ANNUAL REPORT

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

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PERSONNEL

In 1972, the year of reorganization of the Agricultural Research Service, the Laboratory lost its Director, Mr. L. E. Myers, who left in August for Berkeley, California, to become Associate Deputy Administrator of the Western Region of ARS. Acting Director for the Laboratory is Dr. Herman Bouwer. At the end of 1972, Mr. K. G. Mullins, Physical Science Technician and Assistant to the Director, started to prepare for his transfer to the Management Services Division.

Dr. J. B. Robinson arrived at the Laboratory in September on a 6-month sabbatical leave from the University of Guelph, Ontario, Canada, to work on microbiological aspects of nitrogen transformations at the Flushing Meadows Project.

Dr. R. J. Reginato returned in June from his one-year educational leave at the University of California, Riverside. Mr. J. G. Brooks and Mr. R. G. Valdez worked at the Laboratory under the Stay-in-School Program, and Mr. M. L. Jones worked during the summer months under the Neighborhood Youth Program. Mr. O. J. Abeyta, custodian, resigned in April and was replaced by Mr. R. J. Gerard in August.

The Laboratory Staff is as follows:

O. J. Abeyta, Gardener (resigned April)
I. G. Barnett, Janitor
E. D. Bell, General Machinist
H. Bouwer, Research Hydraulic Engineer and Acting Director
J. G. Brooks, Physical Science Aid (Stay-in-School)
D. A. Bucks, Agricultural Engineer
K. R. Cooley, Research Hydrologist
E. E. DeLaRosa, Maintenance Worker
W. L. Ehrler, Research Plant Physiologist
L. J. Erie, Agricultural Engineer
E. D. Escarcega, Hydrologic Technician
D. H. Fink, Soil Scientist
B. E. Fisher, Library Technician
G. W. Frasier, Research Hydraulic Engineer
O. F. French, Agricultural Research Technician
R. J. Gerard, Janitor (employed August)
R. G. Gilbert, Soil Scientist
L. P. Girdley, Engineering Draftsman
J. R. Griggs, Physical Science Technician
C. G. Hiesel, General Machinist
S. B. Idso, Soil Scientist
R. D. Jackson, Research Physicist

M. L. Jones, Agricultural Aid (NYC)
B. A. Kimball, Soil Scientist
R. C. Klapper, Maintenance Worker Foreman
J. C. Lance, Soil Scientist
R. S. Linebarger, Hydrologic Technician
J. M. R. Martinez, Engineering Aid
H. L. Mastin, Physical Science Technician
J. B. Miller, Physical Science Technician
S. T. Mitchell, Physical Science Technician
A. H. Morse, Secretary
K. G. Mullins, Physical Science Technician
L. E. Myers, Research Hydraulic Engineer and Director (transferred August)
F. S. Nakayama, Research Chemist
M. E. Olson, Clerk-Stenographer
L. J. Orneside, Clerk-Stenographer
J. M. Pritchard, Physical Science Technician
B. A. Rasnick, Physical Science Technician
R. J. Reginato, Soil Scientist
J. A. Replogle, Research Hydraulic Engineer
R. C. Rice, Agricultural Engineer
M. S. Riggs, Laboratory Technician (Salt River Project
J. B. Robinson, Soil Microbiologist (visiting scientist)
M. A. Seiler, Clerk-Stenographer
R. G. Valdez, Mathematics Aid (Stay-in-School)
F. D. Whisler, Soil Scientist
M. F. Witcher, Clerk-Stenographer

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

CRIS WORK UNIT: SWC-018-gG-4 CODE NO.: Ariz.-WCL 65-2

INTRODUCTION:

Emphasis on work in Hawaii has been changed in direction and the priorities reordered. Water harvesting projects are near completion, except for continued observation of weathering characteristics of existing installations. The major research emphasis is being directed to rainfall-runoff and erosion studies and work on trickle irrigation. New outlines covering runoff erosion and trickle irrigation will be initiated in the near future.

PART I. WATER HARVESTING

Treatments and procedures at the Maui catchments remained the same as described in previous annual reports. Analysis has been completed for the rainfall-runoff results from the plots. Runoff results from Plot No. 4, natural grass, have been prepared in a manuscript for publication. The results from the other three plots proved unreliable for a variety of reasons. Some of these faults remained undetected until belated analysis of the data. Plot No. 1, covered with Hypolon, had developed a seam failure at the lower end of the plot that would not remain sealed, so the data collected was unreliable, as expected. Not expected, however, was the undetected leak caused by failure of the sealing compound holding the butyl sheeting on Plot No. 2 to the flow-metering flume. This was not detected until questionable results initiated a close inspection for possible flow loss. Likewise, the unreasonable results of too much runoff, often exceeding 100% on Plot No. 3, asphalt pavement--asphalt fiberglass was caused by entry of water from outside the plot boundaries at high precipitation rates. The initial efforts to isolate the plots appeared adequate, but subsequent vegetation growth in the top side diversions reduced flow enough to cause overflooding into the treated area. This was not observed until February 1972.

As of 1 December 1972, measurements of rainfall and runoff at the Maui site were stopped. Observations of material weathering performance will be maintained. The asphalt-fiberglass plot and the butyl plot are considered in excellent condition. The Hypolon is stretched very tightly and some seams are starting to fail.

RESULTS: WATER HARVESTING

A summary of the results from the manuscript on the grassed area of the Maui plots follows:

Precipitation runoff from a grassed surface in Hawaii was found to yield 23% runoff from 2260 mm (89 inches) average annual rainfall. Studies on a small plot where water losses in channels were minimized showed the runoff was greatest during the winter months. Runoff measurements for a 39-month period from individual storms showed that an average of 2 mm of precipitation is required before runoff occurs. After runoff has started, approximately 49% of any additional precipitation will run off.

Rainfall measurements showed that many of the rainfall events occur as small showers of low intensity, approximately 40% of the total precipitation occurs as storms of less than 6 mm, and 55% comes in storms with a rainfall intensity less than 6 mm per hr. The fact of small rainfall events, low runoff efficiency and high runoff threshold can account for the relatively low total runoff efficiency. The potential water supplies are very high if low-cost means of collecting the small rain showers can be developed.

PART II. RAINFALL-RUNOFF-EROSION STUDIES

The shift in emphasis on studies in Hawaii can perhaps be understood better in the light of a brief history prepared in August 1972 by L. E. Myers after approximately a 2-month study tour in Hawaii. This history and his findings have been updated for this writing (March 1973), and are reproduced here in condensed form as follows:

History:

Prior to 1966 a number of investigators from the Soil and Water Conservation Research Division had visited Hawaii and had written reports describing urgent problems. Following a visit to Hawaii in late 1965, Mr. Myers decided that the USWCL (U. S. Water Conservation Laboratory) should initiate water harvesting research in that state to extend our findings to high rainfall areas and to demonstrate ARS interest in their problems. The Administrator, ARS, concurred. Through the combined efforts of a number of cooperators, experimental installations were made on the Islands of Hawaii and Maui in June 1966. They are still being maintained by cooperators and ARS. (The cooperator contact is Robert Warzecha, Hawaiian Commercial and Sugar Company.)

During April 1971 the Administrator, ARS, made reserve funds in the amount of $33,355 available to USWCL for work in Hawaii. In consultation with SCS, five fields of pineapple and sugar cane were instrumented to obtain data on rainfall, runoff, and erosion. The fields ranged in size from 2-6 acres. Three sites were selected on Oahu and two on Hawaii. Recording rain gages and water-stage recorders were purchased. Water-measuring flumes were designed, prefabricated, air freighted to Hawaii, and installed in June 1971. We learned that satisfactory devices for sediment measurement were not available and it became necessary to initiate research at the USWCL to design, calibrate, and construct the required devices. Installation was made in December 1973. (The SCS, which has maintained the rain gages, water-stage recorders, and measuring flumes, is completing the process of turning the responsibility over to the University of Hawaii under the terms of a cooperative agreement.)

Beginning in FY 1972, Senator Fong of Hawaii obtained a $100,000 annual appropriation, to continue for 5 years, for soil and water research in Hawaii. These funds were not sufficient to establish an independent SWC unit in Hawaii. The funds were allocated to the USWCL to continue and expand research on runoff and erosion, efficient irrigation systems, and waste-water renovation in Hawaii. ARS personnel could not be immediately transferred to Hawaii so arrangements were made with the Agricultural Experiment Station, University of Hawaii to establish a cooperative research program with active participation by University staff members. Cooperative Agreement No. 12-14-100 11, 173(41), between ARS and the Hawaii Agricultural Experiment Station was signed on 15 March 1972. Under the agreement, the University of Hawaii will be reimbursed up to $30,000 per year, renewable annually, if mutually agreeable by both parties. Dr. Samir A. El-Swaify was appointed as a collaborator to represent SWC. A collaborator's appointment has been processed for Dr. Edgar W. Dangler who will conduct much of the field and laboratory work during the sabbatical leave of Dr. El-Swaify, January-December 1973.

Dr. El-Swaify has prepared a detailed research outline on "Erosion of Tropical Soils" to cover the initial stages of our cooperative work. The objectives as he lists them are:

1. Compare the rainfall, runoff, and erosional characteristics of selected Hawaiian soils under natural and artificial rainfall conditions.
2. Identify those properties which are most related to the erodibility of tropical soils for the purposes of evaluating current predictive capabilities, and also establishing future predictions of soil loss. More specifically to evaluate the applicability of "Soil-Loss Equation" to tropical soils.

3. Investigate interrelationships involving the yield, transport, and recovery of sediments produced by erosion.

At the request of SCS, Walter Wischmeier was asked to inspect Hawaii erosion problems and did this the last of April 1972. His report, received the last week in May, recommended shipping a rainulator from Watkinsville, Georgia, to Hawaii to obtain data needed to allow use of the "Universal Soil Loss Equation" for erosion control design in Hawaii. The Director, SWC, made arrangements for this to be done in June 1972. Arrangements were also made for a crew from Watkinsville to operate the machine in Hawaii for a month beginning in July 1972. The Laboratory was not a party to these arrangements.

Early in 1972 Mr. Lloyd Myers was given approximately a 2-month assignment in Hawaii, beginning 7 June 1972, to obtain information useful in planning our future research efforts. Upon his arrival he found that all other planned activities had been overshadowed by the pending arrival of the rainulator. No one in Hawaii, including Mr. Myers, had realized the magnitude of logistical problems associated with the operation of the rainulator. Actually, two machines were involved to cover plots 12 x 35 and 12 x 75 ft in size. They are large, complicated, difficult to assemble and disassemble, and require large trucks for moving. They also require at least a four-man field crew, large volumes of water, farming equipment for plot preparation, and a two-man laboratory crew to analyze the hundreds of water and sediment samples generated. In addition, there are many measurements necessary on the plots before the rainulators are operated. Assistance was ultimately received from A. P. Barnett and a crew from SCS of Watkinsville, Georgia. The logistical problems have been solved by University of Hawaii, SCS, and ARS personnel, the rainulator studies are in progress and should be completed in April 1973. Mr. Myers agreed to commit funds for Dr. El-Swaify to hire a crew for the Watkinsville group to train to run the rainulator after their return to Watkinsville. The 1-month effort by the Watkinsville crew and the University continuation should provide data from at least 12 sites.

Major Findings of the June-July Study Tour:

1. Erosion and sediment pollution are unquestionably the most urgent soil and water research problems in Hawaii.
2. The future of the sugar cane industry will be in jeopardy if problems in trickle irrigation, erosion control and mill waste disposal are not solved within the next 2 or 3 years. Three plantations have recently gone out of production.
3. Disposal of wastes from dairies, hog farms, chicken ranches, and cattle feed lots is expected to become a large and critical problem within the next 10 years. These operations will increase as sugar cane and pineapple lands are diverted to sorghum production.
4. Soil and water problems such as seepage reduction, water harvesting and supplemental irrigation are still important to Hawaii, but are now given lower priority than they had 5 years ago.
5. The present state government appears to believe that Hawaii's future lies in tourism and that most of the required agricultural products should be imported. This could have serious implications for the future of agricultural research in Hawaii.

Mr. Myers concluded that research priorities should be as follows:

1. First priority should be given to studies of rainfall, runoff, and erosion. There is an urgent need for reliable data for solving problems in erosion, sediment pollution, and flood control.

a. Rainulator studies on small plots on representative soil types should be continued for 4 months by ARS, the University of Hawaii, and SCS. Data should then be analyzed and reviewed before deciding if additional ARS funds can be justified for this project. If SCS and EPA wish to finance the field work beyond 4 months, we should have no objections if it does not damage our other research.

b. The five large field plots should be instrumented as soon as possible to measure sediment as well as rainfall and water runoff. Careful and continuous maintenance of instruments must be performed to insure obtaining accurate data. These plots will obtain the most reliable data we will have on erosion from pineapple and sugar cane fields and the effect of various stages of crop cover. These data will be needed to confirm or to adjust data obtained with the rainulators.

c. Laboratory studies of soil characteristics associated with erodibility should be initiated. Laboratory findings will be correlated with rainulator and large field plot data. Although this work will be delayed by demands of the rainulator field work, Dr. El-Swaify should be encouraged to initiate some laboratory studies before he leaves on a 6- to 12-month sabbatical in February 1973.

2. Second priority should be given to assisting the sugar cane plantations with the design and evaluation of trickle irrigation systems. A number of plantations will go out of business if these systems are not successful. Work on clogging and hydraulic design at the USWCL can be of

value. An ARS engineer working on trickle systems should consult with the Hawaiian Sugar Planters' Association to coordinate ARS research with extensive investigations being conducted by the plantations.

3. An ARS technician, experienced in runoff, erosion, and water management field work and preliminary data analysis with a desk-type computer, should be transferred to Hawaii as soon as possible. Such competence is badly needed for the existing studies and is not available to the Hawaii Agricultural Experiment Station.
4. Consideration should be given to research on disposal of waste water from sugar mills, sewage treatment plants, dairies, and hog farms, and on land disposal of wastes from cattle feed lots and sewage treatment plants. Initiation of any sizeable research projects of this nature will require additional funding. However, it is recommended that a team of ARS experts visit Hawaii to explore the urgency and feasibility of such research.
5. Research on lower priority problems, such as water harvesting and seepage control, should be conducted as opportunities for cooperative projects arise. These should be joint projects between ARS scientists at mainland locations and investigators located in Hawaii with the University or other investigative agencies. The objective should be to extend mainland research to solve problems in Hawaii.

RESULTS AND DISCUSSION, RAINFALL-RUNOFF-EROSION:

Instrumentation of the five small watersheds was completed in December 1972. Following is a brief chronological history of the instrumentation phase of the study.

1. April-May 1971 - Selection of sites. Two of the sites are on sugar cane in a 100-200-inch rainfall zone on the Island of Hawaii. The other three sites are on the island of Oahu, two pineapple and one sugar cane in an approximately 100-inch rainfall zone.
2. June 1971 - Installation of critical-depth measuring flumes with assistance of Soil Conservation Service personnel.
3. February 1972 - Installation of weighing raingages and water-stage recorders at each site with assistance of Soil Conservation personnel.
4. December 1972 - Installation of sediment samplers and flume modifications at each site with assistance of University of Hawaii and Soil Conservation Service personnel.

Also during December 1972 the site survey of the size of each watershed was completed. Following are the location and size of each area.

1. Laupahoehoe - 2.12 acres, sugar cane, Island of Hawaii, Laupahoehoe Homesteads, Lot 16, Laupahoehoe Sugar Co.
2. Honokaa - 5.34 acres, sugar cane, Island of Hawaii, Field 11, Honokaa Sugar Co.
3. Waialua Sugar - 6.20 acres, sugar cane, Island of Oahu, Waialua Sugar Co., Field No. 24B, Haleiwa Quad. 21°35'45" North by 158°02'15" West. (Old Site No. 3).
4. Waialua Pineapple - 1.97 acres, pineapple, Island of Oahu, Dole Pineapple Co., Field No. 4707, Haleiwa Quad. 21°35'58" North by 158°02'09" West. (Old Site No. 2).
5. Mililani - 5.16 acres, pineapple (temporarily fallow) Island of Oahu. Dole Pineapple Co. Near inlet to siphon across Kipapa stream, Mauka of Waiahole Ditch, Waipahu Quad 21°27'13" North by 157°59'51" West. (Old Site No. 1).

Inspection trips to the sites by Laboratory personnel after the original flume installation, 1971, revealed that the flumes were being plugged with sediment from the watershed areas. Some runoff events would deposit up to 3 inches of sediment in the flume entrance. This necessitated the construction of a flume modification which would maintain higher water velocities and hopefully move the sediment through the flumes. The modification consisted of an insert, constructed at the Laboratory and shipped to Hawaii. This modification changed the flume entrance from 3-ft to 1-ft bottom width and the throat section from a 1-ft trapezoid to a V-notch. The entrance section was also raised 0.1 ft above the throat elevation. To permit spreading of the flow for sediment sampling, a 3-ft-long, 1-ft-wide trapezoid extension was added to the flume.

The sediment samplers for each site consist of 9 splitters 4 ft long, spaced 5 inches apart with a 1/8-inch slot at the top constructed for 1/16-inch thick stainless steel sheet metal. The splitters sample 2.5% of the total flow. Water from the splitters is collected and 1.067% of this flow is sampled by two slots in a rotary sampler and stored in a 32-gal plastic container.

Originally, the raingages and water-stage recorders were serviced at monthly intervals by Soil Conservation Service personnel. After installation of the sediment samplers, servicing and maintenance at the sites is being performed by University of Hawaii personnel.

A translater has been purchased which is being used to convert the raingage and water-stage recorder data to punched tape for processing by computer. Data analysis has been started and, hopefully, the backlog will be completed by July 1973.

SUMMARY AND CONCLUSIONS:

Water harvesting studies have been completed except for periodic weathering observations on present installations.

Precipitation runoff from a grassed surface in Hawaii was found to yield 23% runoff from 2260 mm (89 inches) average annual rainfall. Studies on a small plot where water losses from channel losses were minimized showed the runoff was greatest during the winter months. Runoff measurements for a 39-month period from individual storms showed that an average of 2 mm of precipitation is required before runoff occurs. After runoff has started, approximately 49% of any additional precipitation will run off.

Many of the rainfall events occur as small showers of low intensity. Approximately 40% of the total precipitation occurs as storms of less than 6 mm, and 55% comes in storms with a rainfall intensity less than 6 mm per hour. Small rainfall events and high runoff threshold can account for the relatively low total runoff efficiency. The potential water supplies are very high if low-cost means of collecting the small rain showers can be developed.

Emphasis is being redirected toward rainfall-runoff and erosion relationships which appear to be the most urgent soil and water research problems in Hawaii. A second emphasis is developing in the area of trickle-irrigation research. A short-range objective of the latter is to reduce plugging of emitters on trickle irrigation systems now finding extensive use on the sugar cane plantations.

The five watersheds for the rainfall-runoff-erosion studies have been instrumented and are being serviced by University of Hawaii personnel under a cooperative agreement. The watersheds have been surveyed by the Soil Conservation Service. They range in size from 2 to 6 acres. Data analysis of rainfall runoff from the sites has been started by USWCL personnel. To date, the siltation problem appears to have been solved by the modified flumes.

PERSONNEL: G. W. Frasier, J. A. Replogle, L. E. Myers, and J. R. Griggs

CURRENT TERMINATION DATE: 1972

TITLE: PHYSICAL AND CHEMICAL CHARACTERISTICS OF HYDROPHOBIC SOILS

CRIS WORK UNIT: SWC-018-gG4 CODE NO.: Ariz.-WCL-67-2

Rangelands of the arid West have traditionally been a major supplier of food and fiber to consumer markets. The livestock-carrying capacity of these rangelands often is limited not so much by the shortage of graze as by a shortage of drinking water. Streams in this area often are ephemeral, and storage facilities to concentrate the precipitation runoff often go dry each year--not because of lack of rainfall but because of the low runoff characteristics of the contributing watershed. A cheaper, reliable water source is needed, and water harvesting offers promise of being that source.

Research at this laboratory showed that common paraffin wax could be used to effectively reduce evaporation from water storage tanks. The solid wax was floated onto the tanks and allowed to melt and spread in the sun until it formed a completely solid, floating cover. It was postulated that these waxes similarly might be used for water harvesting by spreading ground or powdered wax onto soil to render the surface water-repellent.

Two experimental plots were selected at the Granite Reef experimental site: one 10-m^2 and the other a 200-m^2 ridge and furrow plot. The 10-m^2 plot was treated on June 29, 1972 at a rate of 1.35 lbs/yd^2 of 143-150 F melting point wax, and the 200-m^2 plot was treated on September 29, 1972 at a rate of 1.25 lbs/yd^2 of 128-130 F melting point wax. Most of the ground wax melted on the hot soil surface within a couple days, resulting in a water-repellent soil. Runoff was collected in tanks and measured at the end of each storm. Results from the wax plots were compared to those from adjacent untreated plots and to a butyl-sheet cover plot.

Total precipitation at the test site for the 6-month period commencing in July was about 50% above normal. Table 1 shows that the 10-m^2 plot received 8.48 inches from 15 storms and the 200-m^2 plot 7.73 inches from 12 storms. Runoff from the wax plots averaged about 90% of the total precipitation, while that from the untreated plots averaged only about 30%. Four rains ranging from 0.08 to 0.21 inch and totaling 0.53 inch produced no runoff at all from the untreated plot, yet produced 0.44 inch or 82% runoff from the wax plot. As expected, the butyl-covered plot yielded approximately 100% runoff; however, the wax plots yielded 92% as well as the butyl.

Some other favorable characteristics of the wax plots are: (1) weeds were eliminated because of the sustained loss of subsoil moisture; (2) quality of the runoff water was very good because of low salt content, low sediment content and absence of toxic organic residue; (3) potential costs of harvested water are low because of low material costs (10¢ to 15¢ per yd^2 for wax compared to $2.00 to $3.00 per yd^2 for butyl rubber).

The plots will continue to undergo testing to evaluate long-term durability. Also, additional plots are planned to check on minimal effective application rates of wax. A machine is being developed to spread the wax. The technique seems especially well adapted for the rancher who needs additional water supplies in remote areas, and who does not wish to invest a large amount of money in supplies or equipment. Hopefully, with slight additional purification, the water from these paraffin plots even will be completely safe for human consumption.

PERSONNEL: Dwayne H. Fink

CURRENT TERMINATION DATE: December 1972

Table 1. Precipitation runoff yields (%) of wax-treated soil vs. untreated and butyl-covered soil.

Date (1972)	Precip. (inch)	Runoff (%)					
		10-m^2 plots				200-m^2 plots	
		Wax	Untreated	Butyl	Wax/Butyl	Wax[1]	Untreated[2]
Jul 17	0.44	90	20	94	96		
Aug 12	0.21	98	0	100	98		
Sep 2	0.10	76	0	80	95		
Oct 4	1.00	89	31	101	88	84	32
Oct 5	0.30	99	33	89	111	78	41
Oct 5	0.14	71	0	86	82	54	0
Oct 6	1.30	97	41	104	93	93	41
Oct 18	1.44	94	35	98	96	89	35
Oct 19	0.31	90	27	98	92	91	22
Oct 25	0.08	69	0	89	78	87	0
Nov 11	0.81	94	31	104	91	91	41
Nov 17	0.54	92	32	99	93	98	33
Dec 8	0.35	82	8	99	82	95	20
Dec 28	1.30	95	21	100	95	96	21
Dec 28	0.16	85	32	100	85	80	19
Total yield %		92	28	100	92	90	31
(inches)	8.48[3]	7.80	2.63	8.48			
"	7.73[4]					6.96	2.40

1 Actual area 197.4 m^2.

2 Actual area 194.5 m^2.

3 Accumulated rainfall on 10-m^2 plots.

4 Accumulated rainfall on 200-m^2 plots.

TITLE: WASTE-WATER RENOVATION BY SPREADING TREATED SEWAGE FOR GROUND-WATER RECHARGE

CRIS WORK UNIT: SWC-018-gG-4 CODE NO.: Ariz.-WCL 67-4

INTRODUCTION:

The year of 1972 was the fifth full year of operation of the Flushing Meadows Project, which is an experimental project for renovating secondary sewage effluent by ground-water recharge with infiltration basins. The project is located in the Salt River bed about 1 1/2 miles downstream (west) from the 91st Avenue Phoenix Sewage Treatment Plant. The project was constructed in 1967 and the basins have been inundated according to various flooding and drying schedules since September 1967.

The excellent cooperation with the Salt River Project, which received a grant from the Environmental Protection Agency for partial support of the project, was continued in 1972. The grant terminated in December 1969, at which time the financial support for the laboratory technician was assumed by the Salt River Project.

The operation of the basins in 1972 was aimed at determining the effectiveness of "rejuvenating" the soil profile for nitrogen removal. This rejuvenation was done by using short, frequent flooding periods for basins 1, 2, 5, and 6 (Figure 1) in 1971. In 1972, these basins were flooded with long periods to determine if the low ammonium levels in the renovated water would continue. Short flooding periods were used for basins 3 and 4 in 1972, and sudangrass was grown in these basins to see if the ammonium levels in the renovated water below basins 3 and 4 could be reduced. In November and December, long flooding periods were used for all basins in connection with a detailed study of the chemistry and microbiology of nitrogen transformations in the upper 3 ft of the soil profile (see Annual Report by R. G. Gilbert).

To facilitate orderly presentation of the results, the report is divided into three sections:

I. Infiltration studies.

II. Water quality studies.

III. Future projects.

I. INFILTRATION STUDIES

1. Recharge Basin Management.

A plan of the Flushing Meadows Project showing infiltration basins, observation wells, and experimental ponds, is shown in Figure 1.

The condition of the basins at the start of 1972 was as follows:

Basin 1. Bare soil.

Basin 2. Gravel layer.

Basin 3. Essentially bare soil with some bermudagrass, especially along sides.

Basin 4. As basin 3.

Basin 5. Dead grass, mainly bermuda and sprangletop.

Basin 6. As basin 5.

On 4 April 1972, basins 3 and 4 were "shaved" with a front-end loader to remove sludge flakes that had accumulated during the winter and spring. On 11 May, basins 3 and 4 were shaved, harrowed, and seeded with sudangrass (variety Monarch). A good stand of sudangrass was obtained. From 11 May, the water depth in basins 3 and 4 was about 6 inches, while the other basins were continued to be flooded at a water depth of about 12 inches. In August 1972, basin 1 was in bare soil, basin 2 had a gravel layer, basins 3 and 4 had a mature stand of sudangrass, and basins 5 and 6 had dead grass. The sudangrass was not harvested, so that at the end of 1972, basins 3 and 4 had a dead sudangrass cover, and the other basins were as in August, with more bare soil areas appearing in basins 5 and 6. In November, the effluent started its usual winter quality deterioration. The increased suspended solids content gave it a gray appearance and sludge started to accumulate in the basins, especially in the upper one-third.

2. Infiltration Rates.

The infiltration rates again were fairly uniform over the year and good recovery in the infiltration rates was generally obtained during drying, especially during the long dry periods (Figure 2). The cleaning of basins 3 and 4 on 4 April yielded good infiltration recovery, as did the extended dry periods from 26 July to 19 September for basins 1, 2, 5, and 6. Basin 1 was kept dry in October in preparation for the detailed studies on nitrogen transformation. On 21 October, the effluent stream contained considerable sediment due to heavy rainfall and resulting runoff and erosion in the valley. Silt-laden effluent entered the basins for about 24 hours. The deposition of sediment in the basins apparently did not have an appreciable effect on subsequent infiltration rates. For some flooding periods, accurate infiltration data could not be obtained because of recorder failure or lack of outflow. These periods are indicated with a question mark in Figure 2. The overflow structures in the basins were set at 12 inches, which yielded a water depth of around 13 inches. Basins 3 and 4 were operated at a depth of about 6 inches after the sudangrass was seeded.

The accumulated infiltration amounts for 1972 are shown in Figure 3. The average for all basins is 250 ft. Basins 3 and 4 are on the low side because of the lower water depth after the planting of sudangrass and the mainly short, frequent inundations that were held from May through October. The other basins had higher infiltration amounts, except basin 1, which was dry in October while the others were flooded. The high infiltration in basin 2 is of interest, since the gravel cover had previously always yielded the lowest infiltration amounts.

Adding 30 ft to the annual infiltration amount for basin 1 to correct for the dry-up in October, thus making the schedule comparable to that of the other basins, the infiltration amounts for basins 1, 2, 5, and 6 were compared to the bench-mark or potential infiltration rates when these basins were first flooded, to yield the following indexes of relative infiltration.

Basin	Accumulated infiltration 1972 ft/yr	Bench-mark infiltration 1967 ft/day	Accumulated infiltration / Bench-mark infiltration	Index of relative infiltration
1	200	3.2	62.5	75
2	325	4.0	81.2	97
5	325	3.9	83.4	100
6	258	3.1	83.3	100

The last column shows that basins 2, 5, and 6 were yielding similar infiltration rates in relation to their soil permeability, but basin 1 yielded lower infiltration. Drying and cleaning of the basins to remove accumulated sludge are needed.

The flooding period in April was used to measure the response of the water level in ECW to infiltration. The usual rise to a pseudo-equilibrium level was observed, in this case from -3.2 ft to -1.5 ft local BM. The average infiltration rate while the water level in ECW was at pseudo-equilibrium was 1.95 ft/day. The resulting water-level rise per unit infiltration rate is thus 1.70/1.95 = 0.87. This is higher than the value of 0.73 obtained in December 1970 and would indicate an approximately 20% decrease in the hydraulic conductivity of the aquifer. However, the figure of 0.87 was obtained in the spring when the suspended solids content of the effluent was still high. These solids settled on the soil surface in the upper 1/3 or so of the basins, causing the infiltration rates in the center portion of the basins, which have a dominant effect on the water-level rise in ECW, to be higher than the average rate for the entire basins. The resulting figure of 0.87 for the water-level rise per unit infiltration rate may, therefore, be too high and the measurements should be repeated in the summer or fall when the suspended solids content of the effluent is low, as was done in previous years.

The static water table in the spring of 1972 was 2 ft lower than in December 1970.

3. Pond Seepage Studies.

The seepage measurements in the unlined ponds receiving renovated sewage water from the East Well were discontinued in 1972, partly because of a pump failure, and partly because the seepage had pretty well stabilized at the 0.1-0.4 ft/day level.

The permanent-effluent pond was filled again after having been dry in 1971 and the first part of 1972 due to a pump failure. The seepage rates were generally at the 0.1 ft/day level, with increased rates occurring in the fall (Figure 4). The water depth in the pond is about 4 ft, so that the seepage at the 1-ft depth would be about 0.1 ft/day. This is much less than the seepage in the recharge basins at 1-ft depth, where flooding periods are rotated with drying periods to maintain high infiltration rates.

II. WATER QUALITY STUDIES

1. Sampling Observation Wells, and Analytical Techniques.

Sampling schedules, observation wells, and analytical techniques are the same as described in Annual Report 1971.

2. Total Organic Carbon.

The TOC-content of the sewage effluent was generally in the 20-30 ppm range for the winter and spring period. In the summer and fall, the effluent was of better quality and the TOC-content was in the 10-20 ppm range (Figure 5). The TOC-content of the renovated water from ECW was usually in the 2-7 ppm range except for two peaks in the 10-15 ppm range which seemed to occur after the extended dry periods in March, April and August. These peaks could be due to a decrease in bacterial activity in the soil during extended drying. The TOC-content of the renovated water from the outlying wells (1, 7, and EW) averaged 4.7 ppm (Table 1). Native ground water (WCW, 8, and 91st Ave.) had an average TOC-content of 3.6 ppm (Table 1).

3. Nitrogen.

The total nitrogen content of the secondary sewage effluent was generally in the 30-40 ppm range (Figure 6). The summer "dip" of the effluent nitrogen content was not as pronounced as in prior years.

The NH_4-N level of the renovated water from ECW was high at the beginning of the year (Figure 6), due to several years of long flooding periods for basins 3 and 4. After planting sudangrass in basins 3 and 4 on 11 May and subsequent use of short flooding periods, the NH_4-N level for ECW started to decline and reached about 6 ppm in December (Figure 6).

The NO_3-N concentration in the renovated water from the ECW showed the characteristic peaks and low values in January, February, and March (Figure 6). No nitrate analyses were performed in April because water level determinations in ECW made sampling undesirable. There was probably another NO_3-N peak in April, however, due to the 10-24 April flooding. Since only small, frequent amounts of sewage were applied to basins 3 and 4 in May, June, and July, the nitrate peaks in June and July are probably due to water that arrived from basins 1 and 2, and 5 and 6, during the long flooding periods in these basins in June and July. In August, the nitrate level in the renovated water below basins 3 and 4 started to increase, indicating nitrification of ammonium in the soil and leaching of the nitrates to the ground water. The nitrate release was not great, and less than beneath the non-vegetated basins 1 and 2 in 1971 when short, frequent floodings were used for those basins. This shows again that vegetation may have a stimulating effect on denitrification in the soil. In November and December, the NO_3-N content of the renovated water from ECW again showed the characteristic peaks and low values for the long flooding periods in these months.

Samples of the sudangrass were taken on 23 August and analyzed for total nitrogen content. The above-ground plant parts yielded 6.5 tons of dry matter per acre, which contained 174 lbs of N per acre for basin 3 and 211 lbs of N per acre for basin 4. This is small compared to the total nitrogen loading, which in 1972 averaged about 20,000 lbs per acre for basins 3 and 4.

Short flooding periods were used for basins 1, 2, 5, and 6 for the first three months of 1972 as a continuation of the short periods used in 1971 to lower the NH_4-N content of the renovated water. The NH_4-N content of the renovated water for these months was in the 6-10 ppm range below basins 1 and 2 (well 1-2, Figure 7) and in the 4-7 ppm range below basins 5 and 6 (well 5-6, Figure 8). The NO_3-N levels in the renovated water for the first 3 months of 1972 were slightly higher below basins 5 and 6 than below basins 1 and 2. For all four basins, the total nitrogen in the renovated water was about the same as that in the effluent for the first 3 months. The long flooding and drying periods in April, June, and July yielded the characteristic peaks and low values of the nitrate nitrogen in the renovated water (Figure 7 and 8). The NH_4-N concentration remained low below basins 5 and 6 (Figure 8), but increased to about 25 ppm below basins 1 and 2 during the long flooding period of June. The NH_4-N level in the renovated water from well 1-2 then decreased again to about 4 ppm in November but increased somewhat during the long flooding period of November. It then increased appreciably during the very long flooding period of December. This flooding period also caused a rise in the NH_4-N level for well 5-6, which had remained below 5 ppm for most of the year.

The renovated water from wells 1-2 and 5-6 both showed an increase in the NO_3-N content starting at the end of September and continuing through October. This release of nitrates was probably due to the almost 2-month dry period from 26 July to 19 September, which must have produced intensive nitrification of stored ammonium in the soil. The broad nature of the NO_3-peaks in October is due to the use of short flooding periods, which gave rather small amounts of infiltration and caused high-nitrate renovated water to "linger" around the intake of the wells. When long flooding was resumed in November, the high-nitrate water was replaced and low nitrate levels were observed in the renovated water.

The nitrogen levels in the renovated water from wells 1-2 and 5-6 indicate that the low NH_4-N levels obtained in 1971 by using short, frequent flooding periods could be maintained in 1972. The long flooding periods in basins 1 and 2 in June and December showed, however, that the NH_4-N levels in the renovated water can easily increase again, which demonstrates the need for careful scheduling of flooding and drying cycles to minimize the ammonium content in the renovated water.

Renovated water from the outlying wells (wells 1, 7, and EW) had average NO_3-N concentrations in the 4-6 ppm range (Table 2). Occasional high-nitrate levels, such as for well 7 (Table 2), are the result of a sequence of short flooding periods or they indicate the arrival of nitrate peaks when long flooding periods are used. The native ground water, as yielded by wells 8, WCW, and 91st Ave. contained little or no nitrate nitrogen (Table 2). The NH_4-N concentration in the renovated water from the outlying wells was around 3 ppm for wells 1 and 7, and about 7 ppm for EW (Table 3). Low ammonium levels were observed in the native ground water (Table 3).

4. Phosphates.

The PO_4-P concentration in the secondary effluents was around 10 ppm (Figure 9). The PO_4-P content of the renovated water from the wells inside the basin area averaged about 5 ppm, but showed considerable variations which are difficult to explain. The phosphate removal for the wells inside the basin area was about the same as in previous years. The renovated water from the outlying wells 1 and 7 contained about 1-2 ppm PO_4-P, except for a few higher values for well 7 in the summer. The average PO_4-P concentration for the EW was 4 ppm (Table 4), whereas the native ground water (well 8 in Figure 10, and WCW and 91st Ave. well in Table 4) contained essentially no phosphate.

The phosphate removal percentages have been rather constant during the last 4 years of the project, indicating that precipitation rather than adsorption is the main mechanism at hand.

5. Fluoride.

The average fluoride concentration of the effluent was 4.2 ppm (Table 5). The F-content of the renovated water from the wells inside the basin area was about 3 ppm or a reduction of about 30%. The average F-content for the outlying wells 1 and 7 was 1.8 or a reduction of almost 60%. The native ground water had an F-content of about 0.6 ppm (Table 5, WCW, well 8, and 91st Ave. well).

6. Boron.

Boron concentrations in the effluent were 0.7 to 0.8 ppm (Table 6). The same concentrations were observed for the wells inside the basin area. Somewhat higher levels occurrred in the ground water (well 8, Table 6). Boron is not removed as the effluent water moves through the sands and gravels of the Salt River bed.

7. Dissolved Salts.

The TDS content of the effluent remained in the 1,000-1,200 ppm range (Table 7). The salt content of the well waters shows that wells 1, 1-2, ECW, 5-6, 7, and EW yielded renovated water, but that WCW and well 8 yielded native ground water, as did the 91st Ave. well. Wells WCW and well 8 previously yielded renovated sewage water (see previous annual reports).

The intrusion of native ground water into WCW and well 8 may be due to an increased eastward gradient in the ground water caused by heavy ground-water withdrawals in the urban areas of the valley. This increased gradient could reduce the lateral and vertical spread of the renovated water into the aquifer.

The natural gradient of the ground water will be determined in 1973 by careful water level measurements in the observation wells. Additional wells may have to be installed in a downstream direction from the Flushing Meadows Project to evaluate the effect of additional underground movement on the quality improvement of the renovated water.

8. pH.

The pH of the renovated water was around 7, which is about 1 unit less than the pH of the effluent (Table 8).

9. Fecal Coliform Density.

The fecal coliform density, which is of the order 10^5 to 10^6 per 100 ml in the secondary effluent, was between 0 and 10/100 ml for the renovated water from ECW during the first 3 months of the year when long flooding periods were used in basins 3 and 4 (Figure 11). Counts of close to 100/100 ml were obtained in April and June, following the start of new flooding periods. The short flooding periods after 20 June produced coliform counts of less than 10/100 ml (except for 10 September). Coliform peaks were obtained after the start of the long flooding periods in November and December.

Low coliform densities in the renovated water from ECW are apparently obtained during long flooding periods (several weeks) alternated with short drying periods, or with a sequence of short, frequent flooding periods (for example 2 days wet and 5 days dry). The highest coliform count in the renovated water from ECW occurred after the start of a long flooding period following a long dry period. Continued removal of fecal coliforms takes place, however, with additional underground travel of the renovated water. Fecal coliform data for wells 7 and EW are shown in Figures 12 and 13, respectively. The WCW and well 8 yielded water that was free of fecal coliforms.

III. FUTURE PROJECTS

The grant application for the 23rd Avenue Project, which would be a 40-acre high-rate infiltration system renovating about 15 mgd, was modified by the City of Phoenix at the request of EPA so that the project could be financed in three equal yearly installments. Hopefully, the grant will be awarded before 1 July 1973.

Effluent samples taken from the 23rd Avenue Plant show that there is not much change in the effluent as it goes through the two oxidation ponds (Table 9). The visual appearance indicates, however, that the suspended solids content decreases and the algae content increases. The second oxidation pond, which is 40 acres in size, would be divided into 4 infiltration basins for the proposed project.

Following one of the recommendations of the Phase I Rio Salado Report, a proposal for a demonstration project in the Tempe area of the Salt River bed was developed. The project consists of conversion of abandoned gravel pits in the river bed between McClintock and Rural Road to recreational lakes. Water from these lakes would flow into a 2,000 m section of the flood control channel, mainly between Rural Road and Mill Avenue, to create an Olympic-size rowing course. From the rowing course the water would flow to a small recreational lake in the Salt River bed north of the Tempe Beach park. Water for this project would be supplied by a well to be constructed in the Salt River bed near McClintock Road. This well would pump a mixture of native ground water and renovated sewage water. The source of the sewage water is the Mesa sewage treatment plant, which discharges about 4.5 mgd of secondary effluent in the river bed about a mile east of McClintock Road. All of this effluent seeps into the Salt River bed in the first half-mile of the effluent channel.

SUMMARY AND CONCLUSIONS

The average accumulated infiltration of the six Flushing Meadows Project basins for 1972 was 250 ft. This is less than the potential maximum infiltration, because short, frequent inundation periods were used along with several long drying periods for other studies. For the first time, the infiltration in the gravel-covered basin was not significantly lower than that in the other basins. The Flushing Meadows Project is an experimental ground-water recharge facility in the Salt River bed west of Phoenix. It was installed in 1967 to study renovation of secondary effluent by high-rate soil filtration.

The Total Organic Carbon content of the effluent was in the 20-30 ppm range for winter and spring and in the 10-20 ppm range for summer and fall. The TOC content of the renovated water was usually in the 2-7 ppm range, except for a few periods of higher values (10-15 ppm) at the beginning of a flooding period following a long drying period.

The total nitrogen content of the secondary effluent was mostly in the 30-40 ppm range. The ammonium levels in the renovated water below basins 3 and 4, which were high at the beginning of the year because of continued use of long flooding periods in previous years, decreased from a range of 20-25 ppm NH_4-N in the first 5 months of the year to about 6 ppm NH_4-N in December. This reduction was the result of using short, frequent flooding periods (2 days wet, 5 days dry) and growing a crop (sudangrass) in the basins. Some release of nitrate nitrogen occurred, mainly in September and October, when the NO_3-N concentration in the renovated water below basins 3 and 4 increased to about 20 ppm. Use of two long flooding periods in November and December again yielded the usual nitrate pattern of peaks and almost zero levels between peaks in the renovated water, while the ammonium level in the renovated water remained low. Thus, a sequence of short, frequent flooding periods and the growing of a crop were effective in reducing the amount of adsorbed ammonium in the soil, enabling again the use of long flooding periods for maximum nitrogen removal. The NH_4-N levels below basins 1, 2, 5, and 6, for which short, frequent flooding periods were used in 1971 to reduce the ammonium levels in the renovated water, generally remained below 5 ppm for basins 5 and 6 during the entire year, and below 10 ppm for basins 1 and 2 during the first 5 months of the year. After this, the ammonium level increased due to a long inundation period and resulting saturation of the cation exchange complex in the soil with ammonium.

The PO_4-P concentration in the effluent was about 10 ppm. Phosphate removal was about the same as in previous years, i.e., about 50% for the renovated water pumped in the center of the basin area and 80 to 90% for the renovated water from a well 100 ft north of basin 1. Fluoride removals from the renovated water from these wells were 30% and 60%, respectively. The average fluoride concentration in the effluent was 4.2 ppm. Boron levels were about 0.8 ppm in the effluent as well as in the renovated water. The pH of the effluent continued to be about 8 and that of the renovated water about 7.

The salt content of the effluent remained in the 1,000-1,200 ppm range. The most distant well and the deep well in the center of the basin area both showed replacement of renovated water by native ground water, possibly due to increased ground water gradients caused by heavy pumping in the Salt River Valley east of the Flushing Meadows Project.

The fecal coliform count of the renovated water below basins 3 and 4 was usually less than 10 per 100 ml during the short, frequent flooding periods and during the later stages of long flooding periods. Higher coliform densities (about 100/100 ml) were observed at the beginning of a long flooding period following an extended dry period.

As regards future projects, the grant application for the 40-acre basin system to renovate about 15 mgd of effluent from the 23rd Avenue Sewage Plant was revised. Plans for a pilot Rio Salado Project in the Salt River bed north of Arizona State University were developed. The plan includes several recreational lakes and a rowing course, using renovated sewage effluent as a water source.

PERSONNEL: H. Bouwer, R. C. Rice, E. D. Escarcega, and M. S. Riggs

CURRENT TERMINATION DATE: 1973

Table 1. Total organic carbon in mg/l for various wells (1972).

Date	1	7	EW	WCW	8	91st Ave.
19 Jan	3.5	1.4	2.8	0.8	1.2	-
30 Mar	0	1.0	0	0	0	-
27 Apr	5.4	5.4	2.4	2.8	2.2	-
24 May	8.6	4.0	6.6	7.4	3.8	4.6
21 Jun	5.0	7.5	8.0	2.6	3.2	-
19 Jul	4.0	5.5	6.5	3.8	3.3	1.5
31 Aug	4.0	0.1	1.5	1.2	0.7	-
27 Sep	8.1	8.4	-	9.2	10.5	-
25 Oct	4.8	5.5	7.6	3.6	2.4	-
21 Nov	3.8	3.9	5.2	0	0.8	-
20 Dec	3.4	5.9	6.1	6.9	-	-
Ave.	4.6	4.4	5.2			

Table 2. Nitrate-nitrogen concentrations in mg/l for various wells (1972).

Date	1	7	8	EW	WCW	91st Ave.
19 Jan	10.6	14.8	0	15.7	2.5	–
30 Mar	8.7	0.1	0.1	13.1	0	–
27 Apr	2.0	1.3	0.4	2.3	0	–
24 May	2.5	1.5	0.4	1.1	0	3.5
21 Jun	3.4	0.3	0.8	2.2	3.1	–
19 Jul	1.2	23.8	0.8	0.1	0	2.8
31 Aug	3.6	1.8	0.6	0.3	0.1	–
27 Sep	2.7	1.9	0.2	–	0	–
25 Oct	5.2	22.5	0.1	16.3	0.1	–
21 Nov	1.2	0.5	0.2	5.8	0	–
20 Dec	5.5	0.6	–	5.1	0	–
Ave.	4.2	6.3		6.2		

Table 3. Ammonium-nitrogen concentrations in mg/l for various wells (1972).

Date	1	7	8	EW	WCW	91st Ave.
19 Jan	6.4	1.9	0	8.9	0	-
30 Mar	4.5	0.5	0.2	8.1	0.4	-
27 Apr	4.8	2.9	0.1	5.4	0.3	-
24 May	4.8	4.9	0.3	6.2	0.3	0.4
21 Jun	4.3	2.5	0.3	4.9	0.3	-
19 Jul	3.7	3.8	0.4	4.6	0.5	0.6
31 Aug	2.9	5.7	0.5	8.7	0.6	-
27 Sep	2.3	5.4	0.6	-	0.4	-
25 Oct	1.0	4.4	0.7	10.2	0.7	-
21 Nov	1.6	2.1	0.6	9.6	0.7	-
20 Dec	1.9	1.4	-	7.7	0.6	-
Ave	3.5	3.2		7.4		

Table 4. Phosphate-phosphorus concentrations in mg/1 for various wells (1972).

Date	WCW	EW	91st Ave.
19 Jan	0	2.0	-
30 Mar	0	1.8	-
27 Apr	0.1	5.6	-
24 May	0	4.0	0
21 Jun	0	5.3	-
19 Jul	0	6.2	0.1
31 Aug	0	3.8	-
27 Sep	0	-	-
25 Oct	0	2.6	-
21 Nov	0	2.9	-
20 Dec	0	6.0	-
Ave.		4.0	

Table 5. Fluoride concentrations in mg/l for effluent and wells (1972).

Date	Effl.	Date	1	1-2	ECW	5-6	7	8	EW	WCW	91st Ave.
3-7 Jan	5.3	-	-	-	-	-	-	-	-	-	-
7-14 Jan	5.0										
14-21 Jan	4.7	30 Mar	1.0	2.2	3.0	2.1	1.3	0.7	1.6	0.4	-
21-28 Jan	4.4										
28-31 Jan	4.2	27 Apr	1.5	4.2	3.2	4.2	2.3	0.7	1.8	0.5	-
14-18 Feb	5.4										
18-25 Feb	4.0	24 May	-	-	-	-	-	-	-	-	0.6
28-29 Feb 1-3 Mar	4.1										
3-10 Mar	3.7	21 Jun	1.5	3.2	2.7	4.6	3.4	0.8	2.7	0.7	-
10-15 Mar	3.3										
10-14 Apr	4.1	19 Jul	-	-	-	-	-	-	-	-	0.6
14-21 Apr	3.9										
21-24 Apr	3.2	31 Aug	1.8	2.7	2.1	2.3	2.0	0.7	2.3	0.7	-
31 May 1 Jun	5.3										
5-9 Jun	4.1	27 Sep	-	-	-	-	-	-	-	-	-
12-16 Jun	3.5										
16-23 Jun	3.0	25 Oct	1.3	2.1	1.8	2.3	1.7	0.5	1.9	0.6	-
23-28 Jun	3.0										
5-7 Jul	3.7	21 Nov	-	-	-	-	-	-	-	-	-

Table 5. Fluoride concentrations in mg/l for effluent and wells (1972) - Continued.

Date	Effl.	Date	1	1-2	ECW	5-6	7	8	EW	WCW	91st Ave.
12-14 Jul	3.5										
14-21 Jul	3.9	20 Dec	1.5	4.2	4.2	3.6	2.5	-	3.0	0.7	-
24-28 Jul	3.6										
3-4 Aug	4.0										
9-11 Aug	4.6	Ave.	1.4	3.1	2.8	3.2	2.2	0.7	2.2	0.6	0.6
16-18 Aug	4.9										
23-25 Aug	4.9										
31 Aug-1 Sep	4.6										
6-8 Sep	4.5										
19-21 Sep	4.6										
5-6 Oct	3.8										
18-19 Oct	4.4										
25-26 Oct	4.9										
26-27 Oct	4.6										
3-10 Nov	4.1										
10-11 Nov	4.4										
4-8 Dec	4.3										
8-15 Dec	4.3										
15-22 Dec	4.6										
22-29 Dec	2.3										
Ave.	4.2										

Table 6. Boron concentration in mg/l for effluent and wells (1972).

Date	Effl.	1	1-2	ECW	5-7	7	8	EW	WCW
30 Mar	-	0.74	0.80	0.66	0.87	-	-	-	-
27 Apr	-	-	-	-	-	0.78	1.12	0.74	0.80
19 Jul	0.80	0.80	0.73	0.86	0.81	-	-	-	-
31 Aug	0.74	-	-	-	-	1.21	1.55	0.83	0.99
21 Nov	-	0.76	-	-	-	-	1.54	-	-
20 Dec	0.72	-	0.72	0.70	0.70	0.76	-	0.72	1.05

Table 7. Total salt concentration in mg/l for effluent and wells (1972).

Date	Effl.	1	1-2	ECW	5-6	7	8	EW	WCW	91st Ave.
18-19 Jan	1184	1050	1101	1146	1088	1184	2310	1152	2060	-
30 Mar	-	992	1043	1011	1082	1222	2560	1280	2200	-
27 Apr	-	1158	1210	1222	1184	1466	2624	1152	2480	-
24 May	-	1030	1101	1094	1312	2035	2496	1274	2560	2240
20-21 Jun	1216	1165	1216	1216	1158	1184	3008	1165	3520	-
18-19 Jul	1120	1152	1146	1274	1280	1331	3194	1094	3580	2304
31 Aug	-	1216	1229	1216	1485	2880	3776	1504	3510	-
27 Sep	-	1261	1421	1395	1651	3584	4320	-	3440	-
25 Oct	-	1171	1197	1146	1280	2432	4096	1427	3200	-
21 Nov	-	1018	1101	960	986	1024	3584	1101	3380	-
19-20 Dec	992	1024	915	896	934	1024	-	960	4160	-

Table 8. pH of effluent and water from wells (1972).

Date	Effl.	1	1-2	ECW	5-6	7	8	EW	91st Ave.
18-19 Jan	7.9	7.3	7.1	6.9	6.9	7.4	7.1	6.8	-
30 Mar	-	8.0	6.8	6.8	6.8	7.4	7.0	6.7	-
27 Apr	-	7.2	7.0	7.0	7.0	6.9	7.2	6.7	-
24 May	-	7.5	6.8	6.7	6.7	6.7	6.8	6.6	6.8
20-21 Jun	7.6	7.3	7.1	6.9	6.8	6.9	6.9	6.7	-
18-19 Jul	7.9	7.3	6.8	6.7	6.8	6.6	6.8	6.7	6.9
31 Aug	-	7.0	7.2	6.9	6.8	6.8	6.9	6.7	-
27 Sep	-	7.5	6.9	6.8	7.0	6.9	7.0	-	-
25 Oct	-	7.6	7.0	6.9	7.2	6.8	6.5	6.8	-
21 Nov	-	8.1	7.2	6.9	7.2	7.9	7.0	7.0	-
19-20 Dec	7.6	7.6	7.1	6.9	7.1	7.1	-	6.8	-
Ave.	7.8	7.5	7.0	6.9	6.9	7.0	6.9	6.8	6.9

Table 9. Quality parameters in mg/l of secondary effluent, 23rd Avenue Phoenix Sewage Treatment Plant (samples taken 2 November 1972).

	TOC	NH_4-N	NO_3-N	NO_2-N	PO_4-P	TDS	pH
Effluent entering first oxidation pond	20.7	17.7	0	0.1	6.4	781	7.3
Effluent leaving first oxidation pond and entering second oxidation pond	19.6	25.3	0	0.1	9.6	896	7.7
Effluent leaving second oxidation pond	21.3	23.7	0	0.1	9.0	896	8.6

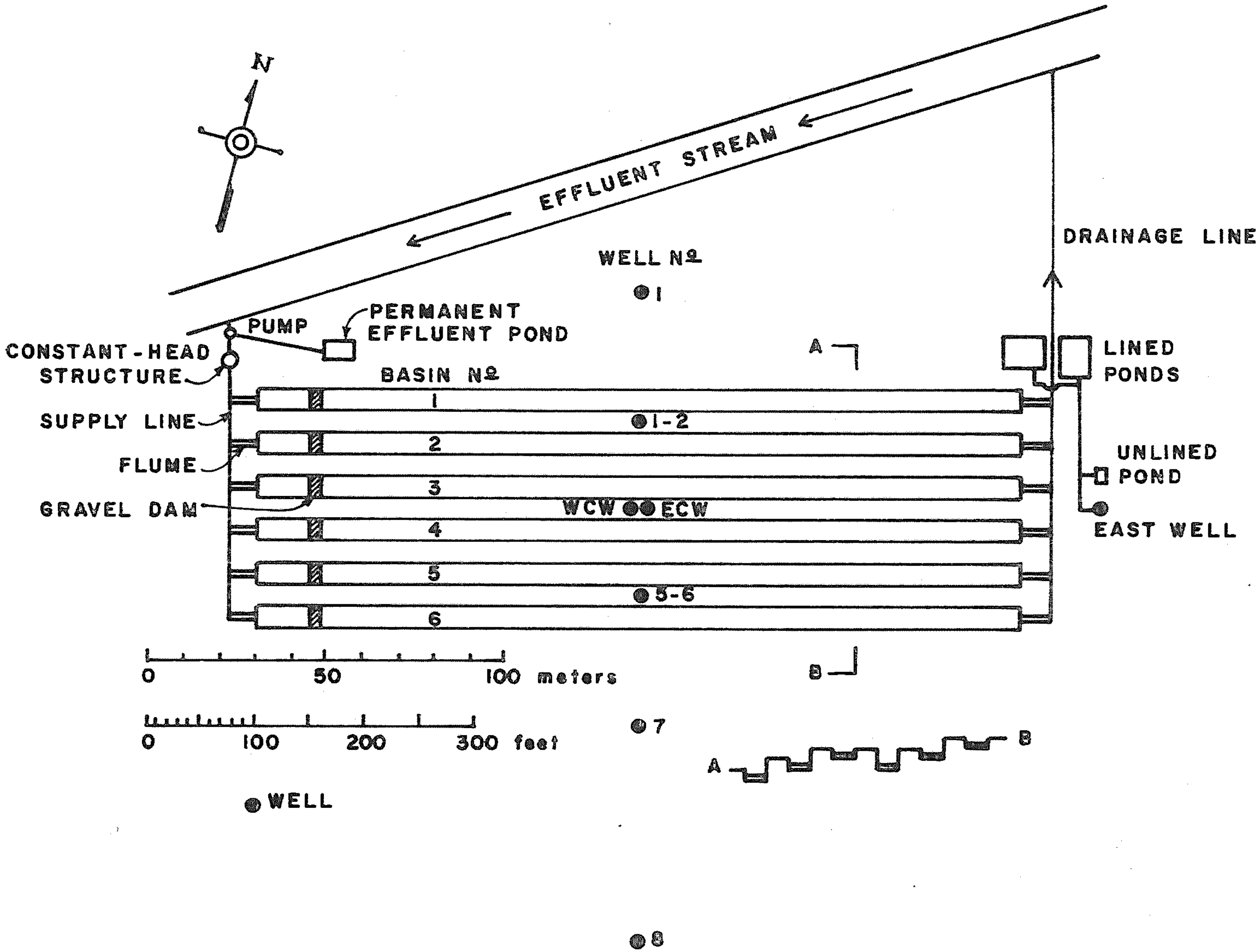


Figure 1. Schematic of Flushing Meadows Project.

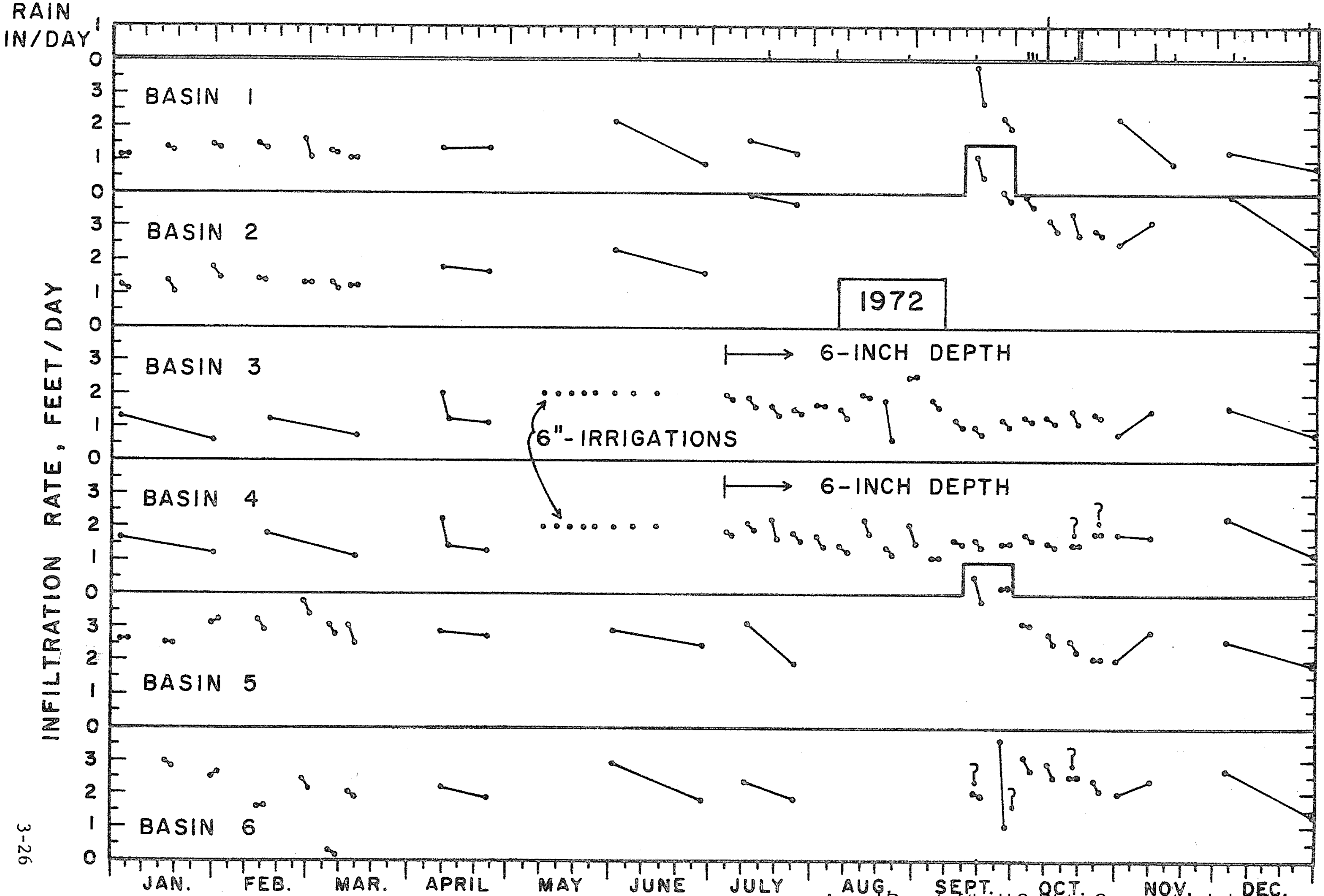


Figure 2. Infiltration rates in recharge basins and rainfall.

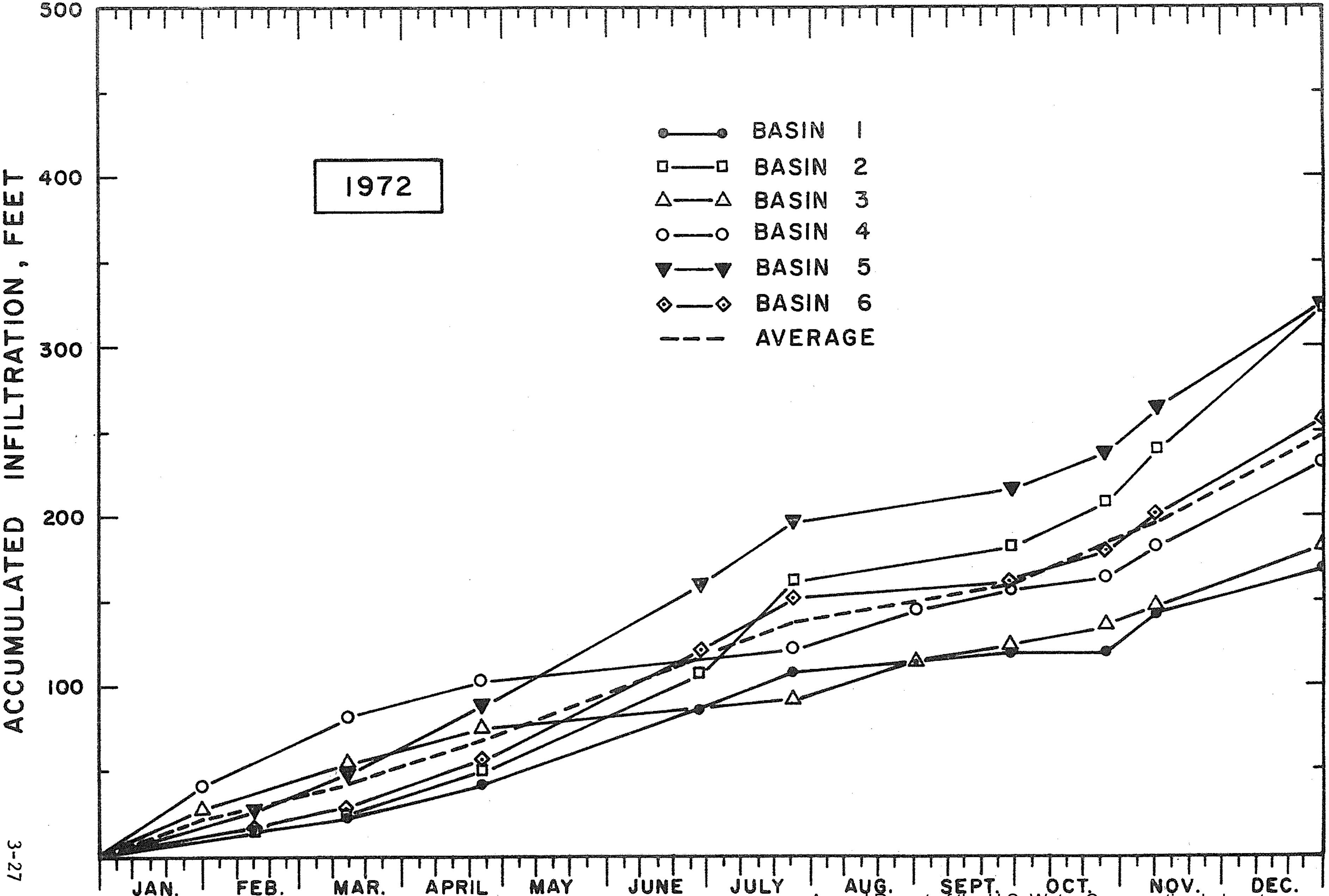


Figure 3. Accumulated infiltration in recharge basins.

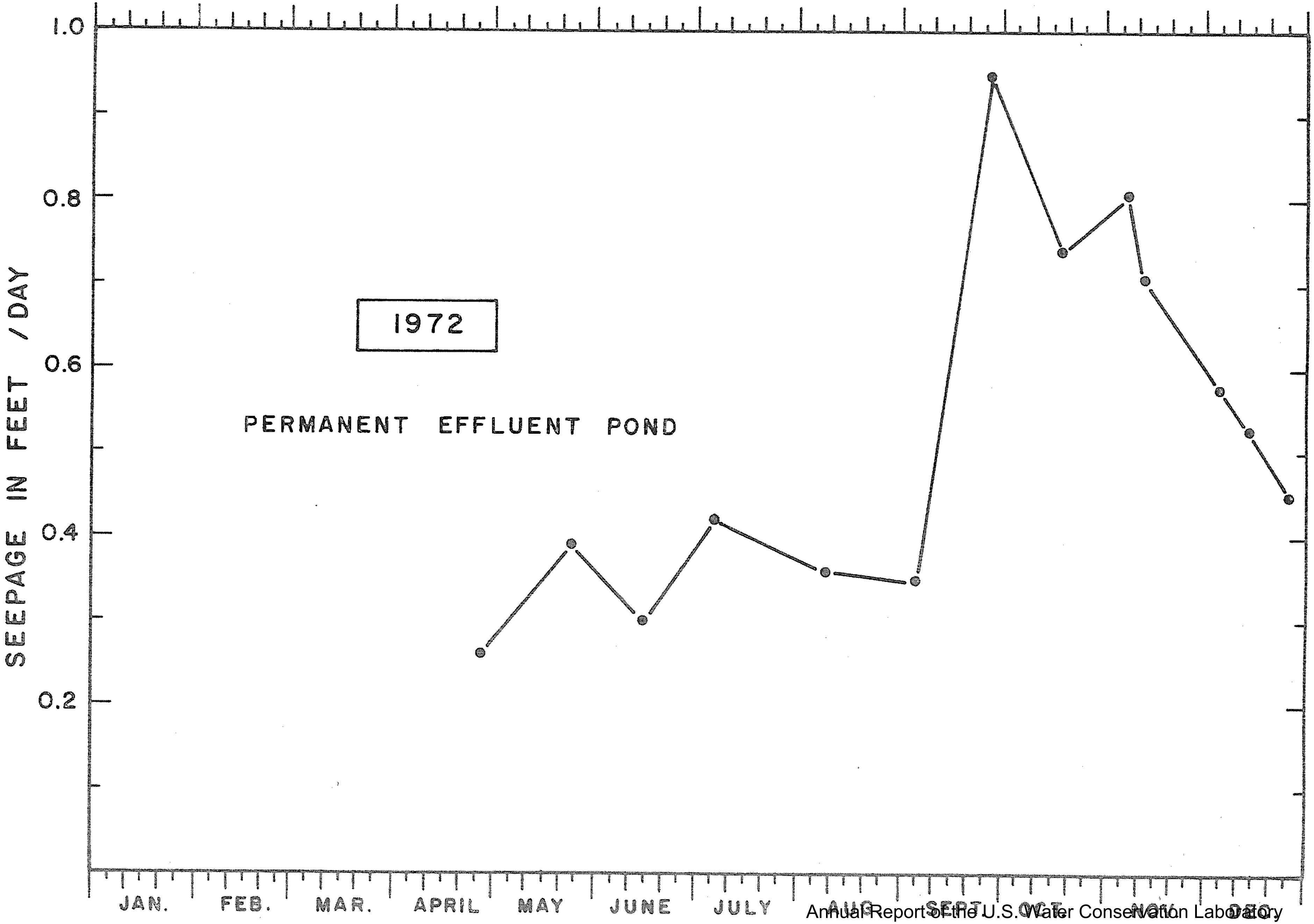


Figure 4. Seepage rate in permanent effluent pond.

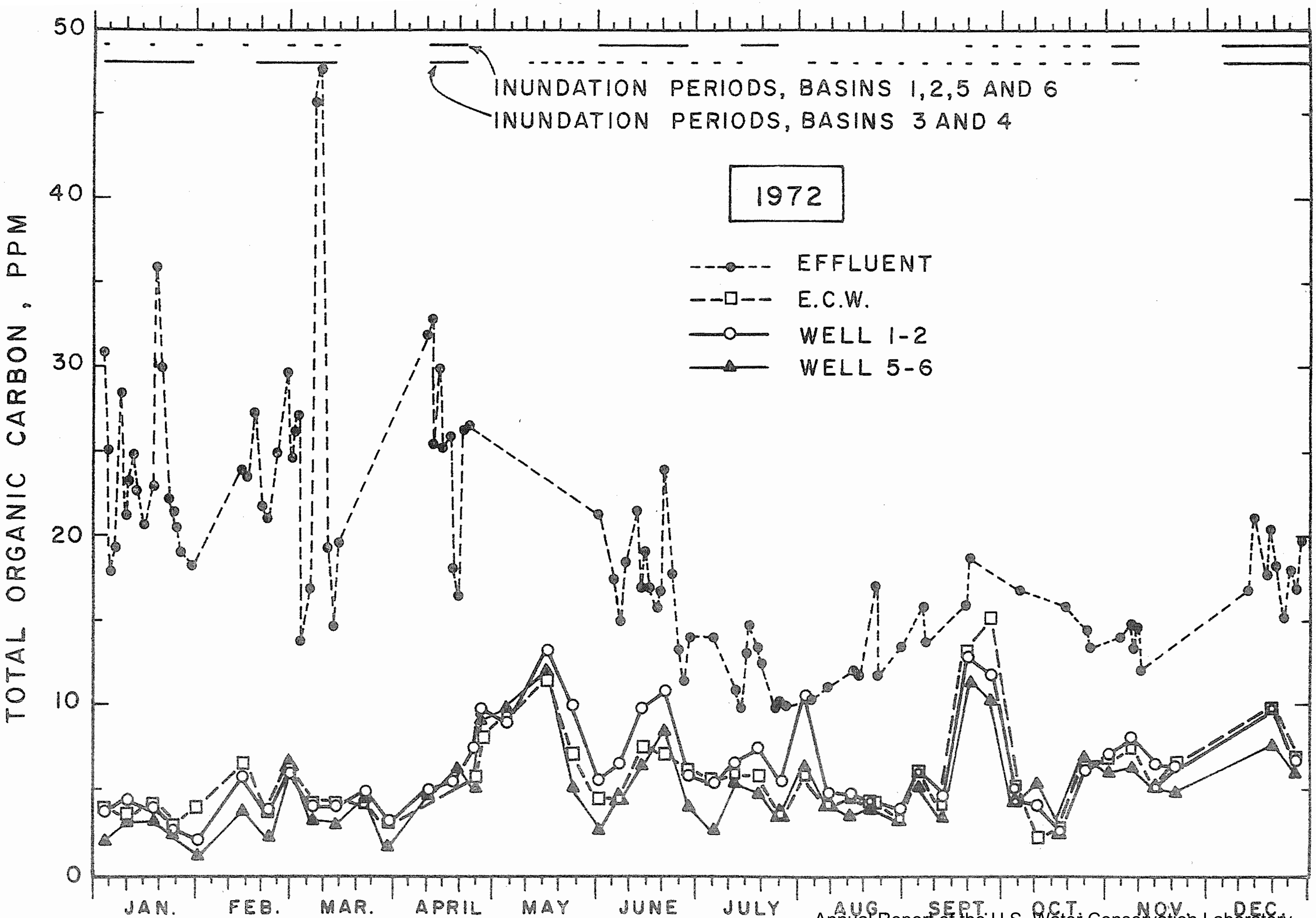


Figure 5. TOC of effluent and renovated water.

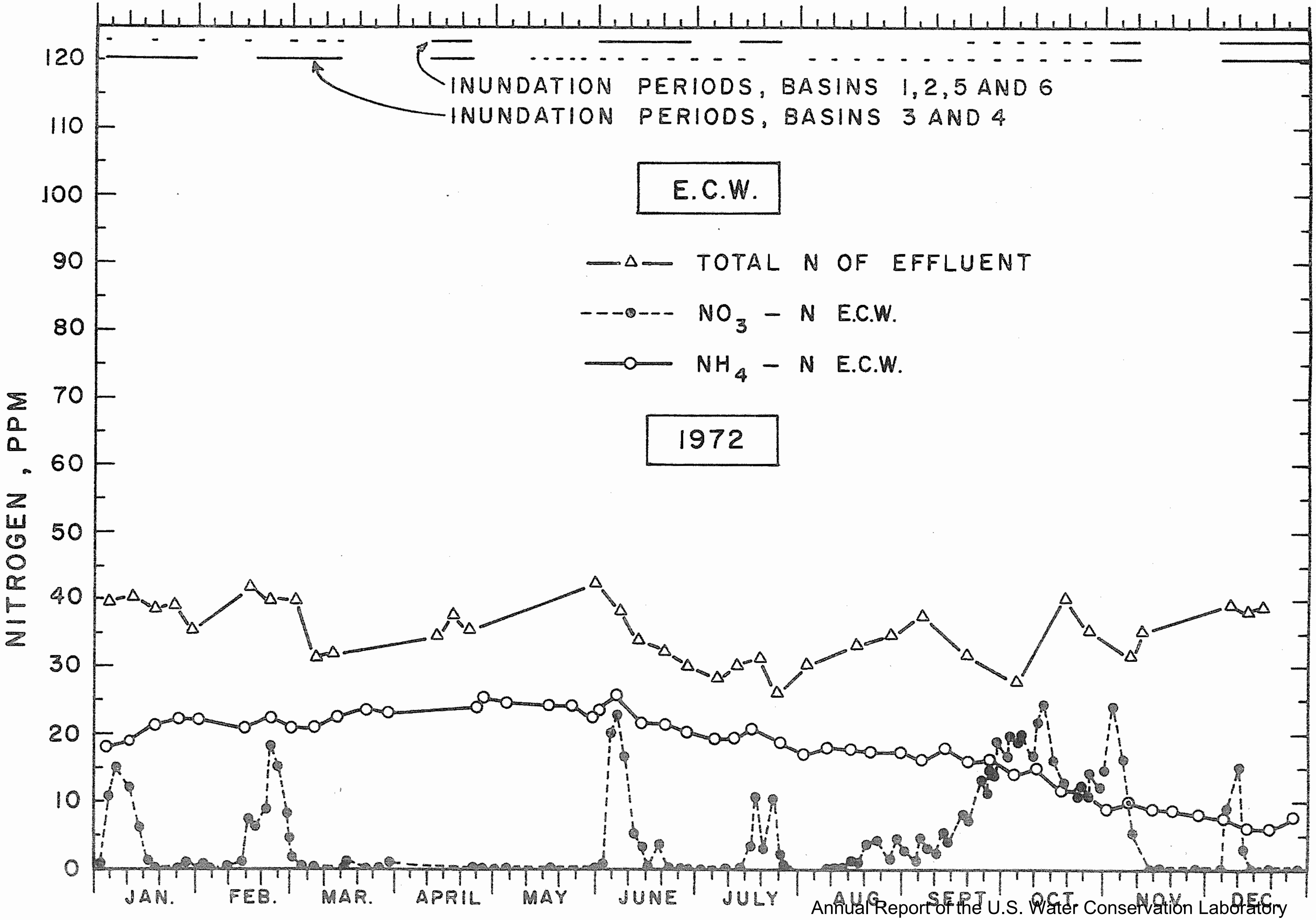


Figure 6. Total nitrogen in effluent and nitrate-N and ammonium-N in renovated water from ECW.

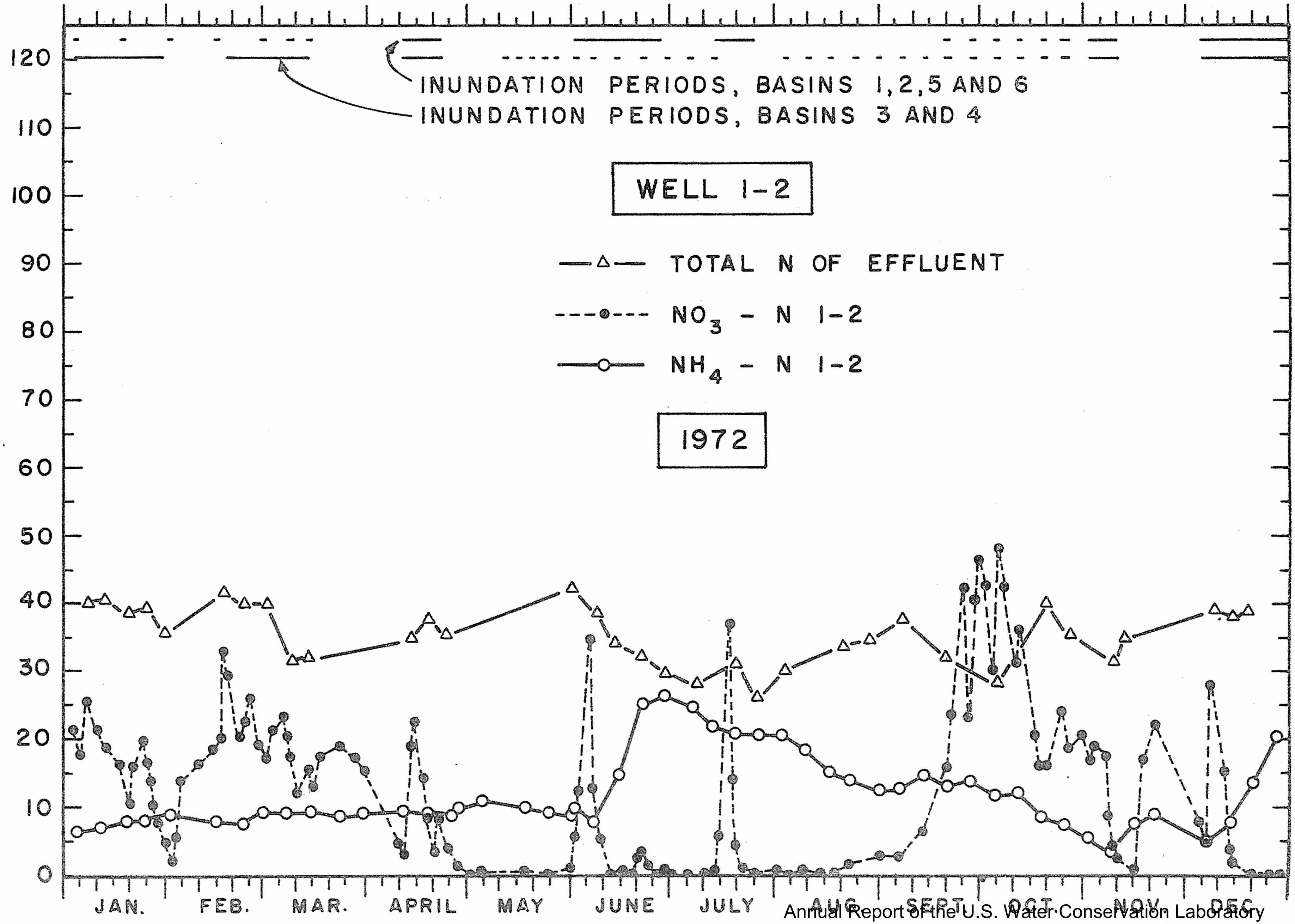
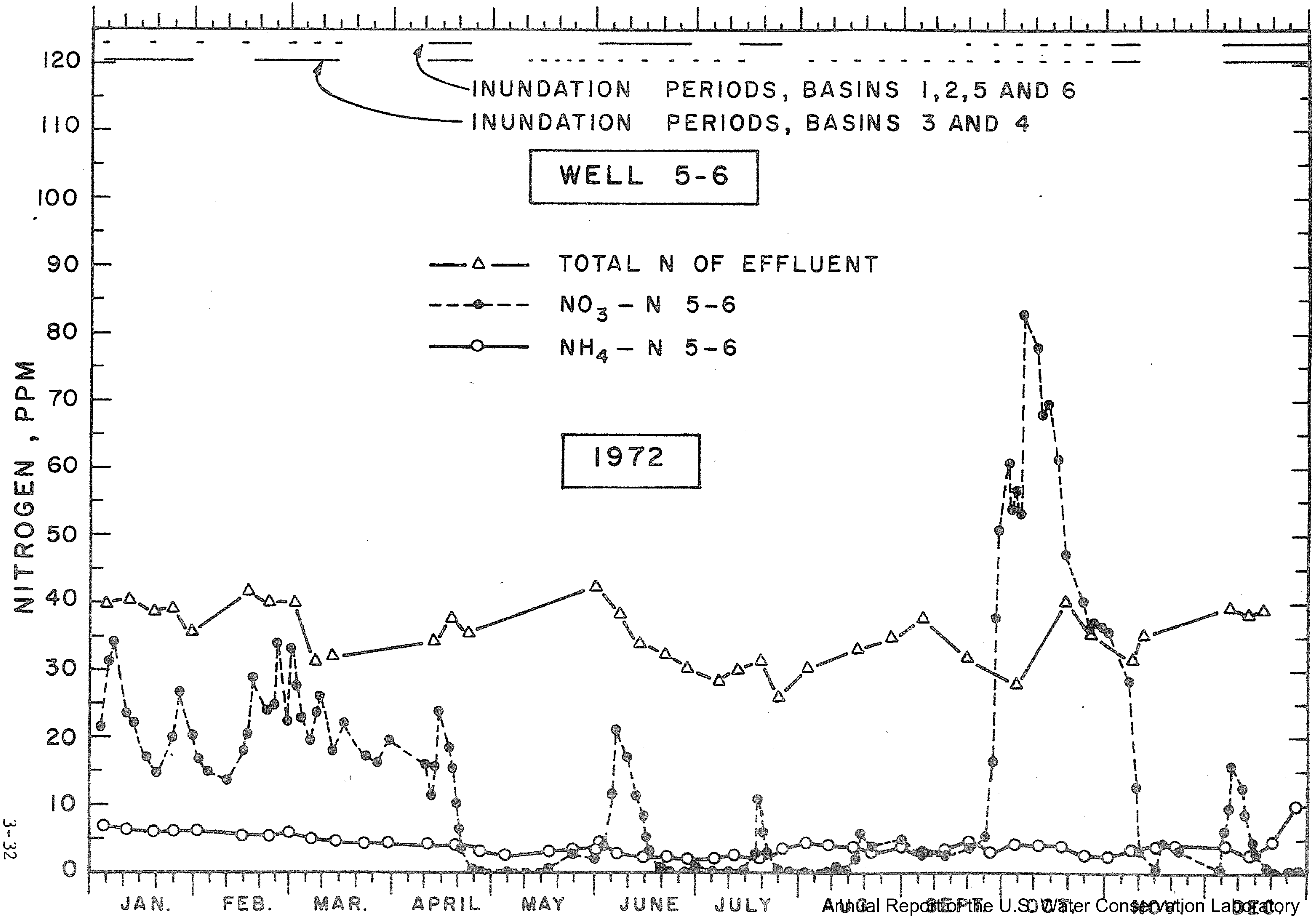


Figure 7. Total nitrogen in effluent and nitrate-N and ammonium-N in renovated water from Well 1-2.



Annual Report of the U.S. Water Conservation Laboratory

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

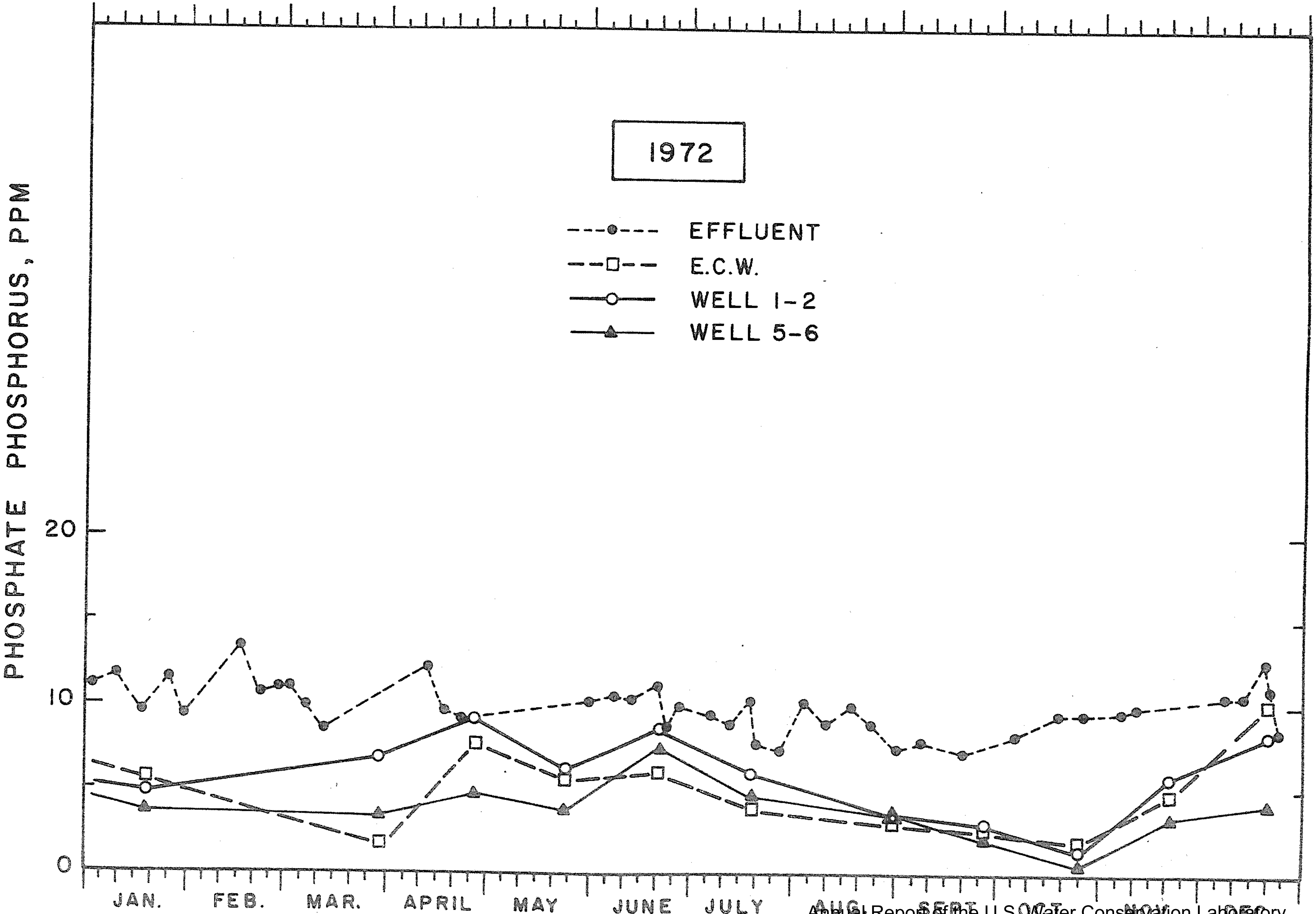


Figure 9. Phosphate-P concentrations in effluent and renovated water from ECW and Wells 1-2 and 5-6.

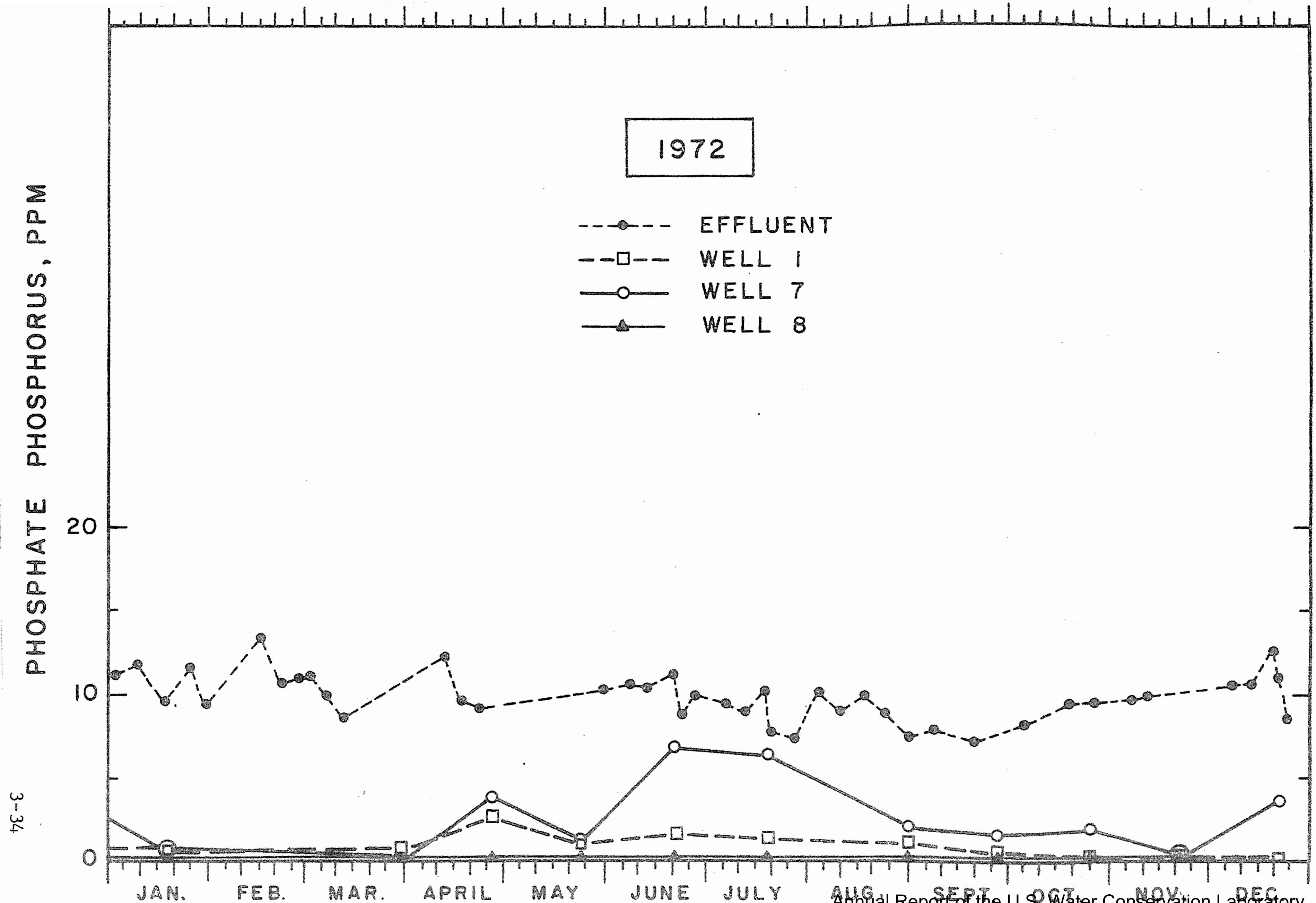


Figure 10. Phosphate-P concentrations in effluent, renovated water from Wells 1 and 7, and native ground water from Well 8.

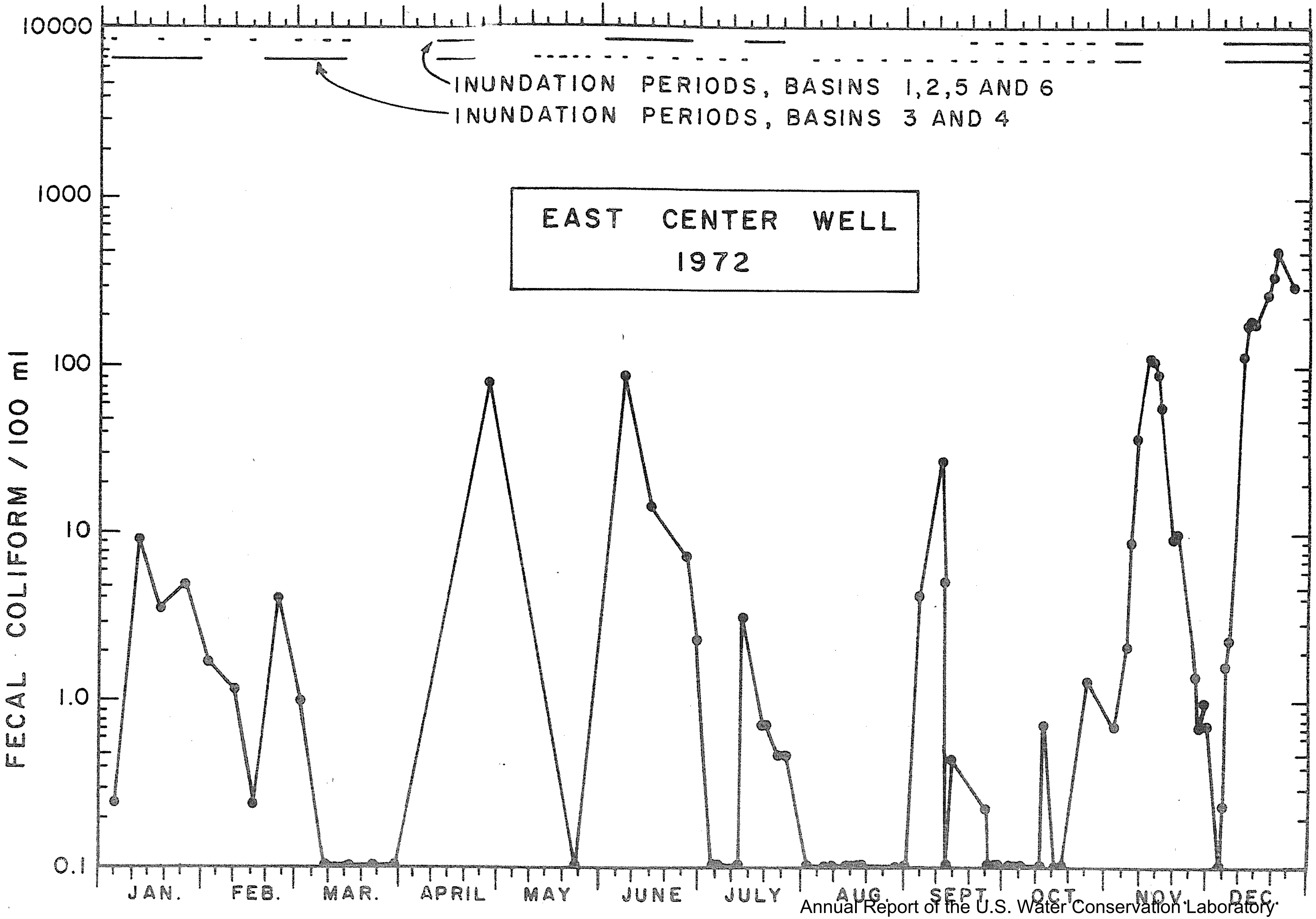


Figure 11. Fecal coliform density in renovated water from ECW.

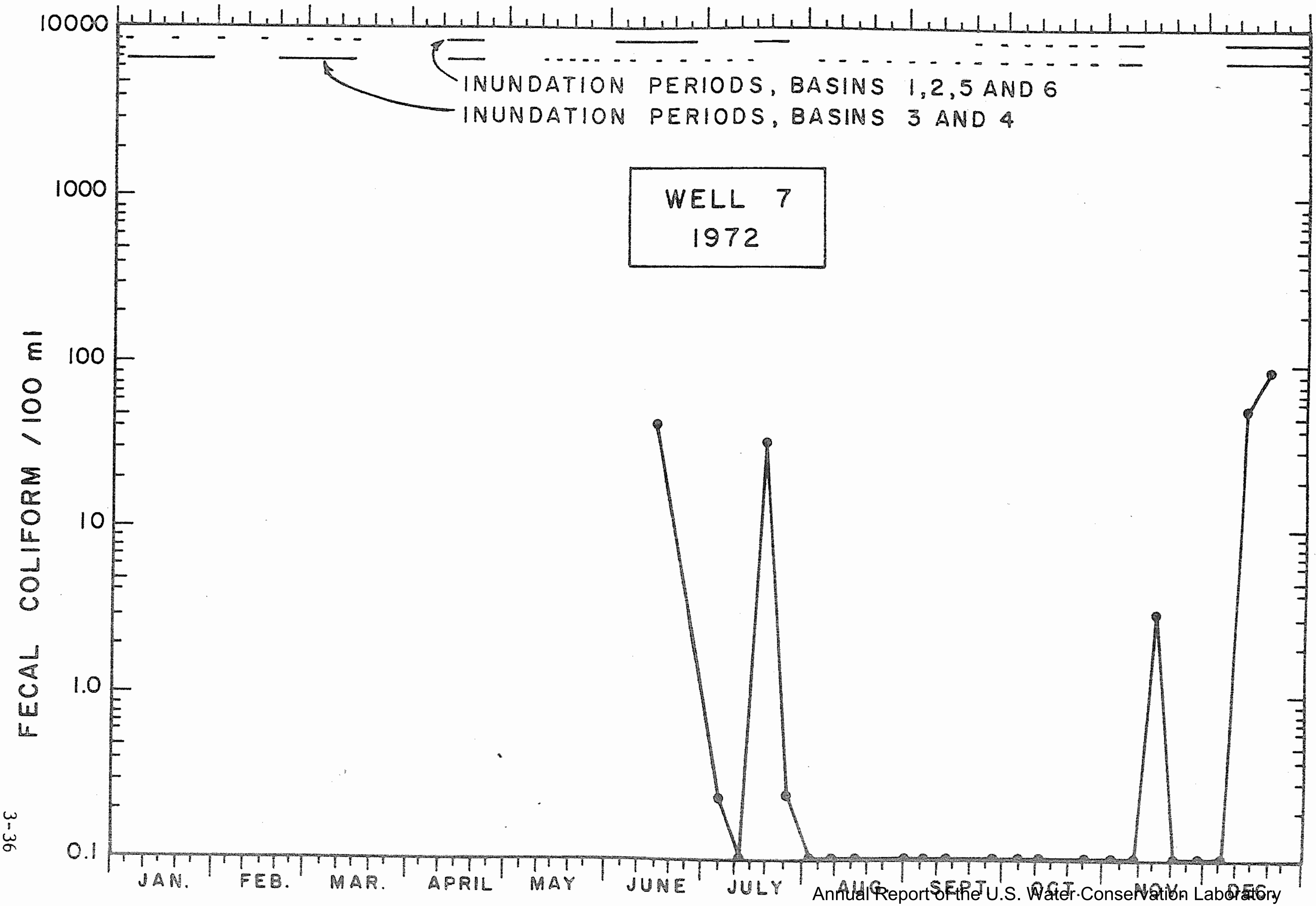


Figure 12. Fecal coliform density in renovated water from Well 7.

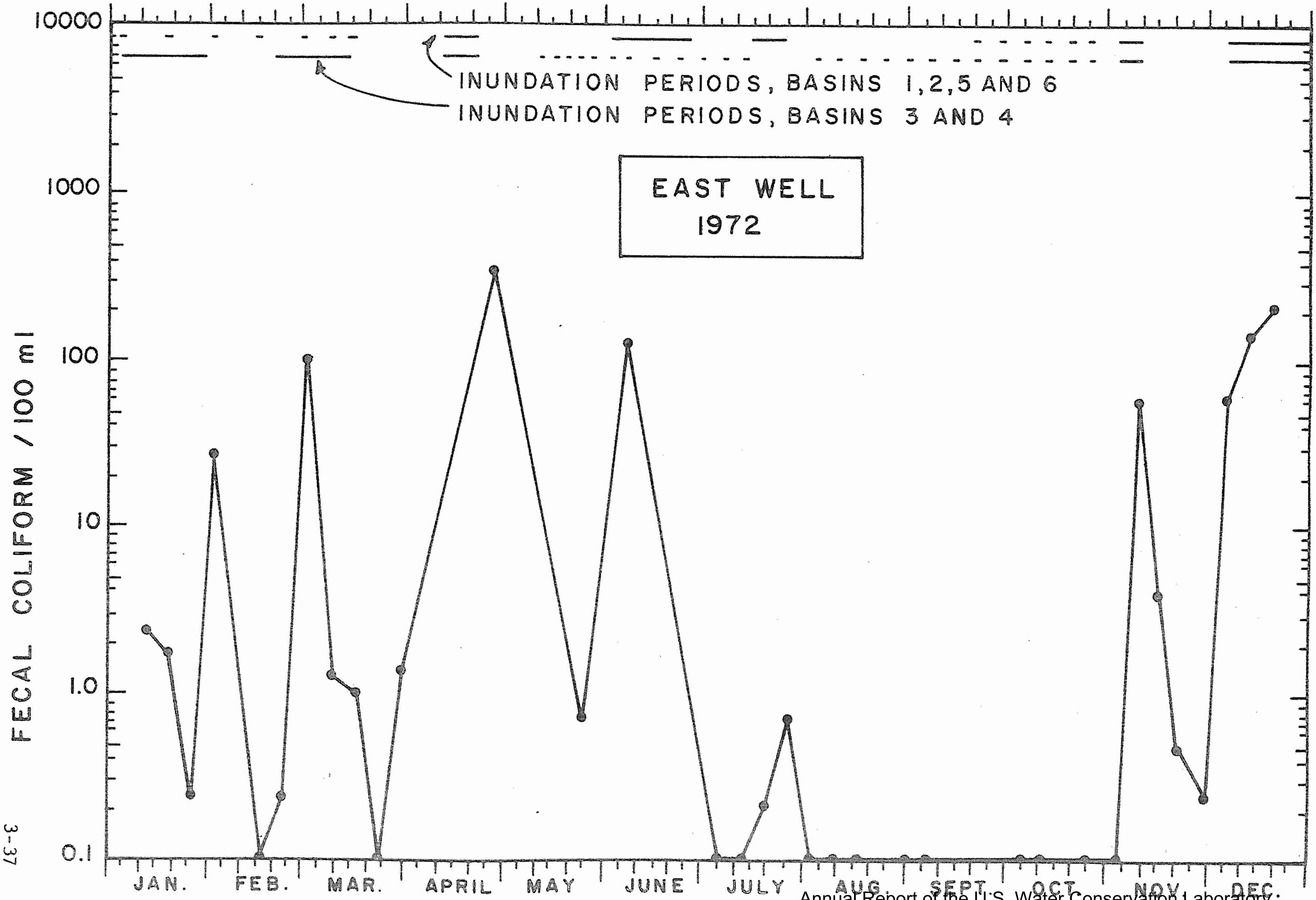


Figure 13. Fecal coliform density in renovated water from EW.

TITLE: EVAPORATION OF WATER FROM SOIL

CRIS WORK UNIT: SWC-018-gG-4 CODE NO.: Ariz.-WCL-68-1

The objective and need for the research reported under this research outline appeared in the USWCL 1969 Annual Report. Two field experiments were conducted, one in July 1970, the second in March 1971, in which soil-water content and soil temperatures were measured as a function of depth and time. Evaporation rates and various meteorological parameters were also measured. The 1970 and 1971 Annual Reports contain detailed information on these experiments. During 1972 work continued on the analysis of data from the experiments. Manuscripts were prepared (and abstracted below) on soil-water flux patterns as a function of time and depth, and movement and accumulation of salt under diurnal evaporating conditions. Current work not yet in manuscript form is concerned with the mathematical description of soil-water flux under diurnal conditions using the theory of Philip and DeVries (Trans. Amer. Geophys. Union 38:222-232, 1957), the calculation of soil heat flux using a calorimetric procedure, and the calculation of salt flux.

In addition to work on evaporation, a manuscript was prepared on the subject of soil and water management practices for calcareous soils. This manuscript was a background paper for a lecture given at a symposium in Cairo, Egypt, by invitation of The Food and Agriculture Organization and the United Nations Development Program.

DIURNAL SOIL-WATER EVAPORATION: TIME-DEPTH-FLUX PATTERNS

R. D. Jackson, B. A. Kimball, R. J. Reginato, and F. S. Nakayama

The rapid changes in direction and rate of soil-water movement within the surface zone of a field soil were demonstrated for the first time. During the morning and midday hours, water moved upward toward the surface in about the top centimeter of soil and moved downward below that depth. This two-directional movement caused the soil surface to dry very rapidly. The soil-water flux at 9 cm showed from 2 to 4 maxima and minima during a 24-hour period. These results provide aid for understanding the evaporation process and may lead to means for reducing evaporative losses of water from soil.

DIURNAL SOIL-WATER EVAPORATION: CHLORIDE MOVEMENT AND ACCUMULATION NEAR THE SOIL SURFACE

F. S. Nakayama, R. D. Jackson, B. A. Kimball, and R. J. Reginato

Chloride and water contents near the soil surface of a bare soil were intensively measured under field conditions. Soon after irrigation, chloride content near the surface followed a diurnal pattern, but out-of-phase from the soil water content. This pattern for the chloride became less with time as the soil dried out. No cycling of chloride accumulation was present at the 1- to 2-cm and deeper depths even though the diurnal cycling was present for the water. Most of the total chloride accumulation at the surface occurred in the early stages of drying. The chloride moved at water contents as low as 4% in the Adelanto soil. Thus, to conserve water, leaching of soluble salts can be made at water contents much below the saturated state as long as downward movement of the soil solution predominates.

SOIL AND WATER MANAGEMENT PRACTICES FOR CALCAREOUS SOILS

R. D. Jackson and L. J. Erie

Soil-water flow theory is being used to predict infiltration rates, drainage from the root zone, and the requirement for artificial drains. From basic studies on salt and water movement, an improved concept of leaching of salts has evolved. By using intermittent ponding or low intensity sprinkling, as much salt can be leached with less water than with continuous ponding. This concept led to an improved method of calculating the leaching requirement. Minimum tillage is recommended to maintain adequate infiltration rates on calcareous soils. Irrigation trends are toward "dead level" basins for maximum water application efficiency and salt control. Consumptive use data for specific crops and computer forecasting are now used for irrigation scheduling.

PERSONELL: R. D. Jackson, F. S. Nakayama, B. A. Kimball, R. J. Reginato, H. Mastin

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

CRIS WORK UNIT: SWC-018-gG4 CODE NO.: Ariz.-WCL-68-2

INTRODUCTION:

Observations were continued of weathering performance of surface coatings for asphalt-fiberglass membranes. Field studies consisted of applying a new seal coat to the Tombstone catchment.

RESULTS AND DISCUSSION:

Part I. Operational Field Catchments.

In July 1972, a report was received on the Tombstone catchment that the sealcoat was "chipping off." Photographs taken of the catchment showed exposed fiberglass on the tops of wrinkles, indicating insufficient clay emulsion was used during installation. In September 1972, laboratory personnel assisted in applying a new sealcoat of clay emulsion to the catchment. It required 3 hours for six men to brush on a new layer of asphalt clay emulsion at a rate of 0.2 gal of emulsion per yd^2.

The asphalt-fiberglass catchment at the Maui test site was in excellent condition when inspected in February and December 1972. The operational catchment on Kukaiau Ranch was considered in excellent condition when inspected in February 1972. Inspection of the catchment in December 1972 revealed grass had started to grow through the membrane along the edges as a result of inadequate soil sterilization. The grass had been treated prior to the December visit and appeared dead but should be removed and the edges of the covering repaired.

The other operational catchments of asphalt-fiberglass were not visited the past year. It is assumed, in the absence of reports, that the catchments are performing satisfactorily.

Part II. Laboratory Studies.

Limited studies were conducted to determine the weathering properties of various protective coatings on asphalt-fiberglass using the small soil trays at the Granite Reef Testing Site. Samples of runoff were collected from each treatment during each rainfall event and the degree of water discoloration was measured with the Hach colorimeter. Previous work has shown that the degree of discoloration of runoff water from asphalt-coated surfaces can be correlated to the quantity of runoff and the time between rainfall events. This permits a quantitative evaluation of the effectiveness of various coatings to protect asphalt-coated surfaces.

Ten coating treatments were applied to trays which had been treated with asphalt-fiberglass in July 1971. Table 1 lists the treatments and a summary of their performance.

Trays Nos. 2, 3, and 10 treated with United Paint, Chevron D. T., and highway paint, respectively, are considered to have the best weathering performance. This was determined by visual observation and verified by the water discoloration measurements. The Enjay two-part butyl was found to have a very short pot life for application. The yellow highway paint is "chipping off" the fiberglass. It is expected the water discoloration will start to increase. The poor bonding is believed a result of dust on the asphalt at time of application. The studies will be continued to observe the performance of the coatings with time.

Additional studies are planned to develop coatings for asphalt-fiberglass which are capable of supporting depths of water to 30 ft. All coatings checked to date develop pinholes which cause small amounts of water to be lost. The actual quantity of water lost through these holes has not been determined.

Part III. Evaporation covers.

The test panel of supported asphalt-fiberglass for reducing evaporation from open water storage at Granite Reef was damaged by wind before any effectiveness tests could be conducted. The fiberglass was not physically tied to the framework or wire and was blown off before the asphalt had completely hardened.

The Safford District Office of the Bureau of Land Management constructed six water harvesting catchments of asphalt-fiberglass in the past year. Two of these structures have asphalt-fiberglass-lined reservoirs with supported panels of asphalt-fiberglass for reducing evaporation. These two operational units will be used to evaluate this idea of evaporation reduction.

SUMMARY AND CONCLUSIONS:

Observations and reports on the operational field catchments of asphalt-fiberglass indicate the units are performing satisfactorily. The Tombstone catchment was given a new sealcoat after inspection of the unit indicated insufficient asphalt had been applied in the original sealcoat. Grass was found growing through the edges of the Kukaiau catchment showing the necessity for adequate soil sterilization at the time of catchment installation and periodic maintenance.

Limited studies at the Granite Reef test site on 1-m^2 trays covered with asphalt-fiberglass indicated the discoloration of runoff water can be reduced over 90% with low cost protective coatings. Four coatings were rated good after 6 months to 1 year exposure. Measurements of the water discoloration and observations will be continued to determine the long-term effectiveness of these coatings.

PERSONNEL: G. W. Frasier and Lloyd E. Myers

CURRENT TERMINATION DATE: December 1973

Table 1. Performance of protective coatings on asphalt-fiberglass at the Granite Reef Test Site on 1-m^2 trays.

Tray No.	Treatment	Treatment Date	Treatment Rate (kg/m^2)	Visual Appearance 1/	Reduction in Discoloration (% of base-coat alone)
1	Enjay 2-part butyl	27 Oct 71	.325	Pinholes in coating	80
2	United paint	27 Oct 71	.325	Good	90
3	Chevron D. T.	27 Oct 71	.325	Good	95
4	Enjay 2-part butyl	5 Nov 71	.400	Fair pinholes	80
5	Gaco hypolon	10 Apr 72	.400	Fiberglass showing on 80% of area	10
6	Basecoat alone	16 Jul 71	-	-	-
7	Gaco K4230 aluminum	10 Apr 72	.400	Asphalt bleeding on 5% of area	85
8	Chevron D.T. No. 100	10 Apr 72	.400	Asphalt bleeding on 3% of area	85
9	Chevron D.T. No. 440	10 Apr 72	.400	Failed - coating did not bond	85
10	Base coat alone	16 Jul 71	-	-	-
11	Highway paint yellow	Jun 72	.400	Brittle-chipping off 5% of area	99
12	Gaco K4210R black	10 Apr 72	.400	Good	90

1/ Observations on 15 Jan 72

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

CRIS WORK UNIT: SWC-018-gG-4 CODE NO.: Ariz.-WCL 68-3

PART I. CHEMICAL AND BIOLOGICAL PROCESSES DURING RENOVATION

INTRODUCTION:

Experiments on the renovation of secondary sewage effluent with soil columns were conducted during 1972 to develop management practices which would increase nitrogen removal above the 30% level obtained under simulated field conditions. The three approaches tried were:

(1) Collection of water containing the high nitrate peak, mixing it with sewage water at the rate of 2 parts sewage to 1 part high-nitrate water and cycling it through the columns a second time.

(2) Operating the column at different nitrogen loading rates by varying fluxes through the columns, the length of the flooding period, and the concentration of nitrogen in the sewage water.

(3) Growing plants in columns flooded with sewage water.

PROCEDURE:

The 8 PVC pipes were packed with soil taken from the Flushing Meadows recharge basins in the same manner as described in previous reports. High-nitrate water from columns with fluxes of 25 cm/day or greater was mixed with the sewage water and recycled through the columns. At least one column with an average flux greater than 25 cm/day was maintained as a control. The columns with fluxes less than 25 cm/day were not used for recycling because preliminary data indicated that their nitrogen removal rate was already high. These columns were monitored to establish the nitrogen removal rate at low fluxes. All of the columns were operated with schedules of 9 days flooding, followed by 5 days dry, and were sampled daily.

Water with nitrate concentrations between 20 and 100 ppm were collected from the columns with fluxes greater than 25 cm/day during the second and third day of flooding or the third and fourth day depending upon the flux. The high-nitrate water was refrigerated at 3 C until it could be recycled through the columns. Each day, beginning with the day following the collection of the last high-nitrate water, this water was mixed with sewage water at the rate of 2 parts sewage to 1 part high-nitrate water and recharged through the columns, using a jug with a mariotte siphon to maintain a constant head as described in earlier reports. The water was sampled at the beginning and at the end of the day to monitor the change in the nitrate concentration while the water was held in the jugs. When high-nitrate water was mixed with sewage at this ratio, all of the water could be recycled during a 9-day flooding period and full strength sewage could be infiltrated during the final 8-24 hours.

After preliminary tests showed that reductions in the nitrogen load applied during a flooding cycle increased the N removal, the sewage applied to five columns was diluted by mixing it with an equal volume of distilled water. This reduced the nitrogen load but maintained the same C:N ratio in the sewage water. These columns were continued on a schedule of 9 days flooding followed by 5 days dry. The nitrogen load applied per cycle was reduced for three other columns by reducing the length of the flooding period from 9 to 6 days.

Nine other columns were constructed and enclosed in a special shelter to test the effect of plant growth on nitrogen removal. Polyvinyl chloride pipes, 6 inches in diameter, were packed with material taken from the recharge basins at Flushing Meadows. The columns were enclosed in an insulated shelter with the top of the pipes protruding through the roof. The pipes were packed with soil to the level of the roof. The soil surface was therefore exposed to the atmosphere, and six of the columns were planted to Bartel barley on December 5, 1972. The columns were flooded with sewage water on an irrigation schedule of 2 inches of water per week until the barley was about 15 cm high. A schedule of 9 days flooded and 5 days dry was then used. The sewage water for the columns was held in a tank inside the shelter where the temperature was maintained at 70-75 F. A constant head was maintained by a float which activated a pump by means of a solenoid switch. The three treatments imposed on these columns were: (1) a bare soil surface, (2) a vegetative cover with the forage harvested and removed, and (3) a vegetative cover with the forage harvested and deposited on the soil surface.

RESULTS AND DISCUSSION

The effect of flux on N removal. Nitrogen removal by the soil columns was greatly increased by reducing the flux of water through the columns (Figure 1). The relationship between the flux and the percent nitrogen removal appeared to be exponential. The nitrogen removal increased from about 10% to about 30% as the flux decreased from 50 cm/day to 30 cm/day. However, the nitrogen removal increased from 30% to 80% when the flux decreased from 30 cm/day to 15 cm/day. The nitrate concentration of the water collected from columns with a low flux (around 15 cm/day) was consistently around 5 ppm with little evidence of a nitrate peak (Figure 2). The concentration of the nitrate peak increased as the flux increased and the percent nitrogen removal decreased.

The relationship between the nitrogen load applied per flooding cycle and percent nitrogen removal was similar to the relationship between flux and percent nitrogen removal (Figure 3). Since flux and nitrogen load were very closely related, there was some doubt about the relative importance of each factor. For this reason the nitrogen load rate was reduced in several columns without changing the flux to evaluate the effect of these variables separately.

When the N load was reduced by diluting the sewage by the addition of distilled water, the percent N removal was about the same as it was with full strength sewage after a few transition cycles (Figure 4). In other words, the relationship between the percent N removal and flux remained about the same, but the relationship between N load and percent removal did not hold. When the N load was reduced by reducing the length of the flooding period from 9 days to 6 days, the relationship between flux and percent N removal again remained the same (Figure 4). Finally, the relationship between N removal and flux did not change when the N load was drastically reduced by flooding with half-strength sewage water for 6 days. Since the percent N removal did not change when the N load was reduced, the total nitrogen concentration in the reclaimed water decreased. For example, the average nitrogen concentration in the water collected from one column dropped from 6.8 ppm to 3.8 ppm when the sewage was diluted with an equal volume of distilled water.

The increase in percent nitrogen removal with a decrease in flux must be due to a change in the flow characteristics of the system. The nitrate formed in the soil during the dry period is leached from the soil in a narrow concentrated "band" when the flux is high. A decrease in the flux apparently causes the nitrate to be leached from the soil in a more diffuse wave, which allows the nitrate to nix with the advancing wetting front of sewage water. The mixing of sewage water with nitrate provides a C:NO_3-N ratio which is more favorable for denitrification than the ratio obtained when nitrate is leached in a concentrated band. The increase in detention time within the columns with the decrease in flux may also increase the opportunity for denitrification.

Recycling high-nitrate water. The percent nitrogen removal was increased to 75-80% by recycling the reclaimed water which contained the high nitrate peak and comprised 20-25% of the total volume of water from the columns (Table 1). The high-nitrate water was effectively mixed evenly with the incoming sewage water when two parts of sewage were mixed with 1 part high-nitrate water. Higher ratios of sewage to high-nitrate water would not have allowed complete recycling of the high-nitrate water. Lower ratios were not tried because complete denitrification was not obtained with the 2:1 ratio.

The percent nitrogen removal during the recycling experiments was also affected by the flux. The greatest increase in nitrogen removal above that which would be expected without recycling occurred at a flux of 30-35 cm/day where the percent N removal was increased from about 30% to 75% (Table 1). About 80% N removal was obtained when columns with a flux of about 25 cm/day were included in the recycling experiment. However, 40-50% removal would be expected at this flux without recycling. Only 40% N removal was obtained when high-nitrate water from columns with a flux near 50 cm/day was recycled. This low percent nitrogen removal was partly due to a NH_4-N concentration of about 7 ppm in the water from the columns with a 50 cm/day flux as compared to a NH_4-N concentration of $<$ 1 ppm in water from columns with a flux below 40 cm/day. The amount of oxygen entering the soil during the dry period was not sufficient to oxidize all of the NH_4-N adsorbed by the soil during 9 days of flooding when the flux was around 50 cm/day. Another reason for the decrease in percent N removal as the flux increased is that little nitrate was denitrified during the first passage of the nitrate peak through the columns with a high flux. This means that the nitrate concentration of the recycled water was fairly high even after dilution to one-third strength with sewage water. For example, the nitrate concentration of the water recycled through column 2 (49 cm/day flux) was 24 ppm as compared to 18 ppm in the water for columns 3 and 4 (33 cm/day flux) as shown in Table 2. The C:NO_3-N ratio of 0.5 to 1 in the water from column 2 was too low for complete denitrification.

About 13 ppm NO_3-N was removed from the water recycled through columns 3 and 4 while the NO_3-N concentration of the water entering columns 7 and 8 was only 10-11 ppm (Table 2). Yet all of the nitrate was not denitrified in columns 7 and 8. It may be that more carbon was available in columns 3 and 4 from organic sediments than was available in columns 7 and 8. The higher flux in columns 3 and 4 would have resulted in the deposit of more organic material on the surface. Another factor may be that some nitrogen is always unavailable for denitrification as microorganisms utilize and release nitrogen when microbial cells multiply, die, and decompose.

The recycling method could be used with a tiled land filtration system to remove 75% of the nitrogen from 60 meters of sewage per unit of land area (Table 3). The same percent removal could be obtained by adjusting the flux so that 45 meters of water is applied per unit area.

The effect of plant growth on N-removal. Since the columns were put into operation near the end of 1972, data were not available for this report.

The effect of flux on phosphate removal. The PO_4-P concentration in the reclaimed water decreased as the flux decreased (Figure 5). There was a fair amount of scatter in the data which represents one 9-day flooding cycle for 5 columns and two 6-day flooding cycles for 3 other columns. The effect of flux on PO_4-P removal is being investigated further.

PART II. REDOX POTENTIAL MEASUREMENTS

INTRODUCTION:

In the 1969-1971 Annual Reports the methods and results of redox potential, E_{Pt}, measurements have been discussed. A manuscript has been prepared on these past results as well as the results from the recycling experiments (Whisler et al., 1). Some of the results of the recycling experiment will be discussed herein.

PROCEDURE:

The soil columns were fitted with redox probes at 2, 20, and 40 cm depths. The column outflow water from the first two days of infiltration was mixed in a 1:2 mixture with sewage water and recycled through the columns. The last day or so of infiltration was run with sewage water only. The observations discussed in Part I and the E_{Pt} measurements were made.

RESULTS:

Figure 6 shows the E_{Pt} measurements versus time at 2 cm in a soil column treated with recycled sewage water. The symbols I, R, E, and D on the time scale are the days on which infiltration, recycled water, effluent only, and drainage were started, respectively. The time scale starts on the day the probes were installed in the soil columns. One can observe the rapid drop in E_{Pt} at the start of an infiltration and then a rise to 200-300 mv when the recycled mixture was used. This level of E_{Pt} is where nitrates are unstable, and thus indicates that denitrification may be taking place (Whisler et al., 1). This observation, along with the observations discussed in Part I, shows that in fact denitrification did take place. The deeper probes did not respond in this same manner but behaved as though straight sewage water was being used, as has been reported in other annual reports; therefore, the zone of denitrification was limited to the top 20 cm or less of the soil column. The sharp drop in E_{Pt} when ordinary water was added at the end of an infiltration indicates how quickly the probes respond and how quickly the environment for denitrification can be changed.

SUMMARY AND CONCLUSIONS:

Soil columns filled with material from the Flushing Meadows recharge basins were operated under various management systems during 1972. The flux was varied by packing the columns to achieve different pore volumes. The nitrogen load applied per cycle was varied without changing the flux or the C:N ratio of the sewage by diluting the sewage with an equal volume of distilled water and by reducing the length of the flooding period. The high-nitrate water was collected from several columns, mixed with sewage water in a ratio of 2 parts sewage to 1 part high-nitrate water, and recycled through the columns. Other columns were constructed so that the top of the columns protruded through the roof of an insulated shelter and plants could be grown. All of the columns were equipped with redox electrodes at various depths.

The percent nitrogen removal by the soil columns increased exponentially as the flux decreased. This relationship held when the nitrogen load was reduced by diluting the sewage or by reducing the length of the flooding period. As much as 80% of the nitrogen was removed from the sewage when the flux was reduced to 15 cm/day. The increase in nitrogen removal was probably due to a change in the flow characteristics of the system as the flux decreased. The nitrate peak moved through the soil in a diffuse band rather than a sharp peak, resulting in some mixing of the nitrate with incoming sewage water. The C:NO_3-N ratio was then favorable for denitrification.

Nitrogen removal was increased to 75-80% by collecting the high-nitrate water from the columns, mixing it with sewage, and recycling it through the soil. This kind of management could be used with a tiled land filtration system. The recycling method could be used to remove 75% of the nitrogen from 60 m of sewage applied per unit of land area in one year. The same percent removal could be obtained by adjusting the flux so that 45 m of water is applied per unit area. Phosphate removal also appeared to increase when the flux decreased.

The redox potentials (E_{Pt}) near the surface dropped rapidly when the soil was flooded, rose to 200-300 mv when the high-nitrate water was recycled, and dropped rapidly again when full strength sewage was used. The deeper probes (20 cm and below) behaved in the same manner as they did when only full strength sewage was used. This indicates that a zone of denitrification was established in the top 20 cm or less of the soil columns. The rapid rise and drop in E_{Pt} when high-nitrate water was added and removed showed that the soil environment changed rapidly and the probes reacted rapidly.

Experiments on the effect of plant growth on nutrient removal were begun in 1972, but data are not yet available.

REFERENCES:

1. F. D. Whisler, J. C. Lance, and R. S. Linebarger. Redox potentials in soil columns intermittently flooded with sewage water. Jour. Environ. Qual. 1973. (in review)

PERSONNEL: J. C. Lance, F. D. Whisler, R. S. Linebarger, and J. G. Brooks

Table 1. The nitrogen removal by columns where high nitrate water was recycled.

Cycle	Columns 3 - 4		Columns 7 - 8		Column 8		Column 2	
	% N removal	flux cm/day	% N removal	flux cm/day	% N removal	flux cm/day	% N removal	flux cm/day
1	75.4	41.8	81.4	31.2	75.7	25.6	38.5	52.7
2	78.7	28.0	86.2	24.5	79.0	24.2	42.0	45.9
3	78.4	28.7	83.7	24.2	82.1	21.4	40.7	48.0
4	71.2	30.8			82.8	22.4		
5	71.7	35.7						
Avg	75.1	33.0	83.8	26.6	79.9	23.4	40.4	48.9
	(30.0)*		(41.5)		(50.0)		(17.0)	
% of water recycled		23.5		19.9		23.2		22.6

*% removal expected according to graph of flux vs. % removal (Figure 2).

Table 2. The concentration of NO_3 and NO_2 and organic C in the high-nitrate sewage mixture recycled through the columns.

Cycle No.	Columns 3 - 4*		Columns 7 - 8*		Column 8		Column 2	
	NO_3+ NO_2	Org. C	NO_3+ NO_2	Org. C	NO_3+ NO_2	Org. C	NO_3+ NO_2	Org. C
1	22.1	22.2	12.7	21.3	11.8	10.2	24.2	12.8
2	17.7	14.9	9.6	14.5	10.6	8.0	23.3	-
3	17.3	11.7	9.5	12.0	10.7	13.3		
4	16.8	10.2			11.8	-		
5	14.0	8.0						
Avg	17.8	13.4	10.6	13.2	11.3	10.5	23.8	12.8
Avg NO_3 concen. remaining in water	5.0		3.6		3.8		14.3	

*High NO_3 water from two columns mixed and recycled through both columns.

Table 3. The percent N removal and volume of reclaimed water obtainable with different management systems.

Treatment	Flux (cm/day)	% Removal	Capacity (m/yr)
Recycle	33	76	60*
Recycle	25	81	45
Low load rate	18	75	45
Low load rate	15	80	38
High load rate	35	30	85

*Represents the net volume of reclaimed water.

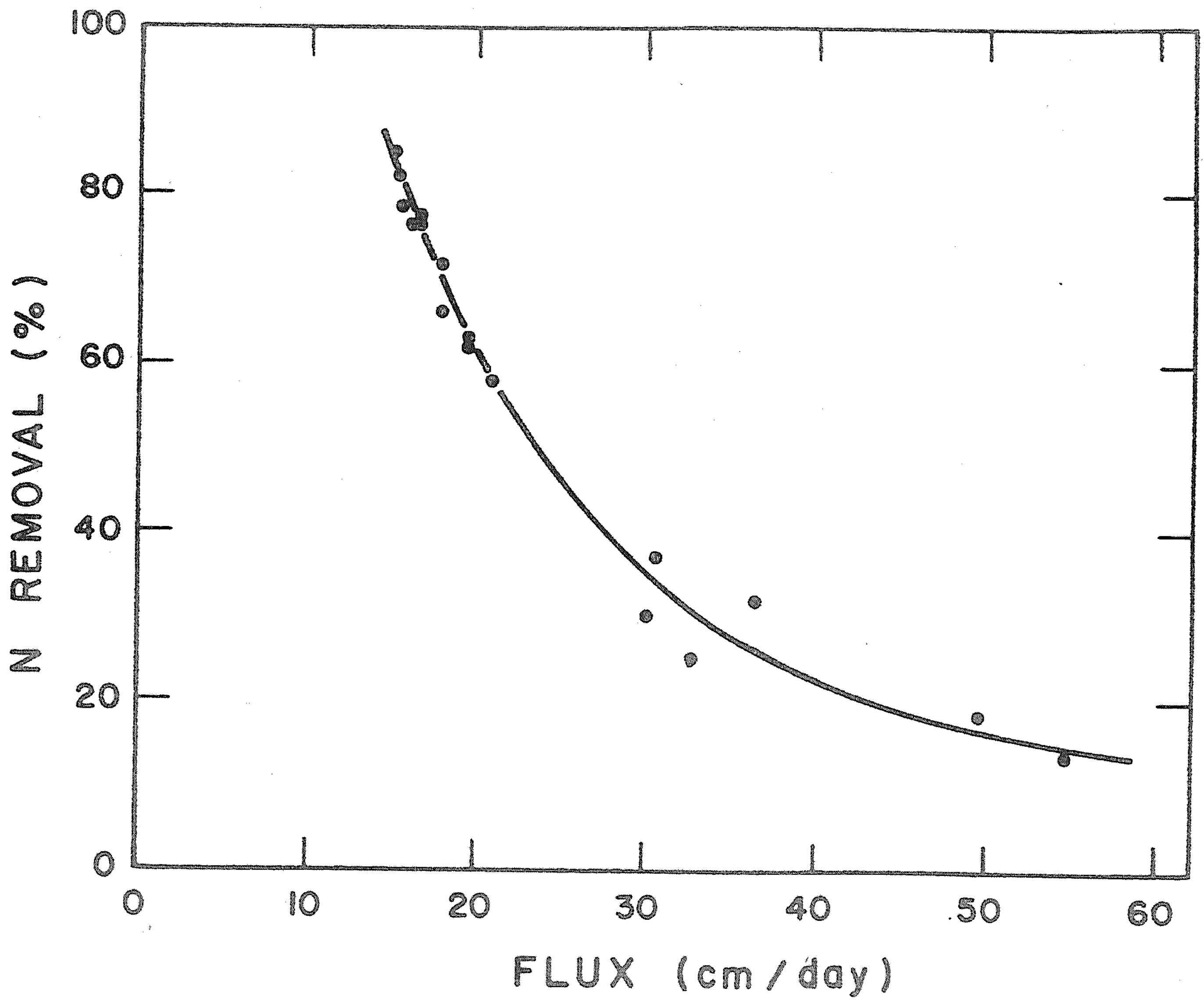


Figure 1. The effect of flux of sewage water through soil columns on the percent N removal. Points represent averages of data from one column over 2-5 consecutive cycles of 9 days flooded followed by 5 days dry.

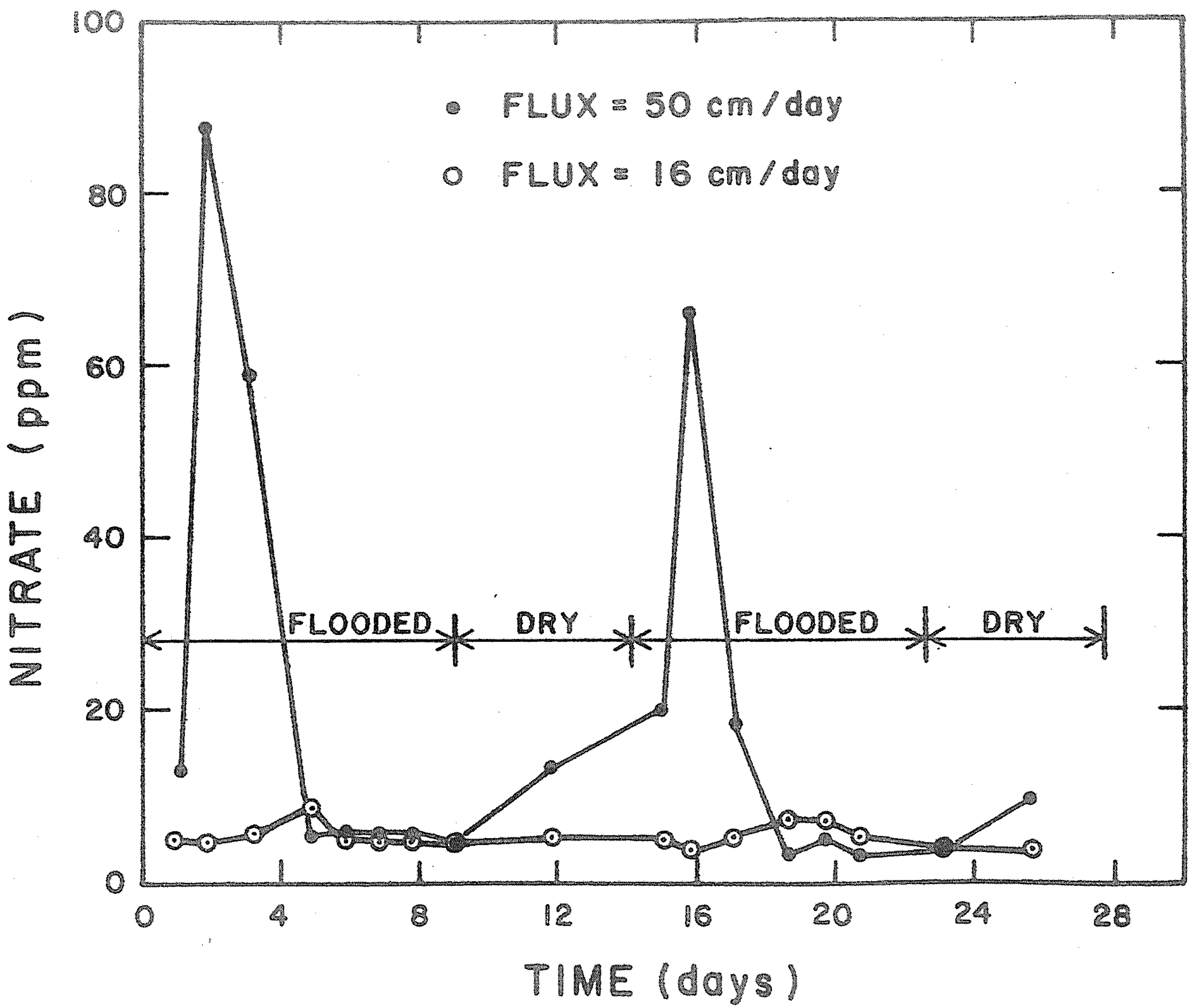


Figure 2. The nitrate content of water collected from two columns with different fluxes of sewage water through the soil.

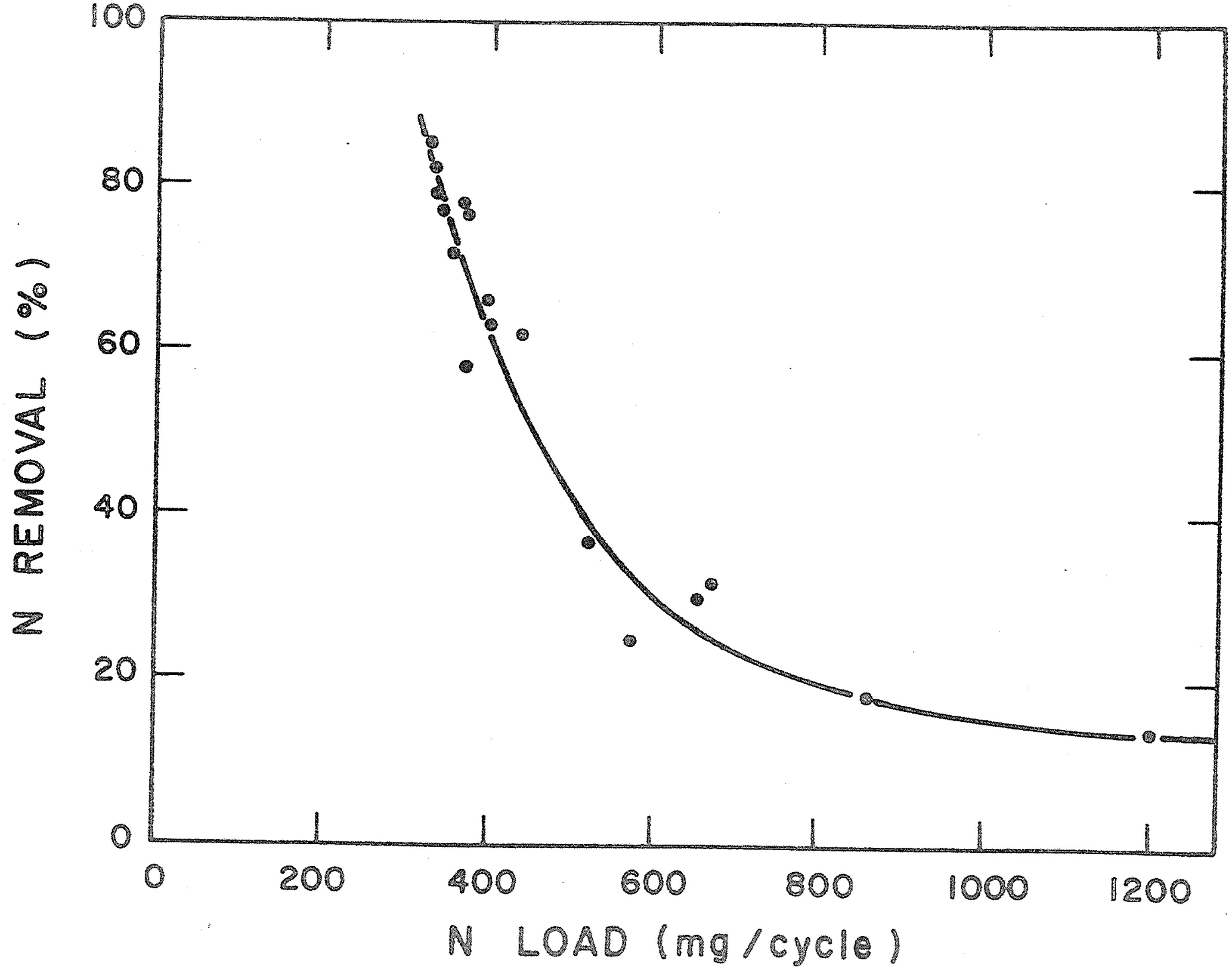


Figure 3. The effect of the N load per cycle on N removal by soil columns. Points represent averages of data from one column over 2-5 consecutive cycles of 9 days flooding followed by 5 days dry.

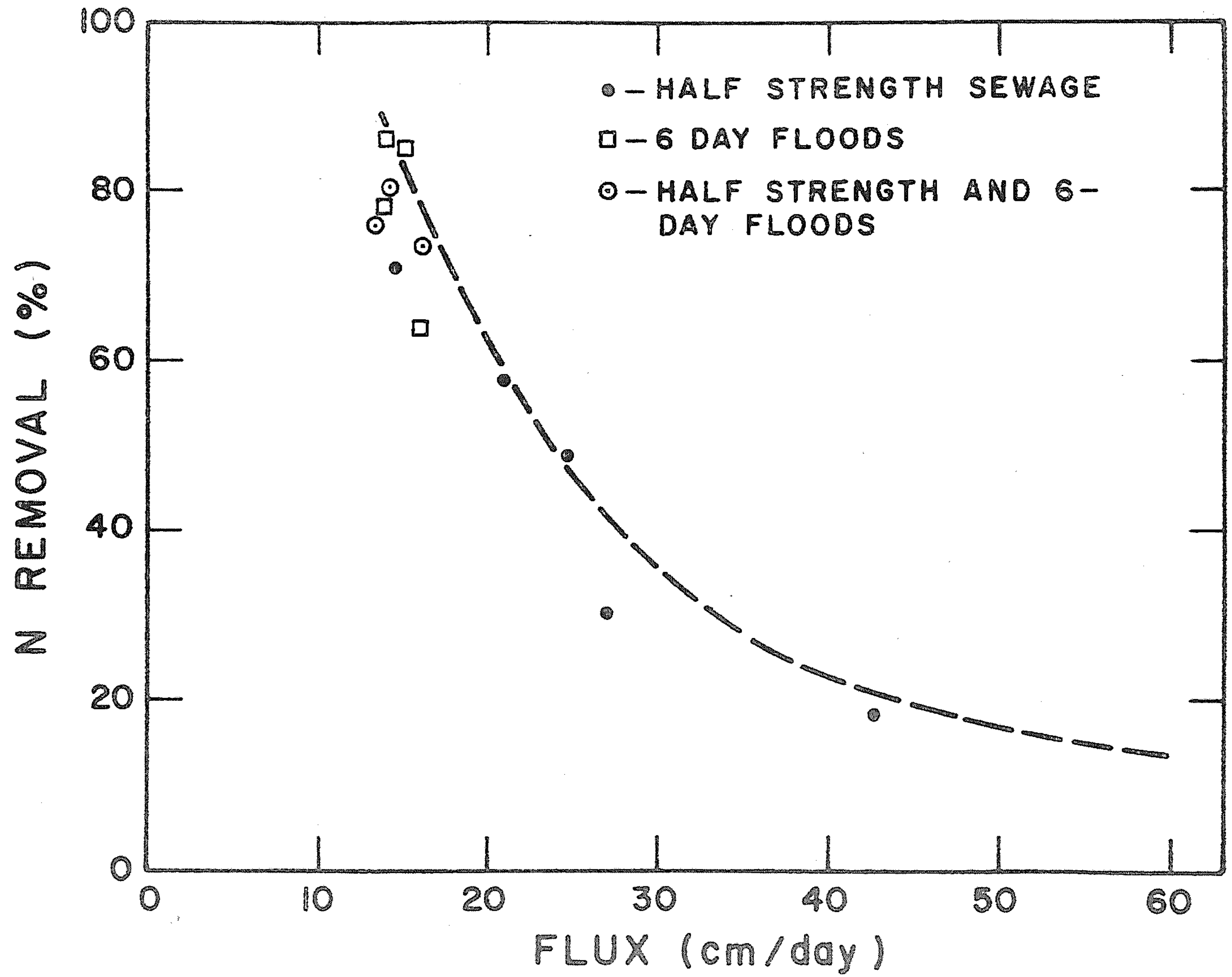


Figure 4. The effect of flux of sewage water through soil columns on the percent N removal at different loading rates of N. The dashed line is from Figure 1 where the N load varied only when the flux changed.

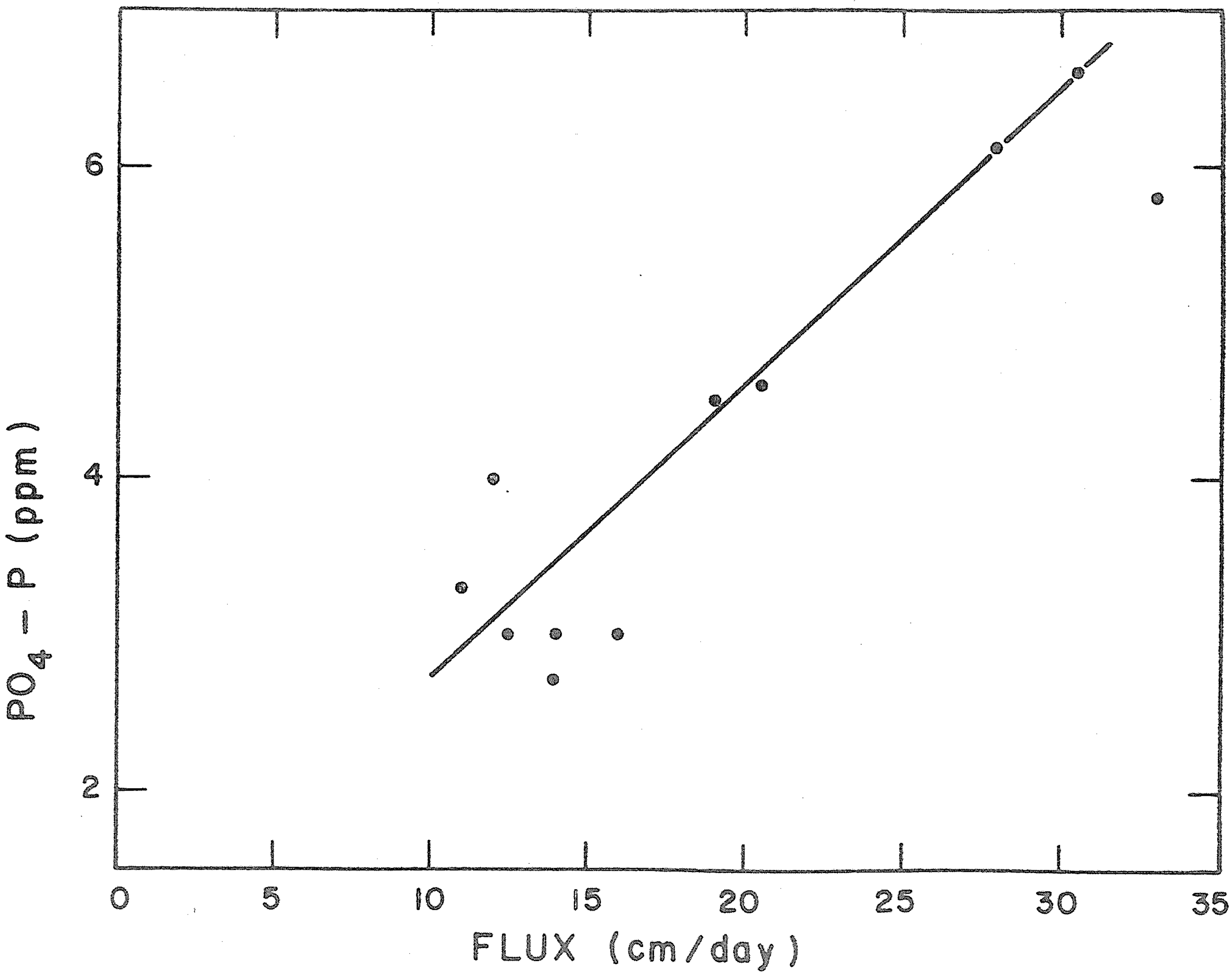


Figure 5. The effect of flux of sewage water through soil columns on the PO_4-P concentration of water collected from columns. PO_4-P of incoming sewage water was 11.8 ppm.

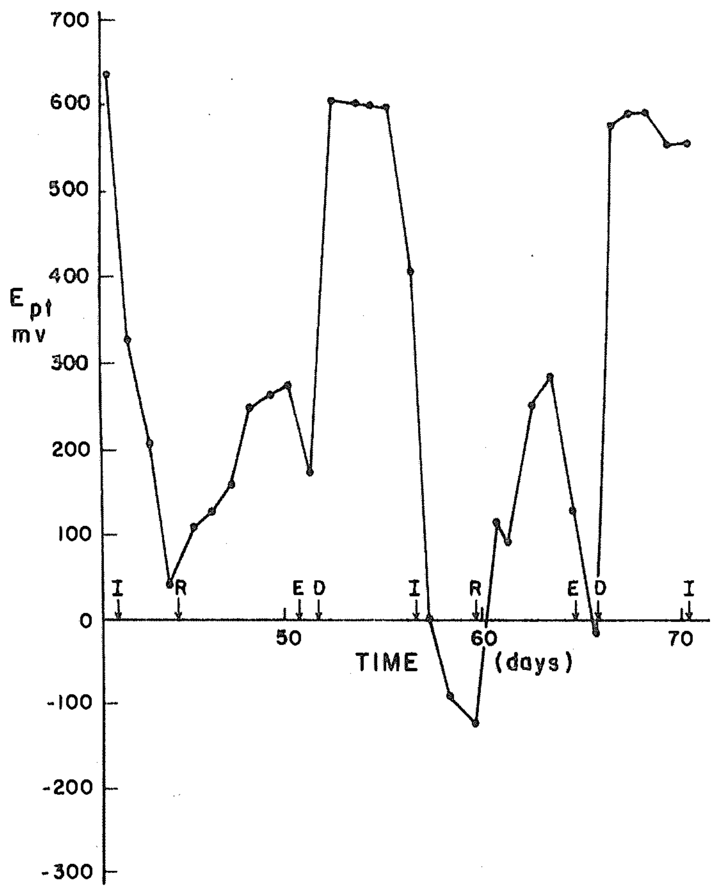


Figure 6. Redox potentials at 2-cm depth in a soil column intermittently flooded with sewage water and recycled column effluent. The I, R, E, and D symbols indicate times when infiltration, recycling, effluent only, and drainage were started, respectively.

TITLE: CHARACTERIZATION OF THE SOIL MICROFLORA AND BIOLOGICAL PROCESSES OCCURRING IN SOIL USED FOR WASTE WATER RENOVATION.

CRIS WORK UNIT: SWC-018-gG-4 CODE NO.: Ariz.-WCL-70-2

INTRODUCTION:

Field research at the Flushing Meadows Project was initiated to determine the nature and mechanism by which biological processes affect the performance and management of soil basins used for reclamation of secondary sewage effluent by means of ground water recharge. The nitrogen in conventionally treated sewage effluent is mostly in the ammonium form. To reclaim the water for recreational and agricultural use, the nitrogen levels must be decreased. The biological process of nitrification and of denitrification is the primary mechanism of nitrogen removal in a soil system. The ammonium must first be nitrified to nitrate by aerobic autotrophic nitrifying bacteria. Then heterotrophic denitrifying bacteria under conditions of low oxygen supply may reduce the nitrogen to gaseous forms that escape to the atmosphere.

The objectives of the present work were 1.) to characterize the microbial environment in the surface soil of the basin in relation to the flooding and drying cycles; 2.) to determine the rates of microbial activity, particularly as they affect nitrogen transformation, in relation to environmental conditions induced by flooding and drying cycles; and 3.) to locate specific zones of such microbial activity in the soil profile, thus providing information for engineering and management of soil basins for maximum nitrogen removal from waste water.

PROCEDURES:

Basin No. 1 at Flushing Meadows was instrumented in late October 1972. All instrumentation will be maintained and data collected for a one year period. This will insure that seasonal effects on the biological efficiency of the soil system, relative to nitrogen removal, are evaluated.

Redox probes (platinum blocked) were buried in the soil at 5 levels: 2, 15, 30, 60 and 90 cm with 3 probes at each level. A single reference electrode was fitted into an anchored float sitting on the soil surface in such a way that the circuit was completed during both floods and dry periods. A multipoint clock mechanism, a pH meter, and a single pen recorder permitted scanning all 15 electrodes once each hour. Periodically, additional redox probes were used to measure redox potentials in the effluent water and at the surface of the soil during the flood. Also, during these periods an O_2-probe was installed and dissolved oxygen levels of the effluent was measured continuously for the entire flooding period.

Duplicate thermocouples were buried at the same depths as the redox probes and in addition were placed above the soil surface to measure both water and air temperature. Thermocouples were scanned once each hour and temperatures recorded.

Gas sampling probes were installed to provide duplicate gas samples from each of the 15, 30, 60 and 90 cm soil depths. The gas probes were stainless steel tubing of 0.6 mm ID to which an 18 Ga. hypodermic needle was silver soldered. A rubber serum cap was placed over the needle to permit gas-tight sampling using a disposable plastic hypodermic syringe.

Soil samples were taken periodically during dry periods with a King tube. Ten cores each from 0-15 cm and 15-30 cm and 5 cores each from 30-60 and 60-90 cm depths were collected. The cores were pooled to provide a single sample of each depth. The following analyses were carried out on the soil samples: soil moisture contents, pH, inorganic forms of nitrogen, numbers of bacteria and fungi, and numbers of nitrifying organisms. In addition soil respiration rates and rates of nitrification were determined.

RESULTS AND DISCUSSION:

The results obtained thus far are representative of winter conditions only. Similar data will be collected for the summer months before the data will be analyzed completely. However, the preliminary results from the winter data justify the following tentative conclusions:

1. Algae in the water and their growth on the soil surface during flooding cycles introduce sufficient oxygen into the water to effect the redox potentials of the surface soil. Diurnal cycles of dissolved oxygen ranging from 4 to 20 ppm have been measured in the effluent.

2. Redox potentials in the soil profile decline rather slowly during flooding, possibly the result of unsaturated flow, trapped air and no demand for O_2.

3. After the flood most of the energy in the system resides at the surface and is used up very rapidly during the dry period. There is virtually no demand of O_2 at lower depths by the end of the dry period.

4. Winter conditions of high suspended solids in the effluent, short days and low temperatures cause slow recovery of redox and probably inhibit nitrification at the beginning of the dry period. This might explain the annual rise in ammonium occurring from February to April.

5. Gas samples of soil atmosphere show that slight amounts of nitrous oxide are produced during the dry period, indicating that denitrification is occurring in anaerobic microsites throughout the soil profile.

6. Numbers of nitrifiers, Nitrosomonus and Nitrobacter, are not limiting nitrification processes in the soil basins. When environmental conditions favor nitrification (dry period) the rates of nitrification are very rapid and complete conversion of ammonium to nitrate occurs in a few days. In laboratory incubation studies at 28^{o} C and 30^{o} C the conversion occurred within 24 to 36 hours.

7. Nitrogen removal in these high rate infiltration systems will be difficult because redox potentials are high and energy levels are very low when nitrate is passing into lower zones at beginning of flood. In surface zones where redox potentials are dropping at

the beginning of the flood, nitrate is being rapidly removed by the infiltration of the effluent. Thus, conditions for denitrification and maximum nitrogen removal do not occur in any zone of the soil profile (0-90 cm) during the flooding period.

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

COOPERATION: J. B. Robinson, visiting scientist, University of Guelph, Guelph, Ontario, Canada

CURRENT TERMINATION DATE: 1975

TITLE: DESIGN AND PERFORMANCE OF TRICKLE IRRIGATION SYSTEMS

CRIS WORK UNIT: SWC-018-gG-4 CODE NO.: Ariz.-WCL 70-3

INTRODUCTION:

The need and objectives for this study are given in the 1970 Annual Report. A method for improving uniformity of water application by varying diameters of a stainless-steel emitter for row-crop usage was developed in 1971. This year the concept of varying emitter sizes was expanded to include a multiple-diameter and -length microtube system for orchard-crop usage.

SUMMARY AND CONCLUSIONS:

Application uniformity from low-pressure trickle irrigation systems can be greatly improved by varying emitter sizes to compensate for friction-induced pressure changes in the lateral pipe. Procedures for design and construction of a multiple-diameter and -length microtube system for orchard-crop usage were developed. Microtubes or spaghetti tubes are short lengths of plastic tubes cut from inexpensive, small-diameter polyethylene tubing. Mean discharge deviations for these simple microtube emitters operated at a constant pressure were from 1.8% to 2.5%. Theoretical performance of a 650-ft lateral, with three emitters per tree and 25 ft between trees, using combinations of two diameters and seven lengths of microtubes, showed a mean deviation of 2.9% and a maximum deviation of ± 5.0% from design discharge. The multiple-diameter and -length microtube system should not be expensive or difficult to produce.

PUBLICATIONS:

1. Myers, Lloyd E., and Bucks, D. A. Uniform irrigation with low-pressure trickle systems. Jour. Irrig. and Drain. Div., Amer. Soc. Civil Engin. Proc. 98(IR 3):341-346. September 1972.

2. Bucks, Dale A., and Myers, Lloyd E. Trickle irrigation -- application uniformity from simple emitters. Trans., Amer. Soc. Agric. Engin. (Submitted for publication).

PERSONNEL: Dale A. Bucks and Lloyd E. Myers.

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

CRIS WORK UNIT: SWC-018-gG-4 CODE NO.: Ariz.-WCL 71-1

INTRODUCTION:

The objective of this research is to improve the water-use efficiency (WUE) of crops and thereby conserve agricultural water supplies. The technique will be to survey a wide range of plant species by subjecting them to a short-term drought, seeking those species with the lowest transpiration ratio (TR) as judged from simultaneous measurements of transpiration and photosynthesis in a controlled environment chamber.

PROCEDURE:

The research will be carried out in a controlled environment room in which a large plant chamber (122 cm × 61 cm × 61 cm) has been built, to substitute for the single-leaf, small chamber described in the 1971 annual report. The top, bottom, and two sides of the chamber are made of 0.1-mm-thick polyvinyl chloride. The door constituting a third side is made of 6.4-mm lucite, and the remaining side is made of wood to accommodate a squirrel-cage blower and heat exchanger coils to provide rapid circulation of cool air through the chamber.

CONTROLLED ENVIRONMENTAL FACTORS:

Air Temperature. The controlled environment room containing the plant chamber can maintain air temperature to $\pm$ 0.2 C over a wide range of temperatures. In the dark the plant chamber is in equilibrium with room temperature. In the light, however, absorption of radiant energy would overheat the chamber. Therefore, a heat exchanger supplied with chilled water is installed behind the blower to recirculate chilled air in the chamber. This method has been found adequate to maintain the plant chamber at the desired level of 30 C (room temperature) when as many as forty-eight

400-watt lamps are on 1.5-m directly above the chamber.

Light. Despite the extremely high light transmission of polyvinyl chloride plastic film, it was not found necessary to make use of a water barrier between the lamps and the plant chamber to help dissipate the infrared rays.

A bank of 48 lamps turned on in a solid block directly above the plant chamber provided an irradiance of 1.7 ly min^{-1} (illuminance 140 kilolux) at the top of the chamber and 0.80 ly min^{-1} (68 kilolux) 61 cm (half way down) from the top of the chamber. Since the saturation light level for stomatal opening is about 65 kilolux, the chamber is fully capable of achieving light levels found in the field in the Southwest, or even higher levels. Therefore, minimal leaf diffusion resistance (R_L) values can be expected when a plant is well watered. A card programmer can be used to raise the light level gradually to simulate a sunrise and therefore not to shock the plant.

Air Flow. Air circulation within the plant chamber is sufficient to maintain a low boundary layer resistance (R_A), as documented later. In front of the inlet from the air handler (squirrel-cage blower), located in the wooden wall at the upper part of the chamber, the velocity is sufficient to cause visible leaf flutter but not buffeting. The circulating air leaves the chamber through a port near the bottom of the chamber.

In addition to the mixing of the air there is a mass flow through the chamber, the air entering through a 10-cm circular pipe extending from the wooden box into the bottom center part of the transparent chamber, and leaving from another pipe of the same diameter oriented vertically in the wooden box. The exit pipe removes air which has previously been in the transparent chamber and has circulated into the adjacent wooden box. Suction for the mass flow comes from a blower attached to the other end of the exit pipe. The blower has a maximum capacity of 744 l/min, adjustable by a gate valve down to a minimal flow of 1.2 l/min, governed by the stalling speed of the rotor in the turbine meter used to measure the flow. An electrical readout of the turbine meter gives a linear calibration curve for frequency of the rotor versus the volumetric flow rate.

Carbon Dioxide (CO_2) Content of the Air: No direct control of CO_2 is available for the plant chamber. However, the room containing the chamber can be maintained to within 10 ppm of the normal level of 350 ppm CO_2 by use of gas masks by personnel entering the room. The air that is sucked into the plant chamber is room air monitored for the absolute level of CO_2 by an infrared gas analyzer (IRGA) calibrated from 0-500 ppm CO_2. In addition, a differential IRGA measures the change in CO_2 between inlet and outlet air streams in the plant chamber (from a subsample of air pumped to the analyzer by a small electric diaphragm pump). The differential IRGA has a range of 0-50 ppm CO_2, readable to 0.5 ppm. The difference in CO_2 multiplied by flow rate through the chamber gives the rate of photosynthesis by the plant, when the soil is sealed off (or respiration in the dark).

Vapor Pressure. In order to greatly increase the precision of measurement and to decrease maintenance time, a dew point hygrometer has been substituted for the micro-psychrometer described in the previous report. Use of a cam switch with solenoids makes possible alternate measurements of the dew point of inlet and outlet air streams from the plant chamber, recorded every 3 minutes on a strip chart. Calculation of transpiration consists of conversion of the dew point difference to vapor pressure and then to water vapor concentration and multiplying this value by the flow rate.

VARIABLE FACTORS:

Soil Water Potential (ψ_T). When the standard soil is irrigated to the "pot capacity" value of 0.39 by volume with half-strength Hoagland nutrient solution, ψ_T is -0.58 bar, consisting of a soil matric potential (ψ_M) of -0.02 bar and a soil osmotic potential (ψ_π) of -0.56 bar. During continued transpiration the decrease in ψ_M is measured with a minimal-displacement transducer tensiometer and the decrease in ψ_π with an in-place salt sensor, provided that the sensitivity of the latter instrument is adequate. Summation of the two values gives ψ_T, an important parameter because it regulates the decrease in leaf water potential when coupled with the evaporative demand. Eventually, ψ_T will be measured by means of soil psychrometers that will give an integrated reading of ψ_T in one measurement.

Leaf Water Potential (ψ_{leaf}). Indirect measurements of ψ_{leaf} are made by following the drought-induced decrease in leaf thickness with a β-ray gauge and then by calibrating the leaf thickness against ψ_{leaf}. The ψ_{leaf} values are measured with a thermocouple psychrometer from readings of a small leaf disc taken from a leaf with a known leaf thickness and relative water content.

RESULTS AND DISCUSSION:

Boundary Layer (R_A). A simulated cotton plant was manufactured of green blotting paper supported by wire and a lucite rod. The plant had 10 leaves with the shape and orientation of those on a living plant. Each leaf was instrumented with a 0.1-mm diameter copper-constantan thermocouple for monitoring the temperature of the evaporating surface of the wetted leaves during a determination of R_A. It was assumed that the water vapor pressure of a thoroughly wetted leaf corresponded to the saturation value for its measured temperature. By maintaining the ambient water vapor pressure at a prescribed value in the plant chamber, a given gradient was established to govern evaporation from the blotter paper, as in the numerator of the following equation:

$$R_A = \frac{\Delta d_v}{E} ,$$

in which Δd_v is the difference in water vapor concentration between blotter leaf and air, in g/cm^3, and E is the evaporation rate, in $g/cm^2/sec$, calculated from the air flow rate through the chamber multiplied by the difference in vapor pressure (converted to vapor concentration) between the inlet and outlet air streams of the plant chamber.

Seven tests under carefully controlled conditions gave the following results for R_A: in low illumination, 0.79 and 0.52 sec/cm; in high illumination (68 kilolux), 0.39, 0.48, 0.74, 0.69, and 0.76 sec/cm, for an average value of 0.62 sec/cm. This value is considered sufficiently low that it will not mask the effect of R_L in determining the transpiration rate. Therefore, stomatal closure and its consequent raising of R_L can be closely correlated with a decrease in transpiration as drought progresses.

Transpiration Rates of Different Plant Species.

Well-watered plants

(1) Under a range of illuminance. In sunflower both transpiration rate and R_L responded to a great range in illuminance as might be expected (Table 1). In the dark, R_L was high (27.9 sec/cm), but fell to the low value of 2.4 sec/cm under high illuminance, as stomates presumably opened wide. Although additional illumination, 68 kilolux (brought about by 48 lamps instead of 24) did lower R_L somewhat, neither R_L value in the light was as low as the 1.1 sec/cm value achieved during a previous test (22 November, Table 2). This suggests that 50 kilolux (measured at the midpoint of the chamber) was saturating for stomatal opening in sunflower.

Although transpiration was 24% greater at an illuminance of 68 kilolux than at 50 kilolux (Table 1), the increase is not much different from the 20% variation in transpiration of well-watered plants from one experiment to the other. For example (Table 2), under the same conditions sunflower transpired at the rate of 224 $g/m^2/hr$ on 22 November as compared to 187 $g/m^2/hr$ on 5 December.

Therefore, it may be concluded that the transpiration data in Table 1 are reasonably consistent with the R_L values in indicating that sunflower transpiration is maximal at an illuminance of 50 kilolux. Some of the variation in transpiration rates may possibly be explained by differences in self-shading due to different plant size; another possibility, considered less likely, is an error in measuring leaf area.

(2) At a given high illuminance. Transpiration on a leaf-area basis was similar for corn, sorghum, and tomato, but much higher for sunflower under comparable conditions (Table 2). R_L values were consistent with the transpiration rates, being about 5 sec/cm for the three species that transpired at about 100 $g/m^2/hr$, and as low as 1 to 2 sec/cm for sunflower during transpiration rates about double those of the other species.

These results confirm data obtained at this Laboratory 5 years ago when transpiration was measured by weight loss (Ehrler and Van Bavel, 1). In the previous experiments sunflower transpired at more than 3 times the rate of lemon, cotton, and bean at a very low level of illuminance (0-7 kilolux) and at twice the rate of cotton and bean under an illuminance of 50-60 kilolux. It is possible that sunflower's higher-than-normal rates of transpiration are due to a more permeable cuticle than that of the normal plant, rather than to a different stomatal opening.

Droughted plants

Both tomato and sunflower responded to drought by reduced transpiration and increased R_L values due to partial stomatal closure (Table 3). It was necessary for the soil water content to be reduced almost to the wilting point before R_L increased appreciably in sunflower (13.2 sec/cm). This value was attained after three days of continued transpiration from a plant in a 7.6-liter pot. Tomato, on the other hand, developed an R_L of 20.9 sec/cm under drought, a value approaching that characteristic of darkness in many plants, and coinciding with a transpiration rate only one-third that of a well-watered plant.

In sunflower (Table 3) there is a definite indication of the kind of response that this research has as its major objective, viz., a greater water-use efficiency, in this instance induced by drought. In both tests, November and December, a drought caused a greater depression of transpiration than of photosynthesis, thus making the water-use efficiency higher (or the transpiration ratio lower).

SUMMARY AND CONCLUSIONS:

A plant chamber has been constructed which permits precise, short-term measurements of the transpiration ratio (the inverse of water-use efficiency) as a plant is subjected to drought. Preliminary tests have been successful, showing a suitably low boundary layer resistance, the achievement of saturation illuminance, at least with sunflower, the ability to measure precisely both transpiration and photosynthesis, and to calculate leaf diffusion resistance values. Species differences already are becoming apparent, since sunflower has been found to transpire at about twice the rate of corn, sorghum, and tomato.

It is concluded that the equipment is suitable for further investigation into the drought responses of plants, with special attention to be paid to characterizing the decrease in soil and plant water potential.

REFERENCES:

1. W. L. Ehrler and C. H. M. van Bavel. Leaf diffusion resistance, illuminance, and transpiration. Plant Physiol. 43:208-214. 1968.

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

CURRENT TERMINATION DATE: 1975

Table 1. Transpiration (E) and leaf diffusion resistance (R_L) of a well-watered sunflower plant as affected by illuminance* in the chamber.

Date	Illuminance (kilolux)	E ($g/m^2/hr$)	R_L (sec/cm)
6 Dec 72	0	16.0	27.9
5 Dec 72	50	187	2.4
5 Dec 72	68	231	1.7

*As measured half-way down from the top of the chamber.

Table 2. Transpiration (E, $g/m^2/hr$), photosynthesis (P, $mg/dm^2/hr$), and leaf diffusion resistance (R_L, sec/cm) of four plant species with freely available soil water, as measured in a plant chamber at an ambient vapor pressure of 15 mb, an air temperature of 30 C, and an illuminance of 50 kilolux.

Species	Date	E	R_L	P
Corn	26 Jul 72	94.5	5.4	-
Corn	24 Nov 72	112	5.6	5.9
Sorghum	2 Aug 72	84.2	6.0	8.2
Tomato	6 Oct 72	102	5.4	-
Sunflower	22 Nov 72	224	1.1	10.5
Sunflower	5 Dec 72	187	2.4	17.3

Table 3. Effect of drought on transpiration, photosynthesis, and leaf diffusion resistance of tomato and sunflower plants,* as measured in the plant chamber.

Species	Date	Soil condition	E	R_L	P
Tomato	6 Oct 72	wet	102	5.4	-
Tomato	6 Oct 72	dry	33.7	20.9	-
Sunflower	22 Nov 72	wet	224	1.2	10.5
Sunflower	21 Nov 72	dry	167	2.6	9.2
Sunflower	5 Dec 72	wet	187	2.4	17.3
Sunflower	8 Dec 72	dry	63.2	13.2	9.6

*Units the same as those in Table 1; environmental conditions were: air temperature, 30 C; vapor pressure, 15 mb; illuminance, 50 kilolux.

TITLE: THE EFFECT OF IRRIGATION REGIMES AND EARLY CUT-OFF OF IRRIGATION WATER ON THE YIELD OF HIGH POPULATION COTTON

CRIS WORK UNIT: SWC-018-gG4 CODE NO.: Ariz.-WCL 71-2

INTRODUCTION:

See Annual Report, 1971.

OBJECTIVES:

1. To evaluate the effects of various irrigation regimes on recommended varieties of high-population cotton.

2. To determine the effect of an early cut-off of irrigation water on the yield of high-population cotton.

PROCEDURE:

The experiment was located on Field C-1 at the University of Arizona Cotton Research Center, Phoenix, Arizona. The field had been in cotton in 1969, barley in the winter of '69-'70, fallow during the summer of 1970, barley again in the winter of '70-'71, and cotton in 1971. The field was plowed on 6 January 1972, ripped on 14 January, and 30 tons/acre of manure applied on 18 January. The field was furrowed out into 40-inch furrows and the pre-plant irrigation was given on 6 March.

A weed control mixture of Treflan and Karmex was incorporated into the furrows with a "Lilliston" on 14 March.

Two-thirds of the furrows were shaped into beds with a "Side-winder" and bed-shaper for the high plant populations, two rows to a bed, as per plot design. The remaining one-third of the furrows were left to accommodate single row plantings of 20,000 and 40,000 plants/acre.

Deltapine 16 and Pima S-4 were planted on 29 March and a germination irrigation given on 30 March. Each irrigation treatment included 4 beds of Pima S-4, 4 beds of Deltapine 16, and 4 furrows random-planted to the two varieties. This sequence was randomly repeated three times in each replication to accommodate the three irrigation treatments.

Plants were thinned to their respective populations around 10 May. At the same time, yield measurement areas were marked off in each respective plot and a few selected tagging areas were also marked off. The yield areas contained either 2 rows or 2 beds each 10 ft long while tagging areas were 6 ft long, all with the proper number of plants within these areas, as per population scheme. The spacing variables consisted of 6 spacings of 20,000 and 40,000 plants per acre in single 40-inch rows, and 40,000, 60,000, 80,000, and 100,000 plants per acre in 40-inch beds, 2 rows to a bed. Generally, measurement plots were the inner two rows, or beds, of 4-row, or 4-bed, plots. In a few plots, stands were not ideal and buffer rows were substituted to obtain the designated yield area. Buffer rows and plants at the end of each plot were thinned to correspond to the specific population treatment.

Timing of irrigations was based on soil moisture samples, along with visual plant symptoms on the medium and wet treatments.

RESULTS AND DISCUSSION:

In nearly all plots, a good stand was obtained and plants developed quite rapidly, as mean temperatures remained above normal from planting date.

Because of the rapid plant development, flowering commenced 10 days earlier than usual; hence, tagging began on 11 June and continued through 16 September. A few days of tagging information were lost due to insecticide regulations barring entry to the field. Again, as in 1971, most lost information occurred at times when flower production was at a minimum.

On the medium and wet treatments, irrigations were given during the major blossoming period when the soil was somewhat drier than desired. For the wet treatment, the average soil moisture depletion in the top 3 ft of soil before irrigation was 74%. For the medium treatment, depletion was 83%.

The wet treatment was given 8 irrigations, the medium, 6, and the dry, 4. The dry treatment received its final irrigation on 25 July. This treatment was then designated as an early cut-off situation to replace the original plan of dividing the field into halves. By not dividing the field in two, replications were increased from 4 to 8 to compensate for field variability.

Insect control was excellent throughout the season. Although 16 insecticide applications were given, there was no buildup of insect population.

Table 1 shows the mean plot weights of Dpl-16 seed cotton and each weight represents the mean of 8 plots. Both irrigation and population differences were large enough to be statistically significant at the 1% level. The dry treatments were significantly lower than the wet and medium. The data shows that populations over 60,000 had no yield benefits and even indicated reduced production. Increasing the population from 20,000 to 40,000 in a 40-inch row was not beneficial, but planting 40,000 plants in a bed increased production enough to be statistically significant for the wet and medium irrigation treatments. The increase averaged nine percent. There was a trend of reduced production from wet to medium, but generally no significant differences. This probably was because all irrigation treatments were drier than was planned. Lint cotton yields for the wet and medium irrigation treatments averaged over 3¼ bales per acre.

The number of bolls increased as populations increased, but the weight per boll decreased (Table 2). The decreased boll weight was sufficient to cause yield reductions for the highest population treatments. For the dry treatment, the number of bolls did not change much with population changes, but weight per boll decreased with increased populations. For the medium treatment, the number of bolls were as great as the wet treatment, but the weight per boll was decreased enough to cause the decreased production trend. When identical populations were planted in beds and rows, no increases in production resulted for the 20,000 and 40,000 populations. Rows had larger bolls; however, bed plantings resulted in more bolls for the wet and medium irrigations.

The percentage of cotton that can be classified as late set was greater this year than in most prior years. Table 3 shows that nearly 40% of the wetter treatment yield was late set. Late-set yield was grown from blossoms opening after 1 August. This was a year when an August cut-out was less pronounced; i.e., the plants seemed to continue to produce. Less late production resulted from the dry treatment; however, its last irrigation was given on 25 July, thus reducing the plant's ability to continue producing. There was no clear-cut indication that density of population had any effect on hastening production.

For Pima S-4, differences in yield between the wet and medium regimes were not large enough to be statistically significant, but population differences were. Production increased with increased populations, principally when beds were utilized. These increases were the result of increased number of bolls coupled with small decrease in boll sizes (Table 5). The yield measurements for the dry treatment are not included in the analysis because of the plot variability; however, Table 5 shows the drastic decrease in number of bolls and weight per boll for the dry treatment.

When late-season production is considered (Table 6), it is obvious that about 30% of the cotton can be classified as late-season production, with a lesser percentage of late-season production for the drier treatments. Late season for Pima S-4 was for blossoms opening after 15 August.

1971 data on Pima S-4 is included in this report since cotton was not processed when last year's report was prepared. Table 7 shows the yield for 3 populations and 3 irrigation treatments. Irrigations were statistically significant but, unlike 1972, populations were not. The number of bolls were increased with increased populations (Table 8), but reduced boll-size nullified higher production possibilities. The first killing frost came two weeks earlier than was normal and undoubtedly decreased the chances for late-season blossoms to develop on the wetter treatments. Regardless of the early frost, over 25% of the production was from blossoms opening after 15 August, thus late set. It seems questionable whether the percentage of late set was changed by varying populations.

Table 10 shows the effect of an early season cut-off of irrigation water on yield, number and weight of bolls. The lower half of each plot was given its last irrigation in July, then irrigations were continued in a normal way on the upper half, up to September. Though drying up the lower half made yield from plots very erratic because of residual moisture, it is obvious from picking data that yields were reduced between 40% and 50% in spite of the early frost. The yield reduction was the result of decreased number of bolls and reduced boll weight. The number of bolls was reduced by an average of 40%.

SUMMARY AND CONCLUSIONS:

In 1972, Dpl-16 and Pima S-4 were produced with three irrigations and six population variables in an 8-replication study. Dpl-16 yields were increased by increasing populations up to 60,000. Increasing the population from 20,000 to 40,000 in a 40-inch row did not increase yield. A definite reduction in yield resulted for the dry regime for all populations, and a slightly reduced trend was observed for the medium treatment over the wet. The number of bolls increased with increased moisture and increased population, but weight per boll decreased with drier moisture regimes and increased populations. Nearly 40% of the wet treatment yield could be considered late-season set, if late season is considered after 1 August.

For Pima S-4 in 1972, yield differences between wet and medium treatments were small, but population differences were large enough to be statistically significant. Yields increased as population increased, resulting in increased number of bolls and only small decrease in boll sizes. Trends showed that reducing water reduces production, number of bolls, and weight per boll. About 30% of the production was late-season production; i.e., after 15 August, for the Pima S-4.

Studies on Pima S-4 in 1971, on three irrigation treatments and three populations, showed reduced yield with reduced water, but no effect due to varying populations. The number of bolls were increased by increasing the population, but boll weights were drastically reduced, nullifying any advantage in production. The early frost could have been a factor. Irrigation treatment advantages were due to increased number of bolls and boll weight. Twenty-five percent of the production came from blossoms opening after 15 August, regardless of the early frost. When irrigations were cut off in July, yields were reduced from 40% to 50%. The average number of bolls were decreased about 40%.

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

CURRENT TERMINATION DATE: December 1973.

Table 1. Mean seed cotton weight in grams, for eight replications of Deltapine-16 for three irrigation treatments and six populations - 1972.

Irrigation	Population						
	20M	40M row	40M bed	60M	80M	100M	Mean
Wet	3024	2978	3387	3239	3138	3090	3143
Medium	2956	2857	3127	3125	3016	2977	3009
Dry	2088	2140	2036	2020	1843	1753	1980

Irrigation -- sig. 1% LSD 188

Population -- sig. 1% LSD 169

Table 2. Mean number of bolls per plot and average weight per boll of Dpl-16 - 1972.

Irrigation	Population					
	20M	40M row	40M bed	60M	80M	100M
Wet	656 (4.61)[1/]	659 (4.52)	780 (4.34)	758 (4.27)	745 (4.27)	801 (3.86)
Medium	680 (4.21)	678 (4.21)	786 (3.98)	795 (3.93)	759 (3.96)	823 (3.62)
Dry	477 (3.98)	520 (3.94)	519 (3.69)	526 (3.61)	514 (3.47)	510 (3.11)

1/ Weight per boll in grams

Table 3. Percentage of Dpl-16 production classified as late season set - 1972.

Irrigation	Population					
	20M	40M row	40M bed	60M	80M	100M
Wet	33.6	33.5	41.2	33.7	43.1	40.7
Medium	39.7	34.7	41.6	40.3	40.2	41.8
Dry	12.4	18.7	19.0	17.6	18.8	22.0

Table 4. Mean seed cotton weight in grams, for eight replications of Pima S-4 - 1972.

Irrigation	Population					
	20M	40M row	40M bed	60M	80M	Mean
Wet	1925	2191	2266	2263	2522	2233
Medium	2081	2078	2070	2282	2346	2171
Dry 1/	1343	1472	1411	1552	1418	------

Irrigation -- NS

Population -- sig. 1% LSD 176

1/ Considerable variability between plots. Not included in statistical analysis.

Table 5. Mean number of bolls per plot and average weight per boll of Pima S-4 - 1972.

Irrigation	Population				
	20M	40M row	40M bed	60M	80M
Wet	728 (2.65)1/	784 (2.71)	837 (2.71)	840 (2.54)	913 (2.63)
Medium	714 (2.71)	776 (2.68)	802 (2.58)	841 (2.51)	946 (2.48)
Dry	544 (2.47)	603 (2.44)	594 (2.37)	507 (2.22)	518 (2.18)

1/ Weight per boll in grams.

Table 6. Percentage of Pima S-4 production classified as late season set - 1972.

Irrigation	Population				
	20M	40M row	40M bed	60M	80M
Wet	34.5	32.1	31.8	36.0	30.0
Medium	28.0	22.8	30.8	29.2	27.0
Dry	20.7	20.8	23.1	24.4	26.0

Table 7. Mean seed cotton weight in grams, for four replications of Pima S-4 - 1971.

Irrigation	Population		
	20M	40M	80M
Wet	6488	6280	6612
Medium	6097	5960	5717
Dry	5113	5672	5841

Irrigation -- sig. 1% LSD 88.0

Population -- NS

Table 8. Mean number of bolls per plot and average weight per boll of Pima S-4 - 1971.

Irrigation	Population		
	20M	40M	80M
Wet	2441 (2.66)[1/]	2622 (2.40)	2814 (2.35)
Medium	2395 (2.55)	2555 (2.33)	2554 (2.24)
Dry	2140 (2.39)	2492 (2.28)	2635 (2.22)

1/ Weight per boll in grams.

Table 9. Percentage of Pima S-4 production from flowers opening after 15 August 1971.

Irrigation	Population		
	20M	40M	80M
Wet	20.6	21.5	26.9
Medium	25.3	31.9	27.6
Dry	16.2	16.9	20.5

Table 10. Effect of early irrigation cutoff[1/] for Pima S-4, 1971.

Population	Irrigation					
	WET		MEDIUM		DRY	
	Upper	Lower	Upper	Lower	Upper	Lower
			COTTON SEED WEIGHT (grams)			
20M	6488	3684	6097	2571	5113	3352
40M	6280	4206	5960	2960	5672	2673
80M	6612	3977	5717	2864	5841	3389
			NUMBER OF BOLLS			
20M	2441	1548	2395	1196	2140	1555
40M	2622	1788	2555	1397	2492	1315
80M	2814	1636	2554	1430	2635	1723
			WEIGHT PER BOLL (grams)			
20M	2.66	2.39	2.55	2.15	2.39	2.16
40M	2.40	2.35	2.33	2.12	2.28	2.03
80M	2.35	2.43	2.24	2.00	2.22	1.97

[1/] Last irrigation on lower half -- wet, July 28; medium, July 20; dry, July 21.

TITLE: HEAT AND LIGHT TRANSFER IN PONDS

CRIS WORK UNIT: SWC-018-gG-4 CODE NO.: Ariz.-WCL-71-3

The intensive measurement of air and water temperatures and the solar and thermal radiation fluxes incident upon, within, and leaving a small pond of tertiary treated sewage water begun in May 1971 was terminated in March of this year. Much time was then spent on the analysis of these data and several technical articles were prepared for publication. Two of these dealt with the temperature structure of water bodies and resulted in the development of a new formulation for the concept of thermal stability and the verification of a turbulent mechanism for the downward transport of heat. The other two dealt with the absorption of solar radiation in the water and the resultant implications for algal photosynthesis. A mathematical model of this relationship was developed that led to the establishment of several general criteria for the planning and operation of man-made systems of aqua-culture. A more detailed description of each of these subjects is given below.

Idso, S. B., and Foster, J. M. Light and photosynthesis in phytoplanktonic ecosystems. Ecology (Submitted for publication).

To illuminate the many aspects of the light-forced photosynthetic behavior of phytoplanktonic ecosystems, the photosynthetic capacities of such systems were considered under the assumption that all other environmental factors were constant or invariable. An equation was then derived that predicts the relative rate of instantaneous integral photosynthesis for such generalized phytoplanktonic ecosystems in terms of chlorophyll a concentration, light extinction coefficient due to non-chlorophyllous suspended material (tripton), and the rate of increase in light extinction coefficient due to unit increase in chlorophyll a concentration. Experimental work was described that yielded a determination of the value of this latter parameter and allowed the formation of a family of curves depicting the interrelations between the other two factors and the relative photosynthetic rate.

Experimental work was also described which yielded an *in situ* evaluation of the photosynthetic response of certain freshwater phytoplankton to light intensity. This information, along with similar information for two other characteristic types of response, was used to develop several equations for predicting the actual rate of instantaneous integral photosynthesis as a function of subsurface light intensity, chlorophyll *a* concentration, light extinction coefficient, and the photosynthetic efficiency of the phytoplankton at optimum light intensity. These equations were then used to calculate the diurnal trends of instantaneous integral photosynthesis for several different latitudes and seasons and finally the day-rate integrals of photosynthesis as a function of time of year at several latitudes.

The results of these investigations were lastly applied to the problem of intensive aqua-culture in man-made systems. Several general criteria were developed that may aid in both the planning and operation of such projects.

Idso, S. B., and Gilbert, R. G. On the universality of the Poole and Atkins Secchi disk-light extinction equation. J. Appl. Ecol. (Submitted for publication).

It was demonstrated that the Poole and Atkins equation relating light extinction coefficient (K) to Secchi disk depth (Z_{SD}) via the relation $K = 1.7\ (Z_{SD})^{-1}$ may be used successfully over a range of Secchi disk depths extending from 0.09 m to 35 m.

Idso, S. B. On the concept of lake stability. Limnol. Oceanog. (Submitted for publication).

A new equation was derived to represent the limnological concept of lake stability. It was shown to be more meaningful than the previous mathematical formulation of this concept in that the classical formulation supplied no information on the variation of stability with depth and could not be combined directly with the mathematical expression for the work of the wind concept to yield a similar representation of the total work function.

Idso, S. B., and Cole, G. A. Studies on a Kentucky Knobs Lake. V. Some aspects of the vertical transport of heat in the hypolimnion. J. Ecol. (In press).

Analyses of two time series of temperature profiles obtained in Tom Wallace Lake, Kentucky, reinforced the validity of Hutchinson's (Ecol. Monogr. 11:21-60) technique for obtaining the transport of heat in the hypolimnion as one applying to a real heat transfer mechanism in bodies of water well sheltered from the wind. For the few such lakes that have been similarly treated, the clinolimnetic coefficient of turbulence was found to be inversely related to clinolimnetic volume. For lakes more exposed to the wind, however, turbulence was found to be more directly related to surface area. For lakes of this type Hutchinson's technique requires an enormous number of data in order to average out the intermittent and irregular effects of the seiche-induced transfer of heat.

Turbulence calculations were also made by the procedure of Dutton and Bryson (Limnol. Oceanog. 7:80-97). The resulting clinolimnetic turbulence coefficient for Tom Wallace Lake was 30% greater than that derived by Hutchinson's technique. However, it was shown that Dutton and Bryson's technique was not completely consistent with certain experimental observations, and that this fair agreement was largely fortuitous.

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

TITLE: MEASUREMENT AND PREDICTION OF THE SOLUBILITY BEHAVIOR OF THE CALCIUM MINERAL CONSTITUENTS OF SOILS

CRIS WORK UNIT: SWC-018-gG-4 CODE No.: Ariz.-WCL 71-4

INTRODUCTION:

The importance of the Ca^{2+} originating from the dissolution of Ca-minerals in soils has been discussed in the 1970 and 1971 Annual Reports.

Solubility measurements of gypsum ($CaSO_4 \cdot 2H_2O$) were continued in the more concentrated salt solutions to study the basic process of the dissolution of solids by water. Because of some misunderstanding in the use of and interpretation of the principle of solubility and solubility products, a report was put out to clarify some of the computations involved in defining the thermodynamic solubility constant and the measurement of solubility when ionic association is present.

It was also found possible to apply the ion association model to the sodium and calcium exchange phenomenon in the sulfate and chloride soil systems. Manuscripts (1) and (2) cited in the References section elaborate on the two preceding subject matters.

RESULTS AND DISCUSSION:

The results of gypsum solubility in concentrations NaCl, $NaNO_3$, $NaClO_4$, and NaOAc are presented in Figure 1. The differences in solubility in the various salt solutions have been explained on basis of the interactions of the Ca^{2+} with the anion (Nakayama, 3). At 1 $\underline{M}$ salt concentration and higher, however, the theory developed for the less concentrated solutions was not applicable. Additional modifications to the original theory, including water activity, ion hydration, and modification of ion-activity function, were tested, but a complete treatment to account for the solubility of gypsum both in dilute and concentrated solutions has not been successful so far.

Gypsum solubility increased to a maximum and then decreased as a function of increasing salt concentration for the different salts (Figure 1). In the case of NaOAc, the limit in the solubility of NaOAc was reached before a minimum in gypsum solubility was reached.

SUMMARY:

The solubility of gypsum decreased at the higher salt concentrations. Theoretical treatment for explaining this solubility behavior was successful only up to 1 M electrolyte concentration. The solubility theory needs further refinement to explain solid solubility at the high salt concentrations.

REFERENCES:

1. Nakayama, F. S. On solubility and solubility product constants. Soil Sci. Soc. Amer. Proc. (submitted for publication, 1972).

2. Nakayama, F. S. Evaluation of the sodium-calcium exchange constants in the chloride- and sulfate-soil systems based on the ionic association model (approved by National Technical Editor; to be submitted to Soil Sci. Soc. Amer. Proc., 1973).

3. Nakayama, F. S. Calcium complexing and the enhanced solubility of gypsum in concentrated sodium-salt solutions. Soil Sci. Soc. Amer. Proc. 35:881-883. 1971.

PERSONNEL: F. S. Nakayama and B. A. Rasnick

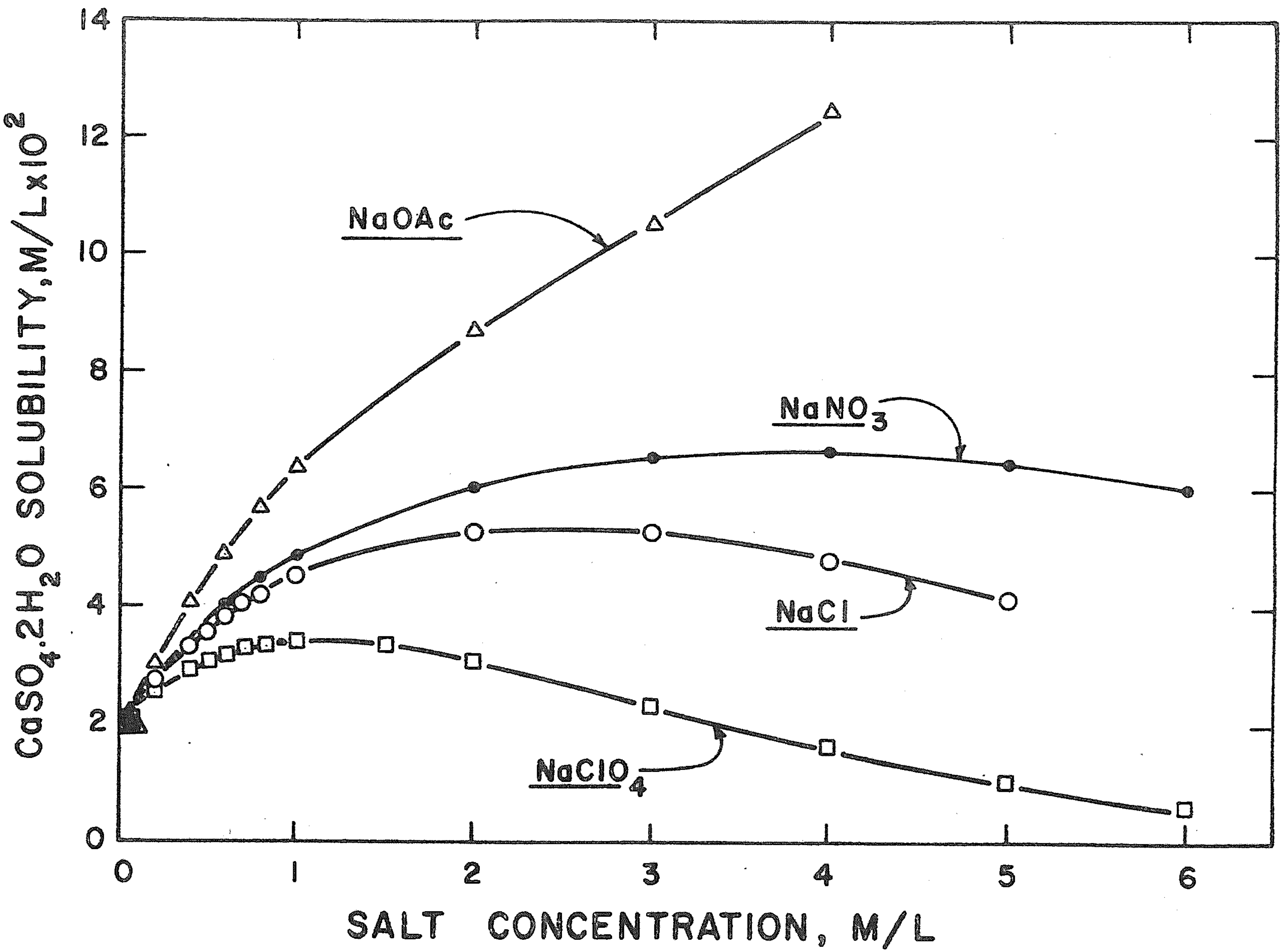


Figure 1. Solubility of gypsum ($CaSO_4 \cdot 2H_2O$) in high salt concentrations.

TITLE: WATER VAPOR MOVEMENT THROUGH MULCHES UNDER FIELD CONDITIONS

CRIS WORK UNIT: SWC-018-gG-4 CODE NO.: Ariz.-WCL 71-5

The project was initiated to evaluate the relative contribution of molecular diffusion and mass flow to the movement of water vapor through mulches under field conditions. This objective has been realized, and the details of the experiment are written in the manuscript entitled "Water Vapor Movement Through Mulches Under Field Conditions" by B. A. Kimball which has been submitted to the Soil Science Society of America Proceedings.

During the experiment, the loss of water vapor through 0.5-, 1-, and 2-cm depths of waterproofed mulches was measured under field conditions with lysimeters. Concurrent measurements of wind velocities, air vapor pressures, and temperatures at the moist soil-mulch interfaces permitted calculations of effective diffusion coefficients to be made. The average effective diffusion coefficient for afternoon periods was found to be 1.26 times greater than the molecular diffusion coefficient. This figure could have been as low as 0.90 or as high as 1.63 if possible systematic errors were additive. Therefore, it was concluded that mass flow processes contribute significantly to the movement of water vapor during evaporation, more so than has generally been presumed.

PERSONNEL: B. A. Kimball

CURRENT TERMINATION DATE: June 1973

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

CRIS WORK UNIT: SWC-018-gG4 CODE NO.: Ariz.-WCL-71-6

INTRODUCTION:

Long range durability and efficiency studies, initiated in 1970 and 1971 using SSP foamed butyl, mini-vaps, foamed wax blocks, and two continuous layers of wax, were continued during 1972. (See 1971 Annual Report.) Also studied were three new wax covers consisting of granular wax, plain wax blocks, and wax blocks covered with charcoal. These three were chosen in order to evaluate the various methods of application.

The different evaporation rates of the Young pans, stock tank #2, and the pond were monitored, and relationships compared with previous records.

A summary of all previous evaporation reduction studies up to mid 1972 was compiled and submitted to the Journal of the Irrigation and Drainage Division of the American Society of Civil Engineers for publication.

PROCEDURE:

Evaluation of the various treatments was the same as in previous years, the procedure being to compare evaporation from a treated tank to that from an identical untreated tank. The mini-vaps, SSP foamed butyl, and granular wax were tested at the laboratory site. The granular wax was applied at a rate of 2 lb/yd^2 to tank #4. This amounted to 8.25 pounds total, and provided a complete cover under calm wind conditions.

Tested at the Granite Reef site were the covers of foamed wax blocks and the two continuous layers of wax on tanks #1 and #4, as well as the new covers of plain wax blocks and charcoal-covered wax blocks on tanks #3 and #5, respectively. The covers on tanks #3 and #5 consisted of four identical 125^{o} melting point wax blocks about 10" x 20" x 1½" in size. Before application, the four blocks on tank #5 were covered with a layer of powdered charcoal to darken the surface.

Evaporation relationships between the Young pans, tank #2 and the pond were determined from evaporation measurements as in the past.

RESULTS AND DISCUSSION:

A. Laboratory Studies.

The efficiency of the SSP foamed butyl cover continued to decrease slightly during 1972. Covering about 80% of the surface area, this cover reduced evaporation 74% in 1970, 67% in 1971, and 63% in 1972. It appears the cover is weathering slowly; however, varying climatological conditions could account for part of this slight reduction in efficiency.

The apparent increase in efficiency of the mini-vaps to 27% in 1971 did not continue in 1972, as efficiency dropped to 22%. Again, climatological factors may cause some reduction but weathering is probably the main cause of the decrease in efficiency.

The granular wax was not applied until late in the year and only a small amount of data is usable due to numerous rainstorms. The average efficiency based on this data is 30%. Longer exposure will be required to properly evaluate this material.

B. Granite Reef Studies.

The overall evaporation reduction efficiency of the foamed wax blocks and the two continuous layers of wax remaining on the exposed wall tanks from last year increased slightly; the averages now being 38%, 78%, and 90% for the foamed wax blocks, the 120^{o}-135^{o} wax layer, and the 120^{o}-125^{o} wax layer, respectively.

The 125^{o} charcoal-covered wax blocks on tank #5 melted within less than a month and covered the entire surface. Evaporation reduction efficiency averaged 71% for the 7 months of treatment. The plain 125^{o} wax blocks on tank #3 melted very slowly and never did cover more than about 40% of the surface area. Evaporation reduction efficiency averaged only 15% over the same 7-month period, thus showing the importance of the darker color and faster melting.

C. Evaporation Relationships.

The ratio of the evaporation rates from the north and south Young pans, respectively, changed significantly during the last half of 1972. This ratio averaged 0.95 for all previous years and the first half of 1972, with monthly values ranging from 0.87 to 1.04. The ratio then gradually changed until it reached 1.15 for December, and averaged 1.00 for the year. The cause of this change was not evident after visual inspection of the pans and their surroundings.

A comparison of evaporation from tank #2 to that from each of the Young pans shows both ratios to be higher during 1972 than for previous years. The ratio involving the south pan exhibits the greatest change.

The ratios of evaporation from the pond and the Young pans were also higher during 1972. However, the waterstage recorder malfunctioned and data were available for only the first 9 months of the year.

SUMMARY AND CONCLUSIONS:

The evaporation reduction efficiency of a foamed butyl cover has decreased each of the last two years from 74% in 1970, to 67% in 1971, to 63% in 1972, with 80% of the surface covered. This reduction in efficiency is probably due to weathering of the surface. The efficiency of a commercial plastic material called mini-vaps also decreased, from 27% in 1971 to 22% in 1972. Again, weathering was probably the main reason for the reduction in efficiency, although varying climatological factors could cause some variation in efficiency from one year to the next.

The overall efficiency of three wax treatments at the Granite Reef test site increased slightly during 1972. These covers, consisting of (1) foamed wax blocks, (2) a continuous layer of

120°-125° melting point wax, and (3) a continuous layer of 120°-135° melting point wax have reduced evaporation by 38, 78, and 90%, respectively, during the past 3 years.

Three methods of applying wax to the water surface of a stock tank were tested. Two of the methods were similar in that four blocks of wax with a melting point of 125° were placed on the surface of each of two tanks. However, the surface of the four blocks on one of the tanks was covered with powdered charcoal. The four charcoal-covered blocks melted within a couple of weeks and covered the entire surface area. The evaporation reduction efficiency of this cover averaged 71% over the 7-month study period. The four blocks on the other tank melted slightly but never covered more than 40% of the surface area, and reduced evaporation by only 15% during the same 7-month period.

High-melting-point granular wax was applied to the water surface until a complete cover was maintained in the third method of application. This treatment did not melt and reduced evaporation by 30% during the last part of 1972.

The ratios of evaporation from the pond and tanks to that from the two Young pans were generally higher during 1972 than those calculated for previous years. There was also a shift in the relationship of evaporation between the two Young pans. All previous data indicated the south pan evaporated at a higher rate than the north pan. This relationship was reversed during the last 6 months of 1972 and no apparent cause has been determined.

PERSONNEL: Keith R. Cooley

CURRENT TERMINATION DATE: December 1972

TITLE: ONE-DIMENSIONAL FLOW IN SCALED HETEROGENEOUS POROUS MEDIA

CRIS WORK UNIT: SWC-018-gG-4 CODE NO.: Ariz.-WCL 71-9

Infiltration into a porous medium in which the hydraulic conductivity increases with depth is shown to approach at quite early times a limiting flux condition. This condition is defined by a pressure head profile in the saturated zone becoming tangential to the water entry value profile. Equations are presented enabling the values of the limiting flux (f_ℓ) and the elevation of the point of contact (z_ℓ) to be calculated in terms of the material properties and the boundary conditions. Below z_ℓ an unsaturated zone exists and wetting up in this zone continues under the condition of limiting flux. A method is presented whereby the pressure and water content profiles for this zone can be determined. A paper has been accepted for publication on this material (Watson, Perrens, and Whisler, 4). The material in the 1971 Annual Report has been published in references 1-3.

REFERENCES:

1. Watson, K. K., and F. D. Whisler. Numerical analysis of drainage of a heterogeneous porous medium. Soil Sci. Soc. Amer. Proc. 36:251-256. 1972.

2. Whisler, F. D., and K. K. Watson. The numerical analysis of flow in heterogeneous porous media, Vol. I, pp. 245-256, Proc. Symposium on Fundamentals of Transport Phenomena in Porous Media, Guelph, Ontario, Canada, 1972.

3. Whisler, F. D., K. K. Watson, and S. J. Perrens. The numerical analysis of infiltration into heterogeneous porous media. Soil Sci. Soc. Amer. Proc. 36:868-874. 1972.

4. Watson, K. K., S. J. Perrens, and F. D. Whisler. A limiting flux condition in infiltration into heterogeneous porous media. Soil Sci. Soc. Amer. Proc. 1973. (in press)

PERSONNEL: Frank D. Whisler

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

CRIS WORK UNIT: SWC-018-gG-4 CODE NO.: Ariz.-WCL 71-11

INTRODUCTION:

The objectives of this study have been covered in the 1971 Annual Report.

Further microscopic examination of plugged orifices in other types of trickle emitters showed that a combination of suspended solids and of crystallized materials which originated from the dissolved phase made up the obstructions. As a consequence of the microscopic analysis and the hypothesis that a major part of the clogging problem can be prevented by the proper filtration of the irrigation, a separate research outline has been initiated by others (Bucks, D. A., "Design and Performance of Trickle Irrigation Systems," WCL 70-3).

Investigation into the dissolution property of various mineral acids relative to gypsum ($CaSO_4.2H_2O$) was continued further at higher acid concentrations. In the course of this and related experiments, it was found necessary to develop a method for determining sulfate (SO_4) which would decrease the time required for analysis and which would also have an equivalent sensitivity and accuracy as the standard method.

RESULTS AND DISCUSSION:

1. Gypsum solubility in acids. Further distinction of the solubility behavior of gypsum in HNO_3, HCl, $HClO_4$, and HOAc was evident at the higher acid concentrations (Figure 1). Gypsum solubility increased to a unique maximum for HNO_3, HCl, and $HClO_4$, and then decreased as the acid concentration increased. Acetic acid, HOAc, unlike its salt NaOAc, did not dissolve much gypsum. This behavior is most likely due to the limited dissociation of the HOAc molecule in water, even though from previous studies the

interaction between the acetate ion OAc^- and Ca^{2+} to form $CaOAc^+$ is greater than that for NO_3^- or Cl^-.

2. Sulfate analysis. The nitrochromeazo titrimetric method (Basargin, 1) was modified and was tested with the standard method for the determination of sulfate in irrigation and well water, sewage effluent, and soil-water extracts. By using NH_4F and low pH (1.7-2.0) to avoid Ca^{2+} and other heavy metal interference, and by titrating in an acetone-water medium, reliable titration endpoint could be obtained. The method was applicable to a variety of aqueous samples with salinity ranging from 500 to 32,000 ppm. The procedure required only a few minutes to run compared to the standard gravimetric method requiring at least 1-1/2 days to complete. It also required only one-fifth the sample volume. Another advantage of the nitrochromeazo technique was the elimination of sample pretreatment with ion exchange resin as required by other titrimetric method. A manuscript covering this work has been prepared (Rasnick and Nakayama, 2)

REFERENCES:

1. Basargin, N. N., and T. G. Akimova. Rapid titrimetric determination of sulfate ions in fertilizers with the new indicator nitrochromeazo. Agrokhim. 5:122-125. 1967.

2. Rasnick, B. A., and F. S. Nakayama. Nitrochromeazo titrimetric determination of sulfate in irrigation and well-water, soil extract, and sewage effluent. 1972.

PERSONNEL: F. S. Nakayama and B. A. Rasnick

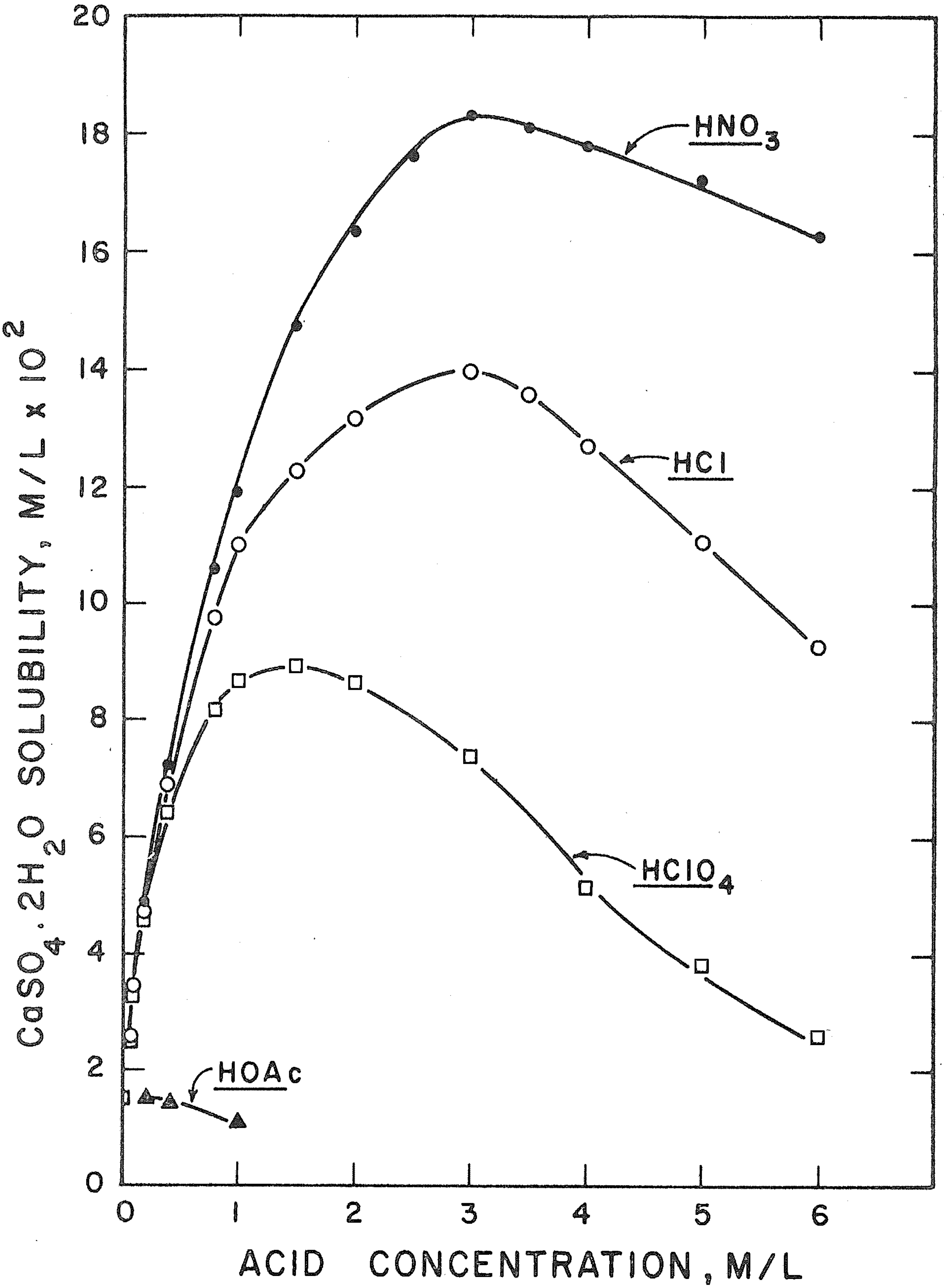


Figure 1. Solubility of gypsum ($CaSO_4 . 2H_2O$) in high acid concentrations.

TITLE: LOWER COST WATER HARVESTING SYSTEMS

CRIS WORK UNIT: SWC-018-gG4 CODE NO.: Ariz.-WCL-71-12

INTRODUCTION:

Measurements of rainfall and runoff were continued on the large watersheds at the Monument Tank test site, on the plots at the Granite Reef testing site, and at the Seneca catchment. Evaluation of the weathering performance of low-cost soil-stabilizer and water-repellent treatments on small test plots at Granite Reef were continued.

Preliminary data analysis and interpretation of rainfall-runoff relations has been completed for all the treatments on the large plots at the Granite Reef test site.

PART I. GRANITE REEF TESTING SITE

Rainfall during 1972 totaled 243.8 mm. All of the rainfall occurred after 6 June 1972 with 80% (201 mm) coming the last 3 months of the year.

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

Runoff from the plots covered with thin films, L-1 (30 mm chlorinated polyethylene), L-4 (15 mm butyl), and L-7 (1 mm aluminum foil) averaged 94.9%, 67.9%, and 85.4%, respectively. The aluminum foil and chlorinated polyethylene have not changed in physical appearance the past year. Several small holes have developed in the chlorinated polyethylene sheeting, possibly caused by small animals. The butyl plot continues to deteriorate but still maintains a respectable runoff efficiency after 11 years of exposure.

The two-phase asphalt treatments on plots L-5 and L-6 averaged 92.4% and 87.4% rainfall runoff, respectively. The cracks in the plots were sealed with asphalt and sand in January 1972. The runoff measurements indicate the cracks in L-6 have reopened. Runoff from L-5 shows that sprayed asphalt pavements can be maintained at high efficiency with a minimum of maintenance.

The aluminum-vinyl coated asphalt-fiberglass treated plot A-1 yielded 94.9% runoff. Cracks are visible in the aluminum-vinyl coating but they do not penetrate the underlying asphalt. The quality of runoff water from this plot shows no evidence of discoloration from oxidized asphalt. The standard gravel roofing catchment A-2 averaged 79.8% runoff. This treatment continues to lose approximately 2 mm of runoff per storm by water retention within the gravel covering.

Runoff from the concrete catchment A-5 averaged 82.1% for 1972. This compares to an average of 56.0% for 1971. On 18 June 1972 the transverse cracks in the catchment were sealed with strips of asphalt-fiberglass. Observations during rainfall events indicate the concrete absorbs a significant quantity of water before runoff occurs. This would account for the lower than expected efficiency from the plot.

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

Rainfall runoff from the three watersheds W-1, W-2, and W-3 averaged 24.0%, 9.5% and 29.9%, respectively. The runoff from W-1 and W-3 was significantly higher than measured in previous years. Runoff from the smoothed untreated plots L-2 and A-3 was 29.5% and 37.5%, respectively. The two untreated ridge and furrow plots R-1 and R-3 averaged 37.1% and 32.2% runoff. The higher runoff from these untreated plots was higher than measured in previous years. This was possibly a result of the rainfall patterns which did not permit the soil to dry between rainfall events.

PART II. STABILIZED HYDROPHOBIC SOILS

Runoff from bare soil catchments treated with low cost water repellents appear promising as an inexpensive method of collecting water for a multiple of uses. Even with a drought the first

6 months of 1972, runoff from these low-cost treatments was equal to, or better than, the preceding year.

Plot R-4, treated with low-cost soil stabilizer and water repellent, averaged 75.6% runoff for 1972. Plot A-4, treated similarly to plot R-4 but with 1 year less exposure, produced 86.4% runoff. The water-repellent-alone plot L-3, treated in 1965 and retreated in 1969, averaged 63.3% runoff. The trend in runoff efficiency between these three plots with respect to time since treatment show the gradual decline in effectiveness of the water-repellent treatment.

Plot R-2b, which was treated with a granular wax in September, produced 90.0% runoff from 202.8 mm rain, while L-2, an untreated plot, had only 29.0% runoff. Further discussion of this treatment is presented in other sections of the annual report.

Weathering and erosion resistance studies of 1-m^2 plots of natural soil at Granite Reef treated with water repellents and various soil stabilizers were continued in 1972. A summary of treatments and results is presented in Table 5. Twelve of the 16 original treatments are still being observed. The effectiveness is checked by dropping 1000 drops of water, 5 mm in diameter from a height of 2 m onto the treated soil. After the dripper studies have been made, observations are made of the soil surface to determine if any erosion occurred and also to measure the depth of water repellency of the soil. Ten of the treatments have little or no erosion. This changes from time to time as soil blown onto the test areas in between tests will erode. Also, there is very little water repellency on the surface of any treatment, but under the surface, repellency is good to excellent. This study will continue into the next year with newer chemicals also being observed.

PART III. RAINFALL-RUNOFF STUDIES AT GRANITE REEF

Preliminary data analysis and interpretations of rainfall-runoff relations for all the treatments on the large plots at Granite Reef have been completed for all data collected prior to 1 January 1972. A summary of the effectiveness of these treatments is presented in Table 6.

For each treatment, the measured runoff for each rainfall event was plotted for all storms, and the best-fit straight line of the points was computed by least-squares techniques. The threshold rainfall in Table 6 represents the rainfall value of the best-fit line needed before runoff occurred. The runoff efficiency in Table 6 represents the slope of the best-fit line and would correspond to the runoff efficiency after the threshold rainfall requirement had been satisfied.

The results show that all the plots which did not have a chemical treatment required over 2 mm of rainfall before runoff occurred. The runoff efficiency for these treatments was then 20 to 40%. As was expected, the threshold rainfall decreases and runoff efficiency increases as additional plot preparation or soil smoothing is performed. For the low-cost chemical treatments, the threshold rainfall was 1.5 to 2+ mm and runoff efficiency was 45 to 90%.

The remaining plots are classified as paved or covered treatments. Threshold rainfall for these treatments is less than 2 mm and runoff efficiency is greater than 75%. The thin film covering of aluminum foil, butyl, chlorinated polyethylene and polyethylene do have a measurable threshold rainfall value.

PART IV. MONUMENT TANK

Mechanical problems were encountered with the mechanical weather stations which record rainfall intensity, windspeed, wind dimension and temperature. Rainfall at the site was 306.8 mm for the year, which was approximately 100 mm less than normal.

There are indications that the majority of the rainfall occurred as low-intensity storms. Sedimentation of the flumes was not a problem this year, although a considerable amount of loose rock and gravel appears upstream in the unlined channel of R-4. This undoubtedly will have to be removed or a large runoff event could plug the flume. The two lined channels from R-2 and R-3 are very beneficial in transporting the water as losses are minimal. The reservoir has had water in it for wildlife and stock usage since September and this should stay this way for some time with the help of additional rains. Total runoff from the four areas has not been computed.

PART V. OPERATIONAL FIELD CATCHMENTS

Runoff from Seneca increased somewhat this year as most of the rain came late in the year. The results are still very low due to the ineffectiveness of the treatments used. Total rainfall for 1972 was 415.5 mm, which is close to the annual rainfall. Some test treatment of a soil stabilizer was applied to the plot, and if the results are encouraging, the entire catchment will be treated in the summer of 1973.

SUMMARY AND CONCLUSIONS:

Rainfall-runoff measurements were continued at the Granite Reef Testing Site. Runoff from all the plots was higher than measured in 1971 despite a 6-month period of no rainfall at the beginning of the year. The water repellent and water-repellent soil-stabilizer treatments continue to show a slow decline in efficiency with time. Sealing of cracks in the two-phase asphalt treatments with sand and asphalt were successful in rejuvenating the plots to a high efficiency level. Cracks in the concrete catchment were successfully sealed with strips of asphalt-fiberglass. The concrete still has less efficiency than expected because the surface will absorb some water into the concrete.

Measurements of water drop impact on small plots of natural soil treated with various soil stabilizers and water repellents indicate the Granite Reef soil type can be treated to withstand erosion that might be caused by raindrop impact. Ten of these treatments are still effective after 2 years.

Preliminary analysis of the rainfall-runoff relations from all the treatments at Granite Reef show the threshold rainfall varies from 3 mm per storm for the uncleaned watersheds to less than 0.5 mm for the bonded film treatments. A corresponding increase in runoff efficiency is also present. As expected, the threshold rainfall decreases and runoff efficiency increases with increasing soil smoothing or chemical seal applications.

Runoff measurements at Monument Tank and Seneca were continued. The data has not been completely processed but no major changes in runoff characteristics are expected.

PERSONNEL: G. W. Frasier, L. E. Myers, J. R. Griggs.

CURRENT TERMINATION DATE: September 1974

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

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

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

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

Date 1972	Total Runoff mm	L-1 Runoff mm	L-1 Runoff %	L-4 Runoff mm	L-4 Runoff %	L-7 Runoff mm	L-7 Runoff %
6 Jun	1.8	1.3	72.7	0.7	38.9	1.1	61.1
8 Jun	1.3	0.9	69.2	0.7	53.8	0.7	53.8
21-22 Jun	17.8	17.2	96.6	14.2	79.8	15.6	87.6
22 Jun	1.3	0.6	46.2	0	0	0.7	53.8
17 Jul	11.0	11.3	102.7	7.9	71.8	9.4	85.5
12 Aug	5.3	5.8	109.4	4.0	75.5	4.8	90.6
2 Sep	2.5	3.4	136.0	2.1	84.0	3.1	124.0
18 Sep	1.8	1.5	83.3	0.9	50.0	1.1	61.1
3- 4 Oct	25.3	23.8	94.1	16.5	65.2	20.9	82.6
4- 5 Oct	7.5	6.5	86.7	4.6	61.3	5.8	77.3
5 Oct	3.5	2.8	80.0	0.9	25.7	1.7	48.6
6 Oct	32.9	32.3	98.2	25.3	76.9	30.7	93.3
18-19 Oct	36.6	33.0	90.2	24.2	66.1	31.6	86.3
19 Oct	8.1	7.4	91.4	4.6	56.8	6.8	84.0
25 Oct	2.0	2.2	110.0	1.1	55.0	1.4	70.0
11 Nov	20.5	20.7	101.1	14.3	69.8	17.8	86.8
17 Nov	13.7	12.9	94.2	9.4	68.6	11.3	82.5
4 Dec	4.3	4.2	97.9	3.0	68.7	3.3	76.5
8 Dec	9.0	8.4	93.3	5.3	58.9	7.1	78.9
28 Dec	33.5	31.6	94.3	23.2	69.3	30.0	89.6
28 Dec	4.1	3.5	85.4	2.6	63.4	3.3	80.5
Total	243.8	231.3	94.9	165.5	67.9	208.2	85.4

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

Date	Total Runoff	L-5 Runoff		L-6 Runoff		A-1 Runoff	
1972	mm	mm	%	mm	%	mm	%
6 Jun	1.8	0.7	38.9	1.1	61.1	1.4	77.8
8 Jun	1.3	0.5	38.5	0.7	53.8	0.7	53.8
21-22 Jun	17.8	16.7	93.8	17.6	98.9	17.2	96.6
22 Jun	1.3	0.4	30.8	0.5	38.5	0.8	61.5
17 Jul	11.0	10.5	95.5	10.7	97.3	10.8	98.2
12 Aug	5.3	4.9	92.5	5.0	94.3	5.5	103.8
2 Sep	2.5	1.1	44.0	3.3	132.0	3.2	128.0
18 Sep	1.8	2.5	138.9	1.2	66.7	1.8	100.0
3- 4 Oct	25.3	23.2	91.7	24.1	95.3	23.8	94.1
4- 5 Oct	7.5	6.4	85.3	6.6	88.0	6.8	90.7
5 Oct	3.5	1.5	42.9	2.0	57.1	3.0	85.7
6 Oct	32.9	35.3	107.3	28.1	85.4	31.0	94.2
18-19 Oct	36.6	33.9	92.6	33.5	91.5	34.2	93.4
19 Oct	8.1	7.2	88.9	6.7	82.7	7.6	93.8
25 Oct	2.0	1.4	70.0	1.6	80.0	2.2	110.0
11 Nov	20.5	20.8	101.5	18.5	90.2	20.1	98.0
17 Nov	13.7	13.4	98.0	11.8	86.4	12.8	93.6
4 Dec	4.3	3.5	80.3	1.2	27.3	3.9	90.7
8 Dec	9.0	6.7	74.4	6.8	75.6	8.3	92.2
28 Dec	33.5	31.5	94.0	29.3	87.5	32.9	98.2
28 Dec	4.1	3.2	78.0	2.7	65.9	3.4	82.9
Total	243.8	225.3	92.4	213.0	87.4	231.4	94.9

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

Date	Total Runoff	A-2 Runoff		A-5 Runoff	
1972	mm	mm	%	mm	%
6 Jun	1.8	0	0	0.7	38.9
8 Jun	1.3	0	0	0.3	23.1
21-22 Jun	17.8	13.9	78.1	13.2	74.2
22 Jun	1.3	0	0	0.7	53.8
17 Jul	11.0	9.6	87.3	7.9	71.8
12 Aug	5.3	4.5	84.9	4.3	81.1
2 Sep	2.5	1.5	60.0	2.3	92.0
18 Sep	1.8	0	0	0.8	44.4
3- 4 Oct	25.3	21.7	85.8	21.2	83.8
4- 5 Oct	7.5	6.2	82.7	6.0	80.0
5 Oct	3.5	1.9	54.3	2.1	60.2
6 Oct	32.9	29.1	88.4	28.8	87.5
18-19 Oct	36.6	29.4	80.3	31.4	85.8
19 Oct	8.1	6.9	85.2	7.5	92.6
25 Oct	2.0	0.4	20.0	1.5	75.0
11 Nov	20.5	17.7	86.3	17.0	82.9
17 Nov	13.7	10.7	78.1	10.9	79.6
4 Dec	4.3	2.5	58.1	3.1	72.1
8 Dec	9.0	5.6	62.2	7.2	80.0
28 Dec	33.5	30.2	90.1	30.0	89.6
28 Dec	4.1	2.8	68.3	3.3	80.5
Total	243.8	194.6	79.8	200.2	82.1

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 R-9 at 0.057 kg m^{-2}
	6 Nov 1969	Retreated with R-9 at 0.04 kg m^{-2}
R-1	1 Mar 1965	Ridge and furrow, 20% sideslope
R-2a	1 Mar 1965	Ridge and furrow, 10% sideslope
R-2b	29 Sep 1972	Ridge and furrow, 10% sideslope treated with wax water repellent at 1.3 lbs/yd^2
R-3	1 Mar 1965	Ridge and furrow, 20% sideslope
R-4	13 May 1966	Ridge and furrow, 10% sideslope, treated with 44.9 g m^{-2} sodium carbonate
	3 Nov 1970	Treated with 3% silicone water repellent and 2% soil stabilizer - 1.2 liters of solution m^2
A-3	1 Aug 1967	Smoothed soil, 6 m x 30 m plot
A-4b	10 Nov 1971	Smoothed soil treated with 3% silicone water repellent and 2% soil stabilizer - 1.2 liters of solution m^{-2}
W-1	1 Dec 1963	Uncleared watershed
W-2	1 Dec 1963	Uncleared watershed
W-3	1 Dec 1963	Cleared watershed

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

Date	Total Runoff	W-1 Runoff		W-2 Runoff		W-3 Runoff	
1972	mm	mm	%	mm	%	mm	%
6 Jun	1.8	0	0	0	0	0	0
8 Jun	1.3	0	0	0	0	0	0
21-22 Jun	17.8	5.2	29.2	3.0	16.9	7.4	41.6
22 Jun	1.3	0	0	0	0	0	0
17 Jul	11.0	1.8	16.4	0.7	6.4	2.4	21.8
12 Aug	5.3	0	0	0	0	0	0
2 Sep	2.5	0	0	0	0	0	0
18 Sep	1.8	0	0	0	0	0	0
3- 4 Oct	25.3	6.5	25.7	3.0	11.9	8.1	32.0
4- 5 Oct	7.5	2.3	30.7	1.1	14.7	3.1	41.3
5 Oct	3.5	0	0	0	0	0	0
6 Oct	32.9	11.1	33.7	6.0	18.2	13.7	41.6
18-19 Oct	36.6	10.8	29.5	4.1	11.2	13.0	35.5
19 Oct	8.1	0.9	11.1	0.1	1.2	1.5	18.5
25 Oct	2.0	0	0	0	0	0	0
11 Nov	20.5	6.8	33.2	3.1	15.1	7.8	38.0
17 Nov	13.7	3.8	27.7	1.9	13.9	5.2	38.0
4 Dec	4.3	0.3	7.0	0	0	0.5	11.6
8 Dec	9.0	1.3	14.4	0.1	1.1	1.6	17.8
28 Dec	33.5	7.3	21.8	0	0	8.1	24.2
28 Dec	4.1	0.5	12.2	0	0	0.5	12.2
Total	243.8	58.6	24.0	23.1	9.5	72.9	29.9

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

Date	Total Runoff	L-2 Runoff		A-4 Runoff		A-3 Runoff	
1972	mm	mm	%	mm	%	mm	%
6 Jun	1.8	0	0	0.8	44.4	0	0
8 Jun	1.3	0	0	0.8	61.5	0	0
21-22 Jun	17.8	8.4	47.2	16.5	92.7	10.1	56.7
22 Jun	1.3	0	0	0	0	0	0
17 Jul	11.0	4.4	40.0	10.3	93.6	5.4	49.1
12 Aug	5.3	0.8	15.1	5.3	100.0	1.7	32.1
2 Sep	2.5	0	0	2.9	116.0	0	0
18 Sep	1.8	0	0	1.0	55.6	0	0
3- 4 Oct	25.3	8.5	33.6	21.3	84.2	9.8	38.7
4- 5 Oct	7.5	2.7	36.0	5.9	78.7	3.2	42.7
5 Oct	3.5	0	0	1.9	54.3	0	0
6 Oct	32.9	13.6	41.3	30.8	93.6	15.5	47.1
18-19 Oct	36.6	11.8	32.2	31.3	85.5	14.1	38.5
19 Oct	8.1	1.4	17.3	7.0	86.4	1.9	23.5
25 Oct	2.0	0	0	1.4	70.3	0	0
11 Nov	20.5	8.1	39.5	18.2	88.8	9.7	47.3
17 Nov	13.7	4.5	32.6	11.4	83.2	5.4	39.4
4 Dec	4.3	0.4	9.5	3.4	79.1	1.6	37.2
8 Dec	9.0	1.2	13.3	7.0	77.8	2.5	27.8
28 Dec	33.5	5.6	16.7	30.4	90.7	9.4	28.1
28 Dec	4.1	0.5	12.2	3.0	73.2	1.1	26.8
Total	243.8	71.9	29.5	210.6	86.4	91.4	37.5

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

Date	Total Runoff	R-1 Runoff		R-2a Runoff		R-2b Runoff	
1972	mm	mm	%	mm	%	mm	%
6 Jun	1.8	0	0	0	0		
8 Jun	1.3	0	0	0	0		
21-22 Jun	17.8	10.1	56.7	9.7	54.5		
22 Jun	1.3	0.2	15.4	0.2	15.4		
17 Jul	11.0	3.6	32.7	4.4	40.0		
12 Aug	5.3	1.1	20.8	1.4	26.4		
2 Sep	2.5	0	0	0	0		
18 Sep	1.8	0	0	0	0		
3- 4 Oct	25.3	9.0	35.6			21.3	84.2
4- 5 Oct	7.5	3.3	44.0			5.8	77.3
5 Oct	3.5	0	0			1.9	54.3
6 Oct	32.9	15.8	48.0			30.7	93.3
18-19 Oct	36.6	15.5	42.3			32.6	89.1
19 Oct	8.1	2.2	27.2			7.2	88.9
25 Oct	2.0	0	0			1.8	90.0
11 Nov	20.5	8.4	41.0			18.6	90.8
17 Nov	13.7	5.8	42.4			13.4	97.8
4 Dec	4.3	1.9	44.2			3.7	86.0
8 Dec	9.0	2.8	31.1			8.5	94.6
28 Dec	33.5	9.7	29.0			32.1	95.8
28 Dec	4.1	1.0	24.5			3.3	80.5
Total	243.8	90.4	37.1	15.7	36.7	180.9	90.0

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

Date	Total Runoff	R-3 Runoff		R-4 Runoff		L-3 Runoff	
1972	mm	mm	%	mm	%	mm	%
6 Jun	1.8	0	0	0	0	0	0
8 Jun	1.3	0	0	0.1	7.7	0	0
21-22 Jun	17.8	9.4	52.8	16.0	89.9	12.1	68.0
22 Jun	1.3	0	0	0.5	38.5	0	0
17 Jul	11.0	4.3	39.1	9.0	81.8	7.3	66.4
12 Aug	5.3	1.3	24.5	4.1	77.4	3.4	64.2
2 Sep	2.5	0	0	2.5	100.0	0.4	16.0
18 Sep	1.8	0	0	0.7	38.9	0	0
3- 4 Oct	25.3	8.4	33.2	19.2	75.9	16.7	66.0
4- 5 Oct	7.5	3.1	41.3	5.4	72.0	4.2	56.0
5 Oct	3.5	0	0	1.2	34.3	0.2	5.7
6 Oct	32.9	13.5	41.0	28.3	86.0	26.4	80.2
18-19 Oct	36.6	12.9	35.2	28.2	77.0	24.8	67.8
19 Oct	8.1	1.7	21.0	6.0	74.1	4.9	60.5
25 Oct	2.0	0	0	0.9	45.0	0	0
11 Nov	20.5	8.4	41.0	15.6	76.1	14.8	72.2
17 Nov	13.7	4.6	33.6	10.2	74.5	9.0	65.7
4 Dec	4.3	1.3	30.2	3.1	72.1	2.1	48.7
8 Dec	9.0	1.8	20.0	5.6	62.2	3.8	42.2
28 Dec	33.5	7.0	20.9	25.1	74.9	21.9	65.4
28 Dec	4.1	0.8	19.6	2.7	65.9	2.3	56.1
Total	243.8	78.5	32.2	184.4	75.6	154.3	63.3

Table 5. Results of erosion and water repellency tests on 1-m^2 plots at Granite Reef.

	TREATMENT			TEST DATE 31 Jul 70	
	Soil Stabilizer 1/	Water Repellent 1/	TREATMENT DATE	Erosion 3/	Water Repellency 4/
1.	DCA 70	Dow 772	14 Jul 70	No	3
2.	Dupont 46-22	Dow 772	14 Jul 70	No	3
3.	Dupont 72-60	Dow 772	14 Jul 70	No	3
4.	Dow 460	Dow 772	14 Jul 70	No	3
5.	Dow 620	Dow 772	14 Jul 70	No	3
6.	Dow 636	Dow 772	14 Jul 70	No	3
7.	Morton 561-6	Dow 772	14 Jul 70	No	3
8.	Dresinate 80F	Dow 772	14 Jul 70	Immediately	0
9.	National Starch 2813	Dow 772	14 Jul 70	No	3
10.	DCA 70	Mobil 46 2/		350 drops	0
11.	Dow Corning 40219	--	21 Oct 70	--	--
12.	Soil Seal 'A'	Dow 772	31 Dec 70	--	--
13.	Dow 880	Dow 772	31 Dec 70	--	--
14.	National Starch 1251	Dow 772	31 Dec 70	--	--
15.	Aerospray Binder 52	Dow 772	8 Jun 71	--	--
16.	Aerospray Binder 70	Dow 772	8 Jun 71	--	--

1/ Application rate was 2% stabilizer and 3% water repellent in Y3 gal solution per yd^2.

2/ 5% concentration.

3/ Dripper tests. 200 drops per minute for 5 minutes.

4/ Repellency code: 3 - highly repellent; 2 - surface wets slowly, high repellency below surface; 1 - surface wets, fair repellency below surface; 0 - no repellency.

Table 5. Results of erosion and water repellency tests on 1-m^2 plots at Granite Reef (continued).

	TEST DATE 21 Oct 70		TEST DATE 26 Jan 71	
	Erosion	Water Repellency	Erosion	Water Repellency
1.	No	3	No	1
2.	No	3	No	1
3.	No	3	No	1
4.	No	3	No	1
5.	1000 drops	3	No	2
6.	No	3	No	2
7.	No	3	No	1
8.	Immediately	0	Immediately	0
9.	No	3	No	1
10.	No	0	Immediately	3
11.	--	--	Slight	3
12.	--	--	No	3
13.	--	--	No	3
14.	--	--	No	3
15.	--	--	--	--
16.	--	--	--	--

Table 5. Results of erosion and water repellency tests on 1-m^2 plots at Granite Reef (continued).

	TEST DATE 26 Mar 71		TEST DATE 7 May 71	
	Erosion	Water Repellency	Erosion	Water Repellency
1.	No	2	No	2
2.	No	2	No	2
3.	No	2	400 drops	2
4.	No	2	700 drops	2
5.	No	2	1000 drops	2
6.	No	2	No	2
7.	No	2	No	2
8.	Abandoned	--	--	--
9.	No	2	No	2
10.	Abandoned	--	--	--
11.	Immediately	3	Abandoned	--
12.	No	3	No	2
13.	No	3	No	2
14.	No	3	No	2
15.	--	--	--	--
16.	--	--	--	--

Table 5. Results of erosion and water repellency tests on 1-m^2 plots at Granite Reef (continued).

	TEST DATE 22 Jul 71		TEST DATE 23 Sep 71	
	Erosion	Water Repellency	Erosion	Water Repellency
1.	No	2	No	2
2.	No	2	No	2
3.	No	2	No	2
4.	No	2	No	2
5.	No	2	1000 drops	2
6.	No	2	No	2
7.	No	2	No	2
8.	--	--	--	--
9.	No	2	No	2
10.	--	--	--	--
11.	--	--	--	--
12.	No	2	No	2
13.	No	2	No	2
14.	No	2	No	2
15.	800 drops	0	Abandoned	--
16.	No	3	No	3

Table 5. Results of erosion and water repellency tests on 1-m^2 plots at Granite Reef (continued).

	TEST DATE 4 Nov 71		TEST DATE 10 Feb 72	
	Erosion	Water Repellency	Erosion	Water Repellency
1.	No	2	No	2
2.	No	2	No	2
3.	No	2	No	2
4.	1000 drops	2	No	2
5.	No	2	No	2
6.	1000 drops	2	No	2
7.	No	2	No	2
8.	--	--	--	--
9.	No	2	300 drops	2
10.	--	--	--	--
11.	--	--	--	--
12.	No	2	No	2
13.	No	2	No	2
14.	No	2	No	2
15.	--	--	--	--
16.	No	2	No	3

Table 5. Results of erosion and water repellency tests on 1-m^2 plots at Granite Reef (continued).

TEST DATE

26 Jun 72

	Erosion	Water Repellency
1.	No	2
2.	No	2
3.	No	2
4.	No	2
5.	No	2
6.	No	2
7.	500 drops	2
8.	--	--
9.	No	2
10.	--	--
11.	--	--
12.	No	2
13.	No	3
14.	No	2
15.	--	--
16.	500 drops	1

Table 6. Rainfall-runoff results from large plots at Granite Reef testing site.

TREATMENT	LENGTH OF STUDY (years)	THRESHOLD RAINFALL (mm)	RUNOFF EFFICIENCY (%)
Uncleaned watershed	8	3.0	22
Cleaned watershed	8	2.7	31
Smoothed untreated	10	2.5	33
Ridge and furrow	7	2.4	39
Sodium carbonate	5	2.2	47
Water repellent	8	1.5	83
Water repellent plus stabilizer	1	1.5	90
Single-phase asphalt	7	1.5	75
Concrete	4	1.2	82
Roofing	5	1.3	92
Two-phase asphalt	9	0.5	95
Aluminum foil	8	0.4	85
Asphalt-fiberglass	5	0.4	98
Butyl	10	0.3	94
Chlorinated polyethylene	4	0.3	98
Polyethylene	4	0.1	90
Polyvinyl fluoride	2	0	100

TITLE: MODIFYING FURROW IRRIGATION PRACTICES FOR CABBAGE PRODUCTION

CRIS WORK UNIT: SWC-018-gG4 CODE NO.: Ariz.-WCL 71-13

INTRODUCTION:

A valid comparison of different irrigation methods is possible only when optimum management criteria for each irrigation method has been determined. The objectives of this field investigation were (1) to develop criteria for managing a modified-furrow irrigation practice on cabbage for increased water-use efficiency and improved crop production, and (2) to support a study on trickle irrigation.

RESULTS AND DISCUSSION:

A field investigation was conducted to evaluate quantity and frequency of modified-furrow irrigation practice, using a moderately saline water on a fine-textured, clay-loam soil. Modified-furrow irrigations consisted of 1.3, 1.05, 0.8, and 0.5 times the consumptive use, as measured for a standard-furrow irrigation practice, applied every 6 days, and 1.05 times the measured consumptive use applied every 12 days. The modified furrow was a small furrow, constructed in the center of the cabbage bed to facilitate a comparable practice to trickle irrigation where moisture movement is away from the center of the bed. Cabbage production with modified-furrow irrigation was the same at the 1.3 and 1.05 consumptive-use quantities, whereas yields were decreased 19% and 52%, respectively, at the 0.8 and 0.5 consumptive-use quantities. Therefore, the amount of soil moisture needed by the cabbage plant for high production with trickle irrigation was approximately the present consumptive-use estimate. Frequencies of 6 or 12 days at the 1.05 modified-furrow quantity caused no difference in production.

A standard-furrow irrigation was based on plant symptoms early in the growing season, and on a 55% soil-moisture depletion criteria in the top 90 cm of soil after full root development. Cabbage production with the standard-furrow irrigation, compared to the highest-yielding treatments for trickle and modified-furrow irrigation, was about the same; however, the water delivery requirement was about 20% greater for the standard-furrow irrigation. Therefore, irrigation efficiency can be improved by using these newer irrigation methods rather than conventional methods.

PUBLICATION:

Bucks, Dale A., Erie, Leonard J., and French, Orrin F. Quantity and frequency of trickle and furrow irrigation for efficient cabbage production. Agronomy Journal. (Submitted for publication).

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

TITLE: EVALUATING TRICKLE IRRIGATION FOR CABBAGE PRODUCTION

CRIS WORK UNIT: SWC-018-gG4 CODE NO.: Ariz.-WCL 71-14

INTRODUCTION:

Irrigated agriculture, in the future, will demand programs and practices of even greater water conservation. One such practice, now under development, is trickle irrigation. Possible advantages of trickle irrigation over other irrigation methods include increased crop yields and decreased water delivery requirements. However, a valid comparison of irrigation methods is possible only after the optimum management criteria of each method has been established. The objective of this field investigation was to develop criteria for managing trickle irrigation on cabbage for increased water-use efficiency and improved crop production.

RESULTS AND DISCUSSION:

A field investigation was conducted to evaluate quantity and frequency of trickle irrigation, using a moderately saline water on a fine-textured, clay-loam soil. Trickle irrigations consisted of 1.3, 1.05, 0.8, and 0.5 times the consumptive use, as measured for standard-furrow irrigation practice, applied at frequencies of 3, 6, and 12 days. Cabbage production with trickle irrigation was the same when water was applied at 1.3 and 1.05 times the consumptive-use requirement, but yields decreased 10% and 43%, respectively, when 0.8 and 0.5 times the consumptive-use requirement were applied. Therefore, the amount of soil moisture needed by the cabbage plant for high production with trickle irrigation was approximately the present consumptive-use estimate. Frequency of trickle irrigation caused no difference in production between 3, 6, and 12 days at the 1.3 consumptive-use quantity; however, a trend of reduced production with increased frequency did result at 1.05, 0.8, and 0.5 consumptive-use quantities, amounting to a 9% mean reduction for the 3-day compared to the 6-day frequency, and a 13% mean reduction for the 3-day compared to the 12-day frequency for the three smaller quantities. This indicates that frequent trickle irrigations may not necessarily be advantageous for all vegetable crops on fine-textured soils, because of possible increased evaporation and decreased water penetration when less than consumptive use was applied.

PUBLICATION:

Bucks, Dale A., Erie, Leonard J., and French, Orrin F. Quantity and frequency of trickle and furrow irrigation for efficient cabbage production. Agronomy Journal (Submitted for publication).

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

TITLE: SOIL CLOGGING DURING INTERMITTENT INFILTRATION WITH SECONDARY SEWAGE EFFLUENT

CRIS WORK UNIT: SWC-018-gG-4 CODE NO.: Ariz.WCL-71-15

Laboratory studies were continued in the investigation of soil clogging when using secondary sewage effluent. (See Annual Report 1971, section WCL-71-15). The results of this study are presented in a paper "Soil clogging during infiltration with secondary sewage effluent," and are summarized below.

Physical clogging due to deposition of suspended solids on the soil surface was the predominant cause of infiltration reduction. Little evidence of surface biological clogging was found. Maintaining low suspended solids concentration in the sewage water was the most important factor in optimizing infiltration. Concentrations below 10 mg/l should be maintained. Low solids concentrations can usually be obtained by sedimentation. During long periods of intermittent inundation, clogging developed below the surface because entrapped gases blocked the soil pores. This clogging was probably due to microbial activity. High hydraulic gradients should be maintained in the soil system even though infiltration rates decreased faster than at low gradients. Drying the clogged layer restored infiltration rates. Algal growth on the soil surface increased infiltration rates during inundation because the algal mat became buoyant, thereby freeing the soil surface from clogging materials.

PERSONNEL: Robert C. Rice

CURRENT TERMINATION DATE: 31 December 1972

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

CRIS WORK UNIT: SWC-018-gG-4 CODE NO.: Ariz.-WCL 72-1

INTRODUCTION:

Summaries of studies on 16 simple critical-depth flumes with cross-sectional shapes that were trapezoidal, triangular, or rectangular appear in previous reports under research outline Ariz.-WCL 67-1 (see Annual Reports for 1966-1971). Technical papers "Flow measurement with critical depth flumes" (1969) and "Critical depth flumes for determining flow in canals and natural channels" (1970) were followed by a presentation entitled "Tayloring critical-depth measuring flumes" before the Instrument Society of America, Pittsburgh, Pennsylvania, May 1971. The first paper presented some theoretical aspects for predicting the calibration results for flumes and also summarized the effects of installation anomalies; the second paper proposed sizes for several common ditch shapes frequently constructed; and the third described methods of incorporating the head-loss effects, based on boundary layer development, into more accurate prediction techniques.

It soon became apparent that to control the head-discharge relation for a specified velocity that may be needed to move sediment bedload, or to provide a required sensitivity in a named flow range, a method of computing complex-shaped flumes was needed. The problem of bedloads that plugged certain field installations had prompted the concern since they originally were thought to be invulnerable to plugging.

PROCEDURE:

The mathematical model for flume calibrations was modified to allow the introduction of more complex shapes into the computation for cross-sectional area. Laboratory calibrations were made in the usual way as described previously (Annual Reports 1969-1971).

A ~~printed~~ painted plywood flume was constructed that incorporated most of the conceivable extremes of a flume. Figure 1 shows the mixed geometry of the cross-sectional shape of the "complex flume." The lower portion of the flume was a rectangle, 0.75 ft deep and 0.45 ft wide. Above that the flume side walls were broken so that in the approach section the side slopes were 5.1 horizontal to 1 vertical, then changed to 1.5:1 at a channel depth of 1 ft. The main throat section was 15 ft long with the same rectangular bottom portion but side slopes of 3.1:1 and 1:1, respectively, also changing side slopes at channel depths of 1 ft. A warped transition section was used between these.

To test the feasibility of using a flume within a flume, 1-ft-long restrictions were placed in the transition section that acted as a low-flow, rectangular, critical-depth flume, 0.322 ft wide. The transition length to this restriction was also 1 ft. The pressure tap readings were taken 1 ft above this for both this inserted rectangular flume and the main flume. At stilling well depths greater than about 0.8 ft deep, control began to shift from the contraction to the throat of the main flume, completing this transition at a depth of about 1.0 ft.

Pitot tube mappings using a traverse mechanism designed originally for use on the glass-sided channel were made in the approach section and throat section of one flume for a selected flow rate.

To further test the concepts for the cross-sectional shape of the flume, analyses of contractions that extend from only one side of the canal were made. The analyses indicated that these single contractions should work as well as two symmetrically placed contractions and should be less expensive to construct in an already lined canal. Two shapes were considered: a side sill that was parallel to the canal side slope, and a side sill that was vertical at the water contact face. Both styles could accommodate a wide flow range and canal bottom slope by changing the sill size.

Families of such flumes were computed for a slip-formed canal (1 to 1 side slopes and 1-ft bottom width). Each flume size was then checked against computed ditch flow so that the ditch into which the flume should be placed would be steep enough to avoid downstream submergence.

Laboratory models were tested of representatives from each of these two families of flumes.

RESULTS AND DISCUSSION:

The computed curves and the laboratory results for the complex flume are shown in Figure 1. The dashed lines on the plot indicate the extrapolation of computer results.

The results expressed as a discharge coefficient (a computed flow including calculated friction effects divided by the flow of an ideal frictionless flow) are shown in Figure 2. Three roughness heights are plotted. The laboratory data are plotted and generally follow a computed roughness somewhat greater than smooth glass. The surface was sanded and carefully painted. Thus, this was the expected roughness value. The transition of control was also expected and indicates that a combination flume of this nature would be impractical for several reasons, from being a trap for small boulders at the small contraction to having no unique rating in what would probably be an important flow range.

The very grotesqueness of the flume demonstrated several important points:

1) Flumes of nearly any geometric shape can be computer rated.
2) The conjecture concerning the estimates for α_3 must be reasonably accurate since the total flow prediction was satisfactory to within $\pm$ 3% on this extreme example.

Further attempts to evaluate α_3 and α_1 directly in the flume were made. Pitot traverses mapped the velocity field at a point near the center of the 15-ft-long throat (for α_3) and at the pressure tap location in the approach section (for α_1). The velocity distribution for one flow is shown in Figure 3. The graphically determined value for α_3 was 1.08 compared to the computer estimate of 1.063. This is considered to be satisfactory justification for continued usage of the present computation method for α_3, especially since discharge rate is affected inversely as the square root of α_3.

The results for α_1 measured 1.07, compared to the fixed average open channel value of 1.04 used in the computation. In retrospect, the extreme nature of the cross-sectional shape should have indicated an α_1 value greater than 1.04, so the value of 1.07 could have been anticipated. The influence of α_1 is small, and large errors in its selection on the order of $\pm$ 10% can be tolerated in most instances.

The one-sided flumes proved interesting. Some questions came to mind about the proper length of throat to use since this value is needed in the boundary layer development computation. On one side, the sill side, the throat length is obvious. On the unaffected ditch side, however, where is the origin of the boundary layer development? In the absence of a "tripping" mechanism for the boundary layer such as a seam in the concrete wall, etc., a shift in calibration with a discharge slightly greater than predicted could result. Since there is no defined transition or converging section length on one side, the energy losses would be reduced.

Examination of the laboratory data indicated that using the average length for L_1, L_2, and L_3 worked well. Average length here needs some explanation. The length L_1 is the distance of the stilling-well tap from the next downstream disturbance, usually the converging section. Thus L_1 (average) = $(L_1 + 0)/2$. Likewise the transition length on one side is zero, giving $(L_2 + 0)/2$; and the throat length taken as the average of the sill length on one side and the throat length, plus the added distance to the stilling well tap, made up the final length.

The transition must be long enough to avoid drastic shock waves. Shorter transitions can be used, if properly curved to avoid forming the shock wave, to shorten the overall flume length. The 3:1 (or more) convergence ratio used from entrance to throat section on the other flumes appeared to be adequate. The depth detection should be on the unaffected side of these flumes at, say, 0.5 to 1 ft before beginning the transition section. The exact location is not important since the computer program uses the measured location as part of the calibration computation. Accuracy is comparable to symmetrical flumes in all aspects.

SUMMARY AND CONCLUSIONS:

Previous studies completed on critical-flow flumes for flow metering in open channels have resulted in the successful prediction of hydraulic characteristics for simple geometry types of flumes that are rectangular, triangular, or trapezoidal in cross-sectional shape. Field experience disclosed siltation problems in connection with some flume installations.

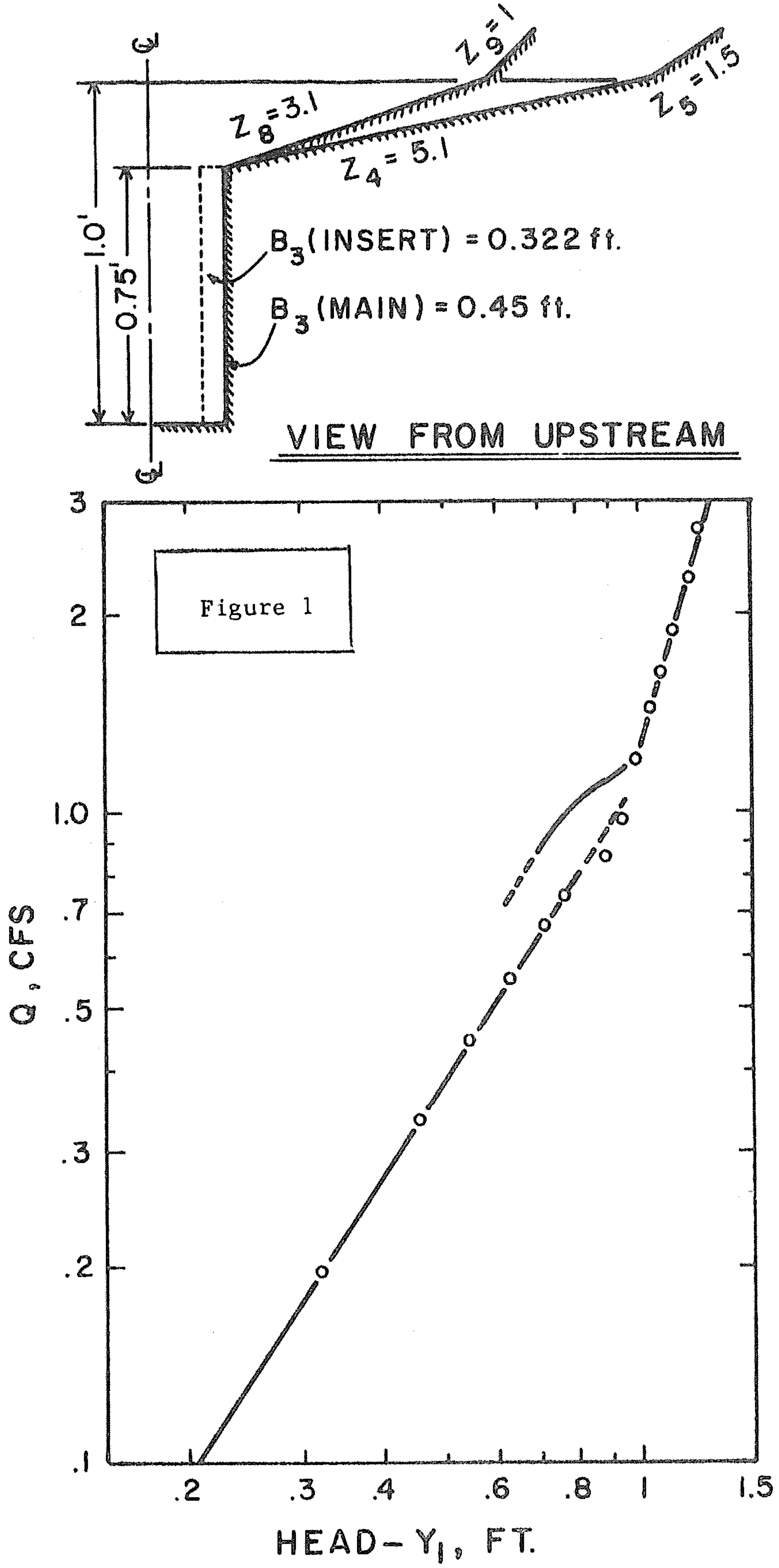
Complex-shaped flumes were then developed to provide control of the head-discharge relation for a specified velocity that may be needed to move sediment bedload, or to provide a required sensitivity in a particular flow range. These complex shapes may be almost any cross-section whose area can be mathematically represented for computer solution. It need not even be symmetrical with the canal centerline.

Pitot tube mappings of the velocity distribution were made in a rather extreme complex flume, a rectangular bottom portion that expanded into a trapezoidal portion at deeper flows and finally into another shape at yet deeper flows. The resulting hydraulic parameters verified by this direct measurement supported the computer model as being sufficiently refined to successfully predict flow characteristics of all flume shapes.

Flume sills that can be inserted on one side, only, of slip-formed concrete ditches to produce low-cost flumes were computed, tested, and found to be as accurate as the more conventional, symmetrical two-contraction styles.

PERSONNEL: John A. Replogle and C. G. Hiesel

CURRENT TERMINATION DATE: 1975



Z9 = 1
Z8 = 3.1
Z4 = 5.1
Z5 = 1.5
1.0'
0.75'
B3 (INSERT) = 0.322 ft.
B3 (MAIN) = 0.45 ft.
VIEW FROM UPSTREAM
Figure 1
Q, CFS
HEAD - Y1, FT.

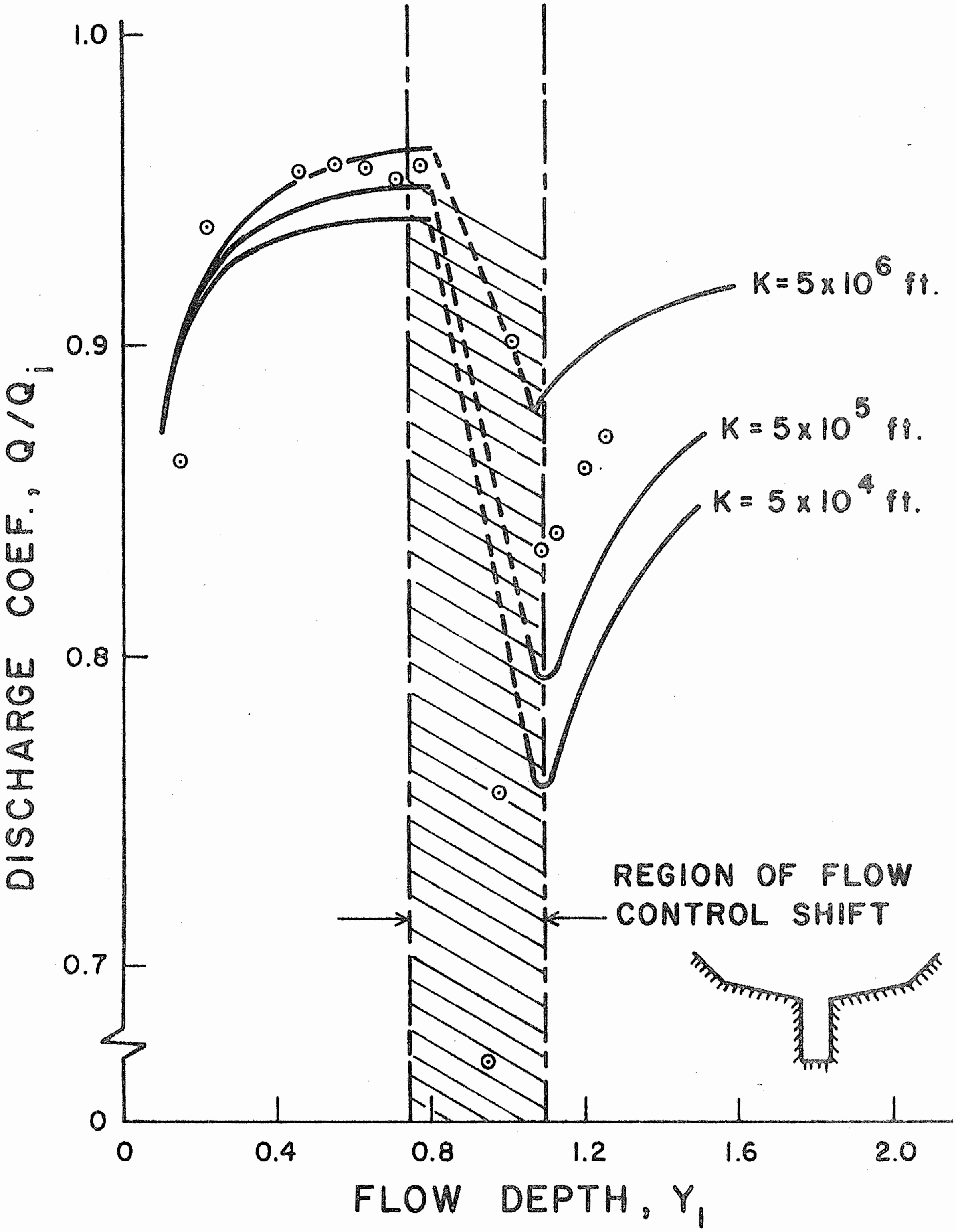

1.0
0.9
0.8
0.7
0
DISCHARGE COEF., Q/Q_i
0
0.4
0.8
1.2
1.6
2.0
FLOW DEPTH, Y_1
K=5x10^6 ft.
K=5x10^5 ft.
K=5x10^4 ft.
REGION OF FLOW CONTROL SHIFT

Figure 2

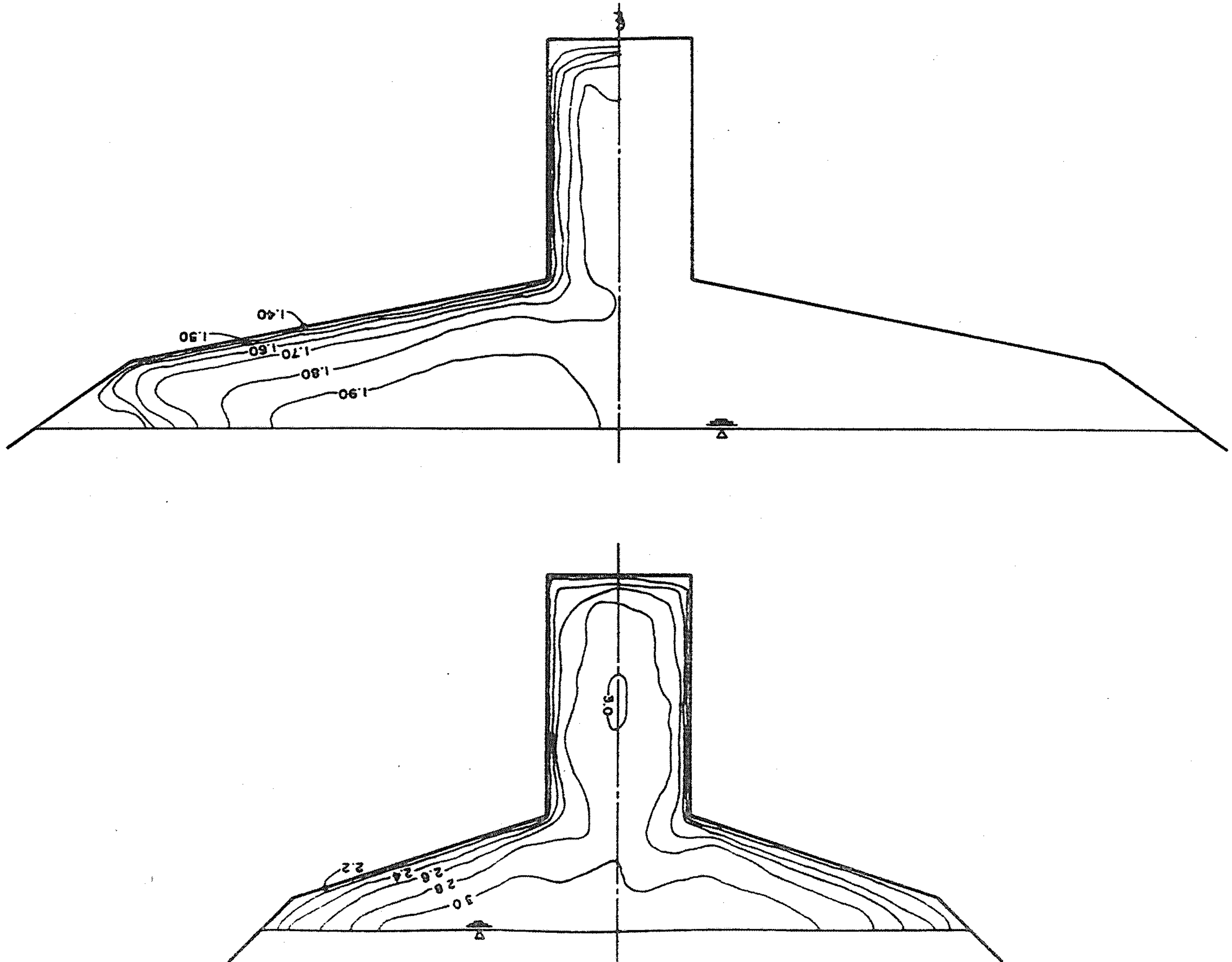


Figure 3 Annual Report of the U.S. Water Conservation Laboratory

TITLE: SEDIMENT TRANSPORT CHARACTERISTICS OF CRITICAL-DEPTH FLUMES

CRIS WORK UNIT: SWC-018-gG-4 CODE NO.: Ariz.-WCL 72-2

INTRODUCTION:

Most of the investigations concerning flumes were reported in past years under research outlines Ariz.-WCL 67-1, and under another outline for the current year, WCL 72-1. The latter outline concerned the computer and mathematical manipulations necessary to provide the tools for designing flumes of such shape that they might meet the sediment-carrying criteria that could hopefully be developed. Certain field-installed flumes had become plugged with sediment and prompted this investigation, since they were originally thought to be invulnerable to plugging.

PROCEDURE:

An attempt at literature review on sediment transport indicated the problem would be extremely difficult. At a meeting in Oxford, Mississippi, May 1972, some of the things brought out as necessary parameters before design criteria for sediment-free flumes could be formulated were: a) particle size, b) concentration of particles in the flow, c) velocity of the flow, and (d) the discharge rate, though this is interrelated to the others.

Field site experience varied; some flumes remained clean, some silted up with sediment. Therefore, the various reasons for their successes and failures were studied. Photographic records of the channels over the years provided one means of assessing the channel changes imposed by the flumes.

Unfortunately, no daylight flows of storms have been observed during the history of installation, and the much desired photographic record of storm flow has not been obtained.

Efforts have concentrated on studying the possible effects of the above-mentioned parameters, and on the additional problems of sediment movement regimes where dunes are formed instead of flat bed flows or if much of this information could be bypassed with proper hydraulic design information.

RESULTS AND DISCUSSION:

Several of the long-established field installations were again observed from the aspect of sediment-carrying ability.

Field installations:

Tucson A. This flume is passing a sand bedload satisfactorily. No major problems.

Tucson H. The extremely small bedload and stable channel offer no problems. The flume has been overtopped, exceeding its 470 cfs design limit.

Tucson R. Problems exist due to heavy sand and gravel load moving into the stream. Originally, the channel grade was stable and apparently in equilibrium with an imposed long-term (> 30 years) of oil washings from a railroad roundhouse. The channel was grease paved to a considerable extent above the flume. A continuous trickle flow passed through the flume the year around and eventually infiltrated further downstream. The train washing operation that supplied the grease and oil was suspended sometime in 1971. The channel walls then appeared to collapse in response to the change in a long-established practice and the channel now has a continual bedload of sand and gravel that is about 1 ft deep above, through, and below the flume, rendering it useless. It has been suggested that the sand load is temporary, and that in a few seasons the channel will again find equilibrium and the flume may again function properly.

K-3B. This flume near Tombstone, Arizona, was patterned after one designed to be installed in the relatively clear flows of irrigation canals. It was installed in a heavily sediment-laden channel. It almost immediately plugged with bedload gravels. Remedial attempts to increase the flume velocities also were not adequate. The shape of the supplying stream and the shape of the flume are such that the sediment-carrying capacity of the stream was greater than the flume, thus the flume acted as a sediment trap. Subsequent analysis indicated that the flume should have been nearly rectangular in shape, narrower than the channel, and installed so that the flow in the flume was deeper than the flow in the approach channel. None of these criteria were met. The site is suitable for reinstalling a possible corrected flume. The cost may be prohibitive.

Hawaii, Modified. To clear bedload sediments, a raised approach section was designed for several flumes. This represents a significant departure from past flume practice which normally used a sill in the throat section. The result is a level approach section, a sloping converging section in the direction of flow, and a level throat section. The effect is to increase the Froude Number at low flows, and thus increase the bedload movement capabilities in order to flush out the flume. At some selected low-flow depth the flow in the approach section goes critical and flow measurement capability is lost, but this should provide the flushing action desired. Figure 1 indicated the shift in velocity and Froude Number provided by the changed flume shape.

Laboratory checks and limited field exposure indicate that the design is satisfactory. The flume side slopes are so flat that the abrupt entrance and short entrance length compared to the flow width gives some observable backflow near the edges. This should increase the value for α_1 to an estimated 1.2. This value used in computer analysis matches the laboratory-measured flow closely. Again, it should be pointed out that the calibration is rather insensitive to α_1 and bold choices between 1.04 and 1.20 can be readily made by simply observing the flume in operation. If backflow is obvious along the edges, use $\alpha_1 = 1.20$.

The stilling-well intake was modified to conform to the method used by Dr. Smith of the Watershed Hydrology Lab on K-3B, which was adapted by the University of Arizona for the three Tucson flumes. These systems used a slotted plate over a box with a pipe connecting from the box to the stilling well so that sediment tended to be trapped in the box. An elbow was placed on the box end of the pipe. It was turned downward to further discourage entry of sediment. The slots in the flume side of the box were cut in a direction either parallel to the flow or perpendicular to it. The correct direction is elusive. On the one hand, perpendicular slots in the floor tend to trap all bedload crossing the slot field; but the slot, if made in thick enough material to allow the depth to exceed two times the width, should give an accurate pressure response, based on piezometer tap experience. On the other hand, parallel slots would tend to limit their sediment collection activities to about the sum of the slot widths, but may not respond with accurate pressure readings since the slot length in the flow direction would be several times the material thickness. Unable to readily select between these alternatives, we compromised and made 95 holes, 3/16-inch diameter, in quarter-inch plate placed in a field approximately 8 inches up the side of the flume and about 1-1/2 inches wide. One and one-half inch plastic pipe connected the sediment box (approximately 13 inches wide, 8 inches deep, 12 inches long) to the stilling well. To avoid air-lock, a 1/4-inch hole was drilled through the top of the elbow. The hole was drilled horizontally so that sediment could not fall directly into it.

DISCUSSION OF PROPOSED SOLUTIONS:

Sediment Transport Through Flumes. The channel resisting force to a flowing fluid may be explained by principles of fluid dynamics. The channel can be conceived as a flat plate warped into a cylinder but unclosed on one side, which corresponds to the free surface of the open-channel. A fluid flowing in the unclosed cylinder will create a drag force on the inside surface. This force is similar to the drag created by a flow along the two sides of a flat plate whose surfaces offer resistance to the flow. The resistance of one side of such a plate of area A is equal to $C_d \rho V^2 A/2$, where C_d is the coefficient of drag and ρ is the mass density of the fluid, and V is the fluid velocity. The resistance or tractive force τ_o per unit area, A, would thus be

$$\tau_o = C_d \frac{\rho V^2}{2}$$

Since the Froude Number is defined as

$$F^2 = \frac{V^2}{gD}$$

where D is the hydraulic depth, then

$$\tau_o = \frac{C_d \rho g F^2 D}{2}$$

Now, looking at a bedload sediment particle on a level surface, the unit tractive force for impending motion τ_L given by Ven Te Chow (Open Channel Hydraulics, 1959, page 171) is

$$\tau_L = \frac{W_s}{a} \tan (R_L)$$

where W_s = submerged weight of particle
a = effective particle area
R_L = repose angle of particles

The tractive force τ_o must exceed τ_L in a flume to avoid deposition in the flume. Since in general not much can be known about the bedload of a stream except that it will be quite variable, recourse to simplifications are necessary.

W_s, a, and R_L would remain essentially the same for both a particular stream and a flume installed in it. The factors F, D, and perhaps C_d can be different. Thus, it would appear that simply requiring $\tau_{o(flume)} > \tau_{o(channel)}$ or

$$F_f^2 D_f C_{df} > F_c^2 D_c C_{dc}$$

where the subscripts f and c refer to the flume and channel, respectively, or quite expectedly

$$V_f^2 C_{df} > V_c^2 C_{dc}$$

and likewise, since $\tau_o = \gamma RS$

$$R_f S_f > R_c S_c$$

How much more these relations for the flume should exceed those for the channel has not been determined.

What is desired is that the bedload moves down the channel at some rate less than the ability of the flume to handle it. Thus, the depth of sediment in the flume will be less than the depths in the stream, or else some turbulent action will suspend most of the material long enough to clear the flume and then allow it to resume its normal channel activity beyond the flume. The least that can be desired is that the flow regime in the flume is such that flat bed movement predominates rather than dune movement.

Methods to Achieve Clearing of Flumes. Several methods are being investigated for causing or maintaining clear flumes.

1. Cross-sectional shape tailoring: This method consists of making the flume narrow and deep compared to the channel. This makes R_f larger than R_c within certain limits. To match a particular stream, complex flume shapes are often required. Figure 2 is an example of this approach.

2. Energy gradient tailoring: Steepening the energy gradient through the flume so that S_f is greater than S_c is possible on a limited basis. To retain computer-calibration ability the flumes would have to absorb the slope, S_f, in the transition section, leaving the approach and critical sections level; hence, the concept of a "negative sill" height, discussed earlier. Since low flow rates tend to become supercritical and thus not measured, the low flow range of this method may be a limitation in some applications.

3. Turbulence: Another form of energy gradient tailoring is achieved by placing a dropbox above the flume. This should break up the dunes by metering the bedload over the sill of the dropbox, and the resulting turbulence generated will be strong enough to assist movement of the sediment through the flume as mostly a suspended load. An alternate to this is to steepen S_f in the beginning sections of the flume with roughness elements. This should tend to prevent dune formation.

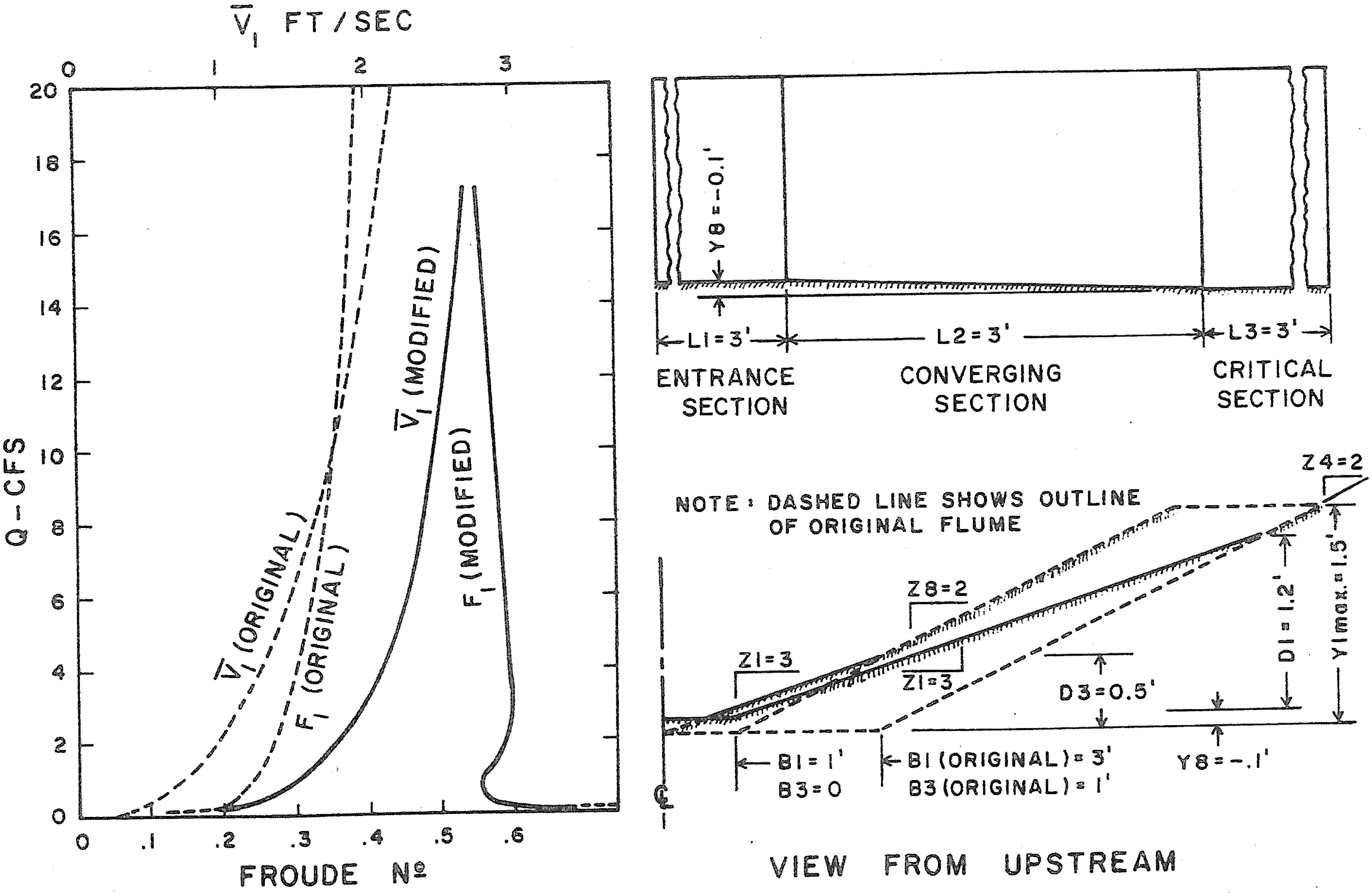
All of these methods may be applicable to a problem site. Criteria for identifying the severity of the problems at potential flume sites are being studied.

SUMMARY AND CONCLUSIONS:

Sediment movement through flumes is continuing to be studied. Three general approaches are apparent from analysis: (a) keep the hydraulic radius of the flume greater than that of the channel; (b) make the energy slope through the flume greater than that of the channel; (c) induce additional turbulence into the flow with a dropbox entrance to the flume. Efforts will concentrate on determining a more quantitative relation for these three approaches, and to examining the requirements for avoiding dune formation through the flumes.

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

CURRENT TERMINATION DATE: January 1975



$\overline{V}_1$ FT/SEC
0
1
2
3
20
18
16
14
12
10
8
6
4
2
0
Q - CFS
$\overline{V}_1$ (ORIGINAL)
F_1 (ORIGINAL)
$\overline{V}_1$ (MODIFIED)
F_1 (MODIFIED)
0
.1
.2
.3
.4
.5
.6
FROUDE Nº
Y8 = -0.1'
L1 = 3'
L2 = 3'
L3 = 3'
ENTRANCE SECTION
CONVERGING SECTION
CRITICAL SECTION
NOTE: DASHED LINE SHOWS OUTLINE OF ORIGINAL FLUME
Z4 = 2
Z8 = 2
Z1 = 3
Z1 = 3
D3 = 0.5'
D1 = 1.2'
Y1max. = 1.5'
B1 = 1'
B3 = 0
B1 (ORIGINAL) = 3'
B3 (ORIGINAL) = 1'
Y8 = -.1'
℄
VIEW FROM UPSTREAM

Figure 1

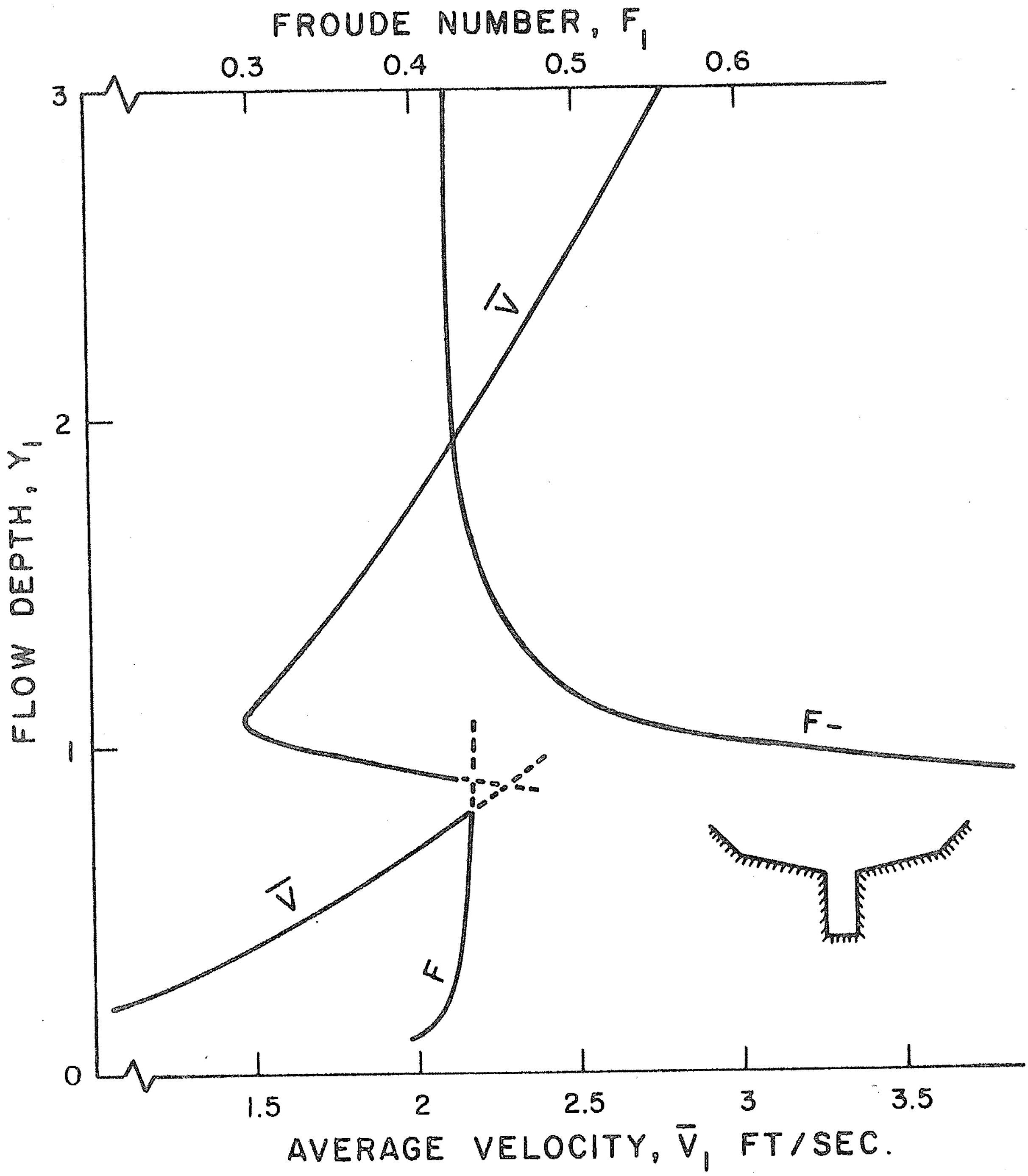

FROUDE NUMBER, F1
0.3
0.4
0.5
0.6
3
2
1
0
FLOW DEPTH, Y1
V̄
F
V̄
F
1.5
2
2.5
3
3.5
AVERAGE VELOCITY, V̄1 FT/SEC.

Figure 2

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

CRIS WORK UNIT: SWC-018-gG4 CODE NO.: Ariz.-WCL-72-4

The objective of this study was to develop equipment and procedures to measure the rate, magnitude, and depth of swelling and shrinking of a soil pedon, and to follow changes in bulk density in 1-cm soil layers following irrigation. Calculation of soil-water flux under field conditions requires information on the rate of change of volumetric water content with time. This water content is usually obtained from measured gravimetric water content multiplied by an average bulk density for the soil depth under consideration. An assumption in this calculation is that bulk density is constant over the measurement period. The only nondestructive, accurate method of measuring bulk density *in situ* involves the use of two gamma-ray energy sources.

Bulk density changes of 1-cm depth increments in the surface 10-cm of a soil pedon were used to characterize the swell-shrink properties of the subject soil. These changes were measured with a dual energy gamma-ray transmission technique. Results of this study have demonstrated that the two gamma-ray sources cannot be used simultaneously but rather separately, when the sources and detector are not collimated. The separation of sources was necessary because the backscattered ^{137}Cs photons could not be separated from the lower energy unattenuated ^{241}Am photons in the soil-water system.

In the field, density changes were very rapid, dropping from 1.33 to 0.75 g cm^{-3} in the 1- to 2-cm layer about 30 minutes after water was applied to the soil surface. The soil surface elevation, monitored with a linear variable differential transformer transducer, also showed a rapid change in height after the water addition (+ 0.6 mm 10 minutes after the fourth irrigation).

Shortly after the water disappeared from the soil surface, the bulk densities returned to nearly the pre-irrigation values for the various 1-cm thick soil layers. Swelling and shrinking occurred to a depth of 4 to 6 cm even after four irrigations. Repeated irrigations (wet-dry cycles) decreased the magnitude of density changes, but the changes still occurred as rapidly and as deeply as they had in earlier irrigations.

These findings support the common practice of using a measured bulk density profile to convert gravimetrically determined soil-water contents to a volumetric basis. Previously, workers had to assume that, even in moderate swelling soils, bulk density did not change appreciably with time even over a wide water content range. These data confirm that point for Adelanto loam. Also, for this soil, swelling and shrinking took place in the top 6 cm, a small part of the soil with respect to the total depth available for water use by most economic crops, but extremely significant in terms of describing the evaporation near the soil surface.

The results also demonstrate that a single energy gamma-ray source can be used to monitor water content changes in the upper part of the Adelanto loam soil pedon once irrigation water has subsided. The simultaneous use of two gamma-ray energy sources is not necessary to follow these water content changes, and as a consequence, instrumentation and procedures are greatly simplified.

Details of this report are presented in a manuscript in preparation titled, "Swelling and shrinking of a soil pedon."

PERSONNEL: Robert J. Reginato

CURRENT TERMINATION DATE: January 1974

TITLE: GRAVEL BED COOLERS FOR GREENHOUSES

CRIS WORK UNIT: SWC-018-gG-4 CODE NO.: Ariz.-WCL 72-5

This project was initiated during the past year to design, test, and evaluate evaporative coolers made from gravel beds for the cooling of sealed greenhouses.

It is well known from greenhouse studies that CO_2 fertilization can substantially increase the yields of almost all crops. However, the effectiveness of CO_2 fertilization of greenhouses has been limited at high light intensities, (when CO_2 fertilization should be most effective) because growers have had to ventilate their greenhouses to lower the inside temperature, and much CO_2 has been lost. If, however, a means can be developed to control economically the temperature of a greenhouse under high light conditions without resorting to any form of ventilation, growers could practice CO_2 fertilization more advantageously, and yields of greenhouse crops per unit of area, labor, and water could be increased.

Preliminary calculations have indicated the feasibility of cooling a sealed greenhouse using the thermal storage characteristics of evaporatively cooled gravel beds. However, progress to date has been limited to assembling the laboratory apparatus necessary to make measurements of heat capacity and heat transfer coefficients under various flow conditions for commercial grades of gravel. When these laboratory measurements are completed, more refined design calculations will be made, and it is anticipated that a prototype, gravel-bed-cooled greenhouse will be built.

PERSONNEL: B. A. Kimball

CURRENT TERMINATION DATE: June 1976

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

CRIS WORK UNIT: SWC-018-gG-4 CODE NO.: Ariz.-WCL-72-6

The indication from last year's work that atmospheric dust may tend to warm the earth via an enhanced "greenhouse effect" rather than cool it due to increased solar radiation reflection was followed up by two additional studies of dust effects. Previous hypotheses were confirmed by a more ideal set of post-duststorm measurement conditions and by a climatological assessment of summer and winter aerosol distribution and radiation differences. In addition, the scope and mechanics of the great duststorms that often occur in the Arizona deserts were delineated in a third study. More details on each of these aspects of this year's work are given below.

Idso, S. B. Thermal radiation from a tropospheric dust suspension. Nature. (In press).

Measurements of the thermal radiation from cloudless skies in July and August of this year showed that the fine residue from a decaying dust storm one evening caused the atmosphere to radiate as a blackbody on the following day, as compared to the normal efficiency at this time of year of about 0.955. It was shown that this effect could conceivably overpower the cooling effect of dust, due to its increased reflectance of solar radiation, and thereby warm the earth.

Idso, S. B. Water vapor and aerosol effects upon thermal radiation from cloudless skies. Quart. J. Roy. Meteorol. Soc. (Submitted for publication).

Results of intensive measurements of clear sky atmospheric thermal radiation were presented for summer and winter conditions at Phoenix, Arizona. Large deviations were found between the mid-afternoon measured values in summer and the results of calculations with the Swinbank and Idso-Jackson equations. It was shown that this discrepancy was caused by a breakdown in the correlation between surface air temperature and vapor pressure brought about by locally strong convective mixing, whereby only a Brunt- or Ångström-type equation incorporating surface vapor pressure in addition to air temperature could realistically predict the atmospheric radiation.

An anomaly was also noted between the relative magnitudes of the winter and summer radiation fluxes that was explainable in terms of a large vertical redistribution of the mean atmospheric aerosol concentration with season. The existence of this redistribution was verified and the causative mechanism presented. It was then shown that this phenomenon could create an enhanced atmospheric "greenhouse effect" at the earth's surface without any loss of solar radiation to the earth-atmosphere system.

Idso, S. B., Ingram, R. S., and Pritchard, J. M. An American haboob. Bull. Amer. Meteorol. Soc. 53(10):930-935. Oct. 1972.

Photographs and meteorological data were presented to show that the duststorms of the arid southwestern United States are identical in form and origin to the legendary "haboob" of Egypt and the Sudan.

PERSONNEL: Sherwood B. Idso, J. M. Pritchard, and R. S. Ingram (cooperator with National Weather Service).

APPENDIX I

SUMMATION OF IMPORTANT FINDINGS

SWC-018-gG-4 INCREASING AND CONSERVING AGRICULTURAL AND RURAL WATER SUPPLIES

Water harvesting plots treated with paraffin wax yielded an average of 90% precipitation runoff compared to only 30% runoff for comparable untreated plots. The wax was applied as granules on top of the soil and allowed to melt and spread in the hot sun to form a hydrophobic soil surface. Preliminary cost analysis indicates that this method will harvest water for less than $1.00 per 1000 gallons. (WCL 67-2).

Infiltration rate and quality of renovated sewage effluent remained stable during more than 5 years in an experimental project to renovate sewage effluent by high-rate infiltration basins. The total infiltration for this period was about 1400 ft. Nitrogen removal was maximized by alternating sequences of long flooding periods with sequences of short flooding periods, thus avoiding build-up of ammonium in the renovated water. High-rate infiltration systems for renovating effluent in sandy soil have a long, useful life. (WCL 67-4).

Soil-water movement, and chloride accumulation and movement near the surface of a bare soil was found to be very dynamic. During the morning and midday hours, water moved upward toward the surface in about the top centimeter of soil and moved downward below that depth. This two-directional movement can explain the very rapid drying of the soil surface. Soon after irrigation, chloride content near the surface followed a diurnal pattern, but out-of-phase from the soil water content. No cycling of chloride accumulation was present at the 1- and 2-cm and deeper depths even though the diurnal cycling was present for the water. Most of the total chloride accumulation at the surface occurred in the early stages of drying. The chloride moved at water contents as low as 4% in the Adelanto soil. (WCL 68-1).

The percent nitrogen removed by soil columns was found to increase exponentially as the flux decreased. This relationship held when the nitrogen load was reduced by diluting the sewage or reducing the length of the flooding period. The nitrogen removal was 80% at a flux of 15 cm/day and 30% at 35 cm/day. Approximately 38 m of water per unit area could be reclaimed in a year using a 15 cm/day flux while 85 m of water per unit area could be reclaimed in a year using a 35 cm/day flux. The increase in nitrogen removal was probably due to a change in the flow characteristics of the system which allowed more mixing of the nitrate in the soil with the incoming sewage water and provided a C:NO_3-N ratio favorable for denitrification.

Nitrogen removal was increased to 75-80% by collecting the high nitrate water, mixing it with the incoming sewage water and recycling it through the soil columns. The change in oxidation reduction potentials with recycling showed that the increased nitrogen removal was due to denitrification near the soil surface. The recycling method could be used with a tiled land filtration system to remove 75% of the nitrogen from 60 m of sewage per unit area in 1 year. (WCL 68-3).

Zones of microbial activity in soil profiles used for waste water renovation by ground-water recharge were characterized. It was found that the microbial environment favorable for the biological processes of nitrification and denitrification were essentially limited to the top 15 cm of the soil profile. These results indicated that deep soil profiles are not necessary for renovation of waste water by ground-water recharge systems, provided the flooding and drying cycles are managed properly to enhance the biological processes of nitrogen removal in the top 15 cm of the soil profile. (WCL 70-2).

Application uniformity from low-pressure trickle irrigation systems can be greatly improved by varying emitter sizes to compensate for friction-induced pressure changes in the lateral pipe. This year the concept of varying emitter sizes was expanded to include a multiple-diameter and -length microtube system for orchard-crop usage. Microtubes or spaghetti tubes are short lengths of plastic tubes cut from inexpensive, small-diameter polyethylene tubing. Theoretical performance of a 650-ft lateral, with three emitters per tree and 25 ft between trees, using combinations of two diameters and seven lengths of microtubes, showed a mean deviation of 2.9% and a maximum deviation of 5.0% from design discharge. The multiple-diameter and -length microtube system should not be expensive or difficult to produce. (WCL 70-3).

A chamber has been constructed that gives precise measurements of transpiration and photosynthesis of whole plants. Sunflower has been found to transpire at about twice the rate of corn, sorghum, or tomato. Under drought, transpiration of sunflower is diminished to a greater extent than photosynthesis, making it more efficient in its water use than when well watered. (WCL 71-1).

A mathematical model was developed that relates algal photosynthesis to the absorption of solar radiation by water. Application of the model led to the establishment of several general criteria for the planning and operation of man-made systems of aquaculture. (71-3).

Mass flow processes were found to increase the rate of water vapor loss through shallow mulches during afternoon periods to 126% of the loss attributable to molecular diffusion. Therefore, mass flow processes contribute significantly to the movement of water vapor during evaporation, more so than has generally been presumed. (WCL 71-5).

Evaporation losses from small stock ponds and tanks can be reduced effectively using paraffin wax covers. The paraffin wax is applied as either high melting point foamed blocks or low melting point blocks which form a continuous layer when melted by the sun. The foamed blocks are recommended for use on irregular shaped ponds and the continuous cover for use on stock tanks. Evaporation reduction has averaged 40% for the foamed blocks and 90% for the continuous cover, during the past two years. Cost of the paraffin varies from 10 to 15 cents per square foot depending on the type of treatment. Translated to cost of the water saved, this amounts to 45 to 75 cents per 1000 gallons assuming a material life of 5 years. (WCL 71-6).

An analytical analysis of infiltration into heterogeneous porous media where the saturated hydraulic conductivity increased with depth confirmed the numerical analysis results of earlier studies. They also pointed up the fact that the soil water pressure head and water content profiles of such a heterogeneous system are quite different from a homogeneous one. (WCL 71-9).

A rapid and simple titrimetric method was developed for the analysis of sulfate in irrigation and other types of saline waters. (WCL 71-11).

Trickle or modified-furrow irrigation methods have the potential to reduce water delivery requirements, but not consumptive use, under many field conditions. An investigation was conducted to evaluate quantity and frequency of trickle, modified-furrow, and standard-furrow irrigation on the growth of cabbage, using a moderately saline water on fine-textured, clay-loam soil. Irrigations consisted of different quantities, based on ratios of the plant's consumptive-use estimate, applied at different frequencies. Maximum production was almost identical for all irrigation methods tested, and the amount of soil moisture needed by the cabbage plant for high production was approximately the present consumptive-use estimate. Frequency of irrigation caused no difference in production when more than the consumptive-use requirement was applied; however, a trend of reduced production with increased frequency did result when less than consumptive-use requirement was applied. Trickle and modified-furrow irrigation reduced the water delivery requirement as compared with that in standard-furrow irrigation, showing that a higher irrigation efficiency can be attained using these newer irrigation methods over conventional methods. (WCL 71-13 and WCL 71-14).

Flow characteristics of complex-shaped flumes, including flumes that are not symmetrical with respect to the flow centerline, were successfully predicted. This enables the design of flumes with prescribed head-discharge relations and flumes in which sediment will not accumulate. (WCL 72-1 and WCL 72-2).

Swelling and shrinking in a field soil were measured with alternating gamma-ray radioisotopes. Bulk density decreased to a depth of 6 cm with water ponded on the soil surface, but when the water disappeared from the surface, the bulk density increased to the pre-irrigation level. The development of procedures and equipment to measure soil bulk density in situ now makes it possible to evaluate the importance of swelling and shrinking of soils in the field studies. (WCL 72-4).

Measurements of solar and atmospheric thermal radiaton indicated that increases in the concentration of low-level aerosol at Phoenix, Arizona, generally result in a net increase of radiation to the ground surface. An important implication of this work is that increasing particulate pollution near the earth's surface will tend to warm the earth, and not cool it as was for so long supposed by many scientists. (72-6).

APPENDIX II

LIST OF PUBLICATIONS PUBLISHED AND MANUSCRIPTS PREPARED IN 1972

		MS No.
SWC-018-gG4	Increasing and conserving agricultural and rural water supplies.	
Published:	<u>Bouwer, Herman, Rice, R. C., Escarcega, E. D., and Riggs, M. S.</u> Renovating secondary sewage by ground water recharge with infiltration basins. Office of Research and Monitoring, Environmental Protection Agency. Project No. 16060DRV. March 1972. (Supt. of Documents, Government Printing Office, Washington D. C.).	399
	<u>Cooley, Keith R., and Cluff, C. Brent.</u> Reducing pond evaporation with perlite ore. Jour. Irrig. and Drain. Div., Amer. Soc. Civil Engin. Proc. 98(IR 2):255-266. June 1972.	377
	<u>Cooley, Keith R., Myers, Lloyd E., and Frasier, Gary W.</u> Lower cost water harvesting methods. Proc., Symp. on Interdisciplinary Aspects of Watershed Management. Montana State Univ., Bozeman, MT, 3-6 August 1970. Pp. 27-41. (Published 1972).	355
	<u>DeBoer, Darrell W., Bucks, Dale A., Lembke, Walter D., and Wiersma, John L.</u> Envelope performance in a coarse-silt base material. Proc., Amer. Soc. Agric. Engin. National Drainage Symp., Chicago, IL, December 1971. Pp. 5-7.	381
	<u>Erie, Leonard J., Bucks, Dale A., and French, Orrin F.</u> Irrigation and water management for economical cotton production. Proc., Western Cotton Production Conf., Bakersfield, CA, 1-3 March 1972. Pp. 21-24.	389

MS No.

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Frasier, Gary W., and Myers, Lloyd E. Bonding films to soil surfaces for water harvesting. Trans., Amer. Soc. Agric. Engin. 15(5):909-911. Sept-Oct 1972. 382

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Idso, Sherwood B., Ingram, R. S., and Pritchard, J. M. An American Haboob. Bul. Amer. Meteorol. Soc. 53(10):930-935. October 1972. 390

Jackson, R. D. On the calculation of hydraulic conductivity. (NOTE) Soil Sci. Soc. Amer. Proc. 36(2):380-382. Mar-Apr 1972. 376

Kimball, B. A., and Lemon, E. R. Theory of soil air movement due to pressure fluctuations. Agric. Meteorol. 9(3/4):163-181. January 1972. 332

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Watson, Keith K., and Whisler, Frank D. Numerical analysis of drainage of a heterogeneous porous medium. Soil Sci. Soc. Amer. Proc. 36(2):251-256. March-April 1972. 373

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Whisler, Frank D., Watson, Keith K., and Perrens, S. J. The numerical analysis of infiltration into the heterogeneous porous media. Soil Sci. Soc. Amer. Proc. 36(6):868-874. Nov-Dec 1972. 393

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Prepared:	Bouwer, Herman. Renovating secondary effluent by groundwater recharge with infiltration basins. Proc., Natl. Symp. on Recycling Treated Municipal Waste Water and Sludge Through Forest and Cropland. (University Park, PA, August 1972) (In press).	403
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	Bucks, Dale A., Erie, L. J., and French, O. F. Limiting quantities and varying frequencies of trickle irrigation on cotton. Trans., Amer. Soc. Agric. Engin. (Submitted for publication).	415
	Bucks, Dale A., Erie, L. J., and French, O. F. Quantity and frequency of trickle and furrow irrigation for efficient cabbage production. Agronomy Journal. (Submitted for publication).	416
	Cooley, Keith R., and Myers, Lloyd E. Evaporation reduction with reflective covers. Jour. Irrig. and Drain. Div., Amer. Soc. Civil Engin. Proc. (Submitted for publication).	409
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	Ehrler, Wm. L. Cotton leaf temperatures as related to soil water depletion and meteorological factors. Agron. Jour. (In press).	394

MS No.

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Kimball, Bruce A. Simulation of the energy balance of a greenhouse. Agric. Meteorol. (In press).	349
Kimball, Bruce A. Water vapor movement through mulches under field conditions. Soil Sci. Soc. Amer. Proc. (Submitted for publication).	411
Lance, J. C., Whisler, F. D., and Bouwer, H. Oxygen utilization in soils flooded with sewage water. Jour. of Environmental Quality. (In press).	398
Linderman, R. G., and Gilbert, R. G. Influence of volatile compounds from alfalfa hay on microbial activity in soil in relation to growth of Sclerotium rolfsii. Phytopathology. (Submitted for publication).	404
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Mitchell, S. T., Kimball, B. A., and Ehrler, W. L. A miniature gravity-fed thermocouple psychrometer. Agron. Jour. (In press).	391

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Nakayama, F. S. On solubility and solubility product constants. Soil Sci. Soc. Amer. Proc. (Letter to the Editor). (Submitted for publication).	417
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Rice, Robert C. Soil clogging during infiltration with secondary sewage effluent. Jour. Water Pollution Control Fed. (Submitted for publication).	413
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