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ANNUAL REPORT

1974

U. S. WATER CONSERVATION LABORATORY
Western Region
Agricultural Research Service
United States Department of Agriculture
4331 East Broadway
Phoenix, Arizona 85040

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PERSONNEL

The Laboratory Staff is as follows:

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E. D. Bell, General Machinist
H. Bouwer, Research Hydraulic Engineer and Director
J. G. Brooks, Physical Science Aid (resigned May)
D. A. Bucks, Agricultural Engineer
K. R. Cooley, Hydrologist
A. R. Dedrick, Agricultural Engineer
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G. C. Emery, Physical Science Technician (employed January)
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R. G. Gilbert, Soil Scientist
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J. R. Griggs, Physical Science Technician
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TITLE: EVAPORATION OF WATER FROM SOIL

CRIS WORK UNIT: 5510-12260-002 CODE NO.: Ariz.-WCL 68-1

The objective and need for the research reported under this research outline appeared in the USWCL 1969 Annual Report. Six field experiments were conducted, July 1970, March 1971, May 1973, July 1973, September 1973, November-December 1973, in which soil-water content and soil temperatures were measured as a function of depth and time.

Much of 1974 was spent on data analysis. Some of the results are reported under WCL-72-6, this report. The following sections report on heat flux calculations, salt effects on soil water vapor pressures, and an analysis of soil water hysteresis in a field soil.

PART I. DIURNAL SOIL-WATER EVAPORATION: SOIL HEAT FLUX MEASUREMENT AND CALCULATION

A complete description of the soil-heat measurements and the comparable theoretical computations is contained in the manuscript, "Diurnal Soil-Water Evaporation: Comparison of Measured and Calculated Soil Heat Fluxes." Briefly, soil-heat fluxes calculated from the theory of DeVries (1958, 1963) were compared with soil-heat fluxes experimentally determined in a field of Avondale loam at Phoenix, Arizona, on six days representing different seasons of the year. A fair agreement between measured and computed fluxes was obtained only after modifying the air shape factor curve and ignoring heat transfer due to water vapor movement. The omission of the latter implied that heat transfer by pure conduction was most important and that thermal and isothermal vapor fluxes exactly cancelled during the day and were insignificant at night.

"Measured" thermal conductivities were also determined from the ratio of the measured heat fluxes to the corresponding temperature gradient for those times when it was unlikely that isothermal vapor movement was significant. The lack of a temperature dependence in these data as well as the flux comparisons strongly indicate that the theory overestimated thermal vapor movement. These data plus

others in the literature indicate that an individual "calibration" of the theory for a particular soil is required before reliable predictions of soil-heat flux can be obtained.

Even though the measured and theoretical soil-heat fluxes described in the above manuscript did not agree well at the same depths, an immediate application of the results was that surface soil heat flux could be determined using theoretical fluxes computed at deeper depths. This application is described in the manuscript, "Soil-Heat Flux Determination: Temperature Gradient Method with Computed Thermal Conductivities."

Surface soil-heat fluxes were determined for six days in a field of Avondale clay loam using the null-alignment method, the combination method, and four variations of the temperature gradient method with thermal conductivities computed from the theory of DeVries for particular reference depths. For all methods calorimetry was used to obtain the surface flux from the flux determined for the reference depth.

There was 10% or less difference between the null-alignment, combination, and temperature gradient methods for a 20-cm reference depth. However, the difference with respect to the null-alignment method increased to 35% for a 5-cm reference depth when DeVries' theory was closely followed. This difference was reduced to 3% when a modified air shape factor was used in the computations and thermal vapor movement was ignored. It was concluded that the temperature gradient method with conductivities computed from DeVries' theory could be reliably used with a reference depth of 20-cm, but that a "calibration" of the theory for a particular soil should be obtained before the method is used with a 5-cm reference depth.

When properly used, the temperature gradient method with computed conductivities has the advantage that reliable estimates of surface soil-heat flux can be obtained without the heat flux plates required for the usual combination method and without as many

computations as required for the null-alignment method.

PERSONNEL: B. A. Kimball

PART II. VAPOR PRESSURE OF SOIL WATER AS AFFECTED BY SALTS

The salts present in the soil have a great influence on the amount of water adsorbed by natural soils. The water adsorption data in Table 1 show that the unleached Avondale soil adsorbed more water than the leached soil at the higher relative humidities, especially at the 0- to 0.2-cm and 0- to 0.5-cm depths where the salt contents are much larger than the lower depths. This salt effect is shown more clearly in Figure 1 for another set of Avondale soil where the amount of water adsorbed at 97% relative humidity is compared with the extractable salt content for the different soil depths. For saline soils then, the water content per se is not the complete criterium for evaluating water availability to plants, nor for predicting the direction of liquid or vapor flow through the soil profile since the total thermodynamic potential of the soil water governs the direction of water movement.

PERSONNEL: F. S. Nakayama

PART III. SOIL-WATER HYSTERESIS IN A FIELD SOIL

The requirements for the measurement in the field of the hysteresis characteristics of the water content (θ) - soil water pressure (h) relationship are discussed in a manuscript entitled "Soil-Water Hysteresis in a Field Soil." Details given of the method whereby an undisturbed hexagonal monolith of soil of area 1.5 m^2 was isolated from the surrounding soil. The instrumentation used in measuring the soil water movement in this monolith, with particular reference to h and θ measurements at points in the soil profile, is described. The shapes of typical θ-time and h-time curves are then discussed in relation to possible hysteresis, and the actual h-θ relationship for soil at the 8- to 9-cm depth determined. Results indicated that approximately half of the "available" water is subjected to hysteresis during its movement through soil.

PERSONNEL: R. D. Jackson

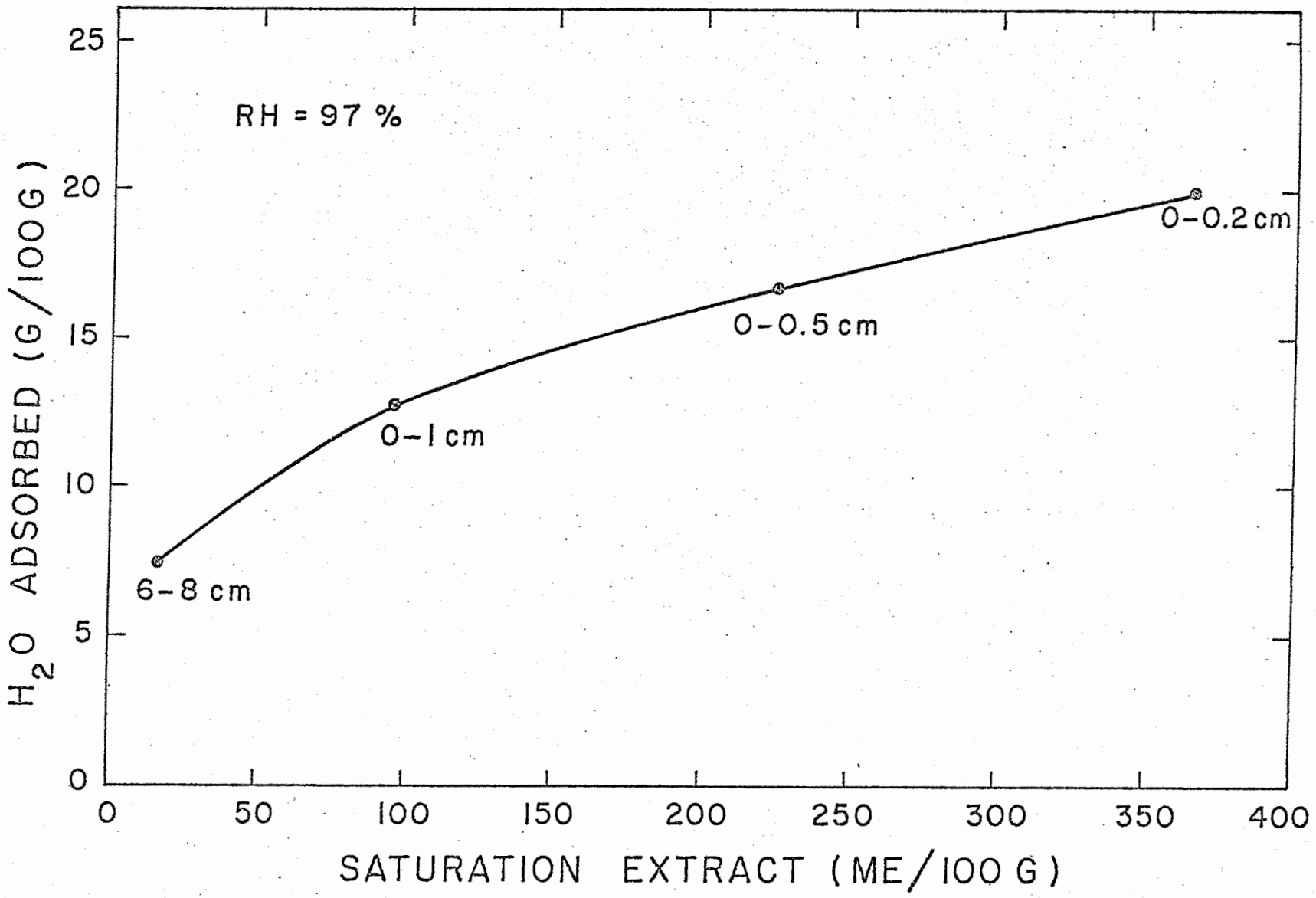

Figure 1. Water adsorption by Avondale soil at 97% relative humidity for the different depths and salt contents.

Table 1. Comparison of water adsorption for leached and unleached Avondale soil at various relative humidities.

WATER ADSORPTION CAPACITY AS FUNCTION OF DEPTH AND RELATIVE HUMIDITY (UNLEACHED SOIL)

SOIL DEPTH (cm)	WATER CONTENT (%) AT RELATIVE HUMIDITY				
	11.8	33.0	75.5	85.0	97.0
0-0.2	1.73	2.52	4.74	5.60	14.84
0-0.5	1.66	2.47	4.69	5.46	11.38
0-1	1.37	2.28	4.39	5.02	8.20
6-8	1.54	2.40	4.70	5.48	7.86

WATER ADSORPTION CAPACITY AS FUNCTION OF DEPTH AND RELATIVE HUMIDITY (SALT LEACHED SOIL)

SOIL DEPTH (cm)	WATER CONTENT (%) AT RELATIVE HUMIDITY				
	11.8	33.0	75.5	85.0	97.0
0-0.2	1.40	2.31	4.28	5.00	7.54
0-0.5	1.47	2.33	4.22	4.98	7.48
0-1	1.41	2.30	4.24	5.04	7.61
6-8	1.35	2.30	4.50	5.44	8.14

TITLE: RELATIVE CHANGES IN TRANSPIRATION AND PHOTOSYNTHESIS INDUCED BY SOIL WATER DEPLETION IN A CONSTANT ENVIRONMENT

CRIS WORK UNIT: 5510-12260-002 CODE NO.: Ariz.-WCL 71-1

INTRODUCTION:

This research is a continuation of last year's efforts; the objective remains the same: to improve the water-use efficiency (WUE) of crops and thereby conserve agricultural water supplies.

PROCEDURE:

See the 1972 Annual Report for a detailed account. In brief, a given plant species was subjected to a short-term drought in a controlled environment while measurements were made of the simultaneous rates of transpiration and photosynthesis. In this type of research what is sought is a species with a high WUE under drought, i.e., one with a low transpiration ratio (TR). A plant with the desired drought response will reduce its transpiration proportionately more than its photosynthesis. A crop made up of such a species would tend to yield more dry matter per unit of water than a crop composed of species with a high TR.

RESULTS AND DISCUSSION:

In last year's annual report the results for only Vigna sinensis (black-eyed pea) were presented, showing no decrease in the TR under drought. In the present report the data for five more species will be presented, showing contrasting results depending on species. The standard procedure was to take the plants from the greenhouse to the test chamber, irrigate the soil, and let the plant equilibrate overnight in the dark under the test conditions of 30 C, vapor pressure of 15 mb, and ambient levels of carbon dioxide of about 350 ppm. The next morning lamps were turned on sequentially until saturation illuminance was attained in the plant chamber. Then transpiration was permitted to proceed without further irrigation

to ascertain the relative effects of drought on transpiration and photosynthesis.

Cotton (Gossypium barbadense L., cv. Pima S-4). The plants began the test in a fully hydrated condition; the initial soil matric potential (ψ_M) was -40 mb and the relative leaf water content (RLWC) 92.2% at 1100, the time taken as the reference condition, i.e., one at which the plant would have fully opened stomates (Figure 1).

$$\text{RLWC} = \frac{\text{leaf weight during a test (obtained nondestructively by a beta ray gauge)} - \text{leaf weight when oven dry (100)}}{\text{fully hydrated leaf weight} - \text{oven dry leaf weight}}$$

At this time the transpiration rate was 147 g m^{-2} h^{-1} and the rate of photosynthesis 10.71 mg CO_2 dm^{-2} h^{-1}; leaf diffusion resistance (R_L) was 1.7 sec cm^{-1}, indicative of open stomates, and the so-called "mesophyll" resistance (R_M') was 16.9 sec cm^{-1}, a value that is high as compared to the few published values. The R_M' indicates the resistance to photosynthesis separate from the R_L' value associated with stomatal closure. In this fully hydrated state cotton was using water quite efficiently, as judged by its very low TR of 94 (TR being defined as the number of grams of water transpired per gram of carbohydrate produced, the latter value being the product of the photosynthetic rate and a constant that is the ratio between the molecular weights of carbon dioxide and carbohydrate (CH_2O). By making use of this conversion it is assumed that gain in dry matter is proportional to the photosynthetic rate.)

Measurements of transpiration, photosynthesis, ψ_M, and leaf density-thickness (mg cm^{-2}) from a β-ray gauge began in darkness and continued from 0800 through 1530 on the first day. Gradual illumination simulated a "sunrise" which ended at 1000 when 24 lamps were on directly above the plant chamber, giving saturation

illuminance at mid-chamber height (65 kilolux or more). As continued transpiration (evaporation was minimized by the presence of a vapor barrier over the soil surface) gradually depleted the available soil water, both transpiration and phytosynthesis declined along with the RLWC, shown in Figure 1, which also portrays the changes in R_L and the TR associated with drought. Since the objective was to stress the plants sufficiently to reduce transpiration by about 90%, i.e., to a level prevailing in the dark, the experiment had to be continued for another day. The plants were not subjected to continuous drought whenever this procedure would prolong the test much beyond the normal time of sunset. This was to eliminate possible autonomic rhythms of stomatal closure unrelated to leaf water deficit.

On the second day (Figure 2) sunrise was over by 1005, at which time the TR had declined to 53, because transpiration had been limited more severely than photosynthesis. One hour before irrigation, at 1500, the TR was about half the reference value of the preceding day, thus indicating a 100% improvement in WUE. At this point the leaves were wilted, having a RLWC of only 70.7% and a calculated R_L of 37.4 sec cm^{-1}, indicative of tight stomatal closure. In fact, the 22-fold increase in R_L more than compensated for the 2-fold increase in R_M' and thereby explains the lowered TR.

Unfortunately, this dramatic example of what was sought by this type of research was not verified by a replicate experiment with cotton. Although transpiration was limited by almost the identical amount as in the first experiment, the rate of photosynthesis started out at a higher rate and declined much more steeply, resulting in a large <u>increase</u> in the TR, from 80 to 184, i.e., much less efficient use of water under drought than when well irrigated.

<u>Sunflower (Helianthus annuus L., cv. Greystripe)</u>. At the reference time (1000 in Figure 3) the transpiration rate of 337

g m^{-2} h^{-1} was the highest, and the R_L value of 0.8 sec cm^{-1} the lowest, of the six species studied in these experiments. Therefore, in spite of the second highest rate of photosynthesis, the TR of 122 was the highest well-hydrated value (RLWC 90.2%) of the six species.

Progressive drought lowered the TR along with the RLWC until at 1400, just before irrigation, the TR reached its minimum of 49 and R_L increased to 12.2 sec cm^{-1}. Such a great decrease in TR was due to an 82% decrease in transpiration accompanied by only a 56% decrease in photosynthesis. The R_M' value actually decreased during drought; therefore, the decline in photosynthesis was due solely to stomatal closure. As was true for cotton, a second experiment with sunflower did not confirm the one illustrated here. Drought increased the TR.

Mulberry (Morus alba L., male). The plant was well hydrated during the first day (Figure 4); the RLWC remained about 95%. At the reference time, 1300 on Day 1, transpiration was high, 206 g m^{-2} h^{-1}, due primarily to the second lowest R_L value of the six species, 1.1 sec cm^{-1}. At this time the TR was 102; it hardly deviated from this level all day.

On Day 2, Figure 5, progressive drought steadily lowered both transpiration and photosynthesis as the RLWC declined. At intermediate drought levels, where the RLWC ranged from 84 to 75% and the corresponding R_L values from 5 to 15 sec cm^{-1}, the TR ranged from 85 to 75, indicating more efficient water use than during the first day when the plant was well hydrated. However, as the drought progressed, photosynthesis declined proportionately more than transpiration, resulting in a very high TR before irrigation, 352. At this time R_L was 51 sec cm^{-1} and R_M' the exceedingly high value of 703 sec cm^{-1}.

Corn (Zea mays L., cv. Mexican June). At the reference time, 1030 (Figure 6), the RLWC was very high, 98.7%. With saturation

illumination one would expect full stomatal opening and hence a low R_L. That full stomatal opening must have prevailed is indicated by the fact that while the leaf-air vapor pressure deficit remained at 28 $\pm$ 1 mb for several half-hour periods, transpiration reached its peak at 1030. However, the value of 4.1 sec cm^{-1} at 1030 was the highest fully hydrated R_L of the six species. Such a difference between the R_L of corn and that of other species was not observed in previous experiments at this Laboratory, and suggests that a detailed comparison between calculated and directly measured R_L might be useful in helping resolve the discrepancy. The R_M' value of 12.3 sec cm^{-1} is much higher than the few published values.

Leaf dehydration was more effective in corn than in cotton in causing stomatal closure and the consequent drastic reduction in both transpiration and photosynthesis. For example, as R_L increased from the well-hydrated value (1.7 sec cm^{-1} in cotton and 4.1 sec cm^{-1} in corn) to a value of 35 sec cm^{-1}, the RLWC decreased only about half as much in cotton as corn. Nevertheless, transpiration in corn was decreased almost as much in corn as in cotton (83 and 89%, respectively). However, at the same time, photosynthesis was decreased 78% in cotton but 96% in corn. The large difference in the photosynthetic rate during drought is reflected in the high value for R_M' in corn, 486 sec cm^{-1} as compared to 36 sec cm^{-1} for cotton. It is apparent that for corn to maintain its favorably low TR it must be irrigated frequently. A second experiment verified the results found here, viz., that drought caused a decrease in the TR.

Sorghum (Sorghum bicolor L., cv. Northrup King 310). At the reference time, 1030 on Day 1 (Figure 7), the RLWC was 92.1%; a relatively low rate of transpiration (140 g m^{-2} h^{-1}) combined with the highest rate of photosynthesis of the six species (23.73 mg dm^{-2} h^{-1}) to yield by far the lowest TR of any species studied, 40. The moderate transpiration rate was consistent with the R_L value of

3.1 sec cm^{-1}. The concurrent R_M' value of 3.3 sec cm^{-1} was by far the lowest of any of the six species.

Only toward the end of the first day was there a slight indication that progressive drought was beginning to affect plant response. On Day 2, when all the lamps were on, transpiration was only 63 as compared to 140 g m^{-2} h^{-1} on the previous day, a 55% reduction caused by an increase in R_L from 3.1 to 8 sec cm^{-1} as the RLWC decreased from 92.1 to 84.7%. Since photosynthesis decreased by 50%, the TR was down slightly (from 40 to 36).

Nevertheless, as the drought worsened, the rate of photosynthesis decreased more steeply than transpiration, resulting in a TR of 144 at 1430 on Day 2. At this time the RLWC had decreased to 69.5%; R_L had risen to 37 sec cm^{-1}, and R_M' to 144 sec cm^{-1}. Therefore, the recommendation for sorghum is the same as that for corn: to maintain a low TR, irrigate the crop frequently. As was true for corn, a second experiment with sorghum also confirmed the results of the first, that drought caused a decrease in the TR.

SUMMARY AND CONCLUSIONS:

The six species studied in these experiments give mostly negative evidence for the hypothesis that drought causes a decrease in the TR and thereby increases WUE. If drought is defined as a deficiency of soil water great enough to cause R_L at saturation light levels to rise to values characteristic of darkness, then the data for cotton, sunflower, and mulberry are not consistent enough to accept the hypothesis. In the case of the two monocots, corn and sorghum, there is consistent evidence <u>against</u> the hypothesis.

On the other hand, if only a small degree of stomatal closure is allowed, e.g., as represented by a rise in R_L from values characterized by open stomates to about 5 to 10 sec cm^{-1}, a small decrease in TR does occur, as shown by cotton, mulberry, and even sorghum. If this kind of data could be demonstrated to occur

consistently, the results would lend support to research with biochemical antitranspirants. Antitranspirants tend to close stomates only partially. Such a partial closure with its increased R_L in suitable species could reduce the TR immediately upon application of the antitranspirant instead of being delayed for the time required for transpiration to deplete soil water sufficiently to cause partial stomatal closure.

The main conclusion, however, is that six species probably is too small a number to use for drawing any generalization about the hypothesis. A greater number of species should be tested, with emphasis on desert-adapted species. A second conclusion, already stated, is that such crops as corn and sorghum should not be allowed to endure very much leaf dehydration for maximum WUE.

PERSONNEL: W. L. Ehrler, B. A. Kimball, and S. T. Mitchell

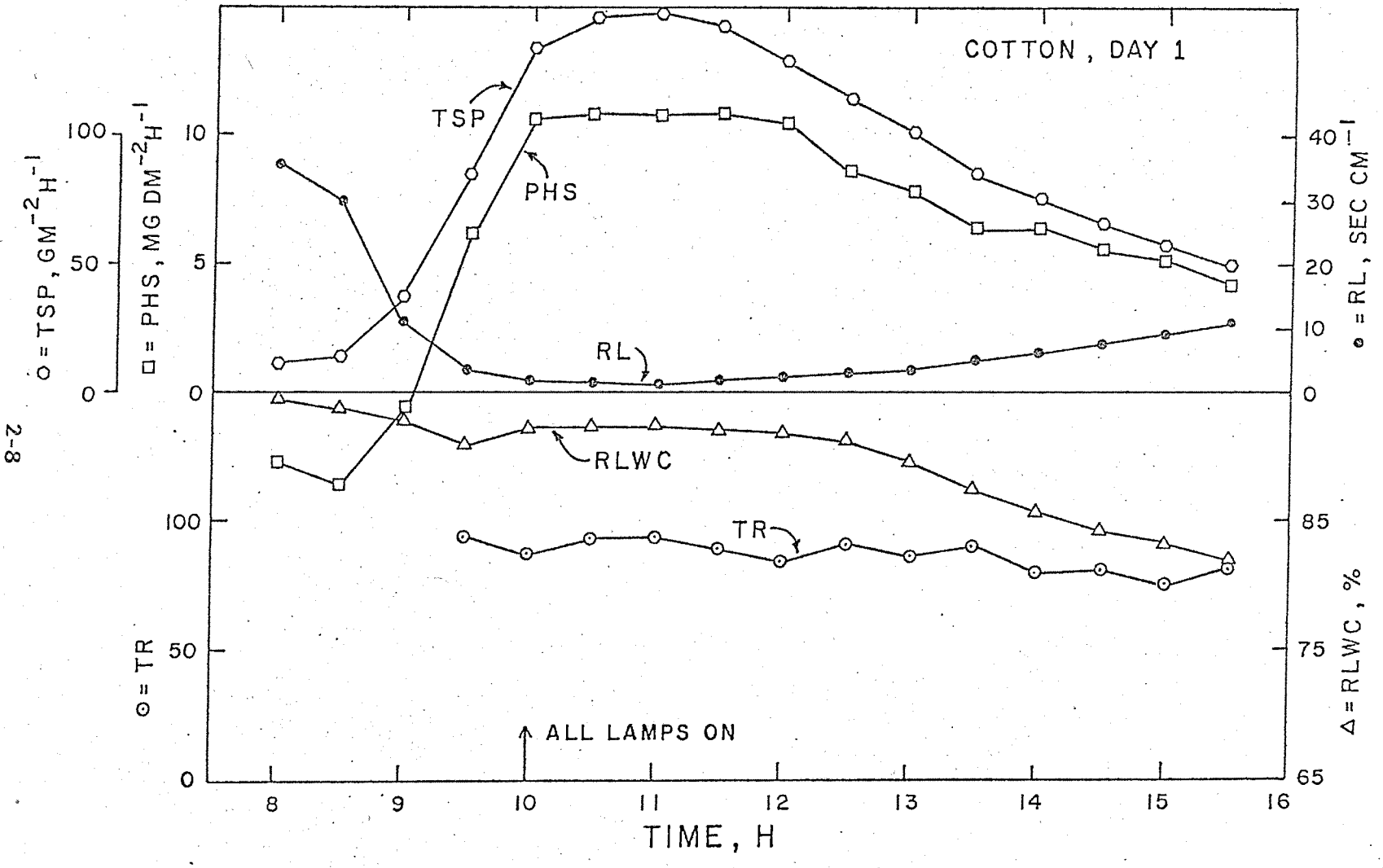

Figure 1. Half-hourly values of transpiration (TSP), net photosynthesis (PHS), calculated leaf diffusion resistance (R_L), the transpiration ratio (TR, defined as grams of water per gram of carbohydrate), and the relative leaf water content (RLWC) of cotton in a controlled environment during a drought. Day 1.

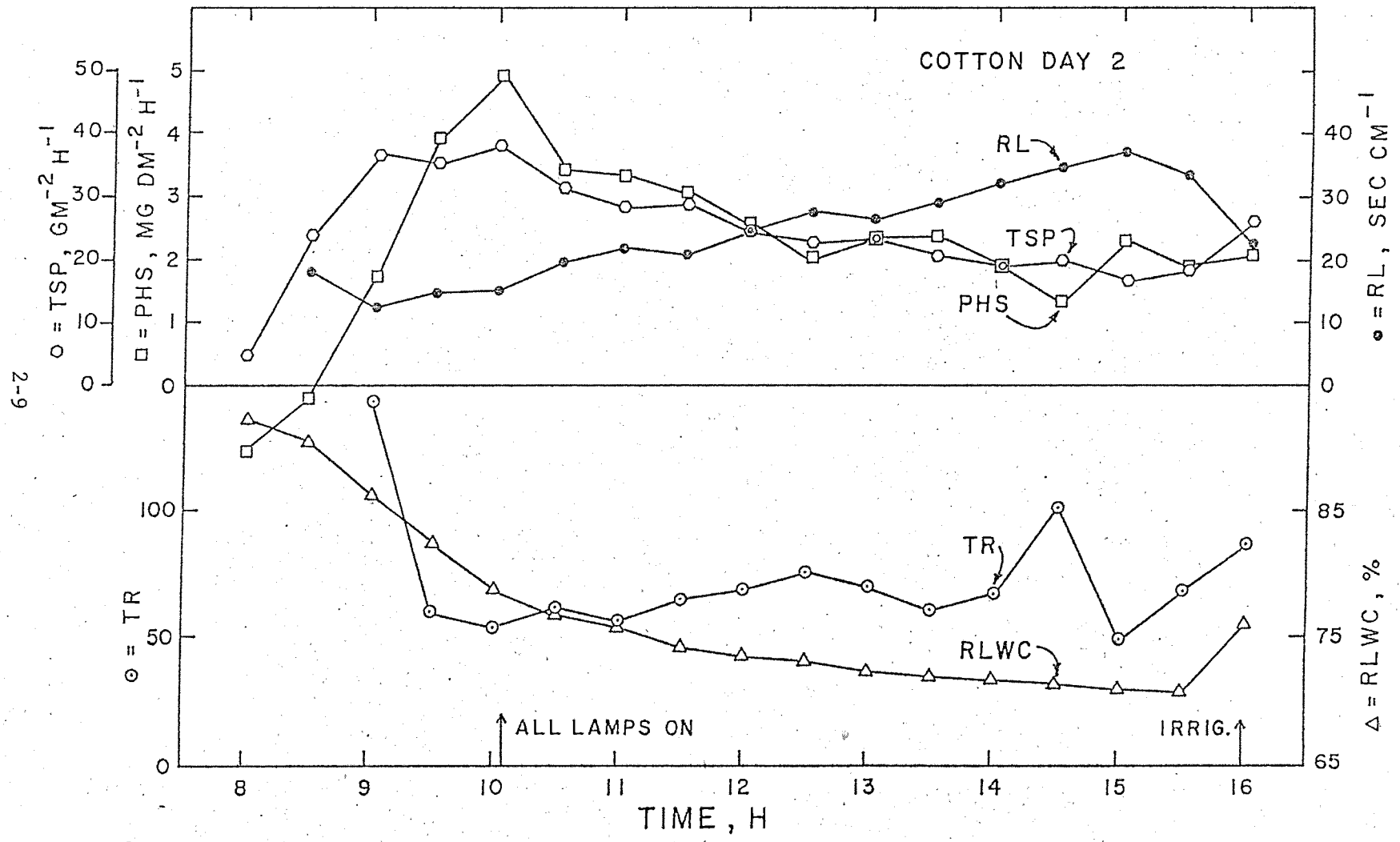

Figure 2. Half-hourly values of transpiration (TSP), net photosynthesis (PHS), calculated leaf diffusion resistance (R_L), the transpiration ratio (TR, defined as grams of water per gram of carbohydrate), and the relative leaf water content (RLWC) of cotton in a controlled environment during a drought. Day 2.

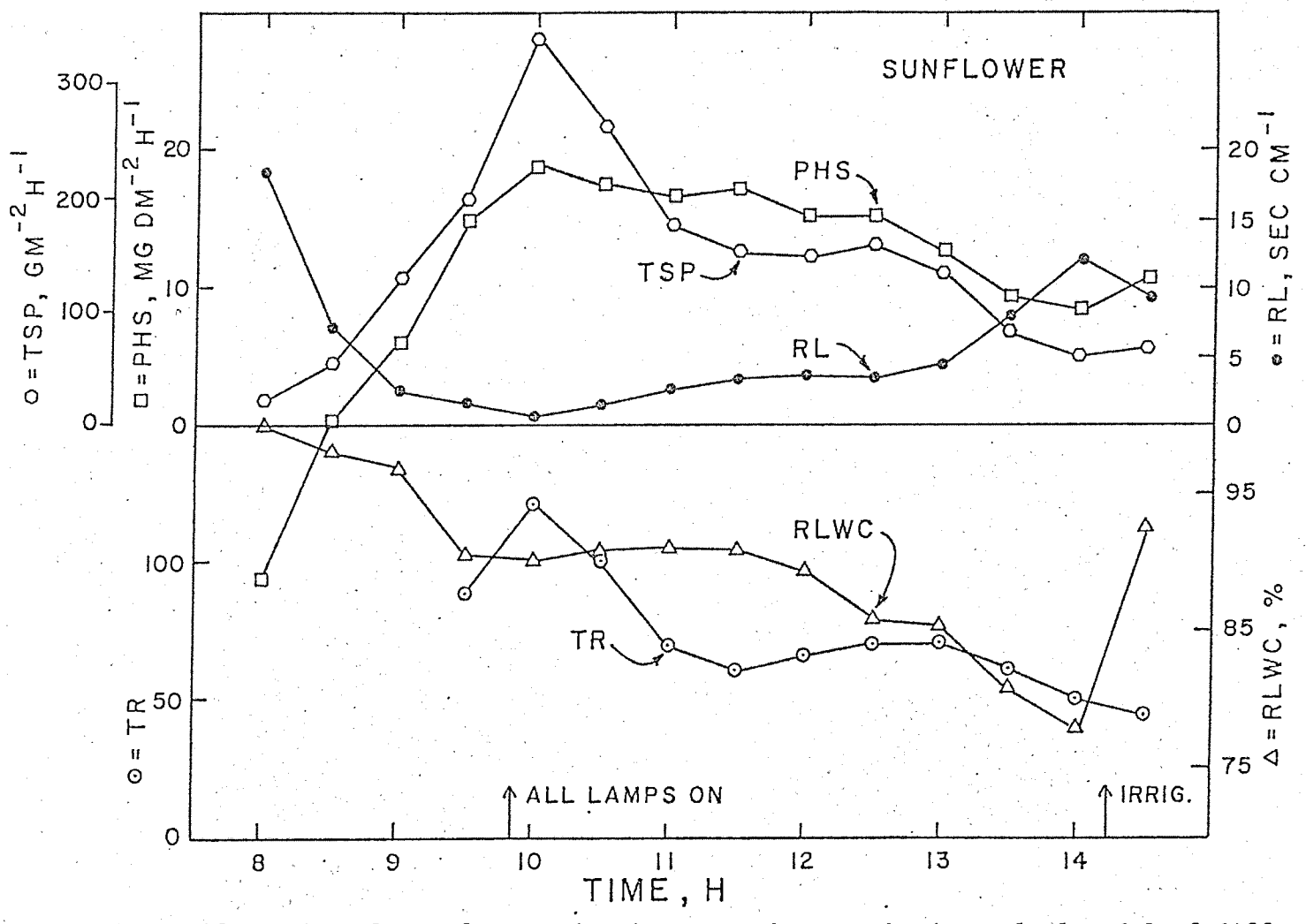

Figure 3. Half-hourly values of transpiration, net photosynthesis, calculated leaf diffusion resistance, the transpiration ratio, and the RLWC of sunflower in a controlled environment during a drought.

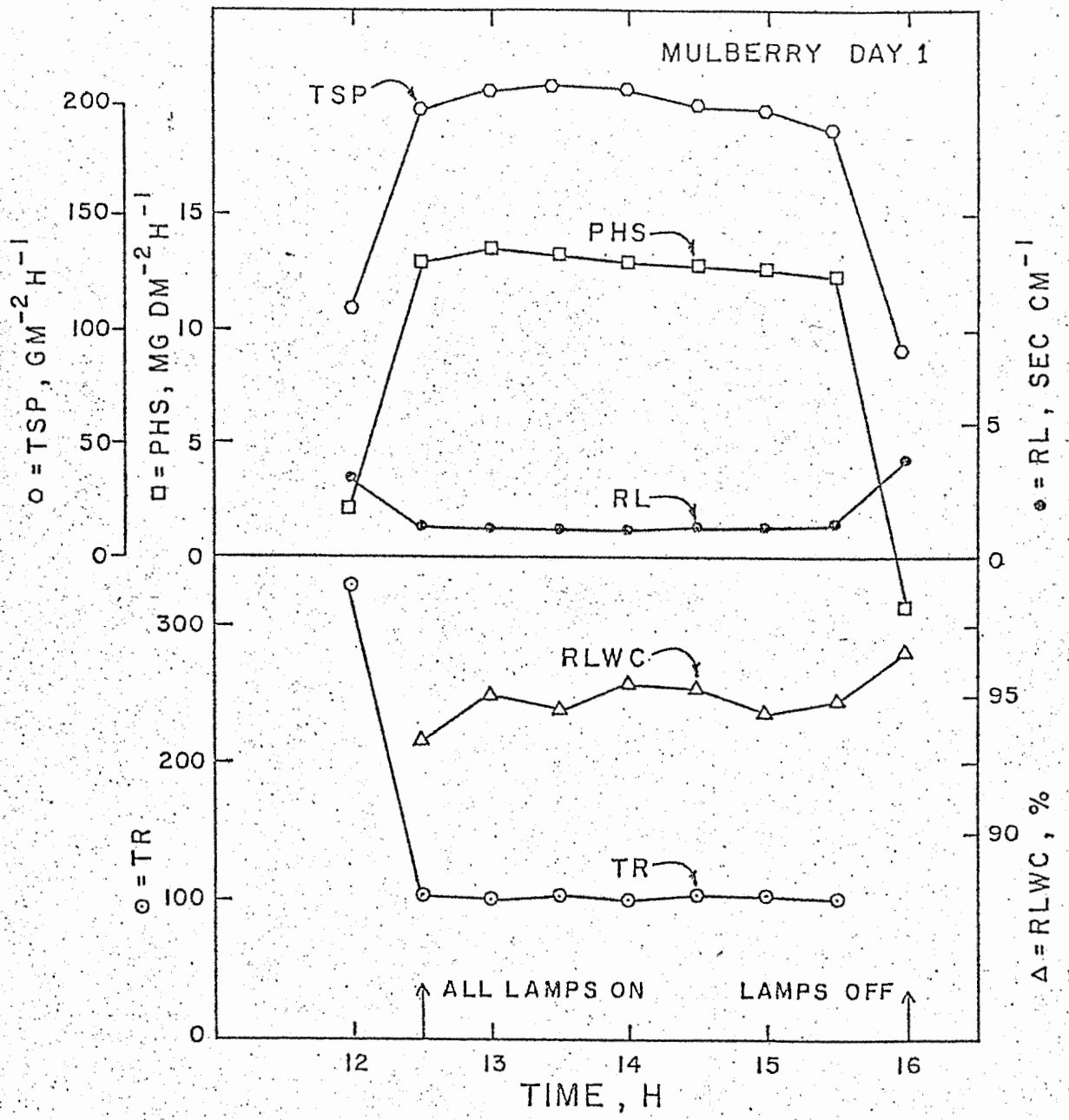

Figure 4. Half-hourly values of transpiration, net photosynthesis, calculated leaf diffusion resistance, the transpiration ratio, and the relative leaf water content of mulberry in a controlled environment during a drought. Day 1.

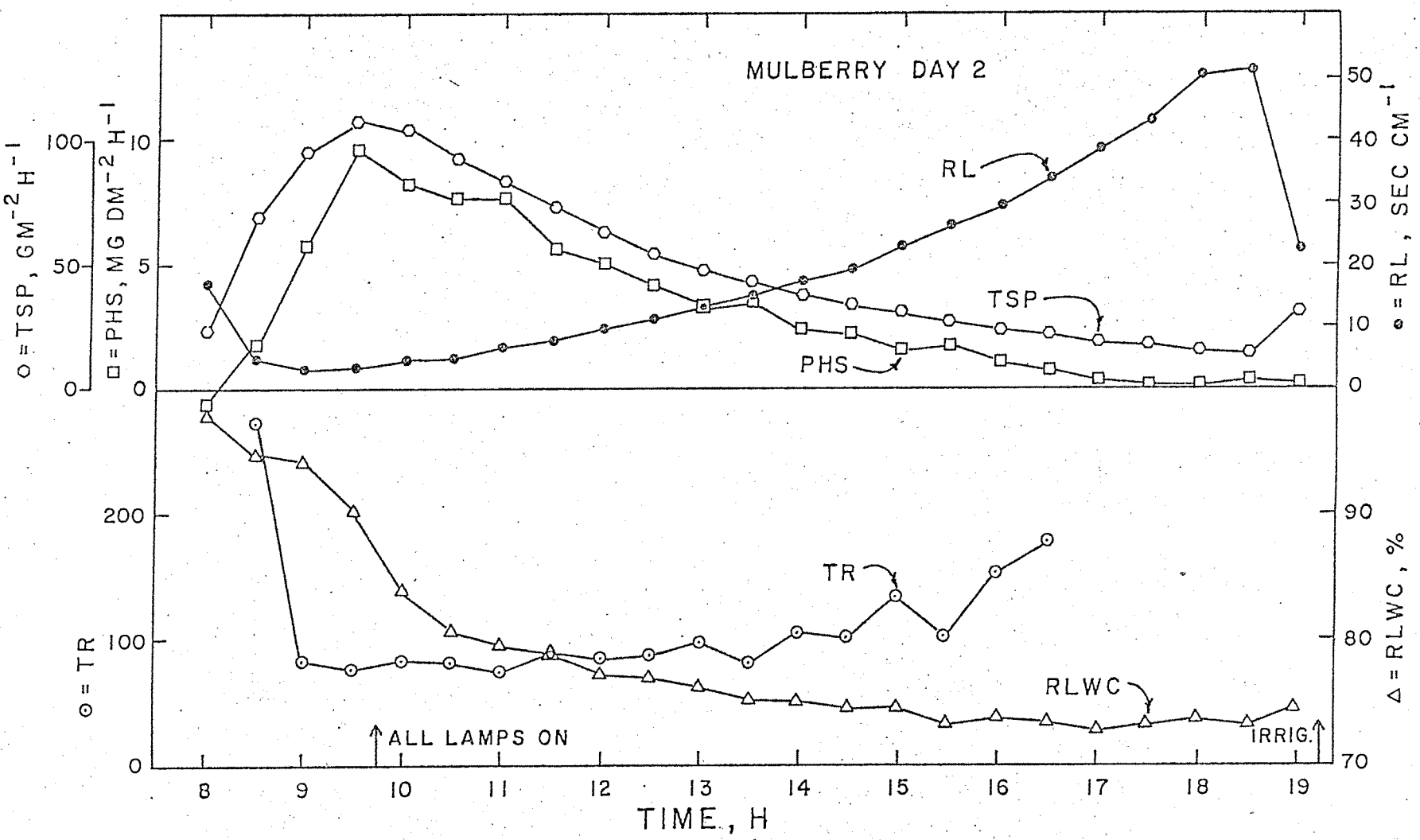

Figure 5. Half-hourly values of transpiration, net photosynthesis, calculated leaf diffusion resistance, the transpiration ratio, and the relative leaf water content of mulberry in a controlled enrivonment during a drought. Day 2.

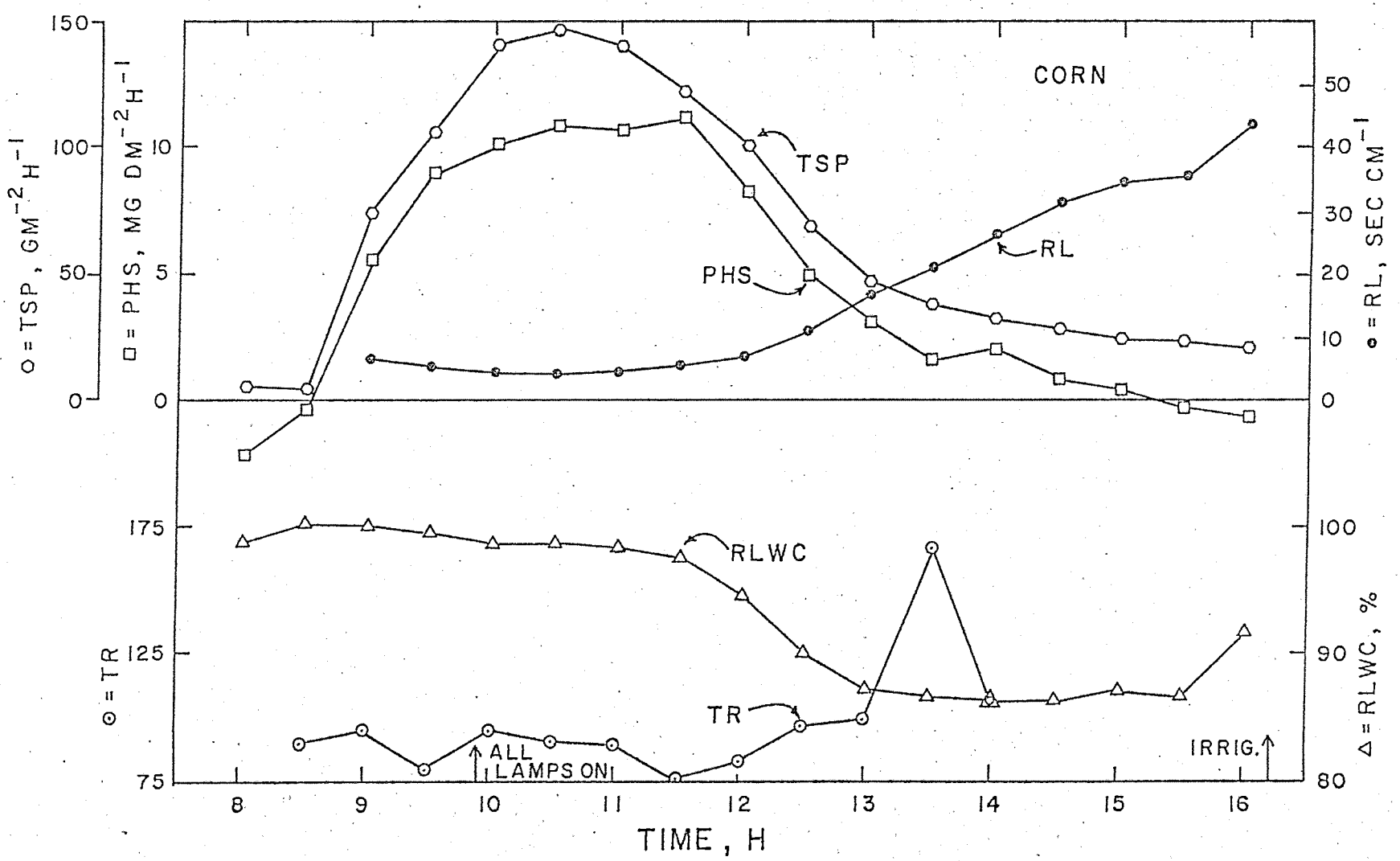

Figure 6. Half-hourly values of transpiration, net photosynthesis, calculated leaf diffusion resistance, the transpiration ratio, and the relative leaf water content of corn in a controlled environment during a drought.

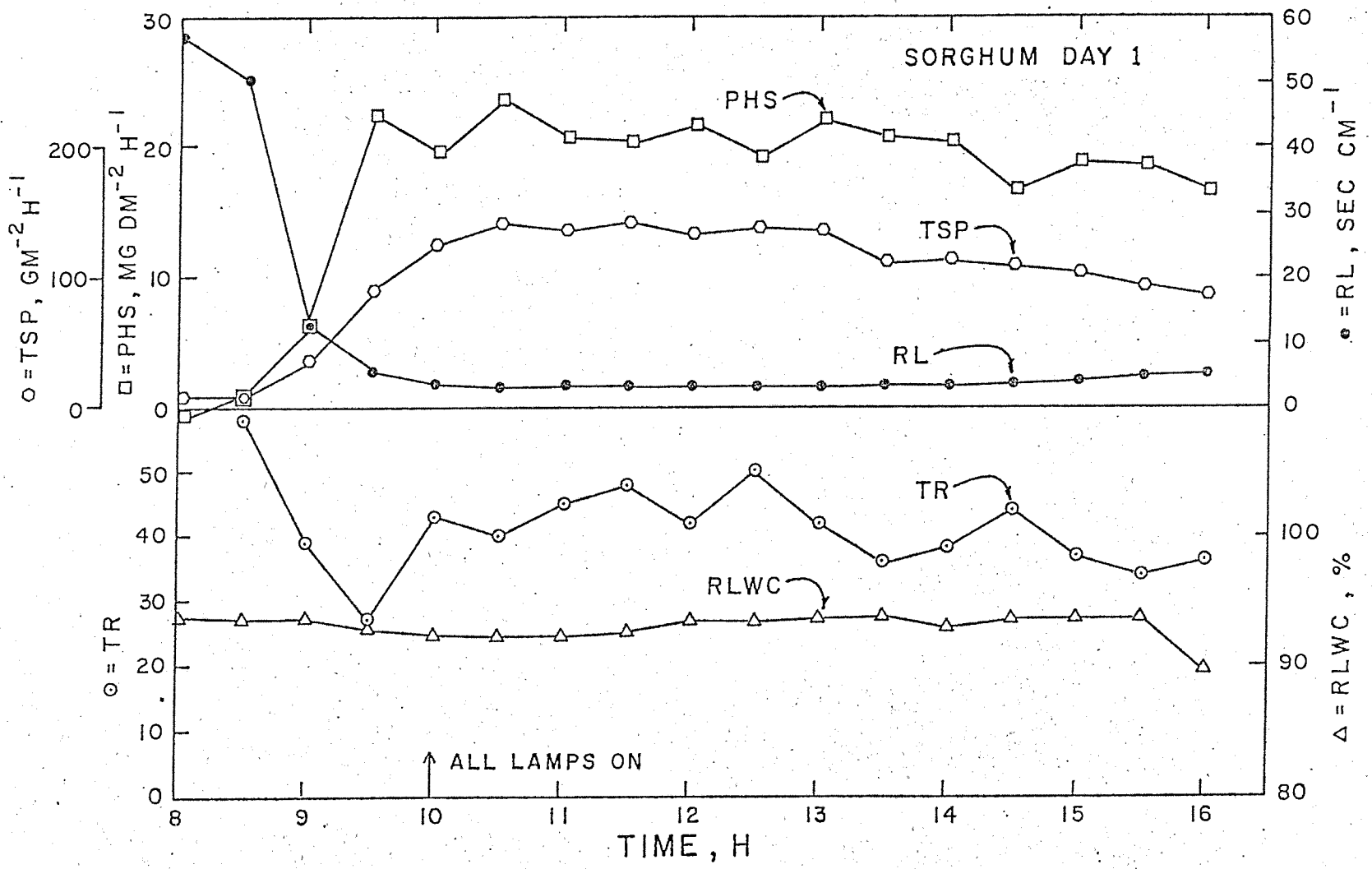

Figure 7. Half-hourly values of transpiration, net photosynthesis, calculated leaf diffusion resistance, the transpiration ratio, and the relative leaf water content of sorghum in a controlled environment during a drought. Day 1.

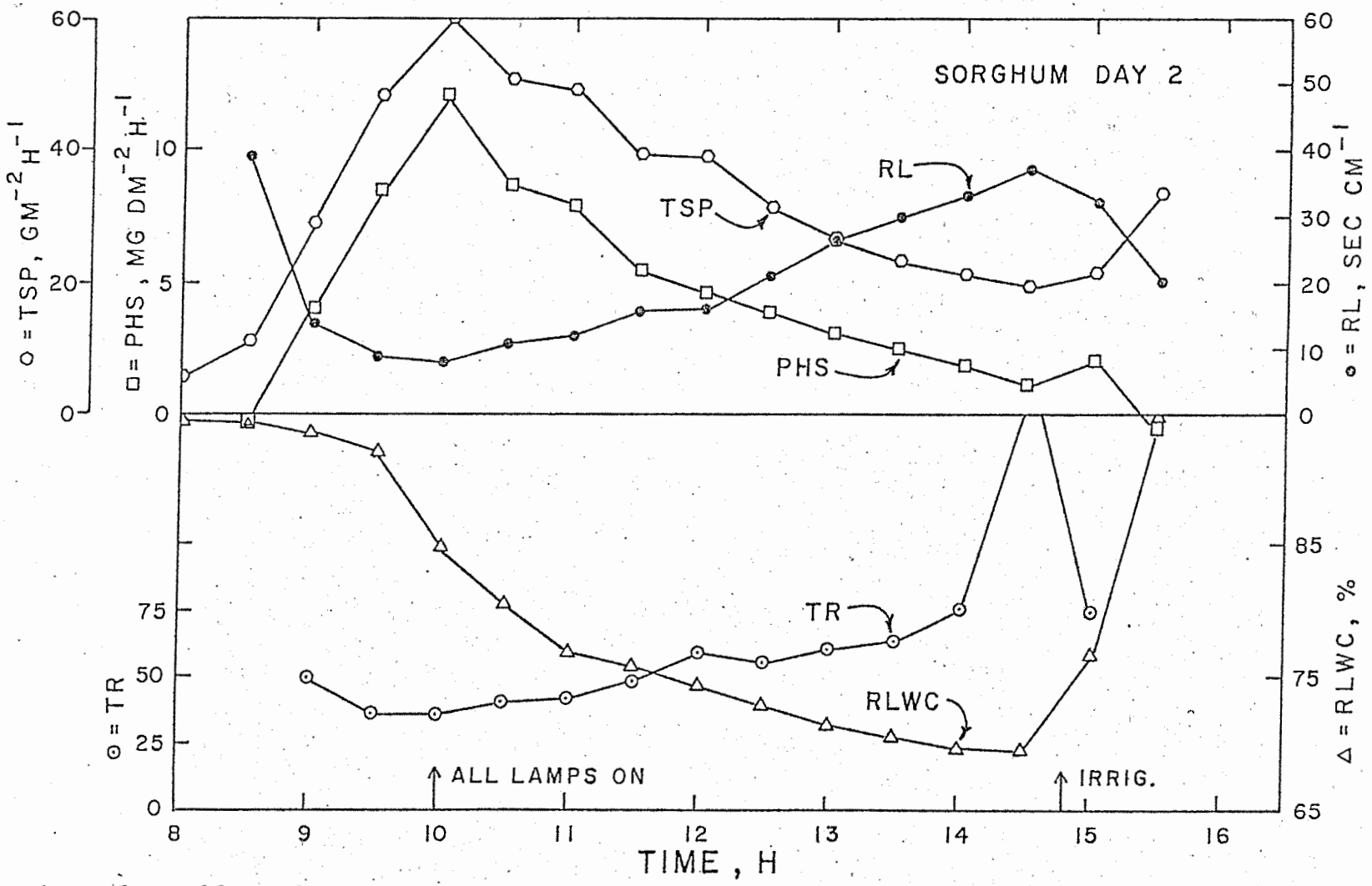

Figure 8. Half-hourly values of transpiration, net photosynthesis, calculated leaf diffusion resistance, the transpiration ratio, and the relative leaf water content of sorghum in a controlled environment during a drought. Day 2.

TITLE: CHEMICAL TREATMENT OF IRRIGATION WATER FOR THE PREVENTION OF CLOGGING AND THE REMOVAL OF FLOW OBSTRUCTIONS IN TRICKLE IRRIGATION SYSTEMS

CRIS WORK UNIT: 5510-12260-002 CODE NO.: Ariz.-WCL 71-11

INTRODUCTION:

Problems of emitter clogging in trickle systems began to appear in 1974 for a grape experiment started in May 1973 (See USWCL 73-1, Evaluating trickle irrigation for grape production). The flow rate was reduced 25 to 50% in the 2 years that the system was in operation (Table 1).

The source of the water was a tailwater pond where the water quality (dissolved + suspended) varied during the irrigation season because of the irrigation scheduling of the farm and rainfall. Chemical analysis of the water sampled in July 1974 is given in Table 2, and shows a surprisingly low salt content for this part of the country. However, the suspended load is very high based on visual observation, ranging from cloudy to very turbid conditions. Filtration analysis showed suspension of 50 to 450 mg/1. The water used in the trickle system is filtered through a sand filter and then a bag filter (25 μ). This treatment still does not remove all of the suspended materials. Laboratory and field studies were started to determine whether the plugging problem could be alleviated.

In 1973 the Laboratory was asked by the University of Arizona to cooperate in a project for raising cantaloupes under trickle irrigation (See USWCL 73-3, Evaluating trickle irrigation for cantaloupe production). The source of the irrigation water is the Colorado River (Table 3). The water from the irrigation lateral at the Yuma Valley Experiment Station rapidly clogged the screen filters used in the drip system. To avoid this problem, and also to prevent possible clogging of the trickle emitters, a chemical water treatment program was initiated on the irrigation water.

PROCEDURE:

Laboratory. Laboratory studies involved the removal of residues from the trickle lines in the grape experiment with different acids and oxidizing agents and their combinations.

Field. Reclamation of plugged emitters was attempted by treating the pond water with acid and hypochlorite and passing this through the trickle system. The chemical injections were made on the inlet side just before the sand filter.

Low levels of acid and hypochlorite (1 me/l acid + 1 ppm chlorine in final concentration) were injected on a continuous basis into the trickle irrigation water used in the cantaloupe experiment.

RESULTS AND DISCUSSION:

Laboratory. Various degrees of residue removal from the trickle lines ranging from excellent to poor were obtained with the different types of chemical cleaning treatments. The relative effectiveness observed is listed as follows:

	Excellent	Good	Fair	Poor
A. Acid-dichromate (40 g $Na_2Cr_2O_7$ + 600 cc H_2SO_4)	x			
B. 1:25 dilution of A		x		
C. 1:50 dilution of A			x	
D. Hydrogen peroxide (30%)	x			
E. Ethyl alcohol (97%)				x
F. 1000 ppm Cl_2 + 20 me/l H_2SO_4			x	
G. 1000 ppm Cl_2 + 100 me/l H_2SO_4			x	
H. 1000 me/l H_2SO_4			x	

The residue in the drip lines and emitters could be removed by strong oxidizing agents alone (peroxide) or a combination of and oxidizing agent with acid. The material actually causing the plugging appears to be a combination of organic matrice formed by microbial activity and suspended particles in the water.

Field. Based on the laboratory findings a portion of the partially clogged trickle system in the grape experiment was treated with chemicals. Treatment with acid-dichromate or hydrogen peroxide was deemed impractical from the standpoint of damage to the crop, safety, and economics. Only acid and acid + hypochlorination were tried. The best reclamation of the partially clogged emitters was obtained by treatment with a high concentration of acid and hypochlorite (Treatment T1, Figure 1). Residual chlorine at the end of the lateral was 40 ppm at a pH of 1.6. A chlorine level of 100 ppm was the original goal, but part of the chlorine was used up in the sand filter. The flow rate of the tricklers was increased from 60% of design to 90% in approximately 10 hours of treatment. Flushing of the emitters and lines was necessary to remove suspended residue and to get the chemical more quickly to the partially clogged sites.

Flushing alone (Treatment T9) nor low hypochlorite rate (1/5 of T1) did not improve the flow rate. Acid alone (T5) did not significantly increase the flow rate in 24 hours.

In the cantaloupe experiments where the trickle system was run for two successive crops, the continuous acid-hypochlorite treatment at low concentration showed no plugging of the double-tube emitter orifice. The water used in this study is of poorer chemical quality than the grape experiment, but with initial and continuous hypochlorination possible clogging was prevented. Since a comparative treatment of no acid and hypochlorite was not used, plans are to include this in next year's research.

SUMMARY:

Flushable-type drip emitters started to plug (25 to 50% reduction in flow) after the second year of operation, even with low salinity water and with sand and screen filtration. Reclamation of the partially plugged emitters could be achieved by treating the field system with high acid-hypochlorite concentrations. Plugging was not observed in a double-tube drip system when the water was treated continuously with low acid-hypochlorite concentrations at the very beginning of a 9-month irrigation operation.

PERSONNEL: F.S. Nakayama, B.A. Rasnick, D.A. Bucks, and O.F. French

Table 1. Reduction in flow rate for a trickle irrigation system. (August 1974)

Irrigation levels and schedule		Flow reduction (%)
T1	1.25 × CU*, daily, 1 emitter/vine	38.4
T2	1.25 × CU, daily, 2 emitters/vine	34.6
T3	1.25 × CU, 3-day, 2 emitters/vine	32.0
T4	1.25 × CU, 6-day, 2 emitters/vine	54.7
T5	1.00 × CU, daily, 1 emitter/vine	48.8
T6	1.00 × CU, daily, 2 emitters/vine	36.6
T7	1.00 × CU, 3-day, 2 emitters/vine	26.1
T8	1.00 × CU, 6-day, 2 emitters/vine	24.8
T9	0.75 × CU, daily, 1 emitter/vine	44.9
T10	0.75 × CU, daily, 2 emitters/vine	32.2
T11	0.75 × CU, 3-day, 2 emitters/vine	24.2
T12	0.75 × CU, 6-day, 2 emitters/vine	33.1
	mean	35.9

*CU = consumptive use.

Table 2. Chemical analysis of pond water used in trickle irrigation of grapes.

pH = 6.70; conductivity = 0.40 mmho/cm; 300 ppm

Ca	= 1.07 me/l (21 ppm)	Cl	= 0.51 me/l (18 ppm)
Mg	= 0.43 me/l (5.2 ppm)	SO_4	= 1.42 me/l (68 ppm)
Na	= 2.10 me/l (48 ppm)	HCO_3	= 1.96 me/l (120 ppm)
NH_4	= 0.21 me/l (4 ppm)	NO_3	= 0.01 me/l (0.7 ppm)
		SiO_2	= 2.94 me/l (21 ppm)

Table 3. Chemical analysis of the irrigation water used in trickle irrigation of cantaloupes.

pH = 8.34; conductivity = 1.23 mmho/cm; 790 ppm

Ca	= 4.73 me/l (94.6 ppm)	Cl	= 3.32 me/l (117.7 ppm)
Mg	= 2.56 me/l (31.1 ppm)	SO_4	= 6.24 me/l (299.5 ppm)
Na	= 6.52 me/l (150 ppm)	HCO_3	= 2.47 me/l (150.7 ppm)
		NO_3	= 0.002 me/l (0.14 ppm)
		SiO_2	= 1.78 me/l (12.7 ppm)

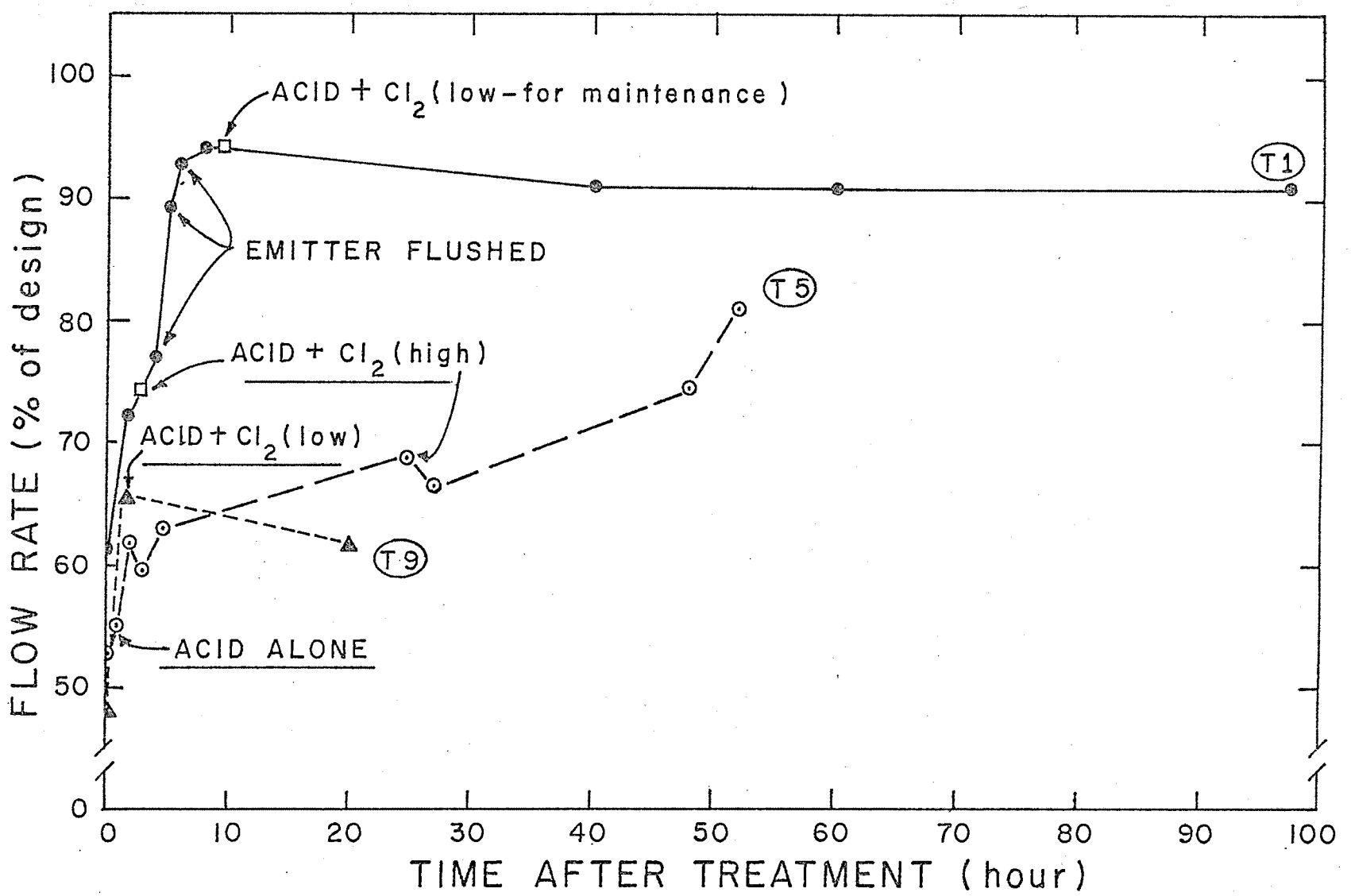

Figure 1. Effect of chemical treatment on the flow rate of partially clogged emitters.

TITLE: SWELLING AND SHRINKING OF SOIL IN SITU AS DETERMINED BY A DUAL-ENERGY GAMMA-RAY TRANSMISSION TECHNIQUE

CRIS WORK UNIT: 5510-12260-002 CODE NO.: Ariz.-WCL 72-4

Water contents and bulk densities were measured in a soil pedon with a gamma-ray transmission technique utilizing ^{137}Cs and ^{241}Am. By alternating the sources for each scan down the soil profile, both bulk density and water content were determined in 1-cm increments in the top 10 cm of the pedon. Bulk density decreased to a depth of 6 cm about 30 min after 4 cm of water was ponded on the soil surface. As soon as the water drained from the surface, bulk density values increased and approached preirrigation levels. Water content increased rapidly, corresponding to the decrease in bulk density. Assuming that the bulk density remains constant during ponding, calculated water contents may be in error by as much as 0.25 g cm^{-3}.

To delineate the soil-water content in layers as thin as 0.1 cm in the upper centimeter of a field soil, a simple, easily constructed soil sampler was used. Samples were taken every 20 min during one day of soil drying after sprinkling the soil with 0.6 cm of water. The soil in this top centimeter dried fairly uniformly, with the 0- to 0.1-cm layer drying from 0.202 to 0.036 cm^3 cm^{-3} in 8 hrs. The 0.8- to 1.0-cm layer dried from 0.238 to 0.152 cm^3 cm^{-3} in the same period. With the techniques and tools described herein, no difficulty was encountered in distinguishing the soil-water content of one layer from another.

Manuscripts cited below elaborate on the two preceding subject matters:

(1) Reginato, Robert J. Water content and bulk density changes in a soil pedon measured with dual-energy gamma-ray transmission. Can. J. Soil Sci. 54:325-328. 1974.

(2) Reginato, Robert J. Sampling soil-water distribution in the surface centimeter of a field soil. Soil Sci. (in press).

PERSONNEL: Robert J. Reginato

TITLE: GRAVEL BED COOLERS FOR GREENHOUSES

CRIS WORK UNIT: 5510-12260-002 CODE NO.: Ariz.-WCL 72-5

This project was initiated to design, test, and evaluate evaporative coolers from gravel beds for the cooling of sealed greenhouses. Progress has led away from gravel beds toward more conventional evaporative cooling towers, as discussed in last year's report. However, the main objective for designing any cooling system is to provide a means to economically cool a sealed greenhouse under high light so that CO_2 fertilization can be effectively practical and yields can be increased.

PROTOTYPE:

Construction. This year a prototype greenhouse was constructed using an aluminum frame with fiberglass (Sol-lite with Tedlar) walls, as shown in Figure 1. The dimensions were 14.42 ft wide by 20.92 ft long by 7.12 ft at the eaves and 10.8 ft at the peak to give an area of 302 ft^2. The air duct was 3.375 ft square.

The original cooling system worked as follows: Outside air was drawn in through the upper "outside" pads of the evaporative coolers. Some water evaporated into this air, thus cooling the remaining water flowing down the pad. This cool water was collected at the bottom of the outside pad and piped inside the greenhouse to the top of the "inside" pad. It then trickled down the inside pad picking up heat from the hot greenhouse air which was being circulated through the pad. At the bottom of the inside pad the now warm water was collected in a sump and then pumped to the top of the outside pad to again be cooled and repeat the cycle.

The outside air which was drawn in through the outside pad was blown through an attic formed by stretching a sheet of transparent polyethylene across the greenhouse from eave to eave. The air exited through louvers in the opposite end wall. This feature lowered the sensible heat load on the greenhouse, but only slightly.

Instrumentation and Energy Balance. In order to evaluate the performance of the cooling system, the greenhouse was instrumented

and measurements were made of many components of its energy balance. Figure 2 shows a computer printout of the data obtained at 1300 6 September 1974. The lower half shows heat fluxes computed from measurements listed in the upper half. A discussion of each component and its measurement follows.

Net solar radiation. The net solar radiation is computed from $R\tau(1-r)$ where R is the downcoming solar radiation measured with an Eppley solarimeter, τ is the transmissivity of the greenhouse cover, and r is the reflectivity of the crop or soil in the greenhouse. The fourth line in Figure 2 shows that R was 1.19 ly/min at the time of this example and the sixth line lists the values of .613 for τ and .3 for r. The r of the dry sand soil was measured by taking the ratio of the output of a solarimeter first facing downward and then upward inside the greenhouse. The transmissivity was measured on 10 July 1974 by taking the ratio between the radiation sensed by a solarimeter inside the greenhouse and another outside. Also on 15 July 1974, pieces of fiberglass and of polyethylene were held over the outside solarimeter and its change in output noted. The fiberglass had a transmissivity of .763 and the polyethylene .946. These readings give a product of .722 so the lower value of .613 inside the greenhouse must have been caused by the aluminum frame and by dust primarily on the polyethylene which separated attic from greenhouse.

A reduction of light intensity of about 15% caused by the polyethylene is not desirable since yields are to be maximized, so in tests this coming year the polyethylene will be removed and the cooler air exhausted directly to the outside. Heat exchange through the polyethylene was not very important anyway, as will be discussed.

Since the net solar radiation is the most important component of the energy balance, next year long tube solarimeters, one facing up and the other down will be constructed in order to continually

measure this component inside the greenhouse. The tube-type instrument should average some of the spacial variability caused by the frame and rows inside a greenhouse.

Soil Heat Flux. The soil heat flux was measured by a pair of commercially available (1/2 inch dia) soil heat flux plates and by a single (2 1/2 inch dia) plate made from epoxy. They had previously been calibrated by the radiation technique of Idso. They were installed at approximately the 1-cm depth. The negative values in Figure 2 indicate that heat was moving out of the greenhouse.

Wall Heat Flux. Wall heat flux plates were constructed from 5 × 2" strips cut from the fiberglass wall material. A 10-pair copper constantan thermopile was wrapped around the strip so that paired junctions were on opposite sides. The plate was then varnished to make the junctions stick to the strip. Two such plates were installed in the walls and one in the ceiling. By multiplying the measured temperature difference by the plexiglass thermal conductivity (22.74 mcal/(cm min C) according to manufacturer) and dividing by the thickness (.105 cm), wall heat flux could be obtained. However, the plates did not work very well. Two developed open circuits almost immediately and ceased functioning entirely, as indicated by the zero reading for roof heat near the bottom of Figure 2. The third had such a small output that electrical noise caused the output to fluctuate markedly from one reading to the next. No investigation was made of the possible radiation errors. It is anticipated that next year the wall heat flux will be estimated from the measured temperature difference between inside and outside air, and from engineering handbook values for the film transfer coefficients. If time permits a better instrument will be built.

Duct Heat Flux. A duct heat flux plate was constructed from a 4 × 4" rectange of the 1" styrofoam insulation covering for the

duct. One thermocouple junction was inserted 1/4" from the top and another was taped to the bottom. The plate was inserted into a hole in the insulation cut to accomodate it exactly. The duct heat flux is computed from the temperature difference between the junctions multiplied by the thermal conductivity (5.166 mcal/(cm min C)) divided by the thickness (3/4 in) between the junctions. The output from this plate was stable and the device served to give reasonable data. However, the position of the plate may have been biased because it was positioned on the top of the west duct, which probably did not represent the side or the north duct very well.

Motor Heat Load. The 1 HP fan motor contributes 178 cal/sec to the greenhouse when operating at high speed and 78 when operating at low (.44 HP) speed.

Ceiling Heat. Was estimated from the dry bulb temperature difference between the attic and greenhouse air and Handbook values of the film heat transfer coefficients. For 70 ft/min and 280 ft/min in greenhouse and attic, ASHRAE Handbook of Fundamentals data lists a value of 1.356E-4 cal/(sec cm^2 C) for the overall transfer, "U", coefficient.

Natural Ventilation (leaks). The greenhouse is tight so this item has been assumed negligible. When the CO_2 system is operating, it will be evaluated.

CO_2 Generation. The burner for CO_2 generation from natural gas has not yet been installed.

Photosynthesis. No crops have been growing during these initial cooling system tests, so this item is zero.

Enthalpy Change of the Cooling Water. The 10-12 lines of Figure 2 indicate the temperature of the water above the outside coolers, below the coolers, and below the inside wet wall as sensed by thermocouples. These temperatures plus the water flow rate (line 4, measured by timing the filling of a bucket by the return flow to the sump) provide an estimate of the heat load of the

greenhouse. Lines 3 and 4 of the second group of items in the lower half of Figure 2 show 3336 and 4215 cal/sec, which is a reasonable check on the sum of the terms in the first group. This sum is 3049 cal/sec, and is dominated by the net radiation term.

Enthalpy Change of the Air. The nine columns of numbers in the 2nd quarter of Figure 2 are data from nine aspirated wet and dry bulb psychrometers. The first two were positioned outside near the intake area of the coolers. The 3rd and 4th were positioned to sample the attic exhaust air. The 5th was inside the duct upstream of the wet wall. The remaining four were positioned at approximate equal thirds of the distance across the greenhouse from the wet wall to its return duct entrance. The symbols in the row headings are TA - air temperatures; D - dry bulb; W - wet bulb; C - centigrade; F - Fahrenheit; VP - vapor pressure; MB - millibar; RH - relative humidity; HUM - absolute humidity ratio; #/# - lb of water/lb of dry air; H - enthalpy; A - dry air; W - moisture in air; T - total dry and moist; C/G - cal/gram of dry air; B/# - British thermal units/lb of dry air.

Saturation vapor pressures were computed from the Goff-Gatch equation and actual vapor pressures from the psychrometer wet bulb calibration constant (Smithsonian tables). The dry air enthalpy was computed as (0.24 cal/gC) $\times$ TAD. The enthalpy due to the moisture content was computed from HUM $\times$ $(597 \frac{\text{cal}}{\text{gm}} + .441 \frac{\text{cal}}{\text{gC}} \times \text{TAD})$.

The heat load can also be computed from the product of the flow rates of the air streams (line 4 in Figure 2), and their change in enthalpy as they pass through the wet pads or through the greenhouse. The flow rates were measured with a hand-held Taylor anemometer. The enthalpy changes were computed from the difference in enthalpy between the various psychrometer data. The results in the 1st, 2nd, and 5th lines in the lower half of Figure 2, and also in the two lines below the roof heat entry all should be equal to each other and to the heat load estimated from the water temperature

changes and the sum of the other fluxes. However, the 775 cal/sec going across the greenhouse is obviously too low, and the 5081 cal/sec change through the wet wall is too high. Similarly, the other 13981, 13981, and 13454 cal/sec values based on the enthalpy change through the pads of the coolers must be too high. These suspicious results occurred many times, and different psychrometers could give similar answers. However, the enthalpy differences are small, and it appears that the psychrometers must be giving a small systematic error, which results in a large error in enthalpy difference computation. For instance, if the dry bulbs were slightly wet inside the greenhouse, they could register too small a change across the greenhouse, and too large a change across the wet wall. The direction of the error across the cooler pads suggests that either the dry or wet bulb in the attic exhaust are too warm relative to those outside at the cooler inlet, but the reason for this error is not obvious.

A gas sampling system is now being installed, and a Cambridge dew pointer will be used to measure the dew point changes across the wet pads. It is hoped the greater accuracy and sensitivity of this instrument will enable more accurate values for the enthalpy changes to be obtained.

Relative Greenhouse Temperatures. The energy load discussed in the previous section must be known in order to adjust and compare data obtained with different meteorological conditions. However, the performance of the greenhouse cooling system at any particular time can best be seen by making a bar graph of the temperatures at four places in the greenhouse relative to the outside wet bulb temperature as in Figure 3. All the data plotted are for times when the heat load on the greenhouse was within 5% of 48,000 BTU/hr, which is about 80% of the maximum heat load expected in June. The shaded area is the range of water temperature. The low edge of this shaded area is the approach to the outside wet bulb temperature, the lowest possible water temperature that

could be achieved by evaporative cooling. Since the 1% design wet bulb for Phoenix is 77 F (ASHRAE Handbook of Fundamentals), an 8 F rise is 85 F, about the highest optimum temperature for many plants, particularly tomatoes (Dalyrmple, 1973, p. 20). Therefore, the 8 F Mark is indicated by a dashed line across Figure 3, and it is desirable for all of the bar graphs to be shorter than this mark.

The 2 August 1974 bar in Figure 3 represents the greenhouse performance as designed and built. There was one 1/3 HP water pump with a maximum in place flow rate of 20 gpm. The inside wet wall was 14' × 3' × 2" thick, and the fan had a flow rate of about 11,000 CFM on HI and about 7,000 on LO. The two outside coolers had a combined pad width of 13.5 ft and were 32" high × 1.5" thick. Their combined blower capacity was about 7,500 CFM on HI and 4,000 CFM on LO. With these conditions the water approach to wet bulb is 4.4 F with a range of 5.5 F. The greenhouse air temp downstream of the wet wall was 8.6 F greater than the outside wet bulb, but it was lower than the warmest water temperature. The greenhouse air range was 5.8 F so the air entering the wet wall was 14.4 F greater than the outside wet bulb.

Temperature profiles such as those at the bottom of Figure 2 revealed only the upper portion of the wet wall was effective in cooling, and therefore increasing the water flow rate should increase its effectiveness and decrease the water range at the same time. However, in order to avoid flooding the wet wall, the thickness had to be increased. The results with a second pump installed so the water flow rate was 34 gpm, and an additional pad thickness added to the wet wall are shown in the bar for 1300 6 September 1974. The water temp range was made smaller and the minimum greenhouse temp was still lower than the warmest water, but now the approach of the water temp to the outside wet bulb was 8 F. Indeed, inspection of the coolers revealed their capacity was exceeded

because the upper pads were flooded. However, there sometimes was some uncertainty in the data as evidenced by the bar for 1300, 7 August 1974, which shows a 2.5 F approach to the wet bulb temp at a water flow rate of 20 gpm. The 1200 and 1300, 28 August 1974 bars show a 2.5 F difference in approach for what must have been very comparable heat loads. In any event, it appeared that the minimum water temp did not approach the outside wet bulb very well, and that the evaporative coolers were more suited to their usual task of producing cool air rather than cool water as needed for this application. Therefore, with the aid of the simulation program soon to be discussed, a cooling tower was designed and built and is currently being tested. As soon as the cooling system performance is satisfactory, a crop of tomatoes will be planted and fertilized with CO_2 from a natural gas generator to demonstrate the yield response.

PAD PERFORMANCE SIMULATION:

The equations which describe the heat and mass transfer between air and water in counter or parallel flow, direct contact, forced draft air conditioning equipment are presented in the ASHRAE Handbook of Fundamentals (1972).

Mass Transfer

$$-dG_L = G_a \, dW = K_D a_M \, (W_i - W) d\ell \qquad [1]$$

where G_L is the liquid mass flow rate per cross-sectional area ($lb/hr/ft^2$), G_a is the air mass flow rate per cross-sectional area ($lb/hr/ft^2$), W is the air humidity ratio (lb of water vapor/lb of dry air), W_i is the humidity ratio at the air-water interface, K_D is the mass transfer coefficients using W as the driving potential ($lb/hr/ft^2$), a_M is the area of mass transfer surface per volume of chamber (ft^2/ft^3), and ℓ is the length or height of the chamber or tower. Equation 1 states that the water evaporated, the moisture increase of the air, and the mass transfer rate are all equal.

Heat Transfer to the Air

$$G_a c_{pm} dt_a = h_a a_H (t_i - t_a) d\ell \qquad [2]$$

where c_{pm} is the humid specific heat defined by $(1 + W)c_p$, t_a is the air temperature (F), h_a is the heat transfer coefficient in the air (BTU/hr/ft^2/F), a_H is the area of heat transfer surface per volume of chamber (ft^2/ft^3), and t_i is the water-air interface temperature (F).

Total Energy Transfer to the Air. Combining Equation (1) and (2) with the enthalpy of vaporization yields

$$G_a (c_{pm} dt_a + i_{fgo} dw) = [K_D a_m (W_i - W) i_{fg} + h_a a_H (t_i - t_a)] d\ell \qquad [3]$$

where i_{fg} is the enthalpy of vaporization and i_{fgo} is the enthalpy of vaporization at base temperature (OF). Assuming complete wetting of all material in the chamber so that $a_H = a_M$, and utilizing the fortuitous Lewis relation for an air-water system which says $h = K_D c_{pm}$, Equation (3) reduces to

$$G_a di = K_D a_M (i_i - i) d\ell \qquad [4]$$

where i is the air enthalpy in the bulk air and i_i is the air enthalpy at the interface.

Energy Balance

$$G_a di = \pm G_L c_L dt_L \qquad [5]$$

where c_L is the specific heat of the water (BTU/lb/F) and t_L is the water temperature. The + sign refers to counter flow and the - sign to parallel flow. The percentage change of G_L due to the evaporation of water is small in most applications and has been

ignored in Equation (5).

Heat Transfer to the Water

$$G_L c_L dt_L = h_L a_H (t_L - t_i) d\ell \qquad [6]$$

Combining Equation (4, 5, and 6) gives

$$\frac{i - i_i}{t_L - t_i} = - \frac{h_L}{K_D} \qquad [7]$$

which relates the driving enthalpy difference between air and interface and the driving temperature difference between water and interface to the ratio of the heat and mass transfer coefficients. Combining Equations (1, 2, and 3) and the Lewis relation gives

$$\frac{di}{dt_a} = \frac{i-i_i}{t_a-t_i} \qquad [8]$$

and

$$\frac{dW}{dt_a} = \frac{W-W_i}{t_a-t_i} \qquad [9]$$

Equation (9) indicates that at any cross-section in the chamber, the instantaneous slope of the airpath, dW/dt_a, on a psychrometric chart is determined by a straight line connecting the air state with the interface saturation state at the cross-section. The interface state can be determined from Equations (5) and (7). Equation (5) describes how the air enthalpy changes with water temperature and Equation (7) shows how the interface saturation temperature changes to accomodate this change in air and water conditions. By starting with a known water temperature at the bottom of a cooling tower with known inlet air condition and a known exit water temperature, one can numerically move air through the tower in

a series of steps, solving for new interface conditions at each step, and arrive at the final exit conditions for the air. This procedure developed by Mickley (1949, Chemical Engineering Progress 45(12):739-745) is described in the ASHRAE Handbook of Fundamentals (1972). Also, Equation (4) can be integrated from the bottom to the top of the apparatus to obtain the required height

$$\ell = \frac{G_a}{K_D a_m} \int_1^2 \frac{di}{(i_i - i)} \qquad [10]$$

Equations (1) through (10) apply only to parallel or counter-flow apparatus. For cross-flow apparatus such as the vertical pads on most greenhouse and residential coolers, more complexity is required. Park and Vance (1971, Chemical Engineering Progress 67(7):55-57) described a computer model developed for cross-flow cooling towers which basically divided up the pad cross-section into equal segments in the water and air flow directions. Each segment was analyzed like a tiny counter-flow tower following the Mickley method. The segments were analyzed starting at the corner where both air and water inlet conditions were known. The analysis then proceeds step-wise with the outlet conditions for one segment becoming the inlet conditions for the adjacent one.

Following the Park and Vance - Mickley method, Nehemiah, Law, and Andre (1972, Investigation of Evaporative Pads for Greenhouse Heating and Cooling with Low Temperature Waste Heat, Part III, ORNL-MIT-148) at Oak Ridge, in an investigation of the possibility of using waste power plant heat to heat and cool commercial greenhouses developed a computer program which modeled cross-flow greenhouse pads. They also determined the mass and heat transfer coefficients for aspen fiber and polyurethane pads for a range of air and water flows. Their FORTRAN program called LANSIM, along with their transfer coefficient relations are proving to be very helpful in designing the best outside evaporative cooling tower and

inside heat exchange pad for the sealed greenhouse application considered here.

Outside Greenhouse Pad Cooling Simulation. Program LANSIM computes the exit air dry bulb temp and humidity and exit water temp given: (1) the pad dimensions, (2) the air and water flow rates, and (3) the inlet air dry and wet bulb temperature and inlet water temperature. This was not particularly convenient for design purposes since the inlet water temperature could not be specified. However, since heat load on the greenhouse could be estimated in advance, the range between inlet and outlet water temperatures was known for a specified water flow rate. Therefore, a main program called OUTSIDEPAD was written which called LANSIM as a subroutine. From OUTSIDEPAD the outside dry and wet bulb and an initial guess for the inlet water temperture were given to Subroutine LANSIM to compute exit dry and wet bulb air temperatures and an exit water temperature. If the difference between the entrance and exit water temperatures did not equal the known water temperature difference based on the greenhouse heat load, a new entrance water temperature was estimated as the computed exit temp plus the known temp difference. The cycle was repeated until the computed water temp difference converged to the known water temp difference.

The ability of OUTSIDEPAD to predict the performance of the actual coolers on the prototype greenhouse can be assessed in Figure 3. The lower pair of bracketing arrows along each bar is the predicted water temperature range for the operating conditions for the particular times the data were obtained. The predicted water temperature ranges generally tended to change in direction of the actual ranges as conditions changed. However, the predicted ranges generally tended to be about 2 F higher above the outside wet bulb than the measured ranges.

Since such an error seemed to be in the conservative direction, and the program did seem to respond reasonably to changes in operating conditions, a series of simulations was run and the results

are Figure 4. The "standard" conditions were 32 in height, a 162 in width, a 1.5 in thickness, a 34 gpm water flow rate, a 5,000 cfm air flow rate, and oriented vertically (V) for cross-flow. The heat load of 45,000 BTU/hr and the dry and wet bulb air temperatures of 98.1 and 73.5 F were not varied. The changes in conditions for the various runs is shown in the row of numbers above the bars. They indicate the multiple of particular parameter compared to standard. On the far right a particularly short bar predicts that the approach temperature can be reduced by a factor more than three if the cooling tower has pads three times as thick and twice as high as the standard pads. On the basis of this prediction, such a cooling tower was built, and it is now being tested.

Inside Greenhouse Pad Cooling Simulation. The inlet air conditions for the inside pad cannot be specified as they were for the outside pad, so another main program called INSIDEPAD was written. In INSIDEPAD an initial guess and an initial older guess of the exit dry bulb temperature was made. The greenhouse heat load was used to compute the inlet air temperature from the guessed exit air temperature. The cold water temperature coming from the outside was specified, and the heat load was used to compute an actual exit water temperature. Then Subroutine LANSIM was called to compute a predicted exit water temperature. The exit dry bulb air temperature was adjusted and Newton iteration was performed until the predicted exit water temperature equalled the known exit water temperature.

The ability of INSIDEPAD to predict the performance of the actual wet wall on the prototype greenhouse can be assessed in Figure 3. The upper pair of bracketing arrows along each bar is the predicted greenhouse air temperature range for the operating conditions for the particular times the data were obtained. The predicted air temperature ranges generally tended to change in the direction of the actual ranges as conditions changed. However, the

predicted ranges generally tended to be about 2 F warmer than the actual, which is about the same error made by OUTSIDEPAD.

Since the error seemed to be in the conservative direction, and the program did seem to respond reasonably to changes in operating conditions, a series of simulations was run and the results are in Figure 5 and 6. The pertinent bars are those having a V in the top row of numerical data which denotes a vertical orientation and cross-flow. A constant heat load of 45,000 BTU/hr and cold water temperature of 76 F were used. The "standard" condition was a pad 34 high by 168 inches wide by 2 inches thick with a water flow rate of 20 gpm and an air flow rate of 10,000 cfm. The changes in conditions for the various runs is shown in the rows of numbers above the bars. The failure of any of the bars to get much below 8 F is discouraging. The fourth bar for double thickness and double water flow rate is about as good as any, and this is the system now installed in the greenhouse. These bars imply that the pad dimensions are already close to the optimum, and that the only way much improvement can be made with this configuration is to scale everything larger including the air flow rate, which makes the operation more expensive. However, counter-flow heat exchangers inherently have a higher effectiveness than cross-flow, so it was thought perhaps the heat exchange could be improved by making the pad horizontal. A discussion of this simulation follows.

Horizontal Pad Cooling Simulation. The Oak Ridge program LANSIM contained a subroutine called MICKLEY which used Mickley's method to compute the transfers occurring in each of the tiny segments for the cross-flow case. For the counter-flow case with a horizontal pad, MICKLEY could be used alone, and the amount of computing was reduced by a factor of 400 since a 20 $\times$ 20 array had been required for the cross-flow case. A main program called HORIZONTALPAD was written which called Subroutine MICKLEY. MICKLEY will compute the exit dry and wet bulb air temps and height of pad

given the inlet air dry and wet bulb temps and the inlet and exit water temps. For the outside case, HORIZONTALPAD requests the outside wet and dry bulb air temps and the desired cold water temperature. The entrance water temp is computed from a specified greenhouse heat load. For the inside case, HORIZONTALPAD makes the assumption that the air is exiting at 85 F at 100% RH and uses the greenhouse heat load to compute the inlet air conditions. It also requests the cold water temp coming from the outside and uses the specified greenhouse heat load to compute the exit water temp. This done, Subroutine MICKLEY is called to compute the height of pad required and a slightly modified exit air temperature and humidity.

The results of several simulations with inside horizontal pads are shown in Figure 6. The bars with an H in the top row of data are for this horizontal case. None of the cases tried reduced the greenhouse air temp more than about 1 F below the 8 F mark, which is little better than the present vertical 4-inch pad. However, when the pads are turned horizontal, the water flow rate per unit area is much less than when the pads are vertical, and is lower than the water flow range covered by the Oak Ridge transfer coefficient data. Before these horizontal simulations can be believed, some transfer coefficient data for the low water flow rates must be obtained, and this is planned for the coming year.

SUMMARY AND CONCLUSIONS:

A sealed fiberglass greenhouse was constructed with a prototype evaporative cooling system. Two commercially available evaporative coolers were mounted outside the greenhouse, and cool water from them was piped inside to wetted aspen pads through which the greenhouse air circulated. Performance tests conducted in late summer revealed that the greenhouse air temperature was about 14 F warmer than the outside wet bulb temperature rather than the desired 8 F. An analysis of the water temperature profiles in the pads suggested some modifications which improved the performance of the inside pad, but worsened the outside cooler performance for little change in greenhouse air temperature.

A computer program for analyzing the heat and mass transfer in aspen pads was obtained from a research group at Oak Ridge. It was modified for the particular applications encountered here, and many simulations were run. As a result of these predicted performances, a cooling tower having twice the height and three times the thickness of the original coolers was built, and it is undergoing current testing. As soon as the cooling system performance is satisfactory, a crop of tomatoes will be planted and fertilized with CO_2 to determine crop response in this sealed greenhouse.

PERSONNEL: B. A. Kimball, W. R. Williamson, J. Pritchard, H. Mastin, S. T. Mitchell

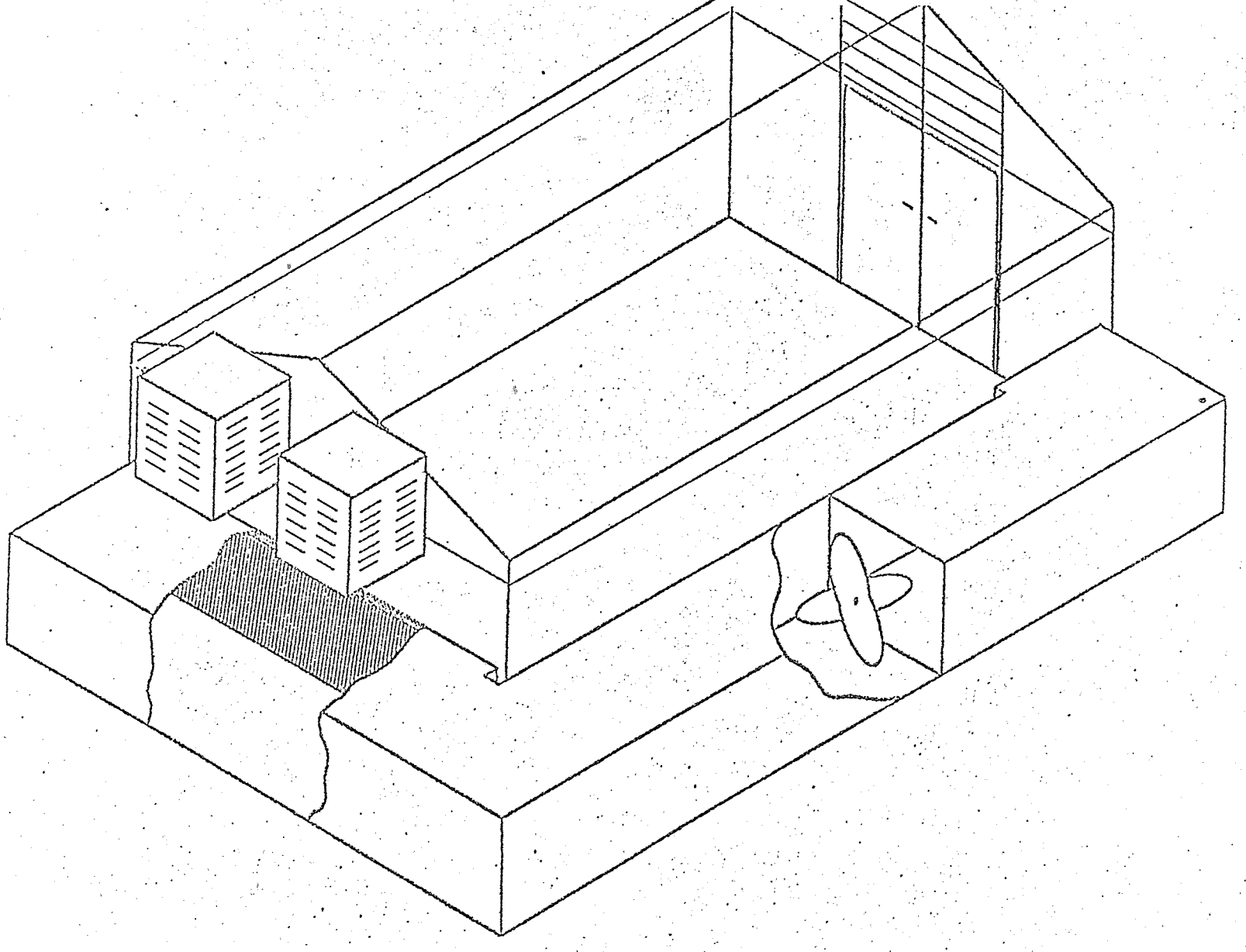

Figure 1. Three dimensional view of prototype sealed-evaporatively-cooled greenhouse.

GREENHOUSE ENERGY BALANCE

DATE: 74 9 6 1300
RUN ID:
SOL RAD OUT = 1.19383 LY/M = 19.8972 MCAL/(CM2 S) = 264.078 BTU/(FT2 H
FLOW: GH= 8500 CFM ATTIC= 7500 CFM H2O= 34 GPM
TRANSMISSIVITY = .613 REFLECTIVITY = .3
BAROMETRIC PRESSURE = 968 MB
GH AIR DENSITY = 1.07525 MG/CM3 = 6.71259E-2 LB/FT3
BATTERY = 9651.3 MV SHORT = .0037 MV
WATER TEMP ABOVE COOLER 29.5 C 85.0 F
" " BETWEEN 27.5 C 81.5 F
" " BELOW WET WALL 29.0 C 84.3 F

	OUTSIDE		ATTIC			GREENHOUSE			
	HIGH	LOW	EAST	WEST	WET W	0/3	1/3	2/3	3/3
TA D (C)	36.7	36.6	30.2	30.2	31.7	29.2	29.7	29.6	30.5
TA W (C)	23.0	22.8	26.3	26.3	30.0	29.0	29.2	29.2	29.5
TA D (F)	98.1	97.9	86.3	86.3	89.1	84.5	85.4	85.3	86.9
TA W (F)	73.5	73.0	79.3	79.4	86.0	84.3	84.6	84.5	85.2
VP (MB)	19.2	18.6	31.6	31.8	41.3	40.1	40.3	40.1	40.7
RH (%)	31.1	30.3	73.7	74.2	88.3	98.9	96.9	96.6	98.2
HUM (#/#)	0.0126	0.0122	0.0210	0.0211	0.0277	0.0268	0.0271	0.0269	0.0273
H A (C/G)	8.8	8.8	7.2	7.2	7.6	7.0	7.1	7.1	7.3
H W (C/G)	7.7	7.5	12.8	12.9	17.0	16.4	16.5	16.4	16.7
H T (C/G)	16.5	16.3	20.1	20.1	24.6	23.4	23.6	23.5	24.0
H A (B/#)	23.5	23.5	20.7	20.7	21.4	20.3	20.5	20.5	20.9
H W (B/#)	13.9	13.5	23.1	23.2	30.5	29.5	29.7	29.6	30.0
H T (B/#)	37.4	37.0	43.8	43.9	51.9	49.8	50.2	50.0	50.9

GREENHOUSE	(CAL/S)	(BTU/H)
NET SOLAR RADIATION	2391	34152
SOIL HEAT	-358	-5120
WALL HEAT	681	9729
DUCT HEAT	158	2256
MOTOR HEAT LOAD	178	2543
CEILING HEAT - SENSIBLE	-0	-4
" " - LATENT	0	0
NATURAL VENTILATION (LEAKS)	0	0
CO2 GENERATION	0	0
PHOTOSYNTHESIS	0	0
SUM	3049	43557
REMOVED FROM GH AIR BY WET WALL	5081	72589
ABSORBED IN GH AIR IN GREENHOUSE	775	11077
ABSORBED INTO WATER BY WET WALL	3336	47658
REMOVED FROM WATER BY BOX COOLER	4215	60217
ABSORBED INTO AIR BY BOX COOLER	13981	199731
ATTIC		
ROOF HEAT	0	0
SUM COOLER + ROOF + CEILING	13981	199727
EXHAUST - INLET	13454	192201

TEMP PROFILE (F)

IN. FROM TOP	WEST PAD	WET WALL
0	81.2	86.8
6	80.5	84.5
12	79.1	85.4
18	76.5	85.2
24	75.8	84.8
30	78.2	85.1
36	0.0	85.4

Figure 2. Typical computer-output from the program which reduces measured data to obtain the energy balance of the prototype greenhouse.

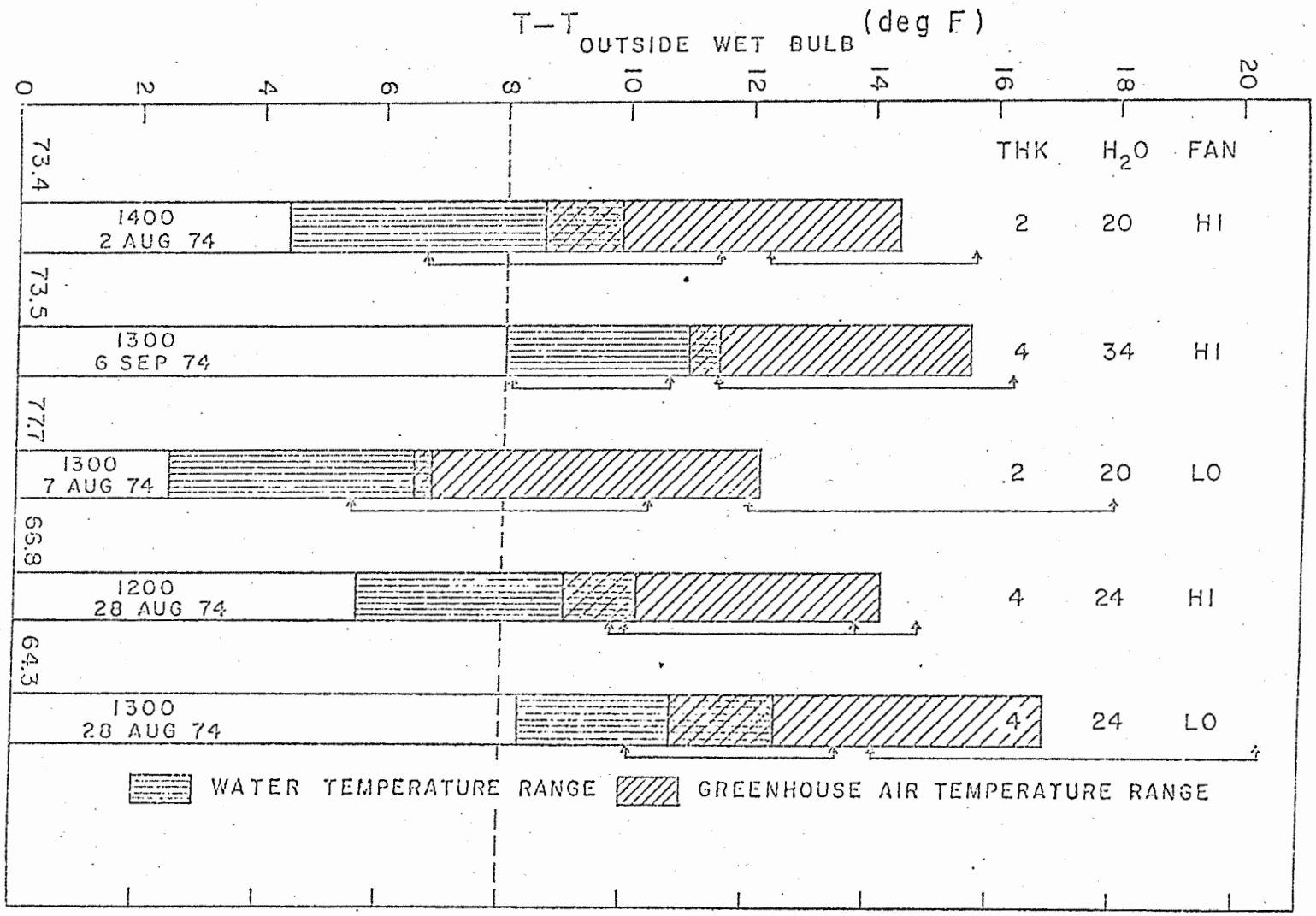

Figure 3. Water and air temperatures relative to the outside wet bulb temperatures for five different times with the various conditions listed in rows at the top. The thicknesses are in inches and water flow rates in gal/min. Actual outside wet bulb temperatures are given at the bottom. The bracketing arrows indicate the temperatures predicted by programs OUTSIDEPAD and INSIDEPAD.

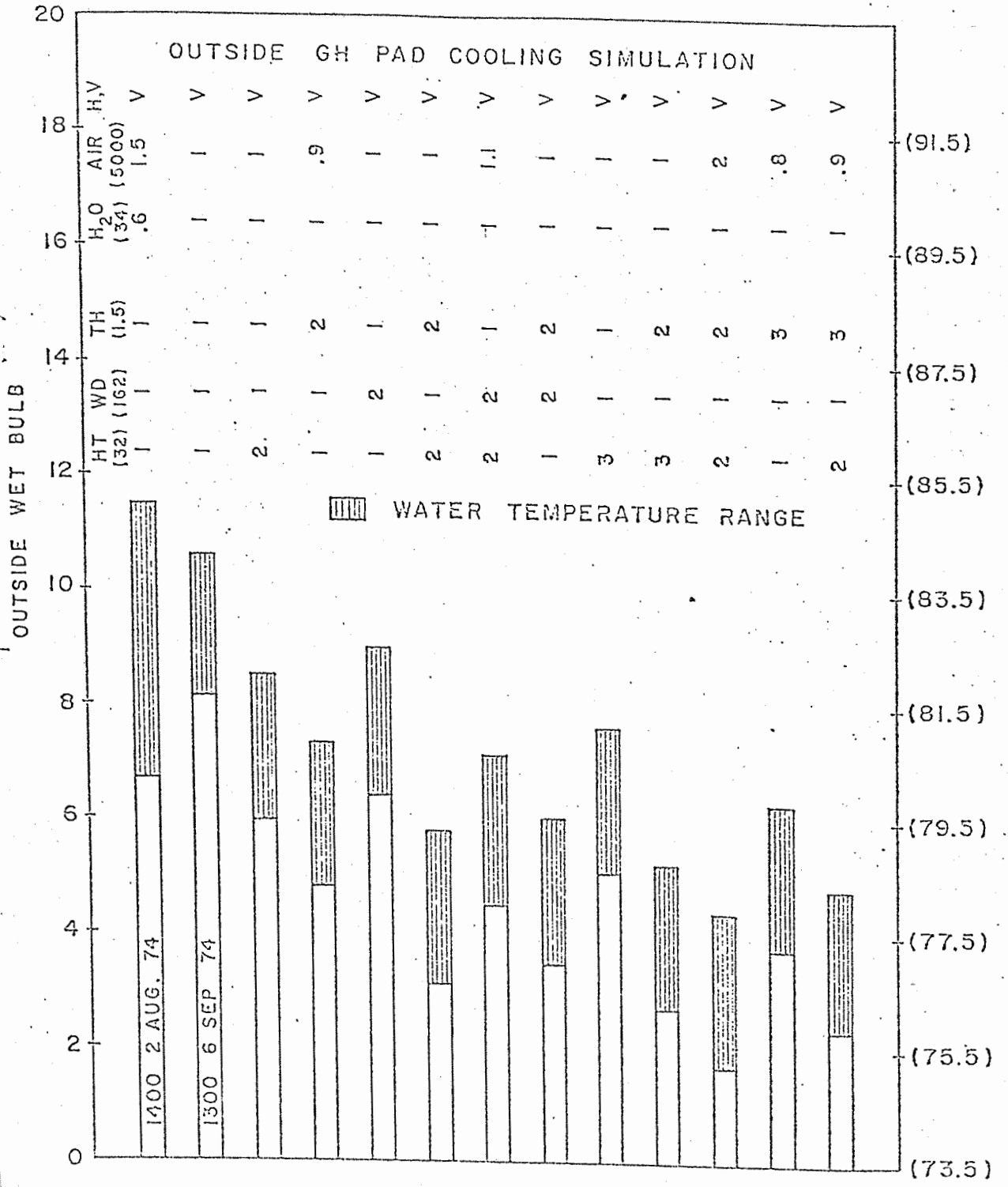

Figure 4. Water temperatures predicted by program OUTSIDEPAD relative to an outside wet bulb of 73.5 F for the various conditions shown in rows at the top of the figure. The numbers in the rows are the multiples of the "standard" conditions given in parenthesis.

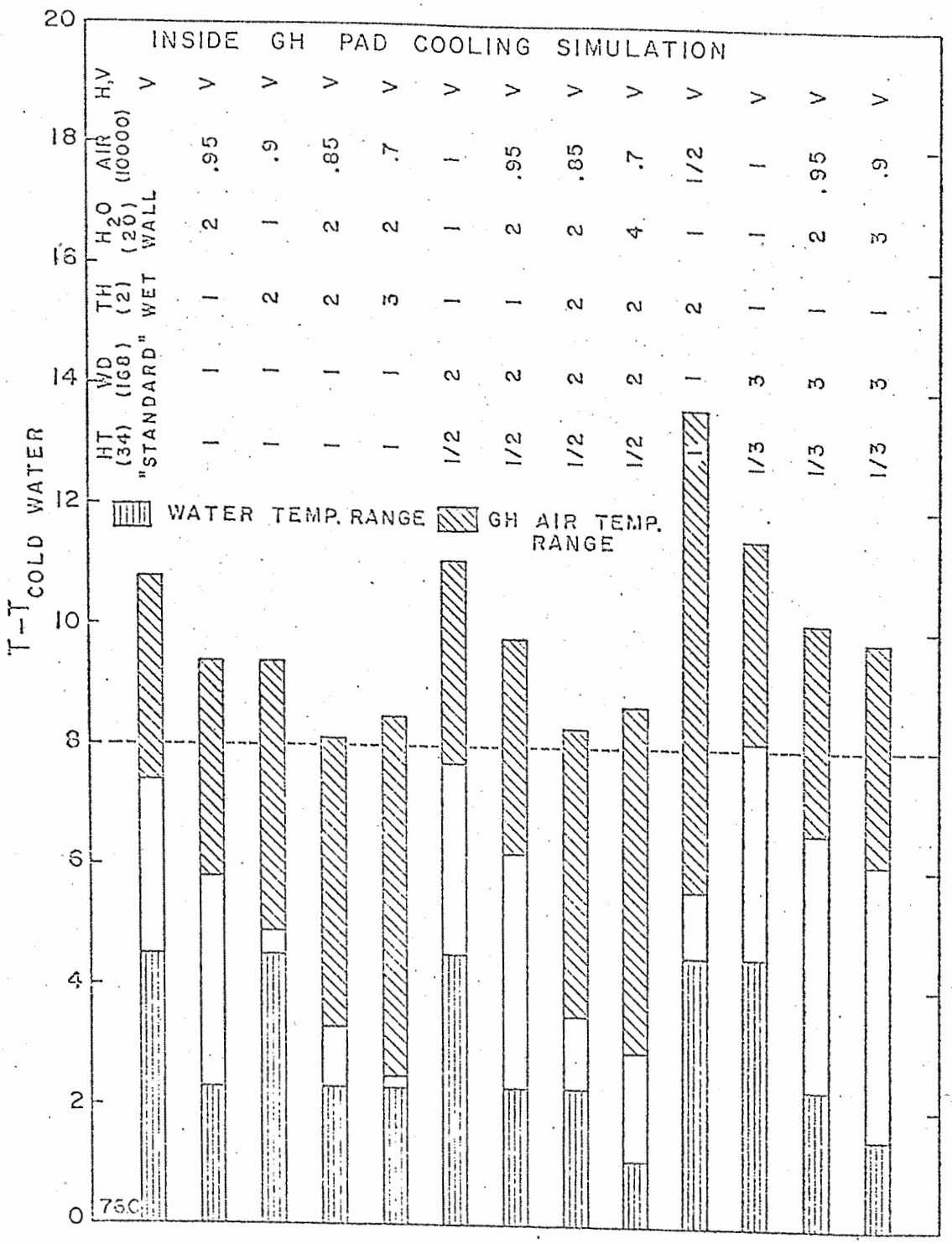

Figure 5. Greenhouse air temperatures predicted by program INSIDEPAD relative to a cold water temperature of 76 F for the various conditions shown in rows at the top of the figure. The numbers in the rows are the multiples of the "standard" conditions given in parenthesis.

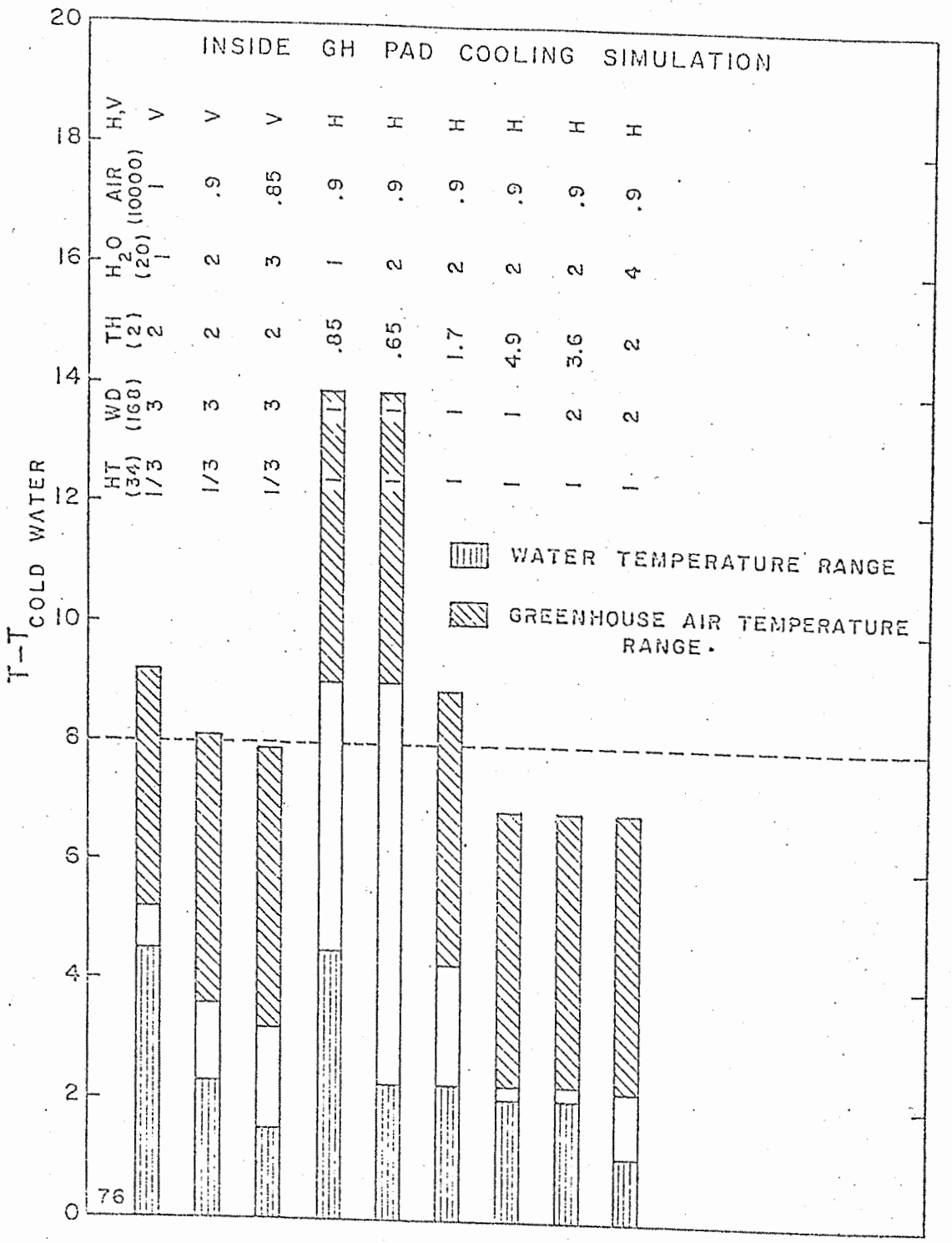

Figure 6. Greenhouse air temperatures predicted by programs INSIDEPAD and HORIZONTALPAD relative to a cold water temperature of 76 F for the various conditions shown in rows at the top of the figure. The numbers in the rows are the multiples of the "standard" conditions given in parenthesis.

TITLE: METEOROLOGICAL FACTORS AFFECTING EVAPORATION FROM BARE SOIL AND CROP SURFACES

CRIS WORK UNIT: 5510-12260-002 CODE NO.: Ariz.-WCL 72-6

Work under this outline this year consisted mostly of analyses of experiments carried out in prior years. Each is described individually below:

1. Idso, S. B., Jackson, R. D., Reginato, R. J., Kimball, B. A., and Nakayama, F. S. The dependence of bare soil albedo on soil water content. J. Appl. Meteorol. (In Press).

Simple albedo measurement may prove useful as a means for the remote sensing of soil water content and as a research tool in the study of evaporation of water from soil. Intensive concurrent measurements of the albedo and soil water content of a drying bare soil indicate that albedo, normalized for sun zenith angle effects, is a linear function of the soil water content of a very thin surface layer (less than 0.2 cm thick) over a sizeable volumetric water content range (0.00 to 0.18 for an Avondale loam). Albedo is also well correlated with the average soil water content of greater soil thicknesses. Measurements to a depth of 10 cm indicate that the relation is relatively independent of season.

2. Idso, S. B., and Reginato, R. J. Assessing soil-water status via albedo measurement. Hydrol. and Water Res. in Ariz. and the Southwest 4:41-54. 1974.

The albedo of a moist soil is approximately one-half that of the same soil in a dry condition. Over most of this range of variation, experiments on a smooth bare field of Avondale loam showed that albedo, normalized to remove solar zenith angle effects, was a linear function of the water content of a very thin surface layer of soil, and that it was also well correlated with the water contents of thicker soil layers. Albedo measurement was additionally used to differentiate between the initial potential rate phase

of evaporation following an irrigation or rain and the subsequent falling rate phase, whereby it was found that in all instances between 20 to 25% of the water added to the soil was lost via potential evaporation. It was then shown that the initiation of the falling rate phase of evaporation could be detected quite accurately by sight. This finding was utilized to evaluate the amount of water evaporated from small pots in the potential rate stage. The results were identical to the irrigations and rainfalls evaluated via lysimeters, indicating that the technique may have potential for watershed application.

3. Idso, S. B., Reginato, R. J., Jackson, R. D., Kimball, B. A., and Nakayama, F. S. The three stages of drying of a field soil. Soil Sci. Soc. Amer. Proc. 38:831-837. 1974.

Six major drying experiments were conducted on a smooth, bare field of Avondale loam at Phoenix, Arizona, during all seasons of the year. Intensive measurements of evaporation, soil-water contents, soil temperatures, soil heat flux, albedo, and net radiation allowed us to delineate the three classical stages of soil drying. The first stage was characterized by potential evaporation; while the second stage was characterized by drying of the soil surface, resulting in a significantly reduced evaporation rate. This stage continued until the volumetric water content at the soil surface reached a value of about 0.06, the predicted starting point for stage three for this soil based on the assumption that physical adsorption takes place in the first two molecular layers of water surrounding the soil particles. Simple albedo measurements often predicted the transition points between the three different stages.

4. Aase, J. K., and Idso, S. B. Solar radiation interactions with mixed prairie rangeland in natural and denuded conditions. Archiv. Meteorol. Geophys. Bioklim., Ser. B. (In Press).

Adjacent plots of native mixed prairie rangeland and bare soil near Sidney, Montana, were observed intensively over the 1973 growing season for reflected solar radiation (albedo) variations induced by surface soil water content variations. Results for the bare soil were nearly identical to those obtained over a bare soil at Phoenix, Arizona, where albedo variations had been linked to the three classical stages of soil drying. Results from the vegetated plot, however, did not show the characteristic water content dependency patterns. Thus, the utility of the albedo technique for assessing soil water status appears to be limited to the remote sensing of essentially vegetation-free soils and the in situ assessment of soil water evaporation via miniature solarimeters situated below the plant canopy or in small open spaces between plants.

5. Idso, S. B., Aase, J. K., and Jackson, R. D. Net radiation--soil heat flux relations as influenced by soil water content variations. Boundary Layer Meteorol. (Submitted for Publication).

Measurements of net radiation, soil heat flux, incoming and reflected solar radiation, and soil water content were made during several clear day periods following approximately 10-cm applications of water to loam soils at Phoenix, Arizona, and Sidney, Montana. Results indicated that the regression of soil heat flux on net radiation changed significantly as the soil dried, and that the difference between the net radiation and the soil heat flux was a linear function of the volumetric soil water content of the uppermost 2 to 4 cm of soil. This latter relation indicated that the net radiation-soil heat flux difference for soil in an air dry state was only about one-half of what it was on the day after irrigation. The techniques discussed allow evaluation of what the net radiation-soil heat flux difference would be under conditions of

no surface saturation deficit at any time of year from measurements of net solar radiation, soil water content, and air temperature, thereby improving the utility of many evaporation models. The data also indicate that the water content measurements may be replaced by the more easily measured soil albedo.

6. Idso, S. B., Schmugge, T. J., Jackson, R. D., and Reginato, R. J. The utility of surface temperature measurements for the remote sensing of soil water status. J. Geophy. Res. (Submitted for Publication).

Experiments carried out on an Avondale loam soil indicated that the thermal inertia concept of soil water content detection from aircraft or orbiting satellites is reasonably sound. The volumetric water contents of surface soil layers between 2 and 4 cm thick were found to be linear functions of the amplitude of the diurnal surface soil temperature wave for clear day-night periods. They were also found to be linear functions of the daily maximum value of the surface soil-air temperature differential. Tests on three additional soils ranging from sandy loam to clay indicated that the relation determined for Avondale loam could not be accurately applied to these other soil types. Using the moisture characteristic curves of each soil to transform water contents into pressure potentials, however, it was found that soil water pressure potential could be determined without prior knowledge of soil type, thereby significantly enhancing its value as a potential global soil-water status survey tool.

7. Idso, S. B., Jackson, R. D., and Reginato, R. J. Determining emittances for use in infrared thermometry: A simple technique for expanding the utility of existing methods. J. Appl. Meteorol. (Submitted for Publication).

A simple laboratory technique is described for making rapid emittance measurements with an infrared thermometer. It is shown

that when the infrared thermometer head is held flush against a surface, its output is a linear function of surface emittance. Thus, viewing two or more surfaces of known emittance in this manner "calibrates" the infrared thermometer, so that viewing an unknown surface at the same temperature in this manner will yield its emittance. Emittance values of the standard surfaces employed may be obtained via any of a variety of emittance measuremnt methods previously developed. A nomograph is presented that shows the possible errors that can occur as a result of temperature differences that may exist between the test and standard surfaces.

8. Idso, S. B. Thermal blanketing: A case for aerosol-induced climatic alteration. Science 186:50-51. 1974

Long-term temperature records at Phoenix, Arizona, indicate the existence of a post-1946 warming trend that may be attributed to the buildup of pollution in the lower layers of the atmosphere. The causative mechanism appears to be an enhancement of the so-called "greenhouse effect," induced by the interaction of aerosol with long-wavelength thermal radiation in the lower atmosphere.

PERSONNEL: Sherwood B. Idso

TITLE: GROWTH AND YIELD OF JOJOBA (SIMMONDSIA CHINENSIS (LINK) SCHNEIDER) ON RUNOFF-COLLECTING MICROCATCHMENTS

CRIS WORK UNIT: 5510-12260-002 CODE NO.: USWCL 73-4

INTRODUCTION:

For details, see the Annual Report for 1973. Briefly, the jojoba plant, a native of the Sonoran Desert, produces a high quality, heat-tolerant wax for which there would be great industrial demand if a reliable supply could be assured. The experiment was set up to improve plant growth and yield of jojoba by augmenting the normal available precipitation through use of simple water harvesting techniques.

PROCEDURE:

Thirty female jojoba plants from a local, native stand were selected and randomly divided into three water harvesting treatments of ten plants each: T_0, control with minimal disturbance of the surrounding soil and natural vegetation; T_1, cleared, smoothed, and rolled individual contributing microcatchments for each plant; and T_2, treatment T_1 plus a water repellent applied to the catchment soil surface. The individual runoff catchments are 20 m^2; the runon areas, each containing one jojoba plant, are 4 m^2.

During the first year 13 separate measurements of soil-water content (θ_v) were made by means of a neutron meter and access tubes installed to a depth of 140 cm in three plots of each treatment. Concomitant with the neutron meter measurements of θ_v were ten samplings of leaves for their relative leaf water content (RLWC) at approximately 1-month intervals. On 19 June 1974 all 30 plots were harvested for seeds which then were air dried and weighed for yield per plot and weight per 100 seeds. Plant growth was assessed by means of plant volume measurements (length x width x height) taken initially (November 1973) and 1 year later. Color photographs accompanied these measurements.

RESULTS AND DISCUSSION:

Rainfall for the 12-month period following initiation of the experiment (November 1973 through October 1974) was 259 mm--approximately the expected average (Table 1). However, rainfall during the critical prefruiting period from autumn to the June harvest was only 108 mm. The negligible crop yields realized from the ten control plots (Table 3) undoubtedly reflected this moisture deficiency.

The rainfall augmentation to the jojoba plants from the two microcatchment types T_1 and T_2 was estimated by direct extrapolation of runoff data obtained from two separate water-harvesting plots (one for each treatment type) equipped with runoff-measuring facilities. Runoff from the two representative plots, as a function of storm size, is summarized in Table 2. Percent runoff increased as storm size increased; overall, percent runoff for treatments T_1 and T_2 was 45 and 95 percent, respectively. The two runoff-measuring plots were operational only after June, 1974; however, the data obtained can be used to estimate the water supplied to the plants commencing with the installation of the plots the previous November. Using this technique and the rainfall data (weighted according to storm size), it is estimated that during the prefruiting period, November to the June harvest, the plants received the following amounts of direct rainfall plus runoff spread over the 4-m^2 growing area: 108, 372, and 642 mm for treatments T_1, T_2, and T_3, respectively. For the 12-month period, the respective values were 259, 864, and 1518 mm.

These runoff differences are clearly reflected in the yearly course of volumetric soil-water contents θ_v as integrated over the soil profile adjacent to the plants from 20 to 140 cm deep (Fig 1); and seasonal trend in θ_v was definitely $T_2 > T_1 > T_0$. A graphic example of the effectiveness of the catchments in recharging the soil profile with water, as compared to the control, is given in Fig. 2. On 21 August 1974, the soil-water content was extremely

low for all treatments, averaging about 4 percent. A total of 102 mm of rain raised the soil-water storage significantly in all treatments, but to a higher value and a much greater depth in treatments T_1 and T_2 than in T_0.

Actual overall trends in relative leaf water contents (RLWC) (Figure 3) approximately paralleled those of θ_v (Figure 1), generally decreasing during the prefruiting season, then increasing after harvest, reaching maximum values in November 1974. Differences between treatments were quite small and rather inconsistent, but during the important spring growing season from late February into May when the fruits were setting, the RLWC of treatments T_1 and T_2 averaged from 2 to 4 percent higher than T_0. This difference in leaf hydration, though slight, may have been sufficient to account for the marked differences in both plant growth and seed yield.

Estimates of plant volume made on 5 November 1974 (calculated from measurements of length, width, and height of the bush) showed a 41% increase in 1 year for T_0 and T_1 as compared to a 69% gain for T_2. A comparison of color photographs taken 1 year apart showed a moderate defoliation in T_0 and T_1 but not in T_2.

Seed yield data are shown in Table 3. A comparison of the average yields between the three treatments is encouraging. Relatively, treatment T_1 yielded 17 times T_0, and T_2 yielded 50 times T_0. Actual absolute yields, however, were small, undoubtedly reflecting both the winter-spring drought and the small size of the jojoba bushes. The mean weight in grams per 100 capsules was 38, 38, and 47 for T_0, T_1, and T_2, respectively. Each capsule usually contained one seed, but at times had two or even three seeds. Yields over several seasons will be necessary in order to draw any final conclusions; nevertheless, the first year's results attest to the effectiveness of water harvesting as compared to only natural rainfall in stimulating both growth and yield.

SUMMARY AND CONCLUSIONS:

Both fruit yield and plant growth of the indigenous desert plant jojoba were enhanced using water-harvesting microcatchments to augment the normal soil-water supply. The amount of water supplied to the 4-m^2 growing area of each plant during the 8-month period preceding harvest was estimated for the three water-harvesting treatments, T_0, T_1 and T_2, to be 108, 372, and 642 mm, respectively. Accordingly, soil-water contents (θ_v) of the soil profile down to 140 cm followed a yearly trend of $T_2 > T_1 > T_0$. Leaf hydration, as determined by the relative leaf water content (RLWC), tended to be rather closely related to the soil-water content. Relative seed yields by treatment were: T_1 yielded 17 times T_0, and T_2 yielded 50 times T_0. Estimated plant growth for the first year of the experiment showed a 41% increase for treatments T_0 and T_1, and a 69% increase for T_2. The improved soil-water content and leaf hydration in plots with microcatchments seem to be responsible for the corresponding increase in yields for the first season. However, these promising results need to be verified in subsequent seasons before a generalization can be made.

PERSONNEL: W. L. Ehrler, S. T. Mitchell, and D. H. Fink

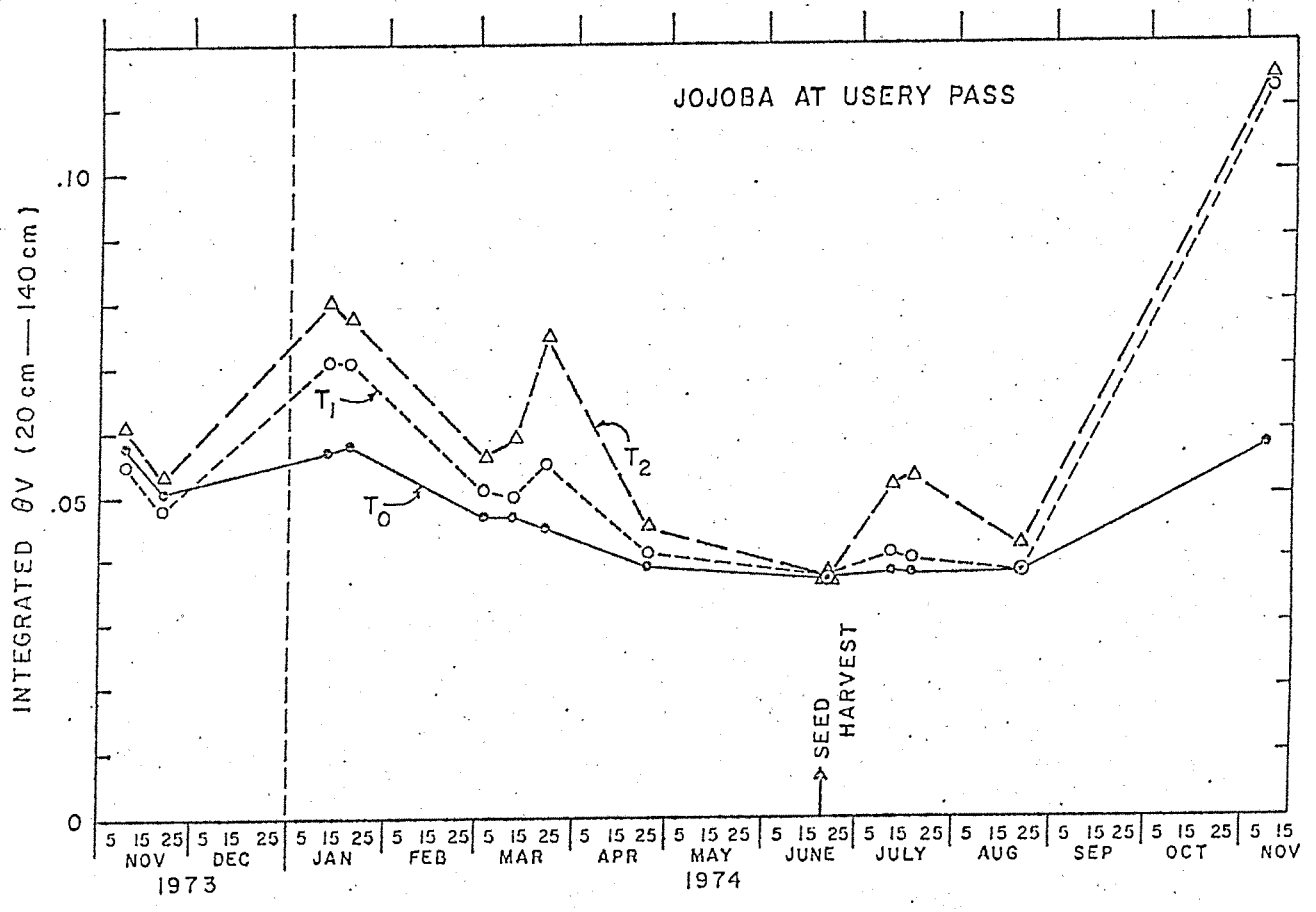

Figure 1. The yearly course of volumetric soil-water content (θ_v) integrated over the depths of 20 to 140 cm, in treatments T_0, T_1, and T_2 as obtained from neutron meter access tubes located 30 cm from the plant crown.

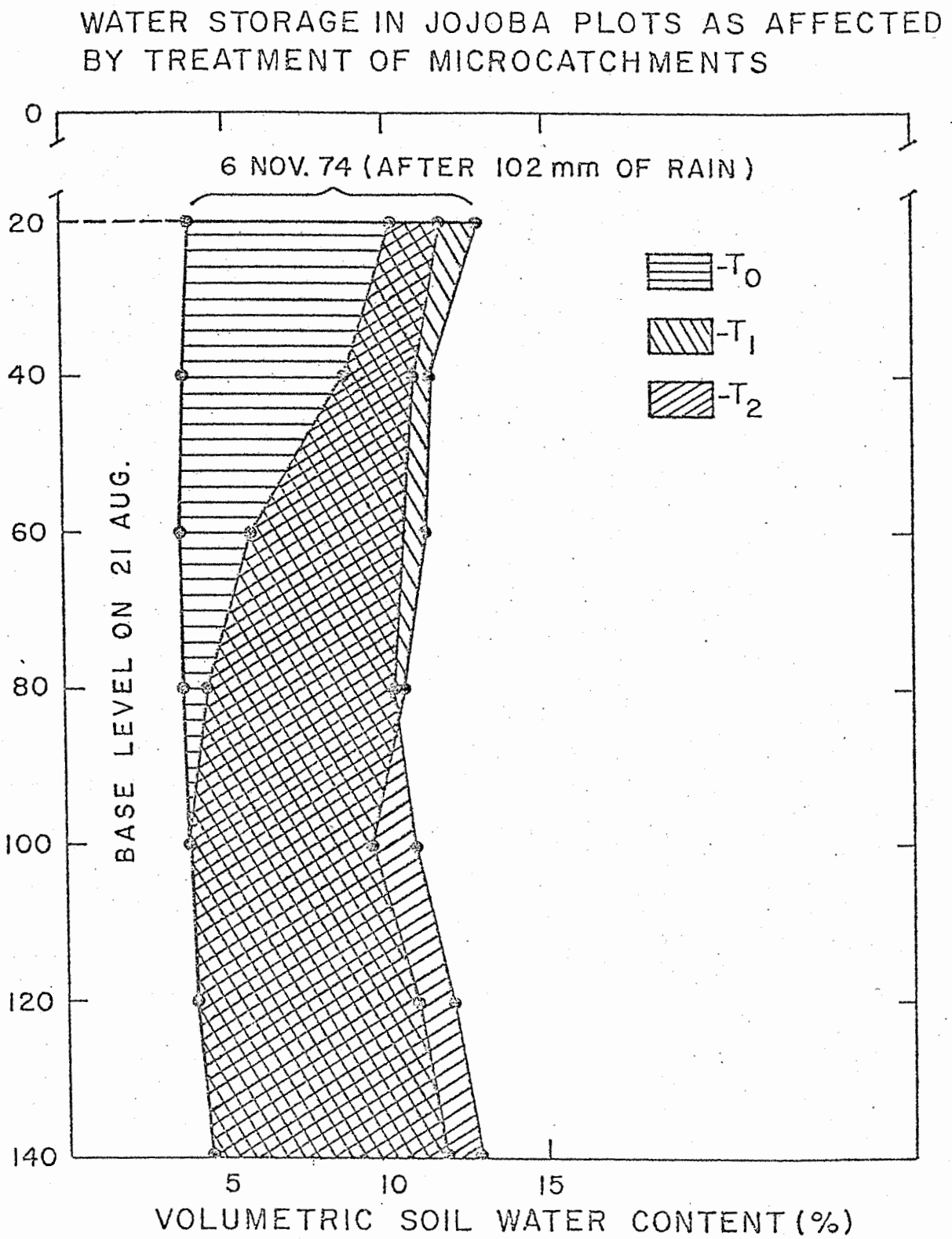

Figure 2. Effect of treatment of a microcatchment on soil-water storage from a substantial amount of rainfall (102 mm).

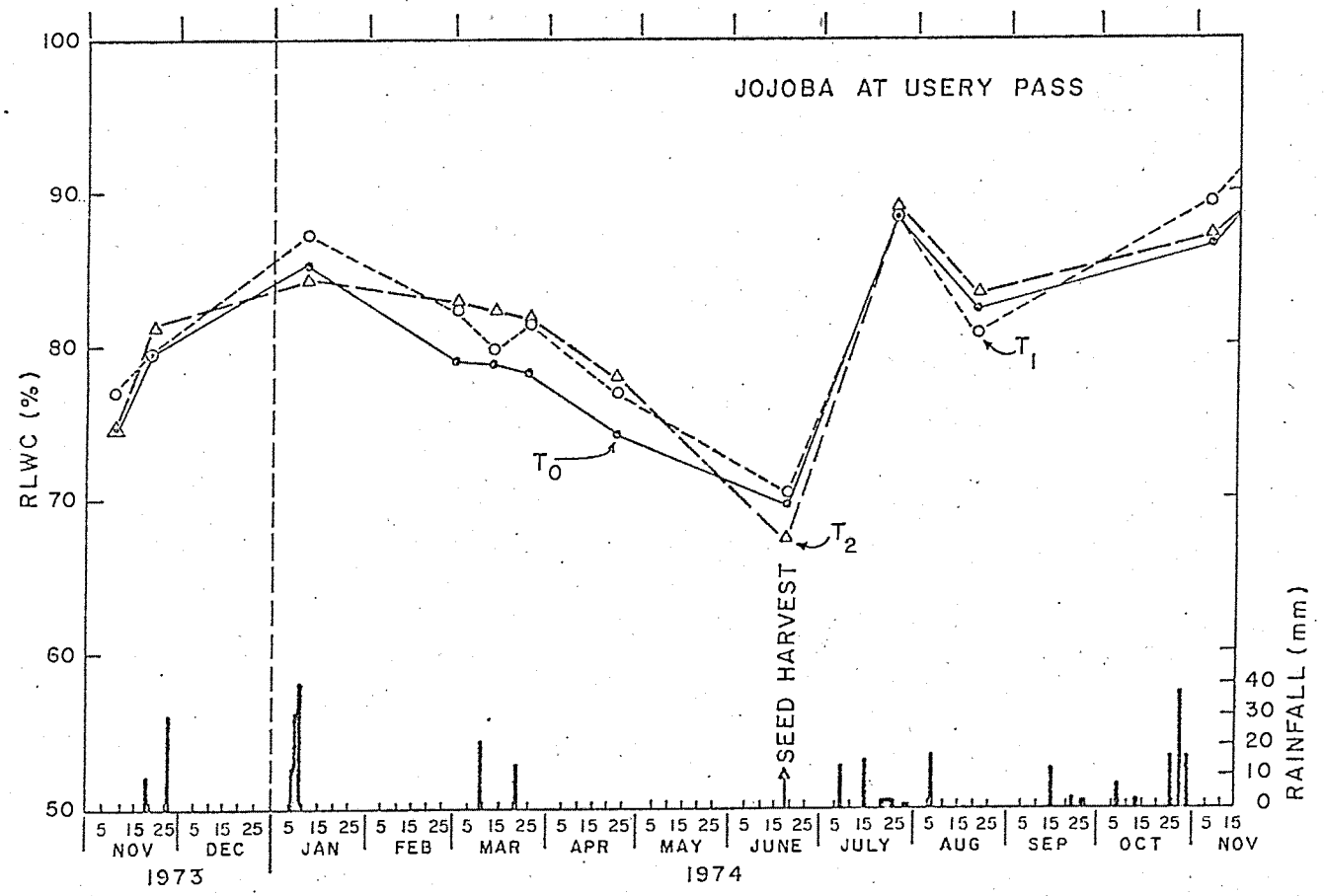

Figure 3. The yearly course of the relative leaf water content (RLWC) of jojoba in treatments T_0, T_1, and T_2 in response to the different amounts of soil-water storage shown in Figure 1.

Table 1. Monthly rainfall as measured at the site during the first year of water harvesting; the values through July are from a tapered plastic rain gauge and thereafter from a "Forester" type gauge 200 mm in diameter.

RAINFALL ON THE JOJOBA PLOTS AT USERY PASS

Month	Rainfall, mm
Nov 1973	29.9
Jan 1974	41.2
Mar	36.6
Total up to harvest on 19 Jun	107.7
Jul	34.5
Aug	17.8
Sep	14.2
Oct	84.9
12-month total	259.1

Table 2. Characterization of the percentage runoff to be expected from the microcatchments for treatments T_1 and T_2, as measured by two plots with collecting barrels in place of jojoba plants.

RAINFALL-RUNOFF CHARACTERISTICS AT USERY PASS

Storm Size, mm	No. of Storms 1/	Total Rainfall, mm	Percent of Total Rain	Percent Runoff T_1 3/	Percent Runoff T_2 4/
< 5	6	10.4	9	1	45
5 - 10	1	7.9	6	18	91
10 - 20	4	65.0	53	46	100
> 20	1	38.9	32	60 2/	100 2/
TOTAL	12	122.2	100	45	95

1/ The catchments for measuring runoff were operational only after 17 July 1974; data were taken through October 1974.

2/ The collection system overflowed; data were estimated.

3/ Soil cleared, smoothed and rolled.

4/ Same as for 3/, but also sprayed with a water-repellent dust-suppressant.

Table 3. Air-dry weight of jojoba seeds (picked 19 June 1974) after water harvesting had been in effect for treatments T_1 and T_2 since 12 December 1974.

SEED YIELD, AIR-DRY WEIGHT, IN GRAMS PER PLOT, OF JOJOBA HARVESTED ON 19 JUNE 1974

TREATMENT					
Plot No.	T_0	Plot No.	T_1	Plot No.	T_2
2	0.00	5	0.00	1	1.36
8	0.00	6	0.00	3	4.39
11	0.00	10	2.07	4	22.85
12	1.09	13	12.32	7	0.00
14	0.00	15	0.00	9	107.30
16	1.02	17	0.00	23	0.00
20	2.33	18	0.22	25	4.16
21	0.00	19	4.69	26	88.37
24	0.00	22	51.49	28	0.69
29	0.17	27	7.98	30	1.64
	0.46		7.86		23.05

COMPARISON OF THE MEAN YIELDS

T_0 and T_1	T_0 and T_2	T_1 and T_2
7.86-0.46 = 7.4 n.s.	23.05-0.46 = 22.6 (sig. at the 0.15 level)	23.05-7.86 = 15.2 n.s.

TITLE: THE EFFECT OF GIBBERELLIC ACID ON THE GROWTH RATE, FLOWERING, AND FRUITING OF SIMMONDSIA CHINENSIS (JOJOBA)

CRIS WORK UNIT: 5510-12260-002

Jojoba, or Simmondsia Chinensis, is a desert shrub of the Southwestern United States and Mexico. The plant is a woody evergreen shrub which is commonly 2-3 ft in the wild, occasionally as high as 6 or 7 ft.

Simmondsia is unique among plants in that its seeds contain an oil which is a liquid wax. The oil is obtained in a remarkably pure state and requires little or no refining for use as a transformer oil, lubricant, in beeswax, candle-making, and in cosmetic products such as soap, hair oil, shampoo and perfume. The oil resembles sperm whale oil both in composition and properties, and it could serve well as a replacement for this oil. Simmondsia seeds yield 50 percent "oil," whereas cotton seed yields 15-18, soybean 18-21, flaxseed 29, and safflower 26 percent. The oil is not the only product that makes this plant important. In recent research the seed has been found to have an appetite depressant, a source for sterols, an anticancer antigen, and the meal can be used as poultry feed. (Jojoba Newsletter, Jan-Feb 1973).

The possibility of Simmondsia as a domestic crop in the Southwest should be given careful consideration. However, there are several factors which will be of importance in determining the success of the development of this plant. Unfortunately, one of the factors is that Simmondsia takes about six years to reach the stage where production is large enough to warrant harvesting on a commercial basis. Another problem is that only the female produces seeds. It is impossible to determine the sex of a plant prior to flowering, which occurs when the plant is 3-4 years old. (Daugherty, Sineath, Wastler, 1953).

A growth regulator such as Gibberellic acid could be applied

as a spray or brushed on to hasten growth of seedlings or cuttings, early flowering, and fruiting. Gibberellin (GA) has been shown to promote seedling growth in pecans (Wiggans and Martin, 1961), early growth in pistachio (Ayfer and Serr, 1960), promote flowering and fruiting in tomatoes (Courter and Drinkwater, 1960). GA has also been shown to promote sprouting of hardwood cuttings collected in winter, and to shorten the dormant period of certain trees and shrubs (Larson, 1960).

An experiment was conducted to investigate the effect GA has on growth rate, early flowering, fruiting, and yield.

This information can be of great importance to the water conservation program of the Southwestern United States. If GA can change the plant morphology of Jojoba, making it photosynthetically more effective and thereby increasing yield - the present study may open a new approach to the possibility of increasing the yield of Jojoba in the Southwestern deserts. As a native desert plant it could withstand drought years, and in rainy seasons it could produce enough to become a potential domestic crop.

MATERIAL AND METHODS:

Simmondsia Chinensis seeds and cuttings from Tonto Forest area were used in this test. The germination and propagation experiment was conducted in the greenhouse in a standard soil mixture (2 parts peat, 2 parts sand, 1 part Avondale clay loam). The greenhouse temperature was maintained at 35 C maximum and 21 C minimum.

Plants were treated at the emerge age of two weeks with 0, 400, 800, and 1000 ppm GA. The GA treatments were applied once every two weeks with a brush. A spray application was used when plants began to produce branches from the main stem. Plants were measured before each spray application. A non-ionic-type spreader was added to all solution to give a 0.1 concentration of the wetting agent. Sprays were applied between 7-8 a.m. when atmospheric humidity was relatively high.

RESULTS:

The plant growth results per treatment did not seem to be much different from the control because after 5 months all the plants began to produce branches. The most significant finding was that the GA treated plants produced flower clusters after 8 months, but the control did not produce clusters until 15 months (Table 1). This suggests that GA can be used as an aid to help hasten the sex determination of Jojoba. An experiment in the field will be conducted to find out if the GA treated plants will react the same in its natural environment. The greenhouse experiment will be continued until the plants produce seeds.

In other experiments Jojoba cuttings were treated with Rootone, (a rooting hormone containing Indole Butyric acid) to promote rooting. The cuttings were obtained every two weeks. The stems were wetted and dipped in the powdered Rootone. Then the cuttings were placed in the standard soil mixture. The cuttings taken from January to May did not root, but the June to July cuttings rooted successfully. The test showed that cuttings should be taken from early June until July in order to have successful rooting. Using this knowledge, a more intensive investigation will be conducted on the June to July cuttings results.

PERSONNEL: S. T. Mitchell

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Table 1. Growth, date of flowering, and flower cluster number of Jojoba as influenced by four levels of Gibberellic acid.

ITEM	GIBBERELLIC ACID PPM			
	0	400	800	1000
Height (cm) at 531 days				
Rep I	37	53	44	63
II	45	40	43	43
III	41	44	82	49
Average -	41	44	56	52
Days until first flowering				
Rep I	413	228	228	238
II	415	230	232	240
III	418	232	234	230
Average -	* 416	231	232	236
Sex				
Rep I	F	F	F	F
II	M	M	M	F
III	M	M	F	M
No. of flower clusters at 531 days				
Rep I	10	15	18	29
II	18	13	24	30
III	28	20	30	13
Average -	18.7	16	24	24

*Means underscored by line is significant at the 1% level by Duncan Multiple Range Test. All others are not significant even at 5% level.

TITLE: WASTEWATER RENOVATION BY SPREADING TREATED SEWAGE FOR GROUNDWATER RECHARGE

CRIS WORK UNIT: 5510-12260-003 CODE NO.: Ariz.-WCL 67-4

INTRODUCTION:

Work at the Flushing Meadows Project in 1974 was centered around (1) basin management for maximizing nitrogen removal, and (2) removal of viruses and specific bacteria in the soil and aquifer beneath the basins. In January Mrs. Gladys C. Emery joined the Laboratory to handle the chemical analyses of the various effluent and renovated-water samples from the field and laboratory studies. At the same time, Mr. Steve R. Kilburn reported for duty as a hydraulic technician, but resigned in August.

Construction was started on the 23rd Avenue recharge project in the fall of 1974. Wells are to be drilled in the spring of 1975 and the project should be operational by late spring or early summer of 1975.

As in previous years, this report is divided into four sections:

I. Infiltration
II. Water Quality
III. Future Projects
IV. Summary and Conclusions

I. INFILTRATION STUDIES

1. Recharge Basin Management.

For the first 3 months of the year, the basins were operated the same as in 1973, i.e. about 13-14 days flooding (12 days pumping) and 14 days drying with water depths of 13 inches in basins 1 and 2 (2 boards in outlet structure), 7 inches in basins 3 and 4 (1 board), and about 4 inches in basins 5 and 6 (no boards). Then, starting 1 April, the water depths were changed to 4 inches (no boards) in basins 1 and 2, 4 inches (no boards) for the first 2 days and 13 inches (2 boards) for the rest of the flooding period

for basins 3 and 4, and 13 inches (2 boards) for basins 5 and 6. The low depth for basins 1 and 2, and the high depths for basins 5 and 6, were selected to reverse previous treatments in order to determine if higher nitrogen removal at lower water depth could also be obtained for basins 1 and 2. The low depth during the first 2 days of flooding in basins 3 and 4 was selected to determine if lower infiltration rates and resulting lower leaching of nitrate formed in the soil during drying would increase denitrification. This would then reduce the height of the characteristic nitrate peaks observed in the renovated water after the start of a new flooding period. Flooding and drying periods of 2 weeks each were essentially maintained for the rest of the year to provide a uniform treatment of the basins for the virus and bacterial studies which were carried out at 2-month intervals during the entire calendar year.

The condition of the basins throughout most of 1974 was as follows.

Basin 1. No vegetation, thin sludge layer (about 1 mm when dry) covering bottom.

Basin 2. Gravel layer covered by about 2 mm sludge (dry condition).

Basins 3 and 4. Occasional clumps of grass, but basically no vegetation. Sudangrass thatch layer of about 2 or 3 cm thick covers most of the basin. The thatch is covered by a few millimeters dry sludge (dry condition).

Basins 5 and 6. Scattered clumps of grass, but mostly old bermudagrass thatch, covered by a few millimeters of sludge (dry condition).

2. Infiltration Rates.

The reduction in water depth from 13 to 4 inches in basins 1 and 2 in April did not significantly affect the infiltration

rates (Figure 1). The opposite was true for basins 3, 4, 5, and 6, where increasing the water depth from 7 to 13 inches (for basins 3 and 4) and from 4 to 13 inches (for basins 5 and 6) essentially doubled the infiltration rates. A gradual decreasing trend occurred in the infiltration rates for basins 3, 4, 5, and 6. Sometimes the infiltration rate increased during flooding, possibly due to buoyancy of the algal mat formed on the bottom. Sprinkling with effluent during the drying periods of basins 1, 2, 3, and 4, during the first few months of the year may have slowed the infiltration recovery.

The curves of accumulated infiltration (Figure 2) show that the average hydraulic loading was 294 ft per year. The shallow basins 1 and 2 had the lowest accumulated infiltration, whereas the deep basins 3, 4, 5, and 6 all had loading rates above 300 ft per year. Basins 4 and 5 exceeded 400 ft per year.

II. WATER QUALITY STUDIES

1. Sampling and Analytical Techniques.

Sampling schedules, sampling tehcniques for effluent and renovated water, and analytical techniques were basically the same as described in previous annual reports.

2. Total Organic Carbon.

Malfunctioning of the carbon analyzer prevented collection of TOC-data for most of the year. Data taken in October (Table 1) show that the TOC content of the secondary effluent was around 15 mg/liter, and that of the renovated water between 3 and 11 mg/liter with an average of 6.4 mg/liter. Steps have been taken in cooperation with the ARS Western Regional Research Laboratory in Berkeley, California to identify the refractory organic carbon in the renovated water.

3. Nitrogen.

The total-N content of the effluent and the NO_3-N and NH_4-N concentrations of the renovated water from the wells between the

basins are shown in Figures 3, 4, and 5. The total-N content of the effluent, which was mostly in the ammonium form, generally varied between 20 and 40 mg/liter with an average of about 28 mg/liter.

The renovated water from the 20-ft deep well 1-2 showed a consistent pattern of NO_3-peaks which occurred mostly about 5 days after flooding of the basins was started (Figure 3). The increasing trend in the NH_4-N content for the first 3 months was reversed in April, concurrently with the decrease in flooding depths from 13 inches to 4 inches. Nitrogen removal was mostly in the 20-50% range with a non-weighted average of 30%. The nitrate peaks in January, February, and March were somewhat lower than average. Whether this may be due to an increase in denitrification because the sprinklers moved nitrates deeper into the soil during drying, or to the lower infiltration rates during flooding as caused by sprinkling during drying, is difficult to say.

The NH_4-N content of the water from the 30-ft deep ECW (Figure 4) generally ranged between 10 and 15 mg/liter, with an increasing trend in the first 4 months and a decreasing trend in the last 4 months of the year. The nitrate peaks greatly diminished in height after March, when a small water depth was maintained for the first few days flooding. Apparently this was effective in stimulating denitrification of the nitrate leached from the upper portion of the soil when flooding was resumed. Nitrogen removal was between 30-50% with a non-weighted average of 43%. No removal percentage could be calculated for the flooding period at the end of August because well samples were inadvertently omitted for that period.

The NH_4-N content of the renovated water from well 5-6 increased in April, when the water depth in the basins was increased from 4 to 13 inches (Figure 5). A decrease in the NH_4-N content occurred in the last 3 months of the year. The NO_3-N peaks after April were drastically lower than before and virtually absent after

June. This sudden change in nitrate peaks is difficult to explain. The nitrogen removal generally varied between 50 and 75%, with a non-weighted average of 62%.

The average sum of ammonium nitrogen and nitrate nitrogen in the wells outside the basin area (Table 2) was 3.9 mg/liter for well 1, 10.1 for well 7, and 9.7 for the East well. A total-N content of 10 mg/liter in the renovated water corresponds to an N-removal of about 64%.

4. Phosphate.

The PO_4-P concentration of the effluent generally ranged between 10 and 20 mg/liter for the first 4 months of the year and between 6 and 11 mg/liter for the rest of the year (Figure 6). The PO_4-P concentrations in the renovated water decreased towards the second half of the year (Figures 6, 7, and 8). For well 1-2, PO_4-P removal was about 51% in the first half and about 69% in the second half of the year. For ECW, these percentages were 55% and 67%, and for well 5-6 77% and 92%. Average removal percentages were 61% for well 1-2, 61% for ECW, and 85% for well 5-6. For the wells outside the basins (Figure 9), PO_4-P levels were less than 1 mg/liter for well 1. For well 7, the PO_4-P concentrations were fairly high in March and April, after which they dropped to below 4 mg/liter for the rest of the year. The high initial values of PO_4-P may have been caused by the high PO_4-P levels in the effluent in the first 3 months of the year.

5. Dissolved Salts.

The total dissolved solids concentrations of the effluent and renovated water were usually around 1,000 mg/liter (Table 3), as in previous years. Lower TDS values were observed in December, except for the WCW which yields water with an underground detention time of 2 years.

6. pH.

The pH of the effluent and renovated water was not determined in 1974. In previous years the effluent pH was usually around 8, and that of the renovated water usually between 6.5 and 7.

7. Fluoride.

The fluoride levels in the effluent were around 3 mg/liter (Table 4), which is less than the 4-5 mg/liter range observed in previous years. Except for WCW, the fluoride concentrations in the renovated water were generally between 2 and 3 mg/liter. It is of interest to note that whereas the water from well 5-6 showed a high removal of phosphate in the latter part of the year (Figure 8), there was practically no removal of fluoride.

8. Boron.

The boron concentration of the effluent averaged about 0.67 mg/liter (Table 5), which is less than the 0.8-0.9 mg/liter observed in previous years. As in the past, boron levels in the renovated water were about the same as in the effluent, indicating no boron removal in the soil.

9. Bacteria and Viruses.

The secondary sewage effluent and the renovated water from ECW, wells 1-2 and 7, and EW were analyzed for viruses and enteric bacteria at bi-monthly intervals throughout 1974. Samples were taken during the second week of flooding to make sure that the wells yielded "fresh" renovated water. The virus work was done in cooperation with the Virology Department of Baylor College of Medicine at Houston, Texas. Using a technique developed at Baylor, viruses from about 350 liters (average volume) of renovated water from each well were concentrated on site into a small volume and shipped to Baylor for assay. Analysis of the various samples for fecal coliforms, fecal streptococci, salmonella, and total bacteria was done at the U.S. Water Conservation Laboratory. A complete report on these studies is presented in the section "Ariz.-WCL 70-2, Characterization of Soil Microflora and Biological Processes Occurring

in the Soil Used for Wastewater Renovation" by R. G. Gilbert. Only a summary will be presented here.

The virus concentration in the effluent ranged from 159 to 7,484 TCID (tissue culture infectious dose) per 100 liters with an average of 2,120 TCID/100 liters. Peak virus levels in the effluent usually occur in the summer. Effluent virus included polio virus types 2 and 3, echo virus 7 and 15, coxsackie virus B4, and reovirus 1 and 2. No virus was detected in any of the renovated water samples, indicating complete removal of virus in 20 and 30 feet of percolation through soil. The range and average number of bacteria in the secondary effluent and renovated water are shown in Table 6. The fecal coliform density in the renovated water is low enough to permit unrestricted irrigation and recreation.

10. Biostimulation of Renovated Water in Ponds.

After being cleaned, filled, and stocked with top minnow and bluegill in August 1973 (see Annual Report, 1973), the inflow of renovated water into the ponds was set so that the water in the East Lined Pond (ELP) was replaced every 12 days and that in the West Lined Pond (WLP) every 32 days. Numerous minnows were observed in 1974 and fish kills apparently did not occur. While the WLP looked cleaner, the depth of visibility as determined with the Secchi disk was about the same for the two ponds (Figure 10). The NO_3-N and NH_4-N levels were also about the same (Figures 11 and 12). Low nitrogen levels occurred from May to August, possibly because of biological activity in the ponds and incorporation of N in animal and plant tissue. After the beginning of August, NH_4-N levels were lower in WLP than in ELP. In both ponds, NO_3-N exceeded NH_4-N in the first 4 months of the year, but the reverse was true for the rest of the year.

The PO_4-P contents of the pond water were generally lower in WLP than in ELP (Figure 13). Fluoride levels in both ponds were usually in the 2-3 mg/liter range, boron in the 0.6-0.9 range, TOC in the 25-40 range and TDS around 1,000/liter.

III. FUTURE PROJECTS

23rd Avenue Project.

Construction of the 40-acre high-rate infiltration basins below the 23rd Avenue Sewage Treatment plant was started in September 1974 and will be completed in January 1975. The first 24-inch well will be drilled in the middle of the center dike in March 1975, as will the observation wells on the north and south sides of the project. Production of renovated water thus should start in late spring or early summer. The material for the dikes was obtained from the basins themselves. Because of this, the underlying sand and gravels were exposed in several places (Figure 14). The average size of the basins is 293 ft by 1,524 ft. The bottom area of the basins is 10.5 acres for basin 1, 10.2 acres for basin 2, 10.1 acres for basin 3, and 10.2 acres for basin 4.

Infiltration into Soil Becoming Increasingly Permeable with Depth.

In estimating infiltration rates for the soil profiles in the Salt River bed, where the hydraulic conductivity abruptly increases with depth at some point, use was made of the Green-Ampt equations. A numerical procedure was developed to extend the theory to the case where the permeability increases gradually with depth. This increase can be linear or in any other fashion. The depth where the soil is no longer completely rewetted by the infiltrating water is found as part of the solution. A manuscript on this procedure was also prepared and it will be submitted for publication in the Irrigation and Drainage Division Journal of the American Society of Civil Engineers.

Underground Movement of Renovated Water.

Slug Test. The research objectives of the 23rd Avenue Project include testing the validity of theories regarding the underground flow system (water table shape, underground detention times), the collection of renovated water from the wells in the center without spread of renovated water into the aquifer outside the basin area,

and the form and concentration of the nitrogen in the renovated water pumped from the wells. This requires knowledge of the hydraulic conductivity of the aquifer. To evaluate this parameter, a slug test technique was developed for wells in unconfined aquifers. The wells can penetrate the aquifer completely or partially. The necessary geometry parameters were determined with the electrical resistance network analog for a wide range of conditions. Existing slug-test techniques described in the literature only apply to completely penetrating wells in confined aquifers. Since the new slug test is a contribution to the general science and art of groundwater hydrology, a manuscript describing the method has been prepared for publication in Water Resources Research.

Minimum Underground Detention Time. The minimum underground travel time from the recharge basins to the collection wells can be determined from flow nets obtained by resistance network analog (see Annual Report, 1969). The macroscopic velocity of each section of the stream tube is determined from the flow net (Figure 15). The travel time for each section of the stream tube is then determined by dividing the velocity by the average length of that section. The times are then summed up over the entire length of the stream tube. A semi-empirical equation has been developed to calculate the minimum travel time in terms of the hydraulic and geometric properties of the recharge basins and the aquifer.

The velocity, V, in any section of the stream tube can be determined from the equation

$$V = IWL_r/H_aW_sf \qquad (1)$$

where

H_a = height of the aquifer = $H_w + H_p$

H_w = effective height of the aquifer at the well = T_e/K

H_p = average equal potential height from flow net

f = porosity

W_s = width of stream tube in section

I = infiltration rate

W = width of recharge basin

L_r = width of strip feeding stream tube

T_e = transmissibility of the aquifer

K = horizontal hydraulic conductivity.

Dividing the average length of the stream tube, L_s, by the velocity and substituting other values yields

$$T_i = RL_sW_s/IWL_r\ (T_e/K + H_p). \qquad (2)$$

The equipotential head (H_p) is a function of the water table elevation drop from the recharge area to the well. This relationship has been previously established from resistance network analog studies, and is a function of L/S and WSI/T_e (see Annual Report, 1969). The total travel time, T, is the sum of the individual times (T_i) for each section of the stream tube from the edge of the recharge basins to the well. The above procedure was used to develop the following relationship

$$T = 0.79\left(\frac{L}{S}\right)^{1.21}\frac{T_e}{K}\ \frac{fS}{IW} + 1.05\left(\frac{L}{S}\right)^{1.57}\frac{fS^2}{T_e}. \qquad (3)$$

This equation is valid for L/S values from 0.4 to 2.5. The values of L, S, W, and I can then be varied to obtain the desired minimum travel time.

Underground Movement of Attenuated Nitrate Peak. The first water that infiltrates after a dry period contains high concentrations of nitrates. As this water moves toward the collection point, however, it is mixed with water containing varying amounts of nitrate. The nitrate peak that is observed in the field directly

under the recharge area will be attenuated at the collection point. The degree of attenuation will depend upon the rate and distance of travel, and the amount of convergence near the well. The theoretical shape of the peak at the well can be calculated from the travel times assuming plug flow and no dispersion. First, the travel time for each stream tube is calculated using the procedure outlined before. Travel times in the recharge area are determined using a similar procedure utilizing horizontal flow theory to obtain the height of the water table. Contours of equal travel time in the recharge area are then constructed as shown in Figure 16. These contours are for the system shown in Figure 15. The area under each contour divided by the total recharge area, A/A_o is the relative amount of newly infiltrated water that has arrived at the well by that time. An arrival time curve for the above system is shown in Figure 17 (a). The slope of curve (a) is the relative rate, R, that the newly infiltrated water arrives at the well, (curve b). Curve (b) is also the attenuated shape of a square nitrate peak, 1 day in duration with the ordinate being the relative concentration. The nitrate concentration at the well is obtained by multiplying curve B by the peak concentration.

Usually the shape of the nitrate peak under the recharge area is triangular or bell-shaped. This shape can be approximated by a series of 1-day square peaks, as shown in the inset in Figure 18. The resulting concentration at the well, then, is the sum of the individual attenuated curves for each square peak, Figure 18. When an intermittent inundation schedule is followed, the resulting concentration at the well will be the sum of the individual peaks for each period as shown in Figure 19. The nitrate peak is spread out into a fairly uniform concentration at the well (7 to 10% of the peak concentration for the example given).

The nitrate concentration at the well was determined for a number of different geometric and hydraulic conditions. The

maximum concentration at the well was 25% of the peak concentration. Recycling the nitrate peak then would not result in efficient nitrogen removal because of the attenuated peak.

Rio Salado Project.

The year 1974 also saw the completion of Phase II of the Rio Salado report. Two pilot projects have been identified for first construction. One of these includes the Tempe-Arizona State University Project where a portion of the flood channel would be used for a rowing course and other aquatic recreation, along with shore developments (see Annual Report, 1973). The City of Tempe received State money to help with the purchase of land for the project. Construction of the Rural Road bridge, which crosses the proposed lake and channel project, has begun.

IV. SUMMARY AND CONCLUSIONS

The average hydraulic loading rate in 1974 for the six infiltration basins of the Flushing Meadows Project was 294 ft/year with two basins exceeding 400 ft/year. The nitrogen content of the renovated water below the basins was approximately 45% less than that of the effluent, indicating a nitrogen removal of 11,000 kg/ha. This removal is most likely due to denitrification and the results show that proper management of high-rate infiltration basins can result in much more nitrogen removal than would be possible with crop uptake. Phosphate removal ranged between 60% and 85% after 20 to 30 ft of underground movement of the effluent water. Additional phosphate was removed with continued underground travel of the renovated water.

Virus could not be detected in concentrated renovated water samples taken bi-monthly from depths of 20 to 30 ft below the infiltration basins. The effluent, however, contained viruses in the range of 159 to 7,484 TCID per hundred liters. Salmonella was not detected in the renovated water either, but the effluent contained 17-26 salmonellae per 100 ml. Fecal coliforms in the renovated

water ranged from 0 to 359 per hundred ml with an average of 96 per 100 ml. The quality and appearance of renovated water in two lined ponds was not significantly affected by the turnover rate, which was 12 days for one pond and 32 days for the other. Depth of visibility was usually in the 20-40 cm range. Fish kills did not occur.

The 1974 studies at the Flushing Meadows Project showed that after 7 years of high-rate infiltration, the system is stable and still producing high-quality renovated water. The renovated water meets the requirements for unrestricted irrigation and recreation.

A 40-acre infiltration system with a design capacity of 15 mgd has been constructed by the City of Phoenix and wells to pump renovated water for unrestricted irrigation should be completed before summer 1975. Preparatory to studies on the underground flow system of this project, a new slug test for measuring hydraulic conductivity of unconfined aquifers was developed. Analyses of the underground flow system showed that the nitrate peaks would be considerably flattened by the time the renovated water is pumped from the wells. Thus, separating the portion of the renovated water with a high nitrate content for special use or recycling through the infiltration basins to obtain more denitrification will not be practical. Basin management and addition of organic carbon are more liekly to be successful in stimulating denitrification.

PERSONNEL: H. Bouwer, R. C. Rice, G. C. Emery, H. L. Mastin

Table 1. Total organic carbon content in mg/liter of secondary effluent and renovated water from various wells (1974).

Date	Secondary effluent	Well samples					
		1	1-2	ECW	WCW	5-6	8
21 Oct	14.2		3.5	7.3		5.0	
22 Oct	15.5		5.0	7.5		6.0	
23 Oct	15.0	4.5	11.5	7.0	5.5	5.0	3.5
24 Oct	15.5		5.0	7.0		5.0	
25 Oct			6.8	8.5		7.0	
30 Oct			8.0	8.5		7.5	

Table 2. Concentration (mg/liter) of NO_3-N and NH_4-N in renovated water from wells outside basins (1974).

Date	Well 1		Well 7		East Well	
	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N
9 Jan	0.6	0.7	6.0	3.0	5.2	4.5
14 Mar	0.2	0.6	8.8	3.1	8.8	3.8
15 Apr	1.6	1.5	0.3	4.3	3.0	3.5
8 May			9.8	4.9		
10 May	8.0	2.5	0.4	5.2	2.8	4.0
18 Jun			2.0	4.9		
5 Jul	0.3	0.4	1.9	5.4	0.3	4.3
27 Aug	1.3	2.6	11.9	8.7		
18 Sep	0.2	4.2	0.1	7.5	0.1	8.1
23 Oct	2.3	4.2				
20 Nov	1.5	3.0				
10 Dec			5.8	6.9		
11 Dec					1.4	8.5
18 Dec	0.5	2.9			11.5	7.7
Average	1.65	2.26	4.7	5.39	4.14	5.55

Table 3. Total dissolved salts (mg/liter) in secondary effluent and renovated water from various wells (1974).

Date	Secondary effluent	Well 1	1-2	ECW	WCW	5-6	7	8	EW
12 Apr	1024	928	973	864	1408	864	979		947
10 May	1024	1056	1088	979		992	960		1024
23 Oct	1018	979	1088	1011	1152	1039		979	
20 Nov	1139	1011	1030	973	1204	1024			
18 Dec	691	845	960	877	1037	947			909

Table 4. Fluoride concentrations (mg/liter) in secondary effluent and renovated water from various wells (1974).

Date	Continuous sample	WO	W 1-2	ECW	WCW	W 5-6	W 7	W 8	WE
15 Apr	3.2	1.1	3.0	3.2	0.4	3.6	3.5		2.3
10 May	3.6	2.1	3.0	3.4		3.5	2.9		3.0
5 Jul	3.0	1.46	3.8	4.0	0.6	3.8	3.4		3.8
27 Aug	2.5	2.0	2.8	3.0		3.3	3.0		
23 Oct	2.95	2.0	2.3	2.8	0.25	3.1		2.5	
20 Nov	2.8	1.85	2.2	2.7	0.3	3.4			
18 Dec	3.7	1.86	2.2	2.4	0.4	3.2	1.7		2.9

Table 5. Boron concentration (mg/liter) in secondary effluent and renovated water from various wells (1974).

Date	Continuous sample	WO	W 1-2	ECW	WCW	W 5-6	W 7	W 8	WE
12 Apr	0.80	0.7	0.70	0.7	0.9	0.8	0.7		0.7
10 May	0.68	0.86	0.78	0.77		0.76	0.8		0.75
5 Jul	0.61	0.73	0.71	0.68	0.96	0.71	0.8		0.74
27 Aug	0.64	0.72	0.80	0.76		0.74	0.78		
23 Oct	0.60	0.64	0.62	0.60	0.75	0.60		0.56	
20 Nov	0.75	0.64	0.60	0.57	0.75	0.58			
18 Dec	0.60	0.63	0.59	0.63	0.69	0.60			0.63

Table 6. Range and average number of bacteria in secondary effluent and renovated water.*

Type of Organism	Effluent		Renovated Water	
	Range	Average	Range	Average
Fecal coliform/100 ml	20,000-770,000	244,071	0-359	96
Fecal streptococci/100 ml	2,500-50,000	28,100	21-24	22
Salmonella sp./100 ml	17-26	21	0	0
Total bacteria/ml	820,000-4,410,000	1,811,400	600-41,000	10,278

* Results are averages of six bimonthly water samples from 3 wells in 1974, except for *Salmonella* which was determined twice in June and July in effluent and ECW water only.

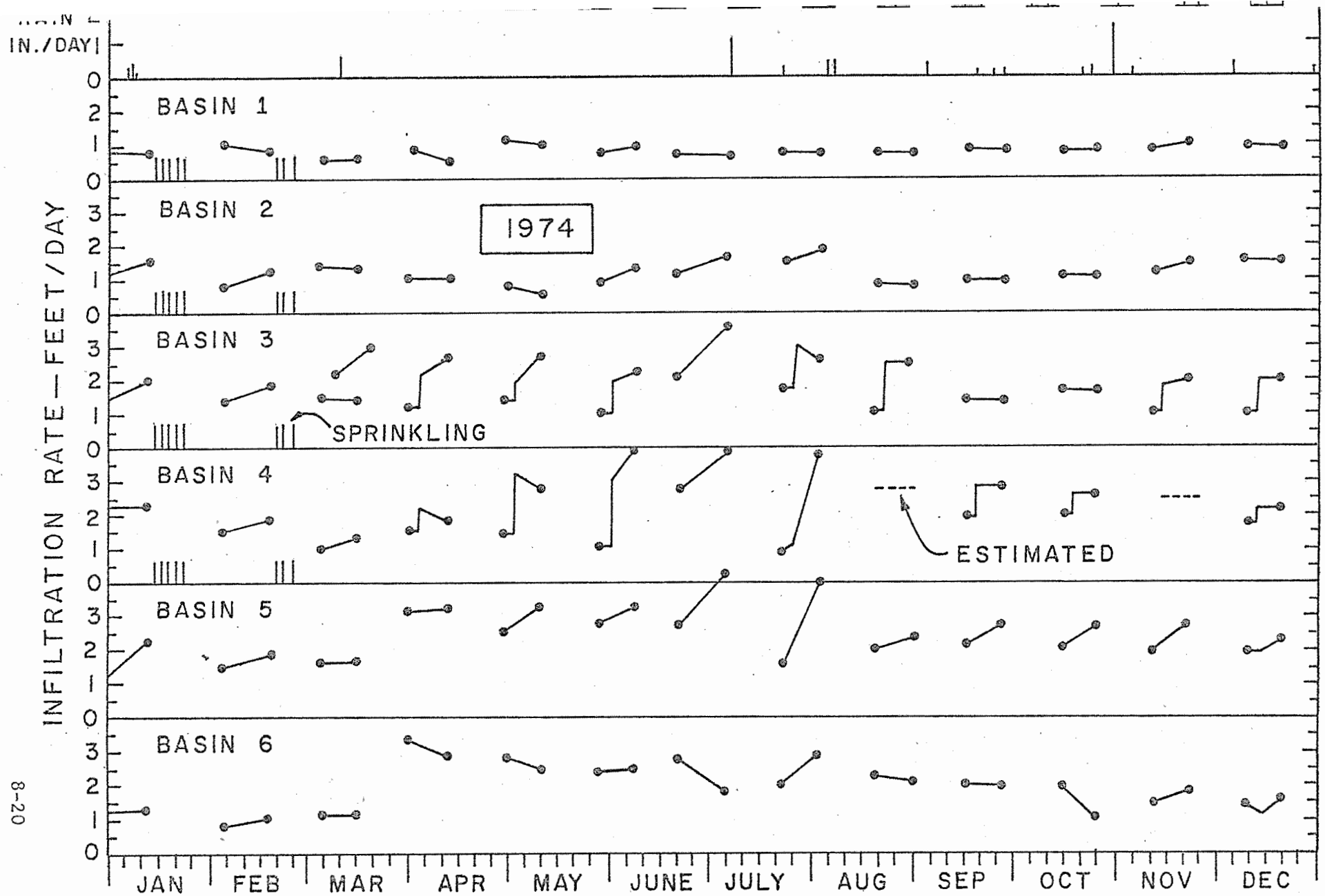


Figure 1. Infiltration rates in recharge basins and rainfall.

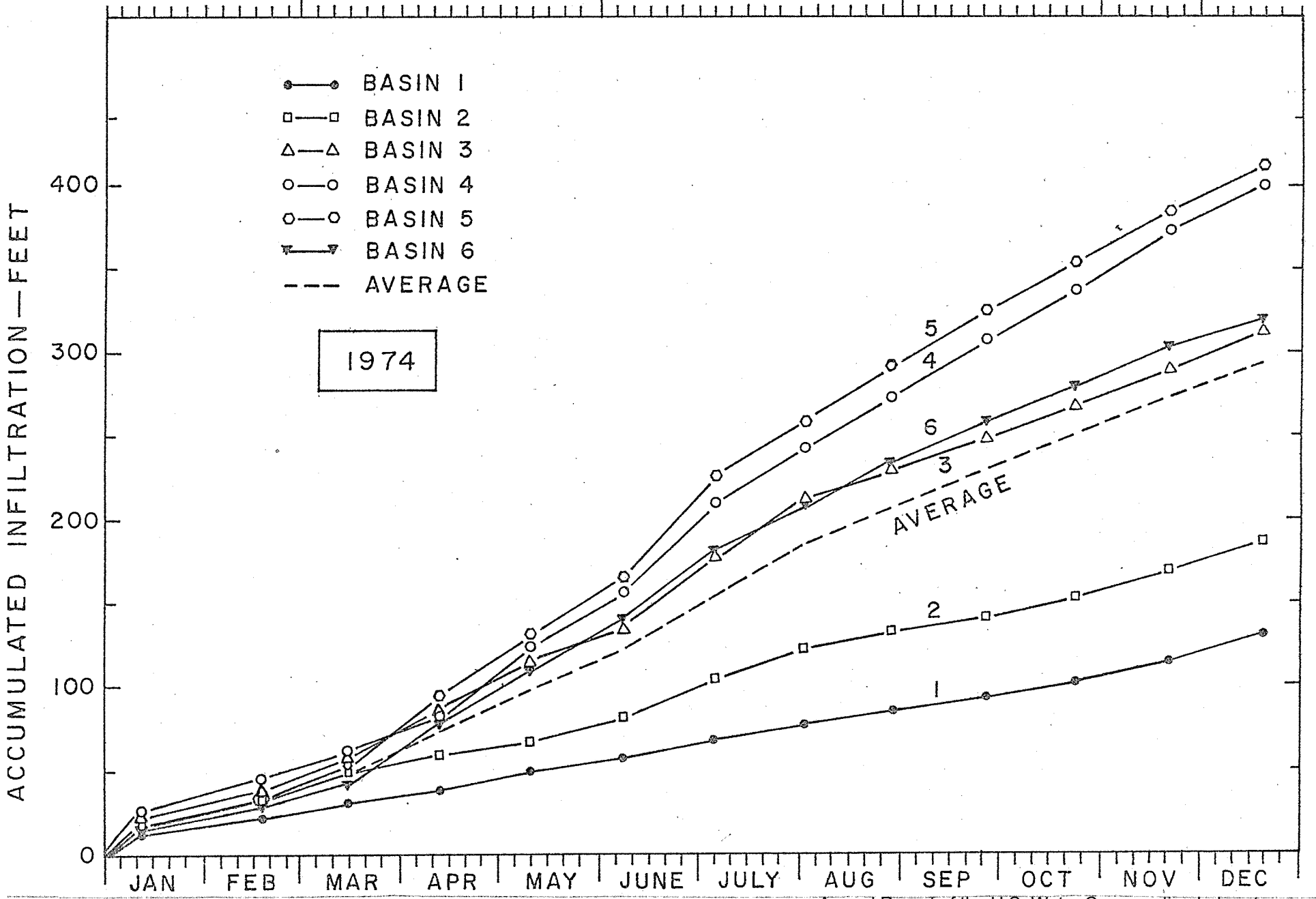


Figure 2. Accumulated infiltration in recharge basins.

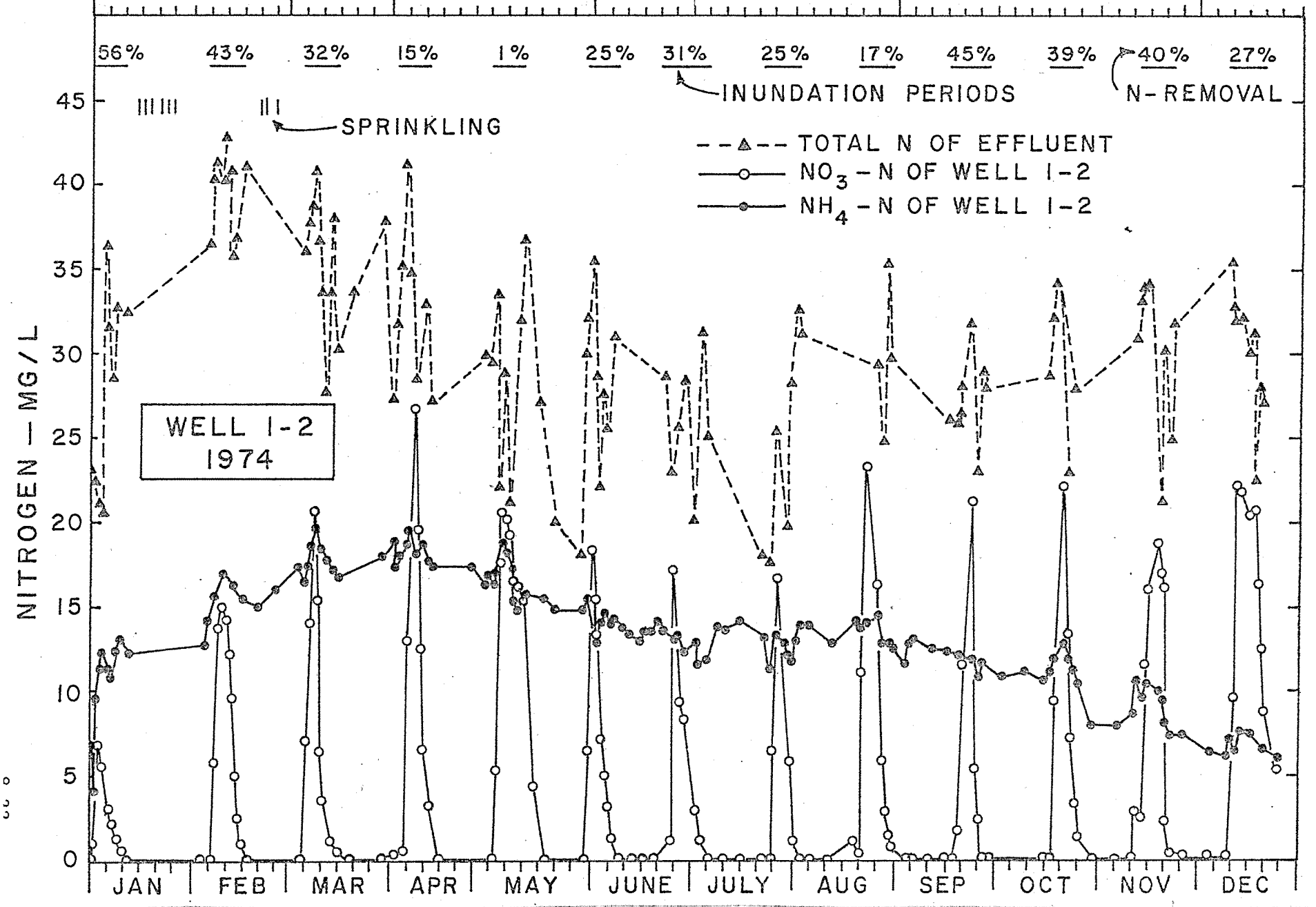


Figure 3. Total N in effluent and nitrate-N and ammonium-N in renovated water from well 1-2.

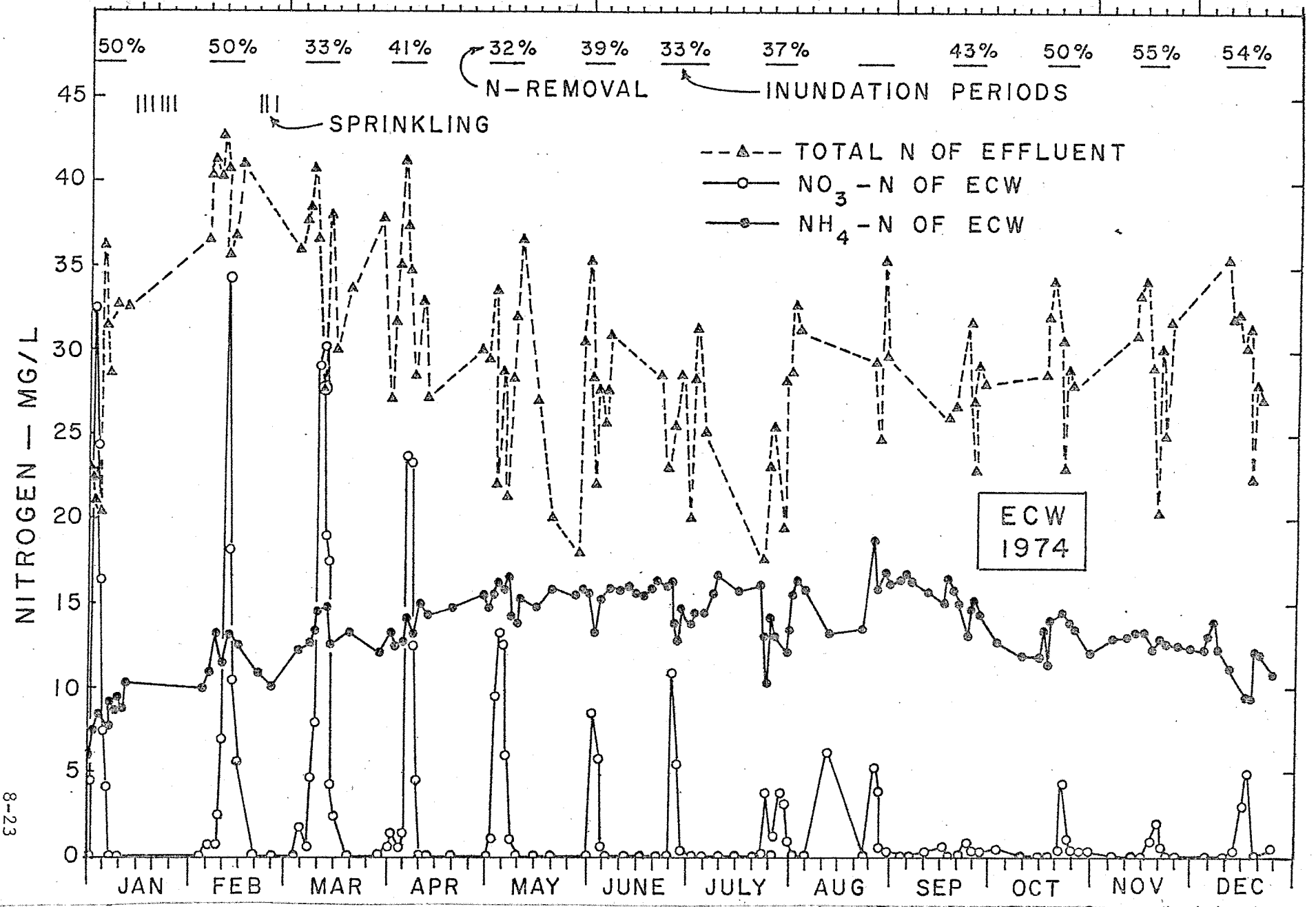


Figure 4. Total N in effluent and nitrate-N and ammonium-N in renovated water from ECW.

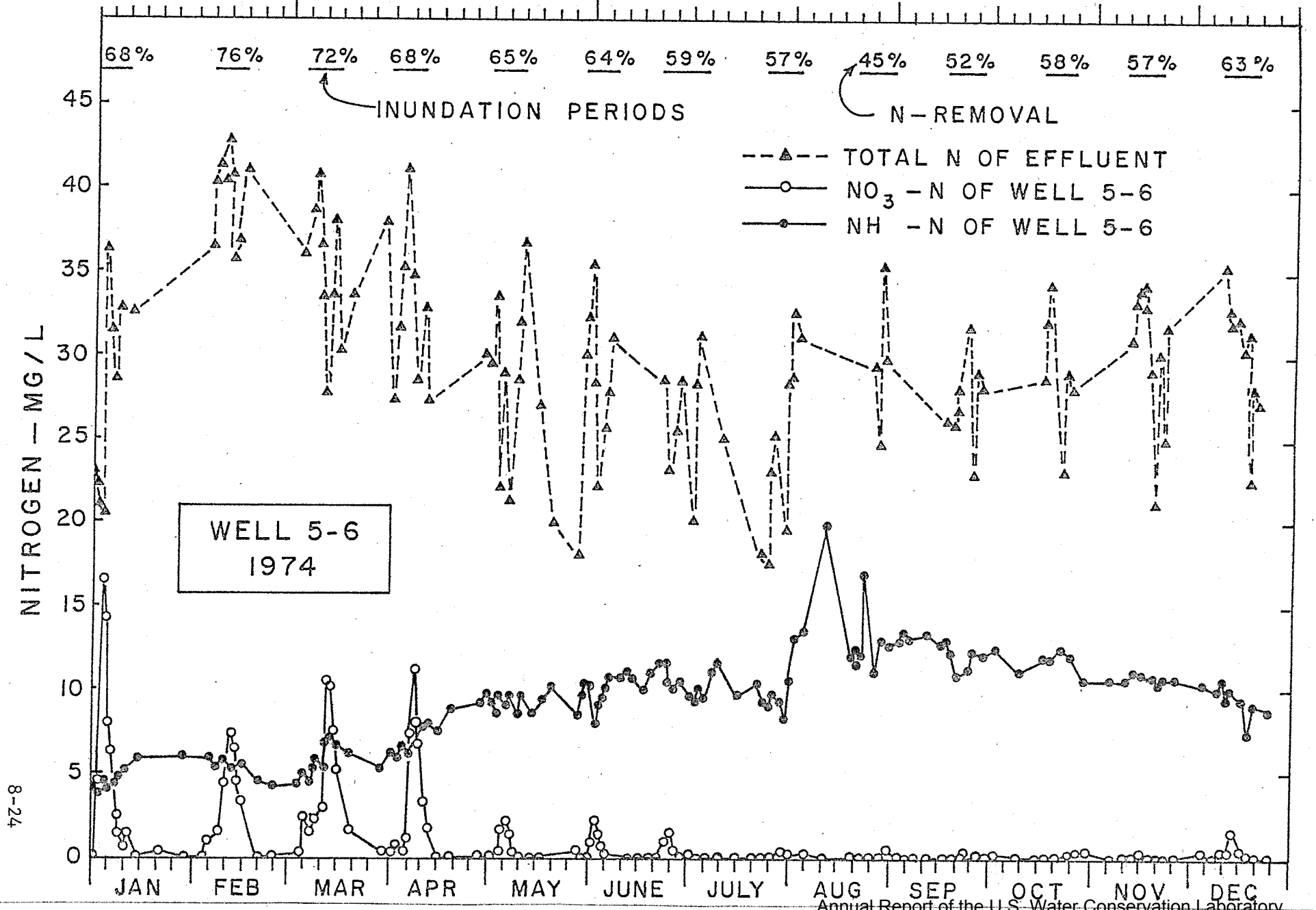


Figure 5. Total N in effluent and nitrate-N and ammonium-N in renovated water from well 5-6.

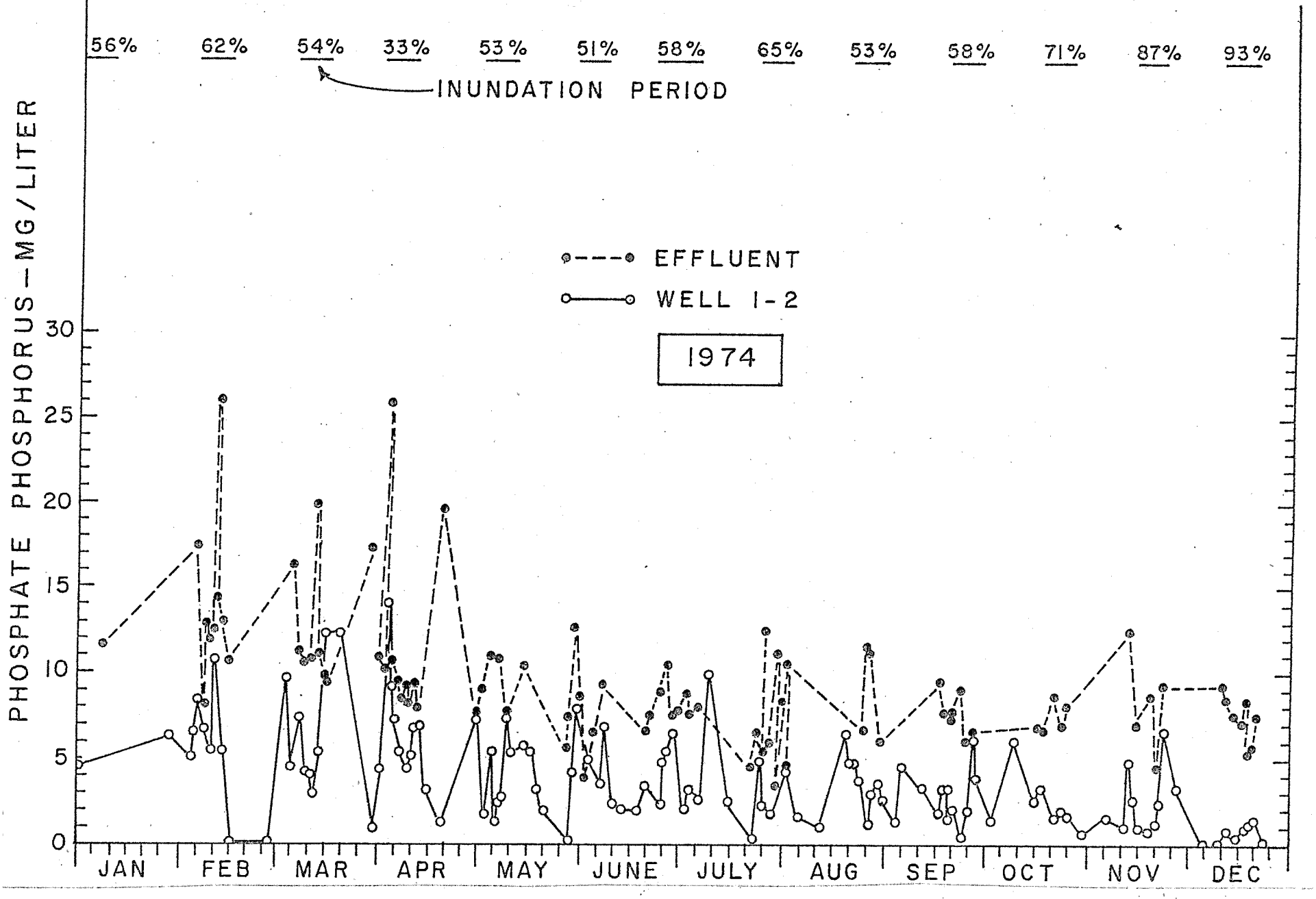


Figure 6. Phosphate-P in effluent and in renovated water from well 1-2.

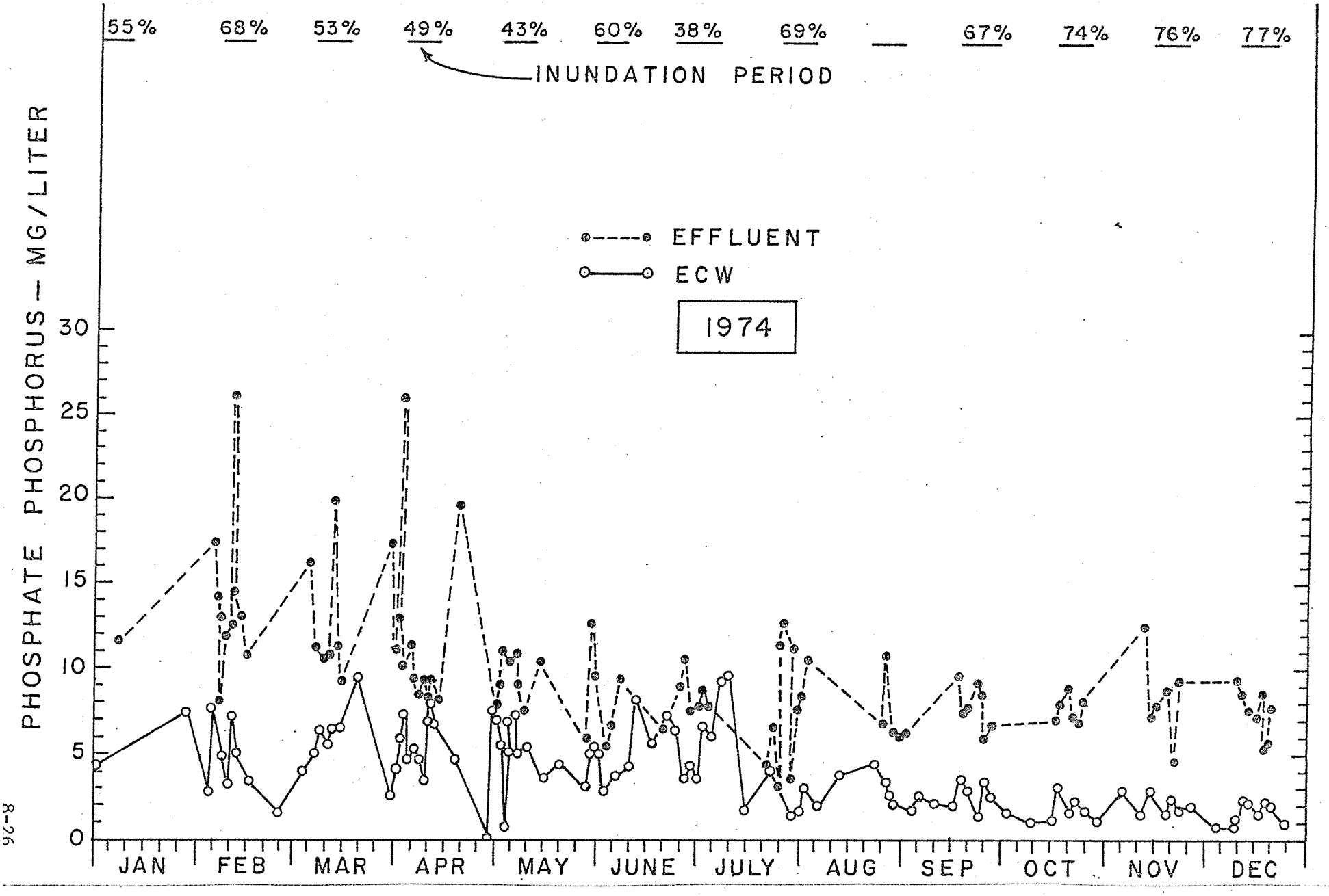


Figure 7. Phosphate-P in effluent and in renovated water from ECW.

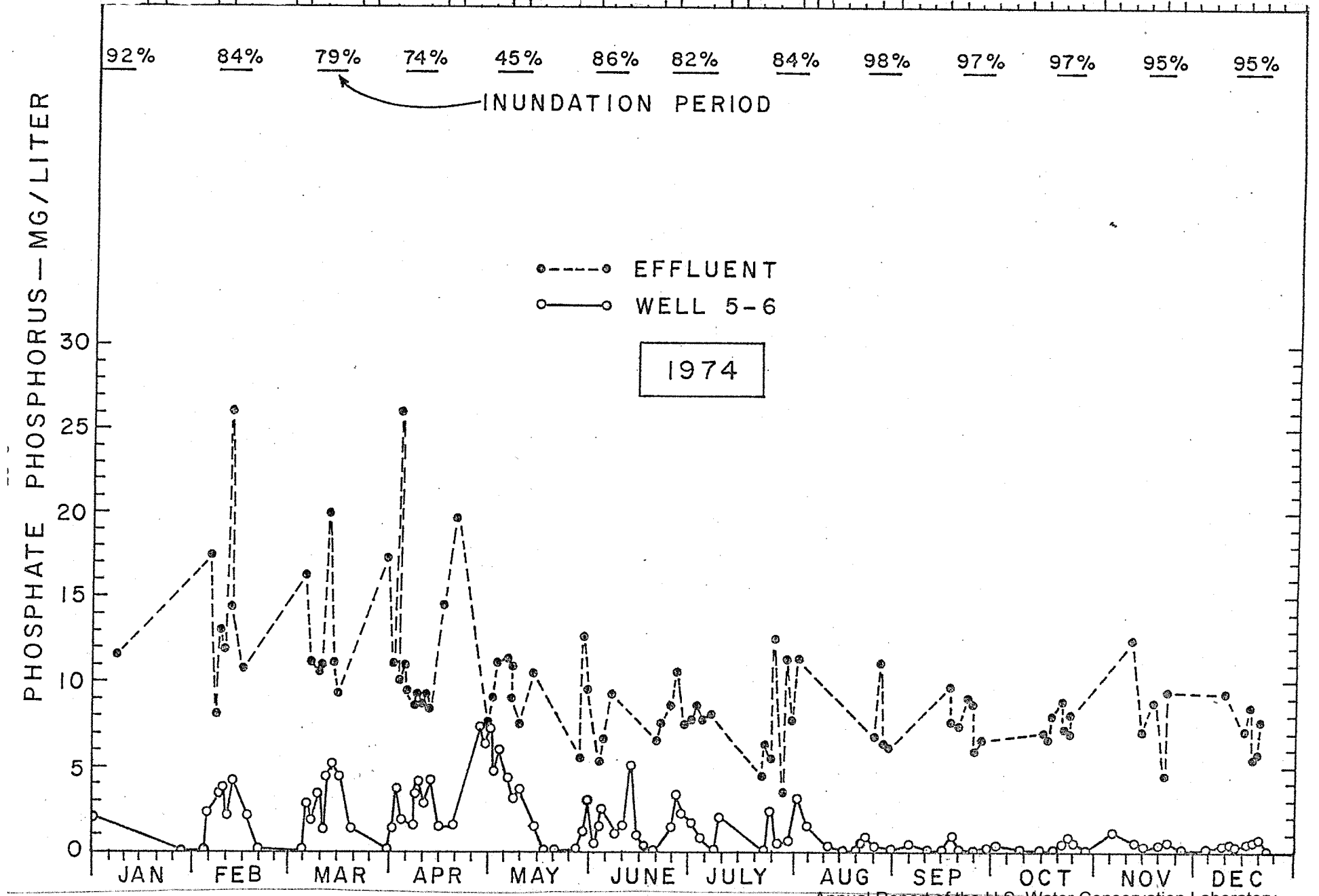


Figure 8. Phosphate-P in effluent and in renovated water from well 5-6.

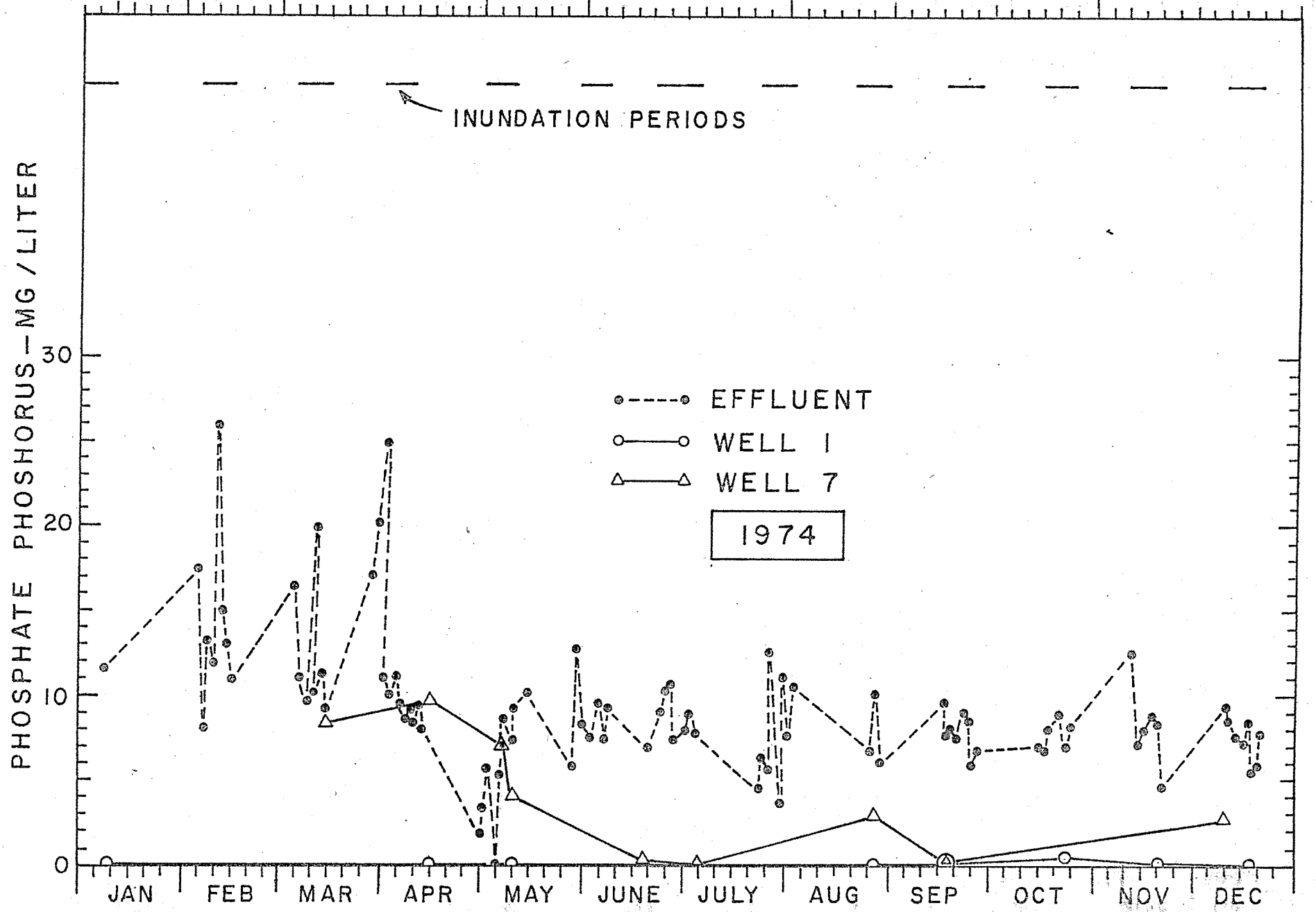


Figure 9. Phosphate-P in effluent and in renovated water from wells 1 and 7.

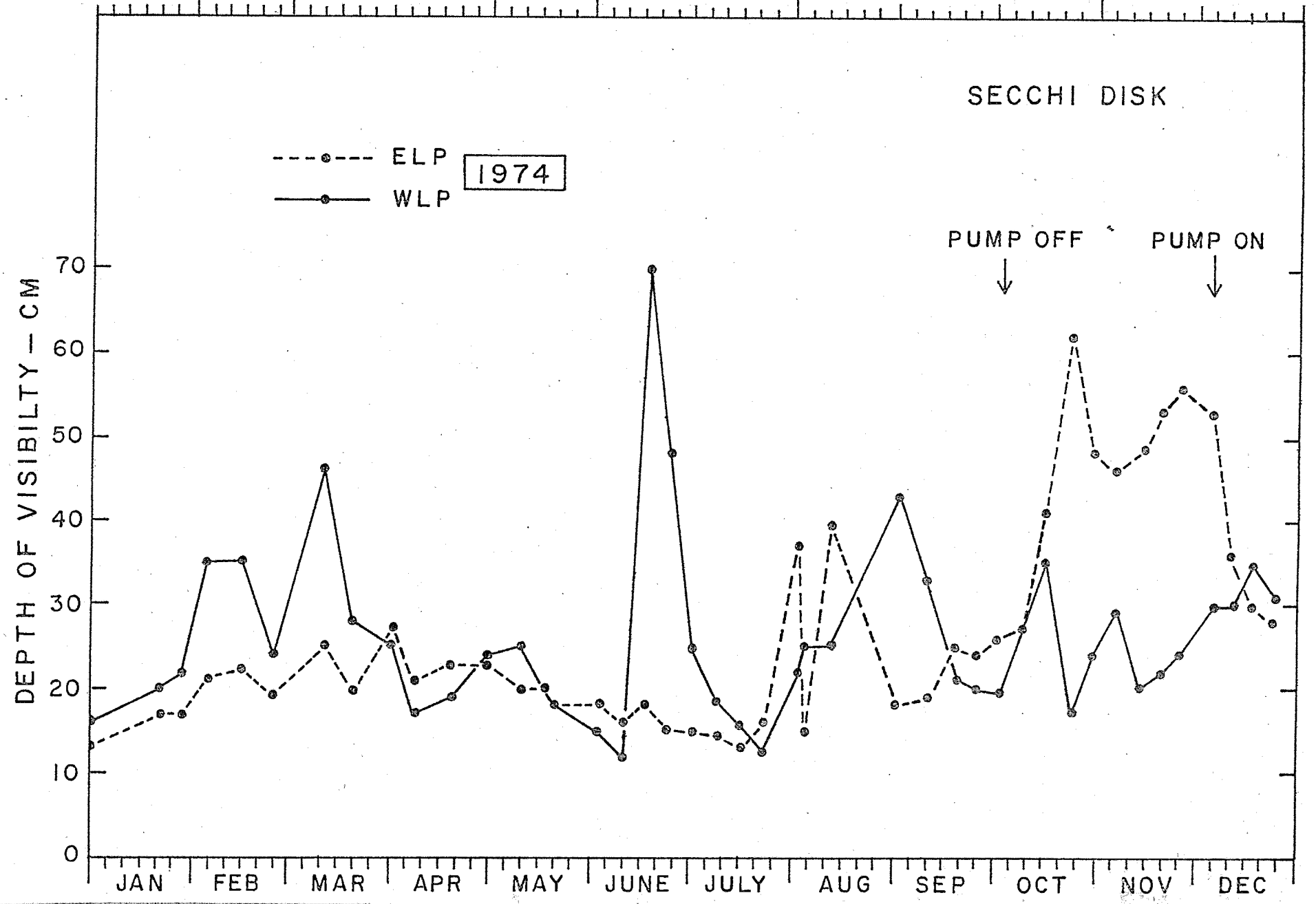


Figure 10. Secchi-disk readings in East and West Lined Ponds.

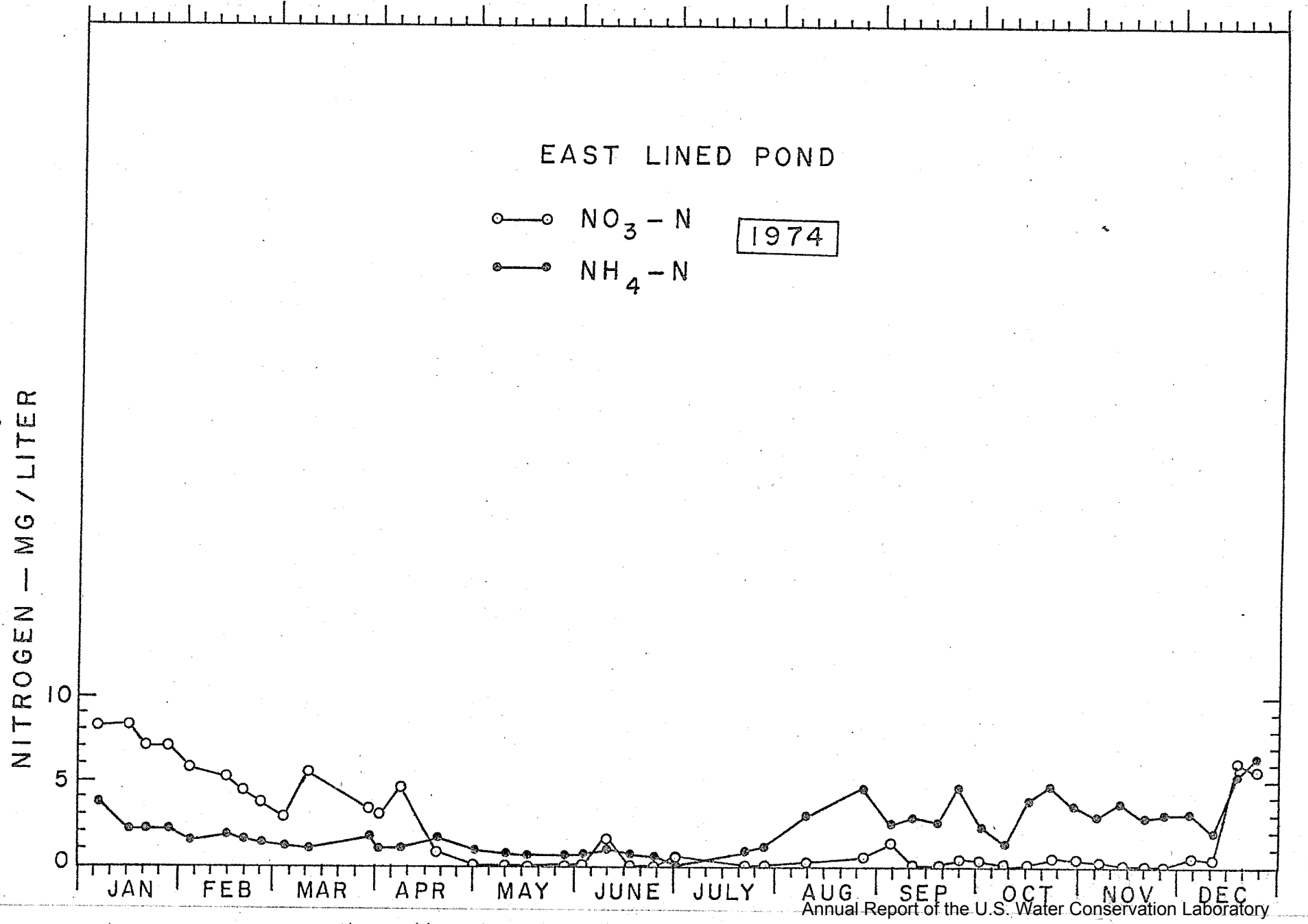


Figure 11. Nitrate-N and ammonium-N in East Lined Pond.

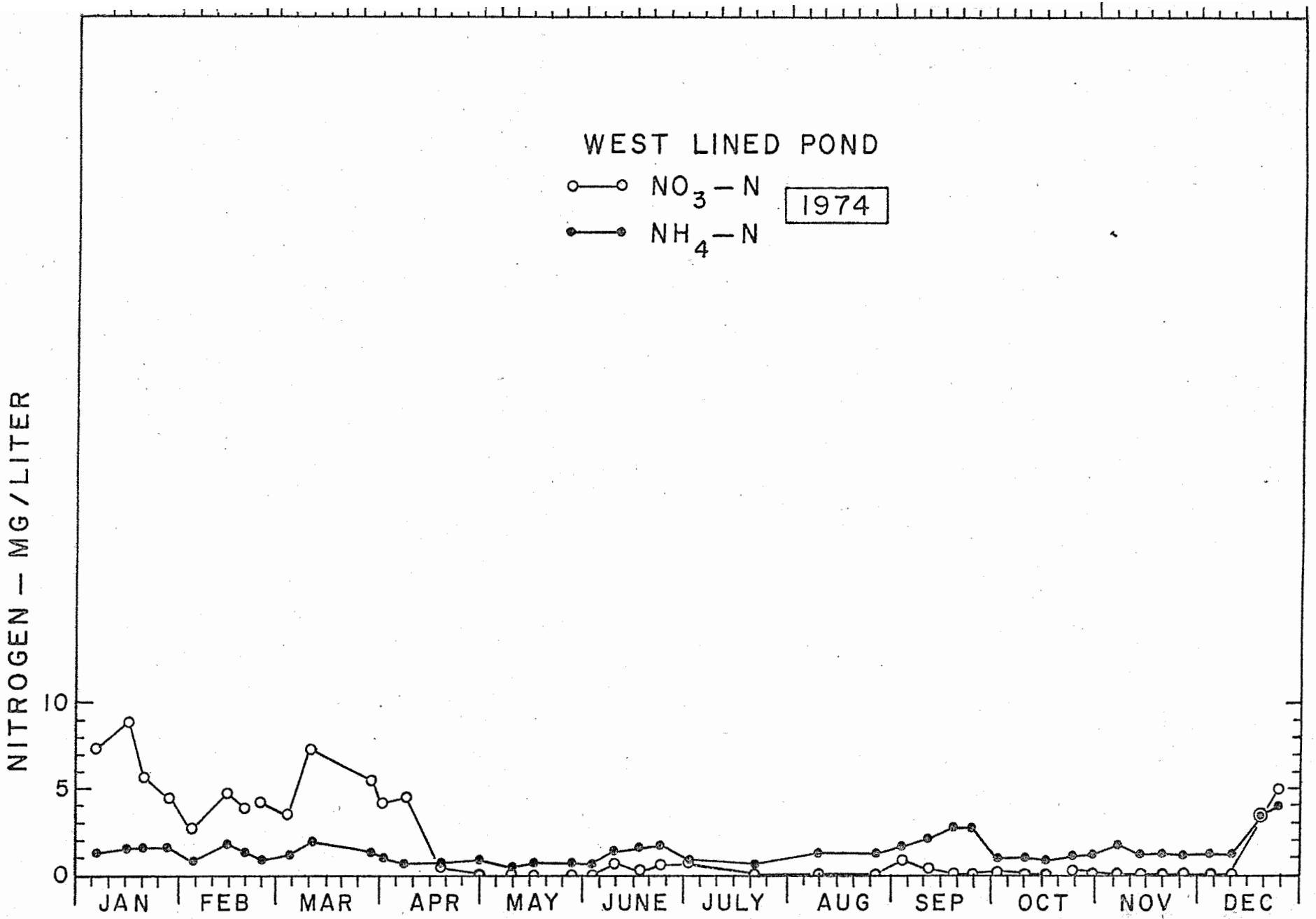


Figure 12. Nitrate-N and ammonium-N in West Lined Pond.

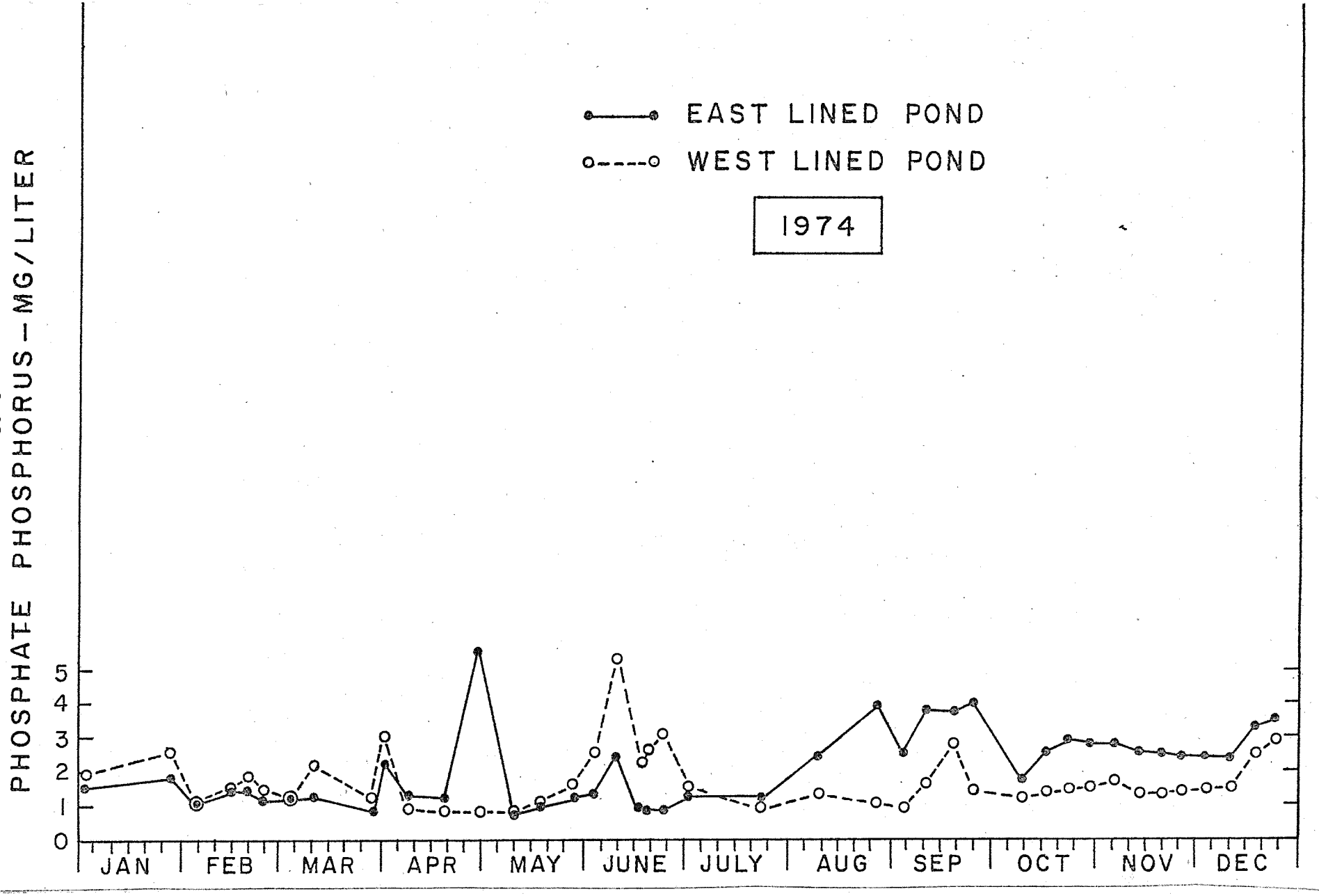


Figure 13. Phosphate-P in East and West Lined Ponds.

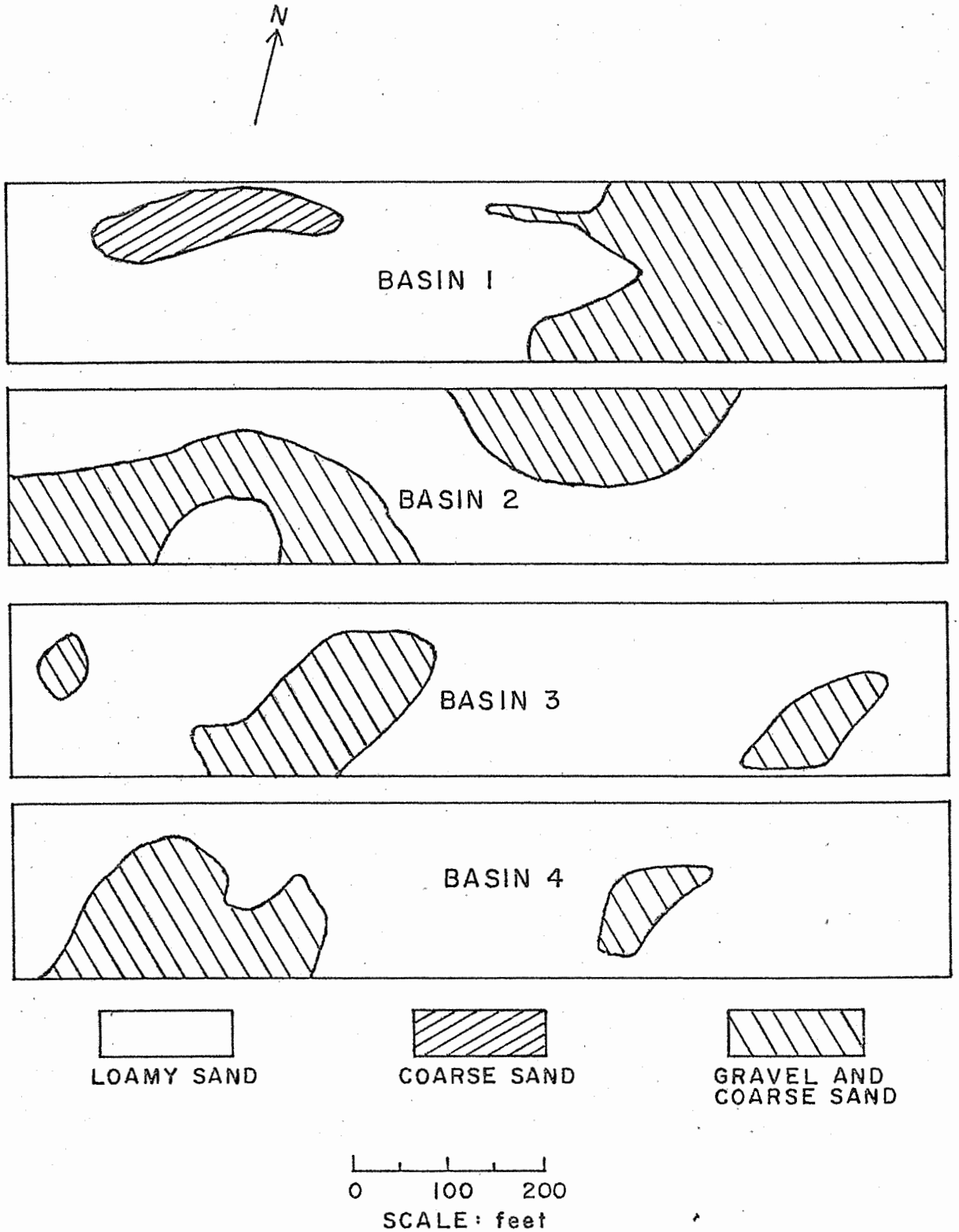


Figure 14. Exposed gravel and coarse sand areas in infiltration basins of 23rd Avenue Project.

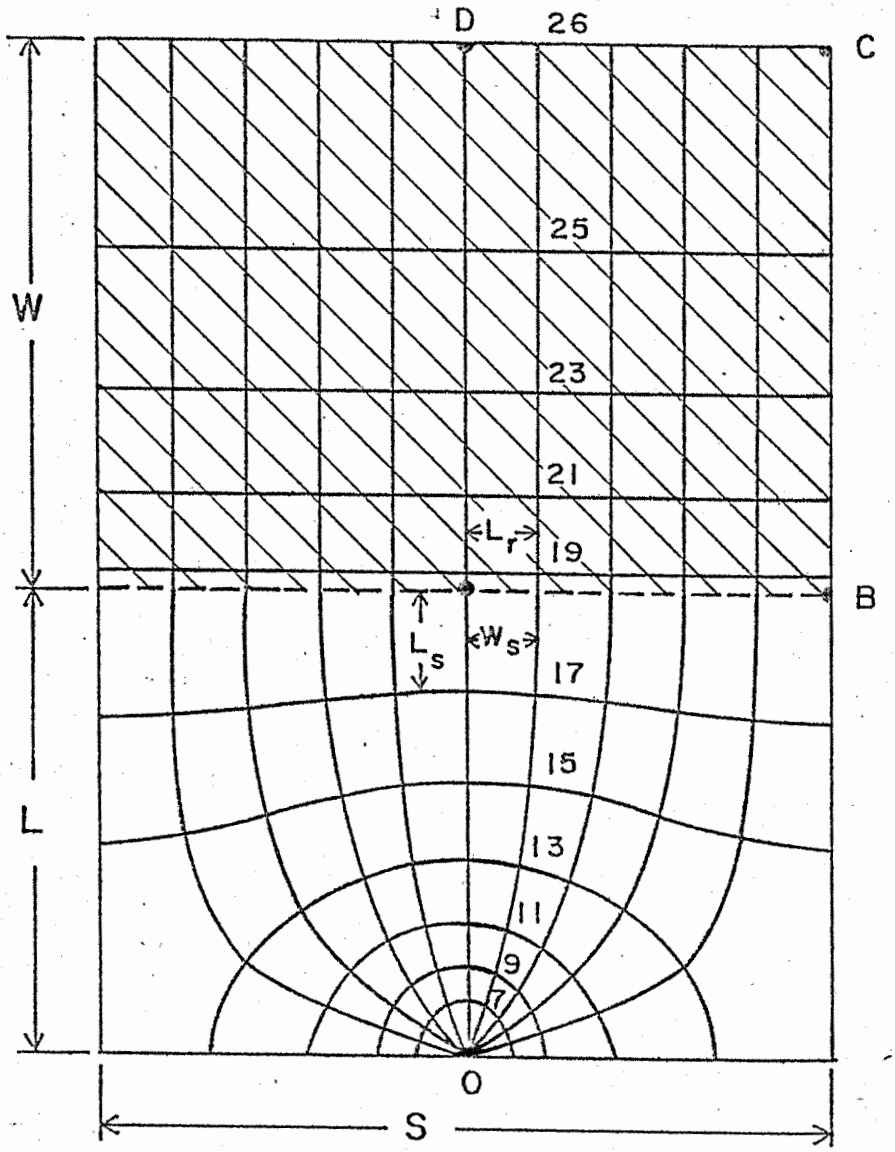


Fig 15. Streamlines and equipotentials (in feet above water table adjacent to well) for hypothetical system.

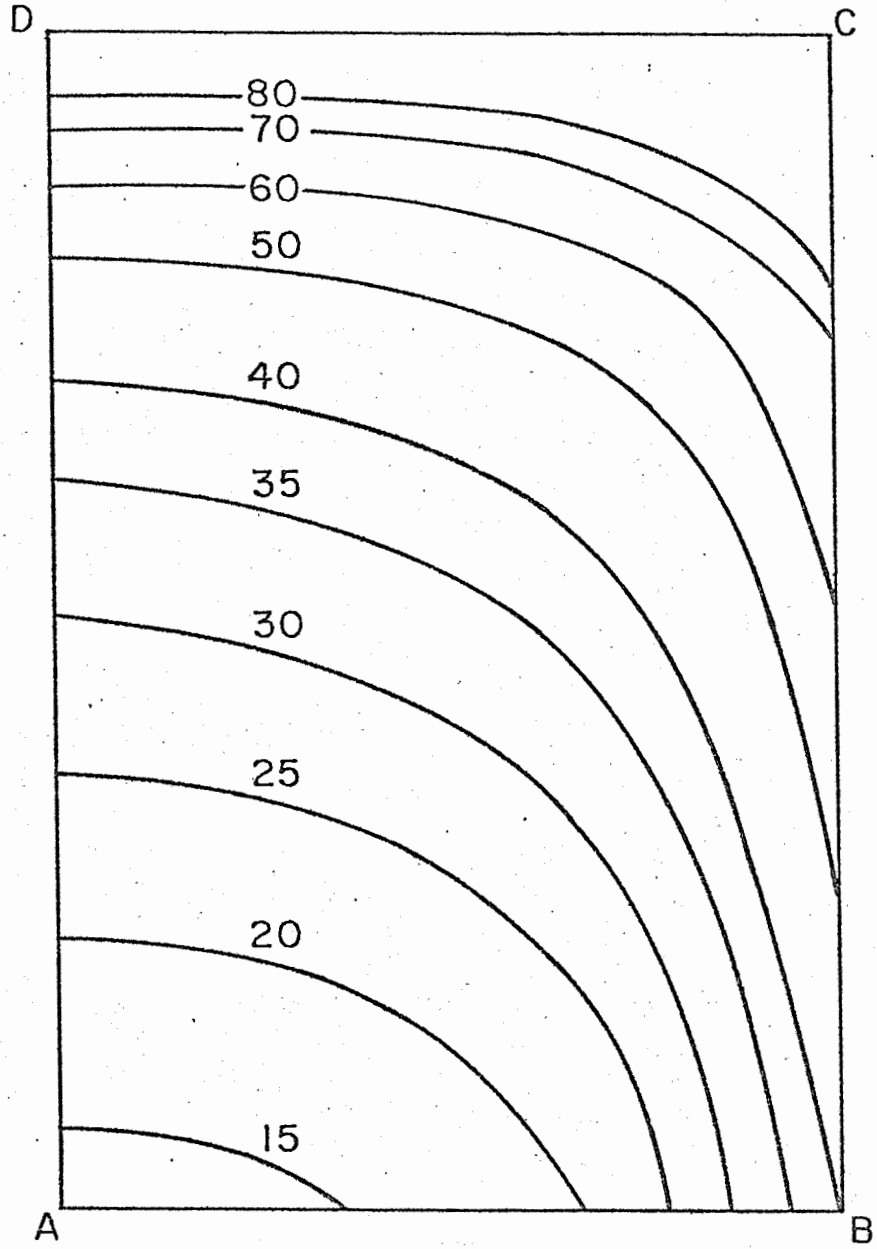


Fig. 16. Contours of equal travel time (on the curves) in days for the recharge system shown in Fig. 1.

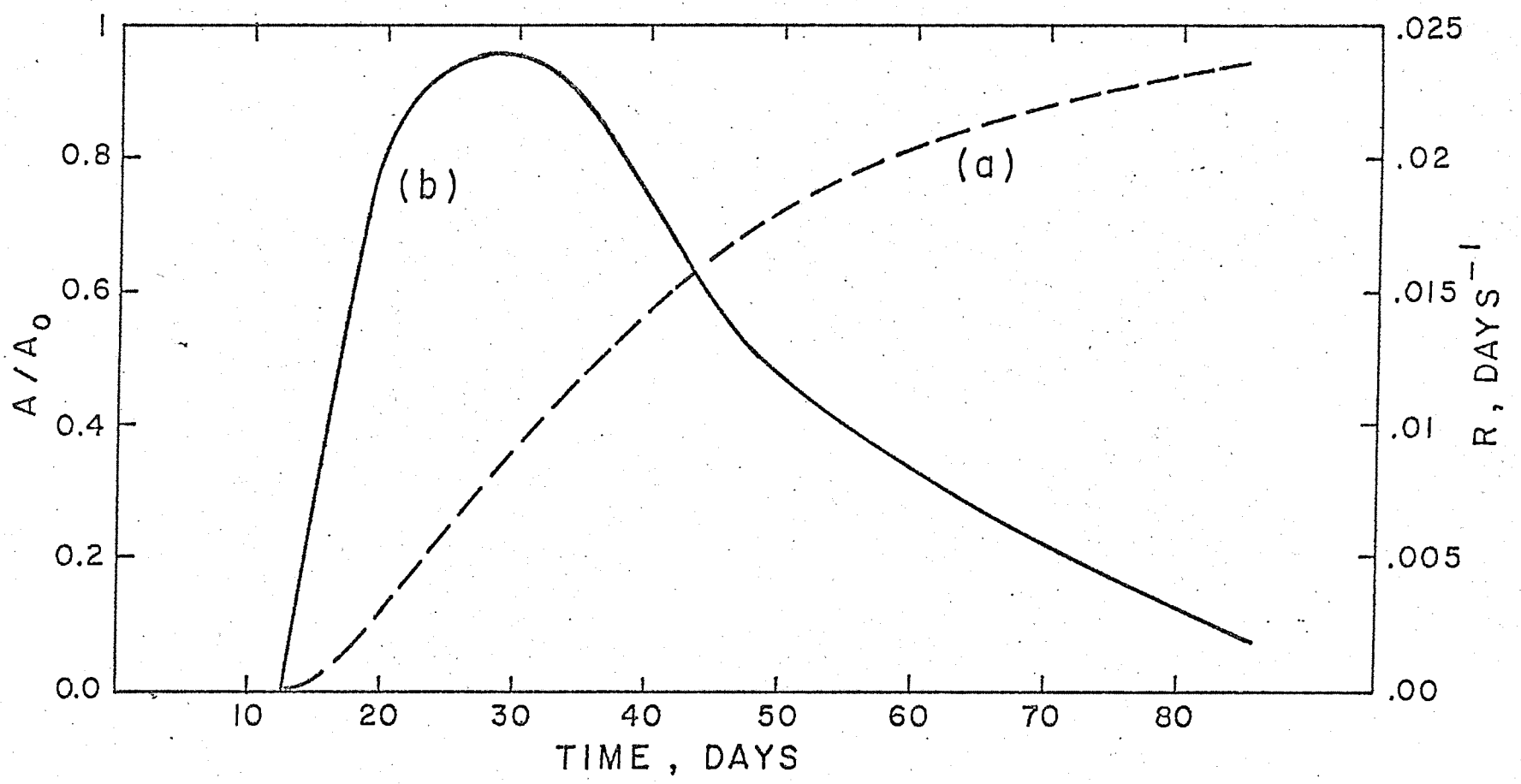


Fig. 17. Relative amount of newly infiltrated water arriving at well, A/A_o, (curve a), and relative rate of arrival, R, (curve b) as a function of time.

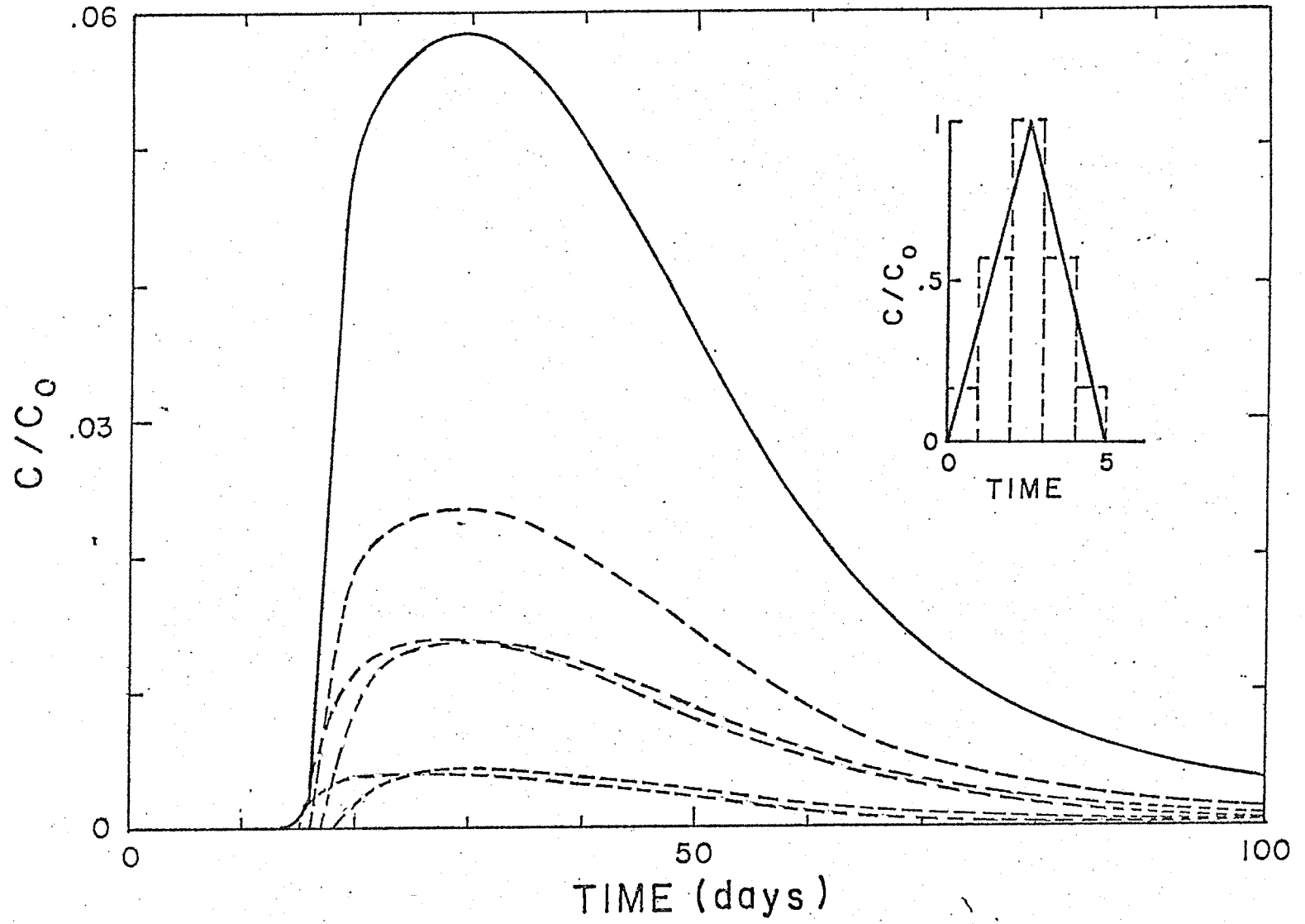


Fig. 18. Relative concentration at well C/C_o, of a triangular shaped nitrate peak in newly infiltrated water. Square wave approximation at nitrate peak (inset) is represented by dashed lines.

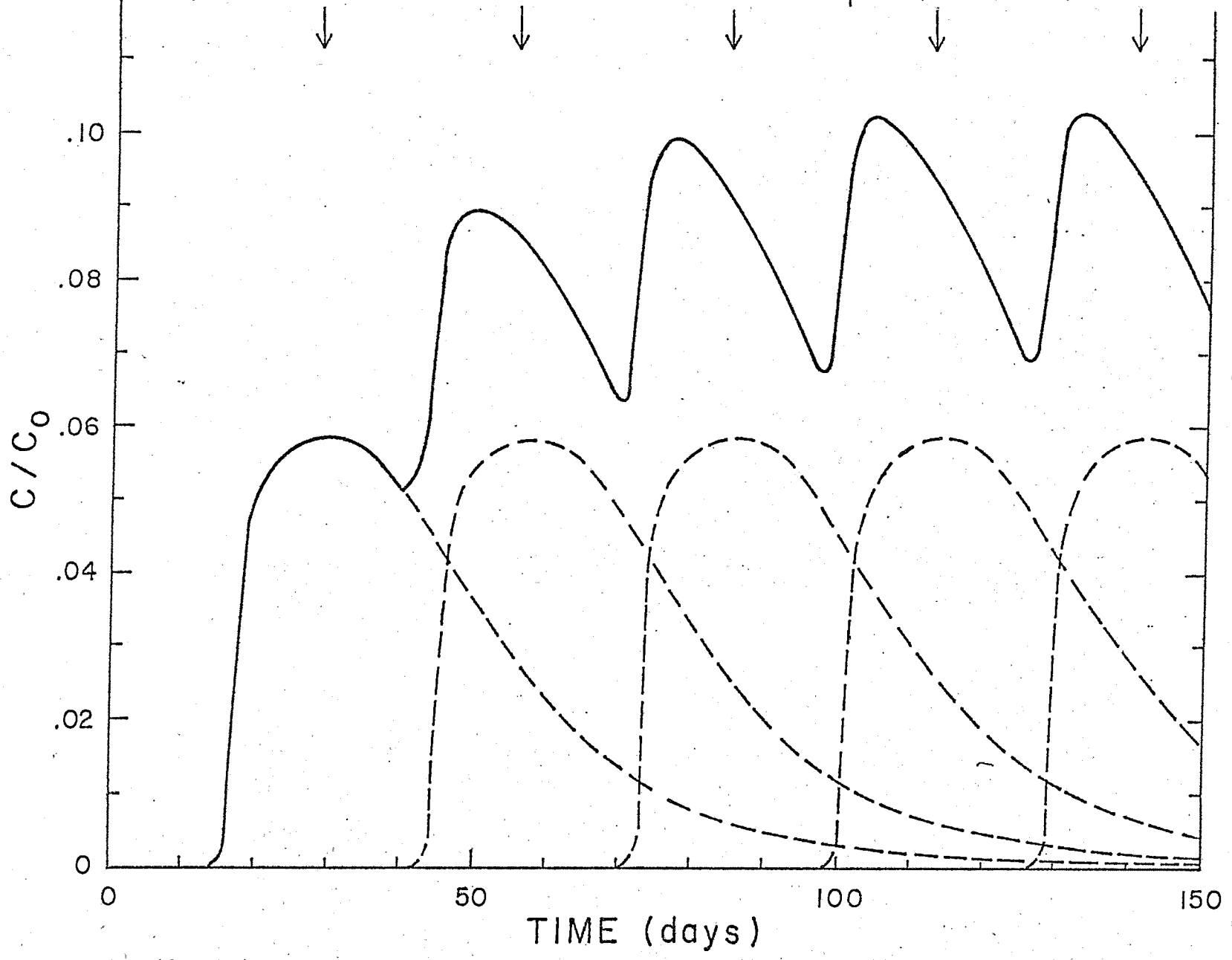


Fig. 19. Relative concentration of nitrate at the collection well after several inundation periods. Arrows represent start of inundation period.

TITLE: COLUMN STUDIES OF THE CHEMICAL, PHYSICAL, AND BIOLOGICAL PROCESSES OF WASTEWATER RENOVATION BY PERCOLATION THROUGH THE SOIL

CRIS WORK UNIT: 5510-12260-003 CODE NO.: Ariz.-WCL 68-3

INTRODUCTION:

Experiments on renovation of secondary sewage effluent by soil columns were concentrated in three areas during 1974:

(1) Additions of organic carbon (dextrose) as a pulse near the beginning of the flooding period in an attempt to stimulate denitrification;

(2) Experiments with vegetated soil columns to determine if denitrification is stimulated significantly by plants during high-rate land filtration;

(3) Experiments on phosphate removal by vegetated and nonvegetated columns at various infiltration rates.

Another experiment on the adsorption of polio virus by soil columns was initiated in December 1974.

PROCEDURE:

Carbon Pulse Experiments. Eight columns were used for laboratory studies including six columns packed in 1972 and two in 1973. The columns were flooded on schedules of 9 days wet alternated with 5 days dry. Addition of a 100 ppm C pulse to columns 4 - 8 was continued from last year until February 14. Then, a 200 ppm C pulse was added until August 30. Carbon was added as dextrose to the first 4 to 6 liters applied to the other columns.

Vegetated Soil Columns. Experiments were continued with nine 15-cm-diameter columns which were placed in an insulated building with the top of the pipes protruding through the roof and planted to bermudagrass. The three treatments used were (1) a bare soil surface, (2) vegetated with the forage removed, and (3) vegetated with the forage cut and returned to the soil surface. The columns were flooded on a schedule of 9 days wet and 5 days dry, and the grass was harvested during each dry period.

Phosphate Removal. Phosphate concentrations were determined on water draining from both sets of columns. Calcium and fluoride were also determined on samples from columns with different infiltration rates.

Virus Movement. A soil column with an infiltration rate of 1.5 to 2.0 ft per day was selected for initial experiments. Polio virus will be added to the sewage water at the rate of 5×10^4 PFU/ml, and samples will be taken at different levels in the profile. Later experiments will include different infiltration rates and virus loads.

RESULTS AND DISCUSSION:

Effect of Carbon Pulses on Denitrification. The percent N removal obtained by adding a 100 ppm carbon pulse was similar to the data collected in 1973, and represented an increase of approximately 20% of the applied nitrogen at each infiltration rate (Table 1). Adding a 200 ppm carbon pulse further increased N removal by approximately 15% of the applied nitrogen on the average. The results for the different carbon rates are difficult to compare in some cases because the infiltration rate usually decreased when additional carbon was added. The results from 1973 and 1974 for columns with similar infiltration rates are summarized in Table 2.

These two columns indicated that an additional 18 to 20% of the applied N was removed when a 100 ppm C pulse was added, and a 200 ppm C pulse further increased N removal by 10 to 12% of the applied N. The infiltration rate for column 8 varied between 21 and 23 cm/day for the three treatments, and the maximum N removal was 66% of the applied N. The maximum N removal rate for column 7 was 90% of the applied N. However, the infiltration rate dropped on the 200 ppm C treatment from 15 to 7 cm/day. These results show that N removal can increase by using carbon pulses. However, the nitrate peak was completely eliminated only in columns with infiltration rates below 15 cm/day. N removal was doubled in columns

at higher infiltration rates, but a nitrate peak still moved through the soil columns. The bacterial population must have been too low to completely denitrify a high nitrate peak during the detention time provided at the high infiltration rate. The reduction in infiltration rate ranged from 5 to 20% when 100 ppm C was added. Infiltration rates dropped 36 to 60% when 200 ppm C was added, except for column 8 which only dropped 6%.

Effect of Vegetation on Denitrification. Nitrogen removal was increased by growing bermudagrass in the soil columns. The grass stayed green throughout the year because it received some heat from the shelter enclosing the columns but produced very little dry matter during the winter months. Nitrogen removal by vegetated columns with the clippings removed was 14.4% more than N removal for bare soil columns for the January 8 - October 15 period (Table 3). The experiment was discontinued on October 15. N removal was increased by 18.5% during the period when the grass was growing vigorously. When the difference in N removal between the vegetated columns and the bare soil columns was plotted vs. time, the changes in N removal closely followed the seasonal changes in dry matter production by the bermudagrass (Figure 1). The grass probably stimulated denitrification by providing organic carbon for the denitrifiers. The stimulation was probably due to root exudates since denitrification was affected only when the grass was growing vigorously. The average infiltration rates for the columns ranged between 18 and 25 cm/day. Each treatment block of three columns averaged 21 cm/day.

When grass clippings were returned to the soil surface, nitrogen removal was less than when the clippings were removed (Table 3). N removal when clippings were returned was only 4% more than N removal by bare soil columns. Apparently, adding clippings to the soil surface did not provide organic carbon for denitrification beneath the surface. Data from 1973 showed that the oxidation-reduction

potential in the sewage water ponded on the soil surface was negative during much of the day for columns where clippings were returned to the soil surface. This might have reduced the amount of NH_4-N oxidized to NO_3-N in the ponded water. The NO_3-N formed in the ponded water would almost certainly be denitrified after it infiltrated below the soil surface. Therefore, inhibition of nitrification in the water before infiltration could reduce the overall amount of nitrate reduced in the soil columns. Nitrification during the dry period was not affected by the clippings because NH_4-N concentrations in water samples from the columns were always below 0.5 ppm.

The total yield of bermudagrass forage was 5.8 kg/m^2 of dry matter during the year (Table 4). This indicates that the grass grew quite vigorously even though it was flooded for 9 out of every 14 days. However, the grass was never completely submerged.

Phosphate Removal. Phosphate removal increased as the infiltration rate decreased (Figure 2). The data from six columns were averaged over a 6-month period (January-July) when the PO_4-P content of the sewage averaged 12.1 ppm. The effect of flow velocity is further illustrated by the decline in phosphate concentration in the water draining from the columns after the application of sewage was stopped (Figure 3). The phosphate concentration in water from column 4 which had the highest flow velocity during the flooding period declined drastically as the flow velocity decreased during the drainage period when no sewage was applied. The phosphate concentration in drainage water from the other columns with lower velocities decreased at a lower rate. The average flow velocities of the different columns were similar during the drainage period when no sewage was applied, even though the velocities of the different columns varied considerably during the flooding period.

Several columns were packed with a mixture of 2 parts sand from field recharge basins and 1 part builders' sand. The sands

from the two sources are similar in composition, but the builders' sand had not previously been flooded with sewage water. Phosphate concentrations in water from these columns were low (0.5 to 1.0 ppm) for more than 200 days of flooding on a schedule of 9 days flooded alternated with 5 days dry. The phosphate concentrations then increased and leveled off at different concentrations according to the various infiltration rates (Figure 4). Phosphate concentrations from columns with high infiltration rates increased more rapidly and equilibrated at a higher level than phosphate concentrations from columns with lower infiltration rates. A decline in phosphate concentrations from all columns occurred after about 460 days due to a decrease in the phosphate concentration of the incoming sewage water. Phosphate removal was 73 and 58% for the 18.2 and 22.3 cm/day infiltration rates, respectively, after the phosphate concentrations in water from the columns leveled off as shown in Figure 4. Phosphate removal was 90 to 95% for all columns for the first 200 days of intermittent flooding. Approximately 35 m of sewage was applied before the phosphate concentration started to increase after 230 to 270 days. The start of the increase in phosphate concentration depended upon the infiltration rate which governed the total amount of sewage applied.

After the level of phosphate in water from a soil column was established, it could also be lowered by decreasing the infiltration rate. Laboratory columns flooded with sewage water declined, and then increased when a pulse of carbon was added to the sewage water and then omitted. The phosphate concentration in water collected from these columns decreased and reached a lower equilibrium concentration when the infiltration rate decreased, and returned to a higher equilibrium concentration when the infiltration rate returned to the higher level (Figures 5 and 6). The column flooded at infiltration rates of 7 to 20 cm/day (Figure 5) responded immediately to changes in infiltration rate, while phosphate

concentrations from another column with rates of 14 to 39 cm/day seem to lag about three flooding cycles behind infiltration rate changes (Figure 6).

Thus, it appeared that initial adsorption of phosphate by a soil mixture containing sand which had not been treated previously with sewage was not time-dependent. The initial adsorption capacity was saturated, and removal continued by some adsorption or precipitation reaction which was time-dependent. The level of phosphate removal appeared to be established by the detention time in the soil column, since the equilibrium phosphate concentration in water draining from the columns could be raised or lowered by increasing or decreasing the infiltration rate. The fact that phosphate removal could be increased by decreasing the infiltration rate after the soil has equilibrated with the sewage water at that rate shows that phosphate removal is more than a simple adsorption reaction.

Fluctuations in phosphate concentrations during the flooding and drying cycles were compared with changes in concentrations of other ions in an attempt to learn something of the nature of the phosphate removal reactions. Phosphate concentrations decreased during the first 4 days of the flooding period, and then increased. The dip in the phosphate concentration corresponded exactly with the occurrence of the nitrate peak which was measured near the beginning of each flooding period (Figure 7). The nitrate peak was due to leaching of nitrate formed during the previous dry periods. Therefore, the nitrate peak can be used as tracer to indicate when the water applied at the beginning of the flooding period begins to move through the outlet of the bottom of the column. The water collected ahead of the nitrate peak was retained in the column during the dry period and then displaced when the next flooding period began. Therefore, the lowest phosphate concentrations measured during the flooding period were in water which had been applied at

the beginning of the flooding period. This may indicate that drying the soil restores some of its phosphate adsorption capacity.

Field observations have indicated that phosphate removal may parallel fluoride removal. However, this does not appear to be true for the soil columns. The fluoride concentration varied only slightly during the flooding period (Figure 8). Also, phosphate concentrations declined as water drained from the columns during the dry period, but the fluoride concentrations increased slightly. Finally, the fluoride concentrations varied only slightly as infiltration rates increased (Table 5).

The dip in the phosphate concentration during the flooding period coincided with a peak in the calcium concentration (Figure 8). However, at other times calcium concentrations varied widely, but changes in phosphate concentrations were relatively small (Figures 9 and 10). Also, the greatest variation in phosphate concentration occurred in the water draining from the columns during the dry period, and calcium concentrations did not vary much in those samples. The calcium concentration in the sewage water was 55 $\pm$ 3 ppm. The calcium concentrations in water samples from the columns were always above that level, and the peak calcium concentrations in column samples were usually more than twice as high as the sewage samples. However, these analyses were for total calcium and do not show how much calcium was present as Ca^{+2}.

Bermudagrass greatly influenced the movement of phosphate through the soil columns. Phosphate concentrations in water from vegetated and nonvegetated columns with similar infiltration rates were about the same until spring when the grass began to grow (Figure 11). Phosphate concentrations in samples from vegetated columns then increased until they were sometimes higher than phosphate concentrations in the incoming sewage water. When plant yield of dry matter and phosphate concentration were plotted vs. time, the curves were almost identical (Figure 12). The plant root

exudates evidently tended to keep phosphate in solution. The phosphate concentration still increased with infiltration rate for vegetated columns. Thus, the phosphate concentration remaining in the reclaimed water was affected by the infiltration rate (or flow velocity), the phosphate concentration of the sewage water, the previous treatment of the soil, and the presence of plants. The effect of other ions on PO_4-P removable is still uncertain.

SUMMARY AND CONCLUSIONS:

Experiments with soil columns during 1974 concentrated on the stimulation of nitrogen removal by adding carbon pulses at the beginning of the flooding period, and by growing plants in the soil columns, and on factors affecting phosphate removal. Nitrogen removal at each infiltration rate was increased by adding a 100 ppm carbon pulse, and was further increased by adding a 200 ppm carbon pulse. Therefore, a relationship between infiltration rate and % N removal probably exists for each level of carbon added. Infiltration rates were decreased 5 to 20% by adding a 100 ppm C pulse, and 36 to 60% by adding a 200 ppm C pulse. However, one column maintained its infiltration rate. A comparison of treatments with similar infiltration rates showed that the 100 ppm pulse increased N removal by about 18 to 20% of the applied nitrogen, and a 200 ppm pulse further increased N removal by 10 to 12% of the applied N. The nitrate peak was completely eliminated in columns with infiltration rates below 15 cm/day.

The bermudagrass increased nitrogen removal by 18.5% of the applied nitrogen during the period when the grass was actively growing. A plot of the difference in % nitrogen removal between the vegetated and nonvegetated columns vs. time followed closely a plot of yield of dry matter vs. time. Returning the grass clippings to the soil surface resulted in less N removal than removing the clippings. This might have been due to a reduction in the amount of NH_4-N nitrified in the water ponded above the soil surface and a subsequent reduction in the total amount of nitrate-N denitrified.

The total yield of bermudagrass forage was 5.8 kg/m^2 of dry matter, indicating that the grass grew vigorously even though it was flooded for 9 out of every 14 days.

Phosphate removal by the soil columns increased as the infiltration rate decreased. Phosphate removal also increased as the flow velocity decreased during the drainage period when no water was applied. A mixture of sand which had never been treated with sewage and sand from basins which had been flooded with sewage water for several years was packed into columns. Phosphate concentrations from these columns were below 1 ppm for the over 200 days of intermittent flooding on a schedule of 9 days wet and 5 days dry. Phosphate concentrations increased and leveled off at different concentrations, depending upon the infiltration rate of the column. This concentration remained relatively stable as long as the phosphate concentration in the incoming sewage water was constant. After the phosphate level in water from a column was established, it could be lowered by decreasing the infiltration rate.

These results indicated that when sand was initially flooded with sewage water, phosphate was adsorbed by a reaction which was independent of flow velocity or detention time. This adsorption capacity was apparently saturated, and then phosphate was removed by an adsorption or precipitation reaction which was dependent on the detention time. The immediate response of some columns to changes in infiltration rate or flow velocity suggested a precipitation reaction.

There seemed to be little relationship between changes in F and phosphate concentrations. Fluctuations in calcium concentrations seem to coincide with fluctuations in phosphate concentrations during the flooding period but not during the drainage or dry period. Also, the magnitude of the calcium fluctuations was much greater than that of the phosphate. Calcium concentrations were always higher in

column samples than in the incoming sewage water, and calcium moved in concentrated peaks which coincided with the nitrate peaks.

Bermudagrass greatly increased the phosphate concentration in column samples. When plant yield of dry matter and phosphate concentration was plotted vs. time, the two curves were almost identical in shape. The plant root exudates evidently kept phosphate in solution.

Future work will include experiments on nitrogen and phosphate removal by columns flooded with primary effluent, virus movement experiments, and the effect of changing the composition of the sewage water on phosphate removal.

PERSONNEL: J. C. Lance

Table 1. The effect of carbon pulses on nitrogen removal

Column	% N removal		Infiltration rate (cm/day)	
	100 ppm C	200 ppm C	100 ppm C	200 ppm C
5	61	67	17.5	11.3
6	44	60	26.2	20.6
7	60	90	16.4	6.9
8	52	65	19.1	21.7

Table 2. Effect of addition of carbon pulse on nitrogen removal in soil columns with similar infiltration rates

Column number	Sewage only	Sewage + 100 ppm C pulse	Sewage + 200 ppm C pulse
		% N removal	
7	61	79	90
8	33	54	66

Table 3. Nitrogen removed by vegetated columns

Date	Grass-H*	Grass-R	No grass
1974	%	%	%
1/8 - 1/22	46.7	44.2	45.7
1/22 - 2/5	19.8	23.8	20.2
2/5 - 2/19	24.7	16.9	25.0
2/19 - 3/5	7.2	21.2	7.8
3/5 - 3/19	21.2	20.1	7.5
3/19 - 4/16	40.1	43.5	29.0
4/16 - 4/30	35.2	29.3	29.4
4/30 - 5/14	22.4	6.4	10.9
5/14 - 5/28	63.2	46.8	46.0
5/28 - 6/11	41.6	23.2	17.8
6/11 - 6/25	64.9	47.4	51.2
7/9 - 7/23	48.1	19.6	15.7
7/23 - 8/6	46.8	22.1	15.6
8/6 - 8/20	56.4	43.6	42.0
8/20 - 9/3	47.0	25.3	12.3
9/3 - 9/17	75.7	69.9	67.5
9/17 - 10/1	38.6	15.7	7.8
10/1 - 10/15	72.5	60.0	62.4
Average	42.9	32.1	28.5
Average 3/5 - 10/15	48.1	33.8	29.6

*Grass-H - clippings harvested.

Grass-R - clippings returned to soil surface.

Table 4. The yield of bermudagrass forage grown in soil columns flooded with sewage water on a schedule of 9 days wet alternated with 5 days dry. 1974.

Date	Columns 1	4	7	2	5	8	Total	Avg.
				grams				
18 Jan	1.3	2.4	1.6	2.1	3.0	1.8	12.2	2.03
1 Feb	1.9	1.2	1.7	1.6	2.4	2.1	10.9	1.82
15 Feb	1.0	1.2	1.1	0.8	1.2	1.2	6.5	1.08
2 Mar	1.3	2.2	1.8	2.2	2.8	2.9	13.2	2.20
15 Mar	3.2	3.9	2.8	3.6	3.5	3.3	20.3	3.38
29 Mar	4.8	4.9	4.3	5.4	4.3	3.9	27.6	4.60
26 Apr	4.9	5.1	5.1	6.0	5.3	4.9	36.8	6.13
9 May	5.1	4.7	6.4	5.5	5.6	5.5	32.8	5.47
23 May	5.4	6.2	6.5	6.1	5.4	5.4	34.6	5.77
7 Jun	7.3	7.4	7.9	7.7	6.8	5.9	43.0	7.17
21 Jun	8.8	8.9	9.7	10.7	8.3	5.6	52.0	8.67
5 Jul	9.1	7.6	8.4	7.3	6.7	5.3	44.4	7.40
19 Jul	9.1	9.6	10.5	7.9	7.7	6.1	50.9	8.48
2 Aug	10.8	10.7	13.0	10.1	9.4	7.2	61.2	10.20
16 Aug	6.5	7.4	9.2	3.4	7.4	4.4	38.3	6.38
16 Sep	7.8	7.1	8.2	5.4	7.1	7.7	43.3	7.22
27 Sep	5.8	4.9	6.4	5.4	5.5	2.9	30.9	5.15
11 Oct	6.8	6.0	6.1	8.1	6.3	2.4	35.7	5.95
25 Oct	3.1	3.4	4.0	4.1	4.8	2.4	21.8	3.63
Total	104.0	104.8	114.7	103.9	105.9	80.9		
Avg.	5.5	5.5	6.03	5.4	5.57	4.26		

Total yield of six columns was 614.2 grams.

Average yield per column was 102.4 grams = 5.8 kg/m^2.

Table 5. Fluoride concentrations in drainage from soil columns flooded with sewage water

Cycle	Column Number							
	1	2	3	4	5	6	7	8
	ppm							
1	2.2	2.4	2.6	2.4	2.4	2.7	2.5	2.7
2	2.2	2.3	2.5	2.5	2.6	2.6	2.4	2.6
3	2.5	2.5	2.5	2.6	2.7	2.6	2.4	2.5
Average	2.3	2.4	2.5	2.5	2.6	2.6	2.4	2.6
Avg. infiltration rate - cm/day	14	21	15	28	18	20	14	22

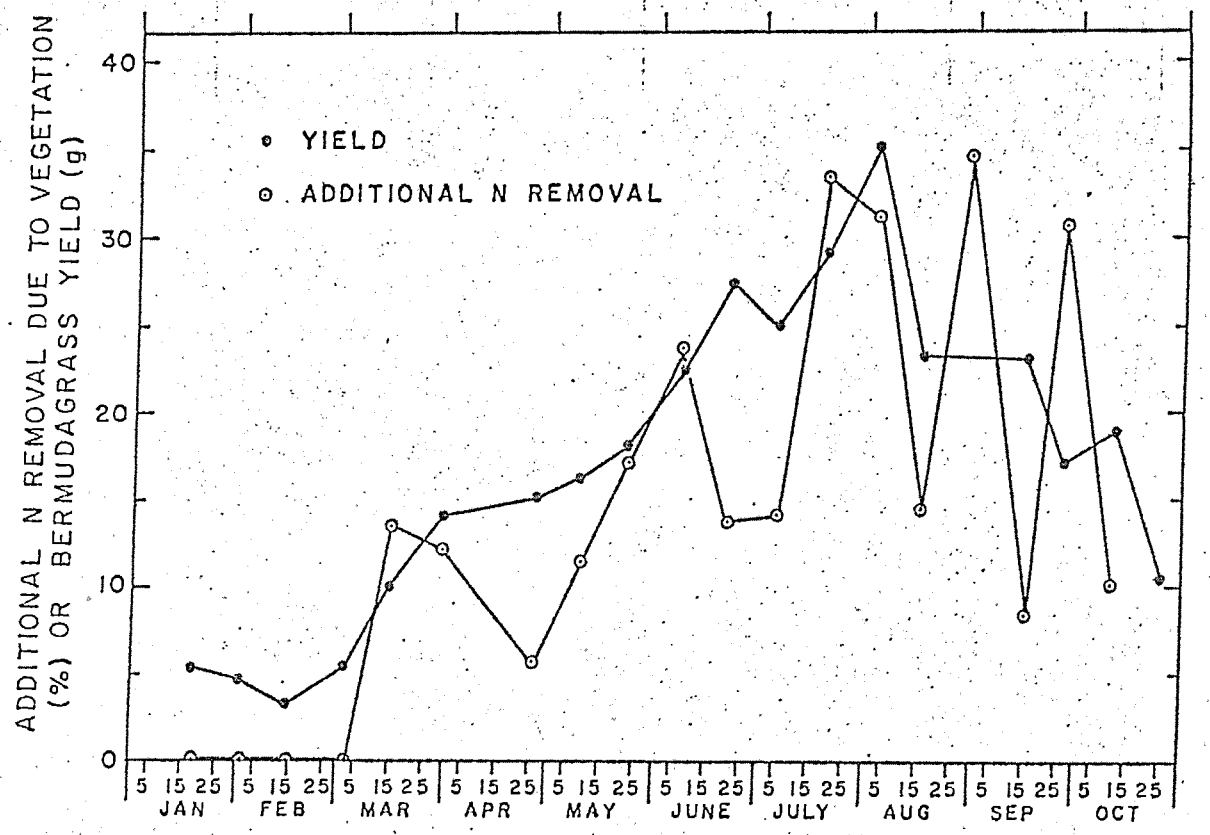


Figure 1. A comparison of differences in nitrogen removal from vegetated and nonvegetated soil columns, intermittently flooded with sewage water, and yield of dry matter. The average % N removal by three bare soil columns was substracted from the average % N removal for three columns planted to bermudagrass which were harvested every 2 weeks.

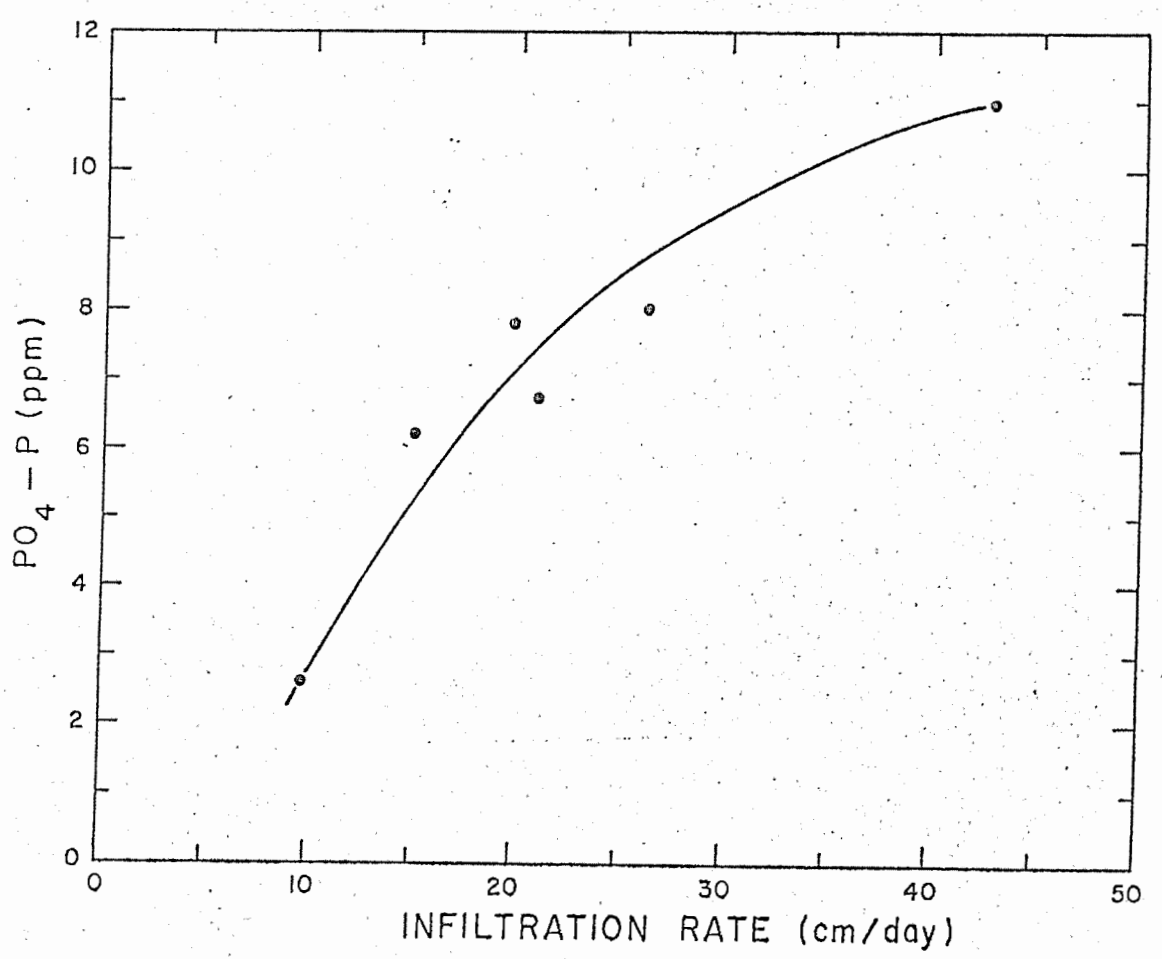


Figure 2. The effect of infiltration rate on phosphate concentrations in water from soil columns intermittently flooded with sewage water. Data from each of six columns were averaged for 6 months of flooding on a schedule of 9 days wet alternated with 5 days dry.

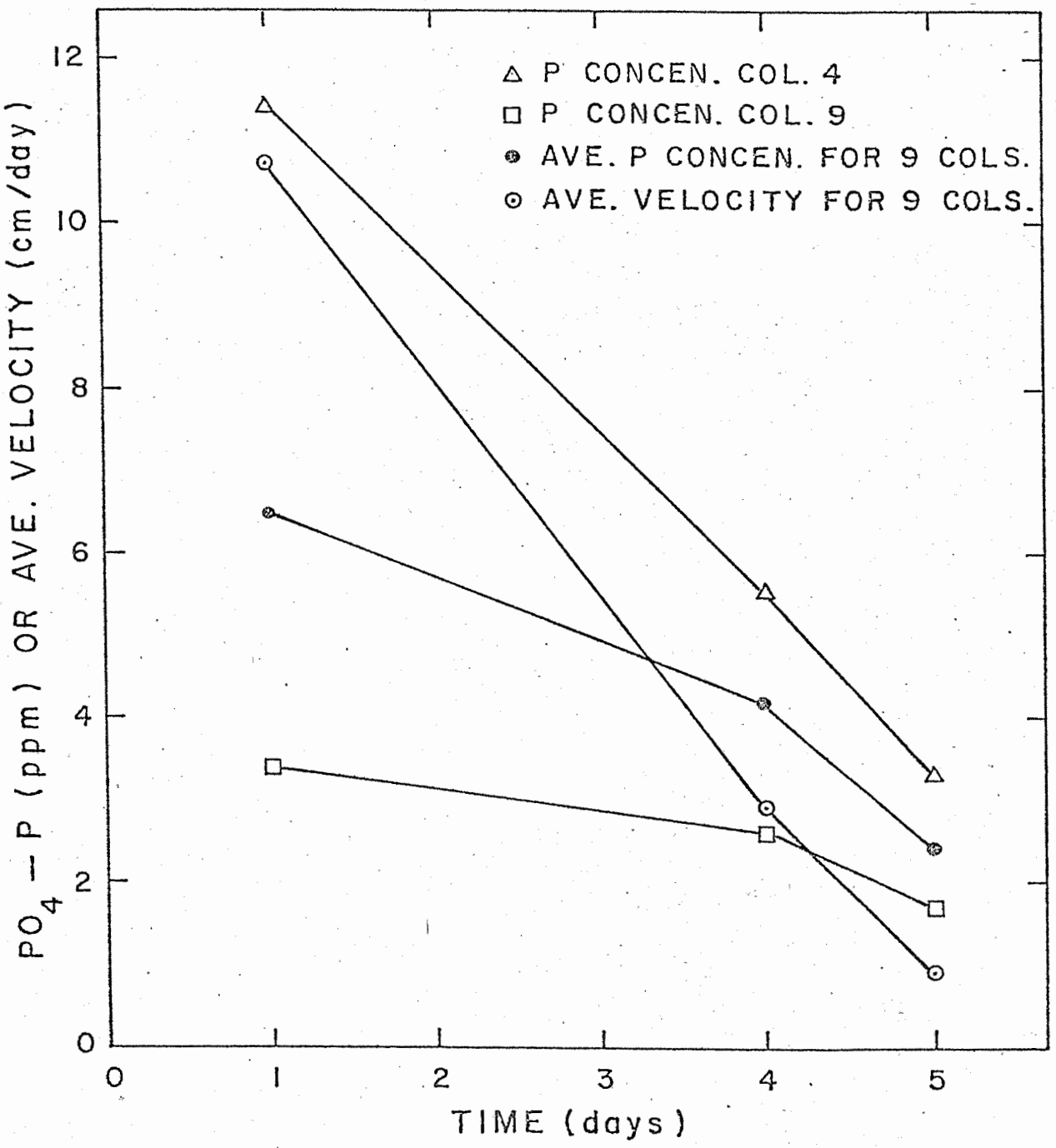


Figure 3. Changes in phosphate concentrations and average velocity for water draining from soil columns during the 5-day dry period of a schedule of 9 days flooded alternated with 5 days dry.

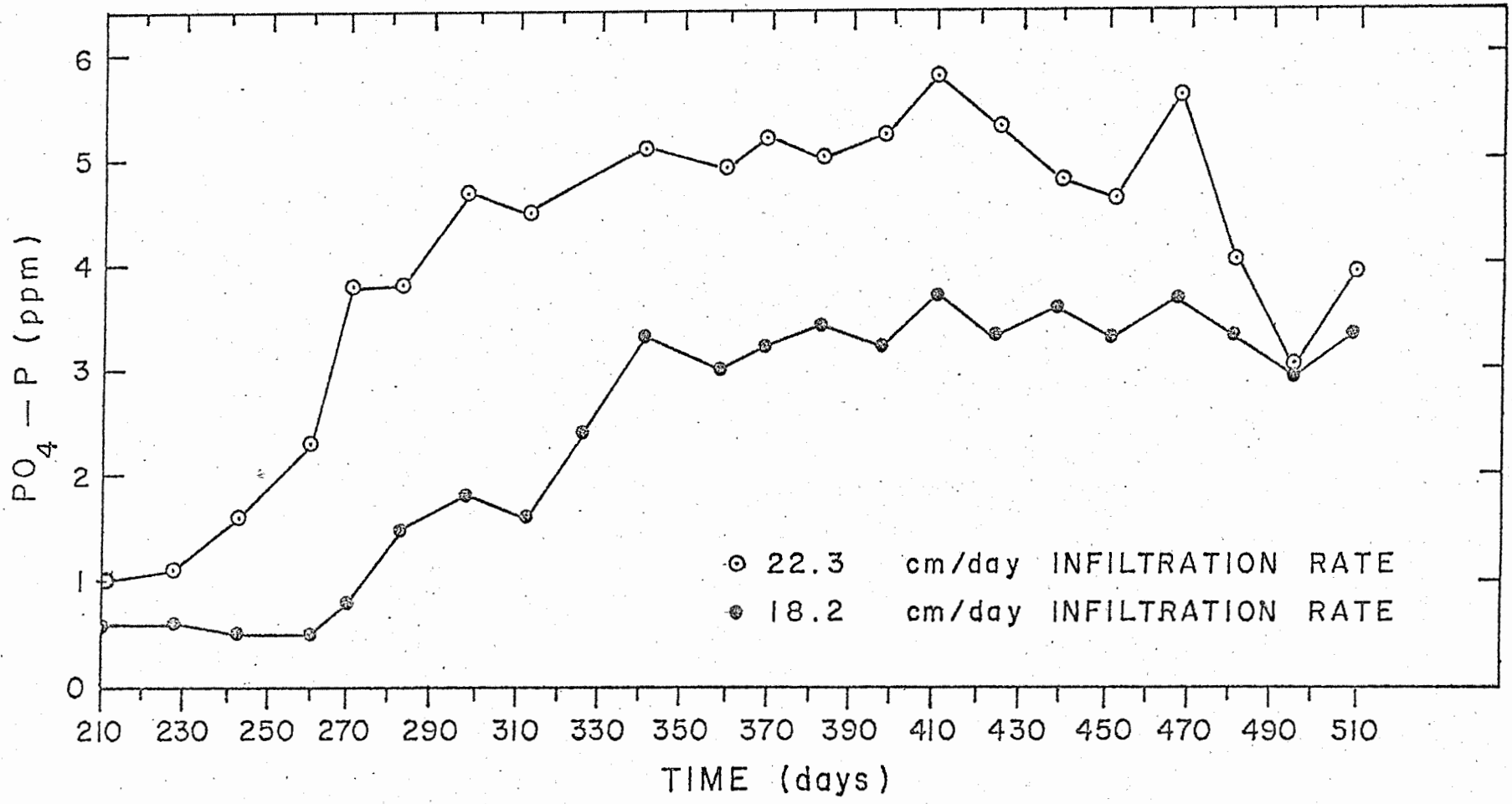


Figure 4. Phosphate concentrations in water from soil columns containing some sand which had not been treated previously with sewage water. The phosphate concentrations were below 1 ppm for the first 210 days of intermittent flooding.

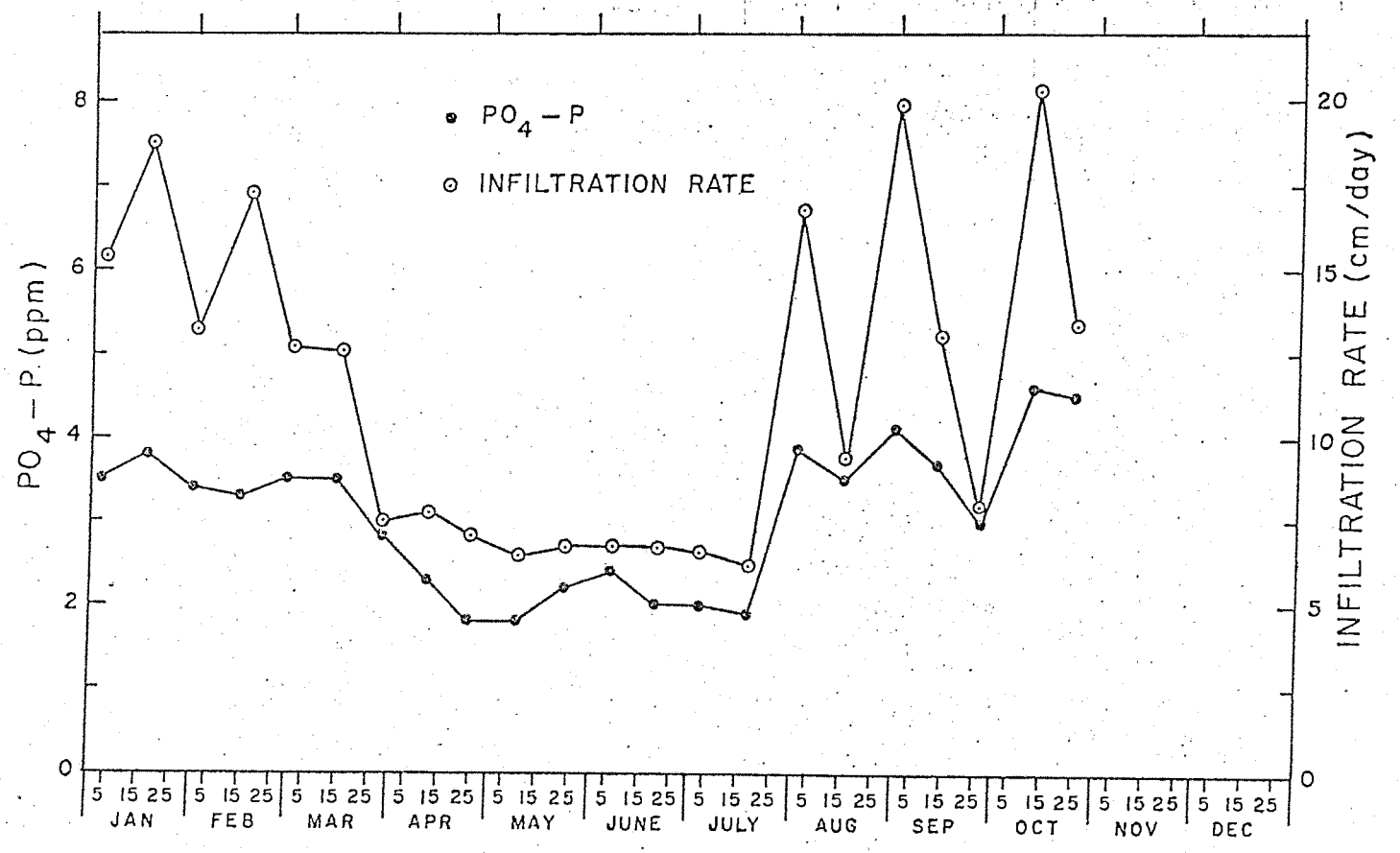


Figure 5. A comparison of changes in phosphate concentration and infiltration rate with time for a soil column intermittently flooded with sewage water at a low infiltration rate.

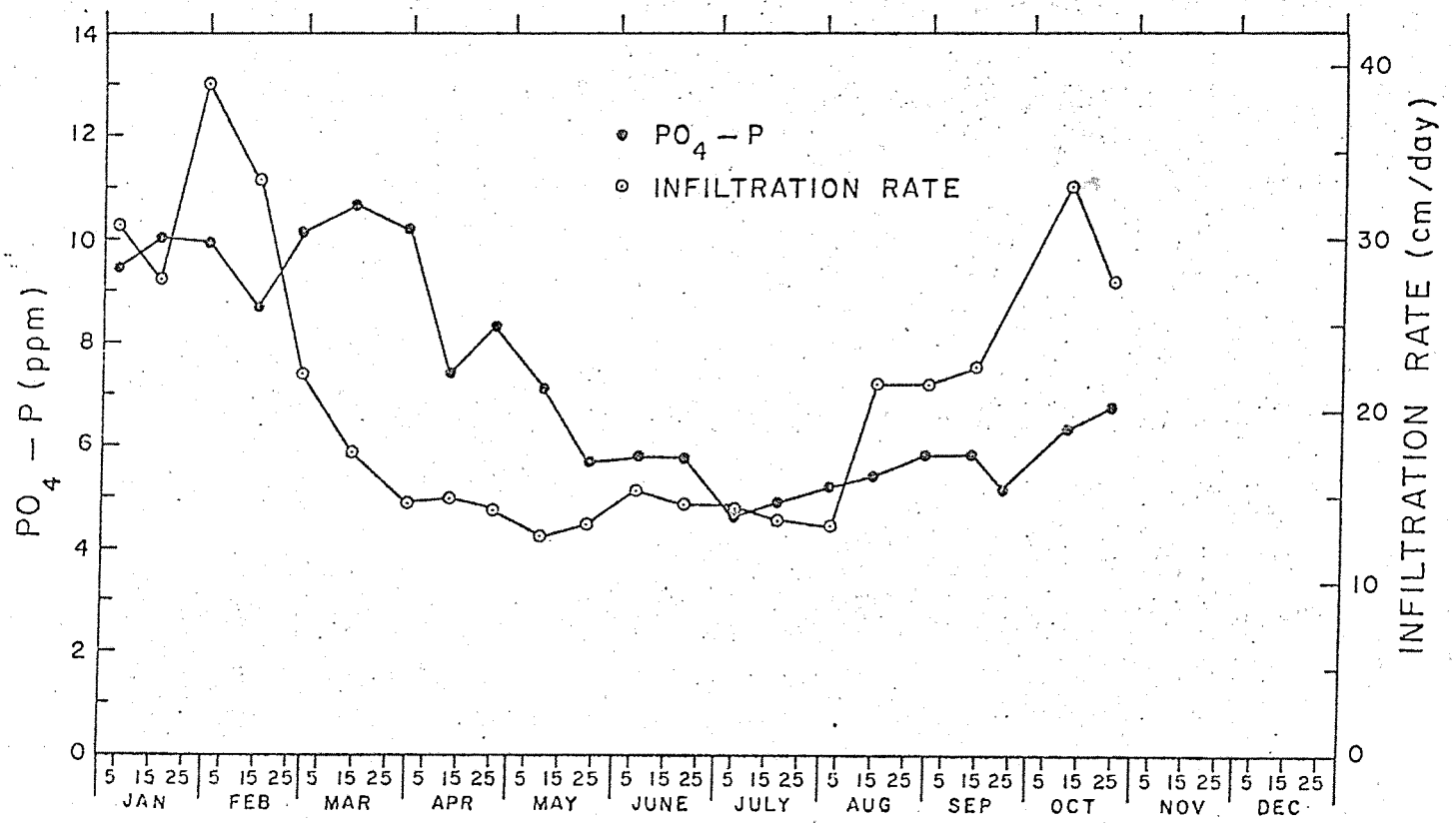


Figure 6. A comparison of changes in phosphate concentration and infiltration rate with time for a soil column intermittently flooded with sewage water at a high infiltration rate.

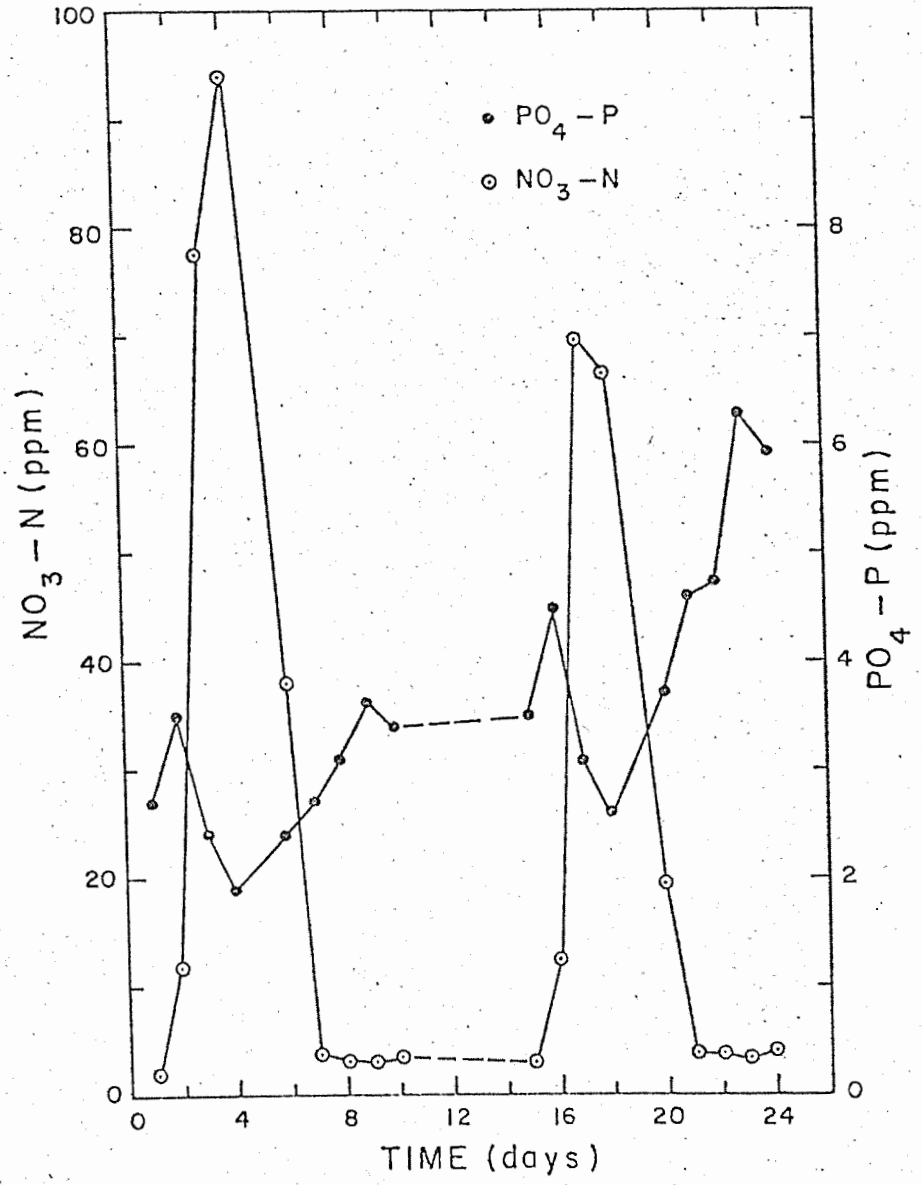


Figure 7. Nitrate and phosphate concentrations in water from a soil column flooded on a schedule of 9 days flooded alternated with 5 days dry. The dashed line indicates the dry period.

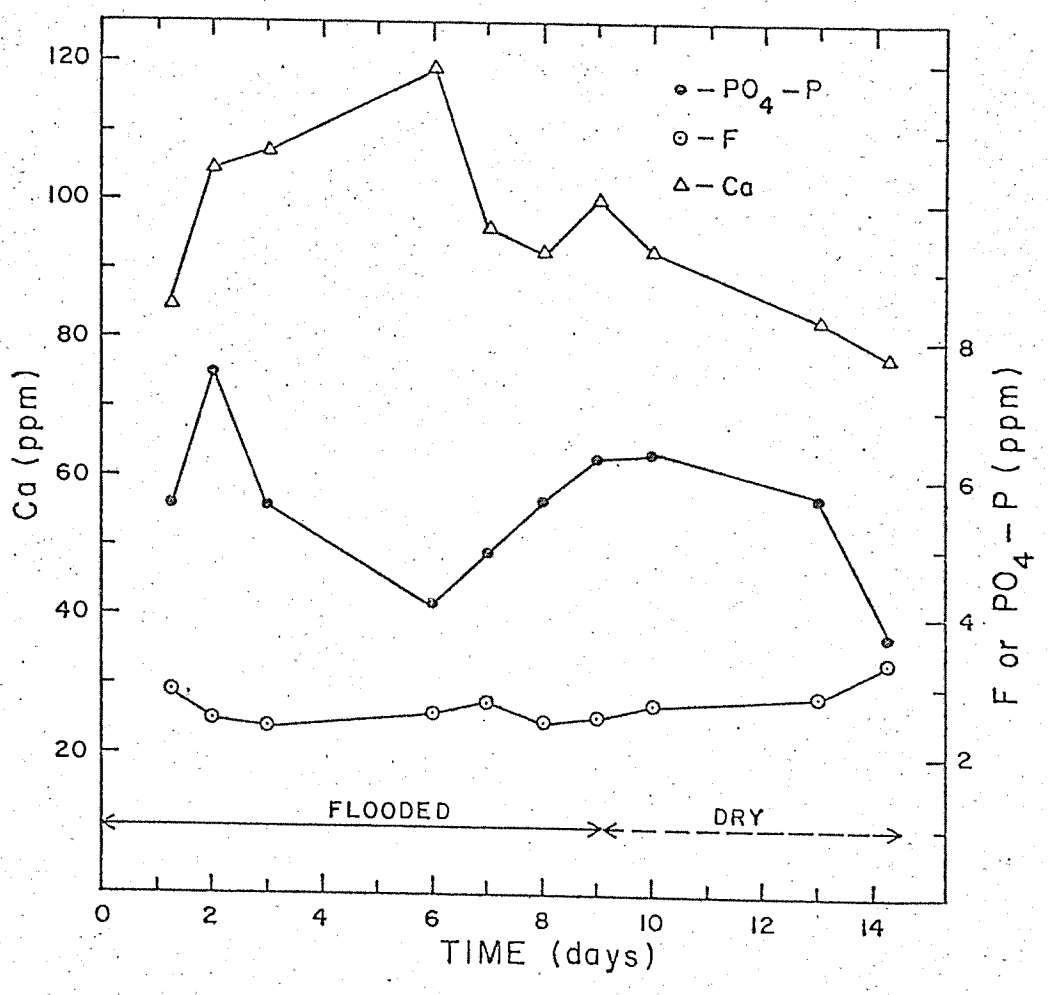


Figure 8. Phosphate, calcium, and fluoride concentrations in water draining from a soil column flooded with sewage water for 9 days followed by 5 days dry.

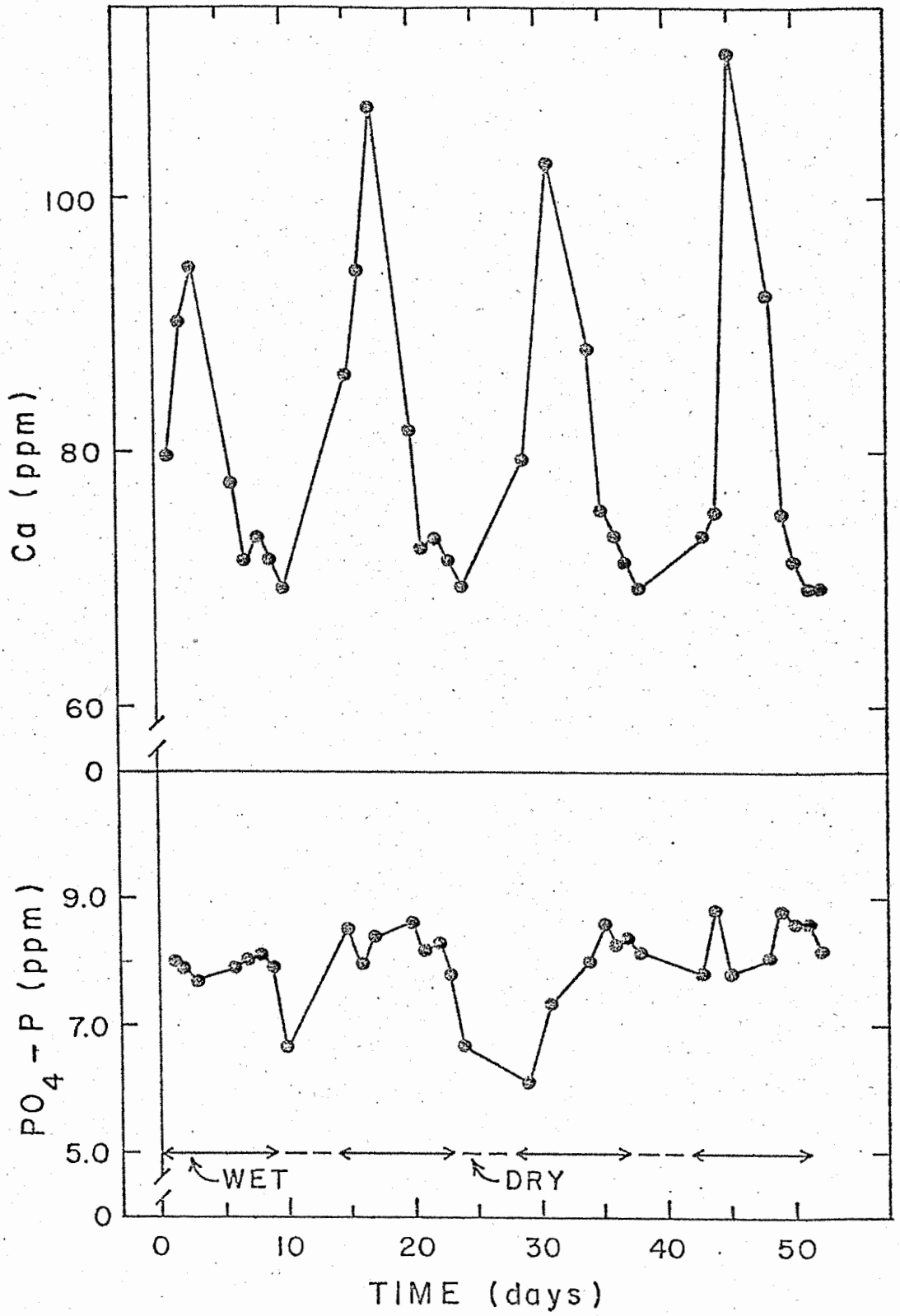


Figure 9. Fluctuations in calcium and phosphate concentrations in water from a soil column (No. 2) intermittently flooded with sewage water. The average calcium and phosphate concentrations in the sewage water were 55 and 9 ppm, respectively.

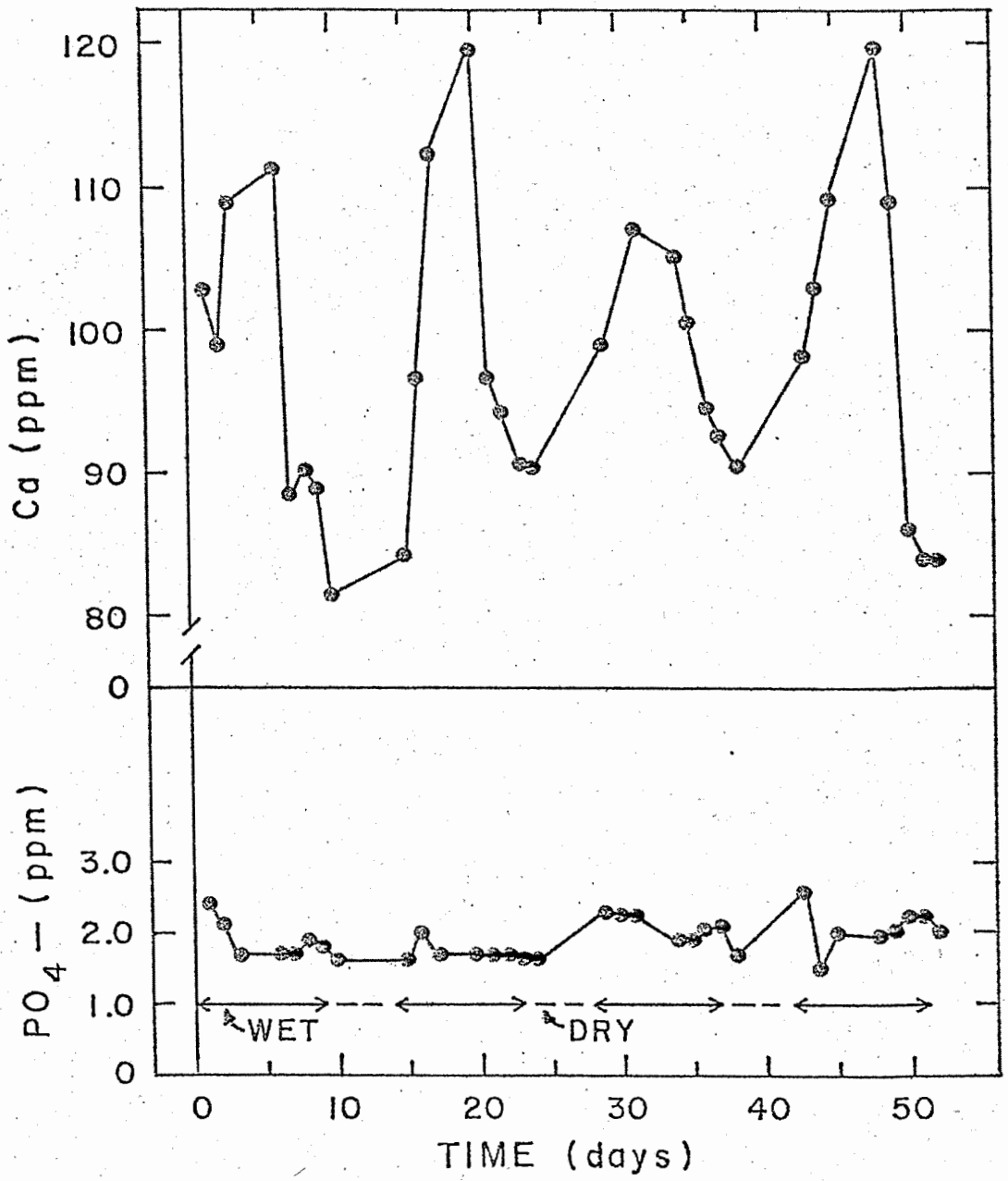


Figure 10. Fluctuations in calcium and phosphate concentrations in water from a soil column (No. 6) intermittently flooded with sewage water. The average calcium and phosphate concentrations in the sewage water were 55 and 9 ppm, respectively.

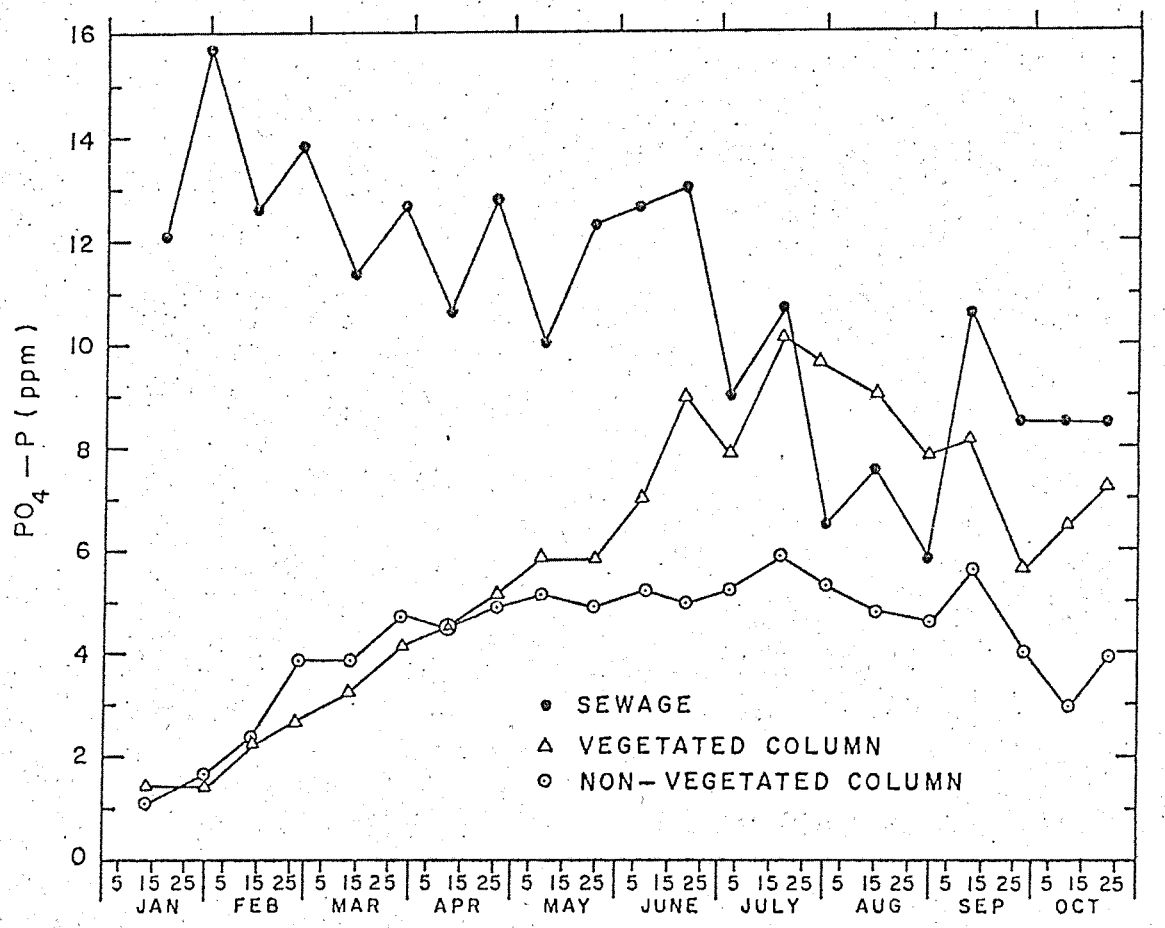


Figure 11. Phosphate concentrations in water from a soil column with bermudagrass and a column with a bare soil surface during intermittent flooding with sewage water.

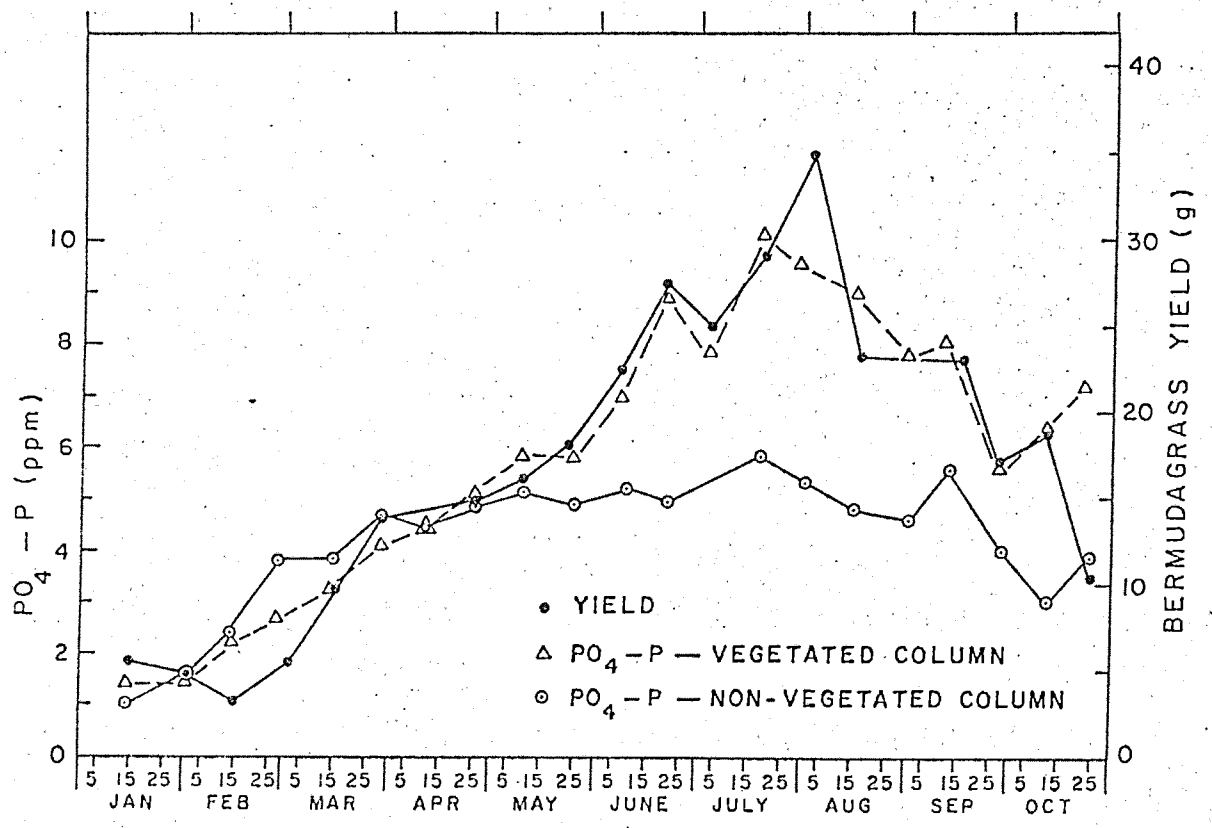


Figure 12. Yield of dry matter and phosphate concentrations in water from soil columns intermittently flooded with sewage water.

TITLE: CHARACTERISTICS OF THE SOIL MICROFLORA AND BIOLOGICAL PROCESSES OCCURRING IN SOIL USED FOR WASTEWATER RENOVATION

CRIS WORK UNIT: 5510-12260-003 CODE NO.: Ariz.-WCL 70-2

INTRODUCTION:

Basic aspects of enteric viral and bacterial movement and survival in soil are not understood; and, more information is needed to prevent pollution of our ground water resources, especially where land is used for disposal of wastewater. Therefore, during 1974 research was initiated (in cooperation with Baylor University) to evaluate the effective removal of microbial indicators of water pollution by a soil basin system that has been renovating wastewater by ground water recharge for several years, the Flushing Meadows Project.

The objectives were, 1) to determine the population density of viruses, enteric bacteria (Fecal coliform, Fecal Streptococci and Salmonella sp.), and total bacteria in the sewage water and renovated water; and, 2) to correlate the viral and bacterial populations detected relative to their movement through soil during flooding periods.

PROCEDURES:

Water samples were collected during flooding periods of 14 days at bi-monthly intervals representing the secondary sewage effluent and renovated water from four well sites at Flushing Meadows (East Center Well, Well 1-2, East Well and Well 7). Viral populations were collected and concentrated by filtration procedures and identified by Baylor University personnel. Various bacterial populations were determined in water samples collected at the same time as the viral samples were obtained. Fecal coliform (FC) and Fecal Streptococci (FS) bacteria/100 ml were determined with the Millipore filter method. Total bacteria/ml were determined with the dilution plate method, using plate count agar. Salmonella

sp./100 ml were assayed with the most probable number method, using a five-tube dilution series; and, positive tubes were confirmed by culturing on selective media (XLD Agar and KIA stab tube slants) as well as serologically with Salmonella "H" antiserum Poly a-z.

RESULTS:

The numbers of viruses, enteric bacteria and total bacteria moving through soil basins intermittently flooded with secondary sewage effluent were greatly reduced (Table 1). No viruses were detected in any renovated well water sample volumes ranging from 46 to 120 gallons and averaging 92 gallons. The sewage effluent sample volumes assayed ranged from 1 to 4 gallons, averaged 3.4 gallons, and contained viral tissue culture infectious dosages (TCID) ranging from 600 to 28,291 TCID/100 gallons and averaging 8,017 TCID/100 gallons during 1974 (Table 2 and 3). The viruses identified in the sewage effluent included poliovirus type 2 and 3, echovirus 7 and 15, coxackievirus B4 and reovirus type 1 and 2, which varied with the time of the year (Table 4).

The average number of enteric bacteria and total bacteria in the sewage effluent and renovated water during 1974 are summarized in Tables 2 and 3. The numbers of Fecal coliform, Fecal Streptococci, and total bacteria were reduced on the average in the renovated well waters by 99.9%; and, Salmonella sp. were not detected in 5-liter well water samples from the east center well on two occasions (Table 3).

SUMMARY AND CONCLUSIONS:

The sewage effluent and four well sites at the Flushing Meadows Project were analyzed for viruses and enteric bacteria during flooding periods on bi-monthly intervals in 1974. No viruses or Salmonella sp. were detected in any renovated well water samples; and, the numbers of Fecal Coliform, Fecal Streptococci, and total bacteria were reduced on the average in the renovated well waters by 99.9%. Our results have indicated that human bacterial and viral pathogens are not concentrating, surviving and moving through the soil, but these organisms are apparently inactivated and degraded by the soil. We feel it is significant that after 8 years of continual operation of the Flushing Meadows Project the viruses, enteric bacterial pathogens and pollution indicator organisms in the sewage effluent are either nondectable or greatly reduced in numbers in the renovated water after filtration of the wastewater through soil recharge basins.

PERSONNEL: R. G. Gilbert, J. B. Miller, R. C. Rice and H. Bouwer

Table 1. Virus and bacteria numbers in secondary sewage effluent and renovated wastewater from four well sites at the Flushing Meadows Project during 1974.

Date (1974)	Days Flooded	Virus (TCID/100 gal)	Fecal Coliform (#/100 ml)	Fecal Streptococci (#/100 ml)	Salmonella (#/100 ml)	Total Bacteria (#/ml × 10^3)
			SECONDARY SEWAGE EFFLUENT			
7 Jan	11	1,820	122,500	-	-	-
11 Jan	15	4,133	68,000	-	-	-
13 Mar	10	10,390	770,000	50,000	-	1,243
7 May	9	16,000	210,000	20,000	-	4,410
9 May	11	2,000	20,000	2,500	-	820
25 Jun	6	600	240,000	28,000	17	1,350
26 Jun	7	900	278,000	40,000	-	1,235
27 Aug	9	28,292	-	-	-	-
20 Nov	9	ND[1/]	5,000	0	-	240
			EAST CENTER WELL			
7 Jan	11	0	252	-	-	-
10 Jan	14	0	11	-	-	-
12 Mar	9	0	152	-	-	15
8 May	10	0	43	26	-	21
25 June	6	0	25	9	0	2
26 Aug	8	0	17	15	-	2
19 Nov	8	ND	9	45	-	4

Table 1. Virus and bacteria numbers in secondary sewage effluent and renovated wastewater from four well sites at the Flushing Meadows Project during 1974. - (continued) -

Date (1974)	Days Flooded	Virus (TCID/100 gal)	Fecal Coliform (#/100 ml)	Fecal Streptococci (#/100 ml)	Salmonella (#/100 ml)	Total Bacteria (#/ml × 10^3)
			WELL #1 - 2[2/]			
10 Jan	14	0	2,920	-	-	-
15 Mar	12	0	2,147	158	-	62
9 May	11	0	62	10	-	24
28 Jun	9	0	69	4	-	10
22 Nov	11	ND	107	18	-	-
			EAST WELL			
8 Jan	12	0	85	-	-	-
13 Mar	10	0	220	40	-	20
6 May	8	0	359	14	-	41
26 Jun	7	0	3	2	-	3
27 Aug	9	0	2	18	-	1
11 Dec	3	ND	1	30	-	1

Table 1. Virus and bacteria numbers in secondary sewage effluent and renovated wastewater from four well sites at the Flushing Meadows Project during 1974.

Date (1974)	Days Flooded	Virus (TCID/100 gal)	Fecal Coliform (#/100 ml)	Fecal Streptococci (#/100 ml)	Salmonella (#/100 ml)	Total Bacteria (#/ml × 10^3)
			WELL #7			
9 Jan	13	0	243	-	-	-
14 Mar	11	0	265	76	-	13
7 May	9	0	66	3	-	17
27 June	8	0	41	-	-	4
28 Aug	10	0	7	7	-	5
10 Dec	2	ND	0	1	-	4

1/ - No data received from Baylor University at this time.

2/ - On 10 Jan and 15 Mar, the fecal coliform numbers were increased when pump was inserted into the well and after 15 Mar the pump was left in the well for the duration of the experiment.

Table 2. Average numbers of viruses and bacteria in secondary sewage effluent and renovated wastewater from four well sites at the Flushing Meadows Project.[1/]

Water Sample	Virus (TCID/100 gal)	Fecal Coliform (#/100 ml)	Ratio FC/FS 3/	Fecal Streptococci (#/100 ml)	Salmonella (#/100 ml)	Total Bacteria (#/ml × 10^3)
Sewage Effluent	8,017	244,071	8.7	28,100	17	1,811
East Center Well	0	73	3.0	24	0	9
Well #1 - 2[2/]	0	1,061	22.1	48	-	32
East Well	0	112	5.3	21	-	13
Well #7	0	104	4.7	22	-	9

1/ The numbers are averages of results from 5 flooding periods analyzed from Jan to Sept 1974 at bimonthly intervals, except for Salmonella which were determined twice in June and July only for the sewage effluent and the east center well.

2/ Averages higher because well was disturbed during installation of pump and first two samples were contaminated.

3/ FC/FS (Fecal Coliform/Fecal Strep.) ratio greater than or equal to 4 indicates pollution derived from human waste.

Table 3. Average number of viruses, enteric bacteria and total bacteria in the secondary sewage effluent and the wastewater after renovation by filtration through soil.*

Type of Organism	SEWAGE EFFLUENT		RENOVATED WATER		%-Reduced
	Range	Average	Range	Average	
Fecal Coliform/100 ml	20,000-770,000	244,071	0-359	96	99.96
Fecal Streptococci/100 ml	2,500-50,000	28,100	21-24	22	99.92
Salmonella sp./100 ml	17-26	21	0	0	100.00
Total Bacteria/ml	820,000-4,410,000	1,811,400	600-41,000	10,278	99.94
Viruses-TCID/100 gal	600-28,292	8,017	0	0	100.00

* Results are averages of five bimonthly water samples from 3 wells in 1974, except for *Salmonella* which was determined twice in June and July in only the East Center Well and the Sewage Effluent. (Data from Well 1 - 2 was excluded; refer to Table 2)

Table 4. Viruses identified in the secondary sewage effluent during 1974.

DATES	TYPES OF VIRUSES
7-11 Jan	Poliovirus 2 Echovirus 15
12-18 Mar	Poliovirus 2 Echovirus 7
5-9 May	Poliovirus 2 and 3
25 Jun - 9 Jul	Poliovirus 2 Coxsackievirus B4
26 Aug - 12 Sept	Reovirus 1 and 2

TITLE: ASSESSMENT OF BIOSTIMULATION AND EUTROPHICATION OF RECLAIMED WASTE WATER

CRIS WORK UNIT: 5510-12260-003 CODE NO.: Ariz.-WCL 71-10

INTRODUCTION:

The assessment of biostimulation and eutrophication in two small fiberglass-asphalt-lined ponds containing reclaimed sewage water was completed in 1974. The first phase of the work was to monitor several biological, chemical, and physical factors that contributed to the growth of phytoplankton, zooplankton, and fish in reclaimed sewage water. Since the Flushing Meadows Project has a field laboratory with electric power, many of the factors monitored were measured at the site. Multichannel recorders were set up to measure temperature profiles in the ponds, solar and thermal radiation, and surface evaporation. Water visibility was measured with a Secchi disc, and the necessary fill-up water from the east well was added to the ponds to maintain a constant water level. Water samples were immediately analyzed in the field laboratory for dissolved oxygen, pH, alkalinity and turbidity. Carbon dioxide was later calculated from the relationships of pH and alkalinity. Primary productivity was determined at two levels, 30-cm and 60-cm depths. Similar water samples were filtered and later analyzed for chlorophyll content photometrically. Other water samples from each pond were stored in the refrigerator prior to chemical analysis for total dissolved salts, carbon, nitrogen, phosphorus, and other minor nutrient elements. Water samples were also concentrated (10-fold), preserved (formalin), and stored (4 C), until they could be analyzed for phytoplankton and zooplankton populations. The total bacteria population was analyzed immediately after returning to the research laboratory. Therefore, a physical-chemical-biological study of ponded reclaimed sewage water from the Flushing Meadows Project was conducted. Pertinent factors were simultaneously evaluated to establish cause-and-effect relationships in the

growth of micro- and macro-organisms in an aquatic ecosystem. This report will present a detailed interpretation and multiple linear regression (MLR) analysis of the results relative to net primary productivity (nPPr) of the ponded reclaimed waste water.

PROCEDURES:

As a first approximation to a quantitative understanding of the factors relating to nPPr a MLR approach was prepared. This work was done in cooperation with Dr. Lorne G. Everett, Department of Hydrology and Water Resources, University of Arizona, Tucson, Arizona. The program used was a (BMD) Biomedical Computer Program, version of April 13, 1965 developed at the UCLA Health Sciences Computing Facility and modified for the University of Arizona CDC 6400 on 13 November 1970.

Multiple regression is used in data analysis to obtain the best fit of a set of observations of independent and dependent variables and gives the least squares "best" value of coefficients for those variables. The solution also gives a measure of the reliability of each of the coefficients so that inferences can be made regarding the parameters of the population from which the sample of observations was taken.

In the stepwise procedure, intermediate results, which are not even recorded by normal calculation methods, are used to give valuable statistical information to each step in the calculation. These intermediate answers are also used to control the method of calculation. Essentially, without adding greatly to the number of arithmetic steps, a number of intermediate regression equations are obtained, as well as the complete multiple regression equation. These equations are obtained by adding one variable at a time and thus give the following intermediate equations:

$$y = b_o + b_1x_1$$

$$y = b'_o + b'_1x_1 + b'_2x_2$$

$$Y = b''_o + b''_1x_1 + b''_2x_2 + b''_3x_3 \qquad (1)$$

Where y is the dependent variable; x_1, x_2, . . . are the independent variables and b_1, b_2, . . . are the coefficients to be determined.

The variable added is that one which makes the greatest improvement in "goodness of fit." The coefficients represent the best values when the equation is fitted by the specific variables included in the equation.

An important property of the stepwise procedure is based on the facts that (1) a variable may be indicated to be significant in any early stage and thus enter the equation, and (2) after several other variables are added to the regression equation, the initial variable may be indicated to be insignificant. The insignificant variable will be removed from the regression equation before adding an additional variable. Therefore, only significant variables are included in the final regression.

RESULTS AND DISCUSSION:

Since net primary productivity (nPPr) rates were our parameter of interest, and since measurement of variables at a point in time was needed for correlation, only those variables that were measured exactly on the day that nPPr was determined were selected for the analysis. The 24 measured variables were assigned a number (Table 1) and the program was set up to use variable 2, nPPr, as the dependent variable, while the 23 independent variables were used to explain the value of the dependent variable. Initial runs indicated that nPPr was a function of gross primary productivity, respiration and other biological factors (i.e., chlorophylls). Consequently, it was decided to omit from the MLR equation those

variables which were not independent of nPPr. Only those variables that management could control were allowed to enter the equation:

Dissolved Oxygen (4)	Carbon Inorganic (16)
pH (5)	Carbon Organic (17)
Alkalinity (6)	Nitrite-N (18)
Carbon Dioxide (7)	Nitrate-N (19)
Turbidity (8)	Ammonium-N (20)
Secchi Disc (9)	Phosphate-P (21)
Temperature (10)	Total Bacteria (24)
Light (11)	

Each parameter is independently investigated by the computer and by a stepwise fashion eventually included all of the independent parameters related to nPPr. The computer program utilized a set of limits which include:

F ratio: Used in analysis of variance, ration of mean square regression to mean square errors, used to describe if regression variance is significantly greater than residual variance.

R^2: - Coefficient of multiple determination, proportion of variance in dependent variable accounted for by independent variables.

r: - Multiple correlation coefficient, strength of linear relationship.

Standard Error of Estimate: 95% confidence limits around regression line, standard deviation around regression line.

The stepwise MLR analysis of the data indicated the first variable entering was temperature (Tables 2 & 3). The constant in the linear equation was -2,49359, the temperature coefficient was 0.11668 and R^2 was 0.44. All of the above constants and

coefficients change as each new step is included (Table 3). Regression step 3 indicated that temperature, nitrite, and light are the dominant variables accounting for the nPPr. The increase in R^2 from step 3 to 13 is considerably smaller than the increase from step 1 to 3 (Table 2). The R^2 of 0.66 at step 3 indicated that 66% of the variability of nPPr was explained by these three variables. The increase in R^2 between step 5 and 6 indicated that the variability was not explained in more detail and thereby provided a cutoff for the MLR equation. The six variables to be included in the MLR equation obtained are: Temperature, Nitrite-N, Light, Carbon-inorganic, Carbon dioxide, and Ammonium-N. Using the constant and coefficients given in step 6 (Table 3) the equation relating the variables to nPPr was:

$$\begin{aligned} nPPr = {} & -5{,}41380 + (0.07925)(\text{Temperature}) + (6.52079)(\text{Nitrite-N}) \\ & + (0.00246)(\text{Light}) + (0.03687)(\text{Carbon inorganic}) \\ & + (-0.42722)(\text{Carbon dioxide}) + (0.14496)(\text{Ammonium-N}) \quad (2) \end{aligned}$$

The stepwise procedure of the MLR analysis was allowed to continue to include the remaining variables, and at step 13 the 95% confidence limits were violated and the program stopped (Table 2).

SUMMARY AND CONCLUSIONS:

A multiple linear regression analysis indicated that 73% of the variability in net primary productivity in reclaimed waste water ponds was accounted for by six parameters: Temperature, Nitrite-N, Light, Carbon inorganic, Carbon dioxide, and Ammonium-N.

It appeared that the data base from the waste water reclamation ponds agreed well with existing works. The control of temperature and light in algal studies indicated a management alternative scheme. The role of nitrogen and phosphorus in limiting amounts has received considerable attention while this study indicated nitrogen forms to be of considerable importance. Several multivariate approaches were used to relate the mass of data collected.

Since each state had been defined chemically, biologically and physically, the simplest step was to linearly relate the variables. This approach implies two assumptions: 1. That the events are linearly related; and, 2. That there is no lag phase. Both of these assumptions are intolerable in biological systems, but they are nevertheless, a natural starting point that may provide direction and background information for further studies, and simultaneously provide predictive tools needed in water quality management.

PERSONNEL: R. G. Gilbert, J. B. Miller, and L. G. Everett

Table 1. Variable names and assigned numbers.

No.	Name
1	Gross Primary Productivity
2	Net Primary Productivity
3	Respiration
4	Dissolved Oxygen
5	pH
6	Alkalinity
7	Carbon Dioxide
8	Turbidity
9	Secchi Disc
10	Temperature
11.	Light (Incoming Solar Radiation)
12	Extinction Coefficient
13	Chlorophyll - a
14	Carotenoids - Animals
15	Carotenoids - Plants
16	Carbon-Inorganic
17	Carbon-Organic
18	Nitrite-N
19	Nitrate-N
20	Ammonium-N
21	Phosphorus
22	Total Zooplankton
23	Total Phytoplankton
24	Total bacteria

Table 2. Results of the stepwise multiple linear regression of net primary productivity (nPPr) against 15 independent chemical and physical variables according to the model: $nPPr = b_o + b_1 x_1 + b_2 x_2 \ldots b_n x_n$

tep No.	1	2	3	4	5	6	7	8	9	10	11	12	13
riable	Temp.	Temp. NO_2	Temp. NO_2 Light	Temp. NO_2 Light Carbon-Inor.	Temp. NO_2 Light C-Inor CO_2	Temp. NO_2 Light C-Inor CO_2 NH_4	Temp. NO_2 Light C-Inor CO_2 NH_4 Alkalinity	Temp. NO_2 Light C-Inor CO_2 NH_4 Alka. NO_3	Temp. NO_2 Light C-Inor CO_2 NH_4 Alka. NO_3 Bacteria	Temp. NO_2 Light C-Inor CO_2 NH_4 Alka. NO_3 Bact. Phosphorus	Temp. NO_2 Light C-Inor CO_2 NH_4 Alka. NO_3 Bact. Phos. Oxygen	Temp. NO_2 Light C-Inor CO_2 NH_4 Alka. NO_3 Bact. Phos. Oxygen Turbidity	Temp. NO_2 Light C-Inor CO_2 NH_4 Alka. NO_3 Bact. Phos. Oxygen Turb. pH
alue	.662	.788	.815	.830	.842	.854	.873	.881	.886	.890	.894	.898	.898

Table 3. Stepwise multiple linear regression analysis summary in which net primary productivity (nPPr) was related to six independent chemical and physical variables according to the model: $nPPr = b_o + b_1 (T) + b_2 (N) + b_3 (L) + b_4 (I) + b_5 (C) + b_6 (A)$

where:

T: Temperature
N: Nitrite-N
L: Light
I: Carbon-Inorganic
C: Carbon Dioxide
A: Ammonium-N

Regression Step No.	Intercept	Regression Coefficients						Coefficient of Determination
	b_o	b_1	b_2	b_3	b_4	b_5	b_6	R^2
1	-2.49359	0.11668						0.44
2	-2.59605	0.09812	7.85437					0.62
3	-3.49811	0.08441	6.94271	0.00238				0.66
4	-4.91984	0.05516	6.53132	0.00326	0.02808			0.69
5	-5.82989	0.07171	7.11134	0.00300	0.04368	-0.32531		0.71
6	-5.41380	0.07925	6.52079	0.00246	0.03687	-0.42722	0.14496	0.73

TITLE: MATERIALS AND METHODS FOR WATER HARVESTING AND WATER STORAGE IN THE STATE OF HAWAII

CRIS WORK UNIT: 5510-12260-004 CODE NO. Ariz.-WCL 65-2

INTRODUCTION:

The major research emphasis in Hawaii continues to be the rainfall-runoff-erosion studies conducted in cooperation with the University of Hawaii. Water harvesting studies consist of observing the Maui test plots to evaluate the long-term weathering characteristics of the treatments.

RESULTS AND DISCUSSION:

Part I. Water Harvesting

The four-plot water harvesting test site on Maui is being maintained only as a materials weathering site. The site was visited by laboratory personnel in July and November 1974. The bonded butyl and Hypolon sheetings show no signs of deterioration from weathering. The Hypolon sheeting is stretched very tight because of material shrinkage. Fiberglass strands on the asphalt-fiberglass plot are beginning to become visible, indicating that a new sealcoat is needed. There are a few small holes believed caused by ants on the asphalt-fiberglass plot and the bonded butyl. There is considerable grass at the edges of all the plots, extending onto the plot surfaces. The grass is not believed to be damaging the membranes.

Part II. Rainfall-Runoff-Erosion Studies

All waterstage and rainfall recorders on the rainfall-runoff-erosion watersheds were replaced in November and December 1974 with new strip chart waterstage recorders equipped with a tipping bucket raingage recorder accessory. The raingages have a sensitivity of 0.01 inches and are located at a distance of less than 200 ft from the flumes. Locating the raingages near the flumes may cause a problem with obtaining a true record from some storms because of inadequate fetch distance. This disadvantage is offset

by the capability of recording rainfall and water stage on the same chart and the advantage of being able to visually inspect the data before processing. A roll of chart paper on the recorders will last about 28 days and has a minimum time scale marking of 5 minutes per division.

Initial processing of the data collected with the old punched paper tape recorders is about 75% completed. This initial processing consists of matching the rainfall and runoff events and tabulating the data into a master table. Events of significant rainfall and/or runoff are then plotted to obtain a visual representation. Table 1 shows an example of the form of the initial tabulation of the data. Figure 1 is an example of the plots of the rainfall and waterstage for this storm event.

The sediment data from the plots is being collected by the University of Hawaii cooperators. To date, the data is limited because of the small quantity of water which has run from the watersheds.

Following is a brief summary of each watershed for the last year.

Honokaa -- The sugar cane was harvested about 6 May 1974 and will be replanted after the next ratoon harvest, which is scheduled for about 1977. By November 1974, the cane was approximately 4 to 6 ft tall and is considered to be essentially a complete cover. The raingage at this site is partially shielded from any Kona storms but will probably be sufficiently accurate for the trade wind storms which are the most common. Runoff from the site has been very low. It is estimated that about 65% of the data can be used in the final analysis.

Laupahoehoe -- This watershed was harvested on 22 January 1974 and replanted on 7 May 1974. By November 1974 the cane was over 6 ft tall and was a complete cover. The plantation has provided a nonplanted area from the road to the flume which may be a

potential source of sediment. The raingage at this site is next to the flume and has sufficient fetch distance if the cane does not grow above the 10-ft height of the gage. Considerable data was lost at this site because of malfunction of the punch motor on the old recorder. Approximately 48% of the data will be usable from this site.

Mililani -- This site has fluctuated between wild plant growth and cultivated crops such as potatoes for the last several years. There is also some question as to the size of the drainage area of the watershed which may be changed under some cultivation practices. Approximately 62% of the data from this site is usable.

Waialua Sugar -- The cane was harvested from this plot in the fall of 1974. There is considerable erosion potential at this site because the rows run up and down the slope. There has been a significant quantity of runoff water through the flume. A total of about 55% of the data will be usable.

Waialua Pineapple -- This plot was converted from pineapple to sugar cane in the spring of 1974. At this time the boundaries of the area slightly changed, leaving a watershed area of 1.02 acres. In April 1974 there was a major storm in the area and the runoff overtopped the diversion dikes around the watershed area. The extra quantity of runoff water exceeded the capacity of the flume causing a break in the dike next to the flume and washing the stilling well and the waterstage recorder loose from the flume. There was no damage to the sediment-sampling equipment. Approximately 72% of the data will be usable from this site.

Kunia -- With the change of the Waialua pineapple site to sugar cane, a new field of pineapple was selected on the Del Monte pineapple plantation near Kunia. This site is 7.02 acres in size and was instrumented in December 1974. The pineapple is planted using recommended conservation practices with respect to reducing soil erosion. To date no runoff data has been analyzed.

Part III. Rainulator Studies

The rainulator studies have been completed and a final report is in the process of being prepared.

SUMMARY AND CONCLUSIONS:

The major research emphasis in the State of Hawaii continues to be the rainfall-runoff-erosion studies conducted in cooperation with the University of Hawaii. New waterstage-raingage recorders were installed on all the watersheds in December 1974. At this time a new pineapple watershed was instrumented near Kunia. This plot was selected because of the conversion of the pineapple on the Waialua pineapple site to sugar cane.

About 75% of the runoff data has been tabulated from the old recorders. Matched rainfall and runoff events have been plotted and this data given to university and Soil Conservation Service cooperators.

PERSONNEL: Gary Frasier and Keith Cooley

Table 1. Rainfall-runoff from Waialua pineapple erosion watershed (1972).

DATE (JULIAN)	TIME (MILITARY)	ACCUM. TIME (HR.)	ACCUM. RAIN (INCHES)	WATER STAGE (FEET)	FLOW (CFS)	ACCUM. OUTFLOW (INCHES)
53	5	0.00	0.2	0.00	0.0000	0.0000
53	10	0.08	0.3	0.09	0.0786	0.0016
53	15	0.17	0.3	0.02	0.0041	0.0034
53	20	0.25	0.3	0.03	0.0091	0.0037
53	25	0.33	0.3	0.00	0.0000	0.0038
53	105	1.00	0.4	0.00	0.0000	0.0038
53	115	1.17	0.4	0.01	0.0011	0.0039
53	120	1.25	0.4	0.00	0.0000	0.0039
53	125	1.33	0.5	0.00	0.0000	0.0039
53	130	1.42	0.8	0.27	0.6772	0.0181
53	135	1.50	0.9	0.51	2.3554	0.0815
53	140	1.58	1.0	0.51	2.3554	0.1802
53	145	1.67	1.0	0.42	1.6099	0.2632
53	150	1.75	1.0	0.26	0.6289	0.3101
53	155	1.83	1.0	0.18	0.3059	0.3296
53	200	1.92	1.1	0.21	0.4138	0.3447
53	205	2.00	1.1	0.19	0.3401	0.3605
53	210	2.08	1.1	0.15	0.2140	0.3721
53	215	2.17	1.1	0.11	0.1165	0.3790
53	220	2.25	1.1	0.07	0.0480	0.3824
53	225	2.33	1.1	0.06	0.0355	0.3842
53	230	2.42	1.1	0.05	0.0248	0.3854
53	315	3.17	1.1	0.04	0.0160	0.3946
53	415	4.17	1.1	0.03	0.0091	0.4025
53	450	4.75	1.2	0.03	0.0091	0.4052
53	520	5.25	1.4	0.18	0.3059	0.4137
53	525	5.33	1.5	0.41	1.5356	0.4523
53	530	5.42	1.6	0.42	1.6099	0.5181
53	535	5.50	1.6	0.38	1.3231	0.5795
53	540	5.58	1.6	0.31	0.8878	0.6258
53	545	5.67	1.6	0.25	0.5824	0.6566
53	550	5.75	1.6	0.22	0.4533	0.6783
53	555	5.83	1.6	0.18	0.3059	0.6942
53	600	5.92	1.6	0.16	0.2428	0.7056
53	605	6.00	1.6	0.12	0.1382	0.7136
53	610	6.08	1.6	0.09	0.0786	0.7182
53	615	6.17	1.6	0.08	0.0624	0.7211
53	620	6.25	1.6	0.07	0.0480	0.7234
53	625	6.33	1.6	0.06	0.0355	0.7252
53	635	6.50	1.6	0.05	0.0248	0.7279

Table 1. Rainfall-runoff from Waialua pineapple erosion watershed (1972) (cont'd).

DATE (JULIAN)	TIME (MILITARY)	ACCUM. TIME (HR.)	ACCUM. RAIN (INCHES)	WATER STAGE (FEET)	FLOW (CFS)	ACCUM. OUTFLOW (INCHES)
53	640	6.58	1.6	0.04	0.0160	0.7288
53	705	7.00	1.6	0.03	0.0091	0.7320
53	715	7.17	1.7	0.10	0.0966	0.7346
53	720	7.25	1.7	0.15	0.2140	0.7411
53	725	7.33	1.8	0.15	0.2140	0.7500
53	730	7.42	1.8	0.16	0.2428	0.7596
53	740	7.58	1.8	0.14	0.1869	0.7788
53	745	7.67	1.8	0.10	0.0966	0.7847
53	750	7.75	1.8	0.08	0.0624	0.7880
53	755	7.83	1.8	0.06	0.0355	0.7901
53	805	8.00	1.8	0.05	0.0248	0.7928
53	830	8.42	1.8	0.04	0.0160	0.7979
53	855	8.83	1.9	0.05	0.0248	0.8014
53	935	9.50	1.9	0.07	0.0480	0.8102
53	940	9.58	1.9	0.08	0.0624	0.8125
53	950	9.75	2.0	0.09	0.0786	0.8181
53	1000	9.92	2.0	0.08	0.0624	0.8243
53	1010	10.08	2.0	0.07	0.0480	0.8293
53	1015	10.17	2.0	0.05	0.0248	0.8308
53	1050	10.75	2.0	0.04	0.0160	0.8379
53	1110	11.08	2.1	0.04	0.0160	0.8406

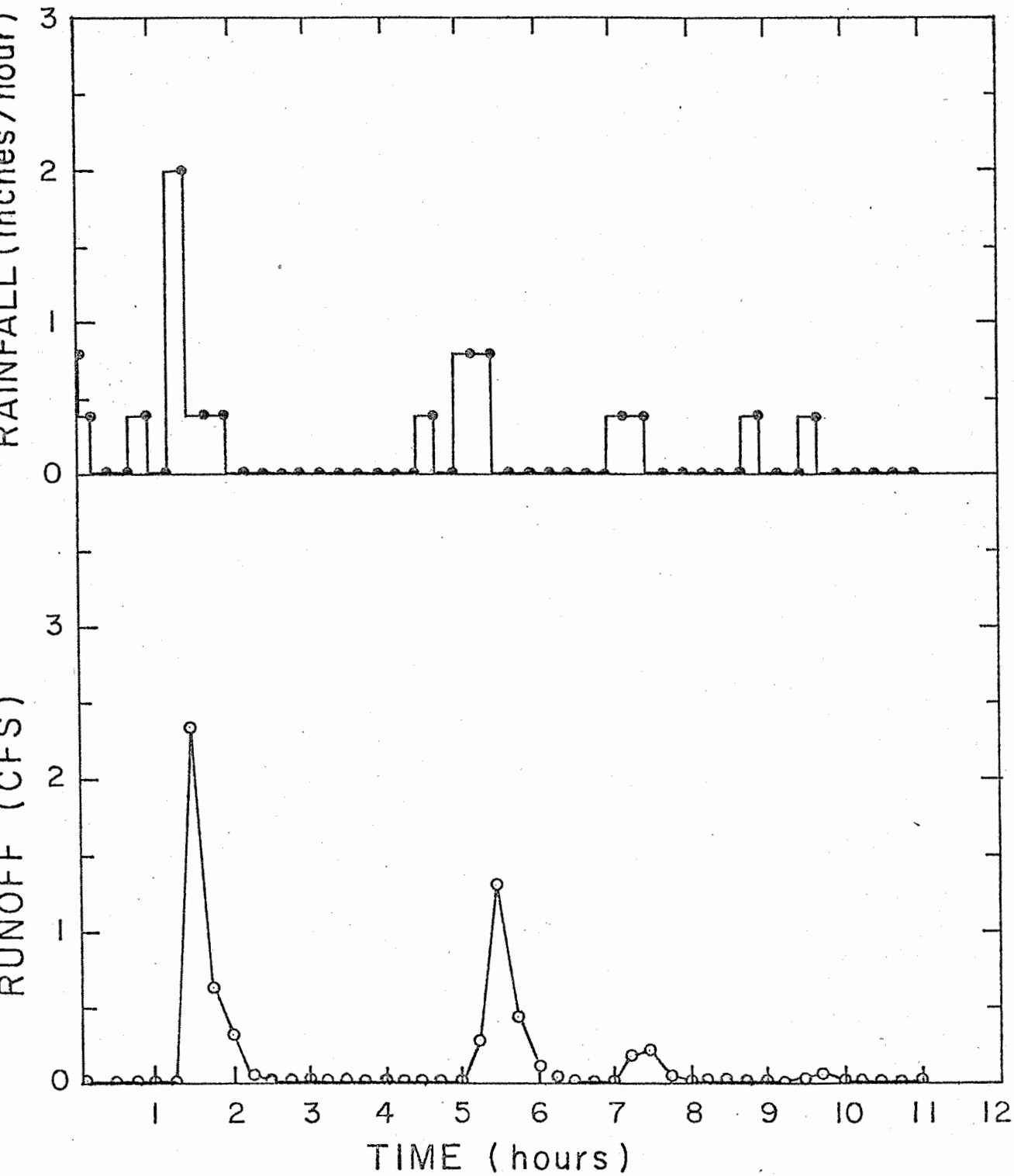


Figure 1. Example of rainfall intensity and rate of runoff from Waialua pineapple erosion watershed on Day 53, 1972.

TITLE: FABRICATED-IN-PLACE, REINFORCED RESERVOIR LININGS AND GROUND COVERS

CRIS WORK UNIT: 5510-12260-004 CODE NO.: Ariz.-WCL 68-2

INTRODUCTION:

Water discoloration studies were continued at Granite Reef in the evaluation of the performance of various protective surface coatings for reinforced asphaltic membranes. Experimental pond liners were installed on two small test ponds and a coated plastic liner installed in the steel grain bin at Granite Reef. A new membrane liner was installed on the water storage pit at the Nelson Road catchment on the Hualapai Indian Reservation. Observations were continued of existing operational field catchments.

RESULTS AND DISCUSSION:

Part I. Operational Catchments.

Field catchments of asphalt-fiberglass membranes continue to give excellent performance with a minimum of required maintenance. Observations and water discoloration studies at the Granite Reef test site indicate that the life of the treatments is significantly extended by application of protective coatings. Several coatings show no signs of deterioration after weathering 4 to 6 years.

The storage reservoir for the Nelson Road Catchment on the Hualapai Indian Reservation was relined in June 1974 with a polypropylene matting saturated with a sprayable asphalt-asbestos-water mix.

The old asphalt-fiberglass lining was removed and the pit sides reshaped slightly and smoothed with a backhoe. A soil sterilant was dusted on the entire area. The polypropylene matting was laid in sheets 15 ft wide extending crosswise of the pit from side to side. Adjoining sheets were overlapped about 8 inches and sealed with the asphalt mixture. The upper edges of the sheetings were anchored in a trench 6 inches deep which were backfilled with soil. Fishmouth wrinkles at the seams were split lengthwise and covered with a patch of asphalt-saturated polypropylene matting.

The coating used was basically an asphalt emulsion (SS-1h anionic with 65% solids) modified as follows. A wetting agent was mixed with the diluting water, then asbestos fibers (fine-run-short) added and mixed until all fibers were wetted. Asphalt emulsion was then added and mixed for about 3 to 5 min. The mixture was placed in a pressure-pot type tank and sprayed on the matting through a 1/8-inch slotted nozzle at a rate of 0.4 gal/yd^2. Problems were encountered with poor quality asphalt (partially broken) and it was necessary to reduce the quantity of asbestos. The desired application rate (0.7 gal/yd^2) was obtained by multiple applications.

Part II. Laboratory Studies.

A 35 x 50-ft pond liner, prefabricated by the manufacturer of oriented polyethylene (Fabrene TM) using a heat seam, was installed in a small test pond at Granite Reef in June 1974. The top dimension of the test reservoir was 26 x 14 ft with a 1:1 to 1:2 (vertical:horizontal) sideslope and a 4.5-ft depth. Seepage tests in August 1974 for a 16-day period showed a water loss of .32 inches a day with the evaporation estimated at .29 inches a day. The median air temperature was 89 F for this period.

A second pond lining of asphalt-asbestos-polypropylene was installed in June 1974 in an adjoining pond (26 x 14 x 4.5 ft). The lining was fabricated in place with 15-ft wide strips of polypropylene sprayed with an asphalt emulsion coating consisting of SS-1h asphalt, wetting agent, water and fine-run-short asbestos fibers at a rate of 0.7 gal/yd^2. A second coat was repeated 3 days later. After allowing adequate time for curing, water was pumped into the reservoir and it has been maintained at a level of 3- to 4.5-ft depth. Water surface elevations checked for a 16-day period in late August showed a water loss of .34 inches a day with the evaporation loss during period estimated at .29 inches a day.

A plastic liner was installed in the grain bin storage in April 1974 at the Granite Reef Test Site. The tank is a galvanized grain bin four rings high, 18.5 ft in diameter and has a depth of 10 ft. The top edge was capped by splitting ½-inch-diameter plastic pipe and placing over the exposed rim of the tank. The liner is a sheet of 30-mil polyvinyl chloride (PVC) film (45 x 45 ft) with protective coating (United Paint Elastuff 400 (gray)). Drying time of the coating was about 30 minutes with the air temperature 80-85 F. The thickness of the coating was a uniform 1 mil and very durable. The liner was carefully unfolded into the tank, draped over the side and a second piece of slit ½-inch pipe placed over the rim to clamp the liner in place. The pipes were held in place with pieces of strap steel formed in the shape of an inverted J with a slot in it bolted to the tank.

Seepage measurements indicate the only water loss is from evaporation. A floating cover was constructed and placed on the water surface in late November. The material is a foamed butyl 1/8 inch thick. Wind gusts up to 40 mph have occurred, but with the tank only about half full. With a full tank, the uplift may have blown the cover completely off of the tank. A wind gust recorder will be placed adjacent to the tank next year.

Seepage losses from a canal liner constructed of polypropylene-asphalt emulsion-asbestos, similar to that used to line the pits at Granite Reef and Hualapai, have been evaluated in a seepage test channel in Logan, Utah. The liner was installed in August 1972. Water depth is maintained at about 1 ft. During a 2-month period in 1974 only a trace of seepage could be detected from one test section and none from six others. The lining material continues to be flexible and does not show unusual signs of weathering. Seepage losses will be checked again during 1975.

SUMMARY AND CONCLUSIONS:

Studies were continued at the Granite Reef test site in the evaluation of protective coating for asphalt-coated fabrics. The

life of the reinforced asphaltic membranes is believed to be able to be extended several times with several of the coatings.

Observations and reports of the field catchments of asphalt fiberglass continues to be favorable with no problems other than ants. A new lining was installed on the storage pit of the Nelson Road catchment. The lining is made from a polypropylene fabric coated with an asphalt-asbestos sealer.

Two small test ponds were successfully lined at the Granite Reef test site using an oriented polyethylene sheeting on one pond and an asphalt-asbestos-polypropylene matting on the other. A precoated sheeting of PVC was used to line the steel grain bin water storage tank. Seepage tests in Logan, Utah, show no seepage through an asphalt-asbestos-polypropylene canal lining.

PERSONNEL: Gary Frasier, Allen Dedrick, and John Griggs.

TITLE: USE OF FLOATING MATERIALS TO REDUCE EVAPORATION FROM WATER SURFACES

CRIS WORK UNIT: 5510-12260-004 CODE NO.: Ariz.-WCL 71-6

INTRODUCTION:

Long-range durability and efficiency studies were continued for a few materials in 1974. Included were Mini-Vaps, granular wax, foamed wax blocks, and three continuous wax covers. Performance of continuous wax covers on the butyl-lined pond and small asphalt-fiberglass pond was also observed. A new cover of foamed rubber was constructed and placed on one of the evaporation tanks to compare efficiency. A report of the evaporation reduction studies was presented at the Water Harvesting Symposium in March at Phoenix, Arizona and will appear in the symposium proceedings.

Field evaluation of two foamed rubber floating covers constructed in the fall of 1971 was continued. The tanks are located in southwest Utah. Covers were installed on four other tanks during 1974 here in Arizona. Different foam rubber thicknesses were used in the construction. A paper entitled "Foam Rubber Covers for Evaporation Control" was prepared and describes materials to use and fabrication techniques necessary for the construction of these covers.

PROCEDURE:

Evaluation of the various treatments on the tanks was the same as in previous years, the procedure being to compare evaporation from a treated tank to that from an identical untreated tank. The Mini-Vaps and granular wax were tested at the laboratory site, and the foamed wax blocks, three continuous wax covers, and the foamed butyl rubber were tested at Granite Reef.

All covers at both sites were the same as reported on last year, except the foamed butyl rubber cover. It was constructed of 3/16- by 36-inch rolls of foamed butyl which was cut and glued to form a circle slightly smaller than the tank diameter. A piece of 1/2- by 1-inch butyl was then attached around the perimeter on the bottom

side to help maintain shape and prevent the wind from blowing the cover from the water surface.

RESULTS AND DISCUSSION:

Laboratory Studies. The efficiency of the Mini-Vaps has gradually decreased from 27% in 1971 to only 6% in 1974. The cost of the 25-pound sample in 1970 was $50. If an annual evaporation rate of 72 inches is assumed, and the efficiencies of 27, 22, 15, and 6% used, the cost of the water saved during the 3-1/2 year period would be $57/1,000 gallons.

The efficiency of the granular wax can be maintained at about 20% over a year's time if three applications are made during the year. Assuming the same evaporation as above, the cost of the water saved by the granular wax would be $18/1,000 gallons, or less than one-third that of the Mini-Vaps.

Although costs to haul water have often been as much as $20/1,000 gallons, other materials being tested save water much more efficiently and at a considerably lower cost. Therefore studies using these two materials will be discontinued.

Granite Reef Studies. The efficiency of the wax covers remained essentially the same during 1974. Averages for the year were 38, 86, and 89%, respectively, for the foamed wax blocks, 120°-125° wax layer, and the 125° charcoal-covered wax layer. Tank #1 with the 125°-135° wax layer was not filled during the year in an attempt to determine what would happen to the wax if the tank went dry and then was refilled. However, the tank did not completely dry up at any time during the year. This test will be continued in order to complete the objective.

The foamed butyl rubber was on the tank for 11 months and reduced evaporation by 85% during this period.

The low-melting-point wax applied to the butyl-lined pond in 1973 only covers about one-third of the water surface, and did not cover more than one-half of the surface even during the hot summer period. Water temperature in the pond may be cool enough to prevent

the wax from melting and spreading. This could mean the continuous wax covers would be limited to the smaller ponds and stock tanks. It may also mean a thicker wax layer is required on larger ponds.

The continuous wax cover applied to the asphalt-fiberglass pond performed very well in the summer months, but became very brittle in late November. It has since broken into numerous small pieces about 1/16 by 2 by 2 inches, and some of these pieces have been blown from the water surface. The remainder will be left in place to see if the cover will re-form as the temperature rises this summer. Breakage may have been caused by a chemical reaction between the wax and the asphalt, or the cover may have been too thin making it susceptible to breaking.

Field Studies, Foamed Rubber Covers.

Jackson Wash tank, northwest of Cedar City, Utah, installed November 1971 -- The cover came off the tank during May when it was refilled with water, which was similar to what happened a year earlier. Again, the precise cause of displacement was not determined but likely was associated with the filling operation. Wind may have been a contributing factor. The maximum wind gust for the period was 57 mph. The cover was patched and placed back on the tank on 23 July 1974. The cover was operating satisfactorily when inspected in August and October.

Beaver Dam tank, southwest of St. George, Utah, installed November 1971 -- The cover was inspected four times during 1974, first in May and last in October. Water levels varied from 1 ft to 3 ft from the top of the tank. The maximum wind gust recorded was 27 mph. The cover is in excellent condition.

Four other covers were installed in the field during 1974 to obtain additional operational information.

Frasier Well tank, Hualapai Indian Reservation, installed 29 May 1974 -- Sheet stock 36 inches wide and 3/16-inch thick was used to construct a cover 40 ft 2 inches in diameter. An overflow pipe was installed to maintain a 6-inch freeboard. A wind gust anemometer

was installed on 28 August. The maximum wind gust recorded since installation was 26 mph. The cover is in excellent condition.

Shipley Well tank, Hualapai Indian Reservation, installed 29 May 1974 -- Sheet stock 24 inches wide and 1/8-inch thick was used to construct a 30-ft 7-inch diameter cover. This material was too thin to maintain the cover shape and tended to bunch up on the water surface. A cover fabricated from 36-inch-wide and 3/16-inch-thick sheet stock replaced the thinner material on 29 August. Minimum freeboard is controlled at 6 inches. A wind gust anemometer was also installed in August. The maximum wind gust recorded was 29 mph. Shortly after installation 5 or 6 holes (tear-type holes) were observed that likely were caused by vandalism. No further damage has been seen since.

Glover Ranch tank, south of Safford, Arizona (Bureau of Land Management), installed 12 September 1974 -- Sheet stock 24 inches wide and 1/4-inch thick was used to fabricate a 25-ft 9-inch diameter cover. Water is supplied from a well. The following is a comment from the 11 October 1974 report: "Pump supply to tank is nonoperative at this time, and rancher is hauling water. Even during hot sunny months just after installation of the cover, he noticed a definite drop in hauling requirements." The cover is in excellent condition.

Hughes Ranch tank, south of Rye, Arizona (Tonto National Forest), installed 20 November 1974 -- Sheet stock 24 inches wide and 1/4-inch thick was used to fabricate a 27-ft 8-inch diameter cover. A wind gust anemometer was installed, but no wind reports have been received. The tank is used for storing water collected from a water harvesting apron. The apron needs to be maintained. Until operating properly, water will be hauled to the tank.

One-inch-wide lap joints are still stronger than the foamed rubber material itself after 36 months in the laboratory under continuously wet conditions. Material thickness has decreased by about 33% (original thickness 3/16 inch), but it is still highly buoyant. All covers in the field have been fabricated with 2-inch-wide lap joints. No failures have been observed.

SUMMARY AND CONCLUSIONS:

Failure of the Mini-Vaps after only 3-1/2 years and the necessity of three applications of granular wax per year make both of these materials uneconomical at $57 and $18 per 1,000 gallons of water saved, respectively. Observations of these covers will therefore be discontinued.

The foamed wax blocks and continuous wax covers tested at the Granite Reef site performed essentially the same as for the past 2 years, and long-range studies will be continued. The efficiency of the wax blocks was 38%, and the continuous wax covers reduced evaporation by 86 and 89%. The foamed butyl rubber cover reduced evaporation by 85% for the 11 months it was in operation.

Continuous wax covers on the ponds at Granite Reef will continue to be observed to see if they will re-form and spread during the hot summer season. It may be necessary to add more wax to obtain complete and durable covers.

Six floating covers of foamed rubber are being field tested to determine their overall operation, performance, and utility. Performance has generally been satisfactory for a 3-1/2 year period for the two covers installed in 1971. One cover that has been displaced from the tank twice during the past 2 years will be carefully watched in an effort to determine the exact cause of the displacement. Observation of all covers will be continued.

PERSONNEL: Keith R. Cooley and Allen R. Dedrick

TITLE: LOWER COST WATER HARVESTING SYSTEMS

CRIS WORK UNIT: 5510-12260-004 CODE NO.: Ariz.-WCL 71-12

INTRODUCTION:

Precipitation and runoff measurements were continued on the water harvesting test plots at Granite Reef, Seneca, and Monument Tank. A new rubberized asphaltic sealcoat was applied on the collection ditches of two of the watersheds at Monument Tank. Observations of weatherability and periodic measurements of material physical properties are being continued on test samples of various experimental membranes and protective coatings for collecting and storing precipitation at the Granite Reef test site.

PART I. GRANITE REEF TEST SITE

An above-average total of 250.7 mm of rainfall was measured from 22 storms at the Granite Reef test site.

Paved or Covered Plots: The treatments applied to the paved or covered plots are listed in Table 1 and the runoff results in Table 2.

The runoff efficiency from the two-phase asphalt treatments, L-5 and L-6, continued to decline, averaging only 53.4% and 66.1%, respectively. The asphaltic pavement catchment surface shows extensive shrinkage with corresponding cracks. There has been no maintenance on the plots for over 3 years.

The membrane-covered plots L-1 (30 mil chlorinated polyethylene), L-4 (15 mil nonreinforced butyl), and L-7 (1 mil aluminum foil) averaged 92.3%, 49.3% and 79.5% runoff efficiency, respectively. Runoff from plots L-1 and L-7 was approximately 5% less than the previous year. The reason for the decrease is not known but may be a result of the storm characteristics or because of increased retention on the plots as the bonded films age with time. The runoff from the butyl plot L-4 shows the effect of the holes in the sheeting enlarging with time. It is expected

that the sheeting will be completely destroyed by wind. The type of butyl does not warrant the effort to repair the plot.

The membrane materials treatments A-1 (aluminum-coated asphalt-fiberglass and A-2 (gravel-coated roofing) averaged 92.5% and 70.3% runoff, respectively. The gravel on A-2 moves downslope with time but this has not been a serious problem. The asphalt-fiberglass is showing no signs of deterioration and the runoff water is completely clear. The vinyl aluminum protective coating is showing no signs of flaking or weathering.

Plot A-5 (concrete) averaged 77% runoff from 182.8 mm of precipitation. Several storm events were not measured because of the failure to completely drain the water storage tank after measuring the 10 m^2 plots.

Bare Soil Plots: The treatment on the bare soil plots is listed in Table 3 and the runoff results are listed in Table 4. These plots are all treatments where the soil surface is not completely covered or paved.

Rainfall runoff from the three watersheds W-1, W-2, and W-3 averaged 15.3%, 8.1%, and 20.3%, respectively, for essentially no change from the previous year. Runoff from the two smoothed untreated plots L-2 and A-3 were 18.6% and 27.2%, respectively. The untreated ridge-and-furrow plots R-1 and R-3 averaged 16.2% and 19.8%, respectively. Runoff from these four plots is slightly higher than the previous year.

Runoff from the silicone-treated plot L-3 averaged 37.7%. Plots R-4 and A-4 treated with the silicone water repellent plus plastic soil stabilizer averaged 45.5% and 66.5%, respectively. Runoff from these three plots is about 7 to 10% less than was measured in the previous year. This decrease is a result of the chemical deteriorating with time as can be seen in Figure 1. Runoff from the untreated plots slightly increased while the treated plots continued a decline in runoff efficiency.

Plot R-2, treated with paraffin wax, averaged 84.8% runoff for the year. The efficiency of this treatment is also plotted in Figure 2. The slight decrease in the runoff efficiency for this treatment may be an indication of possible weathering of the wax. The plot still has no weed growth, indicating that there is insufficient water infiltration to germinate the seeds that might be present.

PART II. MONUMENT TANK

Precipitation at the site totaled only 243.8 mm for the year. This is the third year in a row that precipitation has been about 60% of the long-term average of 400 mm per year. Runoff from the area was very low. The mechanical weather stations were removed from the area in September 1974 because of maintenance problems and the necessity of chart replacement every 30 days. The rainfall intensity is now measured with a tipping bucket raingage attachment to the waterstage recorder on Watershed 3. This now allows all recorders to be serviced on a 90-day schedule.

The diversion or collection ditches at the lower edges of Watersheds 2 and 3 were retreated with two coats of asphalt. In August 1974 an RC 250 cutback asphalt was sprayed on the ditches at a rate of 0.6 gal/yd^2. In September 1974 the ditches were sprayed at a rate of 1.25 gal/yd^2 of rubberized cutback asphalt (Arizona Refinery AR8000). The coating is weathering satisfactorily. After spraying the ditches on Watershed 3 the asphalt excess ran down into the measuring flume and pooled to a depth of about 4 inches. This will have to be removed in the near future.

Outdoor Weathering Panels: Forty-six flexible membrane specimens have been exposed as ground panels at Granite Reef since 6 December 1973 and three new materials during 1974. A description of the materials along with their condition are shown in Table 5. The condition of the materials is a visual observation only without reference to physical property evaluation. Ratings are arbitrary in nature and depend upon the judgment of the individual; hence,

a change from excellent to good would not be considered to be too serious. Ratings and the explanation when dealing with coated substrates refer to the coating material and not to the substrate.

PART III. OPERATIONAL CATCHMENTS

Seneca Catchment: Since application of the wax treatment in June 1973, rainfall at the site has been considerably below the average of 400 mm per year. For 1974 a total of 292 mm was measured which represents about 65% of the long-term average. There are signs that the soil regained a partial regeneration of water repellency during the summer months. An accurate evaluation was not determined because of the scarcity of runoff-producing storms. There is considerable surface detention of runoff on the plot which provided sufficient moisture for some plant growth. This would indicate some moisture does penetrate through the water-repellent soil. There is also evidence of soil erosion downslope. Approximately one-fifth of the butyl liner in the reservoir was damaged by wind in August 1973. This was repaired in September 1974.

Sells Catchment: A small wax catchment was installed in cooperation with the University of Arizona, Water Resources Center, at Sells, Arizona. The water from the catchment is to be used for growing desert-adapted plants. The plot area had inadvertently been treated with a high rate of sodium chloride prior to treatment. In July 1974 paraffin wax was sprayed on at a rate of 1.25 lbs/yd^2. There was a light rain about 2 hours after treatment. Reports from cooperators indicate the wax treatment severely cracked and the runoff efficiency is considerably less than expected.

Arizona Strip Catchments: U. S. Water Conservation Laboratory personnel assisted in the installation of one of two wax catchments constructed by the Bureau of Land Management in the Arizona Strip District. The catchment is slightly over 1 acre in size on a 5 to 8% slope. The plot was scraped of vegetation and treated with a

soil sterilant. To attempt to smooth the soil prior to treatment, the area was rolled with four-wheel drive vehicles which loosened the soil surface. The wax was sprayed on the plot with an asphalt-distributor truck at a rate of 1.25 lbs/yd^2. Reports of the performance of the treatment indicate there was some erosion down the main drainage area but the treatment has performed satisfactorily. It was reported the catchment collected sufficient water to fill and overflow an 80,000-gallon steel storage tank six times during a period when 240 head of cattle were using the facility.

Fishlake National Forest: Most of the field work associated with the project titled "Prevention of small mammal damage to flexible membrane materials used as water barriers," being conducted through a cooperative agreement with Utah State University, has been completed on water harvesting systems and sites on the Forest. The objectives of the study are to identify the small animal species damaging flexible membrane materials being used as water barriers; determine the ecological factors associated with the damage; and develop methods whereby the damage can be prevented.

Two seasons of trapping at ten water harvesting systems resulted in five species of small mammals being caught. Only one species, *Peromyscus maniculatus*, (deer mouse) was trapped at all sites. Experimental modifications were made on seven water harvesting systems in an effort to determine which ecological factors were associated with damages. All field and laboratory research has been completed. Data are being analyzed and the final report, in the form of a Master of Science thesis, will be completed during 1975.

Cache National Forest: The plastic-lined, 30-ft-diameter tank, used to store water collected from the Chicken Creek water harvesting system, had about 1 ft of water when visited on 18 May 1974. Water depth should have been about 3 ft--result of snow melt. Part of the standpipe used as an overflow for the tank had

been removed and resulted in the loss. The standpipe was extended to maintain a freeboard of about 6 inches. The PVC liner appeared to be in excellent condition.

PART IV. RIVER LABORATORY AND TEST SITES AT LOGAN, UTAH

Outdoor Weathering Racks: The appearance and condition of membrane and film specimens exposed on racks at Logan according to ASTM D 1435 are summarized in Table 6. The materials were inspected in May and October 1974. Observation will be continued during 1975.

Outdoor Exposure Panels: Thirty-six potential water barrier materials, of the flexible sheeting and film type, are exposed as ground panels at Logan in a manner similar to that described for Granite Reef. Only four panels changed significantly from the 1973 conditions.

Panel 11, vinyl, 20 mil, black, exposed 25 March 1966, Firestone. Poor condition with extensive cracking.

Panel 17, PE-coated CLS, exposed 19 October 1972, Hercules. Poor condition, coating starting to peel, polypropylene deteriorating where coating peeled.

Panel 27, uncoated PVC, 10 mil, exposed 13 October 1971, Union Carbide. Poor condition, cracked extensively and has fallen apart.

Panel 41, uncoated PE, 8 mil, black. Fair to poor condition with considerable tears and holes.

One of the most extreme changes occurred in panel 27, uncoated 10 mil PVC. It was in excellent condition in October 1973 but when observed in May 1974 it had completely deteriorated. A panel of the film that had been coated with a liquid elastomeric and exposed at the same time is still in excellent condition. Observation will be continued during 1975.

Water Harvesting Catchments: Six prototype catchments remain in Logan and only two changed noticeably since the 1973 observations.

Catchment R1 -- butyl, unreinforced, 30 mil, installed 1958. Condition good to fair with several tears and extreme chalking.

Catchment R4 -- Oriented PE (Fabrene TM), installed October 1972. Material had pulled out of anchor trench when observed in May. Material was reanchored in relaxed condition. The material was extremely tight when observed in October and was starting to pull out of trench again. This tightening effect may be a problem in the use of this material.

A nylon-reinforced apron (R-8) was removed during the year by the Forest Service for use on the Cache National Forest.

Test Reservoirs at Logan: Six small test reservoirs (8,000- to 12,000-gal excavated pits) with various lining materials were maintained during 1974 but seepage measurements were not made. The reservoirs will remain in place until the area is needed by Utah State University. Water will be kept in the reservoirs and maintenance will be continued during 1975. Seepage will not be measured.

SUMMARY AND CONCLUSIONS:

Rainfall-runoff measurements were continued at the Granite Reef testing site. Runoff efficiency continues to decline on the two-phase asphalt treatments, probably a result of no maintenance on the treatments for the past 3 years. The silicone water-repellent treatments continued to decline, a result of a weathering deterioration. The runoff from the paraffin wax plot declined slightly, which may indicate some treatment deterioration. Runoff from the remainder of the covered and bare soil plots did not change significantly from the previous year.

Runoff measurements were continued at the Monument Tank test site. Precipitation was considerably below average with a corresponding reduced runoff. The water collection ditches on two of

the watersheds were re-treated with an asphaltic tack coat and a rubberized asphaltic sealcoat.

Precipitation runoff from the Seneca plot was quite low, a result of freezing and thawing of the treatment during the winter and a high surface retention. The precipitation for the year was also quite low. There were indications of a partial regeneration of treatment water repellency during the summer. A paraffin wax plot was installed in northern Arizona with assistance from laboratory personnel. The 1-acre catchment has performed satisfactorily for years in providing water for about 240 head of cattle.

PERSONNEL: Gary Frasier, Allen Dedrick, and John Griggs

Table 1. Treatments on paved or covered plots at Granite Reef.

Plot	Treatment Date	Treatment
L-1	8 Aug 1967	Basecoat. MC-250 at 1.5 kg asphalt m^{-2}
	22 Aug 1967	Topcoat. RSK asphalt emulsion at 0.7 kg asphalt m^{-2}
	20 May 1968	Top Sheeting. 30-mil chlorinated black polyethylene
L-4	30 Nov 1961	Butyl Rubber Sheeting. 15-mil
L-5	18 Sep 1962	Basecoat. RSK asphalt at 1.04 kg asphalt m^{-2}
	16 Mar 1966	Topcoat. RSK asphalt emulsion at 0.6 kg asphalt m^{-2}
	22 Apr 1970	Sealcoat. Modified SSKH asphalt emulsion at 0.6 kg asphalt m^{-2}
L-6	19 Apr 1963	Basecoat. RC-special at 1.5 kg asphalt m^{-2}
	8 May 1963	Topcoat South Half. S-2 asphalt emulsion at 0.65 kg asphalt m^{-2} with 3% butyl latex
	9 Jul 1963	Topcoat North Half. S-1 at 0.5 kg asphalt m^{-2} with 3% butyl latex
	22 Apr 1970	Sealcoat. Modified SSKH asphalt emulsion at 0.6 kg asphalt m^{-2}
L-7	3 Aug 1967	Basecoat. MC-250 at 1.5 kg asphalt m^{-2}
	22 Aug 1967	Top Sheeting. 1-mil aluminum foil bonded with RSK asphalt emulsion at 0.7 kg asphalt m^{-2}
A-1	3 Aug 1967	Basecoat. MC-250 at 1.5 kg asphalt m^{-2}
	22 Aug 1967	Top Sheeting. 3/4-oz chopped fiberglass matting bonded with RSK asphalt emulsion at 1.4 kg asphalt m^{-2}
	Jan 1968	Top Spray. Vinyl aluminum coating at 0.1 gal yd^{-2}

Table 1. Treatments on paved or covered plots at Granite Reef (continued).

Plot	Treatment Date	Treatment
A-2	3 Aug 1967	Basecoat. MC-250 at 1.5 kg asphalt m^{-2}
	12 Sep 1967	Top Sheeting. Standard rag felt-rock roofing treatment
A-5	Sep 1968	Concrete Slab.

Table 2. Rainfall runoff from paved or covered plots at Granite Reef.

Date	Rainfall	L-1 Runoff		L-4 Runoff		L-5 Runoff	
1974	mm	mm	%	mm	%	mm	%
1 Jan	2.0	2.1	105.0	.2	10.0	.3	15.0
5 Jan	11.0	10.9	99.1	5.7	51.8	5.4	49.1
7 Jan	14.8	14.4	97.3	8.1	54.7	3.7	25.2
8 Jan	6.8	6.6	97.1	3.2	47.1	2.8	41.2
11 Mar	25.5	25.4	99.6	11.3	44.3	8.8	34.5
20 Mar	17.7	17.0	96.0	8.6	48.6	10.0	56.5
20 Mar	1.3	1.1	84.6	.4	30.8	.2	15.4
7 Jul	3.0	1.8	60.0	0	0	0	0
14 Jul	16.3	15.5	95.2	7.6	46.6	10.7	65.6
21 Jul	7.1	5.4	76.7	3.8	53.5	3.5	49.3
22 Jul	8.3	2.7	32.5	6.3	75.9	2.1	25.3
3- 5 Aug	35.5	35.0	98.7	21.2	59.7	26.9	75.8
15 Sep	2.6	2.4	93.3	.4	15.4	.7	26.9
26 Sep	2.5	3.1	124.0	.3	12.0	.5	20.0
6 Oct	5.3	5.2	98.1	.2	3.8	.9	17.0
12-13 Oct	4.4	4.9	111.4	2.0	46.0	2.7	61.4
22 Oct	10.2	10.2	100.0	1.2	11.8	2.6	25.5
28 Oct	37.0	31.2	84.3	25.9	70.0	30.8	83.2
30 Oct	14.6	13.6	93.2	6.9	47.3	10.0	68.5
2 Nov	9.4	8.9	94.9	5.2	55.3	6.8	72.3
4- 5 Dec	10.3	9.7	94.2	3.7	35.9	3.9	37.8
28 Dec	5.1	4.4	86.7	1.3	25.5	.5	9.8
Total	250.7	231.5	92.3	123.5	49.3	133.8	53.4

Table 2. Rainfall runoff from paved or covered plots at Granite Reef (continued).

Date	Rainfall	L-6 Runoff		L-7 Runoff		A-5 Runoff	
1974	mm	mm	%	mm	%	mm	%
1 Jan	2.0	.5	25.0	1.1	55.0	.9	45.0
5 Jan	11.0	6.8	61.8	8.7	79.1	7.9	71.8
7 Jan	14.8	10.4	70.3	12.9	87.2	13.0	87.8
8 Jan	6.8	3.8	55.9	5.4	74.1	6.1	89.7
11 Mar	25.5	16.4	64.3	20.5	80.4	21.1	82.7
20 Mar	17.7	11.1	62.7	13.8	78.0	14.2	80.2
20 Mar	1.3	.5	38.5	.8	61.5	.8	62.0
7 Jul	3.0	0	0	.8	26.7	0	0
14 Jul	16.3	11.0	67.5	12.1	74.2		1/
21 Jul	7.1	5.1	71.8	6.0	84.5	4.0	56.3
22 Jul	8.3	7.0	84.3	6.9	83.1	8.2	98.8
3- 5 Aug	35.5	28.6	80.6	31.1	87.7	26.7	75.3
15 Sep	2.6	.4	15.4	1.8	69.2	.8	31.0
26 Sep	2.5	.4	16.0	1.8	72.0	2.0	80.0
6 Oct	5.3	1.6	30.2	3.2	60.4	3.8	71.9
12-13 Oct	4.4	3.2	72.7	4.5	102.3		1/
22 Oct	10.2	2.8	27.7	5.5	53.9		1/
28 Oct	37.0	31.5	85.1	31.3	84.6		1/
30 Oct	14.6	10.9	74.8	12.5	85.6	12.4	85.0
2 Nov	9.4	6.9	73.4	8.0	85.1	8.0	85.1
4- 5 Dec	10.3	5.2	50.5	8.0	77.3	7.5	73.1
28 Dec	5.1	1.5	29.4	2.5	49.0	3.3	64.7
Total	250.7	165.6	66.1	199.2	79.5	140.7	77.0 2/

1/ Data missing because of failure to drain storage tank after pumping the 10 m^2 plots.

2/ Total rainfall for reported runoff equaled 182.8 mm.

Table 2. Rainfall runoff from paved or covered plots at Granite Reef (continued).

Date	Rainfall	A-1 Runoff		A-2 Runoff	
1974	mm	mm	%	mm	%
1 Jan	2.0	1.8	90.0	0	0
5 Jan	11.0	10.6	96.4	6.3	57.3
7 Jan	14.8	14.9	100.7	13.0	87.8
8 Jan	6.8	6.5	95.6	5.1	75.0
11 Mar	25.5	25.1	98.4	18.5	72.5
20 Mar	17.7	16.4	92.7	13.7	77.4
20 Mar	1.3	1.2	92.3	.2	15.4
7 Jul	3.0	1.4	46.7	0	0
14 Jul	16.3	15.2	93.3	12.3	75.5
21 Jul	7.1	5.8	81.8	4.4	62.0
22 Jul	8.3	5.3	63.9	6.3	75.9
3- 5 Aug	35.5	33.3	93.8	28.2	79.3
15 Sep	2.6	2.1	80.8	.6	23.1
26 Sep	2.5	2.8	112.2	0	0
6 Oct	5.3	4.4	83.0	2.4	45.3
12-13 Oct	4.4	4.4	100.0	.4	9.1
22 Oct	10.2	9.8	96.1	4.4	43.1
28 Oct	37.0	34.7	93.8	33.1	89.5
30 Oct	14.6	13.9	95.2	11.5	78.9
2 Nov	9.4	8.8	93.6	7.3	77.7
4- 5 Dec	10.3	9.3	90.3	6.2	60.2
28 Dec	5.1	4.3	84.3	2.3	45.1
Total	250.7	232.0	92.5	176.2	70.3

Table 3. Treatments of bare soil plots at Granite Reef.

Plot	Treatment Date	Treatment
L-2	30 Nov 1961	Smoothed soil, 14.14 m x 14.14 m plot
L-3	4 Aug 1965	Smoothed soil, 14.14 m x 14.14 m plot treated with silicone water repellent at 0.057 kg m^{-2}
	6 Nov 1969	Retreated at 0.04 kg m^{-2}
R-1	1 Mar 1965	Ridge and furrow, 20% sideslope
R-2	29 Sep 1972	Ridge and furrow, 10% sideslope treated with wax water repellent at 1.3 lbs/yd^2
R-3	1 Mar 1965	Ridge and furrow, 20% sideslope
R-4	13 May 1966	Ridge and furrow, 10% sideslope, treated with 44.9 g m^{-2} sodium carbonate
	3 Nov 1970	Treated with 3% silicone water repellent and 2% soil stabilizer - 1.2 liters of solution m^2
A-3	1 Aug 1967	Smoothed soil, 6 m x 30 m plot
A-4	10 Nov 1971	Smoothed soil treated with 3% silicone water repellent and 2% soil stabilizer - 1.2 liters of solution m^{-2}
W-1	1 Dec 1963	Uncleared watershed
W-2	1 Dec 1963	Uncleared watershed
W-3	1 Dec 1963	Cleared watershed

Table 4. Rainfall runoff from bare soil plots at Granite Reef.

Date	Rainfall	W-1 Runoff		W-2 Runoff		W-3 Runoff	
1974	mm	mm	%	mm	%	mm	%
1 Jan	2.0	0	0	0	0	0	0
5 Jan	11.0	2.3	20.9	1.8	16.4	3.0	27.3
7 Jan	14.8	.9	6.1	.1	.7	.9	6.8
8 Jan	6.8	.1	1.5		0		0
11 Mar	25.5	2.6	10.2	.7	2.7	6.8	26.7
20 Mar	17.7	1.1	6.2	0	0	.7	4.0
20 Mar	1.3	0	0	0	0	0	0
7 Jul	3.0	0	0	0	0	0	0
14 Jul	16.3	.7	4.3	.1	.7	1.3	8.0
21 Jul	7.1	1.2	17.2	.9	13.0	1.9	26.8
22 Jul	8.3	1.8	22.2	1.2	14.8	3.1	37.3
3- 5 Aug	35.5	6.7	18.9	2.9	8.1	9.7	27.3
15 Sep	2.6	0	0	0	0	0	0
26 Sep	2.5	0	0	0	0	0	0
6 Oct	5.3	0	0	0	0	0	0
12-13 Oct	4.4	.2	4.5	.2	4.5	0	0
22 Oct	10.2	0	0	0	0	0	0
28 Oct	37.0	16.6	44.9	10.7	28.9	18.7	50.5
30 Oct	14.6	2.0	13.7	.6	4.1	2.3	15.8
2 Nov	9.4	2.2	23.4	1.0	10.6	2.3	24.5
4- 5 Dec	10.3	0	0	0	0	.2	1.9
28 Dec	5.1	0	0	0	0	0	0
Total	250.7	38.4	15.3	20.2	8.1	50.9	20.3

Table 4. Rainfall runoff from bare soil plots at Granite Reef (continued).

Date	Rainfall	L-3 Runoff		R-1 Runoff		R-3 Runoff	
1974	mm	mm	%	mm	%	mm	%
1 Jan	2.0	0	0	0	0	0	0
5 Jan	11.0	3.7	33.6	1.2	10.9	2.5	22.7
7 Jan	14.8	3.9	26.4	1.6	10.8	.7	4.7
8 Jan	6.8	1.0	14.7	1.0	14.7	.1	1.5
11 Mar	25.5	4.7	18.4	1.7	6.7	3.8	14.9
20 Mar	17.7	5.9	33.3	.9	5.1	1.1	6.2
20 Mar	1.3	0	0	0	0	0	0
7 Jul	3.0	0	0	0	0	0	0
14 Jul	16.3	7.0	43.0	2.6	16.0	1.6	9.8
21 Jul	7.1	2.6	36.6	1.0	14.1	1.1	15.5
22 Jul	8.3	5.8	69.9	1.4	16.9	3.8	45.8
3- 5 Aug	35.5	23.4	65.9	7.7	21.7	11.5	32.3
15 Sep	2.6	0	0	0	0	0	0
26 Sep	2.5	0	0	0	0	0	0
6 Oct	5.3	0	0	0	0	0	0
12-13 Oct	4.4	.8	18.2	0	0	0	0
22 Oct	10.2	0	0	.6	5.9	.4	3.9
28 Oct	37.0	23.2	62.7	10.9	29.5	18.5	50.0
30 Oct	14.6	7.0	47.9	6.2	42.5	2.0	13.7
2 Nov	9.4	3.0	31.9	3.7	39.4	2.6	27.9
4- 5 Dec	10.3	2.5	24.3	0	0	0	0
28 Dec	5.1	0	0	0	0	0	0
Total	250.7	94.5	37.7	40.5	16.2	49.7	19.8

Table 4. Rainfall runoff from bare soil plots at Granite Reef (continued).

Date	Rainfall	R-2 Runoff		R-4 Runoff		A-4 Runoff	
1974	mm	mm	%	mm	%	mm	%
1 Jan	2.0	1.5	75.0	0	0	0	0
5 Jan	11.0	9.8	89.1	4.8	43.6	6.9	62.7
7 Jan	14.8	14.6	98.6	7.7	52.0	11.4	77.0
8 Jan	6.8	6.1	89.8	.3	4.4	4.5	66.2
11 Mar	25.5	23.7	92.9	11.9	46.7	17.0	66.7
20 Mar	17.7	16.1	91.0	7.9	44.6	12.5	70.6
20 Mar	1.3	.9	69.2	.1	7.7	.4	30.8
7 Jul	3.0	1.0	33.3	0	0	0	0
14 Jul	16.3	11.7	71.8	6.9	42.3	11.2	68.7
21 Jul	7.1	6.4	90.1	3.7	52.1	4.8	67.6
22 Jul	8.3	7.2	86.7	5.5	66.3	6.5	78.3
3- 5 Aug	35.5	27.9	78.5	21.2	59.7	26.5	74.5
15 Sep	2.6	2.8	107.7	0	0	.3	11.5
26 Sep	2.5	1.8	72.0	0	0	0	0
6 Oct	5.3	3.6	68.1	0	0	1.8	34.1
12-13 Oct	4.4	4.2	95.5	1.8	40.9	2.6	59.1
22 Oct	10.2	7.6	74.5	.6	5.9	2.8	27.5
28 Oct	37.0	30.7	83.0	25.5	68.9	30.9	83.6
30 Oct	14.6	13.6	93.2	7.4	50.8	11.3	77.6
2 Nov	9.4	8.5	90.4	5.3	56.4	7.3	77.7
4- 5 Dec	10.3	9.0	87.4	2.7	26.2	5.7	55.3
28 Dec	5.1	3.9	76.5	.7	13.7	2.3	45.1
Total	250.7	212.6	84.8	114.0	45.5	166.7	66.5

Table 4. Rainfall runoff from bare soil plots at Granite Reef (continued).

Date	Rainfall	L-2 Runoff		A-3 Runoff	
1974	mm	mm	%	mm	%
1 Jan	2.0	0	0	0	0
5 Jan	11.0	2.4	21.8	2.7	24.5
7 Jan	14.8	.5	3.4	2.3	15.5
8 Jan	6.8	0	0	.6	8.8
11 Mar	25.5	3.4	13.3	5.2	20.4
20 Mar	17.7	.7	4.0	2.5	14.1
20 Mar	1.3	0	0	0	0
7 Jul	3.0	0	0	0	0
14 Jul	16.3	1.7	10.4	3.4	20.9
21 Jul	7.1	0	0	1.1	15.5
22 Jul	8.3	3.8	45.8	4.2	50.6
3- 5 Aug	35.5	11.8	33.3	16.9	47.6
15 Sep	2.6	0	0	0	0
26 Sep	2.5	0	0	0	0
6 Oct	5.3	0	0	0	0
12-13 Oct	4.4	0	0	0	0
22 Oct	10.2	0	0	.7	6.9
28 Oct	37.0	17.4	47.0	12.2	33.0
30 Oct	14.6	2.4	16.6	5.6	38.6
2 Nov	9.4	2.6	27.7	4.8	51.1
4- 5 Dec	10.3	0	0	6.1	59.2
28 Dec	5.1	0	0	0	0
Total	250.7	46.7	18.6	68.3	27.2

Table 5. Condition of potential water barrier materials exposed outdoors at Granite Reef (NE of Mesa, Arizona). Materials exposed 6 December 1973, or as noted.

Panel Number	Material and/or Treatment	Condition and Comments 1/
1	Cross laminated poly film, 4 mil, white, Tu Tuf, Sta-Cote	July - Stiff, brittle, cracking, shrinking. Sample destroyed.
2	Same as 1 except gray	April and July - excellent; Nov - good, very tight
3	Oriented polyethylene, Fabrene TM, duPont of Canada	April, July, and Nov - excellent
4	Same as 3 plus liquid elastomeric coating (coating) 0.27 gal/100 ft^2, Tan Poly-R (5-950), Matcote	April and July - excellent; Nov - good. Coating can be scraped, but not serious
5	Same as 3 plus coating, 0.19 gal/100 ft^2 clear Elastuff 400, United Paint	April and July - excellent, some chalking; Nov - good
6	Same as 3 plus coating, 0.22 gal/100 ft^2, gray 1 part, United Paint	April - excellent, coating not tacky, good bond to substrate; July - excellent to good, coating cracking, chipping; Nov - good, coating stripping off
7	Same as 3 plus coating, 0.14 gal/100 ft^2, gray Elastuff 400, United Paint	April - poor, coating chipping from surface; Nov - poor, 15% coating gone
8	Polyvinyl Chloride (PVC), film, 10 mil, black, Environmental Water Control (EWC)	April and July - excellent, very flexible; Nov - good, tight

Table 5. Condition of potential water barrier materials exposed outdoors at Granite Reef (NE of Mesa, Arizona). Materials exposed 6 December 1973, or as noted (continued).

Panel Number	Material and/or Treatment	Condition and Comments 1/
9	PVC film, 15 mil, black, EWC, plus coating, 0.13 gal/100 ft^2, gray Elastuff 400, United Paint	April & July - excellent; Nov - good
10	Same as 8 plus coating, 0.26 gal/100 ft^2, clear Elastuff 400, United Paint	"
11	Same as 8 plus coating, 0.17 gal/100 ft^2, gray 1 part, United Paint	April - excellent, coating can be scraped from PVC but not easily; July - good, chalking; Nov - good, 3% coating gone
12	Polyethylene (PE) film, 4 mil, clear, Mobil	April - excellent; July - failed, destroyed
13	Same as 12 plus coating, 0.15 gal/100 ft^2, gray Elastuff 400, United Paint	April - fair, coating peeling; July - poor, large hole with coating chipped off around it; Nov - poor, two long tears, deteriorating rapidly.
14	Same as 12 plus coating, 0.10 gal/100 ft^2, gray 1 part, United Paint	April - good, coating can be scraped from surface; July - good to fair, chalking; Nov - failed, destroyed.
15	Same as 12 plus coating, 0.14 gal/100 ft^2, clear Elastuff 400, United Paint	April - excellent; July - failed, destroyed.
16	Same as 12 plus coating, 0.14 gal/100 ft^2, Tan Poly-R (5-950), Matcote	April - excellent, coating can be scraped but not serious; July - excellent; Nov - good, two small holes.

Table 5. Condition of potential water barrier materials exposed outdoors at Granite Reef (NE of Mesa, Arizona). Materials exposed 6 December 1973, or as noted (continued).

Panel Number	Material and/or Treatment	Condition and Comments 1/
17	PVC film, 15 mil, black, EWC	April and July - excellent; Nov - good
18	Chlorinated Polyethylene, nylon reinforced, 32 mil, black Hodgman	April, July, and Nov - excellent
19	Tedlar/ Vinyl Laminate, 14 mil, white, Flexcon	"
20	Fiber reinformced PE, 12 mil, black, Type 85, Griffolyn	April and July - excellent; Nov - good
21	Fiber reinforced PE, 14 mil, black, Type 105, Griffolyn	"
22	Butyl, nylon reinforced, 32 mil, black (KK 243), Hodgman	April, July, and Nov - excellent
23	Hypalon, polypropylene substrate, 37 mil, black, Hodgman	April and July - excellent; Nov - good
24	Hypalon, double coated on nylon, 32 mil, black (KK 206), Hodgman	"
25	Same as 12 plus coating, 0.21 gal/100 ft^2, Tan Chem-Elast (5501), Plas-Chem	April - excellent, some coating peeled previously but not easily now; July - fair, coating chipping, PE deteriorated where coating gone; Nov - fair, several holes

Table 5. Condition of potential water barrier materials exposed outdoors at Granite Reef (NE of Mesa, Arizona). Materials exposed 6 December 1973, or as noted (continued).

Panel Number	Material and/or Treatment	Condition and Comments 1/
26	Same as 8 plus coating, 0.22 gal/100 ft^2, Tan Chem-Elast (5501), Plas-Chem	April, July, and Nov - PVC excellent, coating has remained very tacky with dust adhering to the surface.
27	Same as 8 plus coating, 0.19 gal/ft^2, Tan Poly-R (5-950), Matcote	"
28	Same as 8 plus coating, 0.15 gal/100 ft^2 of primer (9002) and 0.17 gal/100 ft^2 of Black Chem-Elast (5500X), Plas-Chem	"
29	Same as 3 plus coating, 0.28 gal/100 ft^2, Tan Chem-Elast (5501), Plas-Chem	April - excellent, coating can be scraped but not easily; July - excellent, some chipping with dust adhering to surface; Nov - good, some chipping
30	Same as 3 plus coating, 0.23 gal/100 ft^2 of primer (9002) and 0.20 gal/100 ft^2 of Black Chem-Elast (5500X), Plas-Chem	April, July, and Nov - Substrate excellent, coating can be scraped, not as good as panel 29, dust adhering to surface
31	Neoprene, nylon-reinforced, 31 mil, black (KK235), Hodgman	April, July, and Nov - excellent
32	Hypalon, nylon-reinforced, 32 mil, black (KK205), Hodgman	April and July - excellent

Table 5. Condition of potential water barrier materials exposed outdoors at Granite Reef (NE of Mesa, Arizona). Materials exposed 6 December 1973, or as noted (continued).

Panel Number	Material and/or Treatment	Condition and Comments 1/
33	Hypalon, nylon-reinforced, 37 mil, black (KK208), Hodgman	April and July - excellent
34	Butyl/EPDM blend, 35 mil, black (MBM), Miner	"
35	Chlorinated Polyethylene, nylon reinforced, 32 mil, white (KK209), Hodgman	April, July, and Nov - excellent, some chalking
36	Butyl, nylon reinforced, 55 mil, black (KK244) with seam, Hodgman	April and July - excellent, seam excellent; Nov - good
37	Hypalon, nylon-reinforced, 40 mil, black, Burke	April and July - excellent; Nov - good
38	PVC coated polypropylene mesh, 22 mil, black (24B), Hercules	"
39	PVC coated polypropylene mesh, 22 mil, black (24F), Hercules	"
40	PVC coated polypropylene mesh, 12 mil, black (24E), Hercules	"
41	PVC film, 20 mil, black, EWC	April, July, and Nov - excellent
42	PVC film, 30 mil, black EWC	April and July - excellent; Nov - good
43	Butyl, non-reinforced, 30 mil, originally exposed 18 May 1961, Carlisle	April, July, and Nov - good, chalking
44 2/	Laminated non-woven polypropylene, nominal thickness 11 mil, black, Westpoint Pepperell	April - excellent, July - failed

Table 5. Condition of potential water barrier materials exposed outdoors at Granite Reef (NE of Mesa, Arizona). Materials exposed 6 December 1973, or as noted (continued).

Panel Number	Material and/or Treatment	Condition and Comments 1/
45 2/	Laminated non-woven polypropylene coated each side with copolymer of ethylene and vinyl, nominal thickness 17 mil, black, Westpoint Pepperell	April and July - excellent; Nov - good
46 3/	Oriented polyethylene, Fabrene TM, duPont of Canada, sample of material exposed in test pond at Granite Reef	July - excellent; Nov - good

1/ Ratings excellent, good, fair, poor -- visual observation only.

2/ Material exposed 19 April 1974

3/ Material exposed July 1974

Table 6. Condition of materials on exposure racks--Logan, Utah--inspection October 1974.

Sample No.	Material	Initial exposure date	Condition 1/	Physical description
2	Butyl-coated cotton, TDA-3909, Hodgman	1/02/64	Excellent	Slight chalking
3	Ethylene vinyl acetate copolymer, 20 mil	1/02/64	Excellent	Slight shrinkage
4	Nylon-reinforced hypalon, Burke	10/26/71	Excellent	Slight shrinkage
9	1 Chlorinated PE, white, Dow	8/25/70	Excellent	Slight stiffening
	3 Chlorinated PE, white, Dow	8/25/70	Poor	Extensive cracking, stiffening
11	Butyl-coated cotton TDA-3909, Hodgman	2/13/64	Good-Fair	Stiffening, cracking, slight chalking, one tear
12	1 Chlorinated PE, white, Dow	8/25/70	Fair	Stiffening, surface cracking, shrinking
14	PE film, 6 mil	7/10/63	Excellent	Slight shrinkage
15	Ethylene vinyl acetate copolymer, 6 mil	7/10/63	Excellent	Slight shrinkage
16	Nylon-reinforced hypalon, yellow, Canton	8/20/70	Good	Fading, surface checking, some reinforcing exposed
18	Asphalt-coated jute, Flintkote	1/02/64	Excellent	Slight stiffening

1/ Excellent, good, fair, poor---visual observation only.

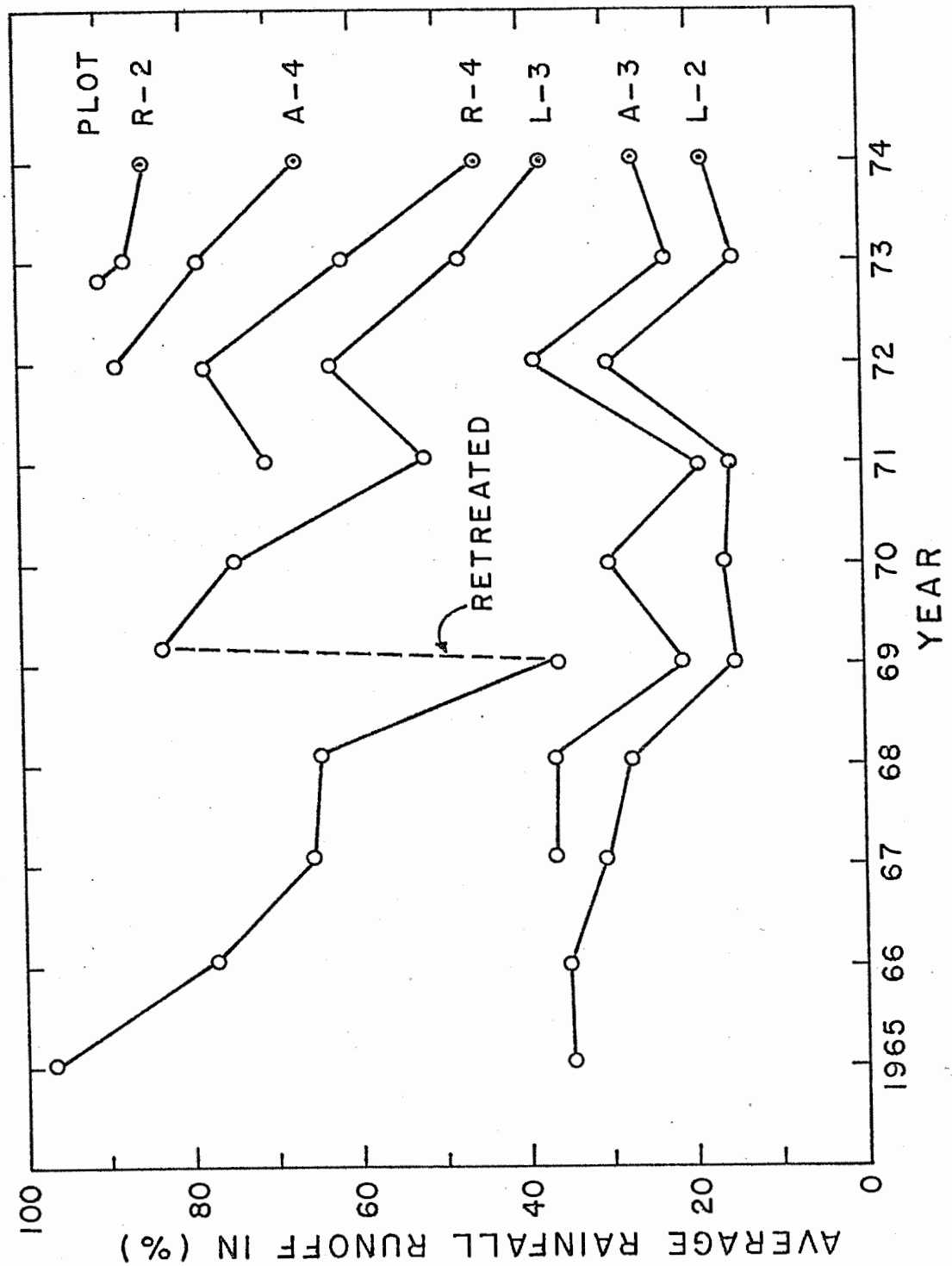


Figure 1. Rainfall-runoff results from six bare-soil treatments at the Granite Reef Testing Site.

TITLE: PREDICTING HYDRAULIC CHARACTERISTICS OF CRITICAL-DEPTH FLUMES OF SIMPLE AND COMPLEX CROSS-SECTIONAL SHAPES

CRIS WORK UNIT: 5510-12260-004 CODE No.: Ariz.-WCL 72-1

INTRODUCTION:

Annual Reports for 1966-1973 contain summaries of studies on numerous critical-flow flumes with cross-sectional shapes that were trapezoidal, triangular, or rectangular. The mathematical model was extended to allow the introduction of more complex shapes into computation for cross-sectional area. These shapes included non-symmetrical flumes, and flumes whose sideslopes are not the same at all flow depths. Usually, the sideslopes are flatter at the higher flow stages. Predictions of the non-symmetrical and complex shapes were satisfactory. The computational procedure has not changed significantly from that reported in Annual Report, 1973. There are some errors in the descriptive comments regarding the kinematic viscosity value on page 17-9. (This should have read "Use $V1 = 1.228 \times 10^{-5}$ ft^2/sec, in English system or $V1 = 1.408 \times 10^{-6}$ m^2/sec, in metric system at 18 C)." The computational changes are hardly noticeable even using the values as given.

NEW FLUMES DESIGNED:

Several flumes were designed using the program for other projects. Most were routine and presented no new problems. One situation was sufficiently different to warrant description. The irrigation efficiency studies near Yuma, Arizona, connected with the Colorado River Research, needed accurate water application quantities to test areas of citrus and alfalfa. The test areas are currently irrigated from slip-form field ditches with 2-ft bottom widths and 1:1 sideslopes. They are intended to deliver a "standard-head" of 15 cfs. In most instances the true flow rate, the backwater response, the tailwater conditions, etc., could not be very easily determined without detailed engineering surveys and

computations before a device such as a concrete critical-flow flume could be installed. Usually sites could be readily located that were potentially suitable, but the elevation margins on water surface maximums to avoid both ditch overtopping and submerged flow operation were very narrow, frequently only ± 0.1 to 0.2 ft.

To cope with these problems and similar sites a portable "caliper-flume" was designed and built. It consisted of a throat section and a transition section. The throat section had a bottom width of 1 ft, and sideslopes of 1:1. This section was mounted in a frame such that once the frame was placed in the concrete-lined ditch, the section could be raised and lowered relative to the channel floor, thus changing the sill height. This provided for adjusting between rather close restrictions on ponding at the upstream end and free outflow on the downstream end. The range of movement relative to the channel bottom is from 0.3 ft to 1.0 ft. This provides for a discharge range, at an upstream water depth of 2 ft, of 16 cfs when the flume is in the lowest position to 5.2 cfs when the flume is raised to its highest postion. At 2.5 ft deep the range is from 12 cfs to 28 cfs. The calibration changes about 5% from lowest to highest setting, so separate tables were computed for each 0.1-ft change in elevation of the throat-section floor. The raising and lowering is accomplished with 4 crank-handle screwjacks, one on each corner of the frame holding the throat section. A special transition section was built using sliding pieces of aluminum sheet to accommodate the vertical flume movement. The sheet metal also formed the seal with the concrete sides of the canal. Leakage around the flume was well within acceptable limits.

Depth detection presented another problem. The flow depth is referenced from the elevation of the flume floor. Using a movable flume floor, the standard method of stilling-well and water ponding for determining the zero in the stilling well was not practical.

Besides, the flume frequently may be placed into a flowing channel precluding the ponding method. Surveying instruments could provide the zero for each flume setting, but this is also impractical.

The solution selected was to mount a point gage over the reference point in the flume throat, which normally is the flume throat center. The point gage was secured to the throat section itself so that it moved when the throat section was moved. Thus, the zero point was readily set by lowering the point gage until it touched the flume throat. This could be done even through flowing water.

The stilling-well sensing hole could not be drilled through the canal wall at each trial site so a section of pipe with pressure sensing holes in its side was used. This length of pipe, approximately 18 inches of 3/4-inch water pipe, was capped at both ends with plastic tubing attached to one end. It was placed in the canal about 1 ft ahead of the transition section and parallel to the flow. The plastic tubing which normally could be used to siphon over into a stilling well near the sensing location was, instead, led to a cup, which served in principle as a short stilling well, that was clamped beneath the point gage. A level bubble on the throat-section structure was used to check that the flume was satisfactorily leveled with the four screwjacks. Since the point gage relation is integral to the flume-throat section, precision leveling is not necessary.

Under flowing conditions, the two sections of the flume could be easily lowered into place in the ditch by two people. One person can manage it under no-flow situations.

Two locations were measured with the flume. The selected floor height on one site was determined to be 0.3 ft or lower in order to avoid overtopping the ditch. Tailwater elevation at this site on the Synder Ranch near Tacna, Arizona, was low and caused no problems. At a second site on Spencer and Spencer, Desert Valencia Ranch, the floor has to be located at 0.6 ft in order to

avoid downstream tailwater. Here, upstream capacity is adequate.

FIELD RATING OF STRUCTURE:

In Annual Report, 1973, the design example chosen to use with the BASIC Computer Program was that of a special compound flume built in the Roosevelt Water Conservation District near Mesa, Arizona. The Salt River Project, who delivers this water to the District, performed the flow-meter measurements from 7 February 1974 through 9 February 1974 and provided our laboratory with a copy of the data. Two current meters were used for comparison, an "Ott" propeller-type and a "Price" cup-type. The cup-type was used regularly. Differences between the discharges as determined by the two meters were approximately 5%. The metering station, although several hundred feet downstream from the flume, still experienced surges and eddies, making accurate current metering difficult.

Table 1 provides the data of 37 meterings during the period. The flow ranged from a low of 38 cfs to a high of 220 cfs. A plotting of the points indicated that the current meterings averaged about 4% higher than the flume-indicated discharge for flows above 100 cfs; about zero percent different at 75 cfs; and about 7% low for flows near 40 cfs (Fig. 1). However, the current meter ratings for the same flume-indication had a spread of up to 10%. Past experience would indicate that the flume repeats a discharge for a particular stage to within $\pm$ 1%. The variation indicated would have required a stilling-well depth-detection error of nearly 0.08 ft on the flume. This is over 20 times the expected detection-equipment error. Since the current-meter technician reported strong eddies at the metering station, as noted by the variability of the "clicking-rate" of the current meter, the tentative conclusion is that the flume rating as originally computed is accurate.

SUMMARY:

Prediction of calibrations for critical-depth flumes by mathematical modeling has remained essentially unchanged during the past reporting period. The method permits handling complex cross-sectional shapes and non-symmetrical shapes as well as the usual trapezoidal, rectangular, and triangular shapes. The computer program is now available in both BASIC and FORTRAN versions. Efforts have turned to applications to specific streams, canals, and field ditches. A portable flume with special jacks to change the throat elevation with respect to the channel bottom and special stilling well and depth sensing arrangements is being used as a field-survey device before casting low-cost concrete throat sections. This "caliper-flume" can be installed and removed from a flowing canal by two persons. It can measure flows from 0.09 cfs to 35 cfs in slipformed canals with 1-ft and 2-ft bottom widths and 1:1 sideslopes. The jacking arrangement allows accurate determination of backwater effects and submergence limitations at prospective sites for permanent flume installations.

PERSONNEL: John A. Replogle

Table 1. Comparison of current-meter discharge measurements with flume-indicated discharge.

Date	Flume stage (ft)	Flume (cfs)	Current meter (cfs)	Difference (%)*
2/07/74	2.06	43	43	0.00
2/27/74	2.01	40	36	-10.00
2/27/74	2.01	40	38	-5.00
3/07/74	2.30	60	62	+3.33
3/14/74	1.98	38	36	-5.26
3/21/74	2.70	100	100	0.00
3/28/74	2.59	88	91	+3.41
4/03/74	2.81	113	113	0.00
4/04/74	2.73	103	106	+2.91
4/10/74	3.03	142	148	+4.23
4/11/74	3.03	142	151	+6.34
4/17/74	3.09	151	159	+5.30
4/22/74	3.19	166	175	+5.42
4/25/74	3.19	166	178	+7.23
4/26/74	2.79	110	113	+2.73
5/09/74	2.64	93	91	-2.15
5/16/74	3.11	154	164	+6.49
5/23/74	2.94	130	138	+6.15
5/30/74	3.14	159	168	+5.66
6/06/74	3.08	149	159	+6.71
6/18/74	3.49	219	224	+2.28
6/18/74	3.49	219	222	+1.37
6/20/74	3.49	219	223	+1.83
6/20/74	3.49	219	233	+6.39**
6/27/74	3.50	220	229	+4.09
7/11/74	3.09	151	160	+5.96
7/18/74	2.83	115	110	-4.35
7/25/74	2.56	85	77	-9.41
8/01/74	3.47	215	224	+4.17
8/08/74	3.08	149	152	+2.01
8/15/74	3.45	211	215	+1.90
8/22/74	3.47	215	222	+3.26
8/29/74	3.24	175	172	-1.71
9/05/74	3.07	148	148	0.00
9/12/74	2.67	96	90	-6.25
9/19/74	2.56	85	78	-8.24
9/26/74	2.46	75	71	-5.33

* $\left[\left(\frac{\text{meter-flume}}{\text{flume}}\right)100\right]$

** "Ott" meter

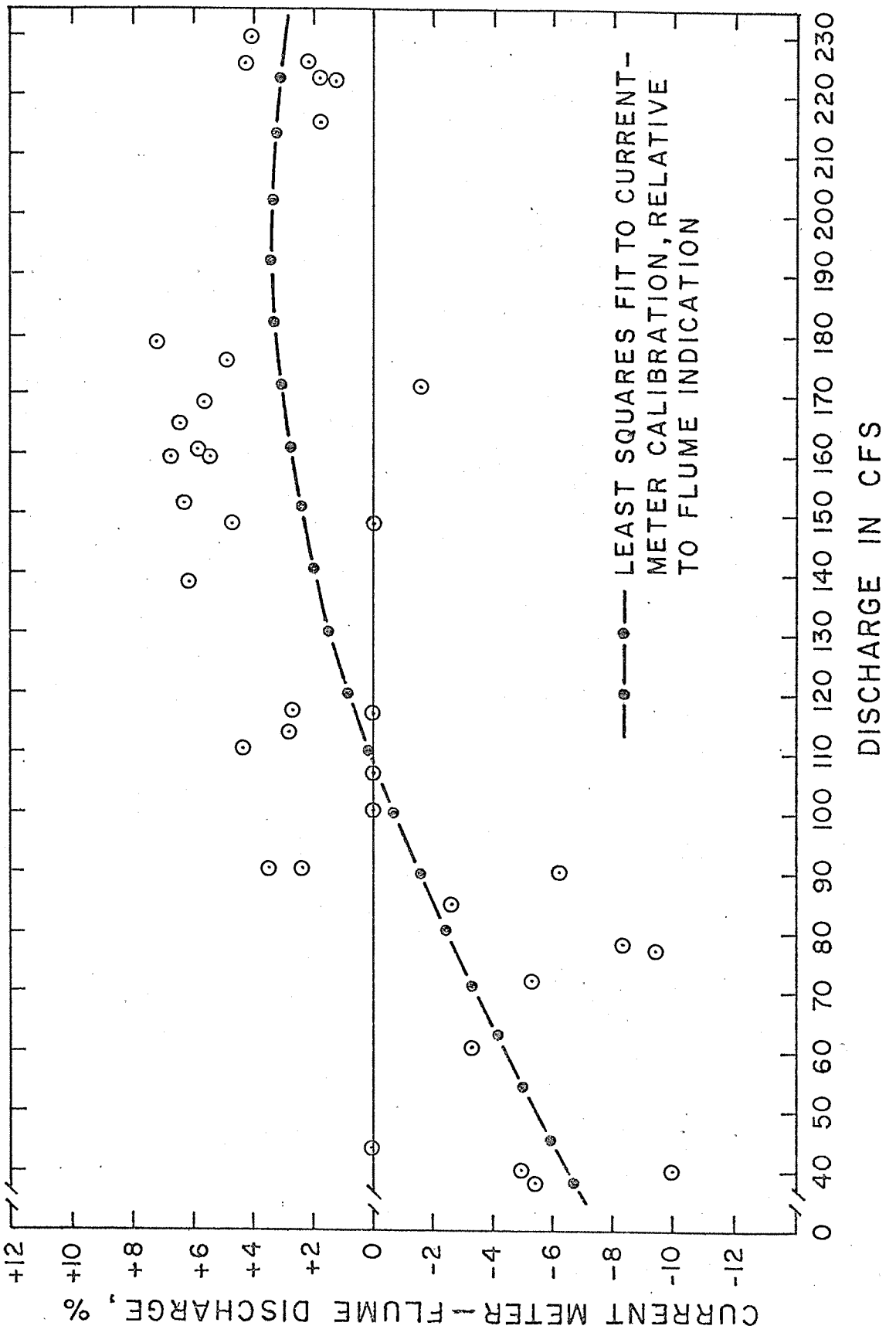

LEAST SQUARES FIT TO CURRENT-METER CALIBRATION, RELATIVE TO FLUME INDICATION
DISCHARGE IN CFS
CURRENT METER—FLUME DISCHARGE, %
0
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
+12
+10
+8
+6
+4
+2
0
-2
-4
-6
-8
-10
-12

Figure 1.

TITLE: SEDIMENT TRANSPORT CHARACTERISTICS OF CRITICAL-DEPTH FLUMES

CRIS WORK UNIT: 5510-12260-004 CODE NO.: Ariz.-WCL 72-2

INTRODUCTION:

Computer and mathematical techniques were previously developed that permitted tailoring flume shapes to produce hydraulic characteristics that might assist sediment movement and thus avoid sediment accumulations in the flume. The main design feature was the use of sidewall contractions and a "negative-sill." The "negative-sill" feature consisted of a throat floor that was an inch or so lower than the approach section of the flume. The effect is to achieve increasing Froude number values with decreasing flow depth, which is the reverse of most previous flume behavior, and maintain sediment-carrying capacity to relatively low flow depths. The method is effective for only small sediment loads but was not sufficient to move sand (D_{50} = 0.5 mm) when the sediment concentrations approached one-quarter percent. Higher concentrations of sand were passed by placing "vortex-vanes" on the sidewalls of the approach section of the flume. These vanes were simple angle-iron strips affixed to the walls at 45° upward in the direction of the flow. The optimum height and spacing for the vanes were the primary concern of studies this past year.

PROCEDURE:

Two types of sediment-carrying tests were attempted. The first was to introduce, in the upstream end of the flume, a quantity of sand at a steady rate representing 1/4%, 1/2%, and 1% of the water flow rate and to observe the sediment accumulation effects of the introductions. The sand was weighed into buckets and hand-fed while being paced with a stop watch. Thus, the feed rate, while not completely constant, at least introduced in a given 30-second or 1-minute period the correct quantity of sand for the flow rate. The feed rate was maintained for sufficient time, usually 5 to 10

minutes, to assure stabilization of effects. An observation of accumulations was then made to evaluate whether the accumulations were significant enough to be detrimental to the flume rating. The level of successful transport for several flow depths was determined. The method involved considerable inputs of observer judgments and thus lacked considerably in objectivity. A second method, while still requiring some subjectivity, was more easily implemented. This method consisted of introducing, rapidly, a fixed quantity of sand into the approach section of the flume and observing the time to clear this amount with 3 vane sizes and 2 spacing intervals. This method indicated relative transport ability but did not give rate of transport directly, since only in the initial phases of clearing is full capability for transporting sediment used.

DISCUSSION:

The "vortex-vanes" are the most effective of three measures to control sediment movement through flumes. Sloping-flume-floor and Froude-number-control methods are less effective. The Froude number relations do not describe the ability to move sediment as well as simple threshold-velocity concepts. This might be expected since the Froude number used is based on flume size and not on particle size, and the sediment movement is more related to the flow-velocity energy. Flume slope is effective only as it affects flow velocity. Since the gravity component is small in the direction of flow, the moving force on the particle is dominated by the flow velocity. Sloping the flume changes flow cross-sectional relations that increase flow velocity, but similar velocities can be designed into the flume without floor slope. In one instance, sediment accumulated on the sloping-floor section of a flume where a negative sill was used for Froude number control. Other sections of the flume remained clear because of the installation of vanes in the approach section.

Much was to be learned concerning the behavior of sediments in flumes. In a sand-bed stream the flow adjusts to move the maximum sediment at lowest energy. This results in a wide stream with the bulk of the flow shear carried by the stream bottom. When a flume is installed, side contractions are usually included and the flow may even be forced into a trapezoidal or triangular configuration. The heavy sediments remain on the bottom, but now the bulk of the shear is wasted on the sidewalls. An example in the laboratory sand movement model was a 4-ft-wide sand bed in a glass-sided channel that fed a trapezoidal flume that had a 1-ft-bottom width, 1:1 sideslopes, a 1-inch-wide throat, and a negative sill of 0.1 ft. A typical sand dune pattern for say a 0.9-ft flow depth was for a 0.4-ft-deep dune, relative to the flume floor, to approach the flume with a water flow velocity of 1.23 ft per second, be contracted in width to approximately 1 ft but with a flow velocity of 1.83, an approximate 1.5 times increase in velocity but a 4-fold increase in sediment per unit width. This was further contracted at the throat to approximately 1-inch wide, or a total contraction of 48:1. If the available energy to move sediment is proportional to the square of the flow velocity, then to maintain capacity the velocity in the approach section would have to be double that in the approach channel and be nearly 7-fold more for the narrow throat (actually, the flows were only 1.5 times and 2.9 times, respectively). Sediment accumulations occurred in the flume approach section. The throat did not clog, possibly because the flow time was not prolonged to complete equilibrium. Vanes that were 1-1/2 inches high were installed on 6-inch spacing. The dune disappeared in the approach section, but now the throat section plugged. The local vane-clearance-opening velocity calculated to be 2.26 ft per second, or 1.8 times the approach velocity.

The throat was then modified to produce a wider bottom without changing the net flow area-depth relation of the throat. The

negative sill was raised from 0.1 ft to 0.05 ft, and an equivalent rectangle was inserted to replace the removed trapezoidal section. The replacement rectangle measured 0.347 ft wide and 0.082 ft deep. The throat was now approximately one-twelfth as wide as the channel, and the velocity, V_3, was 3.6 ft per second or 2.86 times the channel velocity. Based on the square-of-the-velocity assumption, it should have been 3.4 times as great to carry the same sand load, or conversely the throat should have had a bottom width of approximately 0.5 ft. Based on the imprecision of the velocity determination over the dune formation in the approach channel, this is a reasonably good indication that the suggested design criteria based on velocity ratios may be valid.

The optimum vane spacing and permissible maximum size came under discussion as a result of the presentation at the C.I.G.R. meetings in the Netherlands, September 1974 [Replogle, John A. Avoiding sediment accumulation in flow-metering flumes. Proc. 8th International Congress of Agricultural Engineering, Wageningen, The Netherlands, September 24-28, 1974. (in press)]. A discussion by H. N. C. Breusers, Head, Density Currents and Transport Phenomena Branch, Delft Hydraulics Laboratory, The Netherlands, points out that all sediment transport relations are based on the use of mean velocity or on shear stress and that the Froude number is not important, just the mean velocity. Also, the development used in the paper indicated that shape effects are unimportant, although he mentions that experiments with sediment transport in pipes have shown that a pipe cross section with a relatively wide horizontal bottom has better sediment transport characteristics. He also noted that in pipes the optimum configuration for continuous vanes for sediment transport was with a relatively small angle with the flow direction. The flumes used 45° with the flow direction in order to convert a maximum amount of energy into lifting. In pipe flow, this would cause excessive energy loss and would be unacceptable.

Thus, the optimum configuration he mentions may refer to a compromise between friction losses and transport capability. In the flume the 0.1 ft, or so, of extra friction loss for the vanes is considered acceptable.

Energy gradient alone was tried using vanes along the wall placed at 90° to the flow direction. This was quickly abandoned since visual observation of the sediment accumulation showed that it was greatly inferior to the 45° slope configuration. Relative to the vertical strips, the optimum spacing for maximum friction loss is discussed in various texts (Chow, "Open Channel Hydraulics," McGraw-Hill, N.Y. 1959. p. 196). Three possibilities are offered that might apply to the vortex-vane spacing, even though they are on a 45° slope. These are isolated-roughness flow, wake-interference flow, and quasi-smooth flow. The first occurs with widely spaced elements, the second when the wake of one interfers with the next, and the third when the elements are so close together that the flow skips over them and the depth between contains stable eddies. The absolute spacing and heights are usually experimentally determined because in isolated-roughness flow both vane height and spacing are important, while in wake-interference flow spacing is most important, and in quasi-smooth flow, spacing and height are again considerations. The spacing would appear to be a function of flow Reynolds number. This would require changing the vane spacing for each flow velocity to maintain maximum sediment-carrying capacity for a particular flume. Since this is impractical, the spacing should be adjusted to produce best results at the lower flow stages when the absolute velocity is lowest.

Experimental results for clearing times of a fixed sample of sand injected into the approach section of the flume for 3 heights of vanes and 2 spacings are given in Table 1. The size of the fixed slug was arbitrarily chosen as that amount in a conveniently available container, which turned out to be about 21 pounds of sand. The closer spacings were significantly better for the 1.5 and 2.0 vanes,

but interference on the close spacing for the 3-inch height with 6-inch spacing appeared to be occurring. Therefore, if the vanes are closer than about 3 or 4 times their height, the lifting effects are decreased because quasi-smooth flow is starting to occur. If spacing is as much as 8 times the vane height, isolated-roughness flow appears to be occurring. The practical optimum spacing would thus appear to be a spacing of about 3 to 5 times the vane height. This supports the original estimate for spacing.

The time-to-clear values do not reflect directly the carrying capacity of the flume in terms of transport rates. Table 2 shows the discharge rates, vane sizes, percent sediment injection, the clearing time for a bulk sample, and the apparent percent transport rate based on the clearing time. The clearing time for a slug injection was about 5 to 7 times longer than the capability of the flume to handle the same quantity as a steady rate. Thus, it appears that a good approximation of transport capacity is about 6 times the slug clearance rate. One value noted in Table 2 deviates considerably from the 6-times range because the steady-state rate of sand injection was below the carrying capacity for the flow rate and thus does not provide a valid base for computing the transport ratio.

Calibration changes due to installation of the vanes are most evident with the 3-inch vanes. The effects were $\pm$ 5% from the "no-vane" calibration for flow depth in excess of 0.5 ft. The 2-inch and 1 1/2-inch vanes caused changes from the "no-vane" calibration of less than 1% for flow depths greater than 0.5 ft deep. As the flow further decreased in depth, this difference increased to about + 10% at 0.3 ft deep. This could be partially accounted for by high α_1 values of say 1.5 for these lower flows. The obstruction of the vanes relative to the total open flow area is greatest at low flows, representing 40% obstruction at 0.2 ft deep, 44% at 6.5 ft deep, and 24% at 1.0 ft deep.

SUMMARY:

Of the methods available to assist critical-flow flumes in passing bedload sediments, the "vortex-vanes" installed in the approach section are most effective—capable of moving bedloads equal to about 1 to 3% of the mass flow of water. In a sandbed stream, the stream adjusts to wide, shallow flow, using most of the stream shear forces on the bottom. Flumes should be designed with this principle in mind. When side contractions are used, they must be accompanied by a designed increase in velocity energy to handle the decreased bed-shear area. This energy is proportional to the square of the velocity. The large increase in velocity in the flume throat compared to the approach section and the stream section usually permits the floor to be as narrow as 0.1 of the stream width, but this should be designed based on relative velocities. The vanes increase the effective shear area while causing negligible calibration changes above about 0.5 ft deep in the test flume (0.1 discharge capacity), provided the net obstruction is such that Froude numbers are on the order of 0.7. The larger the Froude number, the more sediment-carrying capability available. For example, vanes large enough to cause Froude numbers in excess of 0.8 (3-inch vanes in a 1-ft-wide trapezoidal approach section with 1:1 sideslopes) could handle an estimated 3% sediment bedload, but the calibration accuracy was reduced to ± 5%.

These findings add to the design criteria that are to be considered in developing critical-flow flumes that can be computer calibrated, have wide flow-range capability, good sediment-handling capability--accuracy better than ± 5%, and rugged enough for prolonged use.

PERSONNEL: John A. Replogle

Table 1. Times for 21 pounds of sand to be cleared from flume at a flow depth of 0.9 ft.

Vane height	Vane spacing	Clearing time
(in.)	(in.)	(sec)
1.5	6	150
1.5	12	210
2	6	80
2	12	150
3	6	30
3	12	25

Table 2. Comparison of transport rates.

Vane size	Flow depth	Flow rate	Steady-state sand inj. rate	Observation of handling	Slug clearing time	Slug sand inj. rate	Transport ratio steady/slug
(in.)	(ft)	(cfs)	(%)		(sec)	(%)	
1.5	0.46	0.585	0.5	fair	-	-	-
1.5	0.64	1.166	0.5	fair	420	0.07	7.1
1.5	0.66	1.155	0.25	good	270	0.10	5.0
1.5	0.89	2.30	0.5	good	150	0.097	5.1
2.0	0.66	1.15	0.5	very good	180	0.16	3.1*
2.0	0.90	2.46	1.0	good	80	0.17	5.8
							average = 6

*Steady-state rate was considerably below the carrying capacity of flow.

TITLE: EVALUATING TRICKLE IRRIGATION FOR GRAPE PRODUCTION

CRIS WORK UNIT: 5510-12260-004 Code No. USWCL 73-1

INTRODUCTION:

The objectives and need for this research project appeared in the U.S. Water Conservation Laboratory 1973 Annual Report. Results for the second year are presented in this report.

FIELD PROCEDURE:

After harvesting of the 1973 Perlette table grapes on June 30, the same amount of water was applied on all trickle and furrow irrigation treatments. On the trickle irrigation plots, one-half inch of water was applied per week between July 1 and October 13. The furrow irrigation plots were given irrigations of 2.5 inches on July 3, 2.5 inches on August 13, and 2.5 inches on September 26, 1973.

Twelve trickle irrigation treatments for 1974 included: Three irrigation quantities, based on ratios of the 1973 consumptive-use data; three irrigation frequencies -- daily, 3-day, and 6-day; and either one or two trickle emitters per vine. Six furrow irrigation treatments included the same three seasonal quantities used for the trickle irrigation, applied in two or three furrows per vine, with the irrigation frequency based on the consumptive-use curve. The predetermined quantities of irrigation water applied were calculated by multiplying 0.75, 1.00, and 1.25 times the estimated consumptive-use rate based on the entire surface area between vines. Figure 1 shows the 1973 consumptive-use curve used to determine the different irrigation quantities.

New growth began about February 13, and canes were at least 4 inches long by March 1. Furrow and trickle irrigations were started on February 25 and 28, respectively. The 1.00 furrow treatments were given irrigations of 4.5 inches on February 25, 3 inches on April 22, 3 inches on May 8, and 3 inches on May 28. The 1.00 trickle treat-

ments were given an initial irrigation of 2.0 inches on February 28, followed by 11.4 inches between April 8 and June 10, in accordance with the three different irrigation intervals. The 1.25 and 0.75 trickle and furrow irrigations were given ratios of these amounts described for the 1.00 irrigation treatments.

Other procedures for the collection of data, such as soil-moisture, tensiometer, evaporation, salinity, and yield and fruit quality were the same as the previous year. Grapes were harvested on June 10, 11, and 12 by four workers, two supervisors, one weigh-man, and one berry sampler. Two replications were picked each day on June 10 and 11, followed by the stripping of all four replications on June 12. The possible error due to the differences in fruit picking and trimming techniques between harvesters was substantially reduced from the previous year.

RESULTS AND DISCUSSION: The actual amounts of water made available for consumptive use were calculated from the sum of the water applied and rainfall (Table 1). On the 1.00 consumptive-use plot, the soil-moisture samples were nearly the same at the beginning and end of the growing season. Therefore, the adjusted trickle and furrow irrigation quantities were 1.35, 1.00, and 0.80 times the 1974 measured consumptive use. Figure 1 shows that the 1974 measured consumptive use was 13.0 inches. This seasonal use compares closely with the 1973 consumptive use of 13.5 inches up to the harvest date in 1974, although the total seasonal use for a later, longer growing season was 17.0 inches in 1973. The difference between the 1974 and 1973 curves for May is possibly due to an earlier emergence and girdling date in 1974.

Figure 2 depicts the relationship between pan evaporation, atmograph evaporation, and the 1974 measured consumptive use. Semi-monthly correction factors given are ratios of evaporation to the measured consumptive use. These evaporation measurements vary with time of growing season and instrument location, as well as changes in climatic conditions.

Full-season grape production for the various 1974 trickle and furrow irrigation treatments are shown in Table 2. Yields were increased by 9% for trickle irrigation with two emitters per vine over one emitter per vine, and yields were increased by 6% for two trickle irrigation emitters over furrow irrigation. Only on the trickle irrigation treatments were yields increased by 11% for the 1.35 compared to the 0.80 times consumptive-use quantity. These yield differences were small and not necessarily consistent within all treatment combinations; thus, the results are best described as possible trends for improving grape production. Additional results showed little difference in yield between trickle irrigation frequencies of 1 day, 3 days, and 6 days. This appears to be of particular significance, since the soil is classified as an Antho sandy loam. As for furrow irrigation, there was little difference in yield between 3- or 2 furrows per vine, and little difference in yield between different irrigation quantities.

Berry size and sugar content for the trickle and furrow irrigation treatments are shown in Tables 3 and 4, respectively. There was little variation in the berry size or sugar for the different irrigation treatments. The 1974 berry size averaged 0.84 lbs per 100 berries, which was 27% larger than the 1973 berry size of 0.66 lbs per 100 berries. The 1974 sugar content averaged 17.5%, which was an increase of about 2% over the 1973 sugar content. This larger berry size with a high sugar content could explain the overall decrease in 1974 yields of 5.8 tons per acre from the 1973 yields of 8.0 tons per acre.

Table 5 compares yield and quality results obtained for 1973 and 1974 grapes. In both years, yields were slightly increased with two trickle emitters per vine over furrow irrigation, and with two trickle emitters over one. There was a small difference in 1974 yields for different trickle irrigation quantities, whereas the unusually heavy rainfall early in 1973 probably accounted for the absence of this result

in the previous year. No reason is known for the lack of an increase in berry size for the 1974 trickle over furrow irrigation. The remaining findings were nonsignificant for both years.

Problem of clogging of emitters began to appear during the 1974 grape experiment. After harvest, hand-flushing and chemical treatments were used to determine whether the plugging problem could be reduced (See USWCL 71-11, Chemical treatment of irrigation water for the prevention of clogging and the removal of flow obstructions in trickle irrigation systems).

SUMMARY AND CONCLUSIONS:

Alleged advantages of increased yield and improved fruit quality with daily trickle irrigations may often have been exaggerated. In many previous field investigations, both trickle irrigation amount and interval have not been varied. Various production measurements on table grapes were made to evaluate quantity of trickle and furrow irrigations, frequency of trickle irrigations, and number of trickle emitters or furrows required. Two years of research on grapes have shown that yield and quality were maintained or slightly increased with two trickle emitters over furrow irrigation. The consumptive-use requirement for Perlette grapes ranged from 13.0 to 17.0 inches, depending on the growing season. Yields were slightly increased with two trickle emitters per vine over one, but they did not change with three, or with two furrows per vine. Most interestingly, yields did not always increase for daily irrigations over 3- and 6-day irrigations on a sandy-loam soil. Before growers can be assured that trickle irrigation will improve grape production, the possible risk of emitter plugging must be eliminated.

Personnel: Dale A. Bucks, Leonard J. Erie, and Orrin F. French.

TABLE 1. Available moisture and adjusted quantities for trickle and furrow irrigation of grapes, 1974.

Irrigation Quantity Consumptive-Use Ratio	Water Applied (inches)	Rainfall (inches)	Total Available Moisture for Consumptive Use (inches)	Adjusted Irrigation Quantity Consumptive-Use Ratio *
TRICKLE:				
1.25	16.9	0.5	17.4	1.35
1.00	13.4	0.5	13.9	1.05
0.75	10.0	0.5	10.5	0.80
FURROW:				
1.25	16.9	0.5	17.4	1.35
1.00	13.5	0.5	14.0	1.05
0.75	10.1	0.5	10.6	0.80

* Based on the measured seasonal consumptive use of 13.0 inches for 1974.

Table 2. Grape Production for Trickle and Furrow Irrigation, 1974.

Irrigation Treatment	Irrigation Quantity			Mean
	Consumptive-Use Ratio			
	1.35	1.00	0.80	
	(pounds per plot)			
TRICKLE:				
Daily / 1 emitter	136*	140	119	132 b**
Daily / 2 emitters	133	140	145	139 ab
3-day / 2 emitters	138	159	137	145 a
6-day / 2 emitters	159	151	133	148 a
MEAN	142 ab	148 a	134 c	
FURROW:				
3 Furrows per vine	136	138	135	136 ab
2 Furrows per vine	132	137	139	136 ab
MEAN	134 c	138 bc	137 bc	

*Mean, 4 replications, 7 vines harvested per plot.

**Numbers followed by the same letter are not significantly different at the 0.05 level by Duncan's Multiple Range Test.

Table 3. Berry Size for Trickle and Furrow Irrigation of Grapes, 1974.

Irrigation Treatment	Irrigation Quantity			Mean
	Consumptive-Use Ratio			
	1.35	1.00	0.80	
	(pounds per 100 berries)			
TRICKLE:				
Daily / 1 emitter	0.79*	0.87	0.78	0.81 a**
Daily / 2 emitters	0.85	0.82	0.84	0.84 a
3-day / 2 emitters	0.84	0.86	0.84	0.85 a
6-day / 2 emitters	0.85	0.85	0.87	0.86 a
MEAN	0.83 a	0.85 a	0.83 a	
FURROW:				
3 Furrows per vine	0.85	0.87	0.81	0.85 a
2 Furrows per vine	0.85	0.79	0.86	0.83 a
MEAN	0.85 a	0.83 a	0.84 a	

*Mean, 4 replications, 7 vines harvested per plot.

**Numbers followed by the same letter are not significantly different at the 0.05 level by Duncan's Multiple Range Test.

Table 4. Sugar Content for Trickle and Furrow Irrigation of Grapes, 1974.

Irrigation Treatment	Irrigation Quantity			Mean
	Consumptive-Use Ratio			
	1.35	1.00	0.80	
	(percent sugar)			
TRICKLE:				
Daily / 1 emitter	17.2*	17.7	18.5	17.8 a**
Daily / 2 emitters	17.9	17.7	17.3	17.6 a
3-day / 2 emitters	18.2	17.2	18.0	17.8 a
6-day / 2 emitters	17.1	17.0	17.9	17.3 a
MEAN	17.6 a	17.4 a	17.9a	
FURROW:				
3 Furrows per vine	17.5	17.3	17.2	17.3 a
2 Furrows per vine	17.4	16.9	16.9	17.1 a
MEAN	17.5 a	17.1 a	17.0 a	

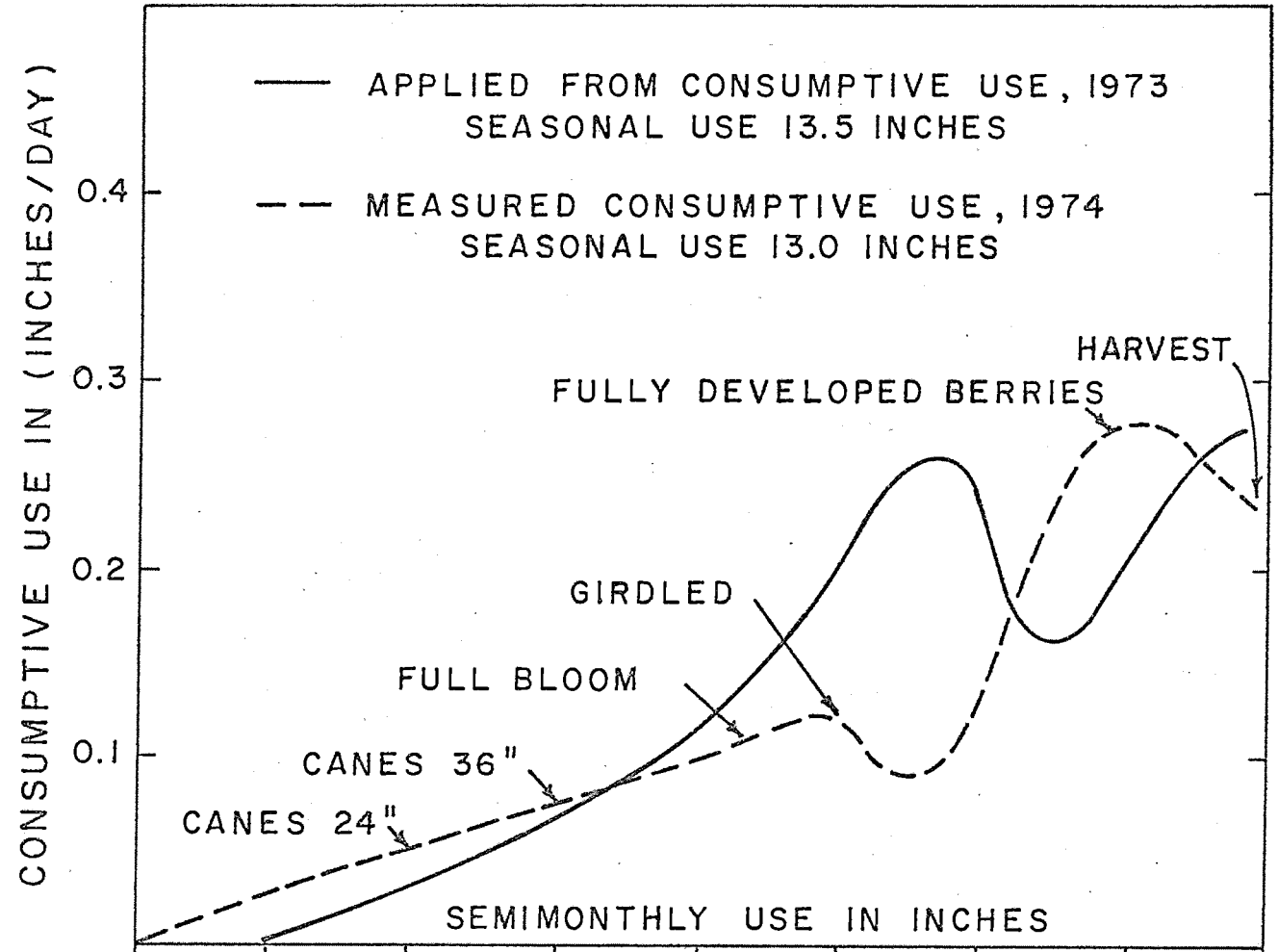
*Mean, 4 replications, 7 vines harvested per plot.

**Numbers followed by the same letter are not significantly different at the 0.05 level by Duncan's Multiple Range Test.

TABLE 5. Comparison of 1973 and 1974 results for trickle and furrow irrigation of grapes.

COMPARISON	1973	1974
Yield for two emitters versus one emitter per vine.	9% increase	9% increase
Yield for two emitters per vine versus furrow irrigation.	13% increase	6% increase
Yield for different trickle irrigation frequencies.	N.S.	N.S. *
Yield for three versus two furrows per vine.	N.S.	N.S.
Yield for different trickle irrigation quantities.	N.S.	11% increase for 1.35 over 0.80 consumptive-use rate.
Yield for different furrow irrigation quantities.	N.S.	N.S.
Berry size for trickle versus furrow-irrigated fruit.	6% increase	N.S.
Sugar content for trickle versus furrow-irrigated fruit.	N.S.	N.S.

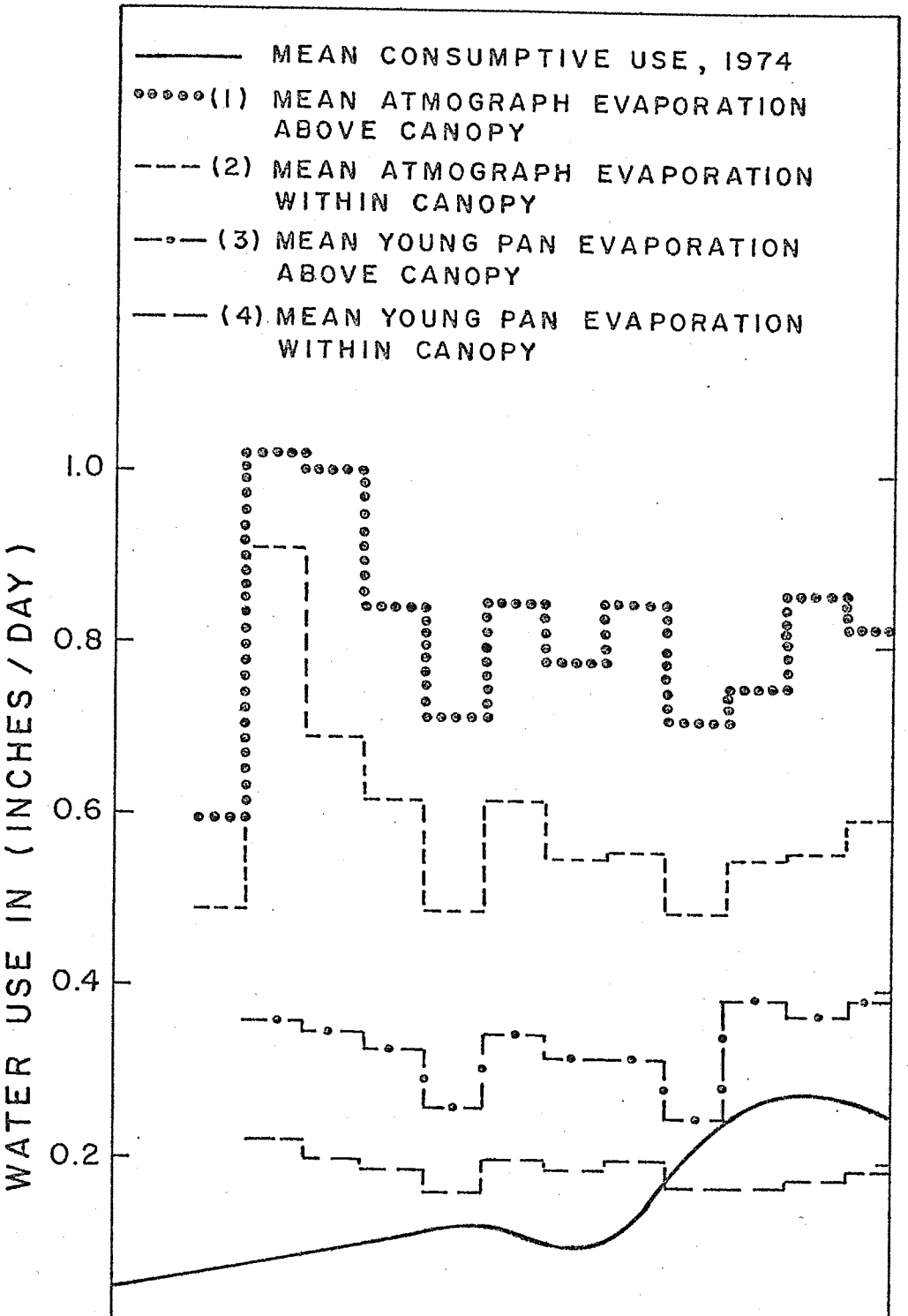
* N.S. : No Significant difference at the 5% level.



SEMIMONTHLY USE IN INCHES

APPLIED		.24	.78	1.38	2.36	3.95	2.51	2.33
MEASURED	.20	.62	1.02	1.32	1.75	1.32	3.81	2.99
	FEB	MARCH		APRIL		MAY		JUNE

Figure 1. Applied and measured consumptive use for grapes, 1974.



K, FACTORS	MARCH	APRIL		MAY		JUNE
(1)	0.12	0.09	0.14	0.11	0.32	0.24
(2)	0.14	0.12	0.18	0.15	0.46	0.35
(3)	—	0.26	0.36	0.27	0.75	0.56
(4)	—	0.42	0.65	0.45	1.36	1.10

Figure 2. Evaporation measurements for grapes, 1974.

Annual Report of the U.S. Water Conservation Laboratory

TITLE: EVALUATING TRICKLE IRRIGATION FOR CANTALOUPE PRODUCTION

CRIS WORK UNIT: 5510-12260-004 CODE No. USWCL 74-1

INTRODUCTION:

Several possible advantages of trickle irrigation over other irrigation methods include increased yield, improved fruit quality, decreased water requirement, increased fertilizer efficiency, reduced labor costs, and improved salinity control. These advantages, however, have not been proved for many soil, water and crop conditions. Prior research at Phoenix, Arizona, has demonstrated that success of trickle irrigation depends upon optimum water management, proper maintenance, and adapted cultural practices.

With present-day surface irrigation practices in the Southwest, approximately one U.S. No. 1 cantaloupe is marketed from each vine (spaced 12 inches apart) within a 20- to 25-day harvest period. Since each vine bears several cantaloupes, an additional marketable cantaloupe could be produced if plant growth were extended over a longer harvest season. Furrow irrigation is usually discontinued before harvest begins, to allow for equipment and workers in the fields and to eliminate fruit rot. Some growers, however, have attempted to furrow-irrigate about two weeks after harvest begins, to revitalize plant growth, and the results have not been successful because plants are already severely stressed, harvesting is interrupted, and cantaloupe rot tends to increase. If surface or subsurface trickle irrigation can be continued through harvest, cantaloupe harvest could be extended to as much as 35 to 40 days.

The objective of this study was to develop criteria for managing trickle irrigation on cantaloupes for a longer harvest season. This criteria includes a larger fruit set, greater plant vigor, improved fruit quality, and increased production. The first year was used to determine effects of different irrigation frequencies, using the surface and subsurface trickle methods. Furrow irrigation was used as a check on the water-use efficiency, fruit production, and fruit quality for the trickle irrigation methods.

FIELD PROCEDURES:

The five irrigation treatments for the first year consisted of surface trickle irrigation at a daily and weekly frequency, subsurface trickle irrigation at a daily and weekly frequency, and furrow irrigation. These treatments were replicated six times in a randomized-block design. Each trickle irrigation plot was three beds wide and 150 feet long, and each furrow irrigation plot was four beds wide and 150 feet long. The trickle irrigation system used was Anjac's Bi-Wall [1/] tubing, with a 12-inch spacing of outside holes. The surface trickle was placed along the plant row, and the subsurface trickle was buried 6 inches below the plant row. Water was filtered through a sand filter followed by a 325-mesh (44 micron) screen filter for both trickle systems.

Cantaloupe seed, PMR-45 variety, was planted at the Yuma Valley Experiment Station, Yuma, Arizona, on February 4 and July 17, respectively, for spring and fall crops. Spring cantaloupes on the furrow plots were planted on the south-sloped, east-west oriented beds. It was hoped that the flat beds would eliminate the necessity for topping or leveling the beds after germination, and reduce the labor requirement for training of vines to grow on top of the beds. The sloped bed results in warmer temperatures for seed germination. Fall cantaloupes on all treatments were planted on flat, east-west oriented beds. It was necessary to pick up and replace the surface trickle tubing before and after planting; whereas subsurface trickle tubing was left underground during fall planting. Plants were thinned to 12-inch spacing on March 20 and August 2, respectively, for spring and fall crops.

Fertilizer applications were 100 lbs of actual N per acre (Feb 2) prior to bedding in the spring, followed by 50 lbs of N per acre (May 28) on surface and subsurface trickle plots prior to harvesting. The fertilizer applications in the fall were 100 lbs of N per acre (July 16) prior to planting on the furrow plots, 50 lbs of N per acre prior to planting on the subsurface and surface trickle plots, and

50 lbs of N per acre (August 15) on subsurface and surface trickle plots, when melons were about 2 inches in diameter.

Water applications were based on the estimated consumptive-use rate for a furrow irrigation practice (1). Tensiometers were installed at a 12-inch depth and 12-inch distance from the plant row for the spring cantaloupes. Additional tensiometers were installed at 12-, 24-, and 36-inch depths in two replications of all treatments for the fall cantaloupes. The amount of water applied to the furrow plots was measured with an impeller meter, and water applied to the surface and subsurface plots was measured with turbine-vane meters.

Cantaloupe harvesting from 100 feet of the center row on each plot began on June 3 in the spring and September 23 in the fall. The fruit was harvested three times per week, sized, counted, and graded as being U. S. No. 1 or culls. The reason the fruit was labeled a "cull" was recorded. From these data, yields were calculated on a crate-per-acre basis. The fall harvest was divided into an early and late season, which will be explained in the results.

RESULTS AND DISCUSSION:

The spring planting began to emerge on February 19 on the furrow irrigation plots, compared to March 6 on the trickle irrigation plots. This two-weeks difference in emergence was attributed to a soil temperature effect caused by the different bed configurations. At the 1" depth, the slanted, furrow irrigation beds were 5° to 10° F warmer than the flat, trickle irrigation beds (Table 1). There was no appreciable difference between soil temperatures of both beds in the morning or in the afternoon at the 6" depth. The difference in emergence dates was not believed to be due to soil salinity along the seed row (Table 2). The U. S. Salinity Laboratory's Agricultural Handbook No. 60 indicates that germination of a moderately salt-tolerant crop such as cantaloupes would not be significantly reduced at a saturated soil conductivity of less than 5 mmhos/cm. No difference in the number of plants germinated was observed, as there was an ample

plant stand for thinning on all plots. Next year, spring cantaloupes will be planted on slanted beds for both furrow and trickle treatments.

The amounts of irrigation water applied on spring and fall cantaloupes are shown in Tables 3 and 4. Water applications were the same with subsurface and surface trickle in the spring; however, 2.4 inches of additional water were applied with subsurface over surface trickle to achieve plant emergence in the fall. Difficulty was experienced in subbing moisture to the soil surface with the subsurface trickle method. Considerable soil cracking above the subsurface tubing was the result of allowing the soil to dry before planting fall cantaloupes. Next year, moderate irrigations will be given between final spring harvest and fall planting on the subsurface trickle treatments.

Mean tensiometer readings at the 12-inch depth before each furrow irrigation were as follows: 72 centibars on May 2, 78 centibars on May 21, 75 centibars on May 28, 70 centibars on August 8, 85 centibars on August 28, 82 centibars on September 12, 79 centibars on October 1, and 75 centibars on October 21. Previous research in Yuma County on a silt-loam soil indicated that cantaloupes need not be irrigated until tensiometer readings reached 50 to 75 centibars at a depth of 10 inches (2).

Nitrate nitrogen analysis of cantaloupe petioles for the various treatments are shown in Table 5. These nitrate levels indicate that there was no significant difference or deficiency in nitrogen fertilizer, although the petiole NO_3-N for the fall over spring cantaloupes was sizeably higher. Pew and Gardner (3) suggested that an adequate level of petiole NO_3 for cantaloupes grown in Arizona was 4,000 ppm, and that harmful effects or reduction in yields were not found when petiole NO_3-N levels were in the upper limits of the adequate range, or even higher.

Table 6 shows yield and quality data for spring cantaloupes. Marketable yields were greater for subsurface over surface trickle

and furrow irrigation; however, the percentage of unmarketable fruit was higher than expected. There was a 34% increase in marketable crates-per-acre for subsurface over surface trickle irrigation, and a 29% increase for subsurface over furrow irrigation. There was little difference in marketable yield between daily and weekly irrigation frequencies for the surface and subsurface trickle methods. The increased marketable yield with subsurface trickle came during the first week of harvest and resulted in a larger number of U. S. No. 1 fruit. The number of unmarketable spring cantaloupes was not significantly different between furrow, surface trickle, or subsurface trickle. A 67% mean culls was due to larger number of slick, split, and sunburned cantaloupes (Table 8). An explanation for the poorly netted fruit is not entirely known. Cantaloupe mildew or wilt did not appear to be a visual problem. Possible reasons for the unmarketable melons were too wet a soil moisture condition, or extremely high temperatures just before and during spring harvest.

At the beginning of the fall cantaloupe harvest, an excessive percentage of culls was again noted -- 65% for the first week in the fall, compared to 41% in the spring. A large number of these unmarketable melons were sunburned (Table 8). This was believed to be due to a planting date earlier than necessary, and too high temperatures during fruit ripening. All remaining cantaloupes, therefore, were stripped from the vines, and a second fruit set was encouraged by the continuation of furrow and trickle irrigations.

Table 7 shows yield and quality data for fall cantaloupes. Fall harvest is represented by the sum of an 8-day early harvest and a 26-day late harvest. Total marketable yields were greater for subsurface and surface trickle than for furrow irrigation, and the percentage of unmarketable fall melons was reduced from that of the spring melons. There was a 38% increase in total marketable crates-per-acre for subsurface and surface trickle over furrow irrigation, and the marketable yields, again, showed no difference between

irrigation frequencies for the subsurface and surface trickle methods. This increased marketable yield for subsurface and surface trickle included a 53% increase in U. S. No. 1 fruit over furrow irrigation. The improved yield and quality with trickle over furrow irrigation resulted from the late fall harvest and was probably due to the irrigation practice of vine stripping and the continuation of trickle irrigations throughout the harvest period. After stripping of vines, the late fall harvest more than doubled the total marketable yield for all irrigation methods.

Comparing early and late fall cantaloupes (Table 7), the total mature fruit harvested was significantly greater for the subsurface trickle and furrow irrigation for late harvest. The cantaloupe plant appears to have inherent characteristics for regrowth and recovery. Comparing unmarketable early and late fall cantaloupes, (Table 8) the late melons had a smaller percentage of culls and sunburned fruit than the early melons. The largest number of unmarketable late melons were either soft or rotten-spotted fruit.

Subsurface trickle may have several practical field advantages over surface trickle. First, the subsurface system is not in the way for equipment and hand operations of thinning, weeding, and harvesting. Second, the subsurface system does not require staking of tubing during early plant growth, which is necessary on surface trickle because of wind movement. Third, the surface trickle system requires removal of tubing between spring and fall cantaloupes, to facilitate use of machinery. Possible disadvantages for subsurface compared to surface trickle irrigation are that an additional quantity of water may be required for germination, and that system plugging with roots (not yet observed) could be a problem.

SUMMARY AND CONCLUSIONS:

Spring and fall cantaloupes were grown with a surface and a subsurface trickle system, to determine if continued irrigation during the harvest period would increase the quality and late-season production. Standard practice is to discontinue furrow irrigations at the beginning of harvest. Spring cantaloupe emergence was delayed on the surface and subsurface trickle treatments planted on flat beds as compared to furrow irrigation planted on south-sloped, warmer temperature beds. Visual plant growth on the subsurface trickle appeared to be the same as the furrow irrigation treatment by harvest. Marketable spring yields were improved for subsurface trickle over surface trickle and furrow irrigation, although the quantity of slick, split, and sunburned fruit was unusually large for all irrigation methods.

Fall cantaloupes were divided into an early and late-season harvest. The early harvest, again, had an excessive number of sunburned fruit for all irrigation methods. However, the late harvest more than doubled the total marketable yield for all irrigation methods. Total marketable fall yields were greater for subsurface and surface trickle over furrow irrigation. Interestingly, daily compared to weekly subsurface or surface trickle treatments did not improve yield or quality of spring or fall cantaloupes. More research is needed on the reduction of unmarketable fruit with the extended cantaloupe harvest season.

Subsurface over surface trickle may have several practical field advantages in terms of less interference with field operations such as thinning, planting, and harvesting. The major disadvantage of subsurface compared to surface trickle could be system plugging with roots, which did not occur in the first year of this investigation.

Table 2. Grape Production for Trickle and Furrow Irrigation, 1974.

Irrigation Treatment	Irrigation Quantity			Mean
	Consumptive-Use Ratio			
	1.35	1.00	0.80	
	(pounds per plot)			
TRICKLE:				
Daily / 1 emitter	136*	140	119	132 b**
Daily / 2 emitters	133	140	145	139 ab
3-day / 2 emitters	138	159	137	145 a
6-day / 2 emitters	159	151	133	148 a
MEAN	142 ab	148 a	134 c	
FURROW:				
3 Furrows per vine	136	138	135	136 ab
2 Furrows per vine	132	137	139	136 ab
MEAN	134 c	138 bc	137 bc	

*Mean, 4 replications, 7 vines harvested per plot.

**Numbers followed by the same letter are not significantly different at the 0.05 level by Duncan's Multiple Range Test.

Table 3. Berry Size for Trickle and Furrow Irrigation of Grapes, 1974.

Irrigation Treatment	Irrigation Quantity			Mean
	Consumptive-Use Ratio			
	1.35	1.00	0.80	
	(pounds per 100 berries)			
TRICKLE:				
Daily / 1 emitter	0.79*	0.87	0.78	0.81 a**
Daily / 2 emitters	0.85	0.82	0.84	0.84 a
3-day / 2 emitters	0.84	0.86	0.84	0.85 a
6-day / 2 emitters	0.85	0.85	0.87	0.86 a
MEAN	0.83 a	0.85 a	0.83 a	
FURROW:				
3 Furrows per vine	0.85	0.87	0.81	0.85 a
2 Furrows per vine	0.85	0.79	0.86	0.83 a
MEAN	0.85 a	0.83 a	0.84 a	

*Mean, 4 replications, 7 vines harvested per plot.

**Numbers followed by the same letter are not significantly different at the 0.05 level by Duncan's Multiple Range Test.

Table 4. Sugar Content for Trickle and Furrow Irrigation of Grapes, 1974.

Irrigation Treatment	Irrigation Quantity			Mean
	Consumptive-Use Ratio			
	1.35	1.00	0.80	
	(percent sugar)			
TRICKLE:				
Daily / 1 emitter	17.2*	17.7	18.5	17.8 a**
Daily / 2 emitters	17.9	17.7	17.3	17.6 a
3-day / 2 emitters	18.2	17.2	18.0	17.8 a
6-day / 2 emitters	17.1	17.0	17.9	17.3 a
MEAN	17.6 a	17.4 a	17.9a	
FURROW:				
3 Furrows per vine	17.5	17.3	17.2	17.3 a
2 Furrows per vine	17.4	16.9	16.9	17.1 a
MEAN	17.5 a	17.1 a	17.0 a	

*Mean, 4 replications, 7 vines harvested per plot.

**Numbers followed by the same letter are not significantly different at the 0.05 level by Duncan's Multiple Range Test.

TABLE 5. Comparison of 1973 and 1974 results for trickle and furrow irrigation of grapes.

COMPARISON	1973	1974
Yield for two emitters versus one emitter per vine.	9% increase	9% increase
Yield for two emitters per vine versus furrow irrigation.	13% increase	6% increase
Yield for different trickle irrigation frequencies.	N.S.	N.S. *
Yield for three versus two furrows per vine.	N.S.	N.S.
Yield for different trickle irrigation quantities.	N.S.	11% increase for 1.35 over 0.80 consumptive-use rate.
Yield for different furrow irrigation quantities.	N.S.	N.S.
Berry size for trickle versus furrow-irrigated fruit.	6% increase	N.S.
Sugar content for trickle versus furrow-irrigated fruit.	N.S.	N.S.

* N.S. : No Significant difference at the 5% level.

TITLE: EVALUATING TRICKLE IRRIGATION FOR CANTALOUPE PRODUCTION

CRIS WORK UNIT: 5510-12260-004 CODE No. USWCL 74-1

INTRODUCTION:

Several possible advantages of trickle irrigation over other irrigation methods include increased yield, improved fruit quality, decreased water requirement, increased fertilizer efficiency, reduced labor costs, and improved salinity control. These advantages, however, have not been proved for many soil, water and crop conditions. Prior research at Phoenix, Arizona, has demonstrated that success of trickle irrigation depends upon optimum water management, proper maintenance, and adapted cultural practices.

With present-day surface irrigation practices in the Southwest, approximately one U.S. No. 1 cantaloupe is marketed from each vine (spaced 12 inches apart) within a 20- to 25-day harvest period. Since each vine bears several cantaloupes, an additional marketable cantaloupe could be produced if plant growth were extended over a longer harvest season. Furrow irrigation is usually discontinued before harvest begins, to allow for equipment and workers in the fields and to eliminate fruit rot. Some growers, however, have attempted to furrow-irrigate about two weeks after harvest begins, to revitalize plant growth, and the results have not been successful because plants are already severely stressed, harvesting is interrupted, and cantaloupe rot tends to increase. If surface or subsurface trickle irrigation can be continued through harvest, cantaloupe harvest could be extended to as much as 35 to 40 days.

The objective of this study was to develop criteria for managing trickle irrigation on cantaloupes for a longer harvest season. This criteria includes a larger fruit set, greater plant vigor, improved fruit quality, and increased production. The first year was used to determine effects of different irrigation frequencies, using the surface and subsurface trickle methods. Furrow irrigation was used as a check on the water-use efficiency, fruit production, and fruit quality for the trickle irrigation methods.

FIELD PROCEDURES:

The five irrigation treatments for the first year consisted of surface trickle irrigation at a daily and weekly frequency, subsurface trickle irrigation at a daily and weekly frequency, and furrow irrigation. These treatments were replicated six times in a randomized-block design. Each trickle irrigation plot was three beds wide and 150 feet long, and each furrow irrigation plot was four beds wide and 150 feet long. The trickle irrigation system used was Anjac's Bi-Wall [1/] tubing, with a 12-inch spacing of outside holes. The surface trickle was placed along the plant row, and the subsurface trickle was buried 6 inches below the plant row. Water was filtered through a sand filter followed by a 325-mesh (44 micron) screen filter for both trickle systems.

Cantaloupe seed, PMR-45 variety, was planted at the Yuma Valley Experiment Station, Yuma, Arizona, on February 4 and July 17, respectively, for spring and fall crops. Spring cantaloupes on the furrow plots were planted on the south-sloped, east-west oriented beds. It was hoped that the flat beds would eliminate the necessity for topping or leveling the beds after germination, and reduce the labor requirement for training of vines to grow on top of the beds. The sloped bed results in warmer temperatures for seed germination. Fall cantaloupes on all treatments were planted on flat, east-west oriented beds. It was necessary to pick up and replace the surface trickle tubing before and after planting; whereas subsurface trickle tubing was left underground during fall planting. Plants were thinned to 12-inch spacing on March 20 and August 2, respectively, for spring and fall crops.

Fertilizer applications were 100 lbs of actual N per acre (Feb 2) prior to bedding in the spring, followed by 50 lbs of N per acre (May 28) on surface and subsurface trickle plots prior to harvesting. The fertilizer applications in the fall were 100 lbs of N per acre (July 16) prior to planting on the furrow plots, 50 lbs of N per acre prior to planting on the subsurface and surface trickle plots, and

SUMMARY AND CONCLUSIONS:

Spring and fall cantaloupes were grown with a surface and a subsurface trickle system, to determine if continued irrigation during the harvest period would increase the quality and late-season production. Standard practice is to discontinue furrow irrigations at the beginning of harvest. Spring cantaloupe emergence was delayed on the surface and subsurface trickle treatments planted on flat beds as compared to furrow irrigation planted on south-sloped, warmer temperature beds. Visual plant growth on the subsurface trickle appeared to be the same as the furrow irrigation treatment by harvest. Marketable spring yields were improved for subsurface trickle over surface trickle and furrow irrigation, although the quantity of slick, split, and sunburned fruit was unusually large for all irrigation methods.

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1. Erie, L. J., French, O. F., and Harris, K. 1968. Consumptive Use of Water by Crops in Arizona. Univ. of Ariz. Tech. Bul. No. 169.

2. Halderman, A. D., Gardner, B. R., and Pew, W. D. 1974. Irrigation Schedule for Cantaloupes. Univ. of Ariz. Agri-File No. Q-249.

3. Pew, W. D., and Gardner, B. R. 1972. Nitrogen Effects on Cantaloupes. Soil Sci. and Plant Analysis 3(6):467-476.

PERSONNEL: Dale A. Bucks, Gordon K. Tritz (Univ. of Arizona), Leonard J. Erie, and Orrin F. French.

1/ Trade names and company names, when included, are for the convenience of the reader and do not imply preferential endorsement by the U. S. Department of Agriculture of a particular product or company over others.

TABLE 1. MEAN SOIL TEMPERATURES WITHIN THE SEED ROW DURING GERMINATION OF SPRING CANTALOUPES, 1974.

Treatment	Depth	Morning (0800-0900 Hrs.)	Afternoon (1300-1600 Hrs.)
Furrow	1"	56 *	84
	6"	56	59
Subsurface Trickle	1"	51	74
	6"	57	59
Surface Trickle	1"	51	74
	6"	56	58

* Dry-bulb soil temperatures in °F taken on 7 selected days between February 13 and February 26.

TABLE 2. MEAN SOIL SALINITY MEASUREMENTS WITHIN THE SEED ROW DURING EARLY PLANT GROWTH FOR SPRING CANTALOUPES, 1974.

Treatment	Depth	February 21 (mmhos/cm)	April 4 (mmhos/cm)
Furrow	0 - 1"	1.48 *	4.50
	0 - 6"	2.50	1.51
Subsurface Trickle	0 - 1"	1.20	3.37
	0 - 6"	2.15	2.27
Surface Trickle	0 - 1"	0.93	3.60
	0 - 6"	2.20	3.96

* Mean of two samples.

TABLE 3. IRRIGATION WATER APPLIED FOR SPRING CANTALOUPES, 1974.

Treatment	Irrigation Dates		Water Applied (inches)*
Furrow	February 4-5 (Germination)		13.3
	May 2		7.2
	May 21		7.8
	May 28		6.5
		Total	34.8
Subsurface and Surface Trickle	February 5-7 (Germination)		3.3
	May 2 - May 20		5.5
	May 21 - May 27		2.5
	May 28 - June 25		4.0
		Total	15.3

*Calculated on basis of total plot area, 3000 sq ft.

REFERENCES:

1. Erie, L. J., French, O. F., and Harris, K. 1968. Consumptive Use of Water by Crops in Arizona. Univ. of Ariz. Tech. Bul. No. 169.

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	May 2		7.2
	May 21		7.8
	May 28		6.5
		Total	34.8
Subsurface and Surface Trickle	February 5-7 (Germination)		3.3
	May 2 - May 20		5.5
	May 21 - May 27		2.5
	May 28 - June 25		4.0
		Total	15.3

*Calculated on basis of total plot area, 3000 sq ft.

TABLE 4. IRRIGATION WATER APPLIED FOR FALL CANTALOUPES, 1974.

Treatment	Irrigation Dates	Water Applied (inches)*
Furrow	July 18 (Germination)	10.1
	August 8	4.9
	August 28	4.9
	September 12	3.9
	October 1	4.2
	October 21	3.5
	Total	31.5
Subsurface Trickle	July 18-22 (Germination)	4.1
	August 2 (Thinning)	0.6
	August 8 - August 27	1.0
	August 28 - Sept 11	3.5
	Sept 12 - Sept 31	3.8
	October 1 - October 20	2.8
	October 21 - November 4	2.0
	Total	17.8
Surface Trickle	July 18-19 (Germination)	1.2
	August 1 (Thinning)	0.4
	August 8 - August 27	1.7
	August 28 - Sept 11	3.5
	Sept 12 - Sept 31	3.8
	October 1 - October 20	2.8
	October 21 - November 4	2.0
	Total	15.4

*Calculated on basis of total plot area, 3000 sq ft.

Table 6. YIELD AND QUALITY OF SPRING CANTALOUPES, 1974.

	Treatment	Mkt. Crates per Acre	No. per plot 36 & Larger	Total No. per Plot Mature Fruit Harvested	Percent Culls	Total Green Ungraded Fruit
First 7 days	Furrow	34.2 b *	9.5 ab	40.3	49.8	
June 3	Subsurface/daily	45.4 a	10.7 ab	50.1	41.0	
through	" /weekly	50.0 a	14.8 a	43.0	34.5	
June 9	Trickle/daily	27.8 bc	9.7 ab	30.3	42.0	
	Trickle/weekly	22.8 c	5.2 b	26.8	37.0	
	$S_{\bar{x}}$	2.84	2.01	N.S.	N.S.	
Last 14 days	Furrow	13.6	3.8 bc	56.8 b	36.1	
June 17	Subsurface/daily	14.6	2.7 c	50.6 b	39.8	
through	" /weekly	18.9	6.0 ab	71.6 ab	33.2	
June 30	Trickle/daily	14.9	3.5 bc	72.5 ab	34.1	
	Trickle/weekly	25.4	7.8 a	89.3 a	31.3	
	$S_{\bar{x}}$	N.S.	0.94	8.87	N.S.	
Total 28 days	Furrow	89.7 b	23.6 b	154.0 b	66.0	18.3 b
June 3	Subsurface/daily	106.8 ab	28.1 ab	166.7 b	63.3	13.8 b
through	" /weekly	124.0 a	37.3 a	193.8 a	63.3	23.5 ab
June 30	Trickle/daily	86.1 b	21.6 b	171.0 b	70.5	19.6 b
	Trickle/weekly	86.7 b	23.5 b	177.8 b	71.2	32.5 a
	$S_{\bar{x}}$	8.54	3.41	6.67	N.S.	3.793

N.S. N o significant difference.

* Significant difference at 5% level.

a, ab, etc. Means followed by same letter belong to same population at 5% level of significance.

TABLE 7. YIELD AND QUALITY OF FALL CANTALOUPES, 1974.

	Treatment	Mkt. Crates per Acre	No. per plot 36 & Larger	Total No. per Plot Mature Fruit Harvested	Percent Culls	Total Green Ungraded Fruit
Early Harvest	Furrow	61.7	21.5 b*	101.1 a	69.7 bc	
8 days	Subsurface/daily	69.8	25.0 b	113.5 a	68.8 bc	
Sept. 23	" /weekly	64.9	24.8 b	111.3 a	72.0 c	
thru	Trickle/daily	62.3	25.8 b	78.2 b	63.3 b	
Sept. 30	" /weekly	83.5	32.3 a	94.7 ab	53.3 a	
	$S_{\bar{x}}$	N.S.	2.21	6.68	2.69	
Late Harvest	Furrow	66.7 b	16.0 b	84.7 b	53.8 b	
26 days	Subsurface/daily	98.1 a	28.2 a	102.5 b	45.5 a	
Nov. 4	" /weekly	101.8 a	30.7 a	103.7 b	45.2 a	
thru	Trickle/daily	116.4 a	30.0 a	125.0 a	46.3 ab	
Nov. 29	" /weekly	115.7 a	32.2 a	127.3 a	50.0 ab	
	$S_{\bar{x}}$	8.27	2.54	7.21	2.19	
TOTAL -	Furrow	128.4 b	37.5 c	185.8 b	62.8 b	43.3
34 days	Subsurface/daily	168.9 a	53.2 b	216.0 a	58.0 ab	31.8
	" /weekly	166.7 a	55.5 ab	215.0 a	59.5 b	46.3
	Trickle/daily	178.6 a	55.8 ab	203.2 ab	52.7 a	32.2
	" /weekly	199.2 a	64.5 a	222.0 a	52.0 a	42.2
	$S_{\bar{x}}$	10.21	3.24	8.29	1.97	N.S.

N.S. No significant difference.

* Significant difference at 5% level.

a, ab, etc.: Means followed by same letter belong to same population at 5% level of significance.

TABLE 5. NITRATE NITROGEN IN CANTALOUPE PETIOLES, 1974

Treatment	Full-size Spring Melons May 10	Pre Harvest Spring May 28	Full-size Fall Melons August 15	Pre Harvest Fall September 9
		(PPM NO_3 - N x 10^3)		
Furrow	9.2	8.3	23.2	20.2
Subsurface Trickle/daily	5.1	4.3	21.6	18.3
" Trickle/weekly	6.4	5.8	22.8	20.1
Surface Trickle/daily	4.9	5.2	22.1	18.7
" Trickle/weekly	6.7	6.0	22.4	18.5
$S_{\bar{x}}$	--- *	N.S.	N.S.	N.S.

* Number of samples too few for accurate statistical analysis.

N.S. No Significant difference.

TABLE 8. DESCRIPTION OF UNMARKETABLE FRUIT FOR SPRING AND FALL CANTALOUPES, 1974

		AVERAGE MELONS PER PLOT								
	Treatment	Slick	Split	Sunburn	Soft	Rotten Spot	Ground Spot	Small	Other	Total Culls
Spring Harvest	Furrow	25.0	32.5 a*	29.2	4.0	1.0	.8	5.7	1.3	101.7 a
June 3	Subsurface/daily	36.0	30.3 a	27.7	4.5	.2	.5	4.0	.2	104.0 a
through	" /weekly	34.7	41.5 b	33.5	6.8	1.0	1.3	3.7	.7	123.5 b
June 30	Trickle/daily	36.8	34.2 ab	33.0	4.5	3.8	2.0	2.7	.7	119.3 ab
	Trickle/weekly	38.1	41.8 b	31.7	4.2	2.5	2.7	4.3	.5	126.5 b
	$S_{\bar{x}}$	N.S.	3.45	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	6.22
Early Fall Harvest	Furrow	10.7 bc	13.2	41.8 b	1.2	3.3	0.2	0	0	70.5 ab
Sept 23	Subsurface/daily	12.0 c	15.2	46.8 b	1.5	3.5	0	0	0	79.0 c
through	" /weekly	11.5 bc	18.2	44.3 b	0.8	5.7	0.3	0	0	80.8 c
Sept 30	Trickle/daily	5.8 ab	14.5	23.7 a	0.5	5.2	0	0	0	49.7 a
	Trickle/weekly	4.7 a	14.8	29.8 a	0.7	4.8	0.3	0	0	53.2 ab
	$S_{\bar{x}}$	1.95	N.S.	3.71	N.S.	N.S.	N.S.	N.S.	N.S.	5.92
Late Fall Harvest	Furrow	5.8 a	4.0	0.7 a	18.7	16.2 bc	0.3	0.3	0	46.0 ab
Nov 4	Subsurface/daily	5.3 a	2.8	3.3 b	25.0	9.5 a	0.2	0.7	0	46.8 a
through	" /weekly	5.3 a	4.8	2.3 ab	19.8	13.8 abc	0.8	0.3	0	47.3 ab
Nov 29	Trickle/daily	11.2 b	3.7	3.0 b	27.0	11.7 ab	1.2	0	0	57.7 bc
	Trickle/weekly	8.8 ab	3.8	2.0 ab	27.7	18.0 c	1.3	0.3	0	62.0 c
	$S_{\bar{x}}$	1.50	N.S.	.56	N.S.	1.78	N.S.	N.S.	N.S.	3.61

N. S. No significant difference.

* Significant difference at 5% level.

a, ab, etc.: Means followed by same letter belong to same population at 5% level of significance.

TITLE: CHEMICAL MODIFICATION OF SOILS FOR HARVESTING PRECIPITATION

CRIS WORK UNIT: 5510-12260-004 CODE NO.: USWCL 74-1

The objectives of this study remain to (1) develop and evaluate in the laboratory, chemical soil treatments suitable for water harvesting; (2) develop and refine laboratory methods suitable for such evaluation; and (3) to field test the most promising of the materials and techniques under a variety of soil and weathering conditions.

Laboratory Testing Procedures

The laboratory methods for evaluating chemical soil treatments for water harvesting continue to undergo gradual refinement. As reported in last year's Annual Report, the various soils under test are compacted wet into petri dishes using a standardized procedure, dried, then treated with stabilizers and/or water repellants.

The treated samples then undergo a battery of tests. First, their relative water-repellancy is determined using the drop height test. Height of an approximately 3-cm-diameter water drop is measured relative to the soil surface. The water height (ℓ) is measured immediately after application of the drop, and 5 to 10 minutes later to note any infiltration. This height value (of the delayed measurement) is normalized by dividing it by the theoretical height (ℓ_n = 0.3855 cm) of a water drop with a 90° contact angle, when resting on a smooth, nonporous solid surface. Treatments having relative values of ℓ/ℓ_n equal to or greater than 1.30 were adjudged adequately water repellant.

The second test permits evaluation of the treated soil when flooded for an extended time period. The test is simply to note whether the large water drop from the previous test (ℓ/ℓ_n) infiltrates into the soil within 4 hrs and/or whether the treated soil under the drop swells excessively and cracks upon drying. It thus is both a repellancy and a stability test.

The third test subjects the treated soil to cyclical freezing and thawing. The samples are placed in a freeze-thaw chamber; approximately a 3-cm-diameter water drop is placed atop the treated soil near one side of the petri dish; and the chamber then is cycled between approximately -20 to +20 Celsius. Usually, after a number of cycles the water drop will completely infiltrate the soil. The sample is then redried, tested for structural stability by brushing the soil surface with a stiff brush, and then given another 4-hr infiltration test. If the sample passes these two checks it again is placed in the freeze-thaw chamber. This process is repeated until the sample permanently loses either repellancy or structural stability. Failure always occurs on the area under the water drop--never on the dry soil area.

The fourth test permits evaluation of soil stability against water erosion. For this test, 1000 5-mm-diameter water drops drop onto the treated soil surface in 5 min from a height of 2 m. Degree of erosion is evaluated as none (N), moderate (M) for soil pitting of 2 or 3 mm, severe (S) for pitting into the treated soil zone greater than 3 mm, and failure (F) if pitting extends deeper than the treated soil zone. This test utilizes that portion of the sample not destroyed by the freeze-thaw cycling.

Thus, all four tests for evaluating water repellancy and soil stability are performed on only one small petri dish sample. This greatly simplifies and accelerates the testing of materials, soils and treatment procedures. The tests are all a bit subjective, but demarcation limits of acceptance or failure are based on experience acquired by observing hundreds of samples. At year's end, two additional laboratory tests are contemplated. Both accelerate the weathering process by degrading the molecular structure of the organic additives. One subjects the treated samples to high-intensity ultraviolet radiation and the other to high concentrations of atmospheric ozone.

Laboratory Testing of Water Repellant Soil Treatments

Most of the water repellant soil treatments tested in the laboratory during 1974 appear in Tables 1-7. A number of repellants and repellants with additives were examined on various soils using the tests described in the previous section. The testing procedures continued to evolve during the year, undergoing gradual refinement; thus, while materials, treatments and soils can be compared generally, between experiments, they can not be compared absolutely.

Soils, unless otherwise specified, were from the surface horizon (0-3"), and were seived to < 2 mm. Salts, when added, were mixed with the soil prior to placing in the petri dishes. After packing in the petri dishes (see previous section), stabilizers, when applied, were added by flooding the material onto the soil surface with a pipette; rate of application of stabilizers in all cases was 3% solids at 1.5 ℓ/m^2. The four stabilizers were Dow 620, 209, and 233, and Elvanol 72-60 polyvinyl alcohol. The straight paraffin wax was applied as a powder, then melted into the soil using a heat lamp. The wax emulsion and silicone were flooded onto the soil with a pipette. The dust suppressant oil was brushed on. The paraffin wax plus antistripping agent (Dow Z06076) and tackifying agent (Hercules L-60) and butyl were brushed on as a hot melt.

The results of the testing procedure for each treatment--soil combination appear in cipher notation in columns under each soil. The code is as follows. (1) Column one is for relative water repellancy; plus (+) denotes ℓ/ℓ_n equal to or greater than 1.30; (-) denotes values less than 1.30. (2) Column two shows results of the 4-hr infiltration test of the large sessile water drop; (+) denotes no infiltration or structure failure in 4 hrs; I denotes complete infiltration of the drop in that time period; S denotes structure failure either during the 4-hr wetting period or upon subsequent drying. (3) Column three lists the

number of freeze-thaw cycles required to destroy either the repellency or soil structure; values are listed 1 through 10, or rounded to multiples of 10 thereafter. (4) Column four denotes results of the dripolator test; N denotes no erosion, M denotes moderate, S severe, and F fail. An asterisk (*) denotes that that test is still in progress. Small a (a) denotes the data for various reasons was not taken. A zero (0) in the freeze-thaw column denotes the sample was adjudged a failure by the 4-hr test; therefore, was not run.

The following are some general conclusions gleaned from these laboratory tests. None are definitive, assuring direct extrapolation to field situations; rather, they are suggestive, and will require further testing both in the laboratory and then with pilot field studies. (1) Generally, sandy soils are easier to treat than fine-textured soils--they require less material, are not so subject to structure failure when ponded, and can better withstand the rigors of freeze-thaw cycling. (2) Both the paraffin wax and the dust suppressant produce highly water-repellant soil surfaces; however, their durability under water ponding or freeze-thaw cycling is dependent both on application rate and soil type. For example, the Seneca surface soil was effectively treated with dust suppressant--yet nothing yet tried worked on either the Seneca sub-soil or the Monument Tank soils. (3) Adding a tackifyer (L-60) and an anti-stripping agent (Z-6076) to paraffin improved the treated soil's resistance to breakdown by freeze-thaw cycling. (4) Adding $A\ell C\ell_3$ salt (acidifying) to Granite Reef soil seems to improve the weatherability of the dust suppressant. (5) Adding wax (either paraffin or the cheaper slack grade) to dust suppressant appears to markedly improve freeze-thaw weatherability. (6) Apparently the emulsifying agent used in the paraffin wax emulsion would readily resolubilize into the sessile water drop to reduce the surface tension--hence, water repellency. (7) Possible poor product quality control of the dust suppressant

may explain some of the variability noted with this material to withstand freeze-thaw weathering. (8) The silicone (XZ-8-5079) treatment was not impressive. (9) Removing the clay fraction from the Granite Reef soil did not materially improve weatherability; possibly concurrent pH lowering and/or reduction of salt content would.

Field Testing of Materials

Runoff studies continued on the water repellant treated plots reported in the 1973 Annual Report. The runoff data for the two paraffin wax plots and the dust suppressant plot at the Granite Reef test site are shown in Table 8. Results are compared on a storm-by-storm basis to runoff from adjacent smoothed-only and butyl-covered plots.

After 2½ years of weathering, the two wax-treated plots show only an insignificant reduction in runoff efficiency (90% for 1972 vs 85% for 1974 on plot R-2). Also, quality of the runoff water of these two plots remains high, and both remain completely free of vegetation.

Initially, runoff yields off the dust suppressant (D.S.) treated plot (Table 8, and 1973 Annual Report) equalled those of the wax plots, but yields declined rapidly after only 6 months of weathering, until by year's end, the dust suppressant treatment had failed completely. Cause of failure is not known, but laboratory studies have been initiated to determine and to circumvent the causal factors.

Data off the plots reported in Table 8 was of rather poor quality in 1974. The 10-m^2 plots were particularly vulnerable: runoff for several storms was missed completely because of faulty equipment; runoff from one and possibly two storms exceeded the storage capacity; and in general the correlation between the two wax plots Nos. 13 and R-2 was both poor and inconsistent. The 10-m^2 data was adjudged too poor in quality to attempt any overall yearly runoff evaluation.

Both the dust suppressant and the paraffin wax are undergoing field evaluation at other sites. The dust suppressant currently is being utilized in a runoff farming experiment to increase the yield of the desert plant jojoba (see WCL 73-4 of this Annual Report). An associated on-site runoff measuring plot has averaged 95% runoff for the 6-month period following installation. This laboratory also has installed four additional paraffin wax plots (see WCL 71-12 of this Annual Report). Two are functioning satisfactorily at the time of this writing, one has failed completely, and one has failed partially. The causal factors precipitating failure are not known definitely, but may relate to the presence of shrink-swell clay, aggravated in one case by cyclical freezing and thawing of free water entrapped by a rough soil surface, and in the other case, aggravated by applying the wax to an inadequately dried soil. These and other factors are being evaluated in the laboratory to permit, eventually, the correct matching of repellant, soil, climate, and installation procedure, to substantially reduce the risk of failure.

PERSONNEL: Dwayne H. Fink

Table 1. Preliminary laboratory testing of soils treated with water repellants.

EXPERIMENT NO. 1	SOIL																			
TREATMENT	GRANITE REEF				SENECA				MONUMENT TANK (1-3)				MONUMENT TANK (2-3)				PULLMAN			
PARAFFIN WAX (143-150)																				
PW at 0.68 kg/m^2	+	+	20	F	+	+	20	F	+	+	20	F	+	+	10	F	+	+	4	F
" at " + DOW 620	+	+	a	N	+	+	60	N	+	+	a	N	+	+	10	N	+	+	10	N
" at 0.27 + PVA	+	I	8	N	+	+	100	N	+	+	10	N	+	+	10	N	+	+	20	N
" at 0.54 + "	+	+	50	N	+	+	30	N	+	+	20	N	+	+	20	N	+	+	20	N
" at 0.81 + "	+	+	60	N	+	+	30	N	+	+	20	N	+	+	50	N	+	+	a	N
" at 0.27 + DOW 209	+	+	10	N	+	+	60	M	+	+	8	F	+	+	8	F	+	+	8	F
" at 0.54 + "	+	+	20	N	+	+	30	N	+	+	10	M	+	+	10	F	+	+	8	M
" at 0.81 + "	+	+	8	N	+	+	50	S	+	+	8	N	+	+	8	M	+	+	8	N
" at 0.27 + DOW 233	+	+	8	N	+	+	20	N	+	+	a	M	+	+	8	M	+	+	8	M
" at 0.54 + "	+	+	20	N	+	+	30	N	+	+	8	N	+	+	8	M	+	+	8	F
" at 0.81 + "	+	+	20	N	+	+	40	N	+	+	8	M	+	+	8	M	+	+	8	M
PARAFFIN WAX EMULSION (128-130)																				
PW at 0.68 kg/m^2	-	+	0	F	-	+	0	F	-	+	0	F	-	+	0	F	+	+	0	F
" at " + DOW 209	-	+	0	N	-	+	0	S	-	+	0	M	-	+	0	F	-	+	0	S
" at " + DOW 233	-	+	0	M	-	+	0	N	-	+	0	M	-	+	0	M	-	+	0	M
DUST SUPPRESSANT (NO. 1)																				
DS at 0.56 1/m^2	+	+	30	N	+	+	30	N	+	+	2	F	+	+	2	F	+	+	10	F
" at 1.13	+	+	110	N	+	+	840*	N	+	+	10	N	+	+	10	S	+	+	60	N
" at 2.26	+	+	70	N	+	+	900*	N	+	+	20	N	+	+	40	N	+	+	40	N
" at 0.56 + DOW 209	+	+	60	N	+	+	940*	N	+	+	30	N	a	+	10	N	+	+	10	N
" at 1.13 + "	+	+	100	N	+	+	820*	N	+	+	10	N	+	+	10	N	+	+	10	N
SILICONE DOW (XE-8-5079)																				
SI 3% at 1.5 1/m^2	+	I	0	F	-	I	0	F	-	I	0	F	-	I	0	F	-	I	0	F
" " at 3.0	-	+	0	N	+	I	0	F	+	I	0	a	+	I	0	a	-	I	0	a
" 6% at 1.5	-	+	0	N	+	I	0	F	+	+	0	F	+	I	0	F	+	I	0	F
" " at 3.0	+	+	0	a	+	I	0	a	-	+	0	a	+	I	0	F	+	I	0	M

Table 2. Laboratory testing of soils treated with paraffin wax and dust suppressant water repellants as affected by rate, stabilizer and clay removal.

EXPERIMENT NO. 2	SOIL				
TREATMENT	GRANITE REEF	SENECA	MONUMENT TANK (2-3)	ARIZONA SILT	ARIZONA FINE SAND
UNTREATED SOIL (< 2 mm)					
PARAFFIN WAX (128-130)					
PW at 0.25 kg/m^2	+ + 10 a	+ + 10 a	+ + 6 a	+ + 60 a	+ + 40 a
" at 0.50	+ + 10 a	+ + 20 a	+ + 6 a	+ + 420 N	+ + 100 a
" at 0.75	+ + 10 a	+ + 10 a	+ + 6 a	+ + 120 a	+ + 110 a
" at 0.25 + DOW 209	+ + 10 a	+ + 40 a	+ + 6 a	+ + 150 N	+ + 120 a
" at 0.50 + "	+ + 10 a	+ + 50 a	+ + 6 a	+ + 810* *	+ + 640* *
" at 0.75 + "	+ + 20 a	+ + 40 a	+ + 6 a	+ + 140 a	+ + 200 a
DUST SUPPRESSANT				700* *	
DS at 0.5 1/m^2	+ + 40 a	+ + 150 N	+ + 6 a	+ + 10 a	+ + 220 a
" at 1.0	+ + 20 a	+ + 880 *	+ + 10 a	+ + 700* *	+ + 850* *
SOIL DISPERSED WITH Na_2CO_3					
PW at 0.25 kg/m^2	+ - 0 a	+ - 0 a	- - 0 a		
" at 0.50	+ - 0 a	+ - 0 a	+ - 0 a		
" at 0.75	+ - 0 a	+ - 0 a	- - 0 a		
" at 0.25 + DOW 209	+ - 0 a	+ - 0 a	+ - 0 a		
" at 0.50 + "	- - 0 a	+ - 0 a	+ - 0 a		
" at 0.75 + "	+ - 0 a	+ - 0 a	+ - 0 a		
DS at 0.5 1/m^2	- - 0 a	- - 0 a	- - 0 a		
" at 1.0	- - 0 a	- - 0 a	+ - 0 a		
CLAY REMOVED (2μ-2 mm)					
PW at 0.25 kg/m^2	+ + 10 a				
" at 0.50	+ + 50 a				
" at 0.75	- + 30 a				
" at 0.25 + DOW 209	+ + 30 a				
" at 0.50 + "	+ + 40 a				
" at 0.75 + "	+ + 30 a				
DS at 0.5 1/m^2	+ + 30 a				
DS at 1.0	+ + 30 a				

Table 3. Laboratory testing of soils treated with dust suppressant repellant as affected by various salt additions to the soils.

EXPERIMENT NOS. 3 and 4	SOIL						
TREATMENT	GRANITE REEF	SENECA 0-3"	SENECA 3-6"	MONUMENT TANK (2-3)	ARIZONA SILT	ARIZONA FINE SAND	SUPERSTITION SAND
DUST SUPPRESSANT (NO. 1)							
DS at 0.5 l/m^2	a + 70 N		a S 0 a	a a 7 a	a + 200 N	a + 530* *	
" at 1.0	a + 60 N		a S 0 a	a a 7 a	a + 180 N	a + a a	
" at 1.5	a + 650* *		a S 0 a	a a 7 a	a + 670* *	a + 680* *	
" at 0.5 + NaCl (34 meq/100 g soil)	a S 0 a		a S 0 a	a a 7 a	a + 100 N	a + 680* *	
" at 1.0 + " "	a S 0 a		a S 0 a	a a 7 a	a + 30 N	a + 670* *	
" at 1.5 + " "	a S 0 a		a S 0 a	a a 7 a	a + 30 N	a + 660* *	
" at 0.5 + KCl "	a + 30 a		a S 0 a	a a 7 a	a + 30 N	a + 2 a	
" at 1.0 + " "	a + 30 N		a S 0 a	a a 10 a	a + 3 a	a + 580* *	
" at 1.5 + " "	a + 580* *		a S 0 a	a a 10 a	a + 550* *	a + 580* *	
" at 0.5 + K_2CO_3 "	a S 0 a		a S 0 a	a a 10 a	a + 50 N	a I 0 a	
" at 1.0 + " "	a S 0 a		a S 0 a	a a 10 a	a + 50 N	a + 7 a	
" at 1.5 + " "	a S 0 a		a S 0 a	a a 10 a	a + 2 a	a + 2 a	
" at 0.5 + $CaCl_2$ "	a + 640+ *		a S 0 a	a a 7 a	a 560* *	a + 630* *	
" at 1.0 + " "	a + 30 N		a S 0 a	a a 7 a	a + 50 N	a + 70 N	
" at 1.5 + " "	a + 30 N		a S 0 a	a a 7 a	a + 70 N	a + 160 N	
DUST SUPPRESSANT (NO. 2)							
DS at 0.5 l/m^2	+ + 160 N	+ + 330 N			+ + 711* *		+ + 740* *
" at 1.0	+ + 400 N	+ + 680* *			+ + 210 N		+ + 780* *
" at 1.5	+ + 430 N	+ + 820* *			+ + 680* *		+ + 740* *
" at 0.5 + $AlCl_3$ (34 meq/100g soil)	- + 760* *		- S 0 S	- S 0 N			
" at 1.0 + " "	- + 580* *		- S 0 N	+ + 10 N			
" at 1.5 + " "	- + 660* *		- S 0 N	+ + 10 S			

Table 4. Laboratory testing of soils treated with paraffin wax repellant as affected by addition of NaCl to soil.

EXPERIMENT NO. 5 TREATMENT	GRANITE REEF SOIL
PARAFFIN WAX (128-130)	
PW at 0.50 kg/m^2	+ + 20 a
" at 0.75	+ + 30 N
" at 0.50 + NaCl at 2.5 tons/acre	+ + 30 M
" at 0.75 + " at "	+ + 50 N
" at 0.50 + " at 5.0	+ + 30 M
" at 0.75 + " at "	+ + 70 N

Table 5. Laboratory testing of soils treated with combinations of waxes and dust suppressant.

EXPERIMENT NO. 7	SOIL	
TREATMENT	GRANITE REEF	SENECA
PARAFFIN WAX (128-130) + Dust Suppressant (No. 1)		
PW/DS:10/90 at 0.5 l/m^2	+ + 690* *	
" " at 1.0	+ + 560* *	+ + 740* *
" " at 1.5	+ + 790* *	
SLACK WAX + DUST SUPPRESSANT (No. 2)		
SW/DS:10/90 at 0.5 l/m^2	+ + 150 a	
" " at 1.0	+ + 770* *	+ + 830* *
" " at 1.5	+ + 730* *	
" :25/75 at 0.5	+ + a a	
" " at 1.0	+ + 710* *	+ + 710* *
" " at 1.5	+ + 690* *	
" :50/50 at 0.5	+ + 800* *	
" " at 1.0	+ + 640* *	+ + 720* *
" " at 1.5	+ + 700* *	

Table 6. Laboratory testing of soils treated with paraffin wax modified with antistripping agent (Z-6076) and butyl.

EXPERIMENT NO. 8	SOIL											
TREATMENT	GRANITE REEF				SENECA				SUPERSTITION SAND			
PARAFFIN WAX (128-130 FMP) + (Z-6076)												
(100/0) at 0.25 kg/m^2	+	+	20	S	+	I	0	F	+	+	80	M
" at 0.50	+	+	30	N	+	+	20	M	+	+	30	N
" at 0.75	+	+	30	N	+	+	40	N	a	+	80	A
(99.9/0.1) at 0.25	+	+	10	S	+	+	a	F	+	+	90	S
" at 0.50	+	+	20	N	+	+	10	M	+	+	100	*
" at 0.75	+	+	30	N	+	S	0	M	+	+	120	*
(99/1) at 0.25	+	+	30	S	+	S	0	F	+	+	70	N
" at 0.50	+	+	30	M	+	S	0	M	+	+	170	N
" at 0.75	+	+	60	N	+	+	10	S	+	+	190	*
PW (BUTYL REINFORCED) + (Z-06076)												
(100/0) at 0.25 kg/m^2	+	+	40	N	+	I	0	F	+	+	5	N
" at 0.50	+	+	40	N	+	+	90	N	+	+	70	N
" at 0.75	+	+	20	N	+	+	160	N	+	+	120	N
(99.9/0.1) at 0.25	+	+	5	S	+	S	0	F	-	I	0	F
" at 0.50	+	+	40	N	+	+	20	S	+	+	120	N
" at 0.75	+	+	40	N	+	+	20	M	+	+	110	*
(99/1) at 0.25	+	I	0	N	-	I	0	N	-	I	0	N
" at 0.50	+	+	50	N	+	+	30	S	+	+	220*	*
" at 0.75	+	+	60	N	+	+	5	N	+	+	260*	*

Table 7. Laboratory testing of soils treated with the tackifying resin (L-60) and antistripping agent (Z-6076).

EXPERIMENT NO. 9	SOIL			
TREATMENT	GRANITE REEF	SENECA	MONUMENT TANK (2-3)	SUPERSTITION SAND
PARAFFIN WAX (128-130) + (L-60) + (Z-6076)				
(89.9/10/0.1) at 0.25 kg/m^2	+ + 10 S	- I 0 F	+ S 0 F	+ + 80 N
" at 0.50	+ + 20 N	+ S 0 F	+ S 0 F	+ + 150 N
" at 0.75	+ + 100 N	+ S 0 F	+ S 0 F	+ + 270* *
(89/10/1) at 0.25	+ + 30 N	- S 0 F	- S 0 F	+ + 210 *
" at 0.50	+ + 70 N	- S 0 S	+ S 0 F	+ + 240* *
" at 0.75	+ + 110 N	+ S 0 N	+ S 0 M	+ + 310* *

Table 8. Precipitation runoff yields of paraffin wax-treated and dust suppressant-(D.S.)-treated soils vs smoothed and butyl-covered soil.

		Runoff					
		10 m^2 plots				200 m^2 plots	
		#14	#11	#12	#13	R-3	R-2
DATE	Precip.	Smoothed	Butyl	D.S.	P. Wax	Smoothed	P. Wax
1974	mm	%					
1 Jan	2.0	0	100	*	95[1]	0	75
5 Jan	11.0	38	105	*	102[1]	22	89
7 Jan	14.8	19	99	101	99	5	99
8 Jan	6.8	13	98	98	96	1	90
8 Mar	25.5	23	99	93	101[1]	15	93
20 Mar	17.7	15	94	89	98	6	91
20 Mar	1.3	0	0	0	0	0	72
7 Jul	3.0	0	63	30	43	0	33
14 Jul	16.3	24	82	*	97	10	72[1]
21 Jul	7.1	0	77	56	77[1]	15	90
22 Jul	8.3	*	*	*	*	46	87
3- 5 Aug	35.5	36	92	78	93	32	78[1]
15 Sep	2.6	0	62	0	50	0	109[1]
26 Sep	2.5	*	*	*	*	0	71
6 Oct	5.3	*	*	*	*	0	68
12-13 Oct	4.4	0	64	16	49[1]	0	96
22 Oct	10.2	8	90	14	79	4	75[1]
28 Oct	37.0	*	*	*	*	50	83[1]
30 Oct	14.6	40	93	42	92	13	93
2 Nov	9.4	56	102	62	103[1]	28	90
4- 5 Dec	10.3	15	158	15	129[1]	0	88
28 Dec	5.1	0	88	14	78	0	76
Summaries[2]							
1972	243.8	28	100		92	31	90
1973	207.8	17	94	87	88	14	87
1974	250.7	-	-	-	-	20	85

1. Data from wax plots suspect.
2. Data for 1972 and 1973 taken from annual reports.
* Data lost.

APPENDIX I

SUMMATION OF IMPORTANT FINDINGS

5510-12260-002 Water Transfer in the Soil-Plant-Atmosphere System as Related to Water Conservation

A well-known theory for predicting soil-heat flux did not adequately predict field-measured fluxes. The prediction of heat transfer due to water vapor movement particularly appeared to be inaccurate. Thus, adequate theory does not exist for describing combined water and heat movement in a field soil.

A new method for determining soil surface heat flux, called the temperature gradient method with computed thermal conductivity, was developed and found to be reliable. The new method has the advantages of not requiring heat flux plates as does the usual combination method, and of not requiring as many computations as the null-alignment method. (WCL 68-1)

Both corn and sorghum, monocotyledons capable of the highest photosynthetic rate among plant species, were consistently less efficient in their water use during drought than when well hydrated. Certain dicotyledons, like cotton, at times were more efficient during drought, but not consistently so. (WCL 71-1)

It was demonstrated that the albedo and the amplitude of the diurnal surface soil temperature wave are well correlated with the water content of the upper 2 to 4 cm of a smooth, bare field. The temperature correlation appears to be independent of soil type when water contents are transferred into water pressures. These two correlations bode well for the possibility of remotely determining soil water contents from aircraft or satellites. They have already been used to (1) identify the three classical stages of soil drying in natural field conditions, (2) specify the amounts of water lost by different soils in stage I (potential evaporation), and (3) reconstruct the values of the primary parameters required to calculate

potential evaporation from a wet field when the measurements are made over a dry field.

A study of long-term temperature records at Phoenix, Arizona, indicated the existence of a post-1946 warming trend that may be attributed to the buildup of pollution in the lower layers of the atmosphere. The causative mechanism appears to be an enhancement of the so-called "greenhouse effect," induced by the interaction of aerosol with long-wavelength thermal radiation in the lower atmosphere. (WCL 72-6)

Water harvesting micro-catchments augmented the soil-water supply to the indigenous desert plant jojoba, which led to correspondingly better leaf hydration and yields. For the first year, seed yield exceeded the control values by 17 times in the smoothed-soil treatment and by 50 times in the dust-suppressant treatment. (WCL 73-4)

Gibberellic-acid-treated jojoba plants produced flower clusters after an average of 233 days, whereas the control did not produce clusters until an average of 416 days. This suggests that Gibberellic acid can be used to hasten the sex determination of jojoba.

5510-12260-003 Management of Subsurface Water Movement Systems for Renovation and Conservation of Water

After 7 years of operation, the Flushing Meadows sewage infiltration system continued to yield high hydraulic loading rates (90 m in 1974) and significant removal of nitrogen (45%) and phosphorus (60-85% below the infiltration basins, more at some distance away). Virus and salmonella were present in the sewage effluent, but could not be detected in renovated water sampled at depths of 6 to 9 m below the basins. High-rate land treatment thus is an effective way to renovate sewage effluent for reuse.

A slug test was developed to determine hydraulic conductivity of aquifers from the rate of rise of the water level in a well after it was suddenly lowered. The technique is applicable to partially or completely penetrating wells in unconfined aquifers, thus supplementing existing slug-test procedures which were restricted to completely penetrating wells in confined aquifers.

Analysis of the underground movement of nitrate in a planned rapid sewage infiltration system showed that the nitrate peaks will be greatly attenuated when the renovated water reaches the collection wells. Thus, separating renovated water with high nitrate contents for special use or recycling through the basins to increase nitrogen removal will not be practical. Other methods, such as proper scheduling of flooding and drying periods, adding organic carbon to the effluent, or lowering infiltration rates should be more effective to increase denitrification. (WCL 67-4)

During the growing season, vegetated soil columns (bermudagrass) removed 18% more of the applied nitrogen than bare soil columns. The increase in nitrogen removal closely followed the seasonal yield curve of the bermudagrass, but nitrogen removal was several times normal plant uptake, indicating that plants stimulated denitrification.

An increase in phosphate concentrations from vegetated soil columns intermittently flooded with sewage water closely followed

the seasonal yield curve of bermudagrass, indicating that root exudates kept phosphate in solution.

Phosphate was removed by two processes when soil columns were intermittently flooded with sewage water. The soil has an initial adsorption capacity which was saturated. Then, phosphate was removed by what appeared to be precipitation reaction which can continue for a number of years, and the amount removed depended upon the detention time. Thus, phosphate removal, as well as nitrogen removal, can be increased by management practices which decrease the infiltration rate or flow velocity.

Addition of a 100 ppm carbon pulse (dextrose) to secondary effluent during the first 3 days of a 9-day flooding period increased nitrogen removal in soil columns by 18 to 20% of the total applied nitrogen and a 200 ppm C pulse increased N removal by an additional 10 to 12% of the applied N. Nitrogen removal can be increased proportionately over a range of infiltration rates by adding a pulse of organic carbon to secondary effluent, but the nitrate peak was completely eliminated only in columns with infiltration rates below 15 cm/day. (WCL 68-3)

The sewage effluent and four well sites at the Flushing Meadows Project were analyzed for viruses and enteric bacteria during flooding periods on bi-monthly intervals in 1974. While human bacterial and viral pathogens were detected in the sewage effluent entering the basins, they could not be detected in water samples obtained at 6- and 9-m depth below the basins. (WCL 70-2)

A multiple linear regression analysis of the biostimulation data base from reclaimed wastewater ponds indicated that temperature, nitrite-N, light, carbon inorganic, carbon dioxide, and ammonium-N are the six major parameters that accounted for 73% of the variability in the net primary productivity in the ponds. (WCL 71-16)

5510-12260-004 Increasing, Conserving, and Managing Surface Water Supplies for Agricultural Use

Evaporation losses from stock tanks and ponds can be nearly stopped with foamed-rubber sheeting or paraffin wax. Both systems have reduced evaporation by nearly 90%. The quality of the water is also improved under the floating covers since they reduce algae growth and dust in the water. Paraffin wax is particularly suited to the hot desert climates because it is continuous and pliable during the summer heat, yielding virtually zero water loss. Cost of water saved has been a small fraction of the cost of hauling water, and in one case, has been less than 50 cents per 1,000 gallons over a 3 1/2-year period. The wax in this case is still in good condition with no deterioration noted. (WCL 71-6)

Paraffin-wax water-harvesting systems were installed in northern Arizona. Two 1-acre catchments have performed satisfactorily for the past year, providing water for about 240 head of cattle. (WCL 71-12)

A portable flume with special jacks to change the floor elevation and special stilling-well and flow-depth sensing arrangements was designed and used as a field-survey device. This "caliper-flume" can be installed and removed from small slipformed canals while the canal is flowing. The flume can measure discharges ranging from 0.1 to 35 cubic feet per second, and provides accurate determination of flow rates, backwater effects and submergence limitations at prospective permanent flume sites. (WCL 72-1)

Alleged advantages of increased yield and improved fruit quality with daily trickle irrigations may often have been exaggerated. Two year's research on grapes have shown that yield and quality were maintained and slightly increased with trickle over furrow irrigations. Yields were increased with two trickle emitters per vine over one, but not for daily over 3- and 6-day irrigations. (WCL 73-1)

Spring and fall cantaloupes were grown with a surface and subsurface trickle system to determine if continued irrigation during

the harvest period would increase both quality and late-season production. Standard practice is to discontinue furrow irrigations at harvest. Total marketable fall yields were greater for subsurface and trickle than for furrow irrigation. Subsurface over surface trickle may have several practical field advantages in terms of less interference with operations such as thinning, planting, and harvesting. (WCL 73-3)

Before crop growers can be assured that drip irrigation will improve crop production, the high risk of emitter plugging must be eliminated. Reclamation of the partially plugged emitters was achieved by treating the field system with high acid-hypochlorite concentrations. (WCL 71-11)

The two water harvesting plots at the Granite Reef test site that were treated with paraffin wax show no signs of degradation after 3 years of natural weathering: water yield still exceeds 85% of the precipitation--compared to 90% originally, and the plots remain essentially free of troublesome vegetation.

Freeze-thaw cycling can destroy a water-repellant treated water harvesting catchment in a matter of days. Laboratory studies designed to evaluate such treatments have shown that resistance to these destructive forces relate to type and application rate of water repellant and soil stabilizer, soil texture, soil moisture, excess salt, and type of cation on the soil exchange complex. Most treatments failed after only a few cycles; however, several show promise, and one, still under test, has withstood over 1,000 such cycles. (WCL74-1).

APPENDIX II

LIST OF PUBLICATIONS PUBLISHED
AND MANUSCRIPTS PREPARED IN 1974

		MS No.
5510-12260-002	Water transfer in the soil-plant-atmosphere system as related to water conservation	
Published:	Ehrler, Wm. L., Mitchell, S. T., and Fink, D. H. Water harvesting for native Jojoba. News item in "Jojoba Happenings", No. 6-7, Pg. 6, May 1974. (Office of Arid Land Studies, U. of Az., Tucson).	477
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	Idso, Sherwood B. The calibration and use of net radiometers. In "Advances in Agronomy" (ASA) Vol. 26, N. C. Brady, Editor. Pp. 261-275. Academic Press, New York, N.Y. 1974.	448
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	Idso, Sherwood B. Review of book: "Net Radiation Received by a Horizontal Surface at the Earth," by B. de Jong. Jour. Hydrol. 24(3/4):351-352. 1974.	475
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Reginato, Robert J. Water content and bulk density changes in a soil pedon measured with dual energy gamma-ray transmission. Canad. Jour. Soil Sci. 54(3):325-328. Aug 1974. 447

		MS No.
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5510-12260-
004 Increasing and managing surface water supplies for agricultural use.

Published: Bucks, Dale A. Trickle irrigation design requirements for row crops. In "Agricultural and Urban Considerations in Irrigation and Drainage". (Selected papers from Proc. of Irrig. and Drainage Specialty Conf., Irrig. and Drain. Div., Amer. Soc. Civil Engin., Ft. Collins, Colo., April 1973). 1974. Pp. 673-689. 449

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