EVAPOTRANSPIRATION OF PHREATOPHYTES IN THE SAN LUIS VALLEY, COLORADO

by

Frederick L. Charles

June 1987

Colorado State University

Colorado Water Resources Research Institute

Technical Report No. 48

THESIS

EVAPOTRANSPIRATION OF PHREATOPHYTES IN THE SAN LUIS VALLEY, COLORADO

Submitted by

Frederick L. Charles

Department of Agricultural and Chemical Engineering

In partial fulfillment of the requirements

for the Degree of Master of Science

Colorado State University

Fort Collins, Colorado

Summer 1987

ABSTRACT OF THESIS

EVAPOTRANSPIRATION OF PHREATOPHYTES IN THE SAN LUIS VALLEY, COLORADO

The San Luis Valley of south-central Colorado contains a hydrologically closed basin within which a water salvage project has been planned and is partly in operation. This project's goal is to pump water from the unconfined (water table) aquifer which would otherwise be lost through evapotranspiration (ET) from the native rangeland. In order to determine the proper design pumping rate (which will affect subsequent water table drawdown), an accurate estimate of the water use of these plants must be obtained. The basic purposes of this research were: to further develop and apply gas analysis technology for making ET measurements from phreatophytes; to compare these measurements with measurements of ET taken from U.S. Bureau of Reclamation (USBR) lysimeters operating in the same area; and to observe the trends in ET for several different water table depths and drawdown conditions.

Measurement of ET in this area was carried out using the chamber method during several periods of 1985 and 1986. Measurements were made of greasewood (*Sarcobatus vermiculatus* Hook. Torr.), rabbitbrush (*Chrysothamnus nauseosus* Pall. Britt.), and salt grass (*Distichlis stricta* L. Greene) since these plants constitute the major indigenous vegetation of the closed basin plant community. At a site of

continuous pumping, the greasewood plots appeared to suffer a reduction in ET whereas the rabbitbrush plots exhibited no detectable reduction in ET from the same water table drawdown. There appear to be no substantial differences in the ET of greasewood and rabbitbrush plots between two sites where the ground-water levels have historically been 1.25 meters (m) and 4.3 m.

Bare soil evaporation decreased with increasing depth to water table. Bare soil contributes significantly to the total ET of greasewood and rabbitbrush plots in areas of shallow water table (1.25 m). A direct comparison shows that the USBR lysimeters accounted for only 40 percent of the mean total salt grass ET measured by the chamber over a period of 77 days. Additional discrepancies in ET measured by the USBR lysimeters and the chamber at the same site indicate possible erroneous estimates of ET by the former for undisturbed vegetation in the surrounding plant community.

Frederick L. Charles
Agricultural and Chemical
Engineering Department
Colorado State University
Fort Collins, CO 80523
Summer 1987

ACKNOWLEDGEMENTS

I would like to acknowledge and express my appreciation to a number of people through whom this study was made successful. Dr. Walter C. Bausch and Dr. Jack A. Morgan, my research project co-advisors, were very helpful in directing my efforts throughout the duration of this research. Dr. E. Gordon Kruse provided helpful advice and suggestions as well as access to several alfalfa lysimeters operated by the U.S. Department of Agriculture - Agricultural Research Service (USDA-ARS) at the Colorado State University Farm near Center, Colorado for purposes of measurement comparisons. Mr. Barry Weaver of the USDA-ARS constructed the chambers which were used for ET measurements.

Many long hours were spent in the closed basin area of the Valley during the summer of 1986, and my thanks go to Mr. Joseph May and Mr. Segundo Diaz for their excellent assistance and perseverance in data collection. Also, a number of the students and USDA-ARS employees from the Agricultural Engineering Research Center at CSU assisted in the data collection of 1985.

The USBR office in Alamosa provided storage for some of the equipment during weekends and a place for telephone messages to be received. Mr. Doug Gober, of the Alamosa office, has been a great help in coordinating details of the project area research in addition to providing information on project design and operation.

Special thanks go to Mr. Eldon Johns of the USBR - Engineering and Research Center, who provided an exhaustive file of phreatophyte ET literature for my review. This proved invaluable for purposes of relating my research with previous and current ET studies.

Dr. Norman A. Evans, Director of Colorado Water Resources Research Institute, provided the vital service of coordination of funds and communication with the USBR, U.S. Geological Survey, and State Engineer of Colorado concerning this project.

Finally, I would like to thank the faculty and staff of the Agricultural and Chemical Engineering Department at CSU, and the CSU and USDA personnel at the AERC - Foothills Campus for their support and encouragement during my graduate studies.

CONTENTS

TABLES

Table		Page

FIGURES

Figure		Page

CHAPTER I

INTRODUCTION

1.1 THE SAN LUIS VALLEY

The San Luis Valley (the Valley) of south-central Colorado encompasses an area of 7,800 square kilometers, is 160 kilometers (km) long and up to 65 km wide. The valley floor is mostly flat with an average elevation of 2,350 m. Several rugged mountain ranges surround the Valley - the San Juan Mountains to the west and the Sangre de Cristo Mountains to the east. A map, courtesy of the USBR (1982b), is shown in Figure 1.1.

Typical Valley weather consists of cold winters, moderate summers, light precipitation, and abundant sunshine. Annual precipitation in the Valley typically ranges from 18 to 25 centimeters (cm), most of it occurring from July to September. The surrounding mountains receive an average annual precipitation of 75 cm. The mean annual temperature is 6.4 degrees Celsius. Due to the high altitude the growing season is short (90 to 120 days), so agricultural crops are restricted to alfalfa, barley, potatoes, and other short-season crops.

1.1.1 Hydrology

The Valley subsurface fill has resulted from erosional debris and consists of gravel, sand, silt, clay, lava flows, and other volcanic

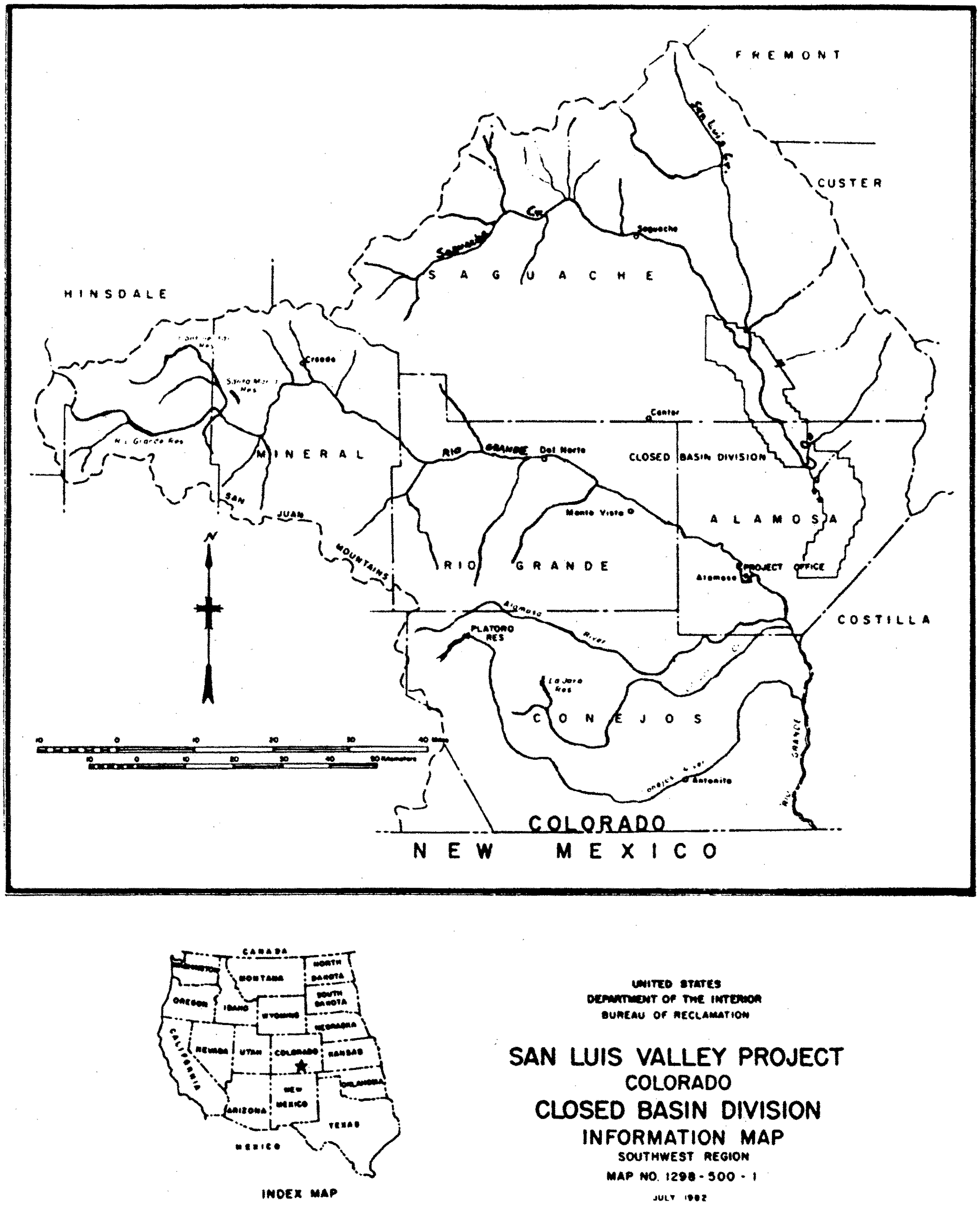

Figure 1.1 The San Luis Valley, Colorado. (USBR, 1982b)

debris to a depth of 9,000 m below the ground surface. Sediments are coarser at the valley boundary and finer toward the center.

The Valley contains an unconfined aquifer up to 60 m deep; its source of ground water is from surface runoff, irrigation, percolation from streams, canals, and ditches, seepage from a confined (artesian) aquifer, and precipitation (Figure 1.2). The confined aquifer is recharged along the valley boundary and is separated from the unconfined aquifer by a relatively impermeable layer of clayey strata and lenses which vary from 1 to 15 m thick. Elevation head of this aquifer is up to 6 m above the ground surface and varies throughout the Valley. There is some upward leakage from the confined to the unconfined aquifer, but it is assumed to be negligible.

A closed basin encompassing 760,000 hectares (ha) is situated in the northeast portion of this valley (bounded on the south by the Rio Grande and U.S. Highway 160 to the east of Alamosa). The surface water in this area is hydrologically separated from the Rio Grande by a low geologic divide consisting of alluvial deposits (USBR, 1979b). A ground-water divide along this geologic divide is caused by recharge from canal leakage and applied irrigation water; ground water does not flow over this divide (Emery et al., 1971). There are no surface flows departing nor significant losses due to water migration in the unconfined (water table) aquifer. A sump area is located in the lowest part of the closed basin; ground water in the unconfined aquifer moves toward this sump area where it is lost through ET (USBR, 1963). The water table depth in this area is from 0.15 to 6.1 m.

The major sources for the surface flows in the closed basin are natural streams (the Saguache and San Luis Creeks) and springs,

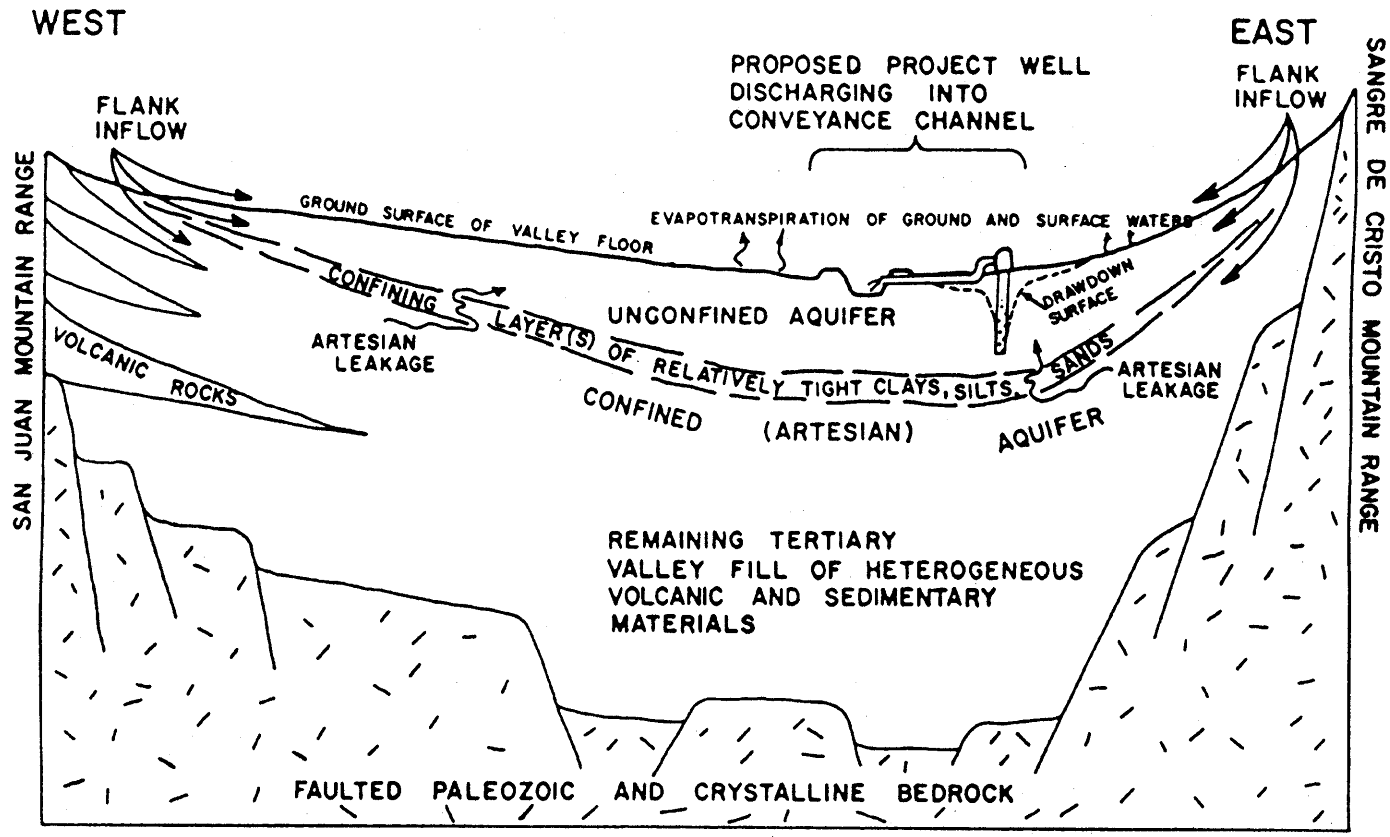

Figure 1.2 Diagrammatic cross section of San Luis Valley, Colorado. (No scale: Maximum distance across valley is about 65 kilometers; maximum estimated depth to bedrock is 3,000 to 9,000 m) (USBR, 1979b)

artesian wells, irrigation return flows, precipitation, and upward seepage from the confined aquifer. Sources of ground-water recharge in the sump area are direct precipitation, seepage of snowmelt runoff from surrounding mountains, ground water migration from the valley edges, seepage from irrigation supply and return flow ditches, and seepage of applied irrigation water (USBR, 1979b).

The sump area has only had the mechanism of evapotranspiration (ET) to rid itself of this water; pan evaporation data indicate up to 1.37 m water loss per year from a free water surface (USBR, 1979b). The conditions here are favorable for growth of native phreatophytic vegetation such as greasewood (*Sarcobatus vermiculatus* Hook. Torr.), rabbitbrush (*Chrysothamnus nauseosus* Pall. Britt.), and salt grass (*Distichlis stricta* L. Greene). Native vegetation water use accounts for nearly half of the total ET in the Valley (Emery et al., 1971). Water management and quality problems have caused the sump area to deteriorate in usefulness and economic value. This area is essentially rangeland which has been classified as poor to very poor (USBR, 1984a).

1.1.2 Historical water development

The Valley water supply provides water for irrigation as well as for export in the Rio Grande (river) to New Mexico, Texas, and the Republic of Mexico. Extensive irrigation development in the Valley commenced in the 1880's and many of the irrigation conveyance channels that still exist were developed during that time. When downstream water shortages occurred several years later, immediate blame went to the irrigators. Irrigation also resulted in increases in waterlogging and salt buildup on the soil surface due to drainage into the sump area; productive agriculture eventually shifted away from this area. Although a portion of the closed basin had historically been unproductive, tens of thousands of hectares of previously prime wheat land became a barren waste and only native vegetation types which were tolerant to the harsh growth conditions could establish and survive in this area.

Additional specific problems in the Valley water system include (Emery et al., 1971):

1) large amounts of "unproductive" ET,
2) deterioration of ground-water quality, and
3) Colorado's failure to deliver water to New Mexico and Texas according to the Rio Grande Compact.

1.2 THE CLOSED BASIN PROJECT

Because of the high water table, the sump area was considered as a major source of water supply for the Rio Grande. This area was first considered as a source to meet flow requirements for downstream users at the time of the Rio Grande Convention of 1906 between the United States and Mexico. In 1938 the Rio Grande Compact between Colorado and New Mexico and Texas was ratified, specifying delivery requirements from Colorado. However, from 1950 to 1967 Colorado was unable to deliver required flows for all but two years (1958 and 1966) yielding an accrued debt at the end of 1967 of 1,165,000 cubic dekameters (dam^3; 1 dam^3 = 0.1 hectare-meter).

In 1966, New Mexico and Texas filed suit against Colorado in order to enforce the Compact. The case was continued indefinitely under the condition that Colorado would in some way fulfill the requirements for each subsequent year. Since that time, Colorado has met or exceeded delivery requirements - usually at the expense of the Valley agricultural economy. Approximately 1,110,000 dam^3 of water debt remained in 1984, and the Compact required repayment (USBR, 1984a; and Radosevich and Rutz, 1979). Consequently, all of the debt which was held against Colorado was erased in 1985 when the Elephant Butte Reservoir in New Mexico spilled; likewise, this same reservoir spilled in 1986.

After research on the potential for water salvage from this area, design and construction of shallow wells in connection with a lined-ditch water conveyance system was authorized in 1972 by Public Law 92-514. The general project design includes a network of 170 shallow wells over an area of 53,000 ha; all within the sump area. The plans call for annual displacement (pumping) of 128,000 dam^3 of water out of the sump area and into the Rio Grande (USBR, 1984b). The project's authorizing legislation specifies that project pumping may not cause a decline in excess of 0.6 m in any well outside of the project boundary that existed prior to the project's construction.

As stated in the Final Environmental Statement (USBR, 1979b);

> "... a project objective is to salvage those waters that are otherwise being consumed by evaporative processes."

Surface water is not proposed for salvage - only the ground water of the unconfined aquifer. No significant decrease in the amount of free-standing water is anticipated because of the highly permeable soils in such areas. A major concern of ranchers in the closed basin pertains to the effect of pumping on ground-water conditions, especially effects on the artesian aquifer as a water source. However, preliminary design studies have shown that the project will not affect artesian flows (USBR, 1979b). No well permits have recently been given within the project area in order to maximize ground-water control by the project operators. Concerns of adverse effects on wetlands, vegetation, and wildlife are also being addressed in the design of the project.

Previous research on salvageable water in areas supporting phreatophytes shows that the soil evaporation contribution to ET will become negligible when the depth to water is 2.5 m (USBR, 1963) and will decrease to zero when the depth to water is 4 m (Emery et al., 1971); the remainder of needed moisture for the plant's water supply would come from precipitation, moisture stored in the soil, and any root growth reaching a deep water table. General trends indicate that when the depth to water is less than 3 m, growth of the phreatophytic species in this study is dense and vigorous and, as the depth to water increases to 10 m, the growth becomes less dense but may continue to be vigorous (Robinson, 1967).

The project goal, as outlined by the USBR, is to lower the water table by 1.2 to 2.4 m over the project area (USBR, 1984b). This will decrease the soil evaporation contribution toward ET to a negligible amount. Phreatophytic ET data are important to a better understanding of the basin's water budget and project design; these will aid planners in the proper assessment of this hydrological parameter which is subsequently used to assist in the determination of the project's design pumping rates.

1.3 PROBLEM AND RESEARCH OBJECTIVES

Four lysimeters are operated by the USBR at a site in the closed basin area, in conjunction with the water salvage project, to obtain ET data from native phreatophytes. The critical importance of accurate ET estimates to the successful operation of the project suggests that other methods be investigated. The gas analysis (portable chamber) method was selected in this study because of its potential for instantaneous ET measurement and its portability, making possible measurements at several different sites.

Objectives of this research were :

1) to develop and apply gas analysis technology through the use of the portable chamber to measure diurnal ET of plots containing the predominant species of native phreatophytic vegetation in the closed basin area of the San Luis Valley,
2) to compare ET data in the USBR lysimeters to that obtained using the portable chamber outside of the lysimeters,
3) to observe daily ET of plots containing native vegetation under naturally occurring shallow and deep ground-water levels, and
4) to observe the ET response of plots containing native vegetation to a falling water table (where pumping occurs).

CHAPTER II

LITERATURE REVIEW

2.1 PHREATOPHYTE ET RESEARCH

Phreatophytes are of major concern in the arid areas of the Western U. S. because of their great consumption of water; annually they use (or, lose to the atmosphere) approximately 31 million dam^3 of water over an area of 6.5 million ha (Robinson, 1958). These plants are generally low in economic value, grow where the water table is from 0.5 to 6 m below the ground surface (often in low-lying or drainage areas), and transpire 50 to 100 percent more water than most cultivated crop plants (Blaney, 1951). Alfalfa and some pasture grasses are the most common phreatophytes possessing any substantial economic value. Erosion control is increased by the growth of native phreatophytes, especially greasewood - the most common native phreatophyte in the Western United States.

Several methods have been suggested to decrease the large amount of water transpired by phreatophytes. These water salvage methods include: 1) removal or destruction of the phreatophytes; 2) lowering the water table by ground-water pumping or diversion of the upstream water supply; and 3) substitution of phreatophytes with plants of higher economic value (Muckel, 1966).

2.1.1 Measurement studies

Research on ET of phreatophytes is vital to the determination of water salvage feasibility (potential savings and water availability). The first major study on phreatophytic ET was conducted by Lee (1912) in the Owens Valley, California. Data from the study were used to assist the Los Angeles Department of Water and Power (LADWP) in the estimation of the amount of water available for salvage through pumping. Subsequent study sites included major valleys in California, Nevada, New Mexico, Colorado, Utah, and Arizona. Data obtained from these studies involving greasewood, rabbitbrush, and salt grass are summarized in Table 2.1.

Table 2.1 Summary of greasewood, rabbitbrush, and salt grass evapotranspiration research.

Location	Measurement period span	Methodology	Depth to Water	Average ET Rate	Reference
			m	mm/day	
GREASEWOOD					
Escalante Valley, Utah	May-Oct. 1926	Water table diurnal fluctuation	0.89	2.0	White (1932)
	May-Oct. 1927		0.66	4.3	
Humboldt River Valley, Winnemucca, Nevada	4/3-10/20 1962	Lysimeter	1.52	2.4	Cohen et al. (1965)
			1.52	1.8	
	5/1-10/20 1963	Lysimeter	1.52	3.2	Robinson (1970)
	4/1-10/20 1964		1.83	1.9	
	4/1-10/20 1966		2.29	1.8	
	4/1-10/20 1967		2.39	2.1	
	4/1-10/20 1966	Lysimeter	1.88	2.1	Grosz (1972)
	4/12-10/20 1968		2.34	2.0	
	5/23-10/21 1969		2.46	2.1	
	4/19-10/20 1970		2.49	1.9	
Soda Lake, Fallon, Nevada	1983	Eddy-correlation; Bowen ratio	--	0.8	Carman (1986)

Table 2.1 continued

Location	Measurement period span	Methodology	Depth to Water	Average ET Rate	Reference
			m	mm/day	
RABBITBRUSH					
Humboldt River Valley, Winnemucca, Nevada	5/1-10/20 1963	Lysimeter	1.52	3.9	Robinson (1970)
	4/1-10/20 1964		1.52	2.4	
	4/1-10/20 1966		1.63	2.5	
	4/1-10/20 1967		1.88	2.6	
	4/12-10/20 1968	Lysimeter	1.88	2.5	Grosz (1972)
	5/23-10/21 1969		2.54	2.5	
	4/16-10/21 1970		2.46	2.2	
	4/19-10/20 1971		2.49	2.1	
Smith Creek Valley, Austin, Nevada	1983	Eddy-correlation; Bowen ratio	--	0.9	Carman (1986)
SALT GRASS					
Owens River Valley, California	Jan.-Dec. 1911	Lysimeter	0.46	3.4	Lee (1912)
			0.56	3.1	
			0.89	2.8	
			1.17	1.7	
			1.50	0.9	
Middle Rio Grande Valley, Los Griegos, New Mexico	Oct. 1926 - Sept. 1927	Lysimeter	0.13	3.4	Houk (1930)
			0.36	2.3	
			0.64	1.3	
	Oct. 1927 - Sept. 1928		0.15	3.2	
			0.41	2.4	
			0.66	1.6	
			0.94	0.7	
Escalante Valley, Utah	May-Oct. 1926	Water table diurnal fluctuation	0.79	2.5	White (1932)
	May-Oct. 1927		0.58	3.8	
	May-Oct. 1927		0.66	3.0	
Santa Ana River, California	May 1929 to Apr 1930 (17 mo.)	Lysimeter	0.30	3.0	Blaney et al. (1933)
	(31 mo.)		0.61	2.5	
	(11 mo.)		0.91	1.7	
	(17 mo.)		1.22	0.9	
	(16 mo.)		1.52	1.4	

Table 2.1 continued

Location	Measurement period span	Methodology	Depth to Water	Average ET Rate	Reference
			m	mm/day	
SALT GRASS (continued)					
San Luis Valley, Colorado	June-Oct. 1927	Lysimeter	0.15	3.6	Blaney et al. (1938)
			0.38	3.8	
			0.64	2.8	
	Apr.-Oct. 1928		0.13	3.8	
			0.36	3.4	
			0.61	2.9	
	May -Oct. 1930		0.10	4.6	
			0.23	3.6	
			0.58	3.2	
	Apr.-Nov. 16 1931		0.08	3.4	
			0.30	3.5	
			0.64	2.7	
			0.94	2.5	
Middle Rio Grand Valley, Isleta, New Mex.	June 1936 to May 1937	Lysimeter	0.20	2.2	Young and Blaney (1942)
Mesilla Valley, New Mexico	July 1936 to June 1937	Lysimeter	0.36	2.8	Young and Blaney (1942)
			0.66	1.6	
Carlsbad, New Mexico	Jan.-Dec. 1940	Lysimeter	0.61	3.8	Blaney et al. (1942)
Virgin River, Utah	Feb.-Nov. 1957	Lysimeter	--	2.6	Criddle et al. (1964)
Ogden Bay Waterfowl Mgmt. Area, Utah	May-Oct. 1955	Lysimeter	0.25	5.6	Christiansen and Low (1970)
			0.61	5.5	
Humboldt River Valley, Winnemucca, Nevada	5/1-10/16 1967	Lysimeter (wet meadow conditions)	0.66	3.4	Dylla et al. (1972)
	4/29-10/28 1968		0.66	2.7	
	4/28-10/27 1969		0.66	2.7	
	4/19-10/20 1971	Lysimeter	2.54	1.2	Grosz (1972)
	4/19-10/21 1972		2.54	1.6	
	4/24-10/21 1972		2.49	0.9	

Table 2.1 continued

Location	Measurement period span	Methodology	Depth to Water	Average ET Rate	Reference
			m	mm/day	
SALT GRASS (continued)					
Bernardo,	1969	Lysimeter	0.30	2.0	USBR
New Mexico	1970		0.30	1.9	(1979a)
	1971		0.30	2.2	
			0.61	1.3	
	1972		0.30	1.9	
			0.61	1.4	
	1973		0.30	2.4	
			0.61	1.3	
	1975		0.76	1.6	
			0.91	1.3	
	1976		0.76	1.4	
			0.91	1.2	
	1977		0.76	1.6	
			0.91	1.6	
	1978		0.76	1.3	
			0.91	1.4	
	1979		0.61	1.6	
			1.22	1.3	
GREASEWOOD, RABBITBRUSH, AND SALT GRASS COMMUNITY					
San Luis Valley, Colorado	1985	Eddy-correlation; Bowen ratio	--	1.4	Weaver et al. (1986)

Several methods have been successfully used for consumptive use (ET) estimation of field crops. Measurement of ET from native phreatophytes has involved methods such as plant tanks (lysimeters), soil moisture monitoring, and ground-water fluctuations (Robinson, 1966). The lysimeter method receives the most widespread use. Methods receiving more recent attention for use on native vegetation include energy balance and aerodynamic/ turbulent transport approaches (Brutsaert, 1982) and gas analysis (the portable chamber method) (Reicosky and Peters, 1977).

Empirical formulae which imply a uniform vegetation cover have been developed to estimate phreatophyte ET through the use of weather variables (Blaney, 1951). However, these are of limited value for application to most plant communities because of the composition heterogeneity, plant size variability, and varying water table depths at different sites.

The lysimeter method has received the most widespread use (Muckel, 1966). Limitations include the "oasis effect" - a phenomenum in which isolated plants (in lysimeters) use more water than their counterparts growing naturally in dense growths (Robinson, 1966). Additionally, accumulation of salts poses a threat to plant vigor and health. Extrapolation of ET data from the place of measurement to other locations is limited by differences in soil texture; soil moisture; water table depth; vegetation type, size, and distribution; and climatic variables. Two methods have been used to decrease the differences caused by plant size variability; the areal basis method and the volume of foliage basis method (Robinson, 1966).

Measurement studies are ongoing in the Owens Valley, California (Duell, 1985), the Great Basin region of Nevada and Utah (Carman, 1986), the San Luis Valley, Colorado and the Pecos River floodplain between Artesia and Acme, New Mexico (Weaver et al., 1986). These four studies are using the eddy-correlation method, based on aerodynamics and turbulent fluxes, and the Bowen ratio method, based on energy balance (Brutsaert, 1982). Both methods measure ET while avoiding disturbance of the vegetation from its natural state.

2.1.2 Depth to water table relationships

The goal of many studies on phreatophyte ET has been to determine the relationship between ET and depth to the water table. This relationship was recognized as early as 1916 (White, 1932). Simple ET-water table depth curves have been demonstrated in several studies (Houk, 1951; Thompson, 1958; Muckel, 1966; and Anderson, 1976) and have been summarized (Sorooshian and Ritzi, 1984). Harr and Price (1972) found that ET was a function of depth to water table for ground-water levels as deep as 2.3 m, but observed a more complicated relationship at depths of up to 13 m. These studies generally agree that ET is inversely related to depth to the water table.

2.2 USBR PROJECT-AREA STUDIES

The closed basin area of the Valley contains a typical phreatophytic vegetation composition; greasewood, rabbitbrush, and salt grass (Robinson, 1958). Soil conditions coupled with a high water table have encouraged establishment of these species. Typical species habitat with respect to water table depth includes salt grass (2.5 m), rabbitbrush (2.4 to 4.6 m), and greasewood (1 to 10 m) (Meinzer, 1927).

2.2.1 Phreatophyte ET

In 1984, the USBR utilized three methods for estimating ET of phreatophytes in the closed basin of the Valley during the measurement period (20 March to 9 November): 1) water table lysimeters, 2) ET modeling using weather data, and 3) combined ET estimation (USBR, 1984c). All three methods were investigated in a part of the Closed Basin Division project area where the water table depth typically ranges from 0.5 to 2.0 m.

During 1984, four lysimeters were operated - one each containing greasewood, rabbitbrush, salt grass, and bare soil surfaces. The greasewood and rabbitbrush lysimeters were installed during April of 1984; the salt grass and bare soil lysimeters were installed in 1983. Correct operation of water table lysimeters requires that the water levels inside and outside of each lysimeter are maintained at the same depths. Because of poor plant performance in the two newer lysimeters, lysimeter water was not removed as the ground-water levels fell. Consequently, water levels in these lysimeters did not fall as rapidly as the adjacent ground water; these two lysimeters were not included in the soil moisture analysis. Variability in weekly ET for the other two lysimeters was credited to errors in soil moisture measurement (USBR, 1984c) - a major input to the mass balance equation for calculating lysimeter ET. For 1984, bare soil E was unexpectedly greater than salt grass ET although both were situated at the same depth to the water table. The lowest ET rates were observed for the greasewood and rabbitbrush lysimeters. Poor plant performance in the lysimeters and inconsistent results brought the lysimeter installations and data into question.

The second method utilized dry bulb and dewpoint temperature data collected at the USBR lyimeter site in conjunction with wind and solar radiation measured at the Colorado State University Farm near Center, Colorado. The data were analyzed in three ET models, using actual ET (ET_a) from the USBR lysimeters. The modified Penman model (alfalfa reference) (Penman, 1963), Jensen-Haise model (alfalfa reference) (Jensen and Haise, 1963), and modified Hargreaves model (grass reference) (Hargreaves, 1956) were used, reference crop ET (ET_r)

values were calculated, and crop coefficients ($K_c = ET_a/ET_r$) were determined. No correlation was found to exist between K_c, depth to water, and date (USBR, 1984c).

Combined ET estimation, the third method studied, used transpiration well ET, rainfall, and soil water data to balance a soil water equation. The transpiration wells were used to estimate the draft (net rise or fall) on the ground water due to ET according to the Walter White method (White, 1932), the basis for the original design of the pumping project. The major problem with this method occurs in determining specific yield (S_y). Specific yield relates the saturated aquifer volume change to the volume of extractable water. Assumed values of S_y were used because S_y is difficult to measure. Along with the ground-water component, soil water content was measured using a calibrated neutron probe at regular intervals above the water table. A decrease in soil water in the soil profile indicated a positive ET.

Results of this combined estimation were compared with lysimeter data at the sites and all comparisons showed considerable scatter (USBR, 1984c). A major problem with this method lies in the assumption that aquifer water and soil water are entirely separate (no water migration from the water table aquifer to the unsaturated soil above). Since there is a net change in water table level over the season, this interaction may be substantial. Coupled with errors in S_y estimation, ET data obtained from this method may not be highly reliable. After the beginning of pumping, the ground water that had previously contributed to ET will no longer be as available for ET. At the time of this USBR study (1984) there remained a great amount of uncertainty concerning the effects of the falling water table on ET and the portion of water actually available for withdrawal (salvage).

2.2.2 Vegetation response to drawdown

The project's greatest effect on vegetation will occur where the previous water table depth was less than 1.5 m (42 percent of the project area) (USBR, 1979b). The effects of drawdown on vegetation will largely be determined by the type of vegetation, extent of vegetative cover, original depth to ground water, and texture of the soil.

As the water table falls, evaporation will be significantly reduced. Because of this lowering of the water table, the plants will no longer have as much gravitational water available. Many of the major species in areas of 0 to 1.5 m water table are also found in areas of deeper water table (1.5 to 4.6 m); any major shifts in vegetative composition and relative species density due to lowering of the water table may not be easily observed (USBR, 1979b).

A two-year continuous pump test at 36.3 liters per second pumping rate in the unconfined aquifer provided results on growth of greasewood, rabbitbrush, salt grass, and wire grass (USBR, 1982a). During 1980 and 1981 several fenced exclosures containing the major species within 1,070 m of the pumping well were observed for effects caused by water table drawdown. Leaf biomass weights for 1980 showed a decrease in rabbbitbrush growth only; this was probably caused by the rapid lowering of the water table.

The 1981 data of the USBR pump study showed that both greasewood and rabbitbrush suffered reduced growth (a decrease in above-ground production) near the well (380 m). Actively growing portions of each major species increased with distance from the well. Greasewood displayed the most profound changes due to drawdown and may be affected up to 1,070 m from the well (USBR, 1982a). Thus, rabbitbrush may have a better capability to utilize soil and surface moisture when ground water is less available to the deep roots. Salt grass appeared to be unaffected by drawdown, but this may have been due to the removal of grazing pressures (the test area was fenced).

2.3 CHAMBER METHOD OF ET MEASUREMENT

A representative sample of ET for the major species of native vegetation in the Valley was desired in this study. Although lysimeters provide accurate short-term ET estimates, the lack of portability and desireability of a uniform crop cover limit their use in this type of situation. A portable chamber is inexpensive to construct and operate and can be used effectively for rapid measurement of ET on various plots (Reicosky and Peters, 1977; Harmsen et al., 1982; and Peterson et al., 1985). These same studies have indicated the usefulness of a portable chamber as a research tool.

Initial calibration of a portable ET chamber was demonstrated by Reicosky and Peters (1977) using a hydroponically-grown soybean plant with measured water uptake (absorption). The transpiration from the plant was measured with the chamber and showed very good agreement with water uptake.

Several studies have been done to compare chamber ET with lysimeter ET. Reicosky et al. (1983) found general agreement between hourly ET values. In 1985, Peterson et al. measured ET on two separate days. Their findings indicated good agreement in the mid-season stage of corn (93 percent similarity) and less satisfactory agreement in the late-season stage of corn (78 percent similarity). This variability in agreement was credited to corn physiological maturity differences between the two days of measurement. Reicosky (1985) provides an accurate synopsis of details concerning calibration and accuracy of the portable chamber method of estimating ET.

Although the portable chamber is useful and accurate for estimating ET, there are several limitations. During measurement, the microclimate within the chamber is slightly altered because of re-radiation exchange and turbulent transfer (Businger, 1963). These effects increase with an increase in measurement period. A portion of this alteration of the microclimate results from the chamber material and its effect on re-radiation of infrared light wavelengths (IR) (Harmsen et al., 1982).

The second limitation, a result of the chamber's portability, is that repeated readings are required throughout the day if daily values are desired, and this repetition can be very laborious. On a clear day one measurement per hour is usually sufficient (Reicosky, 1981); with partial (intermittent) cloud cover more frequent measurements are desirable.

CHAPTER III

METHODOLOGY

3.1 SITE SELECTION

Evapotranspiration measurements using a portable chamber were made during three five-day periods of 1985 (20-24 May, 24-28 June, and 22-26 July) and regularly during the period of 26 May through 13 August 1986. During 1985, the only site measured was the USBR Lysimeter site. In 1986, three sites were measured in each week (one site per day) and were chosen according to similarities in species composition and plant size to represent three different water table situations; shallow, varying, and deep. Ground-water levels at most project-area sites were measured weekly in conjunction with ET measurement. The varying water table site (due to pumping) had a corresponding nearly constant water table site nearby for same-hour ET measurements. Site locations with respect to the entire USBR Closed Basin Division project area are shown in Figure 3.1; the plots measured are indicated in Table 3.1.

Attempts were made to select greasewood and rabbitbrush bushes intermediate in size relative to those existing in the surrounding plant communities so that plant transpirational surface area was not a confounding factor in the study. Average heights of greasewood and rabbitbrush sampled were 71 and 53 cm, respectively, although there was

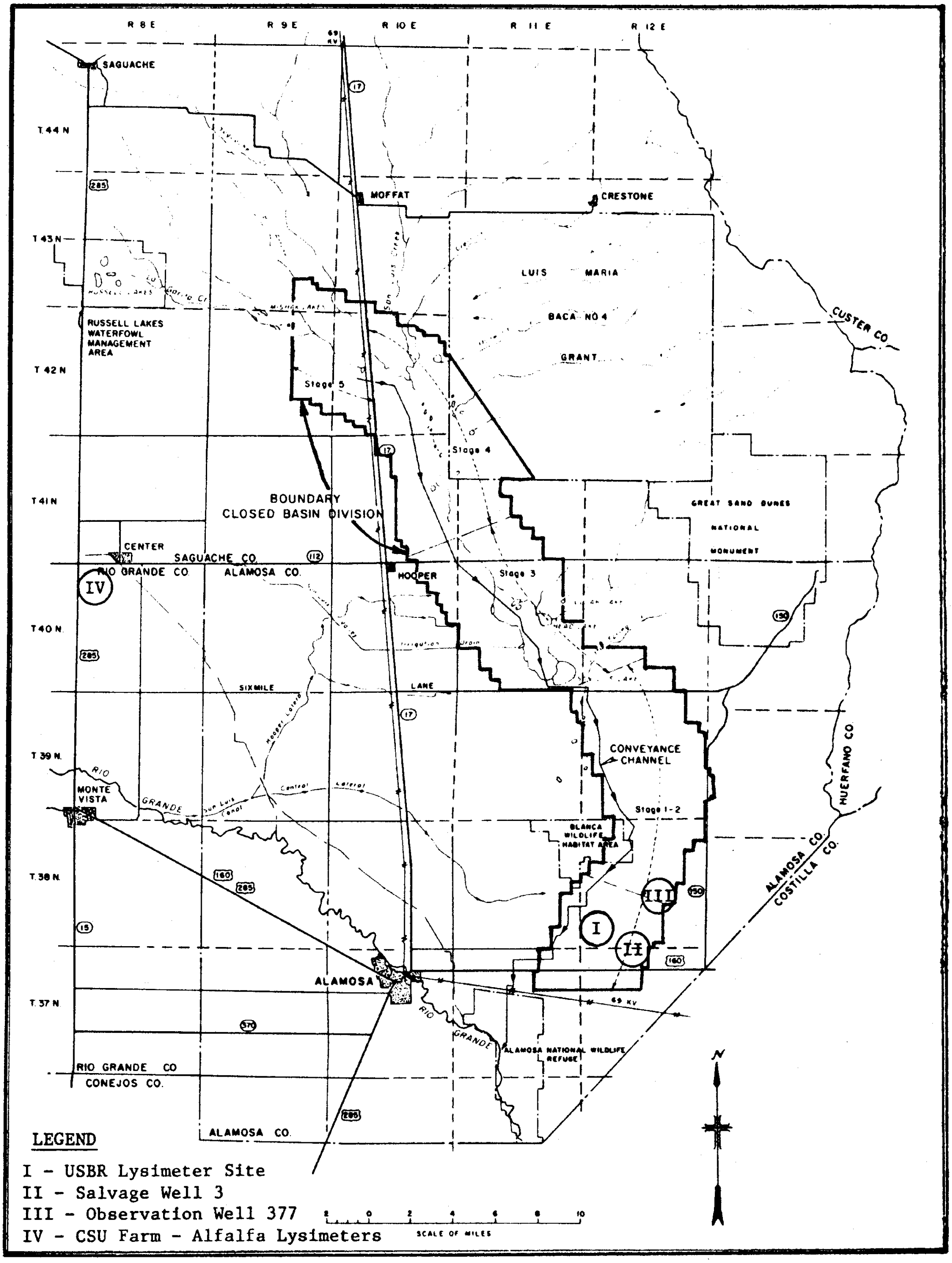

Figure 3.1 U.S. Bureau of Reclamation Closed Basin Division project area, San Luis Valley, Colorado. (USBR, 1982b)

Table 3.1 Description of ET measurement sites. 1985, 1986.

Year	Site Number	Site Location	Depth to Water	Number and Type of Plots Measured
			m	
1985	1	USBR Lysimeter Site	---	2 Greasewood† 1 Rabbitbrush 2 Salt Grass† 1 Bare Soil§ 2 Bare Soil†##
1986	1	USBR Lysimeter Site	0.6 to 1.5	3 Greasewood 3 Rabbitbrush 3 Salt Grass 3 Bare Soil
	2	Salvage Well 3	varying and constant (control)	3 Greasewood 3 Rabbitbrush 3 Greasewood (control) 3 Rabbitbrush (control)
	3	Observation Well 377	4.2 to 4.6	5 Greasewood 4 Rabbitbrush

† One of the plots indicated was a USBR lysimeter.
§ upland area
lowland area

some variability in plant size and density between sites due to different natural depths to the ground water.

Of the three closed basin sites of ET measurement, Salvage Well 3 (Site #2) and Observation Well 377 (Site #3) were sampled only in 1986. Measurements were made at the USBR Lysimeter site (Site #1) during both 1985 and 1986. However, only two of the plots at this site were measured both years (Greasewood #1 and Rabbitbrush #1). During 1986, a minimum of three replicate plants for each species (treatment) were measured at each site. This provided data applicable to the one-way analysis of variance (ANOVA) and the least significant difference (LSD) tests where appropriate.

3.2 CHAMBER ET MEASUREMENT

Proper construction and operation of the chamber was required for reliable ET estimates. Design considerations included chamber material selection, chamber size, choice of instumentation, placement of measuring instruments and fans, timing of measurement, chamber effects on the plant response, and the data aquisition system.

3.2.1 Materials

The main goal in selection of the chamber material was to minimize trapping of solar re-radiation while maintaining a sturdy structure. Lexan, the material chosen, was sturdy and re-radiates more IR than Plexiglass (Harmsen et al., 1982). Propafilm c/110 was not chosen because of its vulnerability to damage and rupture, although it is a better re-radiator. For reliable measurements minimal sunlight was blocked by the instruments and, also, the instrumentation was silver or painted white.

Two cylindrical clear Lexan chambers, measuring 0.95-m diameter by 0.91-m height and 1.61-m diameter by 0.91-m height were used for ET measurements. The chambers were designed to fit over the USBR lysimeters with minimal plant disturbance and damage. During 1985 most plots were measured with the smaller chamber, and during 1986 all plots at all sites were measured with the smaller chamber. Two fans were located on opposite sides of the chamber to ensure well stirred air. Instrumentation included a fast response capacitance-type relative humidity probe (Qualimetrics, Inc., Model 5120-C) and a fine wire copper-constantan thermocouple (36 gauge), both located inside and near the top of the chamber wall. Both sensors were shielded from direct sunlight. A portable data acquisition system (Campbell Scientific 21X micrologger) sampled temperature and relative humidity and stored these data on cassette tape every two seconds during the measurement period. The data were used to determine vapor pressure changes in the chamber, from which ET was calculated.

3.2.2 Procedure

Measurements were made every hour for all plots at the site for that day from shortly after sunrise to shortly before sunset. Prior to each measurement period, the fans were run while holding the chamber aloft for 20 to 25 seconds to allow the chamber air to equilibrate with the surrounding air. The chamber was then placed over the plant, rapidly sealed with soil at the ground, and the data acquisition system started. Data were collected for a period of sixty seconds. After this period, data acquisition was ended and the chamber was lifted off of the plot and carried to the next plot where the chamber air was again allowed to mix with the surrounding air prior to the beginning of the next measurement period.

3.2.3 Raw data analyses

To calculate each plot's water loss (ET), the raw chamber data (relative humidity and dry bulb temperature) were analyzed to determine the actual vapor pressure which, in turn, was used in the Ideal Gas Equation to determine the amount of water in the chamber volume for every two seconds during each sixty-second period of measurement. The Lowe equation (Lowe, 1976) determined saturation vapor pressures:

$$SVP = 0.6107799961 + 0.04436518521\ t + 0.001428945805\ t^2 + 2.65064847\times10^{-5}\ t^3 + 3.031240396\times10^{-7}\ t^4 + 2.034080984\times10^{-9}\ t^5 + 6.136820929\times10^{-12}\ t^6 \qquad 3.1$$

where t = dry bulb temperature (°C), and

SVP = saturated vapor pressure (kPa).

The depth of water in the chamber was calculated by the following form of the Ideal Gas Equation:

$$DEP = \frac{(AVP)(VOL)}{(\rho_w)(A)(R)(T)} \qquad 3.2$$

where DEP = depth of water (m),

AVP = actual vapor pressure (kPa),

VOL = volume of the chamber (m^3),

ρ_w = water density = 1000 kg/m^3,

A = soil surface area (m^2),

R = gas constant = 0.46152 kN•m/kg•K, and

T = temperature (K).

Actual vapor pressure is equal to saturated vapor pressure (kPa) multipied by relative humidity.

Average hourly rates of ET were calculated from each measurement period (one period per plot per hour) and were based on the maximum ten-second vapor pressure gradient for each period. These hourly ET rates provided a diurnal curve for each plot assuming linearity between measured points. Using a numerical technique, the computed area under the diurnal chamber-measured ET curve yielded a daily ET value (Figure 3.2). For purposes of daily ET estimation, no ET was assumed to occur before sunrise and after sunset.

3.2.4 <u>Method validation</u>

In addition to the sites of ET measurement in the USBR project area, a site (Site #4) was chosen in an alfalfa field at the Colorado State University Farm near Center, Colorado (Figure 3.1). Measurements

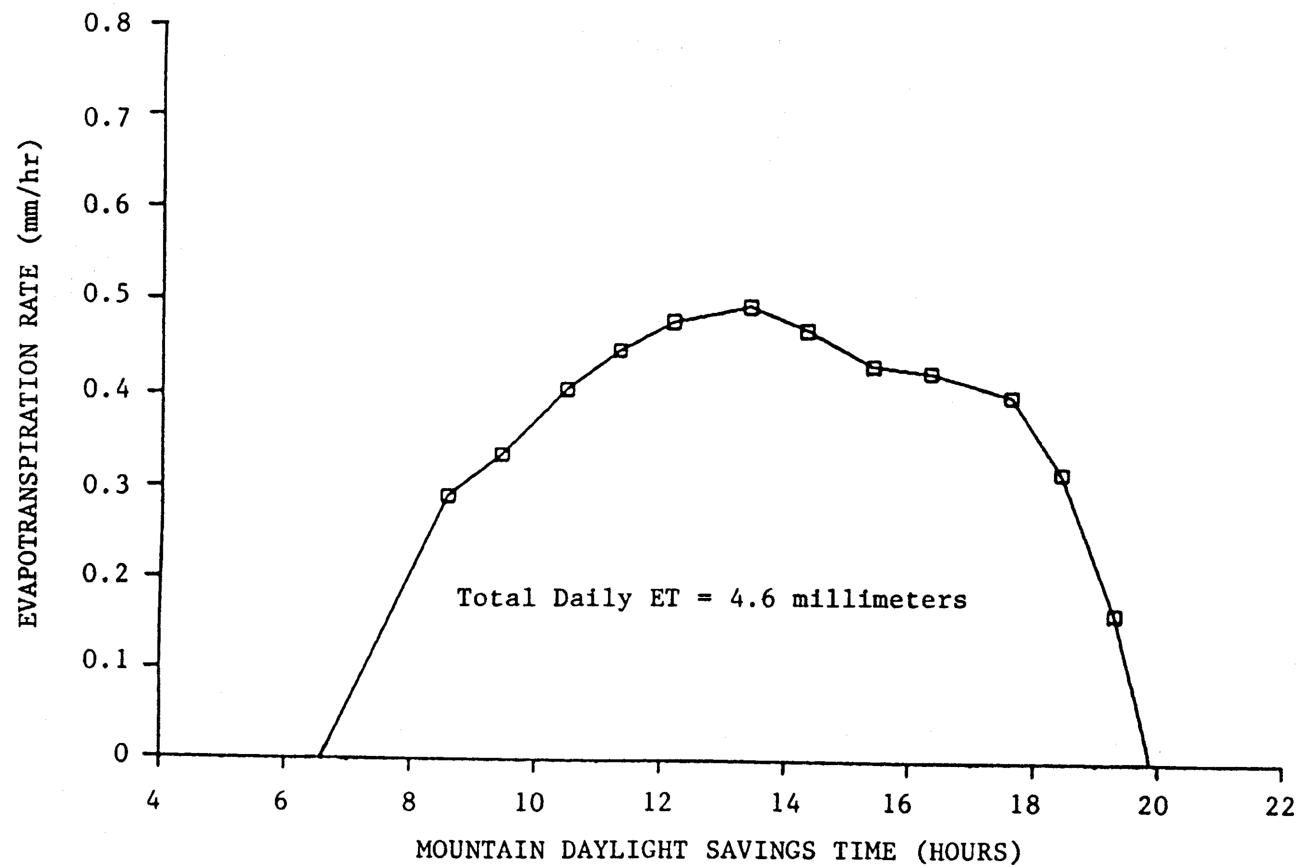

Figure 3.2 Diurnal evapotranspiration measured with a portable chamber. (Rabbitbrush #1, USBR Lysimeter site, 28 July 1986)

were obtained at this site for comparison of ET measured with the chamber to ET measured from several established lysimeters containing alfalfa (maintained by the USDA-ARS, referred to herein as the ARS lysimeters).

Alfalfa ET was measured on two days (6 June and 25 July 1986). The two hydraulic weighing lysimeters used for comparison purposes were installed in the spring of 1983 by the USDA-ARS for determination of alfalfa water use. Kincaid et al. (1979) presented results of a study using paired hydraulic lysimeters which were of a similar design to the lysimeters at Center, and found that an average daily difference in water use between paired lysimeters of 18 percent was reasonable under normal operating conditions.

The ARS lysimeters were in excellent condition on both days of measurement, with the alfalfa at a similar stage of growth inside and outside of the ARS lysimeters. Six plots outside of the ARS lysimeters but in the same field, chosen according to similarity in average plant height and growth density, were sampled each hour for a period of nine hours on 6 June and six other similarly chosen plots were sampled every half-hour for a period of seven hours on 25 July. Data from the two ARS lysimeters were used for each comparison (Table 3.2).

Table 3.2 Means and standard deviations for ARS lysimeter and chamber data, Colorado State University Farm, Center, Colorado, 1986.

Day of Year	Chamber ET		ARS Lysimeter ET		Chamber/Lysimeter ET ratio
	$\overline{ET}$	s	$\overline{ET}$	s	
	mm		mm		mm/mm
157	6.5	0.7	6.7	0.4	0.96
206	5.4	0.4	6.0	0.7	0.90

Average plot ET as determined by the chamber was 96 percent (6 June) and 90 percent (25 July) of the average ARS lysimeter ET for the corresponding periods.

3.3 CLIMATIC VARIABLES

3.3.1 Measurement

Along with chamber measurement of ET, a weather station was operated at the USBR Lysimeter site to measure (parentheses denote equipment used) dry bulb air temperature (thermistor), relative humidity (hair element with transducer), wind speed (DC tach anemometer), solar radiation (LiCor pyranometer), and precipitation (weighing bucket raingage). These climatic parameters were recorded using a Campbell Scientific CR5 datalogger at five-minute intervals on days of ET measurement and every hour at other times. Precipitation data were obtained from a USGS tipping bucket raingage at Site #1 and were combined with the corresponding data of this study (Table A.1). Tables A.2 and A.3 show daily weather summary data for 1985 and 1986, respectively; Figures 3.3 through 3.6 show examples of diurnal wind speed, solar radiation, temperature, and vapor pressure data.

3.3.2 Analysis - The Penman method of ET estimation

Weather data were collected on all days of chamber measurement during 1985 and for the entire period (26 May to 13 August) of measurement during 1986. These data provided the necessary information for use of the Penman Combination Equation to calculate alfalfa reference ET for each day of measurement (Tables A.4 and A.5).

The Penman method of potential ET estimation is one of the best methods for calculating daily ET if adequate weather data are available (Jensen, 1973). The original formula was developed by Penman (1948)

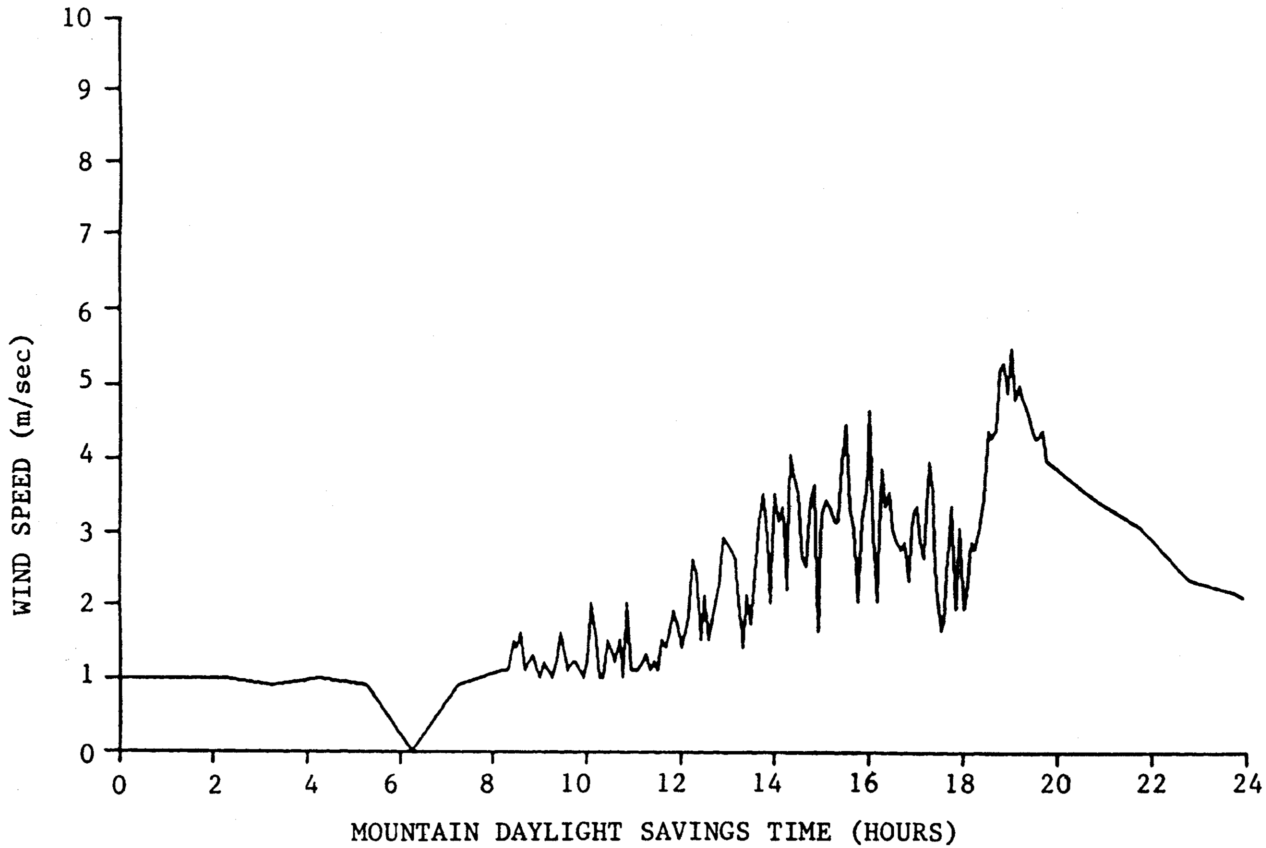

Figure 3.3 Diurnal wind speed. (USBR Lysimeter site, 28 July 1986)

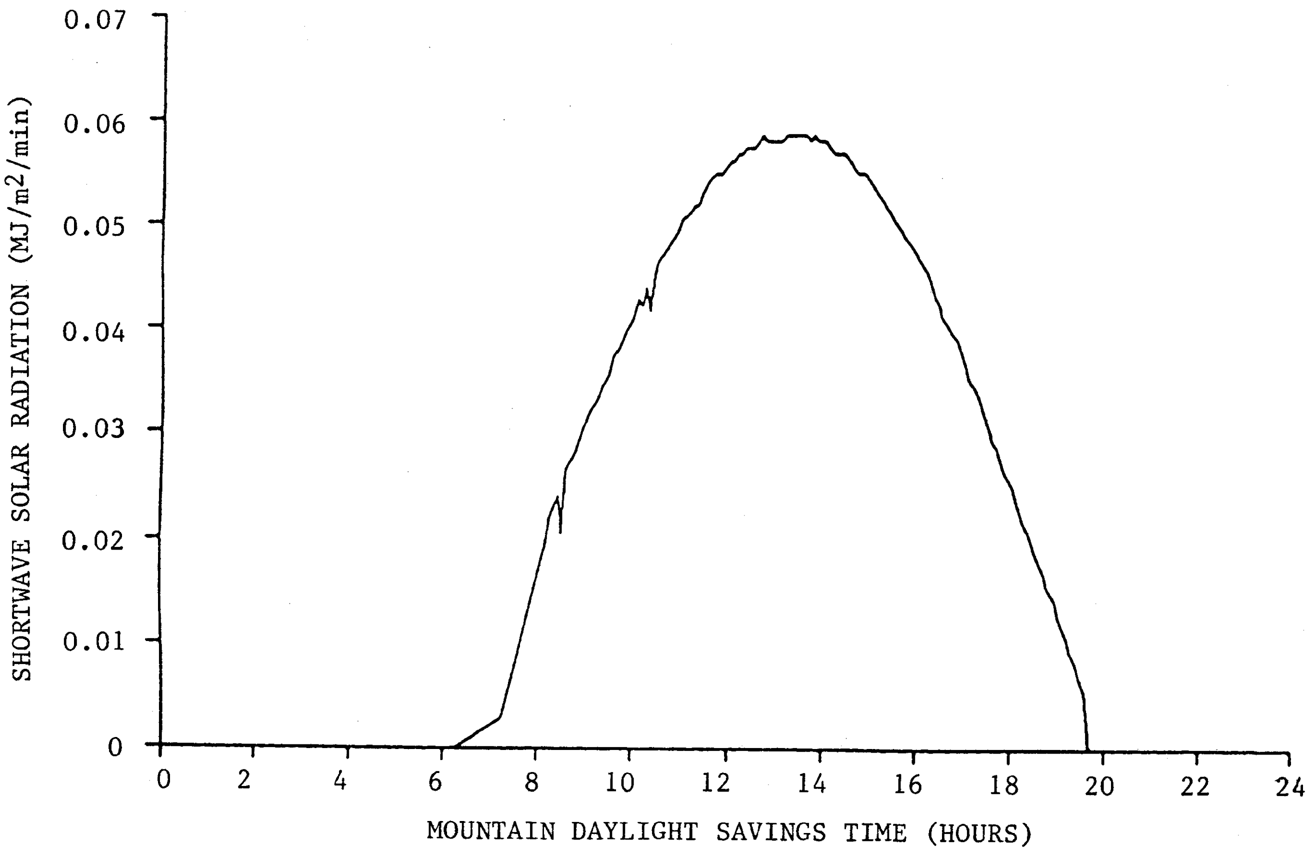

Figure 3.4 Diurnal solar radiation. (USBR Lysimeter site, 28 July 1986)

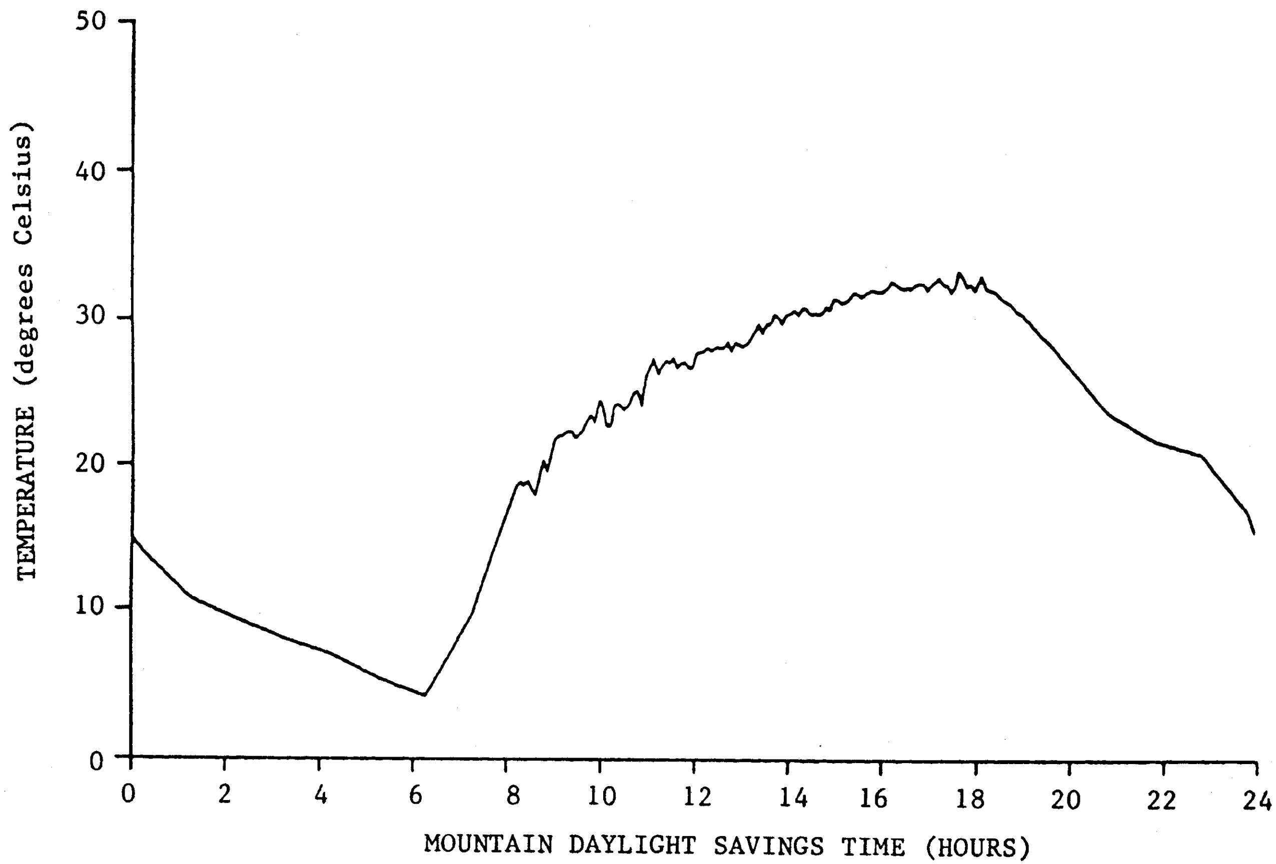

Figure 3.5 Diurnal temperature. (USBR Lysimeter site, 28 July 1986)

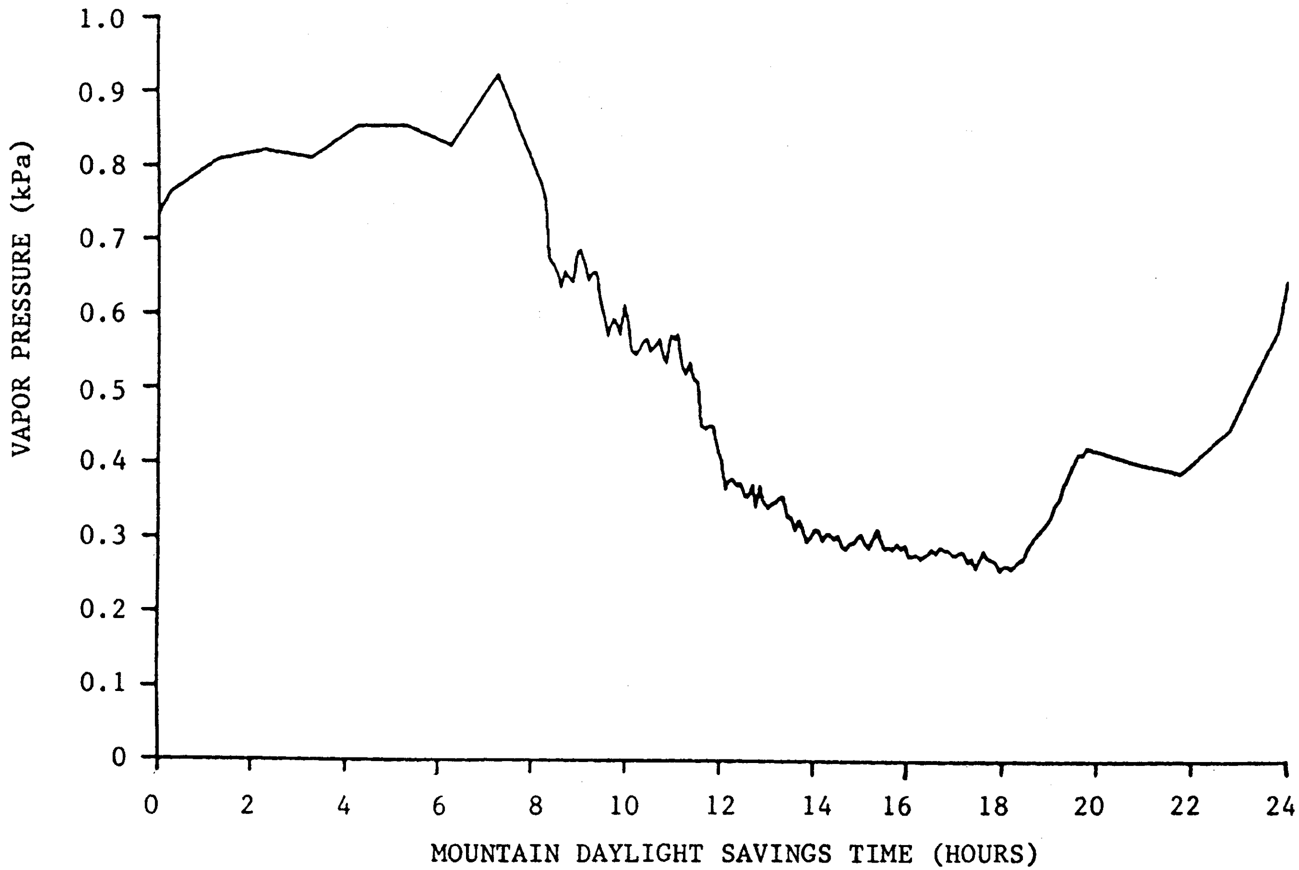

Figure 3.6 Diurnal vapor pressure. (USBR Lysimeter site, 28 July 1986)

and simplified by Penman (1963). Several forms and calibrations of this formula have been applied. The form of the Penman method chosen for ET calculation using 1985 and 1986 weather data was calibrated in Kimberly, Idaho by Wright and Jensen (1972).

Alfalfa lysimeter data collected by Mr. Segundo Diaz 1/ at the Colorado State University Farm near Center, Colorado indicated that during 1985 this calibration of the Penman equation was closer than were several other commonly used equations to the actual ET measured on the corresponding days of chamber measurement. Daily alfalfa reference ET is computed from daily meteorological data with the modified Penman Combination Equation (Wright and Jensen, 1972):

$$E_{tr} = \left[\frac{\Delta}{\Delta+\gamma} (R_n - G) + \frac{\gamma}{\Delta+\gamma} 6.426 \, W_f \, (e_s - e_d) \right] (L\rho_w)^{-1} \qquad 3.3$$

where

E_{tr} = reference evaporative flux as a water depth (m),

R_n = net radiation (MJ/m^2),

G = soil heat flux (MJ/m^2),

W_f = wind function (dimensionless),

e_s = saturation vapor pressure (kPa),

e_d = saturation vapor pressure at the dewpoint temperature (kPa),

Δ = slope of the saturation vapor pressure-temperature curve (kPa/°C),

γ = psychrometric constant (kPa/°C),

L = latent heat of vaporization (MJ/kg), and

ρ_w = water density = 1000 kg/m^3.

1/ personal communication on unpublished data in master's thesis draft.

Weighting factors multiply the net radiation-soil heat flux and advection terms of the Penman equation and represent their relative importance in estimating ET, with the net radiation-soil heat flux term receiving more weight. They are estimated from two physical properties of air; Δ and γ. The slope of the saturation vapor pressure-temperature curve (Δ) can be estimated by taking the first derivative of the expression for saturation vapor pressure (Lowe, 1976) with respect to t such that:

$$\Delta = 0.044365185 + 0.002857892\,t + 7.95194541\text{x}10^{-5}\,t^2 + 1.212496158\text{x}10^{-6}\,t^3 + 1.017040492\text{x}10^{-8}\,t^4 + 3.682092557\text{x}10^{-11}\,t^5 \qquad 3.4$$

where t = temperature of the evaporating surface (°C).

The psychrometer constant, γ, as a property of dry air represents the balance between latent heat and sensible heat and can be estimated using Brunt's (1952) formula:

$$\gamma = \frac{C_p\ P}{0.622\ L} \qquad 3.5$$

where C_p = specific heat of air = 0.001 MJ/kg•°C,

P = atmospheric pressure (kPa), and

L = latent heat of vaporization (MJ/kg).

Atmospheric pressure, P, can be estimated from (Jensen, 1973):

$$P = 101.3 - 0.01055\ EL \qquad 3.6$$

where EL = elevation above sea level (m).

The latent heat of vaporization changes with temperature and is estimated (Brunt, 1952) from:

$$L = 2.4907 - 0.002135\ t \qquad 3.7$$

where t is the temperature (°C).

The first main energy input accounted for in the Penman equation includes net radiation, R_n, and soil heat flux, G. Net radiation, R_n, is the difference between the downward and upward short and longwave radiation flux passing through a horizontal plane above the ground surface (Jensen, 1973). It can be estimated from:

$$R_n = (1-\alpha)\ R_s - R_b \qquad 3.8$$

where

R_s = measured incoming shortwave solar radiation (MJ/m^2),

R_b = net outgoing longwave radiation (MJ/m^2), and

α = albedo of the surface.

Albedo is a coefficient which represents the fraction of incoming shortwave radiation that is reflected back into the atmosphere. For most field crop situations, albedo ranges from 0.20 to 0.25 with an average value of 0.23 commonly used (Jensen, 1973). The net outgoing longwave radiation, R_b, can be estimated (Jensen et al., 1971) as:

$$R_b = (a\ \frac{R_s}{R_{so}} + b)\ R_{bo} \qquad 3.9$$

where

R_s = measured incoming shortwave solar radiation (MJ/m^2),

R_{so} = incoming shortwave radiation under clear conditions (MJ/m^2),

R_{bo} = net outgoing longwave radiation under cloudless sky conditions (MJ/m^2), and

a, b = empirical coefficients determined by linear regression.

The coefficients "a" and "b" used in this research are 1.22 and -0.18, respectively; radiation units for computation with these coefficients are calorie/square centimeter. Clear sky incoming shortwave solar radiation, R_{so}, is estimated using an equation (Heermann et al., 1984) of the form:

$$R_{so} = A' + B' \cos(2\pi d/365 - C') \qquad 3.10$$

where d = day number of the year. The coefficients may be estimated according to:

$$A' = 31.54 - 0.2734\ LAT + 0.0007813\ ALT \qquad 3.11$$

$$B' = -0.2986 + 0.2678\ LAT + 0.0004102\ ALT \qquad 3.12$$

$$C' = 2.92 \qquad 3.13$$

where

LAT = latitude (degrees), and

ALT = elevation (m).

R_{bo} can be calculated as:

$$R_{bo} = (a_1 - 0.139\sqrt{e_d})\ \sigma\ [(T_a^4 + T_b^4)/2] \qquad 3.14$$

where

a_1 = a parameter for estimating the effective emittance of the atmosphere = 0.325 (Wright and Jensen, 1972),

e_d = saturation vapor pressure at mean dewpoint temperature (kPa),

σ = the Stefan-Boltzman constant = 4.895×10^{-9} $MJ/m^2 \cdot day \cdot K^4$,

T_a = maximum daily Kelvin air temperature, and

T_b = minimum daily Kelvin air temperature.

Soil heat flux, G, can be estimated by several empirical approximations, one of which (Jensen et al., 1971) is:

$$G = 0.37656\ [\ t - \frac{1}{3}\ (t_{-1} + t_{-2} + t_{-3})] \qquad 3.15$$

where

t = mean daily temperature (°C), and

t_{-i} = mean air temperature for the i^{th} previous day (°C).

In this research, soil heat flux is assumed to be negligible due to the large diurnal temperature variation; large amounts of energy are lost to the atmosphere at night due to the elevation and climate of the Valley.

The aerodynamic term in the Penman equation is defined as:

$$E_a = W_f\ (e_s - e_d) \qquad 3.16$$

where

W_f = wind function,

e_s = average of saturation vapor pressures at the daily maximum and minimum temperatures (kPa), and

e_d = saturation vapor pressure at mean daily dewpoint temperature (kPa).

The saturation vapor pressure can be estimated from the Lowe equation (3.1). The saturation vapor pressure at mean daily dewpoint temperature can be estimated from a procedure using simultaneous temperature and relative humidity data collected at regular intervals (e.g. every four hours) throughout the day (Kincaid and Heermann, 1974). The wind function, W_f, is:

$$W_f = a_w + b_w U_2 \qquad 3.17$$

where

a_w, b_w = empirical coefficients dependent upon the aerodynamic characteristics of the crop surface and the general nature of the location as it affects sensible heat advection, and

U_2 = the daily wind run at 2 m height (km).

The coefficients a_w and b_w used here are 0.75 and 0.0115, respectively (Wright and Jensen, 1972).

3.4 XYLEM WATER POTENTIAL MEASUREMENT

In conjunction with ET measurement at each site, xylem water potential data of the three species were collected throughout the summer of 1986 using a Soilmoisture Equipment Corporation pressure chamber; these data are presented in Appendices B.1 through B.3. Water potential data are useful in the observation of plant responses to various conditions, especially in areas of rapid water table fluctuation (i.e. drawdown).

Original work on the measurement methodology for the pressure chamber or "pressure bomb" was done by Scholander et al. (1965). The pressure chamber is essentially a strong metal chamber which is pressurized with compressed air or nitrogen during the water potential measurement. A freshly cut plant branch or leaf is placed inside of the chamber, with the stem or petiole protruding to the atmosphere through a tight gasket for observation. Hosing and valves regulate the rate of pressurization and exhaust of the gases after completion of measurement. A gauge is used to monitor the pressure within the chamber.

The basic principle involved follows that when a pressure measurement is made, the pressure within the chamber forces the water within the xylem to the cut end of the stem. The magnitude of the equalizing pressure which causes sap to arrive at the stem end is an indicator of the (negative) plant water potential.

CHAPTER IV

RESULTS AND DISCUSSION

4.1 EVAPOTRANSPIRATION COMPARISON - USBR LYSIMETER VS. CHAMBER DATA

Lysimeter ET data were obtained from the USBR for 1985 and 1986 for comparison with chamber ET data. Chamber measurements were made over the USBR lysimeters and several surrounding plots of vegetation of the same species in 1985. However, chamber data were not gathered over the USBR lysimeters during the summer of 1986 because of the extremely poor condition of the vegetation existing inside of the lysimeters - mainly the greasewood and rabbitbrush lysimeters. These lysimeters contained vegetation which was not representative of the surrounding vegetation in size and vigor. The greasewood exhibited a yellowish color and was much smaller than typical greasewood plants at this site. A replacement for the rabbitbrush of 1985 had been introduced in the rabbitbrush lysimeter in mid-Spring 1986, but had not established sufficiently to yield useful data as was observed by size, maturity, and color appearance differences from surrounding rabbitbrush plants.

4.1.1 1985 Data

Each plot at Site #1 provided data (of three five-day periods) for ET comparison of USBR lysimeter versus chamber measurements for greasewood, rabbitbrush, salt grass, and bare soil (evaporation comparison) plots (Figures 4.1 through 4.4). Visual comparison of the 1985 data shows that lysimeter ET (a seven-day average) was generally

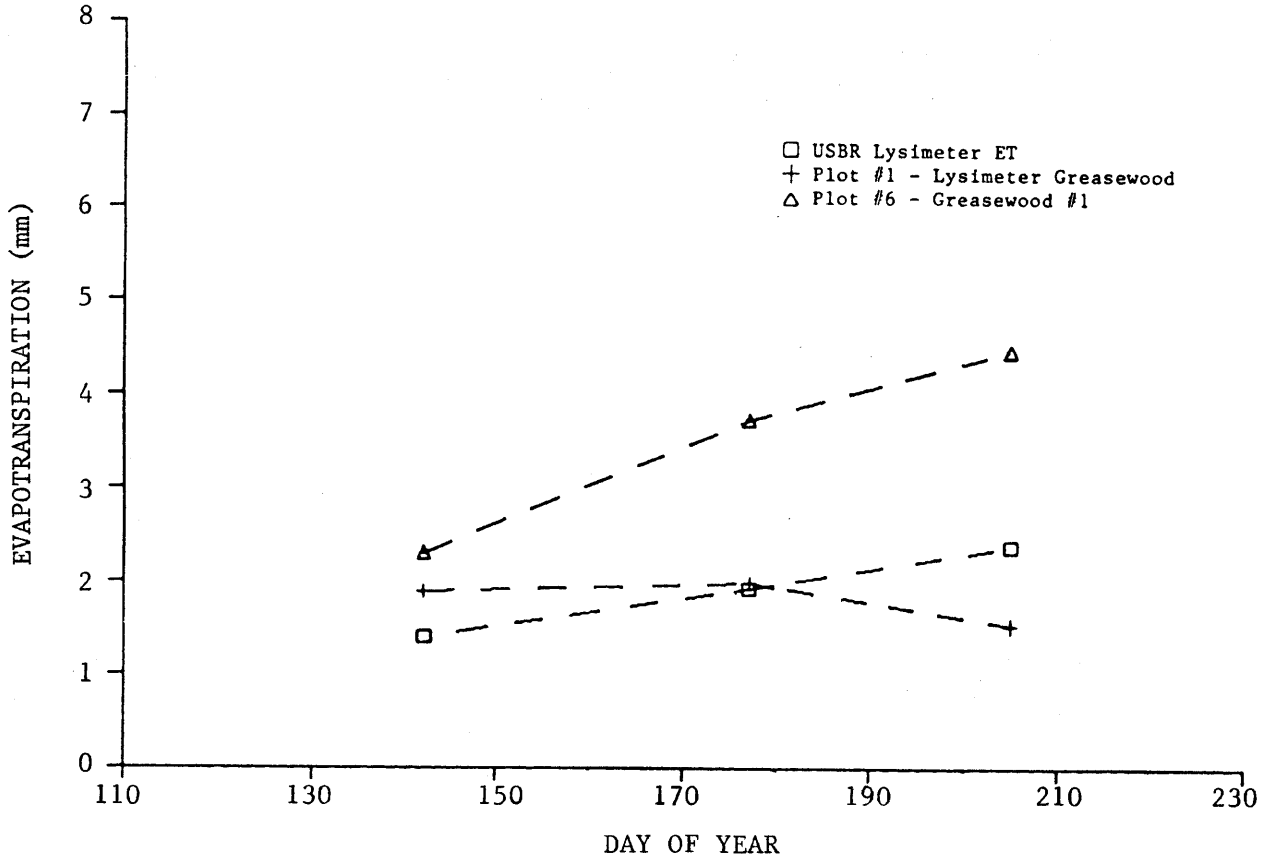

Figure 4.1 Evapotranspiration comparison of USBR lysimeter versus chamber measurements. (Greasewood plots, USBR Lysimeter site, 1985)

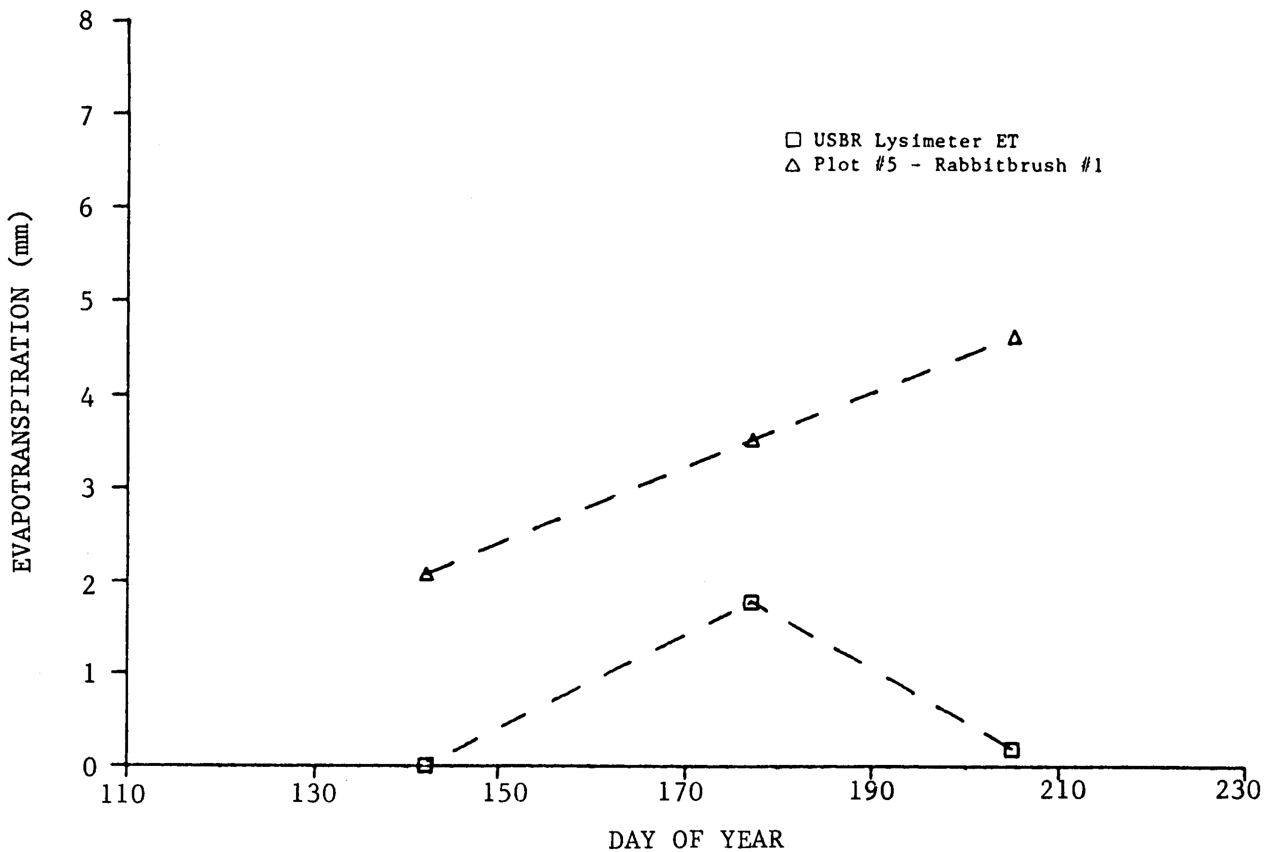

Figure 4.2 Evapotranspiration comparison of USBR lysimeter versus chamber measurements. (Rabbitbrush plots, USBR Lysimeter site, 1985)

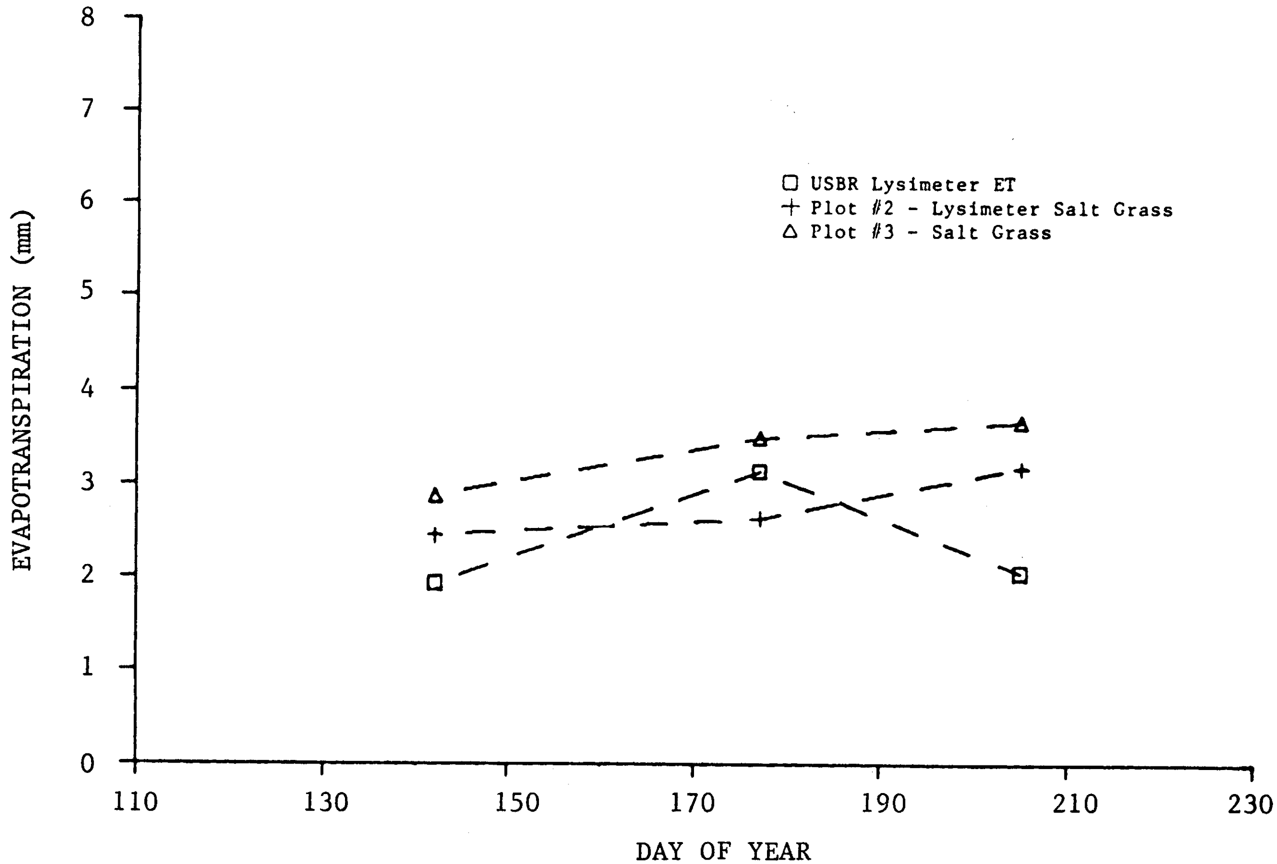

Figure 4.3 Evapotranspiration comparison of USBR lysimeter versus chamber measurements. (Salt Grass plots, USBR Lysimeter site, 1985)

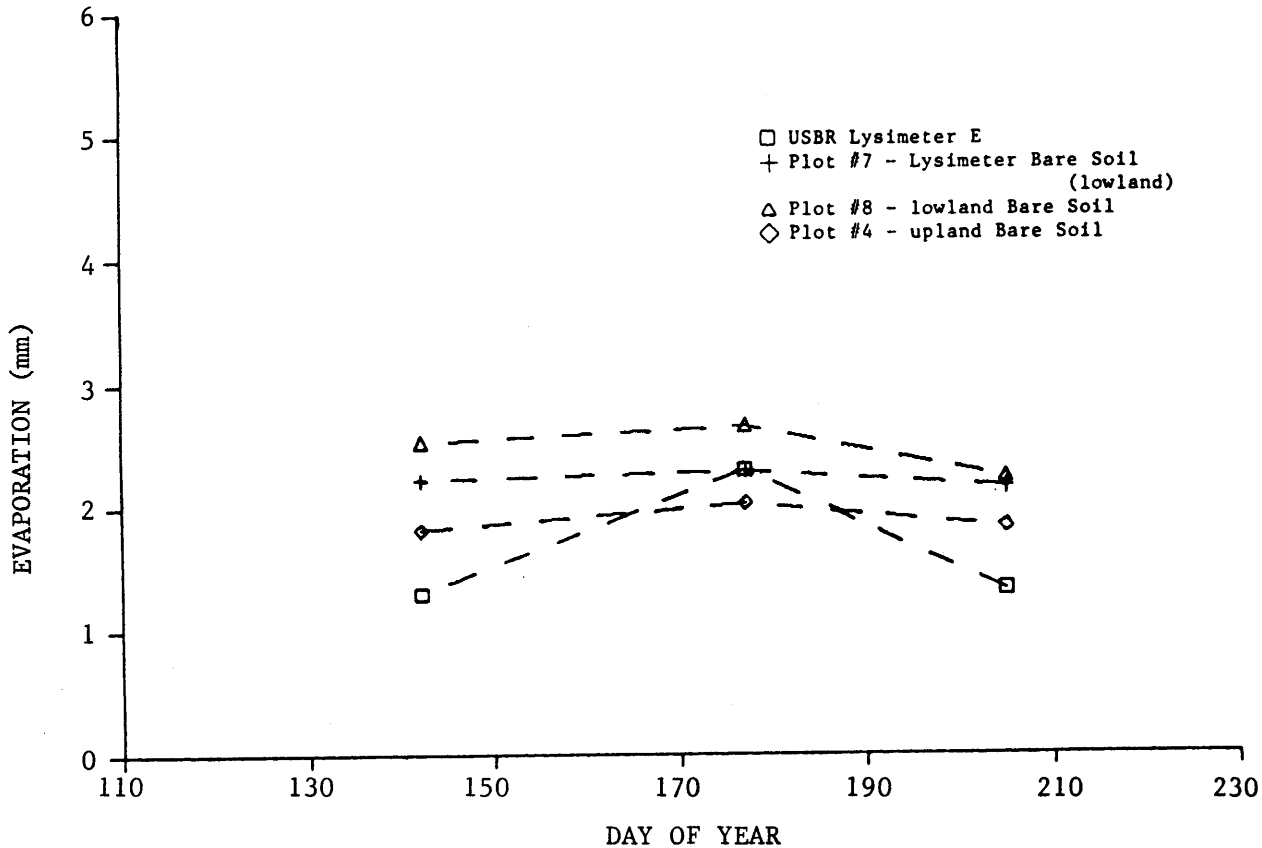

Figure 4.4 Evaporation comparison of USBR lysimeter versus chamber measurements. (Bare Soil plots, USBR Lysimeter site, 1985)

lower in magnitude than chamber ET (a five-day average) for each corresponding week of measurement. The best agreements in weekly ET and evaporation (E) were found for salt grass and bare soil plots (Table 4.1). The poorest agreement in ET was found for the rabbitbrush comparison. Although the ET and E rates from the USBR water table lysimeters were not representative of the surrounding vegetation, these rates were similar to those measured by the chamber over the salt grass, bare soil, and greasewood lysimeters.

Table 4.1 USBR lysimeter versus chamber method ET or E comparison data for three weeks in 1985, USBR Lysimeter site.

Type of Plot	Week	Ratio of Lysimeter/Chamber ET or E	
		LET/LCET	LET/CET
Greasewood	20-24 May	0.74	0.61
	24-28 June	0.95	0.51
	22-26 July	1.60	0.55
Rabbitbrush	20-24 May	--	0
	24-28 June	--	0.51
	22-26 July	--	0.04
Salt Grass	20-24 May	0.76	0.66
	24-28 June	1.19	0.89
	22-26 July	0.63	0.56
Bare Soil	20-24 May	0.59	0.52
	24-28 June	1.00	0.85
	22-26 July	0.62	0.59

LET = USBR lysimeter average daily ET (or E)
LCET = Chamber average daily ET (or E) measured at the lysimeter
CET = Chamber average daily ET (or E) measured at a nearby plot away from the lysimeter.

4.1.2 1986 Data

A summary of total and average daily ET for each plot at Site #1 is shown in Table 4.2; point values are shown in Figures 4.5 through 4.8. Although no chamber measurements of vegetation in the USBR lysimeters

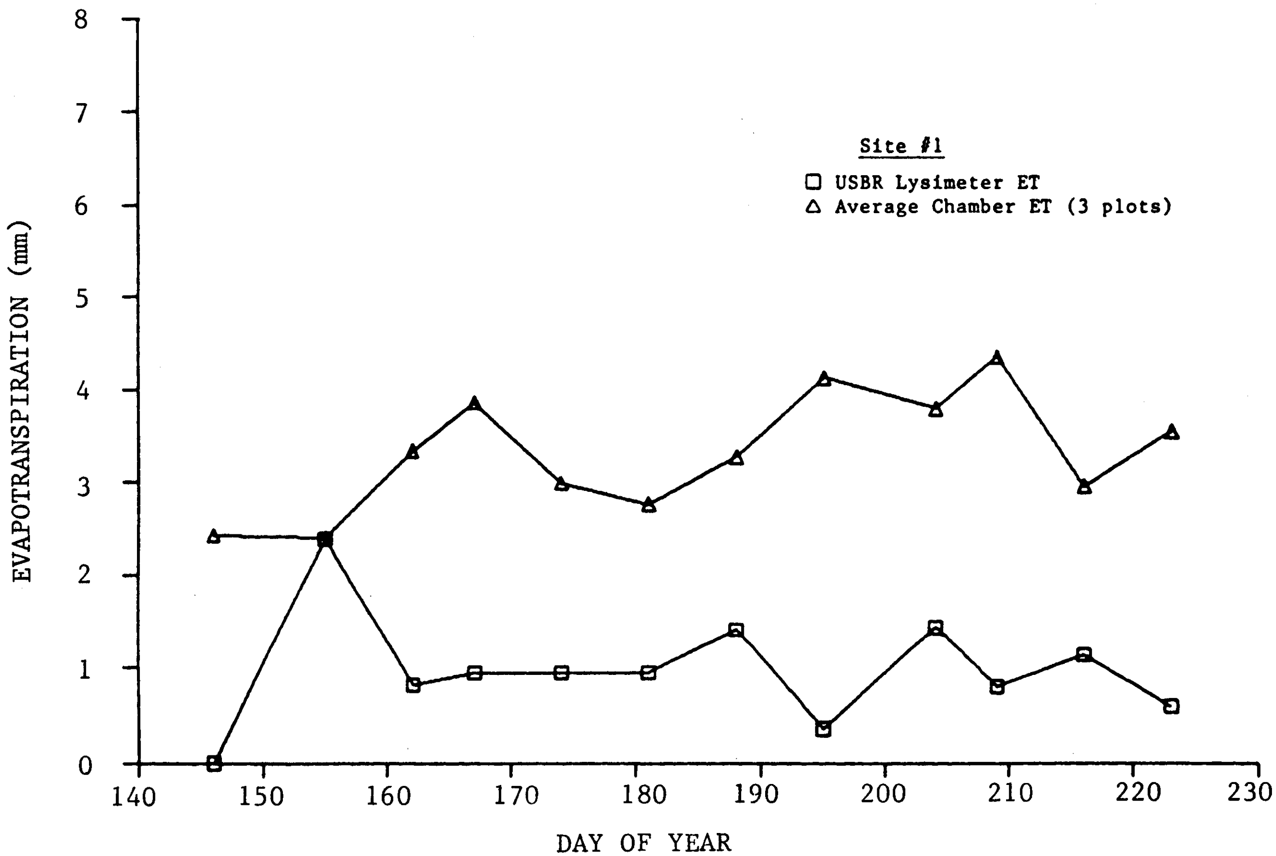

Figure 4.5 Evapotranspiration comparison of USBR lysimeter versus chamber measurements. (Greasewood plots, USBR Lysimeter site, 1986)

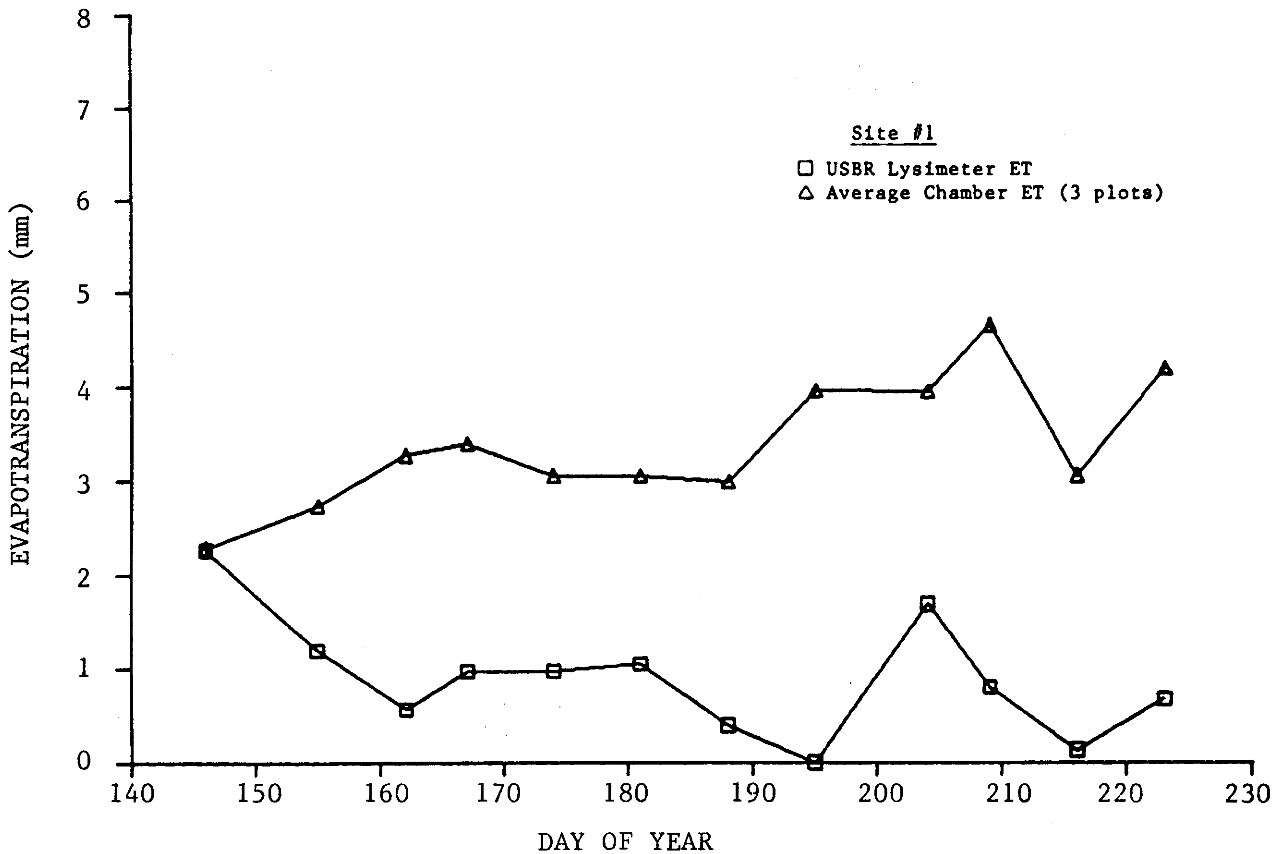

Figure 4.6 Evapotranspiration comparison of USBR lysimeter versus chamber measurements. (Rabbitbrush plots, USBR Lysimeter site, 1986)

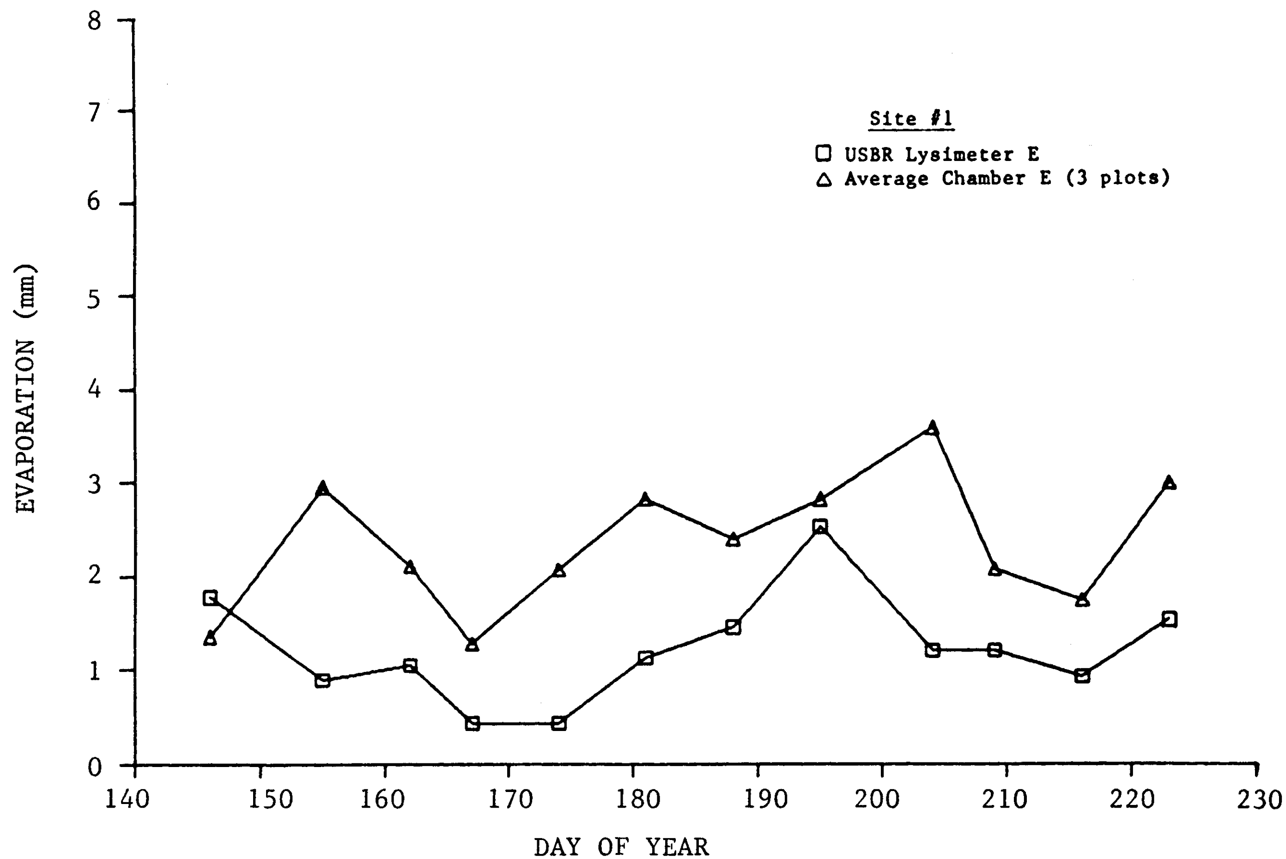

Figure 4.7 Evaporation comparison of USBR lysimeter versus chamber measurements. (Bare Soil plots, USBR Lysimeter site, 1986)

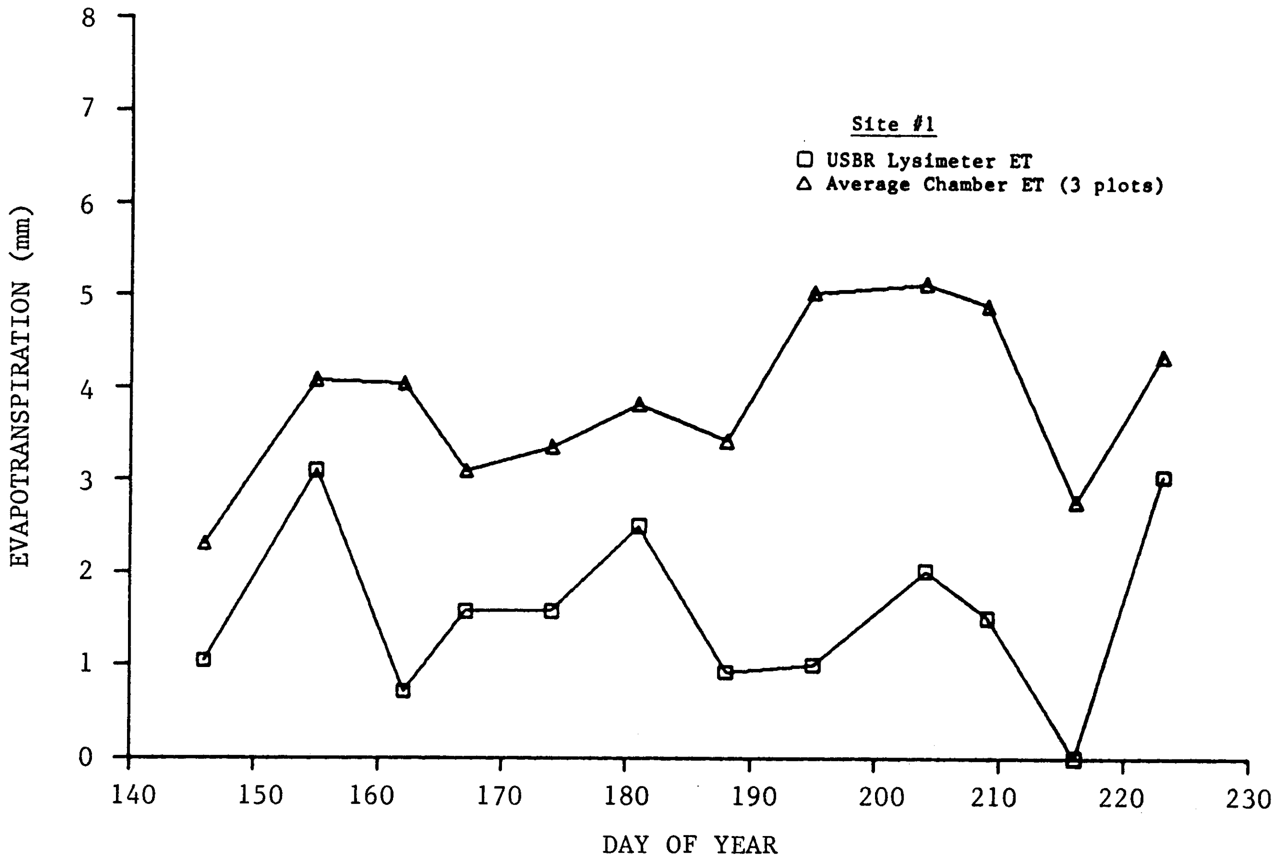

Figure 4.8 Evapotranspiration comparison of USBR lysimeter versus chamber measurements. (Salt Grass plots, USBR Lysimeter site, 1986)

Table 4.2 Evapotranspiration summary of Site #1 for the period span of 26 May to 11 August, 1986.

Year	Plot Description	Methodology	Evapotranspiration Avg. Total	Avg. Daily
			mm	mm/day
1986	Greasewood (3 plots)	Chamber	253	3.3
	Lysimeter Greasewood	Lysimeter	80	1.0
	Rabbitbrush (3 plots)	Chamber	258	3.4
	Lysimeter Rabbitbrush	Lysimeter	64	0.8
	Salt Grass (3 plots)	Chamber	299	3.9
	Lysimeter Salt Grass	Lysimeter	118	1.5
	Bare Soil (3 plots)	Chamber	183	2.4
	Lysimeter Bare Soil	Lysimeter	90	1.2

were obtained in 1986, the USBR lysimeter data (average values for a seven-day period) were obtained for purposes of comparison with the chamber data; each chamber value was for one day of the seven-day period represented by the lysimeter data.

Alfalfa reference ET values were calculated for each day of the measurement period in order to observe representativeness of daily chamber values for each week. An average daily reference ET value was calculated for each complete period of each USBR lysimeter measurement (usually one week, sometimes two weeks). Then, each average ET value was compared with the reference ET value for the day of chamber measurement (Table A.6); the period differences in ET ranged from 0 to 37 percent. The weekly chamber versus USBR lysimeter value differences ranged from 1 to 96 percent; the USBR greasewood, rabbitbrush, and salt grass lysimeters measured no ET for one week each of the measurement season. Most of the non-zero lysimeter ET values were less than 50 percent of the corresponding weekly chamber ET measurements.

The differences in reference ET were minor when compared with differences in measured ET for the two methods. Error associated with the representativeness of daily chamber ET to the entire week was exaggerated by the fact that alfalfa reference ET assumes a full cover, well-watered alfalfa crop and is an overestimation of the actual ET in most situations. Thus, error introduced by the day of chamber measurement was minimal when compared with the magnitude of differences in chamber and lysimeter values.

The greasewood and rabbitbrush lysimeters accounted for only 31 percent and 25 percent of the respective chamber mean ET. The bare soil USBR lysimeter and chamber data show similar trends for daily E (Figure 4.7). Quantitative results show that the mean 77-day chamber E was consistently higher than the lysimeter E (an average difference of 1.2 mm per day) (Table 4.2), although the chamber E was expected to be lower due to the location of the chamber plots in an area which was approximately 0.6 m higher above the water table than the lysimeter.

Lysimeter and chamber data for salt grass (Figure 4.8) provide the best comparison because the plots had the same depth to ground water and the vegetation was similar in density, composition, and quality. The data show similar trends for most of the season. Total USBR lysimeter ET averaged 40 percent of total mean chamber ET (Table 4.2). The 1986 comparison data may be more accurate than data from 1985 because of a longer and more intensive continuous measurement season.

4.1.3 Possible causes for ET differences

The differences between the measured ET of the lysimeters and the chamber are too large to be ignored and may be partially due to differences in the sizes of the measured plants. The plants in each lysimeter were smaller than the corresponding plants of the chamber - measured plots. For relative comparison, each plant's dimensions were measured in three directions (foliage height and perpendicular spread) only during 1986; each dimension was considered to be a diameter measurement. A spherical surface area was calculated using each radius separately; the mean plant spherical surface area was the average of all spherical surface areas from the corresponding radius measurements. These values provided a rough estimate of relative plant size (transpirational area) assuming each plant could be approximated as a sphere (Table 4.3).

Table 4.3 Mean plant dimensions for chamber-measured plants and USBR lysimeter vegetation, Site #1, 1986.

Plot Description	Methodology	Average Dimensions Height y	Spread x	Spread z	Mean Plant Spherical Surface Area
		m	m	m	m^2
Greasewood (3 plots)	Chamber	0.79	0.84	0.96	2.36
Lysimeter Greasewood	Lysimeter	0.31	0.50	0.91	1.23
Rabbitbrush (3 plots)	Chamber	0.60	0.75	0.95	1.91
Lysimeter Rabbitbrush	Lysimeter	0.43	0.64	0.67	1.09
Salt Grass (3 plots)	Chamber	0.23	--	--	--
Lysimeter Salt Grass	Lysimeter	0.18	--	--	--

For the USBR Lysimeter site, lysimeter greasewood and rabbitbrush plants were approximately 52 and 57 percent of the size of the corresponding plants measured by the chamber. Similarly, the lysimeter salt grass was about 78 percent of the height of the salt grass measured by the chamber; the differences in lysimeter and chamber ET were much greater than 22 percent, indicating that factors other than size were affecting ET. Direct comparison of ET per plant size was not made for the chamber and lysimeter ET measurements because 1) the size measurements were rough estimates and would have introduced additional error along with the length-of-period differences and 2) the soil surface areas of the chamber plots and lysimeters were not equal. The evaporational (and transpirational) surface areas were different.

Additional causes for the differences may be from problems inherent in the installation procedure of the lysimeters. The construction process included driving the lysimeters (steel cylinders) into the ground. This may have compacted the soil sufficiently to inhibit its hydraulic conductivity for a number of years which, in turn, could impede ET. The driving of the casings may have also damaged some of the roots of the vegetation, which would be reflected in reduced ET. The rabbitbrush lysimeter was the only exception to this potential damage because the rabbitbrush bush was transplanted.

Normal operation of the USBR lysimeters involves measuring soil moisture changes (as related to ET) in each lysimeter with a neutron probe. This method typically does not account for all of the soil moisture, especially in the soil volume in the top 0.15 to 0.25 m of the soil profile; this region contributes a major portion of water for soil E. Other problems may be insufficient lysimeter volume (depth) for plant roots or accumulation of toxic solutes in the lysimeters (Robinson, 1966).

4.2 OBSERVATION WELL 377 AND USBR LYSIMETER SITES

Mean ET data for greasewood and rabbitbrush plots at Site #3 are shown in Figure 4.9. Three replicates (plots) each of greasewood and rabbitbrush were sampled for ET at this site during the study; an additional three plots (two of greasewood and one of rabbitbrush) were sampled from Day 196 to the end of the study.

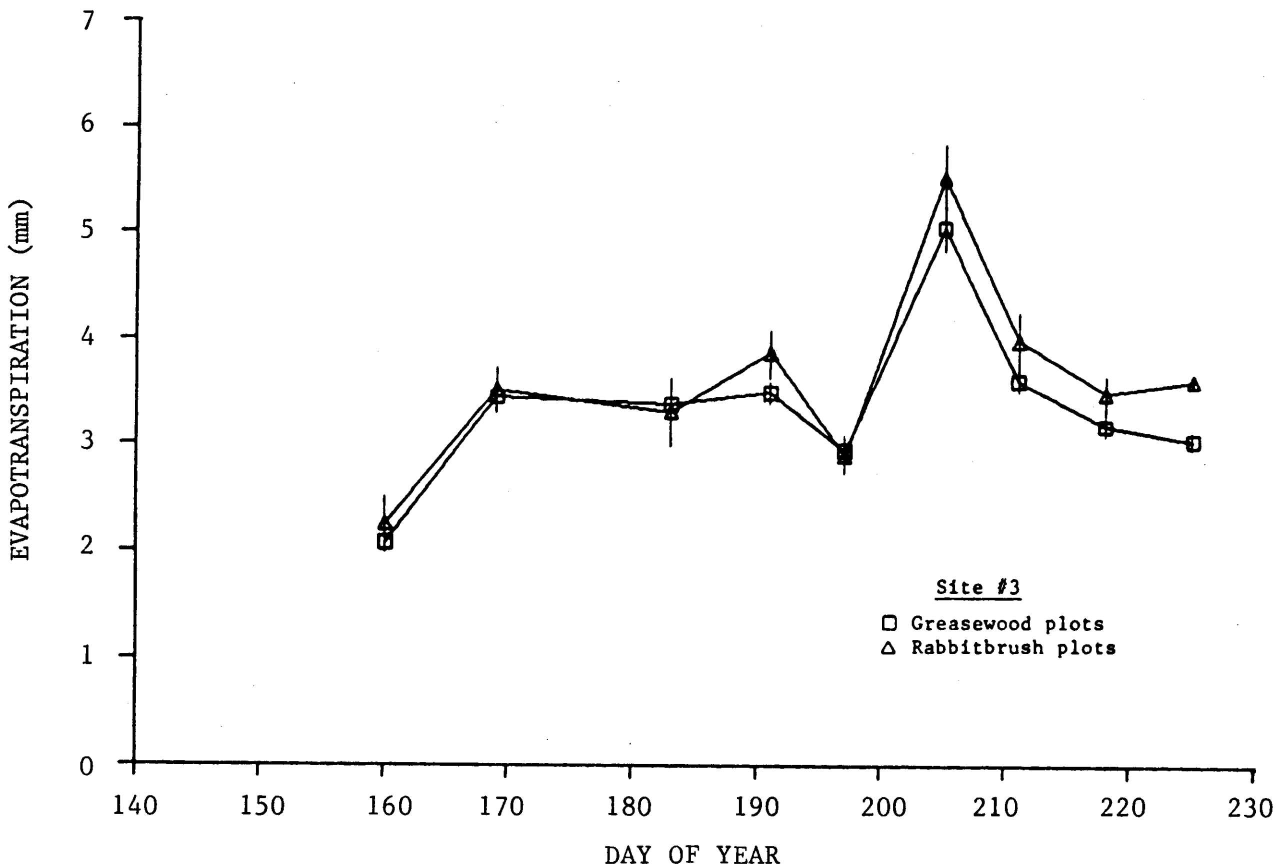

Figure 4.9 Mean evapotranspiration ± standard error. (Greasewood and Rabbitbrush plots, Observation Well 377 site, 1986)

WT= 4.2-4.6 m

A statistical analysis of these data shows that greasewood and rabbitbrush ET values at this site were usually not significantly ($\alpha \leq 0.05$) different (Appendix C.1). A significant difference in ET of the two treatments (species) existed for only one day, Day 225. There are no apparent reasons for this difference on this particular day; greasewood and rabbitbrush plants were of similar size (Table 4.4).

Table 4.4 Mean plant dimensions for measured plants, Site #3, 1986.

Plot Description	Methodology	Average Dimensions Height y	Spread x	Spread z	Mean Plant Spherical Surface Area
		m	m	m	m^2
Greasewood (5 plots)	Chamber	0.68	0.68	0.82	1.67
Rabbitbrush (4 plots)	Chamber	0.49	0.68	0.86	1.51

The ground-water level at this site (#3) remained nearly constant at 4.3 m for the entire season. The water table level below the ground surface in the hummocks area of the USBR Lysimeter site (Site #1) peaked in early June at 1.25 m and then dropped steadily to 1.7 m in mid-August (Figure 4.10).

Mean ET for the greasewood plots as measured by the chamber was about the same at Sites #1 and #3 for the longest corresponding period during 1986 - Days 160 to 223 (Figures 4.9 and 4.11). Rabbitbrush plot mean ET was nearly equivalent, as well, for plants measured at both sites (Table 4.5). The plants at the two sites were of slightly different size and woody material and were measured on different days with different weather conditions, so for purposes of comparison, no significant conclusions could be made concerning the effect of water

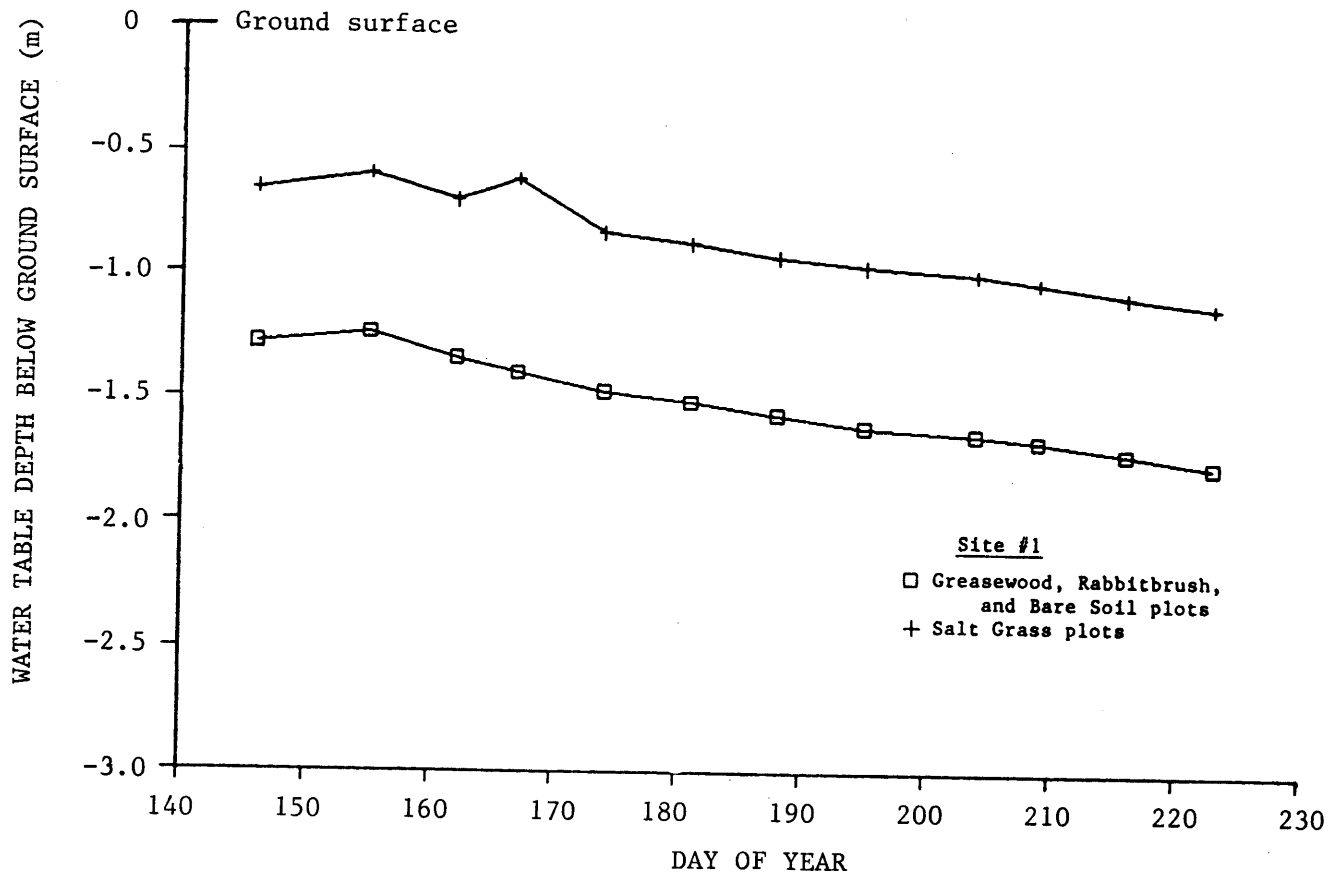

Figure 4.10 Ground-water levels for the seasonal measurement period. (USBR Lysimeter site, 1986)

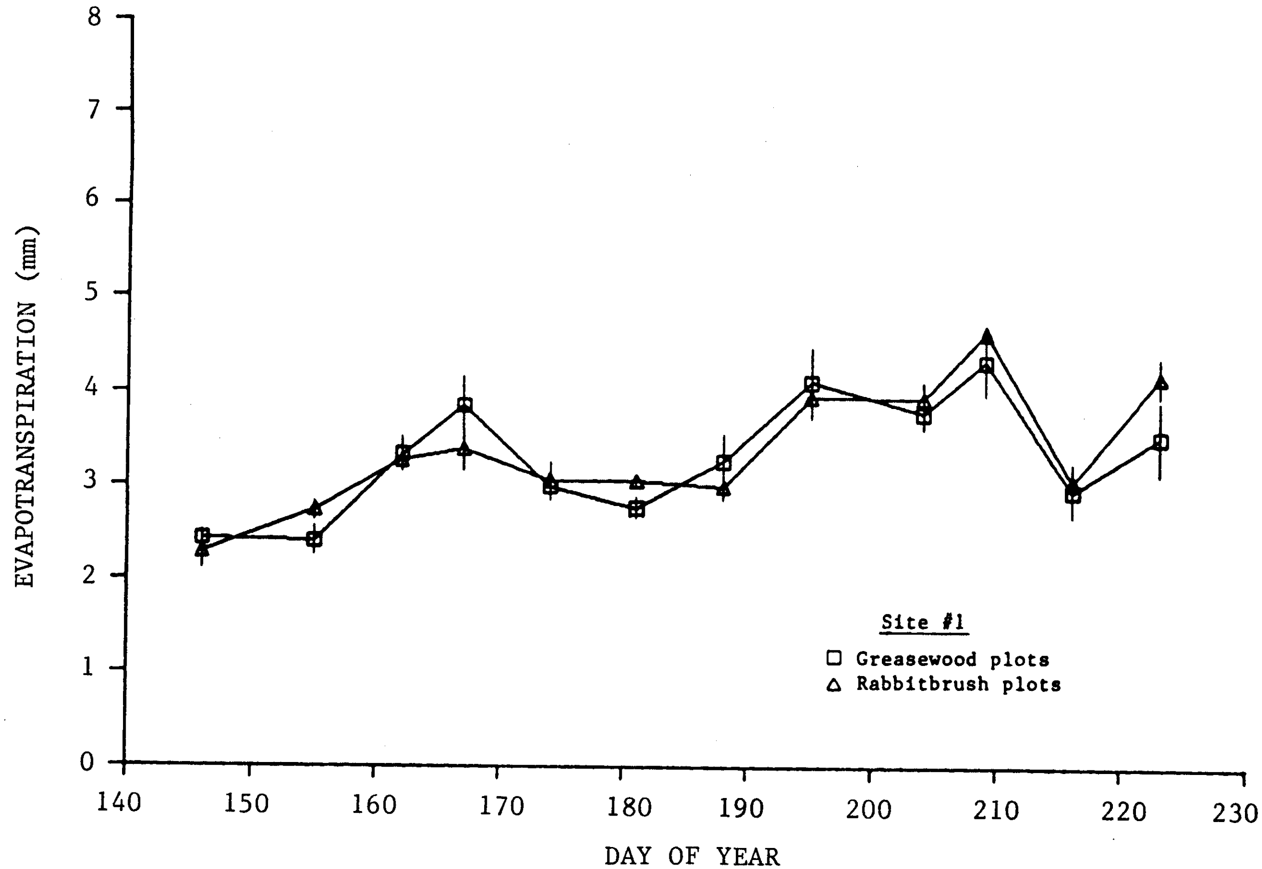

Figure 4.11 Mean evapotranspiration ± standard error. (Greasewood and Rabbitbrush plots, USBR Lysimeter site, 1986)

Table 4.5 Evapotranspiration summary for greasewood and rabbitbrush plots at Sites #1 and #3, 1986.

Plot Description	Methodology	Days in Period	Evapotranspiration Total	
			Total	Avg. Daily
			mm	mm/day
Site #1				
Greasewood (3 plots)	Chamber	77	253	3.3
Rabbitbrush (3 plots)	Chamber	77	258	3.4
Site #3				
Greasewood (5 plots)	Chamber	65	222	3.4
Rabbitbrush (4 plots)	Chamber	65	235	3.6

table depth on ET. It appeared that the plants at each of these sites had adapted well to their corresponding ground-water levels.

At Site #1, greasewood and rabbitbrush ET values were not significantly ($\alpha \leq 0.05$) different for any day of measurement (Appendix C.2). The ET of these two species and salt grass ET were significantly different for half of the days of measurement. Bare soil E and salt grass ET were always significantly different; bare soil E was usually significantly different from greasewood and rabbitbrush ET.

Seasonal salt grass plot ET (Figure 4.12) for 1986 averaged nearly 17 percent greater than both greasewood and rabbitbrush plot ET (Table 4.5). This may be due to the location of the salt grass in a low-lying area closer to the water table (Figure 4.10). The seasonal average bare soil evaporation at this site was 72 percent of the seasonal average ET found for greasewood and rabbitbrush plots.

No corrections for size differences were made at Sites #1 and #3 because replicates of each species were of similar size. At each site salt grass, rabbitbrush, and greasewood displayed values of ET in relative descending order as listed.

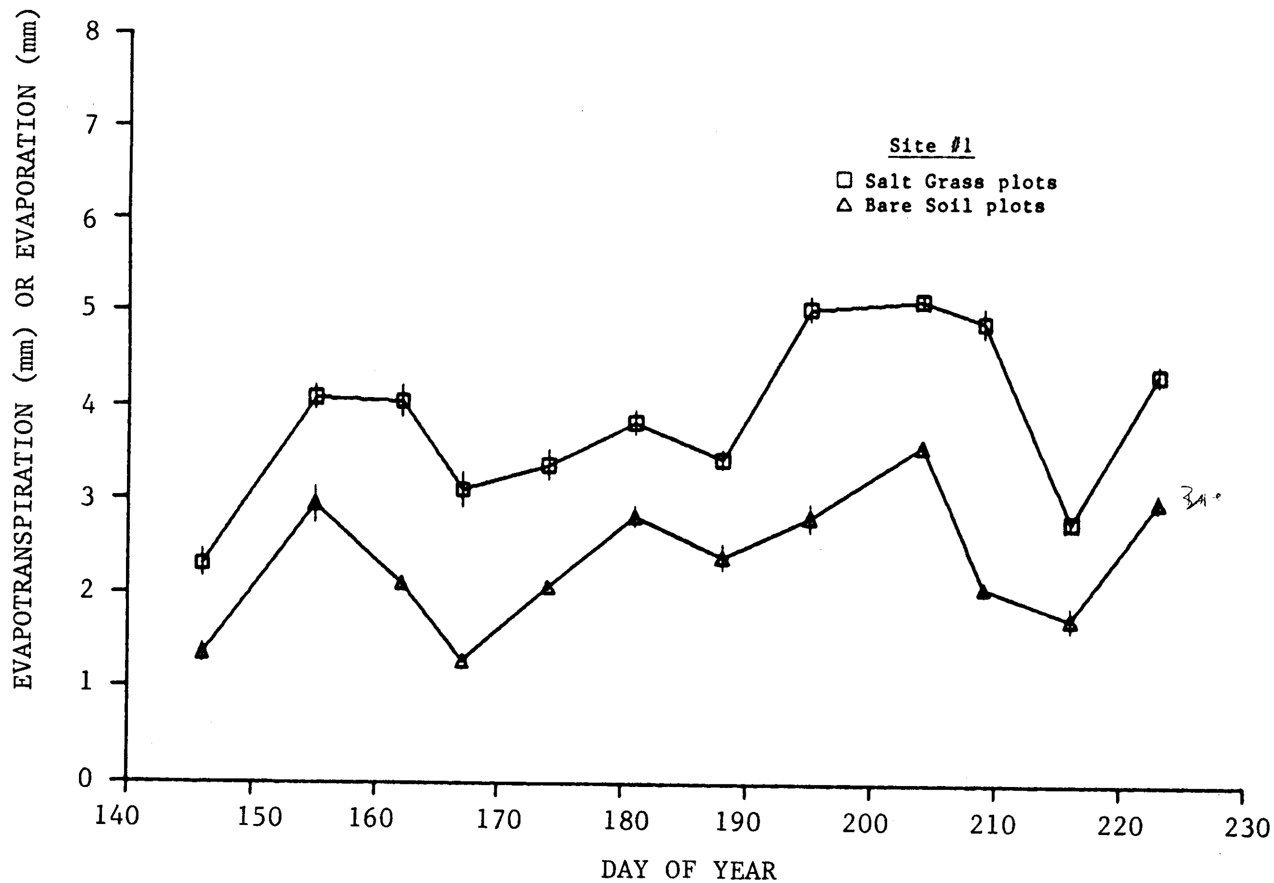

Figure 4.12 Mean evapotranspiration ± standard error (Salt Grass plots) and mean evaporation ± standard error (Bare Soil plots). (USBR Lysimeter site, 1986)

4.3 SALVAGE WELL 3 SITE

The plots at the Salvage Well 3 site (Site #2) provided twelve weeks of ET data. At 30.5 m from the pumping well (Figure 4.13) the water table was 2.6 m below the surface (for the first five weeks) then decreased gradually to 5.2 m below the surface (at twelve weeks; Day 224). As shown in this figure, there were data from two observation wells at 7.6 m from the pumping well; the one observed early in the season was shallower and dried up later in the season due to an increase in pumping rate. In addition to three plots each of greasewood and rabbitbrush within 30 m of the well, three plots each of greasewood and rabbitbrush were measured 90 m from the well to serve as a control with constant water table. Although there was no observation well at the control area, its distant location from the well ensured that water table variations from pumping were minimal. Evapotranspiration was measured at all of these plots within the same hour during each day of measurement (one day per week). Average total ET and average daily ET for the two species at the two locations at Site #2 are shown in Table 4.6.

Table 4.6 Evapotranspiration summary for greasewood and rabbitbrush plots at the pumping well and control site, Site #2, 1986.

Plot Description	Methodology	Days in Period	Evapotranspiration Total	
			Total	Avg. Daily
			mm	mm/day
Pumping Well area				
Greasewood (3 plots)	Chamber	77	261	3.4
Rabbitbrush (3 plots)	Chamber	77	376	4.9
Control area				
Greasewood (3 plots)	Chamber	77	282	3.7
Rabbitbrush (3 plots)	Chamber	77	338	4.4

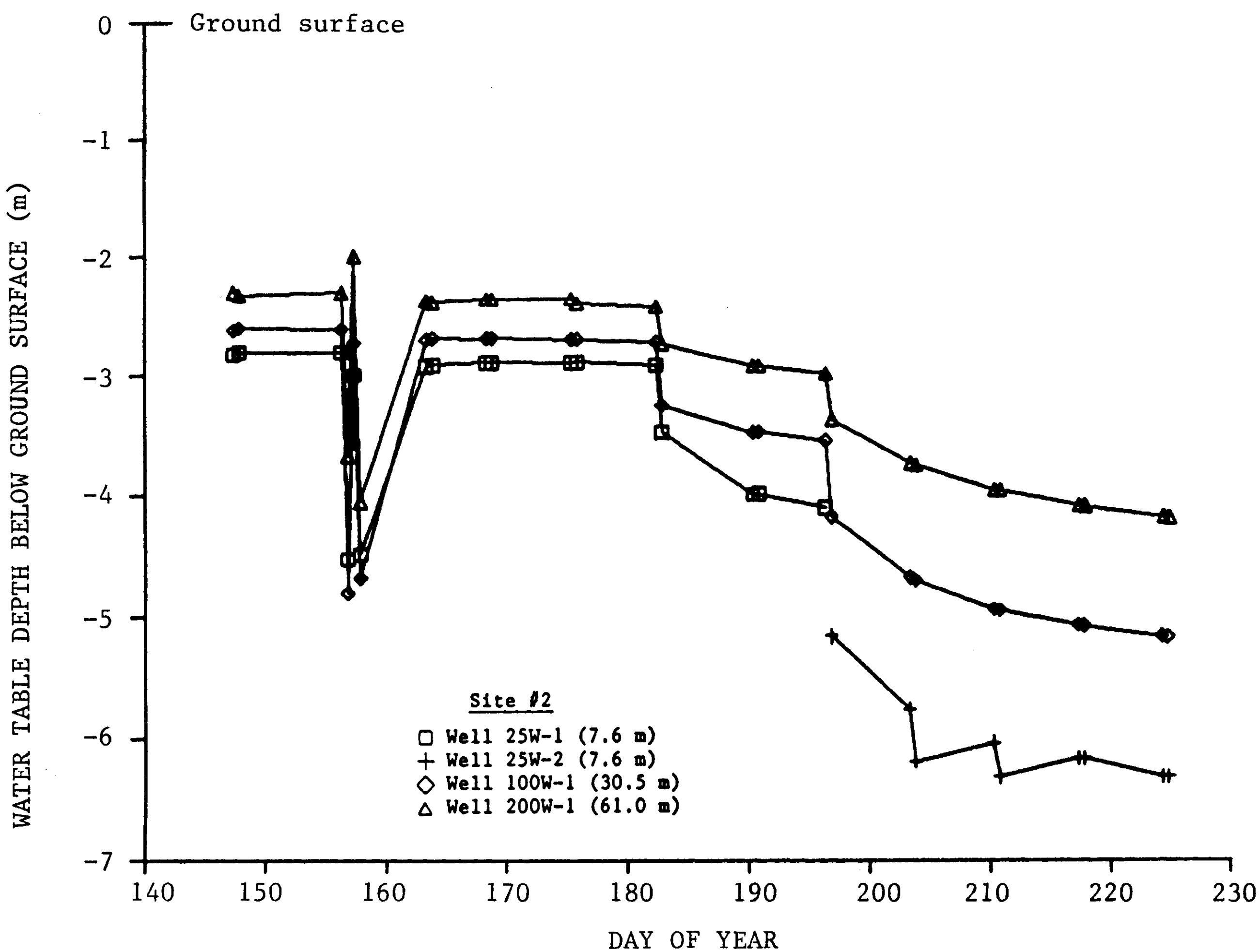

Figure 4.13 Ground-water levels for the seasonal measurement period. (Salvage Well 3 site, 1986) (distances from the salvage well are denoted by values in the parentheses)

The mean ET data for the greasewood plots near the well at Site #2 and for the control greasewood plots were compared (Figure 4.14). The same comparison was carried out for the rabbitbrush plots (Figure 4.15). There were significant ($\alpha \leq 0.05$) differences in the ET of greasewood and rabbitbrush plots (Appendix C.3); rabbitbrush plot ET always exceeded greasewood plot ET. There were several days of significant difference for greasewood ET in comparison to values obtained at the well and control sites; the same observation held for rabbitbrush. There were no indications of significant pumping effects on both greasewood and rabbitbrush plots at the two locations. However, ET was expressed only in terms of depth (mm) and not in terms of plant size, which affected each plot's ET.

Since there was some variability in plant size, a more adequate comparison between the two locations involved accounting for plant size. Mean ET per plant size was estimated from plant dimensions taken several times throughout the summer. From three dimensions (average foliage height and spread in two perpendicular directions), the mean spherical surface area was estimated for both measured species at the control (check) and pumping (salvage well) areas (Table 4.7). The area closest to the salvage well supported the larger vegetation, so it is important that the comparison accounts for plant size.

In comparison of greasewood ET per mean plant spherical surface area, only one day showed a significant ($\alpha \leq 0.05$) difference between the pumping well and control areas during the period after initiation of continuous pumping (Appendix C.4). However, there was a pronounced difference in the graphical representation of the mean greasewood ET

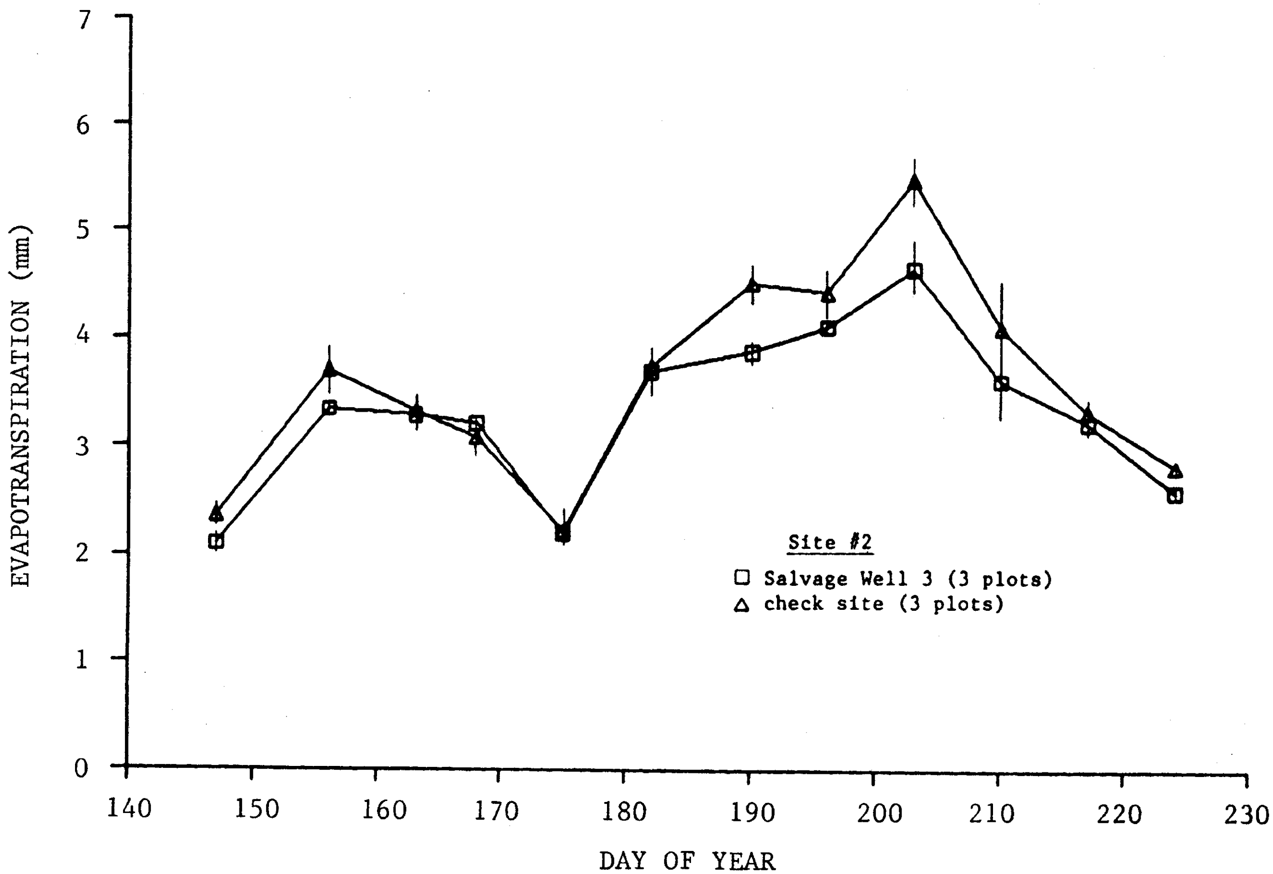

Figure 4.14 Mean evapotranspiration $\pm$ standard error. (Greasewood plots, Salvage Well 3 and check sites, 1986)

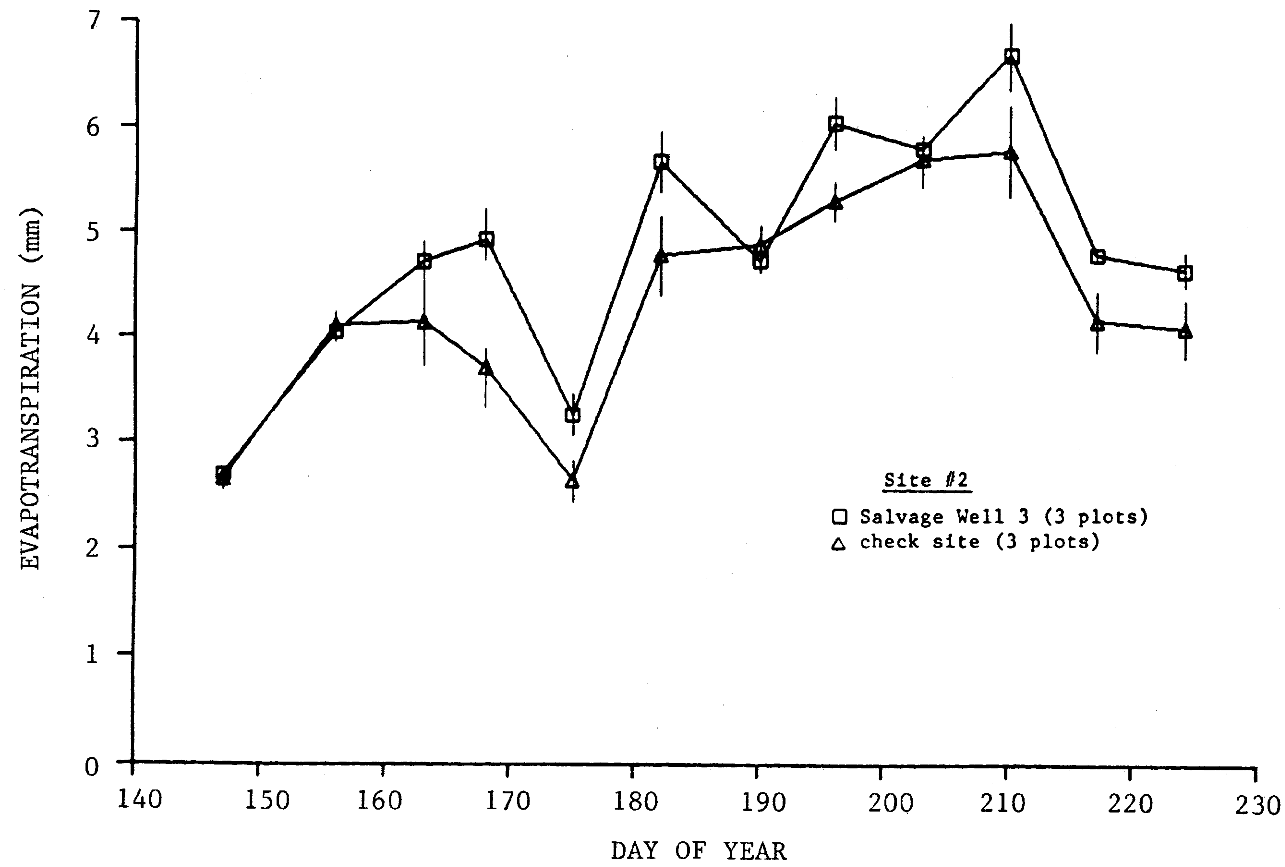

Figure 4.15 Mean evapotranspiration ± standard error. (Rabbitbrush plots, Salvage Well 3 and check sites, 1986)

Table 4.7 Mean plant dimensions for greasewood and rabbitbrush plots at the pumping well and control site, Site #2, 1986

Plot Description	Methodology	Average Dimensions Height y	Spread x	Spread z	Mean Plant Spherical Surface Area
		m	m	m	m^2
Pumping Well area					
Greasewood (3 plots)	Chamber	0.73	0.70	0.81	1.76
Rabbitbrush (3 plots)	Chamber	0.55	0.88	0.92	2.01
Control area					
Greasewood (3 plots)	Chamber	0.64	0.68	0.78	1.55
Rabbitbrush (3 plots)	Chamber	0.48	0.74	0.87	1.61

per mean plant spherical surface area (Figure 4.16) for the period of continuous pumping.

The rabbitbrush ET per mean plant spherical surface area data were analyzed with the same procedure as was used with the greasewood data. No significant ($\alpha \leq 0.05$) differences were observed between the pumping well and control areas for the entire measurement season. Likewise, there were no obvious differences indicated in the graphical comparison (Figure 4.17).

The reasons for the different (ET per mean spherical plant surface area) observations for the two species do not appear to be related to potential (expected) rooting depth because greasewood generally develops roots deeper than rabbitbrush (Meinzer, 1927); less water stress would be expected for greasewood. According to the observation well data (Figure 4.13) for the season, the depth to water at the salvage well plots (30 m radially from the salvage well) was no greater than 5.2 m, which might be too deep for rabbitbrush but is ample for greasewood. The roots of both species may have developed at this site to the same natural depth but, with a sudden artificial drop in the

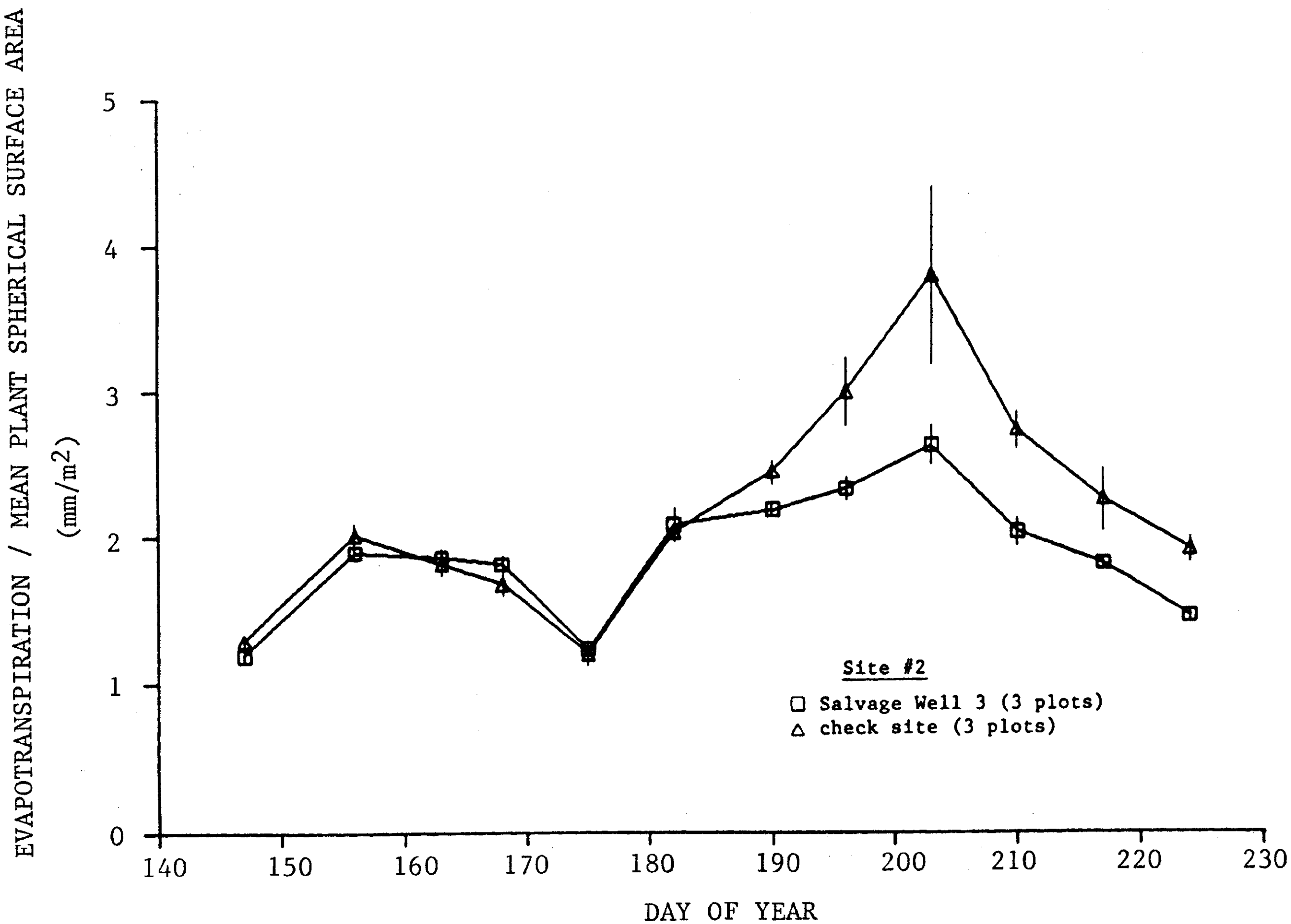

Figure 4.16 Mean evapotranspiration per mean plant spherical surface area ± standard error. (Greasewood plots, Salvage Well 3 and check sites, 1986)

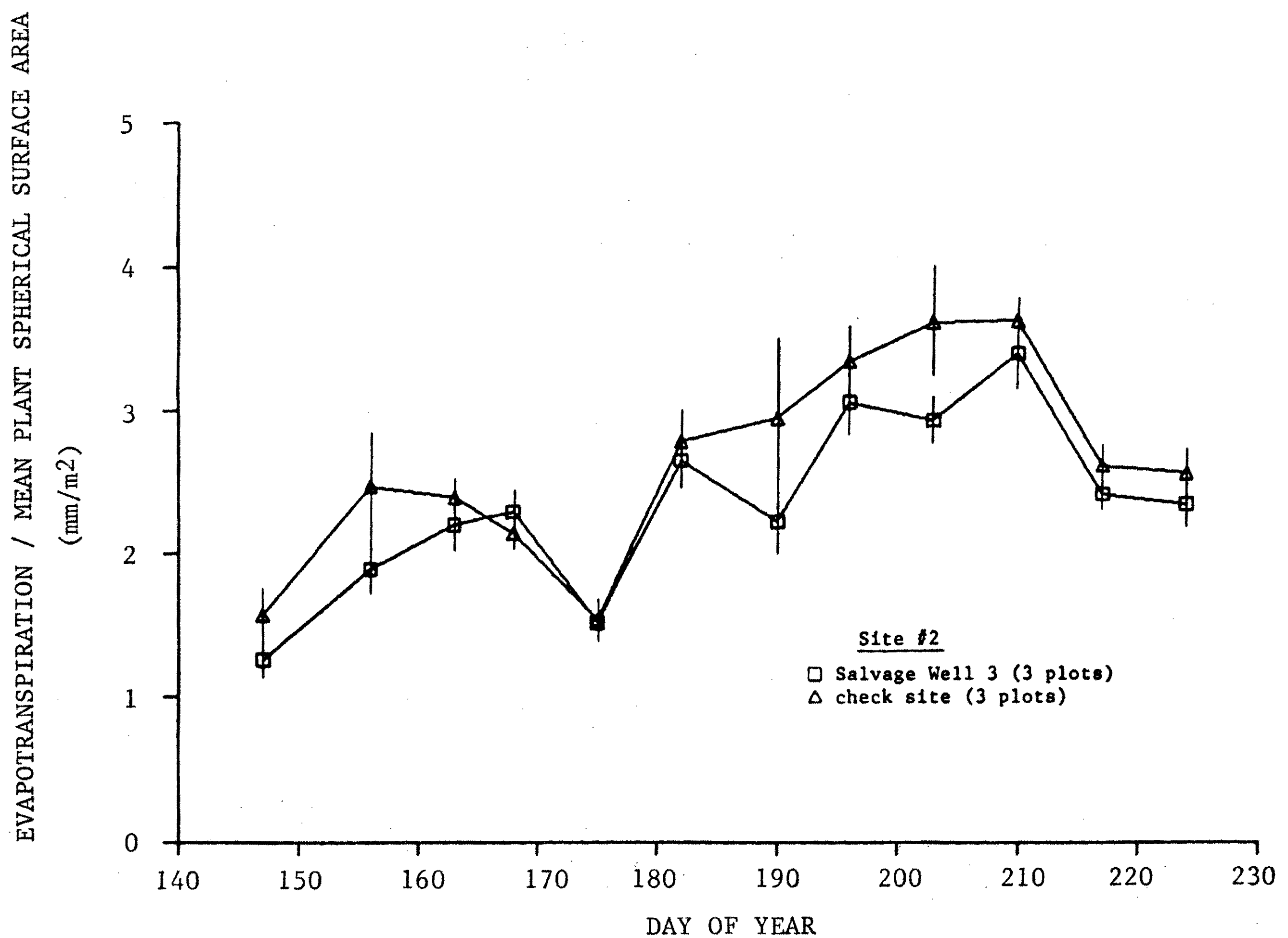

Figure 4.17 Mean evapotranspiration per mean plant spherical surface area $\pm$ standard error. (Rabbitbrush plots, Salvage Well 3 and check sites, 1986)

ground-water level, greasewood appeared to suffer more, although there were no marked visible signs of stress to any of the plants in the salvage well plots.

4.4 CROP COEFFICIENTS

In an attempt to assist in the prediction of salt grass ET from weather data, crop coefficient (K_c) values were calculated for each week of chamber measurement in 1985 and for each day of (salt grass) chamber measurement in 1986. Salt grass was chosen for K_c calculations because the measurement plots had a uniform cover. Three average weekly K_c values (0.66, 0.45, 0.65) resulted from the three weeks of ET data in 1985. Some of the differences in these values are due to the occurrence of precipitation in the weeks previous to the first and last week of ET measurement, especially events of the period from days 198 to 203 (Table A.1). This would have elevated the actual ET because of increased soil evaporation.

Salt grass K_c values for 1986 varied from 0.27 to 0.84; the mean K_c for the season was 0.58 with a standard deviation of 0.156. Most K_c values ranged from 0.51 to 0.68. There did not appear to be any obvious trend toward higher or lower K_c values later in the season.

4.5 PLANT WATER POTENTIAL

Xylem water potential data for all three major sites are shown in Tables B.1 through B.3. Data from Site #1 were statistically analyzed and show that the three treatments (greasewood, rabbitbrush, and salt grass) were significantly ($\alpha \leq 0.05$) different for each of the hours of 0900, 1300, and 1900 compared seasonally (Appendix D.1). This was expected and held for Site #3 data as well (Appendix D.2).

Statistical tests were performed for selected data at Site #2 (Appendix D.3) and show that:

1) control and well site greasewood xylem water potential values before pumping commenced were not significantly ($\alpha \leq 0.05$) different, and

2) control and well site greasewood xylem water potential values after pumping commenced were significantly ($\alpha \leq 0.05$) different for data collected at the same time on Day 210.

These observations indicate that pumping probably caused water stress in greasewood, but not in rabbitbrush plants. This finding confirms indications of this occurrence provided by the ET per mean spherical plant surface area data.

4.6 <u>CONSTRAINTS OF THE STUDY</u>

The data obtained in this study show some important trends and effects of water table depth on the ET of native vegetation plots under several conditions. However, these results must be viewed within the constraints of the study. Only intermediate-sized shrubs were sampled, but plant size varied throughout the basin. Sampling plants of similar size allowed a reasonable number of replicate measurements to be made, giving additional confidence in the ET data.

Although daily measurements were obtained at all three sites, there are no same-day ET values for any two sites, with the exception of the Salvage Well 3 site and corresponding check site. Caution should be observed when comparing the ET obtained at any two sites because of differences in relative plant size and density, depth to water table, and weather variables. In comparing site characteristics, smaller plant sizes and lower densities were observed in areas of historically deeper water tables.

Direct comparison of these data with previous research was beyond the scope of this research. Any comparison of ET data from different locations must consider differences in vegetation size and distribution; depth to water; climatic variables; and the measurement period span in relation to the total length of the ET season.

CHAPTER V

SUMMARY AND CONCLUSIONS

5.1 SUMMARY

Gas analysis technology was applied by using the portable chamber method for instantaneous measurement of evapotranspiration. Measurement of ET on plots containing three major phreatophytic species was accomplished during three five-day periods in 1985 and for twelve consecutive weeks in 1986. The three species measured were greasewood (*Sarcobatus vermiculatus* Hook. Torr.), rabbitbrush (*Chrysothamnus nauseosus* Pall. Britt.), and salt grass (*Distichlis stricta* L. Greene); each are common to the vegetation community of the sump area in the closed basin of the San Luis Valley, Colorado.

This study was initiated because of a need for more ET data for these species in the closed basin area. Several lysimeters are operated by the USBR in this area, and the chamber method data was collected to also show differences and trends of similarity for these two methods.

Evapotranspiration data were collected at three different sites in the sump area to represent ET in areas of shallow, deep, and fluctuating water table depths. Data were also collected at one site in an alfalfa field for validation of the chamber method with corresponding ET data from several established lysimeters. Xylem water potential data for each species were collected regularly during the 1986 ET data collection period in order to observe relative plant water stress where the water table was fluctuating due to pumping, and to view differences in water potential for the species measured for ET.

5.2 CONCLUSIONS

The following major conclusions may be drawn from the research conducted in this study:

1) The chamber method of ET measurement is a useful tool for obtaining accurate water use data without the expense and initial vegetative disturbance of the lysimeter method. The portable chamber used in this study yielded data which were 90 to 96 percent of the corresponding reliable ARS lysimeter ET data.

2) The USBR greasewood and rabbitbrush lysimeter ET data were substantially lower than those obtained by chamber measurements for the years of 1985 and 1986, and do not show similar trends. The USBR salt grass and bare soil lysimeter data, while consistently lower, exhibited similar ET or E trends when compared with the corresponding chamber data. The USBR lysimeters accounted for the following percentages of chamber ET for undisturbed (non-lysimeter) vegetative plots in 1985 (weekly values) and 1986 (seasonal values).

   Note: The rabbitbrush comparison should be used with caution because of plant problems in the USBR lysimeter.

PLANT / YEAR	1985	1986
Greasewood	51-61 %	31 %
Rabbitbrush	0-51 %	25 %
Salt Grass	56-89 %	40 %
Bare Soil	52-85 %	*

3) Greasewood and rabbitbrush plots with either shallow or deep ground-water levels may use similar amounts of water (ET) as long as the plants have become well established in these areas and there is little variation in the deep ground-water level (4 to 5 m).

4) Evaporation from bare soil is decreased with a deeper water table and is a significant component of ET in areas of shallow water table (Figure 4.4).

5) ET of greasewood may be reduced more than that of rabbitbrush by rapid fluctuations in water table depth, suggesting that greasewood may be more easily stressed.

6) Crop coefficient (K_c) values (alfalfa reference crop) calculated from the 1985 and 1986 growing season salt grass ET data were mostly in the range of 0.5 to 0.7.

7) Water potential values for greasewood, rabbitbrush, and salt grass were significantly different from each other for all site locations.

8) Pumping was the probable cause for a significant difference in the water potential of greasewood near the pumping well and at a nearby water table control area.

---

* The USBR bare soil lysimeter was maintained at a different water table depth than the chamber-measured bare soil plots. Thus, no direct comparison was made.

The objectives of this study on evapotranspiration of native vegetation in the closed basin of the San Luis Valley, Colorado have been fulfilled. Additional study will be imperative in order to determine long-term effects of continuous project pumping on the vitality of the phreatophytic vegetation. Also, the USBR lysimeters should be examined and evaluated in terms of their adequacy for obtaining representative ET data.

REFERENCES

Anderson, T.W. 1976. Evapotranspiration losses from flood-plain areas in central Arizona. U.S. Geol. Survey Open-File Report 76-864 (in cooperation with Arizona Water Commission), Tucson, Arizona. 91 pp.

Blaney, H.F. 1951. Determining evapotranspiration by phreatophytes from climatological data. Trans. Am. Geophys. Union. 33(1):61-66.

Blaney, H.F., C.A. Taylor, H.G. Nickle and A.A. Young. 1933. Water losses under natural conditions from wet areas in southern California. Calif. Dept. of Public Works, Div. of Water Resources Bull. No. 44.

Blaney, H.F., P.A. Ewing, O.W. Israelsen, C. Rohwer and F.C. Scobey. 1938. Water utilization, Upper Rio Grande Basin. National Resources Committee, Part III.

Blaney, H.F., P.A. Ewing, K.V. Morin and W.D. Criddle. 1942. Consumptive water use and requirements. Pecos River Joint Investigation, National Resources Planning Board. pp. 170-230.

Brunt, D. 1952. Physical and Dynamical Meteorology. 2nd ed. University Press, Cambridge. 428 pp.

Brutsaert, W. 1982. Evaporation into the atmosphere. D. Reidel Publishing Co., Dordrecht, Holland. 299 pp.

Businger, J.A. 1963. The glass house (greenhouse) climate. In: W.R. van Wijk (Editor), The physics of plant environment. North Holland Publishing Co., Amsterdam. pp. 277-318.

Carman, R.L. 1986 (in review). Field measurement of evapotranspiration in areas of phreatophytes in northern Nevada (Abstract). U.S. Geol. Survey.

Christiansen, J.E. and J.B. Low. 1970. Water requirements of waterfowl marshlands in northern Utah. Publ. No. 69-12, Utah Div. of Fish and Game, Salt Lake City, Utah. 98 pp.

Cohen, P., et al. 1965. Water resources of the Humboldt River Valley near Winnemucca, Nevada. U.S. Geol. Survey Water-Supply Paper 1795.

Criddle, W.D., J.M. Bagley, R.K. Higginson and D.W. Hendricks. 1964. Consumptive use of water by native vegetation and irrigated crops in the Virgin River area of Utah. State Engineer of Utah - Info. Bull. No. 14. 39 pp.

Duell, L.F.W., Jr. 1985. Evapotranspiration rates from rangeland phreatophytes by the eddy-correlation method in Owens Valley, California. Proc. Am. Meteor. Soc., 17th Conf. pp. 44-47.

Dylla, A.S., D.M. Stuart and D.W. Michener. 1972. Water use studies on forage grasses in northern Nevada. Univ. of Nevada Agric. Exp. Sta. and USDA-Agric. Research Service, Soil and Water Conservation Res. Div. T10. 56 pp.

Emery, P.A., A.J. Boettcher, R.J. Snipes and H.J. McIntyre, Jr. 1971. Hydrology of the San Luis Valley, south-central Colorado. U.S. Geol. Survey Hydrol. Investigation HA-381.

Grosz, O.M. 1972. Humboldt River Project studies on evapotranspiration of woody phreatophytes and salt grass (1972 Progress Report). U.S. Geol. Survey, Menlo Park, California. pp.25-44.

Hargreaves, G.H. 1956. Irrigation requirements based on climatic data. Am. Soc. Civil Engr., J. Irrig. and Drain. Div. Paper 1105-IR3. 10 pp.

Harmsen, E.W., G.A. Peterson, T.L. Loudon and G.E. Merva. 1982. A chamber technique for measuring plant water use. ASAE Paper No. 82-2598. Presented at the Am. Soc. Agric. Engr., 1982 Winter Meeting. Chicago, Illinois. 18 pp.

Harr, R.D. and K.R. Price. 1972. Evapotranspiration from a greasewood-cheatgrass community. Water Res. Research. 8(5):1199-1203.

Heermann, D.F., G.J. Harrington and K.M. Stahl. 1985. Empirical estimation of daily clear sky solar radiation. J. Clim. and Appl. Meteor. 24(3):206-214.

Houk, I.E. 1930. Evaporation from soils. Trans. Am. Soc. Civil Engr. 94:982-985.

Houk, I.E. 1951. Irrigation Engineering; Volume I, Agricultural and Hydrological Phases. John Wiley and Sons, New York. pp. 310-313.

Jensen, M.E. 1973. Consumptive Use of Water and Irrigation Water Requirements. Rep. Tech. Comm. on Irrig. Water Requirements. Irrig. and Drain. Div. of the Am. Soc. Civil Engr. New York. 215 pp.

Jensen, M.E. and H.R. Haise. 1963. Estimating evapotranspiration from solar radiation. Am. Soc. Civil Engr., J. Irrig. and Drain. Div. 89:15-41.

Jensen, M.E., J.L. Wright and B.J. Pratt. 1971. Estimating soil moisture depletion from climate, crop and soil data. Trans. Am. Soc. Agric. Engr. 14(5):954-959.

Kincaid, D.C. and D.F. Heermann. 1974. Scheduling irrigations using a programmable calculator. USDA Bull. ARS-NC-12. 55 pp.

Kincaid, D.C., E.G. Kruse and H.R. Duke. 1979. Paired hydraulic weighing lysimeters for evapotranspiration measurement. ASAE Paper No. 79-2513. Presented at the Am. Soc. Agric. Engr., 1979 Winter Meeting. New Orleans, Louisiana. 8 pp.

Lee, C.H. 1912. An intensive study of the water resources of a part of Owens Valley, California. U.S. Geol. Survey Water-Supply Paper 294. 135 pp.

Lowe, P.R. 1976. An approximating polynomial for computation of saturation vapor pressure. J. Appl. Meteor. 16:100-103.

Meinzer, O.E. 1927. Plants as indicators of ground water. U.S. Geol. Survey Water-Supply Paper 577. pp. 29-41.

Muckel, D.C. 1966. Phreatophytes - water use and potential water savings. Proc. Am. Soc. Civil Engr., J. Irrig. and Drain. Div. Paper 5033-IR4. 8 pp.

Penman, H.L. 1948. Natural evaporation from open water, bare soil and grass. Proc. Roy. Soc. London. A198:116-140.

Penman, H.L. 1963. Vegetation and hydrology. Tech. Communication No. 53. Commonwealth Bur. of Soils. Harpenden, England. 125 pp.

Peterson, G.A., T.L. Loudon and G.E. Merva. 1985. A comparison of ET measured by portable chamber with lysimeter data. Advances in Evapotranspiration - Proc. of the Natl. Conf. on Advances in Evapotranspiration. Am. Soc. Agric. Engr. pp. 439-446.

Radosevich, G.E. and R.W. Rutz. 1979. San Luis Valley water problems; a legal perspective. Colo. Water Res. Res. Inst. Colorado State University. Fort Collins, CO. 44 pp.

Reicosky, D.C. 1981. A research tool for evapotranspiration measurements for model validation and irrigation scheduling. Irrig. Sched. for Water and Energy Conservation in the 80's - Proc. of the Am. Soc. Agric. Engr. Irrig. Sched. Conf. Am. Soc. Agric. Engr. pp. 74-80.

Reicosky, D.C. 1985. Advances in evapotranspiration measured using portable field chambers. Advances in Evapotranspiration - Proc. of the Natl. Conf. on Advances in Evapotranspiration. Am. Soc. Agric. Engr. pp. 79-86.

Reicosky, D.C. and D.B. Peters. 1977. A portable chamber for rapid evapotranspiration measurements on field plots. Agron. J. 69:729-732.

Reicosky, D.C., B.S. Sharratt, J.E. Ljungkull and D.G. Baker. 1983. Comparison of alfalfa evapotranspiration measured by a weighing lysimeter and a portable chamber. Agric. Meteor. 28:205-211.

Robinson, T.W. 1958. Phreatophytes. U.S. Geol. Survey Water-Supply Paper 1423. 84 pp.

Robinson, T.W. 1966. Evapotranspiration losses - the status of research and problems of measurement. Phreatophyte Symposium, Pacific Southwest Inter-Agency Committee. Albuquerque, New Mexico, 30 August 1966. pp. 7-18.

Robinson, T.W. 1967. The effect of desert vegetation on the water supply of arid regions. International Conf. on Water for Peace. Washington, D.C. 569 pp.

Robinson, T.W. 1970. Evapotranspiration by woody phreatophytes in the Humboldt River Valley near Winnemucca, Nevada. U.S. Geol. Survey Prof. Paper 491-D. 41 pp.

Scholander, P.F., H.T. Hammel, E.D. Bradstreet and E.A. Hemmingsen. 1965. Sap pressure in vascular plants. Science 148:339-346.

Sorooshian, S. and R. Ritzi. 1984. Reduction of ground-water losses due to phreatophyte uptake, Spring 1984 initial investigation. Dept. of Hydrol. and Water Res., Univ. of Arizona. Unpublished report submitted to U.S. Water Conserv. Lab., USDA-Agric. Research Service, Phoenix, Arizona. 8 pp.

Thompson, C.B. 1958. Importance of phreatophytes in water supply. Am. Soc. Civil Engr., J. Irrig. and Drain. Div., Vol. 84. Paper 1502-IR1. 17 pp.

U.S. Bureau of Reclamation. 1963. Appendices. Closed Basin Division, San Luis Valley Project, Colorado: Amarillo, Texas. USBR, Region 5. pp. B58-B66.

U.S. Bureau of Reclamation. 1979a. Evapotranspiration studies of saltcedar near Bernardo, New Mexico. File Report; Albuquerque Development Office, Albuquerque, New Mexico. 50 pp.

U.S. Bureau of Reclamation. 1979b. Final environmental statement. The San Luis Valley Project, Colorado - Closed Basin Division. FES 79-37. pp. B1-B12, C5-C13.

U.S. Bureau of Reclamation. 1982a. Final supplement to final environmental statement. The San Luis Valley Project, Colorado - Closed Basin Division. FES 82-44. pp. III-14 to III-19.

U.S. Bureau of Reclamation. 1982b. Information map. The San Luis Valley Project, Colorado. Closed Basin Division. USBR - Southwest Region. Map No. 1298-500-1.

U.S. Bureau of Reclamation. 1984a. Facts and concepts about the project. The San Luis Valley Project - Closed Basin Division, 27 pp.

U.S. Bureau of Reclamation. 1984b. Design and planning. The San Luis Valley Project - Closed Basin Division, p. 2.

U.S. Bureau of Reclamation. 1984c. Evapotranspiration study progress report. San Luis Valley Project, Closed Basin Division. Alamosa, Colorado.

U.S. Government. 1970. A report on closed basin division, San Luis Valley project, Colorado. House Doc. No. 91-369, 91st Congress, 2nd Session. Washington, D.C. pp. 16, 55-56, 68, 147.

Weaver, H.L., E.P. Weeks, G.S. Campbell, D.I. Stannard and B.D. Tanner. 1986. Phreatophyte water use estimated by eddy-correlation methods. Proc. Am. Soc. Civil Engr. Spec. Conf. at Long Beach, Calif. pp. 847-854.

White, W.N. 1932. Method of estimating ground-water supplies based on discharge by plants and evaporation from soil - results of investigations in Escalante Valley, Utah. U.S. Geol. Survey Water-Supply Paper 659-A. 105 pp.

Wright, J.L. and M.E. Jensen. 1972. Peak water requirements of crops in southern Idaho. Am. Soc. Civil Engr., J. Irrig. and Drain. Div., 96(IR1):193-201.

Young, A.A. and H.F. Blaney. 1942. Use of water by native vegetation. Calif. Dept. of Public Works, Div. of Water Resources Bull. No. 50. 160 pp.

APPENDIX A

Weather data and weather-related data.

Table A.1 Precipitation data for 15 May to 26 July (Days 135 to 207) 1985, and 22 April to 22 August (Days 112 to 234) 1986, Site #1, Closed Basin Division project area, San Luis Valley, Colorado.
Source: unpublished data from H.L. Weaver, USGS, Denver,CO.

1985			1986		
Day	Hour of End	Precipitation	Day	Hour of End	Precipitation
		mm			mm
136	10	1	114	20	5†
160	17	1†	149	15	2§
169	18	1	153	8	1§
176	1	1	177	8	3§
190	21	4†	186	16	1
195	21	1	187	1	2
196	23	1	188	18	1
198	21	36	189	23	3
200	2	1	190	17	1
203	21	2	193	16	1
			200	22	3
			201	23	6
			204	20	4§

† Precipitation occurred more than 10 days before ET measurement.
§ Weighing bucket data (USGS data missing).

Table A.2 Daily weather summary at USBR lysimeter site, 1985.

			Climatic Variables						
Date	Day of Year	Hours of data†	T_{max}	T_{min}	Average Vapor Pressure	Solar Radiation	Wind Run	Average Wind Speed
			°C	°C	kPa	MJ/m²	km	m/sec
20 May	140	0-22	17.6	-0.9	0.717	23.7	191.5	1.9
21 May	141	0-23	16.2	4.5	0.883	20.3	234.3	2.9
22 May	142	1-23	15.0	3.4	0.852	16.3	131.0	1.7
23 May	143	0-23	18.7	0.6	0.825	24.5	176.6	2.0
24 May	144	1-14	21.7	-0.6	0.746	30.1	149.8	1.6
24 June	175	0-22	26.9	13.1	1.344	24.1	381.0	4.3
25 June	176	0-22	23.2	10.8	1.130	25.7	318.0	4.0
26 June	177	0-22	19.2	3.5	0.515	30.6	321.6	3.8
27 June	178	0-22	24.8	-2.9	0.515	32.2	109.7	1.5
28 June	179	0-15	25.4	2.4	0.697	30.9	158.4	1.6
22 July	203	2-22	25.7	10.3	1.386	22.9	164.6	2.2
23 July	204	1-22	24.7	11.9	1.418	20.8	183.4	2.7
24 July	205	1-23	23.6	8.5	1.133	23.3	215.3	2.5
25 July	206	2-22	24.3	7.9	1.151	23.1	233.1	3.2
26 July	207	1-14	24.2	7.1	1.100	20.9	131.7	1.2

† Time span of complete weather data collection (beginning-end).

Table A.3 Daily weather summary at USBR lysimeter site, 1986.

Date	Day of Year	Hours of data†	Climatic Variables: T_{max}	T_{min}	Average Vapor Pressure	Solar Radiation	Wind Run	Average Wind Speed
			°C	°C	kPa	MJ/m^2	km	m/sec
26 May	146	8-23	21.0	11.5	0.514	28.3	278.7	4.4
27 May	147	0-23	27.3	10.3	0.985	29.0	254.6	3.1
4 June	155	0-23	22.5	3.8	1.008	19.6	162.7	1.9
5 June	156	0-23	22.9	3.5	0.886	23.9	158.4	1.9
9 June	160	0-23	18.8	7.7	0.867	25.2	317.0	3.8
11 June	162	7-23	22.2	7.9	0.446	31.1	160.0	2.1
12 June	163	0-23	28.3	2.1	0.576	32.1	174.1	2.0
16 June	167	0-23	28.3	1.7	0.541	23.2	248.6	2.9
17 June	168	0-23	27.4	7.4	0.911	25.1	193.8	2.2
18 June	169	0-17	26.8	7.9	1.094	26.6	290.0	2.4
23 June	174	0-23	26.0	9.7	1.188	18.3	234.2	2.7
24 June	175	0-23	20.4	8.6	1.254	11.0	147.0	1.7
30 June	181	0-23	27.2	9.2	1.337	19.1	170.8	2.0
1 July	182	0-23	31.3	7.6	0.898	27.7	195.1	2.3
2 July	183	0-23	31.4	11.9	1.174	24.4	201.4	2.4
7 July	188	0-23	28.2	8.8	1.427	17.5	153.1	1.7
9 July	190	0-23	28.1	13.3	1.511	17.7	145.9	1.6
10 July	191	0-23	28.0	9.2	1.168	17.5	149.8	1.5
14 July	195	0-23	32.8	10.0	1.268	23.8	172.1	2.1
15 July	196	0-23	33.5	13.2	1.346	27.9	253.8	2.8
16 July	197	0-23	27.0	14.8	1.538	19.6	308.5	3.5
22 July	203	0-23	26.3	9.8	1.356	24.4	195.1	2.3
23 July	204	0-23	28.9	13.1	1.551	22.0	256.7	2.9
24 July	205	0-23	30.2	9.2	1.072	26.1	151.8	1.7
28 July	209	0-23	32.8	4.2	0.552	29.0	176.6	2.0
29 July	210	0-23	34.5	5.2	0.737	28.0	160.6	1.8
30 July	211	0-23	34.2	8.8	0.978	30.6	159.4	2.0
4 Aug.	216	6-23	28.9	9.7	1.260	14.6	209.1	2.7
5 Aug.	217	0-23	31.4	7.9	1.190	20.0	203.3	2.4
6 Aug.	218	0-23	33.2	12.9	1.156	27.5	205.7	2.3
11 Aug.	223	0-23	32.5	8.4	1.180	23.3	182.4	2.2
12 Aug.	224	0-23	34.6	13.0	1.496	19.8	181.1	2.1
13 Aug.	225	0-23	33.1	10.4	1.298	25.9	167.8	1.9

† Time span of complete weather data collection (beginning-end).

Table A.4 Penman Equation reference ET, ET_r, 1985.

Day of Year	ET_r	Day of Year	ET_r	Day of Year	ET_r
	mm		mm		mm
140	4.94	175	8.42	203	5.66
141	4.61	176	7.57	204	5.44
142	3.32	177	8.26	205	6.09
143	5.23	178	7.05	206	6.12
144	6.36	179	7.52	207	5.12

Table A.5 Penman Equation reference ET, ET_r, 1986.

Day of Year	ET_r	Day of Year	ET_r	Day of Year	ET_r
	mm		mm		mm
146	8.70	171	7.55	197	6.89
147	8.67	172	9.78	198	7.64
148	7.30	173	8.78	199	5.84
149	2.18	174	5.97	200	6.23
150	3.70	175	2.89	201	2.72
151	5.10	176	3.82	202	2.85
152	2.82	177	6.16	203	6.22
153	3.76	178	7.91	204	6.97
154	4.42	179	8.11	205	7.33
155	4.84	180	5.45	206	8.21
156	5.79	181	5.56	207	8.97
157	8.94	182	8.52	208	9.60
158	8.22	183	7.95	209	8.90
159	5.76	184	7.79	210	8.62
160	6.93	185	8.77	211	8.80
162	7.61	186	6.22	216	5.41
163	8.63	187	8.48	217	7.19
164	10.26	188	5.07	218	8.92
165	8.51	189	5.37	219	7.58
166	7.91	190	5.39	220	7.47
167	8.56	191	5.53	221	8.93
168	7.33	194	8.18	222	6.29
169	8.29	195	7.57	223	7.45
170	6.34	196	9.65	224	7.21
				225	7.68

Table A.6 Relative comparison of daily chamber and weekly USBR lysimeter measurements - weekly representativeness of chamber ET data, Site #1, 1986.

Days of Lysimeter Measurement Span	Daily Penman Reference ET		
	Period Avg.	Day of Chamber Measurement	Percent Difference
	mm/day	mm/day	%
146-152	5.50	8.70	37
153-159	5.96	4.84	19
160-166	8.31	7.61	8
167-180	6.92	8.56	19
167-180	6.92	5.97	14
181-187	7.61	5.56	27
188-194	5.91	5.07	14
195-201	6.65	7.57	12
202-215	7.65	6.97	9
202-215	7.65	8.90	14
216-222	7.40	5.41	27
223-229	7.45	7.45	0

APPENDIX B

Xylem water potential data.

Table B.1 Means and standard deviations for xylem water potential, Site #1, 1986.

Day of Year	Plant Species	Hour of Day	Xylem Water Potential mean	s	Number of Samples	Comments
			MPa			
167	Greasewood	9	-2.06	0.23	2	
		10	-1.88	0.20	2	
		11	-2.01	0.16	2	
		12	-2.24	0.00	2	
		13	-2.01	0.37	3	
		14	-2.71	0.01	2	
		15	-2.45	0.01	2	
		16	-2.03	0.01	2	
		17	-2.33	0.04	2	
		18	-1.80	0.14	2	
174	Greasewood	9	[illegible]	0.15	2	
		10	-1.83	0.01	2	
		11	-1.81	0.16	2	
		12	-2.20	0.17	2	
		13	-1.91	0.16	2	Rain began
		14	-1.72	0.06	2	at 1350 hours.
181	Greasewood	9	-1.52	0.00	2	
		10	-1.89	0.13	2	
		11	-2.32	0.03	2	
		12	-2.58	0.17	2	
		13	-2.81	0.07	2	Increasing wind.
		14	-2.87	0.01	2	
		15	-2.89	0.13	2	Rain began
		16	-2.30	0.06	2	at 1620 hours.
188	Greasewood	9	-1.87	0.01	2	
		10	-1.97	0.47	3	
		11	-2.29	0.23	3	
		12	-2.66	0.03	2	
		13	-2.42	0.00	2	
		14	-2.11	0.10	2	
		16	-2.41	0.43	3	
195	Rabbitbrush	9	-0.95	0.14	3	
		10	-1.02	0.00	2	
		11	-1.18	0.00	2	
		12	-1.50	0.03	2	
		13	-1.56	0.00	2	
		14	-1.60	0.00	2	High clouds.
		15	-1.45	0.04	2	
		16	-1.50	0.03	2	
		17	-1.47	0.01	2	
		18	-1.18	0.11	3	
		19	-0.90	0.03	2	

Table B.1 continued

Day of Year	Plant Species	Hour of Day	Xylem Water Potential mean MPa	s	Number of Samples	Comments
204	Rabbitbrush	9	-0.84	0.11	3	Very sunny.
		10	-0.91	0.01	2	
		11	-1.38	0.03	2	
		12	-1.42	0.00	2	
		13	-1.47	0.04	2	
		14	-1.27	0.04	2	
		15	-1.25	0.10	3	
		16	-1.30	0.03	2	Clouds.
		17	-0.82		1	Rain.
209	Greasewood	9	-1.78		1	Clear, dry, sunny.
		10	-2.12		1	
		11	-2.12		1	
		12	-2.14		1	
		13	-2.08		1	
		14	-2.42		1	
		15	-2.02		1	
		16	-2.30		1	
		17	-2.02		1	
		18	-3.06		1	
		19	-2.96		1	
		20	-2.08		1	
209	Rabbitbrush	9	-1.20		1	Clear, dry, sunny.
		10	-1.24		1	
		11	-1.34		1	
		12	-1.42		1	
		13	-1.48		1	
		14	-1.60		1	
		15	-1.52		1	
		16	-1.52		1	
		17	-1.56		1	
		18	-1.44		1	
		19	-1.43		1	
		20	-1.28		1	
216	Greasewood	9	-2.23		1	Clear, cool.
		13	-2.44		1	Cloud cover
		19	-2.69		1	at 1200 hours.
216	Rabbitbrush	9	-1.00		1	Clear, cool.
		13	-1.10		1	Cloud cover
		19	-0.80		1	at 1200 hours.
216	Salt Grass	9	-2.50		1	Clear, cool.
		13	-2.46		1	Cloud cover
		19	-1.07		1	at 1200 hours.

Table B.1 continued

Day of Year	Plant Species	Hour of Day	Xylem Water Potential mean	s	Number of Samples	Comments
			MPa			
223	Greasewood	9	-2.30		1	Clear.
		13	-2.55		1	
		19	-1.38		1	Cloudy, cool.
223	Rabbitbrush	9	-1.00		1	Clear.
		13	-1.58		1	
		19	-1.04		1	Cloudy, cool.
223	Salt Grass	9	-2.40		1	Clear.
		13	-2.47		1	
		19	-1.60		1	Cloudy, cool.

Table B.2 Means and standard deviations for xylem water potential, Site #2, 1986.

Day of Year	Plant Species	Hour of Day	Xylem Water Potential mean	s	Number of Samples	Comments
			MPa			
156	Greasewood	9	-1.52		1	
	⊗	10	-1.43	0.01	2	
		11	-1.83	0.01	2	
		12	-1.70	0.17	2	
		13	-1.79	0.01	2	
		14	-1.81	0.30	2	
		15	-1.85	0.01	2	
		16	-1.92	0.06	2	
		17	-1.65	0.01	2	
157	Greasewood	9	-1.72	0.21	3	Clear, sunny.
	⊗	10	-1.75	0.17	4	
		11	-1.82	0.13	4	
		12	-1.83	0.13	4	
		14	-1.62	0.00	2	
		15	-1.92	0.09	4	
		16	-1.76	0.27	4	
		17	-1.83	0.15	4	
157	Greasewood	9	-2.07	0.04	3	Clear, sunny.
	⊙	10	-1.87	0.29	4	
		11	-1.96	0.07	4	
		12	-1.96	0.32	4	
		14	-1.79	0.17	4	
		15	-2.01	0.29	4	
		16	-1.75	0.16	4	
		17	-2.05	0.07	2	
175	Greasewood	9	-1.77	0.54	3	
	⊗	10	-1.72	0.13	3	
		11	-1.77	0.16	2	
		12	-1.87	0.01	2	Rain began
		13	-1.87	0.07	2	at 1350 hours.
182	Greasewood	9	-2.09	0.07	4	Pump started
	⊗	13	-2.33	0.34	3	at 910 hours.
190	Greasewood	9	-1.47	0.01	2	Wet, humid,
	⊗	10	-1.48	0.03	2	overcast.
		11	-1.49	0.07	2	
		12	-1.90	0.00	2	
		13	-2.31	0.04	2	Clearing skies.
		14	-2.69	0.10	3	Clear-1330 hours.
		15	-2.43	0.18	3	
		16	-2.18	0.03	2	
		17	-2.88	0.20	2	Rain began
		19	-1.29	0.28	4	at 1700 hours.

Table B.2 continued

Day of Year	Plant Species	Hour of Day	Xylem Water Potential mean	s	Number of Samples	Comments
			MPa			
196	Rabbitbrush	9	-0.83	0.04	2	
	⊗	10	-0.87	0.08	3	
		11	-1.00		1	
		12	-0.98		1	
203	Rabbitbrush	9	-0.74	0.09	3	Wet, drying soil.
	⊗	10	-0.65	0.04	2	
		11	-0.81	0.01	2	
		12	-0.85	0.04	2	
		13	-0.97	0.01	2	Mostly clear.
		14	-0.77	0.10	3	Cloud cover.
		16	-0.90	0.07	3	Mostly clear.
		17	-0.75	0.04	2	Breezy.
		18	-0.79	0.01	2	
		19	-0.71	0.01	2	Cool.
		20	-0.70	0.01	2	
210	Greasewood	9	-3.06		1	Very dry, sunny,
	⊗	10	-3.00		1	clear.
		11	-3.02		1	
		12	-3.22		1	
		13	-2.96		1	
		14	-3.34		1	
		16	-3.16		1	
		17	-3.60		1	
		18	-3.56		1	
210	Rabbitbrush	9	-1.10		1	Very dry, sunny,
	⊗	10	-1.18		1	clear.
		11	-1.16		1	
		12	-0.94		1	
		13	-1.10		1	
		15	-1.00		1	
		16	-1.16		1	
		17	-1.08		1	
		18	-1.08		1	
		19	-1.04		1	
210	Greasewood	10	-2.56		1	Very dry, sunny,
	⊙	13	-2.34		1	clear.
210	Rabbitbrush	10	-1.20		1	Very dry, sunny,
	⊙	13	-1.76		1	clear.
		19	-1.03		1	

Table B.2 continued

Day of Year	Plant Species	Hour of Day	Xylem Water Potential mean MPa	s	Number of Samples	Comments
217	Rabbitbrush	9	-1.16		1	Clear, sunny.
	⊗	13	-1.16		1	
		14	-1.18		1	
		19	-0.86		1	Mostly cloudy.
217	Rabbitbrush	9	-0.82		1	Clear, sunny.
	⊙	13	-1.22		1	
		14	-1.64		1	
		19	-0.80		1	Mostly cloudy.
224	Rabbitbrush	9	-1.02		1	Mostly cloudy.
	⊗	13	-1.02	0.07	2	Clear, sunny.
		19	-0.80		1	Mostly cloudy.
224	Rabbitbrush	9	-1.09	0.01	2	Mostly cloudy.
	⊙	13	-1.40		1	Clear, sunny.
		19	-0.80		1	Mostly cloudy.

⊗ Pumping Well area (significant water table drawdown).
⊙ Control area (relatively stable water table level).

Table B.3 Means and standard deviations for xylem water potential, Site #3, 1986.

Day of Year	Plant Species	Hour of Day	Xylem Water Potential mean	s	Number of Samples	Comments
			MPa			
160	Greasewood	9	-1.93	0.24	2	
		10	-1.82	0.06	2	
		11	-1.82	0.06	2	
		12	-1.62	0.09	2	
		13	-1.83	0.10	2	Small shower
		14	-1.61	0.01	2	at 1320 hours.
		15	-2.26	0.06	2	
183	Greasewood	9	-2.95	0.12	3	
		13	-3.28	0.28	3	
		19	-2.38	0.24	3	
191	Greasewood	9	-1.81	0.12	3	
		10	-2.35	0.01	2	
		11	-2.78	0.03	2	
		12	-3.06	0.03	2	
		13	-3.17	0.01	2	
		14	-3.19	0.04	2	
		15	-2.93	0.01	2	
		16	-2.24	0.17	2	
		17	-2.62		1	
		18	-2.76		1	
197	Rabbitbrush	9	-1.19	0.01	2	Clear.
		10	-1.28	0.19	3	
		11	-1.39	0.12	3	
		12	-1.03	0.13	3	Cloudy.
		13	-1.23	0.01	2	
		14	-1.36	0.06	2	Clear.
		15	-1.28	0.06	2	Very breezy.
		16	-1.32	0.03	2	Cloudy.
		17	-1.08	0.03	2	
		18	-0.83	0.08	3	
205	Rabbitbrush	9	-0.85	0.07	2	Clear.
		10	-0.97	0.07	2	
		11	-0.96	0.06	2	
		12	-1.11	0.20	3	
		13	-1.07	0.01	2	
		14	-1.18	0.03	2	
		15	-1.04	0.06	2	Cloudy.
		16	-1.14	0.06	2	Clear.
		17	-1.37	0.07	2	
		18	-0.83	0.15	3	Cloudy.
		19	-0.93	0.01	2	
		20	-0.97	0.01	2	Clear.

Table B.3 continued

Day of Year	Plant Species	Hour of Day	Xylem Water Potential mean	s	Number of Samples	Comments
			MPa			
211	Greasewood	9	-2.40		1	Clear.
		13	-3.34		1	
		19	-3.78		1	
211	Rabbitbrush	9	-1.03		1	Clear.
		13	-1.26		1	
		19	-1.08		1	
218	Rabbitbrush	9	-0.94	0.00	2	Clear.
		13	-1.55		1	
		14	-1.49		1	
		19	-0.79	0.01	2	Cloudy.
225	Rabbitbrush	9	-0.63	0.00	2	Foggy.
		13	-1.38	0.06	2	Clear, breezy.
		19	-1.28	0.03	2	Partly cloudy.

APPENDIX C

Statistical tests for ET data.

Table C.1 One-Way Analysis of Variance to detect interspecies (greasewood and rabbitbrush) ET differences, Site #3, 1986.

Treatment #1 = Greasewood
Treatment #2 = Rabbitbrush

$p < 0.05$ indicates a significant ($\alpha \geq 0.05$) difference among treatments.

Day of Year	Treatment	Mean ET	s	p
		mm		
160	1	2.07	0.16	
	2	2.24	0.47	0.591
169	1	3.44	0.18	
	2	3.51	0.33	0.728
183	1	3.37	0.15	
	2	3.30	0.54	0.847
191	1	3.48	0.23	
	2	3.86	0.44	0.135
197	1	2.93	0.27	
	2	2.88	0.32	0.807
205	1	5.04	0.44	
	2	5.52	0.63	0.223
211	1	3.59	0.25	
	2	3.97	0.56	0.213
218	1	3.16	0.25	
	2	3.47	0.36	0.172
225	1	3.02	0.19	
	2	3.59	0.11	0.001

Table C.2 One-Way Analysis of Variance and Least Significant Difference (LSD) tests to detect interplot (greasewood, rabbitbrush, salt grass, and bare soil) ET differences, Site #1, 1986.

Treatment #1 = Greasewood
Treatment #2 = Rabbitbrush
Treatment #3 = Salt Grass
Treatment #4 = Bare Soil

Day of Year	Treatment	Mean ET	s	p	$LSD_{0.05}$
		mm			
146	1	2.42	0.18		
	2	2.29	0.31		
	3	2.31	0.24		
	4	1.35	0.14	0.001	0.43
155	1	2.40	0.27		
	2	2.73	0.20		
	3	4.08	0.21		
	4	2.94	0.46	0.001	0.57
162	1	3.32	0.35		
	2	3.26	0.17		
	3	4.03	0.26		
	4	2.10	0.09	0.000	0.44
167	1	3.84	0.61		
	2	3.38	0.40		
	3	3.09	0.37		
	4	1.27	0.01	0.000	0.77
174	1	2.97	0.27		
	2	3.04	0.38		
	3	3.35	0.31		
	4	2.06	0.07	0.003	0.54
181	1	2.75	0.20		
	2	3.04	0.13		
	3	3.81	0.25		
	4	2.81	0.15	0.000	0.36
188	1	3.25	0.54		
	2	2.97	0.21		
	3	3.41	0.19		
	4	2.39	0.21	0.020	0.61
195	1	4.09	0.67		
	2	3.93	0.41		
	3	5.01	0.22		
	4	2.80	0.23	0.002	0.79

Table C.2 continued

Day of Year	Treatment	Mean ET	s	p	$LSD_{0.05}$
		mm			
204	1	3.76	0.32		
	2	3.92	0.34		
	3	5.10	0.09		
	4	3.56	0.13	0.000	0.47
209	1	4.31	0.71		
	2	4.62	0.20		
	3	4.86	0.30		
	4	2.06	0.12	0.000	0.76
216	1	2.92	0.54		
	2	3.03	0.27		
	3	2.75	0.14		
	4	1.73	0.30	0.006	0.64
223	1	3.51	0.56		
	2	4.15	0.40		
	3	4.31	0.18		
	4	2.96	0.20	0.007	0.70

Table C.3 One-Way Analysis of Variance and Least Significant Difference (LSD) tests to detect inter-area (pumping well and control areas) ET differences for greasewood and rabbitbrush plots, Site #2, 1986.

Treatment #1 = Greasewood (pumping well area)
Treatment #2 = Rabbitbrush (pumping well area)
Treatment #3 = Greasewood (control area)
Treatment #4 = Rabbitbrush (control area)

Day of Year	Treatment	Mean ET	s	p	$LSD_{0.05}$
		mm			
147	1	2.10	0.13		
	2	2.69	0.08		
	3	2.36	0.15		
	4	2.65	0.17	0.002	0.25
156	1	3.34	0.10		
	2	4.03	0.15		
	3	3.70	0.37		
	4	4.10	0.24	0.016	0.45
163	1	3.28	0.06		
	2	4.71	0.31		
	3	3.32	0.27		
	4	4.13	0.63	0.005	0.71
168	1	3.20	0.07		
	2	4.92	0.49		
	3	3.07	0.25		
	4	3.70	0.61	0.002	0.77
175	1	2.18	0.10		
	2	3.25	0.32		
	3	2.21	0.36		
	4	2.63	0.31	0.006	0.55
182	1	3.68	0.39		
	2	5.67	0.49		
	3	3.73	0.07		
	4	4.77	0.62	0.001	0.83
190	1	3.86	0.17		
	2	4.72	0.17		
	3	4.49	0.31		
	4	4.87	0.31	0.005	0.48
196	1	4.09	0.08		
	2	6.03	0.41		
	3	4.41	0.36		
	4	5.29	0.31	0.000	0.60

Table C.3 continued

Day of Year	Treatment	Mean ET	s	p	$LSD_{0.05}$
		mm			
203	1	4.63	0.41		
	2	5.79	0.21		
	3	5.47	0.34		
	4	5.69	0.42	0.015	0.67
210	1	3.60	0.48		
	2	6.67	0.54		
	3	4.08	0.76		
	4	5.77	0.71	0.001	1.19
217	1	3.20	0.16		
	2	4.77	0.09		
	3	3.31	0.20		
	4	4.14	0.45	0.000	0.50
224	1	2.57	0.11		
	2	4.62	0.25		
	3	2.80	0.11		
	4	4.07	0.44	0.000	0.50

Table C.4 One-Way Analysis of Variance and Least Significant Difference (LSD) tests to detect inter-area (pumping well and control areas) ET per mean spherical surface area differences for greasewood and rabbitbrush plots, Site #2, 1986.

Treatment #1 = Greasewood (pumping well area)
Treatment #2 = Rabbitbrush (pumping well area)
Treatment #3 = Greasewood (control area)
Treatment #4 = Rabbitbrush (control area)

Day of Year	Treatment	Mean ET/AREA mm/m^2	s	p	$LSD_{0.05}$
147	1	1.19	0.05		
	2	1.26	0.25		
	3	1.29	0.09		
	4	1.57	0.34	0.228	†
156	1	1.89	0.06		
	2	1.89	0.38		
	3	2.01	0.19		
	4	2.47	0.80	0.406	†
163	1	1.86	0.10		
	2	2.20	0.38		
	3	1.81	0.13		
	4	2.39	0.26	0.054	†
168	1	1.81	0.10		
	2	2.29	0.31		
	3	1.67	0.11		
	4	2.14	0.21	0.019	0.38
175	1	1.23	0.03		
	2	1.52	0.21		
	3	1.20	0.17		
	4	1.54	0.24	0.098	†
182	1	2.08	0.17		
	2	2.65	0.38		
	3	2.03	0.08		
	4	2.78	0.38	0.025	0.54
190	1	2.18	0.06		
	2	2.22	0.45		
	3	2.44	0.15		
	4	2.94	1.02	0.387	†

Table C.4 continued

Day of Year	Treatment	Mean ET/AREA	s	p	$LSD_{0.05}$
		mm/m^2			
196	1	2.32	0.15		
	2	3.05	0.45		
	3	2.99	0.47		
	4	3.34	0.40	0.063	†
203	1	2.62	0.20		
	2	2.93	0.32		
	3	3.79	1.15		
	4	3.61	0.63	0.197	†
210	1	2.03	0.19		
	2	3.39	0.57		
	3	2.73	0.25		
	4	3.62	0.19	0.002	0.64
217	1	1.81	0.03		
	2	2.41	0.26		
	3	2.25	0.39		
	4	2.61	0.29	0.037	0.52
224	1	1.45	0.03		
	2	2.34	0.33		
	3	1.91	0.37		
	4	2.56	0.29	0.007	0.54

† No $LSD_{0.05}$ values were calculated for days when $p > 0.05$.

APPENDIX D

Statistical tests for xylem water potential data.

Table D.1 One-Way Analysis of Variance to detect interspecies (greasewood, rabbitbrush, and salt grass) xylem water potential differences by the hour, Site #1, 1986. Replicates were taken on different days at regular intervals throughout the ET measurement period.

Treatment #1 = Greasewood
Treatment #2 = Rabbitbrush
Treatment #3 = Salt Grass

Hour	Treatment	Mean Xylem Water Potential	s	p
		MPa		
9	1	-2.05	0.22	
	2	-1.00	0.13	
	3	-2.45	0.07	0.000
13	1	-2.48	0.13	
	2	-1.45	0.20	
	3	-2.47	0.01	0.000
19	1	-2.02	0.56	
	2	-0.97	0.20	
	3	-1.34	0.37	0.012

Table D.2 One-Way Analysis of Variance to detect interspecies (greasewood and rabbitbrush) xylem water potential differences by the hour, Site #3, 1986. Replicates were taken on different days at regular intervals throughout the ET measurement period.

Treatment #1 = Greasewood
Treatment #2 = Rabbitbrush

Hour	Treatment	Mean Xylem Water Potential	s	p
		MPa		
9	1	-2.39	0.57	
	2	-0.93	0.21	0.002
13	1	-3.26	0.09	
	2	-1.30	0.18	0.000
19	1	-2.97	0.72	
	2	-0.98	0.20	0.001

Table D.3 One-Way Analysis of Variance to detect inter-area (pumping well and control areas) xylem water potential differences for greasewood and rabbitbrush, Site #2, 1986.

CASE I : Difference between mid-day greasewood water potential at the pumping well and the control areas before Day 182 ?

Treatment #1 = Greasewood (pumping well area)
Treatment #2 = Greasewood (control area)

Day of Year	Treatment	Mean Mid-Day Xylem Water Potential	s	p
		MPa		
156	1	-1.75	0.11	
157	1	-1.83	0.13	
175	1	-1.87	0.04	
157	2	-1.96	0.32	0.165

CASE II: Difference between mid-day greasewood water potential at the pumping well and the control areas after Day 182 ?

Treatment #1 = Greasewood (pumping well area)
Treatment #2 = Greasewood (control area)

Day of Year	Treatment	Mean Mid-Day Xylem Water Potential	s	p
		MPa		
210	1	-2.98	0.03	
210	2	-2.45	0.16	0.000

COLORADO WATER RESOURCES RESEARCH INSTITUTE

LIST OF PUBLICATIONS

AVAILABLE FROM: Bulletin Room
171 Aylesworth Hall
Colorado State University
Fort Collins, CO 80523

PLEASE ENCLOSE PAYMENT & POSTAGE FOR ORDERS OF $25.00 OR LESS.

Amount of Order	Postage
Up to 99¢	75¢
$1.00 to $4.99	$1.00
$5.00 to $9.99	$1.50
$10.00 and over	$2.00

COMPLETION REPORT SERIES

Number		Date	Price
1.	BACTERIAL RESPONSE TO THE SOIL ENVIRONMENT, by J. W. Boyd, T. Yoshida, L. E. Vereen, R. L. Cada, and S. M. Morrison.	June 1969	$ 4.50
2.	COMPUTER SIMULATION OF WASTE TRANSPORT IN GROUNDWATER AQUIFERS, by D. L. Reddell and D. K. Sunada.	June 1969	3.00
3.	SNOW ACCUMULATION IN RELATION TO FOREST CANOPY, by J. Meiman, H. Froehlich, and R. E. Dils.	June 1969	2.50
4.	RUNOFF FROM FOREST AND AGRICULTURAL WATERSHEDS, by M. E. Holland.	June 1969	4.00
5.	SOIL MOVEMENT IN AN ALPINE AREA, by W. D. Striffler.	June 1969	2.00
6.	STABILIZATION OF ALLUVIAL CHANNELS, by N. G. Bhowmik and D. B. Simons.	June 1969	4.00
7.	STABILITY OF SLOPES WITH SEEPAGE, by C. D. Muir and D. B. Simons.	June 1969	4.00
8.	IMPROVING EFFICIENCY IN AGRICULTURAL WATER USE, by W. D. Kemper and R. E. Danielson.	June 1969	2.00
9.	CONTROLLED ACCUMULATION OF BLOWING SNOW, by J. L. Rasmussen.	June 1969	3.50
10.	ECONOMICS AND ADMINISTRATION OF WATER RESOURCES, by J. Ernest Flack.	June 1969	3.50
11.	ORGANIZATIONAL ADAPTATION TO CHANGE IN PUBLIC OBJECTIVES FOR WATER MANAGEMENT OF CACHE LA POUDRE RIVER SYSTEM, by D. Hill, P. O. Foss, and R. L. Meek.	June 1969	4.00
12.	ECONOMICS AND ADMINISTRATION OF WATER RESOURCES, by K. C. Nobe.	June 1969	4.00
13.	ECONOMICS OF GROUND WATER DEVELOPMENT IN THE HIGH PLAINS OF COLORADO, by D. D. Rohdy.	June 1969	2.50
14.	HYDROGEOLOGY AND WATER QUALITY STUDIES IN THE CACHE LA POUDRE BASIN, COLORADO, by James P. Waltz.	June 1969	6.00
15.	HYDRAULIC OPERATING CHARACTERISTICS OF LOW GRADIENT BORDER CHECKS IN THE MANAGEMENT OF IRRIGATION WATER, by D. Heermann and N. A. Evans.	June 1968	4.00
16.	EXPERIMENTAL INVESTIGATION OF SMALL WATERSHED FLOODS, by George L. Smith, V. Yevjevich, and M. E. Holland.	June 1968	3.00
17.	AN EXPLORATION OF COMPONENTS AFFECTING AND LIMITING POLICYMAKING OPTIONS IN LOCAL WATER AGENCIES, by Duane W. Hill, Charles L. Garrison, and P. O. Foss.	Nov. 1968	6.00
18.	EXPERIMENTAL INVESTIGATION OF SMALL WATERSHED FLOODS, by E. F. Schulz and V. M. Yevjevich.	June 1970	6.00
19.	HYDRAULICS OF LOW GRADIENT BORDER IRRIGATION SYSTEMS, by Norman A. Evans, Dale F. Heermann, Orlando W. Howe, and Dennis C. Kincaid.	June 1970	4.00
20.	IMPROVING EFFICIENCY IN AGRICULTURAL WATER USE, by W. D. Kemper.	July 1970	4.00
21.	WATERFOWL-WATER TEMPERATURE RELATIONS IN WINTER, by Ronald A. Ryder.	June 1970	6.00
22.	AN EXPLORATION OF COMPONENTS AFFECTING AND LIMITING POLICYMAKING OPTIONS IN LOCAL WATER AGENCIES, by Duane W. Hill and R. L. Meek.	June 1970	4.00
23.	A SYSTEMATIC TREATMENT OF THE PROBLEM OF INFILTRATION, by H. J. Morel-Seytoux.	June 1971	4.00
24.	STUDIES OF THE ATMOSPHERIC WATER BALANCE, by J. L. Rasmussen.	Aug. 1971	6.00

Number		Date	Price
25.	EVAPORATION OF WATER AS RELATED TO WIND BARRIERS, by S. B. Verma and J. E. Cermak.	June 1971	6.00
26.	WATER TEMPERATURE AS A QUALITY FACTOR IN THE USE OF STREAMS AND RESERVOIRS, by John C. Ward.	Dec. 1971	4.00
27.	LOCAL WATER AGENCIES, COMMUNICATION PATTERNS, AND THE PLANNING PROCESS, by Duane W. Hill and R. L. Meek.	Sept. 1971	6.00
28.	COMBINED COOLING AND BIO-TREATMENT OF BEET SUGAR FACTORY CONDENSER WATER EFFLUENT, by George O. G. Lof.	June 1971	6.00
29.	IDENTIFICATION OF URBAN WATERSHED UNITS USING REMOTE MULTISPECTRAL SENSING, by R. R. Root and L. D. Miller.	June 1971	6.00
30.	GEOHYDRAULICS AT THE UNCONFORMITY BETWEEN BEDROCK AND ALLUVIAL AQUIFERS, by J. P. Waltz and D. K. Sunada.	June 1972	6.00
31.	SEDIMENTATION AND CONTAMINANT CRITERIA FOR WATERSHED PLANNING AND MANAGEMENT, by Hsieh W. Shen	June 1972	6.00
32.	BACTERIAL MOVEMENT THROUGH FRACTURED BEDROCK, by S. M. Morrison and Martin J. Allen.	July 1972	6.00
33.	THE MECHANISM OF WASTE TREATMENT AT LOW TEMPERATURE, PART A: MICROBIOLOGY, by S. M. Morrison, Gary C. Newton, George D. Boone, and Kirke L. Martin.	Aug. 1972	6.00
34.	THE MECHANISM OF WASTE TREATMENT AT LOW TEMPERATURE, PART B: SANITARY ENGINEERING, by John C. Ward, John S. Hunter, and Richard P. Johansen.	Aug. 1972	6.00
35.	AN APPLICATION OF MULTI-VARIATE ANALYSIS IN HYDROLOGY, by V. Yevjevich, M. Dynr-Nielsen, and E. F. Schulz.	Aug. 1972	6.00
36.	URBAN-METROPOLITAN INSTITUTIONS FOR WATER PLANNING DEVELOPMENT AND MANAGEMENT: AN ANALYSIS OF USAGES OF THE TERM "INSTITUTIONS," by Norman Wengert.	Sept. 1972	6.00
37.	SEARCHING THE SOCIAL SCIENCE LITERATURE ON WATER: A GUIDE TO SELECTED INFORMATION STORAGE AND RETRIEVAL SYSTEMS - PRELIMINARY VERSION, by Fred Hogge and Norman Wengert.	Sept. 1972	6.00
38.	WATER QUALITY MANAGEMENT DECISIONS IN COLORADO, by Steven R. Nichols, Gaylord V. Skogerboe, and Robert C. Ward.	June 1972	6.00
39.	INSTITUTIONS FOR URBAN-METROPOLITAN WATER MANAGEMENT: ESSAYS IN SOCIAL THEORY, by Norman Wengert.	Nov. 1972	6.00
40.	SELECTION OF TEST VARIABLE FOR MINIMAL TIME DETECTION OF BASIN RESPONSE TO NATURAL OR INDUCED CHANGES, by H. J. Morel-Seytoux.	Dec. 1972	4.00
41.	GROUND WATER RECHARGE AS AFFECTED BY SURFACE VEGETATION AND MANAGEMENT, by A. Klute, R. E. Danielson, D. R. Linden, and Philip Hamaker.	Dec. 1972	6.00
42.	THEORY AND EXPERIMENTS IN THE PREDICTION OF SMALL WATERSHED RESPONSE, by E. F. Schulz and V. Yevjevich.	Dec. 1972	6.00
43.	EXPERIMENTS IN SMALL WATERSHED RESPONSE, by E. F. Schulz and V. Yevjevich.	Dec. 1972	6.00
44.	ECONOMIC, POLITICAL, AND LEGAL ASPECTS OF COLORADO WATER LAW, by G. E. Radosevich, K. C. Nobe, R. L. Meek, and J. E. Flack.	Feb. 1973	6.00
45.	MATHEMATICAL MODELING OF WATER MANAGEMENT STRATEGIES IN URBANIZING RIVER BASINS, by Wynn R. Walker and Gaylord V. Skogerboe (Partial Completion Report).	June 1973	8.50
46.	EVALUATION OF URBAN WATER MANAGEMENT POLICIES IN THE DENVER METROPOLITAN AREA, by Wynn R. Walker, Robert C. Ward, and Gaylord V. Skogerboe (Partial Completion Report).	June 1973	8.50
47.	COORDINATION OF AGRICULTURAL AND URBAN WATER QUALITY MANAGEMENT IN THE UTAH LAKE DRAINAGE AREA, by Wynn R. Walker, Thomas L. Huntzinger, and Gaylord V. Skogerboe (Partial Completion Report).	June 1973	8.50
48.	INSTITUTIONAL REQUIREMENTS FOR OPTIMAL WATER QUALITY MANAGEMENT IN ARID URBAN AREAS, by Wynn R. Walker, Gaylord V. Skogerboe, Robert C. Ward, and Thomas L. Huntzinger.	June 1973	4.00
49	IMPROVEMENTS IN MOVING SPRINKLER IRRIGATION SYSTEMS FOR CONSERVATION OF WATER, by Donald L. Miles.	June 1973	8.50
50	SYSTEMATIC TREATMENT OF INFILTRATION WITH APPLICATIONS, by H. J. Morel-Seytoux.	June 1973	6.00
51	AN EXPERIMENTAL STUDY OF SOIL WATER FLOW SYSTEMS INVOLVING HYSTERESIS, by A. Klute and R. W. Gillham.	Aug. 1973	8.00
52	CONSOLIDATION OF IRRIGATION SYSTEMS: PHASE 1 - ENGINEERING, LEGAL, AND SOCIOLOGICAL CONSTRAINTS AND/OR FACILITATORS, by Gaylord V. Skogerboe, George E. Radosevich, and Evan C. Vlachos.	June 1973	25.00
53	SYSTEMATIC DESIGN OF LEGAL REGULATIONS FOR OPTIMAL SURFACE - GROUNDWATER USAGE - PHASE 1, by H. J. Morel-Seytoux, R. A. Young, and G. E. Radosevich.	Aug. 1973	8.00

Number		Date	Price
54	GEOLOGIC FACTORS IN THE EVALUATION OF WATER POLLUTION POTENTIAL AT MOUNTAIN DWELLING SITES, by L. K. Burns, D. R. McCrumb, and S. M. Morrison.	Dec. 1973	11.00
55	WATER LAW IN RELATION TO ENVIRONMENTAL QUALITY, by David R. Allardice, George E. Radosevich, Kenneth R. Kobel, and Gustav A. Swanson.	Mar. 1974	30.00
56	EVALUATION AND IMPLEMENTATION OF URBAN DRAINAGE AND FLOOD CONTROL PROJECTS, by Neil S. Grigg, Leonard R. Rice, Leslie H. Bothan, and W. J. Shoemaker.	June 1974	9.00
57	SNOW-AIR INTERACTIONS AND MANAGEMENT OF MOUNTAIN WATERSHED SNOWPACK, by James R. Meiman and Lewis O. Grant.	June 1974	4.00
58	PRIMARY DATA ON ECONOMIC ACTIVITY AND WATER USE IN PROTOTYPE OIL SHALE DEVELOPMENT AREAS OF COLORADO: AN INITIAL INQUIRY, by S. Lee Gray.	June 1974	3.00
59	A SYSTEM FOR GEOLOGIC EVALUATION OF POLLUTION AT MOUNTAIN DWELLING SITES, by James P. Waltz.	Jan. 1975	4.50
60	RESEARCH NEEDS AS RELATED TO THE DEVELOPMENT OF SEDIMENT STANDARDS IN RIVERS, by Johannes Gessler.	Mar. 1975	4.00
61	ECONOMIC AND INSTITUTIONAL ANALYSIS OF COLORADO WATER QUALITY MANAGEMENT, by Robert A. Young, G. E. Radosevich, S. L. Gray, and Kenneth Leathers.	Mar. 1975	6.00
62	FEASIBILITY AND POTENTIAL OF ENHANCING WATER RECREATION OPPORTUNITIES ON HIGH COUNTRY RESERVOIRS, by Robert Aukerman.	June 1975	5.00
63	ANALYSIS OF COLORADO PRECIPITATION, by Marie Kuo and Stephen Cox.	June 1975	3.00
64	COMPUTER ESTIMATES OF NATURAL RECHARGE FROM SOIL MOISTURE DATA - HIGH PLAINS OF COLORADO, by Robert A. Longenbaugh.	July 1975	5.00
65	URBAN DRAINAGE AND FLOOD CONTROL PROJECTS: ECONOMIC, LEGAL AND FINANCIAL ASPECTS, by Neil S. Grigg, L. S. Tucker, Leonard Rice, and J. Shoemaker.	July 1975	11.00
66	INDIVIDUAL HOME WASTEWATER CHARACTERIZATION AND TREATMENT, by Edwin R. Bennett and K. Daniel Linstedt.	July 1975	9.00
67	TOXIC HEAVY METALS IN GROUNDWATER OF A PORTION OF THE FRONT RANGE MINERAL BELT, by Kenneth W. Edwards and Ronald W. Klusman.	June 1975	4.00
68	SYSTEMATIC DESIGN OF LEGAL REGULATIONS FOR OPTIMAL SURFACE-GROUNDWATER USAGE - PHASE 2, by H. J. Morel-Seytoux.	Sept. 1975	13.00
69	ENGINEERING AND ECOLOGICAL EVALUATION OF ANTITRANSPIRANTS FOR INCREASING RUNOFF IN COLORADO WATERSHEDS, by Frank Kreith.	Sept. 1975	3.50
70	AN ECONOMIC ANALYSIS OF WATER USE IN COLORADO'S ECONOMY, by S. Lee Gray.	Dec. 1975	6.00
71	SALT TRANSPORT IN SOIL PROFILES WITH APPLICATION TO IRRIGATION RETURN FLOW - The Dissolution and Transport of Gypsum in Soils, by T. K. Glas and D. B. McWhorter.	Jan. 1976	6.00
72	TOXIC HEAVY METALS IN GROUNDWATER OF A PORTION OF THE FRONT RANGE MINERAL BELT, by Ronald W. Klusman and Kenneth W. Edwards.	June 1976	5.00
73	PRODUCTION OF MUTANT PLANTS CONDUCIVE TO SALT TOLERANCE, by M. W. Nabors.	July 1976	5.00
74	THE RELEVANCE OF TECHNOLOGICAL CHANGE IN LONG TERM WATER RESOURCES PLANNING, by Roger G. Kraynick and Charles W. Howe.	Oct. 1976	4.50
75	PHYSICAL AND ECONOMIC EFFECTS ON THE LOCAL AGRICULTURAL ECONOMY OF WATER TRANSFER TO CITIES, by Raymond L. Anderson, Norman I. Wengert, and Robert D. Heil.	Oct. 1976	4.00
76	DETERMINATION OF SNOW DEPTH AND WATER EQUIVALENT BY REMOTE SENSING, by Harold W. Steinhoff and Albert H. Barnes.	June 1976	3.00
77	EVAPORATION OF WASTEWATER FROM MOUNTAIN CABINS, by John C. Ward.	Mar. 1977	9.00
78	SELECTING AND PLANNING HIGH COUNTRY RESERVOIRS FOR RECREATION WITHIN A MULTIPURPOSE MANAGEMENT FRAMEWORK, by Robert Aukerman, Clarence A. Carlson, Robert L. Hiller, John W. Labadie.	July 1977	7.00
79	EVALUATION OF THE STORAGE OF DIFFUSE SOURCES OF SALINITY IN THE UPPER COLORADO RIVER BASIN, by Jonathan B. Laronne and Stanley A. Schumm.	Sept. 1977	5.00
80	ACHIEVING URBAN WATER CONSERVATION, A HANDBOOK, by J. Ernest Flack, Wade P. Weakley, and Duane W. Hill.	Sept. 1977	7.00
81	ACHIEVING URBAN WATER CONSERVATION: TESTING COMMUNITY ACCEPTANCE, by Robert W. Snodgrass and Duane W. Hill.	Sept. 1977	6.00
82	DEVELOPMENT OF A SUBSURFACE HYDROLOGIC MODEL AND USE FOR INTEGRATED MANAGEMENT OF SURFACE AND SUBSURFACE WATER RESOURCES, by H. J. Morel-Seytoux.	Dec. 1977	4.00

Number		Date	Price
83	MODELLING THE DYNAMIC RESPONSE OF FLOODPLAINS TO URBANIZATION IN EASTERN NEW ENGLAND, by Donald O. Doehring and Mark E. Smith.	Jan. 1978	7.50
84	POLLUTIONAL CHARACTERISTICS OF STORMWATER RUNOFF, by Edwin R. Bennett and K. Daniel Linstedt.	Sept. 1978	8.00
85	DEVELOPMENT OF A DRAINAGE AND FLOOD CONTROL MANAGEMENT PROGRAM FOR URBANIZING COMMUNITIES - PART I, by Eugene J. Riordan, Neil S. Grigg, and Robert L. Hiller.	Sept. 1978	3.00
86	DEVELOPMENT OF A DRAINAGE AND FLOOD CONTROL MANAGEMENT PROGRAM FOR URBANIZING COMMUNITIES - PART II, by Eugene J. Riordan, Neil S. Grigg, and Robert L. Hiller.	Sept. 1978	8.00
87	DEVELOPMENT OF A STREAM-AQUIFER MODEL SUITED FOR MANAGEMENT, by H. J. Morel-Seytoux.	Aug. 1978	4.00
88	INSTITUTIONAL ARRANGEMENTS FOR EFFECTIVE WATER MANAGEMENT IN COLORADO, by Phillip O. Foss.	Nov. 1978	5.00
89	SYNTHESIS AND CALIBRATION OF A RIVER BASIN WATER MANAGEMENT MODEL, by John M. Shafer and John W. Labadie.	Oct. 1978	4.00
90	MODELS FOR SYSTEM WATER PLANNING WITH SPECIAL REFERENCE TO WATER REUSE, by D. W. Hendricks and H. J. Morel-Seytoux.	June 1978	6.00
91	ECONOMIC BENEFITS FROM INSTREAM FLOW IN A COLORADO MOUNTAIN STREAM, by John T. Daubert, Robert A. Young, and S. Lee Gray.	June 1979	6.00
92	HYDRAULIC CONDUCTIVITY OF MOUNTAIN SOILS, by Owen R. Williams, Stanley L. Ponce, James R. Meiman, and Mark Spearnak.	Sept. 1978	4.00
93	APPLICATION OF GEOMORPHIC PRINCIPLES TO ENVIRONMENTAL MANAGEMENT IN SEMIARID REGIONS, by S. A. Schumm, M. T. Bradley, and Z. B. Begin.	Feb. 1980	4.00
	WATER RESOURCES FOR URBAN LAWNS, by William R. Kneebone, Ian L. Pepper, Robert E. Danielson, William E. Hart, Larry O. Pochop, and John Borelli (Regional Project - CWIC).	Sept. 1979	5.00
	SALINITY MANAGEMENT OPTIONS FOR THE COLORADO RIVER, by Jay C. Anderson and Alan P. Kleinman (Regional Project - B-107-UTAH).	June 1978	6.00
94	CONSOLIDATION OF IRRIGATION SYSTEMS: PHASE II, ENGINEERING, ECONOMIC, LEGAL AND SOCIOLOGICAL REQUIREMENTS, by Evan C. Vlachos, Paul C. Huszar, George E. Radosevich, and Gaylord V. Skogerboe.	May 1980	9.00
95	DROUGHT-INDUCED PROBLEMS AND RESPONSES OF SMALL TOWNS AND RURAL WATER ENTITIES IN COLORADO: THE 1976-1978 DROUGHT, by Charles W. Howe.	June 1980	5.00
96	THE PRODUCTION OF AGRICULTURALLY USEFUL MUTANT PLANTS WITH CHARACTERISTICS CONDUCIVE TO SALT TOLERANCE AND EFFICIENT WATER UTILIZATION, by Murray W. Nabors.	Oct. 1979	4.00
97	WATER REQUIREMENTS FOR URBAN LAWNS IN COLORADO, by Robert E. Danielson, William E. Hart, Charles M. Feldhake, and Peter M. Haw.	Aug. 1980	4.00
98	THE EFFECT OF ALGAL INHIBITORS ON HIGHER PLANT TISSUES, by Paul Kugrens.	July 1980	3.50
99	APPLICATIONS OF REMOTE SENSING IN HYDROLOGY, by William D. Striffler and Diana C. Fitz.	Sept. 1980	4.00
100	A WATERSHED INFORMATION SYSTEM, by Anton G. Thomsen and William D. Striffler.	Sept. 1980	5.00
101	AN EMPIRICAL APPLICATION OF A MODEL FOR ESTIMATING THE RECREATION VALUE OF INSTREAM FLOW, by Richard G. Walsh, Ray K. Ericson, Daniel J. Arosteguy, and Michael P. Hansen.	Oct. 1980	4.00
102	MEASURING BENEFITS AND THE ECONOMIC VALUE OF WATER IN RECREATION ON HIGH COUNTRY RESERVOIRS, by Richard G. Walsh, Robert Aukerman, and Robert Milton.	Sept. 1980	4.00
103	EMPIRICAL APPLICATION OF A MODEL FOR ESTIMATING THE RECREATION VALUE OF WATER IN RESERVOIRS COMPARED TO INSTREAM FLOW, by Richard G. Walsh.	Dec. 1980	4.00
104	DETECTION OF WATER QUALITY CHANGES THROUGH OPTIMAL TESTS AND RELIABILITY OF TESTS, by Roy W. Koch, Thomas G. Sanders, and Hubert Morel-Seytoux.	Sept. 1980	5.00
105	MUNICIPAL WATER USE IN NORTHERN COLORADO: DEVELOPMENT OF EFFICIENCY-OF-USE CRITERION, by Anne U. White, A. N. DiNatale, Joanne Greenbert, and J. Ernest Flack.	Sept. 1980	5.00
106	URBAN LAWN IRRIGATION AND MANAGEMENT PRACTICES FOR WATER SAVING WITH MINIMUM EFFECT ON LAWN QUALITY, by Robert E. Danielson and Charles M. Feldhake.	May 1981	7.00
107	ROLE OF SEDIMENT IN NON-POINT SOURCE SALT LOADING WITHIN THE UPPER COLORADO RIVER BASIN, by H. W. Shen, J. B. Laronne, E. D. Enck, G. Sunday, K. K. Tanji, L. D. Whittig, and J. W. Biggar.	Aug. 1981	9.00
108	WATERLOGGING CONTROL FOR IMPROVED WATER AND LAND USE EFFICIENCIES: A SYSTEMATIC ANALYSIS, by Angus Simpson, H. J. Morel-Seytoux, R. A. Young, G. E. Radosevich, and W. T. Franklin.	Dec. 1981	6.00

Number		Date	Price
109	SALT- AND DROUGHT-TOLERANT CROP PLANTS FOR WATER CONSERVATION, by Murray W. Nabors.	Oct. 1981	6.00
110	GEOMORPHIC AND LITHOLOGIC CONTROLS OF DIFFUSE-SOURCE SALINITY, GRAND VALLEY, WESTERN COLORADO, by Richard K. Johnson and Stanley A. Schumm.	Apr. 1982	6.00
111	INVESTIGATION OF OBJECTIVE FUNCTIONS AND OPERATION RULES FOR STORAGE RESERVOIRS, BY Vujica Yevjevich, Warren A. Hall, and Jose D. Salas.	Sept. 1981	4.00
112	DAILY OPERATIONAL TOOL FOR MAXIMUM BENEFICIAL USE MANAGEMENT OF SURFACE AND GROUNDWATERS IN A BASIN, by H. J. Morel-Seytoux, Kristine L. Verdin, and T. H. Illangasekare.	Mar. 1982	4.00
113	A WATER HANDBOOK FOR METAL MINING OPERATIONS, by Thomas R. Wildeman.	Nov. 1981	6.00
114	PLANNING WATER REUSE: DEVELOPMENT OF REUSE THEORY AND THE INPUT-OUTPUT MODEL, VOL. I: FUNDAMENTALS, by Charles D. Turner and David W. Hendricks.	Sept. 1980	13.00
115	PLANNING WATER REUSE: DEVELOPMENT OF REUSE THEORY AND THE INPUT-OUTPUT MODEL, VOL. II: APPLICATION, by Darrel Klooz and David W. Hendricks.	Sept. 1980	6.00
116	EFFECTS OF RELEASES OF SEDIMENT FROM RESERVOIRS ON STREAM BIOTA, by James V. Ward.	Sept. 1982	4.00
117	DYNAMIC WATER ROUTING USING A PREDICTOR-CORRECTOR METHOD WITH SEDIMENT ROUTING, by D. B. Simons, R. M. Li, J. Garbrecht, and R. K. Simons.	Sept. 1982	6.00
118	ECONOMIC ASPECTS OF COST-SHARING ARRANGEMENTS FOR FEDERAL IRRIGATION PROJECTS: A CASE STUDY, by Ghebreyohannes Keleta, Robert A. Young, and Edward Sparling.	Dec. 1982	4.00
119	ECONOMIC ISSUES IN RESOLVING CONFLICTS IN WATER USE, by S. L. Gray and R. A. Young.	Feb. 1983	4.00
120	THE EFFECTS OF WATER CONSERVATION ON NEW WATER SUPPLY FOR URBAN COLORADO UTILITIES, by Carol Ellinghouse and George McCoy.	Dec. 1982	9.00
121	SOLAR HEATING OF WASTEWATER STABILIZATION PONDS, by Stanley L. Klemetson.	Mar. 1983	5.00
122	ECONOMIC IMPACTS OF TRANSFERRING WATER FROM AGRICULTURE TO ALTERNATIVE USES IN COLORADO, by Robert A. Young.	Apr. 1983	6.00
123	ARTIFICIAL GROUNDWATER RECHARGE, SAN LUIS VALLEY, COLORADO, by Dan Sunada.	May 1983	7.00
124	EFFECTS OF WILDERNESS LEGISLATION ON WATER-PROJECT DEVELOPMENT IN COLORADO, by Glen D. Weaver.	May 1983	8.00
125	A RIVER BASIN NETWORK MODEL FOR CONJUNCTIVE USE OF SURFACE AND GROUNDWATER: PROGRAM CONSIM, by John W. Labadie, Sanguan Phamwon, and Rogelio C. Lazaro.	May 1983	8.00
126	INCREASING THE ECONOMIC EFFICIENCY AND AFFORDABILITY OF STORM DRAINAGE PROJECTS, by Harold C. Cochrane and Paul C. Huszar.	Sept. 1983	4.00
127	MATHEMATICAL MODELS FOR PREDICTION OF SOIL MOISTURE PROFILES, by H. J. Morel-Seytoux.	July 1983	4.00
128	DISSOLVED SOLIDS HAZARDS IN THE SOUTH PLATTE BASIN, VOL. I: SALT TRANSPORT IN THE RIVER, by Ramon V. Gomez-Ferrer and D. W. Hendricks.	Dec. 1983	7.00
129	DISSOLVED SOLIDS HAZARDS IN THE SOUTH PLATTE BASIN, VOL. II: SALT BALANCE ANALYSIS, by C. D. Turner and D. W. Hendricks.	Dec. 1983	7.00
130	CONJUNCTIVE OPERATION OF A SURFACE RESERVOIR AND THE GROUNDWATER STORAGE THROUGH A HYDRAULICALLY CONNECTED STREAM, by Hubert J. Morel-Seytoux.	Feb. 1984	3.00
131	THE EFFECT OF LITHOLOGY AND CLIMATE ON THE MORPHOLOGY OF DRAINAGE BASINS IN NORTHWESTERN COLORADO, by Sandra L. Eccker.	June 1984	7.00
132	SPECIFIC YIELD BY GEOPHYSICAL LOGGING POTENTIAL FOR THE DENVER BASIN, by David B. McWhorter.	July 1984	4.00
133	VOLUNTARY BASINWIDE WATER MANAGEMENT: SOUTH PLATTE RIVER BASIN, COLORADO, by Neil S. Grigg, H. P. Caulfield, Jr., N. A. Evans, J. E. Flack, D. W. Hendricks, J. W. Labadie, D. B. McWhorter, H. J. Morel-Seytoux, W. L. Raley, and R. A. Young.	Oct. 1984	
134	EFFECTS OF ALTERNATIVE ELECTRICITY RATES AND RATE STRUCTURES ON ELECTRICITY AND WATER USE ON THE COLORADO HIGH PLAINS, by Richard L. Gardner, Robert A. Young, and Lawrence Conklin.	Oct. 1984	4.00
135	COST-EFFECTIVE DESIGN AND OPERATION OF URBAN STORMWATER CONTROL SYSTEMS: DECISION-SUPPORT SOFTWARE, by John W. Labadie, Neil S. Grigg, Dennis M. Morrow, and David K. Robinson.	Oct. 1984	7.00
136	VARIABILITY OF UNUTILIZED SURFACE WATER SUPPLIES FROM THE YAMPA AND WHITE RIVER BASINS, by Hsieh Wen Shen, Raymond Anderson, Henry P. Caulfield, Jr., and Song-Kai Yan.	Jan. 1985	7.00

Number		Date	Price
137	THE ENDANGERED SPECIES ACT AND WATER DEVELOPMENT WITHIN THE SOUTH PLATTE BASIN, by Lawrence J. MacDonnell.	Aug. 1985	6.00
138	THE POTENTIAL OF MODIFIED FLOW-RELEASE RULES FOR KINGSLEY DAM IN MEETING CRANE HABITAT REQUIREMENTS--PLATTE RIVER, NEBRASKA, by Hsieh Wen Shen, Kim Loi Hiew and Eric Loubser.	Nov. 1985	7.00
139	GUIDELINES FOR DEVELOPING AREA-OF-ORIGIN COMPENSATION, by Lawrence J. MacDonnell, Charles W. Hcwe, James N. Corbridge, Jr. and W. Ashley Ahrens.	Dec. 1985	5.00
140	MONITORING STRATEGIES FOR GROUNDWATER QUALITY MANAGEMENT, by Jim C. Loftis, Robert H. Montgomery, Jane Harris, David Nettles, P. Steven Porter, Robert C. Ward, and Thomas G. Sanders.	April 1986	5.00
141	POTENTIAL GROUNDWATER IMPACTS FROM CHEMIGATION, by James W. Warner and Kit Nielsen.	Sept. 1986	5.00
142	THE EFFECT OF CONSERVATION PROGRAMS ON THE QUALITY OF URBAN LAWNS, by Andrew S. Winje and J. Ernest Flack.	Sept. 1987	5.00
143	EVAPOTRANSPIRATION OF NATIVE VEGETATION IN THE CLOSED BASIN OF THE SAN LUIS VALLEY, COLORADO, by F. L. Charles, J. A. Morgan and W. C. Bausch.	June 1987	5.00

INFORMATION SERIES

1	AN INVENTORY OF ENVIRONMENTAL RESOURCES RESEARCH IN PROGRESS - Colorado State University.	Jan. 1971	Free
2	ECONOMICS OF WATER QUALITY--SALINITY POLLUTION - Abridged Bibliography, by Constance A. Miller.	June 1971	12.00
3	AN INVENTORY OF ENVIRONMENTAL RESOURCES RESEARCH IN PROGRESS - Colorado State University.	July 1972	Free
4	PROCEEDINGS WORKSHOP ON HOME SEWAGE DISPOSAL IN COLORADO, edited by Robert C. Ward.	June 1972	Free
5	DIRECTORY OF ENVIRONMENTAL RESEARCH FACULTY - Colorado State University.	Dec. 1972	Free
6	WATER LAW AND ITS RELATIONSHIP TO ENVIRONMENTAL QUALITY: A BIBLIOGRAPHY OF SOURCE MATERIAL, by George E. Radosevich, David R. Allardice, Gustav A. Swanson, and Kanneth R. Koebel.	Jan. 1973	8.00
7	WILDLIFE AND THE ENVIRONMENT, Proceedings of the Governor's Conference, March, 1973.	Mar. 1973	Out of print
8	INVENTORY OF CURRENT WATER RESOURCES RESEARCH AT COLORADO STATE UNIVERSITY.	July 1973	Free
9	PROCEEDINGS OF THE SYMPOSIUM ON LAND TREATMENT AND SECONDARY EFFLUENT.	Nov. 1973	4.00
10	PROCEEDINGS OF A WORKSHOP ON REVEGETATION OF HIGH-ALTITUDE DISTURBED LANDS, Co-Chairman: W. A. Berg, J. A. Brown, and R. L. Cuany.	July 1973	6.00
11	SURFACE REHABILITATION OF LAND DISTURBANCES RESULTING FROM OIL SHALE DEVELOPMENT, by C. Wayne Cook (Executive Summary).	June 1974	Free
12	WATER QUALITY CONTROL AND ADMINISTRATION LAWS AND REGULATIONS, by George E. Radosevich and Peggy Allen.	1974	16.00
13	FLOOD PLAIN MANAGEMENT OF THE CACHE LA POUDRE RIVER NEAR FORT COLLINS, COLORADO, by Glendol M. Combs, Robert A. McDonald, Marvin R. Martens, and Garry M. Rowe (Limited Number).	Aug. 1974	3.75
14	BIBLIOGRAPHY PERTINENT TO DISTURBANCE AND REHABILITATION OF ALPINE AND SUBALPINE LANDS IN THE SOUTHERN ROCKY MOUNTAINS, by Ordell Steen and William A. Berg.	Feb. 1975	4.00
15	PROCEEDINGS OF THE SYMPOSIUM ON WATER POLICIES ON U.S. IRRIGATED AGRICULTURE: ARE INCREASED ACREAGES NEEDED TO MEET DOMESTIC OR WORLD NEEDS? by Victor A. Koelzer.	Mar. 1975	5.00
16	ANNOTATED BIBLIOGRAPHY ON TRICKLE IRRIGATION, by Stephen W. Smith and Wynn R. Walker.	June 1975	Free
17	CACHE LA POUDRE RIVER NEAR FORT COLLINS, COLO. - FLOOD MANAGEMENT ALTERNATIVES - RELOCATIONS AND LEVIES, by Robert E. Koirtyohann, Ronald L. Miller, Loren W. Pope, and Charles C. Stein.	Aug. 1975	6.00
18	MINIMUM STREAM FLOWS AND LAKE LEVELS IN COLORADO, by Charles G. Rhinehart.	Aug. 1975	9.00
19	THE ENVIRONMENTAL QUALITY OBJECTIVE OF PRINCIPLES AND STANDARDS FOR PLANNING, by Garry D. McGinnis, Robert W. Plott, and Richard D. Swanson.	Aug. 1975	8.00

Number		Date	Price
20	PROCEEDINGS, SECOND WORKSHOP ON HOME SEWAGE DISPOSAL IN COLORADO, edited by Robert Ward.	Sept. 1975	4.00
21	PROCEEDINGS: HIGH ALTITUDE REVEGETATION WORKSHOP NO. 2, edited by R. H. Zuck and L. F. Brown.	Aug. 1976	6.00
22	IMPLEMENTATION OF THE NATIONAL FLOOD INSURANCE PROGRAM IN LARIMER COUNTY, COLORADO, by Dwayne A. Landenberger and Howard M. Whittington.	Sept. 1976	5.00
23	INVENTORY OF COLORADO'S FRONT RANGE MOUNTAIN RESERVOIRS, by Robert Aukerman, William T. Springer, and James F. Judge.	May 1977	6.00
24	FACTORS AFFECTING PUBLIC ACCEPTANCE OF FLOOD INSURANCE IN LARIMER AND WELD COUNTIES, COLORADO, by Joel W. James, Joel B. Kreger, and R. Dru Barrineau.	Sept. 1977	4.00
25	SURVEILLANCE DATA, PLAINS SEGMENT OF THE CACHE LA POUDRE RIVER, COLORADO, 1970-1977, by S. M. Morrison.	Jan. 1978	6.00
26	WATER USE AND MANAGEMENT IN AN ARID REGION (Fort Collins, Colorado and Vicinity), by John W. Anderson, Craig W. DeRemer, and Radford S. Hall.	Sept. 1977	6.00
27	PROCEEDINGS, COLORADO DROUGHT WORKSHOPS, Sponsored by Colorado Water Conservation Board and Colorado Drought Coucil.	Nov. 1977	Free
28	PROCEEDINGS: HIGH ALTITUDE REVEGETATION WORKSHOP NO. 3, edited by S. T. Kenny.	June 1978	6.00
29	PROCEEDINGS, THIRD WORKSHOP ON HOME SEWAGE DISPOSAL IN COLORADO - COMMUNITY MANAGEMENT, by Robert C. Ward.	July 1978	5.00
30	THE LARIMER-WELD COUNCIL OF GOVERNMENTS 208 WATER QUALITY PLAN: AN ASSESSMENT AND SUGGESTIONS FOR FUTURE DIRECTIONS, by Leonard F. Bryniarski, Kenneth W. Carter, Howard D. Danley, and Joseph E. Gurule.	Aug. 1978	3.00
31	THE DENVER BASIN: ITS BEDROCK AQUIFERS, by M. W. Bittinger.	Jan. 1979	Free
32	SNOWPACK AUGMENTATION BY CLOUD SEEDING IN COLORADO AND UTAH, by Roderick A. Chisholm II and Ronald L. Grimes.	Aug. 1979	5.00
33	THE IMPACTS OF IMPROVING EFFICIENCY OF IRRIGATION SYSTEMS ON WATER AVAILABILITY IN THE LOWER SOUTH PLATTE RIVER BASIN, by H. J. Morel- Seytoux, T. Illangasekare, M. W. Bittinger, and Norman A. Evans.	Jan. 1979	Free
34	SAN LUIS VALLEY WATER PROBLEMS: A LEGAL PERSPECTIVE, by G. E. Radosevich and R. W. Rutz.	Jan. 1979	5.00
35	FEDERAL WATER STORAGE PROJECTS: PLUSES AND MINUSES, by C. W. Howe.	June 1979	Free
36	CUTTING CITY WATER DEMAND, by J. Ernest Flack.	May 1979	Free
37	WATER FOR THE SOUTH PLATTE BASIN, by D. W. Hendricks, H. J. Morel-Seytoux, and C. Turner.	Mar. 1979	Free
38	PUBLIC PARTICIPATION PRACTICES OF THE U.S. ARMY CORPS OF ENGINEERS, by Charles E. Crist and Ronald Lanier.	July 1979	4.00
39	ADMINISTRATION OF THE SMALL WATERSHED PROGRAM, 1955-1978 - AN ANALYSIS, by Wildon J. Fontenot.	Aug. 1979	4.00
40	PROCEEDINGS OF THE WORKSHOP ON INSTREAM FLOW HABITAT CRITERIA AND MODELING, edited by George L. Smith.	Dec. 1979	6.00
41	EXPLORING WAYS OF INCREASING THE USE OF SOUTH PLATTE WATER, by John Labadie and John Shafer.		Free
42	PROCEEDINGS: HIGH-ALTITUDE REVEGETATION WORKSHOP NO. 4, edited by Charles L. Jackson and Mark A. Schuster, Climax Molybdenum Company.	June 1980	6.00
43	AN EVALUATION OF THE CACHE LA POUDRE WILD AND SCENIC RIVER DRAFT ENVIRONMENTAL IMPACT STATEMENT AND STUDY REPORT, by Michael J. Eubanks.	Aug. 1980	6.00
44	THE NATIONAL FLOOD INSURANCE PROGRAM IN THE LARIMER COUNTY, COLORADO AREA, by Harry Shoudy.	Aug. 1980	4.00
45	PROCEEDINGS: FOURTH WORKSHOP ON HOME SEWAGE DISPOSAL IN COLORADO - STATE/COUNTY COOPERATION IN MANAGING SMALL WASTEWATER FLOWS, by Robert C. Ward.	Aug. 1981	5.00
46	THE DECLINING ROLE OF THE U.S. ARMY CORPS OF ENGINEERS IN THE DEVELOPMENT OF THE NATION'S WATER RESOURCES, by Charles Yoe.	Aug. 1981	8.00
47	SECTION 404 OF THE CLEAN WATER ACT - AN EVALUATION OF THE ISSUES AND PERMIT PROGRAM IMPLEMENTATION IN WESTERN COLORADO, by Dennis W. Barnett.	Aug. 1982	6.00
48	PROCEEDINGS, HIGH-ALTITUDE REVEGETATION WORKSHOP NO. 5, edited by Robin L. Cuany and Julie Etra.	Dec. 1982	6.00

Number		Date	Price
49	PROCEEDINGS: FIFTH WORKSHOP ON HOME SEWAGE DISPOSAL IN COLORADO: OPERATION AND MAINTENANCE OF ON-SITE WASTEWATER TREATMENT SYSTEMS, by Robert C. Ward.	June 1983	5.00
50	POSSIBLE CAPTURE OF THE MISSISSIPPI BY THE ATCHAFALAYA RIVER, by John D. Higby, Jr., P.E.	Aug. 1983	5.00
51	ENVIRONMENTAL REGULATION: APPLICANT BEHAVIOR AS A FACTOR IN OBTAINING PERMITS, by Barney M. Opton.	July 1984	8.00
52	A CRITICAL ASSESSMENT OF METHODOLOGIES FOR ESTIMATING URBAN FLOOD DAMAGES-PREVENTED BENEFITS, by David Plazak.	July 1984	3.00
53	PROCEEDINGS: HIGH-ALTITUDE REVEGETATION WORKSHOP NO. 6, edited by Thomas A. Colbert and Robin L. Cuany.	Dec. 1984	8.00
54	ARTIFICIAL AQUIFER RECHARGE IN THE COLORADO PORTION OF THE OGALLALA AQUIFER, by Robert Longengaugh, Donald Miles, Earl Hess, and James Rubingh.	Nov. 1984	2.00
55	WORKSHOP ON WATER QUALITY MONITORING IN COLORADO, edited by Robert C. Ward and William L. Raley.	July 1985	5.00
56	GROUNDWATER QUALITY PROTECTION POLICIES FOR THE ROCKY MOUNTAIN REGION AND THE NATION, Transcript of Proceedings.	April 1986	6.00
57	PROCEEDINGS: SIXTH WORKSHOP ON ON-SITE WASTEWATER TREATMENT IN COLORADO, Edited by Robert C. Ward.	May 1986	5.00
58	PROCEEDINGS: HIGH ALTITUDE REVEGETATION WORKSHOP NO. 7, Edited by Mark A. Schuster and Ronald H. Zuck.	Oct. 1986	10.00

TECHNICAL REPORT SERIES

1	SURFACE REHABILITATION OF LAND DISTURBANCES RESULTING FROM OIL SHALE DEVELOPMENT, by C. Wayne Cook, Study Coordinator.	June 1974	11.00
2	ESTIMATED AVERAGE ANNUAL WATER BALANCE FOR PICEANCE AND YELLOW CREEK WATERSHEDS, by Ivan F. Wymore.	Aug. 1974	Free
3	IMPLEMENTATION OF THE FEDERAL WATER PROJECT RECREATION ACT IN COLORADO, by John A. Spence.	June 1974	Free
4	VEGETATIVE STABILIZATION OF SPENT OIL SHALES, by H. P. Harbert and W. A. Berg.	Dec. 1974	4.00
5	REVEGETATION OF DISTURBED SURFACE SOILS IN VARIOUS VEGETATION ECOSYSTEMS OF THE PICEANCE BASIN, by P. L. Sims and E. F. Redente.	Dec. 1974	5.25
6	COLORADO ENVIRONMENTAL DATA SYSTEMS (abridged), by Ross A. Whaley and A. A. Dyer.	Oct. 1972	6.00
7	MANUAL FOR TRAINING IN THE APPLICATION OF PRINCIPLES AND STANDARDS (Water Resources Council), by Henry Caulfield, Jr.	Dec. 1974	11.00
8	MODELS DESIGNED TO EFFICIENTLY ALLOCATE IRRIGATION WATER USE BASED ON CROP RESPONSE TO SOIL MOISTURE STRESS, by Raymond L. Anderson, Dan Yaron, and Robert Young.	May 1977	5.00
9	THE 1972 FEDERAL WATER POLLUTION CONTROL ACT'S AREA-WIDE PLANNING PROVISION: HAS EXECUTIVE IMPLEMENTATION MET CONGRESSIONAL INTENT? by Dennis F. Stark.	Nov. 1977	6.00
10	EFFICIENCY OF WASTEWATER DISPOSAL IN MOUNTAIN AREAS, by Richard G. Walsh, Jared P. Soper, and Anthony A. Prato.	Jan. 1978	6.00
11	FEDERAL WATER RECREATION IN COLORADO: COMPREHENSIVE VIEW AND ANALYSIS, by Kharol E. Stefanec.	May 1978	6.00
12	RECREATION BENEFITS OF WATER QUALITY: ROCKY MOUNTAIN NATIONAL PARK, SOUTH PLATTE RIVER BASIN, COLORADO, by Richard G. Walsh, Ray K. Ericson, John R. McKean, and Robert A. Young.	May 1978	5.00
13	IMPACT OF IRRIGATION EFFICIENCY IMPROVEMENTS ON WATER AVAILABILITY IN THE SOUTH PLATTE RIVER BASIN, by M. W. Bittinger, R. E. Danielson, N. A. Evans, W. E. Hart, H. J. Morel-Seytoux, and M. M. Skinner.	Jan. 1979	6.00
14	ECONOMIC VALUE OF BENEFITS FROM RECREATION AT HIGH MOUNTAIN RESERVOIRS, by Richard G. Walsh, Robert Aukerman, and Dean Rudd.	Dec. 1978	4.00
15	WEEKLY CROP CONSUMPTIVE USE AND PRECIPITATION IN THE LOWER SOUTH PLATTE RIVER BASIN (Fort Morgan, Sterling and Julesburg) 1947-1975.	Feb. 1979	Free

TECHNICAL REPORT SERIES (continued)

Number		Date	Price
16	WATER MANAGEMENT MODEL FOR FRONT RANGE RIVER BASINS, by John W. Labadie and John M. Shafer.	Apr. 1979	6.00
17	LAND TREATMENT OF MUNICIPAL SEWAGE EFFLUENT AT HAYDEN, COLORADO, by K. A. Barbarick, B. R. Sabey, and N. A. Evans.	Oct. 1977	4.00
18	AN INTERACTIVE RIVER BASIN WATER MANAGEMENT MODEL: SYNTHESIS AND APPLICATION, by John M. Shafer.	Aug. 1979	5.00
19	AN ECONOMIC EVALUATION OF THE GENERAL MANAGEMENT FOR YOSEMITE NATIONAL PARK, by Richard G. Walsh.	Mar. 1980	5.00
20	DEVELOPMENT OF METHODOLOGIES FOR DETERMINING OPTIMAL WATER STORAGE STRATEGIES, by Darrell G. Fontane and John W. Labadie.	Sept. 1980	[illegible]
21	THE ECONOMY OF ALBANY, CARBON, AND SWEETWATER COUNTIES, WYOMING - DESCRIPTION AND ANALYSIS, by John R. McKean and Joseph C. Weber.	Jan. 1981	4.00
22	AN INPUT-OUTPUT STUDY OF THE UPPER COLORADO MAIN STEM REGION OF WESTERN COLORADO, by John R. McKean and Joseph C. Weber.	Jan. 1981	5.00
23	THE ECONOMY OF MOFFAT, ROUTT, AND RIO BLANCO COUNTIES, COLORADO - DESCRIPTION AND ANALYSIS, by John R. McKean and Joseph C. Weber.	Jan. 1981	5.00
24	THE SURVEY-BASED INPUT-OUTPUT MODEL AS A RESOURCE PLANNING TOOL, by John R. McKean.	Jan. 1981	4.00
25	THE ECONOMY OF NORTHWESTERN COLORADO - DESCRIPTION AND ANALYSIS, by S. L. Gray, J. R. McKean, and J. C. Weber.	Jan. 1981	5.00
26	AN INPUT-OUTPUT ANALYSIS OF SPORTSMAN EXPENDITURES IN COLORADO, by John R. McKean.	Jan. 1981	5.00
27	AN INPUT-OUTPUT STUDY OF THE KREMMLING REGION OF WESTERN COLORADO, by John R. McKean and Joseph Weber.	Mar. 1981	4.00
28	AN ASSESSMENT OF WATER USE AND POLICIES IN NORTHERN COLORADO CITIES, by Kelly N. DiNatale.	Mar. 1981	6.00
29	AN ECONOMIC INPUT-OUTPUT STUDY OF THE HIGH PLAINS REGION OF EASTERN COLORADO, by John R. McKean, Ray K. Ericson, and Joseph C. Weber.	Feb. 1982	8.00
30	ENERGY PRODUCTION AND USE IN COLORADO'S HIGH PLAINS REGION, by Emm McBroom.	Feb. 1982	8.00
31	COMMUNITY AND SOCIO-ECONOMIC ANALYSIS OF COLORADO'S HIGH PLAINS REGION, by Robert Burns.	Feb. 1982	8.00
32	HYDROLOGIC AND PUMPING DATA FOR COLORADO'S OGALLALA AQUIFER REGION, 1979, by Robert Longenbaugh.	Feb. 1982	8.00
33	PROJECTED POPULATION, EMPLOYMENT, AND ECONOMIC OUTPUT IN COLORADO'S EASTERN HIGH PLAINS, 1979-2020, by John R. McKean.	Feb. 1982	8.00
34	ENERGY AND WATER SCARCITY AND THE IRRIGATED AGRICULTURAL ECONOMY OF THE COLORADO HIGH PLAINS: DIRECT ECONOMIC-HYDROLOGIC IMPACT FORECASTS (1979-2020), by Robert A. Young, Lawrence R. Conklin, Robert A. Longenbaugh, and Richard L. Gardner.	Feb. 1982	8.00
35	THE ECONOMIES OF MESA COUNTY AND GARFIELD, MOFFAT, RIO BLANCO, AND ROUTT COUNTIES, COLORADO, by John R. McKean, Joseph C. Weber, and Ray K. Ericson.	Apr. 1981	5.00
36	THE ECONOMY OF THE POWDER RIVER BASIN REGION OF EASTERN WYOMING: DESCRIPTION AND ANALYSIS, by John R. McKean, Joseph C. Weber, and Ray K. Ericson.	Jan. 1981	4.00
37	AN INTERINDUSTRY ANALYSIS OF THREE FRONT RANGE FOOTHILLS COMMUNITIES: ESTES PARK, GILPIN COUNTY, AND WOODLAND PARK, COLORADO, by John R. McKean, Warren Trock, and David R. Senf.	July 1982	6.00
38	GROUNDWATER QUALITY REGULATION IN COLORADO, by Thomas J. Looft.	Dec. 1982	6.00
39	SPORTSMEN EXPENDITURES FOR HUNTING AND FISHING IN COLORADO - 1981, by John R. McKean and Kenneth C. Nobe.	Jan. 1983	5.00
40	THE ECONOMY OF LINCOLN, SUBLETTE, SWEETWATER AND UINTA COUNTIES, WYOMING, ROCK SPRINGS BLM DISTRICT, by John R. McKean and Joseph C. Weber.	May 1983	5.00
41	THE ECONOMY OF ALBANY, CARBON AND FREMONT COUNTIES, WYOMING, RAWLINS BLM DISTRICT, by John R. McKean and Joseph C. Weber.	May 1983	5.00
42	THE ECONOMY OF BIG HORN, HOT SPRINGS, PARK, AND WASHAKIE COUNTIES, WYOMING, WORLAND BLM DISTRICT, by John R. McKean and Joseph C. Weber.	May 1983	5.00
43	THE ECONOMY OF EASTERN WYOMING, CASPER BLM DISTRICT, by John R. McKean and Joseph C. Weber.	May 1983	5.00
44	DIRECT AND INDIRECT ECONOMIC EFFECTS OF HUNTING AND FISHING IN COLORADO - 1981, by John R. McKean and Kenneth C. Nobe.	Jan. 1984	5.00

TECHNICAL REPORT SERIES (continued)

Number		Date	Price
45	THE ECONOMY OF SOUTHWEST COLORADO, DESCRIPTION AND ANALYSIS, by John R. McKean and Wendell D. Winger.	May 1984	5.00
46	EXPANSION OF WATER DELIVERY BY MUNICIPALITIES AND SPECIAL WATER DISTRICTS IN THE NORTHERN FRONT RANGE, COLORADO, 1972-1982, by Raymond L. Anderson.	Oct. 1984	4.00
47	MANAGING AN INTERRELATED STREAM-AQUIFER SYSTEM: ECONOMICS, INSTITUTIONS, HYDROLOGY, by J. T. Daubert, R. A. Young, and H. J. Morel-Seytoux.		

SPECIAL REPORT SERIES

Number		Date	Price
1	DESIGN OF WATER AND WASTEWATER SYSTEMS For Radid Growth Areas and Resorts, by J. Ernest Flack.	1976	5.00
2	ENVIRONMENT AND COLORADO - A HANDBOOK, edited by Phillip O. Foss.		5.00
3	IRRIGATION DEVELOPMENT POTENTIAL IN COLORADO, by Norman K. Whittlesey.	May 1977	5.00
4	ENVIRONMENTAL INVENTORY OF A PORTION OF PICEANCE BASIN IN RIO BLANCO COUNTY, COLORADO.	Dec. 1971	11.00
5	A GUIDE TO COLORADO WATER LAW, by Ward H. Fischer, Steven B. Ray, Glen D. Rask, and Windol L. Wyatt.	Sept. 1978	3.50
6	NETWORK ANALYSIS OF RAW WATER SUPPLIES UNDER COMPLEX WATER RIGHTS AND EXCHANGES: Documentation for Program MODSIM3, by John W. Labadie, Andrew M. Pineda, and Dennis A. Bode.	Mar. [illegible]	5.00