STATE OF LOUISIANA
DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT

WATER RESOURCES
TECHNICAL REPORT
No. 52

WATER REQUIREMENTS FOR GROWING RICE IN SOUTHWESTERN LOUISIANA, 1985-86

Prepared by
U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY
In cooperation with
LOUISIANA DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT

1992

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By

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U.S. Geological Survey

Published by

LOUISIANA DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT

Baton Rouge, Louisiana

1992

STATE OF LOUISIANA

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DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT

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Cooperative projects with the

U.S. DEPARTMENT OF THE INTERIOR

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
inch (in.)	25.4	millimeter
inch per year (in/yr)	25.4	millimeter per year
foot (ft)	0.3048	meter
million gallons (Mgal)	3,785	cubic meter
million gallons per day (Mgal/d)	3,785	cubic meter per day
acre	4,047	square meter
mile	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
millibar	0.0145	pound per square inch
millibar	1.0197	gram per square centimeter

Temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) as follows: °F = 1.8 X °C + 32.

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929--a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

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ABSTRACT

Hydrologic instruments were installed in two typical rice fields in southwestern Louisiana, and the amount of water used to grow rice in these fields was measured during 1985-86. The total water used at one site in 1986 (two crops) was 41.9 inches per year, and of that amount, irrigation with ground water supplied 29.1 inches per year. These water use estimates are in good agreement with total water requirements (rainfall plus irrigation) for rice farming in Louisiana reported in the 1960's and are about 30 percent greater than water requirements for rice farming in the late 1940's and early 1950's. Evapotranspiration accounted for the largest loss of water from the rice fields. Evapotranspiration losses during the two-crop 1986 growing season at one of the rice fields were estimated at 14.8 to 27.0 inches. The second largest loss of water from this field in 1986 was water drained from the field during or after the growing season (13.1 inches).

INTRODUCTION

Rice, as a naturally occurring plant, has existed in Louisiana since before European exploration and settlement. Commercial production of rice and the associated flooding and draining of rice fields in Louisiana began about 1718 (Jones and others, 1956). Rice production has increased dramatically since that time and by 1989, an estimated 496,000 acres were in rice cultivation and the crop was valued at $157.6 million (Louisiana Cooperative Extension Service, 1990, p. 11).

Water use for rice irrigation is a major component of the total water use in Louisiana. Total withdrawals for rice irrigation from both surface- and ground-water sources were estimated at 646 Mgal/d and accounted for 7 percent of the total water use in Louisiana in 1990 (Lovelace, 1991). Irrigation places large demands on the water resources of Louisiana and an accurate determination of the amount of water used for growing rice is needed if local and State managers are to manage and protect the State's water resources.

Beginning in 1960, data on water use in the State, including water used for rice irrigation, have been collected every 5 years by the U.S. Geological Survey (USGS) and published by the Louisiana Department of Transportation and Development (DOTD). The amount of water used for rice irrigation historically has been determined by multiplying the number of acres planted in rice by an average or representative amount of water applied annually per acre of rice. Typically, different application rates were assumed for irrigation using ground water and surface water.

To obtain the most accurate application rates feasible, the USGS and DOTD have, since 1946, jointly studied and quantified the water requirements for growing rice in Louisiana. In 1983, a cooperative study was begun by USGS and DOTD to ascertain current (1985-86) requirements for growing rice.

Purpose and Scope

This report presents the results of a study to refine and improve estimates of the water requirements for growing rice in two representative rice fields in southwestern Louisiana that are irrigated with ground water. The report also presents reported water requirements for rice irrigation in Louisiana dating back to the late 1940's, and compares historical water requirements with those determined during this study.

Data were collected for this study during 1985 and 1986 at two irrigated rice fields on the Hollier and Bourgeois farms near Jennings in southwestern Louisiana (fig. 1). Data collected as part of this study included the volume of ground water withdrawn for irrigation, rainfall, the volume of water drained from the fields both during and after plant growth, incoming and outgoing solar radiation, temperature, relative humidity, and wind speed measured at an elevation of about 3 and 6 ft above land surface. Data on rainfall, solar radiation, temperature, relative humidity, and wind speed were reported by Sasser and others (1988).

Description of Study Area

The rice fields are located in the central part of Jefferson Davis Parish near the east and west parish lines (fig. 1). Local relief averages 5 to 10 ft above sea level. The average annual temperature in southwestern Louisiana is 20 °C, and prevailing southerly winds provide a humid tropical climate in the summer. Rainfall ranges from 52 to 59 in. annually. Additional information about the description of southwestern Louisiana is presented by Jones and others (1956).

Location and Nature of Rice Production at the Study Sites

Rice production at the study sites on the Hollier and Bourgeois farms is typical of rice-farming practices in southwestern Louisiana. The fields are leveed, graded, and completely flooded to a depth of 3-6 in., perhaps several times before and during rice-growing periods. Irrigation water at both study

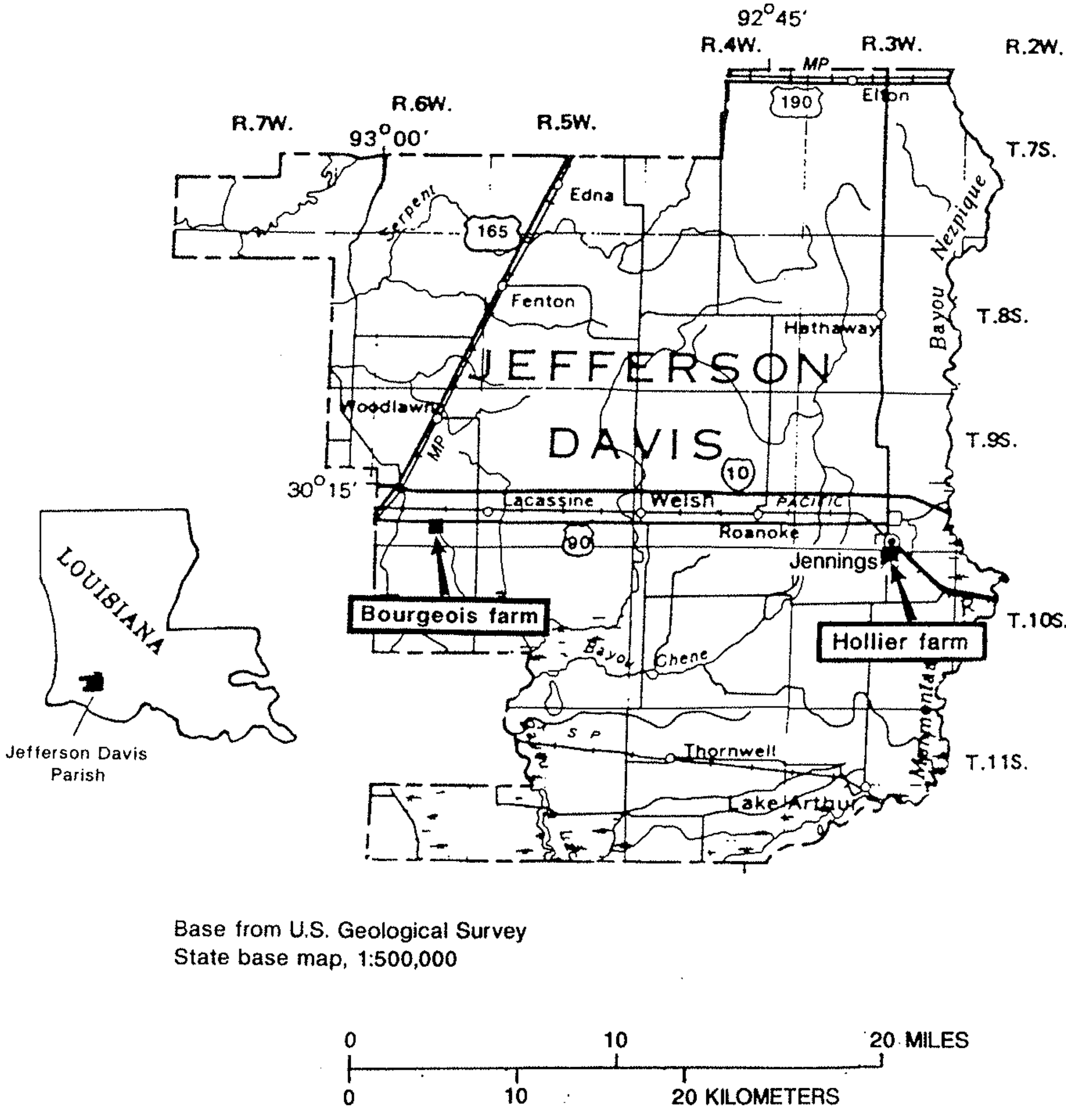

Figure 1.--Location of rice farms in study areas, southwestern Louisiana.

sites is withdrawn from ground-water wells and is applied to the fields through irrigation ditches.

At the Hollier farm, the fields are flooded in the late winter to prevent and retard emergence of weeds and as a requirement of the planting technique. Rice is planted by an airplane-broadcast method. Fields planted by this method are flooded before planting and drained soon after germination of the seed. After some plant growth the Hollier farm fields are flooded again.

At the Bourgeois farm, fields are usually left dry until after planting, and fields are planted using tractor-driven farm machinery known as a drill. After seed germination, the fields are flooded for the duration of the growing season.

Water is added to the fields, while rice is growing, to replace evapotranspiration and to control weeds. Fields are sometimes drained or partly drained during the growing season, however, to allow application of fertilizer and to induce root development at certain stages of plant growth.

In preparation for harvesting, fields are drained and allowed to dry so they will support harvesting machinery. The first crop is usually harvested in July. If weather and soil conditions are favorable, the rice plants will produce a second crop that is harvested in October. Irrigation practices for the second crop are virtually the same as those used with the first crop.

Water-Requirement Terms and Concepts

The term water requirement, as previously used (Jones and others, 1956, p. 125) and as used in this report, refers to the total volume of water used on a rice field. In terms of source or supply, the water requirement is the sum of water supplied by irrigation and by rainfall. The amount of water supplied by irrigation is usually called irrigation requirement or sometimes application rate.

The irrigation requirement is of primary interest to water managers because it represents the water demand on the available water resources of the State. The irrigation requirement or application rate commonly varies depending on whether the source of supply is ground water or surface water because of the different costs and losses associated with different forms of withdrawals and delivery. This report discusses only those water requirements associated with ground-water irrigation.

The amount of water supplied to a rice field by rainfall is less than the total rainfall by that portion intercepted by the rice vegetation and eventually lost to evaporation. Effective rainfall, which refers to the total rainfall less that intercepted by the vegetation, commonly averages between 60 and 75 percent of the total rainfall (Jones and others, 1956).

The total water requirement also can be characterized as the sum of various use or loss components. These use or loss components include the following:

1. Water entering soil-moisture storage and deep seepage,

2. Water intentionally drained or accidentally lost from the fields during and after the growing season, and

3. Water transmitted to the atmosphere through evaporation and transpiration (usually referred to as evapotranspiration).

Transpiration is the natural transmission of water to the atmosphere through vegetation. Jones and others (1956, p. 126) classified evapotranspiration as consumptive use. Evapotranspiration is the largest component of water used or lost in rice production.

The water requirement can be represented in equation form in terms of supplied amounts and used or lost amounts:

$$\begin{aligned}&\text{Rainfall less interception} + \text{Irrigation requirements}\\&= \text{Evapotranspiration} + \text{Soil moisture}\\&+ \text{Drained amounts during and after the season.}\end{aligned} \tag{1}$$

This equation is a budget equation that, on the left, quantifies the source of the water and, on the right, quantifies the fate of the water requirements of rice production.

Acknowledgments

The authors extend their thanks to the Hollier and Bourgeois families who provided access to the study sites and helped make this study possible. The authors also gratefully acknowledge the technical assistance provided by Z. "Bo" Bolourchi, Chief, Water Resources Section, Louisiana Department of Transportation and Development.

HISTORICALLY REPORTED WATER REQUIREMENTS

Jones and others (1956) described the water resources of southwestern Louisiana with an emphasis on the amount of water required for growing rice. They concluded that the average total water requirements (irrigation plus effective rainfall) for rice was about 32 in/yr and that the ground-water irrigation requirements averaged 22 in/yr during the period 1946-51. In their study, they estimated that effective rainfall for rice plants averaged between 62 and 71 percent of total rainfall and increased with decreasing rainfall.

For a very dry year they indicated that effective rainfall might be as high as 75 percent of total rainfall.

The fate of water applied to rice fields also was quantified by Jones and others (1956) who determined water losses due to soil-moisture storage and seepage losses from infiltration. They reported that a field in an extremely dry condition will absorb and store about 2 in. of water as soil-moisture. In their study, evapotranspiration was calculated by quantifying other components of the water-requirement budget and solving for evapotranspiration. A summary of annual water use and loss components for surface water irrigated rice fields reported by Jones and others (1956, p. 446) is listed below:

Component	Amount (inches per year)
Evapotranspiration during period of submergence	22.4
Drained from fields during period of submergence	2.1
Drained from fields at end of season	5.2
Soil-moisture storage	2.0
Total water requirements	[1]32.0

[1]Number has been rounded.

In a 1961 study, Whitman and Kilburn (1963) reported that the ground-water irrigation requirement for growing rice in southwestern Louisiana was about 24 in/yr. This rate (24 in/yr) was based on the least amount of ground water withdrawn for irrigation from the 37 wells they monitored during 1946-61. This rate was in reasonably good agreement with the 22 in/yr previously reported by Jones and others (1956) for the period 1946-51.

Zack (1971) reported the ground-water irrigation requirements in the 1960's ranged from 26.4 to 34.3 in/yr. He also described a relation, based on data collected during 1960-69, between ground-water rice-irrigation requirements and total rainfall. Zack's premise was, "The amount of water needed to grow rice is the same each year; the more rainfall the less ground water that can be used..." (Zack, 1971, p. 5). The relation Zack reported was:

$$\text{Ground-water irrigation requirement (in feet)} = 3.84 \text{ feet} - 0.04 \, X \text{ (February - August rainfall, in inches)}, \quad (2)$$

Converting irrigation requirements to inches and rearranging equation (2) yields:

$$\text{Ground-water irrigation requirement (in inches)} + 0.48 \, X \text{ (rainfall, in inches)} = 46 \text{ inches}. \quad (3)$$

This equation, developed using data collected in the 1960's, empirically implies a total water requirement of 46 in/yr and a rainfall interception rate of about 50 percent.

In a more recent study, Cardwell and Walter (1979) estimated that in 1974, the ground-water requirement for rice irrigation in Louisiana was 23 in/yr. This estimate was based on measurements of ground-water withdrawals from selected wells irrigating representative farm acreages.

APPROACH

Two rice fields were instrumented so that each component of the water requirement budget equation could be measured or calculated. The types of instruments and an assessment of error associated with the various measurements are described in this section.

Instrumentation

A variety of hydrologic instruments were used to measure the inflows and outflows of water to the two rice fields. To quantify the source (rainfall and irrigation) side of the water-requirement budget equation, rainfall was measured with a wedge-type volumetric rain gage and a tipping bucket recording rain gage.

Irrigation requirements were derived from records of calibrated well pumps. At the Hollier farm study site, water used for irrigation is supplied from a 246-foot deep, 8-inch diameter well. The well penetrates the Chicot aquifer system and is screened below a depth of 173 ft. A 145-horsepower pump is used to bring the ground water to the surface where it is delivered to the rice fields by way of an irrigation ditch. The amount of water pumped was determined from the number of revolutions per minute of the pump, duration of pump operation, and a rating that had been developed from flow measurements made at the pump discharge (or in the irrigation canal).

At the Bourgeois farm, irrigation water is supplied from a well about 300 ft deep with a diameter of 8 in. The well probably is screened in the Chicot aquifer system but the depth and length of the screened interval are unknown. A 145-horsepower pump is used to bring the water to the surface where it is delivered to the rice fields. The pump was monitored and calibrated similarly to the Hollier farm pump.

Fate of water applied to the rice fields through different processes was measured and computed through various means. Water drained from the fields during and after the growing season was measured using standard stream-gaging techniques at the outflow point. At the outflow points of both study fields, a gaging station was installed.

Evapotranspiration and seepage were measured using microlysimeters. A diagram of a typical microlysimeter installation is shown in figure 2. Microlysimeters are containers from which the amounts of water being used can be measured. Some of the microlysimeters used in this study were filled with soil only, but others contained soil and growing rice plants. The microlysimeters were fabricated from polyvinyl chloride (PVC) pipe with an inside diameter of 7.9 in. The length of the microlysimeters was 23.6 in. The

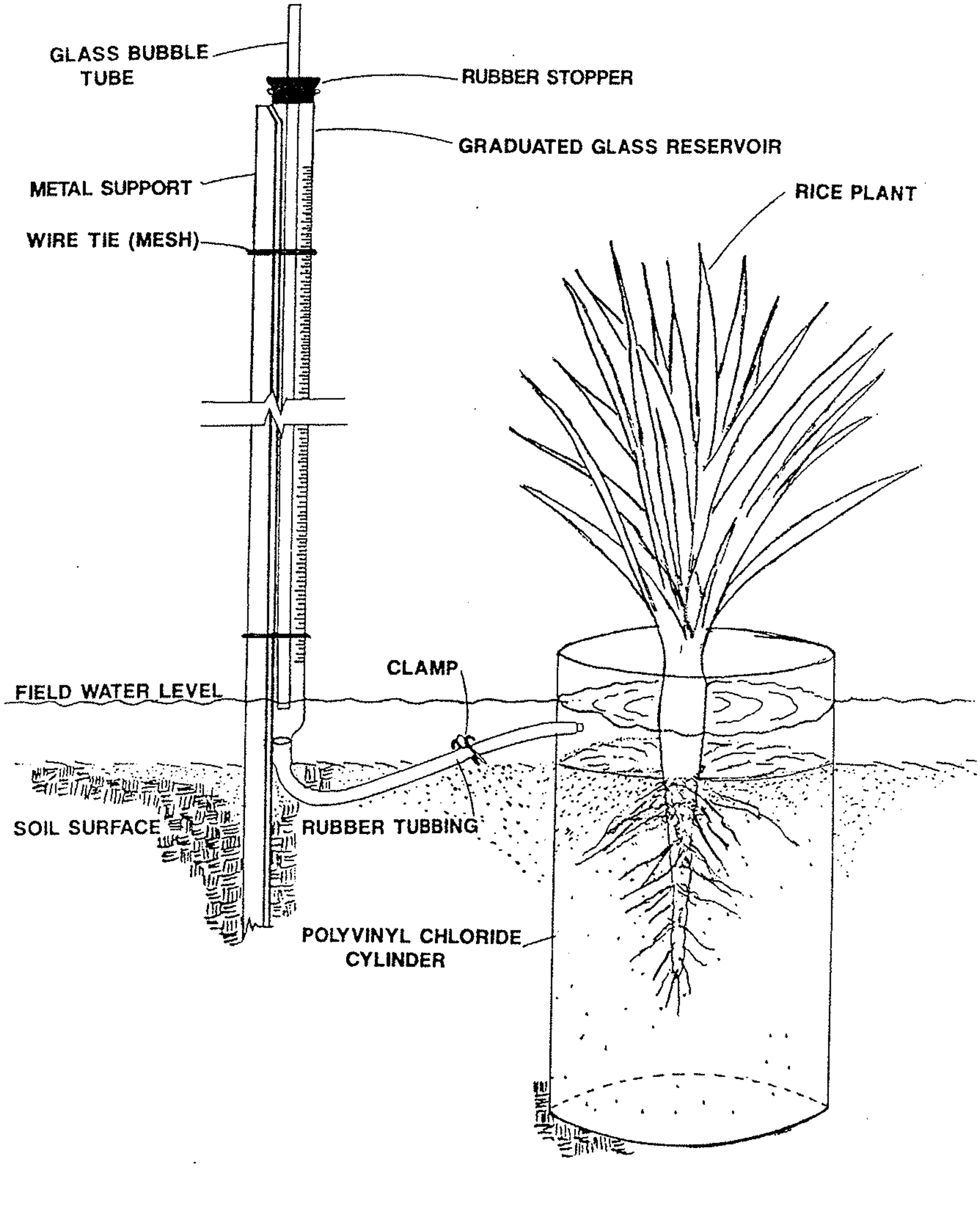

Figure 2.--A typical microlysimeter installation.

microlysimeter construction has been described by Tomar and O'Toole (1980). Each microlysimeter was modified by covering the tops and/or bottoms with plastic, depending upon which components were to be measured. For example, all microlysimeters that were used to measure seepage had an open bottom. The microlysimeters used to measure evaporation and transpiration had a closed bottom and an open top with emerging rice plants. The use and loss components measured with microlysimeters were as follows:

Microlysimeter site number	Components measured	Design
1	Seepage	Open bottom, plastic cover
2	Evaporation and transpiration	Closed bottom, with rice plants, no cover
3	Evaporation and seepage	Open bottom, no rice plants
4	Evaporation	Closed bottom, no rice plants
5	Seepage and transpiration	Open bottom, with rice plants coming through plastic cover
6	Transpiration	Closed bottom, with rice plants coming through plastic cover
7	Transpiration, seepage, and no evaporation	Open bottom, with rice plants coming through plastic cover

The microlysimeters were installed 19.7 in. into the ground at the edge of the rice field to facilitate field observation and maintenance procedures. The microlysimeters were read daily and serviced as needed to maintain the head in the graduated glass cylinder (reservoir) which served as the water-supply system. A summary of the microlysimeter calculations is presented in a data report by Sasser and others (1988).

Evapotranspiration was calculated and measured in two ways. The first method involved measuring other components of the water requirement budget, equation 1, and then solving the equation for evapotranspiration. The second method used to quantify evapotranspiration involved a direct measurement using microlysimeters. Water losses from a microlysimeter containing soil, water, and emergent rice plants were monitored in 1985 and 1986.

Analysis of Errors

Volumes of water quantitatively measured or estimated in this study included precipitation, water pumped to and drained from the rice fields, evapotranspiration from the rice fields, and water stored as soil moisture. Measurement errors are associated with each of these measurements. Rain gages, of the type used in this study, can under record precipitation by 15 to 30 percent. Measurement errors for rain gages can be even larger during short periods of heavy downpour (Winter, 1981). Techniques used to determine the amounts of water pumped to and drained from rice fields in this study were based on surface-water discharge measurements. Surface-water discharge measurements generally are considered to be accurate within ± 5 percent (Winter, 1981).

Provided there is no deep seepage from the flooded rice fields, the amount of water lost to soil moisture is volumetrically small compared to the other measured amounts of water in this study. Thus, any error associated with the amount of water lost to soil moisture will not greatly affect the overall error in estimating a total water budget.

WATER REQUIREMENTS FOR GROWING RICE

Rainfall, effective rainfall, irrigation requirement, and total water requirements for growing rice as measured for individual crops in 1985 and 1986 for the Hollier and Bourgeois farms study sites are listed in table 1. An effective rainfall rate of 60 percent of total rainfall was used because this represented a reasonable value between the 62 and 71 percent reported by Jones and others (1956) and the 50 percent value indicated by Zack (1971). The ground-water irrigation requirements ranged from 13.9 to 17.7 in/yr for one crop and for the year (two crops) averaged 29.1 in/yr.

The total water requirement for each crop ranged from 20.6 to 23.1 in. The total annual water requirement for growing two crops of rice at the Hollier farm in 1986 was 41.9 in. The water requirements for one crop were about one half the requirements for growing two crops, one in the spring and one in the fall. Thus, the number of crops grown each year is an important factor that affects the annual water requirements for rice.

Data previously reported for water requirements are listed in table 2. A total water requirement of 46 in/yr, implied by Zack (1971) for the 1960's is considerably larger (more than 30 percent) than the value of 32 in/yr for the period 1946-51 reported by Jones and others (1956). Part of this increase may have been due to changes in planting techniques, different strains of rice that require more water, and more farms producing two crops during the year. A slight difference in the total requirements (46 in/yr as compared to 42 in/yr, a change of less than 10 percent) is indicated between the 1960's and 1986. Given the uncertainty in the measurement of these numbers, these two values should probably be considered about equal. Water requirements increased from 1946-51 to the 1960's but seem to have remained constant from the 1960's through 1986.

Table 1.--Summary of water requirements by source and use, in inches, at study sites at the Hollier and Bourgeois farms

[--, no data]

Water budget component	Hollier farm Apr. 24- July 15, 1985	Hollier farm Apr. 8- July 9, 1986	Hollier farm July 31- Oct. 19, 1986	Hollier farm Total for 1986	Bourgeois farm Apr. 30- July 12, 1986
Source:					
Rainfall	11.2	10.5	10.8	21.3	9.0
Effective rainfall (0.6 X rainfall)	6.7	6.3	6.5	12.8	5.4
Irrigation requirement	13.9	14.5	14.6	29.1	17.7
Total requirement	20.6	20.8	21.1	41.9	23.1
Use:					
Seepage	[1].4	[2]1.4	[3].33	1.7	[4]2.0
Drained from field during submergence	.5	3.2	2.5	5.7	.0
Drained from field after season	4.0	2.0	5.4	7.4	6.2
Evapotranspiration calculated from:					
Budget equation	15.7	14.2	12.8	27.0	15.0
Microlysimeter measurements	[1]7.2	[2]10.0	[3]4.8	14.8	--

[1]Totals based on the average value of 39 days of record.
[2]Totals based on the average value of 68 days of record.
[3]Totals based on the average value of 32 days of record.
[4]Estimated, based on Jones and others (1956, p. 446).

The ground-water irrigation requirements for growing rice are also listed in table 2. In general, changes in irrigation requirements follow changes in measured total requirements. The value reported by Cardwell and Walter (1979) is less than values reported either in the 1960's or in 1986. This may be due to increased sensitivity of farmers to energy costs brought on by the energy crisis in 1973 or it may simply be due to unusually large rainfall amounts or poor weather which would cause some farmers to attempt to produce only one crop. It is important to note that Zack's (1971) relation, using the rainfall measured at the Hollier farm in 1986, predicted almost exactly the ground-water irrigation requirement measured for that season.

Table 2.--Summary of past and current (1986) water requirements for growing rice in Louisiana

[in/yr, inches per year; --, no data]

Study	Period of record	Total requirement (in/yr)	Ground-water irrigation requirement (in/yr)
Jones and others (1956, p. 445)	1946-51	32	22
Whitman and Kilburn (1963, p. 5)	1961	--	24
Zack (1971, p. 5)	1960-69	46	[1]29
Cardwell and Walter (1979, p. 3)	1974	--	23
Current (1985-86)	1986	42	29

[1] This value was computed using Zack's (1971, p. 5) equation and the rainfall total recorded at the Hollier farm in 1986. It represents the amount of ground-water irrigation predicted by Zack's relation given the 1986 rainfall and is included here for comparison purposes.

Effective rainfall provided approximately one-third of the water required for growth of rice at both the Hollier and Bourgeois farms over the period of study. The remaining two-thirds was provided by irrigation. Both the budget equation and microlysimeter measurements indicated that evapotranspiration was the largest sink for water placed on rice fields accounting for approximately one-half to two-thirds of water consumption. The remaining water consumption was accounted for mainly by water drained from the fields with a small portion being lost to seepage.

The major water use on loss component of the water budget for the two rice fields studied was evapotranspiration (table 1). As described earlier, evapotranspiration was estimated using two methods: the budget equation and microlysimeter measurements. Estimates of evapotranspiration based on the budget equation approach and microlysimeter data ranged from 7.2 to 15.7 in. per crop. Total evapotranspiration for the two crops grown on the Hollier farm in 1986 was 14.8 to 27.0 in. based on these two methods (table 1). Problems with the microlysimeters and the widely varying values of evapotranspiration they produced bring into question their reliability in this instance.

After evapotranspiration, drainage from the fields during or after the growing season constituted the second largest loss category. The amount drained from the fields ranged from 4.5 to 7.9 in. per crop and from 6.2 to 13.1 in. annually for the study. Seepage losses were measured at the Hollier farm study site and ranged from 0.4 to 1.4 in. per crop and totaled 1.7 in. for 1986.

SUMMARY

Water use for rice irrigation is a major component of the total water use in Louisiana. To determine the water requirements for growing rice and to evaluate the changes in these water-requirements since the late 1940's and early 1950's, water budgets for two rice fields in southwestern Louisiana were studied in 1985 and 1986. At one of the sites, the total water requirement for two rice crops grown in 1986 was 41.9 in. Ground-water irrigation supplied about 29.1 in. of the 41.9 in. of water required to grow rice (two crops) at this site. These estimates are in good agreement with the estimated water requirement for growing rice in the 1960's and were about 30 percent greater than reported water requirements for growing rice in the late 1940's and early 1950's. Ground-water irrigation requirements in 1985-86 also were about the same as those reported for the 1960's.

Evapotranspiration loses were the major component of water used or lost in rice production. Evapotranspiration estimates for the two-crop 1986 growing season at one field were 14.8 to 27.0 in. The second largest loss of water was water drained from the rice field during or after the growing season. Water drained from one field in 1986 (two crops) totaled 13.1 in. Measured seepage losses were less than 2 in/yr at one rice field (two crops).

SELECTED REFERENCES

Cardwell, G.T., and Walter, W.H., 1979, Pumpage of water in Louisiana, 1975: Louisiana Department of Transportation and Development, Office of Public Works Water Resources Special Report No. 2, 15 p.

Jones, P.H., Hendricks, E.L., Irelan, Burdge, and others, 1956, Water resources of southwestern Louisiana: U.S. Geological Survey Water-Supply Paper 1364, 460 p.

Louisiana Cooperative Extension Service, 1990, Louisiana Summary: Agricultural and natural resources, 1989: Baton Rouge, La., Louisiana State University Agricultural Center, 214 p.

Lovelace, J.K., 1991, Water use in Louisiana, 1990: Louisiana Department of Transportation and Development Water Resources Special Report No. 6, 131 p.

Sasser, D.C., Sturrock, A.M., Jr., and Covay, K.J., 1988, Meteorological and microlysimeter data for a rice irrigation study in southwestern Louisiana, 1985 and 1986: Louisiana Department of Transportation and Development Water Resources Basic Records Report No. 15, 24 p.

Taylor, S.A., and Ashcraft, G.L., 1972, Physical edaphology: The physics of irrigated and nonirrigated soils: San Francisco, Calif., W.H. Freeman, Chapters 2, 3, and 13.

Tomar, V.S., and O'Toole, J.C., 1980, Design and testing of a microlysimeter for wetland rice: Agronomy Journal, v. 72, p. 689-692.

Whitman, H.M., and Kilburn, Chabot, 1963, Ground-water conditions in southwestern Louisiana, 1961 and 1962, with a discussion of the Chicot aquifer in the coastal area: Department of Conservation, Louisiana Geological Survey, and Louisiana Department of Public Works Water Resources Pamphlet 12, 32 p.

Winter, T.C., 1981, Uncertainties in estimating the water balance of lakes: American Water Resources Association, Water Resources Bulletin, v. 17, p. 82-115.

Zack, A.L., 1971, Ground-water pumpage and related effects, southwestern Louisiana, 1970, with a section on surface-water withdrawals: Department of Conservation, Louisiana Geological Survey, and Louisiana Department of Public Works Water Resources Pamphlet 27, 33 p.