WATER DISPOSITION IN EPHEMERAL STREAM CHANNELS

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INTRODUCTION

Questions have been raised concerning the contribution of flows from small watersheds to ground water recharge. Empirical methods have been developed to estimate infiltration and recharge for ephemeral stream channels but knowledge about the infiltration characteristics of small ephemeral stream channels is lacking.

Water disposition in the stream channel depends on the infiltration characteristics of the channel and the evapotranspiration characteristics of the channel vegetation. The amount of water infiltrating during a flow event is a function of the initial moisture content which is determined from the evapotranspiration rate and the time since the last flow event. Consequently, the study of transmission losses in ephemeral stream channel can be divided into two areas. The first area is the study of the infiltration parameters, and the second area is the study of the evapotranspiration parameters.

The generalized objectives of the study was to develop an infiltration equation for estimating transmission losses during a flow event in an ephemeral stream channel near Tucson. Involved in the study was the investigation of the effect of soil texture and water content on the infiltration function, and a method for determining soil moisture disposition after a flow event.

THE STUDY AREA

The study was conducted at the Santa Rita experimental range located 30 miles south of Tucson, Arizona (Figure 1). The investigation site is located at T18S, R14E Sec. 14 SE 1/4 of the Santa Rita Quadrant in an area which is operated by the Rocky Mountain Forest and Range Experiment Station as an outdoor laboratory. Stream channels in the area form a massive dendritic pattern, but the research site consists of 1/4 mile of channel without any major tributaries. The area of the watershed contributing to the selected channel is about 5 square miles.

VEGETATION

The riparian vegetation cover on the research area is slightly different from the surrounding vegetation because of the localized increased soil water storage in the sandy channel bed. The major species along the banks of the ephemeral channel in the study area are: Palo Verde (Cercidium microphyllum), Desert Hackberry (Celtis pallida), Cholla (Opuntia fulgida), Mormon Tea (Ephedra trifurca), Mesquite (Prosopis juliflora var. velutina).

SOILS

The channel reach where the research was conducted consists of a sandy bed 95% sand varying in depth from 3 feet, where the channel in narrow, to about 8 feet on the wider reaches. The width varies from about 8 feet to 35 feet. Some reaches have many little islands which are flooded only during high flows. Since the stream channel under investigation is high on an alluvial terrace the sediment load of the flood waters would be expected to be low.

INSTRUMENTATION

Installation of equipment at the Santa Rita Experiment Range was completed in July 1970. A climatic station to collect meteorologic data consisted of a

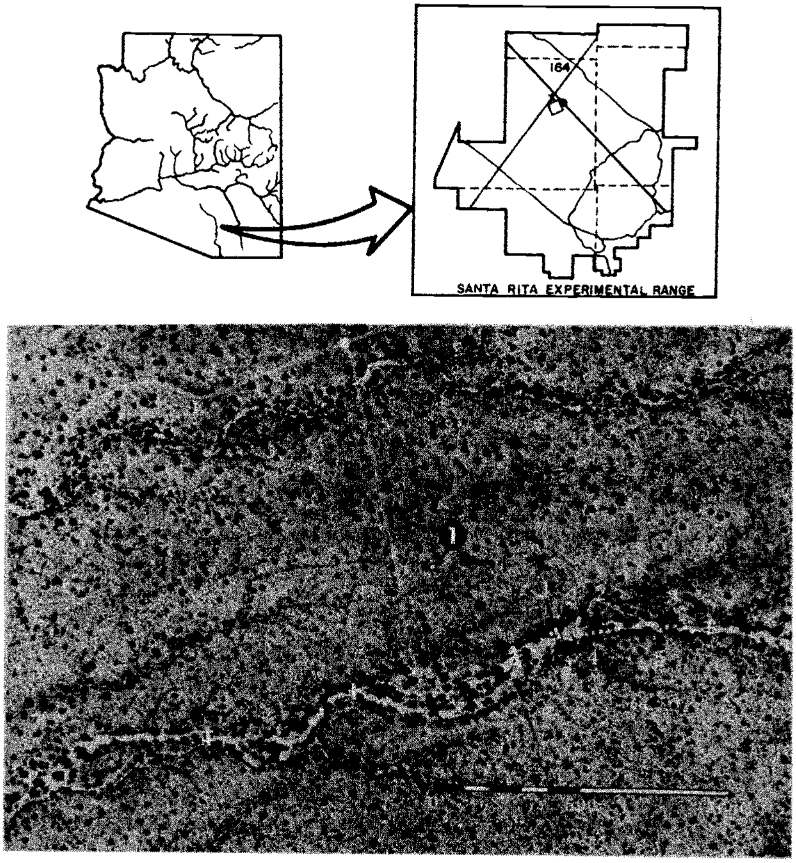

Figure 1. A Map of the Study Area

Legend

‡ Neutron Probe Access Tube Transect (each box represents one tube)
□ Infiltrometer Area
○ Ring Infiltrometer (Number corresponds with infiltrometer)
△ Locations of Soil Samples
● Climate Station
X Flume

hydrothermograph installed in a shelter, a universal recording rain gauge, and a Glass "A" U.S. Weather Bureau evaporation pan.

Evapotranspiration was determined in the ephemeral channel by a water balance method using soil water content measurements determined by the neutron scattering technique described by Stone, Kirkham and Road (1955), Van Bavel (1958), Gardner and Kirkham (1952).

Infiltration measurements were made at the site using an infiltrometer (Figure 2) designed by the author to simulate a flow event in the channel. The infiltrometer consists of water tanks and flow system to supply water at a rate greater than the infiltration rate. Excess water is collected in two tanks on the outlet of the infiltrometer area. Water stage recorders on the inlet and outlet tanks have ten-turn precision resisters connected to a float which change resistance value as the depth in the tank changes. The resistance value is recorded using a Hewlett-Packard Data Acquisition System.

The infiltration simulator was calibrated for accurate measurement of inflow and outflow of water over the meter area and a computer program was written to derive the infiltration function.

A buffer soil zone, around the infiltrometer, was supplied with water from another supply tank. The size of the area of infiltration in the simulator is adjustable and can be changed, but because of a limited water supply, a one-meter area was selected. Inifltration measurements were conducted at three areas in the channel (Figure 1). Repeated infiltration measurements were made at different locationsin the channel. Neutron Access tubes were installed at each location where the simulator was operated and water content of the soil was measured before and after each run.

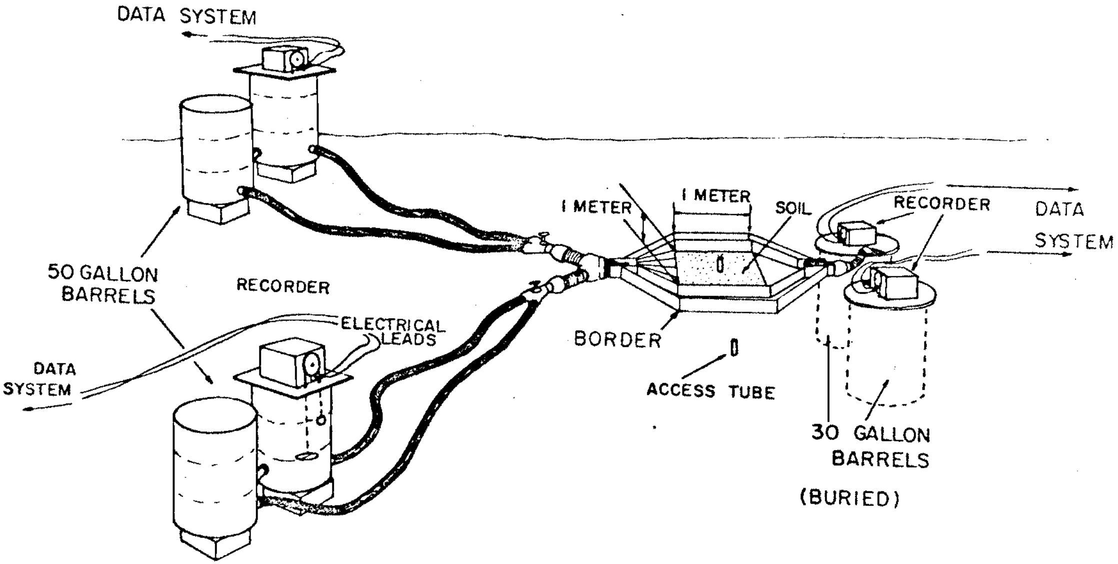

Figure 2. Infiltration Simulator

INFILTRATION

The infiltration function has been described mathematically by both physically based models and empirical equations. Philip (1957a-f) derived an equation based on the assumption that infiltration is a process of diffusion. The following assumptions apply for the derivation of that equation:

1. The soil is homogeneous.
2. Darcy's law applies for unsaturated flow (Pressure head of soil water less than zero).
3. The system is isothermal.
4. Biological, chemical and hysteresis forces are negligible.
5. The only force retarding flow is viscosity.

The equation used in this study which was developed by Philip (1957a-b) is

$$Q = At^{1/2} + Bt$$

where Q is the accumulative infiltration, T is Time, and A and B are constants which are normally determined empirically rather than by numerical integration and, consequently, the equation is considered an empirical equation.

A computer program was written to calculate accumulative infiltration for individual infiltration areas. The coefficients A and B in equation (1) were estimated using a least square fitting technique (Table 1). Recorded infiltration data did not always fit a smooth curve. The variability was attributed to experimental errors evolving from changes in head and thus storage of water over the square-meter area. However, Philip's equation still represented the infiltration curves for the different runs (correlation coefficients), comparing field data with computed infiltration using Philip's equation, range from 0.87 to 1.00 with most of the values around 0.98 (See Table 1).

TABLE I

INFILTRATION ANALYSIS

Date, Location[1] of Sample		Average Soil Moisture % in Top 2.5 ft. before	after	Philip's Equation Constants A cm/min	B cm/min	Correlation Coefficient	Duration of Measurements Minutes
4/25	01	6.7	--	.29	1.73	.99	35
6/25	11	7.6	27.8	1.62	1.47	.96	15
6/29	11	8.4	23.6	1.31	2.04	1.00	40
7/1	21	4.2	24.0	4.16	2.71	.99	35
7/9	21	6.9	24.1	.79	2.32	1.00	50
5/2	02	3.1	29.5	.012	.20	1.00	50
5/9	02	7.0	28.5	.31	.05	.97	15
5/26	02	4.0	19.7	2.25	.03	.87	52
7/10	03	4.6	21.5	1.98	2.35	.98	33
7/16	03	5.4	19.9	2.80	1.06	.99	40
7/23	13	10.0	--	.82	1.13	.99	45
7/28	13	5.6	24.7	.85	.35	.98	30
				Double Ring Infiltrometer			
8/26	3.1	8.0	--	2.42	1.44	.99	30
8/27	12	9.0	24.1	2.61	1.70	.99	20
9/14	22	7.0	23.8	4.65	1.63	1.00	25
9/26	23	4.3	24.6	1.08	1.61	1.00	25
9/26	33	4.3	24.3	3.57	1.53	1.00	27
9/26	43	4.3	--	.82	1.09	1.00	13

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1. The first number is the Location Number. The second number is the Area Number given on Figure 1.

The constants A and B in equation (1), the correlation coefficient, duration of run and the average soil moisture in the top 2.5 feet of the channel are tabulated in Table 1 for each infiltration run made.

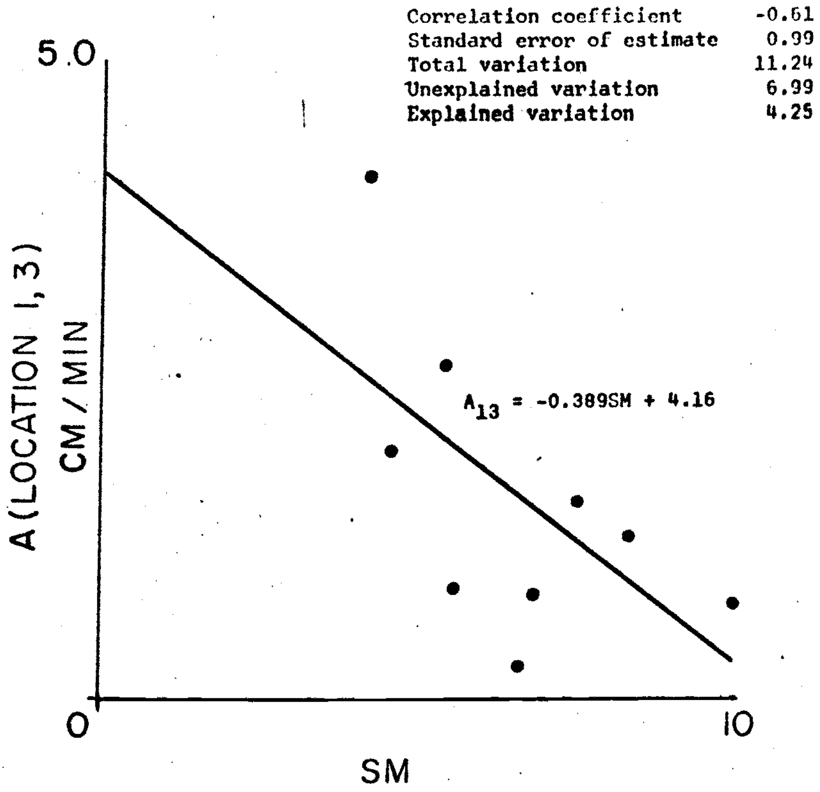
The constant B represents the saturated hydraulic conductivity of a homogeneous soil. Depending upon the initial moisture content, constant (B) appeared to be reached in 15 minutes after the start of an infiltration run. The runs were of durations from 20 to 55 minutes. The mean value of B for each area in the channel was determined and then assuming a normal population distribution, a statistical test was made to determine if the values represented the same or different populations. Location 2 was from a different population.

The coefficient A in equation (1) reflects the absorptive characteristics of soil and is a function of the initial moisture content. The coefficient A for the different runs using the infiltration simulator were plotted against the average soil moisture content in the top 2.5 feet of the channel (Figures 3).

Infiltration measurements were made with a double ring infiltrometer (Table 1) at the three locations. The average B value for the infiltration simulator (location 1 and 3) and the double ring infiltrometer is 1.59 cm/min. This is the value that should be used as representative of the channel soil saturated hydraulic conductivity.

EVAPOTRANSPIRATION

Water losses from emphemeral channels in the desert are due to two major processes: evaporation from the soil surface, and transpiration by riparian vegetation. The sum of the two losses is referred to as evapotranspiration. There are many methods for estimating potential evapotranspiration. The determining factors for choosing a method are: (1) the available data, (2) the degree



Correlation coefficient	-0.61
Standard error of estimate	0.99
Total variation	11.24
Unexplained variation	6.99
Explained variation	4.25

Figure 3. Linear Correlation to Soil Moisture of Coefficient "A" in Philip's Equation for Sample Sites 1 and 2

Subscripts refer to sampling location.
SM denotes soil moisture content in percent.

of accuracy required, and (3) the length of period for which PET is required.

Thornthwaite's (1948) method for estimating ET is probably the most widely used empirical method. The only data required to apply Thornthwaite's formula is mean daily temperature data. The equation can be solved using a nomogram and tables supplied by Thornthwaite. This method has a temperature limitation. It can only be applied for mean daily temperatures equal to or less than 38.0 degree Centrigrade, a mean temperature that can be exceeded in desert areas.

Thorthwaite and Mather (1955) stated that in arid areas where some energy is used in heating the air, use of Thornwaite's method will result in some error.

U.S. Weather Bureau Glass A evaporation pans have been used also as an index of evapotranspiration. Pruitt (1964) using weighing lysimeter data showed that evapotranspiration from grass areas is proportional to pan evaporation. However, Pruitt (1960) determined that the pan exposure made a big difference when comparing pan evaporation to computed evaporation. A pan located in a dry land environment showed 25-35 percent higher evaporation rates than a pan located in an irrigated field.

When soil moisture becomes a limiting factor evapotranspiration rate decreases. There seem to be two main views on how soil moisture status affects evapotranspiration. Veihmeyer and Hendrickson (1950) contend that for both annuals, perennials and trees, the rate of moisture extraction is not influenced by the amount of water present in the soil when the soil moisture is above the permanent wilting percentage. Thornthwaite and Mather (1955) stated that as the soil dries the transpiration rate diminishes over all the range at a rate proportional to the ratio of available water to that present at field capacity. A complete discussion and comments for both points of view by noted experts is presented in a paper by Veihmeyer and Hendrickson (1955). As moisture decreases below field capacity the physiology of the plant, the soil texture and depth, and the root system of the plant seem to play the determining roles in controlling evapotranspiration rate.

Evapotranspiration for a given duration was calculated as the loss in total soil moisture storage for the period between measurements plus any rainfall. Monthly calculations of ET were determined by the extrapolating ET values when no end of month readings were taken. (Table 2)

For each measured time period, a ratio of evapotranspiration to pan evaporation and the ratio of total soil moisture at the end of the time interval to the maximum total soil moisture that the channel could hold (SMFC) were determined (Table 2). These variables were plotted with the ratio of evapotranspiration to pan evaporation being the dependent variable (See Figure 4).

Thornthwaite's method was used to determine potential evapotranspiration (Table 3) and a linear regression coefficient was determined using the calculated ET/PET (Figure 5).

These results support Thornthwaite's and Mather's contention that transpiration rates diminish linearly as soil moisture diminishes.

The relationship of evapotranspiration to soil moisture applies only during the active growing season and thus the linear regression coefficients determined for the different methods of calculating the ET/PET and SM ratios apply only to the period April through October. During the dormant period ET/PET ratios are very low and do not correlate with soil moisture availability. Therefore, ET/PET coefficients should be used during this period independent of soil moisture content.

TABLE 2

EVAPOTRANSPIRATION PARAMETERS

Period Ending 1970	No of Days	Total[1] Soil Moisture cm	Change in Soil Moisture cm	Precipitation cm	Evaporation from soil surface ET. Measured cm	Evaporation from soil surface ET. Estimated cm	Accum ET cm	Pan Evap cm	Accum Pan Evap cm	ET/EP	SM/SMFC
7-27	3	42.8					0.0	0.0	0.0		
7-31	4	38.4	4.4	0.0	4.4		4.4	3.6	3.6	1.22	0.90
8-05	5	36.6	1.8	2.0	3.8		8.2	5.5	9.1	0.69	0.86
8-10	5	33.6	3.0	0.2	3.2		11.4	4.2	13.3	0.76	0.78
8-17	7	32.0	1.6	1.1	2.7		14.1	5.2	18.5	0.52	0.75
8-21	4	29.8	2.2	0.1	2.3		16.4	3.1	21.6	0.73	0.70
8-26	5	27.3	2.5	0.0	2.5		18.9	6.2	27.8	0.40	0.64
9-02	7	25.5	1.8	0.0	1.8		20.7	7.2	35.0	0.25	0.60
9-07	5	40.0	+14.5	6.0		1.3	22.0				
9-15	12	32.4	7.6	0.0	7.6		29.6	8.8	43.8	0.86	0.76
10-3	14	27.0	5.3	0.4	5.7		35.3	10.8	54.6	0.53	0.63
11-28	56	18.9	8.1	0.4	8.5		43.8	33.5	88.1	0.25	0.44
1971											
1-15	48	18.3	0.6	1.5	2.1		45.9	16.3	104.4	0.13	0.43
3-21	95	17.9	0.4	2.4	2.8		48.7	44.5	148.9	0.06	0.42
4-17	27	18.4	+0.5	0.8	0.3		49.0	28.1	177.0	0.008	0.43
6-03	47	12.7	5.7	0.0	5.7		54.7	74.4	251.4	0.08	0.30
6-24	21	12.3	0.4	0.0	0.4		55.1	54.8	306.2	0.006	0.29
7-08	14	14.0	+1.7	1.0		0.2	55.3	36.4	342.6	0.006	0.33
7-21	13	13.4	0.6	0.8	1.4		56.7	24.8	367.4	0.06	0.31
7-24	3	16.3	+2.9	1.8		0.3	57.0	3.8	371.2	0.08	0.33
7-29	5	33.0	+16.7	1.7				6.7	377.9		

1. Depth of soil profile 8.5 ft.

TABLE 3

POTENTIAL EVAPORATION PARAMETERS

Month 1971	Measured ET cm	Thornthwaite Potential ET cm	ET/PET	SM/SMFC
Jan	1.14	1.98	0.57	0.43
Feb	0.82	1.57	0.51	0.42
Mar	0.70	4.39	0.15	0.42
Apr	1.73	5.28	0.33	0.39
May	3.60	8.79	0.42	0.30
Jun	0.80	15.49	0.05	0.31
Jul	3.29*	17.88	0.18	0.31
1970				
Aug	15.82	17.88	0.88	0.61
Sep	13.71	11.51	1.19	0.66
Oct	5.40	5.48	0.99	0.54
Nov	4.32	3.38	1.28	0.44
Dec	1.39	1.45	0.96	0.43

*Date ended 7/21

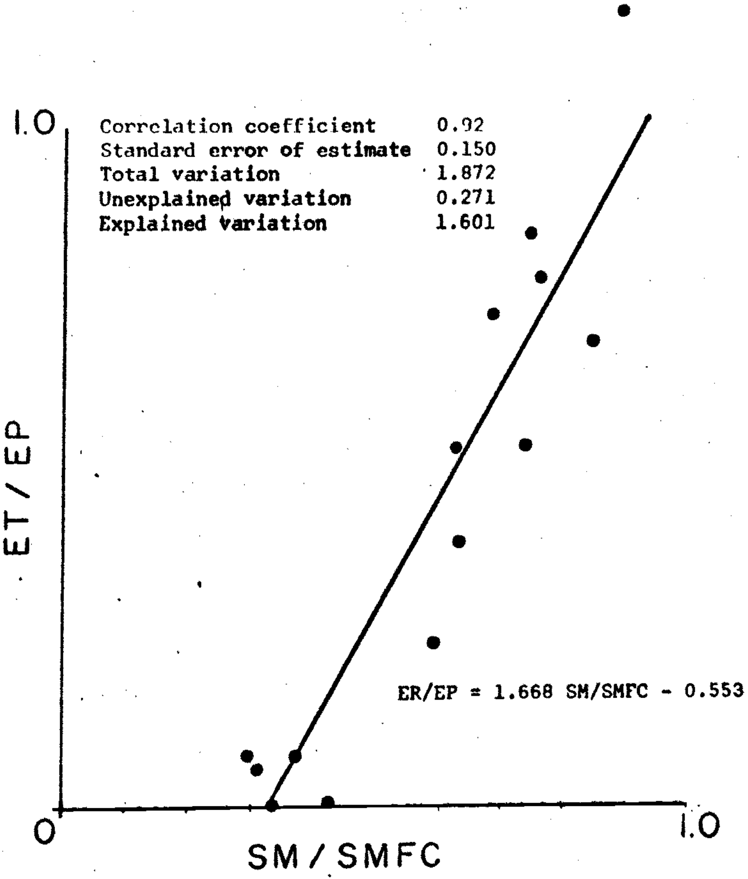


Figure 4. Linear Correlation of ET/EP and SM/SMFC

Correlation coefficient	0.94
Standard error of estimate	0.162
Total variation	1.159
Unexplained variation	0.131
Explained variation	1.027

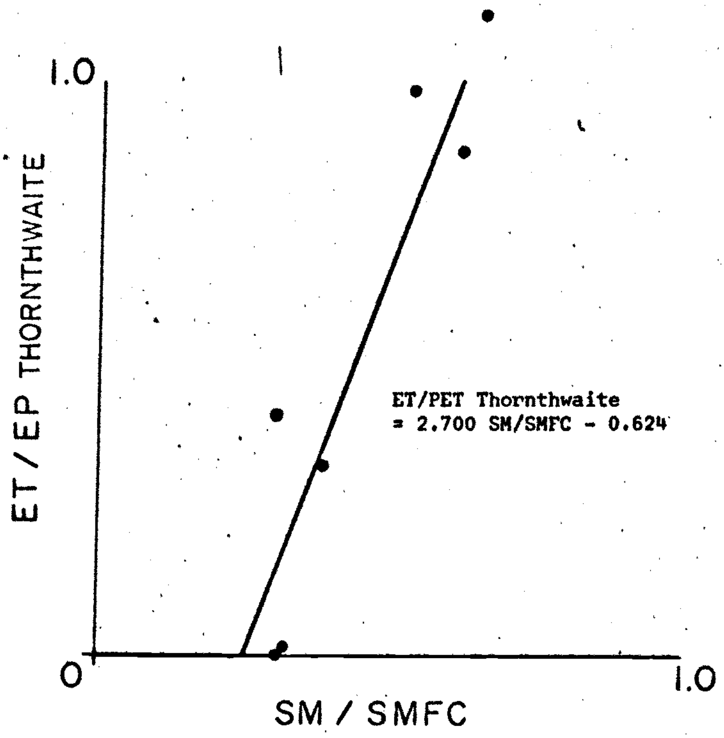


Figure 5. Linear Correlation of ET/PET Thornthwaite and SM/SMFC

For the time period August 1970 to July 1971, under the existing moisture conditions (Table 2) the consumptive use of riparian vegetation was 57.0 cm. Because this period represented a dry year the consumptive use in a normal year of rainfall may be larger.

Measured ET for each month of the year was less than the measured and computed pan evaporation and was less than the Potential Evaporation calculated by Thornthwaite's method except during the months of September and November.

The measured Evapotranspiration of riparian vegetation was low from January to March. In April Et rate increased as the plants commenced growth and continued to increase until water became limiting and the channel moisture storage was depleted usually by the end of May or June. When the summer rains commenced in July and August, ET rates increased and approached the Potential rates. ET rate then decreased in September through December as the plants became less active due to low temperatures and most of the mesquite lost their foliage.

RESULTS

In field studies more data and data covering repeated measurements in time would give greater confidence to conclusions reached. In this study an attempt was made to reduce the time by simulating flow events and develop some prediction models. The following conclusions were reached:

1. Philip's equation

$$Q = At^{1/2} + Bt$$

when applied under the assumptions in its derivations is an excellent model to mathematically represent infiltration in a homogeneous sandy ephemeral channel. The correlation coefficient comparing the variables, accumulated infiltration measured in the field with an infiltrometer range from 0.87 to 1.00.

2. Initial moisture content seems to affect the initial infiltration rate. In Philip's equation this rate is determined mainly by the absorptivity coefficient "A" and this coefficient appears to be linearly related (correlation coefficient -0.61) to the soil moisture in the top 75 cm of the stream channel bed.

3. The infiltration simulator and the ring infiltrometer both gave measurements of the B coefficient in Philip's equation close to the average value of 1.59 cm/min. This coefficient approaches the saturated hydraulic conductivity for infiltration measurements of long duration. Some of the scatter for measurement of the B coefficient using the infiltration simulator can be explained by the fact that some of the runs were of short duration and the coefficient B is then not the saturated hydraulic conductivity but depends on the initial moisture content. The higher the initial moisture content relative to the saturated moisture content, the closer the coefficient B will be to the saturated hydraulic conductivity for infiltration runs of short duration. Using this average B coefficient in Philip's equation to compute accumulative infiltration and comparing the answer to the measured infiltration for short flow events, the computed value falls with ± 30%. Although the B coefficient is high compared to values obtained by other investigators who measured saturated hydraulic conductivity (average value of 0.25 cm/min) the difference may be attributed to the fact that the channel under investigation was 95 to 98 percent sand and no valve effect occurred from sediment load in the channel water as other

investigators measuring hydraulic conductivity have observed in large ephemeral channels.

4. Infiltration rates are affected by the soil structure of the stream channel bed. All locations in the channel had similar textural analysis of the soil profile but the average final infiltration rate measured at location 2 (0.09 cm/min) was 18 times lower than the measured value at the other locations. This difference can be attributed to the difference in the structure of the soil profile at location 2 as compared to the other locations. The soil material at location 2 was compacted and held together to such a degree that taking soil samples was extremely difficult.
5. Consumptive use measurements of the riparian vegetation and measured climate data support Thornwaite's and Mather's (1945) contention that transpiration rates diminish linearly proportional to the ratio of available water to that present at field capacity. This concept applies only to active growing plants. Assuming an active growing season from April to October the linear correlation coefficient comparing the variables measured ET/Ep and SM/SMFC, was 0.92. Substituting Thornthwaite's computed potential ET for Ep resulted in a 0.94 linear correlation coefficient. Given climate data and an initial moisture content of a ephemeral channel a depletion water budget of the channel can be determined using one of the linear regression equations comparing transpiration rates to soil moisture. Knowing the initial soil moisture and the duration of flow, Philip's equation can be used to determine the channel recharge or transmission loss.

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