A N N U A L R E P O R T

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PERSONNEL

The Laboratory Staff is as follows:

R. F. Allen, Hydrologic Technician (employed April)
E. D. Bell, General Machinist
H. Bouwer, Research Hydraulic Engineer and Director
D. A. Bucks, Agricultural Engineer (returned from educational leave, May
D. Carr, Student Aid, (ASU Work-Study-Grant, employed May)
A. J. Clemmens, Hydraulic Engineer (employed August)
K. R. Cooley, Hydrologist
A. R. Dedrick, Agricultural Engineer
B. D. Dorman, Engineering Aid (employed November)
W. L. Ehrler, Research Plant Physiologist
G. C. Emery, Physical Science Technician
L. J. Erie, Agricultural Engineer
E. W. Errickson, Laboratory Technician (City of Phoenix, resigned October)
D. H. Fink, Soil Scientist
B. E. Fisher, Library Technician
G. W. Frasier, Research Hydraulic Engineer
O. F. French, Agricultural Research Technician
R. J. Gerard, Laborer (transferred to Laboratory, December)
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L. P. Girdley, Engineering Draftsman
J. R. Griggs, Physical Science Technician
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M. A. Seiler, Clerk-Stenographer
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TITLE: CHEMICAL TREATMENT OF IRRIGATION WATER FOR THE PREVENTION OF CLOGGING AND THE REMOVAL OF FLOW OBSTRUCTION IN TRICKLE IRRIGATION SYSTEMS

NRP: 20740 CRIS WORK UNIT: 5510-20740-003

CODE NO.: Ariz.-WCL 71-11

INTRODUCTION:

Emitter clogging experiments using various water treatments that were started in late 1974 were continued in 1976. The objectives and initial phases of the study were described in the 1975 Annual Report. In addition to the original design, other chemical treatments were initiated for this year. The clogging problem caused by suspended material was low in this well water and could be controlled by sand filtration. However, the problem caused by chemical precipitation still remained so that theoretical analysis of calcium carbonate precipitation from the water and dissolution of precipitates already present by acid application was made. Both experimental measurements and previous theoretical modeling have demonstrated that the well water used in this experiment had a strong tendency for carbonate to precipitate out from solution on to the emitters and supply lines.

PROCEDURE:

Details of the field equipment setup, flow measurement, and analytical procedures were presented in 1975.

The code designations for the water treatments were:

A. Sand and screen filtration plus continuous hypochlorite-acid treatment. The total available chlorine level was set at 1 ppm with calcium hypochlorite and the pH of the water adjusted to 7 by sulfuric acid injection.

B. Sand and screen filtration alone.

C. No treatment.

The well water was temporarily stored in a 700-gallon galvanized steel storage tank. Ammonium nitrate was added to maintain 10 ppm N to enhance microbial activity.

The three types of emitters were:

1. Long-path, capillary tubing
2. Long-path, spiral-grooved, manual flush
3. Double-walled or double-chambered tubing with 1-ft spaced outer and 5-ft spaced inner orifices

Where rapid clogging occurred in the case of Emitter 3, reclamation using either sulfuric acid, phosphoric acid, or a combination hypochlorite-acid treatment was made.

At the end of the experiment, the Emitter 3 tubing was cut into 5-ft sections at various points along the line and analyzed for the amount of residue deposited in the tube.

A chemical model was developed to test for the possibility of carbonate precipitation and the effectiveness of acid treatment as a preventive measure for controlling precipitates in the trickle lines and emitters. This required a knowledge of the chemical condition of the water in the pipeline ("closed" system) and of the water in the open canal or reservoir ("open" system). In both cases information on the amount of total carbonate in the irrigation water ($[\text{carbonate}]_{iw}$), total calcium ($[Ca]_{iw}$), together with the concentrations of the other dissolved constituents, namely, $[Na^+]$, $[Mg^{2+}]$, $[SO_4^{2-}]$, $[HCO_3^-]$, and $[Cl^-]$ are needed.

Closed System. The system can be defined with either calcium carbonate present or absent. In the former case, the equilibrium calcium concentration is a function of the solubility constant, K_{sp}, of the solid such that $[Ca^{2+}]_{eq} = f(K_{sp})$. The mass balance for the carbonate species is represented by

$$[\text{carbonate}]_{iw} = ([HCO_3^-] + [CO_3^{2-}] + [H_2CO_3]) + ([CaCO_3]\downarrow) \quad (1A)$$

or

$$= ([HCO_3^-] + [CO_3^{2-}] + [H_2CO_3]) + ([Ca^{2+}]_{iw} - [Ca^{2+}]_{eq}) \quad (1B)$$

Thus the quantity of calcium carbonate precipitation, $[CaCO_3]\downarrow$, is the difference between the original calcium concentration in the irrigation water $[Ca^{2+}]_{iw}$ and the final equilibrium calcium concentration $[Ca^{2+}]_{eq}$.

The charge balance for all the ions in solution is given by

$$2[Ca^{2+}]_{eq} + 2[Mg^{2+}] + [Na^{+}] + [H^{+}] =$$

$$= [HCO_3^-] + 2[CO_3^{2-}] + 2[SO_4^{2-}] + [Cl^-] + [OH^-] + [A^-] \quad (2)$$

The term $[A^-]$ is the equivalent concentration of acid anions which could be added to the system to control the carbonate precipitation.

Equations (1B) and (2) were solved simultaneously after the various equilibrium constants for the $H_2CO_3 - HCO_3 - CO_3$ relations were incorporated into the preceding equations.

If the irrigation water system is defined with calcium carbonate absent, then $[Ca^{2+}]_{eq} = [Ca^{2+}]_{iw}$ so that equation (1B) simply becomes

$$[\text{carbonate}]_{iw} = [HCO_3^-] + [CO_3^{2+}] + [H_2CO_3] \quad (3)$$

This equation (3) was combined with equation (2) and solved simultaneously for the concentrations of various constituents.

The mathematical solution of the two different combinations of equations was developed based on the original well water composition so that the presence or absence of $CaCO_3$ could be tested and the effect of acid addition to the pH and dissolution of $CaCO_3$ could be made.

Open System. In the open system, the total carbonate dissolved in the water is conditioned by the partial pressure of the carbon dioxide of the surrounding atmosphere and the solution pH, and only the use of the charge balance equation (2) is necessary to solve for the concentration of the various carbonate constituents. In the solution of this system, the model was set up so that the concentration of calcium at equilibrium was defined either as $[Ca^{2+}]_{eq} = f(K_{sp})$

with $CaCO_3$ present, or $[Ca^{2+}]_{eq} = [Ca^{2+}]_{iw}$ with $CaCO_3$ absent. Similarly, as in the "closed" system, the effect of acid addition on pH and $CaCO_3$ dissolution, if $CaCO_3$ solid is present, could be determined.

RESULTS AND DISCUSSION:

Clogging occurred with all three types of emitters without the use of acid-hypochlorite treatment. The double-tube Emitter 3 design exhibited the largest rate of flow reduction. Daily flow rates of Emitters 1 and 2 as a function of water treatments A and B and time are presented in Figure 1. With the acid-hypochlorite treatment, both Emitters 1 and 2 (Code: A1, A2) maintained their flow rates over the 2 years of operation. The system was run continuously 7 days a week, except for one week each in January 1975 and 1976 when the water became frozen in the lines caused by low morning temperatures. The Emitters 1 and 2 in the sand filtration alone (Code: B1, B2) began to show a drop in flow rate approximately 200 days after installation. The start of the decrease coincided with the onset of warmer spring temperatures in April, and approximately 1 year after emitter operation (Table 1) the flows were cut to one-half the initial rate.

The flow performance in Treatments A and B for the individual Emitters 1 and 2 at the end of the 2 years when the system was dismantled is listed in Tables 2 and 3, respectively. Thirty-one of the 50 Emitters 1 in Treatment B were completely plugged, whereas only 5 were clogged in Treatment A. Microscopic examination of these five stopped emitters showed that the capillary tubes were either crimped at the insertion site where the microtube was friction fastened into the 1/2-inch polyethylene supply line or sand grains had lodged in the capillary fastened water pathway. Otherwise, the inner wall of the capillary tube appeared clean and its wall characteristic compared favorably to the new, unused microtubes. The microtubes in Treatment B were filled with slimy, discolored deposits.

Emitter 2 flow behavior in Treatments A and B (Table 3) behaved similarly as Emitter 1; flow was maintained satisfactorily in the A, but not in the B treatment. The three plugged emitters in Treatment A had sand granules embedded in the spiral-grooved section of the inner

body. Flushing was not made on any of the individual emitters, although these emitters are designed for manual flushing.

The spiral grooves of emitters in Treatment B were full of slimy and crystalline-like materials that could drastically reduce the passage of water. Thirty-one of the emitters were completely inoperable and most of the emitters that were still running had flow rates much below their designed value.

A chronological resume of treatment effects and flow behavior for Emitter 3 are presented in Figures 2 and 3. With Treatment A the double-tube system operated well without much change in flow. The original A3 line (Row I) had to be abandoned after 1 year because of seam cracking problems in the heat-welded polyethylene tubing. Twenty-five of the 150 orifices were clogged for system A3.1 (Row II) after the 1-year run. The clogged orifices were randomly distributed throughout the 150 ft of tubing, and since the emitters are spaced 1 ft apart and since this type of tubing is used in row crops, water application may be sufficient for adequate distribution. With this type of double-chamber device, orifice closure can lead to an increase in pressure in the outer chamber so that the flow rate of the open orifices can increase to compensate for blockages present.

Orifices in the sand filter alone Treatment B3 clogged fairly rapidly. The original B3 flow rate (Row III, Figure 2) had decreased by one-half in 238 days (Table 4). The clogging rate was faster in the April than October installation date (B3, Row V) and took 99 days to reach the one-half flow rate; the June startup (B3, Row IV) reached the one-half flow rate requiring only 48 days. Comparison of the various starting dates and times to reach clogging (Table 4) indicates that very little actual clogging occurred over the October through February period. It may be possible during this period to reduce the amount of chemical addition from the usual treatment rates. Once flow reduction commences as represented by the data of B3.4 and B3.5 in Figure 4, the change is very rapid, occurring over a matter of weeks, particularly during the warmer summer months when microbial activity and solubility factors are affected the most.

Emitter 3 operation in Treatment C behaved like those in Treatment B. The condensed schematic and flow rate graphs (Figures 3 and 4) show rapid clogging rates during the warmer periods than the cooler ones. Significant orifice stoppages occurred within 6 weeks after tube installation.

The high salt, high water hardness well water combined with the increased microbial activity from the added nitrogen nutrient in the storage tank contributed to the rapidity of clogging. However, there were some chemical treatments which could maintain emitter operation even under this type of adverse condition. Treatments that failed included polyphosphates (Figure 3, Row II, Code C3/P) which were supposed to prevent calcium precipitation; acid alone in Treatment C (Code C3/H) which was to dissolve the carbonate did not help in the reclamation and maintenance scheme. Hypochlorite alone (Row VII, Code C3/CL) for calcium hypochlorite did not prevent clogging. In this case the clogging problem could have been caused by calcium precipitation at the uncontrolled pH combined with the lack of adequate filtration.

When a clogged line used in the C Treatment (Row III, Code C3N) was transferred to the A Treatment water source (Code C3N/HCL) and subjected to hypochlorite-acid water and reclaimed by wiping off the residue from the clogged orifices, the emitters regained their original flow rate and were able to perform satisfactorily. In this case, 15 out of the 150 emitters were found to be clogged in June 1976 and only 18 in October 1976 covering the period when the orifices in the chemically untreated A and B Treatments were being rapidly clogged.

In the B Treatment (Figure 2) where filtration was the only water treatment, reclamation of clogged emitters and their subsequent maintenance could be achieved by pH control with either continuous addition of sulfuric acid (Row V, Code B3F/H) or phosphoric acid (Row VI, Code B3.3/HP) from the total flow standpoint. It is fortunate that phosphoric acid will work since now the phosphoric can be applied through the trickle system with the knowledge that clogging will not

be a problem with this fertilizer source. In actual practice it may be wise to follow the phosphoric acid addition immediately with some sulfuric acid application to avoid possible calcium phosphate precipitation as the water starts to revert back to its original alkaline pH as the phosphoric acid is diluted during the end of the injection.

In both acid treatments there was approximately 20% emitter stoppage compared to the 15% for the acid-hypochlorite treatment over the 1-year run. As in the A3.1 tubing results, plugged orifices were randomly scattered, and the row crops for which this tubing is used could possibly tolerate such flow blockages.

There was a significant difference in the amount of residual material buildup in the tubing for the different water treatments (Figure 5) which could be readily differentiated visibly. The least quantity was present in the A Treatment (A3.1) and the most in the C Treatment (C3.5). The values for B Treatment (B3.5) were also close to C. The acid alone treatments represented by sulfuric acid (B3F/H) resulted in a low residual deposit close to the A Treatment. The residual material in Treatments B and C were mushy textured, rust colored, and slimy with rounded granular substances, and contrasted markedly with the smooth, white, barely visible deposits on the tube walls for Treatment A. The residue in Treatments B and C also reacted with acid to give positive identification to its carbonaceous nature. The material buildup reached its maximum value at approximate three-fourths the distance along the 75-ft line. Apparently, the velocity of the water in the line is sufficient to move the particulate material with deposition occurring along this point. Flushing of the lines by opening the end plugs was not made so that it would be purely speculative as to whether this practice would have prevented or even delayed plugging.

The possibility that acid treatment alone may be able to alleviate plugging problems was presented and shown to exist in the 1975 Annual Report where it was indicated that the well water had a strong tendency for calcium carbonate precipitation. With the further expansion of the theoretical chemical model in this year's study, acid titration

curves and the effect of pH modification on carbonate precipitation and dissolution were developed. The acid titration curves (Figure 6) for a typical Phoenix City water (Na = 3.7 me/L, Ca = 2.2 me/L, Mg = 2.0 me/L, HCO_3 = 3.2 me/L, Cl = 3.2 me/L, SO_4 = 1.5 me/L) and Laboratory well water (Na = 15.6 me/L, Ca = 5.5 me/L, Mg = 4.4 me/L, HCO_3 = 3.8 me/L, Cl = 15.3 me/L, SO_4 = 6.4 me/L), both with quite different salt contents, could be derived theoretically and also fitted the experimental curves obtained previously.

The extent to which a given quantity of acid can dissolve away carbonate deposits was observed to be very different for the "closed" and the "open" water systems. As previously defined in the procedure section, the "closed" condition would be more typically represented by water in a pipeline with little contact with atmospheric condition (not necessarily pressure), whereas the "open" condition would be that of water in an irrigation ditch or storage basin. Less acid is required in the "closed" than "open" system to remove or to prevent the same quantity of carbonate deposition. This is indeed fortunate, since microscopic inspection of the clogged orifices from the chemically untreated systems showed that the deposits contributing to emitter blockage were building up from the inside of the pore outward. In our experiments, we controlled the pH of the water from 6.5 to 7 (untreated pH of 8.1) that required approximately 1 me/L of acid (Figure 6). Based on the $\Delta CaCO_3$ values and pH relation of Figure 7, the water is conditioned so that $CaCO_3$ precipitation is avoided. For the reclamation of emitters already clogged, a pH of 2 or approximately 10 me/L of acid was used first, in which case sufficient carbonate dissolving ability was present in the treatment water. The two waters of quite different salinity composition have about the same property in terms of carbonate dissolution, even though their titration curves are different.

Results of microbial population monitoring demonstrate the effectiveness of bacterial control with the bactericide. Microbial counts in samples at the filter outlet were in the order of 100 per ml and less in sand filtered and hypochlorite-acid Treatment A, and 100,000

per ml in the sand filtered alone Treatment B (Figure 8). In contrast, microbial population of the Colorado River water is about 1,000 counts per ml. The number of bacteria in Treatment C without sand filtration was also close to that with sand filtration. In both Treatments B and C, the population reached its peak over the May to June period, but even in the cooler December to February period the microbial counting was high.

Microbial population of water sampled from Emitter 1 (Figure 9), 2 (Figure 10), and 3 (Figure 11) 75 ft from the inlet end closely followed that taken at the sand filter outlet. Lack of hypochlorite in the chemical storage container led to high microbial population on days 150 and 340. Microbial reproduction was very rapid even when the bactericide was not applied for a few days. The flow rates of all three types of emitters in Treatment A were maintained even without absolute microbial control. For this well water and environmental condition, microbial population in the order of 200 counts per ml could be tolerated.

ADDITIONAL EXPERIMENTATION:

A second system of emitters and water treatment was installed after the dismantling of the 1974 to 1976 investigation. This new study was aimed at determining whether lower concentrations of bactericide, and with various modes of application such as intermittent instead of continuous, would also maintain trickle emitter operation. The study will also go further into understanding the basic mechanism of the clogging process.

SUMMARY AND CONCLUSIONS:

Water treatment based on filtration to control particulate load, and acid-hypochlorite addition to control chemical precipitation and microbial activity, was successful in maintaining the operation of three types of trickle emitters over a 2-year period. Since water with high salinity and microbial population was used in the study to intensify the clogging problem, it appears that trickle systems using irrigation water of better quality could be run for much longer periods with this kind of preventive maintenance practice.

Theoretical models designed in understanding the chemical aspects of clogging, namely, the carbonate precipitation and dissolution process in trickle lines, have shown that less acid is needed to prevent precipitation or to dissolve carbonate scaling for the water in closed supply lines than for the water in the ditches and reservoirs open to the atmosphere. For alkaline waters, pH control with either sulfuric or phosphoric acid to 7 would be adequate to avoid calcium carbonate precipitation problems in the supply lines.

PUBLICATIONS:

1. Bucks, D. A., Nakayama, F. S., and Gilbert, R. G. Clogging research on drip irrigation. Proc. Intern. Drip Irrig. Assoc. 1977. (in press)

2. Nakayama, F. S., Bucks, D. A., and French, O. F. Reclaiming partially clogged trickle emitters. Trans. Amer. Soc. Agr. Engr. 1977. (in press)

PERSONNEL: F. S. Nakayama, B. A. Rasnick, R. G. Gilbert, O. F. French, D. A. Bucks

Table 1. Comparison of Treatments A and B on the flow behavior of Emitters 1 and 2.

Code	Date			Elapsed days
	Start	1/2-flow	End	
A1	01 Oct 74	–	17 Oct 76	747
A2	01 Oct 74	–	17 Oct 76	747
B1	01 Oct 74	10 Oct 75	–	374
B2	01 Oct 74	14 Dec 75	–	439

Table 2. Flow rate of Emitter 1 as a function of water Treatments A and B.

Position	Treatment A West line	Treatment A East line	Treatment B West line	Treatment B East line
1	1.85	1.95	1.85	2.00
2	1.85	1.95	.00	.00
3	1.62	0.62	.00	.00
4	1.95	1.95	.00	1.62
5	1.85	1.75	1.09	1.81
6	1.24	1.57	1.85	.00
7	1.66	.00[a]	1.38	1.09
8	1.95	2.04	1.33	.00
9	1.71	1.90	1.09	2.00
10	1.74	2.09	.00	.00
11	1.62	1.95	.00	.00
12	2.19	1.90	.00	.52
13	.00[a]	1.28	1.76	1.19
14	1.85	1.76	.00	.00
15	2.00	1.19	.00	.00
16	.00[a]	1.85	.00	.00
17	2.00	2.14	.00	1.76
18	0.28	1.90	.00	.43
19	2.00	1.90	.00	.00
20	1.85	.00[a]	.00	.38
21	1.95	2.23	1.28	.00
22	.00[a]	2.14	.76	.00
23	.43	1.81	.00	.00
24	1.85	1.33	.00	.00
25	2.19	1.90	.00	.00
	Overall avg = 1.57 gph		Overall avg = 0.50 gph	
	Plugged = 5		Plugged = 31	

a/ Tubing crimped or clogged by sand granule.

Table 3. Flow rate of Emitter 2 as a function of water Treatments A and B.

Position	Treatment A West line	Treatment A East line	Treatment B West line	Treatment B East line
1	0.90	0.95	0.00	0.45
2	0.71	.76	.00	.00
3	0.90	.90	.00	.33
4	0.95	1.00	.00	.48
5	1.00	.90	0.12	.00
6	.95	.95	0.24	.52
7	.90	.95	0.66	.48
8	1.00	1.00	.00	.00
9	1.14	.95	.00	.81
10	1.00	.00 a/	.00	.00
11	.95	.95	.38	.00
12	1.00	1.00	.00	.00
13	.00 a/	1.00	.00	.00
14	.00 a/	.95	.00	.00
15	.95	.95	.00	.00
16	1.00	1.00	.00	.00
17	1.00	.86	.00	.00
18	.90	.57	.78	.43
19	1.00	.86	.31	.19
20	.95	.86	.00	.40
21	1.09	.90	.81	.00
22	.90	.90	.95	.00
23	1.00	.62	.00	.00
24	1.00	.86	.24	.00
25	1.04	.38	.00	.14
	Overall avg = 0.86 gph		Overall avg = 0.14 gph	
	Plugged = 3		Plugged = 31	

a/ Sand granule in spiral-groove.

Table 4. Effect of water Treatment B on flow behavior of Emitter 3.

Code	Date		Elapsed days
	Start	1/2 flow rate	
B3	01 Oct 74	17 May 75	238
B3F	11 Apr 75	19 Jul 75	99
B3	18 Jun 75	05 Aug 75	48
B3.3	05 Aug 75	24 Nov 75	111
B3.4	06 Jan 76	29 May 76	144
B3.5	24 Jun 76	15 Sep 76	83

Table 5. Effect of water Treatment C on flow behavior of Emitter 3.

Code	Date		Elapsed days
	Start	1/2 flow rate	
C3	01 Oct 74	22 May 75	243
C3N	11 Apr 75	24 Jun 75	76
C3	18 Jun 75	25 Aug 75	69
C3.3	05 Aug 75	28 Oct 75	84
C3.4	29 Dec 75	26 May 76	147
C3.5	18 Jun 76	17 Aug 76	61
C3/CL	18 Jun 76	02 Aug 76	46

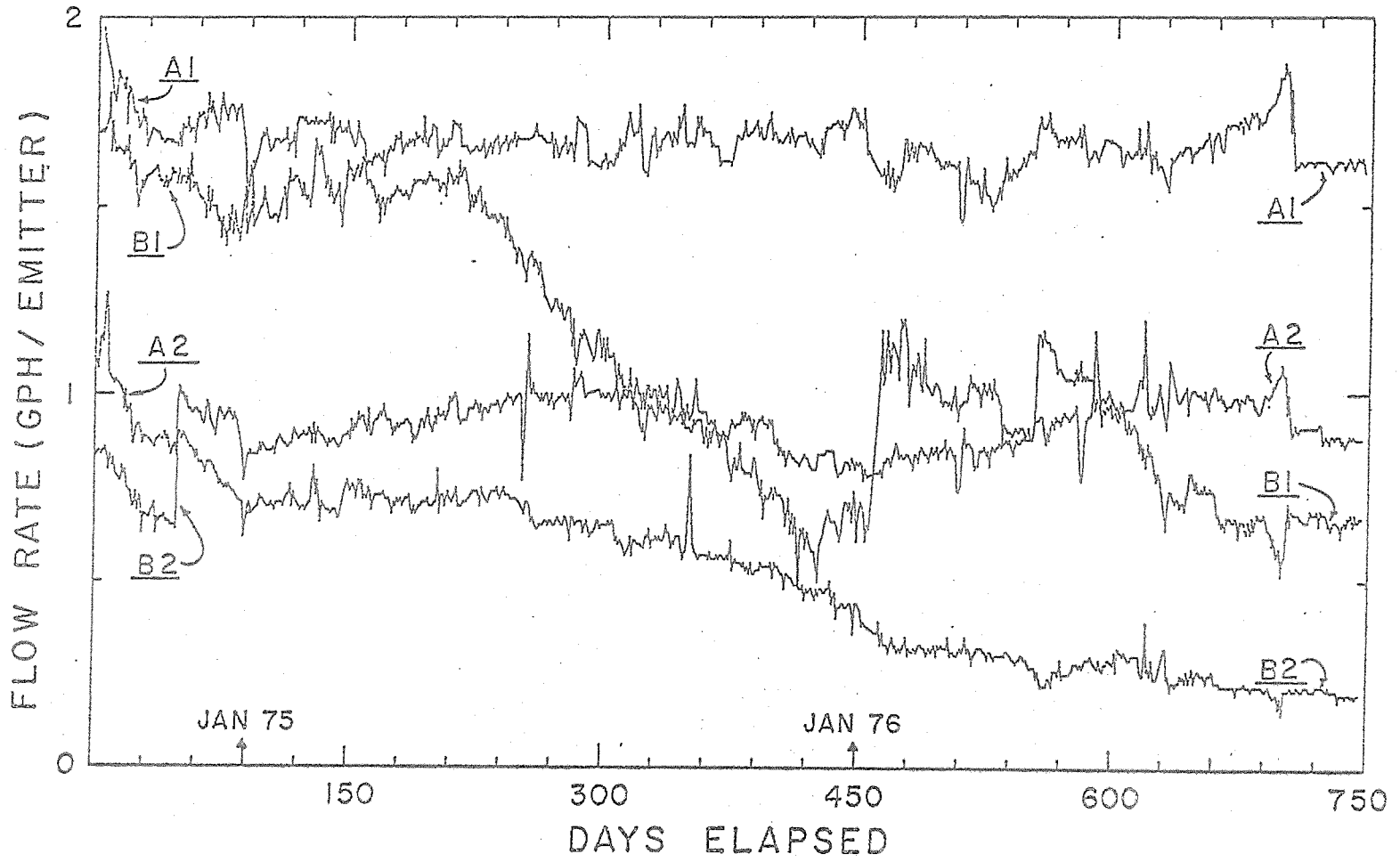

Figure 1. Flow rates of Emitters 1 and 2 as a function of water Treatments A and B, and time.

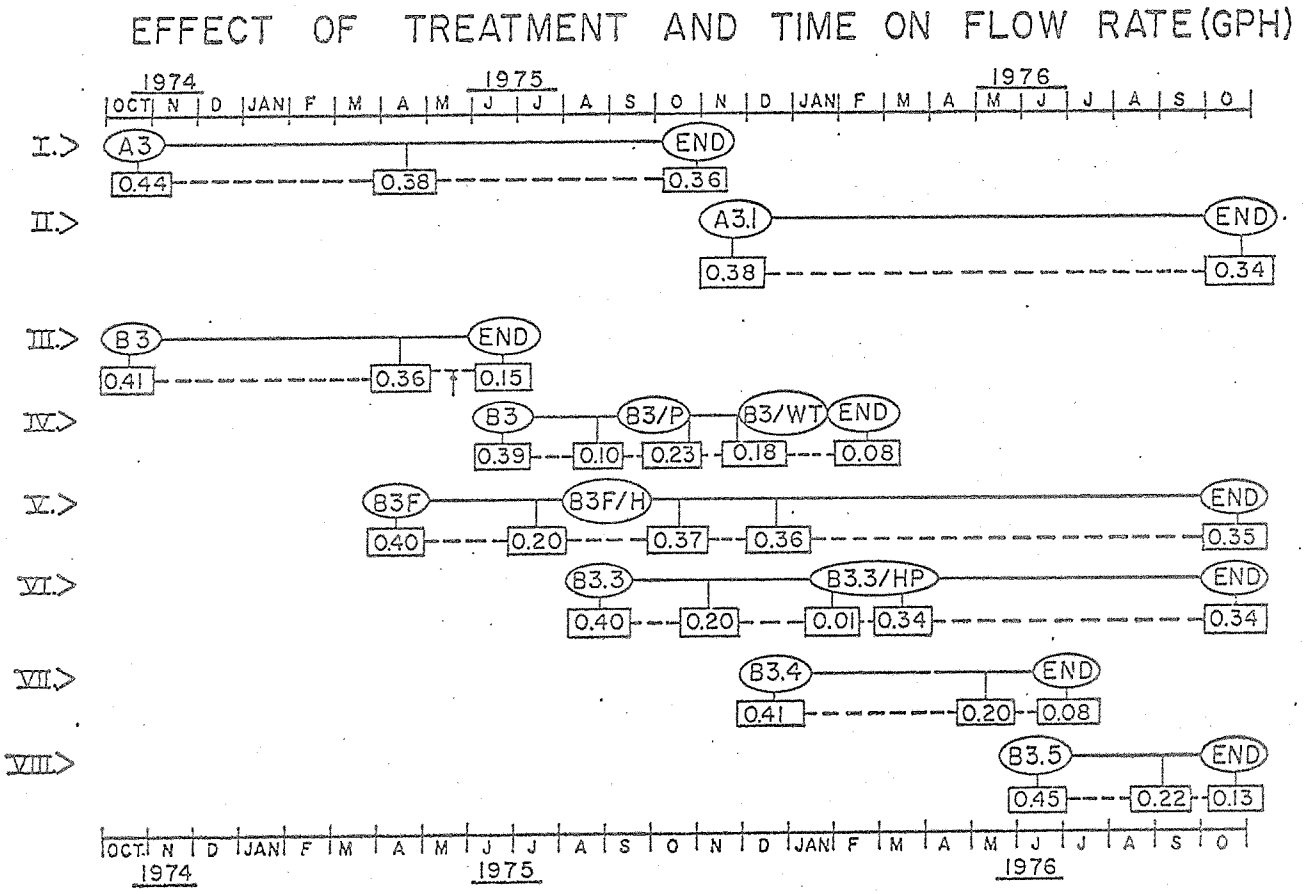

Figure 2. Condensed schematic on the effect of water Treatments A and B on the flow behavior of Emitter 3.

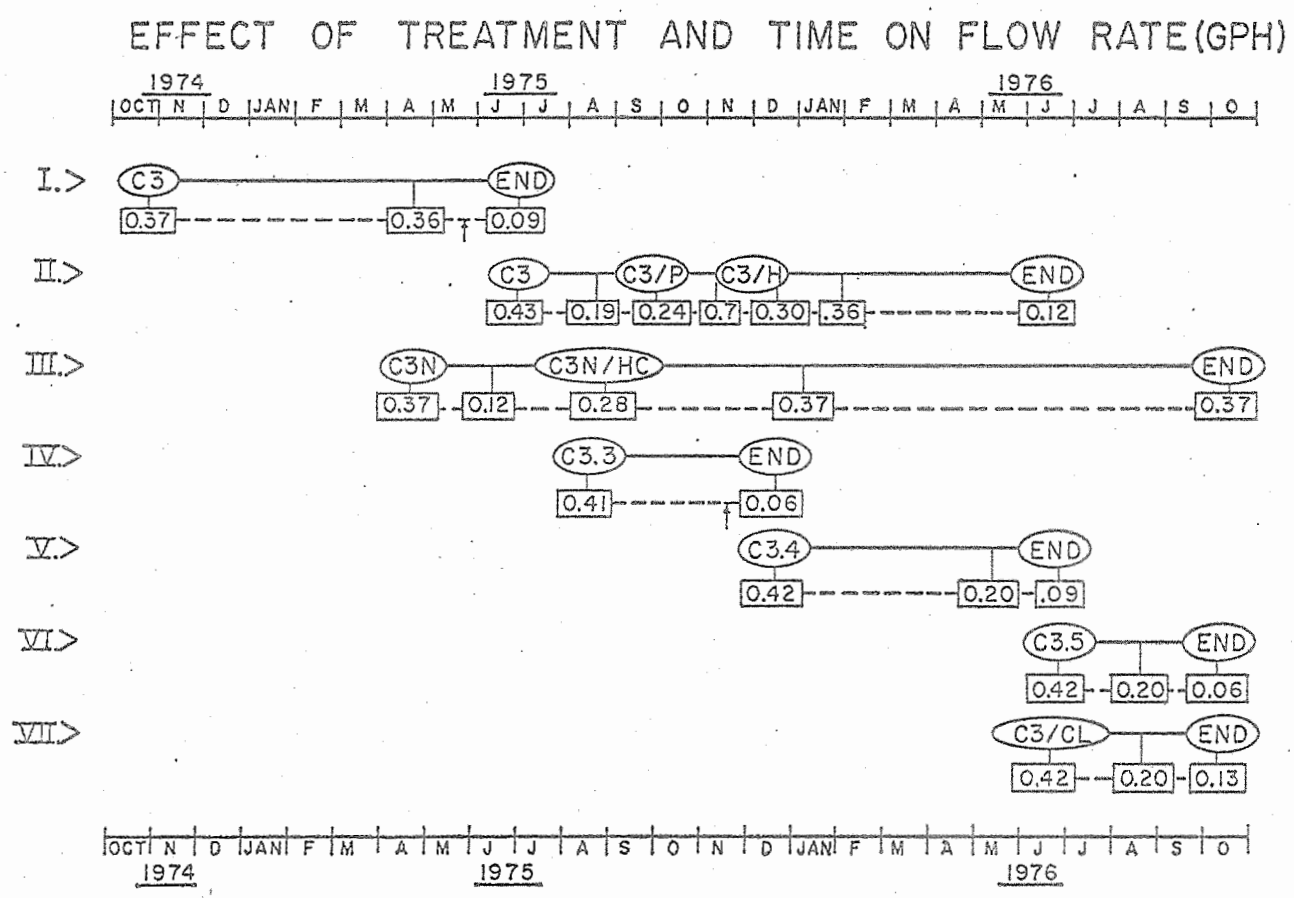

Figure 3. Condensed schematic on the effect of water Treatment C on the flow behavior of Emitter 3.

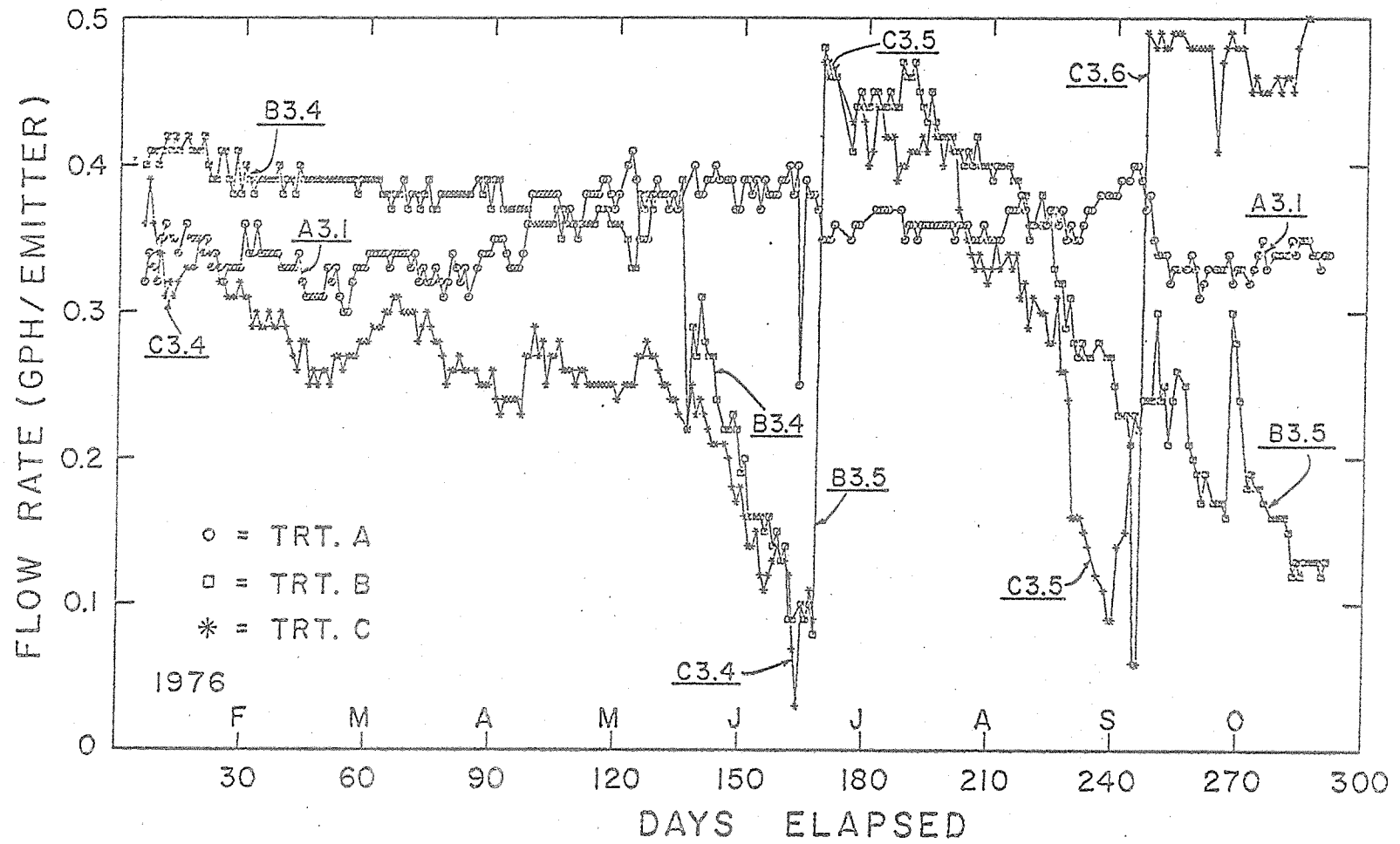

Figure 4. Flow rates of Emitter 3 as a function of water Treatments A, B, and C, and time.

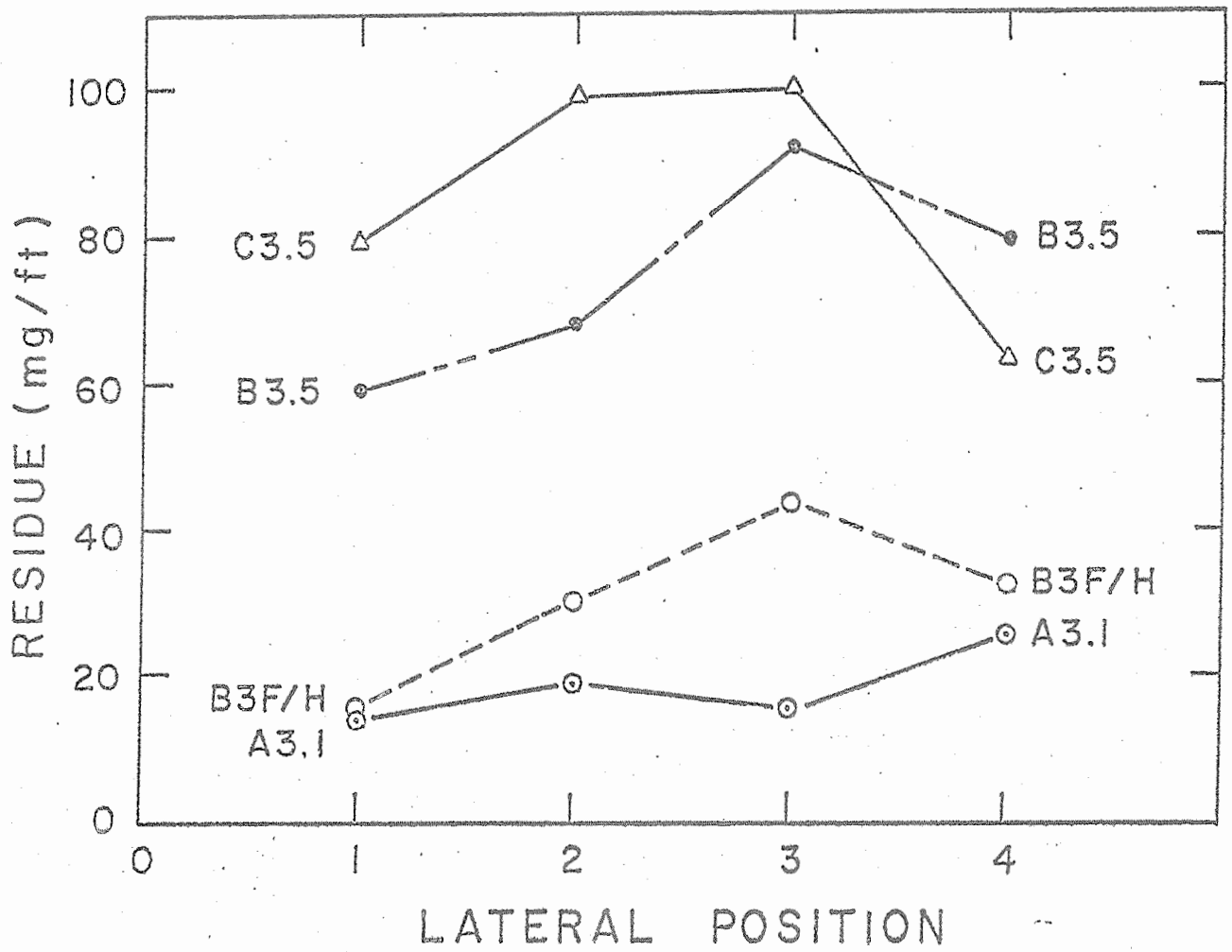

Figure 5. Amount of residual materials in Emitter 3 line. (Position 1 = 0 to 5 ft from beginning of line; position 2 = 25 ± 2.5 ft from beginning of line; position 3 = 50 ± 2.5 ft from beginning of line; position 4 = 70 to 75 ft from beginning of line.)

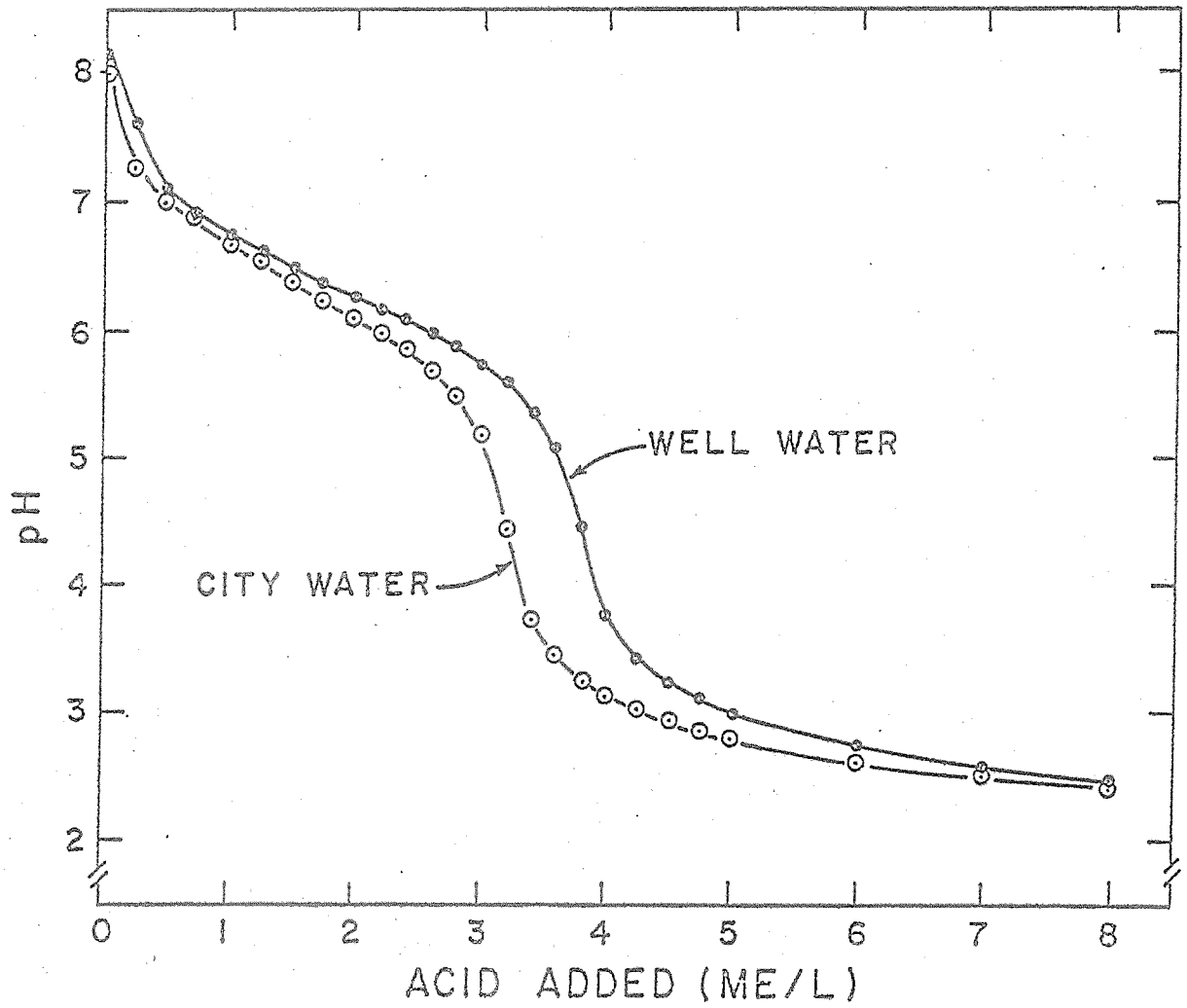

Figure 6. Theoretical acid titration curve for city and well waters.

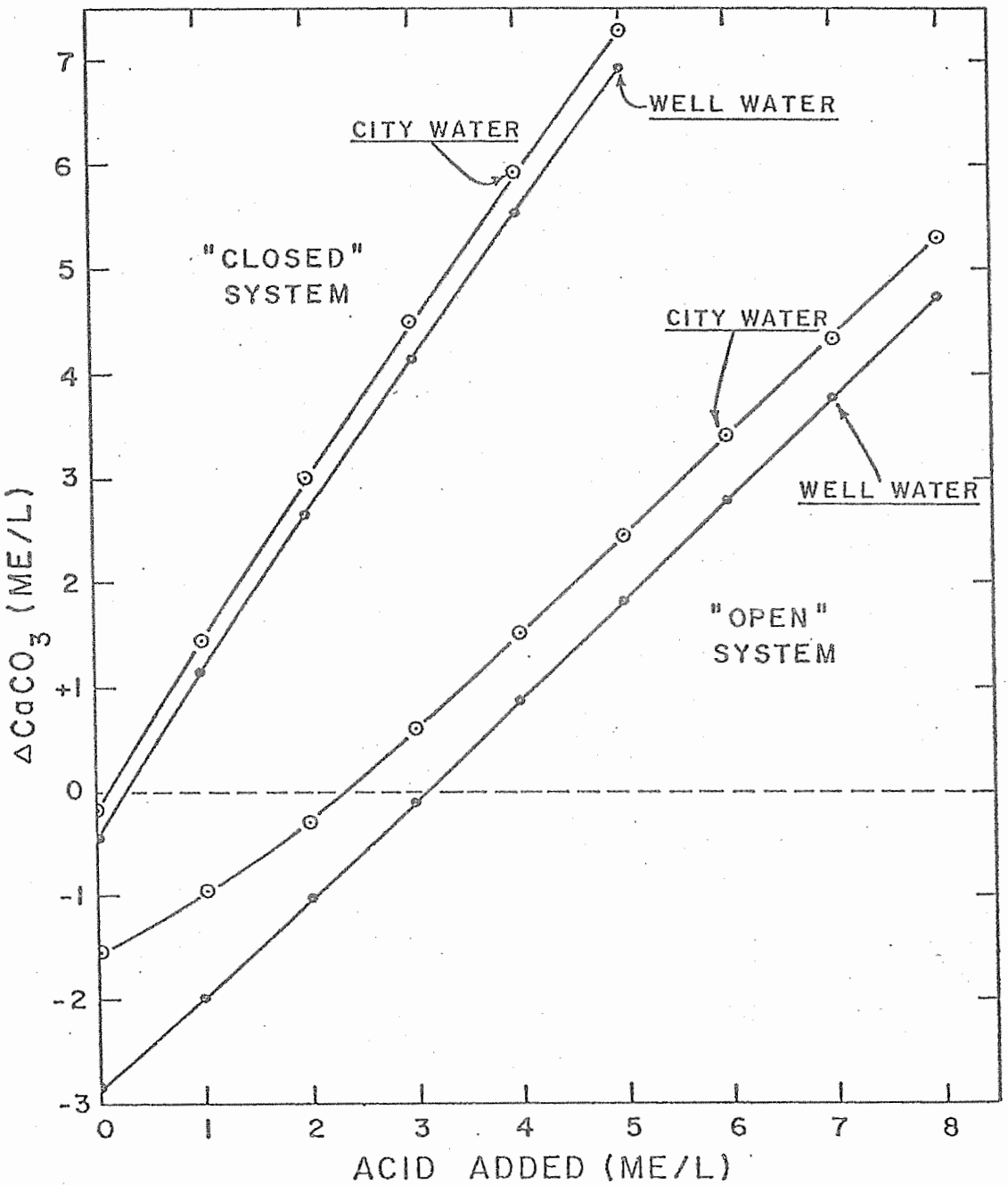

Figure 7. Calcium carbonate dissolution potential of acid addition in the city and well waters.

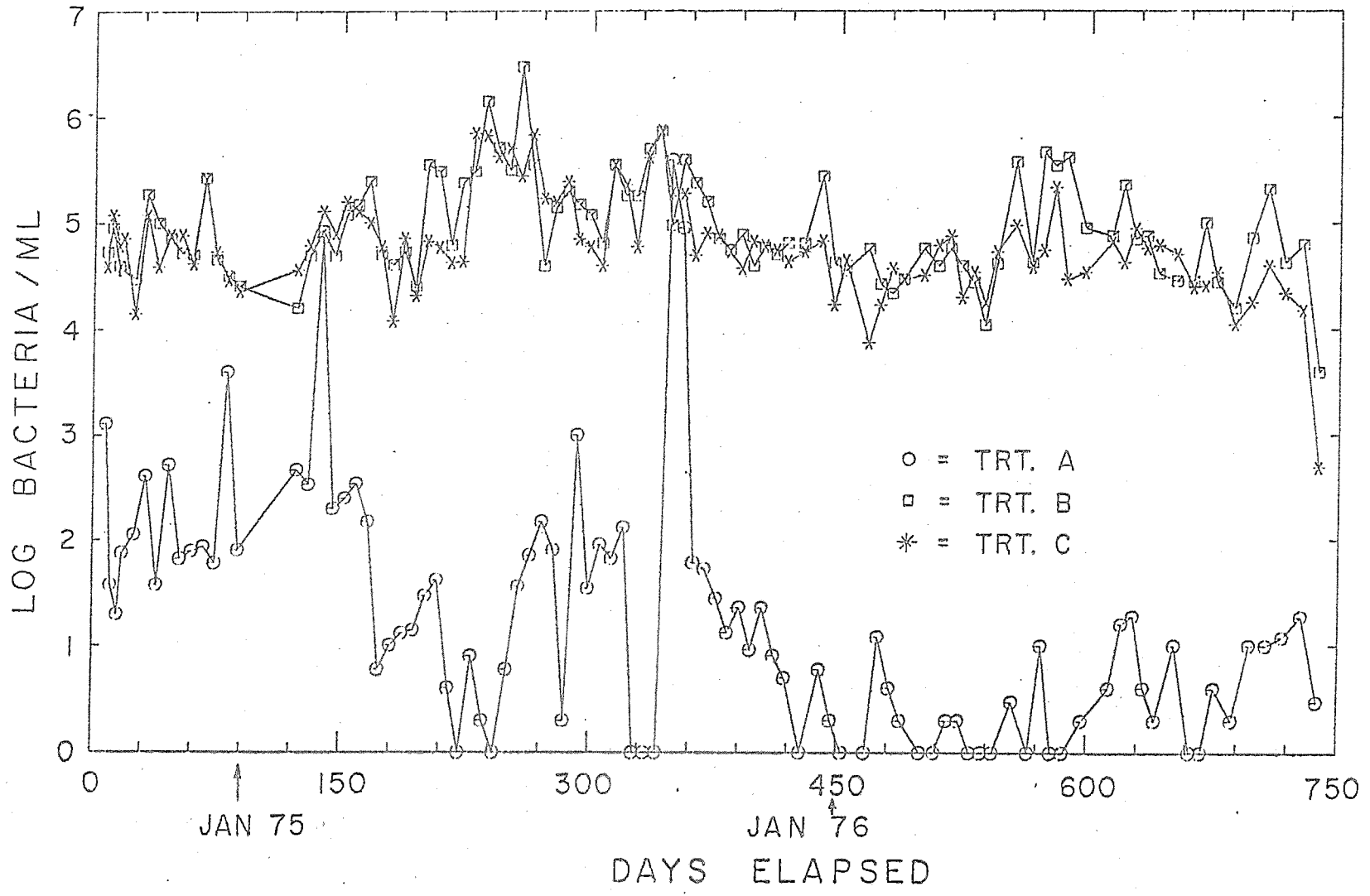

Figure 8. Microbial population in water from Treatments A, B, and C before entering trickle tubing laterals.

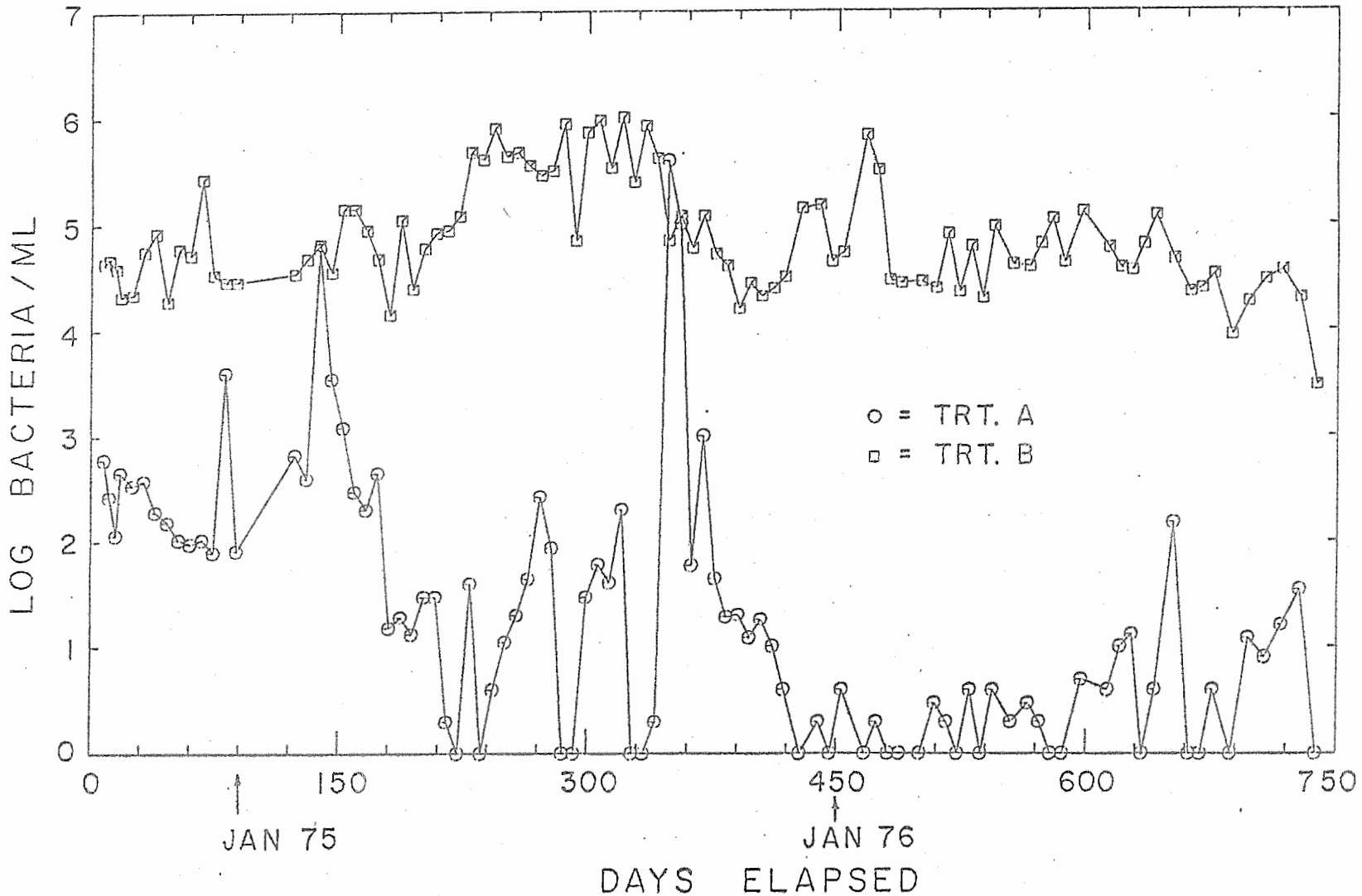

Figure 9. Microbial population of water sampled from Emitter 1 with Treatments A and B.

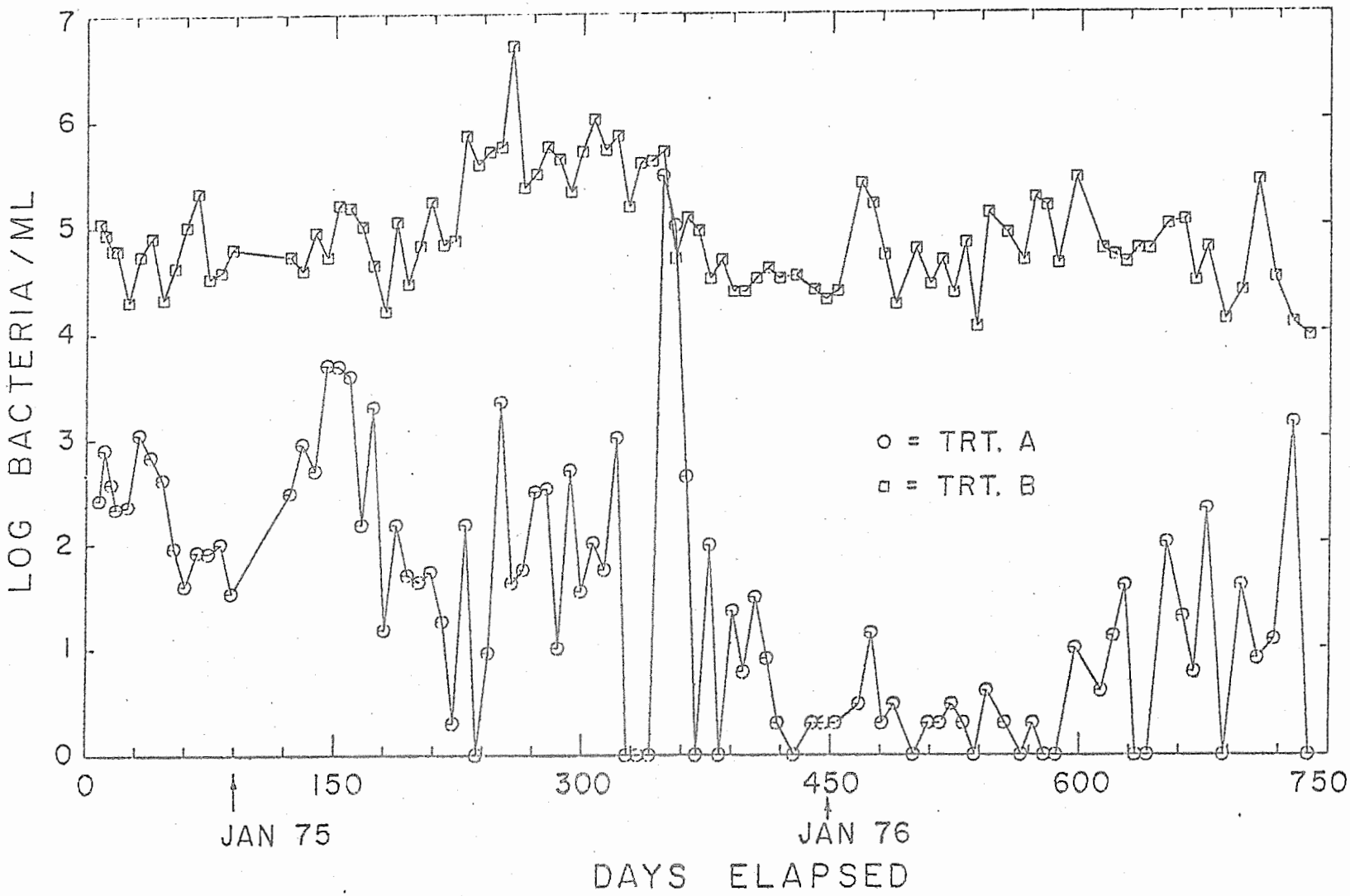

Figure 10. Microbial population of water sampled from Emitter 2 with Treatments A and B.

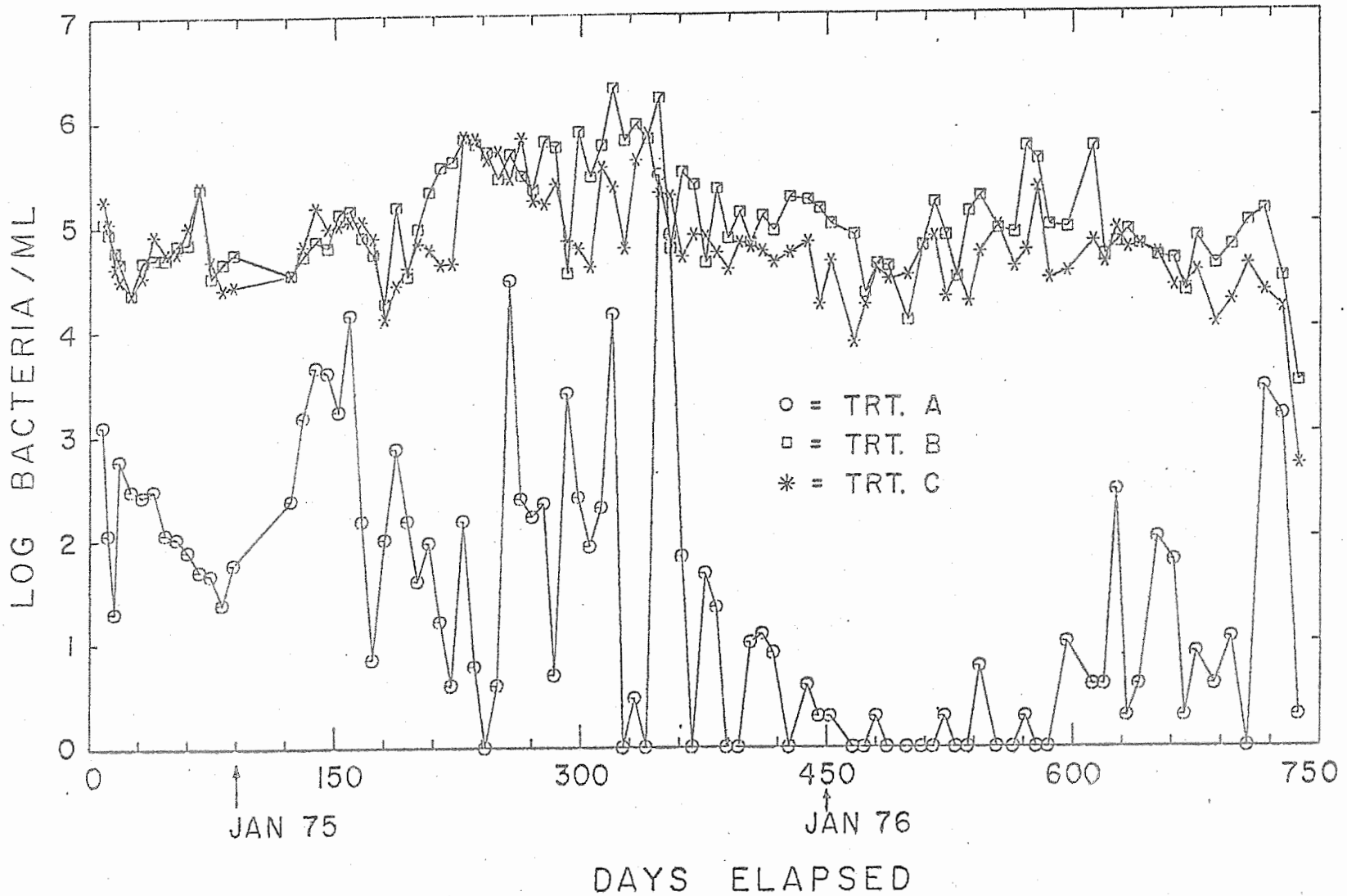

Figure 11. Microbial population of water sampled from Emitter 3 with Treatments A, B, and C.

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

NRP: 20740 CRIS WORK UNIT: 5510-20740-003

CODE NO.: Ariz.-WCL 72-1

INTRODUCTION:

The Annual Reports for 1966-1974 contain summaries of many critical-flow flumes calibrated with computer modeling and verified with laboratory testing. These included rectangular, triangular, trapezoidal, complex and non-symmetrical flumes.

PROGRESS:

A manuscript, "Compensating for Construction Errors in Critical-flow Flumes and Broad-crested Weirs," was prepared for presentation at a planned symposium sponsored by the National Bureau of Standards on Errors in Open Channel and Closed Conduit Flow Measurement; Their Sources, Assessment, and Resolution. It is completed and will be published in the Symposium Proceedings.

The paper is based on the ability of the computer model to predict the calibration of critical-flow flumes accurate to about $\pm$ 2 percent. This permits computation of discharge errors that would be introduced by construction anomalies. Procedures were developed and used on a series of primary devices in irrigation canals, including trapezoidal flumes and broad-crested weirs that identified construction errors and accurately related a readout mechanism to the primary device, as constructed, so that the original intended accuracy could be restored. Templates were used to accurately define field dimensions of the flume throat section which is the most sensitive portion of a flume. Errors in defining the cross-sectional area of the throat are shown to approximate the error in discharge. Errors in the approach section and the converging section are about one-tenth as important.

The accurate field measurements of flume dimensions were then used to compute a tailored calibration table for the particular construction.

The template was also used to accurately relate the readout mechanism to the flume. Direct reading discharge-rate gages that

were prestamped were mounted, using a modification of the template technique, to reserve the highest accuracy for any selected flow rate on the gage. Discharge errors, if any, could be relegated to the least used flow range. The techniques are described in more detail in the manuscript.

Model Verification: Past reports have discussed the laboratory verification of the computer model for flumes. Field verification continues whenever an opportunity becomes available. Three more field checks by others have been reported. These include:

1. Trapezoidal flumes, designed for the Soil Conservation Service, have been installed on a wide scale in the Wellton-Mohawk Irrigation District. Fifty or more have been installed by contractors with many more anticipated to be constructed. They are designed to fit into a standard 2-ft bottom, slip-form canal with 1:1 side slopes. The flow range is from 1 to 30 cfs. One of the flumes was downstream from a constant-head orifice. The orifice was carefully adjusted to discharge 20 cfs. The flume confirmed this discharge as read from a wall-mounted gage.

2. A sill in a trapezoidal canal was fitted with a sloping approach. It was thus a trapezoidal broad-crested weir with the equivalent of a rounded upstream edge. A staff gage was fastened to the sloping canal wall. Irrigation District personnel, using a propeller meter in the delivery pipe to the canal lateral, reported "a strong 15-1/2 cfs" when the meter was in place. About 1000 ft downstream, 15.7 cfs was read, indicating excellent agreement.

3. A particularly interesting field verification occurred as a result of testing the model against existing published data. Standard flume Number 2 from ASAE Standard S359.1 would not conform. It was originally calibrated against a 15-ft wide rectangular weir in an outdoor facility near Fort Collins, Colorado, by A. R. Robinson. The discharge as published deviated by as much as + 7% for a flume flow depth of 0.5 ft. Fortunately this is in the seldom-used lower range for this size of flume. The upper range of flows were within $\pm$ 5%.

Recent recalibration against a 4-ft suppressed rectangular weir by Allan Humpherys and James Bondurant at the Snake River Conservation Research Laboratory, ARS, confirms the model. Their results are presented in Table 1 and plotted onto Figure 1. The standard deviation from model predicted is ± 1%.

Broad-crested Weirs: Two broad-crested weirs designed with the computer model were installed on cooperators' farms near Tacna, Arizona in connection with automation experiments. The flume on the Woodhouse farm is designed to measure irrigation canal discharges primarily at 15 cfs with an expected range of 12 to 16 cfs, and an occasional need to measure as low as 2 cfs. A one-time measurement had been made with the portable, adjustable, trapezoidal flume (see Annual Report 1975) indicating that 16.1 cfs was flowing in the canal at a depth of 1.8 ft. This left a freeboard of 0.7 ft, more than adequate for installing a critical flow device to obtain the desired measurements. The weir was designed to cause 0.25 ft of water-depth increase upstream at 15 cfs to avoid submergence. This was a liberal allowance, since this flume was found to operate satisfactorily with only 0.15 ft head difference. (Equal to 85% submergence.) Since the tailwater control in this case was primarily due to channel friction, this liberal allowance was needed to handle changes in channel roughness due to algae growth and Bermudagrass infringements over the canal edges. For construction economy, diverging Section 4, was omitted. This could be added later, in the event that submerged flow were threatening, to increase the submergence limit to nearly 95%.

Construction Procedure: The broad-crested weir was poured directly into an existing trapezoidal concrete canal with nominal 2-ft bottom, 1:1 sideslopes and 2.5-ft depth. Calculations with the computer model indicated that the sill should be 1.1 ft high to avoid submergence as discussed earlier. Plywood end forms for the sill were fit to the channel and held in place with spacers and wire ties. The form tops were carefully leveled across the channel and with respect to each other so that they served as finishing guides for the sill surface. After the initial set of the concrete, the upstream form was removed and a concrete ramp was formed. This was

hand plastered into place with little requirement for accuracy, except that there be no sharp discontinuities between this section and the previously poured sill. The sill was 2 ft long and the ramp approximately 3 ft long. A sheet-metal template was used as mentioned earlier to establish the true cross-sectional shape and to obtain a correct zero registration for a wall mounted gage.

The details of the wall gage will be discussed under another Annual Report on "Depth Detection in Flumes."

The second broad-crested weir was installed at the Naquin Farm. It has a sill height of 1.5 ft. Other aspects of this installation were similar to the Woodhouse installation.

Other Studies: Recent publication of laboratory ratings for flumes intended for use in sewers shows a continued international interest in flumes. However, that work did not have the computer model available, and like the number 2 flume from S359.1, was compared with a rectangular weir that was probably too wide for the low discharges it was trying to measure (Diskin, M. A., "Venturi Flumes for Circular Channels" Technical Note, American Society of Civil Engineers, Journal of the I & D Division, September 1976, pp. 383-387).

The computer model was revised to accommodate the circular cross-sections. The calibrations did not match the model. Evidence pointed to a zero error in the original weir used as the measuring standard. The weir width is not known, but the errors are consistent with a 1-mm zero error on a 1-meter-wide weir. A discussion outlining this finding has been submitted to the Journal.

Recommendations: With the continued interest in flumes and the apparent difficulty of getting the computer model used by others, a continuing effort to publish the method, expand its use to other shapes such as parabolas, and even publishing pre-computed tables for usable broad-crested weirs to be used in canals of different shapes should be considered. Modular limit design for five-section flumes should be considered. This can produce submergence values approaching 95%. (Modular limit is that submergence ratio that causes no more than 1% change in discharge indication). These high submergence limits challenge the desirability of ever considering submerged flow operation

with its inherent inconveniences of two points of measurement and inaccuracy of results.

SUMMARY AND CONCLUSIONS:

The ability to predict the calibration of long-throated flumes and broad-crested weirs of almost any cross-sectional shape was used to study errors in flume measurements, their sources, assessment and resolution. Procedures were developed and used on a series of primary devices in irrigation canals, including trapezoidal flumes and broad-crested weirs that identified construction errors, which could then be resolved, and related to a readout mechanism to the flume, as constructed, so that the original intended accuracy of $\pm$ 2% could be restored. Templates were used to define field dimensions of the flume throat section, which is the most sensitive portion of a flume.

The accurate field measurements of the flume dimensions were then used to compute a tailored calibration table for the particular construction. The template was also used to establish the correct zero elevation for a wall-mounted gage stamped directly in discharge units. The technique permitted reserving the highest accuracy for the most-used flow range, relegating gage errors if any to little used flow ranges.

Several field measurements substantiated the model predictions. Two instances of calibration errors in results published by others were found. In one case, recalibration by others substantiated the finding after it was pointed out by the model. In the other case, the error has been identified but recalibration has not yet occurred.

The model can be expanded to the design of exit sections (5-section flumes) to increase the submergence limit to nearly 95%. With this possibility, the desirability of even considering submerged flow operation of a flume to be installed is seriously challenged.

PERSONNEL: John A. Replogle

Table 1. Recalibration of trapezoidal flume (S-351.1, #2: B1 = 2 ft, B3 = 1 ft, Z1 = 1.25, L2 = 3 ft, L3 = 2.5 ft, X1 = 0.5 ft, K = .005) against a 4-ft suppressed rectangular weir.

Flow Depth X1	Discharge (weir) Qw	Discharge (model) Qm
ft	cfs	cfs
0.23	0.418	0.419
0.263	0.531	0.528
0.347	0.868	0.860
0.433	1.57	1.571
0.512	1.75	1.749
0.627	2.616	2.587
0.664	2.865	2.875
0.763	3.762	3.772
0.887	5.068	5.093
0.954	5.78*	5.897
1.045	6.85*	7.12

* Weir not aerated at last two readings.

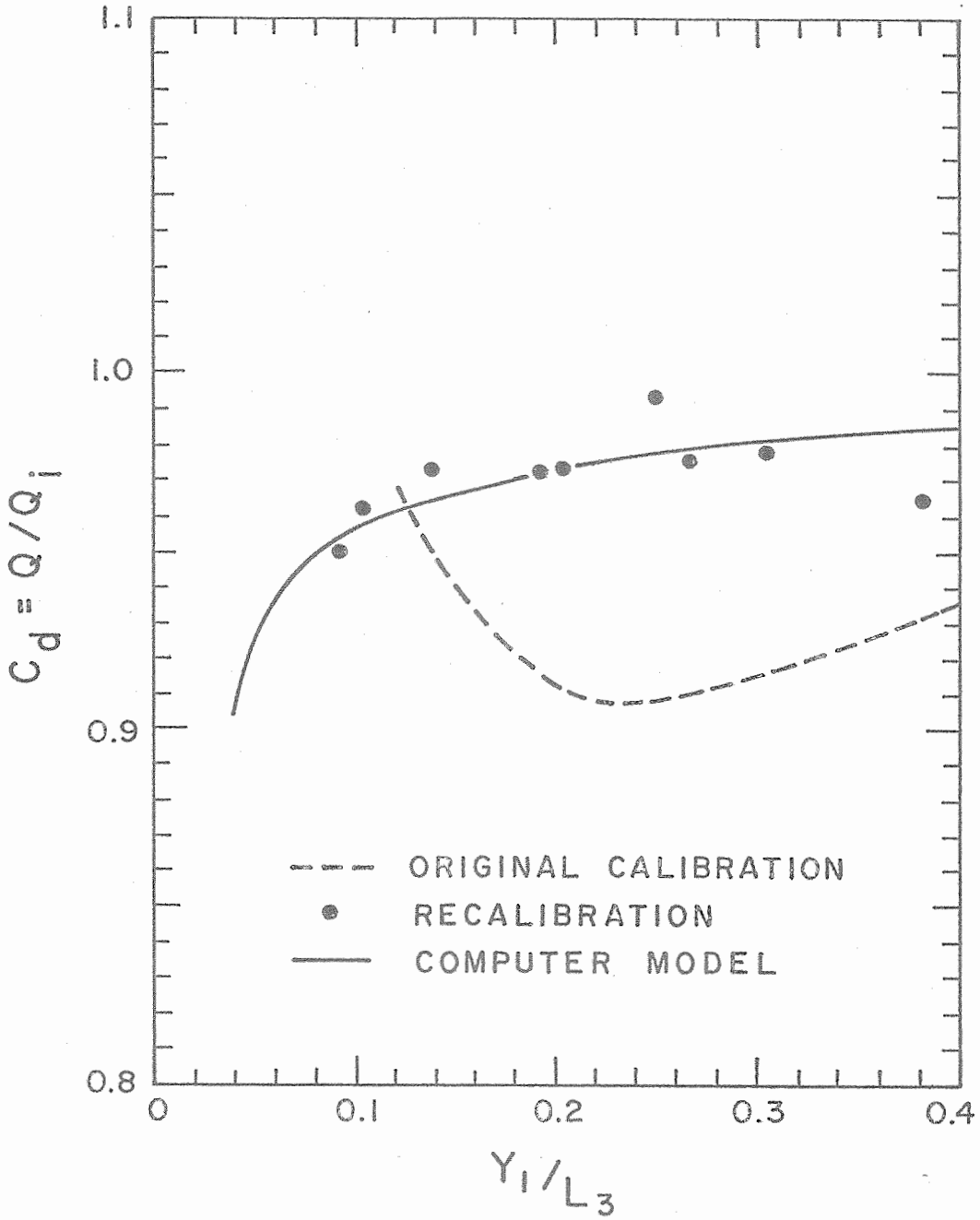

Figure 1. Original and recalibration shown with computer model prediction of discharge coefficient (actual discharge ÷ ideal fluid discharge) as a function of Y_1/L_3, a dimensionless depth.

TITLE: DEPTH DETECTION IN CRITICAL-DEPTH FLUMES

NRP: 20740 CRIS WORK UNIT: 5510-20740-003

CODE NO.: Ariz.-WCL 72-3

INTRODUCTION:

The project was initiated several years ago with the expectation that more work would be done on methods to sense the flow depth in flumes carrying sediments. The program was suspended and reinitiated this year in connection with flumes in irrigation canals not necessarily carrying high sediment loads. The objective is to still provide "reliable readout systems to use with critical-depth flumes," but not necessarily in connection with "sediment loaded streams."

APPROACH:

The problem of depth sensing for use with computer-operated automatic systems has not been satisfactorily solved in a reliable or economical way. A quick survey of the available commercial devices disclosed a number of methods that were being used. These included the following:

1. Sonic or ultra sonic surface detection: Wind problems exist and resolution may be limiting or expensive.

2. Capacitance surface detectors: These are suitable devices for trained technicians to use, but are not considered convenient for an irrigator to employ. Calibration procedures are probably too lengthy.

3. Capacitance wall implants: Some fiberglass, or plastic flumes, have had a capacitance device, or strip, implanted in the wall for depth detection. The signal is very low and requires expensive equipment to condition it.

4. Optical encoders have been used and are being considered. One design problem is that it shows change only. A zero calibration method that is automatic would have to be designed. This method would require a stilling well and float such as is used on standard recorders. Cost may be limiting. The signal output, though, is probably in better format than some other systems.

5. Pressure transducers: Resolution, drift and reliability seem to be the major problem. Also, expense of conditioning and transmitting the output may be limiting.

6. Stilling well and standard recorder: This is probably the most reliable if only a chart is required. Maintenance is a problem and interfacing with a computer can be expensive.

Common Problems: The problems in depth sensing depend on the mechanical components that are used. For example, if a stilling well is used with any system, plugging is possible. If a float is used, the zero setting can drift as the float ages and gets heavier with deposits and water absorption (plastic floats). With electronic detection, zero drift, signal attenuation, and operational reliability seem to be too common.

As yet, no system has been identified that has all the desirable qualities of a good flume sensor, reliability, precision, and accuracy; with low maintenance requirement, ready interfacing with electronic equipment, and convenient operation and installation.

Sample Systems:

Staff Gage: A readout system was selected for flumes and broad-crested weirs in the Wellton-Mohawk Irrigation System near Tacna, Arizona. It stressed reliability, accuracy, low maintenance, and ease of installation and operation. No provision for electronic interface was attempted. The devices were simple sloping canal gages mounted directly on the canal wall. The gages were pre-marked in cfs for direct discharge reading. The usable flow range was from about 1 cfs to 30 cfs. Different gages are required for each shape of flume, but these can be developed readily from computer modeling that produces a calibration table for each flume. (See Annual Report, 1976: "Predicting Hydraulic Characteristics of Critical-Depth Flumes of Simple and Complex Cross-Sectional Shapes".

The model was used to study the precision of each flume type and methods developed to assure correct zero registration for the flume.

The flumes and gages were analyzed to see if the precision and accuracy requirements could be met. A practical goal was to have the readout device produce no more than half the total uncertainty in flow

measurement. Thus, if ± 5% were the desired accuracy, the readout device should contribute no more than ± 2-1/2% of this.

Two general styles of flumes were equipped with the gages. One was a broad-crested weir, the other was a trapezoidal flume. For the weir, the relation between discharge, Q, and flow depth, Y1, is given by

$$Q = 16.1\ (Y1)^{1.65}$$

for the region between 2 and 16 cfs. Thus a 1% error in Y1 will cause 1.65% error in Q. In order to hold the error contribution from the readout device to less than 2.5%, the weir gage must be capable of less than (2.5/1.65) = ± 1.52% random error of detection. At 15 cfs this translates into detecting ± 0.0144 ft vertically or ± 0.02 ft on the sloping wall gage. In the field, even with gusting winds of 20 to 30 miles per hour, the canal water surface was stable enough to be easily read to within half of 0.02 ft on the gage. Thus, sensitivity in the most used flow range of 15 cfs was no problem. The gages are rugged; are fastened tightly to the canal wall and do not trap debris; are passive, in that there are no moving parts; and can be read from a distance of about 10 or 12 feet. For 2 cfs, however, similar reasoning requires detecting ± .006 ft on the sloping gage, a more difficult task, but probably acceptable in most irrigation situations where this flow range is seldom used.

The trapezoidal flume is represented by the equation

$$Q = 5.34\ (Y1)^{2.11}$$

for the region of 10 to 20 cfs. Thus, a 1% error in Y1 causes 2.11% error in discharge. As was computed for the broad-crested weir, this requires that the readout device be readable to no more than ± 1.17% random error of detection. At 15 cfs this means detecting ± 0.019 ft vertically or 0.028 ft on the sloping gage. Thus, sensitivity should be no problem. At 2 cfs the equation changes to $Q = 5.31\ (Y1)^{1.86}$ and the gage must be readable to ± 0.11 ft.

At 1 cfs, this flume would require detecting 0.008 ft which is approaching the limit of accurately reading a wall gage unless 5% random error in the reading is acceptable.

Purge-Bubble System: A purge-bubble system was devised using the principle of bubbling air slowly through a nozzle placed at a fixed elevation in the flume approach section. The bubble back pressure required indicates the flow depth and hence the discharge vote.

The system was installed on the Woodhouse farm in combination with the broad-crested weir. One thousand feet of 3/16-in. I.D. plastic tubing (5/16-in. O.D.) was laid between the flume and the control shed for automation equipment. About five bubbles per second of air was introduced into the tubing at the control shed using a needle valve and a water-filled bulb for monitoring the bubble rate. The nozzle at the flume was clamped at the zero elevation on the side wall gage. The pressure was detected in the control shed with a U-tube manometer filled with water. One leg of the manometer was a large pot allowing the readout indication to be observable on the other leg made of plexiglass tubing. A staff gage marked directly in cfs was mounted behind this transparent tubing. This transferred the reading from the flume to the control shed 1000 ft away.

SUMMARY:

A project on depth sensing in flumes placed in sediment-loaded streams has been redirected to the detection of flow depth in the flumes placed in irrigation canals. The need is for electronic sensing compatible with microprocessors that might be incorporated into automatic irrigation. Most existing methods are expensive to interface, have distinct problems of reliability, or are difficult to operate, perhaps requiring re-zeroing with each use.

Some simple devices have been installed on some flumes with no intention of computer interfacing. These are staff gages mounted directly on the canal wall and premarked in discharge units instead of flow-depth units. A bubbler purge-meter system was installed at one location to transfer the flume reading 1000 ft to a control shed where it is manually read.

PERSONNEL: J. A. Replogle, A. R. Dedrick

TITLE: EVALUATING TRICKLE IRRIGATION FOR GRAPE PRODUCTION

NRP: 20740 CRIS WORK UNIT: 5510-20740-003

CODE NO.: USWCL 73-2

INTRODUCTION:

The objectives and need for this research project appeared in the U. S. Water Conservation Laboratory 1973 annual report. Procedures and results for the fourth year are presented in this report. The 1976 treatments were changed to increase the number of replications, to further refine the effects of trickle irrigation amounts and extremes in trickle irrigation frequency, and to further investigate yield and fruit quality under trickle and furrow irrigation.

PROCEDURE:

After harvesting the 1975 Perlette table grapes on June 30, a total amount of 12 inches of water was applied on all trickle and furrow irrigation plots between growing seasons. The trickle irrigation plots were given irrigations of 1.0 inch per week between September 1 and October 3. The furrow irrigation plots were given irrigations of 4.0 inches on July 14, 4.0 inches on August 11, and 4.0 inches on September 11.

Trickle irrigation treatments for 1976 included: Three irrigation quantities -- 1.50, 1.25, and 1.00 times the average consumptive use measured for 1973-75; and two irrigation frequencies -- daily and at 6-day intervals, applied with two emitters per vine. The following are the changes made on the field experiment from previous years: All original plots given 0.75 times the estimated consumptive-use rate became the 1.50 quantity; daily trickle plots with one emitter per vine became daily trickle plots with two emitters per vine; and 3-day trickle plots became 6-day trickle plots. The furrow irrigation treatments included the same three seasonal quantities used for the trickle irrigation, applied in three furrows per vine, with the irrigation frequency based on the consumptive-use curve. The only change made on the furrow treatments was the elimination of the two-furrow-per-vine plots.

Therefore, treatment combinations were reduced from 18 to 9 in a split-plot design, and replications were increased from 4 to 8. Each plot remained 3 rows wide, with 6 vines per plot.

New growth in 1976 began about February 1, and canes were at least 12 inches long by March 1. Furrow and trickle irrigations were started on March 1 and March 3, respectively. The 1.00 furrow treatment plots were given irrigations of 4.0 inches on March 1, 4.0 inches on April 20, 4.0 inches on May 18. The 1.00 trickle treatment plots were given an initial irrigation of 3.0 inches on March 3, followed by 9.7 inches between April 11 and June 10, in accordance with three different irrigation intervals. The 1.50 and 1.25 trickle and furrow irrigation plots were given ratios of these amounts described for the 1.00 irrigation treatments.

Leaf water potential was measured for the second consecutive year, using the Scholander pressure bomb or chamber. Measurements were made on three plots -- 1.25 and 0.75 times the consumptive-use rate for the daily trickle, and 1.25 times the consumptive-use rate for the furrow method. The 0.75 times consumptive use was a separate plot of 30 vines located directly south of replication #2 in the main experiment. Leaf water potential was measured on nine dates during the growing season, usually in hourly intervals between 10:00 a.m. and 1:00 p.m., using the first mature leaf from a southerly-exposed grape cane, and sampling one leaf from each of five vines per plot at each time interval. Other procedures for the collection of data, such as soil moisture, evaporation, and other weather information were the same as in previous years.

Grape clusters were thinned and tipped on March 30, under the order and supervision of the manager of the commercial vineyard. This was a full two weeks before full bloom, and at least two or three weeks earlier than in prior years. The thinning was accomplished with a plastic brush, and resulted in overthinning of most clusters. Since grape yields were drastically reduced, only a total weight of fruit produced for the experiment was obtained to verify the extent of yield reduction.

RESULTS AND DISCUSSION:

Figure 1 shows the 1976 measured consumptive use was 13.5 in. This seasonal use was somewhat lower than the previous three years, because of the shorter growing season. Since temperatures were higher earlier, with new growth commencing almost two weeks early, the consumptive use rate was greater in March and April. Lower temperatures in late May and early June resulted in lower consumptive use at the end of the growing season.

Table 1 shows the actual amounts of water made available for consumptive use, which were calculated from the sum of the water applied plus rainfall. Although the total amount of water applied on the furrow treatments was less than on the trickle, the irrigation quantities of 1.00, 1.25, and 1.50 times the consumptive-use essentially agreed for the two irrigation methods.

Table 2 presents mean daily values of leaf water potential from May 14 to June 15 for selected irrigation treatments. The seasonal mean was -14.9 bars for both trickle and furrow irrigation, with no significant differences in leaf water potential between irrigation quantities.

Full-season grape production for 1976 trickle and furrow irrigation treatments was about one-third that of previous years, as shown in Table 3. Because of the erratic and uneven thinning of grape clusters, any yield comparisons between irrigation treatments would be unrealistic. Therefore, the irrigation treatments were maintained throughout 1976 so that the entire experiment could be conducted again in 1977.

SUMMARY AND CONCLUSIONS:

A fourth year of study using trickle and furrow irrigation on Perlette grapes did not answer the questions of how much water, how often should it be applied, or what are comparisons in plant response between irrigation methods? Overthinning of grape clusters drastically reduced yields, and eliminated all possibility of obtaining realistic yields. The same irrigation treatments will be used next year.

PERSONNEL: Dale A. Bucks, Leonard J. Erie, William L. Ehrler, Francis S. Nakayama, and Orrin F. French.

Table 1. Available and adjusted quantities for trickle and furrow irrigation of grapes, 1976.

Irrigation Quantity / Consumptive-use ratio	Water Applied (inches)	Rainfall (inches)	Total available moisture for Consumptive Use (inches)	Adjusted Irrigation Quantity / Consumptive-use ratio*
Trickle:				
1.50	19.0	0.9	19.9	1.50
1.25	15.8	0.9	16.7	1.25
1.00	12.7	0.9	13.6	1.00
Furrow:				
1.50	18.0	0.9	18.9	1.40
1.25	15.9	0.9	15.9	1.20
1.00	12.0	0.9	12.9	0.95

* Based on the measured seasonal consumptive use of 13.5 inches for 1976.

Table 2. Leaf water potential for trickle and furrow irrigation of grapes, 1976.

	Date									
	May					June				
Irrigation Treatment	14	18	20	25	28	02	04	11	15	Mean
Trickle:	(negative bars)									
Daily/ 2 emitters/ 1.25 cu	13.8	12.9	11.6	14.9	14.9	16.8	14.0	14.8	19.1	14.8
Daily/ 2 emitters/ 0.75 cu	14.8	12.2	12.5	15.0	16.7	17.1	13.0	15.2	17.9	14.9
Mean	14.3	12.5	12.1	14.9	15.8	16.9	13.5	15.0	18.5	
Furrow:										
3 furrows/vine 1.25 cu	14.0	12.4	13.4	16.7	16.4	16.6	12.9	15.2	16.6	14.9

Table 3. Average grape production for trickle and furrow irrigation for 1973-76.

Year	Mean yield (pounds/vine)
1973	24.1[1/]
1974	19.9
1975	22.4
1976	6.9[2/]

1/ 1973-75 based on 504 vines.

2/ 1976 based on 1550 vines, 76% graded #1 quality.

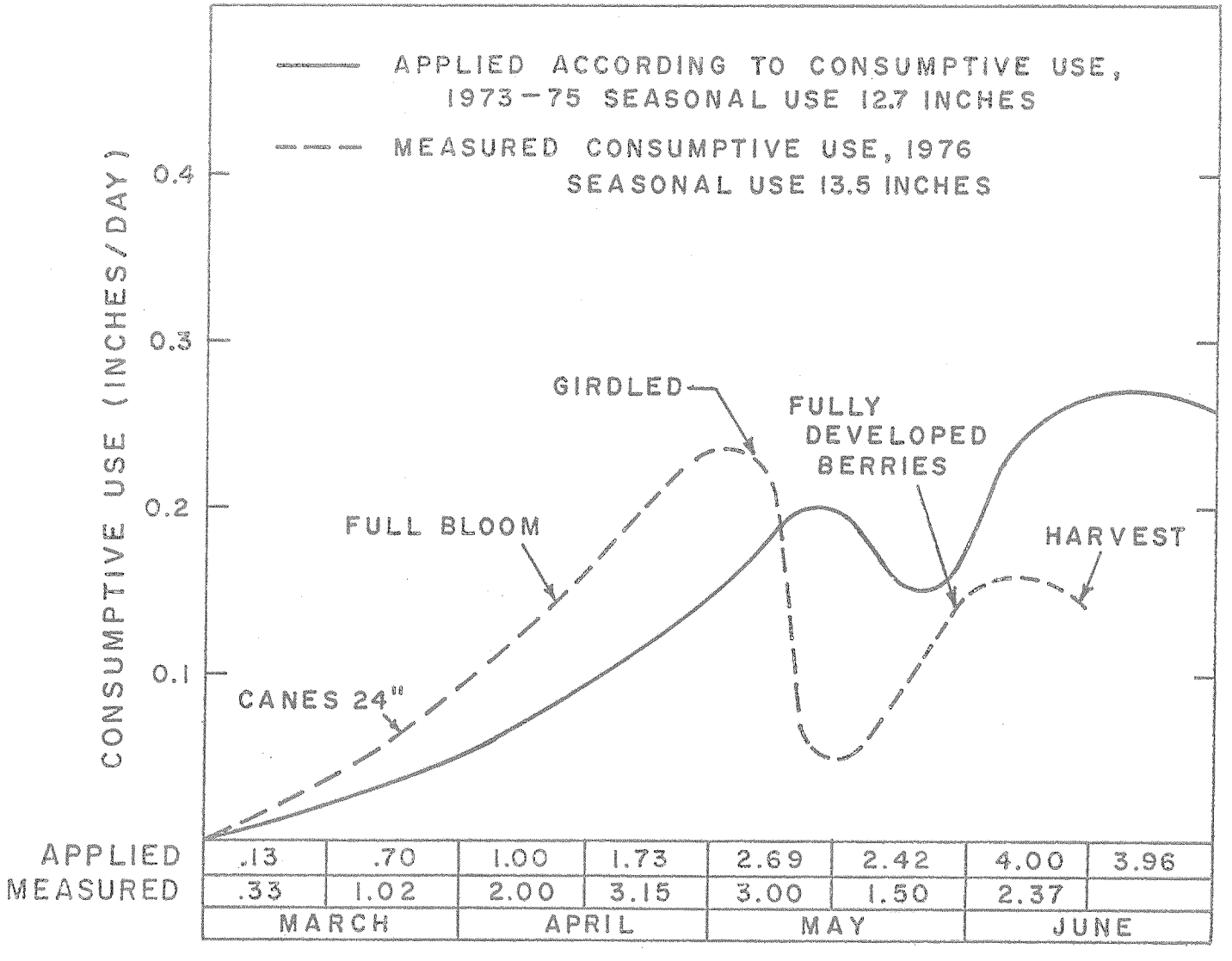

Figure 1. Applied and measured consumptive use curves, 1976.

TITLE: EVALUATING TRICKLE IRRIGATION FOR CANTALOUPE PRODUCTION

NRP: 20740 CRIS WORK UNIT: 5510-20740-003

CODE NO.: USWCL 73-3

INTRODUCTION:

The objective and need for this research appeared in the U. S. Water Conservation Laboratory 1974 annual report. Procedures and difficulties encountered in the 1976 cantaloupe study -- conducted at the Yuma Valley Experiment Station, University of Arizona, Yuma, Arizona -- are presented in this report.

During the second and third weeks of the 1975 cantaloupe harvest, disease problems arose, particularly on Reps. #2 and #4 in the southwestern corner of the experiment. There were no visual symptoms of cantaloupe wilt prior to this time. Samples of the diseased plants and roots were collected and given for analysis to Dr. J. L. Troutman, Plant Pathologist, Yuma Citrus Station, University of Arizona. He was unable to isolate the specific cause of the disease; however, he did indicate possible signs of either root-knot nematodes, fusarium fungus, or verticillium wilt. A recommendation was made by Dr. Troutman and Jim Park, Superintendent of the Yuma Valley Experiment Station, University of Arizona, to plant Sesbania as a green-manure crop in the fall and to use a soil fumigant, "Teylon C", (dibromochloropropene), prior to the next planting of cantaloupes.

PROCEDURE:

Three weeks prior to the 1976 planting, the soil fumigant was injected to a depth of 6" - 8", using a chisel tiller followed by a drag to help seal the soil. Fertilizer in the amount of 75 lbs of actual N per acre was broadcast over the entire field prior to planting. Cantaloupe seed, PMR-45, was planted on February 24 on south-sloped, east-west oriented beds for the furrow and trickle irrigation plots. Plants were thinned to a 12-in spacing on March 14.

The five irrigation treatments for the third spring consisted of sub-surface trickle irrigation at a daily, weekly and bi-weekly frequency, and surface trickle irrigation at a weekly frequency.

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These treatments were replicated six times in a randomized block design. Each trickle irrigation plot was three beds wide and 150 ft long, and each furrow irrigation plot was four beds wide and 150 ft long. The trickle irrigation system used was Anjac's Bi-Wall 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 200-mesh (75 micron) screen filter for both trickle systems.

Water applications were based on the estimated consumptive-use rate for a furrow irrigation practice (1). 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 a turbine-vane meter.

RESULTS AND DISCUSSION:

The spring planting began to emerge on March 1 on both trickle and furrow irrigation plots, with little difference in early plant growth for the different treatments. By late April, all treatments were observed to be lacking in vegetative growth. However, the amount of blossoming and setting of fruit was exceptionally good in May for the small plants.

Even though soil fumigant had been applied, the cantaloupe vines began to wilt about the time harvesting should have commenced. The disease problems appeared to occur earlier and with greater severity than in the previous year; therefore, we decided that no valid yield determinations could be made. The various trickle irrigation treatments were continued through the expected harvest period, and we did note that the trickle plots remained greener for at least a week longer than did the furrow plots. Also, the replications which were the least affected by disease in the previous year appeared to have more plants die earlier, in 1976.

Because of the disease problems in the Yuma area, a 1977 cantaloupe study is planned for the Mesa Experiment Farm, Mesa, Az.

Objectives of the new experiment are: (1) To develop water management practices for surface and subsurface trickle irrigation on spring- and fall-planted cantaloupes for a larger fruit set, greater plant vigor, improved fruit quality, and an extended-harvest season to increase yield. (2) To evaluate the potential of multiple-cropping, using the same trickle system.

REFERENCE:

1. Erie, L. J., French, O. F., and Harris, K. 1968. Consumptive Use of Water by Crops in Arizona. Univ. of Arizona Agric. Exper. Sta. Tech. Bul. 169.

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

TITLE: EROSION PREVENTIVE STRUCTURES TO DISTRIBUTE WATER INTO IRRIGATED FIELDS

NRP: 20740 CRIS WORK UNIT: 5510-20740-003

CODE NO.: USWCL 73-5

INTRODUCTION:

Increasing costs and shortage of labor, the need for improving irrigation efficiency, and increased use of marginal lands (sandy soils), have made it necessary for farm owners to design their irrigated farms in such a way that large streams of water are utilized. This use of large streams has necessitated outlet structures to reduce soil erosion. Originally, we designed structures in various sizes and configurations, made of various materials, and built on many different types of soil in Arizona. A design for such a non-erosive structure was developed.

Recently, outlets in the form of jack-gates have become popular. From these, 10 to 30 cfs of water may be discharged, thus necessitating additional erosion-preventive structures. Some have been modified in the field, others reconstructed, and all are being observed. The Ft. Collins office has designed and built a structure in Blythe, CA, to handle flows up to 40 cfs, using some of our original design criteria. It has operated successfully, thus proving valid our original ideas, as first used in the small structures.

The use of automation has changed the erosion patterns, and structures have been designed and built to accommodate these changes. Structures are being used in Blythe, CA, and near Tacna, AZ. These structures are for streams as large as 7 cfs, although most of the streams are in the 4 cfs range.

PROCEDURE:

In 1977, our original structures will be observed, and at least one farmer-built jack-gate outlet structure will be amended. Two structures on an automated PVC 16-inch tile outlet will be built.

SUMMARY:

The eight new structures built on the outlet side of 16-inch tile outlets in an automated irrigation system are preventing erosion. The structures are still vulnurable to machinery breakage. Perhaps the structures should be set lower in order to minimize plugging in the automation equipment, but setting them lower would result in more water storage -- a natural breeding place for mosquitoes. However, new structures will be lower and will be developed further into the 'rail-road fill' to minimize machinery breakage.

The frames for the rubber gaskets on the jack-gates started to 'rust out' during the year. The supplier was contacted, new rubber and channel equipment were purchased, and five structures were repaired. Normally, the original jack-gate would have to be replaced, necessitating the rebuilding of our automation equipment. A procedure to make repairs was developed, and the old jack-gates now seem to be as good as new.

PERSONNEL: Leonard J. Erie, Allen R. Dedrick, Dale A. Bucks, Harold Duke, Orrin F. French, and Bud Payne.

TITLE: PRACTICAL APPLICATION OF AUTOMATION TO UNDERGROUND AND SURFACE DISTRIBUTION SYSTEMS FOR GRAVITY IRRIGATION

NRP: 20740 CRIS WORK UNIT: 5510-20740-003

CODE NO.: USWCL 73-6

INTRODUCTION:

See 1973 annual report.

PROCEDURE:

The 160-acre automation system in Blythe, CA, is being used. The controls in the new storage shed were changed to make them compatible with the portable power unit being used on this farm's newly-installed automation equipment. Jack-gate checks were equipped with pistons, and revised safety-overflow equipment is being installed by the farm's automation foreman, who has designed a float device.

No changes were made in the system installed on the 10-acre citrus grove near Mesa, Arizona. A screen was designed, built, and installed to further clean the water of material picked up by the irrigation project supply line. The principle plugging material is the pecan blossoms which float in the water during the springtime.

RESULTS AND DISCUSSION:

The new frame installed in Blythe to contain the air pillow and plate is operating without fault. This frame was grouted into the tile outlet, and solves the problem inherent in the original structures of sliding off the outside of the 16-inch tile when the system is accidentally over-pressured. No plugging seems to occur, such as was experienced with the same frame design when it was installed in a more compact erosion-preventive structure near Tacna, Az.

It is planned to amend the structures on the Hall Grove system, so they will accept the pecan blossoms without plugging. At the same time, new pillows and air lines will be installed. The air lines will be buried, as originally planned, on the premise that the system is now a permanent installation.

SUMMARY:

The pneumatic automation system at the Hall Grove is approaching its 7th year of continuous operation. Components are withstanding the weather, and the presently-incorporated automation ideas seem to be sound. The plugging by debris still persists during the springtime, partly caused by falling pecan blossoms.

The owner of the farm at Blythe, CA, indicated that one advantage of the tile outlet is the ease of distributing water for row crops, as compared with the piston equipped jack-gate system.

PERSONNEL: Leonard J. Erie, Allen R. Dedrick, Dale A. Bucks, Bud Payne and Orrin F. French.

TITLE: RESEARCH, DEVELOPMENT, AND DEMONSTRATION OF AUTOMATED SURFACE WATER DISTRIBUTION SYSTEMS FOR GRAVITY IRRIGATION

NRP: 20740 CRIS WORK UNIT: 5510-20740-003

CODE NO.: USWCL 74-2

INTRODUCTION:

An automated irrigation system reduces farm labor requirements and as an irrigation tool, assures more precise control of the quantity of water applied. Better control of water results in water saving and generally crop yield improvement. Improving the irrigation efficiency will reduce the water return flow associated with the water quality degradation to a river system such as the Colorado River.

OBJECTIVES:

This study is part of an effort to improve the irrigation efficiency in the Wellton-Mohawk Irrigation and Drainage District and resultant low water quality return flow to the Colorado River with objectives

1. To demonstrate (on-farm) the use of presently available schemes for automating surface water distribution systems in the Wellton-Mohawk area of Arizona,

2. To design, develop, and demonstrate improved automated systems.

Two fields were automated in 1975 to demonstrate first a jack-gate-operated surface distribution system, and then a concrete port outlet system in combination with jack-gates. Each system is pneumatically actuated by a clock-controller at a central location which signals irrigation field changes according to preset times.

For further introduction, see 1975 Annual Report.

RESULTS AND DISCUSSION:

Woodhouse Automation -- Jack-gates

All irrigations during 1976 were accomplished using the automated jack-gates. The eight level basins were cropped to wheat during the Spring and required five irrigations. The basins were laser leveled during August and planted to alfalfa in early October. Three irrigations were completed during the fall. U. S. Water Conservation Laboratory personnel were present while irrigating the first two

times on the alfalfa to check new and modified equipment to assure proper operation and adjustment.

Several design changes and new features were added during 1976.

Commercial Cylinders and Helical Springs

Air cylinders, originally used on the Woodhouse farm and constructed here in the laboratory shop, were replaced by commercially available 4-1/2-inch diameter cylinders. Helical springs, which could lift the gates without air assist, were designed, constructed in Phoenix, and loaded into the cylinders. Characteristics and calibration of nine of the springs are shown in Table 1 and the average calibration curve is illustrated in Figure 1. The cylinder stroke was 33 inches, which resulted in preloading of about 160 lbs. The cylinder specifications were: bore diameter, 4-1/2 inch; rod extension outside cylinder when piston retracted, 8 inches; piston rod, stainless steel, 1-inch diameter. Cylinder sizing is based on the following items:

1. Gate opening required (Do)
2. Distance from top of gate frame (surface on which cylinder rests) to top of gate leaf (Ds)
3. Maximum solid of spring (Dms)
4. Allowance from solid, approximately 1 inch

From this information

Cylinder stroke = Do + Dms + 1

Rod Extension (when piston retracted) = Ds - Do

Operation of the shop-constructed cylinders was generally satisfactory during the 15-month service period. Inspection of the cylinders upon dismantling showed no deterioration to the cylinder wall and all U-cups were in excellent condition. Long-term performance of these materials will be important to the maintenance requirements of automated systems. The change to the new cylinders was made in August, mainly to demonstrate the utility of commercially available products. Even though the large helical springs were used, compressed air was still used to assist in the opening of the gates.

Automatic timer (controller) startup. A pneumatically operated microswitch was installed to start the timer. Prior to irrigation, the automatic jack-gates are pressurized and the timer is set to an

off position which closes all gates. Irrigation water is then turned into the farm canal by irrigation district personnel. A pneumatic signal, overflow signal line 1 (OF-1) in this case, is used to actuate a microswitch to start the timer, Figure 2. Any overflow signal, thereafter, has no effect on the timer. Automatic startup was used for all three irrigations during the fall.

Isolation of rundown and overflow functions. In the original design the system rundown (disposal of water in the canal or coming into the canal after the last basin irrigated) and safety overflow functions were selected by one set of switches and were controlled pneumatically. After a year's experience with the system it became apparent that the two functions should be separate since there would generally be more designated safety overflow than rundown basins and the rundown basin(s) could be different from the overflow basins. Further, if safety overflow basins were used as rundown areas, run-back from higher elevation basins into the canal and out into lower elevation basins could occur. Isolation of the functions was accomplished by using solenoid-operated air valves, relays, and toggle switches for operator selection, Figure 2. A totally pneumatic isolation scheme is shown as Figure 3. In both schemes the overflow signals operate only the four gates associated with the particular overflow from which the signal is received. Operation in this manner is possible on the Woodhouse system but is not manageable at Naquin's because of the delay time in opening ports compared to jack-gates. In the pneumatic scheme, the jack-gate check would operate during the rundown function if any of the four lower fields were selected while it would be inoperable if an overflow signal were received from OF-2. Again this could not be used at Naquin's.

Time recorders. Individual timers were added to the control panel of the Woodhouse system to give them a record of the actual irrigation time for each basin. They are resettable between irrigations and read in 1/100-hour increments.

A control box was constructed that contained all of the fixed valving illustrated in Figure 2. The cover to the box was a panel on which both electrical and pneumatic on/off switches, sequence

selection equipment, overflow and rundown selection switches, and timers were mounted. Items exposed were those features that involve irrigation control, adjustment, or selection.

Naquin Automation -- Ports and Jack-Gates

The automated system was used a total of 17 times during 1976. The upper four basins were cropped to alfalfa until late fall, re-leveled, and planted to wheat in December. The lower four basins were cropped to wheat during the Spring, were laser-leveled in September, and planted to alfalfa in the Fall. Since two different crops were being grown throughout most of the year, more usage than normal was required of the equipment. This will also be the case during 1977. U. S. Water Conservation Laboratory personnel were present during the first five irrigations in 1976 (system used first time during December 1975). These irrigations were used to operate and adjust the system. The following observations were made and problems encountered:

The trapezoidal jack-gates used as checks between basin levels tended to bind during operation with a full head of water. The water pressure against the lower, unsupported section, was the cause. The binding was eliminated by welding 1/2-inch rods to the gate frame, against which the gate sheet could glide. Binding of rectangular gates has never occurred, hence we would recommend that trapezoidal jack-gates not be used if automation is planned.

Operating pressure of the air bellows, closures into fields 1 through 4, was originally planned to be about 25 psi. Port closure was much quicker than port opening at this pressure. Reducing the pressure to 12 or 14 psi helped balance the system but the overflow sensors still activated when water switched from field 1 to 2 or 3 to 4. An air throttling valve was installed in the supply side of the airlines going to the upper four basins to further delay the port closure. The delay eliminated overflow device activation during irrigation change.

A few hours after the 20 January 1976 irrigation of the upper four basins of alfalfa, the air compressor failed to start -- when all ports and gates are closed--which allowed the ports to open and

some water to drain back into the canal and into the lower basins of wheat. The startup failure was due to a malfunction of the pressure switch on the compressor. The problem has not recurred.

Debris of various types and from various sources has restricted complete closure of some of the ports before and during some irrigations. Moss, floating weeds, cans, sticks, etc., have occasionally caught on the port outlet closure equipment. When the bermudagrass is burned from the canal invert, some drops into the canal and is picked up by the water during the next irrigation and catches on the equipment. Mowed grass and weeds have fallen between the closure plate and ring between irrigations (ports depressurized and open) which would not allow complete closure once the system was pressurized. Some modification of the structure may help minimize the debris problem. One structure was changed by eliminating one support leg and turning the cross-leg part of the equipment 45°. The result was a three-legged support for the permanent stop with a leg on each side and one on the top. Complete evaluation of the change has not been completed. Other changes may be necessary. Effort should be made to make the system as debris-free as possible to insure reliable closure.

Two polyethylene plastic air lines were damaged during the bermuda burning operation. The damaged sections were where the tubing exited the 3/4-inch galvanized pipe, used for protection coming into the turnout area, and the air bellows. Copper tubing was used to replace the burnt sections. The air bellows were undamaged.

The four ports leading to either fields 5 or 6 can not handle the flow when irrigating with 20-22 cfs. This results in periodic overflow sensing and water dumpage to a designated basin which, on a regular basis, is undesirable. Since the cooperator plans to use this flow rate when available, an additional port will be added to each field with the associated automatic equipment. The system can operate, without overflowing, at about 18 cfs or less (approximately 4.5 cfs/port).

All port outlet closure devices except one were galvanized before installation. Although the ungalvanized closure is extensively rusted, operation is still satisfactory.

General

Broad-crested weirs were installed on both the Woodhouse and Naquin farms. They supply the irrigator with a flow measurement at his convenience rather than requiring contact with Irrigation District personnel. Detail of these devices and their use is described in Annual Report Code No. Ariz.-WCL 72-1, "Predicting Hydraulic Characteristics of Critical Depth Flumes of Simple and Complex Cross-Sectional Shapes."

Charts were developed for all basins on each farm which relate required irrigation time to flow rate and amount of irrigation planned. The charts are located in the control centers for use by the irrigator. Operation instructions describing air compressor usage, control panel settings, and timer settings were also located in each control center. Irrigation record sheets were also furnished in which actual irrigation time for each basin can be recorded along with average flow rate.

We demonstrated the systems to visiting groups when requested, as did University of Arizona, Soil Conservation Service, Bureau of Reclamation, or Wellton-Mohawk Irrigation and Drainage personnel. We discussed and demonstrated the automated systems as well as dead level basins and laser leveling to students from Mexico, a group of farm managers, the Technical Advisory Committee on the Wellton-Mohawk, an international salinity conference tour group, and a Russian delegation along with other individuals. We cooperated with Deere and Company in making a short movie on irrigation practices including automation. Several other discussions dealing with the automatic systems were held here at the U. S. Water Conservation Laboratory. The field installations were, on occasion, also shown and explained by our two cooperators. We appreciate their assistance in this endeavor.

Two papers were prepared and orally presented at the Summer Meeting of the American Society of Agricultural Engineers. They are "Automation of On-Farm Irrigation Turnouts Utilizing Jack-Gates" and "Automation of an Open-Ditch Irrigation Conveyance System Utilizing Tile Outlets." Publication in the Transactions of the ASAE is expected.

The Soil Conservation Service has asked us to design an automated jack-gate system for a farm near Wellton, Arizona. This will be the

first cost-shared automated system as part of the onfarm irrigation system improvement program administered by the SCS. We have completed the design and provided an equipment listing. Installation is expected during the first half of 1977. We expect to provide direction and assistance in attaining a properly installed and operating system. One major change in the jack-gate modification for this installation is planned. Rather than centering the cylinder and moving the manual jack, as done at the Woodhouse and Naquin farms, the air cylinder will be offset from the center of the gate by about 4-1/2 inches and the manual jack will remain in its original position. The procedures for this modification were developed here at the laboratory shop and tested as modified. Operation was satisfactory. Steps required to adapt the cylinders to the gates are:

1. Construct plate for cylinder attachment (5" x 6").
2. Cut notch in angle iron frame to allow for piston travel.
3. Align cylinder with plate onto gate and weld plate to gate frame.
4. Construct rod receiver bracket.
5. Attach bracket to gate slide.

The modification of jack-gates using these techniques will be simpler and less costly than those being used at Woodhouse's and Naquin's.

FUTURE PLANS:

1. Changes or additions on the Naquin system to be made during 1977 include: isolation of rundown and overflow functions, installation of time recorders, automation of the jack-gate leading to basin 8 and changes needed in the control center to accomplish this addition, and addition of two port turnouts, one each, into basins 5 and 6 and the associated equipment for automating.

2. Continue to work with prospective controller/timer suppliers incorporating many of the requirements needed for properly automated systems. This will include such features as: improved timer readout (digit), low voltage d.c. operation, sequencing capabilities, station combination, and eventually to accept a remote open channel flow

sensor signal for controlling the stepping of irrigations from field to field.

3. Evaluation of eliminating the live air source at the site (compressor).

4. Expand on the use of portable control centers rather than permanent ones as used at Woodhouse and Naquin's.

5. Work with potential automatic irrigation system contractors to encourage entry into the field.

SUMMARY AND CONCLUSIONS:

Thirty-six irrigations have been completed through 1976 using the automated systems:

	1975	1976
Woodhouse	10	8
Naquin	1	17

Most of the irrigations have been completed by the farmer/irrigator once initial adjustments and/or modifications were made.

Changes or additions during 1976 to the Woodhouse system included installation of commercially purchased cylinders, adding automatic timer startup, isolation of rundown and overflow functions, installation of time recorders and an improved control box. Operation of the Woodhouse jack-gate system has been excellent.

Modifications and adjustments to the Naquin system have included attachment of guides to eliminate binding of trapezoidal gates and air throttling to ports to balance port opening and closure rates. Early in the year, the air compressor failed to start shortly after an irrigation was complete which allowed water to drain to lower fields. The problem has not recurred. The main operational problem with the port system is debris restricting proper closure of the ports. One structure has been modified and other changes may be made if not satisfactory.

Broad-crested weirs, operation instructions, irrigation schedule sheets, and irrigation record sheets were added during the year for irrigator convenience.

The systems were demonstrated by U. S. Water Conservation Laboratory staff over 10 times during the year and were the subject of numerous discussions here at the laboratory. Two papers describing

the automatic systems were presented at the Summer Meeting of the American Society of Agricultural Engineers and have been submitted for publication in the Transactions of the ASAE.

The first automated system to be cost-shared as part of the onfarm irrigation system improvement program administered by the SCS is scheduled for installation during 1977. We have completed the design and provided an equipment listing as requested by the SCS.

PERSONNEL: Leonard J. Erie, Allen R. Dedrick, and John A. Replogle.

Table 1. Characteristics and calibration summary for helical springs used in commercially purchased air cylinders on Woodhouse Farm, August 1976.

Original free length, 48 in.
Wire Diameter, 0.375
Number Coils, Total 27, Active 25
Maximum Solid, 10.2 in.
Spring Diameter (O.D.), 4.1 in.

Cylinder Stroke, 33 in.

Cylinder Spring No.	Spring Constant (K)	Preload Force (A)	Preload Compression (B)	Freelength After Test
	lbs/in.	lbs	in.	in.
1	19.9	129	6.5	39.5
2	19.3	174	9.0	42.0
3	18.9	153	8.1	41.1
4	19.7	170	8.6	41.6
5	20.8	149	7.2	40.2
6	19.9	166	8.3	41.3
7	20.8	163	7.8	40.8
8	18.5	167	9.1	41.1
9	19.9	166	8.3	41.3
Mean	19.8	160	8.1	41.1

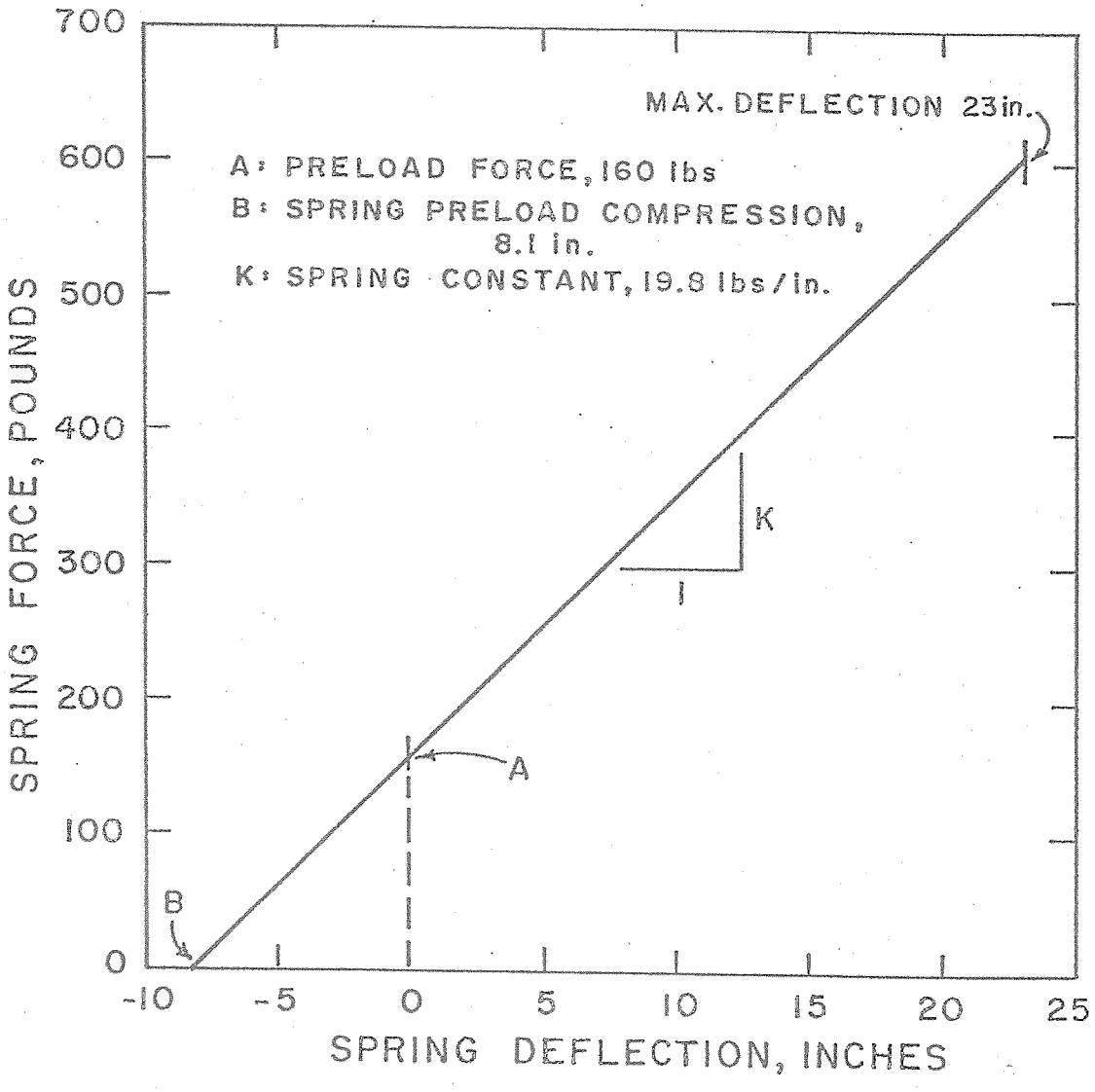

Figure 1. Calibration of helical springs installed in commercially purchased cylinders on Woodhouse farm in August 1976. Values shown are averages for nine Springs, see Table 1.

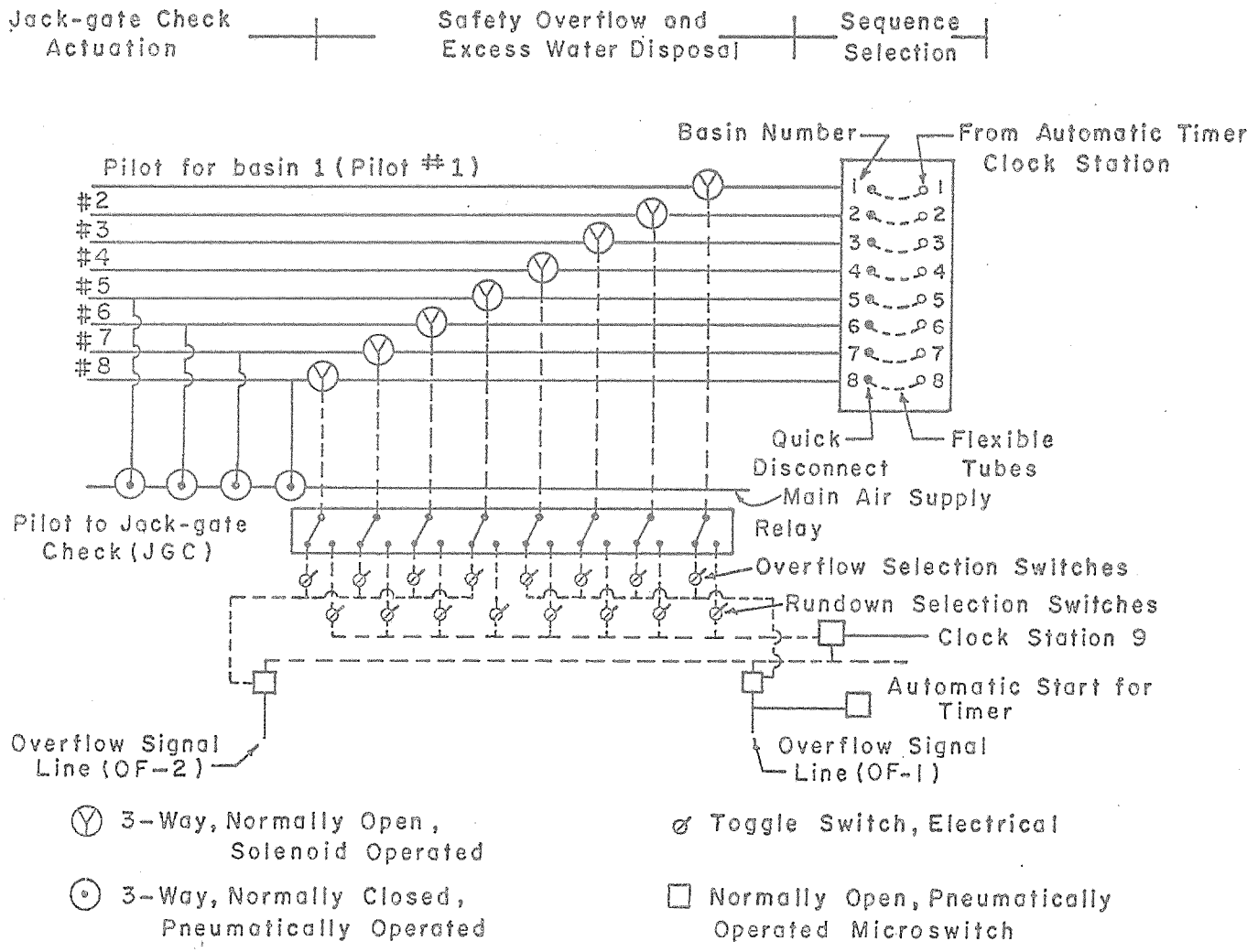

Figure 2. Schematic diagram of the control panel used on the Woodhouse farm. Safety overflow and rundown isolated electrically.

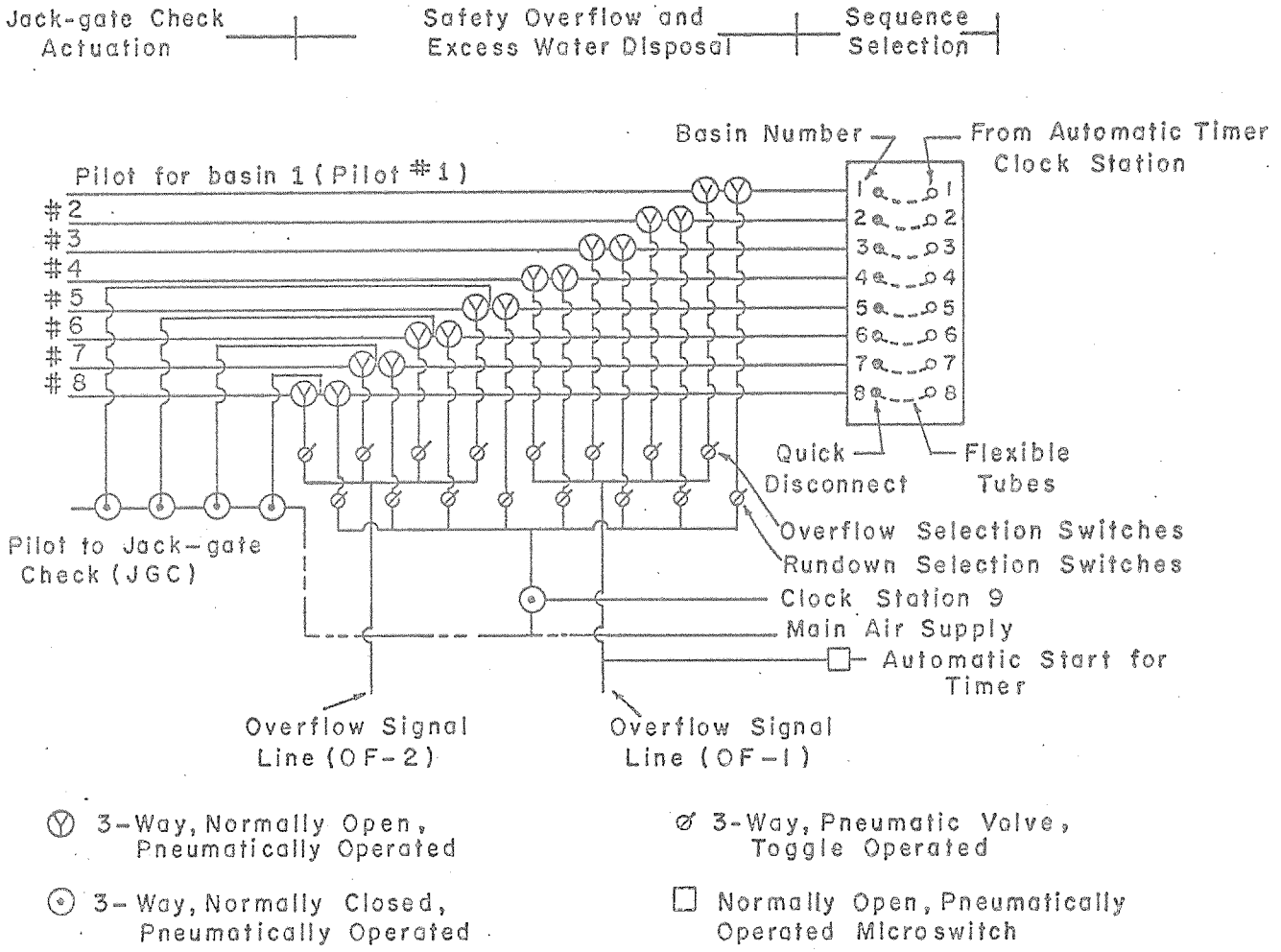

Figure 3. Design of safety overflow and rundown isolation using pneumatic rather than electrical actuation. Control requirements same as those used on Woodhouse farm.

TITLE: TIME RATE MOVEMENT OF WATER FOR DEAD LEVEL IRRIGATION

NRP: 20740 CRIS WORK UNIT: 5510-20740-003

CODE NO.: USWCL 74-3

INTRODUCTION:

To reduce the quantity of salt in the water returned to the Lower Colorado River system near Yuma for desalinization, from the Wellton-Mohawk Irrigation Project, the application efficiency of irrigation water used in the Wellton-Mohawk Project must be improved.

In order to improve the land owner's knowledge about timing of irrigation and reduction in the quantity of water used in irrigating, existing research knowledge must be made available to him through Extension Service education and demonstration.

The irrigation application efficiency can be improved in many cases by changing the farm irrigation system. A highly efficient method of irrigation referred to as 'dead level' is one such change. This research project was initiated for the purpose of studying dead-level irrigation and preparing a publication on the results of the study.

For further introduction, see 1974 annual report.

PROCEDURE:

A great advance in the utilization of dead-level irrigation this year was the expanded use of laser beams for leveling land in the Wellton-Mohawk area. This method was introduced in 1974, and now between 30 and 40 are in operation, with most of the valley land being leveled by this method.

During the year, several fields which had been dead-leveled in the normal way were surveyed. Differences of as much as .45 ft existed within some of the fields, and .35 ft differences were common. These high or low areas were evident during irrigation merely by observing the water level, and when not being irrigated, the high areas visually showed low production, and the low areas planted to alfalfa showed scalding and weed takeover. After these same fields were leveled by the laser equipment, differences were less than 1 inch. This may be partly due to the placement of the

surveying rod, and is of no consequence when the field is being irrigated.

Several length-of-run studies were conducted on square, 10-acre areas, with water entering from 6 outlets on one side. Water flowing in at 15 cfs had completely covered the field in about 2 hrs and 15 minutes. Final intakes averaged about .15 inches/hr. Obviously, no part of the field was underwatered by more than ($2\frac{1}{4}$ x .15 =) .34-ft, and that only in a very small area farthest from the turnout. For the weakest point in the field, the distribution efficiency would be about 94%. No water was involved in runoff.

Various methods of utilizing water on row crops (distribution among rows) were observed and discussed with farmers. Obviously, there are several choices in the methods which can be used.

SUMMARY:

The introduction of laser levelers is making dead-level irrigation systems even better than originally visualized. Nearly all the Wellton-Mohawk Valley farms (silty-clay soils) are being developed to a dead-level status. Length-of-run studies demonstrated the very high irrigation efficiency and distribution of irrigation water. Several surveys showed the accurate ability of the laser beam leveler to level the land.

A prospectus, or outline, was prepared for the possible publication of a Farmers Bulletin, which will be subject to approval in March. The manuscript is now being prepared and, hopefully, will be published this year.

PERSONNEL: Leonard J. Erie and Allen R. Dedrick.

TITLE: CLOGGING POTENTIAL OF COLORADO RIVER WATER IN TRICKLE IRRIGATION SYSTEMS AND DEVELOPMENT OF METHODS FOR PREVENTING PLUGGING

NRP: 20740 CRIS WORK UNIT: 5510-20740-003

CODE NO.: USWCL 75-2

INTRODUCTION:

A detailed 1976 report of our study convering the above titled research has been submitted to the Soil Conservation Service, the agency through which funding and related administrative matters are handled for this project. This report is available from this laboratory on request. The basic objectives and descriptive materials on experimental site, equipment, types of emitters, and water treatments including filtration and chemical additives and emitter flow measurements were presented in our 1975 Annual Report. The original 2-year contract period was extended to 3 years, thus permitting more latitude in conducting the experiment and improving on the reliability of the results obtained.

SUMMARY:

Detailed bi- and tri-weekly physical, chemical, and biological analyses, and emitter flow measurements are being made in evaluating water treatment needs for a variety of drip emitters using the Colorado River water in southwestern Arizona. Calculations based on the chemical composition of the water indicate a tendency for calcium carbonate to precipitate from this water and that the amount of acid needed to prevent carbonate scaling can be estimated from theoretical models developed.

Results of the 2-year study show that emitter operation can be maintained by water treatment that includes filtration and chemical treatment. It is too early at this time to determine whether filtration alone would be adequate for this location and for the various types of emitters used. Besides the problem of the decrease in emitter flow rate due to clogging, there is a contrasting one relating to an increase in flow rate caused by emitter malfunction which can also lead to nonuniform water application.

From the long-term standpoint, buildup of sediment can become significant in the lower water velocity lateral lines even with sand and screen filtration, so that preventive maintenance to rid the lines of particulate materials by flushing and chemical treatment is desirable for this system.

PUBLICATIONS:

1. Roth, R. L., and Nakayama, F. S. Operational guidelines for trickle irrigation systems for citrus in the Yuma, Arizona, area. Univ. Ariz. Agr. Eng. & Soil Sci. Rep. 76-10. 1976.

2. Bucks, D. A., Nakayama, F. S., and Gilbert, R. G. Clogging research in drip irrigation. Proc. Intern. Drip Irrig. Assoc. 1977. In press.

PERSONNEL: F. S. Nakayama, R. G. Gilbert, D. A. Bucks, B. A. Rasnick, O. F. French

TITLE: SIDE-WEIR FLOWS INTO SUPERCRITICAL CHANNELS

NRP: 20740 CRIS WORK UNIT: 5510-20740-003

INTRODUCTION:

A hydraulic model study was performed for the Soil Conservation Service. It consisted of Froude Modeling supercritical flow in an open channel with the effects of adding small amounts of additional flow from the side of the channel over a broad-crested weir. The study covered both trapezoidal and rectangular channels. The objective was to predict the water surface profiles from knowledge of channel geometry, flow quantities and normal channel depth.

PROCEDURE:

For predicting the water surface profiles, a form of the momentum equation was developed and compared to expected and observed water depths.

RESULTS AND DISCUSSION:

The first part of the study was successful and design curves were developed for general problem solution. For the second part some empirical equations were developed to help predict the effects of waves caused by the addition of sideflow. Further experimental and theoretical verification of these equations are necessary. Predicted energy losses caused by the hydraulic jump in trapezoidal versus rectangular channels may be helpful for further development. A second aspect of the study was the development of a theory to predict the length and location of standing waves that were caused by sideflows. Standard hydraulic references cover general standing waves in rectangular channels caused by depth changes. However, the same relationships did not appear to exist for trapezoidal channels.

A draft copy of a report was reviewed by Harry Firman of the SCS-EWP Unit in Portland, Oregon, and George Kalkamus, SCS, California. The reviews have been answered and a final draft is being prepared for distribution. Comments from a joint ARS-SCS group to whom the results were presented seem to indicate that it may be a useful design aid. A shorter version of the report is also being prepared for outside publication.

SUMMARY:

In a hydraulic model study, sideflow was added to an open channel with water flowing at supercritical velocities. Small amounts of sideflow caused a standing wave to form. The height and location of this wave can be found from the momentum equation where the force of the wall friction balances the effects of channel slope. In this case, the specific force before, at and after the wave is the same. When enough sideflow is added to cause a hydraulic jump to form, the flow properties change. The wall friction and slope forces no longer balance and the specific force changes. The problem solution is now indeterminate. A graphical solution was presented to solve for the location of the jump and the depth at the end of the inflow region.

From this theory, there appears to be a distinct separation between these two flow regimes. For a point inflow and an instantaneous jump this would be true. In practical situations this is not true. A transition between the two flow situations was developed to explain the observed results, but has no practical usefulness for design.

Open channel junctions of this type (side weir inflows) are often avoided because of the large standing waves that may occur. In order to help predict the waves observed in our model, an examination of hydraulic jumps in trapezoidal channels was necessary. We found that the hydraulic jump formed an isosceles triangle (as viewed from above), where the jump began at the walls and moved inward. Experimentally it appeared that the angle of this jump could be predicted from the Froude Number of the inflow and the ratio of actual and hydraulic depths (maximum/average). It was also shown that the angle of the jump could be related to the velocity of the celerity wave.

The entry of sideflow caused a change in the angle of the disturbance waves (angle of jump). Energy relationships were useful in explaining this change in angle. Energy relationships were also useful in determining other wave properties. It was found that the velocity head of the horizontal component of the sideflow as it entered the channel plus the velocity head of the lateral component of the celerity wave accounted for the height of the standing wave

within the junction over that predicted by momentum relationships. The ratio of these energy heads also appears to be a measure of the extent of influence downstream.

PERSONNEL: A. Clemmens and J. Replogle

TITLE: IRRIGATION ADVANCE AND RECESSION MODELING

NRP: 20740 CRIS WORK UNIT: 5090-20741-002-A

INTRODUCTION:

Surface irrigation is practiced on an estimated 30 million acres in the United States. Present efficiencies typically range from 30 to 60% application efficiency. In some areas, dead level irrigation has been used to greatly improve these efficiencies. This type of system eliminates losses from runoff at the end of the field. In other areas, it is a practice to collect runoff for reuse, either by irrigating the next field down slope or with a pump back system. While application efficiencies for a particular field may be low (say 30-40%), the overall efficiency of an area where runoff is reused may be 70%. In this case, water, minerals (and salts), and fertilizer are lost through deep percolation. Eliminating these losses has been the goal of surface irrigation researchers for many years.

The objective of this project is to develop mathematical models of surface irrigation systems and correlate them to existing field data. The results of these models should be in a form usable for the prediction of optimum flow rate and time for maximum application efficiency and minimum deep percolation loss. This project began in 1976 in cooperation with the University of California at Davis. The cooperative agreement terminates in 1977.

LITERATURE REVIEW:

A. Field studies.

The hydraulics of surface irrigation are extremely complex. For this reason, many researchers have resorted to field studies in an attempt to solve irrigation system design problems. The first step in the problem solution was the evaluation of present irrigation systems. This consisted of physical field measurements made on individual fields. The Soil Conservation Service put out a handbook in 1956 summarizing previous work (Bouwer 1957, USDA 1956a). From these studies, researchers such as Bishop (Bishop 1961) began looking at the relationship between the numerous parameters involved.

In the mid-1960's, attention was given to the Lewis-Milne equation which takes a volume balance approach. A series of investigators attempted to use this equation to mathematically solve the irrigation advance problem. The major contributors were Wilke and Smerdon; Phillip and Farrell; Chen, Fok and Bishop; and Christiansen et al. Success was limited in that the Lewis-Milne equation is poor at determining the effects and results of a total irrigation including runoff, recession and deep percolation. Other researchers began to look at the solution in terms of application efficiency (Willardson and Bishop; Willardson, Smerdon, and Glass; Jensen and Howe; and Lim).

In the late 1960's, intensive field studies at the University of Colorado produced published data (Payne, Gilley) which indicated that slope and discharge rate had little effect on application efficiency, and that the system operation (i.e., cutoff time) was the most important factor effecting application efficiency (Evan, Heerman, Howe, and Kincaid).

From these and other field data, attempts were made to come up with new parameters or methods to evaluate and/or design irrigation systems from estimated field parameters (Willardson, Sastry, and Agarwal; Stewart, Hagan, and Pruitt; and Bowman 1976). These, in general, require the estimation of parameters that cannot be accurately determined or assumptions that are not universally true. The Soil Conservation Service, in its National Engineering Handbook No. 15, Chapter 4 (USDA 1974), has a graphical method for determining the optimum time based on estimated field parameters and efficiencies. This is a first step but it cannot be used to improve efficiency. Physical models of surface irrigation have been attempted, but their application to actual field situations is limited (Jobling and Turner, and Collis-George).

B. Hydrodynamic models.

With the aid of digital computers, the complexities of the irrigation process can now be accurately modeled. Initial theories for model solution were presented by Hart, Bassett, and Strelkoff; Wilke; and Kincaid, Heerman, and Kruse. Previous solutions required

detailed measurement of the irrigation process and were essentially a check on the irrigation. The hydrodynamic approach, on the other hand, requires somewhat detailed knowledge of hydraulic field parameters. Precision border experiments were run at the University of Arizona to be used as a check on hydrodynamic models (Roth, Fonken, Fangmeier, and Atchison). Data from a number of field studies are shown in Table 1. Refinements on the early models were made by detailed hydraulic analysis (Strelkoff 1969; Strelkoff 1970; Heerman, Wenstrom, and Evans; Sakkas and Strelkoff; and Basset). These detailed models were used to determine the effects of varying field parameters by Fonken and Powell.

The computer time and expense involved with these detailed models are prohibitive. Simplified models have been presented by Strelkoff, and Strelkoff and Katopodes, which can be checked by a more exact model (Katopodes and Strelkoff).

C. Roughness.

Evaluation of hydraulic roughness has been investigated by several researchers (Heerman, Wenstrom, and Evans; Bowman; and Roth, Fonken, Fangmeier, and Atchison). The combined effects of surface roughness and vegetative drag represent hydraulic parameters that must be estimated (or evaluated) in terms of standard roughness coefficients (Manning, Chezy, or Sayre-Albertson) for use in hydrodynamic models.

D. Infiltration.

In surface irrigation work, infiltration of water into soil is usually assumed to be a power function, where the cumulative depth of water infiltrated is equated to a constant times application time to a power. The Kostiakov or power function equation is used because of its simplicity when used in complex hydrodynamic solutions. No relationship between soil parameters and the constants in this equation has been made. However, infiltration into soils appears to be approximated well by this equation.

In many irrigation field studies, ring or cylinder infiltrometers are used to measure infiltration rates. The irrigation

border itself can also be used to estimate the infiltration characteristics of the soil. Comparison of ring versus border infiltration shows different functions for the same soil. This is primarily due to the lateral flow around the infiltrometer as opposed to strictly vertical flow over the entire border (Erie, Smerdon, and Bouwer and Jackson).

The Philip infiltration equation has been used by many soil scientists to estimate infiltration into soils (Philip 1957, Philip 1966, Smiles and Knight, and Smiles and Fleming). It appears to have strong theoretical basis but fails in that it cannot be applied to a soil with varying moisture content without field measurement at each moisture content. This limitation makes it particularly impractical for engineering applications such as hydrodynamic surface irrigation modeling.

The Green-Ampt equation is finding wider application in infiltration studies. Several researchers (Bouwer 1966; Bouwer 1969; Bouwer 1976; Whisler and Bouwer; Whisler and Watson; and Whisler, Watson, and Perrens) have shown how it can be used to solve practical problems. Instabilities have been shown to exist for several situations (Philip 1975a, Philip 1975b). But, the bounds of these instabilities can be found analytically (Bouwer 1976).

DISCUSSION:

A. Advance and recession.

A simplified model of advance and recession on irrigation borders developed by Strelkoff (Strelkoff 1977) was programmed and run on the laboratory computer. The gross assumptions made by the model caused significant errors in the solutions. An attempt was made to obtain optimum values of flow rate and cut off time for constant values of roughness, slope, length of run, and infiltration function. While optimum values were obtained, serious doubt about the solutions arose when a change in the time interval changed the optimum values of time. These differences were caused by volume errors which effected the efficiency calculations. With appropriate time intervals, solutions for maximum application efficiency

at 100% adequacy can be obtained. Here runoff is assumed to be lost, application efficiency is the volume of water desired in terms of irrigation depth divided by the total volume applied, and 100% adequacy occurs when the desired irrigation depth is met at all points within the field. Further evaluation of these optimum values is necessary.

In practice situations, the slope and length of run are both fixed. Depending on the situation, the irrigator can vary both flow rate (per unit width) and time of cutoff. The two unknown parameters are roughness and infiltration function. If the Kostiakov infiltration function is used, $I = Kt^A$, both K and A are unknown. Bowman (1976) suggested that if hours are used for the units of time, that for a given soil the value of K remains relatively constant. The units of K are length divided by time to the power A, (L/T^A). Other data (Gilley, Payne) show similar results.

B. Separation of variables.

Strelkoff's simplified model, "Cheapy Border," was used to determine the effect of roughness (Manning's n) and the infiltration parameters K and A on the time of advance. The time it would take the stream to advance to 20, 40, and 60 meters was calculated. In comparing these advance times, it was found that for a given value of roughness, n, a unique solution existed for any combination of K and A. However, it does not appear that advance time can be used to estimate K and A since the uniqueness of the solution is extremely sensitive to measurement error and/or inconsistancies in the field. The effects of n and K are similar in that a large value of n may cause advance to slow just as a large value of K would. The results of "Cheapy Border" indicate that separation of these two variables is impractical. Thus, separation of the infiltration function and the roughness with advance distance is not feasible.

The difference between a low roughness coefficient and high infiltration coefficient and the reverse is the volume of surface storage. The former will have a higher infiltrated volume and a lower surface volume and depth than the latter. Separation of

n and K can be accomplished with surface depth measurements. These depths are exceedingly difficult to measure accurately, and thus this method is also not feasible.

Direct separation of variables (k, A and n) by advance measurement does not appear practical. The usefulness or application of irrigation models may come from hindsight. In other words, by observing the results of an irrigation, it can be inferred what should have been done. Over a period of time, the experience of estimating what should have been done may help to improve the overall irrigation of a particular farm. It may be that the best implementation of such an approach would be through the use of an automated irrigation system. With increasing labor, power, and water costs, this type of approach may be more practical than it appears at present.

C. Roughness.

Estimation of hydraulic roughness in irrigation borders and furrows may develop along the lines of estimating roughness in natural channel. The Soil Conservation Service has a procedure for visually estimating the roughness in open channels (USDA 1956b). They also require an estimate of field roughness in their method for estimating the optimum cutoff time in NEH 15, Chapter 4. This indicates the need for a visual means of estimating roughness in surface irrigation. Field correlations of surface irrigation models may be helpful (indirectly) in developing a method for visually estimating hydraulic roughness for various crops at various stages of growth.

D. Infiltration.

Both field studies and hydrodynamic models indicate that the infiltration function is the prime factor in optimizing irrigation efficiencies. The ability to use irrigation models in optimizing irrigation may be closely related with the ability to estimate soil conditions. If this is the case, knowledge of infiltration rates before irrigation would be desirable. Theoretically, with enough field measurements, the infiltration rates at any moisture

content could be determined. This is impractical on a large scale, since soil moisture contents are difficult and expensive to obtain. Present research on the use of infrared thermometers may make soil moisture readings economically feasible. It may be that with prior knowledge of some soil parameter(s), that advance times could be used to further refine the knowledge of soil conditions.

Figure 1 shows the results of field data from the sites in Table 1 (solid dots). Note the wide range and variation in both K and A. In most cases, measured field data were fitted to a power function with a regression analysis. Regression coefficients ranged from 1.0 to 0.8 with most values around 0.99. The SCS intake families (USDA 1974) are plotted as open circles with the .1 in/HR family at the lower left and the 4 in/HR family at the upper right. It would appear that these families do a poor job of estimating actual field conditions.

A simplified version of the Green-Ampt equation was used to estimate infiltration rates for various soil classes based on the methods of Bouwer (1969). All parameters were held constant with depth. The general area of the results is plotted by word description of the soil classification. Changes in moisture content and hydraulic conductivity with depth were made to result in powers, A, of 0.3. Further refinements are being made on the solutions of the Green-Ampt equation in an attempt to correlate observed field data.

SUMMARY:

In the past, many methods have been suggested for optimizing efficiencies. In most cases, these methods represent empirical results based on years of field data at limited locations and are neither universal nor exportable to areas with different soil types. Several other methods have a theoretically sound base, but in application are subject to the same limitations as empirical methods. To date, no universal method exists for optimizing surface irrigation efficiencies.

Initial evaluation of the simplified model indicates that it may be impractical to determine optimum application time and flow rate from the measurement of advance versus time alone. It appears that more knowledge of actual field parameters will be necessary. However, limited field data are available that are useful in applying the computer models to actual field condition. Further assessment of these field parameters (roughness and infiltration) is necessary.

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PERSONNEL: Albert J. Clemmens, John A. Replogle

Table 1. Ranges of field data.

Site	Soil	Slope	Length of run (Meters)	Flow Rate (m^2/s)	Manning Roughness	Depth (cm)	Infiltration K (cm/HR^A)	Infiltration A	Crop
Grand Junction, CO	Billings silty clay loam	.0047	340	.004 to .013		4 to 14	5.2 6.1	.529 .049	alfalfa and brome grass
Grand Junction, CO	clay loams	.00002 to .005	150 to 350	.003 to .008	.07 to .22		4.7 4.1	.428 .161	milo, alfalfa and brome grass
Bozeman, MT	silty clay loams	.005 to .01+	100 to 200	.006 to .024			0.6 3.2	.251 .42	alfalfa and alfalfa grass
Univ. of Arizona	sandy loam	0.0 to .003	9 to 90	.0018 to .0033	.017 to .035	3.3 to 9.4	5.6 9.4	.441 .11	
Alabama Exp. Station			305	.0027 to .008		5 to 10	2.2	.21	Sudan grass
College Station, TX		0.0 to .013	200	.0017 to .009			3.1 1.4	.5 .2	
Scottsbluff, NE	Tripp fine sandy loam	.00007 to .0008	116 to 223	.0042 to .007		8.5 to 28			alfalfa, beans, corn, sugar beets

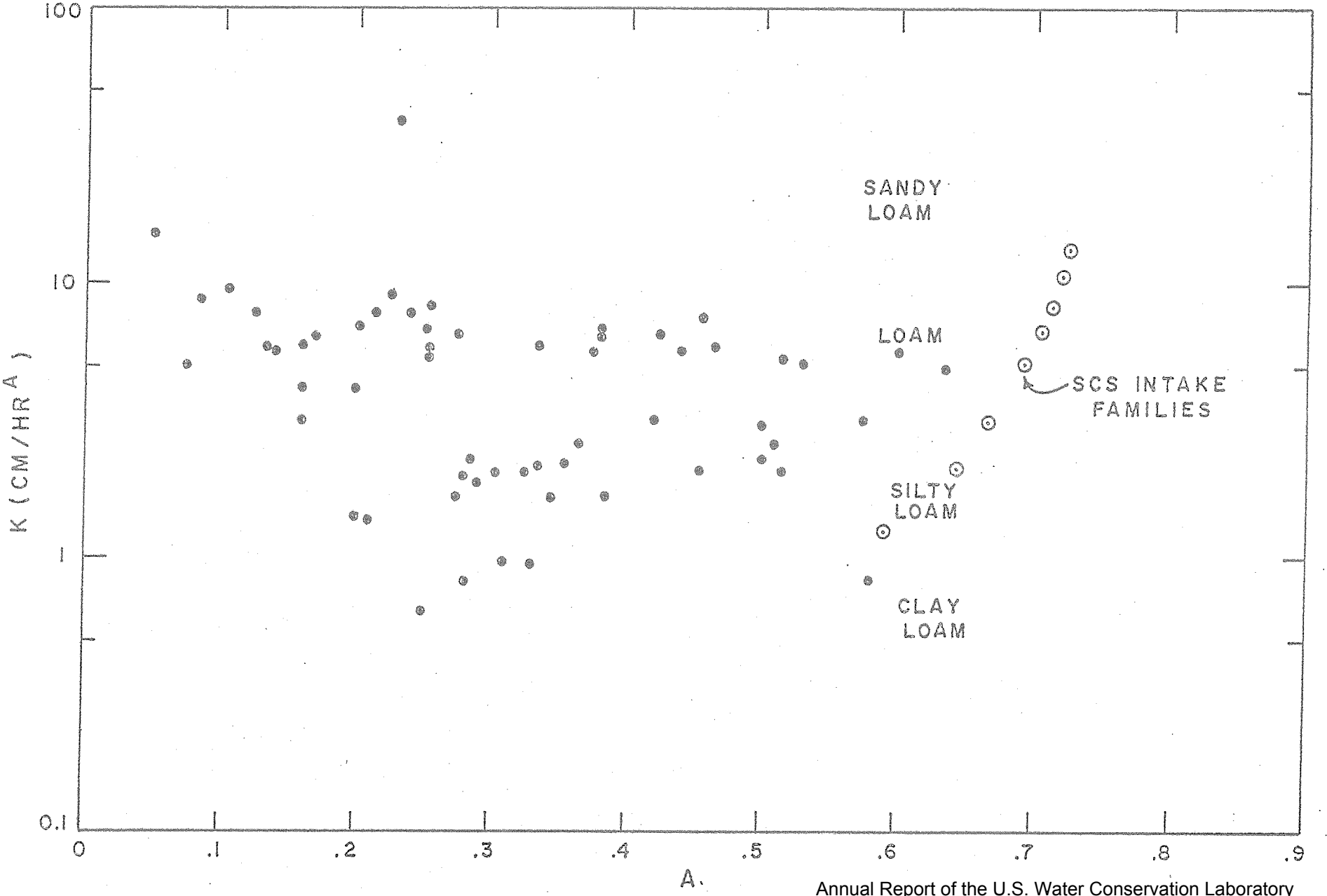

Figure 1. Field infiltration data.

TITLE: EVAPORATION OF WATER FROM SOIL

NRP: 20760 CRIS WORK UNIT: 5510-20760-001

CODE NO.: Ariz.-WCL 68-1

Most of the work conducted under this outline during 1976 consisted of developing techniques to use remotely sensed crop canopy temperatures to predict wheat yields, and for determining water requirements of wheat. Also, spectral band ratioing techniques were used to determine their practicality in estimating soil water content. The results are summarized in five manuscripts that have been accepted or submitted for publication.

1. Ehrler, W. L., Idso, S. B., Jackson, R. D., and Reginato, R. J. Wheat canopy temperature: Relation to plant water potential. (to be submitted to Agron. J.)

Since water is one of the main limiting factors in crop production, an improved capability to measure soil moisture could greatly improve yield forecasts. It now appears feasible to utilize aircraft or satellites for routine monitoring of crop data. However, it is desirable for the reliability of such remote measurements for them to be tested out with a groundbased system. The present experiment made use of hand-held infrared thermometers to obtain daily measurements of the canopy temperature at predawn and 1400 hours. The basis of this method is the detection of the rise in canopy temperature minus air temperature (the temperature difference) as the soil dries out. Measurements of plant water potential (a fundamental indicator of plant water stress) accompanied the temperature difference readings.

As the soil dried out, the wheat canopy temperature difference gradually rose, attaining 4.8 C when the soil reached the wilting point. At this stage the 1400-hour plant water potential was low, -48 bars (indicating great plant water stress). Two days after a heavy irrigation the plant water potential at 1400 hours was high, -15 bars (indicating low water stress), and the canopy temperature was as much as 3.8 C below air temperature.

In demonstrating the relationship between canopy temperature difference and plant water potential, these results substantiate the temperature difference method for sensing plant response to drought. A logical progression of these results would be the use of aircraft and/or satellites to monitor wheat canopy temperatures as a guide to soil moisture under crops, with the goal of measurement on an extensive scale, and the consequent potential of increased effectiveness of plant yield forecasts, as well as greater crop production.

2. Idso, S. B., Jackson, R. D., and Reginato, R. J. Remote sensing of crop yields. Science (In press).

A technique was developed that enables crop yield predictions to be made from remotely acquired canopy temperature measurements. Somewhat analogous to the centuries-old concept of growing degree day, a "stress degree day" concept was devised that relates the final yield (Y) to the accumulated stress degree days (SDD). Mathematically

$$Y = \alpha - \beta\left(\sum_{1=b}^{e} SDD_i\right)$$

where SDD is the midafternoon (1340 to 1400 hours) value of the canopy temperature minus the air temperature on day i. The SDD can also be expressed as the afternoon minus the predawn canopy temperature difference, normalized to minimize environmental variables. Albedo data was used to delineate the starting and ending times for the summation. Albedo plots showed a distinct change at heading, and again when the plants were mature. SDD summed over this period was closely correlated with final yield. SDD monitored beginning at heading can be used as a day-to-day predictor of potential final yields.

3. Idso, S. B., Reginato, R. J., and Jackson, R. D. Albedo measurement for remote sensing of crop yields. Nature (In press).

Albedo, the ratio of reflected to incoming solar radiation, was well correlated to final yields. Once soil reflectance is made

negligible by canopy coverage, the albedo decreases with time due only to plant reflectance changes. At heading a shift in albedo occurs, then it continues to decrease, the decrease due to the growth of heads. At maturity albedo abruptly increases. The minimum albedo occuring at maturity was correlated to final yields. In contrast to the SDD, albedo values are not very useful for prediction of yields, but can adequately assess fields once maturity is reached.

4. Jackson, R. D., Reginato, R. J., and Idso, S. B. Wheat canopy temperature: A practical tool for evaluating water requirements. Water Resources Res. (In press).

Irrigation, formerly unique to arid areas, is rapidly increasing in regions that previously relied solely on rainfall to supply water to plants. In all irrigated areas, water must be carefully managed. Also, irrigation usually requires energy consumption. Thus, we seek better methods to guide irrigation water management.

Remote measurement of canopy and air temperatures about 1 to 1 1/2 hours after solar noon each day may prove to be a useful tool in predicting when to irrigate and how much to apply. Canopy temperatures were measured with hand-held portable radiation thermometers on a crop of durum wheat. The field was divided into 6 plots; each received a different irrigation treatment. Soil water contents were measured at two locations within each plot. A stress degree day concept (the summation of canopy temperature minus air temperature measured each day) appears to be a viable way of predicting the need for irrigation. A simplified evapotranspiration expression that utilizes the canopy-air temperature difference was found useful in predicting the amount of irrigation water needed.

Most of the input data required can be obtained from airborne scanners and possibly satellites.

5. Reginato, R. J., Vedder, J. F., Idso, S. B., Jackson, R. D., Blanchard, M. B., and Goettelman, R. An evaluation of total solar reflectance and spectral band ratioing techniques for estimating soil water content. Jour. Geophys. Res. (In press).

For several days in March of 1975, reflected solar radiation measurements were obtained from smooth and rough surfaces of wet, drying, and continually dry Avondale loam at Phoenix, Arizona, with pyranometers, located 50 cm above the ground surface, and a multispectral scanner, flown at a 300-m height. The simple summation of the different band radiances measured by the multispectral scanner proved equally as good as the pyranometer data for estimating surface soil water content if the multispectral scanner data were standardized with respect to the intensity of incoming solar radiation or the reflected radiance from a reference surface, such as the continually dry soil. Without this means of standardization, multispectral scanner data are most useful in a spectral-band ratioing context. Our results indicated that, for the bands used, no significant information on soil water content could be obtained by band ratioing. Thus, the variability in soil water content should insignificantly affect soil-type discrimination based on identification of type-specific spectral signatures. Therefore, remote sensing, conducted in the 0.4 to 1.0 μm wavelength region of the solar spectrum, would seem to be much more suited to identifying crop- and soil-types than to estimating of soil water content.

PERSONNEL: R. D. Jackson, S. B. Idso, R. J. Reginato, W. L. Ehrler

TITLE: COMPUTER SIMULATION OF GREENHOUSES

NRP: 20760 CRIS WORK UNIT: 5510-20760-001

CODE NO.: Ariz.-WCL 70-1

INTRODUCTION:

The first objective of this project was to develop a computer model to simulate all significant heat exchange processes occurring in a greenhouse. This initial objective was accomplished several years ago [Kimball (2)], but the model was intended primarily for short-term studies of the feasibility of various methods for cooling sealed, CO_2 fertilized greenhouses. Now the need has arisen to compute the annual operating costs (energy and $) of greenhouses which store solar energy, and of greenhouses cooled by cooling tower water. The original program did not model these additional devices and therefore required revision.

MODULAR ENERGY BALANCE PROGRAM:

The first attempt to meet the need for a greenhouse program that would also model devices such as cooling towers and hot water storage tanks, was to make additions to the old program. However, the additions did not mesh easily, and the cumbersome result proved to be too big to fit the minicomputer (32K 16-bit-word memory) at load time.

Fortunately, at about this time, Klein et al. (3) reported they had developed a program named TRNSYS for simulating solar processes. They claimed to have component models for solar collectors, controls, storage tanks, heat exchangers, furnaces, etc. Since they had already modeled several of the devices to be attached to the greenhouse in this project, a copy of their program was purchased from the University of Wisconsin.

The TRNSYS program consists of a large main executive FORTRAN program and a set of subroutines. Each subroutine models a particular device such as a solar collector, thermostat, pump, etc. The program is highly versatile because the user specifies at run time which of the devices he wishes to include in a particular run, and how they are connected to each other (wire, pipes). The main program

keeps track of the interconnections and iterates and tests for convergence.

The TRNSYS program was purchased to avoid duplicating the models of the many energy-handling devices, and many of these simulation subroutines are being used with minimal modification. However, the main program proved to be of most value in a way not anticipated before purchase. All of the actual modeling is done in the subroutines, so the main program is relatively small. This feature makes the program ideally suited for implementation on a minicomputer with a disk operating system such as owned by the U. S. Water Conservation Laboratory. Therefore, a new modular energy balance (MEB) program was written which incorporates TRNSYS concepts. It differs from TRNSYS first by being as "lean" as possible (Klein et al. could afford to put a lot of extras since they had access to a huge university computer) and secondly, by having all the subroutines stored as overlays on the disk. This modular organization allows a small portion of computer memory to be dedicated to the main program, while the remainder can be used for subroutine modules. The main program brings subroutine modules in from the disk as called. The program can model many devices, but the subroutine for only one device needs to be in memory at one time.

The MEB main program has been written and debugged. Then the previous greenhouse model equations [Kimball (2)] were reorganized into a new subroutine compatible with MEB. A second greenhouse subroutine was also written based mostly on the model of Walker (5). It is a simple model in that only solar, wall conduction, ventilation, and externally-imposed heat fluxes are considered, whereas the Kimball model considers all solar, thermal radiation, sensible, latent, ventilation, and soil heat fluxes from several surfaces in the greenhouse. Comparisons will be made between the two models to see if greater complexity is justified by sufficiently greater accuracy. The two greenhouse subroutines are now being debugged.

DECODER FOR NATIONAL WEATHER SERVICE DATA:

In order to compute the annual operating costs (energy and $) of greenhouses which store thermal energy, or which are cooled with cooling tower water, etc., the modular energy balance (MEB) program must run with input weather data for a particular geographical location. Since the performance of thermal energy storage devices is affected by the sequence of warm and cold weather, it was decided to compute the costs using actual weather data, rather than fabrications based on average maximum temperatures, or whatever. Accordingly, a magnetic tape of National weather Service data was purchased from the National Climatic Center, Ashville, North Carolina, for the year 1973. The tape contained all the routine weather data observed at 3-hour intervals for 9 locations representative of different geographical areas in the United States. The locations were Flagstaff, Montgomery, Dodge City, Cleveland, Midland, Phoenix, Sacramento, Bismark, and Spokane. Since the USWCL does not have magnetic tape equipment, the weather tape had to be taken to a local computer company for copying from tape to a magnetic disk compatible with our minicomputer.

Even after the data were on the disk, additional processing was required to make them compatible with the MEB program. Hourly values were interpolated from the 3-hourly observations using the 4-point method of Snyder (4). Windspeed, pressure, wet and dry bulb temperature dew point, and relative humidity were converted to SI units and output in a different format. Solar radiation was considerably more difficult, however. It was not on the tape because the National Weather Service does not record solar radiation on a routine basis. Instead, they observed cloud amount and cloud type, from which solar radiation had to be approximated. First, the clear sky radiation was computed from sun angle equations as before [Kimball (2)]. Then the method of Kimura and Stephenson (1) was used to adjust the clear sky radiation using the cloud cover information on the tape.

SUMMARY:

In order to evaluate the annual operating costs (energy and $) of greenhouses which store solar energy or which utilize cooling towers for temperature control, a more complicated computer model was needed. Therefore, a modular energy balance (MEB) was written patterned after a program from the University of Wisconsin. The modules are subroutines, each of which simulates the performance of some energy-related device (solar collector, pumps, etc.). The prior greenhouse model was rewritten in subroutine form compatible with the MEB program. The program is highly versatile because the user specifies at run time which of the devices he wishes to include in a particular run and how they are connected (wires and pipes) together. The main program keeps track of the interconnections and iterates and tests for convergence. The program virtually has no size limit as implemented on the USWCL minicomputer with disk operating system because the subroutines are stored on the disk as overlay modules. The main program calls them into core memory one at a time as needed for the particular simulation. The main program and several subroutines are debugged and running. The greenhouse subroutine is currently being debugged.

The MEB program requires weather data for input. Therefore, a magnetic tape of the routine weather observations made by the National Weather Service for 1973, for the Flagstaff, Montgomery, Dodge City, Cleveland, Midland, Phoenix, Sacramento, Bismark, and Spokane locations was purchased, and a decoding program was written to process the data into a format compatible with the MEB program. Except for solar radiation, the processing mostly involved interpolation of hourly values from the 3-hourly observations and conversion to SI units. The solar radiation, however, had to be computed from clear sky equations and then adjusted for cloud cover using cloud amount and cloud type information recorded by the National Weather Service. Use of these data should enable the MEB program to compute reliable estimates of the annual operating costs and conditions of greenhouses with many different potential energy-saving devices.

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PERSONNEL: B. A. Kimball

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

NRP: 20760 CRIS WORK UNIT: 5510-20760-001

CODE NO.: Ariz.-WCL 71-1

No additional experiments have been run this year. The data from the six species mentioned in the 1975 report have been included in a manuscript to be submitted to the Agronomy Journal.

The controllers for the Environment Room have been updated by purchase of solid-state equipment to control air temperature and vapor pressure. Further research will focus on differences in water-use efficiency of (1) high- versus low-yielding wheat cultivars, (2) isogenic lines of barley with specific chlorophyll mutations, and (3) Pima versus Deltapine species of cotton.

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

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

NRP: 20760 CRIS WORK UNIT: 5510-20760-001

CODE NO.: Ariz.-WCL 72-4

Work on this research outline consisted of the publication of two manuscripts.

Understanding the swelling behavior of soils in the field has important implications in agriculture and engineering. Traditional field measurements have consisted of measuring the cracks formed as soils dried or changes in elevation of the soil surface as soils wet and dried. More recently, laboratory techniques have been developed to describe, in more detail, the effects of soil swelling in terms of changes in bulk density and soil-water content. Theoretical developments in swelling soil-water-air systems allow the calculation of position changes of an element of soil relative to a space-fixed coordinate frame. Information required to make this calculation are bulk density and water content changes with time together with elevation changes of the soil surface. Measurements of these parameters can be made rather easily in the laboratory, but with much more difficulty in the field because of instrumentation problems. Recent research was successful in making *in situ* measurements of these parameters.

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PERSONNEL: Robert J. Reginato

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

NRP: 20760 CRIS WORK UNIT: 5510-20760-001

CODE NO.: Ariz.-WCL 72-6

Work conducted under this outline this year fell into two major categories: processes of climatic change, and responses of plants to their environment. Five manuscripts were prepared on the first of these topics, and two on the second.

All of the papers on climatic change were reviews of past work at this laboratory that has previously been described in past annual reports. The primary thrust of these reviews was that tropospheric aerosols tend to warm the earth by a process known as "thermal blanketing," whereby terrestrial radiation from the earth's surface is absorbed by such particles and radiated back towards earth, restricting the loss of this heat radiation to deep space. A secondary point made was that certain current ideas of desertification being caused by increasing the albedo of the earth's surface are out of keeping with reality.

The two papers dealing with the response of plants to their environment were results of new research. Specifically, they derived from an experiment conducted on the laboratory's adjacent field that in years past was used in bare soil studies of remote sensing techniques to estimate soil water content and evaporation rates. Similar studies were conducted this year on the site with spring wheat (Triticum durum Desf. var. Produra).

In the first study, we found that an equation we had developed the year before for calculating potential evaporation from bare soil surfaces worked equally well for the wheat crop. In extensions of this experiment, we found that it also worked for an adjacent open water surface, as well as for grass, field beans, and alfalfa grown in California. The equation is adaptable to use in a remote sensing context. It is given by

$$E = 1.72 \times 10^{-2} \, [S_N + 1.56 \, (R_A - R_G) + 156]$$

where E is the 24-hour evaporation rate in mm day^{-1}, 1.72×10^{-2} is a conversion factor for changing from energy evaporation units of cal cm^{-2} to mm of water evaporated, S_N is the net solar radiation absorbed by the surface during the day, 1.56 and 156 are empirical coefficients previously derived from bare soil data, and R_A and R_G are 24-hour totals of incoming thermal radiation from the atmosphere and outgoing thermal radiation from the surface, respectively. R_A is calculated by means of the Idso-Jackson equation (Idso and Jackson, 1969), based solely on screen-level air temperature. A tabulation of this equation is given in Brown (1973). A daily input value is obtained by using the average of the daily maximum and minimum air temperatures. R_G is calculated by means of the Stefan-Boltzmann equation, which is also tabulated in Brown (1973). The average of the daily maximum and minimum surface temperatures provides the input for this equation.

The second study to come out of the wheat experiment had to do with an extension of the classical "degree day" concept of plant phenological development to include water stress effects. We found that the reproductive growth stage of the wheat we grew in six different irrigation treatments varied from 32 days for plants growing in the driest plot to 57 days for plants growing in the wettest plot. However, we showed that by a proper scaling and addition of "stress degree days" - the new parameter developed by us to predict crop yields (Idso, et al., 1977) and indicate need for irrigation (Jackson, et al., 1977) - this great variability in duration of reproductive growth period could be adequately modeled.

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4. Jackson, R. D., Reginato, R. J., and Idso, S. B. Wheat canopy temperature: a practical tool for evaluating water requirements. Water Resources Res. (In press). 1977.

PERSONNEL: Sherwood B. Idso, Ray D. Jackson, Robert J. Reginato, John Pritchard, and Harold Mastin

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

NRP: 20760 CRIS WORK UNIT: 5510-20760-001

CODE NO.: USWCL 73-4

INTRODUCTION:

For background information, see the Annual Reports for 1973-1975, inclusive.

PROCEDURE:

Rainfall and runoff data were collected for every storm throughout the year. A second collector barrel was installed in tandem with the original below the T_2 catchment to permit measurement of 100 percent runoff from storms with as much as 35 mm of rain.

RESULTS:

Rainfall in 1976 was almost identical with that for 1975, but with a better distribution (Table 1). Treatment T_2 continued to be far better at collecting water than T_1 (Table 2), the superiority being evident throughout all storm sizes, and averaging 92 percent runoff as compared with 31 percent as a weighted average for the whole year. When these percentages are applied to the measured rainfall, the estimated usable water collected on the plots is given in Table 3. These appreciable differences should be reflected in the varying amounts of stored water in the soil profile.

Neutron meter readings taken in January, February, March, and April did reflect the differences in harvested water (Figure 1). Readings were discontinued after April, but it is likely that the showers in May ameliorated somewhat the precipitous decline in soil water content that occurred in the previous two years during May and June. If so, conditions would have been excellent for a good yield if cold weather injury had not developed in March.

A fall evaluation (04 Sep 76) showed luxurious new growth on plants of the T_2 treatment, a somewhat lesser amount on T_1 plants, and virtually none on the controls (T_o). Unfortunately, cold weather injured the plants on 04 and 05 March, and for the second successive year there was no harvest on jojoba "nuts" in June.

SUMMARY AND CONCLUSIONS:

The jojoba plant's cold tolerance seems to be one of the main limiting factors to full utilization of the potential of water harvesting. The type of catchment utilized in this study provides no flexibility in the timing of irrigation, since the plants are irrigated whenever it rains. Therefore, when frequent showers occur in the fall or early winter, the plants on treatments T_1 (smoothed soil) and T_2 (soil sprayed with dust-suppressant) may be less hardy than they would have been under drought and hence more susceptible to frost injury. Continuation of the present experiment must be done on a probability basis, in which the odds for encountering a year with optimum rainfall distribution are increased in proportion to the number of years' duration of the test.

The other alternative, offering flexibility in irrigation scheduling, would be to utilize water harvesting to establish a reservoir from which timely irrigations could be applied on demand. This latter type of irrigation would require a major alteration in the present system, but may be worth considering.

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

Table 1. Monthly rainfall on the jojoba plots.

Month		Rainfall, mm
Feb 1976		51.8
Mar		10.9
Apr		40.6
May		23.2
Jul		19.6
Sep		39.4
Oct		30.9
Nov		4.8
	1976 total	221.2
	1975 total	222.5
	1974 total	256.4

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

USERY PASS PRECIPITATION-RUNOFF CHARACTERISTICS FOR 1976

STORM SIZE, mm	NO. STORMS	TOTAL PRECIP., mm	PERCENT OF TOTAL PRECIP.	PERCENT RUNOFF	
				T_1	T_2 1/
< 5	4	13.9	6	7	72 3/
5-10	3	22.6	10	10 3/	85 3/
10-20	5	69.4	32	28	92 3/
> 20	4	115.3	52	40	95 3/
TOTAL	15	221.2	100	31 4/	92 4/

1/ General recorded runoff events constitute multiple storms.

2/ Original water repellent ("dust suppressant") supplemented with a coating of paraffin wax (AMP, 61-69 C) at 0.5 kg/m^2 on 12 Jun 75.

3/ Estimated using best available data.

4/ Estimated weighted average for whole year.

Table 3. Estimated usable water for 1976 on the three treatments.

Treatment	Harvested Water, mm
T_o	221
T_1	563
T_2	1293

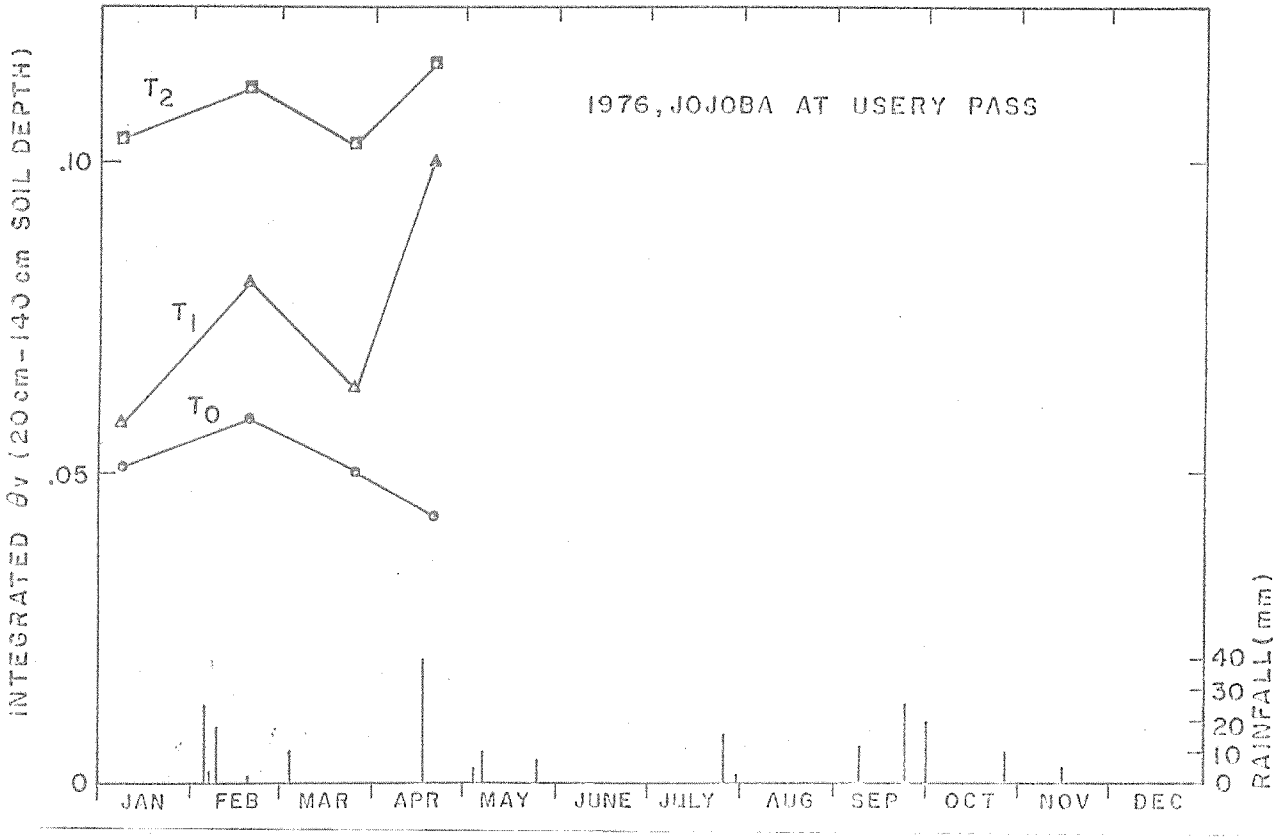

Figure 1. The 1976 course of volumetric soil-water content (θv) integrated over the depths of 20 to 140 cm, in treatments T_o, T_1, and T_2 as obtained from neutron meter access tubes located 30 cm from the plant crown.

TITLE: TEMPERATURE CONTROL OF CO_2-FERTILIZED, SEALED GREENHOUSES

NRP: 20760 CRIS WORK UNIT: 5510-20760-001

CODE NO.: USWCL 75-1

INTRODUCTION:

One of the major objectives of this project is to demonstrate the positive yield responses attainable with CO_2 fertilization in a sealed greenhouse. Last year we reported on the construction of a test greenhouse and the associated CO_2 concentration controls. This year funds were obtained for three more houses, bringing the total to four (4). For all of 1976, construction of the houses has been the major activity. The houses are completed, and presently are being instrumented for collecting data such as CO_2 concentration, radiation, water temperature, air temperature, vapor pressure, etc.

"Tropic", a greenhouse variety tomato, was sown in peat cubes on 7 January 1977, and will be transplanted in approximately two weeks into rows 3 ft apart. The plants will be staggered 18 inches apart each row. Each house will have 50 plants.

Figure 1 shows the physical layout of the greenhouses and utility lines. Greenhouses 3 and 4 have evaporative cooling towers outside the greenhouse for cooling the water, which is then piped to heat exchanger pads inside the sealed greenhouses. Greenhouse No. 2 is not sealed, and is the experimental control at ambient CO_2 concentration. It has evaporative pads at one end, and an exhaust fan at the other. However, its cooling pads are also a cooling tower furnishing cool water for greenhouse No. 1, while furnishing cool air for greenhouse No. 2. All pads are horizontal, 2-inch thick aspen as described in our 1975 Annual Report.

PERSONNEL: S. T. Mitchell, B. A. Kimball, M. Turner, B. Dorman

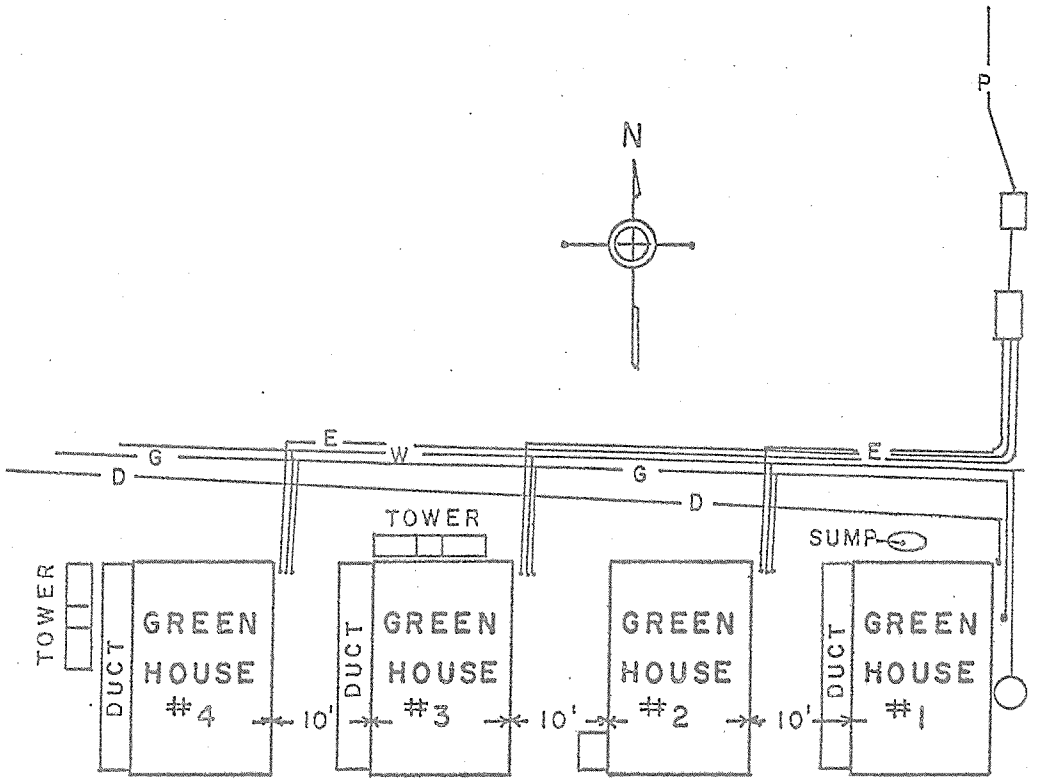

Figure 1. General plan of the test greenhouses and utility lines.
E = electricity; W = water; G = gas; D = drain.

TITLE: WASTEWATER RENOVATION BY SPREADING TREATED SEWAGE FOR GROUNDWATER RECHARGE

NRP: 20790 CRIS WORK UNIT: 5510-20790-001

CODE NO.: Ariz.-WCL 67-4

INTRODUCTION:

The work at the Flushing Meadows Project in 1976 essentially was a continuation of the studies in 1975, when the main objectives were to see how much nitrogen removal could be increased by a reduction in the length of flooding periods and in the infiltration rate, and to what levels the ammonium concentrations in the renovated water, which started to decline in 1975, would eventually drop.

The work at the 23rd Avenue Project was centered around the effect of algae in the effluent on infiltration to determine the feasibility of by-passing the 80-acre lagoon from which the infiltration basins now receive their water. Progress was made in efforts to enable pumping renovated water from the production well at a lower electric rate. Pending the outcome of these negotiations, the pipeline has not yet been extended to pump renovated water into an irrigation canal for unrestricted use on crop land.

Mr. E. W. Errickson, a City of Phoenix employee assigned to the U. S. Water Conservation Laboratory to work on the 23rd Avenue Project, resigned in October. Dr. J. C. Lance left in November for a 1-year assignment with the National Program Staff in Beltsville, Maryland. The Wastewater Renovation Group was joined by Mr. A. Roeloffzen from May to November. Mr. Roeloffzen is a student of the National Agricultural University of Wageningen, The Netherlands, and worked at the laboratory as part of his post-graduate practical training requirements.

I. FLUSHING MEADOWS PROJECT

1. Basin Management and Infiltration Rates.

The condition and management of the basins in 1976 was the same as in 1975 (see 1975 Annual Report), except that the water depth in the basins was held at about 7 inches (one 6-inch board in each

outflow structure) in all basins and during the entire length of the flooding period. Thus, reduced depths as maintained in 1975 at the beginning of flooding periods to enhance denitrification by lower rates of nitrate leaching from the root zone, were not used again in 1976, primarily for simplicity's sake and because the 1975 data did not show that it materially enhanced denitrification. The pumping schedule was 8 days on and 13 days off, producing a sequence of 9 days flooding and 12 days drying. The infiltration rates (Figure 1) mostly were between 1 and 2 ft/day, except for basin 3, which had rates of 2 to 3 ft/day for most of the year. Infiltration rates generally did not decline much during flooding and fully recovered during drying. The accumulated-infiltration curves (Figure 2) showed that basin 1, which had always been in bare soil, had the lowest infiltration. Basins 2, 4, 5, and 6 did not show much difference, whereas basin 3 had significantly higher infiltration rates. The trend for increased infiltration in basin 3 already started in July 1975, when the accumulated infiltration curve started to rise from an average position to reach the highest value at the end of the year. The average accumulated infiltration for all six basins in 1976 was 198 ft, which is slightly higher than the 173 ft obtained in 1975. This difference may primarily be due to the high infiltration rate in basin 3. Disregarding basin 3, the average accumulated infiltration of the other five basins in 1976 was 175 ft, which is close to the average infiltration for all basins in 1975.

2. Response of Water Table to Infiltration.

Where the aquifer is deep, the rise of the water table in the first few days of flooding is a good measure of the hydraulic conductivity of the aquifer when the rise is expressed per unit infiltration rate. The water table rise per unit infiltration rate was already evaluated several times in the period 1968-1970. The resulting values were characteristic of the first few years of the project (which started in September 1967) when the aquifer was still in its original condition. The data in 1976 indicate that the rise of the water table per unit infiltration rate still is essentially

the same as that at the beginning of the project (Figure 3). Thus, the hydraulic conductivity of the aquifer did not change and clogging of the aquifer due to recharge did not occur. The rise per unit infiltration rate increased with declining elevation of the static water table, indicating that the hydraulic conductivity of the aquifer decreased with depth in the zone of water table fluctuation.

3. Nitrogen.

Total-N content of the secondary effluent normally ranged between 20 and 40 mg/l and averaged 29.2 mg/l (Figures 4, 5, and 6). Most of this nitrogen was in the ammonium form. The NO_3-N content in the renovated water showed the typical peaks, which occurred 3 to 7 days after the start of a new flooding period. The height of the peaks generally was well below the total-N level of the effluent. Samples of renovated water normally were not obtained during drying. Thus, the straight lines connecting the last N-content of the renovated water during flooding to the first N-content after drying, probably did not represent the true situation. Since the groundwater beneath the basins is relatively stagnant during drying, N-contents of renovated water during flooding are more significant than during drying. The NH_4-N concentrations of the renovated water in 1976 reached stable levels, after their gradual decline in 1975. Average N-concentrations in mg/l for the renovated water and percent removal (based on an average total N of 29.2 mg/l in the effluent) were as follows:

Well	Basins Served	NO_3-N	NH_4-N	Total N	Percent N-Removal
1-2	1 and 2	11.1	1.4	12.5	57
ECW	3 and 4	5.5	5.0	10.5	64
5-6	5 and 6	7.4	1.8	9.2	68

The higher NH_4-N content in the water from ECW may be due to the high infiltration rate in basin 3. The reason for the lower total-N in water from well 5-6 as compared to that from well 1-2 may be that

basins 5 and 6 have been vegetated for a number of years, while basins 1 and 2 were never vegetated (basin 2 is covered with a gravel layer). Also, basins 5 and 6 are at the end of the sewage supply line and receive more suspended solids with the effluent water than do basins 1 and 2. The additional organic carbon in basins 5 and 6 thus may stimulate denitrification. A third possible reason for the difference between total N in water from well 1-2 and that from well 5-6 is that well 5-6 is in finer-textured material than well 1-2.

4. Phosphate.

The average PO_4-P content of the secondary effluent generally ranged between 5 and 12 mg/l with an average of 8.7 mg/l. This is about the same as the 8.4 mg/l observed in 1975. The PO_4-P concentrations in the renovated water tend to be lower at the beginning than at the end of a flooding period (Figures 7, 8, and 9). Thus, there apparently was a decrease in PO_4-P immobilization in the soil as flooding progressed. Average PO_4-P concentrations in mg/l and removal percentages were:

Well	Average PO_4-P	Percent PO_4- P Removal
1-2	3.1	64
ECW	1.9	78
5-6	1.6	82

The ECW, which is 30 ft deep, and well 5-6, which is in finer-textured material, showed greater P-removal than well 1-2. Additional P-removal takes place with continued lateral movement through the aquifer. A sample of water from well 1 outside the basins, taken on 18 May, for example, had a PO_4-P concentration of essentially zero.

5. Organic Carbon.

Average organic-carbon concentrations were 24 mg/l for the secondary effluent and 4 mg/l for the renovated water (Table 1). The range of total organic carbon content in the renovated water was 0 to 9 mg/l.

6. Fluoride.

Fluoride concentrations averaged 2.3 mg/l for the effluent and 1.8 mg/l for the renovated water (Table 2). The effluent fluoride concentration was almost half of what it was in previous years.

7. Boron.

Boron concentrations also dropped to almost one-half the previous values. Concentrations in 1976 were about 0.5 mg/l in both effluent and renovated water (Table 3).

8. Total Dissolved Salts.

The total-dissolved salts content of sewage and renovated water remained at around the 1,000 mg/l level (Table 4).

9. Summary and Conclusions.

Shorter flooding and drying periods (i.e. 9 and 12 days, respectively) and lower water depths in the basins (7 inches) continued to produce high nitrogen removal (57 to 68%) from the sewage effluent at the rapid infiltration Flushing Meadows Project. Total-nitrogen content of the renovated water pumped from below the groundwater table averaged 10.7 mg/l, whereas the NO_3-N content averaged 8 mg/l. The rest (2.7 mg/l) was NH_4-N, which reached a stable concentration in the renovated water after a gradual decline that started in 1975 when shorter flooding periods were first used. Average phosphate concentrations of the renovated water sampled after 20 to 30 feet of underground movement were 1.6 to 3.1 mg/l PO_4-P, yielding removals of 64 to 82%. Fluoride and boron levels in the sewage effluent were lower than in previous years, i.e. 2.3 and 0.5 mg/l, respectively. The fluoride concentrations in the renovated water were slightly less (1.8 mg/l), whereas the boron concentrations were the same as in the effluent. Refractory organics were present in the renovated water at concentrations of 0 to 9 mg/l (average 4 mg/l). There is a need for identifying these organics to determine if they may be hazardous to human health when the renovated water is used for drinking. The TDS-content of the sewage effluent and renovated water remained at about 1,000 mg/l.

The flooding sequence of 9 days wet—12 days dry, which was started in 1975, thus continued to produce about twice as much nitrogen removal and 1.6 times as much phosphate removal as did the previously used sequence of 14 days wet—14 days dry. The hydraulic loading rate was about one-third less (198 ft in 1976, compared to about 300 ft obtained with the 14-day flooding periods used before), but the system was still very much high rate. The response of the groundwater table to infiltration was the same in 1976 as in the first 2 years of operation of the project 9 years ago, indicating that continued rapid infiltration of sewage effluent had not affected the hydraulic conductivity of the underlying aquifer. Thus, the rapid infiltration system showed no signs of aging after 9 years of operation..

II. 23RD AVENUE PROJECT

1. Basin Management and Infiltration Rates.

Infiltration rates for the four basins are shown in Figures 10, 11, 12, and 13. The basins were flooded for 2 weeks and dried for 2 weeks from January through May when the schedule was changed to 1 week flooding and 4 weeks drying. The average infiltration rate for each flooding period decreased from January to May. The infiltration rate during flooding was maintained at a high level in Basins 2 and 3 for 6 to 10 days during January when the suspended solids concentration of the sewage effluent was relatively low; otherwise, the infiltration rate decreased rapidly to a value generally less than 0.25 ft/day. The suspended solids content (C_s) of the water entering the basins was relatively low (10 to 25 mg/l in January and increased to an average value of > 50 mg/l (mainly algae) by mid-summer, as shown in Figure 14. As the algae concentration increased, infiltration rates decreased, making it necessary to use shorter flooding periods and longer drying periods (1 and 4 weeks, respectively). Accumulated infiltration amounts for the period January through September were:

Basin 1 39 ft

Basin 2 72 ft

Basin 3 42 ft

Basin 4 25 ft

The infiltration rate for basin 4 was considerably below that for the other basins because water would not drain properly from the basin during the drying period. At least half of the ground surface would still be wet when flooding was resumed, yielding poor recovery of infiltration rates. During the 1-week-flooding and 4-weeks-drying cycle, essentially the entire soil surface dried up and the infiltration rates during the succeeding flooding period were higher. The schedule of 1 week flooding—4 weeks drying resulted in an increase in the infiltration rates for basins 1, 3, and 4. Basin 2 did not show an increase in infiltration because the water depth was maintained below 1 ft during this time period for other studies. There are two explanations for the increase in infiltration rate. First, the longer drying period allowed more decomposition of the clogged algae layer. Second, less time was available for algal growth in the basins. Because little water was infiltrated during the second week when 2-week flooding periods were used, the shorter flooding period produced a greater total infiltration. The hydraulic loading rate (taking drying time into consideration) was about the same for the 2 weeks flooding—2 weeks drying as for the 1 week flooding—4 weeks drying schedule.

Infiltration rates tend to decrease linearly when plotted against cumulative infiltration. This can be expressed by the equation

$$I = I_o - \alpha C_s T \qquad (1)$$

where I = infiltration rate, I_o = initial infiltration rate, α = coefficient of clogging, C_s = suspended solids concentration, and T = cumulative infiltration. The equation assumes that any decrease in infiltration rate is due to soil clogging at the surface, and that there is no change in water depth. The α-values were evaluated

for different infiltration periods and basins when the water level was relatively constant. The results (Table 5) show that α ranges between 1.2 and 6.5 m^3 day^{-1} kg^{-1} and averages 3.4 m^3 day^{-1} kg^{-1}. These values are typical of water containing organic suspended solids. The α-values are independent of water depth.

To determine if the secondary effluent from the treatment plant prior to entering the 80-acre oxidation pond would produce higher infiltration rates than the effluent from the 80-acre pond used for the infiltration basins, test plots were installed in basin 2. The plots were 1 meter square and were constructed by placing a 45-cm-high sheet metal barrier 15 cm into the ground surface. A valve was installed in the sheet-metal border at ground level to permit filling and draining of the plot. Plots 1, 2, and 3 were in fine, sandy soil while plot 4 was located in coarse sand and gravel. Initially, the plots were flooded through the open valve when the entire basin was also flooded. Infiltration measurements were taken by closing the valve and measuring the rate of fall of the water surface inside the plot with a point gage over a short period of time. The average α-value of the test plots, which received 80-acre pond effluent like the rest of the infiltration basin, was essentially the same as that obtained for the entire basin, i.e. 3.4 and 2.3, respectively. This indicates that the plots accurately represented the conditions of the basin.

The plots were then used to determine the effect of water quality on infiltration rate. While the rest of the basin was kept dry, straight secondary effluent, 80-acre pond effluent, and renovated water were applied to plots 1, 2, and 3. The following results were obtained:

Plot	Water	Flooding period	C_s mg/l	I_o ft/day	I_{end} ft/day	$I_{average}$ ft/day
1	Renovated	23-30 Sep	0	2.1	2.0	2.0
1	80-acre pond	13-22 Oct	35	1.5	1.1	1.3
2	Effluent	4-16 Oct	9	2.7	2.3	2.4
3	Renovated	14-22 Sep	0	2.2	2.4	2.3
3	Effluent	2-14 Nov	10	1.5	1.8	1.7

The average infiltration rate for the 80-acre pond water was about half of that for the secondary effluent. The infiltration rate remained essentially constant when secondary effluent or renovated water was used but decreased with time when 80-acre pond water was used. The α-value for the 80-acre pond water was 1.2 m^3 day^{-1} kg^{-1}, which is about one-half of the α-value obtained when the entire basin was flooded. This is probably due to the fact that the pond water was stored in a tank, which resulted in a decrease in the suspended solids content. The α-values for the renovated water and secondary effluent were essentially zero because infiltration rates did not decrease during flooding.

The infiltration rates in the test plots, and in the basins when the effluent had a low algae content, indicate that a substantial increase in infiltration rates can be obtained when straight secondary effluent is used instead of water from the 80-acre pond. The plots, for example, show that straight secondary effluent produced infiltration rates almost double those for the pond effluent. Since higher infiltration rates also enable shorter drying periods, annual hydraulic loading rates can be expected to be more than doubled by switching from pond effluent to straight secondary effluent.

2. Groundwater Levels.

Water levels in the observation wells started to decline in March and fell below the bottom of the north well in the latter part of April (Figure 15). This was probably due to general pumping in the area. Water levels in the center well corresponded to those

in the north well until the middle of April. The water-level response of the south well continued to be slow, but it did indicate a declining trend after April. The north well responded to each infiltration period while it contained water (from January to the middle of March). The water level in the center well showed a response to infiltration periods when the well was not pumped.

3. Soil-Air Pressure.

When large areas are used for groundwater recharge, such as the 10-acre basins in this project, entrapped air below the advancing wet front may produce reductions in infiltration rate. To investigate this possibility, the soil-air pressures were measured below basin 2 with three piezometers installed at depths of 10, 20, and 40 ft. A 2-ft diameter rotary-flight auger rig was used in February to drill a 40-ft deep hole. A 2-ft diameter casing was installed in the top 25 ft to prevent sand and gravel from caving in. The size of the hole below 25 ft was larger than 2 ft because sand and gravel did cave until a stable hole was formed. Piezometers were placed in the hole at depths of 10, 20, and 40 ft. The piezometers consisted of a 1-ft section of 3-inch diameter, perforated plastic pipe connected to a 1/2-inch diameter pipe that extended to the surface. Each piezometer was located in a 20-inch gravel layer and the hole was filled with grout between the gravel layers, as shown in Figure 16. The casing was removed as the grout was installed. The grout layer was installed to prevent air movement between the different piezometer locations within the bore hole. The piezometers were connected with 1/4-inch diameter polyethylene tubing to a pressure transducer-recorder system for monitoring air pressures.

Pressure changes did not occur in the piezometers at the two shallower depths. Air pressures at the 40-ft depth, however, increased after flooding was started, as shown in Figure 17 for different infiltration periods. Following the initial increase, air pressures declined and returned to atmospheric before the end of the flooding period. The maximum air-pressure increase varied almost linearly with initial infiltration rate, as shown in Figure 18.

Expressing the air-pressure increase in terms of a water pressure head, the air-pressure increase was about equal to 7 ft of water per ft/day initial infiltration rate. Additional work is planned to assess the effect of air pressure on infiltration rate. The facts that air pressures did not increase for the shallower piezometers and that infiltration rates declined rather than increased as the air pressure at 40-ft depth returned to atmospheric indicate, however, that the air-pressure buildup at 40-ft depth probably did not have a significant effect on infiltration rate.

4. Suspended Solids.

Figure 14 shows the suspended-solids content of the secondary effluent as it enters the 80-acre pond, and then as it leaves the pond to enter the infiltration basins. The suspended-solids contents for the November-December period of 1975 are also included to show data for an entire year. The suspended solids content of the secondary effluent is low in the summer months (< 20 mg/l) and high in the winter months (about 50 mg/l). The suspended solids content of the outflow from the 80-acre pond is lower than that of the in-flowing secondary effluent from December to February, but after the first part of March it is greater. A cross-over occurs again late in November. The higher suspended solids content of the outflow from the 80-acre pond during the summer months was due to algal growth in the pond. The suspended-solids content of the pond outflow as it enters the infiltration basins generally was in the range of 50 to 100 mg/l. The average suspended solids content of the renovated water from the center well was 0.8 mg/l and ranged from 0.5 to 1.2 mg/l.

5. Nitrogen.

The total nitrogen content of the effluent entering the basins from the 80-acre lagoon averaged 23 mg/l (Figure 19). There was a sudden increase from 23 mg/l to 30 mg/l during March and then a gradual decrease to about 15 mg/l by September. The nitrate nitrogen content of the renovated water from the center well gradually

decreased from about 10 mg/l to 5 mg/l with an average of 6.7 mg/l. The NH_4-N content of the renovated water from the center well averaged 0.1 mg/l. Nitrogen removal thus averaged 71%.

6. Phosphorous.

Concentrations of PO_4-P in the effluent ranged from 2 to 10 mg/l and averaged 6.8 mg/l (Figure 20). The PO_4-P levels were lower in summer than in winter. PO_4-P concentration in the center-well water averaged 0.16 mg/l, which represents a 98% removal (essentially the same as in 1975).

7. Fluoride.

Fluoride concentrations in the 80-acre pond effluent and in the renovated water averaged 1.22 and 0.7 mg/l, respectively.

8. Boron.

The boron content was 0.5 mg/l in both the 80-acre pond effluent and the renovated water from the center well.

9. Total Dissolved Salt.

Total-dissolved-salt contents of the 80-acre pond effluent and the renovated water from the center well were essentially the same and averaged 910 mg/l.

10. Fecal Coliforms.

The fecal-coliform content of the effluent going into the 80-acre pond was about 10^6/100 ml, and about 4×10^4/100 ml for the effluent entering the infiltration basins (Figure 21). Fecal-coliform contents were zero in the renovated water except for the January-February infiltration period when counts up to 30/100 ml were observed. The two coliform peaks coincide with flooding periods for basins 2 and 3, which are next to the well. The infiltration rate in the two basins was at its highest level during those time periods and the well was continuously pumped. After that, the well was not pumped for more than 7 consecutive days during any other time of the year. The maximum coliform counts for the renovated water still were well below the 200/100 ml limit for unrestricted irrigation.

11. Delayed Yield.

The aquifer below the 23rd Avenue Project is unconfined and may, like other unconfined aquifers, show a delay in release of pore water when the water table is lowered by pumping a well. This delay produces an inflection in the curve of drawdown versus time on logarithmic paper. Special procedures must then be used to evaluate the aquifer transmissivity and specific yield from such curves. In the past, the mathematics of delayed yield (analysis of well-flow systems with initial yield much smaller than final yield) has received more attention than the physical basis of the phenomenon. Knowledge about the latter, however, is important to develop the proper mathematical model as a basis for correct analysis of well pumping-test data. Since pumping tests may be carried out at some future date to measure the hydraulic properties of the aquifer beneath the basins (as necessary for system design and prediction of underground flow systems), a study was initiated to better define the physics of delayed yield. Specifically, the problem of delayed yield was treated as a situation of restricted air movement in the vadose zone.

The restricted air flow was considered to be caused by saturated or near-saturated layers in the vadose zone. Such layers may consist of material that is finer-textured than the overlying or underlying soil. When the water table is lowered by pumping a well, the air in the vadose zone between the water table and the saturated layer then expands and air pressures reduce to below-atmospheric values. This causes the water table to initially drop faster than the dewatered zone, so that the initial yield is less than the final yield. Equations were derived to relate delayed yield to the air-entry value and to the height above water table of the saturated layers in the vadose zone. The equations agreed with results from a delayed-yield experiment on a vertical soil column and produced ratios between initial and final yield that were on the same order as those calculated by other workers from actual pumping tests. An axisymmetric flow system, simulated by interconnected jars with narrow standpipes, produced delayed-yield drawdown curves that were amenable to analysis by procedures developed for delayed yield.

The work has been written up in a manuscript ("Delayed Aquifer Yield as a Phenomenon of Delayed Air Entry" by Herman Bouwer and R. C. Rice), which will be submitted to Water Resources Research for publication. Reference to this paper is made for more detailed information.

12. Summary and Conclusions.

Growth of algae in the 80-acre oxidation pond, through which the secondary effluent of the 23rd Avenue Sewage Treatment Plant flows before it enters the four 10-acre basins of the rapid-infiltration system, resulted in a high suspended-solids content of the water (50 to 100 mg/l). This caused the infiltration rates in the basins to be low and made it necessary to use short flooding periods (about 1 week) and long drying periods (about 4 weeks). The resulting hydraulic loading rate averaged only 45 ft for the first 9 months of the year, which would be about 60 ft for the entire year. Plot studies with secondary effluent before it enters the 80-acre oxidation pond yielded infiltration rates that were almost double those obtained with the effluent from the 80-acre pond. Considering that these studies were done in the fall when growth of algae was somewhat slower, summer infiltration rates can be expected to be more than double those for the straight secondary effluent. The higher infiltration rates will also make it possible to use longer flooding and shorter drying periods. Thus, construction of a channel to by-pass the 80-acre pond and to get secondary effluent directly into the infiltration basins should more than double the hydraulic loading rate.

The depth of the water table was 60 to 90 ft below the bottom of the basins. Air pressure build-ups equivalent to as much as 9 ft of water were observed at a depth of 40 ft in the vadose zone. The pressure build-up varied almost linearly with the initial infiltration rate of the effluent. The pressure build-up decreased to zero after a few days of infiltration. No build-ups in air pressure were observed at shallower depths in the vadose zone. This indicates

that build-up of air pressure beneath the advancing wet front probably does not have a significant effect on infiltration rate.

The quality of the renovated water pumped from the center well continued to meet the requirements for unrestricted irrigation. The renovated water contained an average of 0.8 mg/l suspended solids, 6.7 mg/l NO_3-N, 0.1 mg/l NH_4-N, 0.16 mg/l PO_4-P, 0.7 mg/l F, 0.5 mg/l B, 910 mg/l total dissolved salts, and 0 to 30 fecal coliforms per 100 ml.

Studies indicated that delayed release of pore water in response to pumping from an unconfined aquifer could be caused by restricted movement of air in the vadose zone. A theoretical analysis produced delayed-yield data that agreed with those from laboratory experiments and also with general values from field observations. The study showed that mathematical analyses in which delayed yield is taken as a step-function where yield increases after the water table has dropped a certain distance, are the most suitable for determining hydraulic properties of unconfined aquifers from pumping-test data under conditions of delayed yield.

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

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

Day	Effluent	Well 1-2	ECW	Well 5-6
4 Mar		2	1.5	12.5
12 Nov	15.5	2.5	5	3
15 Nov	17	6	5.5	8
16 Nov	24.5	3	6	4.5
17 Nov	17.5	4.5	6.5	5.5
18 Nov	11	1	.5	0
2 Dec	40.5	1.5	4	1.5
3 Dec	25	5.5	4.5	6
6 Dec	19	2	1.5	1.5
7 Dec	21	2.5	1	1
8 Dec	21.5	4	4	1
9 Dec	37	3.5	6	3.5
10 Dec	26	3.5	5	3.5
13 Dec		3	1	2
14 Dec		2.5	5.5	4
15 Dec		7	8.5	9
16 Dec		6.5	5.5	8
17 Dec		8.5	3.5	9
20 Dec		3.5		3.5
27 Dec	26	7	3.5	2
28 Dec	28	3	6	4
29 Dec		3.5	1.5	1.5
30 Dec	25.5	3	3	2.5
Average	23.7	3.9	4	4.2

Table 2. Fluoride content (mg/l) of secondary effluent and renovated water from various wells.

Date	Effluent	Well 1-2	ECW	Well 5-6
14 Jan		1.68	1.54	1.6
20 Jan	2.4	1.46	1.6	1.76
3 Mar	2.28	1.76	1.64	1.64
6 Apr	2	1.2	1.46	1.46
18 May	1.57	2	1.4	1.6
7 Jun	2.14	1.8	1.84	1.54
22 Jul	2.26		2.04	1.78
13 Aug	2.88	2.24	2.04	1.92
31 Aug	1.6	2.8	2.04	2.04
27 Sep	2.4	1.76	1.82	2.06
27 Oct	2.6	2.08	2	1.8
19 Nov	2.32	1.7	1.78	1.6
10 Dec	2.74	2	1.86	1.9
Average	2.27	1.87	1.77	1.75

Table 3. Boron content (mg/l) of secondary effluent and renovated water from various wells.

Date	Effluent	Well 0	Well 1-2	ECW	Well 5-6
14 Jan			.5	.54	.54
15 Jan	.51				
10 Feb	.67		.57	.62	.71
3 Mar	.47		.61	.52	.47
6 Apr	.5		.45	.48	.65
18 May	.3		.46	.51	.38
7 Jun	.71		.48	.52	.58
22 Jul	.32			.43	.38
13 Aug	.42		.38	.38	.43
31 Aug	.45	.34	.46	.38	.42
27 Sep	.435		.57	.6	.61
27 Oct	.75		.5	.5	.54
19 Nov	.57		.6	.57	.63
10 Dec	.63		.66	.6	.5
Average	.52		.52	.51	.53

Table 4. Total dissolved solids content (mg/l) of secondary effluent and renovated water from various wells.

Date	Effluent	Well 0	Well 1-2	ECW	Well 5-6
14 Jan			832	883	864
15 Jan	915				
10 Feb	960		1056	896	947
3 Mar	896		1088	1037	947
6 Apr	1075		1088	1030	1344
18 May	960		973	960	1139
7 Jun	973		973	896	1120
22 Jul	960			992	1056
13 Aug	1024		909	1024	1120
31 Aug	960	960	1088	1216	1312
27 Sep	909		1024	960	960
27 Oct	768		960	832	1152
19 Nov	768		768	768	819
10 Dec	973		832	832	851
Average	934		965	948	1049

Table 5. Water depth, initial infiltration rate, suspended solids concentration, and α value for different flooding periods.

Basin	Water depth m	I_o m/day	C_s mg/l	α m^3/day/kg
1	.43	.55	30	3.0
	.61	.40	40	4.4
	.67	.27	46	3.0
	.70	.15	46	2.7
	.52	.18	64	2.0
	.43	.37	60	3.7
			Average	3.1
2	.05	.73	73	2.7
	.76	.58	43	4.2
	.67	.37	69	2.0
	.67	.30	46	2.0
	.73	.30	63	3.7
	.12	.18	50	2.0
	.18	.15	45	2.8
			Average	2.8
3	.43	.58	42	4.8
	.46	.30	74	2.4
	.64	.34	43	3.9
	.70	.18	69	3.5
	.64	.18	69	1.2
	.73	.15	46	2.7
	.67	.24	63	4.1
			Average	3.2
4	.73	.21	19	6.5
	.67	.18	29	4.6
	.76	.15	41	3.6
	.64	.09	46	4.0
	.64	.06	64	2.2
			Average	4.2

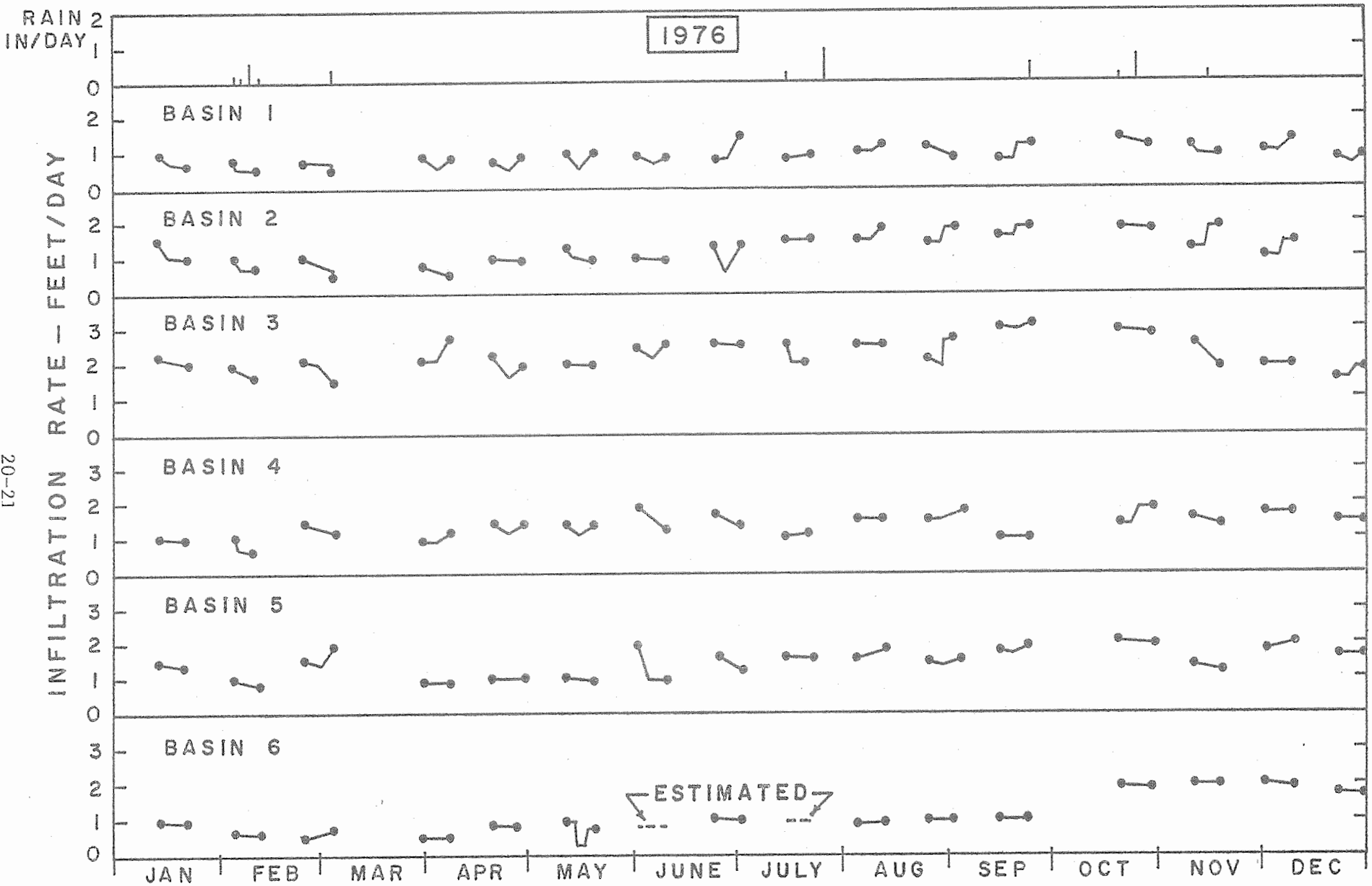

Figure 1. Infiltration rates in Flushing Meadows recharge basins and rainfall.

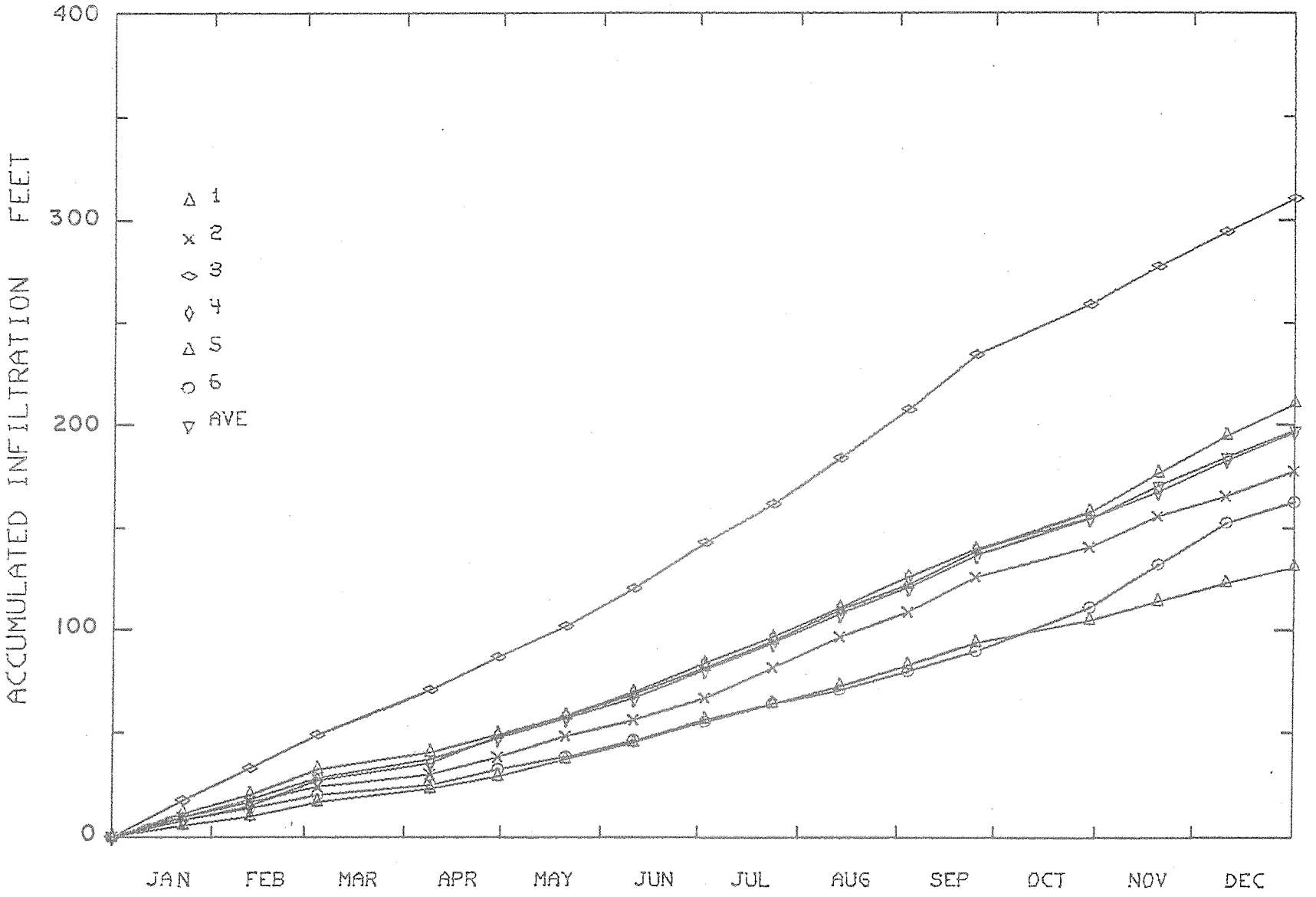

Figure 2. Accumulated infiltration in Flushing Meadows basins.

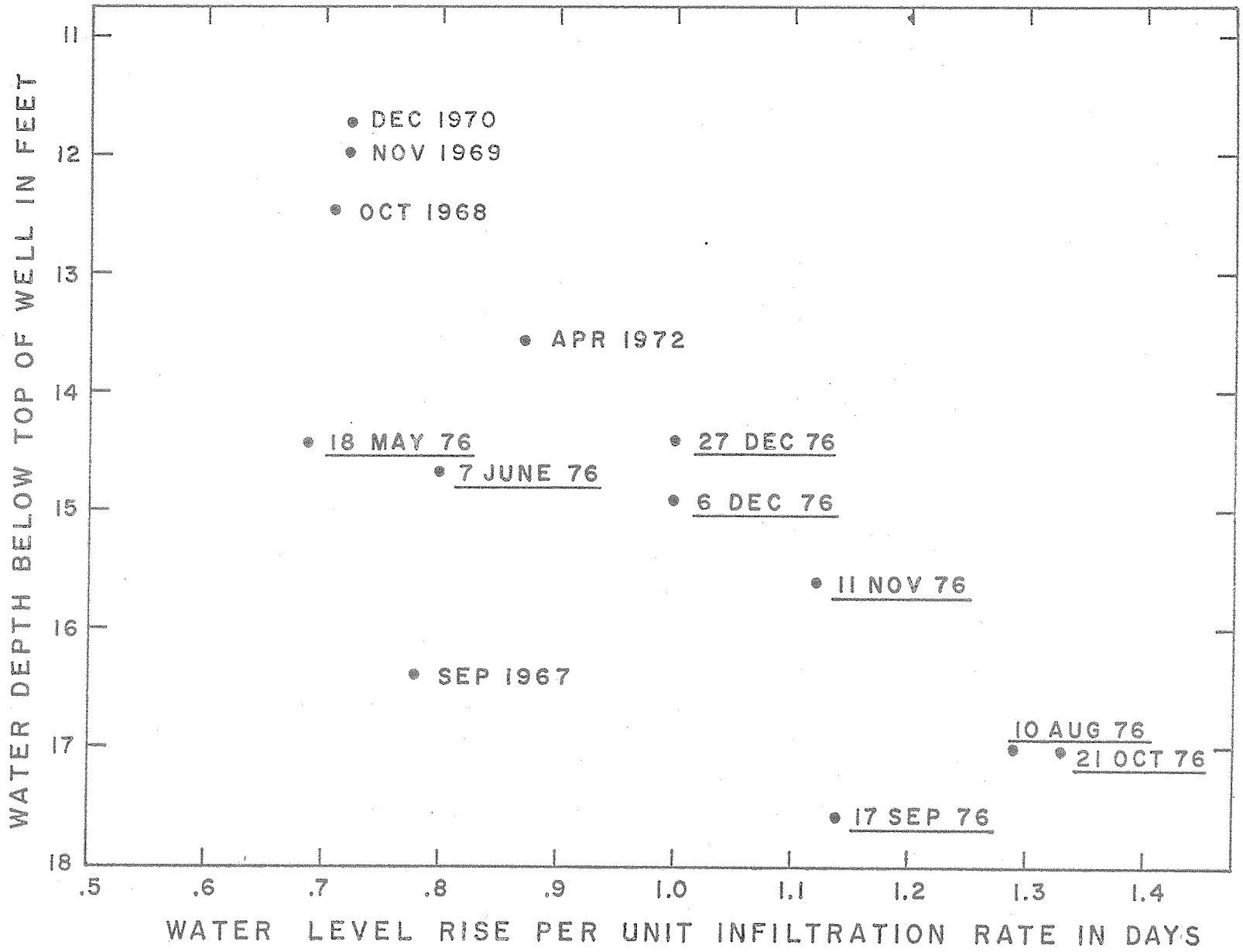

Figure 3. Rise of water level in ECW per unit infiltration rate versus depth of water table at Flushing Meadows.

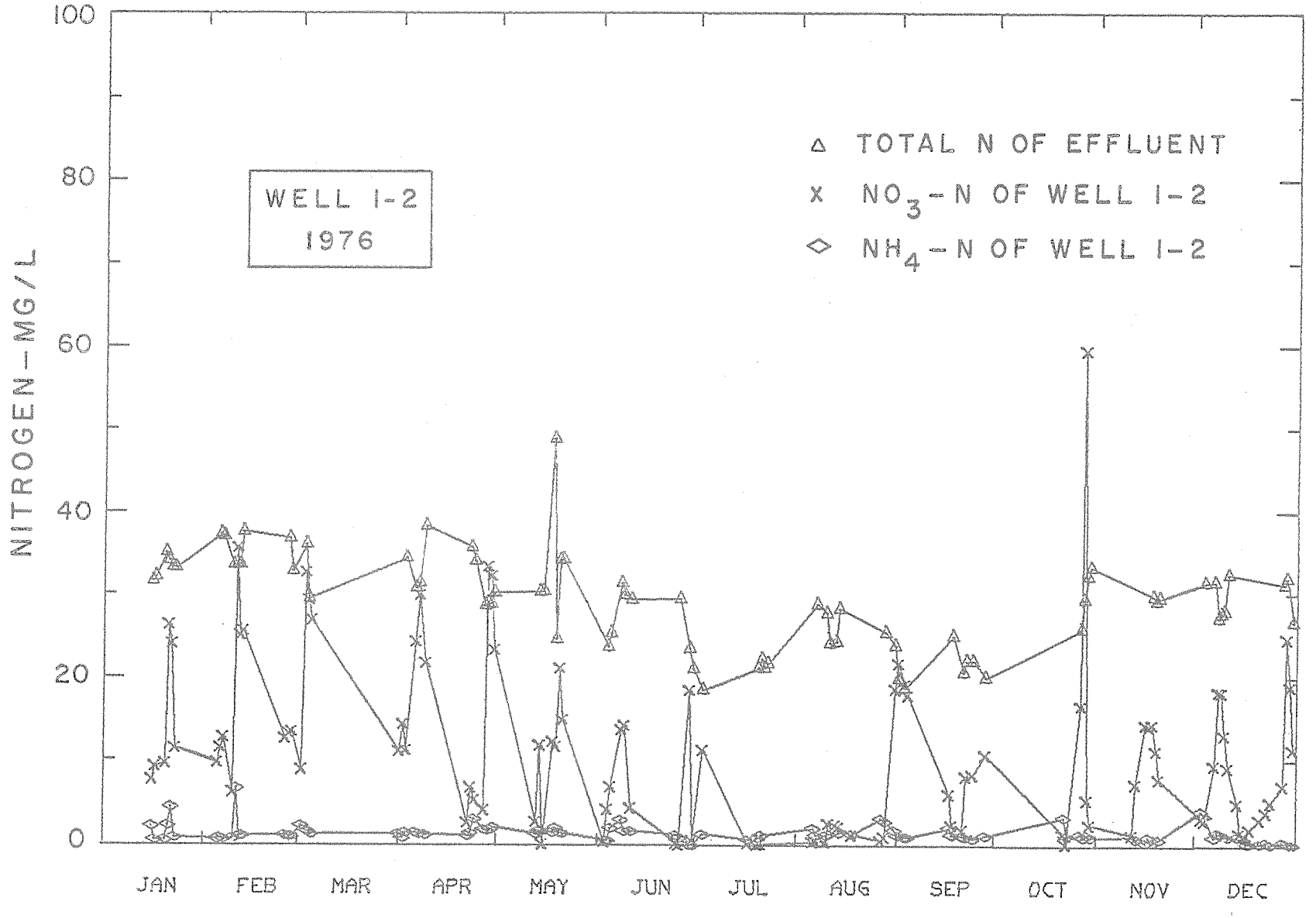

Figure 4. Total N in effluent and nitrate-N and ammonium-N in effluent and water from well 1-2.

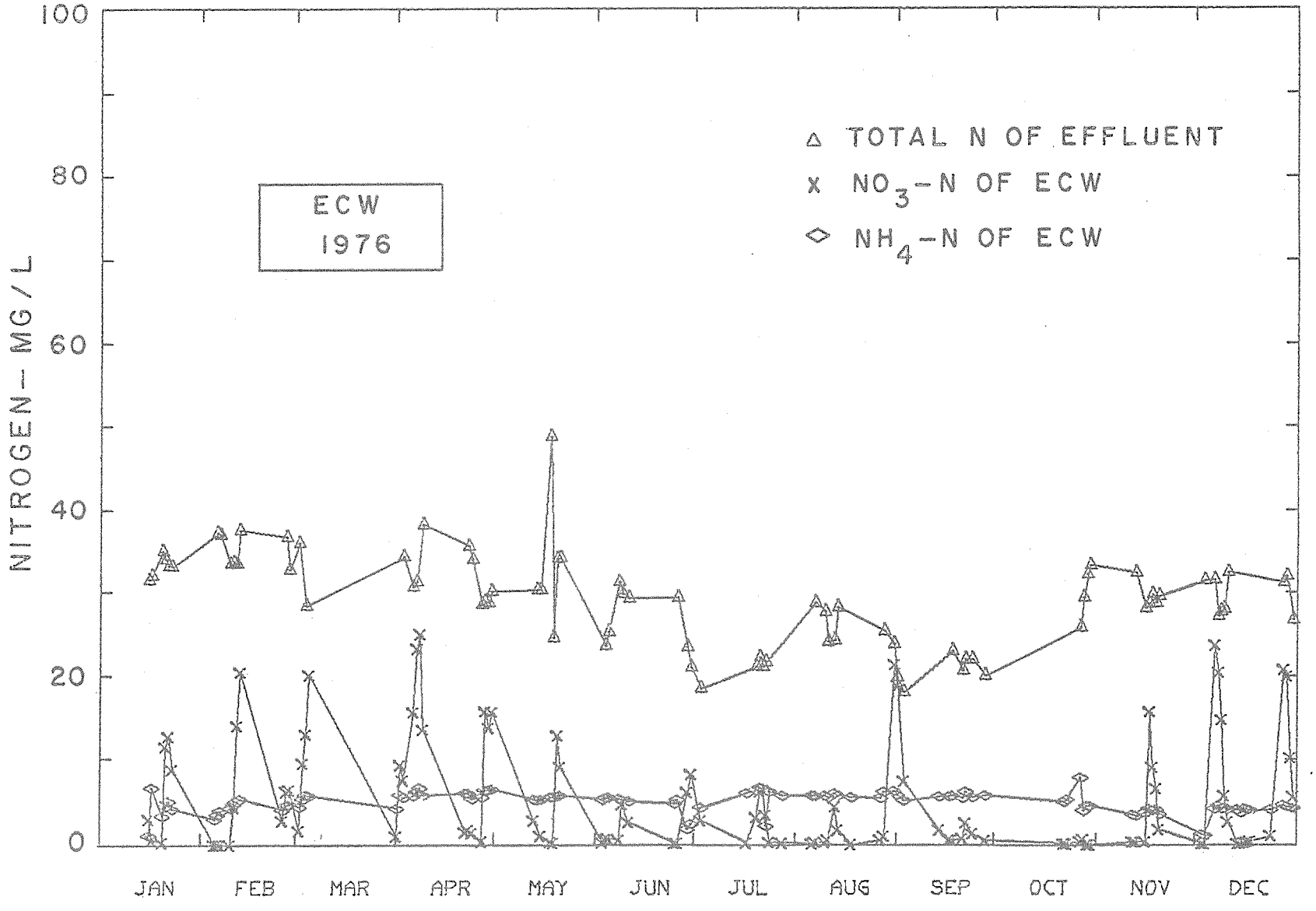

Figure 5. Total N in effluent and nitrate-N and ammonium-N in renovated water from ECW.

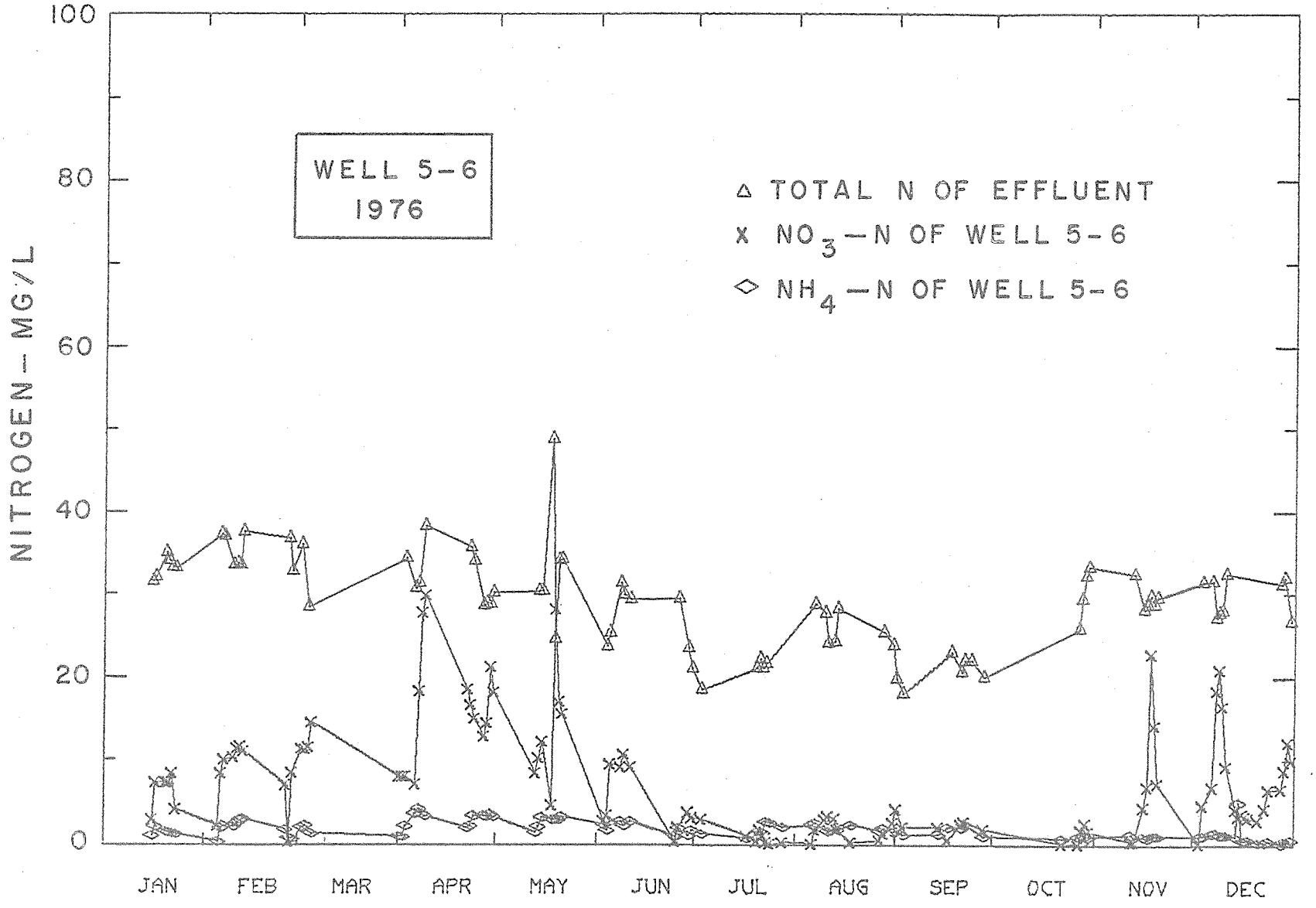

Figure 6. Total N in effluent and nitrate-N and ammonium-N in renovated water from well 5-6.

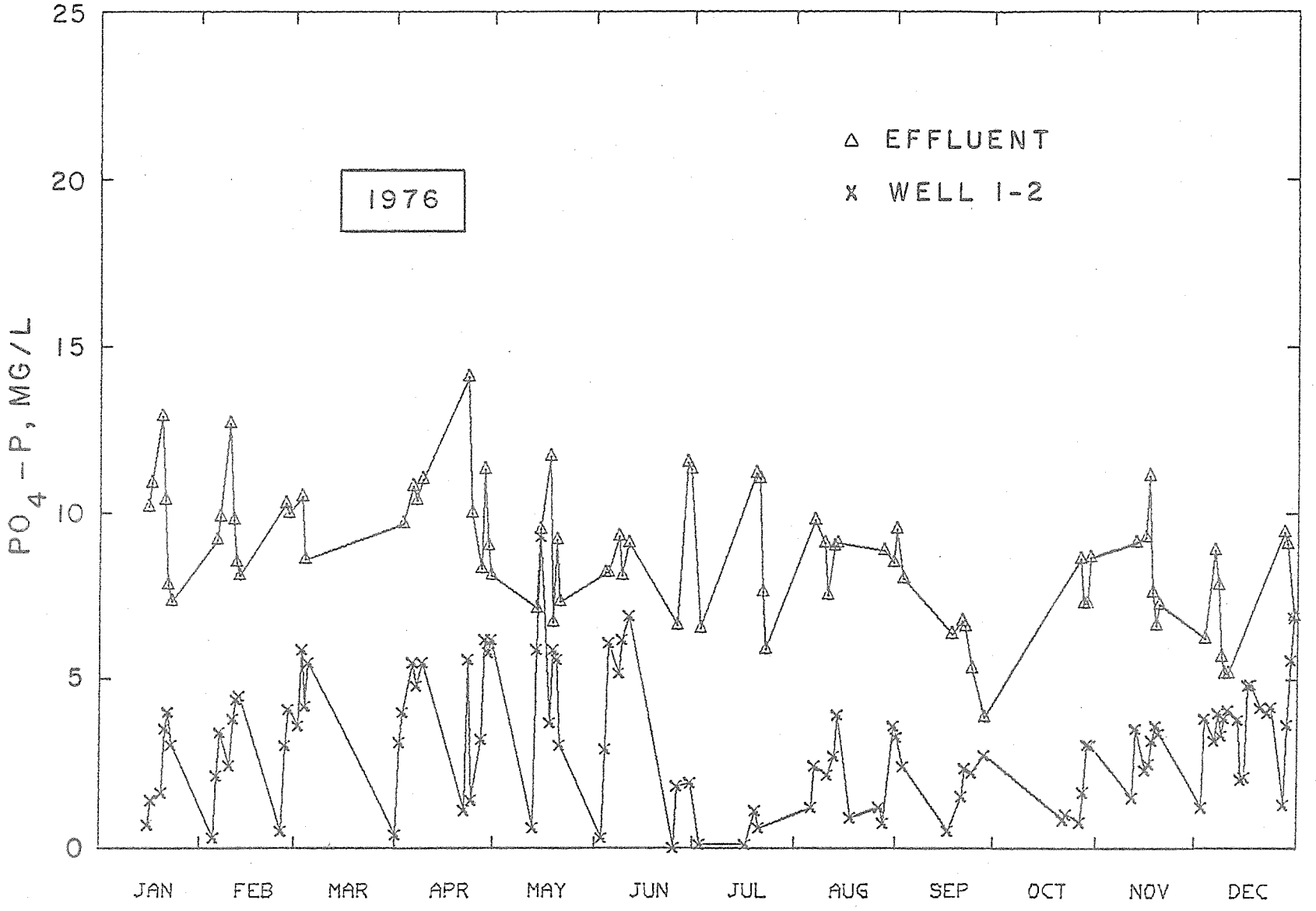

Figure 7. Phosphate-P in effluent and renovated water from well 1-2.

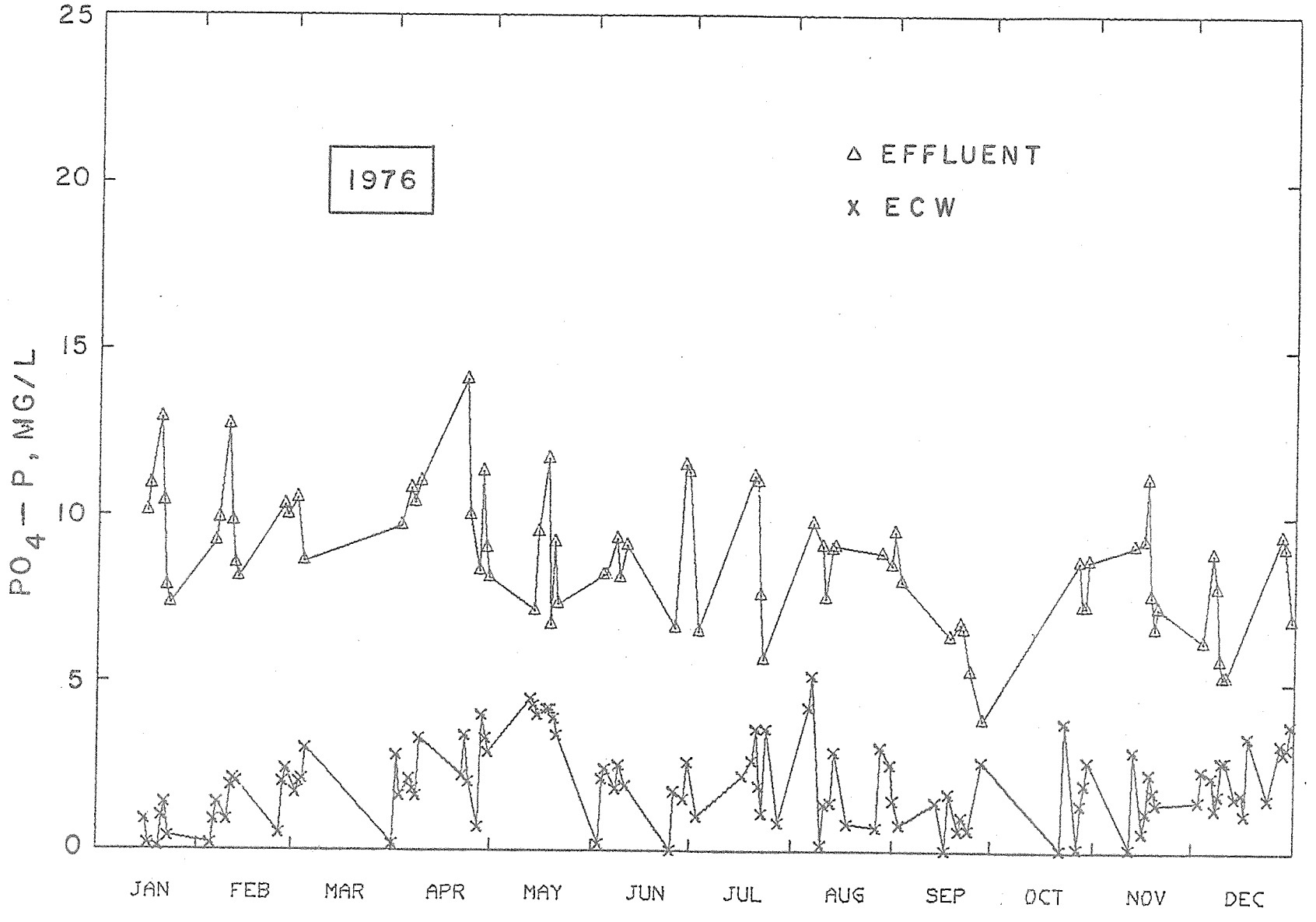

Figure 8. Phosphate-P in effluent and renovated water from ECW.

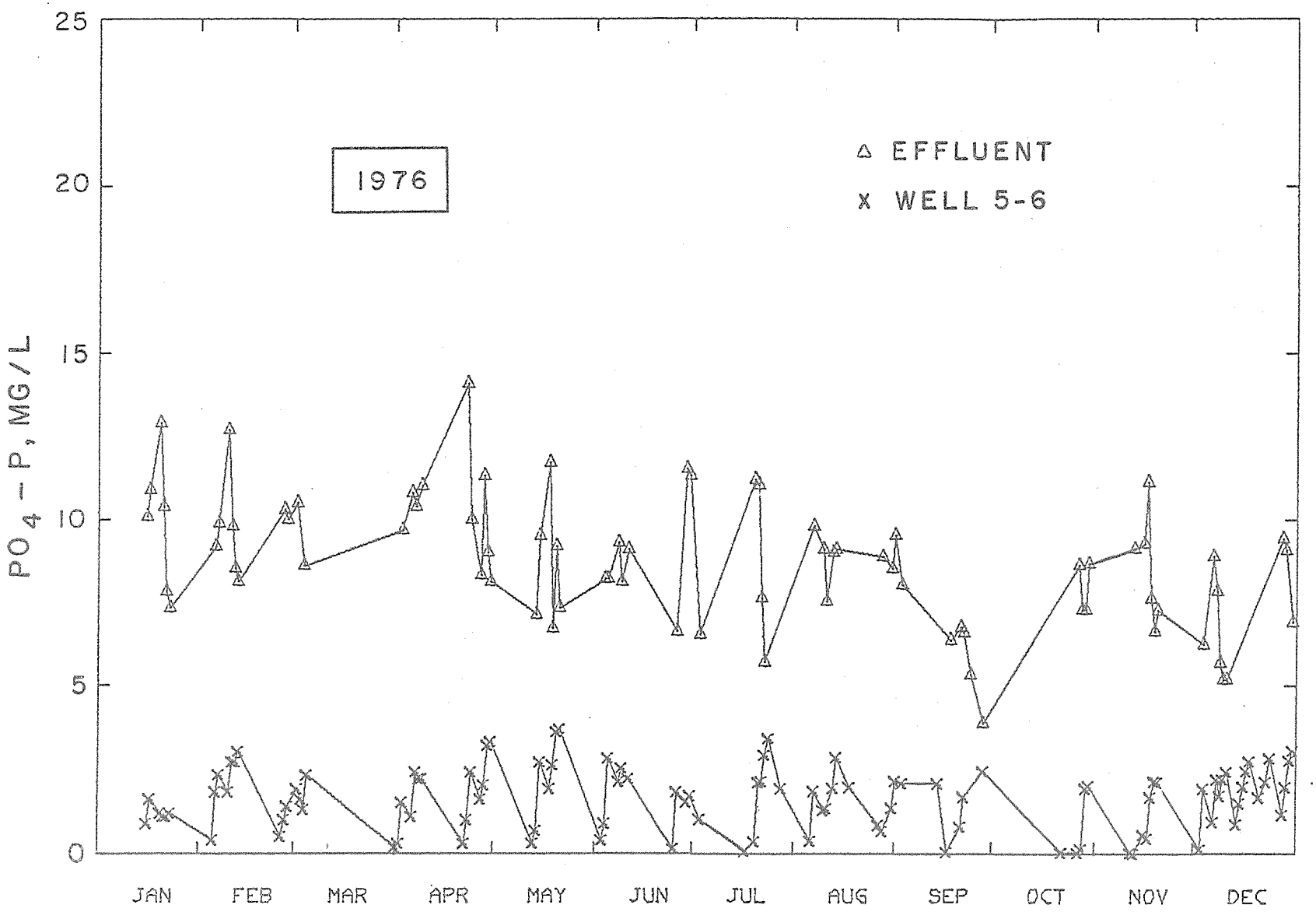

Figure 9. Phosphate-P in effluent and renovated water from well 5-6.

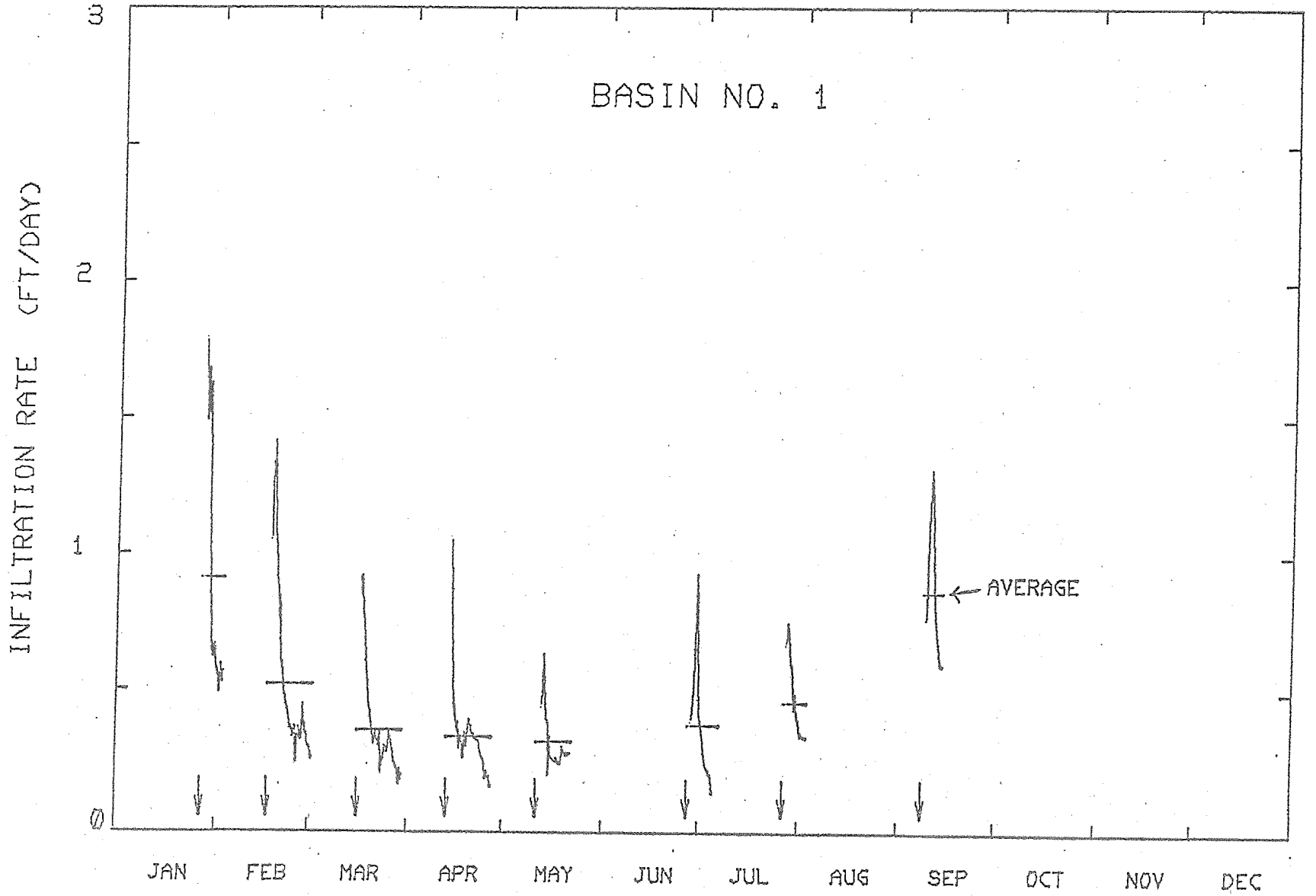

Figure 10. Infiltration rates in Basin 1 of 23rd Avenue Project.

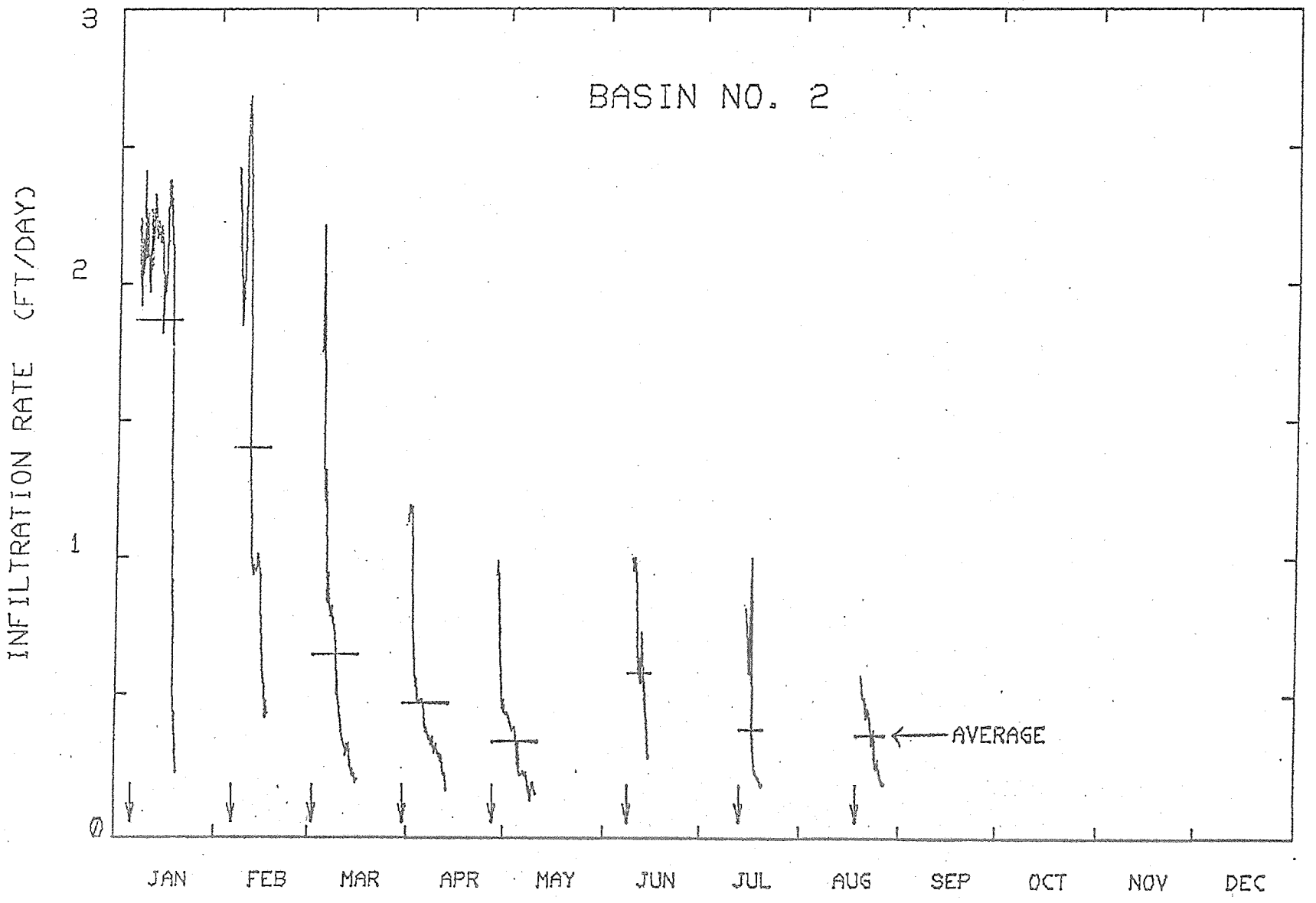

Figure 11. Infiltration rates in Basin 2 of 23rd Avenue Project.

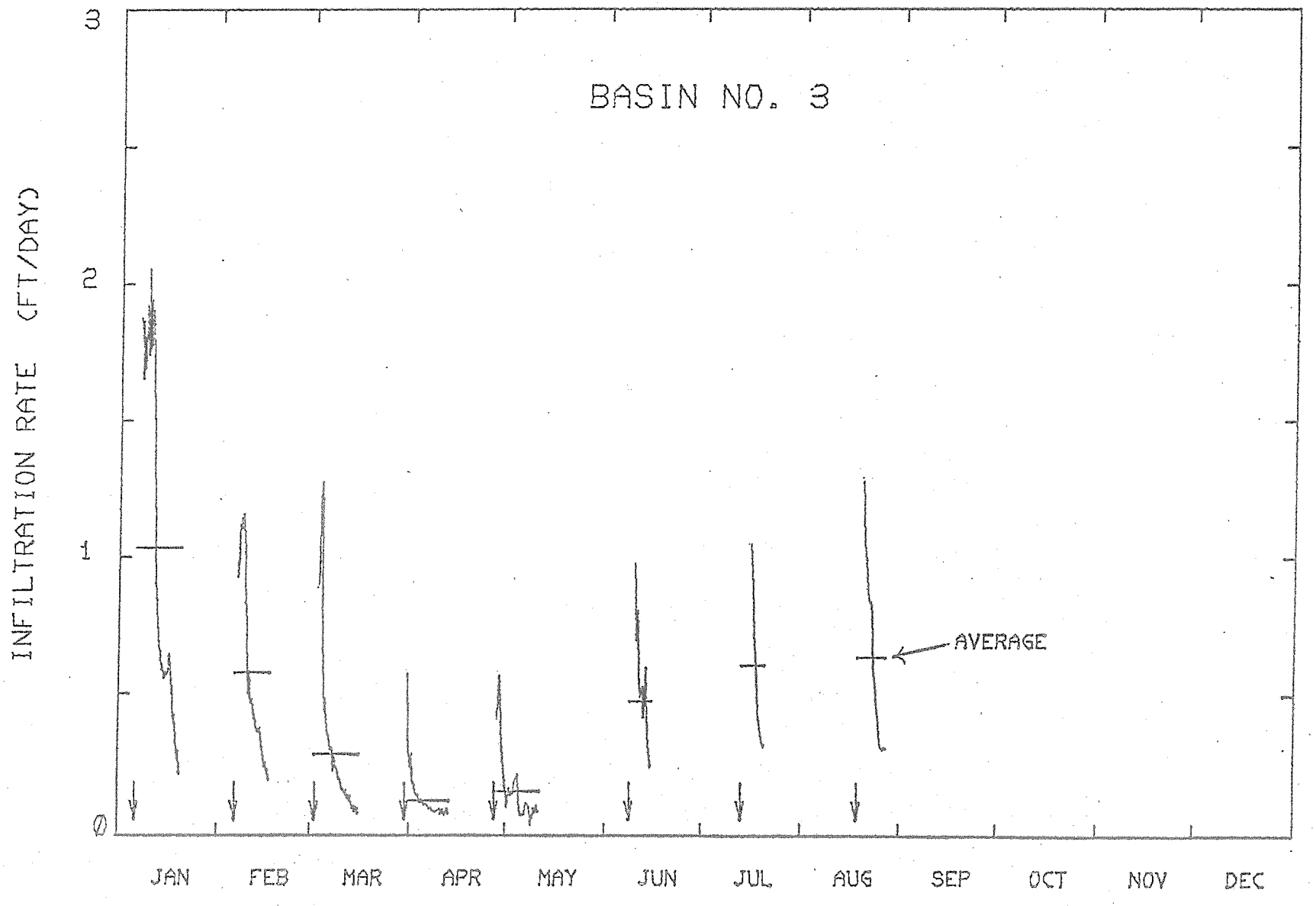

Figure 12. Infiltration rates in Basin 3 of 23rd Avenue Project.

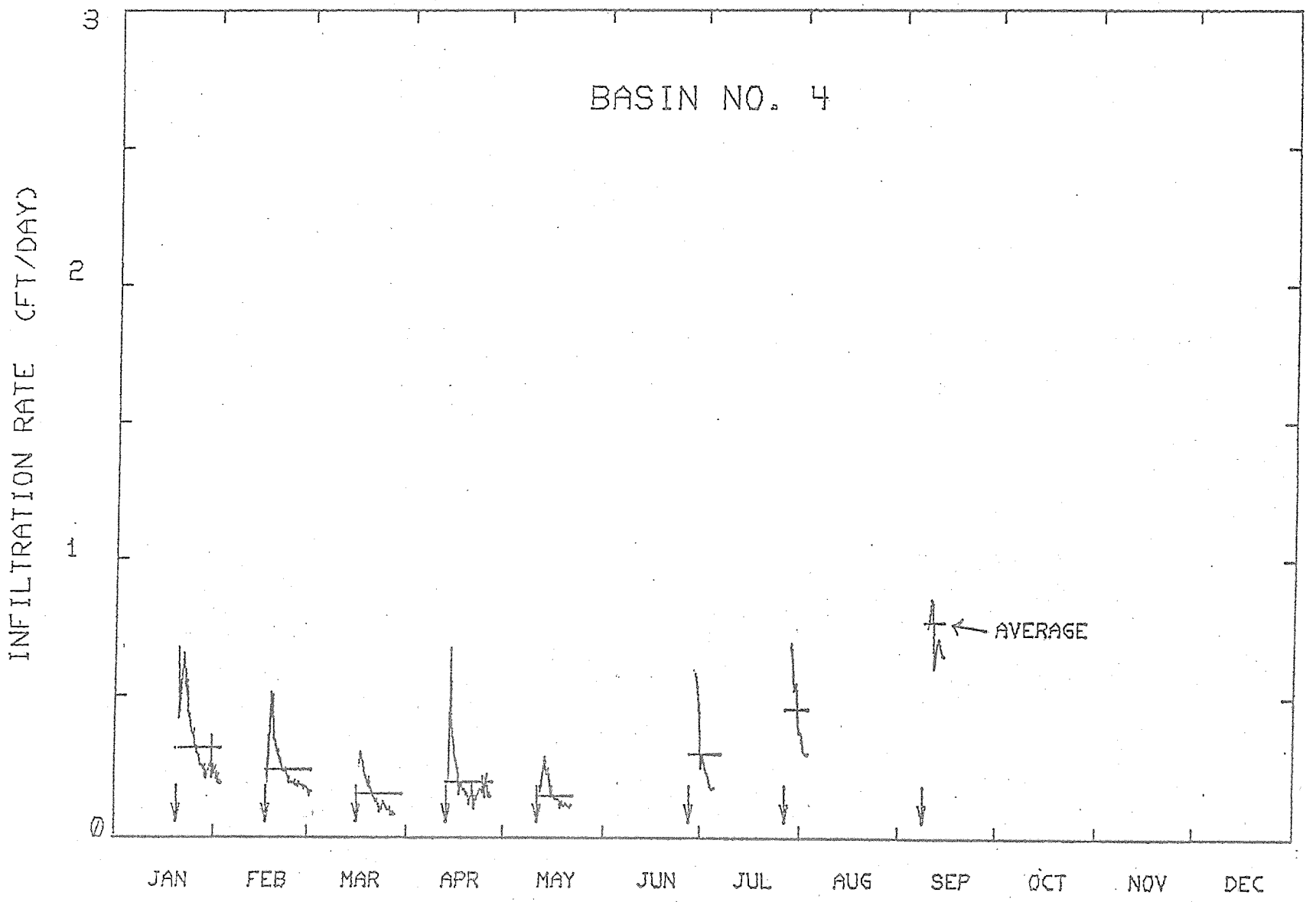

Figure 13. Infiltration rates in Basin 4 of 23rd Avenue Project.

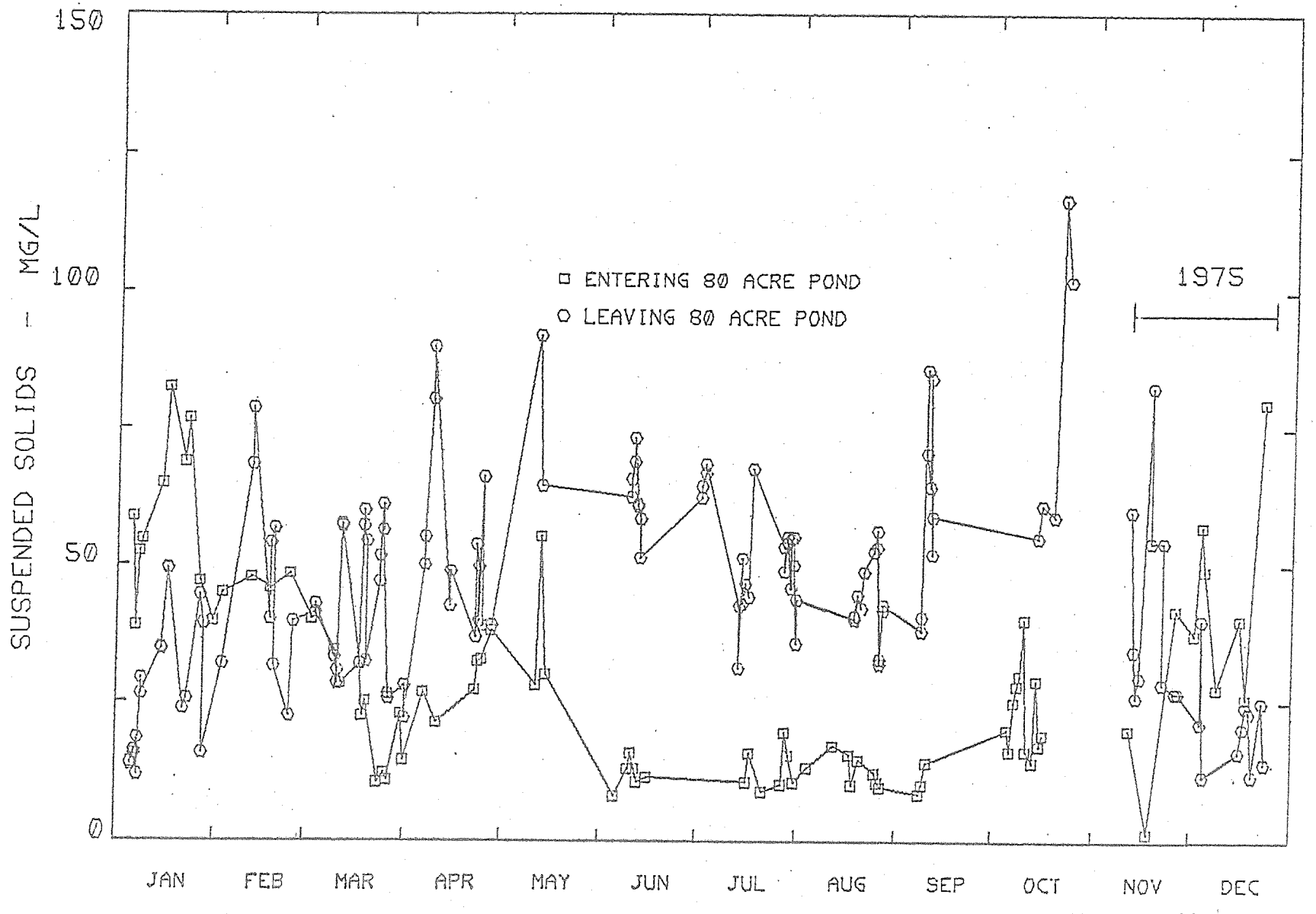

Figure 14. Suspended solids in secondary effluent and 80-acre pond outflow for 1975 and 1976.

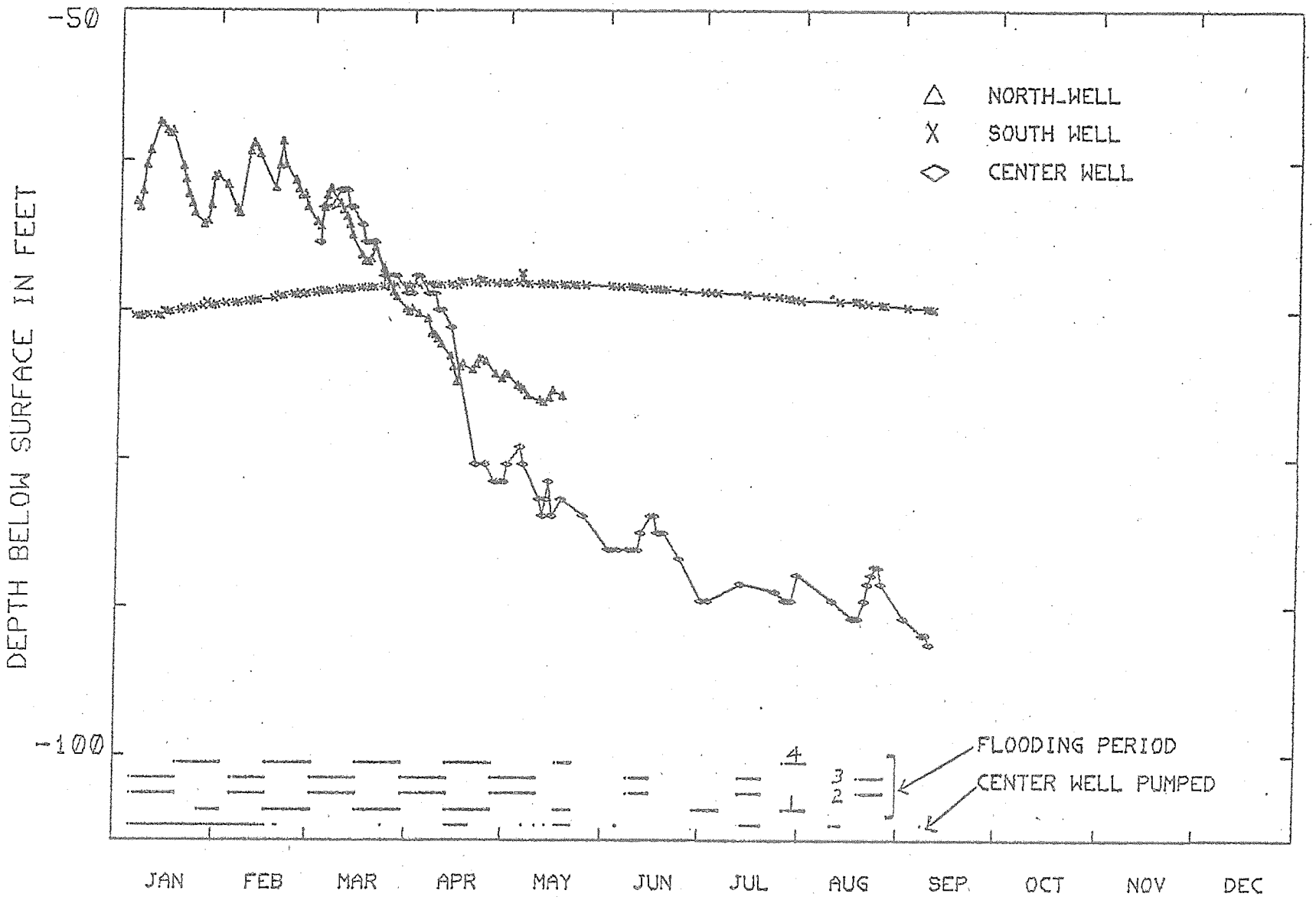

Figure 15. Water levels in north, south and center wells.

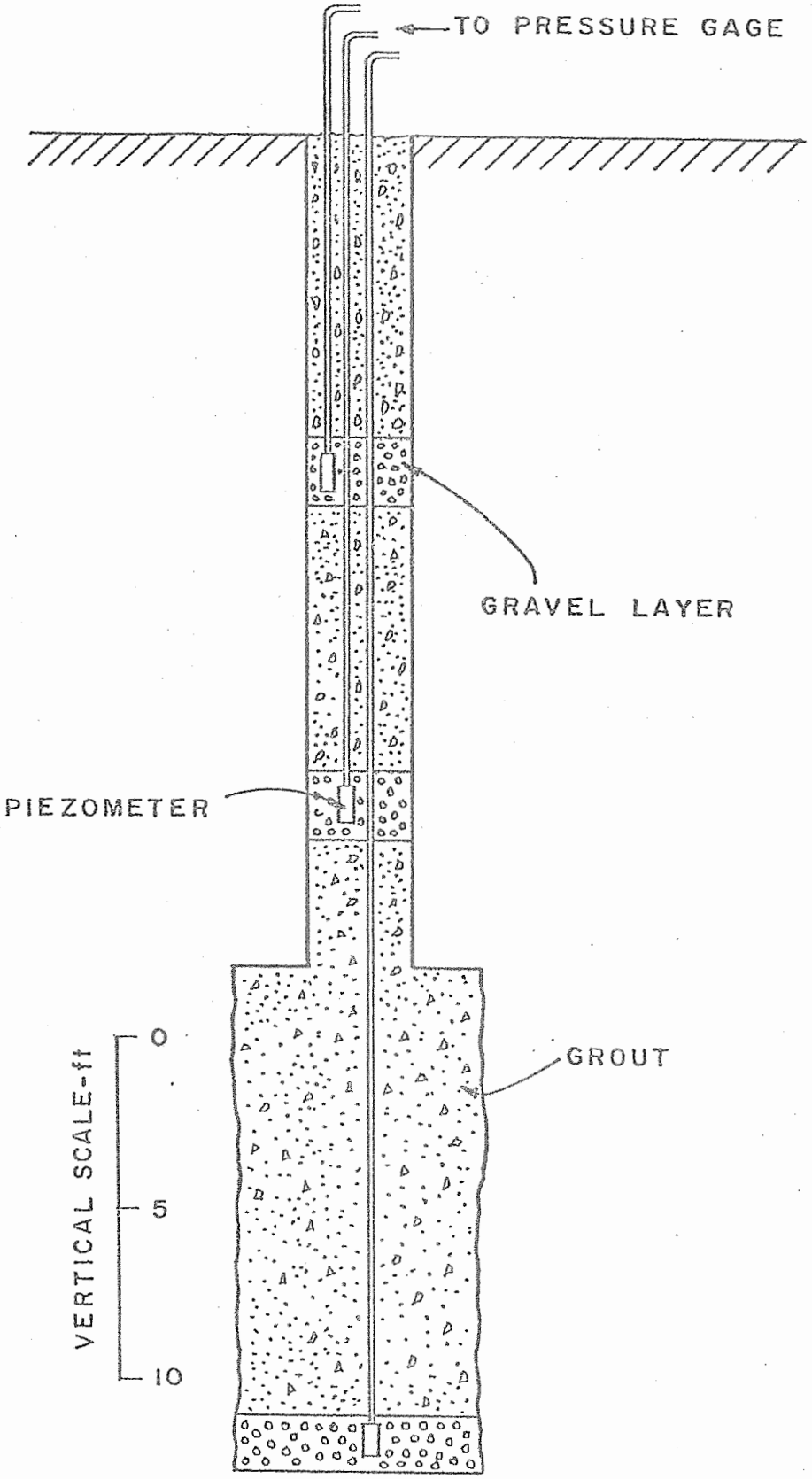

Figure 16. Schematic of air pressure piezometers in vadose zone.

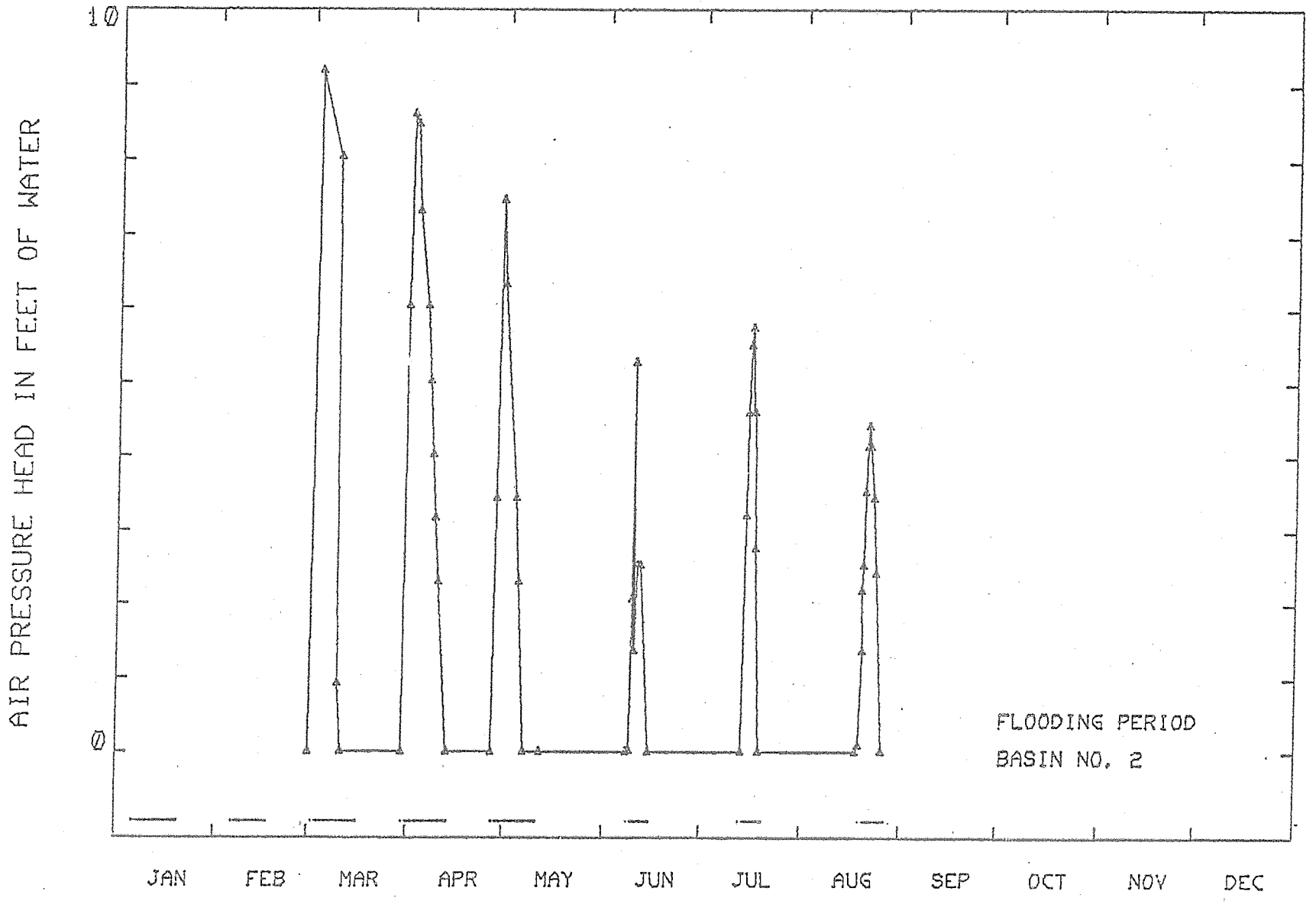

Figure 17. Air pressure at 40 ft depth in Basin 2.

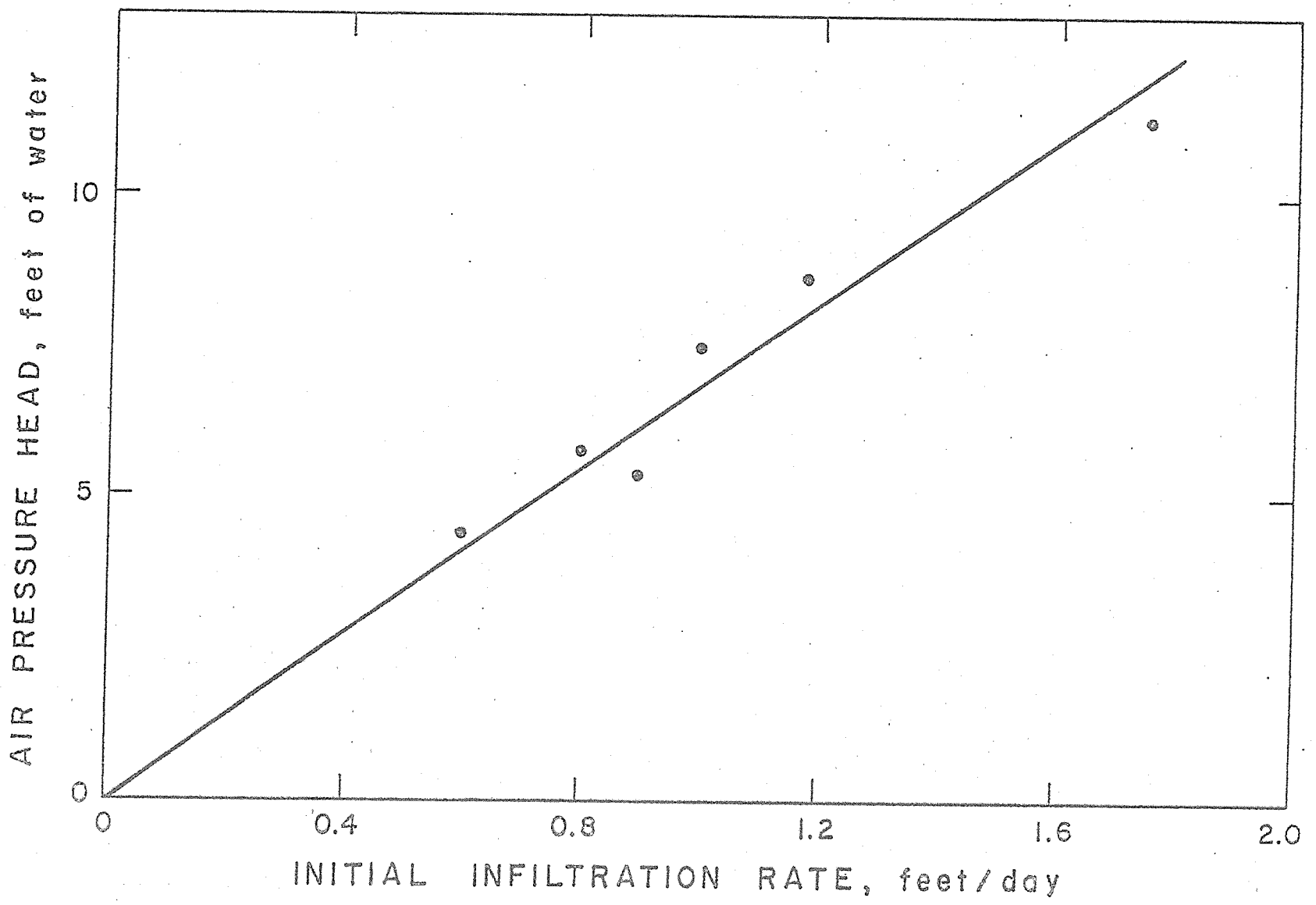

Figure 18. Maximum air pressure at the 40 ft depth in relation to the initial infiltration rate.

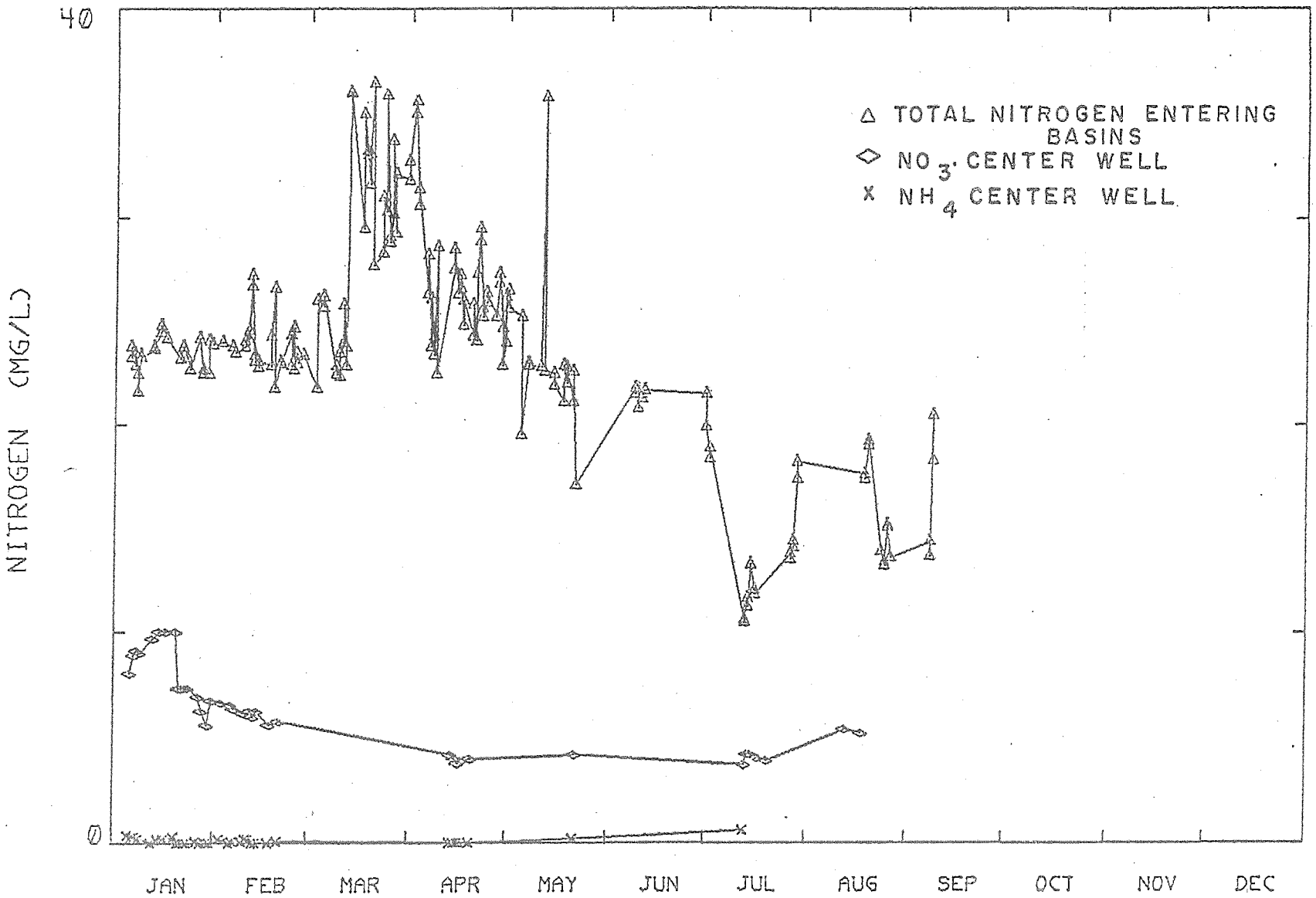

Figure 19. Nitrogen in effluent and in renovated water from center well.

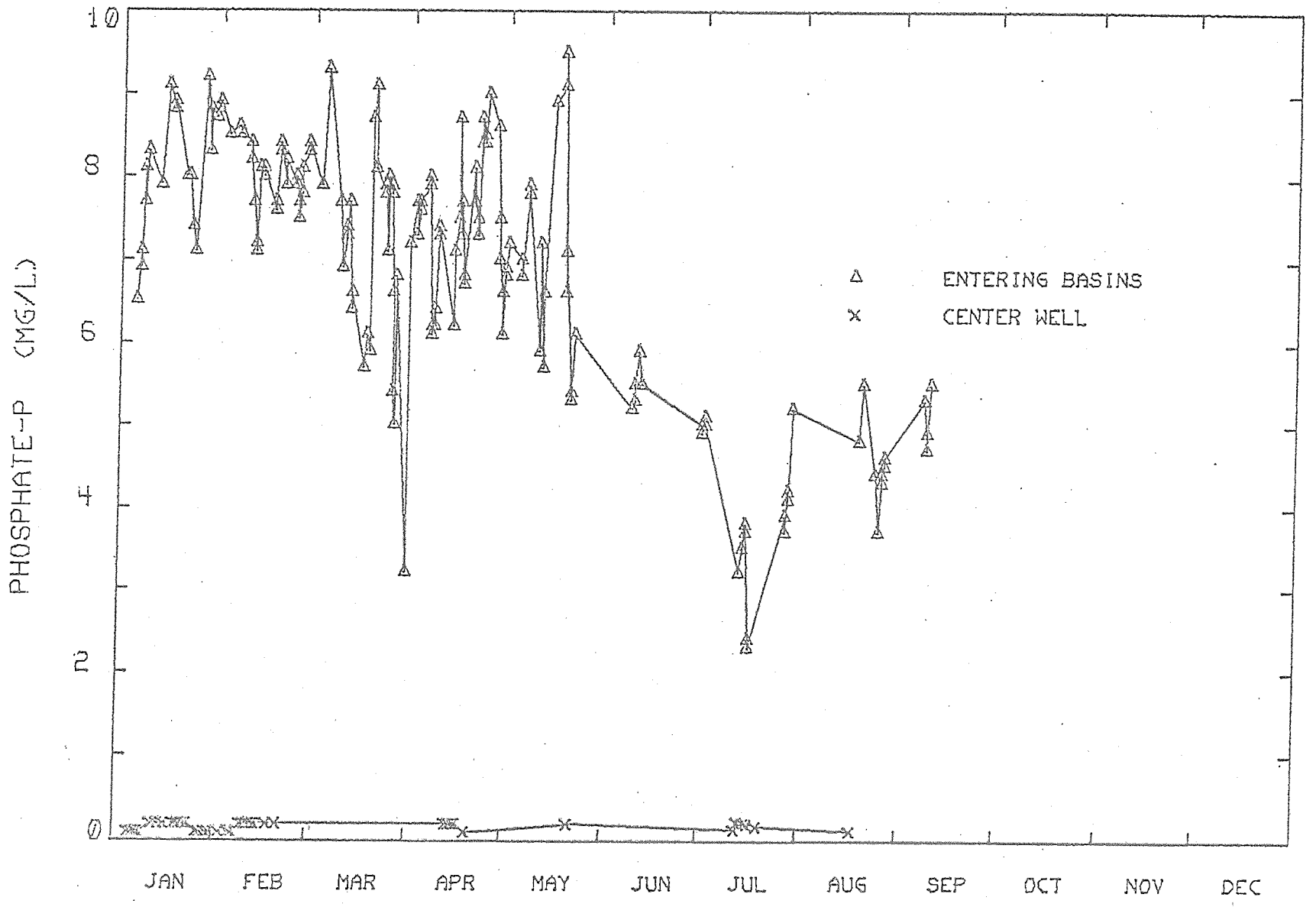

Figure 20. Phosphate-P in effluent and in renovated water from center well.

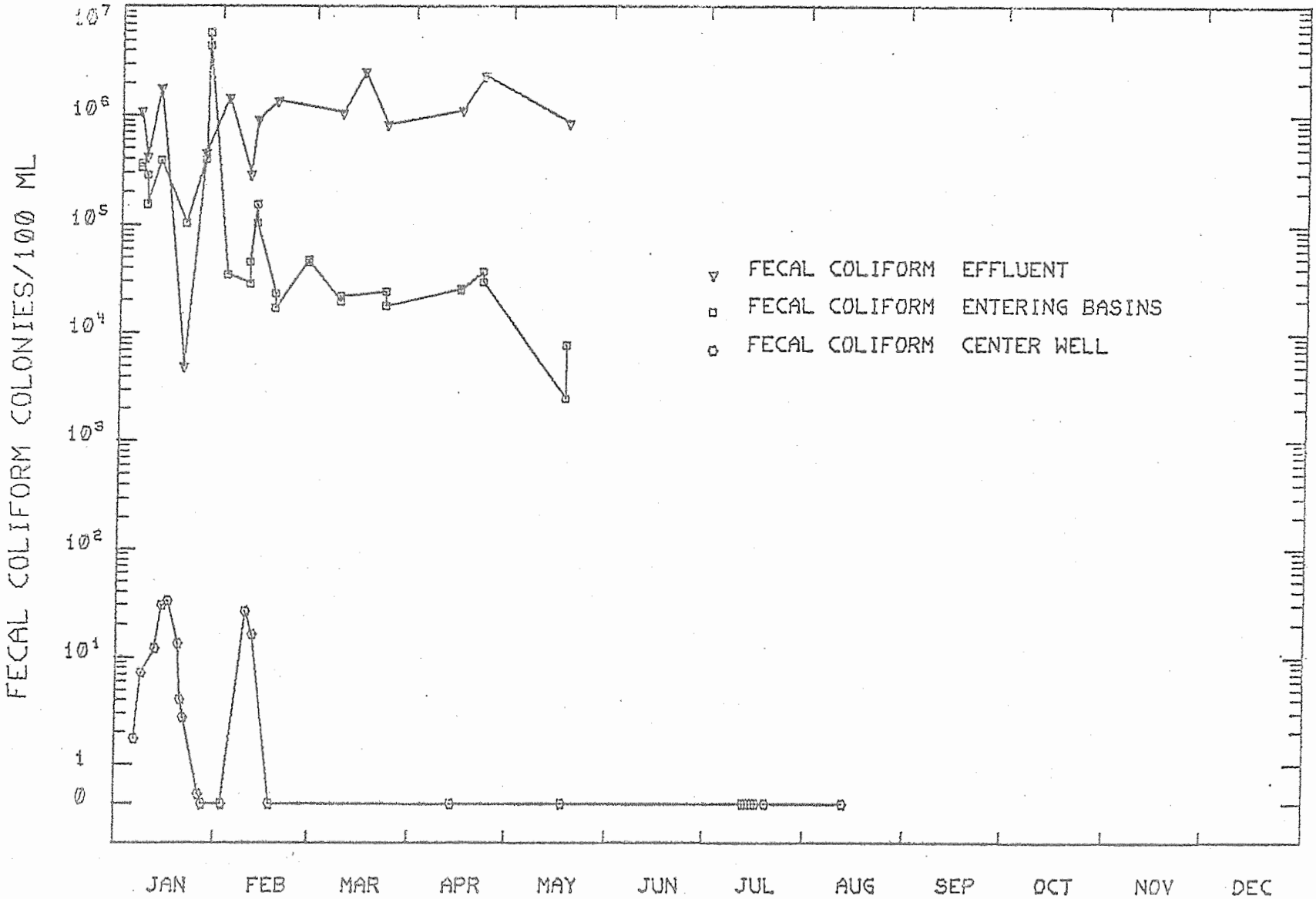

Figure 21. Fecal coliform counts in effluent and renovated water from center well.

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

NRP: 20790 CRIS WORK UNIT: 5510-20790-001

CODE NO.: Ariz.-WCL 68-3

INTRODUCTION:

Experiments on the movement of viruses in soils flooded with wastewater and renovation of primary sewage effluent were continued during 1976.

PART I. VIRUS MOVEMENT

PROCEDURE:

A 250 cm long soil column was flooded with primary sewage effluent enriched with 1 to 2 × 10^4 PFU/ml poliovirus type 1 (LSc). Then the primary effluent was removed and 10 cm of deionized water was added immediately. The column was drained for 5 days and then flooded with deionized water for 1 day. Water samples for virus assay were extracted at various depths during each day of the 9-day flooding period and samples for organic carbon analyses were extracted on days 1, 7, 8, and 9.

Another experiment was conducted with this soil column to study the movement of poliovirus applied at various concentrations. The column was flooded during successive 3-day flooding periods with secondary sewage effluent containing poliovirus concentrations of about 1 × 10^2, 3.9 × 10^3, and 2.6 × 10^4 PFU/ml. Samples were extracted at various depths at the end of each day.

A column was packed with Salt River bed loamy sand which had not been flooded with sewage water previously. It was flooded with a 5 mM $CaCl_2$ solution containing about 5 × 10^4 PFU/ml poliovirus for 2 days, drained for 4 days, and flooded with secondary sewage effluent containing about 5 × 10^4 PFU/ml poliovirus for 2 days. Samples for viral assays were extracted during each day of flooding.

Another column was packed with a coarse sand from the Salt River bed. This soil was 93% sand, 6% silt, and 1% clay. The column was flooded with secondary effluent containing about 3 × 10^4 PFU/ml poliovirus. The height of the overflow device used for an outlet was adjusted to various levels to give infiltration rates ranging from .63 m/day to 11.52 m/day. One set of samples was extracted for each

of the 5 infiltration rates after 1, 2, 3, 3.25, and 3.4 days of flooding.

RESULTS AND DISCUSSION:

Virus adsorption from primary effluent. Adsorption of poliovirus from primary sewage effluent was similar to adsorption from secondary sewage effluent for the upper 40 cm of soil in the soil columns (Figure 1). No virus was detected in 1 ml samples extracted at 80 cm or below during 1 week of flooding the 250 cm long soil columns with primary effluent seeded with about 1.2×10^4 PFU/ml of poliovirus (Table 1). This compares to detection of an occasional virus at the 160 cm level and none below that level in previous experiments where the same soil column was flooded with secondary effluent containing about the same concentration of poliovirus. Thus, the higher organic C content of the primary effluent, which ranged from about 40-70 mg/l in samples, extracted above the 80 cm depth (Table 2) did not inhibit virus adsorption as compared to adsorption from secondary effluent with an organic C content of 10-20 mg/l at the same depths.

Flooding the soil with deionized water immediately after flooding with primary effluent containing virus caused some movement of viruses, but they were not detected below the 80 cm depth (Table 1). Flooding again with deionized water after allowing the soil column to drain for 5 days did not result in detection of viruses at any depth. Thus, viruses were desorbed by application of deionized water to a saturated soil but not by application of deionized water after the free water drained from the soil. This virus movement was similar to that observed with soil columns flooded with secondary effluent seeded with virus and then leached with deionized water after different drying times.

Virus adsorption from secondary effluent at different concentrations of added virus. More viruses were detected at each soil depth as the concentration of added virus in sewage water increased from about 0.9×10^2 to 2.6×10^4 PFU/ml (Table 3). However, the percentage of added viruses remaining at each depth was about the same for each concentration (Table 4). Also, the depth to which viruses

moved was not increased by increasing the concentration of applied virus. This suggests that the adsorption reaction between viruses and soil particles is not concentration dependent.

Virus adsorption by a freshly packed soil column. A column was packed with soil, which had not been flooded previously with sewage water, to determine if the high removal of viruses near the soil surface of old soil columns was due to some effect of conditioning, such as, an accumulation of organic matter near the surface. Viruses were not detected below 5 cm when the column was flooded with a 5 mM $CaCl_2$ solution seeded with poliovirus. No viruses were detected below 40 cm when the column was flooded with secondary sewage effluent seeded with poliovirus (Table 5). The concentration of viruses near the surface of a freshly packed soil column showed that this adsorption pattern was not due to an accumulation of organic matter or salts near the soil surface during prolonged flooding with sewage water.

Virus removal from the salt solution was more rapid than it was from sewage water. Adsorption was probably stimulated by the high Ca content of the salt solution. Also, the organic matter in the sewage might have inhibited virus adsorption.

Effect of flow rate on virus adsorption. A column was packed with coarse sand so that the effect of different flow rates could be tested by changing the height of the column outlet. Increasing the flow rate from 0.6 to 1.2 m/day resulted in more movement of viruses through the soil (Table 6). Viruses did not move below 160 cm at 0.6 m/day but moved to 240 cm at rates of 1.2 m/day and above. Increasing the flow rate from 1.2 m/day to 12.0 m/day seemed to have little effect on virus movement. Previous experiments with loamy sand columns showed that changing the flow rate from 0.15 to 0.55 m/day did not affect virus movement. Thus, it appears that virus adsorption by soil is reduced when the flow rate is increased above some "break point." Flow rate changes above and below the break point do not appear to affect virus adsorption. The break point seems to occur at about 0.6 m for the Salt River bed sand columns, but it might be different for other materials. Flow rates above this level could not be achieved for many soils. It is remarkable that virus concentrations were

reduced by 2 logs when coarse sand columns were flooded at infiltration rates of 12 m/day (Table 6).

A hypothesis to explain virus adsorption patterns in soil columns. One explanation which may account for the virus adsorption pattern in soil columns flooded with sewage water seeded with virus, is that virus adsorption is affected by the strength of the negative charge on the virus particle. It is possible that viruses with a charge below a certain level are immediately adsorbed and other viruses move farther down the column. Adsorption of the second or lower charged population of viruses appears to be concentration dependent. This would explain why a 2-log reduction in virus concentration occurred during the first 5 cm of travel through the soil but the virus concentration was reduced at a lower rate as the water moved farther down the column. The same pattern was observed in freshly packed soil columns, indicating the increased adsorption rate near the surface was not due to an accumulation of material near the surface or modification of the surface layer by flooding with sewage water. This hypothesis is also consistent with our data showing that the percent removal of virus at various depths is similar for applications of sewage water containing different virus concentrations.

Burge (personal communication) has produced data which indicate that batches of ϕX-174 bacteriophage are composed of at least two populations of viruses distinguishable by the rates at which they are adsorbed by soil. This is consistent with our data showing one apparent reaction rate near the soil surface and another for the next segment of the soil column. One population may be adsorbed near the surface and another may move much farther because of a different adsorption rate. It is possible that a very small fraction of the virus population has a strong enough negative charge to make soil adsorption very difficult. There is some evidence that adsorption of viruses by soils delays inactivation. Since inactivation of these unadsorbed viruses would not be delayed by adsorption on soil particles, complete virus removal from the water might be attained with a long detention time in the soil.

SUMMARY AND CONCLUSIONS:

Adsorption of poliovirus from primary effluent was similar to that from secondary effluent indicating that the higher organic content of primary effluent did not affect virus adsorption.

When a soil column was flooded with secondary effluent containing different concentrations of added poliovirus during different flooding periods, the number of viruses detected at every soil depth increased as the calculations of added virus increased from about 0.9×10^2 to 2.6×10^4 PFU/ml. However, the percentage of added virus remaining at each depth was about the same for each concentration. Also, the maximum depth to which virus moved was not increased by increasing the concentration of added virus.

When a freshly packed soil column was flooded with secondary effluent seeded with poliovirus, most of the viruses were removed near the soil surface. This showed that the high virus removal near the soil surface of "old soil columns" was not due to some effect of conditioning such as an accumulation of organic matter near the soil surface.

Increasing the flow rate from 0.6 to 1.2 m/day through a coarse soil column by changing the height of the column outlet resulted in more movement of viruses through the soil. However, increasing the flow rate from 1.2 to 12.0 m/day had little effect on virus movement. Previous experiments showed no effect on virus movement by changing the flow rate from 0.15 to 0.55 m/day. Thus, it appears that virus adsorption by soil is reduced when the flow rate is increased above some break point while flow rate changes above and below the break point do not affect virus adsorption. The break point seems to be about 0.6 m/day for the salt river bed sand columns but it may be different for other soils.

One explanation which may account for the virus adsorption pattern in soil columns flooded with sewage water seeded with virus is that virus adsorption is affected by the strength of the negative charge on the virus particle. It is possible that viruses with a negative charge below a certain level are immediately adsorbed while viruses with a stronger negative charge move farther down the column.

PART II. PRIMARY SEWAGE RENOVATION

PROCEDURE:

Primary sewage effluent was applied to nine soil columns on a routine schedule of 9 days flooding alternated with 5 days drying. The soil columns were in a small, insulated, temperature-controlled building. The tops of all nine protruded through the roof. Six were bare and three were vegetated with common bermudagrass. Both influent and effluent samples were analyzed daily for nitrate, ammonia, and phosphate. Outflow volume was determined by weighing daily. Infiltration rates were calculated from time and volume.

RESULTS AND DISCUSSION:

The 15-cm soil columns (with the exception of column 9) had slower infiltration rates at the end of 1976 than at the beginning of 1976 (Table 7). All nine columns had slower average rates at the end of 1976 than at the end of 1975. Three columns (2-5-8) which had the grass removed in July 1975 had a higher average infiltration rate for the year than those which were undisturbed for a much longer time. However, the last flooding cycle in 1976 negated the higher rate with lower average rates for 2-5-8 than the other six columns. Apparently, the disturbance of removing the grass in July 1975 had opened drainage pores which became clogged after a year's use. Infiltration rate average for columns 2-5-8 was less (10.04 cm/day) than the average for columns 1-4-7 (11.04 cm/day) or for columns 3-6-9 (13.37 cm/day) (Table 8).

Column 3 had generally lower infiltration rates than column 2. Column 3 very frequently had incomplete ammonia oxidation to nitrate whereas column 2 consistently had total oxidation of the ammonia to nitrate. Column 5 had rapid infiltration rates and slight ammonia retention. Therefore, extremely rapid infiltration rate was not the sole contributing factor in non-total oxidation of ammonia to nitrate.

Nitrogen removal. Percent nitrogen removal from primary sewage effluent was neither directly proportional nor inversely proportional to infiltration rates during 1976. However, the range of infiltration rates measured was fairly narrow for the columns flooded during

1976. The columns with bermudagrass vegetation (1-4-7) had much greater percent average nitrogen removal, 48.08%, than the other columns. The columns (2-5-8) which had bermudagrass removed in July 1975, averaged 23.56% and the columns (3-6-9) which have never been vegetated averaged 26.54%. Average percent nitrogen removal was greater in 1975 (58.8% average for the year) than in 1976 (32.73% average for the year)(Table 9).

Carbon. Water samples were taken at various depths of the columns and analyzed for both organic and inorganic carbon. On the three columns studied, organic carbon concentrations decreased steadily at distances beyond 80 cm. The irregular concentrations above 80 cm followed a pattern of decrease until between 5- and 10-cm distances and then increased at the 10-cm distance before again decreasing (Table 10).

Studies involving a single column during the flooding cycle were made. Four separate days of sampling did not indicate a pattern of concentration at the various depths of the column (Table 11).

Phosphate. Phosphate (PO_4-P-ortho) concentrations on column outflow were measured throughout the 23 cycles (11 months) the columns were in use (Table 12).

Columns with common bermudagrass vegetation averaged 21% less phosphate in outflow than nonvegetated columns. Columns 2-5-8 had bermudagrass removed in July 1975 and stabilized after leaching previous quantities of adsorbed phosphate.

Average PO_4-P concentrations in column outflow were 30.3% less at the beginning of the year as compared to the end of the year, indicating an equilibrium being established in soil adsorption of PO_4-P (Table 13).

SUMMARY AND CONCLUSIONS:

Renovation of primary sewage effluent by soil recharge appears to be an inexpensive, satisfactory method of treatment for removal of phosphate, ammonia, and carbon. Average infiltration rates were somewhat lower in 1976 than the previous year. Thus, substantial soil

clogging occurred during the second year of a 2-year flooding period when effluent high in suspended solids was applied and no organic material was removed from the soil surface. This indicates that the soil surface should be scraped at least once a year. The percentage of nitrogen removed was somewhat less in 1976 than in 1975. This may be due to the fact that infiltration rates fluctuated during most of 1976.

Phosphate concentrations on the column outflow were somewhat higher for 1976 than for the previous year. When the columns were flooded in 1976 with primary sewage following a 6-month-long dry period, a wave of phosphate was leached from the columns. Phosphate concentrations were low after the wave leached through the columns, but began to increase later in the year. They continued to increase during 1976 and then appeared to reach a new equilibrium near the end of the year. Thus, phosphate removal in any given year is dependent upon treatment of the soil during previous years.

Infiltration rates on the two laboratory columns varied during the 6 months they were in use with a lower average than the previous year (Table 16).

Percent nitrogen removal was not generally increased by the lower infiltration rates.

Phosphate (as P) in column outflow was lower than in the previous year, varying directly as infiltration rates (Table 17).

PERSONNEL: J. C. Lance, R. C. Rice, G. C. Emery

Table 1. Virus concentrations at various depths in a soil column flooded with primary sewage effluent seeded with poliovirus.

Column depth	PFU/ml on day sample taken										
	1	3	6	7	8	9	avg	9.2**	10	14	15
cm											
0-R_1	4400	25000	22500	20500	9500	-	16300	-	-	-	-
0-R_2	5950	11815	-	-	8500	6500	8191	-	-	-	-
2	2600	2300	1100	3250	1900	2700	2308	100	-	-	0
5	950	600	1250	495	50	280	604	550	-	-	0
10	220	1450	145	290	0	10	352	550	-	-	0
20	175	NS	130	60	0	10	75	450	-	-	0
40	155	50	205	130	0	0	90	500	-	-	0
80	0	0	0	0	0	0	0	5	-	-	0
160	0	0	0	0	0	0	0	0	-	-	0
240	0	0	0	0	0	0	0	-	0	0	0
250	0	0	0	0	0	0	0	-	0	0	0
250 (jug)*	0	0	6	0	0	0	0	NS	0	0	0

NS - No sample

*100-ml samples

**Primary effluent removed and column flooded with deionized H_2O after 9 days.

R_1 = fresh reservoir samples and R_2 = 1-day-old reservoir samples.

Table 2. Organic carbon content of samples extracted for virus assay from soil columns flooded with primary sewage effluent seeded with poliovirus.

Depth cm	- ppm -				
	day 1	day 7	day 8	day 9	Avg
0*	35	115.0	73.0	55.0	69.5
2	34.5	101.0	47.7	57.5	60.2
5	33.7	119.5	61.0	47.5	65.4
10	31.5	119.0	45.3	--	65.3
20	24.3	104.0	43.0	30.5	50.5
40	20.0	97.0	43.5	51.5	53.0
80	14.0	69.0	38.0	50.7	42.9
160	6.0	57.5	38.7	49.0	37.8
240	18.7	26.5	16.0	25.0	21.5
250	15.5	36.0	13.6	32.0	24.3
outflow**	--	16.5	8.0	4.0	9.5

* 1 day old primary effluent.

** cumulative, 24 hours.

Table 3. Virus concentrations at various depths in a soil column flooded with secondary effluent containing different concentrations of poliovirus.

Column Depth cm	Virus Concentration PFU/ml					
	Range	Avg	Range	Avg	Range	Avg
0	70-110	93	3600-4200	3867	23000-28000	26333
2	20-41	33	900-900	900	3700-6400	4833
5	14-41	24	400-900	733	5200-6500	5833
10	4-10	7	150-260	207	1100-2600	1700
20	4-8	6	130-240	170	700-2200	1400
40	2-10	7	100-280	210	900-1700	1233
80	0-6	4	0-10	5	10-240	133
160	0-2	0.7	-	0	-	0
240	-	0	-	0	-	0
250	-	0	-	0	-	0

Data are averages for samples taken on three flooding dates.

Table 4. Percent of added viruses remaining at various depths after flooding soil columns with sewage water containing different concentrations of poliovirus.

Column Depth cm	Added Virus Concentration 10^2	10^3	10^4
	Avg % Virus Remaining*		
2	35	23	18
5	25	19	22
10	7	5	6
20	6	4	5
40	8	5	5
80	4	0.1	0.5
160	0.7	0	0
240	0	0	0
250	0	0	0

*data are averages for samples taken on 3 flooding days.

Table 5. Virus concentrations at various depths in a freshly packed soil column flooded with a 5 mM $CaCl_2$ solution or secondary sewage effluent seeded with poliovirus.

Column Depth	$CaCl_2$ Solution		Secondary Effluent	
	PFU/ml			
cm	Day 1	Day 2	Day 1	Day 2
0*	22000	7600	44000	3000
2	80	140	3400	610
5	100	100	2300	550
10	0	0	2200	220
20	0	0	290	---
40	0	0	0	20
80	0	0	0	0
160	0	0	0	0
240	0	0	0	0
250	0	0	0	0

*0-samples taken 1 day after preparation of virus mixtures. Fresh mixtures ranged from 57000-100000 PFU/ml.

Table 6. Virus concentrations at various depths in a soil column flooded at different infiltration rates with sewage effluent seeded with poliovirus.

Column Depth	Viral assays (PFU/ml) Flow rate (m/day)				
cm	0.6	1.2	2.4	4.0	12.0
			PFU/ml		
0*	5600	4200	3500	28000	28000
2	4000	3600	1600	11000	15000
5	3100	3200	1100	8700	10000
10	1800	2800	2600	6300	9000
20	740	1900	2700	5800	7200
40	830	1800	1800	2900	3300
80	105	640	840	1120	4300
160	60	190	310	310	740
240	0	130	200	460	320
250	0	70	150	150	0

*0 samples were taken 1 day after application of virus for the first three flow rates and 6-9 hours after application for the two highest rates.

Table 7. Infiltration rates (cm/day) OH soil columns, 1976.

Start cycle	End cycle	1	2	3	4	5	6	7	8	9	Avg.
12/30/75	1/13/76	13.97	24.30	20.77	22.35	27.17	22.22	18.17	20.75	13.16	20.32
1/13/76	1/27/76	11.07	17.43	14.55	12.70	17.46	16.07	13.13	16.49	11.82	14.52
1/27	2/10	13.12	18.66	15.75	15.59	19.58	14.53	13.98	18.89	12.09	15.80
2/10	2/24	12.61	18.09	14.72	13.82	19.69	12.33	17.15	13.43	10.17	14.67
2/24	3/9	13.39	21.80	18.60	23.85	25.94	16.91	15.93	15.77	13.21	18.38
3/9	3/23	13.36	19.28	17.99	14.44	20.83	16.69	16.78	17.71	11.38	16.50
3/23	4/6	13.70	21.58	19.42	18.58	26.87	16.35	17.65	20.29	12.04	18.50
4/6	4/20	11.31	17.25	16.22	15.59	19.95	14.88	13.35	15.19	7.88	14.60
4/20	5/4	12.84	17.15	16.61	14.30	16.67	15.20	15.20	17.13	15.33	15.60
5/4	5/18	12.73	16.12	18.22	17.07	20.30	9.80	14.14	9.01	11.47	14.30
5/18	6/1	14.18	20.90	19.24	17.41	22.78	13.11	16.53	10.80	10.75	16.19
6/1	6/15	12.30	17.39	17.60	14.21	19.12	11.41	13.77	16.14	11.19	14.80
6/15	6/30	12.51	17.38	15.77	14.29	17.65	13.01	13.66	13.10	9.60	14.11
6/30	7/13	11.97	14.47	13.44	17.21	18.31	9.71	14.05	16.47	8.69	13.81
7/13	7/27	14.42	21.16	14.95	18.31	23.17	13.36	16.54	18.91	12.74	17.06
7/27	8/10	11.71	14.89	14.07	13.06	17.68	9.93	12.62	12.47	8.70	12.80
8/10	8/24	13.73	21.44	17.57	17.15	25.61	11.93	15.35	16.51	8.40	16.41
8/24	9/7	12.62	17.88	13.85	16.47	16.58	12.66	14.39	17.09	11.05	13.07
9/7	9/21	13.31	18.24	15.36	12.53	20.50	12.24	15.76	9.58	9.73	14.14
9/21	10/5	12.03	16.69	14.76	16.85	21.00	13.50	15.57	14.07	10.75	15.02
10/5	10/19	13.14	18.86	15.60	19.04	20.40	11.17	14.57	12.42	6.88	14.80
10/19	11/2	11.80	15.21	12.92	15.36	19.03	8.20	14.05	20.13	6.42	13.68
11/2	11/16	10.90	14.09	12.85	9.64	11.08	9.21	12.57	6.05	13.93	11.15
		12.72	18.27	16.12	16.08	20.32	13.24	15.00	15.15	10.76	15.3

Table 8. Average infiltration rates,* 1976. OH columns.

Dates	1-4-7	2-5-8	3-6-9
Dec. 30	18.16	24.07	18.72
Jan. 13	12.30	17.13	14.15
Jan. 27	14.23	19.04	14.12
Feb. 10	14.53	17.07	12.41
Feb. 24	17.72	21.17	16.24
Mar. 9	14.86	19.27	15.35
Mar. 23	16.64	22.05	15.94
Apr. 6	13.42	17.46	13.00
Apr. 20	14.11	16.98	15.71
May 4	14.65	15.14	13.16
May 18	16.04	18.16	14.37
Jun. 1	13.42	17.55	13.40
Jun. 15	13.48	16.04	12.82
Jun. 30	13.49	16.04	12.79
Jul. 13	16.42	21.08	13.68
Jul. 27	12.46	15.01	10.90
Aug. 10	15.41	21.19	12.63
Aug. 24	14.49	17.18	12.52
Sep. 7	13.87	16.10	12.44
Sep. 21	14.82	17.25	13.00
Oct. 5	15.58	17.23	11.22
Oct. 19	13.74	18.12	9.18
Nov. 2	11.04	10.40	12.00
Average	13.94	17.94	13.50

*cm/day

Table 9. Percent nitrogen removal, soil columns, 1976.

Start cycle	End cycle	1	2	3	4	5	6	7	8	9	Avg.
12/30/75	1/13/76	40.15	31.27	26.75	38.57	28.00	41.76	31.39	32.80	-0.43	30.03
1/13/76	1/27/76	33.36	5.29	6.93	17.02	9.82	18.29	2.99	6.25	1.91	11.34
1/27	2/10	63.80	27.89	33.58	45.59	16.06	29.81	39.90	34.98	17.06	36.08
2/10	2/24	50.30	10.40	20.14	30.22	1.93	7.38	62.56	-30.46	5.58	17.56
2/24	3/9	47.98	27.27	38.70	65.05	32.21	32.30	47.83	56.06	46.24	43.74
3/9	3/23	46.33	17.10	25.89	8.76	19.94	26.64	55.05	25.87	-12.51	23.67
3/23	4/6	71.42	45.46	39.98	59.13	41.33	43.00	64.50	35.43	41.81	49.12
4/6	4/20	46.09	-16.41	10.21	29.92	35.56	31.37	38.13	-2.80	52.22	24.92
4/20	5/4	83.84	52.35	56.68	64.01	43.34	60.34	86.10	51.89	85.75	64.90
5/4	5/18	55.27	-13.49	18.76	34.42	31.26	-18.83	58.60	-62.39	-18.35	9.46
5/18	6/1	61.94	42.38	33.23	33.65	40.61	38.44	49.94	7.03	21.10	36.48
6/1	6/15	32.08	15.98	33.23	19.62	7.64	33.96	27.97	50.38	28.32	27.69
6/15	6/29	36.68	18.25	35.32	-14.66	13.68	-83.48	46.78	-115.95	4.68	6.53
6/29	7/13	33.99	-45.45	-16.36	9.48	-39.10	-50.89	41.46	24.71	-27.02	-7.69
7/13	7/27	56.99	44.86	52.98	41.51	46.52	56.81	49.00	38.78	44.39	47.98
7/27	8/10	18.44	-7.40	30.41	2.72	-24.17	-0.71	33.85	-19.58	-6.86	2.97
8/10	8/24	91.85	47.07	57.01	66.76	32.00	48.97	89.09	38.93	41.19	57.00
8/24	9/7	81.00	42.33	41.86	23.43	72.88	56.40	59.03	78.82	55.55	56.81
9/7	9/21	55.43	9.16	40.36	-14.19	25.22	9.27	55.32	-44.65	-4.95	14.55
9/21	10/5	75.64	5.02	29.56	54.16	41.38	32.10	78.65	52.68	49.38	52.36
10/5	10/19	82.61	48.43	61.63	71.61	61.34	51.99	79.46	63.89	65.24	65.13
10/19	11/2	60.19	17.25	8.25	49.01	53.01	-28.07	61.62	76.81	14.26	34.70
11/2	11/17	73.14	7.97	57.32	57.07	5.69	36.92	66.96	38.82	11.22	39.46
		56.46	19.47	32.17	34.47	26.72	25.02	53.31	24.48	22.43	32.73

Table 10. Organic carbon (ppm) in primary effluent.

Column Depth cm	Day	Column 3	5	9	Avg.
Reservoir	May 11	63.0	63.0	63.0	63.0
0		46.0	47.0	45.0	46.0
2		25.0	28.0	28.0	27.0
5		13.3	22.5	20.0	18.6
10		54.5	–	39.2	46.9
20		30.0	30.1	30.5	30.2
40		21.0	25.0	30.2	25.4
80		5.5	36.0	16.0	19.2
160		9.2	8.5	7.5	8.4
240		2.5	1.0	0.8	1.4

Table 11. Organic carbon (ppm) in primary effluent.

Column Depth cm	March 23 day 0	March 24 day 1	March 30 day 7	March 31 day 8	April 1 day 9	Avg.
0*	63.5	65.9				64.7
0**		34.9	115.0	73.0***	55.0	69.48
2		34.5	101.0	47.7	57.5	60.18
5		33.7	119.5	61.0	47.5	65.43
10		31.5	119.0	45.3		65.27
20		24.3	104.0	43.0	30.5	50.45
40		20.0	97.0	43.5	51.5	53.00
80		14.0	69.0	38.0	50.7	42.93
160		6.0	57.5	38.7	49.0	37.8
240		18.7	26.5	16.0	25.0	21.55
250		15.5	36.0	13.6	32.0	24.28
Outflow in jug			16.5	8.0	4.0	9.5

* New effluent

** 1-day-old effluent

*** 2-day-old effluent

Table 12. PO_4* average per cycle, soil columns 1-9, 1976.

	Effluent	1	2	3	4	5	6	7	8	9
Dec. 30	6.77	1.34	4.20	3.26	1.28	3.86	2.60	2.08	4.44	1.56
Jan. 13	9.04	1.20	3.76	3.00	1.54	3.27	2.24	1.86	3.96	1.43
Jan. 27	7.93	1.23	4.31	3.30	1.61	3.87	2.44	1.99	4.40	1.47
Feb. 10	7.66	1.45	5.22	4.30	1.97	4.25	3.07	3.02	4.50	1.70
Feb. 24	7.23	1.74	6.00	4.96	2.39	4.16	4.11	3.33	5.14	2.38
Mar. 9	6.63	1.60	5.15	4.12	1.98	4.30	4.00	3.42	4.98	2.65
Mar. 23	8.43	1.46	4.86	4.76	2.40	3.96	3.92	3.38	4.84	3.16
Apr. 6	7.48	1.70	4.47	4.53	3.37	4.13	3.77	3.17	4.30	2.13
Apr. 20	8.50	1.85	3.93	4.73	2.83	3.45	3.88	3.58	4.65	2.65
May 4	7.50	2.28	6.33	6.53	3.62	4.60	4.28	4.27	4.55	4.07
May 18	7.40	2.33	6.04	6.81	3.76	4.36	4.17	4.13	3.97	3.09
Jun. 1	7.30	2.29	5.23	6.09	3.64	3.63	3.69	3.57	4.19	2.54
Jun. 15	6.80	2.39	5.68	5.28	3.75	3.61	3.35	3.45	3.81	2.60
Jun. 30	5.70	2.67	5.26	5.39	4.13	3.60	3.39	3.70	4.29	2.61
Jul. 13	6.14	3.00	5.21	5.21	4.41	3.43	3.43	4.26	4.57	3.24
Jul. 27	5.53	3.60	5.00	5.06	4.83	3.51	3.88	4.30	4.23	3.21
Aug. 10	6.04	3.64	4.80	4.15	4.58	3.60	3.44	4.16	4.41	3.38
Aug. 24	6.94	3.38	4.53	4.06	4.23	3.41	3.44	3.84	3.73	3.38
Sep. 7	6.24	3.16	4.86	4.49	4.50	3.93	3.36	4.19	4.20	3.20
Sep. 21	6.02	3.31	4.60	4.29	4.57	4.16	3.87	4.23	4.31	3.89
Oct. 5	7.34	3.58	4.86	4.85	4.93	4.66	4.16	4.59	4.76	4.03
Oct. 19	7.83	3.53	4.52	4.11	4.50	4.37	3.41	4.10	4.71	2.61
Nov. 2	6.91	3.24	4.26	4.26	4.62	4.02	3.03	3.80	4.18	3.30
Avg.	7.10	2.43	4.91	4.68	3.45	3.92	3.52	3.58	4.40	2.79
Avg. 1-4-7	3.15									
Avg. 2-5-8	4.41									
Avg. 3-6-9	3.66									

*ppm

Table 13. PO_4*, soil columns, 1976.

	Effluent	1-4-7	2-5-8	3-6-9
Dec. 30, 1975	6.77	1.57	4.17	2.47
Jan. 13, 1976	9.04	1.53	3.66	2.22
Jan. 27	7.93	1.61	4.19	2.40
Feb. 10	7.66	2.15	4.66	3.02
Feb. 24	7.23	2.49	5.10	3.82
Mar. 9	6.63	2.33	6.51	3.59
Mar. 23	8.43	2.41	4.55	3.95
Apr. 6	7.48	2.75	4.30	3.48
Apr. 20	8.50	2.75	4.01	3.75
May 4	7.50	3.39	5.16	4.96
May 18	7.40	3.41	4.79	4.69
Jun. 1	7.30	3.17	4.35	4.11
Jun. 15	6.80	3.20	4.37	3.74
Jun. 30	5.70	3.50	4.38	3.80
Jul. 13	6.14	3.89	4.40	3.96
Jul. 27	5.53	4.24	4.25	4.05
Aug. 10	6.04	4.13	4.27	3.66
Aug. 24	6.94	3.82	3.89	3.63
Sep. 7	6.24	3.95	4.33	3.68
Sep. 21	6.02	4.04	4.36	4.02
Oct. 5	7.34	4.37	4.76	4.35
Oct. 19	7.83	4.04	4.53	3.38
Nov. 2	6.91	3.89	4.15	3.53

*ppm

Table 14. Organic carbon (ppm) in primary effluent.

Depth		Column									
cm	Day	1	2	3	4	5	6	7	8	9	Avg.
80	May 12	4.0	8.0	4.5	12.5	5.5	-	3.5	15.5	9.0	7.8
160		8.0	3.5	7.5	5.0	6.5	-	10.0	5.0	2.0	5.9

Table 15. Organic carbon (ppm) in primary effluent.

	Day	Column 1	2	3	4	5	6	7	8	9	Avg.
Outflow in jug	May 13	4.0	6.0	2.0	3.5	4.0	3.0	2.5	4.0	5.5	3.8

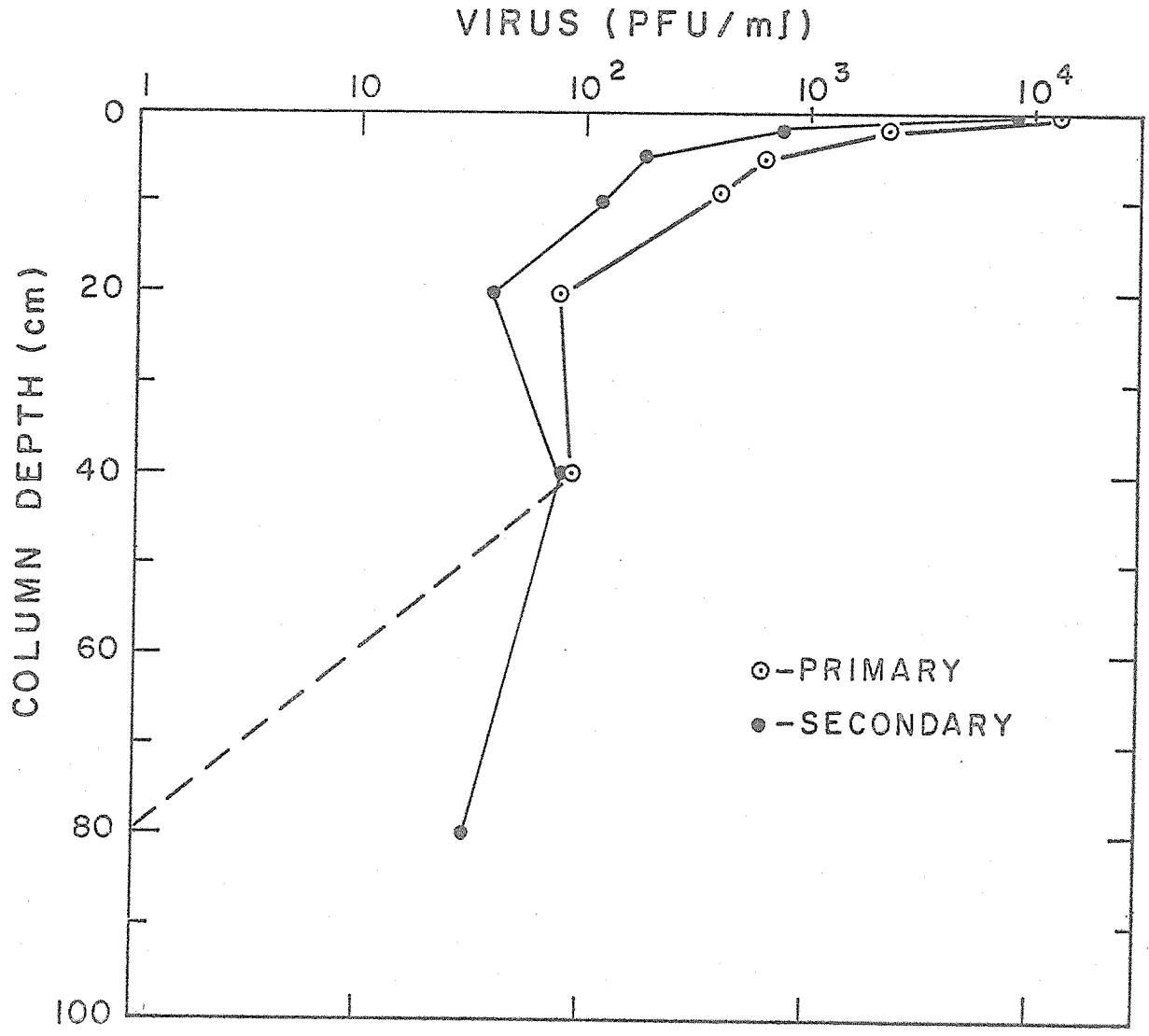

Figure 1. Virus removal from primary and secondary sewage effluent by soil columns.

Table 16. Infiltration rates and nitrogen removal - inside columns, 1976.

Start Cycle	End	Infiltration Rates* Col. 2	Infiltration Rates* Col. 3	% Nitrogen Removal Col. 2	% Nitrogen Removal Col. 3
Dec. 30, 1975	Jan. 13, 1976	21.67	13.62	23.83	-5.55
Jan. 13, 1976	Jan. 27	12.34	14.20	-6.31	38.73
Jan. 27	Feb. 10	12.61	11.49	10.43	23.37
Feb. 10	Feb. 24	10.59	6.93	-24.32	10.55
Feb. 24	Mar. 9	10.46	11.86	-1.20	38.02
Mar. 9	Mar. 23	10.90	11.84	.58	45.99
Mar. 23	Apr. 6	10.39	10.78	55.79	77.94
Apr. 6	Apr. 20	9.20	9.14	39.50	50.01
Apr. 20	May 4	9.47	10.06	36.06	52.92
May 4	May 18	7.78	6.55	-42.12	39.13
May 18	Jun. 1	6.92	22.05	22.15	55.85
Jun. 1	Jun. 15	7.15	20.69	-32.13	47.60
Jun. 15	Jun. 30	7.47	3.90	-29.84	82.61
Jun. 30	Jul. 13	10.20	4.18	6.22	1.95
Jul. 13	Jul. 27	6.35	4.28	17.95	-35.71
Average		10.23	10.77	5.11	34.89

*cm/day

Table 17. Phosphate averages for each cycle inside columns, 1976. (ppm)

Start Cycle	Eff.	Col. 2	Col. 3
Dec. 30, 1975	6.50	3.85	5.83
Jan. 13, 1976	8.87	2.53	4.41
Jan. 27	7.90	2.69	4.41
Feb. 10	7.57	2.68	3.85
Feb. 24	7.63	2.87	3.73
Mar. 9	6.16	2.96	4.60
Mar. 23	8.27	2.98	4.58
Apr. 6	7.48	2.43	4.30
Apr. 20	8.52	2.24	3.68
May 4	7.59	2.10	3.95
May 18	7.48	2.01	5.03
Jun. 1	7.13	2.02	5.52
Jun. 15	6.65	1.63	4.39
Jun. 30	5.73	1.92	3.48
Jul. 13	6.13	2.18	2.50

Table 18. Average suspended solids. Primary effluent, 1976.

Dates	Average ppm
Jul. 22 - Aug. 5	58
Aug. 5 - Aug. 19	56
Aug. 19 - Sep. 2	59
Sep. 2 - Sep. 21	44
Sep. 21 - Oct. 5	79
Oct. 5 - Oct. 19	75

Table 19. Grass clipping yield, 1976.

Date	Column 1	Column 4	Column 7
	grams dry weight		
2/10/76	16.73	11.88	13.55
3/9/76	5.58	5.35	7.08
3/23/76	3.02	3.1	3.57
4/4/76	5.9	18.48	5.15
4/22/76	13.95	5.5	12.02
5/18/76	6.23	3.09	4.9
6/10/76	13.78	4.9	11.46
7/16/76	15.12	3.74	11.88
8/5/76	13.94	7.24	16.1
10/8/76	29.46	11.91	17.97
Total	123.71	75.19	103.68

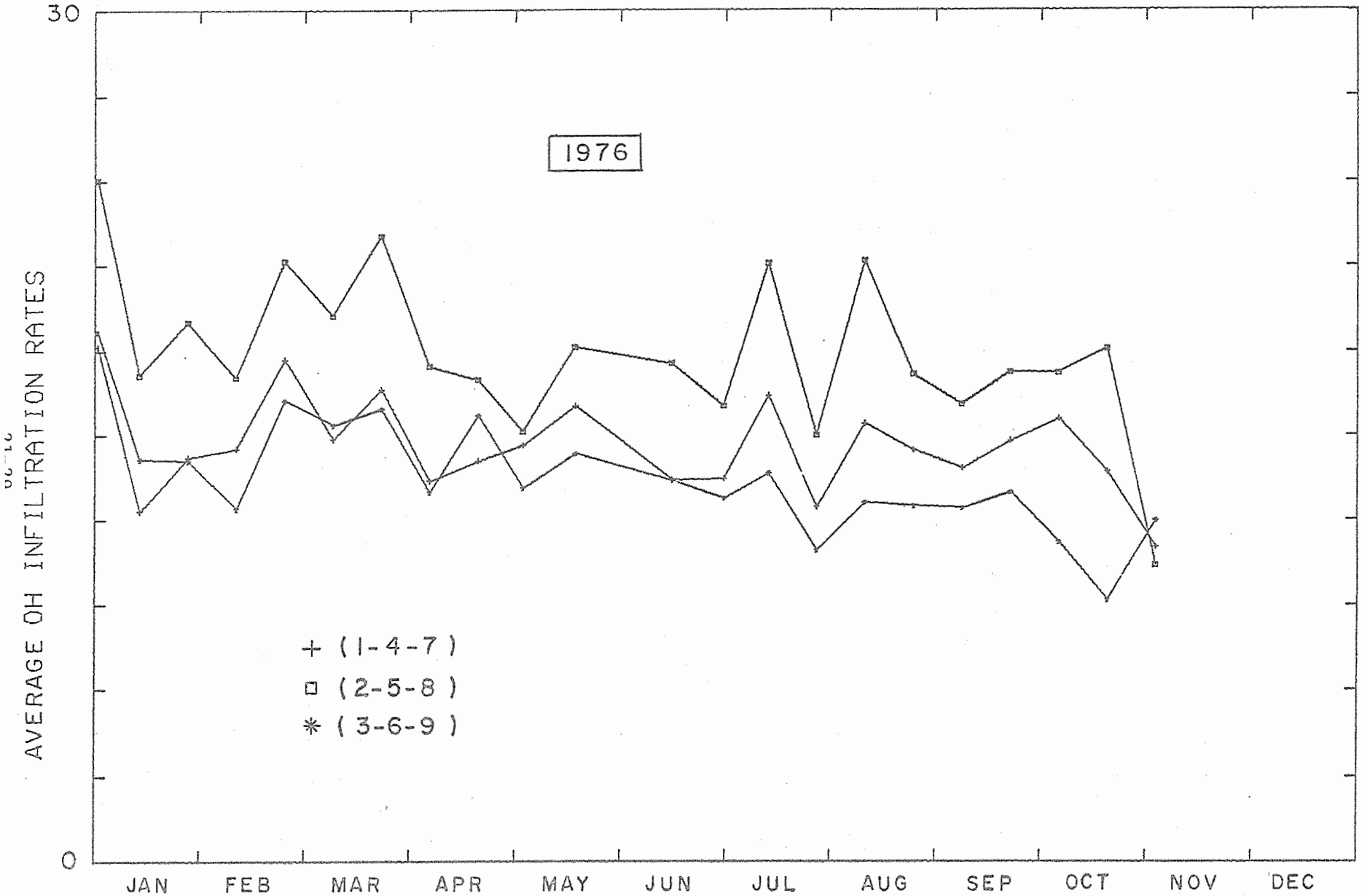

Figure 2. Average infiltration rates (cm/day) for soil columns flooded with primary sewage effluent on a 14-day cycle of 9 days flooding and 5 days drying.

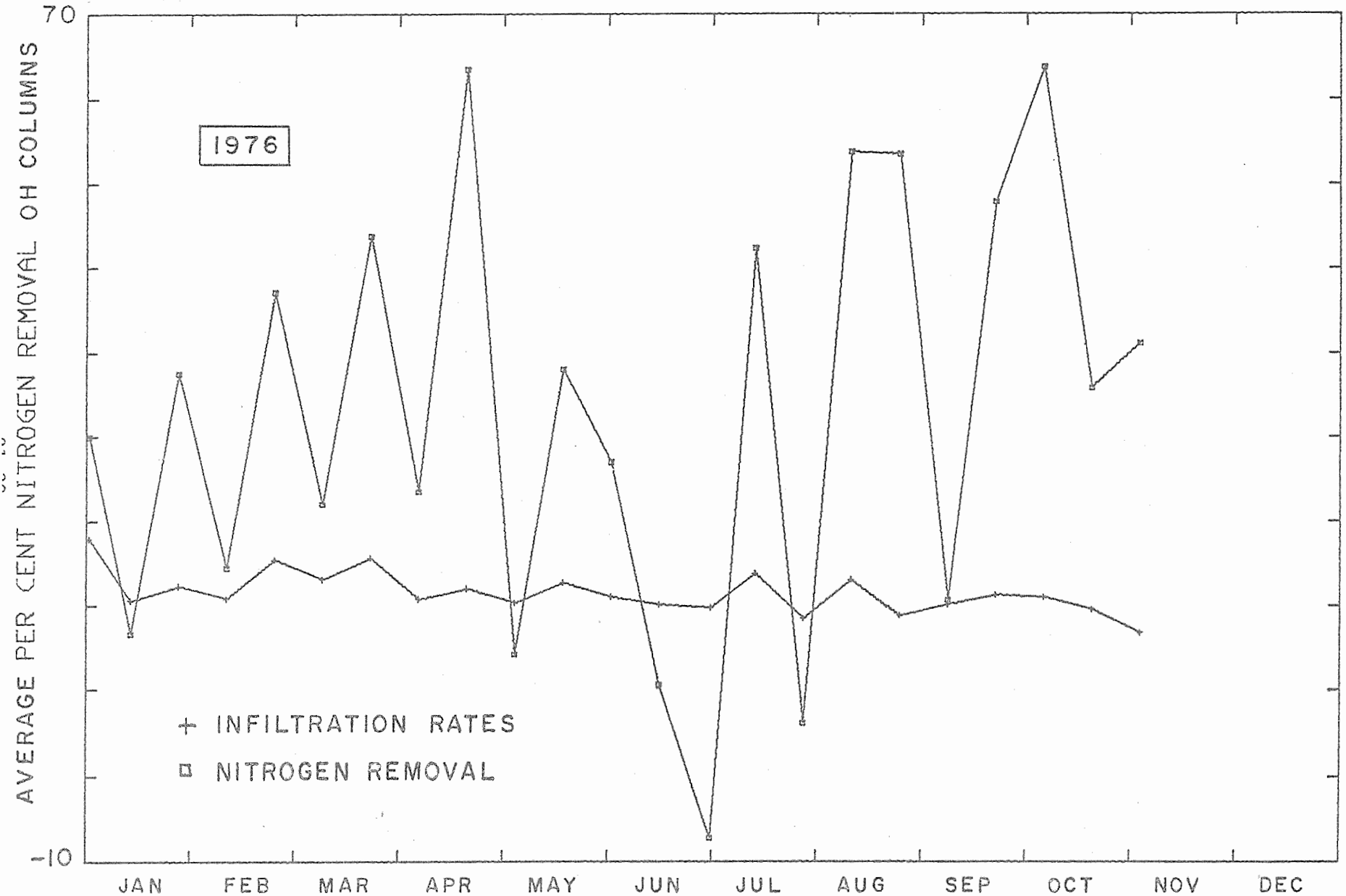

Figure 3. Average infiltration rates (cm/day) and average percent nitrogen removal by soil columns flooded with primary sewage effluent.

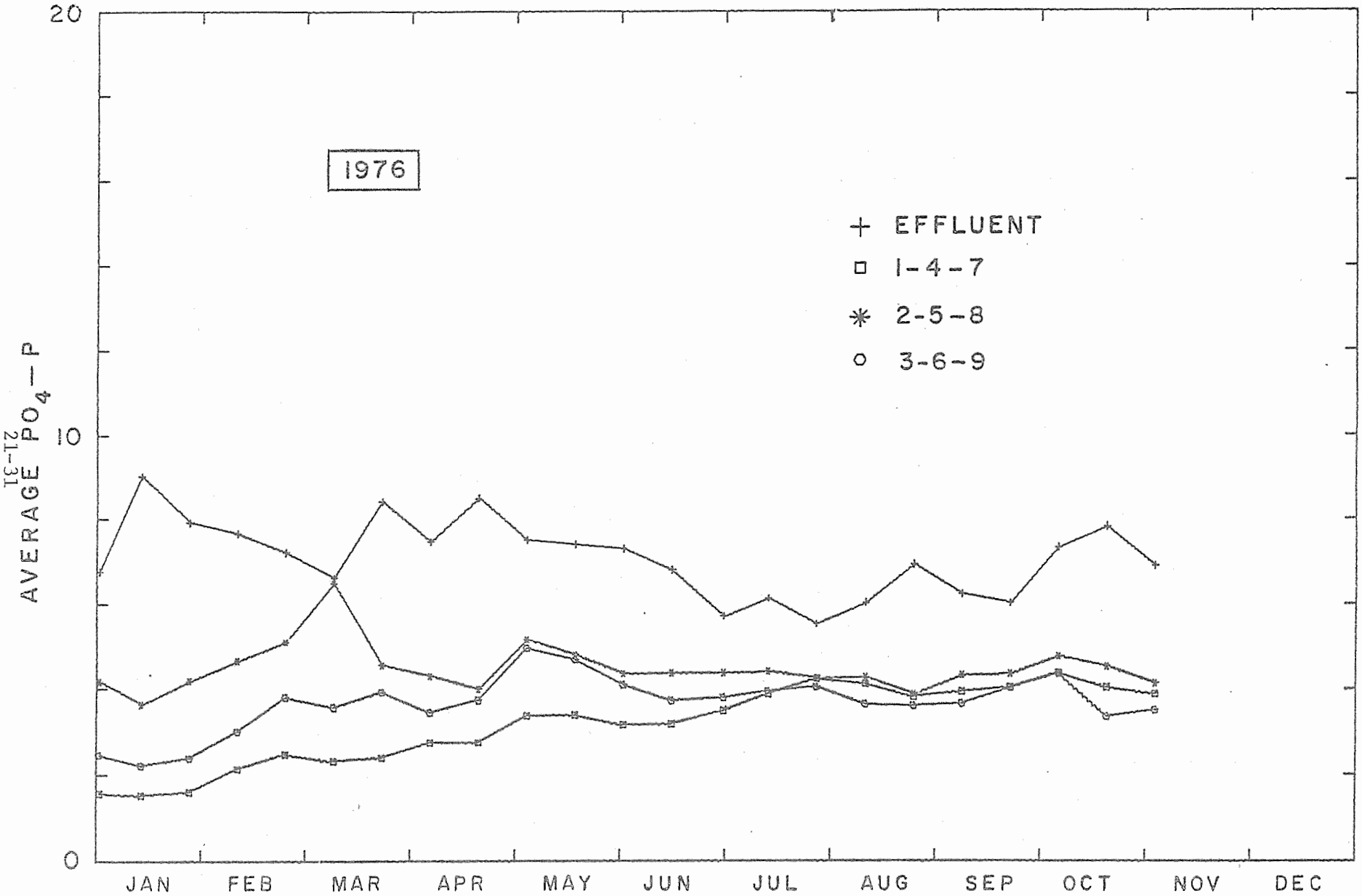

Figure 4. Average PO_4-P (ppm) concentrations in primary sewage effluent and water from soil column outflow.

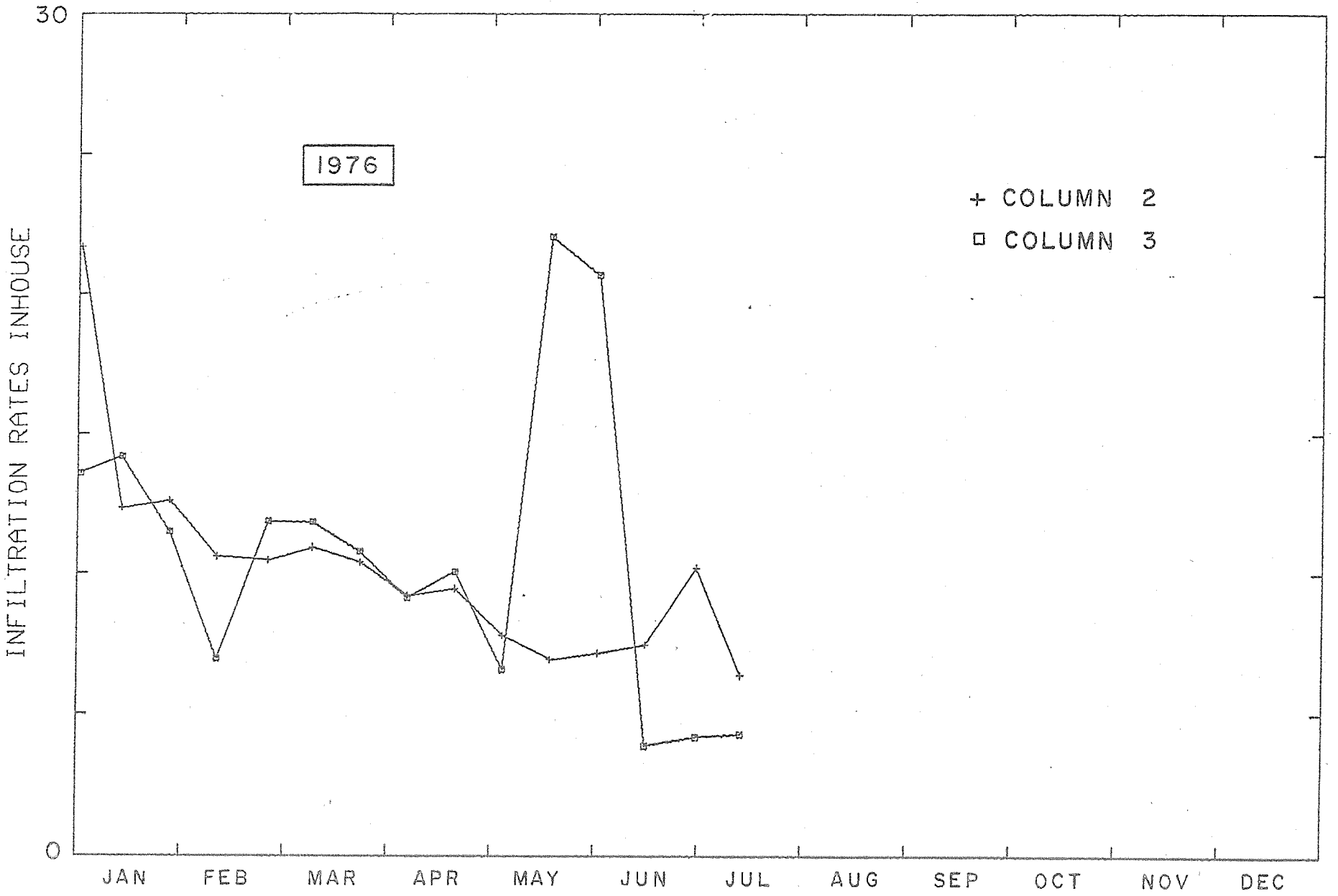

Figure 5. Average infiltration rates (cm/day) of laboratory soil columns flooded with primary sewage effluent on a 14-day cycle of 9 days flooding and five days drying.

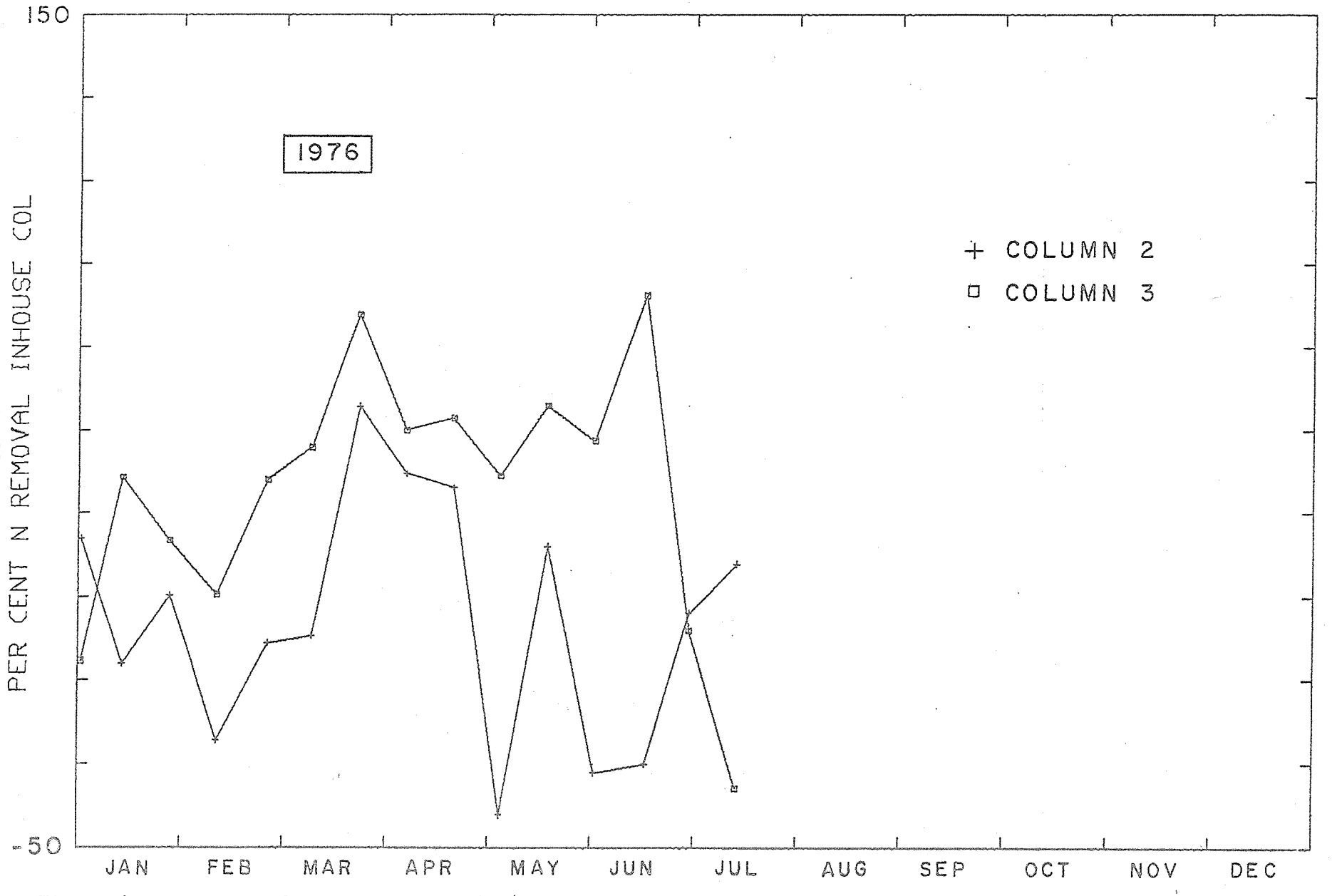

Figure 6. Average infiltration rates (cm/day) and average percent nitrogen removal of laboratory soil columns.

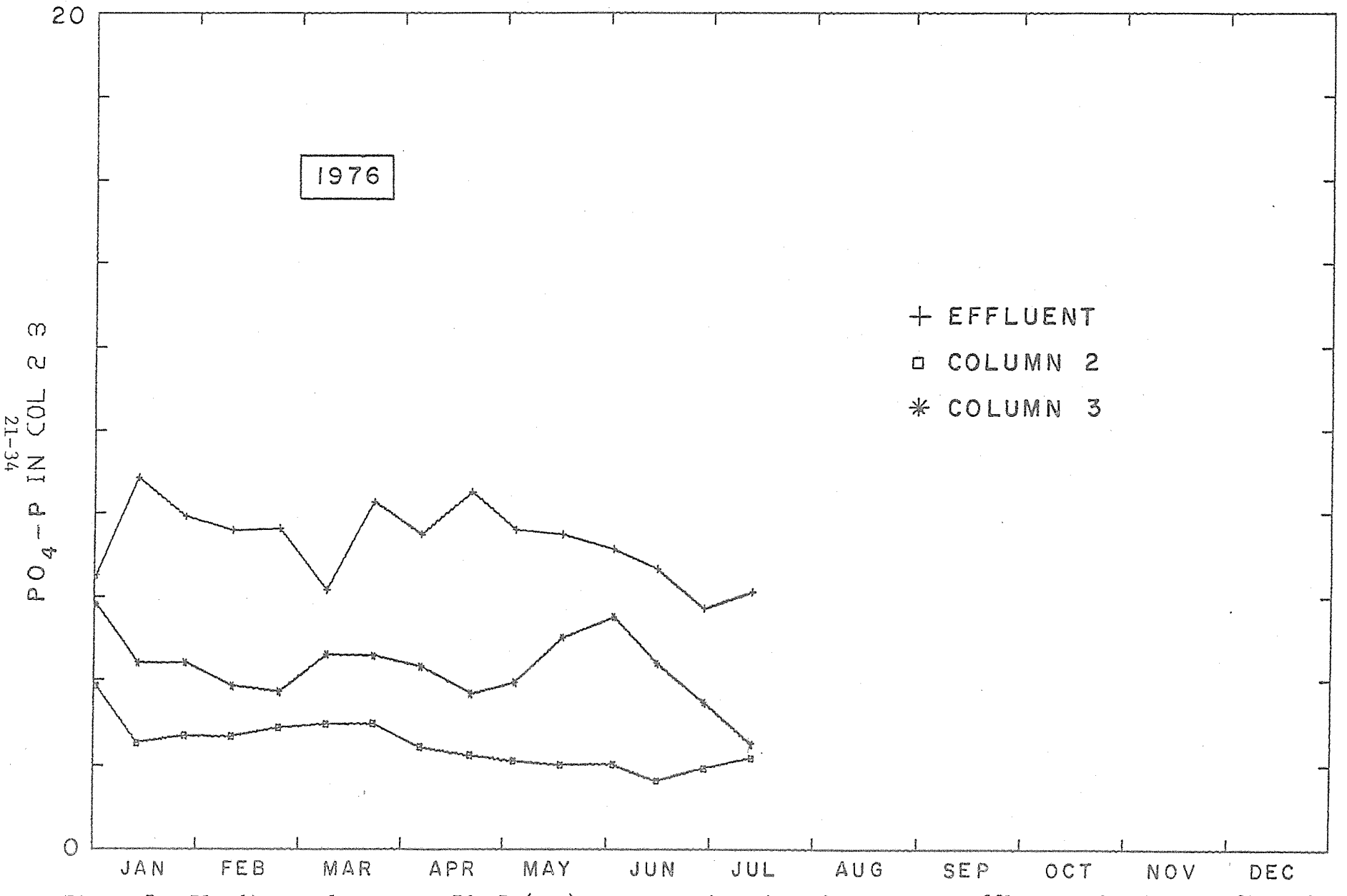

Figure 7. Flooding cycle average PO_4-P (ppm) concentrations in primary sewage effluent and column outflow of laboratory soil columns. Each 14-day cycle consisted of 9 days flooding and 5 days drying.

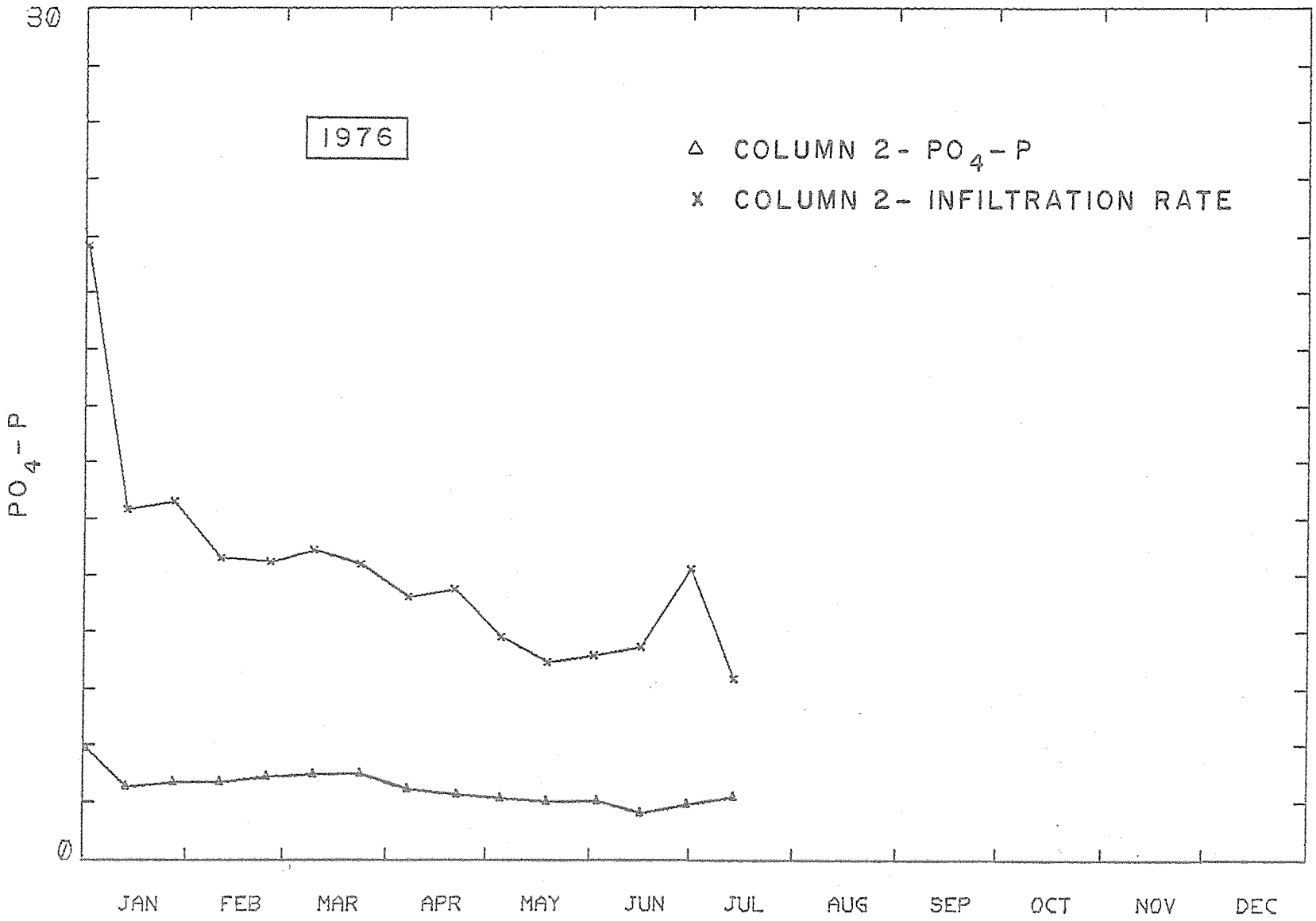

Figure 8. Flooding cycle average infiltration rates (cm/day) for primary sewage effluent and flooding cycle average PO_4-P (ppm) concentrations in column outflow from Column 2, laboratory soil column.

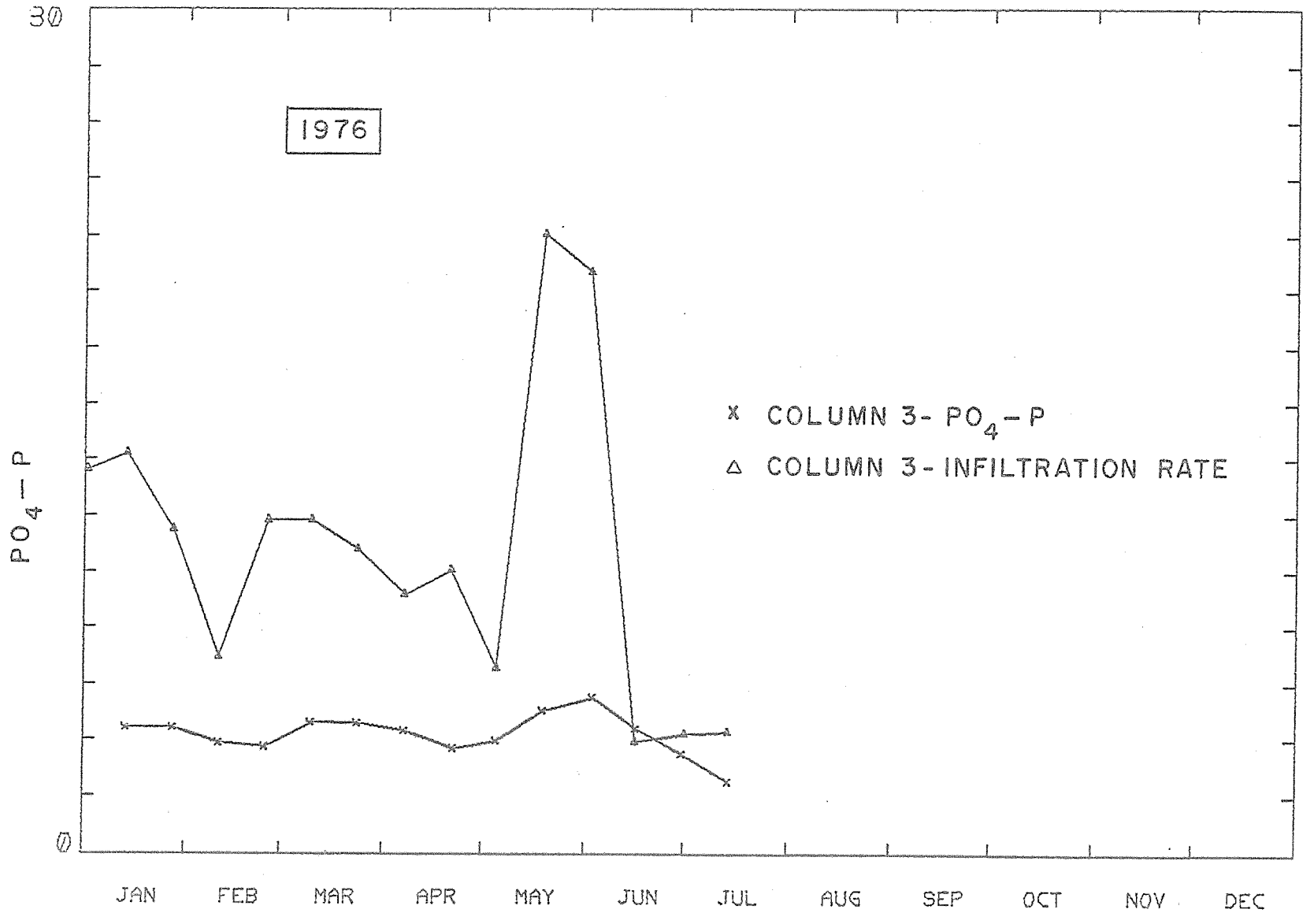

Figure 9. Flooding cycle average infiltration rates (cm/day) for primary sewage effluent and flooding cycle average PO_4-P (ppm) concentrations in column outflow from Column 3, laboratory soil column.

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

NRP: 20790 CRIS WORK UNIT: 5510-20790-001

CODE NO.: Ariz.-WCL 70-2

INTRODUCTION:

During 1976 results of bacteria and virus removal from secondary sewage effluent by land treatment were published in SCIENCE and APPLIED AND ENVIRONMENTAL MICROBIOLOGY. Cooperative research in Idaho on redox potential and denitrification in soil used for renovation of potato processing wastes was concluded, except for preparation of final manuscripts. The primary research effort was concerned with laboratory column studies that evaluated the effects of infiltration rates and carbon treatments on the activity of denitrifying bacteria in soil intermittently flooded with secondary sewage effluent treated with glucose as a carbon source.

PROCEDURES:

Description of Soil Columns. In our initial experiments six soil columns were assembled with plastic Buchner funnels, as described previously (Annual Report, 1975). However, since the infiltration rates were decreased after treatment with glucose, it was necessary to design new soil columns that would accomodate more soil and higher hydraulic heads, so the infiltration rates could be maintained during flood periods.

The new soil columns were assembled with plastic cylinders (7 cm in diameter by 18 cm long) containing about 2 cm of pea gravel in the bottom. Each column was packed to a height of 5 cm with 255 g of Flushing Meadows Soil from Basin #1. The soil was at 10% moisture with a bulk density of about 1.2. Extra drain tubes were added to the plastic cylinder that produced a hydraulic head of about 1 meter, if needed. These tubes were used only for removal of trapped air when the columns were first flooded. An average infiltration rate of about 45 cm/day for each flood cycle was maintained with these soil columns, even after treatment with glucose. These old and new types of soil columns will be referred to as "Low Head" and "High Head

Columns," which gave low and high average infiltration rates per cycle, respectively (Table 1).

Treatment of Soil Columns. Duplicate columns were used per treatment. Three treatments consisted of sewage effluent treated with 200 or 100 mg/l of glucose and effluent only for the low head columns. Whereas, with the high head columns, instead of the 100 mg/l glucose, a 20 mg/l glucose treatment was used.

For the low head columns, sterilizable plastic bottles of 8 liter capacity contained the sewage effluent and one bottle supplied the treatment solution for two columns. The glucose-treated sewage effluent was replaced daily to prevent bacterial buildup in the bottles and maintain the treatment concentrations of glucose.

For the high head columns, effluent was applied to the columns via 45 liter carboys with Marriot syphons that controlled the hydraulic head. One carboy supplied the effluent for two duplicate columns. The carboys were placed on platform jacks to add more vertical adjustment, plus the outlet drain was adjustable with a 10-cm height range for controlling infiltration rates. The glucose was added directly to the soil column on a mg/l basis, that was determined from daily measurements of infiltration rates. The glucose was weighed and dissolved in a small volume of sterile water, added to the effluent head water inside the cylinder, and stirred gently for thorough mixing and uniform application of the glucose into the soil. During 9 days flooding, the columns were either treated continuously, or for only the first 2 days, which was followed with untreated effluent for the remaining 7 days. These types of glucose treatments will be referred to as "continuous" and "pulse glucose treatments," respectively.

Microbial Assay of Soil Columns. The numbers of denitrifying and aerobic bacteria were determined by MPN methods and dilution plate techniques, as previously described (Annual Report, 1975).

RESULTS AND DISCUSSION:

The results are preliminary and are presented here as a progress report. The influence of infiltration rates, glucose concentration,

and glucose dosage rates are summarized in Table 2. An increase in infiltration rate from 18 cm/day to 49 cm/day resulted in higher amounts of glucose applied and increased the relative numbers of denitrifying bacteria throughout the flooding and drying cycles, especially at the start of the flood period. The higher populations of denitrifiers would enhance denitrification during the first few hours of flooding, especially if low heads or sheet flow were used to apply the effluent for the first 24 to 48 hours. Also, the relative numbers of denitrifiers were increased when glucose was applied continuously to the low head columns. In general, the higher the absolute amount of glucose applied (mg/cycle) the greater the increase in activity of denitrifiers.

The treatments that were not effective in promoting the activity of the denitrifiers throughout the flooding and drying cycle were the pulse glucose treatment at 200 and 100 mg/l with low head columns and pulse glucose treatments at 20 mg/l with high head columns. Probably, the lower glucose dosage rates placed less of an oxygen demand on the system for a shorter period of time and did not support the establishment of a facultative anaerobic denitrifying population for the duration of the dry period.

Relative to the control columns flooded with effluent only, the activity of denitrifiers increased slightly, as expected. However, the level of available nutrients in the sewage effluent from an activated sludge-type sewage treatment plant would not cause a large increase of microbial activity in soil.

SUMMARY AND CONCLUSIONS:

The effects of increased infiltration rates and the addition of carbon sources to the effluent on the activity of denitrifying bacteria in soil columns flooded with secondary sewage effluent were determined. Data for glucose treatments during the first 2 days of a 9-day flood period have been completed, and experiments with continuous glucose-treatment for 9-days flooding are in progress. The average rates of infiltration for the soil columns were similar to those obtained in the field project of about 45 cm/day. With

higher infiltration rates greater amounts of glucose (mg/cycle) were applied to the soil, the numbers of denitrifying bacteria were increased in proportion to the amount of glucose applied, and the population of denitrifying bacteria was maintained throughout the dry period. Since nitrate is rapidly leached when the soil is flooded, it is important to maintain an active population of denitrifying bacteria until the end of the dry period. This would, in effect, greatly increase the potential for denitrification and nitrogen removal during the dry period, and especially during the first day of flooding.

During 1977, the activity of denitrifying bacteria in soil used for wastewater renovation will be continued. Complimentary field experiments at the Flushing Meadows Project will characterize the growth and activity (denitrifying potential) of the denitrifying bacteria in soil basins that have renovated secondary sewage effluent for 10 years. The results obtained will be used to enhance the activity of denitrifying bacteria and nitrogen removal mechanisms in high rate-land treatment systems by the timely additions of carbon to the sewage effluent that is being renovated.

PUBLICATIONS:

1. Gilbert, R. G., Rice, R. C., Bouwer, H., Gerba, C. P., Wallis, C., and Melnick, J. L. 1976. Wastewater renovation and reuse: Virus removal by soil filtration. Science 192:4243, 1004-1005.

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PERSONNEL: R. G. Gilbert, J. B. Miller and J. C. Lance

Table 1. Average infiltration rates for two types of soil columns flooded for 9 days with secondary sewage effluent treated with glucose[a].

TYPE OF SOIL COLUMN	Glucose Treatment (mg/l)		
	200	100	Effluent
	(Average infiltration rate) (per cycle - cm/day)		
Low Head (1.5 to 2.0 cm)	18(46-3)	24(118-6)	40(100-6)
High Head (6 to 8 cm)	49(106-6)	43(110-6)	40(76-9)

[a] Results for low and high head type soil columns are averages of 12 and 23 measurements taken at various times during 11 and 4 flooding periods, respectively. Duplicate columns were used per treatment. Parenthesis indicate range of infiltration rates for each treatment during a typical 9-day flood period.

Table 2. Influence of infiltration rate and carbon treatment on the relative activity of denitrifying bacteria in soil columns flooded for 9 days with secondary sewage effluent amended with different glucose concentrations and dosage rates[a].

Glucose Treatment			Infiltration Rate	Days Flooded		
Type	Concentration	Dosage		0	4	9
	(mg/l)	(mg/cycle)	(Average Cycle)	(Denitrifiers - Percent of Control)		
			Low Head Columns			
Pulse	200	277	18	53	157	568
	100	138	24	58	159	233
Continuous	200	1247	18	392	552	336
	100	621	24	277	888	497
			High Head Columns			
Pulse	200	765	49	214	358	163
	20	82	43	118	93	135

[a] Two types of glucose treatments were used: 1) The Pulse Glucose Treatment applied the carbon source for only the first two days of each flood cycle, then sewage effluent was applied the last 7 days of the flood cycle; and 2) The Continuous Glucose Treatment applied the carbon source on every day of each 9-day flood cycle. The data for denitrifier bacteria populations in treated columns are presented as a percent of the denitrifiers in the effluent control columns. The columns were dried for 5 days between each 9-day flood period.

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

NRP: 20810 CRIS WORK UNIT: 5510-20810-002
5510-20810-001A

CODE NO.: Ariz.-WCL-65-2

INTRODUCTION:

The rainfall-runoff-erosion studies conducted in cooperation with the University of Hawaii continue to be the major research project in Hawaii. Data processing has taken the most effort; however, now that 5 years of data have been collected, analysis will assume greater emphasis. Programs to summarize the data have been developed and summary tables and graphs from the first 4 years of data are being studied. A prospectus, intended to describe preliminary findings of rainfall-runoff and erosion characteristics, was approved, and a cooperative report is being prepared as an ARS-WR paper.

A cooperative agreement initiated last year with the State of Hawaii, Department of Land and Natural Resources, is progressing slowly. A new cooperator has been located and reservoir construction is in progress. All equipment and materials needed to install the catchment and instrumentation are ordered and being shipped to Hawaii for an early 1977 installation.

PART I. WATER HARVESTING

RESULTS AND DISCUSSION:

The 4-plot water harvesting test site on Maui was visited once during 1976. The plots are being observed to determine long-term weathering ability of the materials. All plots are still functioning satisfactorily, although ideally, some maintenance should be performed on each. The asphalt-fiberglass plot should have a new sealcoat to extend its life. The butyl plot has a number of small holes that should be patched. The Hypalon plot has two sections of seam about 10 ft long that have come apart. Grass growing in these open sections has held the membrane in place, but runoff efficiency is affected. The grass plot has been grazed occasionally and looks similar to surrounding pastures.

The cooperative agreement initiated with the State of Hawaii to determine quality of water collected from wax-treated catchments did not receive final approval until October 1, 1976. Locating a cooperator who owned sufficient land and had a need for the water has now been completed, and a lined reservoir is under construction. The materials and equipment required to treat the catchment apron have been ordered and shipped to Hawaii, and installation is expected in early 1977. Procedures for collecting samples, analyzing data, and presenting results are the same as described in last year's Annual Report.

PART II. RAINFALL-RUNOFF-EROSION STUDIES

Computer programs to determine rainfall intensities, antecedent moisture, erosion index, daily totals, and other factors have been developed. All data for years 1972 through 1975 have been processed in summary tabular form, and analysis is in progress. Selected events of interest will be investigated in more detail using additional plotting programs. Curve Numbers for all watersheds were provided SCS personnel in Hawaii during 1976, and will be updated as new data are processed.

Preliminary analysis indicates that most of time rain is falling (up to 90%) it occurs as very low-intensity showers. However, because large, high-intensity storms do occur, the erosion index for a single storm may be greater than the published long-term annual average value used in design.

Following is a brief summary of historical items and observations noted for each of the watersheds during 1976:

Laupahoehoe. This site was harvested on 25 and 26 August 1976. From January until harvest, a very thick cover of sugarcane protected the site and no erosion occurred. Shortly after harvest, a rather large storm did cause some erosion (observable in the watershed) and some sediment was collected for analysis. Visual observations indicated that most of the sediment was deposited in front of the flume where a basin was hollowed out during the harvest operation. Runoff from later storms was clear, indicating the soil had regained stability

or the cane was again offering some protection. Watershed boundaries were inspected in September and appear to conform to the last survey. By the end of the year, the ratoon crop was 2 to 3 ft high and provided a limited cover.

Honokaa. This watershed had a complete sugarcane cover until harvested on 25 October 1976. After harvest, it was noted that a berm, originally intended to divert runoff water through the flume rather than along the road, had been removed. A significant amount of sediment had also been deposited above the flume causing a change in runoff direction. A trench was dug through the sediment and a berm built up to redirect runoff through the flume. A quick look at records before and after harvest did not reveal any significant changes in runoff patterns. Due to the rather dry period, all runoff amounts were rather small.

Waialua Sugar. This watershed had an 8- to 10-ft partial cover in January, which gradually changed to a 10-ft complete cover by June, mainly due to weed growth between the sparse cane. This plot is scheduled to be harvested early in 1977.

Waialua Pineapple. The young sugarcane on this watershed was harvested 2 June 1976, using equipment similar to that used to harvest corn. The cane stalks were cut about 2 to 3 inches above the soil surface and chopped into 1- to 2-ft lengths for seed cane. A considerable amount of debris was left on the ground providing almost complete coverage. This debris was burned on 23 June 1976, and the ratoon crop had reached 3 to 4 ft by September, providing a limited cover. At the end of the year the 6-ft cane provided a partial cover.

Mililani. This field remained bare from January until the middle of May and was worked over with a harrow or disk several times during this period. About 20 May the field was planted to pineapple with plastic strips between plantings. The field was irrigated three times between June and November, and by the end of the year the pineapple was 15 to 18 inches high and provided essentially a complete cover.

Kunia. This site has a mature pineapple crop which provides a complete cover. The pineapple was picked in January and was again

ready for harvest by the end of the year. A large storm, which lasted for several days during early February, in the mountains above the site, produced springs on the watershed causing about 1 inch of flow through the flume from 8 February to 8 March.

SUMMARY AND CONCLUSIONS:

The rainfall-runoff-erosion studies conducted in cooperation with the University of Hawaii continued to receive the major research effort during 1976. Processing of rainfall-runoff data was delayed by computer outages, but should be complete through December 1976 by March 1977. Analysis of the data is assuming a greater role now that almost 5 years of data have been collected. Computer programs developed during the year were used to summarize the 1972-1975 data in tabular form, and these tables are being studied. Curve Numbers for all data up to December 1975 and for all watersheds were provided Hawaii SCS personnel. A cooperative report intended to present preliminary rainfall, runoff, and erosion characteristics is being compiled and will be published as an ARS-WR series.

A cooperative agreement initiated last year with the State of Hawaii, Department of Land and Natural Resources, was slow in getting underway because a new site and collaborator had to be located. The new site has been chosen and a lined reservoir is under construction. Installation of the catchment and measuring equipment is scheduled for early 1977.

The four water harvesting plots on Maui were visited during 1976 and appear to be performing satisfactorily, although the three treated plots would need minor maintenance to extend their useful life.

PERSONNEL: Keith R. Cooley, Gary W. Frasier, and John R. Griggs

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

NRP: 20810 CRIS WORK UNIT: 5510-20810-002

CODE NO.: Ariz.-WCL 71-6

INTRODUCTION:

Long-range durability and efficiency studies were continued at Granite Reef for a few materials in 1976. Included were foamed rubber, foamed wax blocks, and two continuous wax covers on the 9-ft-diameter stock tanks. The wax cover on the butyl-lined pond was monitored during 1976, and additional wax was added to determine if a complete cover could be maintained.

Field evaluation of the wax cover installed on the Chino Valley stock tank was continued, and an additional 30-ft-diameter stock tank on the Joronado experimental range in New Mexico was treated with wax.

Field evaluation of the foamed rubber or sponge covers, the first located on a tank in southwestern Utah in 1971 and three others on tanks in Arizona in 1974, was continued. A paper, "Foam Rubber Covers for Controlling Water Storage Tank Evaporation," describing materials, construction procedures, installation, protection, and cost of floating covers of sponge was published as Miscellaneous Report #2 from the University of Arizona.

PROCEDURE:

Evaluation of the various treatments on the Granite Reef tanks was intended to be the same as in previous years (evaporation from a treated tank being compared to that from an identical untreated tank). Unfortunately, three of the tanks, including the control tank, rusted out during the year, and only 5 months of comparative data were obtained.

Two applications of 128° paraffin wax, of about 800 pounds each, were made to the existing cover on the butyl-lined pond, using the laboratory tar kettle to melt and pump the wax.

Evaluation of field installations was based on reports received from cooperators, since the remote locations are seldom visited by laboratory staff members.

All covers were the same as reported on last year except the wax cover at Joronado. This cover consisted of 128° paraffin wax applied

to the water surface as a liquid using the tar kettle. About 750 to 800 pounds of wax was applied during a rather windy period, and essentially all of the surface was covered.

RESULTS AND DISCUSSION:

Granite Reef Studies. The 5 months of comparative data collected from the stock tanks during 1976 indicate that the efficiency of all four covers remained essentially the same as in previous years, although yearly averages could not be calculated. Two repaired tanks will be used during 1977 to maintain continuity on this study.

The wax cover on the butyl-lined pond now contains about 3,200 to 3,500 pounds of wax and still covers about 80% to 90% of the surface area. Original estimates of the amount of wax required, based on the small tank studies, called for only about 2,000 pounds. Results from this study indicate that the larger the water surface, the thicker the wax cover must be. Apparently, even rather light winds have an appreciable effect on the cover as the pond size increases. More data would be necessary to verify this observation and to determine design limits.

Field Studies. Reports from both Chino Valley and Joronado indicate that only 60% to 70% of the surface area is covered with wax. Both of these tanks are in rather windy areas, and may therefore require a thicker layer of wax to maintain a complete cover. Application of additional wax is planned for spring 1977 at both sites.

Neither cover was blown from the surface or floated off the surface, indicating the overflow systems are working. This is especially encouraging at Joronado where water level is maintained near the top of the tank.

Beaver Dam Tank, southwest of St. George, Utah, installed November 1971 -- The cover was inspected three times during 1976. The tank is still actively being used. The sponge sheeting is in excellent condition. Lap joint adhesion is still good but rod stock adhesion generally poor although not separated from cover.

Frasier Well and Shipley Well tanks, Hualapai Indian Reservation, installed May 1974 -- Both covers operated satisfactorily during 1976.

The Shipley Well cover was patched in October 1975. Vandalism, as experienced previously, has not recurred.

Grover Ranch tank, south of Safford, Arizona (Bureau of Land Management), installed September 1974 -- The tank and cover are still actively being used and operation is satisfactory.

Hughes Ranch tank, south of Rye, Arizona (Tonto National Forest), installed November 1974 -- A new sheet metal catchment was installed by the Forest Service in early summer 1976 to supply water to the tank. The cover is in excellent condition. The water system will be used regularly in the future.

SUMMARY AND CONCLUSIONS:

The foamed wax blocks and continuous wax covers tested at the Granite Reef test site have performed essentially the same for the past 4 to 6 years. Evaporation reduction efficiency has been about 36% for the blocks and 85% for the continuous covers. A foamed butyl rubber cover tested for the past 3 years has reduced evaporation about 75%.

Field tests of the continuous wax covers indicate that a thicker layer of wax may be required in windy areas on the larger size tanks. Doubling the wax thickness on a lined pond at Granite Reef improved surface coverage from 30%-40% to 80%-90%, indicating that the thickness may depend both on average wind conditions and on size of surface area.

The five experimental foamed rubber covers being field evaluated continue to operate satisfactorily. The lap joints of the oldest, 5-1/2 years, are still excellent and the sheeting shows no sign of degradation. Covers are now being constructed by various agencies to control evaporation from water storage tanks.

PERSONNEL: Keith R. Cooley, Allen R. Dedrick.

TITLE: LOWER COST WATER HARVESTING SYSTEMS

NRP: 20810 CRIS WORK UNIT: 5510-20810-002

CODE NO.: Ariz.-WCL-71-12

INTRODUCTION:

Studies were continued at the Granite Reef test site on the evaluation of methods and materials for increasing precipitation runoff. The Monument Tank test site is in a secondary or standby phase consisting of maintaining the raingage network and the recorders on two of the watersheds. All instrumentation at the Seneca test site has been removed. The cooperative study with the Bureau of Land Management (BLM), U. S. Department of Interior, is in its second year of evaluating water harvesting systems and methods. Assistance was provided to various units of the Forest Service in Arizona and New Mexico and to the Arizona Game and Fish Department in installation of water harvesting catchments. A new study of growing forage with water harvesting techniques near Tombstone, Arizona, was initiated in cooperation with the Southwest Watershed Rangeland Research Center, ARS, Tucson, Ariz.

PART I. GRANITE REEF TEST SITE

Total rainfall at the Granite Reef test site was 225.1 mm for 1976. Only two storms during the year were greater than 20 mm total precipitation.

Paved or Covered Plots: The runoff efficiency from the two-phase asphalt treatments on plots L-5 and L-6 averaged 36.8% and 71.9%, respectively. Runoff from plot L-5 continues to decline, a result of no maintenance for over 5 years. Large shrinkage cracks have developed in the pavement which have provided a place for plants to become established. There is a curling of the asphaltic pavement at these cracks. Plot L-6 received a new sealcoat of fiber-loaded asphalt emulsion in November 1975. This did improve the runoff efficiency compared to 1975. This sealcoat is now starting to crack.

The membrane-covered plots L-1 (30 mil chlorinated polyethylene) and L-7 (1 mil aluminum foil) yielded 99.0 and 79.6% runoff, respectively,

only slightly less than was measured in 1975. The aluminum foil on L-7 continues to show signs of oxidation which may be forming small pinholes where water is lost. Plot L-4 was re-treated on 13 Sep. 1976, with a polypropylene matting coated with asphalt emulsion similar to the asphalt fiberglass. A sealcoat of clay asphalt emulsion was applied on 29 Sept. 1976. Runoff since treatment averaged 72.8% from a total of 74.0 mm of rainfall. The absence of a sealcoat for the first two storms after installation reduced the average runoff efficiency for the year.

The aluminum coated asphalt fiberglass treatment plot, A-1, yielded 98.4% runoff while the gravel-covered tar paper, plot A-2, averaged 68.5% runoff. No maintenance has been performed on either plot in over 4 years. The concrete apron, plot A-5, averaged 72.9% runoff for the year. Cracks across the apron surface which had been sealed with strips of asphalt fiberglass in June 1972, have partially reopened. This has reduced the runoff efficiency.

Bare Soil Plots: The treatments for the bare soil plots are listed in Table 3 and the runoff results are presented in Table 4. Rainfall runoff from the untreated and smoothed untreated plots were essentially unchanged from the previous year. Smoothed untreated plots L-2 and A-3 averaged 13.9% and 24.8%, respectively. The untreated ridge and furrow plots R-1 and R-3 averaged 21.4% and 16.4%, respectively, and the two undisturbed watersheds W-1 and W-3 averaged 14.2% and 18.4% runoff, respectively, for the year.

Runoff from watershed W-2 treated 3 June 1975 with silicone water repellent averaged 15.6%. There is considerable retention on this plot with trash and dead brush in the drainage channel which has reduced the runoff efficiency to essentially the untreated watershed values. Plot A-4 treated with silicone in 1971 yielded 57.0% runoff while plots L-3 and R-4 re-treated with silicone in 1975 averaged 52.2 and 78.5% runoff, respectively. Plot L-3 has developed a relatively extensive desert pavement with time, which may be reducing the runoff. The wax-treated plot, R-2, continued to give good runoff averaging 86.1% for the year.

The effect of the gradual deterioration of the silicone treatment is shown in Figure 1. The runoff efficiencies (average annual) for plots R-2, A-4, R-4, L-3, A-3, and L-2 are plotted vs. the years since treatment or plot installation. Plots A-3 and L-2 are smoothed untreated and do not show any major change in runoff efficiency. Plot R-2 (wax) has a slight increase in runoff efficiency. The silicone-treated plots L-3, R-4, and A-4 all show a decline in runoff efficiency with time after treatment or re-treatment.

Tank Water Storage: An alternate water storage tank for catchments is undergoing evaluation at the Granite Reef Testing Site. The system is designed for installation in remote areas where large equipment and supplies would be difficult to provide. The storage system consists of a steel rim of small sections which can be bolted together such as a grain bin with no roof or bottom. The rim is assembled from curved corrugated steel pieces with a butyl mastic sealer between joints and self-sealing washers around the bolts. After assembly, all joints and bolts are covered with a roofing tar. The bottom of the tank is sealed with a composite lining of soil and bentonite clay blankets. A sketch of the bottom is presented in Figure 2. These studies were initiated in October 1976. To date, the tank shows no signs of leaking.

Outdoor Weathering Plots: In December 1973, 43 separate materials and/or coating were installed on small exposure plots at the Granite Reef test site. In April and July 1974, three additional materials were installed. A description of the materials and coatings is presented in Table 5 of the 1974 Annual Report, "Lower Cost Water Harvesting Systems," WCL 71-12. Materials under evaluation have thicknesses from 1 mil to 55 mil. Some of them have an additional protective coating for added weathering resistance. A visual inspection of the materials and coatings is performed periodically to evaluate relative weathering performance. Sheeting materials are also checked for elongation or shrinkage by measuring two reference marks which were placed on the materials at the time of installation. For the protective coating evaluation, the substrate material is not considered unless

there is evidence that a substrate failure has occurred because of inadequate protection. If a material is graded as poor it is usually removed and considered to have failed.

A brief description of the evaluation for the past year is presented in Table 5. Mechanical damage from wind or varmints has been minimal.

PART II. MONUMENT TANK

Precipitation at the Monument Tank test site was considerably below normal with only 230 mm measured at the site in 1976. This compares to a total of 297 mm recorded in 1975, and a long term average of 400 mm per year. At present, runoff is only measured from areas Nos. 1 and 2. These data are in the process of being summarized.

PART III. OPERATIONAL CATCHMENTS

With the removal of the instrumentation from the Seneca Test Site in 1975, no field water harvesting systems are being operated or maintained by laboratory personnel. Assistance in design, treatment selection, and installation was provided to operational agencies as time permitted. Actual installation assistance was provided if local expertise in water harvesting techniques was unavailable and the installation could be used as a training exercise. Under this policy a total of five catchments were installed in assistance with the U. S. Forest Service in Arizona and New Mexico. These installations were all asphalt-fiberglass treatments on catchment areas of 300 to over 1000 m^2. Four units installed in New Mexico were replacement aprons for butyl sheeting coverings which had failed.

PART IV. WATER HARVESTING FOR FORAGE PRODUCTION

A study was conducted in cooperation with the Southwest Watershed Rangeland Research Center in Tucson, Arizona, to assess the change in forage production of blue panicgrass (Panicum Antidotale Retz) when additional water is provided in strips of vegetation from companion water collecting areas. By coupling more water with a higher fertility level, the productivity of specialized areas of our rangelands could be significantly increased.

Procedure: A series of small test plots were laid out on a recent sandy loam alluvial terrace, created in part from old mine spoils about 6.5 km west of Tombstone, Arizona on the lower part of the Walnut Gulch Watershed. The plots, laid out on a 2% slope, were enclosed by a metal border 6 cm high and buried 2 cm in the ground. A total of 36 plots were installed in a three-replicate randomized block design utilizing three types of treatments on the runoff area and four runoff:crop-growing-area ratios, 0:1, 1:1, 2:1, and 3:1. The twelve 0:1 plots with no runoff-contributing area are used as controls. The runoff areas and 3 m wide and 3, 6, or 9 m long. The runoff treatments were: cleared smoothed, cleared smoothed waxed, and cleared, seeded with blue panicgrass. On the cleared smoothed runoff areas, all vegetation was removed and the soil surface smoothed and compacted with a smooth steel-drum lawnroller. The wax treatment consisted of clearing and smoothing the soil, then applying refined paraffin wax, 128-135 AMP, heated to 100 C by spraying on to the soil surface at a rate of 1.1 kg/m^2 (2 lbs/yd^2).

All water collected from the runoff area is contained within the 3 x 3-m crop growing area which was seeded with blue panicgrass on 24 June 1974, at a rate of 4.5 kg/ha. After seeding, the plots were sprinkled with water at a daily rate of 8 mm for a period of 2 weeks to insure a stand of grass. All plots were fertilized prior to seeding with triple superphosphate, ammonium nitrate, and agricultural limestone at a rate of 33, 23, and 450 g per m^2 (300, 200 and 4,000 lbs/acre), respectively. On 9 July 1975, ammonium nitrate, triple superphosphate, potassium chloride, and magnesium sulphate were applied at rates of 30, 33, 11, and 13 grams per m^2 (270, 300, 100, and 120 lbs/acre), respectively.

Results: Rainfall for the 1974 growing season was considered "normal" until early August and provided sufficient water to establish adequate growth on all plots. An ensuing drought in August 1974 prompted a decision to harvest all plots on 26 August 1974, even though flower emergence was not uniform among treatments. Rainfall following

the cutting date was minimal and no further harvests were attempted in 1974, although residual available water provided some additional growth on the plots with the larger runoff-contributing areas. This growth and the early 1975 spring growth froze without producing any harvestable vegetation. This growth did, essentially, deplete the soil water as evidenced by the absence of growth on any plots before the summer 1975 rains. Summer precipitation events in 1975 were more uniformly distributed than those of 1974, and the rainy season was longer.

The average yields for 1974 (Table 6) were not statistically different as a result of the effect of the residual soil water left from the sprinkling of the plots during establishment of the grass. This additional water increased the production level of all plots to some undetermined degree. The yield differences for the 1975 season, when the plant growth was totally dependent upon natural rainfall, were statistically significant ($P = .05$). Yields from plots with the waxed runoff surface were superior to the plots with cleared, smoothed or grassed runoff surfaces. Plots with wax runoff areas yielded almost five times greater than from the plots with grassed runoff areas at the 2:1 ratio of runoff:crop area. There was a decrease in forage yield as the wax runoff area was increased from 2:1 to 3:1 ratios. This is possibly a result of some undetermined nutritional deficiency or a leaching of the existing nutrients by the increased water.

PART V. COOPERATIVE WATER HARVESTING PROJECT WITH THE BUREAU OF LAND MANAGEMENT

Catchment Runoff Efficiency: Soil samples have been collected from several sites representing successful, unsuccessful, and proposed catchments, treated with or proposed for treatment with paraffin wax. These samples are being analyzed for textural, chemical, and mineralogical identification. Specially prepared trays of these soils are being treated in the laboratory with various types of waxes for evaluation of treatment performance after being subjected to accelerated weathering in freeze-thaw, ozone, and ultraviolet weathering chambers. These studies are in the initial stages and no definite results are available at this time.

A small portable plot sprinkler for determining the relative effectiveness of various water harvesting catchment treatments on existing field units was designed and constructed. The results of tests on eight separate field sites are presented in Table 7. The relatively low runoff efficiency from the two wax treatments, Snap Point and Hurricane Valley on May 1979 may be a result of the time of the year. These tests were conducted during the early part of the summer when the soil temperature had not exceeded the melting point of the wax. It was observed that the wax on the soil was in a semi-crystalline form, a result of the cooler temperature of the winter period. Runoff results from the August evaluation at Hurricane Valley were significantly higher.

There are indications that the design wax application rate of 0.7 kg/m^2 (1.25 lbs/yd^2) may be a minimal value for the soils of the area. The double-treated area at Hurricane Valley consistently was more effective in producing runoff. Similarly, the area designated as lightly treated on the Westwind catchment was less effective. The low runoff efficiency of the East Hurricane Valley unit is also believed a result of insufficient quantities of wax. A later report indicated this unit was severely damaged by erosion during a large storm. The catchment slope was considered excessive for the wax treatment which also contributed to the treatment failure. The relatively low runoff results from the gravel-covered polyethylene catchment, Boggs Ridge, is possibly an indication of small pinholes in the underlying sheeting. The asphalt-fiberglass butyl, and the fiberglass-resin catchment do give excellent runoff. Average runoff results from an entire catchment may be less than shown in Table 7 if relatively large low spots are present on the catchment surface, which may retain a portion of each runoff event.

Water Harvesting Systems Survey: To obtain information on the performance of existing water harvesting systems, we contacted various units of the Bureau of Land Management, Forest Service, Bureau of Indian Affairs and others in Arizona and New Mexico requesting a brief history and performance evaluation of any water harvesting systems

which were under their control. Response from these agencies is not yet complete. Typical information and comments are as follows: Sheet metal catchments ranging in size from 300 ft^2 to over 5000 ft^2 are still usually in excellent condition. Catchments covered with asphalt planking were some of the most expensive units, and experienced premature failure possibly aggravated by insufficient maintenance. A few properly installed butyl catchments, protected by tall trees with adequate maintenance, are still in good condition. Reported problems with water storages are faulty float valves improperly installed without protection; vandalism; varmint damage; and poor design or construction techniques. A final analysis of the data from the survey will be completed upon receipt of all replies from the various users.

Water Harvesting System Evaluation: An inspection procedure was developed to evaluate existing water harvesting systems to identify components of the system that may be deteriorating, or to indicate improper design, site selection, or installation procedures that are unsatisfactory or faulty. The procedure considers over 60 items, including: the suitability of the treatment, ground topography, climate, catchment shape and location, weathering of catchment and storage, and drains, screens, fences and other peripheral components. Each item is graded on an arbitrary scale of 0 to 5, based upon what would be a desired level of performance. An item failure is graded "0" while a "5" rating represents an excellent or satisfactory performance. Good inspections at periodic intervals may indicate potential failures early enough to permit planning of maintenance or re-treatment. The procedure is divided into five separate parts.

Part I is the background information on the system and includes items such as location, expected usage rate, and type of treatment. It provides a means of recording changes in management practices which may influence the performance of the system.

Part II is the evaluation of the catchment area. The first half considers construction or installation details which may become important in the performance of the treatment at some later date. The second half of this part is concerned with the performance of the

existing catchment treatment. The maintenance portion of this section provides a means of recording the amount of maintenance required and to the degree to which it is being performed.

The storage system evaluation, Part III, and the peripheral components, Part IV, are completed as described for the preceding section. Part V is for noting conditions or comments which are not covered in the other sections, and has a small graph for making a sketch of the area. The evaluation procedure was used on 12 operational water harvesting units located in Arizona and New Mexico on land administered by the Forest Service and Bureau of Land Management. Most of these units are 2 to 6 years old, located in areas which would have annual rainfalls of 12 to 25 inches per year, and were designed to furnish water for livestock. The units were generally not the only source of water in the immediate area.

Each system was evaluated during the spring and summer of 1976. A condensed summary of the rating tabulations of eight units is presented in Table 8. The evaluation indicates that no unit was perfect or completely satisfactory in all features. There were good or satisfactory points on each unit as well as parts that were not performing to specifications or some fault in design. One item consistently below average in most units was the maintenance of the catchment. One item rated satisfactory was the type of fencing. In some installations such as asphalt fiberglass, a fence around the catchment may not be required. Correspondingly, the area fenced was usually excessive. Observations indicate that fences directly adjacent to the catchment can reduce rodent and insect damage to the treatment by elimination of hiding places in the vegetative growth which occurs in the protected area.

Wildlife Water Harvesting Catchments: Two small catchments were installed in cooperation with the Arizona Game and Fish Department and the Bureau of Land Management. These units are designed to provide drinking water for wildlife on the lower desert areas. One unit had originally been covered with butyl sheeting which had been destroyed by wind. The storage consisted of two steel rim tanks (grain

bins) with plastic liners with a cover of galvanized sheet metal on a wooden framework. A new asphalt fiberglass apron was installed in July 1976.

The other unit, installed in December 1976, was also 4000 ft^2 catchment of asphalt fiberglass with a 13,000-gallon grain bin tank storage. The bottom of the tank was sealed with composite blankets of bentonite clay and soil. Evaporation control for the tank was provided with a floating cover of foamed butyl. These units are unfenced.

Water Harvesting System Design: A first generation computer model to design the relative sizes of catchments and storages for a given area is in operation. The input information required is: the period and quantity of water use by interval; and the estimated precipitation patterns. The model then calculates the sizes of catchment and storage required to supply the necessary water. The model is being used to assist in determining the relative sizes of catchment and storage.

Water Quality from Water Harvesting Systems: Initial studies of water quality from various types of water harvesting treatments were initiated. The studies are concerned with determining the presence of heavy trace metals in the runoff water. Procedures have been developed for the analysis of water samples. Samples are being collected from existing operational systems and from the various treatments at the Granite Reef Testing Site at periodic intervals. Water samples are in the process of being analyzed.

SUMMARY AND CONCLUSIONS:

Studies were continued at the Granite Reef Testing Site on the evaluation of methods and materials for water harvesting. A new treatment of asphalt-polypropylene matting was installed on a 200-m^2 plot as a possible alternate treatment for asphalt fiberglass. This treatment is providing satisfactory runoff to date. Runoff from silicone water-repellent treatments continues to decline with time. Conversely there has been no major change in runoff efficiency from a paraffin wax soil treatment originally treated in September 1972.

There were no significant changes in the runoff efficiency of the remaining treatments.

An alternate method to concrete bottom steel rim tanks for water storage is being evaluated at Granite Reef. The storage system consists of a grain bin ring and a blanket of bentonite clay sandwiched between two soil layers for the bottom. Initial results are encouraging.

Studies are being conducted near Tombstone, Arizona, to assess the effect of additional water on forage production of blue panicgrass (Panicum Antidotale Retz). The additional water is obtained using water harvesting techniques from adjacent water-collecting areas treated with paraffin wax. Results show yields in excess of 2000 kg/ha per year were derived on less than 130 mm rainfall from 18 precipitation events. Yields from control plots with unsupplemented rainfall averaged only 186 kg/ha. Almost a 16-fold increase in forage yields compared to control plots was obtained from plots which had runoff areas twice the size of the planted area treated with paraffin wax. When adjustment is made for the land taken out of cultivation, the average yield increase for the system is still five times greater than would have been obtained from a solid planting of grass.

The cooperative study with the Bureau of Land Management to study the performance of existing water harvesting systems and to develop lower cost methods and materials for water harvesting is in its second year. Soil samples from several water harvesting sites are being analyzed, and concurrently treated with various types of waxes to develop criteria for estimating performance of the treatment. Studies are in progress with no definite results at this time. A small portable sprinkler was designed and constructed for use in field determination of the runoff efficiency of various catchment treatments. Initial tests on four operational catchments treated with wax indicate the suggested application rate of 0.7 kg/m^2 is not sufficient for medium- to fine-textured soils.

A method of numerically rating each of the more than 60 items composing a water harvesting system was developed. For 12 systems

evaluated with the method, the most consistent problem found was a deficiency in routine maintenance. Information on the performance of existing water harvesting systems is being obtained by a survey of various governmental agencies and others requesting a brief history of any systems under their control. A final analysis will be made when all replies have been received. Other studies include computer modeling of catchment and storage sizes and quality analysis of water collected from various water harvesting systems.

Two small water harvesting units were installed in cooperation with the Arizona Game and Fish Department. These units, designed to provide water for wildlife, are unfenced and represent the most optimum methods and techniques developed to date.

PERSONNEL: Gary Frasier, Keith Cooley, Dwayne Fink, 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	13 Sep 1976	Polypropylene matting with SS asphalt at 1.4 kg asphalt m^{-2}
	29 Sep 1976	Sealcoat. Clay emulsion at 0.7 kg asphalt m^{-2}
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}
	13 Nov 1975	Sealcoat. SS2h asphalt at 2.0 kg asphalt m^{-2} modified with A-1 fibers
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}
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	
1976	mm	mm	%	mm	%	mm	%
3 Feb	17.3	17.1	98.8			9.8	56.6
4-5 Feb	2.5	2.5	100.0			.2	8.0
5-6 Feb	1.3	1.0	76.9			.1	7.7
9 Feb	12.9	13.8	107.0			5.2	40.3
13-14 Feb	13.0	13.8	106.2			10.3	79.2
3 Mar	6.3	5.7	90.5			.8	12.7
14 Apr	11.4	11.0	96.5			2.4	21.1
16 Apr	8.3		1/			1.7	20.5
3-4 May	7.4	7.0	94.9			1.6	21.6
4-5 May	12.2	11.8	96.7			1.6	13.1
8 May	4.6	4.7	102.2			.1	2.2
23-24 Jul	22.3	21.3	95.5			9.9	44.4
28 Jul	8.2	8.8	107.3			7.2	87.8
20-22 Jul	14.2	14.1	99.3			7.7	54.3
28 Aug	3.4	4.1	120.6			1.2	35.3
10-11 Sep	5.8	5.9	101.7			2.0	34.5
23-24 Sep	11.2	10.7	95.5	4.0	35.7	1.7	15.2
24 Sep	13.8	13.4	97.1	6.7	48.5	8.7	63.0
22-23 Oct	13.5	13.4	99.3	13.0	96.3	4.8	35.6
13 Nov	3.8	3.7	97.4	2.2	57.9	.1	2.6
31 Dec	31.7	30.9	97.5	28.7	90.5	5.7	18.0
Total	225.1	214.7 2/	99.0	53.9 3/	72.8	82.8	36.8

1/ Water meter malfunction.

2/ Total precipitation was 216.8 mm.

3/ Total precipitation was 74.0 mm.

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

Date	Rainfall	L-6 Runoff		L-7 Runoff		A-1 Runoff	
1976	mm	mm	%	mm	%	mm	%
3 Feb	17.3	16.2	93.6	16.0	92.5	17.2	99.4
4-5 Feb	2.5	1.0	40.0	1.4	56.0	2.2	88.0
5-6 Feb	1.3	.5	38.5	.5	38.5	.9	69.2
9 Feb	12.9	6.7	52.0	11.0	85.3	13.9	107.8
13-14 Feb	13.0	13.6	104.6	11.7	90.0	12.7	97.7
3 Mar	6.3	4.5	71.4	4.0	63.5	5.4	85.7
14 Apr	11.4	8.2	71.9	7.4	64.9	10.8	94.8
16 Apr	8.3	5.1	61.4	6.7	80.7	7.8	94.0
3-4 May	7.4	5.7	77.0	5.5	74.3	7.4	100.0
4-5 May	12.2	9.1	74.6	10.1	82.8	11.1	91.0
8 May	4.6	3.5	76.6	3.1	67.4	4.8	104.7
23-24 Jul	22.3	16.7	74.9	18.3	82.1	20.7	92.8
28 Jul	8.2	7.7	93.9	7.8	95.1	7.6	92.7
20-22 Jul	14.2	11.9	83.8	12.8	90.2	12.8	90.1
28 Aug	3.4	2.9	85.3	3.5	102.9	4.0	117.6
10-11 Sep	5.8	4.2	72.4	4.2	72.4	6.3	108.6
23-24 Sep	11.2	5.7	50.9	7.5	67.0	10.1	90.2
24 Sep	13.8	11.2	81.2	11.6	84.1	12.7	92.2
22-23 Oct	13.5	9.4	69.6	10.4	77.0	13.2	97.8
13 Nov	3.8	1.6	42.1	1.8	47.3	3.3	86.8
31 Dec	31.7	16.4	51.7	24.0	75.7	31.2	98.4
Total	225.1	161.8	71.9	179.2	79.6	216.1	96.0

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

Date	Rainfall	A-2 Runoff		A-5 Runoff	
1976	mm	mm	%	mm	%
3 Feb	17.3	14.1	81.5	13.4	77.5
4-5 Feb	2.5	.5	20.0	1.3	52.0
5-6 Feb	1.3	-	-	.6	46.2
9 Feb	12.9	9.5	73.6	10.6	82.2
13-14 Feb	13.0	16.7	82.3	11.2	86.2
3 Mar	6.3	3.5	55.6	3.7	59.0
14 Apr	11.4	6.8	59.6	7.6	66.7
16 Apr	8.3	5.8	69.9	6.8	81.9
3-4 May	7.4	3.9	52.7	4.9	66.2
4-5 May	12.2	9.2	75.4	9.4	77.1
8 May	4.6	3.1	67.4	3.7	80.4
23-24 Jul	22.3	16.9	75.8		1/
28 Jul	8.2	7.2	87.8	5.1	62.3
20-22 Jul	14.2	9.6	67.6	8.9	62.7
28 Aug	3.4	2.4	70.6	2.9	85.3
10-11 Sep	5.8	2.7	46.6	4.1	70.7
23-24 Sep	11.2	6.6	58.9	7.3	65.2
24 Sep	13.8	10.4	75.4	11.5	83.3
22-23 Oct	13.5	8.9	65.9	9.8	72.6
13 Nov	3.8	.8	21.1	0	0
31 Dec	31.7	21.6	68.1	25.1	79.2
Total	225.1	154.2	68.5	147.9 2/	72.9

1/ Water meter malfunction.

2/ Total precipitation was 202.8 mm.

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}
	3 Jun 1975	Retreated at 0.03 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 Jun 1975	Retreated with 3% silicone water repellent - 1.2 liters of solution m^2 - 0.03 kg 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	3 Jun 1975	Uncleared watershed - treated with 3% silicone water repellent - 1.2 liters solution m^{-2} - 0.03 kg m^{-2}
W-3	1 Dec 1963	Cleared watershed

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

Date	Rainfall	L-2 Runoff		L-3 Runoff		R-1 Runoff	
1976	mm	mm	%	mm	%	mm	%
3 Feb	17.3	2.8	16.2	15.3	88.4	5.1	29.5
4-5 Feb	2.5	0	0	.8	32.0	0	0
5-6 Feb	1.3	0	0	.2	15.4	0	0
9 Feb	12.9	.1	0.1	5.8	45.0	1.1	8.5
13-14 Feb	13.0	7.5	62.5	10.5	80.8	8.0	61.6
3 Mar	6.3	0	0	3.8	60.3	0	0
14 Apr	11.4	0	0	2.8	24.6	.9	7.9
16 Apr	8.3	1.7	20.5	7.3	88.0	2.8	33.7
3-4 May	7.4	0	0	4.7	65.5	0	0
4-5 May	12.2	1.0	8.2	9.9	81.1	1.1	9.0
8 May	4.6	0	0	3.1	67.4	0	0
23-24 Jul	22.3	6.6	29.7	7.1	31.8	7.8	35.0
28 Jul	8.2	3.7	45.1	6.7	81.7	5.4	65.9
20-22 Jul	14.2	3.7	21.2 1/	8.3	58.5	4.8	33.8
28 Aug	3.4			1.9	55.9	.2	5.9
10-11 Sep	5.8	0	0	1.7	29.7	0	0
23-24 Sep	11.2	0	0	4.3	38.4	0	0
24 Sep	13.8	3.7	26.8	10.0	72.6	6.5	47.1
22-23 Oct	13.5	0	0	7.1	52.6	3.7	27.4
13 Nov	3.8	0	0	.1	2.6	0	0
31 Dec	31.7	.5	1.8	6.0	18.9	.8	2.5
Total	225.1	31.3	13.9	117.4	52.2	48.2	21.4

1/ Storms combined.

Table 4. Rainfall runoff from bare soil plots at Granite Reef (cont'd).

Date	Rainfall	R-2 Runoff		R-3 Runoff		R-4 Runoff	
1976	mm	mm	%	mm	%	mm	%
3 Feb	17.3	17.1	98.8	4.0	23.1	16.7	96.5
4-5 Feb	2.5	1.6	64.0	0	0	1.3	52.0
5-6 Feb	1.3	.7	53.8	0	0	.5	38.5
9 Feb	12.9	12.3	95.3	.4	3.1	11.9	92.2
13-14 Feb	13.0	12.6	96.9	7.4	57.0	11.9	91.5
3 Mar	6.3	5.1	81.0	0	0	4.6	73.0
14 Apr	11.4	9.7	85.1	.5	4.4	8.3	72.8
16 Apr	8.3	7.3	88.0	2.4	28.9	6.9	83.1
3-4 May	7.4	6.4	86.5	0	0	5.4	73.1
4-5 May	12.2	10.5	86.1	1.7	13.9	9.8	80.3
8 May	4.6	4.4	95.7	0	0	4.2	91.3
23-24 Jul	22.3	17.6	78.9	7.0	31.4	17.9	80.3
28 Jul	8.2	8.0	97.6	5.0	61.0	7.7	93.9
20-22 Jul	14.2	12.1	85.2	4.2	29.6	11.1	78.2
28 Aug	3.4	2.9	85.2	0	0	3.0	88.2
10-11 Sep	5.8	4.6	79.3	0	0	4.2	72.9
23-24 Sep	11.2	7.4	66.1	0	0	6.7	59.8
24 Sep	13.8	11.7	84.8	3.4	24.6	11.4	82.7
22-23 Oct	13.5	11.6	85.9	0	0	9.9	73.3
13 Nov	3.8	2.6	68.4	0	0	1.5	39.5
31 Dec	31.7	27.6	87.1	1.0	3.2	21.7	68.5
Total	225.1	193.8	86.1	37.0	16.4	176.6	78.5

Table 4. Rainfall runoff from bare soil plots at Granite Reef (cont'd).

Date	Rainfall	W-1 Runoff		W-2 Runoff		W-3 Runoff	
1976	mm	mm	%	mm	%	mm	%
3 Feb	17.3	3.7	21.4	6.4	37.0	4.6	26.6
4-5 Feb	2.5	0	0	0	0	0	0
5-6 Feb	1.3	0	0	0	0	0	0
9 Feb	12.9	.5	3.9	1.5	11.6	.8	6.2
13-14 Feb	13.0	6.4	49.2	5.9	45.4	7.8	60.0
3 Mar	6.3	0	0	0	0	0	0
14 Apr	11.4	.3	2.6	.5	4.4	.4	3.5
16 Apr	8.3	1.3	15.7	1.9	22.9	1.3	15.7
3-4 May	7.4	.1	1.4	0	0	.1	1.4
4-5 May	12.2	1.3	10.7	3.4	27.9	1.4	11.5
8 May	4.6	0	0	.1	2.2	0	0
23-24 Jul	22.3	5.4	24.2	5.5	24.7	6.9	30.9
28 Jul	8.2	2.7	32.9	2.5	30.5	3.5	42.7
20-22 Jul	14.2	3.1	21.8	2.4	16.9	4.1	28.9
28 Aug	3.4	0	0	0	0	0	0
10-11 Sep	5.8	0	0	0	0	0	0
23-24 Sep	11.2	0	0	0	0	0	0
24 Sep	13.8	3.7	26.8	2.8	20.3	4.5	32.6
22-23 Oct	13.5	2.7	20.1	2.3	17.0	3.8	28.1
13 Nov	3.8	0	0	0	0	0	0
31 Dec	31.7	.8	2.5	0	0	2.2	6.9
Total	225.1	32.0	14.2	35.2	15.6	41.4	18.4

Table 4. Rainfall runoff from bare soil plots at Granite Reef (cont'd).

Date	Rainfall	A-3 Runoff		A-4 Runoff	
1976	mm	mm	%	mm	%
3 Feb	17.3	5.1	29.5	12.3	71.1
4-5 Feb	2.5	0	0	.3	12.0
5-6 Feb	1.3	0	0	.3	23.1
9 Feb	12.9	1.9	14.7	7.9	61.2
13-14 Feb	13.0	8.2	63.1	10.8	83.1
3 Mar	6.3	0	0	2.6	41.3
14 Apr	11.4	1.5	13.2	4.9	43.0
16 Apr	8.3	3.9	47.0	6.5	78.3
3-4 May	7.4	0	0	3.0	40.5
4-5 May	12.2	3.4	27.9	7.7	63.1
8 May	4.6	0	0	2.7	58.7
23-24 Jul	22.3	9.6	43.0	15.3	68.6
28 Jul	8.2	5.3	64.6	7.0	85.4
20-22 Jul	14.2	4.6	32.4	7.8	54.9
28 Aug	3.4	0	0	2.0	58.8
10-11 Sep	5.8	.1	1.7	2.8	48.3
23-24 Sep	11.2	0	0	3.2	28.6
24 Sep	13.8	5.7	41.3	9.8	71.0
22-23 Oct	13.5	4.7	34.8	7.9	58.5
13 Nov	3.8	0	0	.4	10.5
31 Dec	31.7	1.8	5.7	13.0	41.0
Total	225.1	55.8	24.8	128.2	57.0

Table 5. Condition of potential water barrier materials exposed at the Granite Reef test site.

Panel Number 1/	Condition and comments from inspection on 1 February 1977 2/	
1	Failed	Removed in 1974
2	Good	Some pinholes
3	Excellent	Dusty, some chalking
4	Excellent	Coating poor
5	Excellent	Coating excellent
6	Excellent	Coating gone
7	Poor	Coating peeling, 30% gone, substrate okay
8	Good	Small pinholes occurring
9	Excellent	Coating excellent
10	Excellent	Coating excellent
11	Excellent	Coating chalking; substrate excellent
12	Failed	Removed in 1974
12a	Excellent	Grifflon TM. PE, black, installed 16 Apr 1975. Joint excellent.
13	Failed	Removed January 1976
14	Failed	Removed in 1974
15	Failed	Removed in 1974
15a	Excellent	Grifflon TM. PE with No. 105 coating installed 16 Apr 1975
16	Failed	Removed January 1976
17	Excellent	
18	Excellent	
19	Excellent	
20	Excellent	
21	Fair	Deteriorating; fabric separating from membrane
22	Excellent	No chalking

1/ Description of materials and/or treatments presented in 1974 Annual Report, or as noted.

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

Table 5. Condition of potential water barrier materials exposed at the Granite Reef test site (continued).

Panel Number 1/	Condition and comments from inspection on 1 February 1977 2/	
23	Excellent	
24	Excellent	Slight chalking
25	Failed	Removed January 1976
26	Excellent	Coating fair, some chalking
27	Excellent	Coating poor, some chalking
28	Excellent	Coating poor, extreme chalking
29	Good	Coating nearly gone, extreme chalking
30	Excellent	Coating gone
31	Good	
32	Excellent	Slight chalking
33	Excellent	
34	Excellent	Slight chalking
35	Excellent	Slight chalking
36	Good	Slight chalking
37	Excellent	
38	Excellent	
39	Excellent	
40	Failed	Removed January 1976
41	Excellent	
42	Excellent	Animal scratches, no tears
43	Poor	Chalking, large hole with vegetation growing
44	Failed	Removed in 1974
45	Excellent	

1/ Description of materials and/or treatments presented in 1974 Annual Report, or as noted.

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

Table 6. Average plot yield (kilograms per hectare) from Montijo Flat forage plots.

Year	Runoff-Runon Area Ratio	No Runoff Area	Runoff Area Treatment					
			Wax		Bare Soil		Grass	
1974	0:1	961						
	1:1		954 1/	(1909) 2/	623	(1246)	534	(1068)
	2:1		644	(1932)	588	(1755)	401	(1203)
	3:1		284	(1136)	560	(2338)	273	(1093)
1975	0:1	186d 3/						
	1:1		666	(1333)bc	268	(536)d	216	(433)d
	2:1		973	(2920)a	227	(683)cd	140	(421)d
	3:1		484	(1939)b	237	(949)b	123	(494)d

1/ Includes runoff area in average yield computations.

2/ Excludes runoff area in average yield computations.

3/ Ducan multiple range test (P = .05) for yields excluding runoff area. Means followed by the same letter are not significantly different.

Table 7. Catchment treatment evaluation - field sprinkler tests.

Catchment name and location	Treatment	Test Date	Test location	Threshold rainfall	Runoff efficienc
				(mm)	(%)
Snap Point, Ariz Strip	wax	10 May 76	Northwest corner	1.0	57
			Southwest corner	0.8	66
			Southeast corner	1.5	79
Hurricane Valley, Ariz Strip	wax	10 May 76	Southwest corner	0.9	61
			Southeast corner	0.9	81
			Northeast corner (double treated area)	1.0	91
		23 Aug 76	Southwest corner	1.6	94
			Southeast corner	1.2	93
			Northeast corner (double treated)	1.4	100
Cowhide, Ariz Strip	fiberglass resin	10 May 76	Southwest corner	0.5	97
Van Gusic, Safford	asphalt-fiberglass	29 Apr 76	Northeast corner	0.6	100
			West side middle	0.5	92
			Southwest corner	0.8	97
Boggs Ridge, Safford	gravelled-polyethylene	29 Apr 76	South side	4.2	70
			Middle upper side	4.6	44
Westwind, Ariz Strip	wax	23 Aug 76	Southwest corner	0.8	99
			Southeast corner	0.8	90
			Middle east side (light treatment)	1.6	74
East Hurricane	wax	23 Aug 76	Southwest corner	1.8	58
			Southeast corner (light treatment)	1.8	58
Seegmuller	butyl	23 Aug 76		1.3	100

Table 8. Evaluation ratings of eight separate water harvesting units.

Evaluation Item	Unit Number 1	2	3	4	5	6	7	8
Catchment Installation:								
Type of Treatment	3	2	3	4	1	1	5	5
Shape: Fit to Terrain	5	4	5	4	5	4	4	5
Location Aspect	2	4	4	5	4	4	5	5
Size	3	1	4	5	4	1	5	4
Slope	5	3	5	4	5	5	2	5
Surface Retention	5	1	4	4	5	5	3	1
Berm Size	3	5	3	1	4	3	2	5
Berm Shape	0	4	3	4	5	4	2	4
Catchment Performance:								
Weathering	3	3	4	4	2/	2/	4	5
Maintenance - Required	1	2	4	4	1	1	4	4
- Performed	0	2	0	2	0	0	4	3
Storage Installation:								
Type of Storage	5	4	5	5	4	4	3	4
Size	4	2	5	5	5	4	3	5
Storage Performance:								
Weathering	5	0	5	5	4	4	5	5
Safety	5	2	1	4	4	2	4	5
Maintenance - Required	5	0	5	5	3	1	2	5
- Performed	5	1	5	5	3	2	4	5
Peripheral Components:								
Evaporation Control:								
Type	5	0	5	5	3	3	5	5
Performance	5	0	5	5	1	1	5	5
Fencing:								
Area Enclosed	4	2	3	3	3	4	1	5
Type	5	5	5	5	5	5	5	5
Screens:								
Type	0	1/	5	5	4	0	5	1/
Size	0	1/	5	5	0	0	0	1/
Shape	0	1/	5	5	0	0	0	1/

1/ Catchment discharged directly into pit type storage.

2/ Original butyl treatment failed and was in process of being replaced at time of evaluation.

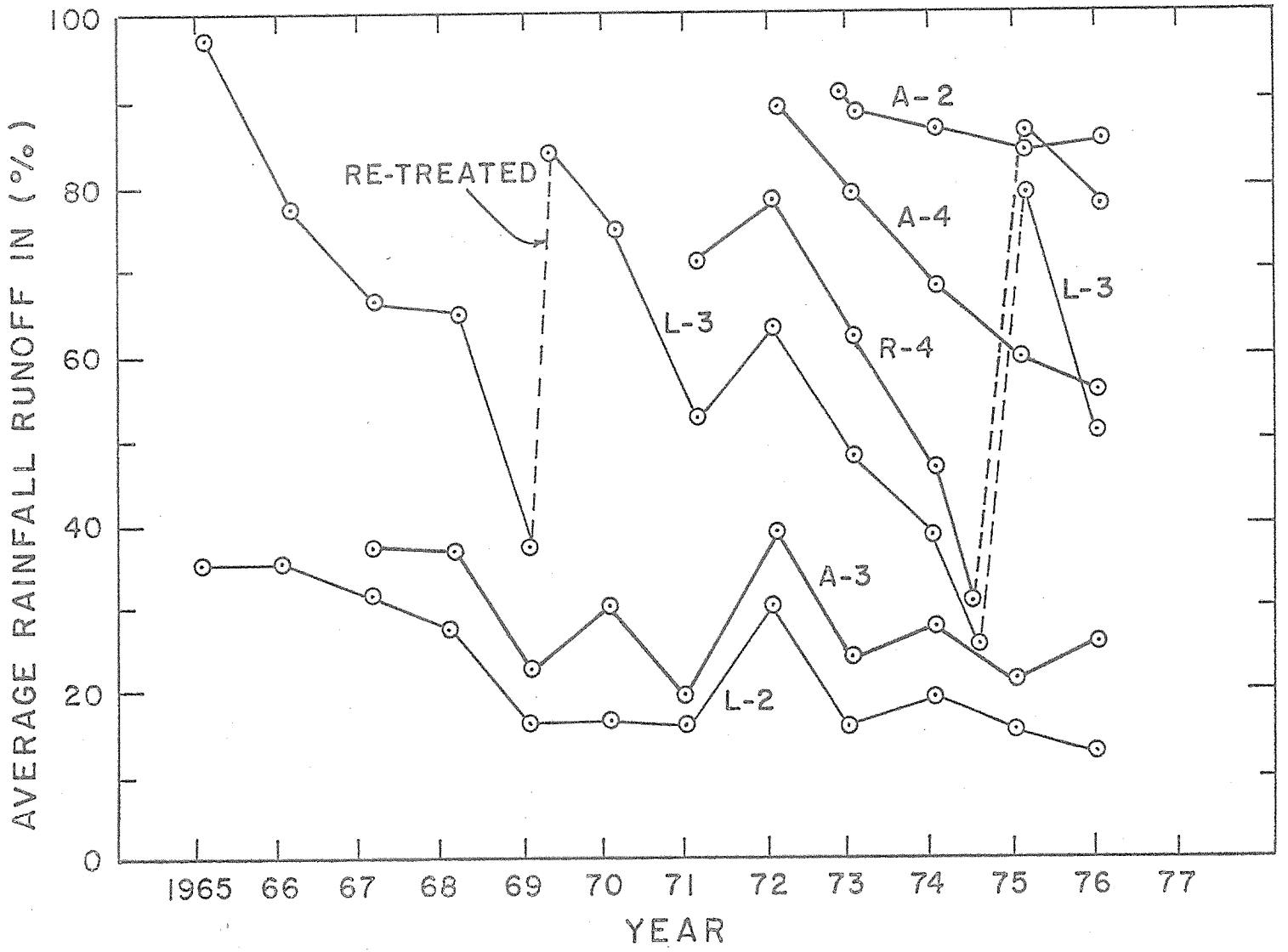

Figure 1. Rainfall-runoff results from six bare-soil treatments at the Granite Reef Testing Site.

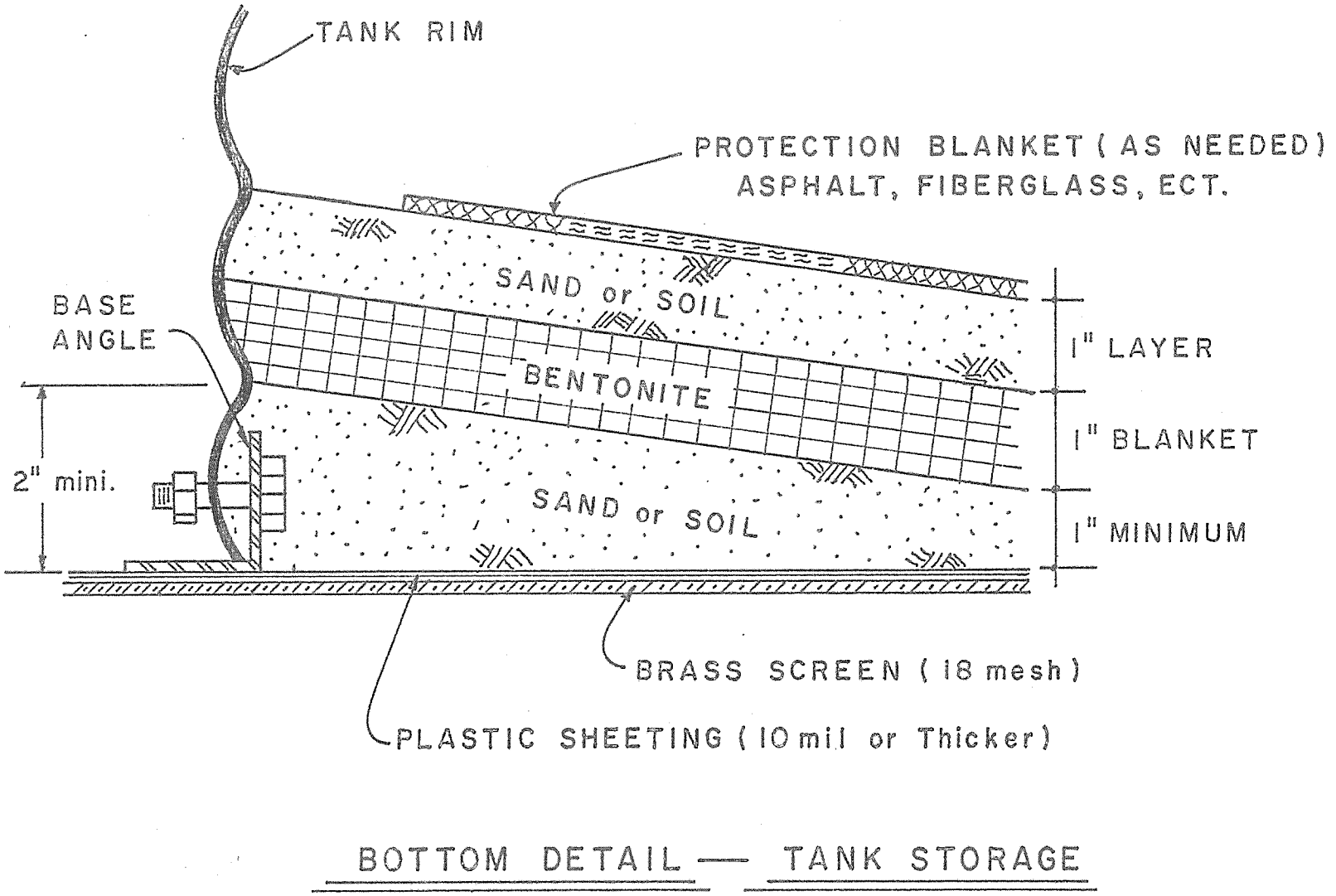

Figure 2. Sketch of tank bottom of bentonite clay bottom.

TITLE: CHEMICAL MODIFICATION OF SOILS FOR HARVESTING PRECIPITATION

NRP. 20810 CRIS WORK UNIT: 5510-20810-002

CODE NO.: USWCL 74-1

INTRODUCTION:

The objectives of this study remain to (1) develop and evaluate, in the laboratory, testing procedures suitable for evaluating chemical soil treatments for water harvesting; (2) evaluate, in the laboratory, soil additives, soils, and treatment techniques for suitability for water harvesting; and (3) field test the most promising of the materials and techniques under a variety of soil and weathering conditions, and try to relate field results to previous laboratory test results.

PART I. LABORATORY TESTING PROCEDURES:

The primary objective of this phase of the study remains to develop laboratory tests which (1) encompass, as much as possible, all the potential major causes of treatment failure which occur in the field; (2) are quickly and easily performed; (3) markedly accelerate the natural weathering processes; and (4) correlate with field test results. The two major types of failure of repellent-treated soils are considered to be lack (or loss) of water repellency and lack (or loss) of soil structural stability.

During 1975, a laboratory testing sequence was established to evaluate the weathering effects of freeze-thaw (FT) cycling, ozone and ultraviolet radiation (UV) on water-repellent water-harvesting treatments. This procedure was modified slightly in 1976 so that samples which passed 500 hrs exposure to either ozone or UV were then weathered in the FT chamber until destroyed.

An attempt was made to quantify the 4-hr-hydration test by determining the amount of a fixed quantity of topically-applied water (5 ml) which was adsorbed by the treated soil during the 4-hr period. Results of this first preliminary test appear in Table 1. Since marked differences were noted, further evaluation of this test is planned for 1977.

It had been noted that the standard laboratory FT test either was not always applicable or else was too severe for properly evaluating those treated soils not normally exposed to FT cycling under field conditions, or to those only exposed when their surfaces were dry. A new

test was developed whereby one set of samples was alternately subjected to FT cycling for 24 hrs and then the standard 5-min dripolator test; a second set of samples was alternately subjected to continuous surface flooding and then the 5-min dripolator test. This was continued until a sample was destroyed (severely eroded) by the dripolator test. Results (Table 2) show that Granite Reef soil treated with paraffin would be quickly rejected as a potential water-harvesting soil by the FT-dripolator approach; yet would pass handily by the hydration-dripolator approach. Five years of field testing corroborate that paraffin works well on Granite Reef soil.

Table 2 also shows that paraffin may work on the Monument Tank soil. This is the first water-repellent treatments which have shown any promise on this particular soil. Caution is required however: 2 kg/m^2 is a very high application rate, and the Monument Tank site is subject to considerable natural freeze-thaw cycling.

Future plans call for testing the effects of prolonged heat and wetting on the weathering of treatments, plus examining interaction effects of all these weathering elements.

PART II. LABORATORY EVALUATION OF TREATMENTS

Water repellents. Laboratory testing of water repellent soil treatments continued in 1976. Procedures as described in the 1975 Annual Report were followed. Some of the recent results are now published (Fink and Mitchell, 1975; Fink, 1976). Other results appear here in Tables 3 to 5, and Figure 1.

Preliminary results in 1975, with a paraffin containing 5% ethylene vinyl acetate copolymer (X528-3) suggested that soil treated with this material was quite resistant to degradation by freeze-thaw cycling compared to unmodified paraffin-treated soil. An expanded test was initiated in 1976, to study weathering effects of freeze-thaw, ozone and UV radiation (Table 3) on this new wax and to compare results to those of normal paraffin and Hawaiian crude slack wax. Results were disappointing. The new wax (X528-3) was hardly better than paraffin alone at resisting FT damage. In other weathering aspects it was equal to paraffin. The X528-3 for the two tests was from separate

batches, indicating product variability. A small field plot of this material has been established at Granite Reef (Table 6).

Apparently the Seneca subsoil (Table 3) can be rather effectively treated with paraffins if the soil is first covered with a thin layer of sand. If not covered, the wax-treated soil fails the preliminary 4-hr-hydration test by first swelling, then cracking upon drying.

An antistripping agent (6860) was tested to see if such additives would improve a paraffin-treated soil's resistance to breakdown by freeze-thaw cycling. Table 4 shows that 6860 did markedly improve stability for the two soils tested. Future testing will be conducted to try to relate optimum antistrip rates to soil specific surface areas, and to try the antistrips with the cheaper slack waxes.

An attempt was made to relate freeze-thaw damage susceptibility to soil textural analysis. Table 5 shows results for four soils from the Arizona strip area treated with four repellent types. The textural range of clay plus fine silt fraction in the soils ranged from 5 to 36%. Resistance to freeze-thaw damage for the two paraffins was inversely related to the clay plus fine silt soil fraction (<20μ). Further proof of the textural effect appears in Figure 1, where freeze-thaw data for 11 paraffin-treated soils are plotted vs. the <20μ soil fraction. Those soils with greater than roughly 20% clay plus fine silt were considerably more susceptible to FT damage than coarser textured soils. Clay type proportions undoubtedly are also a factor; unfortunately quantitative clay type analyses tend to be both difficult and inaccurate. Nevertheless, efforts are being made to incorporate clay type information into evaluation of repellent-treated soils.

Laboratory results relating FT damage to soil texture must be used with extreme caution: (1) paraffin-treated Granite Reef field plots have been steadily yielding nearly 90% rainfall runoff for 4-1/2 years, yet the data of Figure 1 portends failure for this soil; (2) paraffin-treated sands perform well in the freeze-thaw chamber but may be susceptible to erosion without additional stabilization. While tests have been developed which effectively measure repellency

and stability of repellent-treated soils, there remains a need for a better correlation between laboratory and field results. Such is the objective for 1977.

Clay dispersants. Adding small amounts of NaCl salt to osmotically-swelling bentonite clay, in combination with vigorous mechanical stirring, effectively destroys the clay card-house structure to permit near-perfect platelet alignment. Such alignment decreases the portion of external-pore water to essentially zero, permitting all water-of-swelling to imbibe in interstitial position. This improved alignment of clay platelets permits internal surface areas to be determined from swelling data. It also has practical considerations regarding establishment of impermeable layers for pond sealing and water-harvesting catchments (Fink, D. H. Internal surface area of Wyoming bentonite from swelling relationships, 1976).

PART III. FIELD TESTING OF MATERIALS AND TREATMENTS.

Runoff data - 1976. Runoff studies continued on the two paraffin-wax treated plots established in 1972, at the Granite Reef test site. Four additional 10 m^2 catchments were established in 1976, to field test those treatments which showed most promise in the laboratory. Treatment particulars appear in Table 6, and runoff data in Table 7. The two wax plots continue to yield 85 to 90% runoff; thus showed no sign of deterioration after 4-1/2 years' exposure. It is too early to meaningfully judge the four new treatments, but the three containing paraffin are yielding over 85% runoff, while the Hawaiian slack wax is yielding only 54%. Hopefully, the Hawaiian slack will melt more thoroughly next summer to significantly increase runoff efficiency. Outside agencies continue to use the paraffin-treated catchments for a variety of water-harvesting purposes.

X-ray data on the clay mineral suite of a number of soils was obtained from the University of Arizona (Table 8). Several of these sites have associated water-repellent catchment treatments. Small test plots will be established on most of the others during the summer of 1977. Runoff efficiencies and treatment longevities will be monitored and related to these clay-mineral and other physical-chemical properties of the soil.

Runoff data - long-term evaluations of water-repellent water-harvesting catchments. It was hypothesized that linear regression analyses of rainfall-runoff data could be used to evaluate weathering characteristics of water-repellent treated plots (theory appears in the 1975 Annual Report). Statistical testing confirmed this (Fink and Frasier, 1976). This year the regression analyses were completed on all Granite Reef test plots and will soon be submitted for publication.

SUMMARY AND CONCLUSIONS:

Laboratory studies showed that those paraffin-treated soils which contained <20% clay plus fine silt fraction (<20μ) were most resistant to damage by hydration and freeze-thaw cycling. Soil textural distribution thus should be strongly considered when selecting field water-harvesting sites.

Antistripping agents were shown to markedly increase the resistance of wax-treated soils against freeze-thaw damage. A monolayer of the antistripping agent sandwiched between the soil surface and the paraffin increased the number of freeze-thaw cycles required to effect complete structural failure from five to tenfold.

The paraffin-treated plots at the Granite Reef test site continue to yield 85 to 90% precipitation-runoff after 4-1/2 years of weathering. Interest in wax as a water-harvesting treatment continues to grow as more agencies install more of these successful catchments.

Dilute quantities of NaCl salt solution in Na-saturated bentonite, along with agitation, effectively destroyed the card-house clay structure, and aligned the clay platelets. This permitted the internal surface area to be determined from simple swelling relationships. Improved particle alignment should reduce water permeability and improve bentonite performance as a sealant for ponds, tanks, and water-harvesting catchments.

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4. Fink, D. H., and Frasier, G. W. 1976. Evaluating weathering characteristics of water-harvesting catchments from rainfall-runoff analyses. Soil Sci. Soc. Amer. J. Accepted for publication.

5. Fink, D. H. and Mitchell, S. T. 1975. Freeze-thaw effects on soils treated for water repellency. Hydrol. and Water Resources in Ariz. and the Southwest 5:79-85.

PERSONNEL: D. H. Fink.

Table 1. Adsorption of topically applied water on wax-treated soils during 4-hr-hydration test, compared to other standard laboratory tests.

Emulsions	Application rate kg/m^2	Water adsorption 1/ GR 2/ %	SS	L/L_n 3/ GR ±	SS	4-hr hyd. GR ±	SS	Brush test GR ±	SS	Freeze-thaw GR # cycles	SS
76R-3177	0.5	85	10	-	-	-	+	-	+	0	323*
	1.0	54	3	-	-	+	+	+	+	109	2
76R-3178	0.5	38	12	-	-	+	+	-	+	0	133*
	1.0	100	89	-	-	-	-	+	+	22	2
73R-2818	0.5	92	82	-	-	-	-	-	+	0	2
	1.0	46	88	-	-	+	-	+	+	27	2
L-110	0.5	4	3	-	+	+	+	+	+	93	190*
	1.0	0	2	-	-	+	+	+	+	71	304*
Slack waxes											
110	0.5	5	2	-	-	+	+	+	+	22	239*
	1.0	1	0	-	-	+	+	+	+	172	317*
140	0.5	16	3	-	+	+	+	-	-	0	0
	1.0	11	2	+	+	+	+	+	+	22	264*
P-42	0.5	14	3	-	-	+	+	-	-	0	0
	1.0	10	4	+	-	+	+	-	+	0	305*

1/ Represents % of 5 ml adsorbed.
2/ Soils were: GR, Granite Reef; SS, Superstition Sand.
3/ Plus (+) denotes exceeding acceptable levels; negative (-) denotes not meeting them.
* Still cycling.

Table 2. Resistance of water-repellent treated soils to dripolator test subjected alternately to either freeze-thaw cycling or continuous hydration (24 hrs each) then 5 minutes under dripolator.

	Freeze-thaw			Continually wet		
	Soils[1/]					
Treatment	MT (36)[2/]	GR (24)	SS (6)	MT (36)	GR (24)	SS (6)
Paraffin (128-131 AMP)	min.					
0.5 kg/m^2	4	11	27	<1	24*	49*
1.0 kg/m^2	9	12	7	18*	90*	90*
2.0 kg/m^2	22	26	42	90*	90*	90*
Dust-suppressant						
0.5 $1/m^2$	2	13	17	<1	50*	11
1.0 $1/m^2$	2	33	32	2	90*	14

1/ Soils are: MT; Monument Tank; GR, Granite Reef; SS, Superstition Sand.
2/ Numbers under the soils are clay plus fine silt (<20μ) fractions.
* Still under test at time of writing.

Table 3. Water repellency and structural stability of two soils treated with three types of waxes and exposed to the weathering elements: freeze-thaw, ozone, or ultraviolet radiation.

	TREATMENTS			Pre-weathering[1/]		WEATHERING ELEMENT							
						Freeze-thaw		Ozone			Ultraviolet		
								hrs			hrs		
	Soil	Wax	Rate	L/L_n	4-hr hyd.	Cycles	Drip-olator	250	500	Drip-olator	250	500	Drip-olator
			kg/m^2	±	±								
1	Granite Reef (GR)	X528-3	0.50	+	+	13	M	Δ[4/]	1	N	Δ	Δ	N
2	"	"	0.75	+	+	13	N	Δ	Δ	N	Δ	Δ	N
3	"	"	1.00	+	+	13	N	Δ	Δ	N	Δ	Δ	N
4	"	128-131 AMP	0.50	+	+	4	N	Δ	1,2	F	Δ	Δ	N
5	"	Paraffin	0.75	+	+	4	N	Δ	Δ	M	Δ	Δ	N
6	"	"	1.00	+	+	4	N	Δ	Δ	N	Δ	Δ	N
7	"	Hawaiian	0.50	+	+	13	N	Δ	Δ	N	Δ	Δ	N
8	"	Crude	0.75	+	+	29	N	Δ	Δ	N	Δ	Δ	N
9	"	"	1.00	+	+	111	N	Δ	Δ	N	Δ	Δ	N
10	Superstition Sand (SS)	X528-3	0.25	+	+	41	N	Δ	Δ	N	Δ	Δ	N
11	"	"	0.50	+	+	89	N	Δ	Δ	N	Δ	Δ	N
12	"	"	0.75	+	+	114	N	Δ	Δ	N	Δ	Δ	N
13	"	"	1.00	+	+	76	N	Δ	Δ	N	Δ	Δ	N
14	"	128-131 AMP	0.25	+	+	17	N	Δ	Δ	N	Δ	Δ	M
15	"	Paraffin	0.50	+	+	41	N	Δ	Δ	N	Δ	Δ	M
16	"	"	0.75	+	+	52	N	Δ	Δ	N	Δ	Δ	N
17	"	"	1.00	+	+	79	N	Δ	Δ	N	Δ	Δ	N
18	"	Hawaiian	0.25	+	+	103	N	Δ	Δ	N	Δ	1	0
19	"	Crude	0.50	+	+	90	N	Δ	Δ	N	Δ	Δ	N
20	"	Slack Wax	0.75	+	+	110	N	Δ	Δ	N	Δ	Δ	N
21	"	"	1.00	+	+	328	N	Δ	Δ	N	2	2	N
22	Seneca (8-16cm)	X528-3	0.75	+	-	0[3/]	0	0	0	0	0	0	0
23	" + 50g SS	"	0.75	+	+	247	N	Δ	Δ	N	Δ	Δ	N
24	" + 75g SS	"	0.75	+	+	75	N	Δ	Δ	M	Δ	Δ	N

1/ Plus (+) denotes exceeding acceptable levels; negative (-) denotes not meeting them.
2/ Dripolator test: N, none; M, pitting ≤ 3 mm; S, pitting >3 mm; F, pitting through treated zone.
3/ Zero (0) notation means sample failed a previous critical test in testing sequence.
4/ Δ denotes passing of all tests: (1) brush test; (2) L/L_n; (3) 4-hr hydration. Numerals denote which test(s) failed.

Table 4. Effect of anti-stripping agent (6860) on resistance to destruction by freeze-thaw cycling of paraffin-treated soils.

Treatment			Soil	
	Application rate		Granite Reef	Superstition Sand
6860/Par.	Paraffin (128-130) + 6860	6860		
%	kg/m^2		Ft cycles	
0.5	0.5	0.0025	16	45
	1.0	0.005	45	60
	2.0	0.01	24	186*
5.0	0.5	0.025	32	154*
	1.0	0.05	160*	325*
	2.0	0.1	207*	317*

*: Still cycling.

Table 5. Resistance to freeze-thaw cycling by four Arizona Strip soils of different texture treated with four water repellents.

Treatment	Rate	Soil (<2 mm fraction)			
		Cow hide (36)	Snap point (30)	Weathered sand stone (20)	Blow sand (5)
	kg/m^2	FT cycles			
Paraffin (128-131 AMP)	0.5	29	19	76	206
	1.0	19	37	154	253
Paraffin (144 AMP)	0.5	19	29	64	81
	1.0	29	47	137	496*
Hawaiian Crude	0.5	503*	450*	554*	561*
	1.0	535*	487*	573*	501*
	ℓ/m^2				
Dust Suppressant + Paraffin (95/5)	0.5	115	349*	514*	431*
	1.0	196	485*	457*	391*

*: Still cycling.

Table 6. Treatments of Granite Reef plots shown in Table 7.

Plot	Treatment date	Treatment
R-3[1/]	1965	Cleared and smoothed only; 20% sideslope.
T-14[2/]	1967	Cleared and smoothed only.
T-11	21 May 68	10 mil butyl sheeting
R-2	29 Sep 72	Cleared and smoothed; 10% sideslope; chipped paraffin (128-130 AMP) applied @ 0.68 kg/m^2.
T-13	29 Jun 72	Cleared and smoothed; chipped paraffin (143-150 AMP) applied @ 0.73 kg/m^2.
T-3	14 Sep 76	Mixture of dust suppressant (containing antioxidant) and paraffin (128-130 AMP), (ratio of 95/5 by wt) @ 1 ℓ/m^2.
T-4	25 Aug 76	Paraffin wax - stabilizer blend (Suntech, Inc., x-528-3) applied as hot melt @ 0.82 kg/m^3.
T-10	9 Sep 76	Plot covered with river-bed sand to 2.5 cm deep. Treated with blend of paraffin (128-130 AMP)/tackifyer (Hercules, Piccovar L-60 resin)/antistripping agent (Dow, silicone Z-6076), (ratio of 89/10/1 by wt), applied as hot melt @ 0.75 kg/m^2.
T-15	16 Sep 76	Hawaiian-crude slack-wax applied as hot melt @ 1.0 kg/m^2.

1/ R-plots are 200m^2, ridge and furrow, of either 10 or 20% sideslope and 3% longitudinal slope.

2/ T-plots are 10 m^2 and have 5% slope.

Table 7. Precipitation-runoff from Granite Reef field plots treated with those repellants which showed most promise in previous laboratory tests, vs. smoothed, and butyl-covered check plots.

		Treatments 1/								
		200m² plots		10m² plots						
		R-3	R-2	T-14	T-11	T-13	T-3	T-4	T-10	T-15
Date	Precip.	Smooth	P wax	Smooth	butyl sheet	P wax	DS & P wax	P wax & add.	P wax & add.	S wax
1976	mm	% runoff								
3 Feb	17.3	23.18	98.7	2/	2/	2/	-	-	-	-
4-5 Feb	2.5	0.00	63.4	25.2	99.5	94.4	-	-	-	-
5-6 Feb	1.3	0.00	52.6	3/	3/	3/	-	-	-	-
9 Feb	12.9	2.86	95.5	14.0	116.0	93.0	-	-	-	-
13-14 Feb	13.0	57.00	96.8	3/	101.0	101.5	-	-	-	-
3 Mar	6.3	0.00	81.4	4.8	92.8	73.0	-	-	-	-
14 Mar	11.4	4.73	84.9	24.6	94.7	95.6	-	-	-	-
16 Apr	8.3	29.11	88.5	38.6	104.8	94.0	-	-	-	-
3-4 May	7.4	0.00	87.1	23.0	108.1	87.8	-	-	-	-
4-5 May	12.2	13.90	86.0	18.8	102.4	93.4	-	-	-	-
8 May	4.6	0.00	95.8	8.7	95.6	93.5	-	-	-	-
23-24 Jul	22.3	31.58	78.8	35.4	97.3	106.7	-	-	-	-
28 Jul	8.2	60.81	97.9	61.0	108.5	114.6	-	-	-	-
20-22 Aug	14.2	29.32	85.4	19.0	93.0	83.1	-	-	-	-
28 Aug	3.4	0.00	84.2	0.0	85.3	88.2	-	73.5	-	-
10-11 Sep	5.8	0.00	79.0	6.9	96.6	81.0	-	82.8	-	-
23-24 Sep	11.2	0.00	66.5	0.0	93.8	80.4	87.9	81.2	87.5	42.8
24 Sep	13.8	24.40	84.6	45.6	100.0	97.1	99.3	100.0	93.5	68.8
22-23 Oct	13.5	0.00	85.7	4.8	97.8	87.4	88.9	88.1	80.7	50.4
13 Nov	3.8	0.00	68.0	0.0	89.5	71.0	65.8	68.4	63.2	44.7
Summaries										
1972	243.8	31	90	28	100	92				
1973	207.8	14	87	17	94	88				
1974	250.7	20	85	-	-	-				
1975	183.4	13	88	24	93	96				
1976	193.4	19	86	22	99	91	90	87	85	54

1/ Treatment details appear in Table 6.
2/ Data added to next rain.
3/ Not pumped. Data lost.

Table 8. X-ray diffraction and texture analyses of soils at existing or proposed water harvesting sites.

Sample	Clay mineral suite							Soil texture				Gypsum
	Mt	Mi	Vm	Chl	K	Inter.	Other	Gravel 2mm -3"	Sand 50μ -2mm	Silt 2 -50μ	Clay <2μ	Yes No
								% of total	% of <2mm fraction			
Poverty Mtn. #1	3	2	0	1	3	3	Calcite (2) Quartz (2)	50	31	50	19	no
" #2	3	3	1	0	3	0	Quartz (2)	40	25	62	13	no
" #3	4	2+	0	0	2	0	Quartz (2)	8	12	42	46	no
" #4	3	3	0	0	3	0	Feldspar (1)	19	22	55	23	no
" #5	3	3	0	1	3	0	Quartz (2)	42	42	48	10	no
" #6	2	2	0	0	2	3(?)	Quartz (1) Calcite (3) or Cristabolite (2)	**	30	66	4	yes
" #7	2	2	0	0	2	4	Quartz (2)	20.9	28	63	9	no
Seneca 0-3" *	4	3	0	0	2	0	Quartz (3)	--	56	34	10	no
" 3-6" *	4	3	0	0	2	0	Quartz (2)	--	28	23	49	no
WRRC Sells *	3	3	0	0	2	3	Quartz (2)					
WRRC Atterbury	3	2	0	0	2	3+	Calcite (2) Quartz (2)					
Santa Rita *	4	3	0	0	2	0	Quartz (3)	--	69	23	8	
Granite Reef*	4	3	1	0	3	4	Quartz (2+)	--	66	27	7	no
Snap Point *	3	3	0	1	3	3	Quartz (2+)	26	49	44	8	yes
Snap Point sandstone	2	2	0	0	2	4	Quartz (2)	--	68	23	9	
Lindsey Trick Tank*	2	4	0	0	2	0	Quartz (3)	--	63	28	8	
Monument Tank (2-3)	5	2	0	0	1	0	Quartz (1)	--	62	24	14	no
Temple Catch*	2	2	0	0	2	4	Quartz (2)	55	21	69	10	no
West Wind Catch *	2	2	0	0	2	4	Quartz (2)	28	19	70	11	no
Hurricane Valley *	3	3	0	0	3	0	Quartz (2+)	49	23	65	12	no

Mt - Montmorillonite
Mi - Mica
Vm - Vermiculite
Chl - Chlorite
K - Konlin
Inter - Unidentified component

5 - Dominant
4 - Large Amount
3 - Medium Amount
2 - Small Amount
1 - Trace Amount
0 - Looked for, but not detected

* Site of existing water-repellent water-harvesting catchments.
** Contained large amount of coarse, granular gypsum.

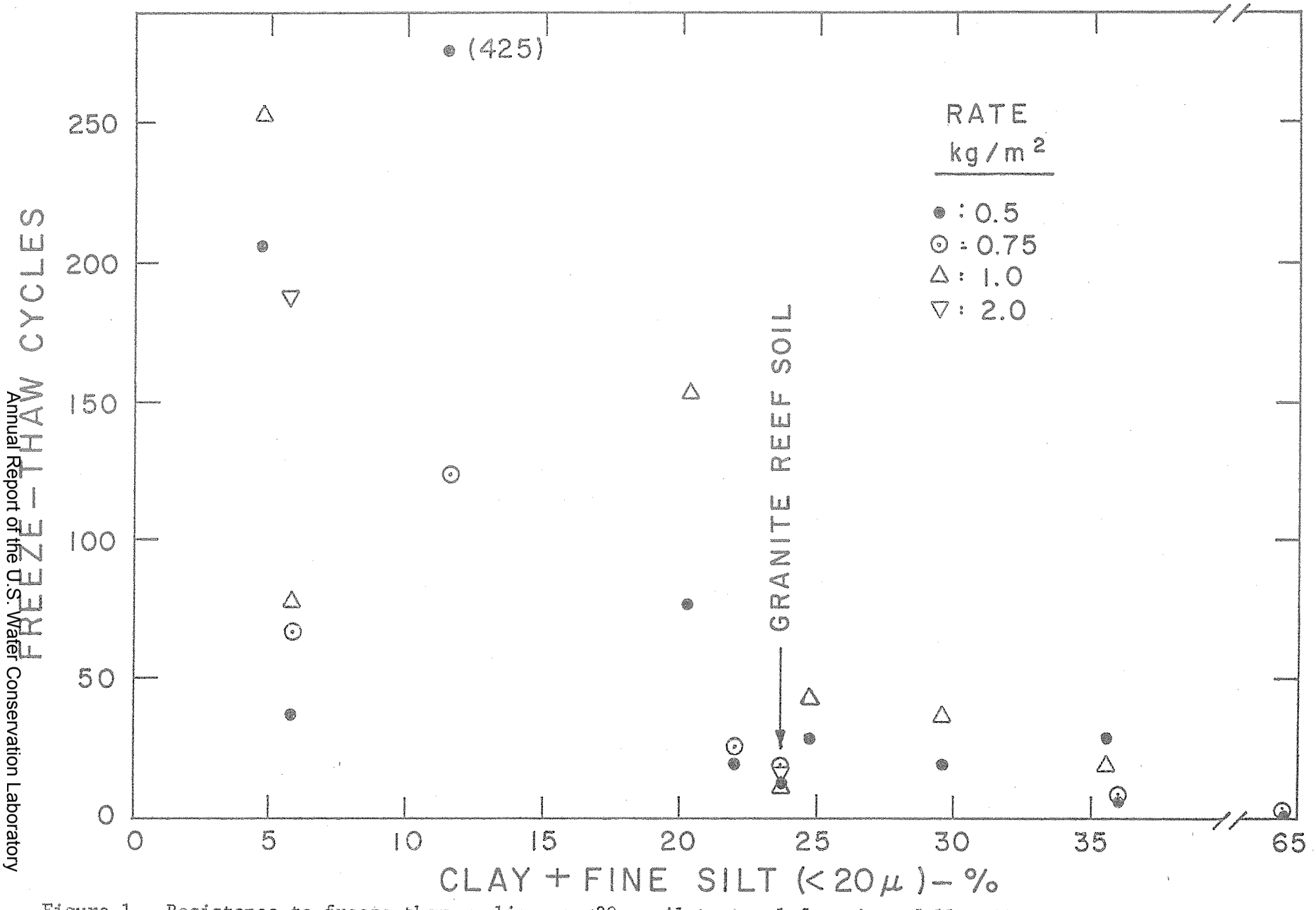

Figure 1. Resistance to freeze-thaw cycling vs <20μ soil textural fraction of 11 soils treated with paraffin wax.

APPENDIX

LIST OF PUBLICATIONS PUBLISHED

AND MANUSCRIPTS PREPARED IN 1976

		MS No.
NRP 20740	Improve Irrigation and Drainage of Agricultural Land	
Published:	Erie, L. J., and French, O. F. Irrigation water management on fall-planted sugar beets in Arizona. In "A Report on Sugar-beets", (P-39) Univ. of Ariz. College of Agric. Co-op. Exten. Service and Agric. Exper. Sta. Pp. 48-50. Dec. 1976.	580
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	Roth, R. L., and Nakayama, F. S. Operational guidelines for trickle irrigation systems on citrus in the Yuma area. Agric. Engin. and Soil Sci. 76-10. Univ. of Ariz. 1976.	560
Prepared:	Bucks, D. A., Nakayama, F. S., and Gilbert, R. G. Clogging research on drip irrigation. Proc., Internatl. Drip Irrig. Assoc. Meeting, Fresno, CA, Oct. 1976. (In press).	579
	Dedrick, A. R., and Erie, L. J. Automation of on-farm irrigation turnouts utilizing jack-gates. Trans., Amer. Soc. Agric. Engin. (Submitted for publication).	569
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Nakayama, F. S., Bucks, D. A., and French, O. F. Reclaiming partially clogged flushable-type trickle emitters and maintaining emitter operation. Trans., Amer. Soc. Agric. Engin. (In press). 565

Replogle, J. A. Portable, adjustable flow-measuring flume for small canals. Trans., Amer. Soc. Agric. Engin. (Submitted for publication). 573

MS No.

NRP 20760 Management and Use of Precipitation and Solar Energy for Crop Production

Published:

Idso, S. B. Atmospheric dust and surface albedo: Effects on desertification. In "Desertification: Process, Problems, Perspectives." Editors, P. Paylore and R. A. Haney, Jr., Office of Arid Land Studies, Univ. of Arizona. Pp. 32-39. Sept. 1976. 564

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NRP 20790 Preventing Pollution of and Improving the Quality of Soil, Water, and Air

Published:

Bouwer, H. Improvement of wastewater quality by movement through soils and aquifers. In "Biological Control of Water Pollution", J. Tourbier and R. W. Pierson, Eds. (Univ. of Penn. Press, 1976). Pp. 259-268. 521

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