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U. S. WATER CONSERVATION LABORATORY
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TITLE: CHEMICAL TREATMENT OF IRRIGATION WATER FOR THE PREVENTION OF CLOGGING AND THE REMOVAL OF FLOW OBSTRUCTIONS IN TRICKLE IRRIGATION SYSTEMS

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

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INTRODUCTION:

The two-year study on emitter clogging reported in last year's Annual Report showed that control of microbial activity and chemical precipitation increased the reliability of emitter performance by reducing or preventing clogging. The treatment consisted of sand filtration and continuous acid-hypochlorite additions to a well water to obtain 1 ppm available free chlorine and pH of 7.0. To reduce treatment costs and to follow the mechanism of the clogging process, lower chemical concentrations and different combination of chemicals were used in a succeeding experiment.

One undesirable feature of exposing trickle systems to direct sunlight is the resultant temperature increase of emitters and lateral lines. Besides possible photochemical degradation of the components, chemical reactions in the water such as precipitation of salts may occur, which consequently can obstruct the emitters and lines with time. A series of experiments were set up to measure the line temperatures; in addition, theoretical models on $CaCO_3$ solubility were developed to predict the solubility behavior of $CaCO_3$ under such temperature regimes.

Clogging of emitters, besides reducing flow rate, can affect the uniformity of water application of the emitters. A reduction in flow rate can be compensated by increasing the length of water application to obtain the equivalent volume of water, but water application uniformity cannot be corrected by this technique. The alternative solution is to increase the number of emitters per plant. A procedure for estimating the number of emitters per plant to get a given degree of uniformity was not available, so a method was derived to develop such a procedure.

PART I. CHEMICAL TREATMENT OF TRICKLE IRRIGATION WATER

PROCEDURE:

The types of trickle system and chemical treatments used are listed in Table 1. Three kinds of point source emitters (Spot, Bowsmith, Drip-Eze), and two kinds of of line sources (Monotube and Bi-wall) were utilized. The point-source Flapper emitter was replaced for the Monotube lines when the latter started to develop extensive cracking. The Drip-Eze (old) emitters were carried over from a previous experiment. These emitters with the continuous acid-hypochlorite treatment were working adequately for two years. Space limitations prevented the use of the various chemical treatment combinations to all the emitters. Earlier results showed that the Bi-wall tube was the easiest to follow in respect to clogging so that the most extensive chemical treatments were made on this system.

Well water was run daily through all emitter systems; once in the morning and once in the afternoon. The operation was controlled by time clocks. The well-water was initially stored in a 700-gal galvanized steel tank and treated with ammonium nitrate to 10 ppm-N to increase microbial activity in the storage water before being pumped into the lines. This water was sand-filtered before being put into the lines.

Water volumes were estimated daily with the water meters installed in each of the lines. Individual emitter flow rates were taken to assess emitter flow uniformity. Microbial population, pH, and available chlorine were monitored on a 10- to 14-day schedule. For the once-a-week treatment G, line 16, microbial population was measured the day before and after treatment had started.

RESULTS AND DISCUSSION:

The experiment was started in November 1976, and is not completed at this time. Experience has shown that one year is too short a period to get adequate answers on the treatments. However, one set of emitters, the monotube, began to decrease in flow rate with no chemical treatment within 60 days so it was replaced with another set of similar type tubing. A condensed log of the experiment is given in Table 2. Furthermore, in July, extensive line cracking of the surface-placed system resulted in abandoning of this tubing. Breakage in the Bi-wall tubing also occurred starting in early spring and had to be replaced by a new type of plastic-formulated Bi-wall tubing in August 1977. The flow rate for the latter set of tubing over a 120-day period was essentially unchanged for the various water treatments (Table 3A).

Similarly, the point-source emitters with only two types of water treatment had changed little in flow rate over a 380-day period (Table 3B). The Spot emitter had the greatest decrease in flow rate in Treatment B. The experiment will be continued for at least another year to get meaningful results.

Microbial analyses are presented in Table 4 which shows that continuous hypochlorination at 1 ppm (Treatments A and C) is controlling microbial population. Population at 0.1 ppm continuous (Treatment E) was higher than the 1 ppm chlorine level. The intermittent type hypochlorination treatments F and G had built up microbes on days on which hypochlorination was absent. Microbial populations in the no chemical treatment B, and acid-alone treatment D were comparable to the control.

PART II: TEMPERATURE EFFECT ON CALCIUM CARBONATE SOLUBILITY

The solubility of salts is temperature dependent - some salts are more soluble at higher than lower temperatures, whereas others have the opposite property. In the case of calcium carbonate, solubility is decreased with increasing temperature, and in such instances, precipitation may occur in the trickle lines and emitters with water containing both calcium and carbonate in solution.

The estimation of dissolved calcium at different temperatures involves the solution for the following mass and charge balance equations:

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

$$[CaHCO_3^{\;+}] + 2[Ca^{2+}] + [H^+] = [HCO_3^{\;-}] + 2[CO_3^{2-}] + [OH^-] \quad (2)$$

The temperature-dependent function for the dissociation constants of H_2CO_3, HCO_3^-, $CaHCO_3^+$, and H_2O the solubility of CO_2, and the solubility constant of $CaCO_3$ were used in solving for the amount of calcium dissolved in the saturated calcium carbonate solutions.

PROCEDURE:

Air, water and polyethylene tube temperatures were measured with thermocouple sensors. Soil temperatures were taken at 1 cm depth in dry and moist soil, the latter located where trickle irrigation was occurring. Thermocouple was epoxied into capillary tubing and then inserted through the polyethylene emitter tubing. Several different environmental conditions were imposed on the tubing, which was buried at 10-cm depth in dry and moist soil, or on the soil surface, with water either running or static.

RESULTS AND DISCUSSION:

Typical temperature values for a May 1977 date are given in Figure 1. The water temperature represents water in the storage tank, and the tube temperature is the polyethylene tube on the dry soil surface under static conditions when no water is running. Tube and soil temperatures of 50 C are similar and reached a maximum at approximately 1300 hours. Temperatures up to 60 C were obtained in the hotter summer months. As expected, the wet soil and tubing on wet soil had temperatures lower than the dry soil and tubing on dry soil (Figure 2), and the buried tube lower than the surface tubing (Figure 3). When water was run in the surface and buried tube, both system temperatures approached that of the water (Figure 4).

Actually, in the dark period of the day, the tube temperature was lower than the supply water temperature, and higher than the water in the light periods, except when the trickle system was in operation when the tube temperature was equivalent to the water temperature.

Calculated solubility of $CaCO_3$ at the temperatures exhibited by the surface-placed tubing is plotted in Figure 5. Solubility was lowest at the 1300-hour period when the temperature of the tubing is the highest. The minimum solubility was approximately one-half that for the maximum value, and conceivably, calcium carbonate could precipitate out in the irrigation water containing large amounts of calcium and carbonate in solution. In the precipitation-dissolution phenomenon, the precipitation rate is higher than the dissolution rate so that the precipitate, once formed, may not redissolve completely when the solubility increases at the lower temperatures.

PART III. ASSESSING UNIFORMITY COEFFICIENT OF TRICKLE EMITTERS

Emitters of the same kind vary in their rate of water application so that in field use plants can be getting different amounts of water. This variation can be related statistically to the coefficient of variation and recommendations have been made to the manufacturers to provide such statistics for their emitters. Even when provided with this number, difficulty arises in mentally relating this "uniformity" of water application. Another question is one of selecting the number of emitters per plant to attain a given uniformity.

Theory. By dividing the total emitter population (N) into subgroups (Y_i) with equal number of individuals in the subpopulation so that $Y_1 = Y_2 = Y_3 = Y_k$ and $\sum_{i=1}^{k} Y_i = N$, flow rates for each subgroup can be calculated ranging from the lowest-flowing to the highest-flowing emitter. The average flow rate ($\bar{X}$) for the total population is defined by

$$\bar{X} = \sum_{i=1}^{k} f_j X_j \Big/ \sum_{j=1}^{k} f_j \qquad (1)$$

where f_j is the frequency for the X_j observation and $\sum_{j=1}^{k} f_j = N$, the total number of observations. By analogy to this, the average flow rate for the i-th subgroup can be estimated by

$$\bar{X}_i = \bar{X} + s\bar{t}_i \qquad (2)$$

where s is the standard deviation, and from statistical consideration, it can be shown that

$$\bar{t}_i = [\exp(-t^2/2) / \sqrt{2\pi}]_{t_1}^{t_2} / [Y(t_1) - Y(t_2)] \qquad (3)$$

where $Y(t_1) - Y(t_2)$ is the fraction of the population included in the t_1 to t_2 range.

For a given incremental subgroup, the $\bar{t}_i$-values will be the same, regardless of the units of the observations as long as they are normally distributed.

When more than one emitter per plant is used, the resultant pooled deviation becomes $s\sqrt{n}$, where n is the number of emitters per plant. The new average for the i-th group becomes

$$\bar{X}_{i,n} = n\,\bar{X} + \bar{t}_i\, s\sqrt{n} \qquad (4)$$

The uniformity coefficient of emitters, UC_E, similar to Christiansen's, defined as the absolute deviation from the mean can be derived from the preceding equation. Thus UC_E becomes

$$UC_E = (1 - (s\sqrt{n} \cdot \sum_{i=1}^{k} |\, \bar{t}_i \,|)/ k\,\bar{X}\,n) \cdot 100 \qquad (5)$$

where k is the number of subgroups used to calculate the $\bar{t}_i$-values.

PROCEDURE:

Values for $\bar{t}_i$ were calculated for a 5% population increment. Numerical equivalent of equation 5 was also estimated from the $\bar{t}_i$-values.

RESULTS AND DISCUSSION:

The computed $\bar{t}_i$-values for the 5% grouping are listed in Table 5, together with the equivalent average emitter flow rate for the given subgroup. A typical emitter flow rate of 3.8 l/hr and coefficient of variation (C_v) of 0.05 was used. From the comparison, it is demonstrated that there is a range in flow rates. Furthermore, the larger the value of C_v, the less uniformity in water application will result (Figure 6). By increasing the number of emitters per plant (Figure 7) the uniformity of application can be improved.

Computed UC_E's for combinations of coefficients of variation and emitter number per plant are compared in Figure 8. For the conditions specified in the example, UC_E of 90% cannot be attained with C_v's of 0.4 and larger, even with 10 emitters per plant; a UC_E of 90% can be achieved with 6 emitters per plant at C_c of 0.30, whereas with a C_v of 0.2 and less, the 90% level can be reached with 4 emitters per plant.

Trickle irrigation systems are operated on the basis of supplying a specified total volume of water , or on basis of a given set time. In either case, the amount of water applied per plant would be different and depends upon the variability of emitter flow rate. This relationship is shown graphically in Figure 9 for four emitters per plant with a C_v of 0.2. The water requirement is set at an arbitrary depth in the figure, but it illustrates that a fraction of the plants with the lowest flowing emitter group would not receive its water needs.

The fraction of the plant adequately irrigated in terms of emitter flow rate variability can be computed by modifying the method of Hart and Reynolds (1) used in sprinkler irrigation. The computed results of fraction of plants adequately irrigated to the emitter uniformity coefficient for three values of the fraction of emitter flow rate equal to or exceeding the average flow rate are presented in Figure 8. The value of 0.95 specifies greater depth of water requirement, then 0.80 to achieve water sufficiency, so that for the same UC_E, the fraction of plants adequately irrigated will be less for the higher than for the lower water requirement value. The relation between UC_E and the fraction of irrigation adequacy can be better illustrated by comparing the change in UC_E that could occur with a change in C_v. For example, with H_a = .90, a change in UC_E from 90 to 80% represents a decrease in irrigation adequacy from 79 to 65%.

Time-set factors for different levels of irrigation adequacy with different emitter numbers per plant and C_v values can be estimated also. These are listed in Table 6. The actual length of irrigation is then determined from the product of the time-set factor, and the application time computed from the volume of water required and average emitter flow rate per plant. For example, if the computed length of irrigation is to be 10 hours for 95% irrigation adequacy using four emitters per plant, the actual irrigation time will be 10.4 hours for a C_v of 0.05 and 13.3 hours for a C_v of 0.30.

Coefficients of variation based on individual emitter flow measurements at the end of the 1975 to 1976 experiment were calculated for a set of emitters. The results are listed in Table 7. As the computation readily illustrates, the acid-hypochlorite treated emitters had the higher average flow rate and lower coefficient of variation than the chemically untreated emitters. The C_v in the order of 1.5 was much too high to attain good uniformity of water application.

SUMMARY:

Experiments have been set up to estimate minimum chemical treatment needed for controlling biological activity and salt precipitation in several types of emitters used in trickle irrigation. Flow rate measurements for the first year run show that the emitters are still operating properly. Calculations of calcium carbonate solubility based on diurnal temperatures of exposed polyethylene trickle tubing and emitters indicate that precipitation could occur in the warmer afternoon temperatures. A statistical method was derived for estimating the uniformity coefficient of emitters and a way of using this concept has been developed. With a knowledge of the coefficient of variation of the emitter, the selection of the number of emitters per plant can be objectively made. Time-set factors for the irrigation system for different levels of irrigation adequacy, with different numbers of emitters and coefficients of variation can be determined.

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2. Nakayama, F. S., D. A. Bucks, and O. F. French. 1977. Reclaiming partially clogged trickle emitters. Trans. Amer. Soc. Agr. Engin. 20: 278-280.

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Table 1. Description of emitter type and chemical treatments.

Line No.	Emitter type	Chemical Treatment
1	Monotube	A. Acid-hypochlorite; 1 ppm; pH=7; continuous
2	Drip-Eze (old)	A. Acid-hypochlorite; 1 ppm; pH=7; continuous
3	Bowsmith	A. Acid-hypochlorite; 1 ppm; pH=7; continuous
4	Drip-Eze (new)	A. Acid-hypochlorite; 1 ppm; pH=7; continuous
5	Spot	A. Acid-hypochlorite; 1 ppm; pH=7; continuous
6	Bi-wall	A. Acid-hypochlorite; 1 ppm; pH=7; continuous
7	Monotube	B. None
8	Bowsmith	B. None
9	Drip-Eze	B. None
10	Spot	B. None
11	Bi-wall	B. None
12	Bi-wall	C. Hypochlorite alone; 1 ppm; ; continuous
13	Bi-wall	D. Acid alone pH=7; continuous
14	Bi-wall	E. Acid-hypochlorite; 0.1 ppm; pH-7; continuous
15	Bi-wall	F. Acid-hypochlorite; 1 ppm; pH=7; alternate days
16	Bi-wall	G. Acid-hypochlorite; 10 ppm; pH=7; once a week

Table 2. Condensed log of trickle irrigation clogging experiment.

DATE CONVERSION AND CONDENSED LOG

DAYS ELAPSED	JULIAN DATE	LOG COMMENTS
1	14 NOV 76	START EXPERIMENT
45	28 DEC 77	CITY WATER 28 DEC 76
45	28 DEC 77	TO 3 JAN 1977
58	10 JAN 77	PIPE BREAKAGE
59	11 JAN 77	FREEZE--SYSTEM OFF
62	14 JAN 77	NEW MONOTUBE: 1. 1; 7. 1
63	15 JAN 77	LOW WATER IN TANK
75	27 JAN 77	NEW P/G IN 1. 1; 7. 1
84	05 FEB 77	LOW WATER IN TANK
137	30 MAR 77	BROKEN LINE IN 11
153	15 APR 77	BROKEN LINE IN 12
166	28 APR 77	BROKEN LINE IN 12
173	05 MAY 77	BROKEN LINE IN 11
179	11 MAY 77	INSTALLED THERMOCOUPLES
180	12 MAY 77	BROKEN LINE IN 11
184	16 MAY 77	BROKEN LINE IN 11
188	20 MAY 77	BROKEN LINE IN 12
191	23 MAY 77	BROKEN LINE IN 6; 11
198	30 MAY 77	BROKEN LINE IN 11
199	31 MAY 77	BROKEN LINE IN 11; 12
201	02 JUN 77	BROKEN LINE IN 11; 12
207	08 JUN 77	BROKEN LINE IN 11
209	10 JUN 77	BROKEN LINE IN 12
214	15 JUN 77	BROKEN LINE IN 11; 12
220	21 JUN 77	BROKEN LINE IN 1. 1; 7. 1
220	21 JUN 77	BROKEN LINE IN 11; 12; 16
222	23 JUN 77	BROKEN LINE IN 12
226	27 JUN 77	NEW LINE: 11. 1; 12. 1; 16. 1
227	28 JUN 77	BROKEN LINE IN 1. 1; 7. 1; 14
241	12 JUL 77	BROKEN LINE IN 1. 1; 6
241	12 JUL 77	REPAIR HYPOCHL. LINE(TRT. 1-6)
243	14 JUL 77	SHUT-OFF 1. 1; 7. 1
247	19 JUL 77	NEW FLAPPER EM. : 1A; 7A
248	20 JUL 77	SHUT-OFF 1A; 7A-LOW PRESS.

Table 2. Continued.

DATE CONVERSION AND CONDENSED LOG

DAYS ELAPSED	JULIAN DATE	LOG COMMENTS
248	20 JUL 77	TO 02 AUG 77
250	21 JUL 77	BROKEN LINE IN 14
255	26 JUL 77	BROKEN LINE IN 14
258	29 JUL 77	BROKEN LINE IN 14
259	30 JUL 77	BROKEN LINE IN 12
262	02 AUG 77	NEW WATER PUMP
270	10 AUG 77	NEW TYPE ANJAC IN LINES
270	10 AUG 77	6. 1; 11. 2; 12. 2; 13. 1; 14. 1;
270	10 AUG 77	15. 1; 16. 2
277	17 AUG 77	REPAIR INJ. PUMP IN 16. 2
334	13 OCT 77	NEW INJ. PUMP IN 16. 2
351	30 OCT 77	ELECT. OUTLET FAILURE
354	02 NOV 77	NEW SUMP PUMP
358	05 NOV 77	SHUT OFF 7A
368	16 NOV 77	EM. REMOVED(14 IN 7A)
369	17 NOV 77	NEW INJ. PUMP IN 14
381	29 NOV 77	CITY WATER USED
389	28 DEC 77	SHUT-DOWN SYSTEM
389	28 DEC 77	BREAK IN SUPPLY LINE

Table 3a. Flow rate (gph) for line-source bi-wall emitter at 120 elapsed days.

	Treatment or Line No.						
	6 A	11 B	12 C	13 D	14 E	15 F	16 G
Start	0.44	0.48	0.45	0.50	0.51	0.45	0.44
End	0.38	0.40	0.40	0.45	0.48	0.43	0.41

Table 3b. Flow rate (gph) for point-source emitter at 380 elapsed days.

	Treatment A		Treatment B	
Emitter	Start	End	Start	End
Drip-Eze (old)	0.80	0.77	---	---
Bowsmith	0.92	0.85	0.82	0.86
Drip-Eze (new)	1.07	0.90	0.94	0.87
Spot	1.08	1.01	1.09	0.72

Table 4. Microbial population for different chemical treatments.

	TREATMENT a/							
DAY	A	B	C	D	E	F	G	CONTROL
6	1	34000	4	35000	0	34000	41000	39000
17	2	10250	5	3500	3530	3500	18000	4500
27	1	4500	3	6500	45	75	60	8000
38	0	7750	2	11000	40	6860	6780	7500
46	6	6750	37	8500	44	65	0	6500
54	0	5750	2	6000	55	4835	100	7500
66	2	4250	2	4500	45	4680	5830	******
76	0	7250	2	5000	60	90	1625	7500
87	0	29000	6	22000	285	17000	9580	34000
97	6	57000	16	62000	1075	10	9860	44000
108	2	26000	4	36000	140	10000	150	12000
118	2	19500	25	42000	405	35	1000	35000
129	0	208000	10	16000	750	121000	128000	105000
139	0	47500	0	39000	400	15	0	43000
150	1	48500	9	46000	250	11000	15000	30000
160	0	21000	4	78000	1705	10	4640	6500
171	2	14500	2	279000	55	2565	125	11000
181	1	15500	208	29000	16000	10	6530	12000
192	1	190500	0	******	12000	25000	34000	11000
199	1	77000	18	7000	1850	16000	7000	71000
209	4	22500	680	9500	6530	75	35000	25000
222	16	111000	8	6000	3700	75	21000	71000
230	1	48500	******	4500	80000	650	4000	46000
241	0	410500	0	242000	21000	90	0	56000
251	0	210000	2	450000	800	60	0	100000
262	0	81500	2	398000	******	35000	1900	56000
272	0	171000	0	140000	4425	0	9840	185000
283	0	201500	0	33000	100	25000	259000	32000
293	0	69500	18	99000	815	26	45000	15000
304	2	18000	2	9000	75	20000	12000	18000
314	0	11500	1	11000	10	6	10000	18000
332	0	11750	0	9500	4	3	7800	9000
342	0	11000	0	7500	2	0	0	16000
356	0	7000	0	7000	645	0	210	10000
367	0	775	0	700	5000	2850	3085	4450
377	0	1800	9	750	2	0	2750	3600
388	0	16675	411	25000	8430	55000	7980	5300
398	2	6967	2	6395	4	0	535	7450

a/ See Table 1 for treatment designation. Control is sample taken at storage tank.

Table 5. Computed $\bar{t}_i$-values for 5 percent grouping of the total population.

Emitter grouping, i	Group increment, %	$\bar{t}_i$	Flow rate l/hr., $\bar{X}_i$
1[a]	0 - 5	-2.060	3.41
2	5 - 10	-1.466	3.52
3	10 - 15	-1.157	3.58
4	15 - 20	-0.932	3.62
5	20 - 25	-0.760	3.66
6	25 - 30	-0.598	3.69
7	30 - 35	-0.454	3.71
8	35 - 40	-0.319	3.74
9	40 - 45	-0.188	3.76
10	45 - 50	-0.063	3.79
11	50 - 55	0.063	3.81
12	55 - 60	0.188	3.84
13	60 - 65	0.319	3.86
14	65 - 70	0.454	3.89
15	70 - 75	0.598	3.91
16	75 - 80	0.760	3.94
17	80 - 85	0.932	3.98
18	85 - 90	1.157	4.02
19	90 - 95	1.446	4.07
20	95 -100	2.060	4.19

$\bar{x}$ = 3.8 l/hr.; $C_{\bar{v}}$ = 0.05; S = 0.19 l/hr; $\bar{X}_i = \bar{X} + \bar{t}_i S$

a/ Group 1 represents the 5% of the lowest flow and group 20 the highest flow rate with intermediate groupings increasing progressively from 1 to 20.

Table 6. Time-set factors for combinations of C_V, emitters per plant and fraction of plants adequately irrigated.

		Time-set factor and emitters/plant				
"a"	C_V	n=1	n=2	n=4	n=6	n=8
95%	0.05	1.09	1.06	1.04	1.03	1.03
	.10	1.20	1.13	1.09	1.07	1.06
	.20	1.49	1.30	1.20	1.15	1.13
	.30	1.98	1.53	1.33	1.25	1.21
	.40	2.91	1.86	1.49	1.36	1.30
	.50	5.55	2.38	1.69	1.50	1.41
90%	0.05	1.07	1.05	1.03	1.33	1.02
	.10	1.15	1.10	1.07	1.06	1.05
	.20	1.34	1.22	1.15	1.12	1.10
	.30	1.62	1.37	1.24	1.18	1.16
	.40	2.05	1.57	1.34	1.26	1.22
	.50	2.78	1.83	1.47	1.35	1.29
85%	.05	1.05	1.04	1.03	1.02	1.02
	.10	1.12	1.08	1.05	1.04	1.04
	.20	1.26	1.17	1.12	1.09	1.08
	.30	1.45	1.28	1.18	1.14	1.12
	.40	1.71	1.41	1.26	1.20	1.17
	.50	2.57	1.58	1.35	1.27	1.22

Table 7. Comparison of coefficients of variation for two emitters under two types of water treatment.

Emitter type	Treatment: Sand filtration alone		Treatment: Sand filtration + acid-hypochlorite	
	Ave. (gph)	C_v	Ave. (gph)	C_v
Microtube	0.49	1.46	1.57	0.42
Drip-Eze	0.17	1.54	0.86	0.19

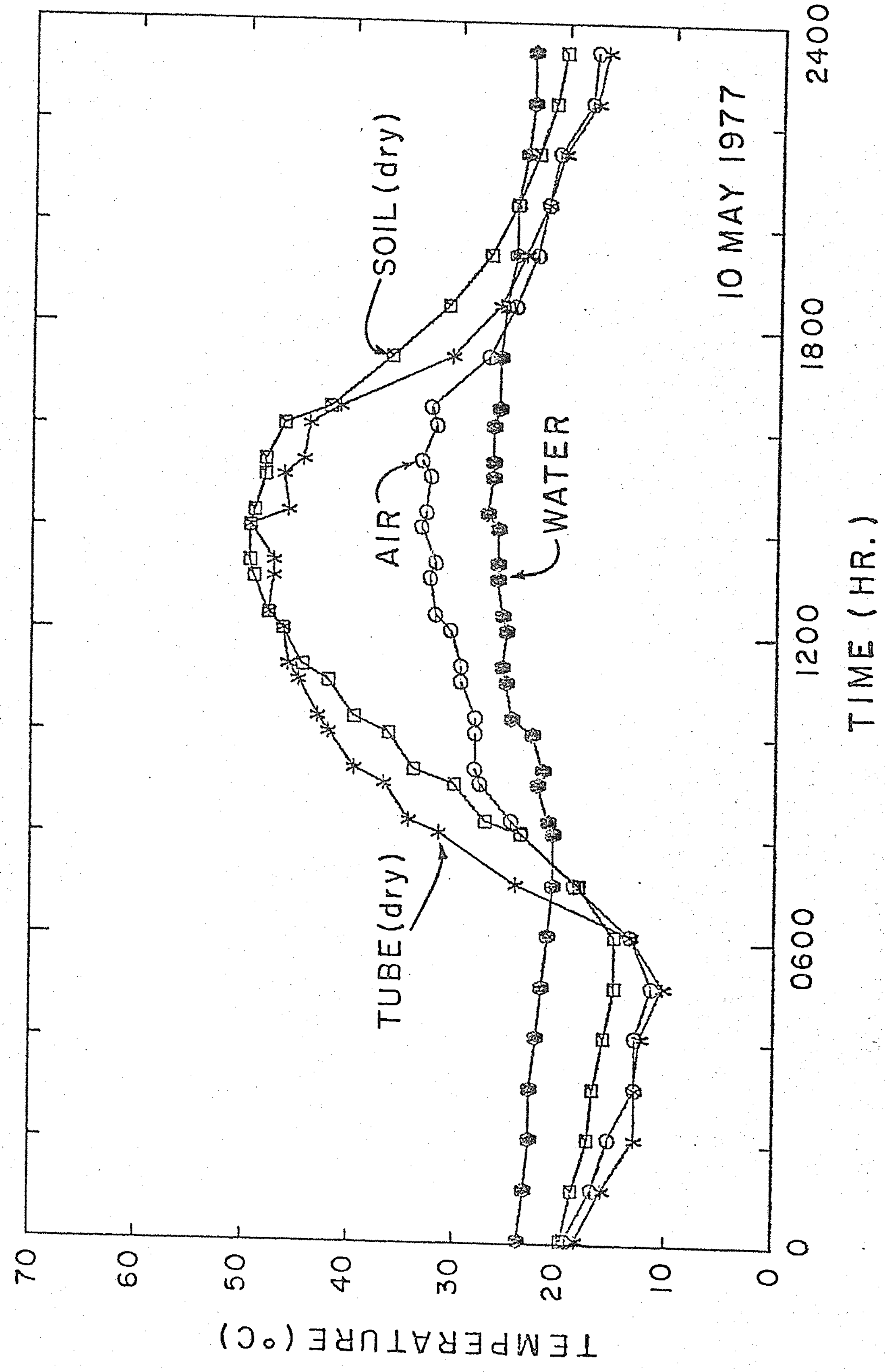


Figure 1. Comparison of air, water, soil and trickle irrigation tubing temperatures.

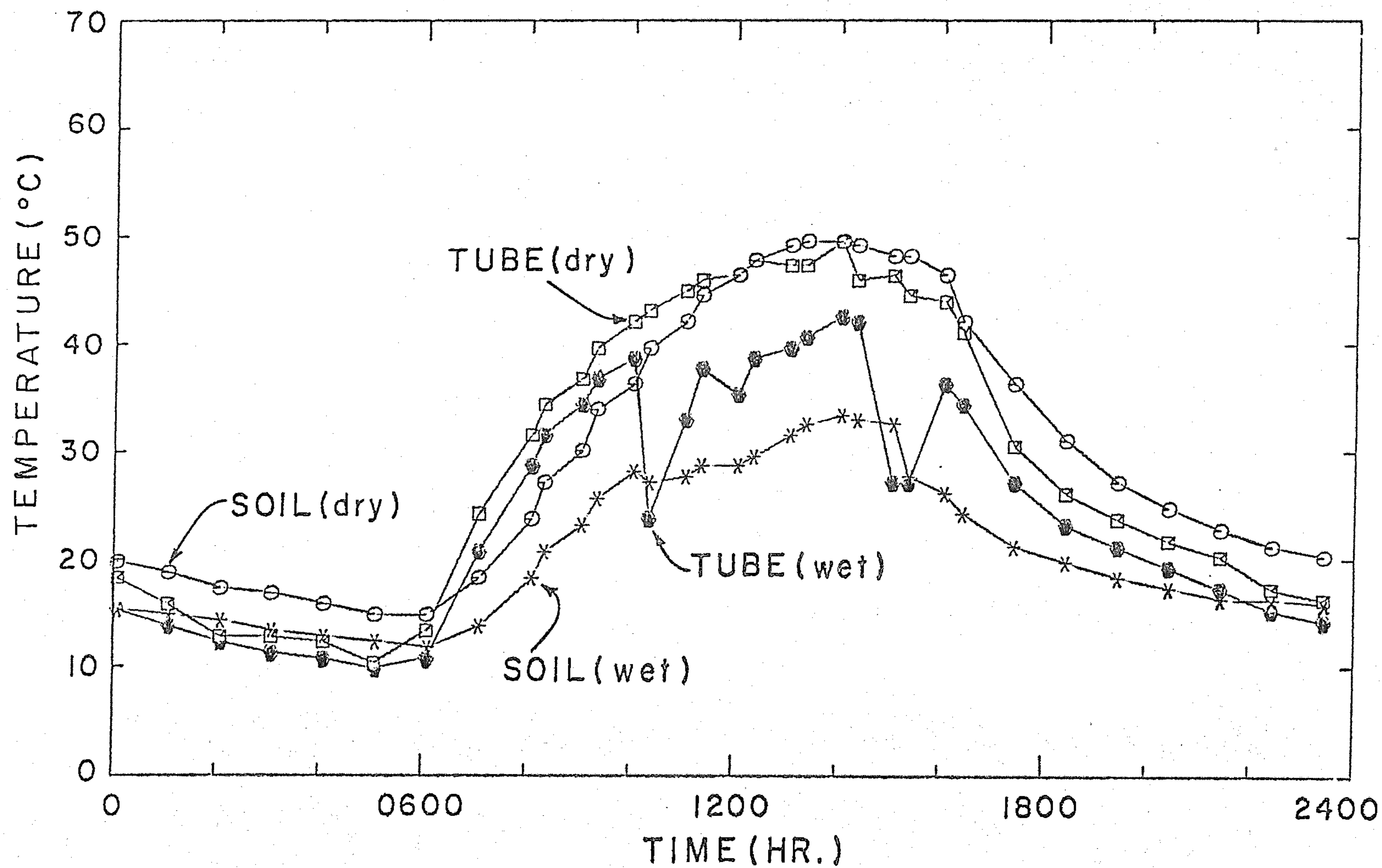


Figure 2. Comparison of wet and dry soils and tubing temperatures.

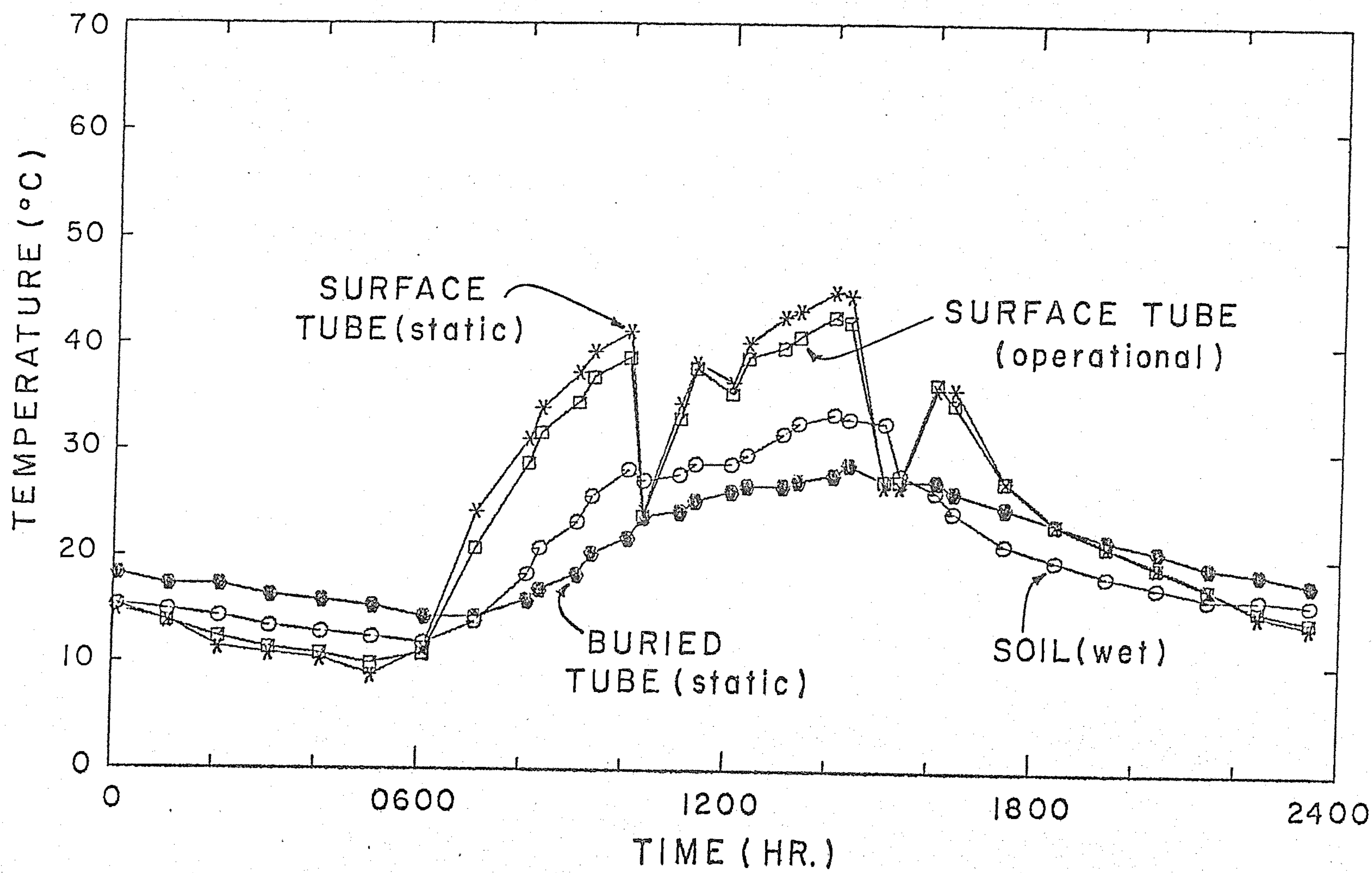


Figure 3. Comparison of buried and surface tubing temperatures.

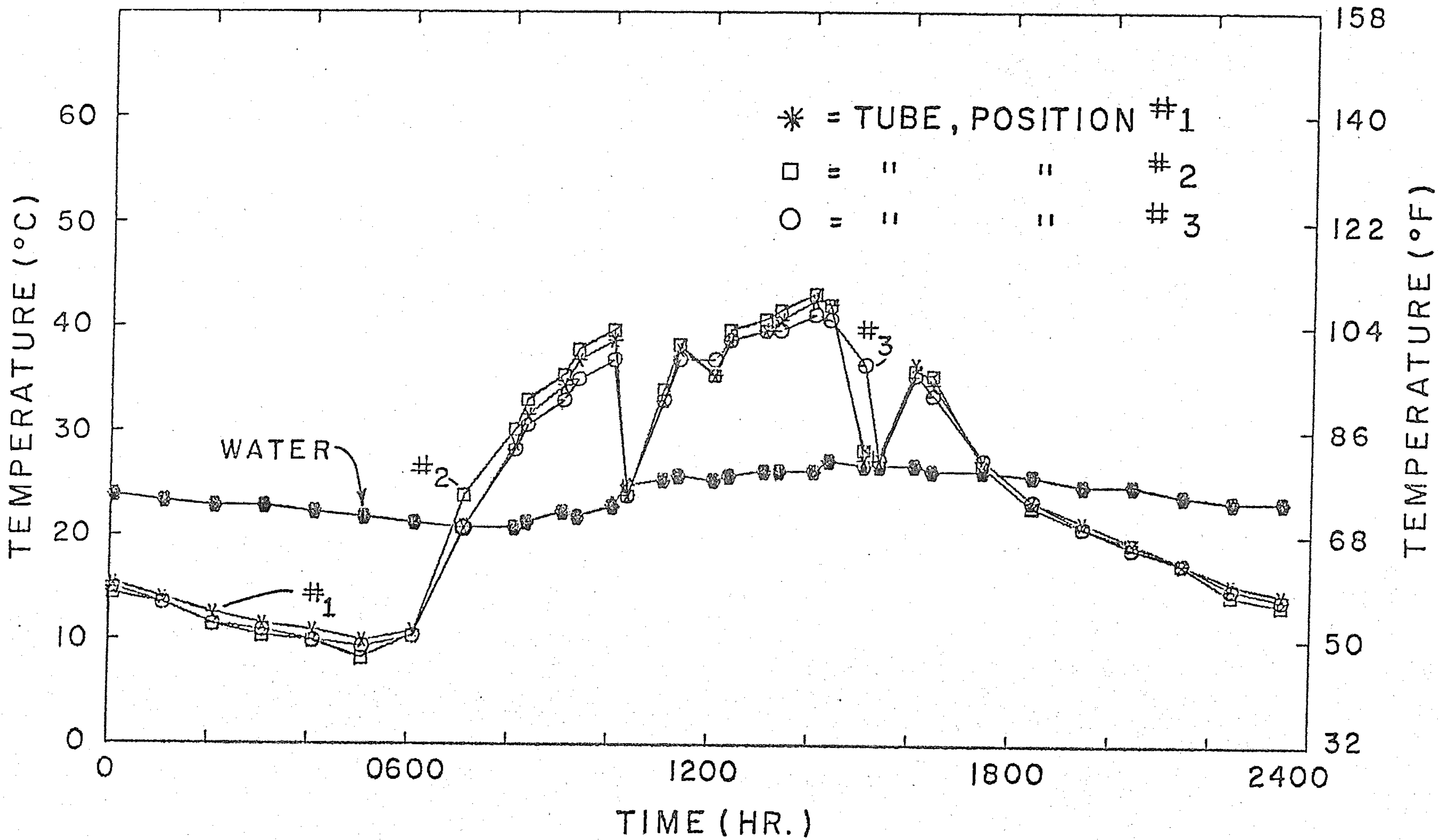


Figure 4. Comparison of water and tubing temperatures under static and operational conditions.

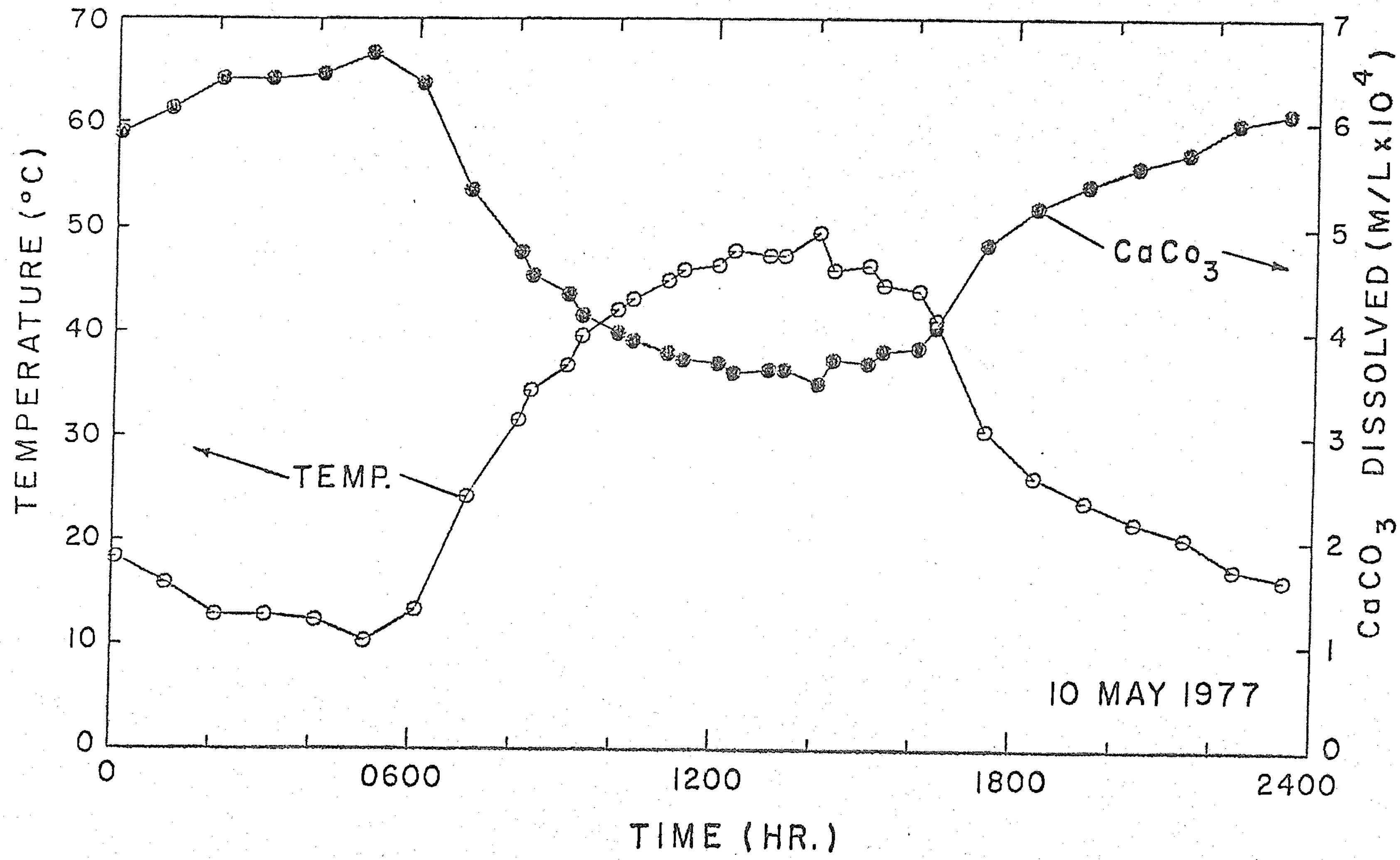


Figure 5. Computed solubility of $CaCO_3$ at temperatures equivalent to the surface polyethylene trickle irrigation tubing.

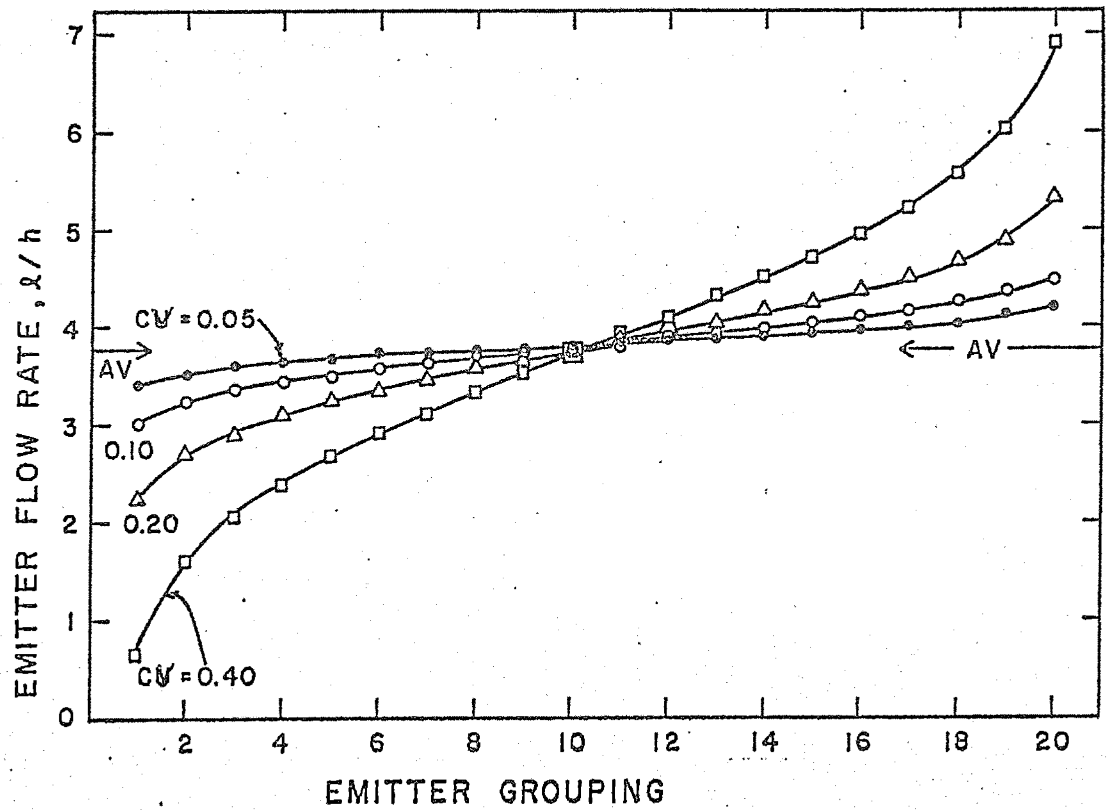


Figure 6. Computed flow rates of subgroups at different coefficients of variation.

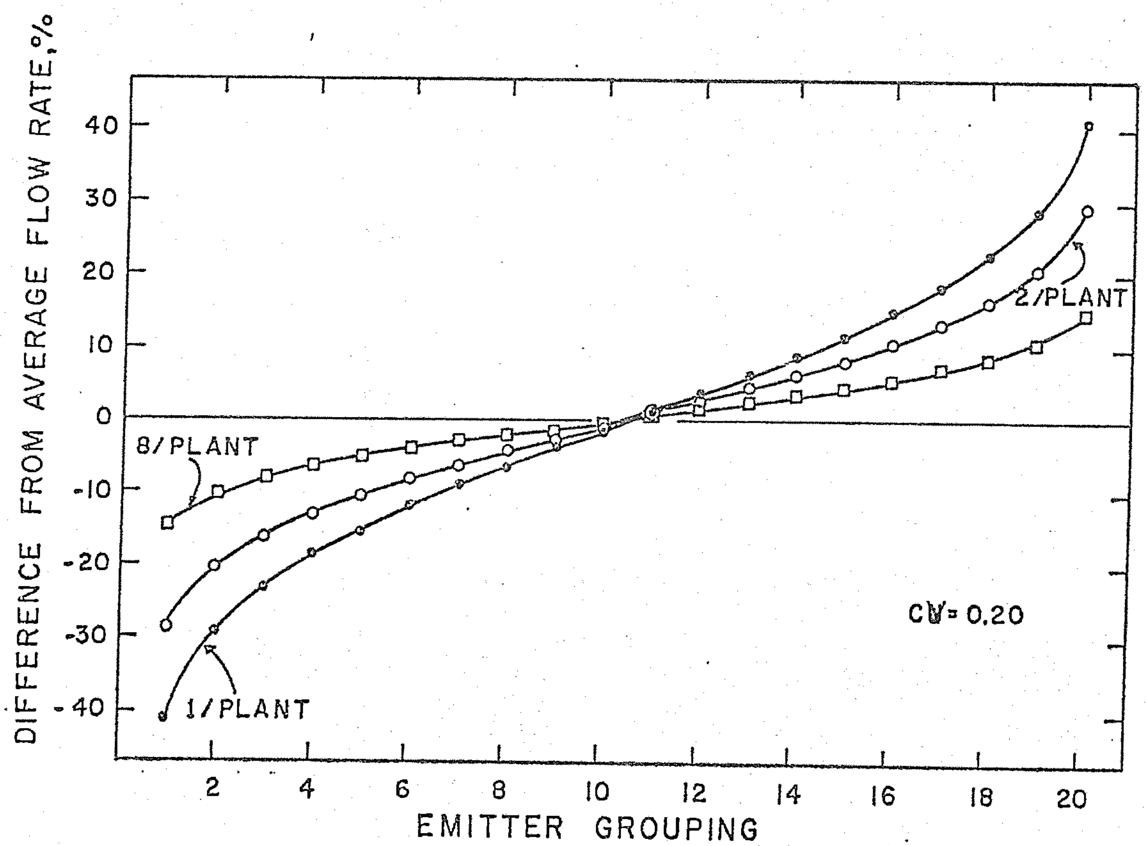


Figure 7. Effect of emitter number per plant on deviation from the average flow rate.

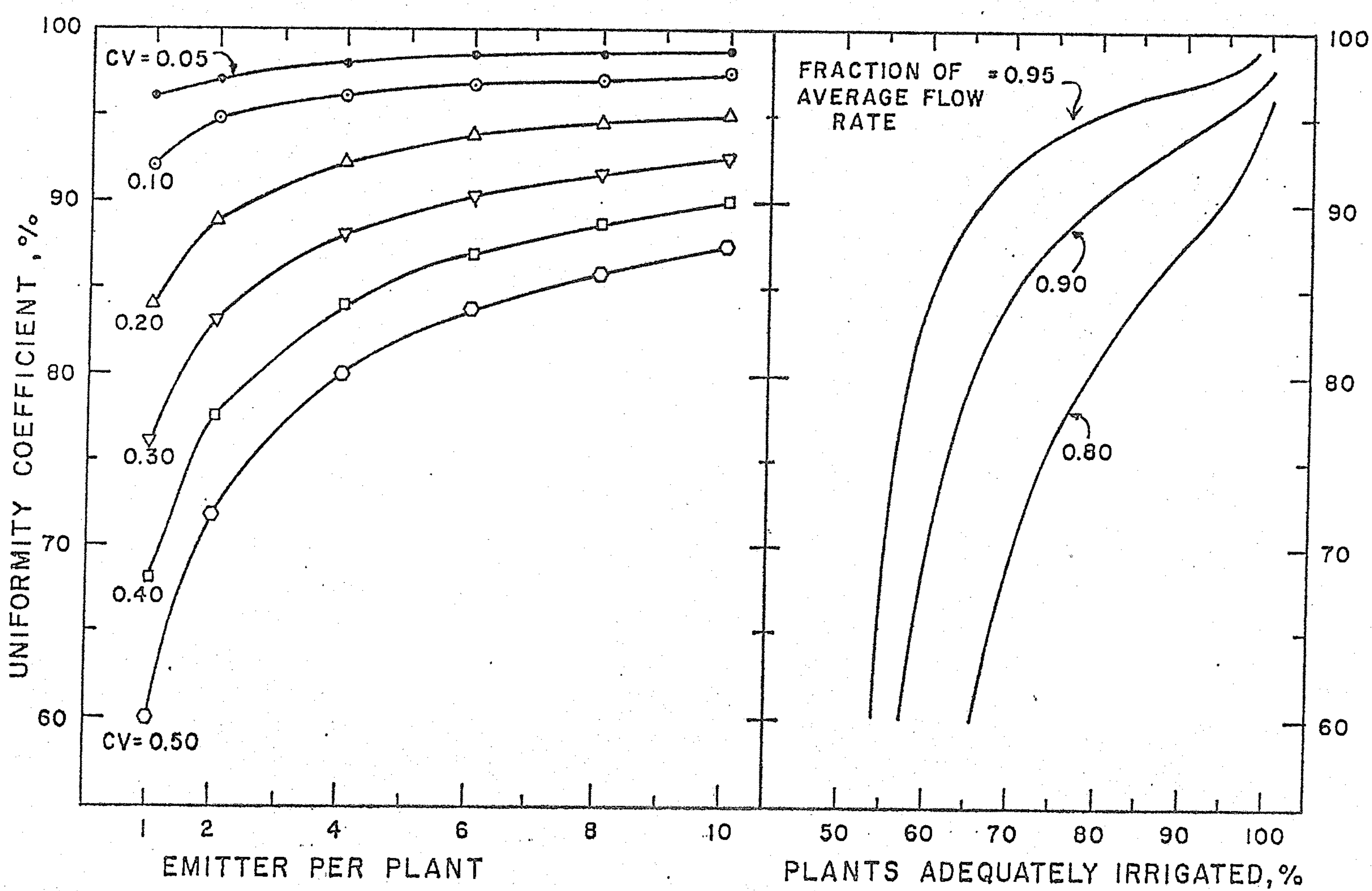


Figure 8. Relationship between coefficient of uniformity, coefficient of variation, and emitter number per plant, and fraction of plants adequately irrigated.

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 1966-1977 contain summaries of many critical-flow flumes calibrated by laboratory techniques. These calibrations were used to verify a computer model that has subsequently been employed to design several field-installed critical-flow flumes. The recent emphasis has been toward using the model to study errors caused by construction deviations and other dimensional changes in flumes. This was done to help identify important dimensional relationships and conversely to identify unimportant parameters.

PROGRESS:

Error analysis using the flume model showed that broad-crested weirs, with sloping upstream ramps, were an attractive compromise between construction costs and accuracy for lined irrigation deliveries. Another attractive advantage of this style is the small absolute head losses required to make it operate. These head losses can be as small as 0.1 ft. in slip-formed canals delivering 15 to 20 cfs. This means that carefully selected, a broad-crested weir can usually be fitted to existing canals without significantly violating the designed freeboard on the original canal.

The sensitivity of the weir style is less than that of the trapezoidal flume at low flows, but can nearly match it at the usual design canal capacity. Irrigation deliveries do not normally require more than a 2:1 or 3:1 range in flow rates, so low flow problems are averted.

The analysis and comparisons are discussed in more detail in the papers "Compensating for construction errors in critical flow flumes and broad-crested weirs," and "Selecting and rating meters for open-channel flows." Efforts to encourage the new flow-metering designs in both the trapezoidal flume style and the broad-crested weir style continued.

Portable Flume: A portable design was developed for use in small concrete-lined canals with 1-ft. bottom width and 1:1 sideslopes. This flume came about because of a request from the Phoenix SCS field office through A. J. Clemmens. They specified the need for a portable device capable of measuring from about 1 to 8 cfs to an accuracy of ± 5% that weighed less than 100 pounds.

From mathematical modeling, it appeared most practical to devise a portable broad-crested weir. The analysis showed that most dimensions in the weir need to be accurate to no more than ± 10%, except those in the throat cross-section, which need to be accurate to the approximate percentage desired for the final discharge measurement. This meant that standard slip-formed concrete ditches with trapezoidal cross-sections were more than accurate enough to provide most of the boundaries for a trapezoidal broad-crested weir. Further analysis showed that the flow area over the sill was the most important parameter. This consisted of a weir-width measurement, a sideslope determination, and a depth calculation, as inferred from an upstream depth measurement. The weirs are usually wide compared to this depth, so that it is relatively easy to maintain sufficient accuracy in both sideslope and width at the 1% level (for example, a weir 1 meter wide can be ± 1 cm). Therefore, the most sensitive dimension in the weir structure is the elevation of the upstream water surface above the elevation plane of the weir crest.

In permanent concrete flume or weir installations, a stilling well, built at the side of the canal, is connected by pipeline to the canal. The canal surface is thus reflected in the stilling well where it can be recorded, or otherwise sensed, with a variety of instruments that are readily zero-referenced to the sill crest by surveying techniques.

From the sensitivity analysis it became apparent that a portable broad-crested weir for use in slip-formed canals required only a sill crest and a converging section ramp. The canal could provide all other necessary surfaces to sufficient accuracy. The analysis also showed that the upstream stilling-well concept would be inconvenient since precision leveling in the canal would be necessary to maintain proper zero reference with the sill crest. Thus, a portable weir, in addition to being light weight, needed to provide a practical method for maintaining proper zero-registration.

A method for accomplishing the two goals of portability and convenient flow-depth determination is shown in Figures 1 and 2. The weir sill causes a flow obstruction in the canal which will cause a rise in the upstream water surface. This water surface elevation above the sill is accurately sensed through a ring of holes in a piece of pipe laid in the canal at a point upstream a selected distance from the flume. In this example, the sensing holes were located 1 ft (0.305 m) upstream from the remainder of the structure. The sensing pipe is constructed with a rounded upstream end and the pressure sensing holes placed 10- to 20-pipe diameters from the point to insure accurate pressure detection, uninfluenced by the point of the pipe itself. This pressure is transferred by siphon to a small version of a stilling well placed, not in the ditch bank as usual, but above the flume throat, or weir crest, near the crest centerline and about 1/4 to 1/3 the throat, or crest, length from the flow outfall. Above this same location, a point gage is mounted rigidly to the flume frame in such a way that it can be quickly lowered and permanently adjusted to read zero when the point touches the crest. The gage is then raised and the small stilling-well cup moved under the point, thus accurately measuring the upstream water surface above the flume-throat reference point. Dimensions are shown in Figure 2. These dimensions and the handbook roughness height for aluminum were used in the mathematical model to produce the calibration table.

Leakage past the flumes is controlled by rubber strips about 4 inches (10 cm) wide attached to the front of the converging section (ramp) and another strip attached across the bottom. It is helpful, if during construction, that this sheeting be warped slightly so that it springs strongly upstream, especially across the bottom of the flume. Water pressure will then cause a good seal against the canal wall and floor. Too little spring will allow the rubber to turn under the flume during placement, negating its effects.

The flume can be quickly placed into standard slip-formed canals with 1:1 sideslopes and 1-foot (0.305 m) bottom widths. Other sizes can be readily adapted. The installation time is usually less than 10 seconds after the bottom of the canal has been properly cleared of debris. The flow must then stabilize to satisfy the ponding that will occur upstream after inserting the flume. Stabilization time varies widely depending on the flow rate and the steepness of the existing canal. Typically, 3 or 4 minutes are required. No precise leveling is needed, just gross adjustments readily observed by eye. This differs from old flume emplacements, such as Parshall flumes, which had to be carefully leveled and often required hours to install and register.

Translocating the point gage and stilling-well cup to a position above the point of zero registration, itself, makes the flume insensitive to minor problems of leveling in all directions and eliminates lateral transfers of elevations by surveying techniques. Thus, careful placement and leveling are not necessary. The location of the sensing holes is likewise not critical, since the pipe can lay on the canal bottom or be at any location below the water surface, parallel to the main flow and extended so that the sensing holes are near the selected distance of 1 ft (0.305 m) upstream from the main structure. A 3:1 sloping ramp has been normally specified for these types of flumes, but here, a rounded shape was used to shorten the total ramp length by about 50%. This shorter ramp is accurately accounted for by the mathematical model. A truncated downstream ramp at a 6:1 slope was added as an option to increase the tolerance to submerged flow operation.

Since analysis showed that refined approach, converging, diverging, and exit sections were unnecessary, the chosen design is reduced to only two main parts, a finished, accurate weir-crest surface, and a rough-shaped ramp, in this case bent roughly to a circular arc with a radius of 1.5 ft (0.457 m). The existing canal is used for all other surfaces. The device is 3-ft (0.915-m) long plus a retractable sensor, 3 feet wide, and weighs about 30 pounds (14 mg) when constructed from aluminum.

Figure 2 shows some of the construction features for the portable weir designed for a standard slip-formed canal with 1:1 sideslopes and a bottom width of 1 ft (0.305 m). The sill is 1-ft (0.305 m) long, 3-ft (0.914 m) wide, and is 1-ft (0.305-m) high. Rubber sealing strips made of 1/8-inch (3.2-mm) thick sheeting cut about 4 inches wide (10 cm) were pop-riveted to the edges of the circular arc ramp to effect a suitable water seal. The sensing pipe can be any practical size. Standard 1/2-inch (13-mm) and 3/4-inch (19-mm) pipe have been used. The end can be plugged with a rubber stopper and then the combined pipe and stopper rough-ground to a rounded point, or the point can be welded shut, then the welded portion ground to a rounded point. The sensing cup can be fashioned from a section of pipe or an end cap for large plastic pipe. The point gage is commercially available through laboratory supply houses.

Field Use: In field practice, the operation is as follows:

1. Extend the sensing pipe and lock into position.
2. Check the zero of the point gage against the crest surface.
3. Place into flowing stream with the sensing pipe pointed upstream, by sliding down canal wall or lowering from top-center of canal.
4. Purge air from the sensing holes and plastic tubing connecting to the stilling-well cup so that pressure and flow to the cup is communicated freely from the depth-sensing holes.
5. Wait for the flow to stabilize, usually 3 or 4 minutes.
6. Read depth in stilling well with the "zeroed" point gage.
7. Refer reading to tables for discharge rate.
8. Remove from flowing canal by lifting upstream end.

A model of the flume was provided to a selected unit of the Soil Conservation Service for field use and evaluation. Three models were initially built, all hydraulically similar but with a variety of external support structures that do not affect the flume ratings.

The lack of sensitivity to handling and ease of operation was tested by three technicians, not previously familiar with the flume, or necessarily with flow metering. After a 10-minute orientation and demonstration, they each placed the flume in the same canal flow but at different locations. All returned similar flow readings. This demonstrated that the flume was not sensitive to operator handling and placement.

Another test for construction sensitivity was conducted by placing two models constructed by different crews, one welded together, the other bolted, into the same canal flow in series with each other. Both read identical discharge readings to three significant figures. This demonstrated that the construction tolerances are not critical and are mostly compensated for by the zeroing technique provided by the stilling-well and point-gage translocations.

A manuscript detailing these features is under preparation.

New Installations: The trapezoidal shape is continuing to be installed in the Wellton-Mohawk Irrigation District and has been well received. Only one instance of poor agreement between the flume and the propeller meters used by the District was brought to my attention. In this case, the flume appeared to read higher than the propeller. Examination of the propeller meter location disclosed a possible cause. To make a measurement, the propeller is placed in the outlet end of a 30-inch diameter pipe that conveys water from the District canal to the farm canal. At this location, there was about 0.5 ft drop in water surface elevation between the inlet and outlet of the 30-inch pipe that was about 60-ft long. Placing the propeller in the pipe could thus increase the total head loss by a large enough percentage to be noticed at the flume. For example, assuming that the propeller caused 0.05-ft of head loss added to 0.5 feet originally, means a 10% increase in head loss. This translates, assuming orifice-type flow, into a 5% decrease in discharge rate. Had the propeller meter been left in place for 30 minutes or longer, the flume would be expected to more nearly match its reading. In most installations the losses through the pipes are about 20 to 30 inches, so the addition of the propeller loss is negligible.

The broad-crested weirs installed on the Woodhouse and Naquin Farms continue to function as intended. Debris was shoveled out of both installations. About a cubic foot of material had gathered on the ramps. It took only 2 or 3 minutes to shovel it out. This should be done at least once a year. The material that gathered reached somewhat of a stable volume and thereafter additional material passed over the weir. There appears to be a possibility that slight lengthening of the ramp on about 4.5:1 slope instead of 3:1 might pass all but heavy stones.

Another flume was installed for pilot operation by the Salt River Project (SRP). It was placed in a 1.25:1 sideslope canal with a 2-foot bottom. It was designed to pass 75 cfs over a 1.5-ft high sill. Like the smaller versions, it was fitted with a direct-reading gage. Standard current metering techniques were used by SRP to check the computed calibration on five dates in September 1977. The data as reported are in Table 1. The flow rates are in Miners inches which, in Arizona, are 1/40th of a cubic-foot-per-second.

The broad-crested weir type was installed on the Cotton Research Station in back of the Water Conservation Laboratory. Eight locations for flumes were selected in order to adequately gage all deliveries to the Station. The eight flumes were installed in October 1977, at a cost of less than $100 each, including readout gages. The sill heights were either 9 inches high or 12 inches high. A manuscript covering these installations is in the review process of National Technical Editing Staff.

A rectangular-throated flume was also designed and installed on the University of Arizona Citrus Experiment Farm in Tempe. The throat was 1 foot wide and was designed to pass 2.5 cfs. The approach section also had to be constructed because the flume was placed in a rough plastered canal with sidewalls that were nearly vertical. The flume was designed using 0.25:1 sideslopes in the approach section to approximate the nearly vertical walls.

Another rectangular-throated flume 2 feet wide, with an 18-inch sill was designed for the Yuma Mesa Experiment Farm, Yuma, Arizona. It measures a flow of 6 cfs.

Two more broad-crested weir types with sills 1.25 feet high were installed in cooperation with the Bureau of Indian Affairs near Parker, Arizona.

Others of the smaller type were installed west of Phoenix by the Phoenix Field Office, SCS, in conjunction with the portable flume. In several cases, after the portable flume was used, permanent concrete sills were installed.

Standard drawings are being prepared by the SCS for the broad-crested weir (sill type for concrete construction), and for construction of the portable type.

The major problem encountered is a reluctance to place the sills in the canals because they appear to plug the canal. The trapezoidal type are more easily accepted without question, although, paradoxically, they require more drop in water surface than the sill-type in order to operate satisfactorily.

Departing from the irrigation applications, three flumes with triangular throats were designed and installed in cooperation with the Forest Service at Gainesville, Florida. They measure runoff from forestry watersheds. It provides an opportunity to also evaluate the flumes under non-desert applications. A manuscript is under preparation in cooperation with the Forest Service and the University of Florida describing the project and the role of flow measurement in it.

SUMMARY:

Several demonstration critical-flow flumes were designed for federal, state, and local governmental agencies. The majority of the new installations were of a broad-crested weir style. The mathematical model provided the flow ratings. Installations include 2 models for the Bureau of Indian Affairs, Parker, Arizona, 1 for the Salt River Project Irrigation District, 8 for the University of Arizona Cotton Research Center, 1 for the University of Arizona Citrus Farm (rectangular flume), 1 for the University of Arizona Yuma Mesa Experiment Farm (rectangular flume), and 3 for the Soil Conservation Service, Phoenix Field Office. The SCS State Engineer is preparing standard drawings and has requested computer ratings for a series of broad-crested weir sizes. This is in addition to the trapezoidal style presently in use by them.

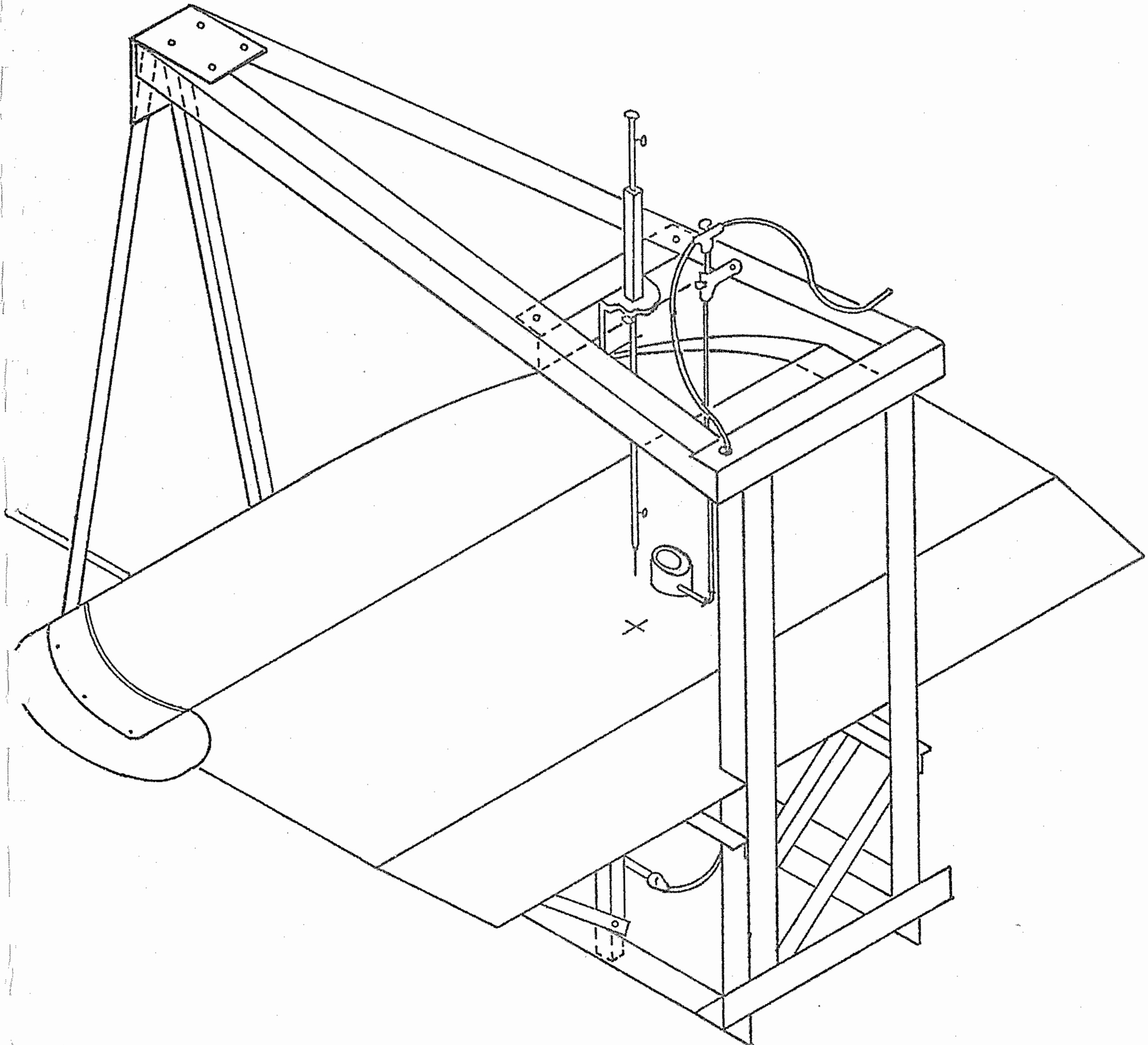
The Soil Conservation Service is cost-sharing the computer-calibrated, trapezoidal-style flumes for flow measurement in the Wellton-Mohawk Irrigation District near Yuma, Arizona. The flumes are being built by contractors for $250 per structure, installed. Sixty have been installed to date. Fiberglass Parshall flumes by contrast are several times this cost. The flumes were computer-designed using the mathematical model developed for complex critical-flow flumes.

A portable flume was developed to measure flow rates in standard concrete, slip-formed canals with 1-foot bottom widths and 1:1 side-slopes. The flume weighs less than 30 pounds and would fit in a 3-foot cube. The flume resembles a broad-crested weir with a sloping approach ramp. The device embodies the essential portions of a flow-measuring flume as determined by mathematical modeling and uses the existing concrete canal for the remainder of the structure. The typical point-gage-and-stilling-well-system is extensively modified and translocated so that it is mounted above the flume throat section. The reduced structure results in a portable device that is relatively insensitive to the usual problems of placement experienced for portable flumes, and is capable of field accuracy to within ± 2%.

PERSONNEL: J. A. Replogle

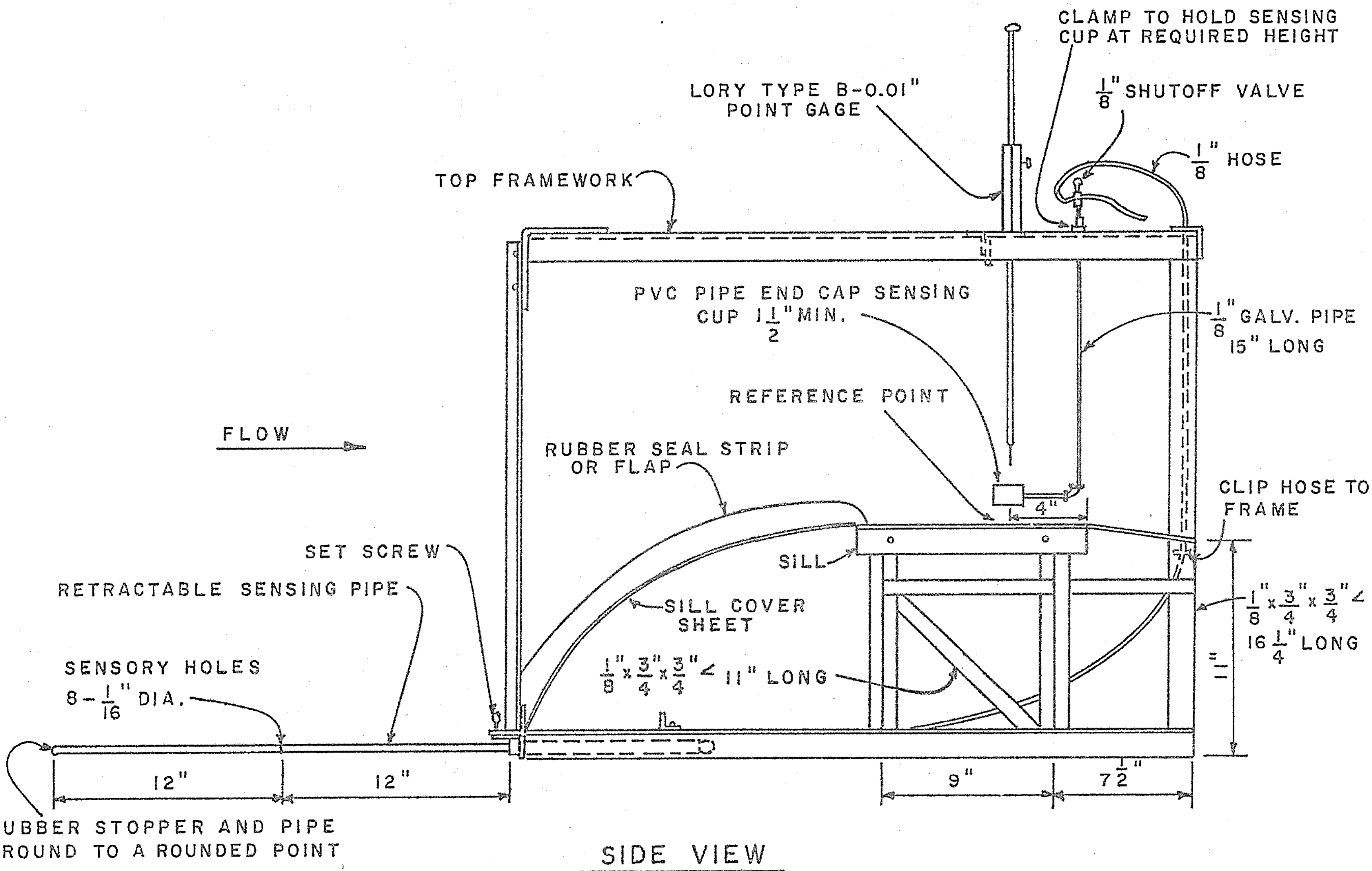
Table 1. Current meter gagings.

Date	Flume scale, Miners In.	Current meter, Miners In.	Difference, %
09-01	625	670	+7.2
09-02	1280	1265	-1.2
09-03	1650	1642	-0.5
09-08	1080	1080	0
09-12	380	374	-1.6



ISOMETRIC VIEW

Figure 1



SIDE VIEW

Figure 2

TITLE: DEPTH DETECTION IN CRITICAL DEPTH FLUMES

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

CODE NO.: Ariz.-WCL 72-3

INTRODUCTION:

Annual Report 1976 detailed some of the desirable features of a good depth-sensing device for flumes. These included reliability, precision, accuracy, low maintenance, ready interface with electronic equipment, and convenient operation and installation.

PROGRESS:

Several commercial developments in sensors are being watched for application. One, by a California consultant, would detect water level stepwise on a series of pins of different length submerged in the flow. Other methods using optical encoders have been casually studied. None have been built or evaluated.

The purge-bubble system at the Woodhouse farm was placed back into service. The air supply tube was encased in hard PVC plastic pipe to evaluate resistance to further rodent damage.

The sidewall gages have worked satisfactorily. The enameled gages purchased on special order by the Wellton Project Office, Soil Conservation Service, are preferable to the individually stamped types because they are very readable. However, the stamped types have proven to be serviceable, but must be brushed seasonally to remove deposits that obscure the markings.

PLANS:

A newly initiated study to develop an automatic flow controller requires flow depth sensing instruments. This will require more emphasis on solving the objectives of this project in order to accommodate the new project. Evaluation of several depth sensors in conjunction with the new project is anticipated.

SUMMARY:

The search for reliable and inexpensive depth-sensing equipment, for use with flumes, continued. No new systems were evaluated during the project year. Observations on ordinary direct-reading, wall-mounted staff gages and a purge-bubble system were continued.

The wall gages need to be wire-brushed periodically to maintain readability. The purge-bubble system worked satisfactorily after the initial installation was protected from rodent damage.

PERSONNEL: J. A. Replogle

TITLE: EVALUATING TRICKLE IRRIGATION FOR GRAPE PRODUCTION

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

CODE NO.: USWCL 73-1

INTRODUCTION:

The objectives and need for this research project appeared in the U. S. Water Conservation Laboratory 1973 annual report. The 1976 thinning technique on the grapes used by the cooperator was not successful and invalidated a realistic yield comparison between irrigation treatments. Therefore, field-scale production studies were continued on a cooperator's farm for this year to complete the 4-year study and to refine the effects of trickle irrigation amounts and extremes in irrigation frequencies.

PROCEDURES:

After harvesting the 1976 Perlette table grapes on June 10 and 14 by the grower, a total amount of 15 inches of water was applied on all trickle and furrow irrigation plots between growing seasons. The trickle plots were given irrigations of 1 inch per week between June 16 to October 1. The furrow plots were irrigated at 4.0 inches on June 16, July 14, and August 18, and 3.0 inches on September 22.

Trickle irrigation treatments for 1977 included: three irrigation quantities -- 1.50, 1.25, and 1.00 times the average consumptive use 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 1973-75 years: all 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. The changes made were the elimination of the two-furrow-per-vine plots and the conversion of the 0.75 times the estimated consumptive-use quantity to a 1.50 furrow treatment. 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 18 vines per plot.

The trickle irrigation system used was 1-gph, flushable Drip-Eze emitters, spaced 3.5 ft apart along the lateral line. All emitters, except for the new emitters installed to double the number of emitters per vine, were from the original 1973 system. Irrigation water from a tailwater-reuse pond was filtered through a pair of 100-micron equivalent sand filters and a 25-micron nylon bag filter. Sodium hypochlorite was injected continuously at 1 ppm before the filters, along with sulfuric acid to reduce the water pH to 7. Two years before, the system had been successfully reclaimed by treating with high concentrations of hypochlorite and acid [Nakayama et al. (2)]. Each of 12 irrigation units was equipped with a turbine-vane, household-type water meter for measuring water applications. Flow rates per irrigation unit were, periodically, checked using the volume reading of the meter over a specific time period at an operating pressure of 1 atm (15 psi).

New growth began about February 12, and canes were at least 8 inches long by March 8, 1977. Furrow and trickle irrigations were started on February 20 and 16, respectively. Water applications on the 1.00 furrow treatment plots included 5.0 inches on February 20, 5.0 inches on April 25, and 4.0 inches on May 25. Water applications on the 1.00 trickle treatment plots included an initial irrigation of 2.5 inches on February 16, followed by 8.2 inches between April 4 and June 13, in accordance with the two irrigation frequencies. The 1.50 and 1.25 trickle and furrow treatments were given ratios of these amounts described for the 1.00 treatments.

Leaf water potential was measured on the same treatments for the third consecutive year, using the Scholander pressure bomb or chamber. Procedures for leaf sampling were the same as in previous years, with samplings made only on six dates. Soil moisture, pan evaporation, and other weather data were again collected during the growing season.

Grape clusters were thinned and tipped on April 15, under the general supervision of the farm manager. Thinning was accomplished at the proper time by a crew of less than 10 workers and resulted in a uniform number of clusters remaining on the vines. About this time, the furrow plots began to show the lack of growth and yellowing of leaves. It was learned that the grower had mistakenly applied a herbicide with the common name of Krovar, which can be used on citrus but is not recommended for grapes, in October 1976. Very little or no damage was observed on the trickle-irrigated grapes; therefore, yield measurements were made only for the trickle irrigation treatments. Grapes were harvested on June 13 by six pickers, three supervisors, one weighman, and one berry sampler. Seven vines were harvested from each plot, and 100 to 200 berries were randomly selected from each plot, from which berry size and sugar content were determined.

RESULTS AND DISCUSSION:

Figure 1 shows that the 1977 measured consumptive use on the 1.00 furrow treatment was 11.2 inches. This seasonal use was somewhat lower than the 1973-75 consumptive-use curve used to schedule the 1977 irrigation treatments. The reduced consumptive-use rate occurred primarily during the last week and was caused by poor condition of the furrow-irrigated vines. Actual amounts of water made available for consumptive use for the trickle treatments is given in Table 1. The adjusted irrigation quantities essentially agreed with the planned amounts of 1.00, 1.25, and 1.50 times the consumptive use for the daily and weekly trickle method and will not be altered.

Performance of the trickle irrigation system in terms of average discharge rate was satisfactory (Table 3). After the 1974-75 slug treatment with high chemical concentrations of sodium hypochloride and sulfuric acid for the reclamation of the 12 trickle irrigation units, low concentrations of hypochloride and acid along with adequate filtration of water helped to maintain emitter flow rates at about 90% to 95% of design until the end of the experiment.

Table 3 presents mean daily values of leaf water potential for 6 days from April 21 to June 8 for selected irrigation treatments. The seasonal mean was -14.3 bars for the trickle method, with no significant difference in leaf water potential between irrigation quantities. These results are similar to prior years.

Full-season grape production for the 1977 trickle irrigation treatments is shown in Table 3. Yields were increased by 13% for weekly over daily trickle and decreased by 18% for the 1.50 compared to the 1.25 and 1.00 times consumptive-use rate with trickle irrigation. This yield reduction for the 1.50 quantity was undoubtedly caused by these plots being irrigated at 0.75 times consumptive use for 3 previous years. Little difference in berry size was noted for the three different 1977 irrigation quantities. The berry size averaged 0.95 lbs per 100 berries, which was considerably larger than the 1973-75 average size of 0.74 lbs per 100 berries. The mean 1977 sugar content was 16.8% compared to 16.6% in 1975, 17.5% in 1974, and 15.8% in 1973. Also, a significant increase in 1977 sugar content resulted from the 1.50 over the 1.00 and 1.25 trickle irrigation quantities.

SUMMARY:

Year 1977 was the final one of this 4-year investigation on trickle irrigation water management for table grapes. The treatments were changed to increase the number of replications from 4 to 8 and to refine further the effects of trickle irrigation amounts (1.50. 1.25, and 1.00 times the average consumptive-use rate) and extremes in trickle irrigation frequency (daily and 6-day intervals). A non-adaptable herbicide was mistakenly applied by the grower, causing plant damage on the furrow-irrigated plots. Very little damage was noted on the trickle-irrigated plots. Weekly trickle applications produced higher yields than daily applications. Yields were depressed when water was applied at 1.50 times consumptive use; however, this was for only 1 year and came from plots that had previously experienced applications of 0.75 times consumptive use. Injection of low levels of hypochlorite and acid into the water helped prevent recurrence of trickle emitter plugging that was experienced 2 years before.

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2. Nakayama, F. S., D. A. Bucks, and O. F. French. Reclaiming partially clogged trickle emitters. Trans., Amer. Soc. Agr. Eng. 20(2):278-280. March-April 1977.

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

Table 1. Available moisture and adjusted quantities for trickle irrigation of grapes, 1977.

	Irrigation quantity	Water applied	Rainfall	Total available moisture for consumptive use	Adjusted irrigation quantity
	consumptive-use ratio	inches	inches	inches	consumptive-use ratio*
	1.00	10.7	0.3	11.0	0.98
Daily	1.25	13.9	.3	14.2	1.27
	1.50	16.6	.3	16.9	1.51
	1.00	10.5	.3	10.8	0.96
Weekly	1.25	13.4	.3	13.7	1.23
	1.50	16.4	.3	16.7	1.50

*Based on the measured seasonal consumptive use of 11.2 inches for 1977.

Table 2. Emitter flow rates after reclamation, 1976-77.

Irrigation unit	Reclamation date*	System flow rate (gallons per hour)**						
		21 Jul 1976	15 Sep 1976	22 Oct 1976	15 Feb 1977	18 Feb 1977	5 May 1977	12 May 1977
T-1	Sep 1974	144	141	144	144	129	127	124
T-2	Feb 1975	119	122	124	123	117	127	121
T-3	Feb 1975	143	139	145	141	131	142	135
T-4	Feb 1975	129	138	143	141	134	142	139
T-5	Nov 1974	139	145	139	137	129	128	124
T-6	Feb 1975	113	119	127	129	125	121	120
T-7	Feb 1975	115	124	125	123	119	118	116
T-8	Feb 1975	134	136	138	138	137	123	122
T-9	Nov 1974	143	155	147	154	128	134	138
T-10	Feb 1975	147	130	131	126	124	124	128
T-11	Feb 1975	132	133	134	121	117	129	127
T-12	Feb 1975	134	134	135	135	124	124	116

*Chemical treatment was slug 100 ppm chlorine at pH 2 for reclamation, followed by continuous 1 ppm chlorine at pH 7 for maintenance.

**Design flow rate for each 144 emitter system, installed in January 1973, was 144 gph.

Table 3. Leaf water potential for trickle and furrow irrigation of grapes, 1977.

	Leaf water potential (negative bars)						
Irrigation treatment	21 Apr	5 May	19 May	27 May	3 Jun	8 Jun	mean
Trickle:							
Daily/2 emitters/ 1.25 cu	13.6	13.2	12.8	15.7	15.8	15.5	14.4
Daily/2 emitters/ 0.75 cu	12.5	13.5	13.4	14.2	15.3	16.1	14.2
Mean	13.1	13.4	13.1	14.9	15.5	15.8	14.3
Furrow:							
3 furrows/vine 1.25 cu	12.2	9.5	10.5	*	*	*	10.7

*Visual herbicide damage to grape vines.

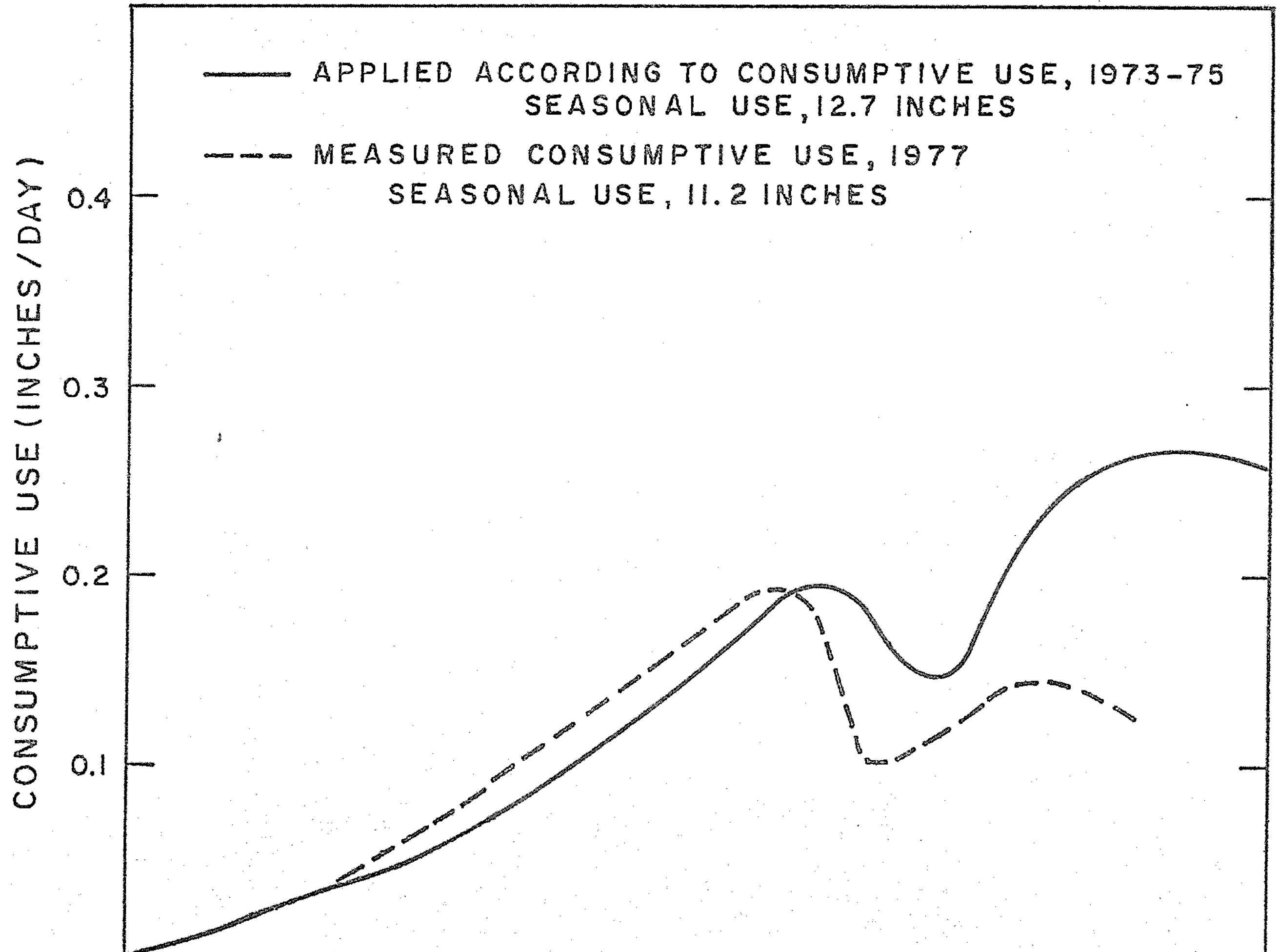
Table 4. Grape production and quality for trickle irrigation of grapes, 1977.

Irrigation frequency	Irrigation quantity consumptive-use ratio 1.00	1.25	1.50	Mean
	Grape production (pounds per plot)			
Daily	94.47*	101.13	78.31	91.30 a**
Weekly	103.75	115.47	90.34	103.19 b
Mean	99.11 a	108.30 a	84.33 b	
	Berry size (pounds per 100 berries)			
Daily	1.00	0.94	0.91	0.94 N.S.
Weekly	0.97	0.93	0.94	0.95
Mean	0.98	0.94	0.92	
	Sugar content (percent sugar)			
Daily	16.9	15.8	17.6	16.7 N.S.
Weekly	16.5	16.2	17.9	16.9
Mean	16.7 a	16.0 a	17.7 b	

*Mean, 8 replications, 7 vines harvested per plot.

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

N.S. No significant difference.



APPLIED	.13	.70	1.00	1.73	2.69	2.42	4.00	3.96
MEASURED	.12	.64	1.37	2.18	2.90	1.76	2.21	
	MARCH		APRIL		MAY		JUNE	

Figure 1. Applied and measured consumptive use for grapes, 1977.

TITLE: EVALUATING TRICKLE IRRIGATION FOR CANTALOUPE PRODUCTION

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

CODE NO.: USWCL 73-3

INTRODUCTION:

The cantaloupe study was moved to the Mesa Experiment Farm, Mesa, Arizona, in 1977 because of an uncontrollable disease problem encountered with the 1976 cantaloupe study conducted near Yuma, Arizona. The objectives of this new experiment are: (1) to develop water management practices for surface and subsurface trickle irrigation of spring and fall 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, reusing the same trickle irrigation system for two or more vegetable jrops.

Conventional furrow irrigation is normally discontinued just before harvest begins, to allow equipment and workers to enter the field and to reduce fruit rot. With such a commercial practice, harvesting normally lasts about 2 to 3 weeks and approximately one cantaloupe is picked from each vine. Since each vine bears several cantaloupes, additional marketable fruits could be produced if plant growth were extended over a longer harvest season. By continuing to trickle irrigate throughout harvest, harvest length and, consequently, yield may be increased. Another possible advantage of trickle irrigating a narrow surface strip is that more than one crop may be produced on the same vegetable bed. Multiple cropping would extend the useful economic life of a trickle system over a larger production base.

FIELD PROCEDURES:

Spring. Spring cantaloupe treatments included two methods of surface and subsurface (6 inches deep) trickle, two irrigation frequencies (daily and weekly), and three irrigation quantities (1.25, 1.00, and 0.75 times the consumptive-use rate). These 12 treatments were replicated five times in a split-plot design, with each plot being two beds wide and 70 feet long. The trickle irrigation system used was Spot Systems' Monotube, a single chamber polybutylene tubing having a 12-inch orifice spacing. Adjacent to the trickle irrigation study was a furrow-irrigated border, 6 beds wide and 280 ft long. The furrow irrigation was used as a standard to check yield, fruit quality, and consumptive use.

Cantaloupe seed, Top Mark, was planted on April 12 on the east slope of north-south oriented beds for both trickle and furrow methods. First, a rounded (5-ft wide) bed was made with a cantaloupe sled, after the field was smoothed and furrowed out. Second, the subsurface trickle tubing was buried 6 inches deep and 1 to 2 inches away from the proposed seed row, using a chisel blade and tubing reel mounted on a tractor tool bar. Third, a planter junior was attached to the cantaloupe sled to plant trickle and furrow plots with the seed row located 10 inches from the bottom of the furrow diagonally up the slope of the bed. Fourth, the surface trickle tubing was placed 1 to 2 inches from the seed row. Lastly, 2 and 6.8 inches of water were applied, respectively, to trickle and furrow plots for germination.

Plants emerged on April 18 and were thinned to a 12-inch spacing on May 11. At this time, 1 and 2.5 inches of water were applied, respectively, to trickle and furrow treatments. The different trickle irrigation quantities and frequencies commenced on May 12 and continued to the end of harvest. Trickle applications were calculated by multiplying 1.25, 1.00, and 0.75 times an estimated consumptive-use rate for a daily or weekly frequency, based on the entire surface area between plants. This rate was taken from a 4-year mean consumptive-use curve measured for cantaloupes at the Mesa Experiment Farm [Erie et al. (1)]. Furrow applications were also based on this curve, and after thinning were 3.6 inches on May 31, 4.1 inches on June 13, and 4.0 inches on June 25. Soil-moisture samples were taken on this furrow border to develop a 1977 consumptive-use curve.

Water applications for the trickle treatments were measured with a turbine-vane, household-type water meter, after the water was filtered through a sand (#20 silica) filter and 200-mesh (75 micron) screen filter. Furrow water applications were measured with an impeller-type water meter.

Fertilizer applications included 150 lbs/acre of ammonium phosphate (16-20-0), sidedressed over the field before planting; 85 lbs/acre of urea (46-0-0) at thinning on May 12, and 85 lbs/acre of urea (46-0-0) at early runners for both methods. After the preplant application, fertilizer applications for the trickle were through the system itself, whereas fertilizer applications for the furrow were banded about 2 inches away from the plant row. The total fertilizer applied was 102 lbs of actual N per acre and 30 lbs per acre of P_2O_5. Petiole samples were taken for nitrate nitrogen analysis on May 27, June 3, June 17, July 1, and July 8 for the duration from early runners to preharvest.

Cantaloupe harvest from 60 ft of the west row for the 60 trickle plots and 6 furrow plots began on July 8 and lasted until July 29 (21 days). Melons were harvested three times per week, sized, counted, and graded as marketable or culls. Four sizes were packed: 23, 27, 36, or 45 jumbo melons per crate and were referred to by their same numbers. The smaller the number, the larger the melons, with the 36's generally the most desirable. All melons smaller than 45, rotten, soft, ground spot, or split were considered the culled or discarded melons. Fruit quality in terms of sugar percentage, general appearance, netting, outside color, flesh color, flesh firmness, cavity dryness, cavity length, and cavity width were also determined.

Fall. Fall cantaloupe treatments included two subsurface trickle methods (5 and 10 inches deep), two irrigation frequencies (daily and weekly), and three irrigation quantities (1.25, 1.00, and 0.75 times the consumptive-use rate). The trickle irrigation system, cantaloupe variety, water filtration, water measurement, thinning, and harvesting procedures were the same for the fall as the spring cantaloupes. A furrow-irrigated border was again used as a standard to check yield, fruit quality, and consumptive use.

After the harvesting of spring cantaloupes, old surface trickle lines were removed, whereas subsurface trickle lines remained in place; old vines were removed, using an onion knife that was mounted to a tractor tool bar to cut off vine tops from roots and hand raking tops into the furrows; and a 1- to 2-inch seed bed was then prepared, using a rotary Lilisten mulcher. The newly prepared cantaloupe beds were about 1-inch shallower than in the spring, leaving the subsurface trickle tubing 5 inches deep. A new subsurface trickle tubing was also buried at a depth of 10 inches, to replace the surface trickle system previously used.

The fall cantaloupes were planted on August 3, less than a week from final harvesting of spring cantaloupes. For germination, 3.75 inches of water was applied to all subsurface trickle plots in order to achieve at least a 4-inch-wide wetted surface strip, and 6.75 inches was applied to the furrow plots. Plants had emerged in 5 days. On August 22, they were thinned, and 1 inch of water was applied on subsurface trickle plots, with 3.3 inches applied on subsurface furrow plots. Subsurface furrow irrigations were applied at 4 inches on September 6, September 23, and October 23. The different trickle quantities (1.25, 1.00, and 0.75 times the estimated consumptive-use rate) and frequencies (daily and weely) began on August 31 and continued to the end of harvest. Fertilizer applications included 150 lbs/acre of ammonium phosphate (16-20-0) banded 2 inches deep near the seed row before planting, 85 lbs/acre of urea (46-0-0) on August 22 (thinning), and 85 lbs/acre of urea on September 6 for both trickle and furrow plots. Cantaloupe harvesting began on October 25 and ended on November 14, lasting 21 days.

RESULTS AND DISCUSSION:

Spring: The 1977 measured consumptive use was 21.4 inches for spring, furrow-irrigated cantaloupes. This was similar to the 4-year seasonal average of 21.2 inches (Figure 1). A high water application efficiency was obtained on the single furrow treatment, since the total water applied for the season was 21.0 inches. For the trickle treatments, the actual amounts of water made available for consumptive use, as calculated from the water applied plus rainfall, are shown in Table 1. The adjusted trickle irrigation quantities were 1.22, 1.07, and 0.84 times the 1977 measured consumptive use for the daily frequency and 1.20, 1.00, and 0.76 ratios for the weekly frequency.

Yields for spring cantaloupes are summarized in Table 2. Weekly surface and subsurface trickle compared to daily surface and subsurface trickle resulted in a 7% increase in the marketable crates per acre, a 9% increase in the number of melons larger than a size 36, and a 11% increase in the total number of marketable fruit harvested (all significant at the 1% level). A slight increase in production was noted with the subsurface over the surface trickle; however, yield differences between the two trickle methods were not statistically significant. Similarly, no statistical yield differences were found between the different trickle irrigation quantities within each irrigation frequency. A lack of plant-water stress during early growth may have been the reason, although visual plant growth was less for the drier compared to wetter treatments by preharvest. The percentages of culled or discarded melons were not changed by the different trickle treatments.

As a strictly observational check on trickle irrigation productions, marketable yields were slightly improved with the weekly trickle over the furrow treatment, while yields for the daily trickle were comparable to the furrow practice. Overall, more than 500 crates per acre was produced for both trickle and furrow methods. Current commercial yield ranges from 150 to 250 crates per acre in Arizona, with about 180 crates per acre required for a successful crop [Pew et al. (2)].

Table 3 shows that the increased production for weekly over daily trickle irrigations was generally represented by increased numbers of fruit, regardless of whether the size was a 23, 27, 36, or 45. Fruit quality in terms of sugar content, general appearance, netting, outside color, flesh color, flesh firmness, cavity dryness, cavity length, and cavity width for the first and second week of harvest is shown in Tables 4 and 5. Trickle irrigation treatments had little effect on fruit quality within each week and between weeks.

Nitrate nitrogen analysis of cantaloupe petioles for the various trickle treatments have not been completed.

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

Fall. The seasonal consumptive use, measured on the furrow treatment, was 15.1 inches for fall cantaloupes (Figure 2). The calculated consumptive use curve, used to determine water applications, overestimated the water-use rate particularly for late season growth. This resulted in adjusted irrigation quantities of 1.50, 1.17, and 1.10 times the 1977 measured consumptive use for the daily frequency, and 1.74, 1.38, and 1.13 ratios for the weekly frequency. The driest treatment, therefore, was closest to the predicted optimum water application.

Fall cantaloupe yields are listed in Table 6. Weekly subsurface (both 5 and 10 inches deep) compared to daily sursurface trickle increased marketable crates per acre by 24%, increased fruit number larger than size 36 by 24%, and increased total marketable fruit numbers by 15% (all significant at the 1% level). The reason for the greater percentage increase for marketable crates and larger fruit than total marketable fruit was due to a greater cull percentage for the daily over weekly trickle, although the total number of culls between trickle treatments showed little difference (Table 7). No significant difference in yields was observed for the three trickle quantities on the 5 and 10 inches depths for the subsurface trickle. Implications are that the most efficient quantity of water applied by the trickle method was near the seasonal fall consumptive use of about 15 inches.

Checking yields with the standard irrigation method, the daily and weekly subsurface trickle produced more marketable fruit than the single furrow treatment (Table 7). Some of this increase can be attributed to a larger number of green fruit remaining at the end of harvest; however, maturing this fruit would not have made up the difference between the two methods. This was not a statistical comparison, and an improved scheduling of furrow irrigations could have eliminated the differences. Harvesting on the furrow plots was 2 to 3 days later than on the trickle plots, because of slower plant growth early in the fall. Total production was lower in the fall than the spring, as expected; however, marketable yields were certainly respectable for both methods [Pew et al. (2)].

Table 7 indicates that the increased yield for weekly over daily trickle was due to a greater number of melons and independent of the fruit size. There was little difference in the numbers of discarded or green fruit between trickle treatments; however, an increase in number of culls (mostly small) and 45's was due to a powdery mildew disease problem affecting the last week of fall production.

No difficulty from roots' clogging the subsurface tubing was noted after the fall harvest; however, orifice enlargement and splitting of the tubing prohibited reuse of the same system for a third vegetable crop in a row. Using a new subsurface trickle system, a second year study is being planned in 1978 for spring and fall cantaloupes, followed possibly by a winter crop of onions, or other vegetables.

SUMMARY:

Surface and subsurface trickle irrigation of spring and fall cantaloupes was investigated to develop advanced water management practices for a larger fruit set, greater plant vigor, improved fruit quality, and increased yields. Results of the 1-year field evaluation showed that weekly surface and subsurface trickle applications increased yields over daily trickle applications. Little difference in yield resulted between surface and 6-inch subsurface trickle in the spring and 5-inch and 10-inch subsurface trickle in the fall. Weekly trickle in the spring and daily and weekly trickle in the fall produced slightly more marketable fruit than the single, unreplicated furrow check. Trickle applications at near the seasonal consumptive use of 21 inches of water in the spring and 15 inches in the fall were sufficient for maximum production. There was little difference in sugar content, size, and fruit appearance in any of the treatments. Subsurface trickle was found to offer several practical advantages over surface trickle systems by causing minimal interference with field operations. No root clogging of subsurface trickle was noted; however, orifice enlargement and tube splitting precluded reuse of the same system for a third crop.

REFERENCES:

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

Table 1. Available moisture and adjusted quantities for trickle irrigation of spring and fall cantaloupes, 1977.

Irrigation treatment		Water applied	Rainfall	Total available moisture for consumptive use	Adjusted irrigation quantity
Frequency (days)	Quantity (consumptive-use ratio)	(inches)	(inches)	(inches)	(consumptive-use ratio)
Spring cantaloupes					
Daily	1.25	25.6	0.6	26.2	1.22*
	1.00	21.4	0.6	23.0	1.07
	0.75	17.3	0.6	17.9	0.84
Weekly	1.25	25.0	0.6	25.6	1.20
	1.00	20.7	0.6	21.3	1.00
	0.75	15.7	0.6	16.3	0.76
Fall cantaloupes					
Daily	1.25	21.1	1.6	22.7	1.50**
	1.00	17.1	1.6	17.7	1.17
	0.75	15.0	1.6	16.6	1.10
Weekly	1.25	24.7	1.6	26.3	1.74
	1.00	19.2	1.6	20.8	1.38
	0.75	15.4	1.6	17.0	1.13

*Based on the measured seasonal consumptive use of 21.4 inches for 1977 spring cantaloupes.

**Based on the measured seasonal consumptive use of 15.1 inches for 1977 fall cantaloupes.

Table 2. Summary of spring cantaloupe yields (mean of 5 replications), 1977.

Irrigation Treatment			Marketable crates per acre	No. fruit per plot 36 and larger	Total no. fruit per plot harvested	Percent culls
Method	Frequency	Quantity				
Surface trickle	Daily	1.22*	508.1	88.7	113.4	12.1 N.S.
		1.07	504.2	85.4	121.6	13.2
		0.84	503.0	83.1	117.9	13.9
		mean	505.1 a**	85.7 a**	117.6 a**	13.1
	Weekly	1.20	547.4	91.0	131.1	10.4
		1.00	538.5	93.6	130.6	11.5
		0.76	534.9	96.6	127.1	11.4
		mean	540.3 b	93.7 b	129.6 b	11.4
Subsurface trickle (6 inches deep)	Daily	1.22	525.3	90.2	117.6	11.7
		1.07	527.7	89.3	124.8	11.9
		0.84	502.9	77.0	116.8	13.7
		mean	518.6 a	85.5 a	119.7 a	12.4
	Weekly	1.20	554.8	93.9	134.4	12.7
		1.00	541.9	92.1	130.5	12.3
		0.76	556.9	95.1	134.2	15.2
		mean	551.2 b	93.7 b	133.0 b	13.4
Furrow	Variable	1.00	515.1	87.3	122.7	11.2

*Ratio of seasonal consumptive use of 21.4 inches measured on furrow irrigation plots.

**Significant difference.

N.S. No significant difference.

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

Table 3. Grading of spring cantaloupes (mean of 5 replications), 1977.

Irrigation Treatment			Average no. of melons per plot					
Method	Frequency	Quantity	23's	27's	36's	45's	Culls	Green Fruit
Surface trickle	Daily	1.22*	32.9	29.7	26.1	10.9	13.8	7.4
		1.07	22.6	32.0	30.8	20.2	16.0	5.6
		0.84	26.6	32.0	24.5	15.0	15.9	4.8
		mean	27.4	31.2	27.1	15.4	16.5	5.9
	Weekly	1.20	20.0	36.5	34.5	26.5	13.6	4.6
		1.00	18.6	36.0	39.0	21.6	15.4	6.4
		0.76	29.0	35.4	32.2	16.0	14.5	6.6
		mean	22.5	36.0	35.2	21.4	14.5	5.9
Subsurface trickle (6 inches deep)	Daily	1.22	29.6	37.2	23.4	13.6	13.8	7.0
		1.07	22.3	36.9	30.1	20.7	14.8	5.2
		0.84	20.9	31.6	24.5	23.6	16.2	4.0
		mean	24.3	35.2	26.0	19.3	15.4	5.4
	Weekly	1.20	23.0	35.7	35.2	23.5	17.0	5.2
		1.00	27.5	35.6	29.0	22.4	16.0	3.4
		0.76	27.2	37.9	30.0	18.7	20.4	5.2
		mean	25.9	36.4	31.4	21.5	17.8	4.6
Furrow	Variable	1.00	20.3	35.8	31.2	21.7	13.7	1.8

*Ratio of seasonal consumptive use of 21.4 inches measured on furrow irrigation plots.

Table 4. First week quality of spring cantaloupes (3 picking dates, mean of 60 fruit), 1977.

Irrigation Treatment											
Method	Frequency	Quantity	Percent sugar[1/]	General appearance[2/]	Netting[2/]	Outside color[2/]	Flesh color[2/]	Flesh firmness[2/]	Cavity dryness[2/]	Cavity length[3/]	Cavity width[3/]
										(cm)	(cm)
Surface trickle	Daily	1.22*	10.0	6.5	6.9	6.9	6.8	7.1	6.4	9.0	5.6
		1.07	10.2	6.8	7.0	6.9	6.9	7.0	6.4	9.0	5.3
		0.84	11.4	6.7	7.0	7.1	7.0	7.3	6.6	9.4	5.6
		mean	10.5	6.7	7.0	7.0	6.9	7.1	6.5	9.1	5.5
	Weekly	1.20	10.5	7.4	7.2	7.2	7.0	7.5	7.1	8.8	5.4
		1.00	11.2	7.4	7.1	6.9	6.9	7.3	6.9	9.1	5.6
		0.76	11.4	6.5	7.0	7.0	6.9	7.2	6.7	9.2	5.6
		mean	11.0	7.1	7.1	7.0	6.9	7.3	6.9	9.0	5.5
Subsurface trickle (6 inches deep)	Daily	1.22	10.5	6.6	7.1	7.0	6.9	7.2	6.6	9.3	5.7
		1.07	10.3	6.6	7.0	7.0	6.9	6.8	6.3	9.2	5.3
		0.84	10.9	6.9	7.1	7.0	6.9	7.4	6.8	9.3	5.4
		mean	10.6	6.7	7.1	7.0	6.9	7.1	6.6	9.3	5.5
	Weekly	1.20	10.7	6.8	6.9	6.9	6.7	7.3	6.7	9.1	5.5
		1.00	10.8	6.8	7.2	7.1	7.0	7.4	6.8	9.1	5.4
		0.76	10.6	6.9	7.0	6.9	6.8	7.2	6.6	9.2	5.4
		mean	10.7	6.8	7.0	7.0	6.8	7.3	6.7	9.1	5.4
Furrow	Variable	1.00	10.6	6.6	6.7	6.8	6.8	7.3	6.9	9.2	5.5

* Ratio of seasonal consumptive use of 21.4 inches measured on furrow irrigation plots.

1/ Measured by a handheld sugar refractometer.

2/ Visual evaluation, rated on a 1 through 9 scale, with 9 the most desirable.

3/ Measured by a handheld ruler.

Table 5. Second week quality of spring cantaloupes (2 picking dates, mean of 40 fruit), 1977.

Irrigation Treatment											
Method	Frequency	Quantity	Percent[1/] sugar	General[2/] appearance	Netting[2/]	Outside[2/] color	Flesh[2/] color	Flesh[2/] firmness	Cavity[2/] dryness	Cavity[3/] length (cm)	Cavity[3/] width (cm)
Surface trickle	Daily	1.22*	11.0	6.2	6.7	6.8	6.8	7.1	6.3	9.4	6.0
		1.07	10.9	6.1	6.5	6.7	6.7	6.7	6.0	9.2	5.8
		0.84	11.0	6.0	6.5	6.6	6.7	6.7	6.2	9.0	5.9
		mean	11.0	6.1	6.6	6.7	6.7	6.8	6.2	9.2	5.9
	Weekly	1.20	10.3	6.2	6.5	6.7	6.6	7.2	6.1	8.8	5.7
		1.00	10.7	6.2	6.5	6.6	6.6	7.0	6.2	8.6	5.7
		0.76	10.7	6.0	6.3	6.5	6.4	6.8	6.2	8.5	5.8
		mean	10.6	6.1	6.4	6.6	6.5	7.0	6.2	8.6	5.7
Subsurface trickle	Daily	1.22	10.5	6.2	6.7	6.9	6.6	6.9	6.1	9.1	5.8
		1.07	10.4	6.0	6.6	6.8	6.7	6.7	5.8	9.3	5.8
		0.84	10.4	5.8	6.2	6.4	6.3	6.5	5.9	8.7	5.6
		mean	10.4	6.0	6.5	6.7	6.5	6.7	5.9	9.0	5.7
	Weekly	1.20	10.5	6.1	6.5	6.5	6.6	7.0	6.0	9.1	5.8
		1.00	10.7	6.2	6.3	6.4	6.5	6.8	5.8	8.8	5.7
		0.76	10.8	6.1	6.5	6.4	6.5	6.8	6.0	9.0	5.6
		mean	10.7	6.1	6.4	6.4	6.5	6.9	5.9	9.0	5.7
Furrow	Variable	1.00	10.6	6.0	6.3	6.4	6.6	6.8	6.0	8.6	5.6

* Ratio of seasonal consumptive use of 21.4 inches measured on furrow irrigation plots.

1/ Measured by a handheld sugar refractometer.

2/ Visual ecaluation, rated on a 1 through 9 scale, with 9 the most desirable.

3/ Measured by a handheld ruler.

Table 6. Summary of fall cantaloupe yields (mean of 5 replications), 1977.

Irrigation Treatment			Marketable crates per acre	No. fruit per plot 36 and larger	Total no. fruit per plot harvested	Percent culls
Method	Frequency	Quantity				
Subsurface trickle (5 inches deep)	Daily	1.50	217.4	30.9	78.9	39.3
		1.17	178.0	25.6	62.2	32.2
		1.10	201.6	29.5	74.3	39.2
		mean	199.0 a	28.7 ab	71.8 ab	36.9 ab
	Weekly	1.74	224.5	26.2	75.2	36.2
		1.38	246.1	36.7	82.4	32.7
		1.13	227.6	30.9	79.8	35.6
		mean	232.7 b	31.3 b	79.1 b	34.8 ab
Subsurface trickle (10 inches deep)	Daily	1.50	171.5	21.9	62.4	38.2
		1.17	183.3	25.6	73.0	42.2
		1.10	216.5	30.4	73.3	33.7
		mean	190.4 a	26.0 a	69.6 a	38.0 b
	Weekly	1.74	211.8	28.7	80.4	39.7
		1.38	249.3	37.9	78.4	30.0
		1.13	288.0	42.3	91.3	29.9
		mean	249.7 b	36.3 c	83.4 b	33.2 a
Furrow	Variable	1.00	156.7	21.6	56.3	31.1

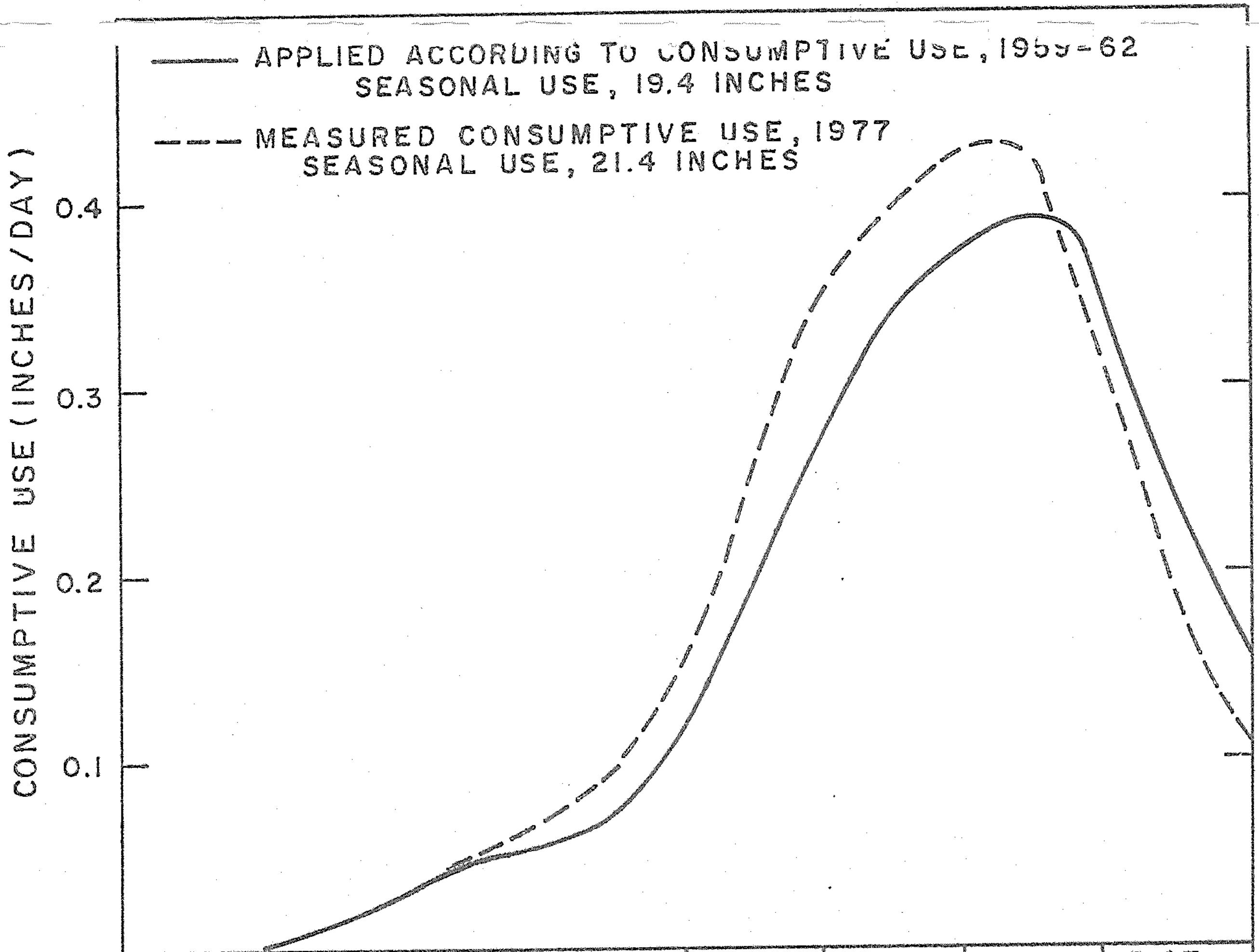
*Ratio of seasonal consumptive use of 15.1 inches measured on furrow irrigation plots.

**Significant difference.

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

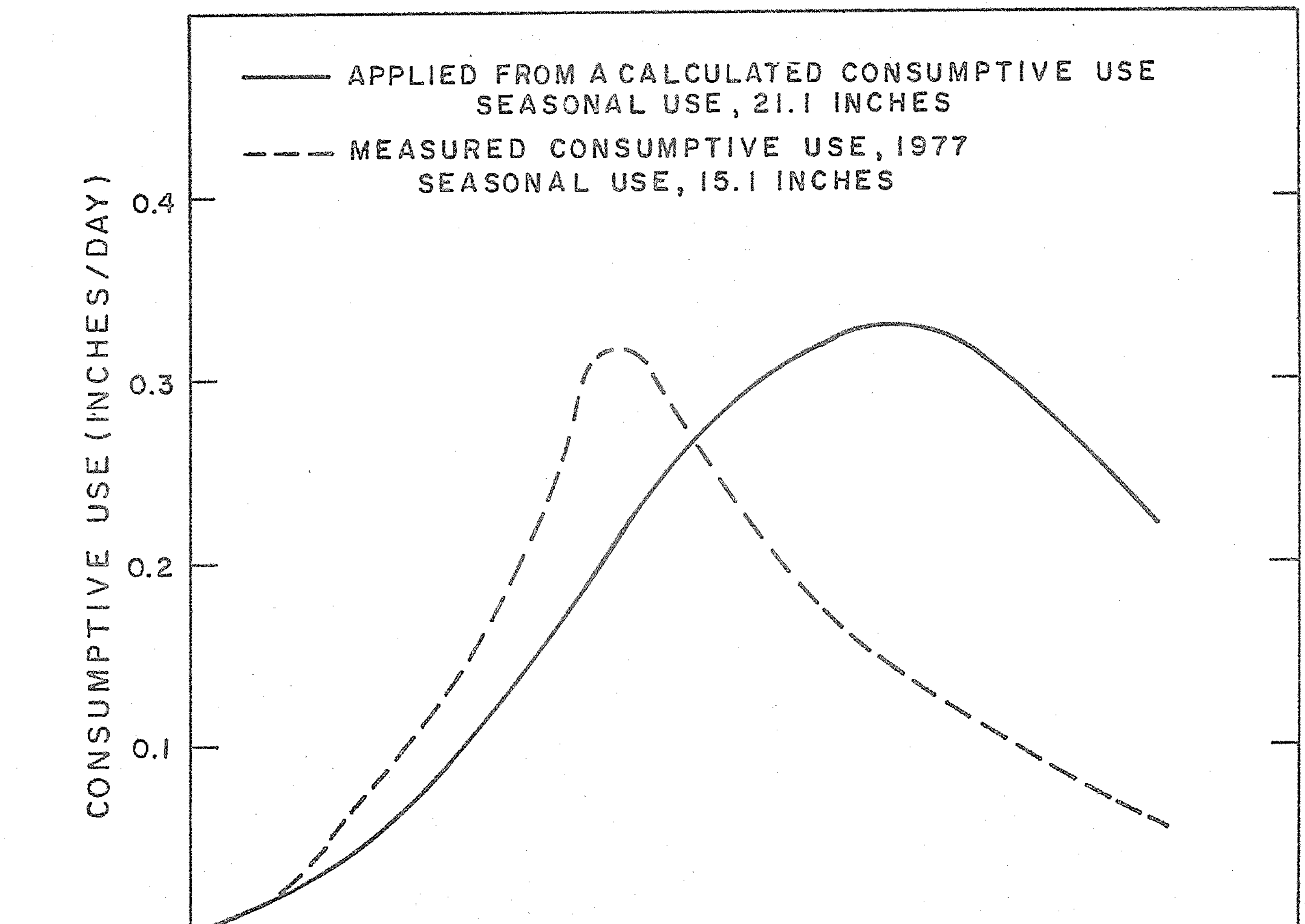
Table 7. Grading of fall cantaloupes (mean of 5 replications), 1977.

Irrigation Treatment			Average no. of melons per plot					
Method	Frequency	Quantity	23's	27's	36's	45's	Culls	Green Fruit
Subsurface trickle (5 inches deep)	Daily	1.50	14.2	4.4	12.4	16.9	31.0	10.5
		1.17	7.6	4.2	13.8	16.6	20.0	8.0
		1.10	13.1	1.6	14.7	15.7	29.1	9.2
		mean	11.6	3.4	13.6	16.4	26.6	9.2
	Weekly	1.74	9.7	4.8	11.7	21.7	27.2	7.4
		1.38	12.2	6.6	17.9	18.8	26.9	6.5
		1.13	13.0	5.4	12.4	20.5	28.4	6.6
		mean	11.6	5.6	14.0	20.2	27.5	6.8
Subsurface trickle (10 inches deep)	Daily	1.50	10.6	3.9	7.4	16.7	23.8	8.1
		1.17	9.6	3.4	12.6	16.6	30.8	7.2
		1.10	11.8	6.1	12.5	18.2	24.7	12.8
		mean	10.7	4.5	10.8	17.2	26.4	9.3
	Weekly	1.74	10.6	5.9	12.2	19.8	31.9	8.2
		1.38	14.0	7.3	16.6	17.0	23.9	8.5
		1.13	16.4	7.4	18.5	21.7	27.3	4.6
		mean	13.7	6.9	15.8	19.5	27.6	7.1
Furrow	Variable	1.00	2.8	6.0	12.8	17.3	17.5	15.5



APPLIED		.17	.70	1.05	2.90	5.08	5.84	3.67
MEASURED		.18	.71	1.49	3.90	5.96	6.24	2.93
	APRIL		MAY		JUNE		JULY	

Figure 1. Applied and measured consumptive-use curve, spring cantaloupe, 1977.



	AUGUST		SEPTEMBER		OCTOBER		NOVEMBER	
APPLIED	.20	.99	2.28	3.86	4.71	5.18	3.87	
MEASURED	.15	1.49	3.30	4.23	2.73	2.03	1.17	

Figure 2. Applied and measured consumptive-use curve, fall cantaloupe, 1977.

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:

Because of water and labor shortages and the poor quality and increasing cost of labor, farm owners have requested assistance in developing automated irrigation systems.

For further introduction, see 1973 Annual Report.

OBJECTIVES:

To design, install, observe and assist in managing demonstration automated gravity irrigation systems.

PROCEDURE:

In 1970, 10 acres of citrus near Mesa, Arizona, was automated from an underground conveyance system. In 1971, an underground conveyance system was automated at the Bruce Church Ranch near Parker, Arizona. In 1973, a 40-acre dead-level field was automated from a concrete surface conveyance system, on the Dana Fisher Ranch near Blythe, California. These systems involved mainly the use of rubber pillows installed on either concrete risers or tile outlets, energized pneumatically by a compressor and controlled by time clocks.

In 1977, a new outside-collar-frame to hold the pillow and adjusting tee-screw was designed and 32 of them built for the 10-acre citrus farm. Two of them were installed for observation and trial preparatory to remodeling the 7-year-old system. These frames were designed to reduce the plugging hazard common to this type of underground system. These new frames seemed to have alleviated the problem on this citrus farm. In the fall of 1977, this farm, owned by the University of Arizona (Hall Grove) was sold and our automation has been removed. During the last 7 years this system was always used to irrigate the citrus. Rubber components including the polyethylene 5/16-inch tubing, which had never been buried or protected from weather, was in excellent shape. Any components on this system that were not rust-proof would have been difficult to repair or work with. The crude hand-made-plastic control valves worked without failure or maintenance during the 7-year period.

The original 40-acre system near Blythe was converted from a simple compressor clock system to a portable control system, to make it compatible with other automated acreages on this farm. The new control system has not been completely successful and the farmer has taken over our original system on which maintenance and other changes should be made.

SUMMARY:

A study on automation of the first pneumatically-controlled underground distribution system, in cooperation with the University of Arizona and the USDA, SEA Soil and Water Office in Fort Collins, Colorado, was completed. This system utilized rubber pillows in conjunction with alfalfa valves and has operated successfully in irrigating an orange grove near Mesa, Arizona, since 1970. The 5/16-inch polyethylene tubing, air compressor, control regulator, and clock idea still represent the basic approach to present-day automation. Equipment longevity for 7 years was demonstrated on all items that were rust proof.

PERSONNEL: Leonard J. Erie, Howard Haise, 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 a 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 lift-gate operated surface distribution system, and then a concrete port outlet system in combination with lift-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.

At the request of the Soil Conservation Service, we designed and installed the first cost-shared automated irrigation system as part of the on-farm irrigation improvement program administered by the Soil Conservation Service and the Wellton-Mohawk Irrigation and Drainage District. The system is on the Ron McDonnell-Bob McElhaney farm near Wellton, Arizona. Twenty-five lift-gates were automated which service 23 fields averaging about 2.6 acres each. The system was installed in May 1977, and has been used to irrigate some 25 times.

RESULTS AND DISCUSSION:

Woodhouse Automation--Lift-gates

The automated lift-gates have been used 33 times since May 1975--15 irrigations during 1977. Two irrigations during 1977 were completed manually while repairs were being made to the system. The eight level basins were seeded to alfalfa during the fall of 1976. Prior to the planting, the basins had been laser leveled. The Woodhouses used the automatic start-up for all automatically-controlled irrigations during 1977. A few system problems occurred during the year that have been evaluated and corrected.

Cylinder rods became extremely dry after one year's operation (commercially-purchased cylinders were installed in August 1976). The dry cylinder rods caused three U-cup rod seals to seize the rod during operation and to be displaced from the cylinder end cap. This caused an air loss and in certain instances losses so excessive that other gates could not operate. Seals were displaced twice for cylinder 3 (cylinder controlling the gate into basin 3) and once for cylinder 2. A new seal was placed in cylinder 3 without cylinder disassembly or lubrication and became displaced during the next irrigation. Upon installing new seals a second time the cylinders were lubricated with a special cylinder lubricant. An oil can was used to squirt oil into both the top and bottom cylinder ports. The lubricating was done in September. We have not had further problems. Introduction of the lubricant into the cylinder may not be necessary if occasional wiping of the piston rod with lubricant proves to be satisfactory. This approach will be evaluated during 1978.

Three extra 1/4-inch polyethylene tubes were included as part of the original installation during 1975. Two extras went to gates 1 through 4 and the check gate, and one to gates 5 through 8. Four air lines have developed leaks, the first in July 1975, only two months after the initial startup, and three others during 1977. The gates affected and changes made were:

Gate	Date	Change
Signal line, 3	JUL 1975	Replaced with one of two extra tubes; worked satisfactorily.
Signal line, 2	29 AUG 1977	Replaced with second of two extra tubes; slight air leak but not enough to prevent operation.
Signal line, 5	5 OCT 1977	Replaced with extra tube to gates 5 through 8; operation satisfactory.
Supply line	21 OCT 1977	No extra tubing available.

All tubes, including the supply tube, were checked for air leaks after each replacement and all, except the replacement to gate 2, were found to be airtight. We decided to replace all tubing when the supply tube developed a leak and all extra tubes had been used. The cause of the leaks was probably gophers, but this has not been specifically determined. We will try to verify this during 1978, but the urgency for replacement did not allow time for evaluation. During September and October, the Woodhouses irrigated twice without the automatic controls.

The original polyethylene tubing was buried in a trench about 3 feet deep along the edge of the basins, hoping that the tubes would not be damaged by gophers. The replaced tubes, installed in November 1977, were encased in 2-1/2-inch PVC pipe. The tubing layout to the various gates follows:

East battery of gates (1 through 4 and check gate):

Signal lines to gates and lift-gate check, 1/4-inch.	5
Supply lines, 5/16-inch (Gates 1 and 3, 2 and 4, check and overflow).	3
Overflow signal line, 1/4-inch.	1
Extra 1/4-inch.	2
Purge bubble-meter, 3/8-inch OD to flume	1

West battery of gates (5 through 8):

Signal lines to gates, 1/4-inch	4
Supply lines, 5/16-inch (Gates 5 and 7, 6 and 8)	2
Overflow signal line, 1/4-inch	1
Extra 1/4-inch	2

The small polyethylene tubing was laid to all gates and the PVC pipe was slid over the bundle of small tubes. We decided to use copper tubing wherever exposed to the weather. Meter boxes, made of plastic, were installed next to each set of gates to make the transition from polyethylene tubing to copper. The meter boxes come with lids, to complete the enclosure, that require a special tool to unlock. The PVC pipe with the polyethylene-encased tubing was placed in a trench, about 12-15 inches deep, next to the concrete-lined ditch rather than at the toe of the fill. The PVC pipe was brought directly into the meter boxes and the tubes necessary for exiting at that point were teed out into the meter box enclosure. All of the extra tubes that were taken to either set of gates were looped up into intermediate meter boxes so they could be tapped into, if necessary.

Cylinders 5 through 8 would not operate when the system was first started after the tubing was replaced. Water had accumulated in the cylinders and would not allow air entry. The source of the water was unknown, but apparently was forced into the cylinders through the break in the original supply line. Once the water was bled from the cylinders, the operation was satisfactory. The system has been used to irrigate twice since the new tubing was installed and the operation has been satisfactory both times. Some intermittant air loss through the 4-way valves at the gates has occurred, but the occurrence is irregular. Recent tests show these air losses to be decreasing. This improvement indicates that the valves were probably fouled by the water in the cylinders and their operation will likely improve over the next year.

Two solenoid-operated three-way normally open valves associated with the operation of the safety overflow and excess water disposal functions of the system have developed leaks during the year. The valves have been replaced and are operating properly at the present time. The problems have been reported to the manufacturer.

The air diverter valve in the controller/timer developed an air leak in August. The problem was one of continuously discharging air through the vent port normally used to vent the pilot tubes leading to the gates. A new valve was installed and worked properly. It was, however, cracked and leaked air when checked two weeks later. We are uncertain of the cause -- either faulty construction or improper installation. Another valve was installed and has operated satisfactorily. The original valve was returned to the supplier for repair and is available as a spare part.

Naquin Automation -- Ports and Jack-Gates

The automated port system at the Naquin Farm was used for 20 irrigations during 1977. The upper 4 basins were cropped to wheat during 1977, and seeded to alfalfa in September. With this alfalfa planting, all 8 basins are now in alfalfa. All basins, when planted to alfalfa, were laser-leveled, both in 1976 and 1977.

Changes or additions made to the system during January and February 1977, included isolation of rundown and overflow functions; installation of time recorders; automation of lift-gates leading to Basin 8 and changes needed at the control center to accomplish this addition; and the addition of two port turn-outs, one each to Basins 5 and 6, and the associated equipment for automating.

In the original design, the system run-down (disposal of water coming into a canal after the last basin was 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 run-down basins and the run-down basins could be different from the overflow basins. Further, if safety overflow basins were used as run-down areas, run-back from higher elevation basins into the canal and out into a lower elevation basin could occur. Isolation of the functions was accomplished by using solenoid-operated air valves, relays, and toggle switches for operator selection, Fig. 1. In the Naquin system the overflow signals operate all designated overflow gates when an overflow is sensed by any one of the three overflow sensors.

Individual timers were added to the control panel of the Naquin system to provide a record of the actual irrigation time for each basin. They are re-settable between irrigations, and read in 1/100 of an hour increments.

An air cylinder was added to the basin 8 lift-gate. Rather than moving the manual jack and centering the cylinder, as had been done in the past, the air cylinder was off-set from the center of the gate by about 4-1/2 inches and the manual jack was left in its original position. The procedure and operation were evaluated here in the laboratory in 1976.

It is occasionally necessary to irrigate the farmstead yards while irrigating the basins. The lift-gate to basin 8 and the third check gate leading to basin 7 require partial opening to accomplish this yard irrigation. To perform this function, a toggle-operated pneumatic valve was installed on the supply side of the 4-way pneumatically-operated valve attached to the respective gates, Fig. 2. The air supply line was directed through the toggle switch. If the toggle switch is in the "on" position, then the air passes through the valve and the gate operates normally. When the gate is closed and the toggle switch is "off", the air in the spring-loaded cylinder is vented to the atmosphere and the spring opens the gate. By placing a ball-valve in the vent side of the toggle valve the amount of air that is vented can be limited by irrigator control of the ball valve. Spring and air pressure forces are balanced to provide the opening desired.

Originally the air cylinders to lift-gate check 3 and basin 7 were closed with air pressure and opened by helical springs. This arrangement resulted in the opening of gate 7 to be delayed compared to lift-gate check 3. This delay caused some undesirable over-topping of gate 7. Four-way valves were added at the gates (air powered closure, air and spring powered opening) which provided prompt gate opening.

The four ports leading to either basin 5 or 6 could not handle the flow when irrigating with 20 to 22 cfs, which resulted in water overflow being sensed and water dumpage into designated basins, which on a regular basis is undesirable. Use of this flow rate was planned when available and hence, an additional port and the associated automatic equipment was added to each basin. The new ports were installed between what was originally the third and fourth port turnouts. Low-head, 16-inch diameter PVC pipe rather than concrete was used to convey the water from the ditch to the basin. Slide-gates were attached directly to the PVC pipe. Erosion control structures were constructed on the ends of the pipe and the necessary equipment for automating was installed. Air for actuating the pillows was supplied from the original fourth turnouts. Operation was satisfactory once these ports were installed.

Three lay-flat air pillows controlling ports to basins 5 and 6 were replaced in August. Leaks were found near the valve stem in two cases, and what appeared to be pin-holing in the third. During an inspection later in the year, a small air leak was discovered in another pillow. All of the air bellows continued to operate satisfactorily. In a few cases, some corrosion is developing, but has not been damaging to date. All port outlet closure devices, except one, were galvanized before installation, and as reported a year ago, the ungalvanized closure is extensively rusted, but operation is still satisfactory.

Two or three polyethylene plastic air lines leading to the ports were damaged during the burning operation. The damaged sections were where the tubing exited from the protective 3/4-inch galvanized pipe and the air bellows. Copper tubing was used to replace the burned sections. No pillows or bellows were damaged.

One closure was modified in the fall of 1976, in an effort to eliminate some of the debris that is normally collected on the closure structures. To date, it has operated satisfactorily, however, our evaluation is not conclusive since only one such modification was made. It is expected that we will make some similar changes during 1978, to more effectively evaluate such a modification. Debris collection continues to be a problem during certain times of the year, especially following bermuda burning or wind storms.

An air-throttling valve was installed in late 1976, in the supply side on the air lines going to the upper four basins to delay port closure, since port closure was much quicker than port opening. Initially we thought we had eliminated the problem since overflow devices were not necessary to make a normal switch from Basin 1 to 2, or 3 to 4. The delay, however, does not appear to be satisfactory. Reduced operating pressure will help balance the system and will be tried during 1978 -- reduce from 12 psi to 9 or 10 psi. If this does not alleviate the problem, then an air valve will be installed near the bellows of each of the four basins for rapid venting of the bellows. At the present time this air must be bled back through the control center, a distance of as much as 1900 feet.

General Comments - Woodhouse and Naquin Systems

The automated jack-gate system at Woodhouse's has generally operated satisfactorily since May 1975, with the exception of the air tube problem encountered during 1977. Special attention will be directed to alleviating port clogging and closure/opening timing of the Naquin port system and will include close observation by U. S. Water Conservation Laboratory personnel during 1978.

In an effort to eliminate the clogging problem associated with the ports, preliminary tests were conducted to evaluate the operation of a pneumatically-operated cylinder coupled to a standard hand-operated slide-gate located on the inside of the concrete-lined ditch. The system showed promise and will be field evaluated during 1978, possibly at Naquin's and in cooperation with the University of Arizona.

Control of the water being applied to the Woodhouse basins has improved since 1975, when the system was installed, and can be attributed to improved land finishing by laser-controlled equipment and automation of the gates. Water applied per irrigation has decreased over the period to the point where moisture deficits, in the third foot, were detected, but were eliminated upon applying slightly more water during the next two irrigations. Such ability to manage the water applied indicates a high degree of irrigation water control — one of the important features of surface irrigation systems of the future.

McDonnell and McElhaney Automation

At the request of the Soil Conservation Service, we designed and installed the first cost-shared automated irrigation system as part of the on-farm irrigation improvement program administered by the Soil Conservation Service in the Wellton-Mohawk Irrigation and Drainage District. The system is on the Ronald McDonnell-Robert McElhaney Farm near Wellton, Arizona, represented schematically in Fig. 3. The system features 23 lift-gate turnouts and 2 lift-gate checks. They were automated using pneumatically-operated cylinders similar to those used at Woodhouses and Naquins. The soils are relatively sandy and the 64-acre field is broken up into 23 basins averaging about 2.6 net acres each. Six separate field benches are included in the 64-acre plot. The overall slope of the plot is from East to West and from South to North. Temporary border dikes are used to separate the benches into the smaller basins within the bench. The system uses compressed air to energize the cylinders and signal opening and closing of the gates to cause the irrigation changes. A control panel, shown in Fig. 3, is permanently fixed to a post in the field. Electricity is available at the control panel. A critical flow flume, part of the SCS program, was installed in the supply ditch coming from the irrigation district. The automated system was installed in May 1977, and has been successfully used to irrigate some 25 times.

Lift-Gate Modification. Rather than centering the cylinder and moving the manual jack, as was done on the Woodhouse automated system, the air cylinder was off-set from the center of the gate by about 4-1/2 inches and the manual jack left in its original position. The procedures for this modification were developed at the U. S. Water Conservation Laboratory shop. Operation to date has been satisfactory. Steps required to adapt the cylinders to the gates are:

1. Construct plate for cylinder attachment, Fig. 4.
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, Fig. 5.

5. Attach rod-receiver bracket to gate slide.

The modification of the gates using these techniques was simpler and less costly than that used in the past. We modified one of the field gates to demonstrate the correct procedures. McDonnell and McElhaney modified the other 24 gates.

Air cylinder sizing. Sizing was based on the following items:

1. Gate opening required (D_o) -- 22 inches.
2. Distance from top of gate frame (surface on which cylinder rests) to top of gate leaf (D_s) -- 30 inches.
3. Maximum solid of spring (D_{ms}) -- cylinders without springs, 0 inches; cylinders with springs, 10.2 inches.
4. Allowance from solid, approximately 1 inch.

From this information: Cylinder stroke equals $D_o + D_{ms} + 1$, or 23 inches without spring and 33.2 or approximately 34 inches with spring. Rod extension (when piston retracted) = $D_s - D_o$ or 8 inches. Twenty-two of the 25 gates were equipped with cylinders without springs.

Gate actuation. Air was supplied commonly to batteries of gates as designated in Fig. 6 -- 4 sets of supply tubes with 5, 6, or 7 gates per tube. The supply line was 5/16-inch OD polyethylene tubing (3/16-inch ID).

Air is supplied to a single pilot-actuated, spring return, 4-way air valve attached to the gate frame that diverts the air either to the rod end of the cylinder to open the gate, or to the opposite end of the cylinder to close the gate. Pilot pressurization results in the air to be diverted for gate opening, and pilot de-pressurization to allow the air to be diverted for gate closure. The 4-way valves are equipped with manual over-ride buttons so that a gate can be opened by the irrigator in case of emergency.

Control Center Design and Development. A control system was designed and built to perform certain functions that are basic to the operation of the automated system, and others that are associated with sequence selection, excess water disposal, lift-gate check actuation, and automatic start-up, Fig. 6. Part of the equipment to complete certain functions is enclosed in a box permanently located at the field, while other equipment is housed in a trailer. The trailer contains an automatic timer, an air compressor, and sequence selection and excess water disposal equipment. Equipment permanently fixed in the box includes the lift-gate check actuation and automatic start-up valves. The connection between the trailer and the box is completed by a quick-tatch coupling to supply the air signal, air supply, and automatic startup air tubes (26 total) and an electric extension cord to supply the electricity for use both for the timer and air compressor.

Automatic timer. A Toro, 23-station, normally closed, pneumatically operated, pedestal mount controller was used. The timing device is electrical/mechanical in nature, automatically actuating an air diverter valve. Time settings are independently adjusted on each of the 23 stations for any period up to one hour. During the time setting for a particular station, air is introduced through the diverter valve within the controller to a pilot line leading to the 4-way valve at the gate to be opened.

Sequence Selection. The sequence in which the air pilot lines are actuated, and correspondingly, the sequence in which the fields are irrigated can be selected by the irrigator. This is done by connecting the field number air lines to the clock station air lines in whatever sequence desired by means of flexible tubes and quick-disconnects.

Excess Water Disposal. The on-farm irrigation and the irrigation district turnout of the water are independent, and water run-down through a long canal system is difficult to time. The automatic closure of the last gate is imperative in order that some means be available to dispense of the water in an orderly manner. McDonnell and McElhaney decided that basin 5 above the first check gate, basin 11 above the second check gate, and basins 13 and 19, operating together below the second check gate would be used as disposal basins. Either basins 5, 11, or 13 and 19, singly or in combination, can be selected by the irrigator for excess water disposal. Selection is made with three toggle-operated pneumatic valves. The toggle valves are located in the control trailer.

Operation of the disposal system depends on a 110 VAC solenoid valve operated by the controller, 3-way pneumatically-operated diverter valves, and toggle-operated pneumatic valves, Fig. 6. The timer powered solenoid valve provides normal system operation while irrigating any of the 23 basins but allows for selected run-down basin gates to be opened after the final basin is irrigated -- timer in "off" position.

Lift-gate Check Actuation. Twelve normally-open, 3-way, pneumatically operated and two, 3-way normally closed pneumatically-operated valves, Fig. 6, are used to control the two lift-gate checks, Fig. 3. When the control timer is in the "off" position the check gates are open. Check gates are opened or closed depending on which basin is being irrigated, as follows:

Basin Being Irrigated	Lift-Gate Check Status	
	1	2
1 through 6	closed	open
7 through 12	open	closed
13 through 23	open	open

The air pilot lines used to signal the operation of the various basin gates are also used to signal the 12, 3-way normally open valves. These valves, in conjunction with the two, 3-way normally closed valves, signal the opening or closing of the lift-gate checks.

Automatic start-up. Two pneumatically-operated micro-switches are activated, by the sensing of a water overflow depth from the overflow equipment between basins 2 and 4, to effect automatic start-up of the system. When the overflow signal is sensed, the microswitch, designated automatic start for timer in Fig. 6, momentarily closes and the controller starts, advancing to the first station and irrigation commences. Any signal thereafter from the overflow has no effect on the timer.

To attain an overflow signal, water must be ponded above the first lift-gate check, hence the gate must be closed at the time water is turned into the canal -- recall that the check gates were normally open when the controller was in the "off" position. A 3-way pneumatic valve that is actuated either by a solenoid or push-button, Figure 6, was connected in series with the valves controlling lift-gate check 1. To set for automatic start the button is pushed and lift-gate check 1 is closed. When the overflow signal is sensed the second microswitch circuit is also closed and the solenoid operator returns the 3-way valve to its normal operating mode -- lift-gate check activation controlled by the irrigation or non-irrigation of the respective basins.

Safety Overflow Equipment. Floats housed in 8-inch diameter asbestos-cement pipe, to serve as a stilling well, were located at 4 locations along the field canal, Figure 3. The stilling well was connected to the concrete-lined ditch by 1-1/2-inch PVC pipe, Figure 7. A cast iron lid was used to enclose the float mechanism.

Signal tubes (1/4-inch OD polyethylene) lead from the 3-way valve, that is mechanically operated by the float in the stilling well, to basin gates designated to receive excess water if an overflow is sensed.

Overflow Located Between	Lift-gates Controlled
Basins 2 & 4	1 & 2, check 1
Basins 8 & 10	7 & 8, check 2
Basins 14 & 16	13 & 14
Basins 22 & 23	22 & 23

In the no-overflow mode the weight of the float device closes the valve and the signal lines are vented. When the float rises (overflow sensed) the 3-way valve is opened and the signal tubes are pressurized. A particular gate will open when an overflow is sensed if the irrigator sets the toggle-operated pneumatic valve to the "on" position, Fig. 8. This selectivity is achieved by the toggle valve and a 3-way, pneumatically-actuated valve attached to the pilot port of the 4-way valves located at the gates. When the overflow is alleviated by the open gates, the signal will be cancelled and all overflow gates will close. The cycle will repeat indefinitely or until the cause of the overflow is determined and corrected.

Water Disposal in Case of Air Loss to System. A normally-open (no air in system) gate is a basic requirement of any water turnout system. In all previous installations all gates have been normally open. However, in the McDonnell-McElhaney installation, only three gates are normally open, while all others are normally closed. The three normally-open gates included the lift-gate checks and the gate to basin 13. Basin 13 was selected since excessive water would flow out the end of the basin, cross a county road, and discharge into the adjoining desert. Helical springs were installed inside the cylinders controlling the three gates. The helical springs, which can lift the gates without air assist, were designed and constructed in Phoenix. A spring force of about 575 lbs. is exerted when the gates are closed (22-inch travel). The characteristics of the springs were: Original free-length, 48 inches; wire diameter, 0.375 inches; number of coils, total 27 and active, 25; maximum solid, 10.2 inches; and spring diameter (OD) 4.1 inches. The spring free-length after testing was about 41 inches. With a cylinder stroke of 34 inches, the springs were compressed about 7 inches when loaded in the cylinders which developed a pre-load force of about 140 lbs.

Tubing. All air pilot lines to the gates and air tubes associated with the overflow equipment were 1/4-inch OD (1/8-inch ID) polyethylene. All supply lines to the cylinders and the supply to the overflows were 5/16-inch OD (3/16-inch ID) polyethylene tubing. This tubing is rated as 250 psi. All tubes were run along the east side of the canal from the control box on the post and were encased in 2-1/2 and 2-inch PVC pipe for protection against rodents. The PVC pipe was split using a table saw and the bundle of small polyethylene tubes was inserted into the split PVC pipe. Once the tubing was inserted the PVC pipe snapped back into its original round position. This encased tubing and PVC pipe was then buried along the concrete-lined ditch in a trench approximately 12 inches deep. Tubes required for control of a particular gate were brought out of the PVC pipe underneath walk bridges across the concrete structures in front of the gates and carried to the various 4-way valves attached permanently to the gate frames. The tubing was also encased in 3/4-inch galvanized pipe from the bridge to the gates, and on the gates where possible. The success of this encasing procedure is untested and will be carefully observed in the future. Copper tubing (1/4-inch) was used from the 4-way valves to the cylinders.

The time required for an air piloted valve to operate depends on the tubing size and length, the operating pressure, and the pilot activation pressure, Fig. 9. Of prime importance, when automatically switching gates during an irrigation, is that the next gate to irrigate opens at the same time or before the finished gate closes. This does occur for the McDonnell-McElhaney automated system since it takes longer for a pilot to actuate when depressurizing (gate closing) than when pressurizing (gate opening). The data presented in Fig. 9 was developed with a 4-way valve, lift-gate, and various lengths of tubing in the laboratory. The actual delay between gate opening and closing or pilot pressurization and depressurization appears to be slightly more in the McDonnell-McElhaney installation than is shown here. The delay is not a problem.

SUMMARY AND CONCLUSIONS:

Two fields were automated in 1975 in the Wellton-Mohawk Irrigation and Drainage District to demonstrate (on-farm) the use of presently available automated schemes for controlling irrigation water to level basins and to design, develop, and demonstrate improved systems. One 65-acre field on the Bob Woodhouse farm uses lift-gates to control the water while on a 70-acre field on the Jim Naquin farm concrete port outlets in combination with lift-gates are used. Each system is pneumatically actuated by a clock/controller at a central location which signals irrigation field changes according to preset times.

Seventy-one irrigations have been completed through 1977 using the automated systems:

	1975	1976	1977
Woodhouse	10	8	15
Naquin	1	17	20

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

A few problems with the Woodhouse system occurred and were corrected during 1977. Cylinder rods became extremely dry after one year's operation (commercially purchased cylinders were installed in August 1976) which caused displacement of U-cup seals. The cylinders were lubricated and it appears to have solved the problem. Several plastic tubes developed air leaks during August and September which led to replacement of all air tubes. The new tubes were encased in 2-1/2-inch PVC pipe to protect the small tubes from damage by gophers--gophers likely caused original damage. The PVC pipe was buried about 12-15 inches deep next to the concrete-lined ditch. Two solenoid-operated valves and the air diverter valve in the controller/timer developed leaks during the year and were replaced.

Changes or additions made in the Naquin system in January and February 1977 included isolation of rundown and overflow functions; installation of time recorders; automation of the lift-gate leading to basin 8 and changes needed at the control center to accomplish this addition; and the addition of two port turnouts, one each, to basins 5 and 6, and the associated equipment for automating. Three lay-flat pillows were replaced in August at Naquins. Leaks were caused by failure near the valve stem in two cases and what appeared to be pin-holing in one pillow. They will be returned to the manufacturer for evaluation. One closure, modified to help eliminate some of the debris collection on the structure, has operated satisfactorily. Evaluation, however, is not extensive enough to be conclusive. Preliminary tests using a pneumatically-operated cylinder coupled to the standard hand-operated slide gate located on the inside of the concrete-lined ditch showed promise as an automatic gate operator, and may minimize debris problems. Further tests are planned and a field evaluation will be conducted during 1978.

We demonstrated the Woodhouse and Naquin automated systems a few times to visiting groups during the year, but most of the responsibility of demonstration has been assumed by the University of Arizona Extension Service and the Soil Conservation Service. More people have become aware of the two demonstration systems and are visiting the sites on their own, rather than contacting us. This type of contact requires more time by the cooperators in showing these systems to the public. We appreciate their assistance.

Two technical papers describing the systems have been prepared and accepted for publication in the Transactions of the American Society of Agricultural Engineers. The papers are entitled "Automation of On-Farm Irrigation Turnouts Utilizing Jack Gates" and "Automation of Open Ditch Irrigation Conveyance Systems Utilizing Tile Outlets."

USDA television featured the level-basin/automation work in two 3-1/2 to 4-minute agricultural features (for "Down-to-Earth"), one titled "Laser Leveling for Irrigation" and the other "Irrigation

Efficiency and Technique". USDA television also used some discussions of laser leveling, irrigation efficiency and automated irrigation systems for their weekly half-hour program "A Better Way". These programs are released to 85 television stations nationwide. They were shown in May and June of 1977.

At the request of the Soil Conservation Service, we designed and installed the first cost-shared, automated irrigation system as part of the on-farm irrigation improvement program administered by the Soil Conservation Service in the Wellton-Mohawk Irrigation and Drainage District. The system is on the McDonnell-McElhaney farm near Wellton, Arizona. It was installed in May 1977, and has been successfully used to irrigate some 25 times. Twenty-three jack-gate turnouts and two jack-gate checks were automated using pneumatically-operated cylinders. The 23 fields average about 2.6 acres each. The system uses control equipment, housed in a trailer, which energizes the cylinders and signals opening and closing of the gates to cause irrigation changes.

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

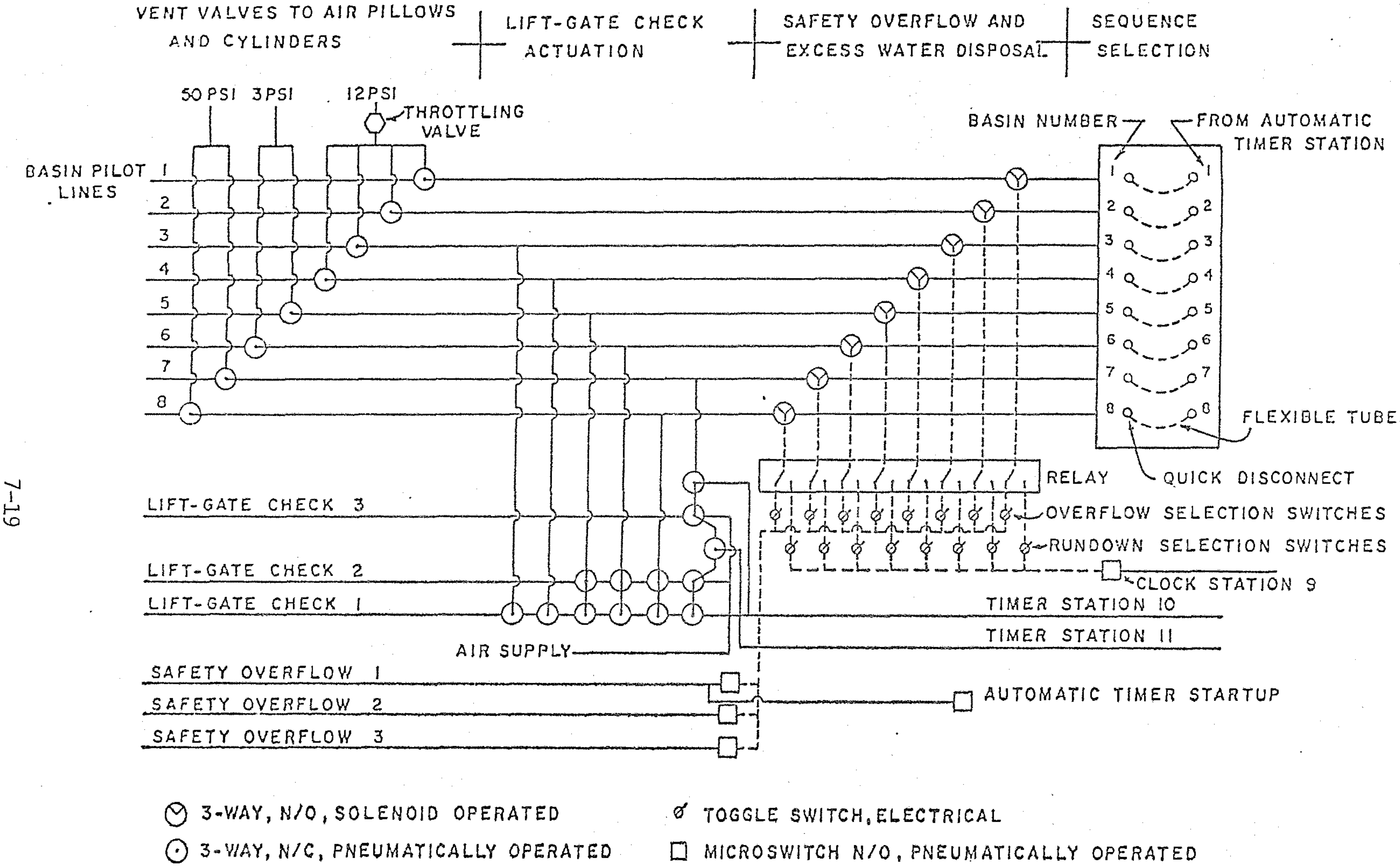


Figure 1. Schematic diagram of the control panel on the Naquin automated system in which the safety overflow and rundown functions are isolated electrically, February 1976.

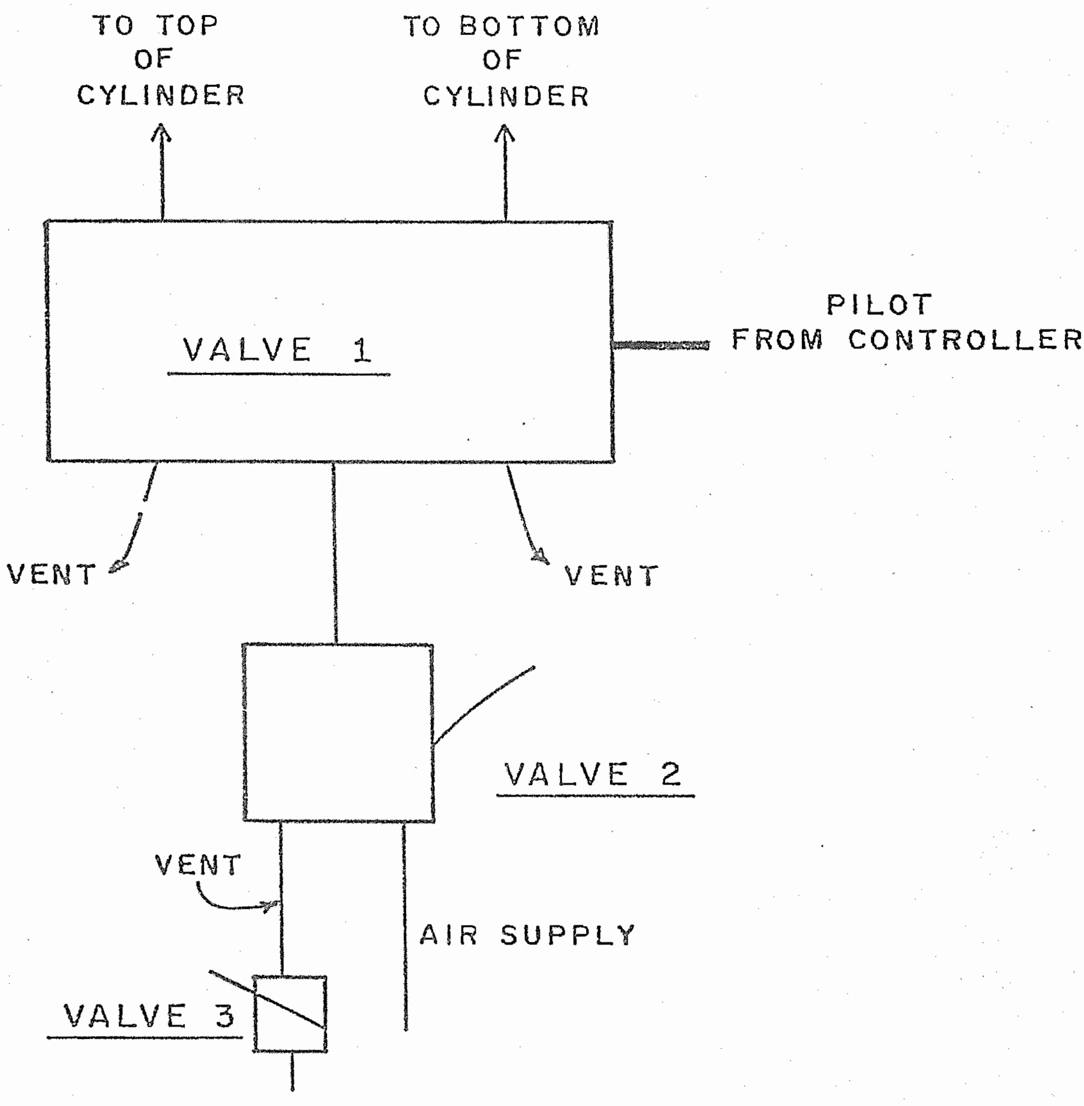


Figure 2. Valve arrangement to allow partial opening of a spring-loaded lift-gate when gate normally closed. Valve 1--four-way pneumatically piloted, spring return valve mounted on lift-gate; Valve 2--toggle operated pneumatic-valve; Valve 3--ball valve.

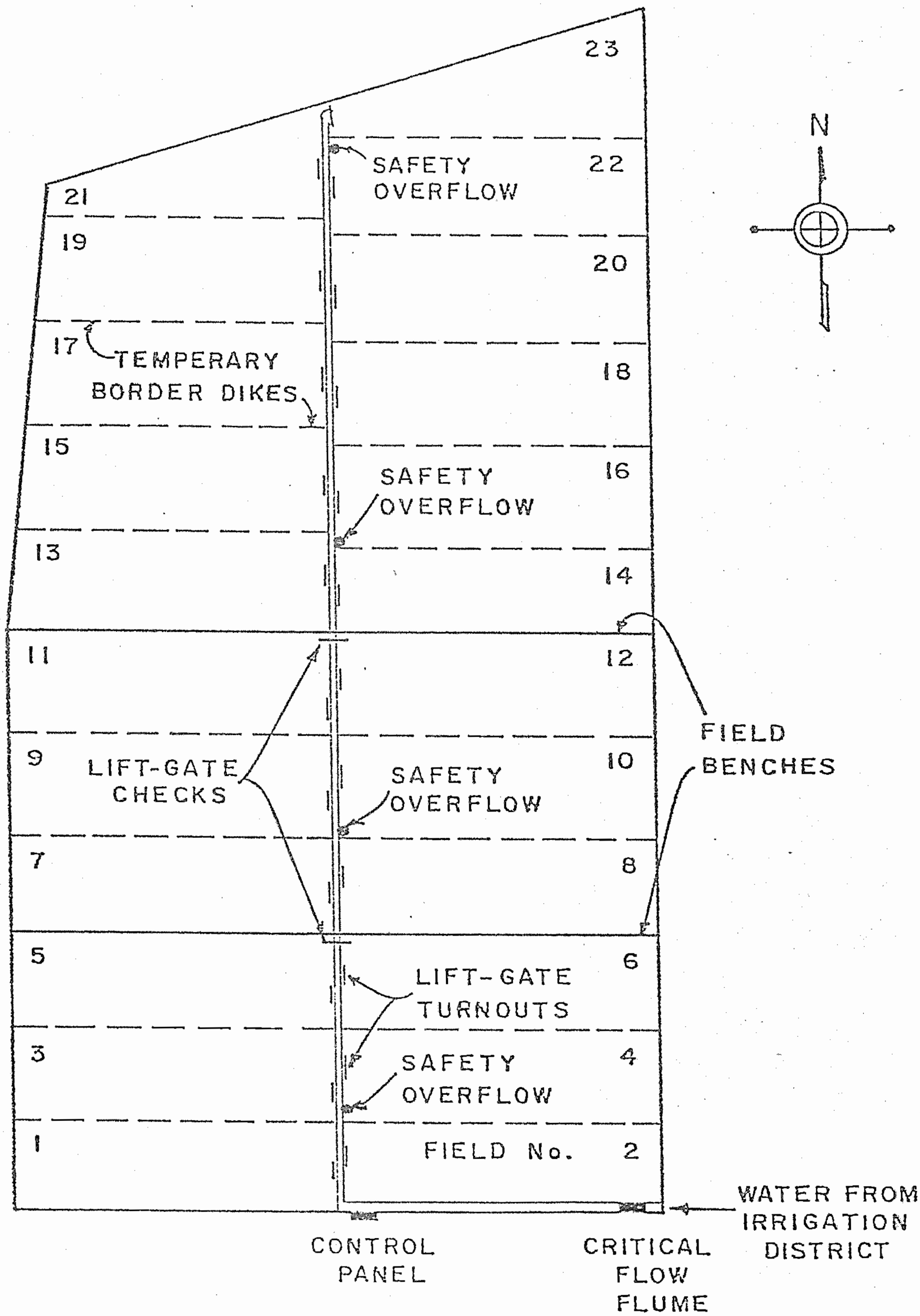


Figure 3. Field layout of 64-acre McDonnell-McElhaney farm that was automated during 1977. The farm is near Wellton, Arizona.

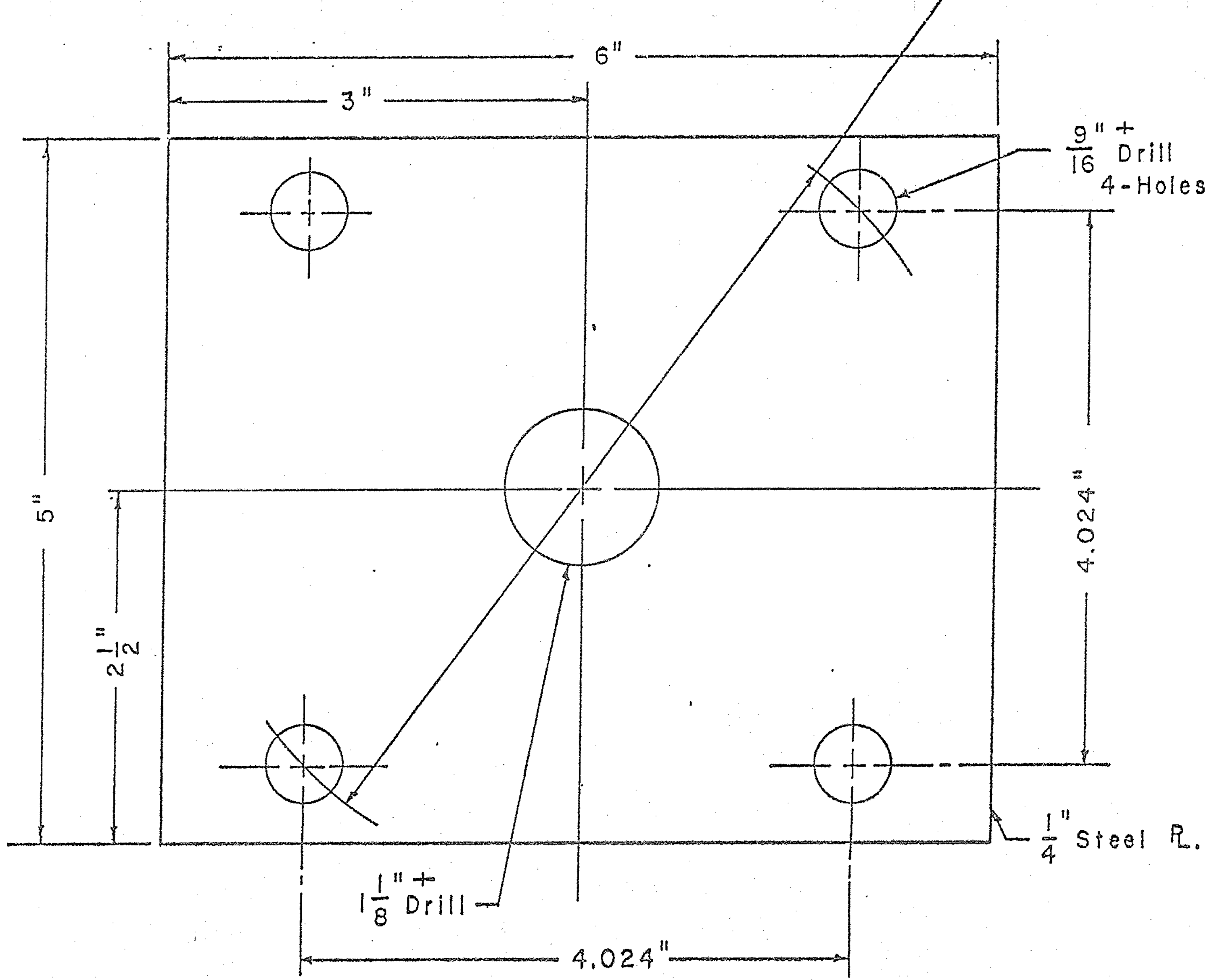


Figure 4. Plate required to adapt air cylinders to lift-gates for McDonnell-McElhaney automatic irrigation system.

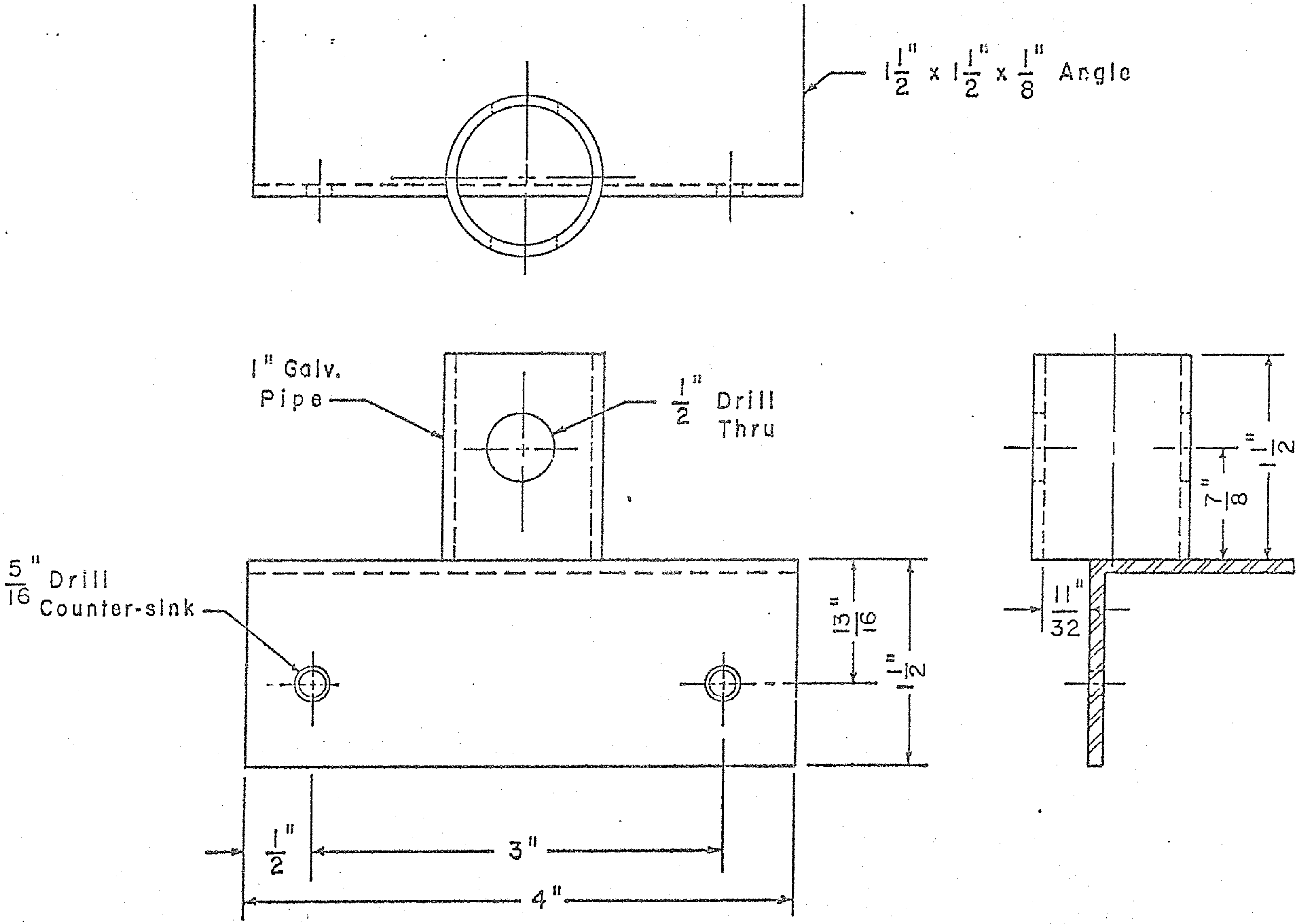


Figure 5. Rod-receiver bracket required in lift-gate modification for McDonnell-McElhaney automatic irrigation system.

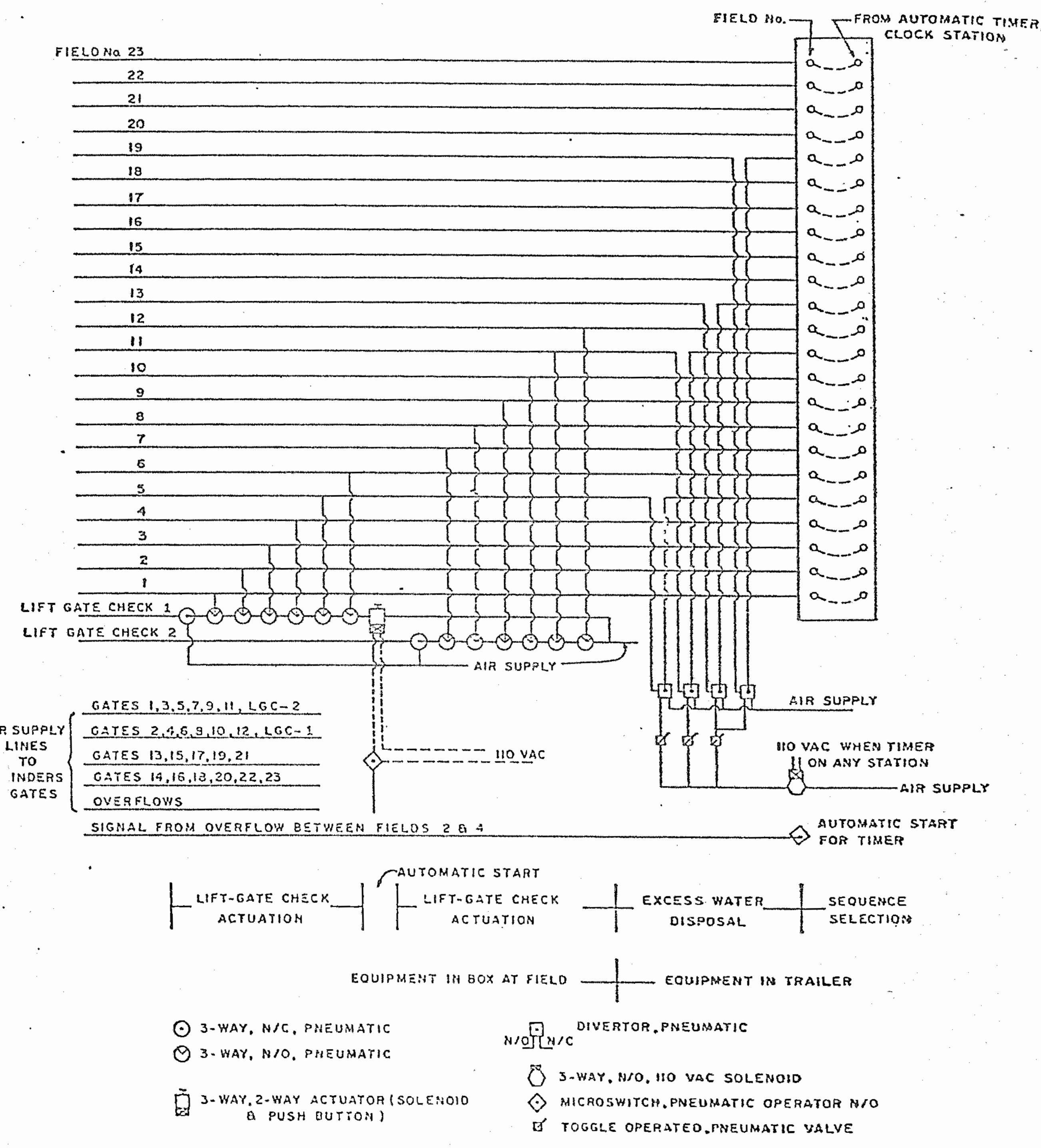


Figure 6. Schematic diagram of the control equipment required for the McDonnell-McElhaney automated irrigation system.

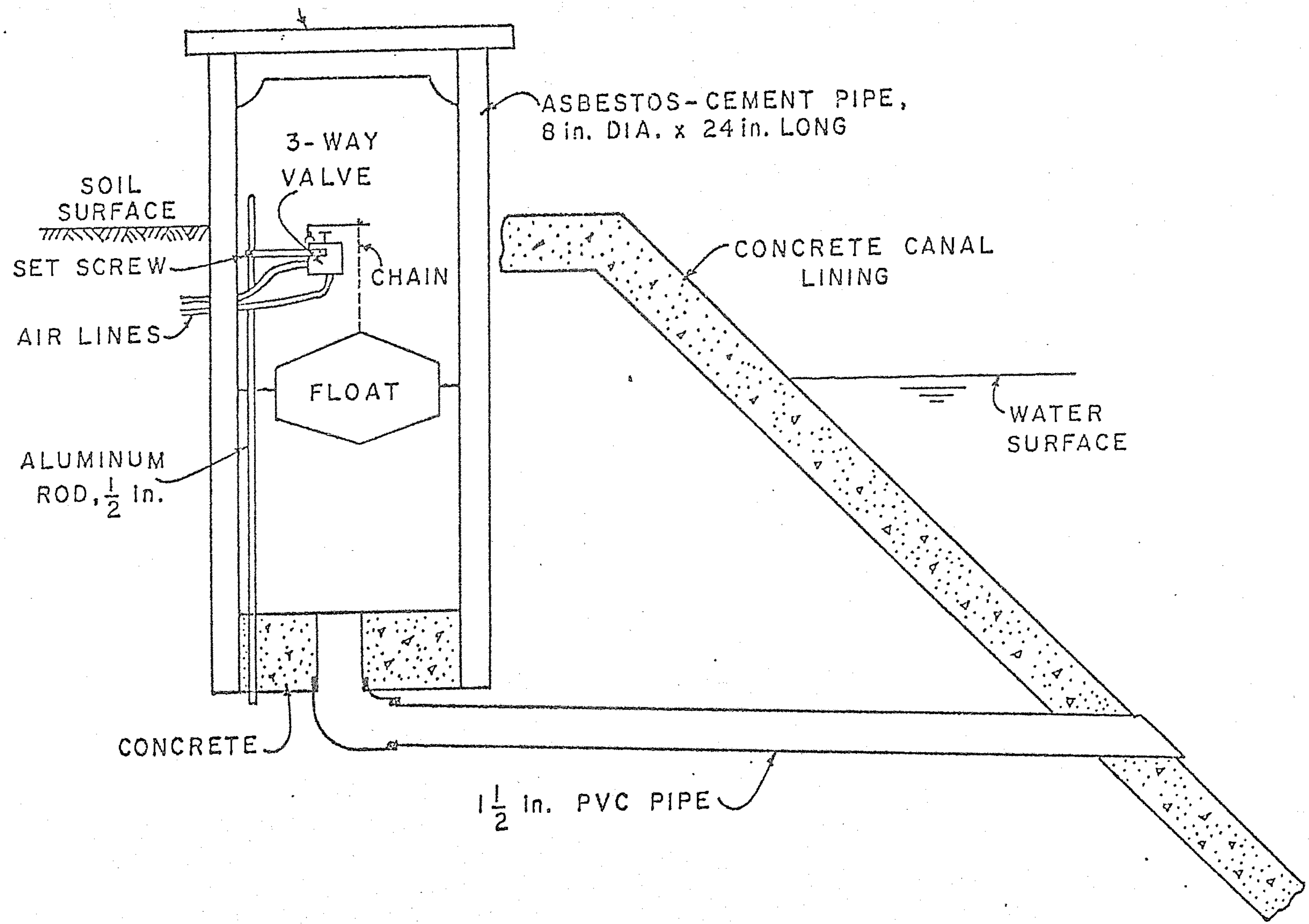


Figure 7. Diagram of safety overflow equipment as used at the McDonnell-McElhaney automated irrigation system.

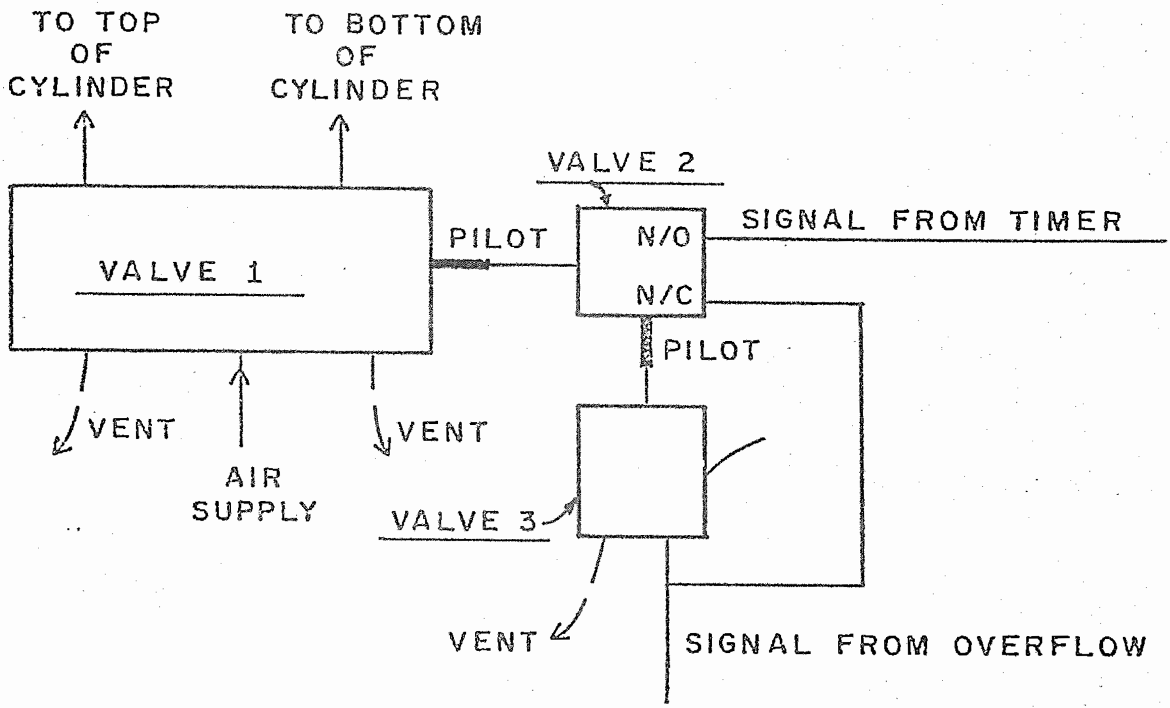


Figure 8. Valve arrangement to allow for irrigator selection of overflow gates at McDonnell-McElhaney automated system. Valve 1--four-way, pneumatically piloted, spring return valve mounted on gate frame; Valve 2--three-way, pneumatically piloted diverter valve; Valve 3--toggle operated pneumatic valve.

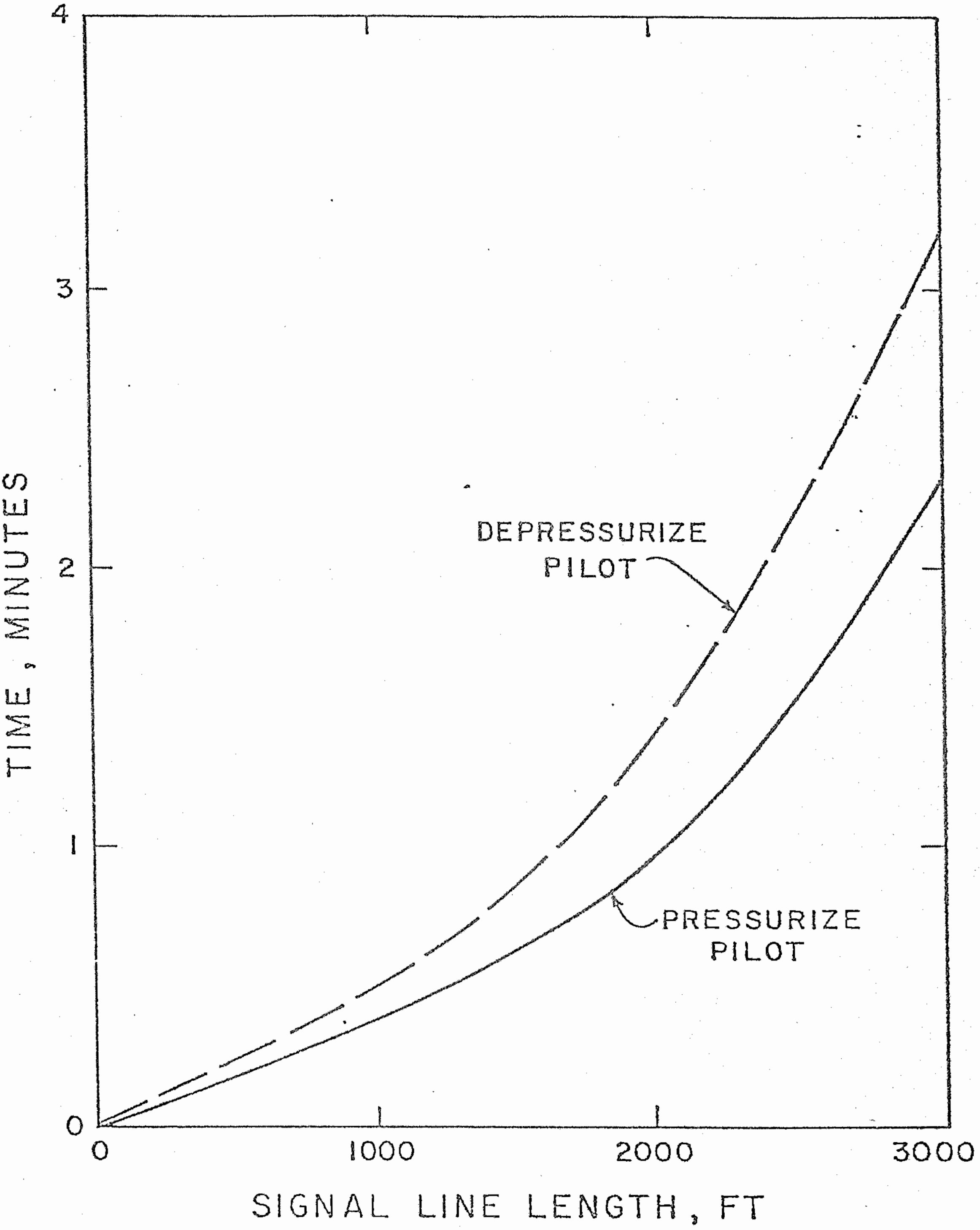


Figure 9. Time required for the pilot of a four-way, pneumatically actuated valve to operate when being pressurized (gate opened) from atmospheric pressure and depressurized (gate closed) from 50 psi operating pressure related to signal line length. The signal line tubes were 1/4-inch OD (1/8-inch ID) polyethylene tubing.

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 drainage water returned to the lower Colorado River system near Yuma for desalinization, from the Wellton-Mohawk Irrigation Project, the application efficiency of irrigation water must be improved.

The irrigation application efficiency in many cases can be improved by changing the farm irrigation system. A method of irrigation referred to as "dead-level" can be highly efficient and represents one such change.

For further introduction, see 1975 Annual Report.

OBJECTIVES:

(1) To determine the effects on time-rate-of-advance for dead-level irrigation systems that are caused by:

(a) Field configuration

(b) Stream size or application rate

(c) Number and location of outlet structures

(2) To publish a practical publication explaining design principles and water management criteria, including consideration of cultural changes for implementing dead-level irrigation.

PROCEDURE:

The utilization and expansion of dead-level systems has continued to expand in Southwestern United States. This method of irrigation has been accepted and made more desirable by the use and availability of laser leveling equipment.

During the year, various ways of preparing the land and managing water have been observed and discussed with farmers. The art is to use large streams of water to reduce labor requirements and still control erosion, prevent over-topping of rows and scalding. Several choices are available and these should be observed, demonstrated, and presented to farmers.

Many lectures were presented at meetings in Arizona, California, and Utah. In addition, several sessions were held with private consultants contracting for design of dead-level irrigation systems.

SUMMARY:

The use of laser levelers is making dead-level irrigation systems more desirable than originally visualized. Farmers, by using this method, are innovating means of distributing water to efficiently and practically accomplish the job of producing a crop.

A Farmers Bulletin has been accepted and is presently at the publisher's.

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:

An Annual Report submitted to the Soil Conservation Service includes the details of the work accomplished for 1977. It covers approximately the complete three years of study at a field site in Tacna, Arizona. The reports for 1975 and 1976 are referred to for the objectives and descriptive materials on treatments and experimental procedures. Further extension of the investigation to cover a fourth year is a possibility so that additional measurements on individual emitter flow rates and uniformity of water application is contemplated.

SUMMARY:

Monitoring of physical, chemical and biological analyses of water and discharge rates of emitters was continued for three years on a trickle irrigation system. Emitter performances with different water treatments were evaluated on the basis of overall average flow rates and on variability in individual discharges. The 9 different types of emitters exhibited different behavior in relation to water treatment. Emitters with moving parts had a tendency to increase in flow with time if the valve or diaphragm unit is affected by the chemical treatment. Some filtration is required for proper emitter operation, but the high suspended load during the summer months for this water may make filtration impractical without automatic backwashing capabilities. Partial results indicate, however, that continuous hypochlorite-acid or continuous acid treatments will maintain better application uniformity than the non-chemical or intermittent hypochlorite-acid treatments.

PUBLICATIONS:

1. Bucks, D. A., Nakayama, F. S., and Gilbert, R. G. 1976. Clogging research on drip irrigation. Proc. 4th Annual Intern. Drip Irrig. Assn., Fresno, CA. 1976.

2. Gilbert, R. G., Nakayama, F. S., and Bucks, D. A. 1977. Trickle irrigation: Prevention of clogging. Am. Soc. Agr. Engin. Preprint 77-2011.

3. Nakayama, F. S., Gilbert, R. G., and Bucks, D. A. 1977. Water treatment in trickle irrigation systems. J. Irrig. and Drain. Div., Am. Soc. Civil Engin. (In Press).

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

TITLE: IRRIGATION ADVANCE AND RECESSION MODELING

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

INTRODUCTION:

Several levels of mathematical models for advance and recession in irrigation borders have been developed. These models range from a simple model (Strelkoff, 1977) which can be hand calculated, to a theoretically complete model (Katopodes and Strelkoff, 1977a), for which a single run may take as much as half an hour on a high speed digital computer. An intermediate model (Strelkoff and Katopodes, 1977b), called the zero inertia model, has a high degree of accuracy and can be run quickly on a relatively slow mini-computer. This model appears to have a great deal of potential for use in irrigation system design and management. The zero inertia model thus deserves the greatest attention.

DISCUSSION:

The original zero inertia model had several problems associated with boundary conditions. Specific problems were (a) the water surface profiles calculated at the downstream end of a field diked to prevent runoff, (b) the water surface profile at the upstream end of the field after an abrupt cutoff, (c) the water surface profile at the receding edge during simultaneous advance and recession. These problems are discussed in more detail in a discussion of Strelkoff and Katopodes, 1977b, by A. J. Clemmens and D. D. Fangmeier, which will be submitted in early 1978. These problems have been sorted out and their solutions will appear in the closure of the same paper.

The Saint Venant equations of continuity and momentum were put in dimensionless form for the solution of irrigation advance with zero inertia model in Katopodes and Strelkoff, 1977b. In that paper, the parameter $\mathbb{P}$ was used as a characteristic parameter and the parameter $\mathbb{K}$ was set to unity. A set of dimensionless graphs of advance for a = .1 to a = .9, each with a set of curves for different values of $\mathbb{P}$ were presented.

Later, analyses of a wide range of field data showed that it would be more appropriate for surface irrigation to let $\mathbb{P}$ be unity and let $\mathbb{K}$ vary. These data and the analysis are presented in a discussion of Katopodes and Strelkoff, 1977b, by Albert J. Clemmens to be submitted in early 1978.

An additional dimensional analysis was performed on the Saint Venant equations for level borders (no slope). By eliminating one parameter (the field slope), more information can be shown on the same number of graphs. In this case, the time of cut-off, or application time, was used as the characteristic time. Now both advance before and after cut-off for level borders can be displayed on the same set of graphs. Another revision in the zero inertia model has been made that allows recession to begin at either end of the field, and will be incorporated in the solution of advance on level borders after cutoff. A manuscript is being prepared to present these results.

Actual advance and recession rates on several borders in Wellton and Phoenix, Arizona, were observed. Some of this data along with data from other sources was compared with the zero inertia solution. The agreement in most cases was good. A manuscript has been prepared to present these results which will be submitted in early 1978.

The major drawback in using the model is the inability to get good field data. Soil infiltration characteristics and surface roughness are difficult to determine accurately. Presently, ring infiltration data adjusted to achieve a volume balance (Merriam, 1971) is used to get an approximation of the cumulative infiltration function expressed in a power form. For low intake soils, a power function does not adequately express the soil infiltration characteristics throughout the time of interest. Initially, the fit can be quite good, but as the infiltration rate approaches some final value, the actual cumulative infiltration rates differ significantly from the power function approximation. For these soils, a three-parameter function may be in order.

SUMMARY:

The zero inertia model for border irrigation advance and recession is now ready for general use. Some care must still be taken in interpreting the results of the model.

ADDITIONAL REFERENCES:

1. Linderman, Charles L., and Stegman, Earl C., 1969. Seasonal variation of hydraulic parameters and their influence upon surface irrigation application efficiency. Amer. Soc. of Agric. Engin. Winter Meeting, December 9-12, Chicago, Illinois.

2. Merriam, John L. 1971. Adjusting cylinder infiltrometer data for field use. Amer. Soc. of Agric. Engin. Pacific Region Annual Meeting, March 31-April 1, Las Vegas, Nevada.

PUBLICATIONS:

1. Katopodes, Nikolaos D., and Strelkoff, Theodor. 1977a. Hydrodynamics of border irrigation - Complete model. Journal of the Irrig. and Drain. Div., Amer. Soc. of Civil Engin. 103 (IR3): 309-324.

2. Katopodes, Nikolaos D., and Strelkoff, Theodor. 1977b. Dimensionless solutions of border-irrigation advance. Journal of the Irrig. and Drain Div., Amer. Soc. of Civil Engin. 103 (IR4): 401-417.

3. Strelkoff, Theodor, and Katopodes, Nikolaos. 1977a. End depth under zero-inertia conditions. Journal of the Hydraulics Div., Amer. Soc. of Civil Engin., 103 (HY7): 699-711.

4. Strelkoff, Theodor, and Katopodes, Nikolaos D. 1977b. Border-irrigation hydraulics with zero inertia. Journal of the Irrig. and Drain. Div., Amer. Soc. of Civil Engin., 193 (IR3): 325-342.

5. Strelkoff, Theodor. 1977. Algebraic computation of flow in border irrigation. Journal of the Irrig. and Drain. Div., Amer. Soc. of Civil Engin. 103 (IR3): 357-377.

PERSONNEL: Albert J. Clemmens, John A. Replogle, Allen R. Dedrick.

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

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

CODE NO.: Ariz.-WCL 71-1

This year's annual report consists of the following abstract from a manuscript sent to the National Technical Editor, entitled "Drought-Induced Changes in Water-Use Efficiency of Six Plant Species in a Controlled Environment," by W. L. Ehrler, B. A. Kimball, and S. T. Mitchell.

"Future urban and industrial competition with agriculture for increasingly scarce water supplies eventually will place a premium on efficiency of water use. Then crops with the highest water-use efficiency (yield per unit of water) will be planted in preference to those yielding the most per unit of land area, as occurs now. To address this problem, a limited survey was undertaken to ascertain differences in WUE among plant species. Drought-induced changes in WUE of six crops were measured in a controlled-environment chamber under saturation light levels. Use of a whole-plant chamber enabled simultaneous, half-hourly rates of transpiration and photosynthesis to be measured as gradual soil moisture depletion decreased transpiration by 90% from the initial rates. Continual measurement of leaf thickness with a beta-ray gauge enabled a non-destructive determination of the relative leaf water content (RLWC) to be made continuously. The leaf diffusion resistance (R_L) and mesophyll resistance (R_M) were calculated from the chamber measurements and a measurement of the boundary layer resistance."

"The data showed a lower WUE for corn and sorghum under drought than when well watered, no change for black-eyed pea, and a higher WUE for cotton, sunflower, and mulberry. The RLWC ranged from 99 to 72% during the imposed drought. Concurrent ranges in R_L were from 4 to above 100 sec/cm in corn and sorghum and 0.8 to about 50 sec/cm in the dicotyledonous species. R_M values were variable, but at their lowest tended to be from 6 to 10 sec/cm. The results suggest that corn and sorghum (and perhaps other tropical grasses with a high photosynthetic rate) should not be stressed for water for greatest WUE, whereas certain dicotyledons such as cotton and sunflower can be stressed sufficiently to save water without sacrificing much yield; they also may be promising candidates for selection and breeding to enhance WUE under drought."

Further studies will deal with a comparison of closely related species or cultivars within a given species known to differ significantly in their field behavior--such as an old line wheat as compared with the new high yielding Mexican cultivars; or Pima versus Deltapine cotton; or isogenic barley cultivars differing only in a gene for chlorophyll, e.g., Campana versus Golden Campana.

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

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

For details, see previous annual reports. A summary of 4 years' experimental results is contained in a manuscript entitled "Growth and Yield of Jojoba Plants Using Runoff-Collecting Microcatchments in a 200-mm Rainfall Region" by W. L. Ehrler, D. H. Fink, and S. T. Mitchell, which has been approved by the National Technical Editor and submitted to the Agronomy Journal for publication. The abstract from this manuscript follows:

"Water-harvesting techniques were applied to a native stand of jojoba to evaluate the method for increasing seed yield and to gain insight into the water needs of the plant. Thirty small, idigenous, female bushes were selected and randomly divided into three treatments: T_0, no catchments; T_1, cleared, smoothed and rolled 20-m^2 catchments; and T_2, treatment T_1 plus water-repellant soil coatings. Data were collected for rainfall, runoff (estimated from similarly treated and monitored catchments), soil moisture, relative leaf water content, plant volume, and seed yield. The 4-year average of precipitation plus runoff to plants during the critical growth-yield period of October through June was: T_0, 154 mm; T_1, 435 mm; and T_2, 876 mm. The plant volume increase averaged 43, 44 and 237% for T_0, T_1 and T_2, respectively. Seed yield in 1974, the first year, averaged 0.5, 8, and 23 g/plant for treatments T_0, T_1, and T_2, respectively. Frost injury destroyed the flowers in 1975 and 1976, but in 1977 yields increased to 27, 76, and 208 g/plant for the respective treatments. Maximum yield was 514 g/plant."

The experiment will be continued. A new approach will consist of conversion of the catchment for the T_1 treatment (smoothed, rolled soil) to a sodium clay surface layer by addition of bentonite and sodium chloride. This will be an attempt to increase the runoff from the approximately 45% annual value to 70% and thereby increase the yield significantly over the control values. An additional feature will be the periodic, simultaneous measurements of soil water content and twig water potential (Ψ_{twig}) to correlate plant water status with levels of soil moisture. A portable Scholander pressure chamber will be taken to the field to measure (Ψ_{twig}). A representative value can be obtained from triplicate measurements of twigs with as few as two nodes per twig. Therefore, the technique will be of minimal disturbance to the plant.

PERSONNEL: W. L. Ehrler and D. H. Fink

TITLE: TEMPERATURE CONTROL OF CO_2-FERTILIZED, SEALED GREENHOUSES

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

CODE NO.: Ariz.-WCL 75-1

INTRODUCTION:

A major objective of this project is to demonstrate the yield responses attainable with CO_2 fertilization in sealed greenhouses. This year we conducted the first actual experiment with a spring crop of tomatoes. In late summer the greenhouses were modified somewhat, and we started a fall tomato crop. The yields and production costs of the first spring crop have been evaluated and also for the second crop up to 1 February 1978.

METHODS:

Greenhouse Description. There are four aluminum frame greenhouses covered with fiberglass (Soil-lite with tedlar). They are 4.4 m wide by 6.4 m long by 2.17 m at the eaves by 3.29 m at the peak to give an area of 28.1 m^2. They are spaced 3 m apart in an east-west row with the ridge of each roof oriented north-south. Counting from the east, greenhouses 1, 3, and 4 are all equipped with cooling systems which allow them to be closed and unventilated even under high light conditions. Table 1 lists the greenhouses by number and the type of cooling for each.

The cooling systems operated as follows. Greenhouses 3 and 4 each had an associated cooling tower positioned a few meters away. The towers had horizontally oriented aspen excelsior pads 4.27 m long, 1.07 m wide x 51 mm thick. Water at a flow rate of 4.04 ℓ/s was pumped through three water distribution pipes positioned about 20 cm above the pads. Two pipes were close to the pad edge and the other was centered. The pipes had 100 3.18-mm-diameter holes per meter of distribution pipe. A fan was mounted at the top of the towers to draw air at 7 m^3/s in through intakes below the pads, up counter flow to the water through the pads and exhaust to the atmosphere above the tower. The cooled water drained to a sump below the towers.

All of the greenhouses were equipped with a horizontal aspen pad spray chamber and water distribution system of the same size and orientation as the cooling towers. Greenhouses 1, 3, and 4 were also equipped with a return air duct and fan to draw air from the southwest corner of each greenhouse and blow it into the bottom of the spray chambers, up counterflow to the falling water and into the north end of each greenhouse. Greenhouse 2 was the conventionally-cooled control house. It was equipped with an exhaust fan on its southwest corner which drew outside air into the spray chamber, up through the pads, into the greenhouse, and out to the atmosphere.

For greenhouses 3 and 4, cool water from the towers was pumped to their spray chambers where the pads served as direct-contact heat exchangers to cool the recirculating greenhouse air. For greenhouse 2, the spray chamber served as a conventional evaporative cooler and the greenhouse air was not recirculated. In addition, for the spring crop, the spray chamber on greenhouse 2 served as the cooling tower for greenhouse 1. Thus, it produced cool air for greenhouse 2 and cool water for greenhouse 1. When the thermostat in 1 called for cooling, but the one in 2 did not, blowers at the top of the spray chamber of 2 were used to draw air through the pads of 2, but not through greenhouse 2, itself. Some cooling of 2 occurred anyway whenever these blowers were on, even though the exhaust fan for 2 was not on. Greenhouse 1 operated like 3 and 4 for the spring crop with its air being recirculated through cool water from an external device. Before the fall crop was started, greenhouses 1 and 2 were slightly re-wired to operate independently (Table 1). Greenhouse 2 operated as a completely conventional fan-pad cooled greenhouse. Greenhouse 1 was modified so that the dust fan drew in dry outside air rather than greenhouse air. After being evaporatively cooled in the pads and passing through the greenhouse, it was exhausted through the roof ridge vent. Thus for the second crop, greenhouse 1 was also conventionally cooled.

In the event the cooling systems broke down or were inadequate when outside wet bulb temperatures were high, each greenhouse was equipped with a "safety valve" that operated from an uninterruptable power supply. All greenhouses had motorized ridge vents, and greenhouses 1, 3, and 4 had motorized dampers at the south end of the air return ducts. If the temperature rose above a set point, vent thermostats activated the motors to open the ridge vents and dampers. If the reason for the temperature rise was mechanical failure of some component, natural ventilation at least would prevent the crop from being cooked. If the reason for the temperature rise was inadequacy from high wet bulb temperature, opening the damper and ridge vent transformed the aspen pad direct-contact heat exchanger into an evaporative cooler, thus providing additional cooling to the greenhouses. A switch turned off the CO_2 generators whenever the ridge vents were open.

All of the greenhouses were also equipped with 7.5 kw electric resistance heaters to provide heat on cold nights.

The heating, cooling, and emergency ventilation systems were all controlled by individual thermostats. The thermostats were set at 60°F (15.5 C), 80°F (26.5 C), and 85°F (29.5 C) for heating, cooling, and emergency ventilation, respectively.

Cultural Procedures. The growing medium was a bed of sand underlain by drain tubes over a sheet of polyethylene film (Jensen, 1971). The sand was 30 cm deep at the south end of the greenhouses and 45 cm at the north end to provide a grade for drainage to a sump.

The conventional polyethylene used on the initial installation proved to be too fragile, and very little drainage water even entered the sumps. Consequently, the water use measurements of the spring crop were useless. Between crops, new plastic was installed. This time, two sheets of 4-mil cross-laminated polyethylene film (Tu-Tuf-4 from Sta-Cote Products, Inc.) was used, and so far it has performed well, as indicated by the drainage water being nearly equal to the irrigation water while the fall tomato plants were small.

While the new plastic was being installed, the sand beds were also divided to form two separate beds lengthwise in each greenhouse. The west beds were 2.3 m wide for three double tomato rows while the east were 1.5 m for two rows.

The greenhouse tomato variety was "tropic." The spring crop was sown in peat cubes on 7 January 1977 and transplanted into the greenhouse on 4 February. The first harvest occurred on 28 March and continued once or twice weekly until 1 August. During August the vines from the first crop were removed, the new plastic was installed under the sand beds, and greenhouses 1 and 2 were rewired to operate as separate conventionally-cooled greenhouses. The fall crop was planted in peat cubes on 19 August and transplanted into the greenhouses on 16 September. The first fall harvest was in November and has continued at weekly intervals into 1978. We plan to continue this crop through the spring so long as the vines are vigorous.

The plants were pruned once or twice a week to maintain single-stemmed plants which were attached to plastic support twine with plastic plant clips and by winding the string around the stem. On 6 July, the terminal buds were pruned to promote faster development of the last fruits. The plants were pollenated near noon on weekdays and generally once each weekend by pounding the cables that held up the support twines.

The crops were planted into five double rows in each greenhouse with the plants alternating on each side of the five tubes of the drip irrigation system. For the fall crop, three of the rows were on the west side and two on the east with the somewhat off-center aisle dividing the two beds. Each irrigation line had 10 4-ℓ/hr Drip-Eze emitters spaced 46 cm apart to accommodate 50 plants per greenhouse. The lines were 76 cm apart except the second and third were 122 cm apart to make an aisle along the east center of each greenhouse. The growing area per plant was 0.35 m^2 not counting aisles or 0.53 m^2 if aisles are counted.

Irrigation and Nutrients. The crop was irrigated a few minutes per hour as set by a time clock for each greenhouse. Concentrated nutrient solution was injected into the irrigation water using two electric injector pumps (Blue White Industries Model C-1730 LP). The nutrients were purchased dry and mixed into two concentrated stock solutions. $Ca(NO_3)_2$, KNO_3, and Fe-330 were in one and the other nutrients were in the other stock solution. The injection ratio of the pumps was measured and the concentration of the stock solution was chosen to give the final nutrient concentrations delivered to the plants as shown in Table 2.

The concentrations in Table 2 for the spring crop are the same as used by Jensen and Eisa (1972). Micronutrients were supplied from boric acid (.44 ppm B), manganous chloride (.62 ppm Mm), zinc sulfate (.09 ppm Zm), cupric chloride (.05 ppm Cu), and molybdenum trioxide (.03 ppm Mo). Several tomatoes from the spring crop developed "gray-wall" or blossom end rot. There also was considerable curling of the leaf petioles which suggested possible boron deficiency.

Leaf petiole samples were taken and tissue analysis was performed by a commercial testing laboratory (Chemonics). Their results in Table 3 suggested possible deficiencies of boron, nitrogen, and calcium. Therefore, the concentration of $Ca(NO_3)_2$ was increased in the nutrient solution on 26 April as indicated in Table 2. One-half of each greenhouse was also sprayed with boric acid at a rate of 9 gm H_3BO_3/gal of water on 28 April. The spray resulted in some leaf burn and no decrease in the incidence of leaf petiole curling.

Because of the possible mineral deficiencies exhibited with the spring crop, we decided to include a nutrient variable with the second crop. Therefore, the sand beds were divided as described previously, and two levels of nutrient were applied for the second crop. The "low" solution was almost the same as with the spring crop except K_2SO_4 was not added (Table 2). It is the same as the standard treatment of Fontes (1977). The "high" concentration was 50% greater than the "low" (Table 2), and it was applied to the three rows on the west side of each greenhouse. Micronutrient concentrations were the same as the spring crop for the "low" and 50% greater for the "high."

As in other years, clogging of the irrigation system continued to be a major problem. A yellow-gray precipitate accumulated in lines and clogged emitters, regulators, and solenoid valves. Chemical analysis showed it to be calcium phosphate. The lines and emitters required flushing every 2 weeks, and regulators stuck at unpredictable intervals. In an effort to reduce the problem, a cam switch was installed on 26 July 1977 to alternate calcium and phosphate injections and separate them with water so that phosphate and calcium would not be in the irrigation system at the same time. The plugging continued with no apparent decrease. Possibly the calcium already in the supply water was enough to react with the phosphate and precipitate. Since the pH of the nutrient solution was somewhat high (6.5), we tried adding HCl to the stock solutions to lower the pH of the calcium and phosphate pulses to 5.5 separated by supply water at pH 7.7. This treatment also failed to stop the plugging and the acidification was discontinued after about 6 weeks. With the next crop we plan to try applying phosphate directly and not through the irrigation system.

Pest Problems. Some problems were encountered with insects, diseases, and rodents. An initial spring planting was ruined by crickets and an initial fall planting by mice, so both crops were delayed by about 2 weeks. Diazinon granules and poison grain and traps were required to solve these problems. Before transplanting the spring crop, Vapam soil fumigant was diluted with three parts water and applied to the sand with a hose attachment. Plastic sheets were spread over the sand in each greenhouse to confine the vapor to the sand bed. Between crops, three 1-lb methyl bromide soil fumigant cannisters were discharged under plastic sheets as before.

Aphids attacked greenhouse 2 shortly before 25 February and were controlled with Pirimore at 1.4 gm/3 gal sprayed in all the houses. A white fly population appeared in greenhouse 2, but never seemed to get large enough to be a problem and no control measures were taken. A spider mite infestation also broke out in greenhouse 2 in the middle of July. They were hosed down twice with a mild detergent, but they persisted. Since the anticipated first harvest was 1 August, no insecticides were applied.

One plant was removed from greenhouse 2 on 14 July that had a virus disease or genetic defect. The leaves were thick, dark, leathery, and there was little fruit production. Also on 14 July one plant each was removed from greenhouse 1, 3 and 4 that appeared to have a wilt disease. The plants were spindly, yellowed, and had almost no leaves left. The crown was dark and rotten at the base of plant from #1, somewhat the same from #3, but #4 appeared to have a healthy crown.

The fall crop had even more insect problems than the spring crop. As seedlings, white flies invaded, and to avoid transplanting them into the greenhouses along with the tomatoes, they were sprayed with Cygon-2E at 1.5 tsp/gal on 14 September 1977. Cabbage-looper-type worms invaded at the end of September so Thuricide at 2 tsp/gal was applied to all the greenhouses. Leaf miners were present in all greenhouses, but never severe enough to be considered a problem. White flies were still a problem in all houses, so all houses were sprayed with 57% malathion at 1 tsp/gal on 5 October 1977 and repeated at 2 tsp/gal on 11 October. Red spider mites infested greenhouse 2 and greenhouse 1 on about 4 December. The "low" side of 2 was more affected. The plants in 1 and 2 were sprayed with a liquid detergent at 1 tsp/gal. The mites survived so were sprayed again on 8 December with Kelthane at 2 tsp/gal. About 2 weeks later, aphids appeared so all houses were sprayed with 50% malathion at 1 tbs/gal, and repeated on 9 January 1978. The aphids persisted particularly in 1 so it was fumigated with Dibrome 8EC at 1 tbs in a bucket on a hot plate. The aphids still survived so Dibrome was applied again with 2 tbs over-night. There was some leaf burn of the tomatoes close to the bucket, but the aphids finally were killed in #1.

The fall crop also had more disease problems than the spring crop, particularly with the lower foliage. Generally, the leaves would become yellowed, then necrotic in spots in the yellowed areas, and then the whole leaf would die. If a diseased leaf fell against a fruit, the fruit would develop a brown splotch at the point of contact. It became necessary to remove the lower diseased leaves very regularly, even above the lower fruits on many plants. About the middle of November, a weekly spraying with Manzate fungicide was started, and this necessitated harvesting on a weekly rather than half-weekly schedule. Toward the end of January, house 1 was most affected, 2 next, and 3 and 4 looking fairly good. In January we started alternating Benlate with the Manzate for the weekly spraying.

CO_2 Treatments. The carbon dioxide concentrations were monitored and controlled with conductimetric CO_2 analyzers which we developed and constructed. They are described in detail in the manuscript, "A Conductimetric Carbon Dioxide Analyser with Temperature Compensation." Their principle of operation, which was first reported by English workers, is based on measuring the increase in electrical conductivity of recirculating, deionized water when a sample air stream is bubbled through the water. An improvement over previous models was the addition of temperature compensation so the instruments could be used in greenhouses. The instruments provided a reliable measurement for CO_2 concentration in the 0-3000 ppm range, and their cost was 1/9 that of infra-red CO_2 analyzers.

Greenhouses 1, 3, and 4 were equipped with carbon dioxide generators (Johnson Gas Appliance Co., Model 1332) which burned natural gas. The conductimetric CO_2 analyzers had relays with adjustable set points. When the CO_2 concentration was below the set point, the generators were turned on, and when the CO_2 concentration increased past the set point the relay opened to automatically control the generator. The capacity of the generators was large compared to our small greenhouses, so an additional timer was installed in the control circuitry which allowed the generators to be on for only about 30 sec of every 5 min that the CO_2 analyzers called for more CO_2 generation. During the daytime the CO_2 concentration would oscillate around the set point with an amplitude of about 50 ppm and a period of about 45 min. At night, photoelectric switches turned off the generators, but the pilot lights and plant respiration produced CO_2, so the CO_2 concentrations were higher than in the daytime. Mechanical switches on the ridge vents also turned off the generators whenever the vents were open.

Table 1 summarizes the features of the environmental treatments imposed on the tomato plants for both the spring and fall tomato crops. Greenhouse 2 served as the conventionally-cooled greenhouse for both experiments. Greenhouse 3 was cooled with cooling tower water, thus permitting it to be sealed and fertilized with 1000 ppm CO_2 for both experiments. Greenhouse 1 was sealed and fertilized with 650 ppm CO_2 in the spring experiment. For the fall experiment, it was conventionally cooled and fertilized with 1000 ppm CO_2 when no cooling was required. By adding a CO_2 generator, a grower could use this treatment without modification of his existing cooling system. Greenhouse 4 was sealed but not enriched with CO_2 in the spring experiment. It was included to separate the effects of the higher humidity in the sealed greenhouses from the effects of CO_2 fertilization.

Instrumentation and Data Collection. In order to monitor the greenhouse environments and to obtain data with which to validate greenhouse energy balance simulation models, numerous data were recorded. The primary recording device was an Acruex Audodata Nine automatic data acquisition system with 130-channel capacity and punched paper tape output. We operated the system in an averaging mode whereby it scanned all the channels continuously and punched out their averages at hourly intervals. The system was used to record the outside solar radiation (Spectran radiometer), windspeed and direction (R. M. Young Gill propellor-vane), dew point (E G & G Cambridge Model 880 dew point hygrometer), dry bulb temperature (copper-constantan thermocouples), and wet bulb temperature (evaporative cooler). Several variables inside the greenhouses were also recorded including down-coming and reflected solar radiation (tube solorimeters to be described later), dry and wet bulb temperatures (thermocouple psychrometers), soil heat flux (Spectran soil heat flux plates), soil temperature, and CO_2 concentration (conductimetric CO_2 analyzers). The CO_2 concentrations were also simultaneously recorded on a multipoint strip chart recorder so that a visual record was always available for monitoring the CO_2 treatments. Hot and cold water temperatures and water temperature differences of the cooling towers and the inside heat exchanger pads were also recorded.

Small rectifiers were constructed to produce a 5V DC signal from 115 V AC. They were connected to the thermostats which controlled the heating, cooling, and emergency ventilation systems. After averaging, the output from these rectifiers was proportioned to the fraction of each hour a particular thermostat was "on," and therefore an automatic record was obtained of the energy use of the environmental control systems.

Elapsed time indicators were also installed on the thermostats, and these were read manually. Manual readings were also taken of water meters to determine the volume of cooling water used, of irrigation water applied to each treatment, and of drainage water from the irrigation sumps. Likewise, gas meters were read manually to determine the natural gas consumption of each greenhouse.

Plant measurements included height until the plants reached the supporting cable and weight of prunings and other plant material carried out of the greenhouse. All fruit was separated into marketable and unmarketable, counted, and weighed. Periodic sub-samples were taken for moisture content determination by oven drying.

Tube Radiometers. A tube solar radiometer was designed by Harper (1977) to measure incoming or reflected solar radiation. His design formed the basis for building a unit with two sensing surfaces, one for measuring incoming and another for reflected radiation.

The sensing surfaces were constructed of copper foil plates with adhesive backing. The plates were mounted on two strips of balsa wood. The sensing surfaces were 120 cm long, 3.5 cm wide, and 0.5 cm thick. The two strips of balsa wood were glued to a 0.5-cm spacer block to form a unit 1.5 cm thick. The strips formed an upper and a lower sensing surface with an air space between. Strips of copper foil 3.5 cm wide were glued to both surfaces with contact cement because the adhesive backing would not hold firmly enough alone. The cement was allowed to dry for 24 hours. The foil was then cut into 1.5-cm x 5-cm plates. The plates were connected by soldering 0.0508-mm constantan wire and 0.0508 copper to form a 20-junction thermopile (Harper, 1977). The constantan wires were placed across two adjacent plates and the copper wires were placed on alternating plates. Liquid solder flux was used to clean the plates to hold the wire in place for soldering, and to assure good soldering contact. After checking for open circuits, the solder joints were cleaned with benzene. A coat of black paint was used to prime the surfaces and all exposed wood was painted with flat black latex paint to prevent moisture absorption. Then the plates were given two coats of flat black and flat white paint with the black and white alternating in a grid pattern. The paint was allowed to dry for a week in sunlight, before placing the unit in a pyrex glass tube 122 cm in length and 4.5 cm diameter. A rubber stopper with holes was used to seal the unit. The lead wires were connected to a terminal strip which was attached to one rubber stopper with screws. Copper tubes inserted through small holes were used to pass the lead wires to the outside and to allow dry air to be pumped through the radiometer to prevent condensation of moisture and paint fumes on the inside of the glass. We found the paint on the radiometer should be allowed to age for about a month in sunlight before calibration because the absorption of latex paints will initially change with exposure to sunlight.

During calibration and use, the sensing surfaces must be carefully aligned with the horizontal plane. The only maintenance the units have needed has been cleaning the outside of the glass, changing the drying column, and routine calibration checks which we did every 3 months.

RESULTS AND DISCUSSION:

Qualitative Growth Characteristics. There was little initial difference in appearance between the treatments (Table 1) for the spring crop. After about a month or two, however, many of the plants began to curl. Two distinct types of curling were observed. The first was a corkscrew curling of the petioles of newly forming leaves suggestive of boron deficiency (Skinner and Purvis, 1949). About 60%, 70%, 60%, and 15% of greenhouses 1, 2, 3, and 4, respectively, were curled on 26 April. There was no pattern related to CO_2 or humidity treatments (Table 1). Spraying half of each house with boron had no effect on this curling as discussed previously. As the crop progressed into the hot summer, this type of curling became no more severe, and greenhouse 4 was still less affected than the others. With the fall crop, some plants did exhibit petiole curling, but the incidence was much less than with the spring crop.

The other type of curling was a rolling of the leaf blades parallel to the petiole, so the leaves were shaped more like yucca leaves. Unlike the other type of curling, this type was more prevalent on older leaves, while the youngest looked normal. This type of curling seemed related to temperature, light intensity, and probably photosynthetic rate. With the spring crop, the CO_2-fertilized houses were affected first in March. Later, as light intensity and temperature (and presumably photosynthesis) occurred at a more rapid rate, all houses were affected. When the fall crop was started, the CO_2-fertilized houses curled almost immediately, but the unfertilized houses did not. As the season turned to winter with lower temperatures and light intensities (and presumably lower photosynthetic rates), the curling in the CO_2 houses ceased. In January 1978, none of the houses were exhibiting curling.

This second kind of curling or leaf blade rolling is similar to that described by Madsen (1974). He found that tomato leaf's curl correlated with CO_2 concentration and with starch content of the leaves. He postulated that in CO_2-fertilized leaves with high photosynthesis rates the starch accumulated faster than it could be translocated out of the leaves, and the accumulated starch granules deformed the chloroplasts and leaves. Our observation of leaf curl and yield data (Tables 4, 5, 6) are consistent with this explanation, because the greatest leaf curl and highest yields were found together in the spring crop, and no curl and low yield in the fall crop.

Tomato Yields. Tables 4, 5, and 6 present the tomato yield results by month for the two experiments. Table 4 is of most economic importance because it contains the marketable yield data. The first group of data for the spring crop were most encouraging. First the 8.58 kg/plant yield of the check greenhouse (#2) was higher than reported any other workers, although our tomato literature search has focussed primarily on CO_2 fertilization results. Then second, the 12.66 kg/plant yield from the sealed greenhouse #3 fertilized with 1000 ppm CO_2 was 48% higher than even the check, a truly record yield so far as we know. The yield of greenhouse 1 with 650 ppm CO_2 was intermediate at 10.04 kg/plant for a 17% increase. The unenriched, yet sealed, greenhouse 4 suffered a yield reduction of 13% due to a slightly lower CO_2 concentration or more likely to the considerably higher humidity (Table 1).

Inspection of the upper right portion of Table 4 shows the yield increase of greenhouses 1 and 3 over 2 was primarily due to more tomatoes rather than larger tomatoes. Table 5 reveals that differences in unmarketable fruit production for the spring crop were small compared to the total amount and differences of marketable fruit production. The differences in total dry matter production in Table 6 for the spring crop are less striking than the marketable yield differences, with the 1000 ppm having a 27% increase. This implies the CO_2-fertilized houses put relatively more dry weight into fruit rather than stems and leaves.

The first months of production from the fall crop have failed to duplicate the results of the spring experiment. Referring to Table 4, the overall yields for all treatments have only been about half those of the spring crop, possibly due to the lower winter light intensities. For the low nutrient concentration, greenhouses

1, 3, and 4 had increases apparently due to CO_2 fertilization of 6, 31, and 6%, respectively. Unfortunately, the "Low" side greenhouse 2 was the site of an infestation of spider mites on 4 December so they could have affected these results. At the "high" nutrient concentration, the sealed greenhouses, 3 and 4, actually suffered a depression in marketable yield with house 1, which receives CO_2 fertilization part-time actually performing the best. There was a greater production of unmarketable fruit (Table 5) in the CO_2-fertilized houses so the total fruit production in houses 3 and 4 was slightly greater than the check house 2. The total dry matter production (Table 6) has shown increases due to CO_2 fertilization from 4 to 22%, but there are no particular trends between the levels of the CO_2 fertilization.

There do not appear to be any consistent or logical differences due to the level of nutrient solution concentration. We expected that possibly there would be an interaction with nutrient level and CO_2 fertilization so that the CO_2-fertilized houses would perform even better with a higher nutrient concentration. However, in greenhouse 3 at 1000 ppm CO_2, the "high" side of the house actually yielded lower than the "low," and the difference between the two sides of the check house was about as large as the other two fertilized houses.

CO2 Consumption. The amount of natural gas supplied to the greenhouses expressed as kg CO_2/plant is presented in Table 7. The winter months with their shorter days required less CO_2. In spite of much caulking, there appear to be differences in degree of sealing between the houses. Greenhouse 4 required less CO_2 than 3 even though it was at a higher concentration. Also shown is the percentage of CO_2 recovered as dry matter in the plants. Again, in spite of much caulking, only 19% overall was recovered from the spring crop. It appears that a somewhat lower figure will result for the current fall crop.

Energy Consumption. The length of time per month that the heating, cooling and emergency ventilation systems were in operation is listed in Table 8. The heaters were on about 8 hrs per night in

January and progressively lesser amounts in spring and fall months to zero in the summertime. Greenhouses 1, 3, and 4 were caulked more than #2 to prevent loss of CO_2, and the sealing also saved energy as evidenced by the longer times of operation of the heater in #2. To help save energy, on 27 October a plastic sheet was placed over the entrance to the cooling pad chamber of #2. When the exhaust fan came on, the sheet was drawn away from the entrance and when the fan went off, it swung back, closing off the entrance. The heating energy use was closer to the other greenhouses after installation.

During July, the cooling systems on the sealed greenhouses were in operation about 15 hrs per day. In the hot humid months and also in September the cooling system was inadequate about 5 hrs per day and the emergency vents opened. This converted the direct contact heat exchange pads to evaporative coolers and thus provided additional cooling capacity, but the greenhouses were no longer sealed during these hours, and CO_2 fertilization was stopped when the vents were open. During July, the fan in greenhouse 2 operated about 100 hrs more than the fans in the other houses. Because the pads in 2 served as the cooling tower for 1, the pads in 2 had greater build-up of salts in the pads. The result was a lower air flow rate in 2, decreased cooling efficiency, and longer operating time.

The column for pumps in Table 8 for the spring experiment refers to the operating time of the pumps connecting the heat exchanger pads of 1 with the cooling tower pads of 2. They were wired to come on when either the thermostat in 1 or 2 called for cooling. In the winter and early spring months, greenhouse 2 generally received enough cooling from the slight connective mixing of its air with the air above its cooling tower pads, so the pump time was essentially equal to greenhouse 1 cooling time. Later into summer, pump time was somewhat more than either greenhouse 1 or 2 cooling time because the two thermostats didn't always call for cooling at identical times.

Table 9 presents the percentage of daylight hours that the greenhouses were sealed or unventilated and CO_2 fertilization could be practiced. During the months of February, March, November, December, and January little cooling was required, and all houses could have been CO_2-fertilized. At the other extreme is July when fan-pad house 2 could not have been fertilized with CO_2 but the sealed houses could have been 60% of the daylight hours. Overall, the spring crop could have been fertilized 60% of the time in a conventional fan-pad house or 90% of the time with the cooling tower systems. The fall crop could have been fertilized 78% and 96% of the time with fan-pad and cooling towers, respectively.

Measurements were taken of the amperage drawn by all of the various heaters, fans, and pumps, and these data were multiplied by 117 volts to obtain the rate of energy consumption of the devices when they were operating. The results are presented in Table 10. These are not the actual data for the pumps. An early design of the cooling towers and heat exchanger chambers called for spraying the water over the pads from nozzles. The resulting drop size proved to be too small, and it "rained" in the greenhouses. Therefore, the perforated pipe distribution system was designed, and its pressure and energy requirements were much less. The measured mechanical power output per pump was 120 watts, and so assuming a properly chosen pump would be 33% efficient, the figure of 360 watts per pump was used. If the cooling towers were on higher stilts so that the water would run by gravity from the towers to the inside heat exchanger pads, only one pump would be needed, and even less pump power would be required.

The actual energy consumption by month in MJ/plant is listed in Table 11. The figures for heating are all directly proportional to those in Table 8 so no additional comment need be made about them. The figures for cooling show considerable differences in energy usage between the greenhouse types. For the spring 1977 crop, greenhouse 2 would have used 118 MJ/plant if it had been cooled completely conventionally, whereas greenhouse 3 with an external cooling tower used 310. This was a 163% increase in cooling energy used to attain the 48% increase in yield (Table 4). The combined cooling system on greenhouses 1 and 2 used 222 MJ/plant or 88% more energy for a possible 24% yield increase averaged for the two greenhouses. Clearly, the cooling tower systems must be made much more efficient and/or yields increased much more in order for the cooling tower systems to be energy conservative.

Water Consumption. During the spring 1977 crop, the cooling towers and spray chambers had numerous leaks so the measurements of water use for cooling were worthless. Similarly, as discussed earlier, the plastic liner for the sand beds leaked so that no good measure of water passing through the sand, or thus of evapotranspiration, could be obtained. Between the spring and fall crops, the bulk of the leaks were sealed, and new liners were installed along with automatic sump pumps and water meters for the irrigation drainage water.

The results are presented in Table 12. Greenhouses 1 and 2 shared a common sump and single water meter so the cooling data for them were obtained by dividing the water meter readings by the total 100 plants in both greenhouses. These two greenhouses, which were cooled by a conventional fan-pad system, consumed 640 ℓ/plant which is less than sealed greenhouses 3 and 4 cooled by the cooling tower system which consumed 761 and 876 ℓ/plant, respectively. Greenhouses 1 and 2 used an average of 172 ℓ/plant for evapotranspiration which was 21% of their total water use. Greenhouses 3 and 4 used an average of 133 ℓ/plant for evapotranspiration or 14% of their total water use. This is less than 1 and 2, with most of the difference coming in October and November, because the cooling systems were operating more than in December and January. The evapotranspiration difference reflects the different humidities resulting from open versus closed cooling systems (Table 1).

A cooling water use of about 730 ℓ/plant and an evapotranspiration use of about 150 ℓ/plant correspond to water depths of 2.12 m and 0.44 m, respectively, at 0.35 m^2 per plant or 1.46 and 0.30 m, respectively, at 0.50 m^2 growing area per plant. Evaporation from open water surfaces in Phoenix is usually about 0.33 m for these 4 months (Cooley, 1970), so the evaporation rate inside the greenhouses was actually fairly close to that outside, indicating, no doubt, that the higher inside temperatures and vapor pressures were compensating the effect of the cover on restricting water loss. Nevertheless, the greenhouses did represent an efficient use of water considering that 0.66 kg/plant at 0.35 m^2/plant is considered a good yield from outdoors (Knott, 1957) while the greenhouses yielded 3-4 kg/plant after only two months of harvesting (Table 4).

Costs of CO_2 Fertilization. A rough idea of the operating costs involved with CO_2 fertilization in sealed greenhouses in Phoenix is given in Table 13. For the spring crop, greenhouse 3 produced an extra 4.08 kg/plant more marketable tomatoes than the check, which was worth about $4.50/plant. The additional operating expense for CO_2 and energy for cooling was about $2.70 per plant plus a few cents for water. Not included, however, are the capital costs of the cooling tower, pumps, and extra ducts, or the labor and marketing costs of handling the extra yield. These costs are probably on the order of $1.80/plant, but the estimates are difficult to make accurately on the basis of our small experimental equipment. Pending a more detailed cost analysis for a larger hectare scale, it appears that CO_2 fertilization in sealed greenhouses in Phoenix becomes profitable for yield increases of more than about 50%, and we were able to achieve a yield increase of this size in only one case (Table 4).

Another objective of this study is to assess the feasibility of utilizing storage of solar energy for heating at night and cooling during the day. Since such a device would reduce heating costs as well as provide cooling of a sealed greenhouse, the yield increase required from CO_2 fertilization to make the practice profitable would probably be lower. We plan to perform such a feasibility study this year, as well as continuing to evaluate the yield increases actually attainable in sealed, CO_2-fertilized greenhouses.

SUMMARY:

A major objective of this project is to evaluate the yield responses attainable with CO_2 fertilization in sealed greenhouses. Last year we reported on the construction of the greenhouses.

Two of the greenhouses are equipped with evaporative cooling towers which provide cool water for pumping inside to aspen excelsior direct-contact heat exchanger pads. The greenhouse air is cooled by recirculation through these pads. Another greenhouse is a conventional fan-pad-cooled house for the experimental control, and a fourth is built to be either sealed or conventional.

This year we conducted the first experiment with a spring crop of tomatoes, and now a second fall-winter crop experiment is under way. Tomato yields as well as CO_2, energy, and water consumption were recorded, the latter only for the fall crop. The yield results of the first experiment were encouraging. High yields were obtained from all greenhouses, even the control. A sealed greenhouse fertilized with 1000 ppm CO_2 yielded 12.7 kg/plant, 48% more than the control house. However, after 2 months of harvesting, the initial results of the second experiment under lower light winter conditions have not duplicated the yield results of the first experiment. Overall yields were about half those of the first experiment. The 1000 ppm CO_2 treatment increased marketable fruit 31% at a standard level nutrient solution concentration, but it decreased the yield 9% at a 50% more concentrated level of nutrient solution.

The CO_2 consumption of the 1000 ppm house averaged about 20 kg per plant for 10 months and cost about $0.50 per plant for 10 months for the natural gas burned to generate the CO_2. The CO_2 fixed as dry matter in the spring crop amounted to 19% of the CO_2 supplied to the greenhouse.

The energy consumption for cooling the sealed greenhouses amounted to about 320 MJ/plant for the spring crop, and this was about three times as much as required by the conventional fan-pad cooled house. Clearly, the cooling tower cooling systems were not energy conservative.

The water consumption figures were accurate only for the fall crop. They showed that the sealed greenhouse required about 830 ℓ/plant for cooling from the middle of September through January whereas the conventionally cooled houses required 640. The evapotranspiration was 130 and 170 ℓ/plant in the sealed and conventionally cooled houses, respectively, but with no difference for December and January.

The cost of providing the CO_2 fertilization was estimated. The value of the additional yield was about \$4.50/plant (at \$1.10/kg) for the spring crop. The operating cost of obtaining this extra yield was about \$0.30/plant for CO_2 (at \$0.024/kg), and \$2.40/plant for energy for cooling (at \$0.0125/MJ) for a total of about \$2.70/plant. A detailed analysis of what the capital costs for the cooling tower, pumps, ducts, and the labor and marketing costs of handling the extra yield for hectare scale greenhouses has not been done, but they are probably on the order of about \$1.80/plant. If so, about a 50% increase in yield is required to break even with the cooling tower cooling system, and this was achieved in only one case with no profit margin.

Next year, the experiments to evaluate the yield increases attainable with CO_2 fertilization in sealed greenhouses will continue. Also, a feasibility study is planned to evaluate the potential for storing solar energy to achieve daytime cooling and nighttime heating of sealed greenhouses. Such a system would reduce the energy cost for heating and would have a lower operating cost than the present cooling towers.

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Table 1. Summary of treatment conditions imposed by different greenhouse cooling methods and different levels of CO_2 enrichment and mineral nutrition.

Treat-ment No.	Green-house No.	Nutrient[a] Conc.	Cooling Method	Relative Humidity Day (%)	Relative Humidity Night (%)	CO_2 Concentration Day (ppm)	CO_2 Concentration Night (ppm)
Spring Crop (January - July, 1977)							
1	1	Low	Cooled water	80-90	85-95	650	2000
2	2	"	Conventional fan-pad	40-90	"	350	600
3	3	"	Cooled water	80-90	"	1000	1400
4	4	"	Cooled water	80-90	"	330	700
Fall Crop (September 1977 -							
1-LO	1	Low	Conventional fan-pad	40-90	85-95	1000[b]	1300
1-HI	1	High	" "	"	"	1000[b]	1300
2-LO	2	Low	" "	"	"	350	600
2-HI	2	High	" "	"	"	350	600
3-LO	3	Low	Cooled water	80-90	"	1000	1500
3-HI	3	High	" "	"	"	1000	1500
4-LO	4	Low	" "	"	"	1350	2000
4-HI	4	High	" "	"	"	1350	2000

a See Table 2.

b The greenhouse was fertilized with CO_2 only during the part of the daylight hours when no cooling was required.

Table 2. Concentration of nutrient elements supplied to the plants.

Fertilizer Source	Concentration of elements (ppm)						
	N	P	K	Mg	Ca	S	Fe
Spring Crop:							
$MgSO_4 \cdot 7H_2O$				50		67	
KH_2PO_4		62	77				
K_2SO_4			45			18	
KNO_3	28		77				
$Ca(NO_3)_2$	116				165		
(after 26 April)	(180)				(216)		
Fe-330							2.5
Irrigation water				16	56	33	
Total	144	62	199	66	221	118	2.5
(after 26 April)	(208)				(272)		
Fall Crop - low concentration:							
$MgSO_4 \cdot 7H_2O$				33		44	
KH_2PO_4		64	77				
KNO_3	28		79				
$Ca(NO_3)_2$	85				121		
Fe-330							2.5
Irrigation water				16	56	33	
Total	113	64	156	49	177	77	2.5
Fall Crop - high concentration:							
$MgSO_4 \cdot 7H_2O$				58		76	
KH_2PO_4		96	116				
KNO_3	42		118				
$Ca(NO_3)_2$	128				184		
Fe-330							3.8
Irrigation water				16	56	33	
Total	170	96	234	74	240	109	3.8

Table 3. Tomato tissue analysis.

Treatment[a] No.	ELEMENT CONCENTRATIONS: % dry weight N	P	K	Ca	Na	Mg	ppm dry weight Fe	Cu	Mn	Zn	B
Spring Crop (12 April 1977):											
1	2.70	0.81	6.25	0.75	0.09	0.43	90	6.5	20	32	11
2	2.52	0.81	6.42	1.10	0.13	0.43	110	11.5	25	36	11
3	2.22	0.81	7.04	0.78	0.15	0.38	70	12.0	23	24	11
4	3.25	0.97	9.61	1.50	0.26	0.59	40	8.0	40	44	6
Fall Crop (22 December 1977):[b]											
1-LO	5.53	0.61	1.90	0.62	0.07	0.40	82	18	66	44	22
1-HI	6.31	0.67	2.54	0.87	0.08	0.49	98	23	74	48	28
2-LO	5.23	0.68	2.32	0.87	0.07	0.43	168	21	80	52	25
2-HI	5.27	0.63	2.38	0.40	0.09	0.34	94	20	64	51	18
3-LO	5.56	0.64	2.38	0.52	0.07	0.37	78	21	46	49	18
3-HI	5.68	0.75	1.40	0.42	0.05	0.21	24	13	28	38	14
4-LO	4.94	0.63	2.32	0.83	0.08	0.34	74	17	43	54	14
4-HI	5.54	0.71	1.30	0.24	0.05	0.18	47	14	19	43	11
Jensen and Eisa (1972)	4.28	0.24	4.05	2.16	0.09	0.79	135	9.7	-	15	38
Lucas and Wittwer (1963)	2.5-3.5	0.50-1.00	6.00-10.00	1.25-3.00	0.02-0.40	0.30-1.00	20-100	5-25	50-200	20-200	20-40
Fontes (1977)											
Experiment 1	2.59	-	10.0	1.92	-	0.64	93	14	37	38	-
Experiment 2	2.10	-	8.1	1.33	-	0.65	52	14	37	49	-

a See Table 1.

b Tissue samples for the fall crop were the lateral shoots from a routine pruning. The other data in the table is from leaf petioles subtending the latest open flower clusters.

Table . . Fresh weight and number of marketable fruit.

	Fresh weight (kg/plant)								Number of fruit/plant							
	Treatment[a]								Treatment[a]							
	Low				High				Low				High			
Month	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Spring 1977 crop:																
CO_2 (ppm)	650	350	1000	330					650	350	1000	330				
April	0.44	0.04	0.74	0.27					1.5	.1	2.2	1.0				
May	4.15	3.13	4.76	3.52					17.0	12.7	17.3	16.4				
June	3.76	4.26	5.16	2.68					16.2	15.4	20.2	14.6				
July	1.69	1.15	2.00	1.01					9.6	6.5	10.2	5.8				
Total	10.04	8.58	12.66	7.48					44.3	34.5	49.8	37.8				
% increase from CO_2	+17		+48	-13					+28		+44	+10				
Ave. fruit size (kg)	0.23	0.25	0.25	0.20												
Fall 1977 - Spring 1978 crop:																
CO_2(ppm)	1000p	350	1000	1350	1000p	350	1000	1350	1000p	350	1000	1350	1000p	350	1000	1350
Nov	0.06	0.02	0.11	0.08	0.09	0.05	0.14	0.14	0.3	0.1	0.6	0.4	0.7	0.3	0.7	0.8
Dec	1.42	1.77	2.05	1.72	1.91	2.02	1.86	1.77	7.0	8.7	9.3	8.4	9.3	8.8	8.7	8.4
Jan	1.59	1.11	1.64	1.27	2.04	1.27	1.04	1.39	7.3	5.5	7.1	6.0	7.6	5.6	4.7	6.4
Total	3.07	2.90	3.80	3.07	4.04	3.34	3.04	3.30	14.6	14.3	17.0	14.8	17.6	14.7	14.1	15.6
% increase from CO_2	+6		+31	+6	+21		-9	-1	+2		+19	+3	+20		-4	+6
Ave. fruit size (kg)	0.21	0.20	0.22	0.21	0.23	0.23	0.22	0.21								
Ave. over CO_2 tmts		3.21				3.43				15.2				15.5		

a See Table 1.

Table 5. Fresh weight and numbers of unmarketable fruit.

	Fresh weight (kg/plant)								Number of fruit/plant							
	Treatment[a]								Treatment[a]							
	Low				High				Low				High			
Month	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Spring 1977 crop:																
CO_2 (ppm)	650	350	1000	330					650	350	1000	330				
April	0.24	0.00	0.04	0.08					2.9	0.1	0.5	0.9				
May	0.20	0.19	0.33	0.20					1.7	1.3	2.0	1.5				
June	0.24	0.28	0.64	0.29					2.2	2.5	1.6	2.5				
July	1.13	1.93	1.60	1.08					7.6	15.6	10.8	8.8				
Total	1.81	2.40	2.61	1.65					14.3	19.5	15.0	13.7				
Cull % of total fruit	15	22	17	18					24	36	23	27				
Fall 1977 - Spring 1978 Crop:																
CO_2 (ppm)	1000p	350	1000	1350	1000p	350	1000	1350	1000p	350	1000	1350	1000p	350	1000	1350
Nov	0.29	0.43	1.28	0.28	0.23	0.14	0.26	0.31	2.0	1.4	2.4	2.2	1.4	0.9	1.6	2.3
Dec	0.12	0.13	0.18	0.19	0.13	0.18	0.20	0.22	1.0	1.2	1.1	1.6	0.9	1.1	1.2	1.8
Jan	0.69	0.36	0.64	0.60	0.49	0.28	0.51	0.77	5.0	1.5	3.6	3.5	3.7	1.9	2.6	3.9
Total	1.10	0.92	2.10	1.07	0.85	0.60	0.97	1.30	8.0	4.1	7.1	7.3	6.0	3.9	5.4	8.0
Cull % of total fruit	26	24	36	26	17	15	24	28	35	22	29	33	25	21	28	26

a See Table 1.

Table 6. Total dry matter production.

Month	Treatment[a] Low 1	Low 2	Low 3	Low 4	High 1	High 2	High 3	High 4
	(kg/plant)							
Spring 1977 crop:								
CO_2 (ppm)	650	350	1000	330				
Feb-Apr	0.14	0.09	0.16	0.08				
May	0.38	0.32	0.45	0.30				
June	0.43	0.47	0.58	0.28				
July	0.38	0.40	0.44	0.28				
Total	1.33	1.28	1.63	0.94				
% increase from CO_2	+4		+27	-26				
Fall 1977 - Spring 1978 crop:								
CO_2 (ppm)	1000p	350	1000	1350	1000p	350	1000	1350
Sep-Nov	0.104	0.063	0.091	0.111	0.093	0.075	0.106	0.107
Dec	0.202	0.247	0.254	0.245	0.241	0.271	0.249	0.242
Jan	0.288	0.193	0.270	0.231	0.322	0.194	0.204	0.266
Total	0.594	0.503	0.615	0.587	0.656	0.540	0.559	0.615
% increase from CO_2	+18		+22	+17	+21		+4	+14
Average over CO_2 tmts		0.575				0.592		

a See Table 1.

Table 7. CO_2 consumption and CO_2 recovery percentage in plant dry matter.

Month	CO_2 supplied			CO_2 recovered		
	Greenhouse No.[a]			Greenhouse No.[a]		
	1	3	4	1	3	4
	(------ kg/plant -------)			(----- % ---------)		
Spring 1977 crop:						
CO_2 (ppm)	650	1000		650	1000	
Feb	0.83	0.75		0	0	
Mar	1.20	1.92		0	1	
Apr	2.35	2.14		9	10	
May	1.82	2.67		31	25	
June	1.92	2.56		33	33	
July	2.03	2.67		27	24	
Total	10.15	12.71	Ave.	19	19	
Fall 1977 - Spring 1978 crop:						
CO_2 (ppm)	1000p	1000	1350	1000p	1000	1350
1/2 Sep	0.81	0.75	0.43	0	0	0
Oct	1.78	2.14	1.82	0	0	0
Nov	2.74	1.82	1.50	4	5	7
Dec	1.92	1.39	1.17	12	18	21
Jan	2.46	1.60	1.60	12	15	16
Total	9.71	7.70	6.52	Ave. 6	8	9

a See Table 1.

Table [illegible]. Monthly time of operation of heating, cooling, and emergency ventilation systems.

Month	Greenhouse No.[a] 1 heat	1 cool	1 vent	1 pumps	2 heat	2 cool	2 vent	3 heat	3 cool	3 vent	4 heat	4 cool	4 vent
	(hours)												
Spring 1977:													
Greenhouse type[a]	sealed				fan-pad			sealed			sealed		
Feb	96.4	49.0	.2	-	185.6	18.3	.0	134.4	58.1	.1	149.6	53.0	.1
Mar	116.8	57.1	1.4	-	209.0	12.1	.0	159.6	75.8	.1	154.5	57.2	.0
Apr	63.4	205.7	5.6	205.5	108.9	59.0	.0	61.2	183.6	.1	80.4	187.4	1.1
May	9.2	197.5	.2	190.1	26.0	67.0	2.3	7.7	185.8	.0	15.8	204.6	2.1
Jun	.0	329.6	21.1	342.6	.0	334.7	.1	.0	326.9	8.3	.0	334.8	36.4
Jul	.0	448.0	214.8	562.8	.0	542.0	1.0	.0	440.6	177.1	.0	463.3	153.8
Total	285.8	1286.9	243.3	1301.0	529.5	1033.1	3.4	362.9	1270.8	185.7	400.3	1300.3	193.5
Fall 1977 - Spring 1978:													
Greenhouse type[a]	fan-pad				fan-pad			sealed			sealed		
1/2 Sep	3.2	112.4	112.6		3.1	108.5	5.3	3.1	122.9	27.6	3.1	111.8	44.2
Oct	16.2	171.0	171.7		12.7	182.6	.1	4.4	223.1	13.7	4.5	198.6	42.2
Nov	94.0	21.7	21.8		144.1	7.4	.0	103.5	57.4	.1	111.4	58.9	.0
Dec	142.9	11.7	14.2		215.9	6.0	3.1	179.7	38.2	3.2	173.5	21.6	3.2
Jan	215.5	12.3	12.4		254.9	2.4	2.5	231.7	36.0	.5	255.3	14.0	.2
Total	471.8	329.1	332.7		630.7	306.9	10.9	522.4	477.6	45.1	471.8	404.9	89.8

a See Table 1.

Table 9. Percentage of daylight hours that greenhouses were sealed and were (or could have been) fertilized with carbon dioxide.

Month	Hours of Daylight		Greenhouse No.[a] 1	2	3	4
	(hr)		(-------------	%	-------------	------)
Spring 1977 Crop:						
Greenhouse type:			sealed	fan-pad	sealed	sealed
Feb	264.0		100	93	100	100
Mar	338.5		100	96	100	100
Apr	390.0		99	85	100	100
May	430.9		100	84	100	99
Jun	431.1		95	22	98	92
Jul	440.8		51	0	60	65
Total	2295.3	Ave.	89	59	92	91
Fall 1977 - Spring 1978 Crop:						
Greenhouse type:			fan-pad	fan-pad	sealed	sealed
1/2 Sep	181.8		38	40	85	76
Oct	352.4		52	48	96	88
Nov	313.5		93	98	100	100
Dec	309.0		96	98	98	98
Jan	315.2		96	99	100	100
Total	1471.9	Ave.	78	79	97	94

a See Table 1.

Table 10. Rate of electrical energy usage (power) of the heating and cooling systems.

Device	Power (kw)	Corresponding Time[a]	Comment
Heating:			
All greenhouses			
heaters	6.85	heat	
Cooling:			
Greenhouse 3			
duct fan	1.46		
tower fan	1.21		
pumps	.72		
total	3.39	3 cool	
Greenhouse 4			
duct fan	1.52		
tower fan	1.40		
pumps	.72		
total	3.65	4 cool	
Spring 1977			
Greenhouse 1 while running alone			
duct fan	1.47		
blowers	1.02		
pumps	.72		
total	3.21	(pumps - 2 cool)	sum of these two for cooling energy cost of greenhouse 1 if it had operated with a cooling tower
Greenhouse 1 and 2 while running simultaneously			
duct fan	1.47		
exhaust fan	1.29		
pumps	.72		
total	3.48	(1 cool + 2 cool-pumps)	
Greenhouse 2 while running alone			sum of these three is cooling energy cost for greenhouse 1-2 combination
exhaust fan	1.29		
pumps	.72		
total	2.01	(pumps - 1 cool)	
Greenhouse 2 if operated alone in conventional way without large cooling tower pumps			
exhaust fan	1.29	2 cool	
Fall 1977 - Spring 1978			
Greenhouse 1 conventional cooling			
duct fan	1.47	1 cool	
Greenhouse 2 conventional cooling			
exhaust fan	1.29	2 cool	

a This refers to the column in Table 8 in which the operating time is listed.

Table 11. Energy consumption.

month	1-alone heat	1-alone cool[b]	1 and 2 combined cool[c]	2-alone heat	2-alone cool[d]	3 heat	3 cool	4 heat	4 cool
	(MJ/plant)								
Spring 1977:									
Greenhouse type[a]	sealed			fan-pad		sealed		sealed	
Feb	47.5	28.2	14.1	91.5	5.4	66.3	14.2	73.8	13.9
Mar	57.6	30.6	14.2	103.1	7.0	78.7	18.5	76.2	15.0
Apr	31.3	48.7	24.4	53.7	17.0	30.2	44.8	39.7	49.3
May	4.5	47.1	23.6	12.8	17.2	3.8	45.4	7.8	53.8
Jun	.0	82.4	85.1	.0	30.3	.0	79.8	.0	88.0
Jul	.0	111.8	60.1	.0	40.8	.0	107.6	.0	121.7
Total	141.0	304.9	221.5	261.1	117.7	179.0	310.3	197.5	341.7
Fall 1977 - Spring 1978:									
Greenhouse type[a]	fan-pad			fan-pad		sealed		sealed	
1/2 Sep	1.5	11.9		1.5	10.1	1.5	30.0	1.5	29.4
Oct	8.1	18.1		6.3	17.0	2.2	54.5	2.2	52.2
Nov	46.4	2.3		71.1	.69	51.1	14.0	54.9	15.5
Dec	70.5	1.2		106.5	.55	88.6	9.3	85.6	5.78
Jan	106.3	1.3		125.7	.22	114.3	8.9	125.9	3.78
Total	232.8	34.8		311.1	28.6	257.7	116.7	270.1	106.5

Greenhouse No.[a]

a See Table 1.

b The spring 1977 data are based on cooling 50 plants in greenhouse 1 if an external cooling tower had been used like for greenhouses 3 and 4. The Fall 1977-Spring 1978 data are based on cooling 50 plants in a conventional fan-pad cooled greenhouse.

c These data are based on cooling 100 plants in greenhouses 1 and 2 with combined cooling system where the pads for 2 were the cooling tower for 1.

d The spring 1977 data are based on cooling 50 plants in greenhouse 2 if it had a completely conventional fan-pad cooling system with no large cooling tower pumps. The same is true for the Fall 1977-Spring 1978 data.

Table 12. Water consumed by the cooling systems, supplied to the plants by the irrigation system, and evapotranspired from soil and plants.

	Cooling Water[a]			Ave. Irrigation Water[b]	Evapotranspiration							
	Greenhouse No.[c]				Greenhouse No.[c]							
					1		2		3		4	
Month	1 and 2	3	4		LO	HI	LO	HI	LO	HI	LO	HI
	(ℓ/plant[d])											
1/2 Sep	237	222	283									
Oct	304	356	454	113	46	48	39	41	30	31	28	24
Nov	53	101	108	102	55	66	51	45	35	39	41	35
Dec	28	55	36	57	30	35	38	-	33	33	31	34
Jan	18	26	15	62	36	35	37	-	30	37	34	35
Total	640	761	896	334	167	184	165	-	128	140	134	128

a Including water used for flushing.

b Not including water used for flushing.

c See Table 1 for greenhouse and treatment descriptions.

d 1.0 ℓ/plant = 2.9 mm @ 0.35 m^2 soil area per plant.

Table 13. Estimate of additional income and additional operating expenses per plant for producing tomatoes in sealed, CO_2-fertilized greenhouses compared to conventional greenhouses.

Item	Estimated Unit Value	Treatment[a] LOW 1	LOW 2	LOW 3	LOW 4	HIGH 1	HIGH 2	HIGH 3	HIGH 4
		($/plant)							
Spring 1977 Crop:									
Income:									
Marketable tomatoes	$1.10/kg($0.50 lb)	11.04	9.44	13.93	8.23				
Change from check		+1.60		+4.49	-1.21				
Operating Expenses:									
CO_2	$0.024/kg($0.12/therm)	0.25	0.00	0.31	0.00				
Water		?	?	?	?				
Energy for cooling	$0.0125/MJ ($0.045/kw hr)	3.81	1.47	3.88	4.27				
(1 & 2 combination)		(2.77)							
Totals		4.06	1.47	4.19	4.27				
Change from check		+2.59		+2.72	+2.80				
Fall 1977 - Spring 1978 crop after 2 months of harvest:									
Income:									
Marketable tomatoes	$1.10/kg ($0.50/lb)	3.38	3.19	4.18	3.38	4.45	3.67	3.35	3.63
Change from check		+0.19		+0.99	+0.19	+0.78		-0.32	-0.04
Operating Expenses:									
CO_2	$1.10/kg	0.23		0.18	0.16	0.23		0.18	0.16
Water	$0.00018/ℓ($220/acft)	0.15	0.15	0.16	0.19	0.15	0.15	0.17	0.19
Energy for cooling	$0.0125/MJ ($0.045/kwhr)	0.44	0.36	1.46	1.33	0.44	0.36	1.46	1.33
Totals		0.82	0.51	1.80	1.68	0.82	0.51	1.81	1.68
Change from check		+0.31		+1.29	+1.17	+0.31		+1.30	+1.17

a See Table 1.

TITLE: DEVELOPMENT OF REMOTE SENSING TECHNIQUES FOR AGRICULTURAL WATER MANAGEMENT AND CROP YIELD PREDICTION

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

CODE NO.: USWCL 77-1

Work conducted under this outline this year consisted of new experiments and analyses designed to verify and improve our remote sensing models for i) root zone soil water content assessment, ii) plant water potential assessment, and iii) crop yield prediction. Our results are summarized in eight manuscripts that have been submitted for publication.

1. Jackson, R. D., Idso, S. B., and Reginato, R. J. Assessing soil water contents of crop root zones from measurements of crop canopy and air temperature. Submitted to Water Resources Res.

Soil water contents in the root zones of cotton, alfalfa, and wheat crops grown at Phoenix, Arizona, were measured with a neutron moisture meter. Concurrently, presunrise and midafternoon (about 2 PM) canopy temperatures were monitored with infrared thermometers. Air temperatures about 1 m above the crops were measured with shielded, aspirated thermocouples and hand-held, aspirated psychrometers. The canopy-air temperature differentials were uniquely related to the soil water contents of the crop root zones; but a different relationship prevailed for each crop, with the range of temperature differential being smallest for wheat and greatest for alfalfa. By using the air temperature measurements to normalize the afternoon-presunrise canopy temperature differential for environmental variability, however, data for both wheat and alfalfa fell within the same limits. Some data for field beans at Davis, California, also fell within these limits. Our results indicated that a potential exists for determining the water content of crop-root zones using remote-sensing techniques.

2. Millard, J. P., Jackson, R. D., Goettelman, R. C., Reginato, R. J., and Idso, S. B. Crop water stress assessment using an airborne thermal scanner. Photogrametric Eng. and Remote Sensing. In press.

An airborne thermal scanner was used to measure the temperature of a wheat crop canopy in Phoenix, Arizona. The results indicate that canopy temperatures acquired about an hour and a half past solar noon were well correlated with presunrise plant water tension, a parameter directly related to plant growth and development. Pseudo-colored thermal images reading directly in stress degree days, a unit indicative of crop irrigation needs and yield potential, were produced. The aircraft data showed significant within-field canopy temperature variability, indicating the superiority of the synoptic view provided by aircraft over localized ground measurements. The standard deviation between airborne and ground-acquired canopy temperatures was 2 C or less.

3. Ehrler, W. L., Idso, S. B., Jackson, R. D., and Reginato, R. J. Diurnal changes in plant water potential and canopy temperature of wheat as affected by drought. Submitted to Agron. J.

Diurnal courses of plant water potential and canopy-air temperature differential were determined for wet, dry and intermediate soil water conditions. The temperature difference for plants in wet soil peaked at 1000 hours, then decreased so that by 1400 hours it was negative in five of six tests. For plants in dry soil, however, the temperature difference rapidly increased to positive values shortly after sunrise, peaked near solar noon, and then decreased only slightly by 1400 hours, remaining positive in all six drought treatments. Thus, the greatest absolute differences in the canopy-air temperature differentials of wheat growing in wet and dry soils occurred near 1400 hours. This would be the best time of day to make temperature measurements for correlation with plant water potential for drought severity assessment.

4. Idso, S. B., Hatfield, J. L., Reginato, R. J., and Jackson, R. D. Wheat yield estimation by albedo measurement. Remote Sensing of Environ. In press.

Last year we published a paper indicating that simple reflected solar radiation measurements appeared to have the potential to be correlated with final grain yields of wheat. We postulated at that time that the relationship should be independent of location, soil type, and density of planting (as long as complete ground cover was achieved), being a function solely of crop species. Additional experiments this year with different planting rates at Phoenix, Arizona, and Davis, California have confirmed these hypotheses.

5. Reginato, R. J., Idso, S. B., and Jackson, R. D. Estimating forage crop production: A technique adaptable to remote sensing. Remote Sensing of Environ. In press.

In this experiment, the stress degree day concept of crop yield prediction which we developed and reported on last year was extended from a grain to a forage crop. It was found to be valid for four sequential cuttings of alfalfa grown at Phoenix, Arizona, over the period May-August.

6. Jackson, R. D., Idso, S. B., and Reginato, R. J. Data requirements for a wheat yield model using remotely sensed canopy temperatures. Proc. Crop Yield Modeling Workshop, Columbia, Missouri. In press.

The stress degree day concept of wheat yield prediction is based on the availability of air temperature data and the remote sensing of crop canopy temperatures. The orbital constraints on satellites designed to remotely acquire such surface temperatures, and the naturally varying cloud cover of the earth, conspire to reduce the availability of the critical canopy temperature data. Our analysis of 2 years' use of the stress degree day concept at Phoenix, Arizona, indicates that for sky conditions there, a 3-day repeat cycle in data availability is about the longest interval that can be tolerated. It is anticipated, however, that for a climatically driven model in which the crop's canopy temperature is not the primary governing factor, less frequently obtained data would not be detrimental. Such models need to be developed, and more studies of the type described here conducted in other areas having different probabilities of cloud cover.

7. Idso, S. B., Hatfield, J. L., Jackson, R. D., and Reginato, R. J. Grain yield prediction: Extending the stress degree day approach. Submitted to Science.

The stress degree day concept of grain yield prediction, as originally developed, was found to be site specific. That is, in a climate different from that of Phoenix, Arizona, where it was developed, it gave incorrect predictions. Modifications incorporating the classical growing degree day concept were thus made. Not only did these changes allow crop yields to be successfully predicted in the two different climates for which data were available, they also allowed the times of cessation of crop growth to be predicted.

8. Idso, S. B., Pinter, P. J., Jr., Hatfield, J. L., Jackson, R. D., and Reginato, R. J. A complete remote sensing technique for the prediction of wheat yields prior to harvest. To be submitted to an appropriate journal.

Data we have acquired in two different years and in two different locations for "Produra" wheat are used to build upon the foundations of prior grain yield models we have developed to construct a new and more powerful model that does not require a ground-based air temperature measurement, as did our earlier models. The resultant model is capable of predicting both when plant growth will cease and what final grain yield will be. It requires measurements of only crop canopy temperature and reflected solar radiation. We feel it represents the first truly complete remote sensing approach to this type of real-time crop condition assessment and potential yield prediction to be developed. As such, it could provide a realistic technique for the assessment of global grain production within the framework of existent technology.

PERSONNEL: R. D. Jackson, S. B. Idso, R. J. Reginato, P. J. Pinter, Jr., W. L. Ehrler, J. L. Hatfield (cooperator in Land, Air and Water Resources Dept., Univ. of Calif. at Davis).

TITLE: EFFECTS OF AIRBORNE PARTICULATES ON SOLAR AND THERMAL RADIATION AND THEIR CLIMATOLOGICAL CONSEQUENCES

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

CODE NO.: USWCL 77-2

One comprehensive experimental study was conducted under the aegis of this outline this year:

Idso, S. B., and Brazel, A. J. Planetary radiation balance as a function of atmospheric dust: Climatological consequences. Science 198, 731-733. 1977.

In this study an analysis of several atmospheric dust-loading events at Phoenix, Arizona, under background cloudless sky conditions, allowed determination of dust-induced changes in both the net solar and net thermal radiation received at the earth's surface. The resultant climatological forcing function for surface temperature change was plotted vs. the ratio of diffuse to normal incidence solar radiation. It was found that initial increases in atmospheric dust concentration tend to warm the planet's surface. After a certain critical concentration has been reached, continued dust buildup reduces this warming effect until at a second critical dust concentration a cooling trend begins. This second critical dust concentration is so great, however, that any particulate pollution of the lower atmosphere by man will have a tendency to increase surface temperatures. Thus, anthropogenically-produced tropospheric aerosols cannot be looked upon as offsetting the the warming tendency of increased carbon dioxide: their concurrent buildups must inexorably tend to warm the planet's surface.

PERSONNEL: Sherwood B. Idso and Anthony J. Brazel (cooperator from Geography Department, Arizona State University)

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 main objective of the work at the Flushing Meadows Project in 1977 continued to be the maximization of nitrogen removal by using reduced lengths of flooding periods and reduced water depths in the basins. At the 23rd Avenue Project, additional infiltration studies were made to determine to what extent the low infiltration rates in the recharge basins were caused by algae and by air-pressure build-up in the unsaturated zone beneath the advancing wet front. Also, a small experiment was set up at the Mesa Sewage Treatment Plant to field test the suitability of primary effluent for rapid infiltration. Previous studies on soil columns in the laboratory indicated that primary effluent gave good results, but field testing is necessary before definite conclusions can be reached.

Dr. J. C. Lance continued his temporary assignment with the National Program Staff in Beltsville, Maryland, and extended his original 1-year period, which was due to expire in November 1977, by 6 months.

I. FLUSHING MEADOWS PROJECT

1. Basin Management and Infiltration Rates.

The surface condition of the basins was essentially the same as in 1976. Over the years, however, bank erosion and digging by animals have caused a gradual flattening of the bank slopes, which in turn resulted in a decrease of the width of the water surface in the basins from the design value of 20 ft, especially at shallow water depths. Below is a summary of the bottom condition of the six basins and the actual width of the water surface at a water depth of 7 inches (one 6-inch board in the overflow structure):

Basin No.	Width of Water Surface, ft	Bottom Condition
1	18	Essentially no vegetation, soil covered by sludge and other organics with a dry thickness of 1/4 to 1/2 inch
2	18.5	Sludge and other organics with a dry thickness of 1/4 to 1/2 inch on top of gravel layer.
3	18	Old grass thatch layer on 40% of bottom area, 2 to 3 inches thick in places. Covered with 1/4 to 1/2-inch layer of organics.
4	16	Covered for 30% with old grass thatch, mostly near sides of basin. Bottom and thatch are covered with 1/4 inch sludge layer.
5	16	Covered for 50% by old grass thatch, live grass along sides covering about 10% of bottom; thatch and soil covered by 1/4-inch layer of organics.
6	18	Old grass thatch covering first 500 ft of basin by about 75%, no thatch in rest of basin; bottom covered with 1/4-inch layer of organics.

The water depth in the basins was kept at about 7 inches during flooding, using one 6-inch board in the outflow structure. The pumping schedule was continued at 8 days on and 13 days off, yielding flooding and drying periods of 9 and 12 days, respectively (it took about 1 day for the basins to become dry after the pump was turned off).

The infiltration rates for the basins, based on the actual widths of water surface, are shown in Figure 1. Infiltration rates generally were lower in the first 5 months of the year, which was most likely due to the high suspended solids content of the effluent which averaged 53 mg/l for this period. For the other 7 months of the year, the average suspended solids content of the effluent was 20 mg/l (Table 1). For the second half of the year, infiltration rates generally ranged between 2 and 3 ft/day, except basin 1 which had rates between 1 and 2 ft/day. The accumulated infiltrations (Figure 2) show that basin 1 had the lowest infiltration rate, followed by basin 2. The other basins all had about the same infiltration rates. The average accumulated infiltration for all six basins was 248 ft in 1977. This is higher than the 198 ft obtained with the same schedule in 1976. However, this figure was calculated on the basis of a water surface width of 20 ft. The actual width in 1976 may have been less. Assuming a width of 18 ft, the adjusted average infiltration rate for 1976 is 220 ft, which is still 28 ft less than the accumulated average infiltration in 1977. The 248 ft actually is close to the maximum hydraulic loading rate of 300 to 400 ft that was obtained in the first few years of the project with longer inundation periods and water depths of 1 ft.

2. Response of Water Table to Infiltration.

The water table in 1977 showed a general decline until about October (Figure 3). This was undoubtedly due to the heavy pumping of groundwater in the Salt River Valley in the low runoff year of 1977. After October, reduced pumping caused groundwater levels to rise again. Water level rises in the East Center Well (ECW) due to infiltration from the basins were based on the average static water-table depth before and after the flooding period. Dividing the equilibrium height of the mound above the average static water-table level by the average infiltration rate of basins 3 and 4 then yielded the mound height per unit infiltration rate shown in Figure 4. This ratio is an indicator of the effective aquifer transmissivity. The average value for this ratio in 1977 was 0.77 days, which is essentially the same as the 0.78 days obtained in 1976 (corrected for the decreased width of the water surface in the basins). The average ratio in the period 1968-1972 was 0.75 days. This includes one outlying high value of 0.87 days measured in 1972. The other values in the 1968-1972 period were relatively close together and averaged 0.73 days. Considering that the water table in 1976 and 1977 was several feet lower than in the 1968-1972 period, a slight difference in the ratio could easily be caused by non-uniformity of aquifer materials near the water table. There is some evidence that more permeable layers are present at the 10-ft level, so that a drop of the water table below this depth would exclude such permeable layers from the aquifer. Since there is no major change in the ratio of mound height to the unit infiltration rate, the conclusion must be drawn that groundwater recharge has had no effect on the hydraulic properties of the aquifer.

3. Nitrogen.

Total-N concentrations of the secondary sewage effluent showed a late-summer dip to about 20 mg/l, but were around 30 mg/l for most of the year (Figure 5). Average total-N concentration for the year was 27.4 mg/l, of which 20.7 was in the ammonium form, 3.05 in the nitrate form, and the rest or about 4 mg/l in the organic form (plus perhaps a few tenths mg/l as nitrite).

Ammonium and nitrate nitrogen concentrations in the renovated water from wells 0, 1-2, ECW, 5-6, and 7 are shown in Figures 5, 6, 7, 8, and 9. NH_4-N concentrations were low, while NO_3-N levels showed the characteristic peaks in response to new flooding periods. Average NH_4-N, NO_3-N, and organic N concentrations in mg/l for the flooding periods (when groundwater movement was strongest) were:

Well	NH_4-N	NO_3-N	Organic-N	N-Removal
0	0.41	6.8	0.7	
1-2	1.45	9.1	0.58	63%
ECW	2.8	6.25	0.58	67%
5-6	0.76	10.46	0.49	59%
7	0.39	0.84	0.54	

The removal percentages were only calculated for the wells within the basin area, assuming piston flow and multiplying

N-concentrations by infiltration rates for both secondary effluent and renovated water to get pounds of N entering the soil with the effluent and pounds of N passing the sampling wells in the renovated water. The removal percentages continued to be relatively high, especially in the latter part of the year when the N-content of the effluent was relatively low (Table 2). Since the total amount of N entering the soil with the effluent was 248 X 27.4 X 2.72 = 18,483 lbs/acre and the average removal percentage was 63%, the amount of N removed was 11,644 lbs/acre. Undoubtedly, almost all of this removal is due to denitrification. Thus, the 9-days flooding--12-days-drying cycle continued to give high N-removal, producing a renovated water whose average NO_3-N content is below the 10 mg/l maximum limit for drinking water, and whose total N of 10.2 mg/l (average for three wells in basin area) is in the lower part of the 5-30 mg/l range where N in irrigation water can be expected to give increasing agronomic problems (lodging, decreasing crop quality, delay of harvest, etc.).

The NO_3-N peaks in the renovated water of ECW were mostly below 20 mg/l, and below 5 mg/l for the August-November period when total N in the effluent was also low. For well 1-2, samples could not be taken in September because the water table dropped below the well bottom, which was 20 ft deep. The NH_4-N peak for the water from this well in November is due to decay of a fairly large animal (probably a badger) that had fallen into the well. Well 7 had low N-concentrations for most of the year because it yielded predominantly native groundwater until about October (see Section 8: Total Dissolved Salts).

4. Phosphate.

Phosphate-phosphorus concentrations in the effluent showed a slight decline over the year, from about 10 mg/l in the beginning to about 6 mg/l at the end of the year (Figure 10). PO_4-P concentrations for the renovated water from the wells inside the basin area were lower at the end of the year than at the beginning (Figures 11, 12, and 13). PO_4-P concentrations for the outlying well 0 at 100 ft from basin 1 were lower than for the wells inside the basin area, indicating additional PO_4-P precipitation in the aquifer. The low PO_4-P levels for well 7 (Figure 14) again were due to the fact that this well yielded mostly native groundwater. Average PO_4-P concentrations and removal percentages were:

	PO_4-P in mg/l	Removal
Effluent	7.9	
Well 0	0.51	94%
Well 1-2	2.61	67%
ECW	2.09	74%
Well 5-6	2.12	73%
Well 7	0.07	

The data show again that PO_4-P removal is a gradual process that increases with additional lateral movement of the renovated water through the aquifer. After 10 years of operation, however, the process is continuing unabatedly and has lost none of its renovation efficiency.

5. Organic Carbon.

Total organic carbon (TOC) concentrations for effluent and renovated water are shown in Figures 15, 16, 17, 18, and 19. Because of instrumentation problems, no TOC measurements were obtained for the period August-November. In that period, the Beckman 915 was replaced by Technicon equipment. The first effluent samples analyzed with the Technicon system were taken in January 1978, and yielded TOC concentrations of 10 to 20 mg/l. Average TOC concentrations in mg/l for 1977 were:

Effluent	26
Well 0	5.2
Well 1-2	6.9
ECW	6.7
Well 5-6	5.2
Well 7	4.2

While the average TOC of the effluent was about the same as the 24 mg/l observed in 1976, the TOC-values for the renovated water were somewhat higher than the 1976 average of 4 mg/l. This may be due to instrumentation malfunction. For example, as the TOC of the effluent went down in the March-June period, that of the renovated water showed a tendency to go up, including well 7 which until June continued to yield mostly native groundwater, as indicated by the relatively high and constant TDS content until the middle of May. These trends were opposite of what could be expected in light of the decreasing TOC of the effluent. Also, when the Technicon analyzer was put into operation in December, TOC-values for all renovated water were mostly on the order of 2 to 3 mg/l, which is considerably lower than the values obtained with the Beckman apparatus. Since the Beckman 915 thus apparently overestimated TOC at low concentrations, additional TOC measurements must be made in 1978 to obtain a more accurate assessment of trace organics in the renovated water. Cooperative work has been initiated with the Western Regional Research Center at Albany, California, to try to identify the trace organics.

6. Fluoride.

Fluoride concentrations of effluent and renovated water are shown in Table 3. The average F-concentration of the secondary effluent was 2.08 mg/l (slightly less than the 2.3 mg/l in 1976), of the renovated water from the wells inside the basin area 1.66 mg/l (1.8 mg/l in 1976), and of that from the outlying well 0, 1.08 mg/l. Thus, additional movement of renovated water through the aquifer produced additional removal of fluoride, similar to what happens to the phosphate. F-concentrations in the water from well 7 were lower when the well yielded renovated water than when it yielded mostly native groundwater.

7. Boron.

Boron concentrations (Table 5) averaged 0.59 mg/l in the effluent, which was slightly more than the 1976 average of 0.52 mg/l. The renovated water contained slightly more B (0.64 mg/l), especially for well 5-6. Water from well 7 had more B when it was mostly native groundwater than when it was predominantly renovated sewage water, as indicated by the TDS content.

8. Total Dissolved Salts.

Average TDS concentration of the secondary effluent was 1,075 mg/l and that of the renovated water 1,095 mg/l (Table 5). The TDS-content of well-7 water initially was in the 1,500-2,500 mg/l range, indicating encroachment of native groundwater. This may have been due to the heavy pumping of groundwater in the Salt River Valley, which created a south-to-north gradient in the groundwater below the Flushing Meadows Project. Thus, native groundwater from the south of the project could have moved north and displaced renovated water at well 7, which is the southernmost well of the project. When groundwater levels rose again (Figure 3) and infiltration rates in the basins also increased in the second half of the year (Figure 1), renovated water pushed further south again and came back in well 7, as evidenced by lower TDS values in the last few months of 1977 (Table 5).

9. Fecal Coliform Bacteria.

Fecal coliform contents were on the order of 3×10^5 per 100 ml for the secondary effluent and normally below 100/100 ml for the renovated water from ECW (Figure 20). Three peaks of 375 to 560 coliforms per 100 ml were also observed. The fecal coliform densities were about the same as in previous years, indicating no deeper penetration of fecal coliforms.

10. Summary and Conclusions.

The year 1977 was the 10th year of operation of the Flushing Meadows Project (the basins were first flooded in September 1967), which is an experimental rapid-infiltration system to renovate secondary sewage effluent by groundwater recharge. In the first 5 years, the main objective of the study was to see how the basins should be managed to obtain maximum hydraulic loading. This loading was about 300 ft/year (in 1 year, 400 ft was obtained) and was achieved with flooding and drying periods of about 2 weeks each, and a water depth of 1 ft. At this schedule, however, N-removal was only about 30% and the NH_4-N content of the renovated water gradually increased. In the second 5 years, the main objective was to determine how nitrogen removal could be increased by reducing hydraulic loading rates, in accordance with results from laboratory studies on soil columns. Using 9-day-flooding and 12-day-drying cycles and reducing the water depth in the basins to 6 inches reduced the hydraulic loading to a range of 170 to 250 ft/year, but doubled nitrogen removal to 60% and sometimes even more. Nitrate-N levels in the renovated water at this removal rate were about equal to or slightly below the maximum limit of 10 mg/l for drinking water. Ammonium-N gradually decreased after the sequences of high loading rates and in 1977 averaged 1.67 mg/l for renovated water sampled at 30-ft depth below the basins. Phosphate removal continued unabated, i.e. 71% for the renovated water sampled below the basins, and 94% after additional movement of 100 ft through the aquifer. Organic carbon concentrations in the renovated water averaged 6 mg/l, which is rather high and may in part be due to instrument problems, which apparently overestimated TOC values of renovated water at low concentrations. A new organic carbon analyzer put into operation at the end of 1977 yielded TOC-values of about 2-3 mg/l for the renovated water. Additional TOC-data will be obtained in 1978. Fluoride concentrations in the effluent averaged 2.08 mg/l and those in the renovated water below the basins were 1.66 mg/l. Additional lateral movement of 100 ft reduced the fluoride content to 1.08 mg/l. Boron concentrations in the effluent averaged 0.59 mg/l and in the renovated water 0.64 mg/l. Total dissolved salts concentrations averaged 1,075 mg/l for the effluent and 1,095 mg/l for the renovated water. Hydraulic loading in 1977 was 248 ft/year, which is not much lower than the maximum of about 300 ft/year obtained previously with longer flooding periods. The response of the groundwater table to infiltration was essentially the same as before, indicating no clogging of the aquifer. All these results indicate that a rapid-infiltration system can function very effectively for a great many years.

II. 23RD AVENUE PROJECT

The work at the 23rd Avenue Project in 1977 only consisted of additional infiltration studies on a small area within infiltration basin no. 2. The purpose of the study was to make sure that the low infiltration rates of the basins were caused by suspended solids (algae) in the effluent and not by air-pressure build-up in the unsaturated zone beneath advancing wet fronts. The studies were necessary because of a proposed construction of a by-pass channel within the 80-acre pond that would bring secondary effluent directly into the infiltration basins without long detention times and algae build-up. If air-pressure were the main cause of low infiltration rates, such a channel would, of course, not be effective in increasing the infiltration rates in the basins. The effect of algae as such on infiltration was studied in detail in 1976 (see previous Annual Report).

1. Infiltration Studies.

Infiltration measurements were carried out on square areas of 1 by 1 m, obtained by installing a sheet metal border in the soil. The square area was flooded with water free from suspended solids (renovated sewage water from the Center Well was used for this purpose) to a depth of 15 cm. This depth was then maintained with a float valve and the rate of flow of water was determined with a flowmeter. The rest of the basin around the square-meter area was kept dry initially. The infiltration rate during this period was essentially constant at about 0.75 m/day (Figure 21). Since the basin around the square-meter area was kept dry during this measurement, there was no air-pressure build-up in the vadose zone below the wetting front. Thus, the infiltration rate from the square-meter area was not affected by air-pressure build-up. If the rest of the basin were also flooded, however, there would be an increase in air pressure in the vadose zone, which in turn would produce a decrease in the infiltration rate of the 1 m^2 area. Flooding the rest of the basin will also reduce the infiltration rate from the square-meter area because divergence of the flow due to edge effects will be eliminated. Previous studies with an electrical resistance network analog have indicated that for the soils of the infiltration basins at the 23rd Avenue Project, which have an air-entry value of -38 cm water, the infiltration rate from a 1 square-meter area will be reduced by about 50 percent if the area surrounding this 1 square meter is also flooded and flow divergence below the 1 m^2 area does no longer take place. Thus, if the infiltration rate in the square-meter area in basin 2 would be reduced by more than a factor 2 due to flooding the surrounding area, the infiltration rate would not only be reduced by a reduction in the divergence of the flow, but also by an increase in air pressure in the vadose zone. The results (Figure 21), however, show that the infiltration rate was reduced from 0.75 m/day to 0.50 m/day due to flooding the area around the 1 square meter. This reduction is less than by a factor 2, indicating that the air-pressure build-up in the vadose zone, which was about 1.4 m of water for the study (Figure 21) had no effect on infiltration rate from the square meter area. The infiltration rate for the entire basin was 0.73 m/day at the beginning of the 5-day period and 0.15 m/day at the end. The increase in infiltration rate from the square-meter area on about 25 June (Figure 21) was caused by a temporary drop in water level in the rest of the basin, which produced divergence of the flow beneath the square-meter area. When flooding the entire basin was stopped on 27 June, the infiltration rate from the square-meter area began to increase (Figure 21). This was probably due to the decrease in negative pressure head of the water in the upper portion of the soil profile as the profile drained toward the groundwater table which was at a depth of 21.34 m. This produced pressure heads that were much more negative than normally occur at the downward moving wetting front in relatively dry soil, and, hence produced an increase in infiltration rates.

Clogging of the bottom soil in the recharge basins and resulting low infiltration rates may not only have been due to accumulation of algae, but could also result from precipitation of $CaCO_3$, caused by the high pH (> 9) of algae-laden effluent during periods of high photosynthetic activity when the algae absorb a lot of CO_2.

The resulting $CaCO_3$ deposits could actually form a cemented surface crust on the soil, as evidenced by a white discoloration. Analyzing soil samples taken in August from different depths for $CaCO_3$ content, however, did not show any increase in $CaCO_3$ of the surface soil, except for site B (Table 6). Better results could probably be obtained if the surface as such (for example the top 1/16-inch of the soil) had been sampled, rather than the top inch. At any rate, however, the effect of ripping the soil to break up algae clogged and possibly $CaCO_3$-cemented surface crusts on infiltration will be studied when the infiltration basins are reactivated following completion of the by-pass channel. Hopefully, this channel will be constructed in early summer 1978.

2. By-Pass Channel.

The levee for the by-pass channel shown as the hatched strip in Figure 22, will start at the east end of the 80-acre pond, parallel the south bank, and curve north at the west end of the pond. Of the three culverts now feeding secondary effluent to the 80-acre pond, culvert A (Figure 22) will be cut so that it will supply secondary effluent to the by-pass channel. The effluent will then flow through the inlets B, C, and D into the infiltration basins. This will be the mode of operation in spring, summer, and fall, when there is considerable algae growth in the 80-acre pond and the treatment plant effluent itself has a low suspended solids content. In the winter, however, there is little algae growth in the 80-acre pond and the plant effluent usually has a much higher suspended solids content. In that case, it will be better to pass the effluent first through the 80-acre pond before it goes into the infiltration basins. This will be accomplished by opening gate E (Figure 22), which will allow 80-acre pond effluent to enter the channel on the west side and then flow into the infiltration basins. The drainage gates F, G, H, and I at the west end of the infiltration basins will be equipped with overflow structures so that water can spill out of the infiltration basins during flooding. Previously, the gates were kept closed during flooding and opened only to drain the ponds for a drying period. The outflow during flooding should reduce the detention time in the infiltration basins, thus reducing algae growth in these basins. The by-pass channel and the outflow structures of the infiltration basins are designed so that the total detention time of the effluent is less than 36 hours. This should avoid problems of algae growth.

3. Summary and Conclusions.

The four 10-acre infiltration basins of the 23rd Avenue Wastewater Renovation Project received secondary effluent that had first been passed through an 80-acre oxidation pond. During the summer months, algae growth in the oxidation pond caused the effluent to have high suspended solids contents when it entered the infiltration basins. The result was a great reduction in infiltration rates, yielding an annual hydraulic loading rate of about 70 ft. To obtain higher infiltration rates, the 80-acre pond should be by-passed so that secondary effluent from the treatment plant directly enters the infiltration basins. This can be achieved by construction of a levee in the 80-acre pond to create a by-pass channel. To make sure that the low infiltration rates were not caused by a build-up of air pressure beneath the advancing wet front in the unsaturated zone, infiltration rates were measured in a 1 m square area of basin 2. Infiltration rates were measured with the small area flooded alone and then with the entire basin flooded also. The results showed that the reduction in infiltration rate when the entire basin was flooded could be entirely attributed to a decrease in divergence of flow from the 1 meter square area. Thus, air-pressure build-up had little or no effect on infiltration and the by-pass channel for bringing plant effluent directly into the basins should be effective in increasing the infiltration rate of the recharge basins.

III. MESA PRIMARY EFFLUENT PROJECT

The studies on the use of primary effluent for groundwater recharge by rapid infiltration were extended to field plots at the Mesa Sewage Treatment Plant. Four recharge basins, 10 ft by 30 ft, were constructed in the summer of 1977 (Figure 23). Primary effluent was pumped from the overflow side of the primary clarifier about 250 ft away. Basins 1 and 2 received effluent directly from the pipeline, while basins 3 and 4 received effluent that was first passed through a sedimentation basin of the same size as the infiltration basins. A flooding schedule of 7 days wet and 7 days dry was followed for the first 5 weeks. Basins 1 and 3 were flooded while basins 2 and 4 were drying, and vice-versa. The water level in the basins was controlled by floats which activated an electric valve and the effluent pump. The floats were set to maintain a water depth of 10 inches. A water meter was used to measure the total infiltration in basins 1 and 2. Infiltration rates in basins 3 and 4 were determined from daily point-gage measurements of water level drop. This was necessary because the water initially passed through a sedimentation pond which also had some infiltration. A drain was installed in each basin so water could be rapidly removed at the start of the dry period. Tensiometers and porous cermaic cups for sampling water quality were installed in each basin at two different depths, as shown in Table 7.

1. <u>Infiltration Rates</u>.

Flooding of the basins was started on 1 November 1977. Infiltration rates for the four basins are shown in Figures 24 and 25. The basins were flooded for 7 days and dry for 7 days for the period 1 November to 6 December, after that, the schedule was changed to 7 days flood and 14 days dry. The infiltration rates at 10 inches water depth ranged between 0.1 ft/day and 2.5 ft/day, with an average of 0.4 ft/day. The yearly infiltration based on 1-week flood and 1-week dry would be 68 ft/year. The initial infiltration rate was higher in basins 1 and 2 than in basins 3 and 4; however, the infiltration rate also decreased from each preceding flood period. The 1-week dry period probably was not long enough to dry the basin surface out sufficiently and to restore the infiltration rate. The rapid decrease in infiltration rate is due to the suspended solids content of the primary effluent, which averaged about 50 mg/l for all basins. Ferrous chloride is added to the raw sewage for odor control at the sewage treatment plant. The ferrous chloride reacts with hydrogen sulfide in the raw sewage and forms ferrous sulfide, which is a fine precipitate that does not settle out. This is indicated by the same suspended solids content for all basins even though the effluent entering basins 3 and 4 passed through the sedimentation basin. The fine particles contribute to lower infiltration rate in two ways: first, the fine particles can move farther into the soil, resulting in internal clogging rather than surface clogging. During drying the organic layer dries and breaks away from the soil surface. However, the ferrous sulfide is inorganic and therefore remains relatively unchanged upon drying. This may also explain why the infiltration rate does not adequately recover after drying.

Negative pressure heads at the 13- to 16-cm depth in basins 1, 3, and 4 indicate that clogging occurs above that depth (Figures 26, 27, 28, and 29). Positive pressures occurred at the 13-cm depth in basin 2 and did not decrease with time, except for the last flood period. This is probably due to leakage around the tensiometer, rather than a restricting layer below the 13-cm depth. During the last flow period, the pressure head did become negative, indicating surface clogging. Leakage along the tensiometer tube is also indicated in basin 4 because of the sudden increase in pressure head in the middle of a flood period.

2. Nitrogen.

The total-N content of the primary effluent ranged between 22 and 40 mg/l and averaged 32 mg/l. About 27 mg/l was in the ammonium form, and 5 mg/l as organic N. The average ammonium content at the 10-cm level was 17, 26, 5.5, and 5.9 mg/l for basins 1, 2, 3, and 4, respectively (Figures 30, 31, 32, and 33). The average nitrate level was below 0.7 mg/l for all basins at the shallower depth. The higher ammonium levels below basins 1 and 2 were probably due to short circuiting from the surface when vacuum was applied to the ceramic for extraction. A nitrate peak was observed on three occasions at 53-cm depth in basin 4 and during one period in basins 1 and 3. No nitrate peak was observed in basin 2; however, the quantity of samples taken at the lower depth was small (less than 5 ml per hour), indicating that the ceramic was located in coarse material. Since samples were only taken daily, it is possible that nitrate could have moved past the ceramic without being sampled. The ammonium concentration at the lower depth was about the same for all basins and averaged 3.2 mg/l. Nitrogen removal at the lower depths averaged 70% for all four basins.

3. Phosphate.

The average PO_4-P content of the primary effluent was 5.7 mg/l. Some phosphate appeared to be leached out of the top 10 cm in basin 2 as the average PO_4-P concentration at a depth of 1 cm was 6.9 mg/l. The PO_4-P concentrations at 10-cm depth below basins 1, 3, and 4 were slightly less, i.e. 4.7, 5.0, and 3.5 mg/l, respectively. At the lower depths PO_4-P concentrations were 1.9, 0.5, 1.1, and 0.8 mg/l for basins 1, 2, 3, and 4, respectively. The average phosphorus removal for all basins was 82 percent.

4. Summary and Conclusions.

The studies on the use of primary effluent for rapid infiltration were extended to field plots at the Mesa Sewage Treatment Plant. Primary effluent was pumped from the primary clarifier to four 10-ft by 30-ft recharge basins. The basins were initially operated on a 7-day flood and 7-day dry schedule. Infiltration rates ranged between 0.12 and 2.5 ft/day, with an average of 0.4 ft/day. This represents an annual hydraulic loading rate of 68 ft. Infiltration rates at the start of each flooding period were lower than the initial infiltration rates of the preceding flooding periods, indicating that the 7-day dry period was not long enough to restore the infiltration rate. The inundation schedule was changed to 7-days flood and 14-days dry at the end of the year. The rapid decrease in infiltration rates is attributed to the high suspended solids content in the effluent, which averaged 50 mg/1. The suspended solids include a very fine precipitate of ferrous sulfide (due to iron chloride treatment of the raw sewage), which appears to clog the soil more than the organic suspended solids of secondary sewage effluent. The total nitrogen concentration in the primary effluent averaged 32 mg/1. Nitrogen concentrations of the renovated water collected at a depth of 50 cm with ceramic cups were 5.7 mg/1 as NO_3-N and 3 mg/1 as NH_4-N. Average PO_4-P concentrations were 5.6 mg/1 and 1.4 mg/1 for the primary effluent and renovated water, respectively. Quality improvement appeared about equal to that received with secondary effluent; however, the hydraulic loading rates were lower due to the composition of the suspended solids.

IV. DELAYED YIELD STUDIES

1. <u>Procedure</u>.

Additional studies were made of delayed yield of unconfined aquifers. Previous studies dealt with completely saturated layers in the vadose zone. When groundwater was pumped, the water table had to drop a certain distance before water pressures in such saturated layers had reached the air-entry value of the layer and air could move down to occupy the space left by the draining water. In 1977, the studies were extended to moist (not saturated) vadose zones to see if delayed yield effects could also be obtained under conditions where there were no saturated layers in the vadose zone. To study this phenomenon, a 6.1-m column was set up with the lower half filled with sand to represent an aquifer and the upper half filled with a clay loam to represent a vadose zone. Eleven strain-gage-type pressure transducers were installed at various depths to monitor air pressure and water-level changes in the column. Beginning with a 12 percent soil-moisture content in the vadose zone, the water table in the sand was lowered and outflow measured in relation to water-table drop and air pressures in the vadose zone. The studies were repeated at successively higher water contents of the vadose zone.

2. Results.

Delayed yield effects occurred only when the water content of the vadose zone was so high that portions of it approached saturation and prevented air from entering the aquifer. After the air-entry value of the essentially saturated layer had been reached, the specific yield and outflow rate increased abruptly to their maximums. Minimum specific yield values were about 1/8 of the maximum value, and they were 1 to 2 orders of magnitude higher than those normally reported from actual pumping tests. A detailed report of the studies is:

S. B. Johnson. Delayed Yield in Unconfined Aquifers. MSC Thesis, Arizona State University, December 1977, 42 pp.

3. Summary and Conclusions.

A laboratory study on soil columns showed that delayed-yield effects of unconfined aquifers by restricted air movement in the vadose zone were only obtained if saturated or near-saturated layers were present in the vadose zone. High water contents in the vadose zone, which consisted of a clay loam, were not sufficient to restrict air movement, as long as saturation was not reached. Thus, restricted air movement in the vadose zone only produced delayed yield effects for the aquifer if saturated or near-saturated layers occurred in this zone.

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*U.S. Water Conservation Laboratory personnel for all four projects.

Table 1. Suspended solids content (mg/1) of secondary effluent at Flushing Meadows in 1977.

14 Feb	49
4 Mar	56
31 Mar	62
14 Apr	64
18 Apr	52
21 Apr	70
6 May	40
27 May	32
17 Jun	10
23 Jun	15
8 Jul	12
13 Jul	14
29 Jul	9
18 Aug	49
14 Sep	13
30 Sep	14
3 Oct	15
25 Oct	25
10 Nov	40
14 Nov	20
12 Dec	19
15 Dec	30

Table 2. Total-N in secondary effluent (mg/l) and percentage N-removal for renovated water from three wells in 1977.

Start of flooding period	Total-N concentration of effluent	Percentage nitrogen removal		
		Well 1-2	ECW	Well 5-6
18 Jan	31.2	57	64	73
10 Feb	27.4	48	39	41
3 Mar	33.9	53	48	21
24 Mar	32	39	50	39
14 Apr	28.6	50	59	57
5 May	25.7	55	52	42
26 May	25.8	79	63	22
16 Jun	30.5	88	79	72
7 Jul	24.7	72	47	66
28 Jul	21.4	74	69	72
18 Aug	20.4	a	80	89
8 Sep	21.8	a	78	81
29 Sep	21.4	62	89	84
20 Oct	19.0	b	85	71
10 Nov	24.7	b	87	63
8 Dec	32.0	75	80	58
Average		63	67	59

a No samples obtained because well was dry.

b Excess N in renovated water because of decaying animal in well.

Table 3. Fluoride concentrations (mg/l) in secondary effluent and renovated water in 1977.

Date	Effluent	Well 0	Well 1-2	ECW	Well 5-6	Well 7
3 Jan	1.16					
17 Jan			2.12	1.64	1.76	
21 Jan	2.88					
28 Jan	2.6		1.64	3.2	1.72	
10 Feb			1.88	1.64	1.64	
24 Feb		0.68	1.52	1.48	1.4	0.92
10 Mar	2.8	1.32	1.84	1.74	1.96	1.1
25 Mar	2.74	1.32	1.84	1.74	1.72	1.1
6 Apr		1	1.74	1.64	1.5	0.74
18 Apr	1.84	1.24	1.94	1.84	1.64	0.94
6 May		1.04		1.28	1.26	0.76
18 May				1.22	1.26	0.76
3 Jun	2.26	1	1.56	1.12	1.4	0.76
16 Jun						0.82
17 Jun	2.24	0.9	1.84	1.4	1.48	0.68
24 Jun	2.26					
29 Jun			1.84	1.62	1.52	
14 Jul	2	1.24	1.68	1.62	1.68	0.9
29 Jul	2.24	1.04		0.96	1.62	0.9
5 Aug	2.32	1.24	1.76	1.68	1.84	0.82
23 Aug	1.4	0.79	1.6	1.6	1.6	0.5
9 Sep	1.84	1		1.84	1.7	
30 Sep	1.04	1.17		1.72	1.52	0.65
20 Oct	1.64	1.24	1.8	1.46	1.5	0.73
14 Nov	1.1	1.56	2.4	2.66	1.96	0.72
28 Nov		1.1	1.38	1.38	1.56	0.44
1 Dec		1.0	1.3	1.48	1.48	0.5
14 Dec	2.3				1.28	0.5
30 Dec	2.2	1.1	1.64	1.56	1.38	0.32
Average	2.08	1.08	1.76	1.62	1.60	0.82

Table 4. Boron concentrations (mg/l) in secondary effluent and renovated water in 1977.

Date	Effluent	Well 0	Well 1-2	ECW	Well 5-6	Well 7
3 Jan	0.6					
17 Jan			0.55	0.56	0.59	
21 Jan	0.59					
28 Jan	0.59		0.64	0.63	0.68	
10 Feb			0.56	0.64	0.6	
24 Feb		0.54	0.91	0.87	0.75	1.2
10 Mar	0.68	0.87	0.81	0.83	0.87	1.03
25 Mar	0.67	0.67	0.72	0.74	0.88	1.2
6 Apr		0.75	0.7	0.7	0.86	1.07
18 Apr	0.65	0.65	0.65	0.65	0.75	1.07
6 May	0.57	0.65	0.67	0.65	0.81	1.11
18 May			0.7	0.77	0.83	1.1
3 Jun	0.67	0.75	0.73	0.75	0.81	1
17 Jun	0.65	0.73	0.64	0.7	0.75	1.04
24 Jun	0.68					
29 Jun			0.7	0.77	0.89	
14 Jul	0.6	0.75	0.65	0.65	0.75	0.85
29 Jul	0.45	0.76		0.68	0.87	0.85
5 Aug	0.48	0.6	0.55	0.6	0.7	1.05
23 Aug	0.58	0.68	0.63	0.63	0.74	0.93
9 Sep	0.55	0.58		0.58	0.69	
30 Sep	0.46	0.51	0.51	0.46	0.5	0.65
20 Oct	0.57	0.55		0.56	0.68	0.73
14 Nov	0.66	0.43	0.47	0.55	0.55	0.61
28 Nov		0.55	0.50	0.50	0.55	0.67
8 Dec		0.52	0.52			
14 Dec	0.48				0.57	0.70
30 Dec		0.44	0.52	0.46	0.43	0.52
Average	0.59	0.62	0.64	0.65	0.71	0.89

Table 5. Total dissolved solids content (mg/l) of secondary effluent and renovated water in 1977.

Date	Effluent	Well 0	Well 1-2	ECW	Well 5-6	Well 7
3 Jan	800					
17 Jan			832	800	768	
21 Jan	960					
28 Jan	973		896	896	1024	
10 Feb			896	909	1024	
24 Feb		832	896	896	1120	2528
10 Mar	1024	1280	1024	1024	1248	2176
25 Mar	1088	1120	992	1024	1472	2176
6 Apr		1088	1069	1088	1267	2144
18 Apr	1152	1216	1101	1101	1728	2240
6 May	1152	1100	1100	1075	1331	2048
18 May			1100	1216	1280	1920
3 Jun	1120	1056	1056	1120	1216	1600
16 Jun						1536
17 Jun	1120	1088	1043	1024	1165	1600
24 Jun	1120					
29 Jun			1088	1088	1280	
14 Jul	1088	1088	1088	1200	1280	1408
29 Jul	1088	992		1088	1184	1344
5 Aug	1165	1152	1152	1100	1230	1408
23 Aug	1120	1088	1120	1088	1152	1344
9 Sep	1152	1088		1088	1152	
30 Sep	1024	1216	1216	1152	1267	1408
2 Oct	1120	1184		1100	1280	1280
14 Nov	845	1280	1216	1088	1280	1345
28 Nov	973	1152	973	960	1152	1152
1 Dec		1165	973	947	1088	1152
14 Dec	1024				1248	1408
30 Dec	960	1024	960	960	1024	1088
Average	1075	1091	1028	1045	1217	1840

Table 6. $CaCO_3$ as percentage of dry soil at different depths and three locations in basin no. 2 at 23rd Avenue Project.

Location	Depth in.	$CaCO_3$ equiv. in %
A	0-1	2.08
A	2-4	2.03
A	4-6	2.09
A	20	2.14
B	0-1	2.08
B	2-4	1.70
B	10-15	1.91
C	0-2	1.80
C	2-4	1.86
C	10-15	1.77

Table 7. Depth of tensiometers and ceramic sampling cups at Mesa Primary Project.

Basin	Depth, cm			
	Tensiometers		Ceramic cups	
1	16	43	10	56
2	13	41	10	56
3	16	42	10	46
4	13	41	10	53

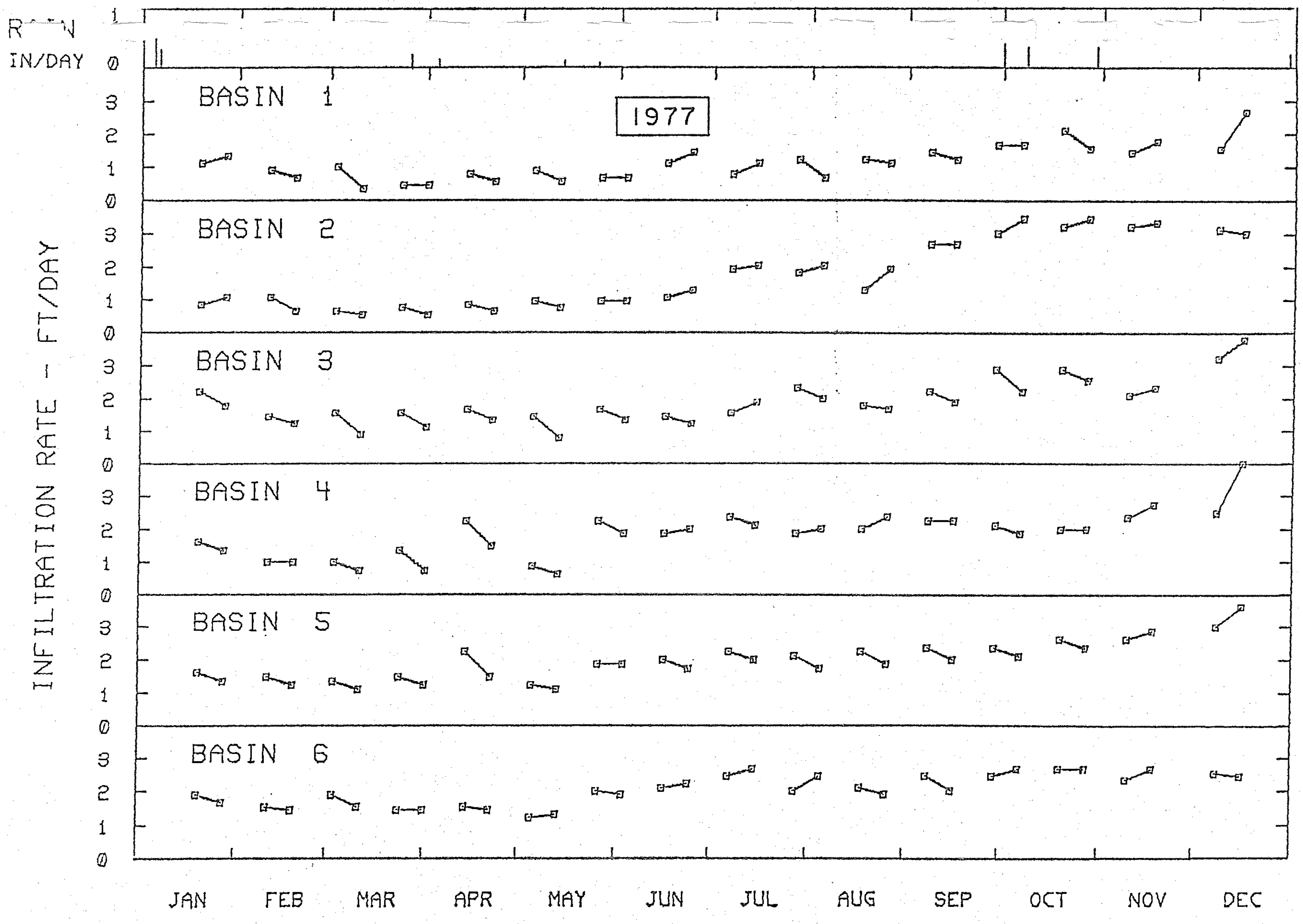

Figure 1. Infiltration rates for Flushing Meadows basins and rainfall in 1977.

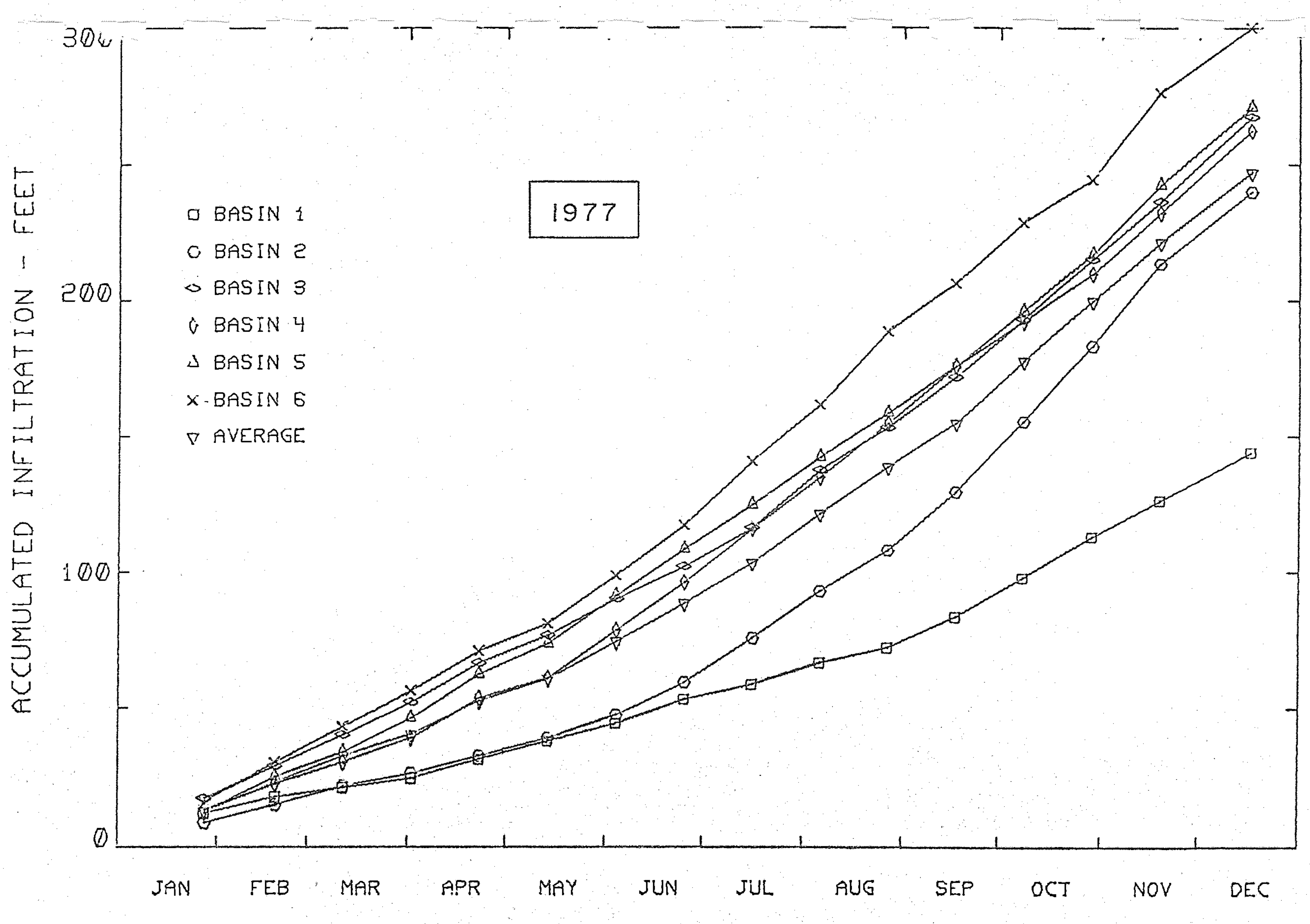

Figure 2. Accumulated infiltration for infiltration basins at Flushing Meadows Project and average infiltration in 1977.

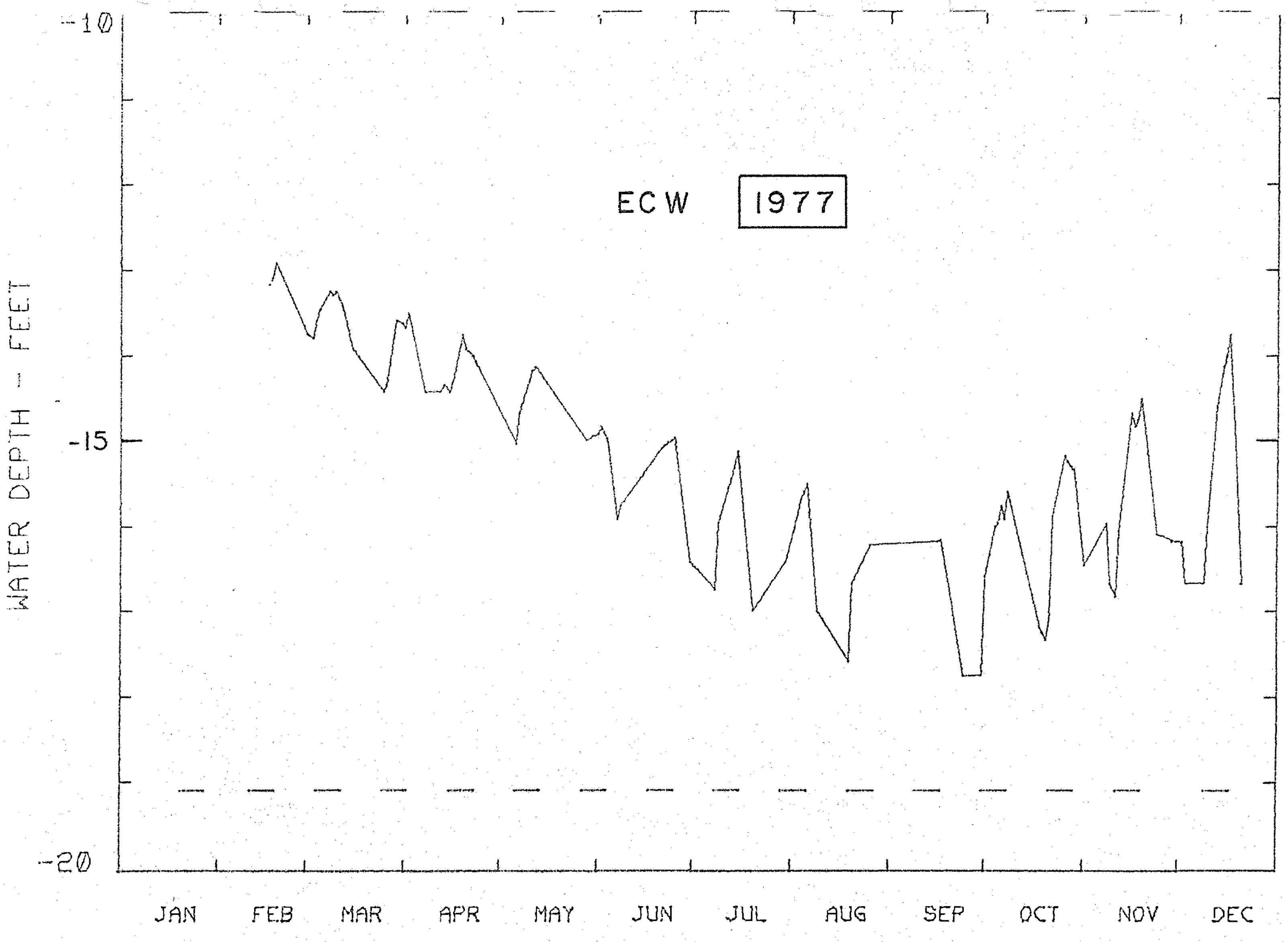

Figure 3. Water table hydrograph in ECW showing general trend in groundwater level and effect of recharge.

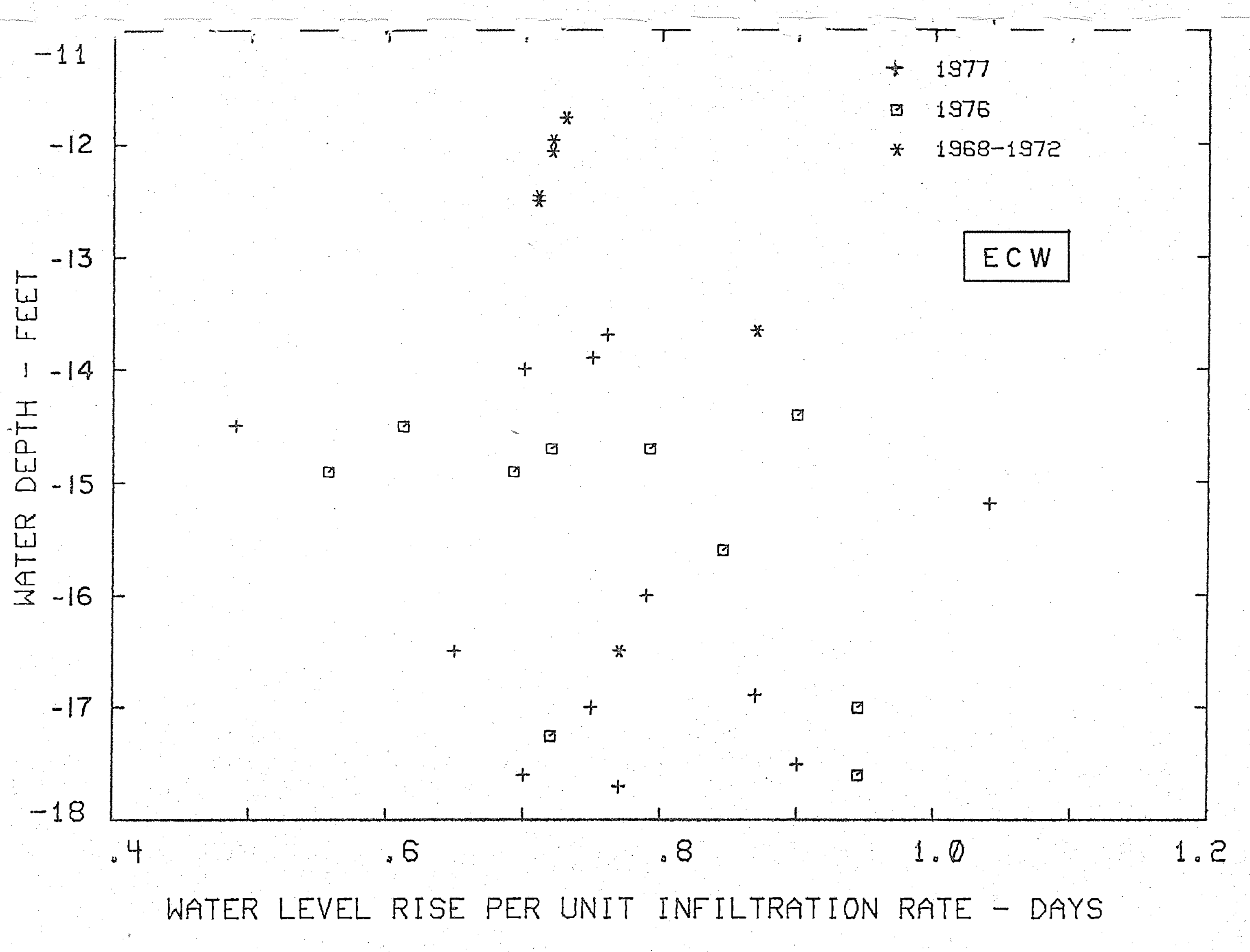

Figure 4. Rise of water level in ECW per unit infiltration rate in relation to depth of water level in well.

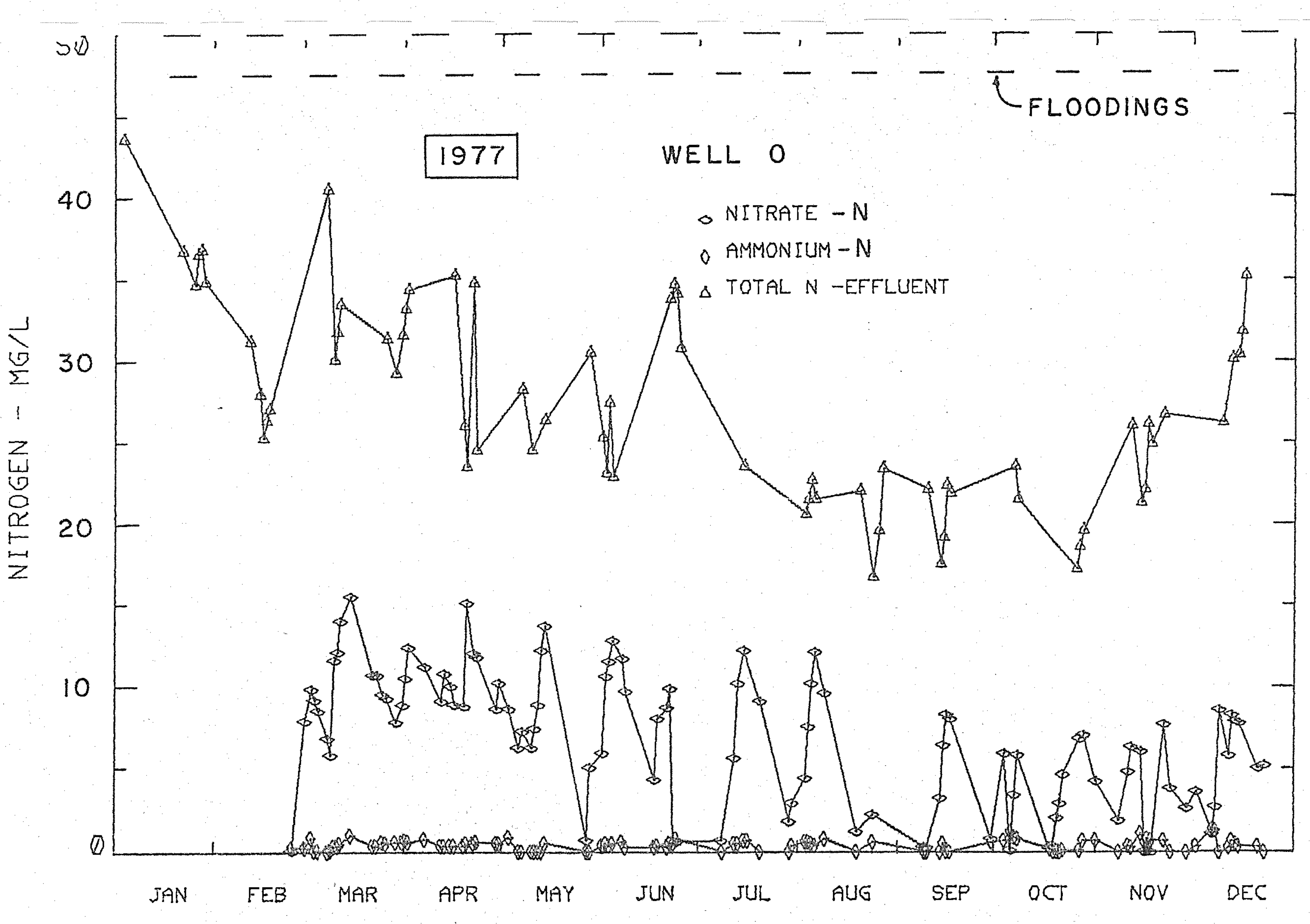

Figure 5. Total nitrogen in effluent and nitrate and ammonium nitrogen in renovated water from well O.

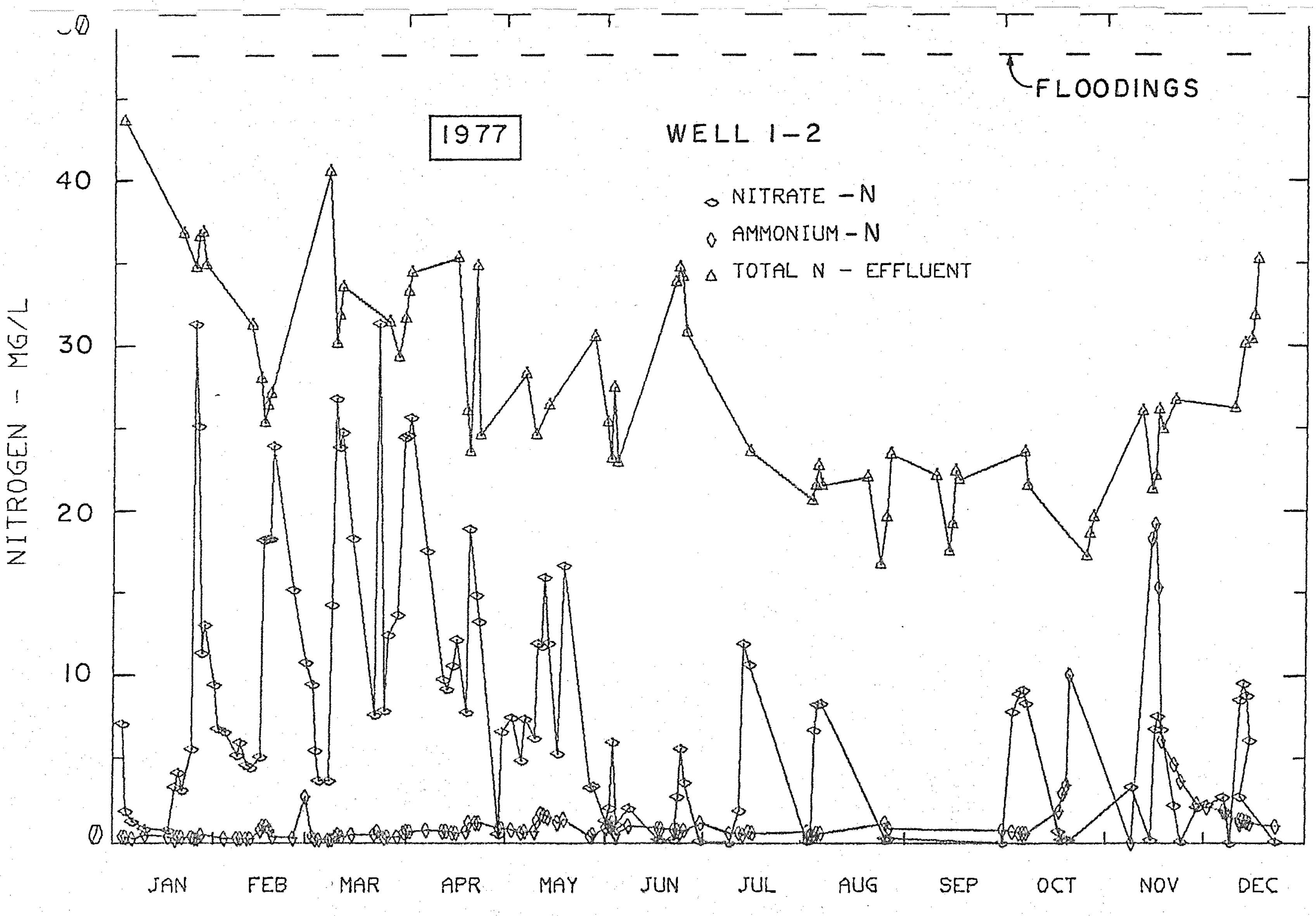

Figure 6. Total nitrogen in effluent and nitrate and ammonium nitrogen in renovated water from well 0.

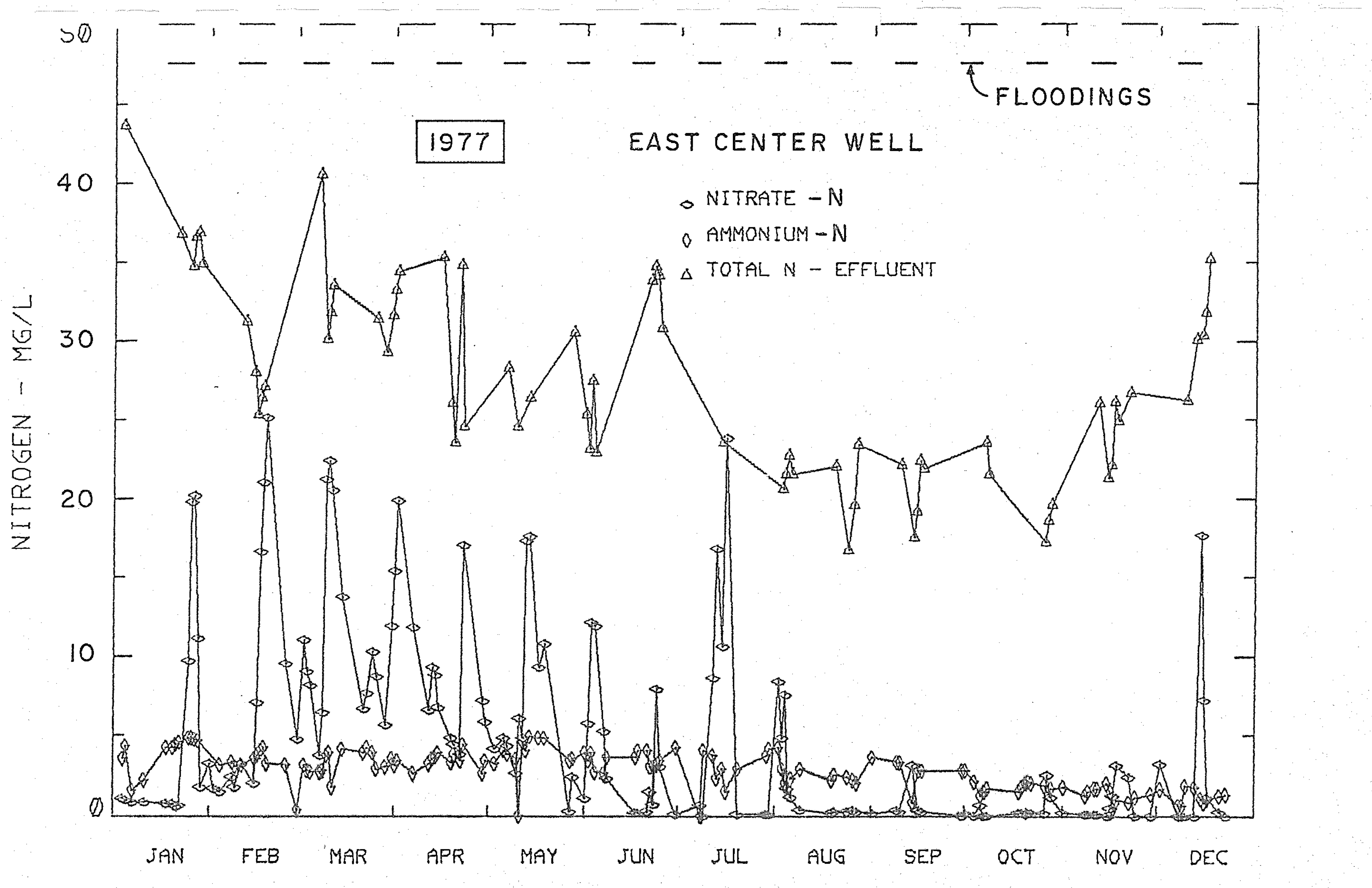

Figure 7. Total nitrogen in effluent and nitrate and ammonium nitrogen in renovated water from East Center Well.

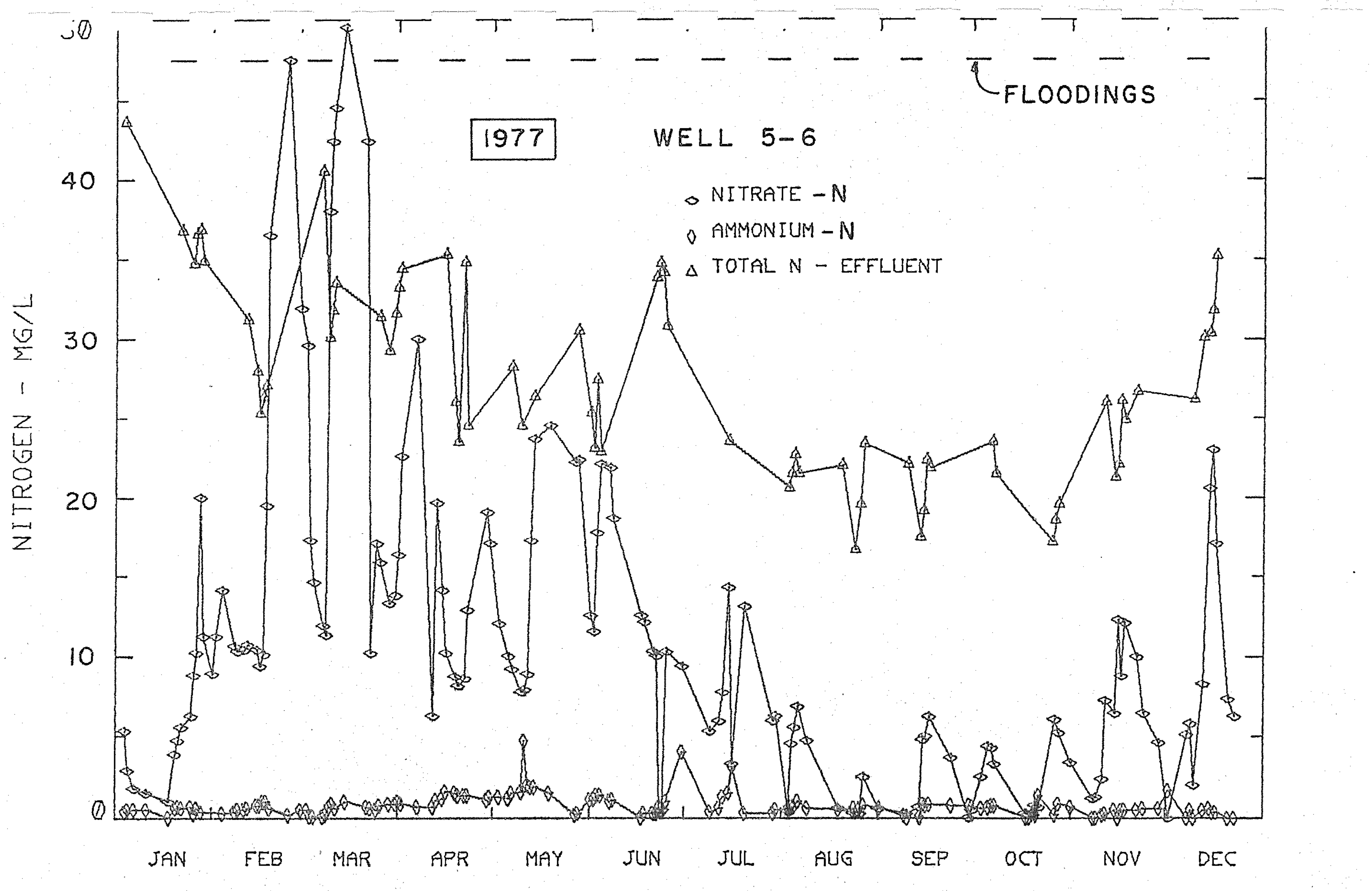

Figure 8. Total nitrogen in effluent and ammonium and nitrate nitrogen in renovated water from well 5-6.

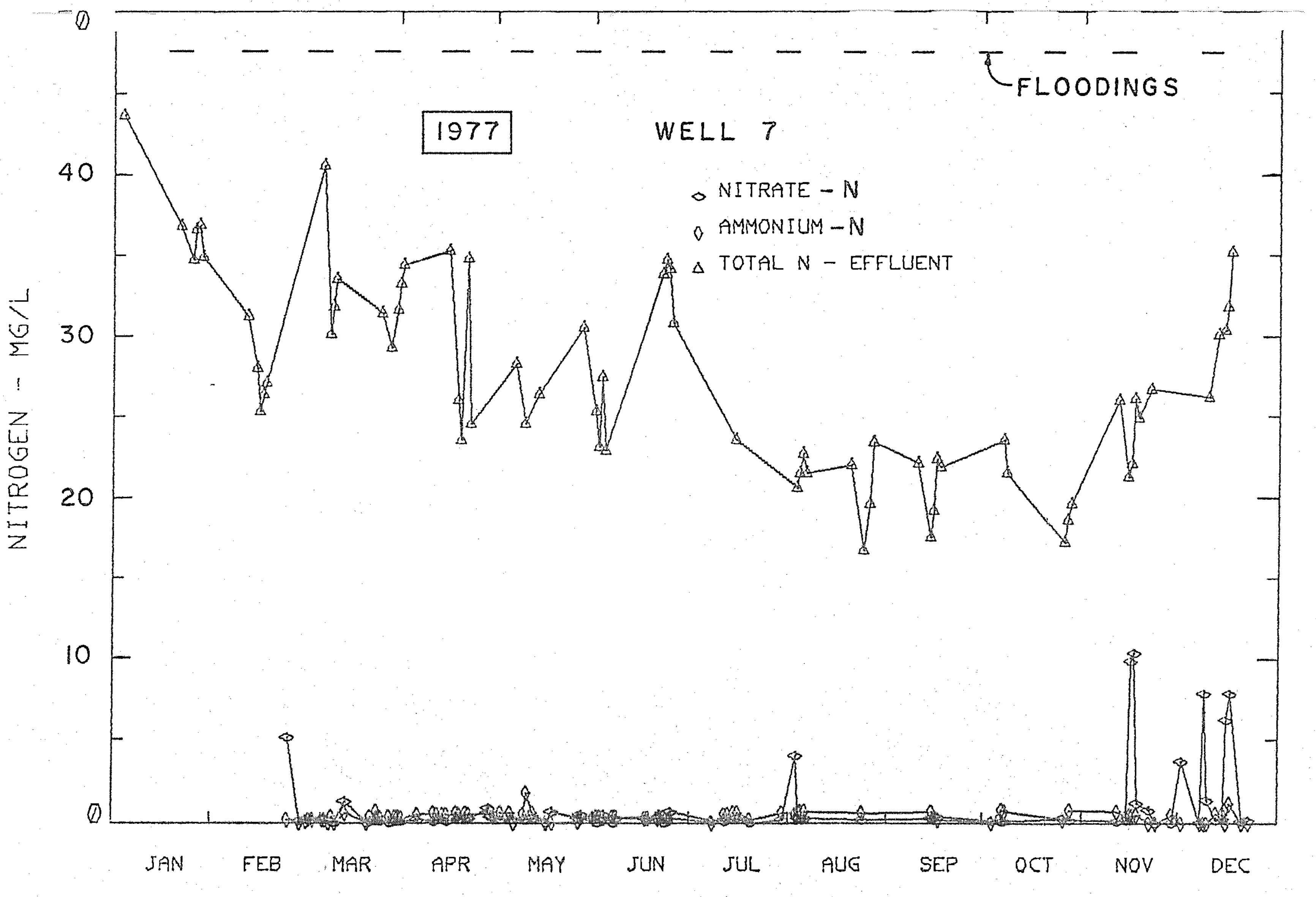

Figure 9. Total nitrogen in effluent and ammonium and nitrate nitrogen in renovated water from well 7.

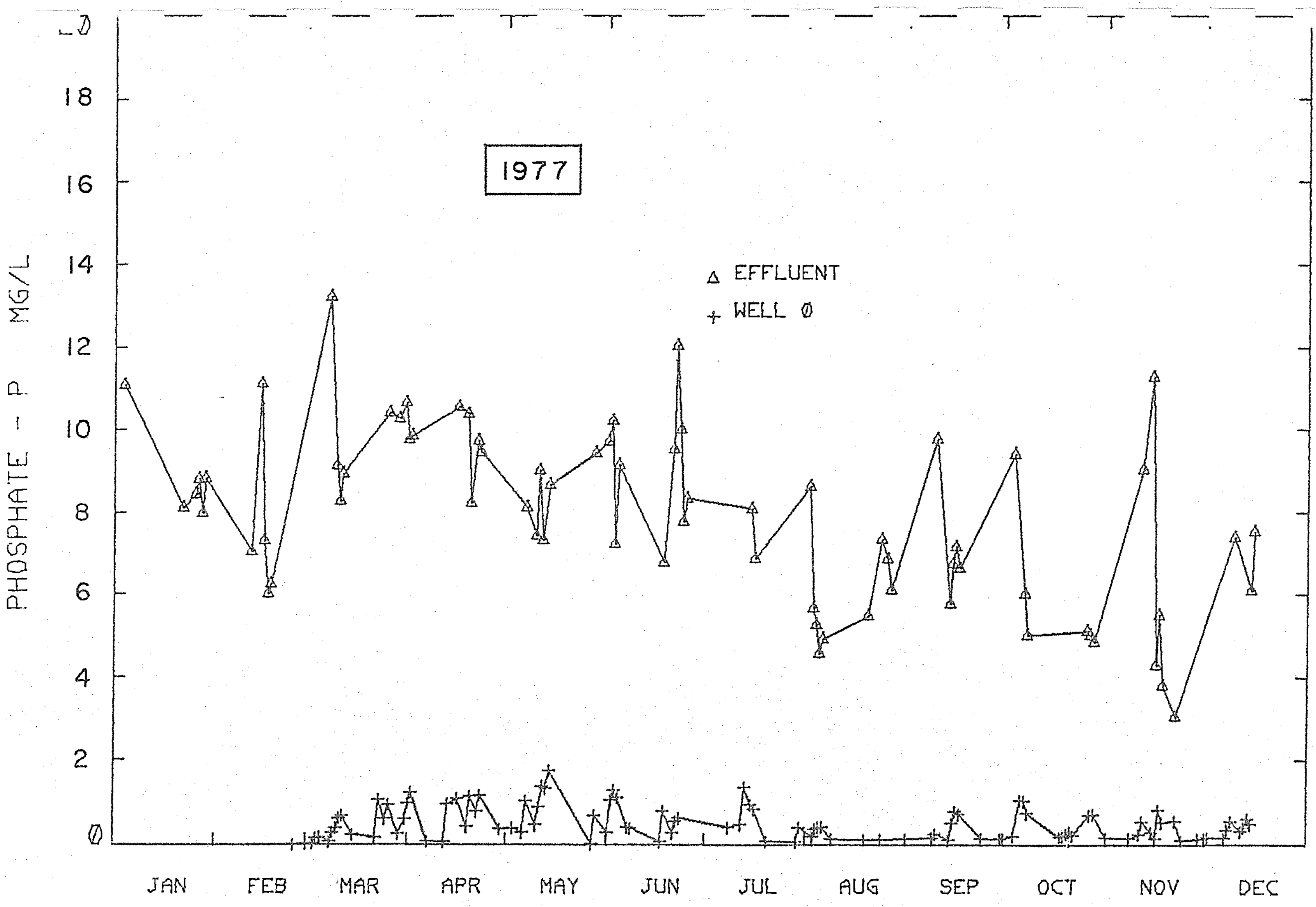

Figure 10. Phosphate phosphorus in effluent and in renovated water from well 0.

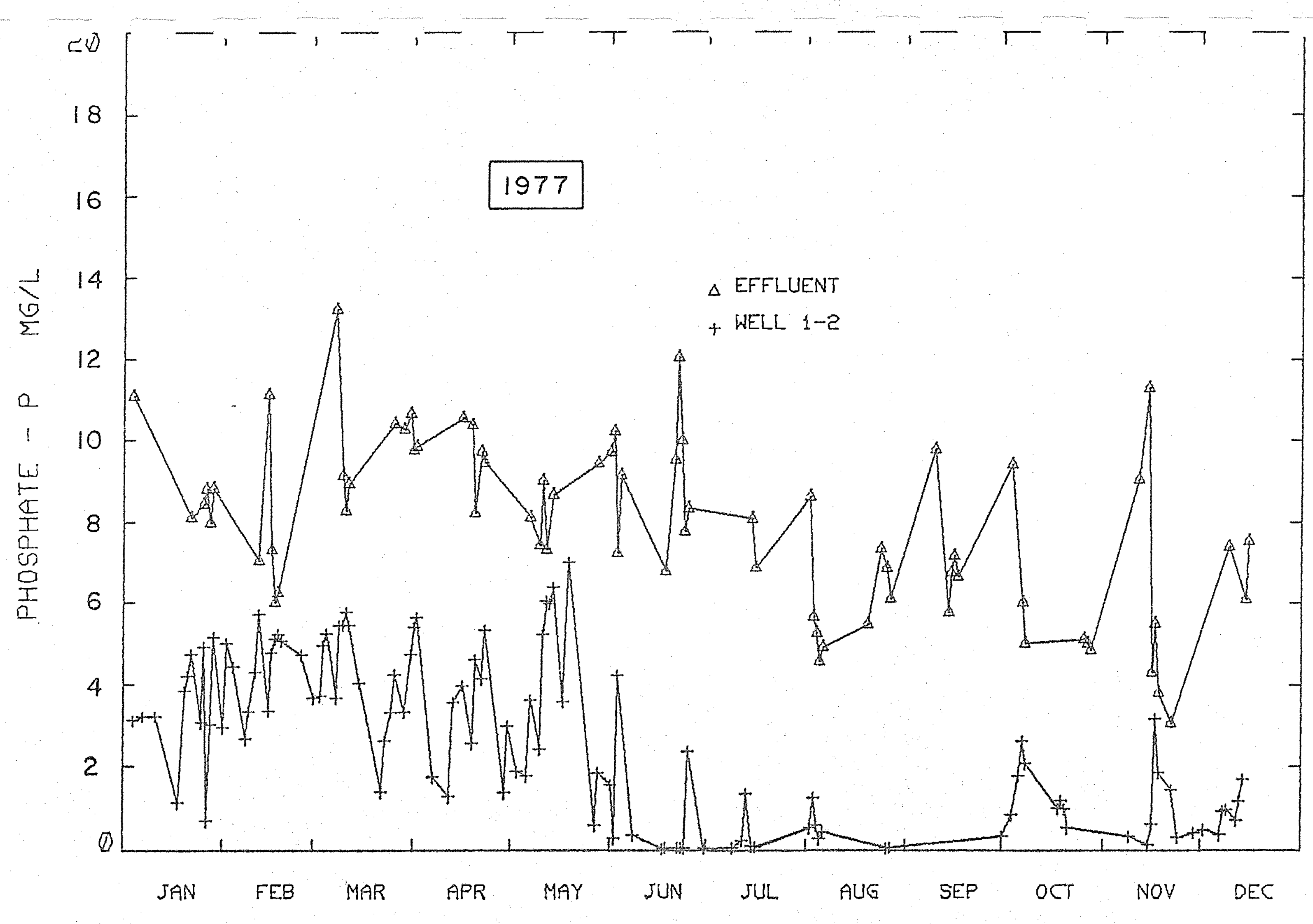

Figure 11. Phosphate phosphorus in effluent and in renovated water from well 1-2.

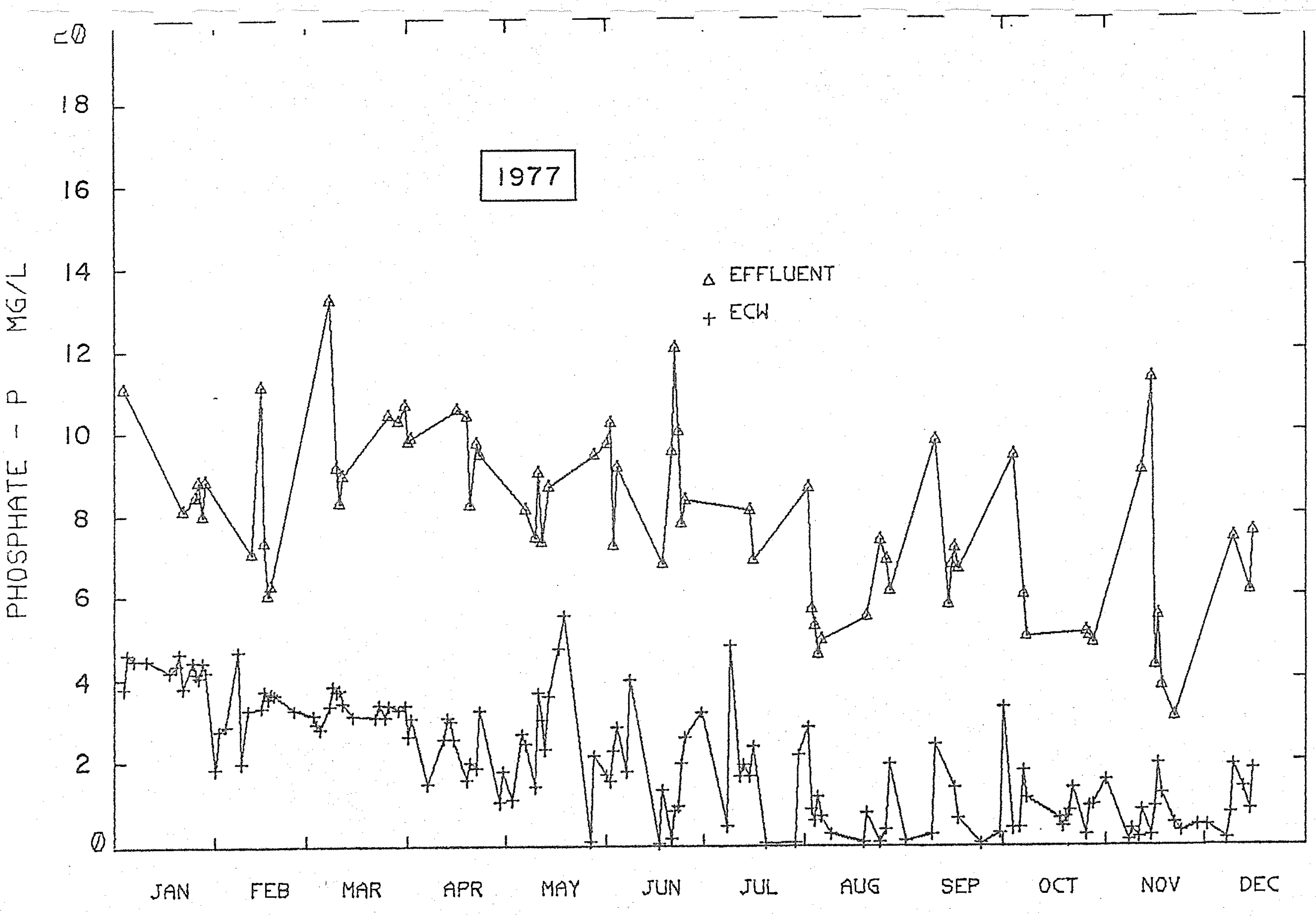

Figure 12. Phosphate phosphorus in effluent and in renovated water from East Center Well.

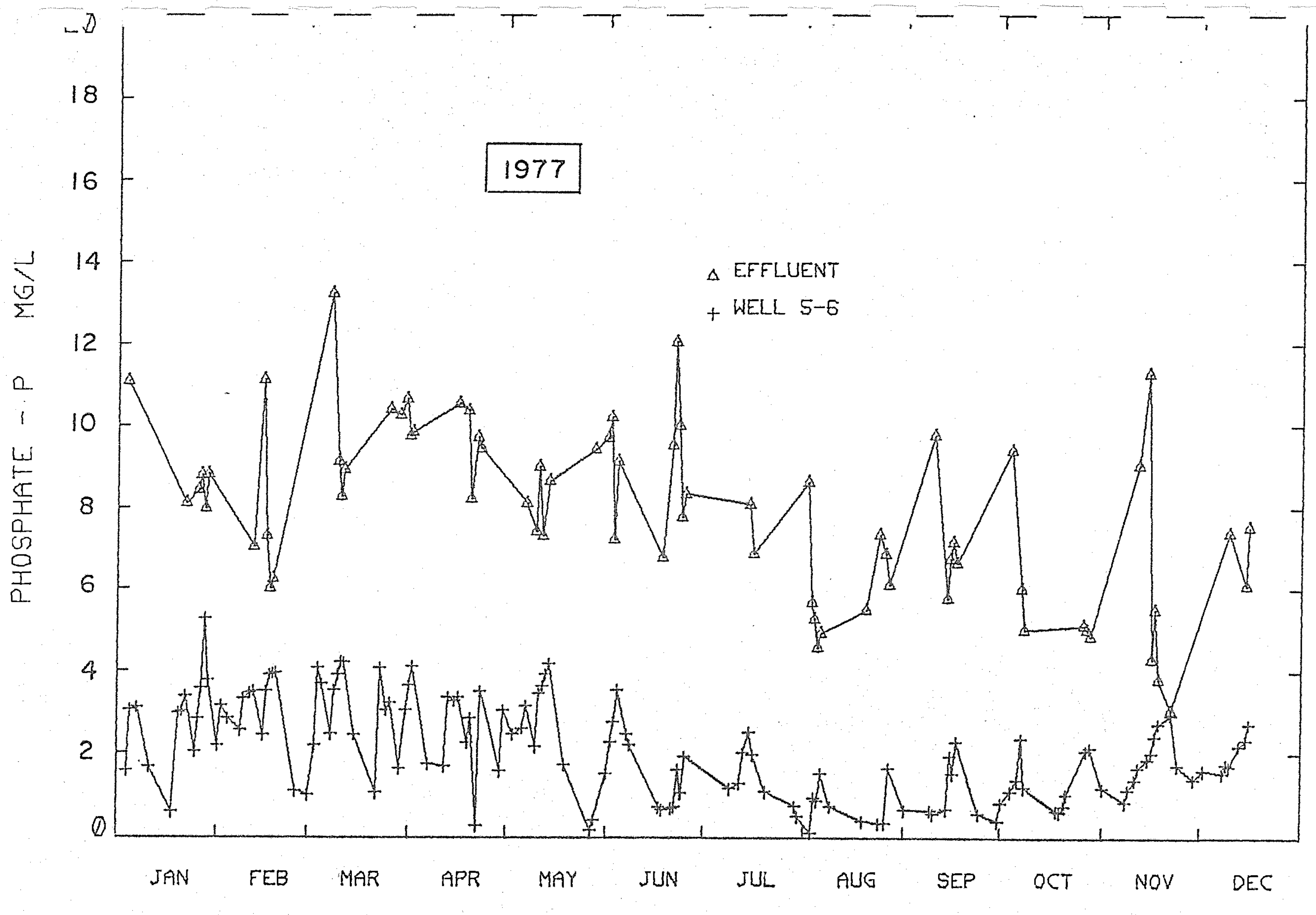

Figure 13. Phosphate phosphorus in effluent and in renovated water from well 5-6.

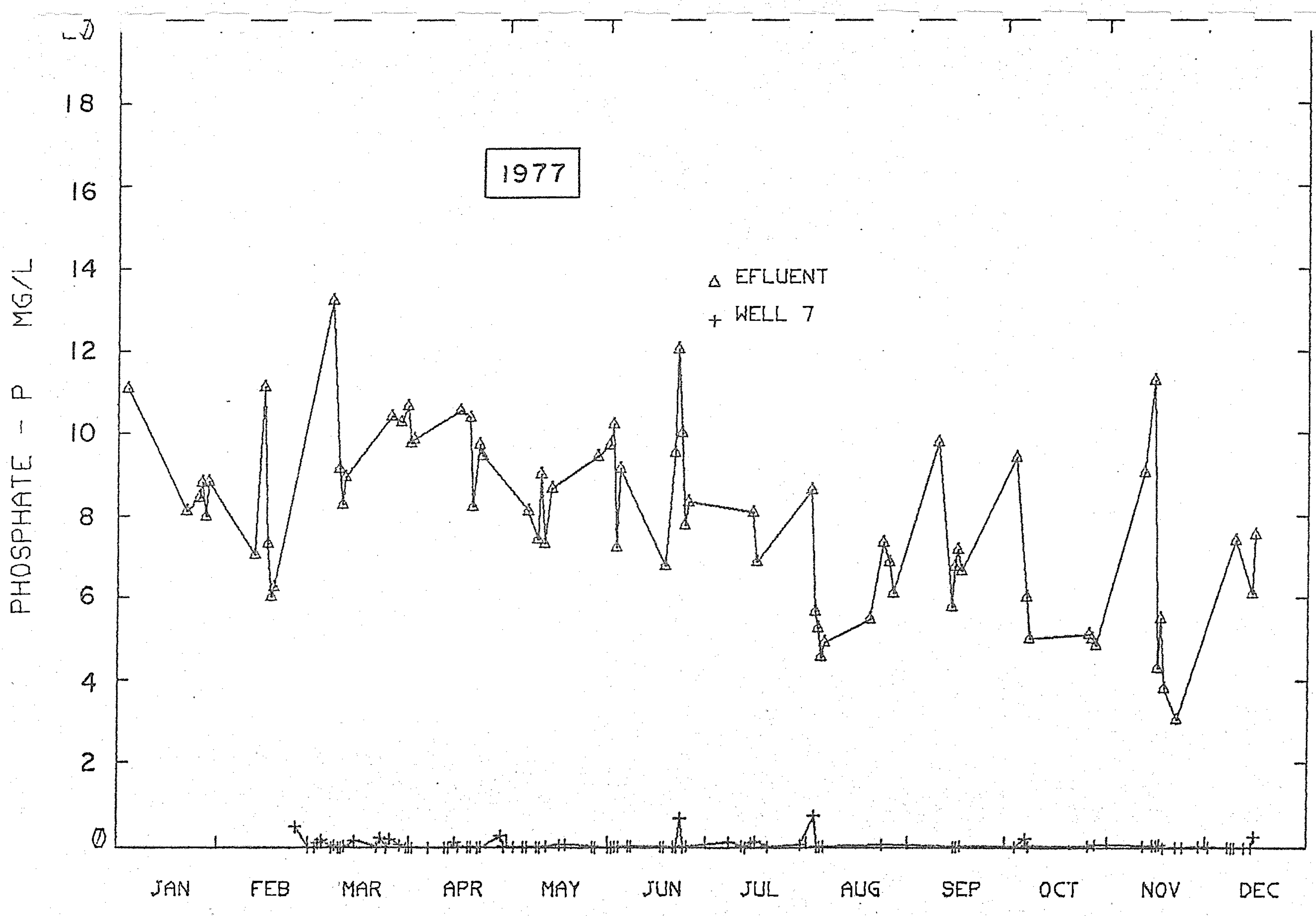

Figure 14. Phosphate phosphorus in effluent and in renovated water from well 7.

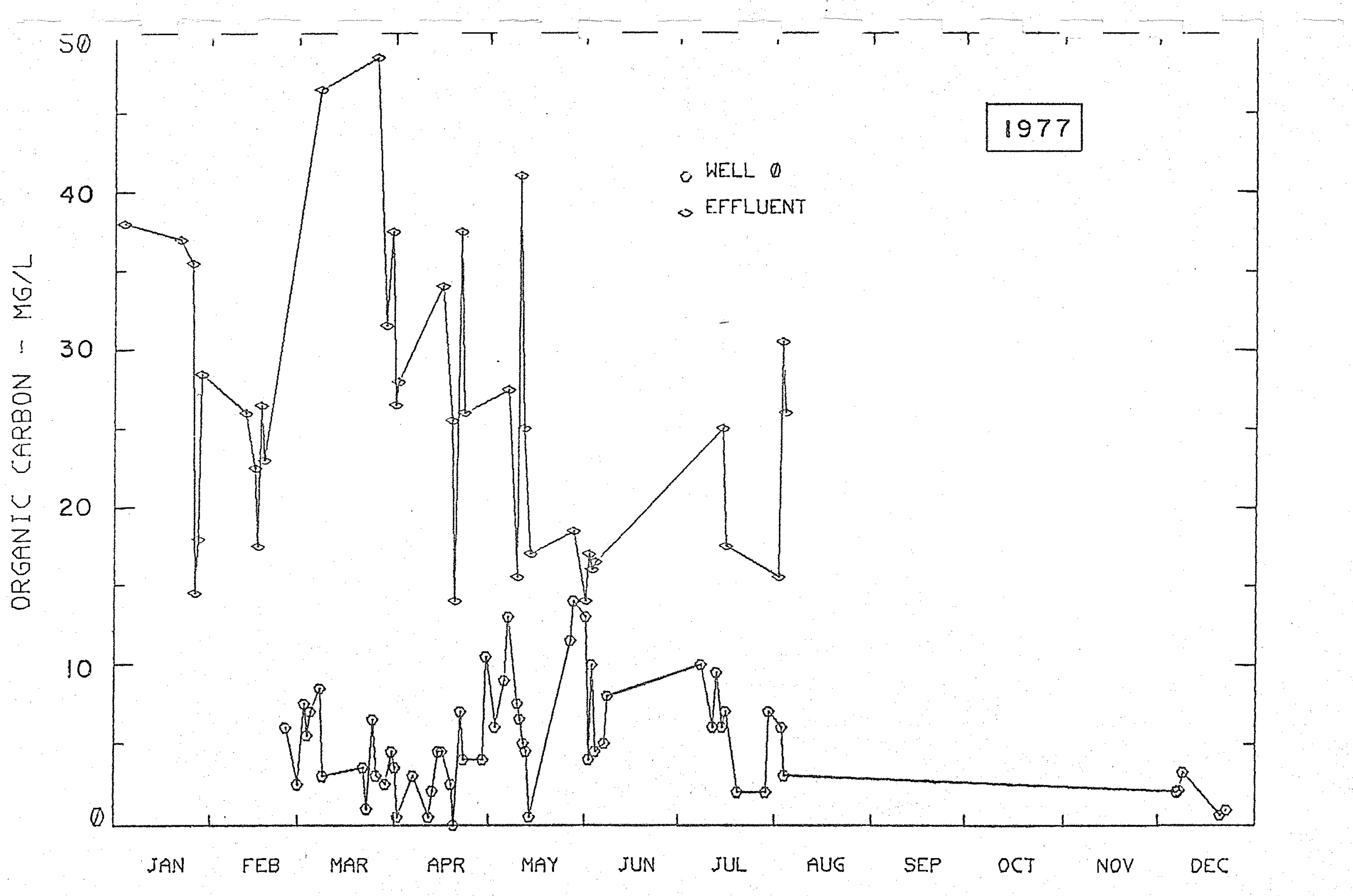

Figure 15. Organic carbon in effluent and in renovated water from well 0.

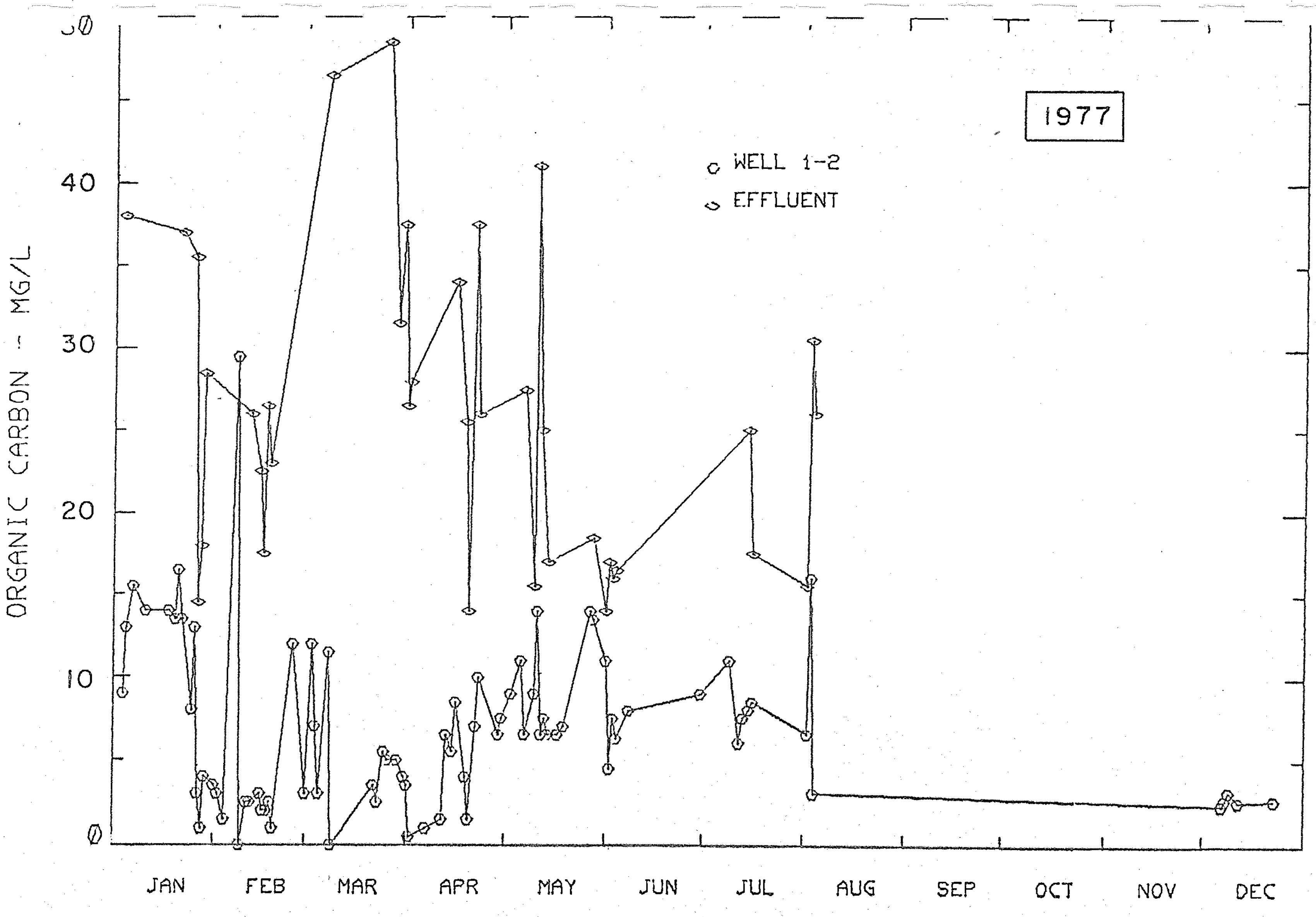

Figure 16. Organic carbon in effluent and in renovated water from well 1-2.

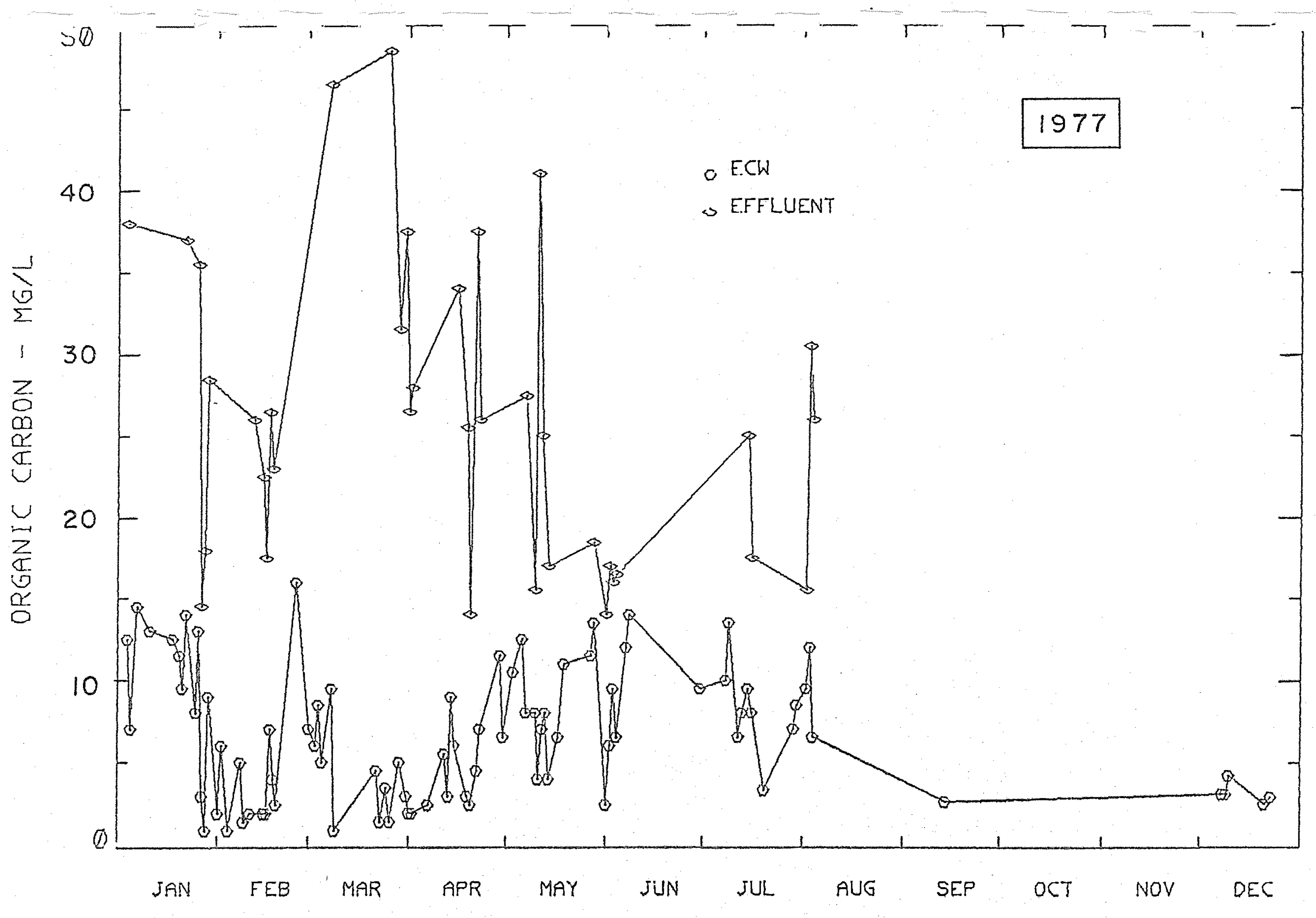

Figure 17. Organic carbon in effluent and in renovated water from East Center Well.

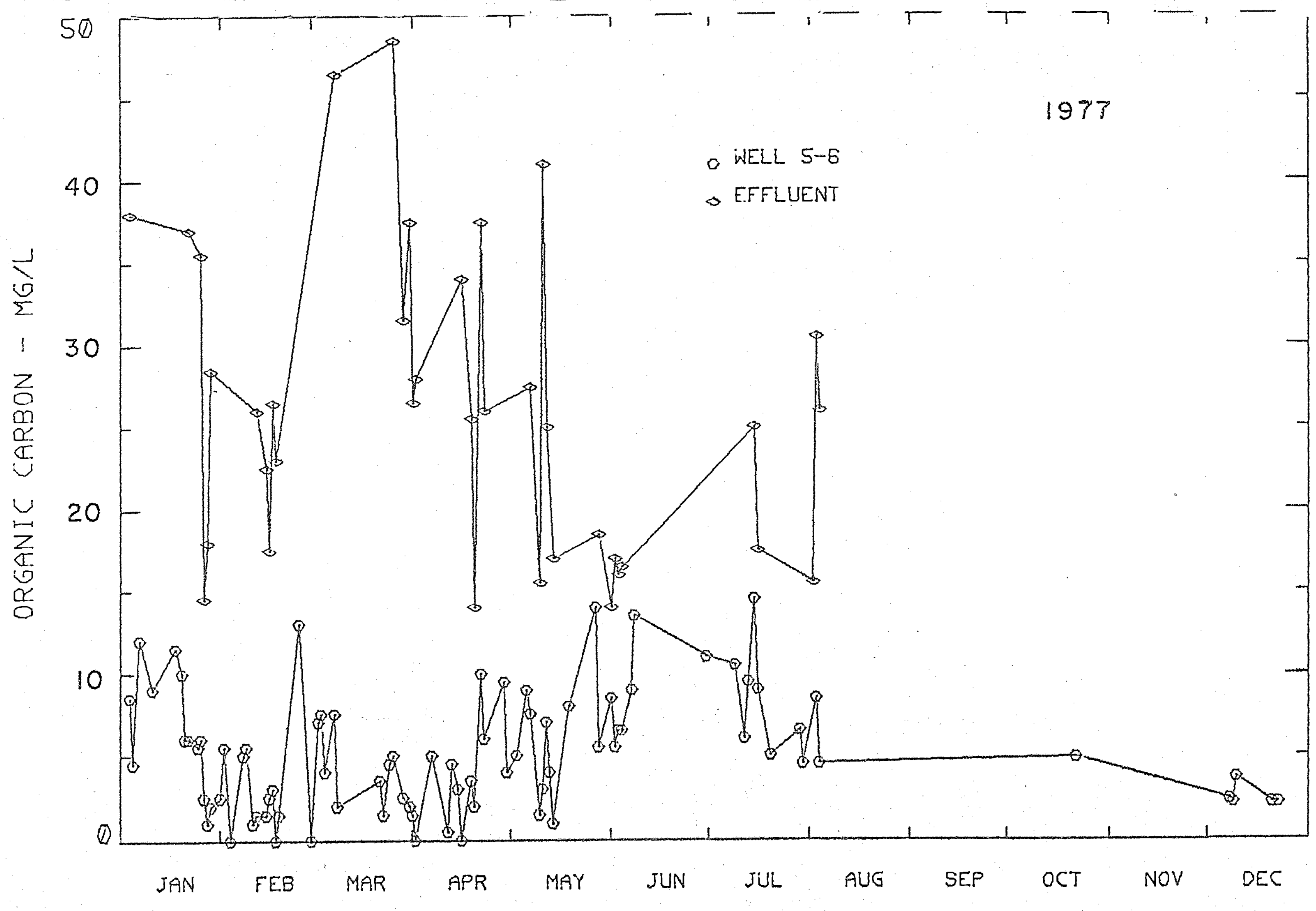

Figure 18. Organic carbon in effluent and in renovated water from well 5-6.

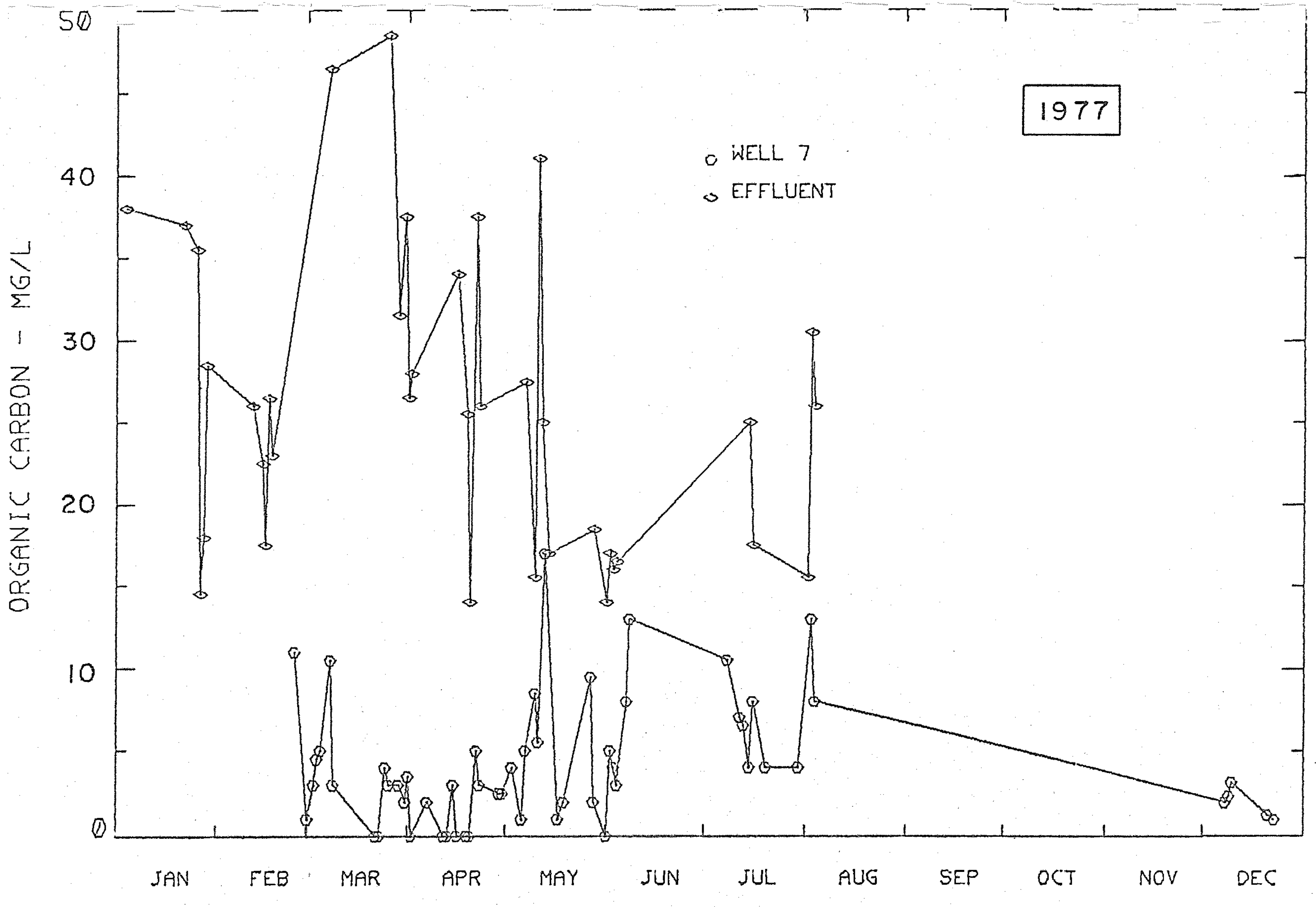

Figure 19. Organic carbon in effluent and in renovated water from well 7.

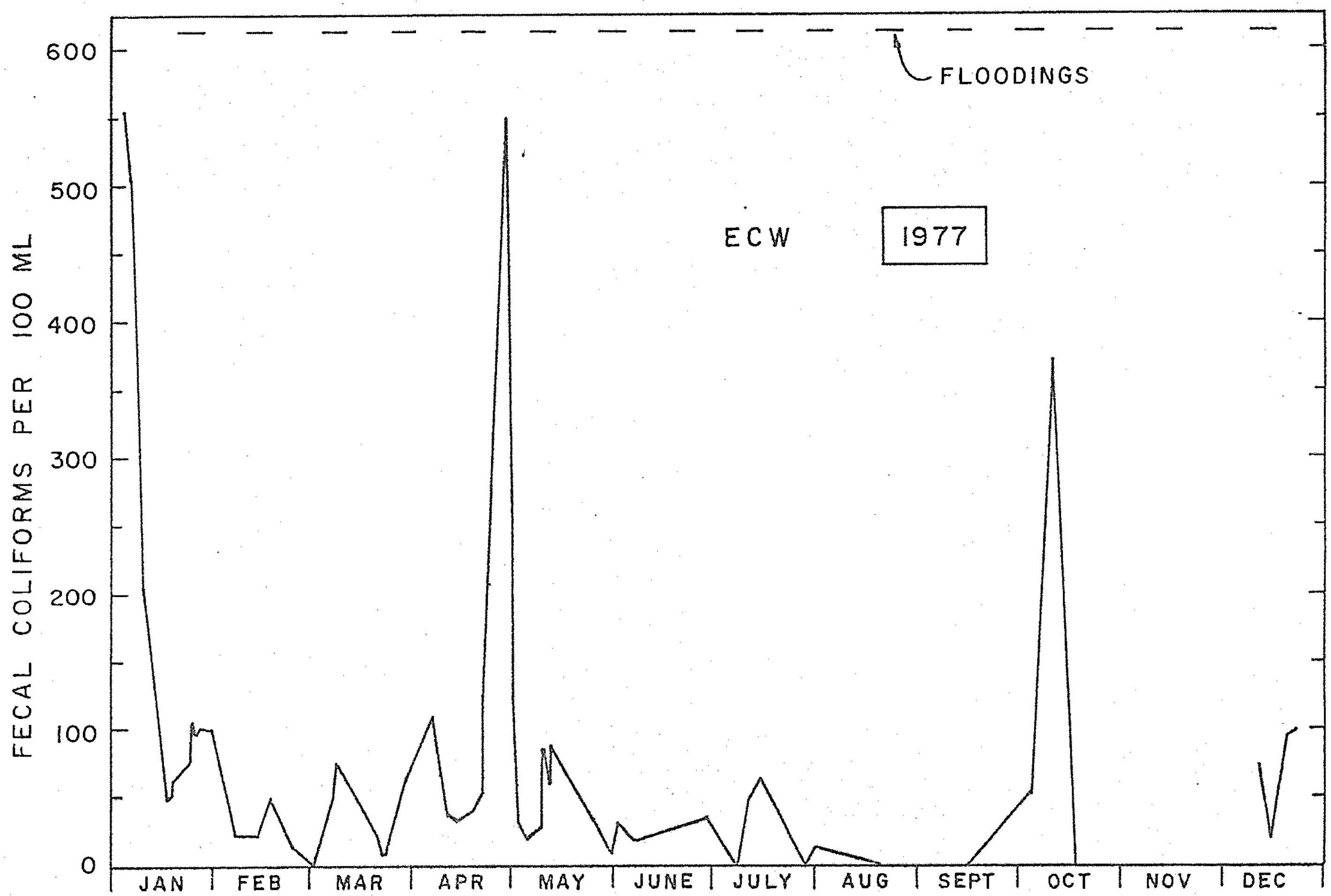

Figure 20. Concentration of fecal coliform bacteria in the renovated water from East Center Well.

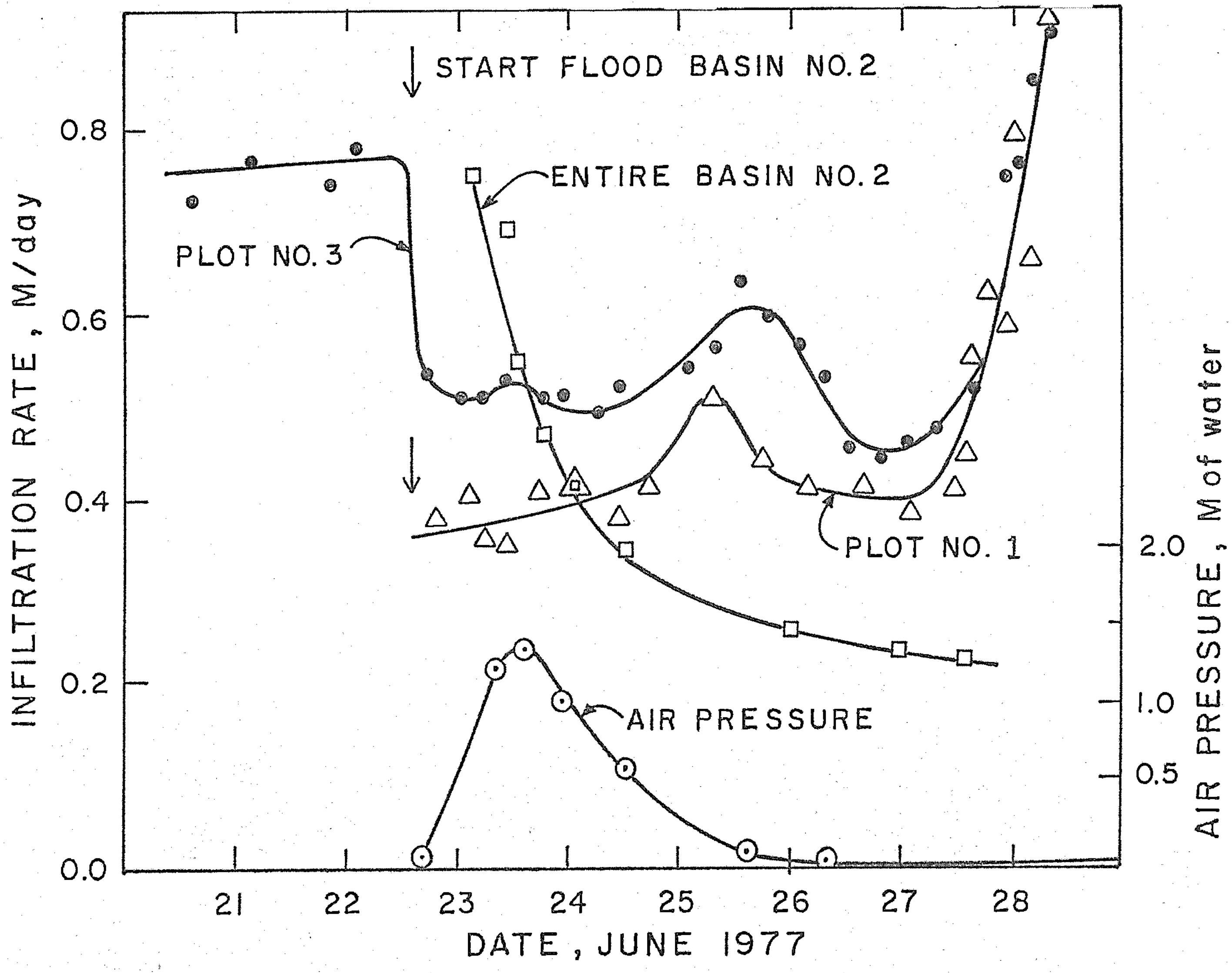

Figure 21. Infiltration rate of 1 m^2 plots before, during, and after flooding of surrounding area, and air pressure at 12.2-m depth in center of basin.

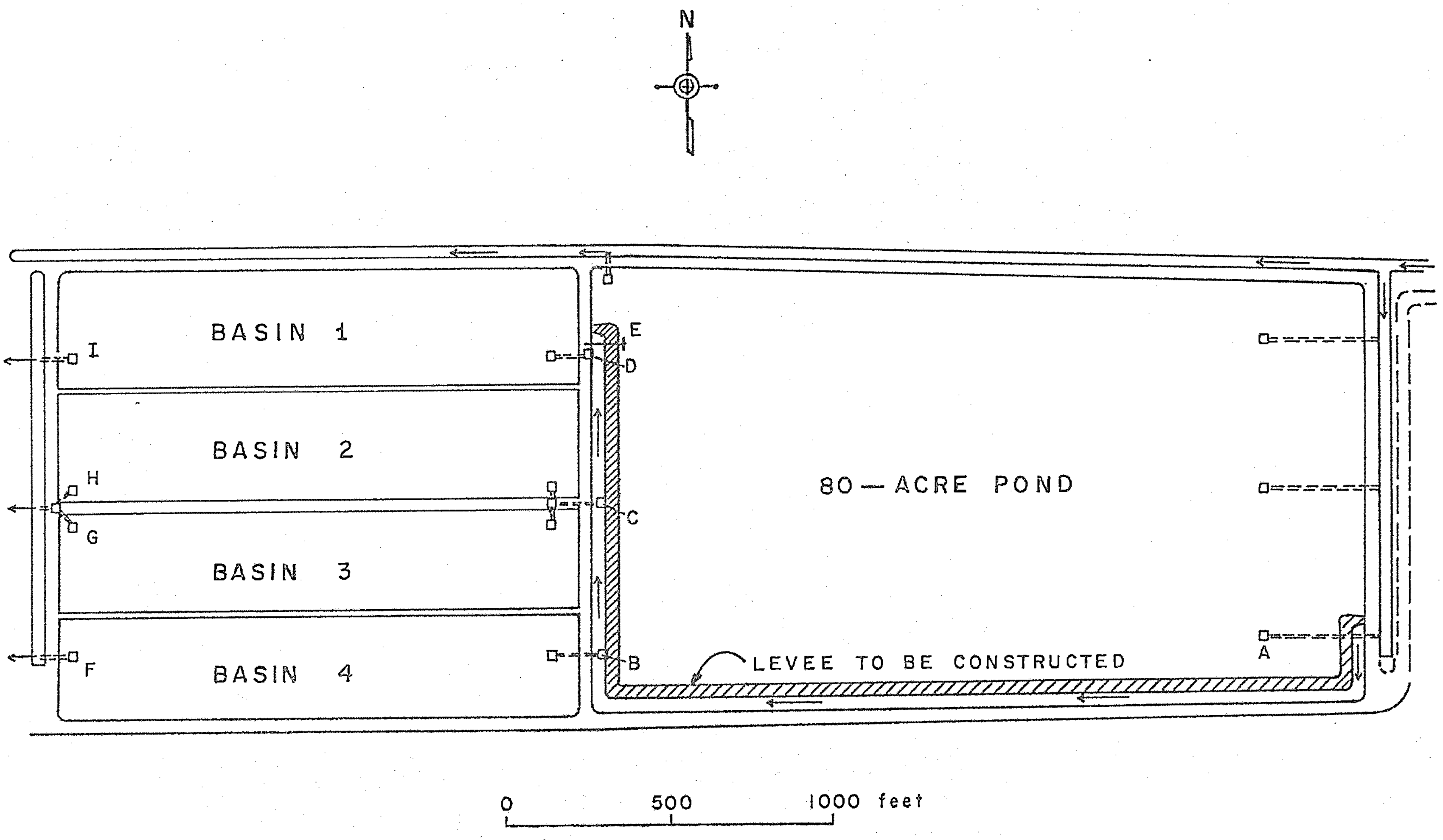

Figure 22. Schematic of 80-acre pond and levee to create by-pass cahnnel so that secondary effluent will flow directly into the four infiltration basins.

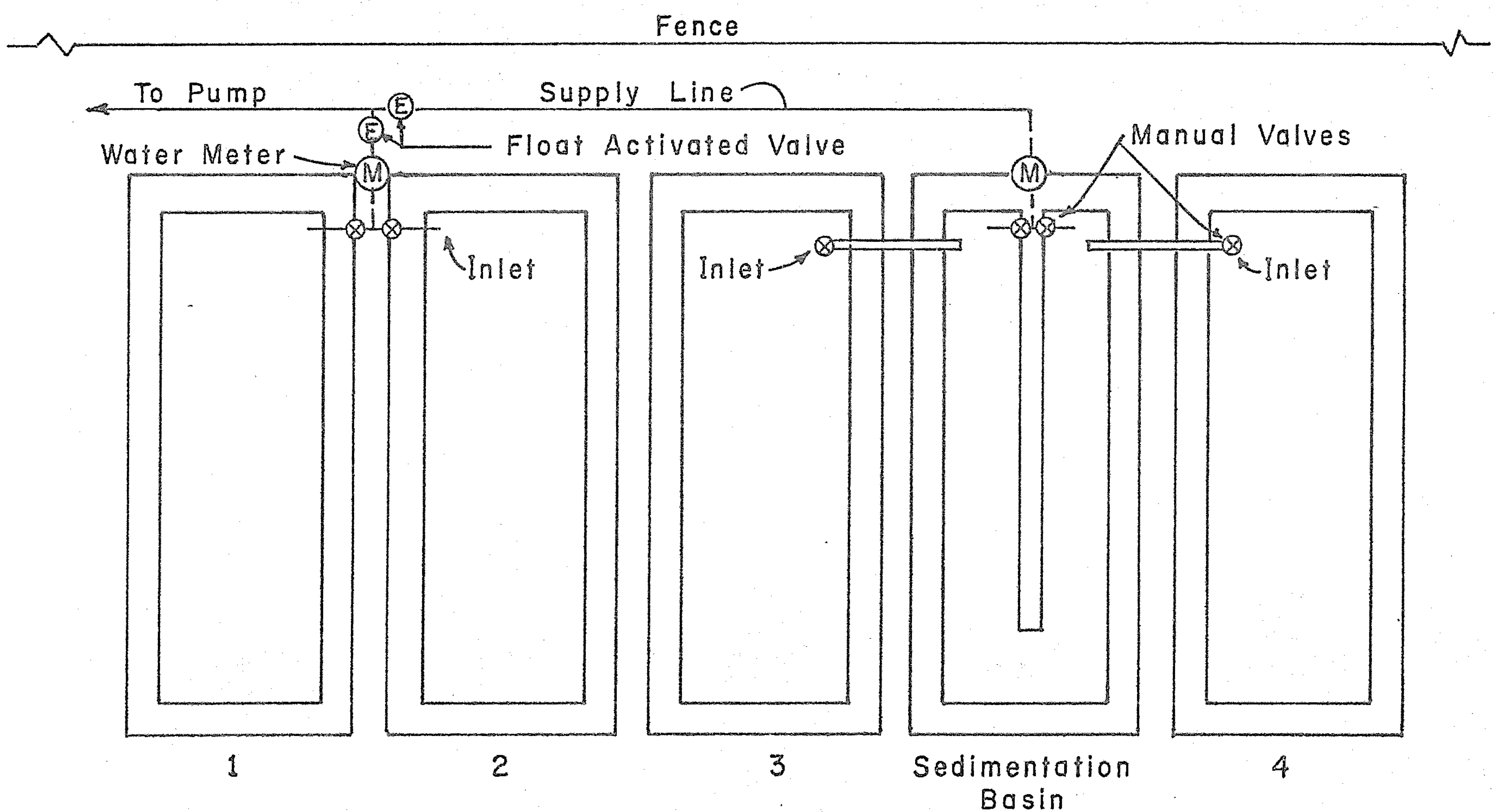

Figure 23. Plan of Mesa Primary Project.

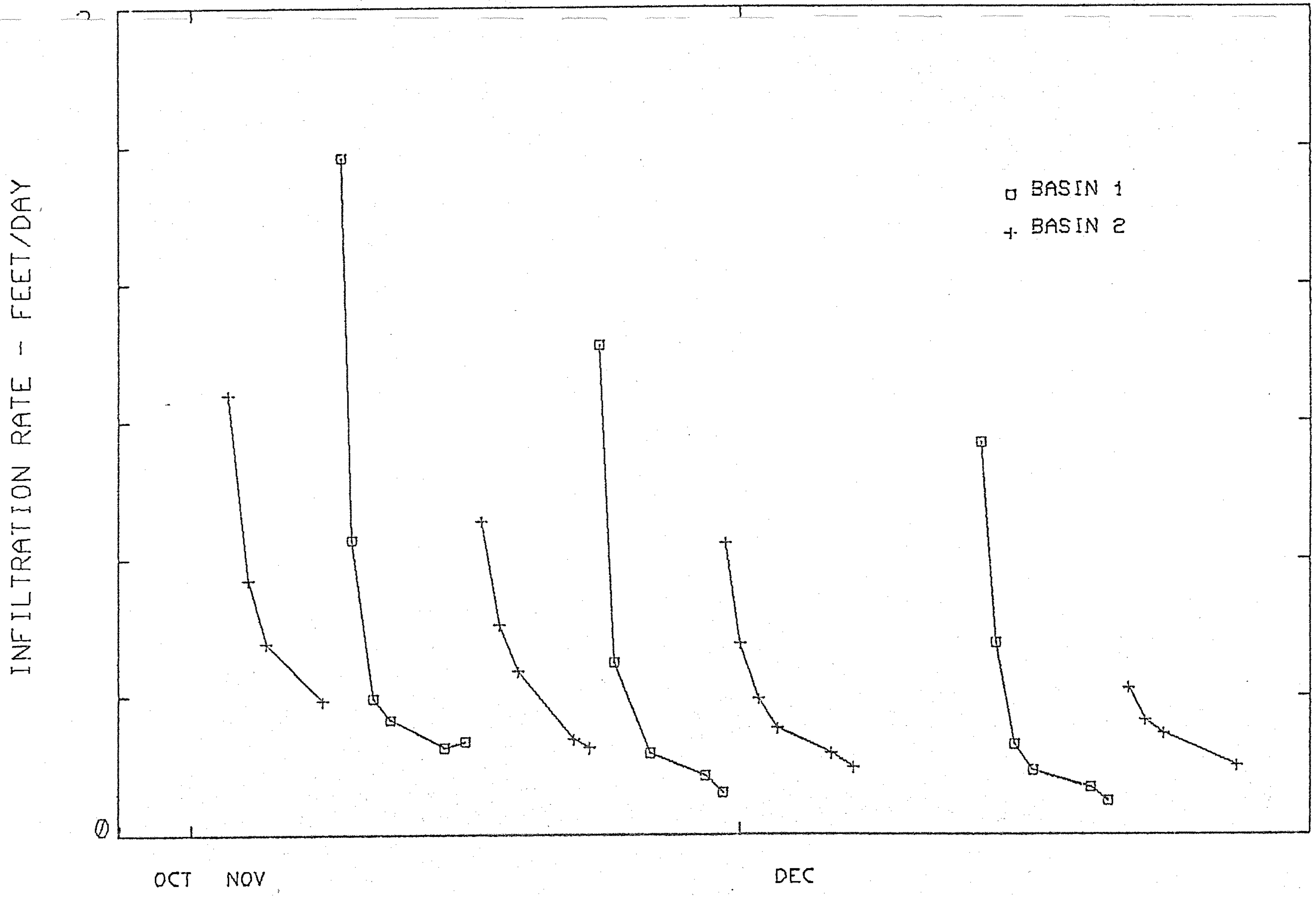

Figure 24. Infiltration rates in basins 1 and 2 of Mesa Primary Project.

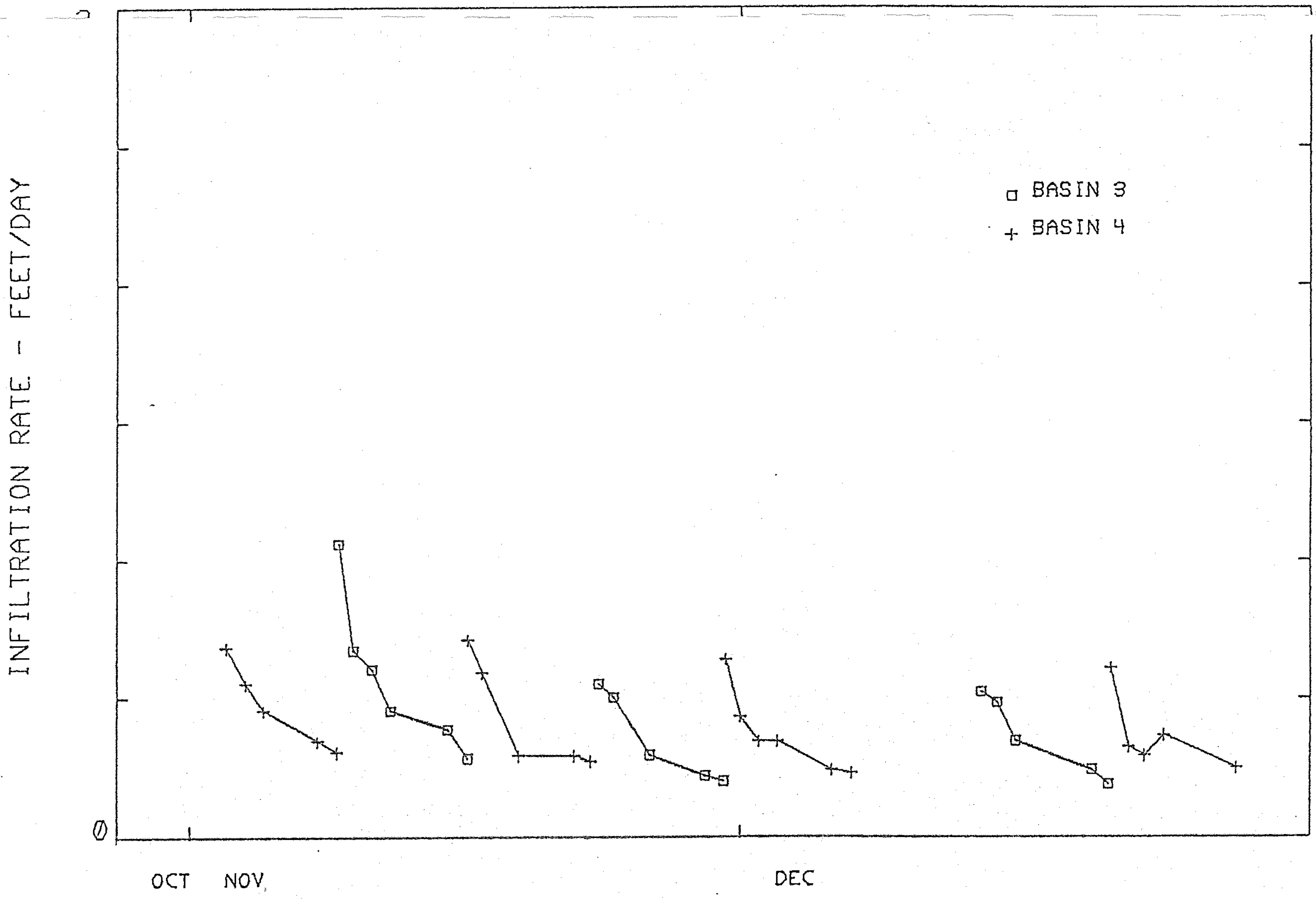

Figure 25. Infiltration rates in basins 3 and 4 of Mesa Primary Project.

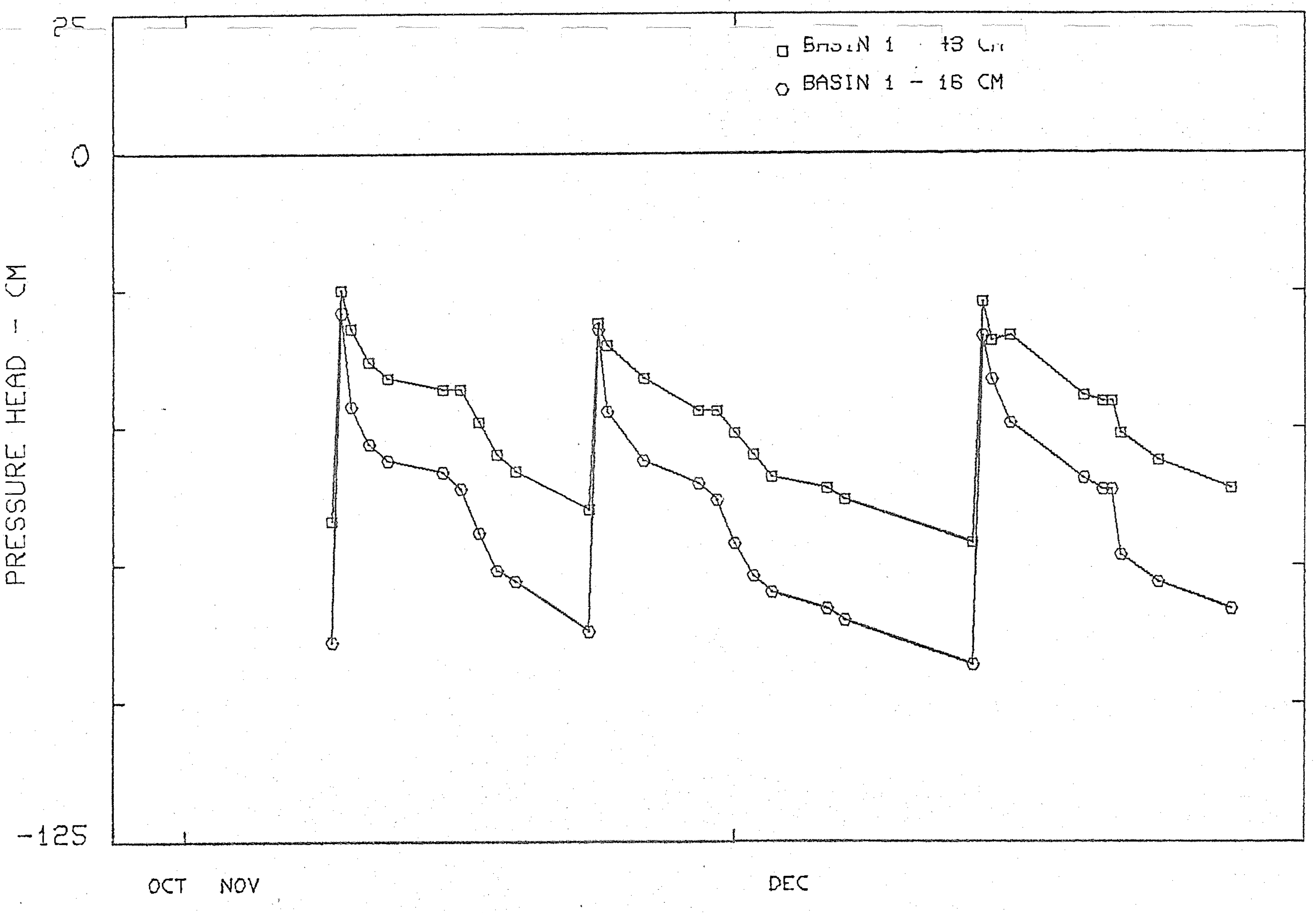

Figure 26. Pressure heads at two depths in basin 1 of Mesa Primary Project.

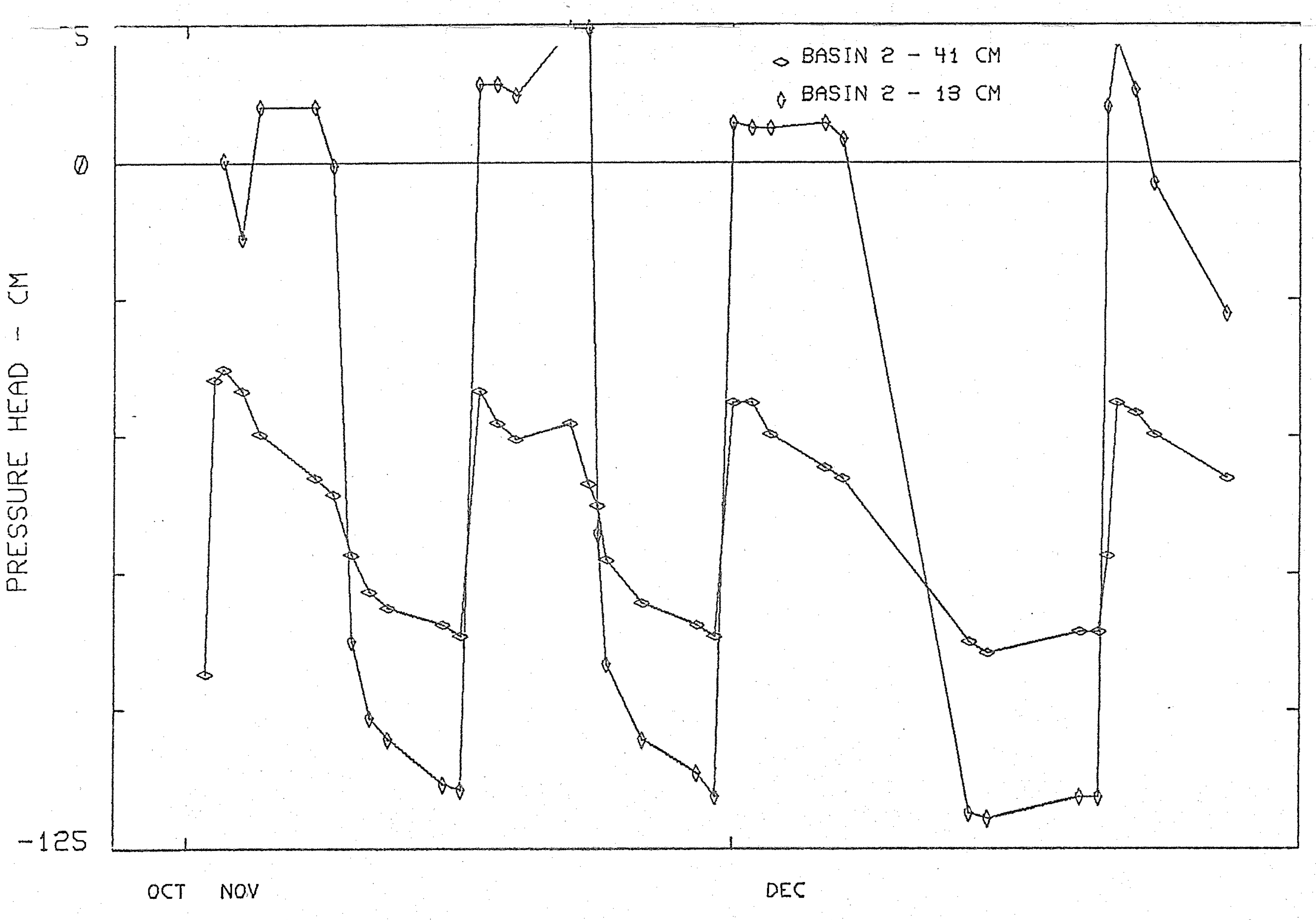

Figure 27. Pressure heads at two depths in basin 2 of Mesa Primary Project.

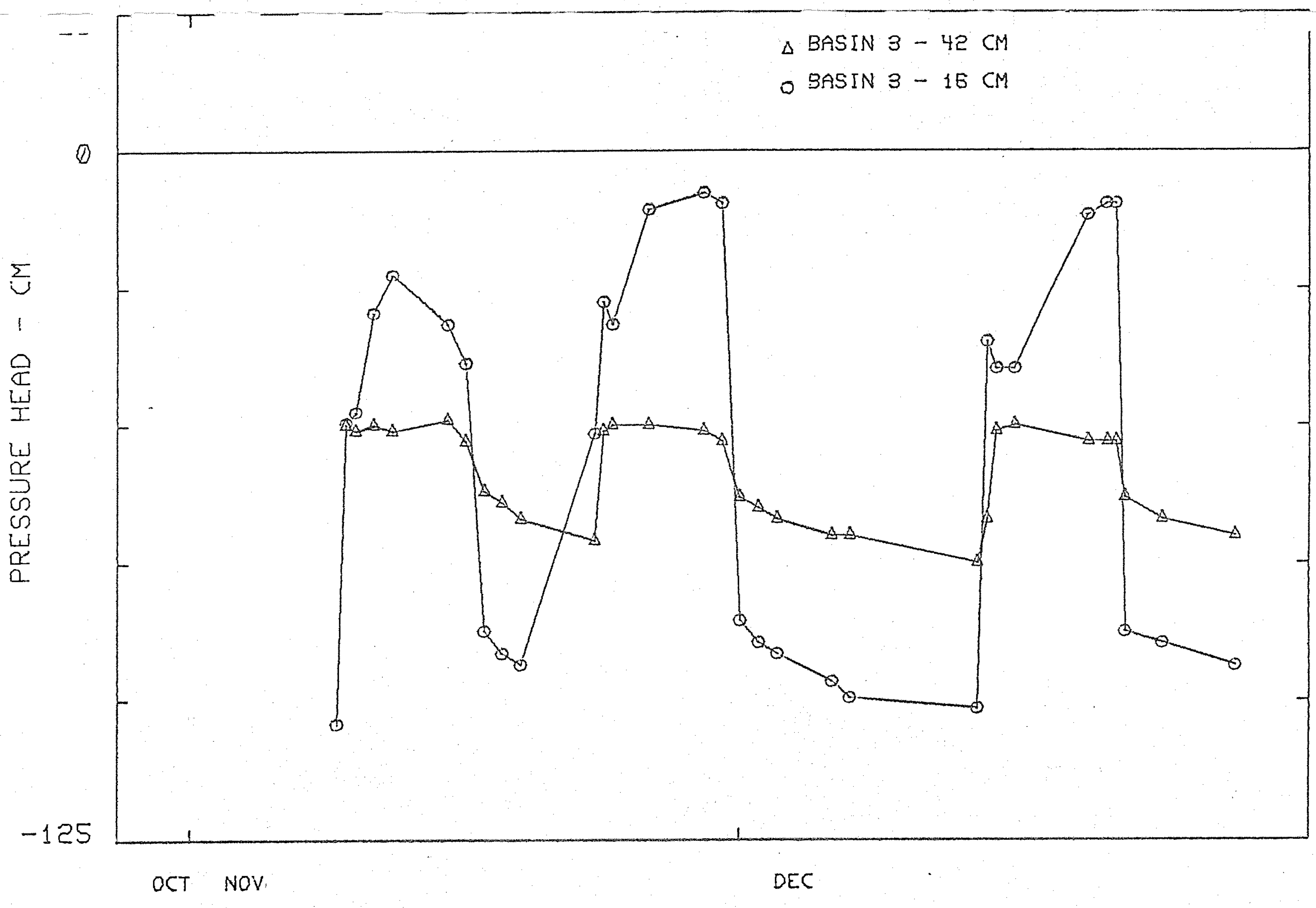

Figure 28. Pressure heads at two depths in basin 3 of Mesa Primary Project.

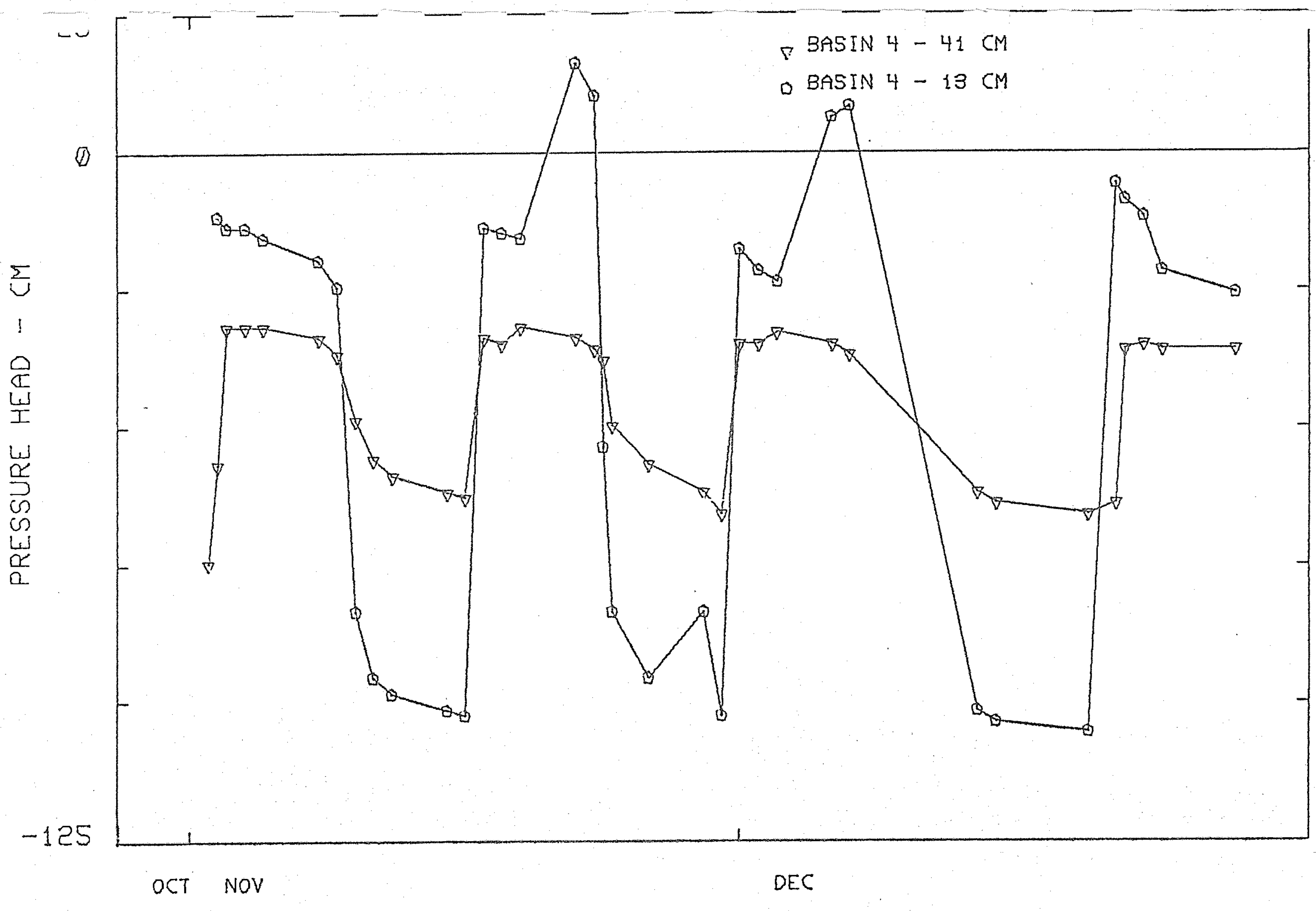

Figure 29. Pressure heads at two depths in basin 4 of Mesa Primary Project.

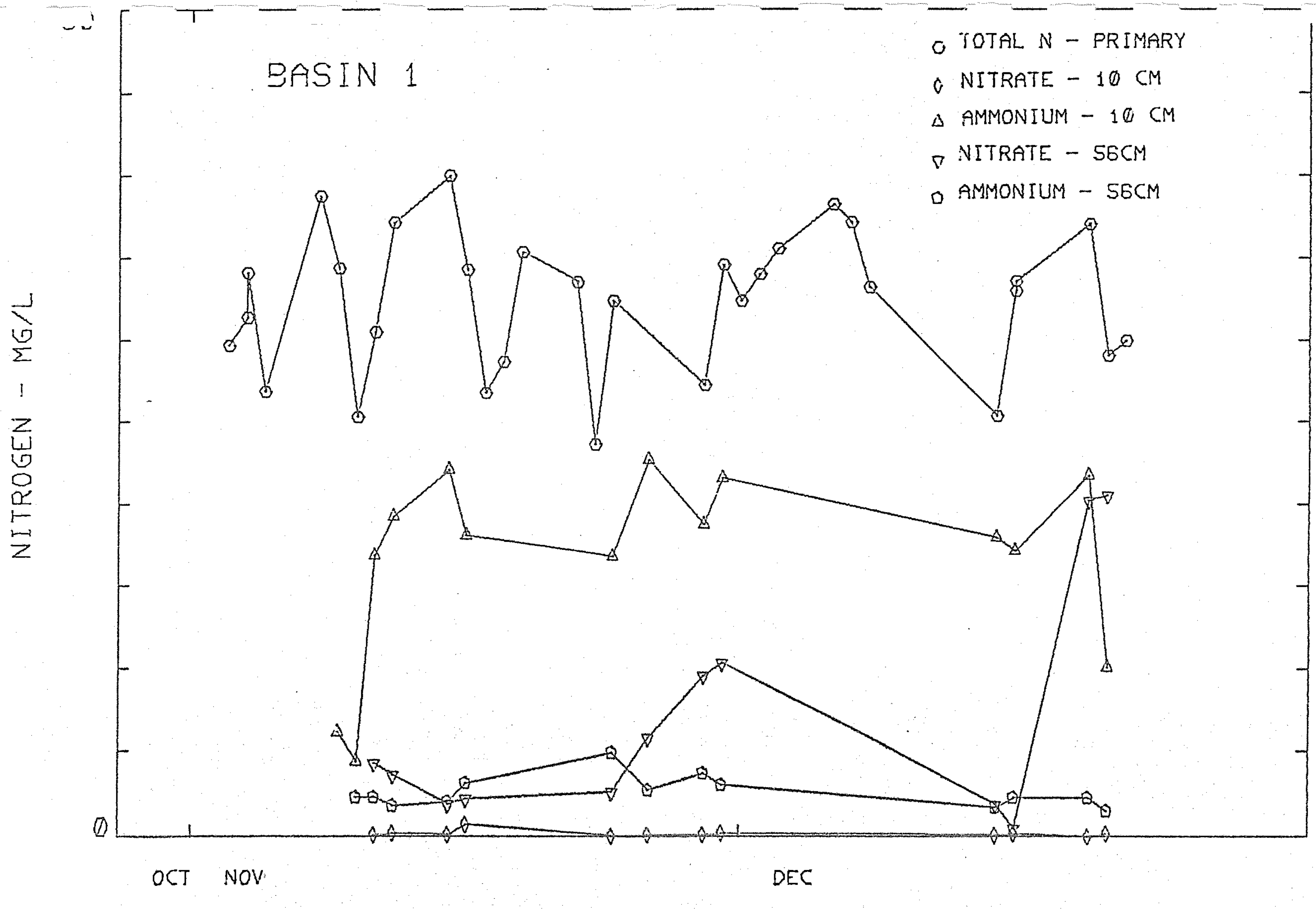

Figure 30. Nitrogen in primary effluent and soil solution at two depths in basin 1 of Mesa Primary Project.

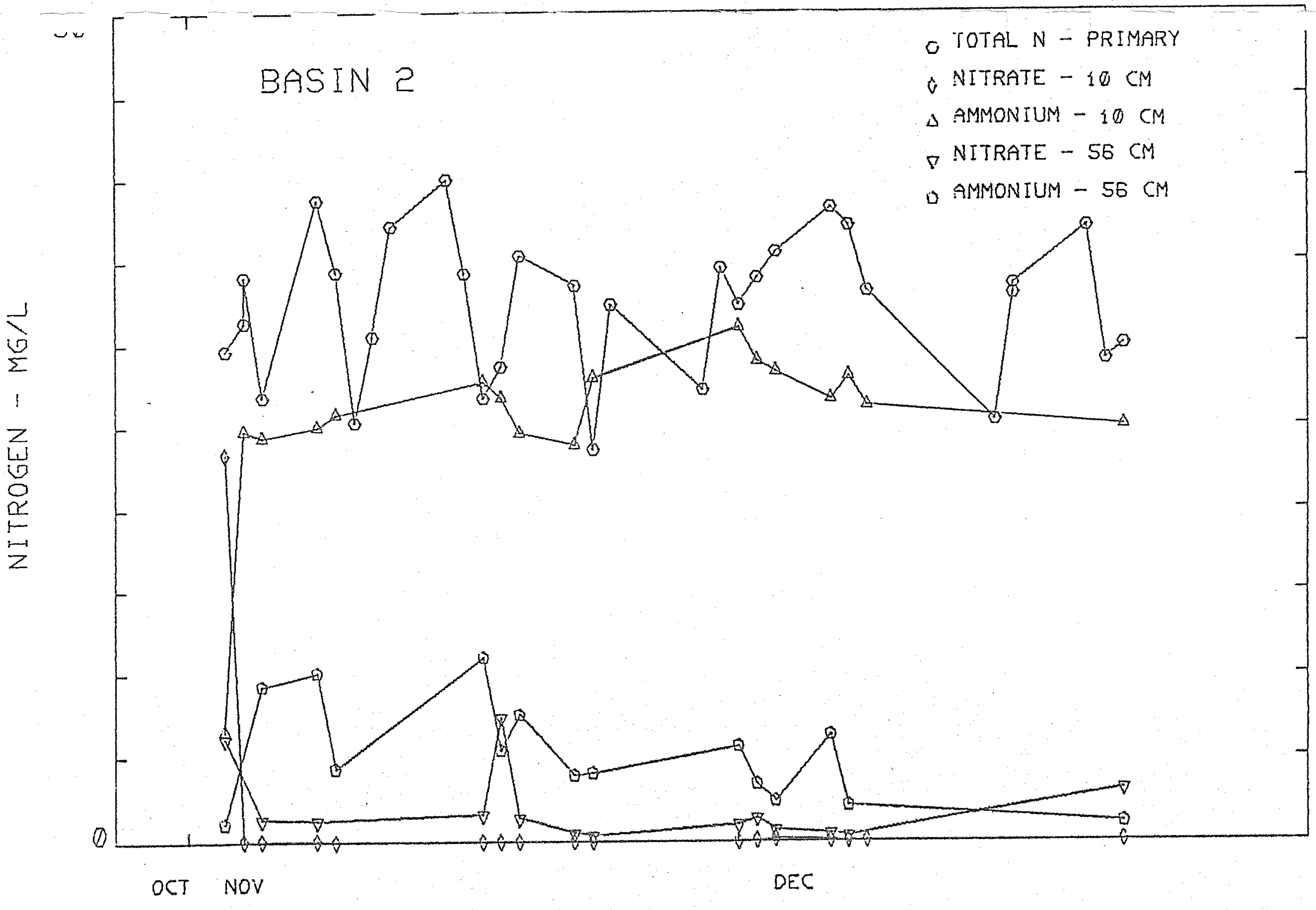

Figure 31. Nitrogen in primary effluent and soil solution at two depths in basin 2 of Mesa Primary Project.

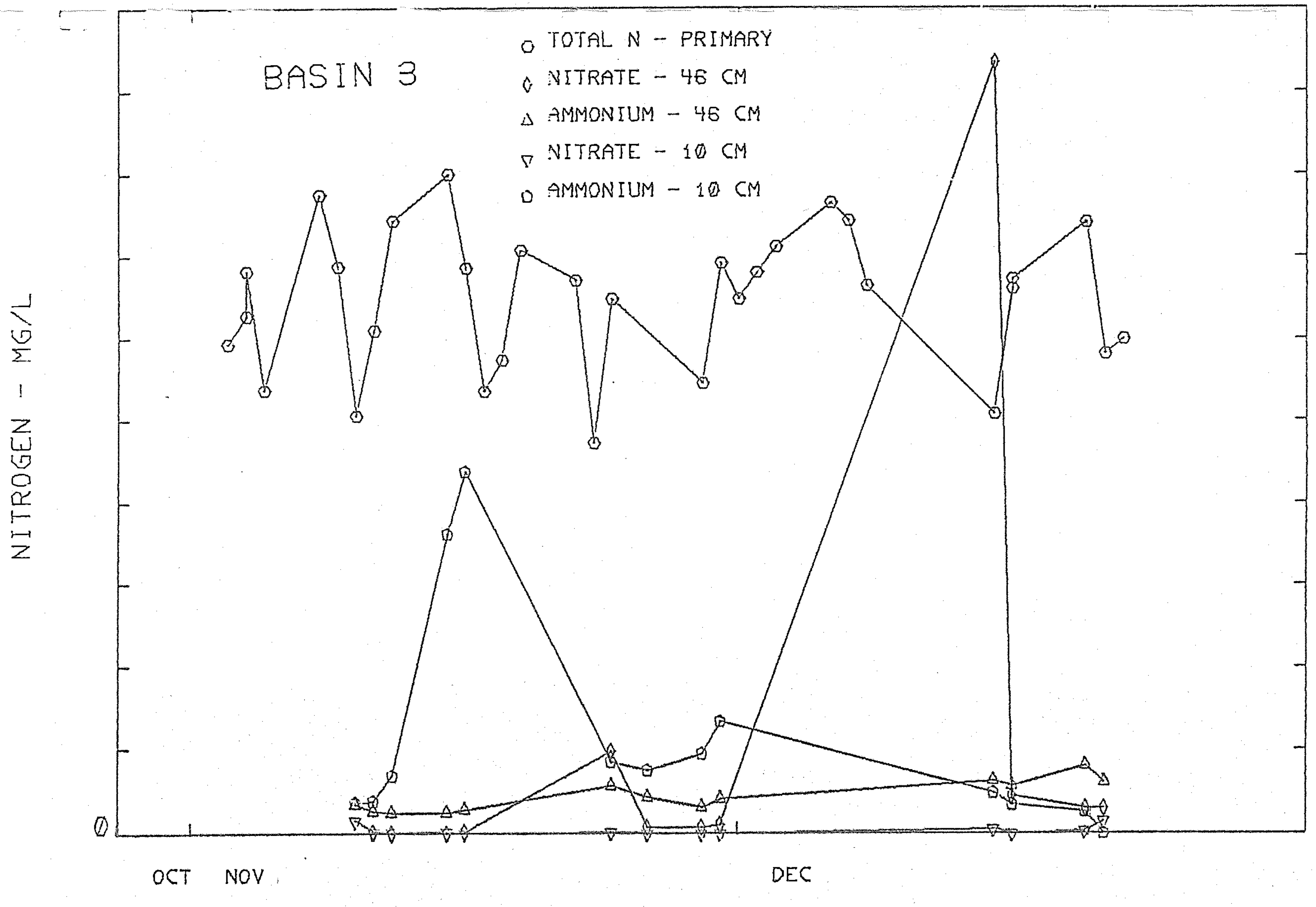

Figure 32. Nitrogen in primary effluent and soil solution at two depths in basin 3 of Mesa Primary Project.

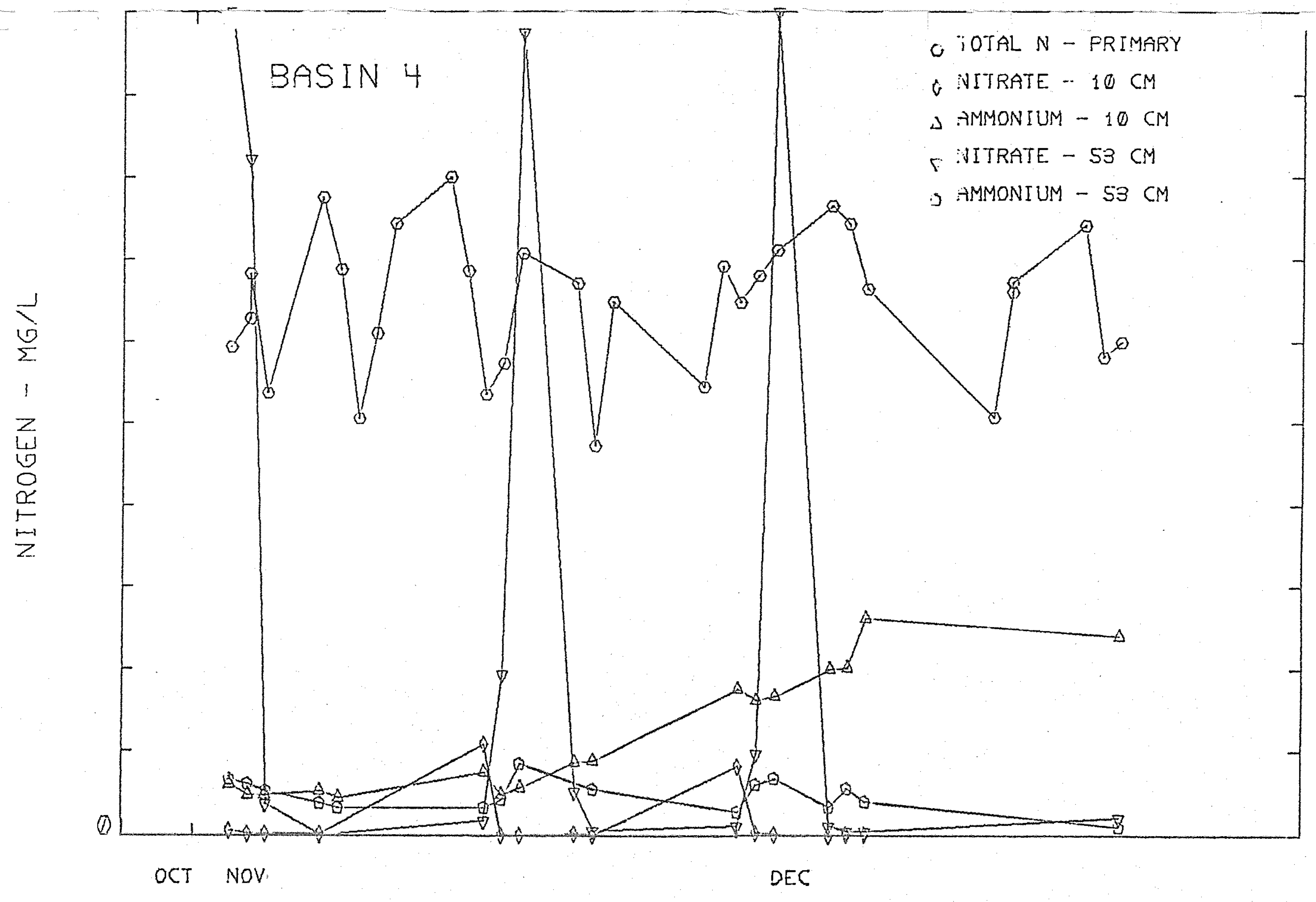

Figure 33. Nitrogen in primary effluent and soil solution at two depths in basin 4 of Mesa Primary Project.

TITLE: COLUMN STUDIES ON 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:

In order to determine the applicability of previous studies on movement of attenuated polioviruses through soil columns flooded with sewage effluent, the studies were repeated using echoviruses as well. Echoviruses apparently are smaller, and thus may be more mobile in soil systems than polioviruses.

PROCEDURE:

Two soil columns, each 250 cm in height and filled with the loamy sand of the Flushing Meadows Project, were flooded with secondary sewage effluent. Attenuated poliovirus and live echovirus obtained from the Virology Department of Baylor School of Medicine, were added to separate batches of secondary sewage effluent to give concentrations of 2×10^4 PFU/ml. One column was flooded with effluent containing poliovirus, and the other with effluent containing echovirus. Since the soil columns had been dried for approximately one year, straight secondary sewage effluent was used for the first cycle of eight days flooding and four days drying, before virus-enriched effluent was added. This seeded effluent was applied for two days. The columns were then drained for five days before they were flooded a second time for two days with secondary effluent, again containing 2×10^4 PFU/ml viruses. This flooding period was followed immediately by one day's flooding with distilled water.

Water samples for virus assay were removed from the holding reservoir, from the effluent standing above the soil (called 0-depth in Tables 1 and 2), and from various depths in the columns (Tables 1 and 2). The samples were sent by air freight to Baylor's Virology Department for assay. Total dissolved salts analysis were also conducted on samples taken at the end of the day of flooding with deionized water.

RESULTS AND DISCUSSION:

Results of the virus assays are shown in Table 1 for the echovirus and in Table 2 for the poliovirus. Table 3 shows the outflow rates and Table 4 the average concentrations of polio and echovirus at the various depths for the two flooding cycles. The virus concentrations in the reservoir differed considerably from the design value of 20,000 PFU/ml. Some virus removal already took place in the tubing connecting the reservoir to the top of the column, as evidenced by the lower PFU values for the effluent standing above the soil in the columns. Based on the PFU values of the effluent above the soil (referred to as 0-depth in the table), percentages of viruses remaining at various depths in the columns were calculated. The results (Table 4) show that, percentage-wise, more echoviruses remained in the soil solution in the top 40 cm than polioviruses (see ratio of percentages remaining listed in the last column of Table 4). These ratios increased to reach a maximum at 20 cm, after which they decreased, became less than 1 between 40 and 80 cm (indicating more echo than poliovirus remaining), and then became 1 at 250-cm depth where echo and polioviruses both were completely absent.

After flooding with deionized water, the numbers of polio and echoviruses remaining at various depths in the column were on the same order. There was no clear relation between the number of viruses remaining and the TDS of the soil water.

The studies will be continued in 1978, rotating soil columns to rule out effects of soil differences on virus adsorption.

SUMMARY AND CONCLUSIONS:

Soil columns were flooded with secondary sewage effluent enriched with polio and echoviruses to evaluate possible differences between adsorption of these viruses in the soil. More polioviruses were adsorbed than echoviruses in the top 40 cm of the column, but both viruses failed to penetrate more than 250 cm. This enhances the validity of poliovirus as an indicator of virus removal below land treatment systems for municipal or other wastewater.

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

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

Column depth (cm)	PFU of Virus per ml					
	Cycle 1			Cycle 2		
		day 1	day 2		day 1	day 2	day 3**
R-0	320000			470000			
R-1		40000			250000		
R-2			43500			66000	
0		160000	385000		280000	17000	200
2		51000	99000		50000	57000	400
5		44000	98000		42000	48000	1300
10		43000	85000		67000	13000	300
20		42000	10000		40000	15000	200
40		4200	3600		8000	3100	150
80		240	650		480	360	55
160		150	0		5	0	15
240		0	0		0	10	0
250		0	0		0	0	0
250 jug*							

R-0 Fresh prepared in reservoir

R-1 Fresh prepared at start of day 2.

R-2 Fresh prepared virus near end of day 2.

* 100 ml sample

** Deionized water used as flooding fluid.

Table 2. Virus concentrations at various depths in a soil column flooded with secondary sewage effluent seeded with poliovirus.

Column depth (cm)	PFU of Virus per ml						
	Cycle 1			Cycle 2			
		day 1	day 2		day 1	day 2	day 3**
1RX							
R-0	117000			195000	26000		
R-1		33500			22000		
R-2						16000	
0		158000	11400		6200	12000	450
2		6700	7800		7300	5900	360
5		6800	5900		4400	5500	1200
10		2300	1200		560	540	210
20		670	900		380	230	90
40		980	150		340	180	240
80		100	440		130	150	240
160		0	350		0	15	15
240		0	200		0	0	0
250		0	0		0	0	25
250 jug*							

1RX Sample from reservoir at end of day 1.

R0 Fresh prepared in reservoir.

R1 Fresh prepared at start of day 2.

R2 One day old from reservoir at end of day 2.

* 100 ml sample.

** Deionized water used as flooding fluid.

Table 3. Outflow rates (cm/day) from soil columns used for virus removal.

Start Cycle	Column 2	Column 4
21 Nov.	44.03	45.59
	50.20	38.49
28 Nov.	75.6	4.72
	63.4	32.23
	44.57	45.59

Table 4. Average of 2 cycles of flooding - 2 days each cycle.

Depth (cm)	Echovirus PFU/ml	Echovirus % remaining	Poliovirus PFU/ml	Poliovirus % remaining	Ratio of echo to polio remaining
Reser-voir	270000		141380		
0	210500	100	60850	100	
2	64250	30.5	6925	11.4	2.67
5	58000	27.6	5600	9.2	3.0
10	52000	24.7	3625	6.0	4.0
20	26750	12.7	545	0.90	14.1
40	4725	2.24	412	0.68	3.29
80	433	.21	205	0.34	.62
160	39	0.19	91	0.15	.13
240	3	0.0014	50	0.08	.02
250 jug	0	0.0	0	0.0	1

Table 5. Total dissolved salts (mg/l) and virus concentrations (PFU/ml) after one day of flooding with deionized water.

Depth (cm)	Column 2 TDS	Column 2 Echo virus	Column 4 TDS	Column 4 Polio virus
0	64	200	0	450
2	32	400	32	360
5	64	1300	32	1200
10	64	300	51	210
20	51	200	13	90
40	32	150	128	240
80	---	55	147	240
160	384	15	---	15
240	---	0	---	0
250	768	0	896	25

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 1977 cooperative research with Dr. J. H. Smith on land disposal of potato processing wastewater in Idaho was completed and a manuscript was prepared for the Journal of Environmental Quality. Laboratory columns studies that evaluated the effects of infiltration rates and organic carbon treatments on the activity of denitrifying bacteria and nitrogen removal in soil intermittently flooded with secondary sewage effluent (SSE) enriched with glucose as a carbon source were completed. The results were presented at the 69th Annual Meeting of the American Society of Agronomy in Los Angeles, California, and a manuscript was written for the Journal of Environmental Quality. The primary research effort this year was concerned with field investigations at Flushing Meadows on the growth and activity of denitrifying bacteria in soil basins intermittently flooded with SSE. This report contains procedures and summary data from several experiments that determined the population fluxes of denitrifying bacteria during flooding and drying cycles and evaluated the rates of nitrate-N loss and/or denitrification capacity in the soil basin during flooding and drying cycles.

PROCEDURES:

Basin #1 at the Flushing Meadows Project was selected as the field site, because it has always been a bare soil basin, that was flooded with secondary sewage effluent. Soil samples were collected with a King tube during flooding and drying periods of 9 and 12 days, respectively. Soil profile samples from 0-90 cm were collected occasionally, but the surface 0-5 cm of the soil basin was routinely sampled. Soil samples were analyzed as soon as possible for water content, bacterial numbers, inorganic nitrogen, and denitrification capacity.

The denitrification capacity of each soil sample was evaluated by following the rate of nitrate-N loss. Soil samples were incubated in sealed glass vials (60 ml) under waterlogged conditions at 28 C. Each vial contained 25 g of soil and 25 ml of 200 mg/l nitrate-N solution. Duplicate soil samples were extracted with 2N KCl after incubation times ranging from 0 to 240 hours and were analyzed with a Technicon autoanalyzer for ammonium-N, nitrite-N, and nitrate-N. Results are reported on a soil dry weight basis.

The numbers of denitrifying bacteria were determined by the Most Probable Numbers Method, using a 5-tube dilution series with nitrate broth. Numbers of bacteria are reported on a soil dry weight basis.

RESULTS AND DISCUSSION:

Nitrogen removal from wastewater is primarily biological and research was conducted to obtain basic information about the populations of denitrifying microorganisms in soil systems used for wastewater reclamation. The effects of infiltration rates and organic carbon treatments on the growth of denitrifying bacteria in soil columns intermittently flooded with secondary sewage effluent (SSE) were determined (Publication #3). At low infiltration rates of 10 to 15 cm/day, N-removal was > 80% and organic carbon enrichment of the SSE was not necessary or beneficial, even though the numbers of denitrifying bacteria were increased tenfold. However, at higher infiltration rates (> 15 cm/day) the number of denitrifying bacteria played an extremely important role in the net N-removal and carbon enrichment of the SSE was essential for maintaining > 80% N-removal. Continuous carbon treatments were more effective than 2-day pulse treatments for enhancing the growth of denitrifying bacteria and N-removal. With continuous carbon treatments of 200 mg/l, > 80% N-removal was obtained at infiltration rates of 40 cm/day.

Additional field studies with SSE applied to soil basins at the Flushing Meadows Project have shown that the numbers of denitrifying bacteria and rates of denitrification were highest in the surface soil of the basins (Table 1) and at the end of each flooding period (Table 2). These results have indicated that the denitrifying potential in soil basins intermittently flooded at high infiltration rates with SSE was greatest at the start of each drying period and that the activity of denitrifying bacteria and nitrogen removal from high-rate land-treatment systems could be enhanced by the additions of organic carbon to the SSE applied to the soil infiltration basins, especially during the last 2 days of the flooding period. Also, intermittent application to land of primary sewage effluent may enhance denitrification, because it has a high level of available organic carbon. If managed properly, considerable savings in energy and cost for treatment of municipal wastewater could be realized with high-rate land filtration of primary sewage effluent.

SUMMARY AND CONCLUSIONS:

Nitrogen removal from wastewater is primarily biological and research was conducted to obtain basic information about the populations of denitrifying microorganisms in soil systems used for wastewater reclamation. Our results have shown that the number of denitrifying bacteria controlled and regulated the net nitrogen removal from soil columns intermittently flooded with secondary sewage effluent, and that timely additions of organic carbon during flooding and drying cycles increased the number of denitrifiers in the soil for extended time periods. Also, additional field studies have shown that the denitrifying potential in soil basins at the Flushing Meadows project was greatest at the start of each drying period and was concentrated in the surface 15 cm of the soil profile. Therefore, increasing the denitrifying bacteria populations increased the denitrifying capacity, which enhanced nitrogen removal; and effective management of wastewaters through nutrient additions, perhaps even in the form of primary effluent, can decrease the hazard of nitrate pollution of groundwater below land treatment systems.

During 1978, the field studies at Flushing Meadows on the growth and activity of denitrifying bacteria in soil basins intermittently flooded with SSE will continue. Techniques and procedures for quantitatively evaluating the denitrification process in the soil basins will be developed. The influence of several environmental factors, such as temperature, water content, oxygen, redox potential, organic carbon enrichment, nitrification rates, and numbers of denitrifying bacteria, on the rate and duration of denitrification in the soil basins will be investigated. Similar field studies will be initiated to evaluate the biological aspects of nitrogen removal from soil basins intermittently flooded with primary sewage effluent at the Mesa, Arizona, sewage treatment plant.

PUBLICATIONS:

1. Bouwer, Herman, R. C. Rice, J. C. Lance and R. G. Gilbert. Controlled recharge of wastewater for aquifer protection and production of renovated water. IAHS-AISH Publ. No. 123. Pgs. 441-447. In: Proc. Symp. Effect of Urbanization and Industrialization on the Hydrological Regime and on Water Quality. Amsterdam, Netherlands, October 1977.

2. Gilbert, R. G., and J. B. Miller. Growth of denitrifying bacteria in soil used for wastewater reclamation. 69th Annual Meeting Amer. Soc. Agron. and Soil Sci. Soc. Amer., Los Angeles, California. 13-18 November 1977. Agron. Abstr. p. 26.

3. Gilbert, R. G., J. C. Lance, and J. B. Miller. Growth of denitrifying bacteria in soil used for wastewater reclamation. J. Environ. Qual. (Submitted for approval.)

4. Smith, J. H., R. G. Gilbert, and J. B. Miller. Redox potentials in a cropped potato processing wastewater disposal field with a deep water table. J. Environ. Qual. (Submitted for publication.)

PERSONNEL: R. G. Gilbert and J. B. Miller.

Table 1. Numbers of denitrifying bacteria and rates of nitrate-N loss in the soil profile of basins intermittently flooded (9 days) with secondary sewage effluent and dried (12 days). 1/

Soil Profile Interval	Denitrifiers/g	Rate of NO_3-N Loss 2/
(cm)	(X 10^6)	(μg/g/day)
0-5	0.33	51
10-15	0.95	24
25-30	0.11	9
30-60	0.08	> 5
60-90	0.07	> 5

1/ Results are from soil profile samples collected after about 12 days of drying.

2/ Soils were incubated at 28C under waterlogged conditions in sealed glass vials (60 ml) containing 25 g soil and 25 ml NO_3-N solution (200 mg/1).

Table 2. Numbers of denitrifying bacteria and rates of nitrate-N loss in surface soil (0-5 cm) of basins intermittently flooded (9 days) with secondary sewage effluent and dried (12 days) 1/.

Condition of Soil Basin	Denitrifiers/g	Rate of NO_3-N Loss 2/
(Days)	($X 10^6$)	(μg/g/day)
12 Dried	0.2	46
5 Flooded	9.5	77
9 Flooded	13.0	92
5 Dried	1.3	35
12 Dried	0.2	46

1/ Results are averages of two flooding and drying cycles in May and August 1977.

2/ Soils were incubated at 28C under waterlogged conditions in sealed glass vials (60 ml) containing 25 g soil and 25 ml NO_3-N solution (200 mg/1).

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

NRP: 20810

CRIS WORK UNIT: 5510-20810-002
5510-20710-001A

CODE NO.: ARIZ.-WCL 65-2

INTRODUCTION:

The rainfall-runoff-erosion studies conducted in cooperation with the University of Hawaii continued to receive the major research effort in Hawaii. Data processing is essentially complete through December 1977, with major effort now being placed on analysis of the data. Several reports are now in progress, an ARS-WR publication in rough draft form being the furthest along.

The flume and equipment from the Waialua Pineapple site were moved to a drip irrigated site called Helemano, during early December 1977. SCS was interested in obtaining data from an irrigated site to determine the effects on erosion of a continually wet soil. The Waialua pineapple site was selected for abandonment because of the problem with watershed boundaries since the start of the project.

Installation and instrumentation of an operational size fiberglass-wax catchment was completed in cooperation with the State of Hawaii, Department of Land and Natural Resources and a local flower grower. Water samples from this site are now being collected to determine water quality.

The four water harvesting plots on Maui were re-instrumented to determine rainfall-runoff relations after 10 years of exposure with essentially no maintenance.

PART I. WATER HARVESTING

PROCEDURE:

The procedures used are described in previous Annual Reports except as follows:

Anthurium Catchment: A new fiberglass-wax catchment was installed in June 1977 on the Island of Hawaii approximately 16 miles southwest of Hilo, Hawaii. The water from the catchment is collected in a 400,000-liter butyl-lined reservoir. The water is used as an emergency water source for the growing of anthuriums. The catchment 32 x 32-meter apron was prepared with a bulldozer on a coarse lava rock base. A 4-cm layer of small volcanic cinders was spread over the pad with a 0.5 to 1.0% slope. The catchment treatment is a 1.5 oz per ft^2 (.45 kg/m^2) chopped fiberglass matting which was sprayed with 2 kg/m^2 of Slackwax 140 heated to 100 C in a tea kettle. The fiberglass matting was unrolled in place, then sprayed with wax using deflector-type nozzles. After the entire catchment area was covered, a top coating of refined paraffin wax, 140-145 AMP, was melted and sprayed on at a rate of 0.5 kg/m^2.

In September 1977, a critical depth water measuring flume equipped with a 30-day strip chart waterstage recorder-tipping bucket-raingage combination was installed. The discharge end of the flume was equipped with a water collection bottle to collect a sample of the runoff water from the catchment. The catchment water sample and a sample from the stored water in the reservoir is collected at a 10- to 14-day interval for water quality analysis.

Maui Plots: The 4-plot water harvest test site on Maui was re-instrumented in September 1977. The water meters were re-installed on all plots. All plant growth immediately in front of the flumes was removed. No attempt was made to repair or retreat any of the plot treatments. The water meters and raingages are read at a weekly interval.

RESULTS AND DISCUSSION:

Anthurium Catchment: Runoff and rainfall are being recorded at the new catchment and water samples are being collected. To date, the data have not been analyzed. The catchment slope is very flat and there is considerable retention on the surface. The treatment was considered in excellent condition when inspected in December 1977.

Maui Plots: Data received from the Maui plots since the time of re-activation are limited. Rainfall in the area has been very low. There was some initial plugging of the meter screens with dry plant matter, but this problem was corrected in November 1977. From 12 November 1977 to 31 December 1977, there was a total of 130.6 mm of precipitation. Runoff from the plots was as follows: Hypalon - 74.6 mm, 57.1%; butyl - 72.7 mm, 55.7%; asphalt-fiberglass - 71.8 mm, 55.0%; grassed - 0.0 mm, 0.0%. All treatments were considered in fair condition when inspected in December 1977. Grass had grown through portions of the butyl and asphalt-fiberglass treatment during the past 10 years. This has created some holes from which water is being lost.

PART II. RAINFALL-RUNOFF-EROSION STUDIES

PROCEDURE:

Rainfall and runoff data from the six small agricultural watersheds was collected on strip charts and processed into engineering units on computer facilities at the laboratory, as described in previous Annual Reports. Sediment data were collected and processed by soil technicians from the University of Hawaii. All rainfall and runoff data are stored on disk cartridges for computer analysis.

RESULTS AND DISCUSSION:

Although almost all of the data for 1977 has been processed, only 1972 through 1976 data have been used in analysis. All of this data has been summarized into various tables and plots for an SEA-WR publication. Examples of a couple of typical tables and a plot will be presented and discussed here.

A summary of the data collected, and calculations made, for each storm is presented in Table 1 for part of 1975 for the Waialua Sugar watershed. Antecedent moisture and curve number are computed according to SCS criteria. Erosion index is described by Wischmeier as the product of the rainfall energy and the maximum 30-minute intensity. The crop code represents the amount of cover or protection provided by the crop and varies with crop growth from 1 for bare soil, to 4 for a complete canopy cover. All other information is standard or self-explanatory.

The frequency distribution of the erosion index EI with time of year is shown in Figure 1 again for Waialua Sugar in 1975. This plot is typical of all the watersheds for most years. It indicates that most of the storms with high erosion potential occur during the winter period from late October to mid-March. This information could be used to schedule harvests to minimize erosion by harvesting erosion-prone areas during early April. This would allow crop cover to re-establish by the time late fall rains begin. Similar information can be obtained from graphs of storm rainfall intensity with time of year.

Rainfall, runoff and sediment data for the Mililani watershed are presented in Table 2. It can be seen that erosion is minimal except during isolated high intensity storms. In this case, which is fairly typical of the other watersheds, more sediment was produced in one large high intensity storm than in all of the other events combined. These large erosion events often occur when a large storm occurs on a bare field; this is especially true for the sugarcane fields where erosion is minimal when a full crop cover exists.

A brief summary of historical events occurring during the year are noted below for each site:

1. Laupahoehoe - Initially the field had a limited cover of 3-4 ft sugarcane. By early March the cane was 5-6 ft high and provided a partial cover. A complete cover was reached by September when the cane was 10 ft high.
2. Honokaa - This field was essentially bare in January, although a ratoon crop of sparse 1-2-ft cane was starting to come back. The cover gradually changed to limited (2-3-ft cane) by mid-February, to partial (4-8-ft cane) by mid-June, and to complete (10-ft cane) by mid-November. A couple of large storms in early spring caused considerable erosion in front of this flume.
3. Waialua Sugar - A complete cover of 10-12 ft high sugarcane was on this field until harvested near the end of May. The field was tilled the first part of June and again near the end of July, but was never planted and remained bare until the end of 1977.
4. Waialua Pineapple - This field had a complete cover of 10-ft high sugarcane until harvested the first part of

August. A limited cover of 1-3 ft high sugarcane existed by mid-November when the recorders and flume were moved to a new drip-irrigated sugarcane site.

5. Mililani - A complete cover of pineapple was on this field throughout the year.
6. Kunia - The complete cover of pineapple that initially covered this field was chopped and tilled into the top 3 or 4 inches of soil in early February. The residue was then allowed to dry until mid-March when it was burned, leaving a bare field. The watershed was reworked and several roads and grass ditches eliminated before replanting to pineapple in late May. The limited cover provided by the new plants and plastic strips changed to partial by mid-September when plants had grown to 18-24 inches, and remained this way until year's end.

SUMMARY AND CONCLUSIONS:

A cooperative report intended to present preliminary rainfall-runoff and erosion data and analysis for the six agricultural watersheds is in rough draft form. Some typical summary tables and plots were presented which show that most storms with high erosion potential occur during the winter between mid-October and late March. Also noted was that erosion produced by one of these storms, especially if occurring on a bare field, may be greater than the total of all other events reported for several years.

Four of the six watersheds were harvested and replanted during or at one end of 1977, and will therefore be partially or completely covered during essentially all of the next two years. The Waialua Pineapple site was abandoned in mid-November and the flume and equipment moved to a new drip-irrigated site called Helemano which will be planted in early 1978.

The study on water quality from water harvesting catchments in cooperation with the State of Hawaii, Department of Land and Natural Resources, was started in September 1977, with the installation of a wax-fiberglass catchment on the Island of Hawaii, near Hilo, Hawaii. The runoff water from the catchment is stored in a butyl-lined reservoir for use as an emergency water supply for growing anthuriums. Water samples are being collected from the catchment and from the reservoir for water quality analysis.

The 4-plot water harvesting test site on Maui was re-instrumented to measure the runoff efficiency of the plots which are over 10 years old and have received no maintenance during that time. Rainfall has been low and runoff data are limited. Initial results showed runoff of 50-60% from the membrane plots, with no runoff from the grass plot.

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

Table 1. Summary of storm data from Hawaiian agricultural watershed.

HAWAII SITE: WAIALUA SUGAR YEAR: 1975

JULIAN DAY	STORM LENGTH (HRS)	RAIN (IN)	--RUNOFF-- (IN)	--RUNOFF-- (%)	ANT. MOISTURE (IN)	TIME INTERVAL (MIN) AND MAXIMUM RAINFALL INTENSITIES (IN/HR) 5	10	15	30	60	AVG INT	CURVE NO	EROSION INDEX	CROP CODE
299	12.04	0.11	0.00	0	0.12	0.24	0.12	0.08	0.04	0.04	0.00	95	0	3
301	5.83	0.03	0.00	0	0.22	0.00	0.00	0.00	0.00	0.00	0.01	98	0	3
307	14.24	0.13	0.00	0	0.00	0.34	0.24	0.16	0.08	0.04	0.00	94	0	3
308	3.40	0.04	0.00	0	0.13	0.00	0.00	0.00	0.00	0.00	0.01	98	0	3
309	3.90	0.05	0.00	0	0.16	0.00	0.00	0.00	0.00	0.00	0.01	98	0	3
309	2.23	0.06	0.00	0	0.21	0.12	0.06	0.08	0.04	0.03	0.03	97	0	3
310	11.88	0.06	0.00	0	0.27	0.00	0.00	0.00	0.00	0.01	0.01	97	0	3
311	7.95	0.34	0.00	0	0.34	0.36	0.18	0.12	0.10	0.07	0.04	86	0	3
312	17.09	0.38	0.00	0	0.67	0.12	0.12	0.16	0.08	0.09	0.02	84	0	3
313	11.56	0.33	0.00	0	0.93	0.60	0.48	0.32	0.20	0.14	0.03	86	0	3
314	8.39	0.05	0.00	0	1.22	0.00	0.00	0.04	0.04	0.03	0.00	97	0	3
315	19.75	0.26	0.00	0	1.23	0.12	0.12	0.08	0.04	0.04	0.01	89	0	3
316	0.48	0.03	0.00	0	1.36	0.00	0.00	0.00	0.00	0.00	0.05	99	0	3
320	4.53	0.04	0.00	0	0.28	0.00	0.00	0.00	0.02	0.01	0.01	98	0	3
323	5.23	0.03	0.00	0	0.04	0.00	0.00	0.00	0.00	0.00	0.01	98	0	3
324	0.02	0.06	0.00	0	0.07	0.14	0.00	0.00	0.00	0.00	3.10	97	0	3
325	13.18	0.10	0.00	0	0.14	0.12	0.06	0.04	0.02	0.01	0.00	95	0	3
327	6.00	0.76	0.05	7	0.20	0.84	0.78	0.76	0.60	0.39	0.38	83	3	3
328	12.33	1.51	0.20	13	0.96	1.68	1.38	1.28	0.68	0.45	0.14	76	8	3
328	33.33	5.89	1.46	25	2.43	2.28	2.04	1.76	1.50	1.03	0.19	55	72	3
330	2.80	0.12	0.04	32	8.26	0.60	0.36	0.32	0.18	0.10	0.06	99	0	3
330	30.22	3.78	1.04	27	8.28	2.76	1.74	1.36	0.78	0.59	0.13	67	23	3
335	0.26	0.06	0.00	0	3.90	0.17	0.12	0.14	0.00	0.00	0.25	97	0	3
336	7.35	0.21	0.07	34	0.06	0.48	0.36	0.36	0.18	0.09	0.04	98	0	3
338	11.87	0.12	0.00	0	0.27	0.12	0.06	0.08	0.06	0.03	0.01	95	0	3
342	9.33	0.53	0.15	28	0.12	0.96	0.84	0.68	0.36	0.24	0.07	94	1	3
346	19.98	2.95	0.79	27	0.53	3.00	2.22	1.76	1.34	0.74	0.17	72	33	3
351	14.87	0.08	0.00	0	2.95	0.00	0.00	0.00	0.00	0.02	0.01	96	0	3

Table 2. Mililani Watershed - Runoff-producing storms with sediment data.

Field Condition	Year	PERIOD Start	End	Rain	#Storms	Runoff	MAX. INTENSITIES 5	15	30	60	SEDIMENT g/ℓ	Tm/HA
Potatoes & 2-3' Weeds	1973	305	331	1.40	2	0.11	1.20	1.20	0.80	0.40	0.20	0.006
" " "	"	331	345	1.70	2	0.06	2.40	1.20	0.60	0.20	0.02	0.0003
" " "	"	345	361	0.90	1	0.02	1.20	1.20	0.60	0.40	0.02	0.0001
4-5' Weeds	1973/74	361	10	6.00	6	0.46	2.40	1.60	1.00	0.80	0.14	0.016
" "	1974	10	22	1.90	2	0.15	1.20	0.80	0.80	0.60	0.10	0.004 B
" "	"	22	32	3.60	3	0.31	3.60	2.00	1.60	1.20	0.48	0.038
" "	"	32	50	1.20	3	0.02	1.20	0.80	0.40	0.20	1.37	0.007
" "	"	50	72	1.80	1	0.03	1.20	0.80	0.60	0.50	0.18	0.001
" "	"	72	87	2.50*	3	0.08	2.40	1.60	1.00	0.60	0.06	0.001
Harrowed & Bare	"	148	161	2.30	1	0.04	4.80	3.20	2.20	1.90	0.51	0.005
" "	"	190	203	2.00	2	0.02	2.40	1.20	1.00	0.60	0.24	0.001
Potatoes & Weeds	"	246	260	1.30	2	0.03	2.40	1.60	1.00	0.60	2.81	0.021
" "	"	260	267	6.90	3	3.51	6.00	5.20	5.20	3.70	53.30	47.50 X
" "	"	318	331	2.40	1	0.38	1.20	1.20	0.60	0.50	0.91	0.088
3-4' Weeds	1974/75	357	8	1.22	3	0.06	0.84	0.64	0.32	0.14	0.15	0.002 B
" "	1975	8	15	2.93*	4	0.78	1.68	1.56	1.24	0.77	0.11	0.022
4-5' Weeds	"	28	35	5.60*	3	1.33	2.64	2.12	1.90	1.75	0.44	0.15
" "	"	84	91	1.65	1	0.02	0.60	0.52	0.48	0.47	0.14	0.001 B

*-Raingage Malfunction
X-Barrel Overflowed
B-Runoff calculated from volume in barrel

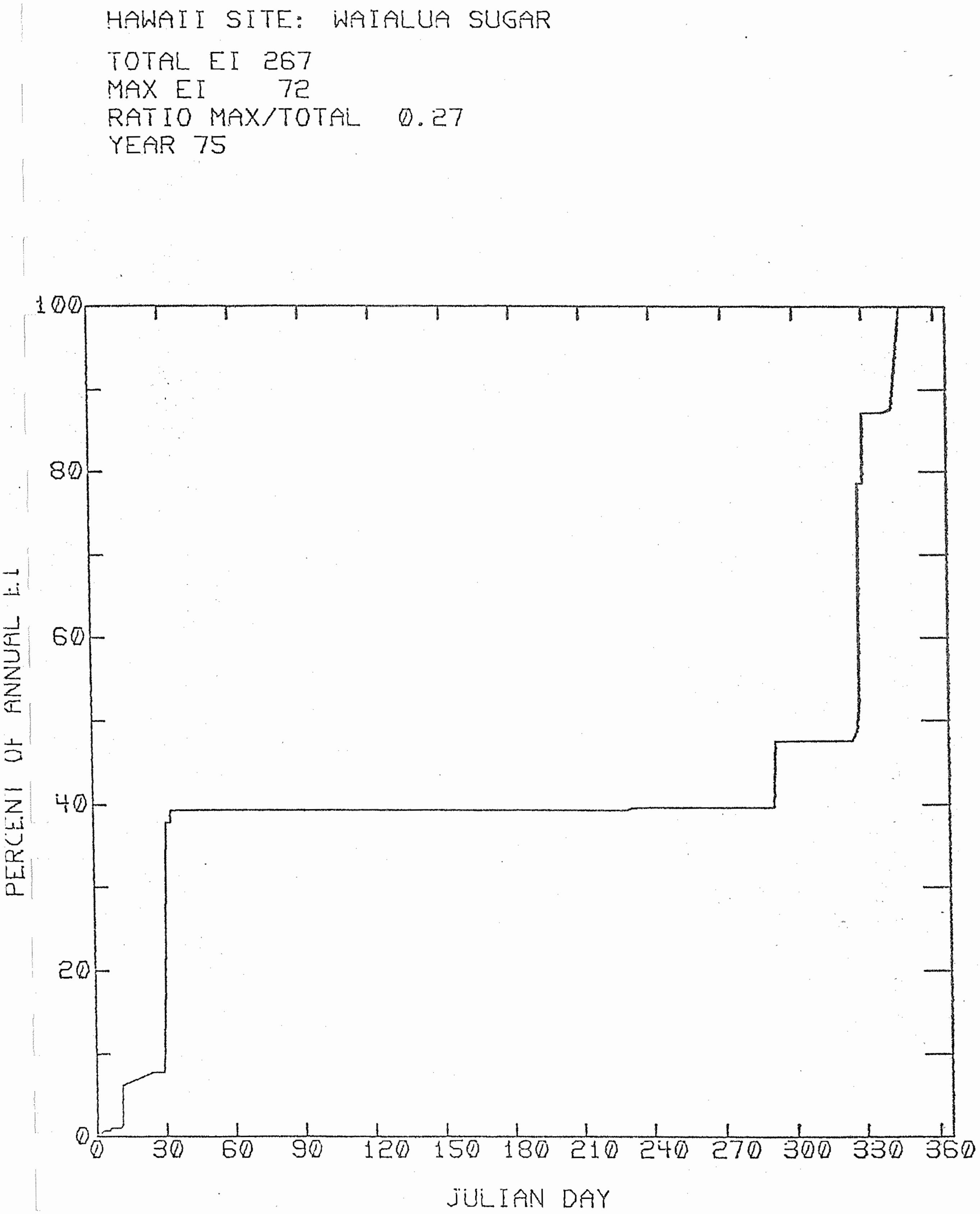

Figure 1. Distribution of erosion index (EI) with time of year.

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 four covers in 1977. Included were foamed rubber, foamed wax blocks, and two continuous wax covers on the 9-ft-diameter stock tanks. Visual observations were also made of the performance of the wax cover on the lined pond. Wax covers on the Chino Valley and Joronado stock tanks were noted.

Field evaluation of the foamed rubber or sponge covers, the first located on a tank in southwestern Utah in 1971 and four others on tanks in Arizona in 1974, was continued.

A final report and paper are in progress on this project.

PROCEDURE:

Evaluation of the four covers on the Granite Reef tanks was the same as in previous years (evaporation from a treated tank being compared to that from an identical untreated tank). Repairs to the control tank were not completed until early March, therefore, only 9 1/2 months of comparative data are available.

Only visual observations were made of the field installations, no measurements being recorded.

RESULTS AND DISCUSSION:

Granite Reef Studies: The 9 1/2 months of comparative data collected from the stock tanks during 1977 indicate that the efficiency of the wax blocks remained about the same, while efficiency of the two continuous wax covers decreased, and the foamed rubber cover increased. The increase noted for the foamed rubber cover was due to a change in tanks during February 1977. The new tank was slightly smaller in diameter, thus the foamed rubber covered a greater percentage of the surface area, and efficiency was increased accordingly.

Reduction in efficiency of the two continuous wax covers is not explained as easily. Monthly efficiencies, which have been near 100%

in summer and only about 60% in winter, were much slower to respond to heating in the spring, and fell off sooner in the fall. Also, November and December values were less than 20% on both tanks, which is considerably lower than previously noted values for these months. It appears that one of the covers is starting to sink, while the other has shrunk and cracked more than before, both of which would reduce efficiency, but it would not be expected to be as low as noted. Leaks could also have developed in the old tanks being used.

The wax cover on the lined pond at Granite Reef still covers about 80-90% and appears to be in good condition.

Field Studies. Reports from the Chino Valley site indicate that only about 1/3 to 1/2 of the surface area is covered. Additional wax may solve this problem based on experience on the Granite Reef lined pond. The wax cover at Joronado sunk shortly after the first of the year and was therefore only on the tank a few months. It was not apparent what the cause of failure was. It could have been sand collecting on top, algae growth on the bottom, or a combination of these plus other factors.

Beaver Dam Tank, southwest of St. George, Utah, installed November 1971. The tank is still actively being used and the cover is in excellent condition. Two small holes, less than 2 inches in length, were likely caused by someone grabbing the cover.

Frasier Well and Shipley Well tanks, Hualapai Indian Reservation, installed May 1974 -- Both covers operated satisfactorily during 1977. The Shipley well cover requires occasional straightening, especially after freezing. 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 tank was about half full on February 1, 1978 after January rains.

SUMMARY AND CONCLUSIONS:

The foamed wax blocks which have been evaluated on the tanks at Granite Reef for more than 7 years maintained essentially the same yearly evaporation reduction efficiency (34%) during 1977. The two continuous wax covers which have been on the tanks for 4 1/2 to 6 1/2 years decreased in average yearly efficiency and appeared to be failing during the last 2 to 3 months of 1977. The foamed rubber cover has been exposed for over 4 years, increasing in efficiency, but only because it was placed on a smaller diameter tank and therefore covered more surface area.

One of the continuous wax covers tested in the field sank at the first of 1977, and the other only covers about 1/3 to 1/2 of the surface area of the water. The wax cover on the lined pond at Granite Reef did not appear to change during the year, and still covers 80-90% of the water surface.

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. Ten such covers are planned by the Bureau of Land Management at Safford, Arizona, during 1978.

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:

Evaluation of materials and methods for increasing precipitation runoff continues at the Granite Reef test site. Measurement of rainfall and runoff at the Monument Tank test site was stopped in December 1977. The flumes, raingages, and recorders will be dismantled and removed in early 1978. The cooperative studies with the Bureau of Land Management (BLM), U. S. Department of Interior, on the evaluation of methods and materials for operational size water harvesting systems continues. Assistance was provided to various units of the Forest Service, USDA, in Arizona, and the Southwest Watershed Rangeland Research Center, Tucson, AZ, on techniques of installing water harvesting catchments. The cooperative study continues with the Southwest Watershed Rangeland Research Center, SEA, Tucson, Arizona, on harvesting of rainfall precipitation to increase forage production.

PART I. GRANITE REEF TEST SITE

Total rainfall for 1977 at the Granite Reef test area was 116.0 mm. Only four storms were greater than 10.0 mm; the largest single storm was 15.2 mm. Compared to the records from the past 15 years, the rainfall in 1977 represented 50% of the previous low rainfall recorded in 1969, and 29.3% of the record high measured in 1965.

Paved or Covered Plots: Treatments for the paved or covered plots are listed in Table 1, and the runoff results are presented in Table 2. Runoff efficiency for L-6, a two-phase asphalt treatment, was 50.3%. The catchment surface is hard but the pavement has cracks causing the low runoff efficiency. Plot L-5 was treated with a fiberglass-polypropylene-wax membrane on 15 April 1977. Only one storm of 13.2 mm, which yielded 106.8% runoff, was measured before high winds destroyed the entire wax-coated sheeting. Some of the wax had penetrated through the matting to the bare soil. The partially sealed soil yielded 57.3% runoff efficiency for the remainder of the year. The 30 mil chlorinated polyethylene membrane plot, L-1, which is almost 10 years old, yielded 99.9% runoff. The sheeting has a low surface retention, with a slick, sturdy appearance and no visible deterioration since installation. Plot L-4, covered with polypropylene matting and asphalt, was given a protective coating of aluminum-vinyl on 2 June 1977. Runoff efficiency on this catchment was only 93.8%. Shortly after installation, the polypropylene matting swelled from solvents in the asphalt which formed a wrinkled surface which traps water, causing relatively high surface retention. The aluminum-covered plot, L-7, had a runoff efficiency of 74.4%. The foil covering has some visible deterioration, primarily pitted holes caused by corrosion and blowing sand and gravel.

The asphalt-fiberglass plot, A-1, yielded 104.8 mm runoff for a 90.3% efficiency. The reason for the low efficiency is unknown as the treatment has no visual damage. Runoff from the gravel roofing treatment, A-2, was 52.3%. The gravel is loose and may move in heavy storms. There is probably an increased quantity of windblown dust trapped in the gravel which would increase the threshold runoff. The concrete catchment, A-5, yielded only 62.3% runoff for the year. This is probably a result of the high water absorption of the concrete, coupled with the small storm sizes.

Bare Soil Plots: Treatments for the bare soil plots are presented in Table 3 and the runoff results presented in Table 4. The smoothed, untreated plot, L-2, had an efficiency of 8.2%, probably a result of small storms with low intensities. There is some annual type vegetation which at times covers up to 30% of the area. While it is sparse, it does have some retention effect. The other smoothed, untreated plot, A-3, yielded 17.2% runoff efficiency. The higher runoff efficiency from this plot may be a result of very little vegetation plus a soil surface which never developed the rough desert pavement. The two undisturbed watersheds, W-1 and W-3, yielded 10.9 and 15.1% efficiency, respectively.

The silicone-treated plots, L-3, A-4, and R-4, averaged 42.2, 45.9, and 53.4% runoff, respectively. Plots L-3 and R-4 were retreated in 1975. The ridge furrow type catchment, R-4, is down about 25% from last year while L-3 only decreased approximately 3%. Runoff from the W-2 watershed was 12.0% compared to 15.6% in 1976. The watershed was treated with silicone in June 1975, but the runoff results indicate the treatment has deteriorated.

Runoff from the wax-treated plot, R-2, decreased slightly, possibly a result of the storm intensity characteristics. Runoff efficiency was 79.9% compared to 86.1% the previous year.

Tank Water Storage: The tank water storage studies described in the 1976 Annual Report were continued. Two test installations of this type were installed, one at the Granite Reef test site and one at the Laboratory. Both installations were successful for approximately 2 months. The one at the Laboratory failed when a rodent burrowed up into the bottom of the tank. This installation did not have the protective wire screen on the bottom.

The tank at Granite Reef was initially filled to a depth of about 1 meter. It was observed that a couple of the seams in the tank ring were leaking. It was decided to drain the tank to permit additional caulking of the joints. During the period of caulking the tank, the bentonite clay dried and formed major cracks. When the tank was refilled, these cracks failed to close and a piping failure occurred. The damaged area was repaired and the bentonite clay remixed. It was observed that during the 2-week repair period that several annual type weeds started to grow. These were cut off at the surface. When the tank was refilled there was an average loss of about 1 cm per day. It is believed this was a result of seepage through or next to the cut stalks of the plants.

A similar type storage installed on a small wildlife water system in cooperation with the Arizona Game and Fish Department is reported to be performing successfully.

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 is performed periodically to evaluate relative weathering performance. If a material is graded poor it is usually removed and considered to have failed.

The panels were evaluated in June 1977, and the results presented in Table 5. Visual signs indicate that some of the substrate materials which were treated with a protective coating are now starting to deteriorate. Some of the coatings are completely gone while others are cracking or chalking and can be rubbed off. The materials were not checked for elongation and shrinkage because the reference markings are obliterated. Most of the materials have not changed in the past year, although it is expected that as some of the protective coatings fail, the substrate materials may start to deteriorate.

PART II. MONUMENT TANK

The precipitation at the Monument Tank test site was very low for the third consecutive year with only 234.5 mm recorded in 1977. There were no significant runoff events recorded. Because of soil type and topography plus a change in research emphasis, it has become impractical to continue the original study. On 1 January 1978, the study will be terminated. The rain gages, recorders, and measuring flumes will be disassembled and removed.

PART III. OPERATIONAL CATCHMENTS

Assistance on design, treatment selection, and installation continues with other Federal and State agencies. One new asphalt-fiberglass catchment was installed on the Alamogordo watershed near Santa Fe, NM, in cooperation with the Southwest Watershed Rangeland Research at Tucson. Initially, the catchment was unfenced, but cattle were damaging the treatment, necessitating fencing the area.

The asphalt-fiberglass catchment on the Walnut Gulch watershed near Tombstone, AZ, was given a new protective coating in October 1977. The original protective coating, highway traffic paint, was cracking, causing damage to the underlying membrane. All loose material was brushed off and a new sealcoat of clay emulsion applied. After curing, a protective coating of aluminum-vinyl was applied to approximately 60% of the area. Two test pattern areas were treated with an experimental water base coating for durability and weathering evaluation.

PART IV. WATER HARVESTING FOR FORAGE PRODUCTION

Procedure: A description of the test plots and procedures are presented in the 1976 Annual Report, Ariz.-WCL-71-12, "Lower Cost Water Harvesting Systems."

In the initial studies, soil fertility was not a variable. Instead, the presumed required fertilizers (N, P, Mg, and K) were applied prior to the start of each growing season. All plots were fertilized before planting in 1974 and again on 9 July 1975. On 13 July 1976, P, Mg, and K fertilizers were applied. It had been decided to withhold application of the N-fertilizer a few weeks to allow for better soil moisture conditions. It was never applied.

All plots were harvested on 26 August 1974, 16 December 1975, 25 August 1976, 10 February 1977, and 18 October 1977. The 1974 harvest cuttings were inadvertently destroyed after determination of the plot yields. The saved clippings of the other harvests were analyzed for total nitrogen content with a Technicon Auto-Analyzer Model II.

Core samples of the roots and rhizomes of the blue panicgrass were taken on all plots on 27 August 1977, by driving a 5-cm diameter coring cylinder 20 cm into the ground. The roots and rhizomes in the cores were washed with distilled water, separated, ground, and analyzed for total nitrogen content, as previously described.

Results: The forage yields from the plots are presented in Table 6. A discussion of the 1974, 1975, and 1976 harvests can be found in the 1976 Annual Report. In 1976, climatic conditions were favorable for an extended growing season, permitting two separate harvests. Statistical analysis of the February 1977 (second cutting, 1976 season) and October 1977 harvests have not been completed. In 1975 and 1976, forage yields tended to increase as the catchment area-to-crop-growing area increased, except for the wax catchments. Yield on the 3:1 catchment ratio was usually less than for the 2:1 ratio, probably because the greater quantity of water applied to the grass leached some of the fertilizer from the root zone. The wax-treated runoff area plots yielded more forage than the bare soil runoff area plots which, in turn, had higher yields than the grassed runoff area plots. These results were expected because the large wax-treated runoff areas produced the most water to the plants. In 1977, similar trends were measured in the yields of the bare soil runoff area plots. Yields from the wax-treated runoff area plots tended to remain constant or even decrease as the runoff area increased. This indicated that available plant water was no longer a limiting factor for forage production.

Observations of the plots in late July 1976, indicated that available nitrogen in the soil was not restricting plant growth, even on treatments producing large forage yields. The vigorous, dark-green plant growth was visual indication that nitrogen was present and available to the plants. Preliminary calculations indicated that the two previous applications of N-fertilizer and other possible natural N sources (organic matter, leguminous forbs) were not present or available in sufficient quantities to explain the observed plant growth.

The nitrogen contents of the harvested forage for the 1974, 1976, and 1977 cuttings are presented in Table 7. To fill in for the destroyed 1975 cuttings, a nitrogen content equal to the February 1977 harvest was assumed. This is believed a conservative estimate because the plots received nitrogen fertilizer in the summer of 1975, which should have resulted in a forage nitrogen content higher than was used in the calculations. Forage nitrogen percentages were 2 to 3 percent in the 1974 cuttings. By 1977, the nitrogen contents were 0.7 to 1.5 percent. The results show that the nitrogen content tends to be lowest on the plots which have produced the most forage. The harvested forage does not represent the total quantity of nitrogen used by the plants during the study. Appreciable quantities of nitrogen can be stored in the roots and rhizomes of the plants.

The nitrogen content of the root-rhizome plant tissue taken with the core sampler from the 4-year-old plots at Montijo Flat was 1.1 to 1.5 percent N. For a conservative estimate of the nitrogen content of the roots-rhizomes in the field plots, a value of 1.2 percent was used.

A summary of the total nitrogen consumed by the plants in the 4-year study for each treatment is presented in Table 8. The root-rhizome dry matter produced was estimated to be one-half of the total harvested forage, with an average nitrogen content of 1.2 percent. The results show that the total nitrogen removed by the plants is directly proportional to the total plant growth produced in the 4 years. On the wax and bare soil runoff treatment plots with runoff contributing areas of 1:1 or larger, the total nitrogen used by the plants was 114 to 225 kg/ha.

To account for the total nitrogen used by the plants, it would be necessary to have a 100% conversion efficiency of the applied fertilizer and organic matter. Assuming a minimum conversion efficiency of 70%, a total of 175 kg N/ha was available to the blue panicgrass. Based on the measurements of nitrogen content of the plants and using the most conservative estimates for all other unknowns, the studies indicate that the higher yielding forage plots would require at least 20 to 50 kg N/ha from some as yet undetermined source, possibly by nitrogen fixation, to complete the nitrogen balance.

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 tested 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.

The portable plot sprinkler was used on operational field-sized catchments and on various treatments at the Granite Reef testing site. The results from the tests at Granite Reef are presented in Table 9 and from 11 operational catchments in Table 10. From the tests at Granite Reef, it appears the sprinkler tends to overestimate the runoff efficiency of the smoothed, untreated and silicone water-repellent plots compared to the average annual runoff. Satisfactory results were obtained on the remaining treatments. The sprinkler does apply water at a higher intensity than most natural storms. On the field catchments, most good wax treatments yielded 70 to 95% runoff and membranes 95 to 100% efficiency. Threshold rainfalls were generally less than 1.5 mm. The sprinkler results are believed a good estimate of the performance of the wax and membrane water harvesting treatments.

Wildlife Water Harvesting Catchments: The two catchments that were installed with the cooperation of Arizona Game and Fish Department are in excellent shape. An attempt was made to determine how much water deer drink in the summer months. Game and Fish personnel monitored the drinking trough at a water harvesting catchment for a time to check the number of deer coming in and the amount of water consumed. The test was not successful because of limited rainfall in the areas which limited available forage. At the time of the checking the deer had moved from the particular ranges. An attempt at a later date will be made to determine the amount and number in the area.

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 operational systems and from the various treatments at the Granite Reef testing site at periodic intervals. Preliminary analyses show that the water from the various catchment treatments does not contain any toxic elements at a level above recommended standards for livestock.

SUMMARY AND CONCLUSIONS:

Studies were continued at the Granite Reef testing site on the evaluation of methods and materials for water harvesting. Total precipitation at the site for 1977 was much below average, primarily consisting of small storms with relatively low intensities. This may have caused the relatively lower runoff efficiency measured on many of the treatments. The silicone treatments which continue to deteriorate showed the greatest change in runoff efficiency. Runoff from the paraffin wax soil treatment was slightly less than the preceding years.

The studies on using a bentonite clay blanket for bottoms of steel-rim tanks were continued. It was found that the bentonite bottoms can fail if the tank is allowed to go dry or if there is inadequate protection from burrowing rodents.

The studies continued of using water harvesting techniques for increasing forage production. Primary emphasis was directed to investigating the nitrogen usage and balance of blue panicgrass (*Panicum antidotale*). The results show that the total nitrogen removed by the plants is directly proportional to the total plant growth produced in the 4 years. On the wax and bare soil runoff treatment plots with runoff contributing areas of 1:1 or larger, the total nitrogen used by the plants was 114 to 225 kg/ha. To account for the total nitrogen used by the plants, it would be necessary to have a 100% conversion efficiency of the applied fertilizer and organic matter. Assuming a minimum conversion efficiency of 70%, a total of 175 kg N/ha was available to the blue panicgrass. Based on the measurements of nitrogen content of the plants and using the most conservative estimates for all other unknowns, the studies indicate that the higher yielding forage plots would require at least 20 to 50 kg N/ha from some as yet undetermined source, possibly by nitrogen fixation, to complete the nitrogen balance.

The cooperative study with the Bureau of Land Management was primarily concerned with evaluation of the runoff efficiency of various water harvesting treatments of operational catchments and the Granite Reef plots using the portable plot sprinkler. From the tests at Granite Reef, it appears the sprinkler tends to overestimate the runoff efficiency of the smoothed, untreated and silicone water-repellent plots compared to the average annual runoff. Satisfactory results were obtained on the remaining treatments. On the field catchments, most good wax treatments yielded 70 to 95% runoff and membranes 95 to 100% efficiency. Threshold rainfalls were generally less than 1.5 mm. The sprinkler results are believed a good estimate of the performance of the wax-and-membrane type water harvesting treatments.

Preliminary results of analysis of water from various catchment treatments indicate there are no toxic elements at a level above recommended standards for livestock.

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}.
	2 Jun 1977	Top spray vinyl aluminum.
L-5a	15 Apr 1977	Fiberglass and polypropylene matting saturated with slack wax 140 at a rate of 1.6 kg/m^2.
L-5b	1 Jul 1977	Membrane removed. Soil treated with slack wax.
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	Rain-fall	L-1 Runoff		L-4 Runoff		L-6 Runoff	
1977	mm	mm	%	mm	%	mm	%
3 Jan	2.3	2.2	95.7	2.2	95.9	1.1	47.8
5 Jan	5.1	5.0	98.0	5.0	98.0	2.6	51.0
8 Jan	2.0	1.7	85.0	1.4	70.0	.3	15.0
25-26 Mar	7.6	7.8	102.6	5.6	73.7	1.5	19.7
28 Mar	3.7	3.5	94.6	3.4	91.9	1.4	37.8
13 May	13.2	14.3	108.3	13.3	100.8	8.7	65.9
5 Jul	4.8	7.3	152.1	6.1	127.1	3.0	63.0
22 Jul	1.2	1.7	141.7	1.6	133.3	.3	25.0
26 Jul	15.2	14.0	92.1	15.1	99.3	12.2	80.3
12-13 Aug	10.7	10.4	97.4	10.8	100.9	6.0	56.1
16 Aug	4.1	3.7	90.2	- a/	-	1.8	43.9
9 Sep	2.0	1.3	65.0	1.4	70.0	0	0
27 Sep	8.1	8.0	98.8	8.0	98.8	4.7	58.0
6 Oct	2.6	2.6	100.0	2.2	84.6	.8	30.8
6 Oct	3.0	2.7	90.0	2.6	86.7	.2	7.7
29 Oct	8.1	7.9	97.5	6.4	79.0	3.9	48.1
5-6 Nov	8.3	8.6	103.6	7.5	90.4	3.0	36.4
26-28 Dec	2.1	1.7	81.0	1.0	47.6	0	0
28-29 Dec	11.9	11.5	96.8	11.4	95.8	6.9	58.0
Total	116.0	115.9	99.9	105.0 b/	93.8	58.4	50.3

a/ Water meter malfunction.

b/ Rainfall for this period was 111.9.

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

Date	Rain-fall	L-5a Runoff		L-5b Runoff		L-7 Runoff	
1977	mm	mm	%	mm	%	mm	%
3 Jan	2.3	–	–	–	–	1.7	73.9
5 Jan	5.1	–	–	–	–	3.9	76.5
8 Jan	2.0	–	–	–	–	.6	30.0
25-26 Mar	7.6	–	–	–	–	4.8	63.2
28 Mar	3.7	–	–	–	–	2.6	70.3
13 May	13.2	14.1	106.8	–	–	11.6	87.9
5 Jul	4.8	–	–	3.4	4.8	4.8	100.0
22 Jul	1.2	–	–	0	0	.9	75.0
26 Jul	15.2	–	–	12.4	81.6	12.8	84.2
12-13 Aug	10.7	–	–	a/	–	8.5	79.4
16 Aug	4.1	–	–	1.8	43.9	2.4	58.5
9 Sep	2.0	–	–	0	0	.8	40.0
27 Sep	8.1	–	–	4.3	53.1	6.2	76.5
6 Oct	2.6	–	–	.6	23.1	1.4	53.8
6 Oct	3.0	–	–	0	0	1.1	42.3
29 Oct	8.1	–	–	3.8	46.9	6.5	80.2
5-6 Nov	8.3	–	–	4.0	48.2	5.9	71.1
26-28 Dec	2.1	–	–	0	0	.3	14.3
28-29 Dec	11.9	–	–	10.6	89.1	9.5	79.8
Total	116.0	14.1 b/	106.8	40.9 c/	57.3	86.3	74.4

a/ Water meter malfunction.

b/ Total precipitation for this period was 13.2 mm.

c/ Total precipitation for this period was 71.4 mm.

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

Date	Rain-fall	A-1 Runoff		A-2 Runoff		A-5 Runoff	
1977	mm	mm	%	mm	%	mm	%
3 Jan	2.3	2.2	95.6	1.1	47.8	1.9	82.6
5 Jan	5.1	4.8	94.2	3.2	62.7	4.0	78.4
8 Jan	2.0	1.6	80.0	.1	5.0	.5	25.0
25-26 Mar	7.6	7.4	97.4	3.0	39.5	3.9	51.3
28 Mar	3.7	3.2	86.5	1.5	40.5	1.3	35.1
13 May	13.2	12.8	97.0	9.7	73.5	10.4	78.8
5 Jul	4.8	6.1	127.1	2.2	45.8	3.6	75.0
22 Jul	1.2	1.5	125.0	0	0	.4	33.3
26 Jul	15.2	11.3	74.3	9.2	60.5	8.9	58.6
12-13 Aug	10.7	9.4	87.9	5.3	49.5	6.4	59.9
16 Aug	4.1	3.9	95.5	1.6	39.4	1.8	43.9
9 Sep	2.0	1.3	65.0	0	0	.2	10.0
27 Sep	8.1	7.2	88.9	5.0	61.7	5.3	65.4
6 Oct	2.6	2.7	103.8	.1	3.8	1.2	46.5
6 Oct	3.0	2.3	76.7	.9	30.0	1.2	40.0
29 Oct	8.1	7.2	88.9	5.0	61.7	5.9	72.8
5-6 Nov	8.3	7.8	94.0	4.3	51.8	7.1	73.5
26-28 Dec	2.1	1.0	47.6	0	0	0	0
28-29 Dec	11.9	11.1	93.3	8.5	71.4	9.3	78.2
Total	116.0	104.8	90.3	60.7	52.3	72.3	62.3

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

ot	Treatment Date	Treatment
2	30 Nov 1961	Smoothed soil, 14.14 m x 14.14 m plot
-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}
1	1 Mar 1965	Ridge and furrow, 20% sideslope
-2	29 Sep 1972	Ridge and furrow, 10% sideslope treated with wax water repellent at 1.3 lbs/yd^2
3	1 Mar 1965	Ridge and furrow, 20% sideslope
-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}
-3	1 Aug 1967	Smoothed soil, 6 m x 30 m plot
4	10 Nov 1971	Smoothed soil treated with 3% silicone water repellent and 2% soil stabilizer - 1.2 liters of solution m^{-2}
-1	1 Dec 1963	Uncleared watershed
2	3 Jun 1975	Uncleared watershed - treated with 3% silicone water repellent - 1.2 liters solution m^{-2} - 0.03 kg m^{-2}
3	1 Dec 1963	Cleared watershed

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

Date	Rain-fall	L-2 Runoff		L-3 Runoff		R-1 Runoff	
1977	mm	mm	%	mm	%	mm	%
3 Jan	2.3	0	0	.7	30.4	.3	13.0
5 Jan	5.1	.3	5.9	2.7	52.9	.9	17.6
8 Jan	2.0	0	0	0	0	0	0
25-26 Mar	7.6	0	0	1.3	17.1	0	0
28 Mar	3.7	0	0	1.2	32.4	0	0
13 May	13.2	3.6	27.3	9.9	75.0	4.8	36.4
5 Jul	4.8	0	0	2.7	56.3	0	0
22 Jul	1.2	0	0	0	0	0	0
26 Jul	15.2	1.5	9.9	7.5	49.3	6.2	40.8
12-13 Aug	10.7	a/	-	4.7	43.9	6.5	60.7
16 Aug	4.1	a/	-	.7	45.3	.6	14.6
9 Sep	2.0	0	0	0	0	0	0
27 Sep	8.1	0	0	3.7	45.7	1.3	16.0
6 Oct	2.6	0	0	0	0	0	0
6 Oct	3.0	0	0	0	0	0	0
29 Oct	8.1	0	0	3.4	42.0	0	0
5-6 Nov	8.3	0	0	2.7	32.5	1.1	13.3
26-28 Dec	2.1	0	0	0	0	0	0
28-29 Dec	11.9	2.9	24.4	7.7	64.7	1.4	11.8
Total	116.0	8.3 b/	8.2	48.9	42.2	23.1	19.9

a/ Water meter malfunction.

b/ Rainfall for this period was 101.2 mm.

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

Date	Rain-fall	R-2 Runoff		R-3 Runoff		R-4 Runoff	
1977	mm	mm	%	mm	%	mm	%
3 Jan	2.3	1.8	78.3	0	0	1.4	60.9
5 Jan	5.1	4.4	86.3	.5	9.8	3.9	76.5
8 Jan	2.0	1.0	50.0	0	0	.4	20.0
25-26 Mar	7.6	6.5	85.5	0	0	2.9	38.2
28 Mar	3.7	2.9	78.4	0	0	2.1	56.8
13 May	13.2	11.9	90.2	4.8	36.4	10.2	77.3
5 Jul	4.8	5.0	104.2	0	0	3.1	64.6
22 Jul	1.2	.7	58.3	0	0	.2	16.7
26 Jul	15.2	9.4	61.8	5.3	34.9	9.3	61.2
12-13 Aug	10.7	a/	-	a/	-	2.1	19.6
16 Aug	4.1	4.9	119.5	0	0	2.7	65.9
9 Sep	2.0	.7	35.5	0	0	0	0
27 Sep	8.1	6.3	77.9	1.0	12.3	4.6	56.8
6 Oct	2.6	1.5	57.7	0	0	.9	34.6
6 Oct	3.0	1.6	61.3	0	0	.5	19.2
29 Oct	8.1	7.3	90.1	0	0	5.0	61.7
5-6 Nov	8.3	7.1	85.5	.3	3.6	4.7	56.6
26-28 Dec	2.1	.7	33.3	0	0	0	0
28-29 Dec	11.9	10.4	87.4	3.0	25.2	8.0	67.3
Total	116.0	84.1 b/	79.9	14.9	14.2	62.0	53.4

a/ Water meter malfunction.

b/ Rainfall for the period was 105.3 mm.

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

Date	Rain-fall	W-1 Runoff		W-2 Runoff		W-3 Runoff	
1977	mm	mm	%	mm	%	mm	%
3 Jan	2.3	0	0	0	0	0	0
5 Jan	5.1	.6	11.8	.3	5.9	.6	11.8
8 Jan	2.0	0	0	0	0	0	0
25-26 Mar	7.6	0	0	0	0	0	0
28 Mar	3.7	0	0	0	0	0	0
13 May	13.2	2.8	21.2	2.4	18.2	3.7	28.0
5 Jul	4.8	.3	6.3	.4	8.3	.5	10.4
22 Jul	1.2	0	0	0	0	0	0
26 Jul	15.2	4.9	32.2	4.6	30.3	6.0	39.5
12-13 Aug	10.7	0	0	0	0	0	0
16 Aug	4.1	.5	12.2	2.0	48.8	1.2	29.3
9 Sep	2.0	0	0	0	0	0	0
27 Sep	8.1	.7	8.6	.9	11.1	1.2	14.8
6 Oct	2.6	0	0	0	0	0	0
6 Oct	3.0	0	0	0	0	0	0
29 Oct	8.1	0	0	.2	2.4	0	0
5-6 Nov	8.3	.1	1.2	.1	1.2	.3	3.6
26-28 Dec	2.1	0	0	0	0	0	0
28-29 Dec	11.9	2.8	23.5	3.0	25.2	4.0	33.6
Total	116.0	12.7	10.9	13.9	12.0	17.5	15.1

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

Date	Rainfall	A-3 Runoff		A-4 Runoff	
1977	mm	mm	%	mm	%
3 Jan	2.3	0	0	.9	39.1
5 Jan	5.1	1.4	27.5	3.2	62.7
8 Jan	2.0	0	0	0	0
25-26 Mar	7.6	0	0	.3	3.9
28 Mar	3.7	0	0	1.5	40.5
13 May	13.2	5.7	43.2	9.8	74.3
5 Jul	4.8	1.4	29.2	2.9	60.4
22 Jul	1.2	0	0	0	0
26 Jul	15.2	2.7	17.7	8.3	54.6
12-13 Aug	10.7	a/	-	5.5	51.4
16 Aug	4.1	a/	-	1.5	36.6
9 Sep	3.0	0	0	0	0
27 Sep	8.1	1.3	16.0	3.5	43.2
6 Oct	2.6	0	0	0.8	31.0
6 Oct	3.0	0	0	0	0
29 Oct	8.1	0	0	3.4	42.0
5-6 Nov	8.3	0	0	3.9	47.0
26-28 Dec	2.1	0	0	0	0
28-29 Dec	11.9	4.9	41.2	7.8	65.5
Total	116.0	17.4 b/	17.2	53.3	45.9

a/ Water meter malfunction.

b/ Rainfall for this period was 101.2 mm.

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

Panel Number [a/]	Conditions and comments from inspection 14 Jun 77 [b/]	
1	Failed	Removed 1974
2	Excellent	
3	Excellent	
4	Excellent	Coating gone
5	Excellent	Coating not visible
6	Excellent	Coating gone
7	Excellent	Coating 30 - 40% gone
8	Good	Characteristic cracks appearing
9	Excellent	Coating excellent
10	Excellent	Coating excellent
11	Excellent	Coating chalking, can be rubbed off
12	Failed	Removed in 1974
12a	Good	Starting to delaminate
13	Failed	Removed in 1974
14	Failed	Removed in 1974
15	Failed	Removed in 1974
15a	Good	Joint starting to come apart
16	Failed	Removed January 1976
17	Excellent	
18	Excellent	Slight chalking
19	Excellent	
20	Excellent	
21	Poor	Delaminating
22	Excellent	

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

b/ 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 a/	Conditions and comments from inspection 14 Jun 77 b/	
23	Excellent	
24	Excellent	
25	Failed	Removed January 1976
26	Excellent	Chalking badly, can be rubbed off
27	Excellent	Chalking
28	Excellent	Extreme chalking
29	Excellent	
30	Excellent	Coating chipping off
31	Excellent	
32	Excellent	
33	Excellent	
34	Excellent	
35	Failed	Removed 1977
36	Excellent	
37	Excellent	
38	Excellent	
39	Excellent	
40	Failed	Removed 1976
41	Excellent	
42	Excellent	
43	Poor	Rodent damage
44	Failed	Removed in 1974
45	Excellent	

a/ Description of materials and/or treatments presented in 1974 Annual Report.

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

Table 6. Blue panicgrass yields (kg/ha) from the Montijo Flat forage plots.

Harvest Date	Area ratio Catchment: crop	Catchment area treatment		
		Wax	Bare soil	Grass
Aug 1974	0:1	961	961	961
	1:1	1909	1246	1068
	2:1	1932	1755	1203
	3:1	1136	2338	1093
Dec 1975	0:1	186d [1/]	186d	186d
	1:1	1333bc	536d	433d
	2:1	2920a	683cd	421d
	3:1	1939b	949b	494d
Aug 1976	0:1	227e	227e	227e
	1:1	1543c	986cde	583de
	2:1	2993a	1616c	951cde
	3:1	2602a	2211b	1308cd
Feb 1977	0:1	21	21	21
	1:1	284	218	60
	2:1	300	360	190
	3:1	326	720	181
Oct 1977	0:1	303	303	---
	1:1	2274	1542	---
	2:1	2124	1564	---
	3:1	1824	3178	---
Total 1974-1977	0:1	1698	1698	1395 [2/]
	1:1	7343	4528	2144
	2:1	10269	5978	2765
	3:1	7827	9396	3076

1/ Duncan multiple range test (P=0.05) for yields from crop growing area. Means within a year followed by no letters in common are significantly different.

2/ For the period of Aug 1974 - Feb 1977. Grass plots removed after Feb 1977.

Table 7. Nitrogen content (%) of blue panicgrass from the Montijo Flat forage plots.

Harvest Date	Area ratio Catchment: crop	Catchment area treatment		
		Wax	Bare soil	Grass
Aug 1974	0:1	3.4	3.4	3.4
	1:1	2.8	2.8	2.9
	2:1	2.3	2.9	3.0
	3:1	2.3	2.8	3.3
Dec 1975 2/	0:1	1.8	1.8	1.8
	1:1	1.3	1.4	1.3
	2:1	1.0	1.1	1.4
	3:1	1.1	1.5	1.4
Aug 1976	0:1	2.2	2.2	2.2
	1:1	1.7	1.9	2.1
	2:1	1.4	1.7	1.9
	3:1	1.4	2.0	2.0
Feb 1977	0:1	1.8	1.8	1.8
	1:1	1.3	1.4	1.3
	2:1	1.0	1.1	1.4
	3:1	1.1	1.5	1.4
Oct 1977	0:1	1.7	1.7	--- 1/
	1:1	.9	1.4	---
	2:1	.7	.9	---
	3:1	.8	1.1	---

1/ Plots removed after Feb 1977.

2/ Estimated the same as measured in February 1977 harvest.

Table 8. Total dry matter and nitrogen balance (kg/ha) of blue panicgrass at the Montijo Flat forage plots, 1974-1977.

	Area ratio Catchment: crop	Catchment area treatment Wax	Bare soil	Grass 4/
Total harvested forage 1/	0:1	1698	1698	1395
	1:1	7343	4528	2144
	2:1	10269	5978	2765
	3:1	7827	9396	3076
Estimated root-rhizome dry matter 2/	0:1	849	849	697
	1:1	3671	2264	1072
	2:1	5135	2989	1382
	3:1	3914	4698	1538
Total nitrogen in harvested forage	0:1	46	46	41
	1:1	120	87	49
	2:1	133	104	63
	3:1	103	169	72
Estimated total nitrogen in roots-rhizomes 3/	0:1	10	10	8
	1:1	44	27	13
	2:1	62	36	17
	3:1	47	56	18
Total nitrogen used by blue panicgrass plants	0:1	56	56	49
	1:1	164	114	66
	2:1	195	140	80
	3:1	150	225	90

1/ From Table 6.

2/ Ratio of 2:1 top growth to bottom growth.

3/ Assumed 1.2% nitrogen content of roots-rhizomes.

4/ For the period of 1974-1976. The plots were removed after the 1976 season.

Table 9. Sprinkler evaluation on the various plots at the Granite Reef test site.

	Treatment	Test Date	Threshold rainfall	Runoff efficiency
			(mm)	(%)
1.	Smoothed-untreated	27 Oct 77	3.5	60
2.	Silicone - Plot L-3	24 Jan 77	2.9	90
		13 Oct 77	2.9	81
3.	Silicone - Plot R-4	24 Jan 77	1.0	100
		13 Oct 77	1.4	79
4.	Silicone - Plot A-4	27 Oct 77	1.6	72
5.	Wax	24 Jan 77	1.2	92
		13 Oct 77	1.1	86
6.	Concrete	27 Oct 77	1.1	75
7.	Polyethylene	24 Jan 77	0.6	100
8.	Asphalt-polypropylene	24 Jan 77	1.2	100
9.	Asphalt-fiberglass	24 Jan 77	1.0	95
10	Aluminum foil	24 Jan 77	1.3	88
11.	Sprayed asphalt	24 Jan 77	1.1	84

Table 10. Threshold rainfall in mm and runoff efficiency in percent as determined by sprinkler testing on 11 operational water harvesting catchments.

Catchment Name	Treatment	Installation Date	Sprinkler Evaluation: Test Date	Threshold Rainfall	Runoff Efficiency
				(mm)	(%)
1. Van Gusic	Asphalt-fiberglass	1972	Apr 76	0.8	96
2. Boggs Ridge	Gravel-covered polyethylene	1972	Apr 76	4.6	57
3. Cowhide	Fiberglass resin	-	May 76	0.5	97
4. Seegmuller	Butyl rubber sheeting	-	Aug 76	1.3	100
5. Slope	Paraffin wax ($0.9\ kg/m^2$)	Sep 74	May 76	1.0	88
			Aug 76	1.3	97
			Aug 77	1.3	84
6. Snap Point	Paraffin wax ($0.9\ kg/m^2$)	Sep 74	May 76	1.0	70
			Aug 77	1.0	70
7. Westwind	Paraffin wax ($0.9\ kg/m^2$)	Jun 76	Aug 76	1.0	88
	Additional wax application ($0.9\ kg/m^2$)	Jul 77	Aug 77	1.3	90
8. Temple	Paraffin wax ($0.9\ kg/m^2$)	Jun 76	Aug 76	1.8	58
	Retreated with wax ($1.5\ kg/m^2$)	Jul 77	Aug 77	1.3	81
9. Burnt Ridge	Paraffin wax ($1.5\ kg/m^2$)	Jul 77	Aug 77	1.5	92
10. Toquer	Paraffin wax ($1.5\ kg/m^2$)	Jul 77	Aug 77	1.3	95
11. Gubler	Paraffin wax ($1.5\ kg/m^2$)	Jul 77	Aug 77	1.3	60

TITLE: CHEMICAL MODIFICATION OF SOILS FOR HARVESTING PRECIPITATION

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

CODE NO.: USWCL 74-1

INTRODUCTION:

Research to develop and evaluate chemical soil treatments to enhance precipitation runoff from soils continues. The search involves both use of water-repellants and clay dispersants, and both laboratory and field studies. Research objectives have been somewhat refined in light of the initial successes with paraffin as a water-harvesting soil treatment. They now are to: (1) reduce the amount of chemical required -- this to comply with national efforts to lower consumption of petro-chemicals, (2) reduce costs by using less and/or cheaper materials, (3) increase treatment longevity, (4) increase the range of treatable soil types, (5) increase the climatic range, and (6) improve the ease of application.

PART I. LABORATORY STUDIES

Major studies for 1977 can be divided into three areas -- the use of: (1) residual waxes, (2) stabilizers, and (3) anti-stripping agents.

Residual Waxes. The residual wax studies have been summarized in the manuscript, "Residual Waxes for Water Harvesting," (1977). It was concluded that residual waxes have several potential advantages for water harvesting: (1) Switching from paraffin to residual waxes for treating water-harvesting catchments would constitute an "energy" savings since residual waxes are byproducts of the petroleum industry; (2) several of the residual waxes outperformed the standard refined paraffin in laboratory tests (treated soils were initially water-repellant and structurally stable against erosion; they also better withstood the ravaging weathering effects of freeze-thaw cycling, ozone, and ultraviolet radiation); (3) mixtures of certain residual waxes and a dust suppressant oil outperformed either alone; (4) most residual waxes are cheaper than refined paraffin. Unfortunately, there also were disadvantages: (1) Unlike the refined paraffins which have remarkable uniformity throughout the industry, properties of residual waxes cannot be determined adequately from their industry-assigned names (a particular residual wax type may encompass a wide variation of physical-chemical properties, and there may even be considerable variation between lots from the same supplier); (2) presently, each material (possibly each lot) must be individually tested for each proposed water-harvesting application; (3) no quickly and easily obtainable "characterization index" of these products presently exists; (4) none have yet been successfully field-tested.

Stabilizers. Three soil stabilizers were evaluated this year: (1) aluminum salts, (2) Terralock -- a commercial water-soluble polymer, and (3) cellulose xanthate, developed at the Western Regional Research Laboratory.

The aluminum salt, $AlCl_3$, was applied to four soils: Granite Reef, Pachappa, Superstition Sand and a quartz sand. In addition, $Al_2(SO_4)_3$ was applied to Granite Reef soil. Salts were applied as water solutions (approximately 10 ml/Petri dish sample) at concentrations such that rates of aluminum applied were approximately one and two times the cation exchange capacities of the Granite Reef and Pachappa soils (10 meq/100 g soil). The sands each received 10 ml of the same $AlCl_3$ solutions. After the soils were compacted and dried, 3 waxes (paraffin (128-131 AMP), Chevron 140 slack wax, and Chevron dust suppressant) were applied at 3 rates (0.5, 1.0, and 1.0 kg/m^2). Tests run were relative contact angle, 4-hour-hydration, brush, freeze-thaw, and finally the dripolator. Only the freeze-thaw (FT) results are reported here.

The number of FT cycles to effect treatment destruction are listed in Table 1. It can be seen that the aluminum salts markedly improved stability against FT damage for all soils and all repellants. Doubling the rate of aluminum did not further improve effectiveness, except for the sulfate salt with dust suppressant on Granite Reef soil. Generally, the sulfate was less effective than the chloride form. Especially gratifying was the fact that FT resistance of the lowest application rates of the repellants was so markedly improved by the aluminum treatments. This not only reduces costs, but saves precious petro-chemicals. Overall, in these laboratory tests the repellants could be roughly rated for resistance to FT damage as: dust suppressant > 140 slack > paraffin. Previous field tests with the dust suppressant, unfortunately, have been discouraging. Possibly the aluminum salt treatment could improve that.

Why the chloride salt outperformed the sulfate is unknown. This is unfortunate because alum (aluminum sulfate) is cheaper, easier to work with, and more readily available than the chloride form. Other soils will be tested and field plots will be installed in 1978.

The Terralock stabilizer is a commercial water-soluble polymer produced by the American Colloid Company. It was applied at three-dilution and two-dilution rates to two soils. After air-drying, the stabilized soils were treated with two rates of two repellants. Tests given were the 4-hour-hydration, brush, FT, and dripolator as finis. Treatment particulars and results of the FT test appear in Table 2.

The addition of the stabilizer markedly improved performance of the Superstition Sand, but not of the Granite Reef soil. Generally, samples are considered acceptable if they withstand 100 or more FT cycles. It is encouraging to note that all the low wax rates (0.5 kg/m^2) on the stabilized sand exceeded the minimal 100-cycle criterion. Effects of rate and dilution of stabilizer, however, were not definitive. Studies in 1978 will be undertaken to evaluate Terralock-stabilized soils using the hydration-dripolator sequence test procedure.

The cellulose xanthate stabilizer was applied to three soils at only one solid weight ratio rate (6.7×10^{-4} g xanthate/g soil), but at two dilution-concentration rates (10 and 20 ml solution/Petri dish sample). The repellants (paraffin 128-131, Chevron 140, and a 1/4-, 3/4-mixture of the two, respectively), were applied at only one rate (1 kg/m^2) in this preliminary experiment. Samples were tested using the hydration-dripolator procedure. Preliminary results are encouraging: no sample has been destroyed after 250 minutes under the dripolator. Tests will be expanded in 1978 to check effects of ozone and ultraviolet weathering, plus resistance to damage by FT cycling. Several field plots also will be installed. It is hoped that this cheap cellulose-derived soil stabilizer will permit a marked reduction in repellant requirements.

Anti-Stripping Agents. These wax additives are designed to bond to soil surfaces with greater energy than either wax or water, thus preventing water from stripping off the overlying repellant-organic coating. Table 3 shows effects of FT cycling on three such agents for two soils treated with paraffin. The Kling Beta-treated samples were not consistently water-repellant, thus, results were erratic. However, both the 6639 and 6860 exhibited a threshold coverage value which undoubtedly related to specific surface area of the two soils. Coverages equal to or greater than that value markedly improved resistance of the paraffin-treated soils to FT damage. Additional work is needed to definitely relate effects of application rate to soil surface area, to evaluate effects on different soils and repellants, and to evaluate results of such additives to prior-stabilized soils. Furthermore, the anti-stripping agents need to be evaluated by the hydration-dripolator test, with and without prior weathering by ozone and ultraviolet radiation.

PART II. FIELD TESTING OF MATERIALS AND TREATMENTS

Runoff Data: 1976. Runoff studies continued on several wax-treated plots at the Granite Reef test site. The summarized results since initiation of the use of wax appear in Table 4. Treatment particulars appear in the 1976 Annual Report. Efficiencies were down in 1977: the two paraffin plots established in 1972 dropped to 70 and 77% runoff; efficiencies of the four wax-plus-additive plots treated in 1976 dropped to only 50 to 60% runoff below acceptable levels.

It was thought that the low efficiencies might relate to the extremely low rainfall during 1977. However, plotting runoff efficiencies of the paraffin plot, R-2, by storm-size-range (Fig. 1) by years since establishment showed that efficiencies of the larger storms (> 5 mm) dropped drastically in 1977, suggesting that the treatment may be finally failing. Strangely, runoff efficiency for the small (0 - 5 mm) storms remained near 75%, quite comparable to earlier years. A possible explanation for the drastic drop for the bigger storms while that of the small storms remained constant is that the soil is still slightly water-repellant, but wets up quickly. This would permit water from short-duration storms to run off as always, but would permit significant infiltration from the larger, longer-duration storms. It is hoped that rainfall patterns for 1978 will be more typical -- permitting more realistic runoff evaluations.

Runoff Data: Long-term evaluations of water-harvesting catchments. Long-term statistical analyses of the rainfall-runoff data of 30 of the major water-harvesting catchments at the Granite Reef test sites were completed. Analyses run were: overall runoff efficiencies, threshold retentions, and runoff efficiencies after threshold (all by years), plus associated confidence limits and correlation coefficients. A portion of the data appear in two papers submitted for publication in 1977 (Fink, Frasier, and Myers, 1977a, b). General conclusions were that such statistical analyses of rainfall-runoff data could be used to show: (1) overall performance of catchments with time; (2) the distribution of the precipitation among runoff, surface retention, and infiltration; (3) why, how, and when certain treatments weathered and failed; (4) when and even how best to repair treatments; (5) how to design catchments (size, site preparation, material selection, etc.); and (6) accuracy of rainfall-runoff measuring equipment.

Some specific conclusions from the Granite Reef data are: (1) several catchment types had both high runoff efficiencies (near 100%) and long durabilities (10 or more years, and still under test), all of which should help dispel any hesitancy in using water-harvesting for supplying needed water; (2) asphalt-fiberglass catchments yield nearly as much runoff as smooth plastic membranes like butyl rubber; they will outlast butyl under Phoenix weathering conditions; and they are considerably cheaper than butyl; (3) paraffin wax-treated catchments had runoff efficiencies approaching those of butyl, showed no weathering effects for 5 years, and were even cheaper to install than asphalt-fiberglass; (4) a standard roofing treatment lost 30% of the total precipitation by surface retention; (5) a concrete catchment lost up to 50% of the precipitation through surface adsorption; and (6) efficiencies of silicone-treated catchments rapidly decreased from near 100% initially to only 50% in 5 years. A complete summary of all rainfall-runoff data from the Granite Reef test site is being prepared.

Rainfall-runoff data from the three silicone-treated catchments (original treatments and retreatments) were summarized and evaluated to try to gain some insight into the quick loss of runoff efficiency for this treatment (Table 5). Based on earlier laboratory data on contact angles and breakthrough pressures which showed that the Granite Reef soil obtained "monolayer" coverage with 1.22×10^{-3} g silicone/g soil, it was concluded that the field applications of silicone should have penetrated the soil from 5 to 10 mm. Thus, it is not likely that loss of soil repellancy was due primarily to erosion. Rather, these data support earlier conclusions, based on linear regression analyses of the rainfall-runoff data, that the silicone was hydrolyzed off the soil throughout the treated zone by ubiquitous water vapor.

A clay-sodium salt treatment was installed on the 10 previously smoothed-only water-harvesting catchments for supplying water to a native stand of jojoba. The smoothed-only treatments had only been yielding about 30% runoff, which was judged inadequate for the plants' needs (see Growth and yield of jojoba plants on runoff-collecting microcatchments in a 200-mm rainfall region, 1977). The treatment consisted of adding (1) a commercial "Arizona clay" (supplied by Superior Equipment Company) at the rate of 10% "clay" to the top 2 inches of soil (3.5 80-lb bags per 20-m^2 plot); and (2) 5 tons per acre of NaCl salt (50 lb/plot). The clay-salt mixture was rototilled into the soil, then after a thorough soaking, the soil was compacted with a vibratory roller. Rainfall since installation has been insufficient to attempt any evaluation of the treatment, but the plants have perked up noticeably.

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PERSONNEL: Dwayne H. Fink

Table 1. Effects of aluminum-salt stabilizers on freeze-thaw damage resistance of repellant-treated soils.

Repellant		Soils [1/]				
Type + Al-salt	Repellant rate	GR	(GR)[2/]	SS	Pach	QS
	kg/m^2	FT cycles				
Paraffin (128-131)	0.5	4	4	12	50	0
	1.0	8	8	75	93	286
	2.0	32	32	105	208	>1000
" + $AlCl_3$(10.5 meq/100g)	0.5	63	(33)	176	391	78
"	1.0	120	(104)	326	833	820*
"	2.0	162	(97)	819	>1000	860*
" + $AlCl_3$ (21 ")	0.5	68	(16)	257	204	203
	1.0	104	(87)	247	481	133
	2.0	210	(217)	453	>1000	631*
Chevron 140 slack	0.5	12	12	43	95	9
	1.0	34	34	106	124	535
	2.0	29	29	133	209	>1000
" + $AlCl_3$(10.5 meq/100g)	0.5	93	(101)	516	>1000	606
	1.0	358	(99)	538	>1000	>1000
	2.0	404	(120)	>1000	>1000	>1000
" + $AlCl_3$ (21 ")	0.5	201	(85)	209	238	282
	1.0	404	(113)	863	>1000	>1000
	2.0	233	(149)	>1000	>1000	806[3/]
	ℓ/m^2					
Dust suppressant #1	0.5	58	58	157	415	433
	1.0	115	115	157	355	228
	2.0	96	96	282	563	911[3/]
" + $AlCl_3$(10.5 meq/100g)	0.5	886	(219)	>1000	948*	869*
	1.0	>1000	(504)	>1000	>1000	>1000
	2.0	>1000	(242)	947*	855*	849*
" + $AlCl_3$(21 ")	0.5	>1000	>1000	>1000	>1000	974*
	1.0	>1000	>1000	956*	>1000	>1000
	2.0	>1000	>1000	>1000	>1000	16

1/ GR: Granite Reef; SS: Superstition sand; Pach: Pachappa; QS: quartz sand

2/ (GR) samples treated with $Al_2(SO_4)_3$ at same rate of Al as with $AlCl_3$

3/ Sample lost inadvertently

* Still under test

Table 2. Effects of Terralock stabilizer on freeze-thaw damage resistance of repellant-treated soils.

	Repellant		Stabilizers Rate (ℓ/m^2)				
			0	1		2	
				Dilution			
Soil	Type	Rate		1:20	1:5	1:20	1:5
		kg/m^2	FT cycles				
Granite Reef	Paraffin (128-131)	0.5	4	4	18	4	21
	"	2.0	16	37	20	16	65
	Chevron 140	0.5	12	21	52	38	4
	"	2.0	50	94	42	38	51
Superstition Sand	Paraffin (128-131)	0.5	12	128	104	251	300
	"	2.0	411	647	708*	854*	647*
	Chevron 140	0.5	43	166	699	149	593*
	"	2.0	206	>1000	937*	862	658*

* still under test

Table 3. Effect of antistripping agents on resistance of paraffin-coated soils to freeze-thaw damage.

TREATMENT	WAX RATE	GRANITE REEF	SUPERSTITION SAND
Paraffin (128-131) with	kg/m[2/]	FT cycle	
Trymeen 6639 @ 0.5%	0.5	9	138
	1.0	36	714*
	2.0	79	869*
" @ 5%	0.5	94	872*
	1.0	360	441*
	2.0	657*	438
Kling Beta 1000 @ 0.5%	0.5	17	147
	1.0	17	481
	2.0	36	921*
" @ 5%	0.5	24	35
	1.0	134	14
	2.0	30	117
Emery 6860 @ 0.5%	0.5	16	45
	1.0	45	60
	2.0	24	911*
" @ 5%	0.5	32	266
	1.0	170	>1000
	2.0	264	>1000

* still under test

Table 4. Summary of rainfall-runoff from wax-treated plots at Granite Reef.

DATE	PRECIP	R-2	T-13	T-6	T-3	T-4	T-10	T-15
		WAX TREATED PLOTS						
		runoff						
1977	mm	%						
3 Jan	2.3	77	T	T	T	T	T	T
5 Jan	5.1	85	94	76	84	83	53	55
8 Jan	2.0	51	40	T	30	40	T	35
25/26 Mar	7.6	85	79	26	37	72	84	37
28 Mar	3.7	77	78	54	62	78	86	59
13 May	13.2	90	95	83	87	83	39	61
5 Jul	4.8	105	81	38	73	62	73	58
22 Jul	1.2	61	T	T	T	T	T	T
26 Jul	15.2	62	82	60	75	72	62	57
12/13 Aug	10.7	59	69	41	57	49	11	41
16 Aug	4.1	119	80	32	54	34	*	54
9 Sep	2.0	36	T	T	T	T	T	T
27 Sep	8.1	78	82	59	62	58	*	60
6 Oct	2.8	59	68	36	54	36	46	64
6 Oct	3.0	54	*	*	*	*	*	*
29 Oct	8.1	90	90	60	64	75	89	49
5/ 6 Nov	8.3	4	87	69	70	76	101	66
26/28 Dec	2.1	35	**	**	**	**	**	**
28/29 Dec	11.9	88	86	66	61	78	94	45
TOTALS:								
1972	244	90	92					
1973	208	87	88					
1974	251	85	*	75				
1975	183	88	96	76				
1976	193	86	91	73	90	87	85	54
1977	116	70	77	53	61	64	53	49

* Lost data
** Two storms on T-plots
T Trace only

Table 5. Calculated depth of silicone penetration into Granite Reef catchment soil.

PLOT	DATE	TREATMENT	SOLU-TION	APPLICATION RATE 772 or R-20		SILICONE 1/		PROBABLE SOIL 2/ PENETRATION
			$1/m^2$	lb/acre	kg/m^2	lb/acre	kg/m^2	mm
L-3	4 Aug 65	3% R-20	1.87	500	0.056	100	0.011	9.0
"	6 Nov 69	"	1.36	363	0.04	73	0.008	6.6
"	3 Jun 75	"	1.00	272	0.03	54	0.006	4.8
R-4	3 Nov 70	" + 2% stabilizer	1.20	325	0.036	65	0.0072	6.0
"	3 Jun 75	"	1.00	272	0.03	54	.006	4.8
A-4	10 Nov 71	" + 2% stabilizer	1.2	325	0.036	65	0.0072	6.0

1/ Assuming 20% silicone in 772 or R-20

2/ Based on 1.22×10^{-3} g silicone/g soil at "monolayer" coverage (adjusted for 38% gravel in soil)

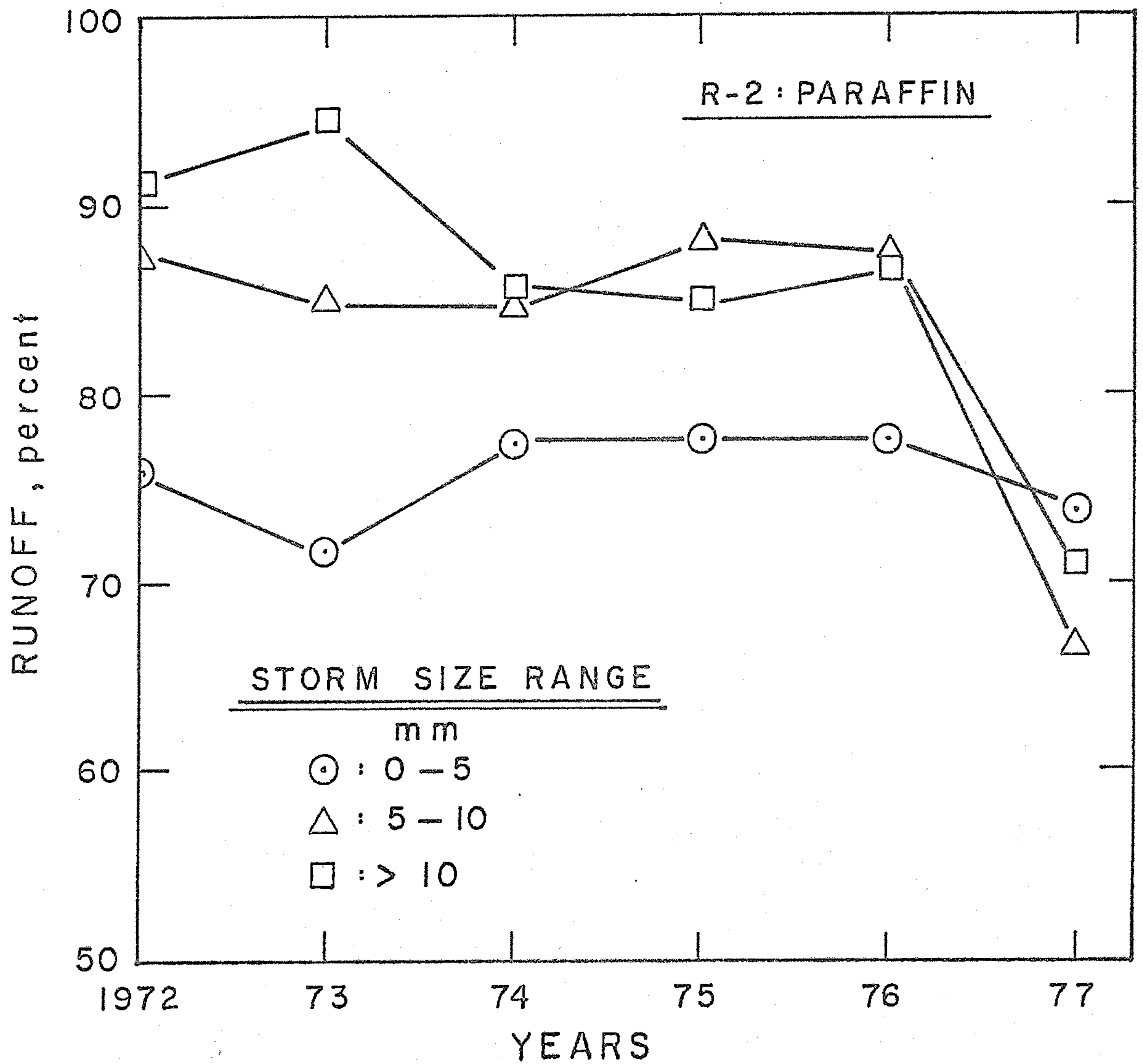

Figure 1. Rainfall runoff as a function of storm size from a paraffin-treated catchment by years since installation.

APPENDIX

LIST OF PUBLICATIONS PUBLISHED
AND MANUSCRIPTS PREPARED IN 1977

		MS No.
NRP 20740	Improve Irrigation and Drainage of Agricultural Land	
Published:	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. Pp. 25-31. 1977.	579
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NRP 20760	Management and Use of Precipitation and Solar Energy for Crop Production	MS No.
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		MS No.
Prepared:	Davies, J. A., and Idso, S. B. Estimating the surface radiation balance and its components. Chap. in "Modification of the Aerial Environment of Plants", (Amer. Soc. Agric. Engin. Monograph. (In press).	630
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	Ehrler, W. L., Fink, D. H., and Mitchell, S. T., Growth and yield of jojoba plants using runoff-collecting microcatchments in a 200-mm region. Agron. Jour. (Submitted for publication).	640
	Ehrler, W. L., Idso, S. B., Jackson, R. D., and Reginato, R. J. Diurnal changes in plant water potential and canopy temperature of wheat as affected by drought. Agron. Jour. (Submitted for publication).	628
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