Mailing Address:
Water Resources Data System
University of Wyoming, Dept 3943
1000 E University Avenue
Laramie, WY 82071

Physical Address:
Wyoming Hall, Room 249
University of Wyoming
Laramie, WY 82071

Phone: (307) 766-6651
Fax: (307) 766-3785

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WATER REQUIREMENTS
AND
APPLICATION RATES FOR LAWNS

Larry O. Pochop
John Borrelli
John R. Barnes
Patrick K. O'Neill

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ABSTRACT

Lawn water application rates were measured for 55 homes in Laramie and Wheatland, Wyoming, during 1975 and 1976. In addition, evapotranspiration rates were measured at both cities during 1976. Lawn water application rates in 1976 were 122 percent of the average seasonal potential evapotranspiration rates in Laramie and 156 percent in Wheatland. Individual homeowners who maintained the lowest application rates were near the consumptive use requirements of lawn grasses.

The lawns were rated on the basis of appearance and according to the percentage of total lawn area that appeared to be stressed from visual inspection. There was no significant correlation between lawn water application rates and the appearance or stress ratings. Factors such as fertilizer, overall lawn maintenance habits, and uniformity of water application apparently exert strong influences on lawn appearance and stress.

The amount of overwatering was measured in both cities. It amounted to 0.0085 acre-feet per day per acre of lawn in Wheatland while in Laramie it amounted to 0.004 acre-feet per day per acre of lawn. The average lawn size was 0.16 acres per home for the 55 homes that were monitored.

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INTRODUCTION

Lawn watering as a factor in the total municipal water demand is without question significant. Watering of lawns causes a large water demand during normally water short periods within a year, a peak loading factor for municipal distribution systems, a large and relatively unknown usage component, and a hazard to fire fighting due to pressure drops in main lines during periods of heavy watering. During severe water shortages such as the drought experienced in most of the western United States in 1977, lawn watering is usually the first major municipal water use upon which restrictions are placed.

Good lawn watering habits by homeowners can help alleviate some of the problems mentioned above by decreasing overall lawn water use. In addition, during periods of rationing both the homeowners and city managers can follow practices which will optimize the trade-off between lawn water use and an aesthetic lawn. To help develop specific recommendations for lawn watering, data have been acquired to define the actual water application rates by individual homeowners. In addition, the actual water requirements of lawn grass have been determined by measurement of potential evapotranspiration rates.

Justification for Study

Since the lawn water component of municipal water demand is very large, its under- (or over-) estimation could cause poorly designed and operated systems. This is especially true for the Rocky Mountain

Region if the projected population increases for these states are accurate. In addition, any use of water by lawns (a nonpecuniary beneficial use) will decrease the water available to industries and agriculture because of the limited water supply. It should be noted that water for lawns is considered municipal water and municipal water needs have priority over industrial and agricultural water needs.

Current lawn watering recommendations are general in nature and use such terms as "apply water about once each week and supply an amount that is sufficient to maintain an actively growing lawn" (Stegman, et al., 1975). This type of recommendation provides little help either to the individual homeowner who would like to save water and money in the care of his lawn or to the municipal water system manager who must restrict water use but do so in such a way that homeowners can maintain aesthetically pleasing lawns.

Location of Study

Lawn water application rates and potential evapotranspiration rates were measured in two Wyoming cities--Wheatland and Laramie. Wheatland, at an elevation of 4,700 feet and at 42°05'N latitude, lies off the eastern slope of the Laramie Range at the transition to Wyoming's eastern plains. Laramie, at an elevation of 7,200 feet and at 41°19'N latitude, lies off the western edge of the Laramie Range on a high broad basin bordered to the west and south by the Medicine Bow mountains and foothills.

The climatic environment of much of the state and also much of the region is typical of that found near the above cities. Wheatland is typical of most communities in the eastern and central lowland plains and basins of the region. The area is primarily a farming community with a normal frost-free period of 133 days and an average annual precipitation of 12.5 inches. Its mean annual temperature of 49.1°F is the highest of any townsite in Wyoming (Becker, et al., 1961). During the growing season the area can be described generally as hot and semi-arid. On the other hand, Laramie is more representative of towns found on the high prairies and mountain valleys of the region. The average frost-free period is only 113 days and the mean annual temperature is 40.9°F. Again, the area is semi-arid with annual rainfall averaging just above 10 inches.

POTENTIAL EVAPOTRANSPIRATION MEASUREMENTS

Potential evapotranspiration (E_{tp}) is defined herein as the evapotranspiration rate experienced when no water shortage exists. Its value is unique for each crop type and is dependent on climatic conditions as well as on the nutrient level of the soil. For the given climatic and soil fertility conditions, vegetative production is maximized and the best possible appearance and health are achieved. This definition is consistent with that originally proposed by Thornthwaite (1948) and later slightly modified by Penman (1956). Penman extended the definition to "the amount of water transpired in unit time by a short green crop, completely shading the ground, of uniform height and never short of water." This definition fits lawn grasses ideally.

Measurement of Evapotranspiration

Evapotranspiration (E_t) rates were measured through the use of small weighable lysimeters installed in lawns surrounding single residence dwellings. A full description of the lysimeters and their use is presented in Appendix A. Six residential homes were selected in Wheatland and Laramie, and five lysimeters installed at each home. Two homes in each town were chosen where more recent construction had taken place and shrubbery and tree growth had not yet had time to establish and effect lawn E_t. This two to one ratio of newer homes to older homes approximates the occurrence rate of the homes found in each town.

Lysimeters were located at each house according to the following criteria: (1) one lysimeter was located on each side of the house, or if a house was not completely surrounded by grass, two or more lysimeters were placed in the larger grassed areas; (2) placement was near the center of the grassed area but positioned to catch sunlight and shade in amounts representative of the surrounding lawn; and (3) one lysimeter was located as close as possible to a potential heat source such as a driveway, sidewalk, or sidewalk-driveway intersection.

Lysimeters were installed and sodded to grass during July of 1975. The grass in the lysimeters had part of a summer plus fall and winter seasons to develop roots and become established before evapotranspiration measurements were made. Subsequent data (1977) indicate that E_t from lysimeters established the previous year show no significant difference to data collected from lysimeters established three years prior to collection. This result should be expected since root development becomes less critical when adequate soil moisture exists continuously.

In order to measure potential evapotranspiration, watering schedules were developed which would ensure adequate available soil moisture at all times. Hagan and Stewart (1972) determined that no more than approximately 35 percent of available moisture can be depleted in order for the potential condition to exist. Using this result, a watering schedule was developed as follows: (1) for a specific soil type (e.g., loam, sandy loam, etc.) the approximate dry specific weight and available water as a percent of dry weight of soil were obtained from tables; (2) the available moisture was multiplied by 0.35 to determine the water loss allowable to the unit; and (3) because weight differences were measured weekly, the weekly change in weight divided by the allowable water loss gave an estimate of the number of waterings that would be required for the upcoming week. Between three and four pounds of moisture depletion (1 lb $\simeq$ 0.24 inches) was allowed for all lysimeters. Soil types were obtained from SCS charts and publications. This information was confirmed by grain size distribution and hydrometer tests.

Field capacity was determined at the start of the growing season when daily evapotranspiration was low. Drain plugs were removed from all lysimeters, and sufficient water was added to saturate the soil column and provide water for deep percolation. Drainage was allowed for two days before the plugs were re-inserted and the lysimeters weighed. Since evapotranspiration was very small for the two days, field capacity was taken as the measured weight.

The lysimeters were fertilized by the individual homeowners along with the rest of the lawn. No additional nutrients were supplied because of the original premise that the experiment was to be conducted under existing urban lawn conditions. Grass appearance in the lysimeters indicated no fertilizer shortage uncharacteristic of the surrounding grass. Weeds and undesirable grasses, however, were handpicked from each lysimeter.

Potential salt buildup was of concern in operation of the lysimeters. All salts were contained within the lysimeter except for deliberate leaching once during the growing season and when individual lysimeters were accidentally overwatered by the homeowners. Because the lysimeters spent five months of each year without drain plugs and were thoroughly leached before and after each growing season, it was felt that sufficient leaching was provided. To verify this assumption, a standard irrigation analysis was made of a drainage sample obtained from an overwatered lysimeter. The water sample was collected about midseason. Conductivity of the extract measured 2.01 mmhos/cm, implying negligible salinity effects for most crops (Luthin, 1973). Analysis of the irrigation water resulted in a low sodium adsorption ratio (SAR) as well as low carbonate and boron hazards.

The lysimeters were weighed generally every seven days on a Detecto 350 lb scale graduated to 0.25 lbs. The scale is accurate to ±0.25 lbs. Before weighing, the lysimeters were wiped clean and the scale zeroed. Lysimeter weights were then compared to the estimated weight of the lysimeters at field capacity. Water was either added, bringing the lysimeter weight up to field capacity or, if the weight exceeded field capacity due to accidental watering or high precipitation, the lysimeter was drained and reweighed.

Discussion of Results

The lysimeters were operated from April 9th to October 31st during the 1976 growing season. Most of the lysimeters remained frozen in the ground until April 9th, preventing the April 1st projected start of measurement. The E_t rates for Wheatland and Laramie are shown in Figures 1 and 2, respectively.

E_t rates from May through September were close to that predicted by Trelease, et al. (1970). On the other hand, April's and October's E_t rates were 17 percent and 53 percent higher respectively than that

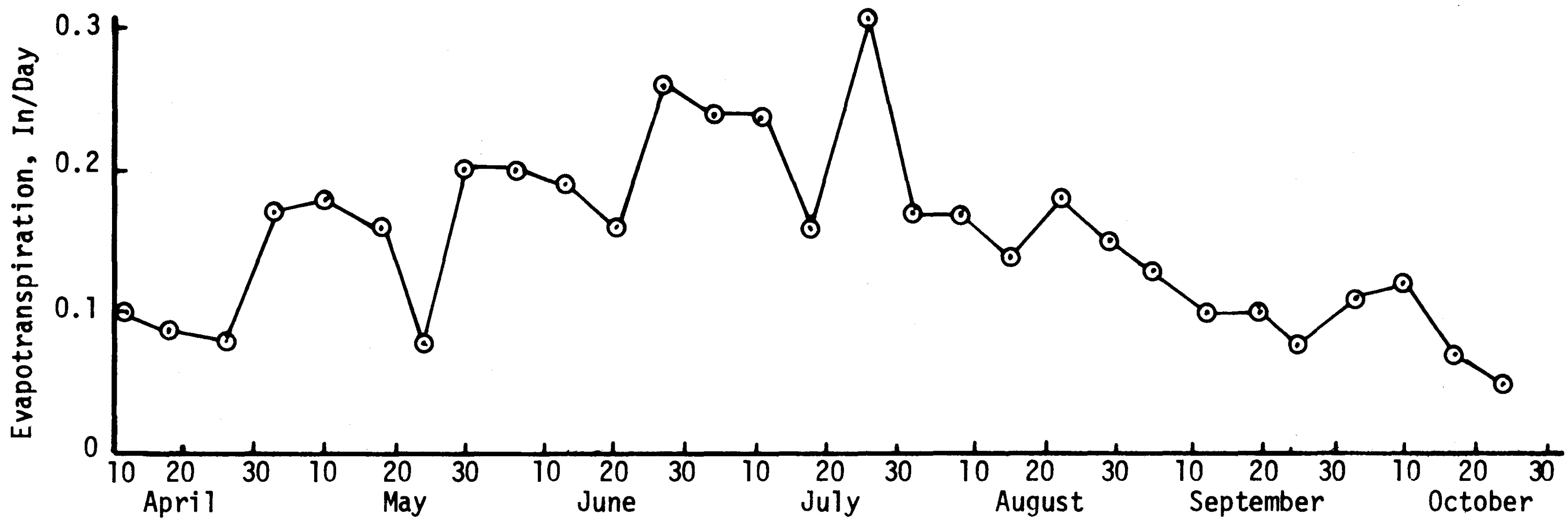

Figure 1. Measured potential evapotranspiration for Wheatland, Wyoming--1976

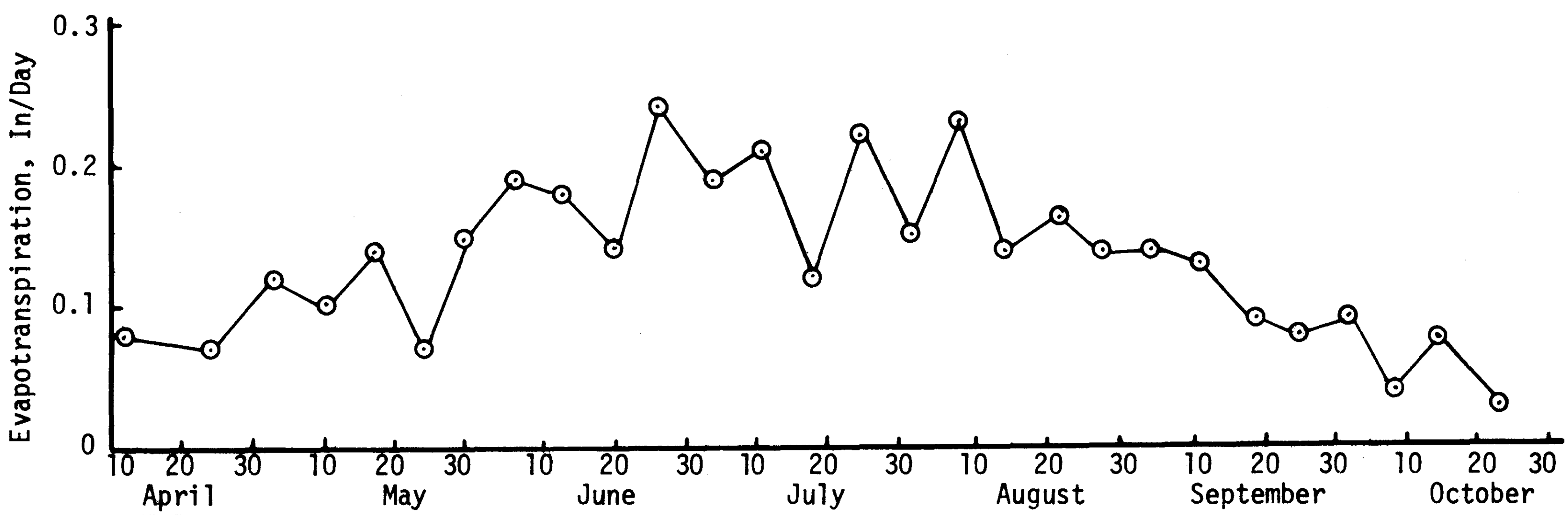

Figure 2. Measured potential evapotranspiration for Laramie, Wyoming--1976

predicted by Trelease, et al. (1970). The differences between measured and predicted E_t for April and October are probably due to the consumptive use coefficient being estimated because of the lack of measured data in Wyoming previous to this project.

It should also be noted that for August and September the E_t in Laramie was greater than that for Wheatland. This occurred even though the mean monthly temperatures were higher in Wheatland than in Laramie. A possible explanation for the lower E_t in Wheatland is the ability of Kentucky bluegrass (poa pratensis) to go into a semi-dormant condition during hot weather (Billick, 1973). When in this semi-dormant condition it transpires less water and is the reason why Kentucky bluegrass is often considered to be drought tolerant. The predominant specie of grass in all the lysimeters was Kentucky bluegrass.

Shown in Tables 1 and 2 are the calibrated consumptive use coefficients, k, for the Blaney-Criddle formula for Laramie and Wheatland respectively. The k values were obtained for each month by the following formula:

$$k = \frac{(E_t)(100)}{(t)\ (p)}$$

where k = consumptive use coefficient for the month;

E_t = measured water loss from the lysimeters for the month in inches.

t = mean temperature for month in °F;

p = percent yearly daylight hours for the month.

It should be noted that these "k" values are calibrated for one year only and that they may be modified slightly with additional years of measured E_t and recalibration.

Table 1. Calibrated consumptive use coefficients for Blaney-Criddle formula for Laramie, Wyoming

Month	Actual E_t* inches/day	Consumptive Use Coefficient "k"
April	0.079	0.66
May	0.114	0.74
June	0.186	0.97
July	0.185	0.84
August	0.166	0.87
September	0.107	0.72
October	0.054	0.55

*Season was between April 9th and October 31th, 1976.

Table 2. Calibrated consumptive use coefficients for Blaney-Criddle formula for Wheatland, Wyoming

Month	Actual E_t* inches/day	Consumptive Use Coefficient "k"
April	0.093	0.64
May	0.153	0.84
June	0.202	0.93
July	0.231	0.95
August	0.162	0.76
September	0.104	0.62
October	0.085	0.74

*Season was between April 9th and October 31st, 1976.

RESIDENTIAL WATER USE

A major objective of this research was to monitor lawn water application rates. Total residential use was also monitored to determine total use and household use. The collection of data began late in the summer of 1975 and continued through 1976.

Methods

The city managers of both towns were contacted to obtain permission to read the city water meters. In addition, the extension offices in Laramie and Wheatland were also contacted, and a list of possible cooperators were obtained from the extension agents. These people were then contacted to obtain permission to monitor their water use. A meter was attached to each outside spigot so as not to inconvenience the cooperator. For the initial five-week period in 1975 there were 21 and 14 cooperators in Laramie and Wheatland, respectively. In 1976, the numbers of cooperators were increased to 29 and 26 in Laramie and Wheatland, respectively.

Meter readings were taken weekly from the last expected freeze in the spring to the first expected freeze in the fall. Data included total residential use, the total water applied to the lawn in gallons, and the amount of precipitation. Precipitation data came from the National Weather Service stations in each town and from rain gauges located at each home with lysimeters. The National Weather Service monthly report also provided the daily maximum and minimum temperatures.

Each cooperator's yard was measured to determine the measured lot size and the total lawn and garden area that was irrigated. The application rate was then determined by the following equation:

$$\underset{\text{in/day}}{\text{Lawn application rate}} = [(\text{Gallons applied}) \times (12\ \text{in/ft})]/$$

$$/[(7.48\ \text{gal/ft}^3)(\text{Lawn area, ft}^2)/(\text{Period, days})].$$

This equation gives the amount of water applied by sprinkling to which the average precipitation for the data period must be added to obtain the total amount of water applied to the lawn.

Lawn Application Rates for 1975

Summaries of lawn water applications by cooperators in Laramie and Wheatland for the five-week period during the 1975 summer are shown in Tables 3 and 4. These preliminary results show that Wheatland has a considerably higher average application rate (44 percent greater) than Laramie. The percentage of total residential water use which was applied to lawns was particularly large with a range from approximately 47 percent to 97 percent of the total residential water use being for lawns during the study period.

Lysimeter data were taken for one home in Laramie during the period August 7, 1975, to October 27, 1975. Water application rates, when averaged for all homeowners in Laramie, were considerably above the measured E_t values (Table 4). Individual homeowners (Table 3) who maintained the lowest application rates were near the consumptive use requirements of lawn grasses. Apparently a considerable amount of overwatering occurred at a few homes to pull the average application rate upward.

Table 3. Lawn water application rates for the summer, 1975

Laramie (July 25 - August 29)

Home	Water Depth Applied† (inches)*	Water Depth Applied† (inches)**/day	Lawn Use/Total Use %
1	10.21	0.29	65.5
2	5.64	0.16	47.4
3	6.31	0.18	81.4
4	5.16	0.15	66.0
5	12.40	0.35	83.4
6	8.50	0.24	
7	14.13	0.40	83.5
8	5.70	0.16	79.8
9	4.23	0.12	77.4
10	7.17	0.20	68.3
11	5.72	0.16	53.5
12	8.44	0.24	
13	12.00	0.34	95.0
14	17.74	0.51	85.6
15	6.74	0.19	92.5
16	13.98	0.40	
17	9.96	0.28	88.3
18	8.29	0.24	
19	3.78	0.11	69.9
20	6.25	0.18	81.5
21	4.88	0.14	76.6
Ave.	8.20	0.23	

*Total precipitation during period: 0.77 inches

**Average precipitation during period: 0.02 inches/day

†Includes precipitation which is averaged for the week in which it occurred.

Wheatland (July 23 - August 28)

Home††	Water Depth Applied† (inches)*	Water Depth Applied† (inches)**/day	Lawn Use/Total Use %
1	8.10	0.23	78.7
2	6.59	0.18	
3	7.60	0.21	64.5
5	10.99	0.31	92.8
6	7.34	0.20	
7	12.52	0.35	
8	7.44	0.21	
9	9.63	0.27	
10	36.86	1.02	97.4
11	13.16	0.37	75.6
12	18.93	0.53	
13	9.05	0.25	80.1
15	17.68	0.49	88.5
16	10.57	0.29	
Ave.	11.67	0.32	

*Total precipitation during period: 1.35 inches

**Average precipitation during period: 0.04 inches/day

†Includes precipitation which is averaged for the week in which it occurred.

††Missing homes were dropped from the study.

Table 4. Weekly lawn water application rates and measured evapotranspiration, 1975

Period	Laramie		Wheatland	
	Water Application (in/day)	ET (in/day)	Water Application (in/day)	ET* (in/day)
July 31 - Aug 7	0.31		0.31	
Aug 7 - Aug 14	0.28	0.15	0.59	
Aug 14 - Aug 21	0.12	0.13	0.22	
Aug 21 - Aug 28	0.25	0.18	0.34	
Aug 28 - Sep 4		0.16	0.32	
Sep 4 - Sep 11		0.12		
Sep 11 - Sep 18		0.09		
Sep 18 - Sep 26		0.11		
Sep 26 - Oct 3		0.07		
Oct 3 - Oct 15		0.07		
Oct 15 - Oct 27		0.03		

*No ET data in Wheatland in 1975.

Lawn Application Rates for 1976

The average application rates, including precipitation, for each home are found in Table 5. Again, the average application rates were higher (27 percent) in Wheatland than in Laramie. The weekly average application rates versus the average weekly consumptive use (E_t) rates for Laramie and Wheatland are given in Table 6. The seasonal average E_t rates were 0.18 inch per day for both Wheatland and Laramie, while the average seasonal application rates were 0.28 and 0.22 inches per day, respectively. These values represent a 129-day study period for Wheatland and a 105-day period for Laramie. The average E_t rate in

Table 5. Lawn water application rates for the summer, 1976

Laramie — Summer 1976

Home†††	Water Depth Applied†† (inches)**	Water Depth Applied†† (inches)***/day	Lawn Use/Total Use %
2	22.26	0.21	
3	24.89	0.24	82
4	17.35	0.17	74
6	26.61	0.25	67
7	41.22	0.39	77
8	19.28	0.18	74
9	18.54	0.18	78
10	25.19	0.24	65
11	19.50	0.19	57
12	19.05	0.18	60
13	35.84	0.34	94
14	44.34	0.42	80
15	20.21	0.19	92
16	36.84	0.35	96
17	23.85	0.23	93
18	30.96	0.29	
19	17.73	0.17	73
20	18.97	0.18	91
21	16.48	0.16	72
22*	9.41	0.12	50
23*	17.85	0.20	55
24*	26.96	0.32	92
25	28.32	0.27	
26*	16.38	0.20	61
27	14.25	0.14	
28*	9.32	0.12	56
29*	9.78	0.13	57
30	24.52	0.23	67
31*	14.31	0.17	
Ave.†	24.83	0.24	

*Homes with less than 105-day period.

**Total precipitation during period: 4.44 inches

*** Average precipitation during period: 0.44 inches/day

†Average for homes with 105-day period.

††Includes precipitation which is averaged for the week in which it occurred.

†††Missing homes were dropped from the study.

Wheatland — Summer 1976

Home†††	Water Depth Applied†† (inches)**	Water Depth Applied†† (inches)***/day	Lawn Use/Total Use %
1*	32.58	0.23	67
2	26.74	0.21	
3*	26.59	0.19	60
5*	38.98	0.28	91
6*	21.25	0.15	
7	45.54	0.35	
9	48.47	0.38	94
10	65.93	0.51	91
11	45.39	0.35	86
12	58.44	0.45	
13*	17.11	0.16	73
15	54.49	0.42	86
16	25.07	0.19	
17	31.40	0.24	86
18*	26.15	0.21	93
19	39.94	0.31	93
20*	19.78	0.17	94
21*	50.73	0.43	87
22*	42.53	0.36	94
23*	50.82	0.43	
24	44.11	0.34	88
25*	33.40	0.27	
26*	33.91	0.29	83
27	45.68	0.35	80
28*	41.54	0.35	
29*	26.69	0.23	
Ave.†	44.27	0.34	

*Homes with more or less than 129-day period.

**Total precipitation during period: 5.52 inches

***Average precipitation during period: 0.04 inches/day

†Average for homes with 129-day period.

††Includes precipitation which is averaged for the week in which it occurred.

†††Missing homes were dropped from the study.

Table 6. Weekly water application rates and evapotranspiration, 1976

Laramie			Wheatland		
Period	Application (in/day)	ET (in/day)	Period	Application (in/day)	ET (in/day)
May 25 - Jun 2	0.20	0.15	May 7 - May 17	0.20	0.18
Jun 2 - Jun 9	0.27	0.19	May 17 - May 21	0.37	0.16
Jun 9 - Jun 16	0.20	0.18	May 21 - May 28	0.34	0.08
Jun 16 - Jun 23	0.21	0.14	May 28 - Jun 4	0.15	0.20
Jun 23 - Jun 30	0.26	0.24	Jun 4 - Jun 10	0.34	0.20
Jun 30 - Jul 7	0.27	0.19	Jun 10 - Jun 17	0.27	0.19
Jul 7 - Jul 14	0.24	0.21	Jun 17 - Jun 24	0.25	0.16
Jul 14 - Jul 21	0.39	0.17	Jun 24 - Jul 1	0.34	0.26
Jul 21 - Jul 28	0.12	0.22	Jul 1 - Jul 8	0.36	0.24
Jul 28 - Aug 4	0.19	0.15	Jul 8 - Jul 15	0.45	0.24
Aug 4 - Aug 11	0.16	0.23	Jul 15 - Jul 22	0.36	0.16
Aug 11 - Aug 18	0.17	0.14	Jul 22 - Jul 29	0.44	0.31
Aug 18 - Aug 25	0.22	0.16	Jul 29 - Aug 5	0.23	0.17
Aug 25 - Aug 31	0.20	0.14	Aug 5 - Aug 12	0.29	0.17
Aug 31 - Sep 7	0.23	0.14	Aug 12 - Aug 19	0.31	0.14
			Aug 19 - Aug 26	0.34	0.18
			Aug 26 - Sep 2	0.31	0.15
			Sep 2 - Sep 9	0.27	0.13
			Sep 9 - Sep 16	0.20	0.10
			Sep 16 - Sep 23	0.18	0.10

Wheatland for the same 105-day study period as Laramie was 0.19 inches per day. Further analysis shows the average application rate to be 122 percent of the E_t rate in Laramie and 156 percent in Wheatland. The higher average application rate in Wheatland is attributed to higher temperatures.

Rating System

Due to the difference in average application rates between Laramie and Wheatland and also between the individual cooperators, a dual rating system was instituted that attempted to measure the effect of the amount of water applied. The rating system was started at the beginning of June, 1976. The lawns were rated weekly at the same time that meter readings were taken.

The lawns were rated on the basis of appearance and according to the percentage of total lawn area that appeared, from visual inspection, to be stressed. The appearance rating considered color, thickness of grass, and the presence of weeds in the lawn but did not consider the overall aesthetic attractiveness of the landscape.

Low correlations were found between the amounts of water applied to the lawns and both the appearance and stress ratings. Apparently other factors besides the total amount of water applied exert strong influences on lawn appearance and stress. Probably the most significant of these factors are fertilizer, overall lawn maintenance habits, and uniformity of water application.

Overwatering

Overwatering of lawns occurs as shown by the low correlation ($R^2 = 0.2$) between lawn appearance and stress and water application rates. This overwatering is caused by using water as a substitute for fertilizer, setting the water and forgetting it is on, watering the entire lawn when a small dry spot appears instead of watering the spot and waiting for the entire lawn to show signs of needing water, and border effects. The extra water percolates into the ground water system or runs into the gutter.

The amount of overwatering was determined by taking the seasonal average E_t rate and subtracting it from the seasonal average application rate for each home. For those homes with application rate above the E_t rate, the difference was multiplied by their particular lawn area to determine the average volume of water per day that would go to deep percolation and end up in the ground water system. The average amount of deep percolation for each town was determined by dividing the total volume of overwatering by the total lawn area of all the homes monitored. In Wheatland the deep percolation amounted to 0.0085 acre-feet per day per acre of lawn while in Laramie it amounted to 0.004 acre-feet per day per acre of lawn. These again seem to be small amounts of water; but, for example, in Cheyenne with a population of 50,000, there are 11,433 residential customers being served (AWWA, 1970). If the deep percolation were 0.0085 acre-feet per day per acre of lawn, 0.16 acres of lawn per home, and the growing season was 140 days, then the volume of overwatering would amount to approximately 2,200 acre-feet of water. This is again a considerable amount of water being fed into the ground water and downstream surface water systems.

Household Water Use

The household water use was determined by subtracting the amount applied to the lawn from the total residential water use (see Tables 7 and 8). No attempt was made to determine the amount of water used for individual uses within the home; instead, only the overall household usage was determined for the summer and winter periods. The summer data consisted of data taken for the weekly periods from the last freeze to the first freeze. The winter household use is based on data taken at the beginning and end of the five month period starting in November and going through March when very little or no sprinkling occurs.

Summer versus winter household use

Household or domestic use is defined as the water used for all purposes within the home. For this study, water used for washing cars was also considered to be part of the household use. Historically, the amount of water used by residents during the winter months when no lawn watering occurred has been used to determine the household use. Household use is then assumed to be constant year-round. An estimate of the amount of water used to water the landscape can then be determined by subtracting the winter household use from the total amount of water metered during the lawn watering season. This is known as the "Winter Base Rate" method (Cotter and Croft, 1974).

A study was conducted to see if a significant difference existed between summer and winter household use with the results being checked at the 90 and 95 percent confidence levels. A paired-sample t-test showed a significant difference at the 95 percent confidence level when data from the two cities were combined. The winter use was higher with an average use of 76.9 gallons per day per capita (gpcd) and a range of 20 to 203 gpcd while the average summer use was 61.6 gpcd with a range from 19 to 148 gpcd. Using the paired-sample t-test for each town found no significant difference between winter and summer household use in Wheatland with an average winter use of 77.3 gpcd and an average summer use of 65.3 gpcd (Table 7). In Laramie, the average winter use was 76.7 gpcd while the summer use was 59.4 gpcd (Table 8). The paired-sample t-test showed a significant difference at the 90 percent confidence level.

These results indicate that in Laramie, for example, by using the "Winter Base Rate" method the amount of water applied to lawns would be underestimated. Even though significant differences exist between summer and winter household use possibly causing the "Winter Base Rate" method to under- or overestimate the lawn water use, it is still the best method available for obtaining an estimate of the amount of water applied to lawns because the lawn water use is a high percentage of the total use.

Average household use and summer peak occurrence

An average estimated household use was obtained by weighing the summer and winter household use by their particular study periods. The estimated average household use in Wheatland was 72 gpcd with a range for the homes monitored of 47 to 106 gpcd while in Laramie the estimated average use was 70 gpcd with a range for the homes monitored of 23 to 141 gpcd.

Table 7. Summer vs. winter household use, Wheatland, 1976

Wheatland				
	Household Use			
	Winter* Use		Summer† Use	
House No.	Total, gals	Use, gpcd	Total, gals	Use, gpcd
1	36,343	59	53,285	95
5	20,684	45	23,955	57
9	25,791	84	11,733	45
10	52,575	68	25,199	39
11	17,346	56	27,940	108
15	23,164	75	15,449	60
17	30,327	98	29,708	115
19	23,025	75	12,680	50
20	22,072	143	4,566	39
21	41,724	54	28,959	49
22	18,680	121	9,652	82
27	29,958	49	22,960	45
Average		77.3		65.3

*Winter Period - November 4, 1976 to April 7, 1977.

†Summer Period - May 7, 1976 to September 23, 1977.

Table 8. Summer vs. winter household use, Laramie, 1976

Laramie				
	Household Use			
	Winter* Use		Summer† Use	
House No.	Total, gals	Use, gpcd	Total, gals	Use, gpcd
3	89,549	203	16,956	54
4	36,728	62	20,303	48
6	44,477	76	36,957	88
7	55,756	126	31,137	99
8	31,386	36	20,539	33
10	31,040	106	22,827	54
11	27,500	94	31,126	148
13	35,640	121	10,392	49
14	54,658	74	30,090	57
15	5,735	20	5,613	27
16	20,181	46	6,118	19
19	52,307	59	32,179	51
20	44,087	60	10,761	20
22	28,898	49	14,808	49
23	32,537	55	28,186	78
24	11,598	79	6,451	78
26	41,553	71	27,938	84
28	19,632	45	17,357	76
29	35,328	60	16,015	38
30	67,549	92	20,174	38
Average		76.7		59.4

*Winter Period - November 9, 1976 to April 5, 1977.

†Summer Period - May 25, 1976, to September 7, 1977.

The average household use in gpcd for the weekly data periods (Figure 3) was used to determine if any peaks occurred in the household use during the summer study period. In Laramie, the peaks occurred at the beginning of the study period in May and again at the end of the study period in early September with lower usage in between. In Wheatland, peaks occurred approximately every other week until the middle of August when a sustained peak occurred until the first part of September. These results again show the lower summer usage in Laramie and the constant year-round usage in Wheatland. These results could possibly have occurred because many of the cooperators in Laramie went on vacations during the summer while in Wheatland many of the cooperators were retired and therefore did not go on vacation.

Design Criteria

Most methods for water distribution system design are based on the average daily per capita use. Multipliers are then used to determine maximum daily, and peak-hour water use for water system design. The average annual daily usage was found to be 303 gpcd and 164 gpcd for Wheatland and Laramie, respectively, based on approximately one year's data shown in Table 9.

The summer usage showed a high weekly average usage of 440 gpcd in Laramie and 988 gpcd in Wheatland. The maximum average month was then determined by adding the four consecutive weeks with the highest usage and taking their average. Wheatland's maximum average monthly usage was 821 gpcd or 2.7 times the average per capita daily usage while Laramie's maximum average monthly usage was 384 gpcd or 2.3 times

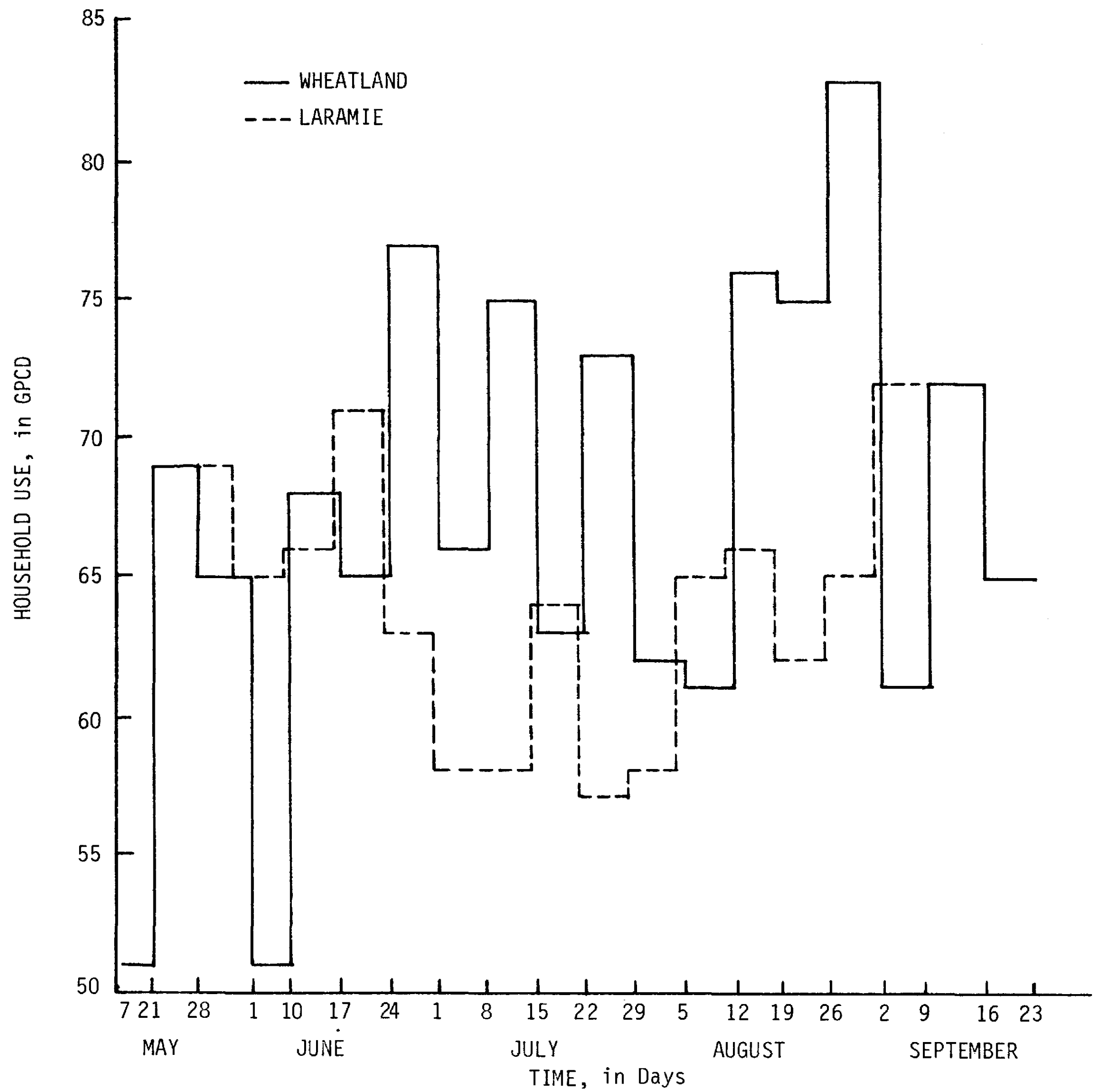

Figure 3. Laramie vs. Wheatland household use, summer 1976

Table 9. Total average yearly residential water use for homes with household use monitored

Wheatland May 28, 1976, to May 26, 1977			Laramie June 23, 1976, to June 22, 1977		
House No.	Total Use (gallons)	Average Use (gpcd)	House No.	Total Use (gallons)	Average Use (gpcd)
1	253,645	175	3	246,696	226
9	249,786	344	4	165,297	114
10	397,341	219	6	220,500	151
15	172,044	237	7	248,740	228
17	273,960	377	8	165,109	76
19	243,511	335	9	73,003	201
20	131,392	362	10	133,392	183
22	214,649	591	11	128,700	177
27	175,769	121	12	89,541	82
29	486,567	268	13	281,373	387
			14	293,214	161
			15	93,580	129
			16	299,805	275
			19	221,737	102
			20	258,889	142
			22	99,591	68
			23*	130,186	88
			24	154,944	426
			26	173,541	119
			28	99,752	91
			29	113,470	78
			30	184,203	101
Average per house		303	Average per house		164

*7 days to June 29, 1977.

the average daily per capita usage. The maximum daily and peak-hour usage were not determined because of the method of data collection.

The values given above represent residential water use only and do not include uses from apartment houses, commercial-industrial, or public uses. The average daily per capita use is higher than most data now used for residential water use criteria. Linaweaver (1967), for instance, found the residential use in ten areas in the West to be 458 gallons per day dwelling unit or approximately 115 gpcd based on four occupants per dwelling unit. Flack (1976) cited total annual residential use in Evergreen, Colorado, to be 95 gpcd. Babbit (1962) found water use to be 210 gpcd for all residential purposes where rainfall was less than 15 inches per year. The higher values found by this study probably occurred because only homes with lawns were monitored.

Although the average daily per capita use is higher than most design criteria, the distribution system in most cases will handle the flow because the design size of the distribution system is controlled by the water requirements for fire demands. This is especially true in very small communities (Flack, 1976). The problem occurs during the peak use periods in the summer when the demand is more than the capacity of the treatment facility. The problem leads directly to the need for water conservation measures.

SUMMARY

A study of residential water use with emphasis on lawn water application rates and requirements was initiated in July, 1975. Lawn water application rates, household use, and potential evapotranspiration (E_{tp}) rates of lawn grass in an urban setting were monitored in Laramie and Wheatland, Wyoming.

Weekly data were taken throughout the summer of 1976, but only during the latter portion of the 1975 summer. Potential evapotranspiration was measured using small weighable lysimeters installed in lawns surrounding single family residential units at three locations in each city. Five lysimeters were placed in various positions at each location. During 1975, however, potential evapotranspiration data included only one home in Laramie and none in Wheatland. Lawn water application rates were monitored by attaching water meters to all outside spigots of cooperators' homes. The number of cooperators were 21 and 14 during 1975 and 29 and 26 during 1976 in Laramie and Wheatland, respectively.

As expected, E_{tp} rates in Wheatland were higher than in Laramie--about 13 percent over the same period of analysis--while lawn water application rates were 27 percent greater in Wheatland than in Laramie with average application rates of 0.22 inches per day in Laramie and 0.28 inches per day in Wheatland during 1976. These application rates were 122 percent of the average seasonal potential evapotranspiration rates in Laramie and 156 percent in Wheatland.

A low correlation was found between the amount of water applied and the appearance of the lawns, indicating that other factors besides the total amount of water applied significantly influence lawn appearance. As would be assumed from the above, it was shown that a considerable amount of overwatering was being done.

Analysis of design information indicates that the "Winter Base Rate" method is still the best method available for obtaining an estimate of the amount of water applied to lawns. The average daily per capita use in both cities was found to be higher than most data now used for residential water use criteria.

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APPENDIX A

OPERATION OF BUCKET LYSIMETERS

Bucket lysimeters can be used to measure the evapotranspiration of lawn grass. The lysimeters should be representative samples of the surrounds, soil, and vegetation. For measurement of potential evapotranspiration, they must be operated in a manner which will insure adequate aeration and development of representative root systems. The following discussion provides specifications and criteria for the installation and operation of bucket lysimeters when used to measure potential evapotranspiration.

Description of Bucket Lysimeters

The lysimeters consist of an outer retaining ring and an inner bucket. The retaining ring (12.5" ID, 1/8" PVC, 26" high) maintains the shape of the hole so the bucket can be removed as needed. The inner bucket (12" IC, 1/2" PVC, 24" high) is set on a 3/4 inch wooden plug placed at the bottom of the hole and underlaid with gravel to adjust the height of the bucket. A 3/8" pipe plug is installed in the bottom plate (1/4" PVC) of the bucket to permit drainage of excess water. Several holes are drilled in the wooden plug to insure drainage from the retaining ring. The bucket has hooks placed on its side to facilitate removal.

Location of Lysimeters

Five lysimeters should be located at each house according to the following criteria: (1) one lysimeter is located on each side of the house and is placed approximately in the center of the grassed area; (2) if a house does not have grass on all sides, two or more lysimeters are placed in the lawn so they are as representative as possible of the lawn; and (3) one lysimeter is located as close as possible to a potential heat source such as a driveway, sidewalk, or sidewalk-driveway intersection.

Each site selected should have a representative stand of grass. It should be as free of weeds as possible. Care should be taken to avoid overlapping sprinkler patterns from neighboring yards and excessive surface water runoff from downspouts or paved areas. In addition, some consideration should be given to dogs and activities of children.

Installation of Lysimeters

Installation of a lysimeter can be summarized in five steps: (1) obtaining and installing the grass plug, (2) escavating the hole, (3) providing a reservoir for excess water, (4) packing the soil, and (5) adjusting the height of the lysimeter.

The Grass Plug: A grass plug (≃5" in depth) with a diameter equal to that of the outer ring should be cut out of the lawn. This may be done by placing the outer ring on the grass and twisting until an outline is formed. A spade, with approximately the same curvature as the outside ring, is used to cut the grass taking care to cut the soil in a vertical direction. After the plug is cut all around it can be popped free with the spade. The bottom of the grass plug should be trimmed flat and the depth of the plug measured.

After the hole has been dug and the bucket filled with soil, the plug is installed in the bucket. The soil in the bucket should be shaped to complement the plug and filled at a depth such that the soil surface of the plug is approximately 1/4 inch above the top of the bucket. The extra height is needed to compensate for soil settling. All of the 30 lysimeters installed in Wyoming have had some settling. The grass plug is placed on the bucket and trimmed with a knife to fit snuggly into the bucket. Considerable pressure may need to be used to force the plug into the bucket.

Excavation of the Hole: The first step in the excavation of the hole is to remove the grass plug as described in the previous section. The remainder of the hole is dug with a spade or post-hole digger. Care should be taken to separate the topsoil from the subsoil and to keep the diameter of the hole the same as that of the outer ring. The outer ring can be used as a guide to check for roundness and diameter size and for determining proper depth of hole. The depth need not be greater than that of the outer ring.

Reservoir for Excess Water: The first step in filling the bucket lysimeter is to provide a reservoir for excess water as follows: (1) the drain plug is installed in the bottom plate; (2) a nylon or plastic fly screen (≈ 30 in^2) is placed over the plug; (3) a two-inch layer of pea gravel is placed over the fly screen; and (4) a one-inch layer of washed sand is placed over the pea gravel. The gravel acts as the reservoir and releases the water readily when the drain plug is removed. The sand acts as a filter to prevent soil from migrating into the reservoir.

Packing the Soil: One of the most unscientific, yet most important, steps is the placing of the soil into the bucket lysimeter. The subsoil and topsoil can easily be placed in their respective places. The packing, however, is an art. Too much packing will produce a poor draining soil and a poor environment for plant growth, while too little packing will lead to excess settling and cause the grass to recede into the lysimeter. Best success has come from placing two shovels of soil into the bucket and then packing the soil with one's closed fist. A medium amount of pressure should be used, much like the pressure exerted in transplanting seedlings. If possible, the soil should be wetted after packing and allowed to settle for two to four weeks before the grass is placed in the bucket.

Adjusting Height of Lysimeter: The tops of both the bucket and outer ring should be level with the surface of the surrounding soil. Since the outer ring is two inches longer in depth than the bucket, some fill must be added to bring the bucket to the same level as the outer ring. The fill is pea gravel below a 3/4" plywood plug which acts as a base for the bucket. Holes are drilled in the plywood to provide drainage for any water that may enter between the outer ring and bucket. A final inspection should be made to make sure lawn mowers can pass over the lysimeter without obstruction.

Water Application

The purpose of the lysimeters is to determine the potential evapotranspiration for lawn grass (Kentucky Blue Grass, *poa pratensis*). Therefore, the watering regime must be kept at a high level of available moisture at all times. Depletion should never be more than 35 percent of available moisture. To insure the plant is using water to its potential, the following procedure should be followed:

1. The available moisture should be estimated or measured (if possible) for the soil in the lysimeter. A medium light soil will have approximately 1.50 inches of available moisture. Therefore, approximately 2.5 to 3.0 lbs of water can be used by the grass without using more than 35 percent of the available moisture.

2. An irrigation schedule should be followed so that the grass would not use more than 35 percent of the available moisture. The following irrigation schedule is recommended:

$$E_t < 0.10''/\text{day} \quad 1 \text{ irrigation per week}$$

$$0.10''/\text{day} \leq E_t \leq 0.20''/\text{day} \quad 2 \text{ irrigations per week}$$

$$0.20''/\text{day} \leq E_t \leq 0.30''/\text{day} \quad 3 \text{ irrigations per week}$$

$$E_t > 0.30''/\text{day} \quad 4 \text{ irrigations per week}$$

Some excess water will probably be added during each irrigation. The irrigation water will bring the soil up to near field capacity, and the excess will go to the storage reservoir. Care should be taken not to add great amounts of excess water because drainage may not be the best and a high water table in the lysimeter will hinder plant growth and thus reduce potential evapotranspiration. Applying great amounts of excess water will also necessitate drainage of the excess water reservoir which is a time consuming process.

The lysimeter, during irrigation of the lawn surrounding the lysimeters, should be covered. If a cover is left on for a prolonged period of time, it will reduce the potential evapotranspiration. However, other than the protection of the lysimeter from normal lawn watering, all other lawn care operations sould be performed without regard for the lysimeters.

Determination of Evapotranspiration

Evapotranspiration is determined by performing a water balance for the lysimeter. The following equation is used:

$$ET = W_1 - W_2 + P + WA - WD$$

where

ET = the weight of evapotranspiration;

W_1 = the weight of lysimeter at the beginning of the time period;

W_2 = the weight of lysimeter at the end of time period;

P = the weight of the precipitation falling on the lysimeter;

WA = the weight of the water added to the lysimeter;

WD = the weight of water drained from the lysimeter.

Note that the water drained is ignored if it is drained between the final weighing in period one and the first weighing of period two. All quantities are for the same time period and have the same units. The normal time period is one week. The ET is then transformed from a weight per time period to inches per day.

An example set of field data is presented in Table 10. The information for each column is always collected in the same sequence each week and follows the sequence of the table columns from left to right. All measurements should be taken at approximately the same time of day. Note that not all the units are in terms of weight. All units are transformed to a weight basis in the calculation procedure.

A sample calculation follows Table 10.

Table 10. Example set of data for determining evapotranspiration

Date	Precipitation (inches)	Weight (lb)	Water Added (liters)	Comments
September 2, 1976	0.35	156.5	1.000	--
September 6, 1976	--	--	1.000	--
September 9, 1976	0.22	154.2*	--	Drained**
September 9, 1976	--	151.6	1.5	--

*This is the final weight used in calculating the ET during the period from September 2, 1976, to September 9, 1976.

**When a lysimeter is drained between the last weighing of the previous period and before the first weighing of the present period, the weight loss does not enter into the calculation of ET for either period.

Sample calculation:

Calculation of ET for the period September 2-9, 1976

Initial weight + 156.5

Water Added + 4.4 (2.00 liters)

Precipitation + 0.9 (0.22 inches)

Final Weight - 154.2

Weight of ET = 7.6 lbs = 1.86 inches

ET = 0.27 inches/day

Areas of lysimeter = 113.1 in^2