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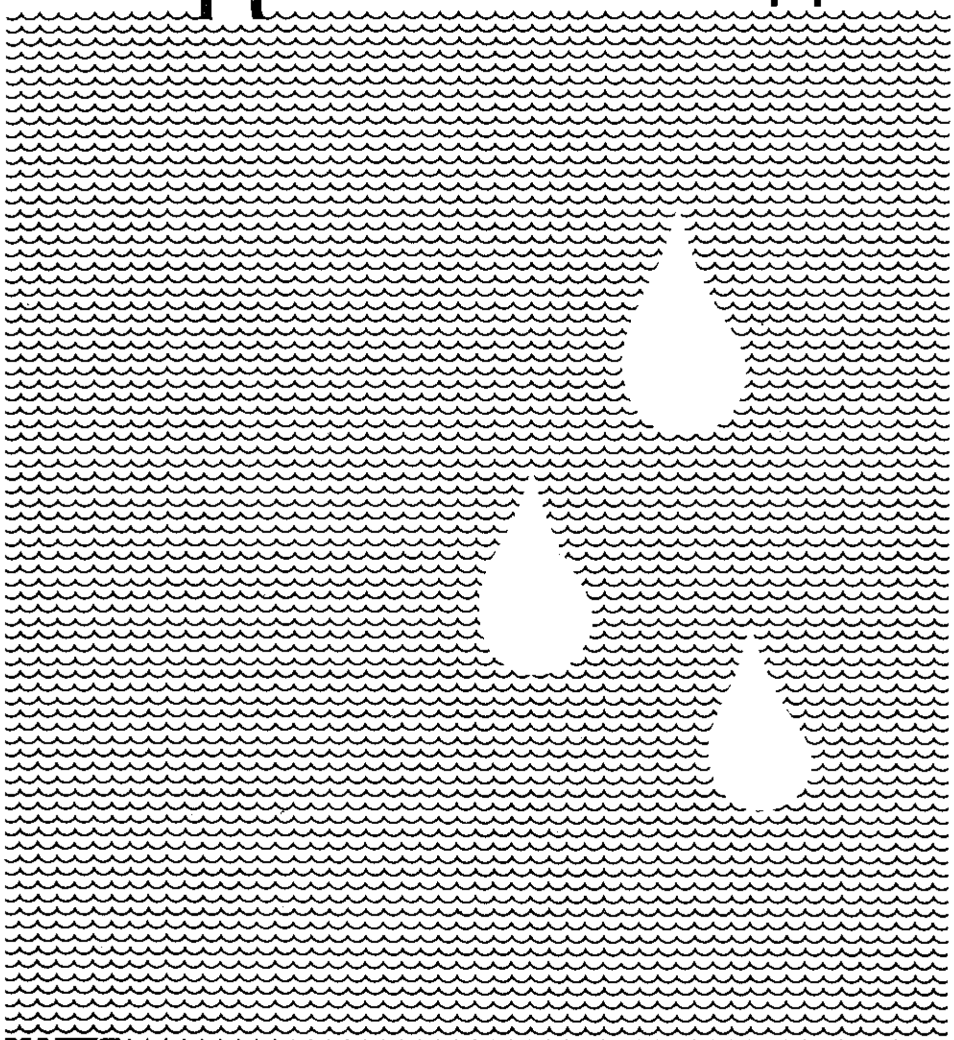
Potential for Use of Rainfall During Permanent Flood Of Rice in Mississippi



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Abstract

Rice production in the Delta of Mississippi requires large amounts of irrigation water. Most of the water is applied during a permanent flood that typically starts about June 1 and lasts through August 31. During this time, irrigation water is added to make up for water lost from the field by evapotranspiration (ET), by percolation through the soil, and by runoff from the low end of the field. Estimates of the amount of water used during this period range from 2 to 4 feet. If rainfall during this time could be held in the field, the amount of irrigation water needed could be reduced. In this study, a computer model is applied to 23 years of rainfall and weather data from Stoneville, Mississippi to estimate the long-term average potential for rainfall capture with different rice water management scenarios. The model assumes that ET is the only loss of water from the field. Loss of water through the soil was assumed to be smaller than the error associated with the ET model and was therefore assumed to be zero. The model also assumed no runoff of irrigation water.

The average rainfall for the 23-year period evaluated was only 9.5 inches during June, July, and August. This amount represents the upper limit for average rainfall capture. The simulation results indicate that with management limitations imposed by most commonly used field irrigation systems (one inlet point for the entire field), an average of about 5 inches of rainfall could be captured each season. With multiple inlets (an inlet from the water source for each levee) the average rainfall capture was about 7 inches per season.

Sensitivity analysis of the model indicated realistically expected inaccuracies (errors in pan coefficient and not including soil infiltration as a water loss) in calculating ET did not substantially effect the simulated rainfall capture and therefore did not change the basic conclusions of the analysis.

Potential for Use of Rainfall During Permanent Flood of Rice in Mississippi

Introduction

Rice production in the Delta of Mississippi requires large amounts of irrigation water, most of which is applied during a permanent flood that typically starts about June 1 and lasts through August 31. During this time, irrigation water is added to make up for water lost from the field by evapotranspiration (ET), by percolation through the soil, and by runoff from the low end of the field. Estimates of the amount of irrigation water applied during this period range from 2 to 4 feet (Griffin et al., 1984, Parsch, 1986), but applications as high as 5 feet (McCauley, 1976) to 14 feet (Robertson, 1917) have been reported.

If rainfall that occurs during permanent flood could be held in the field, the amount of irrigation water needed could be reduced. An estimate of the possible reduction in pumped irrigation water can help quantify the savings in pumping costs a grower can expect by adjusting management to capture rainfall. Furthermore, water resource planners will be able to estimate the potential shifts in ground and surface water use with irrigation management sensitive to the potentials of rainfall capture.

Brown et al. (1978) measured rainfall captured in rice fields in Texas but did not calculate the amount of rainfall actually used to replace irrigation water in the field. Very little data on actual captured rainfall in flooded rice fields are available for the Mississippi Delta region at this time. Published data from Texas (McCauley et al., 1985) and Mississippi (Massey et al., 1987) indicate that under present water management practice in those areas, most rainfall is lost to runoff. Work by Vamadevan and Dastane (1971) and Ha-Woo Chung et al. (1986), however, has shown that rainfall can be effectively used with irrigation under monsoon conditions. Chung et al. reported that in Japan about 65 percent of rainfall could be used in the rice field. Changes in management practice may therefore allow some rainfall to be held on the fields and used to meet the water demands of the crop in Mississippi.

The major environmental variables that influence irrigation requirement of rice are ET and soil infiltration rates. During the June through August flood of rice, some water is lost as water infiltrates the soil surface and percolates below the root zone. Typical rice fields of the Delta have poor infiltration and poor internal drainage. Before water can be transpired it must first infiltrate into the soil. Therefore, only water that infiltrates the soil in excess of transpiration is lost. Brown et al. (1978) found losses of water through the soil to drop to less than 0.05 inch per day after 15 days of flood on a clay soil in Texas. Similar water budgets were calculated for catfish ponds in the Delta by Pote et al. (1988). In their work, loss of water from catfish ponds through the soil was assumed to represent a minor portion of water loss from a pond and was assumed to be zero for approximating water budget calculations.

Computer models using rainfall and other weather data can be used to provide an estimate of ET of rice. Tomar and O'Toole (1979) reviewed measured rice ET data from Southeast Asia and reviewed methods of calculating ET from pan evaporation (Ep). They found the following relationship between pan evaporation and rice ET:

$$ET = K \times Ep \tag{1}$$

where: ET = daily rice evapotranspiration during flood;

Ep = daily evaporation from a standard class A pan;

K = empirically derived constant = 1.2.

This method has been applied to the Mississippi Delta by Pennington and Wolf (1989). Their work compared estimates of ET from various models and calculated seasonal variability of rice ET under Mississippi climate conditions. The daily calculated ET values from those models can be used as a basis for the evaluation of the potential rainfall capture in rice fields. The models presented by Pennington and Wolf are expanded in this publication by adding a component that calculated daily rainfall capture under different management scenarios.

Methods

Rainfall and pan evaporation data from Stoneville, MS, were compiled for the years 1966 through 1988. These data were used to calculate daily ET using Equation 1 and rainfall capture for the model.

A simulated field was considered to be flooded to a set depth on June 1. This depth is used as a reference point for describing the amount of water in the field, and is assigned a depth value of zero as a convenient reference point. For each day, the calculated value of ET was subtracted from the simulated water levels in the rice field. On each day without rain or irrigation, the water level dropped further below zero. Rain falling on any day can be captured and added to the depth of water in the field subject to limitations that will be described later.

Two general field configurations were modeled. Both are presently used in rice production. The first is more common in the Delta.

Field Configuration 1
Single Inlet

An example of a single inlet field configuration is given in Figures 1 and 2. All water is applied to the field at a single inlet point into the first bay at the top of the field. After the first bay fills, water runs through a gate to fill the second bay (Figure 2). This pattern of bay filling continues until sufficient water has been pumped to fill all bays. The well is then turned off. At this time, the field is filled to its zero reference depth and has no capacity to store rainfall.

Immediately after the well is turned off, infiltration and ET begin to decrease the water level in the field below the zero reference depth, and the field begins to develop an increasing capacity to store rainfall. Eventually, the water level will drop to a point where the well must be turned on to refill the field. The difference between the full, zero reference level and this low point is referred to in this paper as the allowed depletion (AD). When the AD level is reached, the field is still covered with water but an irrigation must be started to maintain the flood in the field.

Numerically, AD is the depth in inches between the water level in a filled bay (zero) and the lowest water level allowed before irrigation is initiated. AD is an evaluated variable in this model and ranged from 0.25 to 5.0 inches in 0.25-inch increments. When the field reaches its AD, it has its greatest capacity to store rainfall. When AD is increased from 0.25 to 5 inches, the maximum storage capacity of the field also increases. When an irrigation is started, the well refills each bay reducing the storage capacity until the field is again full of water and the water level is at the zero reference. Due to the nature of the water delivery system in the single inlet field, each bay must be filled to get water to the next bay. Therefore, when an irrigation is completed, each bay is completely filled and at that point the field has zero capacity to store rainfall.

Rainfall can be captured in a single inlet field on days when the water level is below full. Rainfall can be added to the depth of water in the field only up to the point when the field is full and the water level is at the zero reference depth. Any rainfall in excess of that needed to fill the field was considered to be lost as runoff.

Field Configuration 2
Multiple Inlets

An example of a multiple inlet field is given in Figures 3 and 4. Water is delivered directly to each bay from a supply ditch or pipe. Occasionally the supply ditch is a narrow levee running the length of the field and all other levees are supplied with water from this supply levee. Whatever the supply method, each levee can be filled independently of all other levees in the field.

This method has several advantages over single inlet fields. First, if only a few bays in a field need water, the entire field above those bays does not have to be filled to get water to them. Also, by adding water to each bay independently, the bays do not have to be completely filled. Because the bays do not need to be completely filled, the field can almost always have some capacity to store rainfall, even after a completed irrigation. This extra capacity to store rainwater above the highest irrigation-filled level will be referred to as a field's freeboard.

In the multiple inlet field configuration, gates are placed between adjacent bays just as in the single inlet method previously described. In the multiple inlet method, the gate crests are set above the refill irrigation levels. The height of the gate above the full irrigation level determines the fields freeboard. The gates are required only to allow excess rainfall to leave the field without damage to levees and to drain the field. In work reported in this paper, the effect of freeboard on rainfall captured was evaluated for freeboard depths ranging from 0.5 to 3.0 inches in 0.25-inch increments.

Other Model Variables

(a) Allowed depletion

The model assumes that an irrigation will be initiated when the water depth in the field approaches the minimum necessary to cover the field and maintain flooded conditions. That level is the same for all AD's. The water depth to which a field is filled by irrigation is equal to the minimum depth needed to maintain flood plus the AD. This total depth will increase as AD increases. Therefore, a field with an AD of 4 inches will have 3 inches more depth of water than a field simulated with an AD of 1 inch. The extra water required to operate a field with a large AD must be accounted for in net rainfall captured. More rainfall may be captured in a field with a large AD, but the additional water needed for the large AD will reduce the net water savings from the captured rainfall. The AD of a simulation is subtracted from the total rainfall captured to calculate net reduction in pumped water. This amount is referred to as net rainfall captured.

(b) Sensitivity to constant K

The value of 1.2 for the value of K in Equation 1 is from research conducted outside of the Mississippi Delta. The value of K for the Delta may not be 1.2. To test the effect of possible errors in the value of K on simulation results and conclu-

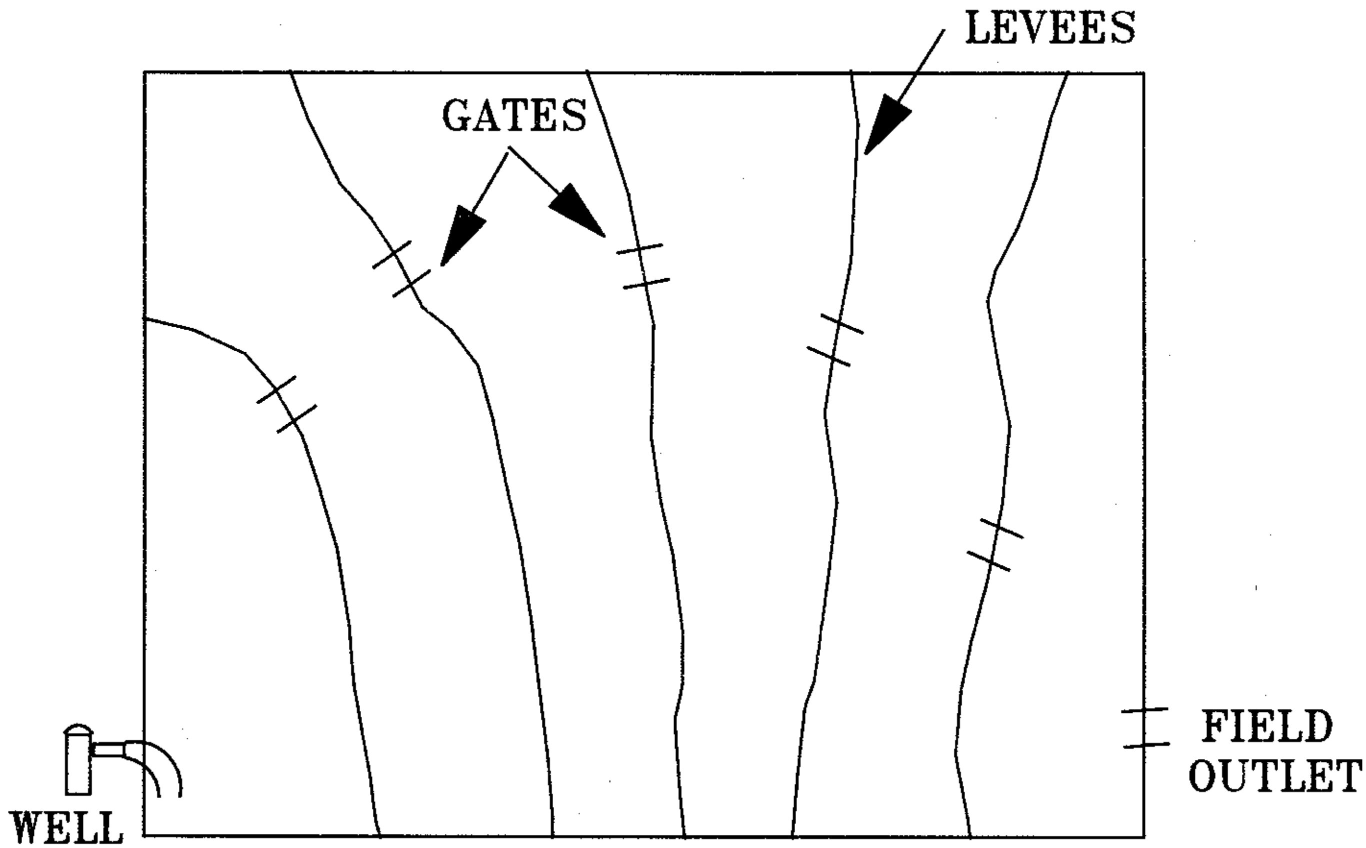

Figure 1. Single inlet field. Entire field is filled with water applied at the well. Each bay must be filled before water will flow to next bay.

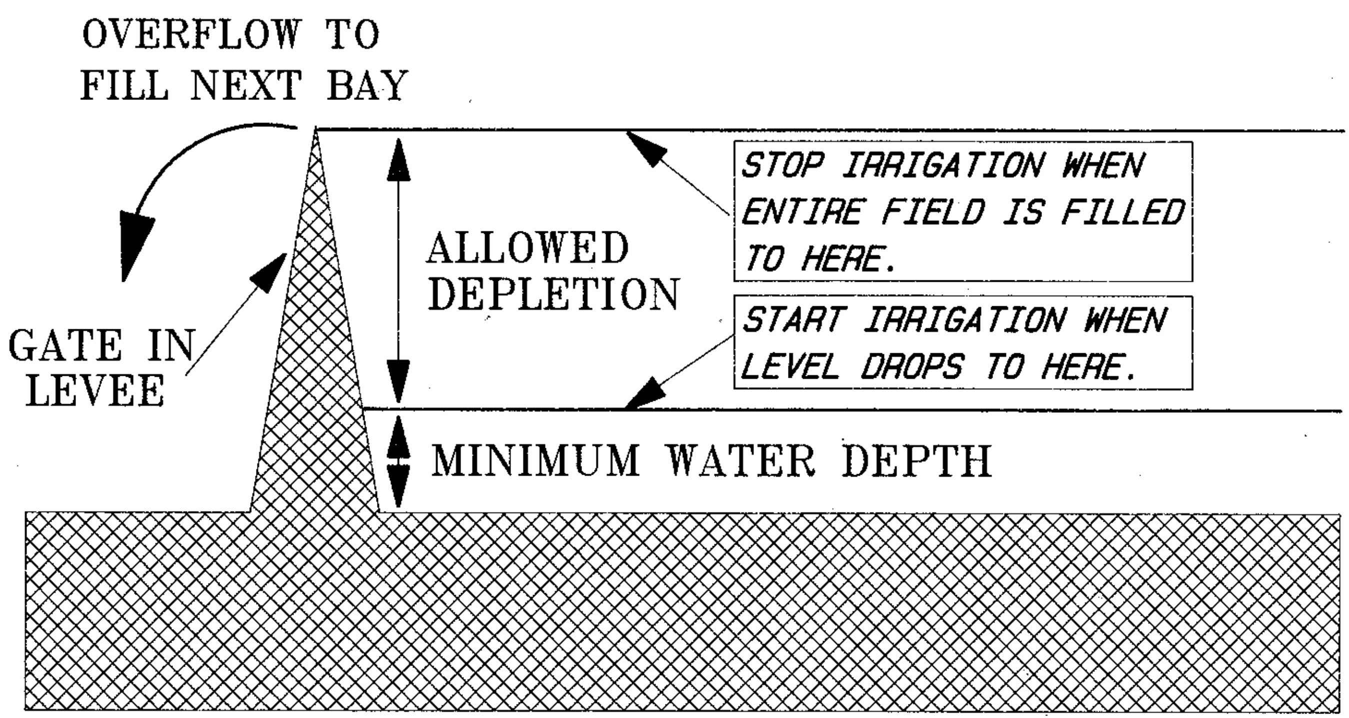

Figure 2. Cross-section of water levels and gate in levee for a field with a single field inlet.

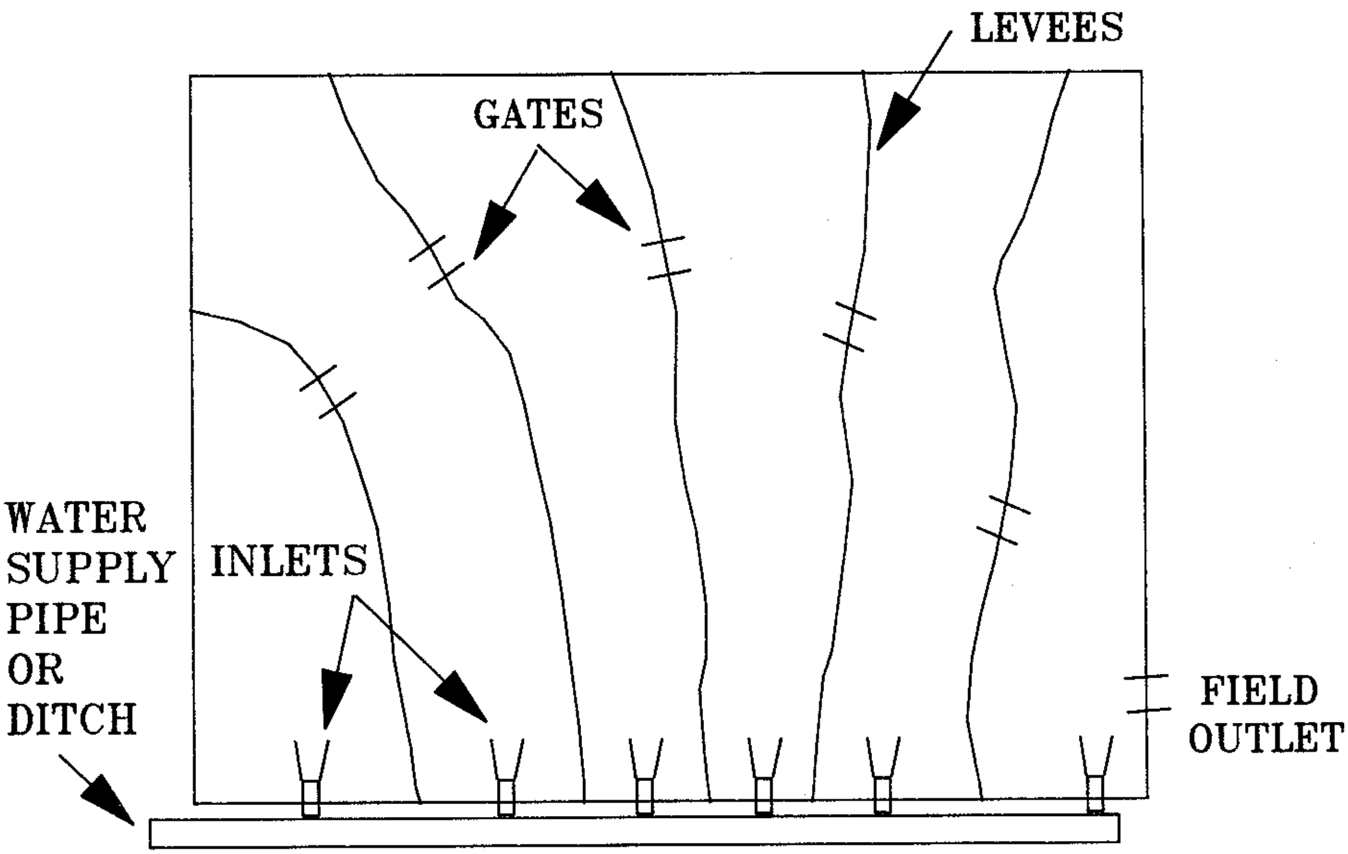

Figure 3. Multiple inlet field. Water can be applied to each bay independent of all other bays. Gates are for rainfall runoff and draining the field.

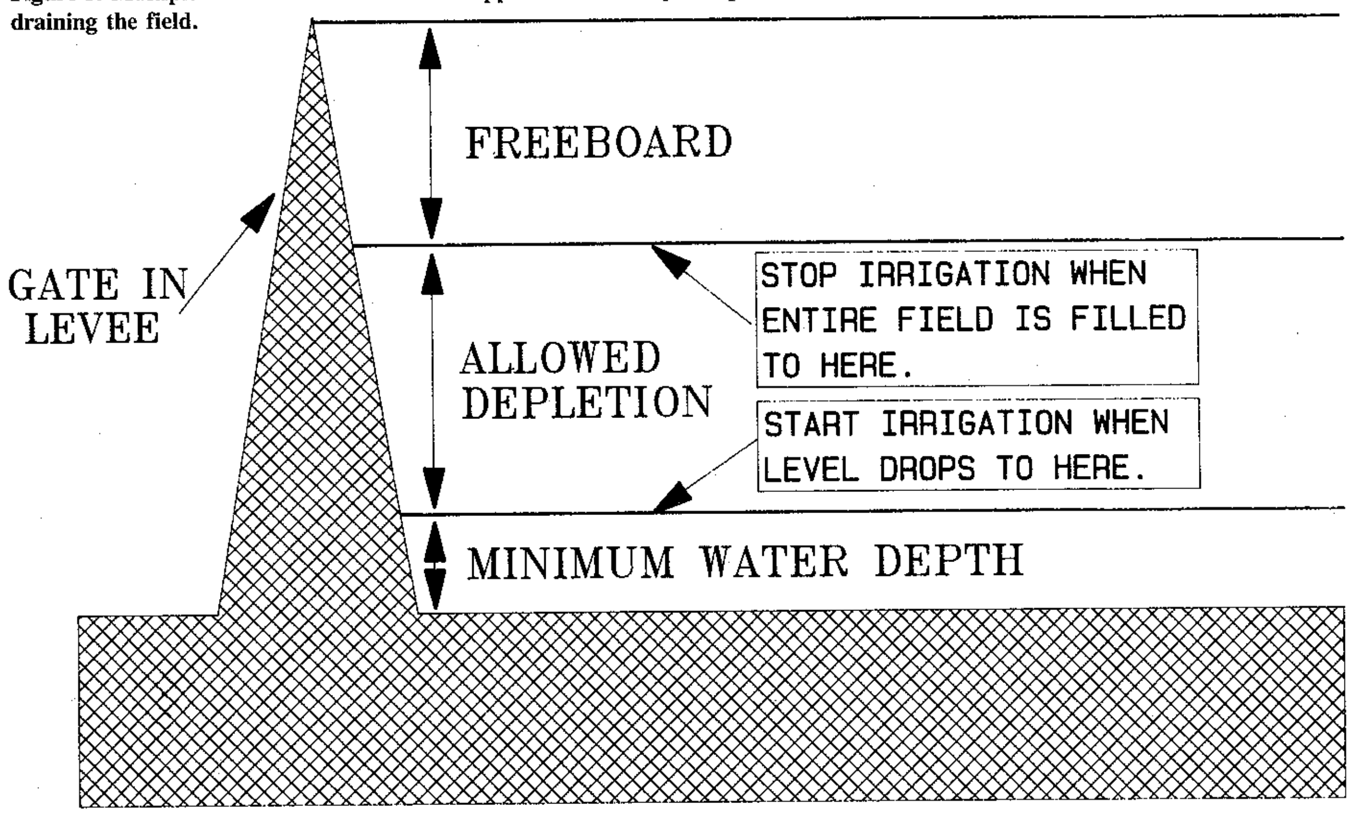

Figure 4. Cross-section of water levels and gate in levee for a field with multiple field inlets.

sions, a series of simulations were run with values of K ranging from 0.8 to 1.6.

(c) Irrigation capacity

The rate at which a rice field can be refilled by irrigation depends on both the size of the well and field. This irrigation rate can generally be described as inches of water that can be applied to the field in a single day. General irrigation guidelines suggest that a well or pump should be able to deliver at least 15 gallons of water per minute for each acre in the field. This is equivalent to about 0.8 inch per acre per day. Information on well flow rates and field sizes indicates that an irrigation rate of about 1.0 inch of water per day is commonly found in the Delta. A range of irrigation rates above and below this value is also expected. A well with an irrigation rate of 0.5 inches per day or less would need to run most of the season to stay ahead of water losses from the field. Irrigation rates from 0.5 to 2.0 inches per day were modeled to evaluate the effect of irrigation rate on potential to capture rainfall.

General model description summary

(1) The field was flooded to the required level on June 1.

(2) Daily ET was calculated from equation 1 using a specified value for K.

(3) The depth of the water in the bay was decreased by that day's ET.

(4) Rain that falls each day was added to the depth of the water in the field. Any rain in excess of the field's storage capacity was lost as runoff.

(5) Rainfall held in the field was accumulated as captured rain.

(6) When water losses from ET dropped the water level in the bay to the AD, an irrigation was initiated.

(7) Irrigation was continued until the field was refilled to the reference water level of zero. ET losses and rainfall additions were continued during irrigation.

The cycle of losses and additions continued from step 2 to 7 until the end of permanent flood on August 31.

Summary of model variables

(a) Twenty-three years of Ep and rainfall data from Stoneville, Mississippi, (1966 through 1988).

(b) AD (0 to 5 inches in 0.25-inch increments).

(c) Freeboard (0 to 3 inches in 0.5 inch increments).

(d) Coefficient K from Equation 1 (0.8 to 1.6 in 0.2 increments).

(e) Irrigation capacity (0.5, 0.75, 1.0, 1.25, 1.5, and 2.0 inches per day).

For most simulations, a K of 1.2 and an irrigation capacity of 1.0 inch per day were used.

Average rainfall captured

For each simulation, an irrigation rate and K value were specified. The model then ran all combinations of freeboard and AD on each year's weather. For a set of K, AD, freeboard, and irrigation capacity, the rainfall captured in the simulated field was calculated for each of the 23 years of weather data. The average rainfall captured over the 23-year period was recorded as the expected potential for rainfall capture for the specific set of conditions.

The model was run in a spreadsheet (Symphony) on a personal computer.

Results

Average rainfall during June, July, and August at Stoneville, Mississippi, for the period of 1966 to 1988 was 9.5 inches and ranged from 5.2 inches in 1980 to 14.1 inches in 1971. The average rainfall at Stoneville from 1960 to 1979 was reported by Hull et al. (1982) as 10.5 inches. These data indicate that about 10 inches was the long-term maximum amount of rain water that could be used in rice fields during permanent flood.

Examples of water levels during the permanent flood in a single inlet field with zero freeboard and multiple inlet field with 2 inches of freeboard are given in Figures 5 to 7. The highest rainfall year in the 23-year period evaluated was 1979 (Figure 5). At the other extreme, 1988 was a very dry year

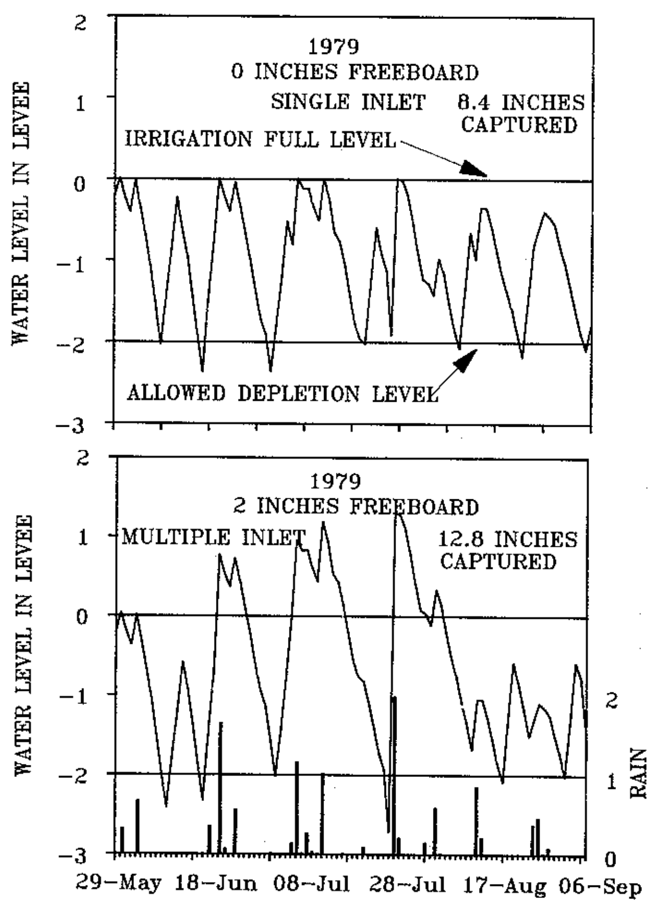

Figure 5. Simulated water levels in field for 1979 with zero and 2 inches freeboard. Zero water level is depth of water at completion of irrigation. Values above zero are rainfall captured by freeboard.

during rice permanent flood (Figure 7). Rainfall during 1987 was near the 23-year average (Figure 6). In these figures, water depth was gradually decreased by ET until the AD was reached. AD for the simulations in Figures 5 to 7 was 2 inches.

Irrigation was initiated and the field filled quickly. The primary difference between the single and multiple inlet fields was that because of freeboard, the multiple inlet field would have rainfall storage capacity even when the irrigation was completed. Because of this, multiple inlet fields consistently captured more rainfall in a season than single inlet fields. Water levels above zero represent rainfall captured due to the freeboard capacity of the multiple inlet field.

Effect of allowable depletion

Results of the 23-year average net captured rainfall for a K value of 1.2 and an irrigation capacity of 1.0 inch per day are given in Figure 8 and Table 1. In the figure, the results for a single inlet field are presented by the data at the front of the figure for zero freeboard. For the zero freeboard, single inlet field net captured rainfall increased with AD to a maximum capture of about 5 inches with an AD of 1 to 2 inches. At AD values above 2 inches, the additional water depth necessary to allow for the larger AD was usually greater than the increase in net captured rainfall. Net captured rainfall therefore decreased with AD above the 1- to 2-inch range. This result indicates that the maximum long-term savings in applied water that could be expected with rainfall capture in single inlet fields was about 5 inches.

Effect of freeboard

Increasing freeboard increased the net captured rainfall at all AD (Figures 5 through 8). The largest net captured rainfall was obtained with the smallest AD once freeboards of about 1.5 inches were reached. Very small (less than 2 inches) AD would be very difficult to manage in the field. With a typical irrigation capacity of about 1 inch per day, a manager would be required to turn wells on or off almost every day. Very frequent irrigations would increase the amount of water lost from a field due to unavoidable over irrigation and would require large amounts of management time. An AD of 2 inches would allow for more realistic management and is typical of current practices.

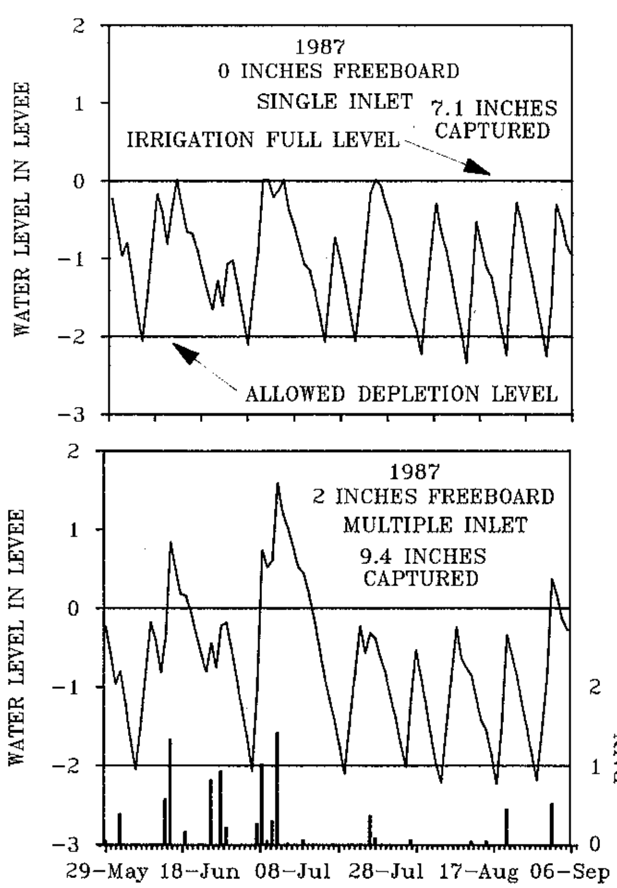

Figure 6. Simulated water levels in field for 1987 with zero and 2 inches freeboard. Zero water level is depth of water at completion of irrigation. Values above zero are rainfall captured by freeboard.

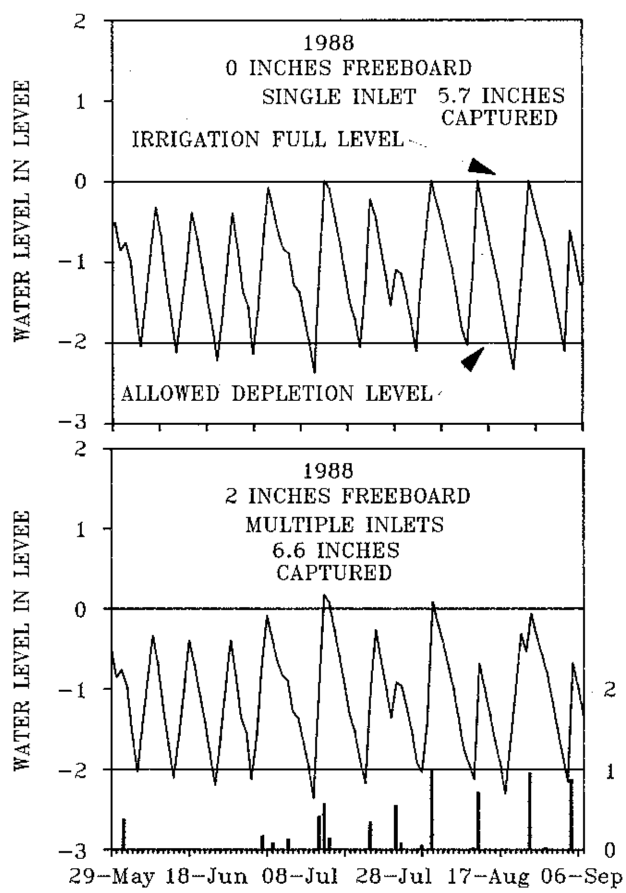

Figure 7. Simulated water levels in field for 1988 with zero and 2 inches freeboard. Zero water level is dept of water at completion of irrigation. Values above zero are rainfall captured by freeboard.

Table 1. Twenty-three-year average net captured rainfall with irrigation capacity of 1.0 inch per day and a K (from Equation 1) of 1.2. All values are in inches. Same data are presented in Figure 8.

ALLOWED	FREEBOARD			
	ZERO	1	2	3
DEPLETION	NET CAPTURED RAINFALL			
0.25	2.46	6.72	8.26	8.72
0.50	3.27	6.83	8.12	8.50
0.75	4.18	7.07	8.04	8.31
1.00	4.96	7.10	7.84	8.11
1.25	5.16	7.06	7.63	7.86
1.50	5.11	6.92	7.47	7.68
1.75	4.94	6.55	7.14	7.36
2.00	5.09	6.42	6.93	7.11
2.25	4.63	6.28	6.69	6.90
2.50	4.73	6.13	6.46	6.63
2.75	4.61	5.90	6.30	6.47
3.00	4.53	5.71	5.99	6.13
3.25	4.50	5.46	5.79	5.93
3.50	4.42	5.34	5.59	5.72
3.75	4.33	5.10	5.34	5.47
4.00	3.77	4.61	5.00	5.18
4.25	3.62	4.49	4.80	4.95
4.50	3.38	4.18	4.52	4.66
4.75	3.16	4.04	4.33	4.45
5.00	3.00	3.87	4.10	4.20

Net captured rainfall, at AD values of 2 inches or greater, is about 7 inches for all freeboards of 1 inch or more. Seven inches appears to be a realistic maximum net captured rainfall for multiple inlet fields. This is only 2 to 3 inches more water than captured in well managed single inlet fields. As the information in Figure 8 and Table 1 suggests, 1 inch of freeboard will capture about 90 percent as much rainfall as 2 inches or more of freeboard.

Sensitivity to value of constant K

Errors in major model variables may change the results of simulations and the conclusions drawn from them. One source of potential error was in the constant K from Equation 1. This value scales Ep data to approximate rice ET. The value of K used in these simulations was 1.2 and was taken from the literature (Tomar and O'Toole, 1979). Research from which this value was drawn was not conducted in the Mississippi Delta and local conditions could require a different value. The potential effect of such an error was evaluated by running simulations of the model with different values of K and comparing the results.

The concern about accuracy of K would be reduced if a relatively wide range of K values does not produce modeled results that would change the general conclusions of the work. Selected results are given in Figure 9. The data in Figure 9 show that relatively large changes in K result in minor changes of net captured rainfall. Freeboard greatly reduces the effect

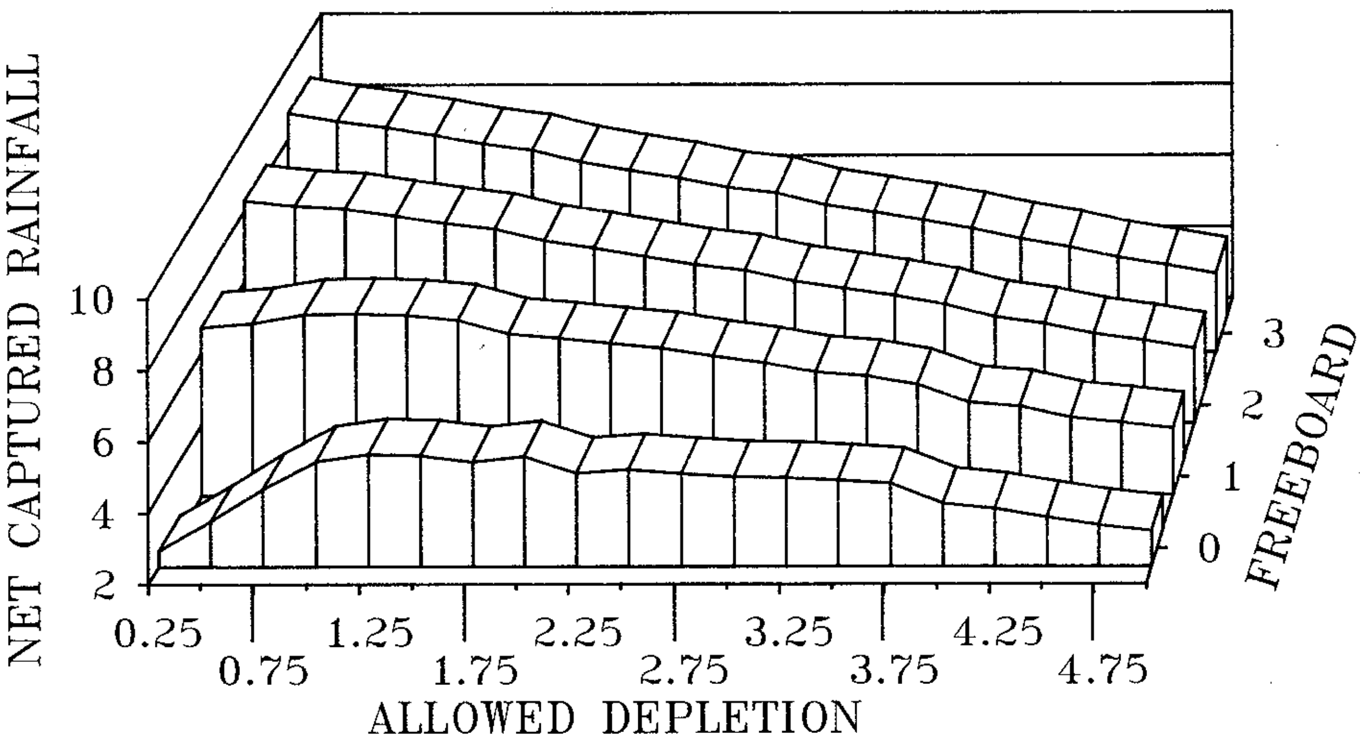

Figure 8. Twenty-three-year average net captured rainfall with irrigation capactiy of 1.0 inch per day and a K (from Equation 1) equal to 1.2. All measurements are in inches.

of K on net captured rainfall. Also, with zero freeboard, the maximum amount of net captured rainfall is very similar for all values of K, and the maximum net captured rainfall occurs at about the same range of AD for all K values. In general, inaccuracies in K will not significantly change the estimates of net captured rainfall and the conditions for maximum net captured rainfall.

The results of simulations with high values of K provide insight into the potential influence of another assumption used in the model. The model assumes that water levels in levees could be realistically modeled with ET alone assuming that soil infiltration was negligible. High levels of water loss by soil infiltration would be approximated by high values of K. Values of K greater than 1.2 mean that more water is leaving the field than expected with the selected K value of 1.2. This extra water loss could be due to more ET than expected or to a significant loss of water due to infiltration and percolation or to levee leakage.

Discussion of results of simulations with elevated K values in the previous paragraph indicated that larger values of K did not change model outcomes of net captured rainfall sufficiently to cause a change in general conclusions about he potential for rainfall capture in rice fields. This same result indicates that infiltration and percolation or levee losses of water will not change the conclusions if the water lost through the soil is significantly less than the water lost to ET.

Effect of irrigation capacity

The capacity to deliver water to a rice field influences how quickly the field can be irrigated or how fast the rice levees can be filled. Model simulations were run to determine if irrigation capacity influenced net captured rainfall. Simulations were run with irrigation capacities of 0.5 to 2.0 inches per day. Selected results are given in Figure 10. Irrigation capacity did not significantly influence net captured rainfall under any conditions used in these simulations.

Conclusions

Results of rice ET models indicated that about 5 inches of rainfall per season could be captured during permanent flood in well-managed single-inlet rice fields of the Mississip-

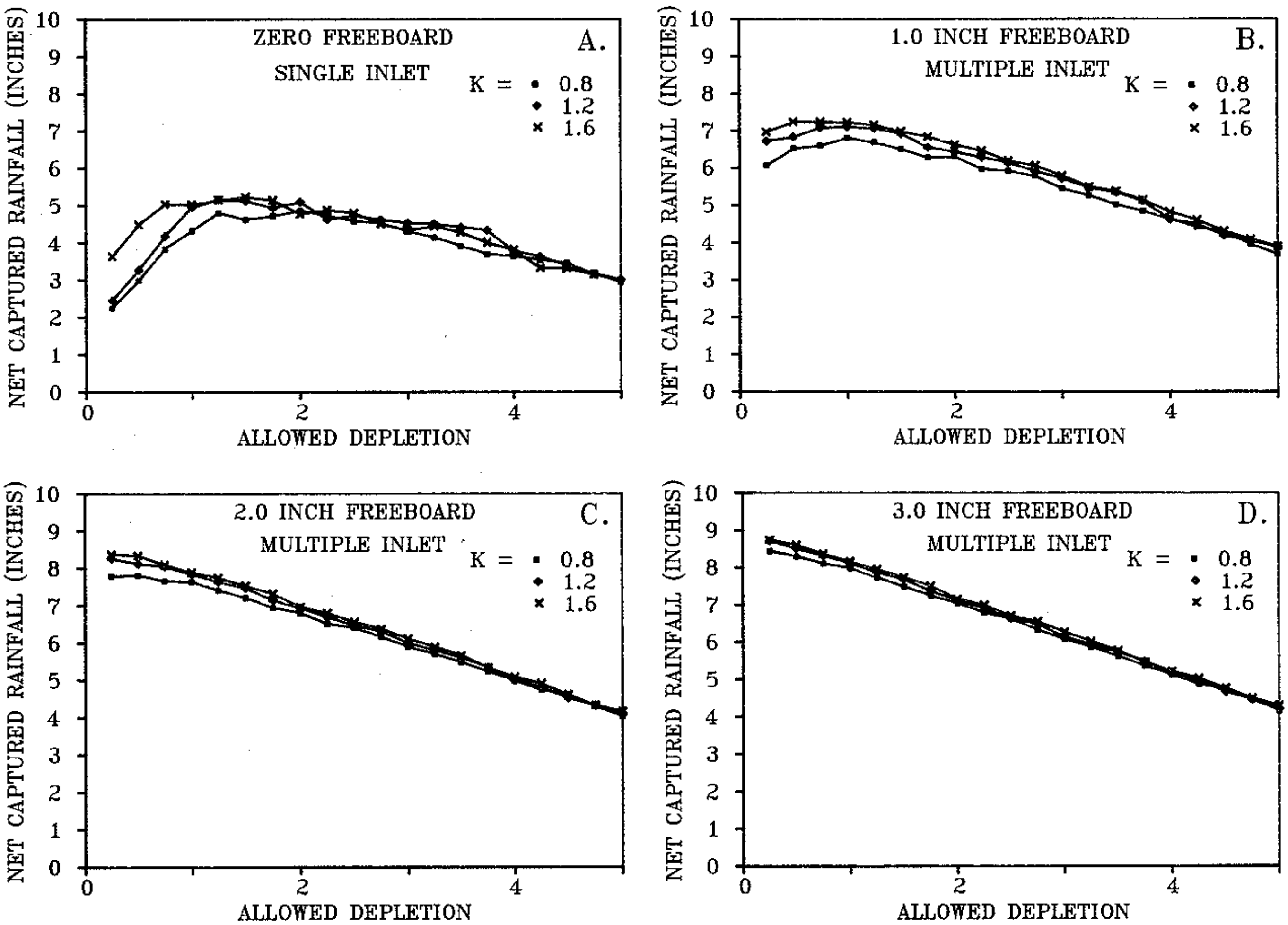

Figure 9. Net captured rainfall for range of allowed depletions for freeboards of (A) zero inches, (B) 1 inch, (C) 2 inches, and (D) 3 inches—each with three values of K from Equation 1.

pi Delta. With multiple inlets and 1 to 3 inches of freeboard remaining in the levees after all irrigations, the captured rainfall could be about 7 inches per season. Very precise water management would be required to approach these levels of rainfall capture and these modeled values should be considered as long-term maximum obtainable amounts, and probably would be greater than typical results for a large population of farm operations.

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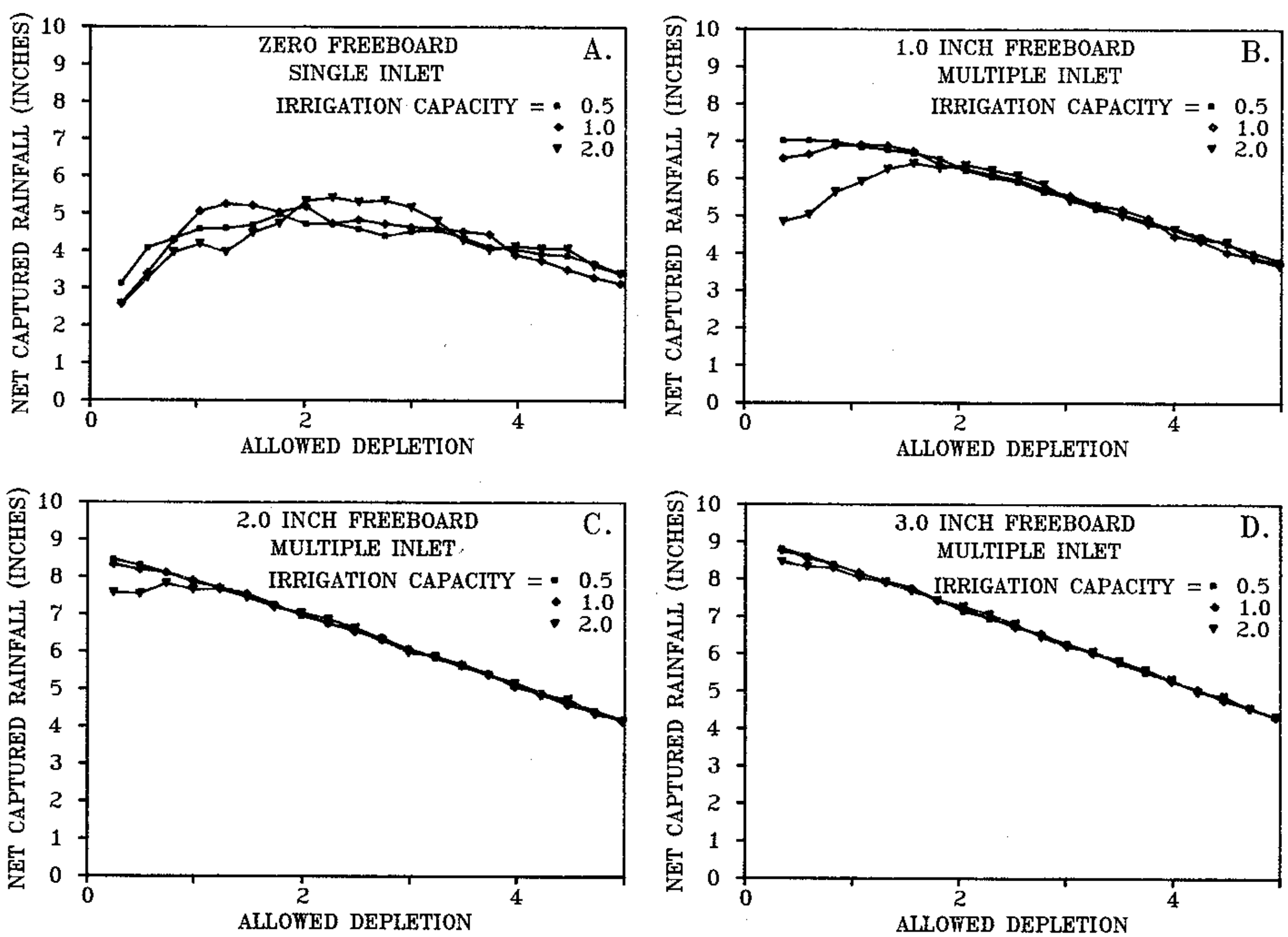

Figure 10. Net captured rainfall for range of allowed depletions for freeboards of (A) zero inches, (B) 1 inch, (C) 2 inches, and (D) 3 inches—each with three irrigation capacities (inches per day).

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