Research Report 118

Irrigation Practices in Illinois

by
Jean A. Bowman and
Brian C. Kimpel

ILLINOIS STATE WATER SURVEY
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Title: Irrigation Practices in Illinois.

Abstract: Biweekly and total irrigation amounts and irrigation scheduling practices were monitored at representative sites in central Illinois during the 1988 and 1989 growing seasons. The purpose was to gather baseline information on average quantities of irrigation water used in normal and drought years and on the general efficiency of irrigation operations in the subhumid climate of Illinois. Soil water-holding capacity is the most important factor in determining irrigation amounts, explaining about 65 percent of the variability in irrigation totals. Other important factors in explaining irrigation variations include weather changes, individual farmer idiosyncrasies, and crop differences. In general, irrigation farmers in Illinois appear to be applying appropriate amounts of irrigation water at appropriate times in the growing season, based on their soil type, crop type, and total evaporative losses.

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Indexing Terms: Evaporation, Illinois, irrigation, irrigation efficiency. irrigation in subhumid climates, irrigation operation and maintenance, irrigation practices, irrigation scheduling, soil water, water balance, water utilization.

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CONTENTS

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ABSTRACT

Irrigation is becoming increasingly important to Illinois agriculture. Yet, because Illinois has traditionally not been heavily irrigated, relatively little has been known about present irrigation water use and irrigation scheduling and efficiency in the state. Questions are arising with greater frequency about irrigation in the subhumid Illinois climate and about the impact of irrigation water use on regional water resources.

Biweekly and total irrigation amounts and irrigation scheduling practices were monitored at 214 sites in central Illinois during the 1988 and 1989 growing seasons to gather baseline information on average quantities of irrigation water used in normal and drought years and on the general efficiency of irrigation operations in the subhumid Illinois climate. Estimates of irrigation water use were based on hours of irrigation system operation and rate of system flow. Flow rate information was based on irrigation system design flow ratings; in many cases, that information was provided by the irrigation farmer. Efforts to independently verify flow rate data with external and internal flow measurement devices were not entirely successful.

Soil water-holding capacity (expressed as average field capacity in the root zone) correlates well with total irrigation water use, suggesting that irrigation farmers largely determine their irrigation timing and amounts based on some understanding of the water-holding capacity of their soil. Total irrigation water use varies with weather conditions; year-to-year variations are greater than variations among irrigation farmers within any single year.

There is some unexplained variability in irrigation water use from year to year and from farmer to farmer, but most irrigation farmers respond uniformly to the more extreme changes in weather such as drought. Surprisingly little variation in total irrigation applications is evident between different crop types, suggesting that irrigation farmers: (1) have no time to adjust water applications on different crops growing in the same field, (2) keep incomplete records of the amount of water applied to their crops, or (3) apply as much water as possible to all crops. Individual irrigation farmers' practices may vary for reasons unrelated to the physical controls of weather, crop type, or soil type. Irrigation farmers are applying irrigation water on corn and soybean crops in appropriate amounts and times according to evaporative demand and rainfall.

INTRODUCTION

Purpose of Study

The irrigation of farmland, a practice traditionally associated with arid western states, is growing in popularity in the Midwest. Irrigation has been one of the fastest-growing categories of ground-water use in Illinois over the last ten years. Although truck and nursery crop irrigation occurs near urban areas across the state, corn soybeans, and a host of specialty crops are increasingly being placed under irrigation in areas with sandy soils that have low moisture-holding capacities. In Mason County, for instance, irrigated acreage expanded from 530 acres in 1960 (Walker et al., 1965) to nearly 91,000 acres in 1989. Similar expansion of irrigated acreage has occurred in Tazewell, Lee, Whiteside, Kankakee, and several other counties. The Illinois State Water Survey estimates that 250,000 acres are currently irrigated in Illinois, and irrigation farmers are expected to place at least 20,000 more acres under irrigation within the next five years.

Although the expansion of irrigated farming in Illinois will likely continue, few research efforts have been undertaken to quantify irrigation ground-water use. Several questions arise:

- How much water is used to irrigate corn and soybeans, the predominant irrigated crop types in Illinois, during a year with normal rainfall?
- How does irrigation water use vary with crop type, soil type, and single- or double-cropping methods?
- How do farmers' irrigation scheduling practices vary?

Questions about irrigation water use, efficiency, scheduling accuracy, soil-water management, and ground-water management are being raised in Illinois and other midwestern states that have expanding agricultural irrigation industries. Answers are being sought by both irrigation farmers and water resources managers. Irrigation farmers would like to know how to reduce energy and water waste and improve the efficiency of their operations; water resources managers would like to know how much water irrigation uses, how much that quantity will likely increase, and what effect irrigation consumption will have on other water uses. With the possibility of large expansions of irrigated acreage, some of the key questions about irrigation in Illinois should be addressed.

With agricultural irrigation clearly gaining importance in Illinois with respect to regional agricultural economies and water resources management, a study was undertaken to gather baseline data on irrigation water use and practices in the state. This report describes the results of this two-year irrigation field study completed in Illinois for the 1988 and 1989 growing seasons. The purpose of the study was to characterize irrigation practices and estimate seasonal irrigation ground-water use at 214 irrigation sites in the Havana Lowlands (Mason and southern Tazewell Counties) and the Green River Lowlands (Lee and Whiteside Counties), the two most heavily irrigated regions in the state. These sites are generally representative of irrigation operations in those regions.

The objectives of the study were:

1. To evaluate irrigation practices by monitoring a sample of irrigation farmers over a specified period of time;
2. To compare irrigation water use during normal and drought years;
3. To evaluate scheduling effectiveness and variability of water use patterns by irrigation farmers; and
4. To evaluate the role of soil type in determining irrigation water use.

Previous Studies

Very little research has been conducted to provide answers to specific irrigation questions in Illinois. However, a number of related studies provided valuable background for this investigation. The studies were primarily directed toward (1) characterizing hydrogeologic conditions in the Havana Lowlands and Lee and Whiteside Counties (including the Green River Lowlands), (2) evaluating the potential for irrigation development in Illinois and the Midwest, and (3) examining the effects of irrigation on crop yields and farm profitability in the Upper Midwest, particularly on southern Illinois claypan soils. These previous studies are briefly reviewed here.

Walker et al. (1965) described the hydrogeology of the Havana Lowlands region in Mason and Tazewell Counties and evaluated hydraulic properties of the sand and gravel aquifer underlying the region. Hanson (1955) examined ground-water quality and yields of municipal, industrial, and some farm and domestic wells in Lee and Whiteside Counties. Foster (1956) described hydrogeologic conditions in Lee and Whiteside Counties and discussed ground-water availability in each township of the area. These studies were completed prior to any significant development of irrigation in either area.

Bowman and Collins (1987) estimated statewide irrigation water use for varied weather conditions using a simple water-balance model and information on soil moisture, precipitation, evaporation, temperature, and crop type. Irrigation water-use quantities were computed on a township basis and compared to ground-water potential yield information by township.

The impact of irrigation development on a dolomite aquifer in eastern Kankakee and northern Iroquois

Counties has been investigated by Cravens et al. (1990) and Cravens and Wilson (1989). Based on ground-water use data, precipitation records, and hydrogeologic conditions, this study concluded that the magnitude of water-level declines in the dolomite aquifer was more a result of variable hydrogeologic conditions than of pumpage or of climatic changes.

The geographic and economic feasibility of using a surface impoundment as a water source for irrigation on claypan soils in southern Illinois was studied by Scott et al. (1986). The researchers concluded that a significant potential for profitable irrigation existed where surface impoundments were available.

In an interinstitutional regional study of efficient irrigation water use in the Midwest, Stout et al. (1983) concluded that many areas of the Midwest possess adequate ground water and surface water to support irrigation development. The researchers also concluded that yield differentials between irrigated and nonirrigated crops would be moderate on soils with high moisture-holding capacities and high on soils with low moisture-holding capacities and claypan soils, even in regions with relatively high annual precipitation.

Walker et al. (1981) and Sipp et al. (1984) investigated the effects of drainage and irrigation methods on crop yields. Walker et al. (1981) concluded that yields on claypan soils in a humid climate increased significantly with the addition of irrigation or drainage alone. Both studies demonstrated that crop yields increased synergistically with the addition of both irrigation and drainage improvements and that the method of irrigation and drainage had little effect on crop yield.

Sipp et al. (1984) also concluded that (1) yields were significantly higher for irrigated corn than for nonirrigated corn, even during years of adequate precipitation; (2) soybeans were less responsive to irrigation than corn; (3) irrigation of corn at less than 50 percent soil-moisture depletion had no effect on yield; (4) most efficient water use was accomplished when irrigation was scheduled using soil-moisture monitoring devices or a checkbook method; (5) double-cropped soybeans were potentially profitable when irrigation was used; and (6) the selection of corn and soybean hybrids strongly influenced irrigated yields.

The work described in this report builds on previous research efforts to gain more specific knowledge of statewide irrigation practices and water use. Information from this report is also summarized in Bowman et al. (1991).

Acknowledgments

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DESCRIPTION OF STUDY AREAS

The study regions, containing more than 150,000 irrigated acres, included Mason County and a portion of Tazewell County in central Illinois (Havana Lowlands) and portions of Lee and Whiteside Counties in northwestern Illinois (Green River Lowlands). The regions are representative of field and vegetable crop irrigation requiring large ground-water withdrawals (figure 1). The Havana Lowlands and the Green River Lowlands have highly permeable soils that require supplemental irrigation even in years with normal amounts of precipitation (36.98 and 35.08 inches, respectively). The regions are also underlain by highly productive shallow sand and gravel aquifers in buried bedrock valleys. These two conditions, sandy soils and abundant ground water, are also found in most of the other irrigated areas in Illinois.

Havana Lowlands Study Area

The Havana Lowlands region encompasses all of Mason County and four townships in Tazewell County. The region is roughly triangular in shape and is bounded on the west by the Illinois River, on the south by the Sangamon River and Salt Creek, on the north by the city of Pekin, and on the east by a north-south line dividing ranges 4 and 5 west (figure 2).

Walker et al. (1965) identified three main physiographic areas within the Havana Lowlands: (1) the floodplains of the Illinois, Sangamon, and Mackinaw Rivers and Salt Creek, (2) the wide sand-ridged terraces east of the Illinois River, and (3) the loess-covered Illinoisan drift upland in southeast Mason County. Land surface elevations in the area range from 433 feet above sea level along the Illinois river near Snicarte in southwest Mason County to nearly 740 feet above sea level in southeast Mason County near Mason City.

Although the Mackinaw River crosses southern and western portions of Tazewell County, surface drainages within Mason County are poorly developed. The Quiver and Crane Creek Basins, however, have been developed to drain formerly marshy areas in northern and southern parts of the county.

Climate

The warmest month on average during the 1960-1989 period was July, with an average mean temperature of 77°F. January was the coldest month on average, with a mean temperature of 23°F.

The Havana station received an average of 36.98 inches of precipitation during the 23-year period. The wettest year was 1973, with recorded precipitation totaling 55.47 inches. The wettest month on average was May, receiving 3.94 inches. The driest month on average was February, receiving only 1.62 inches. The driest summer (June-August) occurred in 1983, when precipitation totaled only 4.44 inches. Only 23.14 inches of precipitation were recorded during 1989, the driest year.

Soils

The soils in the Havana Lowlands are generally characterized by their low moisture-holding capacities. Fehrenbacher et al. (1984) recognized four soil associations in the area. Soils of the Oakville-Lamont-Alvin, Sparta-Dickinson-Onarga, and Plano-Proctor-Worthen soil associations were formed in sandy glacial outwash, sandy alluvium, or sandy aoelian material, and typically exhibit moderate to low water-holding capacities. Soils of the Jasper-LaHogue-Selma soil association were formed under grass in varying thicknesses of silty or loamy material sandy deposits and typically exhibit moderate moisture-holding capacities. Crop stress, fertility management, and wind erosion pose significant problems to crop cultivation on soils in much of the Havana Lowlands. But the high permeabilities of these soils facilitate rapid precipitation recharge to the underlying sand and gravel aquifer.

Human Activity

The predominant economic activity in the 700-square-mile area is crop farming. Irrigation of crops is of increasing importance in the area; currently nearly 117,000 acres are irrigated. More than 1,000 irrigation systems, primarily center-pivots, are present in the area. Irrigated crops include field corn, seed corn, popcorn, soybeans, winter wheat, and numerous vegetable crops. Mason County has a population of 19,492. Havana, the county seat, with a population of 4,277, is the largest town in the county. The largest town in the Tazewell County portion of the study area is Green Valley, with a population of 768. All population data are from 1980.

Figure 1. Counties included in the study: Mason, Tazewell, Lee, and Whiteside

Ground-Water Resources

The productive sand and gravel aquifer underlying the Havana Lowlands originated as a Pleistocene alluvial deposit at the site of the confluence of the ancient Mississippi River, which was roughly coincident in position with the present lower Illinois River valley, and the ancient Teays River, a major river that drained much of the Midwest east of the present Illinois River. The preglacial Mississippi and Teays Rivers had eroded valleys in the bedrock surface, and their confluence at the Havana Lowlands was marked by a broad lowland. Meltwater from Pleistocene glaciers supplied abundant sand and gravel to the ancient Mississippi and Teays River valleys, as well as to other preglacial bedrock valleys in the Midwest, and the valleys were slowly filled with sediment. The Teays River valley was one of several preglacial drainages that was eventually completely abandoned by the stream or river that formerly occupied it. The Teays River valley was abandoned during an early pulse of Pleistocene glaciation, which subsequent glacial advances buried under a thick blanket of comparatively fine-grained glacial sediment, known as glacial drift. Walker et al. (1965) provide a detailed discussion of the origin, composition, and distribution of the Havana Lowlands aquifer.

Wells finished in these sand and gravel deposits supply all of the area's water needs except power generation, which uses Illinois River water. In 1986, ground-water withdrawals totaled 54.312 million gallons per day (mgd) and 32.222 mgd, respectively, in Mason and Tazewell Counties (table 1). Reported withdrawals for public systems totaled 0.899 mgd and 13.117 mgd, respectively, and industrial withdrawals totaled 1.093 and 36.511 mgd, respectively. Ground-water withdrawals for fish and wildlife were reported to be 8.190 mgd in Mason County, of which most was used by the Jake Wolf Memorial Fish Hatchery, and less than 1.001 mgd in Tazewell County. The importance of irrigation in these counties is reflected in the 1989 estimates of irrigation ground-water use, which amount to 89 percent of total daily ground-water use in Mason County and 32 percent of total daily ground-water use in Tazewell County.

Table 1. Havana Lowlands Ground-Water Use, 1986

(million gallons per day)

	County	
User	*Mason*	*Tazewell*
Public +	0.889	13.117
Self-supplied industry +	1.090	36.511
Fish and wildlife +	8.190	1.001
Irrigation (1989 estimates)	82.700	23.300
Totals	92.900	73.900

+ *After Kirk, 1987*

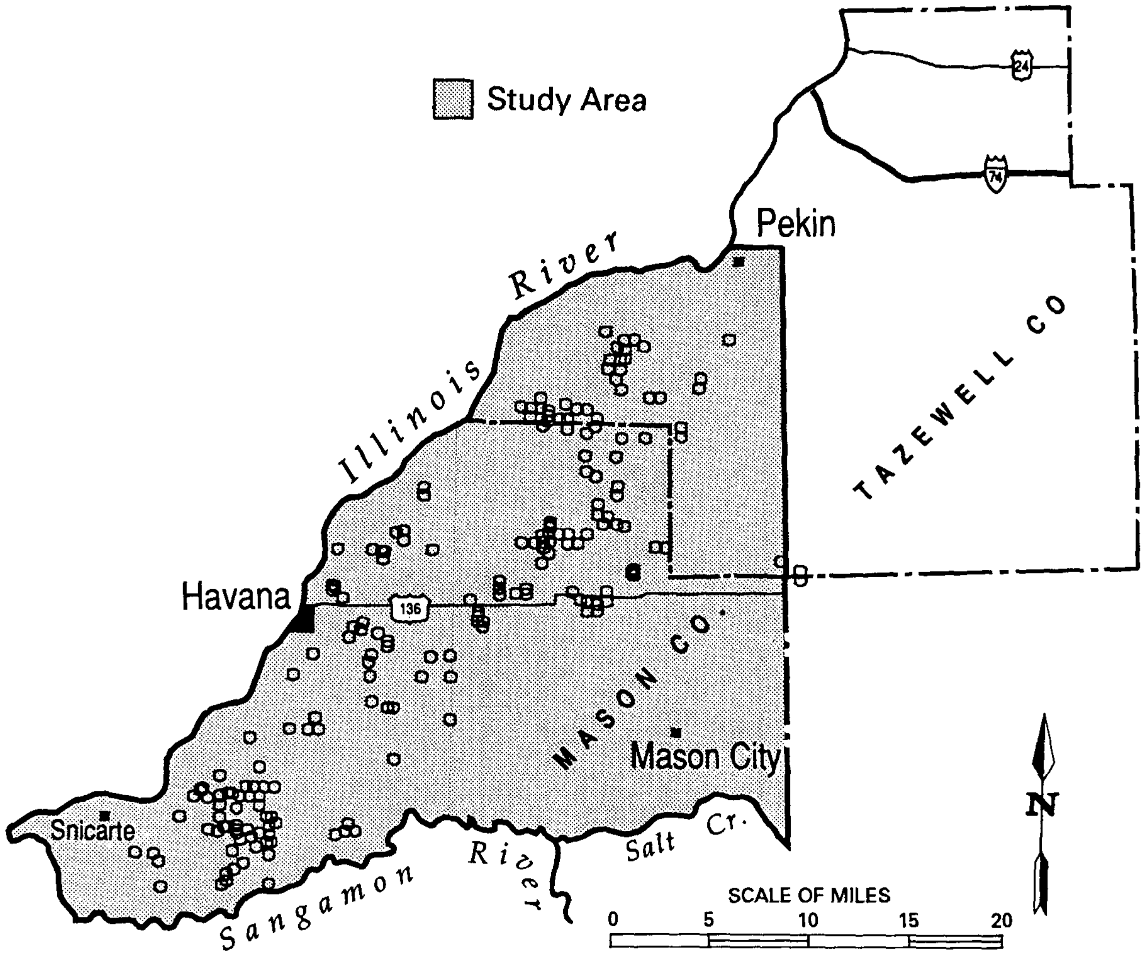

Figure 2. Irrigation study sites in Mason and Tazewell Counties (Havana Lowlands)

Actual daily irrigation ground-water use during the growing season (May 1 to August 31), the period of greatest irrigation, greatly exceeds the figures reflected in table 1. These figures represent averages over a one-year period so that irrigation can be compared to other ground-water withdrawals. Estimates of seasonal irrigation pumpage in the Havana Lowlands were based on data obtained during this field study, approached 425 mgd in 1989.

Green River Lowlands Study Area

The Green River Lowlands region consists of 11 townships in Lee and Whiteside Counties (figure 3). Most irrigation in Lee County occurs in the west central townships of East Grove (T.19N., R.9E.), May (T.19N., R.10E.), Marion (T.20N., R.9E.), and Amboy (T.20N., R.10E.). Another area of irrigation includes the townships of Nelson (T.21N., R.8E.), Harmon (R.20N., R.8E.), and Hamilton (T.19N., R.8E.) in western Lee County. In Whiteside County, most of the irrigation occurs in the southwestern townships of Hume (T.20N., R.6E.), Montmorency (T.20N., R.7E.), Tampico (T.19N., R.6E.), and Hahnamnan (T.19N., R.7E.).

Two physiographic areas are present in Lee and Whiteside Counties: (1) broad floodplain areas formed by the Mississippi, Rock, and Green Rivers, and (2) rolling Illinoisan and Wisconsinan morainal uplands. The Mississippi River forms the western boundary of Whiteside County, where elevations as low as 570 feet above sea level occur near Albany. The Rock River, which flows from northeast to southwest, passes through Dixon and Sterling-Rock Falls to the Mississippi River. The Green

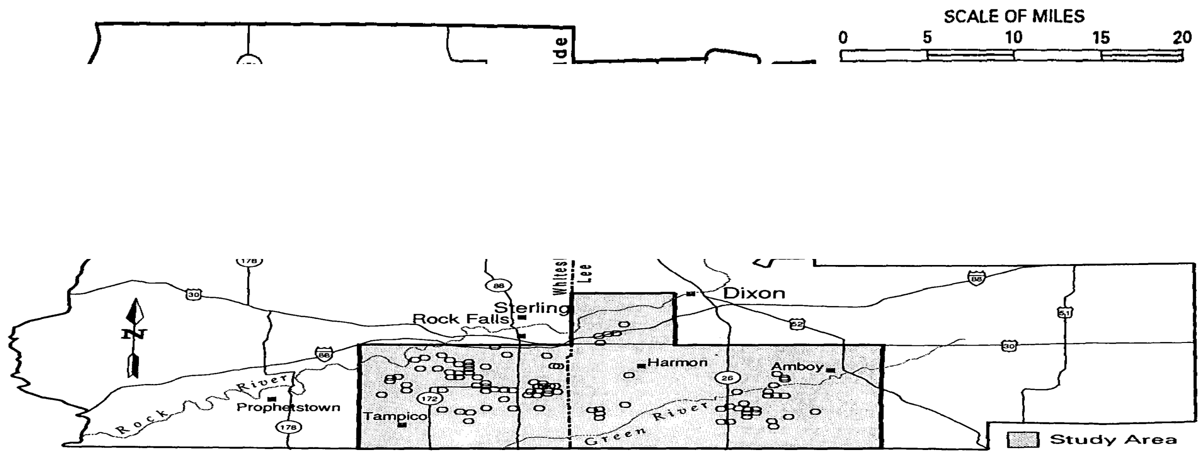

Figure 3. Irrigation study sites in Lee and Whiteside Counties (Green River Lowlands)

River, which has a similar trend, passes through Amboy and southeastern Whiteside County. Gently rolling morainal uplands make up northern Whiteside and central and southeastern Lee Counties. The highest elevations in the two counties, 950-990 feet above sea level, occur in southeastern Lee County near Lee.

Climate

The warmest month on average during the 1960-1989 period was July, with an average mean temperature of 74°F. January was the coldest month on average, with a mean temperature of 19°F.

The Dixon station received an average of 35.08 inches of precipitation during the 30-year period. The wettest year was 1989, and the wettest month on average was June, receiving 4.24 inches of precipitation. The driest month on average was February, receiving 1.11 inches. The driest summer occurred in 1988, when precipitation totaled only 3.55 inches. Only 22.99 inches of precipitation were recorded during 1976, the driest year.

Soils

The soils in the Green River Lowlands are similar to those in the Havana Lowlands and are generally characterized by their low moisture-holding capacities. Fehrenbacher et al. (1984) recognized four soil associations; they are the Sparta-Dickinson-Onarga, Jasper-LaHogue-Selma, Plano-Proctor-Worthen, and Lorenzo-Warsaw-Wea soil associations. The latter occurs in small areas. These soils were formed under grass in loamy and silty materials on sand and gravel outwash deposits. The upper soil strata exhibit moderate to low moisture-holding capacities, and the lower strata exhibit low to very low moisture-holding capacities. The problems associated with crop cultivation on highly permeable soils experienced in the Havana Lowlands are also encountered in the Green River Lowlands.

Human Activity

In the Green River Lowlands, as in the Havana Lowlands, the predominant economic activity is crop farming. Nearly 34,000 acres of cropland are irrigated annually in Lee and Whiteside Counties. Although irrigation is much less predominant at a regional scale than in the Havana Lowlands, the dense concentration of irrigation systems in the 11 townships named above has aroused public concern over irrigation practices and their impact on regional ground-water resources. Irrigated acreage in this area expanded by an estimated 50 percent from 1988 to 1989, and further development is expected. Irrigated crops include field corn, seed corn, soybeans, green beans, peas, and lima beans.

Amboy, in Lee County, is the largest town in the Green River Lowlands, with a population of 2,377. The second largest town is Tampico, in Whiteside County, with a population of 966. The populations in Lee and Whiteside Counties are 36,328 and 65,970, respectively. All population data are from 1980.

Ground-Water Resources

Like that of the Havana Lowlands, the productive sand and gravel aquifer underlying the Green River Lowlands originated as an alluvial deposit in a Pleistocene and pre-Pleistocene lowland north of the confluence of the ancient Mississippi and Rock Rivers in central Bureau County. Meltwater from Pleistocene glaciers deposited sand and gravel in this lowland and in the ancient Mississippi and Rock River valleys bounding it on the east, west, and south. Foster (1956) discusses in detail the origin, composition, and distribution of the sand and gravel aquifer in the Green River Lowlands.

Approximately 65 percent of the ground water used in Whiteside and Lee Counties is supplied by the sand and gravel aquifer of the Green River Lowlands, and nearly all of the irrigation wells in the area obtain water from this aquifer. The remaining 35 percent of ground water used in the area is obtained from Silurian-Devonian and Cambrian-Ordovician aged bedrock aquifers.

Table 2 gives estimates of daily ground-water pumpage in Lee and Whiteside Counties during 1986. In Lee County, ground-water withdrawals for public systems, self-supplied industry, and fish and wildlife categories totaled 3.680 mgd, 0.100 mgd, and 0.001 mgd, respectively. In Whiteside County, these categories respectively totaled 4.234 mgd, 2.325 mgd, and 0.005 mgd. Estimated irrigation ground-water pumpage for 1989 totaled 8.202 mgd (Lee County) and 10.871 mgd (Whiteside County).

Table 2. Green River Lowlands Ground-Water Use, 1986

(million gallons per day)

	County	
User	*Lee*	*Whiteside*
Public+	3.680	4.234
Self-supplied industry+	0.100	2.325
Fish and wildlife+	0.001	0.005
Irrigation (1989 estimates)	8.202	10.871
Totals	11.943	17.435

+ *After Kirk, 1987*

Ground-water withdrawals totaled 11.943 mgd (Lee County) and 17.435 mgd (Whiteside County).

This investigation indicated that daily irrigation pumpage in the Green River Lowlands approached 77 mgd during the 1989 growing season. The method used in this investigation for estimating irrigation pumpage is described in the "Methods" section.

CHARACTERIZATION OF IRRIGATION STUDY SITES

To characterize irrigation practices and quantify irrigation water use in the two study areas, irrigation farmers were interviewed and permission was sought to monitor their irrigation systems through two growing seasons. Each study site included an irrigation well or irrigation system or both at which ground-water levels and water use were monitored. Forty irrigation farmers with 195 study sites in the Havana Lowlands and 27 irrigation farmers with 65 study sites in the Green River Lowlands agreed to participate in the field studies.

During initial site visits, descriptive information was collected regarding well location, type of irrigation system (diesel or electric power source, system pressurization, and center-pivot or traveling gun system), crop types, and soil types. Quantitative information such as pumping rate of the well, irrigated acreage, soil moisture content, and nonpumping water levels in the irrigation wells was also recorded. A subset of these sites was visited biweekly throughout the 1989 growing season to observe irrigation scheduling patterns.

Of the 214 irrigation systems monitored, none were identical. Even system types used by an individual farmer often differed markedly. Characteristics of the sites visited during the field studies can be found in appendices A and B at the back of this report. Center-pivot systems were predominant, but a few traveling gun systems were operated in each area. Center-pivot pressurizations ranged from low (10-20 pounds per square inch (psi)) to medium (30-40 psi) to high (50-60 psi) and covered 40 to 290 acres per revolution. Because buildings, roads, drainage ditches, and treelines frequently limited the pivots to less than one complete revolution, some irrigation farmers were forced to operate their systems in a windshield wiper fashion. The center-pivot systems, usually equipped with end guns or corner systems, were powered by diesel engines or electric motors of various brands and sizes. Pumping rates ranged from 300 to 2300 gallons per minute (gpm).

A wide variety of crops were grown under irrigation in the study areas. Typical crops included field corn, seed corn, popcorn, sweet corn, soybeans, green beans, peas, wheat, cucumbers, and tomatoes. In addition, potatoes, lima beans, pumpkins, watermelons, cantaloupes, and a variety of other vegetable crops were observed. Generally, one or two different crop types were grown in an irrigated field, but one farmer reported producing four different crops during one season under a center-pivot system. Several of the fields produce two crops during one season (double-cropping) by growing successive "short-season" crops of cucumbers, green beans, and sweet corn that require only 8 to 10 weeks to mature. At least one field was known to have grown three cucumber crops during the 1989 season. But an early frost on September 24, 1989 destroyed this third crop as well as the second cucumber crop on many other irrigation farms.

All of the irrigation systems monitored use wells as a water-supply source. Although a few wells in the Green River Lowlands tapped bedrock ground water at a depth of 480 to 505 feet below land surface, the vast majority of the irrigation wells obtain ground water from the sand and gravel aquifers described previously. These wells ranged in depth from 20 to 170 feet below land surface.

A single well may supply one or more stationary or towable irrigation systems. Towable center-pivots may be used with a single well to irrigate several fields using a network of underground pipeline. One participating farmer irrigated as many as five separate 40-acre fields from one well and a towable center-pivot. Another farmer regularly towed a center-pivot system across a highway from one well to another.

METHODS

Estimating Irrigation Water Use

Many irrigation systems are operated for short periods of time to reposition a center-pivot system or test the system without irrigating. Because this time is negligible in comparison to the seasonal total, hours of system operation time recorded are assumed to equal the duration of irrigation pumpage. Irrigation water use, measured in inches of irrigation water applied, was estimated by the following equation:

$$It = 0.00221Q * H/A$$

where It is the total irrigation water applied between field visits (inches), Q is the estimated pumping rate from the irrigation well (gpm), H is the duration of irrigation pumpage between field visits (assumed equivalent of system operation time in hours), and A is the irrigated area in acres. The constant 0.00221 is used to convert gpm to acre-inches per hour.

Estimation of Pumping Rates

Unlike many heavily irrigated, arid western states, Illinois and many other midwestern states do not require metering and reporting of irrigation pumpage. The addition of flowmeters is an optional, yet significant expense for irrigation farmers, who seldom include them at the time of irrigation system installation. Means for measuring irrigation pumpage rarely exist. For a scientific study, researchers could purchase and install permanent metering devices, but the costs for a regional study are usually prohibitive. Because none of the irrigation systems monitored in this study were equipped with permanent metering devices, pumping rates were estimated based on the irrigation system design flow rates. In many cases, this information was provided by participating farmers from installation records for their irrigation systems. Thus, for the purposes of this report, the flow rates used to determine irrigation water use were called "farmer-estimated" flow rates. This is not meant to convey that participating farmers simply guessed at their system flow rates.

Considerable attempt was made to independently verify the farmer-estimated flow rates using both external and internal flow measurement devices. Given the variations in irrigation system configuration, the possibility of improper flowmeter calibration, and the potential for operator error, the flowmeters did not produce reasonable validation of the original farmer-estimates. Although the flowmeter data were not used to compute irrigation water use in this study, the process of collecting and eliminating this data is discussed.

Ultrasonic Flowmeter

The ultrasonic flowmeter, portable and designed for monitoring flow rates through a wide range of pipe diameters, measures flow rate externally. This meter consists of two transducers that are placed on opposite sides of the pipe through which flow is to be measured. One transducer transmits a signal of known frequency into the pipe. The signal, altered by the flow of water through the pipe, is received by the other transducer. If properly calibrated, the ultrasonic flowmeter calculates flow velocity by comparing the frequencies of the transmitted and received signals. Flow rate is calculated by multiplying the flow velocity measured by the ultrasonic flowmeter and the cross-sectional area of the pipe.

Intrusive Flowmeter

The intrusive flowmeter operates by measuring the spin rate of a l-inch diameter paddlewheel protruding ½- inch into the flow. The paddlewheel axis is perpendicular to the flow and the meter housing is normal to the discharge pipe. A signal converter changes the electromagnetic current generated by the paddlewheel to an electric current compatible with datalogging and portable computer equipment. This instrument was used to record short- and long-term pumping rates during six well production tests, ranging in duration from 1 to 5 hours.

Farmer-Estimated Flow Rates

Farmer-estimated flow rates (system design flow rates) were used for final computation of irrigation water use due to apparent inaccuracies with the flowmeters. The irrigation farmers based their estimates on records and personal knowledge of the pumping rates for which the system was originally designed. Though irrigation farmer-estimated pumping rates may be slightly higher than actual pumping rates due to well deterioration or modifications to the system since installation, large discrepancies in pumping rate would cause pressure changes in the irrigation system, creating system malfunction. For that reason, it was assumed that the design pumping rate would be reasonably close to the actual pumping rate.

Ultrasonic flow measurements were made at 70 sites during 1988 to verify irrigation farmer-estimated flow rates. Table 3 compares ultrasonic flowmeter measurements to irrigation farmer-estimated pumping rates. As the table indicates, the flowmeter measurements were generally lower (up to 80 percent). Only 14 measurements fell within 10 percent of the farmers' estimates of pumping rate. Separate flowmeter measurements at the same site were also commonly inconsistent, as were measurements from simultaneous use of two flowmeters.

In 1989, both ultrasonic flowmeters were recalibrated. Optimal flow measurement environments (according to manufacturer's recommendations) at 23 sites were selected in both study areas and visited two or three times during the season. Again, the results were low and inconsistent (table 4).

Similar problems were encountered with the intrusive flowmeter. When pumping rates during well production tests were altered by adjusting a backflow check valve or diesel engine throttle, the measured increases and decreases in flow rates corresponded to adjustments in pumping rates. However, these measurements differed significantly from the farmer-estimated flow rates.

Estimation of Irrigation System Operation Time

Most of the information about irrigation system operation time was collected from the hour meters in the control box of center-pivot systems. There were 118 hour meters in the study, of which 15 were broken. The remaining working hour meters were read in spring and fall 1989 to estimate seasonal water use at these sites. At sites where both diesel engine meters and center-pivot control box hour meters were available, readings from the latter were used to record system operation time. A subset of the most accessible sites with working hours meters were visited biweekly to determine irrigation scheduling patterns in the Havana and Green River Lowlands.

Diesel engine hour meters provided unreliable operation time estimates. Of 49 diesel engines monitored in the Havana Lowlands, 13 lacked hour meters and 13 others had broken hour meters. Where both diesel engine and control box hour meters were available, the former typically recorded more operation time (diesel engines are often run for short periods to warm the motor or to move the system when not irrigating). Estimates of irrigation system operation time were dependent upon diesel engine meters at 30 sites and 23 sites in the Havana and Green River Lowlands, respectively. Seasonable water use was determined from meters read in spring and fall 1989.

Participating irrigation farmers were also asked to record daily water applications in notebooks distributed during spring 1989. Each notebook contained a descrip tion and the location of all irrigation systems operated by the farmer, and tables to record water use and rainfall amounts. Most irrigation farmers kept incomplete records, which will be discussed further in the Results section.

Estimation of Soil Moisture Characteristics

Soil water characteristics for each site in the study were based on regional soil maps from the U.S. Soil Conservation Service. Study sites were superimposed onto the soil maps to determine the percentage of each soil series under the irrigation system. Published information (Fehrenbacher et al., 1984) for each soil series on available moisture in the upper 60 inches of soil was aerially weighted for each site to obtain an average field capacity for the root zone, assumed to be about 36 inches at plant maturity. Also noted for each site were the moisture availability and percentage of area of the most "draughty" soil with the lowest moisture-holding capacity within range of the irrigation system.

Also for the purposes of this report, irrigated fields in which 51 percent or more of the soils possessed moderately rapid to rapid permeabilities, according to soil series descriptions, were considered rapidly permeable soils. Fields in which 50 percent or more of the soils possessed moderate to moderately rapid permeabilities were considered moderately permeable soils.

Rainfall and Evaporation Records

Many of the participating irrigation farmers maintained raingages and recorded rainfall totals in their notebooks. Daily rainfall data were also recorded at National Weather Service stations in Havana, Mason City, Dixon, and Morrison, Illinois. Pan evaporation was measured daily at the Sand Field Research Station in Bath, Illinois (Mason County), operated by the University of Illinois Department of Agronomy. Pan evaporation measurements were not available for the Green River Lowlands study area.

Nonpumping Water Level Measurements

Nonpumping water levels were measured, where possible, using a steel tape, incremented to hundredths of an inch, and carpenter's chalk. Many wells in the study either had no access ports or ones inadequate to make water-level measurements. During this study, it became apparent that such access ports were seldom installed on irrigation wells even though they provide an inexpensive, effective means for an irrigation farmer to maintain important information. Because an irrigation farmer's operation is so inextricably tied to well and ground-water resources, every irrigation well should be expected to be equipped with an access port. Continued education on this important point is needed for farmers, irrigation well drillers, and irrigation system dealers.

Table 3. Comparison of Ultrasonic Flowmeter Measurements and Farmer-Estimated Flow Rates, 1988

	Havana Lowland Sites				*Green River Lowland Sites*		
Site	*Farmer's estimate*	*First meas.*	*Second meas.*	*Site*	*Farmer's estimate*	*First meas.*	*Second meas.*
MT1	950	400	-	LWl	700	431	-
MT2	1100	482	-	LW2	900	353	251
MT5	950	988	-	LW6	800	225	-
MT6	700	575	-	LW7	700	740	-
MT8	1100	330	-	LW15	700	200	-
MT9	1100	1239	941	LW16	1000	868	-
MT24	600	618	-	LW17	650	468	-
MT26	900	884	-	LW18	620	141	-
MT42	300	300	528	LW23	1000	455	-
MT43	350	300	-	LW24	400	440	-
MT44	300	308	615	LW25	350	253	-
MT46	300	550	467	LW26	900	793	-
MT47	400	388	318	LW34	600	649	511
MT50	900	421	852	LW35	900	659	-
MT51	1000	686	-	LW37	500	168	-
MT52	500	437	-	LW42	800	957	-
MT54	1200	627	-	LW43	900	369	560
MT56	600	402	-	LW46	1200	267	-
MT57	1250	386	289	LW47	1200	627	188
MT58	1650	1164	1323	LW49	350	260	-
MT59	1000	641	-	LW50	1200	627	563
MT60	850	488	-	LW52	700	334	-
MT61	950	972	412	LW54	700	1030	-
MT62	800	305	692	LW57	450	525	-
MT63	800	467	-	LW61	800	807	-
MT92	1000	1092	-	LW62	500	478	280
MT93	400	154	260	LW63	900	314	274
MT94	400	447	-	LW64	800	486	345
MT95	400	447	-	LW65	700	388	-
MT97	1000	422	380	LW67	800	708	708
MT99	1000	844	-	LW86	750	692	-
MTll3	1000	766	857	LW87	1000	305	-

Table 3. Concluded

	Havana Lowland Sites				Green River Lowland Sites		
Site	*Farmer's estimate*	*First meas.*	*Second meas.*	*Site*	*Farmer's estimate*	*First meas.*	*Second meas.*
MT136	800	878	-				
MT137	500	549	-				
MT139	560	862	-				
MT142	700	235	857				
MT174	1000	221	-				

Table 4. Comparison of Ultrasonic Flowmeter Measurements and Farmer-Estimated Flow Rates, 1989 (Havana Lowlands)

Site	*Farmer's estimate*	*First meas.*	*Second meas.*	*Third meas.*	*Site*	*Farmer's estimate*	*First meas.*	*Second meas.*	*Third meas.*
MT8	1100	614	-	-	MT108	750	308	-	-
MT10	300	436	-	-	MTll8	1000	954	-	-
MT12	900	355	937	355	MT127	700	275	-	-
MT18	1000	1034	-	-	MT128	850	172	-	-
MT27	900	840	-	-	MT130	850	283	275	-
MT28	1050	133	-	-	MT141	1200	1341	1123	-
MT57	1250	1325	1325	323	MT142	700	1147	1115	1107
MT58	1650	450	-	-	MT165	800	362	436	493
MT61	950	808	792	-	MT171	700	355	242	-
MT81	1000	884	-	-	MT174	1000	282	300	-
MT86	800	986	-	-	MT175	950	1147	-	-
MT92	1000	1033	994	-					

RESULTS

The results from this study are presented in three sections: General Results, Annual Irrigation Totals, and Seasonal Irrigation Time Series. The second section summarizes quantities and explores plausible explanations for variances in irrigation water use. Some emphasis is given to the 1989 growing season because of the limited data available from 1988. The third section summarizes specific watering patterns in the 1989 growing season, based on biweekly observations in the Havana Lowlands study region. Comparisons of water use and evapotranspiration shown in the third section do not reflect the Green River Lowlands study data because of the lack of evapotranspiration information from that area.

General Results

In both the Havana and Green River Lowlands, irrigation water use on double-cropped fields slightly exceeded single-cropped fields. In the Havana Lowlands, double-cropped fields received an average of 15.4 inches of water (25 samples), while single-cropped fields received an average of 14.3 inches of water (38 samples). In the Green River Lowlands, double-cropped fields received an average of 8.1 inches of water (4 samples), while single-cropped fields received an average of 6.8 inches of water (29 samples).

Figure 4 compares average water use on field corn and popcorn (16.3 inches) and soybeans (12.6 inches) in the Havana Lowlands. Because only a few study sites in the Green River Lowlands produced soybeans, no comparison could be made of irrigation water use by crop type.

Variations in single-cropped field water use on rapidly permeable soils were also observed in the Havana Lowlands. Field corn and popcorn received an average of 16.3 inches of water (28 samples) while soybeans received 10.3 inches (4 samples).

Tables 5 and 6 show 1989 biweekly and seasonal total irrigation operation time (irrigation hours). Tables 7 and 8 show computed biweekly and seasonal total water use in inches. For a review of farmer-estimated flow rates used to compute these water use amounts, see appendices A and B. Tables 9 and 10 list soil permeabilities (Fehrenbacher et al.,1984) at selected sites in both study areas.

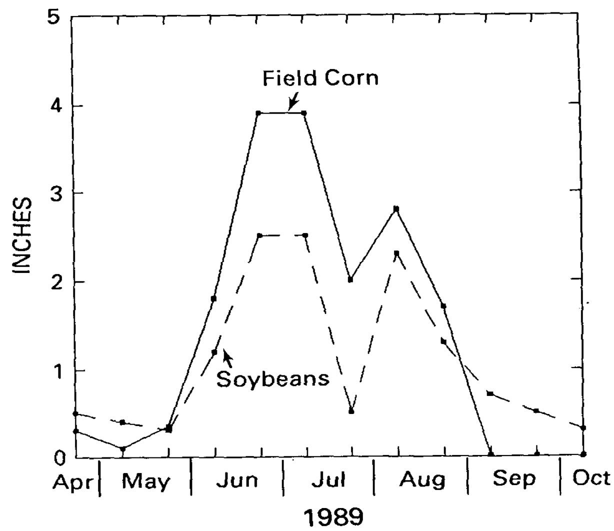

Figure 4. Average 1989 irrigation water use for corn (field corn and popcorn) and soybeans in the Havana Lowlands

Tables 11 and 12 report nonpumping water levels in the Havana and Green River Lowlands. These tables list (1) water levels at 154 sites in September 1988, March 1989, and September 1989, and (2) the change in water level between each measurement. Nonpumping water levels were not measured at a number of the study sites because an access port at the base of the well was either missing or prevented access to the water between the pump column and well casing. Of the 154 sites at which water levels could be measured, 110 were in the Mason-Tazewell County area and 44 were in the Lee-Whiteside County area.

Table 5. Biweekly and Seasonal Irrigation Hours, 1989 (Havana Lowlands)

Site	*3/1-5/10*	*5/10-5/24*	*5/24-6/7*	*6/7-6/21*	*6/21-7/5*	*7/5-7/20*	*7/20-8/3*	*8/3-8/17*	*8/17-8/29*	*8/29-9/14*	*9/14-9/27*	*9/27-10/1*	*Totals*
MT2	0.3	0.0	37.3	82.0	161.9	153.8	51.3	97.3	42.3	0.5	0.0	0.0	627
MT8	10.3	1.0	23.5	171.4	190.8	117.9	93.3	94.7	71.1	9.2	0.0	0.0	783
MT10	7.4	19.3	31.0	106.1	25.6	0.0	18.1	63.7	39.6	21.0	46.7	0.6	379
MT26	0.0	0.0	30.7	102.3	227.4	192.7	62.7	186.0	114.5	0.1	0.0	0.0	916
MT27	35.1	0.0	0.0	170.4	236.0	270.9	168.3	7.6	253.2	0.0	0.0	0.0	1142
MT28	19.9	0.0	0.0	0.8	174.4	82.3	62.4	84.0	64.3	0.6	0.0	0.0	489
MT29	0.7	0.0	1.3	90.8	172.2	209.1	53.5	133.5	96.0	0.0	0.0	0.0	757
MT30	0.0	0.0	0.0	68.0	0.0	73.6	0.0	77.9	45.2	19.3	44.2	14.2	342
MT31	0.0	0.0	0.0	94.0	281.7	309.2	114.9	306.8	43.3	0.0	0.0	0.0	1150
MT32	0.0	0.0	0.0	94.0	281.7	309.2	114.9	306.8	43.3	0.0	0.0	0.0	1150
MT33	75.3	0.0	4.1	69.7	148.4	155.1	55.6	183.8	60.9	43.8	0.0	4.2	801
MT34	0.0	70.6	55.9	106.9	242.3	133.5	0.0	156.9	132.2	48.2	0.0	0.0	947
MT36	0.0	0.0	0.0	62.0	139.1	220.6	103.0	159.8	121.7	0.0	0.0	0.0	806
MT37	2.2	0.0	31.9	72.1	226.5	230.7	37.2	187.4	110.4	50.6	39.4	0.0	988
MT38	0.0	0.0	0.0	87.1	250.7	231.7	125.3	216.5	130.3	0.0	0.0	0.0	1042
MT39	1.0	0.0	128.0	107.4	139.0	0.0	132.0	118.7	93.8	9.4	0.0	0.0	729
MT41	10.6	0.0	14.1	122.7	338.3	144.4	38.7	235.0	84.0	1.7	3.7	0.0	993
MT46	28.1	0.0	0.0	93.1	181.3	204.8	113.5	175.5	113.4	0.0	0.0	0.0	910
MT47	10.9	0.0	0.0	70.2	173.8	160.9	60.7	85.0	85.0	0.0	0.0	0.0	647
MT50	0.3	11.5	0.0	130.3	257.0	196.1	44.6	81.9	68.1	55.7	80.3	43.8	970
MT51	5.5	0.0	40.9	132.4	248.4	179.0	178.6	152.4	9.0	10.7	12.0	0.0	969
MT53	10.0	0.0	0.0	58.1	80.6	50.4	51.6	56.1	29.9	0.0	0.0	0.0	337
MT54	3.4	0.0	0.0	112.0	173.4	181.0	184.1	127.2	52.7	0.4	0.0	0.0	834
MT57	27.5	35.3	10.4	121.2	125.7	207.8	13.3	124.4	0.0	0.0	0.0	0.0	666
MT58	8.4	0.0	25.0	160.0	297.1	245.3	212.4	203.0	100.1	2.3	0.0	0.0	1254
MT59	68.5	31.8	31.7	68.8	120.0	176.4	61.1	175.1	84.5	58.2	19.0	0.0	895
MT60	32.1	47.9	0.0	109.8	181.6	117.6	5.7	119.0	76.0	46.6	72.2	47.1	856
MT61	34.0	0.0	0.8	105.7	195.0	263.5	77.8	165.0	190.7	0.0	0.0	0.0	1033
MT62	17.1	0.0	27.2	143.5	286.9	270.4	110.7	164.5	84.5	0.0	0.0	0.0	1105
MT63	24.2	0.0	98.4	130.8	166.1	248.5	41.4	119.4	120.6	63.4	58.3	27.9	1099
MT66	2.4	0.0	17.5	75.9	115.0	123.8	44.3	120.9	40.8	0.2	0.0	0.0	541
MT71	2.3	0.7	0.7	49.9	70.0	100.2	4.4	84.9	35.1	3.4	0.0	0.0	352
MT72	3.3	1.0	0.4	44.3	43.2	98.1	24.3	73.4	12.2	0.0	0.0	0.0	300

Table 5. Continued

Site	3/1-5/10	5/10-5/24	5/24-6/7	6/7-6/21	6/21-7/5	7/5-7/20	7/20-8/3	8/3-8/17	8/17-8/29	8/29-9/14	8/14-9/27	9/27-10/1	Totals
MT77	42.9	43.0	56.7	90.0	90.3	137.9	21.5	129.0	79.4	21.6	0.0	0.0	712
MT81	2.0	0.0	0.0	50.2	126.4	191.9	48.7	69.2	69.8	0.7	0.0	0.0	559
MT90	0.0	0.0	0.0	39.3	167.7	200.7	46.5	156.0	73.0	23.4	0.0	0.0	707
M~96	24.2	54.0	203.0	262.9	239.0	144.0	54.9	124.2	120.8	77.0	77.0	0.0	1381
MT97	2.9	0.0	24.7	100.9	281.8	136.3	113.4	179.7	98.5	0.0	0.0	0.0	938
MT98	65.8	30.0	47.4	180.8	241.3	220.1	107.6	180.5	101.9	0.0	0.0	0.0	1175
MT99	42.5	60.0	141.0	77.3	120.8	186.7	87.0	164.5	145.3	53.0	0.5	0.0	1079
MT100	1.7	30.0	110.6	152.9	206.6	211.8	33.2	156.3	140.0	38.8	26.9	0.0	1109
MT101	16.6	0.0	123.2	132.0	244.4	207.6	68.5	179.9	102.6	0.0	0.0	0.0	1075
MT102	23.9	38.9	44.8	124.6	243.0	188.3	97.6	116.6	60.3	28.5	0.0	0.0	967
MT103	53.3	86.4	57.8	113.8	0.0	75.0	86.2	118.8	98.1	25.8	58.3	3.3	776
MT104	60.7	149.5	99.7	114.0	0.0	132.0	229.4	149.4	100.0	59.3	67.8	95.3	1357
MT106	0.0	0.0	0.0	94.1	119.0	121.7	22.5	97.2	34.6	11.3	0.0	93.2	594
MT107	350.6	69.0	71.2	84.9	114.9	151.7	4.3	91.4	33.3	33.2	42.2	2.5	1049
MT108	14.9	0.0	58.1	96.2	189.2	229.3	70.4	178.2	40.7	0.0	0.0	0.0	877
MTll0	0.0	0.0	46.3	86.8	137.7	0.2	0.0	67.9	35.8	32.5	7.9	0.0	415
MTll2	18.5	0.0	52.8	75.8	60.3	138.2	69.6	135.5	76.0	41.4	41.2	20.6	730
MT121	47.1	0.0	0.0	49.6	63.4	166.1	20.5	72.3	10.5	0.0	0.0	0.0	430
MT126	1.8	1.0	0.3	83.9	210.7	185.4	31.7	158.3	65.2	4.2	0.0	0.0	743
MT128	24.3	72.2	72.2	41.8	94.5	161.6	27.8	130.9	77.3	59.6	0.0	0.0	762
MT130	0.9	2.3	0.7	111.0	216.7	190.2	108.8	149.2	63.9	29.8	0.0	0.0	874
MT136	1.0	0.0	21.1	131.6	178.5	194.4	41.3	117.8	45.5	0.0	0.0	0.0	731
MT140	2.2	0.0	0.7	82.6	180.0	229.6	55.0	151.0	51.7	0.5	0.0	0.0	753
MT141	9.1	0.0	1.4	94.0	196.3	222.2	77.2	146.4	32.9	0.0	0.0	0.0	780
MT142	0.4	0.0	0.0	67.4	161.3	136.9	78.2	107.2	40.5	0.0	0.0	0.0	592
MT171	9.2	0.0	8.2	105.7	207.1	233.3	70.0	116.0	46.9	65.4	65.0	0.0	927
MT174	6.1	0.0	0.0	86.5	152.1	190.0	102.8	97.4	49.6	0.0	0.0	0.0	685
MT175	0.7	11.2	1.1	45.7	137.4	145.0	39.4	92.4	17.3	4.0	0.0	0.0	494
Average	20.0	15.0	31.0	100.0	172.0	173.0	74.0	135.0	79.0	19.0	12.0	7.0	

Table 5. Concluded

(Seasonal Totals of Hours of Operation for Sites Not Measured Biweekly)

Site	*Totals*	*Site*	*Totals*	*Site*	*Totals*
MT7	503	MT79	412	MT158	996
MTll	608	MT82	499	MT159	960
MT14	902	MTll3	838	MT166	704
MT43	782	MTll4	781	MT170	636
MT45	862	MTll5	798	MT173	966
MT56	649	MTll9	770	MT177	459
MT69	603	MT122	356	MT178	672
MT70	658	MT123	545	MT179	598
MT75	483	MT129	730		
MT76	484	MT150	1137	**Average**	838

Table 6. Biweekly and Seasonal Irrigation Hours, 1989 (Green River Lowlands)

Site	*5/31-6/21*	*6/21-7/5*	*7/5-7/19*	*7/19-8/3*	*8/3-8/17*	*8/17-9/30*	*Totals*
LW1	17	155	177	31	0	0	380
LW2	25	217	304	87	73	0	706
LW3	10	232	188	56	23	0	510
LW4	0	240	247	0	49	0	537
LW5	35	150	130	136	22	5	478
LW6	76	105	86	87	16	48	416
LW7	0	261	248	105	94	0	708
LW13	1	209	224	77	58	1	569
LW14	0	201	249	81	61	0	592
LW15	3	19	142	36	23	30	253
LW16	1	59	309	48	29	68	513
LW17	0	73	276	66	43	50	508
LW18	50	255	224	95	70	0	694
LW26	0	208	167	91	49	0	515
LW28	-	-	135	63	105	2	306
LW29	-	-	92	70	95	1	259
LW31	0	246	140	66	68	0	520
LW32	0	207	131	30	26	0	393
LW34	37	358	73	108	91	34	700
LW35	18	260	97	245	268	96	985

Table 6. Concluded

Site	*5/31-6/21*	*6/21-715*	*7/5-7/19*	*7/19-8/3*	*8/3-8/17*	*8/17-9/30*	*Totals*
LW36	0	160	185	95	86	21	546
LW37	0	185	148	10	112	0	455
LW38	0	156	113	0	54	0	324
LW39	0	267	81	0	0	0	348
LW42	21	209	40	66	33	15	383
LW43	28	378	148	257	148	1	960
LW44	0	370	140	189	116	0	815
LW45	1	358	94	126	0	0	579
LW57	0	260	89	101	66	5	521
LW59	0	289	117	12	98	0	515
LW60	6	199	223	281	169	1	879
LW63	33	309	157	99	50	78	724
LW64	25	400	133	173	97	0	828
Average	12	226	161	91	69	14	573

Table 7. Biweekly and Seasonal Irrigation Water Use, 1989 (Havana Lowlands)

Site	*3/1-5/10*	*5/10-5/24*	*5/24-6/7*	*6/7-6/21*	*6/21-7/5*	*7/5-7/20*	*7/20-8/3*	*8/3-8/17*	*8/17-8/29*	*8/29-9/14*	*9/14-9/27*	*9/27-10/1*	*Totals*
MT2	0.0	0.0	0.8	1.7	3.3	3.1	1.0	2.0	0.9	0.0	0.0	0.0	12.7
MT8	0.2	0.0	0.5	3.5	3.9	2.4	1.9	1.9	1.4	0.2	0.0	0.0	15.9
MT10	0.2	0.4	0.6	2.2	0.5	0.0	0.4	1.3	0.8	0.4	1.0	0.0	7.9
MT26	0.0	0.0	0.5	1.5	3.4	2.9	0.9	2.8	1.7	0.0	0.0	0.0	13.7
MT27	0.6	0.0	0.0	2.7	3.7	4.3	2.7	0.1	4.0	0.0	0.0	0.0	18.0
MT28	0.3	0.0	0.0	0.0	2.2	1.1	0.8	1.1	0.8	0.0	0.0	0.0	6.3
MT29	0.0	0.0	0.0	1.1	2.1	2.6	0.7	1.7	1.2	0.0	0.0	0.0	9.4
MT30	0.0	0.0	0.0	1.5	0.0	1.6	0.0	1.7	1.0	0.4	1.0	0.3	7.6
MT31	0.0	0.0	0.0	1.5	4.4	4.9	1.8	4.8	0.7	0.0	0.0	0.0	18.2
MT32	0.0	0.0	0.0	1.2	3.5	3.9	1.4	3.8	0.5	0.0	0.0	0.0	14.4
MT33	1.4	0.0	0.1	1.3	2.7	2.8	1.0	3.3	1.1	0.8	0.0	0.1	14.4
MT34	0.0	1.3	1.0	1.9	4.4	2.4	0.0	2.8	2.4	0.9	0.0	0.0	17.0
MT36	0.0	0.0	0.0	1.5	3.4	5.4	2.5	3.9	3.0	0.0	0.0	0.0	19.8
MT37	0.0	0.0	0.6	1.3	4.0	4.1	0.7	3.3	2.0	0.9	0.7	0.0	17.5
MT38	0.0	0.0	0.0	1.1	3.2	3.0	1.6	2.8	1.7	0.0	0.0	0.0	13.4
MT39	0.0	0.0	2.0	1.7	2.2	0.0	2.1	1.9	1.5	0.1	0.0	0.0	11.5

Table 7. Continued

Site	*3/1-5/10*	*5/10-5/24*	*5/24-6/7*	*6/7-6/21*	*6/21-7/5*	*7/5-7/20*	*7/20-8/3*	*8/3-8/17*	*8/17-8/29*	*8/29-9/14*	*9/14-9/27*	*9/27-10/1*	*Totals*
MT41	0.1	0.0	0.1	1.3	3.5	1.5	0.4	2.4	0.9	0.0	0.0	0.0	10.2
MT46	0.6	0.0	0.0	1.9	3.8	4.2	2.4	3.6	2.3	0.0	0.0	0.0	18.8
MT47	0.3	0.0	0.0	1.9	4.8	4.4	1.7	2.3	2.3	0.0	0.0	0.0	17.9
MT50	0.0	0.2	0.0	1.8	3.5	2.7	0.6	1.1	0.9	0.8	1.1	0.6	13.3
MT51	0.1	0.0	0.7	2.3	4.2	3.0	3.0	2.6	0.2	0.2	0.2	0.0	16.5
MT53	0.4	0.0	0.0	2.6	3.6	2.2	2.3	2.5	1.3	0.0	0.0	0.0	14.9
MT54	0.1	0.0	0.0	2.3	3.5	3.7	3.8	2.6	1.1	0.0	0.0	0.0	17.0
MT57	0.6	0.8	0.2	2.6	2.7	4.4	0.3	2.6	0.0	0.0	0.0	0.0	14.1
MT58	0.1	0.0	0.3	2.0	3.7	3.1	2.7	2.6	1.3	0.0	0.0	0.0	15.8
MT59	1.2	0.5	0.5	1.2	2.0	3.0	1.0	3.0	1.4	1.0	0.3	0.0	15.2
MT60	0.5	0.7	0.0	1.6	2.6	1.7	0.1	1.7	1.1	0.7	1.0	0.7	12.4
MT61	0.5	0.0	0.0	1.7	3.1	4.3	1.3	2.7	3.1	0.0	0.0	0.0	16.7
MT62	0.3	0.0	0.5	2.5	5.1	4.8	2.0	2.9	1.5	0.0	0.0	0.0	19.5
MT63	0.3	0.0	1.3	1.8	2.3	3.4	0.6	1.6	1.6	0.9	0.8	0.4	14.9
MT66	0.0	0.0	0.2	1.0	1.6	1.7	0.6	1.6	0.6	0.0	0.0	0.0	7.3
MT71	0.1	0.0	0.0	1.8	2.5	3.5	0.2	3.0	1.2	0.1	0.0	0.0	12.4
MT72	0.1	0.0	0.0	0.8	0.8	1.8	0.4	1.3	0.2	0.0	0.0	0.0	5.4
MT77	0.7	0.7	0.9	1.4	1.4	2.1	0.3	2.0	1.2	0.3	0.0	0.0	10.9
MT81	0.0	0.0	0.0	1.1	2.7	4.0	1.0	1.5	1.5	0.0	0.0	0.0	11.8
MT90	0.0	0.0	0.0	0.6	2.4	2.9	0.7	2.3	1.1	0.3	0.0	0.0	10.3
MT96	0.4	1.0	3.7	4.8	4.3	2.6	1.0	2.3	2.2	1.4	1.4	0.0	25.1
MT97	0.0	0.0	0.4	1.7	4.6	2.2	1.9	2.9	1.6	0.0	0.0	0.0	15.4
MT98	1.1	0.5	0.8	3.0	4.0	3.6	1.8	3.0	1.7	0.0	0.0	0.0	19.2
MT99	0.7	1.0	2.3	1.3	2.0	3.1	1.4	2.7	2.4	0.9	0.0	0.0	17.7
MT100	0.0	0.5	1.8	2.5	3.4	3.5	0.5	2.6	2.3	0.6	0.4	0.0	18.2
MT101	0.3	0.0	2.4	2.6	4.8	4.1	1.3	3.5	2.0	0.0	0.0	0.0	21.1
MT102	0.5	0.8	0.9	2.4	4.7	3.6	1.9	2.3	1.2	0.6	0.0	0.0	18.7
MT103	1.4	2.2	1.5	3.0	0.0	1.9	2.2	3.1	2.6	0.7	1.5	0.1	20.2
MT104	1.6	3.9	2.6	3.0	0.0	3.4	6.0	3.9	2.6	1.5	1.8	5.1	35.3
MT106	0.0	0.0	0.0	1.6	2.0	2.1	0.4	1.7	0.6	0.2	0.0	1.6	10.2
MT107	8.5	1.7	1.7	2.1	2.8	3.7	0.1	2.2	0.8	0.8	1.0	0.1	25.6
MT108	0.3	0.0	1.3	2.2	4.4	5.3	1.6	4.1	0.9	0.0	0.0	0.0	20.2
MT110	0.0	0.0	1.1	2.0	3.2	0.0	0.0	1.6	0.8	0.7	0.2	0.0	9.6

Table 7. Continued

Site	*3/1-5/10*	*5/10-5/24*	*5/24-6/7*	*6/7-6/21*	*6/21-7/5*	*7/5-7/20*	*7/20-8/3*	*8/3-8/17*	*8/17-8/29*	*8/29-9/14*	*9/14-9/27*	*9/27-10/1*	*Totals*
MT112	0.3	0.0	0.8	1.2	1.0	2.2	1.1	2.1	1.2	0.7	0.7	0.3	11.5
MT121	0.8	0.0	0.0	0.8	1.1	2.8	0.3	1.2	0.2	0.0	0.0	0.0	7.3
MT126	0.0	0.0	0.0	1.2	3.1	2.7	0.5	2.3	1.0	0.1	0.0	0.0	10.9
MT128	0.4	1.0	1.0	0.6	1.4	2.3	0.4	1.9	1.1	0.9	0.0	0.0	11.0
MT130	0.0	0.0	0.0	1.4	2.8	2.5	1.4	1.9	0.8	0.4	0.0	0.0	11.3
MT136	0.0	0.0	0.3	1.7	2.3	2.5	0.5	1.5	0.6	0.0	0.0	0.0	9.2
MT140	0.0	0.0	0.0	1.3	2.9	3.7	0.9	2.4	0.8	0.0	0.0	0.0	12.2
MT141	0.1	0.0	0.0	1.5	3.2	3.6	1.2	2.4	0.5	0.0	0.0	0.0	12.6
MT142	0.0	0.0	0.0	0.8	1.9	1.6	0.9	1.3	0.5	0.0	0.0	0.0	6.9
MT171	0.1	0.0	0.1	1.4	2.7	3.1	0.9	1.5	0.6	0.9	0.9	0.0	12.2
MT174	0.2	0.0	0.0	2.8	4.9	6.2	3.3	3.2	1.6	0.0	0.0	0.0	22.3
MT175	0.0	0.2	0.0	0.8	2.5	2.7	0.7	1.7	0.3	0.1	0.0	0.0	9.1
Average	0.4	0.3	0.6	1.8	2.9	3.0	1.3	2.4	1.3	0.3	0.2	0.0	

Seasonal Totals of Irrigation Water Use for Sites Not Measured Biweekly

Site	*Totals*	*Site*	*Totals*	*Site*	*Totals*
MT7	5.7	MT79	7.2	MT158	25.2
MT11	15.1	MT82	9.3	MT159	36.4
MT14	15.1	MT113	13.7	MT166	13.8
MT43	18.9	MT114	13.3	MT170	16.8
MT45	17.9	MT115	15.4	MT173	25.6
MT56	13.2	MT119	9.2	MT177	7.1
MT69	7.4	MT122	6.1	MT178	10.9
MT70	12.4	MT123	6.3	MT179	9.0
MT75	8.0	MT129	10.2		
MT76	7.9	MT150	18.5	**Average**	14.5

Table 8. Biweekly and Seasonal Irrigation Water Use, 1989 (Green River Lowlands)

(inches)

Site	*5/31-6/21*	*6/21-7/5*	*7/5-7/19*	*7/19-8/3*	*8/3-8/17*	*8/17-9/30*	*Totals*
LW1	0.2	2.2	2.5	0.4	0.0	0.0	5.4
LW2	0.4	3.2	4.5	1.3	1.1	0.0	10.4
LW3	0.2	3.4	2.8	0.9	0.3	0.0	7.5
LW4	0.0	1.9	2.0	0.0	0.4	0.0	4.3
LW5	0.6	2.7	2.3	2.4	0.4	0.1	8.4
LW6	1.0	1.3	1.1	1.1	0.2	0.6	5.3
LW7	0.0	2.5	2.4	1.0	0.9	0.0	6.8
LW13	0.0	4.2	4.4	1.6	1.1	0.0	11.3
LW14	0.0	3.3	4.1	1.3	1.0	0.0	9.8
LW15	0.1	0.3	2.4	0.6	0.4	0.5	4.4
LW16	0.0	1.1	5.7	0.9	0.5	1.2	9.4
LW17	0.0	0.8	2.8	0.7	0.4	0.5	5.2
LW18	0.6	2.9	2.6	1.0	0.8	0.0	7.9
LW26	0.0	3.1	2.5	1.3	0.7	0.0	7.6
LW28			2.3	1.1	1.8	0.0	5.2
LW29			1.3	1.0	1.4	0.0	3.7
LW31	0.0	3.9	2.2	1.0	1.1	0.0	8.2
LW32	0.0	3.2	2.0	0.5	0.4	0.0	6.1
LW34	0.5	4.4	0.9	1.3	1.1	0.4	8.6
LW35	0.2	2.6	1.0	2.4	2.7	1.0	9.8
LW36	0.0	2.5	2.9	1.5	1.4	0.3	8.6
LW37	0.0	2.5	2.0	0.1	1.5	0.0	6.3
LW38	0.0	2.7	1.9	0.0	0.9	0.0	5.6
LW39	0.0	3.1	0.9	0.0	0.0	0.0	4.0
LW42	0.3	2.6	0.5	0.8	0.4	0.2	4.8
LW43	0.3	3.5	1.4	2.4	1.4	0.0	8.9
LW44	0.0	6.1	2.3	3.1	1.9	0.0	13.3
LW45	0.0	5.4	1.4	1.9	0.0	0.0	8.8
LW57	0.0	15.1	5.2	5.9	3.8	0.3	30.2
LW59	0.0	6.4	2.6	0.3	2.2	0.0	11.4
LW60	0.0	0.7	0.8	0.9	0.6	0.0	3.0
LW63	0.5	4.7	2.4	1.5	0.8	1.2	11.1
LW64	0.3	5.2	1.7	2.3	1.3	0.0	10.9
Average	0.3	2.5	2.5	1.0	0.5	0.1	6.9

Table 9. Generalization of Soil Permeabilities (Havana Lowlands)

(percent of total irrigated area)

Site	*Rapid*	*Moderately rapid to rapid*	*Moderate to moderately rapid*	*Moderate*
MT2	61	18	21	-
MT8	35	27	38	-
MT10	25	10	65	-
MT26	88	12	-	-
MT27	100	-	-	-
MT28	-	-	-	100
MT29	5	3	75	17
MT30	-	-	100	-
MT31	10	76	14	-
MT32	85	-	15	-
MT33	33	10	57	-
MT34	40	12	48	-
MT36	12	86	2	-
MT37	71	12	17	-
MT38	72	27	1	-
MT39	43	26	31	-
MT41	14	86	-	-
MT46	-	85	15	-
MT47	70	30	-	-
MT50	30	14	56	-
MT51	3	75	22	-
MT53	-	100	-	-
MT54	17	52	31	-
MT57	-	-	100	-
MT58	54	21	11	14
MT59	60	17	23	-
MT60	52	20	23	5
MT61	38	27	35	-
MT62	87	13	-	-
MT63	50	15	35	-
MT66	5	-	95	-

Table 9. Concluded

Site	*Rapid*	*Moderately rapid to rapid*	*Moderate to moderately rapid*	*Moderate*
MT62	87	13	-	-
MT71	34	17	17	32
MT72	-	35	25	40
MT77	-	100	-	-
MT81	34	10	35	21
MT90	93	7	-	-
MT96	94	5	1	-
MT97	97	-	3	-
MT98	100	-	-	-
MT99	96	4	-	-
MT100	92	2	6	-
MT101	94	3	3	-
MT102	83	3	14	-
MT103	100	-	-	-
MT104	100	-	-	-
MT106	6	-	94	-
MT107	18	-	82	-
MT108	56	7	37	-
MT110	40	10	50	-
MT112	45	21	34	-
MT121	-	-	-	100
MT126	8	92	-	-
MT128	30	14	56	-
MT130	18	29	53	-
MT136	15	72	13	-
MT140	65	5	30	-
MT141	69	20	11	-
MT142	35	60	5	-
MT171	80	20	-	-
MT174	70	30	-	-
MT175	-	20	78	2

Table 10. Generalization of Soil Permeabilities (Green River Lowlands)
(percent of total irrigated area)

Site	*Rapid*	*Moderately rapid to rapid*	*Moderate to moderately rapid*	*Moderate*	*Moderate to slow*
LW1	28	4	20	48	-
LW2	11	11	31	43	4
LW3	38	6	6	50	-
LW4	-	-	11	89	-
LW5	14	86	-	-	-
LW6	66	20	-	14	-
LW7	58	20	6	14	2
LW13	50	34	-	16	-
LW14	24	76	-	-	-
LW15	30	70	-	-	-
LW16	19	63	-	18	-
LW17	22	73	5	-	-
LW18	8	70	-	14	8
LW26	-	3	8	74	15
LW28	5	54	29	12	-
LW29	-	55	45	-	-
LW31	-	25	75	-	-
LW32	-	-	100	-	-
LW34	15	5	80	-	-
LW35	7	70	23	-	-
LW36	-	15	85	-	-
LW37	-	7	73	20	-
LW38	3	17	67	13	-
LW39	-	-	-	100	-
LW42	-	26	52	22	-
LW43	5	95	-	-	-
LW44	7	69	24	-	-
LW45	-	45	55	-	-
LW57	1	64	25	10	-
LW59	6	20	30	44	-
LW60	2	4	69	25	-
LW63	7	32	47	14	-
LW64	8	92	-	-	-

Table 11. Nonpumping Water Levels, 1988-1989 (Havana Lowlands)

	Feet below land surface			*Absolute differences in water levels*		
Site	*Fall 1988*	*Spring 1989*	*Fall 1989*	*Fall 1988 to Spring 1989*	*Spring 1989 to Fall 1989*	*Fall 1988 to Fall 1989*
MT1	33.93	34.04	34.62	0.11	0.58	0.69
MT2	16.88	16.98	17.25	0.10	0.27	0.37
MT5	22.70	22.88	23.51	0.18	0.63	0.81
MT6	36.52	36.49	37.00	0.03	0.51	0.48
MT9	-	31.45	32.73	-	1.28	-
MT11	-	28.56	-	-	-	-
MT12	-	45.45	46.27	-	0.82	-
MT13	-	49.89	50.93	-	1.04	-
MT15	-	36.55	37.36	-	0.81	-
MT18	-	71.03	71.14	-	0.11	-
MT20	-	34.48	35.40	-	0.92	-
MT21	-	31.76	32.95	-	1.19	-
MT22	-	21.70	21.98	-	0.28	-
MT23	-	22.94	23.23	-	0.29	-
MT24	-	21.13	21.39	-	0.26	-
MT26	-	30.86	32.13	-	1.27	-
MT27	14.02	14.75	15.82	0.73	1.07	1.80
MT29	-	18.55	18.74	-	0.19	-
MT30	-	13.97	14.27	-	0.30	-
MT31	12.00	12.75	13.04	0.75	0.29	1.04
MT32	7.42	8.03	8.20	0.61	0.17	0.78
MT35	12.48	12.12	13.51	0.36	1.39	1.03
MT37	-	15.80	15.58	-	0.22	-
MT39	-	13.90	14.53	-	0.63	-
MT40	-	22.35	23.27	-	0.92	-
MT41	-	10.48	10.74	-	0.26	-
MT51	15.11	14.74	15.15	0.37	0.41	0.04
MT52	15.60	15.10	15.89	0.50	0.79	0.29
MT54	14.80	14.54	15.37	0.26	0.83	0.57
MT55	27.66	27.86	28.38	0.20	0.52	0.72
MT57	13.36	13.12	13.48	0.24	0.36	0.12
MT59	-	16.72	17.28	-	0.56	-
MT60	-	12.26	12.79	-	0.53	-

Table 11. Continued

Site	*Feet below land surface* Fall 1988	Spring 1989	Fall 1989	*Absolute differences in water levels* Fall 1988 to Spring 1989	Spring 1989 to Fall 1989	Fall 1988 to Fall 1989
MT61	11.72	12.12	12.46	0.40	0.34	0.74
MT62	20.84	21.11	20.52	0.27	0.59	0.32
MT63	20.69	18.99	19.42	1.70	0.43	1.27
MT64	-	30.09	31.14	-	1.05	-
MT65	-	27.98	28.25	-	0.27	-
MT66	-	22.73	23.20	-	0.47	-
MT68	-	18.60	18.92	-	0.32	-
MT69	-	7.66	7.79	-	0.13	-
MT73	-	8.89	8.94	-	0.05	-
MT74	-	32.57	33.54	-	0.97	-
MT75	-	11.24	11.56	-	0.32	-
MT77	-	53.26	54.16	-	0.90	-
MT80	-	52.39	54.20	-	1.81	-
MT83	11.76	11.38	11.93	0.38	0.55	0.17
MT84	-	13.68	14.10	-	0.42	-
MT85	-	16.97	17.46	-	0.49	-
MT86	-	21.25	21.85	-	0.60	-
MT87	-	14.04	14.43	-	0.39	-
MT88	19.00	20.40	21.09	1.40	0.69	2.09
MT89	12.58	13.78	14.49	1.20	0.71	1.91
MT91	-	14.74	15.43	-	0.69	-
MT92	-	17.68	18.79	-	1.11	-
MT99	-	33.19	34.83	-	1.64	-
MT100	-	16.14	17.18	-	1.04	-
MT101	-	17.18	17.99	-	0.81	-
MT102	-	23.64	-	-	-	-
MT106	16.30	15.93	15.72	0.37	0.21	0.58
MT108	-	13.38	13.90	-	0.52	-
MT110	-	-	15.35	-	-	-
MT114	-	14.70	15.59	-	0.89	-
MT117	19.45	18.84	18.93	0.61	0.09	0.52
MT118	-	36.66	35.09	-	1.57	-
MT119	-	42.83	44.53	-	1.70	-

Table 11. Continued

Site	*Feet below land surface*			*Absolute differences in water levels*		
	Fall 1988	*Spring 1989*	*Fall 1989*	*Fall 1988 to Spring 1989*	*Spring 1989 to Fall 1989*	*Fall 1988 to Fall 1989*
MT120	-	11.06	11.24	-	0.18	-
MT121	-	7.49	7.55	-	0.06	-
MT124	-	14.81	15.08	-	0.27	-
MT125	-	17.94	18.12	-	0.18	-
MT126	-	9.86	10.56	-	0.70	-
MT129	-	10.51	11.45	-	0.94	-
MT130	-	24.16	25.51	-	1.35	-
MT135	-	5.10	6.44	-	1.34	-
MT137	-	13.53	14.68	-	1.15	-
MT141	-	16.57	17.62	-	1.05	-
MT142	24.70	23.95	25.05	0.75	1.10	0.35
MT145	-	8.08	7.52	-	0.56	-
MT147	-	5.94	7.30	-	1.36	-
MT148	-	41.65	42.69	-	1.04	-
MT151	-	47.76	48.81	-	1.05	-
MT152	-	57.20	-	-	-	-
MT154	-	46.15	47.47	-	1.32	-
MT155	-	54.77	-	-		-
MT156	-	86.46	88.65	-	2.19	-
MT160	-	47.33	48.93	-	1.60	-
MT162	-	48.90	50.07	-	1.17	-
MT165	-	37.05	-	-	-	-
MT168	-	27.00	27.34	-	0.34	-
MT170	-	5.08	5.10	-	0.02	-
MT171	-	30.92	32.18	-	1.26	-
MT172	-	23.67	24.53	-	0.86	-
MT173	9.23	9.52	9.42	0.29	0.10	0.19
MT174	12.07	12.75	13.63	0.68	0.88	1.56
MT175	18.26	17.48	17.41	0.78	0.07	0.85
MT177	-	15.59	16.64	1.05	-	-
MT178	-	15.33	15.52	0.19	-	-
MT179	-	12.39	12.62	0.23	-	-
MT180	-	15.86	16.03	0.17	-	-

Table 11. Concluded

	Feet below land surface			Absolute differences in water levels		
Site	*Fall 1988*	*Spring 1989*	*Fall 1989*	*Fall 1988 to Spring 1989*	*Spring 1989 to Fall 1989*	*Fall 1988 to Fall 1989*
MT183	15.56	15.81	16.22	0.25	0.41	0.66
MT185	-	34.33	35.40	1.07	-	-
MT186	-	46.19	47.21	1.02	-	-
MT187	-	4.90	4.96	0.06	-	-
MT188	-	5.94	5.95	0.01	-	-
MT189	8.30	-	-	-	-	-
MT190	10.17	-	-	-	-	-
MT191	20.13	20.22	-	0.09	-	-
MT192	9.96	-	-	-	-	-
MT193	-	19.82	-	-	-	-
MT194	11.21	12.10	-	0.89	-	-

Table 12. Nonpumping Water Levels, 1988-1989 (Green River Lowlands)

	Feet below land surface			Absolute differences in water levels		
Site	*Fall 1988*	*Spring 1989*	*Fall 1989*	*Fall 1988 to Spring 1989*	*Spring 1989 to Fall 1989*	*Fall 1988 to Fall 1989*
LW4	-	18.03	18.95	-	0.92	-
LW5	-	9.13	9.43	-	0.30	-
LW6	-	13.40	13.70	-	0.30	-
LW8	14.43	14.33	18.07	0.10	3.74	3.64
LW13	-	12.81	13.16	-	0.35	-
LW14	-	-	6.72	-	-	-
LW15	-	9.85	11.71	-	1.86	-
LW17	10.79	-	-	-	-	-
LW18	-	13.15	13.28	-	0.13	-
LW19	-	-	17.96	-	-	-
LW23	13.21	12.58	12.77	0.63	0.19	0.44
LW24	-	10.13	8.48	-	1.65	-
LW26	-	-	97.60	-	-	-
LW27	-	-	33.07	-	-	-
LW30	11.15	10.80	10.78	0.35	0.02	0.37
LW33	10.31	10.15	10.12	0.16	0.03	0.19
LW34	14.12	15.08	15.40	0.96	0.32	1.28

Table 12. Concluded

	Feet below land surface			*Absolute differences in water levels*		
Site	*Fall 1988*	*Spring 1989*	*Fall 1989*	*Fall 1988 to Spring 1989*	*Spring 1989 to Fall 1989*	*Fall 1988 to Fall 1989*
LW35	12.22	10.76	14.07	1.46	3.31	1.85
LW38	-	-	7.20	-	-	-
LW39	-	-	11.43	-	-	-
LW40	-	-	13.25	-	-	-
LW43	19.95	20.43	20.79	0.48	0.36	0.84
LW49	18.74	-	23.41	-	-	4.67
LW50	12.30	11.91	12.06	0.39	0.15	0.24
LW57	13.35	-	-	-	-	-
LW61	9.36	9.21	9.54	0.15	0.33	0.18
LW63	11.19	11.51	12.31	0.32	0.80	1.12
LW65	-	18.34	18.90	-	0.56	-
LW66	-	-	10.31	-	-	-
LW67	15.21	-	14.47	-	-	-
LW68	-	9.46	10.21	-	0.75	-
LW70	-	21.10	24.01	-	2.91	-
LW71	-	18.35	18.71	-	0.36	-
LW72	-	23.26	24.05	-	0.79	-
LW74	-	1.46	2.06	-	0.60	-
LW77	-	7.00	9.15	-	2.15	-
LW79	-	17.47	18.45	-	0.98	-
LW78	-	13.28	13.68	-	0.40	-
LW80	-	15.70	18.53	-	2.83	-
LW81	-	13.74	14.54	-	0.80	-
LW82	-	19.36	20.19	-	0.83	-
LW83	-	15.37	16.19	-	0.82	-
LW84	-	9.34	10.10	-	0.76	-
LW85	-	9.31	10.54	-	1.23	-

Table 13. Comparison of Nonpumping Water Levels, 1960 and 1989 (Havana Lowlands)
(feet)

Site	*Land elevation*	*Water table elevation, 1960*	*Measurement date*	*Water table elevation, 1989*	*Measurement date*	*Difference 1960-1989*
MT1	493	462	7/7/60	458	9/26/89	-4
MT6	495	452	7/7/60	462	9/26/89	10
MT32	458	452	7/7/60	450	9/26/89	-2
MT40	510	489	12/59	487	9/26/89	-2
MT51	463	451	7/8/60	448	9/27/89	-3
MT55	504	481	7/26/60	476	9/27/89	-5
MT64	497	470	8/23/60	466	9/28/89	-4
MT68	503	492	8/10/60	484	9/27/89	-8
MT86	493	483	12/59	471	9/27/89	-12
MT106	500	495	7/7/60	484	9/27/89	-11
MT111	502	491	10/59	487	9/27/89	-4
MT117	516	500	7/26/60	497	9/27/89	-3
MT120	470	460	8/23/60	459	9/28/89	-1
MT121	467	460	8/23/60	459	9/28/89	-1
MT125	494	483	10/59	476	9/28/89	-7
MT126	499	491	10/59	488	9/26/89	-3
MT135	487	480	12/59	481	9/26/89	1
MT151	520	475	7/29/60	471	9/28/89	-4
MT154	510	465	8/23/60	463	9/28/89	-2
MT168	505	495	8/9/60	478	9/28/89	-17
MT171	468	440	7/28/60	443	9/27/89	3
MT174	470	457	7/8/60	456	9/27/89	-1
MT180	500	490	8/9/60	484	9/27/89	-6
MT183	494	484	7/8/60	478	9/27/89	-6

Annual Irrigation Totals

Wide variations in watering patterns were observed during the two years of study. A subset of the collected data was analyzed to gain a better understanding of the reasons for this variability. Figure 5 shows the distribution of total 1989 irrigation amounts observed at the study sites. There are many reasons why irrigation patterns might vary from year to year and among farmers. The sources of irrigation variability considered in this study were:

weather variations and drought

- Do farmers A and B change their watering patterns uniformly from year to year in response to weather patterns, or are they inconsistent?
- Do farmers A and B water differently in year 1 than in year 2 for reasons seemingly unrelated to the weather?

soil type variations

- Does farmer A water twice as much as farmer B in any given year because farmer A's soils contain a higher sand content and therefore hold less water?

variations in crop type

- Do farmers A and B water differently because one is growing field corn and one is growing green beans?

variations in individual farmer behavior

- Do farmers A and B, who are neighbors and have similar soil types, weather, and crops, water differently for unknown reasons?

other variations and possible inaccuracies

- Do the flowmeters work correctly?
- Do the irrigation system hour meters work correctly?
- Do irrigation farmers keep accurate records of irrigation water use?

Weather Variations and Drought

Dramatic differences in irrigation water use were observed during the 1988 and 1989 growing seasons. Table 14 compares irrigation water use during 1988 and 1989. Average irrigation water use was 64 percent higher during 1988 in response to a severe drought; many irrigation farmers participating in the study reported using twice as much irrigation water as they had ever used before. More variability was observed between 1988 and 1989 than during either year alone. Irrigation watering patterns were reasonably consistent throughout the region during both years because irrigation farmers appeared to respond uniformly to the prevailing weather patterns. In short, 1988 was a severe drought year and everybody watered more; 1989 was near normal and everybody watered less than they did in 1988.

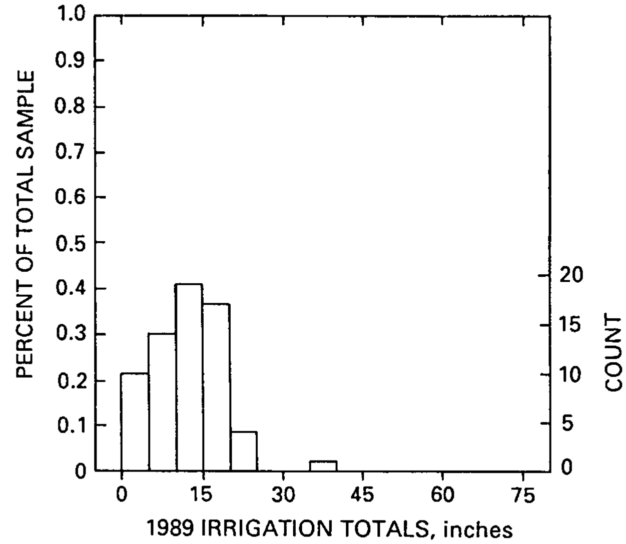

Figure 5. Distribution of total average 1989 irrigation amounts (Havana Lowlands)

Table 14. Total Irrigation Water Use (Havana Lowlands)

(inches)

Year	*Minimum*	*Maximum*	*Mean*	*Standard deviation*
1988	10.8	30.3	23.0	5.0
1989	5.4	25.6	14.1	5.7

Soil Type Variations

There was generally good correlation between total 1989 irrigation water use and soil moisture conditions as characterized by the average field capacity for the upper 36 inches of soil (figure 6). As might be expected, the lower the field capacity, the higher the irrigation water use. Table 15 shows average total irrigation applications for 1989 in a breakdown by average moisture content.

Results from this study indicate that root-zone soil moisture may explain between 44 and 65 percent of the variability in total irrigation water use. Table 16 shows correlation coefficients for a series of bivariate linear

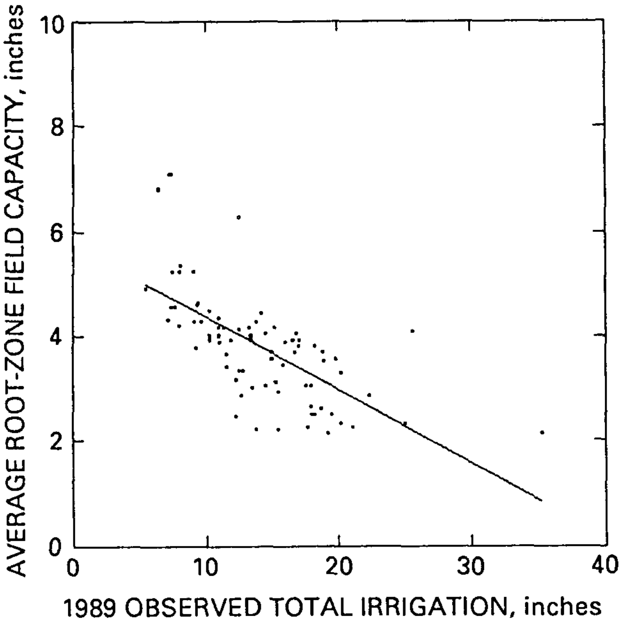

Figure 6. Correlation between average root-zone field capacity and 1989 observed total average irrigation (Havana Lowlands)

regression experiments comparing total irrigation water use for 1989 and root-zone moisture content. Three cases are summarized in the table. Case A considers every site in the study for which soil moisture and total irrigation water use data were available. Case B narrows the sample size to consider only those sites where a single crop was grown and irrigated. Case C considers only single-cropped fields with electric-powered irrigation rigs. The rationale behind this analysis was that a higher percentage of the electric systems monitored in this study had working electric or hour meters that enabled a more accurate estimate of total irrigation water use, while a number of the diesel-powered systems had engine meters that worked only intermittently.

In addition to the general association between root-zone field capacity and irrigation water use, a common belief among the farmers participating in this study was that irrigation farmers "irrigate for their worst soil"; in other words, they irrigate the sandiest soils enough to maximize crop yields, with the understanding that they may be slightly overwatering the better soils on the same irrigated field. A series of linear regression experiments was conducted to test this hypothesis using subsets of the study data based on the percentage of the "worst" soil with the lowest average field capacity of all soil types under the irrigation rig. Most of the study sites had at least some Sparta and Plainfield soils, which have average root-zone field capacities of 2 to 3 inches, so most sites had the same worst soil covering varying percentages of the field. Total 1989 irrigation water use was compared with the average root-zone field capacities for all sites with, for example, 50 percent of all soils having average root-zone field capacities of 3 inches or less. There is some inconclusive evidence of the practice of watering for the worst soil in these study results (table 17). Generally, the higher the percentage of "bad" soil, the higher the total irrigation water use.

In addition to the analysis described above, irrigation practices were compared based on two general soil groups according to their permeability (figures 7 and 8). In the Havana Lowlands, rapidly permeable soils received an average of 16 inches of water (44 samples), while moderately permeable soils received an average of 10.2 inches of water (17 samples). Rapidly and moderately permeable soils in the Green River Lowlands received 8.5 and 7.1 inches of water, respectively (16 and 17 samples). These data suggest that the most important influence on irrigation water use at a given site is soil permeability, or soil water-holding capacity.

Table 15. Irrigation Water Use Comparison by Soil Group, 1989 (Havana Lowlands)

(inches)

Soil group	*Sample size*	*Root-zone moisture*	*Minimum*	*Maximum*	*Mean*	*Standard Deviation*
1	14	2.0 - 2.6	12.2	25.1	18.2	23.3
2	24	2.7 - 3.8	9.2	22.3	15.5	63.3
3	30	3.9 - 4.9	5.4	17.0	11.5	63.1
4	8	5.0 - 7.0	6.3	12.4	8.19	1.9

Table 16. Soil Type Correlation Coefficients, 1989 (Havana Lowlands)

Case	*R*	R^2	*Sample size*
A	-0.66	0.44	82
B	-0.77	0.59	55
C	-0.81	0.65	39

Table 17. "Worst Soil" Analysis, 1989 (Havana Lowlands)

Percentage worst soil	*R*	R^2
50	-0.502	0.252
40	-0.361	0.130
30	-0.336	0.113
25	-0.277	0.077
20	-0.192	0.037
15	-0.148	0.022
10	-0.126	0.016
5	-0.063	0.004
3	-0.055	0.003

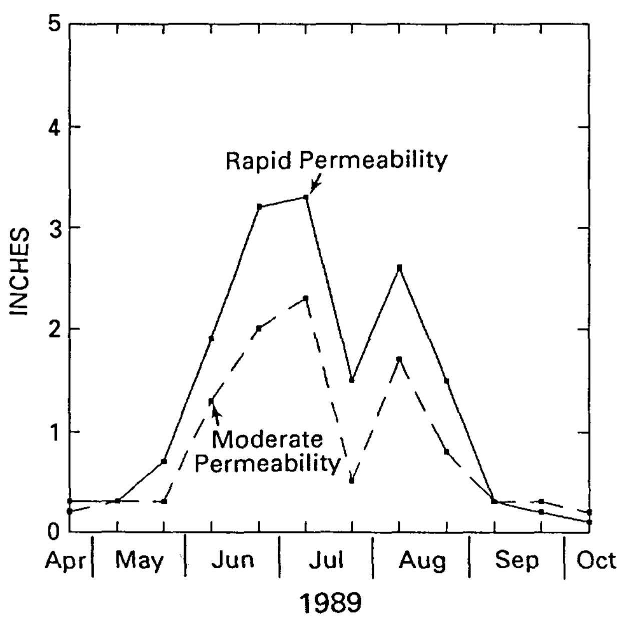

Figure 7. Average 1989 irrigation amounts on soils with rapid versus moderate permeability (Havana Lowlands)

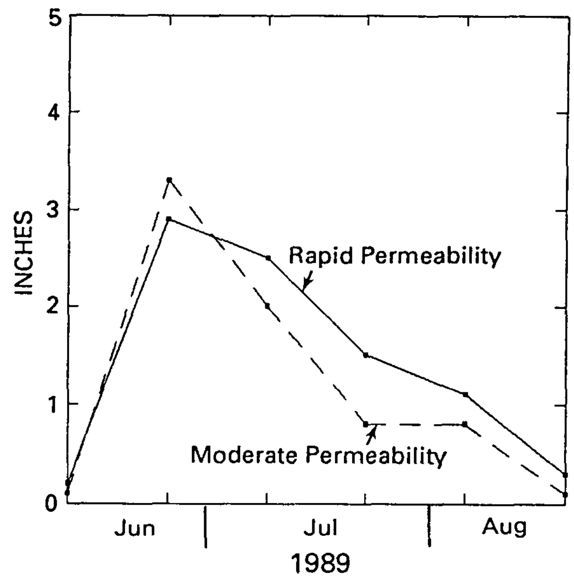

Figure 8. Average 1989 irrigation amounts on soils with rapid versus moderate permeability (Green River Lowlands)

Crop Type Variations

Surprisingly little variability in average total irrigation water use was observed due to differences in crop type. However, comparisons of single- versus double-cropped fields, and of corn and soybeans on the most highly permeable soils, revealed measurable differences.

Table 18 shows 1989 total water use for the major crops. While the water amounts varied widely for all major crop groups (as evidenced by the standard deviations in the table), the mean total irrigation amounts for all crop groups were very similar. Slightly more variability is apparent when the major crop groups are categorized by crop type for corn crops (table 19) and for small vegetables (table 20); however, the total mean irrigation water uses were still fairly consistent. Even average differences between single- and double-cropped fields are small, in spite of the longer season for the double-cropped fields.

Table 18. Average 1989 Irrigation Water Use by Major Crop Group, 1989 (Havana Lowlands)

(inches)

Crop	*Min.*	*Max.*	*Mean*	*S.D.*	*Sample size*
Corn	5.4	22.3	13.6	4.2	62
Small vegetables	7.1	25.6	14.0	6.2	12
Soybeans	12.4	15.2	13.8	2.0	5

Table 19. Average Irrigation Water Use for Corn Crops, 1989 (Havana Lowlands)

(inches)

Crop	*Min.*	*Max.*	*Mean*	*S.D.*	*Sample size*
Popcorn	5.4	20.2	13.0	4.0	19
Field corn	6.9	22.3	14.3	4.2	34
Sweet corn	10.2	18.9	15.0	3.2	6
Seed corn	6.3	7.4	7.0	0.6	3

Table 20. Average Irrigation Water Use for Small Vegetable Crops, 1989 (Havana Lowlands)

(inches)

Crop	*Min.*	*Mix.*	*Mean*	*S.D.*	*Sample size*
Green beans	7.1	25.1	13.6	6.7	6
Cucumbers	9.6	11.5	10.9	1.1	3
Peas	10.9	25.6	18.1	7.4	3

There are several plausible explanations. First, growing different crops simultaneously on one field is a common practice among irrigation farmers participating in this study and other farmers observed throughout the region. More than half of the study sites had more than one crop type growing simultaneously under the same irrigation system: many sites had three different crops, and one site had four different crops. Even though the water demands of these crops may differ, irrigation farmers do not alter the water amount because it is inconvenient to adjust the irrigation spray and the system speed. Second, irrigation farmers apparently do not keep records of total irrigation amounts, so they are unlikely to systematically adjust water amounts according to crop type. Third, many participating irrigation farmers reported applying the maximum amount of water possible, regardless of crop type, since their sandy soil holds so little moisture. Again, they are apparently unlikely to alter their practices according to crop type.

Comparisons were also made of single- and double-cropping methods on soils with rapid and moderate permeabilities. In the Havana Lowlands, double-cropped fields with rapid permeabilities received 18.0 inches of water (17 samples), while single-cropped fields with similar soils received 15.9 inches (27 samples) (figure 9). Double- and single-cropped fields on moderately permeable soils received 11.4 and 9.4 inches of water, respectively (7 and 10 samples) (figure 10). In the Green River Lowlands, double-cropped fields with rapid permeabilities soils received only 7.6 inches of water (2 samples), compared with 8.7 inches for single-cropped fields with

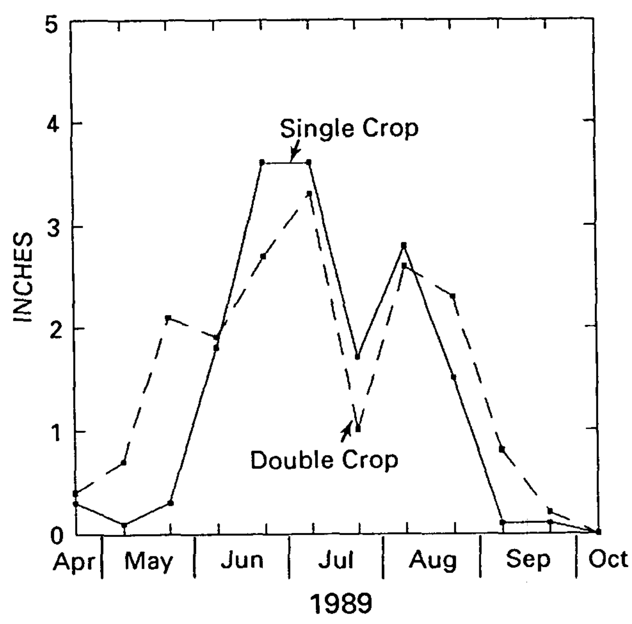

Figure 9. Average 1989 irrigation amounts on single- versus double-cropped fields having soils with rapid permeabilities (Havana Lowlands)

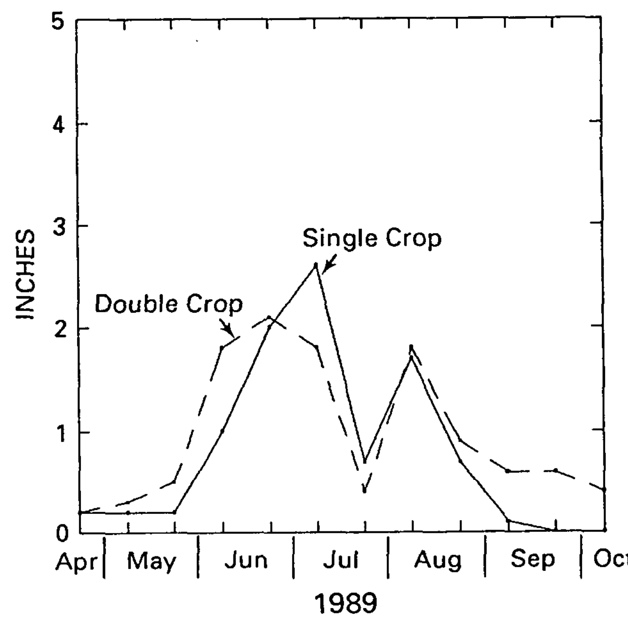

Figure 10. Average 1989 irrigation amounts on single- versus double-cropped fields having soils with moderate permeabilities (Havana Lowlands)

similar soils (14 samples) (figure 11). Double- and single-cropped fields on moderately permeable soils received 8.7 and 7.0 inches of water, respectively (2 and 15 samples) (figure 12).

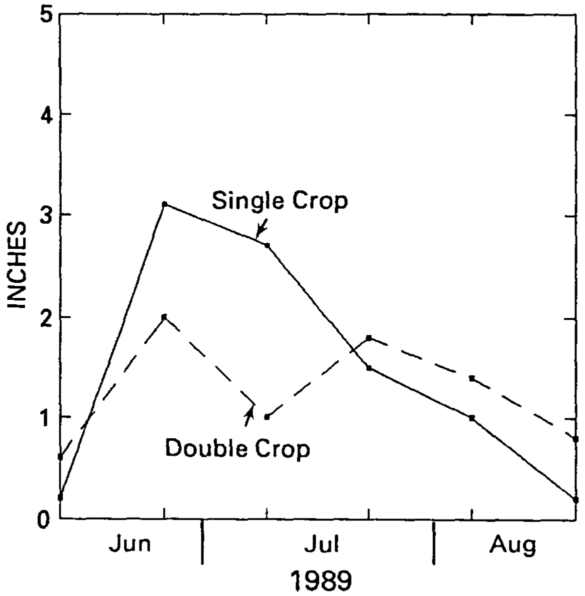

Figure 11. Average 1989 irrigation amounts on single- versus double-cropped fields having soils with rapid permeabilities (Green River Lowlands)

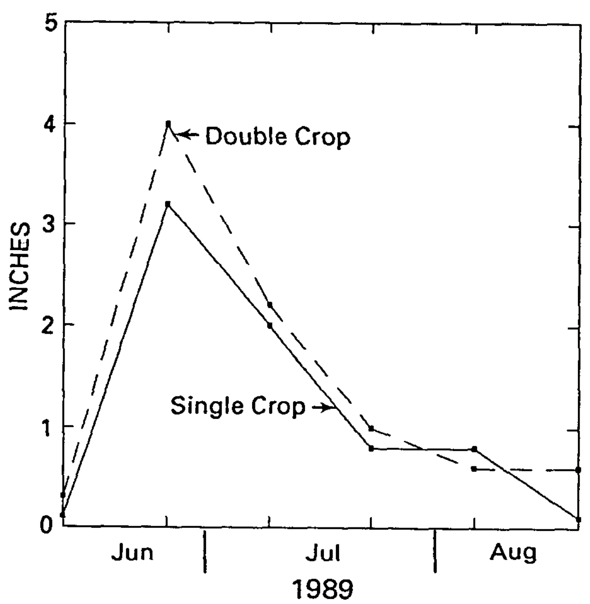

Figure 12. Average 1989 irrigation amounts on single- versus double-cropped fields having soils wilh moderate permeabilities (Green River Lowlands)

Variations in Individual Farmer Behavior

In addition to such physical controls over irrigation water use as weather, soil type, and crop type, there will always be some variation due to individual farmer behavior. Some irrigation farmers simply water more or less than others for reasons that are apparently unrelated to weather, crops, and soils. It is difficult to quantify behavioral variations; however, table 21 compares total 1989 irrigation water use for 11 neighboring participants in the Havana Lowlands study region. Each farmer operated three or more irrigation rigs and corn was the predominant crop. The fields were categorized according to their mean root-zone field capacity; total irrigation water use was then compared among the farmers in each group. The results suggest that even when farmers grow the same crop on similar soils and precipitation patterns are generally similar, total irrigation water use can vary significantly. Water use patterns among the three groups did, however, generally follow soil moisture conditions. Farmers 1-3 (lowest ambient soil moisture conditions) generally watered more than farmers 4-11; likewise, farmers 4-7 ("medium" average ambient soil moisture conditions) watered less than farmers 1-3 but more than farmers 8-11 (highest ambient soil moisture conditions).

Other Variations

Differences in weather, soil type, crop type, and even in farmer behavior do not explain all the variability in total irrigation water use observed in this study. Other plausible causes for variation are possible inaccuracies in both the estimated flow rates and in the hours of operation recorded off system hour meters. Irrigation well flow rates, used to compute total irrigation water use, were based on farmer-estimated flow rates. These estimates may be inaccurate due to a pump's age and deterioration. Similarly, total irrigation water use computations were also based on hours of irrigation system operation measured by the hour meters on the engines or the center-pivots. These meters, particularly the diesel engine hour meters, may have inaccurately logged the hours, causing some error in the water use calculations. For purposes of comparison, figure 13 shows the irrigation farmer-recorded irrigation applications versus the applications observed by researchers. There is a clear lack of correlation. Interviews with the farmers revealed that they often know the amount of water they apply in one revolution of the irrigation system (for example, ½ inch), but they often lose track of the number of revolutions the system makes in

Table 21. Individual Farmer Variability, 1989
(Havana Lowlands)

	Average root-zone field capacity (inches)			*Average 1989 irrigation water use (inches)*		
Farmer	*Minimum*	*Maximum*	*Mean*	*Minimum*	*Maximum*	*Mean*
1	2.1	2.6	2.3 (low)	15.4	25.1	19.4
2	2.8	3.1	3.0 (low)	6.9	12.6	10.6
3	2.6	3.6	3.2 (low)	17.9	18.9	18.4
4	3.0	4.0	3.5 (med)	13.4	19.8	16.4
5	2.4	4.4	3.6 (med)	12.4	19.5	15.3
6	2.1	4.4	3.6 (med)	9.6	35.3	18.7
7	2.9	4.2	3.7 (med)	13.3	15.4	14.1
8	4.1	6.2	5.0 (high)	5.4	12.4	9.0
9	4.1	7.0	5.5 (high)	6.8	13.9	-
10	3.8	4.1	3.9 (high)	10.2	11.3	10.9
11	4.0	5.2	4.4 (high)	7.1	16.8	10.6

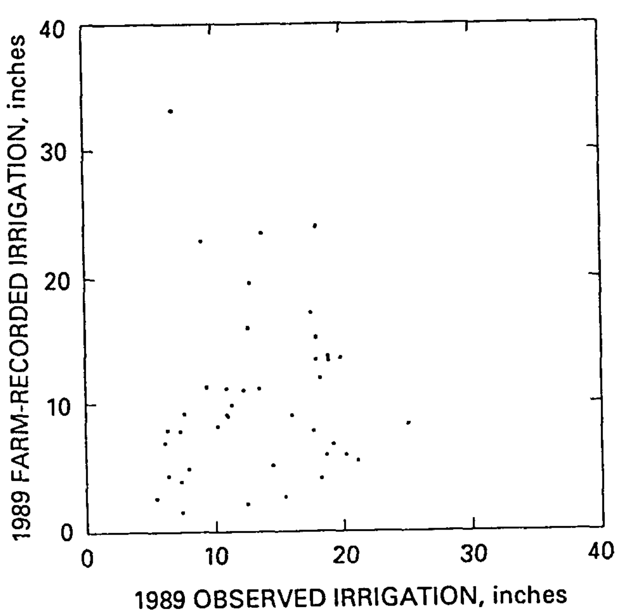

Figure 13. Total 1989 irrigation amounts recorded by participating irrigation farmers versus total 1989 irrigation amounts observed by researchers (Havana Lowlands)

one year. This suggests that the discrepancies seen in figure 13 arise from incomplete rather than inaccurate farm records. It should be emphasized that figure 13 shows farm-recorded irrigation amounts versus observed irrigation amounts, not farmer-estimated flow rates for computing irrigation amounts versus observed irrigation. This is an important distinction since the farmers' tendency to underestimate their irrigation water use (figure 13) does not necessarily mean that the farmer-estimated flow rates (system design flow rates), used in this study to compute irrigation water use, are inherently too low. Figure 13 simply shows what, in fact, happened during the 1989 growing season: many participating farmers kept accurate records for about a month into the growing season and then got too busy to keep complete records. Hence, their estimates of total irrigation water used in 1989 were lower than researcher observations.

Seasonal Irrigation Time Series

Researchers made biweekly visits to 61 study sites between April 26 and October 11, 1989, to track water use throughout the growing season. In the Havana Lowlands, seasonal irrigation water use averaged 14.5 inches. High water use recorded from April 1 to May 10 was reflected in initial irrigation and fertigation of crops, including the first crop of double-cropped fields. At least half the farmers in the study applied nitrogen through irrigation systems (fertigation) during this and other critical growth periods. Peak water use occurred during pollination periods in late June and early July. Decreased water use in mid- to late July reflected cloudy, rainy

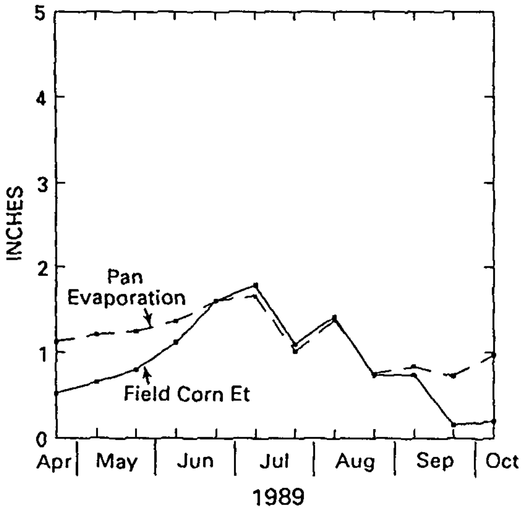

Figure 14. 1989 pan evaporation measurements versus computed field corn evapotranspiration (Havana Lowlands)

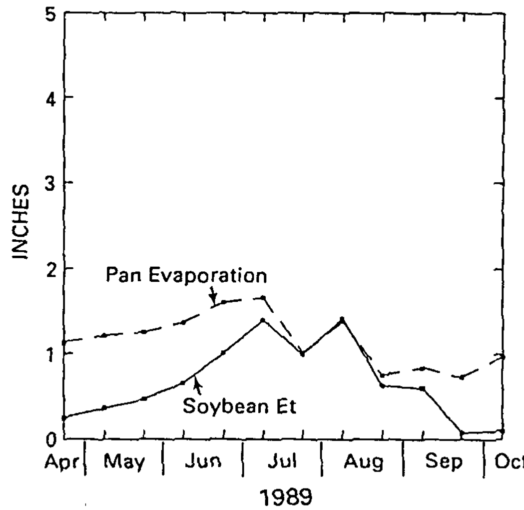

Figure 15. 1989 pan evaporation measurements versus computed soybean evapotranspiration (Havana Lowlands)

Table 22. 1989 Pan Evaporation and Computed Evapotranspiration, 1989 (Havana Lowlands)

(inches)

			Crop coefficients		Evapotranspiration	
Time step	*Dates*	*Pan evaporation*	*Field corn*	*Soybeans*	*Field corn*	*Soybeans*
1	4/26-5/9	1.107	0.46	0.22	0.509	0.243
2	5/10-5/23	1.187	0.46	0.22	0.546	0.261
3	5/24-6/6	1.223	0.54	0.30	0.661	0.367
4	6/7-6/20	1.338	0.64	0.37	0.856	0.495
5	6/21-7/4	1.574	0.82	0.48	1.291	0.756
6	7/5-7/19	1.623	1.00	0.63	1.623	1.022
7	7/20-8/2	0.991	1.08	0.84	1.070	0.833
8	9/8-8/16	1.352	1.08	0.98	1.460	1.325
9	8/17-8/28	0.738	1.03	1.02	0.760	0.752
10	8/29-9/13	0.820	0.97	0.83	0.795	0.680
11	9/14-9/26	0.713	0.89	0.72	0.635	0.514
12	9/27-10/11	0.953	0.50	0.40	0.477	0.381

weather and associated lower evapotranspiration rates. Water use through August and September reflected the demands of the second crop of double-cropped fields.

Pan evaporation measurements from the Sand Field versus computed evapotranspiration for field corn (figure 14) and soybeans (figure 15) were based on the crop coefficients shown in table 22. A relatively cool period in early July drove evapotranspiration and irrigation amounts down at a time during the growing season when both quantities might normally be at their peak. Figure 16 compares computed field corn evapotranspiration and observed irrigation applications on cornfields. It is significant to note that irrigation applications dropped during early July in accordance with decreased evaporative demands. A similar pattern was observed for soybean fields (figure 17). Again, there was a decrease in both evapotranspiration and irrigation in early July. For figures 18 and 19, rainfall was added to irrigation amounts during each 2-week time step; the total was then compared to evapotranspiration.

Figures 18 and 19 show that the irrigation farmers participating in this study were, on the average, adept at applying generally appropriate amounts of irrigation water at the right times. While this may suggest that the farmers formally schedule their irrigation applications, few of the participants actually kept records of water use or reported use of any formal scheduling method. Most reported observing ("looks dry") and feeling ("feels dry") their soil to determine when to irrigate. Irrigation farmers "know their land" and know from experience the appropriate amount of water that their soil and cropping patterns require.

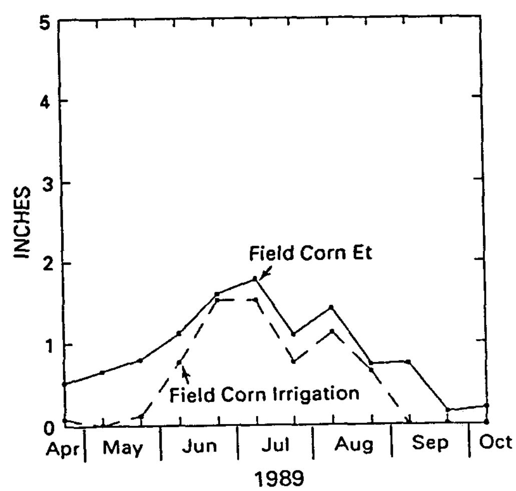

Figure 16. 1989 field corn evapotranspiration versus average irrigation amounts on field corn sites (Havana Lowlands)

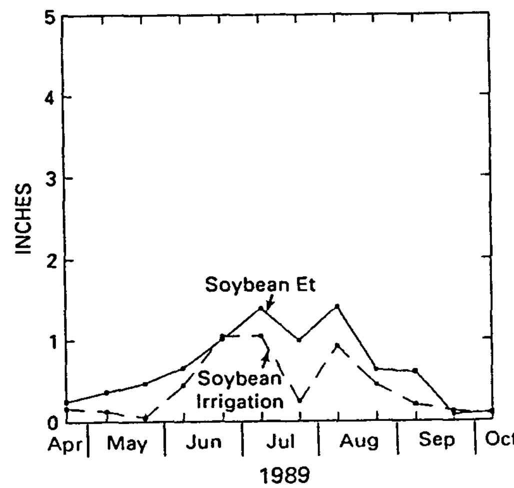

Figure 17. 1989 soybean evapotranspiration versus average irrigation amounts on soybean fields (Havana Lowlands)

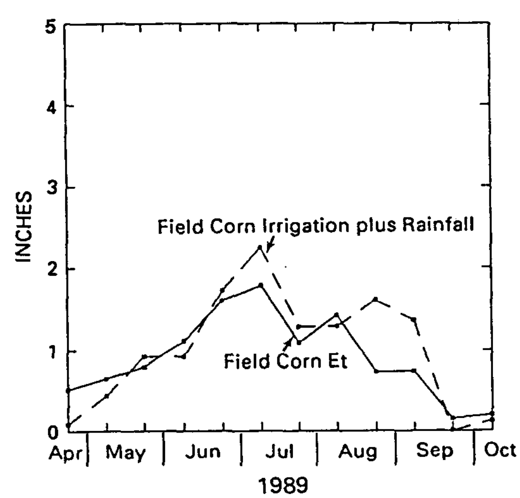

Figure 18. 1989 field corn evapotranspiration versus average irrigation amounts plus rainfall on field corn sites (Havana Lowlands)

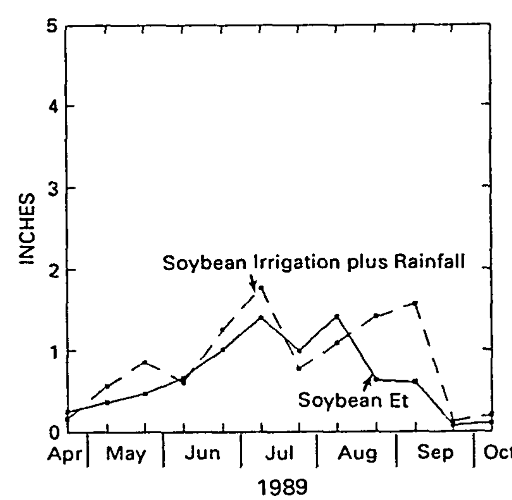

Figure 19. 1989 soybean evapotranspiration versus average irrigation amounts plus rainfall on soybean fields (Havana Lowlands)

CONCLUSIONS

A two-year study was conducted of irrigation water use and scheduling practices in Illinois during the 1988 and 1989 growing seasons. Estimates of irrigation water use for each irrigation system in the study were based on metered hours of irrigation system operation and rate of system flow. Flow rate information was based on irrigation system design flow ratings. In most cases, that information was provided by the irrigation farmer from system installation records, hence, the term "farmer-estimated flow rates" used in this report. Farmer-estimated flow rates should not be confused with farm-recorded irrigation amounts, which were found to be incomplete records of water use.

Attempts were made to independently validate the farmer-estimated flow rates using both external and internal flow monitoring devices at a number of study sites. For many reasons, flowmeter results were found to be inconsistent with the design flow rates, and they were seldom replicated during subsequent measurements. Flowmeter results were not used in this study to compute total irrigation water use.

In general, irrigation amounts were found to be highly variable for many reasons. Tracing the causes for this variation was somewhat complicated because irrigation farmers generally do not keep complete records of irrigation applications. Several specific study results, however, stand out as significant.

First, ambient soil moisture conditions (root-zone field capacity) largely control farmers' decisions about how much irrigation water to apply. Average root-zone field capacity generally correlated well with total irrigation amounts: the lower the field capacity, the higher the irrigation amount. There was additional evidence that farmers may irrigate for their worst or sandiest soil with the lowest moisture-holding capacity, even if that means overwatering the better soils slightly. Generally, the larger the proportion of worst soil in one field, the higher the total irrigation amounts; this association became significantly weaker as the proportion of worst soil in the field decreased.

Second, weather also appears to control farmers' decisions about irrigation. A greater degree of variability was observed in irrigation amounts from year to year than from farmer to farmer within one year. This suggests that irrigation farmers respond uniformly to changes in the weather such as normal versus drought conditions. One assumes that if a severe drought affected one portion of an irrigated region but not another, variations between the two regions would be similar to those observed between a normal year and a drought year.

Third, farmers do not appear to vary their irrigation amounts significantly on different crops. There are several possible reasons for this. Farmers may not take time to adjust the irrigation amounts for different crops growing in a single field. They may not know how much water they apply on any given crop, making it difficult to vary that amount according to crop type. Or they may apply as much water as they can, no matter what crop they are growing.

Fourth, irrigation farmers may display some idiosyncratic behavior; they may water the same crop on similar soils under similar weather conditions differently. This study did not attempt to explain this variability in farmer behavior other than to simply recognize its presence.

Fifth, there is nothing like experience. The participants applied appropriate amounts of irrigation water to their crops at the right times with respect to rainfall and evaporative loss. Because there was no evidence of gross overwatering or underwatering, one might conclude that the irrigation farmers are (1) keeping close track of their irrigation water use and (2) using a formal scheduling program to determine when to turn on their irrigation systems. In most instances, however, neither assumption is true. Irrigation farmers are making accurate decisions about irrigation based on experience-gained knowledge of their soils' moisture characteristics.

With the growing importance of irrigation throughout Illinois, farmers and water resources managers must understand the basics. What amounts of irrigation water are applied in a normal year? What amounts are applied in a drought year? Are irrigation practices efficient? What are the irrigation scheduling tools? Gaining answers to questions such as these will bring both irrigation farmers and water resources managers closer to an appreciation of irrigation's potential impact on Illinois water resources.

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Appendix A. Havana Lowlands Irrigation Study Site Characteristics

Site	*Center-pivot (CP) or traveling gun system (TG)*	*Pressure high (H), med (M), or low (L)*	*Diesel (D) or electric (E)*	*Irrigated acreage*	*Flow rate (gpm)*	*First crop*	*Second crop*	*Well depth (ft)*
MT1	CP	L	E	160	950	Popcorn		62
MT2	CP	L	E	120	1100	Popcorn		126
MT5	CP	L	E	132	950	Popcorn		110
MT6	CP	L	E	61	700	Popcorn		94
MT7	CP	H	E	224	1150	Popcorn		73
MT8	CP	L	D	120	1100	Green beans	Green beans	100
MT9	CP	H	E	135	1100	Field corn, wheat, sweet corn		108
MT10	CP	L	E	32	300	Green beans	Green beans	90
MT11	CP	H	E	98	1100	Green beans, popcorn	Sweet corn	91
MT12	CP	H	E	132	900	Popcorn		92
MT13	CP	H	E	130	1000	Popcorn, field corn		60
MT14	CP	L	E	132	1000	Sweet corn, field corn	Green beans	-
MT15	CP	L	E	80	1000	Popcorn		-
MT16	CP	H	E	70	900	Popcorn		95
MT18	CP	H	E	13	1000	Green beans, seed corn	Sweet corn	102
MT19	CP	H	D	32	450	Popcorn		-
MT20	CP	H	D	32	450	Field corn		123
MT21	CP	H	D	64	900	Popcorn		107
MT22	CP	H	D	140	900	Field corn, popcorn, soybeans, wheat		113
MT23	CP	H	D	140	900	Green beans, field corn	Green beans	127
MT24	CP	H	D	140	600	Popcorn, field corn, soybeans		113
MT26	CP	H	D	145	900	Field corn		129
MT27	CP	L	E	145	900	Popcorn		92
MT28	CP	L	D	180	1050	Seed corn		-
MT29	CP	H	E	160	900	Popcorn, field corn		120
MT30	CP	H	E	40	400	Wheat	Sweet corn	-
MT31	TG	H	D	63	450	Popcorn, field corn, soybeans		73
MT32	CP	H	D	97	550	Field corn		73
MT33	CP	L	D	80	650	Sweet corn	Sweet corn	113

Appendix A. Continued

Site	*Center-pivot (CP) or traveling gun system (TG)*	*Pressure high (H), med (M), or low (L)*	*Diesel (D) or electric (E)*	*Irrigated acreage*	*Flow rate (gpm)*	*First crop*	*Second crop*	*Well Depth (ft)*
MT1	CP	L	E	160	950	Popcorn		62
MT2	CP	L	E	120	1100	Popcorn		126
MT5	CP	L	E	132	950	Popcorn		110
MT6	CP	L	E	61	700	Popcorn		94
MT7	CP	H	E	224	1150	Popcorn		73
MT8	CP	L	D	120	1100	Green beans	Green beans	100
MT9	CP	H	E	135	1100	Field corn, wheat, sweet corn		108
MT10	CP	L	E	32	300	Green beans	Green beans	90
MT11	CP	H	E	98	1100	Green beans, popcorn	Sweet corn	91
MT12	CP	H	E	132	900	Popcorn		92
MT13	CP	H	E	130	1000	Popcorn, field corn		60
MT14	CP	L	E	132	1000	Sweet corn, field corn	Green beans	-
MT15	CP	L	E	80	1000	Popcorn		-
MT16	CP	H	E	70	900	Popcorn		95
MT18	CP	H	E	13	1000	Green beans, seed corn	Sweet corn	102
MT19	CP	H	D	32	450	Popcorn		-
MT20	CP	H	D	32	450	Field corn		123
MT21	CP	H	D	64	900	Popcorn		107
MT22	CP	H	D	140	900	Field corn, popcorn, soybeans, wheat		113
MT23	CP	H	D	140	900	Green beans, field corn	Green beans	127
MT24	CP	H	D	140	600	Popcorn, field corn, soybeans		113
MT26	CP	H	D	145	900	Field corn		129
MT27	CP	L	E	145	900	Popcorn		92
MT28	CP	L	D	180	1050	Seed corn		-
MT29	CP	H	E	160	900	Popcorn, field corn		120
MT30	CP	H	E	40	400	Wheat	Sweet corn	-
MT31	TG	H	D	63	450	Popcorn, field corn, soybeans		73
MT32	CP	H	D	97	550	Field corn		73
MT33	CP	L	D	80	650	Sweet corn	Sweet corn	113

Appendix A. Continued

Site	*Center-pivot (CP) or traveling gun system (TG)*	*Pressure high (H), med (M), or low (L)*	*Diesel (D) or electric (E)*	*Irrigated acreage*	*Flow rate (gpm)*	*First crop*	*Second crop*	*Well depth (ft)*
MT34	CP	L	D	80	650	Popcorn, sweet corn	Sweet corn	113
MT36	CP	L	E	36	400	Field corn		85
MT37	CP	L	D	200	1600	Field corn, soybeans, sweet corn	Cucumbers	105
MT38	CP	L	D	120	700	Popcorn, field corn		90
MT39	CP	H	E	140	1000	Cucumbers, wheat	Cucumbers, lima beans	107
MT40	CP	H	E	60	800	Cucumbers	Cucumbers	118
MT41	CP	H	E	268	1250	Green beans, sweet corn, soybeans	Green beans, cucumbers	108
MT42	CP	L	E	32	300	Field corn		-
MT43	CP	L	E	32	350	Sweet corn	Sweet corn	100
MT44	CP	L	E	32	300	Field corn		95
MT45	CP	L	E	32	300	Field corn		100
MT46	CP	L	E	32	300	Field corn		-
MT47	CP	H	E	32	400	Popcorn		90
MT48	CP	L	E	40	300	Field corn		80
MT49	CP	H	E	40	300	Field corn		80
MT50	CP	L	E	145	900	Sweet corn	Green beans	63
MT51	CP	L	D	130	1000	Field corn		76
MT52	CP	L	E	45	500	Field corn		79
MT53	CP	L	E	25	500	Field corn		79
MT54	CP	L	D	130	1200	Field corn		88
MT55	CP	L	E	130	950	Popcorn		116
MT56	CP	L	E	65	600	Popcorn, Field corn		115
MT57	CP	H	E	130	1250	Popcorn		82
MT58	CP	L	E	290	1650	Field corn		126
MT59	CP	L	E	130	1000	Soybeans		-
MT60	CP	H	D	130	850	Soybeans		-
MT61	CP	L	E	130	950	Field corn, popcorn		-
MT62	CP	H	D	100	800	Field corn, popcorn		106
MT63	CP	L	E	130	800	Popcorn, wheat	Sweet corn	40
MT64	CP	H	E	135	900	Pumpkins, popcorn		-
MT65	CP	H	E	95	800	Field corn, soybeans		104

Appendix A. Continued

Site	*Center-pivot (CP) or traveling gun system (TG)*	*Pressure High (H) med (M), or low (L),*	*Diesel (D) or electric (E)*	*Irrigated acreage*	*Flow rate (gpm)*	*First crop*	*Second crop*	*Well depth (ft)*
MT66	CP	L	E	131	800	Popcorn, field corn, soybeans		115
MT67	CP	L	E	101	800	Popcorn, soybeans		118
MT68	CP	L	E	141	800	Popcorn		105
MT69	CP	L	E	108	600	Seed corn, field corn		-
MT70	CP	H	D	108	850	Field corn, soybeans		103
MT71	CP	L	E	50	800	Popcorn		113
MT72	CP	L	E	98	800	Popcorn, soybeans, field corn		113
MT74	CP	L	E	134	1000	Green beans, field corn		91
MT75	CP	H	D	134	1000	Field corn, soybeans		105
MT76	CP	H	D	136	1000	Field corn, soybeans		113
MT77	CP	L	E	130	900	Peas, seed corn	Sweet corn	94
MT78	CP	H	E	130	800	Pumpkins, green beans		-
MT79	CP	H	E	114	900	Seed corn		-
MT80	CP	H	E	126	900	Seed corn, soybeans		94
MT81	CP	H	E	105	1000	Field corn, soybeans		102
MT82	CP	H	E	118	1000	Field corn, soybeans, wheat		124
MT83	CP	H	D	200	800	Pasture		102
MT84	TG	H	E	60	500	Field corn, soybeans		-
MT85	TG	H	E	40	450	Field corn		40
MT86	CP	L	E	140	800	Field corn, soybeans		-
MT87	CP	L	E	105	800	Field corn, green beans		65
MT90	CP	H	D	160	1050	Soybeans, field corn		106
MT92	CP	M	E	105	1000	Popcorn		97
MT93	CP	M	E	35	400	Potatoes	Cucumbers	-
MT94	CP	M	E	35	400	Potatoes	Cucumbers	-
MT95	CP	M	E	35	400	Cucumbers	Sweet corn	91

Appendix A. Continued

Site	*Center-pivot (CP) or traveling gun system (TG)*	*Pressure High (H) med (M), or low (L),*	*Diesel (D) or electric (E)*	*Irrigated acreage*	*Flow rate (gpm)*	*First crop*	*Second crop*	*Well depth (ft)*
MT96	CP	M	E	280	2300	Green beans, potatoes	Green beans, peas	114
MT97	CP	M	E	135	1000	Field corn		-
MT98	CP	M	E	135	1000	Field corn		120
MT99	CP	M	E	135	1000	Peas, field corn	Field corn, sweet corn	125
MT100	CP	M	E	135	1000	Sweet corn	Sweet corn	93
MT101	CP	M	E	135	1200	Field corn		-
MT102	CP	M	E	160	1400	Pumpkins, cantelope		120
MT103	CP	L	E	34	400	Wheat, sweet corn		95
MT104	CP	H	E	34	400	Wheat, sweet corn		97
MTI05	CP	H	E	36	375	Popcorn		-
MT106	CP	H	E	103	800	Sweet corn	Green beans	65
MT107	CP	H	E	34	375	Peas	Cucumbers	-
MT108	CP	H	E	72	750	Popcorn		-
MT110	CP	H	E	72	750	Cucumbers	Cucumbers	117
MTll2	CP	H	D	140	1000	Cucumbers	Cucumbers	-
MTll3	CP	H	E	135	1000	Field corn		125
MTll4	CP	H	E	135	1000	Field corn		105
MTll5	CP	H	E	35	375	Field corn		102
MTll6	CP	H	E	135	1000	Field corn		68
MTll8	CP	H	D	135	1000	Green beans	Green beans	114
MTll9	CP	L	E	130	700	Field corn, popcorn		100
MT120	CP	L	D	170	1000	Field corn		118
MT121	CP	L	D	130	1000	Field corn		-
MT122	CP	L	E	100	1000	Seed corn		-
MT123	CP	L	E	190	1000	Seed corn		-
MT124	CP	L	E	130	900	Field corn		-
MT125	CP	L	E	130	1000	Seed corn		-
MT126	CP	H	D	120	800	Popcorn, soybeans		105
MT127	CP	H	D	74	700	Popcorn		97
MT128	CP	L	E	130	850	Popcorn, field corn		95
MT129	CP	L	E	134	850	Popcorn, field corn		105
MT130	CP	L	D	145	850	Field corn, soybeans		102

Appendix A. Continued

Site	*Center-pivot (CP) or traveling gun system (TG)*	*Pressure High (H) med (M), or low (L),*	*Diesel (D) or electric (E)*	*Irrigated acreage*	*Flow rate (gpm)*	*First crop*	*Second crop*	*Well depth (ft)*
MT136	CP	L	E	140	800			-
MT140	CP	H	D	137	1000	Popcorn, field corn		113
MT141	CP	L	D	164	1200	Field corn, sweet com	Sweet corn	-
MT142	CP	L	D	132	700	Field corn, popcorn		115
MT145	CP	L	E	110	700	Field corn, popcorn		93
MT148	CP	H	E	102	800	Popcorn		78
MT149	CP	H	D	128	900	Field corn, sweet corn	Green beans, sweet corn	-
MT150	CP	H	D	122	900	Melons, green beans	Melons, sweet corn	94
MT151	CP	H	E	118	800	Popcorn		119
MT152	CP	H	E	183	900	Popcorn, field corn sweet corn	Green beans	118
MT154	CP	H	E	112	900	Field corn, popcorn		114
MT155	CP	H	E	137	900	Field corn, sweet corn	Sweet corn	111
MT156	CP	H	E	134	800	Popcorn, sweet corn	Sweet com	-
MT157	CP	H	E	98	800	Popcorn, sweet corn	Sweet corn	-
MT158	CP	H	D	70	800	Field corn		124
MT159	CP	H	D	182	1200	Popcorn, green beans	Green beans	151
MT160	CP	H	E	134	900	Popcorn, field corn		-
MT161	CP	L	E	108	700	Popcorn, field corn		-
MT164	CP	H	E	37	800	Popcorn		103
MT165	CP	H	D	89	800	Popcorn, green beans	Sweet corn	94
MT166	CP	L	E	90	800	Sweet corn	Sweet corn	-
MT167	CP	H	D	107	800	Field corn, sweet corn	Sweet corn	108
MTI68	CP	H	E	101	800	Seed corn		-
MT169	CP	H	D	59	700	Sweet corn	Green beans	114
MT170	CP	H	E	67	800	Sweet corn	Green beans	-
MT171	CP	H	D	118	700	Field corn, popcorn, wheat	Lima beans	80
MT173	CP	L	D	100	1200	Field corn, popcorn		94

Appendix A. Continued

Site	*Center-pivot (CP) or traveling gun system (TG)*	*Pressure High (H) med (M), or low (L),*	*Diesel (D) or electric (E)*	*Irrigated acreage*	*Flow rate (gpm)*	*First crop*	*Second crop*	*Well depth (ft)*
MT174	CP		D	68	1000	Field corn, popcorn		81
MT175	CP	L	E	114	950	Popcorn, soybeans		122
MTI77	CP	L	E	135	950	Green beans	Green beans	81
MT178	CP	L	E	130	950	Field corn		86
MT179	CP	L	E	140	950	Field corn		-
MT184	CP	H	D	125	1000	Popcorn, field corn		106

Nonpumping Water Level Measuring Sites

Site	*Well depth (ft)*	*Site*	*Well depth (ft)*	*Site*	*Well depth (ft)*
MT88	87	MT172	-	MT190	60
MT89	104	MT180	117	MT191	100
MT91	100	MT183	96	MT192	91
MT117	117	MT185	103	MT193	-
MT135	-	MT186	-	MT194	93
MT137	105	MT187	86	MT195	-
MT139	72	MT188	80		
MT147	-	MT189	122		

Appendix B. Green River Lowlands Irrigation Study Site Characteristics

Site	*Center-pivot (CP) or traveling gun system (TG)*	*Pressure high (H) med (M), or low (L),*	*Diesel (D) or electric (E)*	*Irrigated acreage*	*Flow rate (gpm)*	*First crop*	*Second crop*	*Well depth (ft)*
LW1	CP	H	D	110	700	Field corn, soybeans		45
LW2	CP	H	D	135	900	Field corn		154
LW3	CP	H	D	120	800	Field corn		167
LW4	CP	H	D	275	1000	Seed corn, soybeans		88
LW5	CP	H	E	100	800	Seed corn		67
LW6	CP	H	D	140	800	Seed corn green beans,	Green beans	72
LW7	CP	H	D	160	700	Field corn		480
LW8	CP	H	E	280	800	Field corn		208
LW9	CP	H	D	125	1000	Seed corn		100
LW10	CP	H	D	100	550	Seed corn		70
LW11	CP	H	E	135	800	Peas	Sweet corn	100
LW12	CP	H	E	100	400	Seed corn		40
LW13	CP	H	D	100	900	Field corn		70
LW14	CP	H	D	120	900	Seed corn		69
LW15	CP	H	D	90	700	Field corn		63
LW16	CP	H	D	120	1000	Field corn		62
LW17	TG	H	D	140	650	Field corn		150
LW18	TG	H	D	120	620	Field corn		56
LW19	CP	H	D	200	1000	Seed corn		125
LW20	CP	H	D	141	1200	Seed corn		190
LW21	CP	H	D	172	1200	Seed corn		190
LW22	CP	H	D	150	1000	Seed corn		-
LW23	CP	H	D	160	1000	Field corn, soybeans		76
LW24	CP	L	D	180	400	Lima beans	Green beans	225
LW25	CP	L	D	121	350	Field corn		505
LW26	CP	H	D	133	900	Field corn		192
LW27	CP	H	D	113	1000	Field corn		141
LW28	CP	L	D	110	850	Seed corn		-
LW29	CP	L	E	130	850	Seed corn		-
LW30	CP	H	E	160	900	Green beans, field corn	Green beans	110

Appendix B. Continued

Site	*Center-pivot (CP) or traveling gun system (TG)*	*Pressure high (H), medium (m) or low (L)*	*Diesel (D) or electric (E)*	*Irrigated Acreage*	*Flow rate (gpm)*	*First crop*	*Second crop*	*Well depth (ft)*
LW31	CP	H	E	138	1000	Seed corn, alfalfa		154
LW32	CP	H	E	78	1000	Field corn		-
LW33	CP	H	E	135	900	Seed corn		83
LW34	CP	M	E	108	600	Seed corn		89
LW35	CP	H	D	135	900	Green beans	Green beans	75
LW36	CP	M	E	125	950	Seed corn		-
LW37	CP	H	E	80	500	Soybeans		100
LW38	CP	L	D	90	700	Soybeans		80
LW39	CP	H	E	153	800	Field corn		105
LW40	CP	H	E	62	750	Field corn		80
LW41	CP	H	E	233	1300	Field corn		81
LW42	CP	L	D	140	800	Seed corn		117
LW43	CP	L	D	215	900	Seed corn		117
LW44	CP	H	D	135	1000	Soybeans		89
LW45	CP	H	D	160	1100	Seed corn		75
LW46	CP	H	D	135	1200	Seed corn		159
LW47	CP	H	E	273	1200	Seed corn		79
LW49	CP	L	E	40	350	Soybeans		82
LW50	CP	M	E	135	1200	Field corn		76
LW52	CP	M	E	120	700	Green beans, seed corn	Green beans	100
LW54	CP	M	E	100	700	Green beans, seed corn	Green beans	80
LW55	CP	L	E	210	1050	Seed corn		95
LW57	CP	M	E	60	450	Seed corn		95
LW59	CP	H	D	130	1000	Seed corn		123
LW60	CP	M	E	130	700	Seed corn		73
LW61	CP	H	D	130	800	Seed corn		70
LW62	CP	H	D	140	500	Field corn		122
LW63	CP	H	D	130	900	Green beans	Green beans	80
LW64	CP	H	D	135	800	Field corn		98
LW65	CP	H	D	125	700	Seed corn		102

Appendix B. Concluded

Nonpumping Water Level Measuring Sites

Site	*Well depth (ft)*	*Site*	*Well depth (ft)*	*Site*	*Well depth (ft)*
LW66	-	LW73	168	LW80	49
LW67	70	LW74	94	LW81	134
LW68	126	LW75	-	LW82	68
LW69	-	LW76	110	LW83	57
LW70	-	LW77	101	LW84	-
LW71	186	LW78	67	LW85	103
LW72	190	LW79	64	LW86	-