WATER REQUIREMENTS FOR URBAN LAWNS

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Chapter 1

INTRODUCTION

This paper reports Arizona's contribution to the Wyoming regional research project "Water requirements for urban lawns". This project included Wyoming, Colorado and Arizona and was initiated in 1976 with OWRT funding commencing October 1976.

Throughout the western states, water is an important resource upon which are multiple demands. One major demand is agricultural, another is industrial and a third rapidly growing demand is urban. In the low deserts of Arizona urban growth has been explosive, and lawn areas are heavily keyed to major income sources such as tourism. These increasingly large lawn areas are irrigated with water pumped from underground aquifers. Tucson, Arizona has a population of 450,000 people which are totally dependent on groundwater for their water needs. Groundwater levels have decreased 0.6 to 1.5 meters per year as use exceeds natural replenishment (Groundwater Resource Mangement Data 1977; from Department of Soils, Water and Engineering, University of Arizona). Since southwestern Arizona is located in an arid environment with temperatures in excess of 38° C for many months of the year with low rainfall, water is at a premium and water requirements of urban lawns are of vital interest. This study located at the University of Arizona Rincon Vista Turfgrass Research Center in Tucson investigated these requirements.

Chapter 2

OBJECTIVES

The overall objective was to measure water use of urban lawn areas in southern Arizona, determining the effect of choice of lawn species and management level upon water consumption per unit lawn area. Specific objectives were:

1. Accurately measure water use of different bermudagrass cultivars, Zoysia, St. Augustinegrass, and tall fescue under "high and "low" level managements, correlating water use data with those from a standard weather station adjacent to the test area.

2. Measure soil moisture tensions and temperatures at which watering is conducted.

3. From data obtained, derive estimates of water needs for given areas of lawn under standard water management and determine potential savings from proper choices of species, managements and watering levels. Some of the questions to be resolved were: 1. What effect does level of watering have on consumptive water use by turfgrasses? 2. Are there significant differences between turfgrasses in the amount of water they require under similar management levels? 3. If there are significant management, species or cultivar effects on consumptive water use, of what magnitude are they and how can they be used to conserve water? 4. How does consumptive water use by turfgrasses in Tucson,

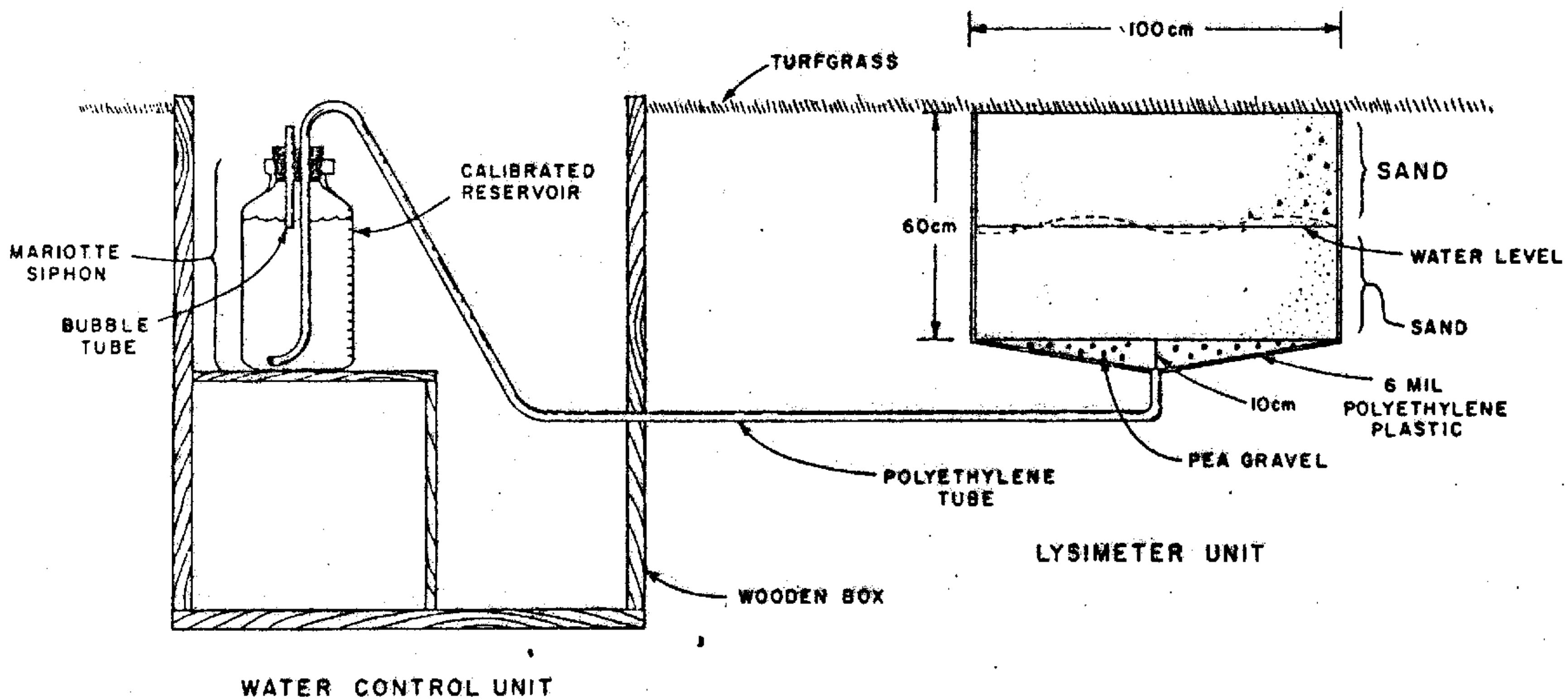

Figure 1. Lysimeter system used for controlled irrigation.

Arizona relate to local microclimatic parameters and are these relationships consistent with those found in Colorado and Wyoming? 5. How does consumptive water use under controlled conditions relate to typical water use on Tucson turfgrass and to previous estimates? 6. What amount of water is necessary for an acceptable turf quality?

Chapter 3

PROCEDURES

Turfgrasses were chosen which were adapted to and are being used under Tucson conditions. The range of similar conditions and adaptation is from El Paso to the Imperial Valley of California at altitudes below 4,000 feet. Grasses chosen to be evaluated were bermudagrass, Zoysia, St. Augustinegrass and tall fesuce. Tall fescue was chosen since it has potential as an all year green, cool season grass in this area. The other grasses are warm season grasses. To evaluate cultivar and management effects, three bermudagrasses, 'Tifgreen', 'Santa Ana', and certified seeded bermudagrass plus a selection of Zoysia japonica similar to 'Mayer' were tested under two management regimes, "high" and "low".

The "high" management regime was chosen to evaluate consumptive water use of lawn areas under growth conditions such as encountered on golf course fairways and commercial lawns. This management included more available water by maintaining the water table consistently 10 cm above that for the "low" regime, heavier nitrogen fertilization, and overseeding of the warm season grasses with annual ryegrass for winter green grass.

The "low" management regime was chosen to evaluate consumptive water use of lawn under typical homeowner management, where energy inputs are usually minimal.

Thirty lysimeter boxes, 1 meter square and 60 cm deep, constructed of 1 inch redwood and lined with a double layer of 6 mil plastic sheeting were buried to ground level at the University of Arizona Rincon Vista Turfgrass Research Center in Tucson, Arizona. At the bottom center of each box a tube was attached and sealed to allow addition or removal of water from the box as desired. Each box was connected by its tube to a large glass water bottle (used water cooler bottles, capacity 18 liters) arranged as a Marriotte siphon (see Fig. 1). Water losses from the bottle were measured daily. Each liter lost from the bottle represented 1 mm lost from the surface of the lysimeter. Liter marks were placed on the bottles to facilitate easy reading. Bottles were refilled regularly so that water levels in the bottle were always above the water level in the box and siphon action was unbroken.

The lysimeters were constructed in two rows of 15 each, all at the same level, leading into a roofed underground service pit. Bottles were set on shelving so that water levels could be adjusted to any desired point in the lysimeters. The lysimeter boxes were filled with washed mortar sand which was puddled to check for leaks. Silt reaching the surface was skimmed off prior to planting the warm season grasses as washed sod free of soil. Moisture blocks, each with a thermistor, were buried at 7.5, 15 and 18 cm depth to measure moisture percentages and temperatures in six of the boxes. Moisture blocks were also buried at four locations and two depths (7.5, 15 cm) in a city park within a mile of the lysimeter location. Moisture block readings were calibrated in a pressure plate apparatus for each soil and location.

"High" management plots were overseeded with annual ryegrass in October, 1976, 1977, and 1978. Plots were scalped, seeded at 75 g/m^2 (15 lb/100 ft^2) and water tables raised to near surface level for the first week to encourage germination. The water tables were maintained 40 cm from the soil surface in 1976-1977 and at 35 cm from June 1977. Fertilization was with ammonium sulfate applied at 4.5 g N/m^2 approximately once per month during the growing season. Mowing height was 2 to 2.5 cm.

"Low" management plots were fertilized every other month during the growing season at a rate of 4.9 g N/m^2 and mowing height was maintained at 4 to 5 cm. Water tables were initially maintained 50 cm below the soil surface, but raised in June 1977 to 45.

Tifgreen, Santa Ana, seeded bermudagrass, and Zoysia were established at "high" and "low" management regimes. Common St. Augustine and Kentucky 31 tall fescue were established only under low management regimes. The bermudagrasses and Zoysia were arranged in randomized split blocks with the split between management levels. St. Augustinegrass and tall fescue were also assigned randomly to boxes in three sets of two interspersed between the bermudagrass-Zoysia replicates (Table 1).

A standard wooden weather station enclosure was placed 15 feet from the lysimeters furthest from the service pit. Daily temperatures were recorded in it. Adjacent to the enclosure were a standard rain gauge and Class A evaporation pan. All of these were surrounded with a minimum 15 foot fetch of maintained bermudagrass turf.

Immediately adjacent to the lysimeters used in this study was an identical set which were used by E. L. Anderson during 1977-78 (1) for a master's thesis studying the effectiveness of turfgrass-soil filters for tertiary treatment of sewage effluent. She used seeded bermudagrass overseeded in winter with annual ryegrass. Watering with measured amounts of effluent at a series of high levels, she collected, measured, and analyzed leachates. The difference between leachate recovered and water applied can be interpreted as a measure of evapotranspiration. Consumptive water use values calculated from this study were compared to those for the seeded bermudagrass under high management during the same weeks in 1977-78 to determine effects of excessive watering upon water use.

Chapter 4

RESULTS

Weekly mean values obtained for consumptive water use for each of the grasses are summarized in detail in appendix tables 1-5 along with weather data in appendix Table 6. The same data are graphed using two week values in figures 2-4. It is obvious from figure 2 that water level does indeed have a significant effect on consumptive water use. Differences between low and high management from February through April are due in large part to the actively growing ryegrass, but from May - October water use was reduced 5-10 mm/week by lowering the water table 10 cm.

Table 1. Lysimeter basins constructed and established at Rincon Vista Turfgrass Research Center 1976. Start with NE corner, count South (1 - 15) returning to NW corner. Again count South (16 - 30). Basins begin at SW corner of service shed.

Planned Management	Grass	Basin Numbers R_1	R_2	R_3
High N	Tifgreen	16	9	14
Winter overseeding	Santa Ana	2	8	29
	Seeded bermuda	1	24	30
	Zoysia	17	23	15
Low N	Tifgreen	20	6	27
No overseeding	Santa Ana	5	22	26
	Seeded bermuda	4	21	11
	Zoysia	19	7	12
Low N	St. Augustine	18	10	13
No overseeding	Ky 31 Tall Fescue	3	25	28

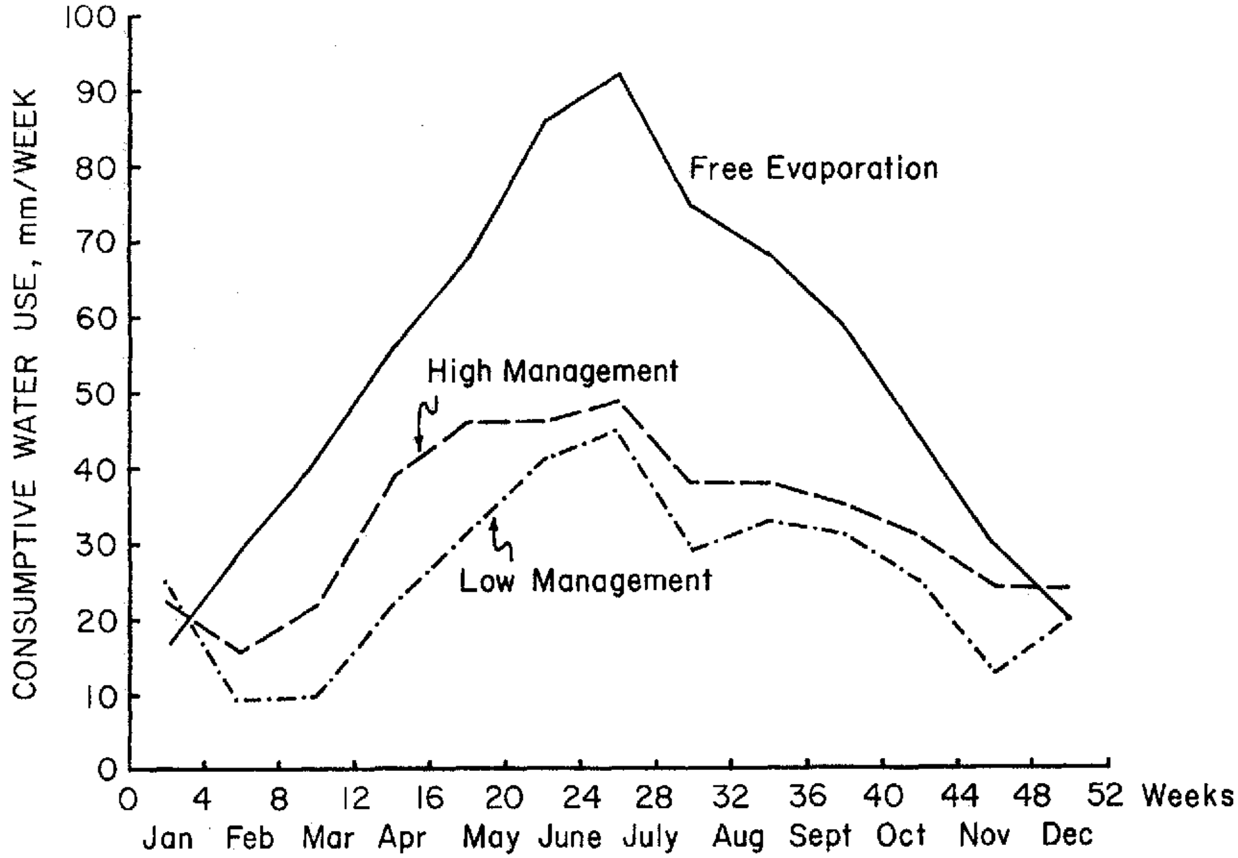

FIG. 2 MEAN CONSUMPTIVE WATER USE OF FOUR WARM-SEASON GRASSES UNDER HIGH AND LOW MANAGEMENT

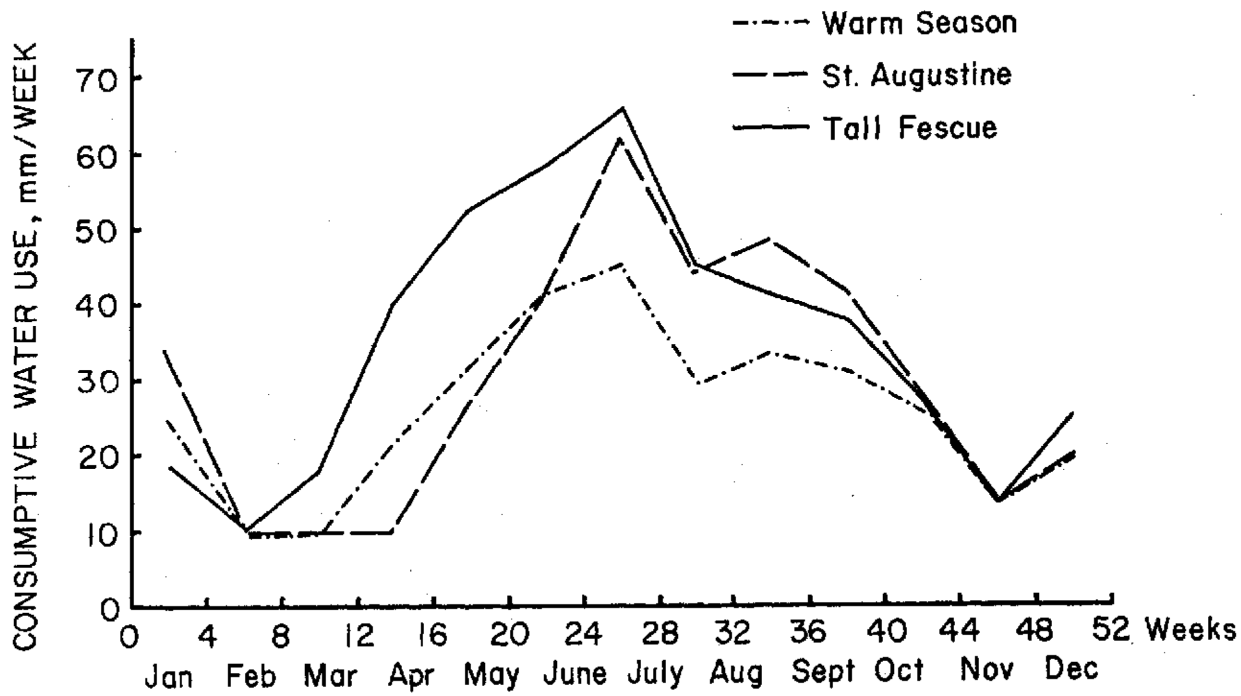

FIG. 3 MEAN CONSUMPTIVE WATER USE OF FOUR WARM-SEASON GRASSES, TALL FESCUE AND ST. AUGUSTINE UNDER LOW MANAGEMENT.

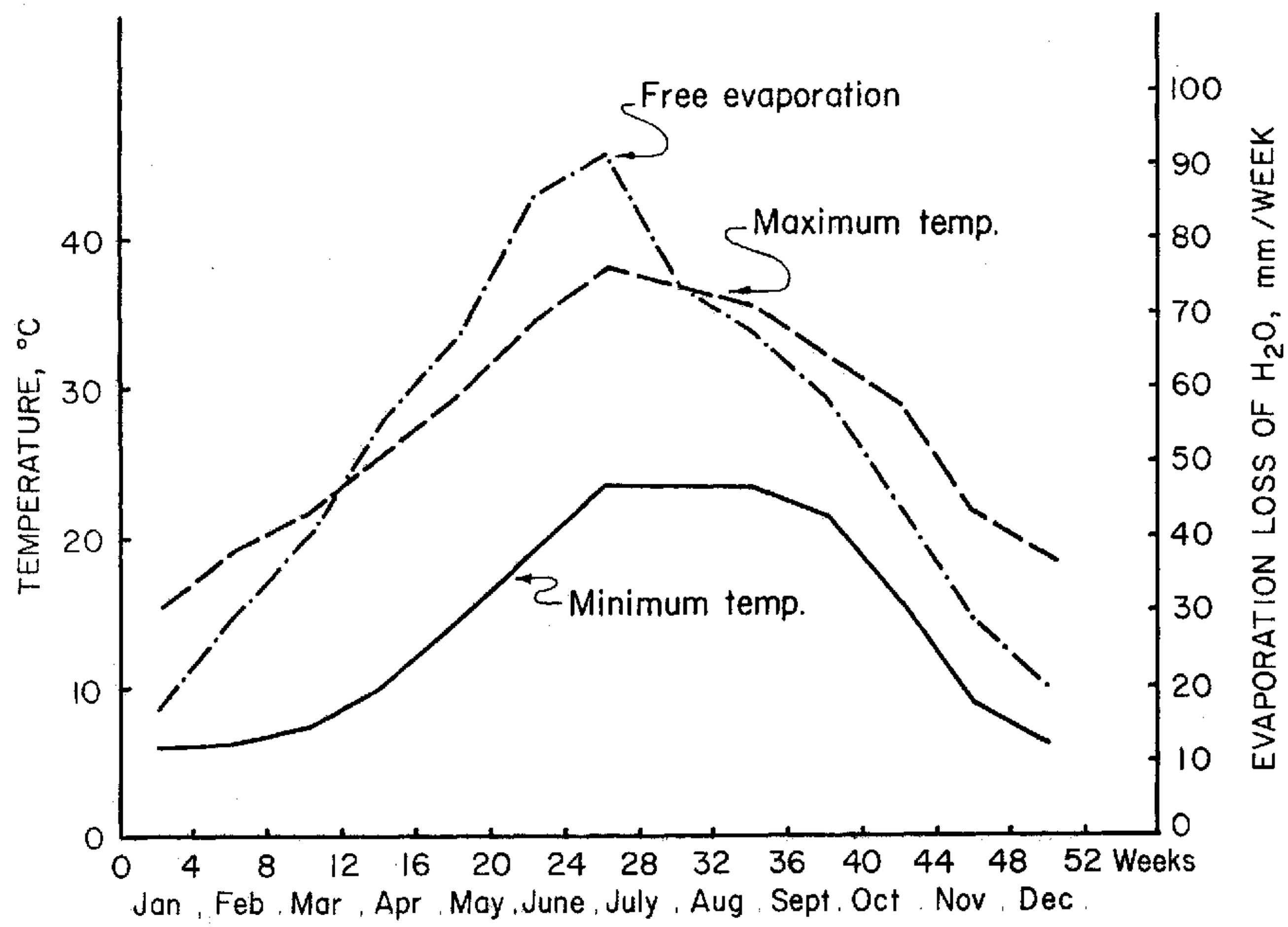

FIG. 4. MEAN WEATHER DATA FOR TUCSON, ARIZONA, 1977 THROUGH 1979.

Increasing water levels leads to luxury consumption by turfgrass as indicated by the data in Tables 2 and 3, but calculated consumptive water use by overseeded bermudagrass did not exceed Class A pan evaporation until application rates reached 7-10 times evaporation. We conclude that water application rates above evaporative demands as indicated by pan data are wasteful and that good turf can be grown at watering levels considerably less. The range of watering should be between 50 and 80% of pan depending upon the balance desired between lush growth and economy. Data in Table 4 show actual measured values for consumptive water use expressed in percent of pan evaporation at three levels of evaporation. Percentages are relatively consistent in spite of the wide range in demand. The somewhat lower percentages for the high management in June reflect the passing of the ryegrass component present in late winter and in April.

One of the assumptions in initiation of this study was that certain grasses might be more efficient water users than others. With more water efficient species or cultivars, appreciable water savings might be made while maintaining turfgrass quality. The three bermudagrasses and Zoysia were nearly equivalent in their consumptive water use at each level of management. Comparisons can be made using appendix Tables 1-4. Values for all four grasses varied around a common mean. For this reason the graphic displays in figures 2 and 3 are in mean values only. Tall fescue and St. Augustinegrass, however, had distinctly higher consumptive water use values than did the bermudagrasses and Zoysia (Fig. 3), with the cool season tall fescue using most water yearlong.

Comparative water use by the different grasses is illustrated by Table 4. Tall fescue did not grow as much as the ryegrass during January and February but responded to warmer temperatures in March and April in the same way with increased growth and water use. St. Augustinegrass, although not quite dormant in early spring, began growth in March and reached peak water use in mid June. Tall fescue water use declined during July and August while water use by the warm season grasses went up (Fig. 3). Soil temperatures shown in Tables 5 and 6 help explain some of the growth cycle differences. Temperatures below 20 C inhibit warm season grass growth and temperatures above 25 C inhibit cool season grass growth.

The higher water use by the St. Augustinegrass and tall fescue may be confounded with differences in mowing height. Youngner in California (3) compared bermudagrass and St. Augustinegrass at the same mowing height (2.5 cm). Their consumptive water use was the same. Since this height may well injure St. Augustinegrass, the lack of difference may be due to differential injury.

Feldhake has shown that raising mowing height of Kentucky bluegrass increases consumptive water use (2). Our studies indicate that bermudagrasses, which are the most prevalent turfgrasses in the low desert southwest, are the most efficient water users of the grasses tested. Although there were no differences in consumptive water use among them, the hybrids Santa Ana and Tifgreen will tend to be more attractive to average homeowners than seeded bermudagrass or Zoysia over most of the range of possible water regimes.

Table 2. Consumptive water use (mm/2 week period) by seeded bermudagrass overseeded with annual ryegrass November 1977 - May 1978.

Week	Sub-irrigation*	Surface Irrigation** Rate applied mm/2 weeks 144	232	304	480	608	Class A Pan evaporation	Precipitation
		consumptive use						
44-45 Nov. 1977	21	42	42	57	75	168	69	10
46-47 Nov. 1977	11	37	36	73	106	173	62	0
48-49 Dec. 1977	27	43	42	73	111	152	56	0
50-51 Dec. 1977	24	51	20	79	94	152	60	0
14-15 April 1978	76	80	60	118	132	155	102	0
16-17 April 1978	97	82	82	118	139	158	142	0
Dec. 1977-April 1978	249	471	355	681	821	1343	446	167

* Consumptive use study, water table 40 cm below surface.

** E. L. Anderson, M. S. Thesis, same design lysimeters 2 meters away. Surface irrigated with measured amounts secondary sewage effluent via drip outlets. Consumptive use = applied effluent + precipitation - measured leachate.

Table 3. Consumptive water use (mm/2 week period) in percent of Class A pan evaporation for the same periods by seeded bermudagrass overseeded with annual ryegrass November 1977 - May 1978.

Week		Sub-irrigation*	Surface Irrigation** Rate applied mm/2 weeks 144	232	304	480	608	Class A Pan evaporation	Precipitation
			percentages						
44-45	Nov. 1977	30	61	61	83	109	243	69	10
46-47	Nov. 1977	18	60	58	118	171	279	62	0
48-49	Dec. 1977	48	77	75	130	198	271	56	0
50-51	Dec. 1977	40	85	33	132	157	253	60	0
14-15	April 1978	75	78	59	116	129	152	102	0
16-17	April 1978	68	58	58	83	98	111	142	0
Dec. 1977-April 1978		56	106	80	153	184	301	446	167

* Consumptive use study, water table 40 cm below surface

** E. L. Anderson, M.S. Thesis, same design lysimeters 2 meters away. Surface irrigated with measured amounts secondary sewage effluent via drip outlets. Consumptive use = applied effluent + precipitation - measured leachate.

Table 4. Consumptive water use during periods of varying evaporative demand expressed in percent Class A evaporation for those same periods. Data based upon 1978-79 averages.

Grass	Mgmt.	Time period and mean evaporation: Late Winter Week 1 - 12 28 mm/week	April Weeks 13 - 17 59 mm/week	June Weeks 23 - 26 91 mm/week
Tifgreen	High	64	67	57
	Low	56	37	48
Santa Ana	High	66	75	59
	Low	50	45	52
Seeded	High	66	65	51
	Low	36	39	46
Zoysia	High	63	63	50
	Low	51	41	56
Bermuda-Zoysia Means	High	65	68	54
	Low	48	40	50
St. Augustine	Low	55	46	67
Tall fescue	Low	59	74	76

Table 5. Temperature (C) and moisture percentage during May and June 1977, at 10 cm below bermudagrass grown under three water managements. Tucson, Arizona. Data are averages from 2 moisture blocks.

	Fairway (45 mm/week)		Lawn (70 mm/week)		Lysimeter (400 mm water table) 45 mm/week	
Date	°C	% HOH	°C	% HOH	°C	% HOH
5/12	--	--	20	50	20	< 5
5/19	18	17	19	43	20	< 5
5/24	18	11	19	43	20	< 5
6/7	26	11	27	43	27	< 5
6/9	24	14	26	44	26	< 5
6/14	26	12	26	45	30	27
6/23	24	18	24	46	--	--

Table 6. Sub-surface soil temperatures, Tucson, Arizona (°C).

Soil depth (cm)	1978					1979						
	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
7.6	26	23	19	10	4	11	11	11	12	17	21	26
15.2	24	23	19	11	4	10	10	11	13	18	21	24
30.4	24	24	22	13	6	11	11	12	14	18	21	24

The higher water use by St. Augustinegrass and tall fescue is illustrated by surface temperature measured by an infrared scanning thermometer during the last two weeks of the lysimeter study (Table 7). They had consistently lower temperature values whenever measured. The difference in temperature between high and low water tables is not obvious but there was a slight trend to lower surface temperatures under the higher water use regime.

The data in Table 4 provide some guides to potential water savings by choice of one alternative tested over another. In June when water use was higher for both bermudagrass and Zoysia at both management levels, the saving in water for the low regime was still nearly 8%. In April under a lower demand but with both warm season grass and ryegrass demand under the high regime the savings for the low management was more than 25%. Tall fescue water demands under low management were 85% higher than the bermudagrass and Zoysia in April.

Figure 2-4 show that consumptive use values followed first, evaporative demand, then maximum temperatures and finally minimum temperatures. Soil temperatures (Table 5 and 6) fluctuated less and affected water use chiefly as they affected grass growth. Data from Arizona, Wyoming and Colorado are being compiled together to draw conclusions as to degree of relationship between various microclimatic parameters and consumptive use patterns.

Various difficulties, from vandalism through changes in water regimes and direct cessation of irrigation prevented measurements of "normal" use planned for this study. However, programmed irrigation of fairways on the city golf course was approximately 45 mm per week - similar to our low management values. An intensively cared for tifgreen bermudagrass lawn at city park headquarters was programmed for 70 mm/week irrigation and a commercially maintained Tifgreen lawn in an office complex received an average of 46 mm/week during June, July and August of 1978. Although this was a well maintained and apparently uniform stand of grass, sprinkler pattern variations were large and delivery varied from 34-58 mm from set to set.

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2. Feldhake, C. M. 1979. Measuring evapotranspiration of turfgrass. M.S. Thesis, Colorado State University.

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Table 7. Surface temperatures (C) at 8AM and 3PM for different turfgrasses and different water regimes July 6-16, 1979. Data are averages from 3 reps and 6 days.

	Water Level			
	Low		High	
Grass	AM	PM	AM	PM
Tifgreen B.	34.8	45.3	35.5	45.2
Santa Ana B.	33.8	43.7	31.5	40.2
Seeded B.	33.8	45.8	32.7	42.2
Zoysia	35.0	43.8	34.3	43.2
Bermuda-Zoysia $\bar{x}$	34.4	44.6	33.5	42.7
St. Augustine	31.8	40.3		
Tall Fescue	29.5	37.5		

Appendix Table 1. Consumptive water use of Tifgreen Bermudagrass, Tucson, Arizona, 1977 through 1979

	Consumptive water use (mm)							
	1977		1978		1979		Mean	
Week	High*	Low*	High	Low	High	Low	High	Low
1 12	188	113	207	181	220	191	205	165
13	48	27	43	18	23	7	38	17
14	35	12	40	20	37	14	37	15
15	39	28	41	22	36	12	39	21
16	46	23	48	27	44	39	46	30
17	39	25	50	30	34	30	41	28
18	34	24	59	55	54	41	49	40
19	67	45	50	35	37	31	51	33
20	47	25	47	30	23	33	39	29
21	59	24	39	30	34	32	44	29
22	–	–	55	48	50	29	53	39
23	–	–	54	54	33	19	44	37
24	–	–	60	64	52	42	56	53
25	–	–	60	52	42	24	51	38
26	–	–	72	57	39	39	56	48
27	–	–	58	47	39	39	49	44
28	–	–	35	36	59	42	47	39
29	20	9	42	26			31	17
30	39	31	41	27			40	29
31	43	37	17	11			30	24
32	39	31	44	34			42	33
33	26	19	34	21			30	20
34	39	27	33	36			36	32
35	43	36	42	35			43	36
36	43	43	34	30			39	37
37	30	27	35	27			33	27
38	19	21	35	29			27	25
39	20	16	28	21			24	19
40	75	72	24	17			50	45
41	–	56	28	24			28	40
42 52	174	119	299	220			237	170

* Management levels – High overseeded with annual ryegrass in winter, water tables 10 cm higher than low (40 cm vs. 50 cm from surface 1977-78, 35 cm vs. 45 cm, July 1978 – July 1979).

Appendix Table 2. Consumptive water use of Santa Ana Bermudagrass, Tucson, Arizona, 1977 through 1979.

	Consumptive water use (mm)							
	1977		1978		1979		Mean	
Week	High*	Low*	High	Low	High	Low	High	Low
1 12	218	105	214	176	223	155	218	145
13	49	27	40	38	30	7	40	24
14	37	17	20	25	38	19	32	20
15	40	22	38	27	30	22	36	24
16	44	25	49	32	43	50	42	36
17	47	26	48	38	35	25	43	30
18	42	27	58	55	59	33	53	38
19	71	49	45	41	51	35	56	42
20	45	28	45	25	36	20	42	24
21	53	27	37	30	43	41	44	33
22	–	–	49	51	39	33	44	42
23	–	–	52	57	44	26	48	42
24	–	–	63	64	50	43	57	54
25	–	–	59	50	49	34	54	42
26	–	–	63	63	51	39	57	51
27	–	–	56	45	46	31	51	38
28	–	–	32	35	65	58	49	47
29	25	12	36	33			31	23
30	49	33	43	38			46	36
31	42	31	22	15			35	23
32	39	34	47	44			43	39
33	25	24	34	28			30	26
34	35	33	35	27			35	30
35	44	39	45	37			45	38
36	42	47	28	36			35	42
37	29	29	35	37			32	33
38	17	21	39	37			28	29
39	21	17	27	28			24	23
40	75	74	21	24			48	49
41	46	53	36	30			46	42
42 52	185	145	300	243			243	194

* Management levels - High overseeded with annual ryegrass in winter, water tables 10 cm higher than low (40 cm vs. 50 cm from surface 1977-78, 35 cm vs. 45 cm, July 1978 - July 1979).

Appendix Table 3. Consumptive water use of Zoysia, Tucson, Arizona, 1977 through 1979.

	Consumptive water use (mm)							
	1977		1978		1979		Mean	
Week	High*	Low*	High	Low	High	Low	High	Low
1 — 12	188	113	207	181	220	191	205	162
13	48	27	41	19	21	5	37	17
14	36	10	39	23	37	15	37	16
15	40	19	39	25	23	16	34	20
16	45	22	47	31	47	52	46	35
17	44	23	50	36	30	21	41	27
18	36	24	58	55	45	32	46	34
19	60	46	50	46	41	32	50	41
20	37	22	44	30	30	29	37	27
21	46	24	30	36	39	37	38	32
22	-	-	47	55	41	37	44	46
23	-	-	47	61	31	29	39	45
24	-	-	58	66	53	46	56	56
25	-	-	57	65	33	43	45	54
26	-	-	48	53	40	43	44	48
27	-	-	53	52	40	41	48	47
28	-	-	34	53	58	56	46	54
29	22	11	40	39			31	25
30	38	35	40	36			39	36
31	49	41	14	15			32	28
32	40	34	47	44			44	39
33	31	24	30	28			31	26
34	37	32	36	35			37	34
35	44	39	46	42			45	41
36	47	44	40	41			44	43
37	34	29	41	37			38	33
38	21	18	41	42			31	30
39	21	17	34	29			28	23
40	77	73	18	23			48	48
41	58	53	38	23			48	38
42 — 52	191	147	297	227			244	187

* Management levels - High overseeded with annual ryegrass in winter, water tables 10 cm higher than low (40 cm vs. 50 cm from surface 1977-78, 35 cm vs. 45 cm, July 1978 - July 1979).

Appendix Table 4. Consumptive water use of Seeded certified bermudagrass, Tucson, Arizona, 1977 through 1979.

	Consumptive water use (mm)							
	1977		1978		1979		Mean	
Week	High*	Low*	High	Low	High	Low	High	Low
1 — 12	237	107	209	182	229	158	225	149
13	47	27	42	23	20	4	36	18
14	36	14	40	25	41	10	39	16
15	41	22	39	25	33	19	38	22
16	46	22	47	27	46	43	46	31
17	46	24	50	37	33	15	43	25
18	40	23	58	56	45	23	48	34
19	65	44	51	35	49	31	55	37
20	42	22	49	23	30	21	40	22
21	54	23	28	28	42	27	41	26
22	–	–	50	48	36	29	43	39
23	–	–	53	52	34	20	44	36
24	–	–	63	65	23	14	43	40
25	–	–	60	53	34	39	47	46
26	–	–	64	57	28	36	46	46
27	–	–	56	45	38	42	47	44
28	–	–	36	30	44	47	40	39
29	28	11	43	42			36	27
30	42	32	39	25			41	29
31	51	39	24	9			38	24
32	40	33	50	32			45	33
33	27	20	33	21			30	21
34	37	22	34	21			36	27
35	47	38	44	38			46	38
36	46	39	34	29			40	34
37	31	25	34	25			33	25
38	22	18	37	31			30	25
39	20	14	31	19			26	17
40	76	74	26	22			51	47
41	58	53	41	21			50	37
42 — 52	181	121	298	220			240	171

*Management levels - High overseeded with annual ryegrass in winter, water tables 10 cm higher than low (40 cm vs. 50 cm from surface 1977-78, 35 cm vs. 45 cm, July 1978 - July 1979).

Appendix Table 5. Consumptive water use of Tall Fescue, St. Augustine and Bermuda-Zoysia grasses under low management, Tucson, Arizona, 1977 through 1979.

	Consumptive Water Use (mm)								
	Tall Fescue			St. Augustine			Warm Season Grasses		
Week	1977	1978	1979	1977	1978	1979	1977	1978	1979
1 — 12	168	198	192	113	183	183	108	179	166
13	35			27		8	27		19
14	29	38	50	21	23	23	16	23	15
15	42	39	34	29	31	13	23	25	17
16	47	47	57	30	38	47	23	32	46
17	54	52	42	37	44	21	24	35	23
18	52	54	58	35	53	50	25	55	32
19	73	56	54	55	51	42	46	39	32
20	52	47	34	39	33	29	24	25	26
21	67	50	49	40	41	40	26	31	34
22	-	77	35	-	70	43	-	51	32
23	-	84	45	-	72	33	-	56	24
24	-	83	69	-	77	47	-	65	36
25	-	82	63	-	77	57	-	55	35
26	-	67	58	-	68	53	-	57	37
27	-	80	54	-	75	40	-	47	38
28	-	42	80	-	44	75	-	39	51
29	32	50		21	55		11	35	
30	60	51		45	48		33	32	
31	61	15		58	22		37	13	
32	43	45		43	54		33	36	
33	32	34		33	37		22	25	
34	40	37		52	41		31	32	
35	47	47		56	46		38	38	
36	50	45		61	54		43	34	
37	31	43		37	51		28	32	
38	19	49		27	50		20	35	
39	23	41		30	40		16	24	
40	77	37		78	23		73	22	
41	27	34		27	27		54	25	
42 — 52	207	255		189	254		133	228	

Appendix Table 6. Weather Data, Tucson, Arizona, 1977 through 1979

Week	Evaporation 1977	Evaporation 1978 (mm)	Evaporation 1979	Maximum Temp. 1977	Maximum Temp. 1978	Maximum Temp. 1979	Minimum Temp. 1977	Minimum Temp. 1978	Minimum Temp. 1979
1	14	20	20	14	19	15	4	8	7
2	11	23	12	12	13	16	1	8	7
3	22	18	14	18	14	16	4	9	8
4	18	19	18	16	18	13	6	4	5
5	19	26	18	17	17	13	4	10	4
6	32	22	36	21	16	18	6	7	4
7	35	22	36	24	11	24	4	3	7
8	42	32	33	23	22	18	5	10	7
9	40	28	35	16	17	17	2	13	7
10	50	34	38	21	18	24	7	9	8
11	46	41	41	22	23	22	4	9	13
12	57	48	28	26	25	17	6	13	7
13	48	58	41	19	26	22	7	14	8
14	40	56	48	26	22	25	7	10	8
15	62	64	53	29	26	33	11	11	9
16	67	65	64	29	27	30	12	10	13
17	75	74	69	30	29	31	16	13	14
18	76	55	66	29	26	29	14	8	15
19	73	83	72	27	33	28	12	16	13
20	66	52	56	26	32	31	12	16	17
21	70	60	61	29	32	31	13	17	18
22	82	102	79	29	36	34	13	16	19
23	98	113	60	37	37	32	22	20	21
24	106	103	94	40	39	39	20	21	24
25	93	108	86	35	40	37	19	23	18
26	109	88	75	38	38	41	22	22	26
27	96	110	91	37	41	39	23	24	22
28	77	90		37	40		24	27	
29	72	83		35	39		23	27	
30	84	80		36	36		23	24	
31	75	70		37	34		24	23	
32	69	52		35	38		24	26	
33	66	56		34	34		24	24	
34	83	49		36	36		23	22	
35	81	79		36	36		23	24	
36	76	56		36	34		23	26	
37	57	60		32	31		20	24	
38	62	62		34	31		21	21	
39	63	56		33	34		21	22	
40	54	58		30	33		21	21	
41	49	53		32	33		18	17	
42	53	43		32	31		17	17	
43	39	37		27	24		15	12	
44	39	36		27	27		12	13	
45	30	31		21	24		11	13	
46	34	25		25	18		10	7	
47	28	23		24	18		8	11	
48	30	23		22	17		7	5	
49	26	14		26	10		7	0	
50	29	20		22	21		6	9	
51	31	14		18	16		9	5	
52	12	13		16	17		7	8	

WATER REQUIREMENTS

FOR

URBAN LAWNS

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COLORADO WATER RESOURCES RESEARCH INSTITUTE
Colorado State University
Fort Collins, Colorado
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TABLE OF CONTENTS

Chapter 1

INTRODUCTION

This report involves the Colorado State University contribution to a three-state research project funded by an OWRT matching grant. The University of Arizona and the University of Wyoming were also included in the study and each of the three institutions conducted research under specific objectives of the study. The Colorado part of the project was:

(1) To determine water requirements of urban lawns at two locations in the state.
(2) To monitor and evaluate water applications practices used by homeowners in the two cities.
(3) To relate lawn management and quality to lawn size, lot size, taxbase and age of development.
(4) To develop lawn watering guidelines for various locations in Colorado based upon results of the research.

The research was conducted at Fort Collins and at Northglenn during the seasons of 1977 and 1978. The major differences between these cities involved the method of water pricing since Fort Collins does not meter the water to consumers and, therefore, imposes a flat rate monthly charge. Northglenn provides meters on the supply line to each home and charges according to the amount of water used. The city of Northglenn was extremely interested in the studies and supported them in several ways, thus allowing more data to be collected and analysed than would otherwise have been possible.

This report is divided into six chapters. The procedures involved in in site selection, lawn irrigation measurements, potential evapotranspiration measurements, lot and lawn area measurement, lawn quality rating, and climatic measurements are described in chapter 2. The results are described, summarized and discussed in chapter 3. Basic data tables are recorded in the appendix to the report. Lawn irrigation guidelines for seventeen cities selected as a cross section of the state are tabulated in chapter 4 and a discussion of the basis for the recommendations is given. Certain supplemental studies were conducted during the course of the investigations and these are described in terms of procedures and results in chapter 5. The sixth chapter involves a summary and conclusions.

Chapter 2

PROCEDURES

The major portion of the study involved measuring the irrigation water applied to the lawns of homeowner cooperators in two cities - Fort Collins and Northglenn - and measuring the evapotranspiration by adequately fertilized and watershed turf in bucket lysimeters installed in the lawns of some of the cooperators. Total lot area and vegetated area was measured at each home site. Lawn quality ratings were obtained weekly by estimation from visual observation. Rainfall was measured at each site where lysimeters were installed.

Data collection occurred over a period of two years, 1977 and 1978. Sites were selected during the fall of 1976 and some lysimeters were installed in Fort Collins before winter. Most lysimeters and all water meters were installed in the spring of 1977 as rapidly as possible after the weather became reasonable for work. Following installation of the lysimeters, considerable time was required for the transplanted sod to establish a root system adequate for reliable evapotranspiration measurements. Water meters could only be used during frost-free periods. Therefore, the irrigation and lawn water use data are not completely comparable over the entire growing season.

Site Selection

Fort Collins and Northglenn were the two cities chosen for the Colorado Studies. Fort Collins was selected as representative of those cities where water supplied to the home is not metered and charges are made on a flat rate basis regardless of quantity used. Northglenn provides meters on their delivery system so that each homeowner is charged for the water used. The average outdoor water use for the two cities can then be compared in terms of the different pricing system and, at Northglenn, the outdoor use can be compared with indoor use. The city of Northglenn provided some funds for travel and considerable help in providing water meters and assistance in data collection. Important help was also provided in the selection of specific homes where measurements could be taken.

In each of the cities, five areas were selected where cooperators could be solicited. It was planned that differences in lawn watering practices, or in evapotranspiration, due to location in the city, age of subdivision, value of property, size of lots, etc. might be identified by this selection pattern. In each of the areas, six homes were identified where lawn water applications could be measured. In three of the areas in each city, one home was chosen where lysimeters could be installed for evapotranspiration measurements. In Fort Collins it was necessary to terminate the water meter reading at three of the homes during the first year and one of them at the begining of the second year. At Northglenn, all thirty houses were used in the study both years. Figure 2.1 and 2.2 identify the areas where measurements were made at Fort Collins and Northglenn respectively.

Both of the cities are in the rapid growing region along the front-range of the Rocky Mountains. Northglenn is at the north edge of Denver and about 90 kilometers south of Fort Collins. Fort Collins has a population of about 73,000, an elevation of 1,525 meters, and is located at 40^{o} 35' N latitude and 105^{o} 05' W longitude. Comparable values for Northglenn are 33,000 population, 1,665 meter elevation, 39^{o} 54' N latitude and 104^{o} 59' W longitude. Fort Collins has an average annual precipitation of 363 mm with 193 mm falling during the 140 day frost free period of 13, May to 30, September. Precipitation at Northglenn is an average of 312 mm annually and 197 mm during the 155 day period between the average frost dates of 7, May and 9, October. Urban lawns at both location start to show vegetative growth about the first of April and continue to transpire until into October depending upon snowfall events.

Lawn Irrigation Measurements

The watering practices at 30 homes in Northglenn and 27 homes in Fort Collins were examined by measuring the outside water use with meters attached to all outside faucets. The water meters were installed in concrete building blocks provided with a wooden lid. They were connected to each outside faucet using suitable adapters and a length of garden hose. The homeowner, in turn, connected his watering hoses to the outlets of the water meters.

Meters at each home were read once each week and the combined water flow since the previous reading was converted to average depth of application over the vegetated area of the site. It is recognized that some error results due to use of water on the street or overlap of sprinklers onto neighboring lawns. However, it is believed that these errors are small in relation to total water application; are partially compensated for by neighbor's overlap to the cooperator's lawn, and can be ignored without significant effect on the conclusions.

At Northglenn, city water meters on the water lines to each of the 30 homes were read each week. Permission to read these meters was provided by the Water Department of the city. These meters were read through much of the winters of 1977-1978 as well as during the lawn watering period. This allowed comparison of indoor water use during winter and summer months.

Potential Evapotranspiration Measurements

Potential evapotranspiration is defined in this study as the maximum evapotranspiration of the turf when the grass is maintained in a healthy, well fertilized condition and soil moisture is not a limiting factor to water absorption by the root system. The evapotranspiration measured as water loss from bucket lysimeters installed in the lawns is considered to be essentially potential E_t. Later discussion will point out that the interval between water additions to the lysimeters in 1977 may have allowed some plant water stress to occur and the measured evapotranspiration (E_{tm}) may have been slightly below the potential. In 1978 the interval was shortened and E_{tm} is considered a very good measure of potential E_t. Application of irrigation water or rainfall in excess of potential E_t would result in deep percolation (drainage) below the root zone.

The weighable bucket lysimeters were designed to contain a column of soil 305 mm in diameter and approximately 510 mm deep. They were constructed from P.V.C. pipe with a wall thickness of 3.2 mm. Details are

Figure 2.1 Map of Fort Collins, Colorado identifying the location of five areas where water meters were used to measure lawn irrigation (M) and of three areas where lysimeters were installed to measure lawn evapotranspiration (L). Water meters were located at twenty-seven home sites and lysimeters at three.

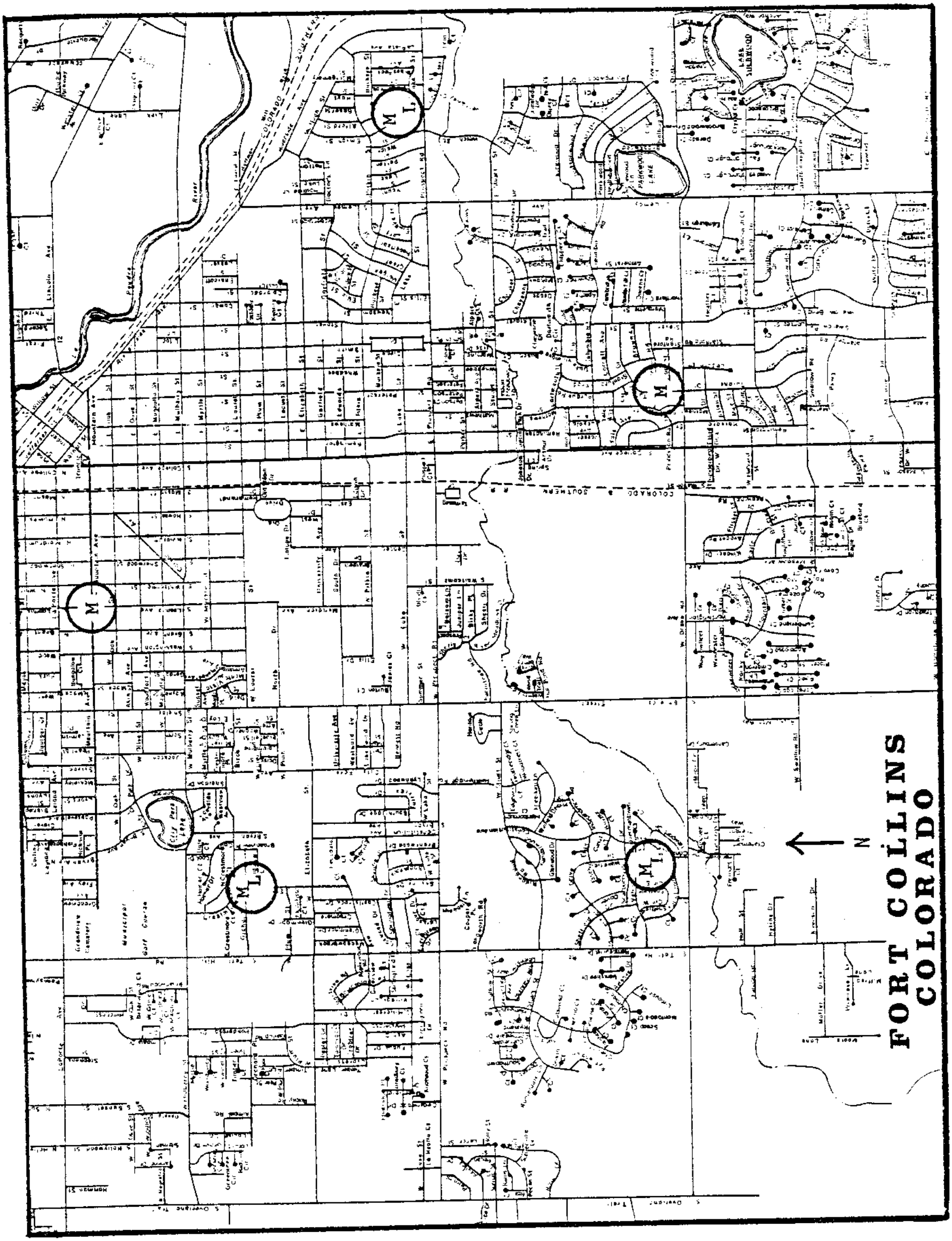
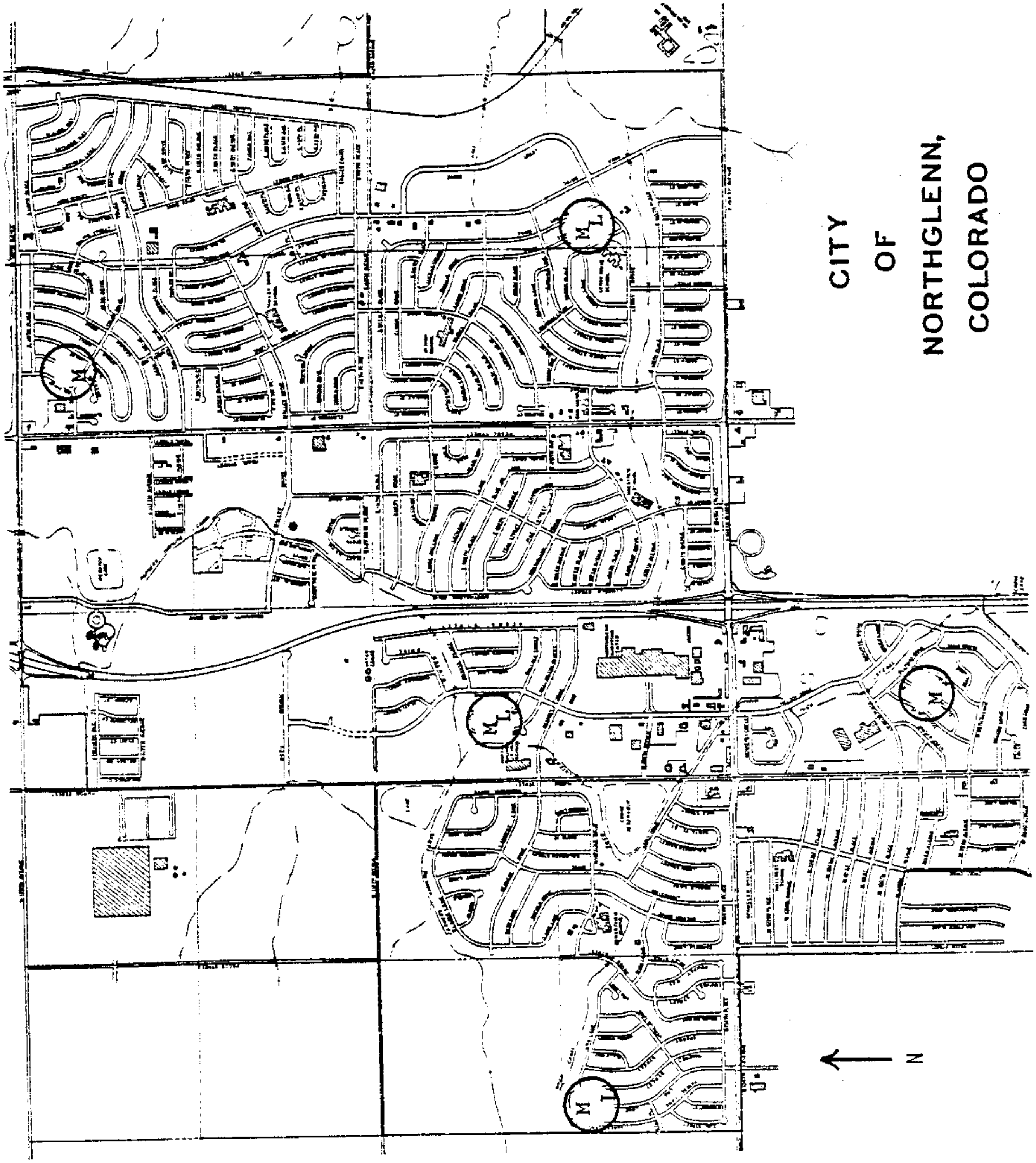

FORT COLLINS
COLORADO
N

Figure 2.2 Map of Northglenn, Colorado identifying the location of five areas where water meters were used to measure lawn irrigation (M) and of three areas where lysimeters were installed to measure lawn evapotranspiration (L). Water meters were located at thirty home sites and lysimeters at three.



CITY OF NORTHGLENN, COLORADO

shown in figure 2.3. A 50 mm gravel layer was placed in the bottom of the lysimeter to facilitate drainage and 25 mm of sand separated the gravel from the soil column. The bottom of the lysimeter consisted of a 6 mm thick P.V.C. plate recessed slightly into the cylinder and glued to make a water-tight seal. This bottom plate contained a removable brass plug to facilitate drainage of excess water when necessary. Slots were cut on opposite sides near the top of each lysimeter to use in lifting them.

An outer shell was constructed by cutting a second piece of P.V.C. pipe and expanding it with a spacer to form a cylinder approximately 318 mm I.D. and 660 mm long.

Installation was accomplished by digging a hole in the lawn, placing some gravel in the bottom of the hole, and inserting the outer shell into the hole. A circular piece of plywood, perforated for drainage, was inserted to the bottom of the shell to help maintain its shape. Soil from the excavation was used to nearly fill the lysimeters and the original sod was placed on the soil. When the lysimeter was lowered into the shell, the grass was level with that of the surrounding lawn. The sod was allowed at least two months to become well established in the lysimeter before evapotranspiration measurements began. An installed lysimeter was difficult to detect visually in the lawns.

The weight of the lysimeters was obtained after thoroughly wetting and allowing them to drain for one day. This was done during cool, cloudy weather when a minimum amount of water was lost through evapotranspiration. This weight, considered the gross weight at field capacity, was the value to which the lysimeters were brought each time they were irrigated. Weights were always obtained to within 0.1 kg.

Residents of the lysimeter sites were provided with lids and asked to cover the lysimeters whenever they watered their lawns. The turf in the lysimeters was mowed and fertilized by the homeowner, with the rest of the lawn and additional fertilizer was added if needed. The lysimeters were pulled out, weighed, and watered twice a week in 1977 and three times a week in 1978. Enough water was added each time to bring the weight of the lysimeters to the weight at the maximum moisture level. The weight before the addition of water was subtracted from the weight at the maximum moisture content to give the amount of water lost due to evapotranspiration for the period. The lysimeters had to be drained when the water content increased above the desired maximum level. This happened periodically due to rainfall or when homeowners failed to cover the lysimeter durning lawn watering.

Fifteen lysimeters were placed in each city with five in each of three lawns. They were placed with the intent of obtaining a representative measurement of evapotranspiration with due consideration given to microclimate, soil and vegetation. Placement of the lysimeters was determined by the following criteria: (1) one lysimeter was located on each side of the house and placed approximately in the center of the grassed areas, (2) if a house did not have grass on all sides, two or more lysimeters were placed on one side so they were as representative as possible of the 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. Sketches of the six home sites where lysimeters were installed are provided in appendix figures A.1 through A.6.

<u>Lot and Lawn Area Measurement</u>

In order to calculate the depth of water applied, it was necessary to

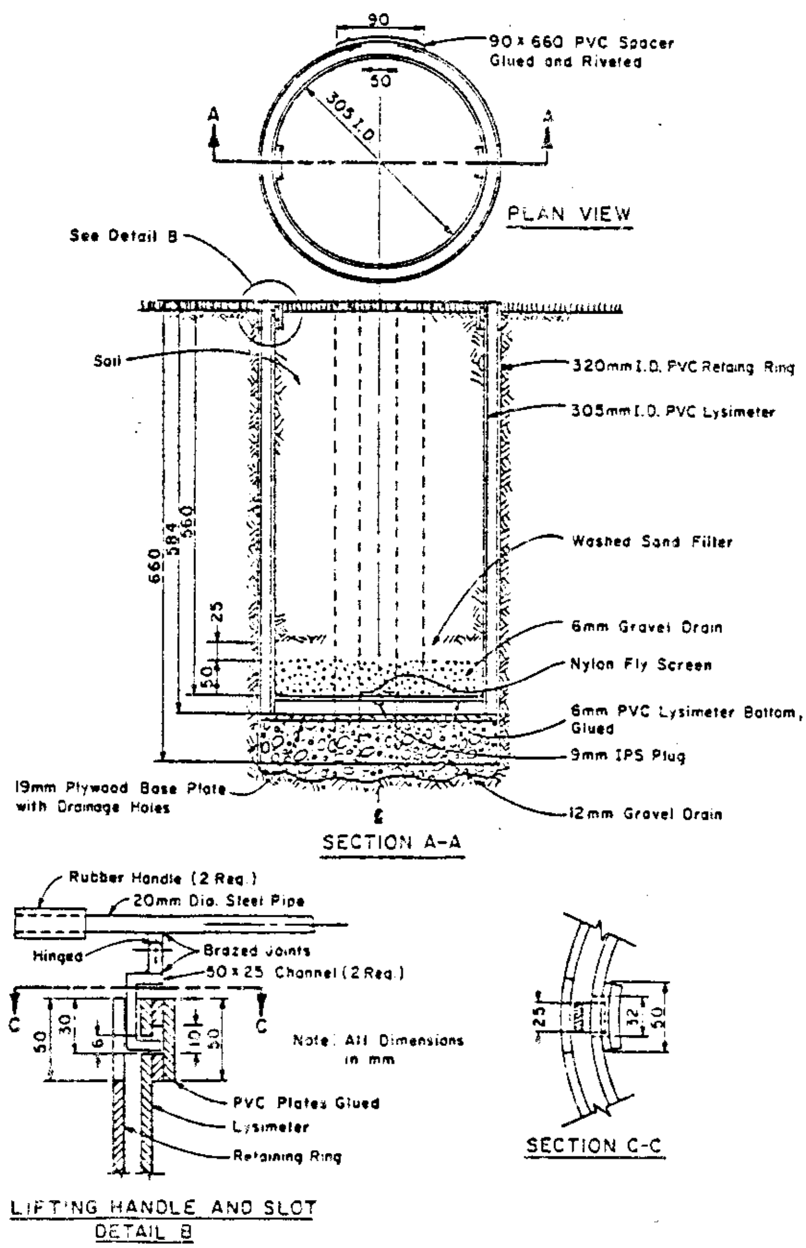


Figure 2.3 Construction details of the bucket lysimeter.

determine the area irrigated in each yard. Through details obtained from city governments, drawings were made of the residential plots and then non-vegetated areas, as determined by on-site measurements, were superimposed on the drawings. Non-vegetated areas were those areas which were not used for planting -- houses, garages, sidewalks, areas covered with stone or bark, garden sheds, etc.

Although the vegetated area was not truly representative of the lawn area (as there were always vegetable gardens, trees, shrubs, flowers, etc.) it was probably watered in much the same way as the lawn. Water used outside for purposes other than irrigation was considered to be insignificant.

Lawn Quality Rating

Each time the meters were read, a visual assessment of the overall aesthetic appearance of the lawn was made. This assessment did not attempt to evaluate the appearance with respect to weeds and length of grass. The evaluation was based solely on the overall "greenness" of the lawn. Lawns were rated on a scale of zero to 10, where a rating of zero would be given a completely brown lawn and a rating of 10 would represent a lush perfectly green lawn with no yellow or brown showing. The lawns in this region would have a zero rating during the middle of winter. A rating was taken for both the front and the back lawn and the arithmetic mean of these was calculated.

Climatic Measurements

Rainfall data was obtained at each home site where lysimeters were located. Rain gages were installed and read each time the location was visited to obtain lysimeter weightings. A slight amount of oil was added to each gage to minimize evaporation losses from the time an event took place until the reading was made.

Other weather data was obtained wherever possible near the study locations. In Fort Collins, an offical Weather Bureau Station is located on the Colorado State University campus near the center of the city. Other measurements were available from the Agricultural Engineering Research Center located about six kilometers northwest of Fort Collins and from the Agronomy Research Center about the same distance southeast of the city. No climatic data is available in close vicinity to Northglenn. However, the official Weather Bureau Station for Denver is located at Stapleton International Airport about 19 kilometers to the southeast.

Chapter 3

RESULTS

During the two growing seasons, repeated measurements were made of evapotranspiration in the weighable bucket lysimeters, of irrigation water applied by homeowners, of rainfall, and of lawn quality. The lot area and vegetated area on the lot was measured for each cooperator site and the home construction date and assessed valuation was obtained. The basic data is, to a large extent, provided in the appendix. Summarized and averaged data, relationships between various measurements, and discussion of the results are presented in this chapter.

Lawn Irrigation

The meters, attached to the hoses used for lawn irrigation, were read each week at 27 home sites in Fort Collins and 30 in Northglenn. The weekly volumes applied through the meters at a given home were combined and divided by the vegetated area to provide the depth applied for the week. The results, expressed as average irrigation per day, are recorded in tables 3.1, 3.2, 3.3 and 3.4 for the two cities and the two years. Since the time period during which irrigation was measured varies slightly for the four tables, it is most meaningful to compare average daily rates. The season average of daily irrigation rates is noticeably higher for Fort Collins (tables 3.1 and 3.2) than for Northglenn (tables 3.3 and 3.4). This reflects the difference in pricing methods for the two cities where Northglenn consumers pay for the amount of water used and Fort Collins charges are a fixed monthly rate for each user. It is also to be noted that the average irrigation rate in 1977 was lower for both cities than in 1978. Water supplies for the entire state were unusually low in 1977 due to a much below normal snowpack in the mountains. Water users were urged to practice conservation and restrictions were imposed on lawn watering for the entire season at Northglenn and for a period at the end of the season at Fort Collins. As an average for the two cities, the irrigation rate in 1977 was 85 percent of that in 1978, and for the two years Northglenn cooperators applied only 65 percent as much water as those in Fort Collins. Tables 3.1 through 3.4 also show the precipitation and the total water application when rainfall is added to irrigation. The season average for total application shows a higher value for Fort Collins in 1977 than in 1978. This, however, is misleading because a large amount of the high rainfall in 1977 occurred in one storm during the week ending 25, July. Much of this rain was probably lost to runoff or to deep percolation below the root zone of the grass.

Potential Evapotranspiration

The five lysimeters at each of the three homesites in each city were averaged to provide the evapotranspiration rates for each site. In some cases the E_{tm} for a specific lysimeter could not be calculated because of unreliable data. This was caused once by heavy rainfall causing overflow of the lysimeters but more often by cooperator errors in not covering the lysimeter when irrigating the lawn or by water additions to the lysimeter from the sprinklers of neighbors. It

Table 3.1 Weekly average values for lysimeter measured evapotranspiration (E_{tm}), rainfall, irrigation, total water application, ratios of irrigation and total application to E_{tm}, and lawn quality rating (Q) for Fort Collins - 1977.

Week ending	E_{tm} * mm/day	ppt mm/day	Irrig mm/day	Total mm/day	$\frac{Irrig}{E_{tm}}$	$\frac{Total}{E_{tm}}$	Q
6 - 13	6.4	1.0	6.9	7.9	1.08	1.23	
20	6.3		6.5	6.5	1.03	1.03	
27	7.7		7.4	7.4	0.96	0.96	
7 - 4	7.3	0.8	10.4	11.2	1.42	1.53	
11	5.9		5.2	5.2	0.88	0.88	
18	4.3	3.1	7.9	11.0	1.84	2.56	
25	5.1	19.1	2.5	21.6	0.49	4.24	
8 - 1	7.5	1.8	3.0	4.8	0.40	0.64	7.5
8	3.1		2.8	2.8	0.90	0.90	7.4
15	3.6	1.4	4.1	5.5	1.14	1.53	7.4
22	4.7	0.2	1.2	1.4	0.26	0.30	7.5
29	4.4		4.5	4.5	1.02	1.02	7.4
9 - 5	4.1	0.6	7.2	7.8	1.76	1.90	7.2
12	3.1	0.7	5.2	5.9	1.68	1.90	7.3
19	3.1		4.9	4.9	1.58	1.58	7.3
Season	5.1	1.9	5.3	7.2	1.04	1.41	7.4

* E_{tm} values corrected for stress occurring during 4-day weighing interval (see text).

Table 3.2 Weekly average values for lysimeter measured evapotranspiration (E_{tm}), rainfall, irrigation, total water application, ratios of irrigation and total application to E_{tm}, and lawn quality rating (Q) for Fort Collins - 1978.

Week ending	E_{tm} mm/day	ppt mm/day	Irrig mm/day	Total mm/day	$\frac{Irrig}{E_{tm}}$	$\frac{Total}{E_{tm}}$	Q
6 - 21	6.6		8.5	8.5	1.29	1.29	7.7
28	6.1		7.3	7.3	1.20	1.20	7.5
7 - 5	6.3	1.1	7.5	8.6	1.19	1.37	7.3
12	4.5	1.5	5.0	6.5	1.11	1.44	7.0
19	5.3		8.5	8.5	1.60	1.60	7.2
26	5.1		7.3	7.3	1.43	1.43	7.2
8 - 2	4.8	2.2	4.7	6.9	0.98	1.44	7.3
9	4.3	1.0	3.3	4.3	0.77	1.00	7.5
16	5.2	1.0	3.4	4.4	0.65	0.85	7.8
23	4.8	0.2	7.3	7.5	1.52	1.56	7.8
30	4.3	1.8	5.6	7.4	1.30	1.40	7.4
9 - 6	5.3		5.3	5.3	1.00	1.00	7.5
13	5.8		4.2	4.2	0.72	0.72	7.7
20	2.6		4.0	4.0	1.54	1.54	
Season	5.1	0.6	5.9	6.5	1.16	1.27	7.5

Table 3.3 Weekly average values for lysimeter measured evapotranspiration (E_{tm}), rainfall, irrigation, total water application, ratios of irrigation and total application to E_{tm}, and lawn quality rating (Q) for Northglenn - 1977

Week ending	E_{tm} * mm/day	ppt mm/day	Irrig mm/day	Total mm/day	$\frac{Irrig}{E_{tm}}$	$\frac{Total}{E_{tm}}$	Q
6 - 30	6.4†		4.3	4.3	0.67	0.67	
7 - 7	7.2†	2.1±	4.3	6.4	0.60	0.89	
14	7.2†		5.0	5.0	0.69	0.69	
21	7.2†	4.2±	3.4	7.6	0.47	1.06	6.0
28	6.6†	4.4±	0.4	4.8	0.06	0.73	6.6
8 - 4	7.3	0.3	2.8	3.1	0.38	0.42	5.8
11	5.2	1.3	1.8	3.1	0.35	0.60	
18	4.6	0.6	2.5	3.1	0.54	0.67	6.0
25	4.5	0.2	2.6	2.8	0.58	0.62	5.8
9 - 1	6.1	0.3	3.4	3.7	0.56	0.61	5.8
8	5.7		3.9	3.9	0.68	0.68	5.7
15	4.3	0.2	3.2	3.4	0.74	0.79	5.9
22	4.6		3.4	3.4	0.74	0.74	5.8
Season	5.9	1.0	3.2	4.2	0.54	0.71	5.9

* E_{tm} values corrected for stress occurring during 4-day weighing interval (see text).

† Estimated from regional weather stations.

± Rainfall measured at Stapleton International Airport.

Table 3.4 Weekly average values for lysimeter measured evapotranspiration (E_{tm}), rainfall, irrigation, total water application, ratios of irrigation and total application to E_{tm}, and lawn quality rating (Q) for Northglenn - 1978.

Week ending	E_{tm} mm/day	ppt mm/day	Irrig mm/day	Total mm/day	$\frac{Irrig}{E_{tm}}$	$\frac{Total}{E_{tm}}$	Q
6 - 23	6.3		5.9	5.9	0.94	0.94	7.0
30	5.6	0.7	5.2	5.9	0.93	1.05	7.2
7 - 7	6.3	1.4	5.7	7.1	0.90	1.13	7.3
14	6.3	1.0	2.6	3.6	0.41	0.57	7.3
21	6.3	0.1	5.4	5.5	0.86	0.87	7.2
28	5.7	0.1	5.5	5.6	0.96	0.98	7.1
8 - 4	4.9	2.5	2.9	5.4	0.59	1.10	7.2
11	5.2	0.2	3.1	3.3	0.60	0.63	7.2
18	5.5	0.8	4.5	5.3	0.82	0.96	7.2
25	4.5		4.2	4.2	0.93	0.93	7.2
9 - 1	5.1	1.4	2.9	4.3	0.57	0.84	6.9
8	4.4		3.7	3.7	0.84	0.84	6.7
15	5.1*		2.9	2.9	0.57	0.57	
22	3.6*		2.9	2.9	0.81	0.81	
Season	5.3	0.6	4.1	4.7	0.77	0.89	7.1

* Calculated from Jensen - Haise equation using Stapleton International Airport climatic data.

was usually easy to ascertain such errors and void the results. Average values were then obtained from the remaining lysimeters.

During most of 1977 the lysimeters were weighed and brought back to the desired water content twice each week. Thus, the interval between weighings was either 3 or 4 days. In 1978 the sites were normally visited three times each week, so there were a 3-day and a 2-day intervals. Sometimes the schedule was altered due to rain. Late season intervals, when evapotranspiration was very low, were longer.

Daily values of E_{tm} are given in the appendix tables A.1 through A.4. In each table the daily average and the cumulative values since initiation of measurements are recorded. The E_{tm} for the period between weighings was assumed to be constant for each day in the period. Average daily E_{tm} values for both cities and both years are platted as a scatter diagram in figure 3.1. The peak occurs during late June when day length is greatest and gradually decreases durings the summer months. The rapid drop in late September is associated with lowering soil and air temperature at that period.

It is believed that the 1977 E_{tm} values recorded in tables A.1 and A.3 should be increased when the weighing interval was 4 days to make them truly represent potential evapotranspiration. This became apparent when, after the data was obtained for the 1977 season, the average E_{tm} for the 4-day intervals was found to be 0.62 mm/day lower than those for the 3-day intervals. It was suspected that plant water stress might have been occurring on the fourth day resulting in actual E_t below potential. Because of this, the three weighings per week schedule was established for 1978. An analysis of the 1977 data was made as follows. Table 3.5 was prepared using average E_{tm} values for the 3-day and 4-day intervals in 1977 and the 2-day and 3-day intervals in 1978 at Fort Collins. Open pan evaporation data and maximum daily temperatures at Fort Collins were also averaged for the two weighing intervals in order to determine whether the differences in E_{tm} could be due to climatic variation. Apparently, (table 3.5) the evaporative demand did not differ significantly between the 4-day and 3-day intervals. Thus, it is assumed that the root systems were not able to remove soil moisture at a rate to meet potential evapotranspiration when there were 4 days between lysimeter weighings and water additions. It is to be noted that the E_{tm} values at site 2 did not vary as much as those at sites 1 and 3. Feldhake (1979) has shown that lawn grass root systems are restricted in depth when fine textured soils are used. Particle size analysis of the soils from the three sites in Fort Collins were made and the results are shown in table 3.6. It may be concluded that the reduced E_{tm} for the 4-day interval at sites 1 and 3 (table 3.5) is associated with limited available water supply due to restricted root growth in the fine texture soils. The average difference in E_{tm} between the two intervals was 12.3 percent. This value multiplied by 4/7 gives an apparent weekly error of 7 percent. Soil textures at Northglenn were similar to those at Fort Collins.

Weekly E_{tm} rates, expressed in millimeters per day, are included in tables 3.1 through 3.4. These values have been corrected (increased by 7 percent) in the 1977 tables as indicated by footnotes. Lysimeter data at Northglenn was not obtained in 1977 until 28, July so estimates are given for earlier periods in table 3.3. These estimates were obtained by altering 1978 at surrounding stations.

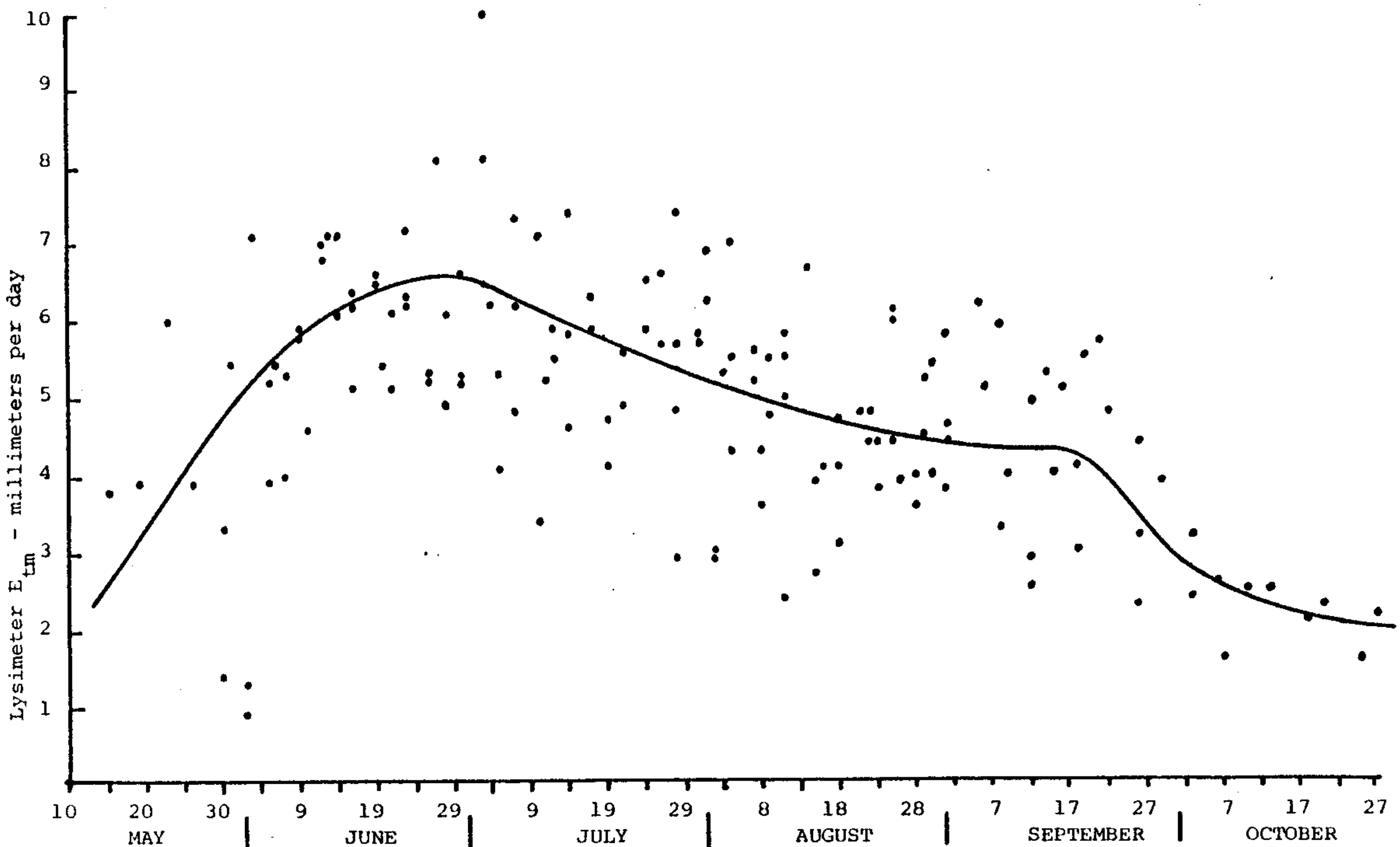


Figure 3.1 Lysimeter evapotranspiration rate during the growing season. Values are for lawns in Fort Collins and Northglenn during 1977 and 1978. The line indicates the trend of E_{tm} for the Colorado area.

Table 3.5 Average measured values of E_{tm}, open pan evaporation, and maximum daily temperature for the 3 day and 4 day intervals between lysimeter weighings at Fort Collins - 1977.

		3 day interval	4 day interval	Percent difference
Measured E_{tm} (mm/day)	Site 1	6.57	5.65	16.3
	Site 2	5.50	5.41	1.7
	Site 3	4.93	4.10	20.2
	Average	5.67	5.05	12.3
Pan evaporation (mm/day)		7.88	7.61	3.5
Maximum Temperature ($^{\circ}$C)		26.76	26.71	0.2

Table 3.6 Particle size analyses of soil from the three lysimeter sites - Fort Collins

		Sand %	Silt %	Clay %	Texture
Site 1	Front	30.0	30.0	40.0	clay
	Back	32.5	32.5	35.0	clay loam
Site 2	Front	50.0	25.0	25.0	sandy clay loam
	Back	67.5	17.5	15.0	sandy loam
Site 3	Front	42.5	32.5	25.0	loam
	Back	35.0	40.0	25.0	loam

The weekly values of E_{tm} in tables 3.1 through 3.4 are compared to irrigation, and to total water application including rainfall, by the ratio values also given in the tables. In Fort Collins - 1977 (table 3.1) the irrigation was 4 percent higher than the E_{tm} value for the season. Total application was 41 percent higher, but, again, this is misleading because of the one large rainfall event. Total water application in Fort Collins - 1978 (table 3.2) was 27 percent over E_{tm}. At Northglenn total water applied was 29 and 11 percent below E_{tm} in 1977 and 1978 respectively. It is important to remember that E_{tm} is based on 15 lysimeters at 3 home sites in each city and that irrigation is based upon 27 homes in Fort Collins and 30 in Northglenn.

Lawn Quality

The lawn quality rating (Q) was obtained weekly for the front and the back lawn of each residence. These were averaged over the three sites to obtain the weekly values in tables 3.1 through 3.4 Seasonal summaries of lawn quality may be seen in table 3.7 where comparisons may be made between homesites. Although front lawns had a slightly higher rating, the difference is small and probably not important. Both average seasonal quality ratings and the minimum value for each home are listed in appendix tables A.5 and A.6 for Fort Collins and Northglenn respectively. These tables also contain average seasonal irrigation values, lot area, vegetated area, year of home construction and assessed valuation. The assessed value is approximately 19 percent of true value.

Average seasonal lawn quality rating for the lawns in the two cities are plotted as a function of irrigation application rate in figure 3.2 for 1977 and figure 3.3 for 1978. It is clear that even the lowest irrigation rate in Fort Collins was sufficient to maintain high quality lawns and additional water did not have much effect. At Northglenn the range of irrigation application was much lower and a significant slope for the regression lines occurred. In figures 3.4 and 3.5 the lowest weekly quality rating at each homesite is plotted. Lawn quality at a given home is surprisingly consistent throughout the season.

In an attempt to evaluate trends of lawn quality as related to age of home or size of lawn, figures 3.6 and 3.7 were prepared from the data in appendix tables A.5 and A.6. In Fort Collins a rather wide range in the age of home showed no quality trend. A similar plot for Northglenn was not made since all of the homes are relatively new. Lawn size (figure 3.7) was also found to be unrelated to lawn quality.

As a matter of interest, since the data were available, the lawn area was compared to total lot area in figure 3.8. As might be expected, a very good linear relationship exists.

Indoor Water Use - Northglenn

The total water delivered to the cooperator homesites in Northglenn was measured by city installed meters. Therefore, it is possible to evaluate the amount of water used in the house as well as that used for irrigation. Weekly rates for the total delivery and for irrigation are recorded as gallons in table 3.8. By coincidence, the weekly readings were made on the same date both years. The percent of the total used for irrigation is given for the summer weeks when outdoor water use was measured. In 1977 the city meters were read weekly until 17, November and then three times during the winter until 21,

Table 3.7 Seasonal average lawn quality ratings for the front lawn and the back lawn of each home site - Fort Collins and Northglenn, 1977 and 1978.

Home No.	FORT COLLINS						NORTHGLENN					
	1977			1978			1977			1978		
	Front	Back	Ave	Front	Back	Ave	Front	Back	Ave	Front	Back	Ave
1	7.50	7.63	7.57	8.00	8.00	8.00	6.56	6.11	6.33	7.23	5.85	6.54
2	7.00	7.63	7.32	7.92	7.62	7.77	6.88	6.75	6.81	7.15	7.31	7.23
3	6.75	6.75	6.75	7.54	7.46	7.50	5.11	4.22	4.67	7.54	7.62	7.58
4	6.13	6.75	6.44	6.69	6.92	6.81	7.56	7.78	7.67	8.46	7.85	8.15
5	6.63	7.75	7.19	6.62	7.04	6.83	6.38	7.25	6.81	8.00	8.00	8.00
6	7.63	8.50	8.07	9.00	8.85	8.92	7.13	7.13	7.13	8.15	8.38	8.27
7	8.75	9.00	8.88	7.92	8.08	8.00	3.89	2.67	3.28	6.46	5.15	5.81
8	7.88	7.13	7.51	7.00	7.50	7.25	5.33	4.78	5.06	8.69	8.15	8.42
9	6.75	6.50	7.63	7.85	7.65	7.75	6.56	5.78	6.17	7.15	6.92	7.04
10	7.88	7.75	7.82	7.23	7.15	7.19	7.33	8.56	7.94	8.12	8.38	8.25
11	7.75	7.63	7.69	7.15	6.92	7.04	7.25	7.00	7.13	7.69	7.85	7.77
12	7.25	6.50	6.88	7.62	7.13	7.38	5.44	4.89	5.17	7.08	6.85	6.96
13	7.13	7.13	7.13	8.15	7.35	7.75	5.22	5.33	5.28	7.00	7.69	7.35
14	7.88	7.50	7.69	7.85	7.69	7.78	4.56	2.89	3.72	6.00	4.73	5.36
15	6.38	7.00	6.69	8.08	7.34	7.73	6.33	6.00	6.17	7.00	7.00	7.00
16	7.25	7.13	7.19	6.69	6.88	6.79	5.67	6.22	5.94	7.00	7.08	7.04
17	8.38	6.75	7.57	7.69	7.23	7.46	6.11	5.89	6.00	7.23	7.23	7.23
18	7.50	6.88	7.19	6.64	6.50	6.57	5.44	5.22	5.33	5.69	7.08	6.38
19	7.88	7.57	7.73	7.83	7.42	7.63	7.25	6.88	7.06	7.15	7.23	7.19
20	9.88	9.75	9.82	9.08	8.69	8.89	4.63	3.88	4.25	5.23	4.54	4.88
21	5.57	7.00	6.29	7.23	7.31	7.27	7.00	6.00	6.50	7.15	7.08	7.12
22	7.88	7.88	7.88	8.08	7.46	7.77	6.71	5.14	5.93	7.47	7.54	7.51
23	7.25	7.25	7.25	6.85	7.00	6.93	5.75	4.75	5.25	6.62	6.69	6.65
24	6.50	7.13	6.82	6.69	6.62	6.66	6.75	6.13	6.44	6.54	6.77	6.66
25	8.00	7.75	7.88	7.92	8.18	8.10	6.50	6.13	6.31	7.15	7.31	7.23
26	7.13	6.63	6.88				3.63	6.50	5.06	7.69	7.69	7.69
27	6.75	6.25	6.50	7.78	7.38	7.58	5.50	4.88	5.19	6.69	6.54	6.62
28							6.38	6.38	6.38	7.38	7.08	7.23
29							5.00	5.38	5.19	7.46	7.85	7.65
30							7.14	6.57	6.86	7.92	7.53	7.73
Ave.	7.38	7.37	7.38	7.58	7.44	7.51	6.03	5.77	5.90	7.20	7.10	7.15

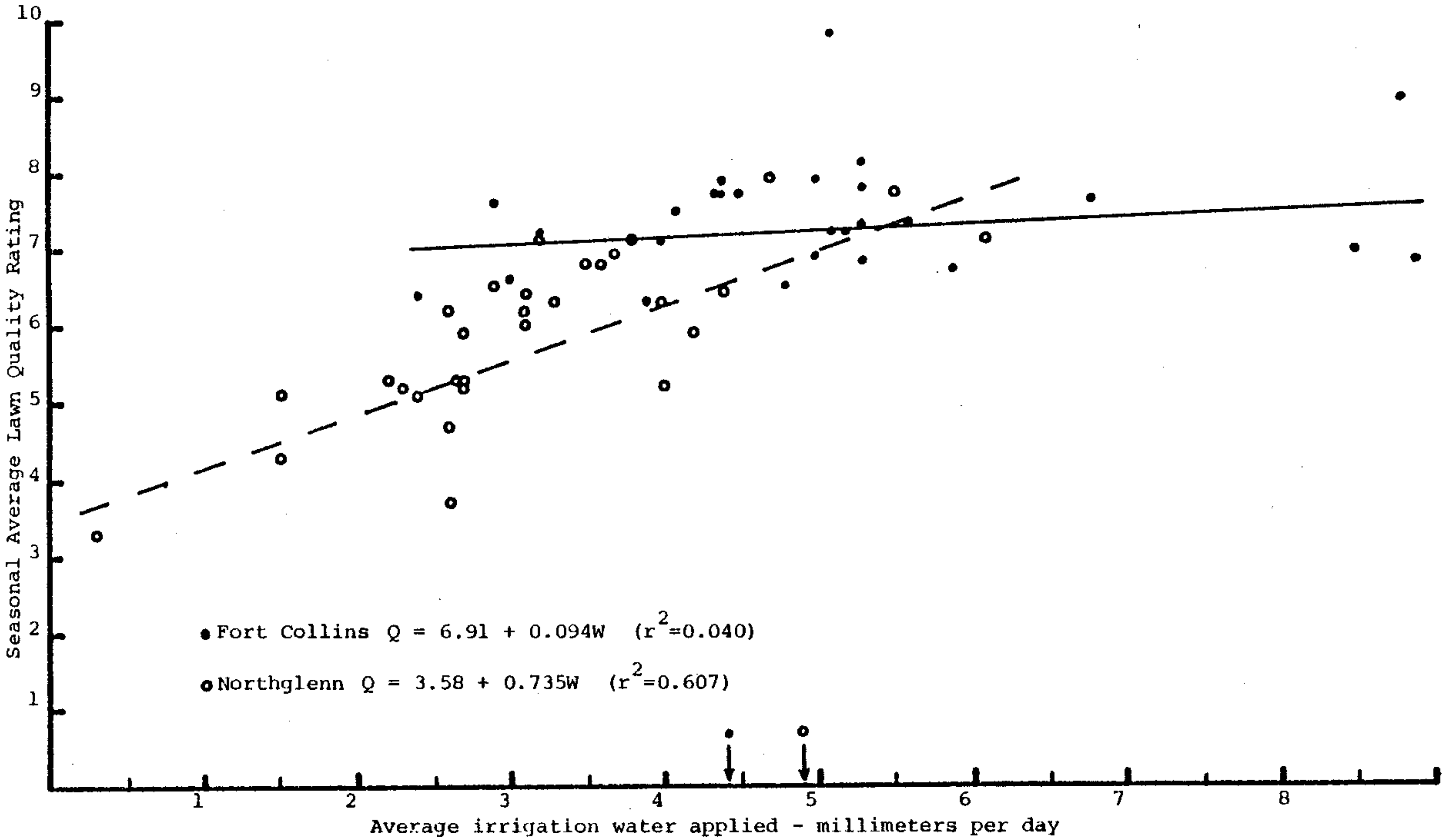


Figure 3.2 Average Lawn Quality rating for home sites as related to irrigation water application - Fort Collins and Northglenn, 1977.

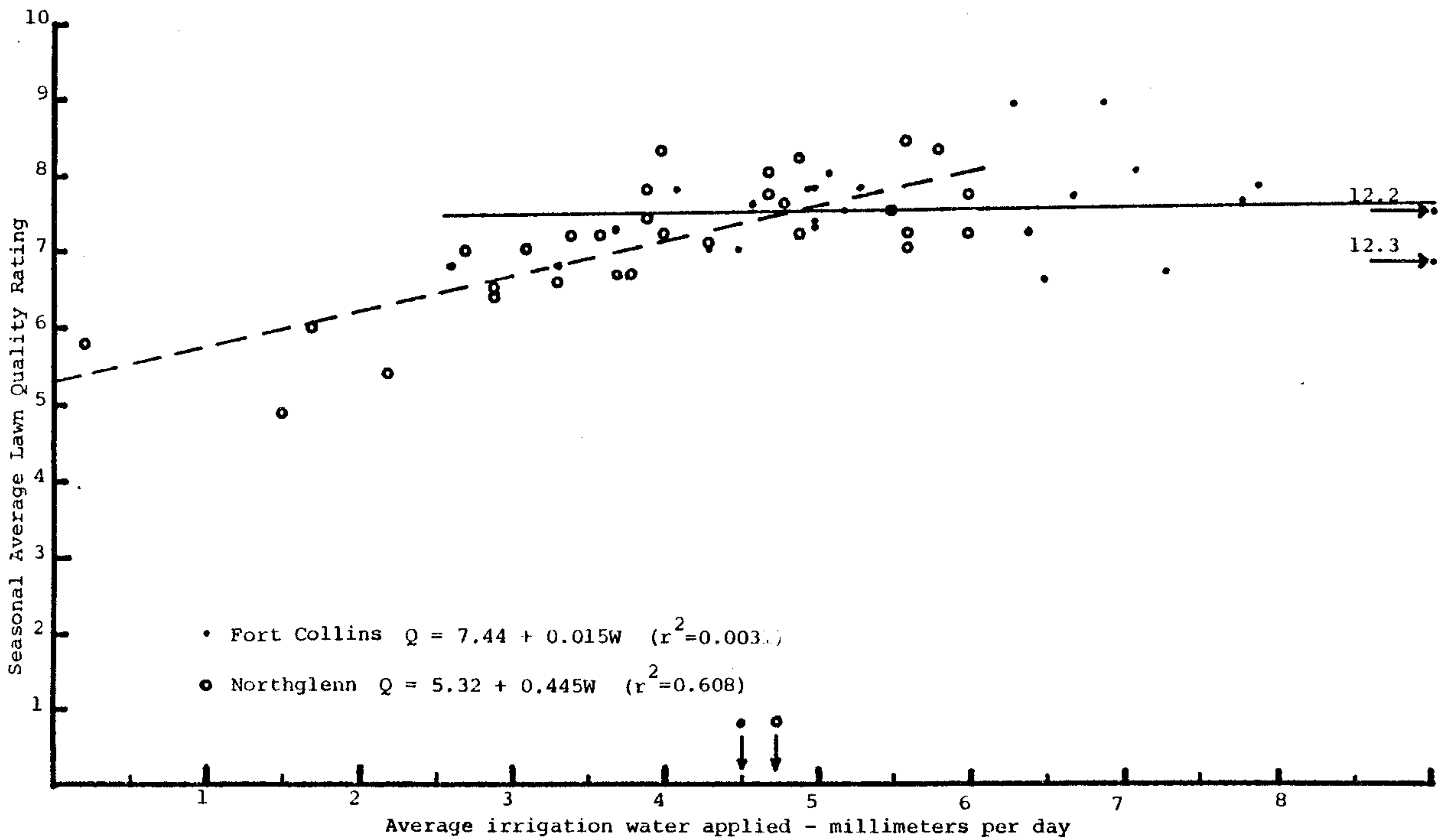


Figure 3.3 Average Lawn Quality Rating for home sites as related to irrigation water application - Fort Collins and Northglenn, 1978.

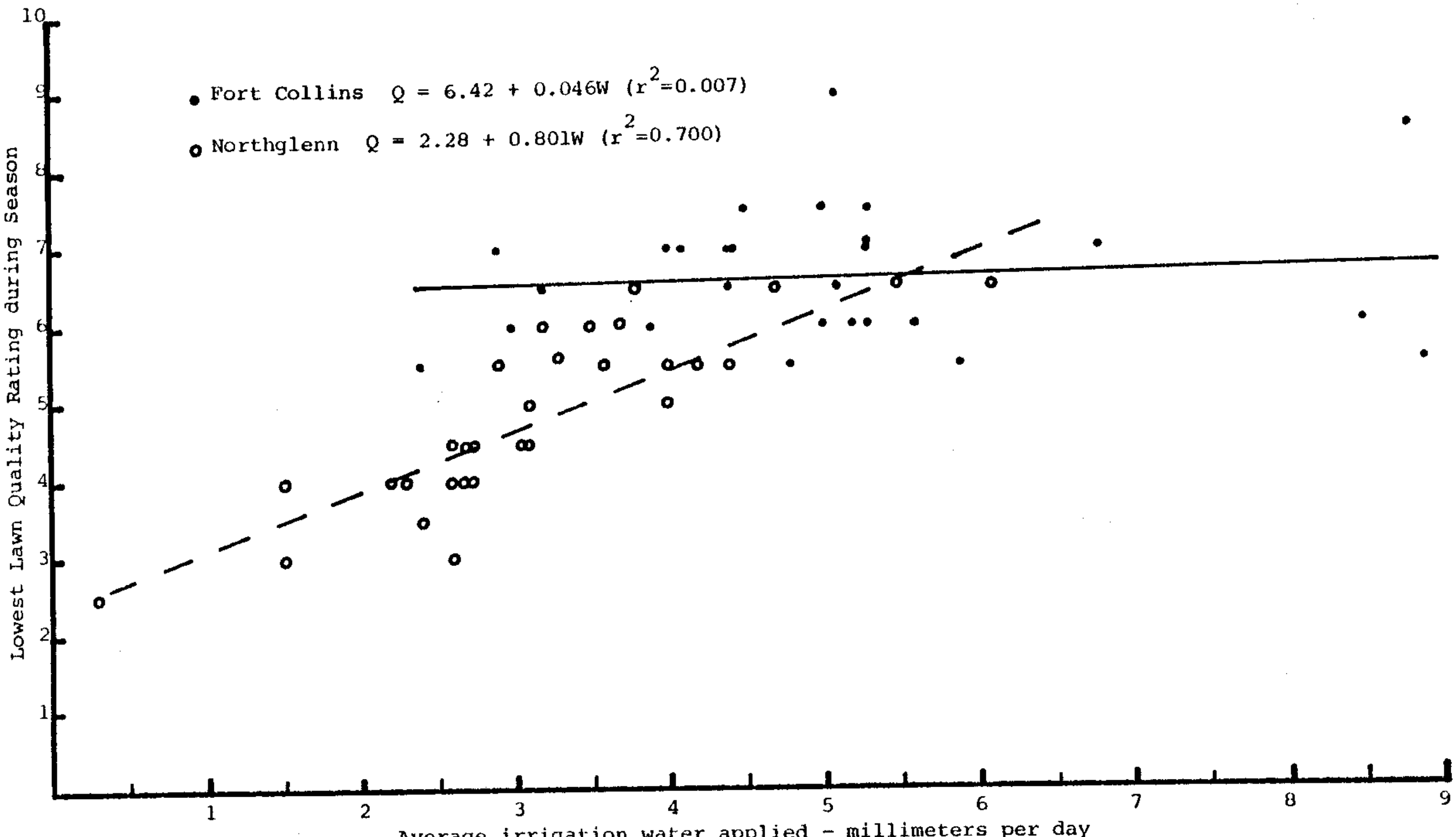


Figure 3.4 Minimum Lawn Quality rating for home sites as related to irrigation water application - Fort Collins and Northglenn, 1977.

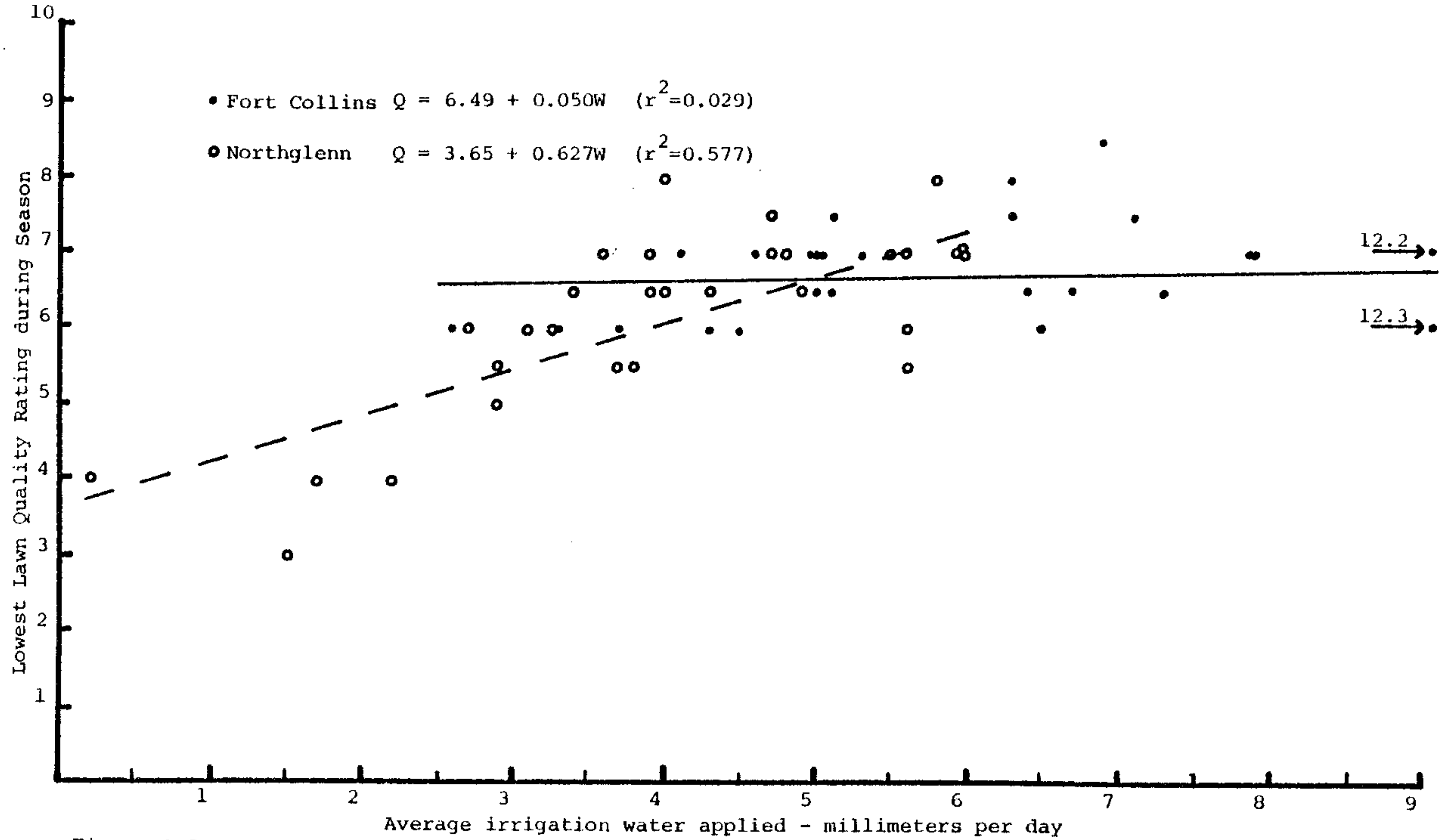


Figure 3.5 Minimum Lawn Quality rating for home sites as related to irrigation water application - Fort Collins and Northglenn, 1978.

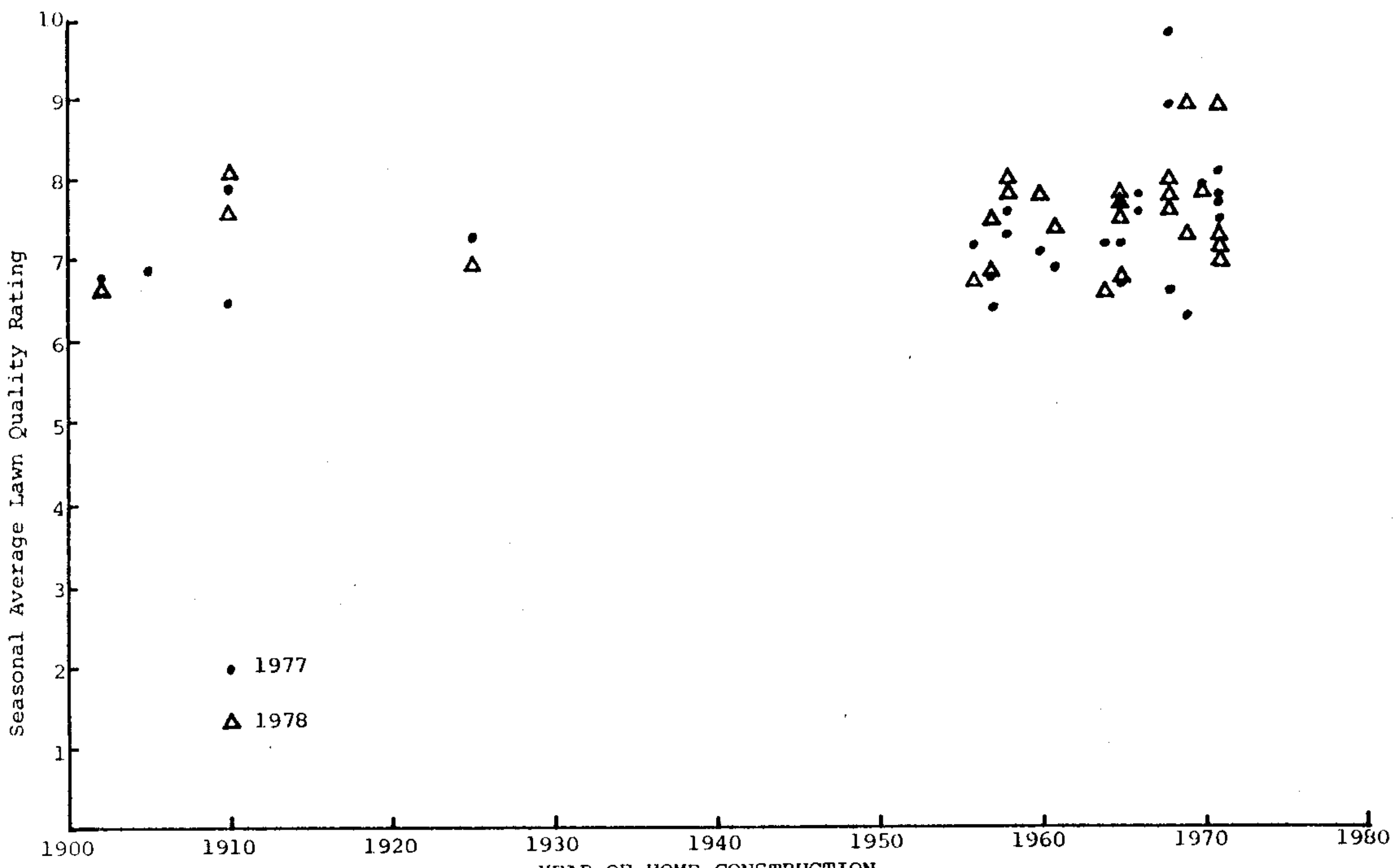


Figure 3.6 Average Lawn Quality Rating for Fort Collins home sites as related to age of home - 1977 and 1978.

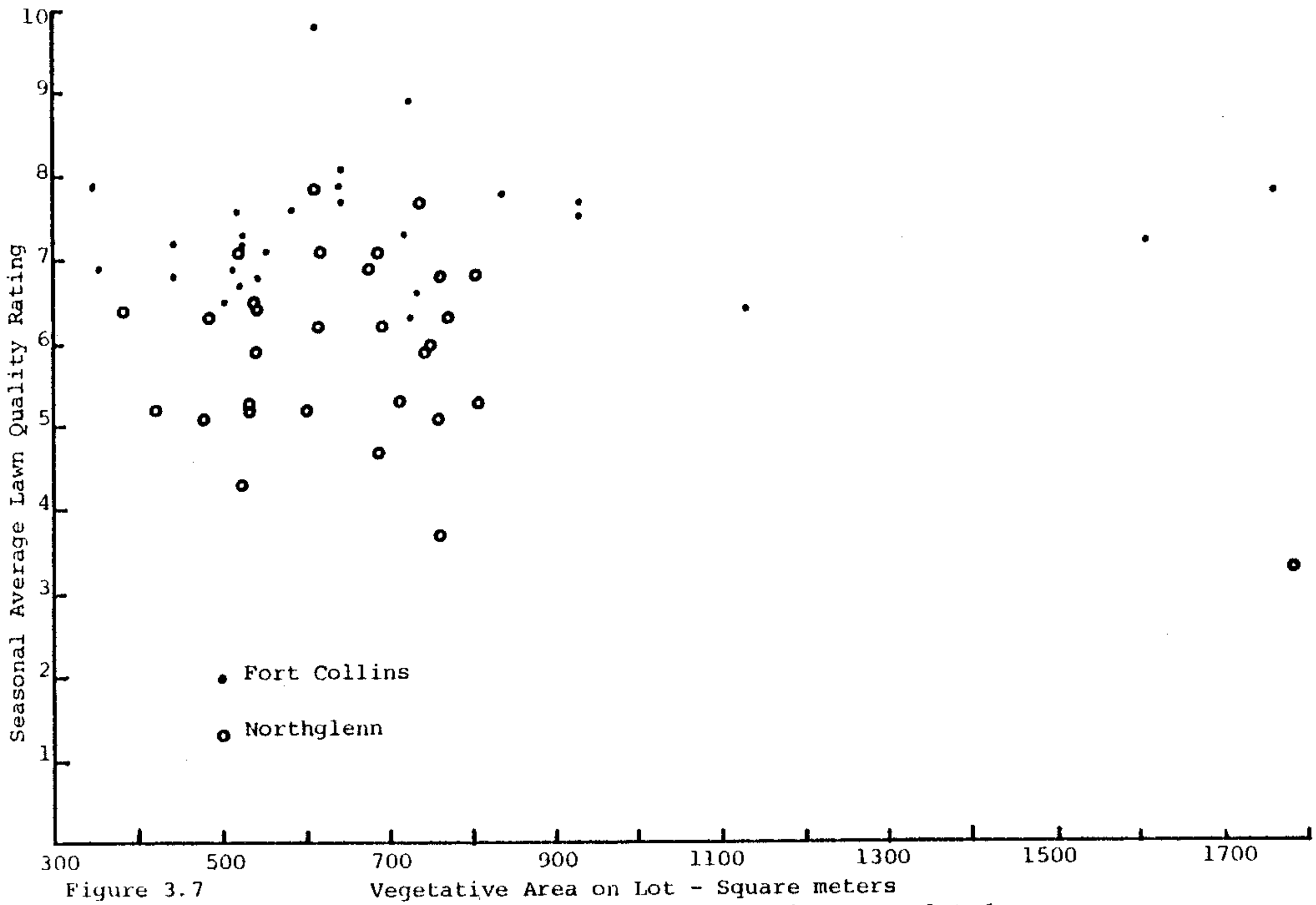


Figure 3.7 Average Lawn Quality rating for home sites as related to size of lawns - Fort Collins and Northglenn, 1977.

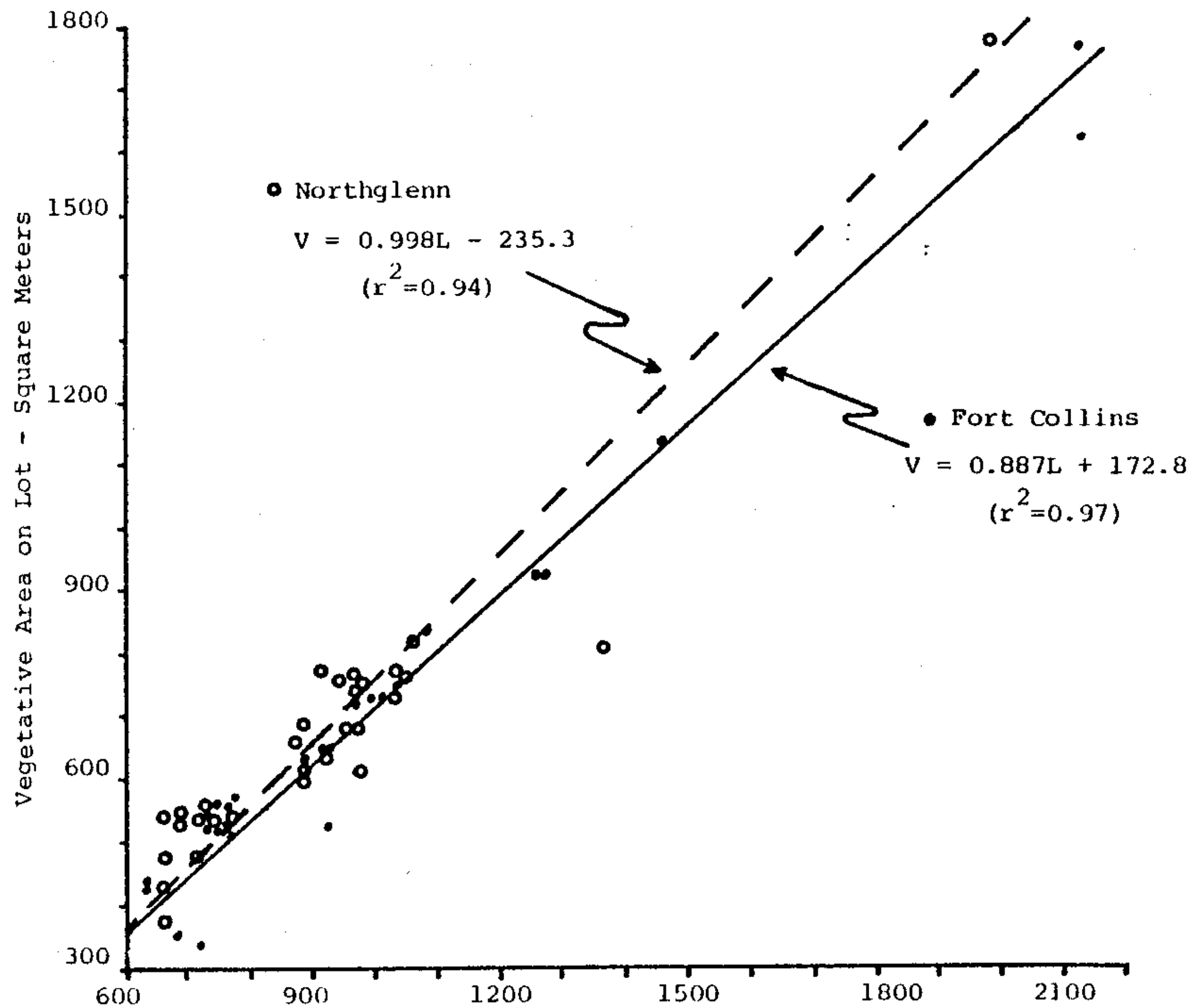


Figure 3.8 Relation of lawn size to total lot size for home sites - Fort Collins and Northglenn

Table 3.8 Total residence and lawn irrigation water use rates at Northglenn. Values are weekly averages of 30 homes.

Period Ending	1977			1978		
	Total	Irrigation		Total	Irrigation	
	gal/week	gal/week	%	gal/week	gal/week	%
6 - 23				8451	7329	87
30	7095	5343	75	7907	6459	82
7 - 7	6896	5343	78	8797	7080	80
14	7479	6213	83	4485	3230	72
21	5518	4225	77	8309	6708	81
28	2050	497	24	8338	6832	82
8 - 4	4910	3479	71	5014	3602	72
11	3639	2237	62	5226	3851	74
18	4513	3107	69	6838	5590	82
25	4470	3231	72	6484	5217	80
9 - 1	5553	4225	76	5226	3602	69
8	5924	4846	82	6197	4596	74
15	5046	3977	79		3602	
22	5518	4225	77		3602	
29	4422					
10 - 6	5031					
13	2605					
20	3560					
27	2843					
11 - 3	1987					
10	1814					
17	1604					
12 - 16	1657					
22	1906					
2 - 21	1782					

February. Water use during the last three periods is also reported as an average rate per week in table 3.8.

A summary of the type of use is given in table 3.9 for comparable 77 day periods during the summers of 1977 and 1978 and for a 77 day period in the winter of 1977-1978. It is assumed that no outdoor water use occurred in the winter.

The outdoor water use, for the 11 week period in the summer, was about 76 percent of the total residence use. The average indoor use for the summer periods was 17.5 percent lower than for the winter period. This difference could be accounted for if the families averaged about 14 days away from home during the summer period.

Table 3.9 Indoor and outdoor water use at Northglenn - 1977 and 1978. Values are averages for 30 homes.

Type of Use	Period		
	1977 24 June - 8 Sept.	1978 24 June - 8 Sept.	1977-1987 11 Nov. - 26 Jan.
Total gal/day	753.9	945.7	247.0
Indoor gal/day	198.8	208.5	247.0
Outdoor gal/day	555.1	737.2	0
Outdoor % of total	73.6	78.0	0

Chapter 4

LAWN WATERING GUIDELINES

Unlike agricultural irrigation, which is justified on the basis of crop yield, urban lawn irrigation is required to help maintain cooler summer temperatures, to reduce the amount of airborne dust, and to provide an aesthetically pleasing environment. It is difficult to quantify the "proper" amount of irrigation for urban lawns because yield is not important and the irrigation requirement is only related to plant appearance - a subjective value.

Lawn Quality

In this project lawn appearance was summarized by a lawn quality rating (Q), which varied from zero (lowest quality) to ten (highest quality). Values for the lawn quality ratings, averaged over two seasons, were 6.5 for Northglenn and 7.5 for Fort Collins. Thus, in neither city was a significant number of residents demanding the highest possible lawn quality and apparently, the sampled residents of Northglenn did not demand as high a quality lawn as did those of Fort Collins. Part of this difference was undoubtedly a result of the different water pricing policies of the two cities. In Northglenn, residents pay for the amount of water used; in Fort Collins, they pay a flat rate based upon lot size and other factors related to the residence.

For the guidelines established, three lawn quality ratings will be considered; namely, high (Q=8), medium (Q=6), and low (Q=4). The water requirements to maintain a lawn at a specific quality rating will be estimated for various cities in Colorado.

Lawn Water Requirements

It is assumed that lawn quality is related to the amount of water available to the grass and that other management practices are constant or, at least, consistent with the watering practices. One way of quantifying water application (irrigation plus rainfall) for a given period is to relate it to the potential evapotranspiration. Thus, the application ratio (L_m) can be defined as,

$$L_m = \frac{d}{E_{tm}}$$

where d is the total applied water and E_{tm} is the measured evapotranspiration by the lawn under conditions of soil moisture non-limiting (i.e., with the bucket lysimeters). The averaged observed values of Q versus irrigation water applied at Fort Collins and Northglenn are provided in figure 3.2 for 1977 and in figure 3.3 for 1978. The average daily irrigation needed to meet E_{tm} requirements is shown on the figures as arrows. The value depends upon seasonal rainfall as well as E_{tm}. The arrow for Fort Collins in 1977 (figure 3.2) represents an irrigation rate where the rainfall was adjusted due to an exceptionally large storm on 24 and 25 of July. Much of that rain was lost either to runoff or to deep percolation. The lawn quality rating, when the amount of irrigation indicated by the arrows was applied, was about 7 in 1977 and about 7.5 in 1978 for both cities. These values were representive of the highest average quality obtained regardless of the amount of irrigation provided. The scatter in the points is, of course, due to differences in timing and distribution of the irrigation between the various cooperators and to their management practices including fertilizer use. Evapotranspiration of the lawn cannot exceed E_{tm}; but since the residents irrigate inefficiently in terms of how often and how evenly the water is applied, application rates exceeding the theoretical minimum to meet E_{tm} are generally required to maintain an entire lawn of high quality. Assuming reasonably good management practices, it may be concluded from figures 3.2 and 3.3 that a total water application rate (irrigation plus rainfall) equal to E_{tm} (L_m=1.00) will result in an average seasonal quality rating of 8 and that quality ratings of 6 and 4 could result when L_m values are 0.78 and 0.36 respectively. If E_{tm} and rainfall values are known, it is possible to calculate the irrigation requirements needed to provide these lawn quality ratings for any location. The measurements of E_{tm} using lysimeters is expensive, however, and would be impractical for large numbers of locations.

Use of Evapotranspiration Estimating Equations

In order to avoid the high cost of measuring E_{tm}, it is desirable to predict it from climatic data at a specific location. Various equations have been developed for this purpose depending upon the type of climatic information available. The recommendations presented here are based upon the use of the Jensen-Haise equation. It has been shown to be quite accurate and requires a minimum of weather data.

The expected evapotranspiration of a crop can be estimated as follows.

$$E_{tj} = c\ E_{tpj}$$

where E_{tpj} is the potential evapotranspiration as calculated by the Jensen-Haise equation, E_{tj} is the expected evapotranspiration of the crop under the existing growing conditions, and c is a coefficient which takes into consideration the crop, the moisture stress in the soil, and how recently the crop was irrigated or received rainfall. Haw (1977) estimated c using information in the literature for agricultural crops and the assumption that urban lawns have a growth response to water similar to that of pasture grass under full cover. His calculations yielded a value of c equal to 0.89 and a plot of the 1977 data indicated that by using his c value

$$E_{tj} \approx E_{tm}$$

A subsequent evaluation of the data obtained in this study at Fort Collins and Northglenn indicates that the ratio of cumulative seasonal E_{tm} to E_{tpj} is about 0.92. A value of c equal to 0.90 (the mean of 0.89 and 0.92) is used to prepare the guidelines. Thus,

$$L_m = \frac{d}{0.9\ E_{tpj}}$$

and

$$di = 0.9\ E_{tpj}\ L_m - dr \qquad (4.1)$$

where di is the required daily irrigation to provide the desired lawn quality rating, L_m is the necessary application ratio for that quality rating, and dr is the average daily long-term rainfall value.

Application

The techniques described above were applied to 17 Colorado cities (figure 4.1). Historical precipitation, temperature, and solar radiation were obtained from appropriate sources (Jensen, 1973; U.S. Dept. Commerce; Siemer, 1977). The results are presented in tables 4.1 through 4.17. In those tables, temperature is the mean for each month,

Figure 4.1 Map of Colorado identifying the location of the 17 cities for which lawn irrigation guidelines are presented.

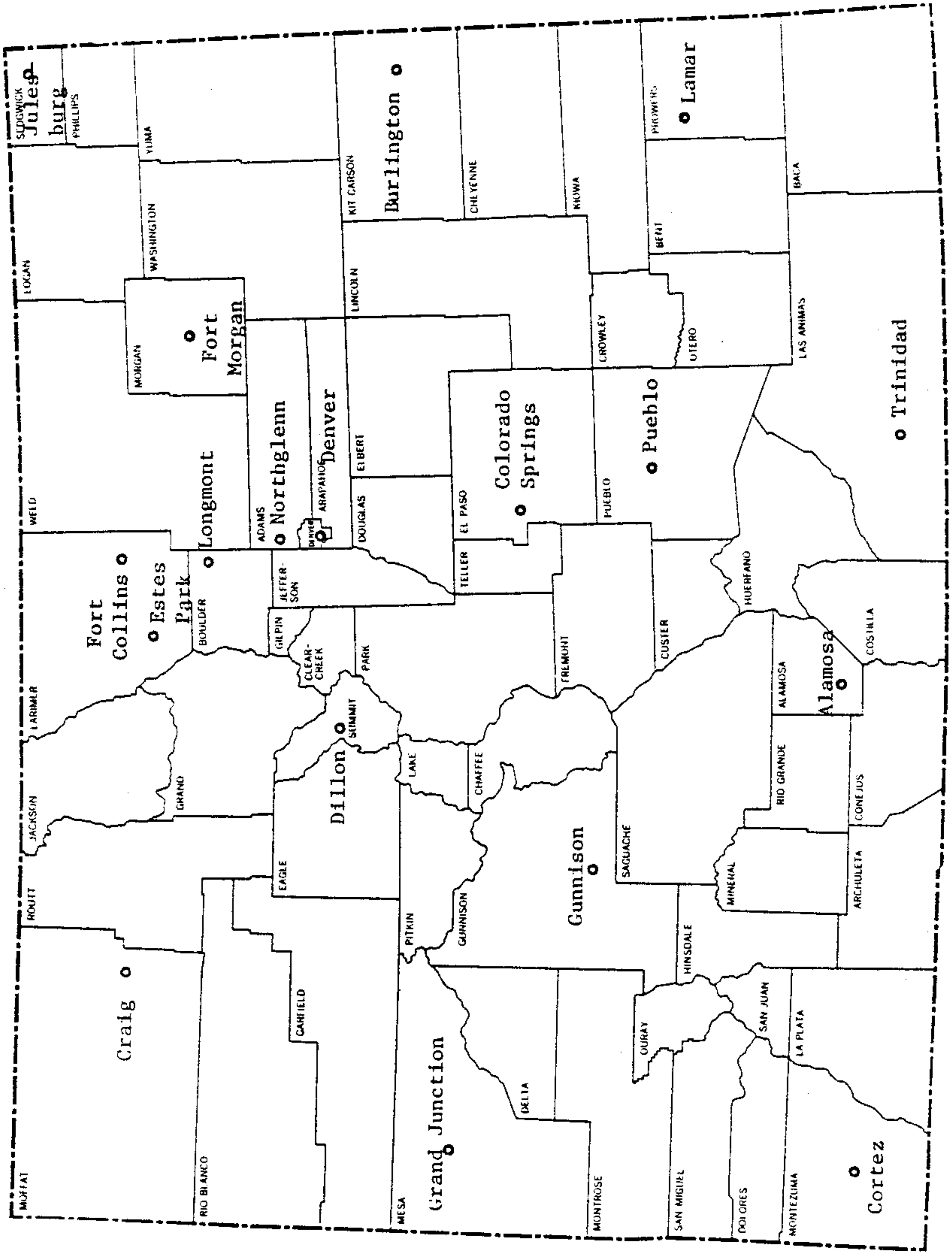

Julesburg
Burlington
Lamar
Fort Morgan
Northglenn
Denver
Longmont
Colorado Springs
Pueblo
Trinidad
Fort Collins
Estes Park
Alamosa
Dillon
Gunnison
Craig
Grand Junction
Cortez
SEDGWICK
PHILLIPS
YUMA
LOGAN
WASHINGTON
KIT CARSON
CHEYENNE
KIOWA
PROWERS
BACA
BENT
LINCOLN
CROWLEY
OTERO
LAS ANIMAS
MORGAN
WELD
ADAMS
ARAPAHOE
DENVER
ELBERT
DOUGLAS
EL PASO
PUEBLO
BOULDER
JEFFER-SON
TELLER
HUERFANO
GILPIN
CLEAR-CREEK
PARK
FREMONT
CUSTER
COSTILLA
LARIMER
ALAMOSA
SUMMIT
LAKE
CHAFFEE
GRAND
JACKSON
RIO GRANDE
CONEJOS
SAGUACHE
MINERAL
ARCHULETA
ROUTT
EAGLE
PITKIN
GUNNISON
HINSDALE
GARFIELD
SAN JUAN
LA PLATA
OURAY
DELTA
MOFFAT
RIO BLANCO
MESA
MONTROSE
SAN MIGUEL
DOLORES
MONTEZUMA

Table 4.1 Average climatic data and recommended average daily irrigation levels for urban lawns to provide lawn quality ratings of 40, 60 and 80 percent of maximum.

City Alamosa, Colorado

Elevation (meters) 2,297

Latitude 37°27' N

Longitude 105°52' W

Month	Ave. Temp. °C	Ave. ppt. mm/day	Pot. E_t mm/day	Irrigation mm/day 40%	60%	80%
May	10.44	0.60	5.51	1.2	3.3	4.4
June	15.33	0.41	7.80	2.1	5.1	6.6
July	18.33	0.88	8.22	1.8	4.9	6.5
August	17.06	0.80	7.09	1.5	4.2	5.6
September	12.89	0.65	5.30	1.1	3.1	4.1
October	6.72	0.49	2.90	0.4	1.4	2.1

Table 4.2

Average climatic data and recommended average daily irrigation levels for urban lawns to provide lawn quality ratings of 40, 60 and 80 percent of maximum.

City Burlington, Colorado

Elevation (meters) 1,269

Latitude 39°19' N

Longitude 102°16' W

Month	Ave. Temp. °C	Ave. ppt. mm/day	Pot. E_t mm/day	Irrigation mm/day 40%	60%	80%
May	15.06	2.32	5.31	--	1.4	2.5
June	20.44	2.12	7.36	0.3	3.0	4.5
July	23.89	2.14	7.88	0.4	3.4	4.9
August	22.89	1.91	6.82	3.0	2.9	4.2
September	18.11	1.09	5.00	0.5	2.4	3.4
October	12.06	0.91	2.93	--	1.1	1.7

Table 4.3 Average climatic data and recommended average daily irrigation levels for urban lawns to provide lawn quality ratings of 40, 60 and 80 percent of maximum.

City Colorado Springs, Colorado

Elevation (meters) 1,873

Latitude 38°49' N

Longitude 104°43' W

Month	Ave. Temp. °C	Ave. ppt. mm/day	Pot. E_t mm/day	Irrigation mm/day 40%	60%	80%
May	13.11	1.74	5.43	--	2.1	3.1
June	18.11	1.35	7.64	1.1	4.0	5.5
July	21.50	1.94	8.10	0.7	3.7	5.4
August	20.61	1.77	7.09	0.5	3.2	4.6
September	16.06	0.90	5.14	0.8	2.7	3.7
October	10.28	0.56	3.04	0.4	1.6	2.2

Table 4.4 Average climatic data and recommended average daily irrigation levels for urban lawns to provide lawn quality ratings of 40, 60 and 80 percent of maximum.

City Cortez, Colorado

Elevation (meters) 1,883

Latitude 37°21' N

Longitude 108°34' W

Month	Ave. Temp. °C	Ave. ppt. mm/day	Pot. E_t mm/day	Irrigation mm/day 40%	60%	80%
May	13.50	0.77	6.85	1.5	4.0	5.4
June	18.11	0.46	9.22	2.5	6.0	7.8
July	22.11	0.93	10.14	2.4	6.2	8.2
August	21.00	1.31	8.71	1.5	4.8	6.5
September	16.78	0.98	6.44	1.1	3.5	4.8
October	10.72	1.26	3.83	—	1.4	2.2

Table 4.5 Average climatic data and recommended average daily irrigation levels for urban lawns to provide lawn quality ratings of 40, 60 and 80 percent of maximum.

City Craig, Colorado

Elevation (meters) 1,916

Latitude 40°31' N

Longitude 107°33' W

Month	Ave. Temp. °C	Ave. ppt. mm/day	Pot. E_t mm/day	Irrigation mm/day 40%	60%	80%
May	10.83	1.11	5.93	0.8	3.1	4.2
June	15.00	1.17	8.04	1.4	4.5	6.1
July	19.22	0.79	9.07	2.1	5.6	7.4
August	18.17	1.24	7.76	1.3	4.2	5.7
September	13.39	0.92	5.51	0.9	2.9	4.0
October	7.44	1.08	3.15	--	1.1	1.8

Table 4.6 Average climatic data and recommended average daily irrigation levels for urban lawns to provide lawn quality ratings of 40, 60 and 80 percent of maximum.

City Denver, Colorado

Elevation (meters) 1,610

Latitude 39°41' N

Longitude 104°53' W

Month	Ave. Temp. °C	Ave. ppt. mm/day	Pot. E_t mm/day	Irrigation mm/day 40%	60%	80%
May	13.89	2.16	5.02	--	1.4	2.4
June	18.89	1.63	6.94	0.6	3.2	4.6
July	22.78	1.46	7.57	1.0	3.9	5.4
August	22.00	1.05	6.60	1.1	3.6	4.9
September	17.11	0.96	4.79	0.6	2.4	3.3
October	11.11	0.96	2.79	--	1.0	1.5

Table 4.7 Average climatic data and recommended average daily irrigation levels for urban lawns to provide lawn quality ratings of 40, 60 and 80 percent of maximum.

City Dillon, Colorado

Elevation (meters) 2,763

Latitude 39°38' N

Longitude 106°02' W

Month	Ave. Temp. °C	Ave. ppt. mm/day	Pot. E_t mm/day	Irrigation mm/day 40%	60%	80%
May	5.94	1.22	4.43	0.2	1.9	2.8
June	9.94	1.07	6.31	1.0	3.4	4.6
July	13.11	1.38	6.97	0.9	3.5	4.9
August	12.22	1.44	5.99	0.5	2.8	3.9
September	8.72	1.04	4.37	0.4	2.0	2.9
October	3.83	0.88	2.47	--	0.9	1.3

Table 4.8 Average climatic data and recommended average daily irrigation levels for urban lawns to provide lawn quality ratings of 40, 60 and 80 percent of maximum.

City Estes Park, Colorado

Elevation (meters) 2,285

Latitude 40°23' N

Longitude 105°31' W

Month	Ave. Temp. °C	Ave. ppt. mm/day	Pot. E_t mm/day	Irrigation mm/day 40%	60%	80%
May	9.11	1.76	3.99	--	1.0	1.8
June	13.44	1.68	5.60	0.1	2.2	3.4
July	16.78	1.88	8.24	0.8	3.9	5.5
August	16.06	1.58	7.20	0.8	3.5	4.9
September	12.11	1.02	5.47	0.8	2.8	3.9
October	7.50	0.83	3.49	0.3	1.6	2.3

Table 4.9 Average climatic data and recommended average daily irrigation levels for urban lawns to provide lawn quality ratings of 40, 60 and 80 percent of maximum.

City Fort Collins, Colorado

Elevation (meters) 1,524

Latitude 40°35' N

Longitude 105°05' W

Month	Ave. Temp. °C	Ave. ppt. mm/day	Pot. E_t mm/day	Irrigation mm/day 40%	60%	80%
May	13.11	2.38	4.85	--	1.0	2.0
June	17.94	1.81	6.70	0.4	2.9	4.2
July	21.56	1.20	7.28	1.2	3.9	5.3
August	20.50	1.27	6.27	0.8	3.1	4.4
September	15.56	0.81	4.49	0.6	2.3	3.2
October	9.78	1.05	2.59	--	0.8	1.3

Table 4.10 Average climatic data and recommended average daily irrigation levels for urban lawns to provide lawn quality ratings of 40, 60 and 80 percent of maximum.

City Fort Morgan, Colorado

Elevation (meters) 1,317

Latitude 40° 15' N

Longitude 103° 48' W

Month	Ave. Temp. °C	Ave. ppt. mm/day	Pot. E_t mm/day	Irrigation mm/day 40%	60%	80%
May	14.44	2.09	5.15	--	1.5	2.5
June	19.72	1.80	7.18	0.5	3.2	4.7
July	23.33	1.55	7.74	1.0	3.9	5.1
August	22.17	1.19	6.66	1.0	3.5	4.8
September	16.78	0.91	4.74	0.6	2.4	3.4
October	10.56	0.76	2.72	0.1	1.1	1.7

Table 4.11

Average climatic data and recommended average daily irrigation levels for urban lawns to provide lawn quality ratings of 40, 60 and 80 percent of maximum.

City Gunnison, Colorado

Elevation (meters) 2,336

Latitude 38° 32' N

Longitude 106° 56' W

Month	Ave. Temp. °C	Ave. ppt. mm/day	Pot. E_t mm/day	Irrigation mm/day 40%	60%	80%
May	8.78	0.56	5.85	1.3	3.5	4.7
June	13.17	0.58	8.12	2.0	5.1	6.7
July	16.61	1.15	8.99	1.8	5.2	6.9
August	15.44	1.23	7.63	1.2	4.1	5.6
September	11.22	0.80	5.46	1.0	3.0	4.1
October	5.56	0.73	3.11	0.3	1.5	2.1

Table 4.12 Average climatic data and recommended average daily irrigation levels for urban lawns to provide lawn quality ratings of 40, 60 and 80 percent of maximum.

City Julesburg, Colorado

Elevation (meters) 1,163

Latitude 41° 00' N

Longitude 102° 56' W

Month	Ave. Temp. °C	Ave. ppt. mm/day	Pot. E_t mm/day	Irrigation mm/day 40%	60%	80%
May	15.28	2.74	5.34	--	1.0	2.1
June	20.50	2.70	7.37	--	2.5	3.9
July	24.50	2.10	8.02	0.5	3.5	5.1
August	23.61	1.47	5.97	0.8	3.4	4.8
September	18.00	1.16	4.97	0.4	2.3	3.3
October	11.61	0.72	2.88	0.2	1.3	1.9

Table 4.13 Average climatic data and recommended average daily irrigation levels for urban lawns to provide lawn quality ratings of 40, 60 and 80 percent of maximum.

City Lamar, Colorado

Elevation (meters) 1,102

Latitude 38° 07' N

Longitude 102° 36' W

Month	Ave. Temp. °C	Ave. ppt. mm/day	Pot. E_t mm/day	Irrigation mm/day 40%	60%	80%
May	17.11	2.07	6.03	--	2.2	3.4
June	22.56	1.91	8.35	0.8	4.0	5.6
July	25.61	1.91	8.65	0.9	4.2	5.9
August	24.50	1.92	7.55	0.5	3.4	4.9
September	19.50	0.92	5.56	0.9	3.0	4.1
October	13.11	0.74	3.29	0.3	1.6	2.2

Table 4.14 Average climatic data and recommended average daily irrigation levels for urban lawns to provide lawn quality ratings of 40, 60 and 80 percent of maximum.

City Longmont, Colorado

Elevation (meters) 1,509

Latitude 40° 10' N

Longitude 105° 04' W

Month	Ave. Temp. °C	Ave. ppt. mm/day	Pot. E_t mm/day	Irrigation mm/day 40%	60%	80%
May	13.67	2.07	5.49	--	1.8	2.9
June	18.33	1.60	7.47	0.8	3.6	5.1
July	22.00	0.99	8.10	1.6	4.7	6.3
August	21.06	0.84	7.01	1.4	4.1	5.5
September	16.11	0.83	5.06	0.8	2.7	3.7
October	10.22	0.86	2.94	0.1	1.2	1.8

Table 4.15 Average climatic data and recommended average daily irrigation levels for urban lawns to provide lawn quality ratings of 40, 60 and 80 percent of maximum.

City Grand Junction, Colorado

Elevation (meters) 1,480

Latitude 39° 07' N

Longitude 108° 32' W

Month	Ave. Temp. °C	Ave. ppt. mm/day	Pot. E_t mm/day	Irrigation mm/day 40%	60%	80%
May	16.78	0.49	6.24	1.4	3.9	5.1
June	21.83	0.35	8.40	2.4	5.5	7.2
July	25.94	0.47	9.17	2.5	6.0	7.8
August	24.11	0.88	7.72	1.6	4.5	6.1
September	19.56	0.77	5.70	1.1	3.2	4.4
October	12.72	0.61	3.33	0.5	1.7	2.4

Table 4.16 Average climatic data and recommended average daily irrigation levels for urban lawns to provide lawn quality ratings of 40, 60 and 80 percent of maximum.

City Pueblo, Colorado

Elevation (meters) 1,428

Latitude 38° 17' N

Longitude 104° 31' W

Month	Ave. Temp. °C	Ave. ppt. mm/day	Pot. E_t mm/day	Irrigation mm/day 40%	60%	80%
May	16.17	1.47	6.38	0.6	3.0	4.3
June	21.50	1.03	8.82	1.9	5.2	6.9
July	24.67	1.49	9.19	1.5	5.0	6.8
August	23.61	1.51	8.03	1.1	4.1	5.7
September	19.00	0.71	5.98	1.2	3.5	4.7
October	12.50	0.81	3.52	0.3	1.7	2.4

Table 4.17 Average climatic data and recommended average daily irrigation levels for urban lawns to provide lawn quality ratings of 40, 60 and 80 percent of maximum.

City Trinidad, Colorado

Elevation (meters) 1,751

Latitude 37° 15' N

Longitude 104° 20' W

Month	Ave. Temp.. ^{o}C	Ave. ppt. mm/day	Pot. E_t mm/day	Irrigation mm/day 40%	60%	80%
May	14.78	1.51	5.92	0.4	2.6	3.8
June	19.94	1.57	8.26	1.1	4.2	5.9
July	23.00	1.52	8.62	1.3	4.5	6.2
August	22.11	1.56	7.55	0.9	3.7	5.2
September	18.00	0.82	5.67	1.0	3.2	4.3
October	11.94	0.74	3.35	0.3	1.6	2.3

precipitation is the mean daily value for the month, and Pot. E_t is a value estimated for the month by the Jensen-Haise equation. This value, when multiplied by 0.90 gives the estimated maximum water use by a lawn when not limited by soil moisture. The irrigation columns contain the irrigation requirement (di), expressed in millimeters per day, to provide a lawn quality rating of 4, 6, or 8 and were obtained from equation (4.1) using L_m values of 0.36, 0.78, and 1.00 respectively. The rainfall (dr) is the long-term average precipitation value for the appropriate month. If desired, the irrigation values can be converted to inches per day by multiplying the value by 0.039.

Controlling Water Applications

In using the guidelines provided by tables 4.1 to 4.17, the homeowner must be able to know when the recommended application has been made. One of three methods may be used to do this.

(1) Several straight sided containers can be placed throughout the sprinkler area and the depth of application determined by averaging the depth of water in the containers. Various types of cans may be used effectively although larger sizes give the most satisfactory results.

(2) The total volume of water applied to a specific area may be determined by use of a water meter. Appropriate meters which can be attached to the sill cocks of the home, may be obtained for about $50. An alternative is to purchase a device which can be set to turn the water off when a desired volume has been delivered. The volume of water divided by the area gives the average depth of application.

(3) The flow rate through the irrigation line may be measured so that time may be used to control the the depth of water applied. Again, the area being irrigated must be known and that area times the desired depth will give the volume required. This method is useful where underground sprinkles systems are installed and the area watered by the system is constant. The application rate of fixed systems can be determined using method (1) and for portable systems by discharging the sprinkler into a container for a given period of time. All components of the system must be in the line when the flow rate is determined.

Chapter 5

SUPPLEMENTAL STUDIES

During the course of the investigations, certain supplemental studies were conducted and certain hypotheses were made and tested under limited conditions. Two of these studies are described and discussed in this chapter.

Evaluation of Bucket Lysimeters for URBAN E_t Measurements

In order to evaluate the use of bucket lysimeters for measuring the potential evapotranspiration by lawn grass, a controlled study area was established on Colorado State University property at the Agricultural Engineering Research Center (AERC) located about six kilometers northwest of Fort Collins. This area is subjected to higher velocity winds than would be expected at the homesites in the city and is bordered on the north and west (the direction from which the prevailing winds occur) by non-irrigated lands with sparse vegetation and low evapotranspiration.

An area of approximately 100 square meters was sodded to blue grass lawn in the early summer of 1977. A series of four 60 centimeter deep bucket lysimeters, identical to those used at the homesites were installed. In addition, four bucket lysimeters of the same diameter but only one-half the depth (30 cm) were installed in order to determine whether they would be suitable for such use in the future. One large lysimeter with an area of one square meter and a depth of one meter was also established at this site. It was of the "floating" type supported by hydraulic pillows so that the change in weight could be calculated from changes in the liquid level in a manometer tube. Evapotranspiration was measured using the three tyoes of lysimeters during 1978.

There was no significant difference between E_{tm} values measured with the 30 cm and 60 cm bucket lysimeters. The advantage of using the shallower types is that the weight is reduced to about 35 kilograms which allows one man to easily handle them.

The average evapotranspiration measured with the bucket lysimeter at the study area is plotted as it cumulated over time on figure 5.1. Estimated potential E_t, calculated using the Jensen-Haisé equation from weather data at both the AERC and the Agronomy Research Center, is also plotted on figure 5.1. The estimated and bucket lysimeter measurements compare very well. Data from the large "floating" lysimeter are presented in figure 5.1 but are appreciably lower than the calculated and the small lysimeter values. Some difficulty with the large unit was experienced and these values are considered to be in error rather than those of the small units.

Also provided on figure 5.1 is the cumulative curve for the 15 bucket lysimeters used at the homes of Fort Collins cooperators. This curve is about 22 percent lower than the one for E_{tm} measured by bucket lysimeters at the AERC. This rather large difference reflects the differences in micro-climate in the urban locations and the "oasis" area at the AERC. Considerable interest has existed concerning the relative

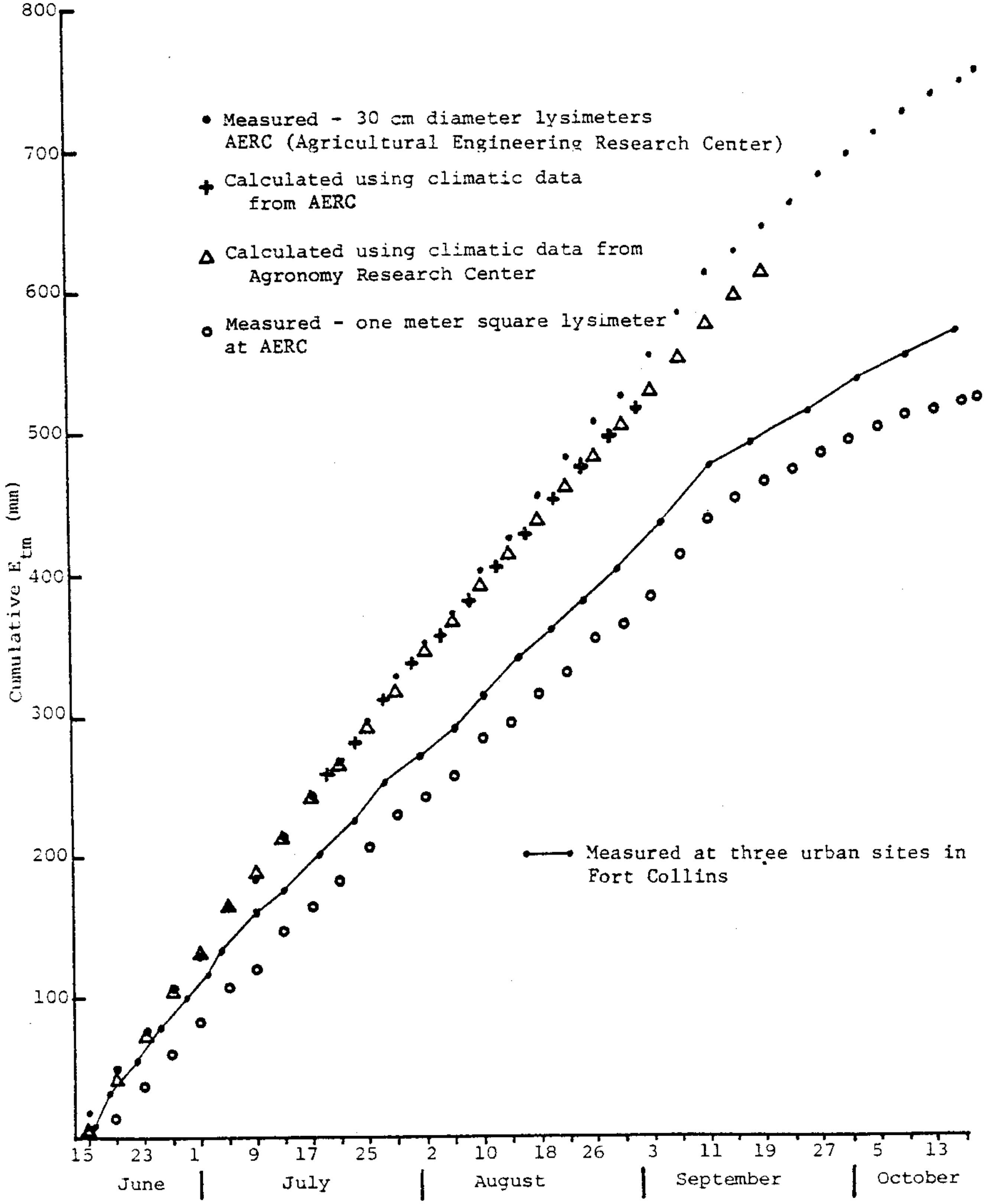


Figure 5.1 Measured and calculated cumulative E_{tm} values - 1978.

water consumption before and after an irrigated agricultural area has been subdivided and developed into homesites. In the urban microclimate temperatures may be elevated at some points as a result of heat reflected from buildings, sidewalks and streets. The temperature of the turf environment may be decreased at other points as a result of shading by trees, buildings, and hedges. Wind velocity near the ground is greatly decreased in the urban environment as a result of the structures and plants. The importance of wind on evaportranspiration by lawns in the city is suggested by the data in Appendix table A.2. The seasonal E_{tm} measured for sites 2 and 3 at Fort Collins in 1978 are consistently about 20 percent lower than that for site 1. The three sites are similar except that site 1 has a school playground adjacent to the west and a non-irrigated pasture for the Colorado State University riding stables across the street to the east. These open and dry fields are in line with the prevailing winds. Sites 2 and 3 are surrounded by residential homes.

It seems reasonable that the average evapotranspiration rate of turf grass within an urban area could be lower than that of turf grass in an open field with no shade and little resistance to wind. However, only the evapotranspiration of the grass was measured in this study. Urban areas also contain a multitude of bushes and trees which often extend considerable distance into the air. Trees not only provide a perpendicular plane of resistance to wind instead of a parallel one like turf, but are also in a position to be influenced more than turf by rising heat from non-transpiring surfaces. The data from this study indicates that the evapotranspiration rate by grass in the city may be lower than that in open areas and therefore probably lower than that for agricultural crops. But the total water use by grass and other vegetation is difficult to evaluate. This study, therefore, does not answer the question of urban vs. irrigated farm water requirements. However, it can be reasoned that energy input to a city area is very comparable to that of a cropped area. Energy loss in terms of sensible heat is much greater for the city. Glider pilot's utilize the warm updrafts over urban areas. The conclusion, then, is that the energy for evapotranspiration in a given day is less in the city than in the irrigated cropland area.

Canopy Temperature Measurements

Lawn quality is a function of applied water only when soil moisture has not been limiting. When moisture is not limiting lawn quality may affect the rate of water use. Since transpiration has a large cooling effect on plants, canopy temperature seemed potentially valuable as an indicator of differences in water use rates.

A Barnes 14-220 infrared thermometer was used to facilitate the acquisition of canopy temperature data. Infrared thermometers are useful because they give instantaneous integrated readings of the turf canopy which eliminates the need for a large number of thermistors or thermocouples. The use of far infrared radiation to measure temperature also eliminates the possibility of mechanical contact inducing temperature changes at the measured site.

The infrared thermometer was calibrated using the Colorado State University Blackbody. The Barnes 14-220 gave a temperature reading for the blackbody that was 8% high in ^{o}C

for the 0-50°C range. This error was not significant when determining relative temperature differences of turf canopies.

All materials do not have the same thermal emissivity, which is the efficiency with which far infrared radiation is emitted. The emissivity of a perfect blackbody is 1.00. Values for the emissivity of lush green vegetation have been reported in the literature as 0.94 to 0.98. No emissivity values for dead vegetation were found in the literature and since poor quality lawns contain a high percent of dead biomass, temperature measurements of turf differing in quality could be subject to error caused by emissivity differences.

A thermal isolation box was constructed by Feldhake (1979) and temperatures of live and dead turf canopies were measured within it. The emissivity of each was calculated utilizing the response equation of the infrared thermometer developed from the blackbody data, the true canopy temperature determined with calibrated thermistors, and the temperature of the canopy determined with the infrared thermometer. The live and dead canopies both were found to have an emissivity of 0.96; therefore no corrections are needed to compensate for quality differences when measuring canopy temperature.

Eight additional shallow (30 cm) lysimeters, with high quality turf, were established in 1978 at the 100 meter square grass plot at the Agricultural Engineering Research Center. They were placed adjacent to each other in a row to minimize differences in micro-climate. Starting on 4 August, irrigation was withheld for 8 days from four of the lysimeters which left the canopies completely desiccated. Two of these lysimeters were then returned to maximum water content to allow regrowth. Water was then withheld from two of the lysimeters which had been maintained at the maximum water level. This procedure was designed to allow E_t and canopy temperature to be compared for the following four treatments under identical environmental conditions.

A. lush, turgid canopy
B. lush, wilted canopy
C. dead, canopy with some regrowth
D. dead, dry canopy

The relative E_t for the four treatments is plotted in figure 5.2, together with the relative canopy temperatures, for 19 days in August which includes a period before treatments were initiated and the period during which irrigation was withheld on some treatments starting on day 4. The relative E_t is the actual E_t divided by that of the control, which was the lush, turgid canopy. The relative canopy temperature is the temperature of each treatment divided by the temperature of the control. It is clear that there is a close correlation between relative E_t and relative temperature of the turf as measured by the infrared thermometer.

On August 18 the quality rating of treatment A was 9, B was 7, C was 3, and D was 0. On this day B with a quality rating of 7 was transpiring at a rate equal to 67% of $E_{t\ max}$ as a result of plant water stress. Treatment C had very little live biomass but was not subject to plant water stress and was transpiring at 75% of $E_{t\ max}$. Visual Quality is not in itself a good indication of the relative E_t rate. Poor quality turf may be transpiring at near $E_{t\ max}$ rates or hardly at all depending on available

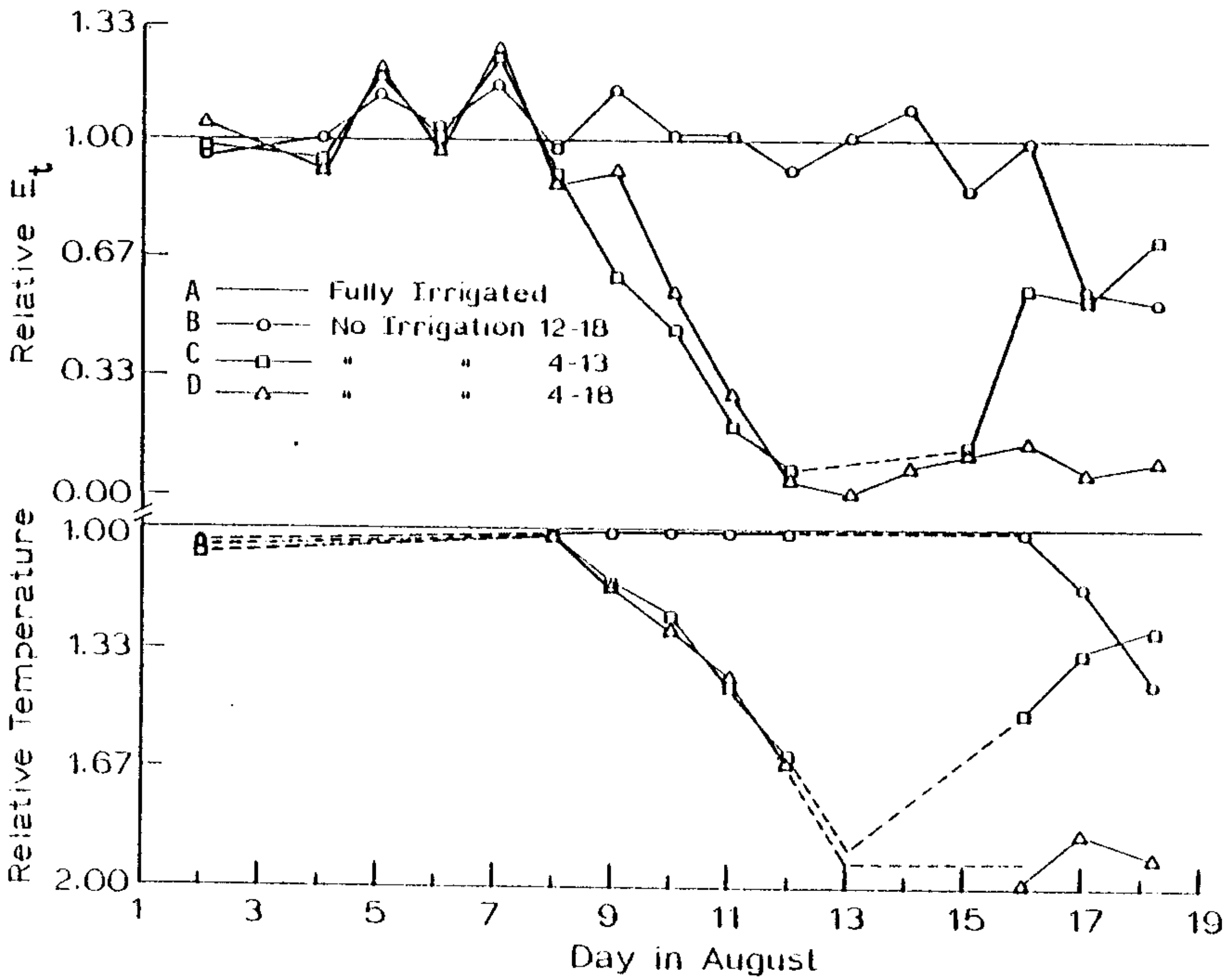


Figure 5.2 Relative E_t and canopy temperatures for three irrigation schedules relative to fully irrigated turf. (Each point is an average of two replications)

soil moisture. High quality turf may transpire at rates significantly less than $E_{t\ max}$ for short periods of water stress and recover to transpire at a rate equal to $E_{t\ max}$ almost immediately upon irrigation. Canopy temperature is more reliable than visual observation at quantifying lawn water use rates.

Chapter 6

SUMMARY AND CONCLUSIONS

Water use and water requirements of urban lawns was studied in 1977 and 1978 in Fort Collins and Northglenn, two rapidly growing Colorado cities located along the front range of the Rocky Mountains to the North of Denver. The major portion of the research was conducted on the lawns of cooperators distributed through the cities.

Lawn water application rates were monitored by meters placed on the outside water spigots of the homes. These meters were read weekly during the frost-free season. The application rates were calculated by dividing the volume of water flowing through the meters by the vegetated area of the homesite.

Maximum water requirements were evaluated by establishing weighable bucket lysimeters in the lawns of three cooperators in each city. Five lysimeters were installed at each homesite. The lysimeters were weighed two or three times each week and water was added to bring the soil moisture back to a pre-determined value representing field capacity. The cooperators were required to cover the lysimeter, with lids provided, each time they sprinkled their lawns. Rainfall was measured at each site. The water loss from the lysimeters between weighings was converted to a depth value which was considered the potential evapotranspiration value for the period.

Lawn quality, at the homes where water application rates were measured, were evaluated weekly by visual examination. A quality rating system was devised whereby the lawn was rated on a scale from zero to ten; weekly ratings were averaged to provide a seasonal value.

Supplemental studies were carried out using lysimeters established on University property where maximum control was possible. Two of these studies involved special evaluation of the bucket lysimeter and an evaluation of canopy temperature measurements for evaluating evapotranspiration rates of the turf.

Using the data obtained during the studies, a set of lawn watering guidelines was prepared for 17 cities in Colorado. Irrigation requirements to maintain lawns at specified quality levels are presented for each city assuming long term average rainfall rates and lawn maintenance practices similar to those used by the cooperators involved in the research.

Results are summarized as follows:

(1) The weighable bucket lysimeters are suitable for measuring evapotranspiration of lawn grass providing the interval between water additions is short enough to prevent E_t deficits due to soil moisture stress.

(2) Lawn water application rates are appreciably higher at Fort Collins than at Northglenn even though the maximum water requirements of grass at Northglenn are slightly higher due to climatic differences. Average irrigation application rates during the measurement periods of the two years was 5.6 millimeters per day at Fort Collins and 3.6 at Northglenn. These values, when adjusted to include the rainfall during the period,

indicate that total water application was approximately 135 percent of potential evapotranspiration at Fort Collins and about 80 percent at Northglenn. These differences probably reflect the type of water pricing for the two cities. Fort Collins has a flat rate charge for water and Northglenn charges for the amount of water delivered.

(3) Potential evapotranspiration for lawn grass, as measured by the lysimeters, had peak weekly rates of about 7 millimeters per day and average seasonal values of 5.1 for Fort Collins and 5.6 for Northglenn.

(4) Lawn quality ratings reflected the amount of water applied to the lawn, in that values at Northglenn were consistently lower than those at Fort Collins. Seasonal averages over the two seasons were 7.4 for Fort Collins and 6.5 for Northglenn on a scale of zero to ten. At Fort Collins, where total water application was in excess of E_{tm} most of the time, there was a rather uniform quality rating for all lawns. At Northglenn, where total application was normally below E_{tm}, quality increased with water application rate. At total application (irrigation plus rainfall) rates equal to E_{tm}, the better managed lawns had quality ratings of about 8 or slightly less. This reflects the fact that application and distribution efficiencies cannot be 100 percent and some over-irrigation may be justified.

(5) Using the sample of 27 homes in Fort Collins and 30 homes in Northglenn, there was no general relation between lawn quality rating and home characteristics of lot size, age of home or assessed valuation of the real property.

(6) Outdoor water use during the summer months at Northglenn was about 76 percent of total outdoor and indoor use. Indoor use during an 11 week summer period was 17.5 percent lower than that during an 11 week winter period.

(7) The effectiveness of imposed schedule restrictions for lawn watering was not satisfactorily evaluated in the study even though they became a factor in water use. Restrictions in Northglenn were in effect during the entire drouth year of 1977. Residents of the study sites applied 3.2 mm of water per day to their lawns and those lawns received a normally unacceptable quality rating of 5.9. In 1978 without restrictions, 4.1 mm per day was applied by irrigation and the quality rating averaged 7.1 which is an acceptable value. Lawn watering restrictions were established at Fort Collins on 15 July, 1977. Unfortunately for the evaluation, this was followed in a few days by a period of wet and cool weather which lasted for about two weeks. The remainder of the summer had a lower E_t potential than the period prior to restriction. Lawn water application before and after restrictions were established was 7.4 and 3.9 mm/day respectively. However, the ratio of irrigation to E_{tm} was 1.37 before controls were applied and 1.43 after and lawn quality ratings remained high all year. It appears that residents of Northglenn responded to the water conservation needs and accepted a lower lawn quality rating in 1977. Fort Collins cooperators used less water after restrictions went into effect, but the reason seems to be related to cooler weather and not a willingness to sacifice lawn quality to conserve water.

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APPENDIX

Table A.1. Daily maximum evapotranspiration (E_{tm}), cumulative E_{tm}, and precipitation for 3 sites at Fort Collins - 1977. All values are in millimeters. Precipitation values are for the period ending on the date they are recorded.

Date		Site 1 Daily E_{tm}	Site 1 Cum. E_{tm}	Site 1 ppt	Site 2 Daily E_{tm}	Site 2 Cum. E_{tm}	Site 2 ppt	Site 3 Daily E_{tm}	Site 3 Cum. E_{tm}	Site 3 ppt	Average Daily E_{tm}	Average Cum. E_{tm}	Average ppt
May	15	4.1	4.1		5.1	5.1		2.2	2.2		3.8	3.8	
	16	4.1			5.1			2.2			3.8		
	17	4.1			5.1			2.2			3.8		
	18	4.1	16.4		5.1	20.4		2.2	8.8		3.8	15.2	
	19	5.3			3.1			3.2			3.9		
	20	5.3			3.1			3.2			3.9		
	21	5.3			3.1			3.2			3.9		
	22	5.3	37.6		3.1	32.8		3.2	21.6		3.9	30.8	
	23	7.9			5.5			4.5			6.0		
	24	7.9			5.5			4.5			6.0		
	25	7.9	61.3		5.5	49.3		4.5	35.1		6.0	48.8	
	26	4.3			3.6			3.7			3.9		
	27	4.3			3.6			3.7			3.9		
	28	4.3			3.6			3.7			3.9		
	29	4.3			3.6			3.7			3.9		
	30	4.3	82.8	6.1	3.6	67.3	7.0	3.7	53.6	7.0	3.9	68.3	6.7
	31	7.0			4.5			4.7			5.4		
June	1	7.0			4.5			4.7			5.4		
	2	7.0	103.8		4.5	80.8		4.7	67.7		5.4	84.5	
	3	8.0			6.7			6.6			7.1		
	4	8.0			6.7			6.6			7.1		
	5	8.0	127.8		6.7	100.9		6.6	87.5		7.1	105.8	
	6	6.0			6.0			4.3			5.4		
	7	6.0			6.0			4.3			5.4		
	8	6.0			6.0			4.3			5.4		
	9	6.0	151.8		6.0	124.9		4.3	104.7		5.4	127.4	
	10	6.0			3.9			3.9			4.6		
	11	6.0			3.9			3.9			4.6		
	12	6.0	169.8		3.9	136.6		3.9	116.4		4.6	141.2	

Table A.1. (cont.) Daily maximum evapotranspiration (E_{tm}), cumulative E_{tm}, and precipitation for 3 sites at Fort Collins - 1977. All values are in millimeters. Precipitation values are for the period ending on the date they are recorded.

Date		Site 1			Site 2			Site 3			Average		
		Daily E_{tm}	Cum. E_{tm}	ppt	Daily E_{tm}	Cum. E_{tm}	ppt	Daily E_{tm}	Cum. E_{tm}	ppt	Daily E_{tm}	Cum. E_{tm}	ppt
June	13	8.8			6.7			5.8			7.1		
	14	8.8			6.7			5.8			7.1		
	15	8.8	196.2		6.7	156.7		5.8	133.8		7.1	162.5	
	16	5.2			5.8			4.3			5.1		
	17	5.2			5.8			4.3			5.1		
	18	5.2			5.8			4.3			5.1		
	19	5.2	217.0	0.5	5.8	179.9	10	4.3	151.0	10.7	5.1	182.9	7.1
	20	6.0			6.2			4.8			5.4		
	21	6.0			6.2			4.8			5.4		
	22	6.0	235.0		6.2			4.8	165.4		5.4	199.1	
	23	7.4			6.2			5.1			6.2		
	24	7.4			6.2			5.1			6.2		
	25	7.4			6.2			5.1			6.2		
	26	7.4	264.6		6.2	223.3		5.1	185.8		6.2	223.9	
	27	10.3			7.7			6.3			8.1		
	28	10.3			7.7			6.3			8.1		
	29	10.3	295.5		7.7			6.3	204.7		8.1		
	30	7.3			7.7			4.7			6.6		
July	1	7.3			7.7			4.7			6.6		
	2	7.3			7.7			4.7			6.6		
	3	7.3	324.7		7.7			4.7	223.5		6.6	274.6	
	4	5.4			7.7			5.6			6.2		
	5	5.4			7.7			5.6			6.2		
	6	5.4	340.9	2.5	7.7	308.0	10.0	5.6	240.3	5.1	6.2	293.2	5.9
	7	8.1			8.2			5.6			7.3		
	8	8.1			8.2			5.6			7.3		
	9	8.1			8.2			5.6			7.3		
	10	8.1	373.3		8.2	340.8		5.6	262.7		7.3	322.4	
	11	5.8			4.6			5.2			5.2		

Table A.I. (cont.) Daily maximum evapotranspiration (E_{tm}), cumulative E_{tm}, and precipitation for 3 sites at Fort Collins - 1977. All values are in millimeters. Precipitation values are for the period ending on the date they are recorded.

Date		Site 1			Site 2			Site 3			Average		
		Daily E_{tm}	Cum. E_{tm}	ppt	Daily E_{tm}	Cum. E_{tm}	ppt	Daily E_{tm}	Cum. E_{tm}	ppt	Daily E_{tm}	Cum. E_{tm}	ppt
July	12	5.8			4.6			5.2			5.2		
	13	5.8	390.7		4.6	354.6		5.2	278.7		5.2		
	14	6.3			6.3			4.8			5.8		
	15	6.3			6.3			4.8			5.8		
	16	6.3			6.3			4.8			5.8		
	17	6.3	415.9		6.3	379.8		4.8	297.9		5.8	360.6	
	18	2.0			2.0			2.0			2.0		
	20	2.0			2.0			2.0			2.0		
	21	2.0			2.0			2.0			2.0		
	22	2.0			2.0			2.0			2.0		
	23	2.0			2.0			2.0			2.0		
	23	2.0			2.0			2.0			2.0		
	24	2.0			2.0			2.0			2.0		
	25	2.0			2.0			2.0			2.0		
	26	2.0			2.0			2.0			2.0		
	27	2.0	435.9	155.5	2.0	399.8	155.5	2.0	317.9	155.5	2.0	380.6	155.5
	28	4.5			5.6			4.3			4.8		
	29	4.5			5.6			4.3			4.8		
	30	4.5			5.6			4.3			4.8		
	31	4.5	453.9		5.6	422.2		4.3	335.1		4.8	399.8	
Aug.	1	7.5			6.9			6.4			6.9		
	2	7.5			6.9			6.4			6.9		
	3	7.5	476.4		6.9	442.9		6.4	354.3		6.9	420.5	
	4	6.4			7.8			6.9			7.0		
	5	6.4			7.8			6.9			7.0		
	6	6.4			7.8			6.9			7.0		
	7	6.4	502.0	15.0	7.8	474.1	11.0	6.9	381.9	12.0	7.0	448.5	12.7
	8	4.1			3.7			3.1			3.6		
	9	4.1			3.7			3.1			3.6		

Table A.1. (cont.) Daily maximum evapotranspiration (E_{tm}), cumulative E_{tm}, and precipitation for 3 sites at Fort Collins - 1977. All values are in millimeters. Precipitation values are for the period ending on the date they are recorded.

Date		Site 1 Daily E_{tm}	Site 1 Cum. E_{tm}	Site 1 ppt	Site 2 Daily E_{tm}	Site 2 Cum. E_{tm}	Site 2 ppt	Site 3 Daily E_{tm}	Site 3 Cum. E_{tm}	Site 3 ppt	Average Daily E_{tm}	Average Cum. E_{tm}	Average ppt
Aug.	10	4.1	514.3		3.7	485.2		3.1	391.2		3.6	459.3	
	11	2.9			1.8			2.5			2.4		
	12	2.9			1.8			2.5			2.4		
	13	2.9			1.8			2.5			2.4		
	14	2.9	525.9		1.8	492.4		2.5	401.2		2.4	468.9	
	15	3.3			3.6			4.9			3.9		
	16	3.3			3.6			4.9			3.9		
	17	3.3	534.3	9.0	3.6	503.2	8.0	4.9	415.9	12,2	3.9	480.6	9.7
	18	2.8			3.6			3.0			3.1		
	19	2.8			3.6			3.0			3.1		
	20	2.8			3.6			3.0			3.1		
	21	2.8	545.5		3.6	517.6		3.0	427.9		3.1	493.0	
	22	5.1			4.5			4.7			4.8		
	23	5.1			4.5			4.7			4.8		
	24	5.1			4.5			4.7			4.8		
	25	5.1	565.9	5.0	4.5	535.6	0.0	4.7	446.7	0.0	4.8	512.2	1.7
	26	4.2			3.8			3.7			3.9		
	27	4.2			3.8			3.7			3.9		
	28	4.2	578.5		3.8	547.0		3.7	457.8		3.9	523.9	
	29	4.1			4.4			5.1			4.5		
	30	4.1			4.4			5.1			4.5		
	31	4.1	590.8		4.4	560.2		5.1	473.1		4.5	537.4	
Sept.	1	4.5			3.5			3.4			3.8		
	2	4.5			3.5			3.4			3.8		
	3	4.5			3.5			3.4			3.8		
	4	4.5			3.5			3.4			3.8		
	5	4.5	613.3		3.5	577.7		3.4	490.1		3.8	556.4	
	6	5.9			4.2			5.1			5.1		
	7	5.9			4.2			5.1			5.1		

Table A.1. (cont.) Daily maximum evapotranspiration (E_{tm}), cumulative E_{tm}, and precipitation for 3 sites at Fort Collins - 1977. All values are in millimeters. Precipitation values are for the period ending on the date they are recorded.

Date		Site 1 Daily E_{tm}	Site 1 Cum. E_{tm}	Site 1 ppt	Site 2 Daily E_{tm}	Site 2 Cum. E_{tm}	Site 2 ppt	Site 3 Daily E_{tm}	Site 3 Cum. E_{tm}	Site 3 ppt	Average Daily E_{tm}	Average Cum. E_{tm}	Average ppt
Sept.	8	5.9	631.0		4.2	590.3		5.1	505.4		5.1	571.7	
	9	3.9			4.0			3.6			4.0		
	10	3.9			4.0			3.6			4.0		
	11	3.9	642.7	4.0	4.0	602.3	5.0	3.6	516.2	3.1	4.0	583.7	4.0
	12	3.2			2.5			2.9			2.9		
	13	3.2			2.5			2.9			2.9		
	14	3.2			2.5			2.9			2.9		
	15	3.2			2.5			2.9			2.9		
	16	3.2			2.5			2.9			2.9		
	17	3.2		5.0	2.5		5.0	2.9		4.0	2.9		4.7
	18	3.2			2.5			2.9			4.0		
	19	3.2			2.5			2.9			4.0		
	20	3.2			2.5			2.9			4.0		
	21	3.2			2.5			2.9			4.0		
	22	3.2			2.5			2.9			4.0		
	23	3.2			2.5			2.9			4.0		
	24	3.2			2.5			2.9			4.0		
	25	3.2	687.5		2.5	637.3		2.9	556.8		4.0	624.3	
	26	2.4			2.1			2.4			2.3		
	27	2.4			2.1			2.4			2.3		
	28	2.4			2.1			2.4			2.3		
	29	2.4			2.1			2.4			2.3		
	30	2.4			2.1			2.4			2.3		
Oct.	1	2.4			2.1			2.4			2.3		
	2	2.4			2.1			2.4			2.3		
	3	2.4			2.1			2.4			2.3		
	4	2.4			2.1			2.4			2.3		
	5	2.4			2.1			2.4			2.3		
	6	2.4	713.9		2.1	660.4		2.4	583.2		2.3	649.6	

Table A.1. (cont.) Daily maximum evapotranspiration (E_{tm}), cumulative E_{tm}, and precipitation for 3 sites at Fort Collins - 1977. All values are in millimeters. Precipitation values are for the period ending on the date they are recorded.

	Site 1			Site 2			Site 3			Average		
Date	Daily E_{tm}	Cum. E_{tm}	ppt	Daily E_{tm}	Cum. E_{tm}	ppt	Daily E_{tm}	Cum. E_{tm}	ppt	Daily E_{tm}	Cum. E_{tm}	ppt
Oct. 7	1.7			1.4			1.6			1.6		
8	1.7			1.4			1.6			1.6		
9	1.7			1.4			1.6			1.6		
10	1.7			1.4			1.6			1.6		
11	1.7			1.4			1.6			1.6		
12	1.7			1.4			1.6			1.6		
13	1.7			1.4			1.6			1.6		
14	1.7			1.4			1.6			1.6		
15	1.7			1.4			1.6			1.6		
16	1.7			1.4			1.6			1.6		
17	1.7	732.6		1.4	675.8		1.6	600.8		1.6	667.2	
18	2.2			1.2			2.8			2.1		
19	2.2			1.2			2.8			2.1		
20	2.2			1.2			2.8			2.1		
21	2.2			1.2			2.8			2.1		
22	2.2			1.2			2.8			2.1		
23	2.2			1.2			2.8			2.1		
24	2.2	748.0		1.2	684.2		2.8	620.4		2.2	681.9	
25	2.0			1.3			1.4			1.6		
26	2.0			1.3			1.4			1.6		
27	2.0			1.3			1.4			1.6		
28	2.0			1.3			1.4			1.6		
29	2.0			1.3			1.4			1.6		
30	2.0			1.3			1.4			1.6		
31	2.0	762.0		1.3	693.3		1.4	630.2		1.6	693.1	

Table A.2. Daily maximum evapotranspiration (E_{tm}), cumulative E_{tm}, and precipitation for 3 sites at **Fort Collins - 1978.** All values are in millimeters. Precipitation values are for the period ending on the date they are recorded.

Date		Site 1 Daily E_{tm}	Site 1 Cum. E_{tm}	Site 1 ppt	Site 2 Daily E_{tm}	Site 2 Cum. E_{tm}	Site 2 ppt	Site 3 Daily E_{tm}	Site 3 Cum. E_{tm}	Site 3 ppt	Average Daily E_{tm}	Average Cum. E_{tm}	Average ppt
May	30	3.97	4.0		3.81	3.8		2.15	2.2		3.31	3.3	
	31	3.97			3.81			2.15			3.31		
June	1	3.97	11.9	15.0	3.81	11.4	15.0	2.15	6.5	11.0	3.31	9.9	13.7
	2	0.46			0.46			1.80			0.91		
	3	0.46			0.46			1.80			0.91		
	4	0.46	13.3	tr	0.46	12.8	tr	1.80	11.9	1.0	0.91	12.7	0.3
	5	7.77			3.95			4.00			5.24		
	6	7.77	28.8	18.0	3.95	20.7	12.0	4.00	19.9	8.0	5.24	23.1	12.7
	7	2.65			5.86			3.54			4.02		
	8	2.65	34.1	7.0	5.86	32.4	12.0	3.54	26.9	9.0	4.02	31.2	9.3
	9	6.95			6.21			5.02			5.94		
	10	6.95			6.21			5.02			5.94		
	11	6.95	53.9		6.21	51.1		5.02	42.0		5.94	49.0	
	12	8.35			5.82			6.71			6.96		
	13	8.35	70.6		5.82	62.7		6.71	55.4		6.96	62.9	
	14	9.59			6.30			5.48			7.12		
	15	9.59	89.8		6.30	75.3		5.48	66.4		7.12	77.2	
	16	6.95			5.85			6.03			6.24		
	17	6.95			5.85			6.03			6.24		
	18	6.95	110.6		5.85	92.9		6.03	84.5		6.24	95.9	
	19	7.67			6.71			5.48			6.62		
	20	7.67	126.0		6.71	106.3		5.48	95.4		6.62	109.1	
	21	4.56			4.79			5.89			5.08		
	22	4.56	135.1		4.79	115.9		5.89	107.2		5.08	119.3	
	23	7.42			6.30			7.95			7.22		
	24	7.42			6.30			7.95			7.22		
	25	7.42	157.4		6.30	134.8		7.95	131.1		7.22	140.9	
	26	6.02			5.48			4.52			5.34		
	27	6.02	169.4		5.48	145.7		4.52	140.1		5.34	151.6	

Table A.2. (cont.) Daily maximum evapotranspiration (E_{tm}), cumulative E_{tm}, and precipitation for 3 sites at Fort Collins - 1978. All values are in millimeters. Precipitation values are for the period ending on the date they are recorded.

Date		Site 1			Site 2			Site 3			Average		
		Daily E_{tm}	Cum. E_{tm}	ppt	Daily E_{tm}	Cum. E_{tm}	ppt	Daily E_{tm}	Cum. E_{tm}	ppt	Daily E_{tm}	Cum. E_{tm}	ppt
June	28	8.11			5.92			4.32			6.12		
	29	8.11	185.6	7.5	5.92	157.6	5.0	4.32	148.7	10.0	6.12	163.9	7.5
	30	6.62			4.84			4.48			5.31		
July	1	6.62			4.84			4.48			5.31		
	2	6.62	205.5		4.84	172.1		4.48	162.2		5.31	179.8	
	3	9.82			6.30			8.05			8.06		
	4	9.82	225.1		6.30	184.7		8.05	178.3		8.06	195.9	
	5	6.70			6.13			3.04			5.29		
	6	6.70	238.5	6.0	6.13	196.9	15.0	3.04	184.4	7.0	5.29	206.5	9.3
	7	6.12			4.57			3.77			4.82		
	8	6.12			4.57			3.77			4.82		
	9	6.12	256.9		4.57	210.6		3.77	195.7		4.82	221.0	
	10	3.42			2.89			3.80			3.37		
	11	3.42	263.7	0.0	2.89	216.4	2.5	3.80	203.3	1.3	3.37	227.7	1.3
	12	6.49			5.98			5.29			5.92		
	13	6.49	276.7	1.0	5.98	228.4	1.0	5.29	213.8	1.0	5.92	239.5	1.0
	14	5.30			3.47			4.97			4.58		
	15	5.30			3.47			4.97			4.58		
	16	5.30	292.6	0.0	3.47	238.8	0.0	4.97	228.8	4.5	4.58	253.3	1.5
	17	5.99			6.44			5.34			5.92		
	18	5.99	304.6		6.44	251.7		5.34	239.4		5.92	265.1	
	19	4.66			3.42			4.24			4.11		
	20	4.66	313.9		3.42	258.5		4.24	247.9		4.11	273.3	
	21	5.39			4.84			4.38			4.87		
	22	5.39			4.84			4.38			4.87		
	23	5.39	330.1		4.84	273.0		4.38	261.1		4.87	287.9	
	24	8.43			5.61			5.34			6.46		
	25	8.43	346.9		5.61	284.3		5.34	271.7		6.46	300.9	
	26	7.36			5.89			6.68			6.64		

Table A.2. (cont.) Daily maximum evapotranspiration (E_{tm}), cumulative E_{tm}, and precipitation for 3 sites at Fort Collins - 1978. All values are in millimeters. Precipitation values are for the period ending on the date they are recorded.

	Site 1			Site 2			Site 3			Average		
Date	Daily E_{tm}	Cum. E_{tm}	ppt	Daily E_{tm}	Cum. E_{tm}	ppt	Daily E_{tm}	Cum. E_{tm}	ppt	Daily E_{tm}	Cum. E_{tm}	ppt
July 27	7.36	361.6		5.89	296.0		6.68	285.1		6.64	314.1	
28	6.33			1.86			3.59			2.93		
29	6.33			1.86			3.59			2.93		
30	6.33	380.6	20.0	1.86	301.6	7.5	3.59	295.9	5.0	2.93	322.9	10.8
31	4.63			6.02			6.57			5.74		
Aug. 1	4.63	389.9	3.6	6.02	313.7	5.0	6.57	309.0	3.8	5.74	334.4	4.1
2	3.95			2.26			2.84			3.02		
3	3.95	397.8	7.0	2.26	318.2	10.0	2.84	314.7	5.0	3.02	340.5	7.3
4	4.11			4.80			4.11			4.34		
5	4.11			4.80			4.11			4.34		
6	4.11	410.1	0.0	4.80	332.6	tr	4.11	327.0	tr	4.34	353.5	tr
7	6.33			4.93			5.65			5.64		
8	6.33	422.8		4.93	342.4		5.65	338.3		5.64	364.8	
9	5.99			3.94			6.41			5.45		
10	5.99	434.8	0.0	3.94	350.3	0.0	6.41	351.1	0.5	5.45	375.7	0.2
11	6.28			5.50			3.15			4.98		
12	6.28			5.50			3.15			4.98		
13	6.28	453.6	8.0	5.50	366.8	8.0	3.15	360.6	5.0	4.98	390.6	7.0
14	4.80			5.20			5.82			5.27		
15	4.80	463.2		5.20	377.2		5.82	372.2		5.27	401.1	
16	4.59			5.79			4.92			5.10		
17	4.59	472.4	2.0	5.79	388.8	2.0	4.92	382.1	0.8	5.10	411.3	1.6
18	4.79			3.66			3.81			4.09		
19	4.79			3.66			3.81			4.09		
20	4.79	486.8		3.66	399.8		3.81	393.5		4.09	423.6	
21	7.36			5.31			4.45			5.71		
22	7.36	501.5		5.31	410.4		4.45	402.4		5.71	435.0	
23	4.37			3.42			5.31			4.37		
24	4.37	510.2	13.0	3.42	417.2	0.0	5.31	413.0	0.0	4.37	443.8	4.3

Table A.2. (cont.) Daily maximum evapotranspiration (E_{tm}), cumulative E_{tm}, and precipitation for 3 sites at Fort Collins - 1978. All values are in millimeters. Precipitation values are for the period ending on the date they are recorded.

Date		Site 1 Daily E_{tm}	Site 1 Cum. E_{tm}	Site 1 ppt	Site 2 Daily E_{tm}	Site 2 Cum. E_{tm}	Site 2 ppt	Site 3 Daily E_{tm}	Site 3 Cum. E_{tm}	Site 3 ppt	Average Daily E_{tm}	Average Cum. E_{tm}	Average ppt
Aug.	25	6.40			4.40			2.38			4.39		
	26	6.40			4.40			2.38			4.39		
	27	6.40	529.4		4.40	430.4		2.38	420.2		4.39	456.9	
	28	3.63			2.09			6.20			3.97		
	29	3.63	536.7	12.0	2.09	434.6	10.0	6.20	421.4	2.0	3.97	464.9	8.0
	30	3.60			5.65			2.74			4.00		
	31	3.60	543.9		5.65	445.9		2.74	426.9		4.00	472.9	
Sept.	1	6.37			5.62			5.39			5.79		
	2	6.37			5.62			5.39			5.79		
	3	6.37			5.62			5.39			5.79		
	4	6.37	569.4		5.62	468.4		5.39	448.4		5.79	496.0	
	5	5.94			4.57			6.85			5.79		
	6	5.94			4.57			6.85			5.79		
	7	5.94	587.2		4.57	482.1		6.85	469.0		5.79	513.4	
	8	6.08			4.37			7.37			5.94		
	9	6.08			4.37			7.37			5.94		
	10	6.08			4.37			7.37			5.94		
	11	6.08	611.5		4.37	499.6		7.37	498.5		5.94	537.2	
	12	3.01			2.28			2.28			2.52		
	13	3.01			2.28			2.28			2.52		
	14	3.01			2.28			2.28			2.52		
	15	3.01			2.28			2.28			2.52		
	16	3.01			2.28			2.28			2.52		
	17	3.01	629.56		2.28	513.28		2.28	512.18		2.52	552.32	
	18	3.48			2.29			3.11			2.96		
	19	3.48			2.29			3.11			2.96		
	20	3.48			2.29			3.11			2.96		
	21	3.48			2.29			3.11			2.96		
	22	3.48			2.29			3.11			2.96		

Table A.2. (cont.) Daily maximum evapotranspiration (E_{tm}), cumulative E_{tm}, and precipitation for 3 sites at Fort Collins - 1978. All values are in millimeters. Precipitation values are for the period ending on the date they are recorded.

Date		Site 1 Daily E_{tm}	Site 1 Cum. E_{tm}	Site 1 ppt	Site 2 Daily E_{tm}	Site 2 Cum. E_{tm}	Site 2 ppt	Site 3 Daily E_{tm}	Site 3 Cum. E_{tm}	Site 3 ppt	Average Daily E_{tm}	Average Cum. E_{tm}	Average ppt
Sept	23	3.48			2.29			3.11			2.96		
	24	3.48			2.29			3.11			2.96		
	25	3.48	657.40		2.29	531.60		3.11	537.06		2.96	576.00	
	26	4.19			3.05			2.25			3.16		
	27	4.19			3.05			2.25			3.16		
	28	4.19			3.05			2.25			3.16		
	29	4.19			3.05			2.25			3.16		
	30	4.19			3.05			2.25			3.16		
Oct	1	4.19			3.05			2.25			3.16		
	2	4.19	686.73		3.05	552.95		2.25	552.81		3.16	598.12	
	3	2.87			2.55			1.92			2.43		
	4	2.87			2.55			1.92			2.43		
	5	2.87			2.55			1.92			2.43		
	6	2.87			2.55			1.92			2.43		
	7	2.87			2.55			1.92			2.43		
	8	2.87			2.55			1.92			2.43		
	9	2.87	706.82		2.55	570.80		1.92	566.25		2.43	615.13	
	10	3.72			1.72			2.03			2.49		
	11	3.72			1.72			2.03			2.49		
	12	3.72			1.72			2.03			2.49		
	13	3.72			1.72			2.03			2.49		
	14	3.72			1.72			2.03			2.49		
	15	3.72			1.72			2.03			2.49		
	16	3.72	732.86		1.72	582.84		2.03	580.46		2.49	632.56	

Table A.3. Daily maximum evapotranspiration (E_{tm}), cumulative E_{tm}, and precipitation for 3 sites at Northglenn - 1977. All values are in millimeters. Precipitation values are for the period ending on the date they are recorded.

Date		Site 1 Daily E_{tm}	Site 1 Cum. E_{tm}	Site 1 ppt	Site 2 Daily E_{tm}	Site 2 Cum. E_{tm}	Site 2 ppt	Site 3 Daily E_{tm}	Site 3 Cum. E_{tm}	Site 3 ppt	Average Daily E_{tm}	Average Cum. E_{tm}	Average ppt
July	28	8.2	8.2		6.9	6.9		7.1	7.1		7.4	7.4	
	29	8.2			6.9			7.1			7.4		
	30	8.2			6.9			7.1			7.4		
	31	8.2	32.8	5.3	6.9	27.6	0.0	7.1	28.4	0.0	7.4	29.6	1.8
Aug.	1	6.7			6.6			5.4			6.2		
	2	6.7			6.6			5.4			6.2		
	3	6.7	52.9		6.6	47.4		5.4	44.6		6.2	48.2	
	4	5.7			5.7			4.4			5.3		
	5	5.7			5.7			4.4			5.3		
	6	5.7			5.7			4.4			5.3		
	7	5.7	75.7	3.0	5.7	70.2	8.9	4.4	62.2	5.8	5.3	69.4	5.9
	8	5.1			4.2			3.7			4.3		
	9	5.1			4.2			3.7			4.3		
	10	5.1	91.0	3.5	4.2	82.8	3.8	3.7	73.3	1.5	4.3	82.3	2.9
	11	5.2			6.1			5.3			5.5		
	12	5.2			6.1			5.3			5.5		
	13	5.2			6.1			5.3			5.5		
	14	5.2	111.8		6.1	107.2		5.3	94.5		5.5	104.3	
	15	4.4			2.3			1.4			2.7		
	16	4.4			2.3			1.4			2.7		
	17	4.4	125.0	3.6	2.3	114.1	4.4	1.4	98.7	4.6	2.7	112.4	4.2
	18	4.1			4.4			3.8			4.1		
	19	4.1			4.4			3.8			4.1		
	20	4.1			4.4			3.8			4.1		
	21	4.1	141.4	1.3	4.4	131.7	1.3	3.8	113.8	0.8	4.1	128.8	1.1
	22	3.4			5.2			4.7			4.4		
	23	3.4			5.2			4.7			4.4		
	24	3.4	151.6	0.5	5.2	147.3	0.0	4.7	128.0	0.0	4.4	142.0	0.2
	25	6.4			6.6			5.4			6.1		

Table A.3. (cont.) Daily maximum evapotranspiration (E_{tm}), cumulative E_{tm}, and precipitation for 3 sites at Northglenn - 1977. All values are in millimeters. Precipitation values are for the period ending on the date they are recorded.

Date	Site 1			Site 2			Site 3			Average		
	Daily E_{tm}	Cum. E_{tm}	ppt	Daily E_{tm}	Cum. E_{tm}	ppt	Daily E_{tm}	Cum. E_{tm}	ppt	Daily E_{tm}	Cum. E_{tm}	ppt
Aug. 26	6.4			6.6			5.4			6.1		
27	6.4			6.6			5.4			6.1		
28	6.4	117.2	2.0	6.6	173.7	2.3	5.4	149.6	1.9	6.1	166.4	2.1
29	4.1			5.6			6.0			5.2		
30	4.1			5.6			6.0			5.2		
31	4.1	189.5		5.6	190.5		6.0	167.6		5.2	182.0	
Sept. 1	3.2			4.7			5.9			4.6		
2	3.2			4.7			5.9			4.6		
3	3.2			4.7			5.9			4.6		
4	3.2	202.3		4.7	209.3		5.9	191.2		4.6	200.4	
5	4.7			7.1			6.7			6.2		
6	4.7			7.1			6.7			6.2		
7	4.7	216.4		7.1	230.6		6.7	211.3		6.2	219.0	
8	1.9			3.8			4.1			3.3		
9	1.9			3.8			4.1			3.3		
10	1.9			3.8			4.1			3.3		
11	1.9	224.0		3.8	245.8		4.1	227.7		3.3	232.2	
12	5.2			5.4			4.0			4.9		
13	5.2			5.4			4.0			4.9		
14	5.2	239.6	1.3	5.4	262.0	1.8	4.0	228.9	1.0	4.9	246.9	1.4
15	4.0			3.9			4.2			4.0		
16	4.0			3.9			4.2			4.0		
17	4.0			3.9			4.2			4.0		
18	4.0	255.6		3.9	277.6		4.2	245.7		4.0	262.9	
19	5.1			5.3			6.2			5.5		
20	5.1			5.3			6.2			5.5		
21	5.1	270.9		5.3	293.5		6.2	264.3		5.5	277.3	
22	5.1			4.1			5.3			4.8		
23	5.1			4.1			5.3			4.8		

Table A.3 (cont.) Daily maximum evapotranspiration (E_{tm}), cumulative E_{tm}, and precipitation for 3 sites at Northglenn - 1977. All values are in millimeters. Precipitation values are for the period ending on the date they are recorded.

Date	Site 1			Site 2			Site 3			Average		
	Daily E_{tm}	Cum. E_{tm}	ppt	Daily E_{tm}	Cum. E_{tm}	ppt	Daily E_{tm}	Cum. E_{tm}	ppt	Daily E_{tm}	Cum. E_{tm}	ppt
Sept. 24	5.1			4.1			5.3			4.8		
25	5.1	291.3		4.1	309.9		5.3	285.5		4.8	296.5	
26	4.6			3.6			4.9			4.4		
27	4.6			3.6			4.9			4.4		
28	4.6	305.1		3.6	320.7		4.9	300.2		4.4	309.7	
29	4.6			3.5			3.5			3.9		
30	4.6			3.5			3.5			3.9		
Oct. 1	4.6			3.5			3.5			3.9		
2	4.6	323.5		3.5	334.7		3.5	314.2		3.9	325.3	
3	3.5			3.3			2.9			3.2		
4	3.5			3.3			2.9			3.2		
5	3.5	334.0	1.5	3.3	344.6	1.3	2.9	322.9	2.0	3.2	334.9	1.6
6	2.3			2.5			3.1			2.6		
7	2.3			2.5			3.1			2.6		
8	2.3			2.5			3.1			2.6		
9	2.3			2.5			3.1			2.6		
10	2.3			2.5			3.1			2.6		
11	2.3			2.5			3.1			2.6		
12	2.3	350.1	0.0	2.5	362.1	0.0	3.1	344.6	0.3	2.6	353.1	0.1
13	2.0			3.0			2.6			2.5		
14	2.0			3.0			2.6			2.5		
15	2.0			3.0			2.6			2.5		
16	2.0			3.0			2.6			2.5		
17	2.0			3.0			2.6			2.5		
18	2.0			3.0			2.6			2.5		
19	2.0	364.1		3.0	383.1		2.6	362.8		2.5	370.6	
20	2.5			1.3			3.0			2.3		
21	2.5			1.3			3.0			2.3		
22	2.5			1.3			3.0			2.3		

Table A.3. (cont.) Daily maximum evapotranspiration (E_{tm}), cumulative E_{tm}, and precipitation for 3 sites at Northglenn - 1977. All values are in millimeters. Precipitation values are for the period ending on the date they are recorded.

Date	Site 1 Daily E_{tm}	Site 1 Cum. E_{tm}	Site 1 ppt	Site 2 Daily E_{tm}	Site 2 Cum. E_{tm}	Site 2 ppt	Site 3 Daily E_{tm}	Site 3 Cum. E_{tm}	Site 3 ppt	Average Daily E_{tm}	Average Cum. E_{tm}	Average ppt
Oct. 23	2.5			1.3			3.0			2.3		
24	2.5			1.3			3.0			2.3		
25	2.5			1.3			3.0			2.3		
26	2.5	381.6		1.3	392.2		3.0	383.8		2.3	386.1	
27	1.9			2.6			2.1			2.2		
28	1.9			2.6			2.1			2.2		
29	1.9			2.6			2.1			2.2		
30	1.9			2.6			2.1			2.2		
31	1.9			2.6			2.1			2.2		
Nov. 1	1.9			2.6			2.1			2.2		
2	1.9	394.9		2.6	410.4		2.1	398.5		2.2	402.1	
3	1.6			1.2			2.0			1.6		
4	1.6			1.2			2.0			1.6		
5	1.6			1.2			2.0			1.6		
6	1.6			1.2			2.0			1.6		
7	1.6			1.2			2.0			1.6		
8	1.6			1.2			2.0			1.6		
9	1.6	406.1		1.2	418.8		2.0	412.5		1.6	413.3	
10	1.5			1.5			2.5			1.8		
11	1.5			1.5			2.5			1.8		
12	1.5			1.5			2.5			1.8		
13	1.5			1.5			2.5			1.8		
14	1.5			1.5			2.5			1.8		
15	1.5			1.5			2.5			1.8		
16	1.5	416.6		1.5	429.3		2.5	430.0		1.8	425.9	
17	0.6			0.6			0.7			0.6		
18	0.6			0.6			0.7			0.6		
19	0.6			0.6			0.7			0.6		
20	0.6			0.6			0.7			0.6		

Table A.3. (cont.) Daily maximum evapotranspiration (E_{tm}), cumulative E_{tm}, and precipitation for 3 sites at Northglenn - 1977. All values are in millimeters. Precipitation values are for the period ending on the date they are recorded.

	Site 1			Site 2			Site 3			Average		
Date	Daily E_{tm}	Cum. E_{tm}	ppt	Daily E_{tm}	Cum. E_{tm}	ppt	Daily E_{tm}	Cum. E_{tm}	ppt	Daily E_{tm}	Cum. E_{tm}	ppt
Nov. 21	0.6			0.6			0.7			0.6		
22	0.6			0.6			0.7			0.6		
23	0.6			0.6			0.7			0.6		
24	0.6			0.6			0.7			0.6		
25	0.6			0.6			0.7			0.6		
26	0.6			0.6			0.7			0.6		
27	0.6			0.6			0.7			0.6		
28	0.6			0.6			0.7			0.6		
29	0.6			0.6			0.7			0.6		
30	0.6			0.6			0.7			0.6		
Dec. 1	0.6			0.6			0.7			0.6		
2	0.6			0.6			0.7			0.6		
3	0.6			0.6			0.7			0.6		
4	0.6			0.6			0.7			0.6		
5	0.6			0.6			0.7			0.6		
6	0.6			0.6			0.7			0.6		
7	0.6			0.6			0.7			0.6		
8	0.6			0.6			0.7			0.6		
9	0.6			0.6			0.7			0.6		
10	0.6			0.6			0.7			0.6		
11	0.6			0.6			0.7			0.6		
12	0.6			0.6			0.7			0.6		
13	0.6			0.6			0.7			0.6		
14	0.6			0.6			0.7			0.6		
15	0.6	434.0		0.6	446.7		0.7	450.3		0.6	443.3	
16	0.9			0.6			1.3			0.9		
17	0.9			0.6			1.3			0.9		
18	0.9			0.6			1.3			0.9		
19	0.9			0.6			1.3			0.9		

Table A.3. (cont.) Daily maximum evapotranspiration (E_{tm}), cumulative E_{tm}, and precipitation for 3 sites at **Northglenn - 1977.** All values are in millimeters. Precipitation values are for the period ending on the date they are recorded.

	Site 1			Site 2			Site 3			Average		
Date	Daily E_{tm}	Cum. E_{tm}	ppt	Daily E_{tm}	Cum. E_{tm}	ppt	Daily E_{tm}	Cum. E_{tm}	ppt	Daily E_{tm}	Cum. E_{tm}	ppt
Dec. 20	0.9			0.6			1.3			0.9		
21	0.9			0.6			1.3			0.9		
22	0.9	439.4		0.6	450.3		1.3	458.1		0.9	448.7	

Table A.4. Daily maximum evapotranspiration (E_{tm}), cumulative E_{tm}, and precipitation for 3 sites at Northglenn - 1978. All values are in millimeters. Precipitation values are for the period ending on the date they are recorded.

Date	Site 1 Daily E_{tm}	Site 1 Cum. E_{tm}	Site 1 ppt	Site 2 Daily E_{tm}	Site 2 Cum. E_{tm}	Site 2 ppt	Site 3 Daily E_{tm}	Site 3 Cum. E_{tm}	Site 3 ppt	Average Daily E_{tm}	Average Cum. E_{tm}	Average ppt
May 30				1.27	1.3		1.60	1.6		1.44	1.4	
31				1.27			1.60			1.44		
June 1			15.0	1.27	3.8	14.0	1.60	4.8	13.0	1.44	4.3	14.0
2				1.14			1.38			1.26		
3				1.14			1.38			1.26		
4			15.0	1.14	7.2	13.0	1.38	8.9	11.0	1.26	8.1	13.0
5				3.78			4.06			3.92		
6		15.9	1.0	3.78	14.8	1.0	4.06	17.1	1.0	3.92	15.9	1.0
7	5.24			4.33			6.25			5.27		
8	5.24	26.4	2.0	4.33	23.5	1.0	6.25	29.6	1.0	5.27	26.4	1.3
9	7.20			5.66			4.91			5.92		
10	7.20			5.66			4.91			5.92		
11	7.20	48.0		5.66	40.4		4.91	44.3		5.92	44.2	
12	7.35			7.88			5.02			6.75		
13	7.35	62.7		7.88	56.2		5.02	54.3		6.75	57.7	
14	7.02			6.03			5.14			6.06		
15	7.02	76.7		6.03	68.3		5.14	64.6		6.06	69.7	
16	6.70			7.64			4.80			6.38		
17	6.70			7.64			4.80			6.38		
18	6.70	96.8	tr	7.64	91.2	1.0	4.80	79.0	0.0	6.38	89.0	0.3
19	6.85			6.85			5.75			6.48		
20	6.85	110.5		6.85	104.9		5.75	90.5		6.48	101.9	
21	7.36			5.14			5.82			6.11		
22	7.36	125.2		5.14	115.2		5.82	102.2		6.11	114.2	
23	6.09			7.88			4.68			6.22		
24	6.09			7.88			4.68			6.22		
25	6.09	143.5		7.88	138.8		4.68	116.2		6.22	132.8	
26	6.68			4.52			4.80			5.33		
27	6.68	156.9		4.52	147.8		4.80	125.8		5.33	143.5	

Table A.4 (cont.) Daily maximum evapotranspiration (E_{tm}), cumulative E_{tm}, and precipitation for 3 sites at **Northglenn - 1978.** All values are in millimeters. Precipitation values are for the period ending on the date they are recorded.

	Site 1			Site 2			Site 3			Average		
Date	Daily E_{tm}	Cum. E_{tm}	ppt	Daily E_{tm}	Cum. E_{tm}	ppt	Daily E_{tm}	Cum. E_{tm}	ppt	Daily E_{tm}	Cum. E_{tm}	ppt
28	5.38			4.72			4.65			4.92		
29	5.38	167.6	7.0	4.72	157.3	5.0	4.65	135.1	2.7	4.92	153.3	4.9
30	5.50			6.21			3.88			5.20		
July 1	5.50			6.21			3.88			5.20		
2	5.50	184.1		6.21	175.9		3.88	146.7		5.20	168.9	
3	9.13			12.47			8.56			10.05		
4	9.13	202.4		12.47	200.8		8.56	163.9		10.05	189.0	
5	4.18			4.55			3.58			4.10		
6	4.18	210.8	7.0	4.55	209.9	8.0	3.58	171.0	14.0	4.10	197.2	9.7
7	6.24			6.42			6.00			6.22		
8	6.24			6.42			6.00			6.22		
9	6.24	229.5	2.0	6.42	229.2	2.0	6.00	189.0	1.0	6.22	215.9	1.7
10	8.14			6.97			6.53			7.21		
11	8.14	245.8	6.0	6.97	243.1	6.0	6.53	202.1	4.5	7.21	230.3	5.5
12	6.84			5.48			4.34			5.55		
13	6.84	259.4		5.48	254.1		4.34	210.8		5.55	241.4	
14	7.19			8.59			6.55			7.44		
15	7.19			8.59			6.55			7.44		
16	7.19	280.7		8.59	279.9		6.55	230.4		7.44	263.7	
17	5.80			7.35			5.65			6.27		
18	5.80	292.3	1.0	7.35	294.6	1.0	5.65	241.7	tr	6.27	276.2	0.7
19	3.28			5.93			4.96			4.72		
20	3.28	298.9		5.93	306.4		4.96	251.6		4.72	285.7	
21	4.54			6.17			6.05			5.59		
22	4.54			6.17			6.05			5.59		
23	4.54	312.5	1.3	6.17	324.9	0.0	6.05	269.8	0.0	5.59	302.5	0.4
24	3.94			7.02			6.68			5.88		
25	3.94	320.4		7.02	339.0		6.68	283.1		5.88	314.2	

Table A.4. (cont.) Daily maximum evapotranspiration (E_{tm}), cumulative E_{tm}, and precipitation for 3 sites at Northglenn - 1978. All values are in millimeters. Precipitation values are for the period ending on the date they are recorded.

Date	Site 1 Daily E_{tm}	Site 1 Cum. E_{tm}	Site 1 ppt	Site 2 Daily E_{tm}	Site 2 Cum. E_{tm}	Site 2 ppt	Site 3 Daily E_{tm}	Site 3 Cum. E_{tm}	Site 3 ppt	Average Daily E_{tm}	Average Cum. E_{tm}	Average ppt
July 26	3.08			7.70			6.16			5.65		
27	3.08	326.5		7.70	354.4		6.16	295.5		5.65	325.5	
28	4.32			4.05			8.74			5.66		
29	4.32			4.05			8.74			5.66		
30	4.32	339.5	2.0	4.05	366.5	2.0	8.74	321.7	18.0	5.66	342.5	7.3
31	4.95			7.86			4.42			5.74		
Aug. 1	4.95	349.4	1.0	7.86	382.3	1.0	4.42	330.5	1.0	5.74	354.0	1.0
2	3.39			1.92			3.37			2.89		
3	3.39	356.2	12.6	1.92	386.1	10.0	3.37	337.3	5.0	2.89	359.8	9.2
4	5.68			6.44			4.50			5.54		
5	5.68			6.44			4.50			5.54		
6	5.68	373.2	1.3	6.44	405.4	1.5	4.50	350.8	1.5	5.54	276.4	1.4
7	5.02			7.25			3.42			5.23		
8	5.02	383.2	0.8	7.25	419.9	0.8	3.42	357.6		5.23	386.8	
9	4.45			4.11			5.71			4.76		
10	4.45	392.1		4.11	428.1		5.71	369.0		4.76	396.4	
11	5.47			6.38			5.47			5.77		
12	5.47			6.38			5.47			5.77		
13	5.47	408.6	1.0	6.38	447.3	1.0	5.47	385.4	1.0	5.77	413.7	1.0
14	7.83			6.68			5.48			6.66		
15	7.83	424.2		6.68	460.6		5.48	396.4		6.66	427.0	
16	2.38			6.01			3.83			4.06		
17	2.38	429.0	9.0	6.01	472.7	3.8	3.83	404.0	1.5	4.06	333.1	4.8
18	3.29			6.67			4.00			4.65		
19	3.29			6.67			4.00			4.65		
20	3.29	438.8		6.67	492.7		4.00	416.0		4.65	449.1	
21	3.94			5.99			4.45			4.79		
22	3.94	446.7		5.99	504.6		4.45	424.9		4.79	458.6	
23	3.88			3.70			3.94			3.84		

Table A.4. (cont.) Daily maximum evapotranspiration (E_{tm}), cumulative E_{tm}, and precipitation for 3 sites at Northglenn - 1978. All values are in millimeters. Precipitation values are for the period ending on the date they are recorded.

	Site 1			Site 2			Site 3			Average		
Date	Daily E_{tm}	Cum. E_{tm}	ppt	Daily E_{tm}	Cum. E_{tm}	ppt	Daily E_{tm}	Cum. E_{tm}	ppt	Daily E_{tm}	Cum. E_{tm}	ppt
Aug. 24	3.88	454.4		3.70	512.0		3.94	432.8		3.84	466.3	
25	5.82			6.94			5.21			5.99		
26	5.82			6.94			5.21			5.99		
27	5.82	471.9		6.94	532.9		5.21	448.5		5.99	484.3	
28	0.82			5.67			4.29			3.59		
29	0.82	473.6	12.6	5.67	544.2	11.0	4.29	457.0	5.5	3.59	491.5	9.7
30	6.85			3.83			5.48			5.39		
31	6.85	487.3		3.83	551.9		5.48	468.0		5.39	502.2	
Sept 1	4.28			4.66			4.28			4.41		
2	4.28			4.66			4.28			4.41		
3	4.28			4.66			4.28			4.41		
4	4.28	504.4		4.66	570.5		4.28	485.1		4.41	519.9	

Table A-5 Lot area, vegetated area, year of home construction, assessed valuation, seasonal irrigation, application rate, average and minimum lawn quality rating for the home sites in Fort Collins.

Home No.	Lot Area M^2	Veg. Area M^2	Year	Value $	Irrig. mm/day 1977	Irrig. mm/day 1978	Quality Rating 1977 Ave	Quality Rating 1977 Min	Quality Rating 1978 Ave	Quality Rating 1978 Min
1	774	585	1958	8,380	6.8	5.1	7.6	7.0	8.0	7.5
2	994	720	1958	10,130	5.3	5.0	7.3	7.0	7.8	7.0
3	616	447	1957	7,500	8.9	12.2	6.8	5.5	7.5	7.0
4	1452	1131	1957	11,720	2.4	3.3	6.4	5.5	6.8	6.0
5	616	444	1956	7,130	5.1	2.6	7.2	6.5	6.8	6.0
6	912	643	1971	11,880	5.3	6.9	8.1	7.5	8.9	8.5
7	1013	724	1968	11,080	8.8	7.1	8.9	8.5	8.0	7.5
8	1272	927	1971	12,890	4.1	3.7	7.5	7.0	7.3	6.0
9	1037	733	1968	11,510	3.0	4.1	6.6	6.0	7.8	7.0
10	1093	838	1971	12,440	5.3	6.4	7.8	7.0	7.2	6.5
11	1260	928	1971	9,690	4.4	4.5	7.7	6.5	7.0	6.0
12	759	515	1961	10,120	5.0	5.0	6.9	6.0	7.4	6.5
13	759	553	1960	8,600	4.0	7.9	7.1	7.0	7.8	7.0
14	927	646	1965	9,770	4.4	5.3	7.7	7.0	7.8	7.0
15	748	521	1965	9,900	5.9	6.7	6.7	5.5	7.7	6.5
16	748	526	1965	9,920	5.2	12.3	7.2	6.0	6.8	6.0
17.	927	520	1966	10,050	2.9	5.2	7.6	7.0	7.5	6.5
18	2118	1609	1964	17,680	3.2	6.5	7.2	6.5	6.6	6.0
19	2118	1762	1966	14,830	4.5	4.6	7.8	7.5	7.6	7.0
20	960	613	1968	11,760	5.1	6.3	9.8	9.0	8.9	8.0
21	995	726	1969	12,540	3.9	5.0	6.3	6.0	7.3	7.0
22	894	640	1970	10,640	4.4	5.0	7.9	7.0	7.8	7.0
23	762	526	1925	7,480	5.6	4.3	7.3	6.0	7.0	6.0
24	762	545	1902	4,610	5.3	7.3	6.8	6.0	6.7	6.5
25	715	347	1910	9,110	5.0	6.3	7.9	7.5	8.1	7.5
26	697	353	1905	8,370	8.5		6.9	6.0		
27	780	503	1910	3,280	4.8	7.8	6.5	5.5	7.6	7.0

Table A.6 Lot area, vegetated area, year of home construction, assessed valuation, seasonal irrigation application rates, average and minimum lawn quality ratings for the home sites in Northglenn.

Home No.	Lot Area M^2	Veg. Area M^2	Year	Value $	Irrig. mm/day		Quality Rating			
							1977		1978	
					1977	1978	Ave	Min	Ave	Min
1	913	772	1970	7,660	4.0	2.9	6.3	5.0	6.5	5.0
2	944	765	1970	7,630	3.5	3.5	6.8	6.0	7.2	7.0
3	974	689	1968	6,940	2.6	4.8	4.7	4.0	7.6	7.0
4	968	741	1969	6,370	5.5	5.9	7.7	6.5	8.2	7.0
5	1159	805	1970	7,770	3.6	4.7	6.8	5.5	8.0	7.5
6	917	619	1970	7,690	3.2	4.0	7.1	6.0	8.3	8.0
7	1979	1784	1964	7,200	0.3	0.2	3.3	2.5	5.8	4.0
8	973	759	1965	7,480	2.4	5.6	5.1	3.5	8.4	6.0
9	893	693	1965	6,600	3.1	2.7	6.2	4.5	7.0	6.0
10	893	613	1965	6,750	4.7	5.8	7.9	6.5	8.3	8.0
11	957	688	1964	7,420	3.8	3.9	7.1	6.5	7.8	7.0
12	893	603	1965	6,160	2.3	4.3	5.2	4.0	7.0	6.5
13	1064	808	1964	8,690	2.2	3.9	5.3	4.0	7.4	6.5
14	1059	763	1964	8,390	2.6	2.2	3.7	3.0	5.4	4.0
15	980	616	1964	8,040	2.6	3.1	6.2	4.5	7.0	6.0
16	961	746	1964	8,320	2.7	5.6	5.9	4.5	7.0	5.5
17	1042	751	1964	7,730	3.1	3.4	6.0	4.5	7.2	6.5
18	1042	715	1964	7,220	2.7	2.9	5.3	4.0	6.4	5.5
19	744	520	1967	6,630	6.1	4.9	7.1	6.5	7.2	6.5
20	694	526	1967	5,860	1.5	1.5	4.3	3.0	4.9	3.0
21	694	540	1967	6,300	2.9	4.0	6.5	5.5	7.1	6.5
22	743	542	1966	6,780	4.2	5.5	5.9	5.5	7.5	7.0
23	743	533	1966	6,690	2.7	3.7	5.3	4.0	6.7	5.5
24	777	544	1967	5,590	3.1	3.8	6.4	5.0	6.7	5.5
25	709	487	1962	6,180	3.3	5.6	6.3	5.5	7.2	7.0
26	662	480	1962	5,810	1.5	1.7	5.1	4.0	6.0	4.0
27	662	543	1962	5,130	2.7	3.3	5.2	4.5	6.6	6.0
28	662	386	1962	5,880	4.4	6.0	6.4	5.5	7.2	7.0
29	662	422	1962	6,360	4.0	6.0	5.2	4.5	7.7	7.0
30	893	679	1962	7,900	3.7	4.7	6.9	6.0	7.7	7.0

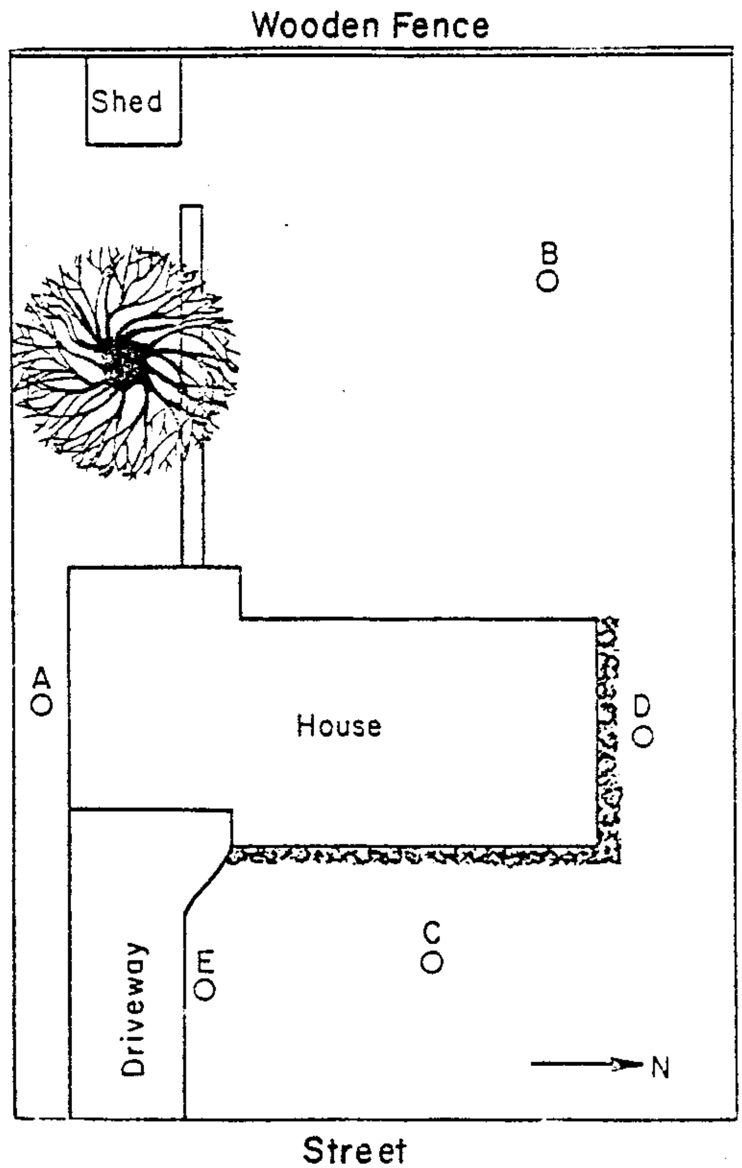

Figure A.1 Diagram of homesite No. 1, Fort Collins, showing lysimeter locations with respect to improvements on the lot.

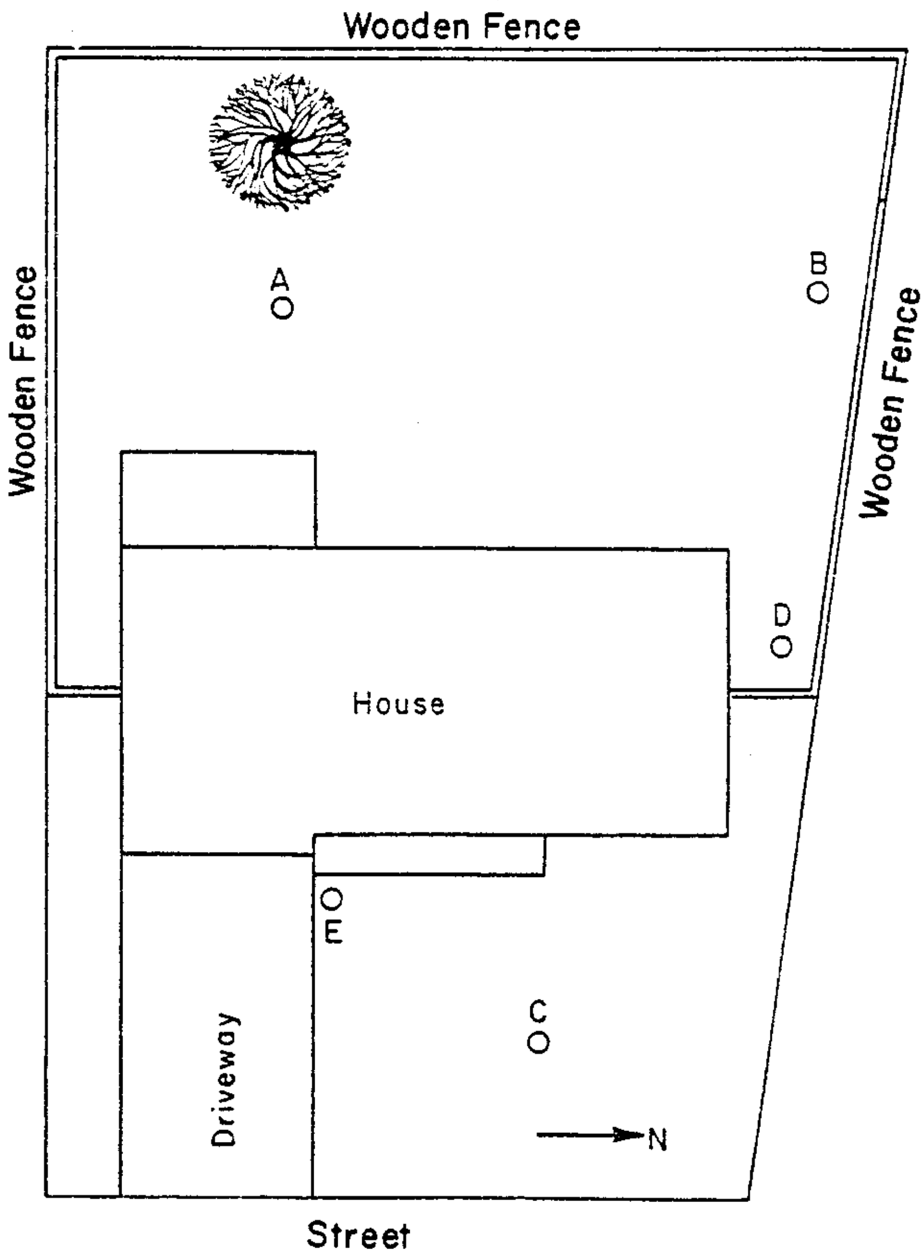

Figure A.2 Diagram of homesite No. 2, Fort Collins, showing lysimeter locations with respect to improvements on the lot.

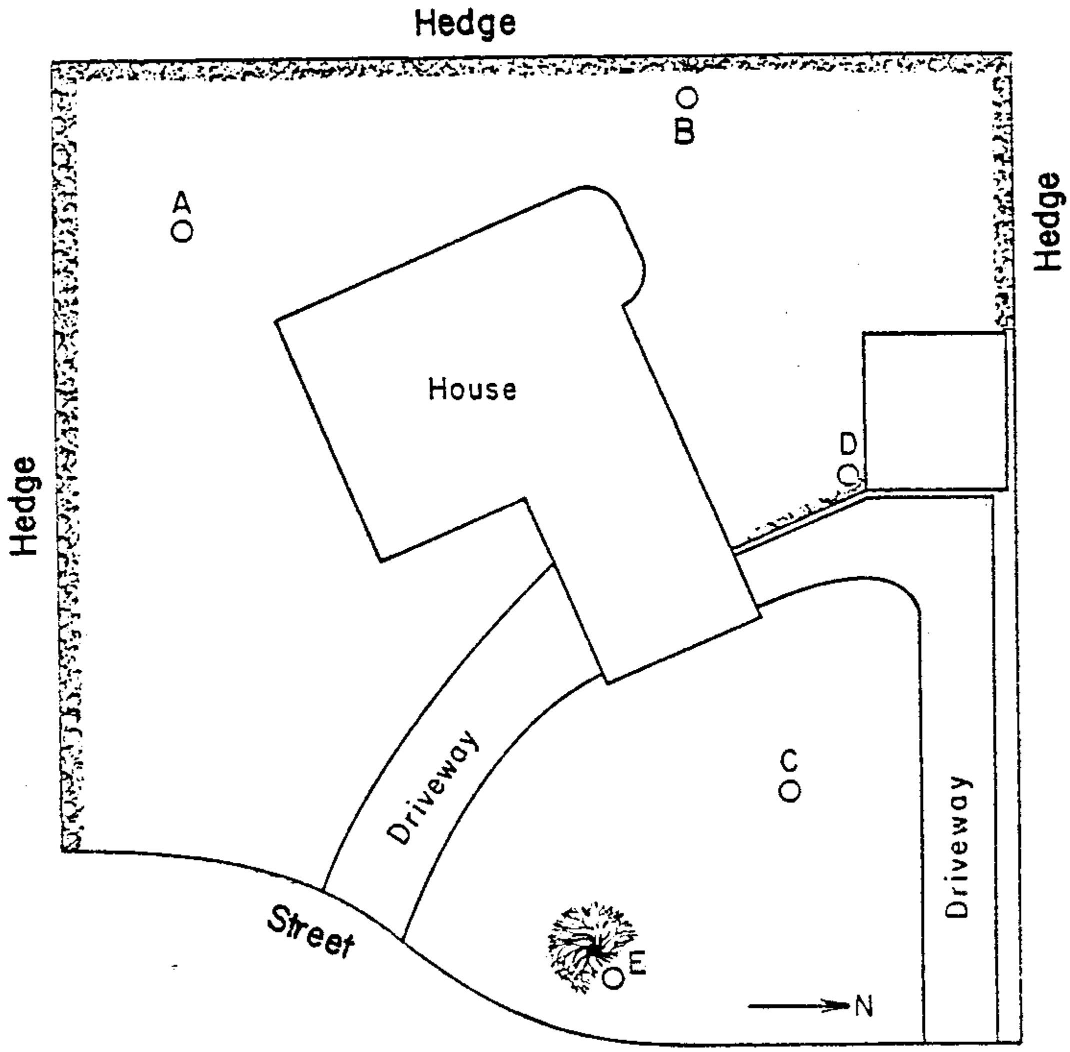

Figure A.3 Diagram of homesite No. 3, Fort Collins, showing lysimeter locations with respect to improvements on the lot.

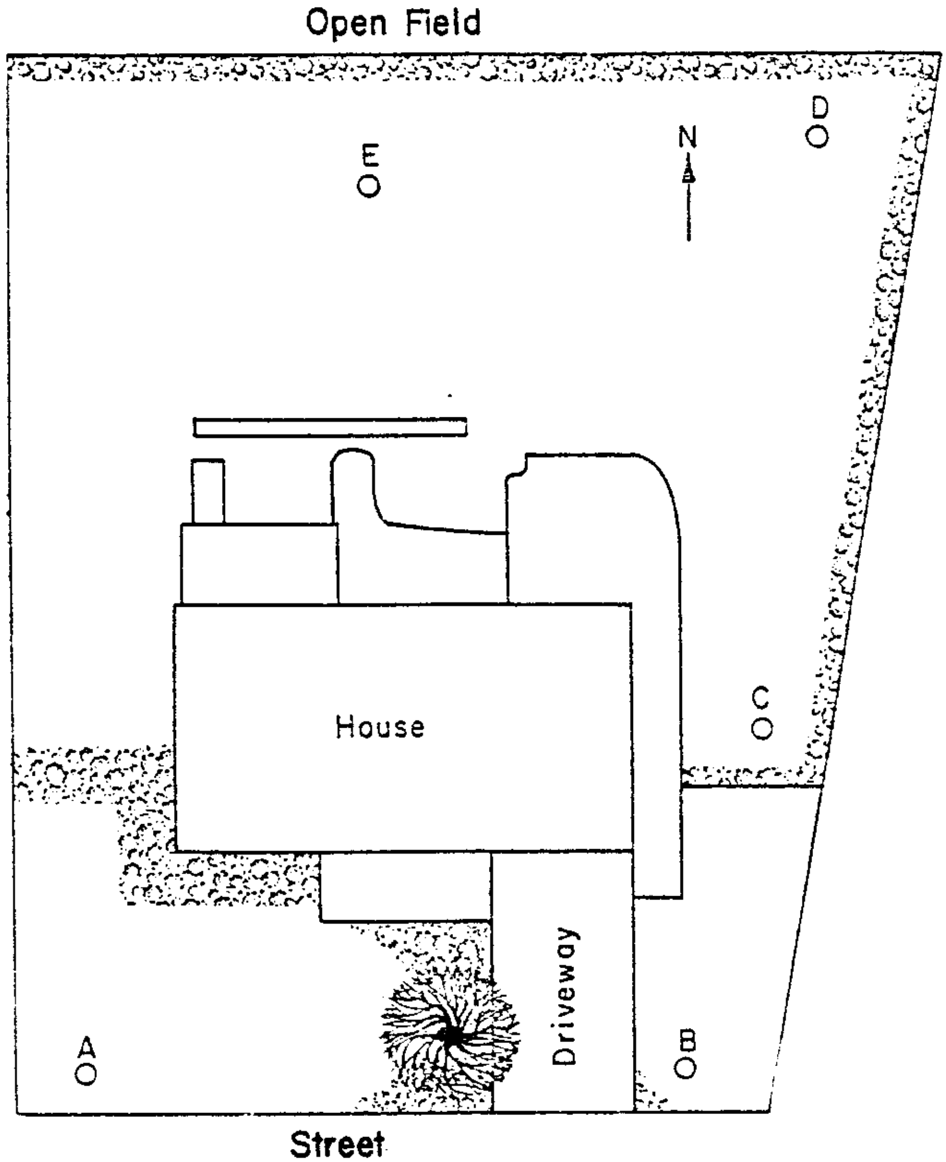

Figure A.4 Diagram of homesite No. 1, Northglenn, showing lysimeter locations with respect to improvements on the lot.

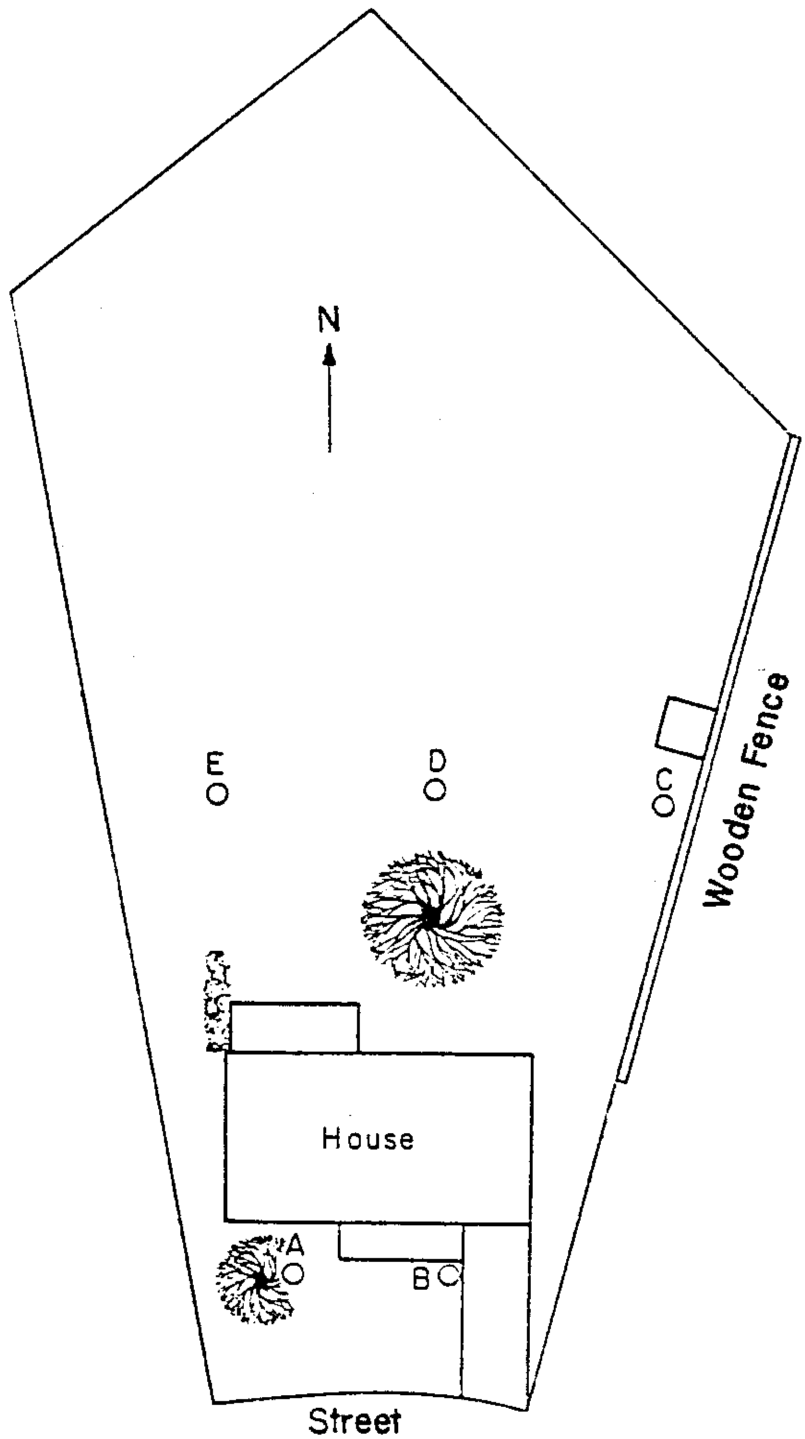

Figure A.5 Diagram of homesite No. 2, Northglenn, showing lysimeter locations with respect to improvements on the lot.

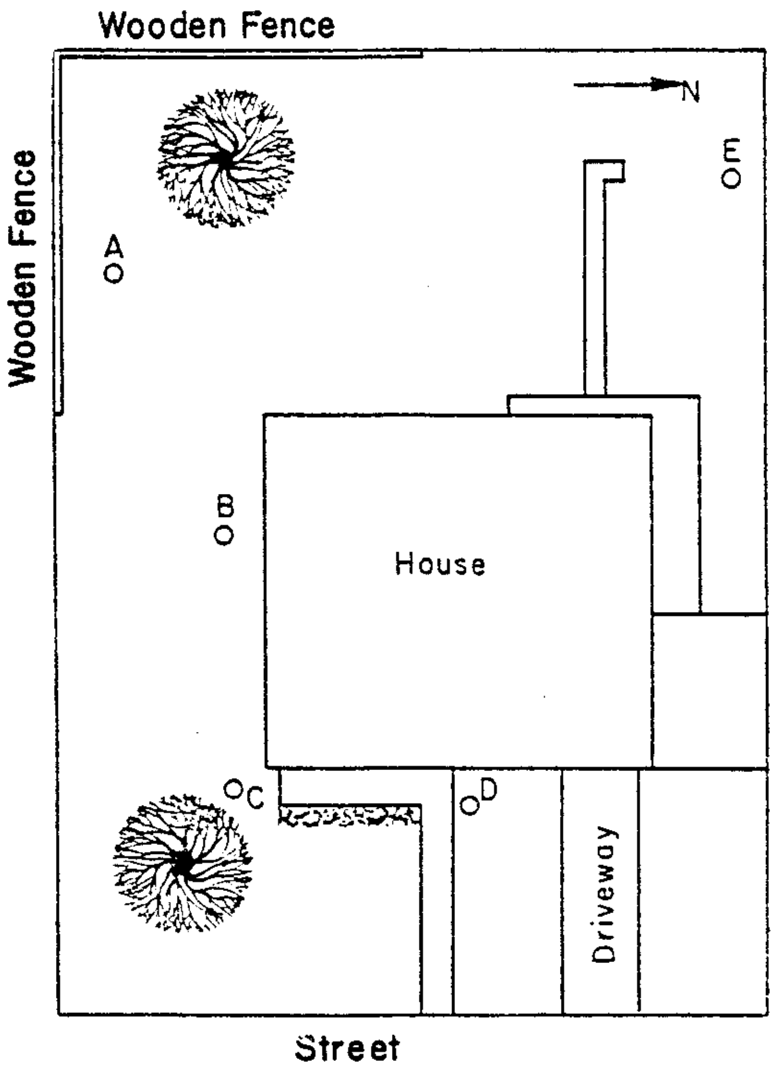

Figure A.6 Diagram of homesite No. 3, Northglenn, showing lysimeter locations with respect to improvements on the lot.

WATER REQUIREMENTS
FOR
URBAN LAWNS

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September 1979

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TABLE OF CONTENTS

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-fesque 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.

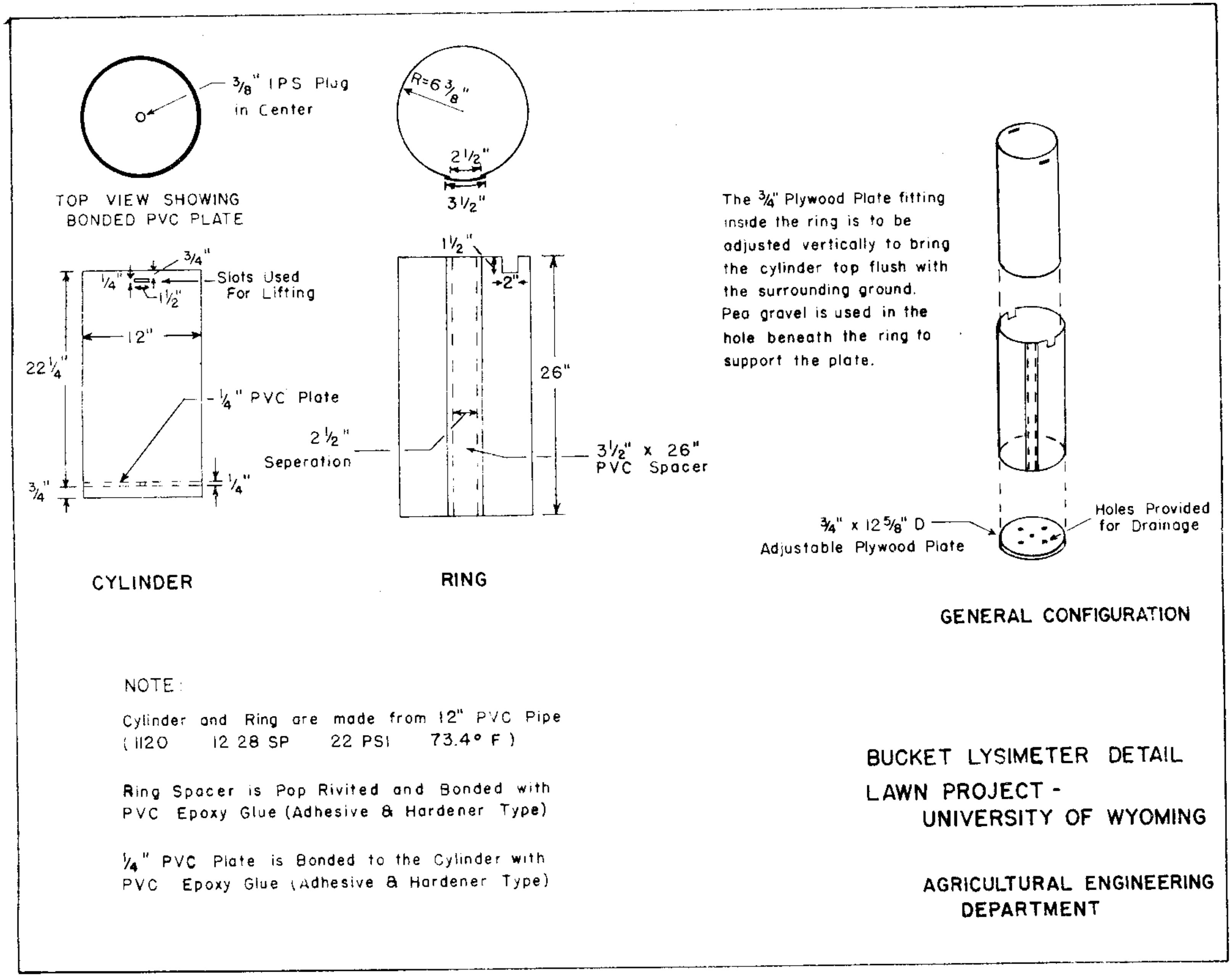

Fig. 2.1 Lysimeter Detail

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)

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

t = mean temperature for the period (°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)

$F = \Sigma f$, 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 (°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

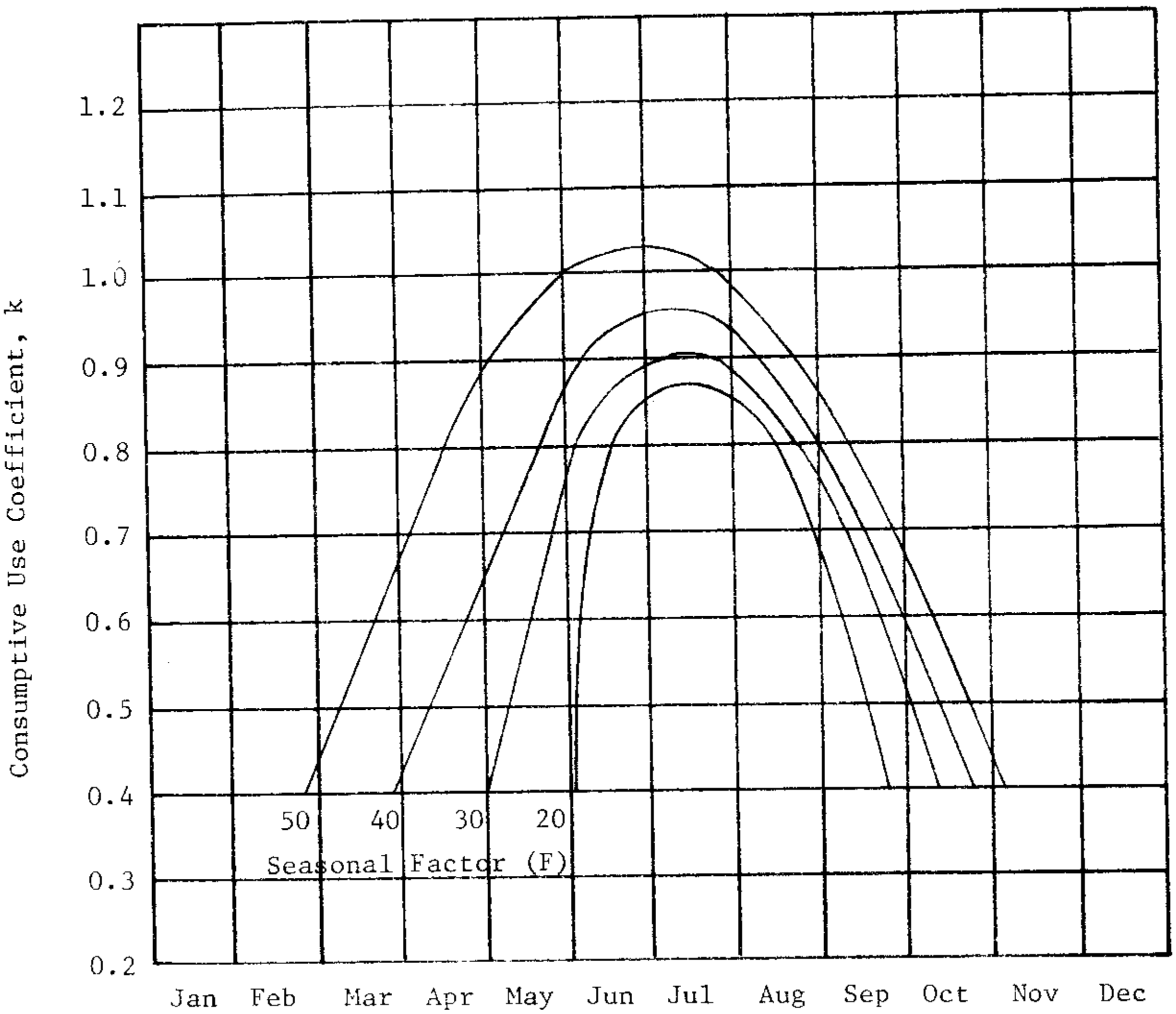

Fig. 2.2. Consumptive use coefficients for grass, hay and pasture (Criddle et al., 1962)

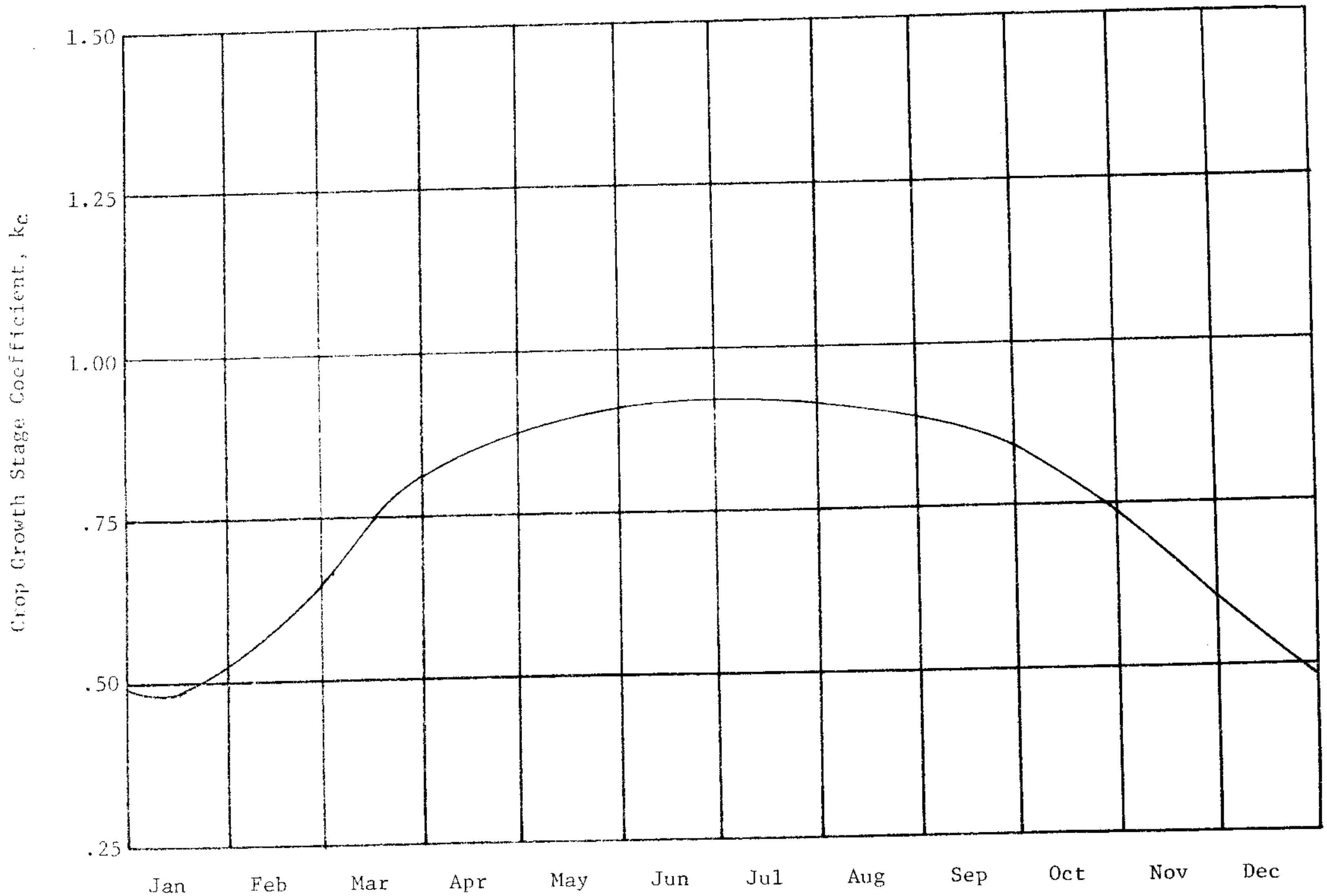

Fig. 2.3. Crop growth stage coefficient curve for pasture grasses (SCS, 1967)

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 semidormant condition during hot weather (Billick, 1973). When in this semidormant 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 considably 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_{crid})

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

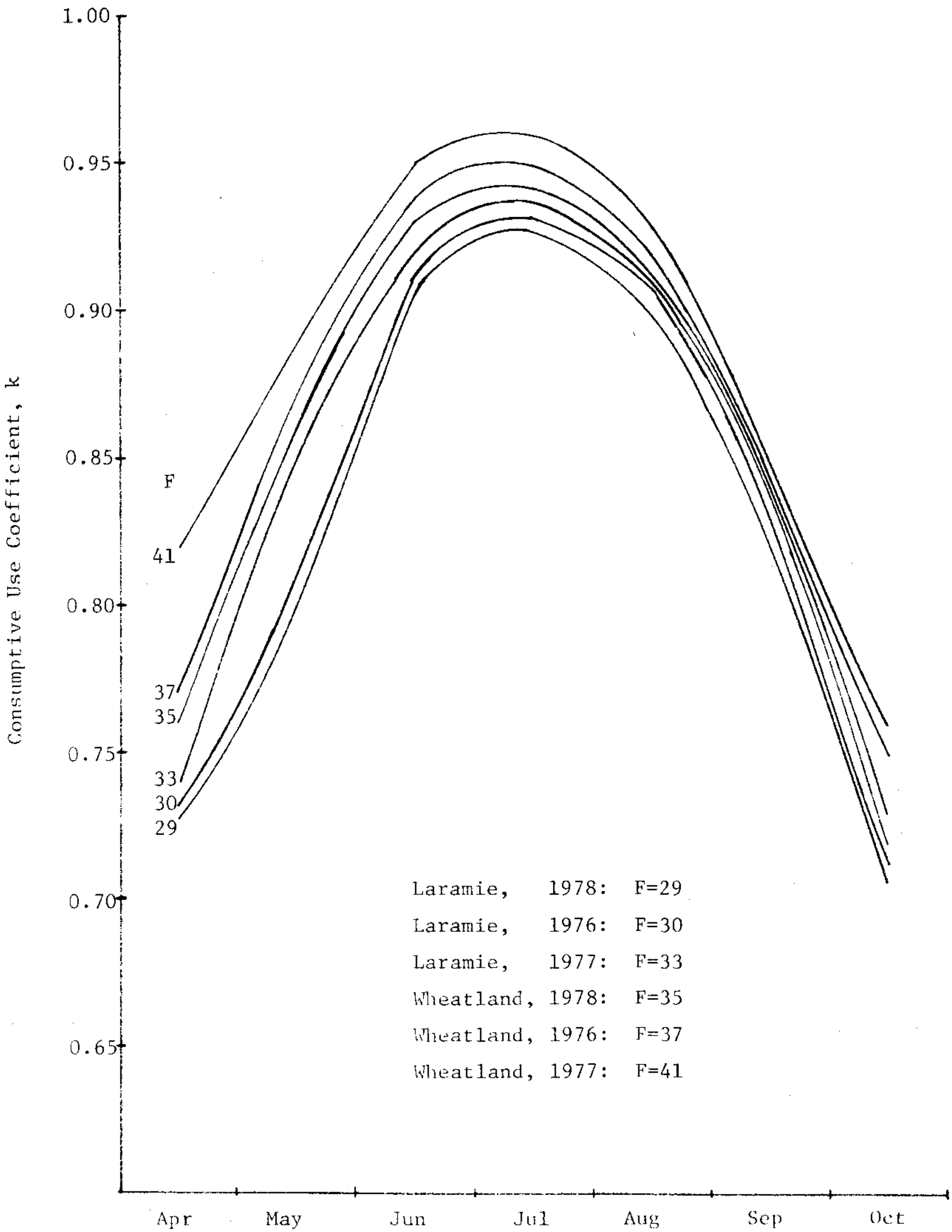

Fig. 2.4. Calibrated consumptive use coefficients for the Criddle formula

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 consumtive 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:

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

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 SCS Estimates	Laramie Calibrated Estimates	Laramie Measured 1978	Wheatland SCS Estimate	Wheatland Calibrated Estimated	Wheatland 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 Criddle Estimate	Laramie Calibrated Estimate	Laramie Measured 1978	Wheatland Criddle Estimate	Wheatland Calibrated Estimate	Wheatland 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)	House-hold 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)	House-hold (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)	House-hold 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)	House-hold (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)	House-hold 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)	House-hold (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)	House-hold 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)	House-hold (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

* 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 (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)

	Laramie Water Depth Applied** (cm/day)					Wheatland Water Depth Applied (cm/day)			
Home ††	1976*	1977*	1978*	3-Year Average	Home ††	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)

	Laramie					Wheatland			
	Average Appearance Rating*					Average Appearance Rating*			
Home †	1976	1977	1978	3-Year Average	Home †	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.

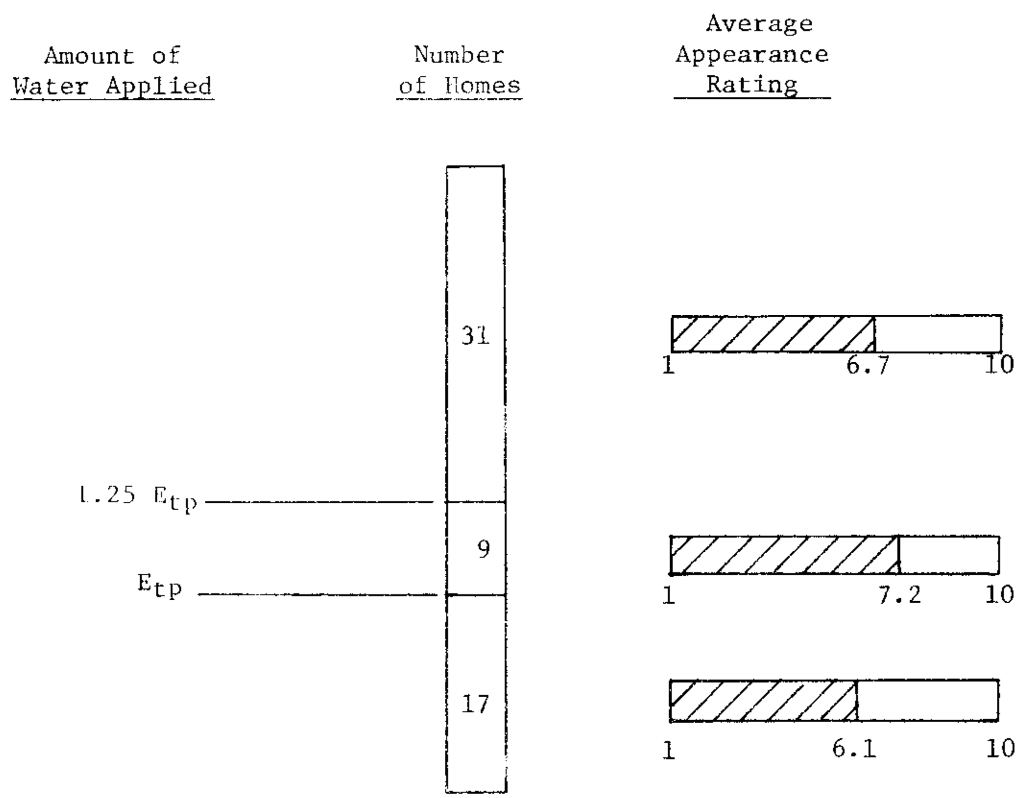

Figure 3.1. Comparison of amount of water applied and lawn appearance.

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

Laramie

House No.	Summer 1976	Summer 1977	Summer 1978	Winter 1976-77	Winter 1977-78	Averages Summer	Averages 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 1976	Summer 1977	Summer 1978	Winter 1976-77	Winter 1977-78	Averages Summer	Averages 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.

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

<u>Overwatering and Deep Percolation</u>

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 percolation. 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 m^2 per home, and the growing season was 140 days, then the volume of overwatering would be about 2.3 x 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 NO_3-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 NO_3-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).

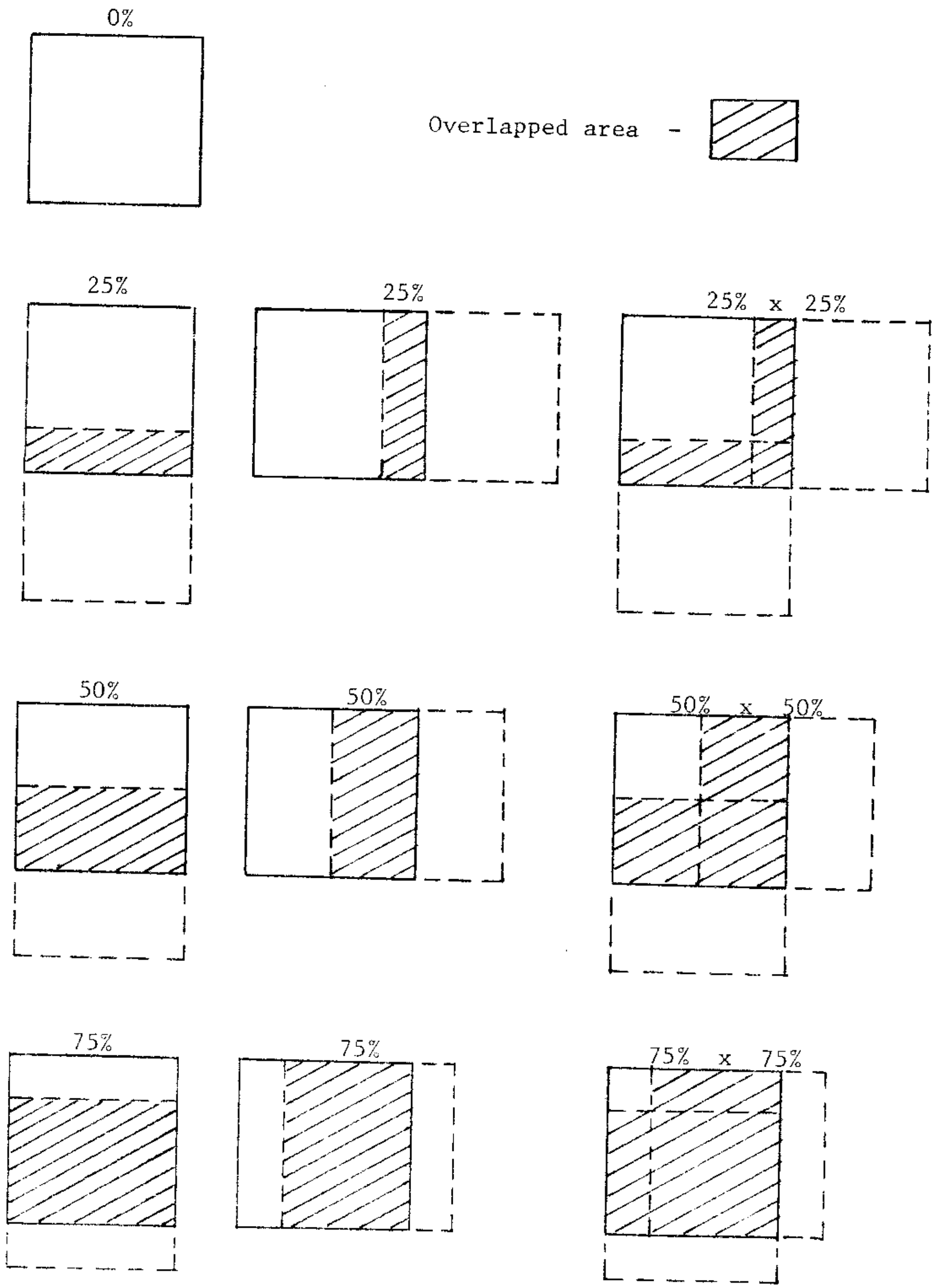

Fig. 4.1. Overlaps used for calculating UCC's.

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 presures, 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

		Overlaps													
		0%		25%		50%		75%		25% X 25%		50% X 50%		75% X 75%	
Source	d.f.	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	Overlaps						
	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

Sprinkler type	Pressure (kPa)	OVERLAPS 0%	25%	50%	75%	25% X 25%	50% X 50%	75% X 75%
Means of all Non-Traveling	69	.22	.30	.47	.58	.39	.65	.85
	138	.35	.41	.54	.66	.49	.69	.90
	207	.38	.49	.56	.65	.60	.75	.93
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

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

Pressure (kPa)	Overlap* 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
Oscilating	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 desseminated 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 evoporation 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

PERSONNEL

Principal Investigators

Pochop, Larry O.	Agricultural Engineering
Borrelli, John	Agricultural Engineering

Graduate Students

Barnes, John R.
O'Neill, Patrick K.
Kerr, Greg L.
Brizuela, Connie

Consultant

Anderson, Donald A.	Statistics

Student Assistants

Sanders, John
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)

	Name	Address	Years Sampled
	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)

	Name	Address	Years Sampled
1.	Pitcher, Warren	1450 Mitchell	(1975-1978)
** 2.	Wakkuri, Myron	1356 Mitchell	(1975-1978)
3.	Dent, George	73 13th	(1975-1978)
5.	Nicholson, Lowella	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

CALIBRATION PROCEDURES FOR BLANEY-CRIDDLE FORMULAS

The following outlines the procedures for estimating evapotransporation (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 mthods used for calibrating each of the formulas.

Criddle et al. (1962) Formula:

The Criddle et al. (1962) version is:

$$u = 25.4\ kf$$

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 (°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 Σf 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° 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°C, from Table 2.2

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

(4) Determine F for the growing season:

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

e.g. Laramie, 1978

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

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

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* 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 $F = 29$ $k_{crid} = 0.57$

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

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

e.g. Laramie, May 1978

$k_{crid} = 0.57$, 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

$t = 7.4°C$, 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

$t = 7.4°C$, 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 determined for each year (Table 2.9) using

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

e.g. Laramie, May 1978

Calculated k_c =

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

(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.

APPENDIX C

WEEKLY APPLICATION RATES AND APPEARANCE RATINGS

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

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	.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	

Table C.8. Appearance Ratings, Wheatland, 1976

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	Seasonal Average
1	9	9	9	9	9	7	7	8	8	8	9	9	9	9	9	8	8	8	8	9	8.5
2		5	7	7	9	7	7	7	6	5	6	6	7	7	8	8	7	7	7	8	6.9
3	5	5	7	7	7	7	5	5	5	5	5	5	6	7	7	7	5	6	6	6	5.9
5	7	7	7	7	7	7	7	7	7	7	9	9	9	9	9	9	8	8	8	8	7.8
6	3	3	7	7	7	7	5	5	6	6	7	7	8	6	7	6	5	5	4	5	5.8
7		9	9	9	9	7	9	7	8	8	8	9	9	8	8	9	9	9	9	9	8.5
9		5	7	5	7	7	7	8	8	8	8	7	7	6	6	7	7	7	7	8	6.9
10		5	5	7	5	3	5	6	5	5	5	5	5	5	5	5	5	5	5	5	5.1
11		7	9	9	9	7	7	9	9	9	9	9	10	9	7	8	8	8	8	8	8.4
12		5	5	5	7	5	7	5	6	5	5	4	5	5	5	5	5	5	6	6	5.3
13						3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	3.5
15		9	9	9	9	9	9	9	9	9	9	9	9	9	8	8	8	8	8	8	9.2
16		7	7	7	7	7	7	7	7	7	7	7	6	5	5	4	4	4	5	5	6.1
17		3	3	3	3	3	5	4	4	4	4	4	4	4	6	5	5	5	5	5	4.2
18			3	5	5	5	5	7	5	6	6	6	6	6	6	5	6	6	6	6	5.6
19		5	5	5	5	7	7	6	6	5	7	7	7	7	7	6	7	7	8	8	6.4
20				3	5	5	5	6	5	4	4	4	4	4	5	4	4	4	4	4	4.4
21				5	5	5	5	4	5	5	6	6	6	5	5	5	5	4	4	5	5.0
22				5	5	5	5	5	6	6	6	6	7	7	6	6	6	7	7	7	6.0
23				7	9	7	7	6	6	6	7	7	7	6	6	5	4	5	5	5	6.2
24		7	9	7	7	7	7	8	8	8	9	8	8	9	7	8	8	8	8	8	7.8
25			7	7	9	7	7	9	8	8	8	8	8	8	8	8	8	8	8	8	7.9
26				7	5	5	5	5	5	5	5	5	4	5	4	4	4	4	4	4	4.7
27		7	7	7	7	5	7	6	6	6	6	7	6	5	5	5	5	6	6	6	6.1
28				9	7	7	7	8	7	7	6	7	7	6	7	7	7	7	7	7	7.1
29				7	7	9	5	7	6	7	7	6	7	6	6	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	6.6	6.5	6.7	6.4	6.4	6.3	5.8	6.2	6.3	6.5	

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	9	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

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* 1976	1977	2-year Average	Home Number	Average Stress Rating* 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

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.

8-77--4C--3 9-77--2M--2

Sprinkler Irrigation

Sprinklers do an excellent job of applying water but they are not perfect. All sprinkler systems will over irrigated 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 ft^2 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	1.67	2.64
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,

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

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

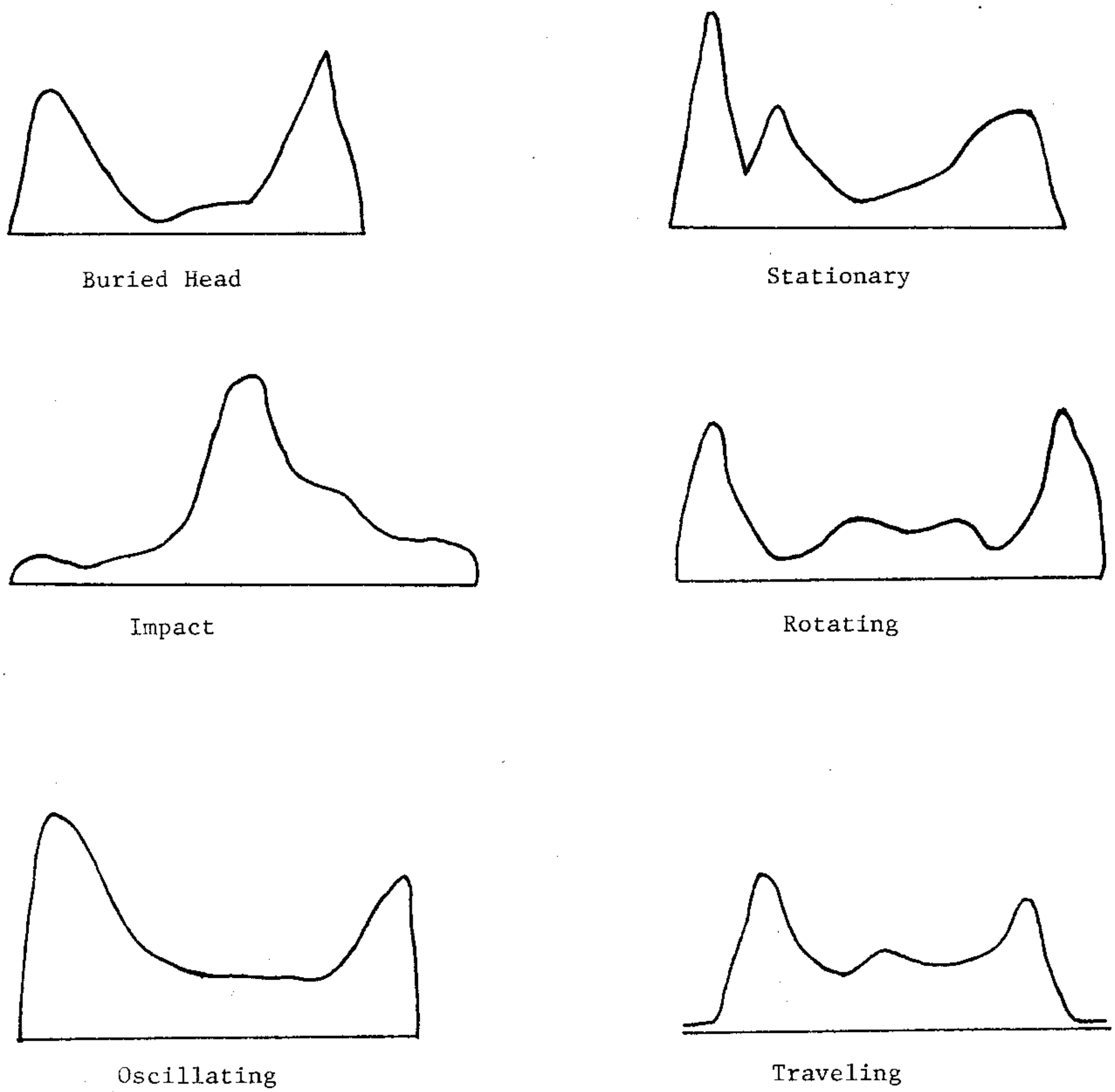

Figure 1. Cross-section of sprinkler patterns

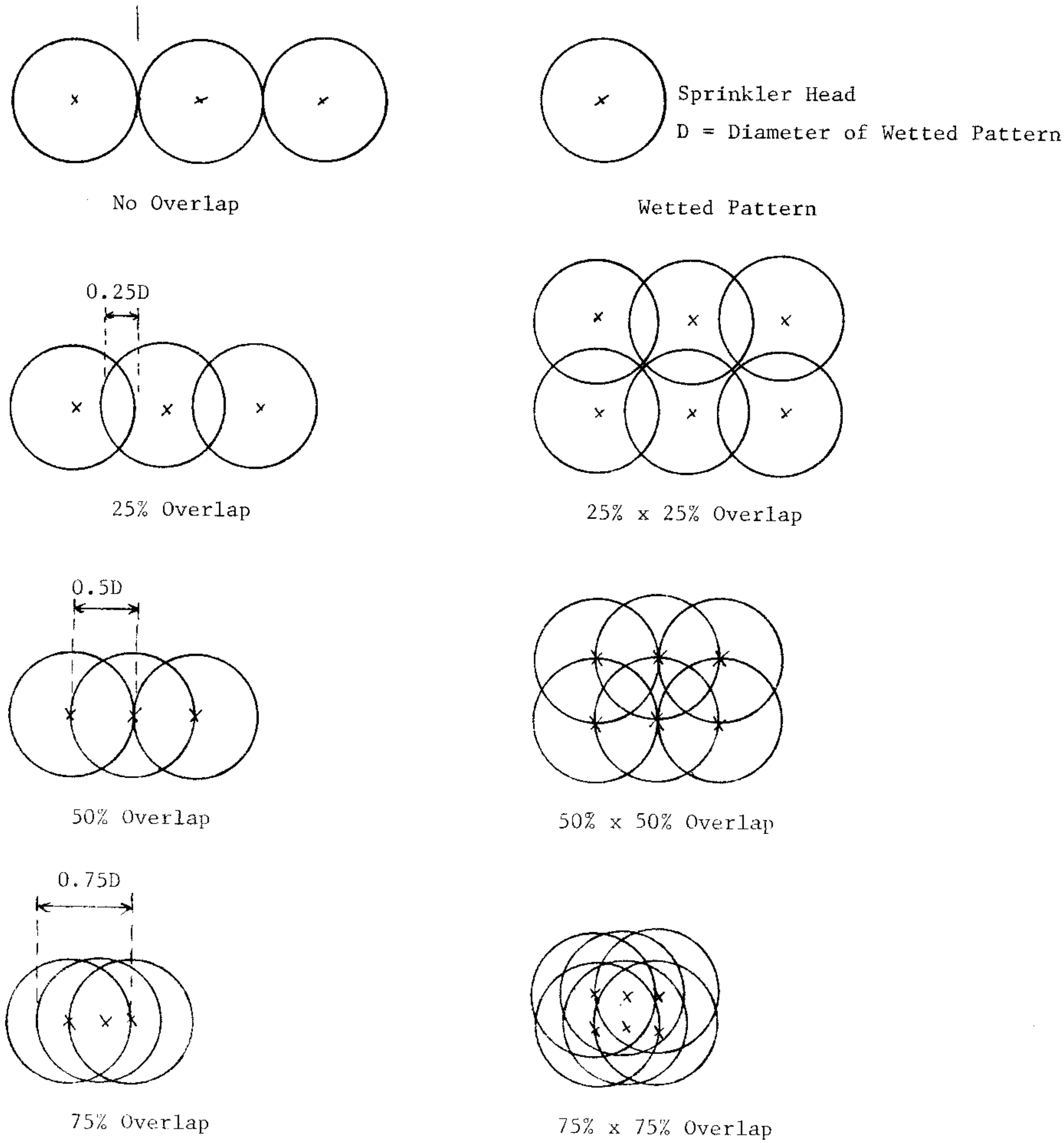

Figure 2. Schematic of overlapped sprinkler patterns.

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	86
	Medium	(20)	30	38	54	75	45	69	93
	High	(30)	27	44	50	68	56	71	95
Stationary	Low	(10)	19	30	54	66	37	66	87
	Medium	(20)	35	43	57	71	50	72	92
	High	(30)	32	47	57	60	61	81	95
Impact	Low	(10)	42	53	59	62	68	82	94
	Medium	(20)	42	55	58	62	70	81	95
	High	(30)	40	56	56	58	77	85	96
Rotating	Low	(10)	10	17	37	55	22	53	79
	Medium	(20)	26	31	50	64	35	63	85
	High	(30)	40	51	57	70	57	67	89
Oscillating	Low	(10)	33	33	49	53	38	56	79
	Medium	(20)	43	38	51	61	45	63	86
	High	(30)	49	48	61	68	49	70	91
Traveling	Low	(10)	65**	57	67	90	--	--	--
	Medium	(20)	61	60	65	85	--	--	--
	High	(30)	61	66	68	86	--	--	--

* 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.