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WATER REQUIREMENTS FOR URBAN LAWNS

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Chapter 1
INTRODUCTION

This publication reports the results of a study to obtain measured data on water use of urban lawns. The specific objectives were to: (1) measure actual water requirements of lawns by the use of lysimeters, (2) monitor actual water application rates by homeowners, (3) test common lawn sprinklers to determine their distribution patterns, and (4) develop a set of lawn watering guidelines.

The study was initiated in Wyoming during the summer of 1975 supported, in part, by OWRT annual allotment funding. The study was expanded into a 3-state regional project, to include Arizona and Colorado under an OWRT matching grant beginning October 1, 1976. Each state had similar, yet distinctively separate, objectives and work plans. This publication reports on the Wyoming accomplishments. Similar reports have been prepared by Arizona and Colorado for their portions of the study.*

The study was conducted in two Wyoming cities—Laramie and Wheatland. The climatic conditions in much of the state and also much of the Western region of the nation are typified by the climate of these two communities. Laramie, at 2195 m elevation and 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. Laramie's mean annual temperature is 4.9°C with mid summer temperatures seldom reaching 32°C. The average frost free period is 113 days, and the mean annual rainfall is just over 25.4 cm. Wheatland, at 1433 m and 42°05'N latitude, lies off the eastern slope of the Laramie Range at the transition to Wyoming's eastern plains. Wheatland's mean annual temperature is 9.5°C with temperatures reaching 37°C several times a year. The average frost free period is 133 days and mean annual rainfall is just over 20.5 cm. In both towns the predominant lawn grass types grown are Kentucky bluegrass and bluegrass-fescue combinations. Soil types in both towns are mainly fine sandy loams.

This report consists of separate chapters (chapters 2 through 5) related to each of the four main objectives. Each chapter consists of a description of the methodology used in performance of each objective followed by a presentation of the results for the objective. In this manner, a reader interested in a specific objective may turn directly to the chapter dealing with that objective. The final chapter (chapter 6) presents a summary of the major findings and recommendations of the overall project.

*Contact the Water Resources Research Institutes in the respective states.

Chapter 2

WATER REQUIREMENTS

Potential evapotranspiration rates (E_{tp}) of lawn grass were measured in Laramie and Wheatland, Wyoming during the summers of 1976, 1977 and 1978. Measurements were taken using small weighable lysimeters containing Kentucky bluegrass located in lawns surrounding single family residences. The measured E_{tp} data were used to calibrate two versions of the Blaney-Criddle formula for estimating evapotranspiration. Some effort was made to calibrate additional formulas—the Thornthwaite, Olivier, Jensen-Haise, and Penman formulas (O'Neill, 1977). Limitations in availability of required climatic data—e.g. solar radiation, wind, etc.—generally make these formulas impractical for use in Wyoming, and most other areas. Thus, the latter four formulas were calibrated using only 1976 data (See O'Neill, 1977). These formulas are of some value if short term (weekly) estimates of evapotranspiration are desired. However, in the West, the Blaney-Criddle method is one of the most popular for seasonal and monthly evapotranspiration estimates and is also the method generally used in court cases transferring water rights from agricultural to municipal usages.

PROCEDURES

Potential Evapotranspiration Measurements

Potential evapotranspiration is defined herein as the evapotranspiration rate experienced when water is never a limiting factor. Potential rates were measured in order to define the water application rate above which the grass would not use additional water. Water applied at a rate in excess of the E_{tp} rate would be expected to end up as either deep

percolation or runoff. To insure that adequate moisture was always present, available moisture depletion was never allowed to exceed 35%.

Measured E_{tp} rates were intended to approximate the average city-wide values which would be expected to occur if adequate water were applied and all other factors, such as fertilization and general maintenance habits, remained unaltered. To accomplish this, three residential lawns were selected in each town. An attempt was made to select lawns to achieve a representative cross section of neighborhood types with respect to the extent of tree and shrubbery and general lawn conditions.

Five lysimeters were located in each lawn 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. The average readings of the fifteen lysimeters (3 homes, each with 5 lysimeters) in each town were used to represent the average city-wide values.

Lysimeters were installed and sodded to grass during July of 1975. The lysimeters measured 30.5 cm diameter by 70 cm deep (Fig. 2.1). They were made from polyvinyl chloride pipe and were surrounded by retaining rings made from the same material.

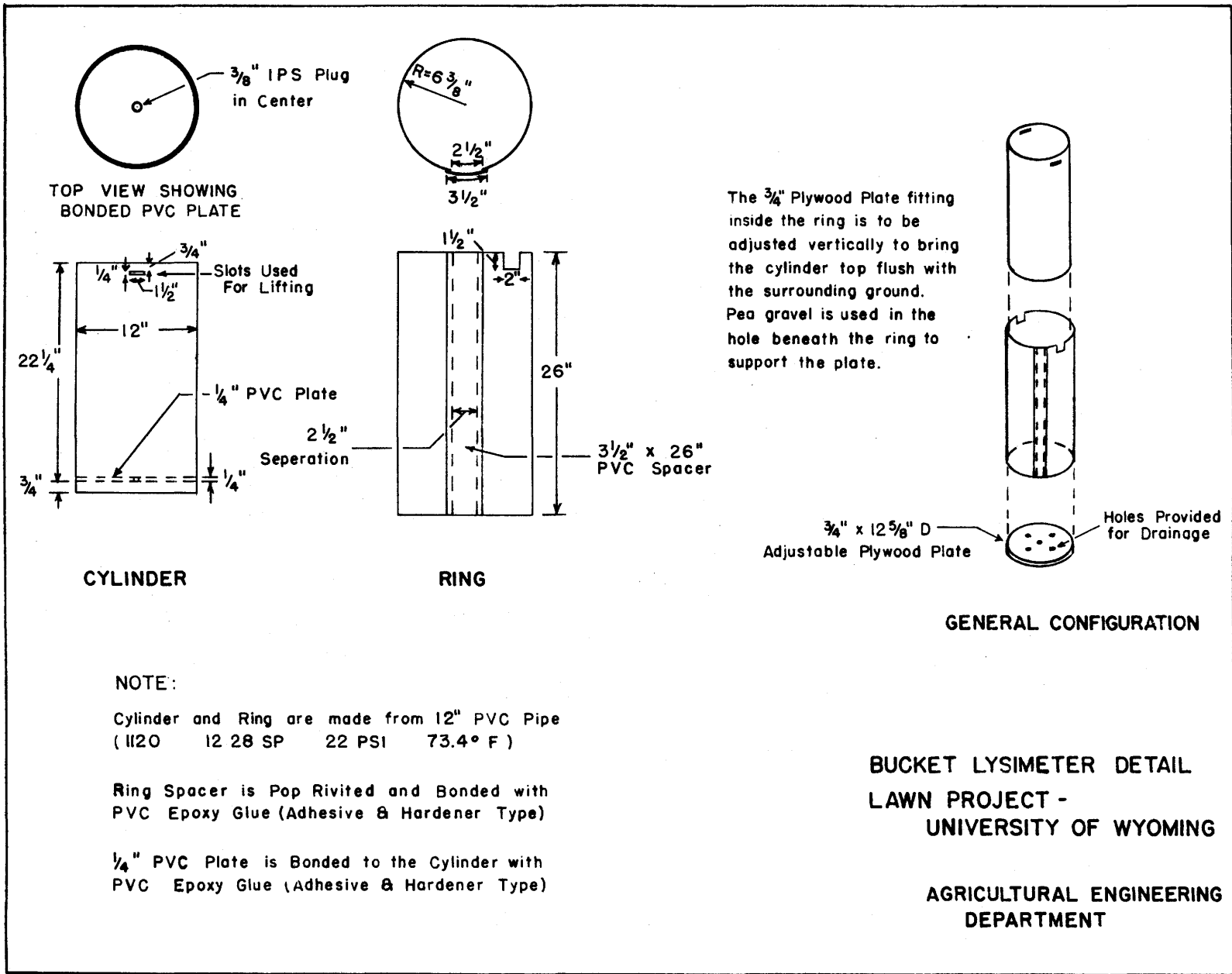


Fig. 2.1 Lysimeter Detail

Evapotranspiration measurements were made weekly. Detailed descriptions of the construction and operation of the lysimeters are given by Pochop et al. (1978).

Evapotranspiration Formulas

Two versions of the Blaney-Criddle formula, as presented by Criddle et al (1962) and the SCS (1967), were selected for calibration. The formulas were calibrated for monthly evapotranspiration estimates.

The Criddle et al. (1962) formula requires mean temperatures for the period, the percent of the yearly daytime hours occurring in the period and a consumptive use coefficient experimentally derived and particular to the crop type grown. These factors are related by:

$$u = 25.4 kf$$

where u = consumptive use, E_{tp} , for the period (mm)

$$f = \frac{(1.8t + 32)p}{100}, \text{ consumptive use factor}$$

t = mean temperature for the period ($^{\circ}\text{C}$)

p = percent of annual daytime hours occurring in the period

On a seasonal basis the equation becomes

$$U = 25.4 KF$$

where U = seasonal consumptive use (mm)

$F = \sum f$, seasonal consumptive use factor

K = seasonal consumptive use coefficient

As given by Criddle et al. (1962) the growing season length is required before the consumptive use coefficient

(k), which is dependent on the seasonal consumptive use factor F , can be determined (Fig. 2.2).

The SCS formula (1967) differs from the formula presented by Criddle et al. (1962) only in that the consumptive use coefficient k becomes the product of k_t and k_c values. The coefficient k_t is related to temperature by the equation

$$k_t = 0.0311t + 0.240$$

where k_t = temperature coefficient for the period

t = mean temperature for the period ($^{\circ}\text{C}$)

The term k_c is a crop growth stage coefficient for the period. The SCS (1967) crop growth stage curve is given in Fig. 2.3.

A detailed description of the procedures for calibrating both formulas are given in Appendix B.

RESULTS

Potential Evapotranspiration

The lysimeters were operated each year beginning in the spring at about the time frost left the soil until the end of October. Although weekly measurements were taken, monthly data (Table 2.1 through 2.3) were calculated and used for most of the formula calibrations. The original data consisting of the weekly readings for each individual lysimeter are given in Appendix B.

Comparing average values (Table 2.1) for the three years, Wheatland's seasonal (April through October) E_{tp} of 85.5 cm was only 7% higher than Laramie's seasonal E_{tp} of 79.7 cm, even though Wheatland's average seasonal temperature (Table 2.2) of 16.9°C was considerably higher than the average seasonal temperature of

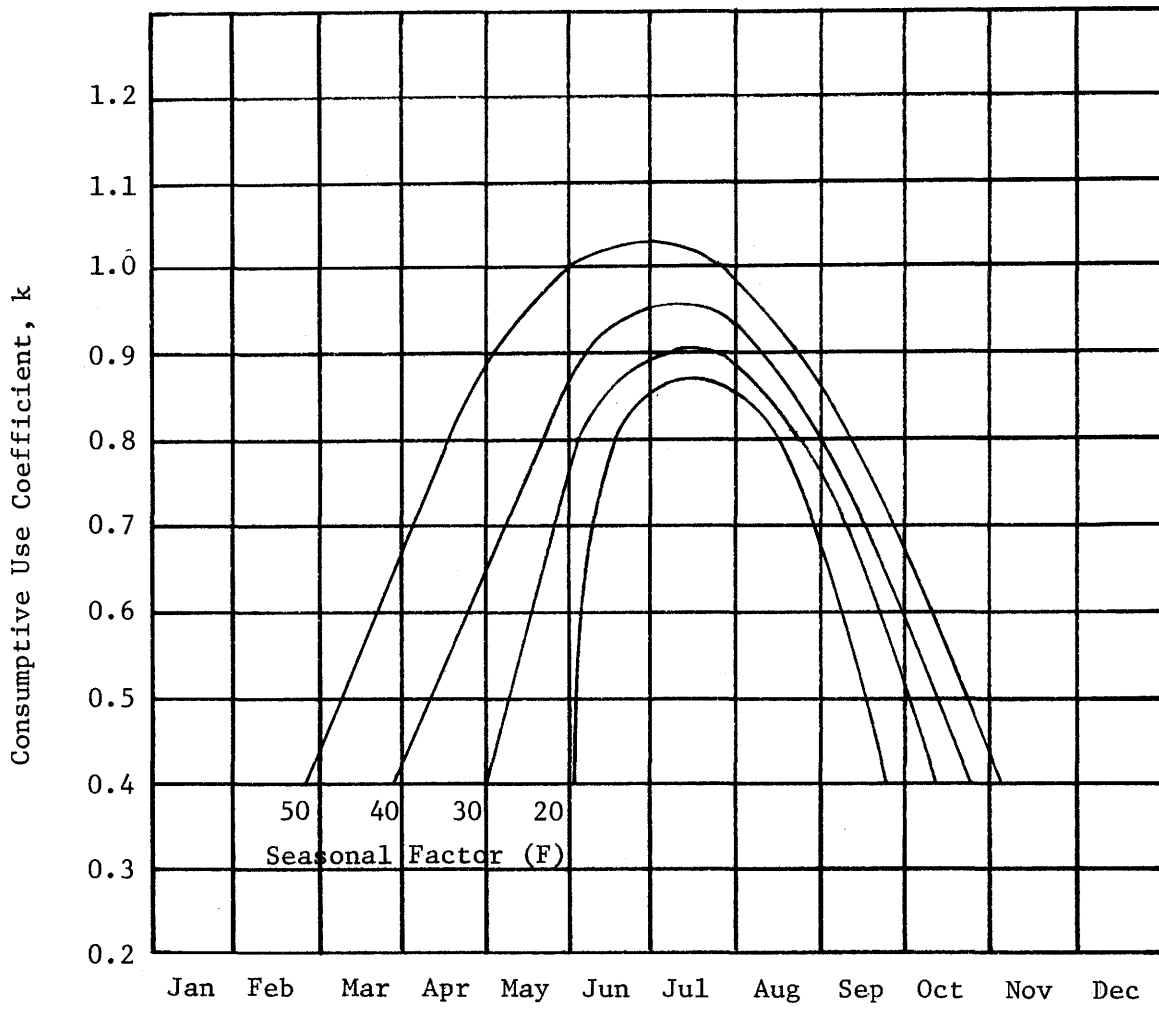


Fig. 2.2. Consumptive use coefficients for grass, hay and pasture (Criddle et al., 1962)

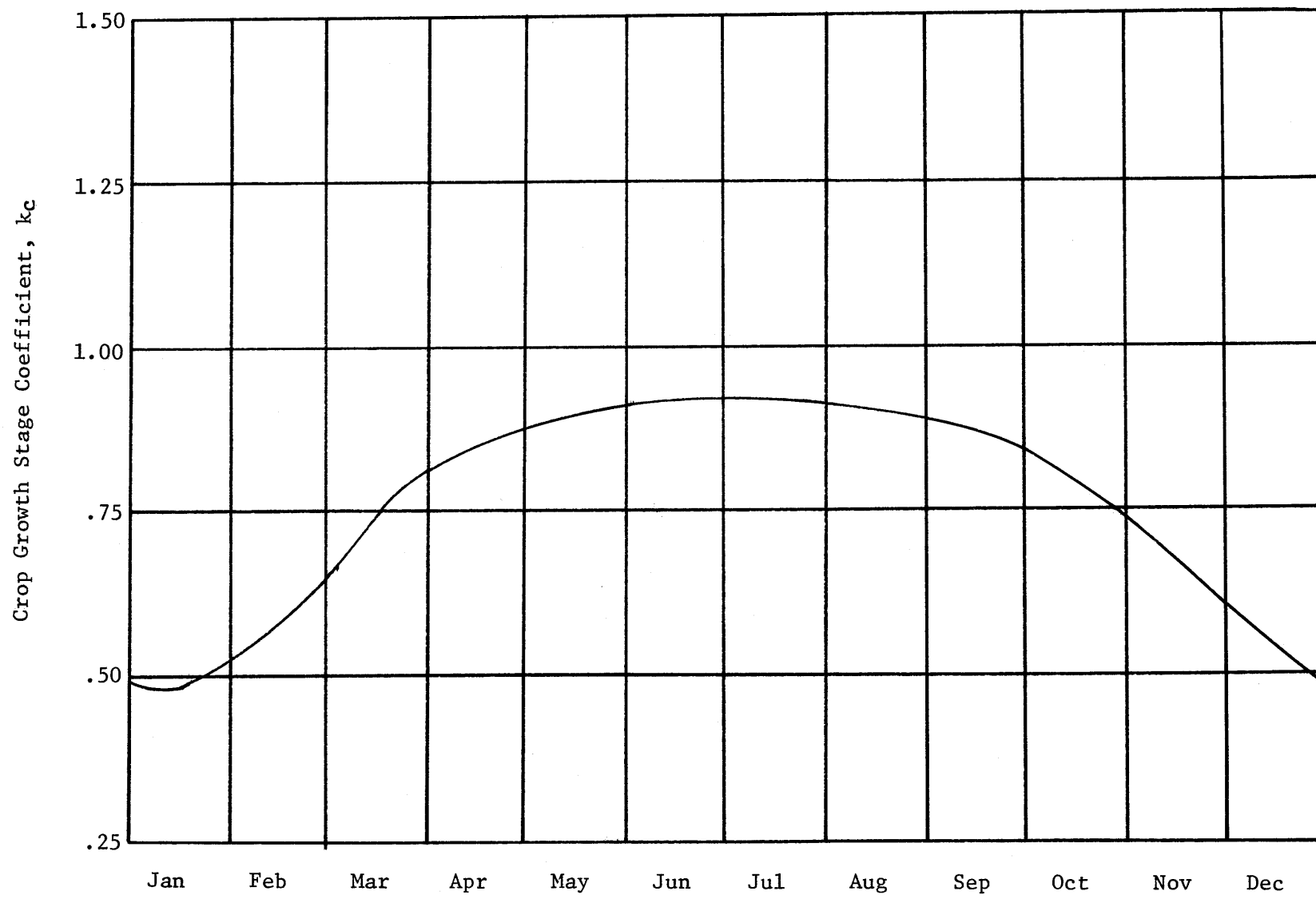


Fig. 2.3. Crop growth stage coefficient curve for pasture grasses (SCS, 1967)

Table 2.1. Measured Potential Evapotranspiration Rates (cm/month).

Month	Laramie				Wheatland			
	1976	1977	1978	Avg	1976	1977	1978	Avg
April	4.4*	3.0*	5.7	-	5.3*	6.7*	10.0	-
May	9.0	11.8	13.5	11.4	12.1	13.6	11.6	12.4
June	14.1	15.3	17.5	15.6	15.9	15.3	15.5	15.6
July	14.6	18.3	22.0	18.3	14.9	16.7	18.9	16.8
Aug	13.0	12.7	14.4	13.4	12.7	12.7	11.9	12.4
Sept	8.1	7.8	12.0	9.3	12.0	10.2	11.6	11.3
Oct	4.3	6.8	6.7	5.9	6.8	7.4	6.8	7.0
Season	69.1**	78.3**	91.8	79.7	81.6**	88.5**	86.3	85.5

* April data is from April 9-30 in 1976 and April 15-30 in 1977.

** Seasonal totals estimated by extrapolating the April data to full months.

Table 2.2. Mean Monthly Temperatures (°C)

Month	Laramie				Wheatland			
	1976	1977	1978	Avg	1976	1977	1978	Avg
April	4.3*	6.2*	4.5	-	8.7*	11.6*	8.8	-
May	8.6	9.3	7.4	8.4	13.3	14.7	11.9	13.3
June	13.5	16.9	14.3	14.9	17.7	21.1	18.5	19.1
July	18.9	18.4	18.5	18.6	22.8	23.1	22.6	22.8
Aug	16.3	16.1	16.0	16.2	20.2	20.1	19.4	19.9
Sept	11.8	13.3	12.4	12.5	15.3	17.5	16.4	16.4
Oct	4.0	6.7	5.8	5.5	7.8	11.2	10.2	9.7
Seasonal** Avg.	12.2	13.5	12.4	12.7	16.2	18.0	16.5	16.9

* April data is from April 9-30 in 1976 and April 15-30 in 1977.

** Average is for May through October.

Table 2.3. Monthly Precipitation (cm).

Month	Laramie				Wheatland			
	1976	1977	1978	Avg	1976	1977	1978	Avg
April	1.70*	0.89*	1.07	-	4.39*	3.61*	2.13	-
May	2.08	2.16	6.45	3.56	6.65	2.41	9.80	6.29
June	2.01	1.50	1.22	1.58	0.91	10.16	1.85	4.31
July	4.39	10.16	1.17	5.24	4.11	8.05	1.98	4.71
Aug	2.92	3.33	1.57	2.61	1.12	2.51	6.78	3.47
Sept	0.23	1.42	0.74	0.80	1.42	0.00	2.08	1.17
Oct	0.43	0.43	1.98	0.95	0.84	0.56	2.03	1.14
Seasonal Total	13.76	19.89	14.20	-	19.44	27.30	26.65	-

* April data is from April 9-30 in 1976 and April 15-30 in 1977.

12.4°C in Laramie. In fact, in the two warmest months of July and August the three-year average E_{tp} in Laramie was greater than in Wheatland, even though the mean monthly temperatures were higher in Wheatland than in Laramie. A possible explanation for the lower E_{tp} in Wheatland during this period is the tendency for Kentucky bluegrass to go into a semi-dormant condition during hot weather (Billick, 1973). When in this semi-dormant condition, grass transpires less water. In general, it appears that for given conditions there is an optimum temperature at which Kentucky bluegrass transpires maximum water. Above or below this temperature the transpiration rate decreases. The consistent higher E_{tp} rates in spring and fall and lower E_{tp} rates in summer in Wheatland vs Laramie support this observation.

Formula Calibration

Criddle et al. formula. As stated previously, determination of the consumptive use coefficient (k) in the Criddle et al. (1962) formula requires definition of the seasonal consumptive use factor F which is dependent on the growing season length. The growing season for lawn grass was defined herein as the period between the last occurrence in the spring and the first occurrence in the fall of three consecutive days of sub 4.5°C mean temperatures (Table 2.4). The seasonal consumptive use factors (F) were then determined for each year at both Laramie and Wheatland (Table 2.5).

To calibrate the Criddle et al. (1962) formula, lawn grass consumptive use curves were developed (see Appendix B for a detailed description of the calibration procedure). These curves are specifically for Kentucky bluegrass grown in an urban setting. Monthly k values, referred to as "calculated" k values, were first determined using measured monthly u and the

relationship:

$$\text{Calculated } k = \frac{u}{25.4f}$$

Calculated k values are given in Table 2.6 (note, each column corresponds to a particular F factor).

Considerable variation exists between the calculated k values (Table 2.6) and the k values from the Criddle et al. (1962) curves (Fig. 2.2). There are also irregularities in the calculated k values from year to year and for specific F factors. These irregularities can be attributed to (1) the natural variation in climatic conditions that occur from year to year, and (2) the semidormancy found in Kentucky bluegrass (Billick, 1973) during periods of high temperatures. To compensate for these irregularities, smooth curve approximations were made for the calculated k values that conform to the general model (that is, low k values corresponding to small seasonal F factors and high k values for large seasonal F factors) of Criddle et al. (1962). Criddle k values (Table 2.7) were regressed against calculated k values (Table 2.6) for all the F factors concurrently, although the final calibrated consumptive use coefficients are given for specific F factors. The resulting equation used for calibration was

$$k_{calb} = 0.5630 + 0.4090k_{crid}$$

where k_{calb} is the calibrated consumptive use coefficients and k_{crid} is the original consumptive use coefficients published by Criddle et al. (1962). The calibration results are given in Table 2.8 and Fig. 2.4.

The calibrated consumptive use coefficients (Fig. 2.4) are considerably different from those given by Criddle et al. for grass (Fig. 2.2). Major differences occur early and

Table 2.4. Beginning and Ending Dates of Growing Seasons.

Year	Laramie	Wheatland
1976	April 28 - Oct. 14	April 14 - Oct. 15
1977	April 21 - Oct. 29	April 5 - Nov. 7
1978	May 8 - Oct. 22	May 7 - Nov. 10

Table 2.5. Seasonal Consumptive Use Factors (F).

Year	Laramie	Wheatland
1976	30	37
1977	33	41
1978	29	35

Table 2.6. Calculated Consumptive Use Coefficients (k_{calc}).

Month	F Values					
	29	30	33	35	37	41
April	0.63	0.66*	0.55**	0.91	0.64*	1.04**
May	1.16	0.74	0.95	0.84	0.84	0.90
June	1.17	0.97	0.99	0.91	0.93	0.84
July	1.28	0.84	0.87	0.99	0.95	0.86
Aug	0.97	0.87	0.84	0.72	0.76	0.77
Sept	1.04	0.72	1.02	0.88	0.62	0.76
Oct	0.81	0.55	0.76	0.69	0.74	0.74

* April 9 - 30, 1976
 ** April 15 - 30, 1977

Table 2.7. Criddle et al. (1962) Consumptive Use Coefficients (k_{crd})

Month	F Values					
	29	30	33	35	37	41
April	0.40	0.40	0.44	0.48	0.51	0.62
May	0.57	0.60	0.69	0.72	0.75	0.81
June	0.85	0.86	0.88	0.90	0.91	0.95
July	0.90	0.90	0.91	0.93	0.94	0.97
Aug	0.83	0.84	0.85	0.86	0.87	0.89
Sept	0.64	0.65	0.67	0.68	0.68	0.71
Oct	0.35	0.36	0.39	0.42	0.45	0.49

Table 2.8. Calibrated Consumptive Use Coefficients (k_{calb})

Month	F Values					
	29	30	33	35	37	41
April	0.73	0.73	0.74	0.76	0.77	0.82
May	0.80	0.81	0.85	0.86	0.87	0.89
June	0.91	0.91	0.92	0.93	0.94	0.95
July	0.93	0.93	0.94	0.94	0.95	0.96
Aug	0.90	0.91	0.91	0.91	0.92	0.93
Sept	0.82	0.83	0.84	0.84	0.84	0.85
Oct	0.71	0.71	0.72	0.73	0.75	0.76

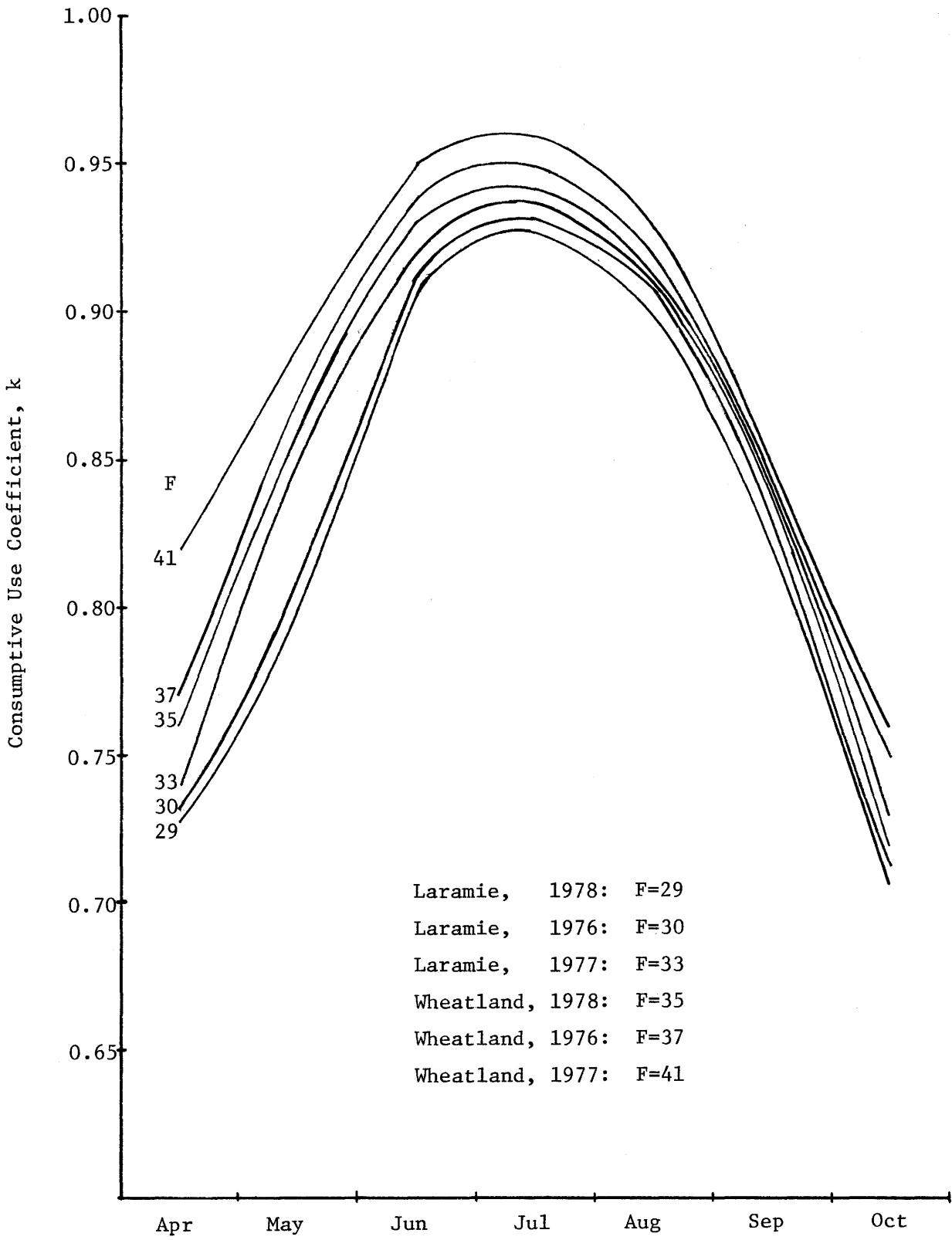


Fig. 2.4. Calibrated consumptive use coefficients for the Criddle formula

late in the growing season where the calibrated coefficients are much higher than the values given by Criddle. The values are reasonably close during the middle portion of the growing season.

SCS Formula. Criddle's curves define consumptive use coefficients that have larger values for correspondingly higher seasonal consumptive use factors. This was not found to be the case for the lawn grasses tested. For this reason the SCS (1967) version of the Blaney-Criddle formula, which uses a single empirical curve, was calibrated.

Calculated k_c values for the SCS formula were determined using monthly measured u (Table 2.1) and the equation:

$$k_c = \frac{u}{25.4k_{tf}}$$

The k_c values from the individual years were smoothed by taking the means of the three years for each town. The resulting mean values are referred to as "calibrated" k_c values. The k_c values for the 7 months are presented in Table 2.9 along with the SCS (1967) recommended values for the same period. Considerable differences occur between the calibrated and SCS values both during the spring and the fall, while midsummer values are approximately the same.

Effect of Calibration. To indicate the effect of calibration on the ability of the formulas to estimate E_{tp} , a comparison was made of the 1978 measured E_{tp} with values estimated using the original formulas and formulas calibrated with '76 - 77' lawngrass data (Tables 2.10 and 2.11). In general, the calibrated formulas give estimates that are closer to measured E_{tp} than do the original formulas.

Table 2.9 Crop Growth Stage Coefficients for SCS Formula.

Period	Calculated k_c Values						Means ("Calibrated" k_c)		SCS
	1976		1977		1978		Laramie	Wheatland	
	Laramie	Wheatland	Laramie	Wheatland	Laramie	Wheatland			
April	1.75*	1.26*	1.30**	1.73**	1.65	1.78	1.57	1.59	0.87
May	1.46	1.28	1.78	1.27	2.47	1.38	1.90	1.31	0.90
June	1.47	1.18	1.37	1.02	1.71	1.12	1.52	1.11	0.92
July	1.01	1.00	1.08	0.89	1.58	1.05	1.22	0.98	0.92
Aug	1.17	0.88	1.13	0.89	1.32	0.86	1.21	0.88	0.91
September	1.19	0.87	1.58	0.98	1.65	1.18	1.47	1.01	0.87
October	1.47	1.54	1.69	1.26	1.92	1.24	1.69	1.35	0.80

* Data for April 9-30, 1976

** Data for April 15-30, 1977

Table 2.10. Calibrated vs SCS Estimates of E_{tp} (cm)

Month	Laramie			Wheatland		
	SCS Estimates	Calibrated Estimates	Measured 1978	SCS Estimate	Calibrated Estimated	Measured 1978
April	-	-	-	-	-	-
May	4.9	8.9	13.5	7.6	10.8	11.6
June	9.4	14.5	17.5	12.7	15.2	15.5
July	12.8	14.6	22.0	16.6	16.9	18.9
Aug	10.0	12.6	14.4	12.6	12.2	11.9
Sept	6.3	10.1	12.0	8.6	9.2	11.6
Oct	2.8	5.5	6.7	4.4	7.7	6.8
Season (May-Oct)	46.2	66.2	86.1	62.5	72.0	76.3

Table 2.11. Calibrated vs Criddle et al. Estimates of E_{tp} (cm)

Month	Laramie			Wheatland		
	Criddle Estimate	Calibrated Estimate	Measured 1978	Criddle Estimate	Calibrated Estimate	Measured 1978
April	3.7	6.1	5.7	5.2	7.9	10.0
May	6.6	8.7	13.5	9.9	11.3	11.6
June	12.7	12.8	17.5	15.3	15.1	15.5
July	15.4	15.2	22.0	17.8	17.2	18.9
Aug	12.3	12.8	14.4	14.1	14.4	11.9
Sept	7.4	8.9	12.0	8.9	10.5	11.6
Oct	2.9	5.4	6.7	4.1	6.8	6.8
Season (April-Oct)	61.0	69.9	91.8	75.3	83.2	86.3

Chapter 3

APPLICATION RATES

Water application rates for residential lawns were monitored in Laramie and Wheatland during the summers of 1975 through 1978. Total residential water use was also monitored to determine household use. Appearance ratings of all lawns were made to determine the application rates required to maintain aesthetically pleasing lawns. Estimates of the amounts of overwatering and deep percolation were made, along with some water quality analyses of the percolate during 1979.

PROCEDURES

Water application rates for individual homes were monitored in Laramie and Wheatland during the summers of 1975 through 1978. Water meters were attached to all the outdoor spigots of selected homes and weekly readings were taken from approximately the last spring freeze to the first fall freeze. Total residential water use was obtained from the city water meters for each

home while precipitation data came from the National Weather Service stations in each town. Precipitation was added to the irrigation water to determine the total amount of water available to the grass.

A lawn appearance rating system was employed which rated the lawns weekly at the same time that meter readings were taken. The appearance rating considered color, thickness of grass, visibly stressed areas (dryness), and the presence of weeds but did not consider the overall aesthetic attractiveness of the landscape. The appearance rating was based on a scale of 1 to 10, with ten being excellent.

In addition to the application rates and appearance ratings, the lysimeter readings reported in Chapter 2 were used to define the actual water requirements of the grass. The potential evapotranspiration (E_{tp}) measurements were obtained on the same weekly

Table 3.1. Summary of Number of Homes Monitored and Study Periods.

Year	Laramie		Wheatland	
	Number of Homes	Study Period	Number of Homes	Study Period
1975	21	Jul 25-Aug 29	14	Jul 23-Aug 28
1976	29	May 25-Sep 7	26	May 17-Sep 23
1977	27	May 25-Sep 2	23	May 19-Sep 22
1978	28	Jun 5-Sep 1	21	May 23-Sep 5

schedule as the water application readings. These E_{tp} rates were used to define the amount of overwatering and to estimate the amount of deep percolation.

A few water quality measurements of the percolate were made for 15 lawns in Laramie. (Appendix A lists names of these cooperators). Samples were collected using suction cup lysimeters consisting of a porous ceramic cup fitted to a plastic tube sealed at the top by a one-hole rubber stopper. Four lysimeters were placed in each lawn at depths of 30, 45, 75, and 105 cm. Weekly samples were collected during the summer of 1979. The samples for all lawns were composited for each individual depth.

RESULTS

General Data

Overall summaries of the lawn water data for each year are given in Tables 3.2 through 3.7 for Laramie and Wheatland. The tables present water use data and appearance ratings for the study period each summer (beginning and ending dates of the study periods are given in Table 3.1). In addition, the number of people per home and the irrigated area for each home are listed. Weekly application rates and appearance ratings for individual homes and years are given in Appendix C.

Water Application vs. Turf Appearance

A low correlation was found between the amount of water applied and turf appearance. However, exceptionally high or low application rates did tend to cause a decrease in appearance. Tables 3.8 and 3.9 summarize the three-year water application rates and lawn appearance ratings. Of 57 homes monitored in Laramie and Wheatland, during the three year period, 17 applied water at a rate which averaged less than the average E_{tp} requirement of the grass, 9 at a rate between the E_{tp} rate and 1.25 times the E_{tp} rate, and 31 at a rate above 1.25 times the E_{tp} rate.

These three groups had average appearance ratings of 6.1, 7.2, and 6.7 respectively (Fig. 3.1). There were 8 homes that watered at a rate of at least twice the E_{tp} rate, and had an average appearance rating of 6.0. Heavy overwatering was probably an indication of overall neglect of good lawn maintenance habits and, of course, an increased leaching of nutrients. Considering low application rates, there were 8 homes that applied water at a rate of 90% E_{tp} or less and had an average appearance rating of 5.6. This would indicate a rapid drop of appearance as application rate is decreased below E_{tp} .

One of the factors which plays an important role in overwatering is the lack of knowledge regarding the amount of water that is being applied. In general, homeowners who applied water at a rate near the E_{tp} rate of the grass could maintain aesthetically acceptable lawns as readily as those homeowners who applied much greater amounts of water, yet a large number of homeowners applied excessive amounts of water (Figure 3.1). It is obvious that homeowners will usually respond to a visible water stress condition and apply water (assuming water is available and is not too expensive). On the other hand, most homeowners have little idea how much excess water they are applying.

Summer vs. Winter Household Water Use

The household water use was determined by subtracting the amount applied to the lawn from the total residential water use (Table 3.10). Summer household use was defined as the household use during the periods that lawn meters were read each year. Winter household use was determined using residential meter readings taken after the fall lawn watering season and before the spring lawn watering season. Historically, the amount of water used by residents during the winter months when no lawn watering occurs has been used to estimate the amount of water applied to lawns.

Table 3.2. Summary of Lawn Water Data, Laramie, 1976.

House No.	Total Use (m ³)	Household Use (m ³)	Lawn Use (m ³)	Study Period (days)	Water Applied (cm)	Water App. + Prec. (cm/day)	Avg. Seasonal Appearance Rating	Lawn Use Total Use (%)	Total Use (lpcd)	Household Use (lpcd)	No. of People per home	Irrigated Area (m ²)
2	257.91	68.15	189.76	105	45.26	.53	7.7	74	1226	326	2	419
3	352.58	64.18	288.40	105	51.99	.61	8.9	82	1117	204	3	555
4	293.39	76.85	216.54	105	32.79	.43	9.4	74	700	182	4	661
6	425.88	139.88	285.99	105	56.31	.64	8.7	67	1014	333	4	508
7	514.12	117.85	396.27	105	93.42	.99	9.0	77	1631	375	3	424
8	300.26	77.74	222.52	105	37.69	.46	8.9	74	477	125	6	590
9	172.45	38.33	134.12	105	35.81	.46	6.8	78	1643	363	1	375
10	247.63	86.40	161.23	105	52.71	.61	6.3	65	1181	204	2	306
11	276.68	117.81	158.87	105	38.25	.48	7.9	57	1317	560	2	416
12	173.64	68.66	104.98	105	37.11	.46	7.7	60	553	212	3	283
13	685.21	39.33	695.87	105	79.76	.86	8.1	94	3263	185	2	810
14	562.39	113.89	448.50	105	101.35	1.07	7.1	80	1071	178	5	443
15	254.26	21.25	233.01	105	40.06	.48	7.3	92	1211	102	2	582
16	580.33	23.16	557.17	105	82.30	.89	6.7	96	1768	72	3	677
17	300.87	22.05	278.82	105	49.30	.58	5.9	93	715	53	4	566
18	--*	--	332.32	105	67.36	.74	9.3					493
19	451.98	121.80	330.18	105	33.76	.43	5.0	73	719	193	6	979
20	437.28	40.73	396.55	105	36.91	.46	8.8	91	833	76	5	1075
21	284.26	79.47	204.80	105	30.58	.41	7.1	72	901	254	3	670
22	115.09	56.05	57.04	76	12.75	.30	5.4	50	189	185	4	447
23	234.79	106.68	128.11	90	34.06	.51	5.1	55	651	295	4	376
24	311.87	24.42	287.45	83	57.33	.81	9.2	92	3759	295	1	501
25	--	--	442.07	105	60.66	.69	6.6					729
26	272.64	105.75	166.89	83	30.45	.51	8.6	61	821	318	4	548
27	--	--	435.01	105	24.92	.36	8.6					1745
28	148.55	65.70	82.86	76	13.72	.30	4.5	56	363	288	3	604
29	140.78	60.62	80.17	76	14.88	.33	5.7	57	189	144	4	539
30	733.55	76.36	157.19	105	51.00	.58	7.1	67	443	144	5	308
31	--	--	72.54	83	26.39	.43	3.8					275

* Missing data due to inoperable meters.

Table 3.3 Summary of Lawn Water Data, Wheatland, 1976

House No.	Total Use (m ³)	Household Use (m ³)	Lawn Use (m ³)	Study Period (days)	Water Applied (cm)	Water App. + Perc. (cm/day)	Avg. Seasonal Appearance Rating	Lawn Use Total Use (%)	Total Use (lpcd)	Household Use (lpcd)	No. of People per Home	Irrigated Area (m ²)
1	618.08	201.68	416.36	139	68.73	.58	8.5	67	1113	360	4	606
2	--*	--	416.28	129	54.46	.53	6.9				4	764
3	962.66	384.66	578.00	139	53.52	.48	5.9	60	3463	1385	2	1080
5	1046.89	90.67	956.22	139	84.99	.71	7.8	91	2509	216	3	1125
6	--	--	333.58	139	39.95	.38	5.8				-	835
7	--	--	943.62	129	102.24	.89	8.5				-	923
9	629.01	44.41	647.60	129	109.68	.97	6.9	94	2684	170	2	591
10	1086.21	95.38	990.82	129	154.03	1.30	5.1	91	1684	148	5	643
11	785.70	105.75	679.64	129	101.85	.89	8.4	86	3043	409	2	667
12	--	--	425.88	129	135.03	1.14	6.3				1	315
13	327.93	88.25	239.67	105	36.47	.41	3.5	73	1563	420	2	657
15	434.98	58.47	376.50	129	124.97	1.07	9.2	86	1684	227	2	348
16	--	--	279.55	129	50.22	.48	6.1				2	557
17	795.02	112.44	682.58	129	66.32	.61	4.2	86	3081	435	2	1030
18	611.31	49.06	567.25	125	52.98	.53	5.6	93			-	1071
19	683.79	48.68	634.82	129	88.01	.79	6.4	93	2650	189	2	721
20	311.10	17.28	293.81	118	42.42	.43	4.4	94	2638	148	1	693
21	835.55	109.61	725.94	118	121.06	1.09	5.0	87	1416	185	5	600
22	563.59	36.53	527.05	118	100.23	.91	6.0	94	4777	310	1	526
23	--	--	427.53	118	121.29	1.09	6.2				1	353
24	351.45	43.10	308.36	129	98.60	.86	7.8	88	2725	333	1	313
25	--	--	480.12	125	71.90	.69	7.9				1	673
26	584.93	102.33	482.60	118	78.33	.74	4.7	83	825	144	6	616
27	436.36	86.90	349.45	129	102.59	.89	6.1	80	844	170	4	341
28	--	--	495.26	118	97.66	.89	7.1				2	507
29	--	--	1085.76	118	59.99	.58	6.8				5	1810

*Missing data due to inoperable meters.

Table 3.4. Summary of Lawn Water Data, Laramie 1977.

House No.	Total Use (m ³)	Household Use (m ³)	Lawn Use (m ³)	Study Period (days)	Water Applied (cm)	Water App. + Prec. (cm/day)	Avg. Seasonal Appearance Rating	Lawn Use Total Use (%)	Total Use (lpcd)	Household Use (lpcd)	No. of People per home	Irrigated Area (m ²)
2	--*	--	138.21	100	32.94	.43	7.7				2	419
3	273.91	62.84	211.06	100	38.02	.48	8.4	77	912	208	3	555
4	335.36	86.71	248.65	100	37.64	.48	9.4	74	840	216	4	661
6	394.42	108.76	285.69	100	56.26	.69	9.4	72	988	273	4	508
7	366.31	94.34	271.97	100	64.11	.76	8.4	74	1223	314	3	424
8	321.15	115.81	243.20	100	41.20	.53	8.3	76	534	129	6	590
9	154.38	32.24	122.14	100	32.61	.46	6.5	79	1544	322	1	375
10	193.83	86.71	107.12	100	35.03	.48	6.4	55	969	435	2	306
11	206.28	64.66	141.62	100	34.09	.46	6.0	69	1033	322	2	416
12	147.10	50.65	96.45	100	34.09	.46	7.4	66	492	170	3	283
13	651.41	49.33	602.08	100	74.35	.86	7.4	92	3259	246	2	810
14	537.25	92.42	444.83	100	100.51	1.12	7.4	83	1075	185	5	443
15	217.23	16.98	200.26	100	34.42	.46	4.8	92	1086	83	2	582
16	627.20	19.81	607.39	100	89.71	1.02	6.0	97	6272	197	1	677
17	347.80	64.60	283.20	100	50.09	.64	6.9	81	871	163	4	566
18	--	--	293.14	100	59.41	.71	7.9				3	493
19	429.65	123.83	305.83	100	31.27	.51	4.7	71	715	208	6	979
21	--	--	255.80	100	38.20	.51	5.3				2	670
22	131.81	57.18	74.63	100	16.69	.28	6.1	57	329	144	4	447
23	194.67	56.48	126.84	100	33.73	.46	5.4	65	488	170	4	376
24	280.14	22.04	258.14	100	51.49	.64	9.2	92	2801	220	1	501
25	--	--	358.28	100	49.15	.61	5.5					729
26	314.91	95.65	219.26	100	40.01	.53	6.5	70	787	238	4	548
27	--	--	605.18	100	34.67	.46	8.4					1745
28	184.74	45.06	139.68	100	23.14	.36	6.1	76	617	151	3	604
29	219.89	89.03	130.86	100	24.28	.36	4.3	60	549	223	4	539
30	305.28	67.68	237.61	100	77.00	.89	7.7	78	765	170	4	308

* Missing data due to inoperable meters.

Table 3.5 Summary of Lawn Water Data, Wheatland, 1977

House No.	Total Use (m ³)	Household Use (m ³)	Lawn Use (m ³)	Study Period (days)	Water Applied (cm)	Water App. + Prec. (cm/day)	Avg. Seasonal Appearance Rating	Lawn Use Total Use (%)	Total Use (lpcd)	Household (pcd)	No. of People per home	Irrigated Area (m ²)
1	481.38	142.36	339.02	126	55.96	.58	8.8	70	954	284	4	606
2	--*	--	423.84	126	55.45	.58	7.0				4	764
3	616.66	300.56	316.10	126	29.26	.38	4.4	51	2449	1192	2	1080
5	890.36	72.43	817.93	126	72.69	.71	8.2	92	2354	193	3	1125
6	--	--	167.77	126	20.07	.30	5.6				2	835
7	--	--	790.75	126	85.67	.81	8.0				2	923
9	463.10	80.58	382.52	126	64.77	.66	7.0	83	1840	318	2	591
10	745.80	73.15	672.66	126	104.55	.97	7.8	90	1185	117	5	643
11	479.45	98.27	381.18	105	57.12	.71	7.7	80	2282	469	2	667
12	--	--	324.17	126	102.77	.97	4.7				1	315
13	--	--	292.44	126	44.50	.48	7.1				2	657
15	388.12	65.36	322.76	126	107.11	.99	7.4	83	1540	261	2	301
16	--	--	308.77	126	55.47	.58	5.1				2	557
17	679.88	74.77	605.11	126	58.78	.61	4.7	89	2699	295	2	1030
18	--	--	575.61	126	53.77	.56	4.8				2	1071
19	483.81	31.25	462.56	126	64.14	.66	6.7	94	1961	125	2	721
20	199.36	17.43	181.93	126	26.26	.36	4.4	91	1582	140	1	693
22	--	--	418.30	126	79.53	.76	7.0				1	526
23	359.31	11.70	347.61	126	98.60	.91	6.9	97	2850	95	1	353
25	--	--	295.62	126	43.14	.48	7.0				1	673
27	603.68	82.09	521.59	126	153.14	1.35	6.7	86	1196	163	4	341
28	--	--	374.93	126	73.96	.74	7.3				2	507
29	657.17	154.59	502.58	126	27.76	.36	6.8	76	1045	246	5	1810

*Missing data due to inoperable meters.

Table 3.6. Summary of Lawn Water Data, Laramie, 1978.

House	Total Use (m ³)	Household Use (m ³)	Lawn Use (m ³)	Study Period (days)	Water Applied (cm)	Water App. + Prec. (cm/day)	Avg. Seasonal Appearance Rating	Lawn Use Total Use (%)	Total Use (lpcd)	Household (lpcd)	No. of People per home	Irrigated Area (m ²)
2	191.77	48.33	143.44	88	34.21	.46	7.0	75	1090	276	2	419
3	--*	--	210.87	78	54.61	.76	7.6	--	--	--	3	386
4	329.17	84.14	245.02	88	37.11	.48	8.1	74	935	238	4	661
6	406.60	108.61	297.99	88	58.67	.74	7.8	73	1154	310	4	508
7	315.31	46.01	269.30	88	63.47	.79	7.1	85	1196	174	3	424
8	368.05	83.13	284.92	88	48.26	.61	7.7	77	696	159	6	590
9	--	--	101.41	57	27.08	.56	7.0	--	--	--	1	375
10	215.64	57.06	158.58	71	51.84	.79	5.8	74	1518	401	2	306
11	207.77	56.57	151.19	88	36.40	.48	6.0	73	1181	322	2	416
12	227.85	48.71	179.14	85	39.70	.53	8.0	79	893	189	3	451
13	679.76	54.16	625.60	88	77.24	.94	7.3	92	3861	307	2	810
14	552.59	69.81	482.78	88	109.07	1.30	6.5	87	1257	159	5	443
15	221.53	23.13	198.40	88	34.09	.46	5.2	90	1260	132	2	582
16	696.83	20.62	676.21	78	99.87	1.35	6.9	97	8933	265	1	677
18	374.96	92.32	282.64	71	57.28	.86	7.0	75	1760	435	3	493
19	489.16	107.81	381.35	88	38.99	.51	4.9	78	927	204	6	979
20	519.37	85.12	434.25	78	40.41	.58	7.8	84	1332	220	5	1075
21	318.41	61.96	256.45	88	38.28	.48	5.9	81				670
22	171.68	51.65	120.03	71	26.82	.46	5.7	70	606	182	4	447
23	172.97	64.12	108.85	88	28.93	.38	5.3	63	492	182	4	376
24	282.10	19.21	262.89	78	52.43	.74	8.1	93	3618	246	1	501
25	--	--	510.44	88	70.03	.86	6.5	--	--	--		729
26	303.22	88.67	214.55	85	39.14	.51	6.1	71	893	261	4	548
27	--	--	443.32	88	25.40	.36	--	--	--	--	1	1745
28	233.63	35.43	198.20	85	32.82	.43	7.2	85	916	140	3	604
29	194.88	82.49	112.39	85	20.85	.30	4.3	58	572	242	4	539
30	342.05	76.01	266.04	88	86.33	1.04	7.0	78	973	216	4	308
32	--	--	256.45	85	51.64	.66	5.4	--	--	--	1	497

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* Missing data due to inoperable meters.

Table 3.7. Summary of Lawn Water Data, Wheatland, 1978.

House No.	Total Use (m ³)	Household Use (m ³)	Lawn Use (m ³)	Study Period (days)	Water Applied (cm)	Water App. + Prec. (cm/day)	Avg. Seasonal Appearance Rating	Lawn Use Total Use (%)	Total Use (lpcd)	Household Use (lpcd)	No. of People per home	Irrigated Area (m ²)
1	-- *	--	306.17	105	50.52	.58	6.9	--	--	--	4	606
2	197.73	75.00	122.73	98	16.05	.25	7.2	62	503	193	4	764
3	--	--	325.13	105	30.10	.38	5.4	--	--	--	2	1080
5	--	--	690.01	105	61.32	.69	7.4	--	--	--	3	1125
6	--	--	240.32	70	28.78	.51	6.4	--	--	--	2	835
7	--	--	660.41	105	71.55	.79	8.1	--	--	--	2	923
9	465.43	48.32	417.12	105	70.64	.76	7.6	90	2218	231	2	591
10	--	--	982.36	105	152.70	1.55	4.1	--	--	--	5	643
12	--	--	309.51	105	98.12	1.04	5.1	--	--	--	1	315
13	444.36	119.21	325.15	105	49.48	.58	7.4	73	2116	568	2	657
15	366.31	51.74	314.58	98	104.39	1.17	7.0	86	1870	265	2	301
16	--	--	348.40	105	62.59	.69	5.5	--	--	--	2	557
18	--	--	718.00	98	67.08	.79	6.1	--	--	--	2	1071
19	542.90	55.52	487.38	105	67.56	.74	5.9	90	2585	265	2	721
20	213.86	18.12	195.73	105	28.24	.38	5.6	92	2036	174	1	693
22	--	--	311.71	105	59.26	.66	6.4	--	--	--	1	526
23	--	--	337.73	105	95.81	1.02	6.2	--	--	--	1	353
25	--	--	408.84	105	60.78	.69	6.2	--	--	--	1	673
26	--	--	205.17	98	53.37	.64	5.7	--	--	--	6	385
27	487.78	50.91	436.87	91	128.27	1.50	5.9	90	1340	140	4	341
30	--	--	282.31	77	57.15	.84	7.3	--	--	--	4	494

* Missing data due to inoperable meters.

Table 3.8. Summary of Lawn Water Application Rates (1976-1978)

Home ††	Laramie				Home ††	Wheatland			
	Water Depth Applied** (cm/day)					Water Depth Applied (cm/day)			
	1976*	1977*	1978*	3-Year Average		1976*	1977*	1978*	3-Year Average
2	0.53	0.43	0.46	0.48	1	0.58	0.58	0.58	0.58
3	0.61	0.48	0.76	0.61	2	0.53	0.58	0.25	0.46
4	0.43	0.48	0.48	0.46	3	0.48	0.38	0.38	0.41
6	0.64	0.69	0.74	0.69	5	0.71	0.71	0.69	0.71
7	0.99	0.76	0.79	0.84	6	0.38	0.30	0.51	0.41
8	0.46	0.53	0.61	0.53	7	0.89	0.81	0.79	0.84
9	0.46	0.43	0.56	0.48	9	0.97	0.66	0.76	0.79
10	0.61	0.46	0.79	0.61	10	1.30	0.97	1.55	1.27
11	0.48	0.46	0.48	0.48	11	0.89	0.71		0.81
12	0.46	0.46	0.53	0.48	12	1.14	0.97	1.04	1.04
13	0.86	0.86	0.94	0.89	13	0.41	0.48	0.58	0.48
14	1.07	1.12	1.30	1.17	15	1.07	0.99	1.17	1.07
15	0.48	0.46	0.46	0.46	16	0.48	0.58	0.69	0.58
16	0.89	1.02	1.35	1.09	17	0.61	0.61		0.61
17	0.58	0.61		0.61	18	0.53	0.56	0.79	0.64
18	0.74	0.71	0.86	0.76	19	0.79	0.66	0.74	0.74
19	0.43	0.43	0.51	0.46	20	0.43	0.36	0.38	0.38
20	0.46		0.58	0.53	21	1.09			1.09
21	0.41	0.51	0.48	0.46	22	0.91	0.76	0.66	0.79
22	0.30	0.28	0.46	0.36	23	1.09	0.91	1.02	1.02
23	0.51	0.46	0.38	0.46	24	0.86			0.86
24	0.81	0.64	0.74	0.74	25	0.69	0.48	0.69	0.61
25	0.69	0.61	0.86	0.71	26	0.74		0.64	0.69
26	0.51	0.51	0.51	0.51	27	0.89	1.35	1.50	1.24
27	0.36	0.46	0.36	0.38	28	0.89	0.74		0.81
28	0.30	0.36	0.43	0.36	29	0.58	0.36		0.48
29	0.33	0.36	0.30	0.33	30			0.84	0.84
30	0.58	0.89	1.04	0.84					
31	0.43			0.43					
32			0.66	0.66					
Avg.†	0.61	0.58	0.66	0.61	Avg.†	0.86	0.69	0.76	0.76
Water Requirement of Grass (cm/day)					Water Requirement of Grass (cm/day)				
Avg.†	0.44	0.46	0.58	0.51	Avg.†	0.46	0.46	0.48	0.46

* Study period changes each year and is different for each city (Refer to the annual summaries).

** Water depth applied includes precipitation.

† Yearly averages are for the full study period each year (Refer to the annual summaries).

†† Missing numbers represent homes dropped from the study.

Table 3.9. Summary of Lawn Appearance Ratings (1976-1978)

Home †	Laramie				Home †	Wheatland			
	Average Appearance Rating*					Average Appearance Rating*			
	1976	1977	1978	3-Year Average		1976	1977	1978	3-Year Average
2	7.7	7.7	7.0	7.5	1	8.5	8.8	6.9	8.1
3	8.9	8.4	7.6	8.3	2	6.9	7.0	7.2	7.0
4	9.4	9.4	8.1	9.0	3	5.9	4.4	5.4	5.2
6	8.7	9.4	7.8	8.6	5	7.8	8.2	7.4	7.8
7	9.0	8.4	7.1	8.2	6	5.8	5.6	6.4	5.9
8	8.9	8.3	7.7	8.3	7	8.5	8.0	8.1	8.2
9	6.8	6.5	7.0	6.8	9	6.9	7.0	7.6	7.2
10	6.3	6.4	5.8	6.2	10	5.1	2.8	4.1	4.0
11	7.9	6.0	6.0	6.6	11	8.4	7.7		8.1
12	7.7	7.4	8.0	7.7	12	5.3	4.7	5.1	5.0
13	8.1	7.4	7.3	7.6	13	3.5	7.1	7.4	6.0
14	7.1	7.4	6.5	7.0	15	9.2	7.4	7.0	7.9
15	7.3	4.8	5.2	5.8	16	6.1	5.1	5.5	5.6
16	6.7	6.0	6.9	6.5	17	4.2	4.7		4.5
17	5.9	6.9		6.4	18	5.6	4.8	6.1	5.5
18	9.3	7.9	7.0	8.1	19	6.4	6.7	5.9	6.3
19	5.0	4.7	4.9	4.9	20	4.4	4.4	5.6	4.8
20	8.8	9.0	7.8	8.5	21	5.0			5.0
21	7.1	5.3	5.9	6.1	22	6.0	7.0	6.4	6.5
22	5.4	6.1	5.7	5.7	23	6.2	6.9	6.2	6.4
23	5.1	5.4	5.3	5.3	24	7.8			7.8
24	9.2	9.2	8.1	8.8	25	7.9	7.0	6.2	7.0
25	6.6	5.5	6.5	6.2	26	4.7	7.5	5.7	6.0
26	8.6	6.5	6.1	7.1	27	6.1	6.7	5.9	6.2
27	8.6	8.4		8.5	28	7.1	7.3		7.2
28	4.5	6.1	7.2	5.9	29	6.8	6.8		6.8
29	5.7	4.3	4.3	4.8	30		2.8	7.3	5.1
30	7.1	7.7	7.0	7.3					
31	3.8			3.8					
32		4.1	5.4	4.8					
Avg.	7.3	6.9	6.6	6.9	Avg.	6.4	6.3	6.4	6.4

* Appearance rating is based on a scale from 1 to 10, with 10 being best. The appearance rating was done by visual inspection and considered color, thickness of grass, and the presence of weeds.

† Missing numbers represent homes dropped from the study.

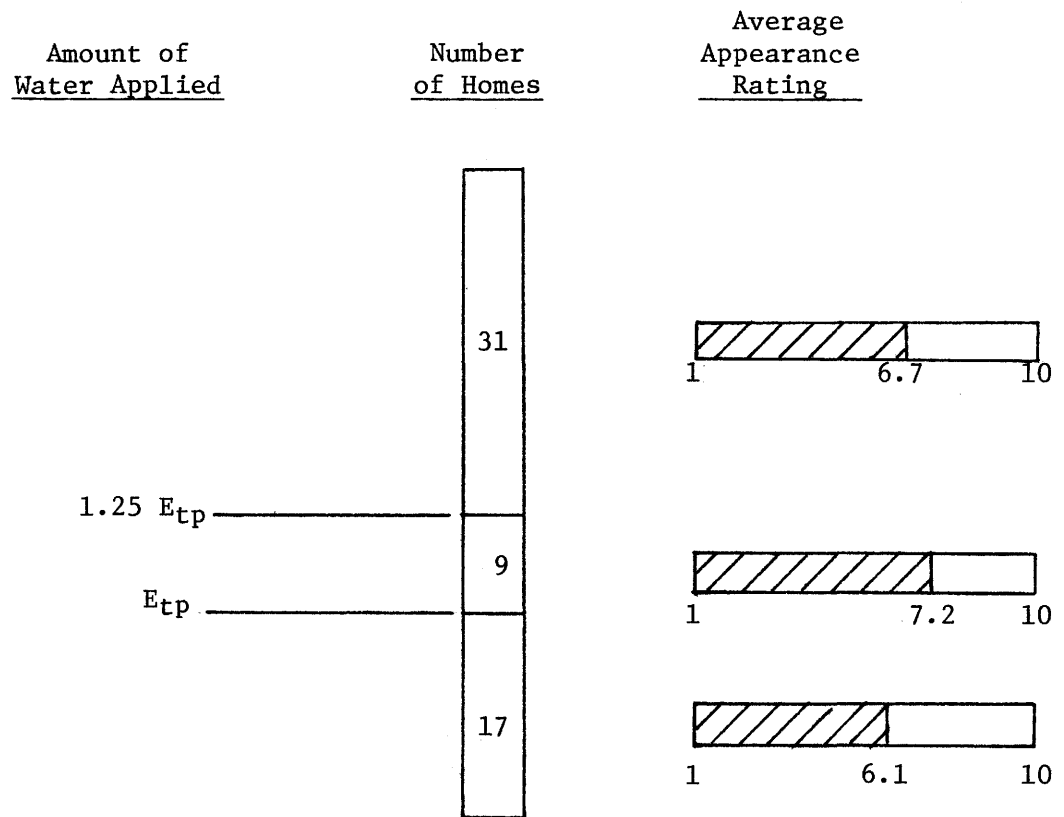


Figure 3.1. Comparison of amount of water applied and lawn appearance.

Table 3.10. Summer vs Winter Household Water Use (lpcd).

Laramie							
House No.	Summer			Winter		Averages	
	1976	1977	1978	1976-77	1977-78	Summer	Winter
4	182	216	238	235	220	212	227
7	375	314	174	477	428	288	454
8	125	129	159	136	144	136	140
10	204	435	401	401	435	348	420
11	560	322	322	356	314	401	337
13	185	246	307	458	193	246	326
14	178	185	159	280	250	174	265
15	102	83	132	76	61	106	68
16	220	197	265	174	367	227	273
19	193	208	204	223	117	201	170
22	185	144	182	185	182	170	184
23	295	170	182	208	185	216	197
24	295	220	246	299	424	254	363
26	318	238	261	269	295	273	284
28	288	151	140	170	117	193	144
29	144	223	242	227	238	204	235
30	144	170	216	348	155	178	254
Laramie Avg.	234	215	225	266	243	225	255

Wheatland							
House No.	Summer			Winter		Averages	
	1976	1977	1978	1976-77	1977-78	Summer	Winter
9	170	318	231	348	288	240	318
10	148	117	-	257	136	133	246
13	420	-	568	632	534	494	583
15	227	261	265	265	265	251	265
19	189	125	265	299	295	193	297
20	148	140	174	507	238	154	372
Combined Avg.	230	210	242	297	256	228	277

The household use which is defined during the winter months is assumed to be constant year-round. The household rate is then subtracted from the summer residential use rate to estimate lawn water use. This is known as the "Winter Base Rate" method (Cotter and Croft, 1974).

The data in Table 3.10 was analyzed on the basis of Laramie alone and with Laramie and Wheatland combined. Wheatland was not considered by itself due to the small number of homes for which good data was available. Several of the city meters in Wheatland were found to be defective, leading to an inability to estimate household water use for many homes.

Winter household use was shown to be higher than summer household use. A paired-sample t-test gave a significant difference at the 95 percent confidence level when data from the two cities were combined. Using the paired-sample t-test for only Laramie data, no significant difference was found between winter and summer household use at the 95 percent confidence level.

The results, although not consistent on a statistical basis when comparing Laramie to the combined

data, indicate that the "Winter Base Rate" method does provide a reasonable estimate of summer lawn water use. Although the summer household use would be overestimated if using the winter household use rate as a base, the lawn water use would not be greatly underestimated using this method. The reason is that the lawn use is a relatively large percentage of the total household use during the summer period and an error in estimating the summer household use translates into a smaller percentage error in estimating the lawn water use. For example, for Laramie, lawn use ranged from 80 to 85% of total use during the study periods* (Table 3.11), while winter household use averaged 30 lpcd greater than summer household use. Using the winter household use rate as a basis for estimating summer household use gives an estimate 13% high.

$$\% \text{ Error} = \frac{255-225}{225} \times 100 = 13\%$$

However, using the 255 lpcd rather than the measured value of 225 lpcd

*The study periods did not include the early spring and late fall lawn watering seasons, which would tend to lower these percentages if included.

Table 3.11. Lawn vs Summer Household Water Use.

		Total Use (lpcd)	Lawn Use (lpcd)	Household Use (lpcd)	Lawn Use Total Use (%)
Laramie	1976	1110	883	227	80
	1977	1280	1062	218	83
	1978	1568	1339	229	85
	Avg	1320	1095	225	83
Wheatland	1976	2159	1850	309	86
	1977	1841	1541	300	84
	1978	1810	1548	262	86
	Avg	1937	1647	290	85

to estimate lawn use would have produced an error in estimating lawn use of only 3%—that is, lawn use would have been estimated as 1065 lpcd as compared to the measured value of 1095 lpcd.

$$\% \text{ Error} = \frac{1095-1065}{1095} \times 100 = 3\%$$

Overwatering and Deep Percolation

As indicated in the section entitled "Water Application vs Turf Appearance," a considerable number of homeowners overwater. The extra water either percolates into the ground water system or runs into the gutter and ends up in the sewer system. Observations indicate that not a great amount of water runs off of lawns in either city; thus most extra water would be expected to end up as deep percolation.

The amount of deep percolation (Table 3.12) was estimated by taking the three-year average seasonal evapotranspiration rate and subtracting it from the three-year average seasonal application rate, as given in Table 3.8, for each home. For those homes with application rates above the E_{tp} rate, the difference was multiplied by the home's lawn area to determine the average volume of water per day that would go to deep percolation. The average deep percolation for each town was determined by dividing the total volume of overwatering by the total lawn area of all the homes monitored.

Deep percolation averaged 0.11 cm/day and 0.22 cm/day in Laramie and Wheatland, respectively. On a city-wide basis these figures add up to a considerable amount of deep percola-

tion. For example, in Cheyenne with 50,000 population there are a reported 11,433 residential customers being served (AWWA, 1973). If the deep percolation was 0.22 cm/day (Cheyenne is probably best approximated by Wheatland's conditions), 650 m² per home, and the growing season was 140 days, then the volume of overwatering would be about 2.3×10^9 liters per season.

The volume of water entering the ground water system is not the only problem. Apparently water quality degradation is also occurring. As shown in Table 3.13, the excess water passing through the root zone dissolves salts from the soil. This is a common occurrence. Nevertheless, research has shown that smaller total amounts of salts will be dissolved if the deep percolation losses are reduced (Van Schilfgaarde, 1977).

Considerable fertilizer is also being leached from the lawn and moved into the ground water system. Shown in Table 3.14 are the NO₃-N concentrations for soil water below lawns. Ceramic suction cups were installed at various levels below the lawn to obtain samples of the water moving through and below the root zone. The root zone during the time of sampling was approximately 45 cm in depth. It is evident that considerable nitrogen is being leached below the root zone. Furthermore, the concentration of NO₃-N in the water below the root zone is far in excess of the 10 mg/l which is the maximum allowable for drinking water. Nursing mothers and young infants should be careful of drinking water from shallow aquifers beneath residential areas.

Table 3.12. Estimated Deep Percolation.

Laramie				Wheatland			
House No.	Estimated* Overwatering (cm/day)	Lawn Size (m ²)	Deep Percolation (l/day)	House No.	Estimated* Overwatering (cm/day)	Lawn Size (m ²)	Deep Percolation (l/day)
2	-0.03	419	-	1	0.12	606	727
3	0.10	555	555	2	0.00	764	0
4	-0.05	661	-	3	-0.05	1080	-
6	0.18	508	914	5	0.25	1125	2813
7	0.33	424	1399	6	-0.05	835	-
8	0.02	590	118	7	0.38	923	3507
9	-0.03	375	-	9	0.33	591	1950
10	0.10	306	306	10	0.81	643	5208
11	-0.03	416	-	11	0.35	667	2334
12	-0.03	283	-	12	0.58	315	1827
13	0.38	810	3078	13	0.02	657	131
14	0.66	443	2924	15	0.61	301	1836
15	-0.05	582	-	16	0.12	557	668
16	0.58	677	3927	17	0.15	1030	1545
17	0.10	566	566	18	0.18	1071	1928
18	0.25	493	1233	19	0.28	721	2019
19	-0.05	979	-	20	0.08	693	554
20	0.02	1075	215	22	0.33	526	1736
21	-0.05	670	-	23	0.56	353	1977
22	-0.15	447	-	25	0.15	673	1010
23	-0.05	376	-	26	0.23	616	1417
24	0.23	501	1152	27	0.78	341	2660
25	0.20	729	1458	28	0.35	507	1775
26	0.00	548	0	29	0.02	1810	362
27	-0.13	1745	-				
28	-0.15	604	-				
29	-0.18	539	-				
30	0.33	308	1016				
Totals		16629	18861			17405	37984
Avg. Deep Percolation = 0.11 cm/day				Avg. Deep Percolation = 0.22 cm/day			

* Estimated overwatering = (Seasonal Application Rate) - (Seasonal E_{tp})

Table 3.13. Total Dissolved Solids (mg/l) of Deep Percolation Water, Laramie

Date	Depth (cm)			
	30	45	75	105
June 5	2560	3320	3000	2980
June 11	1360	1670	1860	2480
June 18	--	2370	2740	2840
June 25	2580	2940	3020	3280
July 2	2470	2510	2910	3020
July 9	2540	3100	2600	3270
July 16	2310	2450	2600	2840
July 23	2330	2770	2930	3040
Average	2307	2641	2708	2969

Table 3.14. Nitrate - N (ppm) of deep percolation water, Laramie

Date	Depth (cm)			
	30	45	75	105
June 5	12.0	0.3	5.0	4.0
June 11	2.3	0.6	19.0	22.0
June 25	3.0	1.5	11.0	15.0
July 2	9.4	1.2	6.8	11.0
July 9	7.5	1.3	4.1	18.0
July 16	7.0	1.2	12.0	11.0
July 23	8.3	1.6	11.0	17.0
Average	7.1	1.1	9.8	14.0

Chapter 4

SPRINKLER TESTS

Distribution patterns of six typical types of lawn sprinklers were determined during the summer of 1977. Tests were conducted on four sprinklers from each type under three pressure levels. Christiansen's Uniformity Coefficients (UCC) were calculated for the original pattern and for various overlaps of the sprinklers. Overlaps required to achieve minimum acceptable UCC values were then determined. The pattern sizes and application rates were determined for each sprinkler at the three pressure levels.

PROCEDURES

Equipment and Layout

The various lawn sprinklers were divided into six basic types: oscillating, impact, rotating, stationary, buried head, and traveling. Four sprinklers of each type, as described in Table 4.1, were then chosen from regular production lines of sprinkler manufacturers. Each sprinkler was tested at three pressures — 69, 138, and 207 kPa — and three replications at each pressure were made. The pressures were regulated at the head of a 1.6 cm inside diameter hose 15.2 m long.

Used as a guide for sprinkler testing was the American Society of Agricultural Engineers' "Recommendation 330," Procedure for Sprinkler Distribution Testing for Research Purposes (ASAE, 1974). The Recommendation states that "a minimum of 80 collectors shall receive water during a test." To meet this criteria, a square grid pattern of collectors was used with the total grid being 29.3 m on a side. This grid was first marked off with a 1.2 m spacing between collector points. Within the large grid, two smaller grids — 7.3 m x 7.3 m and 3.7 m x 3.7 m — were then marked

off from center in increments of 0.61 m and 0.30 m, respectively. This allowed for sprinklers with either a small or large area of coverage to be tested by moving the collector cups in a relatively short time. The collectors used were plastic cups measuring 9.6 cm top inside diameter and 12.1 cm depth with a total volume of 700 ml. The lip at the top of the cups was removed to give a sharp edge to minimize deflection of water droplets.

A platform was built for the sprinklers to sit on to simulate a surface condition relative to the top of the cups. This platform was centered in the grid, and all sprinklers were operated at this level. Buried head sprinklers were recessed into the platform so the spray would come from the level of the top surface of the platform, again to simulate a lawn condition.

Traveling sprinklers were tested using a procedure differing from that of non-traveling sprinklers. A 30.5 cm wide runway was built at the height of the cups. Cups were placed in a single row, side by side, with the sprinkler runway crossing perpendicular to the center of the row. The sprinklers were started with the forward end of the spray pattern entering the cup row and were stopped when the trailing end had completely crossed the row.

All tests were conducted at low wind speeds. The maximum wind speed at which tests were run was 8.0 km per hour. The wind speed was checked throughout each test and tests were terminated during a run when wind speed was found to be at or above the 8.0 km per hour limit. Total wind run during each test was also measured.

Table 4.1. Description of Sprinklers

Buried Head

1. Metal base with plastic interchangeable orifice and no center spray adjustable screw.
2. Metal base with metal interchangeable orifice and center spray adjustable screw.
3. Rubber base with metal interchangeable orifice and center spray adjustable screw.
4. Plastic base with plastic interchangeable orifice and center spray adjustable screw.

Stationary

1. Metal base with single output hole, non-adjustable.
2. Metal base with twin output holes, non-adjustable.
3. Metal base with numerous output holes, non-adjustable.
4. Metal base with single output orifice, non-adjustable.

Impact

1. Plastic base with non-interchangeable 4.0 mm plastic orifice and adjustable lip for spray breakup.
2. Plastic base with non-interchangeable 4.0 mm metal orifice and adjustable screw for spray breakup.
3. Metal base with interchangeable 4.0 mm metal orifice and adjustable screw for spray breakup.
4. Metal base with interchangeable 4.0 mm metal orifice and adjustable screw for spray breakup.

Rotating

1. Metal base with dual arms and plastic orifice, non-adjustable.
2. Metal base with triple arms and metal orifices, non-adjustable.
3. Plastic base with triple arms and metal orifices, non-adjustable.
4. Plastic base with triple arms and plastic orifices, non-adjustable.

Oscillating

1. Metal case with metal arm and metal drilled orifices inserted.
2. Plastic case with metal arm and punched holes.
3. Plastic case with metal arm and metal drilled orifices inserted.
4. Plastic case with metal arm and metal drilled orifices inserted.

Traveling

1. Tractor type, internal gears with dual adjustable arms and plastic orifices.
 2. Tractor type, internal gears with dual adjustable arms and plastic orifices.
 3. Tractor type, external gears with dual adjustable arms and metal orifices.
 4. Tractor type, external gears with dual adjustable arms and metal orifices.
-
-

Data Analyses

The method of analyzing sprinkler tests for uniformity of distribution was adopted from Christiansen (1942). The Christiansen Uniformity Coefficient (UCC) is a numerical expression that serves as an index of uniformity for a sprinkler system's distribution.

$$UCC = 1 - \frac{\sum_{i=1}^n |X_i - \bar{x}|}{n\bar{x}}$$

where X_i = a single observation

\bar{x} = mean of the individual observations

n = the total number of observations

With this numerical value, comparisons of sprinkler patterns and determinations of how various spacings affect the resulting distribution of water could be obtained. As appears to be common practice (e.g., Hart and Heerman, 1976) 0.70 was selected as the minimum acceptable UCC value.

The data from the sprinkler runs were analyzed using a computer program developed by William E. Hart of Colorado State University and modified for use on the University of Wyoming computer. This program derives the UCC from individual sprinkler patterns with or without overlap as desired.

For calculating UCC's using the original matrices, a criterion was established to eliminate those columns and rows in the matrix which contained only overspray and were not part of the main sprinkler pattern. Generally those outer columns and/or rows in which over 50% of the cups individually contained less than 5% of the pattern's highest cup value were eliminated. However, because of their various shapes, some patterns were analyzed on an individual basis.

Ten UCC's were calculated for each test of the non-traveling sprinklers - one for the original pattern and one for each of nine different overlaps. Overlaps were considered in two different directions based on the original matrix in terms of columns and rows. Overlaps used were 25%, 50% and 75% in one direction along the columns, in one direction along the rows, and in both directions (Figure 4.1). Results when overlapping in one direction along the rows are not given herein since no significant difference existed from the results when overlapping in one direction along the columns. It should be noted that the computer program used for calculating the UCC's oriented the matrices so that the prevailing wind was from the same direction for all tests, even though the tests were run only at low wind speeds.

Since the forward movement of the traveling sprinklers provided a continuous overlap of the pattern in one direction the only additional overlaps required were in the direction perpendicular to the forward movement of the sprinklers. Thus UCC's were calculated for the traveling sprinklers for overlaps designated by 0% x 100% overlap, 25% x 100% overlap, 50% x 100% overlap, and 75% x 100% overlap where the 100% refers to the direction of forward movement.

All sprinkler tests did not produce matrices with columns and rows which could be overlapped exactly 25%, 50% or 75%. For example, if an 11 by 11 matrix were overlapped 50%, the edge of the pattern would lie between a column or row. The computer program was designed to sum those values in an overlap which fell on the same point. Therefore, the sizes of patterns which could not be overlapped evenly were rounded to the closest size which could be overlapped evenly (Table 4.2).

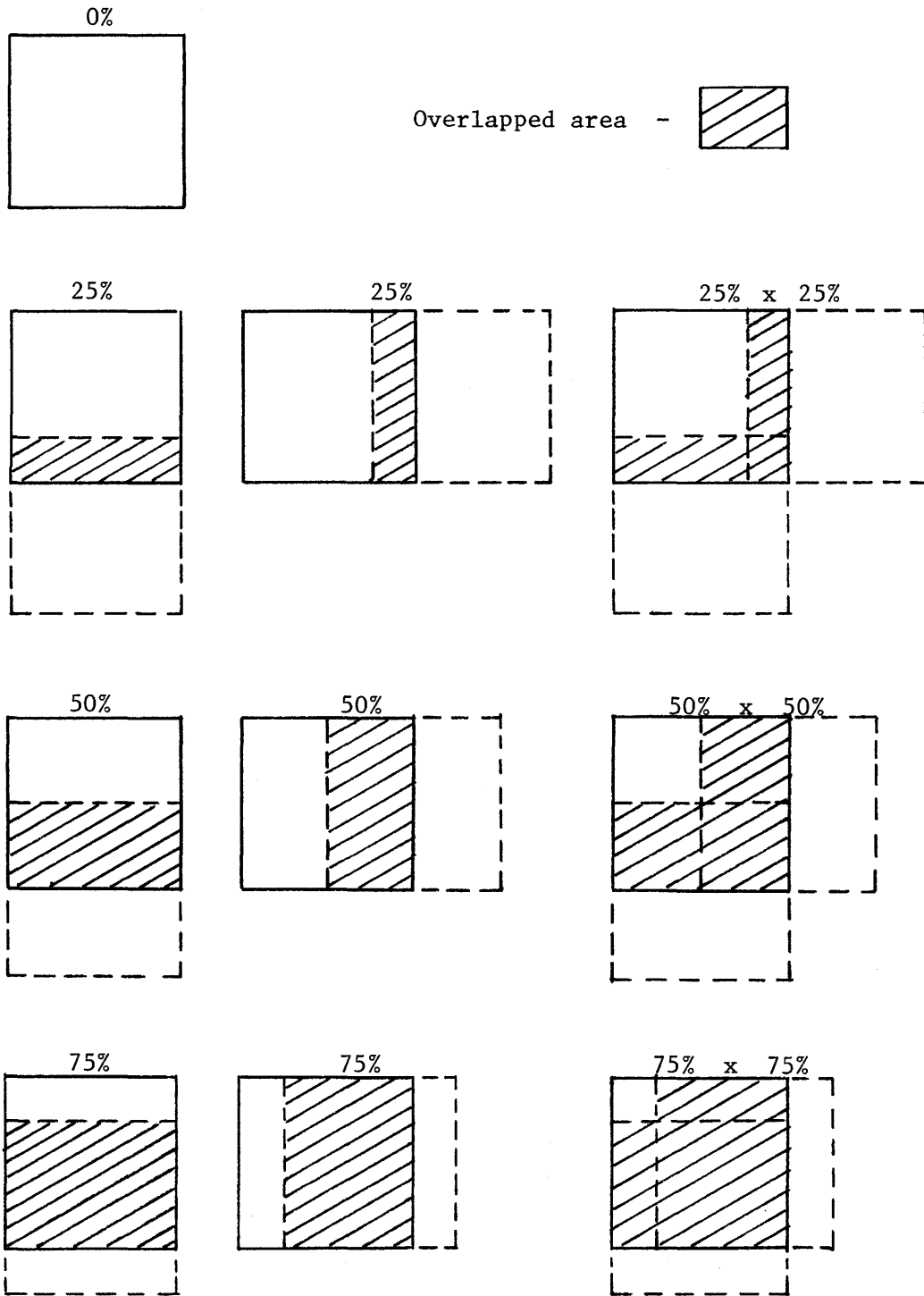


Fig. 4.1. Overlaps used for calculating UCC's.

Table 4.2. Rounding Sequence for Patterns not Overlapping Evenly

Overlap	Number of rows or columns in matrix					
None	7	9	10	11	13	14
25%	5	6	7	8	9	10
50%	4	4	5	6	6	7
75%	2	2	3	3	3	4

RESULTS

Statistical Significance

After the UCC's were calculated for all sprinkler tests, statistical comparisons of these values were obtained, thus providing a reference for determining acceptable distributions of sprinkler patterns and the various overlaps.

To compare sprinkler distributions, the two main factors of concern were the type of sprinkler and water pressure. The main effects of each factor and the interaction of the two factors were investigated. Sprinklers are manufactured by several different companies each with some differences in construction, design, or materials. It was not an objective of this study to compare sprinklers of specific companies. Therefore, a random selection of companies and sprinklers from those companies was made to obtain the sprinklers used in the study. This introduced a third factor of sprinklers nested within type which is a random effect. Thus there are three factors in the experiment—five different types of sprinklers (the sixth type, traveling sprinklers were analyzed separately), three different pressures, and four sprinklers within each type. Three replications were conducted on each of the 5 by 3 by 4 combinations for a total of 180 individual tests.

The means, sum of squares and observed F values are presented in Table 4.3 for the five non-traveling types. The estimate of the variance component $\hat{\sigma}^2_S(T)$ is listed at the bottom of each column, and the estimate of residual error variance is the R (TSP). Statistically significant differences within the factors compared are indicated by stars. The comparison of types (T) shows a significant difference for five of the seven overlaps. This difference is most predominant for the three overlaps in both directions of sprinkler patterns. Upon comparison of the UCC's with respect to pressure (P), a high level of significant difference was found for all sprinkler pattern overlaps. Little significant difference was found for the interaction of sprinkler types and pressure (T x P), meaning sprinklers generally respond the same to a change in pressure.

A high level of significant difference was found throughout all overlaps for the sprinklers within type effect S(T). The S(T) effect also indicates significant variation from sprinkler to sprinkler within type relative to the variation within the three replications of each sprinkler at the three pressure levels. The $\hat{\sigma}^2_S(T)$ variance estimate for sprinkler to sprinkler within type compared to the R(TSP) variance estimate for replications of sprinkler tests reveals this higher variation between sprinklers within type than within replications.

Table 4.3. Analysis of Variance Table for the Non-Traveling Sprinklers

Source	d.f.	Overlaps													
		0%		25%		50%		75%		25% X 25%		50% X 50%		75% X 75%	
		MSS	F	MSS	F	MSS	F	MSS	F	MSS	F	MSS	F	MSS	F
Mean	1	18.06	254.77	29.14	382.04	49.25	779.88	71.25	360.69	43.85	674.36	87.23	201.80	144.26	814.13
Type T	4	.31	*4.36	.27	*3.59	.07	1.12	.02	.78	.62	**9.48	.27	**6.89	.07	**8.77
Pressure P	2	.40	**19.40	.54	**21.77	.13	**6.85	.11	*5.28	.67	**27.30	.16	**8.64	.10	**15.20
Sprinkler S(T)15		.07	**16.85	.08	**21.53	.06	**9.43	.03	**7.74	.07	**20.06	.04	**14.07	.008	**5.63
T X P	8	.05	*2.54	.05	2.03	.03	1.68	.04	2.08	.04	1.74	.01	.62	.004	.63
SP(T)	30	.02	**4.93	.02	**7.05	.02	**2.92	.02	**5.33	.02	**7.53	.02	**6.06	.006	**4.50
R (TSP)	120	.004		.004		.007		.004		.003		.003		.001	
Estimate $\hat{\sigma}^2_{S(T)}$.0074		.0081		.0063		.0029		.0069		.0041		.0007	

* An observed F with one star indicates statistically significant difference at the .05 level

** An observed F with two stars indicates statistically significant difference at the .01 level

Mean UCC's of Non-Traveling Types

The means of the UCC's for each of the non-traveling types and overlaps are presented in Table 4.4. At the bottom of each column is the minimum difference required for two means in that column to be statistically significant at the 0.05 level, using Fisher's least significant differences.

As mentioned earlier the 0.70 minimum acceptable UCC was used as a basis for determining satisfactory performance of sprinklers. By comparing this minimum with each sprinkler's UCC means (Table 4.4), it is shown that none of these types reach the acceptable minimum UCC of 0.70 until overlapped 25% X 25%. Of the five types of sprinklers compared, only the impact shows a UCC greater than the 0.70 minimum at 25% X 25% overlap. When considering the 50% X 50% overlap, three types of sprinklers are within the minimum acceptable range. These include impact, stationary, and buried head, with the latter being on the border line. Not until the largest percentage of overlap, 75% X 75%, are all types of sprinklers considered minimally acceptable. The impact sprinkler type had the highest UCC's when overlapping was combined in both directions of the pattern.

Effects of Pressure for Non-Traveling Types

The main effects of pressure for the non-traveling sprinklers are represented in Table 4.5. Comparing the mean values of all sprinklers for each of the overlaps with the three pressure levels, UCC's for all patterns improve with increased pressure except for the 75% overlap at the 207 kPa level. The greatest overlap, 75% X 75%, gives the highest UCC's--all being well above the minimum acceptable level of 0.70. Generally an increase in pressure will give an increase in the UCC's. When comparing

UCC's for individual types, rather than for the means, some exceptions were noted.

The performances of the five non-traveling sprinkler types on an individual basis under the three pressure levels at various overlaps are also given. The mean UCC's of the three tests for each individual type at each pressure level are given. A wide variation of UCC's can be seen between the five types of sprinklers at the three pressure levels of the various overlaps. This variation is the widest at the 69 kPa level and seems to close as pressure and overlap are increased.

One sprinkler, the impact type, stands out as being affected very little or as showing a smaller variation in UCC when pressure is changed in contrast to the four other types. At 50% overlap, the stationary type also stands out as being insensitive to changes in pressure, but only at this overlap. The buried head type shows a small change in UCC at the 50% X 50% overlap when pressure is altered but shows a large UCC variation at other overlaps.

Comparisons of Traveling Sprinklers

As stated previously, forward movement of the traveling sprinklers provided a continuous overlap of their pattern in one direction and the only additional overlaps required were in the direction adjacent to the forward movement of the sprinklers. These overlaps were designated 0% X 100%, 25% X 100%, 50% X 100%, and 75% X 100%.

The mean UCC values were used to compare the traveling sprinklers with the five non-traveling types. These values at the three pressure levels (Table 4.6) show the UCC's for the traveling sprinklers comparing favorably with the values found for non-traveling types when overlapped in

Table 4.4. Means and Significant Differences of UCC's for Non-Traveling Sprinklers

Sprinkler Type	O v e r l a p s						
	0%	25%	50%	75%	25% X 25%	50% X 50%	75% X 75%
Buried head	.22a*	.34a	.47a	.65a	.43a	.69ab	.92a
Stationary	.28ab	.40ab	.57a	.66a	.50a	.73ab	.91ac
Impact	.41ab	.55b	.57a	.61a	.72b	.83b	.95a
Rotating	.25ab	.33a	.48a	.63a	.38a	.61a	.84b
Oscillating	.42b	.40ab	.53a	.60a	.44a	.63a	.85bc
	.20**	.21	.18	.13	.20	.15	.07

* Numbers within a column followed by the same letter are not significantly different at the 0.05 level.

** Amount of difference between UCC's for sprinkler types to be significantly different at the 0.05 level.

Table 4.5. UCC's at Different Pressures for the Non-Traveling Sprinklers

		O V E R L A P S						
Sprinkler type	Pressure (kPa)	0%	25%	50%	75%	25% X 25%	50% X 50%	75% X 75%
		Means of all Non- Traveling	69 138 207	.22 .35 .38	.30 .41 .49	.47 .54 .56	.58 .66 .65	.39 .49 .60
Buried Head	69	.08	.18	.38	.54	.29	.66	.86
	138	.30	.38	.54	.74	.45	.69	.93
	207	.27	.44	.50	.68	.56	.71	.95
Stationary	69	.19	.30	.54	.66	.37	.66	.87
	138	.35	.43	.57	.71	.50	.72	.92
	207	.32	.47	.57	.60	.61	.81	.95
Impact	69	.42	.53	.59	.62	.68	.82	.94
	138	.42	.55	.58	.62	.70	.81	.95
	207	.40	.56	.56	.58	.77	.85	.96
Rotating	69	.10	.17	.37	.55	.22	.53	.79
	138	.26	.31	.50	.64	.35	.63	.85
	207	.40	.51	.57	.70	.57	.67	.89
Oscillating	69	.33	.33	.49	.53	.38	.56	.79
	138	.43	.38	.51	.61	.45	.63	.86
	207	.49	.48	.61	.68	.49	.70	.91

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Table 4.6. UCC's at Different Pressures for the Traveling Sprinklers

Pressure (kPa)	O v e r l a p *			
	0% x 100%	25% x 100%	50% x 100%	75% x 100%
69	.65	.57	.67	.90
138	.61	.60	.65	.85
207	.61	.66	.68	.86

*The 100% overlap is due to the forward movement of the sprinklers

both directions. For an overlap of 25% X 100%, the traveling type shows little, if any, improvement over its original distribution pattern. For the 50% X 100% overlap, however, the UCC's border on being acceptable and exceed the minimum (0.70) at an overlap of 75% X 100%.

Analysis of Pattern Sizes and Application Rates

Pattern sizes of the individual sprinklers vary with change in pressure. The various pattern sizes covered by each sprinkler within all six types are presented in Table 4.7. In all cases the pattern size increased with an increase in pressure. The impact type in general covered the largest areas under all pressures in comparison to the other non-traveling

types. These measured areas were used for calculating the application rates.

The average application rates (Table 4.8) of the various sprinkler types were calculated from the applied volume of water that was measured with a water meter during the tests. As shown previously by the UCC's of the six sprinkler types, these applications were not evenly distributed. Upon overlapping the sprinkler patterns, however, these applications should develop more uniform coverages.

By increasing the pressure, the area covered also increases, but at the same time the application rate for that area decreases. The application rate for the sprinklers with adjustable arms or deflectors, such as the traveling or impact type, could be changed by directing the spray to cover an area of different size.

Table 4.7. Pattern Size of Sprinklers Tested

Sprinkler type	Pressure (kPa)	Pattern size for each of the four sprinklers described in Table 4.1. (meters x meters)			
Buried Head	69	4.1 x 4.1	2.7 x 3.0	*	4.0 x 4.0
	138	5.5 x 6.1	5.0 x 5.0	5.5 x 5.5	4.6 x 5.0
	207	7.9 x 7.9	6.7 x 6.7	6.7 x 7.3	6.1 x 6.7
Stationary	69	4.1 x 4.1	4.6 x 4.1	3.0 x 3.4	4.1 x 4.1
	138	6.1 x 6.7	7.3 x 6.7	3.0 x 3.4	4.1 x 4.1
	207	7.3 x 6.7	8.2 x 8.2	5.5 x 5.5	6.1 x 5.5
Impact	69	*	6.7 x 6.7	5.5 x 5.5	6.1 x 5.5
	138	11.9 x 11.9	11.0 x 11.0	12.2 x 12.2	9.1 x 9.1
	207	12.2 x 12.2	12.2 x 12.2	13.4 x 13.4	13.4 x 13.4
Rotating	69	5.0 x 5.0	4.1 x 4.1	3.4 x 3.4	3.0 x 3.0
	138	10.1 x 10.1	7.9 x 7.9	7.3 x 7.3	6.1 x 6.1
	207	13.4 x 14.6	10.1 x 10.1	10.1 x 10.1	10.1 x 10.1
Oscillating	69	4.6 x 4.6	4.1 x 4.1	6.7 x 6.1	4.6 x 4.1
	138	8.2 x 9.1	7.3 x 8.2	10.1 x 10.1	8.2 x 11.0
	207	11.0 x 11.0	9.8 x 12.2	12.2 x 13.4	13.4 x 12.2
Traveling	69	8.2	8.8	9.4	10.7
	138	10.7	13.7	13.7	14.9
	207	13.1	15.2	15.2	15.2

*Pressure too low for sprinkler operation.

Table 4.8 Application Rates for Sprinklers Tested

Sprinkler type	Pressure (kPa)	Application rates for each of the four sprinklers described in Table 4.1. (cm/hr)			
Buried Head	69	1.98	1.91	*	1.68
	138	1.55	1.07	1.75	1.75
	207	1.07	0.74	1.35	1.24
Stationary	69	3.43	2.82	6.63	1.55
	138	2.24	1.65	3.00	1.12
	207	2.11	1.55	1.96	0.91
Impact	69	*	0.84	1.14	0.97
	138	0.41	0.51	0.43	0.67
	207	0.48	0.48	0.38	0.38
Rotating	69	1.83	2.41	4.37	5.28
	138	0.74	1.17	1.47	1.96
	207	0.46	0.86	1.02	1.04
Oscillating	69	2.06	2.29	1.12	2.67
	138	0.94	1.12	0.76	0.74
	207	0.76	0.74	0.61	0.66
Traveling	69	2.62	1.52	1.65	1.60
	138	1.88	1.12	0.58	1.30
	207	0.51	0.89	0.56	1.12

*Pressure too low for sprinkler operation.

Chapter 5

LAWN WATERING GUIDELINES

A major objective of this study was to prepare lawn watering guidelines that could be used to conduct educational programs in water use and conservation or that could be used directly by homeowners. Prior to this study, information to properly develop such guidelines was not available. Guidelines which did exist were often general in nature and usually not based on measured data.

GUIDELINE PUBLICATIONS

The Agricultural Experiment Station publications at the University of Wyoming are readily available to potential users. In addition, preparing guidelines in this form makes them easily disseminated by the Extension Service personnel. Copies of published bulletins and drafts of proposed Experiment Station bulletins are included in Appendix E. One bulletin—"Watering of Lawns," University of Wyoming Agricultural Extension Miscellaneous Publication 39—has been published, while two—"Measuring Lawn Water" and "Selection and Use of Lawn Sprinklers"—are in draft form for publication. Each of these publications have been prepared based directly on information obtained during this study. More technical information has been presented in a variety of journal articles and at professional meetings. A list of these papers is given in Appendix F. In addition, joint publications combining pertinent Arizona, Colorado, and Wyoming data are being prepared.

One additional publication is being prepared for Wyoming. The calibrated Blaney-Criddle formula is being used to express lawn water requirements on a probability basis throughout Wyoming. Monthly and annual lawn water requirements will be estimated using the Blaney-Criddle

formula for at least 40 years of existing climatic records. These estimates will then be used to calculate the probability of occurrence of various levels of water requirements.

SUMMARY OF SPECIFIC GUIDELINES

It was found that homeowners who applied water at a rate near the potential evapotranspiration rate (E_{tp}) of the grass could maintain aesthetically acceptable lawns as readily as those homeowners who applied much greater amounts of water (Chapter 3). However, a large number of homeowners applied excess amounts of water, indicating a real potential for developing guidelines to save considerable water on a city-wide basis. Guidelines to make most efficient use of water need to include information concerning:

1. The water requirement of the grass.
2. The amount of water that is actually applied.
3. The desired frequency of application.
4. The uniformity of application.

Water Requirement of the Grass

The water requirements of grass cannot easily be measured directly by the homeowner. However, estimates are readily available. Measured data, such as those acquired in this study (Chapter 2), can be used as a guideline to the water requirements. For example, Table 5.1 is a summary of daily water requirements for Wyoming. Applying water at rates near those of Table 5.1 would be a reasonable guideline for the homeowner—with precipitation included as part of the water applied. Laramie's data would be recommended for locations above 1,800 meters altitude while Wheatland's data would be recommended for lower locations.

Table 5.1 Water Requirements of Kentucky Bluegrass in Wyoming (cm/day).

Month	Laramie	Wheatland
April	0.19	0.33
May	0.37	0.40
June	0.52	0.52
July	0.59	0.54
August	0.43	0.40
September	0.31	0.38
October	0.19	0.23

For locations not having measured data the homeowner is dependent upon information provided by local city water managers through local news media and other sources. A recommended method for obtaining water requirement estimates for dissemination to the public is by use of the empirical formulas which were calibrated in Chapter 2. Another option would be to measure water use directly by methods such as the small weighable lysimeters or evaporation pans.

Amount of Water Applied

One of the factors which plays a critical role in overwatering is a lack of knowledge regarding the amount of water that is being applied. As stated previously in Chapter 3, homeowners can avoid underwatering by noting the visible water stress that occurs and applying water. However, most homeowners whose grass does not become water stressed do not know whether they are applying excess water.

Any of several methods can be used to determine the amount of water applied. The most common methods include: (1) wetting the soil profile to a recommended depth, (2) using

catch cans to calibrate the sprinklers, (3) metering the amount of water applied, and (4) following average estimated application rates for specific sprinklers. Each of these methods are discussed in more detail in the proposed publication "Measuring Lawn Water," included in Appendix E. The most accurate of these methods is direct metering of the amount of water applied, yet any method that provides some guideline to the amount of water applied is useful in reducing excess water application.

Frequency of Application

The frequency of water application and the daily water requirement of the grass (Table 5.1) determine the amount of water that needs to be applied during a single irrigation. Basically, enough water should be applied to wet the soil profile to a depth to which the roots of the grass extend. In this study Kentucky bluegrass roots were found at the bottom of the 24 inch deep lysimeter. The other factor to consider besides depth is the water holding capacity of the soil varying from low for sandy soils to high for clay soils.

Uniformity of Application

The degree of overwatering which occurs depends largely upon the uniformity of distribution of the sprinkler being used. To obtain relatively uniform distribution of water, the distribution pattern for each sprinkler (for solid set systems), or of each set (for movable systems), must overlap with the pattern of adjacent sprinklers, or sets.

In order to obtain acceptable uniformity of distribution, nearly all home lawn sprinklers need to be overlapped in two directions (Chapter 4). Overlapping in only one direction is not usually adequate to produce acceptable uniformity. In general, at least 50% overlap in two directions is desirable for most lawn sprinklers. Detailed information regarding required overlap is given in Chapter 4.

Chapter 6

SUMMARY

A three-year study of residential water use with emphasis on lawn water use was conducted. Lawn water application rates, potential evapotranspiration rates (E_{tp}) of lawn grass in an urban setting, and household use were monitored in Laramie and Wheatland, Wyoming. Tests were also conducted to determine distribution patterns of typical types of lawn sprinklers and the overlaps required to achieve minimum acceptable uniformity of water distribution.

Weekly lawn water application and requirement data were taken during the summers of 1976, 1977, and 1978. Potential evapotranspiration was measured using small weighable lysimeters installed in lawns surrounding single family residences at three locations in each city. Five lysimeters were placed at various positions at each location. Lawn water application rates were monitored by attaching water meters to all outside spigots of cooperator's homes. City water meters were read to obtain household water use.

Distribution patterns of six types of lawn sprinklers were determined during the summer of 1977. Tests were conducted on four sprinklers from each type under three pressure levels. Christiansen's Uniformity Coefficients (UCC) were calculated for the original pattern and various overlaps of the sprinklers. Overlaps required to achieve minimum acceptable UCC values were then determined. The output of each sprinkler was measured and application rates were calculated for individual pattern sizes at the three pressure levels.

Specific findings from this project include:

1. Blaney-Criddle formulas calibrated for lawn grass estimate higher water requirements early and late in the growing season than previously

listed calibrations, which were not prepared specifically for lawn grass. The calibrations compare reasonably well during the middle portion of the growing season.

2. Water use of Kentucky bluegrass was found to decrease as temperatures increased above an optimum level (this appeared to occur as daily maximum temperatures exceeded approximately 33°C). During the warmer months, Laramie's lawn water requirement exceeded Wheatland's even though the temperatures in Wheatland were higher.

3. Homeowners who applied water at a rate near the E_{tp} rate of the grass maintained aesthetically acceptable lawns as readily as those homeowners who applied much greater amounts of water, yet a large number of homeowners applied excessive amounts of water.

4. Few homeowners know the amount of lawn water they are applying. This amount must be defined for each homeowner if significant water conservation is to be achieved.

5. The "Winter Base rate" method of estimating summer lawn water use is reasonable accurate under dry Western conditions where irrigation supplies 75% or more of the required consumptive use.

6. Deep percolation on a city-wide basis was considerable for the two cities monitored. The percolate had high levels of dissolved solids and nitrates.

7. Home lawn sprinklers generally need to be overlapped to achieve acceptable UCC levels. At least a 50% overlap is both directions of the pattern is required for most sprinklers. Observations show that common practices of most homeowners do not approach these acceptable levels.

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APPENDIX A
PROJECT PERSONNEL AND COOPERATORS

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PERSONNEL

Principal Investigators

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Agricultural Engineering
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Kerr, Greg L.
Brizuela, Connie

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Ebsen, Mike
Weihing, Warren
Davidson, Steve
Turner, Mike
Gale, Frank
Irion, Mark
Utter, Kevin

Secretarial Staff

Pliley, Connie
Raymond, Alice
Howell, Beth
Johnson, Sharon
Highland, Holly

Cooperating Homeowners for Water Application Measurements (Laramie)

	<u>Name</u>	<u>Address</u>	<u>Years Sampled</u>
	1. Andersen, James D.	2519 Sheridan	(1975)
**	2. Becker, Clarence	2010 Thornburgh	(1975-1978)
	3. Brosz, Don	1905 Spring Creek	(1975-1977)
		2304 Hillside Drive	(1978)
**	4. Pochop, Larry	1906 Hillside Drive	(1975-1978)
	5. Fair, Bob	2449 Park Avenue	(1975)
	6. Rechard, Paul	316 Stuart	(1975-1978)
	7. Hoadley, M.	1813 Bill Nye	(1975-1978)
	8. Hasfurther, Vic	1710 Bill Nye	(1975-1978)
	9. Haddenhorst, G.	911 Sanders	(1975-1978)
	10. Thompson, Thomas	615 Russell	(1975-1978)
	11. Perkins, J. L.	702 South 5th	(1975-1978)
**	12. Borrelli, John	814 Park	(1975-1977)
		2161 North 16th	(1978)
	13. Hoffman, J.	419 South 11th	(1975-1978)
	14. McNamee, Mike	408 South 11th	(1975-1978)
	15. Goslin, W. A.	456 North 7th	(1975-1978)
	16. Fester, Mrs. John	601 Gibbon	(1975-1978)
	17. Adams, John	1003 Reynolds	(1975-1977)
	18. Spackman, Everett	1132 Curtis	(1975-1978)
	19. Burman, Robert	1214 Downey	(1975-1978)
	20. Fornstrom, Jim	1731 Downey	(1975-1978)
	21. Backer, August	1220 Lewis	(1975-1978)
	22. Pietens, Brad	1516 Rainbow	(1976-1978)
	23. Lush, Jerry	1622 Ord	(1976-1978)
	24. Ankeny, Margaret	2505 Sheridan	(1976-1978)
	25. Spiegelberg, F. W.	1315 La Prele	(1976-1978)
	26. Cerullo, Mike	1705 Symons	(1976-1978)
	27. Guthrie, J.	1200 Ivinson	(1976-1978)
	28. Merrian, Don	1115 Renshaw	(1976-1978)
	29. Miller, Alan	2062 North 16th	(1976-1978)
	30. Pliley, Larry	1868 North 15th	(1976-1978)
	31. Jensen, Randy	770 North 10th	(1976-1977)

** Lysimeter locations

Cooperating Homeowners for Water Application measurements (Wheatland)

	<u>Name</u>	<u>Address</u>	<u>Years Sampled</u>
	1. Pitcher, Warren	1450 Mitchell	(1975-1978)
**	2. Wakkuri, Myron	1356 Mitchell	(1975-1978)
	3. Dent, George	73 13th	(1975-1978)
	5. Nicholson, Lowellla	1254 Loomis	(1975-1978)
	6. Wickam, John	94 13th	(1975-1978)
	7. Bowen, Joe	106 13th	(1975-1978)
	8. Kendig, A.	301 10th	(1975-July 22, 1976)
	9. Chasteen, Russell	408 11th	(1975-1978)
	10. Hoth, Bud	1007 10th	(1975-1978)
	11. Cline, Roy/Erickson, Norm	1008 9th	(1975-1977)
	12. Baker, Mrs. Kathryn	1350 Rowley	(1975-1978)
**	13. Ballard, John	1160 14th	(1975-June 10, 1976)
		1240 11th	(June 10, 1976-1978)
	15. Dunham, James	805 13th	(1975-1978)
**	16. Utter, Emerson	1157 Walnut	(1975-1978)
	17. Payne, Sue	54 14th	(1976-1977)
	18. Chappell, Sharon	68 14th	(1976-1978)
	19. Previt, Charles	72 13th	(1976-1978)
	20. West, Bertha	1357 Loomis	(1976-1978)
	21. Gloyd, Joe	83 13th	(1976)
	22. Stumpff, Mrs. C. R.	1056 High Street	(1976-1978)
	23. Foster, Mrs. Margaret	1004 10th Street	(1976-1978)
	24. Twiford, Ruby	1053 Spruce	(1976)
	25. Rawlings, Mary	1509 11th	(1976-1978)
	26. Lipps, Ray	1250 Rowley	(1976-1978)
	27. Sater, A. M.	803 13th	(1976-1978)
	28. Goertz, Allen	801 14th	(1976-1977)
	29. Eisenbarth, Ron	Box 582	(1976-1977)
	30. Delgado, Denise	14th & Walnut	(June 30, 1977- Sept. 22, 1977)
	30. Patrick, A. G.	809 11th	(1978)

** Lysimeter locations

Cooperating Homeowners for Water Quality Analyses (Laramie)

John Adams	1003 Reynolds
August Backer	1220 Lewis
Clarence Becker	2010 Thornburgh
John Borrelli	2161 North 16th
Don Brosz	2304 Hillside Drive
Dick Cottrill	2449 Park Avenue
W. A. Goslin	456 North 7th
Vic Hasfurther	1710 Bill Nye
J. Hoffman	419 South 11th
Mike NcNamee	408 South 11th
Brad Pietens	1516 Rainbow
Larry Pliley	1868 North 15th
Larry Pochop	1906 Hillside Drive
Jack Raymond	2108 Hillside Drive
Thomas Thompson	615 Russell

APPENDIX B
ET FORMULA CALIBRATIONS AND WEEKLY DATA

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CALIBRATION PROCEDURES FOR BLANEY-CRIDDLE FORMULAS

The following outlines the procedures for estimating evapotranspiration (E_{tp}) using each of the two versions of the Blaney-Criddle formula, as presented by Criddle et al. (1962) and the SCS (1967). Also described are the methods used for calibrating each of the formulas.

Criddle et al. (1962) Formula:

The Criddle et al. (1962) version is:

$$u = 25.4 \text{ kf}$$

where

u = consumptive use, E_{tp} , for the period (mm)

k = consumptive use coefficient for the period

$f = \frac{(1.8t + 32)p}{100}$, a consumptive use factor

t = mean temperature for the period ($^{\circ}\text{C}$)

p = percent of annual daytime hours occurring in the period

Monthly periods were used for all calculations and calibrations herein.

The consumptive use coefficient k is dependent on a seasonal consumptive use factor, F , which is $\sum f$ for each month in the growing season.

(1) Determination of the growing season (Table 2.4): Defined herein as the number of days between the last occurrence in the spring and the first occurrence in the fall of three consecutive days of sub 4.5° mean temperatures. Included the last day of the spring interval and the first day of the fall interval in the count.

e.g. Laramie, 1978

Spring - May 6, 7, 8

Fall - Oct. 22, 23, 24

Growing Season = May 8 through October 22

(or, May = 24, June = 30, July = 31, Aug. = 31, Sept. = 30, and Oct. = 22 days)

- (2) Find p (percent daytime hours of the year) for each month: Use the latitude of the city and interpolation from a table such as in Trelease et al. (1970),* page 6.

e.g. Laramie, May

Latitude = $41^{\circ} 19'$

% daytime hours in May = 10.09

- (3) Determine f for each month in the growing season:

$$f = \frac{(1.8t + 32)p}{100}$$

e.g. Laramie, May, 1978

$t = 7.4^{\circ}\text{C}$, from Table 2.2

$$f = \frac{[(1.8 * 7.4) + 32]10.09}{100} =$$

4.57

- (4) Determine F for the growing season:

$F = \sum f$, correcting for partial months at the beginning and end of the season.

e.g. Laramie, 1978

$$F = \frac{24}{31}f(\text{May}) + f(\text{June}) + f(\text{July}) + f(\text{Aug}) + f(\text{Sept}) + \frac{22}{31}f(\text{Oct}) = 29$$

Other F values for 1976, 1977, and 1978 are given in Table 2.5

* Trelease et al. 1979. Consumptive use of irrigation water in Wyoming, Wyoming Water Planning Report No. 5, July.

- (5) Determine k values:

Consumptive use coefficients, k, as presented by Criddle et al. (1962) for grass, hay, and pasture are given in Fig. 2.2, Chapter 2, of this report.

e.g. Laramie, May, 1978 with
 $F = 29$ $k_{crld} = 0.57$

To determine calibrated consumptive use coefficients for lawn grass, the following procedure was used:

- (1) Actual k values for each month referred to as k_{calc} or "calculated" k values—were determined for each year (Table 2.6) using

$$k_{calc} = \frac{u}{25.4f}$$

where:

u = measured E_{tp} for the month, from Table 2.1

f = consumptive use factor for the month as determined above.

e.g. Laramie, May, 1978
 $u = 135$ mm

$$k_{calc} = \frac{135}{25.4 \times 4.57} = 1.16$$

- (2) The calculated k values (Table 2.6) were regressed against the Criddle et al. (1962) k values (Table 2.7) for all F factors concurrently, with k_{calc} as the dependent variable. The resulting equation was

$$k_{calb} = 0.5630 + 0.4090 k_{crld}$$

e.g. Laramie, May 1978
 $k_{crld} = 0.57$, from Table 2.7
 $k_{calb} = 0.80$

A table of calibrated consumptive use coefficients, k_{calb} , is given (Table 2.8).

- (3) The calibrated consumptive use coefficients k_{calb} (Table 2.8) were plotted for the specific F factors providing a means of estimating k_{calb} for future F values, which will vary with the growing season (Figure 2.4).

SCS Formula:

The SCS version is :

$$u = 25.4 k_t k_c f$$

where all terms are defined the same as for the Criddle et al. (1962) version with the exception of the consumptive use coefficient, k, which is defined as the product of k_t and k_c values. The coefficient k_t is related to temperature by

$$k_t = 0.0311t + 0.240,$$

while the coefficient k_c is a crop growth stage coefficient for the period.

The major advantage of the SCS formula (1967) over the formula presented by Criddle et al. (1962) is that determination of the seasonal consumptive use factor, F, is not necessary, thus definition of the growing season is not required. To estimate evapotranspiration:

- (1) Determine the consumptive use factor f for each month. The method is identical to that used for the Criddle et al. (1962) version described above.

e.g. Laramie, May, 1978

$t = 7.4^\circ\text{C}$, from Table 2.2

$$f = \frac{[(1.8 \times 7.4) + 32]10.09}{100} = 4.57$$

- (2) Determine the temperature coefficient, k_t :

e.g. Laramie, May, 1978

$$t = 7.4^\circ\text{C, from Table 2.2}$$
$$k_t = 0.0311t + 0.240$$
$$= 0.470$$

- (3) Determine the crop growth coefficient, k_c :
The crop growth stage coefficients for pasture grasses as presented by the SCS (1967) are given in Fig. 2.3.

e.g. May

$$k_c = 0.90$$

To determine calibrated crop growth stage coefficients for lawn grass, the following procedure was used:

- (1) Actual k_c values for each month—referred to as calculated k_c values—were deter-

mined for each year (Table 2.9) using

$$\text{calculated } k_c = \frac{u}{25.4k_t f}$$

e.g. Laramie, May 1978

Calculated k_c =

$$\frac{135}{25.4 \times 0.470 \times 4.57} = 2.47$$

- (2) Calibrated k_c values (Table 2.9) were determined for each month by averaging the calculated k_c values across years.

e.g. Laramie, May

Calculated k_c for 1976 = 1.46

Calculated k_c for 1977 = 1.78

Calculated k_c for 1978 = 2.47

Calibrated k_c =

$$\frac{1.46 + 1.78 + 2.47}{3} = 1.90$$

Table B.1. Weekly E_{tp} Rates (cm/day), Laramie, 1976

Period	Becker					Borrelli					Pochop					Avg.
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	
Apr 9 -14	-	-	.20	.18	-	-	.20	-	.15	.15	.28	-	-	.23	.18	.20
15 -20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21 -28	-	-	.15	.20	-	-	.28	-	.20	.15	.15	-	-	.15	.18	.18
29 -5*	.25	.33	.41	.36	.30	.23	.41	.25	.23	.28	.33	.18	.36	.30	.33	.30
May 6 -12	.20	.30	.15	.25	.25	.28	.33	.30	.25	.25	.28	.18	.25	-	.25	.25
13 -19	.33	-	.46	.41	.38	.36	-	.36	.23	.30	.41	.28	.38	.38	.41	.36
20 -26	.15	.15	.15	.08	.13	.28	.20	.23	.20	.23	.20	.15	.18	.23	.18	.18
27 -1*	.33	.38	.43	-	-	.43	.41	.41	.28	.28	.41	.33	.46	.36	.41	.38
Jun 2 -8	.46	.48	-	.48	.41	.51	.46	.56	.41	.51	.51	.51	-	.58	.51	.49
9 -15	.43	.41	.46	.36	-	.43	.43	.48	.38	.41	.61	.56	.46	.56	.38	.45
16 -22	.33	.38	.28	.28	.33	.36	.30	.33	.28	.20	.38	.43	.38	.48	.41	.34
23 -29	.56	.48	-	.53	-	.58	.64	.66	.53	.56	.71	.69	.69	.74	.86	.63
30 -6*	.46	.36	.43	-	.30	.58	.53	.56	.48	.56	.64	.58	.56	.48	.56	.51
Jul 7 -13	.43	.43	.43	.41	.38	.58	.53	.56	.41	.41	.56	.69	.69	.76	.66	.53
14 -20	.36	.36	.51	.48	.36	.46	.43	.38	.33	-	.46	.48	.43	.43	.43	.42
22 -27	.46	.41	.43	-	.25	.56	.69	.58	.51	.51	.64	.76	.69	.69	.64	.56
28 -3*	-	.30	.33	.33	-	.43	-	.41	.38	.38	.43	.38	.41	.46	.41	.39
Aug 4 -10	.51	.51	.51	.43	-	.61	-	.61	-	-	.58	.56	.71	.71	.66	.58
11 -17	-	-	-	.36	-	.23	-	.33	.25	.36	.43	.38	.43	.33	.28	.34
18 -24	.20	.41	.46	.23	.30	.43	-	.46	.36	.41	.41	.43	.43	.48	.48	.37
25 -30	.20	.23	.41	.30	.18	.28	.51	.38	.36	.38	.43	.38	.51	.51	-	.36
Sep 1 -6	.36	.30	.43	.20	-	.33	.48	.30	.20	.23	.43	.41	.56	.41	.51	.37
7 -13	.20	.30	.33	.30	-	.28	-	-	.41	.25	.53	.38	.53	.36	.33	.35
14 -20	.18	.25	.13	.13	-	-	-	.18	.20	.30	-	.23	-	.36	.33	.23
21 -27	.15	.33	-	.15	.10	.18	.18	.13	.23	.20	.25	.18	.23	.25	.23	.20
28 -4*	.23	.20	.28	.13	-	.18	.30	.23	.28	.18	.30	.20	.30	.20	.28	.24
Oct 5 -11	.05	.03	.15	.15	-	-	-	.03	.18	.08	.08	.05	.20	.03	.15	.10
12 -18	.13	.20	.30	.30	.18	.15	.10	.15	.28	.25	.23	.20	.30	.20	.23	.21
19 -27	.03	.10	-	.08	-	.05	.13	-	.10	.05	.20	.08	.10	.18	.10	.10
28 -1	.10	.18	.08	.15	.08	-	.08	.23	.08	.18	-	.08	.23	.18	.08	.13

* These dates are the beginning of the next month.

Table B.2. Weekly E_{tp} Rates (cm/day), Wheatland, 1976

Period	Ballard					Utter					Wakkuri					Avg.
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	
Apr 9 - 14	.28	.20	.30	.23	.20	.28	.38	.28	.38	.25	.10	.20	.20	-	-	.25
15 - 22	.28	.13	.20	.15	.10	.18	.25	.23	.33	-	.20	.28	.20	.23	.30	.22
23 - 29	.15	.15	.18	.15	.23	.20	.28	.20	.33	.15	.13	.20	.20	.18	-	.20
30 - 6*	.51	.36	.48	.36	.33	.38	.53	-	-	.36	.38	.51	.46	.38	.43	.45
May 7 - 12	.33	.43	.56	.43	.41	.51	.53	.41	.46	.36	.46	.51	-	.56	.48	.46
13 - 20	.38	.38	.43	.38	.36	.33	.36	-	.33	.36	.33	.48	.48	.51	.48	.40
21 - 27	.20	.15	-	.28	.23	.20	.23	-	.18	.13	.18	.23	.20	.23	.23	.21
28 - 3*	.53	.53	.48	.56	.46	.48	.48	.41	.38	.43	.51	.66	.69	.64	.58	.52
Jun 4 - 9						.58	.56	.36	.41	.46	.51	.69	.48	.51	.56	.51
10 - 16	.58	.43	.36	.43	-	.36	.51	.30	-	-	.46	.64	.76	.71	.51	.50
17 - 23	.56	.43	.41	.41	-	.43	.43	.36	.28	-	-	.48	.43	.33	-	.41
24 - 30	.81	.69	.56	.56	.48	.69	-	.58	-	.58	.76	.79	.74	.71	-	.66
Jul 1 - 7	.86	.71	.58	.76	.76	.41	.48	-	-	.48	-	.74	-	.53	.53	.62
8 - 14	.79	.66	.48	.58	.56	.46	-	.56	.41	.58	.71	.89	-	.61	.53	.60
15 - 21	.36	.41	.38	.38	.56	.38	.41	-	-	.36	.48	.48	.43	-	-	.42
22 - 28	.87	.76	-	.81	.71	.74	-	.74	.84	.64	1.07	.66	1.04	.65	.65	.78
29 - 4*	-	-	.33	.41	.56	.38	.36	.28	.30	.20	.36	.58	.66	.46	.48	.41
Aug 5 - 11	.41	.46	.41	.38	.46	.46	.48	.43	.43	.43	.36	.61	.30	.48	.46	.44
12 - 18	.20	.36	.36	.46	.25	.33	.33	.36	.43	.33	-	-	-	-	-	.34
19 - 25	.58	.38	.38	.41	.56	.46	.43	.38	.38	.41	.48	.43	-	-	.53	.45
26 - 1*	.41	.33	.36	.25	.48	.33	.36	.38	.37	.30	-	-	.41	-	.53	.38
Sep 2 - 8	-	.38	-	.33	.33	-	.38	.30	.33	.43	.33	.36	.23	-	.28	.33
9 - 15	.36	.25	.23	.33	-	.20	.33	.30	.20	-	.13	.25	.18	-	-	.25
16 - 22	.23	.23	.25	.28	.36	-	.15	.20	.23	.18	.30	.15	-	.15	.23	.25
23 - 29	-	.20	.25	.20	.30	-	.18	.25	.18	.18	-	.25	.05	-	-	.20
30 - 6*	-	.23	.23	.25	.36	.15	.20	.23	.28	.20	.38	.38	.38	.36	.25	.25
Oct 7 - 13	-	-	.41	.30	.48	.15	.20	.20	.23	.18	.33	.33	.38	.43	.25	.30
14 - 20	-	.23	.13	.13	.18	.15	.15	-	.20	.18	-	.20	.15	.23	.15	.17
21 - 27	-	.13	.15	.13	.23	.15	.08	-	.03	.10	.25	.10	.20	.05	.05	.13
28 - 3*	.20	.10	.13	-	.23	-	.13	.18	.18	.08	.36	.18	.23	.23	.15	.18

* These dates are the beginning of the next month.

Table B.3. Weekly E_{Tp} Rates (cm/day), Laramie, 1977

Period	Becker					Borrelli					Pochop					Avg.
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	
Apr 15-19	.03	-	-	.05	-	-	.10	-	-	.25	-	-	-	-	-	.11
20-26	.23	.25	-	.28	.20	-	.38	.25	.28	.25	-	-	-	.20	.20	.25
27-3*	.08	.18	.08	.23	.25	.13	.25	.23	.18	.28	-	-	.41	.25	.23	.23
May 4-10	.28	.36	-	.48	.53	.48	.64	.56	.53	.56	.56	.41	.41	-	-	.48
11-17	.38	.41	.33	-	.41	-	.46	.48	.41	.51	.38	.23	.53	.43	.41	.41
18-24	-	-	.38	.23	.38	-	.33	.33	.36	-	.36	.33	.28	.41	.36	.34
25-31	.30	.41	.41	.36	.36	.33	.28	.43	.33	.38	.46	.46	.53	.48	.38	.39
Jun 1-7	.43	.43	.48	.43	.48	.56	-	.48	-	.66	.66	.41	.58	.48	.53	.51
8-14	.51	.43	.51	-	.41	.61	-	.53	.41	-	.58	.43	.66	.61	.46	.51
15-21	.56	-	.69	.66	.56	.56	.56	.58	.48	-	-	.76	.79	-	.74	.63
22-27	.56	.56	.41	.33	.33	.41	.58	.56	.28	.48	.48	.41	.53	.48	.46	.46
28-29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
30-5*	.56	.53	.53	.41	.28	.61	.74	.61	.48	-	.56	-	.61	-	.61	.54
Jul 6-12	.56	.41	.61	-	.36	.58	.53	.53	.53	.51	.69	.64	.61	.74	.69	.57
13-19	.30	.51	.56	.28	.41	-	-	-	-	-	.51	.61	.61	.48	.61	.49
20-26	.28	.48	-	-	.20	-	.23	.13	.18	.15	-	.28	.25	.28	.36	.26
27-2*	.36	.53	.53	.43	.28	.64	-	.56	.51	.64	.61	.69	.86	.69	-	.56
Aug 3-9	.38	.38	.36	.20	-	.38	.30	.33	.33	.30	.23	.25	.28	.38	-	.32
10-16	-	-	.51	.33	.30	.53	.46	-	.48	.58	.51	.43	.71	.58	-	.49
17-23	.33	.36	.30	.25	.43	.30	.33	.28	.30	-	.36	.30	.51	.30	.33	.33
24-30	.30	.43	-	.20	.33	.53	.46	.51	-	-	.48	.53	.51	.56	.56	.45
31-7*	-	.43	.38	.30	.20	-	.36	.53	.51	.58	.36	.33	.43	.46	.25	.39
Sep 8-13	.33	-	.15	.36	.15	-	-	-	.51	.56	.53	.48	.56	.56	.41	.42
14-20	-	.46	.36	.30	.30	-	.30	-	.46	.58	.36	.43	.48	.41	.36	.40
21-28	.33	.36	.28	.28	-	.41	-	.51	.66	.53	.33	.36	.41	.33	.28	.39
29-5*	.23	.23	.23	.25	.28	-	.38	-	-	.58	.28	.28	.53	.46	.36	.34
Oct 6-12	.20	-	-	.20	.20	-	.13	-	-	.30	.23	.23	-	.25	-	.22
13-19	-	.13	.18	.15	-	-	.15	-	-	.33	.18	.18	-	-	-	.19
20-26	.05	.08	.05	.15	.05	-	.15	-	-	.25	.10	.13	.18	.18	.18	.13
27-2*	.08	.05	.08	.23	.08	-	.18	-	-	.23	.15	.20	.25	.25	.18	.16

* These dates are the beginning of the next month.

Table B.4. Weekly E_{tp} Rates (cm/day), Wheatland, 1977.

Period	Ballard					Utter					Wakkuri					Avg.	
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5		
April	15-21	.58	.23	.30	.15	.38	-	-	-	-	-	.48	.38	.41	-	-	.36
	22-28	.43	.46	.48	.43	.53	-	-	-	-	-	.48	.56	.33	.51	-	.47
	29-5*	.53	.43	.46	.56	.46	.36	.48	.43	.30	.36	.56	.53	.58	.43	-	.46
May	6-11	.46	.38	.53	.41	.66	.46	.46	.38	.33	.33	-	.56	-	.84	.66	.50
	12-19	.41	.53	.43	.36	.46	.36	-	.36	.41	.56	-	.66	.43	.53	.30	.45
	20-26	.41	.36	.48	.28	.53	.25	.38	.33	-	.20	.43	.66	.51	.46	.28	.40
	27-2*	.38	.46	.58	.36	.46	.41	.43	.38	-	.41	.36	.53	.36	.51	.53	.44
June	3-9	.41	.53	.51	.46	.56	.41	.41	.51	-	.43	.56	.48	.58	-	.71	.50
	10-16	.41	.53	.61	.51	.69	.61	.43	.56	-	.64	-	.71	.66	-	1.02	.62
	17-23	-	.33	.23	.20	-	.25	.36	-	-	.33	.61	.38	.51	-	-	.36
	24-28	.51	-	.69	.58	.71	.66	.61	.53	-	.58	-	.53	.38	.56	-	.58
	29-30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
July	1-7	.51	-	.66	.61	.61	.86	-	.64	-	.69	.86	.94	.71	.61	.91	.72
	8-14	.46	.53	-	-	.51	.64	.43	-	.43	.48	-	.76	.71	-	.86	.58
	15-21	.46	.33	-	.38	.61	.58	.61	.38	.36	.49	-	.66	.48	.51	.56	.49
	22-28	.30	.41	-	.28	.38	.38	.38	.23	.33	.36	-	.41	.36	-	.58	.37
	29-4*	.41	.46	-	.48	.53	.46	.64	-	.43	.64	.53	.79	.36	-	.58	.53
Aug	5-11	.30	.36	.25	.25	.36	.33	.33	.20	-	.30	.36	.46	.33	.36	.56	.34
	12-18	.30	-	.38	.43	.33	.25	-	.33	.25	.33	-	.69	.33	-	.66	.39
	19-25	.46	.25	.33	.38	-	.43	-	.33	-	.33	-	.56	-	.43	.71	.42
	26-1*	.41	.38	.38	.36	-	.28	-	.25	.38	.30	-	.56	-	.64	.56	.41
Sept	2-8	.48	.46	.30	.43	.36	-	.56	.20	-	.43	-	.30	.41	-	.61	.41
	9-15	.13	-	.10	-	.13	-	.15	-	-	-	-	-	.36	.28	.36	.23
	16-22	.66	.53	.56	.43	.43	.25	.30	.23	.25	.15	.28	.51	.30	.53	-	.39
	23-29	.43	.30	-	.46	-	.20	.23	-	.36	.38	-	.48	.25	-	-	.34
	30-6*	.18	.20	.15	.05	.05	.38	.38	.30	.38	.33	-	.30	-	.25	.23	.24
Oct	7-13	.25	-	-	.25	.28	.20	-	.20	.30	.36	.18	.23	.15	.18	.25	.24
	14-20	.15	.18	.20	.20	-	.08	.18	.13	.18	.20	.38	.36	-	-	.36	.22
	21-27	.28	-	.15	.18	-	.25	.25	-	.28	-	.15	.10	.15	.23	-	.18
	28-3*	.28	.18	.15	.13	-	.20	.23	.23	.25	-	.33	.38	.61	.36	-	.28

* These dates are the beginning of the next month.

Table B.5. Weekly E_{tp} Rates (cm/day), Laramie, 1978

Period	Becker					Borrelli			Pochop					Avg.
	1	2	3	4	5	1	3	4	1	2	3	4	5	
Mar 30-6*	.13	.15	.20	.18	.15	.05	.10	.08	.13	.28	.15	-	-	.15
Apr 7-13	.08	-	.08	-	-	.23	.20	.13	-	-	.08	.08	.15	.13
14-20	-	.18	.23	.13	.13	.20	-	.15	.15	.15	.30	.20	.25	.19
21-27	.28	.36	.28	.15	.36	.43	-	.43	.30	.25	.20	.41	.30	.31
28-4*	.10	-	.15	-	.23	.20	-	.20	-	-	-	.15	.23	.18
May 5-11														
12-22	.81	.64	.33	.64	.58	-	-	-	.33	.76	.66	.66	.51	.59
23-25	.76	.84	.74	.56	.58	.86	.69	.56	.53	.61	.94	-	-	.70
26-1*	.28	.41	.33	.36	.23	.46	.46	.38	.33	.33	.41	-	-	.36
Jun 2-8	.25	.28	.33	.23	.38	.25	.20	.28	.36	.33	.33	.28	.30	.29
9-15	.41	.74	.64	.56	.58	.74	.71	.71	.61	.36	.71	.38	.66	.60
16-22	.46	-	-	.53	.51	.74	.58	.74	.86	.84	.74	.79	.81	.57
23-29	.66	.79	.81	.58	.74	.71	-	.76	.71	.79	.89	.84	.64	.69
30-6*	.79	.61	.71	.66	.74	.99	.86	.94	.97	.64	1.04	.81	.86	.82
Jul 7-13	.76	1.07	.86	.41	.84	.89	.94	.84	.91	.94	.86	-	.69	.83
14-20	.46	-	-	.58	-	1.07	.74	.94	-	.69	.97	-	.76	.78
21-27	-	-	.48	.43	-	.53	-	.53	-	.56	.46	.69	.41	.51
28-3*	.48	-	.36	-	-	.58	.64	.51	.56	.56	.79	.28	.69	.55
Aug 4-10	.13	-	-	.25	-	.05	-	.25	.23	.10	.08	.10	.08	.14
11-17	.38	-	.48	.28	-	.71	.64	.69	.61	.53	.66	.53	.48	.54
18-24	.30	-	-	.33	.36	.43	.38	.43	.51	.46	.69	.51	.46	.44
25-31	.36	-	.36	.36	-	.56	.58	.53	.33	.36	.51	.46	.38	.44
Sep 1-7	-	-	.33	.33	-	.53	.48	.48	.51	.71	.66	.58	.48	.51
8-14	-	-	.41	-	-	.69	.48	.51	.38	-	.48	.58	.48	.50
15-21	.18	-	.15	-	-	.15	.30	.33	.30	.30	.41	.20	.28	.26
22-28	.25	-	-	.20	.18	.38	.36	.41	.28	.20	.38	.51	.33	.32
29-5*	.33	-	.30	-	.18	.36	.33	.18	.38	.30	.41	.25	.28	.30
Oct 6-12	.28	-	.30	.33	.15	.30	.15	.30	.23	.15	.30	.41	.33	.27
13-19	-	-	.15	.20	-	.15	-	.20	-	.20	.28	.20	.20	.20
20-24	-	-	-	-	-	.10	-	.25	-	-	.13	-	-	.16
25-1*	.13	-	.23	.08	.13	.13	-	.18	.10	.05	.10	.15	.05	.12

* These dates are the beginning of the next month.

Table B.6. Weekly Etp Rates (cm/day), Wheatland, 1978.

Period	Ballard				Utter					Wakkuri					Avg.
	1	2	3	4	1	2	3	4	5	1	2	3	4	5	
Mar 28-4*	.48	.43	.36	-	.33	.28	.33	.36	.33	.36	.46	.38	-	.36	.37
Apr 5-11	.20	.25	.23	.15	.38	.43	.41	.36	.46	.36	.46	.38	-	.33	.34
12-20	.33	.30	.33	.28	.36	.41	.46	.25	.25	.25	.25	.28	.33	.30	.31
21-27	.41	.25	.33	.36	.25	.41	.23	.36	.41	.18	.36	.30	.33	-	.32
28-2*	-	-	-	-	.28	-	.33	-	-	-	-	-	.20	-	.30
May 3-9															
10-16	.36	.23	.46	.33	.46	.46	.25	.30	.25	-	-	.58	.58	-	.38
17-22	.20	-	.36	.28	.43	.33	.30	.30	.43	.58	.33	.41	.23	-	.35
23-30	.33	.53	-	.43	.43	.38	.36	.28	.30	.58	.64	.58	.41	.48	.44
31-6*	.20	.23	.28	.28	.20	.41	.36	.30	.28	-	.41	.25	.30	.36	.28
Jun 7-13	.48	.38	.41	.41	.71	.58	.46	.41	.41	.41	.76	.53	.43	.48	.49
14-20	.43	.41	.64	-	.33	.46	.56	.51	.51	.41	.69	.38	.53	.46	.48
21-27	.69	.71	.58	.71	.64	.66	.58	.61	.58	.41	.89	.64	.79	.81	.66
28-5*	.51	-	.58	-	.66	.64	.53	.46	.61	.43	.86	.33	.53	.66	.57
Jul 6-11	.66	.58	.79	.48	.74	.76	.66	.61	.71	.53	.64	-	-	-	.64
12-18	.74	.64	-	.84	.81	.84	.71	.61	.79	.89	.94	.51	.89	-	.75
19-25	.53	.64	.66	.51	.79	.74	.36	.38	.66	.48	.69	.69	.66	.64	.60
26-1*	.33	.23	-	.43	.41	.46	.41	.25	.28	.30	.58	.46	.28	.48	.37
Aug 2-8	.25	.43	.56	.28	.33	.36	.33	.28	.36	.43	.53	.46	.28	.41	.38
9-15	.33	.41	.20	.48	.28	.36	.43	.25	.25	.18	.36	.36	.36	.51	.34
16-22	.36	-	-	.43	.25	.53	.36	.38	-	.38	.51	.58	.53	.51	.44
23-29	.38	.36	.41	.36	-	.46	.43	.38	.33	-	.33	.38	.51	.61	.41
30-5*	.30	-	-	-	-	-	.38	.28	.30	.36	.48	.56	.64	.38	.39
Sep 6-12	.61	.71	.69	.53	.51	.66	-	-	-	.74	.38	.56	.33	.81	.59
13-19	-	.33	-	.33	-	.25	.33	.25	.25	-	.28	-	.20	.56	.31
20-26	-	.38	.46	.18	.25	.30	.36	-	-	.23	.48	.48	.38	-	.35
27-3*	.25	-	-	-	.13	.28	.25	.18	.25	.15	.28	.41	.18	.48	.26
Oct 4-10	.30	.38	.23	-	-	.25	.25	.20	-	.36	.28	-	.33	.30	.29
11-17	.13	.23	-	.15	.30	.25	.36	.28	.13	.10	.10	.13	.23	.15	.20
18-24	.20	-	-	.23	-	-	-	-	-	-	-	-	.18	-	.20
25-31	.18	.18	.18	.10	.18	.20	.23	.18	.13	.18	.10	.28	.25	.23	.19

* These dates are the beginning of the next month.

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APPENDIX C

WEEKLY APPLICATION RATES AND APPEARANCE RATINGS

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Table C.1. Application Rates Including Precipitation, Laramie, 1976, in cm/day

House No.	May 25 - June 2	June 2 - June 9	June 9 - June 16	June 16 - June 23	June 23 - June 30	June 30 - July 7	July 7 - July 14	July 14 - July 21	July 21 - July 28	July 28 - Aug. 4	Aug. 4 - Aug. 11	Aug. 11 - Aug. 18	Aug. 18 - Aug. 25	Aug. 25 - Aug. 31	Aug. 31 - Sept. 7
2	.46	.41	.41	.41	1.02	.79	.38	1.02	.74	.66	.20	.46	.33	.69	.15
3	.74	.13	.79	.51	.69	1.04	.76	1.40	.41	.25	.36	.41	1.02	.15	.15
4	.61	.08	.56	.30	.61	.30	.48	1.04	.03	.64	.03	.64	.10	.23	.61
6	.48	.64	.66	.51	.61	.74	.81	.86	.61	.91	.41	.64	.51	.46	.79
7	.94	1.02	1.75	.89	1.35	.91	.89	1.09	.71	.81	.99	.97	.46	1.45	.84
8	.41	.33	.28	.33	.64	.51	.61	1.32	.03	.23	.43	.66	.33	.33	.53
9	.43	.64	.20	.61	.58	.38	.81	.76	.25	.48	.25	.36	.33	.18	.41
10	.36	.89	.53	.71	.69	1.07	.53	.97	.03	.79	.69	.53	.51	.74	.13
11	.30	.76	.36	.46	.84	.66	.18	1.02	.03	.61	.18	.48	.56	.18	.43
12	.18	.61	.69	.46	.61	.51	.48	.94	0.0	.61	.38	.30	.36	.36	.43
13	.28	1.57	.76	.33	.56	1.98	.28	1.85	.03	1.14	.94	.58	.94	.20	1.57
14	.81	1.14	.36	.94	.94	1.78	1.68	1.42	.69	1.04	.56	.89	.84	2.08	1.12
15	.51	.48	.43	.43	.58	.74	.36	.89	.23	.28	.51	.43	.53	.48	.43
16	.84	.97	.48	.38	2.11	1.45	.13	1.65	.53	.91	1.42	.51	.46	.64	.91
17	.15	1.04	.08	.36	.23	.41	1.22	1.42	.81	.20	.79	.05	.97	.18	.76
18	.46	.71	.41	.71	1.09	.69	1.24	1.30	.53	.61	.89	.38	.81	.53	.86
19	.48	.51	.61	.46	.46	.30	.64	.84	.03	.20	.10	.15	.94	.41	.28
20	.71	.28	.28	.97	.43	.38	.74	.53	0.0	.18	.03	.86	.61	.43	.43
21	.51	.48	.41	.30	.56	.38	.30	.74	.28	.36	.25	.18	.33	.43	.48
22					.33	.23	.46	.64	0.0	.18	.03	.13	.30	.20	.48
23			.33	.46	.18	.69	.74	.71	.56	.25	.18	.30	.56	.18	.43
24				.69	1.09	1.09	.86	1.07	.33	.56	.61	.36	.79	.53	.97
25	.91	1.40	.18	.76	.53	.25	.84	1.17	.71	.18	.36	.71	.69	.86	.74
26				.53	.76	.69	.53	.69	.25	.46	.28	.25	.46	.58	.25
27	.36	.33	.28	.51	.56	.28	.23	.64	.10	.25	.25	.10	.38	.23	.66
28					.18	.36	.20	.66	.10	.23	.20	.08	.36	.20	.38
29					.48	.25	.71	.46	.08	.43	.03	.10	.18	.15	.08
30	.51	.66	.58	.30	.58	.41	.38	.61	.33	.30	.08	.86	1.02	1.14	1.22
31				.30	.23	.74	.36	1.22	.28	.51	.03	.10	.89	.15	.41
Avg.	.51	.69	.51	.53	.66	.69	.61	.99	.30	.48	.41	.43	.56	.51	.58

Table C.2. Application Rates Including Precipitation, Wheatland, 1976, in cm/day

House No.	May 7 - May 17	May 17 - May 21	May 21 - May 28	May 28 - June 4	June 4 - June 10	June 10 - June 17	June 17 - June 24	June 24 - July 1	July 1 - July 8	July 8 - July 15	July 15 - July 22	July 22 - July 29	July 29 - Aug. 5	Aug. 5 - Aug. 12	Aug. 12 - Aug. 19	Aug. 19 - Aug. 26	Aug. 26 - Sept. 2	Sept. 2 - Sept. 9	Sept. 9 - Sept. 16	Sept. 16 - Sept. 23
1	.66	.43	.81	.20	.97	.66	.48	.71	.56	.79	.84	.91	.46	.33	.56	.53	.61	.43	.43	.43
2		1.09	.99	.25	.56	.36	.53	.71	.71	.33	.89	.66	.41	.20	.74	.71	.43	.53	.30	.51
3	.25	.76	.99	.51	.58	.20	.56	.38	1.07	.05	.79	.69	.58	.38	.30	.51	.48	.41	.25	.20
5	.71	.64	.81	.30	.53	.66	.36	.56	.89	1.17	.89	1.07	.64	.64	.81	.99	.69	.84	.58	.41
6	.41	.08	.81	.25	.18	.43	.28	.48	.53	.51	.51	.91	.20	.28	.51	.41	.25	.33	.03	.23
7		1.17	.81	.56	.94	1.35	.58	.99	1.32	1.83	.33	.99	.48	.89	1.02	.94	.84	.84	.66	.66
9		1.24	.94	.13	1.17	.99	.97	1.22	.99	.99	.89	1.32	1.17	.97	1.12	1.35	1.07	.69	.48	.61
10		2.08	.81	1.30	1.45	1.40	1.63	1.57	1.55	3.28	2.24	1.30	.53	.91	1.75	.86	1.75	.20	.10	.33
11		.94	.81	.56	.81	.81	.91	1.30	.74	2.11	.71	1.07	1.22	.86	.84	.97	.56	.66	.64	.46
12		.05	.81	1.07	1.27	1.42	1.04	1.02	1.37	1.83	.56	2.01	1.85	1.14	1.42	1.19	1.12	.43	.84	.97
13						.30	.36	.30	.38	.76	.43	.79	.43	.25	.41	.30	.46	.46	.30	.25
15		.97	.86	.30	1.47	1.57	.69	1.09	1.50	1.45	1.85	1.32	.43	1.07	1.07	1.45	.91	1.37	.53	.51
16		.56	.81	.25	.28	.56	.33	.71	.66	.66	.46	.74	.20	.56	.56	.36	.51	.51	.30	.36
17		1.93	.84	.30	.41	.56	.64	.58	.53	.74	.76	1.04	.53	.84	.69	.58	.97	.71	.28	.10
18			.81	.13	.86	.30	.38	.69	.69	.74	.56	.86	.25	.48	.61	.58	.58	.61	.23	.20
19		.84	.94	.05	1.02	.99	.64	1.02	1.37	1.42	.79	1.02	.58	.84	.56	.64	.74	.69	.33	.43
20				.08	.51	.36	.43	.46	.41	.53	.41	.79	.51	.20	.58	.41	.58	.53	.33	.05
21				1.37	1.07	0.0	.66	1.57	1.47	1.85	1.27	1.63	.36	.69	1.57	2.16	.74	.81	1.37	.76
22				.36	1.02	.89	.86	1.35	.91	1.27	1.19	1.52	.69	1.02	.76	.81	.76	.84	.71	.64
23				.81	1.04	1.24	.81	1.32	.58	1.45	1.85	1.30	.28	1.52	.38	.99	1.04	1.98	.64	1.37
24		.94	.81	.23	1.02	.94	.76	.94	.86	1.04	1.55	1.40	.58	.71	.74	1.12	1.07	.69	.76	.46
25			1.04	.20	.64	.43	.36	.61	.74	1.17	.38	1.12	.43	.91	.89	.56	.86	1.04	.48	.33
26				.36	.89	.61	.66	1.07	1.02	1.07	1.17	1.17	.58	.66	.56	.79	.64	.61	.36	.30
27		1.47	.81	.10	1.02	.33	1.04	.91	1.35	.99	1.17	1.27	.23	.61	.94	1.65	1.52	.61	.89	.46
28				.30	1.07	.64	.53	.94	1.04	1.27	1.07	1.37	1.47	2.49	1.17	1.30	.76	.58	1.30	1.14
29				.08	1.27	.46	.53	.51	.81	1.07	.51	.86	.51	.28	.56	.41	.89	.64	.30	.18
Avg.	.51	.94	.86	.38	.86	.69	.64	.86	.91	1.14	.91	1.12	.58	.74	.79	.86	.79	.69	.51	.46

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Table C.3. Application Rates Including Precipitation, Laramie, 1977, in cm/day

House No.	May 25 - June 1	June 1 - June 8	June 8 - June 15	June 15 - June 22	June 22 - June 29	June 29 - July 6	July 6 - July 13	July 13 - July 19	July 19 - July 27	July 27 - Aug. 3	Aug. 3 - Aug. 10	Aug. 10 - Aug. 17	Aug. 17 - Aug. 24	Aug. 24 - Sept. 2
2	.20	.43	.46	.25	.61	.28	.64	.76	.91	.15	.36	.76	.05	.38
3	.33	.10	.64	.20	.69	.84	.94	.86	.71	.03	.41	.69	.10	.46
4	.15	.61	.28	.56	.64	.71	.58	.79	.69	.36	.69	.25	.05	.48
6	.36	.69	.91	.79	.76	.53	1.17	.86	.69	.58	.43	.81	.48	.48
7	.46	1.22	1.19	1.40	1.09	.66	.94	.84	.74	.46	.41	.71	.13	.46
8	.71	.41	.71	.28	.74	.48	.79	.53	.81	.53	.25	.36	.33	.41
9	.28	.23	.61	.23	.51	.38	.61	.79	1.12	.38	.18	.53	.18	.20
10	.56	.56	.41	.56	.41	.89	.51	.58	.69	.36	.46	.23	.33	.10
11	.46	.58	.66	.20	.51	.71	.30	.66	.69	.48	.15	.56	.13	.30
12	.28	.58	.56	.74	.46	1.07	.58	.61	.69	.33	.18	.43	.20	.18
13	1.07	1.24	.71	1.24	.84	.91	1.14	1.19	.69	.56	.46	1.24	.10	.71
14	1.07	2.18	.48	1.32	1.55	.71	2.03	1.35	.69	1.12	.41	1.02	.56	1.24
15	.38	.97	.48	.61	.58	.46	.53	.46	.71	.33	.33	.33	.08	.23
16	.64	.20	1.45	1.65	1.65	.56	.89	1.96	.69	.38	.97	1.78	.43	1.09
17	.64	.97	.94	.46	.43	.79	1.14	1.30	.69	.08	.48	.41	.08	.20
18	.30	.99	.84	1.02	.89	.89	1.09	1.12	.69	.46	.36	.91	.18	.43
19	.66	.36	.79	.43	.36	.38	.64	.76	.69	.28	.23	.30	.10	.10
21	.41	1.14	.91	.48	.58	.23	.36	.66	.69	.28	.30	.25	.41	.30
22	.15	.15	.30	.25	.20	.30	.30	.58	.74	.10	.23	.20	.05	.13
23	.30	.43	1.09	.69	.38	.33	.41	.69	.69	.15	.15	.66	.05	.30
24	.48	.48	.66	.91	.74	.84	.76	.86	.71	.69	.56	.58	.30	.38
25	.23	1.45	.43	.89	.84	.20	.94	.41	.69	.15	.15	.18	.13	.20
26	.30	.43	.56	.58	.43	.53	.89	.99	.74	.43	.41	.46	.25	.25
27	.38	.51	.36	.38	.41	.74	.41	.48	.71	.66	.43	.25	.33	.38
28	.28	.25	.51	.48	.28	.46	.36	.46	.69	.18	.28	.23	.15	.23
29	.20	.03	.56	.81	.71	.53	.43	.41	.76	.15	.28	.05	.05	.10
30	.69	1.07	1.35	.89	.81	1.47	1.47	1.65	.74	.46	.97	.61	.38	.18
Avg.	.43	.69	.69	.69	.66	.64	.76	.84	.71	.38	.38	.56	.20	.36

Table C.4. Application Rates Including Precipitation, Wheatland, 1977, in cm/day.

House No.	May 19	May 26	May 26	June 2	June 2	June 9	June 9	June 16	June 16	June 23	June 23	June 30	June 30	July 7	July 7	July 14	July 14	July 21	July 21	July 28	July 28	Aug. 4	Aug. 4	Aug. 11	Aug. 11	Aug. 18	Aug. 18	Aug. 25	Aug. 25	Sept. 1	Sept. 1	Sept. 8	Sept. 8	Sept. 15	Sept. 15	Sept. 22
1	.56	.66	.66	.58	.84	.33	1.12	.66	.64	1.07	.43	.51	.43	.43	.08	.91	1.02	.36	.51																	
2	.64	.53	.61	.69	1.04	.51	.56	.71	.84	.41	.43	.38	.53	.43	.36	1.04	.20	.58																		
3	.23	.66	.69	.48	.81	.30	.33	.69	.25	.23	.51	.30	.33	.13	.38	.13	.20	.08																		
5	.64	.86	1.24	.64	.71	.46	.86	.89	.97	.64	.48	.56	.53	.41	.33	1.83	.56	.38																		
6	.28	.33	.53	.25	.79	.10	.48	.51	.51	.23	.46	.28	.25	.20	.08	0.0	0.0	.05																		
7	.97	.89	.76	.89	1.04	.64	1.09	.97	1.35	.23	.94	.79	.76	.81	.56	.84	.58	.66																		
9	.64	1.07	.89	.58	.89	.25	.91	.99	1.19	.25	1.22	.41	.48	.33	.46	.53	.38	.30																		
10	1.78	1.40	1.52	.76	.97	.46	1.52	.81	1.73	.41	1.50	.48	.38	.38	.69	1.85	.58	.25																		
11	.64	1.17	.74	.61	.81	.86	.97	.94	.23	.28	1.37	.61	.69	.33	.79																					
12	.86	1.19	1.55	1.04	.71	.97	1.32	1.30	.74	.56	1.09	1.07	1.02	.10	1.14	1.27	.64	.64																		
13	.28	.43	.51	.48	.97	.33	.58	.89	.58	.25	.64	.36	.51	.41	.36	.51	.33	.51																		
15	.97	1.47	.84	1.14	.97	1.07	1.24	.91	1.52	.23	1.07	.79	.99	.38	1.09	1.09	.86	1.22																		
16	.64	.36	.41	.61	.76	.20	.66	.66	1.04	.33	.53	.64	.84	.58	.53	.58	.41	.69																		
17	.58	.71	.81	.64	.94	.46	.74	.69	.84	.53	.66	.48	.74	.10	.08	.53	.71	.41																		
18	.30	.99	.64	.53	.99	.66	.38	.66	.89	.28	.81	.43	.81	.38	.20	.69	.33	.23																		
19	.84	.53	.79	.53	.97	.51	.91	.48	1.14	.28	.71	.89	.48	.33	.33	1.02	.53	.46																		
20	.66	.41	.28	.30	.86	.33	.36	.41	.53	.23	.74	.10	.18	.08	.20	.15	.28	.03																		
22	.89	.81	.81	.86	1.12	.38	1.12	1.02	.94	.64	.86	.41	.79	.58	.46	1.14	.69	.33																		
23	.97	.97	1.50	.81	1.04	.71	.64	1.70	1.42	.33	1.45	.20	.53	1.02	.61	1.17	.61	.99																		
25	.56	.25	.58	.38	1.07	.43	.51	.89	.53	.25	.51	.28	.56	.33	.43	.30	.38	.56																		
27	1.35	1.30	1.73	1.35	.94	1.14	1.70	1.47	1.85	.25	1.91	.91	1.42	.61	2.34	1.45	1.35	1.35																		
28		.97	.28	.74	1.07	.36	.86	.89	1.17	.23	1.04	.74	1.12	.64	1.12	.41	.74	.20																		
29	.18	.20	.76	.33	1.04	.20	.33	.56	.38	.33	.25	.15	.43	.10	.41	.43	.30	.13																		
Avg.	.71	.79	.84	.69	.91	.53	.81	.86	.94	.33	.86	.51	.64	.36	.61	.81	.51	.48																		

Table C.5. Application Rates Including Precipitation, Laramie, 1978, in cm/day

House No.	June 5 - June 8	June 8 - June 15	June 15 - June 22	June 22 - June 29	June 29 - July 6	July 6 - July 13	July 13 - July 20	July 20 - July 27	July 27 - Aug. 3	Aug. 3 - Aug. 10	Aug. 10 - Aug. 17	Aug. 17 - Aug. 24	Aug. 24 - Sept. 1
2	.13	.48	.69	.43	.71	.38	.53	.43	.46	.74	.03	.38	.23
3					1.12	.13	1.73	.03	.41	1.37	.36	1.12	.33
4	.13	.66	.13	.74	.61	.51	.76	.46	.64	.97	.03	.25	.30
6			.91	.66	.94	.81	.76	.94	.86	.81	.43	.61	.41
7			.81	.64	1.12	.84	.81	1.24	.53	1.19	.61	.71	.30
8			.74	.71	.61	.46	.74	.97	.66	.56	.10	.51	.64
9						.61	.81	.66	.66	.74	.30	.25	.41
10				1.02	1.35	.94	.89	.69	.97	.99	.13	.74	.36
11			.53	.69	.38	.48	.56	.41	.48	.86	.13	.41	.25
12		.48	.74	.66	.61	.48	.66	.61	.51	.79	.03	.43	.30
13			1.17	.58	.91	1.40	1.50	.81	1.07	1.35	.05	1.27	.18
14			2.18	.84	1.93	1.45	1.80	1.65	1.04	1.19	.38	1.37	.69
15			.36	.81	.58	.41	.48	.36	.53	.66	.23	.36	.41
16			2.18	2.03	.76	1.32	1.85	1.57	.38	1.75	1.17	.36	1.40
18				1.40	.89	1.12	1.09	.94	.69	.79	.48	.58	.81
19			.74	.51	.66	.79	.58	.38	.46	.81	.08	.08	.53
20			.64			1.50	.84	.43	.66	.89	.28	.56	.23
21			1.55	.30	.46	.61	.41	.48	.38	.69	.25	.05	.38
22				.58	.33	.38	.99	1.02	.46	.51	.08	.08	.08
23			.71	.43	.20	.15	1.02	.61	.36	.61	.03	.28	.18
24			.76	1.07	1.09	.69	.61	.79	.66	.86	.15	.76	.58
25			1.32	.84	.89	.48	.76	1.60	1.12	.86	.74	1.02	.76
26		.48	.71	.81	.51	.66	.64	.53	.46	.71	.05	.51	.18
27			.28	.33	.20	.48	.53	.66	.51	.58	.13	.33	.13
28		.30	.53	.58	.43	.48	.51	.38	.51	.69	.10	.33	.43
29		.36	.20	.20	.15	.53	.66	.15	.61	.56	.03	.15	.05
30			1.75	1.17	.99	1.50	1.04	1.12	1.09	.86	.25	1.17	.28
32		.66	.84	1.19	1.24	.56	1.19	1.02	.23	.71	.03	.05	.30
Avg.	.13	.48	.89	.76	.76	.71	.89	.74	.61	.86	.23	.53	.41

Table C.6. Application Rates Including Precipitation, Wheatland, 1978, in cm/day

House No.	May 23 - May 30	May 30 - June 6	June 6 - June 13	June 13 - June 20	June 20 - June 27	June 27 - July 5	July 5 - July 11	July 11 - July 18	July 18 - July 25	July 25 - Aug. 1	Aug. 1 - Aug. 8	Aug. 8 - Aug. 15	Aug. 15 - Aug. 22	Aug. 22 - Aug. 29	Aug. 29 - Sept. 5
1	.79	.64	.38	.43	.56	.74	.86	.84	.48	.64	.36	.23	.74	.53	.66
2		.48	.10	.36	.23	.25	.25	.25	.38	.28	.36	.28	.15	.28	.08
3	.48	.43	.23	.43	.33	.20	.58	.15	.43	.46	.46	.51	.41	.46	.43
5	.76	.43	.58	.58	.97	.66	.99	1.30	.66	.66	.48	.61	.56	.64	.56
6						.48	.51	.41	.79	.46	.43	.30	.79	.48	.46
7	.38	.56	.33	.84	.94	.76	1.24	.99	1.55	.38	.79	.48	.86	1.07	.71
9	.74	.79	.43	.99	1.02	.84	.97	.97	.64	1.07	.48	.56	.94	.91	.38
10	.13	.36	1.60	1.02	3.00	1.98	1.75	3.86	1.32	2.21	.48	1.19	1.02	2.44	1.04
12	.76	.36	.94	.97	1.04	1.50	.89	1.52	1.30	.66	1.02	.36	1.50	1.02	1.68
13	.51	.53	.41	.61	.58	.64	.79	.53	.48	.79	.43	.36	.74	.46	.81
15		.91	1.22	1.17	1.91	1.37	1.63	.81	.99	.99	.86	.66	1.35	1.35	1.22
16	.69	.64	.13	.84	.51	.84	.61	.61	.91	.84	.53	.28	.74	.79	1.55
18		.43	.10	1.30	1.02	1.02	1.40	.46	.58	.94	.36	1.24	.69	.94	.66
19	.43	.58	.51	.76	1.22	.53	1.04	.53	1.02	.76	.43	.89	.76	1.04	.81
20	.18	.36	.08	.36	.36	.46	.64	.33	.23	.53	.36	.46	.28	.71	.33
22	.51	.69	.66	.97	.89	.86	1.04	.56	.97	.91	.74	.43			.20
23	.91	.61	.71	1.60	1.70	.86	1.17	1.35	.86	1.24	.61	.71	1.17	.89	.94
25	.76	.38	.28	.84	.89	.48	1.09	.81	.51	.76	.51	.58	.64	.91	.97
26		.56	.38	.25	.69	.74	.94	.86	.25	.58	.38	.53	.81	1.09	1.07
27			1.07	1.78	1.24	1.93	1.47	1.47	.99	2.44	.86	1.75	1.70	.94	1.88
30					.84	.94	.84	.81	.71	1.14	.46	.94	.76	.97	.76
Avg.	.58	.53	.53	.84	.99	.86	.99	.91	.76	.89	.53	.64	.84	.89	.81

Table C.7. Appearance Ratings, Laramie, 1976

House No.	May 25 - June 2	June 2 - June 9	June 9 - June 16	June 16 - June 23	June 23 - June 30	June 30 - July 7	July 7 - July 14	July 14 - July 21	July 21 - July 28	July 28 - Aug. 4	Aug. 4 - Aug. 11	Aug. 11 - Aug. 18	Aug. 18 - Aug. 25	Aug. 25 - Aug. 31	Aug. 31 - Sept. 7	Seasonal Average
2	9	9	7	7	7	8	7	8	8	8	8	7	7	8	8	7.7
3	9	9	9	9	8	9	8	9	9	9	9	9	9	9	9	8.9
4	9	9	9	9	9	10	8	10	9	10	9	10	10	10	10	9.4
6	7	7	9	9	6	8	8	10	9	9	9	10	10	10	10	8.7
7	9	7	9	9	8	8	8	9	9	9	10	10	10	10	10	9.0
8	9	9	9	9	9	8	8	9	9	10	9	9	9	9	9	8.9
9	7	9	7	5	7	6	6	7	7	8	7	6	6	7	7	6.8
10	7	7	7	5	5	5	5	7	7	7	7	6	6	7	7	6.3
11	9	9	9	9	8	8	7	8	8	8	7	7	7	7	7	7.9
12	7	7	9	9	6	7	7	8	8	8	8	8	8	8	8	7.7
13	7	9	9	9	7	8	8	9	8	8	8	8	7	8	8	8.1
14	7	7	7	7	6	6	7	8	8	8	8	7	6	7	7	7.1
15	7	5	7	9	7	7	8	8	8	8	8	7	7	7	7	7.3
16	9	7	7	5	7	7	7	8	7	7	7	6	5	6	6	6.7
17	3	5	7	7	5	4	4	6	6	7	7	7	7	7	7	5.9
18	9	9	9	9	8	8	8	9	9	8	8	9	8	9	9	9.3
19	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5.0
20	9	9	9	9	9	9	8	9	9	9	9	9	9	9	7	8.8
21	7	7	7	7	7	7	5	7	7	8	8	8	7	7	7	7.1
22		5	5	5	5	5	5	6	6	6	5	6	6	5	5	5.4
23	5	5	5	5	4	4	4	6	6	5	5	5	5	6	6	5.1
24		9	9	9	9	9	9	10	9	10	9	9	9	10	9	9.2
25	9	9	9	7	6	5	5	6	7	6	6	5	7	6	6	6.6
26		9	9	9	9	9	9	9	8	9	8	8	9	8	8	8.6
27	9	9	9	9	8	8	8	8	9	9	10	9	8	8	8	8.6
28			3	3	4	4	4	5	5	5	5	5	6	5	5	4.5
29			7	5	5	5	5	5	6	7	6	6	6	6	5	5.7
30	7	7	7	7	7	7	7	8	7	7	7	7	7	7	7	7.1
31			3	5	3	4	4	5	5	4	4	3	3	3	3	3.8
Avg.	7.6	7.6	7.5	7.3	6.7	6.8	6.3	7.7	7.5	7.7	7.4	7.0	7.2	7.4	7.2	

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Table C.8. Appearance Ratings, Wheatland, 1976

House No.	May 7 -	May 17 -	May 17 -	May 21 -	May 21 -	May 28 -	June 4 -	June 4 -	June 10 -	June 10 -	June 17 -	June 17 -	June 24 -	June 24 -	July 1 -	July 1 -	July 8 -	July 8 -	July 15 -	July 15 -	July 22 -	July 22 -	July 29 -	July 29 -	Aug. 5 -	Aug. 5 -	Aug. 12 -	Aug. 12 -	Aug. 19 -	Aug. 19 -	Aug. 26 -	Aug. 26 -	Sept. 2 -	Sept. 2 -	Sept. 9 -	Sept. 9 -	Sept. 16 -	Sept. 16 -	Seasonal Average									
	May 17	May 21	May 28	June 4	June 10	June 17	June 24	July 1	July 8	July 15	July 22	July 29	Aug. 5	Aug. 12	Aug. 19	Aug. 26	Sept. 2	Sept. 9	Sept. 16	Sept. 23																												
1	9	9	9	9	9	7	7	8	8	8	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	8.5							
2		5	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	6.9						
3	5	5	7	7	7	7	7	7	7	7	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5.9					
5	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7.8				
6	3	3	7	7	7	7	7	7	7	7	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5.8				
7		9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	8.5				
9		5	7	5	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	6.9				
10		5	5	7	5	3	5	6	5	5	6	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5.1				
11		7	9	9	9	7	7	9	9	9	7	7	9	9	9	9	9	9	9	9	9	9	9	10	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	8.4			
12		5	5	5	5	7	5	7	5	7	7	5	6	5	5	5	5	5	5	5	5	5	4	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5.3			
13						3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3.5		
15		9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9.2		
16		7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	6.1			
17		3	3	3	3	3	3	3	3	3	5	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4.2			
18			3	5	5	5	5	5	5	5	5	7	5	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	5.6			
19		5	5	5	5	5	5	7	7	7	6	6	6	5	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	6.4		
20				3	5	5	5	5	5	5	6	5	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4.4		
21				5	5	5	5	5	5	5	4	5	5	5	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	5.0		
22				5	5	5	5	5	5	5	5	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6.0	
23				7	9	7	7	7	7	7	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6.2	
24		7	9	7	7	7	7	7	7	7	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	7.8	
25			7	7	9	7	7	7	7	7	9	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	7.9	
26				7	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	4.7		
27		7	7	7	7	7	7	7	7	7	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6.1	
28				9	7	7	7	7	7	7	8	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7.1	
29				7	7	9	5	7	6	7	6	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	6.8
Avg.	6.0	5.9	6.8	6.6	6.8	6.0	6.2	6.4	6.3	6.2	6.4	6.3	6.2	6.6	6.5	6.7	6.4	6.4	6.4	6.3	5.8	6.2	6.3	6.5																								

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Table C.9. Appearance Ratings, Laramie, 1977

House No.	May 25 - June 1	June 1 - June 8	June 8 - June 15	June 15 - June 22	June 22 - June 29	June 29 - July 6	July 6 - July 13	July 13 - July 19	July 19 - July 27	July 27 - Aug. 3	Aug. 3 - Aug. 10	Aug. 10 - Aug. 17	Aug. 17 - Aug. 24	Aug. 24 - Sept. 2	Seasonal Average
2	7	8	7	7	7	8	7	8	9	8	8	8	8	8	7.7
3	8	7	7	8	8	8	9	9	10	9	8	8	9	9	8.4
4	8	8	8	9	10	10	9	10	10	10	10	9	10	10	9.4
6	9	8	8	9	9	9	10	10	10	10	10	10	10	10	9.4
7	7	8	8	8	9	9	10	9	9	9	9	8	6	7	8.4
8	7	7	7	8	8	9	9	9	9	9	9	8	9	8	8.3
9	6	6	6	7	7	6	7	7	7	7	5	6	7	7	6.5
10	7	7	7	7	5	6	7	7	7	6	6	5	6	6	6.4
11	6	7	6	6	5	5	6	5	7	7	6	6	6	6	6.0
12	6	7	7	7	7	7	7	7	8	8	8	8	8	8	7.4
13	7	7	7	7	7	7	7	8	8	7	8	8	8	8	7.4
14	6	7	7	7	7	7	8	8	8	8	8	8	7	7	7.4
15	4	5	4	5	5	5	4	5	5	5	5	5	5	5	4.8
16	6	5	4	5	6	6	6	6	7	7	7	6	7	6	6.0
17	6	6	7	7	7	7	8	8	8	7	7	7	6	6	6.9
18	8	8	8	8	8	8	8	8	9	8	8	8	8	7	7.9
19	4	5	5	5	5	5	5	5	6	5	4	4	4	4	4.7
20	8	9	9	9	9	9	10	10	10	9	10	8	8	8	9.0
21	5	4	5	5	5	4	4	4	6	6	6	7	7	6	5.3
22	6	6	6	6	5	6	6	6	7	7	7	6	6	5	6.1
23	5	5	5	5	5	5	6	5	6	6	5	5	6	6	5.4
24	9	8	8	9	9	10	10	9	10	10	10	9	10	8	9.2
25	6	6	6	6	6	5	6	6	6	5	5	5	5	5	5.5
26	7	7	6	6	5	6	6	6	7	7	7	7	7	7	6.5
27	6	6	7	7	8	8	8	9	9	10	10	10	10	10	8.4
28	5	5	5	5	5	5	6	7	7	7	7	7	7	7	6.1
29	4	3	4	4	5	4	5	5	5	5	5	4	4	3	4.3
30	7	7	8	8	8	8	8	8	8	8	8	8	7	7	7.7
32		4	4	4	4	4	4	4	4	4	4	4	4	5	4.1
Avg.	6.4	6.4	6.4	6.7	6.7	6.8	7.1	7.2	7.6	7.4	7.3	6.9	7.1	6.9	

Table C.10. Appearance Ratings, Wheatland, 1977

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House No.	May 19 - May 26	May 26 - June 2	June 2 - June 9	June 9 - June 16	June 16 - June 23	June 23 - June 30	June 30 - July 7	July 7 - July 14	July 14 - July 21	July 21 - July 28	July 28 - Aug. 4	Aug. 4 - Aug. 11	Aug. 11 - Aug. 18	Aug. 18 - Aug. 25	Aug. 25 - Sept. 1	Sept. 1 - Sept. 7	Sept. 7 - Sept. 15	Sept. 15 - Sept. 22	Seasonal Average
1	9	9	8	8	9	9	9	9	9	9	10	9	9	8	9	8	9	8	8.8
2	5	5	5	6	7	8	7	7	6	8	8	8	8	7	7	8	8	8	7.0
3	3	4	4	4	4	4	4	4	5	5	5	5	5	6	5	5	4	4	4.4
5	8	8	8	8	9	8	7	8	8	8	9	8	8	8	8	8	9	9	8.2
6	6	5	5	5	7	6	6	6	5	6	7	6	7	6	6	6	6	5	5.6
7	6	7	7	7	8	8	7	8	8	8	9	8	8	9	9	9	9	9	8.0
9	7	7	7	7	8	7	7	7	6	7	7	7	7	7	7	7	7	7	7.0
10	4	2	2	2	2	3	3	3	3	3	3	3	3	3	3	3	3	3	2.8
11	6	7	7	7	8	8	8	8	8	9	8	8	8	8	8	8	7	7	7.7
12	5	4	4	4	5	5	5	5	7	5	5	5	5	5	5	5	5	4	4.7
13	7	7	7	7	7	7	7	7	6	7	7	7	7	8	7	7	7	8	7.1
15	7	7	7	7	8	8	7	8	7	8	7	7	7	8	8	8	7	7	7.4
16	6	5	5	6	7	6	6	6	6	5	5	5	4	5	6	5	6	5	5.1
17	4	4	4	4	5	5	5	5	4	5	5	5	5	5	5	5	5	5	4.7
18	5	4	4	5	5	5	4	4	5	5	5	5	5	5	4	6	6	5	4.8
19	6	6	6	5	7	7	7	7	7	7	7	7	7	6	7	7	7	7	6.7
20	5	5	5	4	5	5	5	5	4	5	5	4	5	5	4	3	3	3	4.4
22	6	7	7	7	7	7	7	7	7	7	8	7	7	7	7	7	7	7	7.0
23	7	6	7	7	8	8	6	6	7	7	7	7	7	7	7	7	7	7	6.8
25	7	7	6	6	7	6	7	7	7	7	7	7	7	8	8	8	8	6	7.0
26				7	7	7	7	7	8	7	7	8	8	7	8	8	8	8	7.5
27	5	6	7	6	7	7	7	7	7	7	7	7	7	6	7	7	7	7	6.7
28	7	7	7	7	8	7	8	8	7	8	8	7	7	7	7	7	7	7	7.3
29	6	6	6	7	7	7	7	7	6	7	7	7	7	7	7	7	7	7	6.8
30						5	4	4	3	3	3	3	3	3	3	2	2	2	2.8
Avg.	6.0	5.9	5.9	6.0	6.7	6.5	6.3	6.4	6.1	6.5	6.6	6.4	6.4	6.4	6.5	6.4	6.4	6.2	

Table C.11. Appearance Ratings, Laramie, 1978

House No.	June 5 - June 8	June 8 - June 15	June 15 - June 22	June 22 - June 29	June 29 - July 6	July 6 - July 13	July 13 - July 20	July 20 - July 27	July 27 - Aug. 3	Aug. 3 - Aug. 10	Aug. 10 - Aug. 17	Aug. 17 - Aug. 24	Aug. 24 - Sept. 1	Seasonal Average
2	7	7	7	7	7	7	7	7	7	7	7	7	7	7.0
3		7	7	7	7	7	8	7	7	7	9	9	9	7.6
4	8	8	8	8	8	8	8	8	8	8	8	8	9	8.1
6		8	8	8	7	8	8	7	7	7	8	8	9	7.8
7		6	7	7	7	7	7	7	7	7	7	8	8	7.1
8		7	8	8	8	8	8	7	7	7	8	8	8	7.7
9					7	7	7	7	7	7	7	7	7	7.0
10		5	5	5	6	6	6	6	6	6	6	6	6	5.8
11		6	6	6	6	6	6	6	6	6	6	6	6	6.0
12	8	8	8	8	8	8	8	8	8	8	8	8	8	8.0
13		8	8	8	7	7	7	7	7	7	7	8	7	7.3
14		7	6	6	7	7	7	6	6	6	7	7	6	6.5
15			5	5	5	5	5	5	5	5	5	6	6	5.2
16		7	7	7	7	7	7	7	7	7	6	7	7	6.9
18			7	7	7	7	7	7	7	7	7	7	7	7.0
19		5	5	5	5	5	5	5	5	5	5	5	4	4.9
20		8	8	8	8	7	8	8	8	8	7	7	8	7.8
21			6	6	6	6	6	5	6	6	6	6	6	5.9
22			5	6	6	6	6	5	6	6	6	6	5	5.7
23		4	5	5	5	5	5	6	6	6	6	5	5	5.3
24		8	8	8	8	9	9	8	7	7	8	9	8	8.1
25		8	7	7	7	6	6	6	6	6	7	6	6	6.5
26	6	6	6	7	6	6	6	6	6	6	6	6	6	6.1
27														
28		6	7	7	7	7	7	7	7	7	8	8	8	7.2
29		5	5	5	5	4	4	4	4	4	4	4	4	4.3
30		7	7	7	7	7	7	7	7	7	7	7	7	7.0
32		6	6	6	6	6	6	5	6	6	4	4	4	5.4
Avg.	7.3	6.7	6.6	6.7	6.7	6.6	6.7	6.4	6.5	6.5	6.7	6.8	6.7	

Table C.12. Appearance Ratings, Wheatland, 1978

House No.	May 23 - May 30	May 30 - June 6	June 6 - June 13	June 13 - June 20	June 20 - June 27	June 27 - July 5	July 5 - July 11	July 11 - July 18	July 18 - July 25	July 25 - Aug. 1	Aug. 1 - Aug. 8	Aug. 8 - Aug. 15	Aug. 15 - Aug. 22	Aug. 22 - Aug. 29	Aug. 29 - Sept. 5	Seasonal Average
1		7	6	7	7	7	7	7	7	7	7	7	7	7	7	6.9
2		9	8	8	7	7	7	6	7	7	7	7	7	7	7	7.2
3		6	6	5	6	6	5	5	5	5	5	5	6	5	6	5.4
5		8	8	7	8	8	7	7	8	7	7	7	8	7	7	7.4
6		7	7	6	7	7	6	6	6	6	7	6	6	6	6	6.4
7		8	8	8	8	8	9	8	8	8	8	8	8	8	8	8.1
9		7	7	7	8	8	8	7	7	8	8	8	8	8	8	7.6
10		2	3	3	3	3	4	5	5	5	5	5	5	5	5	4.1
12		6	5	5	5	6	5	5	5	4	5	5	5	5	5	5.1
13		8	8	8	8	8	8	7	7	7	7	7	7	7	7	7.4
15		7	7	7	7	7	7	7	7	7	7	7	7	7	7	7.0
16		6	6	6	6	6	6	6	5	5	5	5	5	5	5	5.5
18		5	6	6	7	7	6	6	6	6	6	6	6	6	6	6.1
19	6	6	5	5	6	5	6	6	6	6	6	6	7	6	6	5.9
20		6	5	5	5	5	6	6	4	5	5	6	7	7	7	5.6
22		6	6	6	6	6	6	6	6	7	7	7	7	7	7	6.4
23		7	7	6	6	6	7	6	6	6	6	6	6	6	6	6.2
25		6	6	6	7	6	7	7	6	6	6	6	6	6	6	6.2
26		6	6	6	6	6	6	6	5	5	5	5	6	6	6	5.7
27		6	6	6	6	6	6	6	6	6	6	6	5	6	6	5.9
30			7	7	7	7	7	7	7	7	7	8	8	8	8	7.3
Avg.	6.0	6.5	6.3	6.2	6.5	6.4	6.5	6.3	6.1	6.2	6.3	6.3	6.5	6.4	6.5	

Table C.13. Summary of Lawn Stress Ratings (1976-1977)

Laramie				Wheatland				
Home Number	Average Stress Rating*			Home Number	Average Stress Rating*			
	1976	1977	2-year Average		1976	1977	2-year Average	
2	5.0	1.4	3.2	1	2.3	1.1	1.7	
3	1.0	2.9	2.0	2	15.8	4.4	10.1	
4	1.3	0.7	2.0	3	29.3	20.3	24.8	
6	4.7	1.8	3.2	5	13.0	13.1	13.1	
7	0.0	1.1	0.6	6	41.8	15.8	28.8	
8	2.5	0.4	1.5	7	2.1	2.2	2.2	
9	11.3	3.6	7.5	9	1.8	1.1	1.5	
10	3.3	4.3	3.8	10	7.9	9.2	8.6	
11	7.7	16.4	12.1	11	5.0	13.9	9.5	
12	0.0	2.1	1.1	12	6.1	2.2	4.2	
13	1.3	5.7	3.5	13	5.3	0.0	2.7	
14	3.7	1.4	2.6	15	3.9	1.1	2.5	
15	3.7	18.2	11.0	16	16.6	3.1	9.9	
16	3.0	8.6	5.8	17	25.8	20.6	23.2	
17	24.7	8.6	16.7	18	21.4	14.2	17.8	
18	2.7	8.2	5.5	19	13.2	3.6	8.4	
19	38.3	31.8	35.1	20	91.2	31.1	61.2	
20	9.0	2.9	6.0	21	23.5	-	-	
21	20.0	13.9	17.0	22	8.2	0.6	4.4	
22	18.2	10.7	14.5	23	25.9	4.2	15.1	
23	14.7	16.4	15.6	24	1.6	-	-	
24	0.3	1.4	0.9	25	15.8	25.6	20.7	
25	10.7	13.6	12.2	26	45.0	2.3	23.7	
26	7.9	6.4	7.2	27	11.3	0.0	5.7	
27	1.0	1.4	1.2	28	24.1	10.0	17.1	
28	19.2	5.0	12.1	29	24.7	16.1	20.4	
29	41.2	34.6	37.9	30	-	22.3	-	
30	8.7	2.1	5.4					
31	36.5	-	-					
32	-	28.8	-					
Avg.	10.4	8.8	9.6	8.8	18.6	9.5	14.1	14.1

* Stress rating is based on the percent of the lawn showing visible signs of water stress.

Stress ratings were taken for each lawn on the same weekly schedule as water application readings and appearance ratings (see Chapter 3).

APPENDIX D

SPRINKLERS TESTED

Rain Bird 171-D	Buried Head
Rain Bird 1600	Buried Head
Rain Bird 1800	Buried Head
Rain Bird 2600	Buried Head
Nelson 6085	Buried Head
Nelson 6235	Buried Head
Nelson N-48FC	Stationary
Thompson 70	Stationary
Thompson 100	Stationary
Thompson 113	Stationary
Burgess 503	Impact
Melnor 9510C	Impact
Nelson N-137	Impact
Rain Bird SL-25	Impact
Burgess 351	Rotating
Melnor 860	Rotating
Nelson N-54	Rotating
Rain Bird RO-45	Rotating
Burgess 372	Oscillating
Melnor 885	Oscillating
Nelson N-055A	Oscillating
Rain Bird 0-15	Oscillating
Nelson 1049	Oscillating
Craftsman	Traveling
Sears Roebuck	Traveling
Nelson Rain	Traveling
Nelson Rain Train	Traveling
Thompson	Traveling

Nine tests were made for each sprinkler.

APPENDIX E
COPIES OF GUIDELINE PUBLICATIONS

Watering of Lawns, June 1977
Measuring Lawn Water, October 1979
Selection and Use of Lawn Sprinklers, October 1979

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WATERING OF LAWNS

Agricultural Extension Service
University of Wyoming, Laramie

Miscellaneous Publication 39
June 1977

John R. Barnes, Graduate Student
Patrick K. O'Neill, Graduate Student
John Borrelli, Assistant Professor
Larry O. Pochop, Professor
Donald J. Brosz, Irrigation Engineer

A good quality lawn is largely the consequence of proper water management. Correct management is a year-round process that is most intense during the summer growing season. Besides being an important factor in total lawn care, watering represents a major cost item of yard maintenance.

Summer Watering

During the summer months (June, July, and August), a healthy thick blue-grass lawn in Wyoming will require approximately 0.25 inches of water per day or between 1 1/2 to 2 inches of water per week. In general, the higher the altitude the lower the water requirement.

As a rule of thumb, the water should be applied by watering once a week for clay soils and twice a week for sandy soils. However, longer periods between waterings may be possible. A good way to minimize water application is to wait for water stress to appear in the lawn before irrigating. Some dry areas generally will appear between watering due to spots with poor soil, poor distribution of water, or other reasons. Water these small areas by hand with a drag hose to minimize water use. If larger areas than desired show signs of water deficiencies, decrease the time between major irrigations. However, be careful to avoid applying more than 1 1/2 to 2 inches of water in any week.

The depth applied can be determined by placing small cans at least 3 inches deep at varying distances

from the sprinkler but within the watering pattern. (Note: sprinklers with low application angles may be difficult to calibrate with cans much over 3 inches in depth). Once the time required to apply the desired depth of water has been determined, watering may be done by use of a clock rather than measuring the depth of water in cans. There are some commercially available mechanical timer valves that will turn the water off after a prescribed time. Remember that each sprinkler is different so for each different type of sprinkler, the can test must be conducted again.

Spring and Fall Watering

Only 60 percent of the seasonal water use occurs in the three summer months (Table 1). In the spring and fall, time between major irrigations should be increased to take into consideration the decreased water needs of the grass. Again, using stressed areas to signal the need for irrigation will help in timing the irrigations.

It is of special importance to realize that lawns do use considerable water during the five month winter dormant period. Therefore 2 to 3 inches of water should be applied during the last week of October. To start the lawn off in the spring, a 2 to 3 inch application of water may be made during the first week in April or when the frost has left the soil. If desired, early irrigation need not be done and the grass can be left dormant until later in the spring.

Issued in furtherance of Agricultural Extension Work, acts of May 8 and June 30, 1914, in cooperation with the U.S. Department of Agriculture. Neal W. Hilston, Dean and Director, Agricultural Extension Service, University of Wyoming, Laramie.

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Sprinkler Irrigation

Sprinklers do an excellent job of applying water but they are not perfect. All sprinkler systems will over irrigate in some areas and under irrigate in other areas, even though the average application is as desired. For best water efficiency accept these areas of under irrigation and water them with a drag hose by hand as they show signs of water stress.

DO NOT over irrigate to the point where all areas are adequately watered. The cost due to over irrigation is too high.

General Lawn Care

Fertilizer: A healthy, thick lawn will require approximately 3 to 4 lbs of actual nitrogen per 1000 ft² per year. Ideally, it should be applied in small amounts before each irrigation. If this cannot be done, a good compromise would be 4

treatments of 3/4 to 1 lb each. For good results in Wyoming, you should select a fertilizer that contains 1 1/2 to 2 percent iron.

Mowing: Close cutting of the lawn weakens the grass, causes shallow rooting and allows weeds to infest the lawn. Therefore, proper mowing of a lawn is essential. Most varieties of bluegrass grow best at a minimum height of 1 1/2 to 2 inches. When mowing, it is often recommended that no more than one-third of the blade length should be cut off per mowing. The mower should be kept sharp so as not to bruise and fray the grass.

Raking: To achieve good water infiltration, any thatch or accumulation of clipping over 1/2 inch should be removed with a power rake either in the spring or fall. In addition, the lawn should be aerated. Aeration is best achieved by a coring spike mechanical aerator.

Table 1
CONSUMPTIVE USE* FOR KENTUCKY BLUEGRASS
1976 Measured Values**

Period	Consumptive Use (inches)	
	Laramie 7,200 ft altitude	Wheatland 4,700 ft altitude
April	2.37	2.79
May	3.53	4.74
June	5.58	6.06
July	5.74	7.16
August	5.15	5.02
September	3.21	3.12
October	<u>1.67</u>	<u>2.64</u>
TOTAL	27.25	31.53

*Consumptive use represents the sum of transpiration from the grass and evaporation from the soil. Any precipitation must be subtracted from the consumptive use to determine the amount of water to be applied by sprinkling.

**Preliminary data from a study at the University of Wyoming.

MEASURING LAWN WATER

Agricultural Extension Service
University of Wyoming, Laramie

Publication _____
October 1979

John Borrelli, Associate Professor
Larry Pochop, Professor

It is just about impossible to guess how much water is being applied to a lawn without some type of guidelines. In a study of lawn water application rates at the University of Wyoming, it was found that over 50% of the homeowners in a sample from Laramie and Wheatland overwatered their lawns. On the other hand, few homeowners underwatered. It was obvious that most homeowners did not realize how much excess water they are applying, whereas most will avoid underwatering by responding to visible water stress conditions. If an aesthetically pleasing lawn is to be maintained with a minimum of water, the amount of water applied must be known.

There are several methods for determining the amount of water applied. These include (1) wetting the soil profile to a recommended depth, (2) using catch cans to calibrate the sprinklers, (3) metering the amount of water applied, (4) following average estimated application rates for specific sprinklers.

Wetting the Soil Profile

A commonly recommended method for controlling the amount of water applied is to water until the soil is wet to a given depth—usually about 8 inches. This is very difficult, since it can not be determined what has taken place below the soil surface without removing soil samples. Even if the homeowner purchases a proper soil core samples, it is generally impractical to take enough samples to obtain a good indication of the wetting pattern when considering the uneven distribution of most sprinklers. In general, this method

would appear to be the least precise of those discussed herein.

Catch Cans

The use of catch cans to calibrate the application rate of a sprinkler is often recommended. The method consists of simply setting several cans on the lawn to catch the precipitation from the sprinkler. The cans should be set at various distances from the sprinkler head but within the main watering pattern. The major advantage over the above method is that the application rate is easily sampled in many locations of the sprinkler's pattern rather than testing the soil profile in one or two locations. Even then, the "catch can" method is not as accurate as it is usually thought to be—because more cans than are practical are generally required.

The application rate is determined by averaging the depth of water in the cans. If watering is continued for one hour, the average depth in the cans will be equal to the application rate in inches per hour. The irrigation is then timed to put on the desired depth.

Metering the Water

The most accurate method of determining the application rate is to directly measure the amount of water applied. In some cases the city water meter may be used. If not, water meters that attach directly to the lawn hose can be purchased at a relatively low cost.

An alternative to metering is to determine the discharge rate in gallons

per minute. This may be accomplished by discharging the sprinkler into a container for one minute and measuring the gallons of output. A disadvantage of this procedure is that the flow rate of a home water system will change from time to time due to the variabilities of pressure and pressure losses. Also the discharge rate of a sprinkler will change as the area of coverage is varied, so the procedure needs to be repeated whenever the area covered is changed.

Assuming use of meters, the volume of water applied to the entire lawn can be measured. This volume can easily be translated into an average depth applied. For a given number of gallons and area of lawn, the depth applied is

$$\text{Inches of Water Applied} = 1.606 \times \frac{\text{Gallons of Water Applied}}{\text{Square Feet of Lawn Area}}$$

The number of gallons required to apply a desired depth of water can be determined by

$$\text{Gallons of Water Required} = \frac{(\text{Inches of Water Desired}) \times (\text{Square feet of Lawn})}{1.606}$$

For example, if 1.5 inches of water is desired on a 4000 sq. ft. lawn,

$$\begin{aligned} \text{Gallons of Water Required} &= \frac{(1.5 \text{ inches})(4000 \text{ft}^2)}{1.606} \\ &= 3736 \text{ gallons} \end{aligned}$$

It is important that this water be applied as uniformly as possible. (This is also true of the other methods discussed). Few home lawn

sprinklers apply water with adequate uniformity without considerable overlap of sprinkler sets. A study at the University of Wyoming has shown that a 75% overlap of the wetting pattern is desirable for most lawn sprinklers. Observations indicate that common practices of most homeowners do not approach this degree of overlap. Most homeowners that do practice overlapping of hand move systems seem only to move their sprinklers in one direction and with seldom more than 25%, or at most 50%, overlap. Solid set systems are designed to achieve overlap of the wetting pattern of individual sprinkler heads, however, seldom are they designed for more than 50% overlap.

To apply the required volume of water as uniformly as possible, the time needed to discharge the total required gallons should be determined. Next, the number of sets required to cover the lawn should be determined, allowing for as much overlap of sets as possible keeping in mind that the more overlap the better. Then the sprinkler would be left to run at each set an amount of time equal to the total time required to cover the lawn divided by the number of sets. The only exception to this procedure is that if on some sets the area covered by the sprinkler is greater than on other sets, then the time that the sprinkler is left on the larger area should be increased since application rates decrease as the area covered increases (see the next section for guidelines).

Application Rates

The following table gives a general idea of the average application rates and size of wetted pattern for various sprinkler types without overlap. Note that application rates decrease as pattern sizes increase.

Typical† Application Rates for Lawn Sprinklers

Sprinkler Type	Pressure* (lb/in ²)	Application Rate (inches/hr)	Sprinkler** Pattern Size
Buried Head	Low (10)	0.93	12 ft diameter
	Medium (20)	0.86	16 ft diameter
	High (30)	0.55	24 ft diameter
Stationary	Low (10)	1.81	12 ft diameter
	Medium (20)	1.01	16 ft diameter
	High (30)	0.82	25 ft diameter
Impact	Low (10)	0.50	20 ft diameter
	Medium (20)	0.26	25 ft diameter
	High (30)	0.22	40 ft diameter
Rotating	Low (10)	1.74	12 ft diameter
	Medium (20)	0.68	25 ft diameter
	High (30)	0.42	35 ft diameter
Oscillating	Low (10)	0.80	16 ft x 16 ft
	Medium (20)	0.35	30 ft x 30 ft
	High (30)	0.27	40 ft x 40 ft
Traveling	Low (10)	0.73	30 ft width
	Medium (20)	0.48	44 ft width
	High (30)	0.30	48 ft width

† Values are averages of three tests on 4 sprinklers of each type.

* Pressure measured at end of hose.

** Some sprinklers can be adjusted to change size of pattern.

SELECTION AND USE OF LAWN SPRINKLERS

Agricultural Extension Service
University of Wyoming, Laramie

Publication _____
October 1979

John Borrelli, Associate Professor
Larry O. Pochop, Professor

One of the most likely causes of incorrect watering is the poor water distribution efficiency of the sprinklers used by most homeowners. Actually no sprinkler will distribute the water at equal depths over the entire wetted or sprinkler pattern. This unequal distribution will over-irrigate in some areas and underirrigate in others. Most sprinklers do, however, give adequate distribution if overlapped and used properly. The trick is to select the best sprinkler for your situation and then use it correctly.

Sprinkler Patterns

Each sprinkler will distribute the water in a different pattern. By pattern we mean not only the wetted area, but the relative depths of water within this wetted area. Shown in Figure 1 are the cross-sections of sprinkler patterns for the six most common types of sprinklers all operated at a medium pressure. Note that none of them have a very uniform depth of distribution. This points out the need to overlap sprinkler patterns.

Overlapping Sprinkler Patterns

To achieve a relatively uniform distribution of water, sprinkler patterns are overlapped so that more than one sprinkler set or sprinkler contributes water to an area (see Figure 2). Hopefully the total application of water will be about the same in all areas. To measure the success of distributing water, a uniformity coefficient (UC) has been developed. A UC of 100 means a perfect water distribution has been achieved with all areas receiving the same depth of water. On

the other hand, a UC of 70 (the lowest recommended value) means at least 30% of the area will receive 120% or more of the average depth of water, and 30% of the area will receive 80% or less of the average depth of water. As an absolute minimum, no sprinkler should be operated so a UC of less than 60 is achieved.

Shown in Table 1 are UC's for various sprinklers overlapped at various amounts. On comparing UC values for the three pressure levels, no sprinkler is acceptable according to the 70 minimum UC value until overlapped 75% in one direction or 25% x 25% in both directions. In general, the more the overlap of a sprinkler pattern, the higher the UC value. It should be noted that overlapping a sprinkler pattern in one direction only will not achieve a very high UC value.

What Sprinkler Should I Use

Since there is no perfect sprinkler only general recommendations can be made. First of all, the rotating and oscillating sprinklers should be avoided because of their apparent poor distribution characteristics. If used, they should be overlapped in both directions by 75%. A choice between the other sprinklers may be as much a matter of convenience as workability.

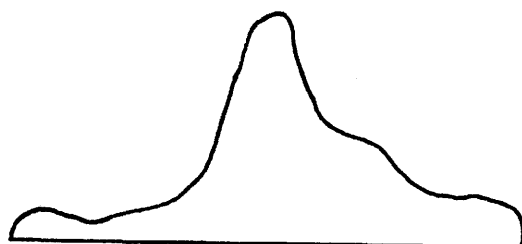
For Square Areas: A part-circle impact sprinkler can be placed in each corner of a square area. If the sprinkler pattern reaches the other side, you have achieved a 50% x 50% overlap. From Table 1 it can be seen that a high (80% or more) UC would be achieved. For large square areas sprinklers



Buried Head



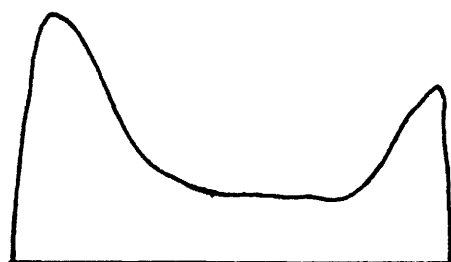
Stationary



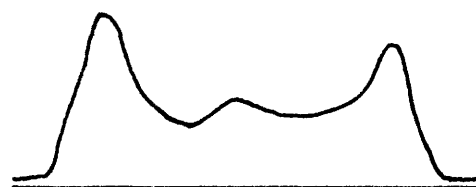
Impact



Rotating

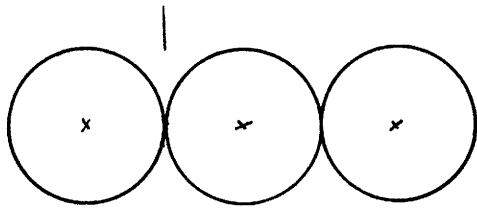


Oscillating

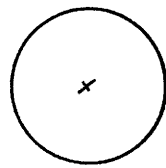


Traveling

Figure 1. Cross-section of sprinkler patterns



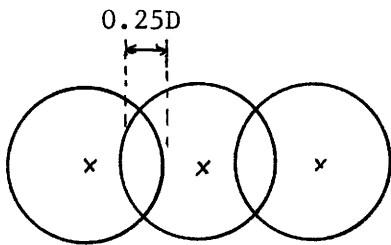
No Overlap



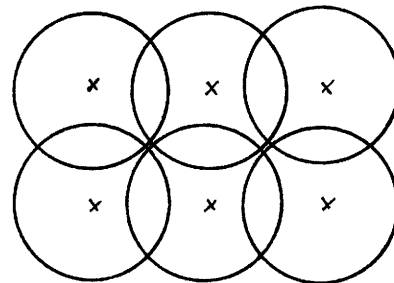
Sprinkler Head

D = Diameter of Wetted Pattern

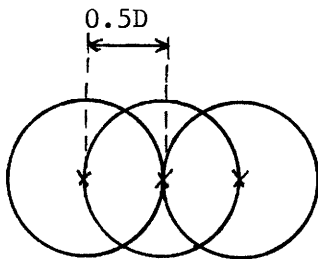
Wetted Pattern



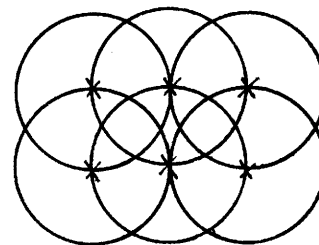
25% Overlap



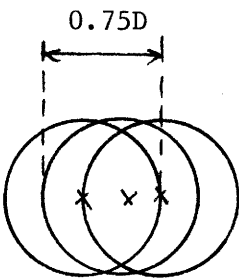
25% x 25% Overlap



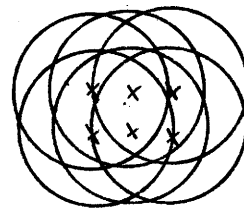
50% Overlap



50% x 50% Overlap



75% Overlap



75% x 75% Overlap

Figure 2. Schematic of overlapped sprinkler patterns.

Table 1. Christiansen's Uniformity Coefficient (UC) for Lawn Sprinklers

Sprinkler Type	Pressure (lbs/sq-inch)		Overlaps						
			0%	25%	50%	75%	25% x 25%	50% x 50%	75% x 75%
Buried Head	Low	(10)	8*	18	38	54	29	66	<u>86</u>
	Medium	(20)	30	38	54	<u>75</u>	45	69	<u>93</u>
	High	(30)	27	44	50	<u>68</u>	56	<u>71</u>	<u>95</u>
Stationary	Low	(10)	19	30	54	66	37	66	<u>87</u>
	Medium	(20)	35	43	57	<u>71</u>	50	<u>72</u>	<u>92</u>
	High	(30)	32	47	57	60	61	<u>81</u>	<u>95</u>
Impact	Low	(10)	42	53	59	62	68	<u>82</u>	<u>94</u>
	Medium	(20)	42	55	58	62	<u>70</u>	<u>81</u>	<u>95</u>
	High	(30)	40	56	56	58	<u>77</u>	<u>85</u>	<u>96</u>
Rotating	Low	(10)	10	17	37	55	22	53	<u>79</u>
	Medium	(20)	26	31	50	64	35	63	<u>85</u>
	High	(30)	40	51	57	70	57	67	<u>89</u>
Oscillating	Low	(10)	33	33	49	53	38	56	<u>79</u>
	Medium	(20)	43	38	51	61	45	63	<u>86</u>
	High	(30)	49	48	61	68	49	<u>70</u>	<u>91</u>
Traveling	Low	(10)	65**	57	67	<u>90</u>	--	--	--
	Medium	(20)	61	60	65	<u>85</u>	--	--	--
	High	(30)	61	66	68	<u>86</u>	--	--	--

* A UC of 100 means a perfect distribution of water with respect to depth. The minimum acceptable UC for Sprinkler-systems is 70.

** A traveling sprinkler has an implied 100% overlap in one direction due to the forward movement of the sprinklers.

can be placed on a grid pattern to achieve the desired overlap. Table 2 gives a general idea of the size of wetted patterns for the various sprinkler types and the average water application rate for that wetted pattern with no overlap. It should be noted that for a part-circle impact sprinkler using only one-fourth of a circle, the average application rate should be multiplied by 4.

For Long Narrow Areas: Long narrow areas can best be irrigated with a traveling sprinkler. Overlapping in this case is difficult, but can be accomplished. Most traveling sprinklers do not apply an adequate depth of water when crossing a lawn only once. So a traveling sprinkler needs to be run across the same area more than once. In so doing the arms may be readjusted for each run to achieve overlapping. However, a traveling sprinkler will provide a relatively high UC without any overlap and is far better than any other sprinkler type with no overlap.

For Rectangular Areas: Many of our lawns are rectangular in shape. In this case, any sprinkler type would work if overlapped properly. An impact or traveling sprinkler would probably work best because they provide relatively high UC values with small overlaps. On the other hand, it is difficult for one to get the 75% x 75% overlap necessary to achieve high UC values with the other types of sprinklers.

For Permanent Set Sprinkler Systems: Buried head sprinklers are generally used with permanent installations. These sprinklers should be overlapped at least 50% x 50%. An overlap of 75% x 75% would be optimal. Impact sprinklers can also be used although they would generally require more work to use.

Caution: Regardless of the type of sprinkler one uses, water will be wasted if one applies a greater depth than needed. Some overirrigation will always occur. To avoid wasting water, measure all your water and overlap your sprinkler properly. Irrigate those small dry spots by use of a drag hose.

Table 2. Typical Application Rates for Lawn Sprinklers

Sprinkler Type	Pressure* (lbs/sq-inch)	Avg. Application Rate (inches/hr)	Avg. Sprinkler Pattern Size
Buried Head	Low (10)	0.93	12 ft diameter
	Medium (20)	0.86	16 ft diameter
	High (30)	0.55	24 ft diameter
Stationary	Low (10)	1.81	12 ft diameter**
	Medium (20)	1.01	16 ft diameter
	High (30)	0.82	25 ft diameter
Impact	Low (10)	0.50	20 ft diameter**
	Medium (20)	0.26	25 ft diameter
	High (30)	0.22	40 ft diameter
Rotating	Low (10)	1.74	12 ft diameter**
	Medium (20)	0.68	25 ft diameter
	High (30)	0.42	35 ft diameter
Oscillating	Low (10)	0.80	16 ft x 16 ft**
	Medium (20)	0.35	30 ft x 30 ft
	High (30)	0.27	40 ft x 40 ft
Traveling	Low (10)	0.73	30 ft (width)**
	Medium (20)	0.48	44 ft (width)
	High (30)	0.30	48 ft (width)

* Pressure measured at end of hose.

** Some sprinklers can be adjusted to change size of sprinkler pattern.

APPENDIX F

PROJECT PUBLICATIONS

1. Borrelli, J., L. O. Pochop, and J. R. Barnes, 1976. Lawn watering - a drain on agricultural irrigation. Paper presented at Rocky Mountain Section, ASAE Meeting, Las Cruces, New Mexico, April 23.
2. Borrelli, J., L. O. Pochop, and J. R. Barnes, 1976. Lush lawns vs. loaded larders. Agricultural Engineering Journal, August, pp. 18-20.
3. Barnes, J. R., P. K. O'Neill, J. Borrelli, L. O. Pochop, and D. J. Brosz, 1977. Watering of lawns. University of Wyoming Agricultural Extension Service, Miscellaneous Publications No. 39, June.
4. Pochop, L. O., J. Borrelli, J. R. Barnes, and P. K. O'Neill, 1978, Water requirements and application rates for lawns. Water Resources Series No. 7., University of Wyoming, February.
5. Kerr, G. L., L. O. Pochop, J. Borrelli, and D. A. Anderson, 1978. Distribution patterns of lawn sprinklers. ASAE Paper No. 78-2011, presented at the Annual Summer Meeting, Logan, Utah, June 27-30.
6. Barnes, J. R., J. Borrelli, and L. O. Pochop, 1979. Optimum lawn watering rates for aesthetics and conservation. Journal American Water Works Association, April, pp. 204-209.
7. Pochop, L. O., and J. Borrelli, 1979. Water use by Kentucky bluegrass. Proceedings 1979 Arizona Turfgrass Conference, May 9-10, pp. 18-20.
8. Borrelli, J., and L. O. Pochop, 1979. Irrigation of lawns: can we continue the practice. Proceedings of ASCE Irrigation and Drainage Division Specialty Conference. Albuquerque, New Mexico, July 19.
9. Kneebone, W. R., I. L. Pepper, R. E. Danielson, W. E. Hart, L. O. Pochop, and J. Borrelli, 1979. Water requirements for urban lawns. Project completion report to OWRT, September.

The following papers have been accepted for publication:

10. O'Neill, P. K., L. O. Pochop, and J. Borrelli. Urban lawn evapotranspiration - measurement and prediction. Transaction of ASAE.
11. Kerr, G. L., L. O. Pochop, J. Borrelli, and D. A. Anderson. Distribution patterns of home lawn sprinklers. Transaction of ASAE.

The following papers are being prepared for publication:

Extension type publications such as those shown in Appendix E.