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BARREN AREA EVAPOTRANSPIRATION ESTIMATES GENERATED FROM ENERGY BUDGET MEASUREMENTS IN THE GILA RIVER VALLEY OF ARIZONA

Leppanen

U.S. GEOLOGICAL SURVEY

OPEN-FILE REPORT 80-1003

UNITED STATES
DEPARTMENT OF THE INTERIOR
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NSTL Station, Mississippi

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UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, Secretary

GEOLOGICAL SURVEY

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CONVERSION TABLE: METRIC UNITS TO INCH-POUND UNITS

Multiply	By	To obtain
kilometer (km)	0.6214	mile (mi)
meter (m)	3.281	foot (ft)
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
millimeter per day (mm/d)	0.03937	inch per day (in/d)
centimeter per minute (cm/min)	566.9	inch per day (in/d)
square centimeter per second (cm^2/s)	3.875	square foot per hour (ft^2/h)
degree Celsius (°C) + 17.78	1.8	degree Fahrenheit (°F)

In the conversions below, calorie means gram (small) calorie

calorie per cubic centimeter (cal/cm^3)	112.4	British thermal unit per cubic foot (Btu/ft^3)
calorie per square centimeter per minute (cal/cm^2min)	221.2	British thermal unit per square foot per hour (Btu/ft^2h)
calorie per square centimeter per degree Celsius ($cal/cm^2{}^oC$)	2.048	British thermal unit per square foot per degree Fahrenheit ($Btu/ft^2{}^oF$)
calorie per cubic centimeter per degree Celsius ($cal/cm^3{}^oC$)	62.43	British thermal unit per cubic foot per degree Fahrenheit ($Btu/ft^3{}^oF$)
calorie per gram per degree Celsius (cal/g^oC)	1.000	British thermal unit per pound per degree Fahrenheit (Btu/lb^oF)

BARREN AREA EVAPOTRANSPIRATION ESTIMATES GENERATED FROM ENERGY BUDGET MEASUREMENTS IN THE GILA RIVER VALLEY OF ARIZONA

By O. E. Leppanen

ABSTRACT

Estimates of evapotranspiration for 479 successive days were created by using energy budget measurements. The measurement point was on the 2-kilometer wide flood plain of the Gila River in east-central Arizona, about 18 kilometers above Coolidge Dam. The flood plain had been cleared of all tall vegetation for distances of about 20 kilometers upstream and 5 kilometers downstream from the measurement site. Chaining, raking, and burning had been used to clear the area immediately surrounding the measurement site about 6 months before measurements began. Ground cover was sparse volunteer Bermudagrass and scattered seepwillow for a distance of at least 1 kilometer in all directions from the measurement point.

The water table was estimated to be at a depth greater than 6 meters so most of the evaporated water came from rainfall, but some came from soil moisture deeper than 2 meters. The March to March water loss (evapotranspiration less rain) was about 47 millimeters, evapotranspiration demanding 377 millimeters. Daily rates varied from very small amounts of condensation to almost 5 millimeters of evapotranspiration.

INTRODUCTION

In 1971 and 1972 an attempt was made to measure evapotranspiration directly, using the energy-budget method, at a large cleared site which was initially devoid of tall vegetation. Although some sparse grass and other vegetation grew during the evapotranspiration measurement period, the site was considered to be in a near bare-ground condition.

This report briefly describes the site, the instrumentation, the data reduction and analysis procedures used, and lists the results. Project goals were to obtain a continuous record of daily evapotranspiration values for a period of at least one year. The measurement period actually was 479 days, from March 10, 1971, through June 30, 1972, during which adequate records were not obtained for 192 days. Daily evapotranspiration for each of the missing days was estimated by using interpolation methods.

The evapotranspiration measurement site was within the Gila River Phreatophyte Project study area which is shown in figure 1. The solid diamond, located between cross sections numbered 21 and 23, indicates the location of the study described in this report. The Gila River Phreatophyte Project, the study area of which was located just above San Carlos Reservoir in east-central Arizona, was a large-scale effort to measure water savings that might result from removal of riparian vegetation of little economic value. The overall plan of the phreatophyte project has been described by R. C. Culler 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). Measurements of water use (evapotranspiration) before and after removal of vegetation were made by using a water budget.

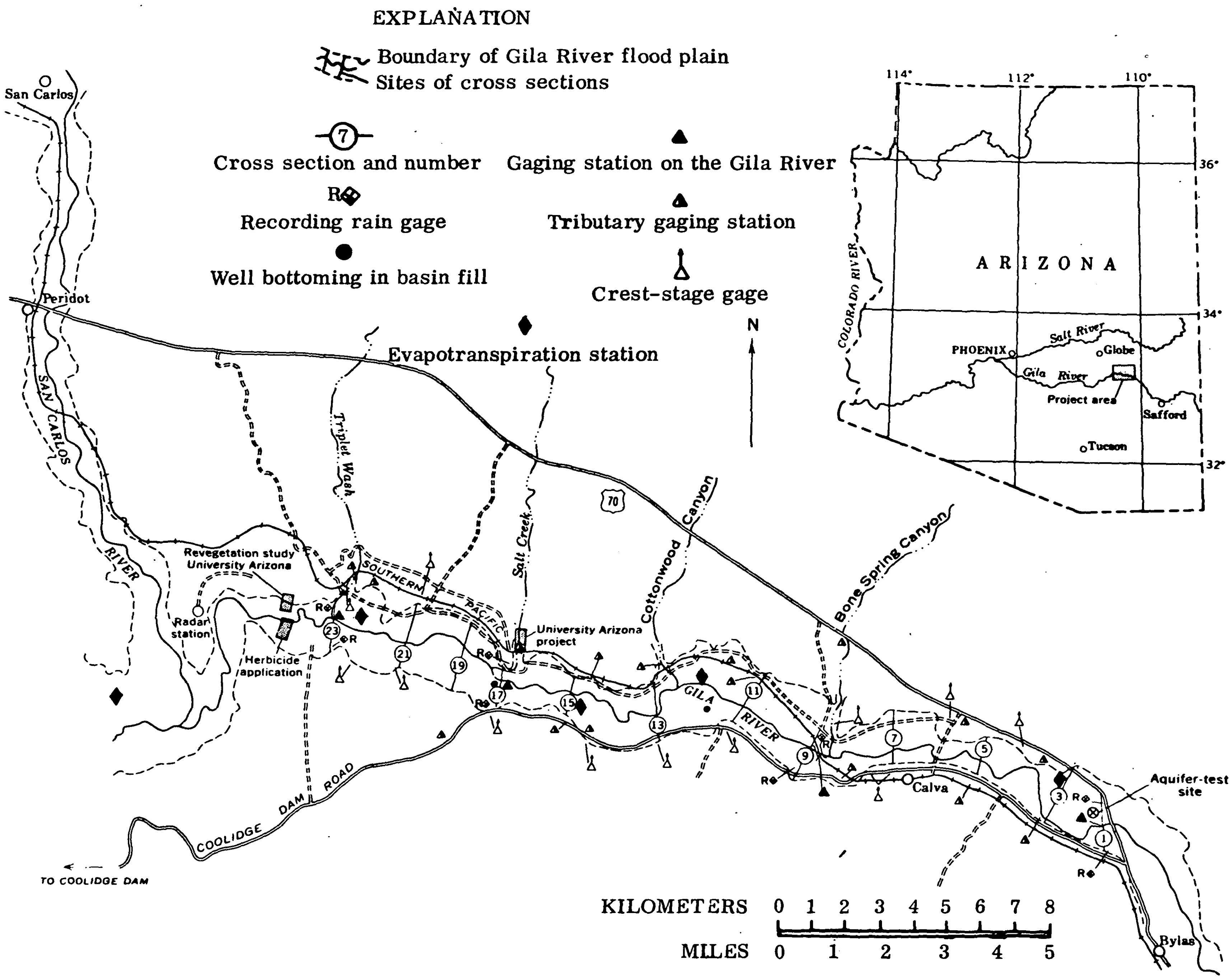

Figure 1.— Project area and instrumentation location.

The procedures described in this report do not depend upon a water budget. The results of this study, and of several similar studies to be subsequently reported, were to furnish estimates of evapotranspiration independent of those resulting from a water budget.

THE SITE

The site for evapotranspiration measurements was on a large, unobstructed flood plain terrace about 600 m north of the Gila River channel at an altitude of 780 m. (In the Gila River Phreatophyte Project orientation scheme it was designated location 22R2.) The wind fetch was clear for at least 500 m in all directions from the measurement point and the ground surface sloped gently (about 1:85) southward toward the river. The entire flood plain around the site had been cleared of Mesquite trees (*Prosopis* sp.) and associated vegetation by chaining, raking, and burning about 6 months before measurements began.

The soil is an alluvial deposit, a sandy silt loam. It appeared homogeneous to a depth of 2.3 m with no pronounced soil horizons readily discernable. No prominent, hard, caliche layer was observed, but some calcareous deposits were found between 25 and 40 cm deep. No mechanical or chemical analyses were made.

There was no observation well at the site, but the water table was estimated to be at a depth greater than 6 m using data from nearby wells and the river stages.

Vegetation cover was mostly sparse volunteer Bermudagrass (*Cynodon* sp.) which never grew very tall or dense because of the aridity and the range cattle grazing the vicinity. Response to rains was very rapid, however, with growth from dessicated tufts to 5-cm height occurring within a few days. Nevertheless, nothing resembling a developed sod existed and the site was considered to be in a nearly bare-soil condition. Scattered seepwillow (Baccharis sp.) grew to a height of about 1 m during the period of measurements. Figure 2 is a view looking south, showing the instrument mast and ground cover. The low angle of the photograph falsely accentuates the seepwillow density.

The climate at the site was severe, hot and dry. Rainfall during the measurement period totaled 370 mm for 479 days. Annual rainfall is usually distributed roughly equally between summer thunderstorms and winter rains, but during the first year of observations the distribution was 198 and 131 mm, respectively. The monsoon and its storms came early the second summer with 40 mm of rain falling in June 1972.

The gentle slope of the ground discouraged large ponding after rains, but the vegetation clearing operation had left many small irregularities which probably encouraged infiltration. Sheet runoff occurred on at least two occasions as evidenced by plant detritus left at the instrument mast base, along a wooden walkway, and at a recorder shelter. The net contribution of this runoff to soil moisture was unknown. For computations, it was assumed that just as much water ran off as ran onto the area, because the duration of the runoff could not be estimated.

INSTRUMENTATION

Use of an energy budget to measure evapotranspiration at a particular spot demands careful and, often, elaborate instrumentation. In this study the remoteness of the site, difficulty of access during poor weather periods, traveltime, and other considerations required instrumentation which could operate for periods of up to 2 weeks without attention.

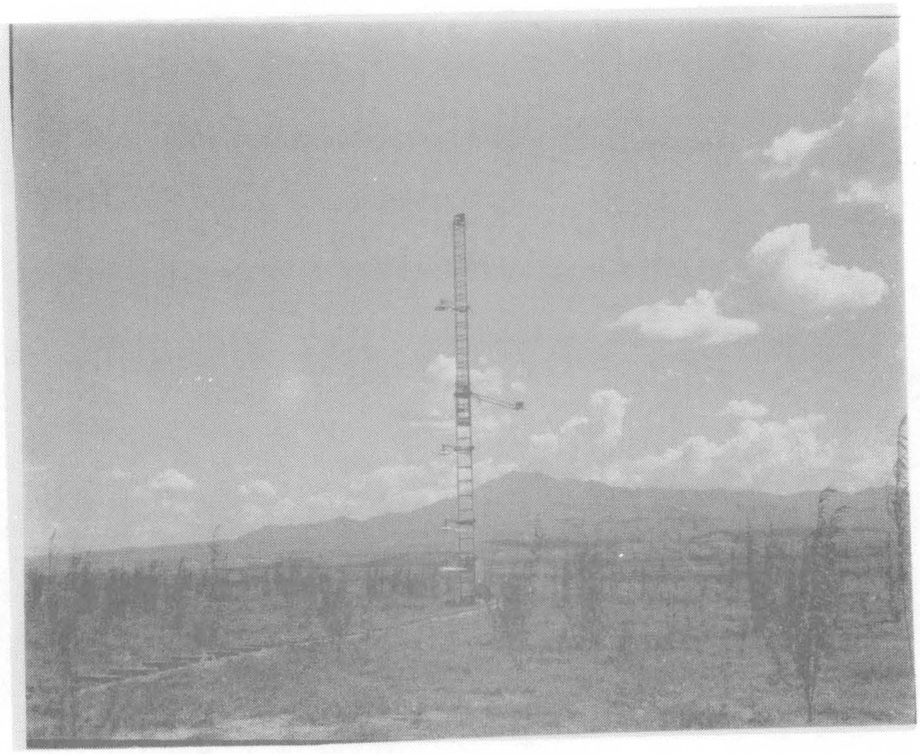

Figure 2.--Energy-budget evapotranspiration site showing ground cover and instrument mast. Photograph taken August 1971.

Service visits were to be made, in fortunate circumstances, at weekly intervals. The goal of obtaining continuous, daily evapotranspiration estimates required rugged, yet accurate, instrumentation that could be serviced with minimum effort.

Variables which must be measured for energy budget computations are: temperature and water-vapor gradients above the evaporating surface; net radiant energy flux; and changes in heat stored in the system being considered. In addition, changes in mass of the system brought about by rain or evaporated water may also be significant, as well as changes in vegetation mass or structure. These variables are the minimum number needed if the net laterally moved (advected) heat is small. Advected heat can be ignored when measurements are made relatively close to the surface of an appropriately large homogeneous area.

Instrumentation at the site was designed to measure very small evapotranspiration values. Vapor pressures at 1-, 2-, 4-, and 8-meter elevations were measured with the same wet- and dry-bulb psychrometer. This was done with a valve and pipe aspirator arrangement. The valve timing was controlled by the strip chart recorder used for recording all variables. The problem of matching psychrometers was eliminated as any small systematic error in the profile measurements was of little consequence because the gradient, or slope of the profile, was the required variable. A disadvantage was that four additional recorder channels were needed because turbulent and conductive heating in the pipes could raise intake air temperatures considerably before the sample reached the psychrometer. Figure 3 shows the psychrometric unit, shielded with aluminum foil. Heating-gas valves located above the psychrometer routed the air flow from each of the four sampling elevations to the psychrometer in a predetermined sequence.

Figure 3.--Wiring terminal box at instrument mast with aspirated wet- and dry-bulb psychrometer. Valves, above the psychrometer, select air-sample elevation to be measured.

All temperatures were measured with thermocouples. A wet- and dry-bulb temperature at each elevation was read once every 24 min. The recording system design was such that all temperatures would be reproducible to 0.1°C. Accuracy was usually about ±0.25°C with occasional upward drifting to +0.4°C. Psychrometric checks were made irregularly with an Assman-type aspirated psychrometer. Vapor pressures calculated from the Assman data were almost always slightly higher than those calculated from the field instrumentation.

Net radiant energy flux, or net radiation, was measured with an exposed-surface, ventilated, flat-plate thermopile radiometer of standard design. The radiometer faced solar south, was at 6-m elevation, and was 3.5 m out from the instrument mast. Radiometer output was recorded every 12 min. The radiometer error was probably between 1 percent and 8 percent, depending upon the condition of the flat plate surfaces. The plate was washed during every service visit and was resurfaced when needed. Occasional checks of the manufacturer's calibration were made, using a shading technique. These checks showed no reason to question or change the calibration.

Heat stored in the soil was measured using data from thermocouples at 50-, 100-, and 200-cm depths, and also at a nominal 2-cm depth. The 2-cm temperature was an approximation of surface soil temperature; attempts at shallower placement often resulted in the thermocouple becoming exposed. Each thermocouple was read once every 24 min. Temperatures at the four depths were sampled with thermocouples in two stacks, one located 2 m north and the other the same distance south of the instrument mast. In addition, two thermopile heat-flow plates were installed at the 50-cm depth, one in each thermocouple stack. These were also read once every 24 min.

Precipitation was measured with a non-recording gage at the site. Soil moisture measurements were made with a nuclear soil moisture meter at 30-cm increments down to 2.13 m. An additional measurement was made at 15 cm. Soil moisture was measured at approximate 2-week intervals. The access tube was located about 12 m from the mast.

Power for the instruments was supplied by a propane fueled motor-generator. With the uncomplicated instrumentation used, the most frequent cause of missing data was powerplant malfunction. The data recorder circuits which measured temperatures were subject to burnout when motor speed fell too low. Variability in motor speed also resulted in poor time scaling, but records were correctable when a mechanical clock-driven recorder was installed to monitor powerplant output.

Cattle frequently damaged the 1-m elevation aspirator assembly, and other piping, despite installation of a fence. Severe winds caused damage resulting in several weeks of missing data. Heavy rains resulted in some missing data, as did icing of the psychrometer wick. This last difficulty was alleviated significantly by the characteristic heating in the aspirator pipes, although, on rare occasions, cooling of the air sample from intake to psychrometer occurred.

When the powerplant was functioning, data quality was excellent. Overall data quantity was not. In 479 consecutive days of field operation, evapotranspiration for 192 days (40 percent) had to be estimated from partial data, empiricisms, or other information. Days with only a small amount of missing data, such as those during which a service visit occurred, were considered to have complete data. Of the 192 missing days, 58 were consecutive, from November 24, 1971, through January 20, 1972.

The meteorological data values needed for energy budget computations were printed on a strip chart by the recorder. Several attempts were made to collect records simultaneously on punched paper tape but none were satisfactory. An observation was made once each minute so a large amount of chart paper was accumulated.

DATA REDUCTION

Charts were reviewed, dated, folded, and filed in project office facilities. Time errors were corrected, usually to the closest 10 minutes. The record of each of the 23 variables measured was in millivolts; each was converted to physical quantities and these formed into 4-hour averages. All 4-hour averages were based on mean solar time. Obvious values of missing data were filled in. Water-vapor pressures at the four levels above the ground were computed from wet- and dry-bulb temperatures with programmable desk calculators.

Precipitation amounts from the rain gage were noted on the strip chart (along with any comments) during service visits. The rain amounts were distributed according to time and intensity from observation of the effect of the rains on the exposed plate of the radiometer. Rain amounts for missing days were estimated using data from several other rain gages, the nearest about 1 km distant.

Soil moisture readings were reduced by a computer to percentages by volume. Values at 15 cm, 30 cm, and 61 cm were weighted to calculate the average soil moisture stored in the top 50 cm of soil at each visit. A continuous daily record of soil moisture storage was then created by assuming a constant depletion rate between visits and adjusting for rains.

DATA ANALYSES

Evapotranspiration for each 4-hour period was first computed using the energy budget in Bowen ratio form:

$$ET = \frac{N + H - Q + P}{L(1 + BR)}$$

where

ET is evapotranspiration (cm/min),

N is net radiation (cal/cm^{2}min),

H is heat flow at 50-cm depth (cal/cm^{2}min),

Q is change-in-heat-storage in top 50-cm soil layer (cal/cm^{2}min),

P is heat content of rain (cal/cm^{2}min),

L is the latent heat of vaporization (cal/cm^3), and

BR is the Bowen ratio.

Each variable is discussed, in turn, below.

The net radiation, N, is the major source of energy available for evapotranspiration. With the measuring instrument at a 6-m elevation, 95 percent of its response resulted from the radiant flux between the upper hemisphere and a 55-m diameter circle on the ground surface. Thus the effect of foreign objects such as the mast base, and of local variations in ground cover was reduced. Because the air was usually quite dry, radiative diffusion between the instrument and the ground surface was not considered important.

The outputs of two heat-flow plates, 4 m apart, were averaged for an estimate of heat flow, H, through a plane in the soil at 50-cm depth.

Change-in-heat-storage, Q, in the 50-cm soil layer above the heat flow plates was calculated using classical methods based on the one-dimensional differential equation of heat conduction into a semi-infinite solid. The boundary condition was the 2-cm soil temperature and the period considered, P, was one day. A solution of the heat-flow equation suitable for use with small programmable desk calculators is

$$T(x,k) = \overline{T}(x) + \sum_N C_N \exp(-x\sqrt{N\pi/\alpha P}) \sin(2\pi Nk/P - x\sqrt{N\pi/\alpha P} + \phi_N) \quad (1)$$

where $T(x,k)$ is the temperature at depth x and time k, with constant thermal diffusivity, α. $\overline{T}(x)$ is the average daily temperature, such that its second derivative with respect to x vanishes. The small daily change in the average temperature is neglected and antecedent days are assumed similar to the day under consideration.

C_N and ϕ_N are daily constants at the boundary which were evaluated by elementary Fourier analysis. The calculators available allowed computation of four harmonics, $N = 1$ to 4, using hourly temperature values. This procedure was numerically adequate.

Methods to simplify computation of the daily constants were sought because of limited computational facilities and time available. Data from 35 selected days showed that the major amplitude coefficient, C_1, related well to the daily range of temperature, R. The second, third, and fourth coefficients could be found from the first by exponential attenuation according to the harmonic number, N, so that

$$C_N = R/\exp(\gamma N - \delta)$$

where γ and δ are parameters unique to the observation station site.

The first phase angles, ϕ_1, were found to deviate from their 35-sample average value by a function of the time of year, and by a small adjustment for varying soil moisture. The generalized value (in multiples of π) was given by

$$\hat{\phi}_1 = \overline{\phi}_1 + \overline{\Delta\phi}_1 + m \sin \left(\frac{2d - 163}{366} \pi\right)$$

where d is the day of the year, and m (0.067) is determined by least-squares regression.

The phase shift with increasing harmonic number could be estimated by introducing another station parameter, ε, defined as equal to $\overline{\phi}_2$, so that $\phi_N = \hat{\phi}_1 - \varepsilon^{N-1}$. Pi radians were added to the odd-numbered harmonics.

Equation 1 was integrated with respect to depth from $x = 0$ to $x = 48$ cm (thus neglecting the heat stored in the top 2 cm of soil and in vegetation). Evaluating at time k and $k + 4$ and then subtracting, yielded the change in average temperature, $\Delta\overline{T}$, over 4 hours. The resulting equation can be readily programmed for desk calculators:

$$\Delta\overline{T} = -R \sum_{N=1}^{4} v_N \tag{2}$$

where

$$v_N = \frac{\cos N\pi \sin N\pi/6}{\exp(\gamma N - \delta)} \left\{ \exp(-\theta_N) \left[\sin(\psi_N - \theta_N) + \cos(\psi_N - \theta_N) \right] - \left[\sin \psi_N + \cos \psi_N \right] \right\} , \tag{3}$$

$$\psi_N = \frac{N\pi}{12} (k + 2) + (\hat{\phi}_1 - \varepsilon^{N-1}) \pi , \tag{4}$$

and

$$\theta_N = 48 \sqrt{\pi N/\alpha P} . \tag{5}$$

To evaluate $\Delta\overline{T}$ the thermal diffusivity, α, must be known. The conventional methods of analyzing phase lag or amplitude attenuation with depth in order to determine α, proved unusable because of errors in and drifting of the 50-cm temperature value. Discrepancies were small, but they were of the same magnitude as the expected diurnal fluctuation at 50 cm. The approach finally chosen required finding circumstances in which evapotranspiration and convected heat are small, and also tend to balance one another. Twenty-one suitable 2-hr periods just before sunrise having strong temperature inversions and comparable net radiation values were found. Equations 2, 3, 4, and 5 were then solved for α by trial, allowing an energy flux imbalance of $N + H - Q = \pm 0.003$ cal/cm^{2}min, in which $Q = C_p\Delta\overline{T}$. The bulk heat capacity, C_p, is discussed below. Values of α ranged from 0.0013 to 0.0055 cm^2/sec, varying with soil moisture. This variation could not be described by any function more elaborate than a straight line: $10^3\alpha = -7.215 + 0.585(SM)$ where SM is the soil moisture by volume. The correlation coefficient was 0.723.

The unit heat capacity was estimated from the volume weight of a similar soil (1.47 g/cm^3), a typical mineral heat capacity (0.195 cal/g$^{\circ}$C), and the soil moisture fraction by weight. During a 4-hour interval the bulk heat capacity for the 50-cm soil layer was then

$$C_p = 0.060 + 0.002(SM)\ \text{cal/cm}^2\text{min}^{\circ}\text{C},$$

where SM is the percentage by volume.

The total ground heat contribution to the evapotranspiration equation was then $H - Q$.

Heat added with added mass from rain, P, was calculated by assuming a base temperature of zero Celsius and a rain temperature synthesized from the 1-m air intake temperature and vapor pressure, using Newton's method with the psychrometric equation. Heat (mass) subtracted by evapotranspiration was small, and at least partly compensated for by heat (mass) brought in from below the 50-cm soil layer. It was therefore neglected.

The latent heat of vaporization, L, is often taken to be constant in energy-budget studies. However, because of the wide range of temperatures encountered during this study, L was varied with temperature (the synthesized 1-m "wet bulb").

The Bowen ratio, BR, is the ratio of sensible heat convected vertically to the latent heat transported vertically. As such, it is proportional to the ratio of the temperature and water-vapor gradients with height. Because of the aridity and high temperatures at the evapotranspiration site, many problems arose in evaluating the Bowen ratio. This was especially true during hours when air temperature structure was in transition between the stable and unstable states.

Simple difference quotients (divided differences) calculated between various pairs of measurement levels gave widely different values to the ratio, resulting in widely varying evapotranspiration values. Some improvement resulted when the temperature and vapor gradients were evaluated using the LaGrange interpolation function, but many questionable values of the ratio remained, mostly during the morning period from 0400 to 0800 mean solar time. Because of the very small vapor gradients frequently encountered, ratio values were erratic, often of seeming improper sign.

The most useful values for the Bowen ratio, although not fully satisfactory, came from fitting logarithmic profiles to the temperature and vapor data. For this procedure, large computer facilities were necessary. Data from at least three of the four elevations had to be present before least-squares fits of temperatures or vapor pressures against the logarithms of the adjusted elevations were computed. A best-fit height used to adjust the elevations was determined from the five vapor pressure profiles computed following each rain event. This best-fit height may be considered analogous to the conventional displacement height, except that it was defined by all conditions of stability, not just the neutral case. Using trial values of the height, the mean-square error of all the fits was computed until a minimum error sum was found. The result was a height of 6 cm. This value was then used for all fits, temperature as well as vapor pressure.

The periods following rains were used because trials with temperature profiles and all vapor profiles failed to give definitive results. At this evapotranspiration measurement site, the availability of water was obviously a controlling variable.

That the profiles are not always theoretically logarithmic was not a primary consideration. The purpose was to obtain useful slopes with an appropriate model using the field data. This was necessary because the field data themselves, due to measurement, sampling, averaging, or roundoff errors, were not suitable for direct use.

Not all Bowen ratios calculated from fitted profiles were satisfactory, so editing procedures were introduced. If all four vapor pressures were identical, evapotranspiration, *ET*, was set to zero. Occasional instances of *BR* near minus one were handled by setting *ET* equal to zero when the vapor gradient indicated condensation. When condensation was indicated (*ET* negative), but with an evaporating gradient, *ET* was considered zero. Most of the anomalous situations occurred in the dry months of April, May, and June.

After editing, a number of suspicious *ET* values still remained in the 1,893 4-hour periods analyzed. Also, of the 981 periods not analyzed, some could not be used because vapor pressure data were missing although temperature data were present. If the convection term in the energy balance could be estimated, these periods would be useable. Accordingly, an analysis of the convected heat was made even though there were no wind data for stability computations.

Convected heat, *C*, was first calculated for 4-hour periods in which the *ET* equation in Bowen ratio form gave a non-absurd result. The corresponding temperature slopes (gradients) were available from the profile models. Then the study period was divided into three seasons, one of winter, and two of spring-summer. Different warm seasons were used because soil moisture was much higher in the spring of 1972 than in 1971, suggesting less convection might occur for the same temperature slope. Within each season, six relations relating convection to slope were found next by fitting least-squares lines to each of the six daily 4-hour sets of data.

The 18 least-squares lines were then analyzed, outlying points were rejected, and new lines fitted, constrained to pass through the origin. An example of such a fit is shown in figure 4 for the spring-summer of 1971, for the 4-hour period between solar noon and 1600. The dimension

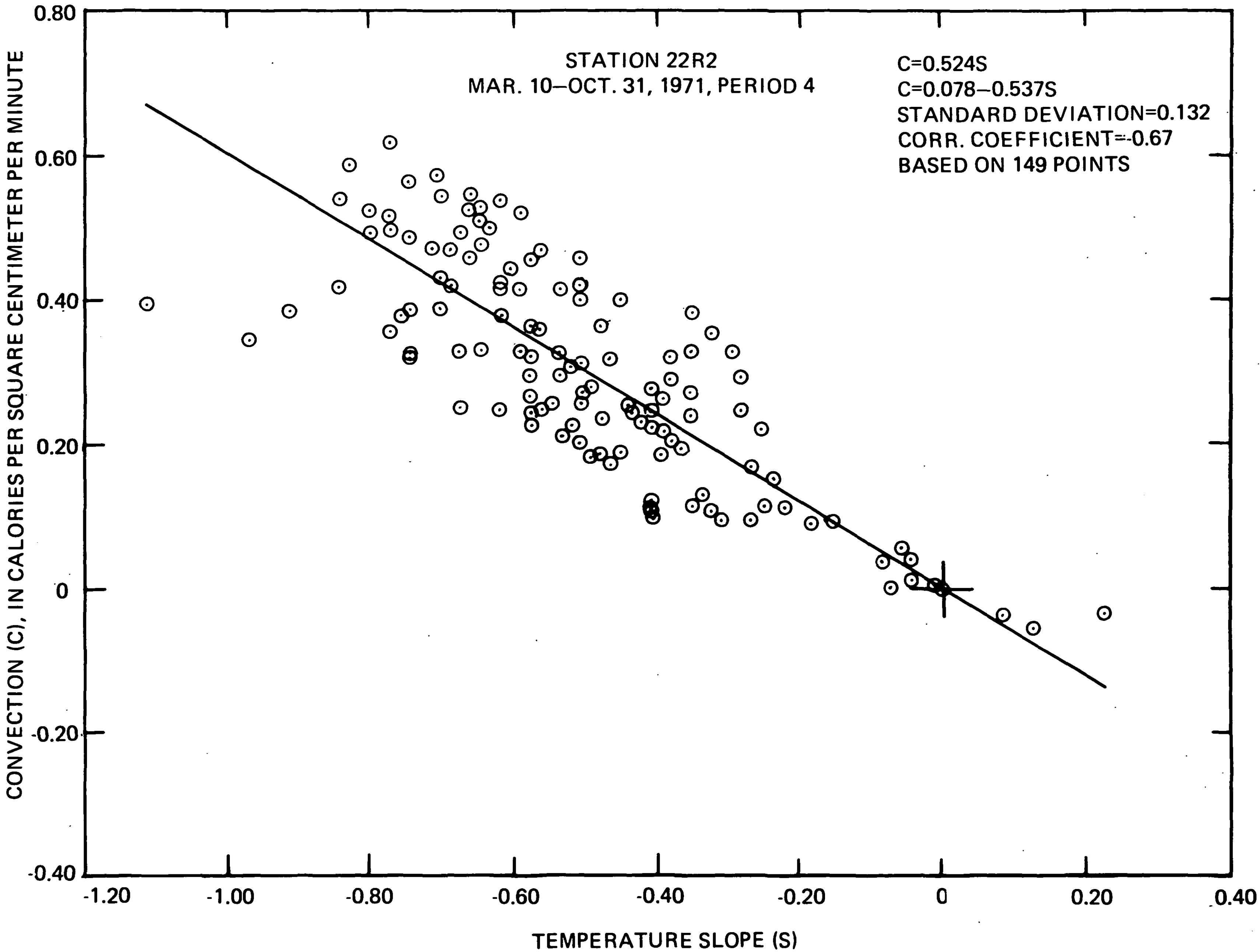

Figure 4.—Convected heat variation with temperature gradient, 1200-1600, spring-summer, 1971.

of the abscissa is not shown because the logarithms of adjusted elevations (in cm) were used in determining a slope value. The *ET* was then recalculated for the questionable periods and estimated for those lacking vapor data, where possible.

Because *ET*, calculated using the various editing, recalculating, and estimating procedures would have varying degrees of accuracy, a quality scale of 0 to 9 was set up for the 4-hour periods. For values 0-3, the scale applied to daily *ET* figures indicates the number of 4-hour periods per day which were not computed wholly from direct energy budget data. Most often the periods 0400-0800 and 1600-2000 were the ones adjusted. The number 4 indicates that more than one type of adjusting procedure was applied to at least one period per day. The numbers 5, 6, and 7 were not required to describe the daily averages. The quality scale values 8 and 9 are explained below. When more than three periods per day required adjustment, the day was considered missing.

The evapotranspiration rate was calculated on a daily basis as the average of six 4-hour periods. One or more missing periods invalidated the daily average. In the 479-day experimental period, 192 days were wholly missing, leaving only 287 complete days.

A station for gathering data to compute evaporation from Lake San Carlos was at Coolidge Dam, about 18 km distant. Variables measured there were total hemispherical radiation, its short wave (less than 3000 nm) component, and the wet- and dry-bulb temperatures. A number of statistical models were devised, using these variables, to test modeled *ET* against measured *ET*. Hemispherical radiation, which correlated strongly with the net radiation at the evapotranspiration site, proved to be a poor variable with which to estimate *ET* because soil moisture was not available much of the time. In fact, no combination of variables from the Coolidge Dam site alone provided a satisfactory linear model.

Continuous records of soil moisture and precipitation were available at the experiment site. Because the immediate function of a model was to be interpolation, and not extension of the *ET* data, these records were added to those from the lake to create variables for the models. The most successful linear model used as variables: square of temperature, vapor deficit, soil moisture (which was not very significant), and one called drying power. This last variable consisted of the product of vapor deficit times the change-in-soil-moisture from the previous day adjusted for rain. The change-in-soil-moisture was that in the top 50-cm soil layer. Data were divided into two sets, summer (April through October) and winter (November through March). The coefficient of multiple correlation for summer data was 0.76 but for winter only 0.32. The winter model analysis attributed no significance (at the 0.1 level) to the variables drying power and vapor deficit and very little to soil moisture. Although the winter model was poor, evapotranspiration rates were relatively low because of seasonal effects.

Where data existed at the Coolidge Dam site, the two models were used to fill in the daily *ET* record. Such *ET* values were rated 8 on the quality scale. The remaining gaps in the record were filled by estimates based on soil moisture and precipitation records and with data from a class A weather station (with evaporation pan) at the dam. Fifty-one days so estimated were rated 9, of which 19 days (17 successive) fell between December 17 and January 17.

RESULTS

The daily evapotranspiration and the water loss, defined as evapotranspiration less rainfall, is listed in table 1. Table 1 also lists the relative quality of the evapotranspiration value. Zero is best, 9 worst. The daily course of evapotranspiration and rainfall is shown in figure 5. The maximum daily rate measured was just under 5 mm. Some of the twelve days with apparent condensation may actually have had some since heavy dew was observed on a few occasions. The quick response of evapotranspiration to rain is clear, especially after the unusual rain on April 15, 1971, and again after July 16, 1971 when the summer monsoon rains began. Some response is evident even in November, after the rain of the 15th.

Throughout the course of the year evapotranspiration continued, even during the long dry periods which began each January. Evapotranspiration during 1972, March to July, was somewhat greater than the same period in 1971 because of ample soil moisture storage. Very little soil moisture was available in 1971, when moisture in the top 50-cm layer of the soil was about 18 percent by volume (12 percent by weight) in March and then decreased to less than 14 percent by volume (9 percent by weight) by mid-July. Nevertheless, evapotranspiration continued.

Soil moisture observations to a 2.13-m depth were made on March 16 and July 6, 1971. Rain totaling 11.3 mm, fell on April 15. A plot of the total soil-moisture-loss rate from March 16 to July 6, 1971, above each of the eight available measurement depths is shown in figure 6. The curve has appreciable slope at the 2.13-m depth, indicating that soil moisture depletion occurs at even greater depths. Presumably most

TABLE 1. -- DAILY EVAPOTRANSPIRATION (ET) AND LOSS, IN MM

DATE	QUAL	ET	LOSS	DATE	QUAL	ET	LOSS	DATE	QUAL	ET	LOSS	DATE	QUAL	ET	LOSS
3-10-71	4	0.07	0.07	4-19-71	2	0.04	0.04	5-29-71	1	0.30	0.30	7- 8-71	8	1.47	1.47
3-11-71	3	0.41	0.41	4-20-71	8	0.61	0.61	5-30-71	0	0.80	0.80	7- 9-71	3	1.63	1.63
3-12-71	8	0.23	0.23	4-21-71	3	0.67	0.67	5-31-71	1	0.49	0.49	7-10-71	1	0.94	0.94
3-13-71	3	0.21	0.21	4-22-71	3	0.71	0.71	6- 1-71	2	0.51	0.51	7-11-71	2	1.59	1.59
3-14-71	2	-0.05	-0.05	4-23-71	3	0.88	0.88	6- 2-71	3	-0.08	-0.08	7-12-71	0	1.38	1.38
3-15-71	8	0.17	0.12	4-24-71	3	0.91	0.91	6- 3-71	2	0.51	0.51	7-13-71	2	1.16	1.16
3-16-71	8	0.24	0.24	4-25-71	3	0.84	0.84	6- 4-71	2	0.04	0.04	7-14-71	2	0.38	0.33
3-17-71	8	0.26	0.26	4-26-71	3	0.67	0.67	6- 5-71	8	0.50	0.50	7-15-71	2	1.77	1.77
3-18-71	8	0.16	0.16	4-27-71	3	0.73	0.73	6- 6-71	8	0.51	0.51	7-16-71	3	2.35	-3.25
3-19-71	8	0.19	0.19	4-28-71	3	0.70	0.70	6- 7-71	9	0.50	0.50	7-17-71	1	4.04	4.04
3-20-71	8	0.36	0.36	4-29-71	3	0.86	0.86	6- 8-71	9	0.50	0.50	7-18-71	1	2.24	2.24
3-21-71	8	0.28	0.28	4-30-71	3	0.92	0.92	6- 9-71	9	0.50	0.50	7-19-71	3	2.24	-0.76
3-22-71	8	0.28	0.28	5- 1-71	3	1.05	1.05	6-10-71	9	0.50	0.50	7-20-71	3	4.48	4.48
3-23-71	8	0.35	0.35	5- 2-71	3	1.09	1.09	6-11-71	9	0.55	0.55	7-21-71	3	2.96	1.86
3-24-71	8	0.34	0.34	5- 3-71	3	0.64	0.64	6-12-71	2	0.60	0.60	7-22-71	3	3.11	2.61
3-25-71	8	0.33	0.33	5- 4-71	3	0.48	0.48	6-13-71	1	1.83	1.83	7-23-71	3	2.14	1.34
3-26-71	1	0.55	0.55	5- 5-71	3	0.51	0.51	6-14-71	9	1.81	1.81	7-24-71	2	3.14	2.34
3-27-71	0	0.73	0.73	5- 6-71	3	0.57	0.57	6-15-71	1	1.36	1.36	7-25-71	3	3.53	2.73
3-28-71	0	0.32	0.32	5- 7-71	3	0.61	0.61	6-16-71	1	0.58	0.58	7-26-71	8	2.41	2.41
3-29-71	1	-0.01	0.0	5- 8-71	3	0.60	0.60	6-17-71	1	0.31	0.31	7-27-71	8	2.45	-0.05
3-30-71	2	-0.05	-0.05	5- 9-71	8	0.65	0.65	6-18-71	2	0.36	0.36	7-28-71	8	2.30	2.30
3-31-71	2	-0.09	-0.09	5-10-71	3	0.54	0.54	6-19-71	1	0.45	0.45	7-29-71	8	2.43	2.43
4- 1-71	2	0.0	0.0	5-11-71	3	0.75	0.75	6-20-71	4	0.01	0.01	7-30-71	8	2.32	-17.30
4- 2-71	2	0.01	0.01	5-12-71	3	0.80	0.80	6-21-71	2	0.42	0.42	7-31-71	8	2.40	2.40
4- 3-71	2	0.03	0.03	5-13-71	3	0.89	0.89	6-22-71	1	1.07	1.07	8- 1-71	8	4.96	-1.14
4- 4-71	2	-0.04	-0.04	5-14-71	2	1.39	1.39	6-23-71	1	1.05	1.05	8- 2-71	9	1.79	1.79
4- 5-71	2	-0.04	-0.04	5-15-71	2	1.23	1.23	6-24-71	1	0.84	0.84	8- 3-71	8	2.17	2.17
4- 6-71	3	-0.06	-0.06	5-16-71	2	1.25	1.25	6-25-71	0	0.81	0.81	8- 4-71	8	2.24	2.24
4- 7-71	1	0.26	0.26	5-17-71	1	0.92	0.92	6-26-71	8	1.31	1.31	8- 5-71	4	3.51	2.01
4- 8-71	1	0.14	0.14	5-18-71	1	0.66	0.66	6-27-71	9	1.30	1.30	8- 6-71	2	2.74	2.74
4- 9-71	8	0.67	0.67	5-19-71	2	0.62	0.62	6-28-71	9	1.25	1.25	8- 7-71	2	2.32	2.32
4-10-71	3	0.74	0.74	5-20-71	0	1.16	1.16	6-29-71	2	1.28	1.28	8- 8-71	1	2.36	2.36
4-11-71	2	-0.05	-0.05	5-21-71	2	1.12	1.12	6-30-71	2	0.74	0.74	8- 9-71	8	2.08	-13.40
4-12-71	2	0.73	0.73	5-22-71	2	0.37	0.37	7- 1-71	2	1.78	1.78	8-10-71	8	1.90	-1.10
4-13-71	2	0.62	0.62	5-23-71	1	0.35	0.35	7- 2-71	3	0.40	0.40	8-11-71	8	2.08	2.08
4-14-71	2	-0.18	-0.18	5-24-71	1	0.51	0.51	7- 3-71	1	0.63	0.63	8-12-71	8	2.11	-3.99
4-15-71	1	1.57	-9.73	5-25-71	1	1.29	1.29	7- 4-71	2	0.30	0.30	8-13-71	8	2.12	-6.48
4-16-71	1	0.31	0.31	5-26-71	1	1.24	1.24	7- 5-71	0	1.33	1.33	8-14-71	8	2.26	2.21
4-17-71	1	-0.10	-0.10	5-27-71	0	0.12	0.12	7- 6-71	2	0.30	0.25	8-15-71	8	2.42	-14.70
4-18-71	2	-0.09	-0.09	5-28-71	8	0.48	0.48	7- 7-71	8	1.88	1.88	8-16-71	9	1.76	1.76

TABLE 1. -- DAILY EVAPOTRANSPIRATION (ET) AND LOSS, IN MM

DATE	QUAL	ET	LOSS	DATE	QUAL	ET	LOSS	DATE	QUAL	ET	LOSS	DATE	QUAL	ET	LOSS
8-17-71	0	3.19	3.19	9-26-71	3	1.17	1.17	11- 5-71	8	0.81	0.81	12-15-71	8	0.09	0.09
8-18-71	4	2.91	2.91	9-27-71	9	1.15	1.15	11- 6-71	8	0.85	0.85	12-16-71	8	0.13	0.13
8-19-71	8	2.63	-7.87	9-28-71	1	1.22	1.22	11- 7-71	8	0.90	0.90	12-17-71	8	0.18	0.18
8-20-71	2	4.03	-1.37	9-29-71	3	1.19	-31.00	11- 8-71	8	0.80	0.80	12-18-71	9	0.16	0.16
8-21-71	2	4.62	4.57	9-30-71	2	1.03	-42.50	11- 9-71	0	0.54	0.54	12-19-71	9	0.15	0.15
8-22-71	2	4.45	4.45	10- 1-71	3	0.90	0.90	11-10-71	0	0.44	0.44	12-20-71	9	0.14	0.14
8-23-71	9	1.93	1.93	10- 2-71	0	3.35	3.35	11-11-71	0	0.30	0.30	12-21-71	9	0.13	0.13
8-24-71	8	3.59	3.09	10- 3-71	2	1.01	1.01	11-12-71	0	0.64	0.64	12-22-71	9	0.11	0.11
8-25-71	8	3.37	3.37	10- 4-71	3	2.78	0.48	11-13-71	1	0.30	0.30	12-23-71	9	0.10	0.10
8-26-71	2	4.94	4.94	10- 5-71	2	3.30	3.30	11-14-71	1	0.31	0.31	12-24-71	9	0.10	0.10
8-27-71	2	1.98	1.98	10- 6-71	1	2.46	2.46	11-15-71	0	0.30	-3.10	12-25-71	9	0.09	0.09
8-28-71	1	3.74	3.74	10- 7-71	1	2.83	2.83	11-16-71	4	0.94	-4.06	12-26-71	9	0.16	-7.64
8-29-71	2	4.10	4.10	10- 8-71	2	2.26	0.66	11-17-71	1	1.00	1.00	12-27-71	9	0.40	0.40
8-30-71	8	4.09	4.09	10- 9-71	1	1.94	1.94	11-18-71	1	0.49	0.49	12-28-71	9	0.30	0.0
8-31-71	4	4.50	4.45	10-10-71	2	1.56	1.56	11-19-71	1	1.43	1.43	12-29-71	9	0.20	0.20
9- 1-71	2	1.76	-8.44	10-11-71	1	1.16	1.16	11-20-71	1	0.34	0.34	12-30-71	9	0.13	0.13
9- 2-71	1	3.03	0.33	10-12-71	9	1.41	1.41	11-21-71	1	0.56	-1.84	12-31-71	9	0.12	0.12
9- 3-71	2	1.33	0.83	10-13-71	0	1.78	1.78	11-22-71	1	0.48	0.48	1- 1-72	9	0.11	0.11
9- 4-71	2	4.17	4.17	10-14-71	1	1.20	1.20	11-23-71	1	0.18	0.18	1- 2-72	9	0.10	0.10
9- 5-71	2	3.10	3.10	10-15-71	2	2.57	-3.23	11-24-71	8	0.15	0.15	1- 3-72	9	0.08	0.08
9- 6-71	8	2.96	2.96	10-16-71	2	1.74	-15.80	11-25-71	8	0.19	0.19	1- 4-72	8	0.08	0.08
9- 7-71	9	2.01	2.01	10-17-71	4	0.33	-17.20	11-26-71	8	0.17	0.17	1- 5-72	8	0.09	0.09
9- 8-71	8	3.14	3.14	10-18-71	8	1.27	-10.20	11-27-71	8	0.19	0.19	1- 6-72	8	0.12	0.12
9- 9-71	1	4.49	4.49	10-19-71	0	1.11	1.11	11-28-71	8	0.19	0.19	1- 7-72	8	0.20	0.20
9-10-71	1	2.30	2.30	10-20-71	1	1.34	1.34	11-29-71	9	0.14	0.14	1- 8-72	8	0.32	0.32
9-11-71	2	2.30	2.30	10-21-71	0	1.55	1.55	11-30-71	8	0.09	0.09	1- 9-72	8	0.28	0.28
9-12-71	2	2.95	2.95	10-22-71	0	2.20	2.20	12- 1-71	8	0.18	-1.52	1-10-72	9	0.26	0.26
9-13-71	9	2.04	2.04	10-23-71	1	1.43	1.43	12- 2-71	8	0.12	0.12	1-11-72	8	0.24	0.24
9-14-71	1	2.78	2.78	10-24-71	3	1.63	-5.97	12- 3-71	8	0.07	0.07	1-12-72	8	0.30	0.30
9-15-71	2	3.08	3.08	10-25-71	2	1.48	-0.32	12- 4-71	8	0.0	-3.00	1-13-72	8	0.39	0.39
9-16-71	1	2.22	2.22	10-26-71	1	1.25	0.25	12- 5-71	8	0.10	0.10	1-14-72	8	0.39	0.39
9-17-71	2	3.11	3.05	10-27-71	0	0.56	0.56	12- 6-71	8	0.0	0.0	1-15-72	8	0.41	0.41
9-18-71	0	3.44	3.44	10-28-71	2	0.36	0.36	12- 7-71	9	0.08	-13.90	1-16-72	8	0.40	0.40
9-19-71	1	2.23	2.23	10-29-71	1	0.88	0.88	12- 8-71	8	0.07	-6.53	1-17-72	9	0.34	0.34
9-20-71	9	1.51	1.51	10-30-71	1	1.22	1.22	12- 9-71	8	0.11	0.11	1-18-72	8	0.29	0.29
9-21-71	1	1.41	1.41	10-31-71	0	0.79	0.79	12-10-71	8	0.11	0.11	1-19-72	8	0.31	0.31
9-22-71	1	0.87	0.87	11- 1-71	1	1.07	1.07	12-11-71	8	0.10	0.10	1-20-72	8	0.33	0.33
9-23-71	1	1.56	1.55	11- 2-71	0	0.71	0.71	12-12-71	8	0.11	0.11	1-21-72	0	0.53	0.53
9-24-71	1	2.04	2.04	11- 3-71	0	1.14	1.14	12-13-71	9	0.14	-4.65	1-22-72	1	0.52	0.52
9-25-71	2	0.76	0.75	11- 4-71	3	0.85	0.85	12-14-71	8	0.11	-0.19	1-23-72	0	0.42	0.42

TABLE 1. -- DAILY EVAPOTRANSPIRATION (ET) AND LOSS, IN MM

DATE	QUAL	ET	LOSS	DATE	QUAL	ET	LOSS	DATE	QUAL	ET	LOSS	DATE	QUAL	ET	LOSS
1-24-72	1	0.07	0.07	3- 4-72	3	0.69	0.69	4-13-72	8	0.58	0.58	5-23-72	2	1.31	1.31
1-25-72	2	0.11	0.11	3- 5-72	3	0.72	0.72	4-14-72	2	0.29	0.29	5-24-72	1	2.52	2.52
1-26-72	2	0.35	0.35	3- 6-72	9	0.73	0.73	4-15-72	1	0.38	0.38	5-25-72	3	0.99	0.99
1-27-72	1	0.06	0.06	3- 7-72	1	0.17	0.17	4-16-72	2	0.65	0.65	5-26-72	2	0.34	0.34
1-28-72	1	0.08	0.08	3- 8-72	2	0.0	0.0	4-17-72	9	0.40	0.40	5-27-72	2	0.14	0.14
1-29-72	0	0.60	0.60	3- 9-72	1	0.12	0.12	4-18-72	1	0.33	0.33	5-28-72	4	0.27	0.27
1-30-72	0	0.29	0.29	3-10-72	2	0.30	0.30	4-19-72	1	0.57	0.57	5-29-72	8	1.24	1.24
1-31-72	9	0.29	0.29	3-11-72	3	0.67	0.67	4-20-72	0	0.69	0.69	5-30-72	2	1.60	1.60
2- 1-72	1	-0.01	0.0	3-12-72	3	0.65	0.65	4-21-72	1	1.64	1.64	5-31-72	1	2.32	2.32
2- 2-72	1	0.24	0.24	3-13-72	3	0.60	0.60	4-22-72	0	0.74	0.74	6- 1-72	2	0.97	0.97
2- 3-72	0	0.11	0.11	3-14-72	3	0.59	0.59	4-23-72	3	0.77	0.77	6- 2-72	2	1.97	0.27
2- 4-72	0	0.41	0.41	3-15-72	3	0.62	0.62	4-24-72	9	0.77	0.77	6- 3-72	3	1.49	0.69
2- 5-72	2	0.48	0.48	3-16-72	3	0.60	0.60	4-25-72	8	0.77	0.77	6- 4-72	2	0.99	-0.51
2- 6-72	0	0.34	0.34	3-17-72	0	1.29	1.29	4-26-72	3	0.34	0.34	6- 5-72	8	1.80	1.80
2- 7-72	1	0.27	0.27	3-18-72	1	1.20	1.20	4-27-72	4	0.30	0.30	6- 6-72	1	1.18	0.08
2- 8-72	2	0.04	0.04	3-19-72	1	1.56	1.56	4-28-72	3	0.13	0.13	6- 7-72	1	1.54	-5.06
2- 9-72	0	0.27	0.27	3-20-72	3	0.62	0.62	4-29-72	3	0.24	0.24	6- 8-72	2	2.37	-2.53
2-10-72	1	0.79	0.79	3-21-72	9	0.62	0.62	4-30-72	1	0.90	0.90	6- 9-72	1	0.54	0.54
2-11-72	1	0.58	0.58	3-22-72	3	0.56	0.56	5- 1-72	0	0.95	0.95	6-10-72	2	1.16	1.16
2-12-72	0	0.73	0.73	3-23-72	2	0.84	0.84	5- 2-72	8	0.96	0.96	6-11-72	1	1.32	1.32
2-13-72	0	0.49	0.49	3-24-72	1	1.04	1.04	5- 3-72	2	2.02	2.02	6-12-72	9	1.91	1.91
2-14-72	2	0.22	0.22	3-25-72	2	0.48	0.48	5- 4-72	4	0.21	0.21	6-13-72	1	2.01	2.01
2-15-72	2	0.03	0.03	3-26-72	0	1.18	1.18	5- 5-72	3	0.50	0.50	6-14-72	2	1.94	1.94
2-16-72	0	0.36	0.36	3-27-72	1	0.46	0.46	5- 6-72	4	0.35	0.35	6-15-72	2	3.09	3.09
2-17-72	1	0.07	0.07	3-28-72	1	1.09	1.09	5- 7-72	2	1.06	1.06	6-16-72	1	2.19	2.19
2-18-72	8	0.43	0.43	3-29-72	0	0.26	0.26	5- 8-72	9	1.00	1.00	6-17-72	2	2.44	2.44
2-19-72	8	0.53	0.53	3-30-72	1	0.44	0.44	5- 9-72	4	0.47	0.47	6-18-72	2	2.58	2.58
2-20-72	8	0.53	0.53	3-31-72	3	0.53	0.53	5-10-72	4	0.41	0.41	6-19-72	8	2.32	2.32
2-21-72	8	0.51	0.51	4- 1-72	2	0.28	0.28	5-11-72	2	1.47	1.47	6-20-72	2	2.36	2.36
2-22-72	9	0.52	0.52	4- 2-72	2	1.00	1.00	5-12-72	4	1.09	1.09	6-21-72	1	2.67	1.17
2-23-72	8	0.54	0.54	4- 3-72	9	0.88	0.88	5-13-72	3	1.51	1.51	6-22-72	1	2.51	-19.10
2-24-72	8	0.48	0.48	4- 4-72	3	0.92	0.92	5-14-72	2	2.36	2.36	6-23-72	0	3.89	3.89
2-25-72	8	0.51	0.51	4- 5-72	3	0.28	0.28	5-15-72	9	1.06	1.06	6-24-72	0	2.62	2.62
2-26-72	9	0.52	0.52	4- 6-72	1	1.03	1.03	5-16-72	4	0.89	0.89	6-25-72	2	2.32	2.32
2-27-72	9	0.54	0.54	4- 7-72	0	0.68	0.68	5-17-72	3	1.80	1.80	6-26-72	8	1.83	1.83
2-28-72	9	0.56	0.56	4- 8-72	3	0.76	0.76	5-18-72	3	1.91	1.91	6-27-72	2	2.51	2.51
2-29-72	8	0.57	0.57	4- 9-72	3	0.68	0.68	5-19-72	3	2.38	2.38	6-28-72	2	2.99	2.99
3- 1-72	8	0.63	0.63	4-10-72	3	0.77	0.77	5-20-72	3	1.18	1.18	6-29-72	2	3.77	3.77
3- 2-72	9	0.62	0.62	4-11-72	4	0.85	0.85	5-21-72	2	2.28	2.28	6-30-72	3	2.32	2.32
3- 3-72	8	0.60	0.60	4-12-72	3	1.00	1.00	5-22-72	9	1.38	1.38				

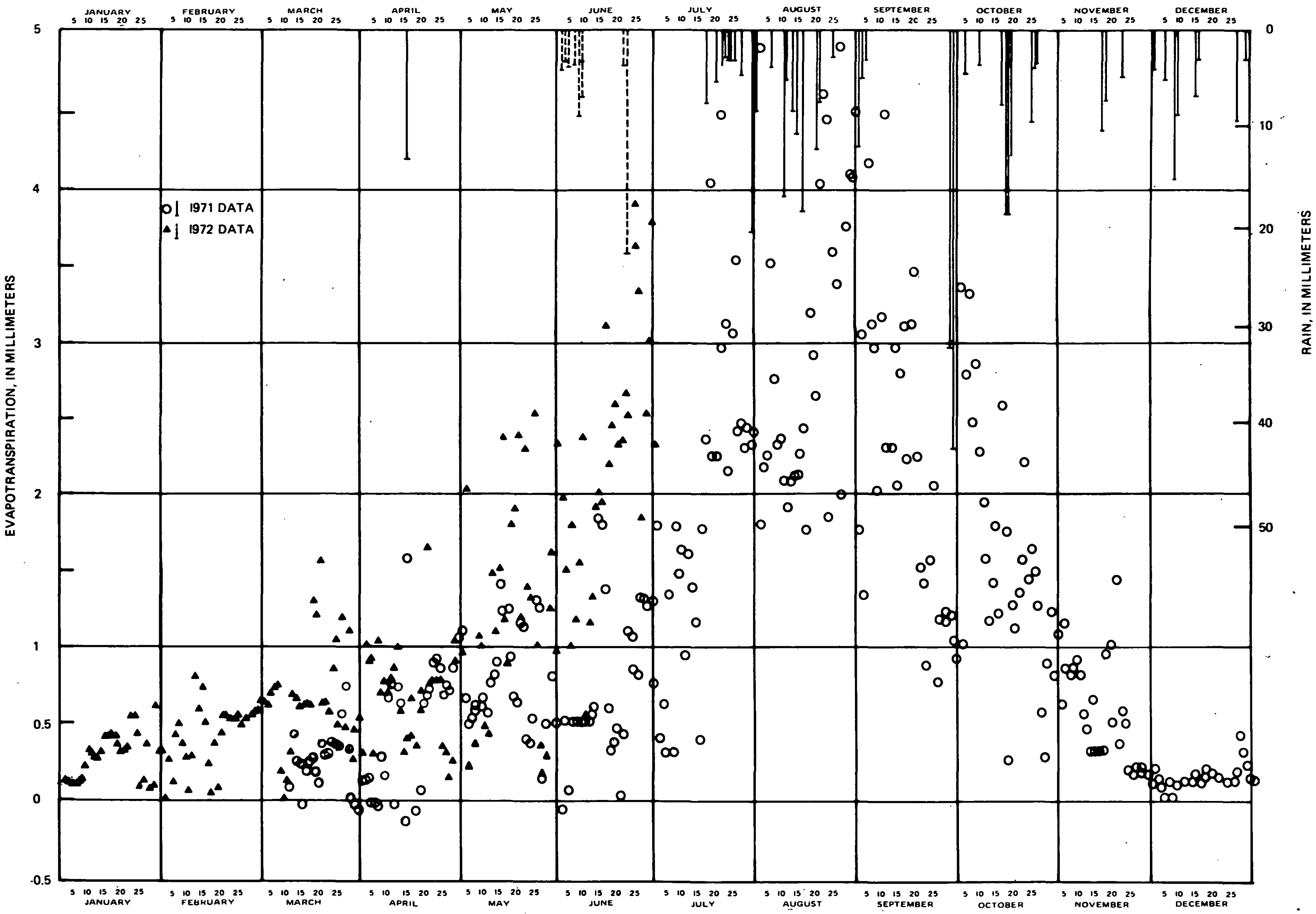

Figure 5.--Daily evapotranspiration and precipitation, 1971 and 1972.

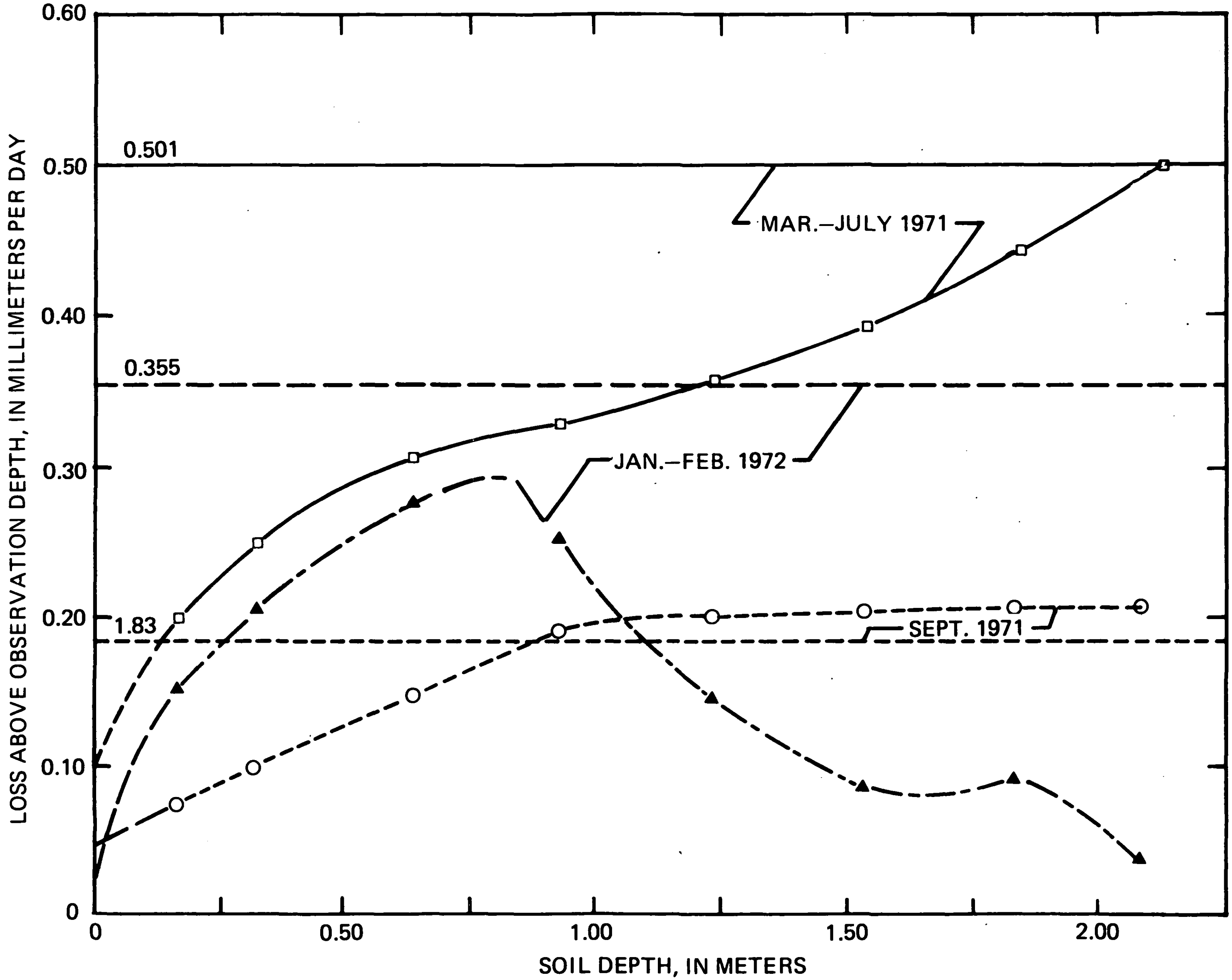

Figure 6.—Cumulative soil moisture loss with depth, adjusted for rain, from March 16 to July 6, 1971, from September 1 to 27, 1971, and from January 25 to February 25, 1972. For the September period, multiply the vertical scale by ten. Horizontal lines represent average losses for the periods calculated from energy budget data.

of the soil moisture went into evapotranspiration by direct evaporation from the soil. It is doubtful whether sparse volunteer Bermudagrass could deplete soil moisture much below 30 cm, and mature turf much below 120 cm. Downward movement of the soil moisture was unlikely because, except for the temporary effect of the one rain event, soil moisture always increased with depth.

Soil moisture observations were also made on August 31 and September 28, 1971, following rains totaling 109 mm in July and August. In early September, 13 mm more rain fell. Soil moisture in the top 50 cm of soil varied from 21 percent by volume near the start of the period to 15 percent at the end. The cumulative loss plotted against depth, also shown in figure 6, has positive slope at the 2.13-m depth, just as does the earlier March-July dry period. The vertical scale for the September data is ten times that marked in figure 6.

Evapotranspiration continues in winter when the vegetation is dormant. After a wet fall (197 mm of rain fell between September 28 and December 28) in 1971, no rain fell until June 1972. The cumulative soil moisture loss between observations on January 25 and February 25, 1972, is plotted against depth in figure 6. The trend of the curve is the same as the March-July 1971 trend up to the 0.61-m depth. This similarity of shape suggests that the loss was due to soil evaporation. The weather was cool (1-m average air temperature 6.3°C) but the soil was damp (50-cm soil moisture, 24 percent by volume). Below 0.61 m, the volumetric soil moisture increased at all but one measurement point at 1.52 m where the moisture was essentially unchanged.

The average evapotranspiration measured with the energy budget from March 17 to July 5, 1971, adjusted for the one rain event, was 0.501 mm/d. The average energy-budget loss between September 1 and

September 27, 1971 was 1.83 mm/d, and between January 26 and February 24, 1972, 0.355 mm/d. These rates are also plotted in figure 6. Discrepancies in the dates above and those in the legend of figure 6 exist because soil moisture observations made in the early morning were considered to represent the previous day. It should be emphasized that data from only one soil moisture observation tube are not sufficient to define a water budget control against which the energy budget results can be tested. But, as figure 6 shows, the results are compatible if the loss rate rapidly becomes constant with increasing depth below 2.1 m.

The annual loss of water from deeper soil layers is difficult to estimate because of experimental errors. The soil moisture data are subject to calibration and spacial-sampling errors. The energy-budget (loss) data contain errors due to evaporation from the rain gage, to estimations, to instrumentation limitations, and probably from other sources as well.

The 356-day period from March 17, 1971, to March 6, 1972, had an average loss of 0.131 mm/d (47.9 mm/yr). The gain in soil moisture storage above 2.13 m was 0.115 mm/d (42.2 mm/yr) so that transport of 0.246 mm/d, or 90.1 mm annually, from below 2.13 m is implied. However, increasing the annual precipitation by only 13 percent would halve the annual contribution from below 2.1 m. An error of this magnitude (44 mm) in the pluvial contribution could easily result from only the sheet-runoff events mentioned previously, without considering rainfall measurement errors.

Table 2 lists quantitative data for the periods mentioned in the text. Soil moisture data for the experiment period, March 10, 1971,

Table 2.--Water data for selected periods. *ET* is evapotranspiration, *P* is precipitation. All data are in millimeters of water except period length which is in days.

Dates	Period length	*ET*	*P*	Soil moisture gain above a depth of: 0.30 m	0.91 m	2.13 m
Mar. 17 - July 5, 1971	111	66.9	11.3	-16.0	-25.0	-46.0
Sept. 1 - Sept. 27, 1971	27	62.9	13.5	-14	-39	-45
Jan. 26 - Feb. 24, 1972	30	10.6	0	-6	-8	-1
Mar. 17, 1971 - Mar. 6, 1972	356	377	330	12	46	41
Mar. 10, 1971 - June 30, 1972	479	516	370	-0.9	-0.2[1/]	

[1/] Soil moisture gain above a depth of 0.61 m. Soil moisture data for the 479-day period are from March 12, 1971 and June 29, 1972.

through June 30, 1972, are actually from March 12, 1971, and June 29, 1972. No soil moisture data at depths greater than 0.61 m were available after March 6, 1972.

DISCUSSION AND CONCLUSIONS

The results of this study show that a reasonably long, continuous record of daily evapotranspiration from a barren site can be generated from direct energy budget measurements if suitable data are available from a nearby location to develop interpolation functions to fill in missing intervals. A local record of soil moisture is also needed for interpolation at this barren site, but such a record may not be a requirement at locations where water is freely available to phreatophytic vegetation.

One of the considerations in planning this study was the possibility of extending the record to other similar areas within the Gila River Phreatophyte Project. The results of this study indicate that this cannot be done without estimates of the daily change of soil moisture in the upper soil. Possibly such estimates could be derived from precipitation records with occasional, shallow, soil moisture sample borings.