated with the precipitation data.

Mean annual precipitation for the 8-year period 1964-71 was 11.15 in. (283 mm) on the project area. Precipitation increased downstream from a mean annual value of 10.35 in. (263 mm) at cross-section 1 to 12.18 in. (309 mm) at cross-section 17; an 18 percent increase. A comparison of the mean annual precipitation between reaches shows that precipitation on reach 2 was 1 in. (25 mm) more than on reach 1. Also, the precipitation on the south bank averaged 11.31 in. (287 mm) compared to an average of 10.98 in. (279 mm) north of the river. This spatial variability in precipitation is attributed to the orographic features of the area. The maximum daily precipitation recorded was 2.39 in. (61 mm) at the north end of cross-section 17 on December 27, 1968. The total annual precipitation for 1964-71 in table 5 is the average from the wedge-gage data for reaches 1 and 2, and ranges from 7.50 in. (191 mm) in 1971 to 14.6 in. (371 mm) in 1966.

SOIL MOISTURE

The flood-plain alluvium constitutes a water-

TABLE 5.—*Precipitation for reaches 1 and 2 by water year*

Water year	Total precipitation (inches)
1964	8.36
1965	11.96
1966	14.68
1967	9.89
1968	14.18
1969	11.00
1970	11.62
1971	7.50
Average	11.15

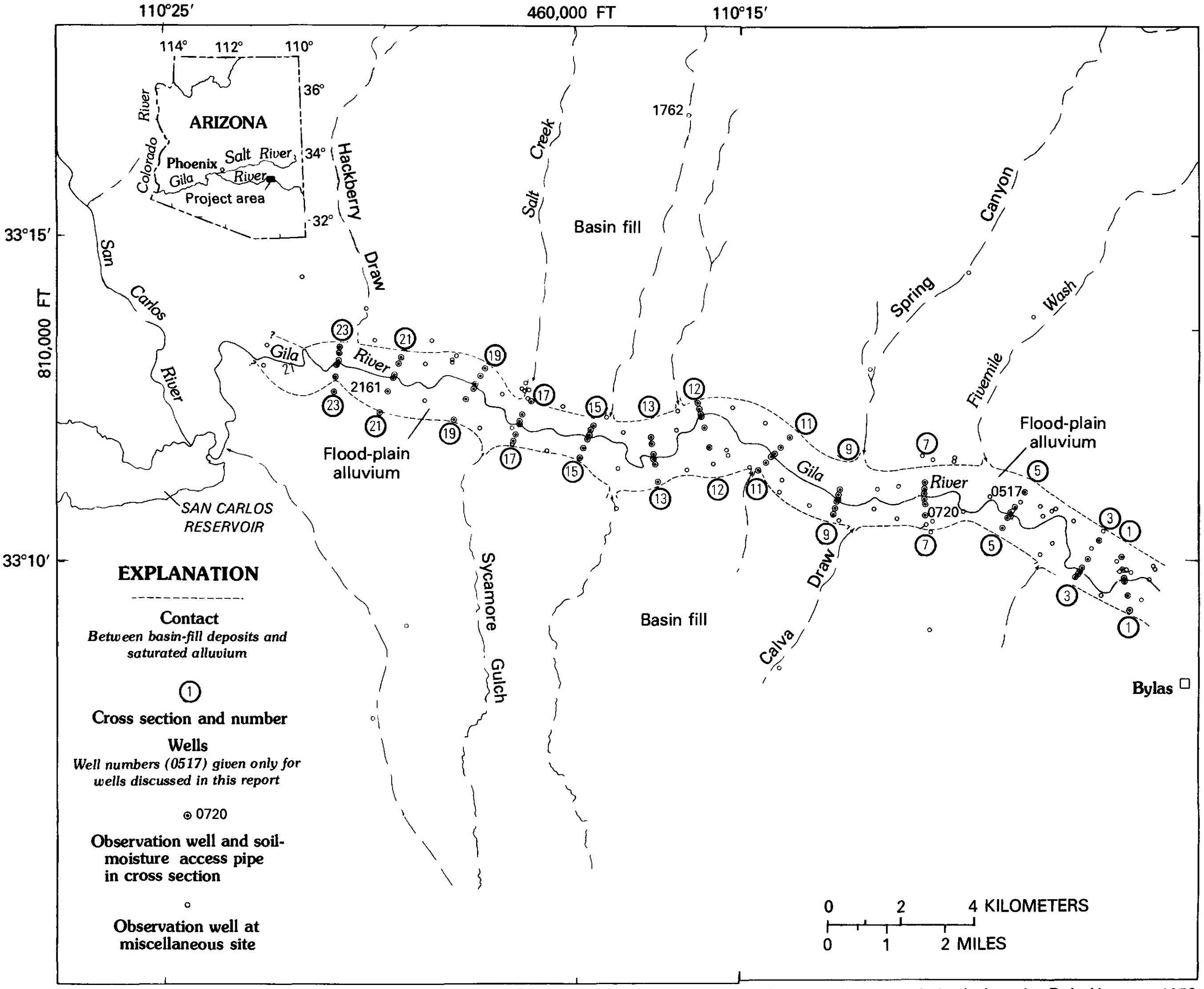

FIGURE 6.—Location of ground-water observation wells and soil-moisture access pipes.

storage reservoir with a capacity of about 25,000 acre-ft (31 hm³) within the study area. Approximately 30 percent of the average annual *ET* is supplied from changes in this storage. The soil-moisture content was measured within two areas of each reach: (1) the flood plain which corresponds to the area for which *ET* is evaluated and (2) the adjacent terrace area which extends out from the flood plain to the contact of the saturated terrace alluvium with the basin fill. Measurements were made with neutron soil-moisture meters at 2- to 3-week intervals, thus defining the water-budget periods. The difference between the moisture content measured at the beginning and end of the period defines the change in moisture content for the budget period. Three access holes for measuring the moisture content were installed on each side of the Gila River at each cross section as shown in figure 6. Each hole was classified as one of the following three types: (1) river hole located adjacent to the river, (2) flood-plain hole located between the river and the terrace, or (3) terrace hole located on the terrace adjacent to the flood plain. The river and flood-plain holes were used to obtain the change in moisture content in the unsaturated zone of the flood-plain alluvium and the terrace holes were used to obtain the change in moisture content in the unsaturated zone of the adjacent terrace alluvium. The installation of access holes and the calibration of soil-moisture meters are described by Myrick in Culler and others (1970).

Moisture content, expressed as percent by volume, was measured with the soil-moisture meter probe at 0.5 ft (0.15 m) and 1 ft (0.30 m) below ground surface and at 1 ft (0.30 m) intervals through the remaining depth of each access hole. The observed moisture content ranged from 3 percent at the soil surface to over 40 percent below the water table. The change in moisture content was determined for three zones in the profile: (1) the soil zone extending from the land surface to 2.5 ft (0.76 m) below land surface in the flood plain and to 5 ft (1.52 m) below land surface in the terrace, (2) the intermediate zone extending from the bottom of the soil zone to about 3 ft (0.9 m) above the maximum observed ground-water level, and (3) the capillary zone extending from the bottom of the intermediate zone to the bottom of the hole in the flood plain and to about 3 ft (0.9 m) below the minimum ground-water level in the terrace. No intermediate zone was defined for the flood plain of reach 1 because of the relatively shallow ground-water table in the reach. The change in moisture content in each of these three zones within the *ET* area of the flood plain corresponds to the water-budget components $\Delta\bar{M}_S$, and $\Delta\bar{M}_I$, and $\Delta\bar{M}_C$, respectively, in equation 1.

The average change in moisture content in a given zone of the reach for a budget period was computed from

$$\Delta\bar{M}_{zt} = \left[\sum_{j=1}^{n} (\Delta M_{zjt} A_j) \right] \Big/ \sum_{j=1}^{n} A_j \qquad (3)$$

where

$\Delta\bar{M}_{zt}$ = average weighted change in moisture content in zone z of the reach during period t.

$$\Delta M_{ztj} = M_{zj(t\text{-}1)} - M_{zjt} \qquad (4)$$

where

$M_{zj(t\text{-}1)}$ and M_{zjt} = measured moisture content in zone z of hole j at the beginning (t-1) and end (t) of the budget period,

A = surface area assigned to hole j, and

n = total number of access holes.

The surface area A_j assigned to each hole was determined using the same modification of the Thiessen Method that was applied in assigning areas to the precipitation gages. When moisture-content data were missing for an access hole, the change in moisture content for the hole was approximated using the average unweighted change computed from the measured access holes of the same type (e.g., river, flood plain, or terrace) in the reach as the unmeasured hole. A negative change in moisture content ($-\Delta M$) indicates an increase of the moisture in the profile (negative *ET* component) during the budget period, whereas a positive change ($+\Delta M$) indicates a loss of moisture in the profile (positive *ET* component).

During some high-flow periods, inundation over the flood plain prevented access to many of the soil-moisture access holes to obtain moisture-content measurements. However, water levels in the ground-water wells adjacent to each access hole were recorded continuously, thus providing a complete set of water-level data for each reach. It was found that when data from over one-half of the access holes were missing, a better estimate of moisture change in the capillary zone could be obtained from the more complete set of water-level data. The estimate of moisture change in this case was determined by the relation

$$\Delta\bar{M}_C = -\Delta\bar{h}\, S'A \qquad (5)$$

where $\Delta\bar{M}_C$ (or $\Delta\bar{M}_{TC}$) is the average moisture change in the capillary zone of the flood plain (or terrace) in acre-ft, $\Delta\bar{h}$ is the average change in the ground-water levels in the flood plain (or terrace) of the reach in feet (positive for a rise and negative for a drop in water levels), S' is the apparent specific yield of the aquifer in the zone of water-level change (dimensionless), and A is the area of the flood plain (or terrace) in acres. An average value of S' was determined for both the flood plain and terrace areas of each reach by relating $\Delta\bar{h}$ to the corresponding $\Delta\bar{M}_C$ (or $\Delta\bar{M}_{TC}$) using budget periods containing a complete set of water-level and moisture-content data (Hanson and Dawdy, 1976).

BASIN-FILL INFLOW

Ground water is conveyed from the steep valley slopes through the saturated zone of the basin fill to the overlying alluvium on the valley floor. This water is under sufficient artesian pressure to rise above the water table in the alluvium. Water-table elevations in 20 existing stock-water wells on the adjacent valley slopes were observed at about monthly intervals. The depth to water in these wells ranges from 22 ft (6.7 m) on the terrace near the flood plain to 360 ft (110 m) 2.5 mi (4 km) south of the river. The slope of the potentiometric surface toward the Gila River, as defined by Weist (1971, fig. 8) is 0.017 north of the river and 0.029 south of the river. The variation of the water levels in the observation wells that were not pumped was insufficient to produce any significant change in the artesian pressure under the flood plain.

The discharge from the basin fill was therefore assumed to be constant.

The hydraulic characteristics of the basin fill were investigated by aquifer tests at two wells, an analysis of water-level recessions, and by analysis of geothermal gradients as described by Hanson (1972). These investigations indicate that the average storage coefficient of the basin fill is 0.0005 and the average transmissivity is 15 ft^2 (1.4 m^2) per day. An analysis of moisture movement in the capillary zone of the deep terrace wells of reach 1 during the selected winter periods indicates that the basin-fill inflow is about 0.3 ft (0.09 m) per year (Hanson and Dawdy, 1976). The ground-water contribution from the area tributary to the flood plain in the project area originates in the basin fill and is therefore assumed to be included in the estimate of artesian discharge from the basin fill. This value was also tested and confirmed in an optimization analysis discussed in a subsequent part of this report.

GROUND-WATER MOVEMENT DOWNVALLEY

A network of 78 recording wells was established to measure depth to and movement of ground water in the project area. Three wells were installed on each side of the river at each cross section as shown in figure 6: one near the river, one between the river and terrace, and one on the terrace. The installation of wells is described by Myrick in Culler and others (1970). Water-table elevations were recorded by digital stage recorders with hourly punch intervals. Records are available for reach 1 from April 1963 to September 1971, for reach 2 from October 1963 to September 1971, and for reach 3 from May 1964 to September 1965. An exception to the preceding periods of record are five wells on cross-section 12 which were not installed until 1966. Several of the wells near the river were relocated at different times during the study when channel changes destroyed the original wells and extensions were required on some wells because deposition of silt during overbank flooding elevated the ground surface.

Thirty-eight additional wells located near the outer boundary of the flood plain between cross sections were drilled, primarily to define the contact between the alluvium and basin fill. Water-table elevations in these miscellaneous wells were observed at about monthly intervals. These data were used to supplement ground-water elevation data from the network of recording wells at the cross sections.

Data from all wells indicate a consistent decline of water-table levels from April through June of each year. The magnitude of this decline depends on the flow of the Gila River during the preceding winter. The lowest level occurs in midsummer either before or after the summer storms, depending on the magnitude of the summer flow. Water-table levels near the river are lower than the river bed during periods of low or zero flow. Highest water-table levels occur either in midwinter or in late summer in response to the flow in the river. The annual variability in water-table levels in reach 1 ranged from 1 ft (0.3 m) in most wells during 1970 to 8 ft (2.4 m) at wells near the river at cross-section 3 in 1968. Prior to 1966, the annual range in water-table levels increased progressively downvalley with the maximum range occurring at cross-section 23. After January 1966, backwater from San Carlos Reservoir raised the water table in reaches 2 and 3. The maximum change recorded during the study was a 25 ft (7.6 m) rise at well No. 2161 between October 1965 and April 1966.

Ground-water movement downvalley through the upstream and downstream ends of each reach was calculated from

$$G = i\,T\,W\,D \qquad (6)$$

where

G = the downvalley ground-water flow through the alluvium in acre-feet per budget period,

i = average downvalley gradient in feet per foot of the ground-water surface during the budget period through the upstream or downstream end of the reach,

T = transmissivity of the alluvium in acre-feet per day per foot,

W = width of the saturated alluvium at the upstream or downstream end of the reach in feet, and

D = number of days in the budget period.

The transmissivity, T, of the alluvium was determined by Hanson (1972, p. F27) to be 0.644 acre-ft per day per ft (2,600 m^3 per day per m) and was assumed to be constant throughout the study area. The width of the saturated alluvium, W, is the distance between the points of contact of the alluvium with the basin fill at the water table on each side of the flood plain. The downvalley slope, i, was computed from the average ground-water levels for the budget period measured at the river wells and flood-plain wells at the cross sections on or adjacent to the ends of the reach. As an example, the slope through the upstream end of reach 1 (cross-section 1) was computed from the average water levels at cross-sections 1 and 3. Similarly, the slope through the downstream end of reach 1 (cross-section 9) was computed from the average water levels at adjacent cross-sections 7 and 11. Average downvalley slopes during a budget period between cross-sections 1 and 3 ranged from 0.00122 in May 1971 to 0.00183 in October 1966 with the latter slope being the maximum average slope observed in the project area during the study. Before 1966, the minimum average slope observed was 0.000305 between cross-sections 21 and 23 in August 1964. After 1966, the slopes between these cross sections approached zero because of the high water levels in San Carlos Reservoir.

GROUND-WATER MOVEMENT CROSSVALLEY

The previously described network of recording observation wells was designed to define also the gradient of the water table perpendicular to downvalley ground-water movement. However, an analysis of the ground-water level data indicated that the crossvalley water-table slopes were too variable to adequately define either the direction or magnitude of the crossvalley ground-water flow component.

Neutron-log measurements of changes in storage in the capillary zone under the terraces indicate, however, that water does move vertically into and out of this zone. Any significant loss of water in the zone by *ET* from the terrace vegetation is not likely because the depth of the water table under the terraces is too deep, 20 to 30 ft (6 to 9 m), to be readily extracted by the overlying vegetation. Therefore, all significant movement of water out of the terrace capillary zone is assumed to be lateral and in the direction of the flood plain in response to an overall drop in ground-water levels with a general water-level gradient towards the Gila River. All significant movement of water into the terrace capillary zone is also assumed to be lateral but originating from the flood plain in response to an overall increase in ground-water levels with a general water-level gradient away from the river. The crossvalley component (ΔM_{TC} in equation 1) was then determined by use of equation 3, which computes the changes of moisture in storage during the budget period.

EVALUATING EVAPOTRANSPIRATION

ET was evaluated by equation 1 for each budget period containing a complete set of water-budget data. The four reaches provided 530 budget periods during the 1963–71 study period. The length of each budget period was 14 or 21 days for most periods, but did range up to 63 days. The duration of a period depended on the frequency of soil-moisture measurements. Because of significant missing data in 116 periods, only 414 periods were actually evaluated to obtain estimates of *ET*. Of these a further 93 were rejected on the basis of criteria described in a following section of this report. *ET* values and their corresponding water-budget components are given in table 6 (at end of report) by water years for each reach. Figure 7 shows a plot of all *ET* values, both accepted and rejected values, expressed in inches per 30 days and monthly pan evaporation at San Carlos Reservoir.

Each *ET* value in table 6 represents the rate from essentially the entire flood plain within the reach as shown by the boundaries in figure 1. Periods of missing data and periods when one or more of the water-budget components were not observed are indicated by blanks in the table. Periods for which no *ET* values were computed generally coincide with high flows in the Gila River that inundated the streamflow gaging stations.

RELATIVE SIGNIFICANCE OF THE WATER-BUDGET COMPONENTS

The quantity of water removed from the project area of the Gila River flood plain by *ET* is small compared to the quantities measured by the water budget. The relative significance of the various sources in providing water for *ET* can be illustrated by grouping the components of the water budget in equation 1 as follows:

1. Surface-water inflow .... $Q_I + Q_T$
2. Soil-moisture storage .... $\bar{M}_S + \bar{M}_I + \bar{M}_C + \bar{M}_{TC}$
3. Ground-water inflow .... $G_B + G_I$
4. Precipitation .... P.

As an example, the inflow from surface water, precipitation, and ground water, and the volume of water in the observed soil profile for each budget period of 1965 in reach 2, are shown by the bar graphs of figure 8. Surface water and ground water are not only sources of inflow but also components of outflow, and soil-moisture storage can be either depleted or recharged during any budget period. The losses (positive as contributions to the reach) and gains (negative as contributions to surface and ground-water outflow and as recharge to soil moisture) are computed as follows:

1. Surface water $Q_I + Q_T + \Delta C - Q_O$
2. Change in soil-moisture storage $\Delta\bar{M}_S + \Delta\bar{M}_I + \Delta\bar{M}_C + \Delta\bar{M}_{TC}$
3. Ground water $G_B + G_I - G_O$.

The resulting gains or losses are also shown in figure 8.

The budget does not imply the disposition of water from each source in the reach but, rather defines the residual of all water moving through the system. For

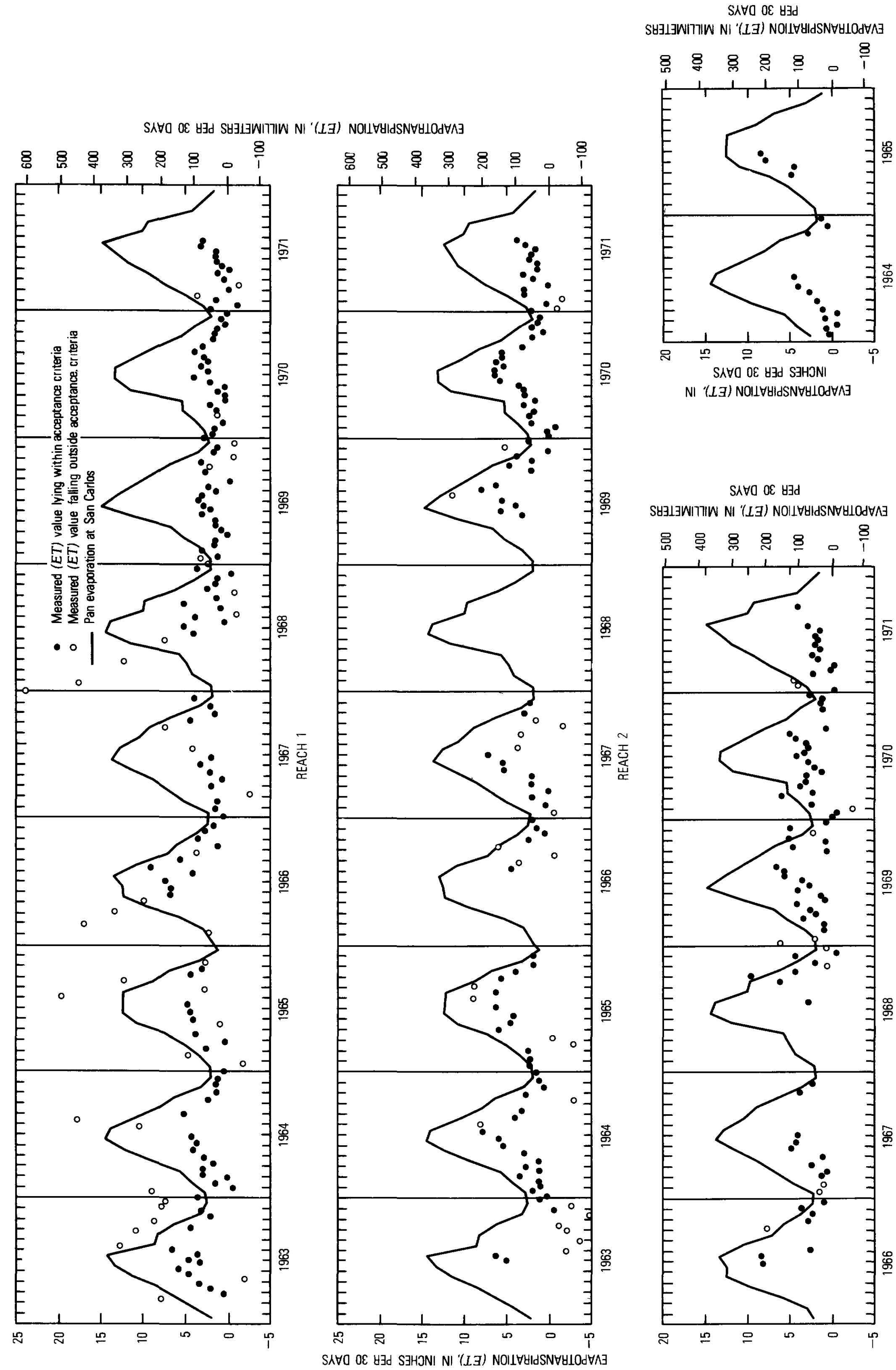

FIGURE 7.—Measured evapotranspiration for each budget period during 1963-71 and monthly pan evaporation at San Carlos Reservoir.

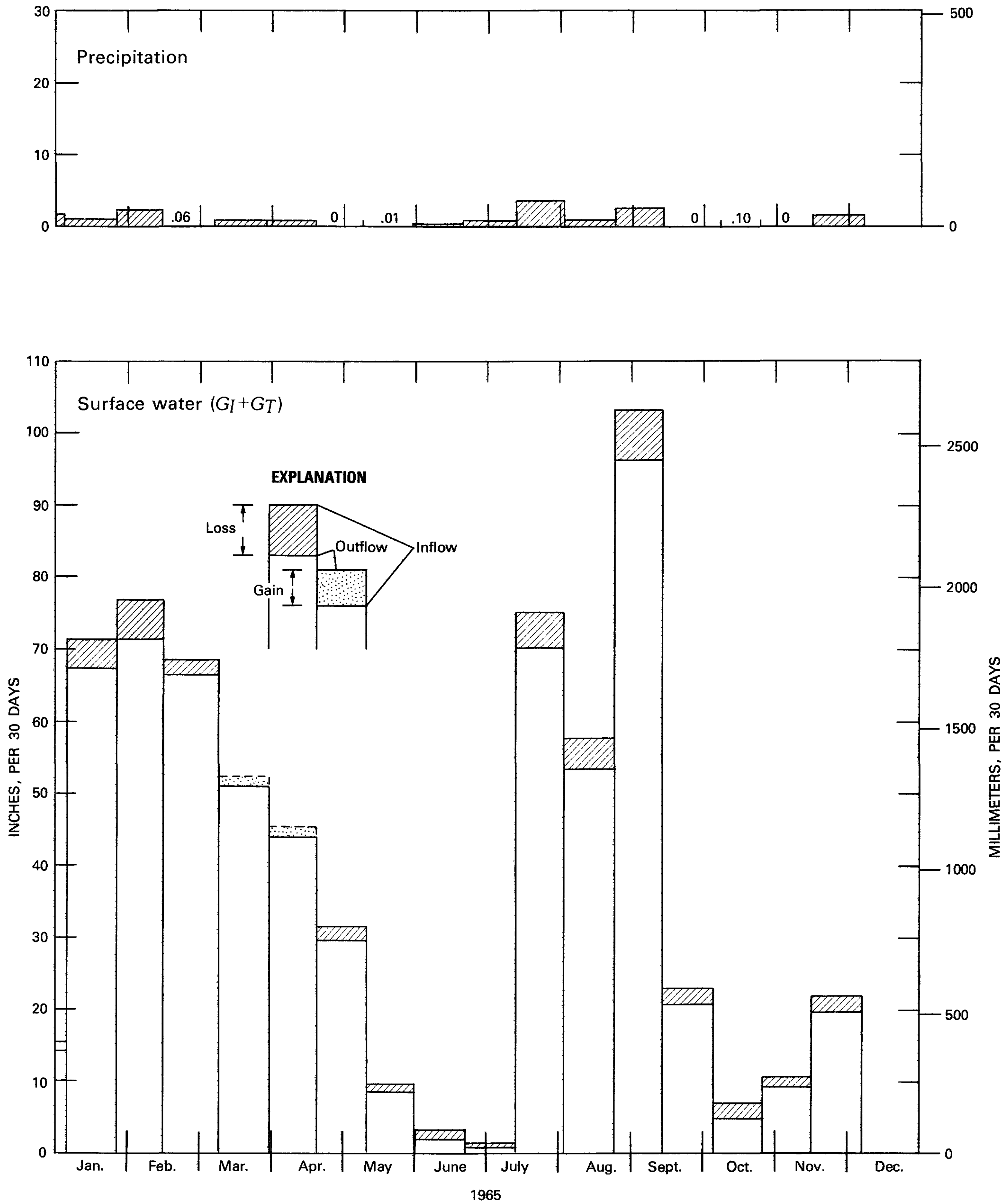

FIGURE 8.—Sources of water available for *ET* in reach 2 during each budget period of 1965.

example, the loss of water from the surface-water source during January and February of 1965 probably went into subsurface storage, to be removed by *ET* during the following growing season.

Figure 8 shows that some sources include much larger volumes of water than other sources. The total annual volume of water supplied to the project area by precipitation is relatively small, but it does provide a significant part of the total *ET* during the late summer rainy season when the potential *ET* is high. Of the four sources in figure 8, surface-water inflow is both the largest and the most variable with time—reaching maximum inflow rates during the winter and late summer storm periods. However, in June and early July, surface-water inflow is a relatively insignificant source. In fact, during this period there was at times no surface-water inflow at all for several days. The loss or gain through the reach per budget

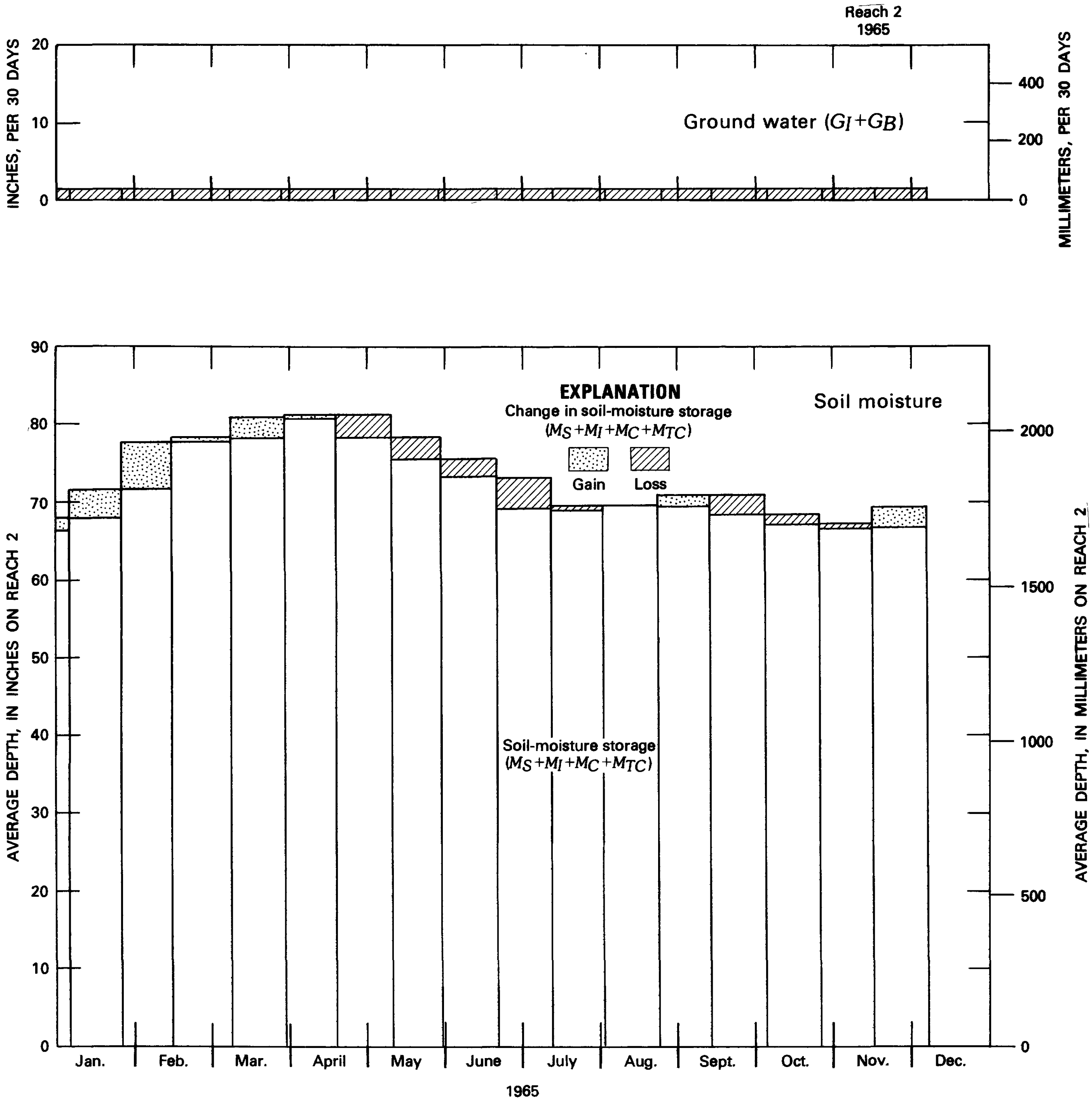

FIGURE 8.—Continued.

period from this source is also highly variable and depends on the potential *ET* rate, the amount of precipitation occurring during the budget period, and the amount of moisture available in the soil profile. Figure 8 shows a loss in flow through reach 2 during all months of 1965 except March and April when a gain in flow occurred.

Ground-water inflow is a relatively small and insignificant source and remains nearly constant throughout the year.

The alluvium underlying the flood plain distributes the water from the various sources to the plants. It also serves as a regulatory reservoir retaining water from periods of large supply and low demand for use during periods of high demand and low supply. The bar graph of soil-moisture storage in figure 8 shows the total moisture measured in the soil profile which extends from the land surface down through the unsaturated zone and several feet into the saturated zone below the ground-water table. The total moisture

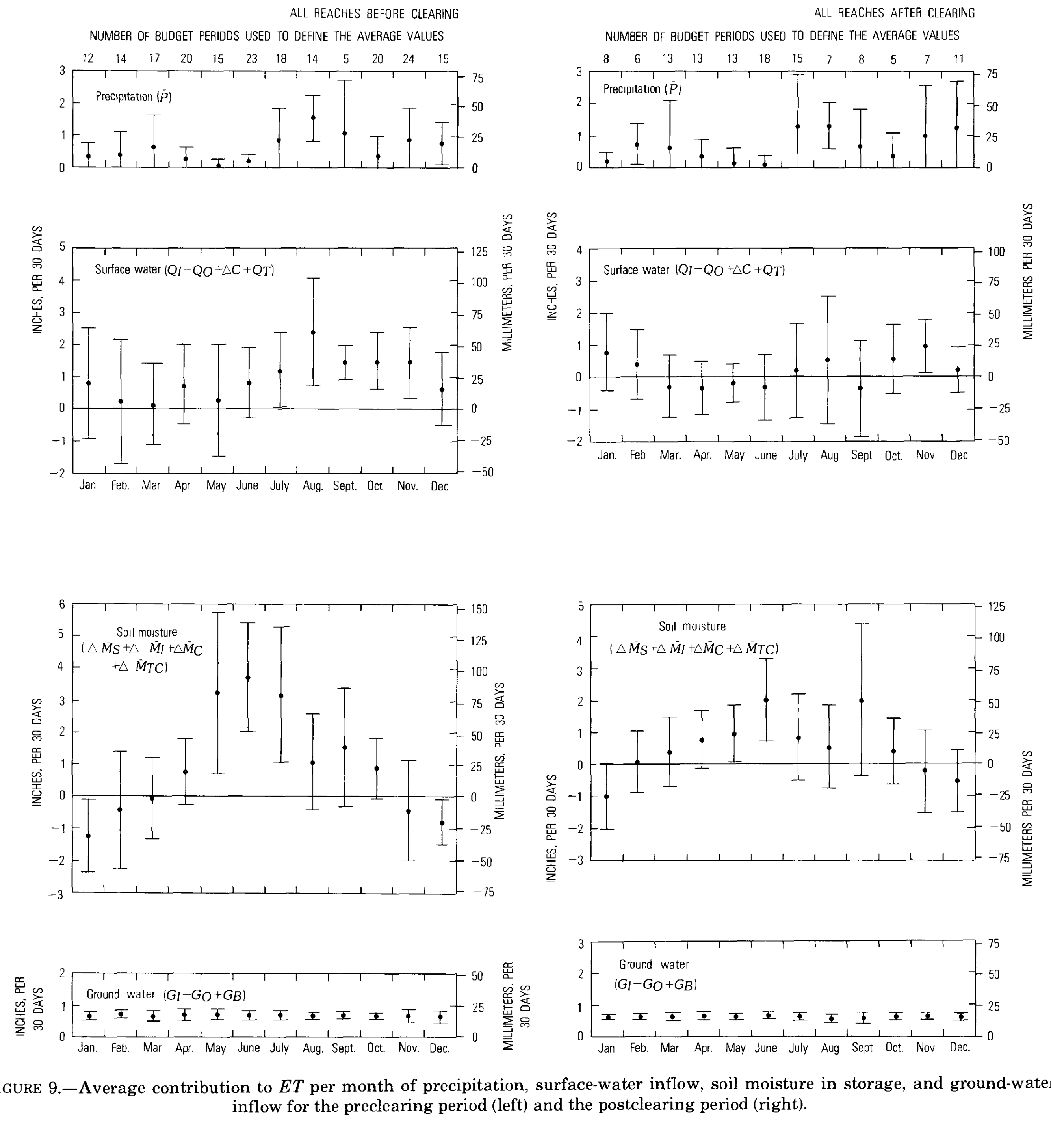

FIGURE 9.—Average contribution to *ET* per month of precipitation, surface-water inflow, soil moisture in storage, and ground-water inflow for the preclearing period (left) and the postclearing period (right).

measured in the saturated and unsaturated zones of the soil profile of reach 2 averaged about 72 in. (1,800 mm) during 1965. The figure indicates that soil moisture is recharged when streamflow is high. Most of the loss of soil moisture occurs during the spring and early summer months (April-July) when precipitation is negligible and the potential *ET* is high.

The soil-moisture graph also indicates that the gain in soil moisture during 1965 nearly equals the loss. For this reason, soil moisture is commonly ignored when evaluating *ET* rates for periods of one or more years.

The losses and gains in water from each source, as shown in figure 8, were computed on a monthly basis for each reach to define the average monthly contribution each source makes to *ET*—both before and after clearing phreatophytes from the flood plain. A plot of these average values is shown in figure 9. Only *ET* values satisfying one or more acceptance criteria (to be described later) are included in the figure. The number of budget periods used in computing each average monthly value is shown at the top of the figure and the extent of the vertical lines through each value defines the standard deviations. Positive values indicate a loss from the system (addition to *ET*) and negative values indicate a gain (recharge) to the system (subtraction from *ET*). As in figure 8, the algebraic summation of the average gains and losses in all sources for a given month gives the average *ET* for that month in inches per 30 days.

ET values from budget periods with excessively high streamflow were not used in this analysis, resulting in a biased estimate of some of the average monthly values shown in figure 9. This bias applies primarily to surface-water and soil-moisture values for the winter. Omission of these *ET* values gives an underestimate of both the average loss in surface water and the average gain in soil moisture for the winter months. However, because these underestimates are opposite in sign and about equal in magnitude, they essentially cancel when computing the average monthly *ET* for the winter periods. These underestimates also explain why the soil-moisture graph of figure 9 shows less gain than loss during the year—when, in reality, the total annual loss should approximate the total annual gain as in figure 8.

Definite seasonal trends are apparent in the graphs of figure 9, particularly for soil moisture which shows a buildup (recharge) during the winter months followed by a loss due to *ET* during the summer months. Obviously, of the four hydrologic sources, soil moisture is the predominant contributor to *ET* during the period of a high potential *ET* from May-July. Surface water and precipitation become the predominant contributors during the winter months and during the late summer thunderstorm period. Variability in gain or loss in a given source for a particular month—as indicated by the vertical lines through each average value—are due primarily to: (1) year to year differences in the volume of moisture available from the source to meet the *ET* demand, (2) random errors in the measurement of the source, and (3) differences in vegetation between reaches and changes in vegetation due to partial clearing. A discussion of these errors is presented below.

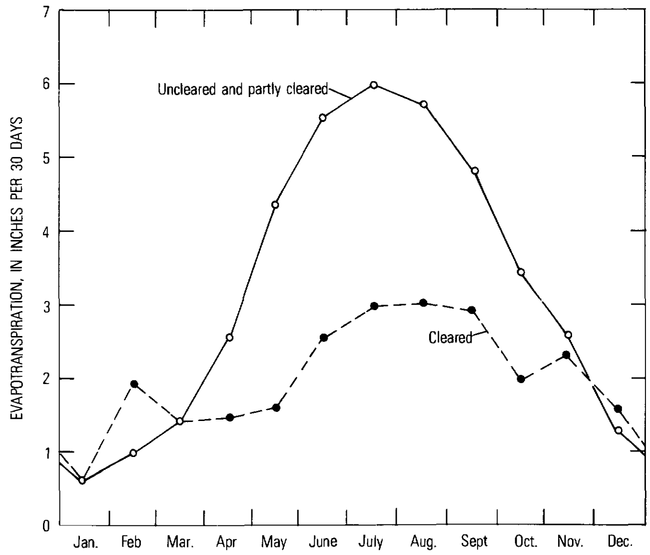

FIGURE 10.—Average monthly *ET* before and after clearing based on selected *ET* data from all reaches.

A comparison between the before and after clearing graphs show similar seasonal trends but substantial differences in the amount of water each source contributes to *ET*. As expected, all sources, other than precipitation, show a reduction in the amount of water contributed to *ET* after clearing. Of particular interest is the surface-water graph which indicates that the Gila River changed, on the average, from a losing stream during the pre- and partial-clearing period to a gaining stream during some months during the postclearing period.

The gains and losses from each source in figure 9 were summed to define the average monthly *ET* for both the pre- and postclearing periods. Graphs of these monthly values are given in figure 10. The average annual pre- and postclearing *ET* rates from these graphs are 39.3 in. (998 mm) and 24.5 in. (622 mm), respectively—thus, defining an average annual reduction in *ET* of 14.8 in. (376 mm). It should be emphasized that these annual *ET* rates represent an average of reaches 1, 2, 2a, and 3 and include precipitation which averaged 11.2 in. (284 mm) per year.

The quantity of phreatophytes varied from reach to reach before clearing and the data in figure 10 represent the average of the observed data not adjusted for the variation in vegetative cover. Empirical equations with coefficients related to the description of vegetative cover will be used in a later section of this report to adjust for this variation.

MEASUREMENT ERRORS IN EVAPOTRANSPIRATION

Evapotranspiration represents a comparatively small loss from a large volume of water as illustrated in figure 8, and the error in the measurement of this loss becomes highly significant as the volume of water measured in the study area increases. This is particularly true of the surface-water components in which the volume of inflow can range from essentially zero to several thousand cubic feet per second. The fact that some *ET* estimates are better than others is apparent in figure 7—i.e., some *ET* values (indicated by 0) follow the expected seasonal trends while other values (indicated by x) are unrealistically high or low and, in some instances, even negative. These outliers are obviously in error and should be discarded, or at least, given little weight when computing average seasonal or annual *ET* rates.

To establish guidelines for selecting the most reliable *ET* data, an evaluation was made of the relative measurement errors associated with each of the 12 measured water-budget components and the corresponding *ET* values expressed in equation 1 (Hanson and Dawdy, 1976).

The total measurement error of each component consists primarily of a sampling error which is dependent on the number of observation points used to measure the component. This sampling error is time variant—reflecting both the variability in repetitive measurements and the error due to missing data. Nine of the 12 water-budget components were found to contain significant sampling errors because the measurement of each component is obtained from an independent observation. The estimate of the sampling error in *ET* may be computed from

$$\epsilon_{ET_s} = \left[\epsilon^2_{Q_I} + \epsilon^2_{Q_O} + \epsilon^2_{Q_T} + \epsilon^2_{\Delta C} + \epsilon^2_{\bar{P}} + \epsilon^2_{\Delta\bar{M}_S} + \epsilon^2_{\Delta\bar{M}_I} + \epsilon^2_{\Delta\bar{M}_C} + \epsilon^2_{\Delta\bar{M}_{TC}}\right]^{1/2} \qquad (7)$$

where ϵ_{ET_S} is the sampling error in *ET* and the error terms on the right side of the equation are the sampling errors of the components indicated by their respective subscripts.

Included in the total measurement error is a bias error which gives a constant over- and under-estimate of the component. Only the three ground-water components (G_B, G_I, and G_O) were found to contain a measurable bias error. This total bias error was computed from

$$\epsilon_{ET_b} = \left[\epsilon^2_{G_B} + \epsilon^2_{G_I} + \epsilon^2_{G_O}\right]^{1/2}, \qquad (8)$$

where ϵ_{ET_b} is the expected bias error in *ET* and the error terms on the right side of the equation are the bias errors for the components indicated by their respective subscripts. Equations 7 and 8 assume that the sampling error and bias error are independent and unknown as to direction. The total measurement error, ϵ_{ET}, of each *ET* value, thus, becomes

$$\epsilon_{ET} = \left[\epsilon^2_{ET_s} + \epsilon^2_{ET_b}\right]^{1/2}. \qquad (9)$$

Because of independence between the components, no covariance term had to be included in the computation of this total measurement error.

Hanson and Dawdy (1976) indicate that the assumptions and criteria used to obtain the total measurement error produce an over-estimate of the true measurement variability in *ET*. This error is shown to be significantly greater than the expected standard deviation of the computed *ET* value and is, therefore, considered to be only an indicator of the relative significance of each *ET* value.

As an example, the total measurement errors computed for each *ET* value are included in table 6, in column ϵ_{ET}. A detailed description of the methods used to derive the sampling and bias error associated with each water-budget component is given by Hanson and Dawdy (1976).

Figure 11 shows the *ET* values computed for each budget period in reach 2 for calendar year 1965—a year prior to clearing when streamflow was moderately high (140 percent of the average annual flow)—and for calendar year 1970—a year when reach 2 was partly cleared and streamflow was relatively low (16 percent of the average annual flow). The extent of the vertical lines through the *ET* values define the total measurement error (ϵ_{ET}) in *ET* as defined by equation 9. The vertical bars indicate the error in *ET* attributed to the streamflow components Q_I and Q_O and to the error attributed to the soil-moisture change components $\Delta\bar{M}_S$, $\Delta\bar{M}_I$, $\Delta\bar{M}_C$, and $\Delta\bar{M}_{TC}$. The increase in the error in soil-moisture measurement between 1965 and 1970 was caused by the partial clearing in 1970. A comparison of the values of Q_I in table 6 with the streamflow errors in figure 11*A* shows that discharge is directly related to the magnitude of the streamflow errors—with the largest errors occurring during periods of highest discharge.

The minimum errors in *ET* frequently coincide with the period of maximum *ET* during May, June,

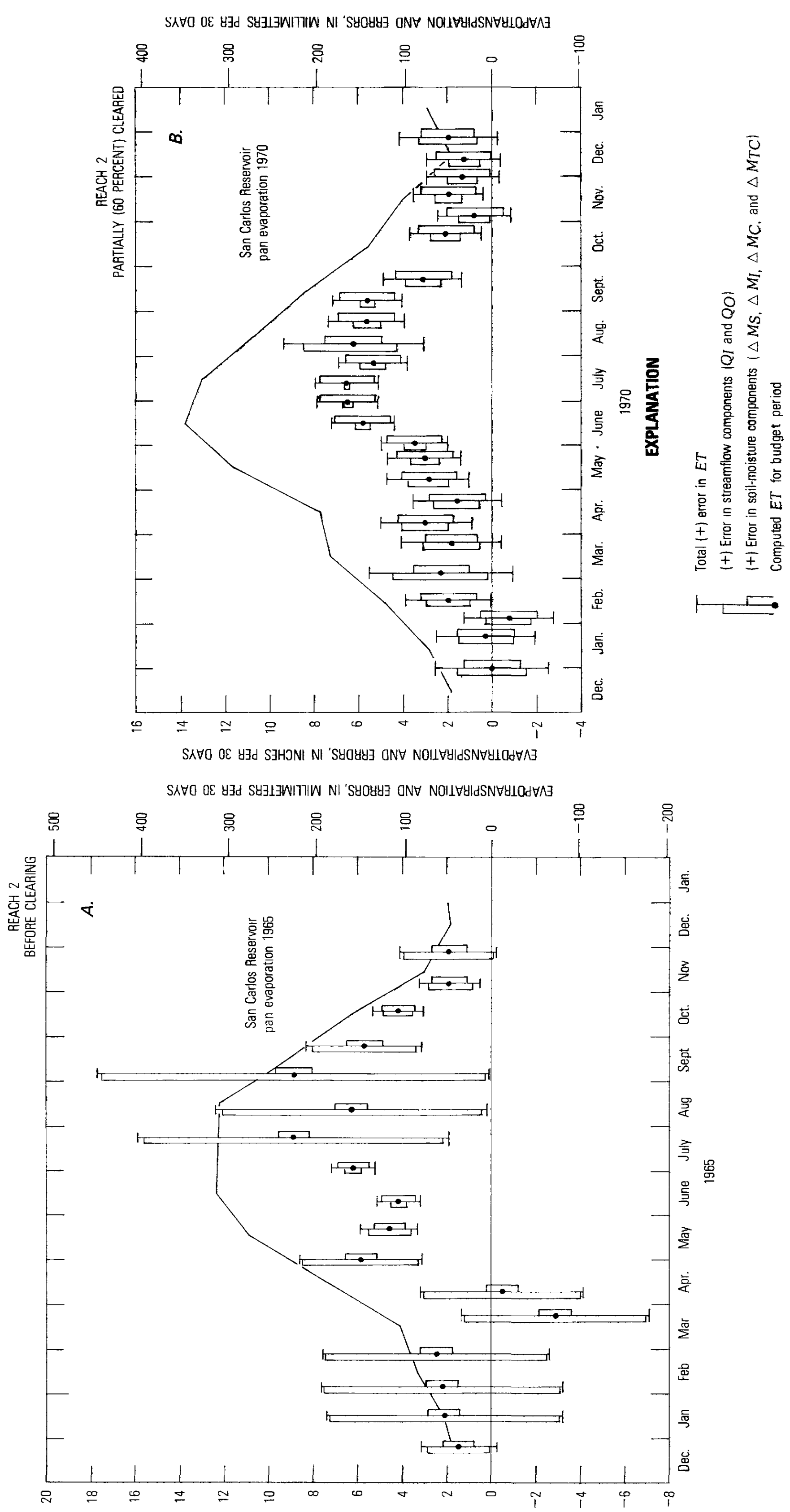

FIGURE 11.—San Carlos Reservoir pan evaporation, evapotranspiration per budget period, and measurement error for reach 2 during calendar years 1965 and 1970.

and early July when streamflow is low and precipitation is negligible. Generally, for those years in which streamflow was below average the computed *ET* values define a definite seasonal trend with relatively little scatter in the data as shown by the 1970 data in figure 11*B*.

An important point to be realized from figures 8, 9, and 11 is that the total measurement error in *ET* is dependent on the volume of water measured in the reach and not on the magnitude of *ET*. This is emphasized in figures 11*A* and 11*B* by the nearly constant error in soil-moisture change for each budget period, reflecting not the large variation in soil-moisture change shown in figure 9, but rather the total volume of soil moisture measured in the reach which fluctuates relatively little with time as shown in figure 8.

The seasonal trends in *ET* data for 1965 and 1970 in figure 11 are indicated by the pan evaporation curves for these years obtained immediately downstream from the project area at San Carlos Reservoir. These curves can be assumed to approximate the upper limit of *ET* throughout the year.

Some negative *ET* values occur in the water budget, but their measurement error is generally large and the error extends into the positive *ET* range. In a few instances the measurement error does not explain a large negative *ET* value or unrealistically high *ET* value. These outliers generally occur during periods of high streamflow and are assumed to reflect large unmeasured changes in the stage-discharge relation which was not fully accounted for in the streamflow error analysis (Burkham and Dawdy, 1970). These outliers may also be attributed to unknown quantities of surface water moving into or out of depression storage as mentioned under "Methods of Analysis."

CRITERIA FOR REJECTING MEASURED *ET* VALUES

As indicated previously, all measured *ET* values that were obvious outliers (fig. 7) or contained large measurement errors, ϵ_{ET}, were omitted in the computation of average seasonal and annual *ET* rates. These values were also omitted in the development of an empirical equation describing the relation between density of plant cover and *ET*.

Reaches 1, 2, 2a, and 3 provided a total of 414 budget periods generally 14 to 21 days in length from which *ET* could be measured. However, *ET* values from 93 of these periods were not considered reliable because of their extreme magnitude or large measurement error.

The criteria used for rejection of the *ET* values were arbitrary, but were based on a consistent set of rules. First, all *ET* values containing a measurement error which exceeds the maximum potential evapotranspiration (*PET*) for the study area (about 4.8 in. or 122 mm per budget period) were discarded.

The *PET* used in this test was computed from the relation

$$PET = (0.014t - 0.37)R \tag{10}$$

where t is the mean air temperature in °*F* and *R* is the short-wave solar and sky-radiation flux expressed as inches per day evaporation equivalent (Jensen and Haise, 1963). Two adjustments were made. Precipitation, an erratic and generally inconsequential source of water to the flood plain, is stored in the upper soil zone and returned to the atmosphere as evaporation from bare soil or is lost by transpiration from either shallow-rooted plants or phreatophytes within hours, or at most, a few days after falling. The *PET* in an arid region is sufficiently high to remove this incidental moisture without significantly changing the average rate of depletion from ground water during a budget period. Precipitation ($\bar{P}$) and the change in moisture content in the upper soil zone ($\Delta\bar{M}_S$) were therefore removed from the water-budget evaluation of *ET* before applying the *ET* data to empirical equations. The adjusted *ET* values (*ET'*) are thus defined as

$$ET' = ET - \bar{P} - \Delta\bar{M}_S\ . \tag{11}$$

Upper and lower boundaries were then established within which the adjusted values (*ET'*) could logically be expected to occur, and all adjusted values falling outside these boundaries were rejected. The following is a summary of the rejection criteria used.

1. Reject if ϵ_{ET} > 4.8 in. (122 mm) per budget period (maximum acceptable error).
2. Reject if *ET'* < -0.5 in. (-13 mm) per budget period (minimum acceptable negative *ET'*).
3. Reject if the preclearing and partial clearing *ET'* > *PET*, provided that *ET'* > 1.8 in. (46 mm) per budget period (maximum acceptable preclearing and partial clearing *ET'* in excess of *PET*).
4. Reject if preclearing and partial clearing *ET'* < 0.25 in. (6.4 mm) per budget period from May through October (minimum acceptable preclearing *ET'* during summer months).
5. Reject if postclearing *ET'* > ½*PET*, provided *ET'* > 1.2 in. (30 mm) per budget period (maximum acceptable postclearing *ET'* in excess of ½*PET*).

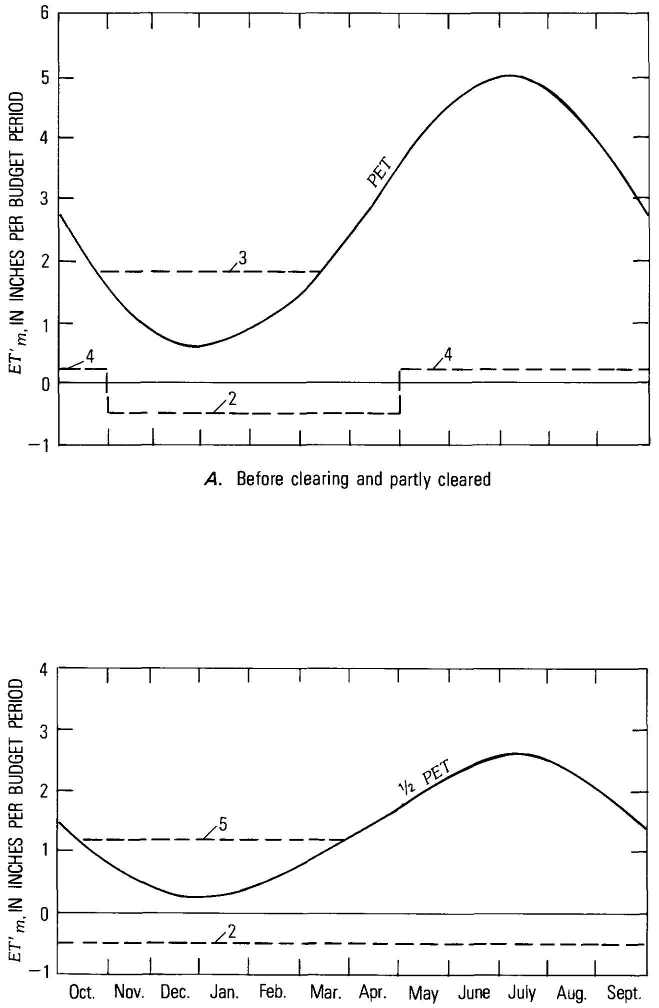

FIGURE 12.—Boundaries within which the adjusted *ET* values (*ET'*) were accepted as reliable estimates. Number within the graphs refer to rejection criteria described in the text.

Figure 12 shows the boundaries within which the *ET'* values (with measurement errors $\epsilon_{ET} < 4.8$ in. (122 mm)) per budget period were accepted for the pre- and postclearing periods.

A summary of the total number of *ET* values measured, both before and after clearing in each reach, and the number rejected by the above-described criteria is given in table 7.

The water-budget data indicate a seasonal variation in *ET* and a significant change in *ET* after clearing. Each reach had a different quantity of phreatophyte cover before clearing as shown by the vegetation surveys. Therefore, a difference in the rate of *ET* between reaches can be expected before clearing but the rate should be similar between reaches after clearing. This hypothesis is tested in the next section of this report by use of the project data in empirical equations.

USE OF *ET* DATA FOR DEFINING A PREDICTION EQUATION

Coefficients for several equations defining the evapotranspiration process were derived in this study by use of the *ET'* data. These coefficients were derived for the following purposes: (1) to compare the measured *ET'* from different reaches with the project area having different quantities of phreatophyte cover; (2) to compare the measured *ET'* for different seasons on the same reach; and (3) to develop methods for estimating *ET* from flood-plain sites in the arid and semiarid Southwestern States. Evapotranspiration is a complex process which is dependent on any of three factors: heat, vapor transport, and water availability. Heat and vapor transport are climatic factors which define the potential evapotranspiration (*PET*) of the site. Water available for vaporization on a flood plain is, to a large extent, dependent on the phreatophytes which extract water from subsurface storage and convey it to the evaporative surfaces of the leaves. The preceding considerations indicate that the desired equation should include a *PET* parameter, based on climatic data, and a coefficient related to a quantitative description of the vegetation.

Many empirical equations for predicting *ET* have been developed from field measurements of *ET*. However, equations such as those presented by van Bavel (1966) and Ritchie (1972), requiring intensive data describing the climate near the ground, are considered inappropriate for this study because of the wide range in spatial variability of these data on the flood

TABLE 7.—*Number of ET values measured in each reach and the number rejected as outliers or because of a large measurement error*

	REACH				SUB-TOTAL	REACH				SUB-TOTAL	TOTAL ALL REACHES
	1	2	2a	3		1	2	2a	3		
	PRE- AND PARTIAL CLEARING					POST-CLEARING					
Number measured	75	118	50	17	260	103	11	40	0	154	414
Number rejected	24	29	10	0	63	26	0	4	0	30	93
Number accepted	51	89	40	17	197	77	11	36	0	124	321

plain. A single species of phreatophyte such as saltcedar or mesquite may be dominant on all or part of a flood plain but the aerial density and height of the canopy is not uniform. Also, irregularly shaped open spaces occur within the canopy where gravel bars or other surface conditions prevent phreatophyte establishment. The heterogeneity of the vegetation produces spatial variability in transpiration resulting in a wide range of surface temperatures and significant differences in the humidity of the air near the ground.

The methods and equations based on macroclimatic data developed and presented by Blaney and Criddle (1962), Jensen and Haise (1963), and Christiansen (1968) are considered more appropriate to this study. Studies by Cruff and Thompson (1967) indicate that the Blaney-Criddle equation (1962) is the most practical and widely used equation for estimating potential evapotranspiration in arid environments such as exist in Arizona. Rantz (1968) expanded on the Blaney-Criddle equation by relating the consumptive use coefficient for various species of phreatophytes to depth to ground water and to density of stand. Thus, only the Blaney-Criddle (BC) method is discussed below. The other methods are described and compared to BC in a subsequent section of this report entitled "A comparison of the Blaney-Criddle method with other methods."

The Blaney-Criddle empirical equation (Blaney and Criddle, 1962, p. 1) applied in this study has been reduced to the basic form

$$U = f\,k \qquad (12)$$

where

- U = computed evapotranspiration in inches per 30 days,
- k = consumptive-use coefficient which is dependent on the kind and quantity of vegetation, and
- f = climatic (consumptive-use) factor which is a measure of the available heat and vapor transport capabilities (PET) of the atmosphere in inches per 30 days.

Blaney and Criddle applied 30-day measurements of ET for various crops to equation 12 and derived monthly consumptive-use coefficient k defined as

$$k = ET/f$$

where

- ET = measured evapotranspiration in inches per 30 days,
- f = $pt/100$,

where

- p = monthly percentage of daytime hours of the year listed in table 8, and
- t = mean temperature in degrees Fahrenheit.

A parameter describing moisture availability was not included in the equations developed in this study because the ground-water table underlying the flood plain provides a relatively constant supply of moisture for transpiration by phreatophytes.

Before applying the budget-period adjusted evapotranspiration values (ET') to a prediction equation, each value was expressed in inches per 30 days. Months were used as the unit of temporal distribution within the year and each budget-period value was assigned to the month within which the midpoint of the budget period occurred.

Hanson, Kipple, and Culler (1972) present preliminary work on developing a consumptive-use coefficient to describe the seasonal variability in ET' and the difference in ET' due to varying phreatophyte covers. An expression relating k, in equation 12, to the phreatophyte cover as described by the vegetation surveys is defined as

$$k = k_o + k_p\,V \qquad (13)$$

where

- k_o = consumptive-use coefficient for no phreatophyte cover,

TABLE 8.—*Monthly percentage of daytime hours of the year for latitudes 24° to 50° north of equator*

[From Blaney and Criddle, 1962, p. 43]

Month	Latitude, in degrees north of equator													
	24	26	28	30	32	34	36	38	40	42	44	46	48	50
January	7.58	7.49	7.40	7.30	7.20	7.10	6.99	6.87	6.73	6.60	6.45	6.30	6.13	5.98
February	7.17	7.12	7.07	7.03	6.97	6.91	6.86	6.79	6.73	6.66	6.59	6.50	6.42	6.32
March	8.40	8.40	8.39	8.38	8.37	8.36	8.35	8.34	8.30	8.28	8.25	8.24	8.22	8.25
April	8.60	8.64	8.68	8.72	8.75	8.80	8.85	8.90	8.92	8.97	9.04	9.09	9.15	9.25
May	9.30	9.37	9.46	9.53	9.63	9.72	9.81	9.92	9.99	10.10	10.22	10.37	10.50	10.69
June	9.19	9.30	9.38	9.49	9.60	9.70	9.83	9.95	10.08	10.21	10.38	10.54	10.72	10.93
July	9.41	9.49	9.58	9.67	9.77	9.88	9.99	10.10	10.24	10.37	10.50	10.66	10.83	10.99
August	9.05	9.10	9.16	9.22	9.28	9.33	9.40	9.47	9.56	9.64	9.73	9.82	9.92	10.00
September	8.31	8.32	8.32	8.34	8.34	8.36	8.36	8.38	8.41	8.42	8.43	8.44	8.45	8.44
October	8.10	8.06	8.02	7.99	7.93	7.90	7.85	7.80	7.78	7.73	7.67	7.61	7.56	7.43
November	7.43	7.36	7.27	7.19	7.11	7.02	6.92	6.82	6.73	6.63	6.51	6.38	6.24	6.07
December	7.46	7.35	7.27	7.14	7.05	6.92	6.79	6.66	6.53	6.39	6.23	6.05	5.86	5.65
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

k_p = the increase in the consumptive-use coefficient for phreatophyte cover,

V = numerical descriptor of the phreatophytes on a reach defined as

$$V = \sum_{\upsilon=1}^{4} A_\upsilon \ \ [C_\upsilon/100 + (C_\upsilon/100^x] / 2 \qquad (14)$$

where

A_υ = fraction of the total area in a given reach having a canopy cover falling in density class υ,

C_υ = average percent of cover for one of the classes of canopy coverage listed in table 2 as: *A, B, C,* and *D*, with A = 13, *B* = 38, *C* = 63, *D* = 88 percent, where υ = 1, . . . 4, respectively, and

x = exponent accounting for the nonlinearity in the relation between k_p and C_υ.

Equation 13 shows that $k = k_o$ when the cover density of phreatophytes is zero ($V = 0$) and $k = k_o + k_p$ when the cover density is 100 percent of the entire area ($V = 1$ in equation 14). As defined in this analysis, k_o applies to surface conditions on areas of the flood plain with no phreatophytes both before and after clearing. These conditions can include seasonal grasses and small areas of exposed surface water in the Gila River channel. The C_υ and corresponding A_υ values were obtained for each reach from field measurements and from aerial photography as described in the section on "Vegetation."

Table 9 summarizes the data from the vegetation survey for each reach. Depth to ground water, although seasonally variable, was estimated for each plot in each reach (see example in table 2 for reach 3) and the averages are shown in table 9. Coefficients for the two dominant species of phreatophytes (mesquite and saltcedar) and depth to ground water were introduced as variables in preliminary attempts to define an expression for k other than that shown by equation 13. Differences between the two species could not be defined because mesquite is relatively insignificant in relation to the total phreatophyte coverage. Thus, no distinction was made between the two species in computing area of canopy cover. Also, the differences in the average depth to ground water for the various reaches are relatively insignificant and were disregarded in all subsequent analyses. Volume of canopy has sometimes been assumed to be

TABLE 9.—*Summary of vegetation survey*

REACH		1		2		2a		3	
TOTAL AREA (acres)		1,723		2,307		1,374		1,440	
AVERAGE DEPTH TO GROUND WATER (feet)		8.5		12.5		11.0		11.5	
CANOPY COVER CLASS	HEIGHT CLASS	CANOPY OF PHREATOPHYTE OVERSTORY							
		AREA (acres)	VOLUME (acre-feet)	AREA (acres)	VOLUME (acre-feet)	AREA (acres)	VOLUME (acre-feet)	AREA (acres)	VOLUME (acre-feet)
SALTCEDAR									
	1	-	-	9	4	9	4	4	2
A	2	184	233	40	51	39	49	23	29
	3	21	35	37	63	34	57	7	12
	1	-	-	14	17	10	12	1	1
B	2	93	345	166	615	95	352	80	296
	3	17	84	102	504	33	163	-	-
	1	5	10	35	72	33	68	1	2
C	2	290	1,781	67	412	62	381	35	215
	3	136	1,114	98	803	84	688	52	426
	1	25	71	69	197	34	97	-	-
D	2	206	1,767	613	5,260	148	1,270	965	8,280
	3	55	629	176	2,013	72	824	235	2,688
SUBTOTAL		1,032	6,069	1,426	10,011	653	3,965	1,403	11,951
MESQUITE									
A	1	3	1	6	3	6	3	-	-
	2	549	500	469	427	398	362	11	10
B	2	45	120	189	503	153	407	13	35
C	2	44	194	164	723	129	569	-	-
D	2	-	-	3	18	3	18	11	68
SUBTOTAL		641	815	831	1,674	689	1,359	35	113
TOTAL		1,673	6,884	2,257	11,685	1,342	5,324	1,438	12,064

Canopy cover in percent—class A=1-25 percent, class B=26-50 percent, class C=51-75 percent, and class D=76-100 percent. Height of canopy in feet—for saltcedar—class 1=0-6.5 feet, class 2=6.5-13.00 feet, class 3=13.0+ feet; for mesquite—class 1=0-7 feet, and class 2=7+ feet.

Volume = Average Cover x Average Height

Note: Some of the area in each reach contained no phreatophytes therefore the area of phreatophytes is less than total area.

TABLE 10.—*Application of vegetation description to empirical equations*

REACH	STATUS OF CLEARING	AREA (acres)	PERIOD	CANOPY COVERAGE: CLASS C_v (in percent)	CANOPY COVERAGE: FRACTION OF TOTAL AREA (A_v)	V FROM EQ. 14 WITH x = 0.75
1	Pre	1,723	3/63-4/65	13	0.439	0.076
				38	.090	.039
				63	.276	.185
				88	.166	.148
TOTAL					.971	.448
1	Partial	1,723	5/65-2/67	13	.327	.057
				38	.074	.032
				63	.241	.161
				88	.120	.107
TOTAL					.762	.357
1	Post	1,723	3/67-7/71		0	0
2	Pre	2,307	7/63-12/69	13	.243	.042
				38	.204	.088
				63	.158	.106
				88	.373	.334
TOTAL					.978	.570
2	Partial	2,307	1/70-2/71	13	.039	.007
				38	.076	.033
				63	.022	.015
				88	.267	.239
TOTAL					.404	.294
2	Post	2.307	3/71-7/71		0	0
2a	Pre	1,374	6/66-11/69	13	.354	.061
				38	.212	.092
				63	.224	.150
				88	.187	.167
TOTAL					.977	.470
2a	Post	1,374	12/69/71		0	0
3	Pre	1,440	1/64-6/65	13	.031	.005
				38	.065	.028
				63	.061	.041
				88	.841	.752
TOTAL					.998	.826

TABLE 11.—*Number of accepted budget period ET data (see fig. 7) for each month as related to the status of clearing on each reach and the numerical vegetation descriptors*

MONTH	REACH 1			REACH 2			REACH 2a		REACH 3	TOTAL	
	PRE-CLEARING	PARTIAL CLEARING	POST-CLEARING	PRE-CLEARING	PARTIAL CLEARING	POST-CLEARING	PRE-CLEARING	POST-CLEARING	PRE-CLEARING	PRE- AND PARTIAL CLEARING	POST-CLEARING
Jan.	3	2	5	3	3			3	1	12	8
Feb.	2	1	4	5	3		1	2	2	14	6
March	5		7	4	2	2	4	4	2	17	13
April	5		7	5	2	2	5	4	3	20	13
May	2	2	7	5	2	2	2	4	2	15	13
June	4	2	9	6	3	3	5	6	3	23	18
July	3	3	10	5	2	2	4	3	1	18	15
Aug.	1	2	5	6	2		3	2		14	7
Sept.		1	5	1	2		1	3		5	8
Oct.	3	3	5	7	1		6			20	5
Nov.	3	2	6	9	2		6	1	2	24	7
Dec.	1	1	7	6	3		3	4	1	15	11
TOTAL	32	19	77	62	27	11	40	36	17	197	124
V	0.448	0.357	0	0.570	0.294	0	0.470	0	0.826	-	-

TABLE 12.—*Summary of monthly and annual k_o and k_p coefficients in equation 13 derived from equations 12 and 14 where $f = pt/100$ and $x = 0.75$*

	VALUES OF f, IN INCHES, k_p AND k_o												ANNUAL TOTAL (inches)	Δmin (inches)
	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.		
Monthly f	3.12	3.58	4.41	5.40	6.71	7.83	8.27	7.68	6.57	5.11	3.91	3.09	65.68	
Monthly k_o	.21	.21	.21	.21	.21	.21	.21	.21	.21	.21	.21	.21		
Midmonthly k_p	-.04	.16	-.04	.17	.52	.76	.69	.69	.73	.68	.10	.17		0.951
Average monthly k_p	.01	.11	.01	.19	.51	.72	.70	.70	.72	.61	.18	.14		
$f\,k_p$	0.031	0.394	0.044	1.026	3.422	5.638	5.789	5.376	4.73	3.117	0.704	0.433	30.70	

a more definitive quantitative descriptor of vegetation than area of canopy. However, the use of volume of canopy as a variable gave a greater error of fitting in the derived expression for k than did area of canopy. Thus, canopy cover as defined by equation 14 is considered to provide the best parameter to use in equation 13.

Table 10 presents the vegetation data found to be significant in defining a relation for the consumptive use coefficient. The only measurable change in phreatophyte cover was that produced by the clearing operations. Clearing was done on the project area during winter months when ET was low and the phreatophytes were defoliated. Values of V, the numerical descriptors of vegetation, are shown for each reach and period used in the analysis. These descriptors were adjusted only after the winter clearing was completed on all or part of a reach. The fraction of total area (A_v) of phreatophytes is shown for each of the four canopy cover classes (C_v) in table 10 with the classes representing average cover densities of 13, 38, 63, and 88 percent. The derivation of the value of "x" as 0.75 will be described later.

The number of accepted budget period ET' data for each month as related to the status of clearing and value of V on each reach is presented in table 11. The seasonal distribution of accepted data is fairly uniform except for September, when the ET' were frequently rejected because of the variability in the flow of the Gila River. Data for all 321 periods were used to define k_o but the data from only 197 periods (data representing pre- or partial-clearing conditions) were available to define k_p and x.

The first attempt to define the factors k_o, k_p, and x was made using Blaney-Criddle's expression for the climatic factor, f. Equations 13 and 14 were substituted in equation 12 and, for each budget period in which an acceptable ET' had been measured, repetitive computations of evapotranspiration (U) were made by varying k_o, k_p, and x simultaneously within preset limits until the computed U agreed closely with the measured ET'. Included in each computation was the known climatic factor ($f = pt/100$) for the budget period, and observed C_v and A_v values corresponding to the reach at the time of year in which ET' was measured. The repetitive computations were performed with a digital computer for a total of 321 budget periods using a trial and error technique developed by Rosenbrock (1960) and applied to hydrologic studies by Dawdy, Lichty, and Bergmann (1972). Numerous preliminary runs of the optimization program were made to determine the seasonal variability and logical limits for k_o, k_p, and x. For the final determination of monthly values, each of the factors

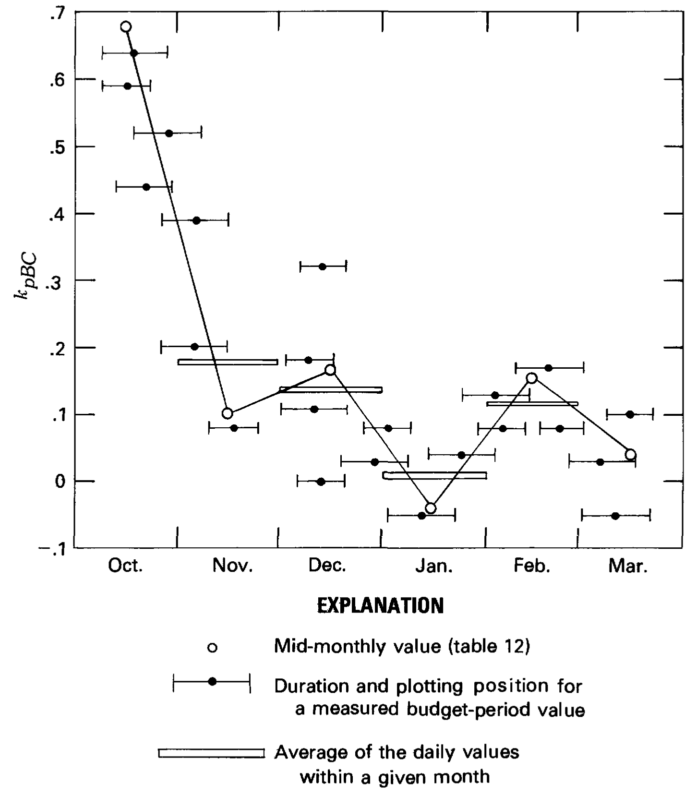

FIGURE 13.—Relation between midmonthly and average monthly values of k_p.

in k, k_o, and k_p in equation 13 were optimized to satisfy the following conditions:

1. Define a linear variation in k_p between the midpoints of each month with the value of k_p at the midpoint for any given month lying within the limits $-0.1 < k_p < 2.0$.
2. Define one x for the year within the limits $0.4 < x < 1.0$.

The best estimates of k_o, k_p, and x were defined when the accumulated sum of the absolute differences between U and the corresponding ET' for all 321 periods reached a minimum value (Δ_{min}) defined as

$$\Delta_{min} = \sum_{t=1}^{321} \left[(ET_t - U_t) \right] /321. \qquad (15)$$

The "best fit" k_o and k_p values obtained from this computation for each monthly f values are shown in table 12. The total annual f, $f\,k_p$, and the minimum fitting error (Δ_{min}) as defined by equation 15 are also included in the table.

Values of k_p were computed for each budget period from the combination and transposition of equations 12 and 13, or

$$k_p = \frac{ET' - f\,k_o}{f\,V} \qquad (16)$$

TABLE 13.—*Average monthly and average annual U rates for each reach before and after clearing phreatophytes, computed from equation 12 using the monthly f and average monthly* k_p *values given in table 12. All values exclude precipitation and are in inches per month.*

	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	ANNUAL
						PRECLEARING							
Reach 1 (V = 0.448)													
k	0.21	0.26	0.23	0.30	0.44	0.53	0.52	0.52	0.53	0.48	0.29	0.27	
U	.66	.93	1.01	1.62	2.95	4.15	4.30	3.99	3.48	2.45	1.13	.83	27.50
Reach 2 (V = 0.570)													
k	.22	.28	.25	.32	.50	.62	.61	.61	.62	.56	.31	.29	
U	.69	1.00	1.10	1.73	3.36	4.85	5.04	4.68	4.07	2.86	1.21	.90	31.49
Reach 3 (V = 0.826													
k	.22	.31	.27	.38	.63	.80	.79	.79	.80	.71	.36	.33	
U	.69	1.11	1.19	2.05	4.23	6.26	6.53	6.07	5.26	3.63	1.41	1.02	39.45
Average annual preclearing U for reaches 1, 2, and 3 weighted by area is: (1,723 × 27.50 + 2,307 × 31.49 + 1,440 × 39.45) / (1,723 + 2,307 + 1,440) = 32.32													
						POSTCLEARING							
All Reaches (V = 0)													
k	.21	.21	.21	.21	.21	.21	.21	.21	.21	.21	.21	.21	
U	.66	.75	.93	1.13	1.41	1.63	1.74	1.61	1.38	1.07	.81	.65	13.79

where U in equation 12 is replaced by ET' and f represents the average climatic factor for the budget period. Measured ET' values for each budget period represent an average rate of ET' for the duration of the period. Figure 13 shows the k_p values for a few selected budget periods during the fall and winter months (October-March) when the values are typically low and erratic. Included in the figure are the optimized midmonth k_p values which were computed assuming a linear variation in k_p between midpoints of adjoining months. The line connecting midmonth points defines the variability of k_p within the month. Midmonth values of k_p for all 12 months are listed in table 12 and were used to determine Δ_{min} in equation 15. The average monthly k_p values are also listed and are the best estimates to be used with average monthly values of f.

Table 13 shows the average monthly and annual rates of U computed for each reach using f and the derived coefficient k_p of table 12. The average preclearing U from all three reaches was 32.32 in. (832 mm). After clearing, the average U was 13.79 in. (350 mm). The water salvaged, computed as the difference between the preclearing average U and the postclearing U is 18.53 in. (471 mm) or 8,447 acre-ft (10.43 hm^3) on the 5,470 acres (2,214 ha).

Assuming that all precipitation is evaporated, the average annual evapotranspiration for the uncleared project area can be estimated as $\bar{U} + \bar{P}$ or 32.32 + 11.15 = 43.47 in. (1,104 mm). The maximum annual U which represents areas of 100 percent phreatophyte cover (v = 1), is computed as the summation of $f\,(k_o + k_p \cdot 1) + \bar{P}$ for 12 months and is 56 in. (1,420 mm). The minimum annual U for areas of no phreatophytes is computed as the summation of $f\,k_o + P$ for 12 months and is 25 in. (630 mm).

The seasonal variability of the f and k_o values listed in table 12 and the fitting error (Δ_{min}) defined by equation 15 can be attributed to three sources: (1) measurement errors in the water-budget data, (2) variability of factors affecting ET which are not defined by equations 12, 13, and 14, and (3) invalid application of the optimization procedure in assigning limits for the variables k_o, k_p, and x, and in defining the optimizing criteria stated by equation 15. The following study was made to determine the source and magnitude of these errors and differences.

EVALUATION OF THE DERIVED EVAPOTRANSPIRATION EQUATIONS

Considerable variability exists in the water-budget ET' data and the climatic factor (f) used to define the coefficients k_o and k_p, in equation 13. Figure 14 shows this variability in f and in ET' for the combined pre- and partial-clearing periods and for the postclearing period. The upper dashed curve in each graph shows the average monthly climatic factor f. These f values are computed from budget-period data which are randomly distributed within the months. The vertical lines define the standard deviation of f for each month. A comparison of the two f curves shows that the average monthly f was nearly the same for both periods and the standard deviation of monthly values averages less than 0.4 in. (10 mm). This variability is not a measurement error but rather a real variability resulting from year-to-year and within-monthly differences in temperature.

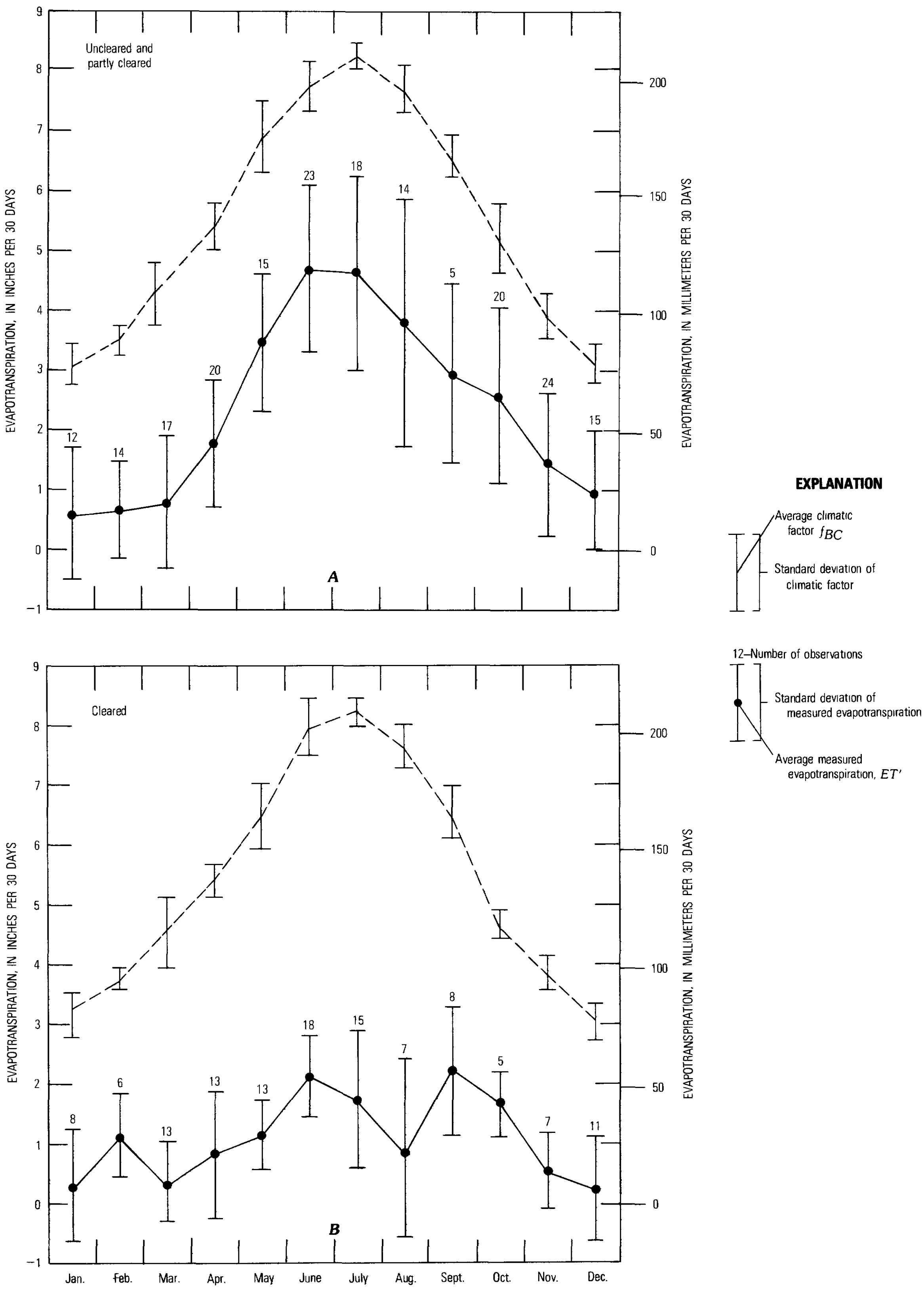

FIGURE 14.—Mean and standard deviation of monthly measured ET' and climatic factor f.

The lower (solid) curve in each graph shows the average monthly water-budget ET'. These ET' values represent the average for all reaches with the vertical lines defining the standard deviation of the water-budget ET' data. The number of observations of ET' used to define the average values are included for each month in the graph. Some of the variability in these ET' data is real, reflecting actual climatic differences and differences in the cover density between reaches. Part of this variability, however, includes measurement errors in the ET' data as illustrated in figure 11. The climatic differences are explained by f in equation 12 and the differences in phreatophyte cover are explained by A_v and C_v in equation 14.

The deviation in the ET' values in the upper graph reflect the differences in both the climatic factor and the phreatophyte cover; the deviations in the ET' values in the lower graph reflect differences in the climatic factor only.

The coefficient k_o was assumed to be seasonally constant and preliminary runs of the optimization program in which k_o was varied indicated some variability from month to month, but no seasonal trend was apparent. Evapotranspiration from precipitation and from shallow soil moisture (see equation 11) have not been included in the development of the empirical equations. Therefore, k_o describes the ET maintained by the upward movement of water from the subsurface source exclusive of phreatophytes, and there is no reason to expect a seasonal trend. Applying the k_o derived from this study to other flood-plain areas in the arid and semiarid regions may give erroneous results because the value of this coefficient is a function of soil type and depth to ground water. The seasonal variability of k_p will be discussed in the comparison of the Blaney-Criddle method with other methods.

The value of k for a given month will change from year to year only if the density of canopy cover changes as indicated by equation 13. The possible ranges of k for July (month of maximum ET') is illustrated in the following table.

Values of k for different ranges and averages of C_v

C_v Range	C_v Average	k
1	0	0.21
1-25	13	0.33
26-50	38	0.51
51-75	63	0.68
76-100	88	0.84
>100	100	0.91

These k values were determined by applying equations 13 and 14 to the full range of possible cover densities (C_v) using k_o = 0.21 and k_p for July = 0.70 (table 12).

In order to show the variability of the consumptive-use coefficient for only that portion of an area having canopy cover, assume that k_o applies only to that part of the area having no phreatophytes ($1\text{-}C_v/100$). If the coefficient for the area with canopy cover($C_v/100$) is expressed as $k'_p = k_o + k_p$ then $k = k_o\ (1\text{-}C_v/100) + k'_p\ (C_v/100)$. As an example, an area having a range of canopy cover of 1-25 percent (C_v = 13 percent) has a k value of 0.33 and k'_p = 0.33 - 0.21 (1-0.13) / 0.13 = 1.13. The following table shows the k'_p values and the percent of total area for which k'_p is valid for each of six classes of canopy cover. These values apply only to July.

Values of k'_p and percentage of area for which k'_p and k_o are valid

C_v		Percent of area for which	
Range	k'_p	k'_p *is valid*	k_o *is valid*
<0	0.00	0	100
1-25	1.13	13	87
26-50	1.03	38	62
51-75	0.96	63	37
76-100	0.95	88	12
>100	0.91	100	0

This table shows that, for instance, an area having a canopy cover falling in C_v class 1-25 percent has an average of only 13 percent of the area under phreatophyte cover. The coefficient k'_p for this part of the area is 1.13 or 124 percent of 0.91, the value of the coefficient (k_p) for an area of complete (100 percent) canopy cover. The relatively high value of the coefficient for the space under canopy in areas of incomplete cover can be explained by the "oasis effect" as defined by Tanner (1957).

It should be noted that the relative value of k' for different percentages of canopy is controlled by the value of the exponent "x" in equation 14. As previously mentioned, the value of "x" was determined as a variable between the arbitrary limits of 0.4 and 1.0 by the optimization procedure. A value of 0.75 provided the minimum value of Δ_{min} in equation 15. However, changes in this value did not produce significant changes in the value of Δ_{min}. The reason for this lack of sensitivity can be explained by an examination of the data in table 10. The value of "V" in equation 14 will have the greatest variation for low values of C_v in response to changes in "x." In table 10, the value of "V" for classes of low C_v (13 and 38) is a small part of the total "V" for the reach. An exact value of "x" could not be determined because the optimized fitting of the variables in equations 13 and 14 are based on the relation of ET' to the total "V." Although seasonal variability in the value of "x" resulting from changes in foliation might be expected, such a trend could not be defined by the available data and a constant value of 0.75 was used for all computations.

The computation of U for areas of phreatophytes involves f and k_p (which have within-month variability), the vegetation descriptor (which varies between reaches but is constant for the month), and k_o (which is constant for the year). Fitting the monthly computed U to the monthly measured ET' by use of the optimization program averages the ET', thereby reducing the scatter in ET' data caused by errors in the measurements but retaining the differences in V and the within-month variability of f and k_p. As an example of the results from the fitting process, table 14 shows the average and standard deviation of measured ET', climatic factor f, coefficients k_p, computed U, and difference between ET' and U for the month of June for pre- and partial clearing.

An estimate of the possible error in monthly values of U can be obtained by analyzing the difference between ET' and U for the budget periods used in the optimization program. The standard deviation of the differences is defined as

$$\bar{s}\Delta = \left[\frac{\sum_{t=1}^{N} \Delta_t^2 \quad \left(\sum_{t=1}^{N} \Delta_t\right)^2 / N}{N-1}\right]^{1/2} \qquad (17)$$

where

Δ_t = $ET'_t - U'_t$,

t = a given budget period, and

N = total number of budget periods in a month.

Table 15 lists the average monthly ET' and U for all reaches, whether cleared, uncleared, or partly cleared, and the standard deviation ($s\Delta$).

The average standard deviation of the difference ($ET' - U$) for an annual estimate of evapotranspiration is defined as

$$\bar{s}\Delta = \left(\sum_{m=1}^{12} s\Delta_m^2\right)^{1/2} \qquad (18)$$

where $s\Delta$ is the standard deviation of the difference, $ET' - U$, for month m. Applying the monthly $s\Delta$ values in table 15 to equation 18 defines average before- and after-clearing values of 4.6 in. (117 mm) per year and 3.2 in. (81 mm) per year, respectively. Thus, annual computed U values obtained from the

TABLE 14.—*Variability of measured ET', coefficients, and computed U for the month of June for preclearing and partial clearing*

REACH	STATUS OF CLEARING	N	MEASURED ET' AVERAGE	MEASURED ET' s	f AVERAGE	f s	k_p AVERAGE	k_p s	COMPUTED U AVERAGE	COMPUTED U s	DIFFERENCE ET' - U AVERAGE	DIFFERENCE ET' - U s
1	Preclearing	4	3.88	1.10	7.62	0.46	0.524	0.015	4.00	0.33	-0.12	1.31
	Partial clearing	2	4.49	.99	7.66	.30	.466	.006	3.57	.85	.92	.90
2	Preclearing	6	5.01	1.10	7.71	.40	.618	.008	4.77	.28	.24	.97
	Partial clearing	3	4.71	1.57	7.92	.54	.416	.014	3.30	.29	1.42	1.31
2a	Preclearing	5	4.04	1.62	7.89	.42	.546	.007	4.31	.27	-.28	1.55
3	Preclearing	3	6.50	.57	7.48	.37	.794	.028	5.94	.50	.55	.73
Total all reaches		23	4.71	1.38	7.73	.40	.570	.111	4.39	.84	.32	1.20

N = number of budget period data
s = standard deviation

TABLE 15.—*Average monthly measured (ET') and computed (U) evapotranspiration for all reaches and the standard deviation (sΔ) of the difference ET' - U. All values are in inches per 30 days*

	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	ANNUAL TOTAL
PRE- AND PARTIAL CLEARING													
N	12	14	17	20	15	23	18	14	5	20	24	15	197
ET'	0.060	0.69	0.80	1.79	3.48	4.71	4.64	3.82	2.98	2.60	1.43	0.99	28.53
U	.68	.93	.94	1.74	3.37	4.39	4.50	4.10	3.25	2.59	1.20	.86	28.55
sΔ	1.13	.83	1.17	.90	1.10	1.20	1.54	2.12	1.76	1.29	1.15	.97	4.55
POSTCLEARING													
N	8	6	13	13	13	18	15	7	8	5	7	11	124
ET'	0.30	1.12	0.35	0.83	1.10	2.12	1.74	0.91	2.22	1.69	0.55	0.26	13.19
U	.66	.75	.93	1.13	1.41	1.64	1.74	1.61	1.38	1.07	.82	.65	13.79
sΔ	.98	.70	.68	1.07	.69	.69	1.13	1.49	1.01	.51	.62	.88	3.15

prediction equation provide estimates of the measured ET' that are accurate within about 15 percent before clearing and within about 25 percent after clearing.

These average standard deviations indicate that monthly winter ET rates cannot be predicted within less than about 150 percent of the measured pre- and postclearing ET' rates. In contrast, monthly summer rates can be predicted within about 30 percent of the measured values for preclearing conditions and within about 55 percent of the measured values for postclearing conditions.

The expected error in the estimate of the average annual water salvage of 18.53 in. (471 mm) (table 13) as a result of clearing the phreatophytes from the flood plain is computed as

$$\bar{s}\Delta_U = [(4.6)^2 + (3.2)^2]^{1/2} = 5.6 \text{ in.} = 142 \text{ mm}$$

per year or about 30 percent of the average salvage.

The validity of the basin-fill discharge, $G_B = 0.3$ ft (0.09 m) per year was evaluated by a specially designed application of the optimization program. As previously described, the quantity of artesian discharge from the basin fill into the alluvium (G_B) could not be accurately determined and was assumed to be constant. G_B was introduced as a variable component in equation 1 which thus alters the value of ET' for all budget periods. The previously optimized values of the coefficients, k_o and k_p shown in table 12, were then held constant and used to recompute U. It was assumed that if the estimated value of G_B was significantly in error, then the optimized value would differ from 0.3 ft (0.09 m). The optimized value of G_B was 0.306 ft (0.093 m) and Δ_{min} in equation 15 was not changed, indicating that no improvement could be made in the prediction equation by changing G_B.

The preceding analysis was based on the derivation of coefficients using all of the measured data and is therefore an examination of the fitting process. Dawdy, Lichty, and Bergman (1972, p. B10) describe the difference between the error of fitting and the error of prediction and indicate the desirability of using split-sample testing to define the error of prediction. In this study, the split-sample test was applied by using part of the ET' data to derive coefficients for estimating U for budget periods not used in the derivation of coefficients. The test was applied to the variability in both time and space.

The optimization program was used in fitting to derive values of k_p and k_o in equation 13 within the previously described limits. The value of x in equation 14 was not optimized but was retained at 0.75. The program was also used to compute the value of U for each budget period for comparison with the measured ET'. The number of budget period data was inadequate to fit coefficients to any single year or to any individual reach. For temporal variability, data from odd numbered years were used to derive coefficients to predict the values of U for budget periods occurring in even numbered years. The process was

TABLE 16.—*Variability in U due to fitting coefficients to data from different periods and areas*

	Δ_{min} (in.)	n		Average annual totals				$\bar{s}\Delta$		Average annual totals			
				Determined from budget periods						Determined from average monthly values			
		Reaches		Reaches				Reaches		$U = f\,k_p$		$U = f\,k_o$	
		Uncleared and partially cleared (in.)	Cleared (in.)	Uncleared and partially cleared		Cleared (in.)		Uncleared and partially cleared (in.)	Cleared (in.)	ET' due to phreatophytes		ET' for no phreatophytes	
				ET' (in.)	U (in.)	ET' (in.)	U (in.)			U (in.)	Percent	U (in.)	Percent
Column number	1	2	3	4	5	6	7	8	9	10	11	12	13
All data	0.95	197	124	28.53	28.55	13.19	13.77	4.55	3.15	30.70	100	13.79	100
Fitted to even years	.84	104	74	25.43[1]	25.81[1]	11.78	12.33	3.76[1]	2.53	33.16	108	12.35	90
Applied to odd years	1.11	93	50	28.85	27.30	13.99	12.38	4.92	3.48				
Fitted to odd years	1.11	93	50	28.85	28.28	14.73	15.74	4.81	3.48	26.04	85	16.42	119
Applied to even years	.86	104	74	25.43[1]	26.47	10.79	17.38	3.67[1]	2.53				
Fitted to reaches 2 and 2a	.96	129	47	28.22	29.45	14.54[2]	14.79	4.59	2.32[2]	26.36	86	16.42	119
Applied to reaches 1 and 3	.97	68	77	27.97	28.72	11.75	16.46	4.78	2.91				

Note: Δ_{min} is the criterion for optimizing (equation 15); n is the number of data (budget periods); $\bar{s}\Delta$ is the average standard deviation (equation 18); percent is the relation, in percent, of U computed from coefficients fitted to data from different periods and areas to U computed from coefficients fitted to all data; [1] no data for September; [2] no data for October.

then reversed and coefficients were fitted to data from even numbered years to predict values of U for odd numbered years. A test of spatial variability was made using data from reaches 2 and 2a to predict the values of U for budget periods measured on reaches 1 and 3. The results were compiled in a manner similar to that shown in table 15 and are summarized in table 16. Annual totals from table 15 for fitting coefficients to all data are shown on the first line of table 16 for comparison. The variability in budget period ET' data together with the inadequacies of the equations for computing U produced some surprising values of Δ_{min} (equation 15). This value was less for fitting to even years than for all data and the value for the application to even years was less than for coefficients fitted to odd years. The variability in differences (ET' - U) for postclearing as indicated by $\bar{s}\Delta$ was also less for even years and reaches 1 and 3 than for the fitting based on all data. The lack of data for September during even numbered years and during October for reaches 2 and 2a produced false values of $\bar{s}\Delta$ for these tests. The data in columns 4-7 compare ET' with U for each fitting or application and are summations of the budget periods, grouped by months. The values are variable because the distribution of budget periods within the year are neither uniform nor complete when the number of data is small. Data in columns 10 and 11 were computed using average values of monthly f from table 12 and average monthly values of k_p derived from each fitting. These values provide a comparison with the average annual total U using all data. Values of annual U for no phreatophytes in columns 12 and 13 varied up to 19 percent from the values determined from all data. The product $f\,k_p$ varied up to 15 percent from values computed from all data. The sums of columns 10 and 12, $f\,(k_o + k_p)$, vary only 5 percent from values computed from all data indicating that high values of k_o are compensated for by low values of k_p and vice-versa.

This limited application of the split-sample test indicates that there are no unique characteristics in the data from different groups of reaches nor from different periods of years that produce bias in the fitting process. The percent difference shown in columns 11 and 13 and the average of these columns is less than the previously estimated errors of fitting. It is therefore concluded that the errors of fitting are a reasonable estimate of the error of prediction.

A COMPARISON OF THE BLANEY-CRIDDLE METHOD WITH OTHER METHODS

As indicated in the previous section, several empirical methods other than the Blaney-Criddle method are considered appropriate for expressing evapotranspiration in arid environments typical of the Gila River study area.

In this section three commonly used expressions for the f and k coefficients are described and compared with the Blaney-Criddle f and k coefficients.

Jensen and Haise (1963) used solar radiation (R) as the climatic factor for computing ET. They applied the ratio ET/R to approximately 1,000 measurements of ET for individual sampling periods for various crops. ET/R is equivalent to k in equation 12 since ET is the actual measured rate of ET and R is the observed solar radiation expressed in in./day evaporation equivalent, assuming that 1 gram of water occupies 1 cm^3 and requires 590 calories to evaporate. The determination of k_R from equation 12 is then

$$k_R = ET'/f_R$$

where ET' = adjusted ET as defined by equation 11, and f_R = solar radiation, R.

Jensen and Haise (1963, equation 8, p. 34) also developed an equation for potential evapotranspiration (PET) which was used previously in this report (equation 10) as a criterion for rejecting measured ET values. The application of the Jensen-Haise PET to equation 12 in defining a consumptive-use coefficient is

$$k_{JH} = ET'/f_{JH}$$

where ET' is as defined previously and

$$f_{JH} = PET = (0.014t - 0.37)R. \qquad (10)$$

Solar radiation data for defining f_R and f_{JH} were obtained during 1964-71 at an installation 350 ft (107 m) north of the National Weather Service station at San Carlos Reservoir. The radiation data were not continuous and the calibration of the pyrheliometer was incorrect after 1967 due to the degeneration of the thermopile coating. Thus, extrapolation of data from the Phoenix and Tucson National Weather Service stations was necessary to obtain a continuous record of solar radiation for the project site. The Phoenix station was used as the primary source of data and the Tucson station was used for periods of missing record at Phoenix.

A linear regression was used to define the relation between the San Carlos Reservoir radiation and the Phoenix and Tucson radiation. Monthly averages for all months of continuous records in 1965 and 1966 were used in the analysis. The relation was defined by an equation of the form

$$R_{sc} = a_o + a_1 R$$

where

R_{sc} = San Carlos Reservoir radiation data,
a_o and a_1 = constants, and
R = Phoenix or Tucson radiation data.

Thirteen months of Phoenix radiation data define

$$R_{sc} = -47 + 1.1 R_p$$

with a correlation coefficient = 0.991.
Twelve months of Tucson radiation data define

$$R_{sc} = -72 + 1.09 R_t$$

with a correlation coefficient = 0.998.

Christiansen (1968), expanding on earlier studies, confirmed the use of pan evaporation as a climatic factor in conjunction with a coefficient related to measured *ET* for various types of crops. Pan evaporation data for the project were available during the 9-year study period (1963-71) from the National Weather Service station at San Carlos Reservoir. The application of pan evaporation to derive a consumptive-use factor using equation 12 is

$$k_{PAN} = ET'/f_{PAN}$$

where ET' is as defined previously and

$$f_{PAN} = \text{measured pan evaporation.}$$

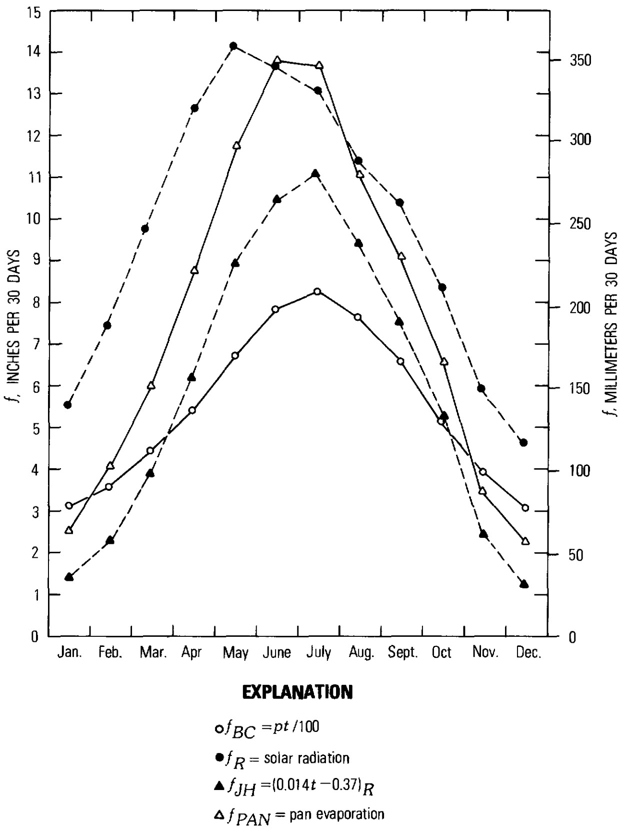

FIGURE 15.—Monthly variability in climatic factors.

Monthly values of the climatic factors for each of the methods of computing f are shown in figure 15. The monthly range in climatic factors when expressed as the ratio of highest to lowest for a particular method is greatest for the Jensen-Haise *PET* equation (f_{JH}) and least for the Blaney-Criddle equation (f_{BC}).

TABLE 17.—*Summary of monthly and k_o and k_p coefficients in equation 13, derived from three expressions for the climatic factor f in equation 12 (× = 0.75 for all computations of k)*

	VALUES OF f, IN INCHES, k_p AND k_o												ANNUAL TOTAL (inches)	Δ_{min} (inches)
	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.		
Monthly f_R	5.51	7.48	9.84	12.65	14.13	13.69	13.06	11.40	10.40	8.35	5.94	4.63	117.08	
Monthly k_{oR}	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11		
Midmonthly k_{pR}	-.03	.04	-.04	0	.27	.43	.50	.51	.63	.40	.14	.08		0.993
Average monthly k_{pR}	-.01	.02	-.02	.03	.26	.42	.49	.52	.59	.40	.16	.07	32.78	
Monthly f_{JH}	1.44	2.28	3.92	6.22	8.98	10.48	11.07	9.42	7.53	4.77	2.44	1.26	69.81	
Monthly k_{oJH}	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16		
Midmonthly k_{pJH}	.04	.54	0	.18	.47	.50	.62	.54	.78	.81	.68	1.03		0.977
Average monthly k_{pJH}	.23	.41	.09	.19	.44	.51	.60	.58	.75	.79	.74	.86	36.49	
Monthly f_{PAN}	2.50	4.05	5.96	8.77	11.70	13.76	13.67	11.04	9.10	6.56	3.46	2.24	92.81	
Monthly k_{PAN}	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13		
Midmonthly k_{pPAN}	-.04	.24	-.04	.13	.34	.38	.42	.43	.46	.61	.40	.60		0.984
Average monthly $pPAN$	.08	.17	.02	.14	.32	.38	.42	.43	.48	.56	.45	.50	32.42	

Figure 15 shows that the total annual factor is greatest for solar radiation (f_R) and least for the Blaney-Criddle equation (f_{BC}). The seasonal distribution of all factors is similar and the location of the apex is dependent on the relative significance of temperature and solar radiation in the determination of the climatic factor. The apex occurs the earliest (May) for solar radiation and the subsequent decrease in f_R is caused by an increase in cloud cover beginning in mid or late June. The factors reach a maximum in June and July for pan evaporation (f_{PAN}), and in July for Blaney-Criddle (f_{BC}) and Jensen-Haise (f_{JH}) because average monthly temperatures are highest during this period.

The optimizing procedure described previously to define the factors f_o and k_p in the Blaney-Criddle expression were similarly applied to obtain best estimates of these factors with f expressed as f_R, f_{JH}, and f_{PAN}, respectively. For this analysis the exponent x in equation 14 was held constant at 0.75. Table 17 summarizes the results of these computations.

The coefficient k_p relates the numerical vegetation descriptor for a reach, determined by A_v and C_v, to the climatic factor f. Since the vegetation descriptor did not change seasonally, the derived k_p must define any seasonal variability in this relation. The phreatophyte cover described by A_v and C_v is deciduous and a distinct seasonal trend exists due to spring foliation and fall defoliation. Leaves are the primary evaporative surfaces of a plant and the leaf area is directly related to the area of air-water interface provided that moisture is available to the leaves. The seasonal changes in the physiological condition of the plants are also involved, not only in the production and maintenance of the leaves, but also in the process of extracting moisture from the soil and conveying it to the leaves. The availability of moisture to the roots of the plants is not a significant factor for the phreatophytes in this study because of the relatively constant level of the water table under the flood plain. The plotting of average monthly values of k_p, from tables 12 and 17, in figure 16 illustrates the seasonal variability. The gradual development of foliation beginning in April and continuing through May and June is indicated by the increase in k_p. During June through September k_p is relatively constant for all coefficients except k_{pJH}. The fall dormancy and ultimate defoliation is defined by the reduction in k_{pBC} and k_{pR} near the end of the year. The symmetrical shape of the graphs of k_{pBC} and k_{pR} which corresponds to the seasonal location and duration of the growing season on the project area, indicates that f_{BC} and f_R provide a better measure of the seasonal variations in climate than do f_{JH} and f_{PAN} which produce unexplained high values of k_{pJH} and k_{pPAN} during October, November, and December. The preceding rationalization can be supported by comparing the shape of the k_p graphs to the seasonal variability of foliation as obtained by field inspection and by interpretation of aerial infrared color photography.

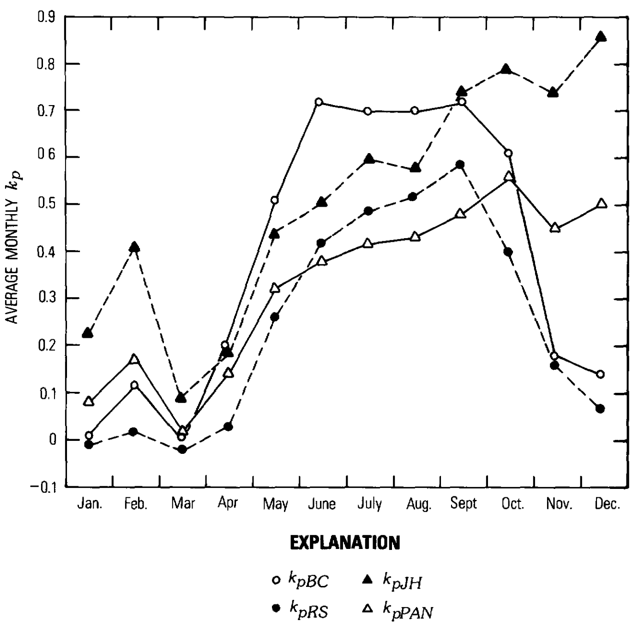

FIGURE 16.—Seasonal variability in average monthly values of the coefficient k_p.

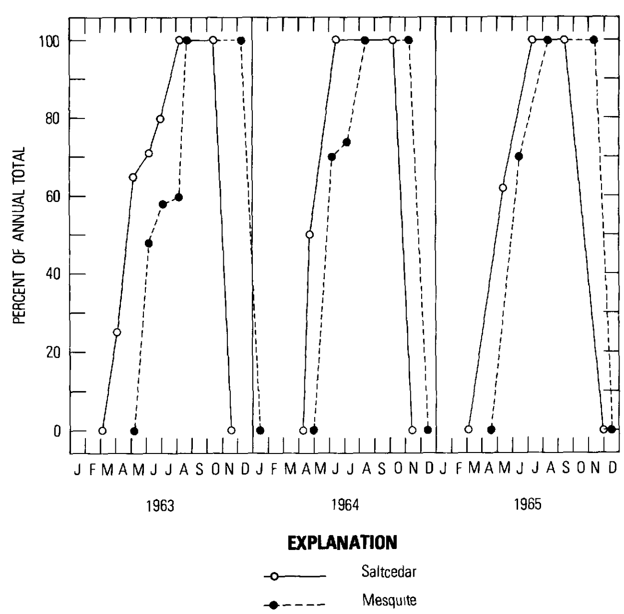

FIGURE 17.—Field estimates of seasonal variability of foliation.

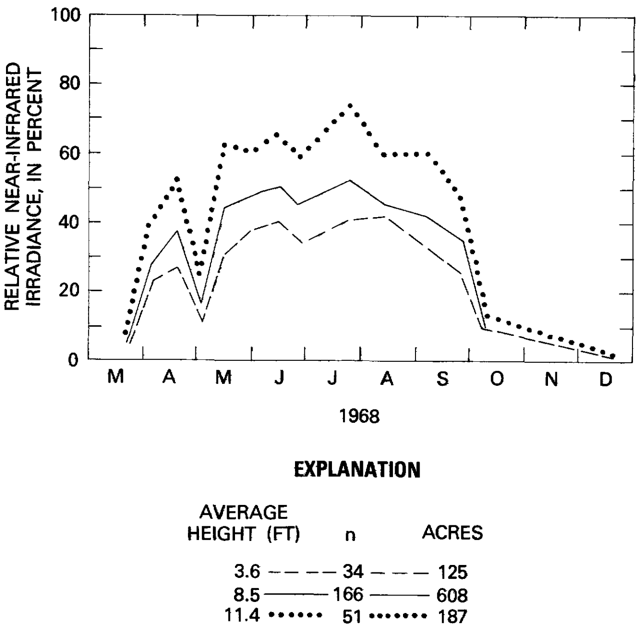

FIGURE 18.—Seasonal variation of adjusted red transmittances obtained from Ektachrome-IR images of saltcedar forest, Gila River, Arizona. Data points are mean density values for forest plots representing three different foliage volume classes. *n* = sample size. (After Turner (1971, figure 7)).

Figure 17 shows the estimated foliation as percent of total annual for 1963, 1964, and 1965 on the project area as obtained by field inspection. The development of leaves begins at least one month earlier on saltcedar than on mesquite. Defoliation of saltcedar occurs after the first frost while mesquite retains its leaves for another month even though the foliage may be dormant and ineffective as an evaporative surface. The graphs in the figure indicate a variation in the seasonal distribution of foliation from year to year. The period of significant foliation for saltcedar typically extends from April through October which corresponds to the period of relatively high values of k_p.

Color-infrared photographs of vegetated areas can be used to derive relative measures of foliation (Turner, 1971). Beginning in 1967 aerial photographs using color infrared film were taken of the project area at frequent intervals. Figure 18 shows the 1968 seasonal variability in densitometric data from photographs of selected areas of saltcedar on the project area. Figure 18 was described by Turner (1971) as follows: "The increase in red transmittance from March 22 to April 5 was in response to spring branchlet growth. The sharp reduction in values between April 19 and May 3 reflects a frost on April 20 which caused partial defoliation. New growth soon restored this loss and the transmittance values increased abruptly in response. The values slowly declined after the maximum of late August as the slow autumnal defoliation typical of the species took place." The shape of the graphs and indicated duration of foliation in figure 18 correspond to the shape and seasonal extent of relatively high values of k_p. Jones (1977) provides additional confirmation for the relation between transmittance on color-infrared photography and *ET* by relating the 1968 photographic data for reach 1 and 2 to the Blaney-Criddle consumptive-use coefficient "*k*."

Both the climatic factor *f* and the consumptive-use coefficient for phreatophyte cover, k_p, have a wide range of seasonal variability as shown in figures 15 and 16. The value of $f\,k_p$ is the difference between an area having a 100 percent areal density of phreatophytes and that from an area of no phreatophytes. The seasonal variability of the product $f\,k_p$ is shown in figure 19 for each of the four methods. The differences in the response of *f* to seasonal changes when fitted to the variable budget-period ET' data by optimizing the consumptive-use coefficients, k_p, produce the differences in the product $f\,k_p$. The most significant differences in $f\,k_p$ occur during the growing season in August and September, the months with the fewest and most erratic ET' data.

Computations similar to those shown in table 13 were made using climatic factors f_R, f_{JH}, and f_{PAN} with appropriate coefficients, and the average annual values of *U* are shown in table 18 and compared with annual values from table 13. The average *U* from all three reaches was 32.38 in. (822 mm) before clearing and the greatest departure from the average was minus 3 percent for U_{PAN}. After clearing, the average *U* was 12.48 in. (317 mm) and the greatest departure from the average was plus 10 percent for U_{BC}. The salvage of water, computed as the difference between the average *U* before clearing minus the average *U* after clearing, is 19.90 in. (505 mm).

By varying the monthly values of k_p and annual values of k_o, the optimization program will fit *U* to ET' with equal success for all of the climatic factors. However, the monthly values of k_{pJH} and k_{pPAN} for

TABLE 18.—*Annual evapotranspiration computed for each reach by the Blaney-Criddle (BC), Solar Radiation (R), Jensen and Haise (JH), and Pan evaporation (PAN)*

[All values exclude precipitation and are in inches per year]

Method	Preclearing 1	2	3	Postclearing 1, 2, 3
U_{BC}	27.50	31.49	39.45	13.79
U_R	27.67	31.81	39.97	12.90
U_{JH}	27.92	31.83	41.26	11.16
U_{PAN}	26.53	30.50	38.88	12.07
Mean	27.40	31.41	39.89	12.48

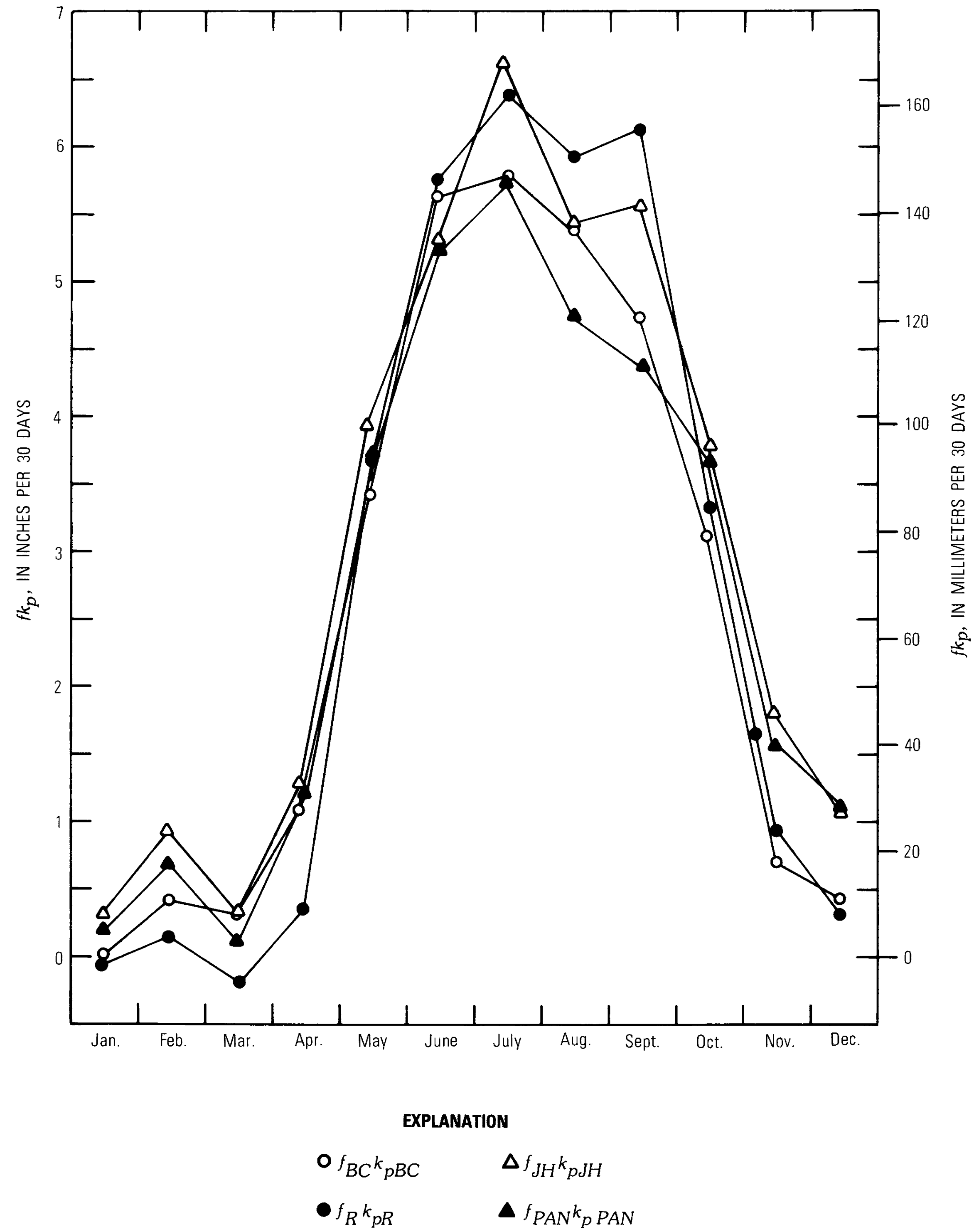

FIGURE 19.—Seasonal variability of fk_p, the difference in U between an area having a 100 percent areal density of phreatophytes and an area having no phreatophytes.

October through December appear unreasonable, as previously mentioned. Obviously, nine years of ET data at one location do not provide an adequate test of the empirical equations used in this study.

COMPARISON OF RESULTS WITH OTHER STUDIES

The results of the Gila River Phreatophyte Project can be compared with data from other studies by use

TABLE 19.—*Derivation of consumptive-use coefficients for Cottonwood Wash during growing season March through October*

	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	Average for growing season
Upper reach k Average 1959-63	.39	.38	.73	.96	1.10	1.23	1.15	.61	.82
Lower reach k_o Average 1961-63	.10	.83	.56	.44	.46	.50	.55	.43	.48
$K_{cw}A_{cw}$	.29	-.45	.17	.52	.64	.72	.60	.18	.34
k_{cw}	1.47	-2.29	.86	2.64	3.26	3.66	3.05	.92	1.70

of the derived empirical equations. Temperature and solar-radiation data for evaluating climatic factors can be obtained for the various sites used in the comparison. The coefficients k_o in equation 13 must be selected on the basis of soil characteristics and depth to ground water and k_p on the basis of species and quantity of vegetation. Differences in phreatophyte species and in methods of quantifying vegetation data require modifications in the methods for applying the coefficients. These modifications will be illustrated in the following comparisons with two other previously conducted flood-plain studies.

Water use by riparian vegetation on the flood plain of Cottonwood Wash in northwestern Arizona was reported by Bowie and Kam (1968). A 4.1-mi (6.6-km) reach of the stream channel was divided into a 2.6-mi (4.2-km) upper reach and a 1.5-mi (2.4-km) lower reach with flood-plain areas of 29 acres (11.7 ha) and 22 acres (8.9 ha), respectively. *ET* from these reaches was measured by the water-budget method during the growing season for the period 1959-63. The flood-plain vegetation, as described by Branson and Aro (Bowie and Kam 1968), consisted primarily of mature cottonwood trees (average height 27 ft [8.2 m]) and red willow trees (average height 19 ft [5.8 m]) distributed as individuals or clumps over the flood plain. Depth to water table on the flood plain ranged from 2.5 to 3.0 ft (0.8 to 0.9 m). The quantitative measurements listed by Bowie and Kam (1968) give a total net canopy cover of 5.7 acres (2.3 ha) on the upper reach and 5.9 acres (2.4 ha) on the lower reach. This measure is described as the equivalent part of the flood plain actually covered by vegetation. The vegetation in the lower reach was defoliated in June 1960 and eradicated in February 1961. No change was made on the upper reach.

The results of the monthly water-budget measurements of *ET* presented by Bowie and Kam (1968, table 7) have been reduced to inches per month on the flood-plain area and plotted in figure 20. The monthly values of *ET* for the two reaches were similar in 1959. A moderate reduction for the lower reach in 1960 is

TABLE 20.—*Application of vegetation description from Gatewood and others (1950, tables 7 and 8) to empirical equations*

[Area in acres]

	Thatcher to Glenbar	Glenbar to Fort Thomas	Fort Thomas to Black Point	Black Point to Calva	Thatcher to Calva
Total gross area	2,159	2,011	1,818	3,315	9,303
Saltcedar					
Gross area	1,302	1,426	852	1,002	4,582
A_v	0.603	0.709	0.469	0.302	0.492
C_v	72.2	63.7	55.0	54.3	62.4[1]
V	0.454	0.479	0.279	0.178	0.326
Baccharis					
Gross area	279	266	202	764	1,511
A_v	0.129	0.132	0.111	0.230	0.162
C_v	46.2	26.3	38.8	27.9	32.4[1]
V	0.066	0.042	0.049	0.076	0.061
Mesquite					
Gross area	54	43	263	624	984
A_v	0.023	0.021	0.145	0.188	0.106
C_v	50.3	57.6	61.1	40.9	47.6[1]
V	0.014	0.013	0.094	0.087	0.056
Total of saltcedar, baccharis, and mesquite					
V	0.534	0.534	0.422	0.341	0.443
Cottonwood and willow					
Area at 100 percent volume density	131	16	60	73	280
A_{cw}	0.061	0.008	0.033	0.022	0.030

A_v = fraction of total gross area covered by the species
C_v = areal density in percent
$V = A_v[C_v/100 + (C_v/100)^{0.75}]/2.$
A_{cw} = fraction of total gross area covered by cottonwood and willow.
[1] weighted average for the four individual reaches.

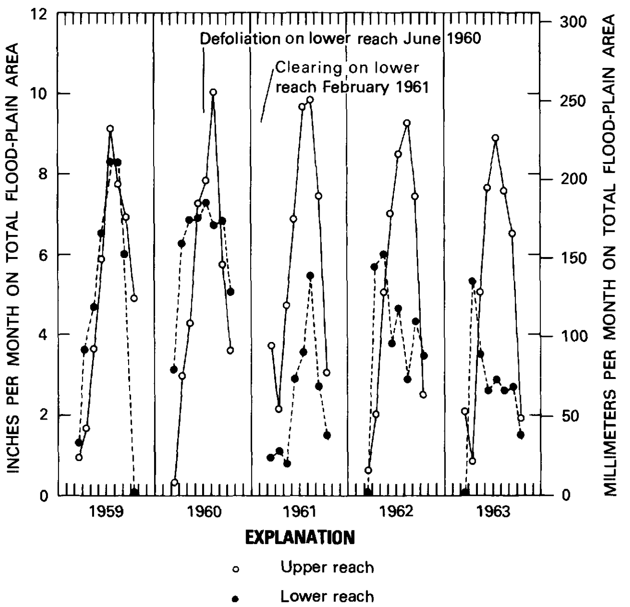

FIGURE 20.—Evapotranspiration from Cottonwood Wash.

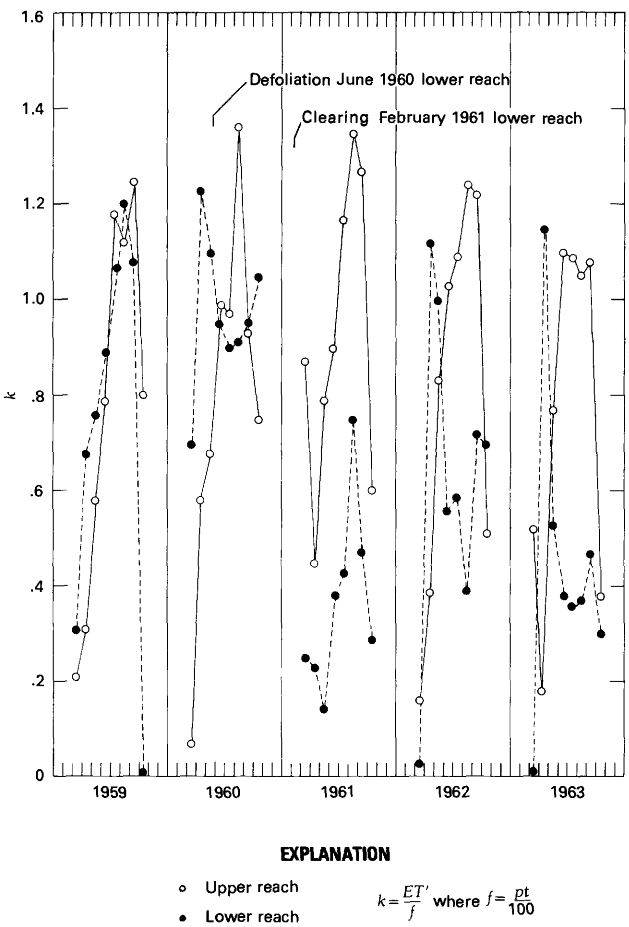

FIGURE 21.—Values of k from Cottonwood Wash.

apparent following defoliation and a drastic reduction following the eradication of vegetation on the lower reach is reflected in the ET data for 1961-63.

Monthly values of the Blaney-Criddle expression for climatic factor "f" were computed using temperatures for the site as given by Bowie and Kam (1968, table 8). Temperatures for periods of missing record at the site were estimated by linear correlation from temperatures recorded at Kingman, Ariz., 30 mi (48 km) northwest of the site (National Weather Service). Monthly coefficients were computed as $k = ET/f$ and plotted in figure 21. The differences between the two reaches, resulting from defoliation and eradication on the lower reach were expanded and a basis for extrapolation of data was developed. The flush of spring transpiration from replacement vegetation on the lower reach is assumed to have produced the relatively high values of k for April and May in 1962 and 1963.

Depth to ground water on the Cottonwood Wash flood plain as recorded at observation wells was less than 3 ft (0.9 m) on both reaches. The soil characteristics were also similar on both reaches. The consumptive-use coefficient for no phreatophytes can therefore be assumed to be equal for both reaches. Equation 13 as applied to Cottonwood Wash can be stated as

$$k = k_o + k_{cw}A_{cw} \qquad (19)$$

where

k = consumptive-use coefficient for a reach,

k_o = consumptive-use coefficient for no phreatophytes,

k_{cw} = the increase in the consumptive-use coefficient for the area under a canopy of cottonwood or willow, and

A_{cw} = the fraction of the total area under cottonwood or willow canopy.

Average values of k for the lower reach during 1961-63, after the phreatophytes were eradicated are equal to k_o for both reaches because A_{cw} was zero for the lower reach. The value of k_{cw} is computed by the transformation of equation 19 from the values of k for the upper reach as

$$k_{cw} = \frac{k - k_o}{A_{cw}}$$

where

$$A_{cw} = \frac{\text{canopy cover of the upper reach}}{\text{total area of the upper reach}} = \frac{5.7 \text{ acres}}{29 \text{ acres}} = 0.197.$$

Monthly and average monthly values of k, k_o, and k_{cw} for the growing season are listed in table 19. The seasonal variation of k_{cw} is similar to the seasonal variation of k_p except for the high value in March and the large negative value in April resulting apparently from unusual transpiration requirements by the replacement vegetation. The erratic values for the spring months do not have a significant effect on the average monthly value for the growing season.

The average value of 1.7 for k_{cw} as shown in table 19 is 3.2 times the Gila River project area k_p value of 0.52 (see monthly k_p values in table 12) during the period March to October. Mature cottonwood and willow in open stands, where each tree is an individual oasis, provide ideal conditions for transpiration. Rantz (1968, fig. 2) indicates a value of 1.6 for k_{cw} in the Blaney-Criddle equation for cottonwood and willow with a depth to water table similar to the Cottonwood Wash flood plain. The coefficients derived from Cottonwood Wash data are used later in this report for comparing k_p from the Gila River project with data from a previous study of the Safford Valley, also dominated by saltcedar but containing some cottonwood and willow.

The water use by bottom-land vegetation in the lower Safford Valley, Ariz., was reported by Gatewood and others (1950). The study reach extended from Thatcher to Calva and included reach 1 of the Gila River Phreatophyte Project. The draft on ground water (identical to ET' in equation 11) was measured during the period October 1, 1943 to September 30, 1944 by six different methods described as tank, transpiration-well, seepage-run, inflow-outflow, chloride-increase, and slope-seepage for four reaches and the sum of the four individual reaches. These data are compared with data from the Gila River Phreatophyte Project by the following method.

The description of vegetation by Gatewood and others (1950, table 7) includes an average areal density for each species of phreatophyte. These data are used to evaluate the vegetation description "V" as shown in table 20. Saltcedar, seepwillow, and mesquite are assumed to be equivalent to the phreatophytes whose transpiration is defined by the coefficient k_p in equation 13. The method used in computing average areal density in the Safford Valley produces a different value of V from that of the summation for each density class as used in equation 14, although the difference is relatively insignificant. The estimation of transpiration by cottonwood and willow is determined by application of the coefficient k_{cw} from the previously described Cottonwood Wash study. The areas listed as having 100 percent volume density are assumed to be equivalent to that part of the flood plain actually covered by vegetation used in Bowie and Kam (1968), and are used to determine A_{CW}.

TABLE 21.—*Comparison of evapotranspiration computed by empirical equations with the measured draft on ground water presented by Gatewood and others (1950, table 58)*

Reach	Area (acres)	ET' (acre-ft)	ET' (inches)	U (inches)	Difference $ET' - U$ (inches)	Difference $ET' - U$ percent of ET'
Thatcher to Glenbar	2,159	7,420	41.24	35.41	5.83	+14
Glenbar to Fort Thomas	2,011	5,810	34.67	29.43	5.24	+15
Fort Thomas to Black Point	1,818	4,700	31.02	29.06	1.96	+ 6
Black Point to Clava	3,315	5,030	18.21	25.45	7.24	-40
Thatcher to Calva	9,303	22,960	29.62	29.31	.31	+ 1

The only available monthly values of ET' for the Safford Valley reaches were measured by the inflow-outflow method; these values and the mean daily maximum and mean daily minimum temperatures for computing average monthly temperatures are listed by Gatewood and others (1950, tables 4, 47, 48, and 49). Monthly values of U were computed by the Blaney-Criddle method using equation 12 with the coefficient k evaluated as

$$k = k_o + k_p V + k_{cw} A_{cw} \qquad (20)$$

where

k_o = 0.21 from table 12 (soil type and depth to water table for the Lower Safford Valley are assumed to be similar to those on the Gila River Phreatophyte Project),

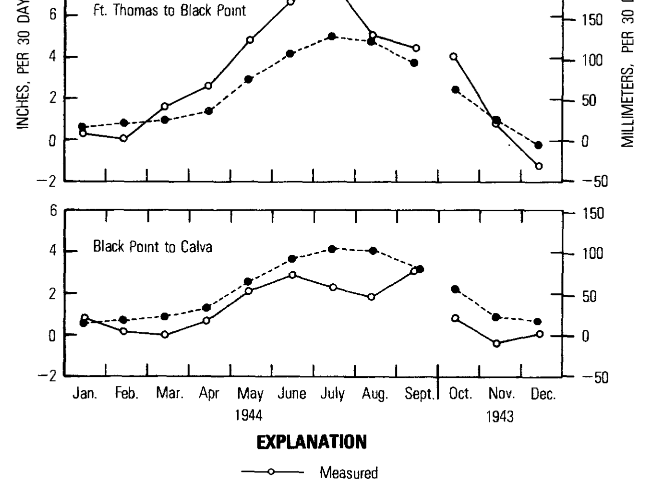

FIGURE 22.—Relation of measured to computed evapotranspiration for reaches in Safford Valley, 1943–44.

k_p = monthly values in table 12,
V = numerical vegetation description from table 20, and
k_{cw} = monthly values from table 19, and
A_{cw} from table 20.

Measured ET' and computed U are shown in figure 22 for October-December 1943 and January-September 1944. Data for 1944 are plotted on the left of 1943 data to show the monthly variability during a calendar year. Computed monthly values for the Glenbar to Ft. Thomas reach are lower for the period March-August and higher during September-December, than the measured values. The values for total annual ET' and total annual U are 29.2 in. (741 mm) and 29.4 in. (747 mm), respectively. ET' is higher than U for the entire growing season on the Ft. Thomas to Black Point reach; annual totals are 37.3 in. and 28.5 in. (947 mm and 723 mm), respectively. On the Black Point to Calva reach, the relationship is reversed with U being higher than ET' for the entire year. Annual totals are 14.7 in. and 25.1 in. (373 mm and 638 mm) for ET' and U, respectively. Differences between monthly ET' and U range up to 126 percent of ET' for September on the Glenbar to Ft. Thomas reach, which indicates the possible error in monthly data for an individual reach measured by the inflow-outflow method when the net ground inflow was not computed for individual months.

The average values of annual ET' determined by the six methods listed by Gatewood and others (1950, table 58) are shown in table 21. Annual computed evapotranspiration U was determined by the application of equations 12 and 19 with the coefficients evaluated as

k_o = 0.21,

$$k_p = \frac{\text{annual total } f\,k_p}{\text{annual total } f} = \frac{30.70}{65.68} = 0.467$$

(average annual value from table 12),

k_{cw} = 1.70 (table 19) + 0.11 (average k_p for November, December, January, and February from table 12), and

A_{cw} from table 20.

The differences between ET' and U are listed in table 21 and show only a +1 percent difference from ET' for the combined reaches but a -40 percent difference for the reach between Black Point and Calva.

Phreatophytes have been grown in evapotranspirometers at various sites throughout the United States to provide accurate data on the consumptive use of water (evapotranspiration) by the vegetation. Data from two sites, one near Buckeye, Ariz., and the other near Bernardo, N. Mex., have been selected for comparison with the results of the Gila River Phreatophyte Project because some of the evapotranspirometers at these sites had the combined features of relatively large area, dense saltcedar, and depths to water table approximating the depth to ground water on the Gila River flood plain.

Six evapotranspirometers, 900 ft^2 (84 m^2) in surface area and 14 ft (4.25 m) deep, were installed and planted with saltcedar at Buckeye in 1959 as described by van Hylckama (1974). Monthly water use, exclusive of rainfall, (corresponding to ET' on the Gila River project) for tank Nos. 2 and 6 during 1962 and 1963 was used for comparison in this study. The depth to water table in these tanks was maintained at 8.9 ft (2.7 m) and the areal cover density of canopy was 80 percent in tank No. 2 and 75 percent in tank No. 6.

Nine evapotranspirometers, 12 ft (3.7 m) deep with a surface area of 1,000 ft^2 (93 m^2) were installed by the U.S. Bureau of Reclamation on the Rio Grande flood plain near Bernardo in 1962. Saltcedar, Russian olive, and saltgrass were planted in the tanks and the water table was maintained at various levels. Water-use data for tank No. 5 during 1971 and 1972 were selected for comparison. Depth to water table was maintained at 9.0 ft (2.7 m) and the saltcedar in this tank had an areal density of 92 percent in 1971 and 97 percent in 1972. The monthly water-use data for comparison with U and Buckeye consumptive use were obtained by subtracting the precipitation listed in U.S. Bureau of Reclamation (1973, table 1) from the water use for tank No. 5 listed in U.S. Bureau of

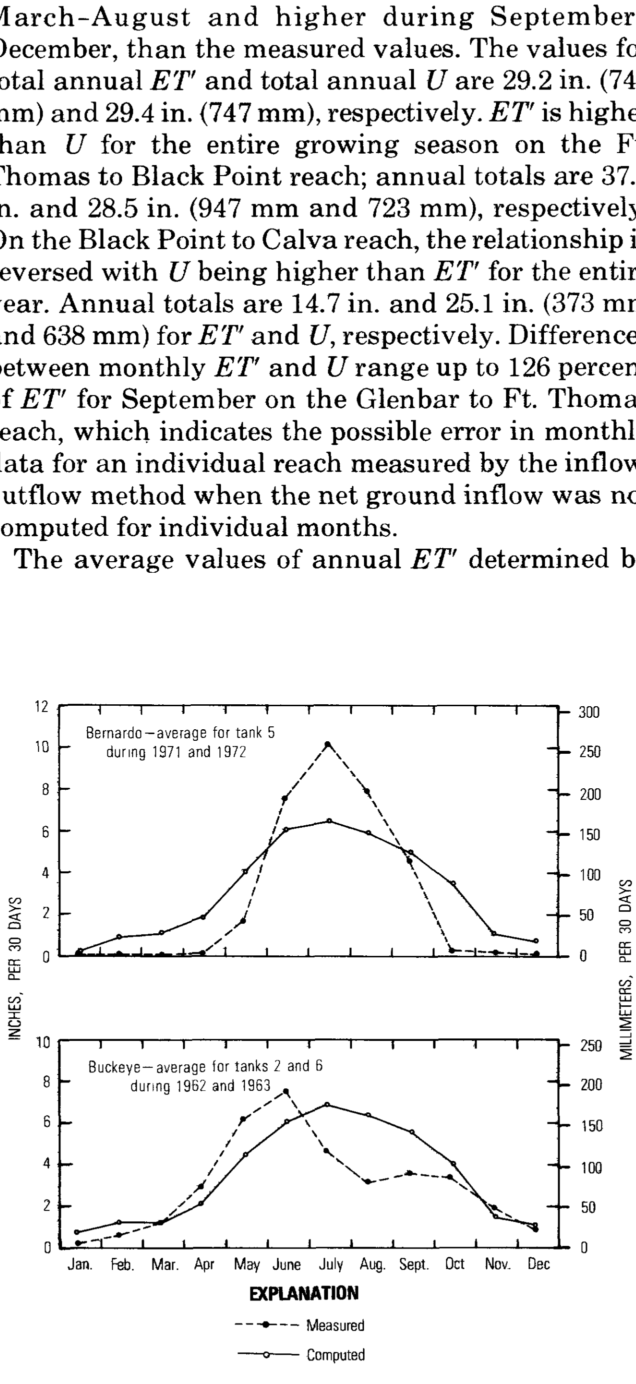

FIGURE 23.—Relation of measured to computed evapotranspiration for evapotranspirometers at Buckeye, Ariz., and Bernardo, N. Mex.

Reclamation (1973, table 15).

Equations 12, 13, and 14, using coefficients k_p and k_o from table 12, were applied to the Buckeye and Bernardo evapotranspirometer sites to provide values of computed U for comparison with the measured evapotranspiration exclusive of precipitation. The results are shown in figure 23. The graph of measured ET' for Buckeye shows greater values during April through June than the computed U. The reduction in ET' during July and August was observed at all tanks at Buckeye and is attributed to extremely high temperatures, up to 115°F (46°C), and to excessive convected heat from the surrounding desert, creating moisture stress in the plants and reducing transpiration (van Hylckama, oral commun., 1976). The difference between ET' and U is 102 percent of U in July and the annual totals are 36.09 in. (917 mm) for ET' and 41.67 in. (1,058 mm) for U, a difference of 15 percent.

The measured ET' for the Bernardo evapotranspirometer, as shown in figure 23, is primarily confined to the period May through September with June through August averaging 27 percent greater than the U values. The annual total is 33.58 in. (853 mm) for ET' and 36.94 in. (938 mm) for U, a difference of 10 percent. Minimum temperatures at Bernardo were freezing or below during November through April, which caused the low ET' values for these months.

The graphs in figure 23 illustrate the limitations of equation 12, and its application to this study, with regard to describing evapotranspiration for wide ranges in climate. Neither the effect of high temperatures nor below freezing conditions are adequately defined to provide monthly averages.

EFFECTS OF PHREATOPHYTE CLEARING ON GROUND-WATER LEVELS AND SEEPAGE MEASUREMENTS

GROUND-WATER LEVELS

An increase in ground-water elevations can be expected as a result of eliminating water withdrawal by phreatophytes. Ground-water levels measured in the observation wells on the Gila River flood plain are primarily controlled by the stage and discharge in the Gila River channel. Annual and seasonal variability in the flow of the river obscures the effects of water use by phreatophytes on ground-water elevation. Therefore, periods of similar river discharge before and after clearing were selected to illustrate the differences in ground-water levels. Discharge during the period February through July of 1964 before clearing and 1969 after clearing were reasonably similar as shown in figure 5. Water-table elevations during these periods for flood-plain wells 0517 and 0720 (see figure 6) are shown in figure 24. Elevations at well 0517 were higher in 1969 than in 1964. The rate of recession was similar for both years until the middle of May when water use by phreatophytes produced an increased rate of recession in 1964. Increased discharge in the Gila River from summer storms after July 15 of both years terminated the ground-water recession. Water-table elevations were higher at well 0720 in February of 1964 than in 1969. There was no flow in the Gila River channel in reach 1 from June 28 to July 14, 1964, whereas, the minimum inflow during this period of 1969 was 2.7 ft^3/s (0.08 m^3/s) and outflow was 4.0 ft^3/s (0.11 m^3/s). The graphs in figure 24 indicate that the removal of phreatophytes reduced the rate of recession in ground-water elevations but the maximum difference in elevations before and after clearing was less than 1 ft (0.3 m).

SEEPAGE MEASUREMENTS

Discharge measurements of the flow in the Gila River channel were made at about six-week intervals to observe the interchange of surface and ground-water flow as described by Burkham *in* Culler and others (1970, p. 14). Measurements were made at each cross section on the same day during periods of uniform flow by two or three stream gagers. These essentially simultaneous measurements were made on 53 dates during the term of the project. The results of measurements taken on seven dates were selected to represent the range and variability in discharge for before clearing (fig. 25*A*) and after clearing (fig. 25*B*).

The flow in the river channel at any cross section is affected by the subsurface conveyance; that is, the depth, width, and transmissivity of the alluvium and the slope of the water table. Differences in channel flow between cross-sections reflect not only differences in subsurface flow but also contributions to or depletions of water from the reach of flood plain between cross sections. Figure 8, based on complete water-budget data, indicates that the Gila River channel was a losing stream before clearing and a gaining stream after clearing. The graphs in figure 25 tend to confirm this characteristic of the channel flow, although the data for certain dates, such as May 2, 1965, before clearing and May 18, 1971, after clearing, are contradictory. Changes in subsurface storage undoubtedly account for the variability in the gain or loss characteristics of the river. The only information provided by these measurements is that the relation between surface and subsurface flow is reasonably constant from cross-section 1 to cross-section 17 in

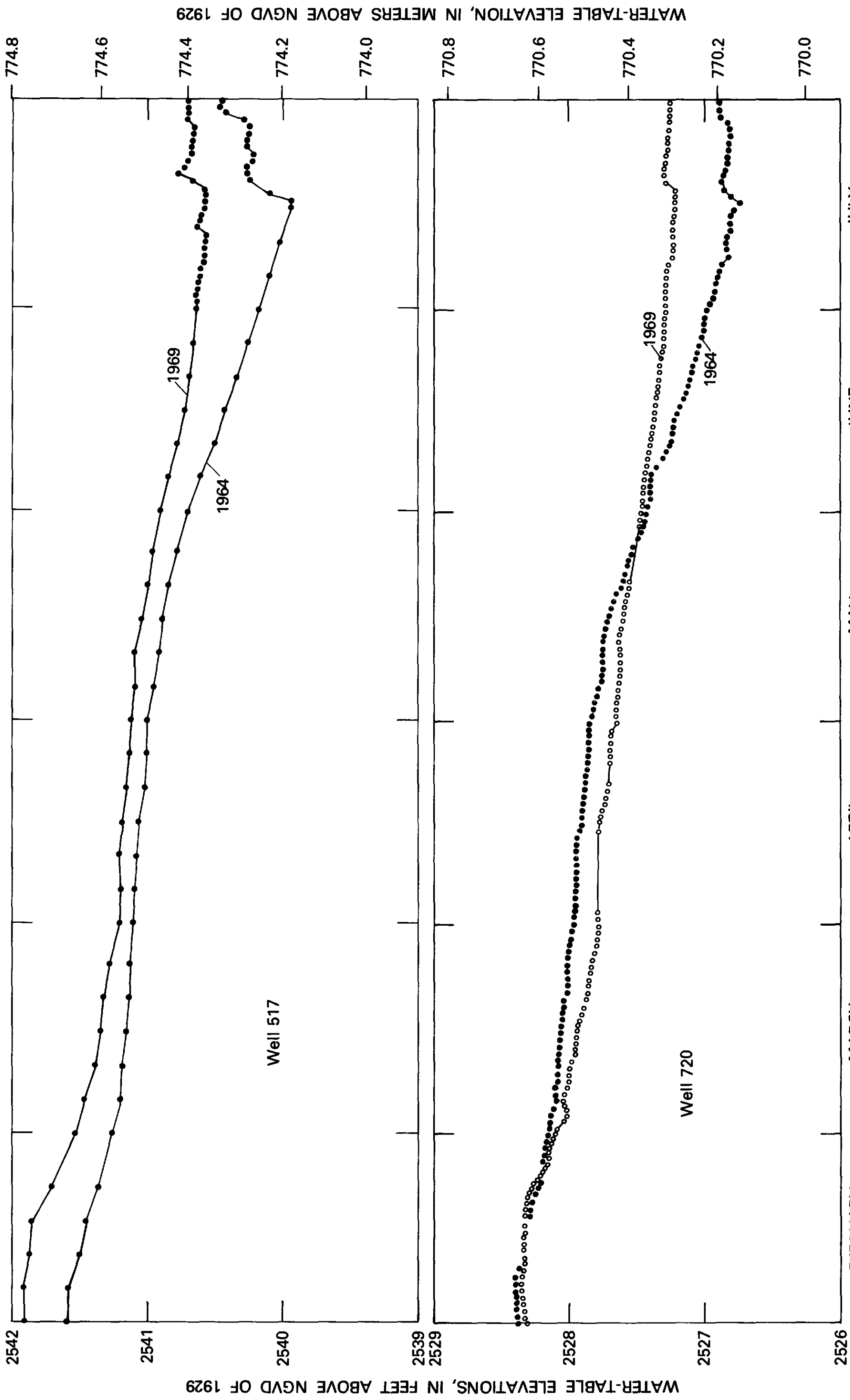

FIGURE 24.—Comparison of water-table elevations before and after clearing phreatophytes.

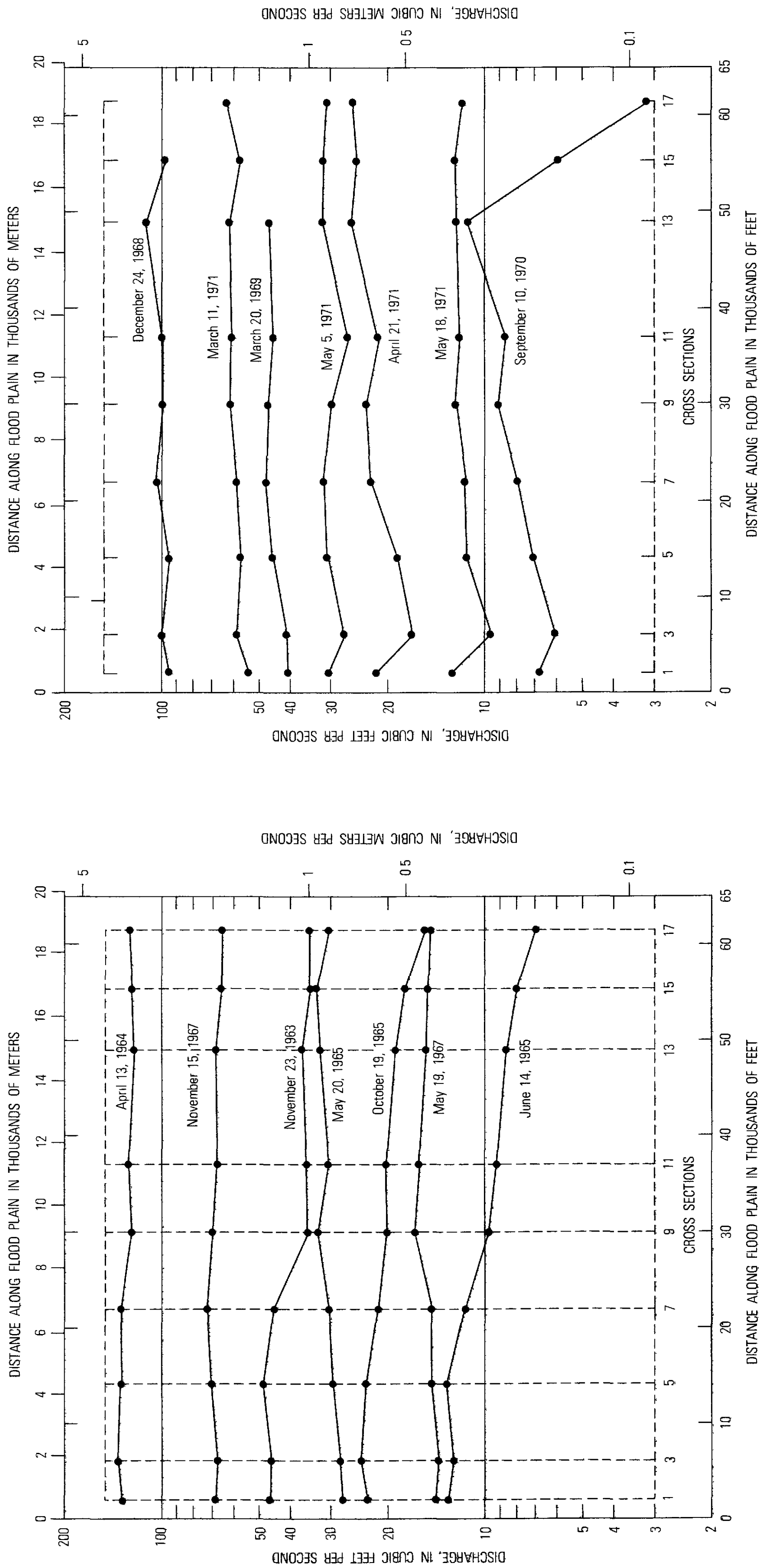

FIGURE 25.—Results of simultaneous discharge measurements in the Gila River channel before clearing (*A*) and after clearing (*B*) phreatophytes.

the project reach. Continuous records of the complete water budget are necessary to accurately evaluate the relation of one component to another.

CONCLUSIONS

Annual evapotranspiration (*ET*), including precipitation, on the project area averaged 43 in. (1,090 mm) before clearing. Annual *ET* ranged from 56 in. (1,920 mm) in dense stands of phreatophytes (100 percent areal coverage) to 25 in. (630 mm) on areas of no phreatophytes. The removal of phreatophytes resulted in a reduction in *ET* averaging 19 in. (480 mm) per year. The reduction ranged from 14 in. (360 mm) on reach 1 to 26 in. (660 mm) on reach 3, a difference attributed to the difference in density of the phreatophytes. This reduction is temporary because replacement vegetation was not established. *ET* after clearing consisted of evaporation from bare ground and transpiration from annual vegetation. An estimate of the permanent reduction can be obtained by comparing the *ET* before clearing with the consumptive use of possible replacement vegetation. Erie, French, and Harris (1965) measured the consumptive-use requirements for optimum crop production of various irrigated grasses near Tempe and Mesa, Ariz., and computed semi-monthly values of the coefficient "*k*" in the Blaney-Criddle equation. The application of these coefficients to the values of the Blaney-Criddle climatic factor for the Gila River flood plain provided annual estimates of 69 in. (1,750 mm) for alfalfa, 49 in. (1,240 mm) for blue panic grass, and 42 in. (1,070 mm) for a Bermuda grass lawn. The consumptive use for alfalfa exceeds the maximum observed *ET*; that for blue panic grass use exceeds the average *ET*; and for Bermuda grass, use is only 1 in. (25 mm) less than the average *ET*. According to these estimates, there would be no significant salvage of water if any of the grasses were established on the entire area, if they maintained optimum production, and if their roots extend to the capillary fringe of the water table. Selective clearing of areas of dense phreatophytes converted to blue panic or Bermuda grass would provide a salvage of 7 in. (178 mm) and 14 in. (360 mm), respectively, from these areas. Because the average depth to ground water exceeds 8 ft (2.4 m) on the project area, it can be postulated that the consumptive use of the grasses would be less than under irrigation, crop production would be less than optimum, and more water would be salvaged. No data are available from this study to prove or disprove this postulation. A flood plain without phreatophytes is in an artificial condition, and the water requirements for maintaining this condition are dependent on the land-management practices applied. The maximum possible salvage for sites similar to the Gila River flood plain, as observed in this study, is 31 in. (790 mm) for areas of 100 percent area coverage of phreatophytes converted to no permanent vegetation.

The preceding data were obtained by computing *ET* as the residual in a water-budget equation, involving twelve measured components, consisting of all inflow and outflow of water. Four contiguous reaches of the flood plain were studied and measurements of *ET* were obtained for budget periods of two or three weeks between 1963 and 1971. The accuracy of the *ET* data is dependent on the quantity of water measured as inflow and outflow; the average annual *ET* for an individual reach was only three percent of the average annual quantity of water moving through the reach before clearing and one percent after clearing. Thus, errors in the water budget can completely obscure the *ET* values. Fortunately, however, maximum rates of *ET* do not generally coincide with maximum rates of flow and *ET* is a significant component of the water budget for many budget periods. Arbitrary criteria based on consistent and unbiased rules were established for rejecting all obviously erroneous data. The errors in each component and in the total budget were evaluated and the maximum potential evapotranspiration for before and after clearing was computed. Acceptance criteria based on the measurement errors and potential evapotranspiration were used to establish acceptable maximum *ET* values and maximum errors in these values. Minimum acceptable negative *ET* values were also established. Applying these tests to the water-budget evaluations provided 321 acceptable *ET* data.

Accepted data were too few and their distribution too irregular to define *ET* accurately for any individual reach during a particular year. The *ET* data were also spatially variable before clearing because of differences in the density of phreatophytes on the various reaches and temporally variable because of seasonal and annual differences in available energy and atmospheric conditions. In order to combine data from all reaches and to compensate for this spatial and temporal variability, four previously developed and widely used empirical *ET* equations were fitted to the accepted *ET* data. The equations provide a climatic factor that compensates for differences in solar radiation and temperature. This factor was used to derive monthly coefficients for each equation related to the areal density of phreatophytes. The following equations or data were used to define the climatic factors: (1) the Blaney-Criddle equation based on the monthly percentage of total daytime hours in the year and mean temperature; (2) solar radiation; (3) the Jensen-Haise equation based on solar radiation and mean temperature; and (4) pan evaporation. Coefficients for no phreatophytes and for varying densities of phreatophytes were derived by fitting the climatic factor to the data by use of an optimization program. Optimum fitting was achieved when the average difference between measured and computed *ET* for all accepted budget periods was minimized.

The average standard deviations of the annual computed *ET* from the measured *ET* indicate a variability of ±4.6 in. (117 mm), or ±15 percent, before clearing, and ±3.2 in. (81 mm) or ±25 percent, after clearing. The deviations indicate an error in the computation of monthly rates of *ET* ranging from a low of 30 percent in summer before clearing to 150 percent in winter for both before and after clearing. These statistical tests of accuracy for fitting measured *ET* to the various equations for the climatic factor indicate no significant difference in the accuracy of prediction among the equations. However, seasonal variation of the coefficients for both the Blaney-Criddle equation and for the solar-radiation equation is similar to the seasonal variation of foliation based on field estimates and on repetitive infrared-color aerial photography. In contrast, the variation of coefficients for the Jensen-Haise and pan evaporation equations differ considerably from the observed variation of foliation. Thus, if it is assumed that the seasonal variations in the monthly coefficients for phreatophyte cover are due to seasonal variation in leaf area, the Blaney-Criddle and solar-radiation equations must be considered to be superior to the other two.

The empirical equations with coefficients derived from this study can be used to estimate *ET* and water salvage for other areas. Annual coefficients for no phreatophytes and monthly coefficients for varying densities of phreatophytes for each of the four climatic factors are listed in tables 12 and 17. The value of the coefficient for no phreatophyte describes evapotranspiration maintained by the upward movement of water from subsurface sources and is related to the soil type and depth of the ground-water table. These features should be considered in projections to other areas. The coefficient for varying densities of phreatophytes is primarily related to the quantity and condition of foliation, which in turn is related to the length of growing season. Coefficients for the transition months, such as May and October, should be increased for growing seasons longer than this season on the Gila River flood plain, or reduced if the growing season is shorter. Average values of the coefficient for the year, or for the growing season, may provide adequate estimates for many purposes. The coefficients for both no phreatophytes and for phreatophyte cover were derived from data which excluded precipitation, therefore, the local precipitation should be added to obtain estimates of total *ET*. The application of the coefficients from this study to areas other than the Southwestern States may provide erroneous estimates.

Usable methods were developed by this study for comparing *ET* from reaches having different quantities of vegetation. However, methods of obtaining the quantitative description of vegetation as related to transpiration, in particular, should be improved. A rational interpretation of the empirical equations used indicates that the climatic factor is an index of potential evaporation and, therefore, the vegetation description should be an index of the area of evaporative surfaces, which for deciduous trees is the seasonally variable foliation. The vegetative measures used in this study were based upon the canopy, which is a function of the species present and the habitat. As such, the canopy is an integration of the growth characteristics during the life of the vegetation and does not vary seasonally. The resulting measure reflects long-term conditions. Seasonal trends in the consumptive use coefficient were calculated from measured *ET*, but were not defined by seasonal trends in the vegetation description. Transfer of the *ET* value determined by this method should be restricted to areas having seasonal, climatic, and environmental trends similar to the project site.

The problem of obtaining an adequate description of the vegetation was recognized at the beginning of the study and various methods were investigated. Repetitive infrared-color aerial photographs were available beginning in 1967 and the development of a technique for relating photographic spectral response to *ET* was described by Jones (1977). The results are encouraging because the photogrammetric data are a measure of the contemporary transpiration characteristics of the vegetation. This method was not available until the latter part of this project and therefore could not be thoroughly developed and tested for use in this report.

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TABLE 6

TABLE 6.—*Water-budget components, resulting ET, and total measurement error for each budget period during water years 1963-71, reaches 1, 2, 2a, and 3*

[All values are in acre-feet per budget period]

REACH 1

Budget period ending	Project day[1/]	Days	ET	Q_I	Q_O	ΔC	Q_T	$\bar{P}$	$\Delta\bar{M}_S$	$\Delta\bar{M}_I$	M_C	G_B	G_I	G_O	$\Delta\bar{M}_{TC}$	ε_{ET}[2/]
3-19-63	170	14	521	4641	-4601	68		99	62		91	41	86	-77	111*	478
4- 2-63	184	14	30	1358	-1529	8		1	60		97	41	86	-77	-15	249
4-16-63	198	14	129	1344	-1477	1		0	105		-7	41	86	-77	113	248
4-30-63	212	14	228	1261	-1255	0	0	69	29		152	41	86	-77	-78	215
5-14-63	226	14	-171	847	-904	11	0	0	14		-8	41	87	-77	-182	194
5-28-63	240	14	312	505	-521	6	0	0	88		67*	41	87	-77	116	193
6-11-63	254	14	389	256	-231	4	0	0	34		171	41	88	-77	103	178
6-25-63	268	14	220	153	-111	5	0	0	41		90	41	89	-77	-11	158
7- 9-63	282	14	306	26	-9	2	0	33	34		86*	41	91	-77	79*	159
7-23-63	296	14	254	7	0	0	0	0	18		96*	41	91	-78	79*	165
8- 6-63	310	14	446	3858	-3574	-128	67	148	-34		6	41	88	-78	52	598
8-20-63	324	14	851	4220	-3613	64	18	175	20		-12	41	87	-77	-72	490
9- 3-63	338	14	4122	30698	-26253	-84	10	309	-21		-377	41	89	-77	-213	1997
9-17-63	352	14	2556	19267	-16780	33	0	49	34		-16	41	88	-77	-83	1336
10- 1-63	366	14	728	8215	-7761	64	0	15	21		69	41	87	-77	54	727
10-15-63	380	14	293	983	-960	28	1	0	7		137	41	87	-77	46	210
10-29-63	394	14	582	11960	-11288	-42	21	96	-24		-128	41	87	-77	-64	1106
11-12-63	408	14	137	5036	-5022	-13		36	26		30	41	85	-77	-5	496
11-26-63	422	14	209	4107	-3873	17		50	-23		-70	41	83	-77	-46	419
12-10-63	436	14	525	3491	-3131	7		24	7		71	41	83	-77	9	364
12-24-63	450	14	494	2691	-2316	18		0	10		-17	41	82	-76	61	315
1- 7-64	464	14	230	2527	-2269	-29		0	0		-18	41	83	-76	-29	311
1-21-64	478	14	-640	4203	-4474	-5		0	-18		-166	41	82	-76	-191	438
2- 4-64	492	14	-40	4322	-4401	7		29	-2		6	41	82	-76	-48	445
2-18-64	506	14	97	2185	-2241	33		0	9		17	41	83	-76	46	296
3- 3-64	520	14	9	1015	-1108	3	0	48	-20		17	41	84	-76	5	200
3-17-64	534	14	195	958	-898	5	0	35	6		21	41	85	-76	18	192
3-31-64	548	14	196	977	-928	0	0	26	-2		7	41	85	-76	66	197
4-14-64	562	14	112	987	-890	0	0	75	-17		-51	41	85	-76	-42	195
5- 4-64	582	20	269	1166	-999	4	0	4	16		27	59	121	-107	-22	200
5-25-64	603	21	410	688	-600	8	0	0	23		127	62	128	-113	87	184
6-15-64	624	21	372	173	-144	7	0	0	17		162	62	131	-113	77	172
7- 6-64	645	21	424	8	-3	0	0	5	15		145	62	132	-114	174	161
7-27-64	666	21	1056	7614	-6839	0	14	93	6		36	62	130	-115	55	819
8-17-64	687	21	1903	18502	-17068	98	176	272	-61		-86	62	128	-113	-7	1427
9- 7-64	708	21	513	1051	-1107	23	252	174	8		82	62	124	-112	-44	341
9-28-64	729	21	2799	24456	-21821	-165	310	289	-73		-272	62	123	-113	3	1732
10-19-64	750	21	229	3080	-3254	148	0	75	27		89	62	127	-114	-11	409
11- 9-64	771	21	132	696	-674	11	0	0	25		1	62	125	-114	0	177

TABLE 6.—*Water-budget components, resulting ET, and total measurement error for each budget period during water years 1963-71, reaches 1, 2, 2a, and 3*—Continued

REACH 1

Budget period ending	Project day 1/	Days	ET	Q_I	Q_0	ΔC	Q_T	$\overline{P}$	$\Delta\overline{M}_S$	$\Delta\overline{M}_I$	M_C	G_B	G_I	G_0	$\Delta\overline{M}_{TC}$	ε_{ET} 2/
11-30-64	792	21	132	2223	-2094	-27		103	-33		-69	62	122	-115	-40	262
12-21-64	813	21	113	2519	-2499	10		88	-18		-24	62	121	-115	-31	275
1-11-65	834	21	42	3907	-3857	-71		78	-8		-72	62	121	-115	-3	408
2- 1-65	855	21	-193	10502	-10619	26		96	-17		-113	62	119	-115	-134	776
2-22-65	876	21	465	10649	-10155	-15		172	-63		-109	62	118	-115	-79	757
3-15-65	897	21	247	8414	-8082	-15		96	-25		-65	62	118	-114	-142	655
4- 5-65	918	21	33	6736	-6785	23		42	29		-35	62	119	-114	-44	545
4-26-65	939	21	378	5631	-5460	11		29	58		-22	62	120	-114	63	470
5-17-65	960	21	82	3098	-3231	46	0	5	66		-11	62	121	-114	40	335
6- 7-65	981	21	407	902	-934	13	0	0	16		235	62	124	-113	102	187
6-28-65	1002	21	448	355	-287	6	0	40	27		146	62	123	-113	89	159
7-19-65	1023	21	469	316	-203	2	0	41	26		115	62	123	-113	100	164
8- 9-65	1044	21	1979	16734	-15225	-26	333	320	-51		-159	62	120	-113	-16	1294
8-30-65	1065	21	265	3078	-3651	-87	456	225	-10		70	62	118	-112	116	600
9-20-65	1086	21	1224	15221	-14261	80	51	124	17		-14	62	114	-113	-57	1247
10-11-65	1107	21	436	1434	-1223	22	0	0	8		92	62	113	-112	40	206
11- 1-65	1128	21	302	1180	-1079	-15	0	0	24		59	62	114	-113	70	192
11-22-65	1149	21	265	1767	-1590	0	0	11	0		5	62	114	-113	9	221
1-24-66	1212	63			-287274			968	-628		-1061*	187	352	-336	-1957	
2-14-66	1233	21	-228	24032	-24629	-2		150	-53		110*	62	135	-120	87	1467
3- 7-66	1254	21	1702	25095	-23774	26		15	105		119*	62	129	-121	46	1464
3-28-66	1275	21			-104514			7	-192		-637*	62	119	-118	-430	
4-18-66	1296	21	-1333	40110	-42587	114		0	254		496*	62	129	-116	205	2214
5- 9-66	1317	21	999	15433	-15584	71	0	0	161		403	62	136	-115	432	1044
5-30-66	1338	21	683	4800	-5399	52	0	2	217		453	62	138	-115	473	456
6-20-66	1359	21	671	1614	-1882	13	0	38	111		340	62	136	-115	354	228
7-11-66	1380	21	738	928	-987	9	28	120	20		234	62	132	-115	307	188
8- 1-66	1401	21	405	758	-1075	-3	382	347	-179		28	62	130	-115	70	428
8-22-66	1422	21	911	3885	-3639	-107	233	69	132		161	62	132	-115	98	501
9-12-66	1443	21	564	6402	-6373	93	0	330	-26		78	62	131	-113	-20	633
10- 3-66	1464	21	366	13093	-12924	-14	42	52	104		-135	62	134	-112	64	1096
10-24-66	1485	21	109	2217	-2338	21	0	9	33		71	62	129	-113	18	264
11-14-66	1506	21	350	2233	-2235	-19		77	7		86	62	128	-113	124	258
12- 5-66	1527	21	263	3346	-3241	13		0	17		2	62	126	-113	51	325
12-19-66	1541	14	110	1382	-1416	0		95	-29		17	41	83	-75	12	215
1-16-67	1569	28	44	2917	-2921	-13		41	-5		-37	83	167	-151	-37	286
2- 6-67	1590	21	144	3901	-3778	16		36	3		-35	62	124	-113	-72	363
2-27-67	1611	21	105	1428	-1420	1		40	-5		-38	62	125	0113	25	206
3-20-67	1632	21	-273	1336	-1477	4		15	1		-98	62	124	-113	-127	206

TABLE 6.—*Water-budget components, resulting ET, and total measurement error for each budget period during water years 1963-71, reaches 1, 2, 2a, and 3*—Continued

REACH 1

Budget period ending	Project day 1/	Days	ET	Q_I	Q_0	ΔC	Q_T	$\overline{P}$	$\Delta\overline{M}_S$	$\Delta\overline{M}_I$	M_C	G_B	G_I	G_0	$\Delta\overline{M}_{TC}$	ε_{ET} 2/
4-10-67	1653	21	199	1138	-1108	0		22	17		14	62	124	-114	44	190
5- 1-67	1674	21	75	910	-936	5		10	11		-9	62	124	-114	12	181
5-22-67	1695	21	221	632	-666	3	0	0	57		103	62	124	-114	20	169
6-12-67	1716	21	327	409	-459	1	9	45	44		105	62	123	-115	103	162
7- 3-67	1737	21	200	440	-541	2	0	31	14		71	62	120	-115	116	166
7-24-67	1758	21	413	5567	-6148	-21	746	280	-55		-59	62	116	-115	40	1048
8-14-67	1779	21			-71778		520	263	-746		-1675	62	116	-114	-400	
9- 4-67	1800	21			-34631		313	82	326		860	62	135	-98	-224	
9-25-67	1821	21	738	8035	-7660	-248	33	145	52		163	62	142	-110	124	810
10-16-67	1842	21	446	9467	-9554	250	0	106	30		125	62	137	-111	-66	805
11- 6-67	1863	21	159	2947	-3116	-10		0	37		86	62	137	-110	126	306
11-27-67	1884	21	212	2890	-3054	3		47	30		44	62	136	-109	163	302
12-18-67	1905	21	397	5000	-4885	-64		582	-179		-48*	62	133	-109	-95	464
1- 8-68	1926	21	-11978	57007	-68105	-95		48	-119		-410*	62	129	-113	-382	4448
1-29-68	1947	21	1767	44924	-42768	-261		49	87		-234*	62	123	-113	-102	2181
2-19-68	1968	21			-125535			209	-205		-499*	62	104	-115	-869	
3-11-68	1989	21	-13600	107485	-120537	-89		130	16		-134*	62	102	-111	-524	4452
4- 1-68	2010	21	1228	78645	-77971	137		12	150		142	62	112	-109	48	3589
4-22-68	2031	21	-1641	59584	-61349	110		48	52		-128	62	114	-109	-25	2927
5-13-68	2052	21	-999	27556	-29324	76	0	1	243		213	62	125	-110	159	1649
6- 3-68	2073	21	752	12212	-12541	85	0	0	256		450	62	131	-112	209	882
6-24-68	2094	21	403	2878	-3239	32	0	11	108		310	62	137	-113	217	314
7- 8-68	2108	14	351	1071	-1106	2	0	66	22		-50*	41	93	-76	288	211
7-22-68	2122	14	25	690	-819	10	0	0	10		7	41	92	-76	70	173
8- 5-68	2136	14	254	2035	-2304	-65	296	244	-39		-74	41	90	-77	107	426
8-19-68	2150	14	-55	12024	-11764	25	70	190	-59		-213	41	80	-77	-372	998
9- 2-68	2164	14	55	6739	-6716	-47	2	66	-5		-47	41	84	-76	14	632
9-16-68	2178	14	348	2275	-2602	79	0	1	63		217	41	87	-76	263	317
9-30-68	2192	14	90	657	-774	10	0	1	15		101	41	90	-76	25	178
10-14-68	2206	14	-42	1225	-1469	5	0	47	0		23	41	95	-81	72	188
10-28-68	2220	14	161	813	-809	-6	0	0	4		57	51	86	-76	51	175
11-11-68	2234	14	97	1584	-1505	-15		8	2		-36	41	84	-75	9	225
11-25-68	2248	14	83	3342	-3358	-28		136	-27		-44	41	81	-75	15	384
12- 9-68	2262	14	-31	4080	-4109	7		14	3		-33	41	80	-75	-39	426
12-23-68	2276	14	244	2832	-2782	11		132	0		-3	41	82	-75	6*	327
1- 6-69	2290	14	-235	4952	-5099	-24		160	-144		-80	41	81	-75	-47	501
1-20-69	2304	14	317	5779	-5569	-16		56	2		-9	41	81	-75	27	535
2- 3-69	2318	14	78	7624	-7408	-10		60	-10		-124	41	80	-75	-100	663
2-17-69	2332	14	199	6172	-6135	33		38	11		49	41	81	-75	-16	573

TABLE 6.—*Water-budget components, resulting ET, and total measurement error for each budget period during water years 1963-71, reaches 1, 2, 2a, and 3*—Continued

REACH 1

Budget period ending	Project day[1/]	Days	ET	Q_I	Q_0	ΔC	Q_T	$\overline{P}$	$\Delta\overline{M}_S$	$\Delta\overline{M}_I$	M_C	G_B	G_I	G_0	$\Delta\overline{M}_{TC}$	ε_{ET}[2/]
3- 3-69	2346	14	105	2893	-3030	34		30	17		73	41	85	-75	37	350
3-17-69	2360	14	99	1600	-1711	2		85	-5		25	41	86	-75	51	251
3-31-69	2374	14	0	1178	-1336	2		0	46		53	41	86	-75	5	225
4-14-69	2388	14	56	1350	-1449	0		13	60		27	41	86	-75	3	234
4-28-69	2402	14	96	1041	-1104	6		0	60		14	41	86	-75	27	213
5-12-69	2416	14	98	989	-1069	-2		120	-18		20	41	85	-75	7	212
5-26-69	2430	14	200	624	-710	9	0	3	60		74	41	85	-75	89	191
6- 9-69	2444	14	138	430	-474	5	0	0	3		85	41	85	-75	38	184
6-23-69	2458	14	192	228	-267	1	0	0	5		78	41	85	-75	96	176
7- 7-69	2472	14	228	187	-195	4	0	10	3		79	41	84	-75	90	176
7-21-69	2486	14	183	442	-747	-8	168	159	-29		71	41	82	-75	79	261
8- 4-69	2500	14	89	397	-437	0	0	13	27		29	41	80	-75	14	183
8-18-69	2514	14	154	508	-782	-5	92	195	-11		68	41	79	-75	44	223
9- 1-69	2528	14	-17	657	-654	-27	6	41	8		-61	41	78	-75	-31	193
9-15-69	2542	14	-233	7144	-7374	-59	46	154	-28		-132	41	74	-75	-24	702
9-29-69	2556	14	183	1608	-1662	91	0	0	35		85	41	76	-75	-16	279
10-13-69	2570	14	208	357	-374	2	0	0	2		62	41	79	-74	113	169
10-27-69	2584	14	207	952	-858	-10	15	73	-12		-22	41	77	-74	25	221
11-10-69	2598	14	-67	1158	-1209	-3		66	-3		-16	41	75	-74	-102	221
11-24-69	2612	14	112	2118	-2054	-29		225	-114		-81	41	75	-74	5	292
12- 8-69	2626	14	86	3014	-2971	-9		110	-18		-25	41	75	-74	-57	346
12-22-69	2640	14	-87	3183	-3286	27		5	7		-33	41	76	-74	-33*	360
1- 5-70	2654	14	106	1467	-1505	1		93	-16		12	41	78	-74	9*	227
1-19-70	2668	14	117	1805	-1703	0		7	17		-37	41	80	-74	-19	247
2- 2-70	2682	14	98	1227	-1188	11		0	20		-1	41	81	-74	-19	215
2-16-70	2696	14	40	1108	-1124	-2		25	4		-10	41	81	-74	-9	208
3- 9-70	2717	21	127	3645	-3746	-20		389	-143		-60	62	121	-112	-9	435
3-23-70	2731	14	81	1596	-1672	17		31	72		-27	41	78	-74	19	242
4- 6-70	2745	14	135	1184	-1253	3		22	72		40	41	81	-74	19	215
4-20-70	2759	14	18	1051	-1146	-1		34	42		5	41	75	-74	-9	207
5- 4-70	2773	14	19	1023	-1063	1		0	30		-6	41	76	-74	-9	204
5-18-70	2787	14	72	722	-743	7	0	0	1		21	41	80	-75	9	186
6- 1-70	2801	14	23	515	-579	3	0	8	12		7	41	82	-75	9	177
6-15-70	2815	14	136	334	-382	5	0	0	7		50	41	82	-75	74	170
6-29-70	2829	14	269	220	-236	1	0	44	12		107	41	81	-75	74	166
7-13-70	2843	14	154	144	-171	3	2	14	9		42	41	80	-75	65	164
7-27-70	2857	14	209	357	-369	-2	8	114	-10		1	41	79	-75	65	176
8-10-70	2871	14	153	1441	-1370	-23	2	63	-3		-37	41	77	-75	37	282
8-24-70	2885	14	183	1164	-1259	19	0	90	26		65	41	75	-75	37	235

TABLE 6.—*Water-budget components, resulting ET, and total measurement error for each budget period during water years 1963-71, reaches 1. 2, 2a, and 3*—Continued

REACH 1

Budget period ending	Project day[1/]	Days	ET	Q_I	Q_O	ΔC	Q_T	$\bar{P}$	$\Delta\bar{M}_S$	$\Delta\bar{M}_I$	M_C	G_B	G_I	G_O	$\Delta\bar{M}_{TC}$	ε_{ET}[2/]
9- 7-70	2899	14	262	213	-235	-1	7	155	-29		73	41	76	-75	37	168
9-21-70	2913	14	193	641	-587	0	16	52	0		-8	41	76	-75	37	196
10- 5-70	2927	14	568	5577	-4727	-154	0	68	-9		-145	41	74	-74	-83	750
10-19-70	2941	14	113	1864	-1922	170	0	1	11		33	41	72	-74	-83	306
11- 2-70	2955	14	97	573	-523	-2	0	0	17		9	41	74	-73	-19	177
11-16-70	2969	14	41	727	-731	2		0	8		12	41	74	-73	-19	187
11-30-70	2983	14	14	585	-597	-1		7	-6		-7	41	74	-73	-9	179
12-14-70	2997	14	55	678	-720	0		6	14		44	41	74	-73	-9	184
12-28-70	3011	14	5	668	-735	-2		53	-10		-2	41	74	-73	-9	184
1-11-71	3025	14	126	2729	-2598	-35		29	-3		-28	41	73	-73	-9	328
1-25-71	3039	14	-40	3498	-3483	1		0	4		-54	41	72	-73	-46	376
2- 8-71	3053	14	91	3211	-3064	4		0	3		-57	41	72	-73	-46	351
2-22-71	3067	14	356	2929	-2648	2		95	-26		7	41	66	-73	-37	326
3- 8-71	3081	14	-8	2096	-2096	7		11	-1		-17	41	61	-73	-37	274
3-22-71	3095	14	-88	1090	-1208	20		5	1		-10	41	74	-73	-28	212
4- 5-71	3109	14	27	739	-739	3		0	5		4	41	75	-73	-28	186
4-19-71	3123	14	74	698	-668	0		54	-8		10	41	77	-74	-56	184
5- 3-71	3137	14	-20	597	-618	1		0	8		12	41	69	-74	-56	180
5-17-71	3151	14	41	434	-444	5	0	0	7		-10	41	63	-74	19	173
5-31-71	3156	14	82	333	-337	1	0	0	1		33	41	65	-74	19	169
6-14-71	3179	14	93	160	-218	4	0	0	12		46	41	76	-74	46	165
6-28-71	3193	14	106	92	-118	2	0	0	7		33	41	77	-74	46	163
7-12-71	3207	14	203	160	-136	1	0	0	12		66	41	77	-74	56	165
7-26-71	3221	14	192	257	-321	-8	42	142	-43		25	41	75	-74	56	177
8- 9-71	3235	14	-728	2701	-3666	-43	199	248	-71		-45	41	74	-73	-93	462
8-23-71	3249	14			-14671		318	176	27		-282	41	71	-72	0	
9- 6-71	3236	14	518	6032	-5803	197	21	5	61		56	41	72	-71	-93	626
9-20-71	3277	14	-183	2939	-3122	-128	0	7	30		46	41	75	-71	0	463

REACH 2

Budget period ending	Project day[1/]	Days	ET	Q_I	Q_O	ΔC	Q_T	$\bar{P}$	$\Delta\bar{M}_S$	$\Delta\bar{M}_I$	M_C	G_B	G_I	G_O	$\Delta\bar{M}_{TC}$	ε_{ET}[2/]
7- 9-63	282	14	427	9	0	2			50	0	312*	42	77	-65	0	154
7-23-63	296	14	573	0	0	0			29	29	461	42	77	-65	0	130
8- 6-63	310	14	-195	3574	-3560	0			-200	-14	-49	42	77	-65	0	566
8-20-63	324	14	-455	3613	-4153	66			32	-7	-60	42	77	-65	0	468
9- 3-63	338	14	329	26253	-24712	-75			-33	0	-1077	42	77	-65	-81*	1832
9-17-63	352	14	-755	16780	-17387	32			65	-17	-246	42	77	-65	-36*	1275
10- 8-63	373	21	-293	8372	-9296	92			113	18	310	64	115	-97	16*	749
10-22-63	387	14	111	7906	-7680	-123		85	-43	8	-116	42	77	-65	20*	967
11- 5-63	401	14	535	5918	-5535	68		43	36	-13	-4	42	77	-65	-32*	543

TABLE 6.—*Water-budget components, resulting ET, and total measurement error for each budget period during water years 1963-71, reaches 1, 2, 2a, and 3*—Continued

REACH 2

Budget period ending	Project day[1]	Days	ET	Q_I	Q_O	ΔC	Q_T	$\overline{P}$	$\Delta\overline{M}_S$	$\Delta\overline{M}_I$	M_C	G_B	G_I	G_O	$\Delta\overline{M}_{TC}$	ϵ_{ET}[2]
11-19-63	415	14	437	4911	-4522	19		31	4	13	-41	42	77	-65	-32*	457
12- 3-63	429	14	-53	3491	-3483	-5		59	-20	-18	-107	42	77	-65	-24*	360
12-17-63	443	14	-246	2870	-3120	9		40	-6	-7	-61	42	76	-65	-24*	322
12-31-63	457	14	97	1670	-1662	23		0	23	12	-12	42	76	-65	-10*	219
1-14-64	471	14	27	3516	-3395	-41		0	-6	-9	-64	42	76	-65	-27*	363
1-28-64	485	14	167	4857	-4605	0		41	-13	-7	-134	42	76	-65	-25*	453
2-11-64	499	14	92	3403	-3342	25		0	-11	0	7	42	76	-65	-43	368
2-25-64	513	14	104	1412	-1394	17		0	0	-9	33	42	76	-65	-8	222
3-10-64	527	14	302	1003	-946	5		108	-13	3	51	42	76	-65	38	191
3-24-64	541	14	103	878	-890	0		48	1	-8	-2	42	76	-65	23	185
4- 7-64	555	14	246	954	-835	1		61	-20	11	15	42	76	-65	6*	159
4-27-64	575	20	143	1100	-1049	3		18	29	-6	-31	61	108	-94	4*	168
5-18-64	596	21	387	749	-646	7	0	0	53	7	101	64	113	-98	37*	153
6- 8-64	617	21	728	280	-166	9	0	0	49	9	372	64	113	-96	94*	135
6-29-64	638	21	789	18	0	0	0	14	50	12	532	64	114	-95	80	141
7-20-64	659	21	1058	3945	-3644	0	3	17	47	1	464	64	115	-94	140	647
8-10-64	680	21	1068	15463	-14642	-9	138	208	-36	3	-142	64	113	-90	-2	1257
8-31-64	701	21	537	5523	-5730	10	356	391	-134	1	6	64	113	-90	27	763
9-21-64	722	21	439	7923	-7941	-43	118	318	-16	-6	-33	64	113	-93	35	791
10-12-64	743	21	-409	16722	-17155	35	0	61	68	0	-178	64	113	-93	-46	1495
11- 2-64	764	21	363	1001	-826	4	0	93	3	-1	77	64	114	-94	-72	177
11-23-64	785	21	85	1388	-1305	-32		141	-43	0	-93	64	115	-95	-55	202
12-14-64	806	21	145	2776	-2568	9		6	1	-7	-83	64	115	-96	-72	269
1- 4-65	827	21	197	2045	-1910	-21		197	-110	1	-91	64	115	-97	4	227
1-25-65	848	21	283	9625	-9040	-45		167	-60	-6	-322	64	115	-94	-121	712
2-15-65	869	21	293	10334	-9643	0		336	-252	-13	-419	64	115	-90	-139	728
3- 8-65	890	21	328	9270	-9021	46		8	102	-7	-147	64	114	-87	-14	680
3-29-65	911	21	-391	6839	-7033	-8		126	2	3	-324	64	114	-88	-86	564
4-19-65	932	21	-65	5914	-6127	1		127	39	4	-89	64	114	-91	-21	491
5-10-65	953	21	793	4224	-3911	28	0	0	201	4	110	64	114	-90	49	368
5-31-65	974	21	616	1287	-1152	13	0	1	74	3	239	64	113	-91	65	171
6-21-65	995	21	563	433	-317	14	0	35	28	2	213	64	113	-90	68	128
7-12-65	1016	21	832	204	-101	-32	0	91	64	8	516	64	113	-91	-4	129
8- 2-65	1037	21	1195	9876	-9236	-210	254	499	-223	-9	97	64	113	-90	60	946
8-23-65	1058	21	842	7569	-7424	219	216	150	65	6	34	64	113	-86	-84	821
9-13-65	1079	21	1188	13715	-12815	-143	188	369	-131	0	-72	64	113	-87	-13	1184
10- 4-65	1100	21	763	3003	-2901	149	72	0	203	-16	107	64	112	-87	57	346
10-25-65	1121	21	562	926	-662	0	0	14	46	-4	92	64	113	-88	61	148
11-15-65	1142	21	250	1414	-1213	-4		0	69	10	-96	64	113	-89	-18	181

TABLE 6.—*Water-budget components, resulting ET, and total measurement error for each budget period during water years 1963-71, reaches 1, 2, 2a, and 3*—Continued

REACH 2

Budget period ending	Project day[1/]	Days	ET	Q_I	Q_0	ΔC	Q_T	$\overline{P}$	$\Delta\overline{M}_S$	$\Delta\overline{M}_I$	M_C	G_B	G_I	G_0	$\Delta\overline{M}_{TC}$	ε_{ET}[2/]
12- 6-65	1163	21	253	2943	-2648	-22		251	-211	-1	-101	64	113	-89	-46	290
2- 7-66	1226	60		299841				1371	-807	-166	-1991*	192	341	-269	-524	
2-28-66	1247	21	-838	25726	-26632	-26		28	137	-15	-78*	64	121	-90	-73	1549
3-21-66	1268	21		82666				0	23	12	-238	64	120	-77	-119	
4-11-66	1289	21		62847				0	239	8	139	64	116	-43	-125	
5- 2-66	1310	21		21203				0	233	27	424	64	115	-30	113	
5-23-66	1331	21		8013			0	0	213	35	456	64	115	-31	84	
6-13-66	1352	21		2515			0	0	141	47	799	64	115	-38	115	
7- 4-66	1373	21		1211			29	38	132	56	556	64	115	-59	121	
7-25-66	1394	21		759			2	155	37	21	375	64	115	-57	151	
8-15-66	1415	21	604	1628	-1557	-15	28	264	-50	13	109	64	115	-65	70	221
9- 5-66	1436	21	460	8132	-8455	-1	120	228	80	1	129	64	114	-74	122	738
9-26-66	1457	21	-98	12617	-12884	-32	120	424	-166	-7	-199	64	112	-78	-69	1117
10-17-66	1478	21	795	2947	-2711	30	0	56	80	10	241	64	112	-80	46	284
11- 7-66	1499	21	323	1781	-1622	-2	0	45	29	-12	8	64	113	-82	1	206
11-28-66	1520	21	64	3387	-3298	-15		43	7	5	-101	64	113	-83	-58	314
12-12-66	1534	14	132	1590	-1572	15		148	-151	-1	40	42	75	-56	2	210
1- 9-67	1562	28	250	2646	-2640	-3		50	18	0	33	85	151	-112	22	253
1-30-67	1583	21	-48	3937	-3915	-16		57	1	-8	-186	64	113	-84	-11	355
2-20-67	1604	21	54	1682	-1908	27		4	23	3	55	64	113	-84	75	214
3-13-67	1625	21	225	1549	-1449	1		81	0	0	30*	64	113	-84	-80*	218
3-27-67	1639	14	17	793	-807	2		24	0	0	24*	42	75	-56	-80*	184
4-17-67	1660	21	285	1106	-1090	2		60	35	-20	39	64	114	-84	59	163
5- 8-67	1681	21	271	813	-805	4		0	74	22	95	64	114	-84	-26	146
5-29-67	1702	21	720	601	-522	4	1	75	51	13	268	64	114	-85	136	135
6-19-67	1723	21	739	422	-286	0	0	26	37	-8	310	64	115	-84	143	131
7-10-67	1744	21	974	973	-694	-18	2	87	0	8	347	64	115	-84	174	170
7-31-67	1765	21	531	9288	-9822	-48	433	625	-253	16	114	64	115	-80	79	991
8-21-67	1786	21		97483			1105	502	-497	-77	-2428	64	107	-76	-385	
9-11-67	1807	21	464	7061	-8088	88	76	115	374	35	744	64	101	-84	-21	664
10- 2-67	1828	21	-212	11784	-12751	11	4	234	137	4	305	64	112	-85	-31	1070
10-23-67	1849	21	219	4454	-4948	38	0	69	108	10	301	64	110	-85	98	421
11-13-67	1870	21	408	3161	-2961	-2	0	0	52	9	69	64	110	-85	-9	291
12- 4-67	1891	21	318	3556	-3447	-16		179	-78	4	36	64	109	-85	-4	323
12-25-67	1912	21	675	37789	-36169	-132		891	-516	-43	-1088	64	110	-84	-147	
1-15-68	1933	21	-3712	46413	-49488	-26		62	-79	-35	-498	64	114	-79	-160	2467
2- 5-68	1954	21		71931				111	-138	-3	-425	64	115	-78	-298	
2-26-68	1975	21		125158				275	-143	-19	-870*	64	114	-73	-313	
3-18-68	1996	21		115935				237	85	-190	-612*	64	110	-39	-263	

TABLE 6.—*Water-budget components, resulting ET, and total measurement error for each budget period during water years 1963-71, reaches 1, 2, 2a, and 3*—Continued

REACH 2

Budget period ending	Project day 1/	Days	ET	Q_I	Q_0	ΔC	Q_T	$\overline{P}$	$\Delta\overline{M}_S$	$\Delta\overline{M}_I$	M_C	G_B	G_I	G_0	$\Delta\overline{M}_{TC}$	ε_{ET} 2/
4- 8-68	2017	21		66744				37	288	-187	-360*	64	109	-16	-73	
4-29-68	2038	21		46889				65	75	-189	320	64	109	-12	-12	
5-20-68	2059	21		24010			0	9	174	26	134	64	111	-10	84	
6-10-68	2080	21		8174			0	21	132	6	521	64	113	-10	190	
7- 1-68	2101	21		2275			0	0	202	118	378	64	114	-12	40	
7-15-68	2115	14		1112			5	169	115	42	220	42	76	-10	196	
7-29-68	2129	14		1003			32	240	-8	96	67	42	77	-12	65	
8-12-68	2143	14		9806			189	221	-37	17	-528*	42	77	-18	-49	
8-26-68	2157	14		6987			0	170	23	42	-188	42	76	-21	-137	
9- 9-68	2171	14		5272			0	25	185	32	167	42	76	-23	76	
9-23-68	2185	14		1088			0	0	80	0	142	42	76	-25	155	
10- 7-68	2199	14		646			0	96	-8	6	99	42	76	-28	55	
10-21-68	2213	14		733			0	0	-3	15	24	42	75	-30	43	
11- 4-68	2227	14		1055			0	4	12	-4	-41	42	76	-33	-36	
11-18-68	2241	14		2162				241	-73	-18	-111	42	75	-36	-17	
12- 2-68	2255	14		4322				20	6	-16	-13	42	75	-37	-31	
12-16-68	2269	14		3411				0	-9	-1	-59	42	75	-38	-47	
12-30-68	2283	14		3917				489	-232	-13	-35	42	75	-39	-51	
1-13-69	2297	14		5022				44	-3	-3	-114	42	75	-39	-88	
1-27-69	2311	14		6204				131	-36	-16	-74	42	75	-38	-34	
2-10-69	2325	14		7608				46	2	-5	-182	42	75	-37	-16	
2-24-69	2339	14		4601				66	4	0	-45	42	75	-36	27	
3-10-69	2353	14		2043				81	16	8	-22	42	75	-36	-35	
3-24-69	2367	14		1515				38	30	7	82	42	75	-36	8	
4- 7-69	2381	14		1346				0	53	13	-25	42	75	-37	39	
4-21-69	2395	14		1328				12	58	20	12	42	75	-38	169	
5- 5-69	2409	14		991				173	32	34	57	42	75	-39	4	
5-19-69	2423	14		991			0	43	13	6	-61	42	75	-41	-5	
6- 2-69	2437	14	289	585	-442	6	0	1	39	8	30	42	75	-43	-12	139
6-16-69	2451	14	527	347	-186	5	0	0	29	23	182	42	75	-45	55	128
6-30-69	2465	14	360	231	-51	2	0	3	16	6	37	42	75	-47	46	119
7-14-69	2479	14	510	222	-25	0	0	3	48	28	105	42	75	-49	61	125
7-28-69	2493	14	1026	802	-88	-11	104	153	-15	8	1	42	75	-50	5	183
8-11-69	2507	14	721	388	-190	8	3	130	-13	17	251	42	75	-54	64	125
8-25-69	2521	14	576	801	-495	-5	29	173	-43	1	48	42	75	-48	-2	155
9- 8-69	2535	14		3345			0	55	3	4	-117	42	75	-48	-55	
9-22-69	2549	14		5879			72	124	-36	3	27	42	75	-51	-58	
10- 6-69	2563	14	194	495	-355	13	0	0	-14	1	47	42	74	-55	-54	128
10-20-69	2577	14	419	353	-207	0	19	192	-21	-5	5	42	74	-57	24	122

TABLE 6.—*Water-budget components, resulting ET, and total measurement error for each budget period during water years 1963-71, reaches 1, 2, 2a, and 3*—Continued

REACH 2

Budget period ending	Project day 1/	Days	ET	Q_I	Q_O	ΔC	Q_T	$\overline{P}$	$\Delta\overline{M}_S$	$\Delta\overline{M}_I$	M_C	G_B	G_I	G_O	$\Delta\overline{M}_{TC}$	ε_{ET} 2/
11- 3-69	2591	14	194	1283	-1096	-18	0	0	11	5	-55	42	74	-58	6	189
11-17-69	2605	14	344	1245	-1128	-19		366	-106	-10	-57	42	74	-59	-4	183
12- 1-69	2619	14	24	2957	-2804	-7		11	-9	-12	-134	42	74	-58	-36	312
12-15-69	2633	14	474	3492	-3139	-10		119	-27	-1	16	42	74	-58	-34	352
12-29-69	2646	14	220	1949	-1872	26		134	-17	-9	-16	42	74	-57	-34	243
1-12-70	2661	14	1	1797	-1779	-6		6	1	1	-45	42	74	-56	-34	228
1-26-70	2675	14	28	1368	-1424	17		4	17	-1	-13	42	74	-56	0	198
2- 9-70	2689	14	-62	1090	-1213	0		0	23	0	-22	42	74	-56	0	179
2-23-70	2703	14	179	1073	-1027	1		69	21	3	6	42	74	-56	-27	174
3-16-70	2724	21	306	4127	-4147	-11		534	-151	-26	-85	64	111	-83	-27	436
3-30-70	2738	14	165	1422	-1465	6		20	86	7	8	42	74	-55	20	202
4-13-70	2752	14	270	1146	-1136	3		4	95	5	73	42	74	-56	20	179
4-27-70	2766	14	143	1134	-1150	1		51	44	3	-27	42	74	-56	27	179
5-11-70	2780	14	257	926	-892	4		0	78	-4	57	42	75	-56	27	162
5-25-70	2794	14	272	660	-636	5	0	0	56	16	77	42	75	-57	34	145
6- 8-70	2808	14	314	482	-378	6	0	15	36	-1	59	42	75	-56	34	133
6-22-70	2822	14	520	297	-102	6	0	0	38	9	156	42	75	-56	55	124
7- 6-70	2836	14	583	204	-8	-1	2	21	37	4	209	42	75	-57	55	122
7-20-70	2850	14	587	120	-8	1	5	109	-11	18	271	42	75	-55	20	125
8- 3-70	2864	14	479	420	-137	-1	0	69	6	3	39	42	75	-57	20	136
8-17-70	2878	14	558	2126	-1647	-55	0	40	29	-6	-14	42	75	-59	27	280
8-31-70	2892	14	505	494	-420	56	43	147	-2	0	103	42	75	-60	27	154
9-14-70	2906	14	507	285	-219	-1	34	286	-58	6	98	42	75	-61	20	137
9-28-70	2920	14	275	571	-443	0	0	0	12	0	60	42	75	-62	20	156
10-12-70	2934	14		6146			0	68	-43	-30	-424	42	74	-63	-61	
10-26-70	2948	14	187	646	-567	12	0	0	33	17	55	42	73	-63	-61	143
11- 9-70	2962	14	71	690	-637	-6	0	0	8	-2	-40	42	73	-64	7	147
11-23-70	2976	14	177	591	-509	2		0	10	3	22	42	73	-64	7	140
12- 7-70	2990	14	122	672	-634	-4		37	-4	-6	9	42	73	-63	0	146
12-21-70	3004	14	110	694	-640	4		82	-17	1	-66	42	73	-63	0	148
1- 4-71	3018	14	177	1297	-1162	-37		91	-13	25	-42	42	73	-63	-34	199
1-18-71	3032	14	-91	3403	-3350	-4		2	0	-7	-154	42	73	-62	-34	353
2- 1-71	3046	14	31	3387	-3334	3		0	1	0	-68	42	73	-59	-14	351
2-15-71	3060	14	-134	2846	-2999	6		0	3	-4	-29	42	73	-58	-14	318
3- 1-71	3074	14	260	2348	-2281	9		152	-28	0	9	42	73	-57	-7	270
3-15-71	3088	14	53	1767	-1745	10		10	-0	-3	-38	42	73	-56	-7	226
2-39-71	3102	14	8	868	-908	9		0	-2	0	-38	42	73	-56	20	161
4-12-71	3116	14	170	660	-678	0		0	17	0	92	42	73	-56	20	146
4-26-71	3130	14	268	638	-583	3		73	9	6	55	42	74	-56	7	143

TABLE 6.—*Water-budget components, resulting ET, and total measurement error for each budget period during water years 1963-71, reaches 1, 2, 2a, and 3*—Continued

REACH 2

Budget period ending	Project day 2/	Days	ET	Q_I	Q_O	ΔC	Q_T	$\overline{P}$	$\Delta\overline{M}_S$	$\Delta\overline{M}_I$	M_C	G_B	G_I	G_O	$\Delta\overline{M}_{TC}$	ε_{ET} 2/
5-10-71	3144	14	125	547	-519	3	0	0	24	0	3	42	74	-56	7	143
5-24-71	3158	14	127	374	-353	2	0	0	23	-4	-2	42	74	-56	27	135
6- 7-71	3172	14	205	285	-238	4	0	0	10	6	51	42	74	-56	27	125
6-21-71	3186	14	188	172	-106	1	0	0	12	5	18	42	74	-57	27	122
7- 5-71	3200	14	144	109	-89	-3	0	0	1	-6	46	42	74	-57	27	122
7-19-71	3214	14	245	168	-184	-18	83	86	3	11	30	42	74	-57	7	154
8- 2-71	3228	14	340	1168	-1432	-49	354	533	-181	-7	-111	42	73	-57	7	429
8-16-71	3242	14		8249			928	360	-101	1	-194	42	73	-53	-41	
8-30-71	3256	14		12702			218	137	1	-18	-273	42	72	-54	-41	
9-13-71	3270	14		2999			0	7	71	4	179	42	71	-55	-7	
9-27-71	3284	14		5504			0	6	82	7	30	42	71	-56	-7	

REACH 2a

Budget period ending	Project day 2/	Days	ET	Q_I	Q_O	ΔC	Q_T	$\overline{P}$	$\Delta\overline{M}_S$	$\Delta\overline{M}_I$	M_C	G_B	G_I	G_O	$\Delta\overline{M}_{TC}$	ε_{ET} 2/
10- 4-65	1100	21		230			19	0	139	-11	98	41	112	-149	47	
10-25-65	1121	21		926			0	6	31	0	74	41	113	-149	46	
11-15-65	1142	21		1414				0	36	2	-25	41	113	-147	-54	
12- 6-65	1163	21		2943				144	-133	0	-26	41	113	-147	-19	
2- 7-66	1226	63		299841				817	-593	-6	-494*	124	340	-401	-334	
2-28-66	1247	21		25726				21	109	-13	0*	41	121	-130	-63	
3-21-66	1268	21		82666				0	-11	-3	-521*	41	120	-135	-59	
4-11-66	1289	21		62847				0	139	-12	796*	41	116	-133	-95	
5- 2-66	1310	21		21203				0	146	15	282	41	115	-118	87	
5-23-66	1331	21		8013			0	0	135	8	290	41	115	-114	73	
6-13-66	1352	21		2515			0	0	98	16	498	41	115	-114	133*	
7- 4-66	1373	21	656	1211	-1106	7	0	23	91	0	301	41	115	-116	89	178
7-25-66	1394	21	663	759	-595	-1	0	55	37	7	229	41	115	-118	134	154
8-15-66	1415	21	203	1628	-1668	-4	4	162	-57	2	41	41	115	-119	58	223
9- 5-66	1436	21		8132			47	131	38	1	89	41	114	-114	71	
9-26-66	1457	21		12617			11	242	-117	-1	-113	41	112	-112	-41	
10-17-66	1478	21	-621	2947	-3881	33	0	37	48	7	109	41	112	-118	44	349
11- 7-66	1499	21	228	1781	-1594	-1	0	14	22	-4	-8	41	113	-120	-16	205
11-28-66	1520	21	180	3387	-3175	-9		39	0	0	-52	41	113	-120	-44	312
12-12-66	1534	14	198	1590	-1402	9		91	-120	-2	8	27	75	-80	2	209
1- 9-67	1562	28	92	2646	-2657	-2		33	19	0	20	55	151	-161	-12	255
1-30-67	1583	21	-125	3937	-4008	-9		37	2	2	-119	41	113	-121	0	361
2-20-67	1604	21	-78	1682	-1904	15		4	11	4	31	41	113	-121	46	219
3-13-67	1625	21	102	1549	-1467	0		49	0	0	14*	41	113	-121	-76	212
3-27-67	1639	14	28	793	-763	1		15	0	0	10*	27	75	-80	-50*	177
4-17-67	1660	21	195	1106	-1077	0		34	26	-4	22	41	114	-122	55	167

TABLE 6.—*Water-budget components, resulting ET, and total measurement error for each budget period during water years 1963-71, reaches 1, 2, 2a, and 3*—Continued

REACH 2a

Budget period ending	Project day[1/]	Days	ET	Q_I	Q_O	ΔC	Q_T	$\overline{P}$	$\Delta\overline{M}_S$	$\Delta\overline{M}_I$	M_C	G_B	G_I	G_O	$\Delta\overline{M}_{TC}$	ε_{ET}[2/]
5- 8-67	1681	21	86	813	-843	2		0	36	15	41	41	114	-122	-11	149
5-29-67	1702	21	388	601	-570	2	1	45	29	3	144	41	114	-122	100	137
6-19-67	1723	21	343	422	-414	-1	0	22	16	-13	188	41	115	-122	89	139
7-10-67	1744	21	323	973	-1024	-6	0	44	9	-7	178	41	115	-123	123	183
7-31-67	1765	21		9288			204	370	-180	13	-11	41	115	-123	51	
8-21-67	1786	21		97483			242	279	-269	-10	-611*	41	107	-128	-306	
9-11-67	1807	21		7061			39	61	237	12	614*	41	101	-128	-12	
10- 2-67	1828	21		11784			4	127	73	-14	205	41	112	-129	-38	
10-23-67	1849	21		4454			0	61	29	8	170	41	110	-130	89	
11-13-67	1870	21	314	3161	-2915	-1	0	0	50	-1	18	41	110	-130	-19	290
12- 4-67	1891	21	188	3556	-3481	-10		96	-37	5	41	41	109	-130	-2	325
12-25-67	1912	21		37789				526	-296	-14	-651	41	110	-128	-128	
1-15-68	1933	21		46413				41	-76	-25	-263	41	114	-135	-109	
2- 5-68	1954	21		71931				53	-100	5	-228	41	115	-136	-208	
2-26-68	1975	21		125158				173	35	-12	-185*	41	114	-138	-219	
3-18-68	1996	21		115935				137	52	-10	-3*	41	110	-122	-157	
4- 8-68	2017	21		66744				22	170	-24	113*	41	109	-70	-19	
4-29-68	2038	21		46889				54	41	10	212	41	109	-41	8	
5-20-68	2059	21		24010			0	7	113	6	94	41	111	-29	62	
6-10-68	2080	21		8174			0	16	85	18	306	41	113	-27	129	
7- 1-68	2101	21		2275			0	0	123	4	255	41	114	-40	36	
7-15-68	2115	14		1112			0	71	46	0	152	27	76	-38	189	
7-29-68	2129	14	151	1003	-1088	-2	15	113	-13	-5	34	27	77	-46	36	177
8-12-68	2143	14		9806			93	156	-44	0	-137*	27	77	-56	-23	
8-26-68	2157	14		6987			0	113	18	-6	-129*	27	76	-57	-107	
9- 9-68	2171	14		5272			0	13	113	5	116	27	76	-56	64	
9-23-68	2185	14	328	1088	-1069	6	0	0	47	6	116	27	76	-56	87	173
10- 7-68	2199	14	379	646	-501	6	0	58	0	-10	91	27	76	-57	43	139
10-21-68	2213	14	232	733	-601	-1	0	0	-1	3	22	27	75	-58	33	144
11- 4-68	2227	14	27	1055	-1043	-7	0	0	9	0	-21	27	76	-58	-11	170
11-18-68	2241	14	106	2162	-2088	-16		136	-40	-2	-80	27	75	-58	-10	255
12- 2-68	2255	14	230	4322	-4101	-4		14	-1	2	-16	27	75	-57	-31	416
12-16-68	2269	14	-31	3411	-3439	11		0	-4	1	-33	27	75	-57	-23	357
12-30-68	2283	14	42	3917	-3969	-21		281	-156	-6	-35	27	75	-56	-15*	418
1-13-69	2297	14	-325	5022	-5268	6		24	-1	0	-85	27	75	-56	-69	487
1-27-69	2311	14	-111	6204	-6327	-11		81	-17	-4	-51	27	75	-57	-31	567
2-10-69	2325	14	-706	7608	-8263	3		29	8	-2	-118	27	75	-57	-16	683
2-24-69	2339	14	47	4601	-4667	17		38	5	2	-19	27	75	-56	24	452
3-10-69	2353	14	55	2043	-2039	13		39	11	-3	-29	27	75	-55	-27	251

TABLE 6.—*Water-budget components, resulting ET, and total measurement error for each budget period during water years 1963-71, reaches 1, 2, 2a, and 3*—Continued

Budget period ending	Project day[1/]	Days	ET	Q_I	Q_O	ΔC	Q_T	$\overline{P}$	$\Delta\overline{M}_S$	$\Delta\overline{M}_I$	M_C	G_B	G_I	G_O	$\Delta\overline{M}_{TC}$	ε_{ET}[2/]
3-24-69	2367	14	186	1515	-1503	3		28	22	1	68	27	75	-56	6	207
4- 7-69	2381	14	102	1346	-1315	-2		0	33	0	-25	27	75	-56	19	193
4-21-69	2395	14	141	1328	-1285	4		8	25	-1	15	27	75	-57	2*	193
5 -5-69	2409	14	223	991	-967	1		101	14	7	18	27	75	-57	13*	169
5-19-69	2423	14	45	991	-964	3	0	36	0	-5	-50	27	75	-58	-10	169
6- 2-69	2437	14	68	585	-567	3	0	1	16	-3	7	27	75	-60	-16	142
6-16-69	2451	14	218	347	-329	3	0	0	15	3	99	27	75	-62	40	130
6-30-69	2465	14	146	231	-198	1	0	1	14	1	31	27	75	-65	28	128
7-14-69	2479	14	187	222	-170	0	0	1	26	-1	28	27	75	-69	48	126
7-28-69	2493	14	302	802	-578	-6	7	84	-11	-2	-20	27	75	-72	-4	165
8-11-69	2507	14	301	388	-349	6	0	76	2	4	111	27	75	-70	31	132
8-25-69	2521	14	350	801	-593	-1	14	99	-33	0	24	27	75	-73	10	174
9- 8-69	2535	14		3345			0	27	-3	-2	-106	27	75	-78	-45	
9-22-69	2549	14		5879			36	68	-26	0	-5	27	75	-73	-54*	
10- 6-69	2563	14	34	495	-533	6	0	0	-10	1	48	27	74	-73	-1	153
10-20-69	2577	14	249	353	-324	0	14	101	4	0	54	27	74	-73	19	128
11- 3-69	2591	14	45	1283	-1239	-10	0	0	-2	3	-27	27	74	-73	9	198
11-17-69	2605	14	269	1245	-1180	-10		217	-40	0	3	27	74	-73	6	186
12- 1-69	2619	14	-114	2957	-2993	-5		6	-12	-5	-62	27	74	-73	-28	321
12-15-69	2633	14	262	3492	-3278	-5		66	-13	-1	0	27	74	-73	-27*	356
12-29-69	2647	14	35	1949	-2027	16		78	-1	-3	-3	27	74	-73	-2*	248
1-12-70	2661	14	-9	1797	-1787	-3		3	-3	-7	-39	27	74	-69	-2*	228
1-26-70	2675	14	-36	1368	-1467	9		1	15	4	7	27	74	-69	-5	199
2- 9-70	2689	14	-131	1090	-1221	0		0	13	-5	-34	27	74	-69	-6	178
2-23-70	2703	14	132	1073	-1039	1		45	15	5	15	27	74	-70	-14	171
3-16-70	2724	21	327	4127	-3998	-6		315	-89	-5	-51	41	111	-104	-14	425
3-30-70	2738	14	125	1422	-1396	3		11	50	3	-14	27	74	-69	14	198
4-13-70	2752	14	202	1146	-1130	1		4	78	-4	60	27	74	-69	15	177
4-27-70	2766	14	160	1134	-1053	1		31	26	0	-29	27	74	-69	18	174
5-11-70	2780	14	161	926	-914	2		0	52	-2	47	27	75	-69	17	162
5-25-70	2794	14	66	660	-686	2	0	0	24	5	13	27	75	-69	15	145
6- 8-70	2808	14	111	482	-462	2	0	5	21	-6	22	27	75	-70	15	134
6-22-70	2822	14	153	297	-292	2	0	0	9	1	72	27	75	-72	34	125
7- 6-70	2836	14	229	204	-164	1	0	12	16	1	97	27	75	-73	33	122
7-20-70	2850	14	180	120	-63	1	0	33	-2	4	52	27	75	-80	13	120
8- 3-70	2864	14	151	420	-345	-2	0	42	1	0	0	27	75	-79	12	135
8-17-70	2878	14	169	2126	-1975	-35	0	27	4	-3	-19	27	75	-80	22	290
8-31-70	2892	14	232	494	-484	36	38	76	-1	0	31	27	75	-81	21	149
9-14-70	2906	14	262	285	-264	-2	0	159	-17	4	65	27	75	-82	12	130

TABLE 6.—*Water-budget components, resulting ET, and total measurement error for each budget period during water years 1963-71, reaches 1, 2, 2a, and 3*—Continued

REACH 2a

Budget period ending	Project day[1/]	Days	ET	Q_I	Q_0	ΔC	Q_T	$\overline{P}$	$\Delta\overline{M}_S$	$\Delta\overline{M}_I$	M_C	G_B	G_I	G_0	$\Delta\overline{M}_{TC}$	ε_{ET}[2/]
9-28-70	2920	14	40	571	-579	0	0	0	-5	0	20	27	75	-81	12	159
10-12-70	2934	14		6146			0	43	-25	-12	-225	27	74	-81	-50	
10-26-70	2948	14		646			0	0	12	9	35	27	73	-77	-50	
11- 9-70	2962	14		690			0	0	0	0	-3	27	73	-74	12	
11-23-70	2976	14	55	591	-607	2		0	9	2	18	27	73	-73	13	141
12- 7-70	2990	14	73	672	-676	-3		16	0	-3	36	27	73	-72	3	145
12-21-70	3004	14	32	694	-710	3		40	-3	2	-23	27	73	-71	0	147
1- 4-71	3018	14	138	1297	-1200	-37		65	-8	14	8	27	73	-70	-31	199
1-18-71	3032	14	-11	3403	-3338	-3		1	0	-2	-70	27	73	-72	-30	351
2- 1-71	3046	14	216	3387	-3155	2		0	-2	0	-36	27	73	-73	-7	344
2-15-71	3060	14	-237	2846	-3092	6		0	0	-2	-15	27	73	-73	-7	321
3- 1-71	3074	14	123	2348	-2348	8		94	-14	0	18	27	73	-73	-10	272
3-15-71	3088	14	10	1767	-1805	13		7	3	0	8	27	73	-73	-10	228
3-29-71	3102	14	-7	868	-900	7		0	-3	-2	-21	27	73	-72	16	159
4-12-71	3116	14	95	660	-682	0		0	11	-3	66	27	73	-72	15	145
4-26-71	3130	14	121	638	-634	2		42	2	5	38	27	74	-72	-1	143
5-10-71	3144	14	77	547	-513	4	0	0	11	0	0	27	74	-72	-1	137
5-24-71	3158	14	112	374	-357	1	0	0	21	0	18	27	74	-72	26	128
6- 7-71	3172	14	92	285	-277	4	0	0	1	4	19	27	74	-72	27	125
6-21-71	3186	14	109	172	-146	2	0	0	6	3	13	27	74	-72	30	121
7- 5-71	3200	14	77	109	-115	-2	0	0	-1	-1	28	27	74	-72	30	120
7-19-71	3214	14	155	168	-140	-11	42	27	8	4	22	27	74	-72	6	131
8- 2-71	3228	14		1168			131	300	-147	-2	-31	27	73	-72	6	
8-16-71	3242	10		8249			507	179	-66	-1	-136	27	75	-70	-33	
8-30-71	3256	14		12702			167	85	5	-4	-170	27	72	-73	-34	
9-13-71	3270	14	219	2999	-3080	142	0	4	55	2	76	27	71	-73	-4	365
9-27-71	3284	14		5504			0	5	58	2	18	27	71	-72	-8	

REACH 3 -- 1964 Water Year

Budget period ending	Project day[1/]	Days	ET	Q_I	Q_0	ΔC	Q_T	$\overline{P}$	$\Delta\overline{M}_S$	$\Delta\overline{M}_I$	M_C	G_B	G_I	G_0	$\Delta\overline{M}_{TC}$	ε_{ET}[2/]
10- 8-63	373	21		9296								35	10	-0		
10-22-63	387	14		7680					8	3	-30	23	7	-0	7*	
11- 5-63	401	14		5535					16	0	30	23	7	-0	-24*	
11-19-63	415	14		4522					-18	0	70	23	7	-0	-10*	
12- 3-63	429	14		3483					34	0	7	23	7	-0	-5*	
12-17-63	443	14		3120					-39	0	-56	23	7	-0	-6*	
12-31-63	457	14		1662					1	4	-7	23	7	-0	1*	
1-14-64	471	14		3395					-25	-2	-23	23	65	-32	-9*	
1-28-64	485	14	25	4605	-4589	0			7	0	-45	23	65	-32	-9*	446
2-11-64	499	14	36	3342	-3322	20			-19	-3	-34	23	65	-32	-4*	361

TABLE 6.—*Water-budget components, resulting ET, and total measurement error for each budget period during water years 1963-71, reaches 1, 2, 2a, and 3*—Continued

REACH 3

Budget period ending	Project day[1/]	Days	ET	Q_I	Q_O	ΔC	Q_T	$\overline{P}$	$\Delta\overline{M}_S$	$\Delta\overline{M}_I$	M_C	G_B	G_I	G_O	$\Delta\overline{M}_{TC}$	ε_{ET}[2/]
2-25-64	513	14	-27	1394	-1495	14			-4	-1	6	23	65	-32	3*	209
3-10-64	527	14	47	946	-1035	2			6	1	70	23	65	-32	1*	168
3-24-64	541	14	-34	890	-934	1			-5	-2	-40	23	65	-32	0*	170
4- 7-64	555	14	70	835	-821	3			-8	2	-4	23	65	-32	7*	165
5-11-64	589	34	246	1529	-1455	6			25	3	-16	57	160	-78	15*	190
6- 1-64	610	21	433	328	-218	8			33	-1	168	35	97	-47	30*	95
6-22-64	631	21	541	5	0	0			47	2	388	35	95	-50	19	94
7-13-64	652	21	580	0	0	0		23	42	2	444	35	94	-54	-6	90
8- 3-64	673	21		16210				146	-26	1	-206	35	91	-36	13	
8-24-64	694	21		7175				90	-3	1	-23	35	90	-17	13	
9-14-64	715	21		4529				250	-46	-3	21	35	93	-26	-16	
10- 5-64	736	21		21548				54	-47	-1	-268	35	93	-24	0	
10-26-64	757	21		999				81	-7	2	57	35	93	-29	-9	
11-16-64	778	21	239	582	-432	-14		51	15	0	-57	35	95	-33	-3	114
12- 7-64	799	21	46	2598	-2509	-12		44	-14	0	-119	35	96	-32	-41	246
12-28-64	820	21	108	1914	-1880	14		73	-19	-3	-86*	35	96	-29	-7	209
1-18-65	841	21		6198				98	-56	-7	-201*	35	95	-26	-82	
2- 8-65	862	21		9378				273	-204	0	-186	35	92	-19	-42	
3- 1-65	883	21		10687				6	161	-2	067	35	86	-19	-28	
3-22-65	904	21		7392				80	-142	-3	-238	35	88	-24	-12	
4-12-65	925	21		6299				78	48	-1	-68	35	90	-28	18	
5- 3-65	946	21	400	4776	-4490	13		0	88	4	-73	35	90	-32	-11	390
5-24-65	967	21	374	1763	-1682	23		0	62	-6	110	35	90	-38	17	191
6-14-65	988	21	661	558	-408	8		1	103	9	269	35	90	-45	41	100
7- 5-65	1009	21	702	40	-5	0		31	84	0	447	35	90	-44	24	83
7-26-65	1030	21		3648				136	-13	2	76	35	91	-39	37	
8-16-65	1051	21		12174				286	-217	0	-288	35	87	-42	19	
9- 6-65	1072	21		9471				67	81	0	-173	35	87	-46	18	
9-27-65	1093	21		6857				134	-30	0	216	35	86	-70	-25	

1/ Project day 1 is October 1, 1962

2/ Measurement error (see text).

* Soil moisture change estimated from change in ground-water levels

The Gila River Phreatophyte Project, Graham County, Arizona

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CONTENTS

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GPO 587-041/47