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EVAPOTRANSPIRATION FROM RAPIDLY GROWING YOUNG SALTCEDAR IN THE GILA RIVER VALLEY OF ARIZONA

By O. E. Leppanen

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CONVERSION TABLE: METRIC (SI) 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/sec)	3.875	square foot per hour (ft^2/h)
gram per square centimeter (g/cm^2)	2.048	pound avoirdupois per square foot (lb/ft^2)
gram per cubic centimeter (g/cm^3)	62.43	pound avoirdupois per cubic foot (lb/ft^3)
liter (L)	0.2642	U.S. gallon (gal)
degree Celsius (°C) + 17.78	1.8	degree Fahrenheit (°F)

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

Multiply	By	To obtain
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 ($cal/cm^2°C$)	2.048	British thermal unit per square foot per degree Fahrenheit ($Btu/ft^2°F$)

calorie per square centimeter per minute per degree Celsius (cal/(cm^{2}min°C)	122.9	British thermal unit per square foot per hour per degree Fahrenheit (Btu/(ft^{2}hr°F))
calorie per gram per degree Celsius (cal/g°C)	1.000	British thermal unit per pound per degree Fahrenheit (Btu/lb°F)

EVAPOTRANSPIRATION FROM RAPIDLY GROWING YOUNG SALTCEDAR IN THE GILA RIVER VALLEY OF ARIZONA

By O. E. Leppanen

ABSTRACT

Estimates of evapotranspiration by young saltcedar, based on energy budget measurements, were made in an unfilled portion of the San Carlos Reservoir in east-central Arizona. Forty-eight days of record were obtained before the site was inundated. The young saltcedar, which had grown from seed earlier in the season, had an average daily evapotranspiration of 5.8 millimeters of water during the period August 17, 1971, to October 3, 1971. Daily values ranged from 9.2 millimeters to a low of 0.23 millimeters which occurred during a stormy day.

INTRODUCTION

Estimates of evapotranspiration spanning 48 days (August 17 to October 3, 1971) from an area covered by young saltcedar (*Tamarix* sp.) were made by using energy budget measurements and interpolation methods. The study-site measurement point was located about 1.5 km below the confluence of the Gila and San Carlos Rivers in east-central Arizona, within the bounds of the maximum pool of the San Carlos Reservoir. The reservoir is formed by Coolidge Dam on the Gila River, about 10 km downstream from the study site. During the 42 years of the reservoir's history, the study site had been under water about half the time, and fine sediments at least 2 m deep had been deposited. These served as a seedbed in which many seeds of saltcedar germinated, and the resulting plants grew rapidly during the summer of 1971.

This report briefly describes the energy budget site, the instrumentation, the data analysis procedure, and lists the results. A period of high discharge by the Gila River in late summer unfortunately terminated the measurement period; the last two days of operation were in conditions of standing water.

Figure 1 is a map of the Gila River Phreatophyte Project, adapted from a report by Culler and others (1970). The young saltcedar study-site location is shown on the figure by the solid diamond at the far left, or downstream end. The Gila River Phreatophyte Project had as a principal objective the comparison of evapotranspiration from existing vegetation within the project area with evapotranspiration after the vegetation had been removed. This objective came to be achieved by using a water budget for time periods as long as ten years.

The study site described in this report was not within the formally defined boundaries of the Gila River Phreatophyte Project, as are the other evapotranspiration measurement sites also shown by solid diamonds on figure 1. However, results from this study, as well as results obtained at the other sites, were to be considered as estimates of evapotranspiration typical of areas of differing ground cover within the project. These estimates would be independent of a water budget.

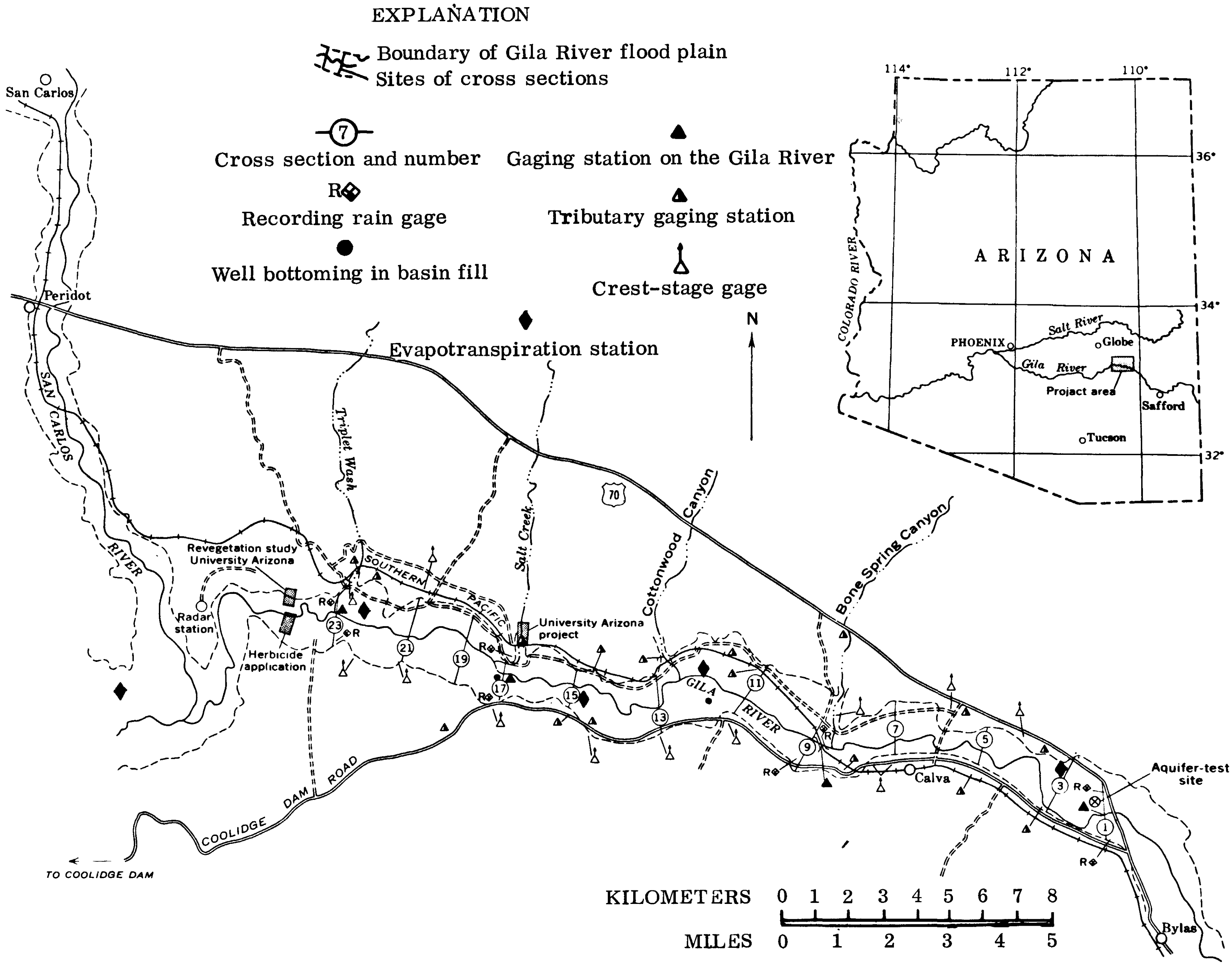

Figure 1.--Project area and instrumentation location.

SITE

The site for evapotranspiration measurements was on an almost level sediment plain (estimated slope 1:100) about 1.2 km north of the Gila River channel at an altitude of about 736 m. The wind fetch was unobstructed for several kilometers in all directions from the site, except toward the north, where a 4-m high terrace approximately 200 m from the study site subtended a quarter-circle sector from about WNW to NNE. Prevailing summer wind was seldom obstructed. Northerly wind was infrequent, except for very light downslope cold-air drainage at night.

The study site was about 60 m south of the northern fringe of the volunteer saltcedar stand that extended many kilometers into the southern quadrants. Figure 2 is a photograph taken from the edge of the young saltcedar stand looking southwest showing the instrumentation mast which is described later. The plants are about 1.4 m tall.

An understory of Bermudagrass (Cynodon sp.) grew verdantly beneath the saltcedar, unaffected by any saline guttation from the upper story. During the measurement period the saltcedar grew from about 0.5 m to 1.6 m high. Height was estimated visually, being the eye-level from which slightly less sky than plants could be seen. The Bermudagrass reached a height of about 10 cm.

No mechanical analyses of the soil were made, but the fine sediments contained a large fraction of clay sizes. This was apparent from observation of the quasi-hexagonal cracking of the soil surface when dry (see fig. 3), and from the tenacious

Figure 2.--Young saltcedar and instrument mast. Photograph taken August 26, 1971, looking southwest.

Figure 3.--Psychrometer in terminal box near base of 20-cm triangular instrument mast. Note soil cracking into quasi-hexagonal patterns.

adhesion of the wet soil to a soil auger used to bore 2-m deep holes for thermocouple installations. More than adequate plant nutrients were present, as evidenced by the lush plant growth.

No observation well was near the instrumentation mast. Heavy rains in early August (which delayed initiation of observations) had saturated the soil. While installing instrumentation four weeks before observations began on August 17, the water table was estimated to be about 4.0 m deep. On September 24, when soil moisture observations were made, the water table was about 2.3 m deep. The water level rose continuously during the observation period until the area became flooded. Three weeks after the observations ended, the area was under 9 m of water.

The late summer climate in the area is characterized by a monsoon-like air mass which gives rise to frequent convective thunderstorms, consistently high temperatures, and high humidities. The first 22 days of observations (August 17 to September 7) had an average air temperature of 26.2°C and an average relative humidity of 60.5 percent measured 8 m above the vegetation. After September 8 drier air intruded occasionally, so that over the 48-day measurement period, the 8-m average air temperature was 23.8°C, and the average relative humidity, 53.4 percent.

INSTRUMENTATION

Meteorological variables must be measured carefully in order to use an energy budget to calculate evapotranspiration, but as yet (1971), there are no standardized instrumentation arrangements. Since the nearest all-weather road was about 17 km from the measurement site, the instrumentation was so designed that it was capable of operating at least a week without servicing but was still rugged and accurate.

The meteorological variables that must be measured are those necessary to evaluate net radiant energy flux, those which allow changes of stored heat in the evaporating system to be calculated, and those needed to determine temperature and water-vapor gradients at a reference plane near the top of the transpiring canopy.

Net radiant energy flux, or net radiation, was measured directly with an exposed-surface, ventilated, flat-plate thermopile radiometer available commercially. The radiometer was mounted on the instrumentation mast shown in figure 2, 3.5 m out from the mast, pointing solar south. The radiometer was at an elevation 4 m above the reference plane which was about 1.6 m above the soil surface. Thus the effect of thermal radiation from the 9-m tall mast upon the upper and lower surfaces of the radiometer was balanced; specular reflection error was small because the mast was painted a dull matte green. The radiometer flat-plate had been resurfaced just before observations began, and its calibration checked by using a shading technique. This calibration check gave a calibration coefficient 3 percent smaller than the manufacturer's coefficient. As this difference was probably within the error limits inherent in the shading procedure, the manufacturer's coefficient was used in calculations. No visible deterioration of the flat-plate surfaces occurred during the 48-day observation period.

Stored heat in the evaporating system may change as a result of temperature changes, or of mass changes such as the addition of rain or vegetation bulk to the system.

The computation of stored heat change was divided into three aspects. The first was to evaluate heat flow into or out of the ground 50 cm below the soil surface. This was done with two commercially available flat-plate thermopile devices that were coated with a film of plastic resin to allow operation in very wet soil. These heat flow plates were carefully installed at a 50-cm depth into the walls of two 8-cm diameter auger holes required to install temperature-sensing thermocouples at 2-, 50-, 100-, and 200-cm depths. The holes were 2 m north and south of the instrument mast. Because of the added plastic coatings, the heat flow plates were recalibrated using an arrangement which measured the heat flow through the plates from one 3-L container of water into another. Although carefully done, the resulting calibration of the plate coefficients was probably no better than ±15 percent.

The second aspect of the computation was to evaluate changes in heat stored in the vegetation mass. Planned quadrat analyses of the biomass were not possible because of flooding of the site, so estimates of mass were made. Needed temperatures were measured using thermocouples near the soil surface, within the vegetation, and just above it.

The last aspect of stored heat change was to determine heat gained or lost in the top 50-cm layer of soil. Temperatures were measured just below the soil surface, and at the 50- and 100-cm depths. The thermal characteristics of the soil minerals did not have to be measured in the laboratory because of the high soil moisture content. Soil moisture was measured with a nuclear meter in an access tube located about 10 m north of the mast. Precipitation was measured about twice a week with a non-recording gage at the site.

Temperatures, needed to determine gradients above the vegetation, were available at a level 1 m below the reference plane (called the (-1)-m level), at the reference plane (the 0-m level), and at the 2-m and 8-m levels above it. All temperatures were measured with thermocouples. Vapor pressures at the same levels were all measured with a single psychrometer using a pipe, valve, and blower arrangement to draw air from each level past wet- and dry-bulb thermocouples located near the foot of the mast. This arrangement eliminated the need for matching four psychrometers. The arrangement is shown in figure 3, as is the lowest air intake unit. The psychrometric unit is protected against extreme temperatures, which could occur in its mounting box, by reflecting aluminum foil, urethane insulation, and double-walled construction with circulating intake-air between the walls. A bleeder system kept a small amount of air moving in the intake pipes between readings, which were made whenever the appropriate heating-gas valve, located above the psychrometer, was opened.

Each of the 20 thermocouple and 2 heat flow plate outputs was measured once every 24 minutes and that of the radiometer every 12 minutes. The scheduling of readings was planned so that optimum accuracy of the required variables in the energy budget computations could be attained. The programming sequence of readings, one each minute, was determined by a modified 24-channel Honeywell Model 15[1] strip-chart recorder.

Power for the instrumentation was supplied by a propane fueled motor-generator. Powerplant malfunction resulted in a considerable amount of missing data until improved gas-pressure regulating devices were installed. Heavy rains also caused loss of data by allowing leakage currents in the highly sensitive thermocouple circuitry.

INITIAL DATA TREATMENT

All observations of the required meteorological variables (except rain and soil moisture) were printed upon a strip-chart, and from this, manually reduced to 4-h averages. The averages were then converted from millivolts to the appropriate physical variables. Vapor pressures were calculated using programmable desk calculators. Time errors due to generator speed variations were corrected by comparison with a mechanical clock-driven recorder which monitored the generator voltage. All tabulated 4-h averages were based on mean solar time.

Rain amounts, noted at each service visit, were distributed according to time-of-fall and intensity by observing the effects upon the exposed plate of the radiometer. Very few rain data were missing, but the collected rain water was subject to evaporation.

Soil moisture data for estimating the moisture content of the 50-cm upper soil layer were obtained from nuclear meter readings at depths of 15 cm, 30 cm, and 61 cm. During the entire experiment

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1/The use of the brand names in this report is for identification purposes only and does not imply endorsement by the U.S. Geological Survey.

period only one soil moisture profile was obtained near the mast (on Sept. 24). Another had been observed about 32 m from the mast on September 9. However, because there was at least 72 mm of rain during the four days preceding the start of observations on August 17, the 50-cm soil layer was assumed to be near saturation, with a soil moisture content of 45 percent by volume. Near the end of the observation period, the soil water content was estimated to be 37 percent by volume. Assuming constant depletion rates between the soil moisture content estimates, and adjusting for rains, daily estimates of soil moisture were made for the 50-cm layer.

DATA ANALYSES

If net advection, that is, the net laterally moved sensible heat at the observation site by ambient air is small, the heat balance, or energy budget at the reference plane near the top of the vegetation can be written:

$$L(ET) = N - H - Q - B - C + P - W, \qquad (1)$$

where

ET is evapotranspiration (cm/min),

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

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

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

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

B is the change-in-heat-storage in the biomass (cal/cm^2min),

C is the vertically transported, or convected, sensible heat (cal/cm^2min), P is the heat content of rain or other advected water (cal/cm^2min), and

W is the heat content of evaporated water (cal/cm^2min).

The latent heat, L, was used as a function of a synthetic wet-bulb temperature, computed from the reference-plane (0-m) air temperature and vapor pressure with the Newton-Raphson algorithm.

The net radiation, N, is the source of most of the heat used for evapotranspiration. Radiative diffusion, usually resulting in advection, was neglected.

The average output of two heat flow plates, H, which were 4 m apart, was used as an estimate of heat flow through the lowest point of the evaporating system considered. The calibration of the plates, as remarked in the instrumentation section was somewhat uncertain, but the variable was small, ranging between ± 0.005 cal/cm^2min in its daily average. Positive values represent downward heat flow. After September 20, heat flow was negative, or upward. The ground surface was always well shaded, minimizing H, the heat flow at the bottom of the system, as well as affecting Q, the heat storage in the soil layer.

Heat gained or lost in the top 50-cm soil layer, Q, was evaluated by change-in-storage methods which would include any heat sources or sinks such as root respiration. An average temperature was calculated at the initial and final instant of each 4-h period. The difference, multiplied by the average heat capacity and divided by the length of the period (240 minutes), gave an average flux value. Since simpler methods proved inadequate, classical Fourier methods (Smith, 1953, p. 323) were adopted to calculate the average temperatures. On each day with a complete record, 24 hourly temperature values taken about 2 cm below the soil surface were used to compute four terms of the Fourier series expansion describing the diurnal temperature fluctuation:

$$T_s(z,k) = \overline{T}_s(z) + \sum_{n=1}^{4} A_n \exp\left(-z\sqrt{n\pi/\alpha p}\right) \sin\left(2\pi nk/p - z\sqrt{n\pi/\alpha p} + \phi_n\right), \quad (2)$$

where T_s is soil temperature; k is time; z is depth; and α is the thermal diffusivity. The time period considered, p, was one day. The amplitude constants, A_n, and the phase angles, ϕ_n, are unique to each daily set of data used. Equation 2 is a solution of the differential equation of one-dimensional heat flow into a semi-infinite homogeneous solid when the second derivative of $T_s(z)$ with respect to z vanishes, and A_n, ϕ_n, and α are assumed to be constants. The analysis neglects the small daily change of the average temperature of the soil layer and the effects of previous days.

It remained to determine α. The usual methods of phase shift of ϕ_n or amplitude decrease of A_n with depth could not be used because of imprecision in and drift of the 50-cm temperature data values so another method had to be found.

Equation 2 is integrable (by parts) with respect to depth, z, so integrations were performed from z = 0 to z = 48 at times k and k + 4, and these were subtracted to yield $\Delta\overline{T}_s(k + 2) = f(\alpha)$. Using C_p, the bulk heat capacity (described later), $Q=C_p\Delta\overline{T}_s$. Neglecting W, P, and B in equation 1 it was found that in fourteen 2-hour periods just before sunrise, L(ET) was very small and was algebraically balanced by C (discussed later). This allowed determination of $f(\alpha)$ by trial under various conditions of soil moisture, after first modifying the time span from 4-h to 2-h intervals. The limits allowed in the trial solutions were $N - H - C_p\Delta\overline{T}_s = \pm 0.003$ cal/cm^{2}min, where $\Delta\overline{T}_s = f(\alpha)$, and N, H, and C_p are known. Diffusivity was found, within the limits of the technique, to vary linearly with soil moisture,

$$10^3\alpha = 2.479 + 0.1953\ (SM),$$

where SM is the soil moisture in percentage by volume and α is expressed in square centimeters per second. The correlation coefficient was 0.79.

The bulk heat capacity, C_p, was estimated by assuming a mineral heat capacity of 0.20 cal/g°C and a soil volume weight of 1.44 g/cm^3. The first assumption could lead to little error because the 50-cm soil layer had a high average water content. The volume weight assumption was made on the basis of a high clay fraction of the soil, with a small organic matter content. For the 50-cm soil layer, over a period of 4 hours, the bulk heat capacity coefficient was

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

where SM is the volumetric soil moisture in percent.

All of the arithmetic was readily performed by small desk calculators with subroutine capability.

The biomass heat change, B, had to be analyzed somewhat subjectively, because quadrat analyses of vegetation were not available. The saltcedar growth was dense, but quite spindly, as can be seen in figures 2, 3, and 4. Saltcedar foliage data, green and oven-dried, from a study by Gatewood and others (1950) were used to convert vegetation height to water content per unit area. The study area of Gatewood and others was on the Gila River approximately 50 km upstream from the energy budget site. These foliage data, plotted and extrapolated to zero saltcedar height, produced estimates of water equivalents of 0.011 g/cm^2 at the 0.5-m saltcedar height and 0.035 g/cm^2 at 1.6-m height. Adding 10 percent for the Bermudagrass and the woody saltcedar material, the estimates of bulk heat capacity ranged from 0.012 $cal/cm^2{}^\circ C$ to 0.039 $cal/cm^2{}^\circ C$. Division by the time period of 240 minutes produced bulk heat capacity coefficients varying from 0.00005 $cal/(cm^2 min^\circ C)$ at the start of observations to 0.00016 $cal/(cm^2 min^\circ C)$ at the end.

Because of its large surface area, the biomass, under conditions of calm-to-moderate winds, could be expected to follow the diurnal trend of the average air temperatures of the (-1)-m and 0-m levels fairly closely. Hence, an estimate of temperature changes of the vegetation was available, if not of actual values. The greatest 4-h average temperature change, -16.7°C, occurred between 1600 and 2000 on September 20. This resulted in a biomass heat storage change, B, of 0.0027 $cal/cm^2 min$ or an evaporation equivalent of 0.065 mm/d of water. However, in the daily average for this day, the evening heat storage change was offset by a morning change of 13.1°C

Figure 4.--View of young saltcedar near the instrument mast, looking east.

between 0400 and 0800, which represented evaporation of 0.051 mm/d. The net change in the average temperature of the vegetation for the whole of September 20 was -1.1°C, probably departing from zero largely because of roundoff errors in the 12 averages used.

The largest temperature changes occurred during the evening (1600 - 2000) and during the early morning (0400 - 0800) although 7 (out of 40) changes exceeding 10°C occurred between the hours 0800 to 1200. The average evening change was -8.2°C, and the average early morning change, 6.4°C. The diurnal temperature changes, and the heat storage changes were asymmetrical about solar noon with heat being released more rapidly near and after sunset than gained after sunrise. This phenomenon was observable from the daily radiometer records of thermal flux which exhibited a dip near sunset before rising to a stable exchange value between the earth and the night sky.

Because the change-in-heat-storage, B, had only a marginal effect on the 4-h average values of evapotranspiration, and a negligible effect on the daily averages, B was not used in the computations. Metabolism and photosynthesis adjustments were not attempted.

No direct theoretical computations of the convected heat, C, were attempted. However, as described later, empirical estimates of C as a function of temperature gradient were developed in order to fill in periods of missing data. The convected heat term, C, entered into most evapotranspiration computations as the numerator of the Bowen ratio, which is defined as the ratio of convected heat, C, to the evaporated latent heat, L(ET).

The heat content, P or W, added or subtracted by thermal mass changes in the evaporating system considered, was not computed except in the case of heavy rains. The rain temperature used was the synthetic wet-bulb at the reference plane. Heat lost with evaporated water was partially compensated for by advected heat brought into the system from below 50 cm. The slowly rising water table also added heat to the system, but this would have had little effect upon the daily averages.

Most computations of 4-h evapotranspiration were done by converting equation 1 to the Bowen ratio (BR) form and dropping terms considered negligible (B and W):

$$ET = \frac{N - H - Q + P}{L(1 + BR)} \quad (cm/min) \quad , \qquad (3)$$

where

$$BR = \frac{C}{L(ET)} = m \frac{K_T \cdot \text{grad } T}{K_e \cdot \text{grad } e} = m \frac{dT/dz}{de/dz} ,$$

where K_T and K_e are eddy-transfer coefficients assumed equal; T is air temperature; e is vapor pressure; and z is height. The coefficient m included unit conversions, and equalled 0.616 with T in degrees Celsius and e in millibars. No wind data were gathered so effects of air stability were not analyzed.

The computation of the gradient ratio was first attempted by using simple difference quotients (divided differences) with data from pairs of the various air-intake levels, but, because of numerical problems and the curvature of the temperature and vapor profiles, different choices of levels gave widely differing values of ET. A more consistent approach, although not completely satisfactory, was found in fitting the temperature and vapor data from the (-1)-m, 0-m, and 2-m levels with the LaGrange interpolation polynomial, and evaluating its numerical derivative at the 0-m level. Previous experience had indicated that the maximum vapor pressure in a similar vegetation blanket would be found somewhere below the top of the vegetation; if measured at that level, the numerical problems resulting from measurement imprecision would be minimized (vapor pressures were calculated to the closest 0.1 mb).

With the lowest level chosen at, or slightly below the saltcedar tops, the approach was mostly satisfactory, both for vertical vapor transport and heat exchange. As the vegetation grew, numerical problems developed. But before the instrumentation could be moved, the site became unusable.

The equation evaluating the derivatives at the reference plane (0-m) is:

$$\delta v = \frac{1}{6} (v_2 + 3v_0 - 4v_{-1})$$

where δv is either the temperature or vapor derivative with height and the subscripts of v are the elevations of the air-sample intakes relative to the reference plane, in meters. The Bowen ratio was thus

$$BR = 0.616 \, \delta T/\delta e.$$

Although data from the same psychrometer were used to calculate vapor pressures at the 4 levels monitored, eliminating the problem of matching psychrometers, sampling and numerical problems resulted in BR values being questionable in about 25 percent of the 4-h periods computed. During morning and evening periods, BR values near -1 greatly magnified observational errors in the numerator of equation 3.

In order to use the periods with questionable BR and also to be able to use periods when psychrometric data were missing but air temperature data existed, a linear relation between the convected heat, C, and the temperature difference between the (-1)-m and 8-m levels was developed. Because of equipment failures and relatively frequent rains, the relation could not be developed separately for each of the six daily periods. One regression line, based on 114 periods with acceptable Bowen ratios was computed by least-squares. A few temperature differences greater than -5°C were rejected beforehand as atypical examples of cold air drainage during the night. The equation was $C = 0.0367\ (T_{-1} - T_8)$ after being constrained to pass through the origin. The correlation coefficient was 0.66.

The regression analysis revealed a surprising number of instances of heat convected downward, especially during August. A comparison of the temperature differences, $T_{-1} - T_8$, and, $T_{-1} - T_0$, showed only 3 instances (of 114) when the signs differed; these occurred in early morning hours and were small.

The regression line for C was used in calculating evapotranspiration with equation 1, neglecting B, P, and W, in slightly fewer than one-third of the needed 4-h periods. When the temperature difference exceeded -5°C (cold air drainage), the Bowen ratio was set to zero for ET computations.

The daily average ET was computed for each day during which six 4-h periods were available. A day with no estimated data was quality-rated 0. If the convected heat equation was used once, the day was quality-rated 1; and if twice, quality-rated 2. A day which required three convection estimates was considered missing if two of the estimates were during daylight hours. Two days were rated of quality 4, but the convection estimates were all during the morning and evening periods.

Sixteen days (33 percent) had no data, or data too fragmentary to use. These days were assigned a quality rating 9. To estimate evapotranspiration on these days, a multiple correlation interpolation function was computed, relating the available daily evapotranspiration figures to the daily averages of total hemispherical radiation and air temperature measured at a location about 10 km distant, where data were gathered to measure evaporation from Lake San Carlos. The correlation was good (coefficient of multiple correlation, 0.95) because of the small range of the radiation and temperature values.

RESULTS AND DISCUSSION

Table 1 lists the quality rating for each day, the daily estimates of evapotranspiration in mm, and the loss, defined as evapotranspiration less rain. Figure 5 is a plot of the daily evapotranspiration and precipitation values.

Water was freely available to the young, vigorously growing saltcedar, and the plants apparently responded directly to available radiant flux. This was evident from the interpolation equation

$$ET_{est} = 13.67(I) + 0.0918(T_1) - 9.302 \qquad (mm/d),$$

in which I is the total incoming hemispherical radiant flux in cal/cm^{2}min, and T_1 is the air temperature in degrees Celsius, both measured at

Table 1.--Daily evapotranspiration (ET) and loss (ET minus rain)

Date	Qual	ET (mm)	Loss (mm)	Date	Qual	ET (mm)	Loss (mm)
8-17-71	9	6.80	6.80	9-10-71	3	7.13	7.13
8-18-71	2	8.37	8.37	9-11-71	9	6.42	6.42
8-19-71	2	5.64	-1.26	9-12-71	9	6.52	6.52
8-20-71	0	6.51	4.11	9-13-71	9	6.52	6.52
8-21-71	1	8.11	7.11	9-14-71	3	6.69	6.69
8-22-71	1	7.19	7.19	9-15-71	4	5.69	5.69
8-23-71	1	8.38	8.38	9-16-71	2	6.03	6.03
8-24-71	1	5.65	5.65	9-17-71	3	5.13	4.63
8-25-71	0	6.70	6.70	9-18-71	3	5.61	5.61
8-26-71	3	6.93	6.93	9-19-71	3	4.06	4.06
8-27-71	1	6.18	6.18	9-20-71	4	4.19	4.19
8-28-71	2	5.40	5.40	9-21-71	3	5.20	5.20
8-29-71	1	9.20	9.20	9-22-71	2	4.18	2.18
8-30-71	9	6.70	6.70	9-23-71	1	4.57	4.57
8-31-71	9	7.59	7.59	9-24-71	1	4.37	4.37
9-1-71	9	4.77	2.27	9-25-71	1	5.43	5.43
9-2-71	9	6.50	5.20	9-26-71	2	4.62	4.62
9-3-71	9	6.59	6.59	9-27-71	2	5.29	5.29
9-4-71	2	6.04	6.04	9-28-71	3	5.48	5.48
9-5-71	9	6.53	6.53	9-29-71	2	1.45	-19.45
9-6-71	9	6.28	6.28	9-30-71	1	0.23	-25.37
9-7-71	9	6.99	6.99	10-1-71	2	2.73	0.23
9-8-71	9	5.87	5.87	10-2-71	9	4.24	1.24
9-9-71	9	7.14	7.14	10-3-71	9	4.12	1.62

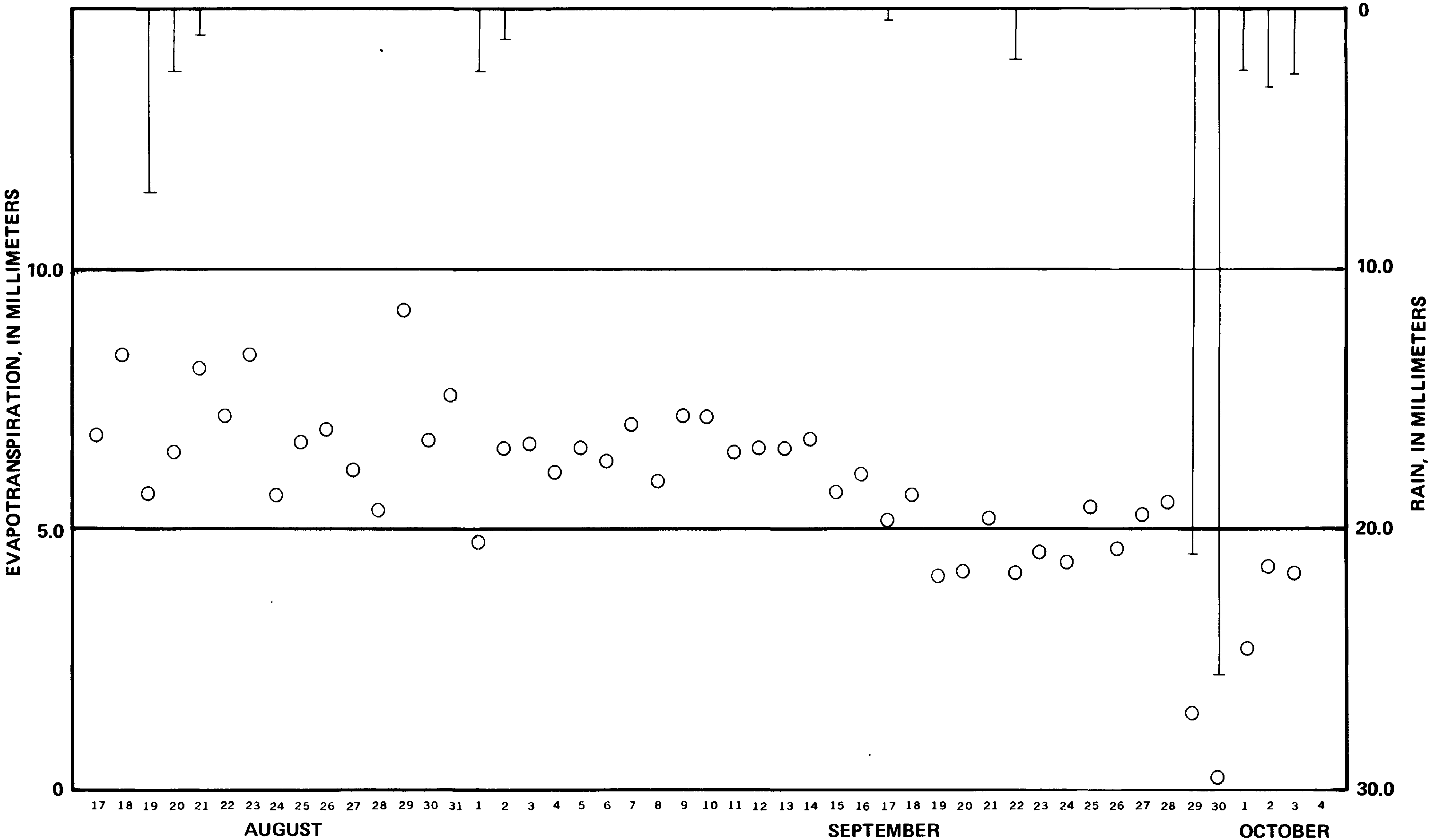

Figure 5.--Daily evapotranspiration and precipitation, 1971.

the Lake San Carlos evaporation station. The 48-day average of I was 0.924 and of T_1, 27.2, which, when used to estimate the evapotranspiration, shows the radiation term to be much more significant. The simple linear correlation between I and N also was good, with correlation coefficient 0.91. The large intercept term, 9.302, severely restricts the range of application of the linear interpolation equation, however.

The temperature dependence of the interpolation equation contains the implicit assumption that C (refer to equation 1) is estimated by an air temperature, if I can be used to estimate N. This again limits the use of such a linear model for extrapolation or extension of evapotranspiration data, even for a few months of the year.

Better linear models can probably be devised based on temperature differences and vapor pressure deficits, using the radiation ratio, N/I. Even these, however, can be confounded by the fact that saltcedar is deciduous, and that both saltcedar and Bermudagrass are warm-weather plants. This experiment did not continue for a period long enough to devise such interpolation models.

A National Weather Service evaporation pan was operated at Coolidge dam. Pan evaporation during the same 48-day period during which this study was conducted was 368 mm. Another study that evaluated evapotranspiration from a barren area about 7 km from the young saltcedar site was also conducted during the same period (Leppanen, 1980, p. 24). Barren area evapotranspiration was 126 mm. The total evapotranspiration from the young saltcedar was 278 mm. Rainfall, however, was substantially greater at the barren area site (106 mm) than at either the evaporation pan (82 mm) or the young saltcedar site (71 mm).

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