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U. S. WATER CONSERVATION LABORATORY
Western Region
Agricultural Research Service
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PERSONNEL

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TITLE: EVAPORATION OF WATER FROM SOIL

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

Most of the work conducted under this outline this year consisted of development of techniques for the remote sensing of bare soil water content and bare soil evaporation. The following summaries outline the accomplishments in these areas.

1. Idso, S. B., Jackson, R. D., and Reginato, R. J. Estimating evaporation: a technique adaptable to remote sensing. Science 189:991-992. 1975.

A procedure is presented for calculating 24-hour totals of evaporation from wet and drying soils. Its application requires a knowledge of the daily solar radiation and the maximum and minimum air temperatures (Standard Weather Service measurements), moist surface albedo (readily estimated or obtainable from a one-time measurement), and maximum and minimum surface temperatures (obtainable from surface or airborne sensors). Tests of the technique on a bare field of Avondale loam at Phoenix, Arizona, have shown it to be independent of season.

2. Idso, S. B., Reginato, R. J., and Jackson, R. D. Assessing bare soil evaporation via surface temperature measurements. Hydrol. and Water Res. in Ariz. and the Southwest 5:199-205. 1975.

It appears that the thermal inertia technique, which has recently been suggested as a possible means for remotely determining surface water contents of bare soils via infrared thermometry, may also be used to evaluate the relative evaporation rates of bare soils. Each of the two variations of this technique, which use $T_{S_{Max}} - T_{S_M}$ and $(T_S - T_A)_{Max}$ as independent variables, worked successfully on a smooth bare field of Avondale loam at Phoenix, Arizona, on clear day-night periods during all seasons of the year. Together with stage I potential evaporation calculations, this approach would allow evaporation rates from bare soil to be calculated throughout all of the classical stages of soil drying.

The empirical relations describing these results also indicate that stage II of soil drying is not a unique physical process, but rather an observational artifact arising from the noninstantaneous transition of the entire soil surface from the basic stage I of soil drying (where energy is limiting the evaporation rate) to the basic stage III of soil drying (where soil water content is the limiting factor). In addition, there appears to be a unique relation between maximum clear-sky, screen-level air temperature and minimum surface soil temperature that is independent of season and soil water content. There are some indications that it, as well as the relative evaporation rate-soil thermal inertia relation, may also be independent of climate and soil type. Research in other areas and on different soils is needed to check these hypotheses.

3. Jackson, R. D., Idso, S. B., and Reginato, R. J. Calculation of evaporation rates during the transition from energy-limiting to soil-limiting phases using albedo data. Water Resources Research (In press).

A method is presented that utilizes albedo measurements to partition the fraction of the soil surface area exhibiting energy-limiting (potential) evaporation and the fraction exhibiting soil-limiting evaporation to calculate actual evaporation rates during the transition phase (energy-limiting to soil-limiting). Since albedo is proportional to the surface water content, the change in albedo from day to day is indicative of the fraction of the soil surface that is dry and evaporating at the soil-limiting rate. Denoting the partitioning factor as β, and using a square root of time relation with a coefficient C for the soil-limiting phase, the evaporation rate (E_C) for day n after the soil was wet is

$$(E_C)_n = \beta_n E_p + C \sum_{i-1}^{n} (\beta_{i-1} - \beta_i)(n-i+1)^{1/2}$$

where E_p is the energy limiting rate. The Priestley-Taylor formula was used to calculate E_p. Calculated evaporation rates were compared with lysimetrically determined rates. It was concluded that this

method was reliable for calculating evaporation rates during the transition phase of soil drying.

4. Reginato, R. J., Idso, S. B., Vedder, J. F., Jackson, R. D., Blanchard, M. B., and Goettelman, R. Soil water content and evaporation determined by thermal parameters obtained from ground-based and remote measurements. J. Geophys. Res. (In press).

Soil water contents from both smooth and rough bare soil were estimated from remotely sensed surface soil and air temperatures. From an air-dry soil water content to a water content corresponding to about field capacity for Avondale loam, an inverse relationship between thermal parameters and gravimetric soil water content was obtained. These parameters, daily maximum minus minimum surface soil temperature and daily maximum soil minus air temperature appear to describe the relationship reasonably well. Relative soil water evaporation (actual/potential) is also described by these two parameters. Surface soil temperatures showed good agreement between three measurement techniques: in situ thermocouples, ground-based infrared radiation thermometer, and the thermal infrared band of an airborne multispectral scanner.

5. Jackson, R. D., Reginato, R. J., and Idso, S. B. Timing of ground truth acquisition during remote assessment of soil water content. Remote Sens. of Environ. (In press).

Remote sensing of soil-water content is, at present, limited to the top few centimeters of soil. During a diurnal cycle the near-surface water content undergoes rather wide diurnal fluctuations. Data from five experiments on Avondale loam at Phoenix, Arizona, at various times of the year demonstrated that soil samples taken between 1100 and 1200 hours (MST) best represented the 24-hour average soil-water content. Also, the average of the daily maximum and minimum water contents closely approximated the 24-hour average. The data showed that time of sampling was an important criterion when obtaining ground truth in remote sensing of soil-water content.

6. Idso, S. B. Complexities of surface albedo determination during duststorms. Atmos. Environ. (In press).

Surface albedo measurements carried out prior to and following the arrival of duststorms at Phoenix, Arizona, have shown no differences that could be attributed to the effects of airborne or deposited dust on any of four different occasions. Kipp solarimeters have registered large variations in their outputs at these times; but it is demonstrated that these perturbations are due to some type of temperature "shock" induced by the rapid change in air temperature that occurs with the passage of the duststorm frontal boundary. Eppley and Lambda pyranometers were not susceptible to this type of erratic behavior.

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

TITLE: COMPUTER SIMULATION OF GREENHOUSES

CRIS WORK UNIT: 5510-12260-002 CODE NO.: ARIZ-WCL 70-1

This project was initiated to develop a computer program which can simulate all significant heat exchange processes occurring in a greenhouse. This objective was met culminating in a computer model described by B. A. Kimball, 1973, Simulation of the energy balance of a greenhouse, Agricultural Meteorology, 11:243-260. The model was intended primarily for short term studies.

Now the need has arisen to compute the annual operating costs (energy and $) of greenhouses cooled by cooling tower water and of greenhouses heated and cooled by solar energy utilizing thermal energy storage devices. Therefore, the model is being updated. The new mechanical components are being simulated by new subroutines. The whole program is being revised to run with a whole year's worth of weather data in order to compute the annual costs of operating greenhouses with various solar heating and cooling devices at various locations across the country. The new program is currently being debugged.

PERSONNEL: B. A. Kimball

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

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

The objective of this research is to improve the water-use efficiency (WUE) of crops by finding those species capable of reducing their rate of transpiration relatively more than photosynthesis during drought. Of the six species studied, corn and sorghum became less efficient under drought; black-eyed pea did not change, and cotton, sunflower, and mulberry became more efficient. The last three crops exhibited the type of response sought in this research, in that a drought caused a greater reduction in water loss than in photosynthesis.

Not enough species have been tested to make broad generalizations yet, but the preliminary tests are encouraging enough to warrant a more extensive survey. Also, it is planned to measure the WUE of Pima and Deltapine cotton, two closely related species with quite different drought responses in the field.

The findings for the six species are being summarized in a manuscript.

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

TITLE: HEAT TRANSFER IN PONDS

CRIS WORK UNIT: 5510-12260-002 CODE NO.: Ariz.-WCL-71-3

Work under this outline this year consisted of publication of two papers derived from experiments carried out in prior years. Each is described below.

1. Foster, J. M., and Idso, S. B. Light and assimilation number in a small desert, recharged-groundwater pond. Oecologia 18:155-164. 1975.

Measurements of irradiance, chlorophyll a concentration, respiration, and net and gross photosynthesis were carried out in a small desert pond containing recharged-groundwater from the Flushing Meadows water reclamation project at Phoenix, Arizona. Over the 6-month period May-October, chl. a concentration averaged 119 mg m^{-3}; and gross primary productivity in terms of the mean daily carbon fixation rate was 8.29 g Cm^{-3}, which is roughly equal to productive fish and farm ponds but less than many polluted eutrophic lakes and streams. Both net and gross assimilation numbers were found to be satisfactorily represented by pure sine waves that implied total inhibition of those two processes near an underwater irradiance value of 0.32 cal cm^{-2} min^{-1}.

The maximum value of the gross assimilation number at 0.16 cal cm^{-2} min^{-1} of 30 mg C hr^{-1} per mg chl. a ranked with some of the highest values that have been found world-wide.

2. Idso, S. B., and Foster, J. M. An analytical study of three characteristic forms of light-forced primary production in aquatic ecosystems. Oecologia 18:145-154. 1975.

Primary production in aquatic ecosystems is largely a function of irradiance, with photosynthetic response to light ranging from "light saturation" through "asymptotic inhibition" to "complete inhibition." Equations describing these three basic types of response have been solved to yield instantaneous integral photosynthesis as a function of irradiance, chlorophyll a concentration, light extinction coefficient, and photosynthetic capacity of the phytoplankton at optimum irradiance. These results were used to calculate diurnal

trends of instantaneous integral photosynthesis for several different latitudes and seasons and finally day-rate integrals of photosynthesis as a function of time of year at several latitudes. The final results allow rapid evaluation of the entire northern hemisphere in terms of potential sites for controlled aqua-culture facilities, using basic phytoplankton and water properties and standardized weather data. Results for the "complete inhibition" case can be used to evaluate both net and gross photosynthesis.

PERSONNEL: Sherwood B. Idso, J. M. Pritchard, and Joyce M. Foster, (cooperator from Zoology Dept., Arizona State University).

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

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

PART I. RECLAMATION OF CLOGGED EMITTERS

INTRODUCTION:

The reclamation of partially plugged emitters used in a trickle irrigation experiment on grapes which started in 1974 was continued in 1975 (See Annual Report of 1974 for a description of the work plan). The results from the chemical treatment showed some promise in getting the emitters to operate to the original flow rate for portions of the system that were treated. The remainder of the trickle system was likewise treated and a more careful monitoring of the flow rate was made.

PROCEDURE:

Chemical treatment was started in February 1975 before the regular irrigation of the grapes commenced. Concentrated hypochlorite and sulfuric acid solutions were injected into the water line just before the sand filter inlet with the injection rate controlled to give a residual chlorine of 50 ppm and pH of 2. The main supply lines, submains, and laterals were all flushed prior to working on the individual emitters. The chemical solution was allowed to stand overnight in the pipes, and the emitters were periodically flushed manually the following day with additional chemically treated irrigation water. The system was then left to stand until the grape irrigation started in April. The entire system was continuously treated with lower concentration of hypochlorite and sulfuric acid for the rest of the irrigation period which lasted to October. The residual chlorine was set at 1 ppm and pH at 7.

RESULTS AND DISCUSSION:

The flow rates of the various systems before and after reclamation treatment are presented in Table 1. Systems T1, T5, and T9 were treated the previous September and November with subsequent improvement in flow rates. Their rates were not changed in the

November 1974 to February 1975 interim while the trickle system was shut down for the winter.

The Feburary 1975 "slug" chemical treatment with high hypochlorite and acid concentrations also increased the emitter flow rates. In the table, the 20 February rates are the pre-treatment and the 28 February are the post-treatment rates, respectively. Further improvement of flow rates occurred with time when the system was followed by the continuous addition of low concentrations of hypochlorite and acid. The 25 to 50% reduction in flow rate as shown by the date of July and August 1974 was improved to that of the original design value after the reclamation project. The October 1975 readings were the last taken before the system was shut down.

Flow-rate monitoring and chemical treatment will be continued for the 1976 grape season.

Part II. EFFECT OF WATER TREATMENT ON TRICKLE EMITTER PERFORMANCE

INTRODUCTION:

Additional experiments were set up at the U. S. Water Conservation Laboratory location to supplement the preceding work on emitter plugging in grape irrigation and on citrus relating to the clogging potential of the Colorado River water (USWCL 75-2). Need for research on this subject is further elaborated in that report. The water qualities of the three locations differ quite markedly and thus the study would provide opportunities for following clogging over a wider range of environmental conditions. The close proximity of the laboratory site would also provide better monitoring and maintenance of the experimental equipment during the progress of the study, even though the actual field conditions are not fully simulated. The system was designed to allow for different kinds of water filtration and chemical treatments, water quality, and emitter types.

PROCEDURE:

Three kinds of water treatments and emitters were used and designated as follows:

Emitter 1. Long-path, capillary tubing

Emitter 2. Long-path, spiral, manual flushable

Emitter 3.	Double-wall or double-chamber tubing, with 1 foot outer and 5 feet inner orifice spacings
Treatment A.	Sand filtration and continuous hypochlorination-acid treatment (1 ppm residual chlorine and pH adjusted to 7)
Treatment B.	Sand filtration
Treatment C.	No filtration or chemical treatment

The number of treatment-emitter combinations was limited primarily by space availability.

Additional chemical and water treatments were utilized later within the existing experiment as the emitters started to clog. These modifications will be so designated where the treatments were introduced during the progress of the experiments.

A schematic of the trickle irrigation system is presented in Figure 1, which shows the relative location of the various equipment. Water from a well (1700 ppm) or city water (500 ppm) supply originating from surface sources was automatically fed into a 700-gallon galvanized steel storage tank. Ammonium nitrate was added to the stored water to get 10 ppm N to increase biological activity in the media. The water pump was activated by a time clock (T/C) which also controlled solenoid valve SV; the water was split up through a manifold arrangement to Treatments A, B, and C. The system was run twice a day in the morning and afternoon. An elapsed timer was made part of the clock circuit so that the operational periods could be monitored. The chemical injectors went on the same time as the water pump. In case of treatment A, the chemicals were injected before the sand filter (sf) which contained number 10 silica sand filtration medium. Water pressure was set at 15 psi by pressure regulator R.

Calcium hypochlorite and dilute sulfuric acid solutions were injected into the lines with diaphragm pumps. Both the concentration of the stock solution and the injector pump feed rate were adjusted to attain a pH of 7 and residual chlorine of 1 ppm in the treated water.

The line length was 75 feet. The double-wall Emitter 3 trickle system had 150 orifices per treatment, and Emitters 1 and 2 had 50 emitters per treatment. All the lines were on the soil surface.

The trickle system was operated on almost a full-year basis except for two weeks in January when low temperatures caused freezing of part of the supply lines. No damage was encountered with the rest of the system. The water meters and elapsed timer were checked daily to obtain the flow rates.

The untreated and treated water, and water sampled from the emitters at the end of each line were analyzed for microbial population, pH, residual chlorine, temperature, and turbidity once a week. A sample analysis of water used in this phase of the study is listed in Table 2. The salinity of 1630 ppm is much higher than the water used in the grape (350 ppm) or citrus (850 ppm) experiments. The Langelier saturation index of 0.7 indicates a tendency of calcium carbonate to precipitate out from the well water supply.

RESULTS AND DISCUSSION:

Flow rate was maintained in Emitter 1 (code A1) with the continuous hypochlorite-acid treatment from October 1974 to December 1975 (Figures 2 and 3), whereas the chemically untreated emitter (B1) started to show a gradual decrease in flow rate starting in May approximately 8 months after installation. The flow data for the individual days were smoothed out in the figures and representative values for the April to June period are listed in Tables 3 to 5.

Similarly, the flow rate in Emitter 2 (code A2) with the chemical and sand filtration treatments remained unchanged over the 15-month operational period. The untreated emitter (B2) did show a decrease in flow with time, but not as drastic a change as that exhibited by Emitter 1.

The flow rate of 0.44 gph in Emitter 3 (code A3, Figure 4) could also be maintained with sand filtration and chemical treatments. The trickle line for this system lasted only 12 months and had to be abandoned because of the appearance of numerous seam cracks in the polyethylene tubing. Both the chemically untreated sand filtration

treatment B3 and the unfiltered treatment C3 showed drastic drop in flow rate 7 months after installation. It was also noted for Emitter 1 that flow reduction commenced in May. The rapid change in flow is further illustrated by comparing the April, May, and June 1975 flow data of Tables 3, 4, and 5, respectively. Flow rates were constant and comparable at about 0.40 gph per emitter from October 1974 through April 1975. Until the first week in May, the flow rates had not changed much, but in the two weeks following this the rate had dropped approximately 75%. About 85% of the individual orifices were completely plugged and those remaining open were putting out water at a much higher rate than the original 0.40 gph per emitter. Water temperature had increased from about 10 C in the winter to 20 C in late April and early May and would enhance biological activity in the trickle system.

The plugged lines B3 and C3 were cut in June and inspected under the microscope. The outer holes were blocked from the inside with crystalline-like materials in sheet-like arrangement. Some of the inner orifices of the high-pressure chamber were also plugged. The inner surfaces of the tubing were coated with slime-like materials, whereas that for the chemically treated lines were clean. These deposits effervesed when treated with acid indicating the presence of carbonaceous matter.

On April 11 before the clogging in the B3 and C3 systems was becoming apparent, new line B3F and C3N were started (Figure 4). By the 15th of July approximately 90 days after installation, 25 to 50% reduction in flow had occurred in these systems. The B3F line was then treated with acid (pH of 2) on 5 August and the plugged and partially plugged orifices were cleaned by scraping off the surface residual materials that collected on the pore openings. After the concentrated acid treatment, the B3F/H line was treated continually with water acidified to a pH of 7 and the flow rate has been maintained from August through December 1975. The C3N system was cleaned with hypochlorite-acid and was treated continuously with a hypochlorite-acid combination (relabelled as C3N/HC) like the A3

system. Flow was similary improved and maintained as for the B3F/H system for the rest of the year.

Another set of B3 and C3 combination was installed on 18 June to replace the original B3 and C3 lines that had become clogged and sacrificed for visual inspection. This time within 70 days of installation, both B and C lines had a 50% reduction in flow. The orifices were cleaned externally and the water entering the lines was treated with organic polyphosphate solutions which did not improve the flow. The polyphosphate addition was stopped 36 days after the flow had further decreased and in system B3/P, the feed water was then passed through commercial "demineralizing" equipment. The treatment did not improve the flow rate and this line was discarded. In case of the C3/P system, acid was injected into the lines like B3F/H (C3/P redesignated as C3/H) and flow was improved to approximately 90% of the initial value. This combination will be continued for 1976.

Another set of B3 and C3 lines (labeled C3.3 in Figure 4, B3.3 not shown) was set up on 5 August 1975. The flow rate in C3.3 had decreased 50% in 54 days and 75% in 90 days. The rate in B3.3 had decreased in 80 days and continued at the low level for the rest of the year.

Filtration of the well water did not help in preventing clogging for Emitter 3 as evidenced by the decrease in flow rates for both B and C treatments. The turbidity measurements showed that the suspended material counts were about the same in the two treatments. In all types of emitters, plugging did not appear until the warmer water temperatures (20 C and higher) started, when microbial and chemical reaction would be enhanced.

The weekly measurements of microbial population for Treatments A, B, and C sampled immediately after treatment and before entering the trickle lines are shown in Figure 5. The hypochlorination Treatment C kept the population down to the 0 to 100 per ml level except for two instances, once when the injector tubing broke and another when the stock hypochlorite solution ran out. The unchlorinated Treatments A and B both had high counts in the order of 10^5

to 10^6 bacteria per ml with no difference present between the sand and no sand filtration treatments. Microbial population from Emitters 1, 2, and 3 samples taken at the end of the laterals (Figures 6, 7, and 8) resembled that for the samples just entering the laterals. Thus, it appears that the decrease in flow for the three emitters could be caused by the microbial activity in the tubes and emitter openings.

Checks of the microbial population in the acid treatments, B3F/H and C3/H of Figure 4 showed high values similar to that of treatments B and C, yet their flow rates had not decreased. The type of microbe growing under the acid condition may be different from the non-acid treated system. Also the acid may inhibit calcium carbonate precipitation. All the lines treated with acid had water with a pH of 6.5 to 7, whereas the untreated water had a pH of 7.8 to 8. The precipitated materials could act as sites for the microbial slimes to build up and cause emitter blockages.

The investigation will be continued in 1976 to look into the effect of other mineral acid besides sulfuric acid on emitter reclamation and performance. Other emitter design and bactericide may be included as space permits. Microbial population will be monitored on a continual basis in all present and new trickle systems under investigation.

SUMMARY:

Plugged emitters with flush provisions were successfully reclaimed in the field by treating them with concentrated hypochlorite and acid solutions. Emitter performance could be maintained by following the shock treatment with continuous low concentrations of the same chemicals. Furthermore, clogging can be prevented by initial treatment of the trickle system with hypochlorite and acid, and sand filtration where the suspended load is high. Where the water has a tendency to form carbonate precipitates, acid treatment alone can help in both the reclamation and maintenance of the emitters.

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

Table 1. System flow rates before and after emitter reclamation treatments in grape experiment.

System	Designed flow (gph)	Flow Rate (gph)									
		30 Jul 1974	14 Aug 1974	20 Feb 1975	28 Feb 1975	29 Apr 1975	17 May 1975	11 Jun 1975	3 Jul 1975	7 Aug 1975	6 Oct 1975
T1	72	36	48	(65)[a]	68	63	65	68	62	65	75
T2	144	95	99	96	112[c]	121	122	122	121	127	136
T3	144	98	104	106	132[c]	140	140	141	139	140	140
T4	144	78	62	71	123[c]	135	141	141	141	135	141
T5	72	48	33	(59)[b]	65	66	62	67	62	61	67
T6	144	90	99	92	111[d]	134	136	141	139	144	128
T7	144	105	113	133	126[d]	125	130	131	132	141	138
T8	144	109	114	79	116[d]	126	130	131	130	142	136
T9	72	46	38	(50)[b]	57	62	65	66	67	70	79
T10	144	100	98	75	119[e]	132	138	140	136	137	161
T11	144	113	106	100	112[e]	133	135	132	133	144	144
T12	144	100	93	102	125[e]	121	138	148	136	131	136

[a]Chemical treatment in Sept 1974

[b]Chemical treatment in Nov 1974

[c]Chemical treatment 21-22 Feb 1975

[d]Chemical treatment 25-26 Feb 1975

[e]Chemical treatment 26-27 Feb 1975

Table 2. Typical composition of storage water used in trickle irrigation experiment.

pH = 7.8	Cl = 15.3 me/l
Na = 17.1 me/l	SO_4 = 3.2 me/l
Ca = 5.7 me/l	HCO_3 = 6.9 me/l
Mg = 4.4 me/l	NO_3 = 10.9 ppm

Suspended load 5.5 mg/l

Total salt = 1630 ppm

Langelier Saturation index = 0.7

Table 3. Flow rates of Emitters 1, 2, and 3 for Treatments A, B, and C during April 1975.

APRIL 1975

FLOW RATE (GPH/EMITTER)

DATE	EMITTER 1		EMITTER 2		EMITTER 3		
	A	B	A	B	A	B	C
91	1.67	1.54	0.92	0.70	0.38	0.36	0.36
92	1.66	1.53	0.92	0.71	0.37	0.36	****
93	1.68	1.52	0.93	0.72	0.38	0.37	0.39
94	1.67	1.53	0.93	0.72	0.39	0.37	0.38
95	1.68	1.55	0.92	0.73	0.39	0.36	0.37
96	1.66	1.57	0.92	0.69	0.38	0.36	0.36
97	1.70	1.56	0.87	0.68	0.38	0.36	0.37
98	1.68	1.57	0.89	0.70	0.38	0.35	0.36
99	1.69	1.57	0.88	0.68	0.38	0.35	0.36
100	1.68	1.57	0.89	0.69	0.38	0.35	0.36
101	1.67	1.56	0.91	0.70	0.39	0.35	0.35
102	1.74	1.57	0.93	0.70	0.40	0.36	0.35
103	1.67	1.56	0.93	0.71	0.38	0.36	0.36
104	1.66	1.57	0.91	0.71	0.38	0.36	0.35
105	1.69	1.59	0.94	0.71	0.39	0.37	0.36
106	1.69	1.58	0.96	0.72	0.39	0.37	0.36
107	1.72	1.57	0.92	0.70	0.38	0.36	0.36
108	****	****	****	****	****	0.35	0.36
109	1.71	1.57	0.90	0.70	0.38	0.36	0.35
110	1.63	1.57	0.94	0.71	0.37	0.37	0.36
111	1.65	1.54	0.92	0.71	0.38	0.35	0.35
112	1.65	1.55	0.96	0.80	0.38	0.39	0.34
113	1.68	1.56	0.94	0.68	0.38	0.35	0.36
114	1.66	1.56	0.94	0.73	0.38	0.36	0.35
115	1.66	1.53	0.95	0.73	0.37	0.36	0.35
116	1.68	1.60	0.93	0.70	0.37	0.36	0.35
117	****	****	****	****	****	****	****
118	1.68	1.58	0.95	0.74	0.37	0.37	0.36
119	1.73	1.56	0.99	0.72	0.39	0.36	0.35
120	1.72	1.57	0.98	0.71	0.38	0.36	0.35

Table 4. Flow rates of Emitters 1, 2, and 3 for Treatments A, B, and C during May 1975.

MAY 1975

FLOW RATE (GPH/EMITTER)

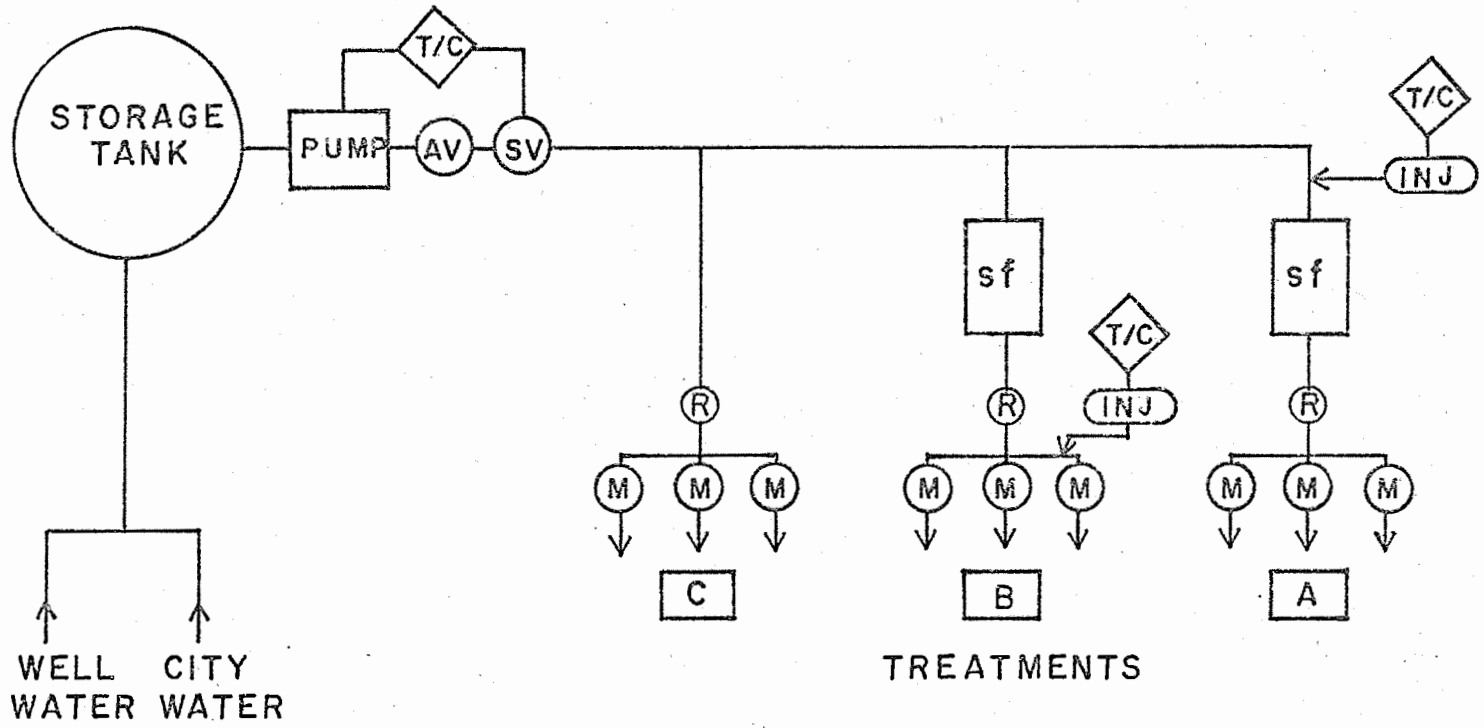
DATE	EMITTER 1		EMITTER 2		EMITTER 3		
	A	B	A	B	A	B	C
121	1.72	1.58	0.99	0.72	0.38	0.36	0.34
122	1.71	1.56	1.00	0.73	0.38	0.33	0.35
123	1.72	1.62	0.99	0.75	0.39	****	0.34
124	1.66	1.58	0.94	0.70	0.36	****	0.34
125	1.66	1.60	0.92	0.70	0.35	0.32	0.33
126	1.66	1.60	0.93	0.70	0.35	0.32	0.32
127	1.66	1.57	0.93	0.71	0.35	0.31	0.30
128	1.65	1.55	0.93	0.71	0.35	0.29	0.30
129	1.64	1.49	0.93	0.71	0.34	0.26	0.31
130	1.65	1.53	0.96	****	0.34	0.24	0.28
131	1.65	1.50	0.96	****	0.34	****	0.30
132	1.66	1.53	0.96	****	0.34	0.21	0.30
133	1.66	1.51	0.96	0.74	0.34	0.20	0.29
134	1.65	1.54	0.98	0.74	0.34	****	0.28
135	1.65	1.55	0.97	0.74	0.33	0.25	0.28
136	1.66	1.49	0.95	0.73	0.33	0.21	0.28
137	1.68	1.50	0.97	0.70	0.33	0.18	****
138	1.63	1.51	0.93	0.75	0.33	0.18	****
139	1.64	1.48	0.96	0.73	0.33	0.17	****
140	1.66	1.47	0.96	0.72	0.34	0.16	0.27
141	1.67	1.47	0.95	0.71	0.34	0.15	0.21
142	1.64	1.48	0.95	0.71	0.33	0.12	0.19
143	1.67	1.47	0.97	0.73	0.34	0.14	0.12
144	1.68	1.48	0.97	0.74	0.34	0.15	0.11
145	1.69	1.46	0.97	0.74	0.34	0.13	0.12
146	1.64	1.46	0.97	0.74	0.34	0.12	0.10
147	1.66	1.48	0.98	0.75	0.34	0.12	0.10
148	1.67	1.47	0.97	0.73	0.33	0.13	0.11
149	1.67	1.47	0.95	0.72	0.34	0.12	0.10
150	1.69	1.42	0.97	0.74	0.34	0.13	0.08
151	1.65	1.47	0.98	0.75	0.34	0.16	0.09

Table 5. Flow rates of Emitters 1, 2, and 3 for Treatments A, B, and C during June 1975.

JUNE 1975

FLOW RATE (GPH/EMITTER)

DATE	EMITTER 1		EMITTER 2		EMITTER 3		
	A	B	A	B	A	B	C
152	1.67	1.44	0.98	0.73	0.34	0.13	0.07
153	1.68	1.41	1.00	0.73	0.36	0.16	0.07
154	1.67	1.42	0.99	0.73	0.35	0.16	0.08
155	1.70	1.39	0.99	0.72	0.36	0.20	0.10
156	1.66	1.39	0.97	0.72	0.37	0.20	0.09
157	1.69	1.35	0.98	0.72	0.38	0.20	0.07
158	1.68	1.39	0.99	0.72	0.35	0.18	0.07
159	****	****	****	****	****	****	****
160	****	1.37	1.00	0.71	0.36	0.21	0.09
161	****	1.34	0.99	0.70	0.34	0.25	0.09
162	****	1.33	0.77	0.69	0.31	0.10	0.08
163	****	1.30	****	0.68	****	0.07	0.11
164	1.68	1.36	1.00	0.71	0.35	0.10	0.14
165	****	1.37	1.16	0.71	0.40	0.15	0.11
166	1.69	1.38	1.02	0.70	0.35	0.14	0.10
167	1.70	1.34	1.00	0.66	****	0.11	0.08
168	1.72	1.36	1.03	0.67	0.34	0.11	0.13
169	1.69	1.35	1.00	0.66	0.32	****	****
170	1.69	1.32	1.00	0.64	0.31	****	****
171	1.69	1.35	0.99	0.64	0.32	****	****
172	1.68	1.31	0.98	0.65	0.35	****	****
173	1.68	1.29	1.00	0.65	0.35	****	****
174	1.67	1.26	0.98	0.65	0.36	****	****
175	1.67	1.25	1.00	0.66	0.36	****	****
176	1.67	1.24	1.00	0.66	0.36	****	****
177	1.70	1.23	0.97	0.65	0.36	****	****
178	1.63	1.22	0.98	0.66	0.38	****	****
179	1.68	1.23	1.00	0.66	0.40	****	****
180	1.66	1.25	0.96	0.65	0.36	****	****
181	1.63	1.25	0.98	0.65	0.35	****	****



T/C = TIME CLOCK
AV = ANTISIPHON VALVE
SV = SOLENOID VALVE
R = PRESSURE REGULATOR
sf = SAND FILTER
INJ = INJECTOR
M = WATER METER

Figure 1. Schematic diagram of equipment arrangement used in trickle irrigation experiment.

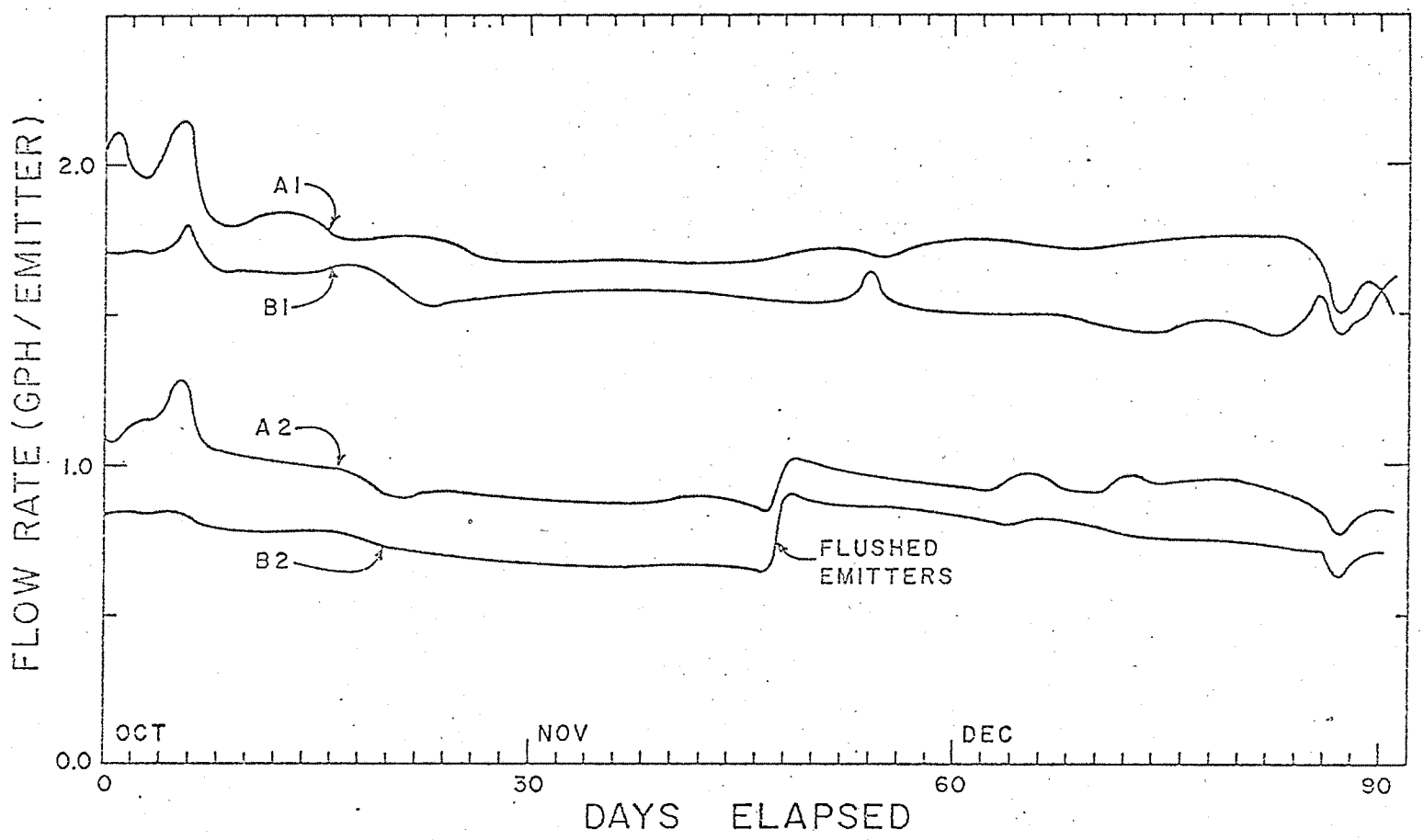


Figure 2. Flow rates of Emitters 1 and 2 with Treatments A and B during October to December 1974.

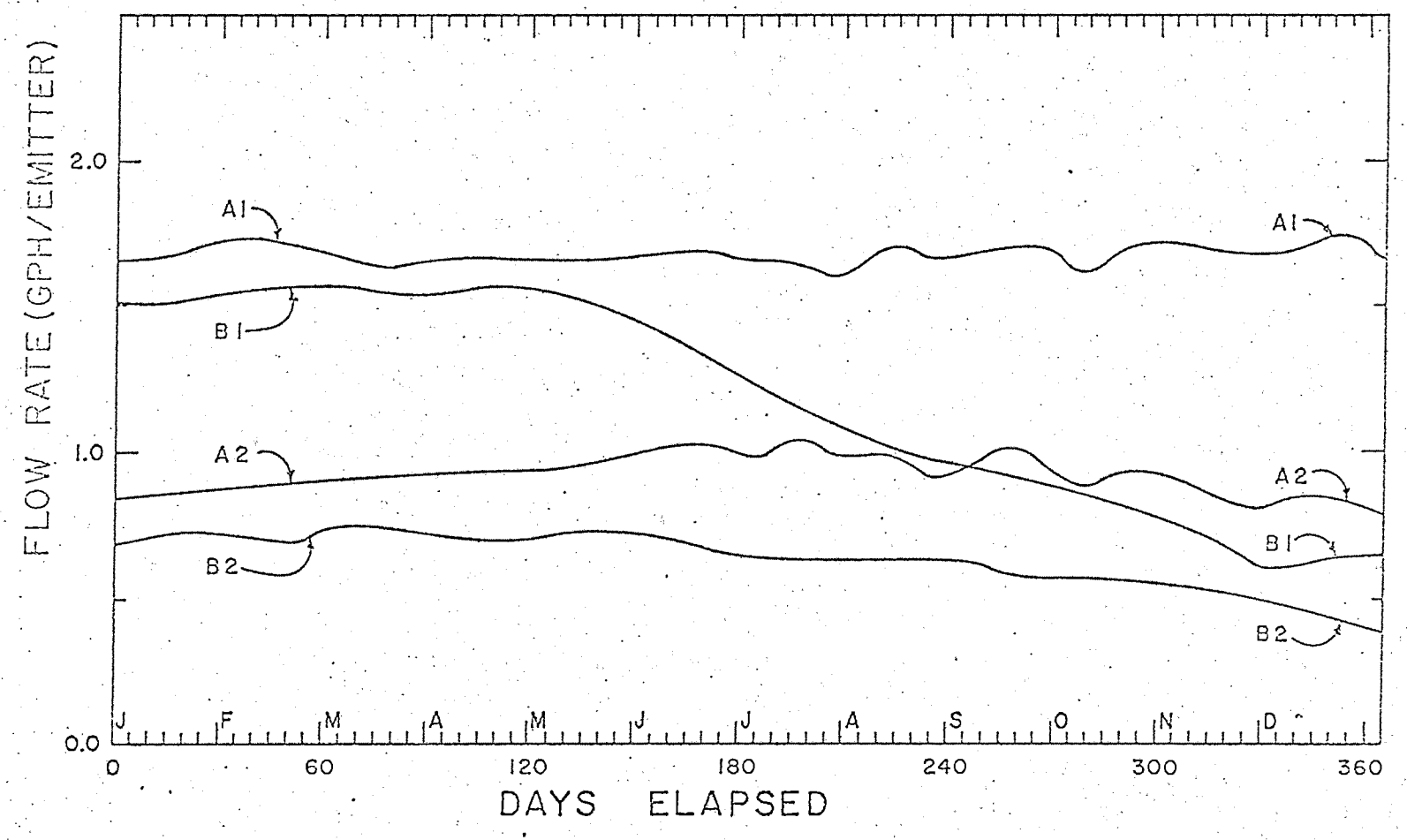


Figure 3. Flow rates of Emitters 1 and 2 with Treatments A and B during January to December 1975.

EFFECT OF TREATMENT AND TIME ON EMITTER FLOW RATE

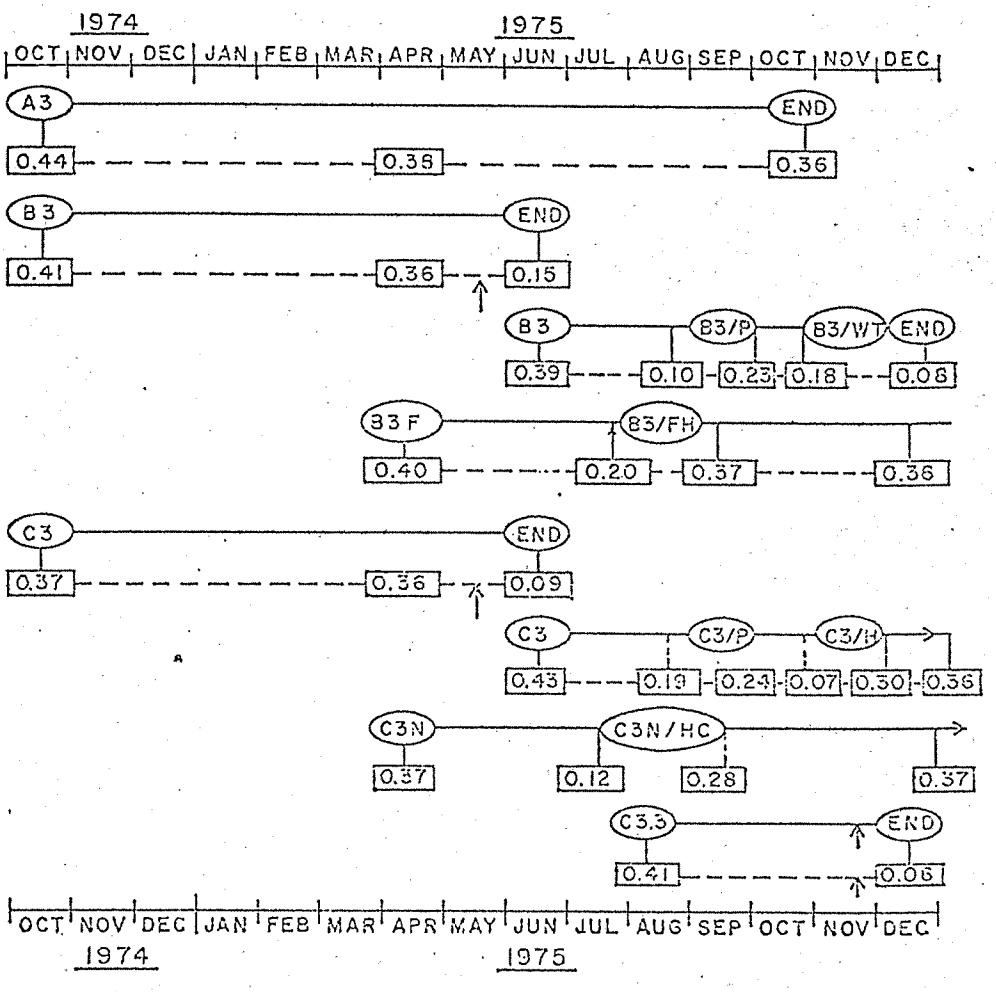


Figure 4. Effect of treatment and time on the flow rate of Emitter 3. (Treatment-emitter combination in ellipse and flow rates, gph per emitter, in blocks. A slash "/" after the treatment-emitter combination indicates an additional chemical treatment had been imposed on the original system and a vertical arrow time when 50% reduction in flow rate had occurred.)

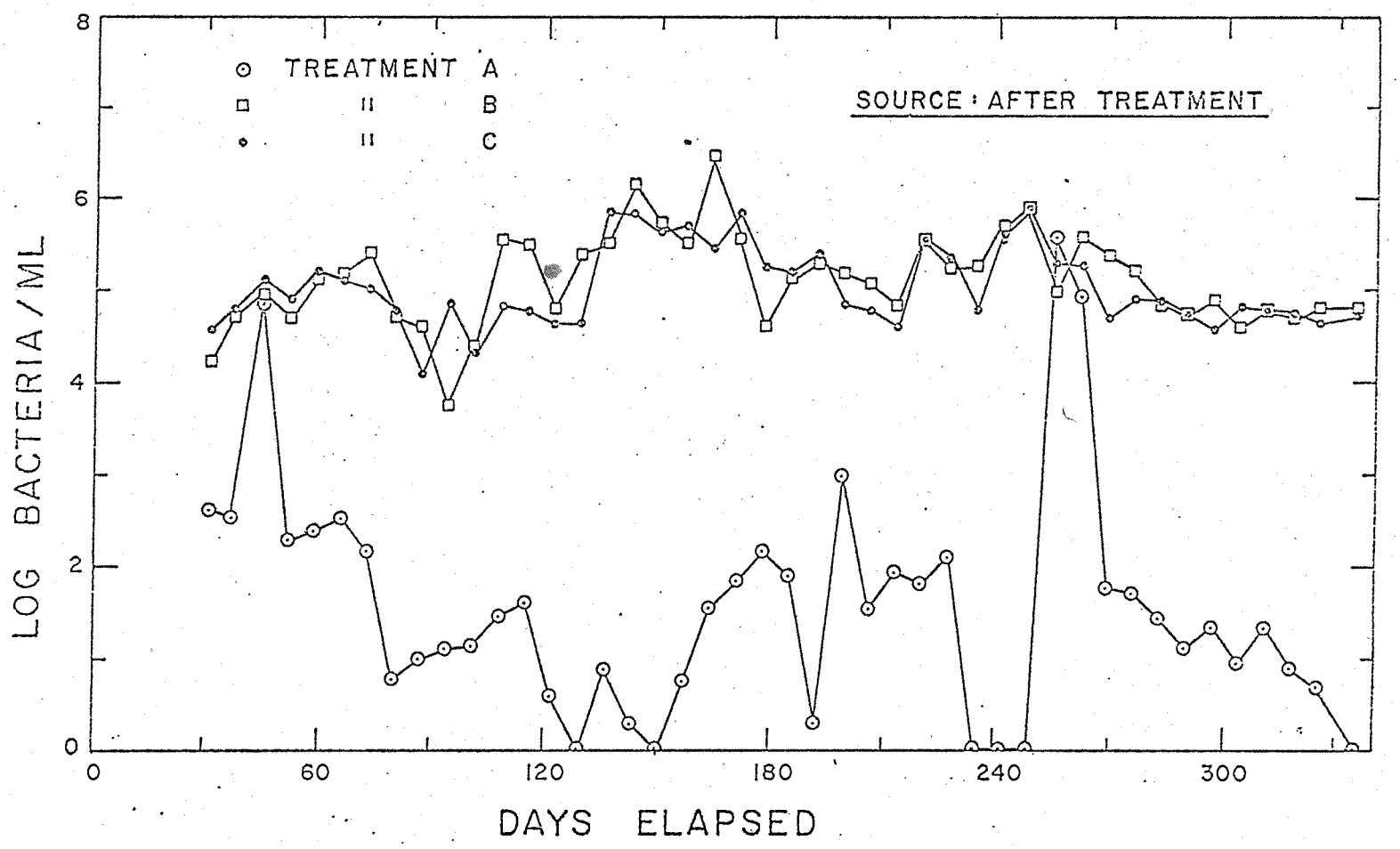


Figure 5. Microbial population in water samples for Treatments A, B, and C.

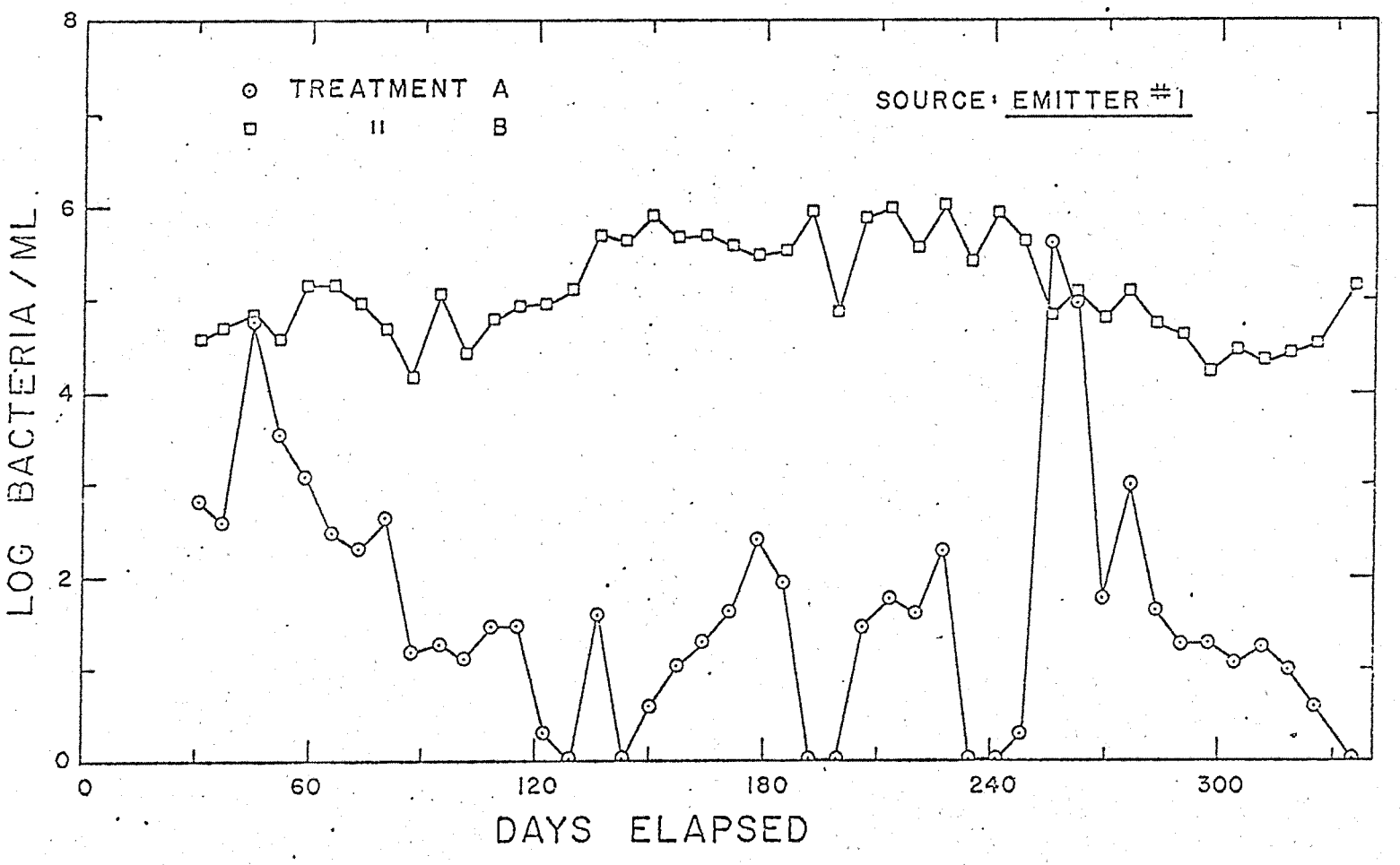


Figure 6. Microbial population in water samples from Emitter 1.

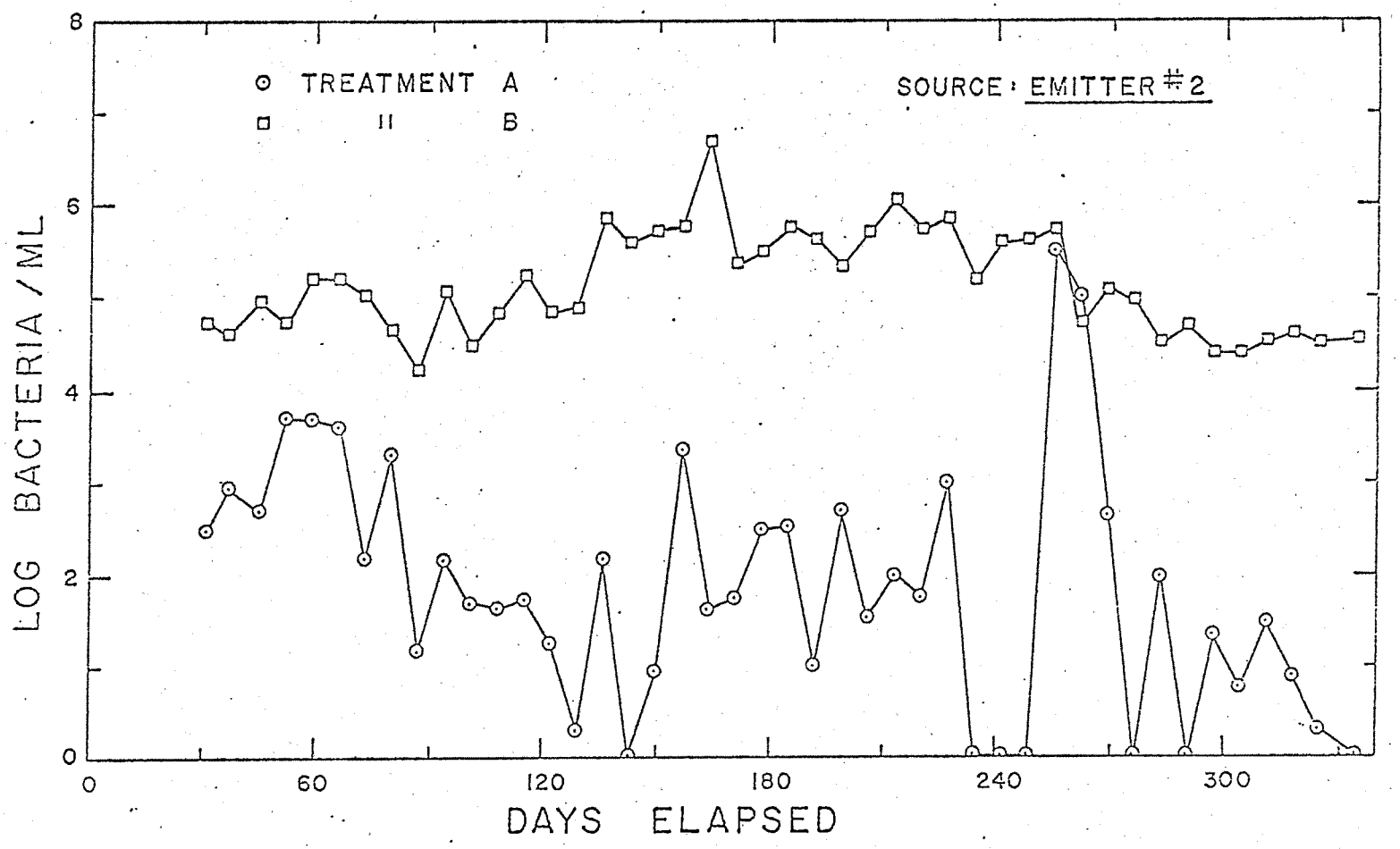


Figure 7. Microbial population in water samples from Emitter 2.

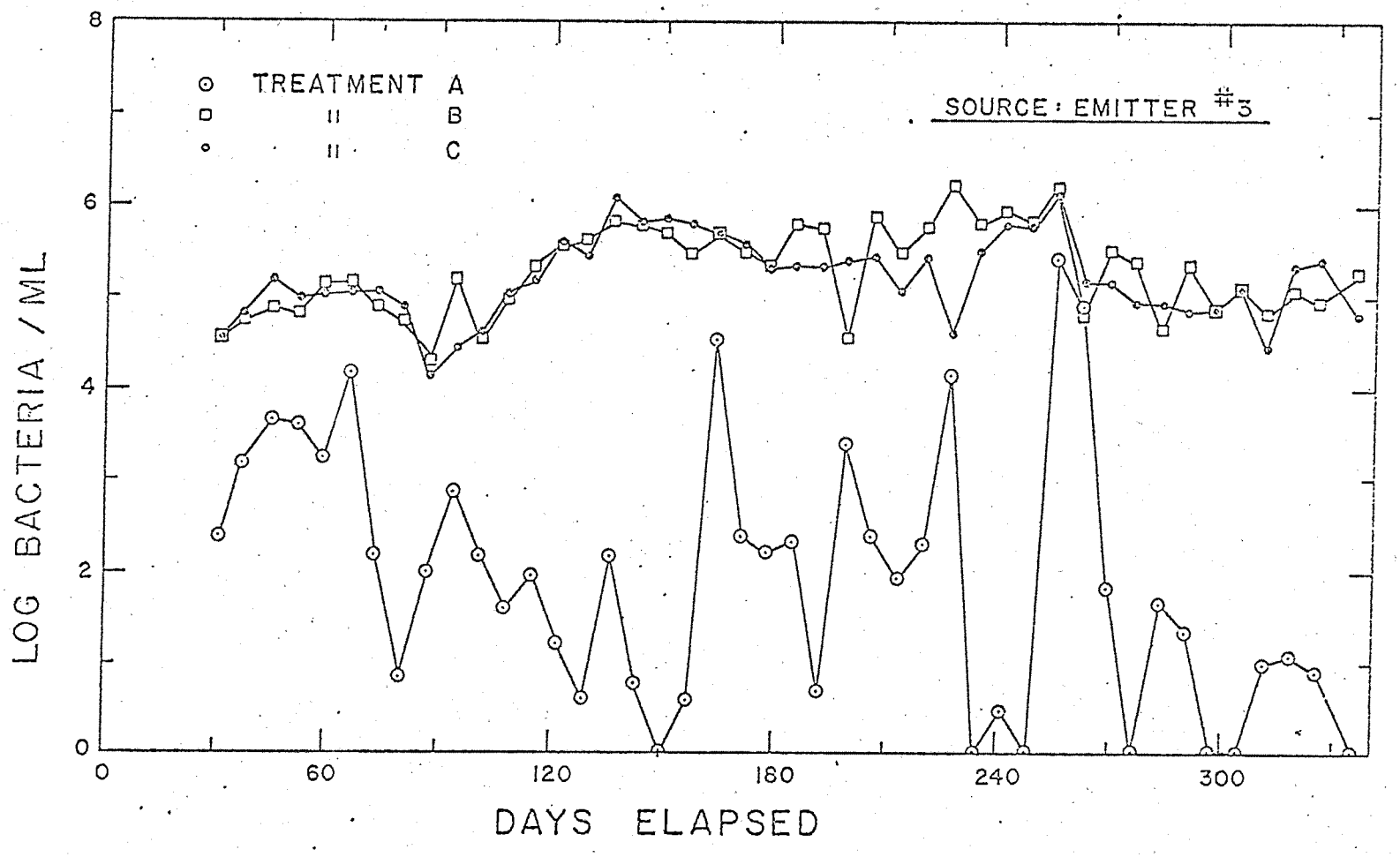


Figure 8. Microbial population in water samples from Emitter 3.

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

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

Most of the work conducted under this outline this year dealt with the development of techniques for the remote assessment of soil moisture of bare and cropped fields. The following summaries of six resultant publications elucidate the goals achieved.

1. Idso, S. B., Jackson, R. D., and Reginato, R. J. Detection of soil moisture by remote surveillance. American Scientist 63:549-557. 1975.

One of the primary resources upon which man directly depends for his existence is soil moisture. Since without it no food can be produced, the distribution of moisture over the land surface of the globe has shaped the development of civilizations and directed much of the course of history. This resource, among others, man now seeks to monitor from space, and toward this end he is applying some of his most sophisticated technology and management expertise.

At the most basic level, soil moisture sustains the many crop plants that man cultivates; its presence in proper amounts is essential for seed germination, crucial early development, and successful maturation. It is also important in partitioning water income from rainfall and irrigation into runoff, deep percolation, and storage. Subsequent evaporation of stored water from the soil surface or through vegetation is further dependent on the soil's water content, as is erosion of the soil by wind. On a more complex level, soil moisture influences crop productivity through its effects on insect pests and plant diseases. Thus, a change in the amount of water in the soil may have both good and bad effects. In this paper we attempt to illuminate some of these relationships and to show how soil-moisture data acquired by remote sensing from aircraft or satellites may be used to improve human life.

Various procedures for radiometrically measuring soil water-content from just above the ground surface, from aircraft overflights, and from orbiting satellites complement each other and hold promise

for improving efficiency in agricultural production and processing. The techniques utilizing reflected short-wave radiation (albedo), emitted long-wave radiation (surface temperature), and natural microwave emission (brightness temperature), and the procedures for using them, have certain limitations, but each is potentially suited to some important application in the management of the earth's land and water resources. Combined in a global program of continuous observation of soil moisture, they could do much to alleviate some of the many food production problems we face. These techniques hold out the prospect of giving us a new set of tools in the battle against worldwide hunger.

2. Reginato, R. J., Idso, S. B., and Jackson, R. D. Assessing soil moisture remotely. Hydrol. and Water Res. in Ariz. and the Southwest 5:191-198. 1975.

Three techniques capable of remotely assessing soil moisture are under study. Two of the methods, reflectance and thermal, are sensitive to the conditions of the bare soil surface, and empirically derived relations between those parameters and water content to any soil depth more than a couple of centimeters are quite tenuous. The third technique, microwave emission, appears to have good potential for assessing soil moisture with depth, because of its greater wavelength. Several technological problems must be investigated and solved before this method can be classified as useful.

Many of the limitations of all three methods should be overcome through improved technology and additional experimentation. Being able to assess soil moisture rapidly over large areas and having the information easily accessible to a variety of users would greatly benefit mankind. From this knowledge it should be possible to predict crop yields with greater accuracy than is currently being done; to predict the potentiality of crop pest infestations, such as locusts; to evaluate various cultural practices for conserving moisture under dryland farming conditions; to assess the persistence of pesticides in the soil; and to assess myriad other soil-moisture-dependent phenomena.

3. Jackson, R. D., and Idso S. B. Surface albedo and desertification. Science 189:1012-1013. 1975.

Otterman has proposed that desertification in regions of marginal rainfall may be due to an increase in surface albedo caused by the removal of vegetation by overgrazing. He hypothesizes that, when high-albedo soils are denuded the resultant increase in surface albedo causes lower surface temperatures, which in turn reduce the heat input to the lower atmosphere, decrease its temperature lapse rate, and hence somewhat reduce convective activity leading to rainfall. Over a period of several years we have measured albedos and surface temperatures of soils and plants in the Sonoran Desert climate of the southwestern United States, and, from the results of our investigations, we would predict that the denuded surface would be warmer than the vegetated one. Since the importance of correctly identifying the climatological mechanisms of desertification cannot be overemphasized in light of the devastation and human suffering caused by these processes in the Sahel, we believe that further analysis is warranted. Furthermore, since our analysis tends to indicate that the denuding of soil may have thermal and climatic effects just the opposite of those that he has postulated, until actual on-site measurements of rainfall and of surface temperatures based upon correct surface emissivities show otherwise, the validity of the rainfall reduction mechanism Otterman postulates should be seriously questioned.

4. Idso, S. B., and Ehrler, W. L. Estimating soil moisture in the root zone of crops: a technique adaptable to remote sensing. Geophys. Res. Letters 3:23-25. 1976.

A technique for estimating water contents within the root zones of crops from measurements of midday leaf-air temperature differentials is developed. Pertinent data used in the analysis were obtained from a cotton crop and two sorghum crops grown on an Avondale loam at Phoenix, Arizona. Since air temperature is the most commonly measured meteorological parameter on earth, and since crop canopy temperatures can be obtained by radiometric means, the technique

appears to point the way toward the eventual development of a procedure for the estimation of crop yields via remote sensing.

5. Idso, S. B., Jackson, R. D., and Reginato, R. J. Normalization of surface temperature data to compensate for environmental variability in the thermal inertia approach to remote sensing of soil moisture. J. Appl. Meteorol. (Submitted).

A technique has been developed that allows using standard maximum and minimum air temperatures recorded by the National Weather Service to reduce the scatter in the estimation of soil-water contents based on remotely acquired surface temperature data. This development makes the use of aircraft and satellites to detect soil moisture via surface temperature measurements a much more viable proposition than it has been in the past. It is possible the technique could also be useful in other thermal inertia applications such as lithographic mapping.

6. Pinter, P. J., and Jackson, R. D. Thermal relations affecting survival of pink bollworm larvae between cutout and pupation. Environ. Entomol. (To be submitted).

Last instar pink bollworm larvae, Pectinophora gossypiella Saunders, leave the protective cotton fruit microhabitat in a midday (1000-1400h) circadian "cutout" rhythm, then drop to the soil surface to search for a suitable pupation site. Before canopy closure completely shades the soil, larvae that fall upon sunlit portions may encounter sufficiently high temperatures for periods long enough to render them ecologically dead. This time-temperature relation, termed the Critical Thermal Maximum (CTM), was determined for 120 larvae at soil surface temperatures ranging from 45 to 68 C under field conditions. Below 50 C all but one insect survived a 10-min exposure and most traveled at least 1 meter. At 51 C, CTM occurred within 2.5 min; at 65 C it was reached within 0.33 min, and the distance traveled was less than 0.2 m. A model developed from larval temperatures monitored with two thermocouple techniques showed CTM occurring when insect cuticle temperatures reach 46 to 53 C.

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

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

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

INTRODUCTION:

For details see Annual Reports for 1973 and 1974. The essence of the experiment is to measure rainfall on the experimental site, determine the percent runoff as affected by two treatments on microcatchments (as compared to controls lacking catchments), and measure any resulting differences in soil water content near the jojoba plant as well as the subsequent growth and yield of jojoba seeds.

PROCEDURE:

Monitoring of the soil water content by neutron meter readings was continued throughout the year, but periodic sampling for the relative leaf water content was discontinued because of the method's poor discrimination among treatments.

Both rainfall and runoff were recorded for every storm. On 12 June an overcoating of paraffin wax (AMP 61-69 C) was applied at 0.5 kg/m^2 to the plots originally treated with "dust-suppressant" (the T_2 treatment). In treatments T_1 and T_2 excessive weed growth was removed from the 4-m^2 area containing the jojoba plant.

RESULTS:

No yield data were obtained this year. Sharp freezes at the end of December 1974 severely injured the jojoba plants. Only three plants out of the total of 30 did not show evidence of severe leaf and bud injury, according to a visual rating made on 2 January 1975. Despite vigorous vegetative growth in late spring on treatments T_1 and T_2, no flowers matured.

Table 1 gives the monthly distribution of rainfall. A notable feature is the complete lack of rain during August; summer rainfall normally peaks in August. The distribution of rain in spring is believed to have been adequate for development of flowers and fruits had the reproductive stimulus been triggered in time (at least for treatments T_1 and T_2).

The percentage runoff from different sized storms was similar to that of the previous year (Table 2). The weighted average derived from these data is 40% runoff from T_1 and 93% from T_2. These are the amounts to be expected on the plots with plants having microcatchments. Applying these figures to the measured rainfall for the year, the control plants had 223 mm of water, whereas T_1 plants had 892 mm, and T_2 plants 1260 mm (Table 3). With such appreciable water harvested, the soil water content can be expected to be augmented correspondingly. As shown in Figure 1, this was true for most of the year, the soil water content being in proportion to treatment, except for two short periods, one in early June and the other in early September.

SUMMARY AND CONCLUSIONS:

If the plant can endure the winter without severe frost injury, there is promise of a significantly higher seed yield in treatments T_1 and T_2 than in T_0, just as in June 1974.

PERSONNEL: W. Ehrler, S. Mitchell, and D. Fink

Table 1. Monthly rainfall on the jojoba plots.

Month	Rainfall, mm
Jan 1975	5.1
Feb	35.0
Mar	42.9
Apr	22.8
Jul	40.9
Sep	13.7
Oct	1.0
Dec	61.1
12-month total	222.5

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

USERY PASS PRECIPITATION-RUNOFF CHARACTERISTICS FOR 1975

STORM SIZE, mm	NO. STORMS	TOTAL PRECIP., mm	PERCENT OF TOTAL PRECIP.	PERCENT RUNOFF	
				T_1	T_2 1/
< 5	7	15.8	7	9	84
5-10	3	28.6	13	26	94
10-20	6	93.6	42	51 2/	92 2/
> 20	3	84.5	38	38	95 3/
TOTAL	19	222.5	100	40 4/	93 4/

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

2/ Data measured.

3/ Data estimated due to overflow of collectors.

4/ Estimated weighted average for whole year.

Table 3. Estimated usable water for 1975 on the three treatments.

Treatment	Harvested Water, mm
T_o	223
T_1	892
T_2	1260

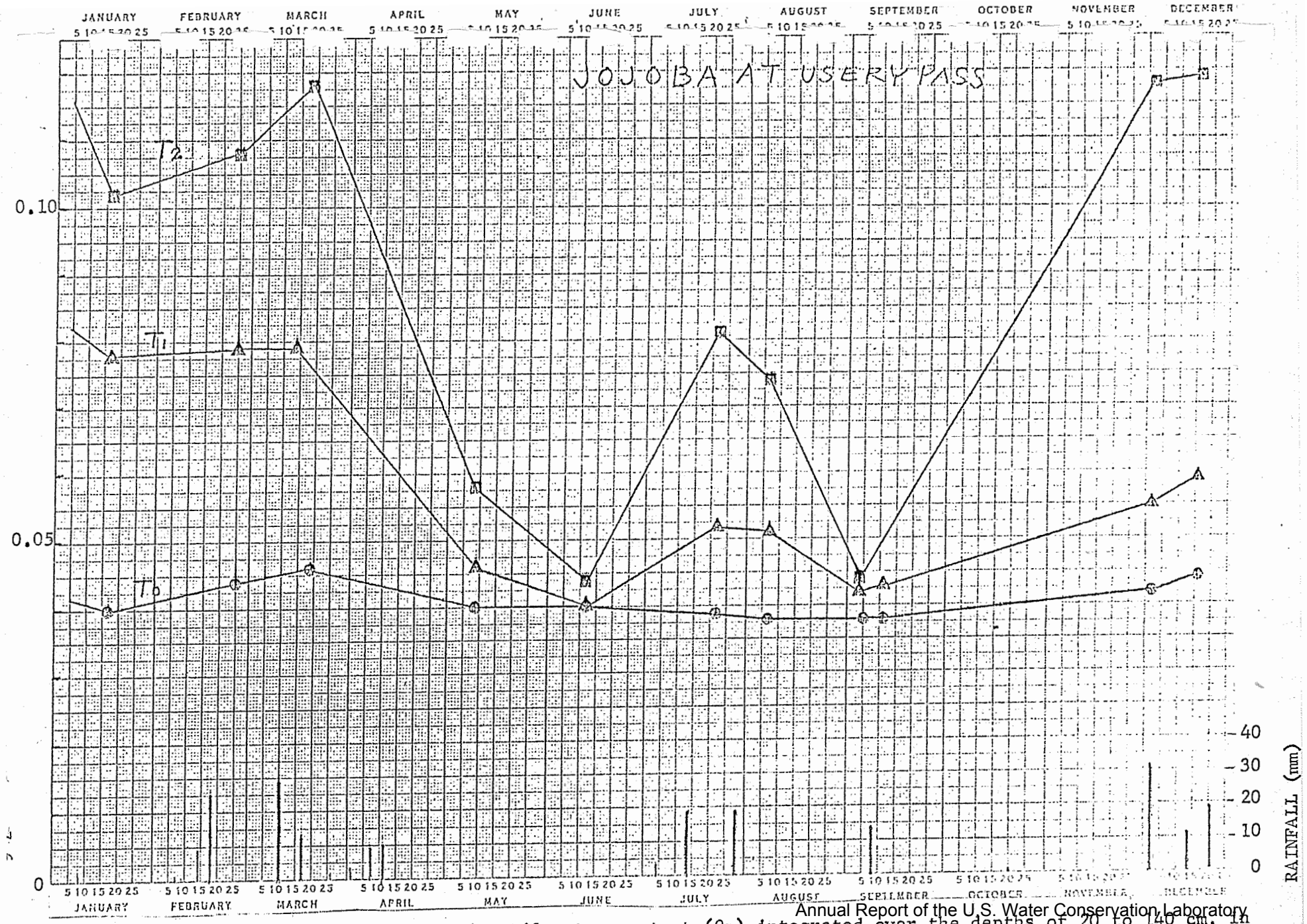


Figure 1. The 1975 course of volumetric soil-water content (θv) integrated over the depths of 20 to 140 cm, in

TITLE: TEMPERATURE CONTROL OF CO_2-FERTILIZED, SEALED GREENHOUSES

CRIS WORK UNIT: 5510-12260-002 CODE NO.: USWCL 75-1

INTRODUCTION:

The first objective of this project is to design, test, and evaluate coolers for sealed greenhouses under summertime conditions. During 1975 a test evaporative cooling tower was installed on the test greenhouse, and heat balance measurements were made. Further computer simulation of the heat and mass exchange performance of aspen pads was done, and measurements were made of the basic heat and mass transfer coefficients in cooperative work at the University of Arizona.

The second objective is to design, test, and evaluate methods of thermal energy storage as an energy saving means to achieve satisfactory heating in wintertime and cooling in summertime of a sealed greenhouse. Work was initiated on the testing of materials which melt and thaw near the midpoint between the optimum day and night temperature for plant growth. Modification of computer simulation programs to incorporate thermal energy storage into the energy balance of the greenhouse was initiated.

The last objective is to demonstrate the positive yield responses attainable with CO_2 fertilization in a sealed greenhouse. A CO_2 sampling and analysis system was installed to monitor and control the CO_2 concentration in the test greenhouse. The first tomato crop was grown, although the CO_2 control system was operative for only the last portion of the crop's growth. Construction of a second greenhouse was started so that an experimental control will be available at ambient CO_2 concentrations.

PART I: COOLING SYSTEM PERFORMANCE AND DESIGN

A. TOWER PERFORMANCE:

In the 1974 Annual Report for the project "Gravel Bed Coolers for Greenhouses," we reported that the computer simulation program, OUTSIDEPAD, predicted that the performance of the outside cooling tower could be markedly improved if the vertical aspen pads were

made three times as thick and twice as high as the standard pads on the previous conventional evaporative coolers. Therefore, a cooling tower was built which had vertical aspen pads 19 inches wide, and 67 inches tall. There were 6 pads 2 inches thick and another 6 were 4 inches thick. They were installed together to make pads of 6 inches total thickness. The two 3500 CFM blowers were removed from the previous coolers and installed in the tower to discharge horizontally in opposite directions.

Figure 1 shows the performance of the tower as indicated by its approach of water temperature to the outside wet bulb temperature. Also shown is the performance predicted previously by the OUTSIDEPAD program. As can be seen, the actual performance was much worse than predicted. The reason for the poor performance seemed to be that the extra pad thickness caused the air velocity to be reduced more than expected, and with the 6 inch pads, a larger fraction of air was going through cracks around the pads rather than through them. The previous air flow rate through the conventional air coolers had been 7800 CFM/36 ft^2 = 217, while through the 6 inch cooling tower pads it was 5500 CFM/53 ft^2 = 104. Apparently OUTSIDESIDE had not adequately compensated for the different air velocity, and of course, it could not account for air by-passing the pads through cracks.

An attempt was made to improve the tower performance by reducing pad thickness to increase air flow. The 4 inch thick pads were removed leaving only the 2 inch thick ones. The water was induced to flow from the slotted pipe distribution system into the 2 inch pad by using a V shaped funnel of polyethylene film that spanned the pipes at the top and that was tucked between the aspen fibers and the wire pad frame on each side at the bottom of the V. The performance was markedly improved as shown by the third bar. This blower-pad combination achieved a 3F approach to wet bulb. The air flow increased to only 6000 CFM (as measured with a hand-held Taylor propeller anemometer) so most of the improved performance was probably due to a larger fraction of the air going through the pads rather than around them.

B. INSIDE PAD PERFORMANCE:

As discussed in the 1974 report, the inside pads performed poorly, and no changes were made in the inside pads installed on the test greenhouse. Figure 2 shows that the inside greenhouse temperature typically would rise about 20F above the outside wet bulb. Since the outside cooling tower provided water that generally was no more than 3 - 4F above the outside wet bulb, most of the temperature rise is due to the poor heat and mass exchange properties of the inside pads. These pads were oriented vertically, 168 inches wide, 34 inches high, and 4 inches thick. The water flow rate was about 30 GPM and the inside air flow rate was about 9000 CFM. In view of this poor performance, considerable effort was expended to design pads for improved cooling of the greenhouse air.

C. HEAT AND MASS TRANSFER COEFFICIENTS FOR DIRECT CONTACT OF WATER AND AIR IN ASPEN EXCELSIOR PADS:

It is generally known that counter-flow is more effective than cross-flow for exchanging heat between two fluids, and Benham and Wiersma (D. S. Benham and F. Wiersma, Design criteria of evaporative cooling, Winter Meeting of the American Society of Agricultural Engineers, paper 74-4527, 1974) had confirmed that horizontal aspen pads are more effective than vertical pads for evaporative cooling of air. Therefore, it seemed logical to determine whether horizontal pads could be used for more effective cooling of the air in a sealed greenhouse. The data presented by Benham and Wiersma were done with water at the wet bulb temperature, so liquid film heat transfer coefficients could not be extracted from their data. Therefore, Benham and Wiersma were contacted at the University of Arizona and a cooperative experiment was performed using various flow rates of water at various water temperatures. The experiment and results are described in the manuscript, "Heat and mass transfer coefficients for water and air in aspen excelsior pads," by B. A. Kimball, Durward S. Benham, and Frank Wiersma.

Using this new data plus that from Nehemiah, Lauw, and Andre, the following correlation equations were obtained.

$$h_L a_H = 2.66\ G_a^{.4}\ G_L^{.83}$$

where $h_L a_H$ is the liquid film heat transfer coefficient for either vertical or horizontal pads (BTU/(min ft^3 F)), G_a is the air flow rate (lb/min/ft^2), and G_L is the water flow rate (lb/min/ft^2 of air face area). The pads were 2 inches thick and 23.4 inches square.

For horizontal pads

$$h_a a_H = .665\ G_a^{1.462}\ G_L^{.1004}$$

and for vertical pads

$$h_a a_H = .428\ G_a^{1.368}\ G_L^{.1362}$$

where $h_a a_H$ is the gas film heat transfer coefficient. The flow rates ranged from 6 to 16 for air and from .5 to 12 for water. The mass transfer coefficient, $K_a a_M$ (lb/min/ft^3), can be determined from the gas film heat transfer coefficient using the Lewis relation which states that $K_a a_M = h_a a_H / C_a$ where C_a is the humid specific heat of the air (BTU/lb/F). For the temperatures generally used in these experiments, C_a can be taken as constant at 0.245.

D. DESIGN OF COOLING TOWERS AND DEHUMIDIFIERS

Using the correlation equations for the heat transfer coefficients in horizontal aspen pads presented in the previous section, a computer program was written called DESIGN TOWER/DEHUMIDIFIER to design cooling systems using aspen pads. This program computes the horizontal pad area required per unit of water flow as a function of approach (difference between cold water temperature and entering air wet bulb temperature) and range (difference bwtween entering and exiting water temperature). The method used is to specify the inlet air conditions and the water and air flow rates and the approach. Then the range is iteratively varied until the computed height of

tower equals the actual height (2 inches). The process is repeated for other water flow rates and approaches. The air flow rate was fixed at 200 fpm, the optimum found by Benham and Wiersma.

Examples of the output of this program are presented in Figures 3,4,5, and 6. Figure 3 would be used to design a cooling tower. Knowing the heat load to be dissipated, the user would select a water flow rate compatible with the maximum range and approach he can tolerate based on his application and the weather conditions in his area. Then, using this range and approach, he can find the required pad area/unit of water flow from Figure 3. Multiplying this figure by his flow rate yields the required pad area, and multiplying the pad area by the 200 fpm air velocity yields the total air flow rate.

Figure 4 shows the wet and dry bulb temperature of the exit air for the same cooling tower of Figure 3.

For most industrial applications the air coming out of a cooling tower is of no direct interest because the large approaches and ranges common in industry result in exit air whose dry bulb is close to or above the ambient dry bulb, as can be seen by the 32F curves in Figure 4. However, for ranges and approaches less than about 8F, the dry bulb temperature of the exit air is almost as cool as from an air cooler with water recirculating at the wet bulb temperature.

By merely changing signs on the definition of what are the approach and range temperatures, the same program can predict the cooling and dehumidifying of air with water at temperatures below the wet bulb temperature of the entering air. Figure 5 shows the required pad areas for air entering at 88.5F dry and 81.5F wet bulb temperatures. The curves are nearly identical to those of the cooling tower in Figure 3. Figure 6 shows the corresponding dry and wet bulb temperatures of the exit air.

E. DESIGN OF SEALED AND CONVENTIONAL GREENHOUSE COOLING SYSTEMS:

1. Assumptions:

a. Heat load = 240 BTU/hr/ft^2

This is based on a maximum solar intensity of 300 BTU/ft/hr with no shading and assuming the effective light transmission lowers

the solar load to 70%, but the sensible load through the walls adds 10%.

b. No evaporation in sealed greenhouse, but 50% of heat load is dissipated by transpiration in a conventionally cooled unsealed greenhouse.

c. A 7F temperature rise through the house is tolerable.

2. Air flow required:

a. Sealed AFLOW = $\dfrac{240 \dfrac{\text{BTU}}{\text{hr ft}^2}}{.246 \dfrac{\text{BTU}}{\text{lb F}} \; .067 \dfrac{\text{lb}}{\text{ft}^3} \dfrac{60 \text{ min}}{\text{hr}}} = 35 \dfrac{\text{cfm}}{\text{ft}^2}$

b. Conventional AFLOW = .5 x 35 = 17 cfm/ft^2

3. Pad size required at 200 fpm air velocity:

a. Sealed PAREA = $\dfrac{35 \text{ cfm/ft}^2 \text{ of GH}}{200 \text{ cfm/ft}^2 \text{ of pad}} = \dfrac{.17 \text{ ft}^2 \text{ of pad}}{\text{ft}^2 \text{ of GH}}$

b. Conventional PAREA = .5 x .17 = $\dfrac{.087 \text{ ft}^2 \text{ of pad}}{\text{ft}^2 \text{ of GH}}$

4. Water flow rate:

a. Sealed

Since heat capacity of water is about four times that of air, choose range to be about 1/3 the air temperature range or range ≈ 3F then the required water flow rate is

$$\frac{240 \dfrac{\text{BTU}}{\text{hr ft}^2}}{1 \dfrac{\text{BTU}}{\text{lb}} \; 8.331 \dfrac{\text{lb}}{\text{gal}} \dfrac{60 \text{ min}}{\text{hr}} \; 3\text{F}} = .16 \frac{\text{gpm}}{\text{ft}^2 \text{ of GH}}$$

b. Conventional

Benham and Wiersma recommend a water flow rate of about 7 times the evaporation rate for good wetting. The required water flow is

$$\frac{(7)(.5)\ 240\ \frac{\text{BTU}}{\text{hr ft}^2}}{1051\ \frac{\text{BTU}}{\text{lb}}\ 8.331\ \frac{\text{lb}}{\text{gal}}\ \frac{60\ \text{min}}{\text{hr}}} = .0016\ \frac{\text{gpm}}{\text{ft}^2\ \text{of GH}}$$

5. <u>Approach temperature for inside pads (sealed only):</u>

Dividing the pad area by the water flow rate

$$\frac{.17\ \text{ft}^2\ \text{of pad/ft}^2\ \text{of GH}}{.16\ \text{gpm/ft}^2\ \text{of GH}} = 1.06\ \text{ft}^2\ \text{of pad/gpm}$$

and using this value in Figure 5 along with a range of 3F shows that the approach ≈ 4F, and from Figure 6 the exit air temperatures are about 81.2F dry and 80.0F wet bulb.

6. <u>Approach temperature for outside pads assuming a cooling system for a conventional greenhouse would be used as the cooling system for a sealed greenhouse:</u>

Again dividing area by flow rate,

$$\frac{.087\ \text{ft}^2\ \text{of pad/ft}^2\ \text{of GH}}{.16\ \text{gpm/ft}^2\ \text{of GH}} = .54\ \text{ft}^2\ \text{of pad/gpm}$$

From Figure 3 with a 3F range, the approach ≈ 6F and from Figure 4 the exit air temperatures are 76.6F dry and 74.1 wet bulb.

7. <u>Resultant greenhouse temperatures:</u>

a. Sealed

Summing the above temperature differences

Approach of water to outside wet bulb	= 6
Range of water temperatures	= 3
Approach of water to inside wet bulb	= 4
Inside exit dry bulb above inside entrance wet bulb	= - .3

Therefore, inside cold air temperature = 13F above wet bulb and with a 7F rise, hot inside air temperature = 20F above the outside wet bulb.

b. Conventional - if not used as cooling tower but as an air cooler, with an efficiency of 76% (Benham and Wiersma), then exit air dry bulb would be about 5F above outside wet bulb and hot inside air temperature would be 12F above the outside wet bulb.

c. Conventional - if used as cooling tower for adjacent sealed greenhouse. From Figure 3 with 3F range and an approach of about 6F, the exit air dry bulb is about 7F above the outside wet bulb, so the hot inside air temperature would be 14F above the outside wet bulb.

8. Equipment and power requirements:

a. Sealed

Fan for inside air

$$35 \frac{\text{cfm}}{\text{ft}^2} \times \frac{1}{8377 \frac{\text{cfm}}{\text{HP}}} = .0042 \frac{\text{HP}}{\text{ft}^2 \text{ of GH}}$$

for .25 in H_2O pressure drop and 33% fan efficiency

Water pump

$$\frac{.16 \text{ gpm}}{\text{ft}^2 \text{ of GH}} / \frac{66 \text{ gpm}}{\text{HP}} = .0024 \frac{\text{HP}}{\text{ft}^2 \text{ of GH}}$$

for lift of 30 feet and 50% pump efficiency

b. Conventional

Cooling tower or air cooler fan

$$17 \frac{\text{cfm}}{\text{ft}^2} \times \frac{1}{8377 \frac{\text{cfm}}{\text{HP}}} = .0021 \frac{\text{HP}}{\text{ft}^2 \text{ of GH}}$$

c. Average power consumption for 2 conventional houses =

$$.0021 \frac{HP}{ft^2 \text{ of GH}}$$

Average power consumption for 1 sealed plus 1 conventional house =

$$.0044 \frac{HP}{ft^2 \text{ of GH}}$$

Average power consumption for a vapor compression air conditioner

$$240 \frac{BTU}{hr\ ft^2} \times \frac{1}{4200 \frac{BTU/hr}{horsepower}} = .0567 \frac{HP}{ft^2 \text{ of GH}}$$

From Grainger catalog

9. Implications:

For a 20F rise above wet bulb for a dual sealed-conventional system if the maximum desired inside temperature were 88, the sealed greenhouse would be too warm whenever the outside wet bulb exceeded 68F. From the data of Schmidli et al. (R. J. Schmidli, P. C. Kangieser and R. S. Ingram, 1971. Climate of Phoenix. NOAA Technical Memorandum NWS WR 38) this means that it would be too warm from about 10:00 to 20:00 hours on the average for the months of July, August, and September in Phoenix. To avoid damage to the plants during these times, the greenhouse could be shaded or alternatively the air duct system could be designed so that dry outside air could be introduced to the inside pads for direct evaporative cooling. The conventional greenhouse, on the other hand, with about a 13F rise above wet bulb would on the average not get too warm. These data are only for Phoenix and of course, for cooler climates the sealed

greenhouse could operate for a larger percentage of the time, and permit CO_2 fertilization of the crop at the same time.

The increased power consumption and equipment requirement over conventional greenhouses is not desirable, particularly at this present energy conscious period of time. To pay for the increased energy, CO_2 fertilization would have to more than double crop yields. Compared to cooling with refrigeration, however, this system requires much less power. There are several sealed experimental greenhouses throughout the country cooled by refrigeration, and this system could be used instead on those where high humidity is of no particular concern.

From purely the economic standpoint, however, since cooling equipment costs are about 25% of an initial investment, and power costs are less than 25% of operating costs in a conventional greenhouse, CO_2 fertilization would have to increase yields about 50% in the sealed greenhouse. Increases of this magnitude have been reported in the literature, but not consistently. Most of the CO_2 fertilization work has been done during the heating season in cold climates where light intensities are not particularly high. The increases consistently attainable under high light intensities such as found in the Southwest are unknown.

10. Plans for next year:

A computer simulation model is to be modified to model the cooling system described. It will predict the annual hours of use of fans and pumps and the percent of time CO_2 fertilization can be practiced. It will be run with weather data for various locations to determine how much relative benefit must be provided by CO_2 fertilization to make the system break even with conventional greenhouses. Data on the yield increases possible with CO_2 fertilization under the high light intensities of Phoenix will also be obtained, as will be described in later sections.

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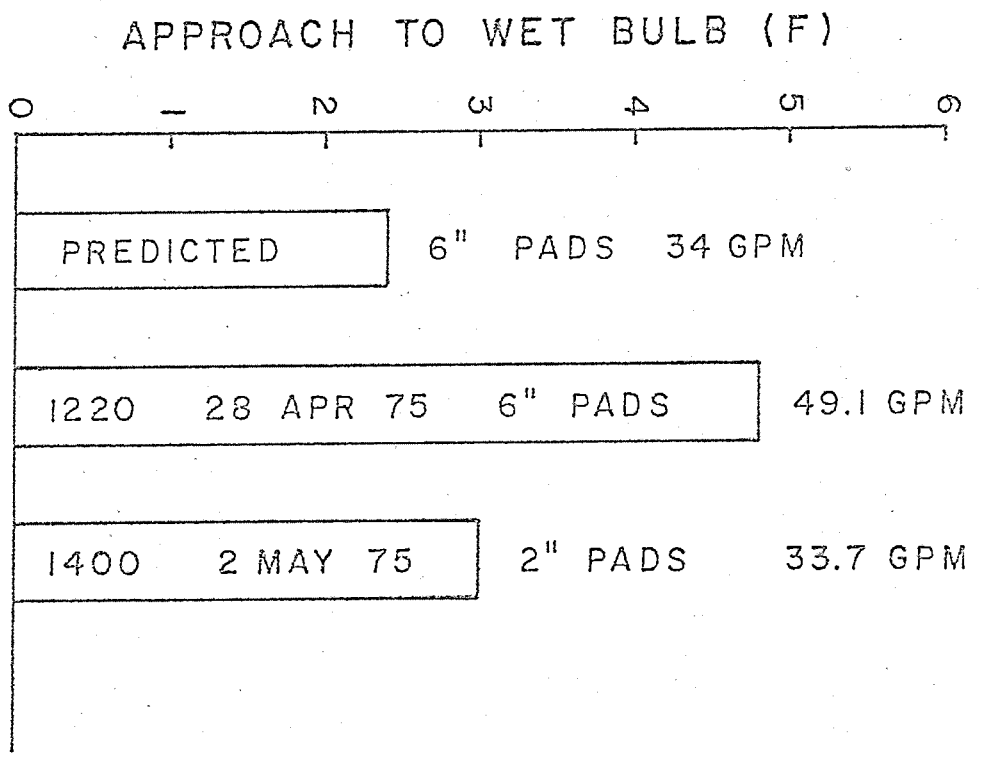

Figure 1. Approach of water temperature to wet bulb temperature for vertical aspen pad tower for 6 and 2 in. thick pads and approach predicted by OUTSIDEPAD program. Heat load was 45,000 BTU/HR.

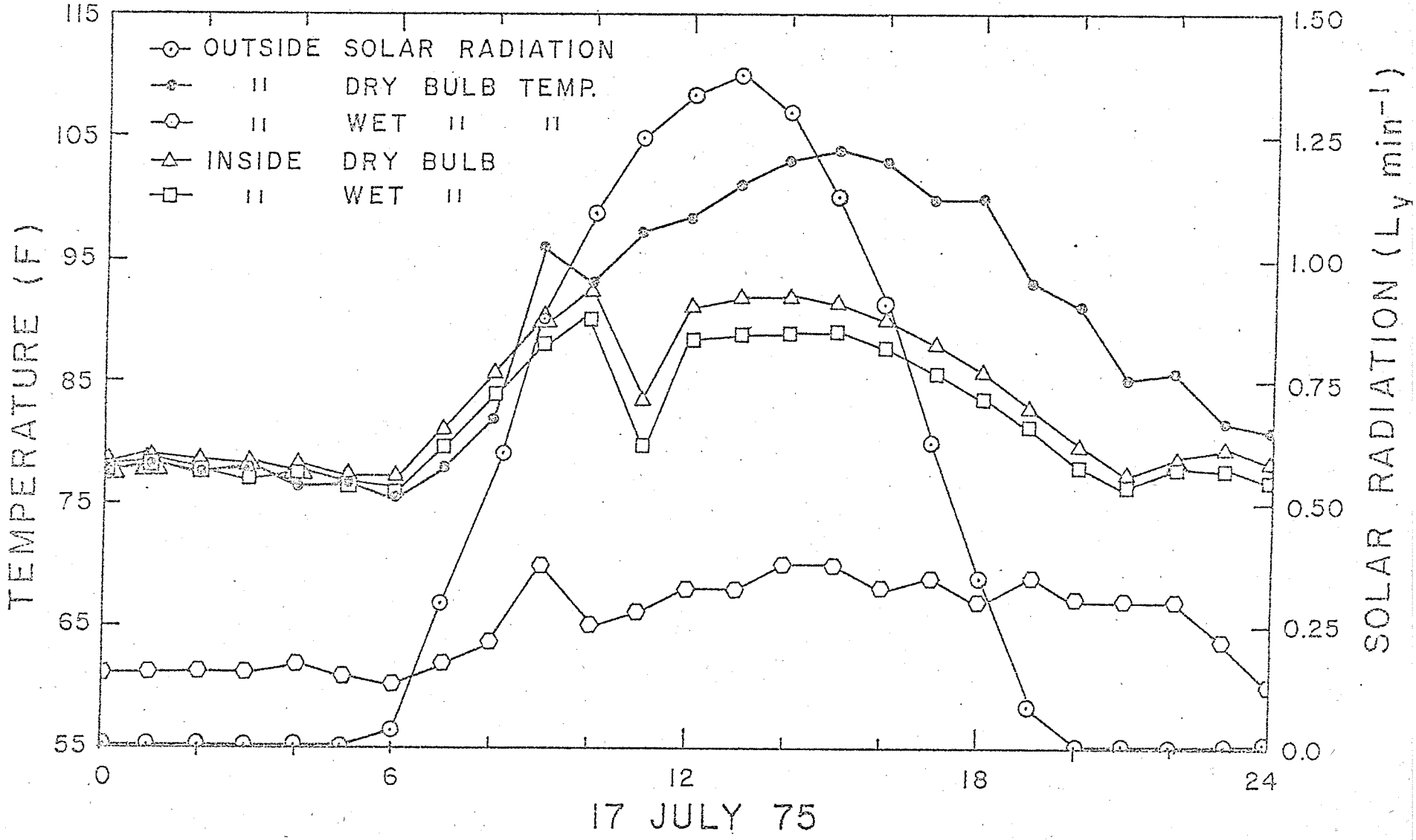

Figure 2. Temperature inside and outside greenhouse and solar radiation outside greenhouse versus time of day on 17 July 1975.

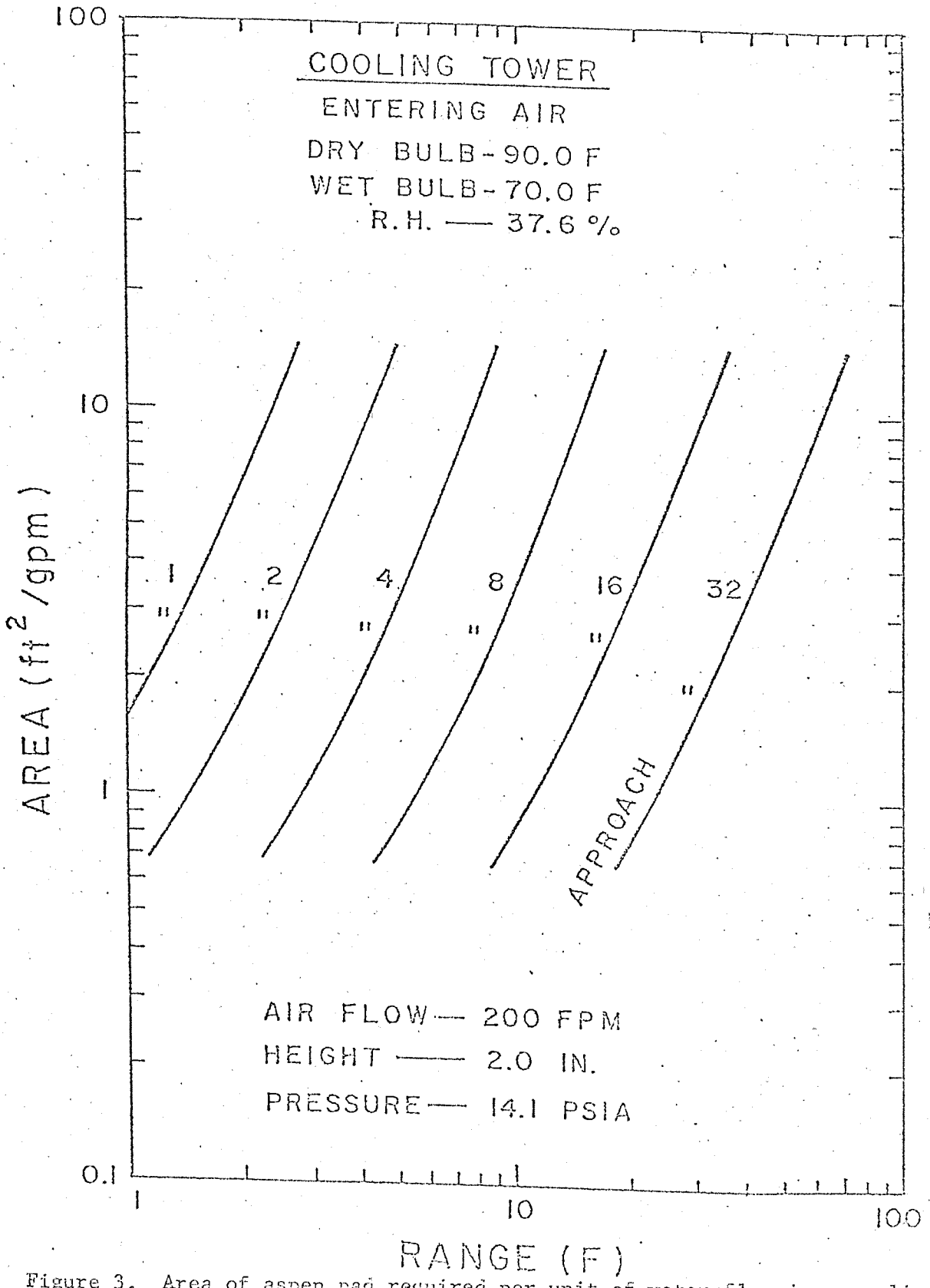

Figure 3. Area of aspen pad required per unit of water flow in a cooling tower as a function of the range of water temperature for several values of the approach of the water temperature to the wet bulb air temperature.

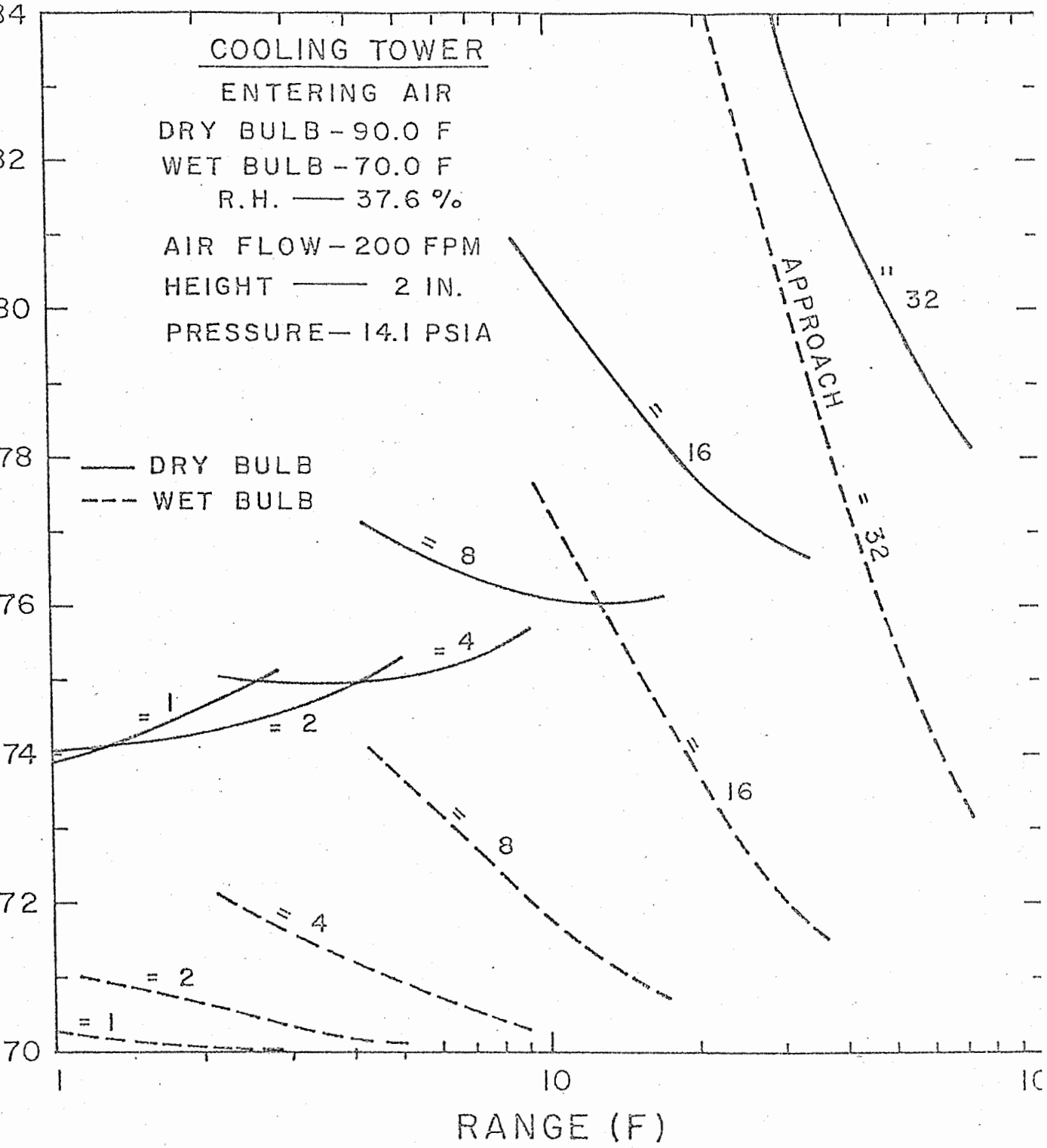

Figure 4. Exit air dry and wet bulb temperatures for the same cooling tower and conditions as Fig. 3.

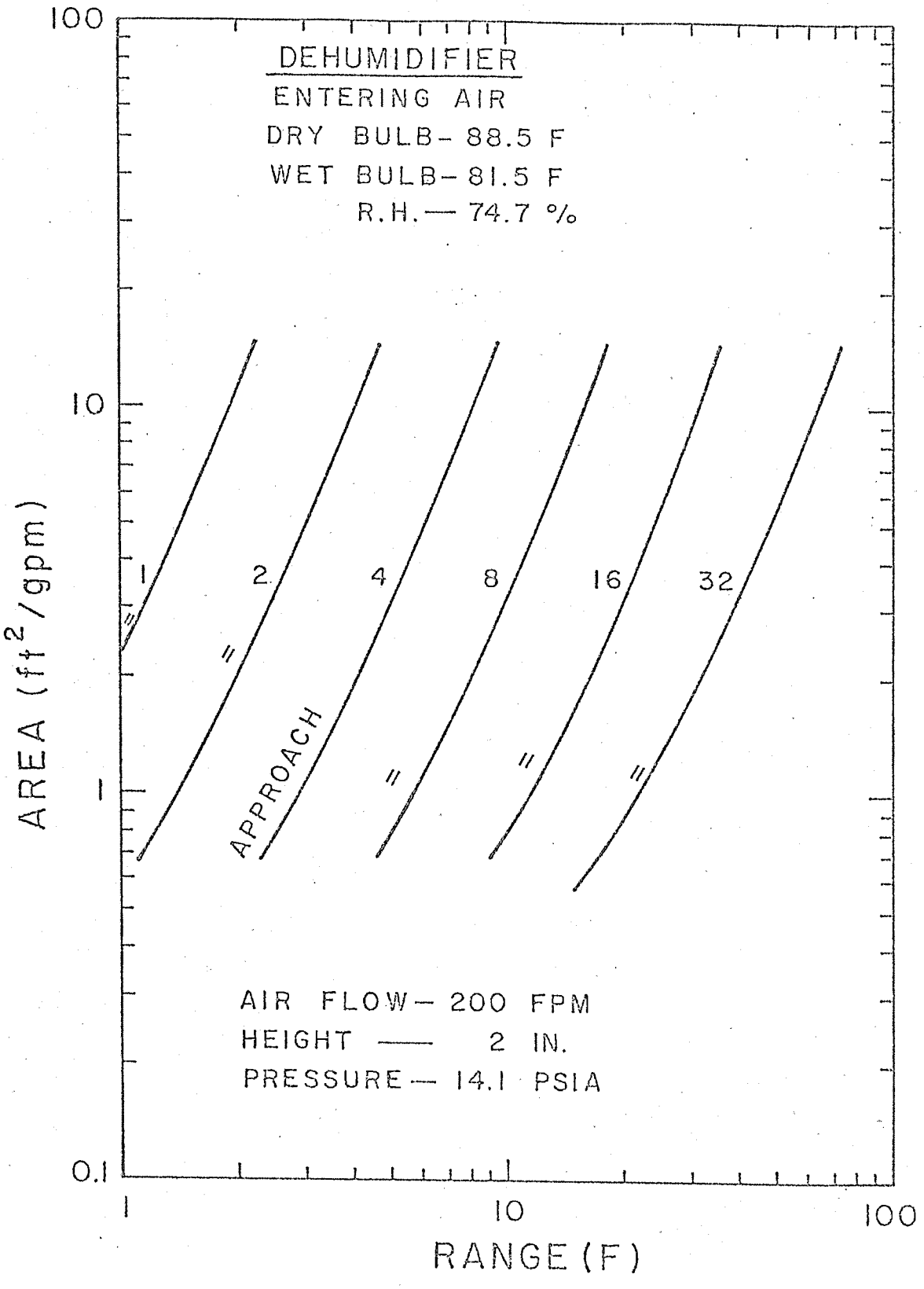

Figure 5. Area of aspen pad required per unit of water flow in pads used as dehumidifiers where the water temperatures are colder than entering wet bulb. Approach in the entering air wet bulb temperature minus the hottest water temperature and range is the hottest water temperature minus the coldest.

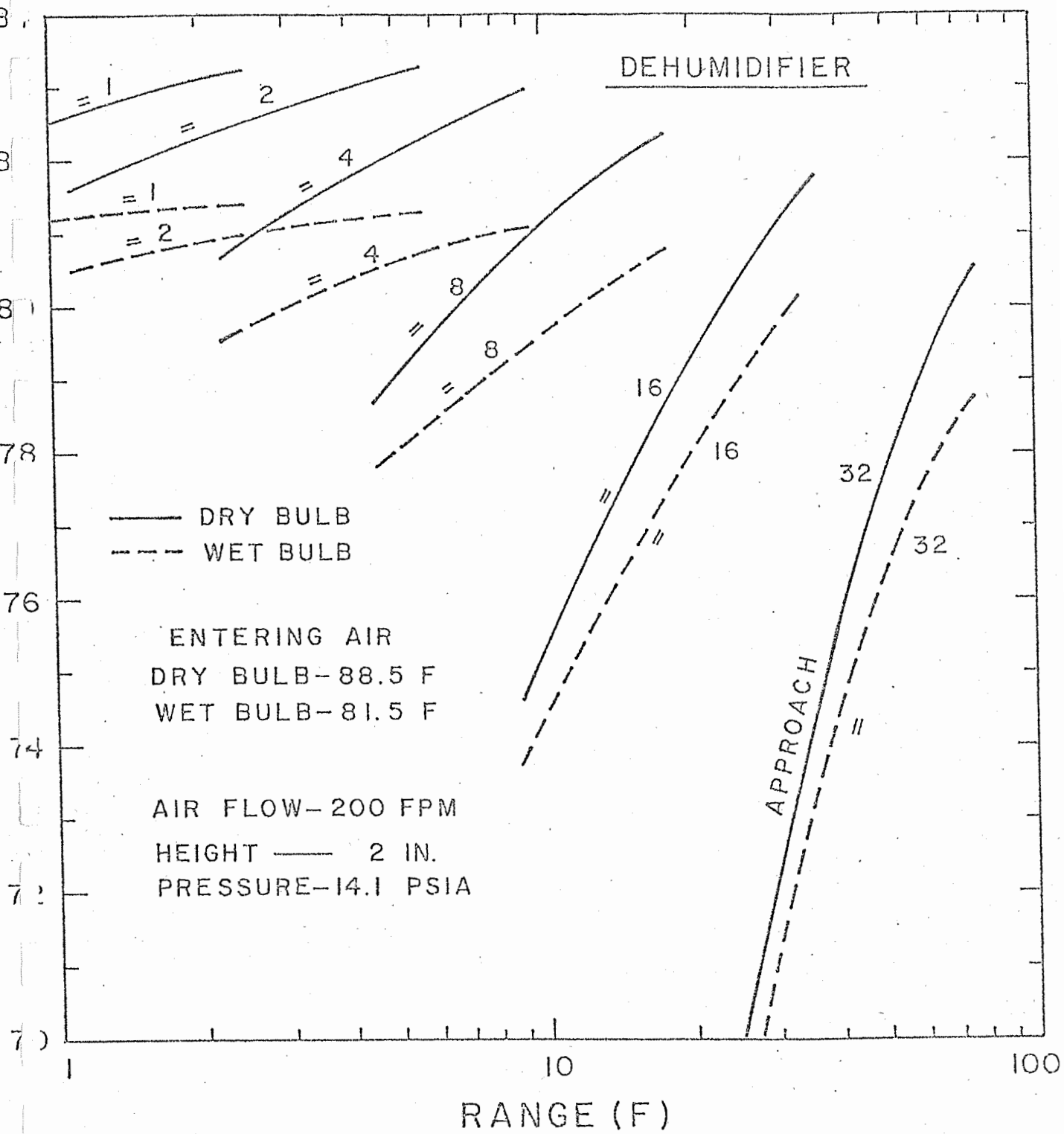

Figure 6. Exit air dry and wet bulb temperatures for the same dehumidifier and conditions as Fig. 5.

PART II: THERMAL ENERGY STORAGE

Greenhouses are notoriously difficult to heat at night because of their poor insulation properties compared to other types of buildings. Yet during large portions of the year, including winter in Phoenix, more solar heat is received during the day than can be dissipated without resorting to some form of ventilation. If a practical means could be found to store the excess thermal energy from the sun during the day and release it into the greenhouse at night, considerable energy savings could be achieved. Such an energy storage device would function to provide daytime cooling and help provide an environment suitable for CO_2 fertilization without resorting to as much ventilation. In cold climates which require heating even at midday, the energy storage device can serve to even the load on the heating system so that it can be sized more for the average condition than the extreme. And especially important is the fact that a viable energy storage system would make possible the use of auxiliary solar collectors to provide the necessary heat beyond the amount absorbed by the greenhouse itself.

Thermal energy can be stored in rocks, water or salt hydrates. Inexpensive mixtures of salt hydrates are available which melt under the influence of solar heating and return the stored heat when it is required. This effect, known as heat of fusion or phase change, requires a much smaller volume than rock (1:25) or water (1:8) (Maria Telkes). The main problems associated with heat of fusion materials have been supercoolings and separation of components after repeated freeze-thaw cycles. Nevertheless, interest in using heat of fusion material for heat storage has increased considerably during the last 15 years. Kauffan and Gruntfest (1973) (K. Kauffan and J. Gruntfest, 1973. Congruently melting materials for thermal energy storage. Report #NCEMP Univ. of Pennsylvania.) listed several $CaCl_2$-$MgCl_2$ mixtures melting from 77 to 81 F. Using these data as a start, an investigation for a suitable mixture to heat and cool the greenhouses was begun.

A eutectic mixture of 41% $CaCl_2$ + 10% $MgCl_2$ + 49% H_2O was confirmed to have a melting point of 77 F. An acrylic tubing 1 inch diameter and 1 inch long was used to test the eutectic melting point. A thermocouple was centrally placed in a cylinder of the 150 ml solutions. The tubes were rapidly cooled in an ice bath at 55 F. The cooling was used to test the behavior of the nucleating agent in decreasing supercooling. The mixture was tested with a number of nucleating agents to reduce supercooling.

Results of nucleating agent tests are shown in Figure 1 and Table 1. Figure 1 shows curves of the mixture temperature versus those traced from strip chart recordings. The mixture with no nucleating agent supercooled 22 F and remained liquid well over an hour before crystalizing and releasing its heat of fusion.

The mixture with dolomite as a nucleating agent crystalized in 20 minutes and supercooled by 12 F. With fiberglass added, it crystalized in 12 minutes and supercooled by 9 F.

Table 1 lists the qualitative results with several potential nucleating agents. Dolomite, which has a crystal structure similar to $CaCl_2$ and $MgCl_2$, appeared to be the most promising of those tested.

A thermostatically controlled cabinet has been constructed to cool and heat the eutectic mixtures. The temperature will be cycled at temperatures typical of those to be expected in a greenhouse application to test its effect of repeated cycling on the behavior of the materials.

During the next year testing of fusion materials will continue. Also, thermal energy storage will be incorporated into the computer simulation model to determine its potential for various locations. A large water storage tank is being tested for water storage by the water harvesting group, and plans are for it to be used to store thermal energy from the test greenhouse also.

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Table 1. Potential nucleating agents for eutectic $CaCl_2$-$Mgcl_2$-H_2O mixture. + indicates supercooling was reduced. - indicates the agent did not look promising.

Name	Amount	Reaction
Fiberglass		+
Sawdust		-
Dolomite ($CaMg(Ca_3)_2$)		++
Kaolinite	.1% solution (1 ml)	-
Bentonite	.1% solution (2 ml)	-
	3.4 gm/150 ml	
Bacto-agar		-
*Ba $(OH)_2$	.2 ml, .5 ml, .3 ml & 1 ml	+
*Clay (acid)		+
Clay (basic)		-
*Asbesto		+
*Perlite		+
Graphite		-
Graphite + 1 gm dolomite		-
Silica sand		-

* After one cycle the material either precipitated out or settled to the bottom. Perlite and dolomite remain in suspension.

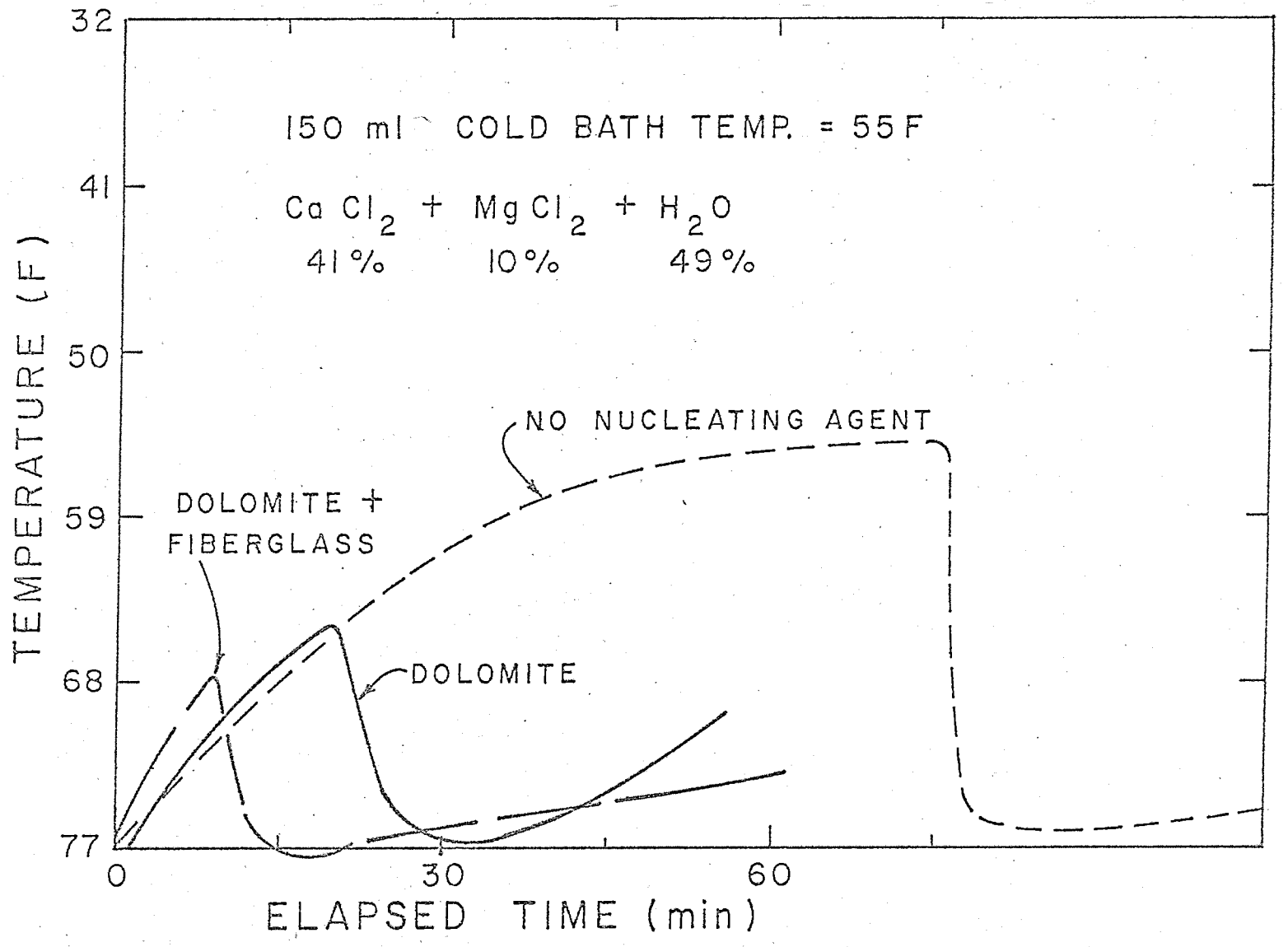


Figure 1. Temperatures versus elapsed time since immersion in a 55 F bath for a eutectic mixture of $CaCl_2$, $MgCl_2$, and H_2O with various nucleating agents.

PART III: THE EXPERIMENTAL GREENHOUSE

A. A GAS SAMPLING AND ANALYSIS SYSTEM FOR CARBON DIOXIDE AND WATER VAPOR:

A sampling system was needed to monitor environmental conditions in order to control the carbon dioxide and measure the water vapor. The system designed by M. Johnson and G. Drake (Johnson, M., and Drake, G., A micrometeorological sampling system for profiles of temperature, water vapor, and carbon dioxide in plant communities. Annual Progress Report of Microclimate Investigations. USDA, ARS, SWCR. Northeast Branch in cooperation with NYS Agricultural Exp. Station at Cornell University. 1966.) was modified to meet the requirements and materials available here.

Air samples are drawn from the greenhouse to the instrument cabin through 1/2 inch polyproylene tubing connected with PVC barb connectors (Figure 1). A plastic insulated nichrome heating cable (.125 ohms/ft) (Chromalox 6WF-1600) and a THW 12-gauge copper wire were pulled through 1/2 aluminum conduit and connected at the greenhouse end. The total length of the heating cable was 200 feet. Then six polypropylene gas sampling tubes were placed around the aluminum conduit to form a bundle. Then the tubing bundle was thermally insulated with 1/2 in. x 4 in. fiberglass wrapping. Aluminized duct tape was added to the outside to provide weather protection. The tubing bundle was fastened to a fence between the greenhouse and cabin and went underground where there was a walkway. The heater wires were connected to a variable transformer. About 135 volts (or 3.6 watts per foot) were required to keep the temperature of the tubing bundle nicely above ambient and prevent condensation. Temperature within the bundle was checked with a few thermocouples taped to the aluminum conduit and with their lead wires extending out through the wrapping.

Figure 2 and Table 1 illustrate the gas analysis system inside the instrument cabin. The system is able to analyze four samples sequentially and two continuously.

The water vapor portion will permit a single Cambridge dew point hygrometer, Model 880, to measure the dew points at four sampling points, two upstream and two downstream, of an inside and an outside cooling pad. The solenoid switching system is installed in an insulated thermostatically controlled cabinet. A fan and a 250-watt lamp are used to maintain the cabinet temperature above ambient.

Carbon dioxide concentration of the greenhouse was monitored continuously with the infrared gas analyzer (Beckman Model 865) once the system was completed.

The conductimetric CO_2 analyzer to be described in the next section was mostly experimental for most of this past year, and the CO_2 concentration in the greenhouse was controlled by the infrared analyzer. The carbon dioxide was produced in the greenhouse with a carbon dioxide generator (Johnson Gas Appliance Co. Model 1332) burning natural gas. The generator was controlled by a microswitch relay attached to the Leeds and Northrup recorder which measured the output of the infrared analyzer. The switch was set to energize the coil and close the contacts whenever the CO_2 concentration dropped below 1000 ppm. Figure 3 shows the wiring details of the CO_2 control system. A manual switch permitted the generator to be turned on independent of the infrared gas analyzer. A photo cell relay normally used to turn on lights at night was included to turn off the generator at night. Since the generating capacity was large for such a small greenhouse and the sampling line long, it was necessary to include a timer switch which allowed the generator to be on only about half of the time the analyzer was calling for CO_2. The elapsed time indicator along with a flow meter in the gas line enable the CO_2 generation rate to be measured. At a gas line pressure of 1.2 in H_2O, the CH_4 burn rate was .635 ft^3/min when the burner was on and .0286 ft^3/min when only the pilot light was on. One change is anticipated in this circuit for next year. A limit switch will stop the CO_2 fertilization whenever the ridge vent on the greenhouse is open.

B. CONDUCTIMETRIC CO_2 ANALYZER:

An infra gas analyzer costs about $3000, an amount which obviously is too much for commercial growers to spend to control the CO_2 concentration in commercial greenhouses. Consequently they now generally use time clocks to turn on their generators during the daytime and off at night with no measurement at all of the actual CO_2 concentration. An inexpensive CO_2 analyzer is needed.

One possibility was reported by Slack and Calvert (Slack, G., and Calvert, A. 1972. Control of carbon dioxide concentration in glasshouses by the use of conductmetric controllers. J. Agric. Eng. Res. 17, 107-115.) who controlled the CO_2 concentrations with a conductmetric analyzer described earlier by Bowman (G. E. Bowman. 1968. The control of CO_2 concentration in plant enclosures. In F. E. Eckardt ed. Functioning of Terrestrial Ecosystems at the Primary Production Level. UNESCO Paris. 335.). The device shown schematically in Figure 4 works as follows. Using an air pump (5), sample gas from the greenhouse is bubbled into the bottom of a tube of deionized water. Some of the CO_2 in the gas bubbles dissolves in the water, changing its electrical conductivity. Excess gas escapes at the top of the tube (2). The water flows into the reservoir circulating around the conductivity cell (3). The conductivity is proportional to the CO_2 concentration in the original gas bubbles and is measured by the conductivity cell. Then the water flows into a side tube into a column of deionizing resin, which again deionizes the water. The water continues to flow in a closed loop pumped by the rising air bubbles to give a continuous measuring process.

We constructed an analyzer similar to that of Bowman. The conductivity meter was a Leeds and Northrup conductivity cell (Model 4905-01-33-113-20)(cell constant .01) and conductivity monitor (Model 7075-2-011). The range calibrator resistor (R7) of the monitor had to be adjusted to make 1000 ppm CO_2 equal 80% of the full scale span (.8V output). The deionizing column was a Van Waters and Rogers Scientific 24823-029 ultra-pure demineralizer.

The apparatus was sensitive to the air flow rate. By trial and error we found that 4.8 mm ID bubbling column worked well with an air flow rate of 30 cc/min. The bubbles were introduced from a 12.7 mm ID tube at a point 76.2 cm below the upper reservoir water surface.

The conductivity monitor has a set point and an alarm relay. This relay was wired to the CO_2 control circuitry as shown in Figure 3, just as the recorder relay had been used previously to make the infrared gas analyzer control the greenhouse CO_2 concentration. After using the infrared analyzer to initially calibrate the set point, the conductivity analyzer controlled the CO_2 concentration in the greenhouse. As monitored by the infrared analyzer, the CO_2 concentration ranged from a low of 900 to a high of 100 ppm. The sampling air flow rate was 30 cc/min and the system response time was 45 seconds. Cost of the system was $300 for the monitor, $150 cell, $20 for the deionizing column, plus perhaps $10 worth of tubing for a total of $480, much less than an infrared type analyzer.

C. THE FIRST TOMATO CROP:

1. Culture:

Work on attaining the last objective of this project, that of evaluating yield increases due to CO_2 fertilization under high light conditions, was started this year by growing an initial crop of tomatoes. "Tropic," a greenhouse variety tomato, was sown in peat cubes on April 2, 1975, and transplanted on April 21 into rows 2 feet apart. The plants were staggered 9 inches apart along each row, to give a high planting density of about 1 plant/3 ft^2. The tomato plants were pruned once a week to maintain single-stemmed plants. Plants were supported with plastic twine. One end of the twine was tied to a plastic plant clip that is attached to the base of the plant. The other end is strung across a plastic covered cable that is strung across the length of the greenhouse. The line is about 7 feet above the plant row. As the plants grew taller, the twine was twisted in a spiral around the plant stem and a clip is placed about 4-6 inches from each other. A slip knot was used for easy loosening and tightening of the line. The plant weight would

cause the line to sag. Therefore, after each pruning and training period the line was adjusted to support plants and fruit. Pollination was promoted by tapping the line supporting each plant. Tapping was done about once a week.

The growing medium was a 1 foot depth of sand underlain by drain tubes over a sheet of polyethylene film (M. H. Jensen. 1971. The use of polyethylene barriers between soil and growing medium in greenhouse vegetable production. Proceedings Tenth National Agricultural Plastics Conference: Chicago, Illinois. pp. 144-150).

2. Irrigation and fertilization:

The crop was irrigated first with Chapin twin-wall tubing, 12 mil and 18 mil, but the maximum pressure rating of 8 psi led to damaging of the tubing because a momentary over-pressure of about 10-12 psi occurred. Then Anjac (20 mil) tubing was tried because it allows a maximum pressure of 12-15 psi. After a routine test up to 15 psi, the Anjac tubing was connected into an automatic irrigation system, which consisted of two barrels of nutrient solution, a pump, two regulators and gauges, a filter, a timer and solenoid valves. The system was operated with a solenoid valve that was energized with a timer for 5 minutes each half hour for 14 hours. The pressure regulator controlled the irrigation output at 0.57 gpm, which gave a total output per day of 67 gal. or .35 inches. This was rather high and more solution than necessary drained into the sump. In next year the irrigation will be regulated so that only a trickle continuously comes out the drain.

The nutrient solutions used are listed in Table 2 from Ellis et al. (N. K. Ellis, Merle Jensen, John Larsen, and Norman Oeblser. 1974. Nutriculture systems: growing plants without soil. Ag. Expt. Sta. Bul. 44. Purdue Univ.). Formula A was used first and then the formula B solution was started on 30 May 1975, after discovering fruit with blossom end rot. The formula B increased the calcium content of the concentration; blossom end rot occurs because of calcium deficiency.

On 27 June 1975, Commander proportioner pumps were installed in the system to feed nutrients from concentrated stock solutions into the irrigation water. The pumps could handle water flow rates in the range of 2 to 400 gallons per hour at pressures up to 85 psi. The nutrients were grouped together in two separate containers as suggested by Johnson, H., et al. Fe, $Ca(NO_3)_2$, and KNO_3 were mixed together in one container. KH_2PO_4, $MgSO_4$, K_2SO_4 and micronutrients in the other container. The concentrations were prepared for a ratio of 1-128. A water reservoir was installed with a float valve to maintain a constant head and an adequate supply of water in case of a water cutoff.

The Anjac tubing and the proportioner pump had to be maintained periodically because of heavy deposits from nutrient residue. The tubing was unplugged by using a small tweezer in the emitter op openings. The proportioner pumps were maintained by cleaning the screens on the water inlet, and the tubing transporting the nutrients. The pumping end was flushed with clear water once a week. Periodically, a 5% solution of hydrochloric acid was pumped through the proportioner pump and wasted outside of greenhouse.

Once a week a sample of the drain, nutrient solution, and irrigation water was collected and tested for pH and salinity. The results were as noted:

	Salinity (m mhos/cm)	pH
TAP WATER	.80 - 1.01	7.6 - 9.0
NUTRIENT SOLUTION	1.81 - 3.50	6.6 - 6.9
DRAIN WATER	1.90 - 3.20	7.1 - 8.0
COOLING SUMP WATER	2.95 - 6.50	6.8 - 8.5

3. Pests:

Some problems with pests and pest control were encountered. On 29 May 1975 we noticed many of the leaves and stems were severely curled, particularly on rows next to edge of greenhouse. Problem was traced to spraying of weeds around the greenhouse with 2-4D herbicide by maintenance personnel. Nearly all the plants in the greenhouse were affected, exhibiting spiral curled stems and leaves.

Most plants seemed to recover after a couple of weeks but some plants near the walls never did.

Then on 23 June 1975 we discovered aphids seriously infesting one plant. The plants were then sprayed twice with malathion, but the aphids persisted. The leaves on the tomatoes had considerable curls either in response to the high humidity or to the earlier 2-4D. Those aphids which happened to be in the middle of the curls were surviving the spray. On 3 July 1975 a vapons bomb was released, but it only discharged about 5 sec, apparently defective, and the aphids persisted. Then a Vapo with Bagon bomb was set off and it discharged for about 30 sec. The aphids were killed but Bagon is long lasting so the fruit had to be destroyed for 10 days afterward.

On 11 July 1975 with the help of Dave Langston, County Extension Agent, predator insects were captured in an alfalfa field east of the Laboratory using about 50 swipes with a sack on a stick. The insects were cooled in a refrigerator and then the predator insects separated out and released in the greenhouse. The predators were seen from time to time after that but gradually disappeared. About 19 August aphids were again starting to infest the greenhouse. Next year a regular insect control program will be followed.

4. Growth and yield:

The tomatoes appeared to grow quite well up until the 2-4D incident and the blossom end rot which disappeared after giving more calcium. The first blossoms appeared on 9 May (5-1/2 weeks old), and the first truit was picked on 27 June. After the plants were about 3 ft tall, there was considerable leaf curl, perhaps a response to the high humidity, or the 2-4D, or plant density. Work was progressing on the CO_2 fertilization system while the plants were growing, but it did not become routinely operational until about 18 June. There was no obvious response from the plants at this time unless the leaf curl was possibly due to CO_2.

On two occasions, mechanical failure of the cooling system sent temperature soaring and obviously stressed the plants. Therefore, a motorized vent opener was installed to open the roof vent whenever the inside temperature went above 100. The opener operates on direct

current from a battery so the vent would open in the event of electrical failure also.

In the middle part of July the outside wet bulb temperature went up to 75 F and more, sending the greenhouse temperature to 95 F. From this point on no more fruit was set, but fruit already on the plants continued to develop to maturity. Next year a motorized damper on the return air duct will open in response to the same thermostat as the vent opener. Then if temperatures exceed say 85 F in this greenhouse, dry air will enter through the damper on the air duct and be evaporative cooled by the inside pads. It will then exit through the upper vent.

In spite of the 2-4D, aphids and high August temperatures, the total first yield was 7 lb/plant or 2.4 lb/ft^2, the last harvest being the first of September. There was much cracking of fruit during August, probably due to the high temperatures. About 36% of the fruit was classified as unmarketable, but the remaining 64% was of high quality and had excellent flavor - according to testimonials from most Laboratory personnel.

5. Plans for next year:

A second greenhouse is currently under construction. It will be cooled by a conventional evaporative cooler and will not be fertilized with CO_2. It therefore will serve as an experimental control with which to compare the response of the crop in the first greenhouse which will be sealed and fertilized with CO_2.

PERSONNEL: S. T. Mitchell and B. A. Kimball

Table 1. Key to schematic diagram (Figure 2) of automatic gas analyzing system.

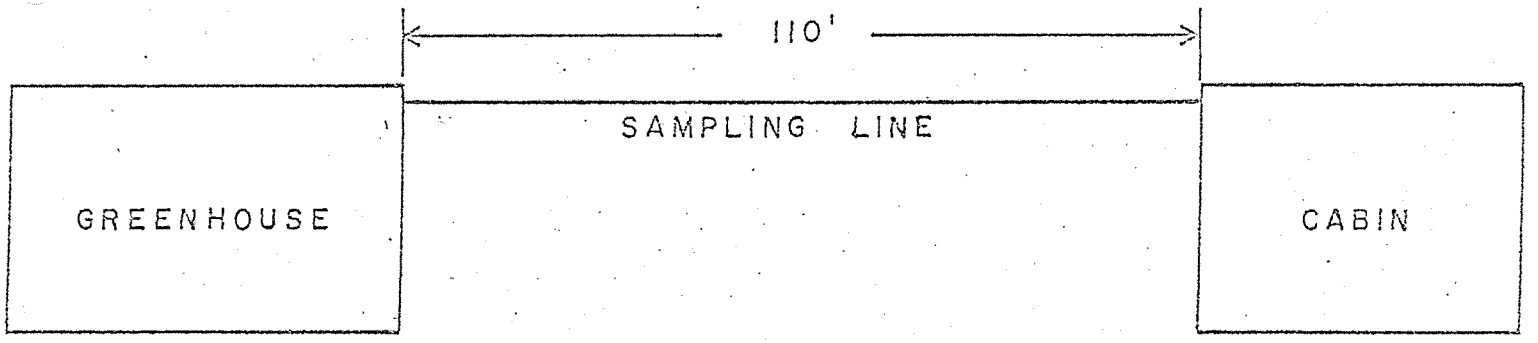
1 - 4	Water vapor sampling line from greenhouse to cabin
5 - 8	Valves (normally closed)
9 - 12	Solenoid switches
13 - 16	Flow control needle valves
17	Carbon dioxide sampling line
18	Flow meter for water vapor air (800 cc/min, 2 min response time)
19	Water vapor analyzer
20	Vacuum line
21	Vacuum pump and waste air to atmosphere
22	Needle valve
23	Cold trap (loop of gas line passes between refrigeration coils of dehumidifier)
24	Drierite column
25	Needle valve
26	Flow meter for carbon dioxide air (1000 cc/min, 30 sec response time)
27	Infrared carbon dioxide analyzer
28	Recorder
29	Pump (Vac-air)
30	Conductimetric carbon dioxide detector and controller unit
31	Sequential timer (6.25 min/sample)
32	Pump (Vac-air)

Table 2. Nutrient solution formulas

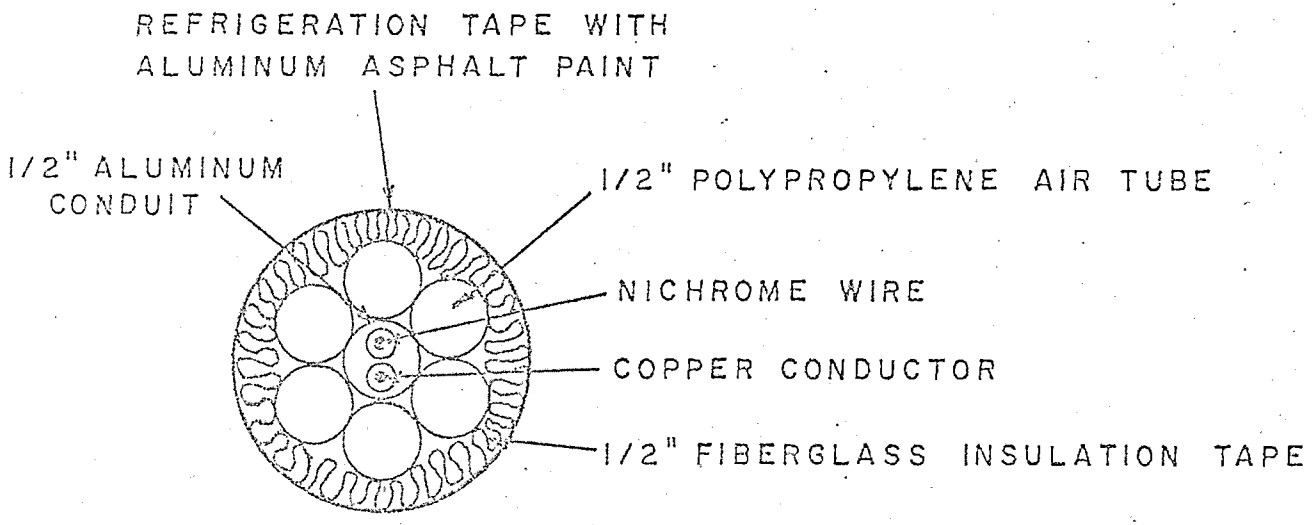
SALT	FORMULA A (seedling - 1st fruit set) ppm	FORMULA B (fruit set - harvest) ppm
$MgSO_4.7H_2O$	Mg 50	Mg 50
KH_2PO_4	K 77	K 77
	P 62	P 62
K_2SO_4	K 45	K 45
MICRO-NUTRIENTS	.15 ml stock solution/1 of nutrient solutions	
$Ca(NO_3)_2$	Ca 122	Ca 165
	N 85	N 116
KNO_3	K 77	K 77
	N 28	N 28
Fe 330	Fe 2.5	Fe 2.5

Micronutrient Stock Solution (450 ml)

Boric Acid (H_3BO_3)	7.5 g
Manganous Chloride ($MgCl_2.4H_2O$)	6.75 g
Zinc Sulfate ($ZnSO_4.7H_2O$)	1.18 g
Cupric Chloride ($CuCl_2.2H_2O$)	0.37 g
Molybdenum Trioxide (MoO_3)	0.15 g

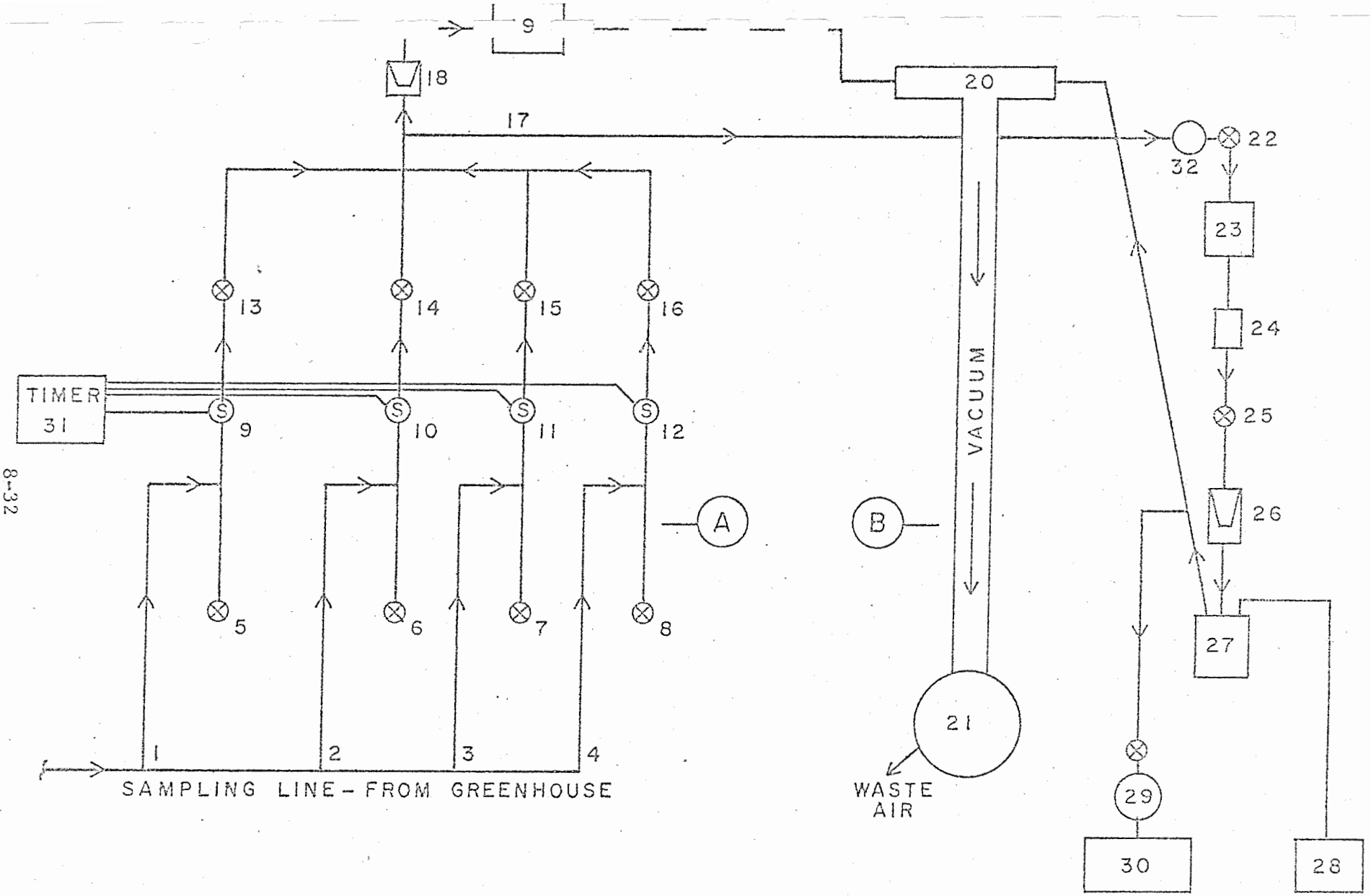


PLOT PLAN



SECTION THRU
HEATED AIR TUBE BUNDLE

Figure 1. Schematic diagram of gas sampling tube bundles.



A

Figure 2. Schematic diagram of gas sampling and analysis system.

B

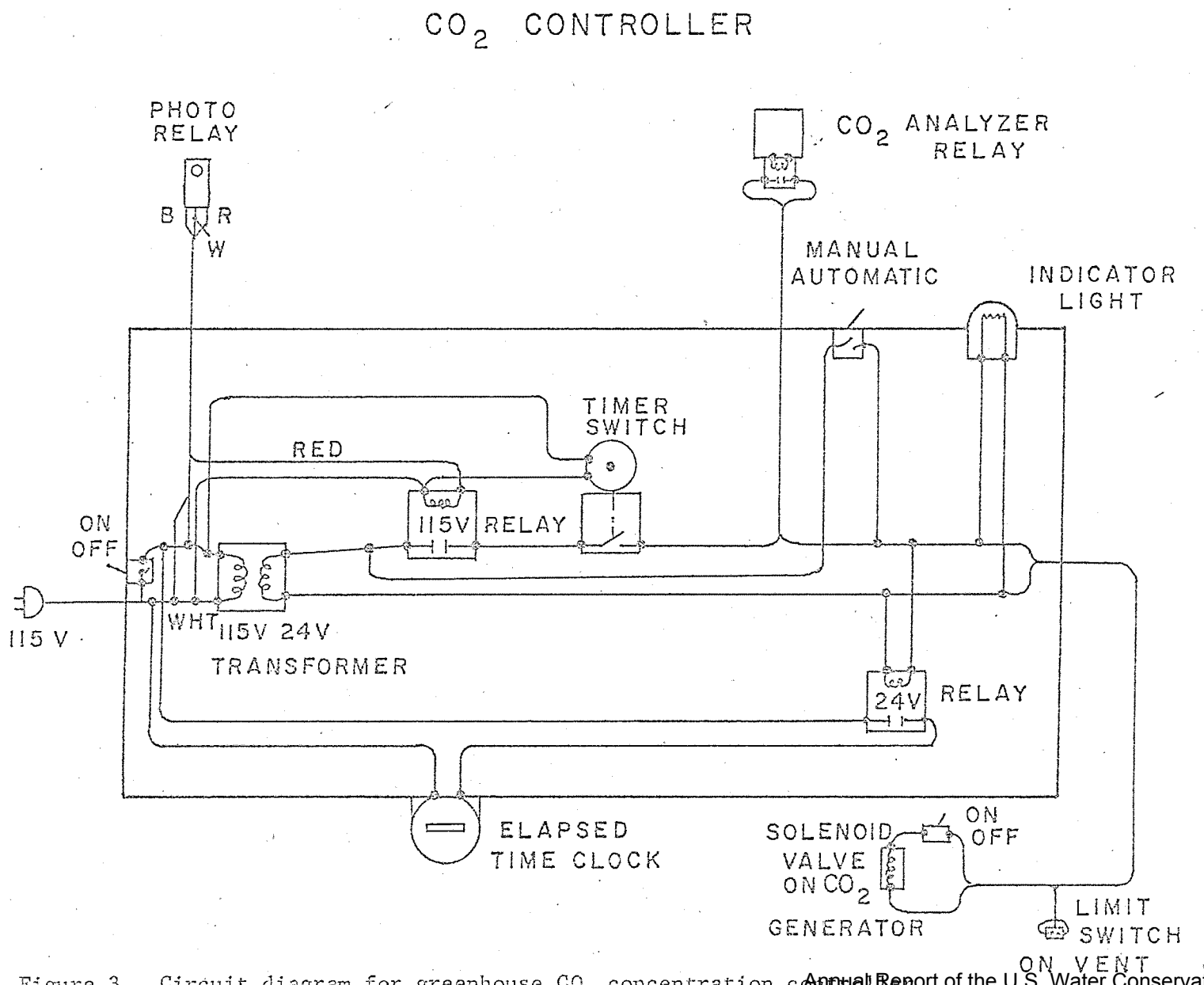
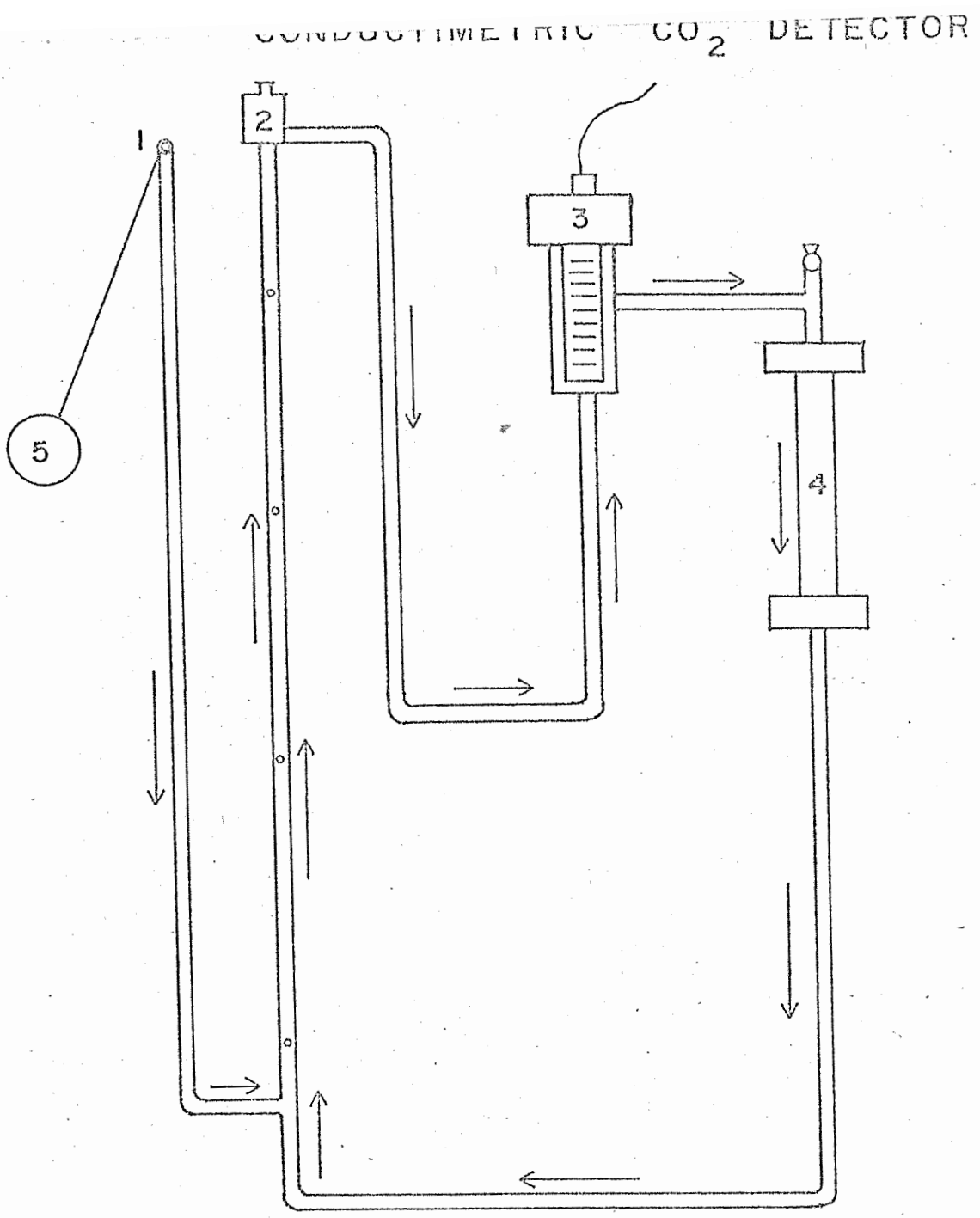


Figure 3. Circuit diagram for greenhouse CO_2 concentration controller.



1. AIR SAMPLING INLET
2. WATER RESERVOIR FOR DISSOLVING CO_2 AND EXCESS GAS TO ESCAPE
3. CONDUCTIVITY CELL (L & N .01K)
4. DEIONIZER
5. AIR PUMP

Figure 4. Schematic diagram of conductimetric CO_2 analyzer.

SUMMARY AND CONCLUSIONS:

Design and testing of coolers for sealed greenhouses continued during 1975. A cooling tower having aspen excelsior pads 2 inches thick and 67 inches tall was able to cool water to within 3 F of wet bulb temperature when the water flow rate was 0.63 gpm/ft^2, the air flow rate was 114 cfm/ft^2 and the water temperature range was 3 F. This good performance of the outside cooling tower stood in contrast to inside heat exchange pads which were rather ineffective. Inside greenhouse temperature rose typically to 20 F above the outside wet bulb at full sunlight, so cooling was adequate until the middle of July at which time the outside wet bulb rose above 65 F to 78 F and then the cooling was inadequate.

In an effort to improve the effectiveness of the inside pads, design data in the form of heat transfer coefficient prediction equations were obtained. These measurements are described in the manuscript "Heat and mass transfer coefficient for water and air in aspen excelsior pads" by B. A. Kimball, Durward S. Benham, and Frank Wiersma. These equations were incorporated into a design computer program to predict the size of pad and fan required for this application. Accordingly, a horizontal pad of 2-inch thickness and 50 ft^2 area is being installed on the test greenhouse. A second greenhouse is also under construction. It will not be sealed, and its evaporative cooler will double as the cooling tower to provide cold water for cooling the first sealed greenhouse.

Design calculations based on the heat transfer equations indicated that the cooling systems of such dual greenhouses (one sealed, one unsealed) would require about double the operating expense (money and power) of conventional unsealed greenhouses on a per area basis. For comparison, the expense of cooling by vapor compression air conditioner would be about 27 times conventional. Since the cooling costs of commercial greenhouses are presently about 25% of the total operating costs during warm months, the CO_2 fertilization made possible by having a sealed greenhouse would have to increase yields by about 50% in the sealed greenhouse in order to be economically practical.

In order to conserve power, CO_2 fertilization would have to increase the yields by more than 100%. Such increases have been reported in the literature, but not consistently.

Work was also initiated on finding a suitable thermal energy storage material for greenhouse use. Such a material could stabilize greenhouse temperatures and conserve heating fuel by storing excess thermal energy during the day for use at night. An eutectic mixture of 41% $CaCl_2$, 10% $MgCl_2$ and 49% H_2O was studied because of its melting point of 77 F. The pure mixture tended to supercool, but several nucleating agents were found to promote freezing, dolomite being particularly effective.

Work also progressed upon construction and installation of equipment to determine the yield response of crops to CO_2 fertilization under the high light conditions of Phoenix. Of particular interest was the construction of a conductimetric CO_2 analyzer of English design for controlling the CO_2 concentration in greenhouses. This analyzer provided satisfactory control at about 1/6 the cost of an infrared gas analyzer. Irrigation equipment was also installed and the first tomato crop was grown. In spite of some pest problems and the high July and August wet bulb temperatures, a respectable yield was obtained. A second greenhouse is under construction. It will be an unsealed conventional greenhouse, and next year controlled experiments will be performed.

PERSONNEL: B. A. Kimball and S. T. Mitchell

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

CRIS WORK UNIT: 5510-12260-002 CODE NO.: USWCL 75-2

INTRODUCTION:

Trickle or drip irrigation has made tremendous growth in the past 5 years because of its certain distinct advantages over existing standard furrow- or flood-type systems, one of which is its better application efficiency. However, as with many other methods, it does have a weak link which involves emitter plugging, and since the emitter is the basic component of trickle irrigation, failure here means failure for the entire system.

The plugging problem has been recognized almost as soon as trickle irrigation began to be widely used. The recurring theme discussed at the Second Drip Irrigation Conference in July 1974 was that emitter failure caused by plugging is one of the greatest limitations to the unrestricted acceptance of trickle systems.

Attempts have been made to relate plugging to water quality. Pelleg et al. (4) have concluded from their studies that irrigation water quality and the clogging characteristics of the emitter should be known for the agricultural region and then should be used in the planning of the irrigation system. Unfortunately, no unique set of formula or guidelines is available to predict the occurrence of plugging for an irrigation water and emitter combination. Other reports [Ford and Tucker (2); McElhoe and Hilton (3)] covering very different types of water and emitters indicate that there is no universal solution to the plugging problem. However, the prevention of plugging appears to be the key to the successful operation of any trickle system.

Our previous experience with the Colorado River water in a trickle study on cantaloupes at Yuma showed that the irrigation water taken from the farm supply ditch seriously overtaxed the filtration system, so that a chemical treatment program using dilute acid and hypochlorite solutions was required to improve filtration and to prevent possible clogging of the double-tube trickle lines. Our other associated investigations on irrigation management with

different types of emitters and waters, some of better chemical quality than the Colorado River, exhibited clogging problems. Thus, it appeared that the river water should be studied closely to determine its effect on the emitters used in drip irrigation systems.

OBJECTIVES:

The objectives of the study established in Tacna, Arizona, are dual natured and are aimed at

(1) Assessing the clogging potential of the Colorado River water used in trickle irrigation in the Wellton-Mohawk Irrigation District, and in anticipating any problems which might arise, and in initiating and developing preventive measured required.

(2) Developing guidelines for the filtration and chemical treatments for the river water for different types of drip emitters for preventing clogging.

In light of the urgency and the short lead time required for the entire project on improving irrigation application efficiency in the Lower Colorado River basin, only the plugging problems of immediate nature will be studied over the 2-year span of the experiment. Thus, the basic causes of plugging will be examined less intensively, but nevertheless will be explored as time permits.

Results from this study should provide data necessary for an economic analysis of water treatment costs for trickle irrigation.

EXPERIMENTAL DESIGN AND PROCEDURE:

Experimental Site and Water Source

A 2-acre experimental site with approximately 200 mature citrus trees was established at Tacna, Arizona, over the November 1974 to January 1975 period in cooperation with the University of Arizona staff. Irrigation water was pumped approximately 16 ft up from the main project canal into a supply and storage ditch (Figure 1) and then fed by gravity through a 1000-ft, 8-inch PVC pipe to the pump and water treatment shed. The treated water was pumped through 600 ft of 1 1/4-inch PVC pipe to the main plot and another 600 ft through the entire length of the plot. The location of the pump shed in relation to the supply ditch and main plot appears awkward,

but in reality our main plot is only part of a larger experiment with the University of Arizona, and the shed is actually midway between the length of the entire experimental field.

Water was then supplied to four trees in the sub-plot (Figure 1) from the submains through 1/2-inch PVC and polyethylene pipes. The polyethylene tubing was circled under the drip line of each tree. Five to thirteen emitters of the same kind were fitted into the tubing, depending upon the flow rate of the type of emitter. This arrangement allowed for a flow rate of 10 to 12 gallons per hour per tree, which is about twice the usual application rate with trickle irrigation, but in our case we had to make allowance for possible decrease in flow rate as plugging started and progressed. Dual water meters to increase measurement reliability were used to determine the volume of water applied and also the emitter flow rates. The supply pressure was 15 psi for all emitters in the field.

The quantity of water applied was based on the consumptive use curves for citrus derived by Erie et al. (1). Initially, two times consumptive use was applied, but the appearance of wet spots later in the summer, possibly caused by impermeable clay lenses in the lower soil profile, made us decrease the application rate to that of consumptive use.

Emitters

Eight different types of emitters were used initially, which were selected on basis of their design. More than 50 different types of emitters are available in the market at present, and using all of these as per a testing program would be impossible to perform with the personnel, land, and time available. The emitters used consisted of the following designs:

1. Automatic, needle-flush emitter
2. Automatic, ball-flush emitter
3. Automatic, diaphragm, orifice-plate emitter, 1 gph
4. Single-vortex emitter
5. Long-path, capillary emitter
6. Long-path, manual-flush emitter, 1 gph
7. Long-path, manual-flush emitter, 2 gph

8. Short-path, plastic insert emitter
9. Automatic, diaphragm, orifice-plate emitter, 2 gph. Emitter 9 was introduced about 9 months after the experiment had progressed.

The fact that many of the emitters presently available have some kind of cleaning device indicates that plugging problems can be encountered.

Water Treatment

Six water treatments were used in the initial tests and designated as:

A. Screen filtration, 40-mesh (after 278 days: 50-mesh)
B. Screen filtration, 200 mesh (after 278 days: 50-mesh, + intermittent hypochlorite-acid treatments)
C. Sand and screen (200-mesh) filtration
D. Sand and screen (200-mesh) filtration + intermittent hypochlorite-acid treatments
E. Sand and screen (200-mesh) filtration + continuous hypochlorite-acid treatments
F. Sand and screen (200-mesh) filtration + continuous acid treatment

In the sand and screen filtration treatment, the screen filter was placed after the sand filter.

The screen filters were "homemade" types that were built from 4-inch PVC pipe and stainless steel screens. These were replaced 9 months later with commercial models that had a larger capacity than the original ones which were not operating properly due to screen breakage and poor seals.

Fiberglass swimming pool filters filled with no. 20 silica sand were used in Treatments C through F. The filters were equipped with backwash valves for manual backflushing as necessary. The sand filters were backwashed every day during the summer months and at least once a week or whenever the pressure dropped to 30 psi from 40 psi at other periods of the year. The screen filters were also cleaned whenever backwashing of the sand was made.

As indicated in the treatment tabulation, calcium hypochlorite solution and sulfuric acid from separate chemical injectors were continuously injected in Treatment E to achieve a pH of 7 and 1 ppm chlorine whenever the system was in operation. In case of the intermittent Treatment D, the chemicals were injected only at the last hour of trickle operation before the system was turned off for the day. This allowed the chemicals to fill the submains and trickle lines between the shed and the end of the laterals in the field. The chlorine content for this treatment was adjusted to 10 ppm with a pH of 7. Chlorine for the treatments was determined by the diethyl-p-phenylene diamine (DPD) method.

In Treatment F, only acid was injected continuously into the system. The acid requirement of the river water was determined from an acid titration curve (Figure 2), and in this instance 0.5 to 1 milliequivalents per liter was required. Each type of water has a different acid requirement and this must be determined before acid additions can be made. The alkaline hypochlorite addition in Treatments D and E increased the pH of the water slightly, but this was accounted for by monitoring the pH of the water after the chemical injection points and adding sufficient acid to bring the pH down to 7.

A brief schematic of the water treatments is shown in Figure 3 with the important components. A 3 h.p. centrifugal pump delivered water to the six sand filters through a manifold system. Actually, there was no sand in sand filters A and B, which were the screen only treatments. The sand filters were pre-installed into the system so that major plumbing changes would not be required if additional filtration was required in the future. Chemicals were injected ahead of the sand filter. The chemical injectors and the water pump were controlled by time clocks and also a set of safety relay switches which prevented pump operation in case the water ran out in the supply line or ditch during an irrigation cycle.

In an actual operation situation when the time clock called for an irrigation, the water passed from the pump through the sand filter (Sf), screen filter (SC), solenoid (S), water meter (not shown),

antisiphon valve (AV), and into the field. The pressure immediately after the pump was approximately 45 psi, and dropped 5 psi to 40 psi going through the filters, and was 40 psi just prior to leaving the pump house. Water pressure was adjusted to 15 psi with the pressure regulator (PR) in the field for all treatments just before the water entered the plots. A check at the furthest end of the plot showed a pressure drop of only 0.5 psi. After the irrigation system was well established, every pressure gauge (PG) in the field lines was checked against one "master" pressure gauge under operating conditions, so that the pressures for Treatments A through F were actually referenced to one standard pressure.

Nitrogen as 20% ammonium nitrate solution was applied through the trickle system during March to July 1975. One and one-half pounds of nitrogen were added per tree. One gallon of 5% iron, zinc, and manganese chelates per acre was also added in March, separate from the nitrogen addition. The fertilizers were injected only during the first hour of operation of the trickle system so that the materials could be flushed out of the lines before the system was shut down.

Water Analyses

The water samples before and immediately after chemical and filtration treatments, and also in the field laterals, and from the individual emitters, were analyzed for the various microbial, chemical, and physical constituents on a bi-weekly basis in the summer and on a tri-weekly basis in the winter.

Chemical analysis. Complete analysis of the Colorado River water was made for Na, Ca, Mg, Cl, SO_4, NH_4, NO_3, and pH using standard atomic absorption, spectrophotometric, and titrimetric methods.

Physical analysis. The turbidity and suspended load of the water were determined with the nephelometric and filtration techniques, respectively. Air and water temperatures were measured with thermocouple sensors. The water temperature in the field laterals was taken with thermocouples sealed into the polyethylene tubing.

Biological analysis. Microbial population for bacteria, fungi, and yeast was determined using the Millipore "water tester" method. Analyses were made on the waters from the same sampling points as

those used for the chemical and physical analyses. In addition, samples were taken from four different types of emitters for the six water treatments.

RESULTS AND DISCUSSION:

Various water quality aspects of the Colorado River water are presented in Figure 4 for the January to November 1975 period. The soluble salts ranged from 1.1 to 1.4 mmhos/cm (700 to 900 ppm) without much of a seasonal trend shown in the salt content. The sodium and sulfate concentrations had the largest changes in the dissolved constituents over the season. The pH of the water ranged from 7.9 to 8.3 without any noticeable seasonal trend either. The mean values for the soluble salts and pH's were approximately the average of the range values.

The total suspended load varied from less than 1 ppm to 60 ppm. The higher values were caused by the cleaning operation for the main project canal upstream from the intake and which was more frequent during the summer than the winter months. During the high suspended load period, the screen and sand filters required frequent cleaning. Daily backwashing practice of the sand filters was followed in the summer.

Microbial population ranged from a few hundred to approximately 4000 bacteria per ml. This latter large value was present once in June. Otherwise, the population was more in the order of 500 bacteria per ml. Populations of fungi and yeasts were very small and were considered insignificant relative to contributing to the plugging problem.

The air and water temperatures, as expected, were the only measured parameters that showed any distinct seasonal trend. The 1400-hour water temperatures in the polyethylene tubing in the field were between the air and water temperatures as long as the trickle system was in operation. When the system was off, the lateral temperatures rose, but not significantly above the air temperature since the tubing was shaded under the tree canopy.

To simplify the comparison among the various water treatment and emitter combinations, only Treatment A (40-mesh screen filtration),

Treatment C (sand + 200-mesh screen filtration), and Treatment E (sand + 200-mesh screen + continuous 1 ppm chlorine and acid) are graphically presented in Figures 5 through 12. A complete listing of the results are given in Tables 1 through 8 for all the combinations as a function of time. The 200-mesh screen alone in Treatment B broke several times during the earlier part of the experiment so that the results are not as reliable as the others, but the flow rates were similar to Treatment A. Treatments D and F with the intermittent 10 ppm chlorine + acid, and the continuous acid addition, respectively, had similar flow rates as Treatment E for all the emitters.

The 40-mesh screen filtration (Treatment A) showed the greatest decrease in flow rate for all emitters, except emitters 3, 6, and 7, during the 10 months of operation. Also, pressure regulators had to be cleaned periodically and water meters had to be changed more frequently in Treatments A and B than with the other water treatments. The "rough" filtration (Treatment A) caused a rapid and earlier decrease in flow rates of emitters 1 (Figure 5, Table 1), 2 (Figure 6, Table 2), and 4 (Figure 8, Table 4) than with the other emitters. In case of emitters 1 and 8, they had to be removed in Treatments A and B by day 187 because their flow rates had greatly decreased to the point that an adequate rate of water application to the trees could not be maintained. Inspection of the emitters showed a large buildup on materials in the emitters.

Sand filtration appears to be adequate for removing suspended materials from the water except when the suspended load of the river was extremely high (Figures 4 and 13; Tables 9 and 11). Part of the particle size is in the less than 75 micron size range, about the limit of the filtration capacity of the screen. Spot checks on the particle size distribution are being started to find exactly how the filters are performing in the finer particle size range. The suspended load built up rapidly in the submains (Figure 14; Tables 10 and 11) from a few parts per million to several thousand. The turbidity values of waters from emitters 3, 4, 5, and 6 (Tables 13 to 16) were much more like those for samples taken in the shed (Table 11) than those of the submain. Some of the suspended materials were apparently

settling out in the larger submains during the flow through approximately 1000 ft of pipe.

Only one complete flushing of the submains and laterals was made for all treatments 278 days after the system was installed. The flushing decreased the suspended load in the submains, but did not change the flow rates of the emitters. In actual use, more frequent flushing of the lines would be desirable, and the system should be designed to allow for adequately handling such practices.

Based on the performances of the various emitters and the frequent breakdown of the "homemade" screen filters, Treatments A and B were changed 278 days after the start of the trickle system to include: Treatment A, a higher capacity (commercial type) 50-mesh screen filter; and Treatment 13, a similar 50-mesh screen + intermittent 10 ppm chlorine and acid addition. The emitters in these treatments were also changed and included four types of emitters instead of the original eight, and, namely, types 3, 6, 7, and 9. Type 9 is the same as type 3, except its designed flow rate is 2 gph instead of 1 gph. The types 3, 6, and 7 which were originally in the treatment combination were left in the system and will be used to compare the same emitter types with other treatments and also as a time-dependent variable for the similar, but newly installed, types.

The intermittent acid and chlorine, continuous acid and chlorine, and continuous acid treatments were able to maintain flow rates of essentially 100% of initial values for emitters 1, 2, 3; 90% for emitter 4; 80% for emitters 5, 6, and 7; and 70% for emitter 8 for 10 months of operation. Emitters 2, 5, 6, 7, and 8 did exhibit some decrease in flow rate with time only with the sand and screen filtration (Treatment C).

Microbial analyses of the samples from the submains and emitters (Figures 15 to 20, Tables 17 to 22) show that both chlorine Treatments D and E were able to control microbial activity, except when the chemical injectors had failed. Treatment D yielded lower bacterial counts than Treatment E, since Treatment D involved a "slug" dose of chemicals 1 hour before the end of the irrigation cycle, and presumably more of the chemicals were in the system just prior to shut down.

Water samples for analyses were taken at the start of the irrigation cycle, immediately after the screens were cleaned and sand filters backwashed. When the samples are taken after a 2- to 3-day shutdown period (weekend plus holiday), a higher microbial count is expected, because of the decline of residual chlorine with time in Treatment E. The flow rate, however, remained essentially unchanged during the period of loss of chlorine injection and indicated that less frequent chlorination and acid treatments may be a suitable management practice.

An adequate explanation as to why the flow rate in acid Treatment F was essentially equivalent to chlorine plus acid Treatments D and E is not available at present. The microbial population was higher in Treatment F than Treatments C, D, and E. However, the types of bacteria growing in Treatment F were different from those in Treatments C, D, and E. Possibly, the bacterial types that were established in the environment of the acid treatment were not the slime-producing types that would cause a decrease in the flow rate through the trickle irrigation system.

SUMMARY AND CONCLUSIONS:

A trickle irrigation experiment to study emitter plugging was set up in early 1975 on a citrus grove in Tacna, Arizona, for estimating the plugging potential of the Colorado River water and for providing methods for preventing plugging if it became a problem. Six types of water treatments, including screen and sand filtration and hypochlorination and acid additions, were used in conjunction with eight different kinds of trickle emitters. The emitter flow rate, together with the biological, chemical, and physical properties of the river and treated waters, are being monitored.

The 10-month span of the investigation on emitter plugging is too short to arrive at any reliable conclusions or make specific recommendations on the type of water treatment, if any, required to maintain maximum performance of the trickle system. However, some emitters continued to operate more effectively than others, even when high levels of suspended materials were present in the treated Colorado River water. In general, our results indicated that

1) a rapid buildup of materials formed by settling of suspended solids can occur, even with a combination of sand and screen filtration; and that

2) chlorine plus acid treatments (D and E) and acid treatment (F) with sand and screen filtration have maintained the flow rates for most of the emitters during the 10 months of operation.

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

Table 1. Flow rate of emitter No. 1 as a function of treatment and time.

EMITTER NO. = 1

FLOW RATE (GPH)

DAYS ELAPSED	TREATMENT A	B	C	D	E	F
0	1.17	0.99	1.02	1.07	1.00	1.06
13	1.22	1.18	0.97	1.08	1.05	1.09
35	0.83	1.08	1.00	1.01	1.01	0.95
48	0.85	0.92	1.04	0.91	0.93	0.94
62	0.66	0.68	1.01	0.92	0.93	0.92
84	0.44	0.60	1.15	0.92	0.93	0.97
104	0.07	0.46	0.97	0.91	0.92	0.81
111	0.87	1.02	1.08	0.94	0.97	0.92
118	0.68	0.51	0.97	0.88	0.94	0.87
130	0.90	0.56	1.04	0.91	0.90	0.88
132	0.83	0.46	0.90	0.92	0.90	0.89
146	0.84	0.41	0.84	0.90	0.92	0.88
154	0.56	0.31	0.88	0.87	0.91	0.77
165	0.48	0.98	0.83	0.87	****	0.66
166	1.01	0.96	0.94	0.93	1.07	0.80
178	0.41	0.32	0.82	****	0.90	0.62
179	0.64	0.50	1.01	****	0.99	0.72
180	0.56	0.27	0.93	0.88	0.95	0.64
187	0.25	0.36	0.84	1.07	0.98	0.69
188	****	****	0.88	0.94	0.98	0.79
200	****	****	0.84	0.98	0.96	0.58
214	****	****	0.73	1.13	0.96	0.69
215	****	****	0.80	1.10	0.94	0.71
230	****	****	0.81	1.30	0.95	0.60
231	****	****	0.90	1.32	0.96	0.70
241	****	****	0.95	1.22	0.78	0.70
242	****	****	0.97	0.94	0.67	0.57
243	****	****	0.98	0.94	0.64	0.62
258	****	****	1.01	0.97	0.54	0.70
259	****	****	1.04	0.92	0.75	0.77
276	****	****	1.00	0.96	0.94	0.82
278	****	****	1.04	0.98	0.97	0.87
294	****	****	1.04	0.98	****	0.88
312	****	****	1.03	1.03	0.88	0.81

Table 2. Flow rate of emitter No. 2 as a function of treatment and time.

EMITTER NO. = 2

FLOW RATE (GPH)

DAYS ELAPSED	TREATMENT A	B	C	D	E	F
0	1.24	1.89	1.42	1.16	1.22	1.21
13	1.22	1.15	1.30	1.28	1.32	1.42
35	0.78	0.85	0.95	1.82	1.02	0.94
48	1.09	1.19	1.65	1.09	1.19	1.22
62	0.32	0.37	0.99	1.06	1.12	0.98
84	0.78	1.07	1.27	1.11	1.30	1.18
104	0.92	0.83	0.97	1.10	1.34	1.12
111	0.85	0.78	0.95	1.16	1.28	1.19
118	0.83	0.76	0.92	1.08	1.44	1.08
130	0.92	0.82	0.92	1.07	1.35	1.20
132	0.92	0.80	0.84	1.14	1.30	1.19
146	0.90	0.58	0.75	1.17	1.28	1.15
154	0.89	0.50	0.70	1.08	1.26	1.16
165	0.78	0.44	0.61	1.08	1.20	1.16
166	0.60	0.82	0.66	1.16	1.29	1.16
178	0.80	0.67	0.56	1.00	1.13	1.02
179	0.69	0.67	0.66	1.12	1.28	1.21
180	0.82	0.65	0.68	1.09	1.17	1.12
187	0.68	0.68	0.66	1.07	1.26	1.09
188	0.69	0.63	0.66	1.04	1.28	1.14
200	0.62	0.64	0.68	1.02	1.09	1.14
214	0.57	0.70	0.67	1.07	1.20	1.14
215	0.61	0.74	0.54	1.07	1.28	1.11
230	0.61	0.59	0.63	1.04	1.34	1.04
231	0.58	0.61	0.68	1.08	1.34	1.19
241	0.54	0.62	1.43	1.04	1.14	1.10
242	0.59	0.60	1.48	1.00	0.96	1.08
243	0.60	0.48	0.73	1.03	0.98	1.06
258	0.53	0.58	0.72	1.06	1.01	1.12
259	0.50	0.64	0.64	1.04	1.05	1.20
276	0.52	0.66	0.72	1.15	1.11	1.12
278	****	****	0.73	1.13	1.18	1.27
294	****	****	0.76	1.15	1.34	1.32
312	****	****	0.78	1.14	1.40	1.14

Table 3. Flow rate of emitter No. 3 as a function of treatment and time.

EMITTER NO. = 3

FLOW RATE (GPH)

DAYS ELAPSED	TREATMENT A	B	C	D	E	F
0	0.88	0.92	1.12	0.83	0.98	0.90
13	0.90	0.91	0.92	0.86	1.20	0.94
35	0.80	0.90	1.01	0.85	1.02	0.88
48	0.86	0.88	0.98	0.84	1.06	0.90
62	0.79	0.81	0.94	0.80	1.10	0.86
84	0.90	0.83	0.96	0.82	1.20	0.92
104	0.74	0.88	0.89	0.83	1.08	0.82
111	0.78	0.73	1.00	0.84	1.07	0.88
118	0.82	0.80	0.98	0.84	1.13	0.90
130	0.90	0.85	0.98	0.84	1.19	0.92
132	0.88	0.82	0.93	0.84	1.07	0.87
146	0.82	0.80	0.92	0.82	1.07	0.92
154	0.84	0.72	0.89	0.87	1.06	0.97
165	0.84	0.68	0.91	0.87	1.08	0.92
166	0.81	0.76	0.90	0.88	1.09	0.89
178	0.67	0.81	****	0.91	1.05	0.87
179	0.75	0.82	0.80	0.91	1.03	0.88
180	0.95	0.79	0.83	0.90	1.03	0.90
187	0.77	0.72	0.81	0.90	1.08	0.88
188	0.78	0.71	0.77	0.90	1.17	0.91
200	0.71	0.71	0.85	0.90	0.98	0.89
214	0.77	0.75	1.00	0.96	1.06	0.89
215	0.73	0.83	0.91	0.96	1.08	0.85
230	0.83	0.88	0.93	0.98	1.10	0.89
231	0.72	0.96	0.96	1.02	1.19	0.92
241	0.75	0.82	0.82	0.95	1.04	0.81
242	0.74	0.90	0.88	0.96	0.92	0.94
243	0.74	0.87	0.90	0.96	0.96	0.86
258	0.89	0.88	0.82	1.01	0.96	0.84
259	0.74	0.81	0.80	0.93	0.93	0.78
276	0.87	0.93	0.82	0.90	0.82	0.79
278	0.89	1.06	0.83	0.94	0.93	0.83
294	0.84	1.04	0.84	0.89	0.98	0.81
312	0.92	0.92	0.86	0.90	1.01	0.84

Table 4. Flow rate of emitter No. 4 as a function of treatment and time.

EMITTER NO. = 4

FLOW RATE (GPH)

DAYS ELAPSED	TREATMENT A	B	C	D	E	F
0	1.08	1.04	1.14	1.13	1.22	1.12
13	1.05	1.24	1.08	1.04	1.30	1.12
35	1.02	1.22	1.03	1.19	1.23	1.10
48	0.92	1.19	1.14	0.95	1.11	1.04
62	0.93	1.15	0.93	0.86	1.23	1.05
84	0.84	1.14	1.08	0.87	1.26	1.04
104	0.76	0.97	1.06	0.91	1.16	1.00
111	0.76	0.97	1.13	0.85	1.14	1.02
118	0.74	1.02	1.11	0.91	1.16	1.03
130	0.77	0.97	1.06	0.91	1.15	0.98
132	0.74	0.95	1.03	0.79	1.10	0.95
146	0.75	0.95	1.00	0.82	1.09	0.95
154	0.73	0.89	0.99	0.80	1.08	0.96
165	0.73	0.89	0.95	0.78	1.05	0.96
166	0.71	0.89	0.96	0.78	1.06	0.94
178	0.68	0.82	0.89	0.77	1.02	0.94
179	0.70	0.78	0.97	0.78	1.02	0.95
180	0.80	0.77	0.95	0.77	1.02	0.95
187	0.70	0.51	1.08	0.80	1.09	0.94
188	0.69	0.42	0.92	0.82	1.11	0.93
200	0.62	0.52	0.93	0.82	0.99	0.93
214	0.46	0.30	0.90	0.72	1.07	0.84
215	0.50	0.46	0.72	0.74	1.08	0.86
230	0.32	0.37	0.88	0.79	1.08	0.88
231	0.31	0.41	0.93	0.82	1.13	0.86
241	0.32	0.49	0.90	0.79	1.03	0.85
242	0.32	0.44	0.84	0.78	0.94	0.92
243	0.30	0.44	0.88	0.80	0.96	0.89
258	0.50	0.32	0.92	0.82	0.88	0.92
259	0.44	0.45	0.90	0.80	0.88	0.88
276	0.39	0.44	0.93	0.84	0.88	0.90
278	****	****	0.96	0.85	0.98	0.92
294	****	****	0.98	0.85	1.06	0.94
312	****	****	1.02	0.91	1.09	0.97

Table 5. Flow rate of emitter No. 5 as a function of treatment and time.

EMITTER NO. = 5

FLOW RATE (GPH)

DAYS ELAPSED	TREATMENT A	B	C	D	E	F
0	1.64	1.69	1.60	1.67	1.76	1.71
13	1.66	1.79	1.63	1.70	1.87	1.77
35	1.53	1.55	1.60	1.75	1.68	1.77
48	1.43	1.61	1.70	1.77	1.55	1.75
62	1.24	1.54	1.58	1.70	1.31	1.71
84	1.03	1.49	1.55	1.70	1.48	1.70
104	0.95	0.98	1.35	1.70	1.28	1.61
111	0.96	0.93	1.43	1.62	1.34	1.61
118	1.16	1.08	1.42	1.60	1.44	1.66
130	1.23	0.98	1.33	1.60	1.47	1.66
132	1.14	1.03	1.29	1.58	1.42	1.57
146	1.20	1.21	1.26	1.57	1.44	1.64
154	1.19	1.00	1.27	1.52	1.44	1.58
165	1.30	1.03	1.08	1.43	1.53	1.51
166	1.24	1.09	1.07	1.43	1.54	1.48
178	1.09	0.98	0.90	1.35	1.47	1.32
179	1.14	0.94	1.02	1.36	1.45	1.45
180	1.36	0.81	1.04	1.37	1.45	1.32
187	0.88	0.72	0.95	1.35	1.45	1.30
188	0.90	0.89	0.96	1.34	1.53	1.33
200	1.05	0.65	1.02	1.31	1.35	1.30
214	1.05	0.81	0.86	1.39	1.48	1.14
215	0.95	0.76	1.02	1.11	1.27	1.13
230	0.98	0.78	0.86	1.37	1.48	1.22
231	1.00	0.92	0.91	1.40	1.58	1.25
241	0.98	0.72	0.74	****	1.30	1.11
242	0.97	0.84	0.86	1.33	1.10	1.25
243	1.05	0.83	0.91	1.35	1.14	1.21
258	1.04	0.76	0.79	1.37	1.01	1.25
259	0.98	0.78	0.83	1.33	1.03	1.20
276	1.03	0.72	0.91	1.31	1.05	1.16
278	****	****	0.93	1.31	1.14	1.18
294	****	****	0.94	1.38	1.15	1.22
312	****	****	0.91	1.37	1.20	1.25

Table 6. Flow rate of emitter No. 6 as a function of treatment and time.

EMITTER NO. = 6

FLOW RATE (GPH)

DAYS ELAPSED	TREATMENT A	B	C	D	E	F
0	0.99	0.90	1.01	0.95	1.08	1.03
13	1.00	1.03	1.00	0.96	1.25	1.05
35	0.92	0.94	0.92	0.96	1.10	0.96
48	0.93	0.96	1.01	0.97	1.14	1.00
62	0.86	0.93	0.92	0.90	1.14	0.93
84	1.00	1.00	0.95	0.98	1.33	1.04
104	0.89	0.99	0.98	0.95	1.10	1.04
111	0.90	0.92	1.05	0.97	1.28	1.05
118	0.95	0.93	1.04	0.94	1.25	1.06
130	1.00	0.95	1.04	0.95	1.31	1.08
132	0.96	0.91	0.99	0.95	1.24	1.02
146	0.92	0.86	0.96	0.91	1.25	1.05
154	0.93	0.77	0.93	0.90	1.21	1.07
165	0.89	0.76	0.93	0.88	1.24	1.06
166	0.86	0.78	0.95	0.89	0.94	1.03
178	0.57	0.73	0.74	0.73	1.02	0.90
179	0.70	0.81	0.90	0.81	1.12	1.02
180	0.88	0.77	0.90	0.80	1.10	0.98
187	0.73	0.82	0.87	0.77	1.17	0.98
188	0.69	0.86	0.88	0.78	1.26	1.02
200	0.75	0.73	0.89	0.76	1.06	1.07
214	0.95	0.90	0.92	0.82	1.17	1.09
215	1.01	0.93	0.88	0.79	1.20	1.05
230	0.89	0.86	0.87	0.78	1.13	1.04
231	0.91	0.93	0.89	0.82	1.22	1.07
241	0.93	0.88	0.76	0.93	1.05	0.98
242	****	1.04	0.78	0.98	1.10	1.11
243	0.96	0.87	0.84	0.93	0.95	1.02
258	0.92	0.85	0.82	0.91	0.93	0.92
259	0.89	0.87	0.75	0.87	0.92	0.94
276	0.64	0.66	0.73	0.73	0.67	0.80
278	0.62	0.77	0.77	0.76	0.74	0.85
294	0.55	0.74	0.73	0.71	0.80	0.81
312	0.60	0.76	0.72	0.66	0.83	0.80

Table 7. Flow rate of emitter No. 7 as a function of treatment and time.

EMITTER NO. = 7

FLOW RATE (GPH)

DAYS ELAPSED	TREATMENT A	B	C	D	E	F
0	1.93	1.03	2.08	1.86	2.10	1.97
13	1.94	2.07	2.07	1.87	1.94	2.00
35	1.94	2.07	2.07	1.87	1.94	2.00
48	1.85	1.94	2.04	1.92	2.21	2.00
62	1.87	1.91	1.90	1.78	2.30	1.92
84	1.96	2.02	1.98	1.89	2.57	1.96
104	1.66	1.98	1.91	1.90	2.29	2.03
111	1.86	1.78	2.17	1.98	2.41	2.09
118	1.86	1.93	2.15	1.92	2.41	2.06
130	2.00	1.92	2.15	1.85	2.59	2.12
132	1.94	1.87	2.07	1.81	2.02	1.99
146	1.91	1.92	2.02	1.93	2.40	2.08
154	1.98	1.72	1.99	1.96	2.47	2.16
165	1.90	1.72	1.99	1.86	2.49	2.11
166	1.87	1.91	1.98	1.93	2.57	2.07
178	1.53	1.88	1.68	1.83	2.39	1.98
179	1.68	1.89	1.90	1.82	2.45	2.07
180	2.15	1.78	1.89	1.81	2.40	2.07
187	1.83	1.86	1.84	1.88	2.52	2.09
188	1.82	1.96	1.85	1.90	2.69	2.13
200	1.84	1.79	1.90	1.87	2.22	2.07
214	2.08	2.06	1.98	1.93	2.50	2.13
215	2.02	2.16	1.90	1.91	2.04	2.05
230	2.04	2.03	2.02	1.89	2.42	2.03
231	1.96	2.18	1.93	1.88	2.60	2.12
241	1.90	2.10	1.62	2.00	2.16	1.96
242	1.92	2.02	1.68	2.12	2.18	2.65
243	1.82	1.91	1.82	2.05	1.94	2.11
258	1.76	1.86	1.75	2.06	1.84	2.04
259	1.76	1.85	1.62	1.93	1.81	1.88
276	1.32	1.62	1.59	1.72	1.45	1.75
278	1.32	2.04	1.76	1.83	1.67	1.89
294	1.21	1.78	1.59	1.64	1.70	1.76
312	1.20	1.74	1.60	1.61	1.66	1.74

Table 8. Flow rate of emitter No. 8 as a function of treatment and time.

EMITTER NO. = 8

FLOW RATE (GPH)

DAYS ELAPSED	TREATMENT A	B	C	D	E	F
0	1.88	1.79	2.01	1.42	1.60	1.47
13	1.46	1.36	1.56	1.36	1.40	1.14
35	1.19	1.04	1.50	1.08	1.28	1.00
48	1.04	1.06	1.61	1.14	1.35	1.11
62	0.66	0.83	1.45	1.07	1.30	1.08
84	0.63	0.75	1.44	1.14	1.49	1.13
104	0.39	0.58	1.30	1.08	1.26	1.04
111	1.52	1.43	1.42	1.09	1.30	1.10
118	1.43	1.27	1.33	1.11	1.34	1.11
130	0.98	0.92	0.90	0.77	0.98	0.79
132	0.95	0.87	0.87	0.78	0.94	0.75
146	1.23	1.31	1.18	1.12	1.33	1.13
154	0.92	0.97	1.13	1.11	1.28	1.13
165	0.87	0.95	1.04	1.12	1.36	1.08
166	0.87	1.04	1.01	1.14	1.38	1.05
178	0.51	0.70	0.69	1.10	1.29	0.98
179	0.56	0.69	0.77	1.13	1.30	1.02
180	0.98	0.27	0.79	1.24	1.30	1.00
187	0.46	1.15	0.64	1.11	1.33	0.92
188	****	****	0.64	1.11	1.43	0.97
200	****	****	0.61	1.10	1.13	0.95
214	****	****	0.64	1.04	1.08	0.90
215	****	****	0.64	1.06	1.18	0.93
230	****	****	0.68	1.10	1.18	0.95
231	****	****	0.74	1.19	1.28	0.99
241	****	****	0.61	1.06	1.07	0.90
242	****	****	0.66	1.06	0.93	1.02
243	****	****	0.69	1.08	0.96	0.94
258	****	****	0.66	1.09	0.84	0.93
259	****	****	0.69	0.99	0.75	0.87
276	****	****	0.67	0.94	0.71	0.79
278	****	****	0.68	0.99	0.82	0.84
294	****	****	0.65	0.95	0.82	0.79
312	****	****	0.68	0.93	0.74	0.79

Table 9. Suspended load of water samples taken in pump shed immediately after treatment as a function of type of treatment and time.

SAMPLE SOURCE: SHED

	SUSPENDED LOAD (PPM)						
		TREATMENT					
DAYS ELAPSED	CRW	A	B	C	D	E	F
0	0.1	0.3	0.1	0.2	0.1	0.2	0.3
13	0.5	0.3	0.3	0.3	0.4	0.6	0.4
35	31.0	88.0	91.0	15.0	21.0	27.0	16.0
48	18.0	36.0	40.0	7.3	5.9	8.1	7.9
62	14.0	92.0	27.0	7.9	21.0	15.0	9.5
84	13.0	28.0	34.0	2.4	7.8	5.5	6.7
104	8.5	22.0	14.0	3.4	2.0	5.1	4.9
118	3.2	10.0	6.8	0.9	0.5	1.0	2.2
130	1.4	1.4	0.9	0.2	0.6	0.3	0.6
146	18.0	34.0	29.0	0.6	0.3	0.2	0.2
154	17.0	16.0	17.0	1.9	1.2	1.6	2.3
166	11.0	10.0	18.0	0.9	0.7	0.7	2.0
179	1.4	3.0	4.5	0.3	0.8	1.2	0.6
188	0.4	0.8	0.6	0.5	0.5	0.5	0.3
200	58.0	217.0	38.0	4.4	4.0	7.0	10.2
214	11.0	8.9	10.0	0.1	0.5	2.0	0.4
231	7.7	21.3	15.0	3.6	0.9	0.6	1.3
243	38.0	110.0	46.0	2.0	3.8	31.0	2.8
258	21.6	22.0	22.0	1.7	1.8	2.2	1.9
278	1.3	1.7	1.3	1.1	0.6	0.7	0.8
294	0.8	2.3	3.0	0.6	0.5	0.7	1.0
312	2.2	5.0	2.1	2.2	1.1	2.0	1.7

Table 10. Suspended load of water samples from submain as a function of treatment and time.

SAMPLE SOURCE: SUBMAIN

DAYS ELAPSED	CRW	A	B	C	D	E	F
	SUSPENDED LOAD (PPM)						
		TREATMENT					
48	18.0	517.0	19.0	29.0	253.0	48.0	34.0
62	14.0	697.0	64.0	37.0	42.0	109.0	58.0
84	13.0	68.0	172.0	174.0	239.0	41.0	25.0
104	8.5	276.0	11.0	8.1	26.0	12.0	23.0
118	3.2	1333.0	201.0	311.0	158.0	226.0	221.0
130	1.4	1566.0	970.0	724.0	435.0	914.0	1360.0
146	18.0	2036.0	1132.0	1048.0	336.0	154.0	2032.0
154	17.0	2568.0	1400.0	731.0	136.0	100.0	130.0
166	11.0	1228.0	729.0	510.0	317.0	264.0	243.0
179	1.4	401.0	2768.0	635.0	1067.0	233.0	607.0
188	0.4	1934.0	304.0	374.0	75.0	302.0	749.0
200	58.0	431.0	107.0	249.0	972.0	270.0	1064.0
214	11.0	572.0	154.0	226.0	271.0	322.0	1070.0
231	7.7	464.0	576.0	98.0	218.0	1354.0	327.0
243	38.0	1470.0	2532.0	67.0	836.0	1889.0	392.0
258	22.0	1074.0	2854.0	69.5	572.0	2572.0	720.0
278	1.3	741.0	1382.0	158.0	140.0	234.0	32.0
294	0.8	706.0	520.0	240.0	85.0	293.0	29.0
312	2.2	322.0	787.0	235.0	39.0	96.0	30.0

Table 11. Turbidity of water samples taken in pump shed immediately after treatment as a function of type of treatment and time.

SAMPLE SOURCE: SHED

TURBIDITY (JTU)

DAYS ELAPSED	TREATMENT CRW	A	B	C	D	E	F
84	3.3	1.3	2.0	1.6	2.5	3.6	2.2
104	5.2	4.5	5.0	3.5	3.6	3.6	2.7
118	3.7	5.1	4.6	1.2	1.3	2.9	1.8
130	2.5	1.4	2.4	0.5	1.2	1.1	1.6
146	7.2	15.0	18.0	2.1	2.8	1.8	9.9
154	4.3	3.5	10.0	1.2	1.0	2.4	1.1
166	5.1	8.9	9.6	1.0	1.8	2.0	1.2
179	2.7	5.5	2.1	1.4	1.5	1.6	1.4
188	1.5	1.6	1.4	1.0	1.0	1.3	1.1
200	26.0	25.0	25.0	2.5	3.3	4.4	3.0
214	5.2	1.7	6.0	1.4	1.6	2.8	1.2
231	4.0	4.0	4.2	0.8	1.3	1.3	1.5
243	9.7	8.7	9.2	0.7	1.3	18.0	1.6
255	14.0	8.0	10.0	1.2	1.6	3.5	2.5
275	0.8	1.1	1.3	0.6	0.7	0.7	0.6
294	1.4	1.7	2.4	1.2	1.5	1.5	1.4
312	1.8	6.2	3.5	1.5	2.0	1.6	1.0

Table 12. Turbidity of water samples in submain as a function of type of treatment and time.

SAMPLE SOURCE: SUBMAIN

TURBIDITY (JTU)

DAYS ELAPSED	TREATMENT A	B	C	D	E	F
84	200.0	13.0	3.5	62.0	91.0	5.3
104	37.0	2.4	1.5	3.2	77.0	2.0
118	320.0	260.0	210.0	160.0	230.0	220.0
130	260.0	320.0	250.0	150.0	220.0	310.0
146	290.0	210.0	250.0	74.0	40.0	120.0
154	280.0	280.0	88.0	74.0	64.0	55.0
166	310.0	230.0	90.0	97.0	73.0	65.0
179	120.0	300.0	130.0	140.0	70.0	90.0
188	275.0	55.0	75.0	120.0	85.0	150.0
200	200.0	28.0	80.0	180.0	97.0	260.0
214	180.0	94.0	88.0	210.0	200.0	270.0
231	220.0	280.0	27.0	175.0	310.0	75.0
243	310.0	265.0	32.0	310.0	300.0	160.0
255	300.0	175.0	74.0	280.0	260.0	300.0
275	170.0	130.0	83.0	39.0	58.0	11.0
294	90.0	160.0	95.0	32.0	50.0	20.0
312	85.0	160.0	80.0	30.0	25.0	28.0

Table 13. Turbidity of water sample from emitter No. 3 as a function of type of treatment and time.

SAMPLE SOURCE: EMITTER NO. 3

TURBIDITY (JTU)

DAYS ELAPSED	TREATMENT A	B	C	D	E	F
84	2.5	2.5	1.3	1.6	4.8	3.3
104	8.1	6.6	3.5	3.0	23.0	4.4
118	3.6	15.0	1.4	1.8	2.4	1.9
130	0.8	1.0	0.6	1.5	0.8	0.7
146	6.8	3.0	1.1	3.3	2.9	2.7
154	7.7	4.0	1.0	2.4	3.0	1.7
166	5.2	2.2	0.7	1.8	3.4	1.7
179	4.0	3.4	1.7	2.3	2.3	2.0
188	0.7	1.4	0.7	1.0	2.3	1.0
200	9.5	17.0	2.0	5.0	5.0	2.4
214	1.0	2.1	0.7	2.5	2.6	1.9
231	18.0	37.0	0.7	0.7	1.0	4.5
243	5.3	4.4	1.0	1.6	8.5	2.3
255	80.0	15.0	1.0	25.0	9.3	7.0
275	1.8	2.8	0.4	1.0	4.7	0.6
294	3.0	7.0	0.9	2.6	2.3	2.3
312	3.0	18.0	18.0	4.7	8.5	4.4

Table 14. Turbidity of water sample from emitter No. 4 as a function of type of treatment and time.

SAMPLE SOURCE: EMITTER NO. 4

TURBIDITY (JTU)

DAYS ELAPSED	TREATMENT A	B	C	D	E	F
84	3.7	1.6	0.6	4.2	8.4	3.4
104	4.5	3.5	1.7	14.0	17.0	4.2
118	2.2	3.2	1.1	3.2	1.8	1.2
130	2.3	1.6	0.6	1.8	1.2	0.5
146	2.4	2.8	1.6	3.8	2.8	1.2
154	3.5	1.0	1.3	6.3	2.4	2.7
166	2.6	1.5	0.5	1.2	1.7	1.0
179	2.4	1.6	2.0	2.5	2.3	1.6
188	1.0	2.1	2.1	3.0	2.0	0.8
200	3.0	3.0	2.3	14.0	7.0	6.1
214	1.1	2.3	0.4	1.9	4.5	3.8
231	2.6	6.0	2.0	1.5	3.0	1.0
243	3.0	52.0	3.4	1.6	8.6	2.2
255	3.0	35.0	1.2	7.0	2.5	1.2
275	1.0	3.2	0.5	2.2	1.6	0.9
294	2.1	3.5	1.5	2.5	1.4	1.5
312	2.7	4.2	1.7	3.6	2.8	2.1

Table 15. Turbidity of water sample from emitter No. 5 as a function of type of treatment and time.

SAMPLE SOURCE: EMITTER NO. 5

TURBIDITY (JTU)

DAYS ELAPSED	TREATMENT A	B	C	D	E	F
84	3.7	30.0	1.4	1.6	6.5	1.4
104	98.0	5.6	4.2	3.4	7.2	6.0
118	8.3	30.0	1.7	1.5	2.3	1.8
130	0.9	2.4	0.9	0.7	0.6	0.6
146	23.0	5.2	1.4	2.0	2.6	1.2
154	28.0	14.0	3.5	4.2	4.0	31.0
166	3.2	3.3	1.1	1.0	2.8	1.3
179	58.0	2.6	1.2	1.2	3.3	1.2
188	*****	1.2	1.3	1.2	2.1	2.9
200	190.0	10.0	2.2	3.5	35.0	3.5
214	6.8	2.9	1.6	3.4	15.0	4.4
231	1.5	3.5	1.0	1.0	4.4	1.6
243	60.0	4.6	4.0	1.4	20.0	4.0
255	18.0	15.0	2.7	14.0	2.7	3.3
275	1.0	1.7	1.3	1.0	0.8	1.6
294	3.0	4.0	1.5	2.5	2.8	1.4
312	8.3	10.0	42.0	3.4	4.6	7.6

Table 16. Turbidity of water sample from emitter No. 6 as a function of type of treatment and time.

SAMPLE SOURCE: EMITTER NO. 6

TURBIDITY (JTU)

DAYS ELAPSED	TREATMENT A	B	C	D	E	F
118	19.0	5.0	7.0	13.0	13.0	22.0
130	1.8	4.9	3.2	1.8	6.3	1.6
146	6.8	9.2	4.9	5.4	7.1	2.8
154	4.0	19.0	4.0	9.4	5.0	4.3
166	6.5	8.2	16.0	1.4	11.0	2.3
179	4.3	7.2	15.0	1.5	4.4	9.8
188	1.6	2.5	2.6	2.6	4.0	2.0
200	9.6	18.0	8.5	33.0	14.0	17.0
214	2.6	4.8	9.4	6.2	6.3	9.0
231	4.5	24.0	8.5	1.4	4.0	5.8
243	30.0	75.0	6.0	3.5	78.0	2.6
255	9.6	22.0	9.1	8.0	50.0	10.0
275	1.0	2.6	0.9	0.7	2.4	1.5
294	4.2	8.5	8.8	1.9	5.5	2.4
312	8.7	38.0	26.0	4.9	17.0	43.0

Table 17. Bacterial population of water samples taken in pump shed immediately after treatment as a function of type of treatment and time.

SAMPLE SOURCE: SHED

BACTERIA/ML

DAYS ELAPSED	CRW	A	B	C	D	E	F
			TREATMENT				
0	90	230	140	130	0	5	60
13	1700	950	340	350	4	5	1560
35	730	650	755	620	450	680	375
48	280	4120	1540	750	360	17	400
62	220	500	450	310	210	82	190
84	300	230	210	200	200	25	100
104	700	900	430	220	0	18	800
118	1000	1900	660	1030	950	0	570
130	4000	2620	1800	200	1020	0	370
146	440	1680	530	370	30	0	680
154	410	6300	300	140	250	200	600
166	350	3500	920	250	187	0	750
179	230	2800	4300	1400	268	0	800
188	130	440	350	230	1200	3	850
200	600	420	320	190	672	20	4000
214	270	500	410	210	330	9	1650
231	210	500	380	150	500	4	510
243	600	720	430	70	300	17	520
255	320	600	1020	150	80	7	170
275	150	500	120	80	450	7	140
294	100	220	120	150	0	75	90
312	100	1020	70	50	80	0	200

Table 18. Bacterial population of water samples in submain as a function of type of treatment and time.

SAMPLE SOURCE: SUBMAIN

DAYS ELAPSED	BACTERIA/ML. TREATMENT A	B	C	D	E	F
0	142	175	294	0	12	400
13	6960	900	1210	0	5	530
35	940	865	725	191	150	325
48	770	850	6400	9	140	1470
62	1400	800	1450	54	670	1080
84	2120	120	60	20	9	270
104	10080	12150	7250	15120	12	200
118	540	380	600	0	10	1150
130	1500	1330	500	0	7	1250
146	620	290	160	10	52	980
154	450	550	40	0	180	7500
166	680	500	260	4	0	430
179	600	260	350	0	37	3750
188	1460	280	360	0	57	28000
200	550	280	40	0	840	890
214	800	800	120	0	200	6700
231	910	250	120	6720	3	4000
243	450	1010	360	0	0	1550
255	960	1000	260	0	430	2000
275	500	10	230	11	4	140
294	170	0	410	0	22	26
312	120	50	10	10	120	150

Table 19. Bacterial population of water samples from emitter No. 3 as a function of type of treatment and time.

SAMPLE SOURCE: EMITTER NO. 3

DAYS ELAPSED	BACTERIA/ML. TREATMENT A	B	C	D	E	F
84	60	630	60	90	7	170
104	2620	1820	1200	60	275	10920
118	1450	650	110	10	35	7400
130	2650	280	260	0	0	500
146	800	1160	430	0	114	4540
154	950	400	700	0	3040	1620
166	500	400	370	12	0	1400
179	1000	350	500	0	0	330
188	1550	620	1190	0	183	1340
200	1250	1440	320	840	0	9240
214	760	300	750	0	336	5600
231	340	1500	620	0	1000	1340
243	1130	210	130	0	0	3250
255	1000	950	120	0	800	1150
275	100	2400	700	32	0	120
294	1800	0	280	0	47	250
312	950	3200	180	1200	50	700

Table 20. Bacterial population of water samples from emitter No. 4 as a function of type of treatment and time.

SAMPLE SOURCE: EMITTER NO. 4

DAYS ELAPSED	BACTERIA/ML TREATMENT A	B	C	D	E	F
84	200	230	180	50	0	170
104	650	330	50	13440	85	3500
118	600	430	370	20	12	1180
130	460	600	1400	0	1000	1150
146	140	140	200	10	346	500
154	420	360	750	0	625	27540
166	390	470	170	437	712	1090
179	280	320	400	0	600	580
188	720	220	10	0	140	2750
200	480	350	80	0	1680	13440
214	560	250	100	0	325	2900
231	370	300	130	1000	250	212
243	300	670	100	1500	3	1200
255	1610	60	180	0	500	460
275	1170	0	120	0	0	10
294	1880	0	80	0	23	1180
312	1550	4000	10	0	20	720

Table 21. Bacterial population of water samples from emitter No. 5 as a function of type of treatment and time.

SAMPLE SOURCE: EMITTER NO. 5

DAYS ELAPSED	BACTERIA/ML TREATMENT A	B	C	D	E	F
84	200	330	100	30	7	110
104	2750	410	420	20	18	2870
118	1320	10	1530	0	17	5000
130	650	600	6000	4000	0	1220
146	320	200	210	100	38	1610
154	310	500	300	28	263	7500
166	400	380	200	625	0	1060
179	1410	600	200	45	2	2000
188	570	220	330	0	140	50
200	640	350	510	840	0	5880
214	760	600	41	17	75	5000
231	600	900	80	840	2	820
243	150	450	190	525	6	650
255	500	140	230	0	500	1870
275	520	500	210	68	0	90
294	25	0	44	0	30	380
312	2500	550	250	1920	1428	750

Table 22. Bacterial population of water samples from emitter No. 6 as a function of type of treatment and time.

SAMPLE SOURCE: EMITTER NO. 6

DAYS ELAPSED	BACTERIA/ML TREATMENT A	B	C	D	E	F
118	780	400	800	0	45	9450
130	290	2580	1780	270	4	3800
146	280	430	820	40	82	1700
154	90	60	530	0	2800	12000
166	330	540	340	325	7	770
179	730	600	370	42	0	2640
188	470	480	110	0	224	3000
200	1000	450	220	1260	0	11000
214	500	560	600	2	420	8400
231	220	120	190	840	7	1880
243	250	120	120	37	4	950
255	680	3750	120	0	1100	4000
275	90	50	140	50	0	50
294	950	0	170	0	80	410
312	1080	22	210	2100	6	3120
326	260	0	1260	5	85	550

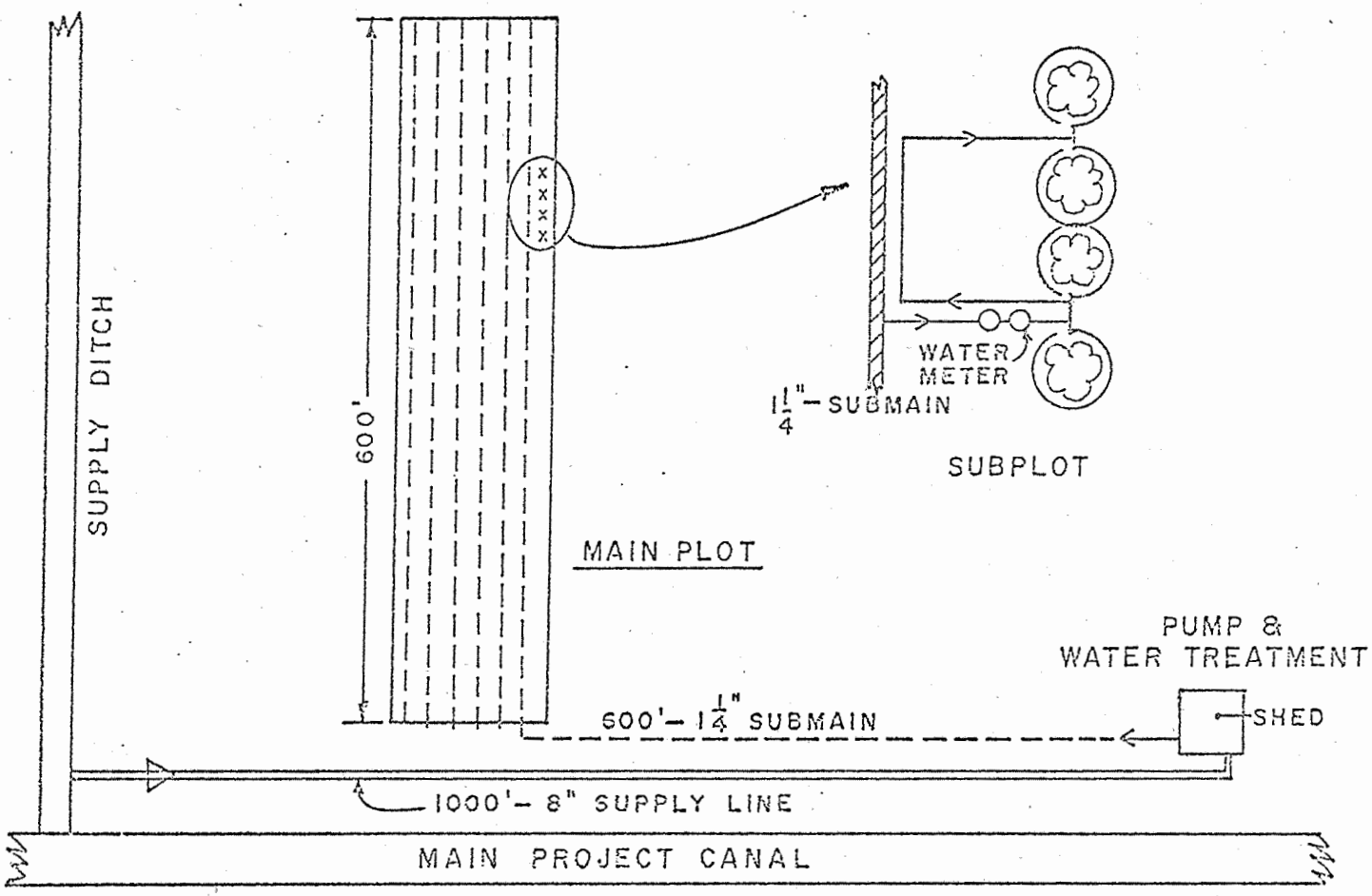

Figure 1. Experimental site showing water source, pump shed, main plot, and subplot arrangements.

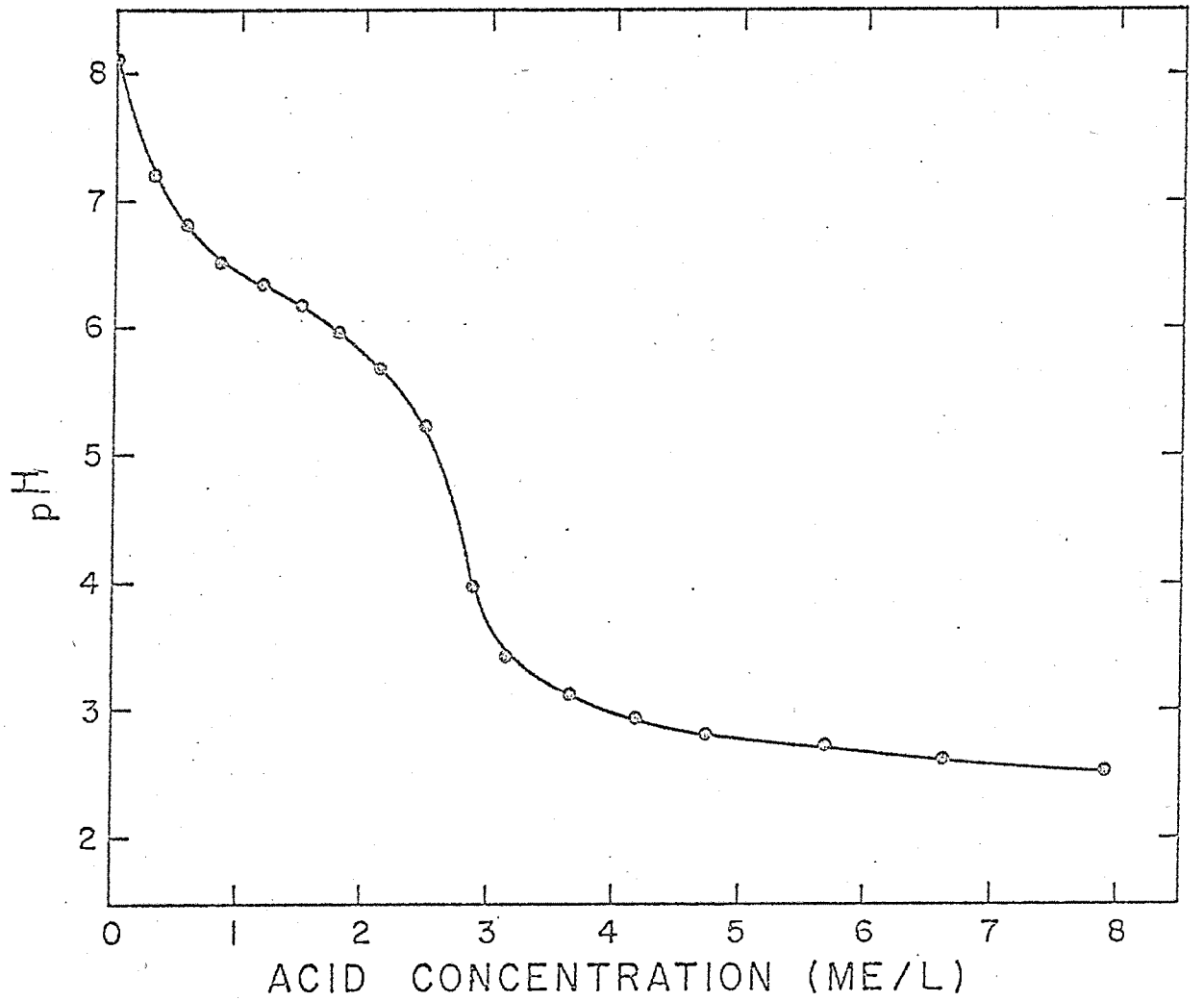

Figure 2. Acid titration curve for the Colorado River water taken at Tacna, Arizona.

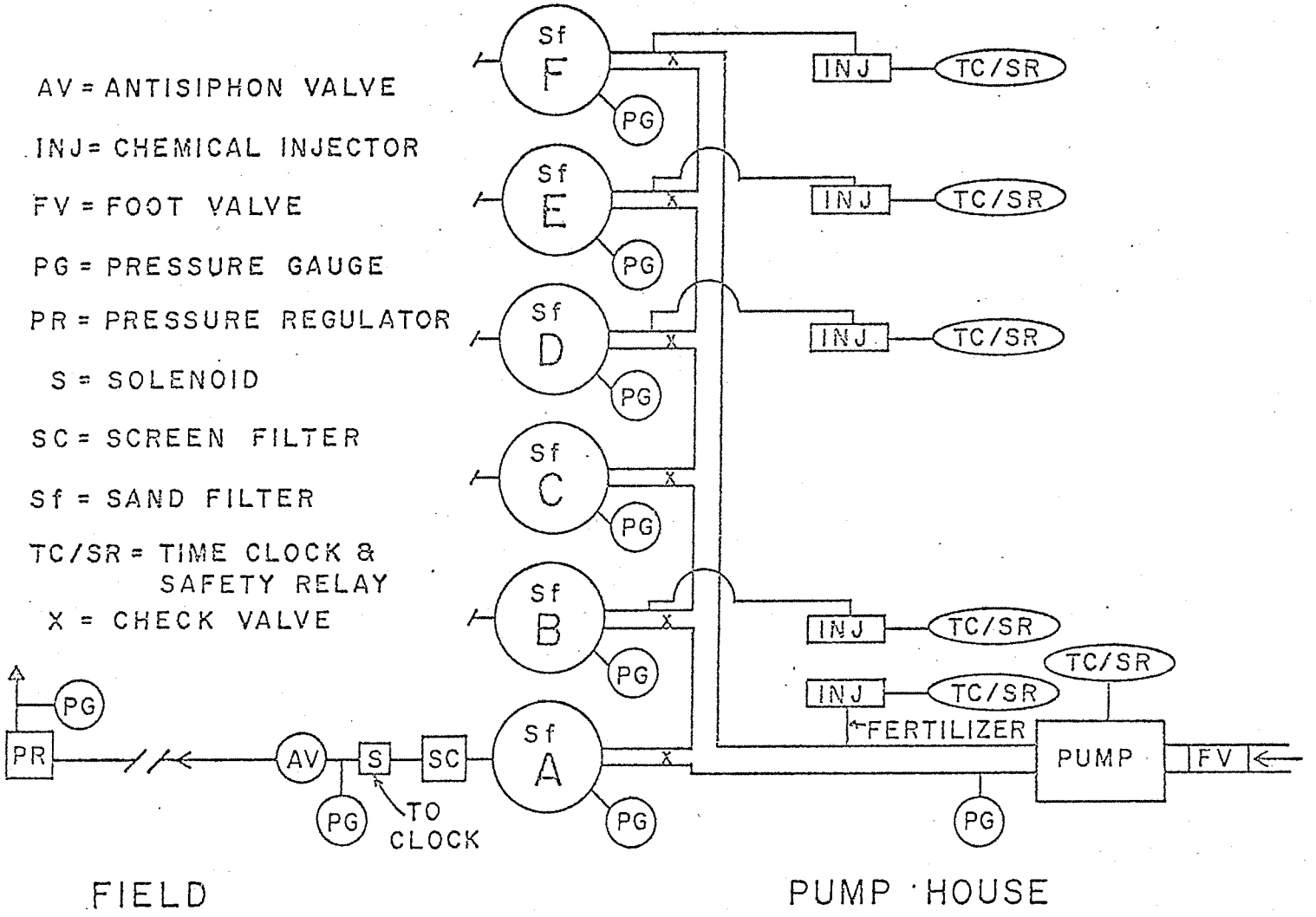

Figure 3. Schematic of water treatment equipment in the pump shed.

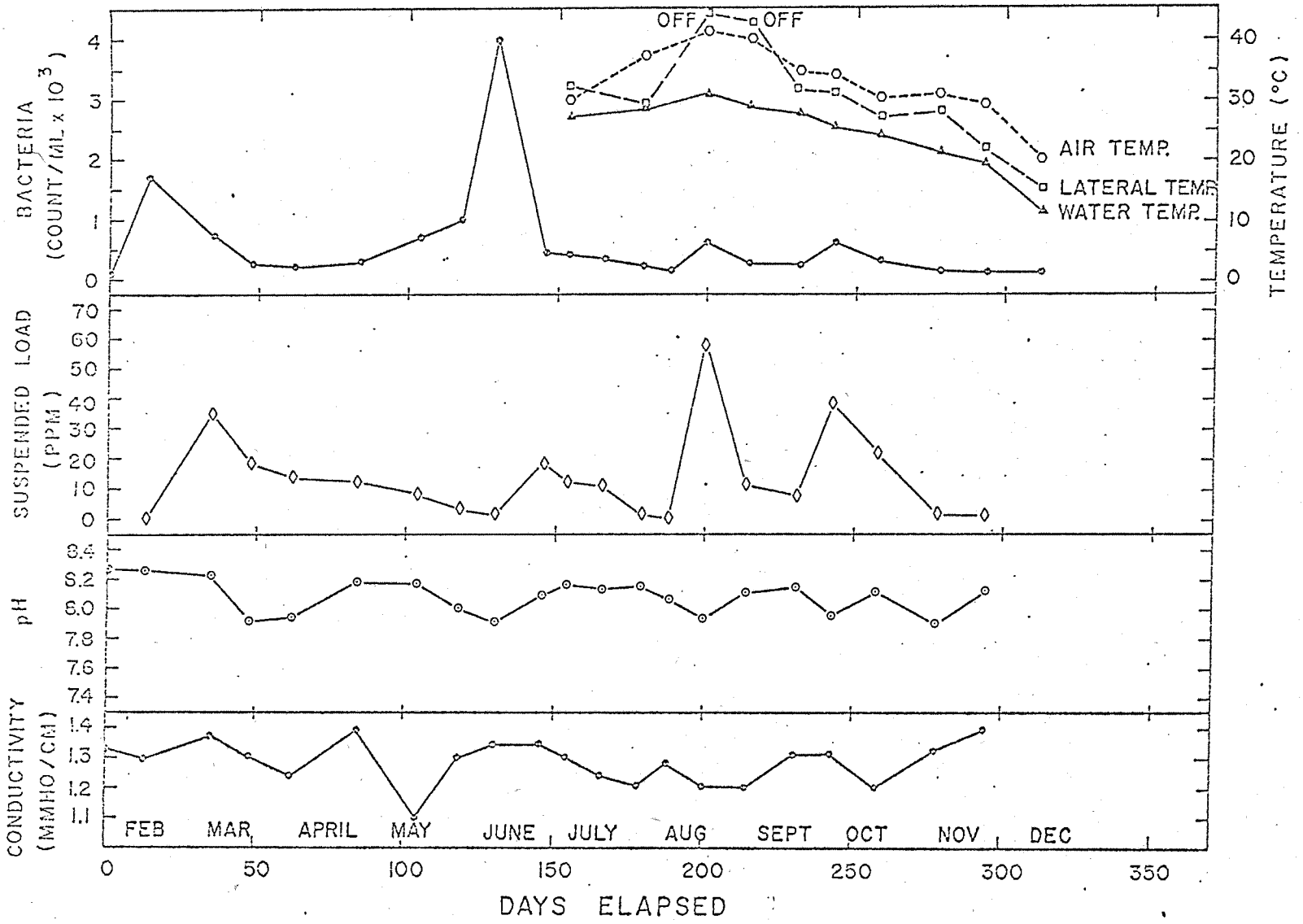

Figure 4. Biological, chemical, and physical analyses of the Colorado River water at Tacna for the February to November 1975 period.

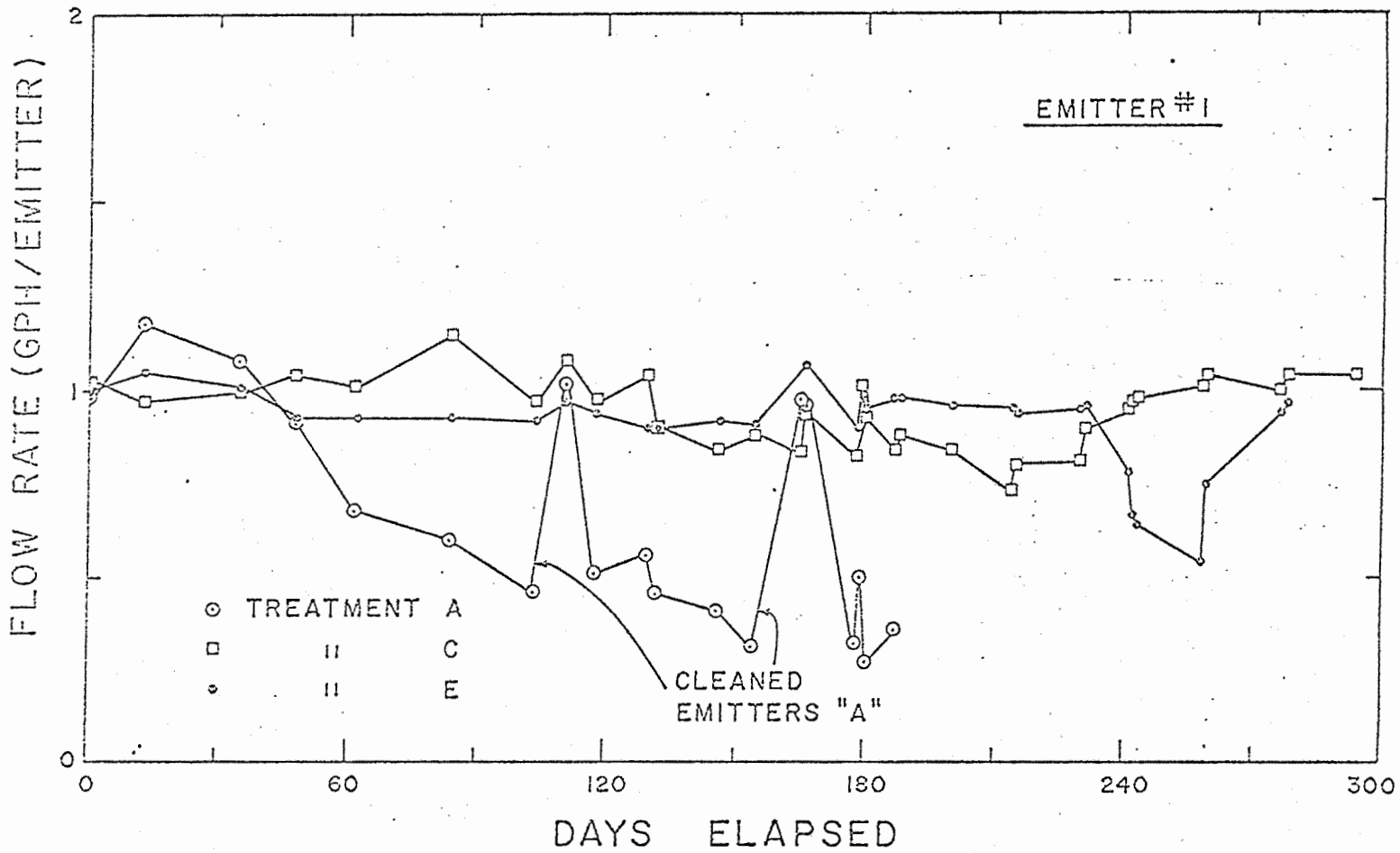

Figure 5. Flow rate of emitter no. 1 as a function of time for Treatments A, C, and E.

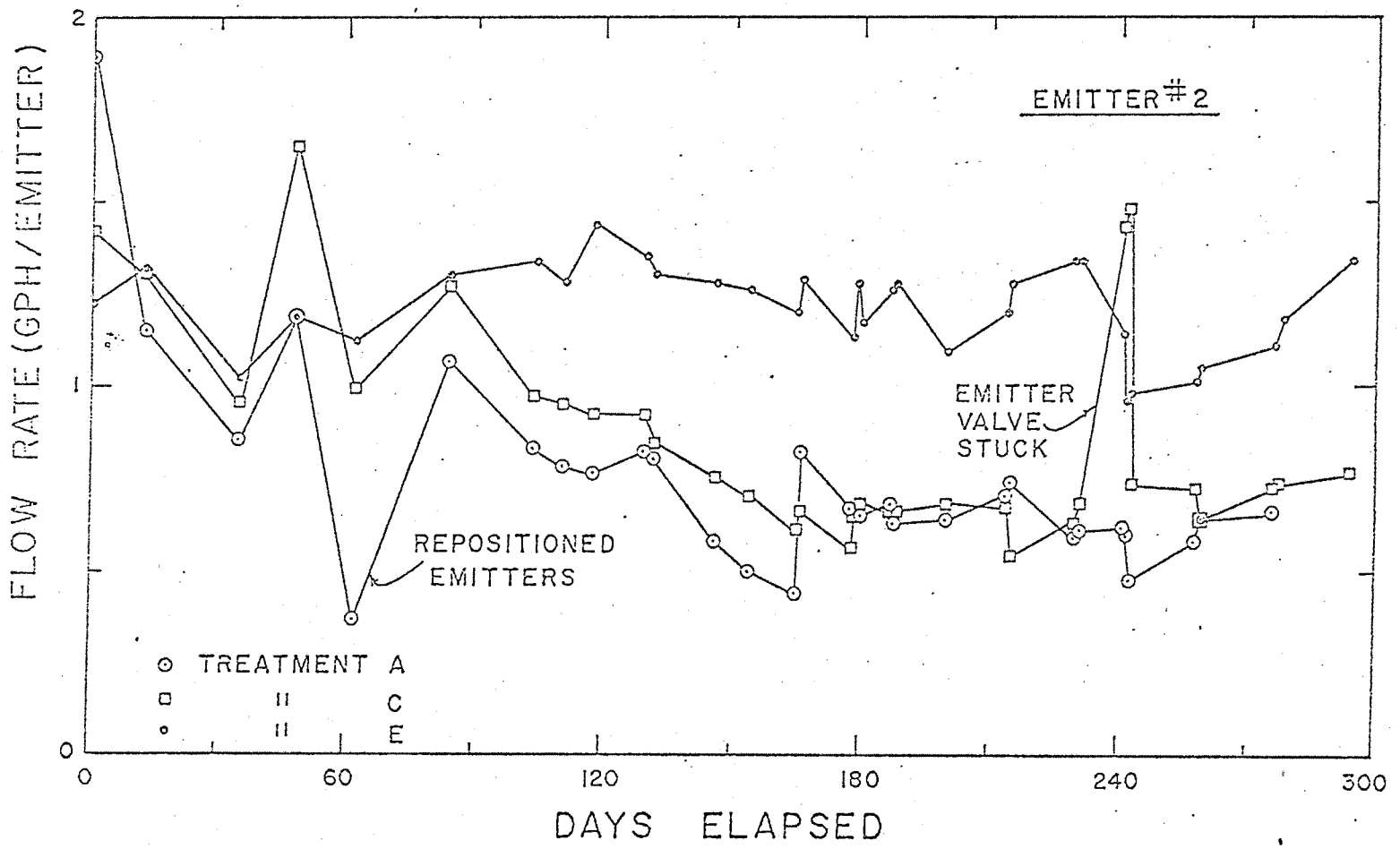

Figure 6. Flow rate of emitter no. 2 as a function of time for Treatments A, C, and E.

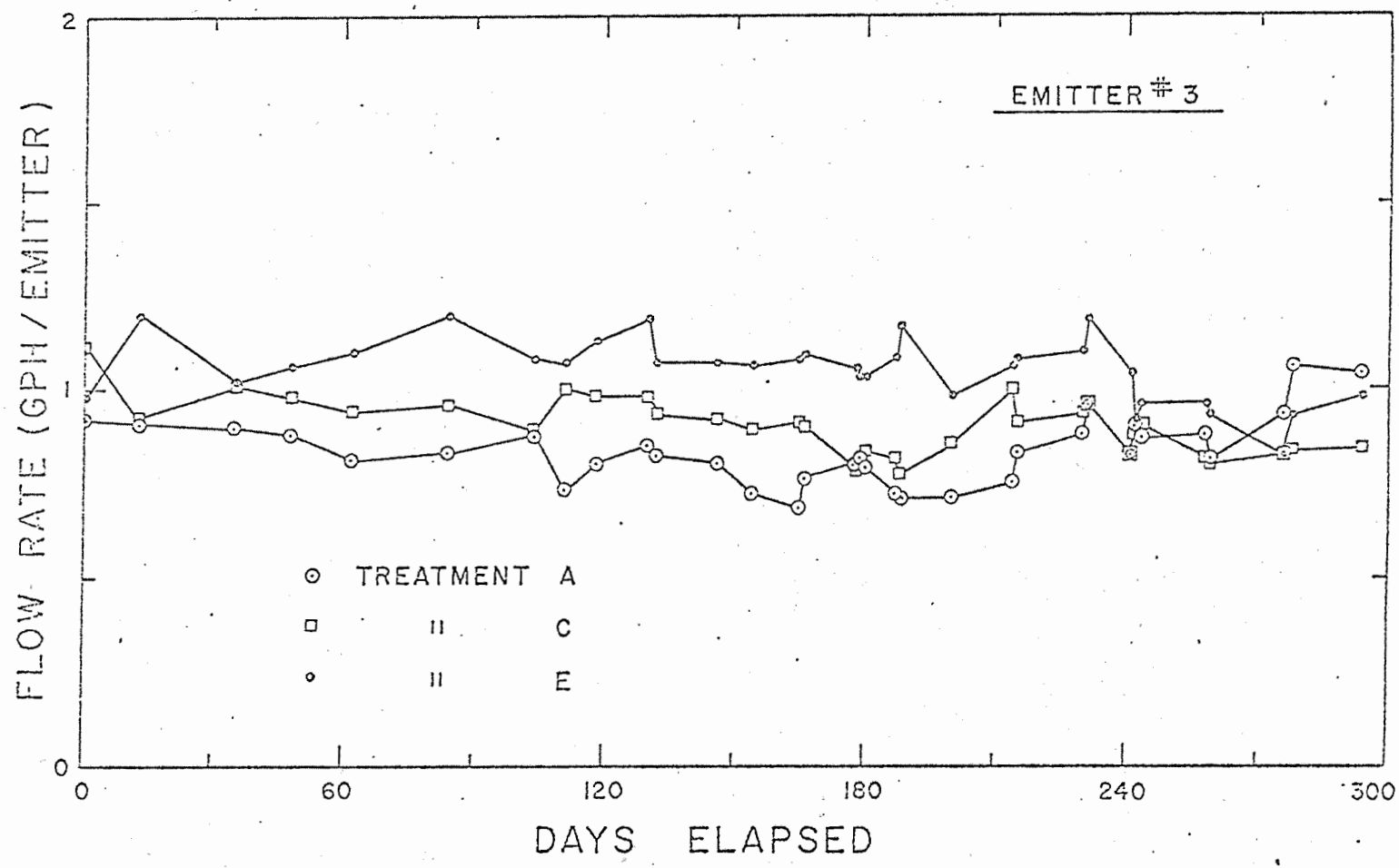

Figure 7. Flow rate of emitter no. 3 as a function of time for Treatments A, C, and E.

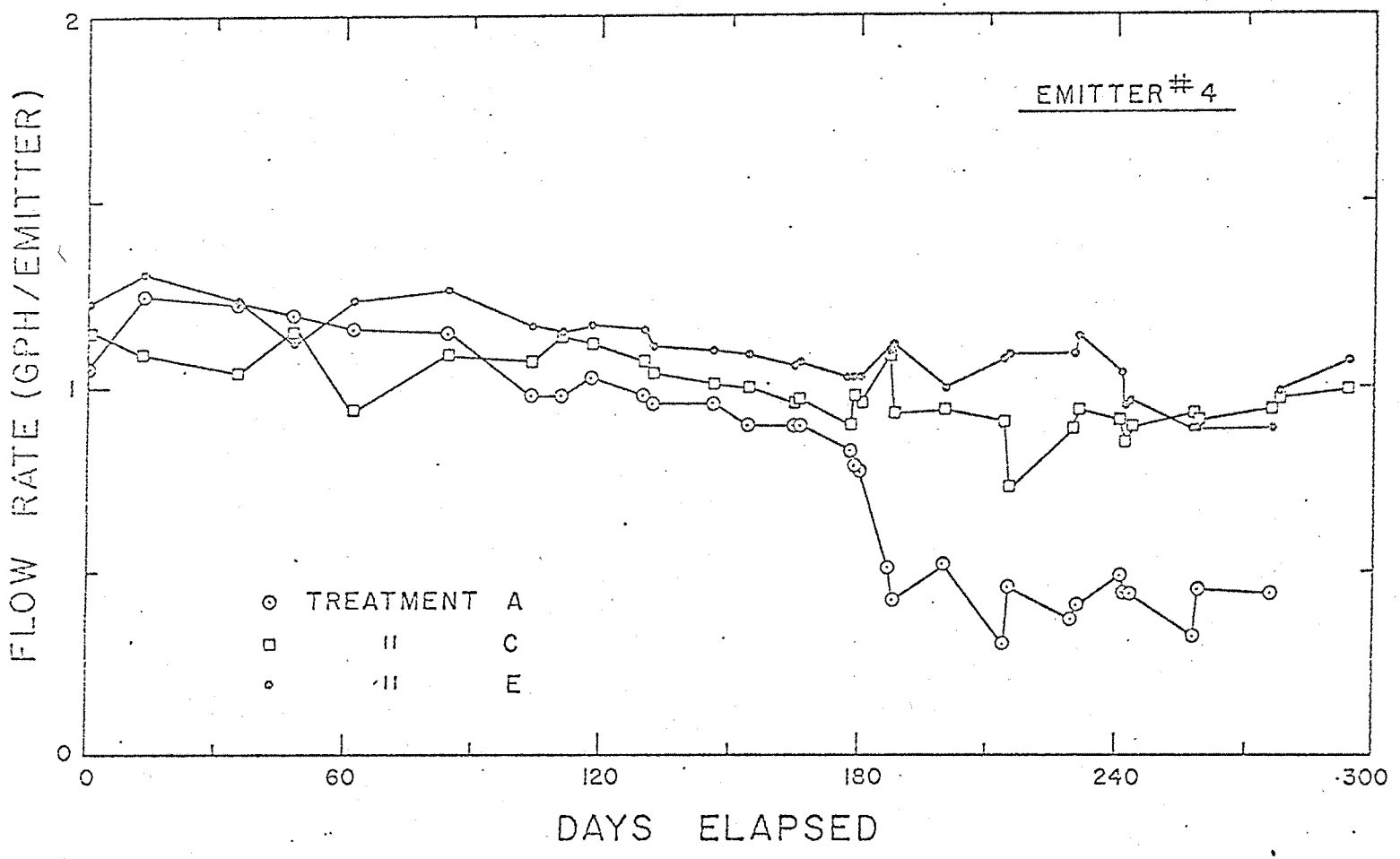

Figure 8. Flow rate of emitter no. 4 as a function of time for Treatments A, C, and E.

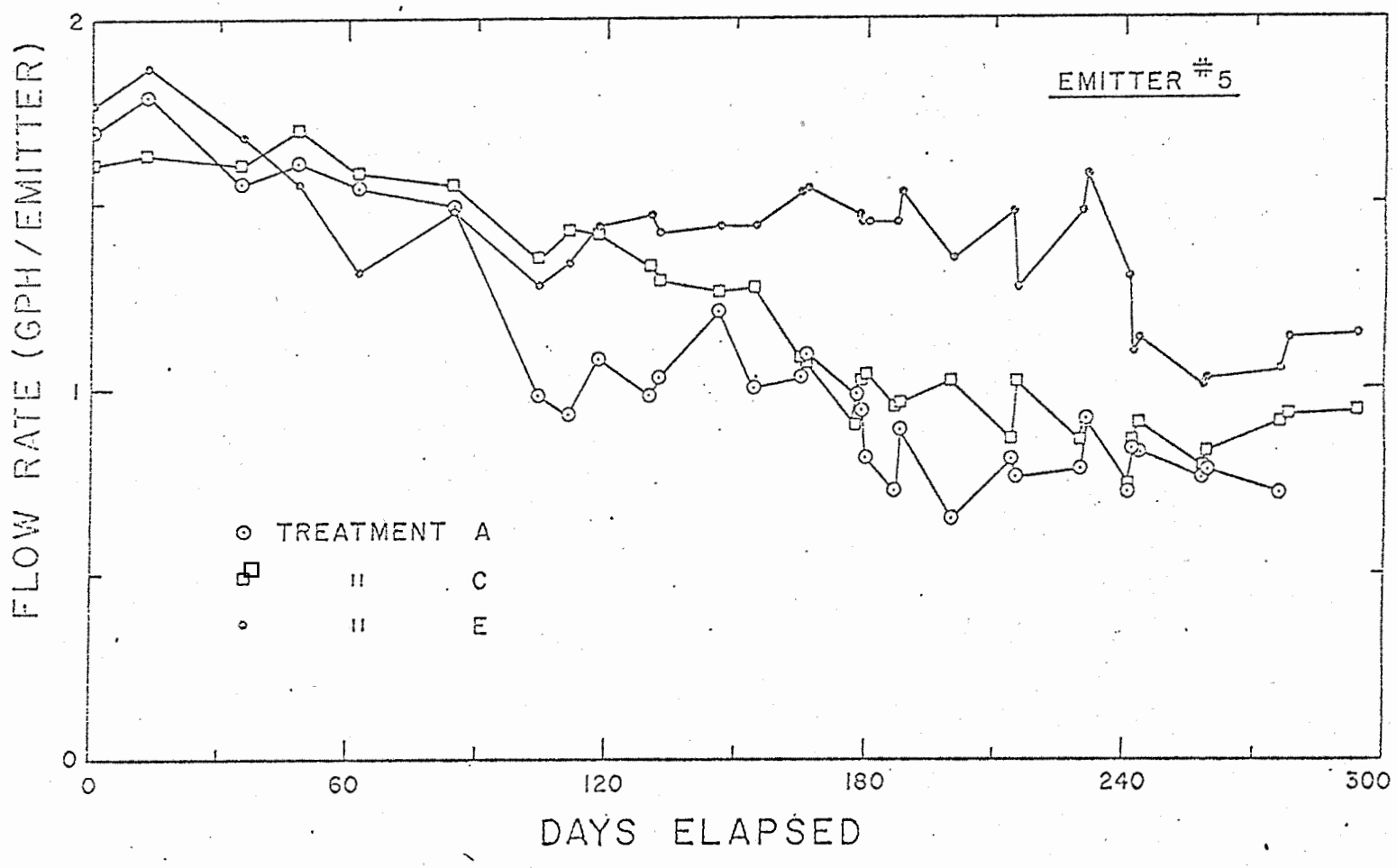

Figure 9. Flow rate of emitter no. 5 as a function of time for Treatments A, C, and E.

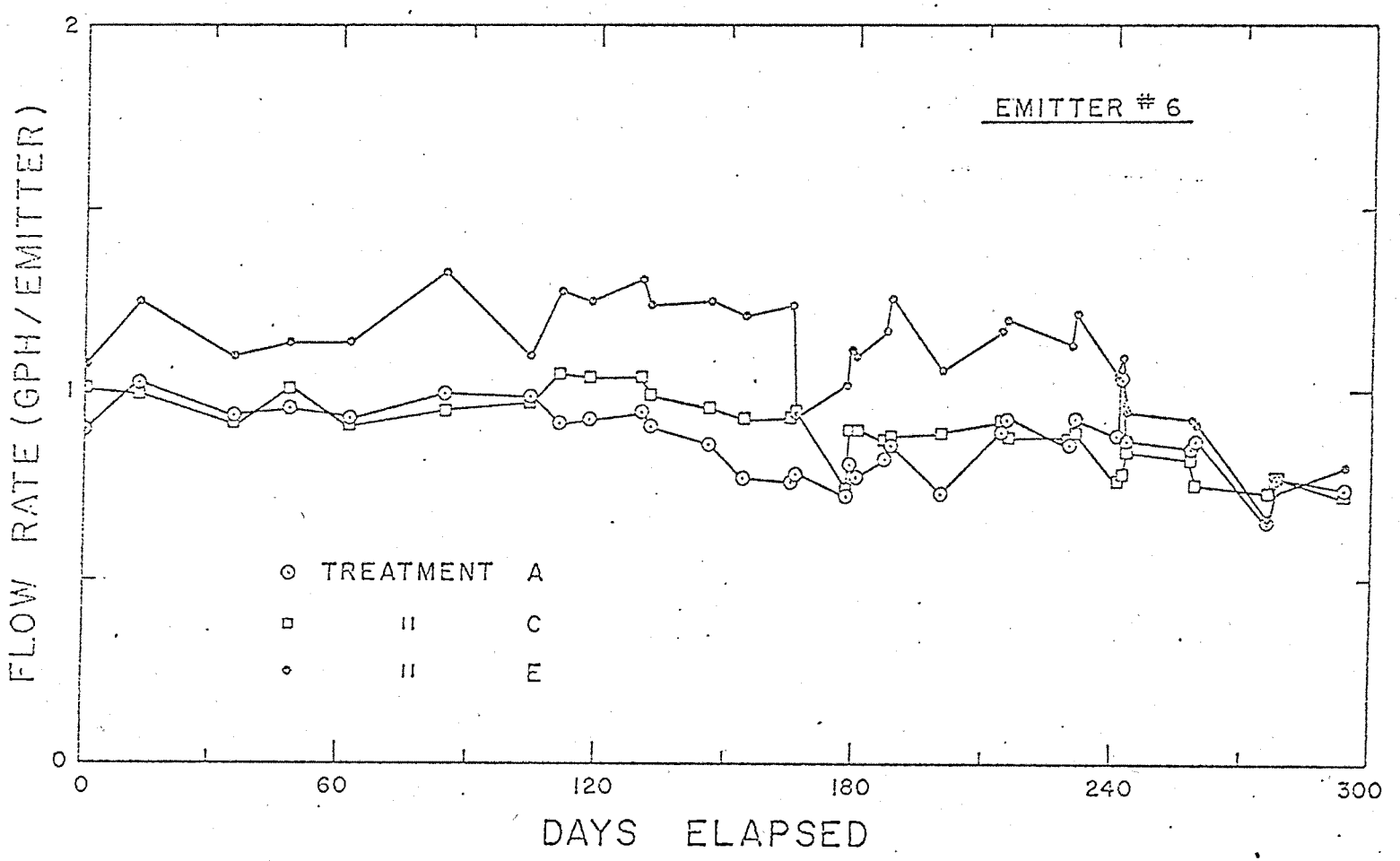

Figure 10. Flow rate of emitter no. 6 as a function of time for Treatments A, C, and E.

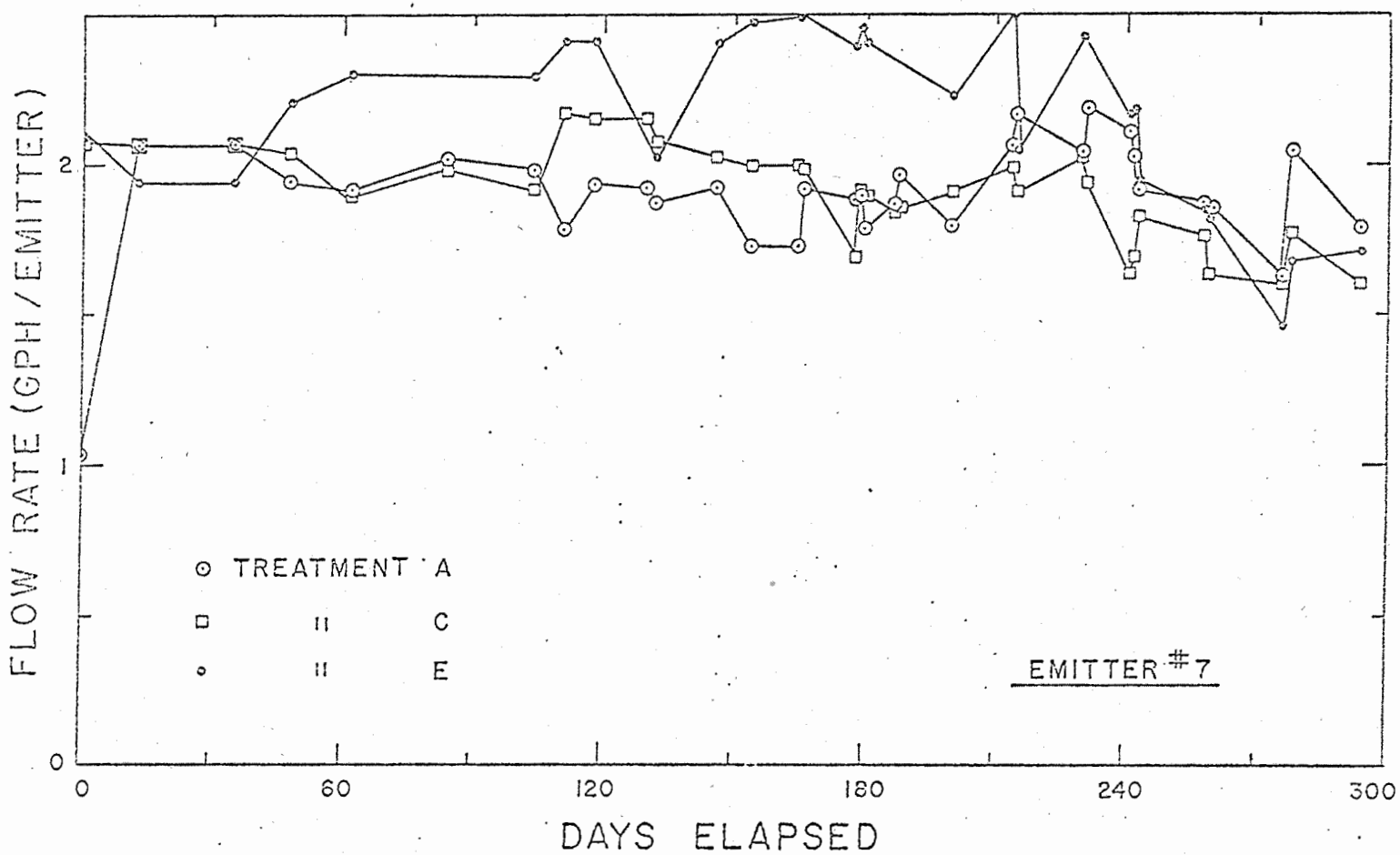

Figure 11. Flow rate of emitter no. 7 as a function of time for Treatments A, C, and E.

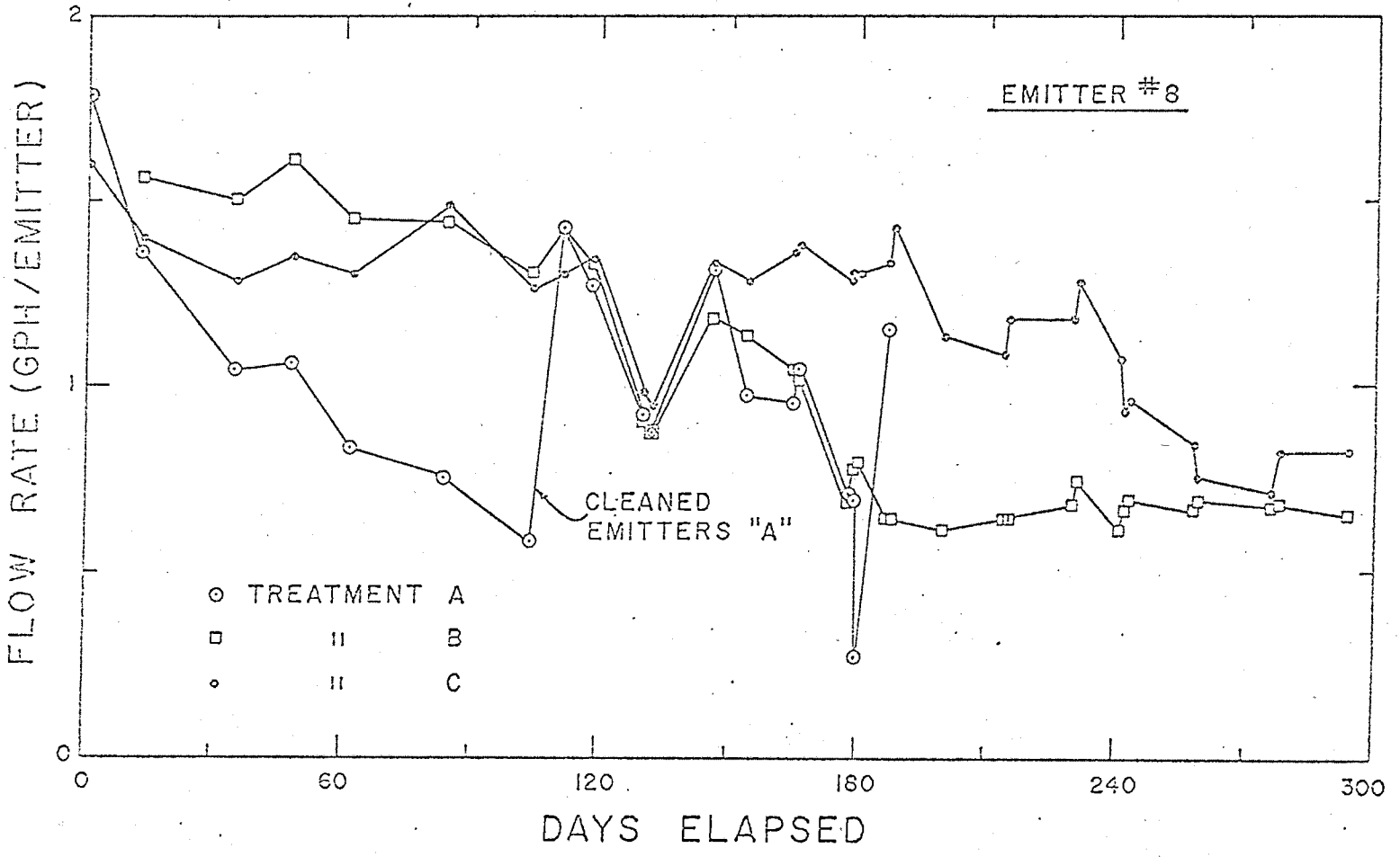

Figure 12. Flow rate of emitter no. 8 as a function of time for Treatments A, C, and E.

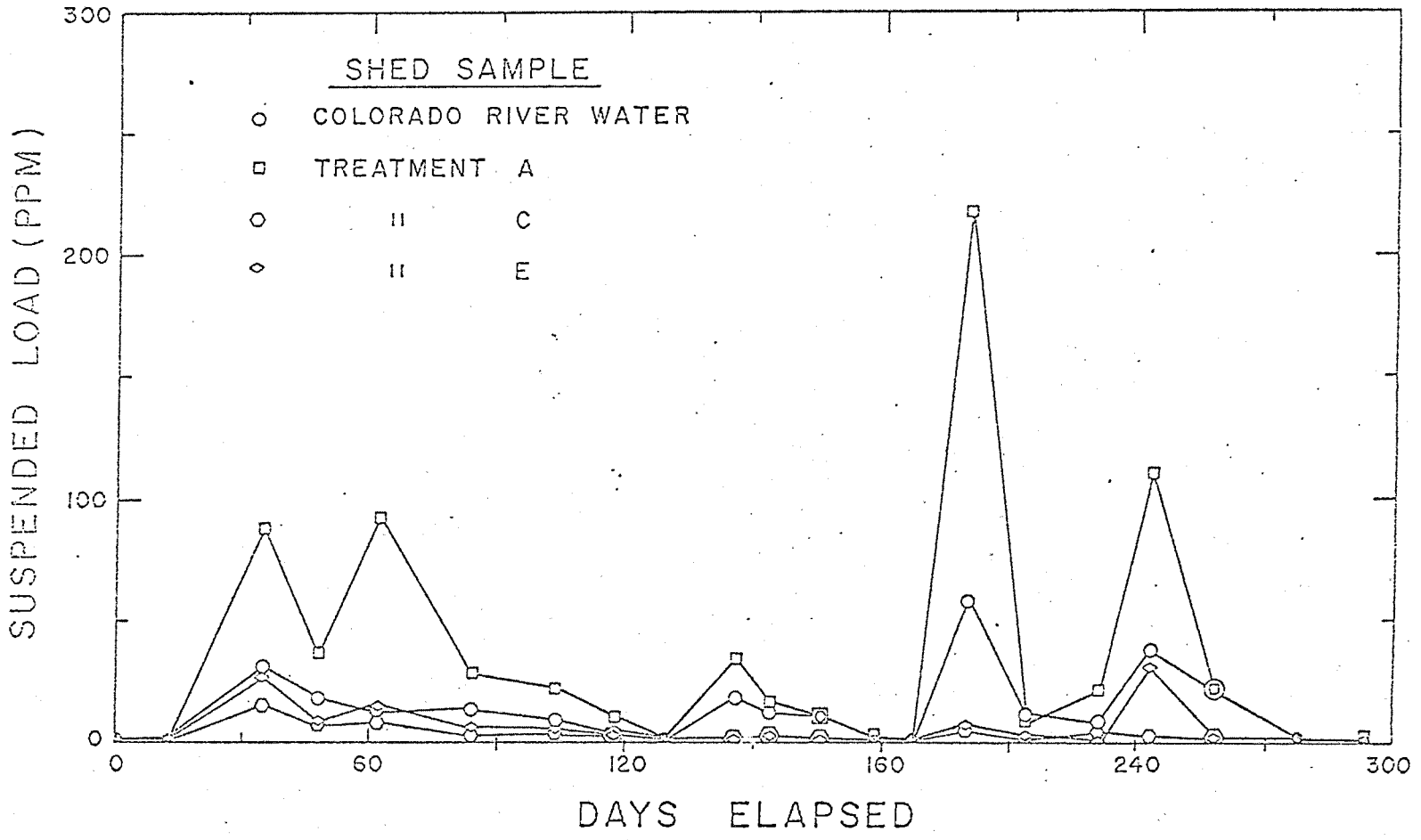

Figure 13. Suspended load of water samples taken in pump shed immediately after treatment.

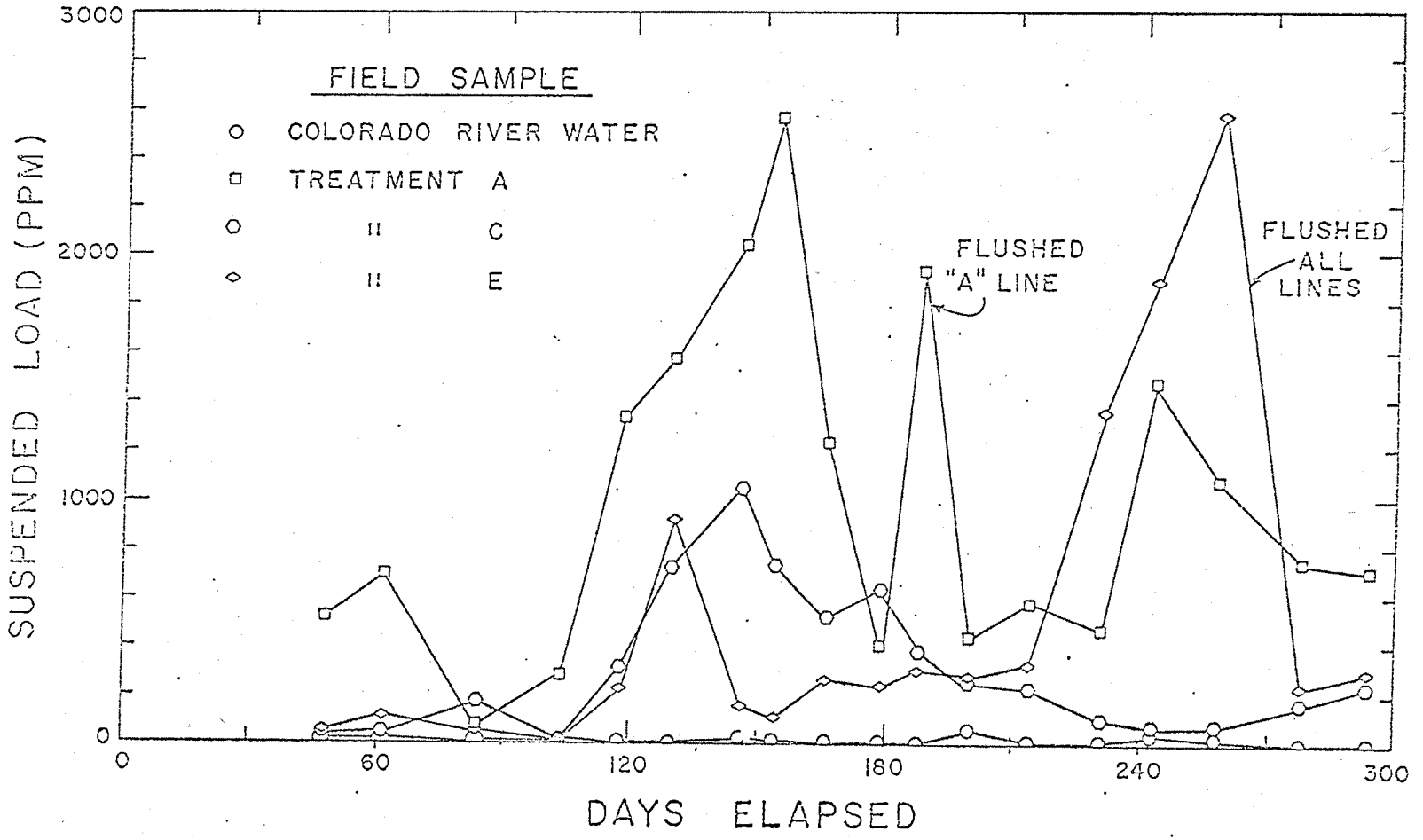

Figure 14. Suspended load of water samples in submains in the field.

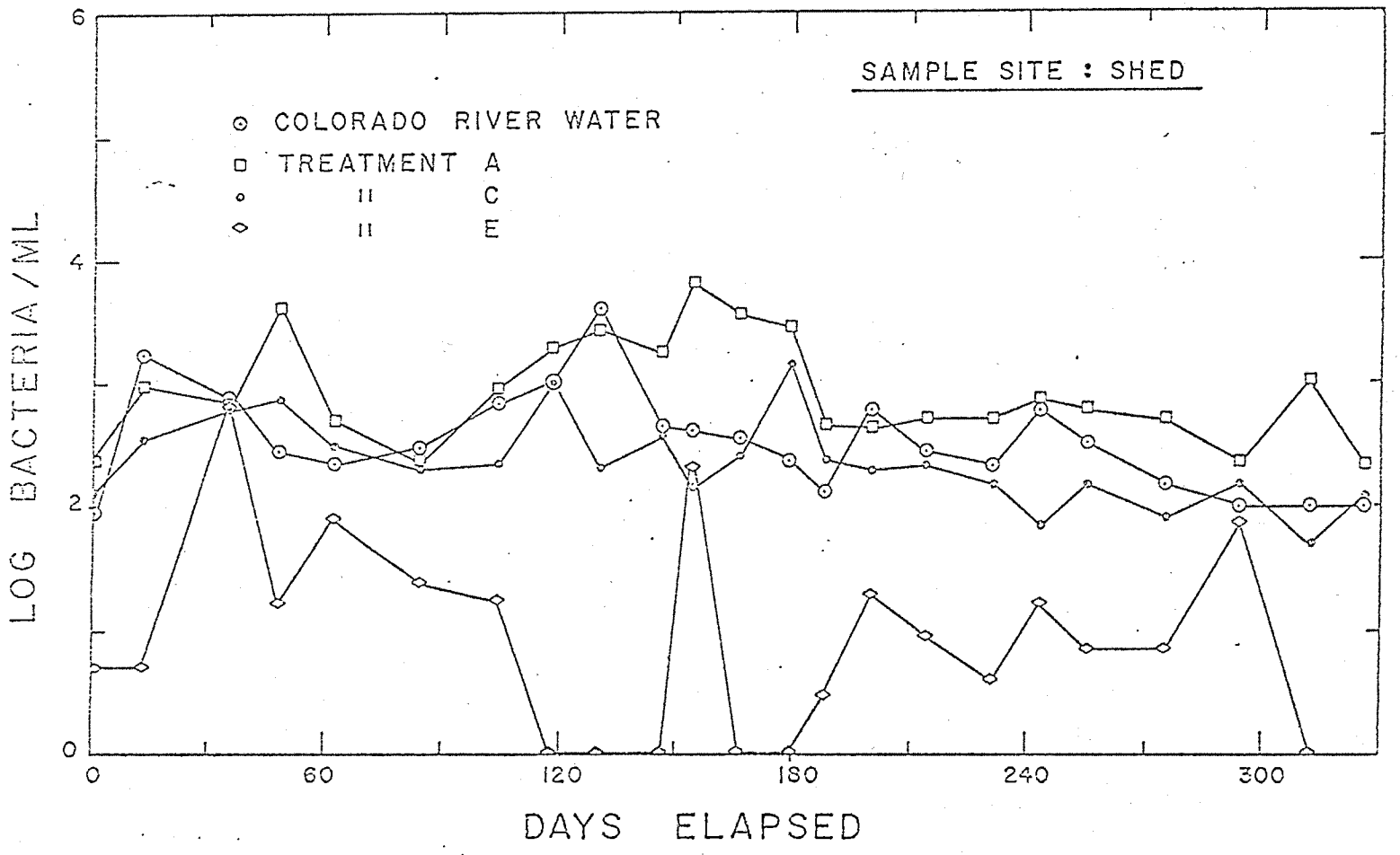

Figure 15. Bacterial population of water samples taken in pump shed immediately after treatment.

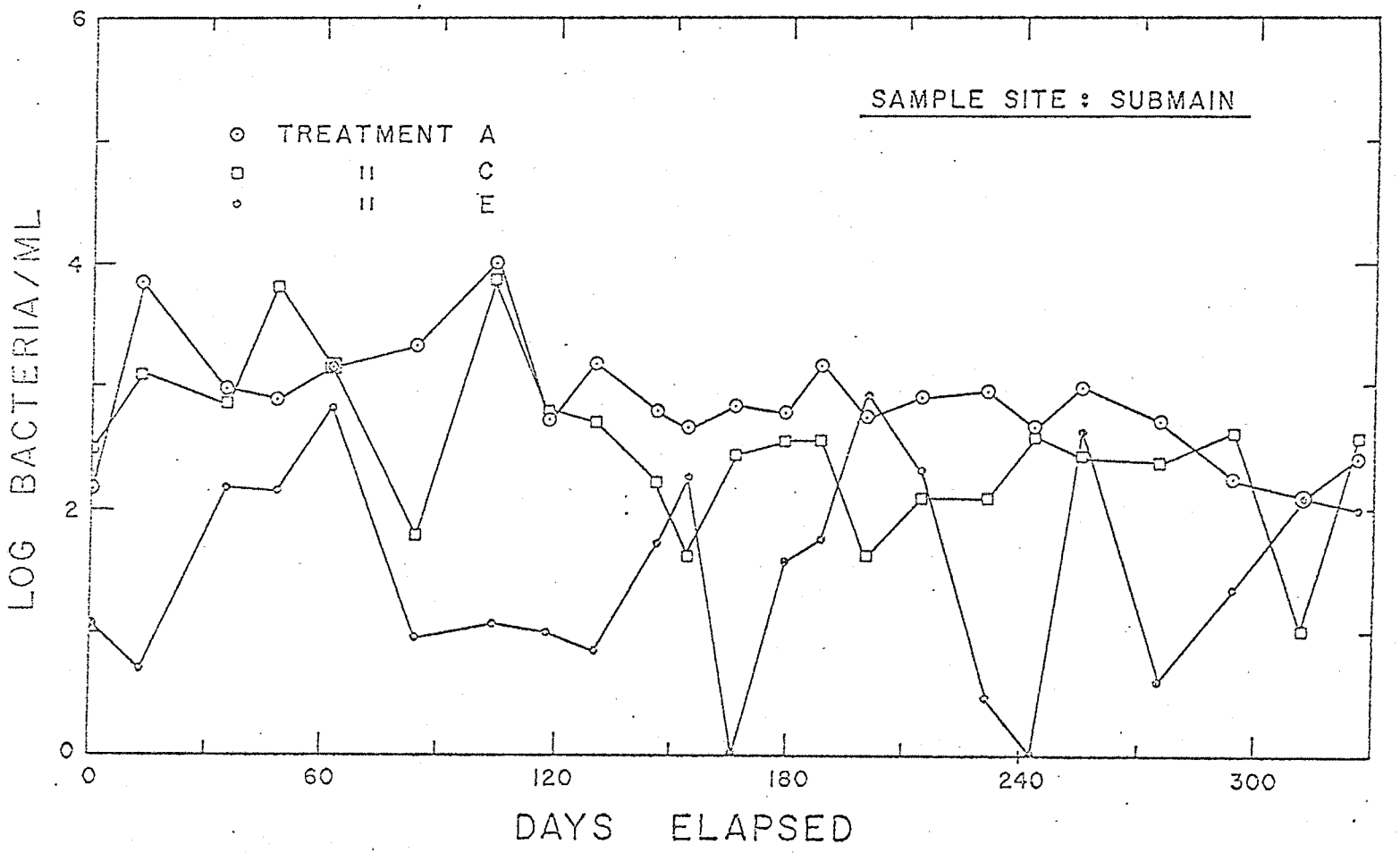

Figure 16. Bacterial population of water samples in submains in the field.

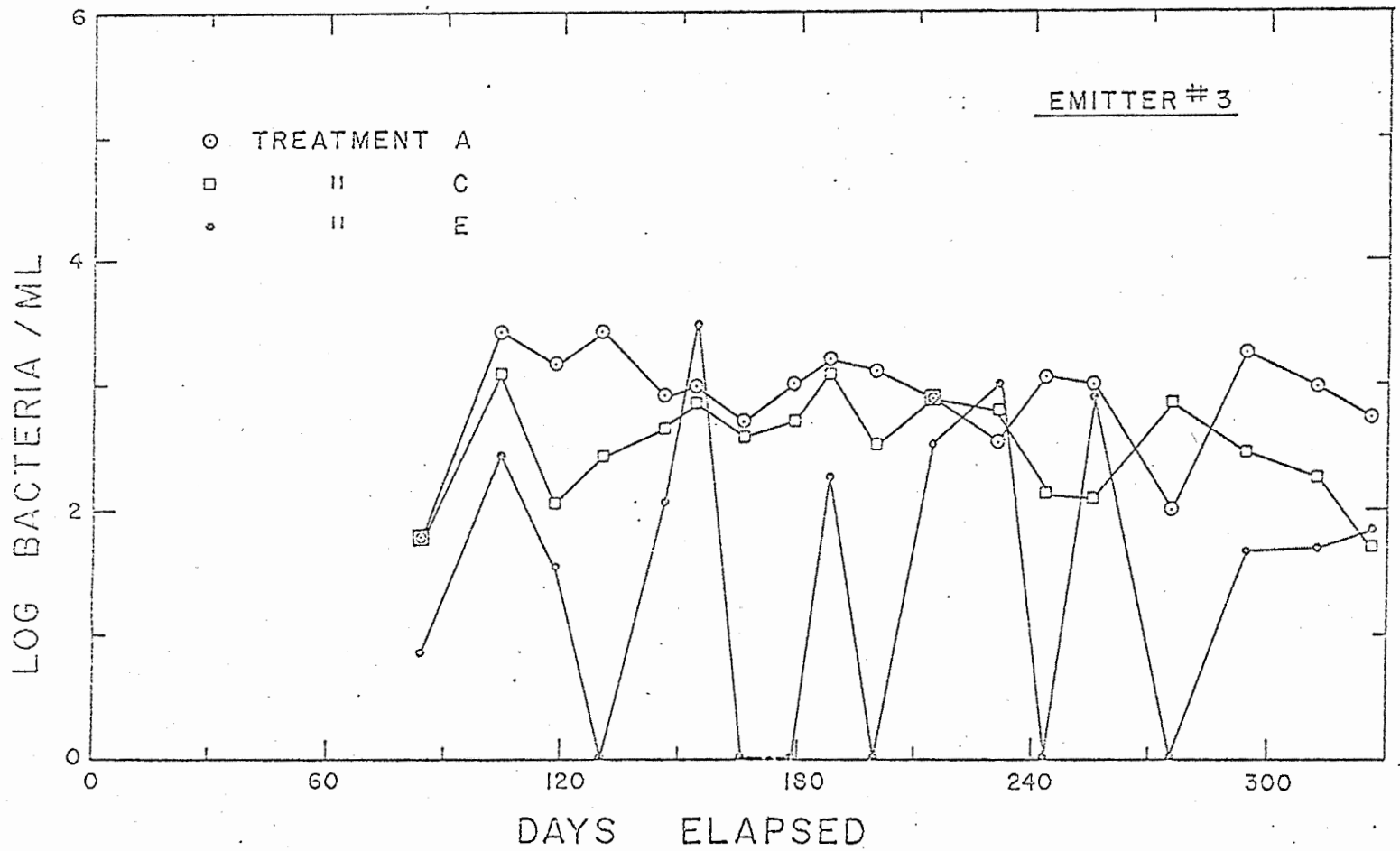

Figure 17. Bacterial population of water samples from emitter no. 3.

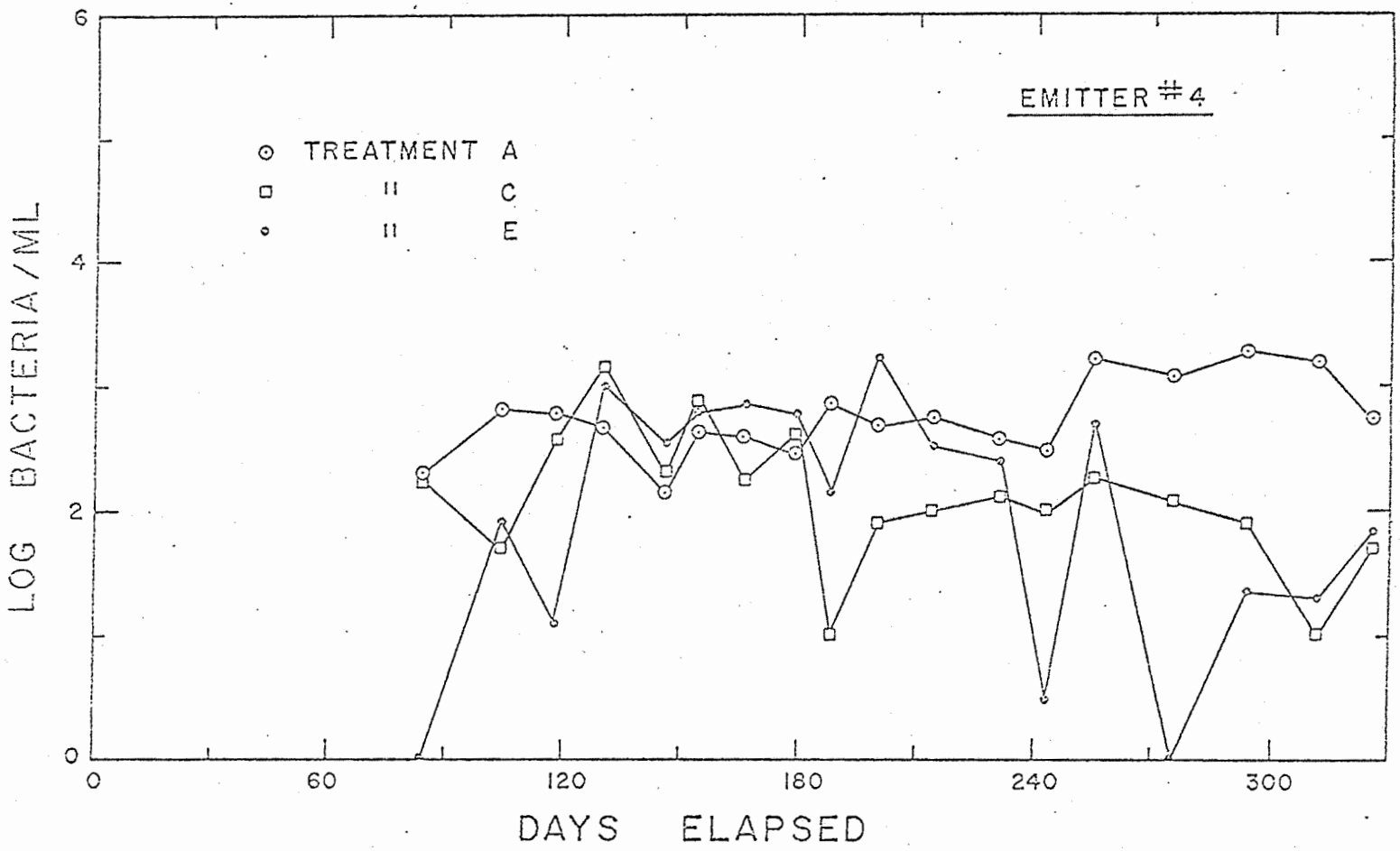

Figure 18. Bacterial population of water samples from emitter no. 4.

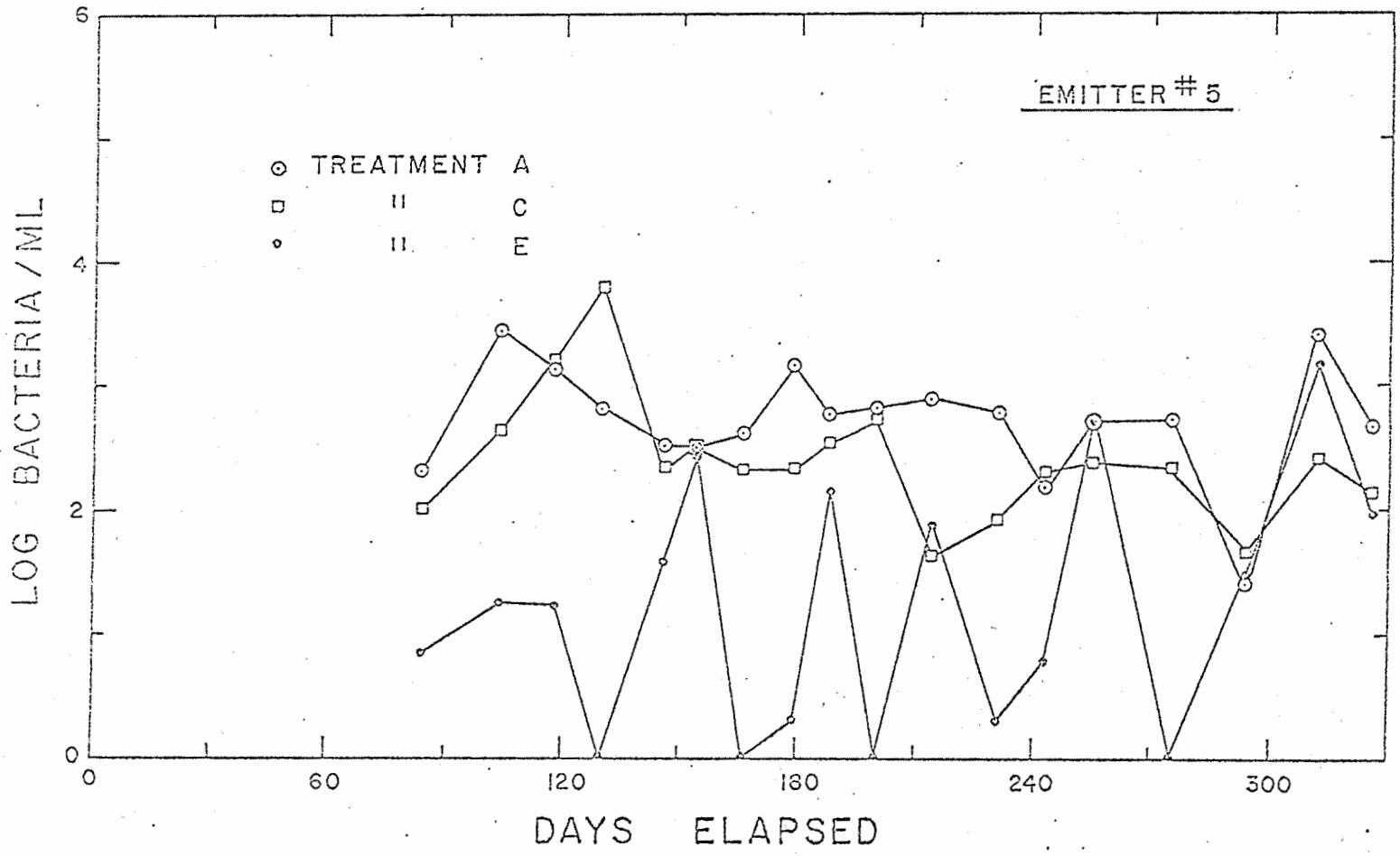

Figure 19. Bacterial population of water samples from emitter no. 5.

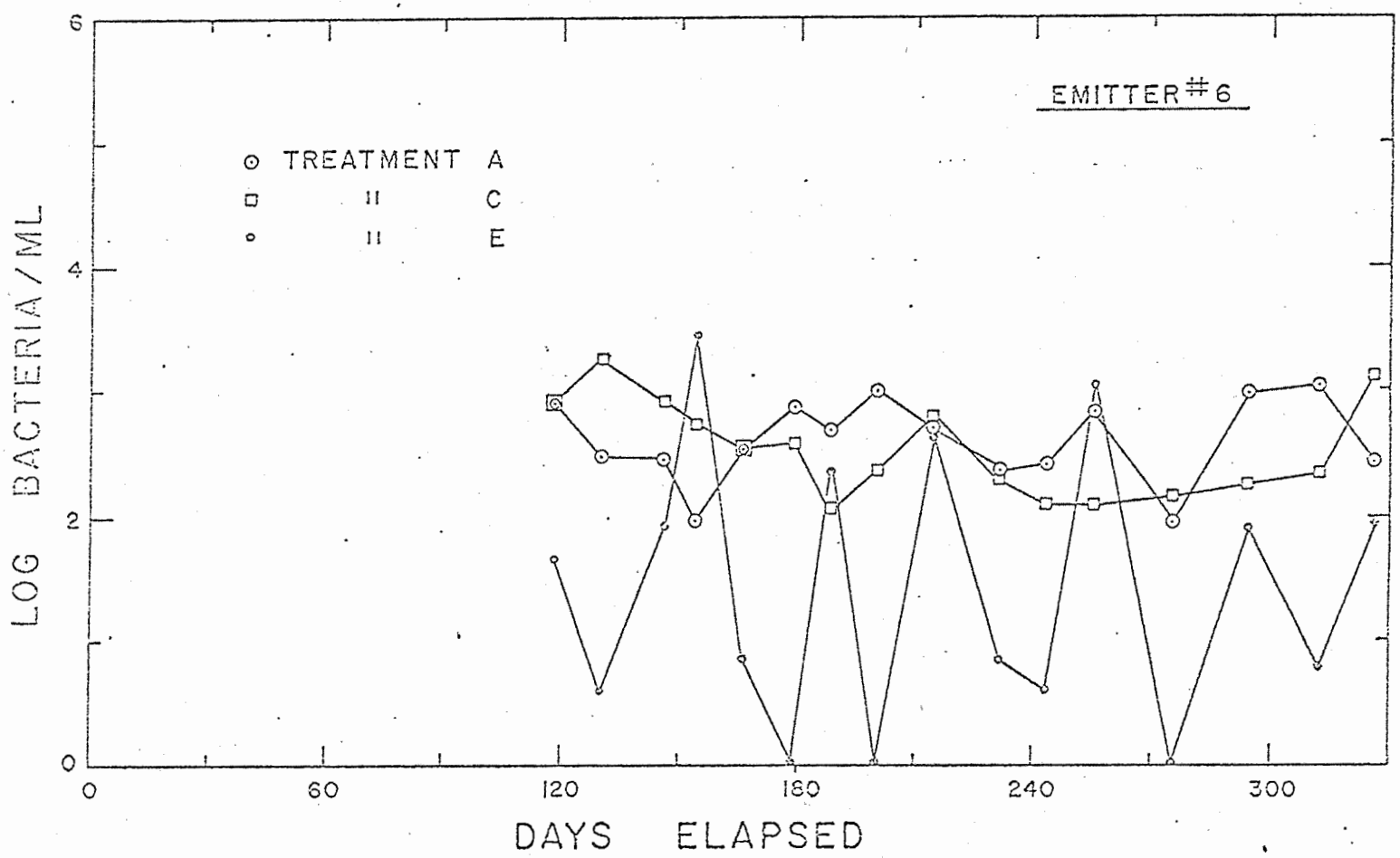

Figure 20. Bacterial population of water samples from emitter no. 6.

TITLE: WASTEWATER RENOVATION BY SPREADING TREATED SEWAGE FOR GROUNDWATER RECHARGE

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

INTRODUCTION:

Intensive work at the Flushing Meadows Project was discontinued in 1975 because of the extremely high incidence of vandalism and burglary. The work in 1975 was primarily aimed at maximizing denitrification in the soil by reducing loading rate and using optimum lengths of flooding and drying periods. Construction of the four 10-acre infiltration basins at the 23rd Avenue Project was completed in the spring of 1975. Observation wells were drilled at the northern and southern boundaries of the project in late spring. The production well for renovated water in the center of the basin area was drilled in the summer and was ready for pumping in early October. On 6 October, Mr. E. W. Errickson was hired by the City of Phoenix and assigned to the U. S. Water Conservation Laboratory to work on the 23rd Avenue Project. The work in 1975 consisted mainly of well tests to determine hydraulic properties of the aquifer, of measuring infiltration rates, and of evaluating the quality of the sewage effluent going into the basin and that of the renovated water from the Center Well.

I. FLUSHING MEADOWS PROJECT

1. Basin Management and Infiltration Rates.

Because maximizing denitrification was the prime objective, the basins were not cleaned so that sludge and other organics could accumulate on the bottom. The resulting sludge layer was about 1/2 to 1 inch thick. This layer probably produced lower infiltration rates and additional organic carbon, both of which tend to increase denitrification. The condition of the basins in 1975 was as follows.

Basin 1. Bare soil with sludge layer.

Basin 2. Gravel with sludge layer.

Basins 3 and 4. Decaying old sudangrass stubble with sludge layer.

Basins 5 and 6. Decaying old bermudagrass stubble with sludge layer.

The flooding schedule was 8 days pumping (9 days flooding) and 13 days no pumping (12 days drying) for all basins. In basins 1 and 2, the water depth was kept at about 3 inches (no boards in outlet) for the first 2 days of flooding and raised to about 7 inches (1 board in outlet) for the remaining 6 days of the flooding period. The purpose of the low depth for the first 2 days of the flooding period was to reduce initial infiltration rates, which has been known to increase denitrification. For the other basins (3, 4, 5, and 6), the water depth was maintained at about 7 inches (1 board in outlet) during the entire flooding period.

The infiltration rates (Figure 1) in basins 1 and 2 were between 0.5 and 1.5 ft/day during flooding, with an average of 0.9 ft/day. Total infiltration for the year was 124 ft for basin 1 and 141 ft for basin 2 (Figure 2). Basins 3, 4, and 5 averaged about 1.4 ft/day infiltration and had total infiltration amounts of about 210 ft in the year. Basin 6 had lower infiltration rates, which may be partly due to the higher amounts of suspended solids that this basin receives because it is located at the end of the supply line. Average total infiltration for all basins was 173 ft in 1975. This was lower than the 300 ft/year obtained in previous years at water depths of 13 inches and flooding and drying periods of about 2 weeks each.

The static water table (during drying) in 1975 was at a depth of about 20 ft, which is some 10 ft lower than in the years before.

2. Nitrogen.

The graphs of total-N in effluent and NO_3-N and NH_4-N in the renovated water (Figures 3, 4, and 5) show that N-removal averaged 53% for basins 1 and 2, 59% for basins 3 and 4, and 69% for basins 5 and 6. The lower infiltration rates during the first two days of flooding in basins 1 and 2 apparently did not produce more denitrification than the normal infiltration rates in other basins. Another reason for the lower N-removal below basins 1 and 2 may be the fact that these basins have never been vegetated, which could result in lower organic carbon levels in the soil and, hence, less denitrification.

Taking the average N-content of the sewage effluent as 30 mg/l, N-removal was 5,688 lbs per acre per year for basins 1 and 2, 9,916 lbs per acre per year for basins 3 and 4, and 9,920 lbs per acre per year for basins 5 and 6. Thus, for basins 3, 4, 5, and 6, total N-removal was about the same as obtained in previous years with loading rates of about 300 ft/year. The lower loading rate (about 190 ft/year) in 1975 thus yielded a greater percentage N-removal and, hence, a lower N-content of the renovated water.

The renovated water showed the characteristic NO_3-peaks. The absence of the peaks for the first four months in the renovated water from well 5-6 is due to the fact that the peaks apparently occurred on week-ends when no samples were taken. The situation was remedied by changing the starting day of the flooding period. The NH_4-N levels in the water gradually decreased over the year, which is desirable and indicates that the management of the basins does not lead to nitrogen accumulation in the soil and resulting decrease in efficiency of nitrogen removal.

Average N-concentrations in the renovated water, based on the N-removal percentages and a total-N content of 30 mg/l in the effluent, were (in mg/l)

Basins	Total N	NO_3-4	NH_4-N
1 and 2	14	10	4
3 and 4	12	3	9
5 and 6	9	3	6

These figures are not exact, but they do show that the NO_3-N content of the renovated water is below the maximum limit of 10 mg/l for drinking water. The low NO_3-N contents in the renovated water may not be immediately apparent from the graphs. It should be remembered, however, that the underground flow system is essentially stagnant during drying, so that NO_3-levels in the renovated water should only be considered during flooding. Grab samples of renovated water from an outlying well showed low N-levels (Table 1). This may be due to

the fact that the well was only occasionally sampled and NO_3-peaks could have been missed.

3. Phosphorus.

The average PO_4-P content of the sewage effluent was 8.4 mg/l (Figures 6, 7, and 8), indicating that the phosphate content in the sewage effluent is still on a downward trend from the 15 mg/l observed in 1967 and the 10 mg/l in the early 1970's. The average PO_4-P contents of the renovated water were 1.7 mg/l for well 1-2, 0.8 mg/l for ECW, and 0.9 mg/l for well 5-6, yielding removal percentages of 80, 90, and 89%. These percentages are higher than the approximately 50% previously obtained when hydraulic loading rates were greater. Thus, lower hydraulic loading rates also increased the phosphate removal efficiency.

4. Dissolved Salts.

The TDS-content of effluent and renovated water was mostly in the 900 to 1,000 mg/l range (Table 2), which is sligthly less than previously observed.

5. Fluoride.

The fluoride content of the effluent was less than the 4 to 5 mg/l concentrations previously observed (Table 3). This may have been due to the slow-down in the electronic industry in the Salt River Valley. F-levels in the renovated water were about the same as before.

6. Boron.

Boron levels in the effluent and renovated water were about 0.5 mg/l, which is lower than the 0.8 and 0.9 mg/l levels observed in previous years. As before, B-levels in the renovated water were essentially the same as in the effluent.

7. Summary and Conclusions.

The annual hydraulic loading rate of the basins at the Flushing Meadows Project was lowered from roughly 300 ft applied in previous years to 173 ft in 1975. This resulted in an increase in the nitrogen removal to about 60% and an increase in phosphate removal to 90% for renovated-water samples taken at 30-ft depth in the

center of the basin area. Reducing the infiltration rates for the first two days of flooding (by reducing the water depths in the basins) did not increase nitrogen removal. Nitrate-nitrogen levels in the renovated water were below 10 mg/1, which is the upper limit for drinking water. Ammonium levels in the renovated water showed a decreasing trend for most of the year and ranged between 1 and 5 mg/1 at the end of the year. Reduced hydraulic loading yields renovated water with lower N and P levels than obtained with maximum hydraulic loading. Fluoride and boron in the sewage effluent were less than in previous years, i.e. about 2.4 mg/1 and 0.55 mg/1, respectively. The studies with lower hydraulic loading rates will be continued in 1976. At 173 feet infiltration per year, however, the system is still very much high-rate.

II. 23RD AVENUE PROJECT

1. Infiltration Rates.

Infiltration rates for basins 1 (the northern most basin), 2, 3, and 4, (the southern most basin) are shown in Figures 9, 10, 11, and 12. The basins were flooded about 2 weeks to a depth of 3 ft and dried for about 2 to 4 weeks. Some basins did not completely drain by gravity. The standing water developed additional algae growth and infiltrated very slowly. This resulted in poor infiltration recovery for parts of the basins and actually rendered these parts ineffective for rapid-infiltration. Infiltration rates generally started at between 1 and 2 ft/day but then dropped rapidly to often less than 0.5 ft/day after 2 weeks of flooding. The low infiltration rates are probably due to the high algae content (about 50 mg/1) of the effluent from the 80-acre pond, which is the influent for the infiltration basins. Additional algae growth took place in the infiltration basins themselves. The algae were of the single-cell type. They did not settle out near the inlet of the basins and formed a filter cake on the entire bottom as water infiltrated into the soil. The filter cake was 1/4 to 1/2 inch thick and did not readily decompose or shrivel up during drying. Harrowing during drying, which was done for basin 3 on 19 September and for basin 4 on 29 August

and 6 November, increased the initial infiltration rate when flooding was resumed, but algae clogging soon dropped the infiltration rates again to low values.

Accumulated infiltration amounts for a period of roughly the last 6 months of the year were

Basin 1	41.3 ft
Basin 2	53.6 ft
Basin 3	41.7 ft
Basin 4	41.2 ft

On an operational basis, longer flooding and/or shorter drying periods could be employed to yield an anticipated loading rate of about 100 ft/year. For the four 10-acre basins, this means 4,000 acre-feet/year or about 3.6 mgd or 2,480 gpm. Higher infiltration rates could probably be obtained by:

1. Lowering the outlets of the infiltration basins at the west end and/or filling the low areas in the basins to avoid incomplete drainage and resulting standing water in the basins during drying.

2. Modifying the outlets to maintain an outflow during flooding, thus decreasing the detention time in the infiltration basins and reducing additional algae growth in the basins.

3. Using secondary effluent from the channel rather than the flow from the 80-acre pond as influent for the infiltration basins. This can be achieved by installing a pipeline from the by-pass channel to the inlet structures on the west end of the 80-acre pond. Engineering plans for such a pipeline are being developed. Secondary effluent will probably yield higher infiltration rates because the solids settle faster. Solids would then only accumulate on the soil surface near the inlet end, leaving the rest of the basin essentially clean. Also, a sludge layer on the soil surface caused by the normal suspended solids in the effluent dries, shrinks, and decomposes better during drying than an algae crust.

2. Well Tests.

The Center Well is 200 ft deep and cased with 2-ft diameter stovepipe for its entire length (Figure 13). The geologic formations

were the typical sand and gravel layers or "river run" found in the Salt River Valley. A clay layer may be present at a depth of about 220 ft. The casing was perforated in place with the louver-type perforator from a depth of 100 ft to 180 ft. The bowls are set from 153 to 161 ft, and the intake strainer is 10 ft long. The static water level is at a depth of 60 ft.

Upon completion of the well and prior to placing the pump, the hydraulic conductivity, K, of the aquifer around the well was determined with a slug test on 30 July, using the procedure of Bouwer and Rice (USWCL Publication No. 523, in press with Water Resources Research). The water level in the well was lowered 7 cm by the rapid removal of a submerged cylinder. The subsequent rise was measured with a Statham Model 131 pressure transducer whose output was recorded on an Esterline Angus Model MS401BB millivolt recorder. The resulting time and water-level readings produced a straight line on semi-log paper (Figure 14), in accordance with the theory. The test yielded a K-value of 29.2 m/day, which is between the horizontal and vertical K-values of 86 and 5.4 m/day, respectively, found at Flushing Meadows, and also within the range of the 10 to 236 m/day obtained with the individual well tests at Flushing Meadows. Since the Center Well had not yet been pumped, some drilling mud and other fines may still have been present in the aquifer around the well at the time of the slug test. Assuming an aquifer thickness of 50 m, the transmissivity of the aquifer below the 23rd Avenue basins is 1460 m^2/day.

After the pump and power unit were installed, a step-drawdown test was performed on the Center Well on 12 November. The well pumping-rate was increased about every 20 minutes while measuring the depth of the water level inside the well with a bubble tube. The resulting data (Figure 15) were analyzed with the logarithmic trial-and-error technique to determine the coefficients and exponent in the equation

$$s_{iw} = C_f Q + C_w Q^n$$

where s_{iw} = total drawdown inside well,

C_f = formation factor,

C_w = well-loss factor,

n = exponent for turbulent flow ($n > 2$), and

Q = discharge

The results were:

$$C_f = 4.34 \times 10^{-4} \text{ day/m}^2,$$

$$C_w = 1.37 \times 10^{-19} \text{ days/m}^2, \text{ and}$$

$$n = 4.79$$

Using these values, the total drawdown is broken down into the head loss s_f in the formation and the head loss s_w due to entry into the well (Figure 16). The sum of s_f and s_w (dashed line) agrees with the observed total drawdowns.

Since $C_f = \ln(r_2/r_w)/2\pi T$, where r_2 is the radius of influence of the well, the transmissivity T can be calculated from C_f if r_2 is known. Assuming r_2 = 100 m and r_w = 0.5 m, this yields T = 1900 m^2/day, which is slightly higher than T evaluated by the slug test and may show the effect of additional well development after the pump was installed.

The water levels in the observation wells showed a rising trend (Figure 17). The observation well in the center of the northern edge of the basin area showed greater response to flooding of the basins than did the well in the center of the southern edge of the basin area. This is apparently due to an accumulation of mud on the bottom of the South Well. The water level in the North Well rose about 10 ft in November and December when basins 1 and 4 and basins 2 and 3 were flooded. Then it declined in December when basin 4 was flooded only. Studies on managing infiltration rates and pumping schedules to obtain a constant level in the observation wells (no groundwater flow to or from the renovation system) will be started when the other two production wells on the center dike are also installed.

3. Suspended Solids.

Figure 18 shows the suspended solids content of the secondary effluent as it enters the 80-acre pond, of the outflow from this pond as it enters the infiltration basins, of the water in the infiltration basins sampled about 800 ft from the inlet, and of the renovated water from the Center Well. The SS-content of the secondary effluent is low in the summer (< 20 mg/l) but reaches an average of about 50 mg/l in the winter. The outflow from the 80-acre pond has a high SS-content (about 50 mg/l) in the summer due to algae growth, but a low SS-content (about 20 mg/l) in the winter when the algae do not grow as rapidly. The lower SS-content in the winter may explain the increase in infiltration rates during the winter. High algae contents are also observed for the water in the infiltration basins, especially towards the end of a flooding period and in stagnant water during drying. SS-concentrations in excess of 200 mg/l have been measured. The renovated water from the Center Well is essentially free from suspended solids, except during the beginning of pumping when fines (including drilling mud) moved from the aquifer into the well during development.

4. Nitrogen.

The total nitrogen content of the effluent from the 80-acre pond as it entered the infiltration basins was about 22 mg/l, mostly as ammonium (Figure 19). The nitrogen of the renovated water from the Center Well was essentially all in the nitrate form and its concentration gradually decreased from about 30 mg/l to 10 mg/l during the first 3 months of sampling and pumping. The NH_4-N content of the renovated water was less than 1 mg/l. One reason for the decrease in total N-content of the renovated water may be that the seepage from the basins when the area was still used as one oxidation pond originally contained more nitrogen. As this water is gradually displaced by the water infiltrating from the recharge basins, lower N-levels can be expected because the intermittent flooding of the basins should produce some denitrifcation in the underlying soil.

5. Phosphorus.

Concentrations of PO_4-P averaged about 8 mg/l in the effluent from the 80-acre pond and about 0.2 mg/l in the renovated water from the Center Well (Figure 20). This is a high degree of phosphate removal (about 97%), which may be due to the relatively large depth to the groundwater and pumping depths. The renovated water must then move through the finer textured layers in the profile above as well as below the water table.

6. Fluoride.

Fluoride concentrations were determined on one set of samples, which yielded a concentration of 1.2 mg/l for the 80-acre-pond effluent and 0.4 mg/l for the renovated water from the Center Well.

7. Boron.

Boron was also determined once, yielding concentrations of 0.6 mg/l for both the 80-acre-pond effluent and the renovated water from the Center Well.

8. Dissolved Salts.

Ignoring the high TDS-level for the 80-acre-pond effluent in October, the effluent had an average TDS content of about 870 mg/l (Figure 21). The renovated water from the Center Well initially had a higher TDS content, about 1,100 to 1,200 mg/l, but this dropped to about 950 mg/l after 3 months of operation. Apparently the infiltration from the basins had displaced groundwater with a higher TDS content.

9. Fecal Coliforms.

The fecal coliform content was about 10^6 per 100 ml for the secondary effluent going into the 80-acre pond, and about 10^4 per 100 ml when it entered the infiltration basins (Figure 22). Fecal coliform contents were zero for the renovated water from the Center Well, except for a count of 1 per 100 ml when the well was first pumped and counts of 10 and 2.5 per 100 ml at the end of November and the beginning of December, respectively. The latter two counts coincided with flooding periods for basins 2 and 3, which are right next to the Center Well. Hence, these counts, which are still well

below the upper limit of 200 fecal coliforms per 100 ml for unrestricted irrigation, are probably due to the arrival of renovated water at the well that did not have much lateral movement below the water table. However, as previously observed at Flushing Meadows, the fecal coliforms dropped to zero with continued flooding.

10. Summary and Conclusions.

The projected annual hydraulic loading rate for the newly constructed 23rd Avenue high-rate recharge system is about 100 ft per year (based on infiltration amounts of 41 to 54 ft for a period of roughly 6 months). For the 40-acre total basin area, this amounts to 4,000 af per year, 3.6 mgd, or 2,480 gpm. This low rate is primarily due to the high algae content of the influent, which is the effluent from an 80-acre oxidation pond receiving secondary (activated sludge) effluent, and to poor surface drainage of the basins during drying. Infiltration rates rapidly decreased during flooding due to formaion of an algae cake on the entire bottom area of the basins. This cake decomposed poorly and did not crack or shrivel up during drying, in contrast to a "normal" sludge layer. Higher infiltration rates can probably be obtained if the secondary effluent is used directly and not after it has passed through an oxidation pond.

Well tests on the 2-ft diameter and 200-ft deep production well in the center of the basin area yielded aquifer transmissivities of 1460 m^2/day (using the slug test before the pump was installed) and 1900 m^2/day (using the step-drawdown test after pumping). These data will be used in later studies of the underground flow system. The water table was at a depth of 60 ft.

The quality of the renovated water was excellent. The concentration of total N decreased from 30 to 10 mg/l during pumping, PO_4-P was about 0.2 mg/l, fluoride 0.4 mg/l, boron 0.6 mg/l, and TDS 870 mg/l. Fecal coliforms were absent, except for counts of 1 to 10 per 100 ml obtained when pumping was first started or when the basins next to the well were flooded. The suspended solids content

was less than 1 mg/l. The water has been certified for unrestricted irrigation by the Arizona State Health Department.

Personnel: H. Bouwer, R. C. Rice, G. C. Emery, H. L. Mastin, E. W. Errickson

Table 1. Concentration (mg/l) of NO_2-N, NO_3-N, and NH_4-N in renovated water from well 1 (1975).

Date	NO_2-N	NO_3-N	NH_4-N
22 Jan	0	1.2	0
26 Feb	0	0	0.7
27 Mar	0.1	0	0.8
11 Jul	0	0	1.1
28 Aug	0.1	0.1	0.8
25 Sep	0	0.1	0.5
22 Oct	0	0.1	0.1

Table 2. TDS-contents (mg/l) of secondary effluent and renovated water from various wells (1975).

Date	Effluent	Well 1	Well 1-2	ECW	Well 5-6
22 Jan			960	947	928
11 Feb				947	
20 Feb	1050				
26 Feb		832	1088	1037	941
27 Mar		896	992	896	960
28 Mar				960	
31 Mar	896				
11 Jul	960	960	1024	1024	1088
28 Aug	947	909	1024	992	966
22 Oct		960	934	973	973

Table 3. Concentration (mg/l) of fluoride in secondary effluent and renovated water from various wells.

Date	Effluent	Well 1	Well 1-2	ECW	Well 5-6
22 Jan			2.8	3.1	3.5
11 Feb				2.6	
26 Feb		0.8	2.0	3.2	2.5
6 Mar			2.1	2.2	3.2
7 Mar	3.2		2.1	2.8	2.5
10 Mar	2.5		2.1	2.8	2.6
13 Mar	3.0		2.0	2.1	2.5
27 Mar		1.3	2.0	2.8	1.9
28 Mar				1.7	
31 Mar	1.4				
11 Jul	0.96	0.8	2.4	2.0	2.1
28 Aug	3.1	1.1	1.5	1.5	2.8
22 Oct		1.3	2.0	2.4	2.4

Table 4. Concentration (mg/l) of boron in secondary effluent and renovated water from variou wells.

Date	Effluent	Well 1	Well 1-2	ECW	Well 5-6
22 Jan			0.55	0.55	0.54
11 Feb				0.64	
20 Feb	0.55				
26 Feb		0.46	0.60	0.62	0.51
27 Mar		0.45	0.63	0.57	0.53
28 Mar				0.56	
31 Mar	0.51				
11 Jul	0.58	0.51	0.67	0.7	0.7
28 Aug		0.45		0.43	0.45
25 Sep		0.52		0.42	0.45

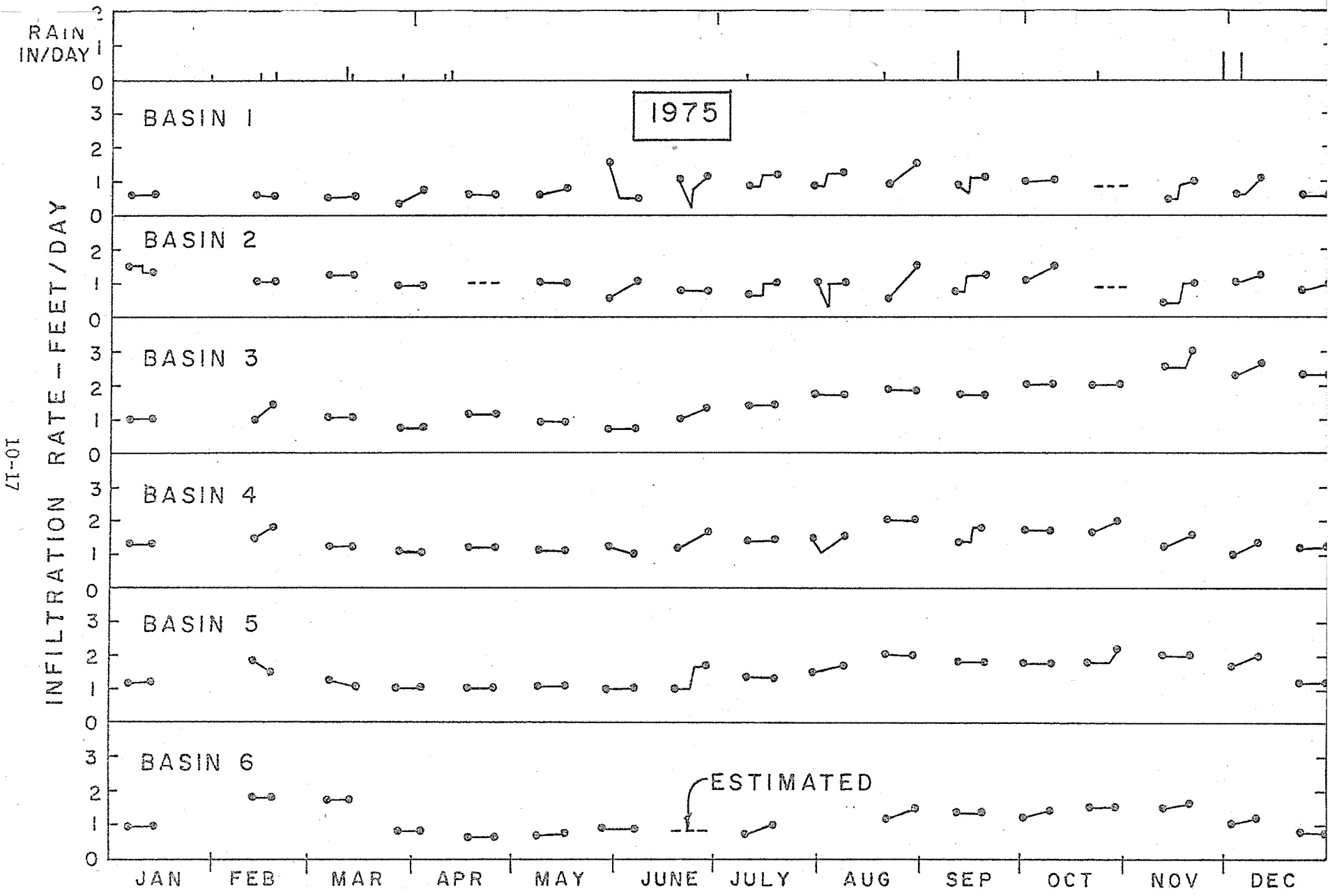

Figure 1. Infiltration rates in Flushing Meadows recharge basins and rainfall.

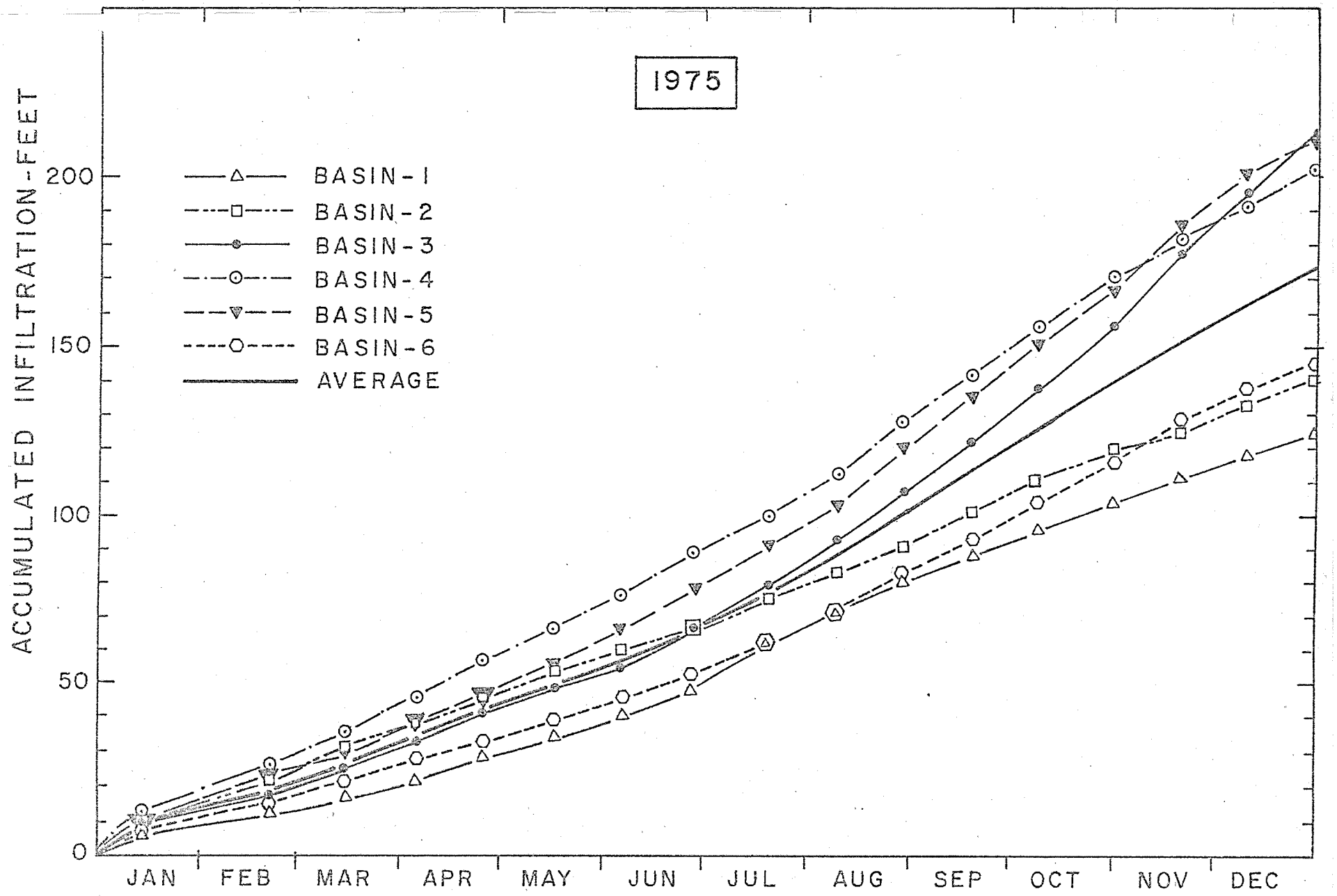

Figure 2. Accumulated infiltration in Flushing Meadows recharge basins.

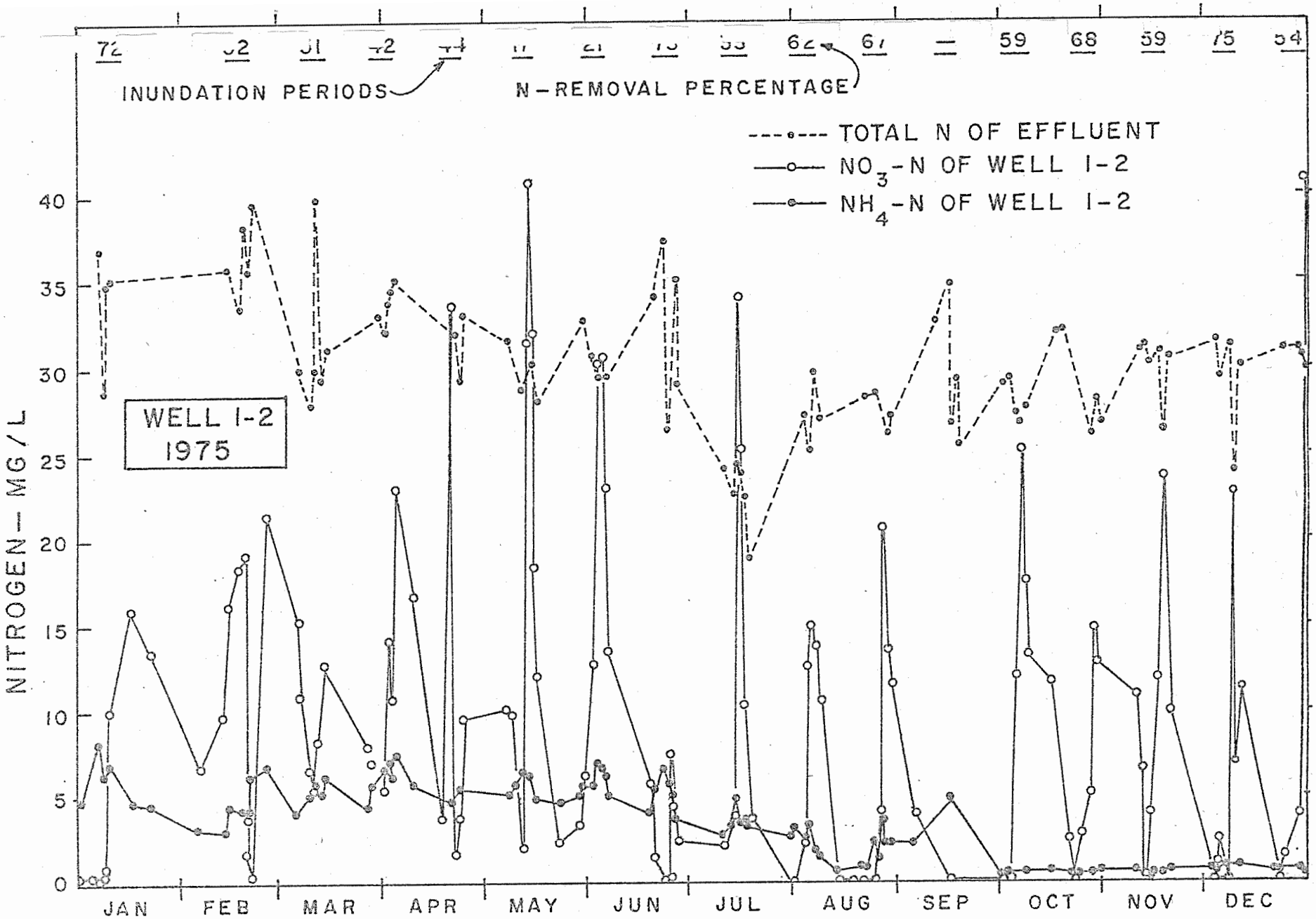

Figure 3. Total N in effluent and nitrate-N and ammonium-N in renovated water from well I-2.

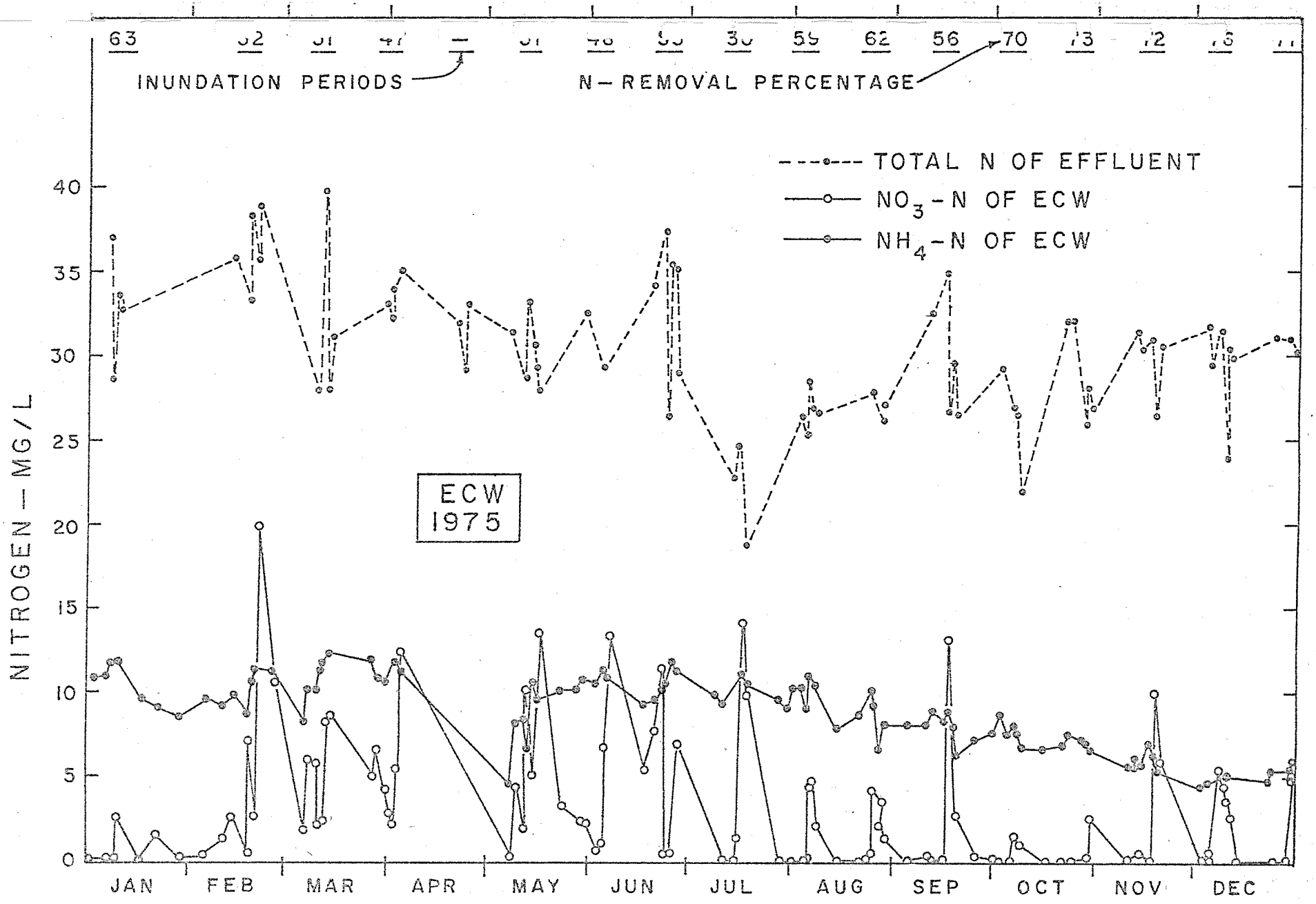

Figure 4. Total N in effluent and nitrate-N and ammonium-N in renovated water from ECW.

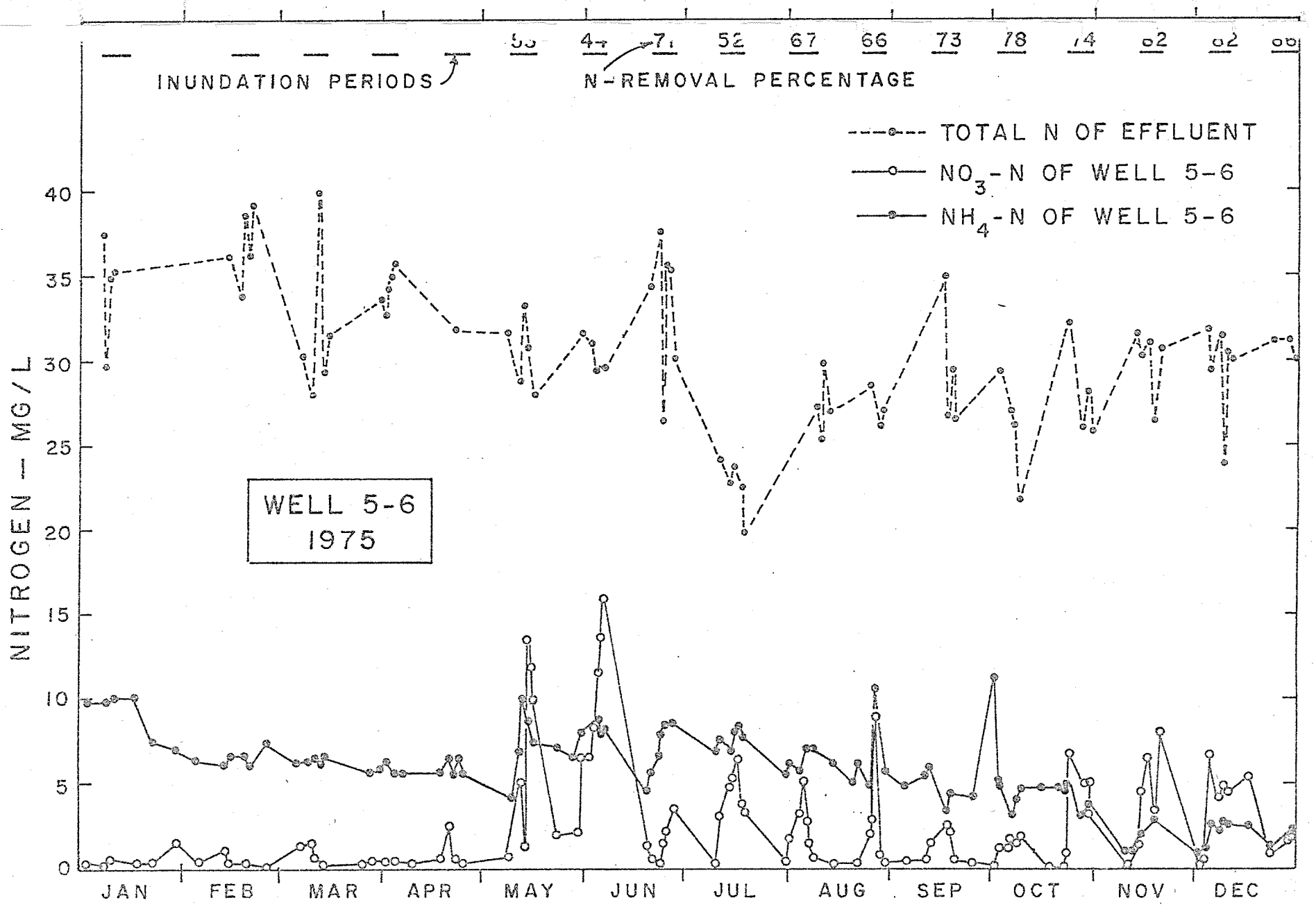

Figure 5. Total N in effluent and nitrate-N and ammonium-N in renovated water from well 5-6.

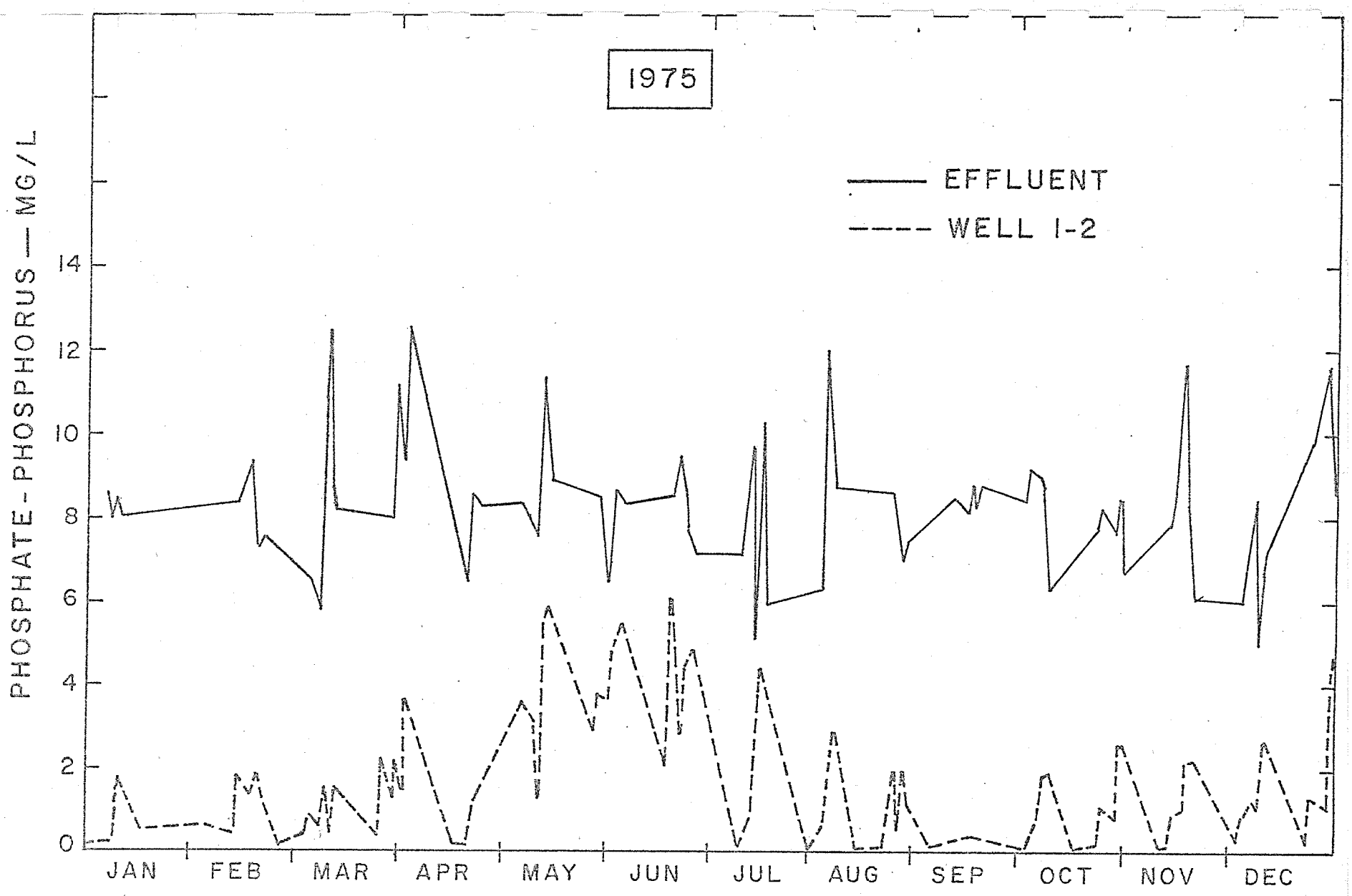

Figure 6. Phosphate-P in effluent and renovated water from well 1-2.

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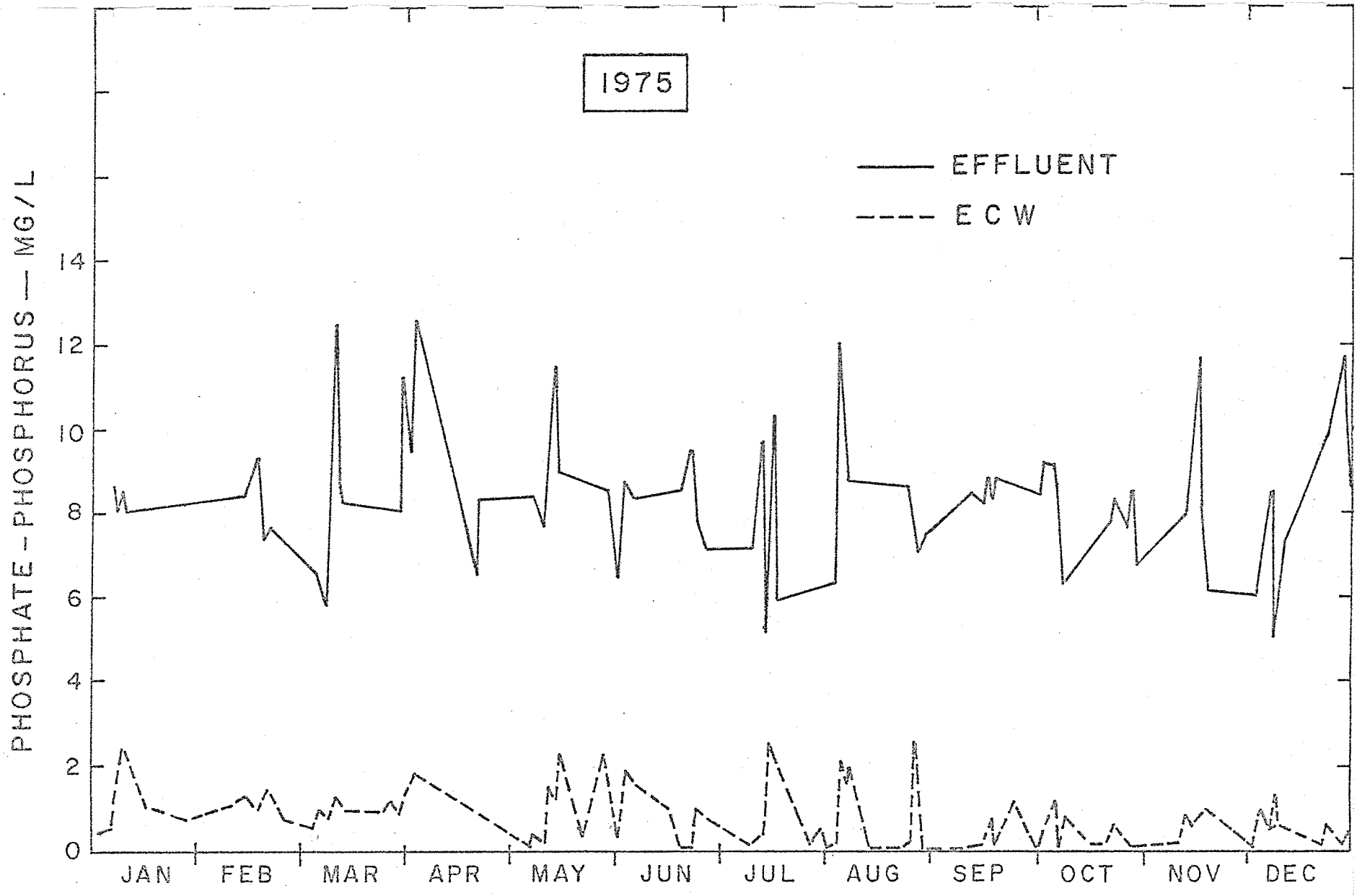

Figure 7. Phosphate-P in effluent and renovated water from ECW.

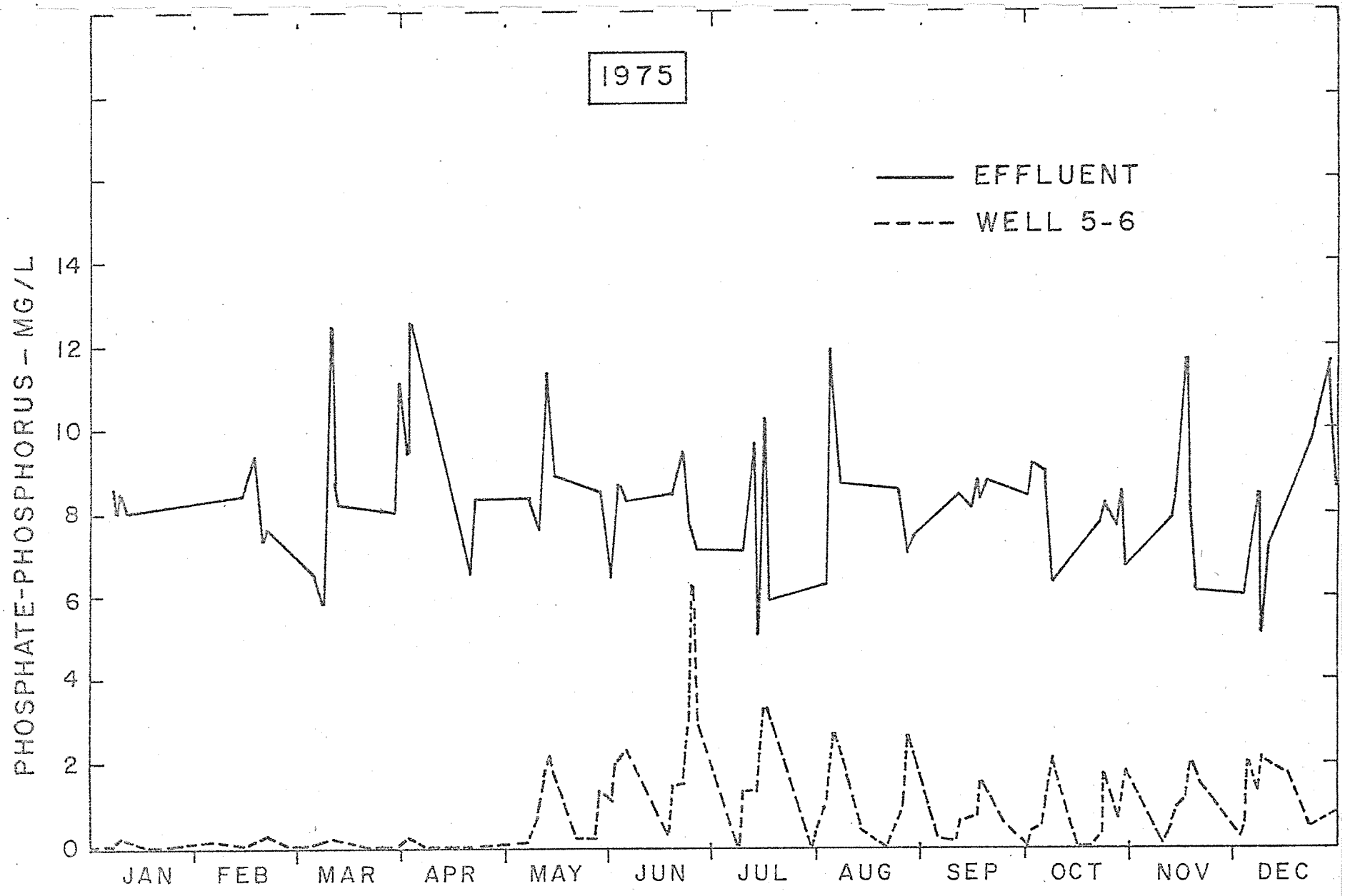

Figure 8. Phosphate-P in effluent and renovated water from well 5-6.

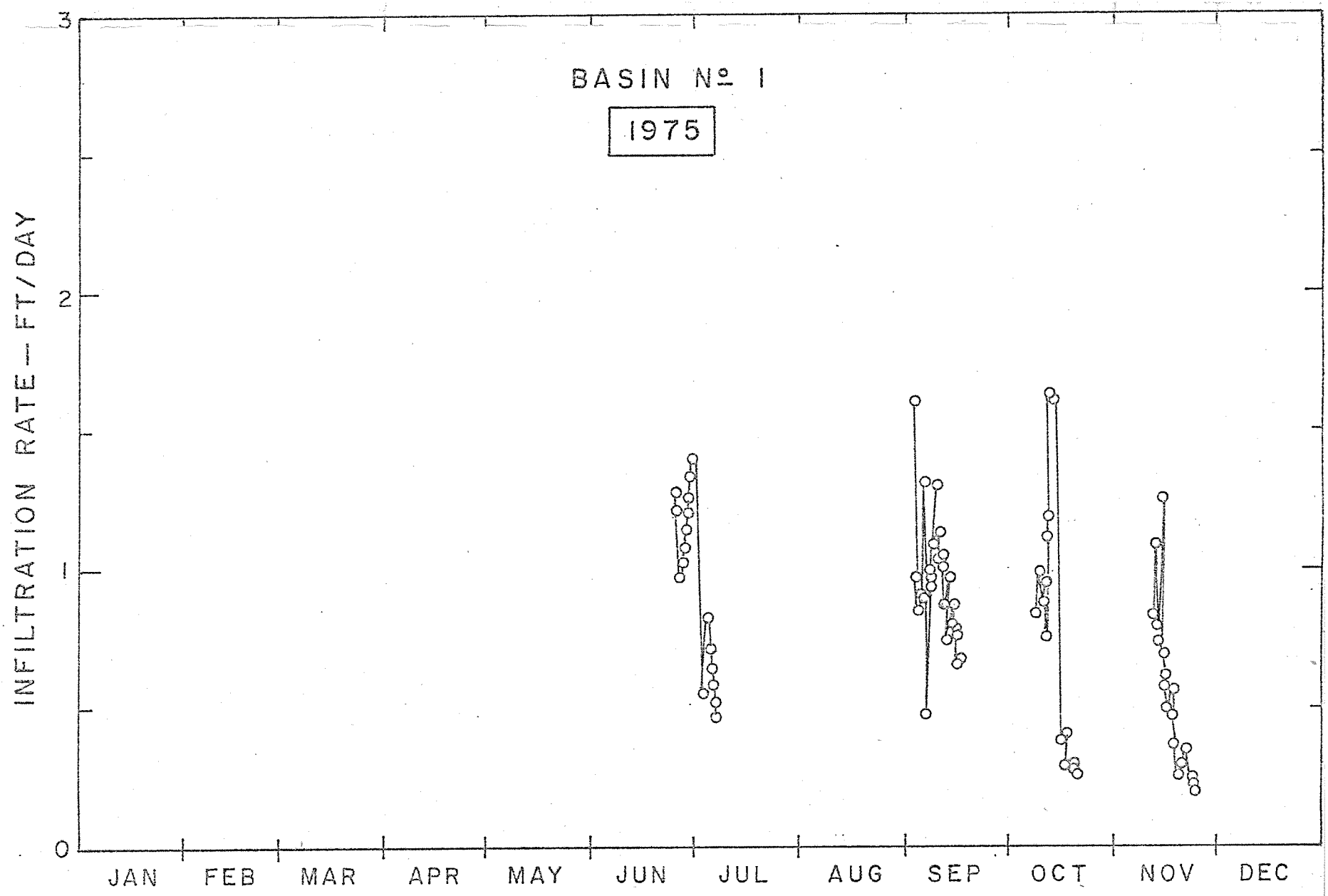

Figure 9. Infiltration rates in basin 1 of 23rd Avenue Project.

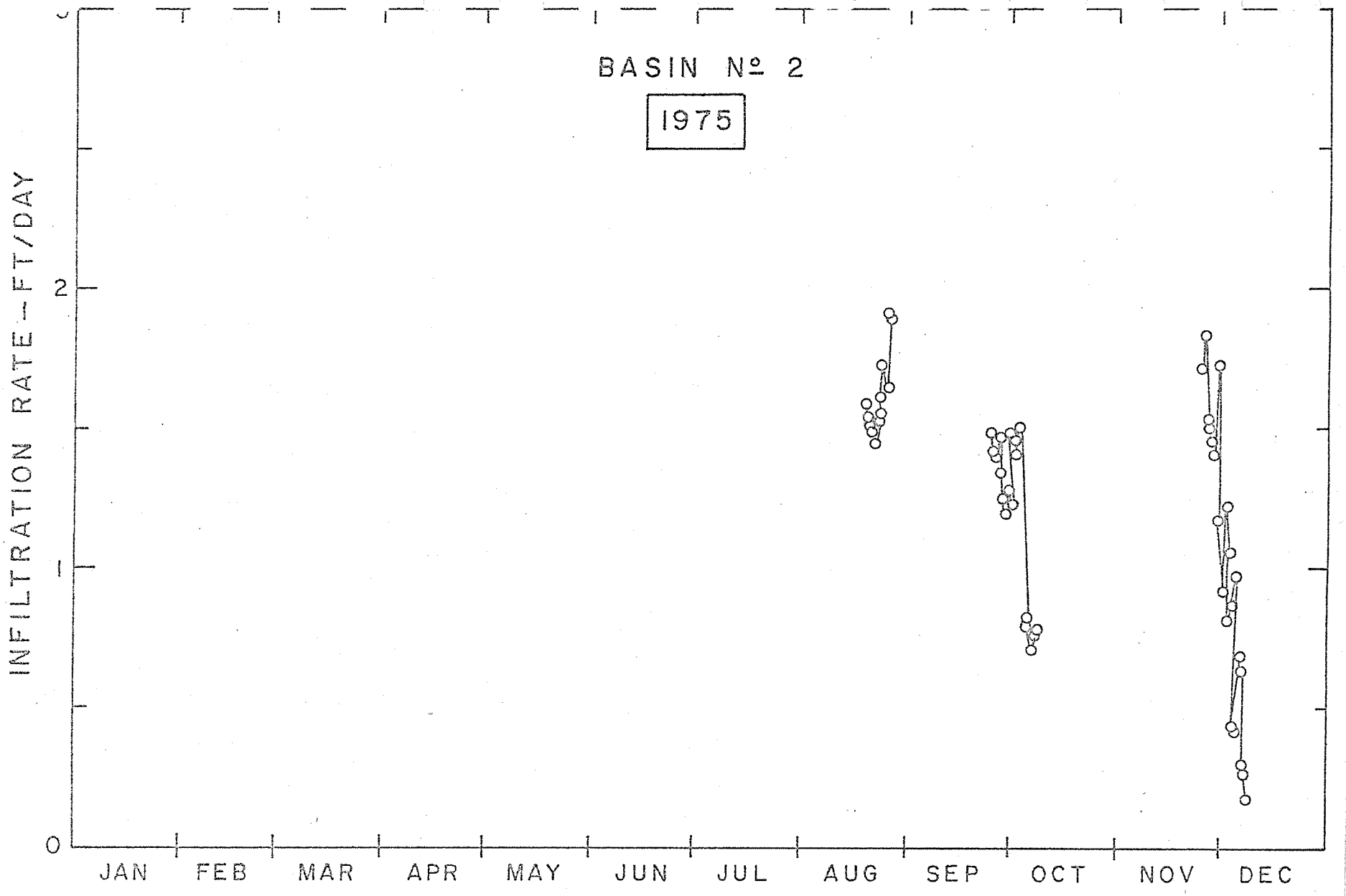

Figure 10. Infiltration rates in basin 2 of 23rd Avenue Project.

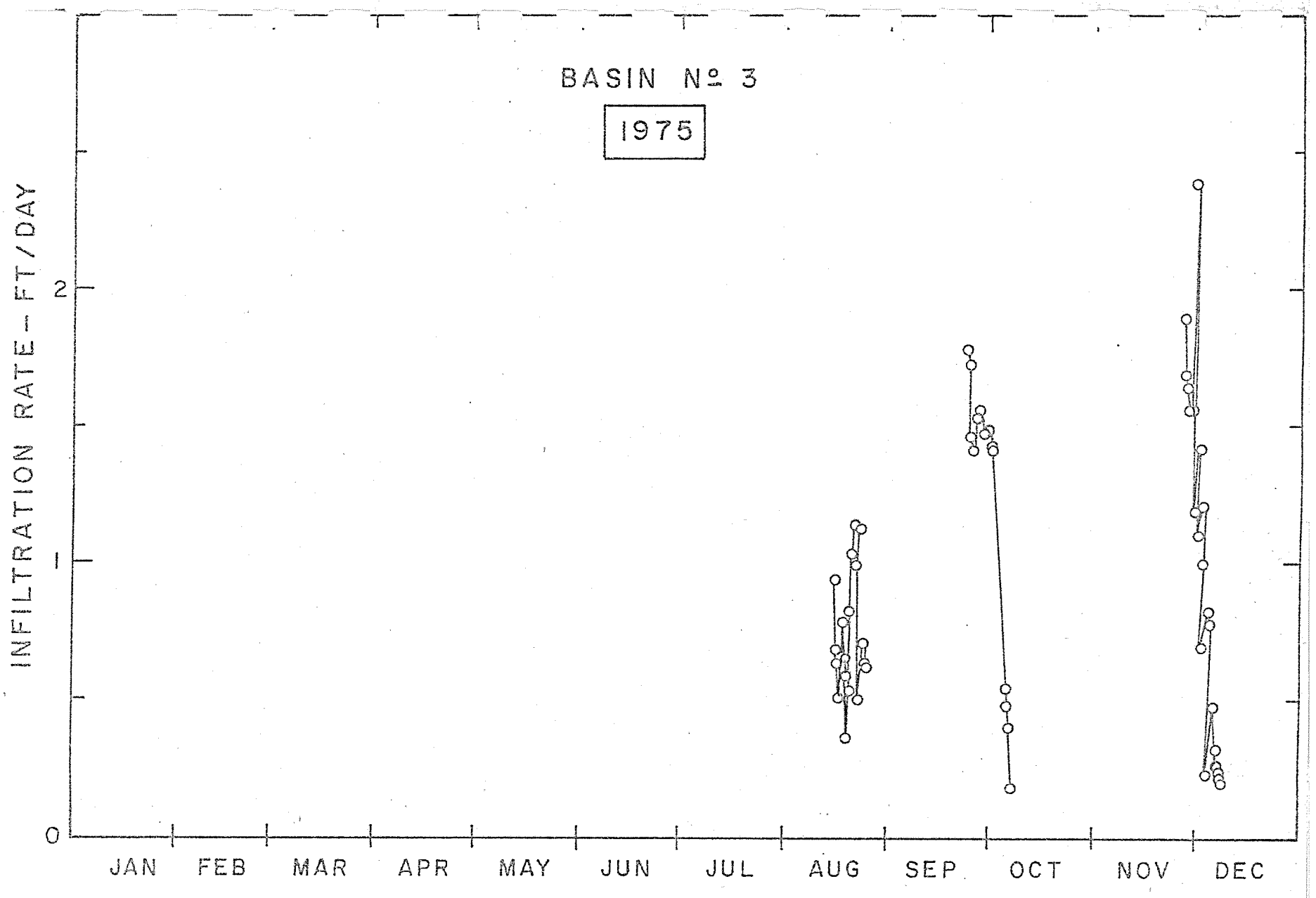

Figure 11. Infiltration rates in basin 3 of 23rd Avenue Pond, 1975.

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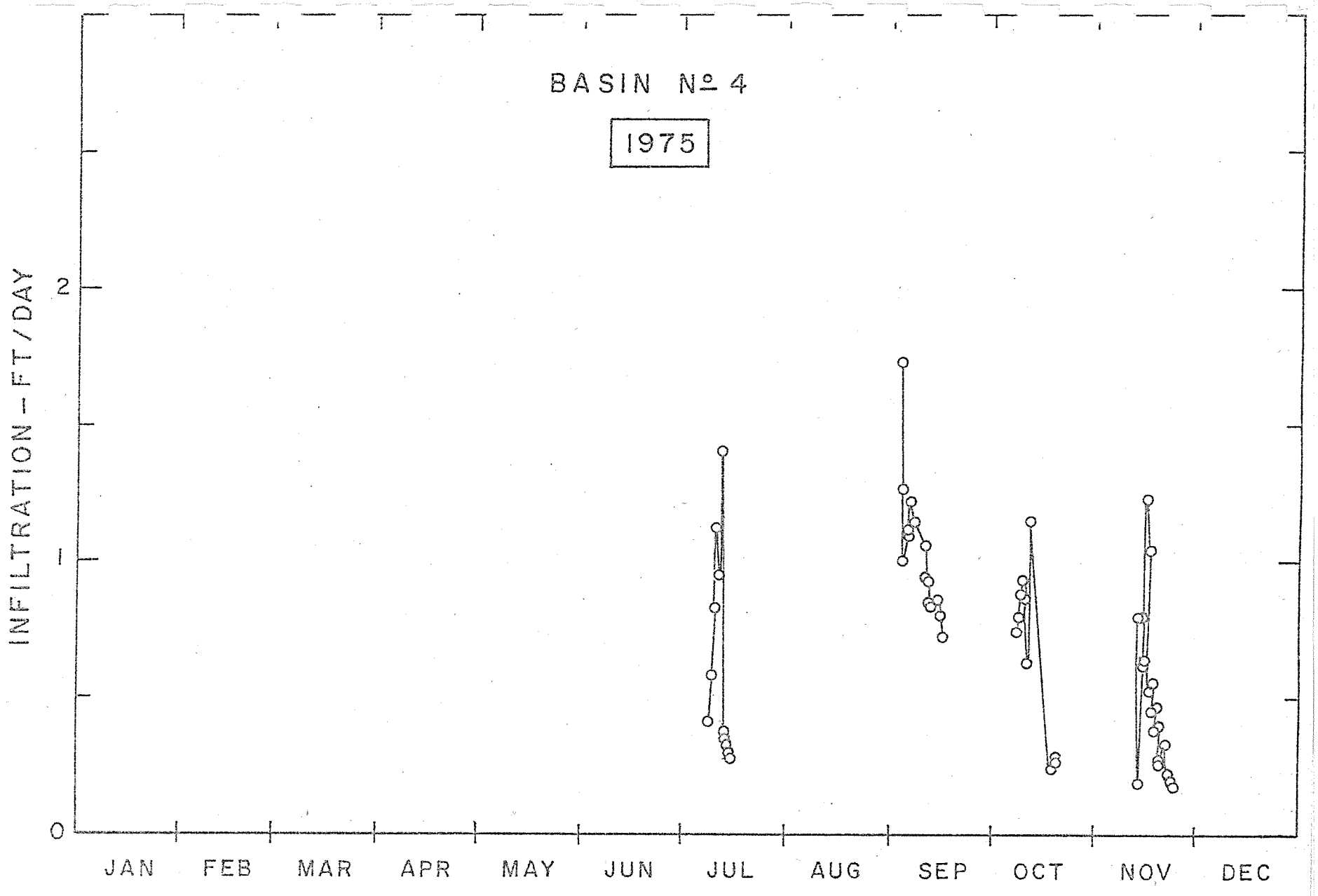

Figure 12. Infiltration rates in basin 4 of 23rd Avenue Project.

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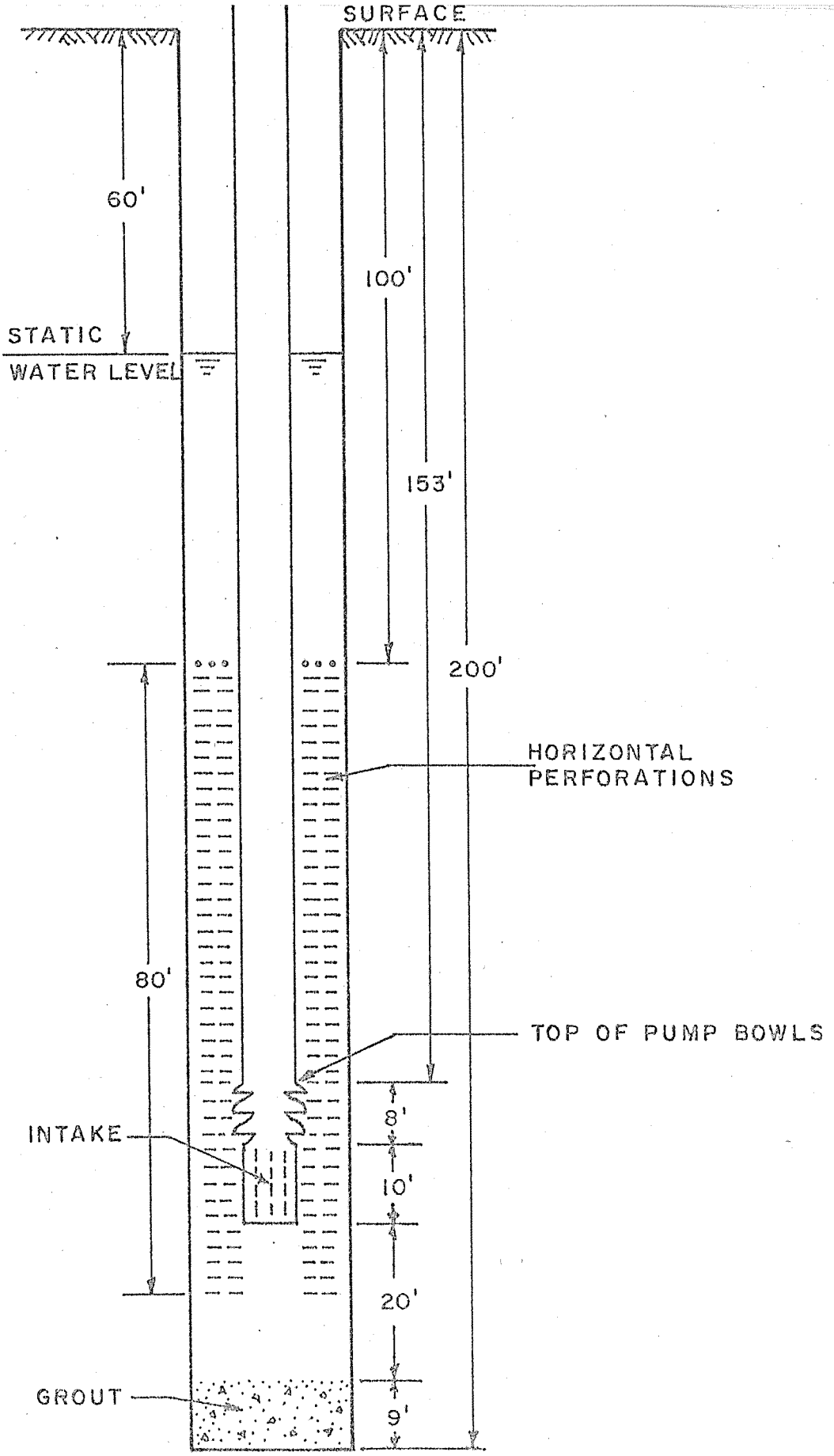

Figure 13. Dimensions of Center Well

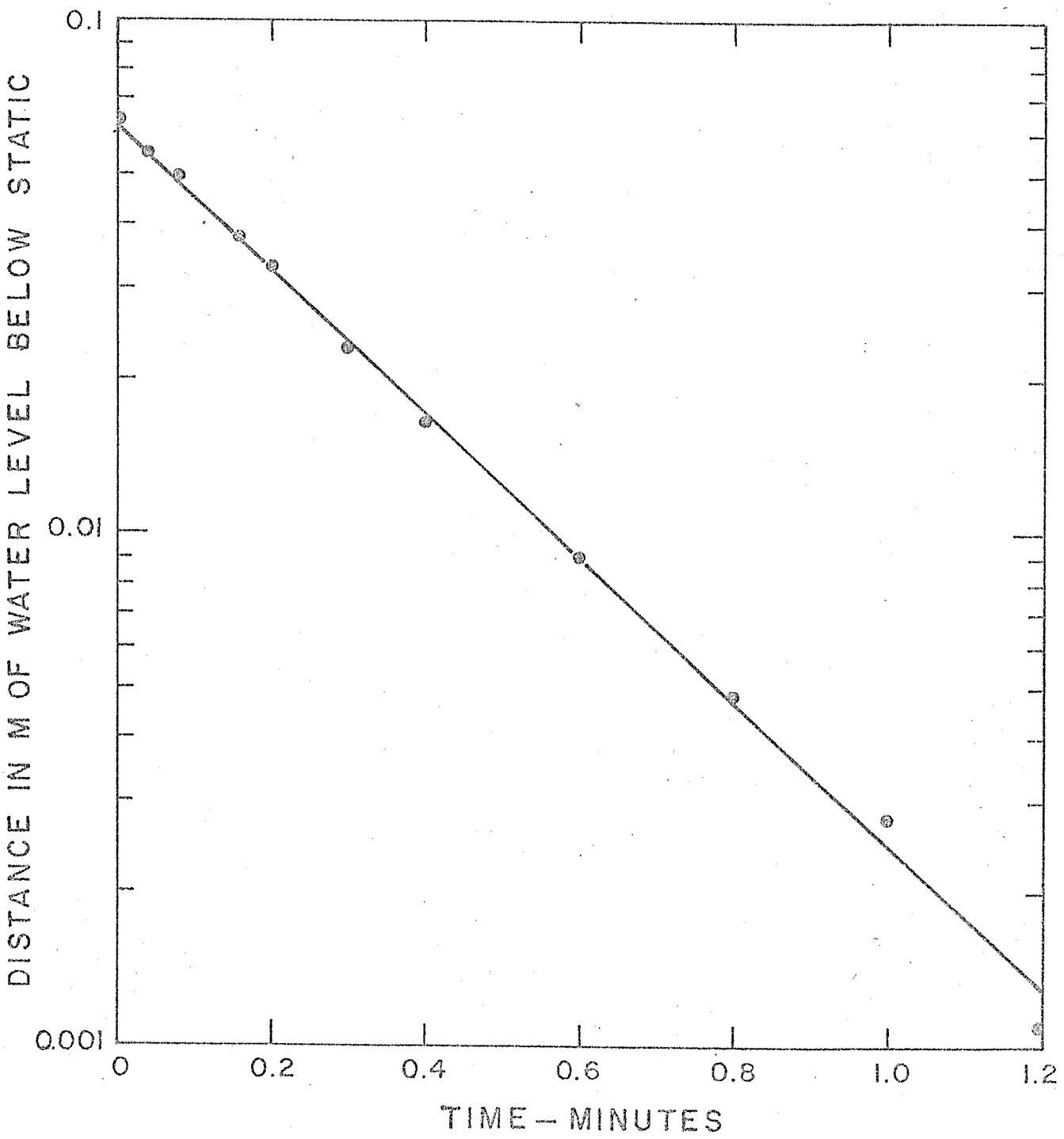

Figure 14. Water level rise in slug test on Center Well.

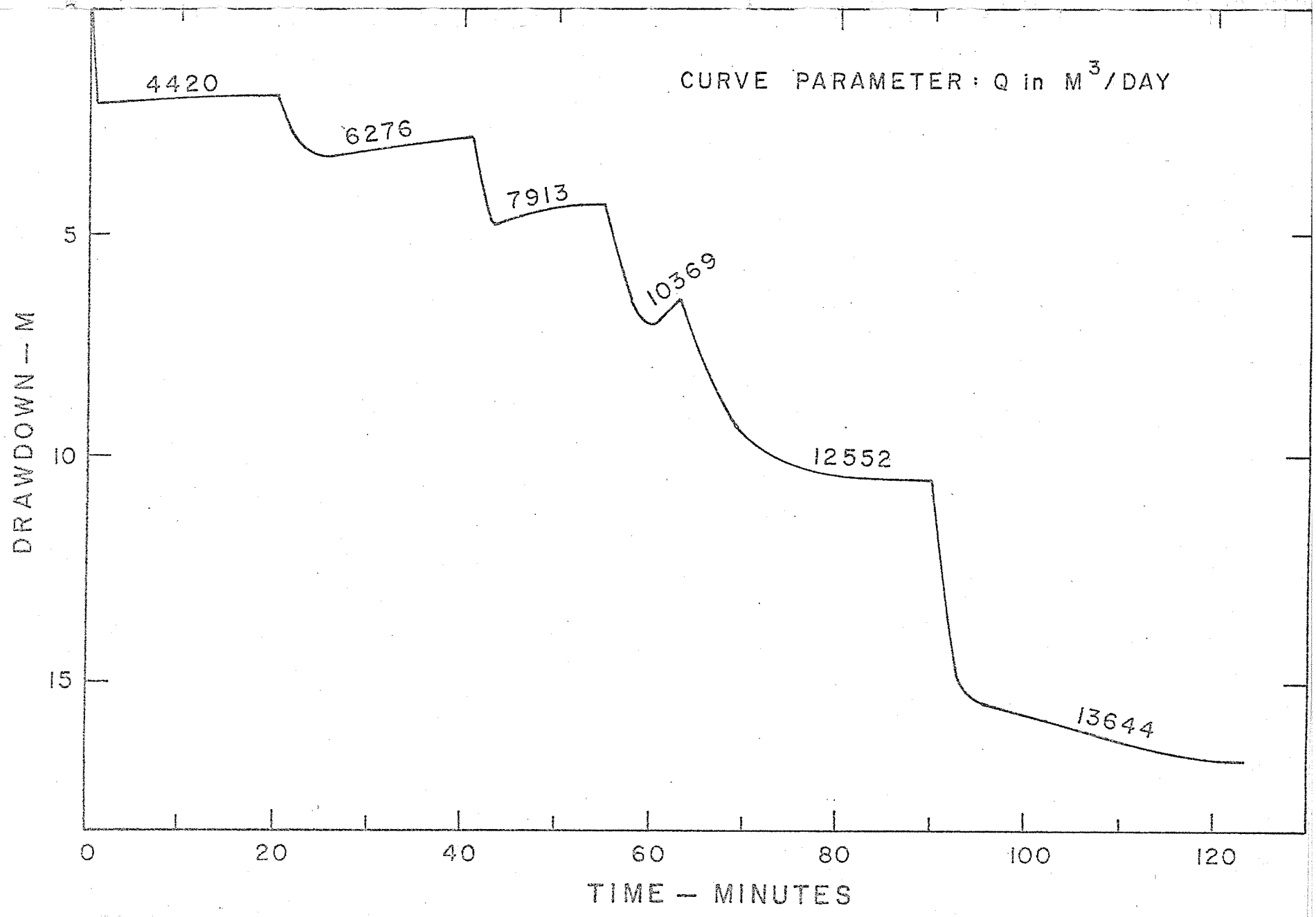

Figure 15. Drawdown in Center Well at different pumping rates in step-drawdown test.

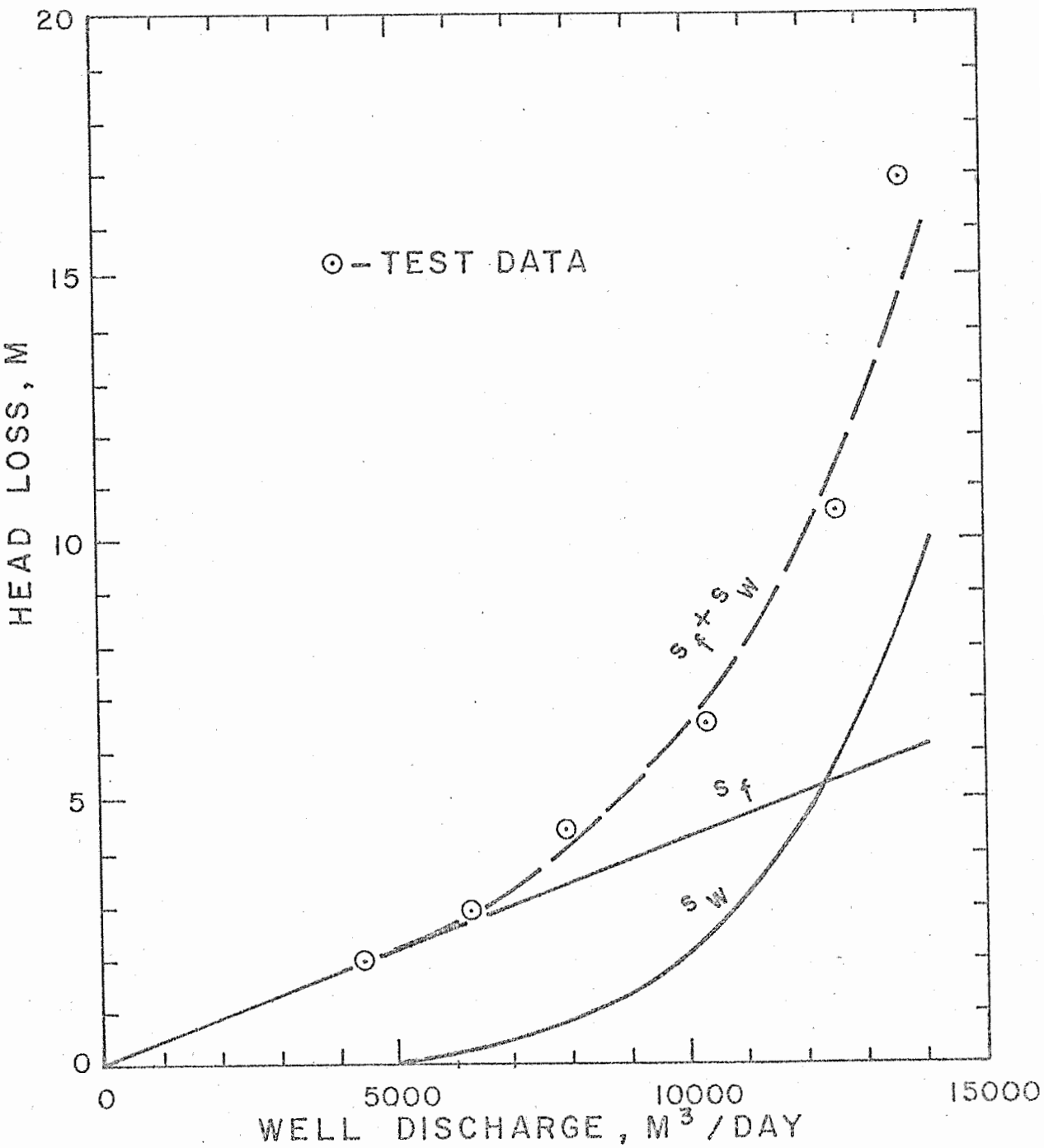

Figure 16. Head losses in formation (aquifer) and upon entry into well, and total head loss (drawdown) for Center Well.

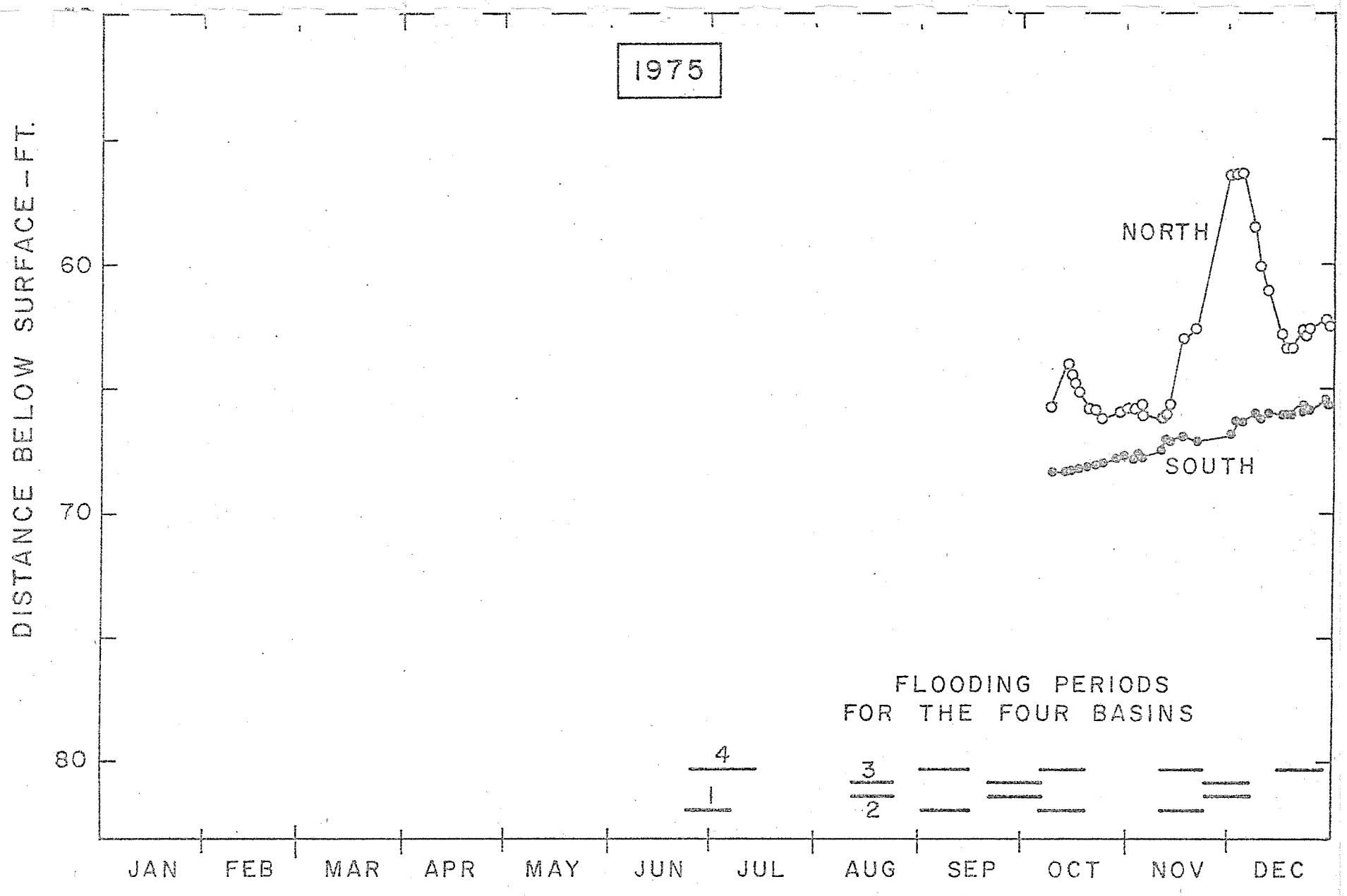

Figure 17. Water levels in North and South observation wells.

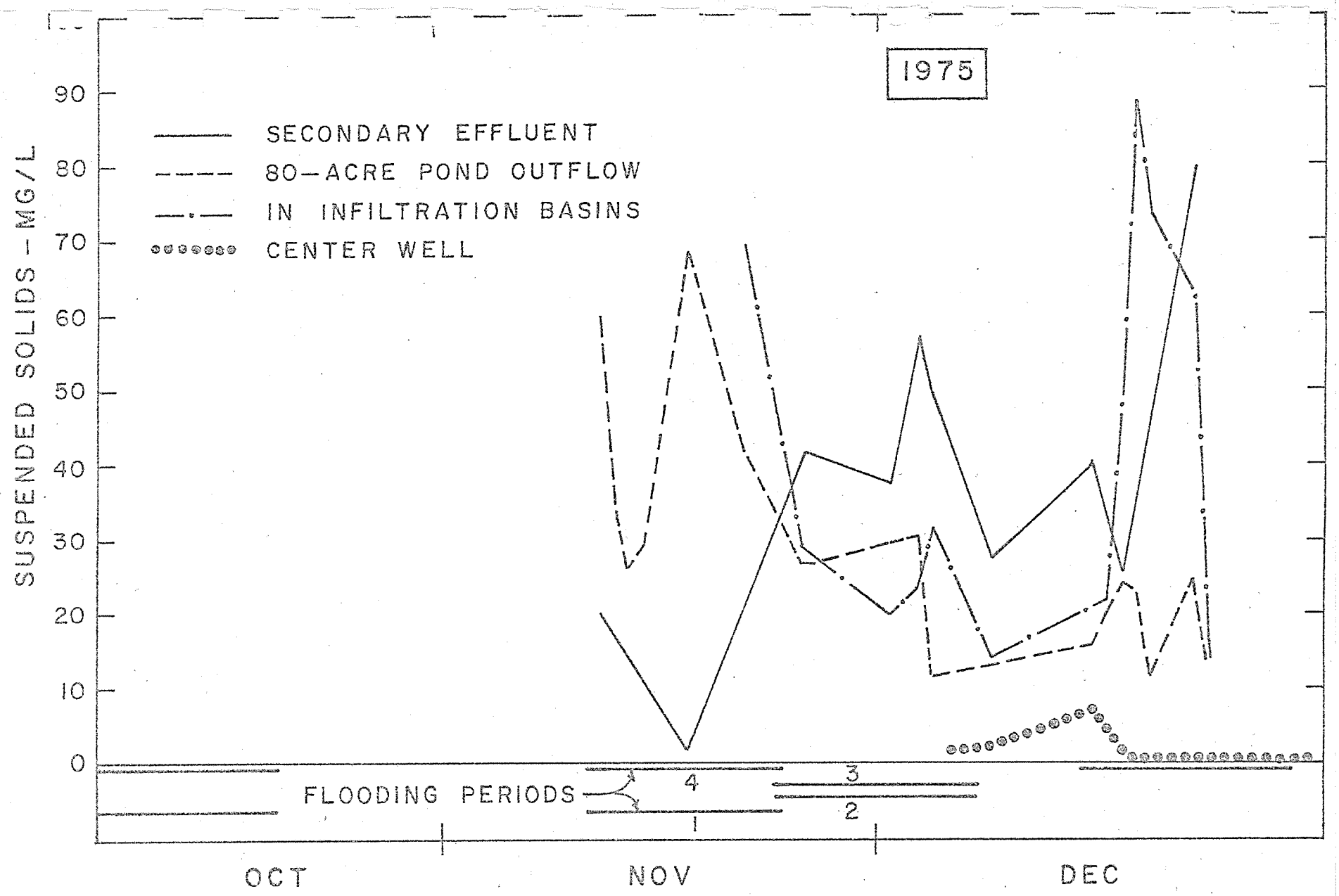

Figure 18. Suspended solids in secondary effluent at various points in the infiltration system.

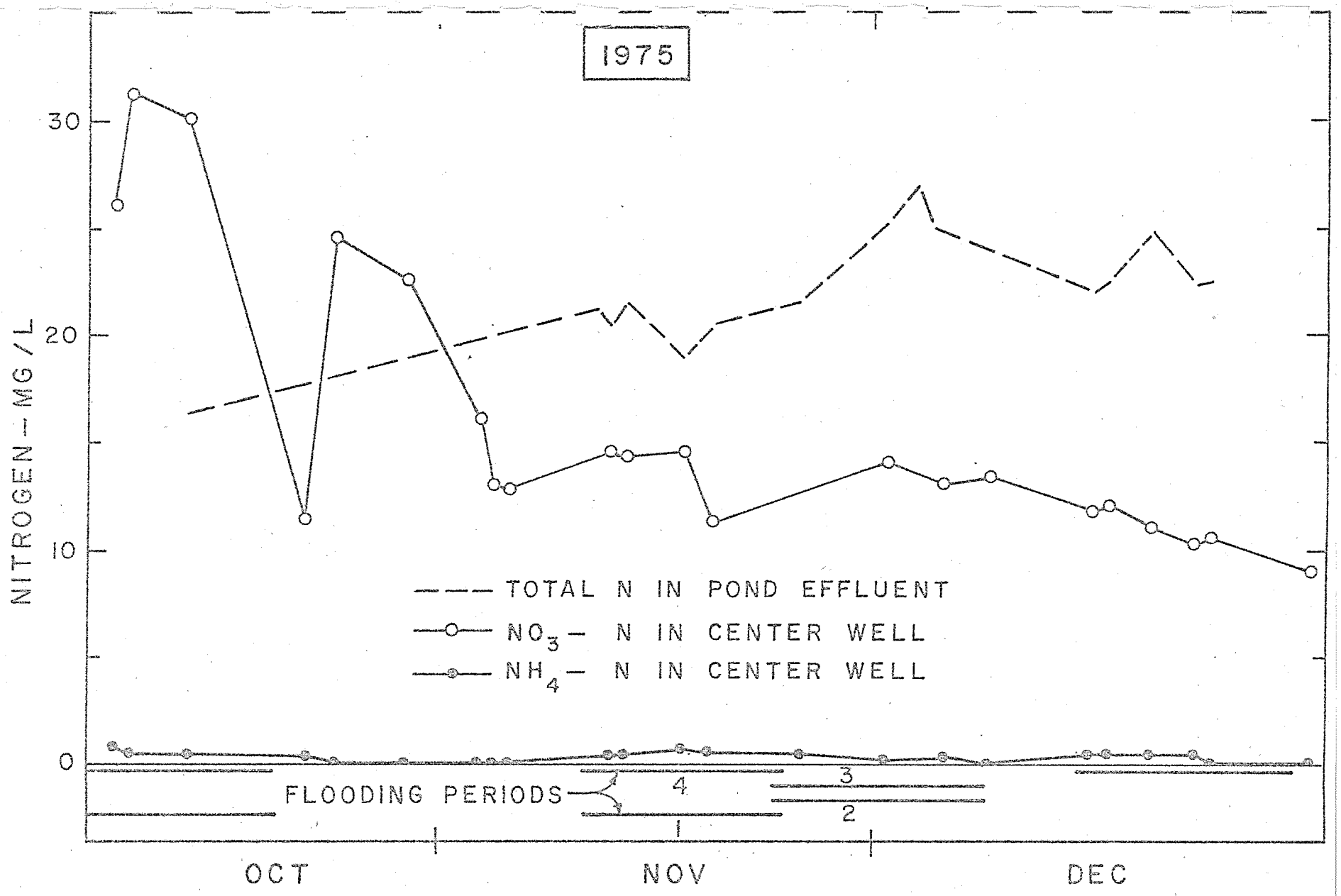

Figure 19. Nitrogen in effluent and in renovated water from Center Well.

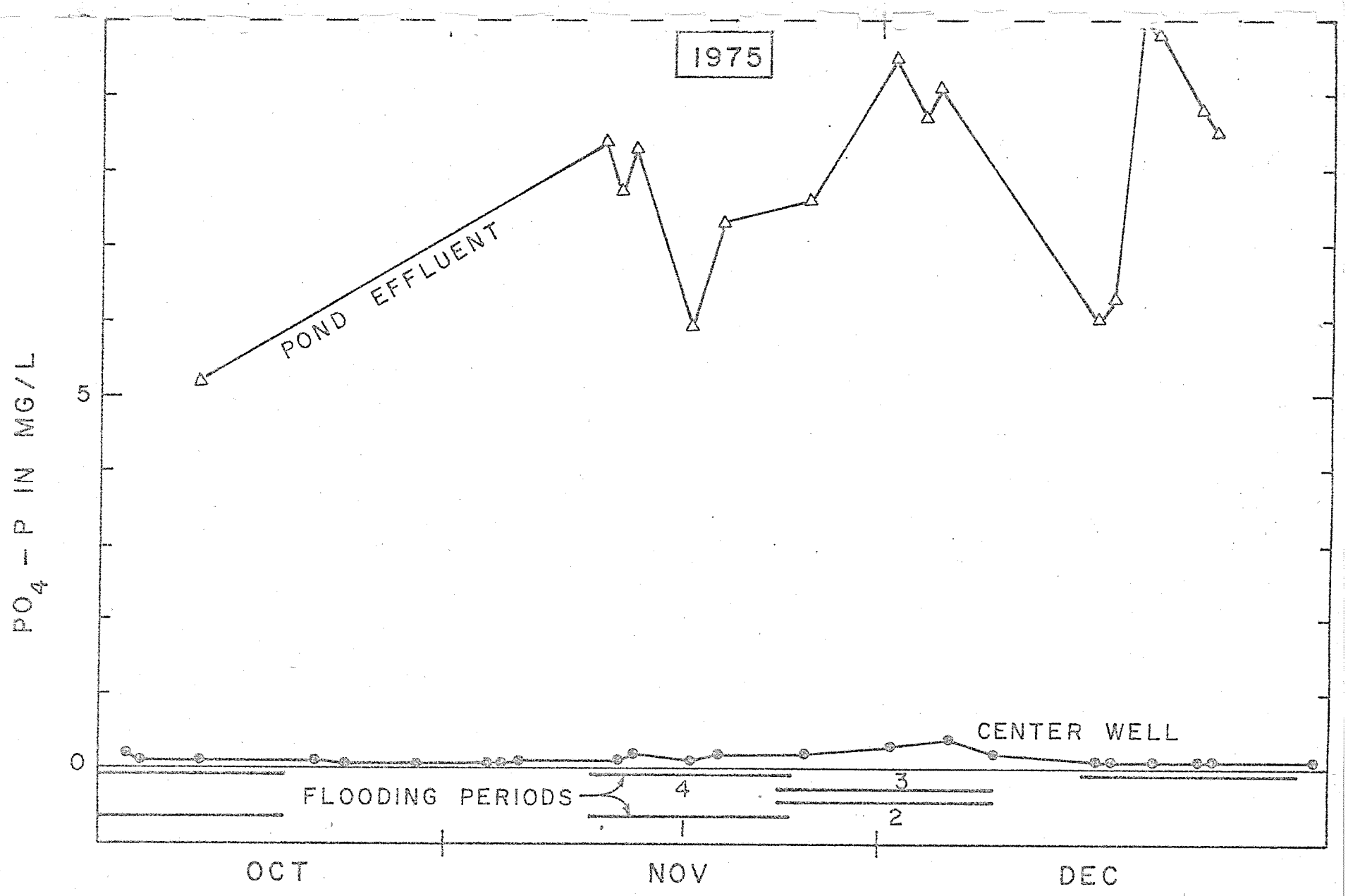

Figure 20. Phosphate-P in effluent and in renovated water from center well.

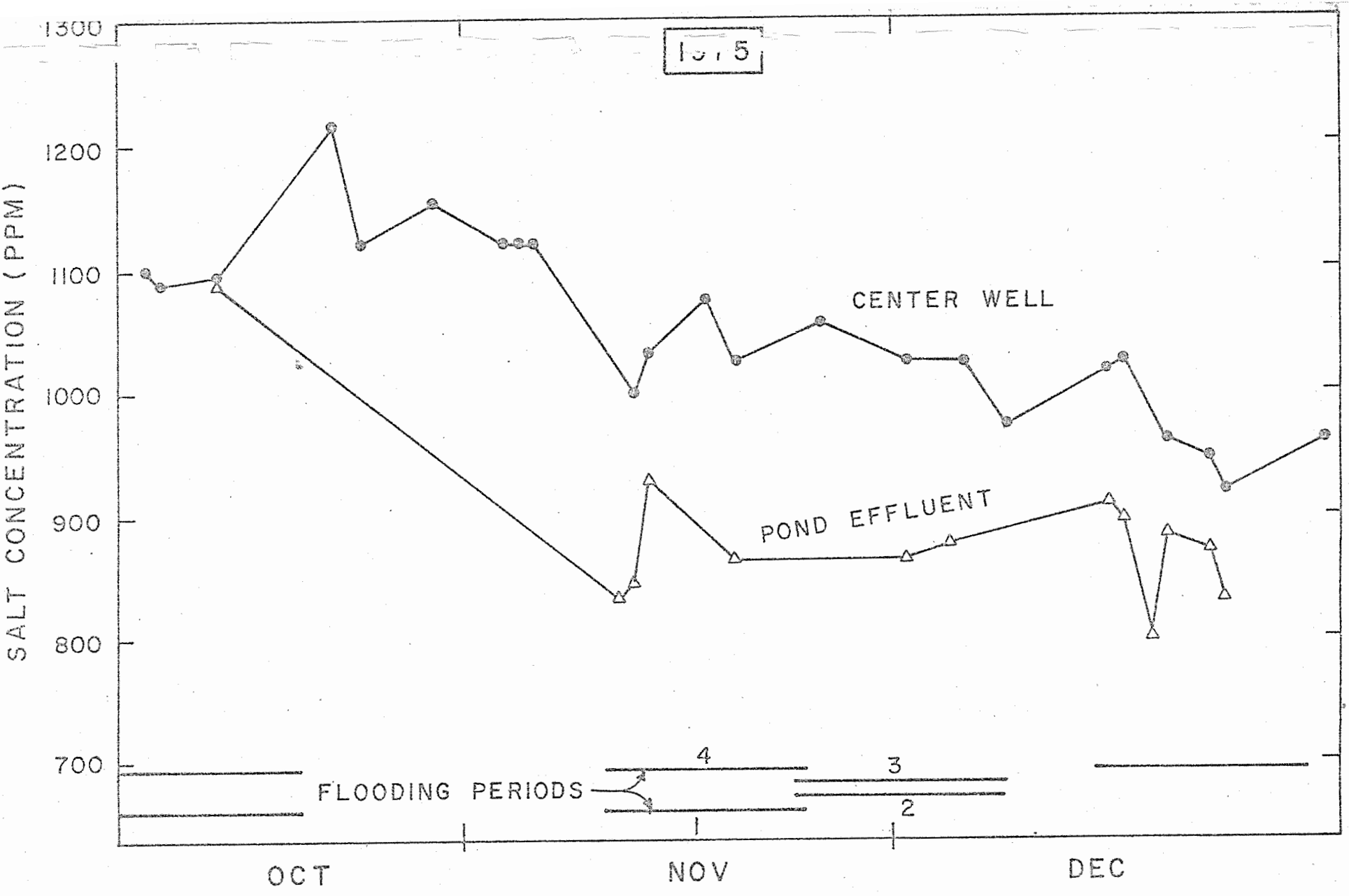

Figure 21. Salt concentration in effluent and in renovated water from Center Well.

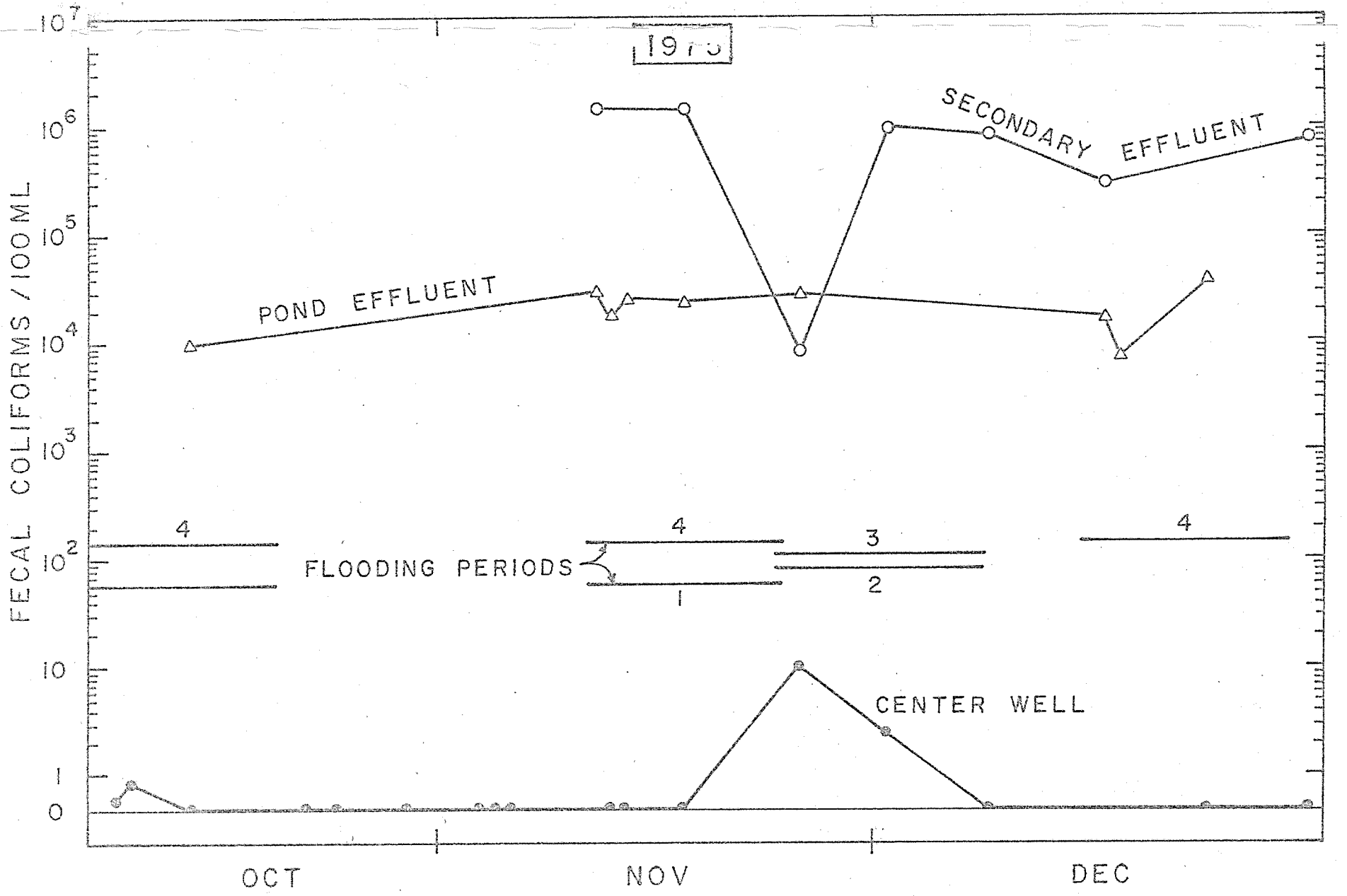

Figure 22. Fecal coliform counts in effluent and renovated water from Center Well.

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

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

INTRODUCTION:

Experiments on renovation of secondary sewage effluent by soil columns were concentrated on the movement of viruses in soil columns flooded with sewage water during 1975. Experiments on the renovation of primary sewage effluent were initiated during 1975. Removal of nitrogen, phosphorus, organic carbon, and fecal coliform bacteria, and maintenance of infiltration rates were studied under conditions similar to those used in studying renovation of secondary effluent.

PART I. VIRUS MOVEMENT

A manuscript entitled "Virus movement in soil columns flooded with secondary sewage effluent" has been prepared. The summary of that paper is presented here:

Secondary sewage effluent containing 3 to 5 x 10^4 PFU/ml polio virus type 1 (LSc) was passed through 250-cm-long columns packed with calcareous sand taken from an area in the Salt River bed used for groundwater recharge of secondary sewage effluent. Viruses were not detected in 1-ml samples extracted from the columns below the 160-cm level. Viruses were detected in 5 of 43 100-ml samples of the column drainage water. Most of the viruses were adsorbed in the top 5 cm of soil. Varying the infiltration rate between 15 and 55 cm/day did not affect the virus removal. Flooding a column continuously for 27 days with the sewage water virus mixture did not saturate the top few centimeters of soil with viruses and did not appear to affect virus movement.

Flooding with deionized water caused desorption of virus from the soil and increased movement through the columns. Adding $CaCl_2$ to the deionized water prevented most of the desorption of virus. Addition of a pulse of deionized water followed by sewage water started a wave of virus moving through the columns, but they were readsorbed and none were detected in outflow samples. Drying the soil for 1 day between the application of the virus and flooding with deionized water

greatly reduced desorption, and drying for 5 days prevented desorption.

Viruses applied in secondary sewage effluent would not be expected to move through 250 cm of the calcareous sand similar to that used in our laboratory columns during groundwater recharge. Some virus movement could occur if heavy rains fell within one day after application of sewage stopped. Such virus movement could be minimized by flooding with sewage soon after the rain fell.

PART II. PRIMARY SEWAGE EFFLUENT RENOVATION

PROCEDURE:

The 15-cm-diameter columns which are located in an insulated building with the tops of the pipes protruding through the roof were flooded with primary sewage effluent during 1975. Initially 6 of the 9 columns were used, e.g., 3 bare and 3 vegetated (commum bermudagrass). The surface of the bare soil columns had not been disturbed since they were flooded with secondary effluent 6 months previously. On 22 July 1975 the grass was pulled from the three remaining columns and they were flooded with primary sewage effluent. All columns were flooded on a schedule of 9-days flooding and 5-days drying, and the grass was harvested during each dry period except during the winter when little growth occurred. Two columns in the laboratory were also flooded with primary effluent on the same schedule.

Samples of sewage and column outflow were analyzed for nitrogen components, PO_4-P, Ca, organic carbon, suspended solids, and fecal coliforms. Infiltration rates were measured by weighing the column outflow daily, and data were collected from oxidation-reduction electrodes and tensiometers.

RESULTS AND DISCUSSION:

Infiltration rates with primary effluent. The infiltration rates of the six columns flooded with primary sewage without disturbing the soil surface did not change much during the 8-1/2 months of flooding (Figure 1 and Table 1). The average infiltration rate for the first cycle was only about 0.6 cm/day more than that of the last cycle. This small decline could have been due to changes in the weather. This

indicates that soil clogging was not increasing with contined flooding, even though the suspended solids content ranged from 51 to 181 mg/l for the fresh primary effluent (Table 2). The average infiltration rate for the six columns was 17.5 cm/day as compared to an average rate of 21.1 cm/day for those columns for 10 months of flooding with secondary sewage effluent during 1974. Previous experiments showed that infiltration rates dropped rapidly when suspended solids content of secondary sewage effluent increased above 10 mg/l. The suspended solids and total organic carbon of the primary effluent dropped rapidly as the sewage was held in the reservoir (Table 2). This indicates that the suspended solids were rapidly degraded, which probably accounts for the low amount of clogging associated with these solids. The tensiometer data showed that clogging was not concentrated near the surface. The infiltration rates for the vegetated columns were about the same as the rates for the bare soil columns.

The three columns where grass was removed and flooding began in July had much higher infiltration rates in the beginning. The rates dropped considerably as flooding continued but were still about 5 cm/day higher than the six undisturbed columns in December (Figure 1). Removal of the grass not only disrupted the soil surface but also opened channels extending down into the columns. Visual observations during flooding showed that gases escaped more rapidly from these columns during flooding than from undisturbed bare soil columns. As flooding continued, the channels created by grass removal probably were broken down and no longer served as vents for the escape of gases. This may account for the decline in infiltration rates with flooding.

Infiltration rates in the laboratory columns have declined to about half the infiltration rate of the first four cycles after 6 months of flooding with primary sewage effluent (Table 3). This decrease in infiltration rates emphasizes the importance of the drying action of sunlight in maintaining infiltration.

Nitrogen removal from primary effluent. Nitrogen removal from three bare soil columns averaged 45.6% from primary effluent as compared to 28.5% N removal from secondary effluent in 1974 (Table 4).

Nitrogen removal increased because the primary effluent contained more dissolved organic carbon, and thus supported more denitrification. The average dissolved organic carbon concentration in the fresh primary effluent was 97.3 ppm, but the organic carbon content decreased while the sewage was held in the reservoir (Table 5). The average residence time in the reservoir was about 1 day, and the average organic carbon concentration in water supplied to the columns was about 75 ppm. Previous laboratory experiments where glucose was added to secondary sewage effluent indicated that increasing the organic carbon content to 75 ppm would increase N removal but would not allow complete denitrification. The data from the primary effluent experiment support that concept.

Nitrogen removed by the three vegetated columns averaged 81.8% compared to 48.1% removed from secondary effluent while plants were actively growing in 1974 (Table 4). N removal by column 7 was low because the column was not completely covered with grass, and dry matter production was much lower than for the other two columns (Table 6). If we assume that the N content of the forage was about the same as it was the previous year (4%), the difference in N removal between vegetated and bare columns was incorporated into vegetation.

However, the difference between N removal by vegetated columns and N removal by bare columns was much greater for the primary effluent than it was for secondary effluent. N removal by denitrification was less in vegetated columns than in bare soil columns when secondary effluent was applied in 1974. N removal by denitrification was about the same for the two sets of columns when primary effluent was applied in 1975.

The two laboratory columns initially had higher infiltration rates than the columns with the surface exposed to the atmosphere. The N removal was less than that of the surface-exposed columns, but it increased as the infiltration rate of the laboratory columns declined (Table 3). The infiltration rate of column 2 was much higher than that of column 3 initially, but the infiltration rate of column 2 was higher after clogging developed in the columns.

The N removal by column 2 was less than column 3 initially, but N removal by the two columns was about equal after the change in infiltration rates.

Phosphate removal from primary effluent. A wave of phosphate was leached from the soil when the columns were flooded with primary effluent following a 6-month dry period (Figure 2). The columns had been flooded with secondary effluent for about 17 months prior to the dry period. The highest PO_4-P concentrations were from the vegetated column with the highest infiltration rate among the vegetated columns. The PO_4-P concentration from that column then declined until it was the lowest PO_4-P level detected in water from any of the columns. Evidently some of the adsorption capacity of the soil was restored when large quantities of PO_4-P were leached from the soil. The bare soil column with the lowest infiltration rate among the bare soil columns had the lowest PO_4-P concentrations in water drawing from the columns during the first several cycles (Figure 3). The PO_4-P concentrations from that column were never as high as the PO_4-P level in the primary effluent. Thus, infiltration rates not only affected the amount of PO_4-P removed from sewage water by the soil but also the amount that can be released by that soil after extensive drying. Vegetated columns released more PO_4-P than have soil columns after extensive drying. However, PO_4-P removal from primary effluent by vegetated columns was about the same as PO_4-P removal by bare soil columns after the initial wave of PO_4-P was leached from the soil (Figure 4). These vegetated columns previously removed less PO_4-P than bare columns from secondary effluent.

The PO_4-P removal from primary effluent by columns 3 and 9 were 66 and 72%, respectively, as compared to 58 and 73% for secondary effluent. The infiltration rates were 20.4 and 14.9 cm/day for columns 3 and 9, respectively, for primary effluent, as compared to 22.3 and 18.2 cm/day for the secondary effluent. The percent removal of PO_4-P remained about the same, as the PO_4-P concentration decreased from 12.1 ppm for the secondary effluent to 7.2 ppm for the primary effluent. Therefore, the PO_4-P concentrations in the

water draining from the columns were less when the columns were flooded with primary effluent than when they were flooded with secondary effluent. These data show no indication that the increased organic content of the primary effluent affected PO_4-P removal.

Samples from various depths in the soil columns showed that PO_4-P removal was not localized at any particular depth. The PO_4-P concentrations near the surface were usually slightly more than those in the primary effluent, indicating that some movement through the soil occurred before removal began (Table 7).

The laboratory soil columns also released large amounts of PO_4-P when they were flooded with primary sewage effluent. The release of PO_4-P by both sets of columns might be due to flooding with water containing only 7.2 ppm PO_4-P (primary effluent) after the soil had been equilibrated with water containing about 12 ppm PO_4-P (secondary effluent). The PO_4-P content in the water decreased as the infiltration rates decreased (Table 8).

Organic carbon removal from primary effluent. Most of the organic carbon was removed from the primary sewage effluent as it moved through the soil columns (Table 9). The organic carbon content of the water from the columns was about the same as it was from columns flooded with secondary sewage effluent. The vegetated columns seemed to allow more carbon to move through the soil initially, but organic carbon concentrations from vegetated and bare soil columns were about the same after three or four flooding cycles.

Organic carbon removal was slightly more than observed when columns were flooded with secondary effluent enriched with dextrose, probably due to lower infiltration rates and a corresponding greater detention time in these soil columns.

Fecal coliform removal from primary sewage effluent. The fecal coliform concentrations in the primary effluent ranged from 0.65 to 23×10^6 coliforms/100 ml of water. The samples from the column outflow ranged from 0 to 186 coliforms/100 ml. The number of coliforms in the column outflow samples was about the same for a vegetated and a nonvegetated column (Figures 6 and 7). The nonvegetated column

seemed to have fewer coliforms in samples taken from the 40 and 80 cm depths after 4 days of flooding. More data would be needed to confirm this trend. A plot of average fecal coliforms with depth in the soil column showed a sharp drop in coliform numbers as the water moved through the first 8 cm, and a more gradual decline in numbers of coliforms from 8 to 250 cm (Figure 8). The plot was almost linear after the initial decline in coliforms near the soil surface. This suggests that coliform bacteria were removed by filtration near the surface, and removal was proportional to detention time as the water moved deeper into the soil profile. Also, these data show that travel through about 1.8 m of fine sand was needed to reduce the coliform concentration below 1,000/100 ml. The length of travel through the soil needed would vary with the flow velocity of the water. Previous studies with secondary sewage effluent containing different concentrations of fecal coliforms showed about 3 logs removal of fecal coliforms by 250-cm-long soil columns with infiltration rates of about 40 to 45 cm/day. These experiments showed about 5 logs removal of fecal coliforms for primary effluent by 250-cm-long soil columns with infiltration rates of about 21 to 22 cm/day.

Oxidation-reduction potentials. The oxidation-reduction potentials dropped as the 2- and 8-cm levels decreased to negative values during the first day of flooding (Figure 8). All of the probes showed negative values by the third day of flooding. These measurements are similar to ones recorded in previous experiments with sugar-enriched secondary effluent. They indicate that the columns were in a highly reduced state during most of the flooding period.

SUMMARY AND CONCLUSIONS:

The renovation of primary sewage effluent by high-rate land filtration was studied by flooding soil columns with primary effluent using the same columns, flooding schedules, and measurement techniques which were used with experiments on renovation of secondary effluent. In soil columns where the soil surface was exposed to the atmosphere, infiltration rates with primary effluent declined only about 3% during 8-1/2 months of intermittent flooding, even though the suspended

solids content of the primary effluent ranged from 51 to 181 mg/l. The infiltration rates were about 15% less than the rates measured in 1974 when the same soil columns were flooded with secondary effluent containing < 10 mg/l suspended solids. The suspended solids were rapidly degraded, and tensiometers indicated no concentration of soil clogging near the soil surface. Infiltration rates were similar for vegetated and nonvegetated columns. Infiltration rates of laboratory soil columns declined about 50% when they were intermittently flooded with primary sewage effluent for 4 months.

Nitrogen removal was 45.6% and 81.8% for nonvegetated and vegetated columns, respectively, as compared to 28.5 and 48.1% N removal from secondary effluent by nonvegetated and vegetated columns, respectively, during 1974. The increased N removal was due to increased denitrification with higher organic carbon concentrations as had been predicted by previous experiments with secondary effluent enriched with sugar. N removal by denitrification was much greater in vegetated columns flooded with primary effluent than it had been in vegetated columns flooded with secondary effluent. The difference in N removal by vegetated and nonvegetated columns could be accounted for by the nitrogen incorporated into harvested plant tissue.

The percent phosphate removal by the columns flooded with primary effluent was about the same as it had been with secondary effluent. The PO_4-P concentrations in water draining from columns flooded with primary effluent were less than they had been when the columns were flooded with secondary effluent, because PO_4-P concentrations were lower in the primary effluent than in secondary effluent. The PO_4-P removal increased as the infiltration rate decreased as was reported for secondary effluent. A wave of PO_4-P was leached from the soil when columns were flooded with primary effluent after they had been dry for about 6 months. The release of PO_4-P might have been caused by equilibration of the soil with primary effluent containing about 7.2 ppm PO_4-P after the soil had previously been flooded with secondary effluent containing 12.1 ppm PO_4-P.

Vegetated soil columns removed about the same amount of PO_4-P from primary effluent as nonvegetated columns but released more PO_4-P during the first few flooding cycles. This was opposite to the effect noted with secondary effluent in 1974 when vegetated columns removed less PO_4-P than nonvegetated columns.

Most of the organic carbon was removed from primary effluent as it moved through the soil columns. Organic carbon concentrations in water draining from the columns were about the same as they had been when secondary effluent was applied.

The fecal coliform concentration of the water was reduced from 0.65 to 23 x 10^6 coliforms/100 ml to 0 to 186 coliforms/100 ml as it moved through the soil.

In summarizing the comparison between the experiments with primary and secondary effluent, infiltration rates were only slightly less for primary effluent, N removal was greater, and removal of PO_4-P, organic carbon, and fecal coliforms was similar when infiltration rates were considered. Thus, high-rate land filtration shows great promise as a method to renovate primary sewage effluent and bypass the expensive secondary treatment.

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

Table 1. Infiltration rates of soil columns flooded with primary sewage effluent (cm/day).

Date	1	2	3	4	5	6	7	8	9	Average 1,3,4,6,7,9	Average 2,5,8
4/5-4/29	14.8		20.5	20.9		17.0	15.7		14.8	17.3	
4/29-5/13	16.3		21.6	20.9		18.0	16.9		16.3	18.3	
5/13-5/27	12.7		22.7	19.3		18.2	16.4		14.6	17.3	
5/27-6/10	12.9		24.3	22.3		20.2	16.2		16.4	18.7	
6/10-6/24	11.8		22.9	23.2		19.1	16.7		16.0	18.3	
6/24-7/8	11.6		19.9	19.9		17.5	15.6		15.5	16.7	
7/8-7/22	12.6		22.5	21.3		16.0	17.2		16.9	17.7	
7/22-8/5	11.9	33.2	18.4	21.5	36.7	21.1	16.9	33.9	15.6	17.6	34.6
8/5-8/19	15.6	23.4	23.4	19.8	30.0	17.8	15.9	23.8	13.8	17.7	25.7
8/19-9/2	16.1	24.8	17.1	21.7	33.9	16.8	17.5	25.8	14.3	17.2	28.1
9/2-9/16	17.8	27.5	21.2	29.2	37.3	21.4	17.5	28.0	16.1	20.5	31.0
9/16-9/30	13.6	22.1	14.1	19.6	29.8	13.3	16.2	22.0	12.5	14.9	24.7
9/30-10/14	14.7	24.2	21.4	25.2	32.0	17.8	20.1	27.7	15.6	19.1	28.0
10/14-10/28	14.4	21.2	17.2	18.6	25.7	15.8	14.9	23.2	12.4	15.6	23.4
10/28-11/11	13.2	20.5	22.1	20.3	26.6	15.5	15.2	22.4	13.6	16.7	23.2
11/11-11/25	16.0	22.2	20.5	20.8	28.7	17.5	19.4	24.2	14.9	18.2	25.0
11/25-12/9	13.1	21.2	19.0	19.2	23.4	15.9	15.8	20.9	13.6	16.1	21.8
12/9-12/30	17.2	20.6	19.2	18.7	21.9	15.1	15.1	21.5	15.7	16.7	21.3
Average	14.2	23.7	20.4	21.3	29.6	17.5	16.6	24.9	14.9		

Table 2. The suspended solids and total organic carbon content in the primary sewage effluent reservoir (mg/l).

Reservoir time date	0		1 day		2 days		3 days	
	S.S.	TOC	S.S.	TOC	S.S.	TOC	S.S.	TOC
18 Apr	182	194			67	115		
21 Apr	143	209					72	68
22 Apr			71	105				
23 Apr					54	116		
24 Apr			64	74				
29 Apr	89	56						
30 Apr			52	48				
1 May	89	118			35	38		
2 May	116	133	46	80				
5 May	95	167					53	60
6 May			58	128				
13 May	63	187						
14 May			37	137				
15 May	51							
16 May			45					
Average	104	138	53	95	52	90	62	64

Table 3. Infiltration rates and percent nitrogen removal by laboratory soil columns flooded with primary effluent.

Date	Infiltration rates		% N removal	
	column number			
	2	3	2	3
1975	cm/day			
22 Jul - 5 Aug	109.2	46.48		
5 Aug - 19 Aug	41.35	26.35	0.5	10.6
19 Aug - 2 Sep	42.65	31.00	32.7	46.2
2 Sep - 16 Sep	39.59	38.86	23.3	55.5
16 Sep - 30 Sep	27.34	28.75	2.3	31.6
30 Sep - 14 Oct	25.06	23.7	15.7	36.8
14 Oct - 28 Oct	23.51	22.81	6.6	62.1
28 Oct - 11 Nov	21.50	22.63	48.3	54.8
11 Nov - 25 Nov	15.53	22.12	26.7	46.5
25 Nov - 9 Dec	17.61	23.79	38.8	49.7
9 Dec - 30 Dec[a]	15.48	20.13	53.6	55.7

[a]12-day drain

Table 4. Nitrogen removal by soil columns flooded with primary sewage effluent.

Date	Grass			Bare			Grass-Removed		
	← column number →								
	1	4	7	3	6	9	2	5	8
1975	% N removal								
4/15 to 4/29[a]	62.5	78.2	59.7	62.9	44.2	35.2			
4/29 to 5/13	69.2	84.0	51.5	39.3	46.1	46.5			
5/13 to 5/27	92.5	89.2	69.4	38.6	29.3	29.2			
5/27 to 6/10	93.3	91.8	81.2	45.9	40.9	48.9			
6/10 to 6/24	97.0	95.6	77.0	52.6	36.9	30.9			
6/24 to 7/8	97.6	94.3	55.6	55.5	72.1	53.2			
7/8 to 7/22	96.3	88.3	43.4	57.9	20.4	40.5			
7/22 to 8/5	95.5	77.3	45.5	32.2	59.0	51.5			
8/5 to 8/20[b]				54.9	36.8	32.3	53.9	36.8	50.0
8/19 to 9/2				-4.1	24.2	44.6	29.9	41.0	39.1
9/2 to 9/16				63.7	68.8	66.3	55.1	57.4	46.5
11/11 to 11/25[c]				61.8	57.6	50.0	50.9	69.1	65.5
11/25 to 12/9				40.8	56.5	33.1	25.6	56.5	61.2
12/9 to 12/30				59.9	51.0	46.1	-	51.3	46.8
Average	87.9	87.2	60.2	47.3	46.0	43.5	43.1	52.0	51.5
	Average grass 81.8			Average bare 45.6			Avg. grass-removed 48.9		

[a]Columns 2, 5, 8 were not flooded until 8/5/75.

[b]Nitrogen data were not collected for columns 1, 4, 7 after 8/5/75.

[c]Data for 9/16 to 11/11 were omitted because of accidental dry ups during flooding periods.

Table 5. The dissolved organic carbon content of primary sewage effluent in the reservoir.

Date	Days in reservoir 0	1	2	3
1975	ppm			
29 Apr	56.5	46.0	37.0	
1 May	118	91.0		
2 May	133			60.5
5 May	167	128	96	
7 May	190	110		
13 May	188.5	127	104	
14 May	75.5	52		
16 May	144	92		66.7
19 May	120.7	73	78	58
27 May	45	46	46	
29 May	108	70		
30 May	76.5	39.5		32.0
2 Jun	126.5	101.5	89.0	
4 Jun	67.5	40.0		
10 Jun	43	49.0		
11 Jun	63.5	46.5	32.0	
13 Jun	65.0			30.5
16 Jun	140	94	86	70
24 Jun	60.5	53	47	
26 Jun		90		
27 Jun	62			43
30 Jun	115	88.5	73.5	50
8 Jul		41.5		
9 Jul	79	45.0	28.0	
10 Jul	44			26.5
14 Jul	140	101.6	56.0	57.5
Average	97.3	73.9	56.9	49.5

Table 6. Bermudagrass yield for vegetated columns flooded with primary effluent during 1975.

Date	Col 1	Col 4	Col 7	Total	Average
	←		g		→
26 Apr	5.8	9.2	1.8	16.8	5.6
9 May	4.4	5.3	1.8	11.5	3.83
23 May	7.4	9.9	4.4	21.7	5.9
6 Jun	6.9	8.1	3.2	18.2	6.07
19 Jun	7.1	9.0	3.2	19.3	6.43
9 Jul	8.5	10.1	3.5	22.1	7.37
17 Jul	7.0	10.2	2.6	19.8	6.6
1 Aug	3.9	6.7	1.7	12.3	4.1
14 Aug	7.1	7.3	2.5	16.9	5.63
26 Aug	6.3	8.6	1.8	16.7	5.57
10 Sep	5.0	7.1	2.4	14.5	4.83
30 Sep	4.0	5.2	2.0	11.2	3.73
13 Oct	2.5	3.9	1.1	7.5	2.5
28 Oct	1.9	2.0	.8	4.7	1.57
Total	77.8	102.6	32.8	213.2	71.1
Average	5.56	7.33	2.34		5.08

Table 7. Phosphate concentrations at various depths in soil columns flooded with primary effluent

Column depth	Column 3 (bare)				Column 4 (vegetated)			
	5 Nov	6 Nov	17 Dec	18 Dec	5 Nov	16 Dec	17 Dec	18 Dec
cm	ppm							
0	8.3	5.5	7.7	7.7	7.5	7.6	7.6	7.6
2	7.7	8.0	8.2	8.0	7.4	7.7	7.6	7.6
5	8.1	8.4	8.5	8.5	8.4	7.7	7.8	7.8
40	8.9	11.2	7.1	8.2	7.8	5.2	5.6	8.0
80	8.3	9.3	5.9	5.9	3.6	3.3	6.6	6.6
160	2.4	4.0	5.5	5.7	0.8	2.6	2.7	2.8
240	2.3	2.4	2.6	2.8	1.4	1.1	1.1	1.1
250	-	-	3.1	3.6	-	1.5	1.7	1.6

Table 8. Phosphate concentrations in laboratory columns flooded with primary sewage effluent.

Date	Effluent	Column 2	Column 3
1975	←	ppm	→
5 Aug	6.6	13.04	14.54
19 Aug	6.16	11.6	14.03
2 Sep	6.12	10.35	11.91
16 Sep	6.92	6.02	9.13
30 Sep	6.79	3.83	7.13
14 Oct	6.6	3.66	7.73
28 Oct	6.47	3.93	8.0
11 Nov	7.81	4.04	7.24
25 Nov	8.56	4.17	7.35
9 Dec	7.79	3.87	7.31

Table 9. Organic carbon concentrations in water draining from soil columns flooded with primary sewage effluent.

Date	Primary effluent	Col 1	Col 3	Col 4	Col 6	Col 7	Col 9
1975	←			ppm			→
16 Apr-25 Apr	-	7.4	5.1	8.1	4.6	9.8	4.7
29 Apr-9 May	102.8	16.6	4.7	15.0	3.9	9.8	3.3
13 May-22 May	98.3	9.7	4.6	11.9	3.9	7.6	4.1
28 May-5 Jun	68.3	8.8	6.3	7.3	6.3	8.2	5.2
11 Jun-19 Jun	72.0	7.3	6.0	7.2	5.4	6.4	6.1
24 Jun-3 Jul	68.3	4.4	6.5	6.6	6.9	6.3	5.7
8 Jul-17 Jul	68.8	7.6	6.6	6.6	6.0	5.4	5.6
Average		8.8	5.7	9.0	5.3	7.7	5.0

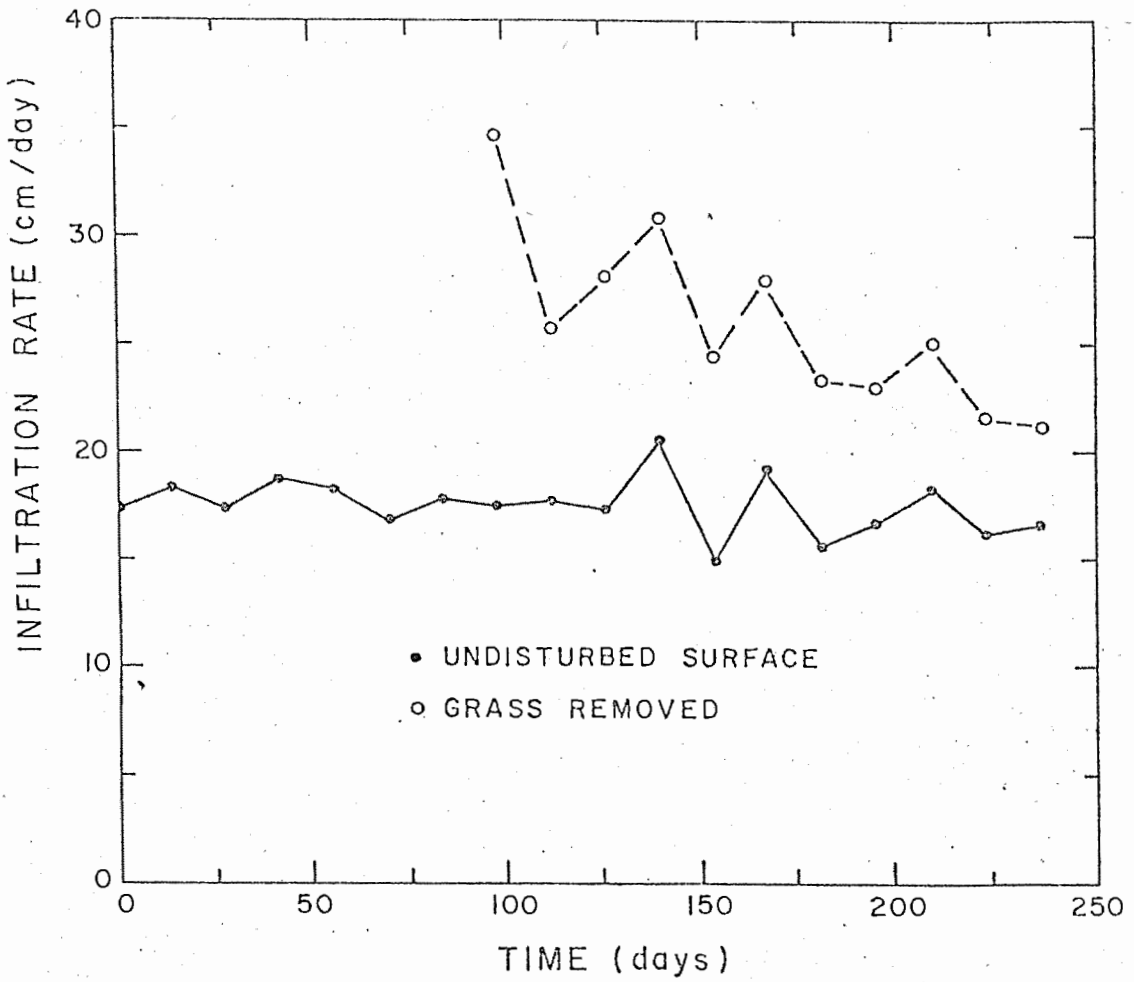

Figure 1. Infiltration rates of soil columns flooded with primary sewage effluent on a schedule of 9-days flooding alternated with 5-days drying. The soil surface in undisturbed surface columns had not been changed since flooding with secondary effluent. Data represent averages of three vegetated and three nonvegetated columns. Grass was pulled from three other vegetated columns which were previously flooded with secondary effluent, and flooding with primary effluent began after the other columns had already been flooded for about 100 days.

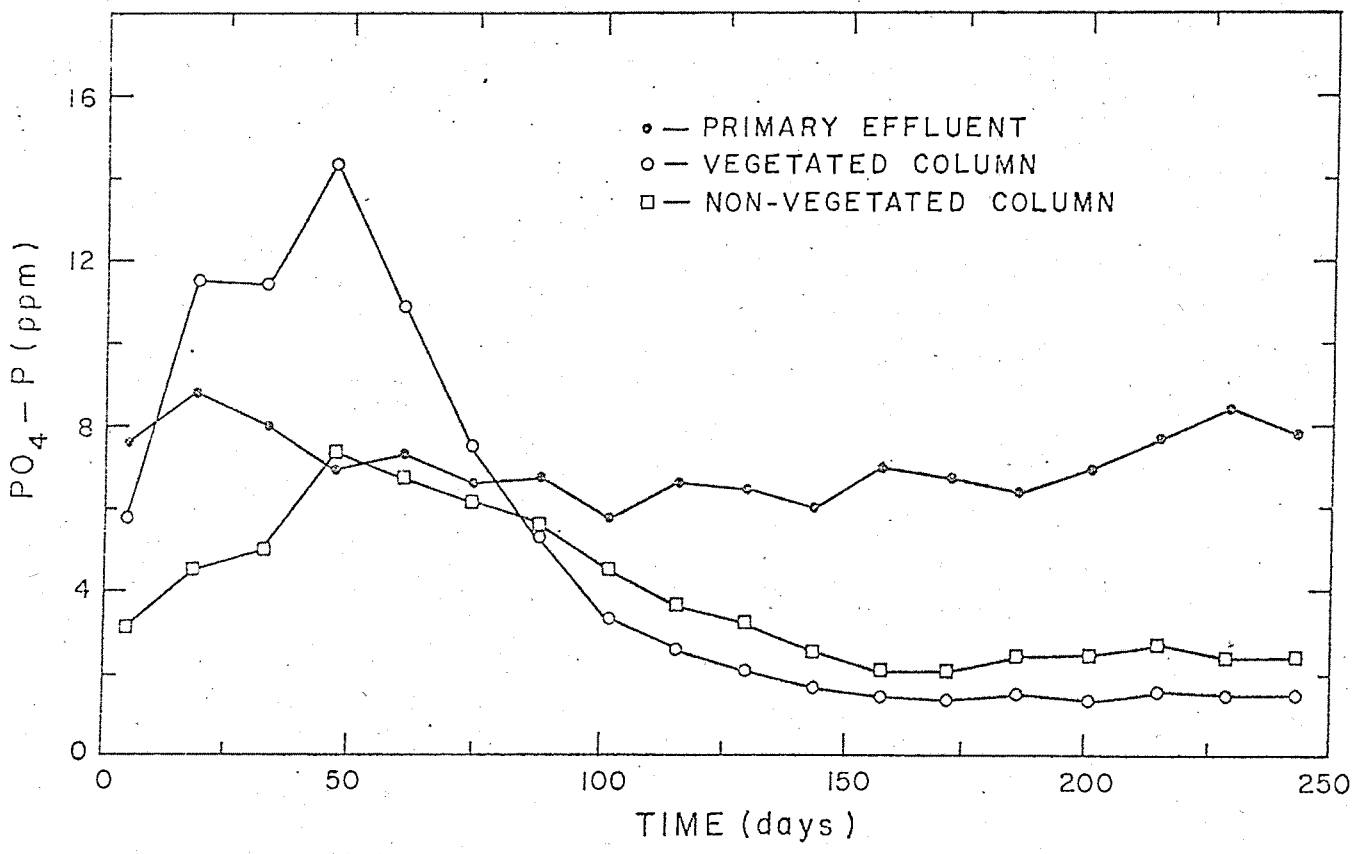

Figure 2. Phosphate concentrations in water from soil columns flooded with primary sewage effluent. Infiltration rates for the vegetated and nonvegetated columns were 21.3 and 20.4 cm/day, respectively.

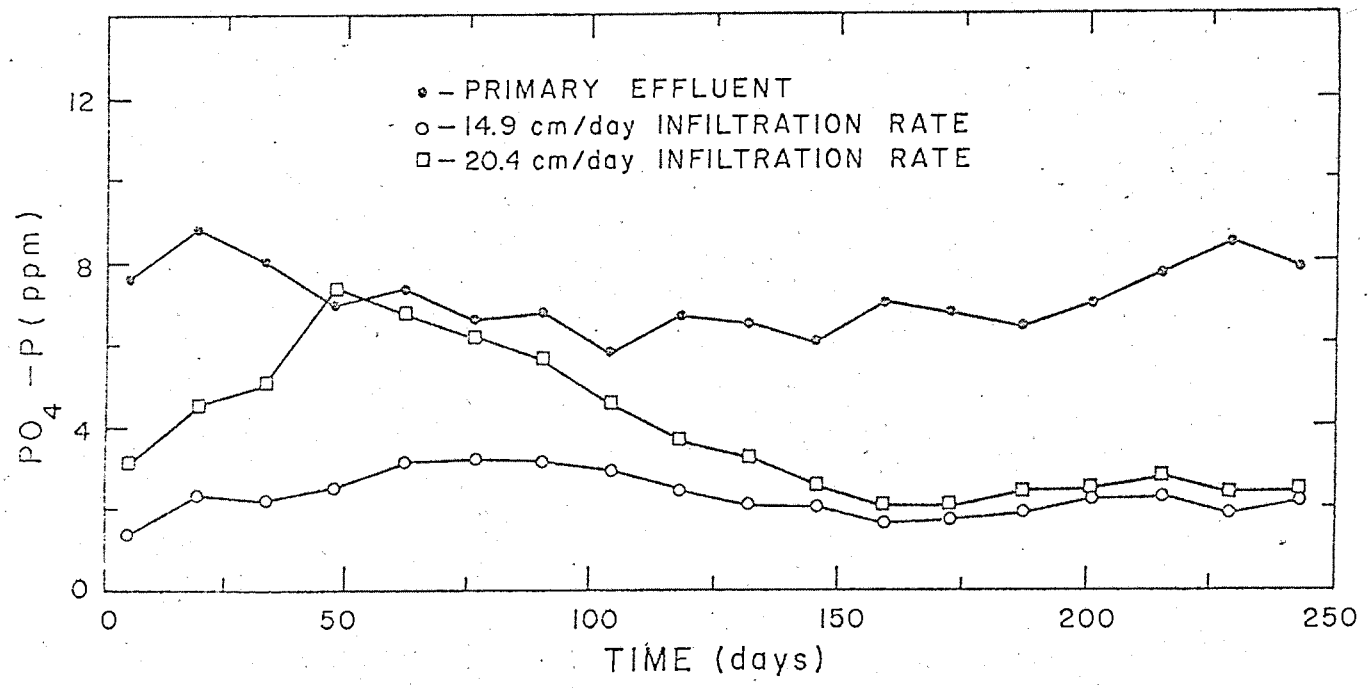

Figure 3. Phosphate concentrations in water from nonvegetated soil columns flooded with primary sewage effluent.

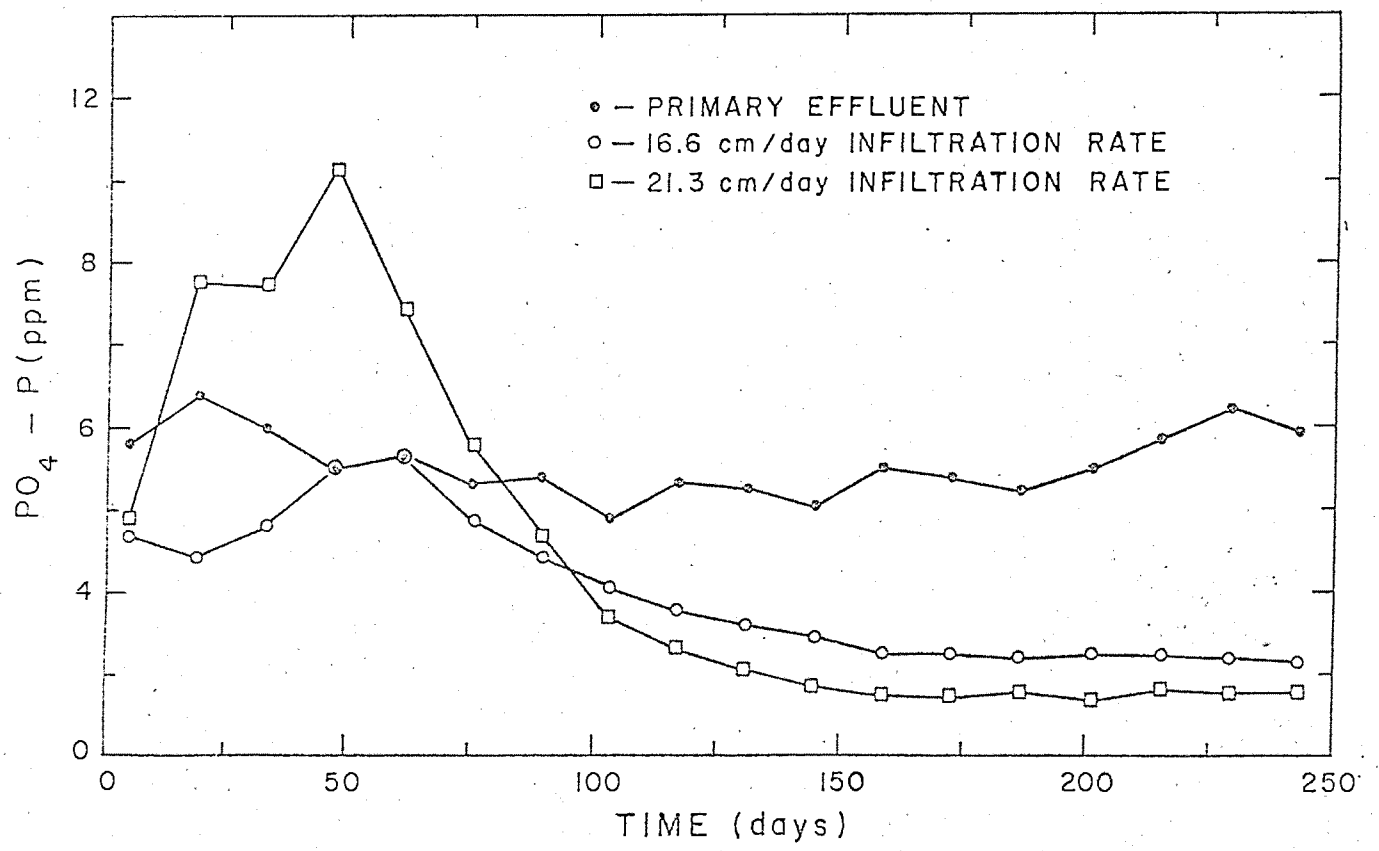

Figure 4. Phosphate concentrations in water from vegetated soil columns flooded with primary sewage effluent.

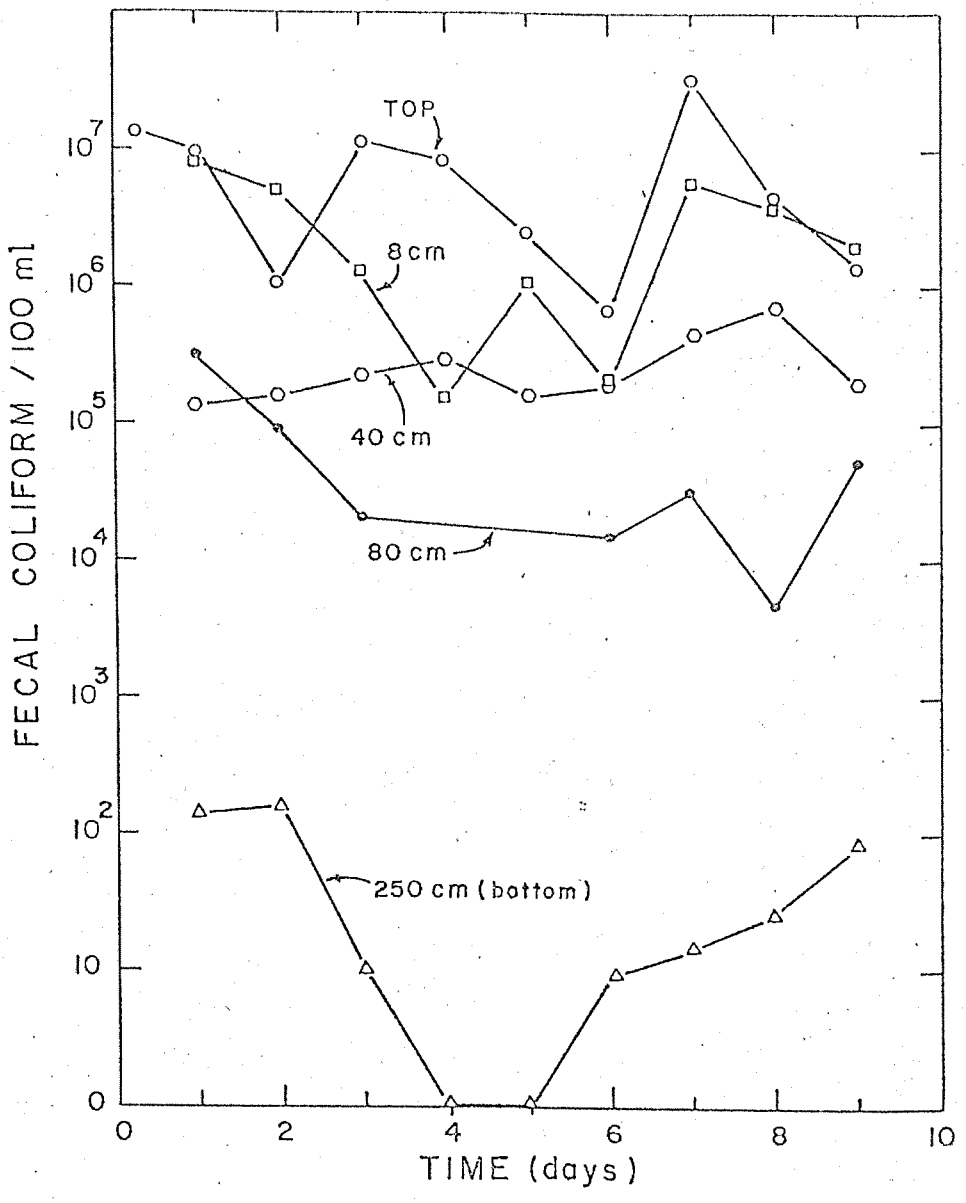

Figure 5. Fecal coliform concentrations at various depths in a vegetated soil column flooded with primary sewage effluent.

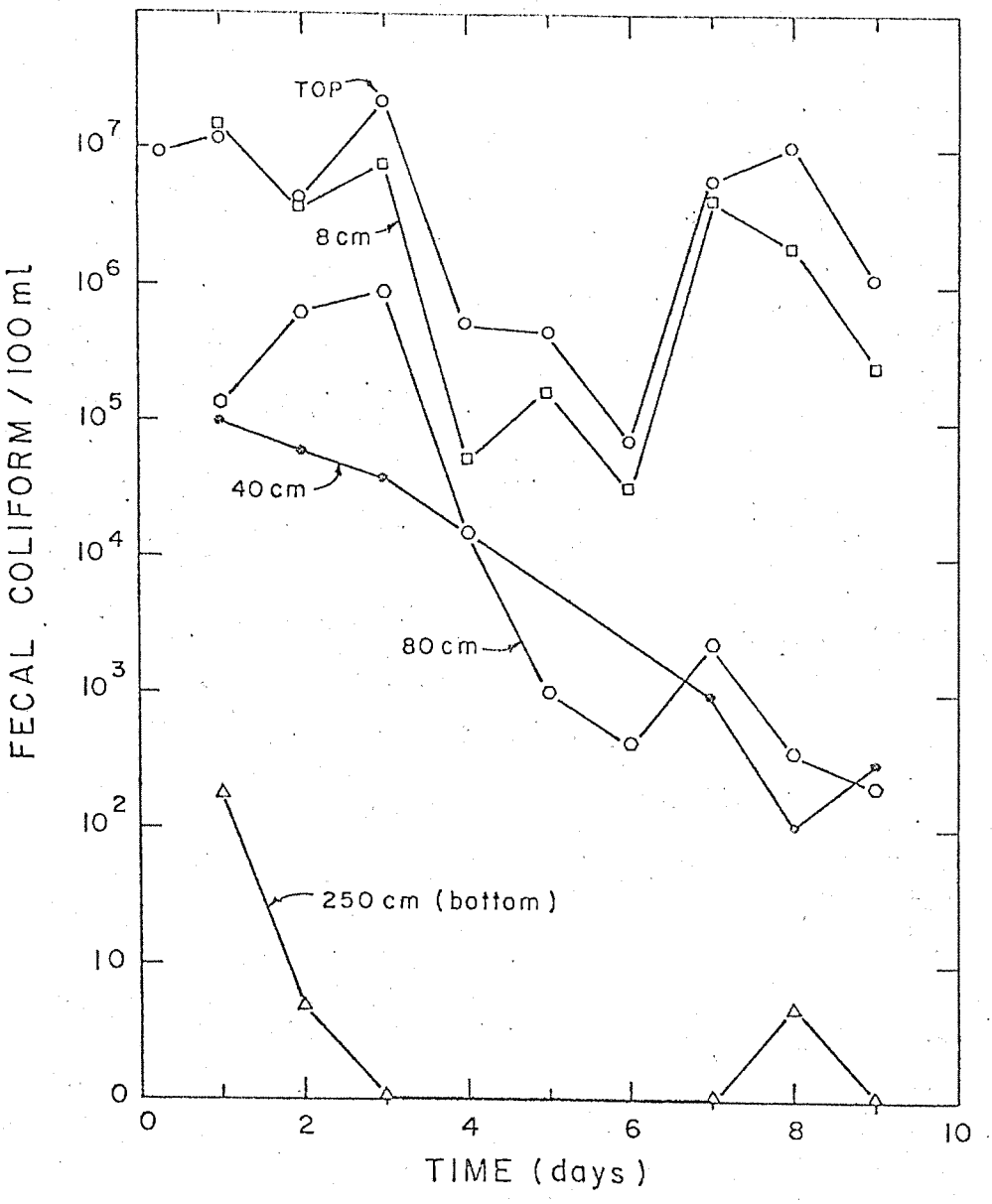

Figure 6. Fecal coliform concentrations at various depths in a nonvegetated soil column flooded with primary sewage effluent.

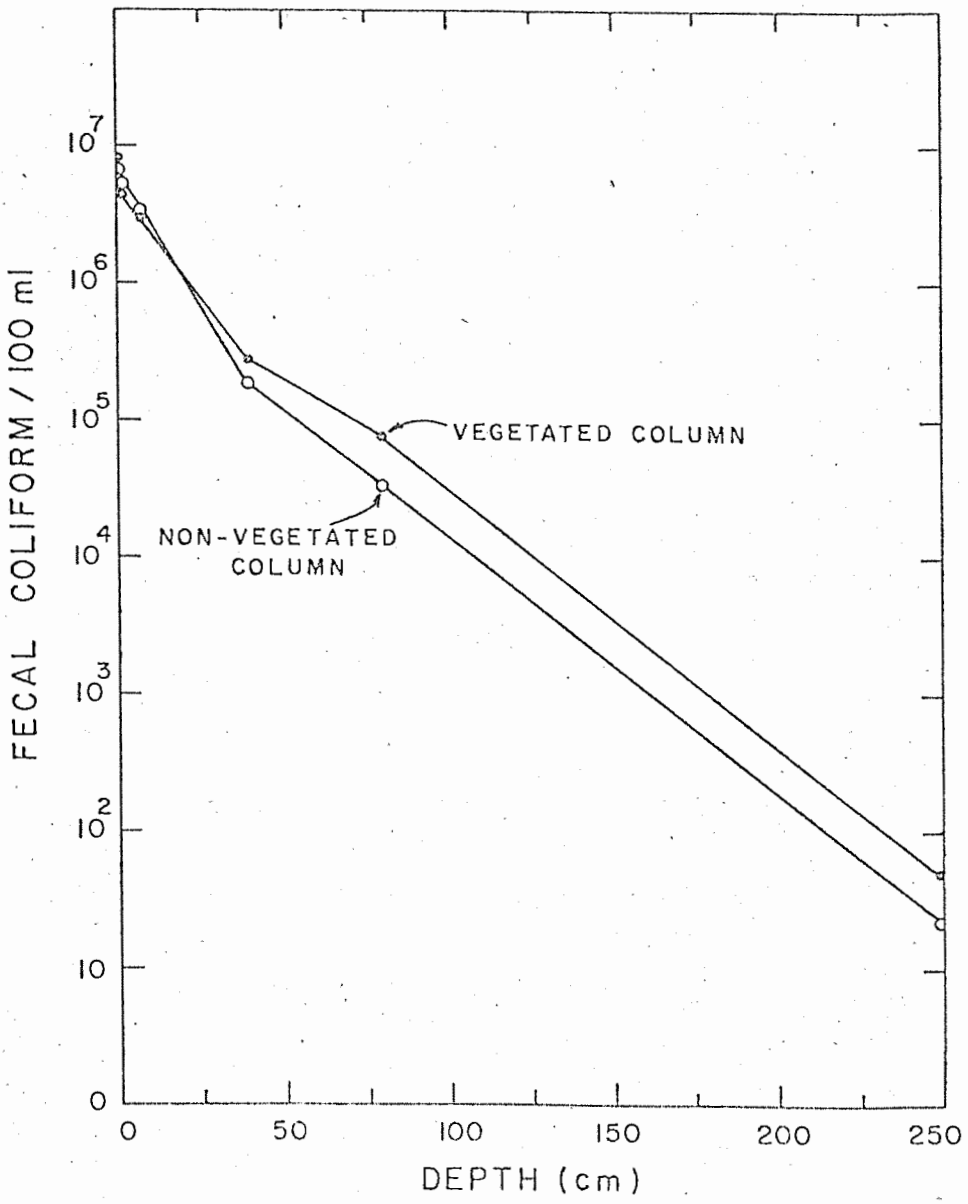

Figure 7. The reduction of fecal coliform concentrations in primary sewage effluent moving through a soil column.

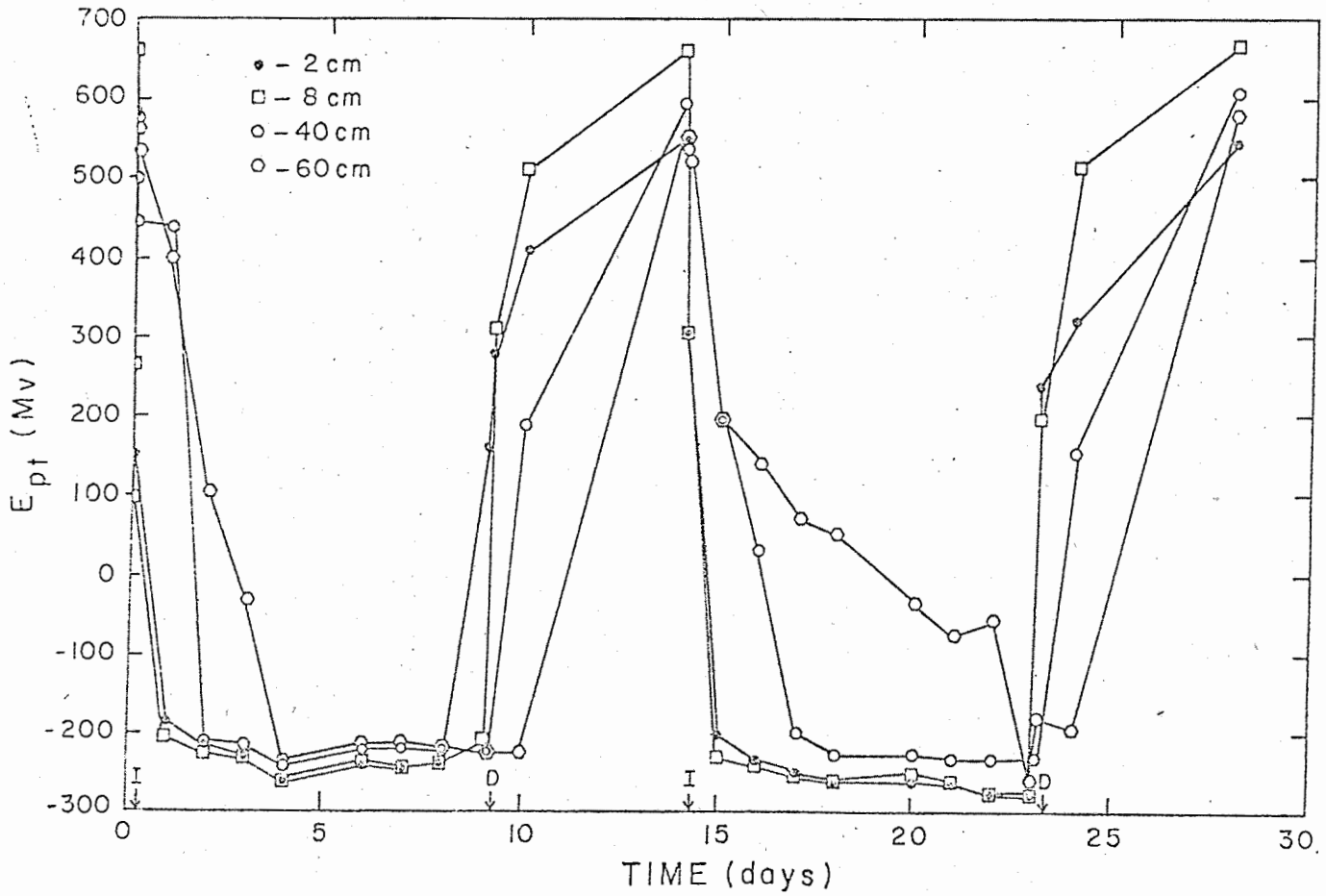

Figure 8. Oxidation-reduction potentials in soil columns flooded with primary sewage effluent. I and D indicate the beginning of 9-day-flooding and 5-day-drying periods, respectively.

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

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

INTRODUCTION:

During 1975 results of virus and bacterial movement in the field soil at Flushing Meadows Project were prepared for publication in SCIENCE and APPLIED MICROBIOLOGY. The results reported are of interest to public health officials and other agencies concerned with environmental quality. Additional work in Idaho on Redox potentials and denitrification in soil used for renovation of potato processing wastes was accepted for publication in the JOURNAL OF ENVIRONMENTAL QUALITY. Other research was started on basic aspects of denitrification in soil used for wastewater reclamation.

Laboratory and field experiments have demonstrated that 30 to 80% of the nitrogen in sewage effluent was removed when the effluent was intermittently applied to soil infiltration basins. The amount of removal depended on the management practice used. Rates of N-removal were increased in the laboratory columns by reducing the infiltration rates and adding carbon (glucose) to the wastewater. Similar N-removal results were obtained in the field when hydraulic heads were lowered to decrease the infiltration rates.

The removal of nitrogen from the wastewater by these land disposal methods was assumed to be caused by biodenitrification. However, no measurements of denitrifying bacterial numbers, activities, or rates of denitrification have been determined. Therefore, laboratory column studies were started to evaluate the activity of denitrifying bacteria populations and their denitrifying potential in soil used for wastewater renovation at the Flushing Meadows Project.

Our objectives were: [1] to determine the ratio of denitrifying (D) to aerobic bacteria (AB) in soil intermittently flooded with wastewater treated with a carbon source (glucose); [2] to determine the effect of different carbon sources on the D/AB ratio; and [3] to determine the numbers of the denitrifying bacteria and their zones

of activity in the soil profile during flooding and drying cycles.

PROCEDURE:

Description of Soil Columns. Six soil columns were assembled with plastic Buchner funnels (9.0 cm dia.) containing 200 g of air-dried soil from the surface 15 cm of basin No. 1 at Flushing Meadows. The soil depth in the column was about 2.5 cm. The soil columns were conditioned, prior to treatment with sewage effluent, with tap water for one flooding and drying period of 9 to 5 days, respectively. Mariotte syphons were used to deliver the wastewater and control the hydraulic head (about 2 cm) on the soil column.

Treatment of Soil Columns. Duplicate columns were used per treatment. The three treatments consisted of sewage effluent with 100 or 200 mg/l of glucose and effluent only. Sterilizable plastic bottles of 2-gal capacity contained the sewage effluent and one bottle supplied the treatment solution for two columns. The glucose-treated sewage effluent was replaced daily to prevent bacterial buildup in the bottles and maintain the treatment concentrations of glucose. During 9 days flooding, the columns were either flooded continuously (continuous treatment) or for only the first 2 days (pulse treatment) which was followed with untreated effluent for the remaining 7 days of flooding.

Microbial Assay of Soil Columns. Numbers of aerobic bacteria were determined in surface soil samples from the columns and sewage effluent samples from the reservoir bottles immediately after treatment with glucose and after 24-hr incubation. Dilution plate techniques were used with plate count agar as the culture medium. Soil samples of 2 to 4 g (dry wgt. basis) were obtained during flooding periods with a sterile spatula. The Mariotte syphon was closed and the flood water on the column was gently removed with a plastic squeeze bottle before sampling the soil. Immediately after sampling, the syphon was opened and the hydraulic head reestablished.

Numbers of denitrifying bacteria were determined in soil samples and sewage effluent samples collected as previously described. The most probable number method with a 5-tube dilution series in nutrient broth was used.

RESULTS AND DISCUSSION:

The results are preliminary and are presented here as a progress report. The initial trials evaluated the operation and design of the soil columns and determined the effects of sewage effluent treated with glucose on the aerobic bacterial numbers in the surface soil of the columns (Tables 1 and 2). The continuous-glucose treatments (Table 1) were surprisingly similar to the pulse-glucose treatments (Table 2). The major difference between them was the magnitude of the bacterial growth response. The 200 mg/l glucose treatment produced greater numbers of bacteria, but the population trends or treatments were identical. In general with both treatments, the aerobic bacterial numbers increased during the first 3 to 4 days flooding and then decreased during the last days of flooding and during the dry period.

The comparison of these results alone are difficult to explain. For example, why did bacterial numbers decrease when soil columns were treated continuously with glucose, as well as produce results similar to those obtained with soil columns treated only with the 2-day pulse of glucose? Subsequent results on the effects of the pulse-glucose treatment on denitrifying bacteria numbers provided some explanation. When the numbers of denitrifying bacteria (facultative anaerobic organisms) and aerobic bacteria were simultaneously determined (Table 3), then it was evident that the facultative anaerobes had an ecological advantage because of the high oxygen demand placed on the soil system in the columns flooded with wastewater treated with 200 mg/l glucose. The ratio of denitrifying to aerobic bacteria continued to increase from 0.10 to 0.94 during the 9-day flooding period. This indicated the relative activity of denitrifying bacteria increased during flooding, and they were the dominant bacterial population in the soil surface at the end of the flood period. However, when the flood was stopped and the soil surface was aerated and dried, these facultative anaerobes quickly died and aerobic bacteria became the dominant competitors. During the

dry periods the number of aerobic bacteria remained low, because the available nutrients and soil moisture decreased rapidly.

The comparison of denitrifying and aerobic bacteria numbers in soil columns flooded with sewage effluent treated with 100 mg/l glucose was similar to the 200 mg/l glucose treatment for 4 days (Table 3). But the lower glucose concentration placed less of an oxygen demand on the system for a shorter period of time and did not support the establishment of a facultative anaerobic population for the duration of the flooding period. Thus, the numbers of denitrifying bacteria decreased after 4 days and the D/AB ratio decreased, indicating that the surface was more oxidized during the latter part of the flood period and aerobic bacteria were more active and increased in numbers.

Relative to the control column flooded with effluent only, the numbers of denitrifying and aerobic bacteria increased slightly during flooding periods. The level of available nutrients in the sewage effluent from an activated sludge-type secondary sewage treatment plant would not be expected to cause a large increase in bacterial numbers.

The addition of glucose to sewage effluent increased the numbers of aerobic and denitrifying bacteria during 24-hr incubation (Table 4). Even though the treated effluent was changed daily, the growth of bacteria was rapid, especially the denitrifying bacteria in effluent treated with 200 mg/l glucose. The increase in numbers of aerobic bacteria was directly proportional to the increase in glucose concentration. These results suggest that the effluent treated with 200 mg/l glucose contains sufficient numbers of denitrifiers in the presence of available nutrients to enhance denitrification in the soil columns.

The infiltration rates of all soil columns were adjusted to about 1.5 ft/day, while flooding the columns initially with tap water. But when effluent was used, the infiltration rates decreased rapidly and remained low throughout our experiments (Table 5). The infiltration rates of the glucose-treated soil column decreased even

more and was proportional to the glucose concentration in the sewage effluent. Additional experiments with sewage effluent will be conducted to evaluate the effect of higher infiltration rates of 1.5 to 2.0 ft/day on the numbers of denitrifying and aerobic bacteria in the soil columns.

SUMMARY AND CONCLUSIONS:

The effects of flooding soil columns with sewage effluent treated with glucose on the growth of denitrifying and aerobic bacteria in the surface soil were evaluated during 1975. Six soil columns were assembled and duplicate columns were flooded with sewage effluent only or sewage effluent treated with either 200 or 100 mg/l glucose. The glucose-treated effluent was changed daily to maintain glucose concentrations and reduce effects of microbial activity in the plastic 2-liter supply reservoir. Flooding and drying periods of 9 and 5 days, respectively, were used. The soil columns were flooded either continuously for 9 days or for the first 2 days only with the glucose treated effluent. Numbers of aerobic bacteria were determined with dilution plate techniques using plate count agar. The numbers of denitrifying bacteria were determined with the most probable number method, using a 5-tube dilution series with nutrient broth.

The glucose-treated effluent promoted the growth of denitrifying bacteria in the effluent and the soil surface. In general, those factors that enhanced the establishment of reduced conditions in the surface soil promoted the development of denitrifying bacteria and increased the potential for nitrogen removal. The addition of glucose to the sewage effluent placed a high oxygen demand on the system and produced reducing conditions as well as provided available carbon necessary for the activity of the denitrifying bacteria. These conclusions, however, are based on the results from the 2-day, pulse-glucose treatment only and will be evaluated further when the results from the continuous-glucose treatment are analyzed. Also, the infiltration rates of 0.2 to 0.6 ft/day are low and additional experiments will determine the effects of higher infiltration rates of 1.5 to 2.0 ft/day on microbial activities in the soil surface of

columns flooded with glucose-treated effluent. The effects of other carbon sources on denitrifying bacteria numbers and activity will also be evaluated; and, longer soil columns will be used in later experiments to study the zones of activity of denitrifying bacteria in the soil profile during flooding and drying cycles.

PUBLICATIONS:

1. Smith, J. H., Gilbert, R. G., and Miller, J. B. 1975. Denitrification in a field irrigated with potato processing waste water evaluated from redox measurements in soil. Abstract. Western Soil Science Society Meeting, Ft. Collins, Colorado.

2. Smith, J. H., Gilbert, R. G., and Miller, J. B. 1976. Redox potentials and denitrification in a cropped potato processing waste water disposal field. J. Environmental Quality. Accepted for publication.

3. Gilbert, R. G., Rice, R. C., Bouwer, H., Gerba, G. P., Wallis, C., and Melnick, J. L. 1976. Wastewater renovation and reuse: Virus removal by soil filtration. Science. Accepted for publication.

4. Gilbert, R. G., Rice, R. C., Bouwer, H., Gerba, C. P., Wallis, C., and Melnick, J. L. 1976. Virus and bacteria removal from wastewater by land treatment. Applied and Environmental Microbiology. Submitted for publication

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

Table 1. Aerobic bacterial numbers in surface soil of columns flooded continuously for 9 days with sewage effluent treated with glucose.[1/]

Sampling Schedule	Glucose treatments, mg/l		
	200	100	Control
	Aerobic bacteria/g (oven dry soil) $\times 10^6$		
End of 5-day dry period	68 (162)	53 (126)	42
Start of 9-day flood period	203 (322)	135 (214)	63
4 days flooded	300 (469)	193 (302)	64
7 days flooded	240 (393)	176 (267)	61
9 days flooded	155 (235)	95 (156)	66
Start of 5-day dry period	115 (169)	84 (124)	68
End of 5-day dry period	68 (162)	53 (126)	42

1/ Data are averages of results from 3 flooding and drying cycles with 2 soil columns per treatment. Parentheses equal percent of effluent control. Soil columns were dried for 5 days between each 9-day flood period.

Table 2. Aerobic bacterial numbers in surface soil of columns flooded for the first 2 days of a 9-day flood period with sewage effluent treated with glucose.[1/]

Sampling Schedule	Glucose treatment, mg/l		
	200	100	Control
	Aerobic bacteria/g (oven dry soil) $\times 10^6$		
End of 5-day dry period	71 (139)	52 (102)	51
Start of 9-day flood period	146 (256)	130 (228)	57
3 days flooded	358 (551)	249 (383)	65
6 days flooded	275 (372)	167 (226)	74
Start of 5-day dry period	90 (200)	104 (231)	45
End of 5-day dry period	71 (139)	52 (102)	51

1/ Data are averages of results from 3 flooding and drying cycles with 2 soil columns per treatment. Parentheses equal percent of effluent control. Soil columns were dried for 5 days between each 9-day flood period.

Table 3. Denitrifying (D) and aerobic bacteria (AB) numbers and ratios (D/AB) in soil columns flooded with sewage effluent treated with glucose for the first 2 days of a 9-day flood period.[1/]

Sampling time	Glucose concentration								
	200			100			Effluent		
flooding period	D	AB	D/AB	D	AB	D/AB	D	AB	D/AB
Days	Bacteria/g (oven dry soil) × 10^6								
0 days (End of dry period of 5 days)	2.1	20.2	0.10	4.6	25.0	0.18	10.5	22.0	0.48
4 days	28.8	72.2	0.40	24.4	45.0	0.54	16.8	50.6	0.33
9 days	32.3	34.0	0.94	12.0	51.0	0.24	16.8	33.5	0.50

1/ Results are averages of 2 trials with duplicate soil columns per treatment. Soil columns were dried for 5 days between each 9-day flood period.

Table 4. Growth of bacteria during 24 hours in sewage effluent treated with glucose.[1/]

Sampling time	Glucose concentration, mg/l			
	200	100	20	Effluent
(hr)	Total bacteria/ml × 10^6			
0	1.39	1.94	1.10	1.67
24	19.10	10.07	4.90	1.46
	Denitrifiers/ml × 10^6			
0	0.14	-	0.17	0.17
24	33.00	-	0.79	0.08

1/ Results of total bacteria are average of 4 tests and the results for denitrifiers were obtained only once.

Table 5. Infiltration rates for soil columns flooded with sewage effluent treated with glucose.[1/]

Glucose concentration	Infiltration rate
mg/l	ft/day
200	0.23 (0.73-0.07)
100	0.38 (1.97-0.08)
Effluent	0.65 (1.67-0.08)

1/ Results are average of 9 measurements taken at various times during 9 flooding periods with duplicate soil columns per treatment. Parentheses indicate range of infiltration rates determined at various times during the flooding period.

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

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

INTRODUCTION:

The rainfall-runoff-erosion studies conducted in cooperation with the University of Hawaii continue to be the major research emphasis in Hawaii. However, a new cooperative agreement was initiated with the State of Hawaii, Department of Land and Natural Resources, to investigate water quality from various water harvesting systems, which will be installed in 1976.

RESULTS AND DISCUSSION:

PART I. WATER HARVESTING

The four-plot water harvesting test site on Maui is presently used only as a materials weathering site. The plots were not visited in 1975.

A new cooperative agreement was initiated with the State of Hawaii, Department of Land and Natural Resources, Division of Water and Land Development (DOWALD) to investigate the water quality from various water harvesting systems. Of primary interest is the water quality from catchment aprons constructed of various types of paraffin wax. Plans were developed for constructing the water harvesting system on recent volcanic flows in the Puna area of the Big Island. Two or three catchments will be constructed and treated with wax. The collected water will be stored in a reservoir lined with artificial rubber. This water will initially be used to supplement irrigation of papaya, but may eventually be used for potable domestic water systems if it exceeds existing quality criteria. Water samples from the catchments and the storage reservoir will be collected at periodic intervals for analysis of inorganic, organic, and biological contaminants according to EPA water quality standards. The quality of this water will also be compared to samples collected from existing rooftop water systems. The study also includes the evaluation of waxes for general purpose water harvesting catchments in Hawaii.

PART II. RAINFALL-RUNOFF-EROSION STUDIES

Data from the waterstage recorders and the raingages are processed routinely as the charts are received. The initial data processing consists of tabulating rainfall and runoff by event. Computer programs are being developed to further investigate items such as: rainfall intensity, antecedent soil moisture, daily rainfall totals, etc.

In 1975, the total rainfall at all the sites was considerably below the long term averages. The low rainfall restricted the growth rate of the crops and thus reduced the protective cover normally afforded by crops of the corresponding age. The result was an increase in runoff and erosion for the few larger storms.

Following is a brief summary of each of the watersheds for the past year.

1. Laupahoehoe -- This watershed is in the last few months of the 24-26 month growing period. The area is covered with a dense stand of sugar cane. Rainfall has been relatively low with no measureable sediment collected. In January 1975 a major storm of 3 days produced over 500 mm of rain with essentially no runoff recorded. Since the original installation of the equipment, runoff has generally been less than 10% except immediately after the crop was harvested. Shortly after harvest in January 1974, a 100-mm (4-inch) storm with intensities less than 50 mm/hr (2 inch/hr) produced 94% runoff. Within 80 to 90 days after harvest the runoff was again less than 10% of the rainfall, indicating the cane was again protecting the soil.

2. Honokaa -- The sugar cane is in the last half of its 24-26 month growing period, completely covering the watershed with a dense growth. Rainfall has been very low at the site with essentially no runoff.

3. Waialua Sugar - This area was harvested in the fall of 1974. Because of the low rainfall, the ratoon sugar cane crop is considerably smaller and less dense than usual. Under these conditions, runoff from the watershed is about twice what it was when a good cover of sugar cane was present. The increased runoff appears to be increasing

erosion. The rows on this watershed run up and down the slope rather than on the contour, thus also contributing to increased erosion.

4. Waialua Pineapple -- This field is one of the original pineapple watersheds, but in May 1974 it was converted to sugar cane. The first crop of cane was harvested for seed cane in April 1975. Regrowth after harvest has been relatively slow because of the drought with a correspondingly poor stand. Runoff from this site is relatively high (up to 75% for the larger storms) even with a good crop cover. Since the stage of the crop growth at this site does not seem to affect the percent of runoff greatly, it may be that this soil is relatively tight (a low infiltration rate).

5. Mililani -- This watershed is presently being prepared for replanting to pineapple. The watershed was originally in pineapple but has been used for a variety of crops such as potatoes and tomatoes since installation of the measuring equipment. It has also been covered with weeds at various times. The new pineapple replanting will permit the comparison of runoff with the other pineapple site, and the effect of the different crops and plant growths on the runoff and erosion.

6. Kunia -- Rainfall at this site was very low during the summer requiring a supplemental sprinkler irrigation of the pineapple during August. This field is planted using recommended conservation practices but there is still some runoff (up to 18% for some of the larger storms) and a corresponding sediment load, apparently coming from the roads in the area. The flume at this site was washed out once during the past year when water piped under the butyl sheeting at the upstream side. The equipment was repaired and is in good condition.

SUMMARY AND CONCLUSIONS:

A cooperative agreement was initiated with the State of Hawaii, Department of Land and Natural Resources, to investigate the water quality from various water harvesting systems. Of primary interest is the water quality from catchments constructed of volcanic cinders and treated with various types of paraffin wax.

The rainfall-runoff-erosion studies conducted in cooperation with the University of Hawaii continued to receive the major research emphasis for the past year. Processing of the rainfall-runoff data is continuing. Initial processing of the data consists of tabulating the rainfall and runoff by storm events and is about 95% completed and up to date. Computer programs are being developed to further analyze the data with respect to items such as: rainfall intensity, antecedent soil moisture, daily rainfall totals, etc. These analyses will be performed in the coming year.

Rainfall at the sites was considerably below the long-term averages. This restricted the crops' growth rate and reduced the protective cover thus increasing the runoff and erosion during the few large storms.

PERSONNEL: Gary Frasier, Keith Cooley and John Griggs

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

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

INTRODUCTION:

Long-range durability and efficiency studies were continued at Granite Reef for a few materials in 1975. Included were foamed butyl rubber, foamed wax blocks, and two continuous wax covers on the 9-ft-diameter stock tanks, and continuous wax covers on the butyl-lined pond and the small asphalt-fiberglass pond.

Field evaluation of wax covers started on 31 July 1975 when a 128° wax cover was installed on a 30-ft-diameter concrete tank in Chino Valley.

Field evaluation of the foamed butyl covers was continued. Two covers were located in southwestern Utah in 1971 and four in Arizona in 1974. Publication of a paper entitled "Foam Rubber Covers for Evaporation Control" is expected during 1976.

PROCEDURE:

Evaluation of the various treatments on the Granite Reef tanks was the same as in previous years, the procedure being to compare evaporation from a treated tank to that from an identical untreated tank. All studies were conducted at Granite Reef since the laboratory site studies were discontinued at the end of 1974. All covers were the same as reported on last year.

RESULTS AND DISCUSSION:

Granite Reef Studies. The efficiency of the wax covers on the tanks remained essentially the same during 1975. Averages for the year were 36, 83, and 85%, respectively, for the foamed wax blocks, 120°-125° wax layer, and the charcoal-covered wax layer. Water was not added to tank No. 1, with the 125°-135° wax layer, again this year in an attempt to determine what would happen to the wax if the tank went dry and was then refilled. Again, the tank did not dry up completely. If the tank does not completely dry up by June 1976, water will be added and effectiveness again recorded for the remainder of the year.

The foamed butyl rubber cover installed on tank No. 3 in January 1974 reduced evaporation by 78% for the year, or 7% less than last year. Approximately 88% of the water surface is covered (cover diameter 104 inches in December 1975).

The 128° AMP wax applied to the butyl-lined pond in 1973 still only covers about one-third of the water surface. It is believed after observations made this year that the wax gets hot enough to spread in the summer, but the wind tends to pile the wax up on the downwind bank. It therefore never spreads enough to cover the entire surface. Additional wax will be applied this summer to determine if a continuous layer can be maintained. If not, it will mean that this type of cover should be restricted to very small ponds or tanks.

The continuous wax cover applied to the small asphalt-fiberglass pond melted and re-formed after breaking into numerous small pieces during the 1974-75 winter. The layer was very thin after re-forming since part of the original wax was blown from the surface while in small pieces. Algae and dirt accumulated in the thin layer of wax causing much of it to sink during the latter part of the year. A change of physical characteristics, due to reaction with volatiles from the asphalt, may cause the sinking and breakage since it has not occurred on the steel tanks and butyl-lined pond.

Field Studies. The wax layer applied to the Chino Valley tank has not been observed since installation and results will not be reported until next year.

Jackson Wash tank, northwest of Cedar City, Utah, installed November 1971 -- This cover had been displaced from the tank twice in previous years and was, again, in 1975. When on the ground this time it was trampled by the cattle. Bureau of Land Management cooperators removed the cover from the site and destroyed it. A sample of the cover material was returned for inspection. The bond strength of the 2-inch lap joints still exceeded the strength of the sheeting material. Thickness of the sheeting had decreased over the 4-yr period by 5 to 10% (original thickness 3/16 inch). The foamed sheeting had remained pliable and appeared to be in excellent condition.

Beaver Dam tank, southwest of St. George, Utah, installed November 1971 — The cover was inspected seven times during 1975, first in February and last in October. Water levels varied when inspected from 7 inches from the top of the tank to empty. The maximum wind gust recorded was 26 mph. Some dust and salts have accumulated on the cover, but the material and joints are in excellent condition. The cover diameter has decreased about 5% since installation or 9% with respect to area (diameter 28 ft, 1 inch on 26 September 1975; original diameter 29 ft, 6 inches).

Frasier Well tank, Hualapai Indian Reservation, installed May 1974 — The cover was inspected in January, March, and June during 1975. About 4 inches of ice had formed under the cover when inspected in January, but no damage had resulted. The cover has five or six small tears, but none are detrimental. About 15 inches of the edge bead material has separated from the cover and needs to be reattached. Generally, the cover is functioning satisfactorily with wind gusts up to 42 mph measured.

Shipley Well tank, Hualapai Indian Reservation, installed May 1974 — This cover was inspected three times during 1975 and was removed from the tank in October for patching purposes. The cover has had a history of damage that has been attributable to vandalism. Damage has ranged from holes being punched by sticks and rocks to tears occurring from pulling on the cover. The cover has operated satisfactorily after being patched.

Glover Ranch tank, south of Safford, Arizona (Bureau of Land Management), installed September 1974 — The cover is functioning satisfactorily. Salt accumulations around the drain holes were noted but do not affect the serviceability of the cover. Such accumulations have been previously noted on other covers.

Hughes Ranch tank, south of Rye, Arizona (Tonto National Forest), installed November 1974 — Cover is in excellent condition. Some water was hauled to the tank during 1975. Maximum depth of water has been about 6 inches since the floating cover was installed. The wind gust anemometer was stolen during the spring or early summer of 1975,

along with the wind gust records that Hughes had been keeping. The maximum gust recorded was about 40 mph.

SUMMARY AND CONCLUSIONS:

The foamed wax blocks and continuous wax cover tested at the Granite Reef site performed essentially the same as for the past 3 to 5 years. The efficiency of the wax blocks was 36%, and the continuous wax covers reduced evaporation by 83 and 85%. The foamed butyl rubber cover reduced evaporation by 78% during the year.

Wax will be added to the ponds at Granite Reef to determine if a continuous, or complete, cover can be obtained on the large pond, and to see if a thicker wax layer will hold up on the small asphalt-fiberglass pond.

A 128° wax cover applied to a concrete tank in Chino Valley will be observed and reported on next year.

Four of the six foamed rubber covers being field tested have operated satisfactorily for up to 4-1/2 years. One of the original floating covers exposed in 1971 was displaced from the tank and trampled by livestock. The cause for displacement was unknown. Another cover was torn, probably by vandals. The cover still operating after 4-1/2 years has shrunk about 5% in diameter. Material condition, however, and bonded joints are excellent.

PERSONNEL: Keith R. Cooley and Allen R. Dedrick

TITLE: LOWER COST WATER HARVESTING SYSTEMS

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

INTRODUCTION:

Evaluation of materials and methods for water harvesting were continued with the measurement of rainfall and runoff from the various plots at the Granite Reef, Seneca, and Monument Tank test sites. Observations were continued at Granite Reef and Logan, Utah, on the weatherability evaluation of various experimental materials and coatings which have potential use for collecting and storing precipitation runoff. A new cooperative study was initiated with the Bureau of Land Management (BLM), U. S. Department of Interior, to evaluate the performance of various existing water harvesting systems and to develop new lower cost methods and materials for use in water harvesting systems.

PART I. GRANITE REEF TEST SITE

In 1975 there were a total of 20 measurable rainstorms producing a total of 183.4 mm of precipitation at the Granite Reef test site.

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

The runoff efficiency from the two-phase asphalt treatments L-5 and L-6 continued to decline, averaging 42.7% and 61.7%, respectively, for the year. A new sealcoat of modified asphaltic emulsion was applied to plot L-6 on 13 November 1976. Runoff after retreatment was 84.5% of a total of 61.1 mm of rain.

The membrane-covered plots L-1 (30-mil chlorinated polyethylene), and L-7 (1-mil aluminum foil) yielded 100.3% and 82.4% runoff, respectively. There are several small holes in the covering of L-1, possibly caused by an animal (coyote). The plastic covering has shrunk and pulled loose from the metal borders at the upper edge of the plot. The aluminum foil on plot L-7 shows signs of oxidation. A third membrane-covered plot L-4 (15-mil nonreinforced butyl) completely failed during the year and was removed from the plot in July 1975. Prior to removal, runoff was only 34.9% from 68.4 mm of

rainfall. Wind action gradually enlarged several holes in the sheeting. This allowed a wind storm to lift the entire covering from the plot. The butyl material had been "chalking" for several years and had lost an estimated 50-75% of the original tensile strength. The covering had been in place for a total of 14 years and was intentionally not maintained during the last 3 to 4 years to observe the type of failures which might occur with no maintenance.

The aluminum-coated, asphalt-fiberglass plot, A-1, averaged 95.8% runoff and the gravel-covered plot, A-2, averaged 70.6% runoff. This is approximately the effectiveness that was measured in the preceding year. Maintenance was not required on either plot the past year. The protective coating on A-1 shows no signs of any deterioration.

Plot A-5 (concrete) averaged 76.3% runoff. This is the same effectiveness that was measured in 1974. The strips of asphalt fiberglass over the cracks are still in place, but do show signs of needing a new seal coat.

Bare Soil Plots: The treatments on the bare soil plots are listed in Table 3 and the runoff results by individual storm events are presented in Table 4.

The runoff from the two undisturbed watersheds W-1 and W-3 averaged 12.9% and 14.6%, respectively. This is slightly lower than was measured in previous years, possibly caused by the below-average rainfall. The smoothed untreated plots L-2 and A-3 averaged 15.8% and 21.4%, respectively. The untreated ridge and furrow plot R-1 averaged 15.0% runoff for the year. These runoff results are all slightly less than was measured in 1974.

The wax-treated plot R-2 and the silicone-treated plot A-4 averaged 83.9% and 59.8% runoff, respectively. The wax plot was only slightly less efficient than the previous year but runoff from the silicone-treated plot was significantly lower. The remaining two silicone-treated plots L-3 and R-4 were retreated on 3 June 1975 along with a new silicone treatment on watershed area W-2. Total rainfall was 68.4 mm before treatment and 115.0 mm after treatment. Plot L-3 averaged 20.5% runoff before treatment and 78.1% after treatment.

Plot R-4 averaged 25.6% and 86.8% before and after treatment, respectively. The undisturbed watershed W-2 yielded only a trace of runoff before treatment and 35.1% for the remainder of the year. There is considerable surface retention on W-2. It was noted that many of the bare soil plots were relatively low in runoff efficiency for the storm of 21 December 1975. The cause of poor runoff results is not known.

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

Outdoor Weathering Plots: In December 1973, 43 separate materials and/or coatings were installed on small exposure plots at the Granite Reef test site. In April and July 1974, 3 additional materials were installed. A description of the materials and coatings is presented in Table 5 of the 1974 Annual Report, "Lower Cost Water Harvesting Systems," WCL 71-12. Materials under evaluation have thicknesses from 1 mil to 55 mil. Some of them have an additional protective coating for added weathering resistance. A visual inspection of the materials and coatings is performed periodically to evaluate relative weathering performance. Sheeting materials are also checked for elongation or shrinkage by measuring two reference marks which were placed on the materials at the time of installation. For the protective coating evaluation, the substrate material is not considered unless there is evidence that a substrate failure has occurred because of inadequate protection. If a material is graded as poor it is usually removed and considered to have failed.

Since initiation of the study, five materials and three coatings are considered to have failed. A brief description of the evaluation for the past year is presented in Table 5. Mechanical damage from wind or varmints has been minimal.

PART II. MONUMENT TANK

Precipitation at the Monument Tank test site totaled 297.2 mm for the year. This is considerably less than the long term average of about 400 mm per year, and as a result, very little runoff occurred from the watershed areas. The flume on Watershed Area No. 3 remained plugged with asphalt from the retreatment of the collection ditches. During a storm in July 1975, sediment transported down the channel of Area 4 was deposited in the flume entrance section and plugged the stilling well tap. At present only the runoff from areas Nos. 1 and 2 is being monitored.

Limited laboratory studies indicate that the soil on Area No. 3 can be made water repellent by the use of a silicone chemical. Studies are being conducted to determine the possibility of using a new rubber latex in combination with the water repellent to stabilize the soil.

PART III. OPERATIONAL CATCHMENTS

Seneca Catchment: The total precipitation at the Seneca Catchment for the year measured 318.2 mm. One major runoff event occurred on 7 September 1975 when 5.8 mm of rain occurred, followed 6 hrs later by a 17.2-mm storm. Total runoff measured was 0.55 mm. The wax treatment on the plot has undergone several cycles of freezing and thawing which has aggregated the soil. The soil aggregates appear to be waterproof for a limited time. There is considerable surface roughness which retains water on the soil surface which causes the waterproofing of the aggregates to decrease and allows water to infiltrate the soil. There has also been a considerable amount of plant growth on the plot indicating that moisture is penetrating through the soil treatment.

The butyl reservoir lining shows considerable evidence of poor weathering. Also, numerous holes have been torn in the lining since installation, primarily from animals walking on the sheeting. These holes have been repaired at periodic intervals, but it is believed that there are other holes which have gone undetected through which water is lost from the storage. The BIA has been advised that the lining should be replaced. Monitoring of the rainfall and runoff from the site has been discontinued.

Arizona Strip Catchments: The two wax catchments on the BLM Arizona Strip District were visited during the summer of 1975. Both catchments have weathered the first year in good condition. There was some concern that soil was being eroded from the lower unit (Snap Point) into the water storage reservoir. This has not been a serious problem but the catchment will be closely watched for any increase in erosion. Both catchments have been able to supply sufficient water for the livestock and wildlife in the areas.

Fishlake National Forest: The project titled "Prevention of Small Mammal Damage to Flexible Membrane Materials used as Water Barriers" being conducted through a cooperative agreement with Utah State University was terminated in 1975. The objectives of the study were: to identify the small animal species damaging flexible membrane materials being used as water barriers; determine the ecological factors associated with the damage; and develop methods whereby the damage can be prevented.

Four of the water harvesting systems involved in the study were visited in August 1975 in the company of the graduate student working on the project. Nine suggestions for designing and installing water harvesting systems were given in an April-June 1975 progress report. Part of these suggestions are expected to be expanded upon in a forthcoming Master of Science thesis which will serve as a final report for the project. Completion of the thesis is expected during 1976.

Cache National Forest: The unreinforced butyl rubber catchment at Chicken Creek was in good condition when visited in August 1975. Two small holes and one larger tear (about 1½ ft) could easily be patched to retain the original usefulness. The 30-ft-diameter, PVC-lined steel storage tank, was nearly empty. It was impossible to determine the quantity of water that had been collected and if it had been beneficially used. Generally the system has not been used regularly and hence the little maintenance required for a successful system has not been performed.

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

Outdoor Weathering Racks: The appearance and condition of membrane and film specimens exposed on racks at Logan, according to ASTM D 1435, are summarized in Table 6. The materials were inspected in August 1975. Observations will be continued during 1976.

Outdoor Exposure Panels: Thirty-six potential water barrier materials, of the flexible sheeting and film type, are exposed as ground panels at Logan in a manner similar to that described for Granite Reef. Material condition is reported in Table 7. Changes from the previous year are marked by an asterisk. The most significant change from the previous year occurred when the 6- to 8-mil PE (panels 41 and 42) deteriorated. Until October 1973 the materials were in excellent condition. Some tearing was noted in 1974 with complete failure in 1975. The effective life of these two thicknesses was about 2 yrs, contrasted to the continued excellent performance of 10-mil PE (panel 40) after 4 yrs.

Water Harvesting Catchments: Six prototype catchments remain in Logan. The status of the catchments when inspected in August 1955 was:

R-1 Butyl, unreinforced, 30 mil, installed September 1958, one piece about 1 ft^2 had been torn out on the upper berm and another 15-inch tear was noted, the flat area of the catchment was in good condition, overall condition of the liner was good to fair.

R-2 Butyl, unreinforced, 30 mil, installed August 1963, some large holes were noted around the berm but none on the flat part of the catchment, condition good to fair.

R-3 Butyl, reinforced, 30 mil, installed June 1963, one small hole (1-inch diameter), condition excellent.

R-4 Oriented PE (Fabrene, TM), installed June 1972, seven holes believed caused by rocks being thrown onto the apron, tears could not be propagated, some burrowing underneath cover, material out of trench along the upper edge-possibly caused by a tightness earlier in the year, condition excellent.

R-5 PVA copolymer, 8 mil, installed October 1966, large number of holes but unchanged for past number of years, condition poor.

R-7b Asphalt emulsion, asbestos, water slurry over polypropylene, installed September 1972, one small hole near upper berm possibly caused by some form of mechanical means, one thistle grew through the liner near the drain, excellent condition.

Test Reservoirs at Logan: Six small test reservoirs (8,000 to 12,000 gal) with various lining materials were maintained during 1975 but seepage measurements were not conducted. The reservoirs will remain in place until the area is needed by Utah State University. Water will be kept in the reservoirs and maintenance will be continued during 1976. Seepage will not be measured.

Seepage losses from a canal liner constructed in August 1972 of polypropylene-asphalt emulsion-asbestos, similar to that used to line the pits at Granite Reef and Hualapai, have been evaluated in a seepage test channel in Logan, Utah. Water depth is maintained at about 1 ft. During a 3½-month period in 1975, no seepage losses were detected from six test sections. Losses from one section ranged from 0.002 $ft^3/ft^2/day$ shortly after water was turned into the test channel to zero loss at the end of the test period. The lining material continues to be flexible and one does not show any signs of weathering. Seepage losses will be checked again during 1976.

PART V. COOPERATIVE WATER HARVESTING PROJECT WITH BLM

A cooperative 3-year project was initiated with the USDI, Bureau of Land Management (BLM), in Arizona to develop, improve, and modify methods and materials for water harvesting and water storage for constructing reliable, low cost systems for livestock and wildlife water supply. Special studies will be concerned with the evaluation of new materials and techniques in addition to an evaluation of present water harvesting systems. Periodic evaluations will be made on selected units to qualitatively evaluate the performance of the system. Part of the study will be devoted to determining the quality of the runoff water from various water harvesting systems.

SUMMARY AND CONCLUSIONS:

Rainfall runoff measurements were continued at the Granite Reef testing site. A 15-mil nonreinforced butyl sheeting, originally installed in 1961, was destroyed by wind. The treatment was intentionally allowed to fail to observe the actual type of failure which occurs when no maintenance is performed. Runoff from two silicone-treated plots had reduced to less than 50%. Retreatment of the plots increased the runoff effectiveness to 80%. The paraffin wax plot continues to yield high runoff efficiency with only a minimal decrease in performance. There was no significant change in the efficiency of the remaining treatments.

Two operational paraffin wax catchments in northern Arizona have successfully weathered a winter of freezing and thawing and provided sufficient water to supply the design carrying capacity of the land in addition to overflowing the water storage tanks. The Seneca plot treated with paraffin wax is considered to have failed. Additional studies are being conducted to determine the cause of the treatment failure.

A new cooperative study has been initiated with the Bureau of Land Management to study the performance of existing water harvesting systems and to develop lower cost methods and materials for water harvesting.

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

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

Plot	Treatment Date	Treatment
L-1	8 Aug 1967	Basecoat. MC-250 at 1.5 kg asphalt m^{-2}
	22 Aug 1967	Topcoat. RSK asphalt emulsion at 0.7 kg asphalt m^{-2}
	20 May 1968	Top Sheeting. 30-mil chlorinated black polyethylene
L-4	30 Nov 1961	Butyl Rubber Sheeting. 15-mil
L-5	18 Sep 1962	Basecoat. RSK asphalt at 1.04 kg asphalt m^{-2}
	16 Mar 1966	Topcoat. RSK asphalt emulsion at 0.6 kg asphalt m^{-2}
	22 Apr 1970	Sealcoat. Modified SSKH asphalt emulsion at 0.6 kg asphalt m^{-2}
L-6	19 Apr 1963	Basecoat. RC-special at 1.5 kg asphalt m^{-2}
	13 Nov 1975	Sealcoat. SS2h asphalt at 2.0 kg asphalt m^{-2} modified with A-1 fibers
L-7	3 Aug 1967	Basecoat. MC-250 at 1.5 kg asphalt m^{-2}
	22 Aug 1967	Top Sheeting. 1-mil aluminum foil bonded with RSK asphalt emulsion at 0.7 kg asphalt m^{-2}
A-1	3 Aug 1967	Basecoat. MC-250 at 1.5 kg asphalt m^{-2}
	22 Aug 1967	Top Sheeting. 3/4-oz chopped fiberglass matting bonded with RSK asphalt emulsion at 1.4 kg asphalt m^{-2}
	Jan 1968	Top Spray. Vinyl aluminum coating at 0.1 gal yd^{-2}
A-2	3 Aug 1967	Basecoat. MC-250 at 1.5 kg asphalt m^{-2}
	12 Sep 1967	Top Sheeting. Standard rag felt-rock roofing treatment
A-5	Sep 1968	Concrete Slab.

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

Date	Rainfall total	L-1 Runoff		L-4 Runoff		L-5 Runoff		L-6 Runoff		L-7 Runoff		A-1 Runoff		A-2 Runoff		A-5 Runoff	
1975	(mm)	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)
14 Feb	8.8	9.3	105.7	2.2	25.0	1.4	15.9	2.4	27.3	6.1	69.3	9.0	102.3	5.8	65.9	5.9	67.2
15 Feb	10.7	10.2	95.3	3.4	31.8	3.4	31.8	3.9	36.4	7.8	73.1	10.1	94.5	6.5	61.0	8.1	75.7
8-9 Mar	7.0	6.8	97.1	2.9	41.4	2.7	28.6	3.7	52.9	5.5	78.6	6.9	98.6	5.1	73.0	5.9	84.3
10-11 Mar	14.3	13.9	97.2	6.4	44.8	7.4	51.7	7.9	83.0	11.9	83.2	14.0	97.9	11.5	80.4	12.6	88.1
11 Mar	3.6	2.9	81.2	1.1	31.2	0.7	19.4	1.2	34.0	2.5	70.1	2.9	80.6	1.6	44.4	2.3	63.9
14 Mar	6.5	6.2	95.4	2.5	38.5	2.5	38.5	2.7	41.5	4.8	74.2	6.1	94.0	3.3	50.9	4.8	73.8
6-7 Apr	8.1	8.5	104.9	1.9	23.5	1.0	12.3	1.1	13.6	5.7	70.1	8.1	100.0	4.9	60.5	5.5	67.9
9 Apr	9.4	8.9	94.7	3.5	37.2	3.1	33.0	3.7	39.1	7.4	78.7	8.7	92.6	6.5	69.1	7.5	79.6
4 Jul	4.3	4.6	107.0	-	a	1.7	39.5	3.4	79.1	4.8	111.6	3.6	83.7	2.3	53.6	2.0	46.5
14 Jul	18.0	21.6	120.0	-	-	8.6	47.8	13.3	73.9	15.7	87.2	16.7	92.8	14.4	80.0	12.0	66.7
27 Jul	9.1	8.6	94.5	-	-	6.2	68.1	4.2	46.2	7.8	85.7	8.3	91.2	5.3	58.3	5.9	64.8
6 Sep	20.5	20.5	100.0	-	-	9.0	43.9	12.2	59.5	17.6	85.9	20.7	101.0	11.2	54.6	16.3	79.5
28-29 Nov	30.0	28.1	93.7	-	-	11.6	38.7	26.7	89.0	24.2	80.7	28.3	94.3	23.3	77.7	24.2	80.7
13-14 Dec	21.3	21.7	101.9	-	-	15.9	74.6	21.4	100.5	19.2	90.1	20.0	93.9	18.4	86.4	17.2	80.8
21 Dec	11.8	12.2	103.4	-	-	3.2	27.1	5.4	45.8	10.1	85.6	12.3	104.2	9.3	78.9	9.8	83.1
Total	183.4	184.0	100.3	23.9	[b] 34.9	78.4	42.7	113.2	61.7	151.1	82.4	175.7	95.8	129.4	70.6	140.0	76.3

[a] Wind destroyed covering on 1 July 1975.

[b] Total rainfall for this period was 68.4 mm.

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

Plot	Treatment Date	Treatment
L-2	30 Nov 1961	Smoothed soil, 14.14 m x 14.14 m plot
L-3	4 Aug 1965	Smoothed soil, 14.14 m x 14.14 m plot treated with silicone water repellent at 0.057 kg m^{-2}
	3 Jun 1975	Retreated at 0.03 kg m^{-2}
R-1	1 Mar 1965	Ridge and furrow, 20% sideslope
R-2	29 Sep 1972	Ridge and furrow, 10% sideslope treated with wax water repellent at 1.3 lbs/yd^2
R-3	1 Mar 1965	Ridge and furrow, 20% sideslope
R-4	13 May 1966	Ridge and furrow, 10% sideslope, treated with 44.9 g m^{-2} sodium carbonate
	3 Jun 1975	Retreated with 3% silicone water repellent - 1.2 liters of solution m^2 - 0.03 kg m^{-2}
A-3	1 Aug 1967	Smoothed soil, 6 m x 30 m plot
A-4	10 Nov 1971	Smoothed soil treated with 3% silicone water repellent and 2% soil stabilizer - 1.2 liters of solution m^{-2}
W-1	1 Dec 1963	Uncleared watershed
W-2	3 Jun 1975	Uncleared watershed - treated with 3% silicone water repellent - 1.2 liters solution m^{-2} - 0.03 kg m^{-2}
W-3	1 Dec 1963	Cleared watershed

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

Date	Rainfall total	L-2 Runoff		R-1 Runoff		R-2 Runoff		R-3 Runoff		A-3 Runoff		W-1 Runoff		W-3 Runoff	
1975	(mm)	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)
14 Feb	8.8	0	0	0	0	8.2	93.2	0	0	0	0	0	0	0	0
15 Feb	10.7	0	0	0	0	9.1	85.0	0	0	0.4	3.7	0	0	0	0
8-9 Mar	7.0	0	0	0	0	6.5	92.9	0	0	1.0	14.3	0	0	0	0
10-11 Mar	14.3	1.5	10.5	2.1	14.7	13.8	96.5	1.1	7.7	3.8	26.6	1.3	9.2	1.1	7.7
11 Mar	3.6	0	0	0	0	2.6	72.2	0	0	0	0	0	0	0	0
14 Mar	6.5	0.5	7.7	0.6	9.2	5.9	90.8	0.3	4.6	1.7	26.2	0.2	3.1	0	0
6-7 Apr	8.1	0	0	0	0	7.7	95.1	0	0	0	0	0	0	0	0
9 Apr	9.4	0	0	0	0	8.4	89.5	0	0	0.8	8.5	1.7	18.1	0	0
4 Jul	4.3	0	0	0	0	3.6	83.7	0	0	0	0	0.3	7.0	0	0
14 Jul	18.0	7.3	40.6	6.5	36.1	13.8	76.7	5.7	31.7	7.5	41.7	3.7	20.6	5.4	30.0
27 Jul	9.1	0	0	0	0	6.4	70.4	0	0	0	0	0.1	1.1	0	0
6 Sep	20.5	2.3	11.2	2.7	9.8	16.9	82.4	1.9	9.3	4.4	21.5	1.7	8.3	2.2	10.7
28-29 Nov	30.0	6.3	21.0	6.5	21.7	27.4	91.3	5.8	19.3	8.1	27.0	5.3	17.7	4.9	16.3
13-14 Dec	21.3	11.0	61.6	9.8	46.0	20.5	96.2	9.7	45.5	11.6	54.5	9.3	43.7	12.9	60.6
21 Dec	11.8	0	0	0	0	3.1	26.3	0	0	0	0	0.1	0.8	0.2	1.7
Total	183.4	28.9	15.8	27.6	15.0	153.9	83.9	24.5	13.4	39.3	21.4	23.7	12.9	26.7	14.6

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

Date	Rainfall total	L-3a Runoff		L-3b Runoff		R-4a Runoff		R-4b Runoff		W-2a Runoff		W-2b Runoff		A-4 Runoff	
1975	(mm)	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)
14 Feb	8.8	0.5	5.7	-	-	0.3	3.4	-	-	0	0	-	-	3.5	39.8
15 Feb	10.7	0.5	4.7	-	-	2.4	22.4	-	-	0	0	-	-	5.8	54.3
8-9 Mar	7.0	2.2	31.4	-	-	3.0	42.9	-	-	0	0	-	-	5.1	72.9
10-11 Mar	14.3	5.5	38.6	-	-	5.6	39.2	-	-	0.3	2.3	-	-	10.6	74.1
11 Mar	3.6	0.5	13.9	-	-	0.8	22.2	-	-	0	0	-	-	1.8	50.0
14 Mar	6.5	2.1	32.3	-	-	2.2	33.8	-	-	0	0	-	-	3.8	58.3
6-7 Apr	8.1	0.2	2.5	-	-	0.6	7.4	-	-	0	0	-	-	2.9	35.8
9 Apr	9.4	2.5	26.3	-	-	2.6	27.7	-	-	0	0	-	-	5.8	61.8
4 Jul	4.3	-	a	2.2	51.2	-	a	3.3	76.7	-	b	1.0	23.3	2.1	47.8
14 Jul	18.0	-	-	13.0	72.2	-	-	15.4	85.6	-	-	10.8	60.0	12.5	69.4
27 Jul	9.1	-	-	8.7	95.6	-	-	7.5	82.4	-	-	2.1	23.1	4.9	53.8
6 Sep	20.5	-	-	16.3	79.5	-	-	17.6	85.9	-	-	3.5	17.1	12.3	60.0
28-29 Nov	30.0	-	-	19.3	64.3	-	-	25.4	84.7	-	-	6.9	23.0	16.7	55.7
13-14 Dec	21.3	-	-	19.7	92.5	-	-	19.7	92.5	-	-	10.0	46.9	15.8	74.2
21 Dec	11.8	-	-	10.6	89.8	-	-	10.9	92.4	-	-	0.8	6.8	6.1	51.7
Total	183.4	14.0	20.5	89.8	78.1	17.5	25.6	99.8	86.8	0.3	0.1	35.1	30.5	109.7	59.8

[a] Plots L-3a and R-4a retreated.

[b] New treatment on W-2a. Total rainfall before treatment 68.4 mm. Rainfall after treatment 115.0 mm.

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

Panel Number 1/	Condition and comments from inspection on 9 January 1976 2/	
1	Failed	Removed in 1974
2	Excellent	
3	Excellent	Dusty, some chalking
4	Excellent	Coating poor
5	Excellent	Coating excellent
6	Excellent	Coating gone
7	Poor	Coating peeling, 30% gone, substrate okay
8	Excellent	
9	Excellent	Coating excellent
10	Excellent	Coating excellent
11	Excellent	Coating extreme chalking, still 100% coverage; substrate excellent
12	Failed	Removed in 1974
12a	Excellent	Grifflon TM. PE, black, installed 16 Apr 1975. Joint excellent.
13	Failed	Removed January 1976
14	Failed	Removed in 1974
15	Failed	Removed in 1974
15a	Excellent	Grifflon TM. PE with No. 105 coating installed 16 Apr 1975
16	Failed	Removed January 1976
17	Excellent	
18	Excellent	
19	Excellent	
20	Excellent	
21	Excellent	
22	Excellent	No chalking

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

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

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

Panel Number 1/	Condition and comments from inspection on 9 January 1976 2/	
23	Excellent	
24	Excellent	Slight chalking
25	Failed	Removed January 1976
26	Excellent	Coating fair, some chalking, still tacky
27	Excellent	Coating poor, some chalking, tacky
28	Excellent	Coating poor, extreme chalking
29	Good	Coating nearly gone, extreme chalking
30	Excellent	Coating poor, extreme chalking
31	Good	Slight chalking; coating cracked where stretched over soil; 3 places 1/8-3/8"
32	Excellent	Slight chalking
33	Excellent	
34	Excellent	Slight chalking
35	Excellent	Surface cracks, slight chalking
36	Good	1/8" dia. hole, cause unknown, slight chalking
37	Excellent	
38	Excellent	
39	Excellent	
40	Poor	Removed January 1976
41	Excellent	
42	Excellent	Animal scratched, no tears
43	Good	Chalking, one hole with vegetation growing. Appears to be flaw from calendared process.
44	Failed	Removed in 1974
45	Excellent	

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

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

ble 6. Condition of materials on exposure racks--Logan, Utah--inspection August 1975.

mple .	Material	Initial exposure date	Condition 1/	Physical description
2	Butyl-coated cotton, TDA-3909, Hodgman	1/02/64	Excellent	Slight chalking
3	Ethylene vinyl acetate copolymer, 20 mil	1/02/64	Excellent	Slight shrinkage
4	Nylon-reinforced hypalon, Burke	10/26/71	Excellent	Slight shrinkage
9	1 Chlorinated PE, white, Dow	8/25/70	Good	Slight stiffening
	3 Chlorinated PE, white, Dow	8/25/70	Poor	Extensive cracking, stiffening, extreme shrinkage
11	Butyl-coated cotton TDA-3909, Hodgman	2/13/64	Fair	Stiffening, cracking, slight chalking, one tear
12	1 Chlorinated PE, white, Dow	8/25/70	Poor	Stiffening, surface cracking, shrinking
14	PE film, 6 mil	7/10/63	Excellent	Slight shrinkage
15	Ethylene vinyl acetate copolymer, 6 mil	7/10/63	Excellent	Slight shrinkage
16	Nylon-reinforced hypalon, yellow, Canton	8/20/70	Good	Fading, surface checking, some reinforcing exposed
18	Asphalt-coated jute, Flintkote	1/02/64	Good	Slight stiffening

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

Table 7. Outdoor exposure panels at Logan, Utah test site.

No.	Material	Date Installed	Condition 1/ and Comments
1	Fabrene (oriented PE), du Pont Canada	17 Oct 72	Excellent, very tight, may have shrunk, sampled for cooperator.
2	Double butyl-coated nylon, TDA 4432, Hodgman	9 Apr 65	Poor, chalking, mechanical damage, numerous holes
3	Double butyl-coated cotton, KK 246, Hodgman	21 Apr 65	Poor, mechanical damage, support material not preventing tearing, chalking
4	Double butyl-coated nylon, TDA 4429, Hodgman	22 Apr 65	Good, one tear appears to be deterioration of substrate, chalking
5	Nylon-reinforced hypalon, Burke	26 Oct 71	Excellent
*9 & 10	Reinforced PE, Griffolyn	26 Oct 72	Excellent, 2 weeds had grown through liner, were removed
11	Vinyl, 20 mil, black, Firestone	25 Mar 66	Poor, excess cracking
12	Polyliner CPE, Goodyear	16 Oct 72	Excellent
13	Polyethylene, 10 mil, black	25 Mar 66	Good to fair, mechanical damage, shrinkage
14	Glass fiber-reinforced butyl, Rainfair, canal liner 1948-1958	11 Aug 66	Good, chalking, slight ozone cracking with 3 small holes, ant activity. Samples returned to cooperator and taken for lab testing.
15	Unreinforced butyl, Goodyear (Fishlake)	16 Aug 66	Good, extreme chalking, some mechanical damage. Samples returned to cooperator and taken for laboratory testing.
16	Chlorinated polyethylene, Dow	26 Aug 66	Good, small holes, may be mechanical damage or stretching.
17	PE-coated, CLS, Hercules	19 Oct 72	Poor, extreme surface peelin polypropylene deteriorated where coating peeled
23	Vinyl, 20 mil, Union Carbide 9234-90-1	15 Apr 71	Excellent, very flexible, sampled for laboratory analysis
*24	Vinyl, 20 mil, Union Carbide 9234-84-1	15 Apr 71	Good, one tear (may be caused by deer) loose around edge of frame

Table 7. Outdoor exposure panels at Logan, Utah test site (continued).

No.	Material	Date Installed	Condition 1/ and Comments
25	Vinyl, 20 mil, Union Carbide 9234-84-2	15 Apr 71	Excellent, still flexible but stiffening around board edging
26	Vinyl, 20 mil, Union Carbide 9236-86-1	15 Apr 71	Excellent, flexible
27	Uncoated PVC, 10 mil, Union Carbide	13 Oct 71	Poor, cracked excessively and fallen apart
32	Coated PE, 8 mil, 0.76 gal/sq (Sample 5)	13 Oct 71	Good, chalking, coating can be scraped from PE
*33	Coated PE, 8 mil, 0.26 gal/sq (Sample 6)	13 Oct 71	Poor, extreme chalking, PE showing through, coating about gone
*34	Coated PE, 8 mil, 0.46 gal/sq (Sample 7)	13 Oct 71	Good, two tears, coating about gone
38	Coated PVC, 10 mil, Union Carbide (Sample 15)	13 Oct 71	Excellent
*40	Uncoated PE, 10 mil	13 Oct 71	Excellent, two small tears
41	Uncoated PE, 8 mil	13 Oct 71	Poor, unserviceable
*42	Uncoated PE, 6 mil	13 Oct 71	Poor, unserviceable
*43	Coated PVC, 10 mil, Goodrich (Sample 16)	13 Oct 71	Poor, two tears, one looks like plasticizer loose
44	Butyl coated CLS, 32 mil, Hercules	1 May 72	Excellent, extreme chalking
45	Butyl coated CLS, 17 mil, Hercules	1 May 72	Excellent, extreme chalking
46	CPE lammate, Goodyear	5 May 72	Excellent, slight stiffening
60	Coated Fabrene (Sample 18)	1 May 72	Excellent, tight--may have shrunk
* 62	Coated Fabrene (Sample 11)	1 May 72	Poor, coating checking badly
* 63	Coated Fabrene (Sample 5)	1 May 72	Poor, coating chalking
* 64	Coated Fabrene (Sample 8)	1 May 72	Poor, coating about gone
65	Coated Fabrene (Sample 9)	1 May 72	Poor, coating about gone
66	Uncoated Fabrene	1 May 72	Excellent, slight shrinkage

1/ Rating: Excellent, good, poor; Date rated: 20 August 1975.

* Indicates changes from previous year.

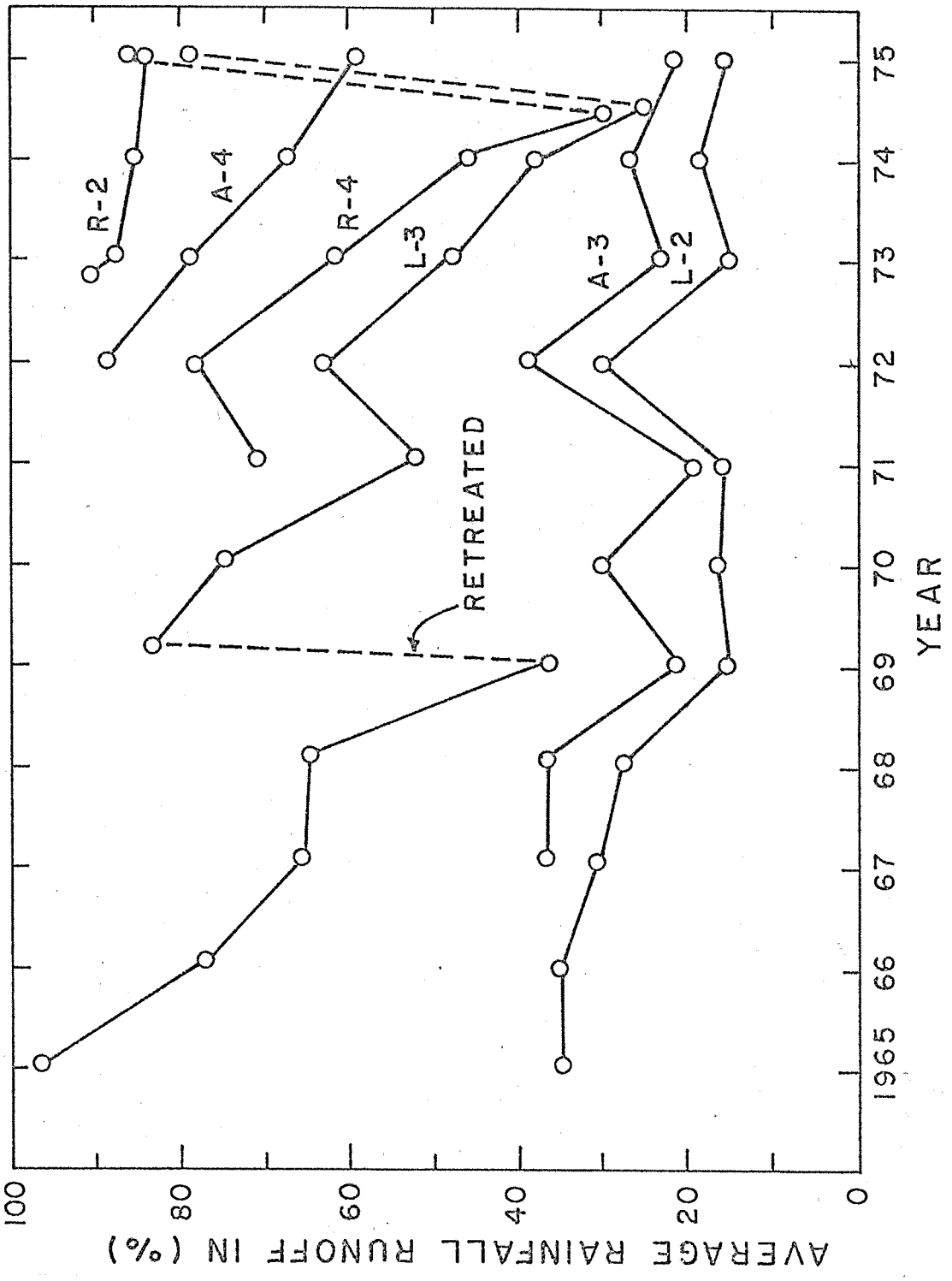

Figure 1. Rainfall-runoff results from six bare-soil treatments at the Granite Reef Testing Site.

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

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

INTRODUCTION:

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

PROGRESS:

A paper "Critical-Flow Flumes with Complex Cross Section" was presented before the ASCE Irrigation and Drainage Division Specialty Conference held at Logan, Utah, August 13-15, 1975. Another paper, "Portable, Adjustable Flow-Measuring Flume for Small Canals" was presented at the ASAE Winter Meeting, Chicago, Illinois, December 15-18, 1975.

Several new sizes and shapes of flume were designed with the computer program. Most required routine procedures presenting no new problems.

The modeling concepts are considered completed. Further uses of the model for circular, parabolic and special complex shapes are yet to be done. Some of these applications require minor modifications to the computer program.

Field Studies: The special compound flume built for the Roosevelt Water Conservation District by the Salt River Project was further checked with current-meter ratings, for the period 10 April to 4 September 1975, by Salt River Project personnel. Table 1 lists the data from these meterings which indicated discharges ranging from 30 to 136 cfs and some comparisons to predicted discharges. Figure 1 includes the 1974 data and the newer data from Table 1. Listings of the 1974 data appear in Annual Report for 1974. Figure 1, however, is plotted for both years in terms of the discharge coefficients Q/Q_i, or discharge divided by ideal-flow discharge for the particular flume.

Plots of the differences between the current-meter measured discharges and the predicted discharges as a possible function of season was not significant for either of the 2 years. Likewise, there was no significant change between years. The metering station, about 200 ft downstream from the flume, still experiences surges and eddies making accurate current metering difficult because of the two wells adding discharges between the flume and the metering station. The data of Table 1 has been adjusted to reflect the additions of the wells. The current meterings averaged about 4% higher than predicted for flows above 200 cfs, about 0% difference for flows near 100 cfs and 5% low for flows near 40 cfs. The current-meter readings vary about their linear least-squares fit by about ± 5%. This variation is wide enough to include the predicted values.

Portable Flume Field Experience: The portable flume described in Annual Report, 1974, was further detailed in the ASAE presentation. This flume has been successfully used by the Soil Conservation Service for several months as a field-survey device to establish the backwater response, tailwater conditions, and thus the proper elevation for placing permanent concrete flumes.

Usually the portable flume was placed in the canal while the canal was dry. On several occasions, it has been placed into flowing water. Removal from flowing water can be difficult if the flume is flowing nearly full with low tailwater elevation, which results in large down-forces. A wooden 2" x 4" plank was fitted with short lengths of chain near each end and was successfully used to lift the approach section by flexing the sides together with the lifting action, breaking the water seal, and permitting removal of the section, Figure 2.

As presently constructed, the flume is more readily raised than lowered. Lowering requires much jumping and stomping because of high thrust forces of the flume against the downstream side of the jack frame. In field use, it quickly became standard practice to start with the flume in the down-most position and progress upward the required amount to overcome submergence effects.

Concrete flumes were constructed on the Snyder Ranch and at the Spencer and Spencer, Desert Valencia Ranch on property leased by the University of Arizona for experimental purposes. The construction was accomplished in two phases. Forms were made to define the ends of the throat section which was 4 ft long. The top of these forms was then used to control the strike-off elevation of the wet concrete. A low-slump mix was able to sustain itself on the 1:1 sideslopes. Steel reinforcing bars were placed in the concrete primarily to act as form ties. Wire ties and spacers should have worked equally well. Two lengths of 2-inch plastic pipe about 10 ft long were laid through the flume floor area parallel to the ditch before pouring the concrete, to allow for complete draining of the canal if desired. The pipes are plugged for canal operations. As soon as the upstream form could be removed, usually in 1 hour, the converging section was poured. Since the tolerances on this section are very liberal no forms were used, just hand plastering techniques. The taper of the converging section was carried on a slope that would have terminated about one throat length upstream, but was rounded-off abruptly when the tapering caused the concrete thickness to be less than 1½ to 2 inches thick to discourage chipping. The rounded edge does not significantly affect flume performance.

The Soil Conservation Service managed to obtain a contractor willing to install several more on private farms. About one-half dozen of these have been cast as of this writing. The technique was to use an inside form for the throat. Some difficulty is being experienced with flotation problems which can exceed 2 tons. The contractor is attempting to hold the forms down with two drums of concrete weighing about half of this, combined. The rest of the force is absorbed as passive pressure of the concrete mix. This has worked successfully for flumes with low sills where the side wall thickness is about 6 or 8 inches. For higher sills and thicker sidewalls, this passive pressure may not be realized and heaving is probable without further weighting.

A photo of the portable flume in place is shown in Figure 4. Figure 5 shows a permanent concrete flume being finished.

SUMMARY:

The mathematical model for predicting discharge through critical-flow flumes is now considered complete and ready for applications to trapezoidal, triangular, rectangular, circular, parabolic, complex-shaped and non-symmetrical flumes, including broad-crested weirs of all shapes that have rounded upstream edges. The basic requirement is geometrical, in that the contracted throat length should be long enough to assure parallel flow for computational purposes, but short enough to avoid channel-type flow, or 2 to 20 times the depth of flow.

A complex-flume with discharges ranging from 30 to 220 cfs, has been field checked with 64 current-meter ratings over the past 2 years. The current-meter ratings substantiate the computer predicted ratings to within $\pm$ 5%.

Use of a portable flume, developed at the U. S. Water Conservation Laboratory, as a field-survey device before casting low-cost concrete flumes in canals has been continued by Soil Conservation Service crews. The flume is capable of throat height adjustment above a canal bottom, has special stilling-well and depth-sensing arrangements, and can be installed and removed from a flowing canal by two persons.

PERSONNEL: John A. Replogle.

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

Date	Flume stage (ft)	Predicted discharge (cfs)	Current meter (cfs)	Discharge * coef.
4-10-75	2.34	64	64	0.9726
4-14-75	1.93	35	37	1.0250
4-24-75	2.21	53	52	0.9434
4-28-75	2.54	82	85	1.0030
5- 1-75	2.54	82	85	1.0030
5- 5-75	2.42	71	71	0.9726
5- 8-75	2.43	72	69	0.9332
5-12-75	2.42	71	68	0.9315
5-15-75	2.95	131	131	0.9780
5-22-75	2.95	131	136	1.0150
5-29-75	2.38	67	65	0.9374
6- 5-75	2.53	81	77	0.9198
6-10-75	2.40	69	62	0.8713
6-17-75	2.63	92	91	0.9651
6-24-75	2.88	122	122	0.9800
6-27-75	2.70	100	102	0.9981
7- 1-75	2.57	86	83	0.9448
7- 8-75	2.58	87	79	0.8886
7-18-75	2.47	76	75	0.9646
7-22-75	2.51	79	79	0.9670
7-29-75	2.06	43	36	0.8130
8- 5-75	2.15	49	42	0.8301
8-12-75	2.63	92	90	0.9545
8-15-75	1.92	34	30	0.8446
8-19-75	2.37	66	60	0.8766
9- 2-75	2.18	51	49	0.9276
9- 4-75	2.08	44	41	0.8984

* Calculated as discharge, Q, divided by an ideal-flow discharge, Q_i.

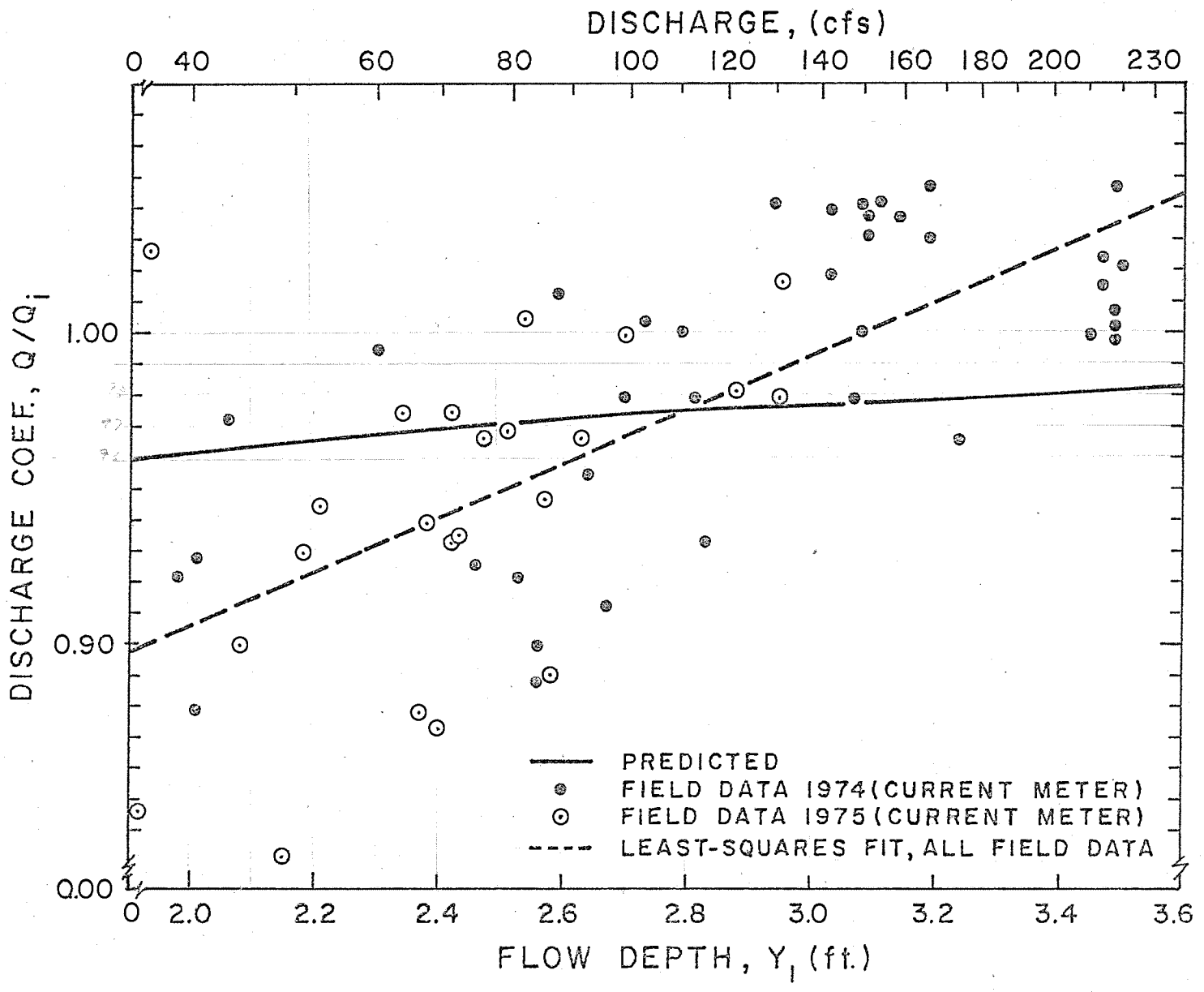

Figure 1. Comparison of predicted and current-meter-measured discharges in a complex flume in an irrigation canal.

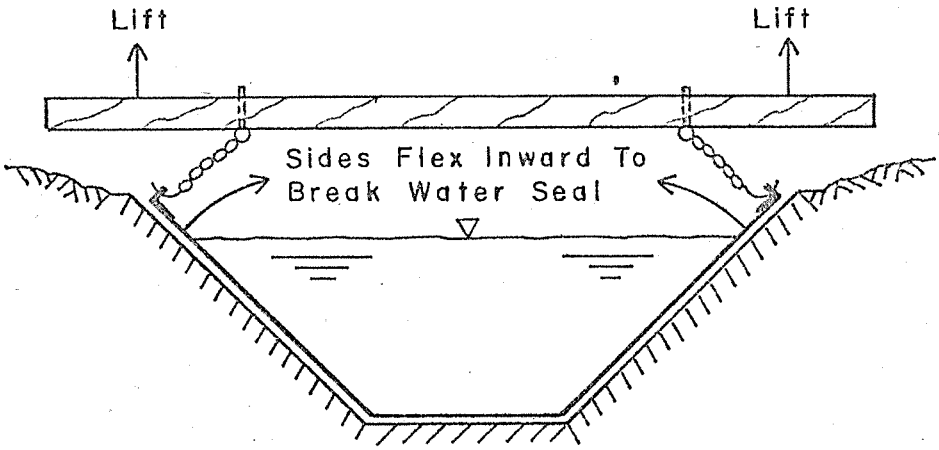

Figure 2. A method used to remove portable flume.

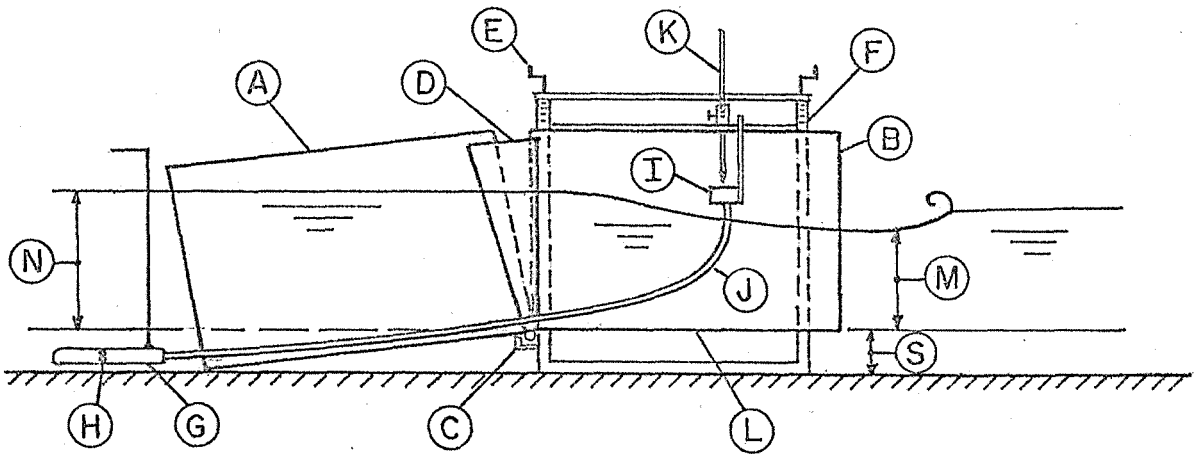

Figure 3. Schematic of Portable Flume Operation. Converging Section, A, is connected to throat section, B, with hinge joint, C. Opening between A and B is covered by sheet metal plate, D, which is attached to B but may slide on A. Throat section, B, may be raised and lowered by threaded jack screws, E, on frame, F. Upstream depth is sensed with pipe, G, laid parallel to flow direction, through holes, H. This flow depth is transferred to shallow stilling well, I, through tubing, J. Point gage, K, which is zeroed to throat floor, L, retains its relation to L by being rigidly attached to throat section B. Stilling well, I, is manually adjusted upward or downward to accommodate depth of flow being tested. Sill height, S, is adjusted with jack screws, E, until unsubmerged flow is observed, i.e., until downstream depth, M, is less than about 75% of upstream depth, N.

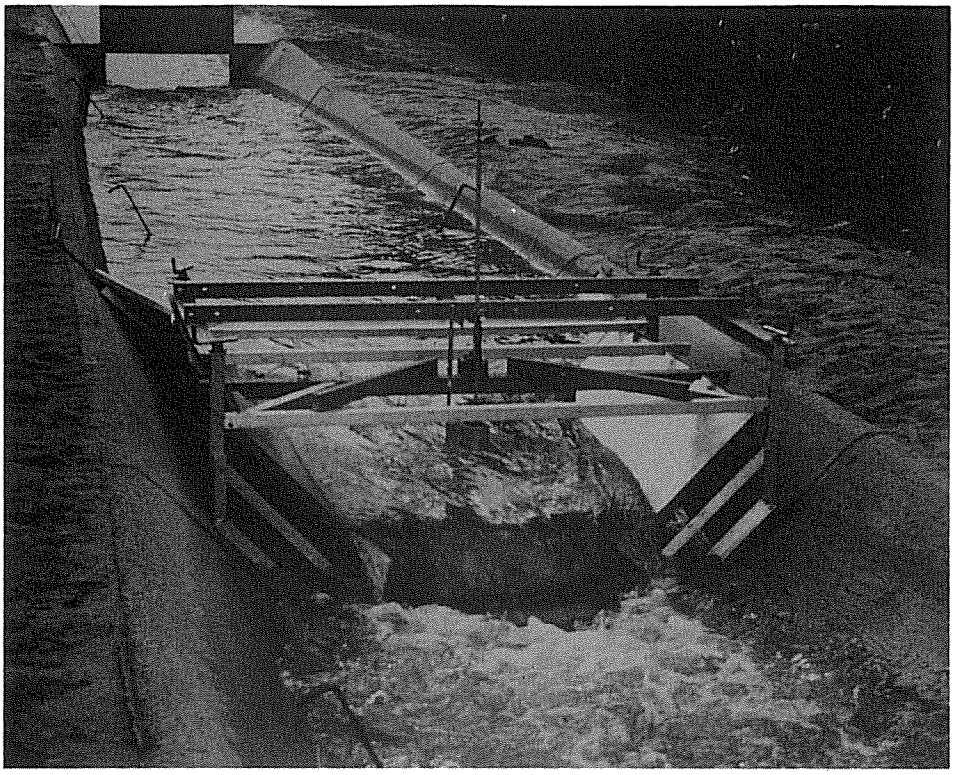

Figure 4. Portable flume in canal.

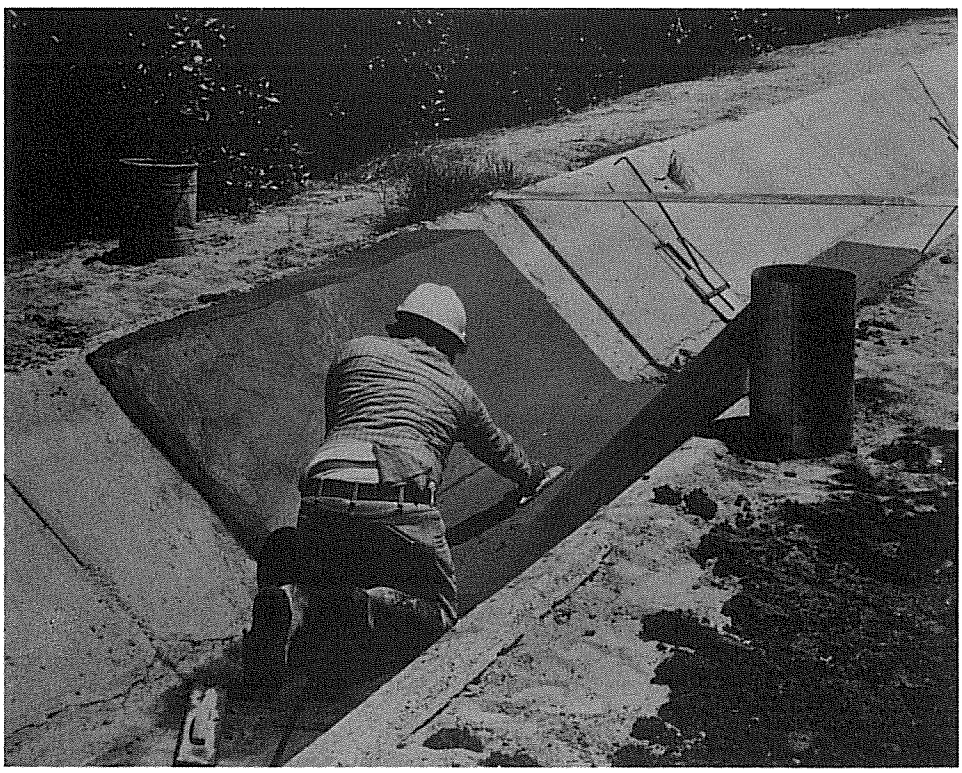

Figure 5. Permanent flume being installed.

TITLE: SEDIMENT TRANSPORT CHARACTERISTICS OF CRITICAL-DEPTH FLUMES

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

BACKGROUND:

The computer and mathematical techniques that were applied to flume design has been described in previous reports. The primary features used to assist sediment movement were the "negative sill" and the "vortex-vanes." The former feature consists of a throat floor that was an inch or so lower than the approach section of the flume. The effect is to cause increasing Froude numbers with decreasing flow depth. This is the reverse of usually configured flumes. The absolute velocities, however, do not increase in the same fashion, so sediment handling improvement was limited to approximately ¼% bedload. The vane method was capable of handling upward to about 2½% to 3% bedload.

A qualitative discussion concerning the maximum side contraction ratio that a flume should cause in a sand bed stream was presented. Basically, if sediment movement is proportional to the square of the velocity, then flume floor widths should be designed to conform to this relation in order to make the flume handle more than the stream bed can deliver. The floor widths would appear to be the governing criteria. Thus, a flume whose approach section has one-fourth the bottom width of the stream bed should have hydraulic characteristics such that the velocity in the approach section is at least double the stream velocity. If the throat section bottom is 1/16 the stream bottom width, then the velocity in the throat should be in excess of four times the stream velocity. This has not yet been tested in a sand channel model.

EXPERIMENTAL PROCEDURES:

An installation at Tombstone, Arizona, of a flume modeled at 2:1 ratio does not pass the now-estimated 10% to 20% bedload of the stream. The model in the laboratory would pass nearly 3% bedload at flows above 1/3 of maximum design-flow depth. As a temporary expedient, the throat center was fitted with a pressure tap and the flume

experimentally rated using that point. Since the prototype had been installed with 1% slope throughout, it was decided that the slope condition, the effects of vanes on normal calibration, and the rating as detected by the throat section center tap should all be investigated on the 2:1 model.

The effects of the vanes in the model, which were 3 inches high and spaced on 12-inch centers, sloping at 45° in the flow direction, were tested for zero flume slope, 1% flume slope, and with one vane removed nearest the pressure tap. The various effects from predicted can be observed in Figure 1.

DISCUSSION:

With no vanes, and zero floor slope, the detected depth corresponded to that predicted. Adding vanes at zero floor slope caused an appreciable anomoly that corresponded to the vortex forming above the pressure-tap hole causing the pressure tap to under-read, indicating too low a value for Q_i (Q-ideal) for that depth thus making Q/Q_i greater than unity (actual discharge = Q). The 1% floor slope showed similar trends but the whole curve moved down about 4%. Removing the vane over the pressure tap placed the calibration within about 3% of predicted.

The calibration in terms of the pressure tap at the throat center and the calibration at the usual location are shown in Figure 2. The least-squares equation in terms of a power function is

$$Q_m = 6.246\ (h_m + .05)^{2.054} \qquad (1)$$

or in terms of a 3rd degree polynomial

$$Q_m = -.1713 + 2.792\ h_m - .6737\ h_m^{\ 2} + 5.626\ h_m^{\ 3} \qquad (2)$$

where Q_m is the discharge in cfs for the model and h_m is the detected flow depth above the throat floor in feet.

For the range considered, equation (1) is easiest to use if non-integer powers offer no computational problems. The prototype

discharge Q_p (cfs) in terms of h_p (ft) is

$$Q_p = 8.508\ (h_p + 0.1)^{2.054} \tag{3}$$

The data from which these equations were derived is in Table 1.

Table 1. Data for Tombstone model and prototype in terms of pressure tap in flume throat.

Model		Prototype	
h_m (ft)	Q (cfs)	h_p (ft)	Q (cfs)
.093	.1145	.186	.6477
.130	.1885	.260	1.066
.184	.313	.368	1.771
.380	1.11	.760	6.28
.545	2.11	1.09	11.94
.659	2.96	1.318	16.74
.799	4.47	1.598	25.29
.880	5.62	1.760	31.79

FUTURE DIRECTIONS:

Shen and Hung (1) empirically determined that the sediment bedload concentration, c, is a function, f, of velocity, V, slope, S, and fall velocity, W, of the median sediment size of the bedload, or

$$c = f\left(\frac{V\ S^{0.57}}{W^{0.23}}\right) \tag{4}$$

This would indicate that for any given sediment delivered to the flume, and with Manning's equation expressed as a function of V^2 then C becomes a new function, f_1, of the same variables, or

$$c = f_1\left(\frac{V\ (V^2)^{.57}}{W^{0.23}}\right) \tag{5}$$

or simply that concentration of the bedload is a function of velocity to approximately the 2.14 power. But Manning's equation applied to

flume throats has been found to over-predict the energy gradient (see Annual Reports for 1970 and prior) so the velocity to the second power may be considered a good approximation.

Another approach, while still empirical, appears more dimensionally correct and shows promise of correlating natural stream and laboratory flume data. It was presented by Ilo (2) in December 1975. The following development based on his study shows that the relationship between channel and flume bottom widths should indeed be proportional to the square of the ratio of velocities in the flume to that in the channel.

Assuming that the governing equation is as described by Ilo (2)

$$\frac{q_t}{q} = .005 \left(\frac{V^2 \, S}{(S_s - 1) \, g \, D_g} \right) \tag{6}$$

where: q_t = sediment transport rate per unit stream width

q = stream discharge per unit width

V = flow velocity

S = energy slope

S_s = specific gravity of the sediment

g = gravitational acceleration

D_g = geometric mean diameter of particles

Then, to assure scour through the flume (subscript f) for sediment delivered by the channel (subscript c) the following relations appear necessary

$$\left(\frac{q_{tf}}{q_f} \right) > \left(\frac{q_{tc}}{q_c} \right) \tag{7}$$

However, we observe immediately that the channel-delivered sediments naturally concentrate to fit the bottom width of the flume so that the necessary (q_{tf}/q_f) must now be

$$\left(\frac{q_{tf}}{q_f} \right) \times \frac{B_f}{B_c} > \left(\frac{q_{tc}}{q_c} \right) \tag{8}$$

just to remain clear.

Thus, expressed in terms of equation (6)

$$.005 \left(\frac{V_f^{\,2}\, S_f}{(S_s - 1)\cdot g \cdot D_g} \right) \frac{B_f}{B_c} > .005 \left(\frac{V_c^{\,2}\, S_c}{(S_s - 1)\, g\, D_g} \right) \qquad (9)$$

and removing common factors from both sides of the inequality, we obtain

$$V_f^{\,2}\, S_f \frac{B_f}{B_c} > V_c^{\,2}\, S_c \qquad (10)$$

or

$$\left(\frac{V_f}{V_c} \right)^2 > \frac{B_c}{B_f} \cdot \frac{S_c}{S_f} \qquad (11)$$

The sediment deposition problem on the Tombstone flume can be partly examined in terms of equation (11). Table 2 lists some values for the flow depth in the flume, h_p, with velocities V_1 and V_3 in the approach section and in the throat section, respectively, and the bottom width ratio, B_1/B_3, between approach section and the throat section.

Table 2. Comparison of velocities at various flow depths through flume. B_3 = .77 ft, B_1 = 2.2 ft.

h_p	V_1	V_3	$(V_3/V_1)^2$	B_1/B_3
ft	ft/sec	ft/sec	---	---
.5	1.17	2.94	6.3	2.85
1.0	1.71	4.03	5.6	2.85
2.0	2.75	5.55	4.1	2.85
3.0	3.69	6.72	3.3	2.85

As long as $(V_3/V_1)^2$ is greater than (B_1/B_3) no sediment should deposit in the throat. This would appear to be valid until the

energy slope in the approach section was steepened, by sediment or vanes, enough to overcome the velocity-ratio advantage. (Division of column 4 by column 5 values would provide an estimate of this slope ratio limit.)

Field Verification:

Specific measurements above the Tombstone flume show the present channel to be about 4 ft wide with about 1:1 sideslopes to a depth of about 1.5 ft. The slope of the sediments for the first 30 ft upstream of the weir was 3.4%.

With the channel bottom width twice that of the flume approach section bottom width, the velocity in the flume approach section, V_1, should be $\sqrt{2}$ times greater than the channel velocity, V_c. Based on a 4-ft channel, with 1:1 sideslopes, the trapezoidal channel velocity V_c is calculated in Table 3.

Table 3. Comparison of flow velocities in upstream channel and in flume approach section.

h_p	Q	V_1	V_c	$V_c\sqrt{2}$
ft	cfs	ft/sec	ft/sec	ft/sec
1	4.81	1.71	0.96	1.36
2	21.5	2.75	1.8	2.53
3	54.7	3.69	2.6	3.68
3.5	78.8	4.13	3.0	4.24

The last column of Table 3 is the minimum velocity that should be present in Section 1. This value should not exceed the values for the corresponding V_1, if the flume is to transport the maximum sediment that can be delivered by the stream. However, the table takes no account of the relative energy slopes in the channel and flume. The measured bottom slope of the channel was 3.4% while the flume had a floor slope of 1%. The energy slope through the flume was probably greater than 1%, because of the installed vanes, and the energy slope in the channel less than 3.4% because of ponding. The marginal conditions calculated from velocity considerations alone, Table 3, indicate that any adverse contribution due to slope

would cause sedimentation in the flume, confirming the field-observed conditions.

Laboratory Study:

Equation (11) also is enlightening in terms of the laboratory studies, where sediment was successfully passed at about the 3% rate. As with the field prototype the passage computes to be marginally successful, but in the laboratory, a 3.4% channel slope did not exist nor was allowed sufficient time to develop. Further tests should allow for this.

The channel sideslopes should be flatter than those chosen for the flume to insure the correct velocity relationships. However, this does not prevent channel bottom widening which would expose more sediment to the sheer forces of the water, affecting the bottom width ratio.

It appears possible to construct an approach channel with a narrow bottom, perhaps equal to that of the flume, but with flatter sidewalls, that should cause the sediment to temporarily store in the channel until high flow rates could pass it. The channel could not store this sediment indefinitely since the slope in the channel would change enough to cause increased transport delivery rates large enough to eventually clog the flume. This has several disadvantages for studying sediment movement from watersheds in that it tends to purposely sort the sediment from the storm flows that produced it. Natural channels do this anyway, to some extent.

CONCLUSIONS:

1. Since S_c can possibly increase with increased sediment load in the channel, it is desirable that S_f be as steep as possible. Thus the vortex vanes appear desirable.

2. The negative sill can assist in controlling velocity, but floor shape and water surface slope cannot necessarily be construed to mean energy slope, since conversion to velocity head would not increase energy slope except as friction is affected by velocity.

3. To maintain V_f greater than V_c with increasing depth of flow, the sideslopes of the flume should be steeper than the sideslopes of the channel.

4. With rectangular channels and flumes, where the velocity ratio varies only slightly with depth, the ratio between B_c and B_f must be less than the square of the velocity ratio.

SUMMARY:

Examination of sediment transport equations continued. A formulation taken from a recently published technical note was used to derive the following relation between the channel and flume bottom widths, B_c and B_f, respectively, and the average velocities in the channel, V_c, and in the flume, V_f.

$$\left(\frac{V_f}{V_c}\right)^2 > \frac{B_c}{B_f} \cdot \frac{S_c}{S_f}$$

This relation, when applied to a laboratory model, verified the successful sediment transport for the conditions tested. The field prototype, however, managed to steepen its channel slope, S_c, to about 3.4% which was more than enough to violate the conditions formulated, and plugged the flume. As a temporary expedient, the plugged flume was laboratory rated for a pressure sensing tap in the flume throat, and is being used in that manner. Efforts are continuing, based on this formulation, to develop recommendations that will best resist sedimentation in measuring flumes. Tentative recommendations include using "vortex" vanes as agitators, which also increase S_f, the friction slope through flumes; using "negative" sill heights to assist in controlling flume velocities; and designing the flume bottom-width-to-channel-width ratio as indicated by the derived relationship.

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PERSONNEL: J. A. Replogle.

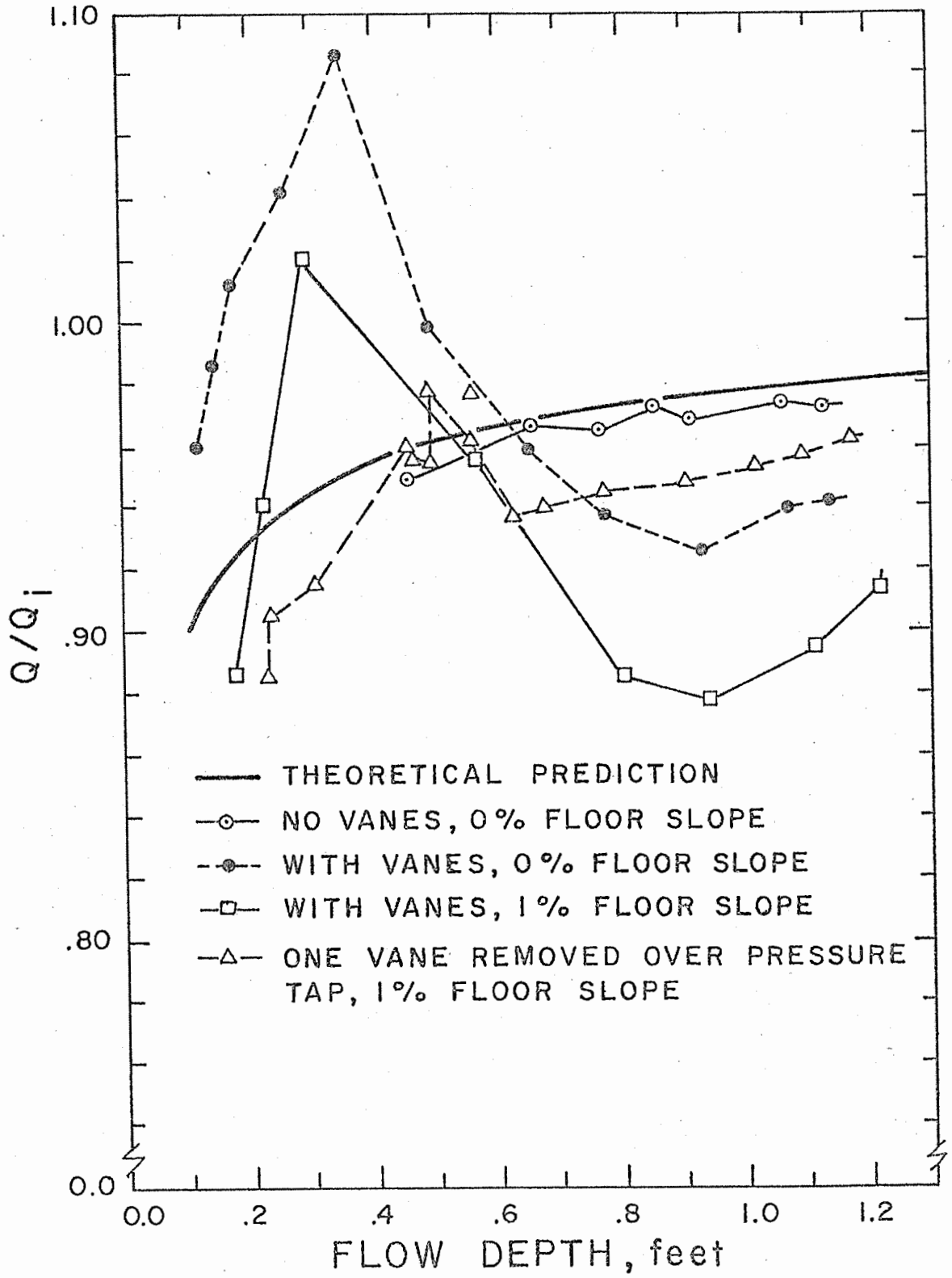


Figure 1. Effect of vanes on pressure tap sensing.

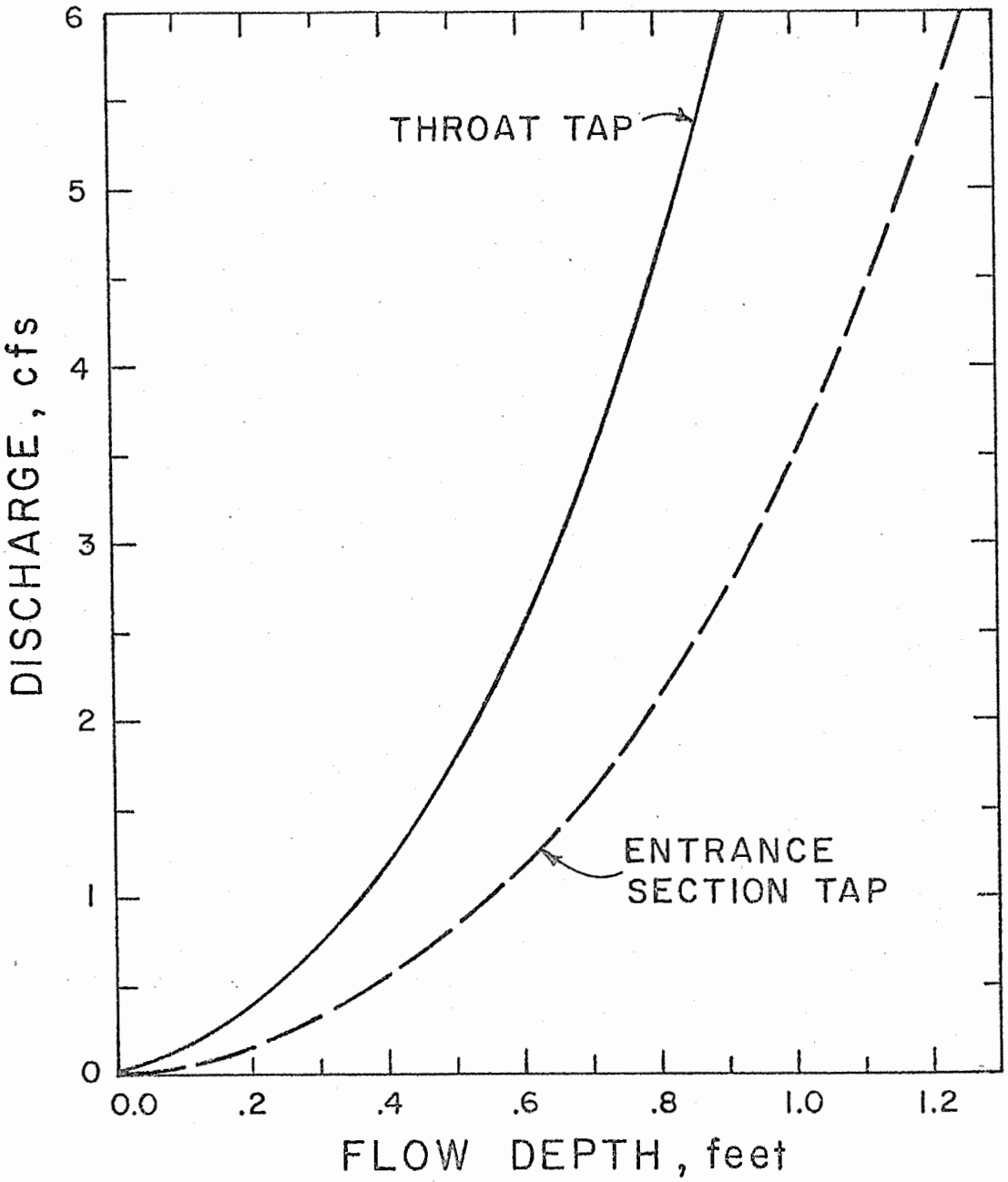


Figure 2. Calibration as sensed at two stilling well locations, at entrance section and at throat center.

TITLE: EVALUATING TRICKLE IRRIGATION FOR GRAPE PRODUCTION

CRIS WORK UNIT: 5510-12260-004 CODE NO.: USWCL 73-1

INTRODUCTION:

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

PROCEDURE:

After harvesting the 1974 Perlette table grapes on June 11, a total amount of 12 inches of water was applied on all trickle and furrow irrigation plots between growing seasons. The trickle irrigation plots were given irrigations of 1.0 inch per week between June 16 and July 20, 0.75 inch per week between July 28 and September 7, and 0.5 inch per week between September 8 and October 12. The furrow irrigation plots were given irrigations of 3.0 inches on June 18, 3.0 inches on July 8, 3.0 inches on August 13, and 3.0 inches on September 16.

Trickle and furrow irrigation treatments during the productive part of the season were the same for 1975 as used in 1973 and 1974. The trickle irrigation treatments included: three irrigation quantities, based on averages of the 1973-74 consumptive use data; three irrigation frequencies -- daily, 3-day, and 6-day; and either one or two trickle emitters per vine. The furrow irrigation treatments included the same three seasonal quantities used for the trickle irrigation, applied in two or three furrows per row, with the irrigation frequency based on the consumptive-use curve. The predetermined quantities of irrigation water applied were calculated by multiplying 0.75, 1.00, and 1.25 times the estimated consumptive-use rate based on the entire surface area between vines. Figure 1 shows the 1973-74 consumptive-use curve used to determine the different irrigation quantities. The 18 treatment combinations were replicated four times in a split-plot design. Each plot was 3 rows wide, with 6 vines per plot.

New growth in 1975 began about February 24, and canes were at least 4 inches long by March 10. Furrow and trickle irrigations were started on March 3 and March 6, respectively. The 1.00 furrow treatments were given irrigations of 4.5 inches on March 3, 3.0 inches on April 30, 3.0 inches on May 21, 3.0 inches on June 9, and 3.0 inches on June 19. The 1.00 trickle treatments were given an initial irrigation of 2.0 inches on March 6, followed by 14.2 inches between April 23 and July 2, in accordance with three different irrigation intervals. The 1.25 and 0.75 trickle and furrow irrigations were given ratios of these amounts described for the 1.00 irrigation treatments.

Leaf water potential was measured for the first time in 1975, using the Scholander pressure bomb or chamber. With this instrument, the amount of pressure which must be applied to force water from the leaf cells back into the xylem is regarded as equal to the water potential of the leaf. The more negative the pressure reading, the greater the plant water stress. Measurements were made on four plots -- 1.25 and 0.75 times consumptive-use rate for the daily trickle, and 1.25 and 0.75 times consumptive-use rate for three furrows per vine for the furrow method. These were taken on 12 dates during the growing season, usually in hourly intervals between 10:00 a.m. and 1:00 p.m., using the first mature leaf from a southerly-exposed grape cane, and sampling one leaf from each of four vines per plot at each time interval. In addition, 3 days were selected where measurements were made for longer periods of time to determine the diurnal pattern of plant water stress.

Other procedures for the collection of data, such as soil moisture, tensiometer, evaporation, salinity, and yield and quality were the same as the previous two years. Grapes were harvested on June 30, July 1, 2, and 3, by four workers, two supervisors, one weighman, and one berry sampler. The most mature fruit was picked in the first two days, followed by stripping of the vines in the last two days. Seven vines were harvested from each plot, and 200 to 300 berries were randomly selected from each plot, from which berry size and sugar content were determined.

RESULTS AND DISCUSSION:

Figure 1 shows that the 1975 measured consumptive use was 17.2 inches. This seasonal use compares closely with the 1973-74 consumptive-use curve which was used to schedule the 1975 irrigations. The slightly lower consumptive use early, and the higher consumptive use late in the 1975 growing season, were probably due to lower temperatures in March and April and higher temperatures in May and June. Table 1 shows the actual amounts of water made available for consumptive use, which were calculated from the sum of the water applied and rainfall. Since the total water applied and measured consumptive use essentially agreed, the irrigation quantities of 0.75, 1.00, and 1.25 times consumptive use were not adjusted.

Full-season grape production for the 1975 trickle and furrow irrigation treatments are shown in Table 2. Yields were increased by 17% for trickle irrigation with two emitters per vine over one emitter per vine, and yields were increased by 18% for two trickle irrigation emitters over furrow irrigation. However, the increased yield for trickle over furrow irrigation may not be valid, because of a greater weed control problem on the furrow compared to the trickle irrigation plots. Weed growth, particularly during the last three weeks of the growing season, could have reduced the available soil-moisture to the plants in the furrow irrigation plots. The yield for the different trickle irrigation quantities showed an increase of 11% for the 1.00 compared to the 0.75 times consumptive-use rate, and an increase of 6% for the 1.25 compared to the 1.00 times consumptive-use rate. The yield for furrow irrigation showed a 29% increase for the 1.25 and 1.00, compared to the 0.75 times consumptive-use rate. Additional results showed little difference in yield between trickle irrigation frequencies of 1 day, 3 days, and 6 days.

An increase in yield was correlated with measurements of leaf water potential in the case of the 1.25 over 0.75 times consumptive-use treatment, but not for trickle over furrow irrigation. Table 3 presents mean daily values of leaf water potential over the irrigation season extending

from April 9 through harvest on July 3 for selected trickle and furrow irrigation treatments. The seasonal mean for the daily trickle irrigation of -12.2 bars was essentially the same as the seasonal mean for furrow irrigation of -12.4 bars. On the other hand, the seasonal mean of plants receiving irrigations at 1.25 times consumptive use was -11.7 bars compared to -13.0 bars for those at 0.75 times consumptive use. This difference in leaf water potential of 1.3 bars, although small, was statistically significant at the 1% level.

Berry size and sugar content for the trickle and furrow irrigation treatments are shown in Tables 4 and 5, respectively. Little variation in berry size was noted for the different irrigation treatments. The 1975 berry size averaged 0.71 lbs per 100 berries, which was approximately the average between the 1973-74 berry size of 0.75 lbs per 100 berries. In terms of yield, 1975 average was 157 lbs per plot, which was approximately the average between the 1973-74 yield of 169 lbs per plot. The mean for the 1975 sugar content was 16.6% compared to 15.8% in 1973 and 17.5% in 1974. Also, a significant increase in 1975 sugar content resulted from the 0.75 over the 1.00 and 1.25 consumptive-use rate for trickle and furrow irrigation treatments.

Table 5 compares yield and fruit quality results for 1973, 1974, and 1975 grapes. Within these years, yields have increased with two trickle emitters per vine over one, and with two trickle emitters over furrow irrigation. Again, the inadequate weed control for the furrow irrigation treatments may have contributed to the increase in yield for the trickle over furrow in the third year. Yields in 1974 and 1975 decreased when less than the measured consumptive-use rate was applied for trickle and furrow irrigation, whereas this result was not found in 1973, probably because of the unusually heavy rainfall early in that year. Daily trickle irrigations did not increase yields over 3- and 6-day trickle irrigations on a sandy-loam soil. As for furrow irrigation, little difference in yield has occurred between three or two furrows per row.

Based on the past three years of field research, a fourth year of Perlette grapes is planned to include eight replications of the following

treatments: Three trickle and furrow irrigation quantities -- 1.50, 1.25, and 1.00 times consumptive use, and two trickle irrigation frequencies -- daily and weekly. The trickle treatments will have two emitters per vine, and the furrow treatments will have three furrows per row. The 1976 treatments are being altered to increase the number of replications, to further refine the effects of trickle irrigation amounts and extremes in trickle irrigation frequencies, and to further investigate yield and fruit quality responses under trickle and furrow irrigation.

SUMMARY AND CONCLUSIONS:

Trickle irrigation provides a means for the precise application of water, when and where needed by the plant for optimum plant growth. It has particular promise wherever water is expensive or scarce, and wherever high-valued crops are produced. However, the management and operation practices for a trickle irrigation system are not yet known for most crops and field situations.

Three years of research using trickle and furrow irrigation have helped to answer a number of questions on irrigation scheduling for Perlette table grapes: (1) How much water should be applied? Yield reductions can be expected when water applications are less than the consumptive-use estimate for either trickle or furrow irrigation. Leaf water potential measurements, taken only in the last year, verified the presence of plant water stress with water applied at 25% less than consumptive-use requirement for trickle and furrow irrigation. Therefore, any savings in the water delivery requirement for trickle over furrow methods would be due to improved irrigation efficiency and not an appreciable difference in the consumptive-use requirement. Within the three years, the consumptive-use requirement during the growing season ranged from approximately 15.0 to 17.0 inches of water.
(2) How often should trickle irrigations be applied? Yields have not increased with daily over 3-day and 6-day trickle irrigation in the three years on a sandy-loam soil. Therefore, no advantage or disadvantage for daily trickle irrigation of grapes has been shown.

(3) How many trickle emitters or furrows per vine are needed? Yields have increased with two trickle emitters per vine over one, but they have not changed with three or two furrows per vine row. Indications are that a single trickle emitter per vine irrigates too small a wetted surface area, whereas irrigations are adequate for furrows on both sides of the vine row and not necessary in a center furrow. (4) How does yield and fruit quality compare between trickle and furrow irrigation? Three-year data has shown that yield and quality were increased with two trickle emitters over furrow irrigation. The largest yield increase was obtained in the third year; however, inadequate weed control in the furrow plots may have accounted for some of the decreased production. Leaf water potential measurements did not indicate a greater plant water stress with the furrow versus trickle irrigation methods. A fourth year of research on Perlette grapes is planned where replications will be increased, only extremes in trickle irrigation frequencies will be tested, and weed control practices will be improved.

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

Table 1. Available moisture and adjusted quantities for trickle and furrow irrigation of grapes, 1975.

Irrigation Quantity	Water Applied	Rainfall	Total Available Moisture for Consumptive Use
Consumptive-Use Ratio	(inches)	(inches)	(inches)
Trickle:			
1.25	20.3	0.7	21.0
1.00	16.3	0.7	17.0
0.75	12.2	0.7	12.9
Furrow:			
1.25	20.5	0.7	21.2
1.00	16.5	0.7	17.2
0.75	12.3	0.7	13.0

Table 2. Grape production for trickle and furrow irrigation, 1975.

Irrigation Treatment	Irrigation Quantity			Mean
	Consumptive-Use Ratio			
	1.25	1.00	0.75	
	(pounds per plot)			
TRICKLE:				
Daily / 1 emitter	163*	145	127	145 c**
Daily / 2 emitters	185	164	157	169 a
3-day / 2 emitters	175	187	166	176 a
6-day / 2 emitters	176	169	147	164 ab
MEAN	175 a	166 b	149 c	
FURROW:				
3 Furrows per vine	154	158	116	143 c
2 Furrows per vine	159	148	125	144 c
MEAN	156 c	153 c	121 d	

*Mean, 4 replications, 7 vines harvested per plot

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

Table 3. Leaf water potential for trickle and furrow irrigation of grapes, 1975.

Irrigation Treatment	Date												
	April			May					June			July	
	09	22	28	06	16	21	22	29	05	06	09	03	Mean
	(negative bars)												
Trickle:													
Daily/2 emitters/ 1.25 CU	4.1*	11.9	13.8	11.1	10.4	13.4	11.5	12.9	13.3	14.4	14.2	11.0	11.8
Daily/2 emitters/ 0.75 CU	3.5	12.0	13.8	11.1	12.2	12.4	13.6	15.4	16.6	16.4	15.1	13.5	13.0
Mean	3.8	12.0	13.8	11.1	11.3	12.9	12.6	14.2	15.0	15.4	14.6	12.2	
Furrow:													
3 furrows per vine 1.25 CU	4.2	12.8	12.7	12.7	10.2	11.6	12.2	13.8	10.3	14.3	13.7	10.4	11.6
3 furrows per vine 0.75 CU	5.4	12.0	14.3	13.7	10.8	11.5	12.6	14.5	14.6	16.5	15.8	13.1	12.9
Mean	4.8	12.4	13.5	13.2	10.5	11.6	12.4	14.2	12.4	15.4	14.8	11.8	

* Mean daily measurements from 4 vines per treatment.

Table 4. Berry size for trickle and furrow irrigation of grapes, 1975.

Irrigation Treatment	Irrigation Quantity			Mean
	Consumptive-Use Ratio			
	1.25	1.00	0.75	
	(pounds per 100 berries)			
TRICKLE:				
Daily / 1 emitter	0.75*	0.74	0.72	0.74 a**
Daily / 2 emitters	0.73	0.70	0.70	0.71 a
3-day / 2 emitters	0.75	0.71	0.69	0.72 a
6-day / 2 emitters	0.74	0.69	0.68	0.70 a
MEAN	0.74 a	0.71 b	0.70 b	
FURROW:				
3 Furrows per vine	0.71	0.70	0.68	0.70 a
2 Furrows per vine	0.71	0.71	0.66	0.69 a
MEAN	0.71 b	0.71 b	0.67 a	

*Mean, 4 replications, 7 vines harvested per plot

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

Table 5. Sugar content for trickle and furrow irrigation of grapes, 1974.

Irrigation Treatment	Irrigation Quantity Consumptive-Use Ratio 1.25	1.00	0.75	Mean
	(percent sugar)			
TRICKLE:				
Daily / 1 emitter	16.2*	16.9	17.1	16.7 a**
Daily / 2 emitters	16.5	16.4	16.6	16.5 a
3-day / 2 emitters	16.4	16.0	16.7	16.4 a
6-day / 2 emitters	16.3	16.2	17.0	16.5 a
MEAN	16.4 c	16.4 c	16.9 ab	
FURROW:				
3 Furrows per vine	16.7	16.6	17.2	16.8 a
2 Furrows per vine	16.9	16.8	16.9	16.9 a
MEAN	16.8 b	16.7 b	17.1 a	

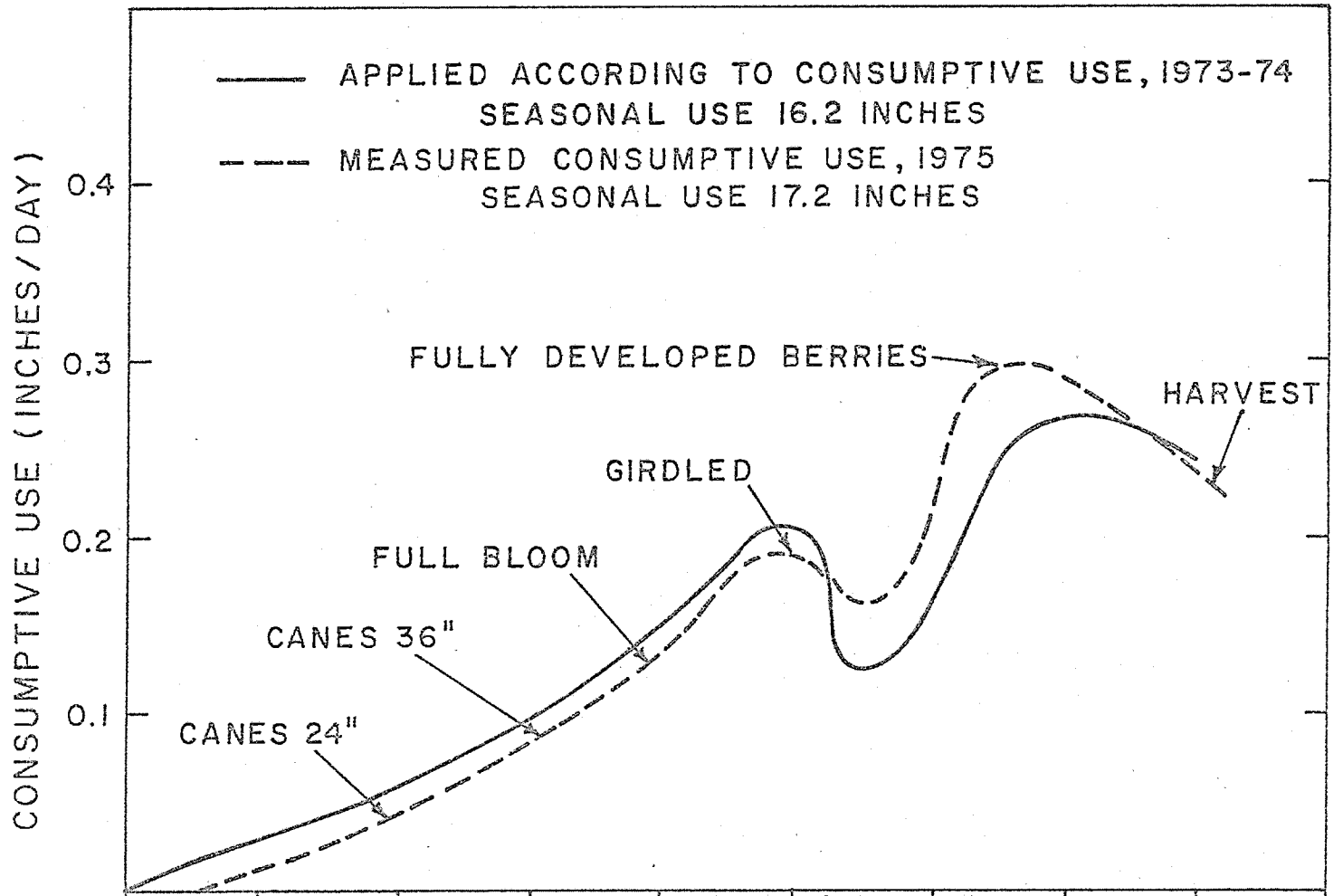
*Mean, 4 replications, 7 vines harvested per plot

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

Table 6. Comparison of 1973, 1974, and 1975 results for trickle and furrow irrigation of grapes.

Comparison	1973	1974	1975
Yield for 2 emitters versus 1 emitter per vine	9% increase	9% increase	17% increase
Yield for 2 emitters per vine versus furrow irrigation	13% increase	6% increase	18% increase
Yield for 1 emitter per vine versus furrow irrigation	N.S.	N.S.	N.S.*
Yield for different trickle irrigation frequencies	N.S.	N.S.	N.S.
Yield for 3 versus 2 furrows per vine	N.S.	N.S.	N.S.
Yield for different trickle irrigation quantities	N.S.	11% increase for 1.35 over 0.80 cu**	11% increase for 1.00 over 0.75 cu and 6% increase for 1.25 over 1.00 cu
Yield for different furrow irrigation quantities	N.S.	N.S.	29% increase for 1.25 and 1.00 over 0.75 cu
Berry size for trickle versus furrow-irrigated fruit	6% increase	N.S.	N.S.
Berry size for different trickle and furrow irrigation quantities	N.S.	N.S.	6% increase for 1.25 over 0.75 cu
Sugar content for trickle versus furrow-irrigated fruit	N.S.	N.S.	N.S.
Sugar content for different trickle and furrow irrigation quantities	N.S.	N.S.	3% increase for 0.75 over 1.25 and 1.00 cu

*N.S.: No Significant difference at the 5% level
**cu : consumptive-use rate



APPLIED	.24	.64	1.13	1.84	2.73	2.30	3.33	3.94	—
MEASURED	.02	.37	.93	1.61	2.64	2.54	4.46	3.98	.69
	MARCH		APRIL		MAY		JUNE		JULY

Figure 1. Applied and measured consumptive-use for grapes, 1975.

TITLE: EROSION-PREVENTIVE STRUCTURES TO DISTRIBUTE WATER ONTO IRRIGATED FIELDS

CRIS WORK UNIT: 5510-12260-004 CODE NO.: USWCL 73-5

INTRODUCTION:

Increasing costs and shortage of labor, the need for improving irrigation efficiency, and increased use of marginal lands (sandy soils), have made it necessary for farm owners to design their irrigated farms in such a way that large streams of water are utilized. This use of large streams has necessitated outlet structures to reduce soil erosion. Originally, we designed concrete structures to handle streams of 3 to 7 cfs. Approximately 30 of these structures in various sizes and configurations, made of various materials, were built on many different types of soil in Arizona. A definite design for non-erosive structures has been developed.

Recently, outlets in the form of jack-gates have become popular. From these, 10 to 30 cfs may be discharged, thus necessitating additional erosion-preventive structure design. Some have been modified in the field; others have been newly constructed, and all are being observed. In the Blythe, CA, area, streams of over 40 cfs are being used. The Ft. Collins office designed a structure for such a requirement. It has proved successful, further strengthening some of the original design criteria used on smaller structures. The use of automation on tile outlets has changed the erosion patterns, and structures have been designed to accommodate these changes. Structures are in and being used in Blythe, CA, and near Tacna, AZ. These structures are for streams of sizes up to about 7 cfs, although most of the streams are in the 4 cfs range.

PROCEDURE:

Original structures will be observed, structures on an automated jack-gate system emitting 15 cfs will be constructed to amend the original structures built by the farmer, and a farmer will be assisted on the smaller, standard-size structures, until his farm help can continue the construction of more of them.

SUMMARY: The development of automation and thus installation of certain equipment on the outlet side of 16-inch tile outlet structures changed the normal erosion patterns, necessitating the development of a structure to cope with the soil erosion so created. Eight structures were built and are operating successfully after 3 irrigations. Structures built for jackgate outlets for the 15 to 40 cfs flow range are being observed and were operating satisfactorily through 1975.

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

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

CRIS WORK UNIT: 5510-12260-004 CODE NO.: USWCL 73-6

INTRODUCTION:

See 1973 annual report.

PROCEDURE:

The 40-acre automation system in Blythe, CA, was expanded to 160 acres. A desirable storage shed was installed and a new compressor purchased after the original one had been stolen. A new model outlet frame, similar to those designed for Tacna, was installed. No changes were made in the system installed on the underground irrigation system on 10 acres of citrus near Mesa, AZ.

RESULTS AND DISCUSSION:

A leak in the buried PVC line on one of the 40-acre sites at Blythe proved to be due to pressure of a truck or tractor over the too-shallow depth of buried PVC pipe. An additional leak exists. The old clock imported from Fort Collins is inoperative and should be replaced.

The 10-acre system at Hall Grove, Mesa, is still in use and has been used for every irrigation since its installation in 1970. Two of the pillows were replaced due to grommet failure. The 5/16 inch polyethelyne tubing, still on the surface, has shown no signs of failure. The 3 pop-off valves have never failed. It is planned that new 5/16 inch tubing and new style pillows will be installed this year. The tubing will be buried as a permanent system should be.

SUMMARY:

One of the two original pneumatic automation systems is being used continually. Major components on both systems are withstanding the weather and present automation ideas seem sound.

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

TITLE: CHEMICAL MODIFICATION OF SOILS FOR HARVESTING PRECIPITATION

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

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

I. LABORATORY TESTING PROCEDURES

The primary objective of this phase of the study remains to develop laboratory tests which (1) encompass, as much as possible, all the potential major causes of treatment failure which occur in the field; (2) are quickly and easily performed; and (3) markedly accelerate the natural weathering processes. The two major types of failure of repellent-treated soils are considered to be lack (or loss) of water repellency and lack (or loss) of soil structural stability. The major factors effecting such failures are envisaged to be freeze-thaw cycling, ozone, and ultraviolet radiation.

A testing sequence has been established (Figure 1) for laboratory evaluation of repellent soil treatments. Three identically prepared petri-dish-size samples of each treatment are tested initially for water repellency and structural stability. Then one each of the samples are subjected to cycling in a freeze-thaw, ozone or UV-light weatherometer, respectively. All samples are checked periodically for degree of repellency and stability (Fink (1)).

II. LABORATORY EVALUATION OF TREATMENTS

A large number of potential water-harvesting water-repellent treatments were laboratory tested in 1975 according to the procedures reported in section I of this report, and outlined in Figure 1. Some results appear in the two manuscripts: "Freeze-thaw effects on soils treated for water repellency" and "Testing of water-repellent soil treatments for water harvesting." Other results are summarized here in Tables 1-4.

In Table 1, a series of different melting point n-paraffins and several slack waxes are evaluated and compared. Resistance to structural failure from freeze-thaw cycling was found to increase slightly as average melting point (AMP) of the paraffins increased — but none performed impressively. Of the slack waxes, only the Hawaiian crude effectively withstood the disruptive forces of freeze-thaw cycling.

The n-paraffins (particularly the higher AMP's) were quite resistant to degradation by ozone or ultraviolet (UV) radiation, and all passed the associated dripolator tests. All samples treated with the several low grade slack waxes were water repellent initially; most adequately resisted ozone attack; but several lost surface repellency when exposed to UV radiation. Nevertheless, most slack-wax-treated samples passed the brush test and the 4-hr hydration tests, even after 500 hr exposure to these two weathering elements, indicating that loss of repellency was primarily a surface phenomenon — the subsurface treated zone remaining relatively unweathered.

Table 2 shows results of similar tests on soils treated with three batches of a dust suppressant oil (DS_a, DS_b, and DS_c), and mixtures of DS_c combined with either paraffin (128-131 AMP) or Bakersfield slack wax. All passed the initial 4-hr hydration test, but several did not quite attain the acceptable L/L_n- value of 1.30. DS_b, which contained an antioxidant, was highly resistant to the forces of freeze-thaw cycling; the other two DS's were not. Adding paraffin to DS_c slightly improved treatment resistance to breakdown by freeze-thaw cycling, and markedly improved resistance to destruction by ozone and UV. Surprisingly, resistance to destruction by freeze-thaw cycling of many of the DS-paraffin mixtures treated samples improved after exposure to ozone and UV.

Table 3 mainly shows that adding 5% ethylene vinyl acetate copolymer to paraffin markedly improved sample resistance to structural breakdown by freeze-thaw cycling. Table 4 shows results of such testing for mixtures of a paraffin, a silicone antistripping agent, and a tackifying agent on several soils. The mixtures did

not materially improve results for Granite Reef soil, and made Seneca and Monument Tank soils worse. However, results with the Superstition sand were quite impressive. Further tests are planned.

III. FIELD TESTING OF MATERIALS

1. Runoff data — 1975:

Runoff studies continued on the two paraffin-wax-treated plots established in 1972 at the Granite Reef test site. Table 5, which compares the runoff off these plots to that from off butyl-covered and smoothed plots, shows that the wax plots continue to yield nearly 90% runoff — on par with that off the butyl-covered plots. Also, weed growth on the wax plots remains completely controlled.

At Usery Pass the dust suppressant plots were overcoated with paraffin wax (143-150 AMP, at 0.5 kg/m^2, on 12 June) because (1) a dust-suppressant-treated plot at Granite Reef failed in less than 1 yr, and (2) laboratory samples of soils treated with mixtures of paraffin wax and the dust suppressant better withstood combined weathering effects than did soils treated with either of the repellents alone. Table 5 shows that the dust-suppressant-treated plot also yielded approximately 90% runoff for the year.

Several other paraffin-wax-treated water-harvesting sites have been established in the Southwest by other agencies. Some are successful; others have failed. Future work calls for establishing relationships between catchment suitability and influencing factors of climate, soil, and installation methodology.

2. Runoff data — long term evaluations of water-repellent water-harvesting catchments:

Better ways of evaluating the weathering properties of water-repellent water-harvesting field catchments are needed. Normally, the ratio of runoff to precipitation from natural storms (percent runoff) is the only measurement taken. This data, when averaged over a large number of storms so as to discount variability from storm size and intensity, and antecedent soil moisture, provides useful information on treatment efficiency and durability, but tells little about why or how a treatment fails.

Linear regression analyses of storm-size vs runoff yield off water-harvesting catchments have been used (Hillel et al. (3) and Frasier (2)) to obtain threshold values, i.e., the minimal rainfall necessary to produce runoff. As expected, it was found that natural or smoothed-only watersheds had high threshold retentions, while most plastic membranes and newly treated water-repellent catchments had low retentions.

The linear regression equation (following Hillel's notation) is: $R = A + BP$, where R is runoff per storm, P is storm size, and A and B are the linearity constants. For such analyses only those precipitation events which produce runoff are included. The threshold value obtained from the P-axis intercept is $(-A/B)$.

Ideally, newly prepared water-repellent catchments should yield practically 100% runoff; thus, they should be independent of the vagaries of storm size and intensity, and antecedent soil moisture. In terms of the parameters of the regression equation: $A \rightarrow 0$, $(-A/B) \rightarrow 0$, $B \rightarrow 1$, and $r \rightarrow 1$, where r is the correlation coefficient. There should be no soil wetting or water spreading on the treated soil surface. Any water retained by the plot would be trapped by surface roughness, but the amount should be small if the soil surface had been carefully smoothed during site preparation.

It was hypothesized that such linear regression analyses might provide information on how water-repellent catchments degraded. If weathering commenced at the exposed soil surface and gradually progressed deeper, yet maintained an unweathered, water-repellent zone, then runoff patterns should be as depicted in Figure 2a. The threshold valve is small initially but gradually increases each year as the weathering front proceeds into the water-repellent zone; B remains equal to unity, since after the threshold value is satisfied for each rain, all the remaining precipitation runs off. Eventually, however, repellency should be completely lost. Then runoff patterns should approach those of smoothed-only plots; i.e.: $(-A/B)$ large; $B \ll 1$; and $r \ll 1$, reflecting considerable data scatter.

If weathering occurred throughout the treated zone the entire treated profile would gradually lose repellency. Hypothetical runoff patterns for such weathering are depicted in Figure 2b. The first year pattern looks the same as that of Figure 2a, i.e., $(-A/B) \rightarrow 0$ and $B \rightarrow 1$. However, as the treatment weathers and loses repellency, the runoff pattern changes in two ways: (1) $(-A/B)$ increases, reflecting increased water retention on the weathered treatment surface, and (2) B decreases, reflecting the infiltration and loss of a portion of the precipitation through the treated zone. This decrease in B could occur either by an overall loss of repellency over the entire plot or by a weathered or degraded portion of the plot which increases in area with time.

Some representative linear regression analysis data are shown in Table 6. The natural, and cleared and smoothed watersheds (W-1 and L-2) have low correlation coefficients (r) which means their runoff characteristics are highly subject to storm size and intensity, and to antecedent soil moisture; B values are low which means much of the precipitation infiltrates the soil and is lost for water harvesting purposes; the number of storms producing runoff (n) is low, which by inference means a high threshold value; and the calculated thresholds $(-A/B)$ are highly variable (-17.53 to 7.14) which reflects the extreme variability of the date (low r).

Linear regression analyses of the runoff data from the three surface membrane treatments (L-1, L-4 and L-7) show that initially all yielded a high proportion of precipitation regardless of storm size ($-A/B \rightarrow 0$, $B \rightarrow 1$, $r \rightarrow 1$, and n approximately equals the total number of yearly storms). Data from L-1 (polyethylene) and L-7 (Al-foil) are comparable throughout their test periods, even though for some reason the Al-foil has a slightly higher threshold and seems to lose a little water through infiltration. Possibly pin holes in the Al-foil are responsible.

The butyl covering yielded nearly 100% runoff from all storms for about 9 years (through 1970); then rapidly lost efficiency. These results clearly mirror the degradation of the treatment — the

sheeting developed tears and separated from the plot edges. The consistently high n-values mean the plot usually produced some runoff whether the storm was small or not; high r values suggest that the proportion of water lost was more dependent on membrane geometry than on the factors causing runoff variability from bare soils.

Linear regression analyses of first year runoff data from the several water-repellent-treated plots at Granite Reef (Table 6) show that they behave as hypothesized: ($B \rightarrow 1$, $r \rightarrow 1$, $-A/B \rightarrow 0$, and n approximately equals the total number of yearly storms. However, already by the second year obvious differences exist between the silicone- and wax-treated plots, and these differences amplify with time. The regression analyses suggest that the silicone-treated plots (L-3, R-4, and A-4)weather according to hypothesis 2 (Figure 2b). The data for plot L-3 are depicted in Figure 3 which shows that B gradually decreases and -A/B increases with time after treatment. Retreating partially restores the plot to original efficiency — but not quite. The B-values did not regain their high values; retreating either does not restore the overall high repellency or possibly a portion of the plot was not treated.

The two paraffin-wax-treated plots apparently weather more like hypothesis 1 (Figure 2a). Four years of runoff data for plot No. 13 are shown in Figure 4. B remains close to unity, and the threshold (-A/B) increased slightly the second year. However, it is not so obvious that the treated repellent profile has continued to weather deeper after the second year. The data suggests that weathering of the wax plots has stabilized. Obviously, longer field evaluation is needed.

SUMMARY:

Laboratory techniques have been developed to shorten the testing period of water-repellent soil treatments for water harvesting. The testing evaluates water repellency and soil structural stability, as affected by the soil, organic additive, water erosion, and weathering by ultraviolet light, ozone, or freeze-thaw cycles. Laboratory studies showed that n-paraffin wax-treated soils resisted degradation

from ozone and ultraviolet radiation, but were rather susceptible to breakdown from freeze-thaw cycling. A dust suppressant oil as repellent reacted oppositely. Proper combinations of the two repellents retained the advantages of both. Other mixtures containing wax as repellent (e.g., wax + certain polymers, and wax + silicone anti-stripping agent + tackifying agent) markedly improved stability of the treatments against breakdown by freeze-thaw cycling on certain soils. Two paraffin-wax-treated catchments at the Granite Reef test site continue to yield 90% runoff after nearly 4 years of weathering. Linear regression analysis of runoff data from the Granite Reef test site has been used to evaluate the weathering properties of the repellent treatments. Hypothetically, a repellent which weathers throughout the treated soil zone should show a gradual increase in water infiltration (runoff data suggest the silicone-treated plots weather this way). A repellent which weathers as a progressing front commencing at the surface, and culminating eventually at the lower treated edge should only show an increase in surface retention of precipitation but no deep infiltration (runoff data suggest the wax-treated plots weather this way).

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PERSONNEL: D. H. Fink.

Table 1. Water repellency and structural stability of wax treated Granite Reef soil samples exposed to the weathering elements of freeze-thaw cycling, ozone, and ultraviolet radiation.

		Pre-weathering 1/		WEATHERING ELEMENT														
				Freeze-thaw		Ozone							Ultraviolet					
						hrs							hrs					
Repellent	Rate	L/L_n	4-hr hyd.	Cycles	Drip-olator 2/	100	200	300	400	500	Drip-olator		100	200	300	400	500	Drip-olator
	kg/m^2	±	±															
n-paraffins																		
kerosene	0.50	-	-	0 3/	N	0	0	0	0	0	—		0	0	0	0	0	—
	0.75	-	-	0	— 4/	0	0	0	0	0	—		0	0	0	0	0	—
116 AMP	0.50	+	+	13	M	△ 6/	△	2	2	2	N		△	3	0	0	0	S
	0.75	+	+	7	N	△	△	2	2	2	N		△	△	△	3	2,3	N
	1.00	+	+	7	N	△	△	2	2	2	N		△	△	2,3	3	3	N
128-130 AMP	0.50	+	+	7	N	△	△	△	△	△	N		△	3	0	0	0	N
	0.75	+	+	16	N	△	△	△	△	△	N		△	△	2	3	3	N
	1.00	+	+	17	N	△	△	△	△	△	N		△	△	3	3	3	N
143-150 AMP	0.50	+	+	22	N	△	△	△	△	△	N		△	△	△	3	3	N
	0.75	+	+	29	N	△	△	△	△	△	N		△	△	△	△	△	N
	1.00	+	+	43	N	△	△	△	△	△	N		△	△	△	△	△	N
160-165 AMP	0.50	+	+	27	N	△	△	△	△	△	N		△	△	△	3	3	N
	0.75	+	+	29	N	△	△	△	△	△	N		△	△	△	3	3	N
	1.00	+	+	29	N	△	△	△	△	△	N		△	△	△	3	3	N
other waxes																		
Bakersfield	0.50	+	+	30	N	△	△	△	△	△	N		△	△	△	△	△	N
slack	0.75	+	+	36	N	△	△	△	△	△	N		—	—	—	—	—	
	1.00	+	+	58	N	△	△	△	△	△	N		△	△	△	△	△	N
Hawaiian	0.50	+	+	237	N	△	△	△	△	△	N		2	2	2	2	2	N
crude	0.75	+	+	314 5/	5/	△	△	△	△	△	N		2	2	2	2	2	N
	1.00	+	+	196	N	△	△	△	△	△	N		2	2	2	2	2	N
Phillips 10	0.50	+	+	16	N	△	△	2	2	2	N		△	2	2	△	1,2,3	—
petro-	0.75	+	+	16	N	△	△	2	2	2	N		△	△	2	2	2	N
latum	1.00	+	+	16	N	△	△	△	2	2	N		△	2	2	△	△	N
Phillips 20	0.50	+	+	16	N	△	△	2	△	2	N		△	2	△	△	△	N
petro-	0.75	+	+	33	N	△	△	△	△	2	N		△	△	△	△	△	N
latum	1.00	+	+	57	N	△	△	△	△	△	N		△	△	△	△	△	N

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

Table 2. Water repellency and structural stability of dust suppressant-wax mixtures treated Granite Reef soil samples exposed to the weathering elements of freeze-thaw cycling, ozone, and ultraviolet radiation.

				WEATHERING ELEMENT													
		Pre-weathering 1/		Freeze-thaw (FT)		Ozone						Ultraviolet					
Repellent	Rate	L/L_n	4-hr hyd.	Cycles	Drip olator 2/	100	200	300	400	Drip-olator	FT-cycles	100	200	300	400	Drip-olator	FT-Cycles
	ℓ/m^2	±	±														
Dust suppressant (DS)																	
DS_a	0.5	+	+	40	N	Δ 4/	Δ	Δ	2,3	N	0 3/	2	2	2	2	N	250 5/
	1.0	+	+	43	N	Δ	Δ	2	2,3	N	0	2	2	2	2	N	3
DS_b	0.5	+	+	793 5/	5/	Δ	2	2,3	2,3	N	0	2	2	2	2,3	N	0
	1.0	+	+	657	N	Δ	Δ	2	2,3	N	0	2	2	2	2	N	82
DS_c	0.5	–	+	37	N	Δ	Δ	Δ	2,3	N	0	2	2	2	2,3	N	0
	1.0	–	+	37	N	Δ	Δ	2	2,3	N	0	2	2	2	2	N	6
DS_c + paraffin wax																	
5% wax	0.5	+	+	71	N	Δ	Δ	Δ	Δ	M	137	2	2	2	2	N	105
	1.0	+	+	202	N	Δ	Δ	Δ	Δ	N	414 5/	2	2	2	2	N	343 5/
10% wax	0.5	+	+	66	N	Δ	Δ	Δ	Δ	M	143	2	2	2	2	N	208
	1.0	+	+	172	N	Δ	Δ	Δ	Δ	N	132	Δ	2	2	2	N	167
25% wax	0.5	+	+	37	N	Δ	Δ	Δ	Δ	M	36	Δ	Δ	2	2	N	86
	1.0	+	+	92	N	Δ	Δ	Δ	Δ	N	97	Δ	Δ	2	2	N	255
DS_c + slack wax																	
5% wax	0.5	+	+	69	N	Δ	Δ	Δ	Δ	N	111	2	2	2	2	N	208
	1.0	–	+	68	N	Δ	Δ	Δ	Δ	N	382	2	2	2	2	N	161
10% wax	0.5	+	+	63	N	Δ	Δ	Δ	Δ	N	169	2	2	2	2	N	277
	1.0	+	+	117	N	Δ	Δ	Δ	Δ	N	377	2	2	2	2	N	254
25% wax	0.5	+	+	64	N	Δ	Δ	Δ	Δ	N	75	2	2	2	2	N	185
	1.0	–	+	885 5/	5/	Δ	Δ	Δ	Δ	N	133	2	2	2	2	N	869 5/

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

Table 3. Water repellency and structural stability of wax treated Granite Reef soil samples exposed to freeze-thaw cycling.

Repellent	Rate	Pre-weathering 1/		Freeze-thaw	
		L/L_n	4-hr hyd.	Cycles	Drip-olator 2/
	kg/m^2	±	±		
Paraffin wax					
116 AMP	0.38	+	+	6	N
	0.50	+	+	6	N
	0.75	+	+	6	N
128-131 AMP	0.38	+	+	21	N
	0.50	+	+	12	N
	0.75	+	+	23	N
Par. wax + 5% ethylene vinyl acetate copolymer	0.38	+	+	18	N
	0.50	+	+	117	N
	0.75	+	+	188	N

1/ Plus (+) denotes exceeding acceptable levels; negative (-) denotes not meeting them.

2/ N denotes no erosion from test.

Table 4. Number of freeze-thaw cycles required to destroy structure of soil samples treated with mixtures of paraffin (128-131 AMP), silicone coupling agent (Z-6076) and tackifying agent (L-60).

	Soil								
	Granite Reef		Seneca (0-8 cm)		Monument Tank (2-3)		Superstition Sand		
	Application rate (kg/m^2)								
Repellent	0.50	0.75	0.50	0.75	0.50	0.75	0.25	0.50	0.75
Wax/Z-6076/L-60	freeze-thaw cycles								
100/0/0	33	33	22	43	— 1/	—	79	32	80
99.9/0.1/0	17	28	12	0 2/	—	—	46	104	161
99/1/0	28	56	0	12	—	—	73	173	1140 3/
89.9/0.1/10	17	103	0	0	0	0	85	147	1098 3/
89/1/10	72	115	0	0	0	0	215	1248 3/	1261 3/

1/ Dash denotes sample was not tested.

2/ Zero (0) denotes sample failed 4-hr hydration test.

3/ Sample still under test.

Table 5. Precipitation runoff off paraffin wax (P wax)- and dust suppressant (DS)-treated soils vs. smoothed and butyl-covered soil.

Granite Reef							Usery Pass			
		10 m^2 plots			200 m^2 plots				10 m^2 plots	
		#14	#11	#13	R-3	R-2				
Date	Precip.	Smoothed	Butyl	P wax	Smoothed	P wax	Date	Precip.	Smoothed	DS + P wax
1975	mm	% runoff					1975	mm	% runoff	
14 Feb	8.8	0	90	89	0	93	8 Jan	1.8	0	84
15 Feb	10.7	20	84	92	0	85	31 Jan	3.3	0	80
8-9 Mar	7.0	21	97	97	0	93	5 Feb	1.3	0	88
10-11 Mar	14.3	36	106	106	8	96	14 Feb	9.1	14	83
11 Mar	3.6	14	69	67	0	71	18 Feb	24.6	46	1/
14 Mar	6.5	1/	1/	1/	5	90	11 Mar	28.7	36	1/
6-7 Apr	8.1	0	96	96	0	95	17 Mar	12.7	46	101
9 Apr	9 4	11	100	96	0	89	27 Mar	1.5	0	0
4 Jul	4.3	1/	1/	1/	0	83	1 Apr	3.3	43	142 2/
14 Jul	18.0	44	1/	1/	31	77	7 Apr	9.6	27	101
27 Jul	9.1	0	1/	88	0	70	11 Apr	9.9	35	96
6 Sep	20.5	24	86	97	9	82	4 Jul	3.6	0	120
28-29 Nov	30.0	25	90	98	19	91	11-13 Jul	18.8	59	93
13-14 Dec	21.3	42	98	100	46	96	28 Jul	18.8	58	86
21 Dec	11.8	14	96	97	0	27 2/	8 Sep	13.7	38	77
							20 Oct	1.0	0	87
							2 Dec	31.2	34	1/
							13-14 Dec	11.4	49	108
							21 Dec	18.5	1/	1/
Summaries 3/										
1972	243.8	28	100	92	31	90		-		
1973	207.8	17	94	88	14	87		-		
1974	250.7	-	-	-	20	85		256.4	44	90
1975	183.4	24	93	96	13	88		222.5	40	93

1/ Data lost.
2/ Data suspect.
3/ Summaries at Granite Reef based on collected data; summaries at Usery Pass based on collected plus estimated data.

Table 6. Linear regression analyses of rainfall runoff data from representative plots at the Granite Reef test site.

Year (storms)	Notation 1/	W-1 Natural watershed	L-2 Cleared and smoothed	L-1 Polyethylene top sheeting	L-4 Butyl top sheeting	L-7 Al-foil on asphalt	L-3 Silicone water repellent treat ⇄ retreat		R-4 Silicone-repellent soil stabilizer treat ⇄ retreat		A-4 Silicone & stabilizer	#13 Paraffin wax	R-2 Paraffin wax
1975	n	10	6	15	8 2/	15	7 2/	8 2/	8 2/	7 2/	15	12	15
(15)	r	0.730	0.596	0.967	0.902	0.992	0.942	0.635	0.694	0.988	0.962	0.997	0.953
	B	0.277	0.310	1.041	0.451	0.857	0.673	0.356	0.376	0.951	0.650	1.023	0.910
	-A/B	6.09	2.97	0.86	1.97	0.48	-2.51	3.68	2.74	1.89	1.01	0.74	0.97
1974	n	13	10	22	21	22		14	17		19	17	22
(22)	r	0.795	0.783	0.987	0.967	0.994		0.907	0.964		0.986	0.995	0.991
	B	0.333	0.363	0.935	0.646	0.868		0.642	0.672		0.816	0.998	0.840
	-A/B	7.14	4.74	0.14	2.69	0.96		5.14	3.86		2.06	0.79	-0.11
1973	n	10	7	28	28	28		18	27		26	25	28
(28)	r	0.645	0.459	0.997	0.970	0.946		0.956	0.969		0.988	0.995	0.997
	B	0.316	0.293	1.014	0.725	0.896		0.780	0.753		0.934	0.990	0.977
	-A/B	4.22	3.06	0.22	1.09	0.70		3.13	1.93		1.40	0.77	0.79
1972	n	13	14	21	20	21		16	20		20	16 2/	13 2/
(21)	r	0.962	0.887	0.998	0.994	0.998		0.991	0.995		0.997	0.999	0.997
	B	0.314	0.334	0.947	0.714	0.898		0.746	0.809		0.904	0.956	0.930
	-A/B	2.90	1.04	-0.24	0.53	0.56		1.80	0.71		0.48	0.49	0.50
1971	n	4	4	22	22	22		18	20		5 2/		
(22)	r	0.357	0.781	0.970	0.901	0.990		0.956	0.997		0.993		
	B	0.164	0.416	0.934	0.651	0.932		0.846	0.898		0.956		
	-A/B	-5.20	1.06	0.44	-0.12	1.00		2.87	1.53		0.74		
1970	n	6	6	17	18	18		13					
(18)	r	0.970	0.954	0.999	0.999	0.999		0.997					
	B	0.181	0.355	0.962	0.942	0.888		0.834					
	-A/B	6.52	0.99	-0.57	0.38	0.51		0.87					
1969	n	15	13	32	32	32	16 2/	5 2/					
(32)	r	0.750	0.426	0.994	0.979	0.838	0.880	0.988					
	B	0.420	0.191	0.963	0.884	0.761	0.522	0.883					
	-A/B	5.17	-1.79	-0.31	-0.12	-1.07	1.30	0.25					
1968	n	11	8	6 2/	10	12	11						
(19)	r	0.612	0.508	1.000	0.998	0.998	0.973						
	B	0.275	0.257	1.020	0.946	0.963	0.790						
	-A/B	0.41	-4.59	0.16	0.29	0.30	2.08						

Table 6. Linear regression analyses of rainfall runoff data from representative plots at the Granite Reef test site (Cont'd).

Year (storms)	Notation 1/	W-1 Natural watershed	L-2 Cleared and smoothed	L-1 Polyethylene top sheeting	L-4 Butyl top sheeting	L-7 Al-foil on asphalt	L-3 Silicone water repellent treat ⇌ retreat	R-4 Silicone-repellent soil stabilizer treat ⇌ retreat	A-4 Silicone & stabilizer	#13 Paraffin wax	R-2 Paraffi wax
1967	n	12	14		23	11 2/	11				
(23)	r	0.735	0.840		0.998	0.990	0.806				
	B	0.299	0.443		1.001	0.886	0.603				
	-A/B	1.57	4.16		0.35	0.24	1.99				
1966	n	12	15		29		22				
(29)	r	0.930	0.949		0.999		0.993				
	B	0.574	0.585		0.981		0.848				
	-A/B	6.28	5.08		0.06		0.79				
1965	n	20	24		26		25 2/				
(46)	r	0.618	0.686		0.990		0.995				
	B	0.221	0.380		0.961		0.969				
	-A/B	-3.37	0.88		-0.62		0.26				
1964	n	8	9		19						
(21)	r	0.706	0.904		0.999						
	B	0.173	0.367		0.987						
	-A/B	1.20	2.83		-0.34						
1963	n		12		13						
(17)	r		0.374		0.998						
	B		0.140		0.981						
	-A/B		-17.53		9.71						
1962	n		11		17						
(24)	r		0.444		0.995						
	B		0.092		0.991						
	-A/B		-2.25		-0.0003						

1/ n = number of usable runoff events in the analysis; r = regression coefficient; B = slope of linear equation; (-A/B) = amount of precipitation necessary to initiate runoff off plots, i. e., surface retention.

2/ Plot treated in mid year.

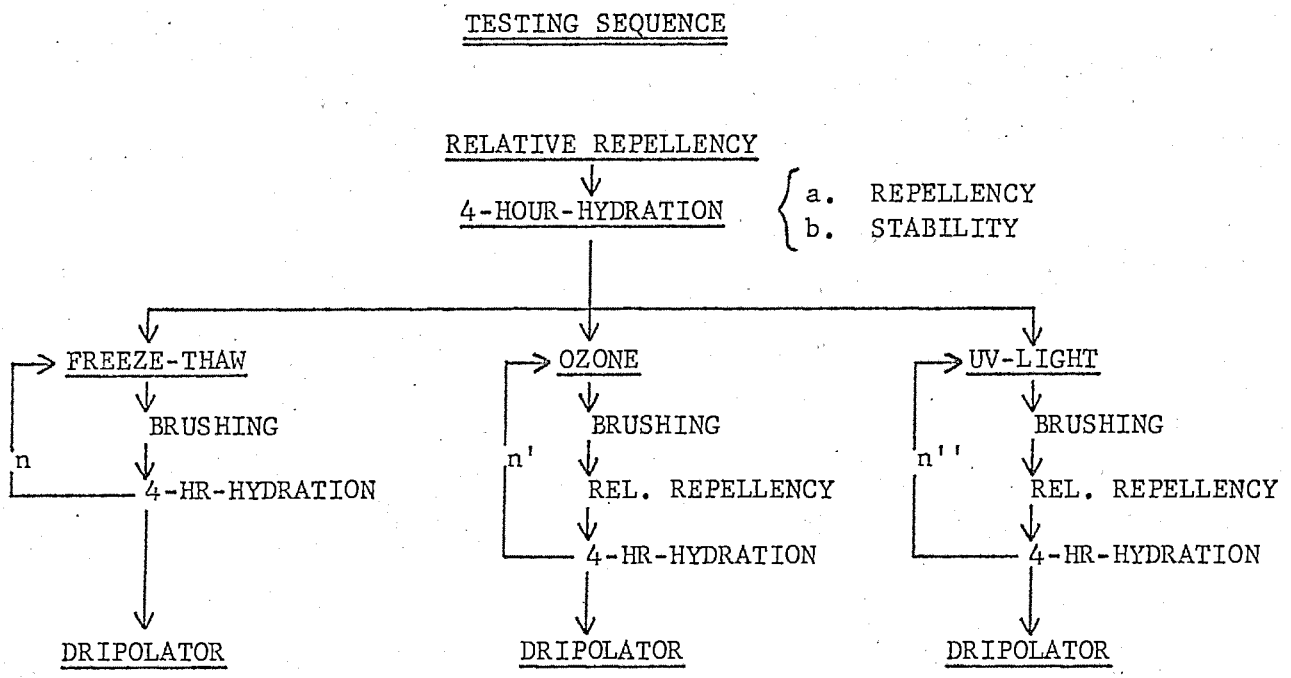

Figure 1. Laboratory testing sequence for evaluating water-repellent soil treatments for water harvesting.

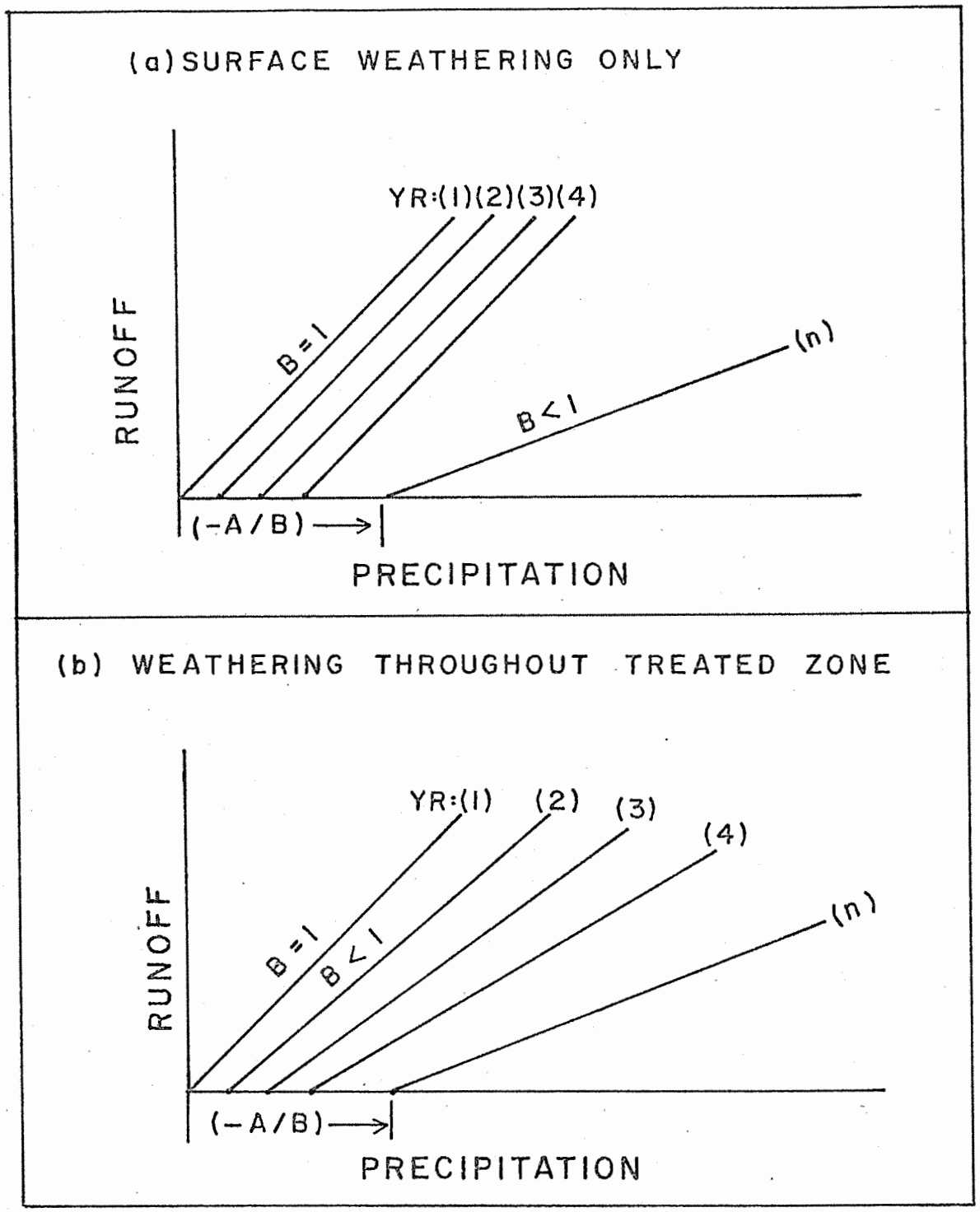

Figure 2. Hypothetical yearly plots of precipitation events vs runoff off water-repellent water-harvesting catchments for (a) increasing depth of surface weathering, and (b) weathering throughout the treated repellent zone.

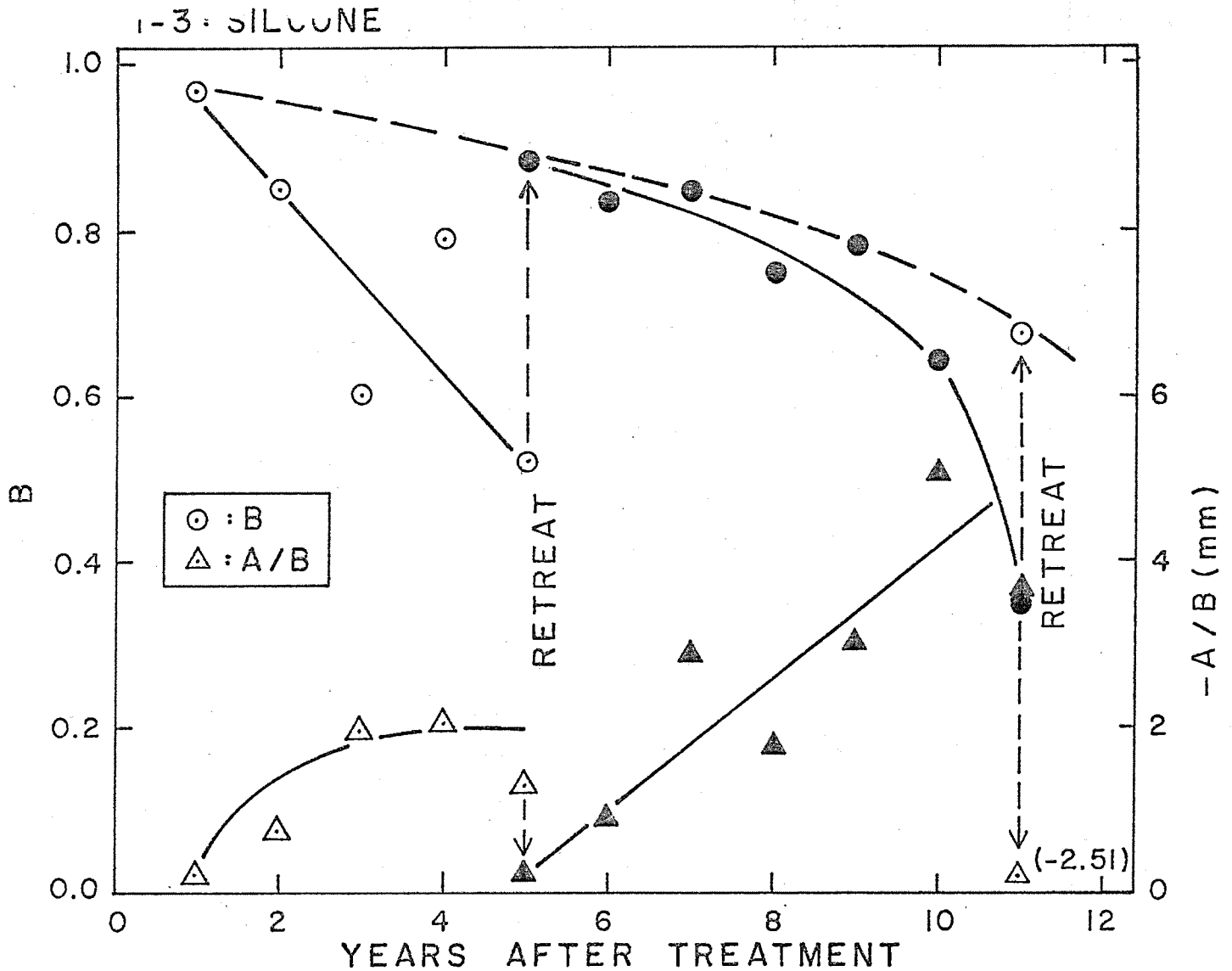

Figure 3. Weathering of a silicone treated water-harvesting catchment as depicted by the yearly constants of linear regression analyses of runoff data: (-A/B) is threshold water retention; B relates to proportion of runoff after threshold is satisfied.

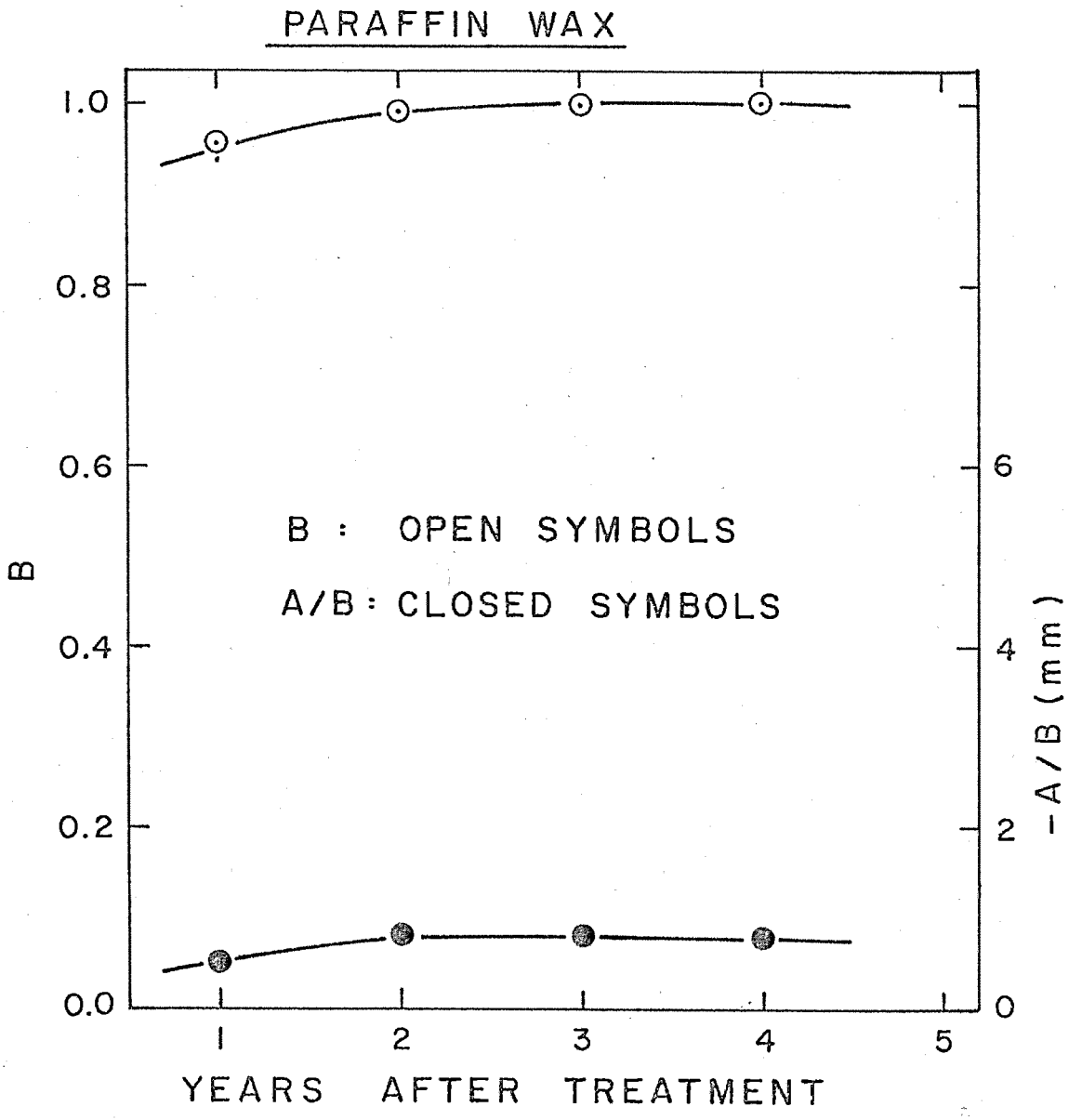

Figure 4. Weathering of a paraffin wax treated water-harvesting catchment as depicted by the yearly constants of linear regression analysis of runoff data.

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

CRIS WORK UNIT: 5510-12260-004 CODE NO.: USWC 74-2

INTRODUCTION:

An automated irrigation scheme reduces farm labor requirements. Automation, as an irrigation management tool, assures more precise control of the irrigation time or quantity of water applied. Such could result in water savings and crop yield improvement by minimizing prolonged inundation time and crop scalding. Water return flow and associated water quality degradation to a river system such as the Colorado River will be reduced. Conveniently, automation also eliminates the need for continuous irrigator attendance.

Automation of farm irrigation systems, both underground and open-ditch, is still in the experimental stage. The systems are moderately successful but need to be refined. A trend in the Southwestern United States is to irrigate level fields (level basins) from single or multiple outlets using 15 cfs or larger streams of water. The single outlet turnout is generally achieved with a manually operated jack-gate. An effort has been made to automate the jack-gates by Agricultural Research Service personnel in Ft. Collins and Phoenix. The technique needs to be evaluated under field conditions and modified if necessary. The multiple outlet scheme is generally accomplished using circular concrete pipe tapped into the side of the concrete lined ditch with water flow controlled by a slide gate on the inlet end of the pipe. Such systems have been automated previously by using a movable plate actuated against the outlet end of the concrete pipe. The system should be improved upon and its use demonstrated in the field.

In addition to emphasizing the relatively large stream turnout automation, future research and demonstrational studies should be aimed at the design of equipment for small farms. Much learned from the large turnout systems will be applicable to the small systems. In all cases, the techniques used must be simple in operation,

reliable, and economical. Further, installation procedures and maintenance requirements should be straightforward and within the capabilities of being done by the farm operator.

OBJECTIVES:

This study is part of an overall 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 automation schemes for surface water distribution systems in the Wellton-Mohawk area of Arizona,

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

WORK PLAN AND RESULTS:

Two fields were selected to complete the field installation, evaluation, and demonstration of the automated systems. A 65-acre field was automated on the Bob Woodhouse farm, on which single outlet jack-gates are used. Single jack-gates are located at the corners of each of eight level basins making up the 65 acres (Figure 1). Installation of the system was completed in May 1975. A 70-acre field was automated in November 1975 on the Jim Naquin farm on which multiple port outlets were the primary means of turning the water out. Sixteen-inch concrete pipe turnouts were used on either side of a centrally located concrete lined ditch to turn water into six level basins. A jack-gate was used to turn water out into a seventh level field while three other jack-gates were used as check gates in the supply ditch (Figure 2). All fields on either farm can be irrigated sequentially, when the irrigation is signalled to commence by the irrigator, or by an overflow float located in the canal on the Naquin farm.

Equipment for mechanizing the fields was designed and/or specified here at Phoenix with assistance from Harold Duke and M. L. Payne of Ft. Collins. The air cylinders used on the Woodhouse farm were patterned after a design by the ARS personnel in Ft. Collins and were

built here at the U. S. Water Conservation Laboratory shop while those used on the Naquin farm were purchased commercially. The fundamental operation and capability of each system was specified and developed here at the laboratory along with the construction of the required controllers and port closure devices. Concrete outlet structures were constructed for energy dissipation and erosion control for the concrete pipe outlets on fields 5 and 6 of the Naquin farm.

We are appreciative of the cooperation that Bob Woodhouse and Jim Naquin have given us during 1975. They have spent much time and effort in making their farms available for our use during development and field days--certainly inconveniencing them at times--and arranging for water from the Irrigation and Drainage District at our request. All aspects are most important for successful development and demonstration of automated equipment. Cooperation from the University of Arizona personnel stationed at Yuma, Arizona, was received during the installation of the systems in the field.

The fundamental means by which the two farms were automated can be illustrated by listing the basic components involved, the function of each, and the respective requirements.

(1) Gate or port actuation - pneumatic, both signal and operation, gate or port required to be normally open in case of air loss to system.

(2) Control center - air compressor, control panel, and timer.

   (a) Air compressor - supply air to system for actuation and control, requires 110 VAC.

   (b) Control panel - means by which certain repeatable functions are built into the system as well as capability of irrigators' selection of certain functions prior to irrigation start-up.

   (c) Timer - electrically driven (110 VAC), used to pneumatically actuate valves according to required time, time set prior to irrigation.

(3) Air lines - compressed air is supplied by the compressor located at the control center to the various gates and/or

port location by means of buried plastic tubing, either 1/8-inch or 3/16-inch ID (1/4- and 5/16-inch OD) polyethlylene. The tubing was buried to a depth of at least 2 1/2 ft along the toe of the canal invert.

(4) Safety overflow equipment - floats in the canal are used to mechanically actuate air valves which signal pneumatically to the control center when flow in the field canal is excessive. The signal is received at the control center and preselected field turnouts are opened.

(5) Field irrigation sequence - capable of any sequence desired by the operator and can be set at the control center.

(6) Excess water at end of irrigation - part of safety overflow circuitry but actuated by specific timer station rather than overflow floats.

The cost of materials and trenching required to convert the jack-gates from manual to automated operation on the Woodhouse farm was about $3300. These same costs on the port turnout conversion on Naquin's (less trenching) were about $4900. The trenching and general installation requirements for the port conversion were more extensive than those for the jack-gates. No information is available, however, on total installation costs. It should be noted that the equipment used on these two farms could feasibly satisfy the requirements for a much larger acreage depending on the particular irrigation layout.

SUMMARY AND CONCLUSIONS:

The automated system on the Woodhouse farm was successfully used for ten irrigations during 1975. A significant point was that the last eight irrigations were completed by the farmer and/or his irrigator without assistance from the developers/researchers.

The automated port system on the Naquin farm was used once during 1975. It is planned that someone from the U. S. Water Conservation Laboratory be present during use of the system until satisfied that operation is satisfactory, reliable, and that the cooperator is familiar with its use. Presently, the upper four fields on the

Naquin farm are in alfalfa and the lower three are in wheat which will generally necessitate separate irrigations until June 1976.

The performance of the automated systems will be evaluated and where necessary modified or redesigned to meet desired performance requirements. Results of this research will be disseminated in cooperation with the Extension Service by publications and meetings, the Soil Conservation Service, farm magazines, field-day demonstrations, and technical journals. The systems were demonstrated to visiting groups on several occasions (4-5 field days) during the summer and early fall of 1975 by U. S. Water Conservation Laboratory personnel. The systems were also visited on other occasions by personnel from the University of Arizona, Soil Conservation Service, Bureau of Reclamation, or Wellton-Mohawk Irrigation and Drainage District as well as individual farmers.

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

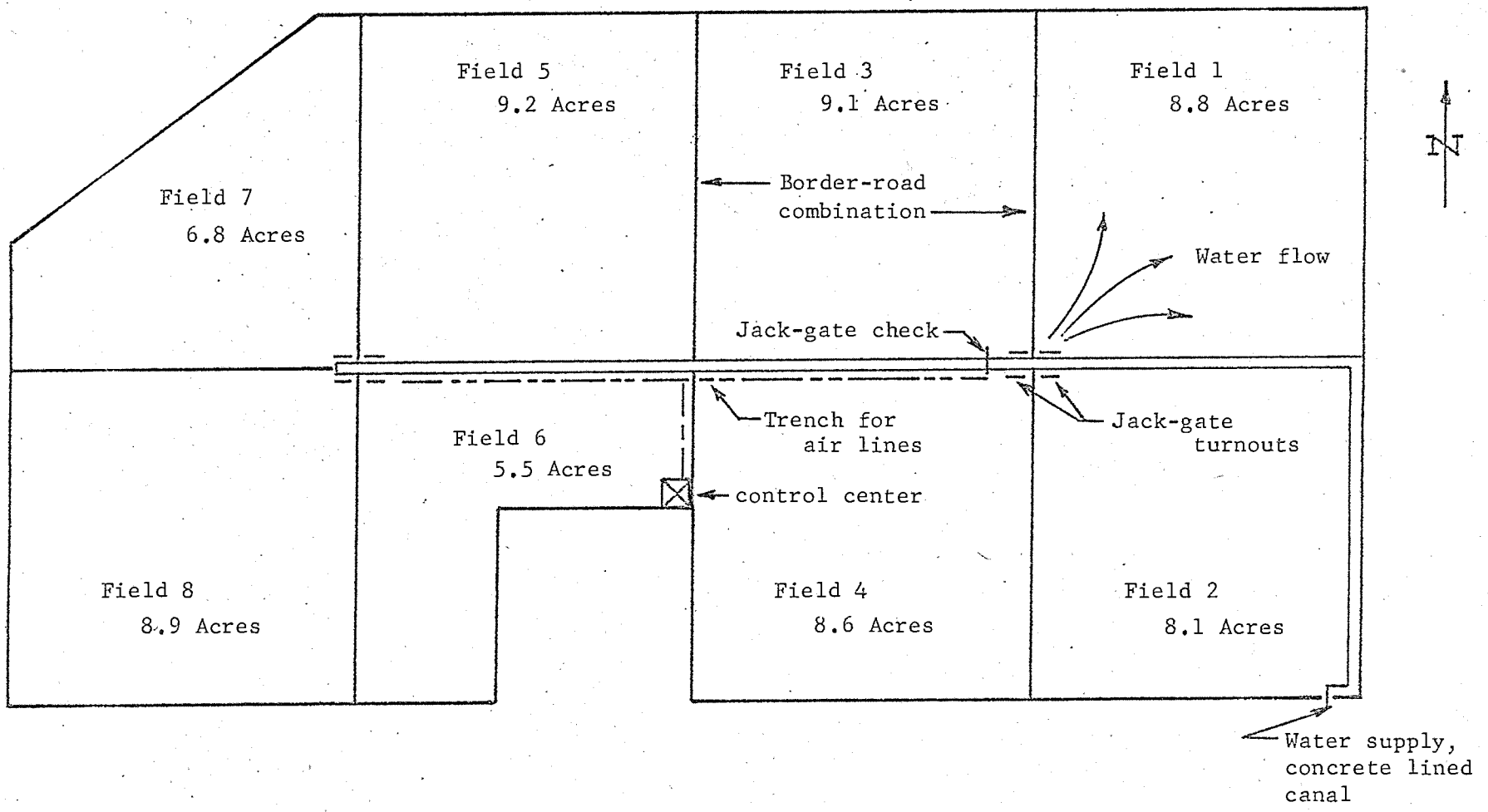

Figure 1. Field layout for automated irrigation demonstration on Woodhouse farm.

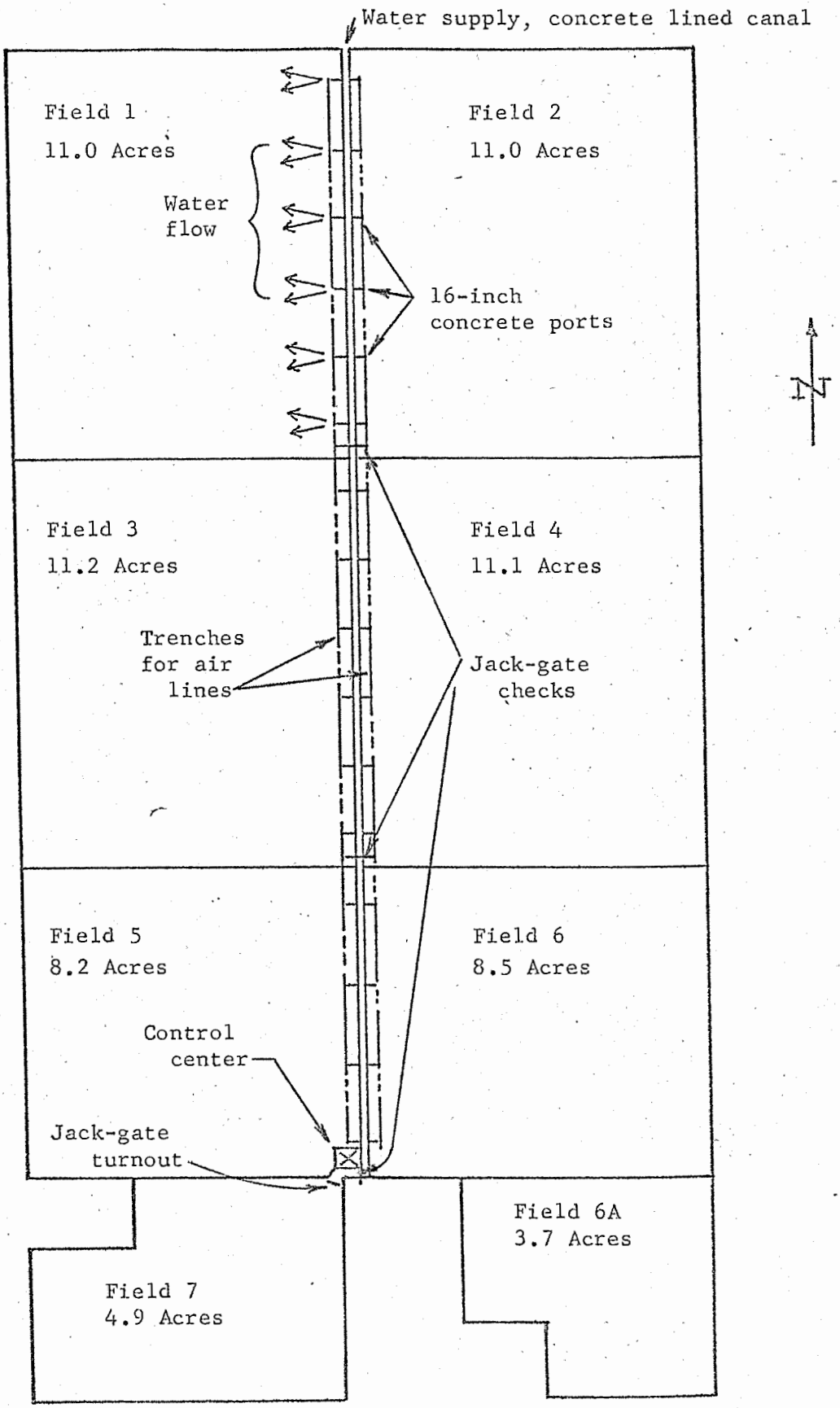

Figure 2. Field layout for automated irrigation demonstration on Naquin farm.

TITLE: TIME RATE MOVEMENT OF WATER FOR DEAD LEVEL IRRIGATION

CRIS WORK UNIT: 5510-12260-004 CODE NO.: USWCL 74-3

INTRODUCTION:

To reduce the quantity of salt water returned to the Lower Colorado River System near Yuma from the Wellton-Mohawk Irrigation Project for desalinization, the application efficiency of irrigation water in the Wellton-Mohawk Project must be improved. Improving the management of timing and the overall irrigation efficiency also decreases the amount of water pumped to the Wellton-Mohawk Project, and this decreases the salt load. Timing of irrigations and quantity of water per irrigation can be improved by Extension education, demonstration, and use of existing research knowledge.

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

A semblance of dead-level irrigation commenced about 1954. At that time, leveling payments would not be paid unless some slope, approximately 3 inches, remained in the overall length of run. Since that time, many farmers on their own initiative have eliminated the required slope, which has resulted in dead-level systems. This has proved so successful that over 50% of the valley lands in the Wellton-Mohawk Irrigation District are designed that way. The farmers' acceptance and positive action in developing their land in this manner is probably the best indication of its success. These successes compare very closely with results obtained in lower Texas by Ross and Swanson (4). Jensen and Howe (3) reported on nearly dead-level fields on sandy soils. They found high efficiencies (80% to 95%), utilizing border checks. In 1965, Dimick (2) reported on low-gradient borders in South Dakota on clay-type soils. Davis and Willhite (1) also reported on low-gradient slopes in Colorado. Most border studies did have some gradient, and generally large flows were not possible. The reported studies are not applicable to large

acreage, dead-level benches (up to 40 acres) and large stream potentials, such as used in the Wellton-Mohawk area. Perhaps the best criteria for design is associated with the systems that are already in and operating efficiently.

Information should be determined as to the actual water movement with time and differing field configurations, as related to various outlet locations and secondary ditches. This information will be a useful guide in designing and managing of dead-level irrigation systems.

OBJECTIVES:

(1) To determine the effects on time-rate-of-advance curves for dead-level irrigation that are caused by
   (a) Field configuration;
   (b) Stream size or application rate; and
   (c) Number and location of outlet structures.

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

RESEARCH APPROACH:

The studies will consist of making various time rates of advance from different types of outlets and sizes of streams of water. These will be conducted on farms near Blythe, CA, Parker, AZ, and on the Wellton-Mohawk project near Yuma, AZ. Supporting data will include infiltration measurements, soil moisture status, crop status, soil cultural status, and general soil types.

RESULTS AND DISCUSSION:

One rate-of-advance project was conducted on a very tight clay soil near Blythe, CA. A 40-acre, dead-level field of row crops was irrigated with a 34 cfs stream. Essentially, all the intake was involved with deep cracks and soaking of the plant bed. Intake potential (and thus potential water storage) was essentially complete when the water arrived at the lower end. For this case, the major question is how much water does it take to fill the cracks and partially sub the beds; then apply this quantity of water. Since this quantity

was impossible to determine by conventional methods, it was a matter of observing the rate of advance, then cutting the water off so that it just arrived at the end of the field with enough surplus to back up through any unirrigated furrows.

One rate-of-advance study was conducted on two 10-acre dead-level fields of very densely planted wheat. The crop was about 12 inches tall, irrigated from a three-point source across a 330 ft frontage on very tight silty soil, with a 15 cfs stream of water. This study was conducted on the farm of a very progressive farmer in the Wellton-Mohawk project near Tacna, AZ, who has been using dead-level irrigation for years. Final intake rates were less than .1 inches per hour, yet the farmer did not wish to change the set until water was out the end of the field. Since initial intake was also low after the cracks (2 inches deep) were filled, it meant that the farmer could irrigate strictly with a clock and not concern himself as to where the water had advanced, as long as he wished to apply a reasonable amount of water to this soil. Since the top soil was rather damp from a recent rain, a very small (2 inch) application could have been possible on a row crop.

SUMMARY AND CONCLUSIONS:

These two length-of-run studies point out the importance of management, even with dead-level irrigation, and with an operator who is progressive and well acquainted with the construction and cultivation phases. Once the proper information is available a teaching/extension program should be initiated. Additional run studies are planned.

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4. Ross, P. Earl, and Swanson, Norris P. Level irrigation. Jour. of Soil and Water Conserv. 12(5):209-214. September 1957.

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

APPENDIX I

LIST OF PUBLICATIONS PUBLISHED
AND MANUSCRIPTS PREPARED IN 1975

		MS No.
5510-12260-002	Water transfer in the soil-plant-atmosphere system as related to water conservation.	
Published:	Aase, J. K., and Idso, Sherwood B. Solar radiation interactions with mixed prairie rangeland in natural and denuded conditions. Arch. Met., Geoph., Biokl., Ser. B. 23(3):255-264. 1975.	490
	Ehrler, Wm. L. The porometer of van Bavel, Nakayama, and Ehrler. In Sect. 3.3 of "Measurement of Stomatal Aperture and Diffusive Resistance", E.T. Kanemasu, Editor. Bul. No. 809, College of Agric. Res. Ctr., Washington State U. June 1975. Pp. 15-17.	465
	Ehrler, Wm. L. Environmental and plant factors influencing transpiration of desert plants. In "Environmental Physiology of Desert Organisms", Neil F. Hadley, Ed. Amer. Inst. of Biol. Sci. 1975. Pp. 52-66.	493
	Foster, Joyce M., and Idso, Sherwood B. Light and assimilation number in a small desert recharged-groundwater pond. Oecologia 18(2):155-164. 1975.	407
	Idso, Sherwood B. Low-level aerosol effects on earth's surface energy balance. Tellus 27(3):318-320. 1975.	442
	Idso, Sherwood B. On the influence of surface albedo on the change in the atmospheric radiation balance due to aerosols. Atmos. Environ. 9:766-767. 1975.	502

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Idso, S. B., Aase, J. K., and Jackson, R. D. Net radiation--soil heat flux relations as influenced by soil water content variations. Boundary-Layer Meteorol. 9(1):113-122. August 1975. 499

Idso, Sherwood B., and Foster, Joyce M. An analytical study of three characteristic forms of light-forced primary production in aquatic ecosystems. Oecologia 18(2):145-154. 1975. 480

Idso, S. B., Jackson, R. D., and Reginato, R. J. Detection of soil moisture by remote surveillance. Amer. Sci. 63(5):549-557. 1975. 515

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Idso, S. B., Reginato, R. J., and Jackson, R. D. Assessing evaporation from bare soil via surface temperature measurements. In "Hydrology and Water Resources in Arizona and the Southwest - Vol. 5". (Univ. of Arizona Press). 1975. Pp. 199-205. 525

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Jackson, Ray D., and Idso, Sherwood B. Surface albedo and desertification. Science 189(4207): 1012-1013. Sept. 19, 1975. 504

MS No.

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