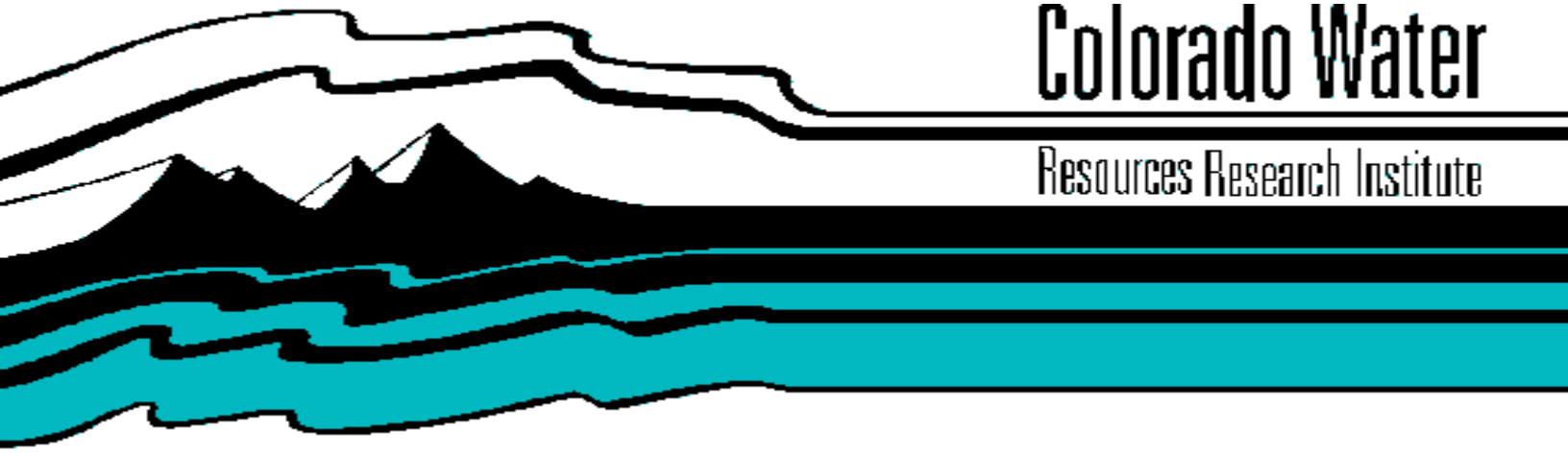
WATER REQUIREMENTS FOR URBAN LAWNS IN COLORADO

by

Robert E. Danielson, William E. Hart, Charles M. Feldhake and Peter M. Haw



Completion Report No. 97

Colorado State University

WATER REQUIREMENTS FOR URBAN LAWNS

Colorado Subcontract Report
OWRT Project No. B-035-WYO

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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.

Reports of the contributions to the project by the University of Arizona and Wyoming may be obtained by contacting the Water Resource Research Institutes of those institutions.

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 watered 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.

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.

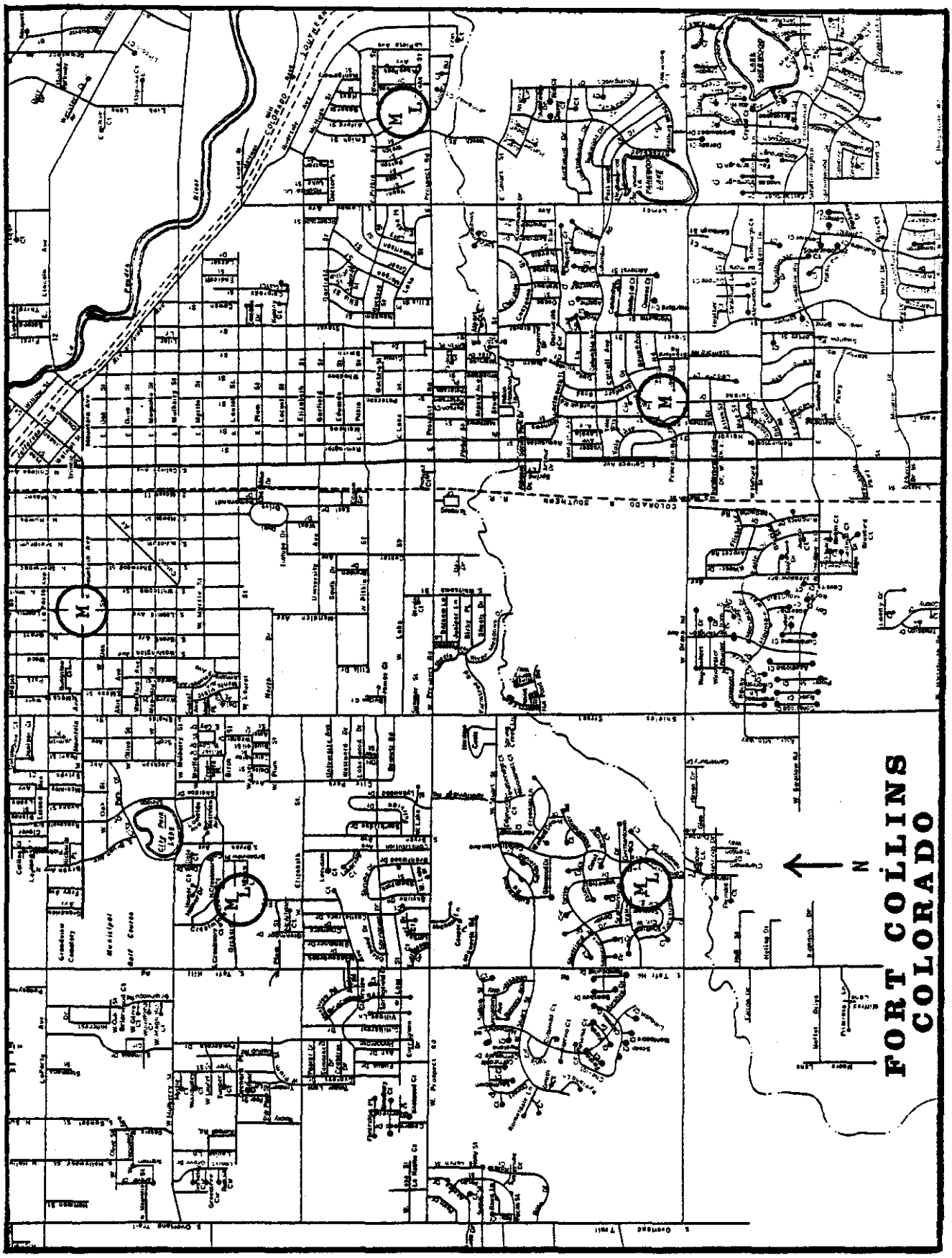
FORT COLLINS
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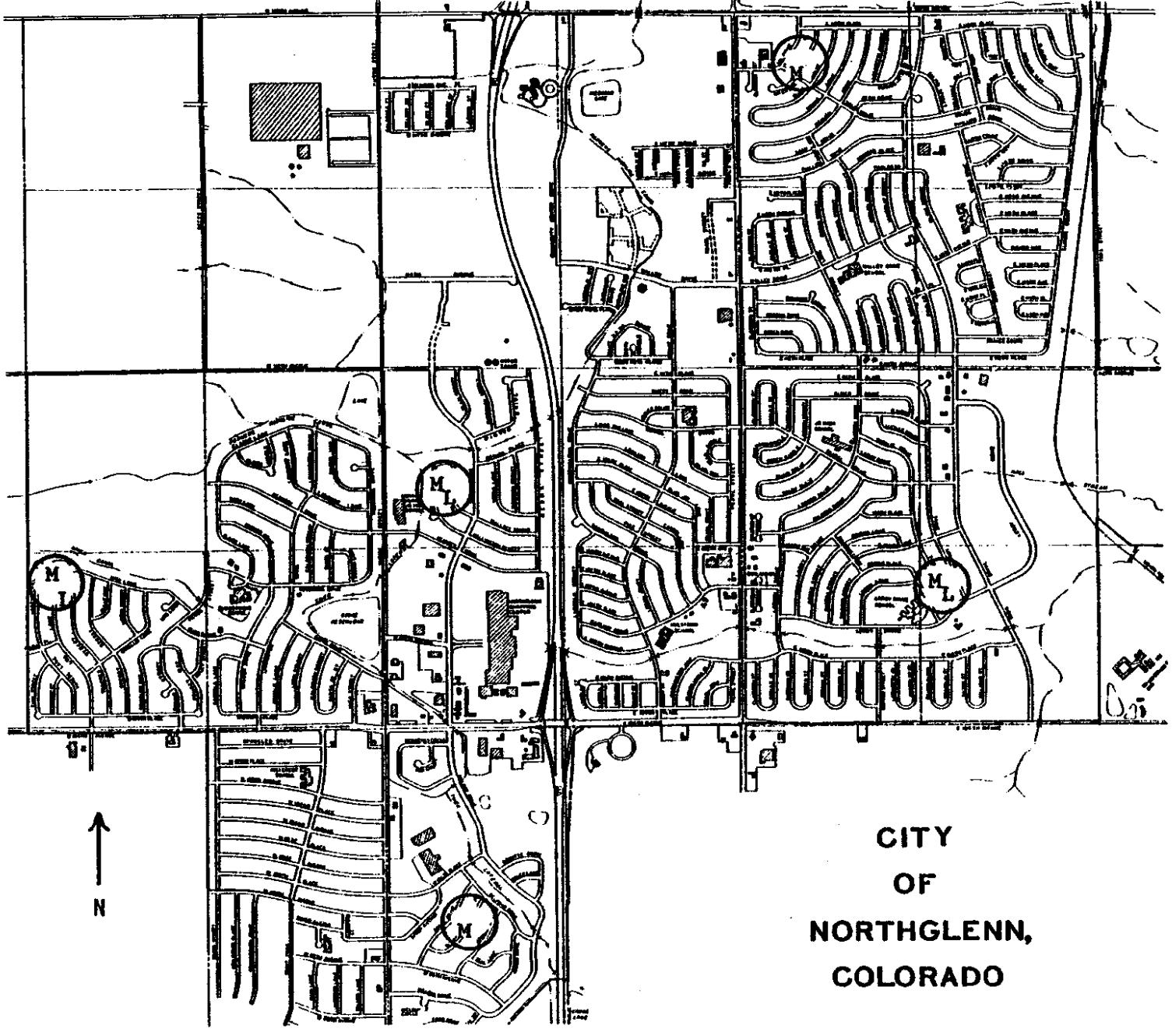
Figure 2.2 Map of Northglenn, Colorado identifying the location of five areas where water meters were used to measure lawn irrigation (M) and of three areas where lysimeters were installed to measure lawn evapotranspiration (L). Water meters were located at thirty home sites and lysimeters at three.



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CITY
OF
NORTHGLENN,
COLORADO

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° 35' N latitude and 105° 05' W longitude. Comparable values for Northglenn are 33,000 population, 1,665 meter elevation, 39° 54' N latitude and 104° 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

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, weighted 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.

Lot and Lawn Area Measurement

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

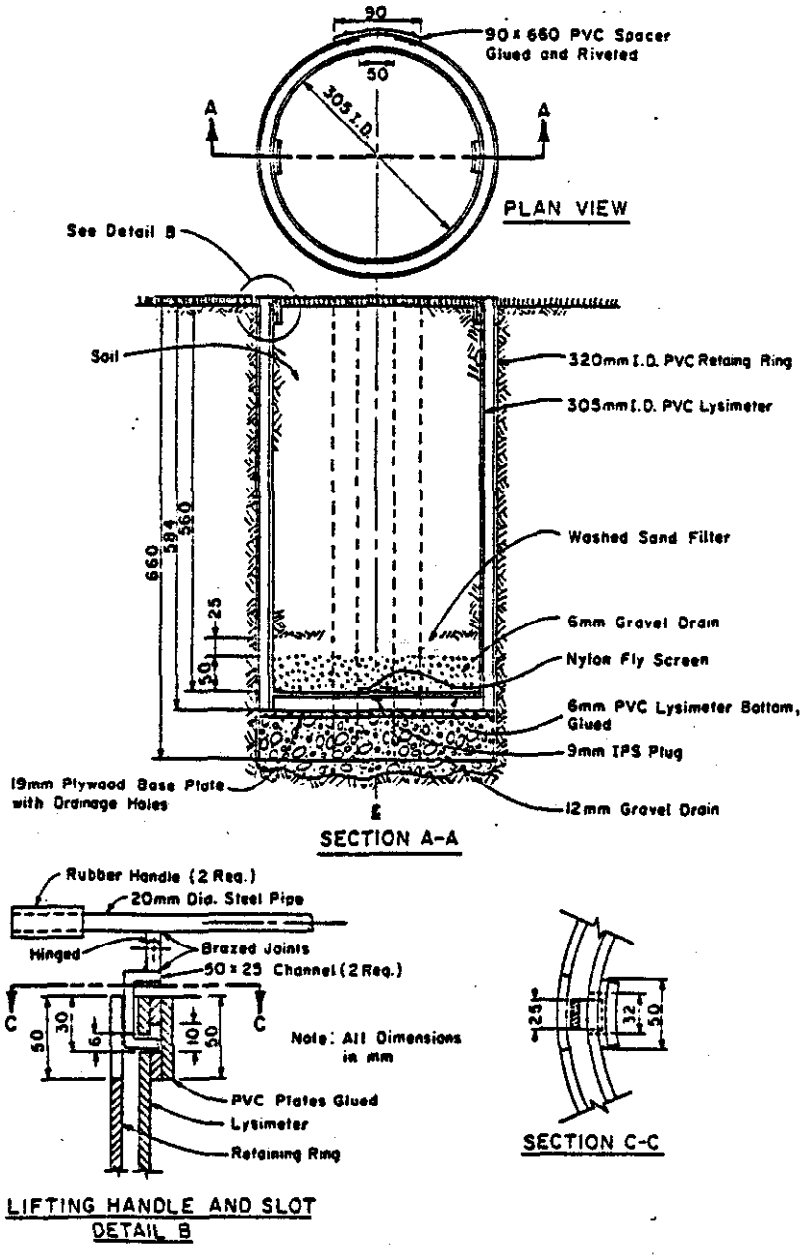

Figure 2.3 Construction details of the bucket lysimeter.

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.

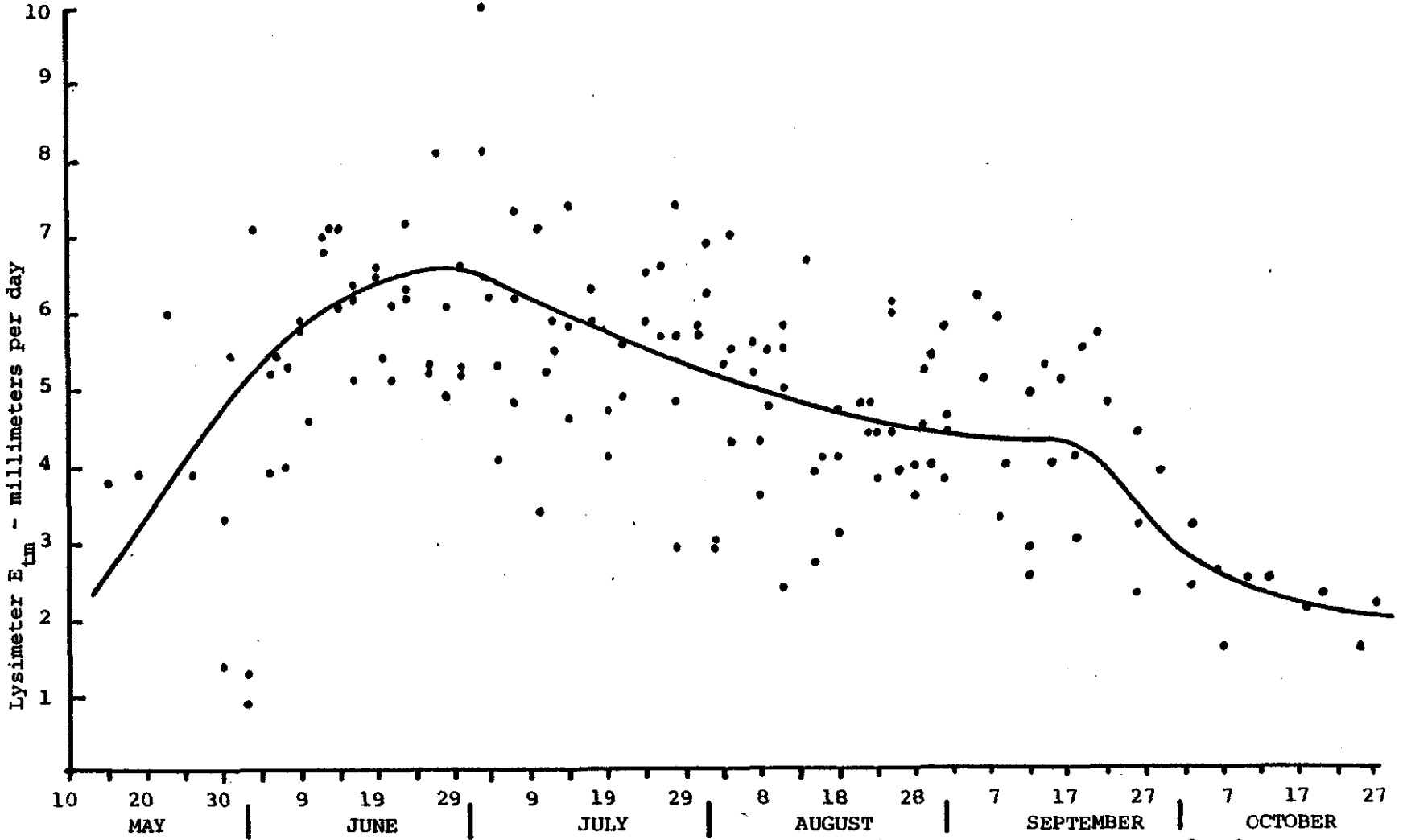

Figure 3.1 Lysimeter evapotranspiration rate during the growing season. Values are for lawns in Fort Collins and Northglenn during 1977 and 1978. The line indicates the trend of E_{tm} for the Colorado area.

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 (°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 platted. 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

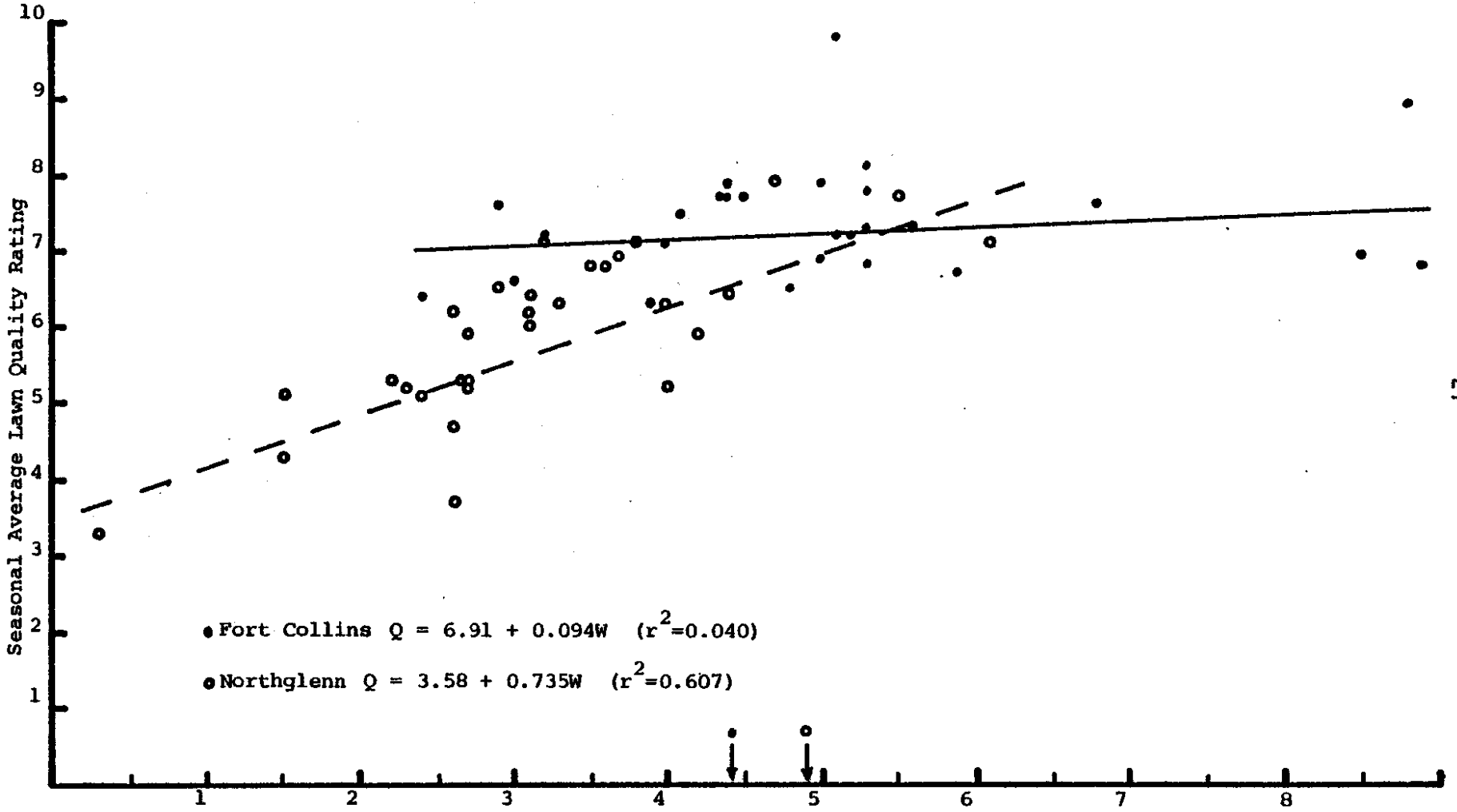

Figure 3.2 Average Lawn Quality rating for home sites as related to irrigation water application - Fort Collins and Northglenn, 1977.

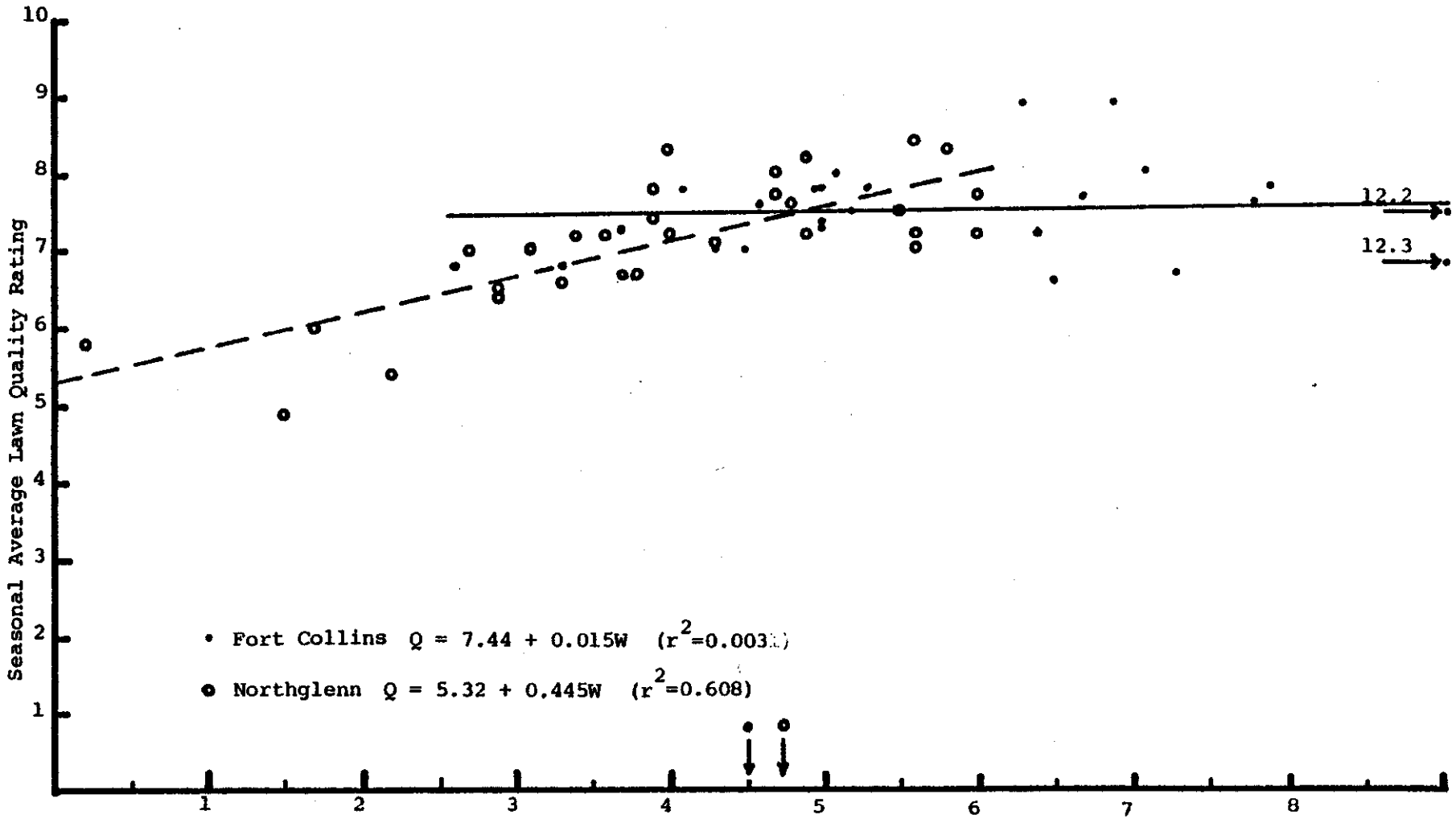

Figure 3.3 Average Lawn Quality Rating for home sites as related to irrigation water application - Fort Collins and Northglenn, 1978.

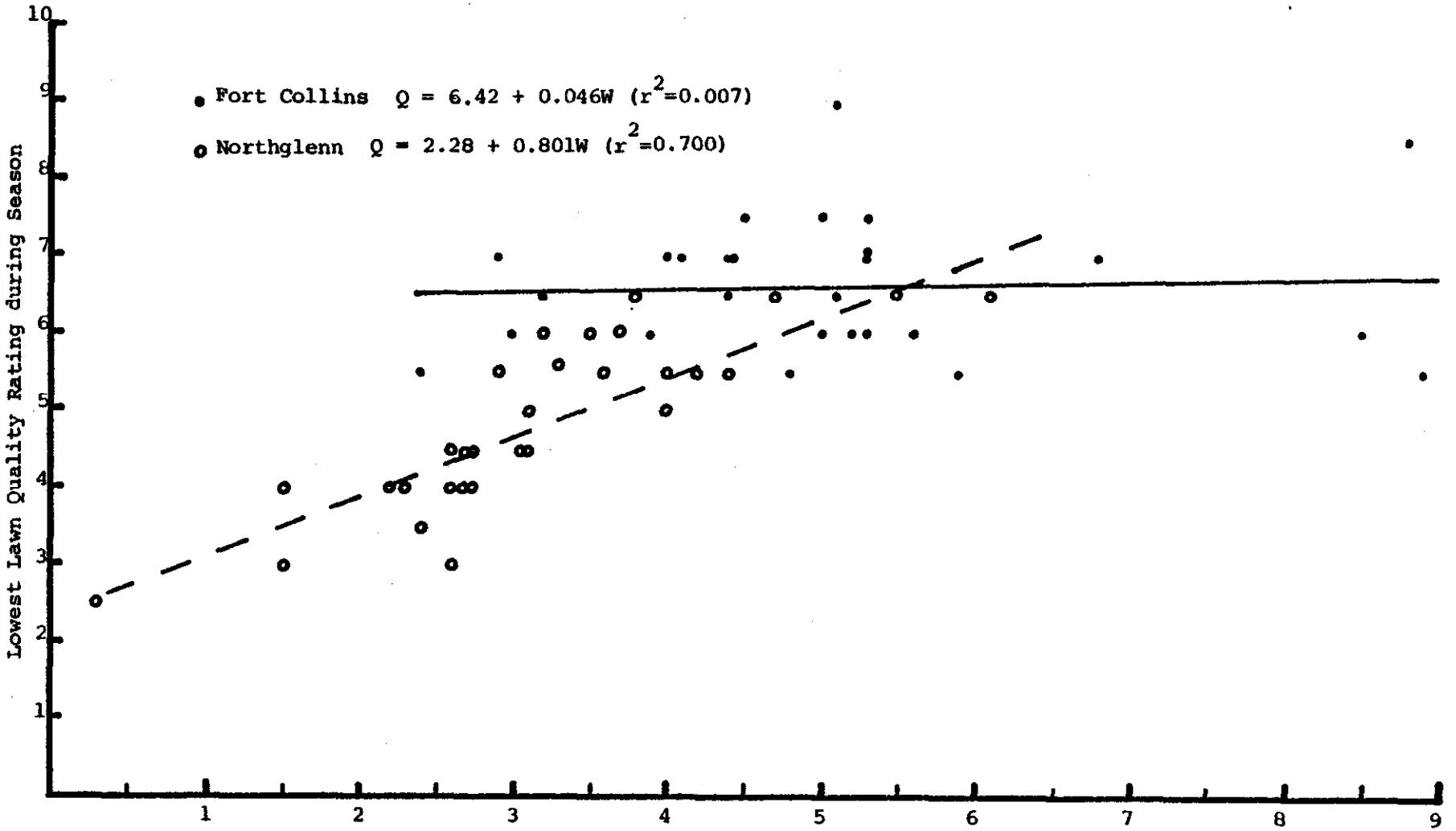

Figure 3.4 Minimum Lawn Quality rating for home sites as related to irrigation water application - Fort Collins and Northglenn, 1977.

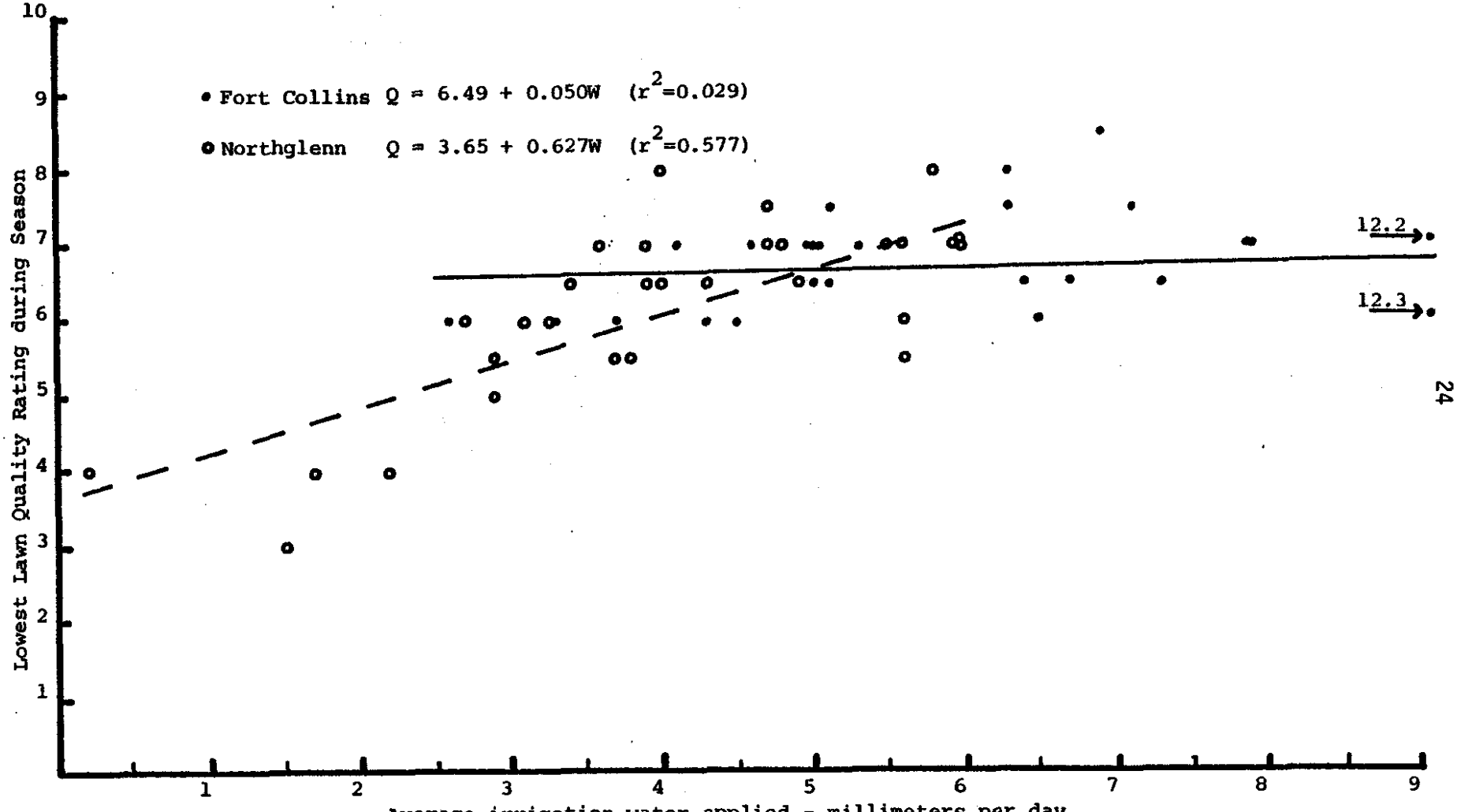

Figure 3.5 Minimum Lawn Quality rating for home sites as related to irrigation water application - Fort Collins and Northglenn, 1978.

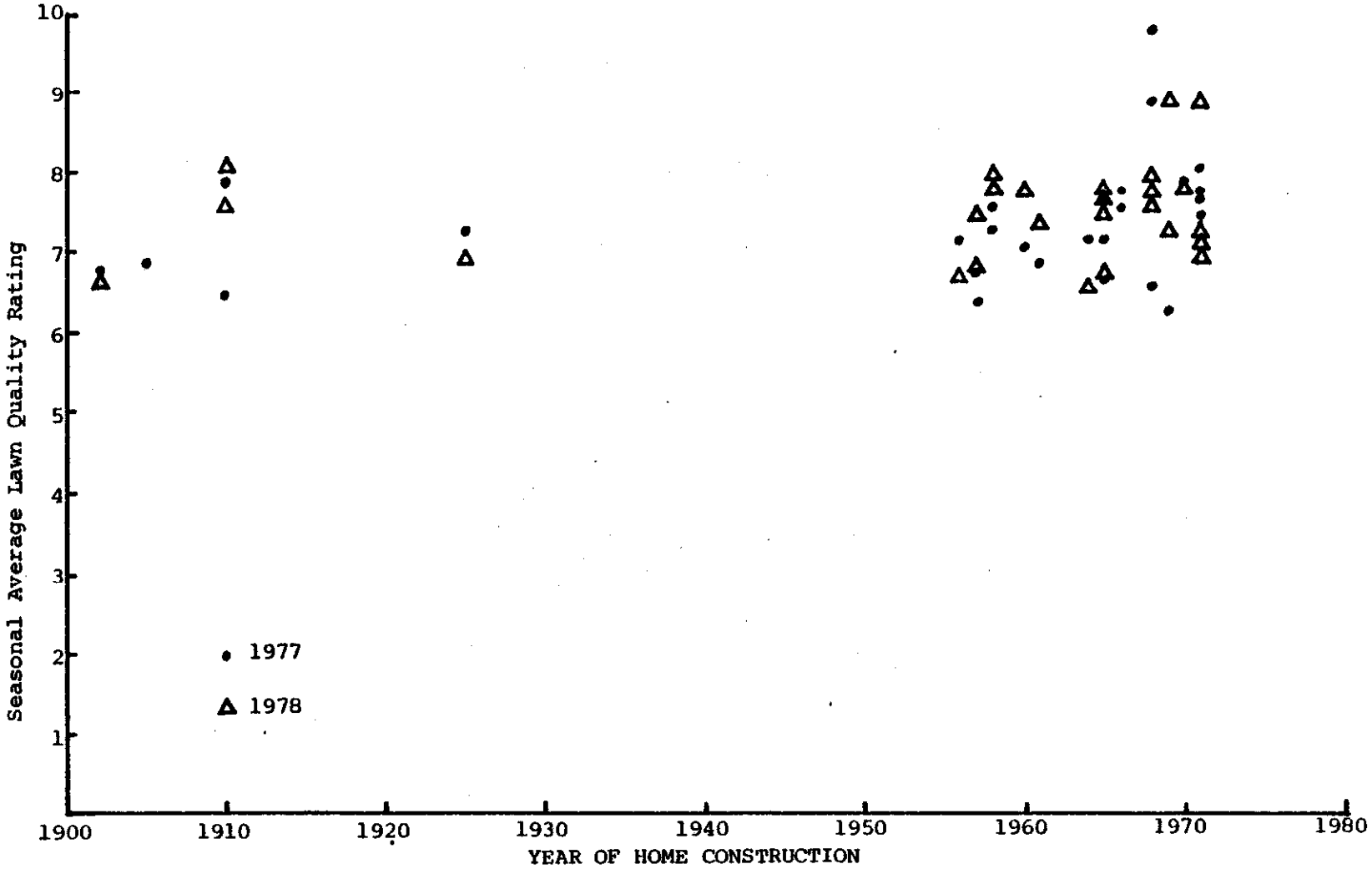

Figure 3.6 Average Lawn Quality Rating for Fort Collins home sites as related to age of home - 1977 and 1978.

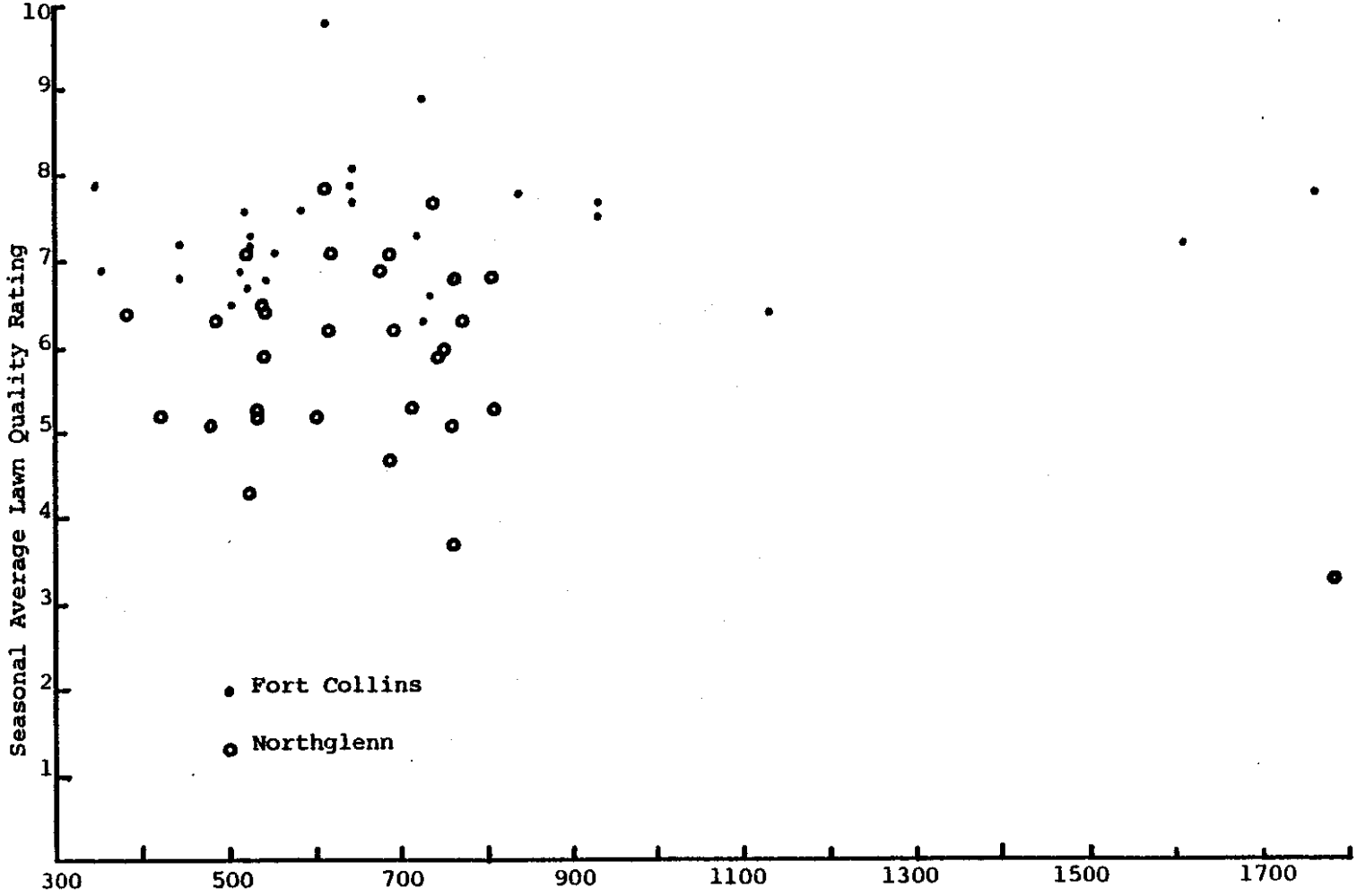

Figure 3.7 Average Lawn Quality rating for home sites as related to size of lawns - Fort Collins and Northglenn, 1977.

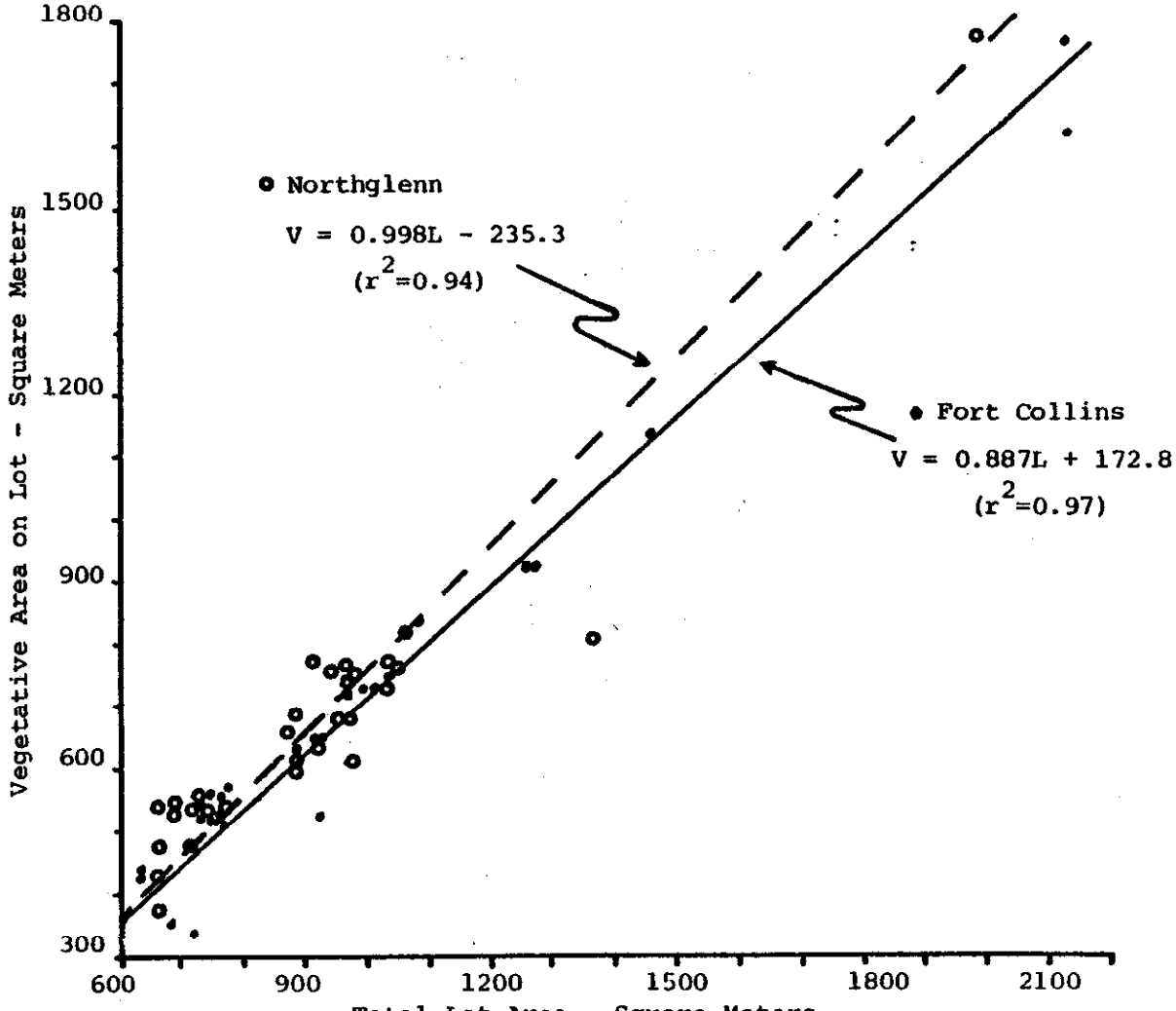

Figure 3.8 Relation of lawn size to total lot size for home sites - Fort Collins and Northglenn

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 gal/week	Irrigation gal/week	Irrigation %	Total gal/week	Irrigation gal/week	Irrigation %
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 3.3) 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 as 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 desireable 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

$$E_{tj} = E_{tm}$$

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

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

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.

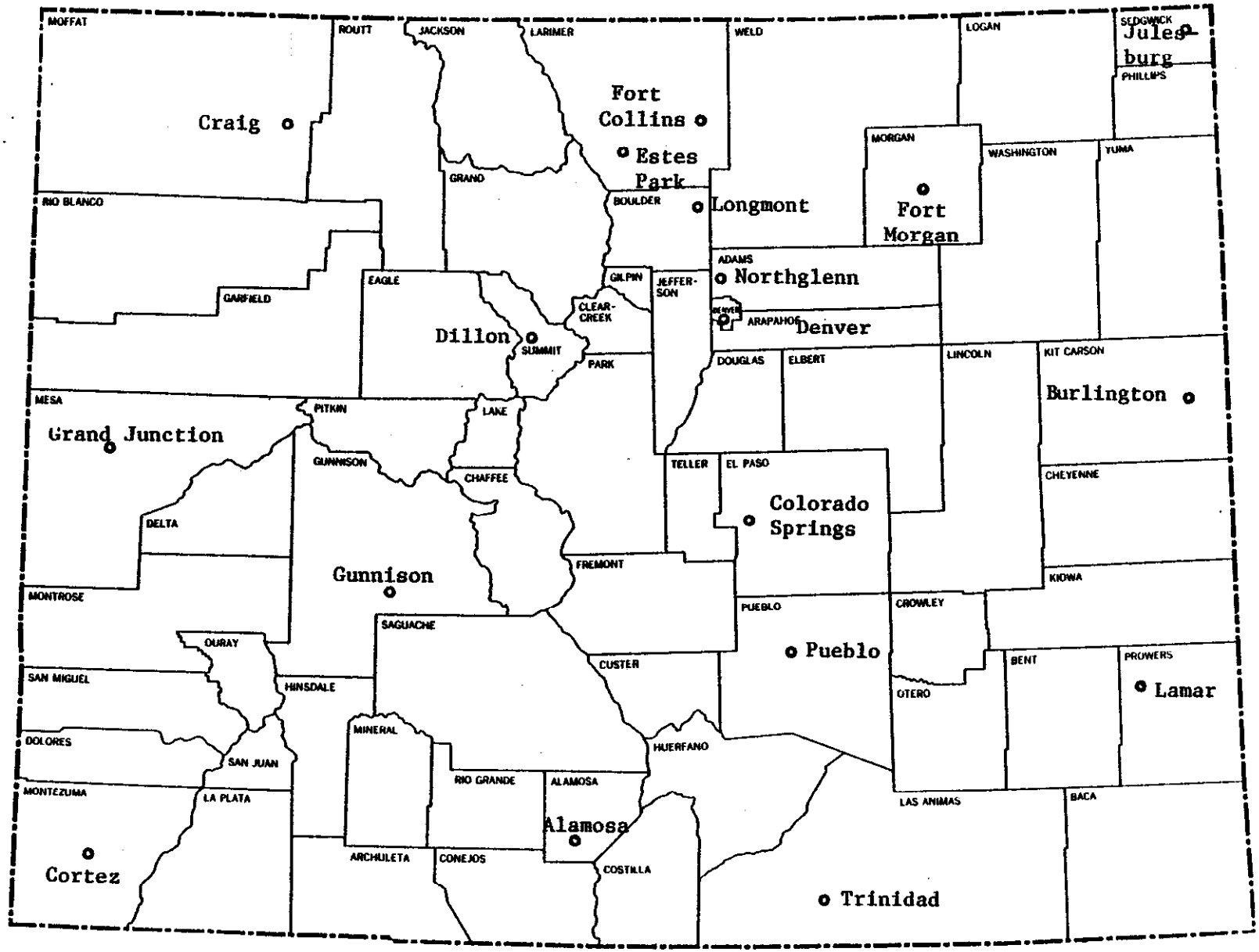
MOFFAT
ROUTT
JACKSON
LARIMER
WELD
LOGAN
SEDGWICK
Julesburg
PHILLIPS
Craig
Fort Collins
Estes Park
MORGAN
WASHINGTON
YUMA
GRAND
RIO BLANCO
BOULDER
Longmont
Fort Morgan
ADAMS
Northglenn
EAGLE
GILPIN
JEFFERSON
GARFIELD
CLEAR-CREEK
ARAPAHOE
Denver
Dillon
SUMMIT
PARK
DOUGLAS
ELBERT
LINCOLN
KIT CARSON
Burlington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

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 $39^{o}19'$ N

Longitude $102^{o}16'$ W

Month	Ave. Temp. ^{o}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.. ^{o}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 $39^{o}38'$ N

Longitude $106^{o}02'$ W

Month	Ave. Temp.. ^{o}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.. ^{o}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. ^{o}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.. °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 controll 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 sparce 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 types 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-Haise 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

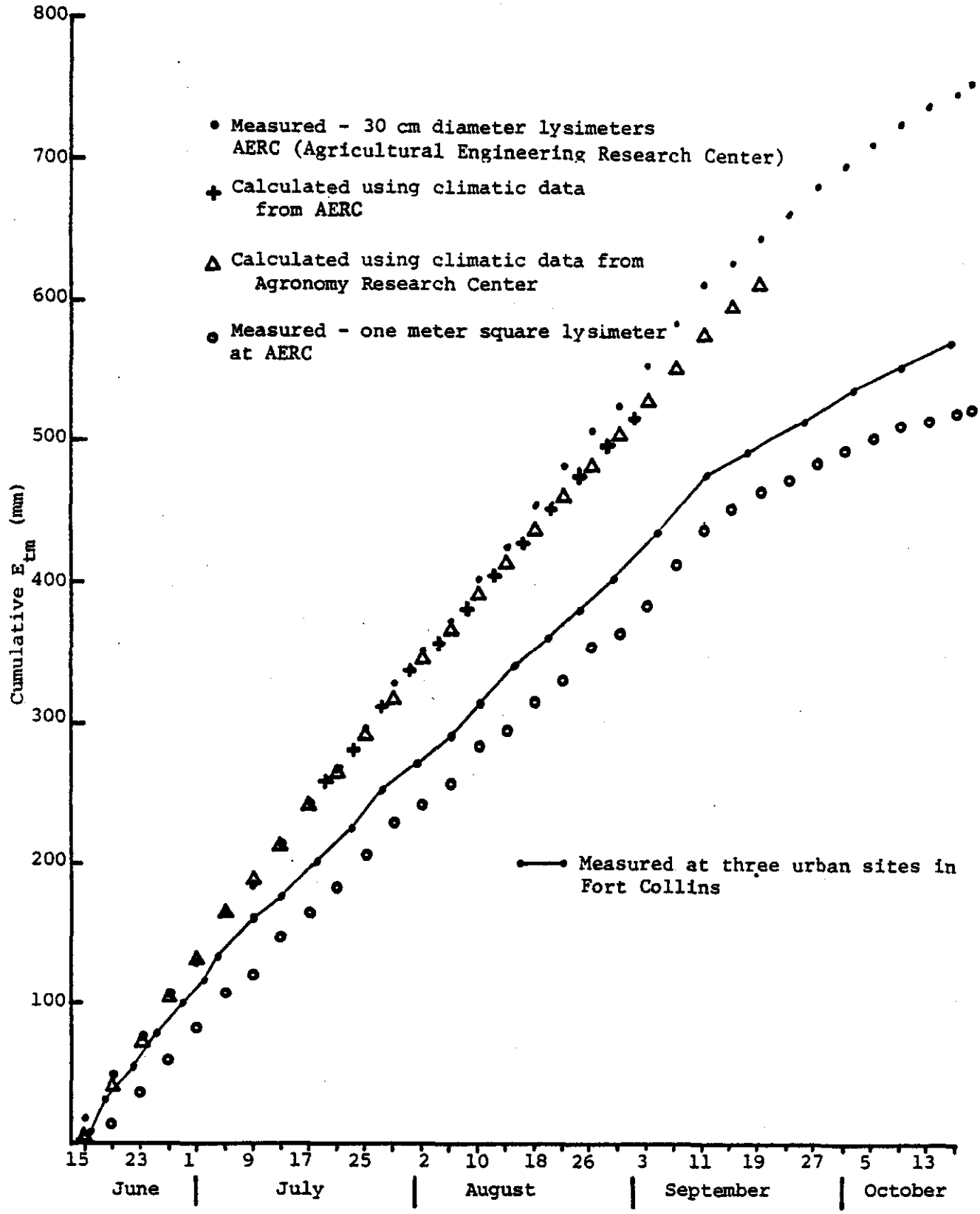

Figure 5.1 Measured and calculated cumulative E_{tm} values - 1978.

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 instantaineous 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

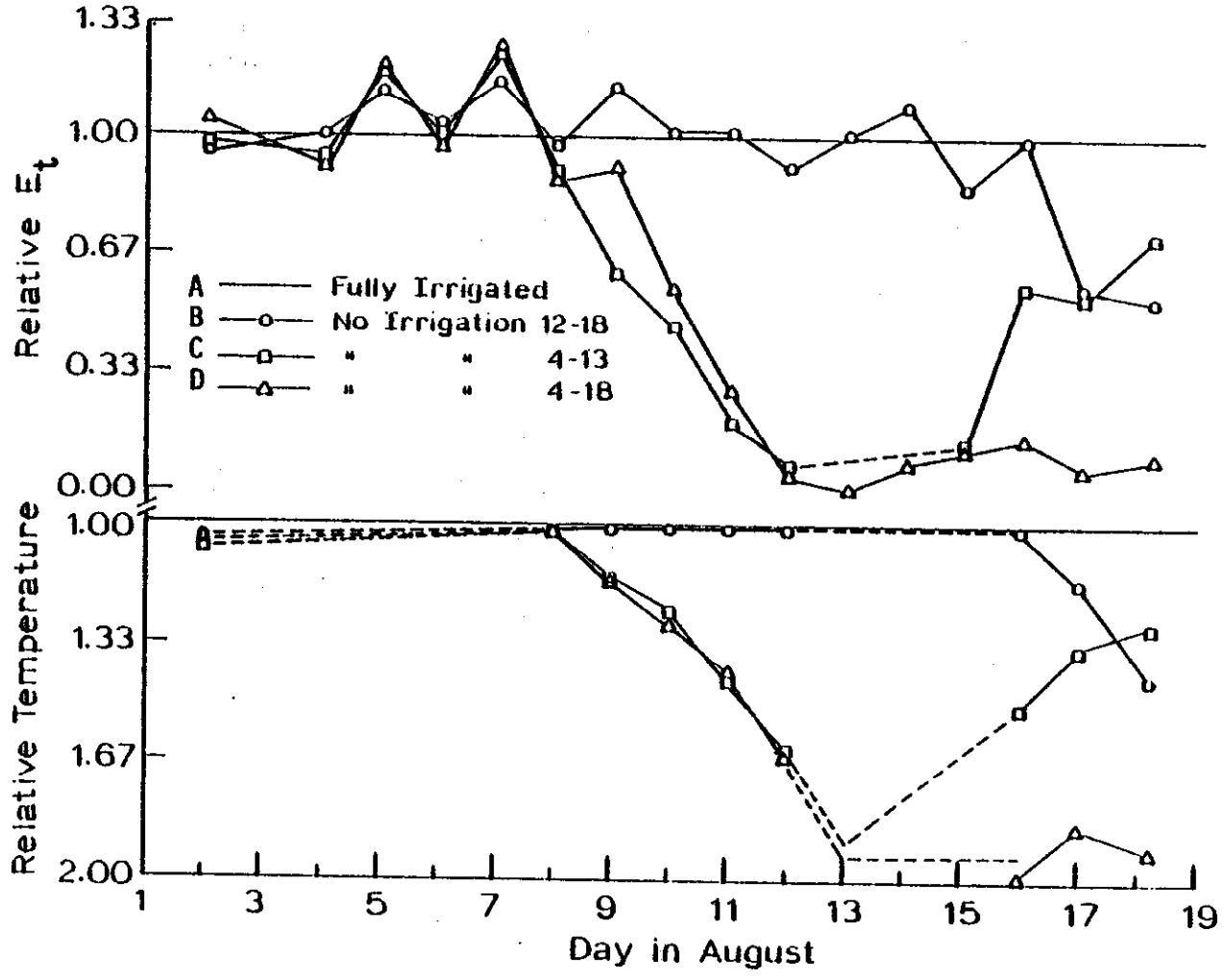

Figure 5.2 Relative E_t and canopy temperatures for three irrigation schedules relative to fully irrigated turf. (Each point is an average of two replications)

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 deviced 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 overirrigation 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.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.

	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
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.

	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
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.

	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. 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.

	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
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.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.

		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
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.

		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
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.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
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.

	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. 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.

	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
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.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.

	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 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.

	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. 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.

	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
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.

	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. 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.

	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
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.

	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 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		Quality Rating 1977		Quality Rating 1978	
					1977	1978	Ave	Min	Ave	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		Quality Rating 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

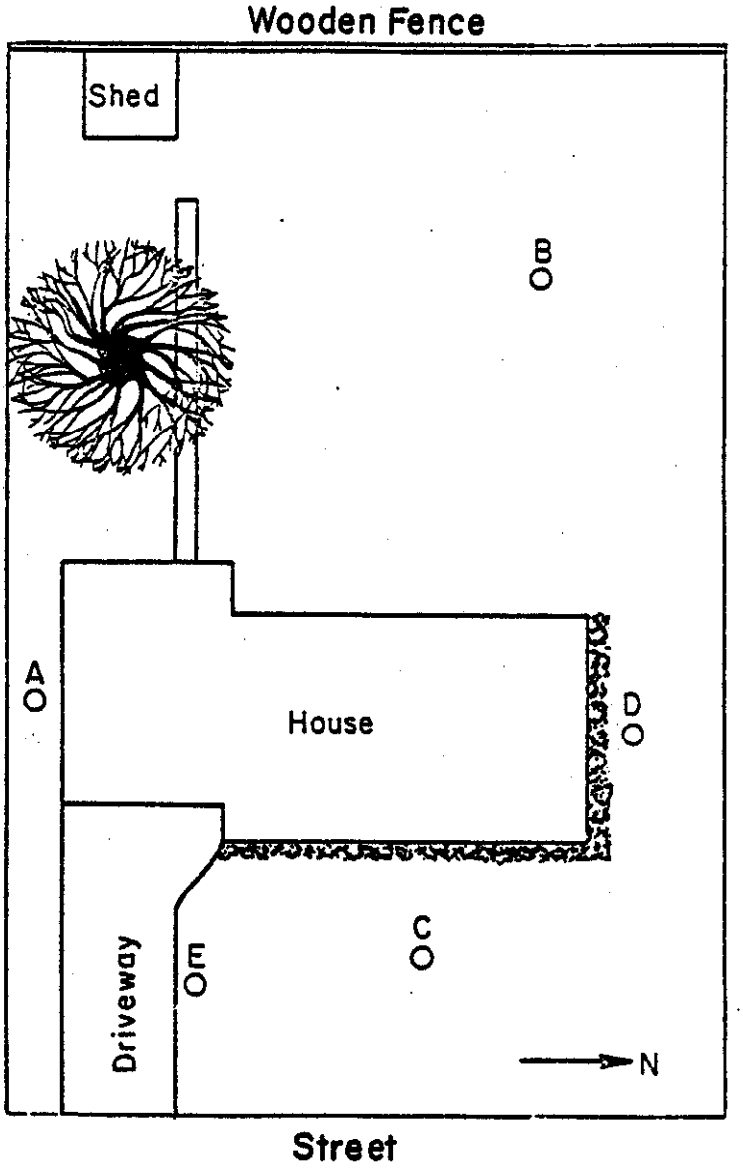

Figure A.1 Diagram of homesite No. 1, Fort Collins, showing lysimeter locations with respect to improvements on the lot.

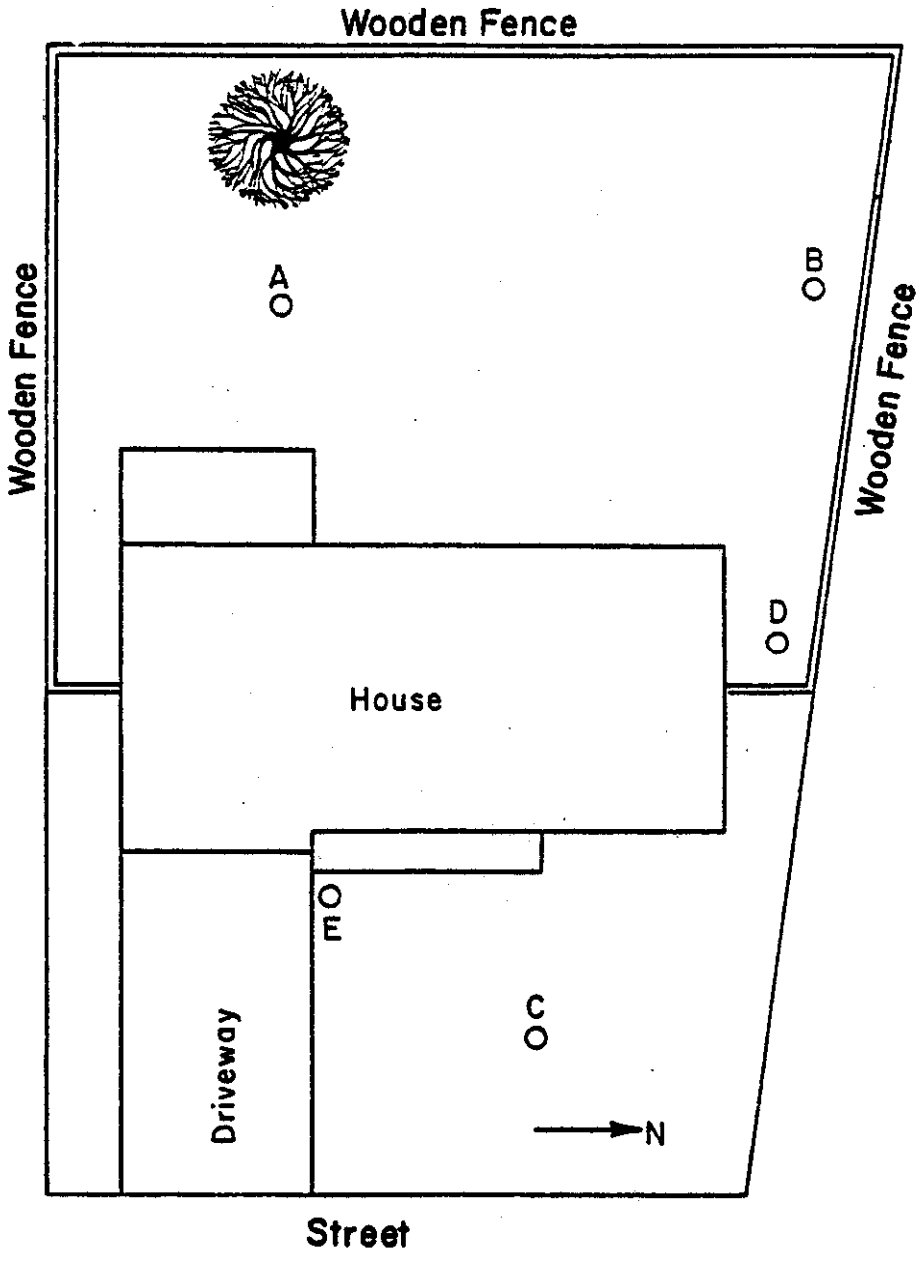

Figure A.2 Diagram of homesite No. 2, Fort Collins, showing lysimeter locations with respect to improvements on the lot.

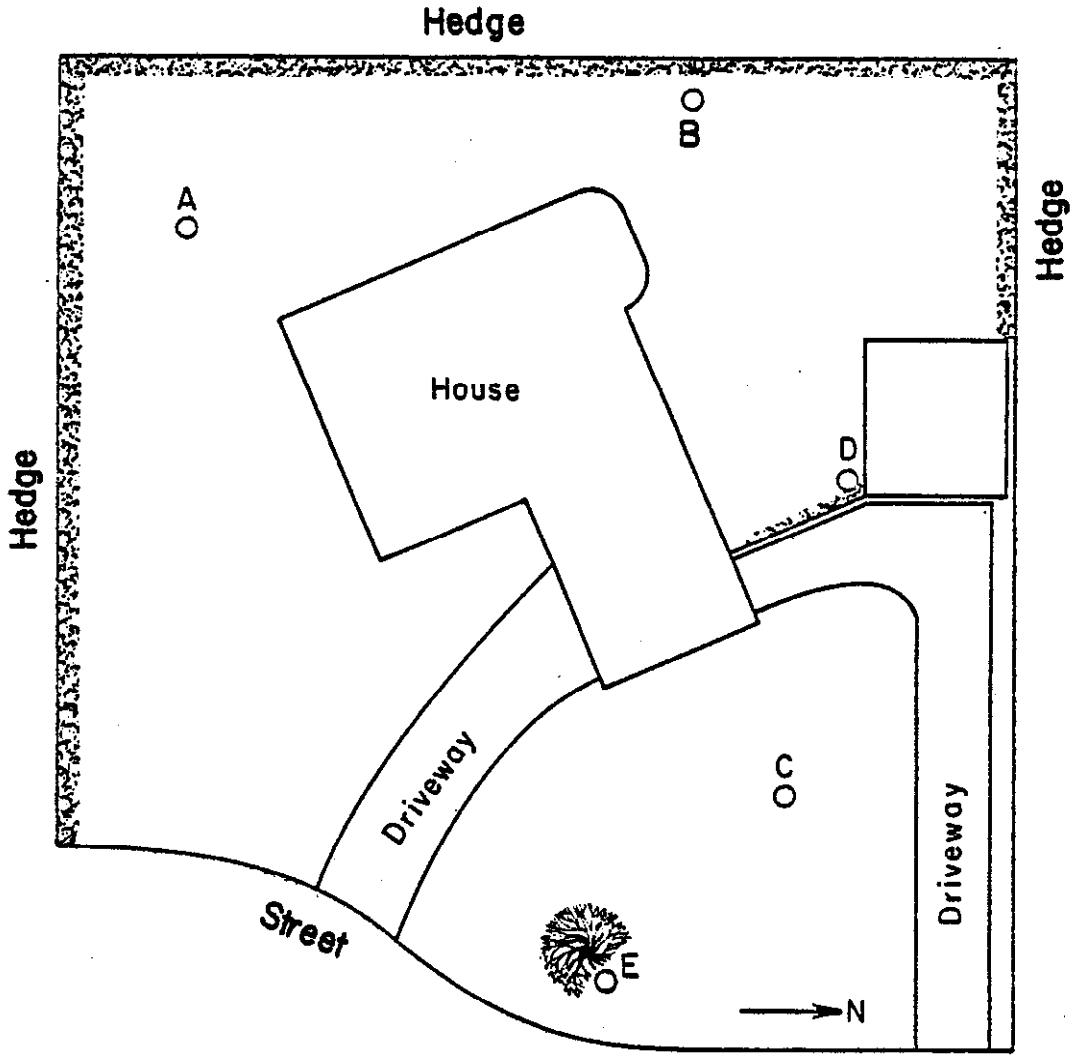

Figure A.3 Diagram of homesite No. 3, Fort Collins, showing lysimeter locations with respect to improvements on the lot.

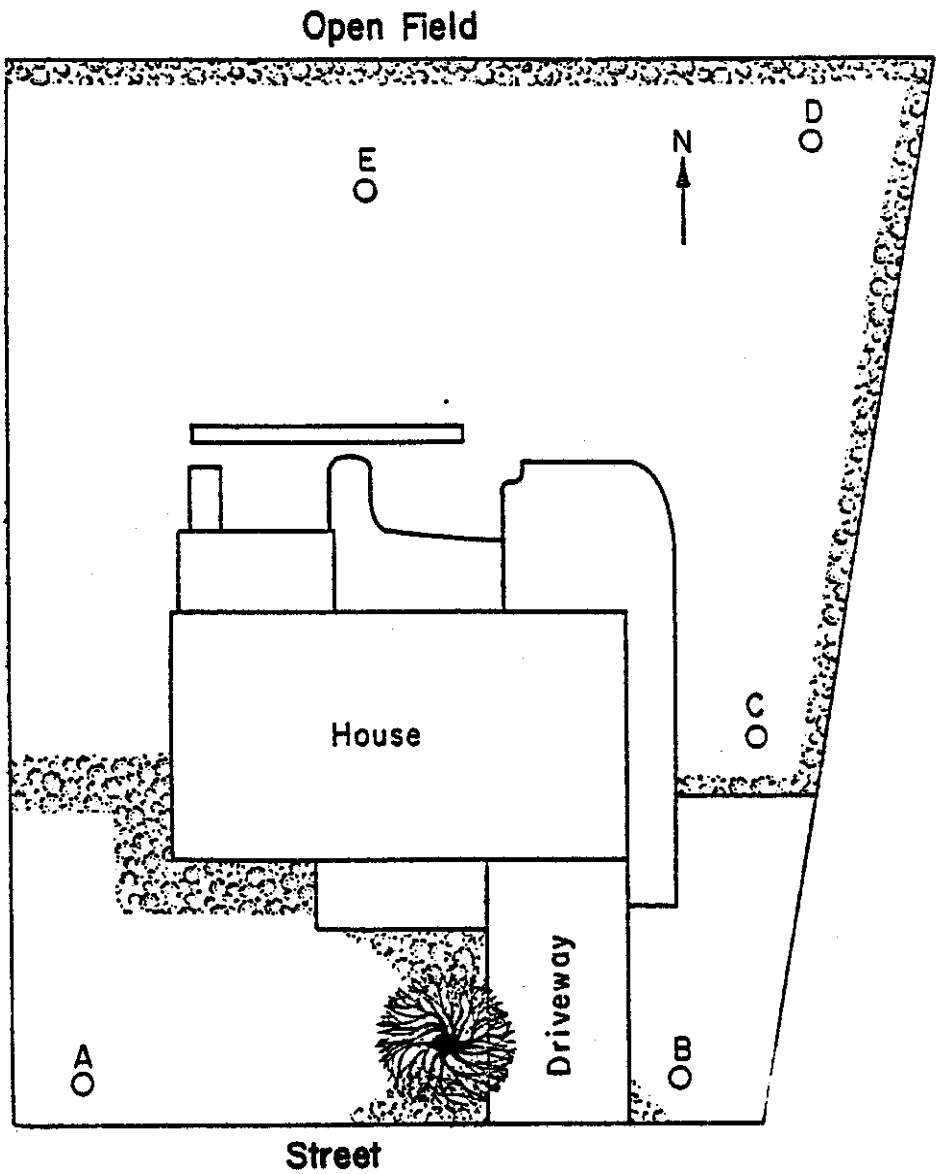

Figure A.4 Diagram of homesite No. 1, Northglenn, showing lysimeter locations with respect to improvements on the lot.

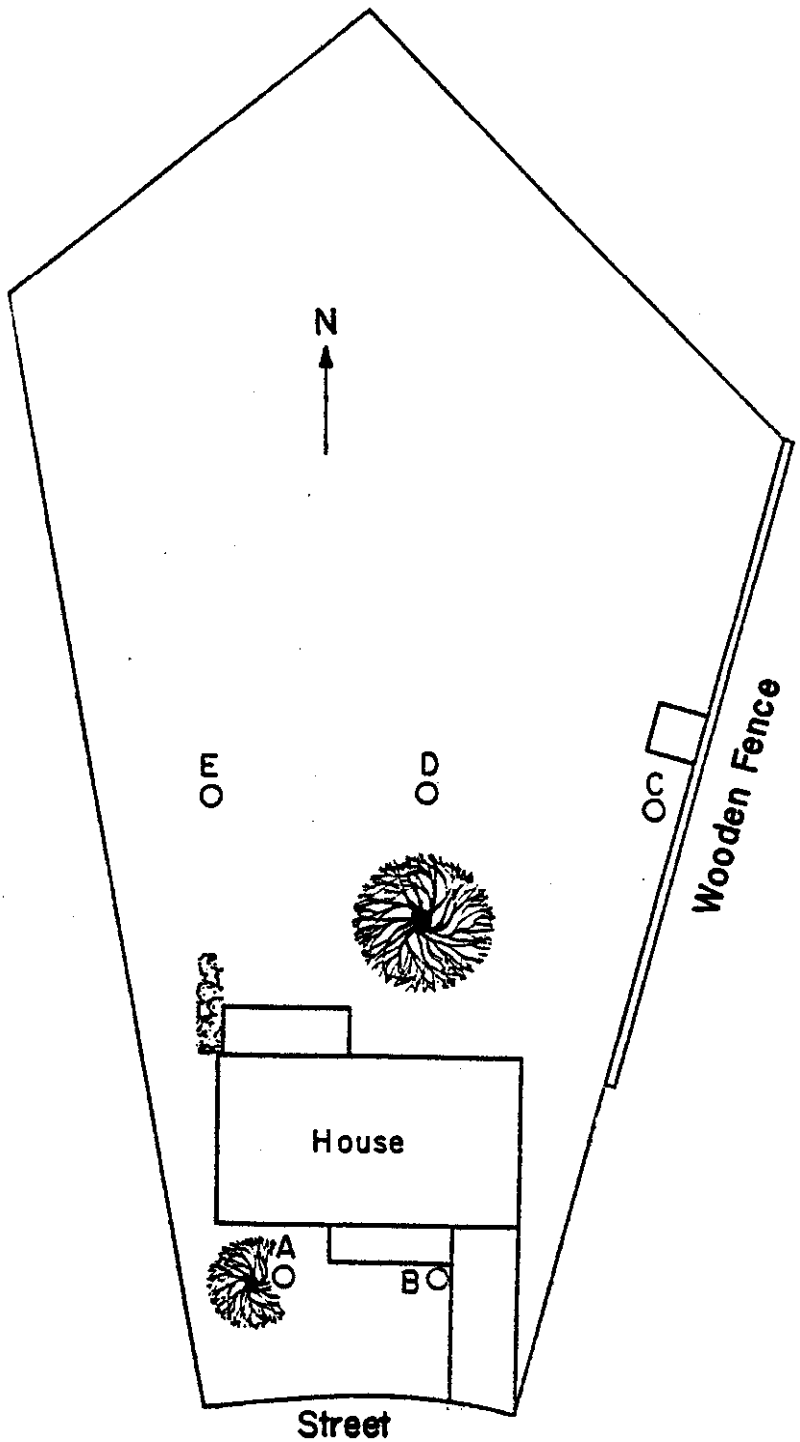

Figure A.5 Diagram of homesite No. 2, Northglenn, showing lysimeter locations with respect to improvements on the lot.

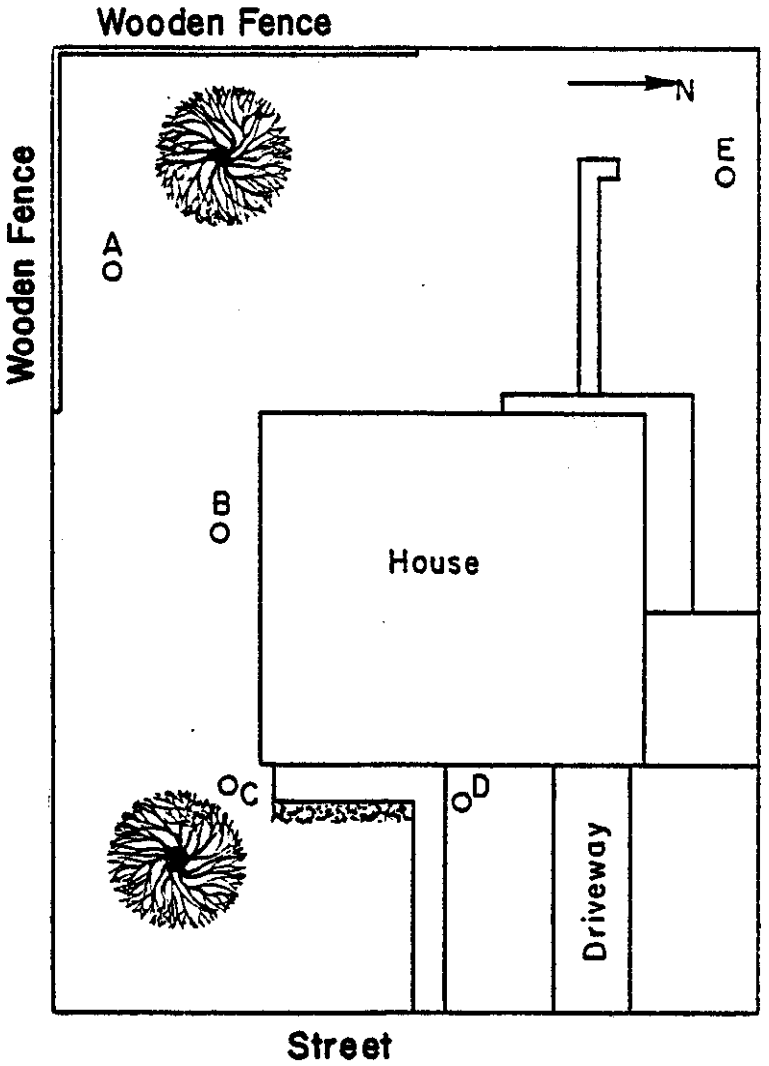

Figure A.6 Diagram of homesite No. 3, Northglenn, showing lysimeter locations with respect to improvements on the lot.