DELTA SALINITY STUDY
1977-1978 PROGRESS REPORT

BY

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THIS RESEARCH WAS SUPPORTED IN PART BY A GRANT FROM THE CALIFORNIA STATE DEPARTMENT OF WATER RESOURCES, CENTRAL DISTRICT, CONTRACT NUMBER B-53226.

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DELTA SALINITY STUDY

BACKGROUND:

Research conducted to investigate the relationship between crop yield and soil salinity indicates that once a certain threshold value of soil salinity is reached, subsequent increases in salinity will result in crop-yield reductions. Maas and Hoffman (1977) state that the relationship between crop yield and soil salinity can be expressed by

$$Y = 100 - B\,(EC_e - A)$$

Y= relative yield for any soil salinity exceeding the threshold value.

A= threshold value (mmhos/cm)

B= percent yield decrease per unit salinity decrease.

EC_e= electrical conductivity of saturated soil extract.

Ayers (1977) summarized the results of past research on salinity effects on crop yield for most crops.

In developing these data, it was assumed that good soil drainage exists and that the water used by plants is the applied irrigation water. As a result, soil salinity is directly related to the irrigation water quality.

In the Delta, the method of irrigation of peat soils is primarily subsurface irrigation. This method consists of flowing irrigation water through shallow "spud" ditches spaced at regular intervals. The irrigation water percolates down to the water table (which is initially about three feet below the ground surface), thus causing the water table rise. The water is maintained in the "spud" ditches until the water table has risen to a depth such that the soil moisture in the root zone is replenished from the subsurface water supply.

Groundwater flow theory indicates that as water percolates down to the water table from a spud ditch, groundwater may be displaced by the downward percolating water as illustrated in Figure 1. Therefore, for the subsurface irrigation method groundwater may be involved in replenishing the soil moisture in the root zone. The water quality of this groundwater may be significantly different than that of the irrigation water. Therefore, soil salinity may be affected by groundwater quality if this displacement process does occur. Knowledge of the groundwater quality, and the relationship between groundwater quality and irrigation water quality may be necessary to determine the effect of channel water quality changes on soil salinity. Thus, information on subsurface water movement is necessary to identify the source of the water used by plants.

OBJECTIVES:

The primary objectives of this research are:

a. To determine the source of water used by plants under subsurface irrigation methods practiced in the peat soils of the Sacramento-San Joaquin Delta.

b. To determine the water quality of the subsurface water and any relationship between ground water quality and irrigation water quality if the displacement process does occur.

PROCEDURES:

The source of water used by the plants can be determined if the subsurface water water flow pattern occurring during subsurface irrigation is known. This flow pattern can be obtained by installing a grid of piezometers between two spud ditches and down to some depth below the surface. These instruments measure the hydraulic head at each point on the grid. Using these values, lines of equal hydraulic head or equipotential lines can be sketched between spud ditches. Since water movement is in the direction of decreasing hydraulic head, subsurface-water flow can be determined

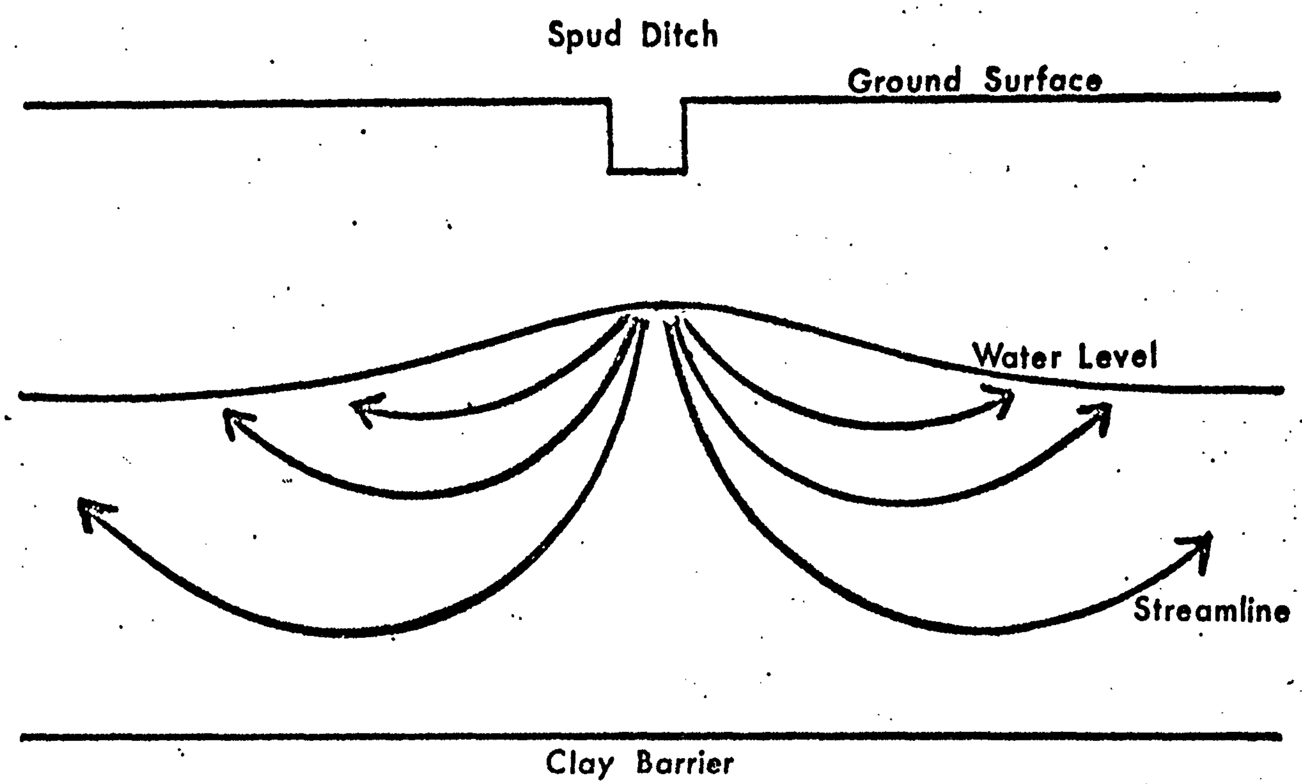

Figure 1. Streamline pattern for displacement of groundwater by irrigation water.

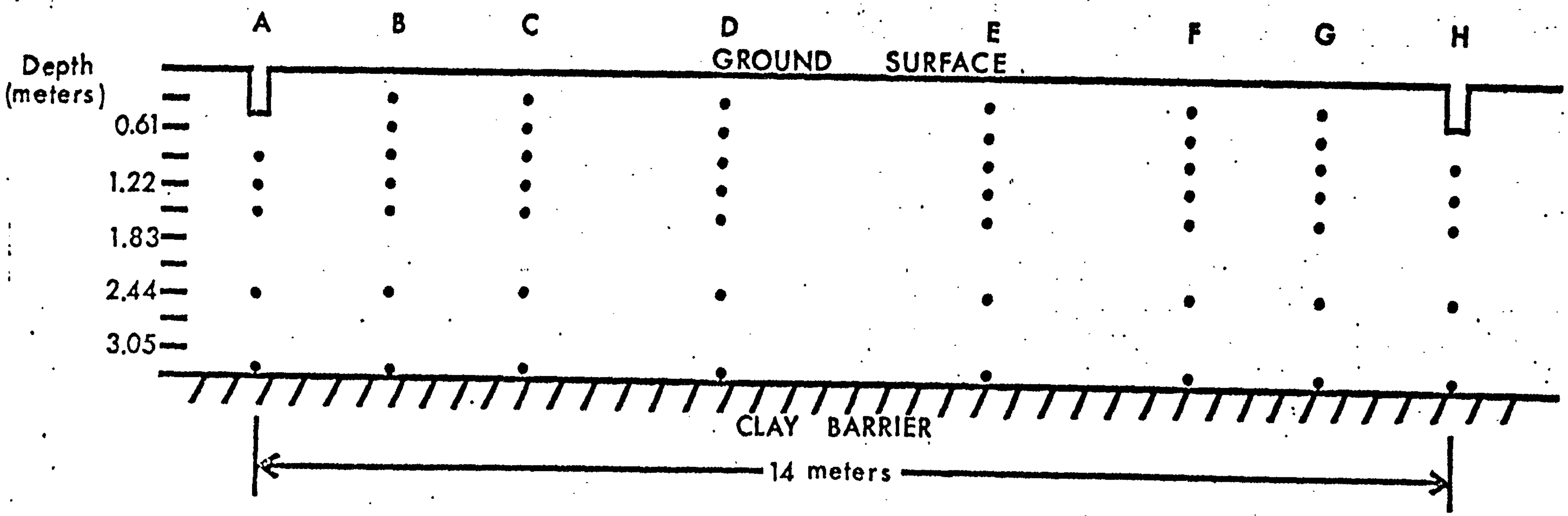

Figure 2a. Grid system- MacDonald Island.

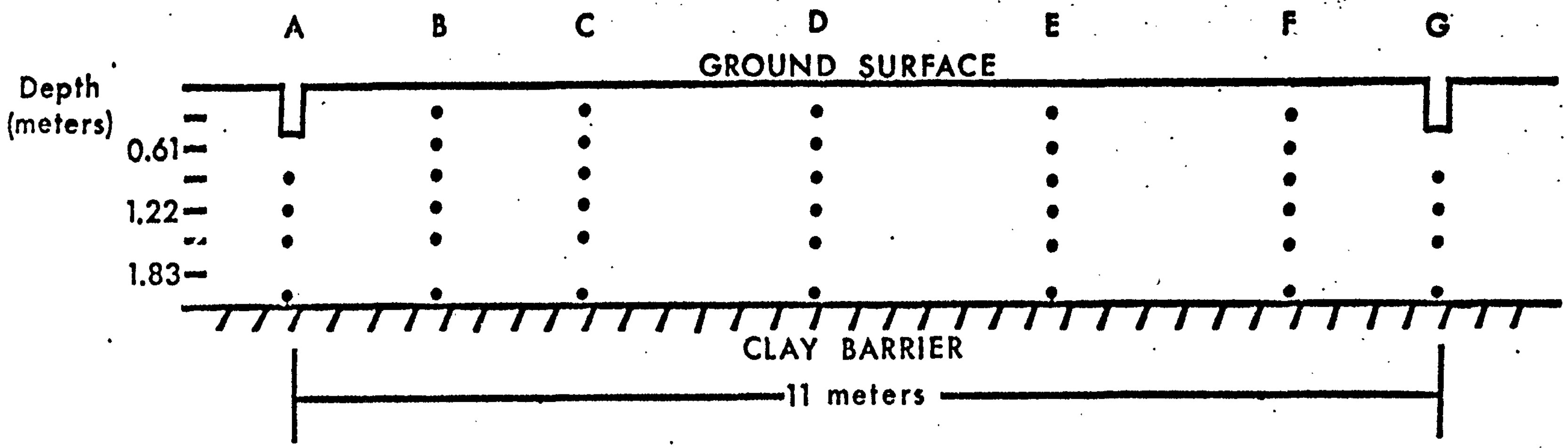

Figure 2b. Grid system- Bacon Island.

from these lines. A brief discussion of flow net theory and the effect of soil stratification on the theory is presented in Appendix A.

Grids were established for three sites; two on MacDonald Island and one on Bacon Island. The MacDonald Island sites were co-located with the Central Delta Water Agency salinity experiment. The instruments were installed in Plots A and B of the salinity experiment.

The grid used on MacDonald Island (see Figure 2a) consisted of eight columns (A thru H) of piezometers located between two spud ditches. The instruments terminated at depths of 0.30, 0.61, 0.91, 1.22, 1.52, 2.44 and 3.35 meters, respectively. The distance between the spud ditches was about 13.72 meters. A clay layer at a depth of 3.35 meters was considered to be the lower boundary of the flow system; no attempt was made to install instruments at deeper depths. (This layer is at least 1.52 meters thick (determined by augering into the layer).

The Bacon Island grid system (Figure 2b) consisted of seven columns (A thru G) of instruments. The distance between spud ditches was about 11.0 meters. The instruments terminated at depths of 0.30, 0.61, 0.91, 1.22, 1.52, and 2.13 meters, respectively. A clay layer at a depth of 2.13 meters was the lower boundary of this system. Since this layer was about 0.15 meter thick, an attempt was made to install instruments in the underlying sand. This was unsuccessful because of compactness and lack of cohesion of the sand underlying the clay layer.

The piezometers were made of 1/2 inch, Schedule 80 PVC pipe. A porous ceramic cup with a bubbling pressure of about 1 bar was cemented at the bottom of the pipe. The cup prevented soil from clogging the pipe and also allowed either positive or negative water pressures to be measured.

Rubber stoppers, each with two small diameter (I.D. 1.1mm) mylon tubes inserted through them, sealed the piezometers. One nylon tube was the manometer and was terminated in a reservoir of mercury located on a manometer board. The second tube was used to flush water through the manometer to remove any air bubbles. This tube was sealed at all times except during flushing. An illustration of an instrument is in Appendix B.

The manometer board was consisted of a scale (meter stick or 10 x 10 cm graph paper) attached to a board or plexiglass sheet. Glass tubing glued on the board or plexiglass supported the nylon manometer tube. A mercury reservoir was located at the bottom of the board. The nylon tube used for the manometer was inserted down through the glass tubing and into the mercury reservoir.

Elevations at the top of the piezometer and on the manometer board were establishe The hydraulic head was determined by first reading the height of the mercury column in the manometer tube and height of the free surface of the mercury in the reservoir. These values were then used in the equation (2) to calculate the hydraulic head at each point of the grid.

$$H = -0.1255\ hm + 0.1355\ h_r + E_m - 1 - 0.12$$

H= hydraulic head (meters)

h_m= height of mercury column in manometer tube (cm)

h_r= height of free surface of mercury in reservoir (cm)

E_m= elevation of top of manometer board above an arbitrary reference point (meters).

The constant, 0.12, is a correction factor used to account for the capillary depression of the mercury-water interface in the manometer tube. Appendix B contains the derivation of this equation.

A grid of water quality probes was also installed at each experiment site. These systems were colocated with the piezometer grids and were of the same dimensions. Subsurface water samples were periodically obtained from these probes and analyzed for electrical conductivity and Na and Cl concentrations.

In addition to these samples, samples of irrigation water (at the experiment sites), the channel water (at the ferry) and the drain water (at the drainage pump by Zuckerman's shop) were also taken throughout the growing season.

Soil samples at each site and at plot C of the Central Delta Water Agency experiment were taken at the beginning and end of the experiment. Samples were analyzed for EC, Na, and Cl.

RESULTS AND DISCUSSION:

Flow Nets

The flow patterns occurring at Plot B on MacDonald Island during the third irrigation are illustrated in Figures 3 thru 7. Flow patterns at Plot A were similar to those at Plot B. The directions of the streamlines (dashed lines) are approximate only, since K_V and K_H are unknown (See Appendix A).

Flow nets for the Bacon Island were not obtained. No irrigations occurred after installation of the instruments.

Figure 3 is the flow pattern existing three days prior to the irrigation, which occurred on August 15, 1977. (The preceeding irrigation was terminated on July 24, 1977 At this time the water table depth below the ground surface was about 0.8 meters.

Above the water table, hydraulic head decreased as depth below the ground surface decreased. Thus upward flow from the water table into the root zone was occurring. The cause of this flow pattern is believed to be increasing soil suction in the root zone as a result of evapotranspiration.

Upward flow below the water table was also occurring. This flow is believed to be due to subsurface water movement near the clay layer (evidence for this movement is discussed later).

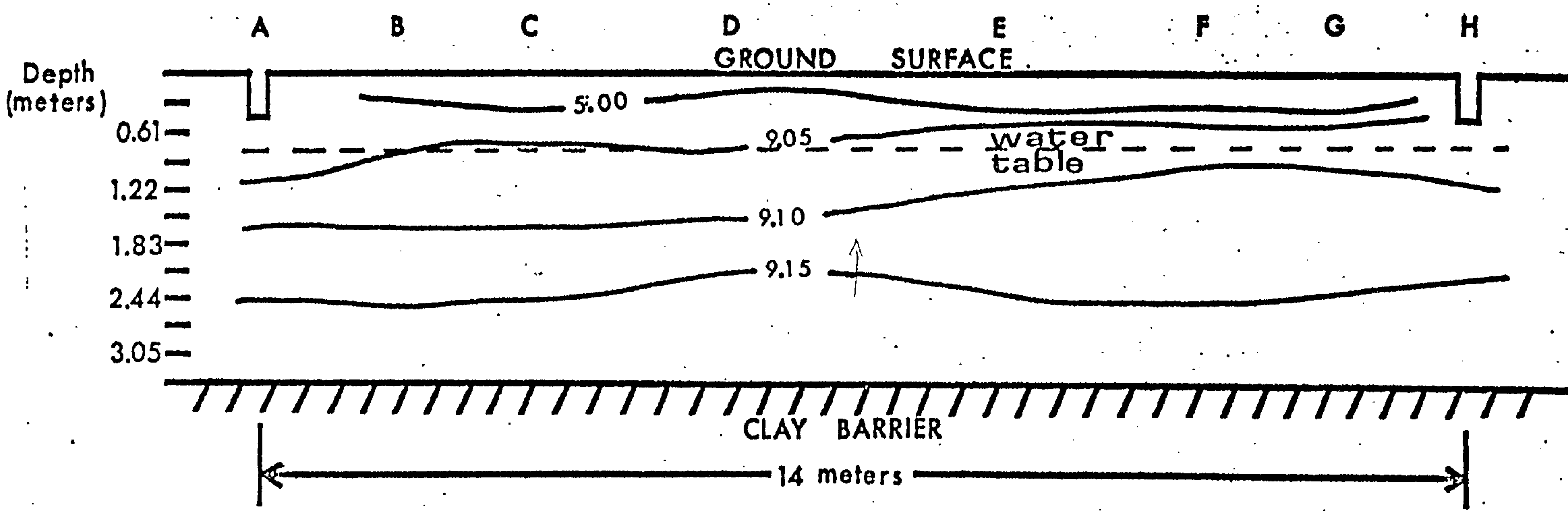

Figure 3. Flow net for August 12, 1977, three days prior to third irrigation.

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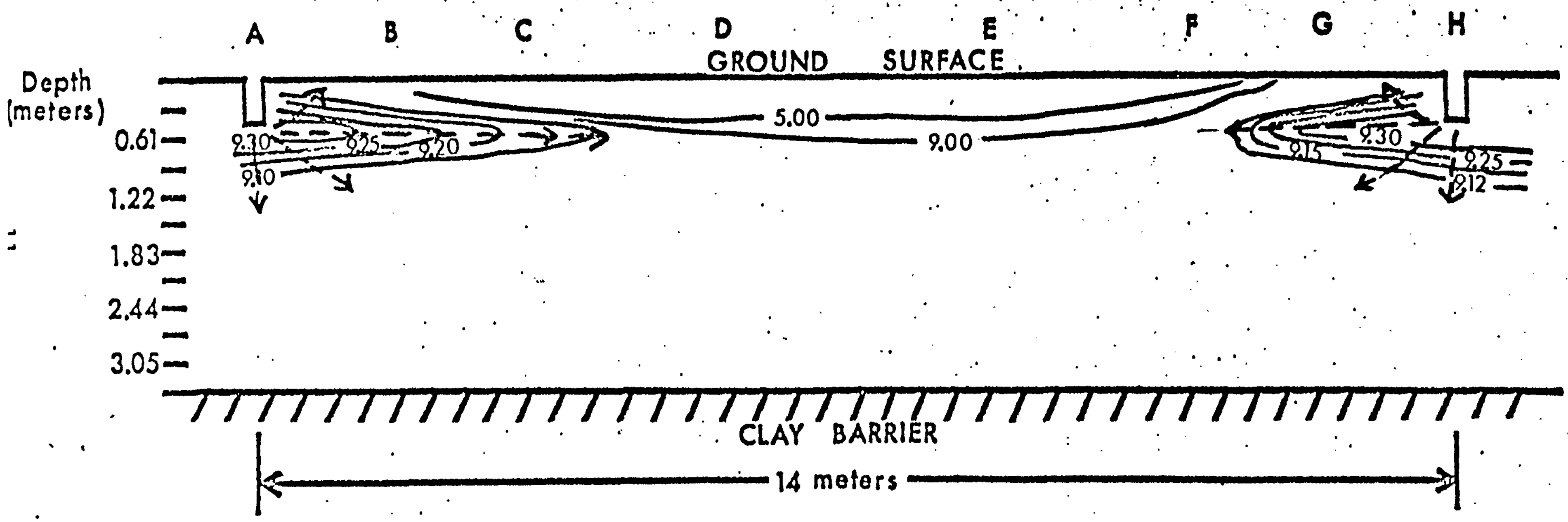

Figure 4. Flow net for August 15, 1977, two hours after start of irrigation.

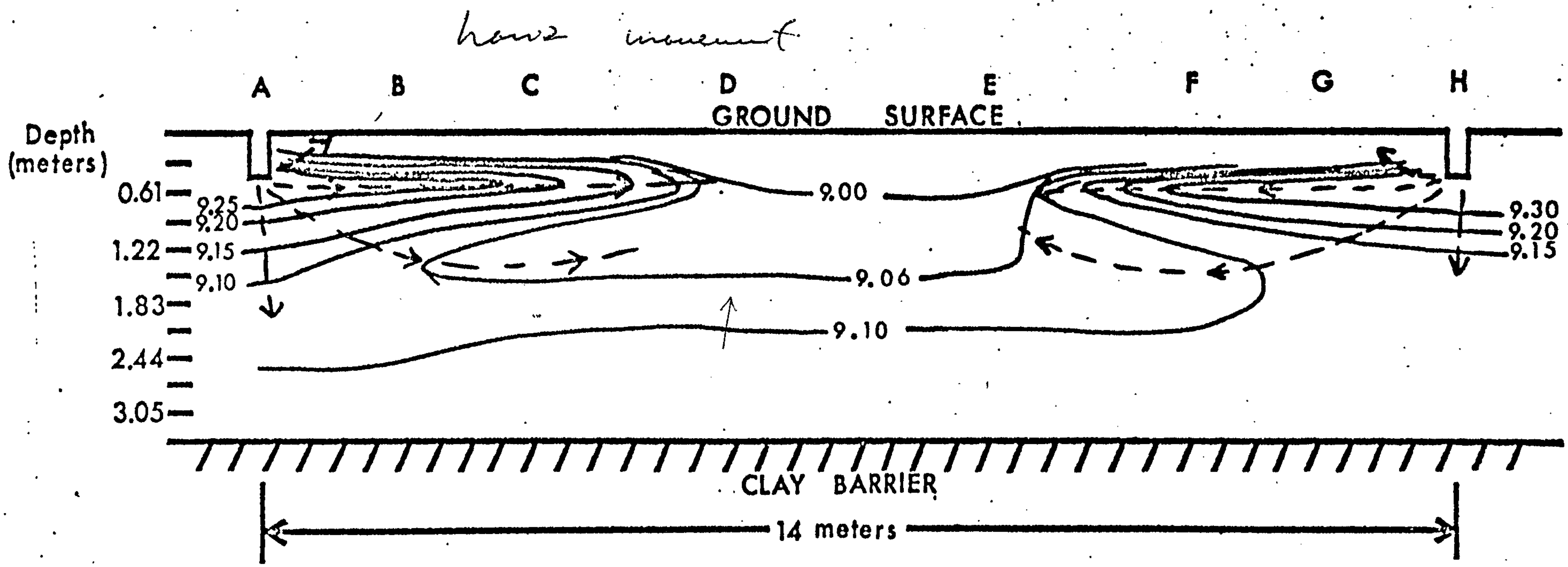

Figure 5. Flow net for August 15, 1977, 3.5 hours after start of irrigation.

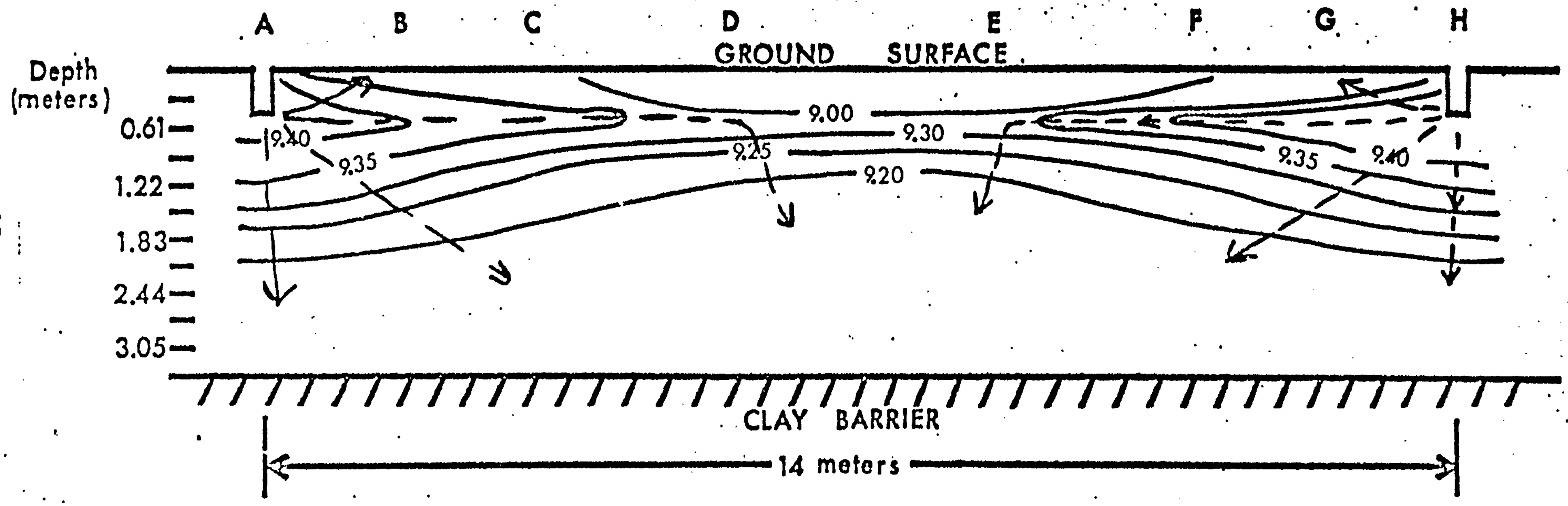

Figure 6. Flow net for August 15, 1977, 10 horus after start of irrigation.

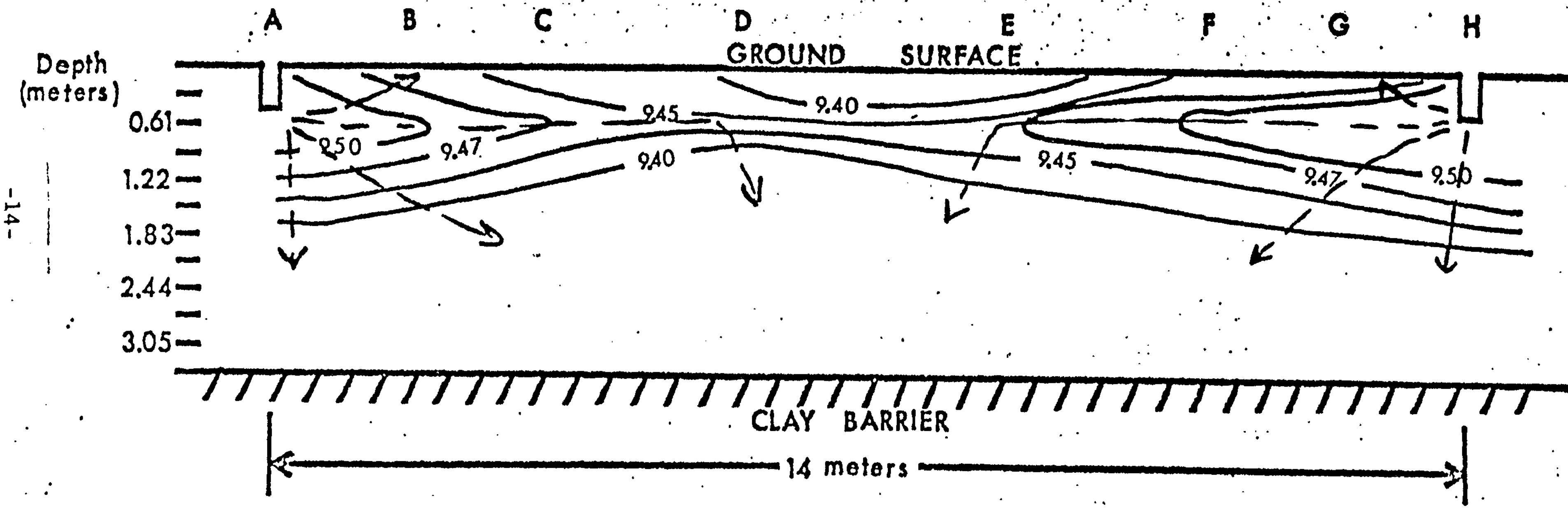

Figure 7. Flow net for August 16, 1977, 24 hours after start of irrigation.

The irrigation was started at about 10:00 a.m. on August 15, 1977. By noon on the same day, the flow pattern illustrated in Figure 4 had developed. This shows that at about the 0.61 meter depth, the horizontal movement of water is much greater than the vertical downward movement of water. This is reflected by the "distortion" of the equipotential lines in the horizontal direction.

The probable reason for this flow pattern is a layer of silt and clay at about 0.61 meter below the surface. The permeability of this layer is believed to be less than that of the overlying material. Consequently, irrigation water is primarily horizontal along the top of the silt layer.

Figure 5 illustrates the flow pattern after about 3.5 hours of irrigation. Again, horizontal movement of water is greater than vertical movement. At this time, the wetting front was about 3-4 meters away from each spud ditch. Unsaturated conditions still exist at the 0.30 meter depth at all positions and at 0.61 meter for positions D and E. Water pressure head at these positions was still negative. No changes in hydraulic head have occurred at positions D and E.

The flow pattern indicates that some displacement of subsurface water may have been occurring. However it is believed that any displacement was minor due to the small time period over which this flow pattern existed.

Ten hours after irrigation commenced, the flow pattern in Figure 6 existed, The wetting fronts appear to have moved into the center area of the plot and as a result, horizontal movement of water in that area is probably very small. Water movement in that area is primarily vertical with water moving upward into the root zone and also moving downward through the silt layer.

Any upward displacement process has apparently ceased since the vertical component of the streamlines is downward at depths greater than 0.61 meter. Unsaturated conditions still exist at locations D1 and E1.

Figure 7 is the flow pattern twenty-four hours after irrigation commenced. The flow pattern is essentially the same as that for ten hours but the values of hydraulic head have increased. This reflects the rise of the water table during this period of time.

The flow pattern after 54 hours of irrigating indicate that a near-static situation existed during the remainder of the irrigation. Water movement was slight, and was probably in response to evapotranspiration and water movement out of the system towards a drain located about 37 meters away.

The irrigation was terminated on August 20, 1977. The water table depth at that time was about 0.15-0.20 meter below the ground surface.

After termination of the irrigation, the near-static condition continued although the magnitude of the hydraulic heads at each grid point decreased. An interesting observation is that the hydraulic head at the 0.30 meter depth remain approximately the same as the head at other depths until about six days after cessation of the irrigation. This indicates that during this time period, little, if any, water was moving up into the root zone, although the water table during this time period dropped to nearly 0.61 meter below the surface.

From an analysis of these flow patterns, it appears that little, if any, displacement of the subsurface-water occurred during the irrigation and that movement of the irrigation water was primarily horizontal due to the silt and clay layer. Thus, it is felt that the irrigation water replenished the root-zone moisture supply at these sites.

Figure 8 illustrates changes with time in the soil water pressure for the D set of instruments at Plot B that occurred throughout the duration of the experiment. Changes in water pressure head with time for the other instrument sets on MacDonald Island were similar.

From this figure, it can be seen that at the 0.30 meter, the water-pressure head was about 0.15 meter just after the second irrigation at the end of July. During the next three weeks, the water-pressure head decreased (became more negative), due to evapotranspiration. A minimum of about -8.0 meters of pressure head existed just prior to the August 15 irrigation. The soil pressure head then increased to almost zero within one day as a result of the irrigation. For a period of about three days, positive water pressures existed indicating that the water table was less than one foot deep. After the last irrigation, the water pressure head again decreased.

The water pressure head at the 0.61 meter depth was about -0.25 meters just before to the last irrigation. This indicates that the soil at this depth was still very wet at that time.

A comparison of the water-pressure head changes at the 0.30 meter depth with those at the 0.61 meter depth provides information on root development. At the 0.30 meter deep, the water-pressure head decreased to about -8.0 meters of water just before the last irrigation indicating substantial depletion of the soil moisture. However, at the 0.61 meter depth, the water-pressure head decreased to

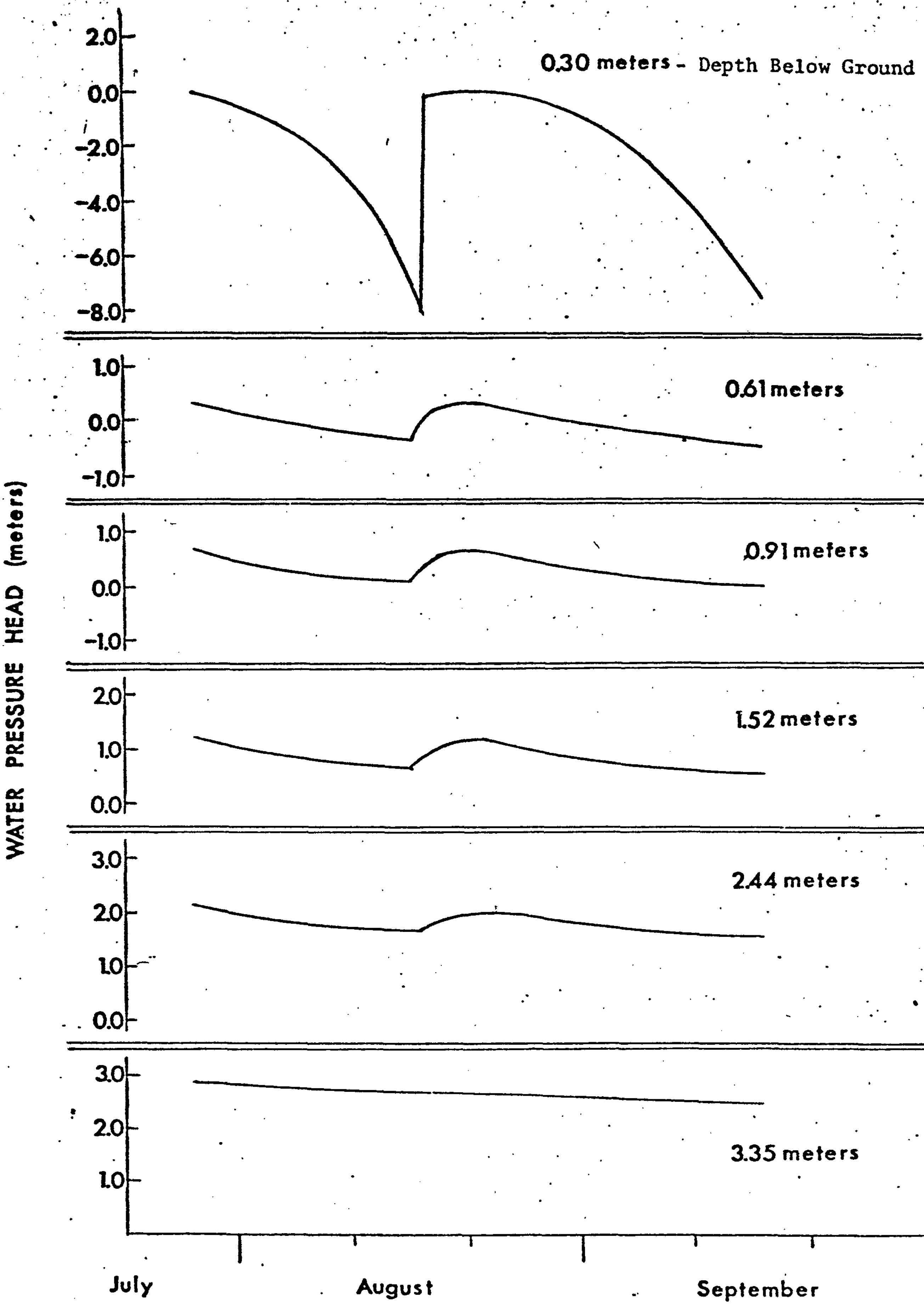

Figure 8. Water pressure head as a function of time and depth below the ground surface for Plot B, D set of instruments, MacDonald Island.

about -0.25 meter indicating little, depletion of the soil moisture. Therefore, root activity appears to be primarily within the top 0.30 meter below the surface.

Water-pressure head changes at depths of 0.91, 1.22, 1.52 and 2.44 meters, respectively, were similar to those at 0.61 meter.

At the depth of 3.35 meters, there was little or no measurable change in the water-pressure head during the irrigation period. This was also observed for the other instrument sets. A possible reason for this lack of change is the possibility that a layer of highly permeable (compare to that elsewhere) material exists between 2.44 meters and 3.35 meters and that the hydraulic head of the water in this layer is controlled by boundary conditions external to the flow system under study. If this is the case, then the instruments located 3.35 meters deep would respond only to changes in the external boundary condition and not to changes occurring within Plots A and B. The small decrease in the water-pressure head that occurred during this study may reflect changes in external conditions.

Subsurface Water Quality

Results of water quality analysis are shown in Tables 1-3 for Plot A on MacDonald Island and in Table 4 for Bacon Island. Similar results were found for samples taken in Plot B. These values represent the water quality of saturated soil only.

It can be seen that the water quality at the lower depths is better than that nearer to the surface. The gradual change in the water quality with depth may indicate that mixing of the groundwater at the lower depths with the subsurface water at the higher depth is occurring.

From Table 1, it can be seen that at the 0.61 meter depth, the EC of water samples obtained at D and E was higher than that at the other sampling points at that depth. A similar pattern was found for Plot B. This may be due to salts being carried into this area by the horizontal flow of subsurface water above the silt layer. At the center of the plot, a stagnation point with regard to horizontal flow (no horizontal flow) would exist. This means that water movement would be in the vertical direction only. Since vertical flow is thought to be small, salt removal in this area may have been slight. Thus, EC values in the center area should be higher than those at points nearer to the spud ditches.

The EC values of water samples taken at Bacon Island are considerably higher than those taken at MacDonald Island. This difference may reflect water quality differences of river water at each location. The irrigation water EC was about 0.6 mmhos/cm at MacDonald Island and about 1.1 mmhos/cm at Bacon Island. Subsurface seepage from the channel into the island may also be a contributing factor to these differences in subsurface water quality.

By observing changes in the subsurface water quality with time throughout the grid system, it was believed that the irrigation water used as a tracer would aid in developing flow patterns. Because of the difference between the water quality of the irrigation water (EC≃ 0.6 mmhos/cm) and that at locations near the spud ditch (EC≃ 0.8-1.0), it is felt that significant changes should have occurred at least near the spud ditches. However, no significant changes with time occurred in the subsurface water quality, even at points next to the spud ditches. Reasons for this phenomenon are not known at this time.

Soil Salinity

Soil salinity measurements of the top 0.30 meter of the soil profile are shown in Table 5 for Plots A, B, and C on MacDonald Island and for Bacon Island. Each value is the average of five to seven samples. The irrigation water of Plot C was salinized by the Central Delta Water Agency. The data for Bacon Island is a

Table 1. Electrical conductivity of water quality samples from Plot A, MacDonald Island (mmhos/cm). Locations of probes are shown in Figure 2a. Sampling date was August 18, 1977.

Depth (meters)	Location of Probe Between Spud Ditches							
	A	B	C	D	E	F	G	H
0.30	-	1.03	1.16	1.23	1.02	-	-	-
0.61	-	0.80	0.88	1.06	1.06	1.00	1.02	-
0.91	0.90	0.60	0.53	0.88	0.89	0.76	0.94	0.74
1.22	0.54	0.46	0.45	0.64	0.75	0.50	0.80	0.49
1.52	0.37	0.35	0.34	0.46	0.54	0.35	0.49	0.39
2.44	0.27	0.24	0.26	0.30	0.28	0.25	0.25	0.22
3.35	0.33	0.28	0.36	0.32	0.29	0.32	0.23	-

Table 2. Na^+ concentration of water quality samples from Plot A (meq/l). Sampling date was August 18, 1977.

Depth (meters)	Location of Probe Between Spud Ditches							
	A	B	C	D	E	F	G	H
0.30	-	3.96	4.47	3.91	3.65	-	-	-
0.61	-	2.52	2.30	-	3.09	3.13	2.65	-
0.91	3.00	2.17	1.73	2.50	2.78	2.17	2.44	2.76
1.22	2.03	1.81	-	2.16	2.32	2.05	2.16	1.83
1.52	1.48	1.51	1.39	1.66	1.74	1.57	-	1.56
2.44	0.95	0.80	0.82	1.04	1.04	0.90	0.86	0.85
3.35	0.91	0.85	0.86	0.87	0.87	0.84	0.79	-

Table 3. Cl^- concentration of water quality samples from Plot A (meq/l). Sampling date was August 18, 1977.

	Location of Probe Between Spud Ditches							
Depth (meter)	A	B	C	D	E	F	G	H
0.30	-	-	4.00	-	5.25	-	-	-
0.61	-	2.50	2.25	2.50	2.75	-	2.75	-
0.91	3.25	1.50	1.50	2.00	2.25	1.75	2.00	3.00
1.22	2.00	1.75	1.50	1.75	2.00	1.75	2.00	2.00
1.52	1.75	1.25	1.25	1.75	1.75	1.50	1.50	1.75
2.44	1.00	1.00	1.00	1.25	1.25	-	1.00	1.25
3.35	1.00	1.00	1.00	1.25	1.25	0.75	0.75	-

Table 4. Electrical conductivity of water quality samples from Bacon Island (mmhos/cm). Locations are shown in Figure 2b. Samples were taken on August 30, 1977.

	Location of Probe Between Spud Ditches						
Depth (meter)	A	B	C	D	E	F	G
0.30	-	-	-	-	-	-	-
0.61	-	-	-	-	-	-	-
0.91	1.50	1.32	1.58	1.73	1.18	2.00	1.60
1.22	0.77	1.26	1.04	1.32	0.85	1.49	-
1.52	0.96	0.98	-	0.96	1.04	1.10	-
2.13	0.80	0.93	-	0.83	0.90	0.90	1.08

comparison of soil salinity occurring under sprinkler irrigation and under subsurface irrigation.

On MacDonald Island the soil salinity was higher for the latter measurements. However, at a level of significance of 0.01, differences between the two sets of samples were not statistically significant. Reasons for this lack of significance are believed to be the small number of samples from each depth, the spatial variability of soil salinity, and the interval between sampling dates and the time of sampling with respect to the growing season. At least two-thirds of the growing season had passed when the first set of samples was obtained.

CONCLUSIONS:

Based upon the results of this research, the following conclusions are made:

a) During the irrigation, flow of the irrigation water was primarily horizontal. A layer of silt located at about 0.61 meter below the surface is the cause of this flow. Little displacement of groundwater appeared to occur. Thus, applied irrigation was primarily responsible for replenishing the root zone moisture.

b) Root activity below 0.30-0.45 meter in depth was negligible based upon change in the pressure head at 0.3 meter and 0.61 meter.

c) The subsurface water quality increased as the depth increased. At MacDonald Island, the EC ranged from an average of 0.30 at 3.35 meters deep to an average of 1.1 at 0.30 meter. The range at Bacon Island was about 0.91 at 2.13 meters to about 1.56 at 0.91 meter.

d) No significant transport of salt in the profile was observed during the irrigation.

e) Soil salinity in the top 0.30 meter increased slightly between the earlier and later sampling dates. The increase was statistically insignificant for a level of significance of 0.01.

f) Sprinkler irrigation substantially reduced soil salinity in the top 0.30 met

Table 5. Electrical conductivity of saturated soil extract of soil samples obtained from the first 0.30 meter (mmhos/cm). Each value represents the average at each depth of samples taken at the locations shown in Figure 2a, i.e. A,B,C,····.

Depth Interval (cm)	Plot A		Plot B		Plot C		Bacon Island	
	July 11	Oct 27	July 15	Oct 27	July 11	Nov 2	Aug 18 1/	Aug 19 2/
0-5	9.0	12.3	10.2	12.5	12.8	14.5	7.9	2.9
5-10	4.6	4.4	4.4	4.2	5.3	8.4	5.3	2.1
10-15	3.9	3.6	4.2	3.8	4.6	6.4	3.9	2.2
15-20	3.8	3.3	3.7	3.5	4.2	6.2	3.5	2.5
20-25	3.3	2.7	3.4	2.9	4.1	4.9	2.9	2.5
25-30	3.1	2.1	3.1	3.1	4.0	4.7	2.4	2.1

1/ Subsurface irrigation.

2/ Sprinkler irrigation.

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