EVAPOTRANSPIRATION OF NATIVE VEGETATION IN THE CLOSED BASIN OF THE SAN LUIS VALLEY, COLORADO

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Project Completion Report

by

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ABSTRACT

EVAPOTRANSPIRATION OF NATIVE VEGETATION IN THE CLOSED BASIN OF 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 measurements of ET from native vegetation; to obtain measurements of plant water use; 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 data indicate the expected trend of a decrease in evaporation with an increase in 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 of ET measured by gas analysis chamber and lysimeters 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 problems in the lysimeter data concerning the estimation of ET for undisturbed vegetation in the surrounding plant community.

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The work was conducted under cooperative agreements with the U.S. Bureau of Reclamation (USBR), Southwest Region, and the U.S. Department of Agriculture, Agricultural Research Service, Mountain States Area. The USBR Closed Basin Division, San Luis Valley Project Office provided access to its lysimeter site and a limited assignment of personnel to assist in data collection details. Much appreciation is due to Mr. Lindell H. Elfrink, Project Engineer, and Mr. Doug Gober. The Agricultural Research Service provided the services of several employees from the Fort Collins office for data collection. The work of Mr. Barry Weaver in construction of the portable ET measurement chamber is acknowledged with appreciation. Mr. Joseph May and Mr. Segundo Diaz provided excellent assistance in data collection.

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Dr. Norman A. Evans, Director of the Colorado Water Resources Research Institute, provided the vital management services of coordination among the participating agencies and fiscal management.

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CHAPTER I

INTRODUCTION

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 (1982), is shown in Figures 1a and 1b.

Average annual precipitation in the Valley 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. 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. Coupled with a vast water supply from the confined (artesian) aquifer, snowmelt runoff provides water supply for irrigation as well as water for natural export in the Rio Grande (river) to New Mexico, Texas, and the Republic of Mexico.

Although the Valley has an abundant water supply, there are several major water problems as outlined by Emery et al. (1971). They include:

1) waterlogging,
2) water wasted by nonbeneficial evapotranspiration,
3) deterioration of ground-water quality, and
4) Colorado's mandate to deliver water to New Mexico and Texas according to the Rio Grande Compact.

A closed basin 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) and encompasses 760,000 hectares (ha). The closed basin is hydrologically separated from the Rio Grande by a low geologic divide. There are no surface flows departing nor significant losses due to water migration in the unconfined (water table) aquifer. Ground water in the shallow, unconfined and deeper aquifers of the closed basin has been found to move toward a sump area where it is lost through nonbeneficial ET (USBR, 1963). The sources for the subsurface and surface flows are snowmelt, rainfall, and irrigation wastes and return flows.

The sump area has had only the mechanism of evapotranspiration (ET) to rid itself of this water. In this part of the closed basin, the conditions are favorable for only native vegetation such as greasewood (*Sarcobatus vermiculatus* Hook. Torr.), rabbitbrush (*Chrysothamnus nauseosus* Pall. Britt.), and salt grass (*Distichlis stricta* L. Greene). This type of vegetation consumes nearly half of the total water available for use to the Valley (Emery et al., 1971). The water quality and water management 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, 1984).

Colorado has been unable to comply with water delivery requirements specified in the Rio Grande Compact of 1938 and the Rio Grande Convention of 1906 without curtailing delivery of Colorado water rights. Since some of the ET from the sump area is in excess of that required for maintaining the community of indigenous vegetation, a portion of the water in the closed basin was considered as a source to meet these requirements without causing hardship to the valley's agriculture. After extensive research on water salvage from this area, design and construction of shallow wells in connection with a lined-ditch conveyance system was initiated. The general project design includes a network of 170 shallow wells over an area of 53,000 ha ; all of which is within the sump area. The plans call for annual displacement (pumping) of 128,000 cubic dekameters (dam^3; 1 dam^3 - 0.1 hectare-meter) of water out of the sump area and into the Rio Grande. 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 (USBR, 1984).

From previous research on water available for salvage from areas supporting phreatophytes (plants with roots reaching the water table), it has been determined 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 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, 1984). This will decrease the soil evaporation contribution toward ET to a negligible amount as observed by previous research. It follows that the accuracy of the estimated rate of ET is critical for proper operation of this system.

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 of native vegetation. 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 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 native vegetation under naturally occurring shallow and deep ground-water levels, and
4) to observe the ET response of native vegetation to a falling water table (where pumping occurs).

CHAPTER II

METHODOLOGY

Several ET measurement methods have been used successfully for consumptive use (ET) estimation of field crops. Typically, lysimeter methods have been most widely applied, with other methods receiving some use. Measurement of the ET of native vegetation has involved methods such as plant tanks, lysimeters, and inflow-outflow ground-water fluctuations. Methods receiving more recent attention for use on native vegetation include energy balance approaches and gas analysis (portable chambers).

Previous research involving ET measurement by gas analysis with a chamber has shown this method to be useful. Studies have shown general agreement between hourly values of chamber and lysimeter measurements for field crops (Reicosky and Peters, 1977; Harmsen et al., 1982; and Reicosky et al., 1983). The chamber has a low material cost, allows a great degree of portability, and requires a very short measurement period; its application to obtain daily ET requires repeated intensive readings in order to track the changing ET throughout the day. One reading per hour has been found to yield 80 to 95 percent agreement between chamber and lysimeter ET (Reicosky and Peters, 1977 and Peterson et al., 1985).

Measurement Procedure

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.

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.

Raw Data Analyses

To find 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. Saturation vapor pressures were obtained from the Lowe equation (Lowe, 1976) as shown :

$$SVP = 0.6107799961 + 0.04436518521*T + 0.001428945805*T^2 + 2.65064847*10^{-5}*T^3 + 3.031240396*10^{-7}*T^4 + 2.034080984*10^{-9}*T^5 + 6.136820929*10^{-12}*T^6$$

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:

$$DEP = \frac{(AVP)(VOL)}{(\rho)(A)(R)(T)}$$

where DEP = depth of water (m),

AVP = actual vapor pressure (kPa) = SVP * Relative Humidity,

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

ρ = 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).

Average hourly rates of ET were calculated from each measurement period (one period per plot per hour) and were based on each maximum ten-second vapor pressure gradient. This usually occurred near the beginning of the sixty-second measurement period. These data provided a diurnal curve for each plot assuming linearity between measured points. Using a numerical technique, the computed area under the curve yielded a daily ET value (Figure 2). For purposes of daily ET estimation, no ET was assumed to occur before sunrise and after sunset.

Site Selection

Evapotranspiration measurements using the 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. The plots measured are indicated in Table 1. In 1986, three sites (Table 1) were measured in each week (one site per day) and were chosen according to similarities in species composition and plant size to provide the following three situations:

Site #1- small depth to ground-water level (0.6 to 1.5 m) at the USBR lysimeter area (used in 1985 and 1986 measurements);

Site #2- falling (pumped) ground-water level with a corresponding ET control site (constant water table) in the same area;

Site #3- large depth to ground-water level (4.2 to 4.6 m).

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

Along with chamber measurement of ET, a weather station was operated at the USBR Lysimeter site to measure air temperature, relative humidity, wind speed, solar radiation, and precipitation. 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. See Table 2 for daily weather summaries and Figures 3 through 6 for examples of diurnal wind speed, solar radiation, temperature, and vapor pressure.

Validation of Chamber Method

In addition to the sites of ET measurement in the USBR project area, an additional site was chosen in an alfalfa field at the Colorado State University Farm near Center, Colorado (Figure 1). The purpose of this site was to obtain data for comparison of ET measured with the chamber to ET measured from several established lysimeters (maintained by the USDA - ARS) containing alfalfa.

Alfalfa ET was measured on two days (6 June and 25 July 1986). The four 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 to expect under noraml operating conditions.

The lysimeters were in excellent condition on both days of measurement, with the alfalfa at a similar stage of growth inside and outside of the lysimeters. Six plots, 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 plots were sampled every half-hour for a period of seven hours on 25 July. Average plot ET as determined by the chamber was 96 percent (6 June) and 90 percent (25 July) of the average lysimeter ET for the corresponding periods (Table 3). Average ET values for the chamber were 6.45 mm and 5.39 mm for the two periods, with corresponding standard errors of 0.287 and 0.153. The results of this comparison lend confidence to the chamber data obtained in this entire study.

CHAPTER III

RESULTS

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, and had not established sufficiently to yield useful data as was observed by size, maturity, and color appearance differences from surrounding rabbitbrush plants.

1985 Data

For the ET comparison data of the 1985 season (Figures 7 to 10), lysimeter ET (a seven-day average) was generally lower in magnitude than chamber ET (a five-day average) for each corresponding week of measurement. Chamber and lysimeter ET values are discussed below only in terms of ET for the seasonal measurement period. These values were obtained by computing the area under each curve constructed from the mean weekly ET values for the three weeks of chamber measurement. The best agreement in terms of total ET and E (evaporation) for the measurement season was found in the salt grass and bare soil plots, with the USBR salt grass lysimeter (160 mm) accounting for 87 percent of ET measured by the chamber over the lysimeter (185 mm) and 71 percent of ET measured by the chamber at a nearby plot (226 mm) (Table 4). Similarly, the bare soil lysimeter (113 mm) accounted for 78 percent of E measured by the chamber over the lysimeter (145 mm) and 71 percent of E measured by the chamber at a nearby plot (159 mm) having the same depth to water table.

The chamber ET value for the greasewood in the lysimeter (116 mm) showed reasonable agreement with the USBR lysimeter value (118 mm). However, a higher average ET for 22 to 26 July (Days 203 to 207) was indicated by the chamber-measured ET of the greasewood plot outside of the lysimeter but not by the USBR greasewood lysimeter (Figure 7). The greasewood lysimeter accounted for only 52 percent of ET measured by the chamber (228 mm) at this (non-lysimeter) plot. The same trend is true for rabbitbrush except that there is little agreement (27 percent) between non-lysimeter chamber plot (216 mm) and USBR lysimeter ET (59 mm) values during 1985. Chamber ET measurements over the salt grass, bare soil, and greasewood lysimeters are in good agreement with the USBR lysimeter data, but the lysimeters yield data which are not representative of the surrounding vegetation.

1986 Data

Although no chamber ET measurements of vegetation in the USBR lysimeters were gathered in 1986, the USBR lysimeter data (average values for a seven-day period) were obtained for purposes of comparison with the chamber data at plots near the lysimeters (Figures 11 to 14) for the period of 26 May to 13 August; the chamber data were for one day of the seven-day period represented by the lysimeter data. 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 13). Results show that the mean 77-day chamber E was consistently higher than the lysimeter E (an average of 1.2 mm per day) (Table 4), 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 14) 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). There is considerable difference between the chamber and lysimeter comparison data of salt grass for 1985 (71 percent) and 1986 (40 percent); the 1986 comparison data may be more accurate because of a longer measurement season, hence, more sampling.

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 (Table 5). For relative comparison, each plant's dimensions were measured in three directions (foliage height and perpendicular spread) only during 1986. The mean plant spherical surface area was determined as the average of the spherical surface areas, using each dimension as a diameter. These values provide a rough estimate of relative plant size (transpirational area) assuming each plant can be approximated as a sphere. 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. These data support the observation of small nonrepresentative plants in the lysimeters. Direct comparison of ET per plant size was not made for the chamber and lysimeter ET measurements because 1) the length of ET measurement was different for both methods (one day versus seven days) and 2) the soil surfaces of the chamber plots and lysimeters were not of equal area. Relative plant size differences probably do not account for all of the discrepancy in the comparison of measured ET.

Additional causes of 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 caused soil compaction which was sufficient to inhibit natural hydraulic conductivity of this soil for a number of years. This, in turn, would impede the outflow of water (ET). The driving of the casings may have also damaged some of the roots of the vegetation, which would be reflected in reduced ET. 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 volume at the top of the soil profile. Also, neutron probe inaccuracies (depending on the calibration) may contribute to errors in lysimeter ET measurement. Other problems may be insufficient lysimeter volume (depth) for plant roots or accumulation of toxic solutes in the lysimeters (Robinson, 1966).

Observation Well 377 and USBR Lysimeter Sites

Mean ET data for greasewood and rabbitbrush plots at Site #3 are shown in Figure 15. The ground-water level at this site peaked in early July (Figure 16), although this was hardly noticeable because the depth to the water table remained nearly constant at 4.3 m. For the same vegetative species in the hummocks area of the USBR Lysimeter site (Site #1) (Figure 17), the water table level below the ground surface peaked in early June at 1.25 m and then dropped steadily to 1.7 m in mid-August (Figure 18).

Greasewood plot mean ET 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 (Table 4). Rabbitbrush plot mean ET was nearly equivalent, as well, for plants measured at both sites. The plants at the two sites were of slightly different size and woody material and were measured on different days (variable weather conditions) so, for purposes of comparison, no significant conclusions can be made concerning the effect of water table depth on ET. It appears that the plants at each of these sites have adapted well to their corresponding ground-water levels.

At Site #1 seasonal salt grass plot ET (Figure 19) for 1986 averaged nearly 17% greater than both greasewood and rabbitbrush plot ET (Table 4). This may be due to the location of the salt grass in a low-lying area closer to the water table (Figure 18). The seasonal average bare soil evaporation at this site was 72% of the seasonal average ET found for greasewood and rabbitbrush plots.

Salvage Well 3 Site

The plots at the Salvage Well 3 site (Site #2) provided twelve weeks of ET data during which the water table varied from 2.6 m below the surface (for the first five weeks) to 5.2 m below the surface (at twelve weeks; Day 224) at 30.5 m from the pumping well (Figure 20). 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, an additional three plots each of greasewood and rabbitbrush were measured 90 m from the well to serve as a control. Although there was no observation well at 90 m, the water table was assumed to be minimally affected by pumping; normal seasonal water table fluctuations occurred. Evapotranspiration was measured at all of these plots within the same hour during each day of measurement (one day per week).

The mean ET data for the greasewood plots near the well at Site #2 and for the control greasewood plots were compared (Figure 21). The same comparison was carried out for the rabbitbrush plots (Figure 22). No substantial differences in ET by location for either greasewood or rabbitbrush are apparent. However, ET was expressed only in terms of depth (mm) and not in terms of plant size, which will affect 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 5). The area closest to the salvage well supported the larger vegetation, so it is important that the comparison accounts for plant size. Pumping and subsequent drawdown were found to influence the mean ET per plant size of some of the vegetation at this site (Figures 23 and 24). Greasewood ET may be influenced more than rabbitbrush ET in the case when continuous pumping has lowered the ground-water level for a period of one week or more. This trend was consistent for the latter part of the season when pumping had been continuous for five weeks.

The reasons for the different responses of the two species do not appear to be related to potential (expected) rooting depth because greasewood has been known to develop roots from 1 to 10 m deep, whereas, rabbitbrush generally prefers a shallower water table to support root lengths in the range of 2.4 to 4.6 m (Meinzer,1927). According to the observation well data (Figure 20) 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 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.

Constraints of the Study

The data obtained in this study show some important trends and effects of water table depth on the ET of native vegetation sites under several conditions. However, these results must be viewed within the constraints of the study. Only intermediate-sized shrubs were sampled and plant size variability existed throughout the basin (see Chapter II, Methodology). 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 taken when comparing the ET obtained at any two sites.

CHAPTER IV

CONCLUSIONS

The following major conclusions may be drawn from the data of 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 lysimeters.

2) The USBR greasewood and rabbitbrush lysimeter ET data were substantially less than that obtained by chamber measurements for the years of 1985 and 1986, and do not show similar trends. The salt grass and bare soil lysimeter data, while consistently lower, exhibit similar ET 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.

PLANT / YEAR	1985	1986
Greasewood	52 %	31 %
Rabbitbrush	27 %	25 %
Salt Grass	71 %	40 %
Bare Soil	71 %	*

Note: Caution should be used when observing the rabbitbrush comparison because of plant problems in the lysimeter.

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* 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.

3) Greasewood and rabbitbrush plots under either shallow or deep ground-water levels may use similar amounts of water (ET) regardless of the water table level 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 10).

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

The objectives of this study on evapotranspiration of native vegetation in the closed basin of the San Luis Valley, Colorado have been fulfilled as outlined in Chapter I of this report. Additional study will be imperative in order to determine long-term effects of continuous project pumping on the vitality of the phreatophytic vegetation.

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APPENDIX

Table 1. Description of ET Measurement Sites , 1985 and 1986.

SITE	PLOTS
1985	
Site #1: USBR Lysimeter Site . . .	2 Greasewood*, 1 Rabbitbrush, 2 Salt Grass*, 1 Bare Soil (upland area), 2 Bare Soil (lowland area)*.
1986	
Site #1: USBR Lysimeter Site . . . (0.6 to 1.5 m water table)	3 Greasewood, 3 Rabbitbrush, 3 Saltgrass, 3 Bare Soil.
Site #2: Salvage Well 3 . . . . . (varying water table and constant water table control)	3 Greasewood, 3 Rabbitbrush, 3 Greasewood (control), 3 Rabbitbrush (control).
Site #3: Observ. Well 377 . . . . (4.2 to 4.6 m water table)	5 Greasewood, 4 Rabbitbrush.

* Indicates that one of these plots was a USBR lysimeter.

Table 2. Daily Weather Summary, USBR Lysimeter site, 1985, 1986.

WEATHER DATA '85 '86		SAN LUIS VALLEY , COLORADO USBR Lysimeter Site						
DATE	DAY #	Tmax (deg. C)	Tmin (deg. C)	ave. vapor pr. (kPa)	Solar Rad. (MJ/m2)	Windrun (km)	ave. Windsp. (m/sec)	Hours of data (beg-end)
20-MAY-85	140	17.6	-0.9	0.717	23.7	191.5	1.9	0-22
21-MAY-85	141	16.2	4.5	0.883	20.3	234.3	2.9	0-23
22-MAY-85	142	15.0	3.4	0.852	16.3	131.0	1.7	1-23
23-MAY-85	143	18.7	0.6	0.825	24.5	176.6	2.0	0-23
24-MAY-85	144	21.7	-0.6	0.746	30.1	149.8	1.6	1-14
24-JUN-85	175	26.9	13.1	1.344	24.1	381.0	4.3	0-22
25-JUN-85	176	23.2	10.8	1.130	25.7	318.0	4.0	0-22
26-JUN-85	177	19.2	3.5	0.515	30.6	321.6	3.8	0-22
27-JUN-85	178	24.8	-2.9	0.515	32.2	109.7	1.5	0-22
28-JUN-85	179	25.4	2.4	0.697	30.9	158.4	1.6	0-15
22-JUL-85	203	25.7	10.3	1.386	22.9	164.6	2.2	2-22
23-JUL-85	204	24.7	11.9	1.418	20.8	183.4	2.7	1-22
24-JUL-85	205	23.6	8.5	1.133	23.3	215.3	2.5	1-23
25-JUL-85	206	24.3	7.9	1.151	23.1	233.1	3.2	2-22
26-JUL-85	207	24.2	7.1	1.100	20.9	131.7	1.2	1-14
26-MAY-86	146	21.0	11.5	0.514	28.3	278.7	4.4	8-23
27-MAY-86	147	27.3	10.3	0.985	29.0	254.6	3.1	0-23
4-JUN-86	155	22.5	3.8	1.008	19.6	162.7	1.9	0-23
5-JUN-86	156	22.9	3.5	0.886	23.9	158.4	1.9	0-23
9-JUN-86	160	18.8	7.7	0.867	25.2	317.0	3.8	0-23
11-JUN-86	162	22.2	7.9	0.446	31.1	160.0	2.1	7-23
12-JUN-86	163	28.3	2.1	0.576	32.1	174.1	2.0	0-23
16-JUN-86	167	28.3	1.7	0.541	23.2	248.6	2.9	0-23
17-JUN-86	168	27.4	7.4	0.911	25.1	193.8	2.2	0-23
18-JUN-86	169	26.8	7.9	1.094	26.6	290.0	2.4	0-17
23-JUN-86	174	26.0	9.7	1.188	18.3	234.2	2.7	0-23
24-JUN-86	175	20.4	8.6	1.254	11.0	147.0	1.7	0-23
30-JUN-86	181	27.2	9.2	1.337	19.1	170.8	2.0	0-23
1-JUL-86	182	31.3	7.6	0.898	27.7	195.1	2.3	0-23
2-JUL-86	183	31.4	11.9	1.174	24.4	201.4	2.4	0-23
7-JUL-86	188	28.2	8.8	1.427	17.5	153.1	1.7	0-23
9-JUL-86	190	28.1	13.3	1.511	17.7	145.9	1.6	0-23
10-JUL-86	191	28.0	9.2	1.168	17.5	149.8	1.5	0-23
14-JUL-86	195	32.8	10.0	1.268	23.8	172.1	2.1	0-23
15-JUL-86	196	33.5	13.2	1.346	27.9	253.8	2.8	0-23
16-JUL-86	197	27.0	14.8	1.538	19.6	308.5	3.5	0-23
22-JUL-86	203	26.3	9.8	1.356	24.4	195.1	2.3	0-23
23-JUL-86	204	28.9	13.1	1.551	22.0	256.7	2.9	0-23
24-JUL-86	205	30.2	9.2	1.072	26.1	151.8	1.7	0-23
28-JUL-86	209	32.8	4.2	0.552	29.0	176.6	2.0	0-23
29-JUL-86	210	34.5	5.2	0.737	28.0	160.6	1.8	0-23
30-JUL-86	211	34.2	8.8	0.978	30.6	159.4	2.0	0-23
4-AUG-86	216	28.9	9.7	1.260	14.6	209.1	2.7	6-23
5-AUG-86	217	31.4	7.9	1.190	20.0	203.3	2.4	0-23
6-AUG-86	218	33.2	12.9	1.156	27.5	205.7	2.3	0-23
11-AUG-86	223	32.5	8.4	1.180	23.3	182.4	2.2	0-23
12-AUG-86	224	34.6	13.0	1.496	19.8	181.1	2.1	0-23
13-AUG-86	225	33.1	10.4	1.298	25.9	167.8	1.9	0-23

Table 3. Alfalfa evapotranspiration data (USDA Lysimeters vs. Chamber), Colorado State University Farm, Center, Colorado, 1986. Plot # refers to six different areas near the lysimeters chosen for replicate measurements of Chamber ET.

USDA/ARS
Alfalfa
Lysimeter ET Site
Center, CO

DATE	DAY	Chamber ET (mm)	Plot #	ET DATA SUMMARY			CET/LET ratio (mm/mm)
					Chamber ET	Lysimeter ET	
6-JUN-86	157	5.4	1	AveET(mm)	6.5	6.7	0.96
		6.3	2	std.dev.	0.7	0.4	
		6.1	3	std.error	0.29	0.30	
		6.7	4				
		6.7	5				
		7.5	6				
25-JUL-86	206	4.9	1	AveET(mm)	5.4	6.0	0.90
		5.0	2	std.dev.	0.4	0.7	
		5.6	3	std.error	0.15	0.50	
		5.4	4				
		5.8	5				
		5.6	6				

Table 4. Evapotranspiration summary. Averages at all (pumping project area) sites, all plots. 1985 and 1986.

ET SUMMARY Plot	Date Span	Ave. Total ET (mm)	Ave. DailyET (mm/day)	Method of Measurement
SITE #1	1985			
Lys.GW	22MY-24JL	116	1.8	Chamber
Lys.SG	22MY-24JL	185	2.9	Chamber
SaltGrass	22MY-24JL	226	3.6	Chamber
upl.BS	22MY-24JL	115	1.8	Chamber
RB#1	22MY-24JL	216	3.4	Chamber
GW#1	22MY-24JL	228	3.6	Chamber
Lys.lowBS	22MY-24JL	145	2.3	Chamber
lowl.BS	22MY-24JL	159	2.5	Chamber
USBR-BS	22MY-24JL	113	1.8	Lysimeter
USBR-GW	22MY-24JL	118	1.9	Lysimeter
USBR-SG	22MY-24JL	160	2.6	Lysimeter
USBR-RB	22MY-24JL	59	0.9	Lysimeter
SITE #1	1986			
Ave. GW	26MY-11AG	253	3.3	Chamber
Ave. RB	26MY-11AG	258	3.4	Chamber
Ave. SG	26MY-11AG	299	3.9	Chamber
Ave. BS	26MY-11AG	183	2.4	Chamber
USBR-GW	26MY-11AG	80	1.0	Lysimeter
USBR-RB	26MY-11AG	64	0.8	Lysimeter
USBR-SG	26MY-11AG	118	1.5	Lysimeter
USBR-BS	26MY-11AG	90	1.2	Lysimeter
SITE #2	1986			
AvGW-SW3	27MY-12AG	261	3.4	Chamber
AvRB-SW3	27MY-12AG	376	4.9	Chamber
AvGW-chk	27MY-12AG	282	3.7	Chamber
AvRB-chk	27MY-12AG	338	4.4	Chamber
SITE #3	1986			
Ave. GW	9JUN-13AG	222	3.4	Chamber
Ave. RB	9JUN-13AG	235	3.6	Chamber

Table 5. Mean plant dimensions for measured plants at all sites, 1986.

MEAN PLANT DIMENSIONS

Site Description	Plant (ET measurement method)	Avg. Height (m)	Avg. Spread x(m)	Avg. Spread y(m)	Mean Plant Spherical Surface Area (sq.m)
Site #1 - USBR Lysimeter Site	Greasewood (Chamber)	0.79	0.84	0.96	2.36
	Greasewood (Lysimeter)	0.31	0.50	0.91	1.23
	Rabbitbrush (Chamber)	0.60	0.75	0.95	1.91
	Rabbitbrush (Lysimeter)	0.43	0.64	0.67	1.09
	Salt Grass (Chamber)	0.23	N.A.	N.A.	N.A.
	Salt Grass (Lysimeter)	0.18	N.A.	N.A.	N.A.
Site #2 - Salvage Well 3 (SW3) and check site (CK)	Greasewood (SW3) (Chamber)	0.73	0.70	0.81	1.76
	Greasewood (CK) (Chamber)	0.64	0.68	0.78	1.55
	Rabbitbrush (SW3) (Chamber)	0.55	0.88	0.92	2.01
	Rabbitbrush (CK) (Chamber)	0.48	0.74	0.87	1.61
Site #3 - Observation Well 377 (OW377)	Greasewood (Chamber)	0.68	0.68	0.82	1.67
	Rabbitbrush (Chamber)	0.49	0.68	0.86	1.51

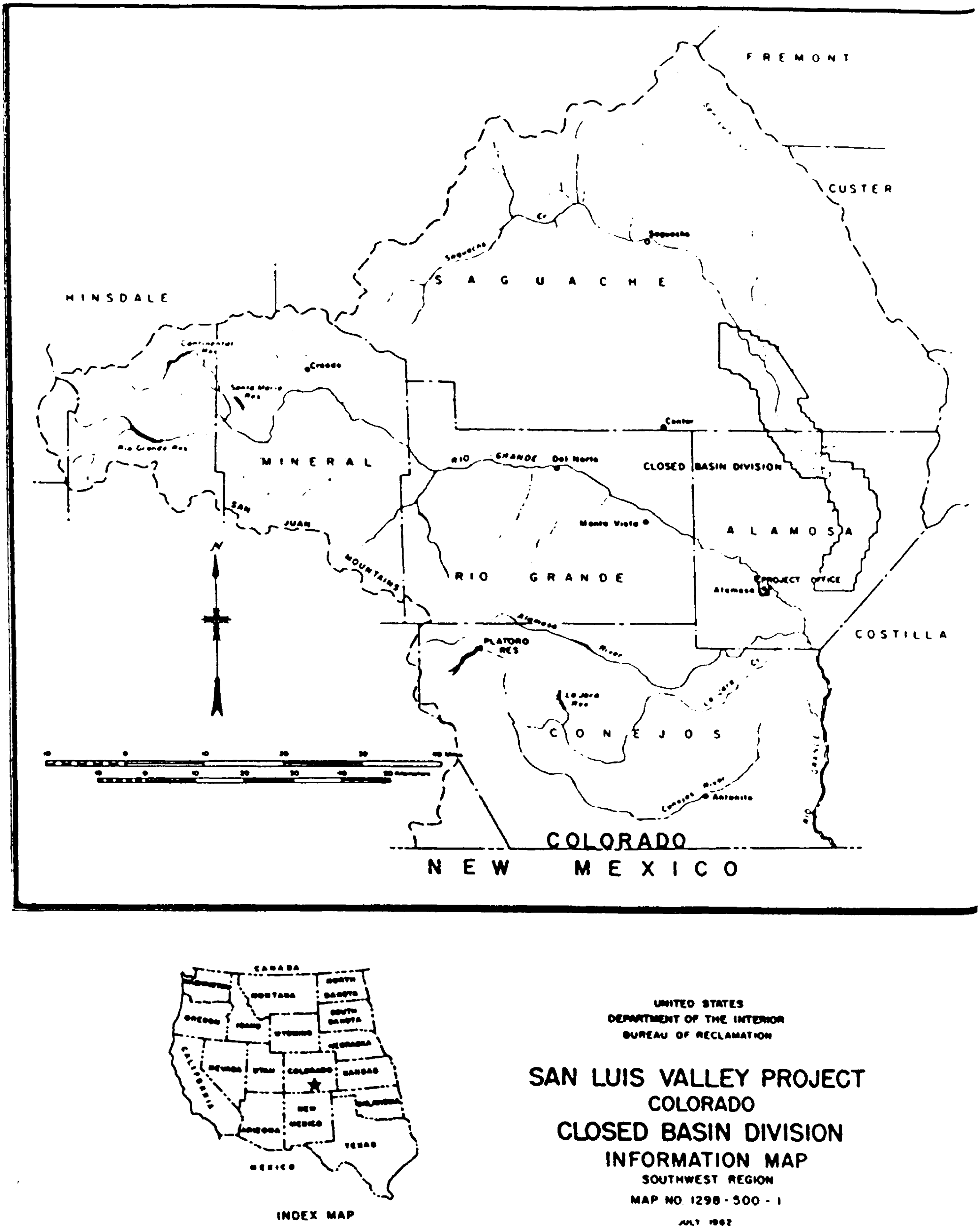

Figure 1a. The San Luís Valley, Colorado.

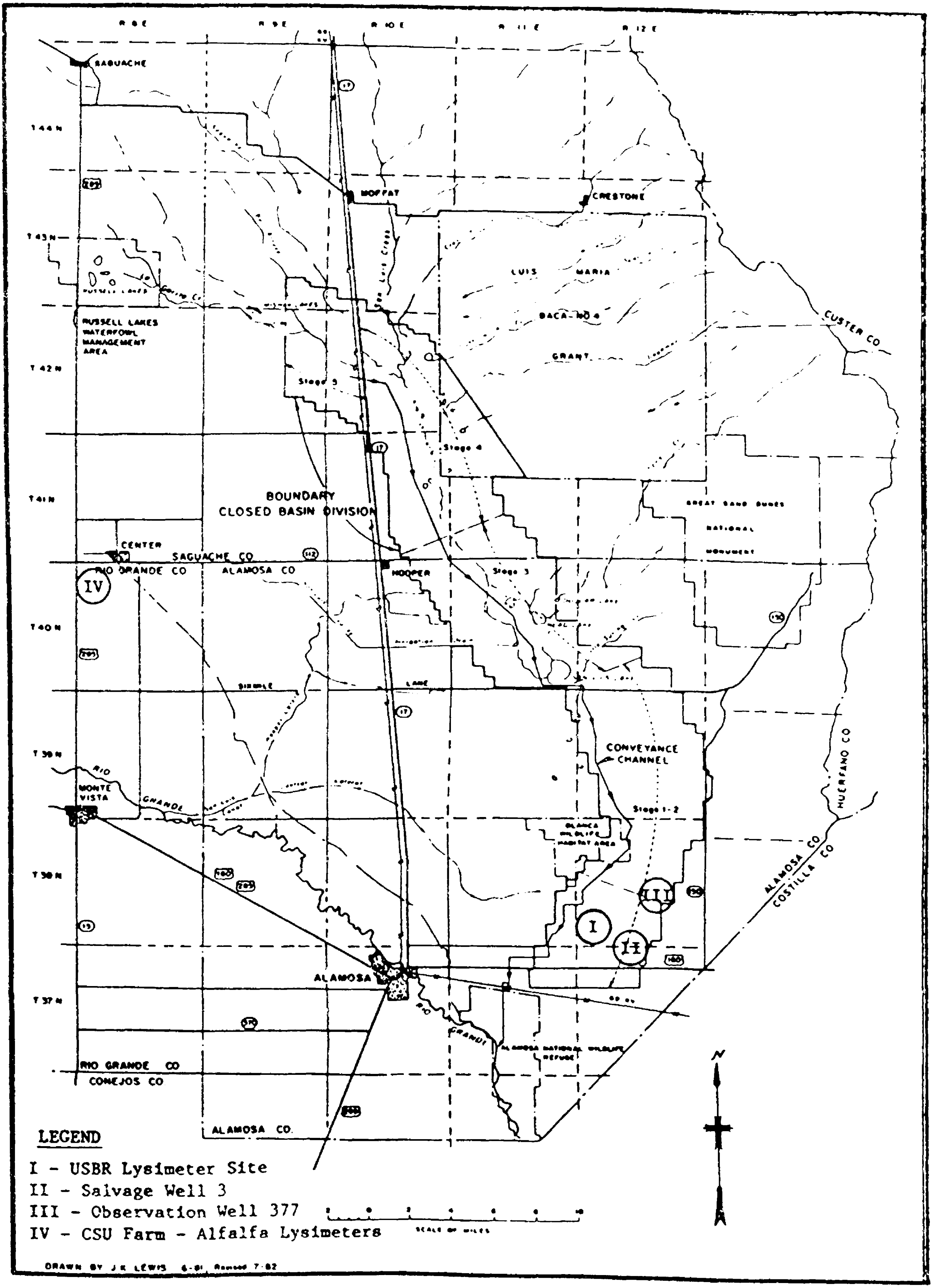

Figure 1b. USBR Closed Basin Division project area, San Luis Valley, Colorado.

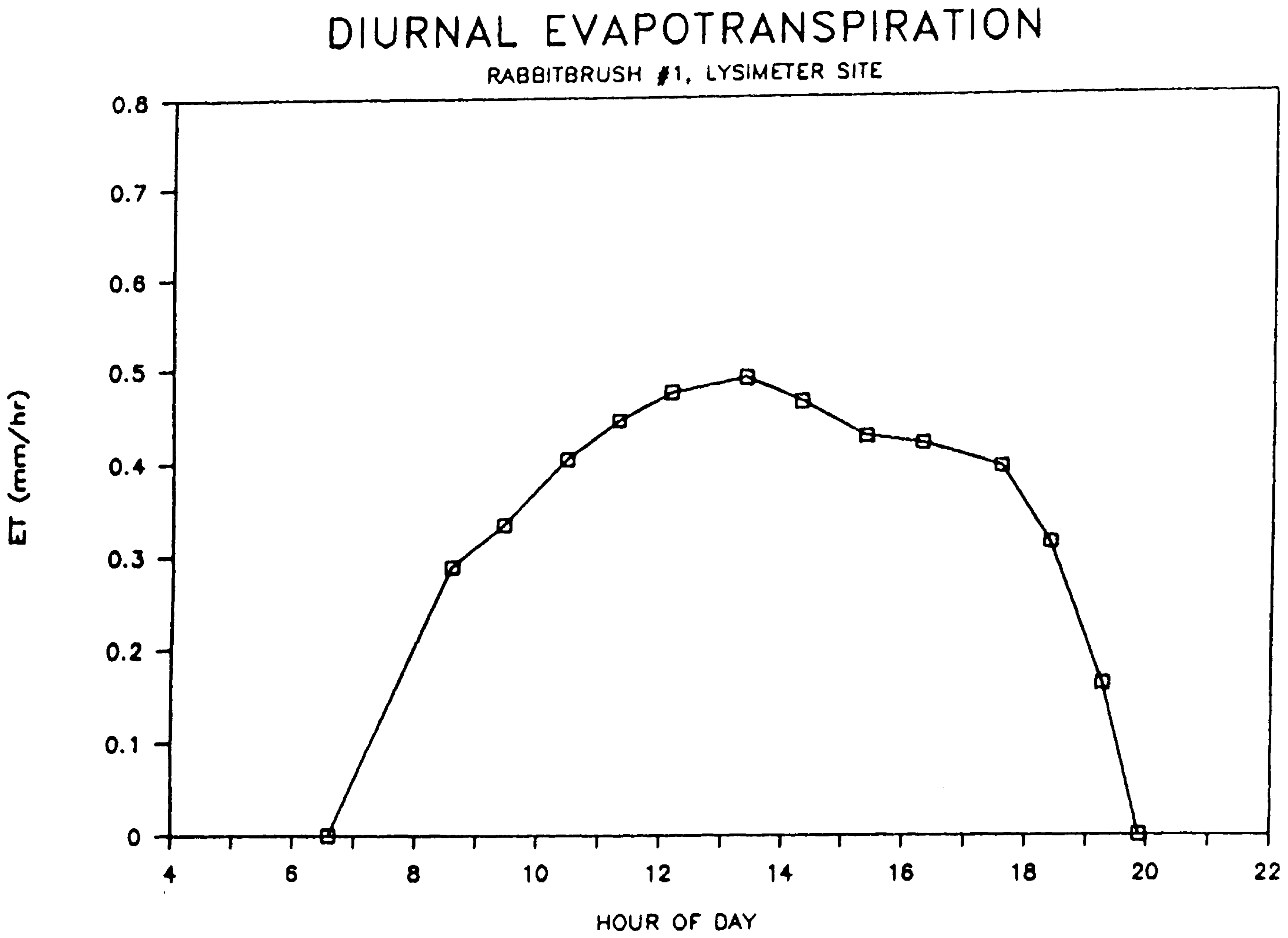

Figure 2. Diurnal evapotranspiration measured with a portable chamber, Rabbitbrush #1, USBR Lysimeter site, 28 July 1986.

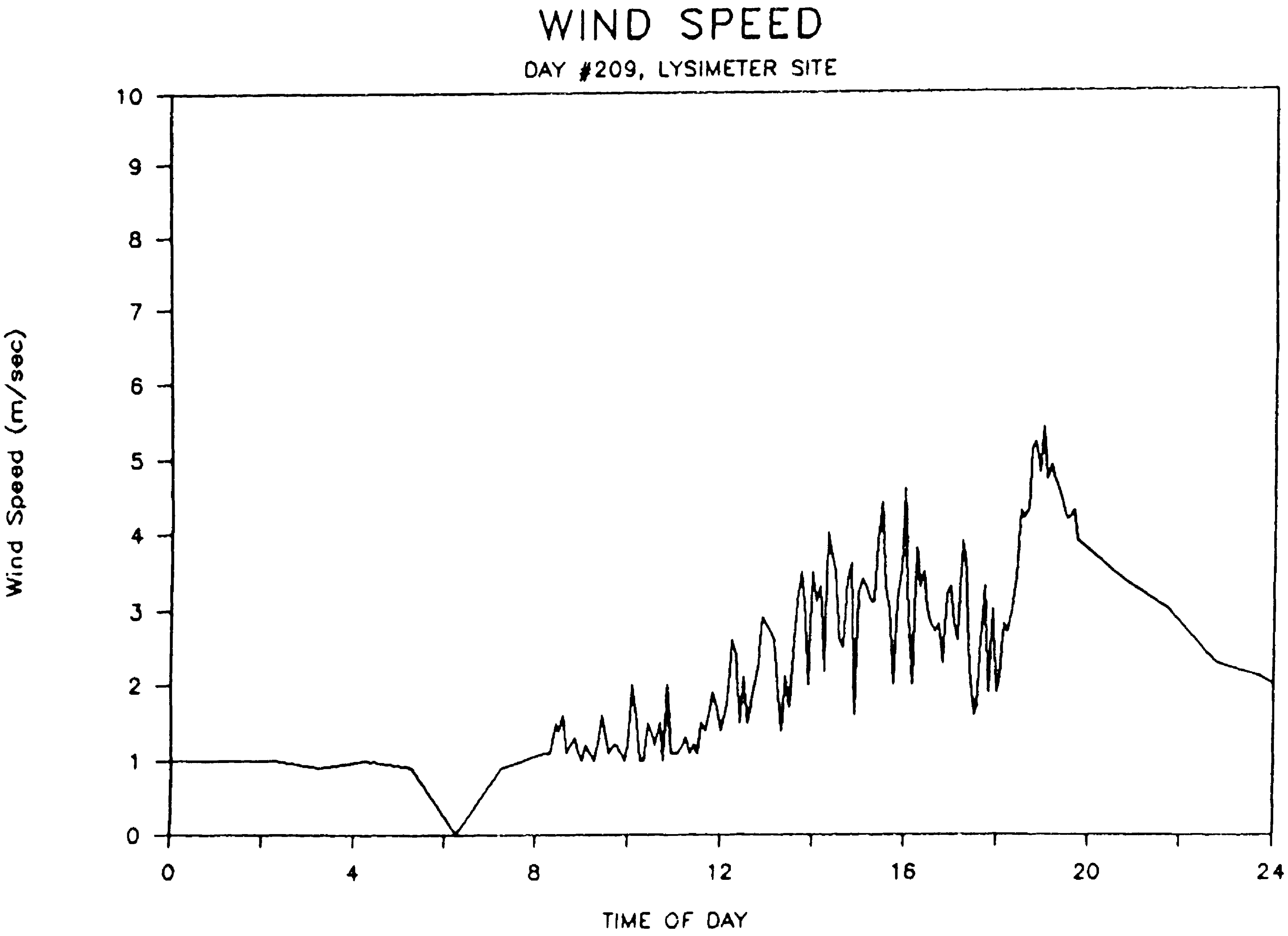

Figure 3. Diurnal Wind Speed, USBR Lysimeter site, 28 July 1986.

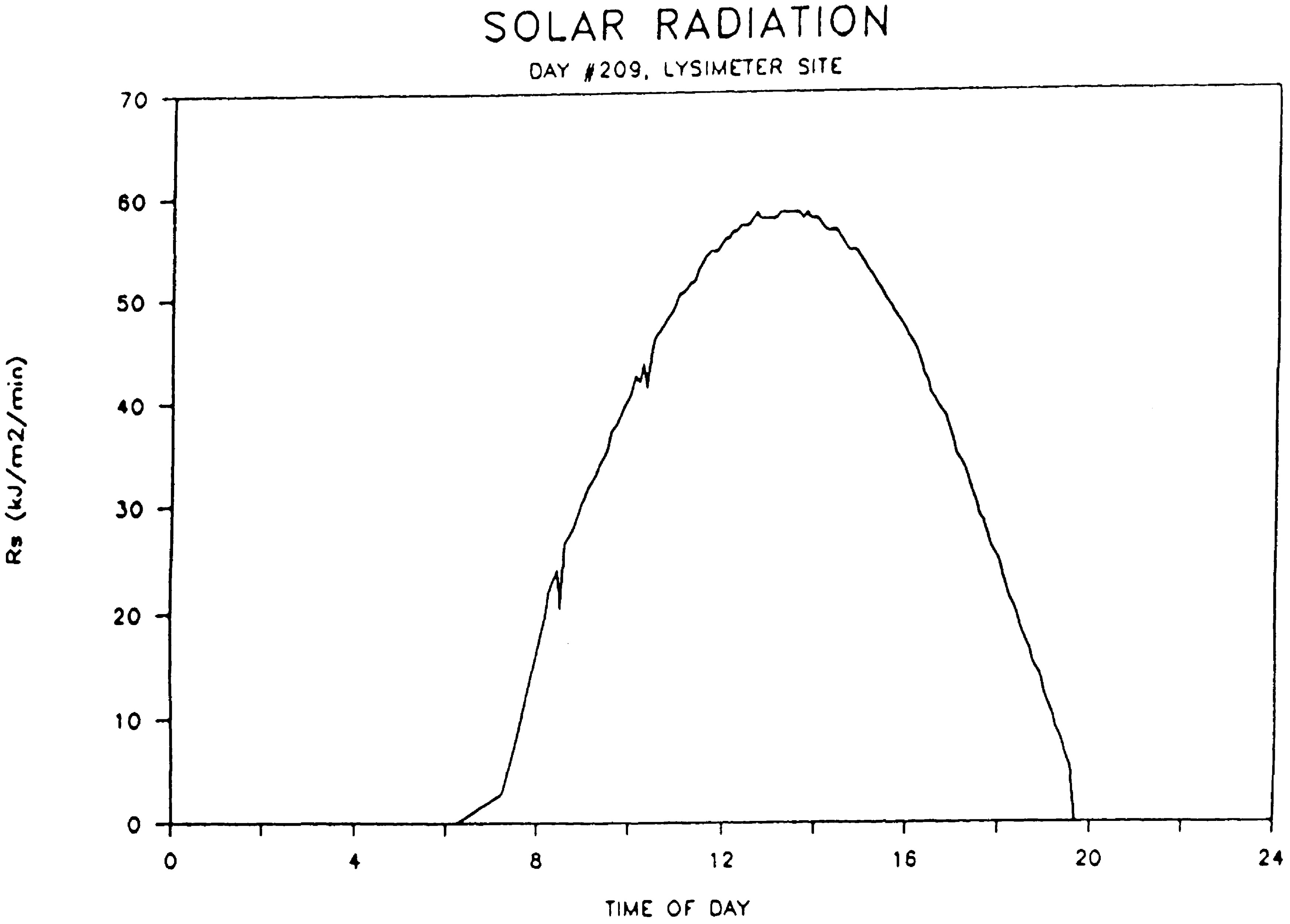

Figure 4. Diurnal Solar Radiation, USBR Lysimeter site, 28 July 1986.

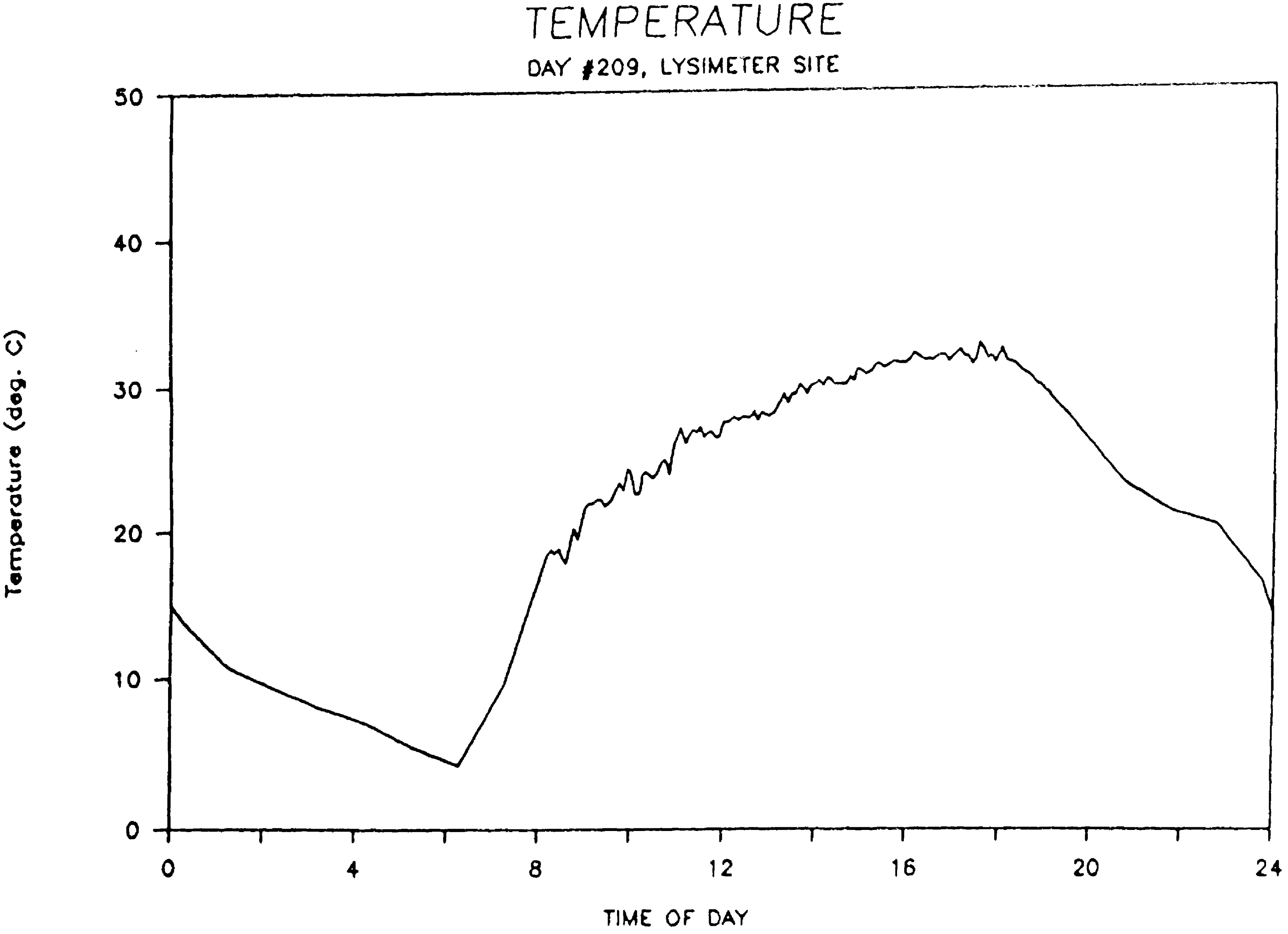

Figure 5. Diurnal temperature, USBR Lysimeter site, 28 July 1986.

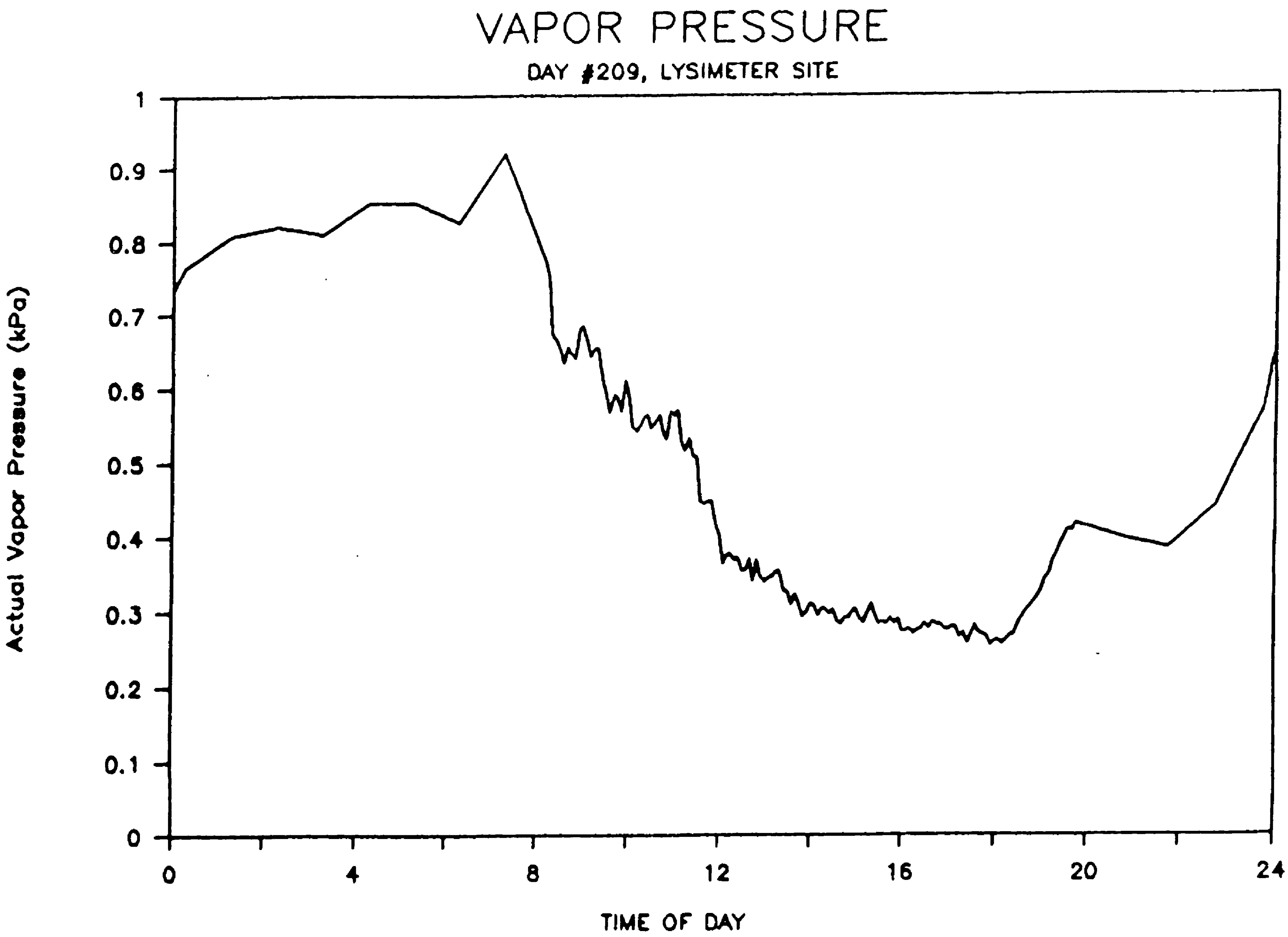

Figure 6. Diurnal Vapor Pressure, USBR Lysimeter site, 28 July 1986.

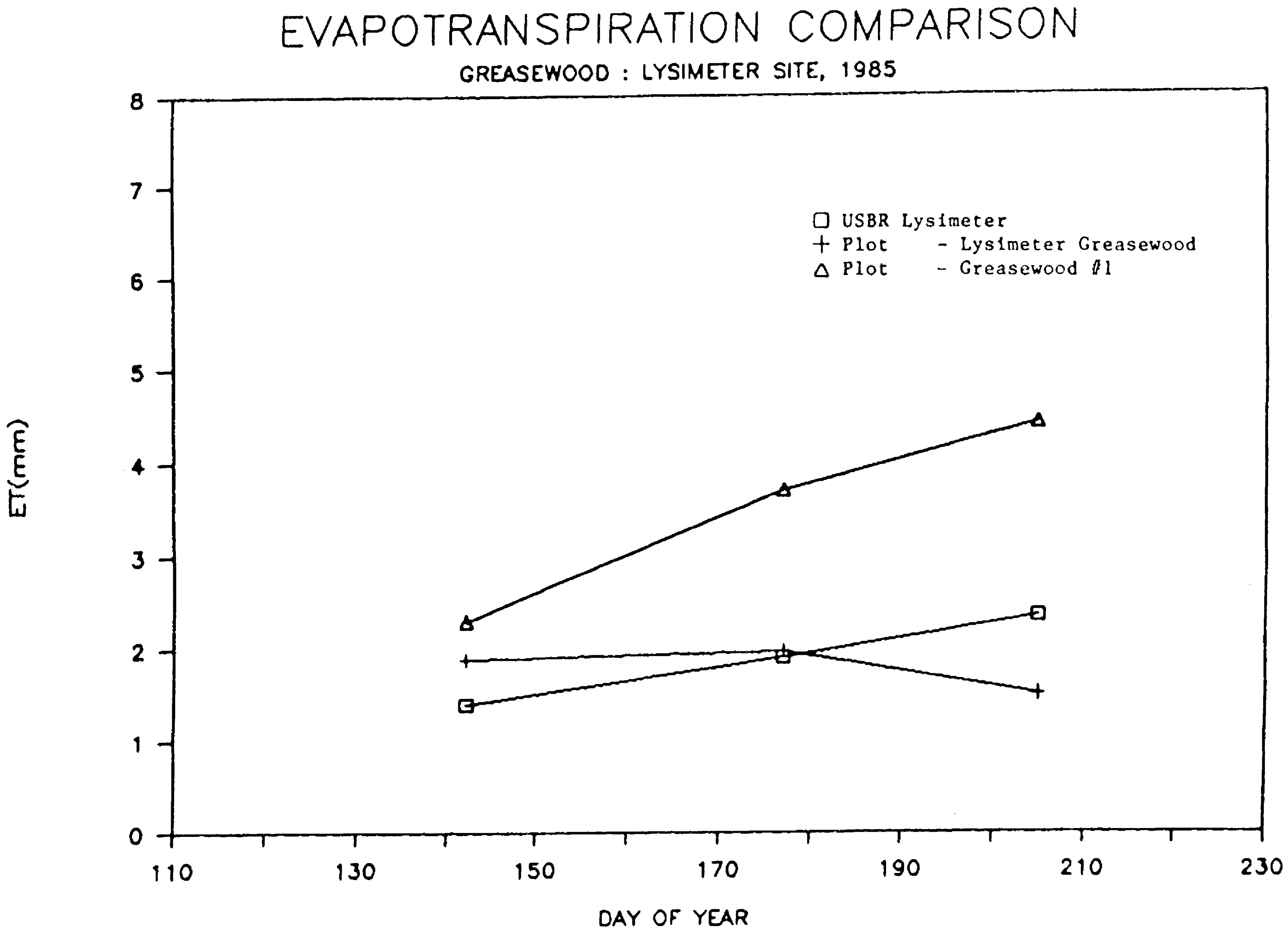

Figure 7. Evapotranspiration Comparison - Lysimeter versus Chamber measurements on Greasewood plots. USBR Lysimeter site, 1985.

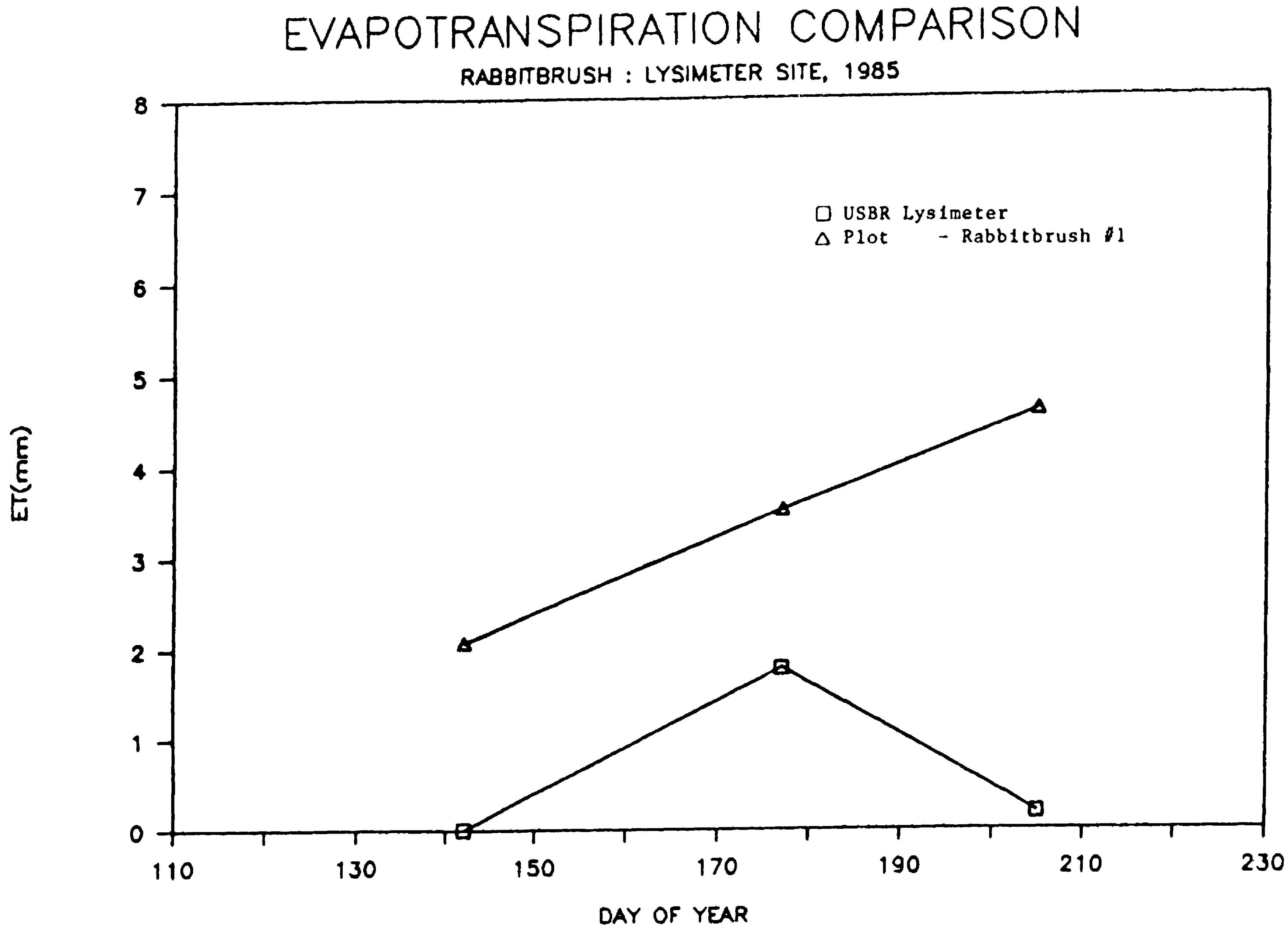

Figure 8. Evapotranspiration Comparison - Lysimeter versus Chamber measurements on Rabbitbrush plots. USBR Lysimeter site, 1985.

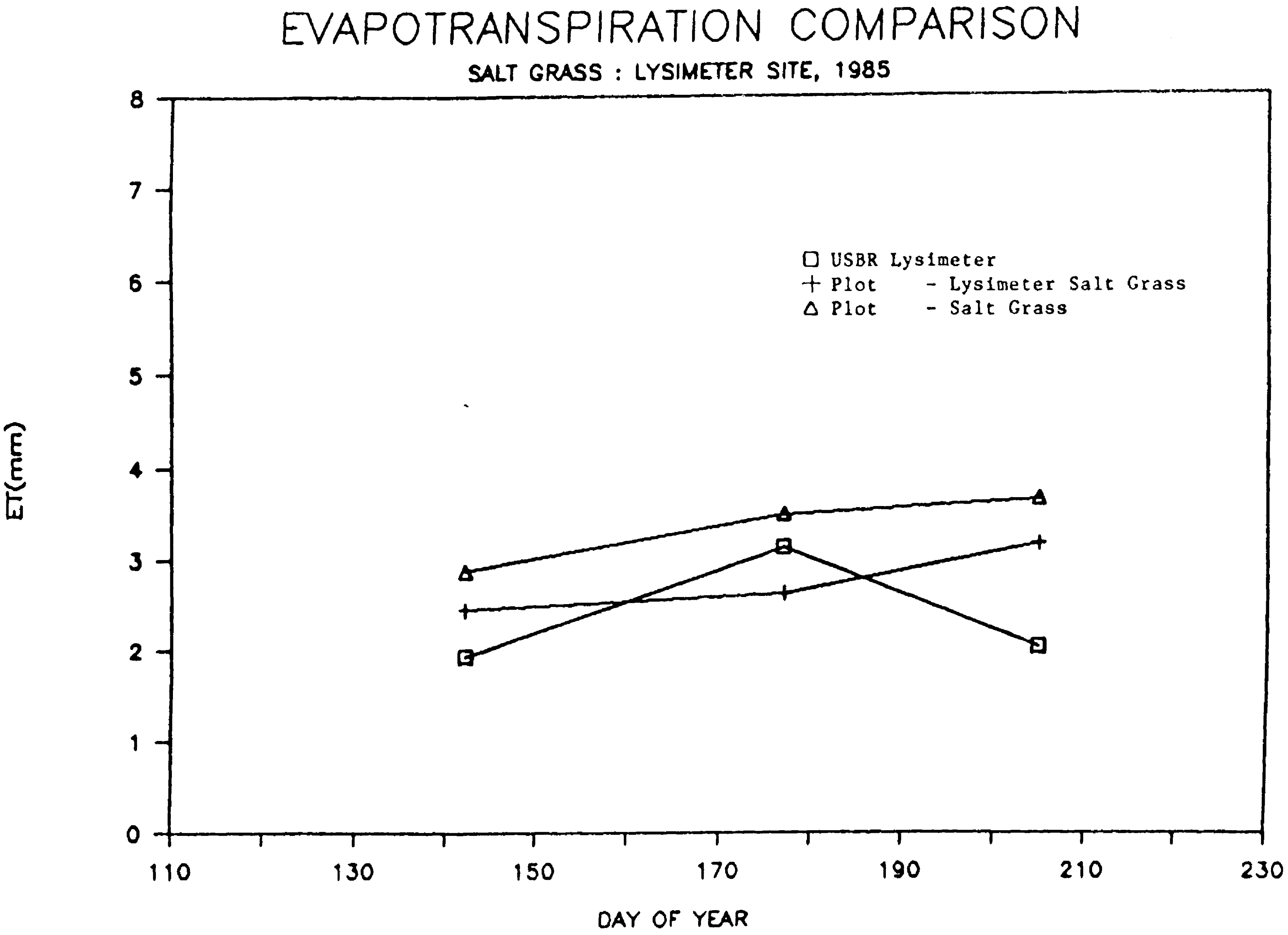

Figure 9. Evapotranspiration Comparison -- Lysimeter versus Chamber measurements on Salt Grass plots. USBR Lysimeter site, 1985.

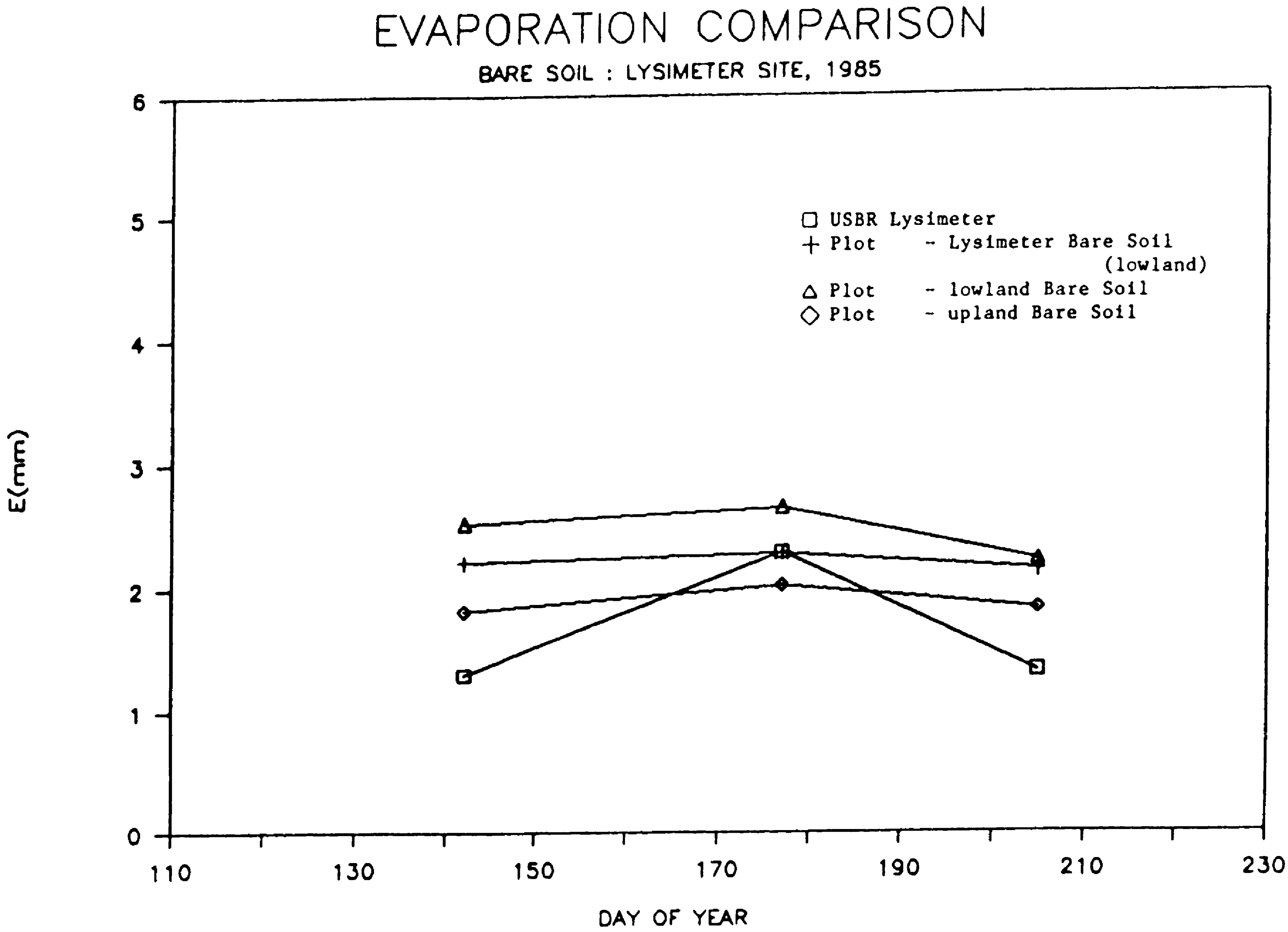

Figure 10. Evaporation Comparison - Lysimeter versus Chamber measurements on Bare Soil plots. USBR Lysimeter site, 1985.

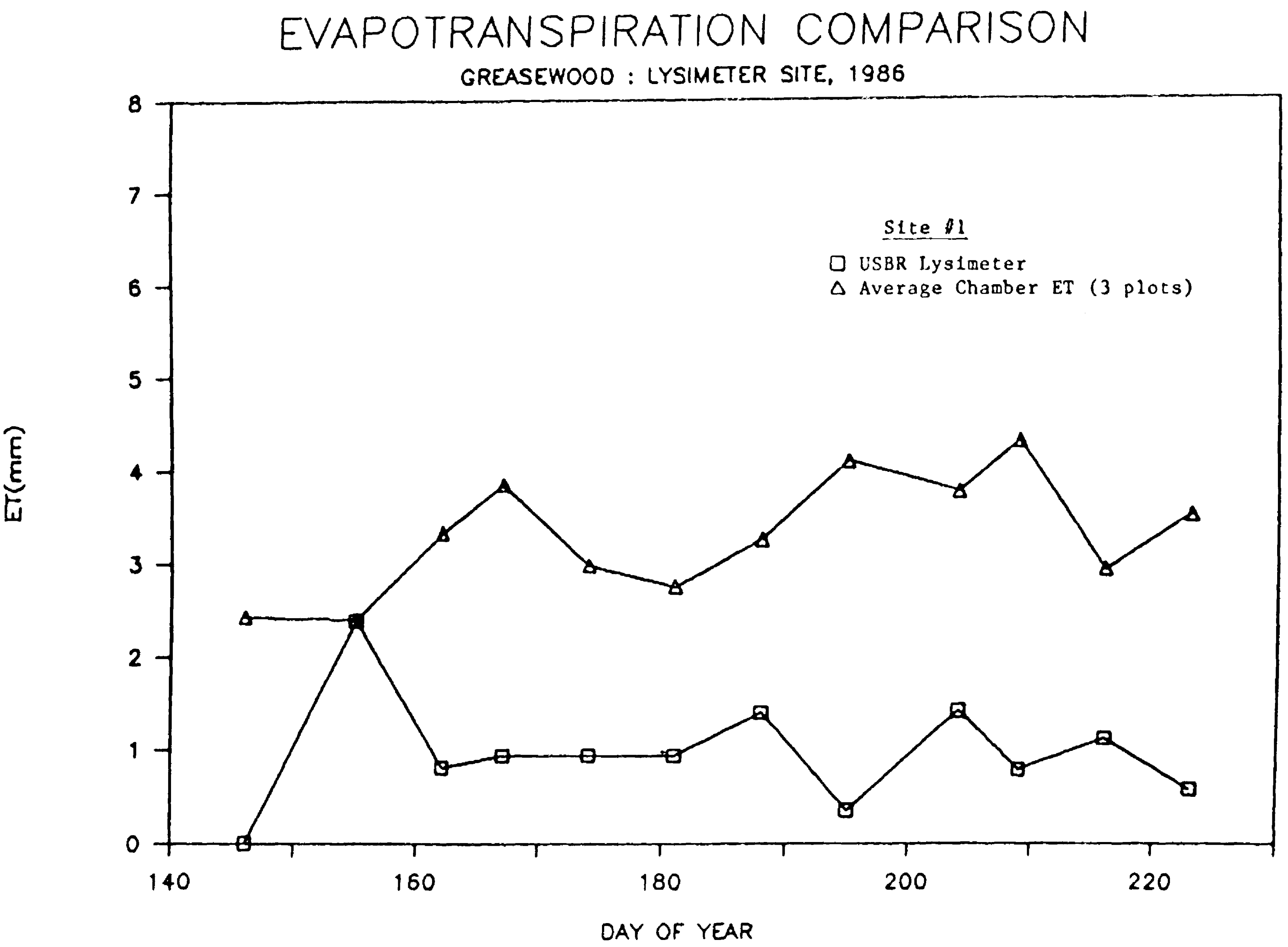

Figure 11. Evapotranspiration Comparison - Lysimeter versus Chamber measurements on Greasewood plots. USBR Lysimeter site, 1986.

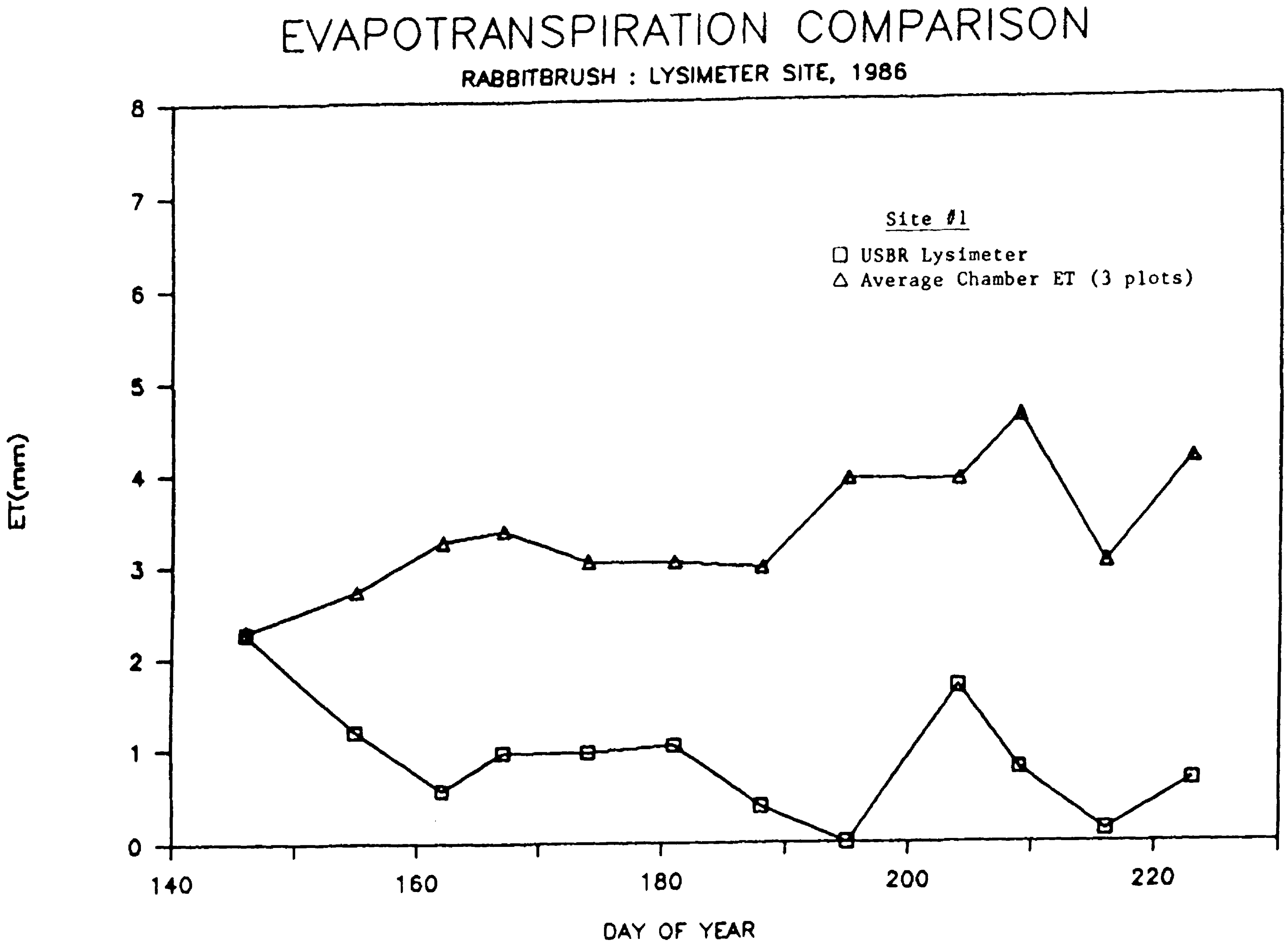

Figure 12. Evapotranspiration Comparison - Lysimeter versus Chamber measurements on Rabbitbrush plots. USBR Lysimeter site, 1986.

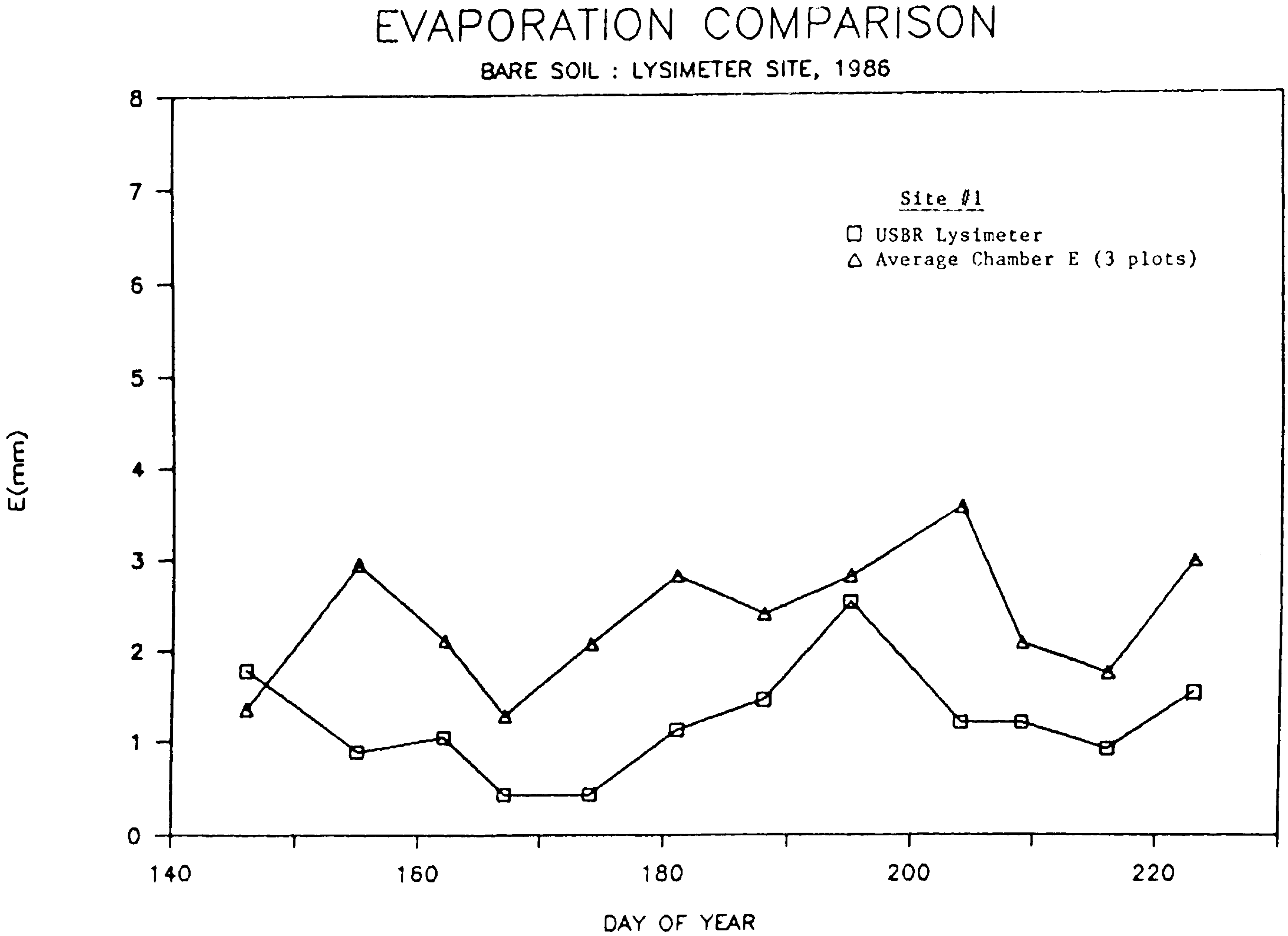

Figure 13. Evaporation Comparison - Lysimeter versus Chamber measurements on Bare Soil plots. USBR Lysimeter site, 1986.

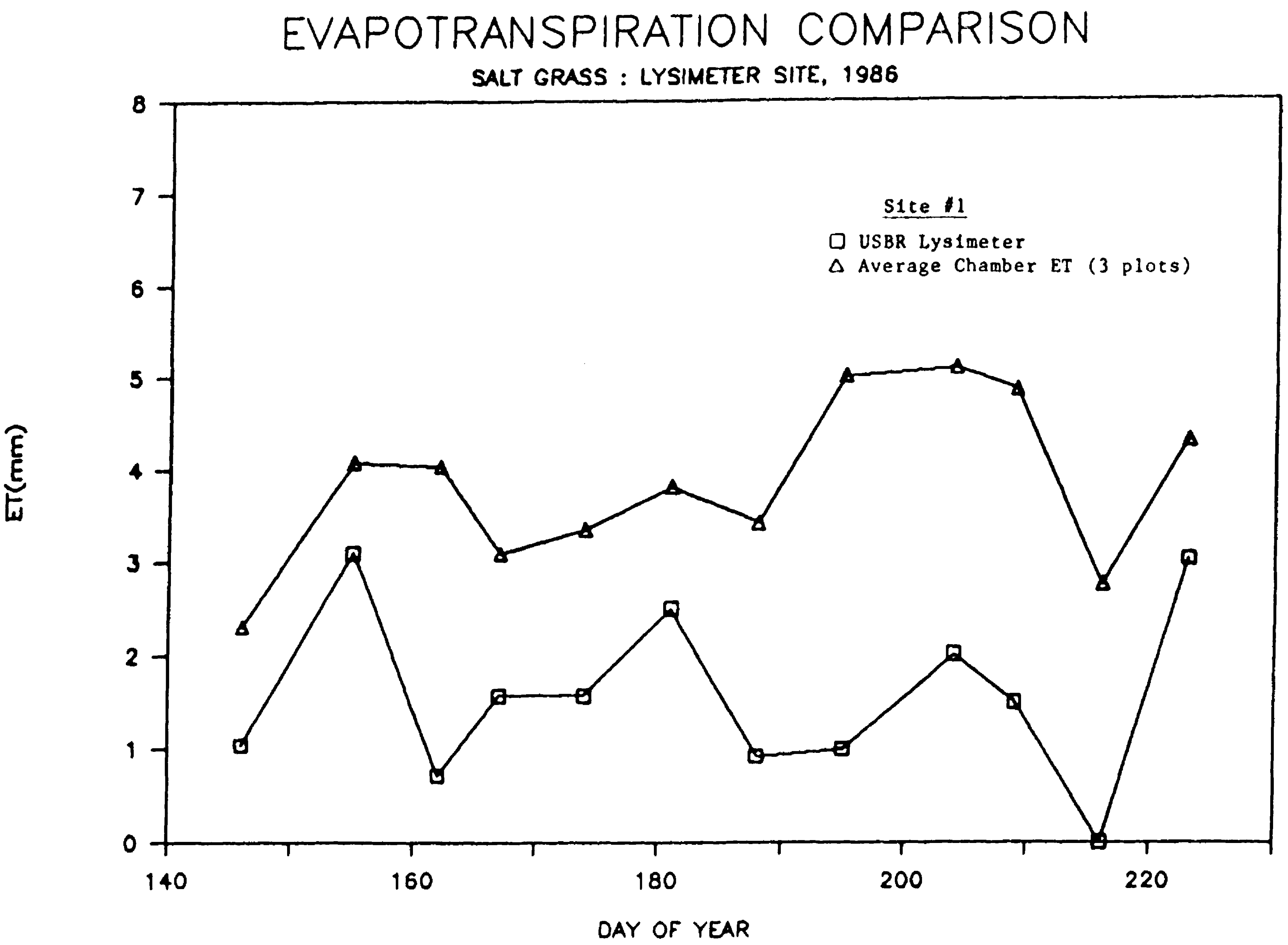

Figure 14. Evapotranspiration Comparison - Lysimeter versus Chamber measurements on Salt Grass plots. USBR Lysimeter site, 1986.

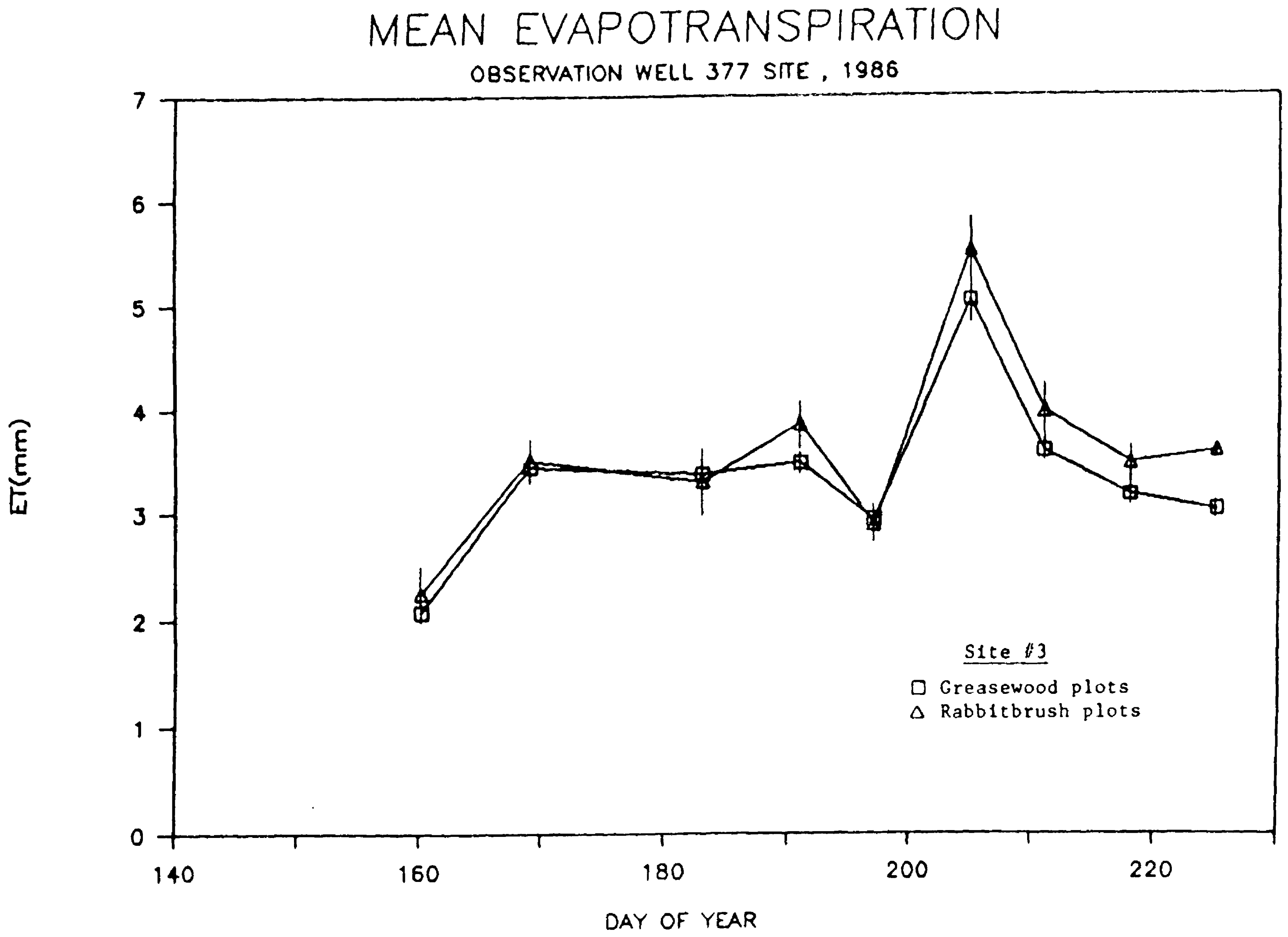

Figure 15. Mean Evapotranspiration ± std. error, Greasewood and Rabbitbrush plots, Observation Well 377 (Site #3), 1986.

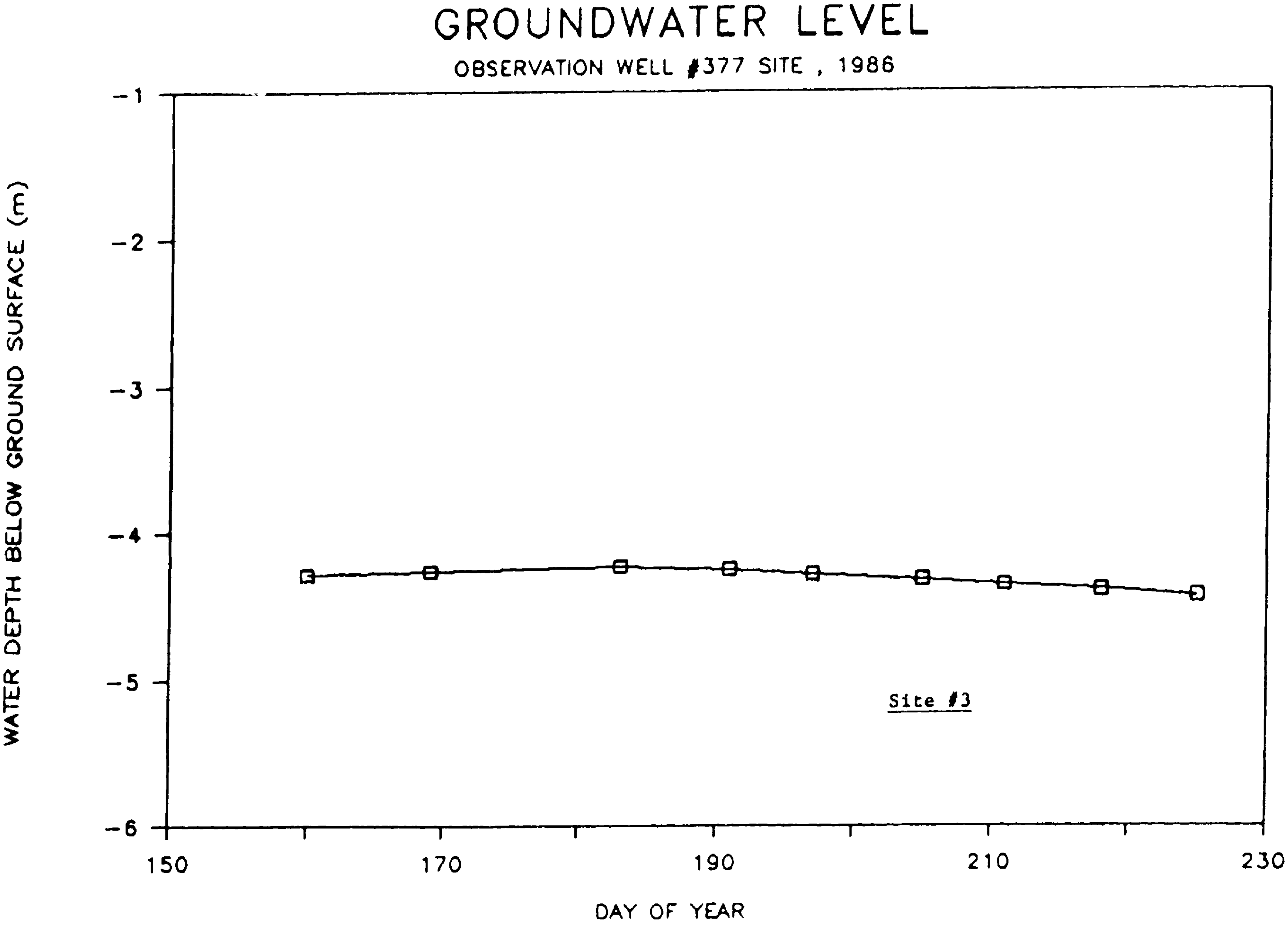

Figure 16. Groundwater levels for the seasonal measurement period. Observation Well 377 (OW377) site, 1936.

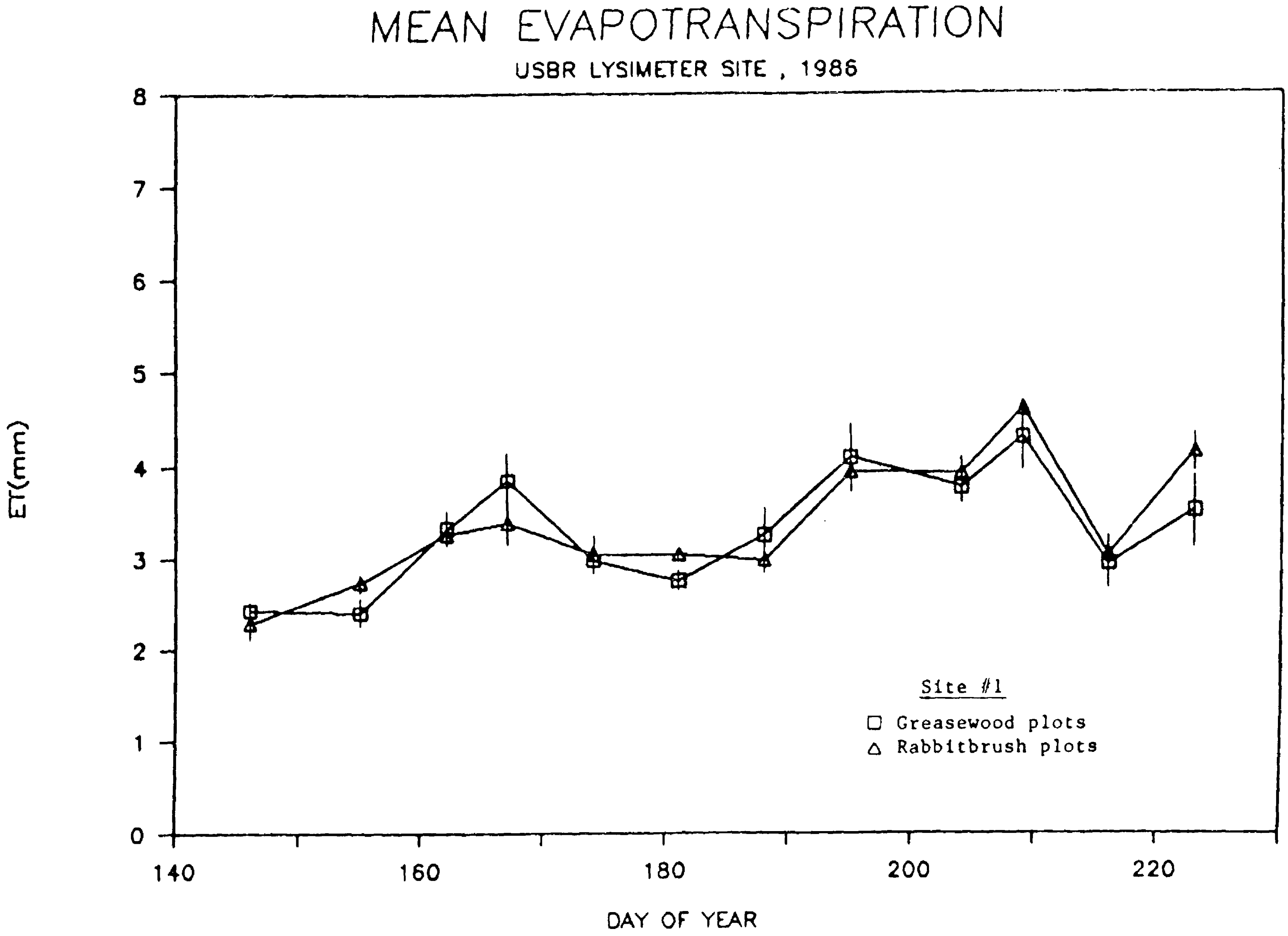

Figure 17. Mean Evapotranspiration ± std. error, Greasewood and Rabbitbrush plots, USBR Lysimeter site (Site #1), 1986.

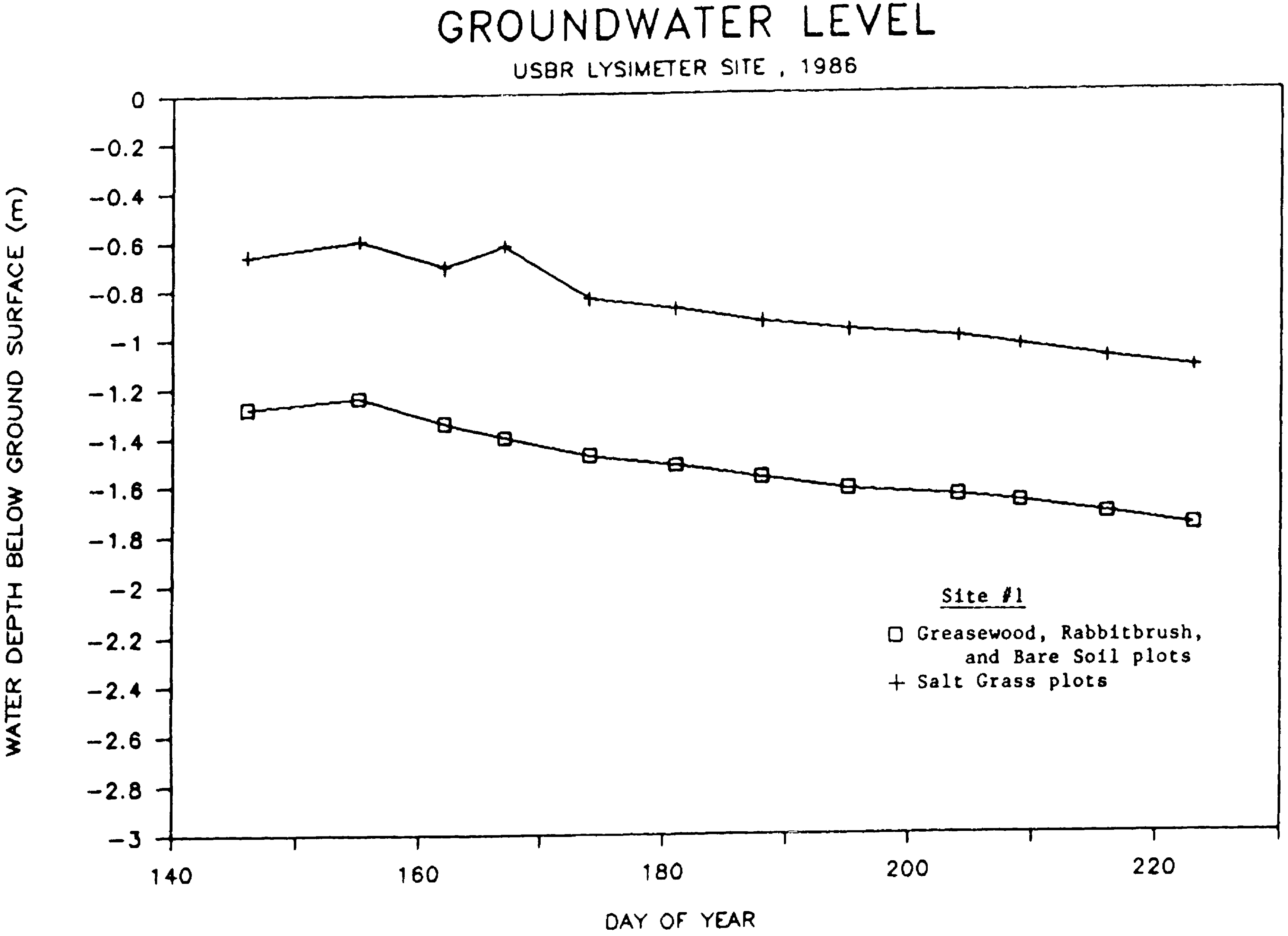

Figure 18. Groundwater levels for the seasonal measurement period. USBR Lysimeter site, 1986.

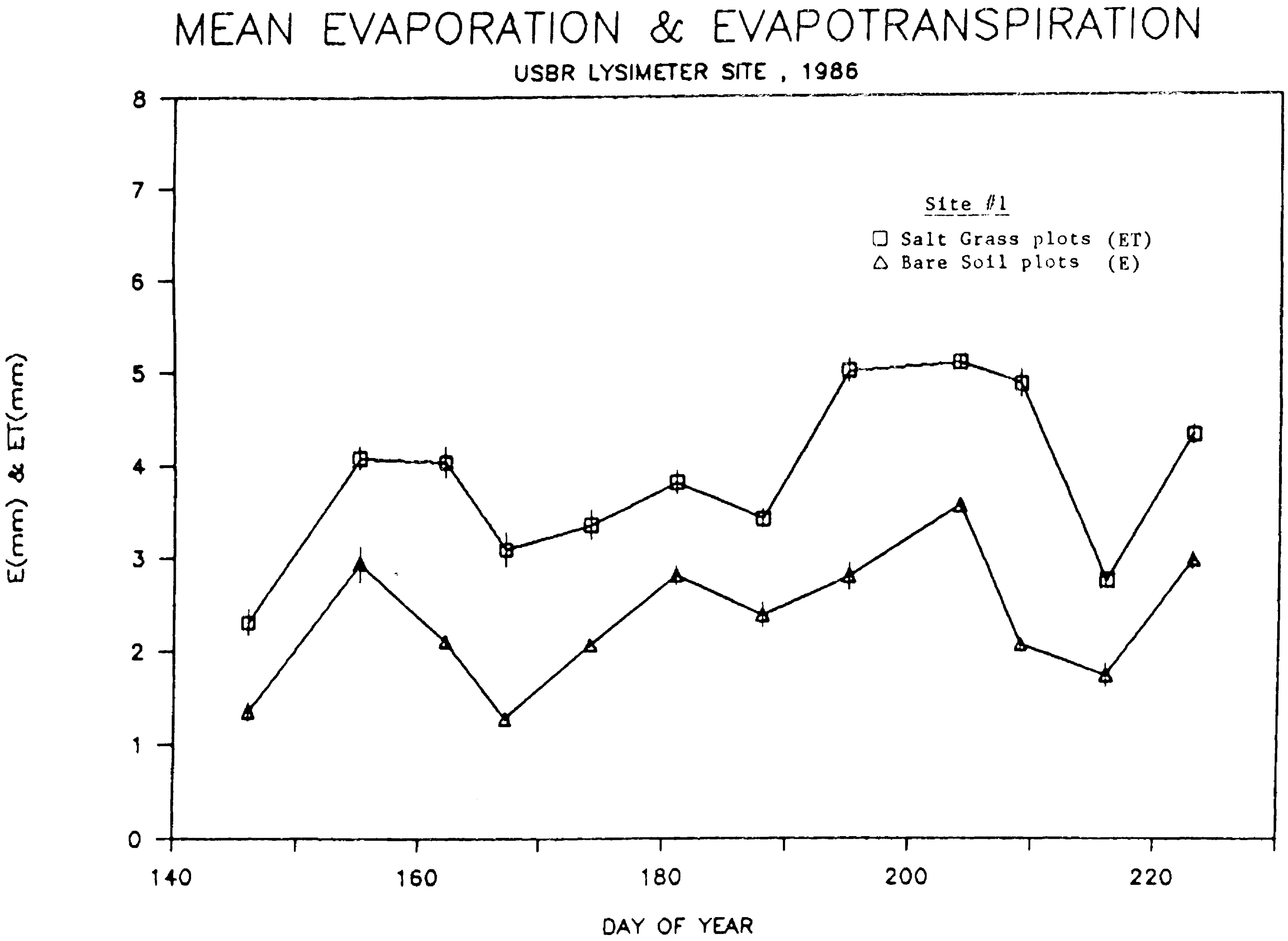

Figure 19. Mean Evapotranspiration ± std. error for Salt Grass and Mean Evaporation ± std. error for Bare Soil plots, USBR Lysimeter site (Site #1), 1986.

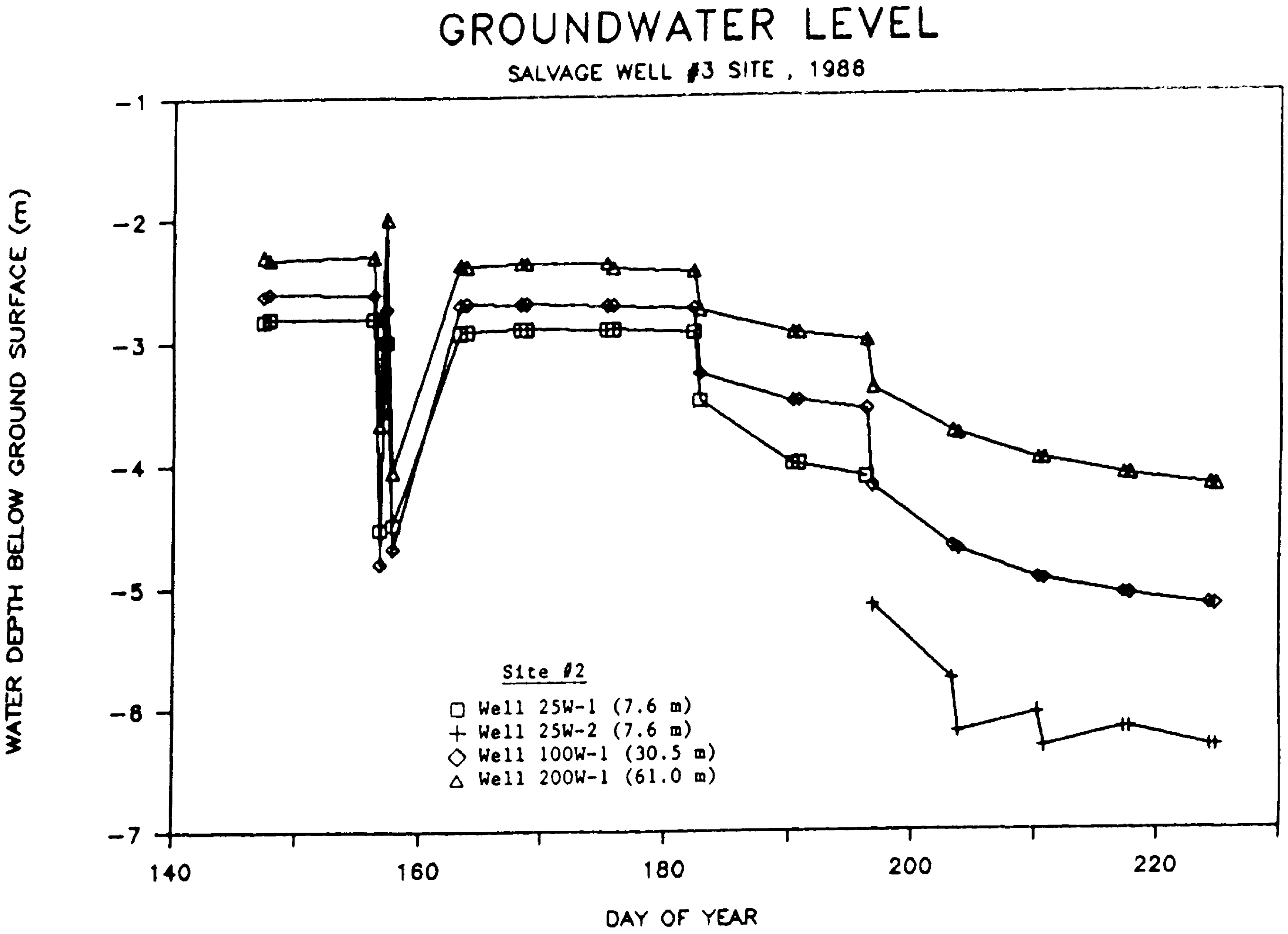

Figure 20. Groundwater levels for the seasonal measurement period. Salvage Well 3 (SW3) site, 1986 (distances from the salvage well are denoted by values in the parentheses).

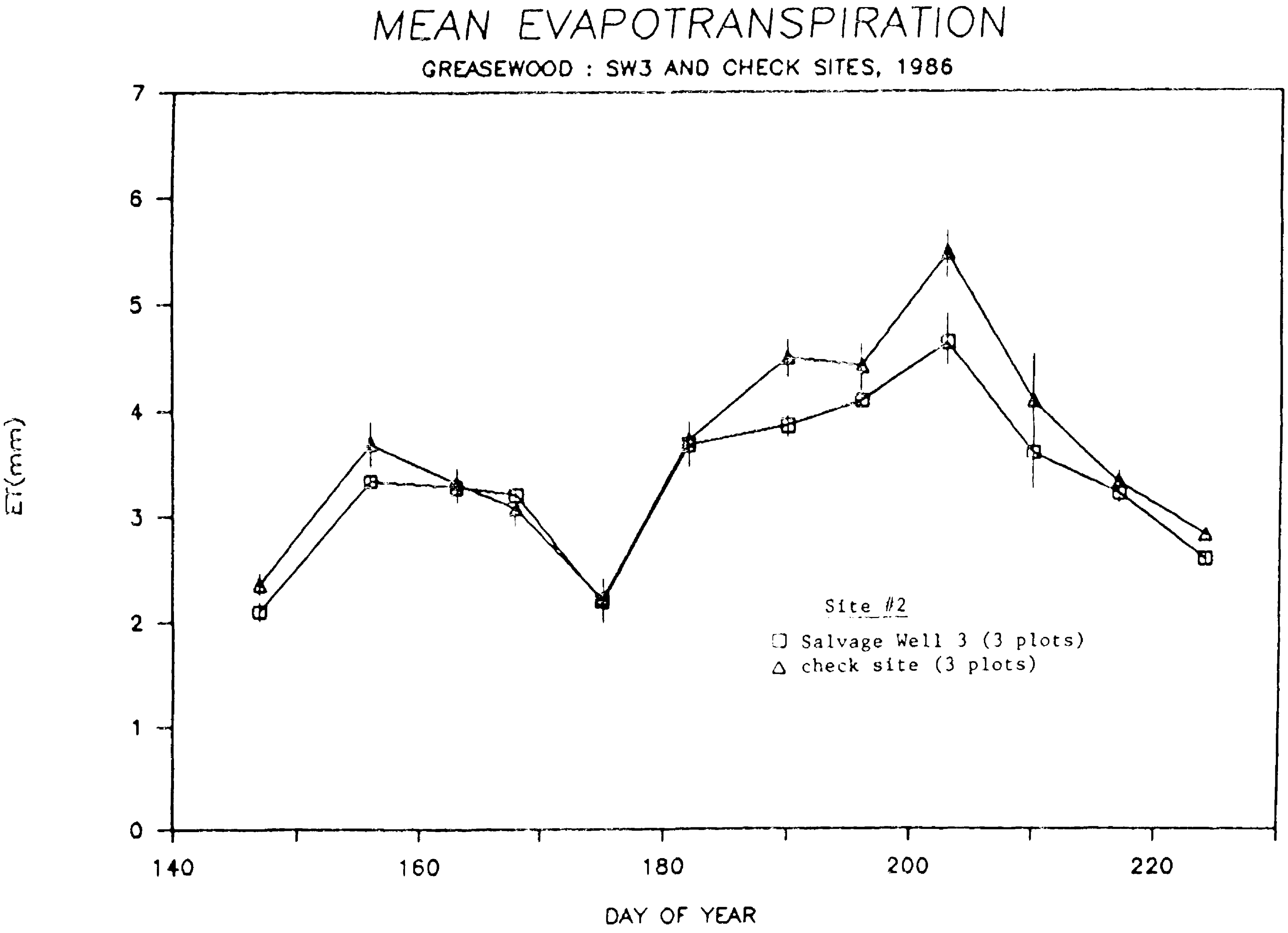

Figure 21. Mean Evapotranspiration ± std. error, Greasewood plots, Salvage Well 3 (SW3) and check sites, 1986.

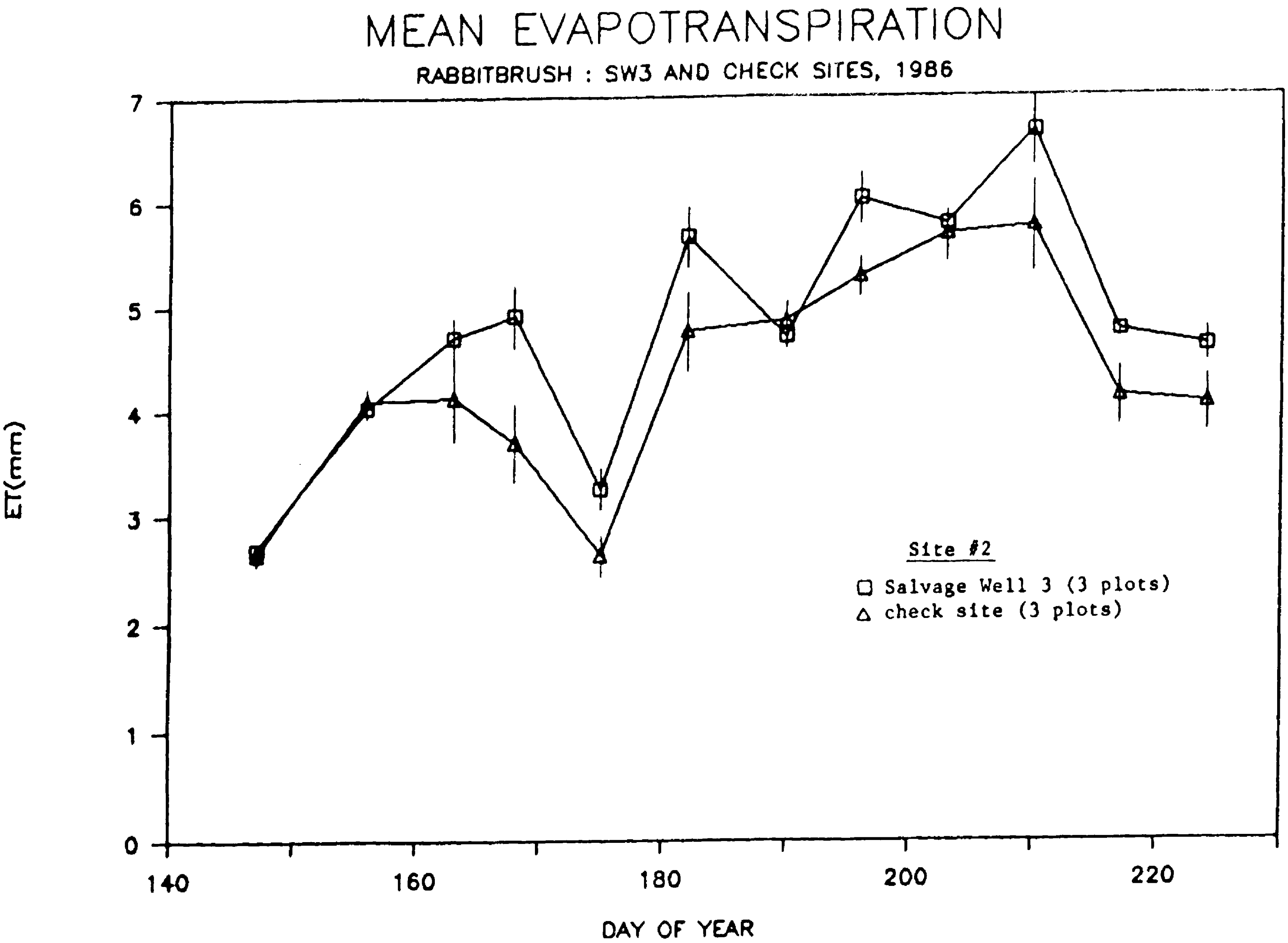

Figure 22. Mean Evapotranspiration ± std. error, Rabbitbrush plots, Salvage Well 3 (SW3) and check sites, 1986.

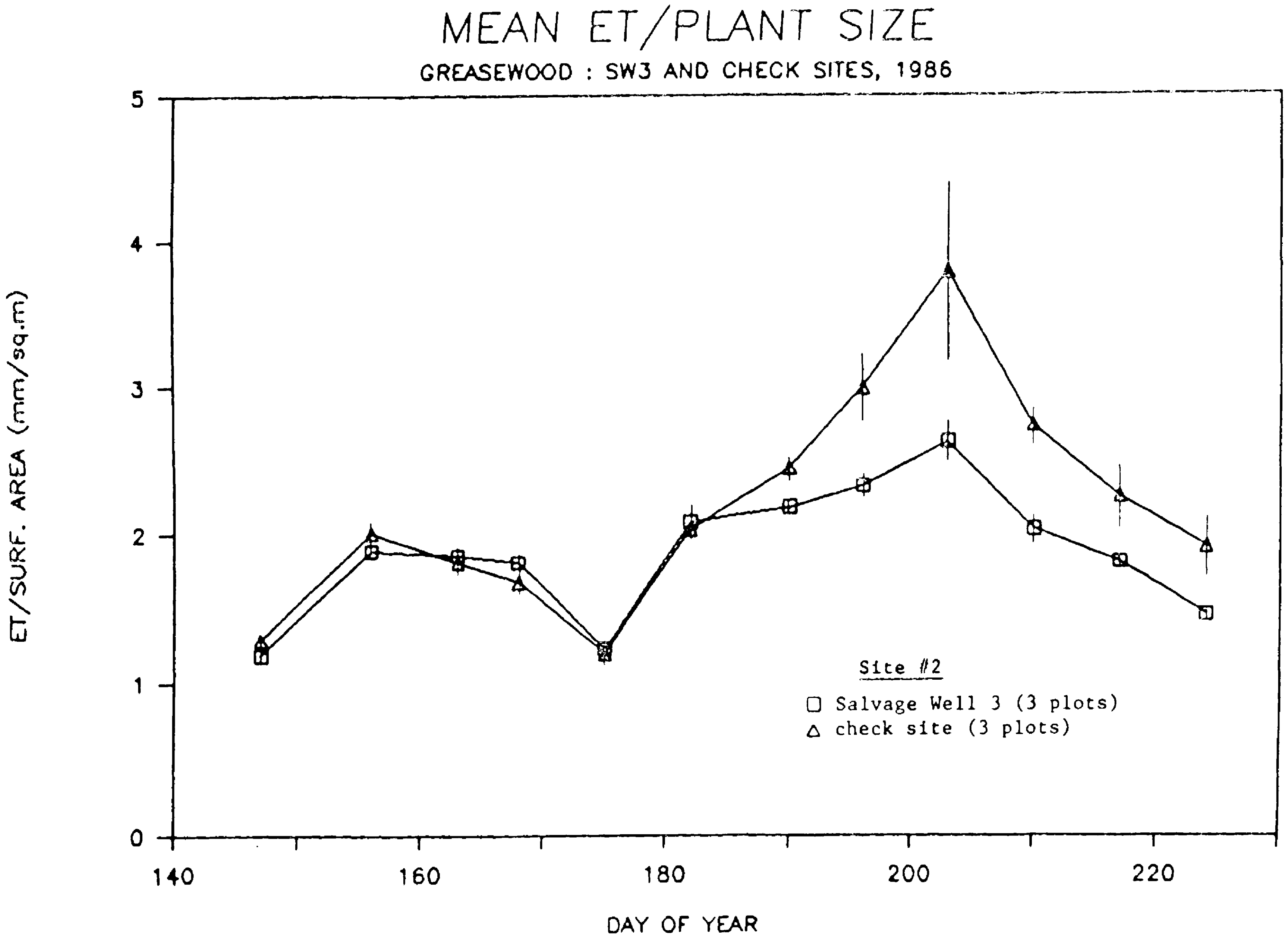

Figure 23. Mean Evapotranspiration per Plant Surface Area ± std. error, Greasewood plots, Salvage Well 3 (SW3) and check sites, 1986.

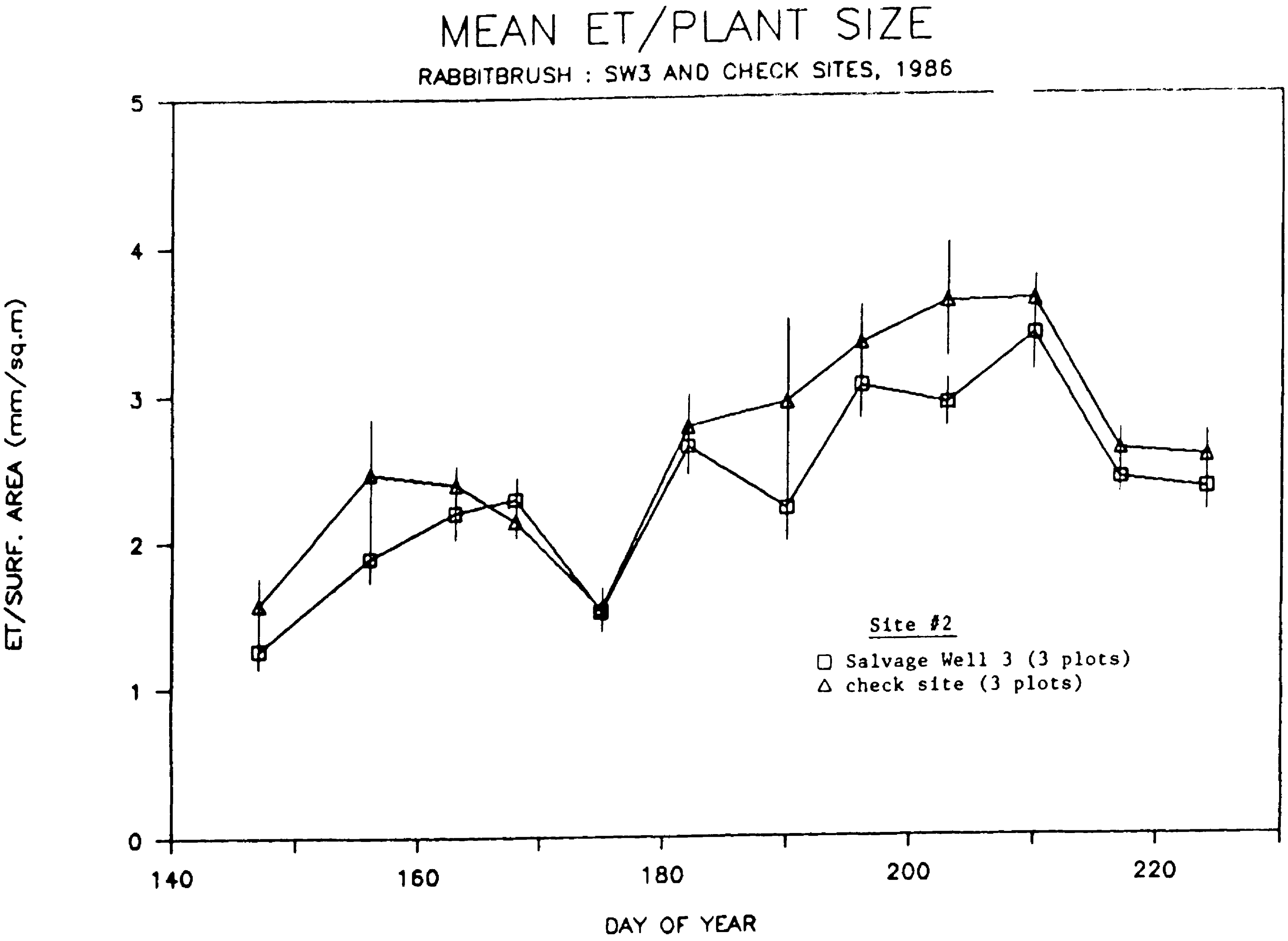

Figure 24. Mean Evapotranspiration per Plant Surface Area ± std. error, Rabbitbrush plots, Salvage Well 3 (SW3) and check sites, 1986.

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